ストレンジネス核物理とハイペロン陽子散乱実験

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ハイペロン陽子散乱実験の意義

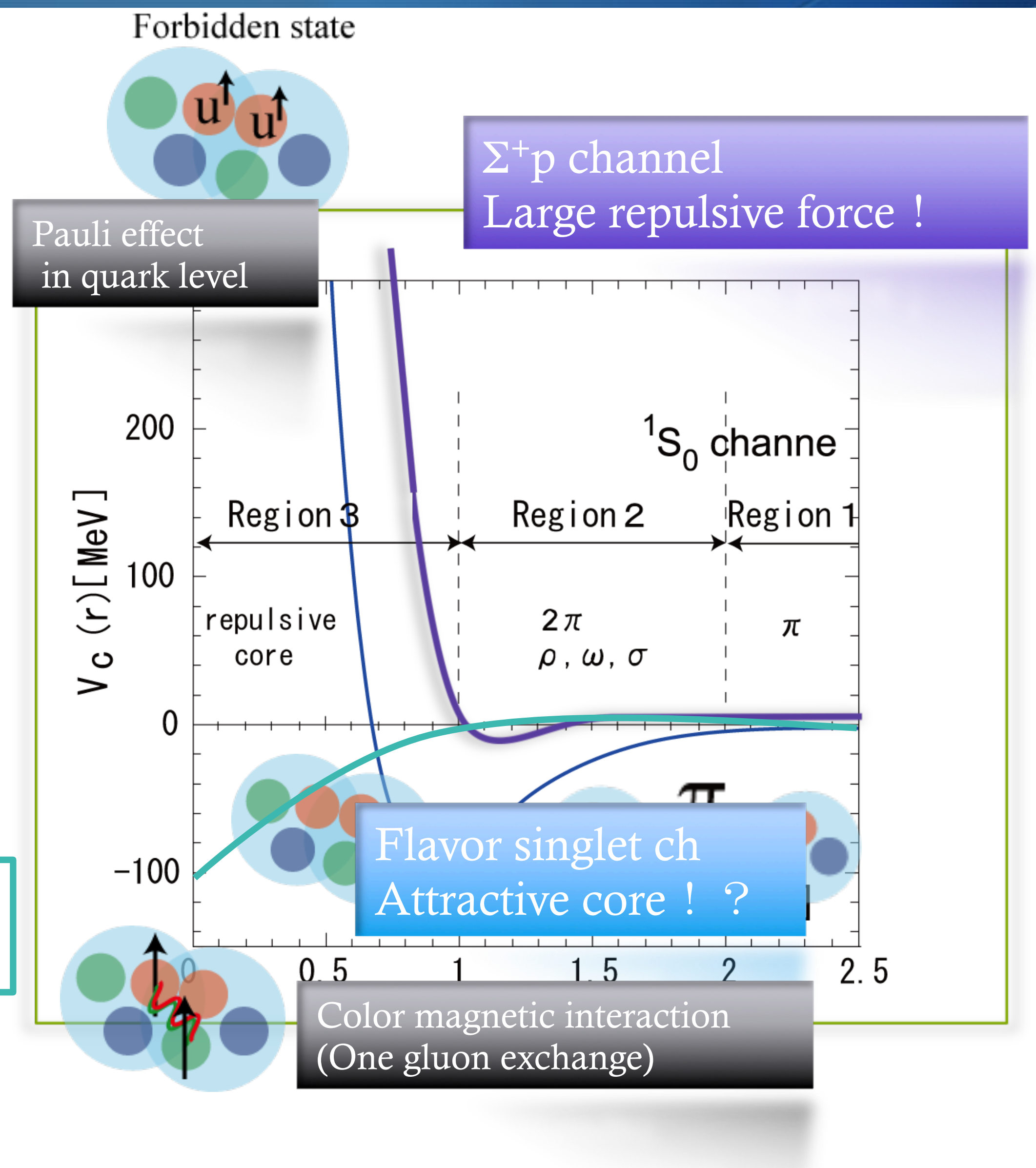
Baryon-Baryon Interaction

- Investigation of BB interaction
  - Basic information to describe the system with Hyperon
    - Hypernuclei
    - High density matter inside neutron star
  - Origin of short range core

Short range interaction by
Quark Cluster model

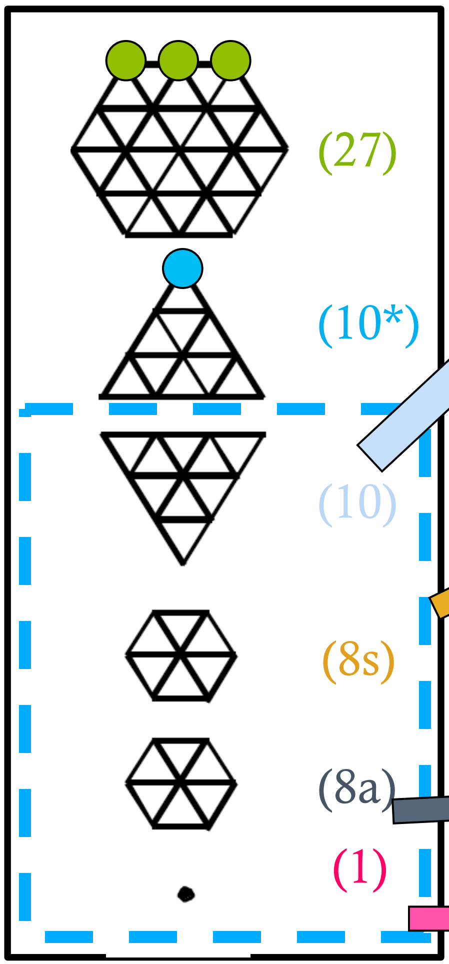
- Pauli effect in quark level
- Color magnetic interaction

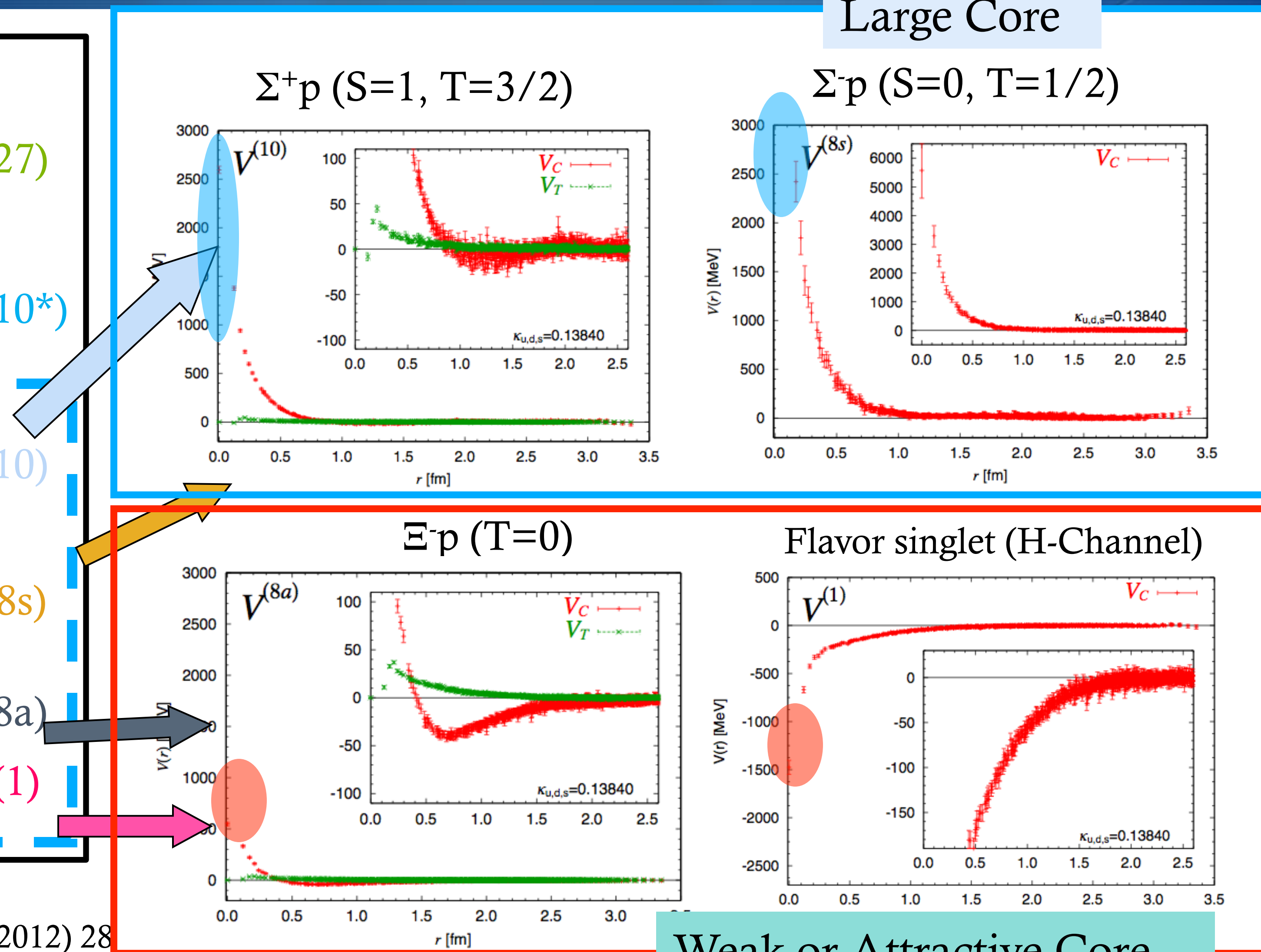
YN, YY interactions show rich aspect especially in short range region



Baryon Baryon interaction by Lattice QCD

- 6 independent forces in flavor SU(3) symmetry





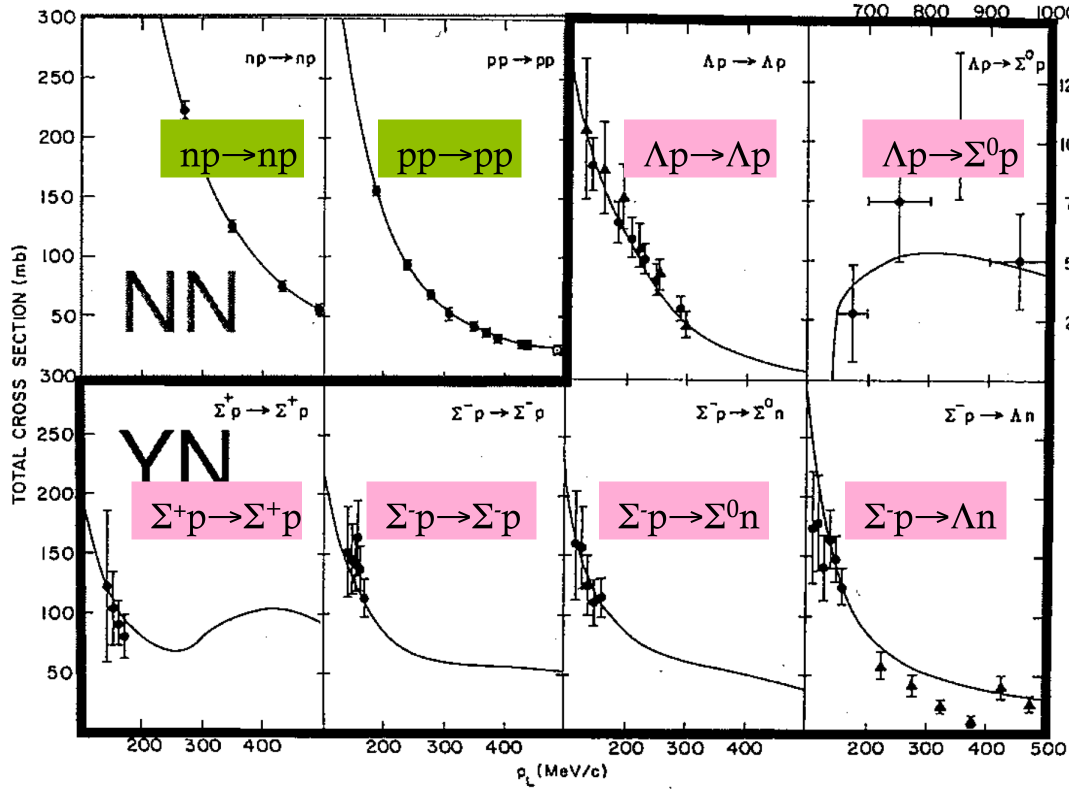
T. Inoue et al.
Nucl. Phys. A 881 (2012) 28

ハイパー核業界の枕詞

通常原子核

豊富なNN散乱データ

原子核構造
核子多体系の特徴を調べる



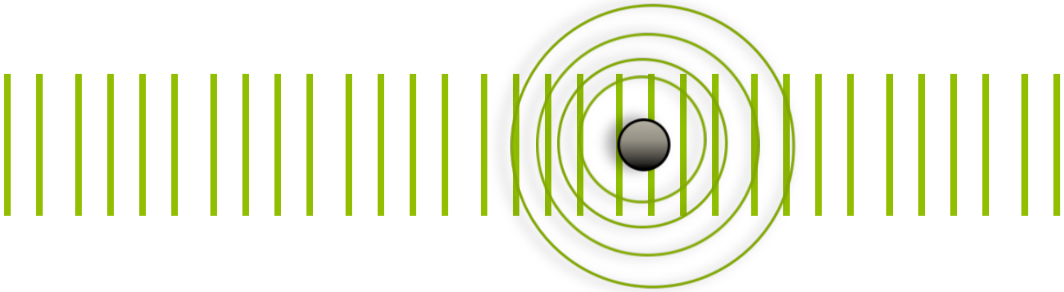
- “ハイペロンは寿命が短
造から相互作用を決める
  - 正しく散乱実験でYN
- “Λハイパー核を調べるこ
拡張する”
  - ΛN以外の相互作用についても明らかにして初めてYN相互作用に拡張したと言える。

散乱理論

- 散乱体から十分は慣れた場所での波動関数を平面波と散乱波の重ね合わせで表す

$$\varphi(r) \rightarrow e^{ikz} + f(\theta)\frac{e^{ikr}}{r}$$

f(θ) : 散乱振幅　(距離の次元を持つ)
$d\sigma/d\Omega = |f(\theta)|^2$



散乱理論

- a

平面波をいろいろな軌道角運動量lを持った部分波に分ける

$$e^{ikz} = \sum_{l=0}^{\infty}(2l+1)i^l j_l(kr)P_l(\cos\theta)$$

j.(kr)は球面ベッセル関数でその漸近形は

$$j_l(kr) \to \frac{1}{kr}\sin(kr - \frac{\pi}{2}l) = \frac{(-i)^l}{2ikr}\{e^{ikr} - (-1)^l e^{-ikr}\}$$

これを使うと平面波の漸近形は

$$e^{ikr} \to \frac{1}{kr}\sum_l (2l+1)i^l \sin(kr - \frac{\pi}{2}l)P_l(\cos\theta)$$

$$= \frac{1}{2ikr}\sum_l (2l+1)\{e^{ikr} - (-1)^l e^{-ikr}\}P_l(\cos\theta)$$

f(q)もルジャンドル球関数Pl(cosq)で展開

$$f(\theta) = \frac{1}{2ik}\sum_l (2l+1)\{S_l - 1\}P_l(\cos\theta)$$

Sl−１は展開計数

散乱理論

- 散乱体から十分は慣れた場所での波動関数を平面波と散乱波の重ね合わせで表す

$$\varphi(r) \to e^{ikz} + f(\theta)\frac{e^{ikr}}{r}$$

S.のぶんだけ形が歪められた

散乱後の波

$$\varphi(r) \to \frac{1}{2ik}\sum_l \{S_l e^{ikr} - (-1)^l e^{-ikr}\} P(\cos\theta)$$

$S_l=e^{2i\delta}$

とおく

元々の平面波

$$\varphi(r) \to \frac{1}{2ik}\sum_l \{e^{ikr} - (-1)^l e^{-ikr}\} P(\cos\theta)$$

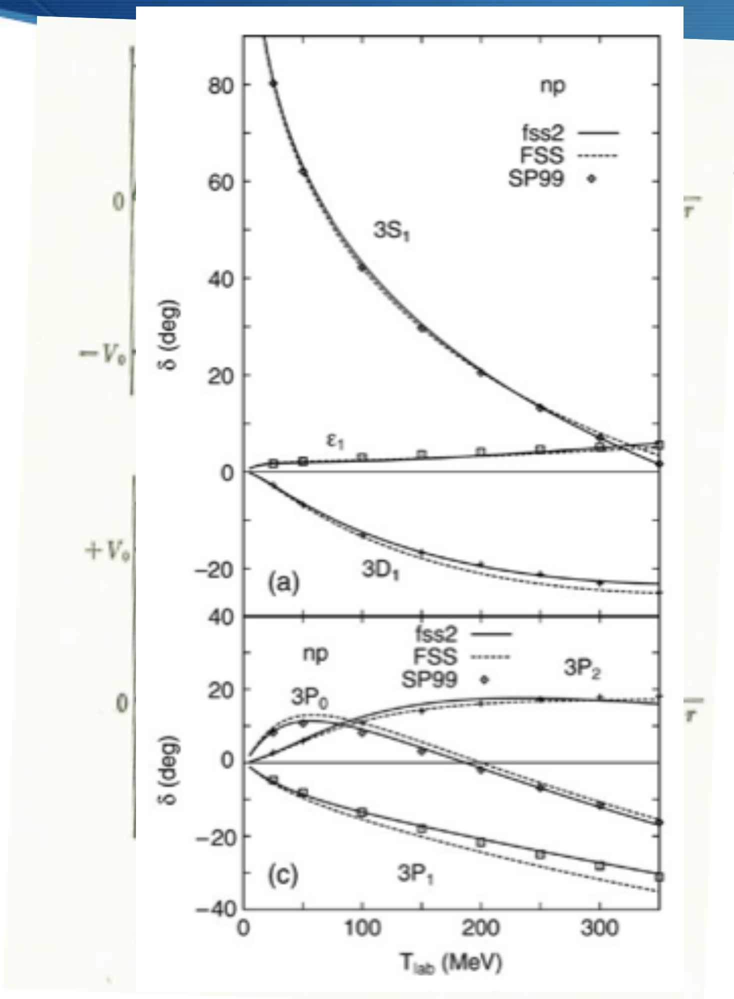
$$\varphi(r) \to \frac{1}{kr}\sum_l (2l+1) i^l e^{i\delta l} \sin(kr - \frac{\pi}{2} l + \delta_l) P_l(\cos\theta)$$

入射波の位相をδ_lだけずらしたことになる

$$f(\theta) = \frac{1}{k}\sum_l (2l+1) e^{i\delta l} \sin\delta_l P_l(\cos\theta)$$

基本的にはポテンシャルの影響がδ_lに含まれる

Phase shift



- 散乱の位相差
  - 引力ポテンシャル
    - 散乱波が引き込まれる → 正の位相のずれ
  - 斥力ポテンシャル
    - 散乱波が押し出される → 負の位相のずれ

位相の大きさがポテンシャルの大きさに対応する

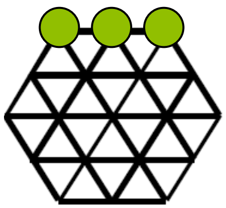
NN間力に関してはphase shift analysisから詳細に位相差が決定されている

⇕

YN間力に関しては一つも決定されていない

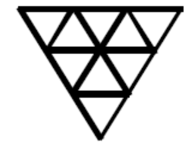
これをはじめて測定したい

Repulsive core in Σ^+p channel



(27)

ΣN (I = 3/2)	Spin Singlet	Spin Triplet
	(27) Same with NN(I=1,S=0)	(10) Almost Pauli forbidden

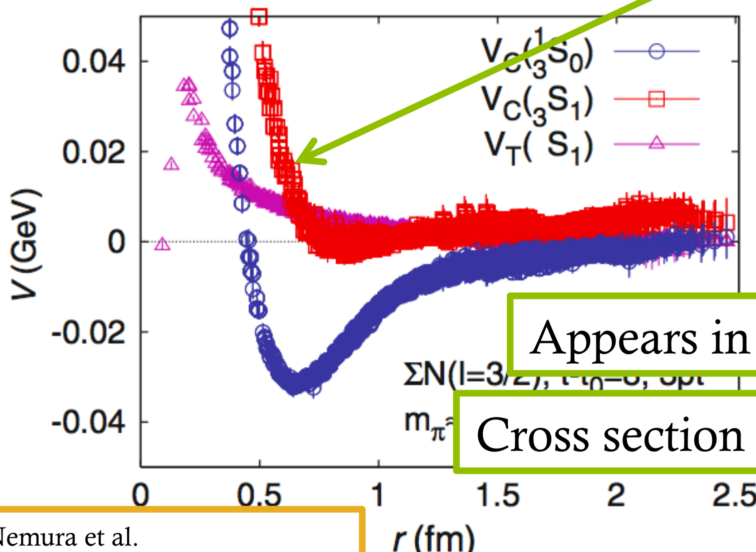


(10)

Spin weight: 1/4

Spin weight: 3/4

Σ^+p potential by Lattice QCD

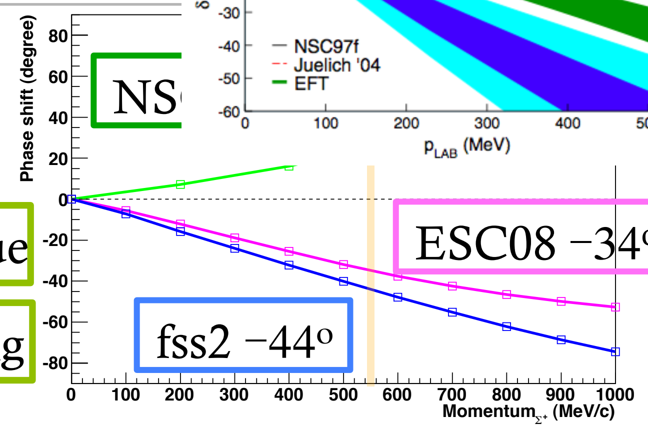


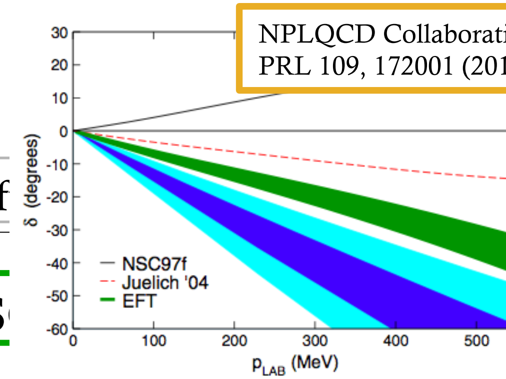
H. Nemura et al.
Few-Body Syst (2013) 54:1223-1226

Appears in phase shift value

Cross section of Σ^+p scattering

Phase shif





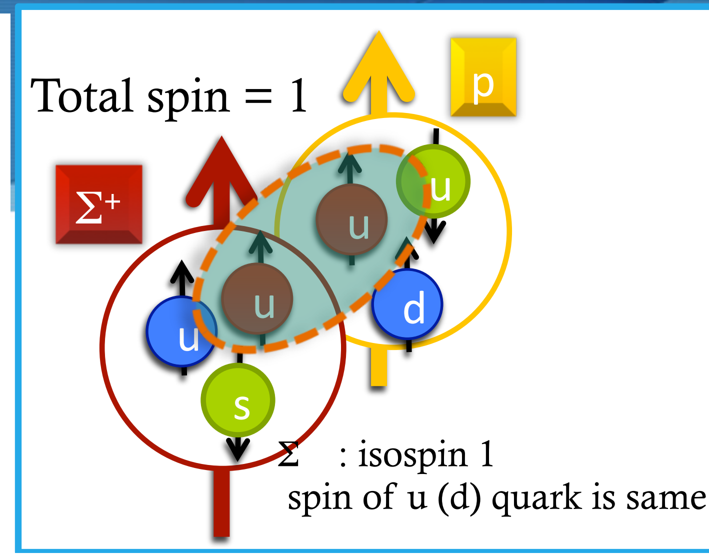
NPLQCD Collaboratio
PRL 109, 172001 (2012)

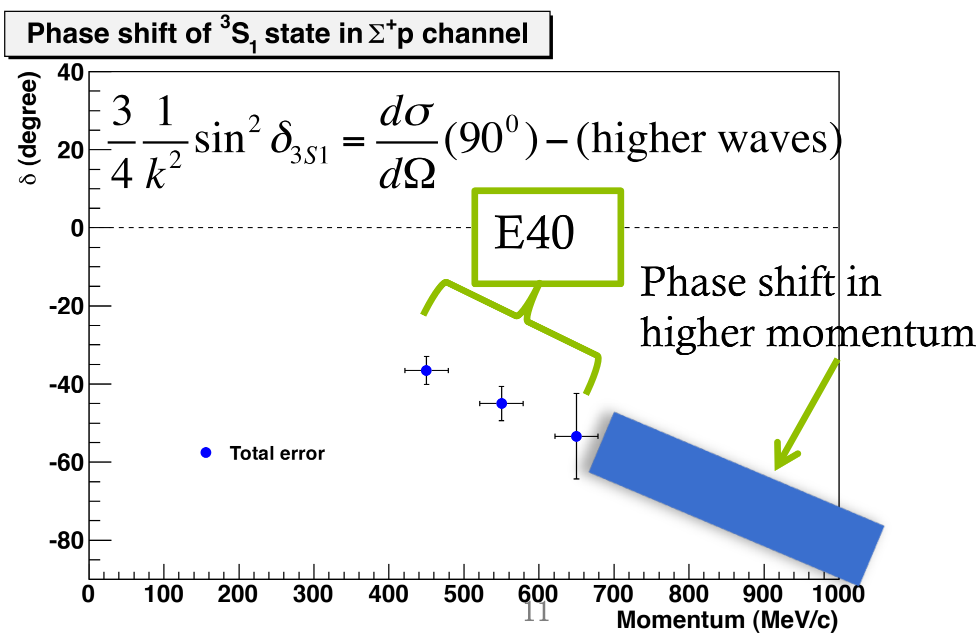
Scattering experiment

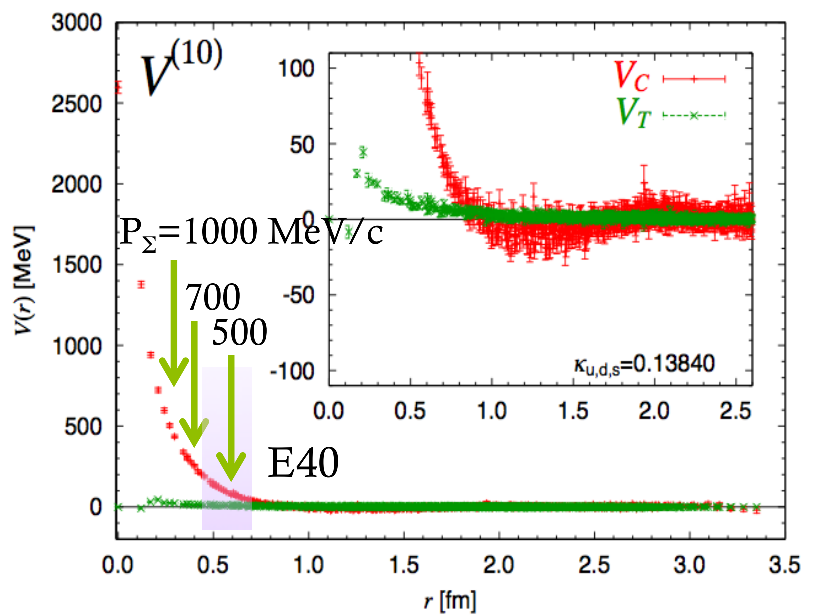
Investigation with radial dependence,
Direct measurement of phase shift value

Quark Pauli effect in the Σ^+p channel

- Large repulsive core due to quark Pauli effect in the ΣN (I=3/2, S=1) channel
  - Main motivation of E40 experiment at K1.8 beamline using π^+ beam
- Derive phase shift up to 1 GeV/c region
  - Radial dependence of potential

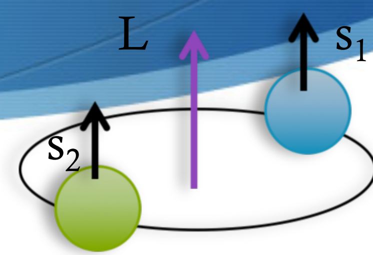






Anti-symmetric LS force

- Anti-symmetric LS force originated by the one gluon exchange between quarks

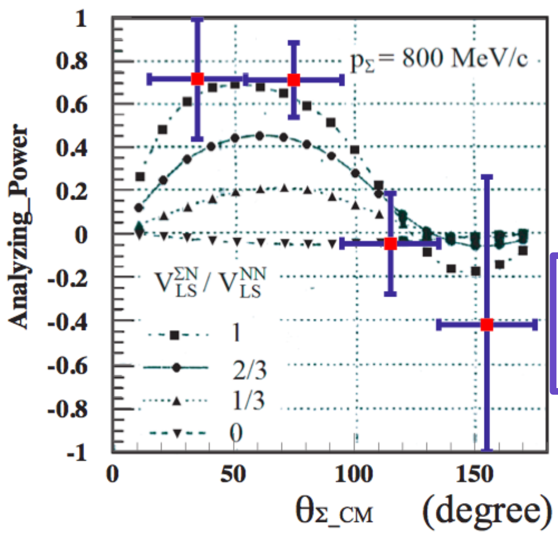


Forbidden in NN channel from isospin symmetry

LS force : $V_{LS} L \cdot (s_1 + s_2)$

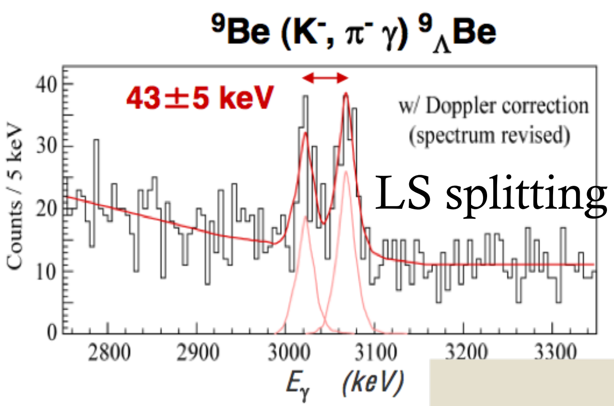
$LS^{(-)}$ force : $V_{ALS} L \cdot (s_1 - s_2)$

Analyzing power in $\Sigma^+ p$ scattering



Large LS force in ΣN system like NN system

Small LS force in Λ hypernuclei
Due to cancellation between LS and $LS^{(-)}$



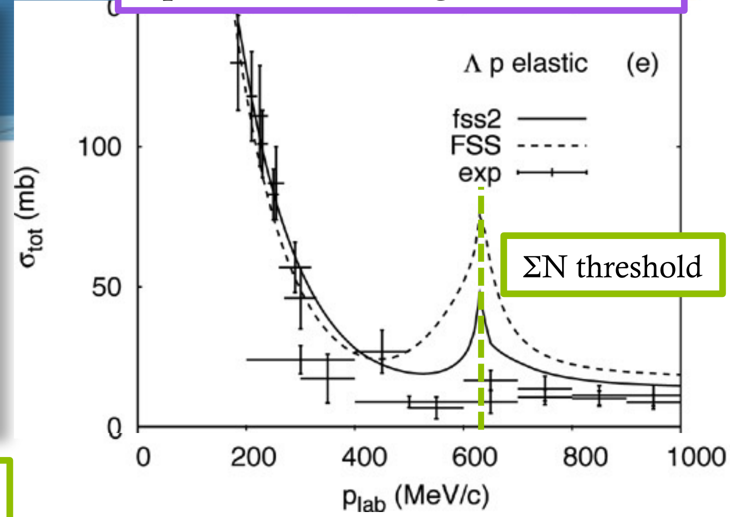
LS splitting

Anti-symmetric LS force in Λp channel

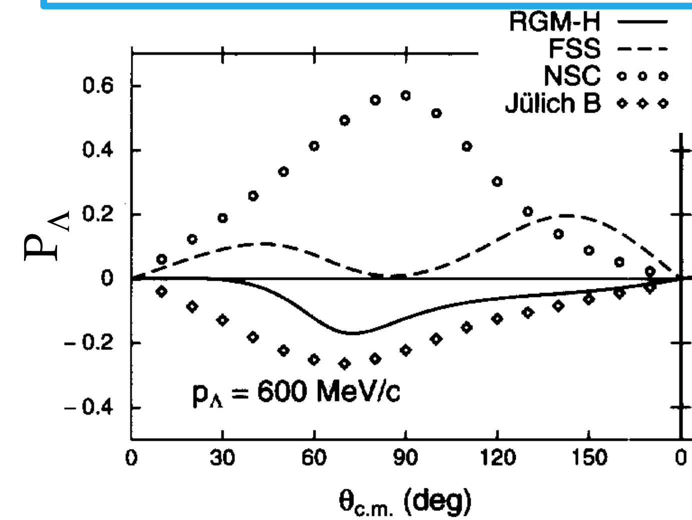
	^1E or ^3O	^3E or ^1O
ΛN (I=1/2)	$1/\sqrt{10}[(8_s) + 3(27)]$	$1/\sqrt{2}[-(8_a) + (10^*)]$
ΣN(I=1/2)	$1/\sqrt{10}[3(8_s) - (27)]$	$1/\sqrt{2}[(8_a) + (10^*)]$
ΣN(I=3/2)	(27)	(10)

LS$^{(-)}$ force can exchange $(8)_a$ and $(8)_s$ states

Λp elastic scattering cross section



Polarization of Λ in Λp elastic scattering

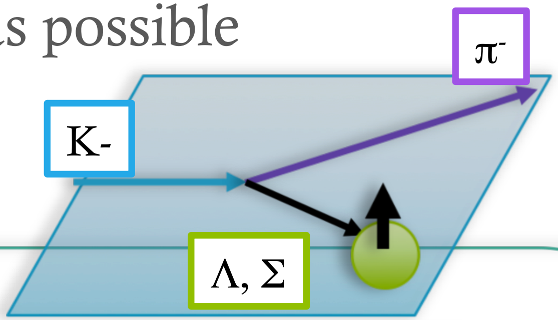


- LS$^{(-)}$ force in Λp channel near ΣN threshold
  - Very prominent contribution comes from the cross term of $(8)_s$ and $(8)_a$
    - Cross section
    - Polarization, Analyzing power

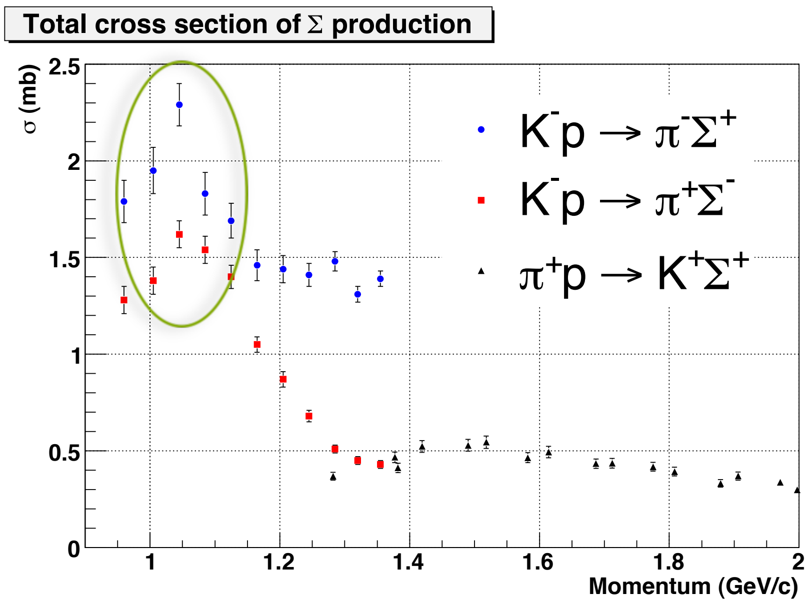
    at ΣN threshold region

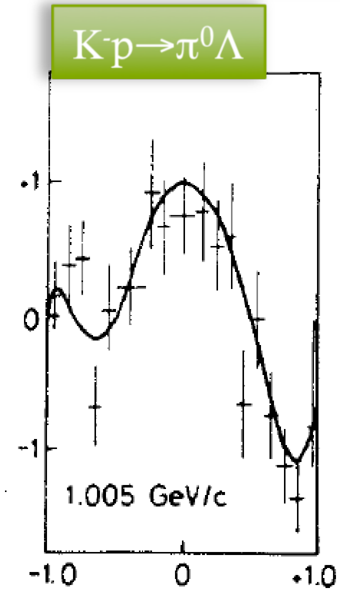
Requirement for Hyperon beams

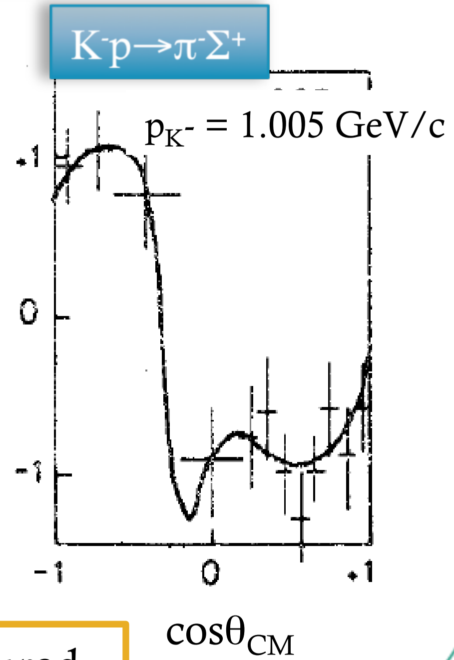
- High intensity hyperon beams as much as possible
- Polarized hyperon beams



K^- beam at p = ~1 GeV/c



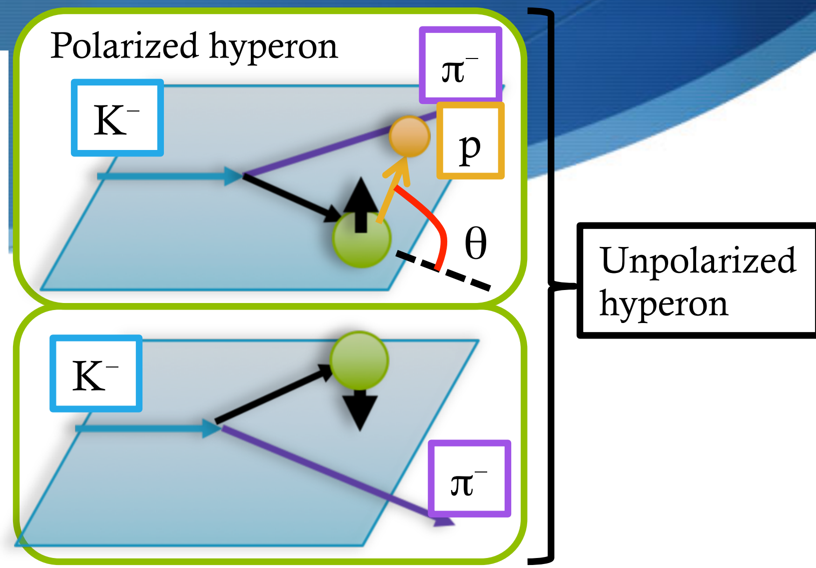


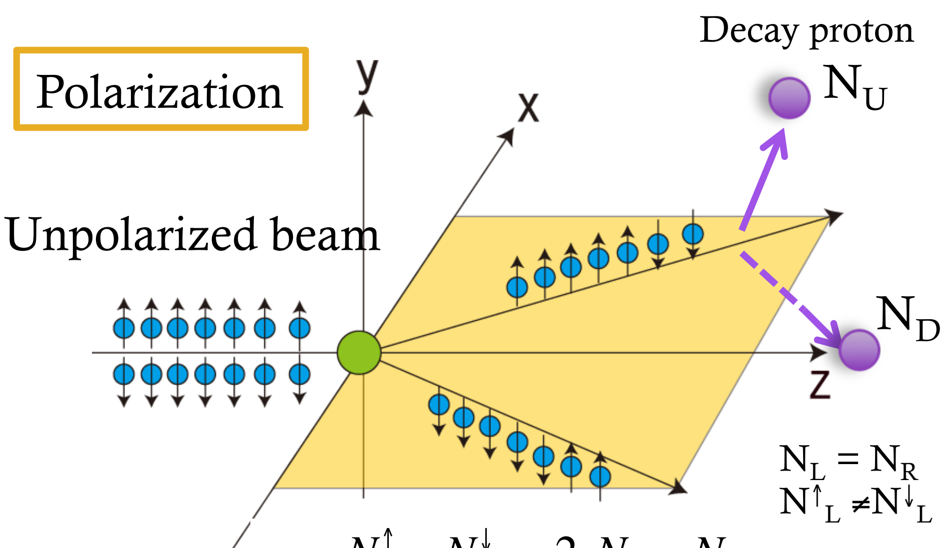


$K^-n \rightarrow \pi^-\Lambda^{\uparrow}$ should be measured

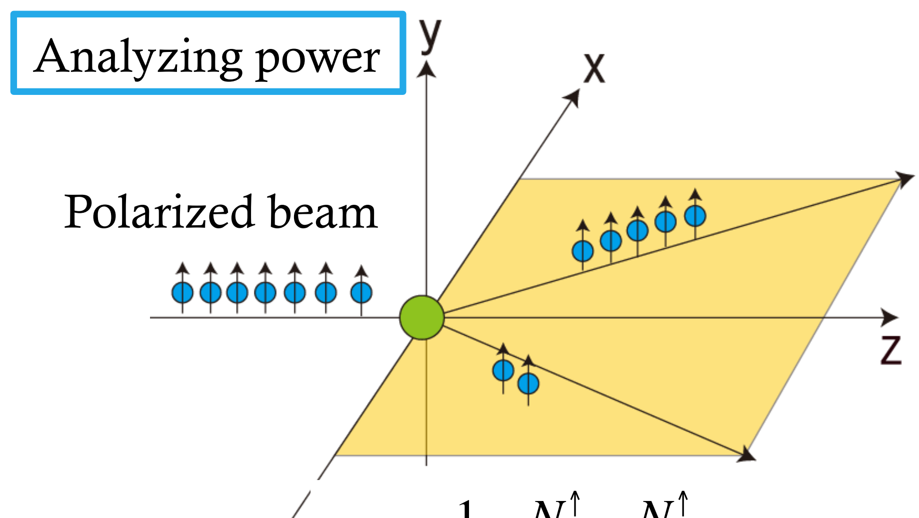
Possible Spin observables

- Advantage of Yp scattering in spin observables
  - Control of polarized Y beam and unpolarized Y beam
  - Spin direction of Y can be identify from the decay proton
    - $I(\theta) = I_0(1+\alpha P\cos\theta)$, α : asymmetry parameter, P : polarization
      - Λ ($\pi^- p$ decay mode) : $\alpha = 0.642 \pm 0.013$
      - Σ^+ ($\pi^0 p$ decay mode) : $\alpha = 0.98^{+0.017}_{-0.015}$





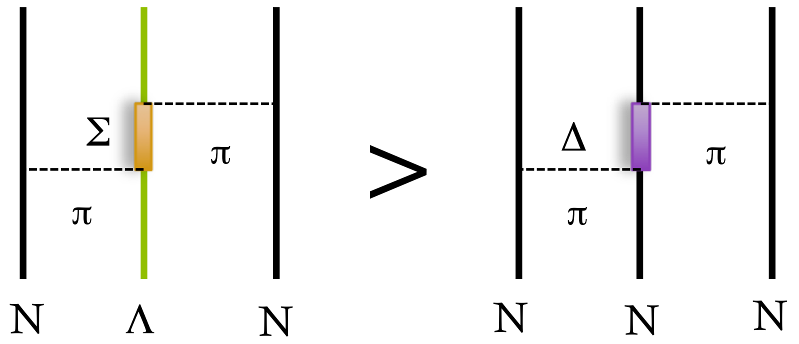
$$P_y = \frac{N_L^\uparrow - N_L^\downarrow}{N_L^\uparrow + N_L^\downarrow} = \frac{2}{\alpha}\frac{N_U - N_D}{N_U + N_D}$$



$$A_y = \frac{1}{P_{beam}}\frac{N_L^\uparrow - N_R^\uparrow}{N_L^\uparrow + N_R^\uparrow}$$

Physics purpose of Yp scatterings

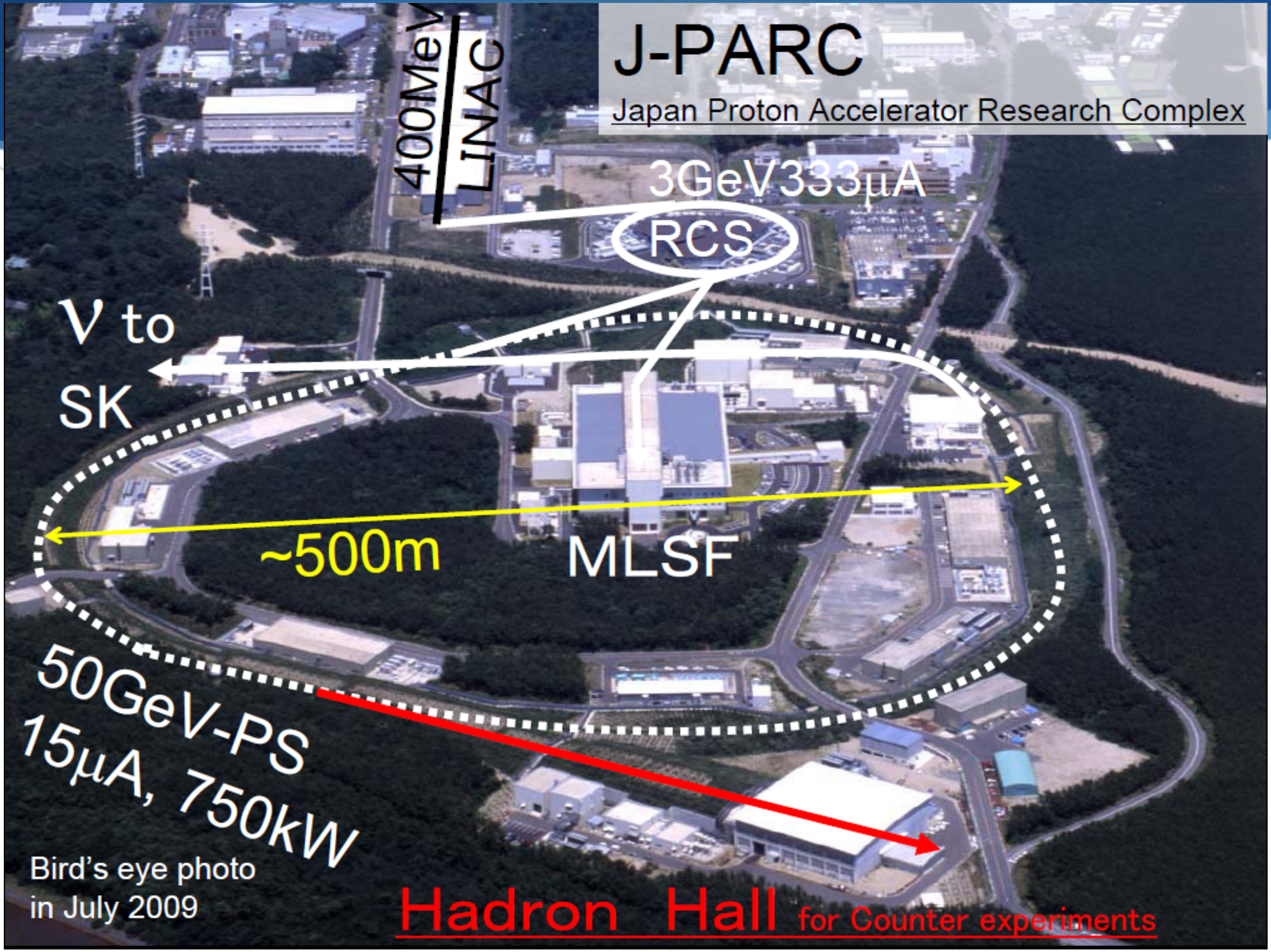
- Precise measurement of dσ/dΩ
  - Phase shift of Σ^+p (quark Pauli forbidden) channel more up to p_Σ ~ 1 GeV/c
    - Size of repulsive core
- Spin observables (Polarization, Analyzing power)
  - Λp channel (Polarization)
    - LS(-) force (spin dependent force from quark picture)
  - Σ^+p channel
- YNN three body interaction
  - Λd channel
  - Σd channel



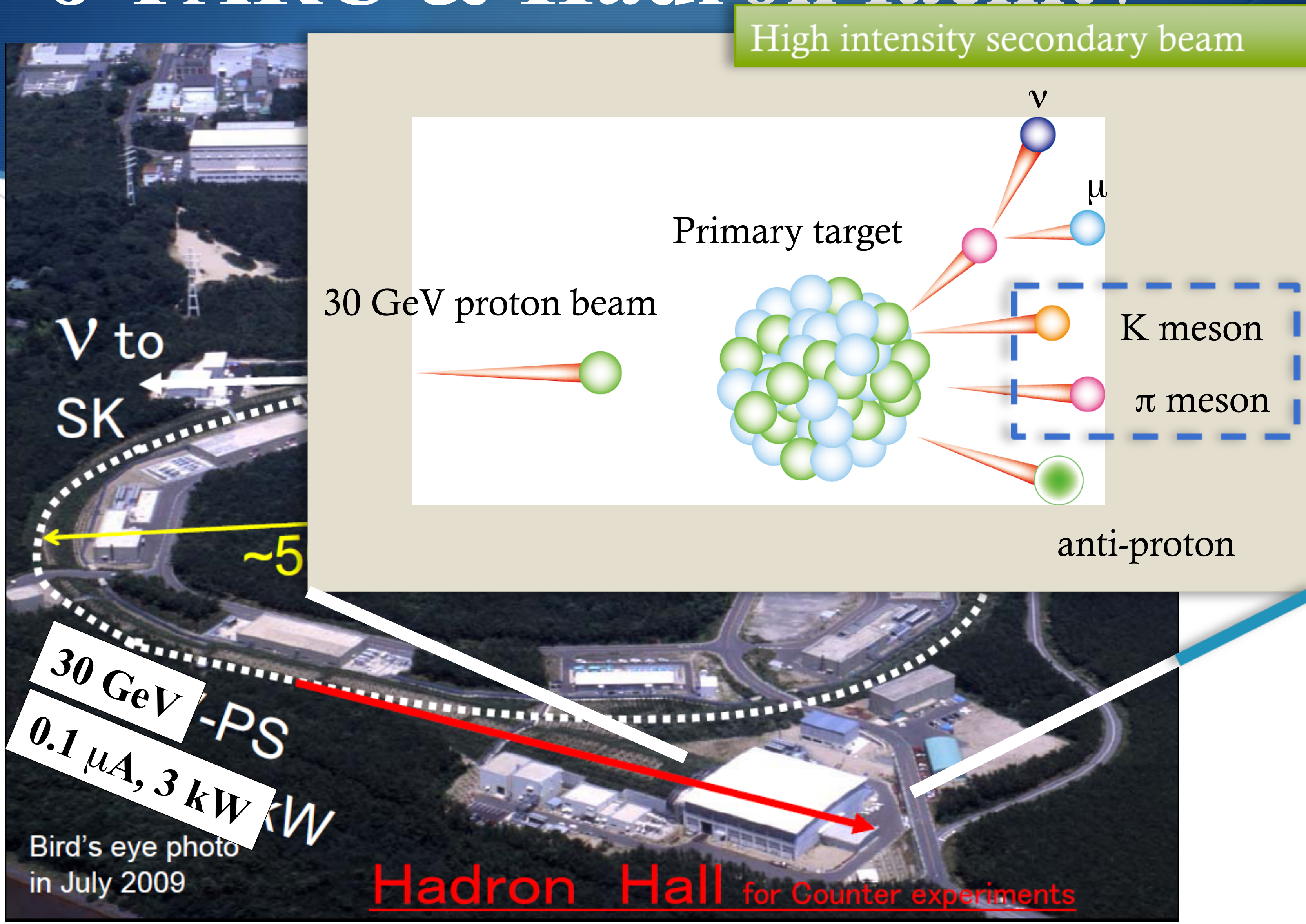
$\Delta m(\Sigma\text{-}\Lambda) < \Delta m(\Delta\text{-}N)$

Σp散乱実験
(J-PARC E40)

J-PARC & Hadron facility

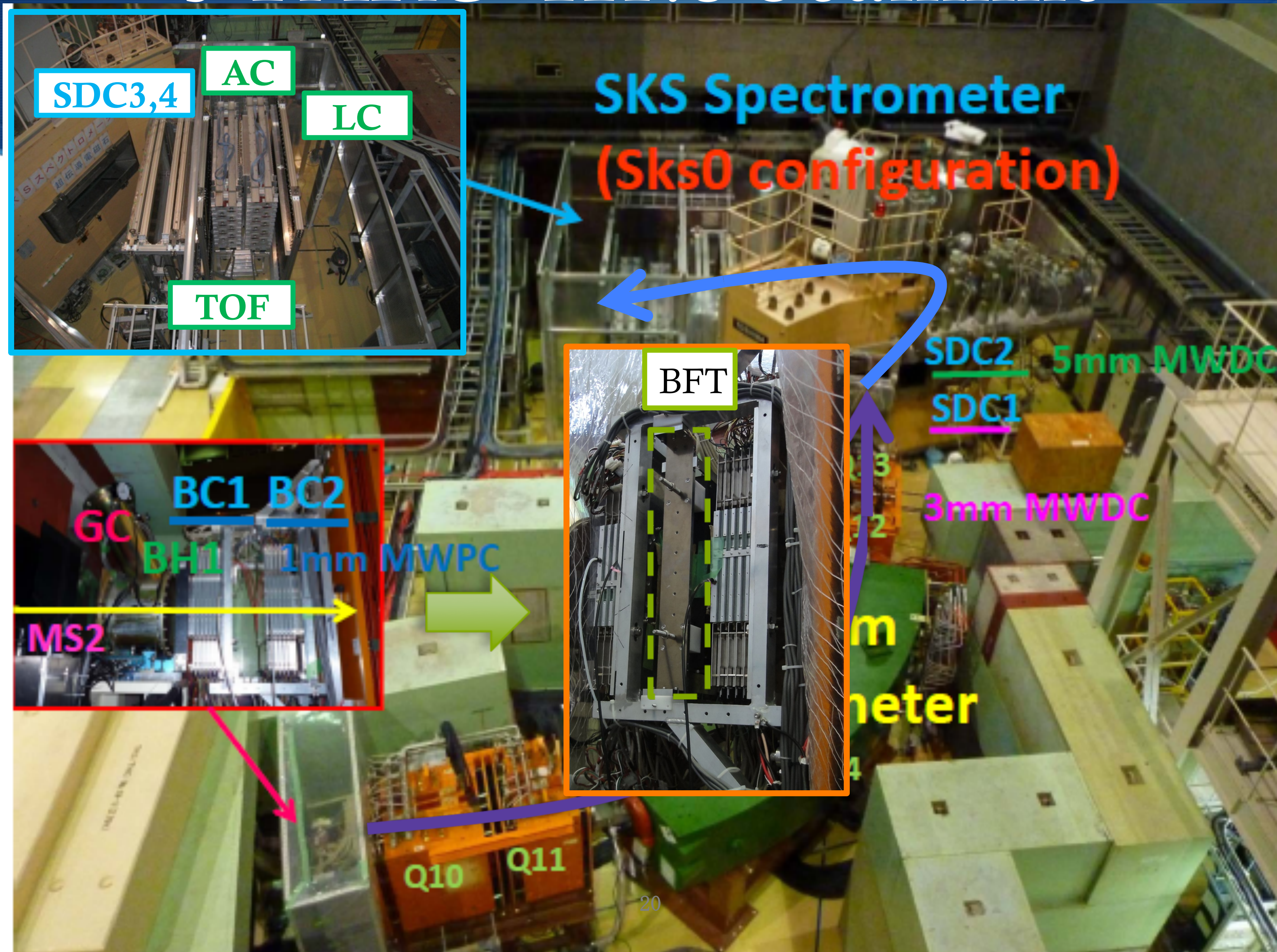


J-PARC & Hadron facility



MR present operation : 30 GeV, 1/100 intensity

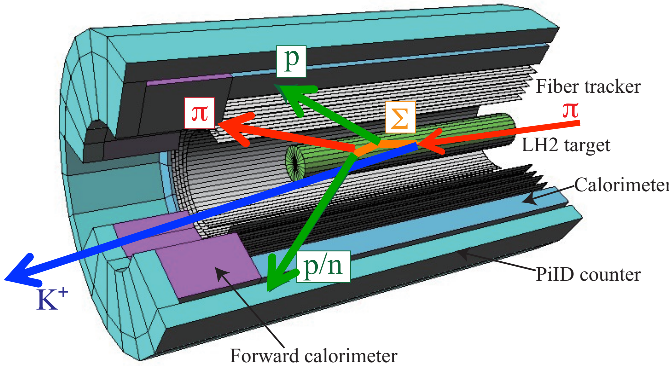
J-PARC K1.8 beamline



J-PARC E40 :
Measurement of dσ/dΩ of Σp scatterings

- Physics motivations
  - Verification of repulsive force due to quark Pauli effect in the Σ^+p channel
  - Systematic study of the ΣN interaction by separating isospin channel

- Measurement of dσ/dΩ
  - Aim to detect 10,000 events
  - Σ^+p elastic scattering
  - Σ^-p elastic scattering
  - $\Sigma^-p \rightarrow \Lambda n$ inelastic scattering



Kinematical identification of Σp scattering
Using LH_2 target and surrounding detector

Experimental key issues
- Usage of high intensity π beam : 2×10^7 / spill (spill = 2 sec)
- Large acceptance detector for scattered proton

Collaborators

Tohoku Univ. : Y. Akazawa, N. Chiga, N. Fujioka, M. Ikeda, H. Kanda,
T. Koike, Y. Matsumoto, K. Miwa, Y. Ogura, S. Ozawa,
Y. Sasaki, T. Shiozaki, H. Tamura, H. Umetsu

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H. Sugimura, K. Tanida

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T. Takahashi, M. Tanaka, M. Ukai, T.O. Yamamoto

Chiba Univ. : H. Kawai, M. Tabata

Kyoto Univ. : M. Naruki

Osaka Univ. : S. Hayakawa, T. Hayakawa, R. Honda, K. Kobayashi, M. Moritsu,
Y. Nakada, M. Nakagawa, A. Sakaguchi

RCNP :, K. Shirotori, T.N. Takahashi

Okayama Univ. : K. Yoshimura

Korea Univ. : J.K. Ahn

OMEGA Ecole Polytechnique-CNRS/IN2P3 : S. Callier, C.d.L. Taille, L. Raux

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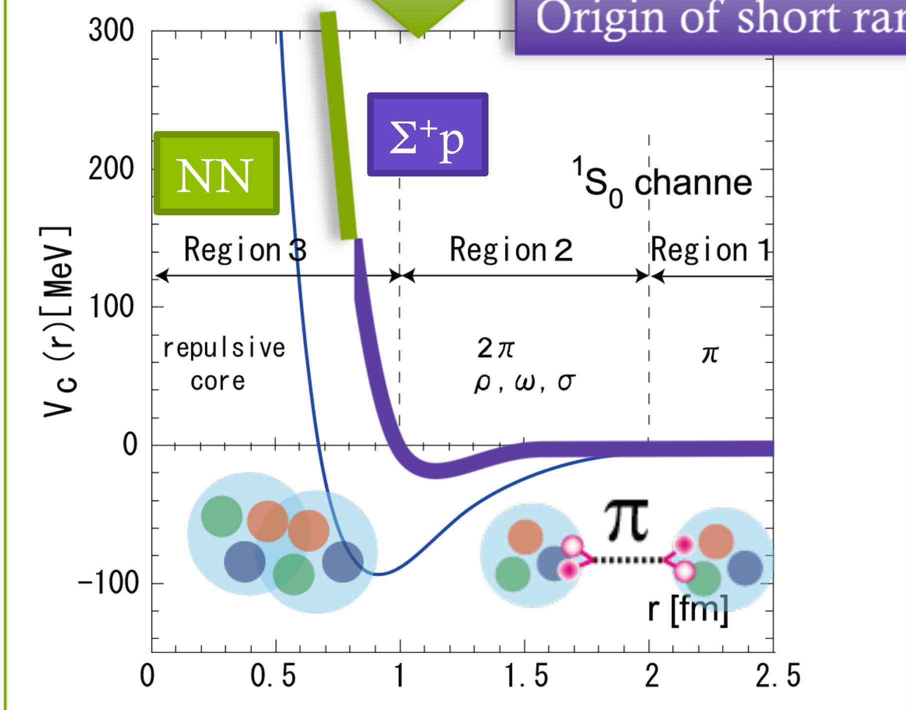
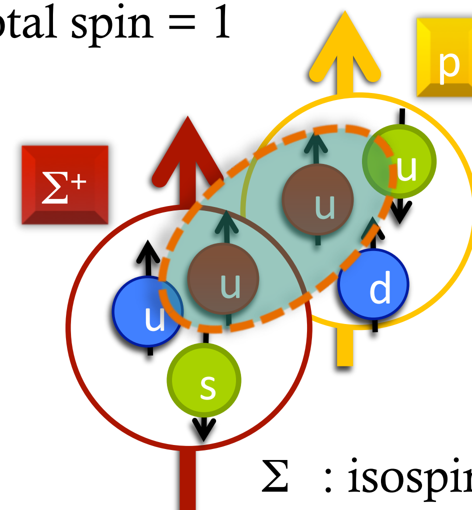
Quark Pauli repulsive force in $\Sigma^+ p$ channel

- Quark picture
  - 2 u quarks have the same state in color, spin, flavor
  - Pauli repulsive force between quarks

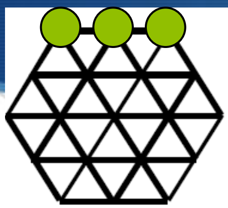
Larger repulsive core
Origin of short range core





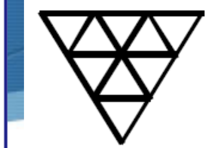
Σ : isospin 1
spin of u (d) quark is same

Repulsive force in Σ^+p ($=\Sigma^-n$) channel



(27)

ΣN (I = 3/2)	Spin Singlet	Spin Triplet
	(27) Same with NN(I=1,S=0)	(10) Almost Pauli forbidden

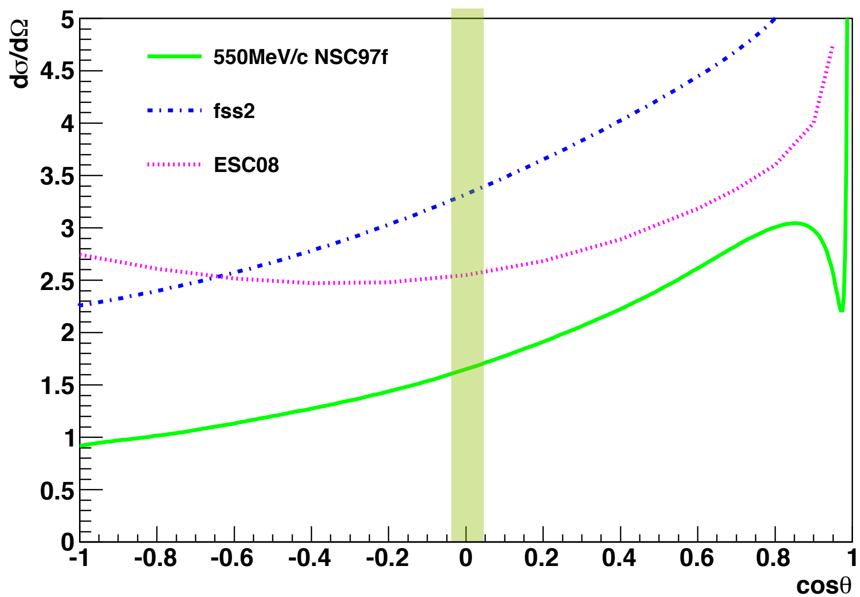


(10)

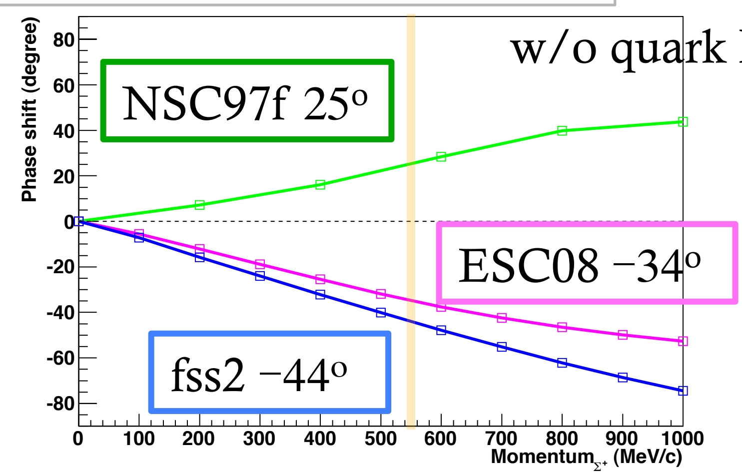
Spin weight: 1/4

Spin weight: 3/4

Σ^+p $d\sigma/d\Omega$ (p = 550 MeV/c)



Phase shift of Σ^+p ($^3S_1$ channel)



w/o quark Pauli

w/ quark Pauli

We will determine δ in $^3S_1$ channel.

Phase shift δ and dσ/dΩ(90°)

- Importance of dσ/dΩ(θ=90°) measurement
  - Contribution from S-wave
  - Behavior of S-wave is sensitive to the inner part of interaction

Negligibly small

$$\sum_{l=0}^{\infty}(2l+1)e^{i\delta_l}\sin\delta_l P_l(\cos\theta)\Big|^2$$

NOT model dependent

1,3,….

$$\frac{d\sigma}{d\Omega}(90^0)=\frac{1}{4}\frac{1}{k^2}\sin^2\delta_{1S0}+\frac{3}{4}\frac{1}{k^2}\sin^2\delta_{3S1}+(\text{higher waves, etc})$$

$^1S_0$ channel | $^3S_1$ channel

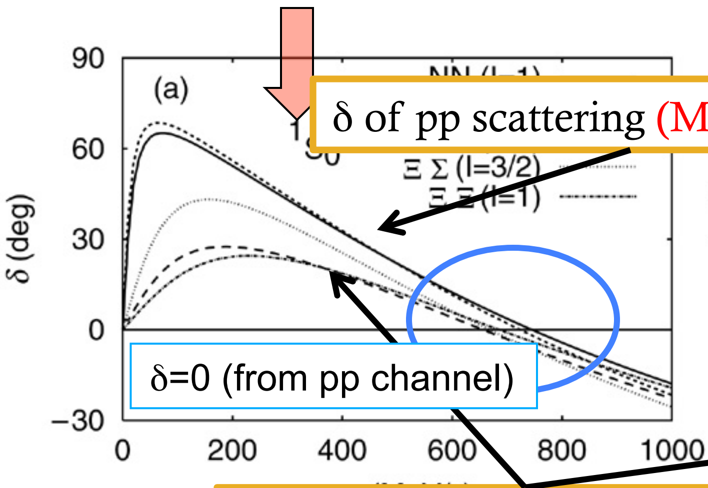
Σ^+p channel | dσ/dΩ(90°) → Phase shift $|\delta_{3S1}|$ | $|\delta|$ of $^3S_1$ (Pauli forbidden)

How about $^1S_0$ contribution ?
How about the contribution of D wave ?

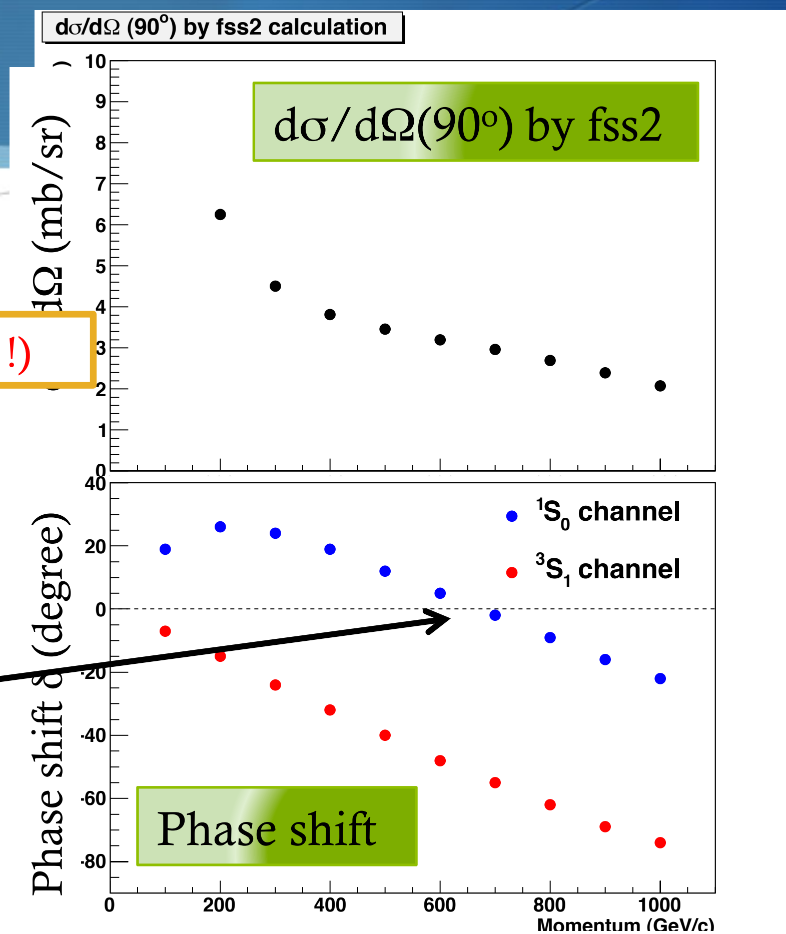
Relation between dσ/dΩ(90°) and each components

-- check by theoretical calculation --

	Spin Singlet	Spin Triplet
ΣN (I = 3/2)	(27) Same with NN(I=1,S=0)	(10) Almost Pauli forbidden



δ of Σ^+p scattering (Reliable !)



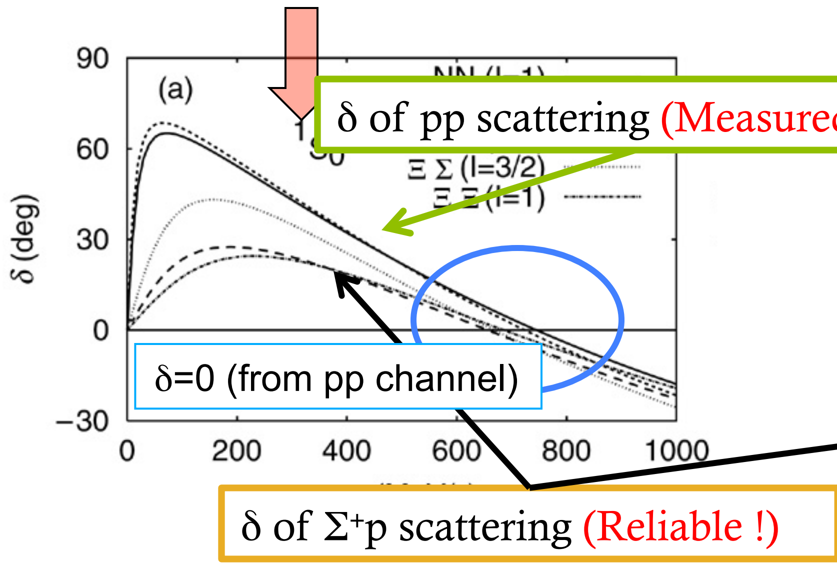
Momentum (GeV/c)

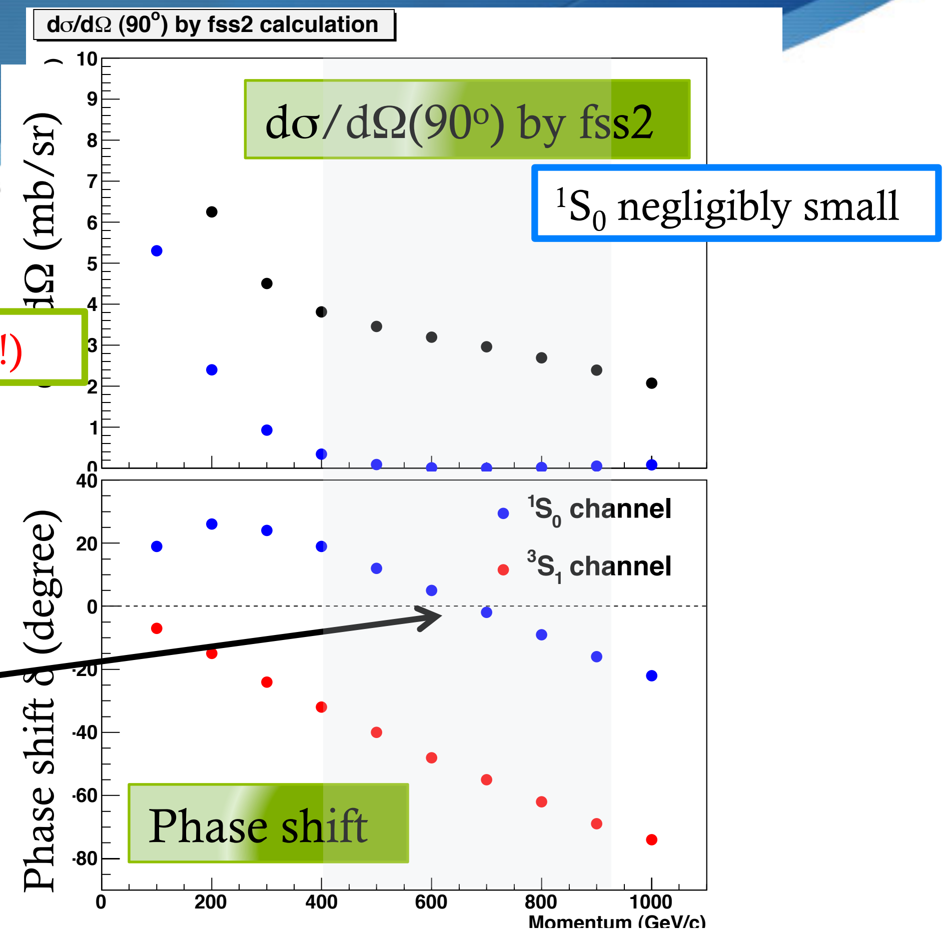
Y. Fujiwara *et al.* Prog. Part. Nucl. Phys. 58(2007) 439

Can we obtain phase shift in Pauli forbidden channel ?

-- check by theoretical calculation --

	Spin Singlet	Spin Triplet
ΣN (I = 3/2)	(27) Same with NN(I=1,S=0)	(10) Almost Pauli forbidden





Y. Fujiwara *et al.* Prog. Part. Nucl. Phys. 58(2007) 439

Momentum (GeV/c)

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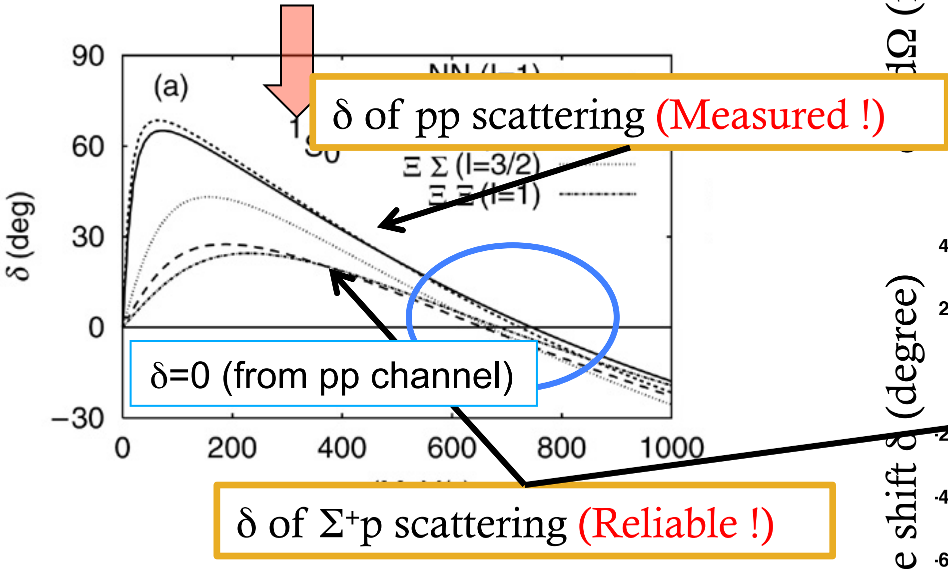

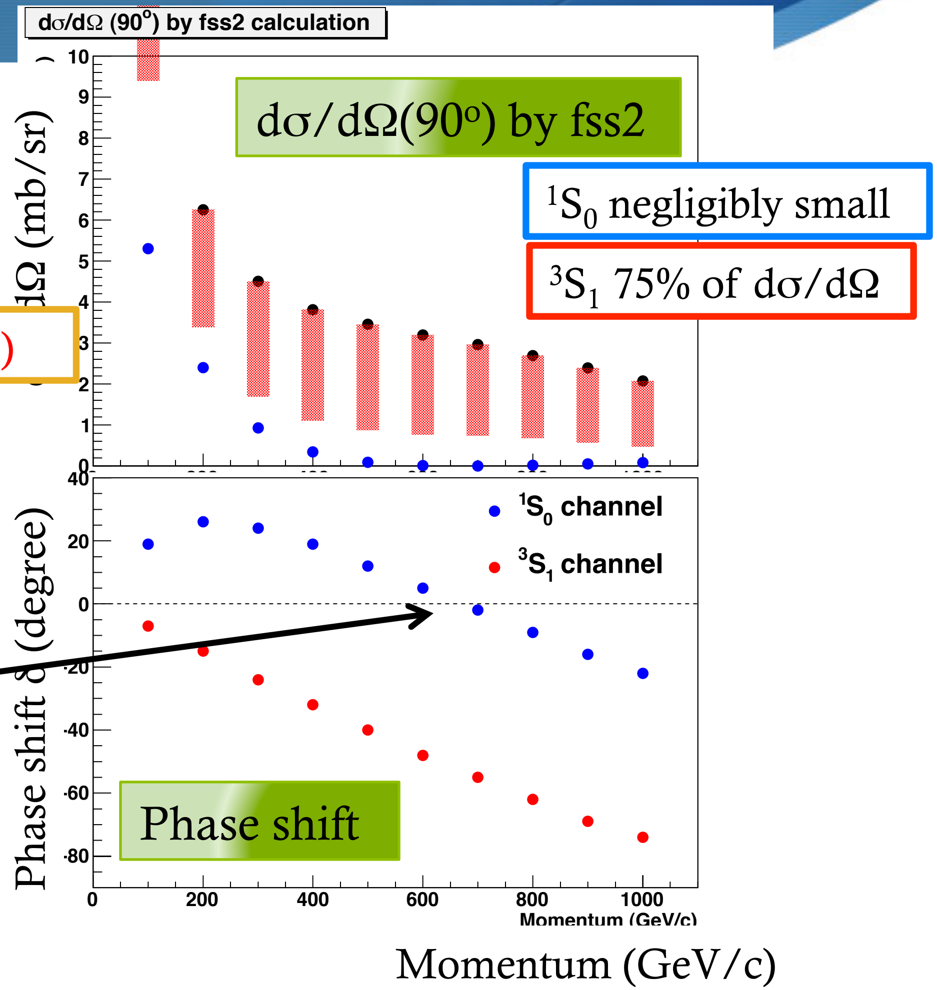

Y. Fujiwara *et al.* Prog. Part. Nucl. Phys. 58(2007) 439

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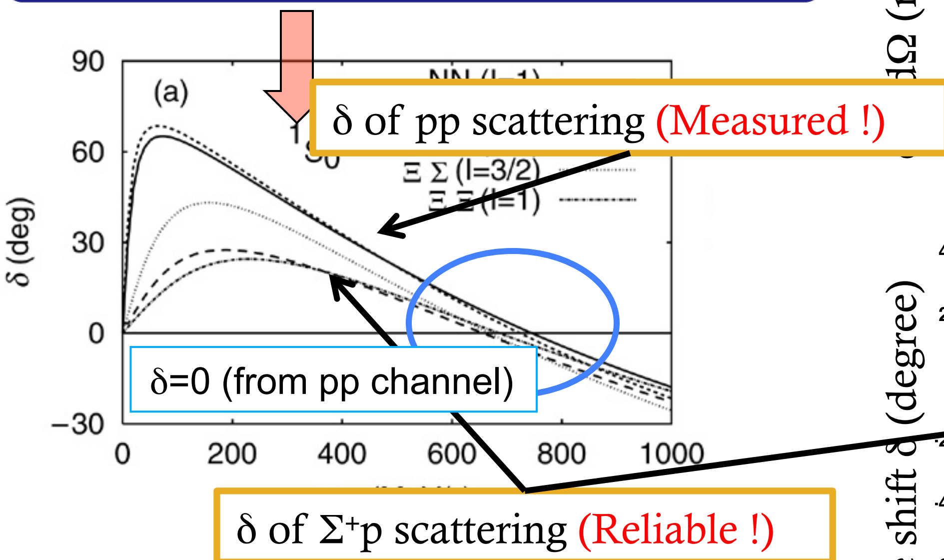
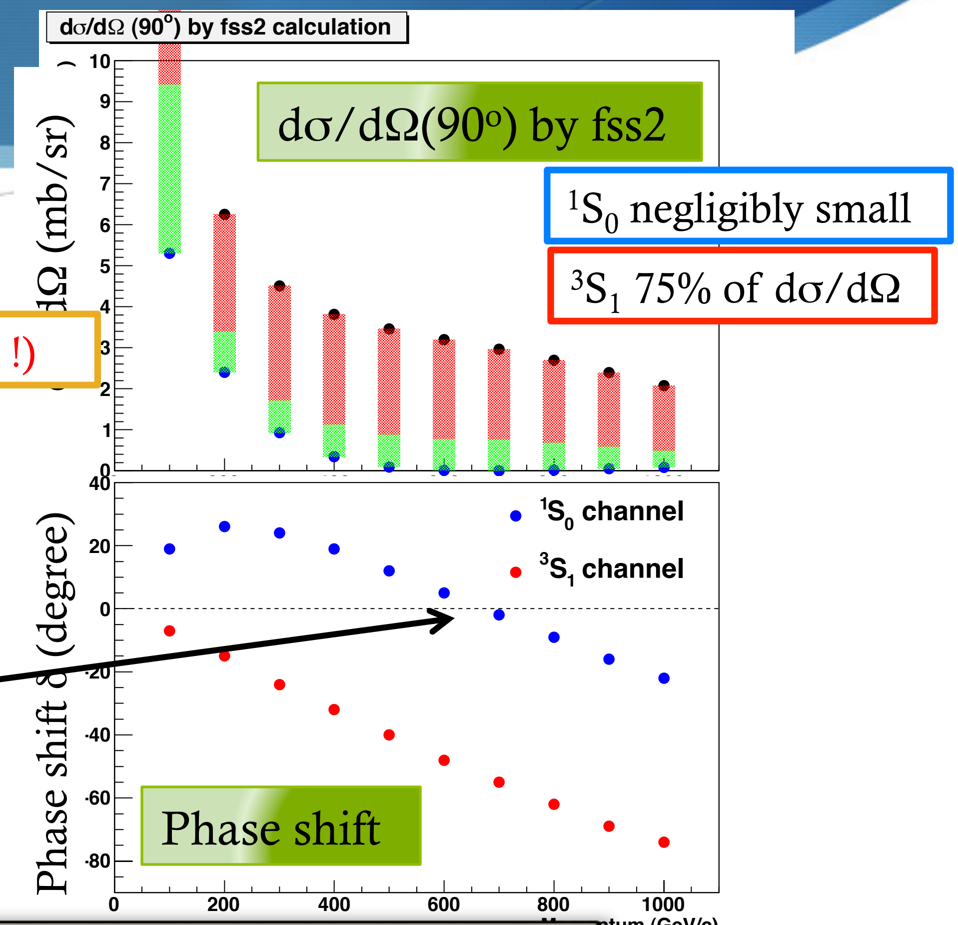




Y. Fujiwara *et al.* Prog. Pa

$d\sigma/d\Omega(90^o)$ is dominated by $^3S_1$ contribution

Constraint δ_{3S1} from $d\sigma/d\Omega(90^o)$

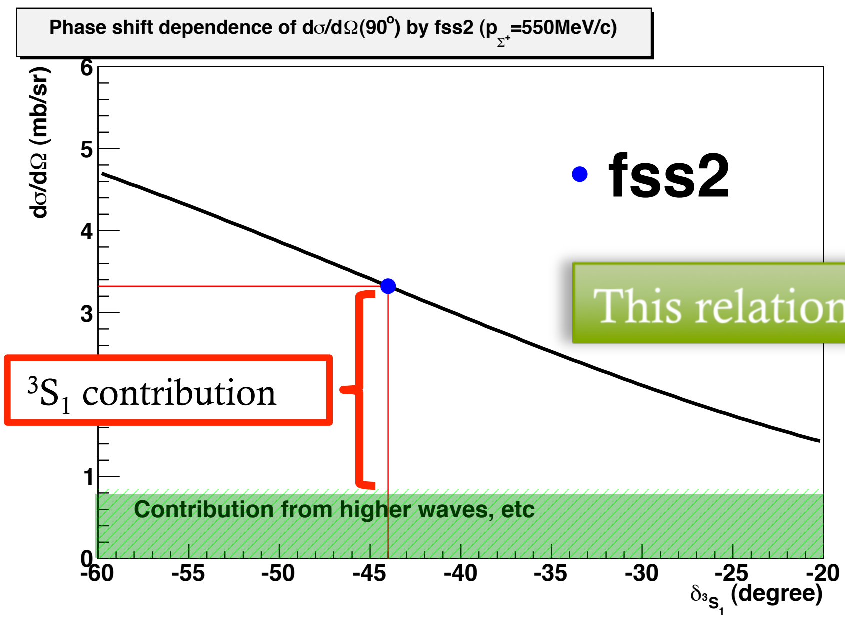
- Estimation of dependence of δ_{3S1} for $d\sigma/d\Omega(90^o)$
  - Large dependence of δ_{3S1} is expected

Calculation from fss2

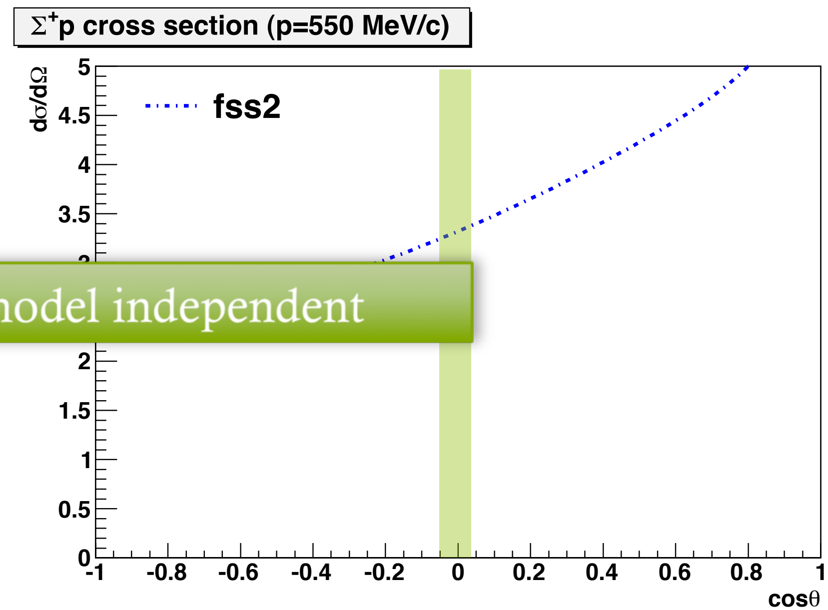
$$\frac{d\sigma}{d\Omega}(90^0) = \frac{3}{4}\frac{1}{k^2}\sin^2\delta_{3S1} + (\text{higher waves})$$

Native estimation

Constant for δ_{3S1}



$^3S_1$ contribution



This relation is model independent

Constraint δ_{3S1} from $d\sigma/d\Omega(90^o)$

- Estimation of dependence of δ_{3S1} for $d\sigma/d\Omega(90^o)$
  - Large dependence of δ_{3S1} is expected

$$\frac{d\sigma}{d\Omega}(90^0) = \frac{3}{4}\frac{1}{k^2}\sin^2\delta_{3S1} + (\text{higher waves})$$

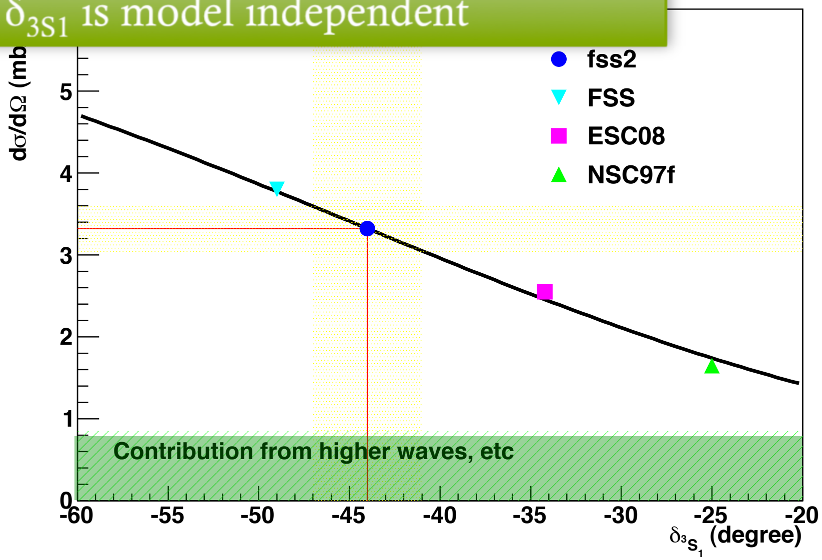
Native estimation

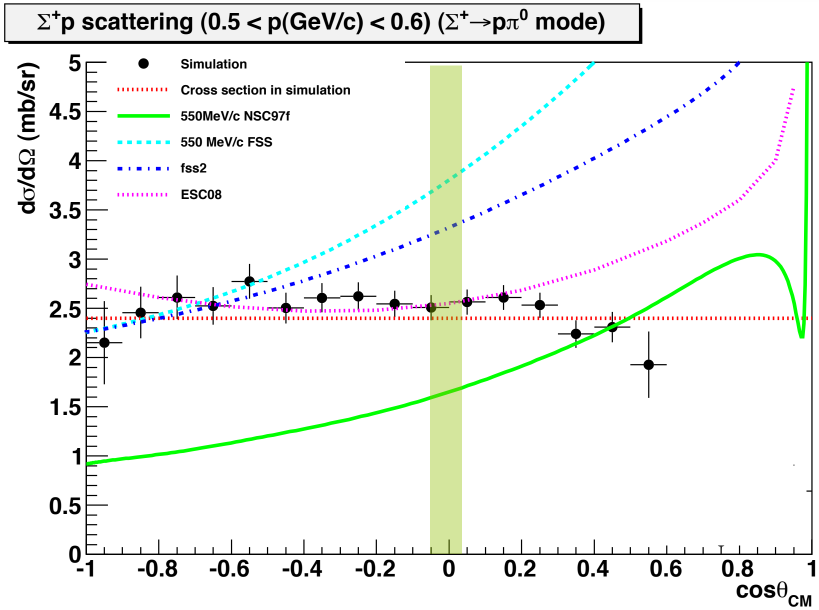
Constant for δ_{3S1}

Not related to short range region

The $d\sigma/d\Omega(90^o)$ for each models can be understood from δ_{3S1}

Relation between $d\sigma/d\Omega(90^o)$ and δ_{3S1} is model independent





Constraint δ_{3S1} from dσ/dΩ(90°)

- Estimation of dependence of δ_{3S1} for dσ/dΩ(90°)
  - Large dependence of δ_{3S1} is expected

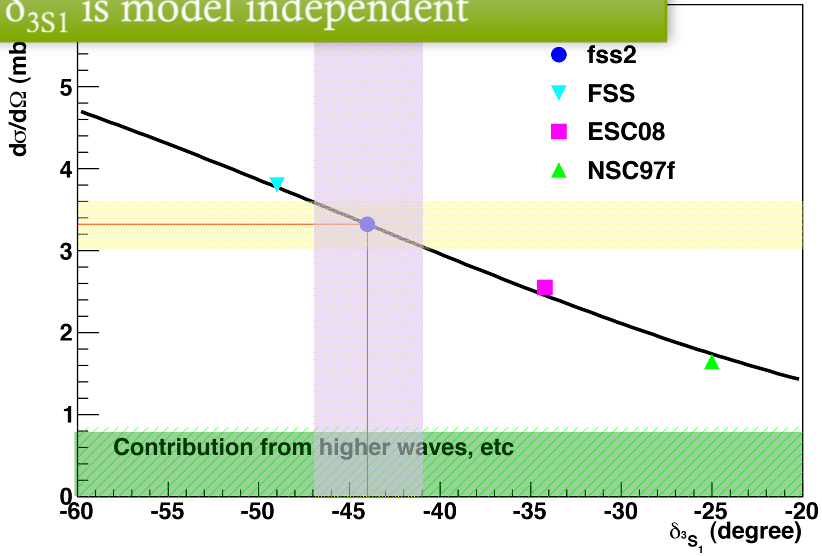
$$\frac{d\sigma}{d\Omega}(90^0) = \frac{3}{4}\frac{1}{k^2}\sin^2\delta_{3S1} + (\text{higher waves})$$

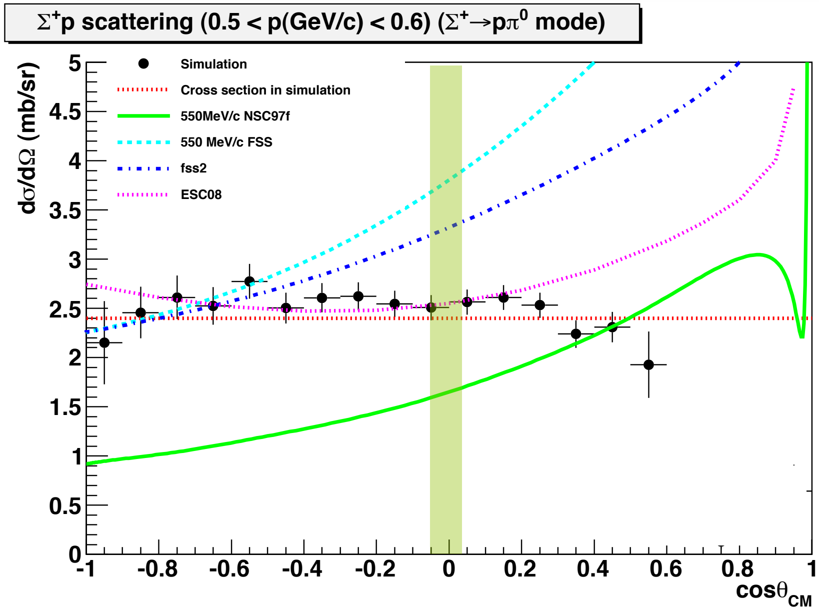
Native estimation

Constant for δ_{3S1}

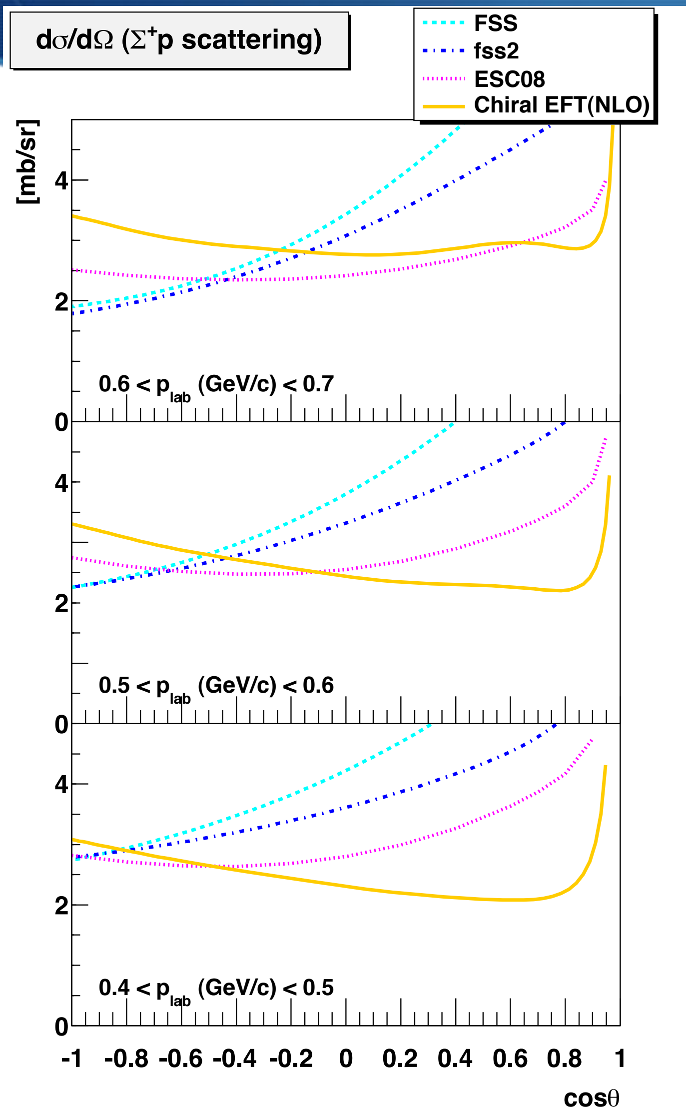
The dσ/dΩ(90°) for each models can be understood from δ_{3S1}

Relation between dσ/dΩ(90°) and δ_{3S1} is model independent



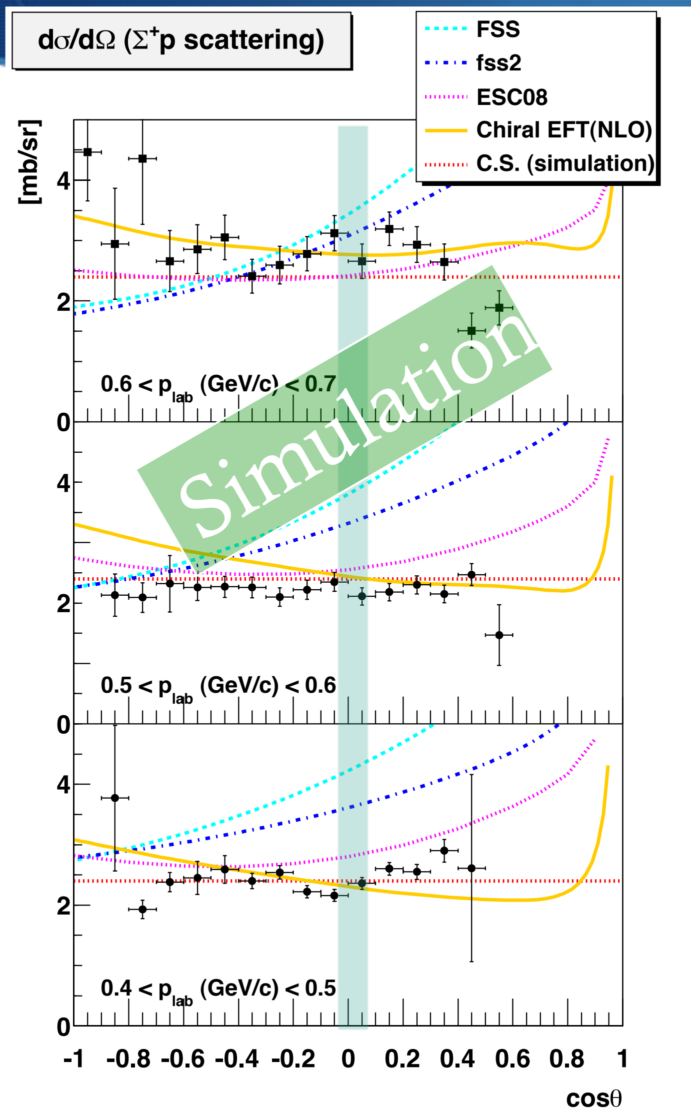


Σ^+p channel ($d\sigma/d\Omega$ and phase shift δ_{3S1})



- Cross section
  - Quark Cluster model (FSS, fss2)
    - Y. Fujiwara et al., Prog. in Part. and Nucl. Phys. 58 (2007) 429, and private communication
  - Nijmegen model (ESC08c)
    - T. A. Rijken, Prog. of Theor. Phys. Suppl. 185 (2010) 14, and private communication
  - Chiral EFT (NLO)
    - J. Haidenbauer et al., Nucl. Phys. A 915 (2013) 24, and private communication
  - Large repulsive core → Cross section large

Σ^+p channel ($d\sigma/d\Omega$ and phase shift δ_{3S1})



- Cross section
  - Quark Cluster model (FSS, fss2)
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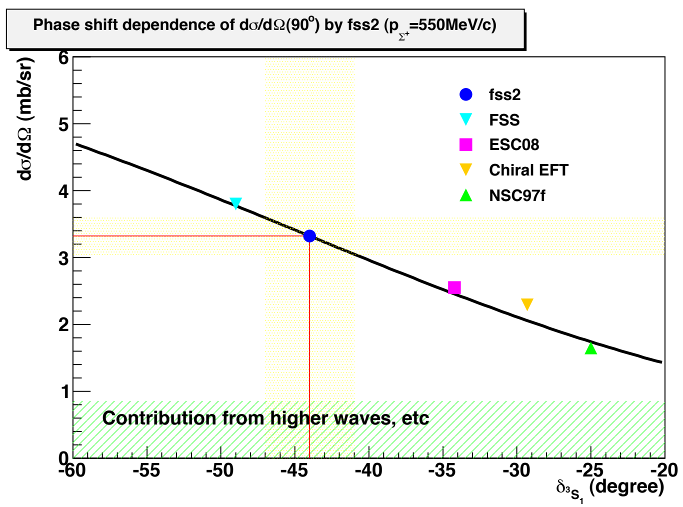
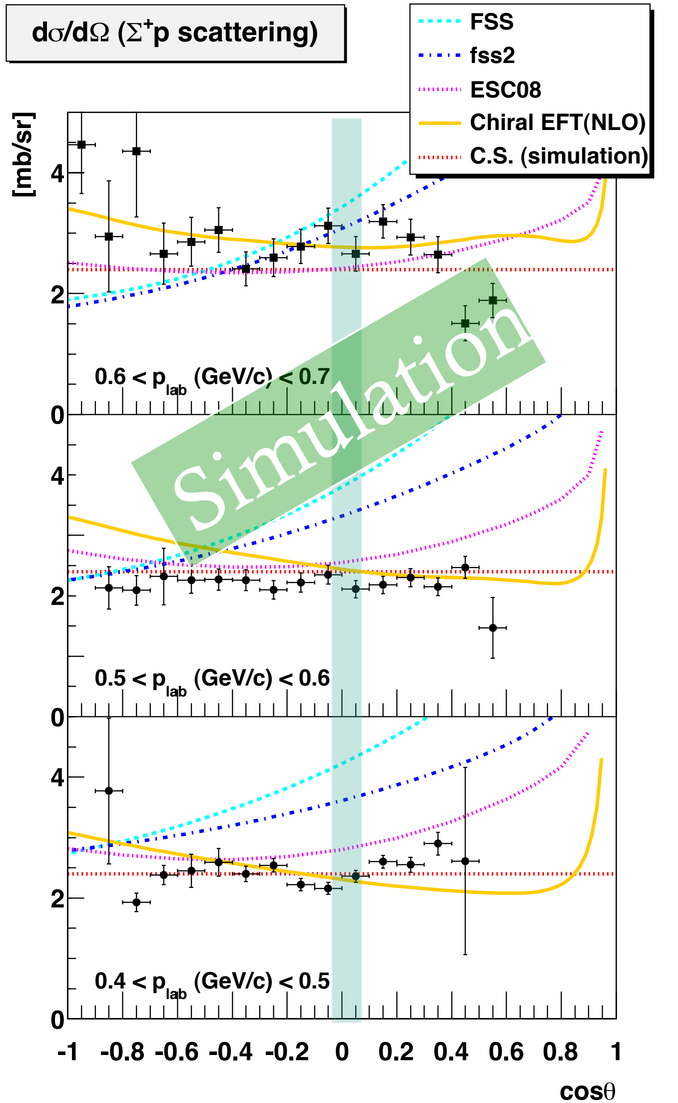
  - Chiral EFT (NLO)
  - Large repulsive core → Cross section large
- $d\sigma/d\Omega(90^o)$: dominated by $^3S_1$ contribution

$$\frac{3}{4}\frac{1}{k^2}\sin^2\delta_{3S1} = \frac{d\sigma}{d\Omega}(90^0) - (\text{higher waves})$$



Σ^+p channel ($d\sigma/d\Omega$ and phase shift δ_{3S1})



- Cross section
  - Quark Cluster model (FSS, fss2)
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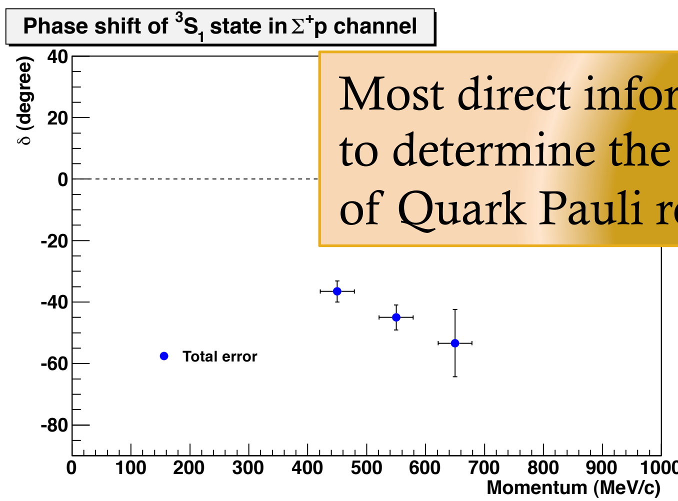


Most direct information to determine the strength of Quark Pauli repulsive force.

Systematic study of ΣN interaction

- Unique spin-isospin dependence in the ΣN interaction

Σ nuclear potential

Model	(I,S) (3/2, 1) (MeV)	(3/2, 0) (MeV)	(1/2, 1) (MeV)	(1/2, 0) (MeV)	Sum (MeV)
ESC08a	44.8	−11.7	−23.9	11.3	+13.4
ESC08b	52.7	−10.6	−26.2	10.3	+20.3
fss2	41.2	−9.2	−23.9	6.7	+7.5

Repulsive Attractive

Most updated theories

Still "qualitative"

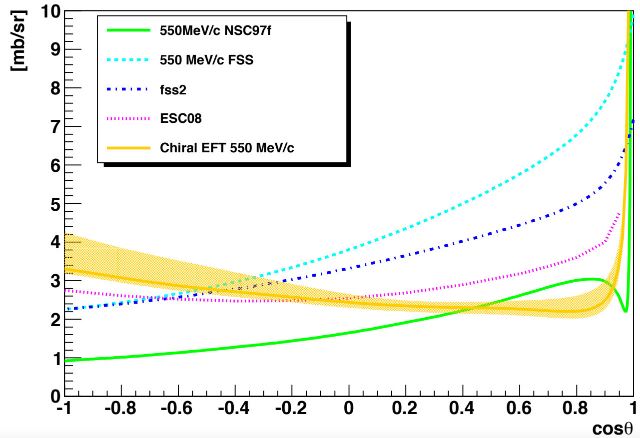
Limited data to ΣN interaction

- Σ-Nuclear data
- $^{4}_{\Sigma}$He hypernucleus

Systematic study of ΣN interaction

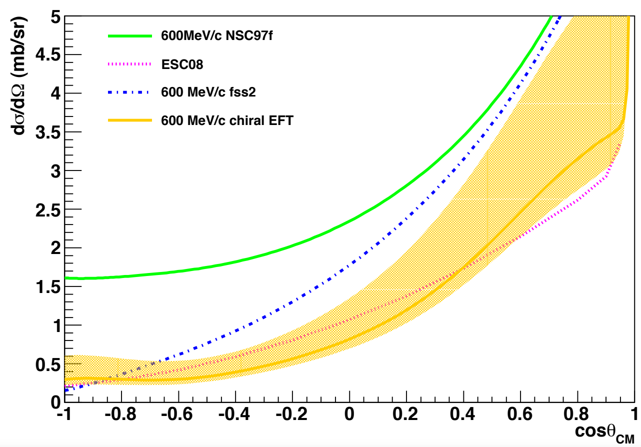
I=3/2

Σ^+p (0.5 < p (GeV/c) < 0.6)



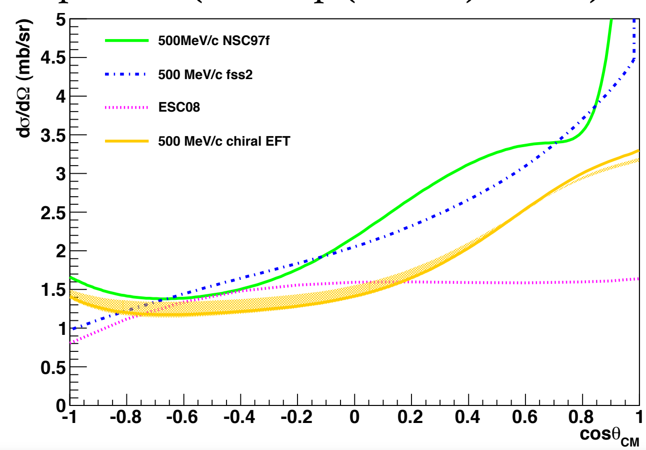
- ΣN interaction
  - limited information
    - No Σ hypernuclei except for $^4_\Sigma$He
- Σp scattering experiment
  - Unique method to investigate ΣN interaction by separating isospin channels
  - First data at higher Σ beam momentum
    - Higher wave contribution

Σ^-p (0.55 < p (GeV/c) < 0.65)



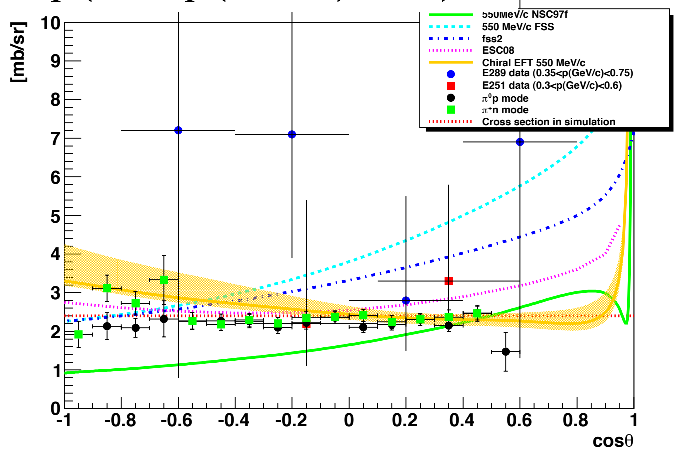
I=1/2

$\Sigma^-p \rightarrow \Lambda n$ (0.55 < p (GeV/c) < 0.65)



Systematic study of ΣN interaction

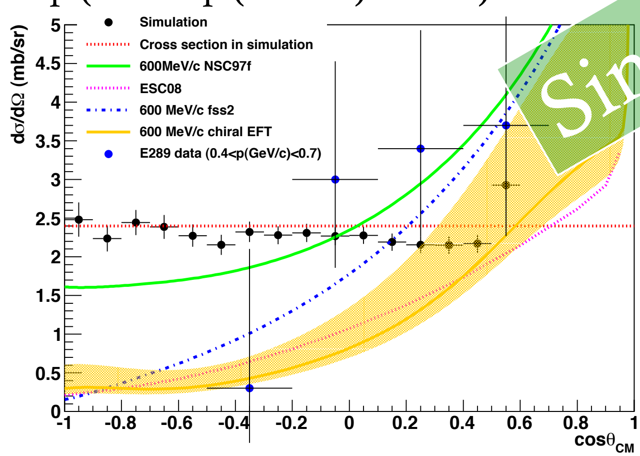
Σ^+p (0.5 < p (GeV/c) < 0.6)



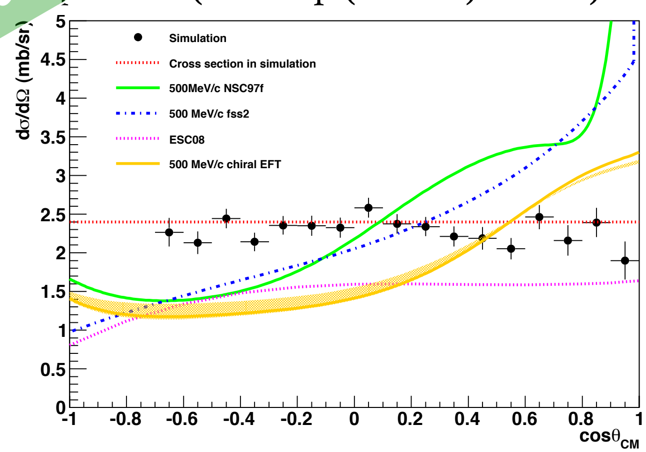
- Expected yield and accuracy
  - ds/dΩ : 2.4mb/sr isotropic distribution (assumed)
    - 20,000 scattering events
    - derive dσ/dΩ for 3 momentum ranges
  - Σ^-p : ±0.11 (stat.) ±0.15 (syst.) mb/sr for 2.4 mb/sr
  - Σ^+p : ±0.15 (stat.) ±0.15 (syst.) mb/sr for 2.4 mb/sr

Simulation

Σ^-p (0.55 < p (GeV/c) < 0.65)

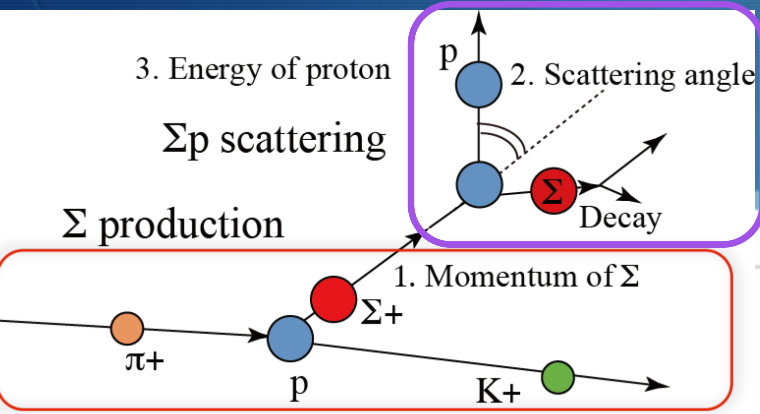


$\Sigma^-p \rightarrow \Lambda n$ (0.55 < p (GeV/c) < 0.65)

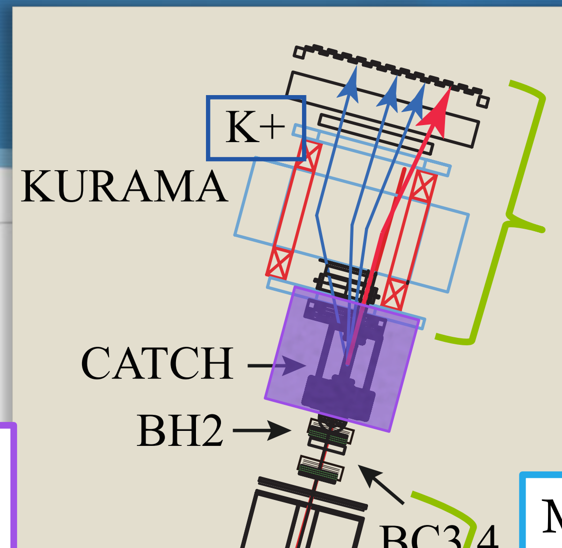


E40 detector setup concept

Two successive two-body reactions



Detection of Σp scattering event by CATCH detector



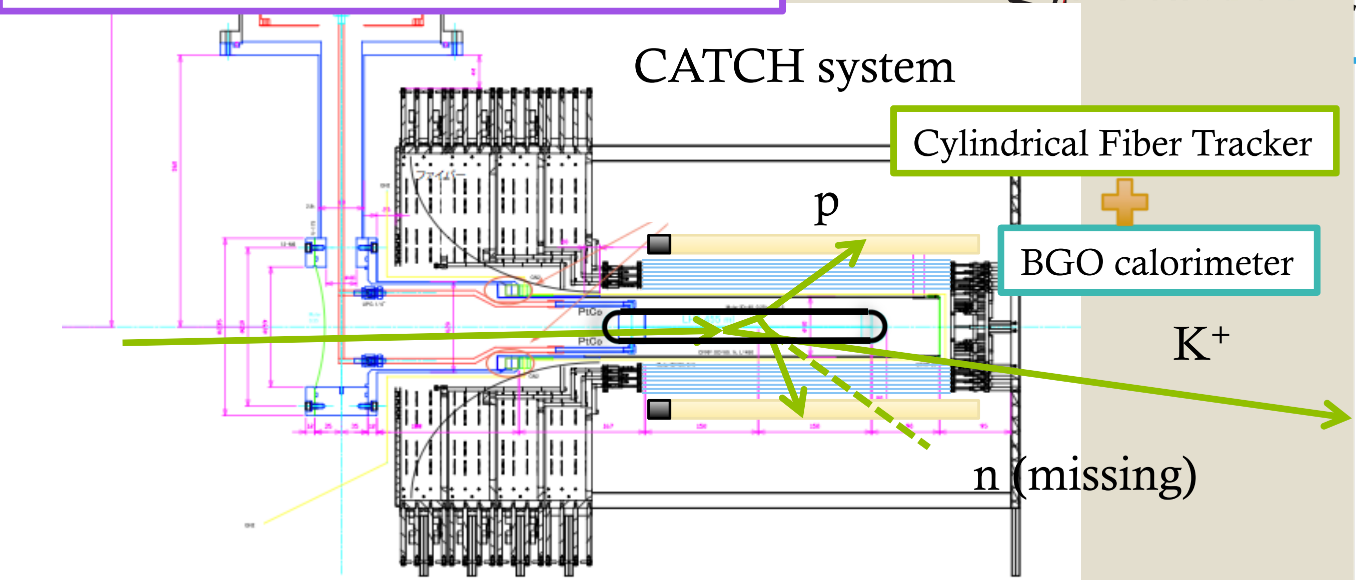
KURAMA spectrometer

- Identification of K^+
- Momentum analysis

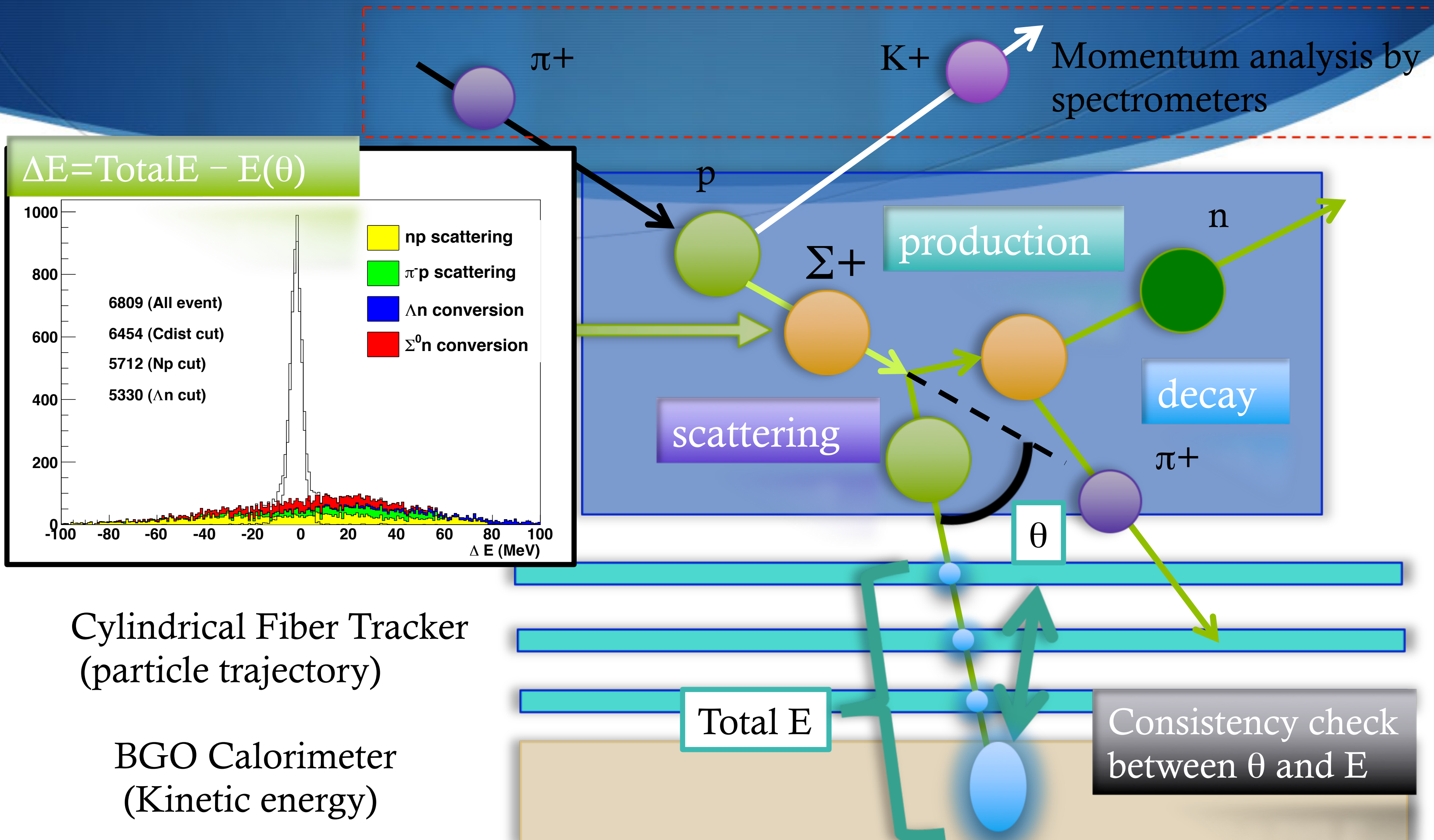
Momentum reconstruction of Σ beam

Beamline spectrometer

- Momentum analysis of π beam

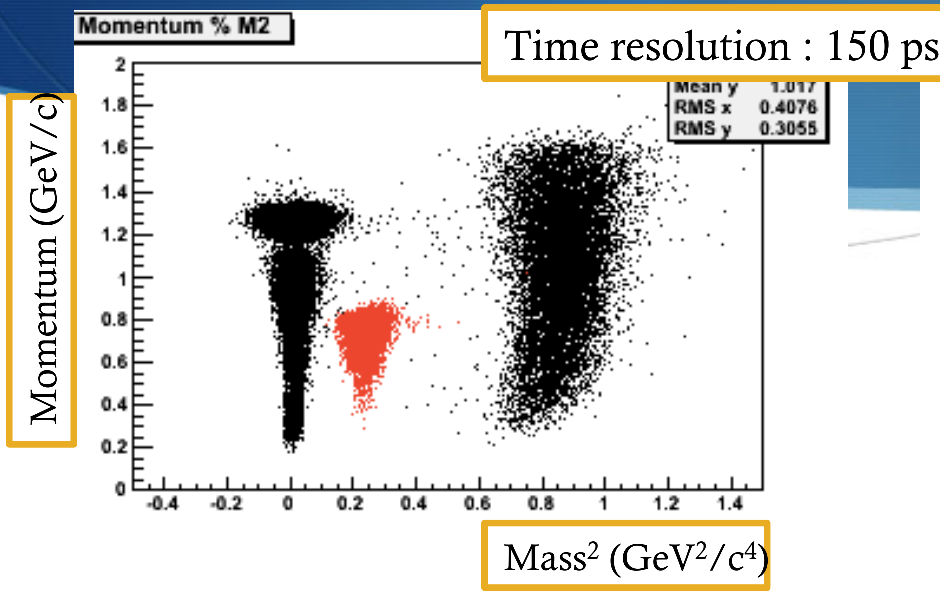


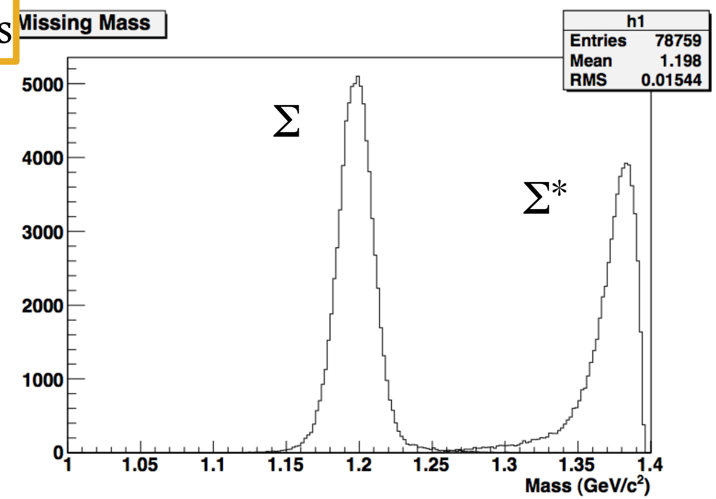
Principal of Σp scattering



Σp scattering simulation with whole detector setup

Σ production identification





- Identification of K^+
  - Can separate $\pi^+/K^+/p$ with time resolution of 150 ps
- Identification of Σ
  - Missing mass resolution of Σ (σ = 14 MeV/c^2)
  - No Λ contamination from neutron thanks to LH2 target
- Acceptance
  - Σ^- : 4.0%, Σ^+ : 6.7% : same with SKS
  - Flight length : 3 m → Improve survival rate 1.5 times

Resolution of KURAMA is rather worse.
However, we can identify Σ particles.

Thanks to the short flight length,
1.5 times more Σ yield is expected.

Σ yield summary

	$\Sigma^- p$ scattering
Cross section	245 μb
π^- beam intensity	2×10^7 /spill (2 sec beam time in6 sec cycle)
LH_2 target thickness	30 cm
KURAMA Acceptance	4.0%
Survival rate of K^+	59%
DAQ live time	70%
Analysis efficiency	70%
Tagged Σ^-/spill	72 /spill
Tagged Σ^-/day	0.97×10^6
Accumulated Tagged Σ^-	24×10^6 (24 days)
	$\Sigma^+ p$ scattering
Cross section	523 μb
π^+ beam intensity	2×10^7 /spill (2 sec beam time in6 sec cycle)
LH_2 target thickness	30 cm
KURAMA Acceptance	6.7%
Survival rate of K^+	65%
DAQ live time	70%
Analysis efficiency	70%
Tagged Σ^-/spill	283 /spill
Tagged Σ^-/day	4.0×10^6
Accumulated Tagged Σ^+	81×10^6 (20 days)

Basically same condition with proposal

Improved by KURAMA

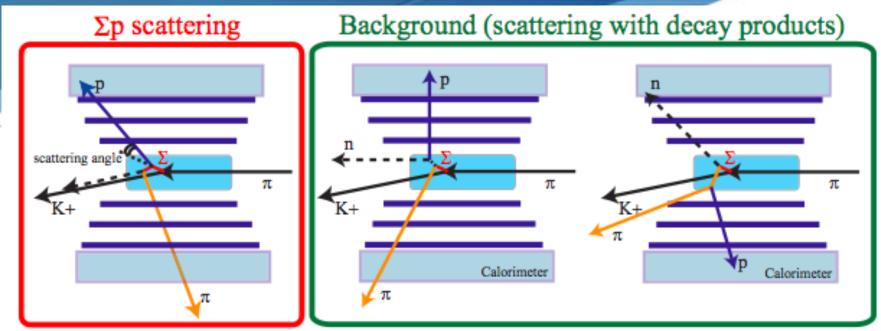
- Thanks to the short flight length in KURAMA, the Σ yield is expected to be ~1.5 times larger than that with SKS

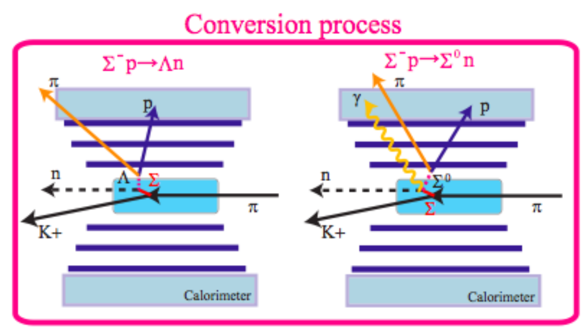
Σp scattering identification and background

- Main background
  - Elastic scattering between decay product of Σ particle and proton
  - Σ^+ case : proton from Σ^+ decay

Generated event

YN event : 2.4 mb/sr isotropic
Background : measured section





Simulation

- background process
  - based on cross section
- hadronic process in Geant
  - reaction of decay products
  - all decay events are simulated

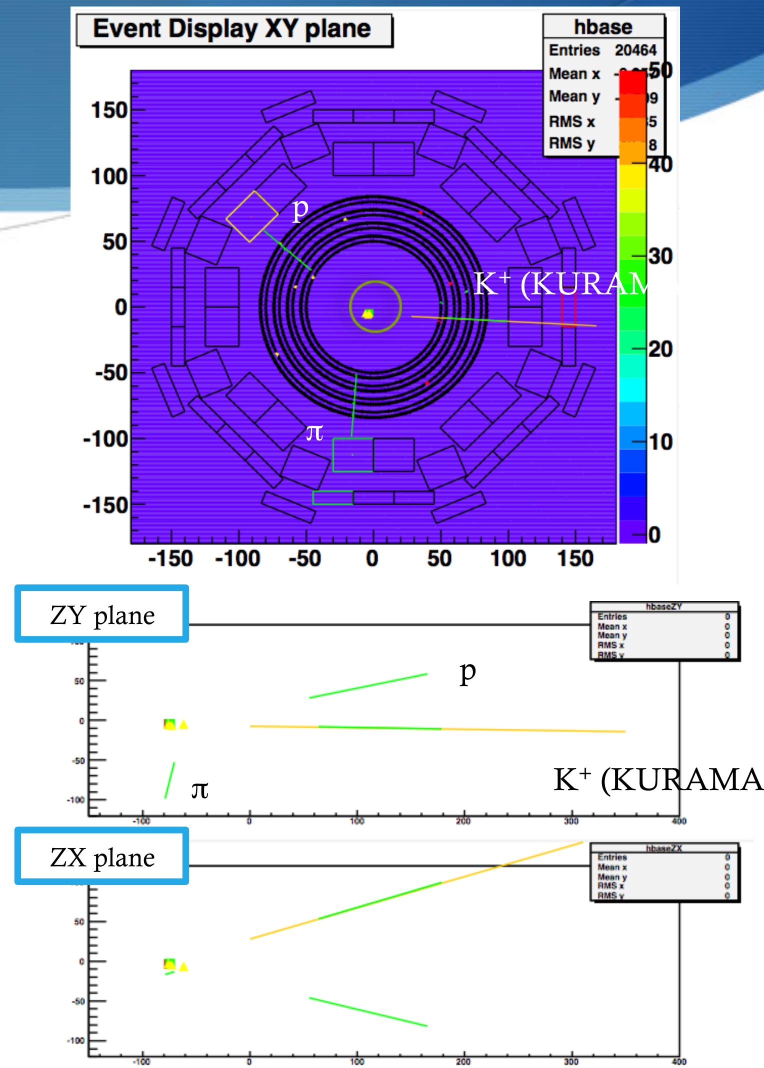
Geant hadronic process

To cover the unexpected reactions

- Interaction with CFT.
- Inelastic scattering etc.

Reconstruction procedure

- KURAMA analysis
  - Σ event selection from missing mass spectrum
- CATCH analysis
  - Select two track event
    - $\Sigma^{-}p$: proton and π^{-}
    - $\Sigma^{+}p$: two protons
    - proton and π^{+}
  - Scattering vertex cut
    - Require vertex is inside the LH_2 target
  - Kinematics reconstruction
    - Σp scattering
    - Background kinematics
      - $\Sigma^{-}p$: np, $\pi^{-}p$, $\Sigma^{-}p \rightarrow \Lambda n$ reactions
      - $\Sigma^{+}p$: pp, $\pi^{+}p$, $\Sigma^{+} \rightarrow \pi^{0}p$ decay
    - Reject background event in order to improve S/N ratio



Reconstruction procedure

$\Delta E = E_{measure} - E_{calculate}$

- KURAMA analysis
  - Σ event selection from missing mass spectrum
- CATCH analysis
  - Select two track event
    - $\Sigma^{-}p$: proton and π^{-}
    - $\Sigma^{+}p$: two protons
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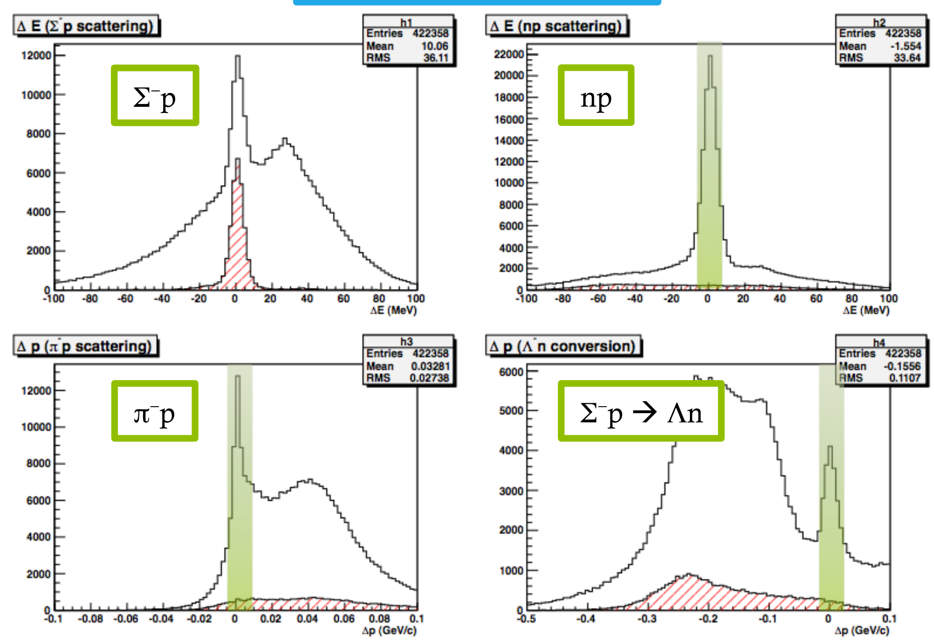
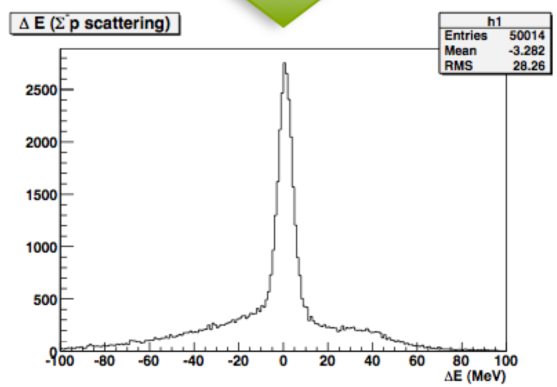
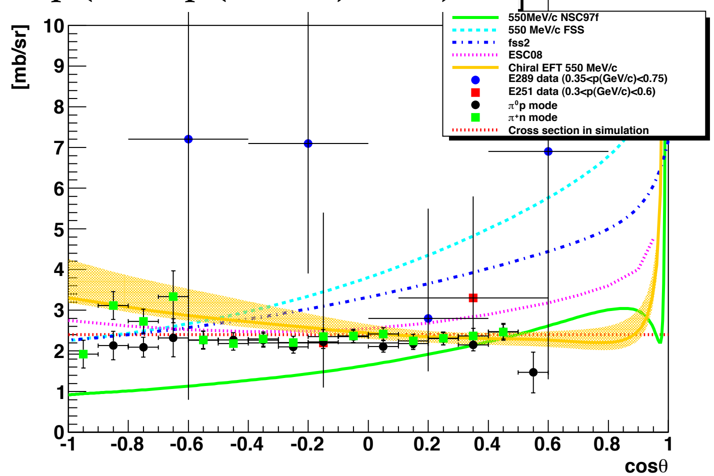




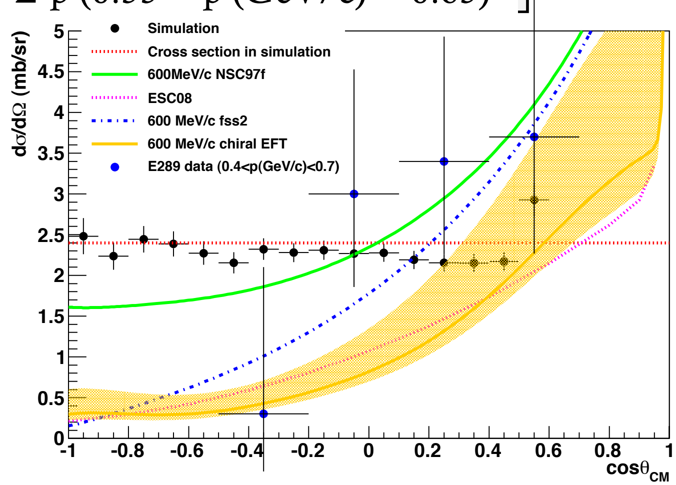
Σp scattering differential cross section

$\Sigma^{+}p$ (0.5 < p (GeV/c) < 0.6)

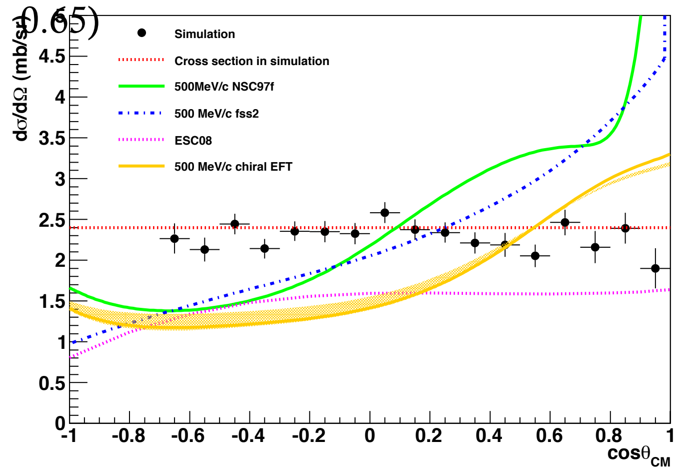


- Expected yield and accuracy
  - ds/dΩ : 2.4mb/sr isotropic distribution (assumed)
    - 20,000 scattering events
    - derive dσ/dΩ for 3 momentum ranges
  - $\Sigma^{-}p$: ±0.11 (stat.) ±0.15 (syst.) mb/sr for 2.4 mb/sr
  - $\Sigma^{+}p$: ±0.15 (stat.) ±0.15 (syst.) mb/sr for 2.4 mb/sr

$\Sigma^{-}p$ (0.55 < p (GeV/c) < 0.65)



$\Sigma^{-}p \rightarrow \Lambda n$ (0.55 < p (GeV/c) < 0.65)



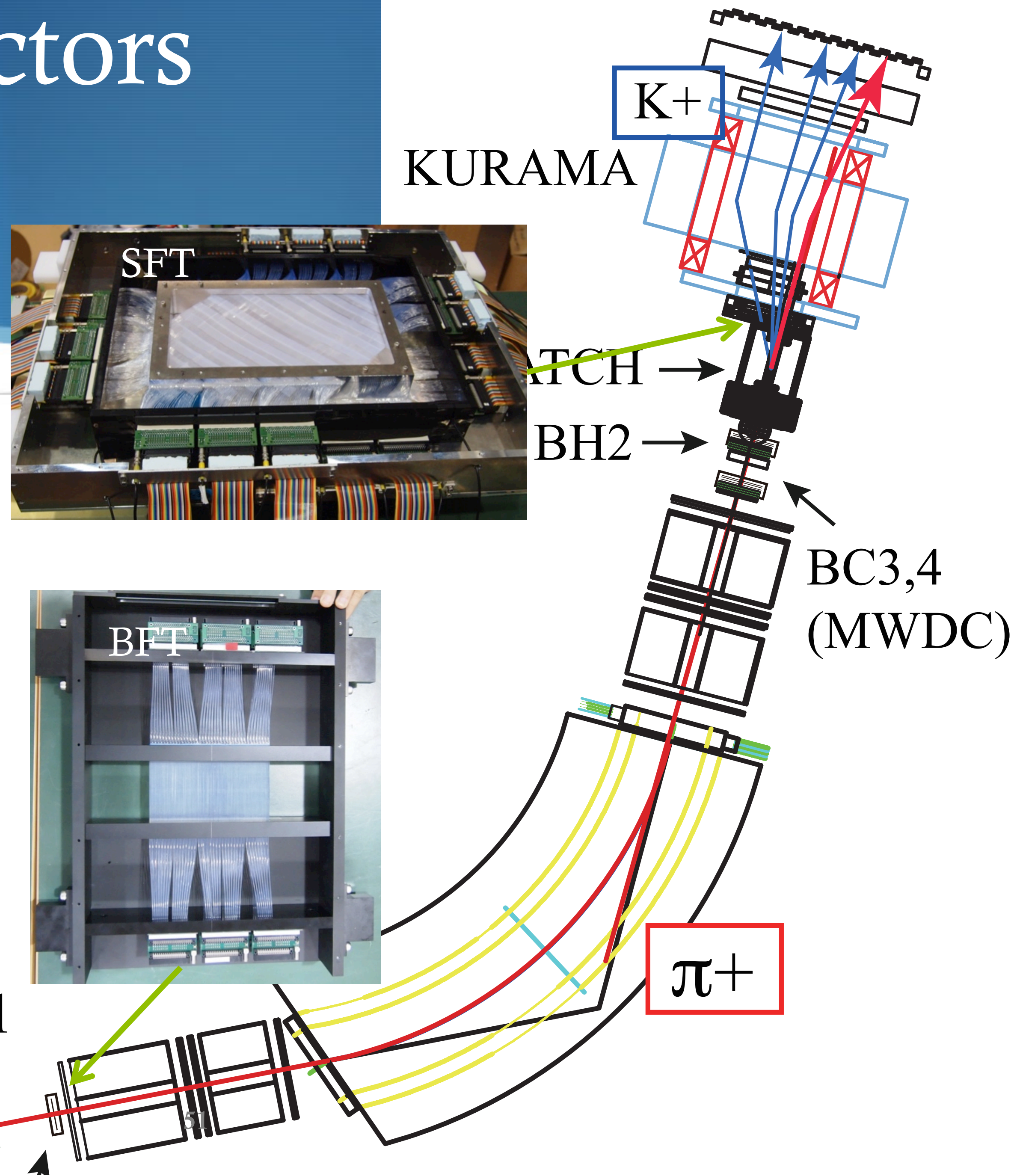
E40 Detector overview

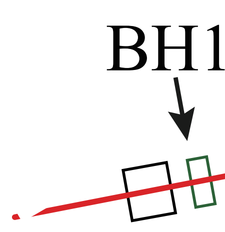
実験のキーポイント

- 出来る限り多くのΣビームを作る
  - 10 MHzのπビームを用いる
- 全て2体反応だけにする
  - 生成 : π+p → K+Σ+
  - 散乱　: Σ+p → Σ+p
  - こうすることで終状態の粒子を検出することで散乱を同定出来る。
    - イメージングする必要がない
- 標的周りを出来るだけ大きな立体角で被う
  - アクシデンタルバックグラウンドを抑えるため高時間分解能のシステムにする
- 出来る限りΣ生成事象だけをトリガーで選択
- また高トリガー環境でも取りきれるDAQシステム

E40 detectors

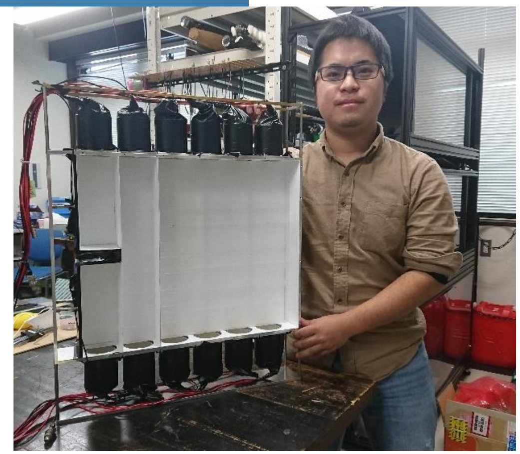
- Beam tracking detectors
  - Fiber trackers
  - MWDC (DL = 1.5mm)



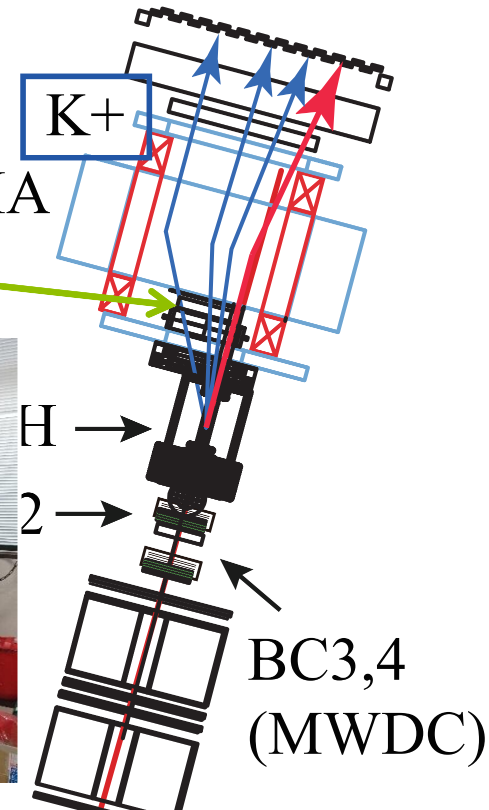


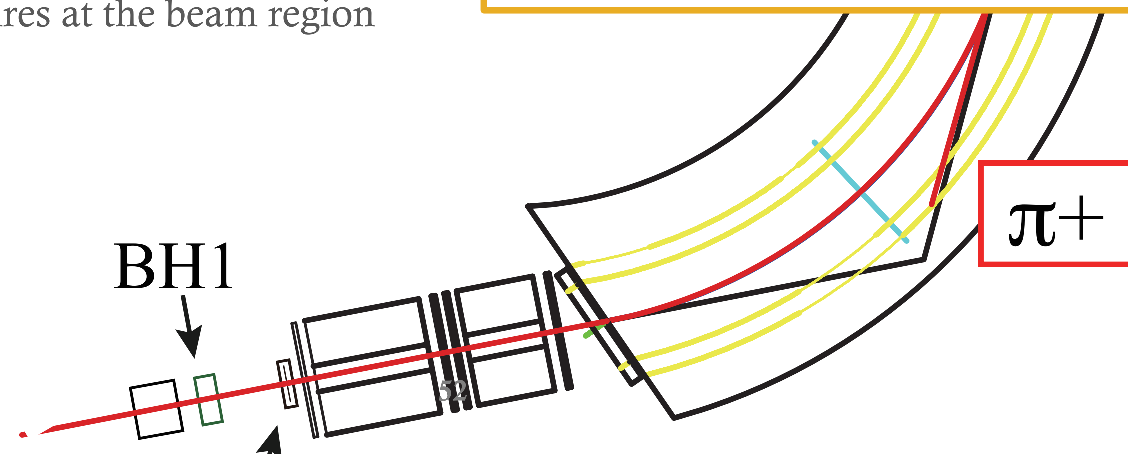
E40 detectors

- Beam tracking detectors
  - Fiber trackers
  - MWDC (DL = 1.5mm)
- KURAMA spectrometer
  - Already constructed by E07 group
  - Modification for E40
    - New AC counter
    - Complex trigger system w/ FPGA module
    - Mask of DC wires at the beam region



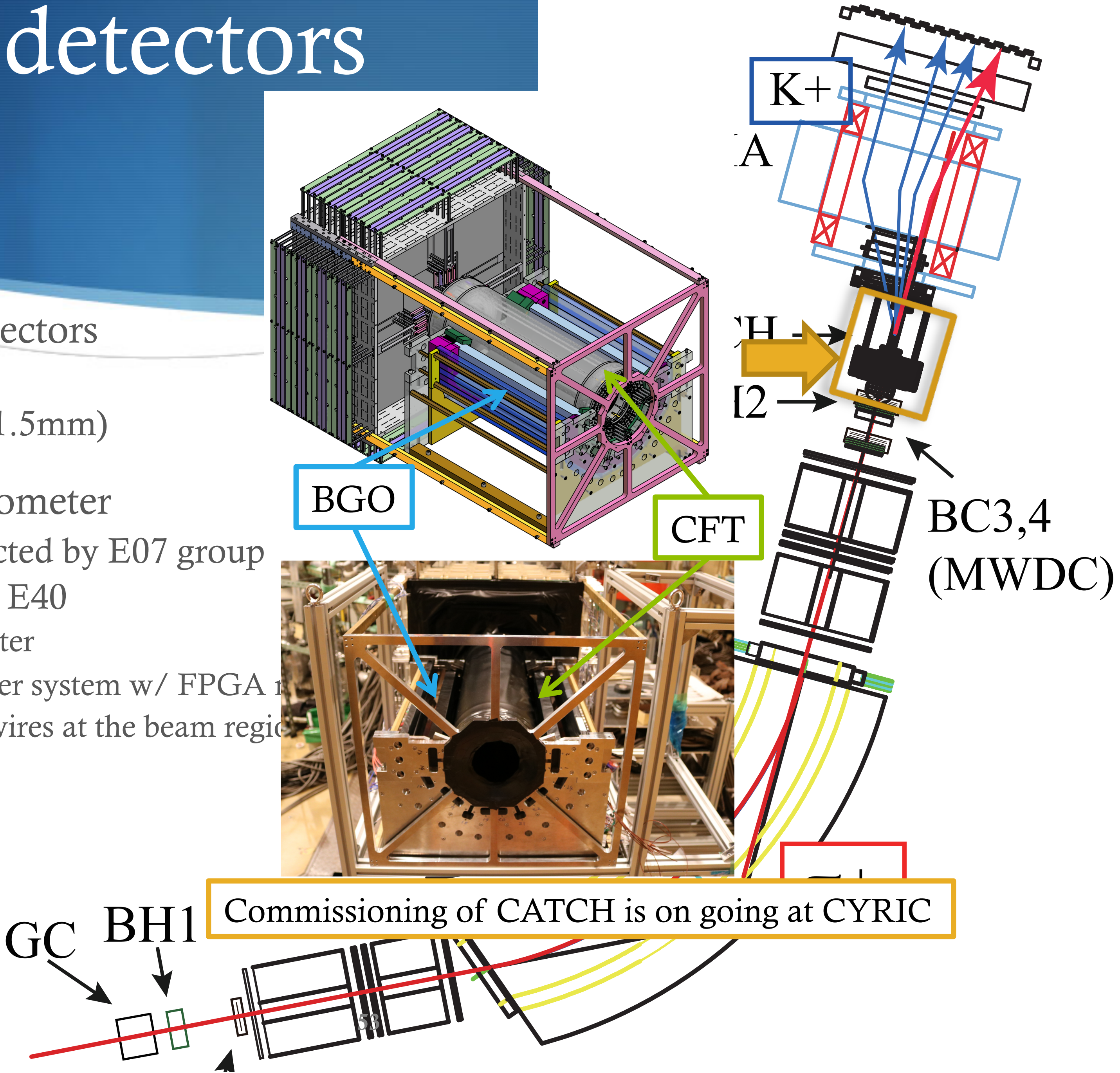
Actual detector of AC counter was fabricated and tested with electron beam.





E40 detectors

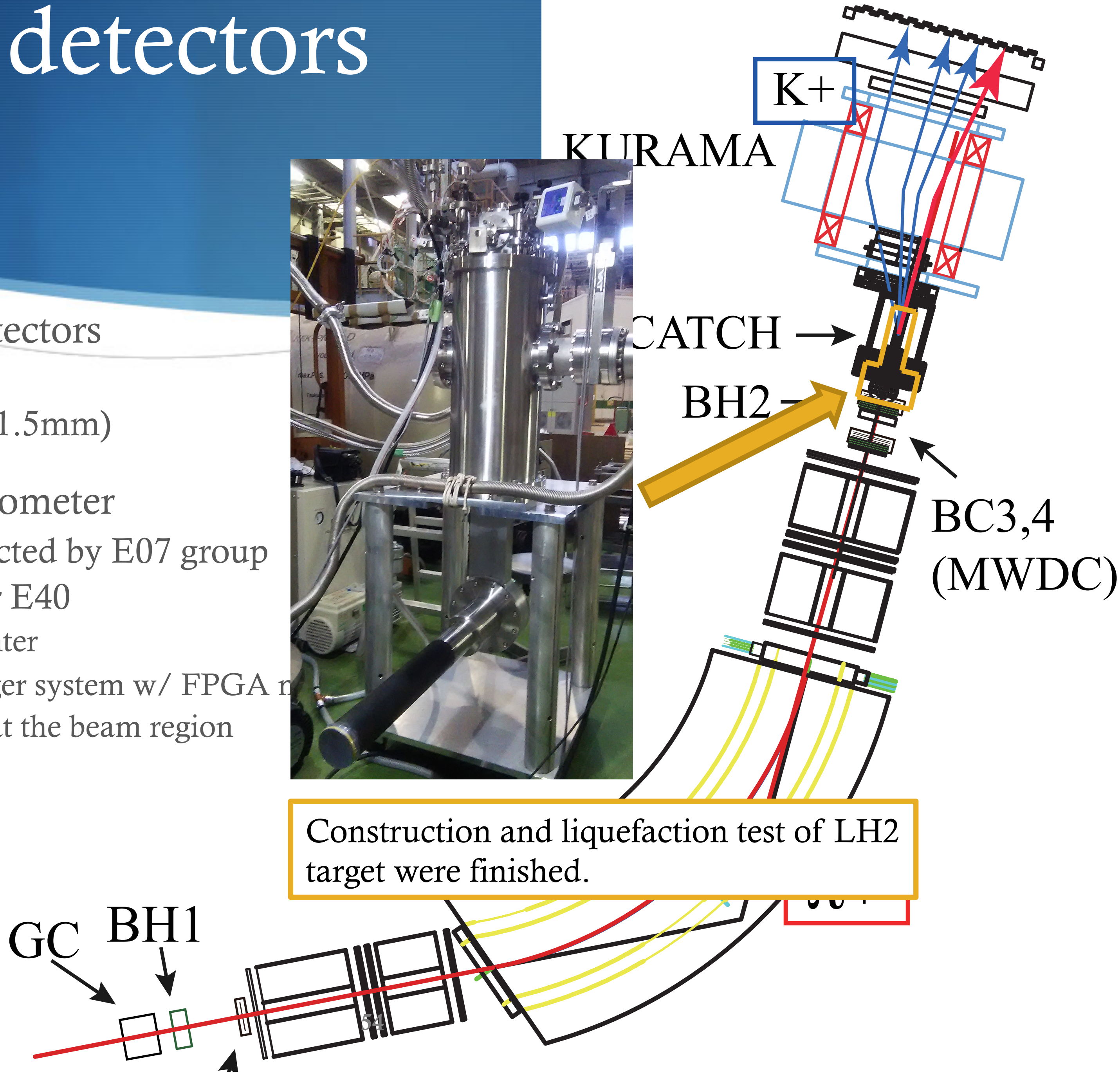
- Beam tracking detectors
  - Fiber trackers
  - MWDC (DL = 1.5mm)
- KURAMA spectrometer
  - Already constructed by E07 group
  - Modification for E40
    - New AC counter
    - Complex trigger system w/ FPGA r
    - Mask of DC wires at the beam regi
- CATCH detector
  - CFT + BGO



Commissioning of CATCH is on going at CYRIC

E40 detectors

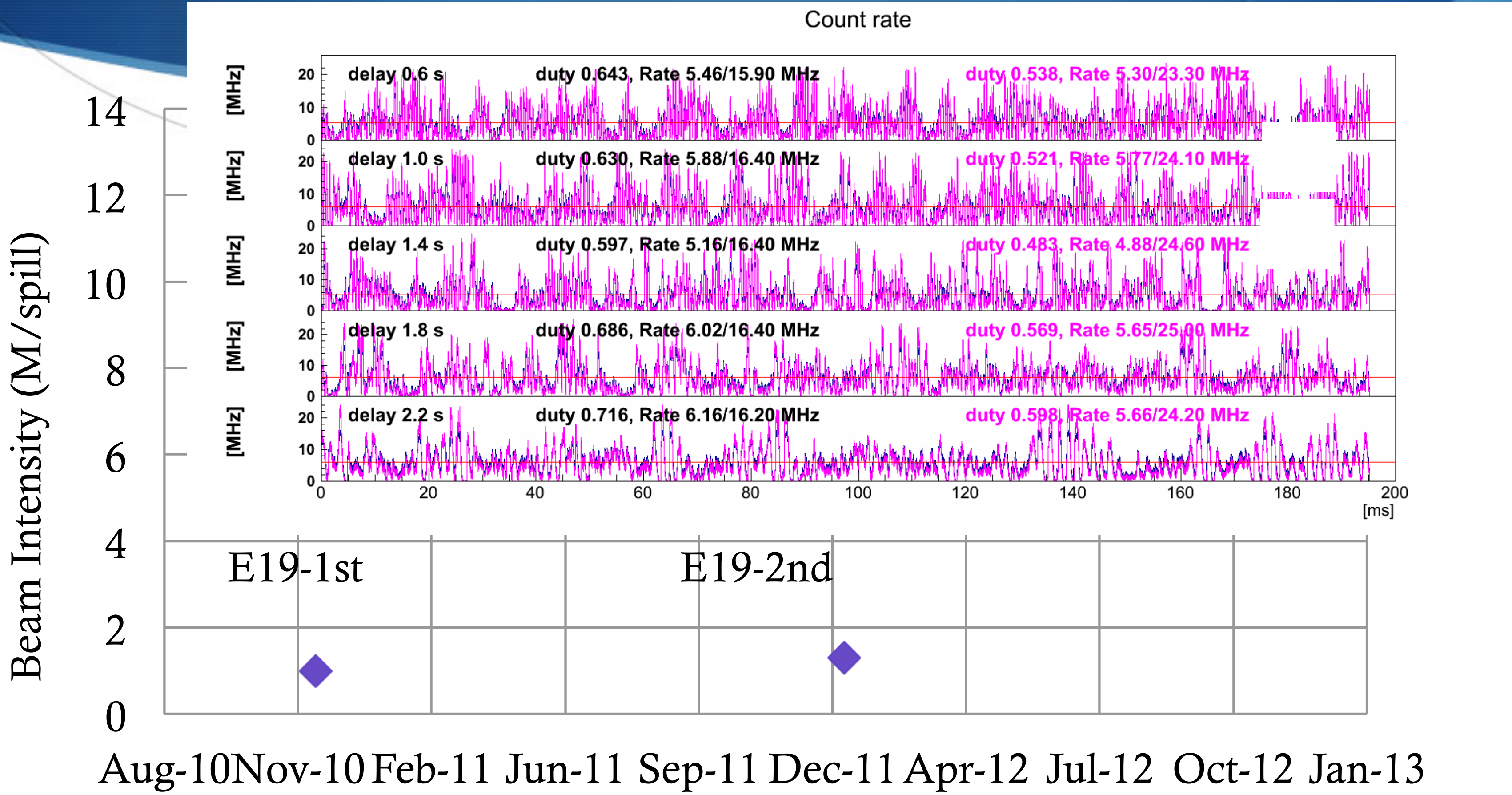
- Beam tracking detectors
  - Fiber trackers
  - MWDC (DL = 1.5mm)
- KURAMA spectrometer
  - Already constructed by E07 group
  - Modification for E40
    - New AC counter
    - Complex trigger system w/ FPGA m
    - Mask of DC at the beam region
- CATCH detector
  - CFT + BGO
- LH2 target



Construction and liquefaction test of LH2 target were finished.

Development fiber tracker system

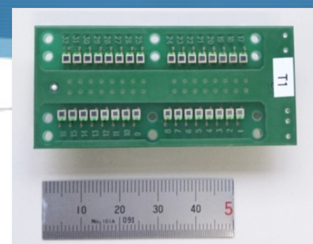
K1.8 Beam Intensity History



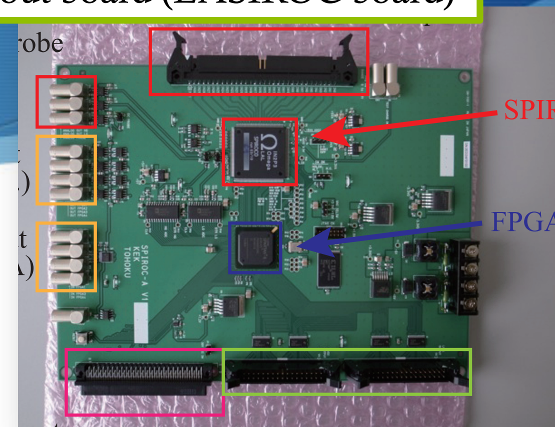
Fiber Tracker for High Intensity Beam

Fiber Detector

Photon Sensor (MPPC)

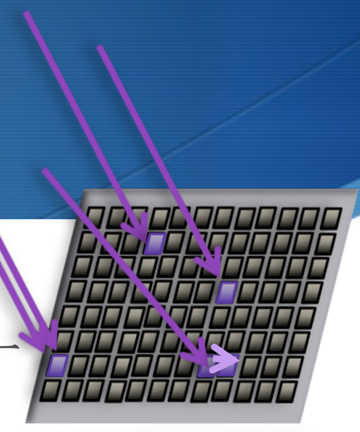


Readout board (EASIROC board)



- KURARAY scintillation fiber
  - Stable under high intensity beam
  - Good timing resolution
- Compact MPPC PCB
  - 32 ch MPPCs
- Readout board
  - 32 ch operation
  - Multihit TDC, ADC

MPPC readout

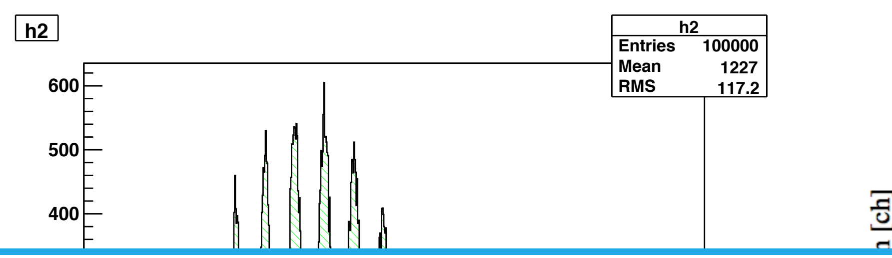


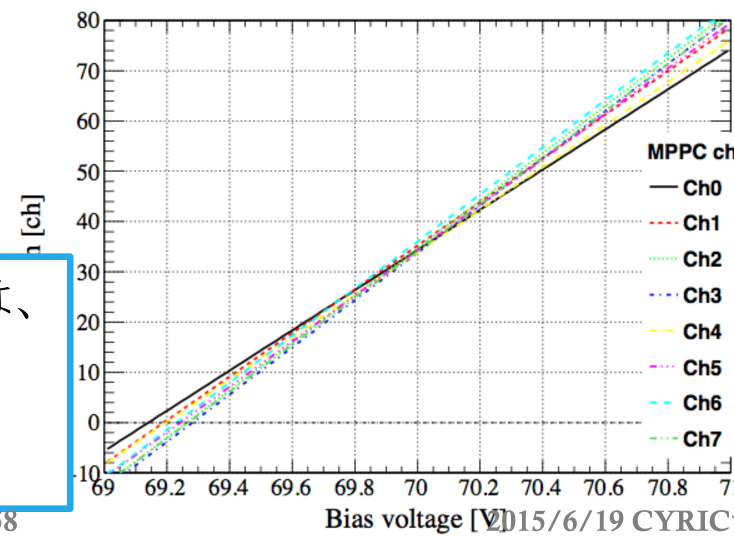
- MPPC
  - APDを多数敷き詰めて、ガイガーモードでオペレー
  - ヒットしたピクセル数に比例した波高が出る

MPPCからの出力

$Q = C(V - V_0)$
C : 容量
V : オペレーション電圧
V_0 : 降伏電圧

} 電圧依存性が大きい





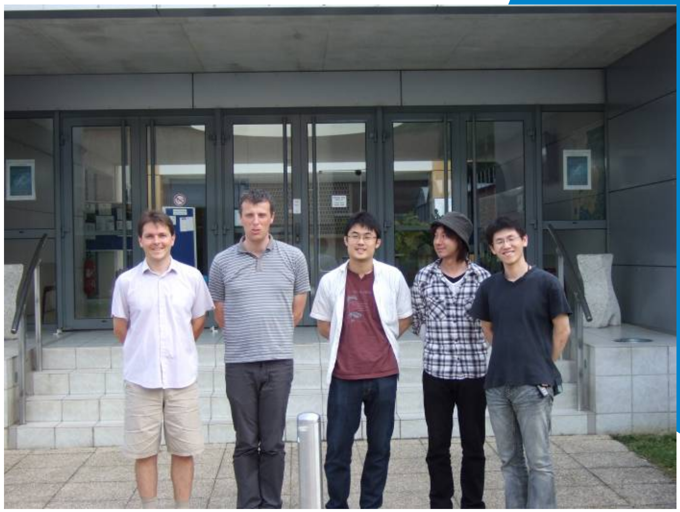
MPPCの多チャンネル読み出しを行うには、
専用の読み出しエレクトロニクスが必須
- シリアル読み出し
- MPPCの動作電圧の調整

SPIROC board development with KEKDTP

- Miwa, Honda (Tohoku)
  - Fiber tracker for YN scattering experiment
    - Multichannel MPPC readout
- Yoshimura, Nakamura (KEK DTP, photon sensor group)
  - Multipurpose Multichannel readout of MPPC
    - Easy to handle multichannel MPPC's
- M. Tanaka (KEK electronics)
  - Hardware surport
  - SiTCP

FJPPL

- C. de La Taille, S. Callier, L. Raux (LAL Omega)
  - SPIROC chip



2010 July @ LAL

2009 Oct — 2010 Apr — 2010 July — 2010 Oct — 2010 Dec — 2011 March

Visit to LAL

Study with SPIROC2

SPIROC2A KEK board (SiTCP controll)

Study with SPIROC1

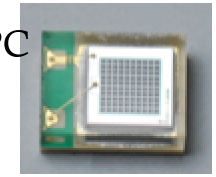
1Month stay in LAL

SPIROC-A board (SiTCP controll)

MPPCの多チャンネル読み出し回路の開発

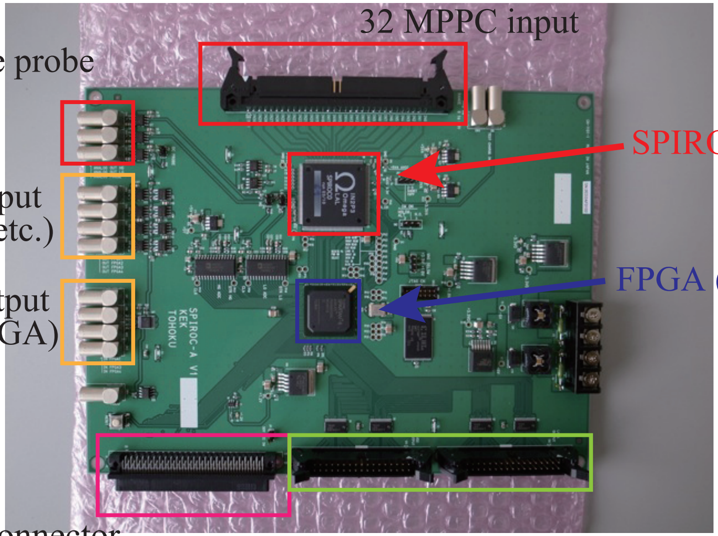
- 新型光検出器MPPC
  - 高い増幅率、磁場中でも使用可能など非常にポテンシャルの高い検出器
  - 検出器が小型なため、多チャンネルのオペレーションが必須

MPPC



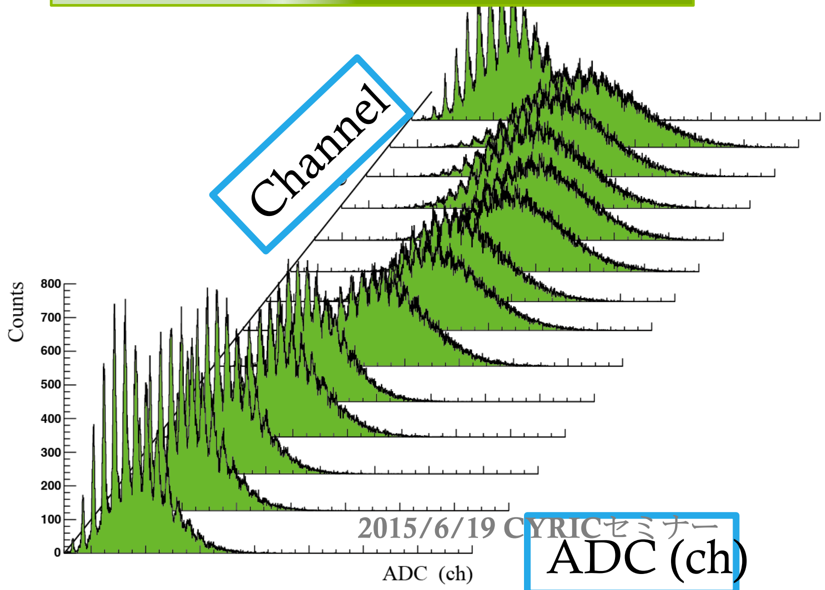
KEK、フランスLAL研究所および東北大で
汎用的かつMPPCの多チャンネル読み出しに特化した回路を初めて開発

(c) KEK-Tohoku test board ver.2



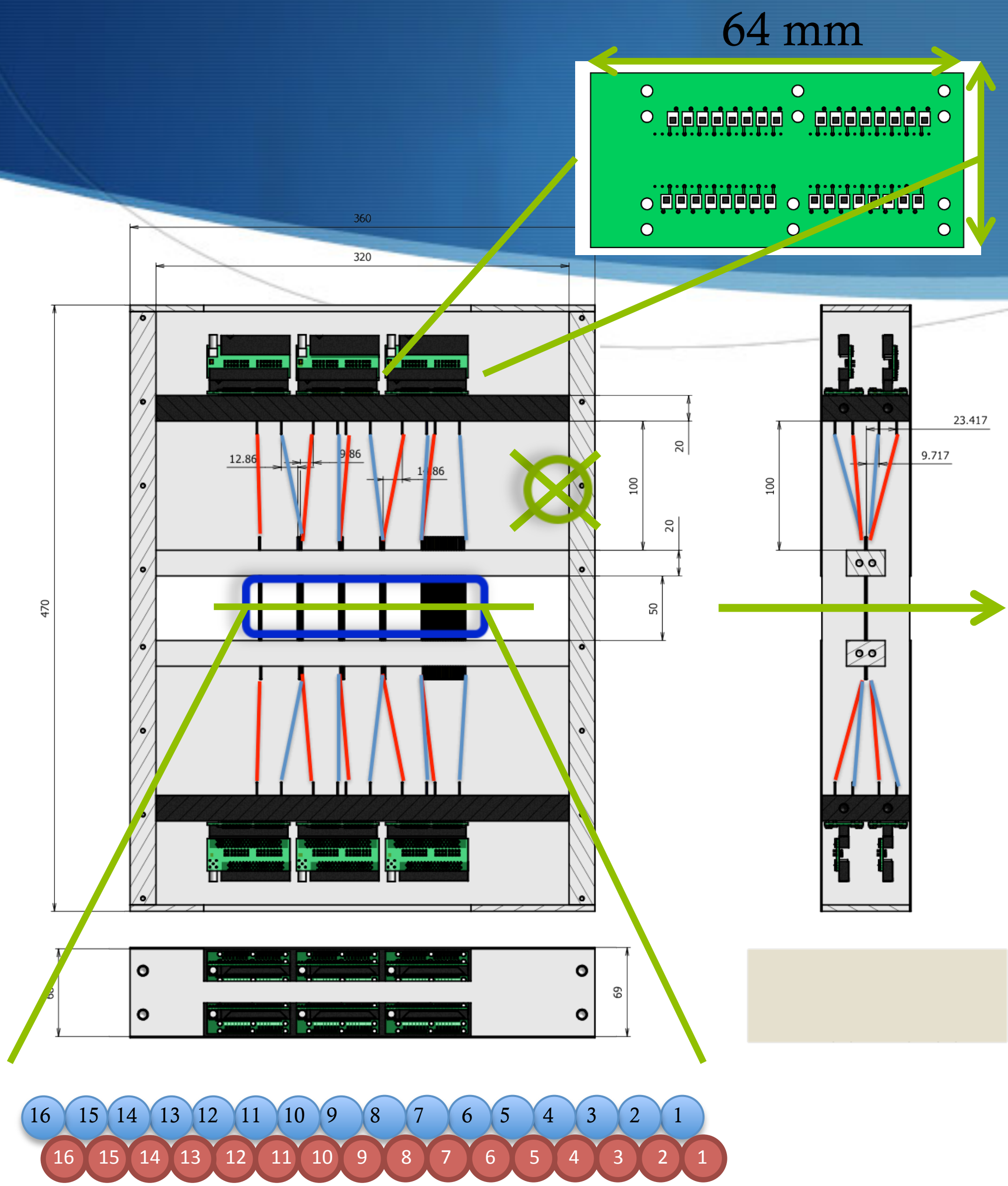
- 32chまでのMPPCのオペレーションが可能
- データ収集および回路の動作設定が
  TCP/Ethernetを用いて簡単に行うことが可

MPPC多チャンネル読み出しの
デモンストレーション



本回路の開発により様々な検出器に
MPPCを用いることが可能
→ ファイバー検出器への応用

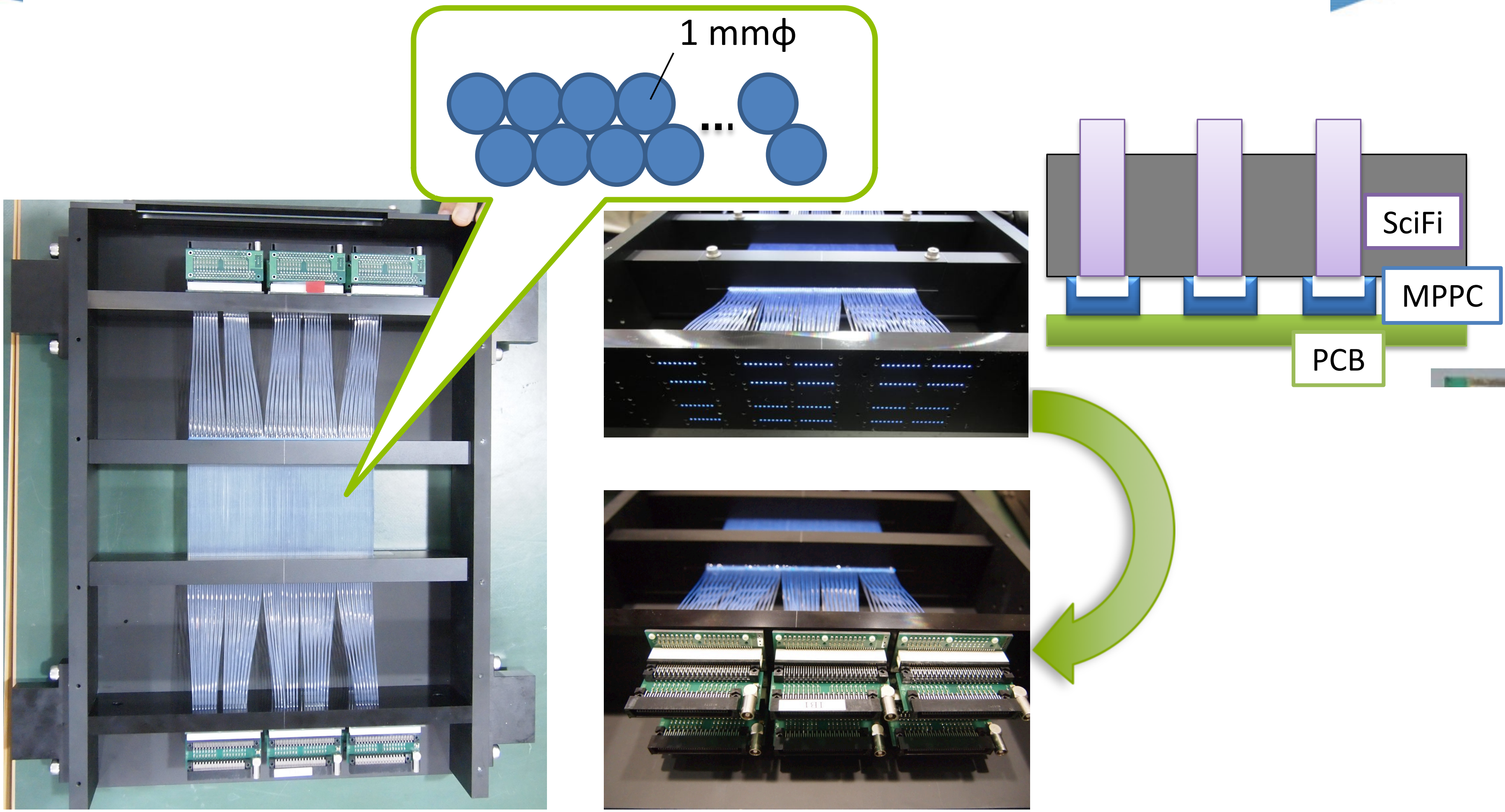
Design of BFT



- Beamline Fiber Tracker
  - Can operate stably under a high intensity beam.
  - Structure
    - 320 ch of 1mm ϕ fibers
    - Two staggered layers
    - MPPC readout
      - We designed the high density MPPC PCB.
- We have finished the design. Detector and MPPC PCB are being produced now.
- We will use 10 EASIROC test board to operate 320 MPPCs, because we want to install this detector as soon as possible.

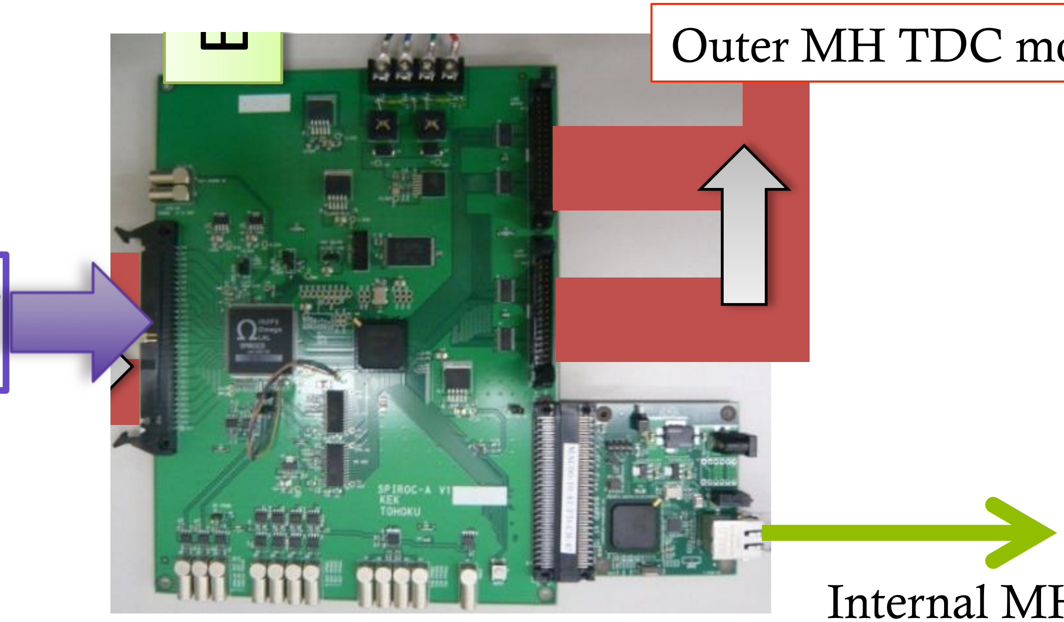
Bamline Fiber Tracker (BFT)

- 320 ch of scintillation fiber and MPPC



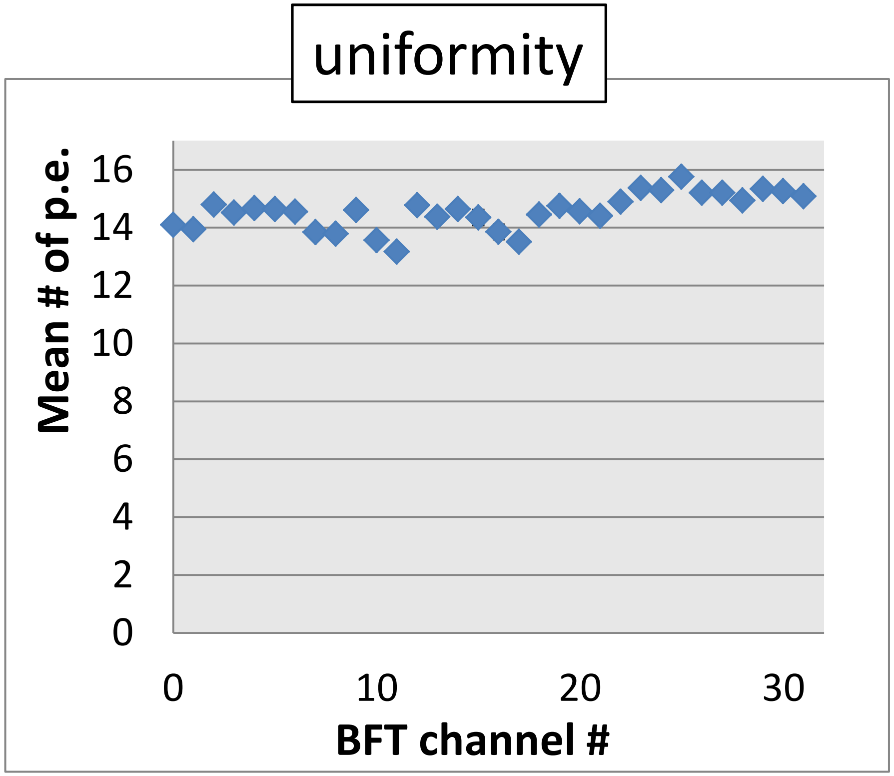
Readout of BFT

- Two kinds of TDC data taking methods
  - Outer MHTDC module (1ch = 1ns)
    - Only reading edge information
  - Inner MHTDC in FPGA (1ch = 1ns)
    - Reading and treading edge information, → TOT information → related to Pulse height
    - In future, we will use this inner MHTDC mainly

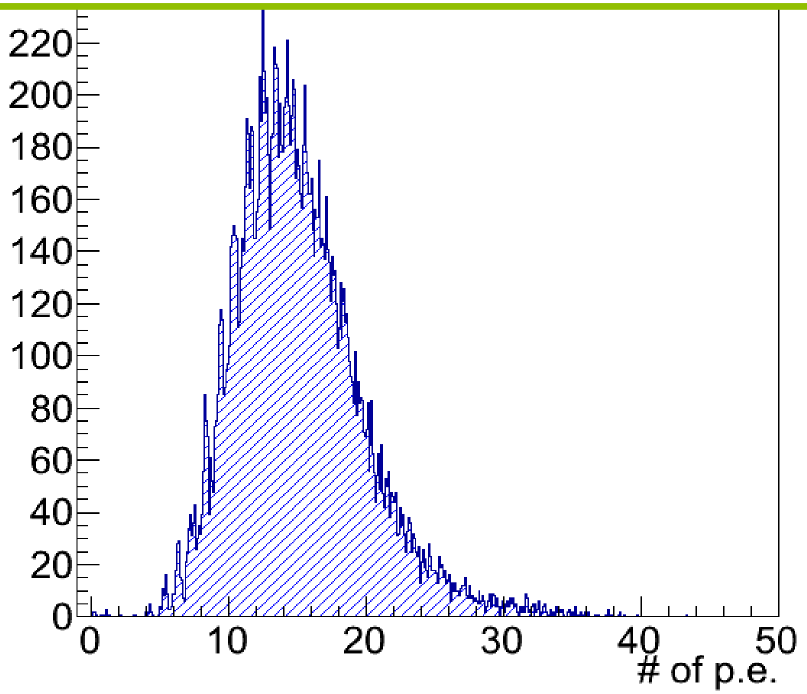


BFT performance (Light yield)

- We have enough and uniform light yield for all channels.
- Gain uniformity is also OK
  - 30 ch between pedestal and single photon

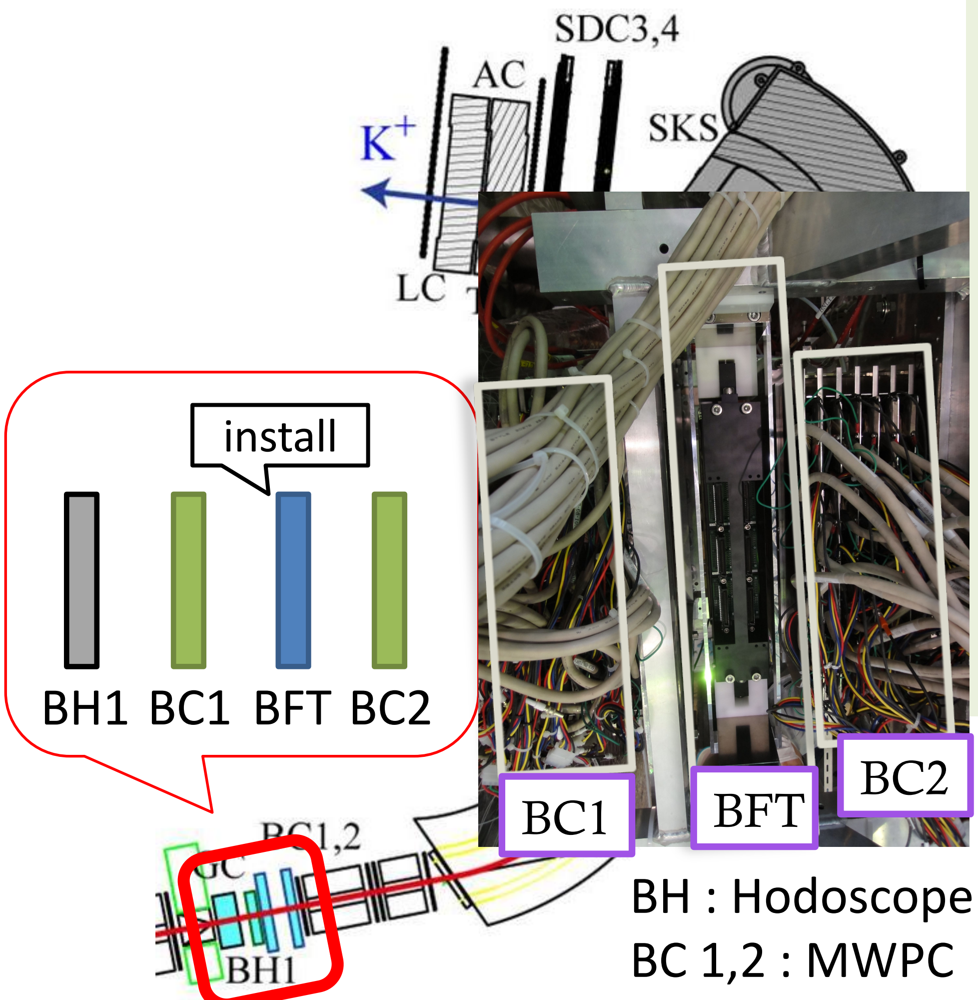


This is results of proto-type detector.
Real detector has more yield of ~18 p.e.



Install of BFT

Experimental setup



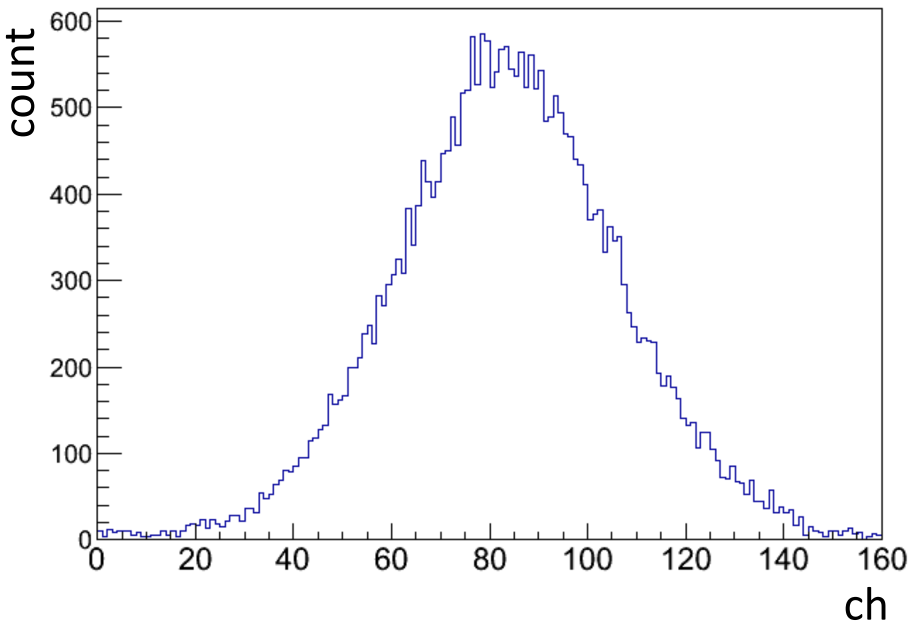
BH : Hodoscope
BC 1,2 : MWPC
BC 3,4 : DC

Purpose

- ☐ Test the performance
  - Requirement for 20M/spill (~2ns)
    - Time resolution
      : 0.8 ns (σ) <
    - Position resolution
      : ~ 150 μm (σ)
      (geometrical limit)
    - Efficiency
      : 99% >
- ☐ Establish new analysis method

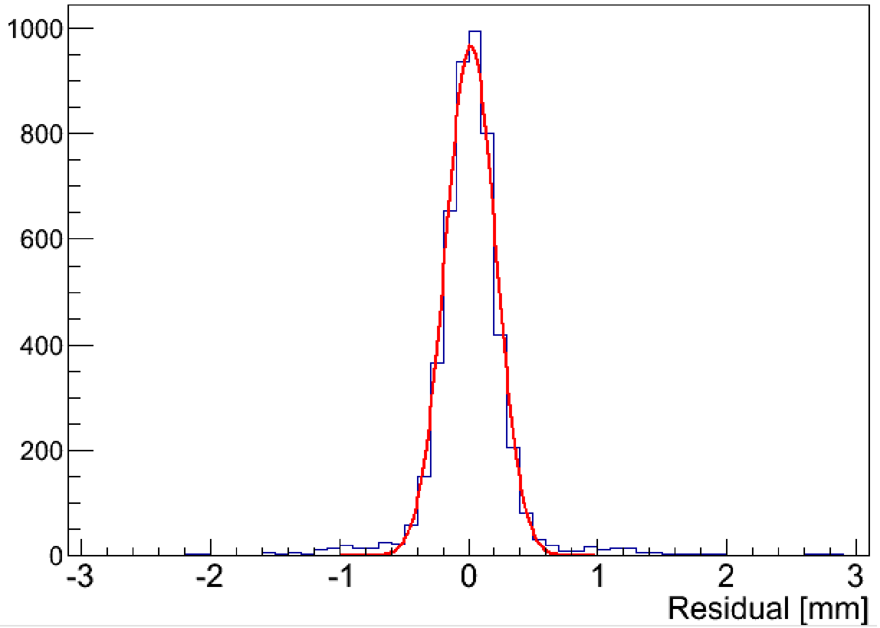
BFT performance

■ Beam profile



- All channels (320) were working well

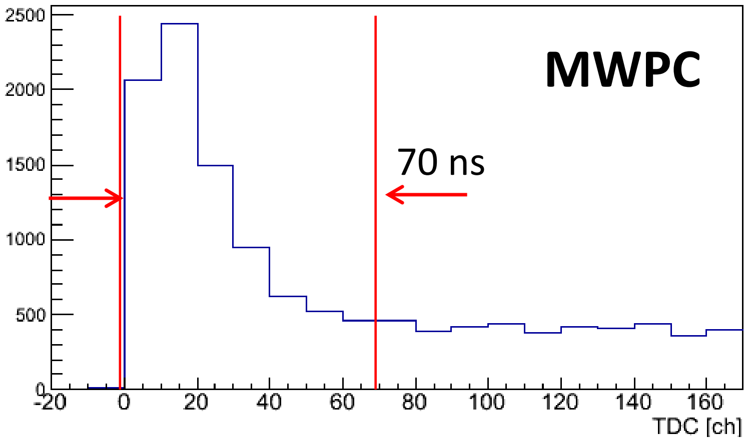
■ Position resolution



- Residual of BFT hit position from BC tracking
- **190 μm (σ)**
- Comparable to geometrical limit

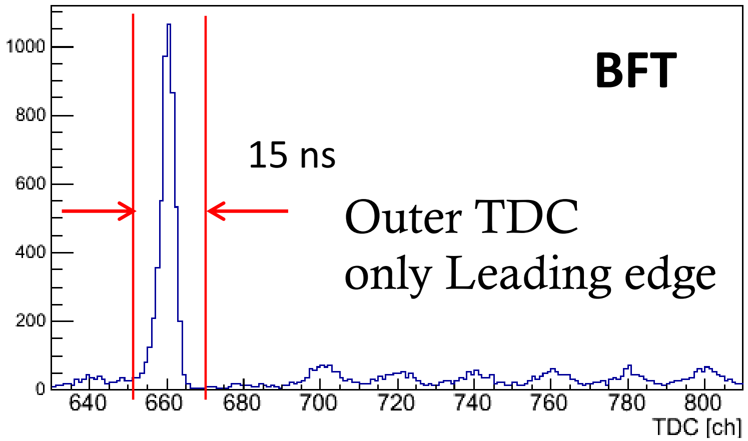
BFT performance (Time resolution)

■ **Time resolution**



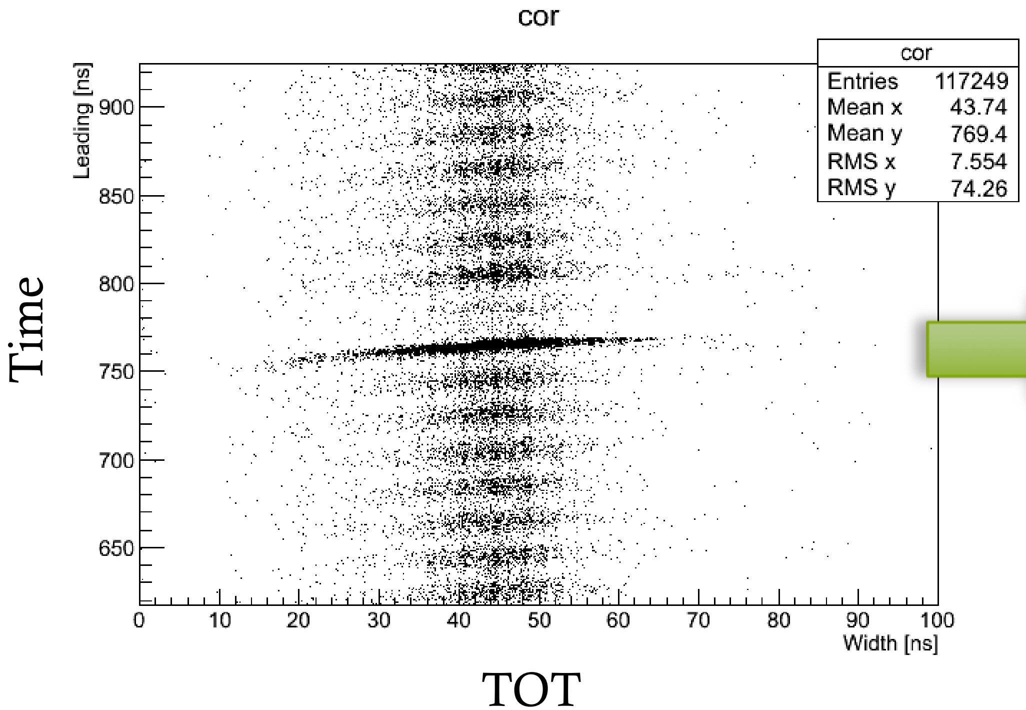
1 ch = 1 ns

- BFT was better than MWPC
- **1.75 ns (σ)** w/o slewing correction



Relation between Time and TOT

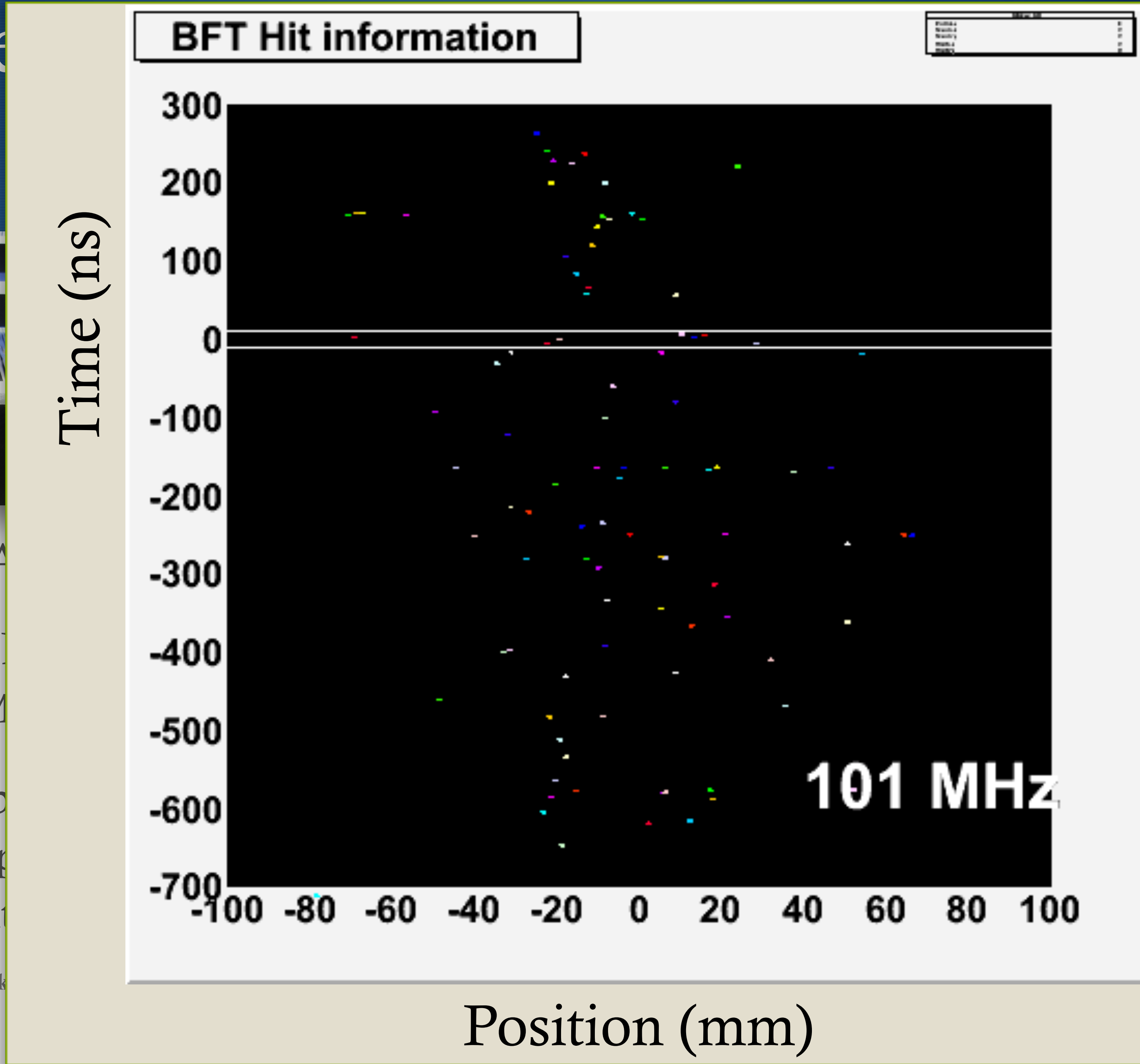
- By using internal TDC, we can correct Time information by using TOT information.



Corrected Time resolution is σ=1.1 ns

Deve

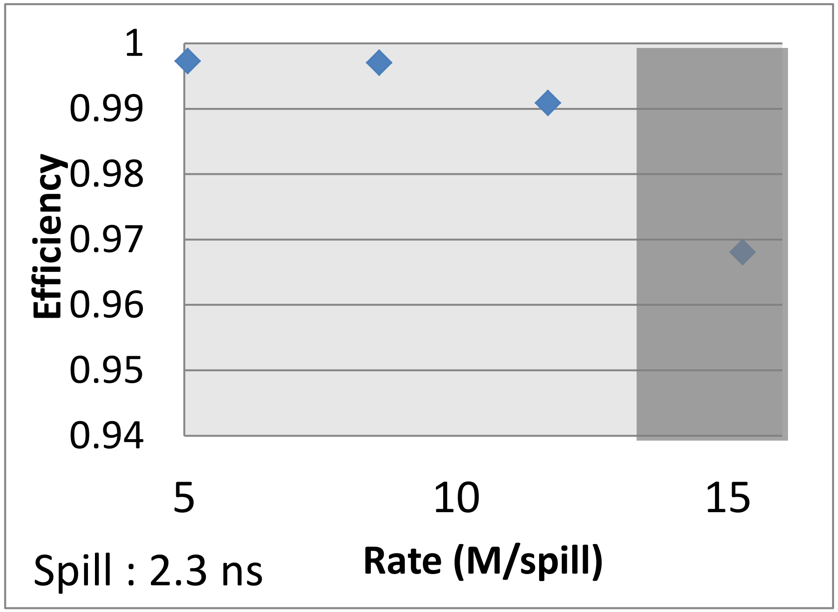
- KURARA
- Compact
  - 32 ch M
- Readout b
  - 32 ch o
  - Multihi



Efficiency

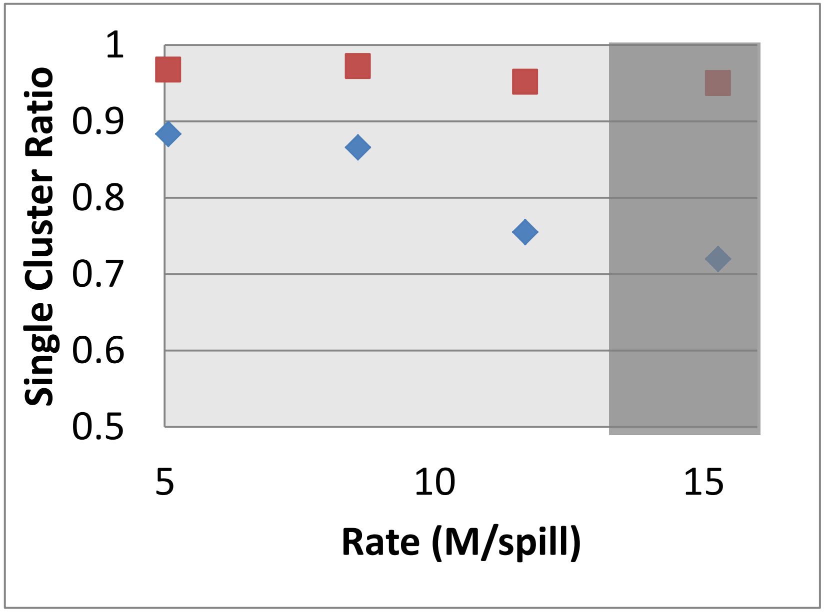
■ Efficiency

- Eff. = BFT hit / BH1 & BH2 hit
  (BH : Timing counter)



■ Single cluster ratio

- Selecting single particle by BH1 & BH2
- Spatial cut with BH1
- ◆: No cut ■ : cut



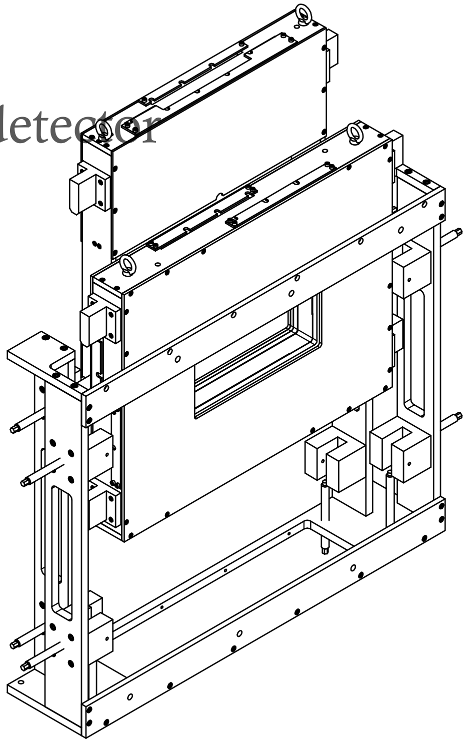
※Grey part … Beam width become broader than BFT sensitive area

- Efficiency is more than 99%
- 5~8M : 85%, 10M~ : 75%>
- More than 95% with BH1 cut

New Fiber Detector (SFT)

- Now we are applying this MPPC readout technology to other fiber detectors.
- Scattered Fiber Detector (SFT) is the second detector
  - X, U, and V planes
  - X : 16 MPPC PCB + EASIROC
  - U, V : 10 MPPC PCB + EASIROC (x 2)
  - Total 36 EASIROC boards.
  - This might be a break through

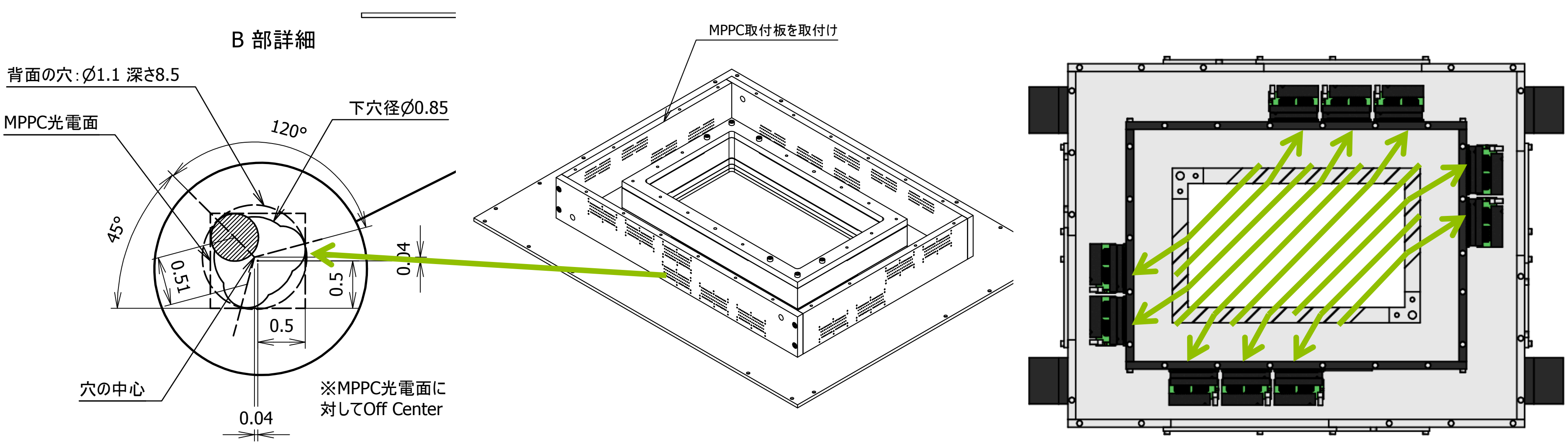
  for MPPC + EASIROC readout



Challenge of SFT UV structure

- For SFT UV, we use 0.5 mm ϕ fibers and 3 fibers were read by one MPPC.
  - 0.5 mm f fiber is for low material
  - 3 fibers readout is to reduce readout channel for reasonably wide sensitive area.

- The SFT is now being fabricated by company and will be ready at end of October.
  - Therefore we ordered 40 EASIROC chips this summer.



SFT detectors

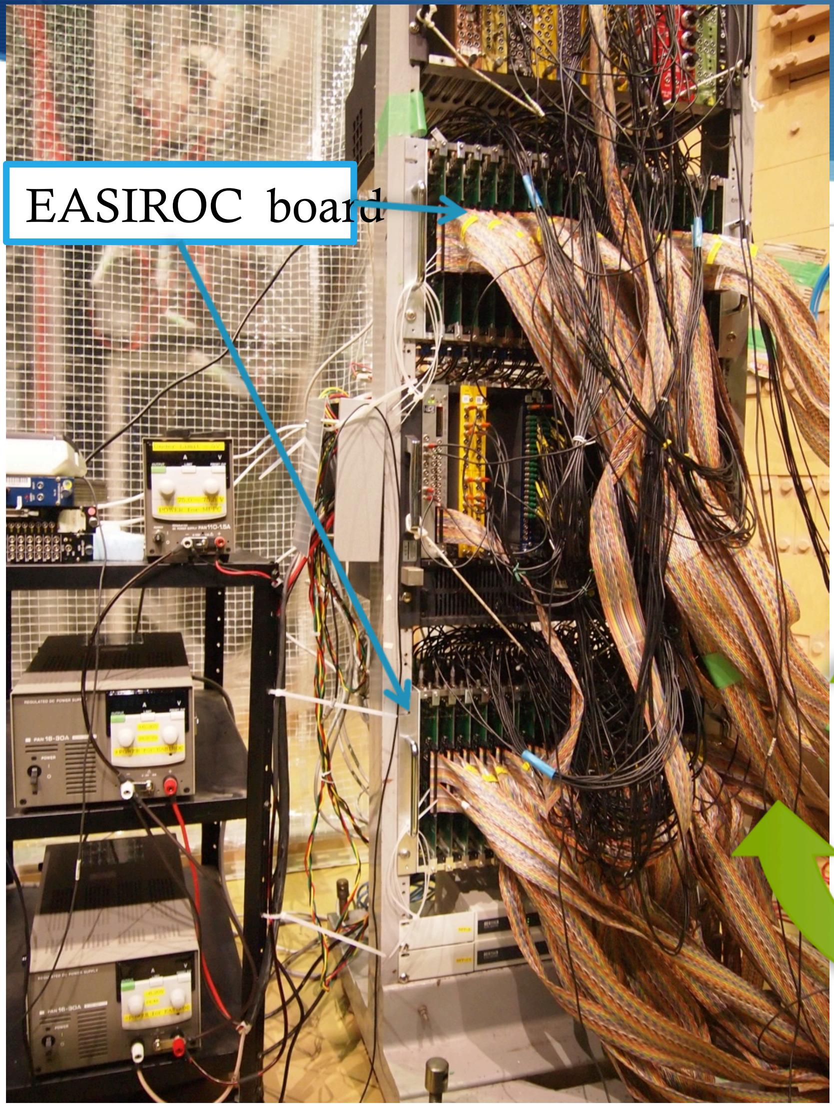
- We made SFT detectors in this autumn.

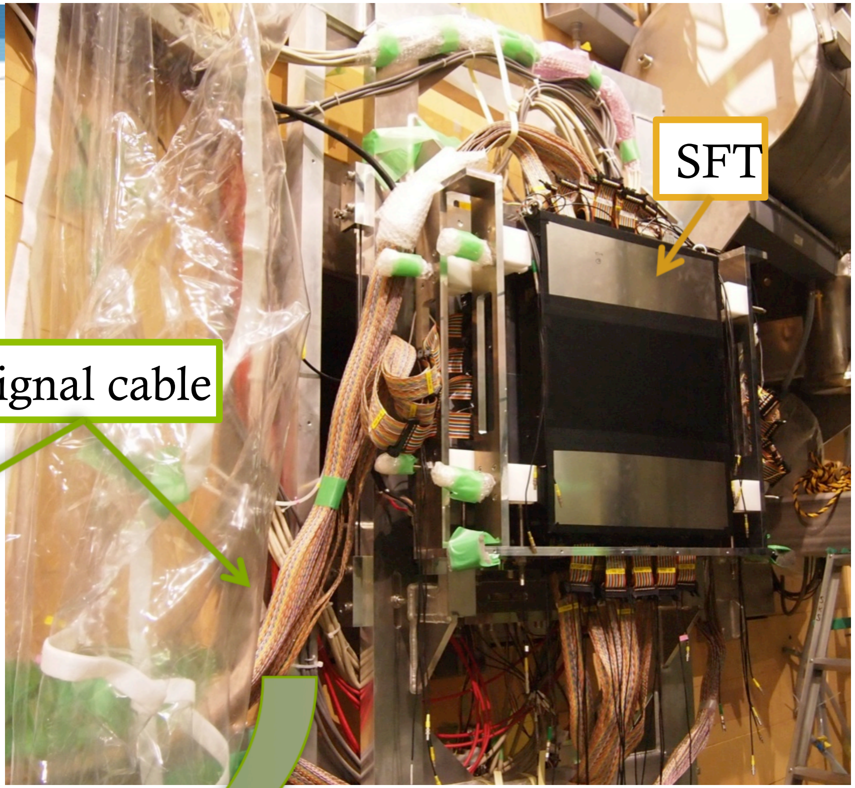
X – plane
16 EASIROC board
512 MPPC channel

UV– plane
20 EASIROC board
640 MPPC channel

Installation of SFT

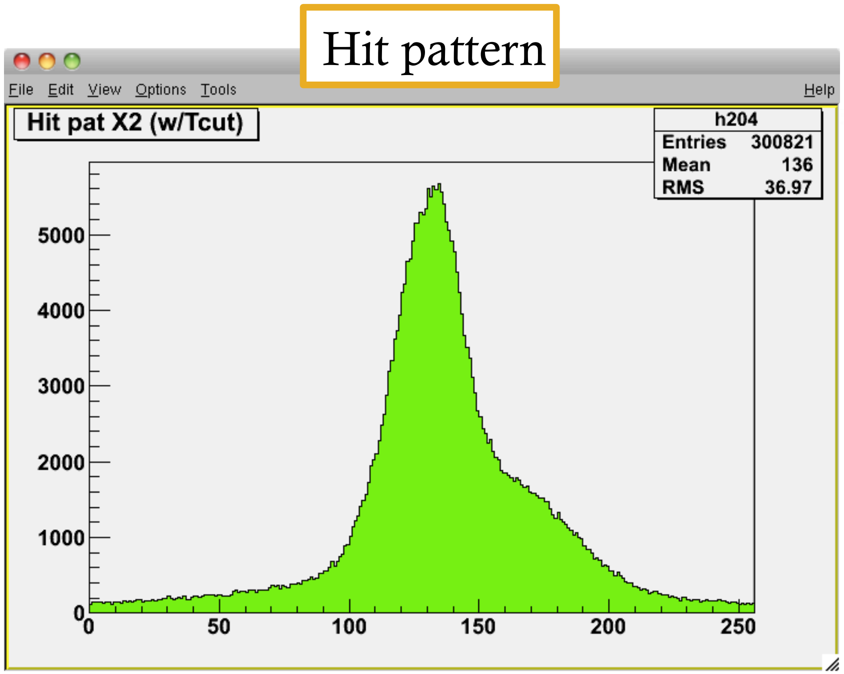
- For SFT, 36 EASIROC boards were used

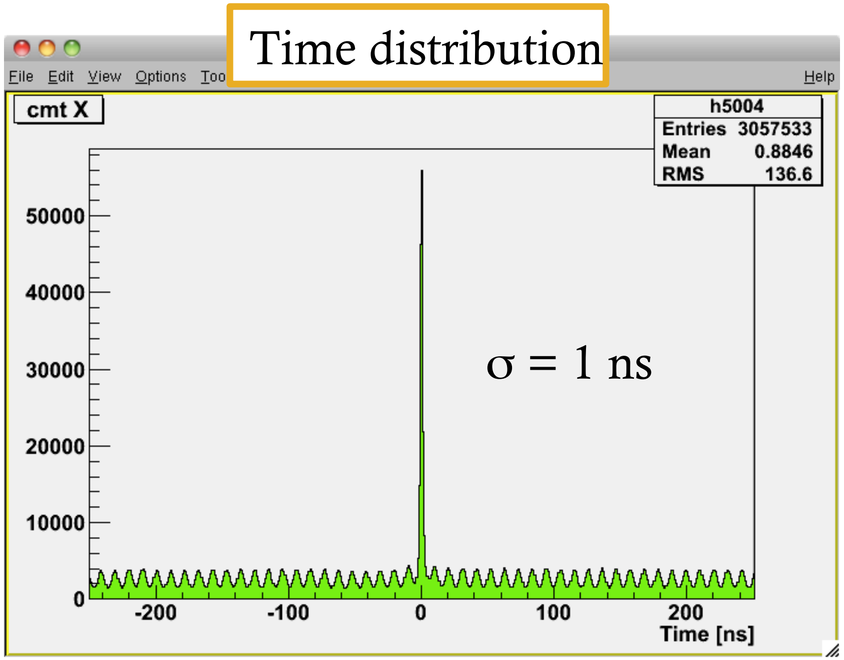




Performance

- SFT and EASIROC board worked very well

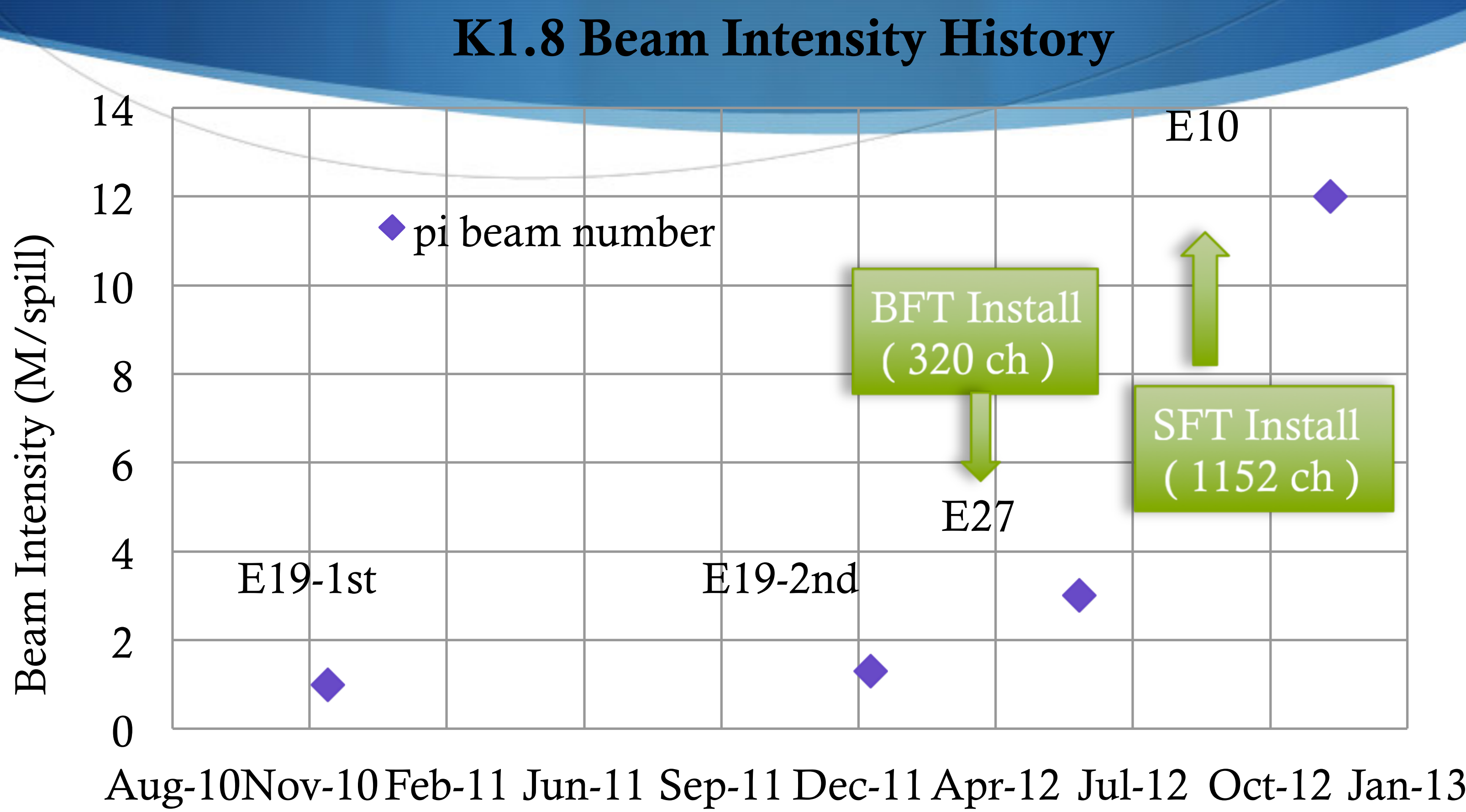




10 M/spill beam (spill=2sec)

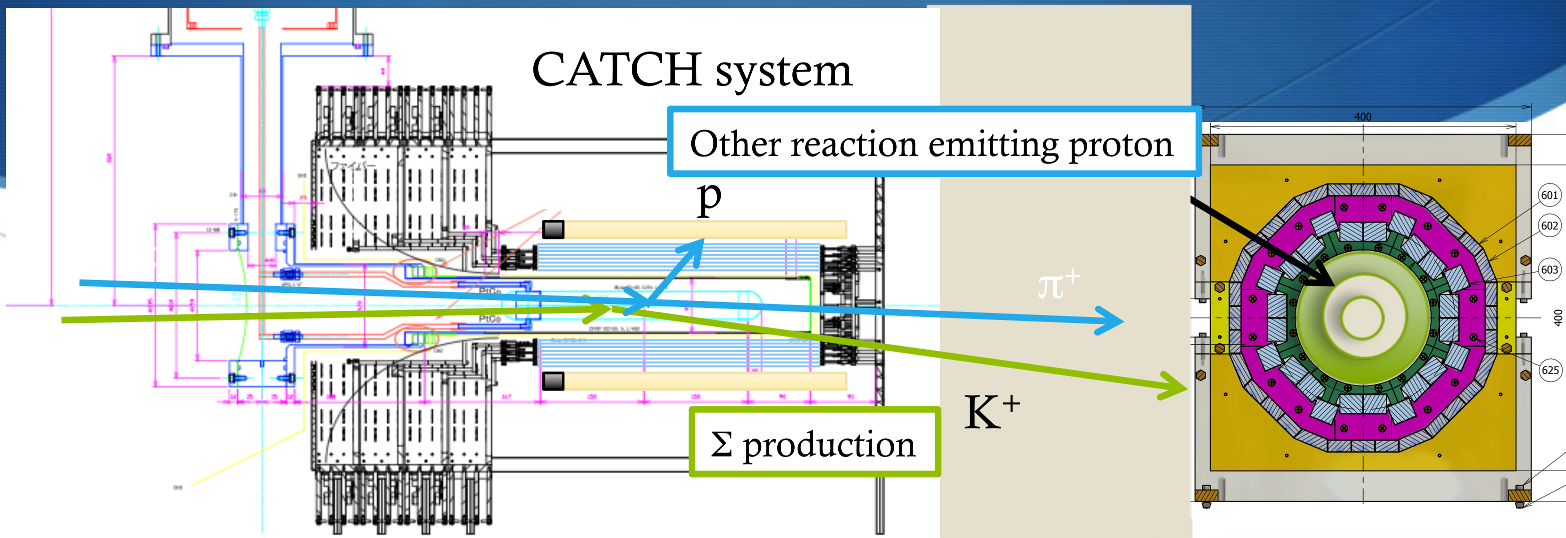
Firmware of EASIROC board was updated by Honda.
Multihit TDC which is sensitive for both leading and trailing edges was implemented in the FPGA.

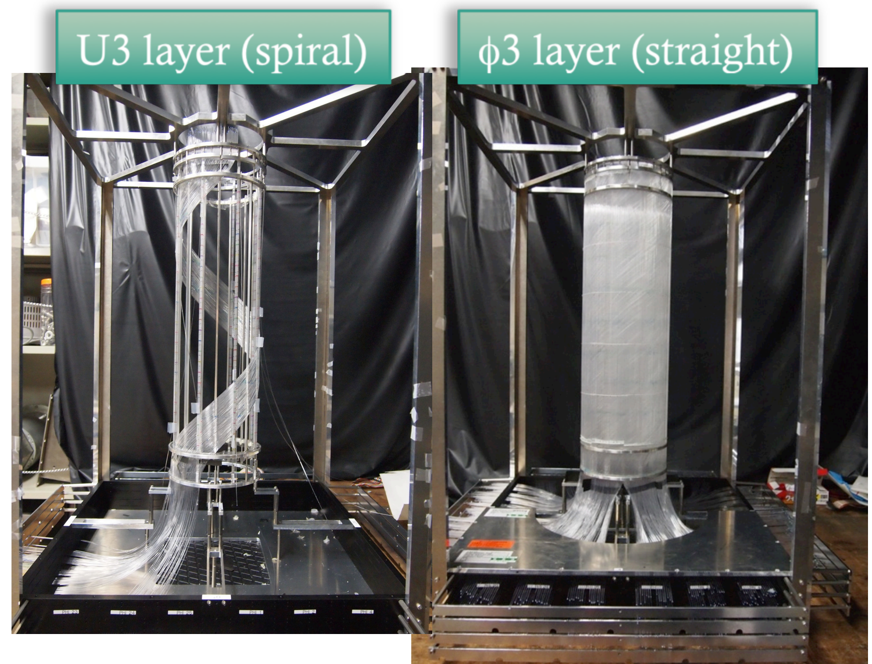
K1.8 Beam Intensity History



CATCH systemのR&D

Cylindrical Fiber Tracker (CFT)

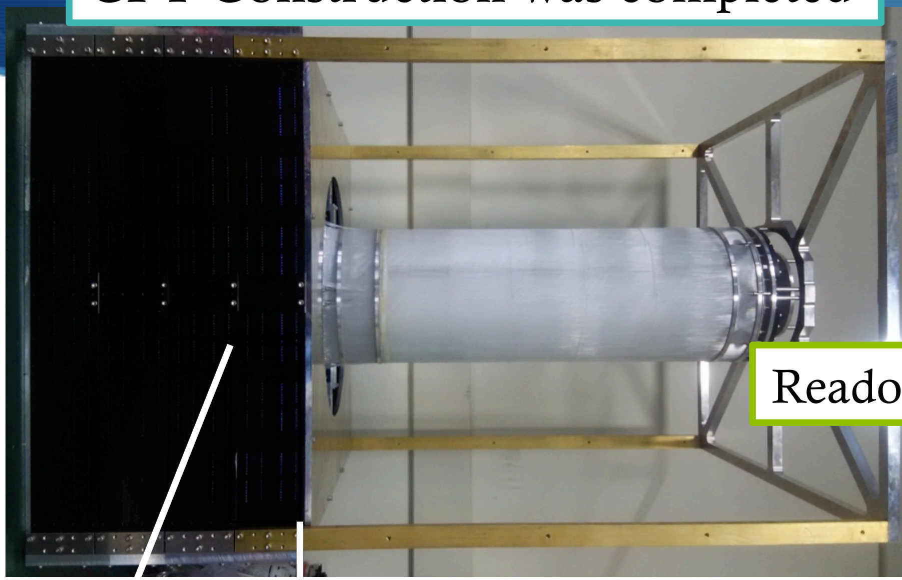




- Cylindrical Fiber Tracker (CFT)
  - Large acceptance for scattered proton
    - 8 layer configurations in limited space
  - Measurement of scattering angle < 1 degree
    - U(V) layer (spiral)
    - ϕ layer (straight)
  - Particle Identification by ΔE information
    - σ/E < 20 % for 1 MeV energy deposit
  - Good timing resolution σ =1 ns
    - To separate accidental background event

CFT construction and its readout

CFT Construction was completed



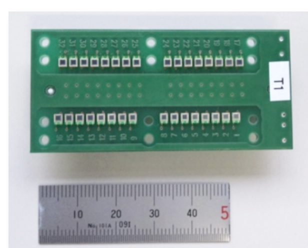
- Total fiber channel number ~ 5,000 ch

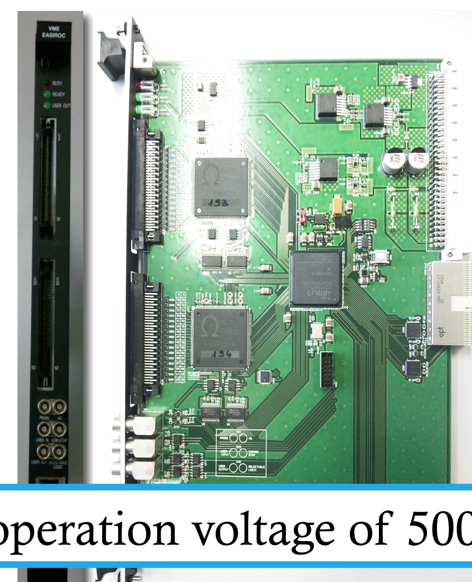
Readout method of multi fibers is also established

Readout board (EASIROC board)

Fiber readout side

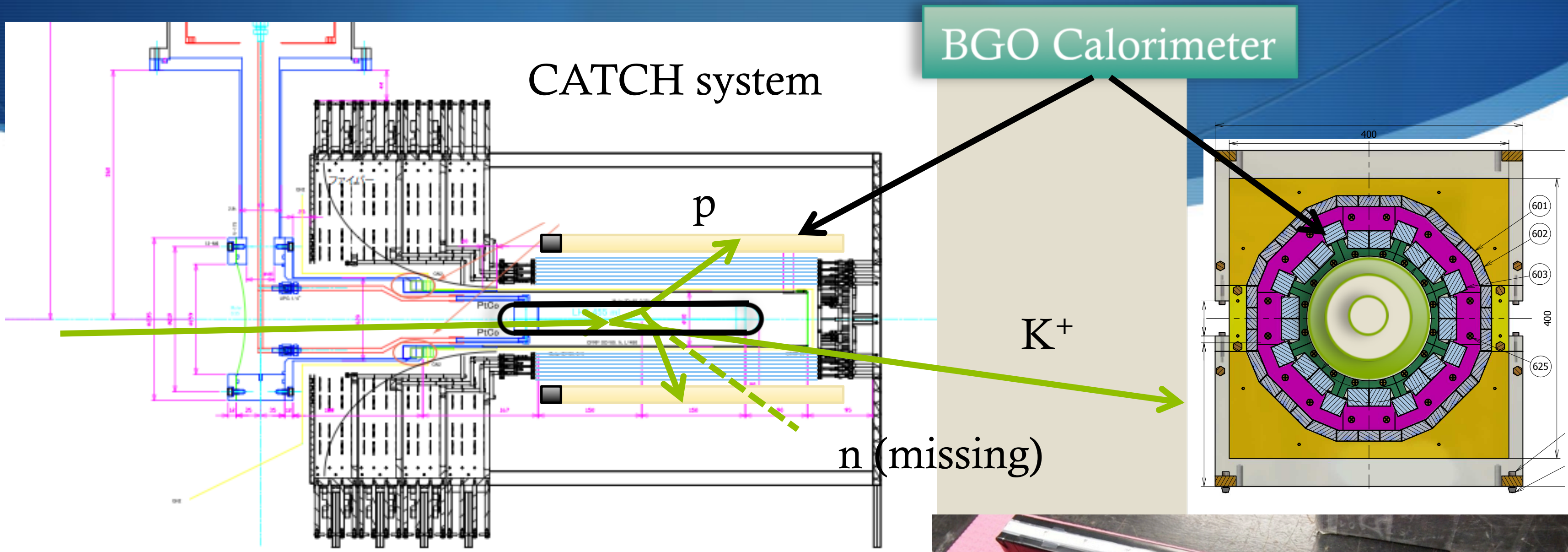
Photon Sensor (MPPC)

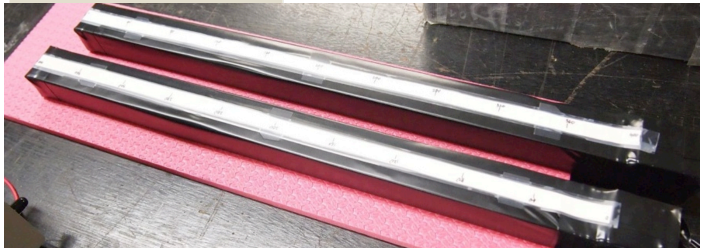




We already determined the operation voltage of 5000 MPPCs

BGO Calorimeter



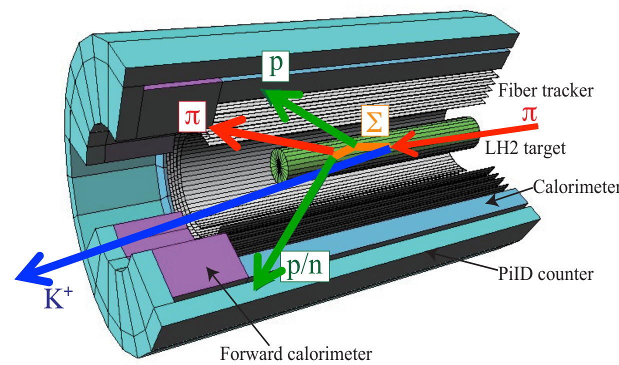


- 24 BGO crystals (25 x 30 x 400 mm^3)
- Energy resolution : 1 % for 80 MeV proton
- Requirement
  - Keep this resolution under the expected single rate of 40 kHz (200 kHz w/ beam structure)
    - Flash ADC readout

Cylindrical Fiber Tracker (CFT)に対する要求

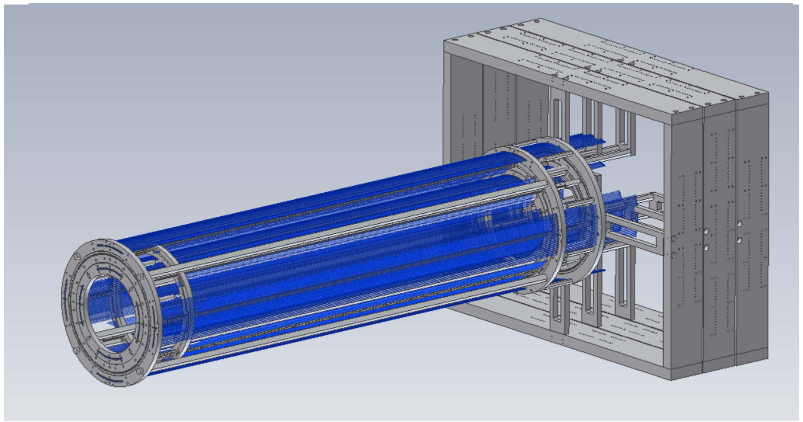
- 3次元トラッキングが可能
  - φ方向(ビームにファイバーが平行) 4層　(動径方向)
  - UV方向(ファイバーが螺旋を描く) 4層　(ビーム方向)
  - 角度分解能としてはファイバー1mm間隔で配置で十分
- 大きなアクセプタンス
  - ビーム方向に40cmのアクティブな領域
  - 動径方向に多数のファイバー層を密に並べる
    - 5cmの中に8層
- 出来るだけファイバー厚を抑える
  - 低エネルギーの陽子まで検出出来るように
  - 0.75 mm φファイバーの使用
- dEによる粒子識別
  - 陽子とπのエネルギー損失による区別
  - 厚みが出来るだけ一様になるように円形ファイバーを配置
- 検出効率
  - 98%以上が望まれる

頭でイメージするのは簡単だけど
実際に作れるのか？
→プロトタイプをまず製作



CFT プロトタイプ

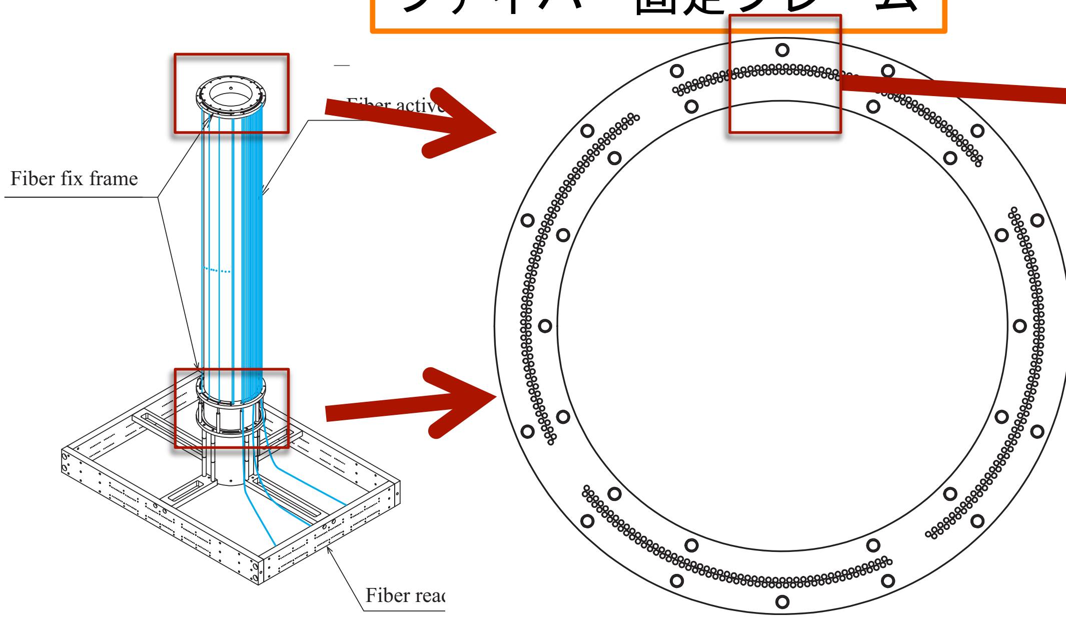
- 目的
  - CFT実機とほぼ同じ大きさのファイバートラッカーを製作し、作製方法を確立する
  - 検出器としての性能の評価
    - 基本性能 : 光量、検出効率、
    - BGOと組み合わせた性能 : PID, 散乱事象の同定
- 構造
  - ϕ1, U, ϕ2の3層構造
  - 3層をそれぞれ製作
  - 入れ子式に3つをドッキング

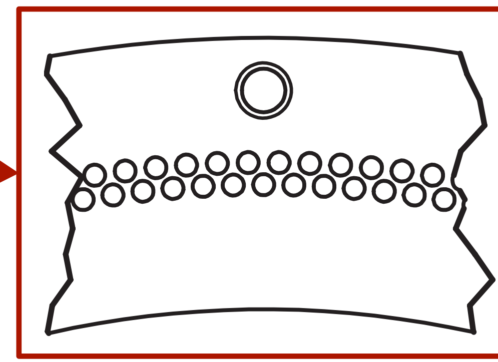


ϕ層のデザイン、製作

- 円筒のファイバーの配置方法
  - 両端のファイバー固定のフレームに位置決めの穴をあけて、1本ずつファイバーを張る

ファイバー固定フレーム



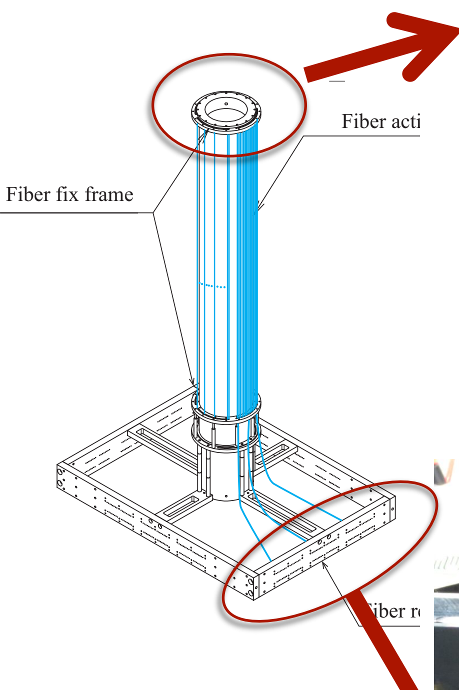


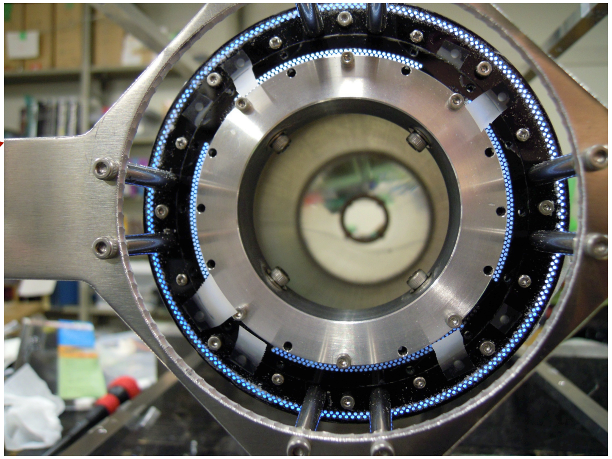
- Ineffectiveな領域がないようにファイバーを配置
- ファイバー厚を出来るだけ均一にする

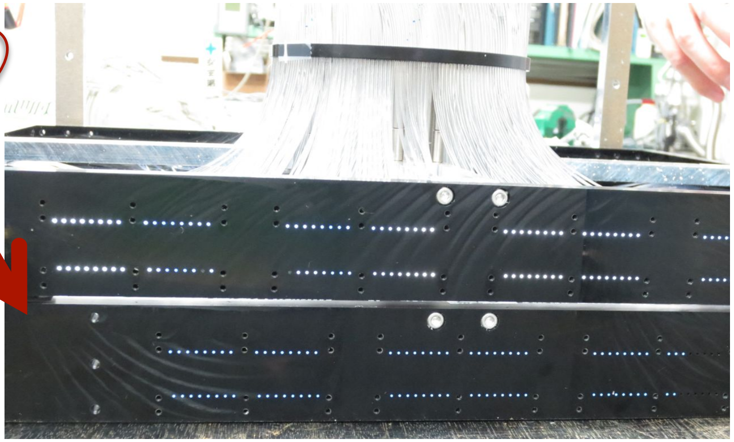
ϕ層の製作(ファイバー張り)

- 製作時のメモ
  - ファイバー間の静電気の反発が強い。それに打ち勝つテンションが必要。
  - 100本程度を一度に重りをかけて固定。次の100本に重りをかけると、すでに固定されているファイバーのテンションが少し緩む。
    - →ファイバー間の隙間。
    - ファイバーのテンションの調整機構が必要。

φ層の製作（端面研磨）







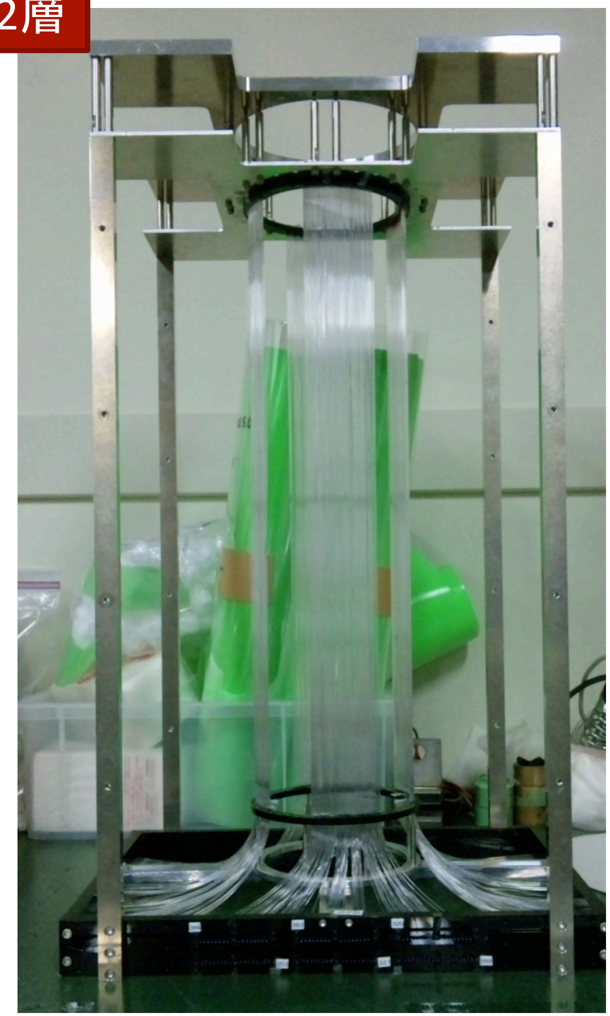
- ファイバー上部
  - ESRを取り付け、鏡面反射させる。
  - 機械が入らないので、紙ヤスリで磨く。
- ファイバー下部
  - MPPCをつないだ読み出し部分。
  - G-techでダイアモンド研磨。

φ層の製作 (完成)

内部にアルミ円筒が有り、
それで支えられている

φ1層

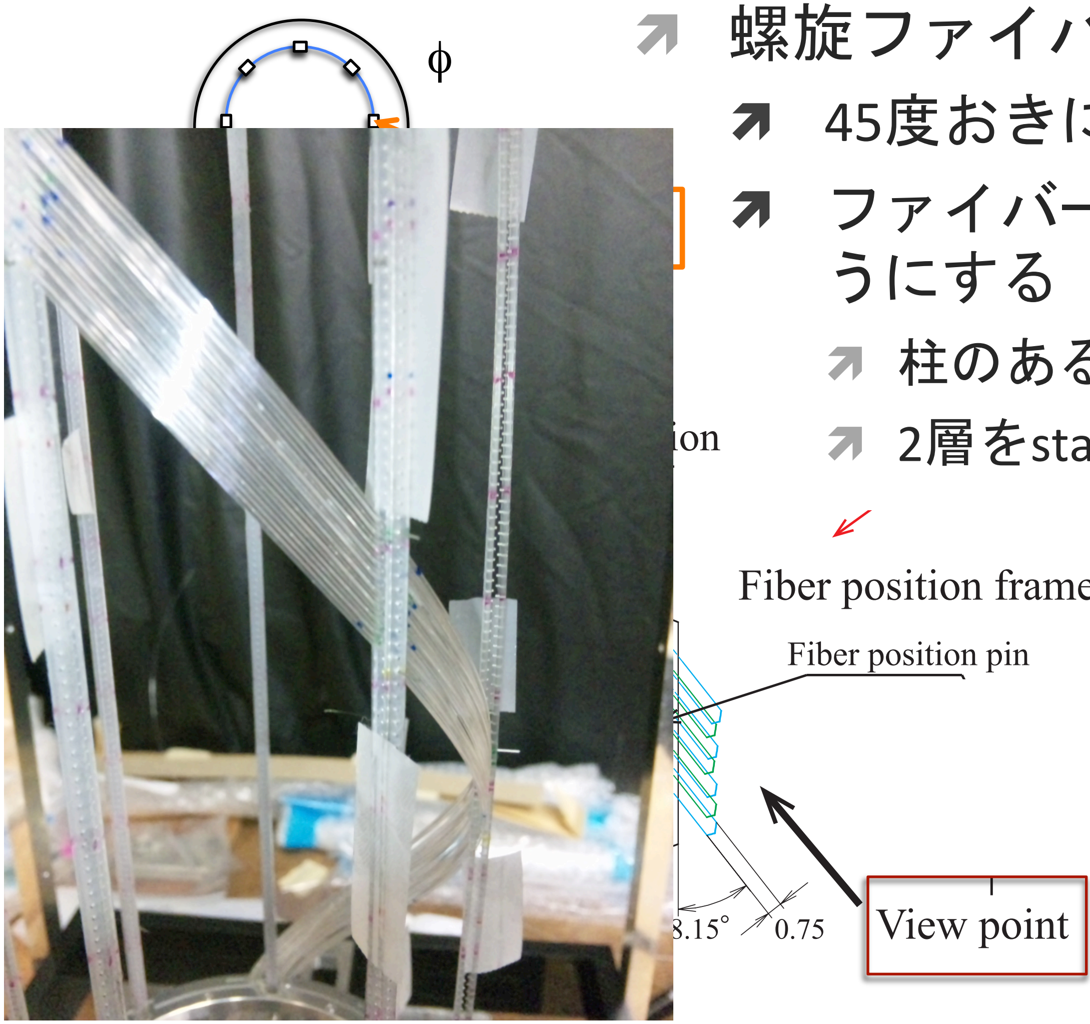
φ2層

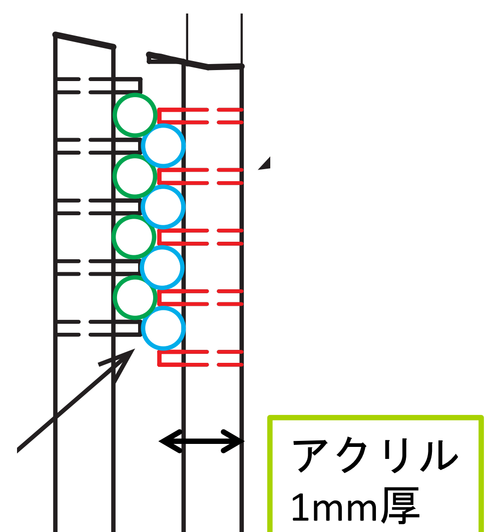


- φ層の次への改善点
  - ファイバーのテンションの緩み
  - 重りを取り付けるパート毎にテンションを調節できる機構が必要

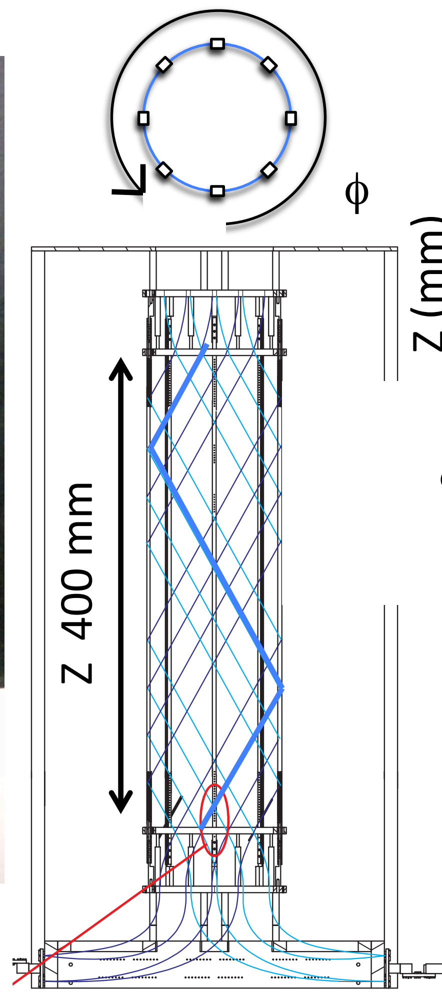
U層のデザイン、製作

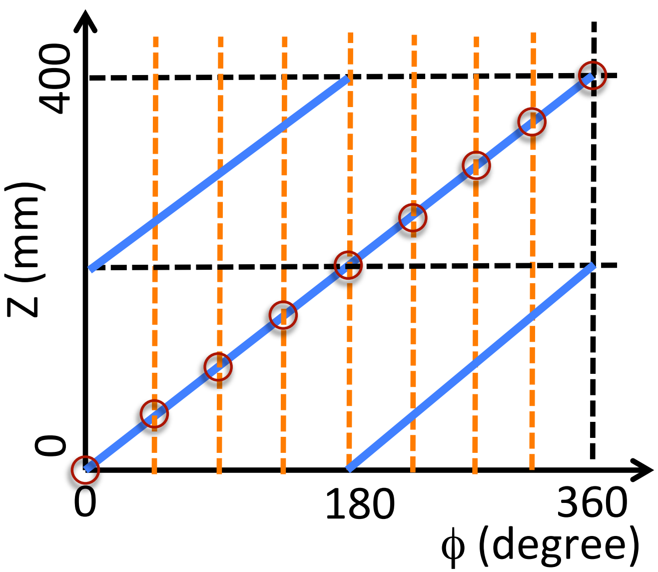
- 螺旋ファイバーの配置
  - 45度おきに位置決めの柱を設置
  - ファイバーの位置が、ピンで決まるようにする
    - 柱のある場所でZの位置が保証される
    - 2層をstaggeredした状態を保つ





U層のデザイン、製作



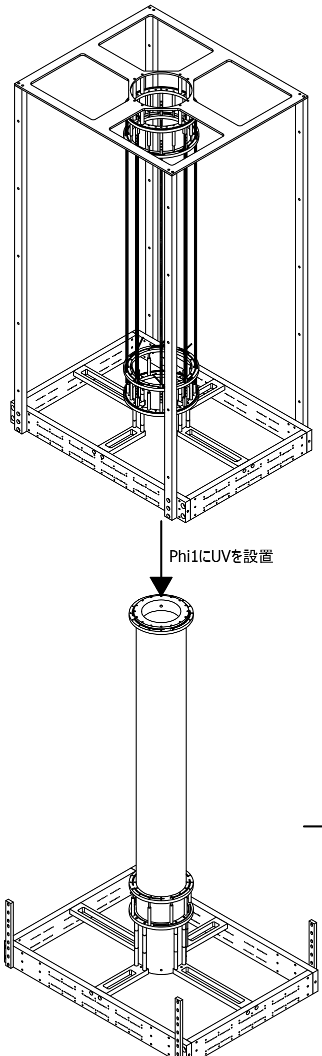


- 一本ずつファイバーを設置していく
- 10日間程度で420本を張り終わる

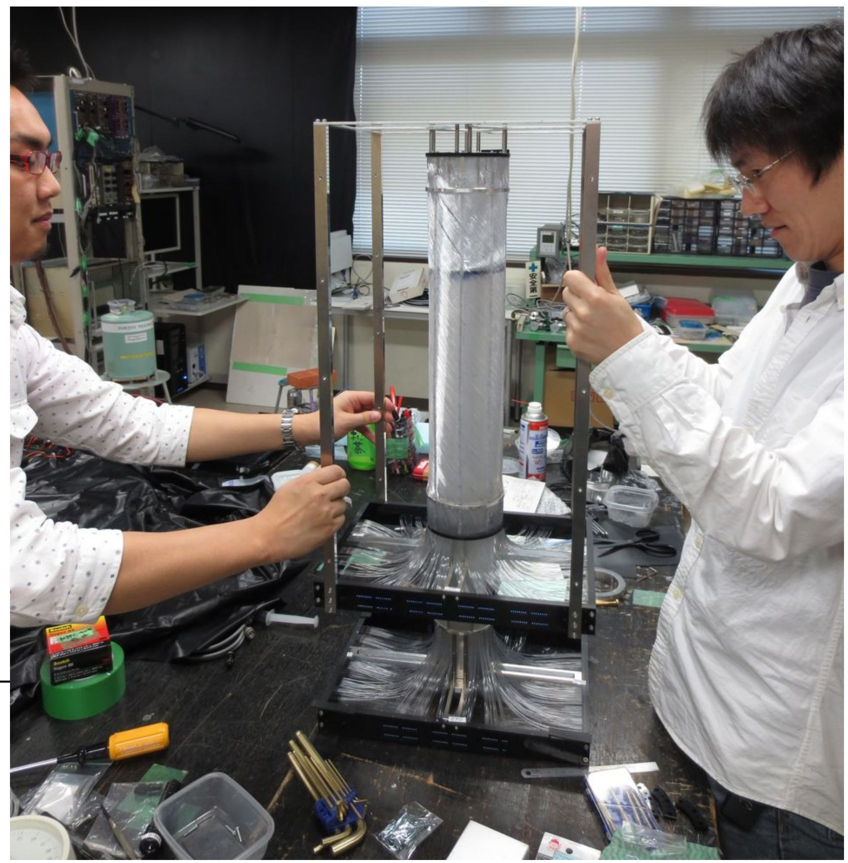
U層の製作

- 位置決めピンを用いた制作方法を確立。
- 次回への改善点
  - 柱が内側に少したわむ
    - 製作時に柱の内側にフレームを入れる

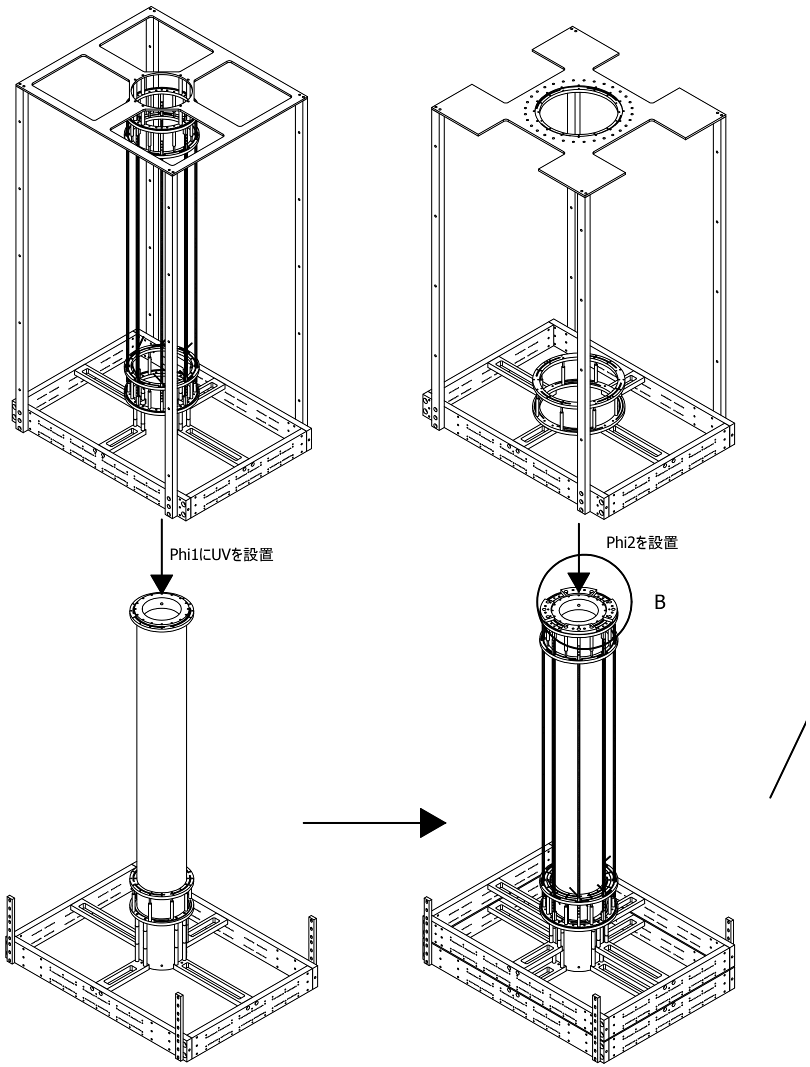
3層をつなぎ合わせる



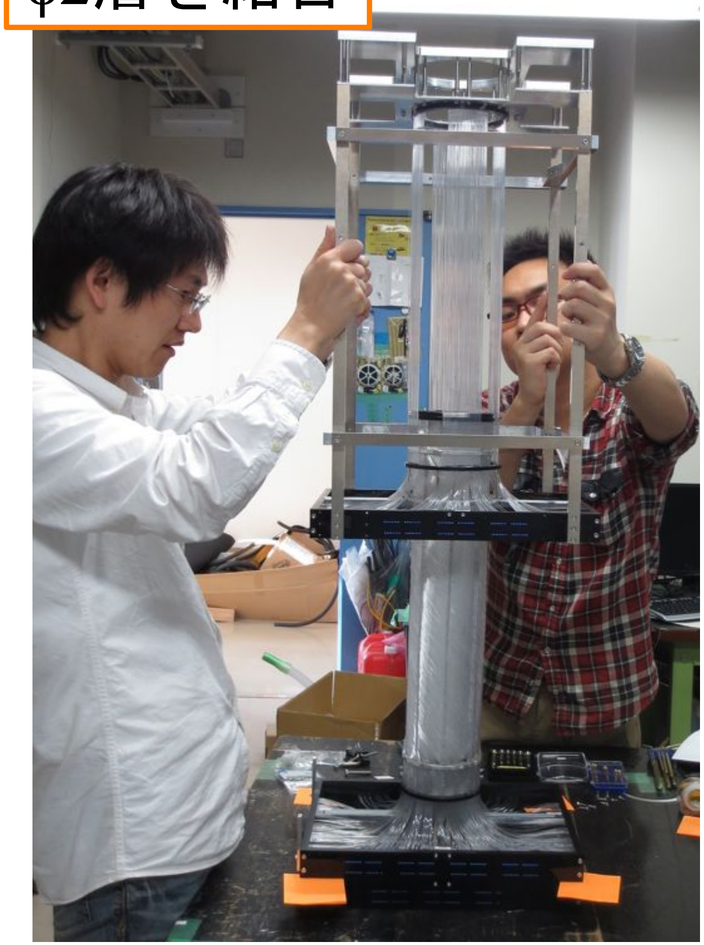
φ1層とU層を結合



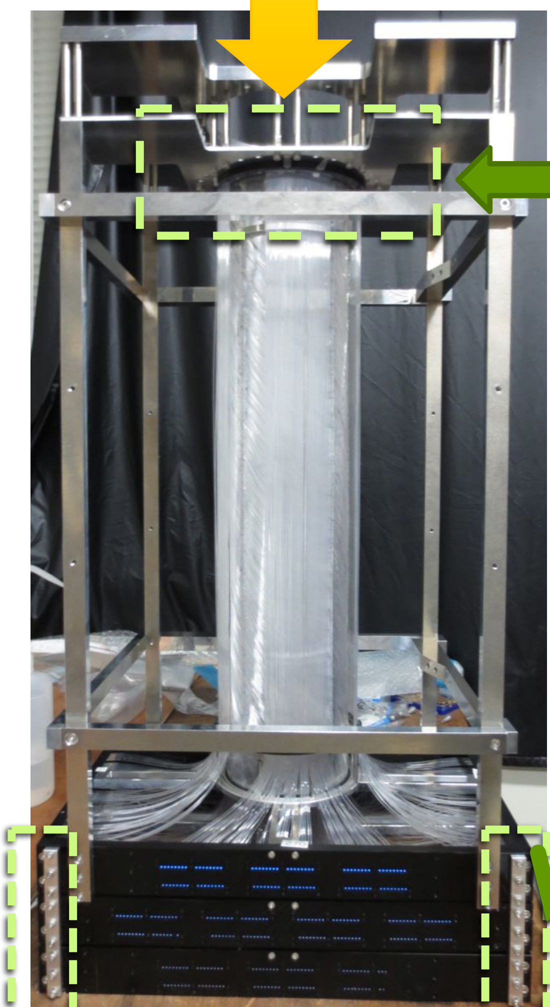
3層をつなぎ合わせる

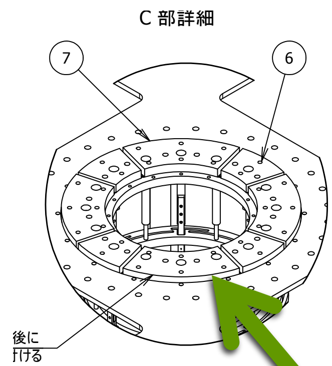


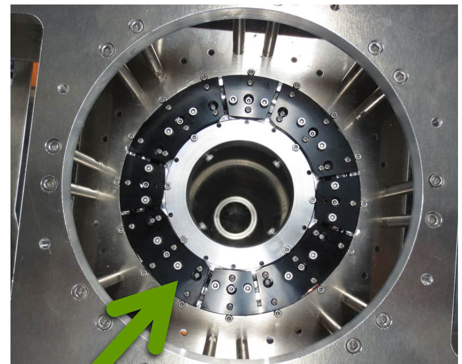
ϕ2層を結合



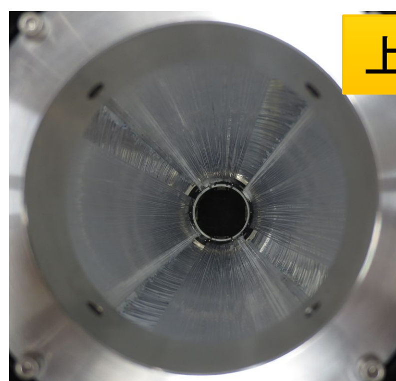
完成







3層のファイバーは上部の治具と下部の治具で一体になっている



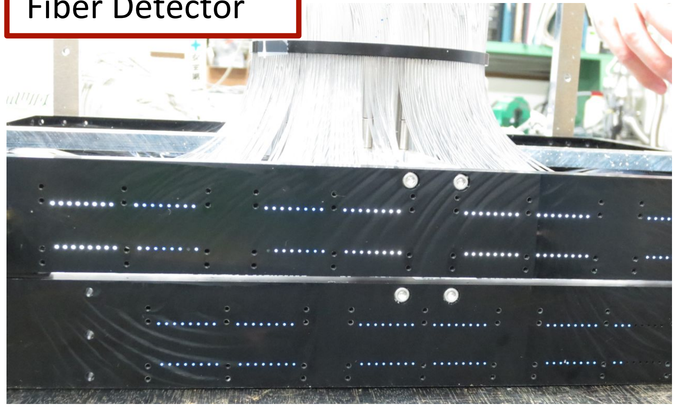
上部から内側を覗いた写真

最後に内側のアルミ筒を引き抜いて完成

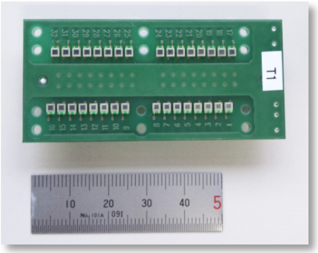
ファイバー読み出し

- ファイバーチャンネル数 1,152 ch
  - MPPCによる読み出し
    - 1 x 1 mm^2, 400 pixel
  - MPPC読み出し回路 EASIROC board 36 枚
    - 32 channel / board
    - Bias adjustment
    - Multihit TDC (1 ns/ch)
    - ADC

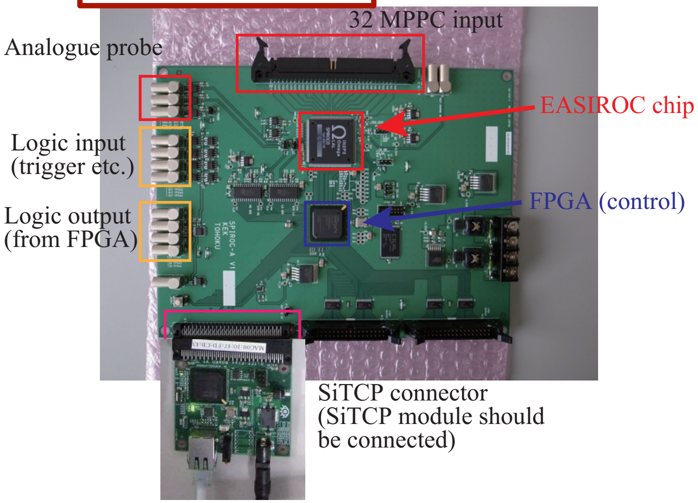
Fiber Detector



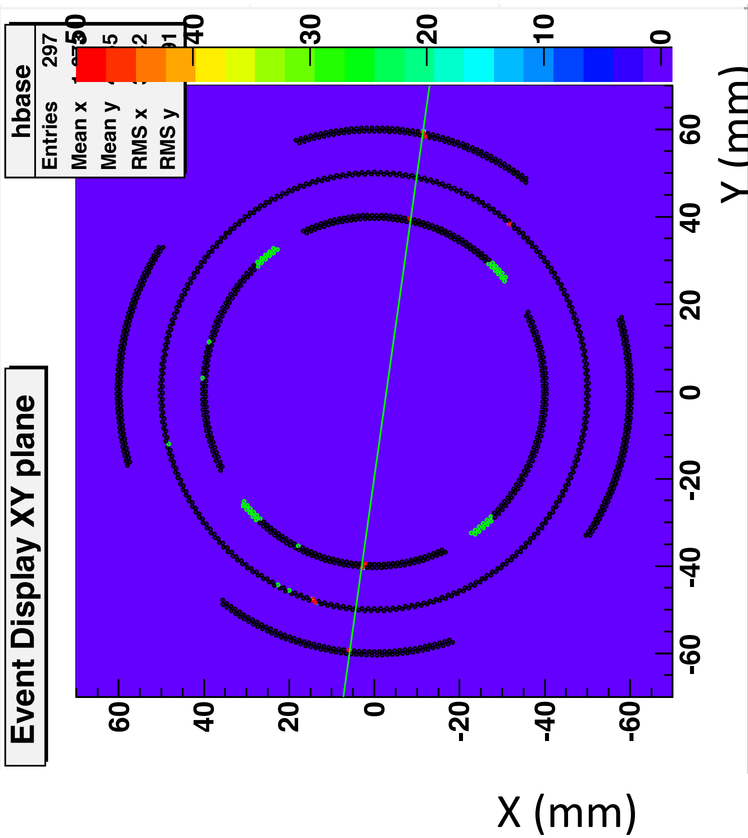
Photon Sensor

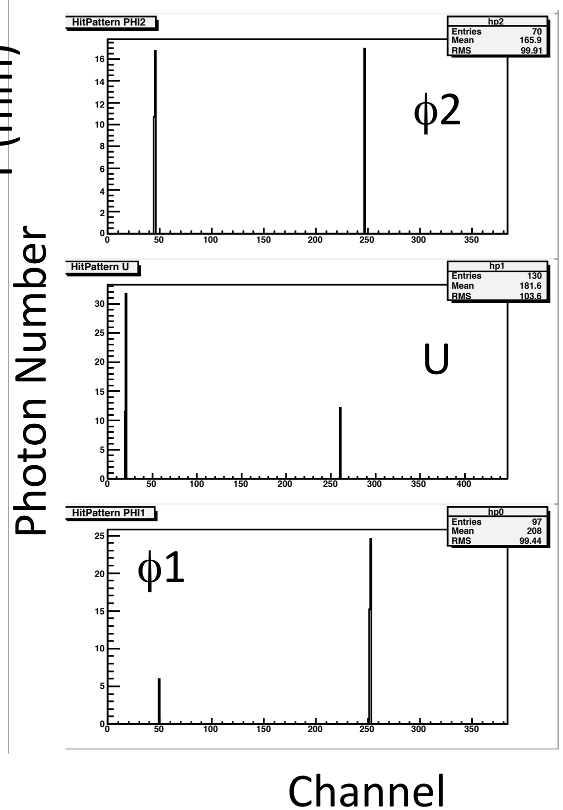


Readout board



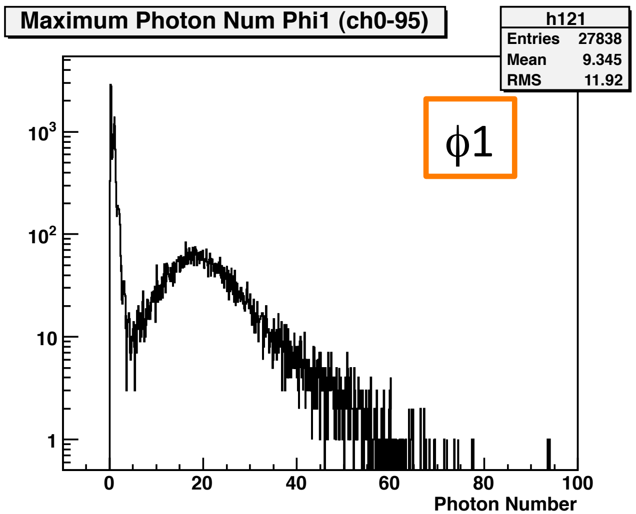
宇宙線を用いたテスト

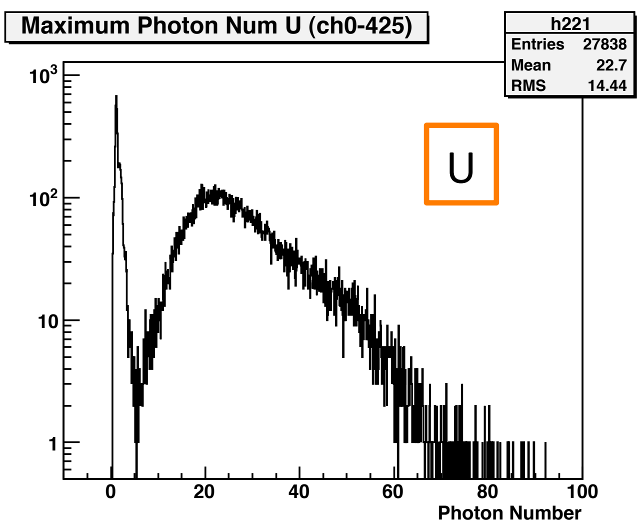




- ϕ1, ϕ2層でxy平面のトラッキング
- U層とxy平面のトラッキングの情報からz方向の位置を出す

宇宙線に対する光量、検出効率

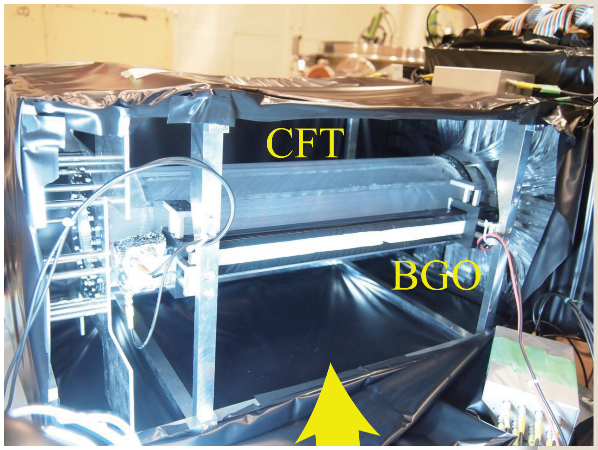


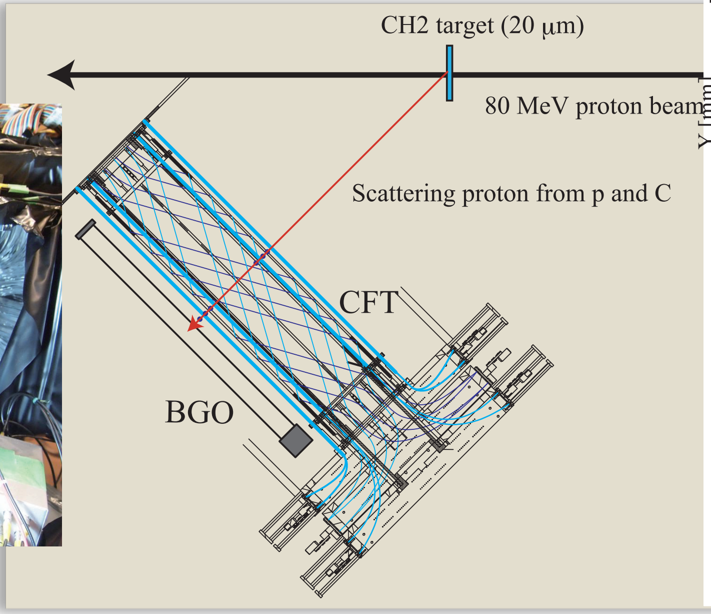


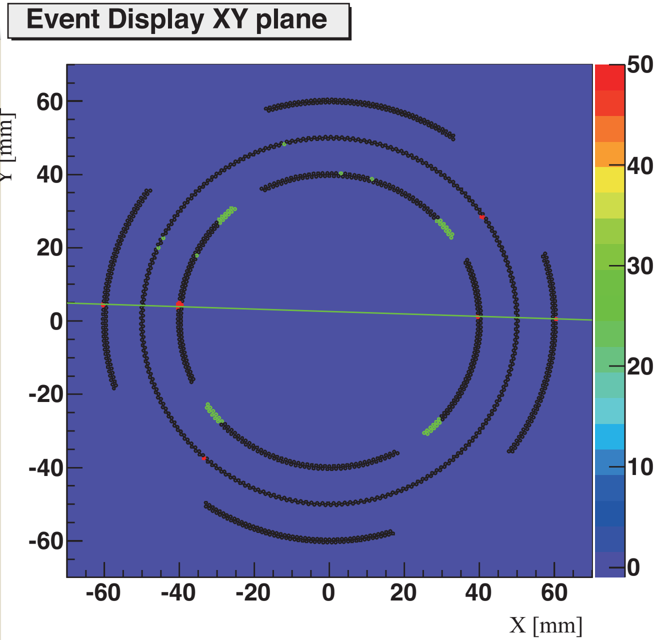
- 光量
  - φ1, φ2層 : 18
  - U層 : 20
  - 十分な光量が得られてた。
- 各層の検出効率
  - φ1, φ2層 : 87 %
  - U層 : 93 %
  - 光量は十分なので、ファイバーの隙間が原因だろう

Experimental proof

- pp, pC scattering experiment using prototype detector
  - 80 MeV proton beam @ Cyclotron Facility at Tohoku university

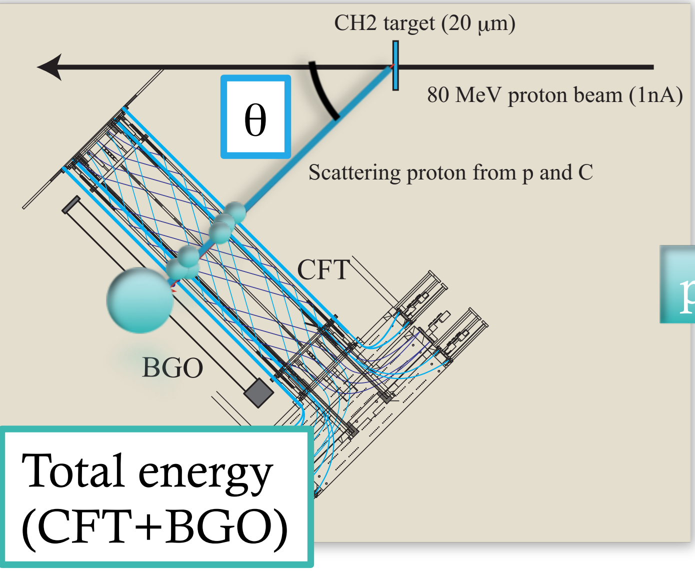




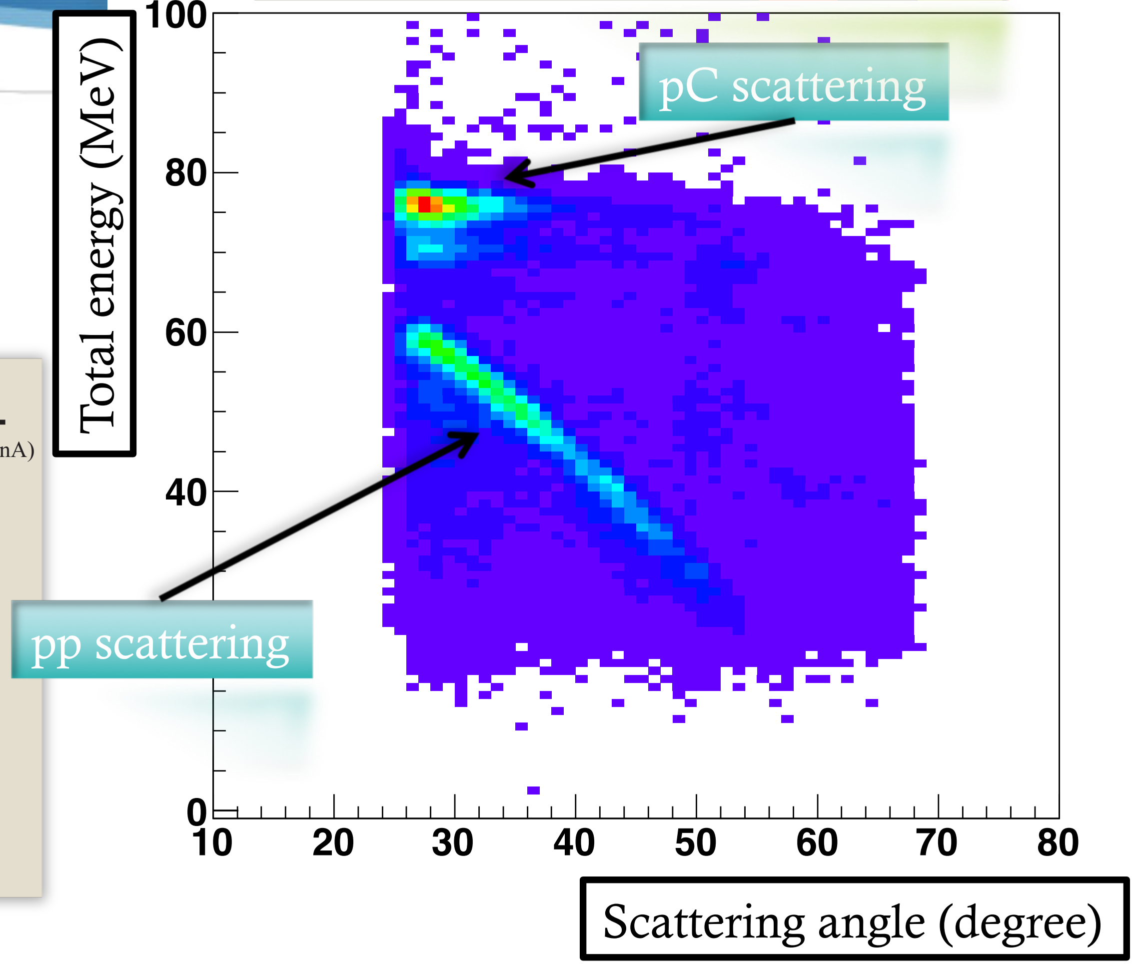


Reconstruction of pp, pC scattering kinematics
Particle identification by ΔE(CFT)-E(BGO) information

Reconstruction of pp, pC scatterings

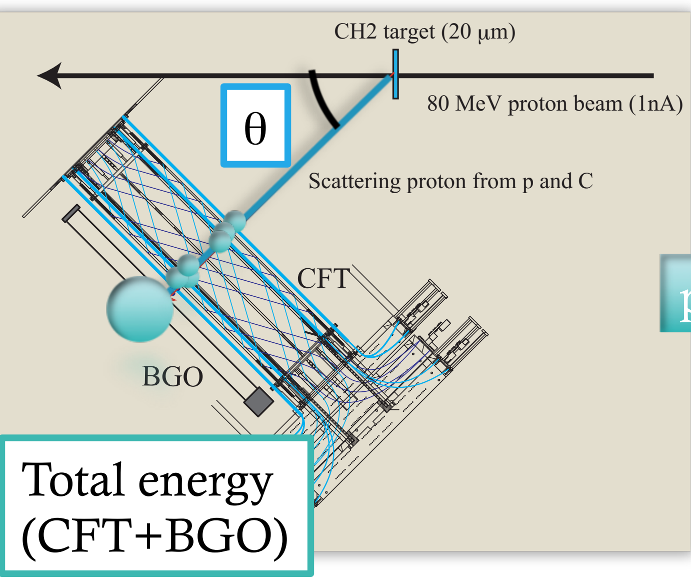


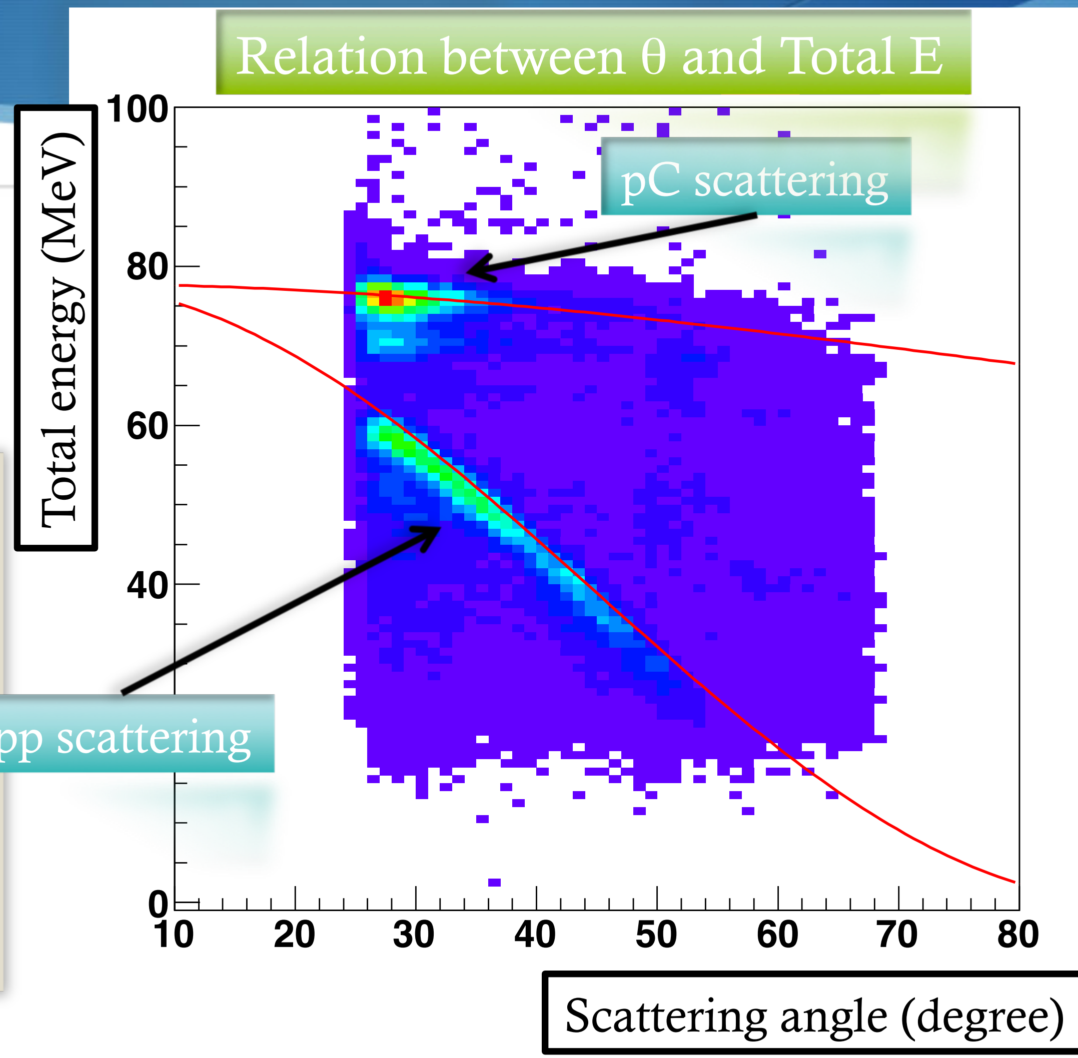
Relation between θ and Total E



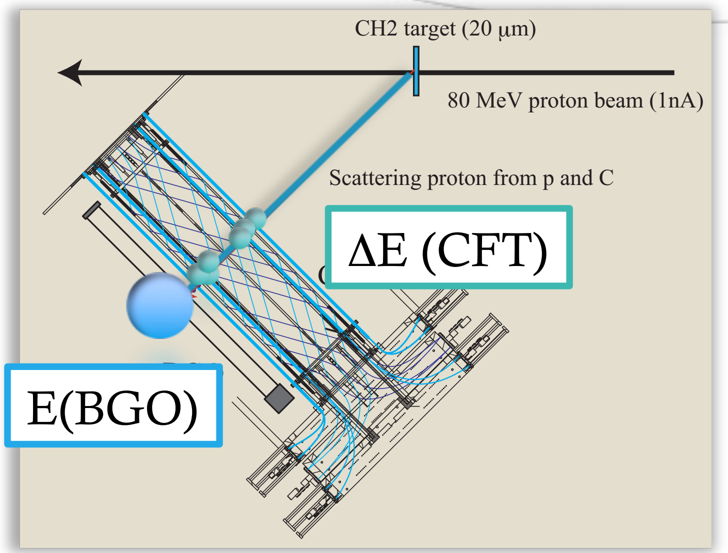
Reconstruction of pp, pC scatterings

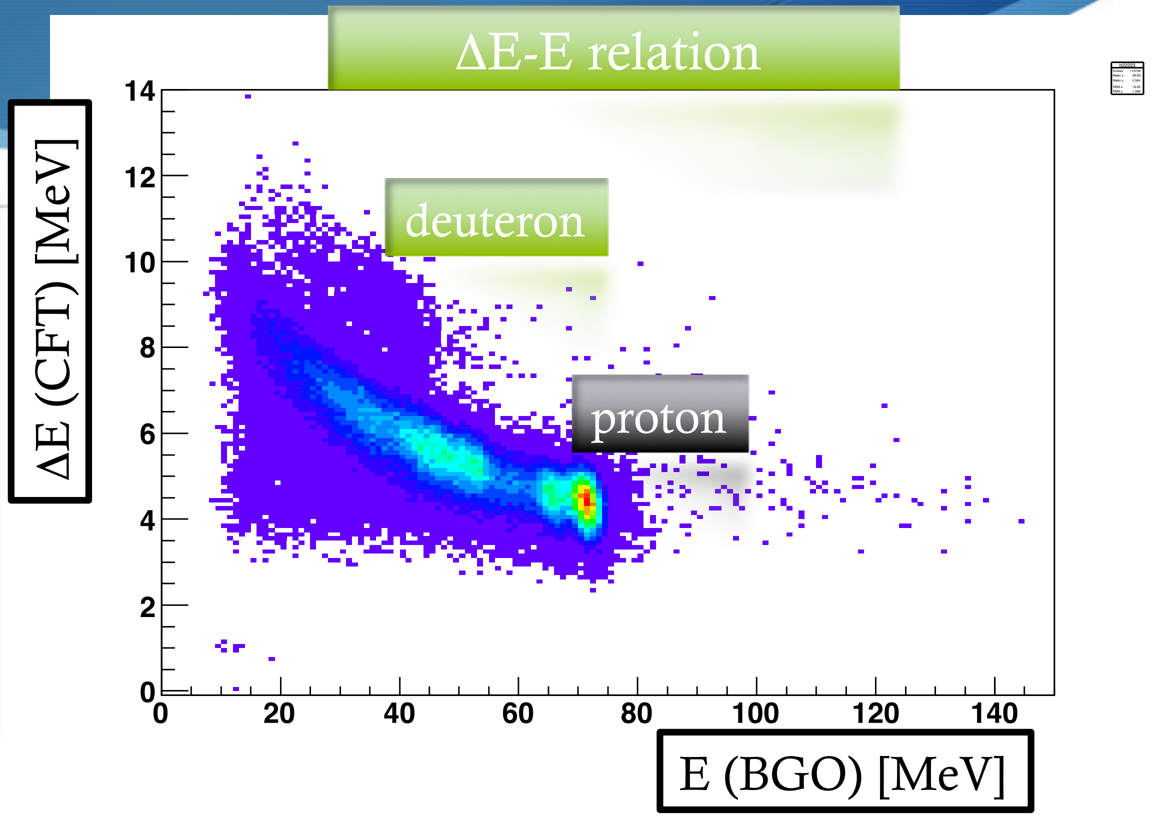
- We confirm that reconstruction of scattering events is possible by this configuration



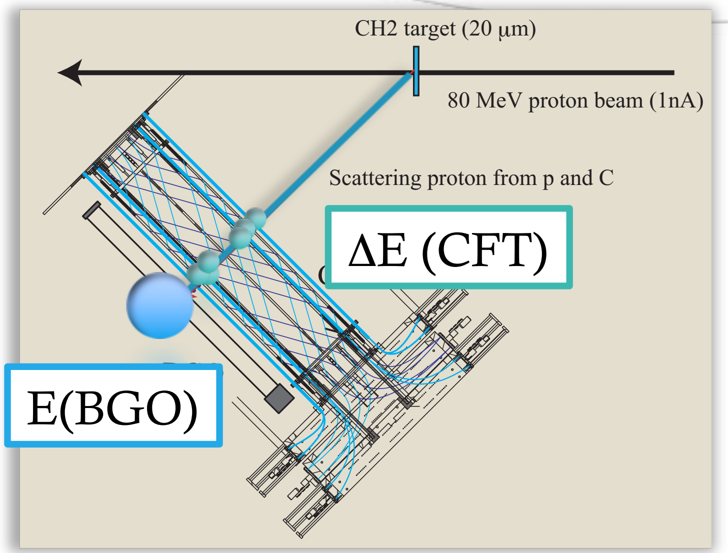


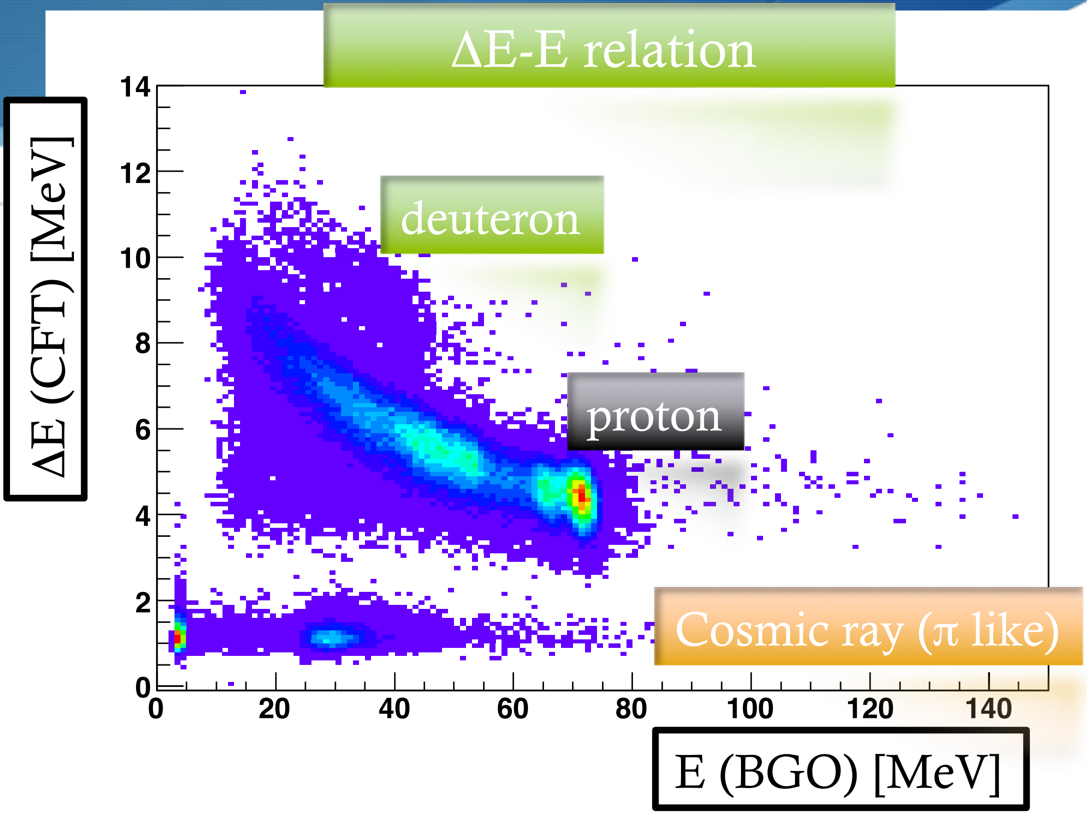
Particle Identification by ΔE-E





Particle Identification by ΔE-E





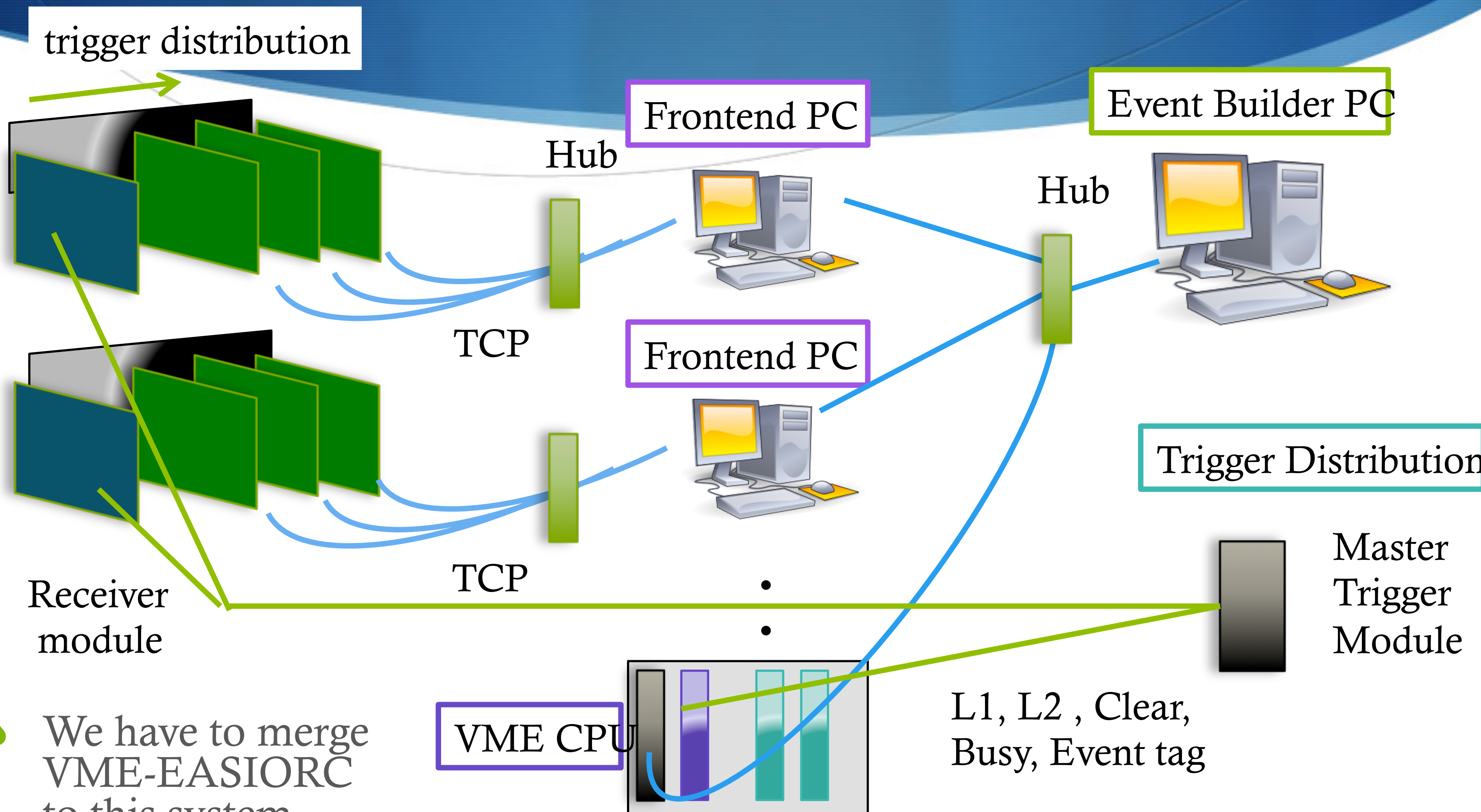
- Proton / π separation requirement
  - 20 % for 1 MeV

16 % for 1 MeV
PID is possible

CATCH system実機の開発

Cylindrical Fiber Tracker

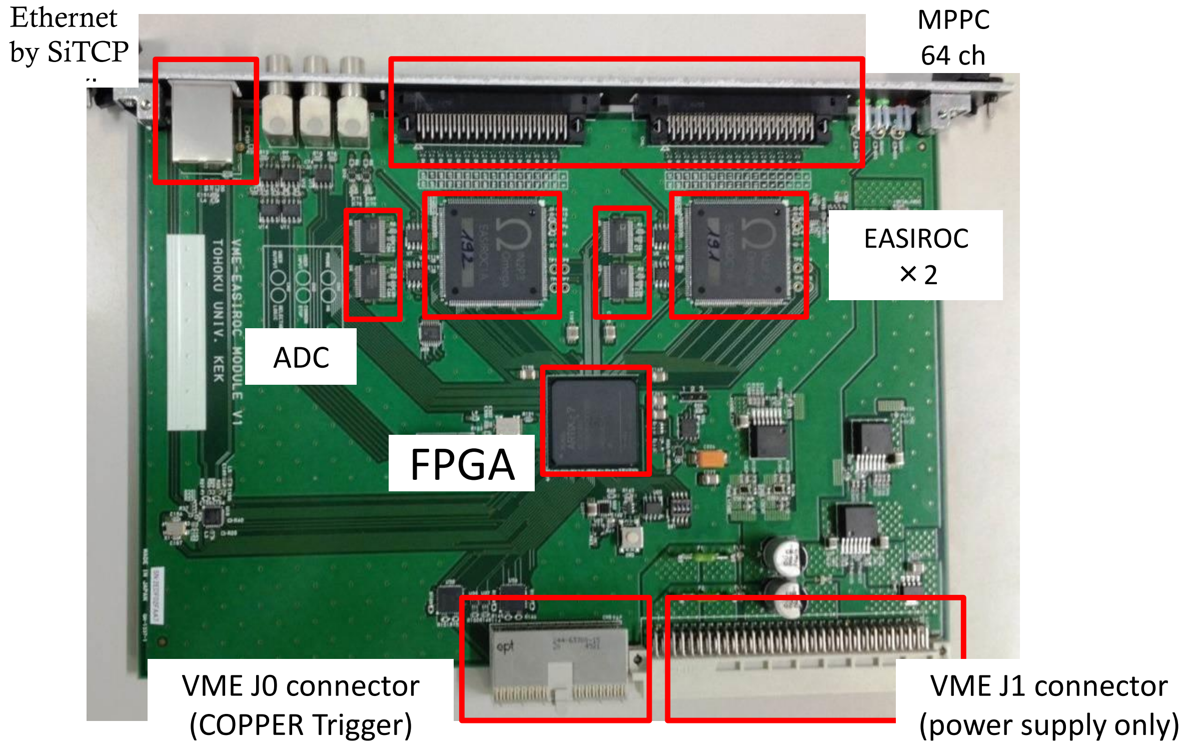
Detector and DAQ framework at K1.8



- We have to merge VME-EASIORC to this system

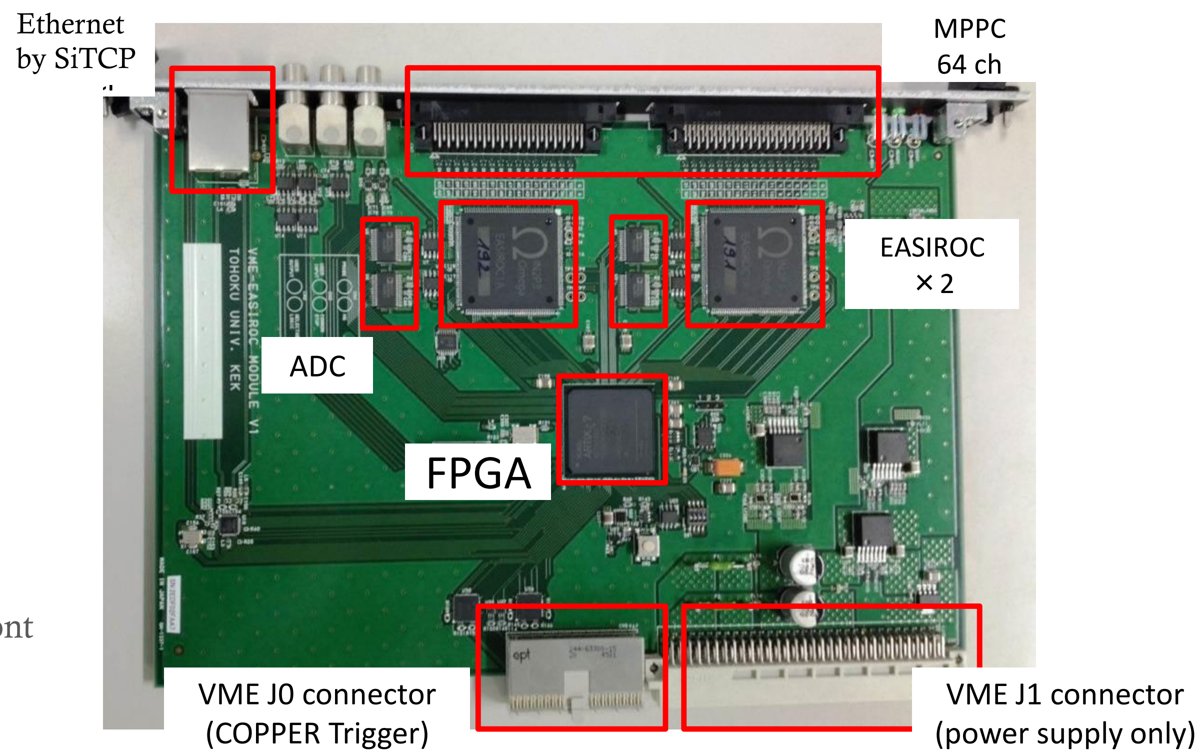
VME-EASIROC board Specification (ADC, TDC)

- VME 6U
- MPPC 64 ch (EASIROC x 2)
- FPGA Artix-7
- ADC
  - Dead time 12 μs
  - w/ Pedestal suppression
  - Fact clear
- MHTDC
  - LSB 1ns
  - hit depth / ch 16
  - Dead time : depend on hit number
    - < 12 μs
  - Fast clear
  - Time window 0~4 μs

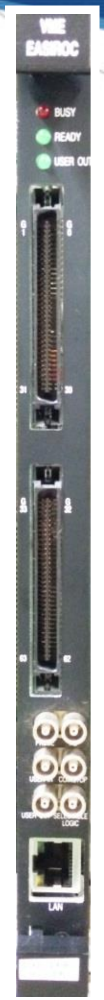


VME-EASIROC board Specification (DAQ)

- SiTCP 100 Mbps
  - FPGA internal
- Double Buffer
  - Transmit time of DATA is not included in BUSY
- COPPER Trigger
  - VME J0 bus
  - Common for all board in the same VME crate
    - Hold
    - L2 trigger
    - Busy
    - Clear
    - Event Tag
  - Common stop is input from front panel I/O for each module



VME-EASIROC board Specification (I/O)

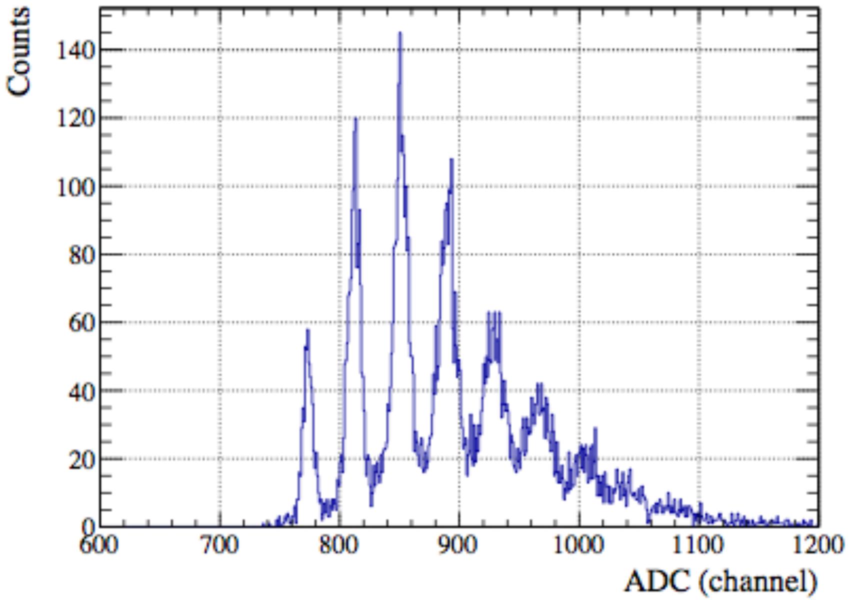


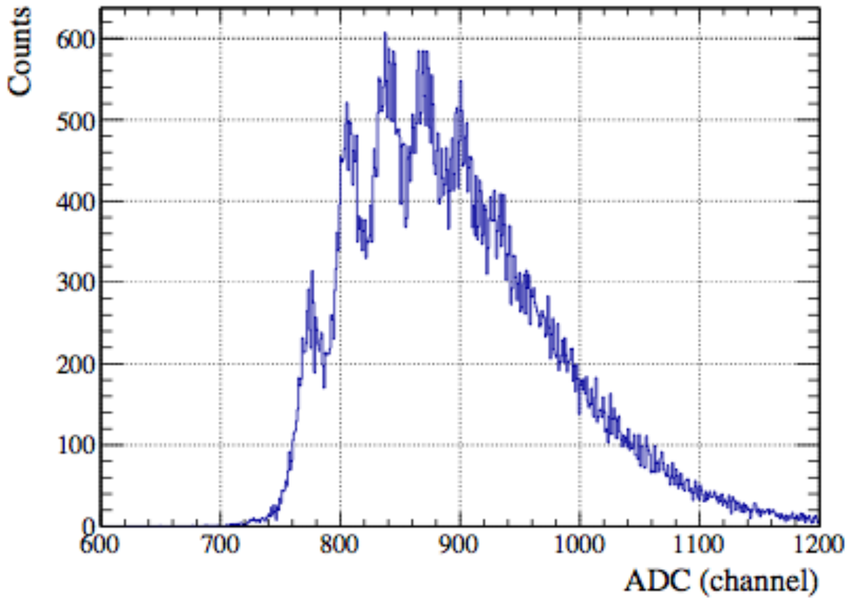
- MPPC input x 64
- Analog out x 2
  - High gain
  - Probe
- NIM out x 2
  - Selectable Logic (Discri out of each MPPC)
  - User out (e.g. : BUSY etc.)
- NIM in x 2
  - Common stop
  - User in

ADC spectra with MPPC (400 pixel)

Shaping time : 50 ns
Preamp gain : 75

Shaping time : 175 ns
Preamp gain : 75



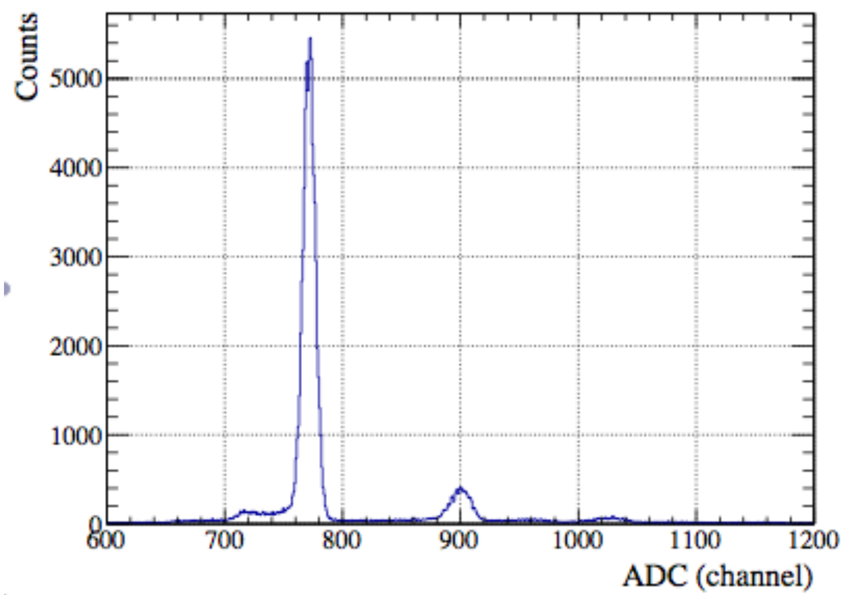


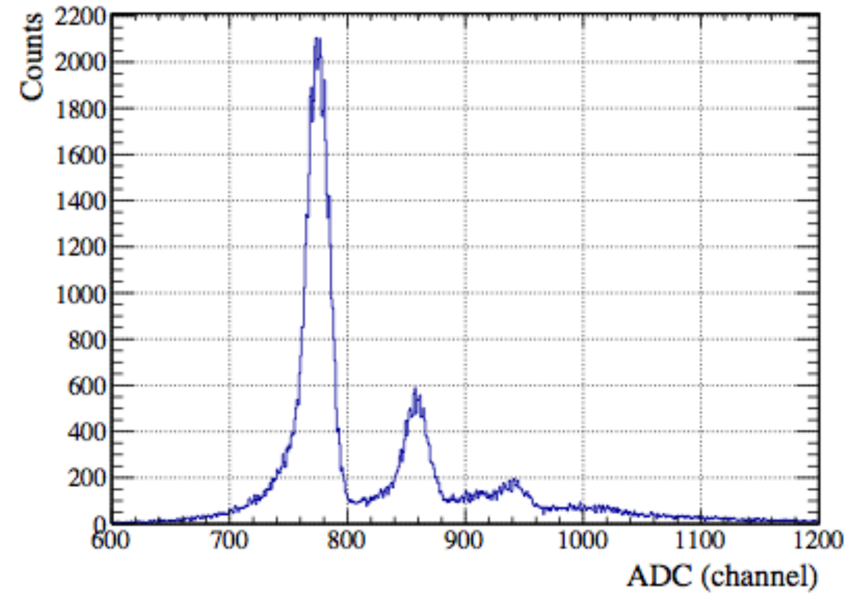
- aa

ADC spectra with MPPC (100 pixel)

Shaping time : 50 ns
Preamp gain : 75

Shaping time : 175 ns
Preamp gain : 75

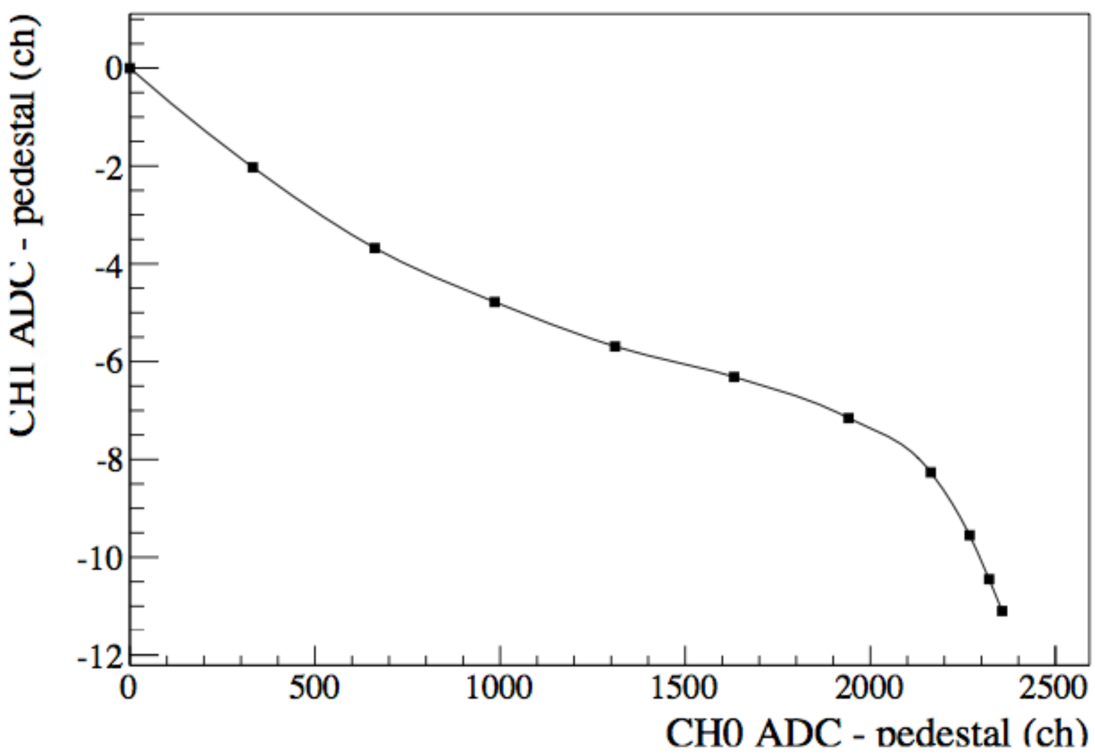




Cross talk

- Ch 1 : Input charge
- Ch 2 : No input

Check relation

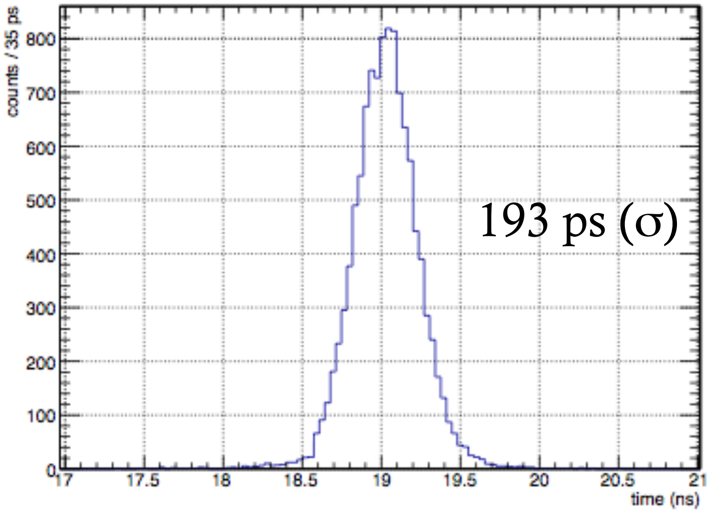


Cross talk : 0.35 %

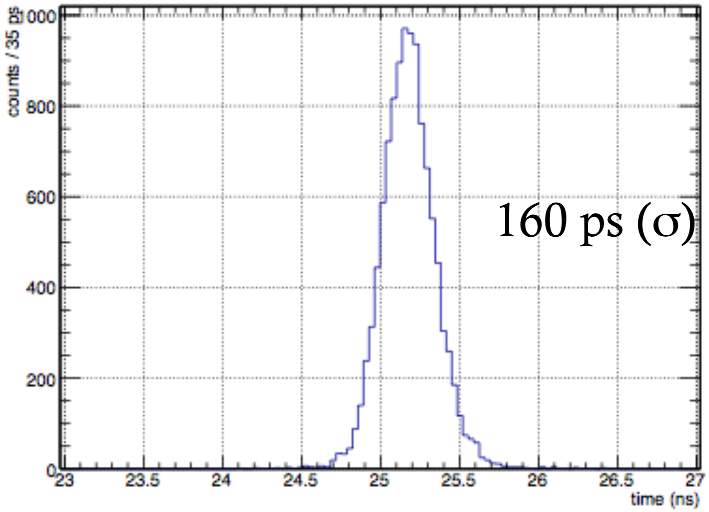
Time resolution of Discriminator in EASIROC

- Input test charge to EASIROC and discriminated signal was output from frontend User Out. Then this Output is connected to CAEN V775.

1 p.e. corr. charge



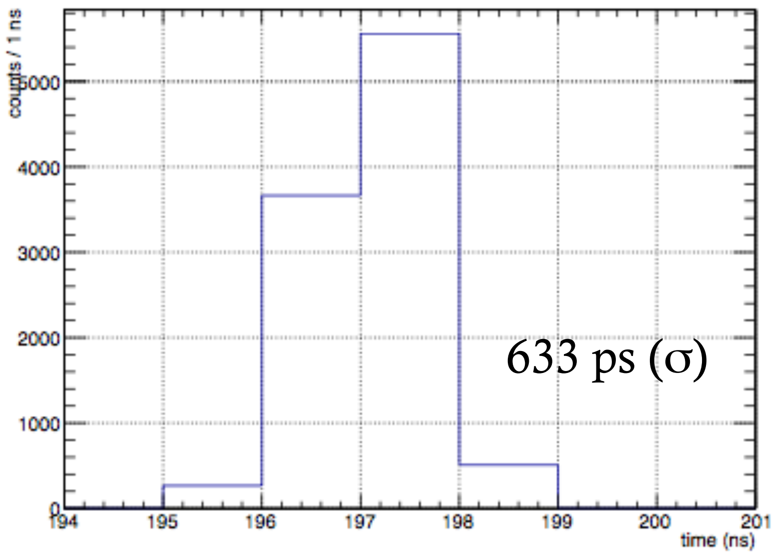
20 p.e. corr. charge



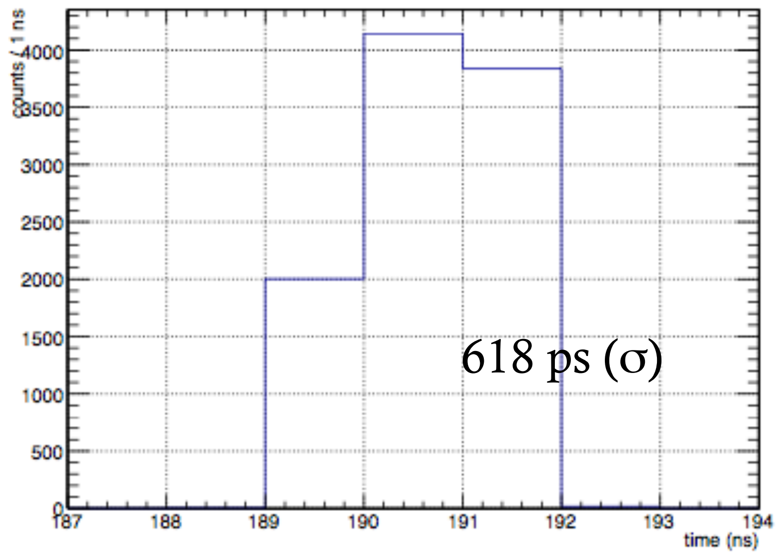
Time resolution by Multi hit TDC

- Time resolution with FPGA implemented TDC (1ch = 1ns)

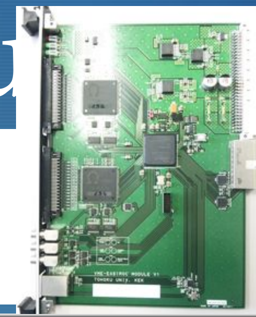
1 p.e. corr. charge



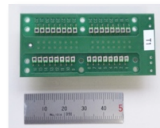
20 p.e. corr. charge



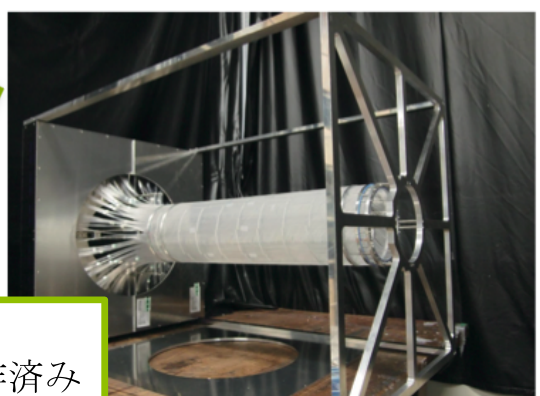
CFT channel su ary



- 円筒形ファバー検出器
  - ストレート層 (f 層) 4 層
  - 螺旋ファイバー層 (U, V層) 4 層



Layer	r (mm)	channel number	MPPC PCB	VME-EASIROC	single rate (kHz)
U1	50	426	14	7	14
ϕ1	54	584	19	9.5	7
V2	60	472	15	7.5	10
ϕ2	64	692	22	11	4.5
U3	70	510	16	8	7.5
ϕ3	74	800	25	12.5	
V4	80	538	17	8.5	
ϕ4	84	910	29	14.5	
Total		4932	157	79	

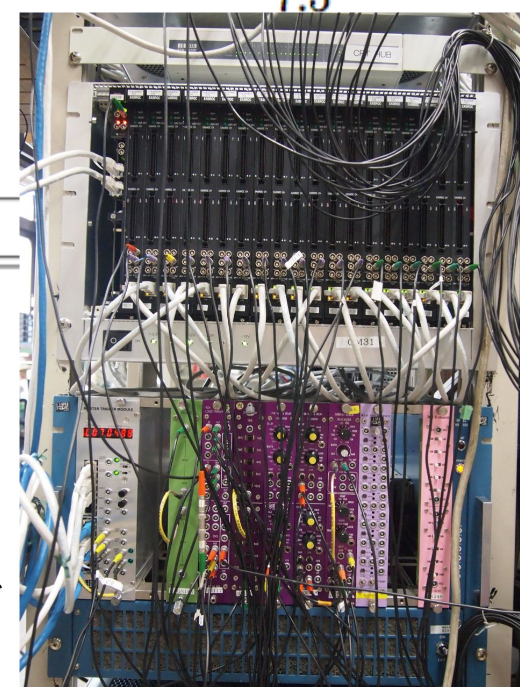


残りの層も
フレームは製作済み

必要数を
製作中

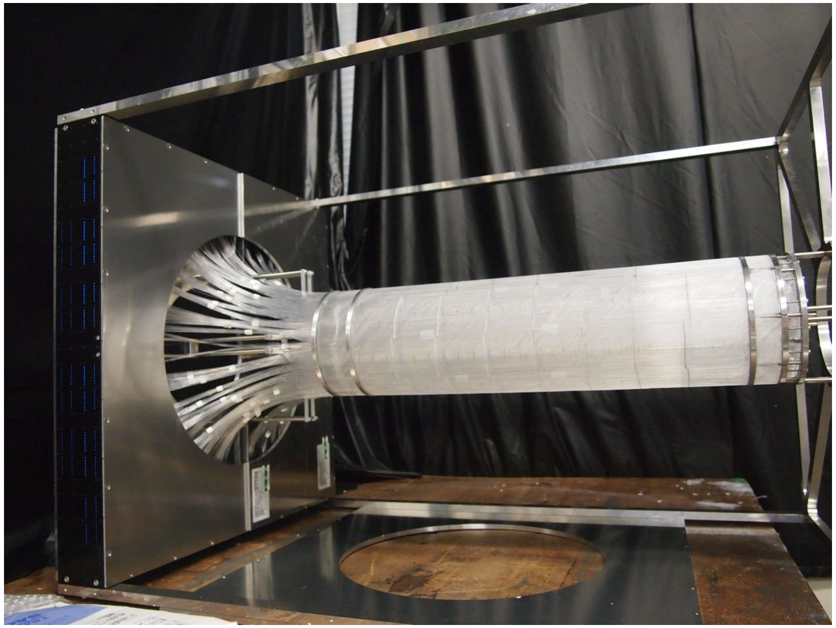
必要数を
製作済み

Firmware開発も終了
複数台用いてDAQテスト

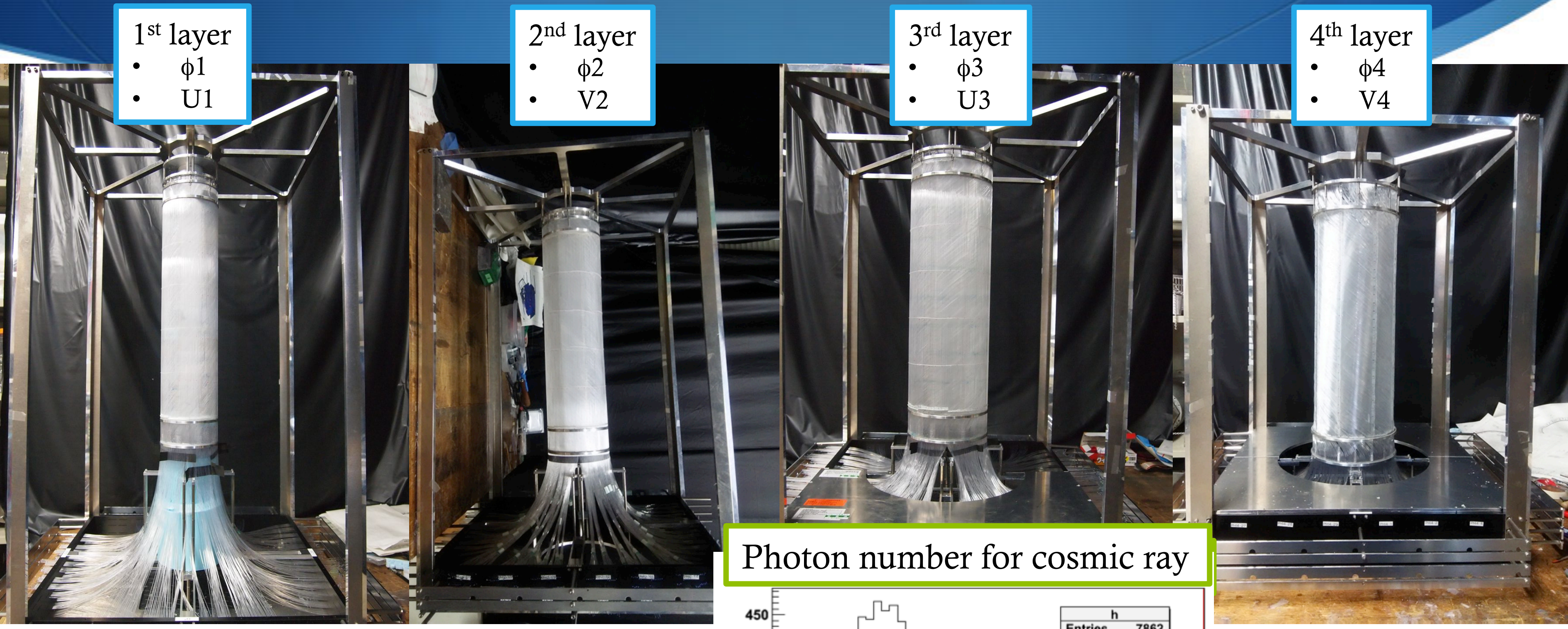


円筒形ファイバートラッカー(CFT)の製作

- 2フレーム目の製作
  - 螺旋状の層 (U layer)
  - ストレート層 (φ layer)
    - テンション調整機構
    - ポジションガイド

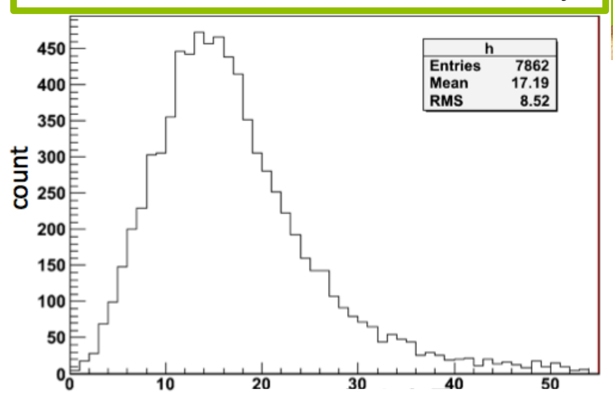


Cylindrical Fiber Tracker (CFT) is just constructed



- Finish construction of all layers
  - It took ~1 year
- Combine all layers in this August.
  - Commissioning using cosmic ray.

Photon number for cosmic ray



Number of photo electron

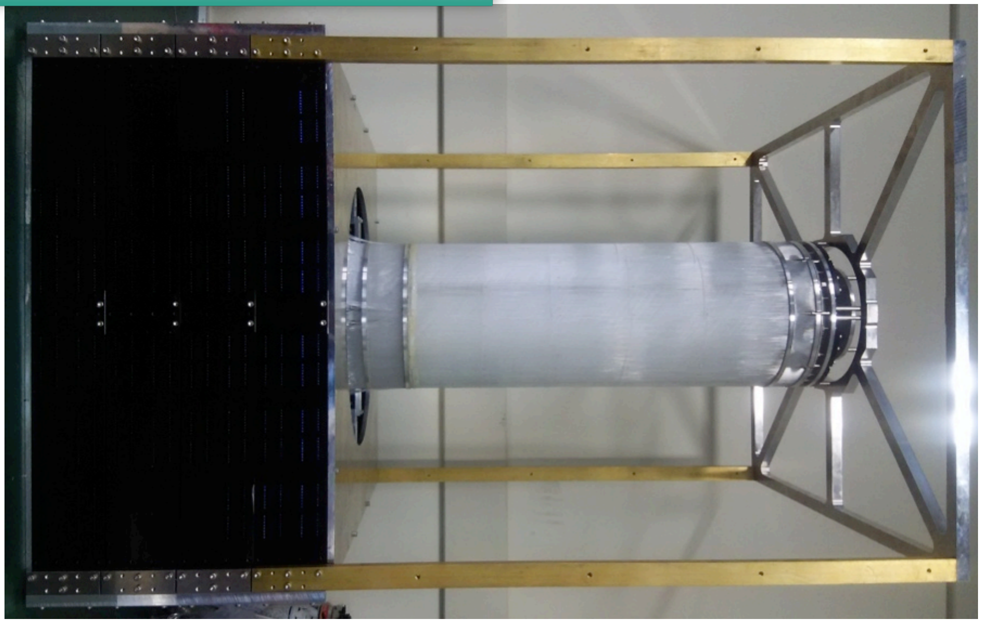
Efficiency
- ϕ3 : 98 %
- U3 : 96 %

Acceptable value was obtained

CFT was constructioned

- CFT
  - All frame structures are combined into full system.
  - Operation voltages of all MPPCs were optimized.

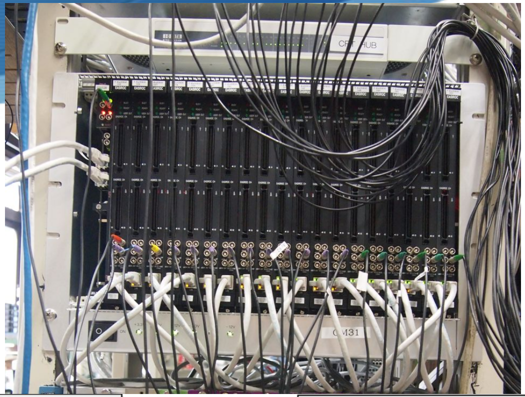
Cylindrical Fiber Tracker (CFT)

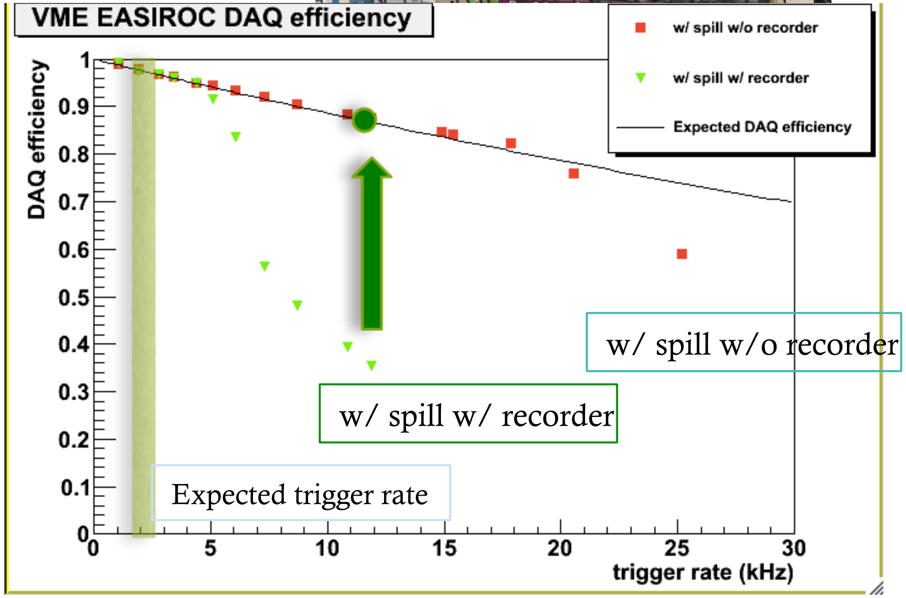


CFT DAQ system

- VME-EASIROC performance
  - 14 μs busy time
  - Multi boards can work in parallel
    - If there is no bottle neck due to data transfer or HD access, busy time of CFT system is also 14 μs
  - ADC pedestal suppression (data size → 1/100)

- Performance test
  - 55 VME-EASIROC boards
  - Data size : 1500 word/event (1.5 times bigger than expected size)
  - Results
    - 5 kHz w/ recorder
    - 12 kHz 86% efficiency w/ recorder
      - Recorder : Data uncompressed mode
      - Adjust ring buffer size
      - Recorder process can continue during spill off period





BGO Calorimeter

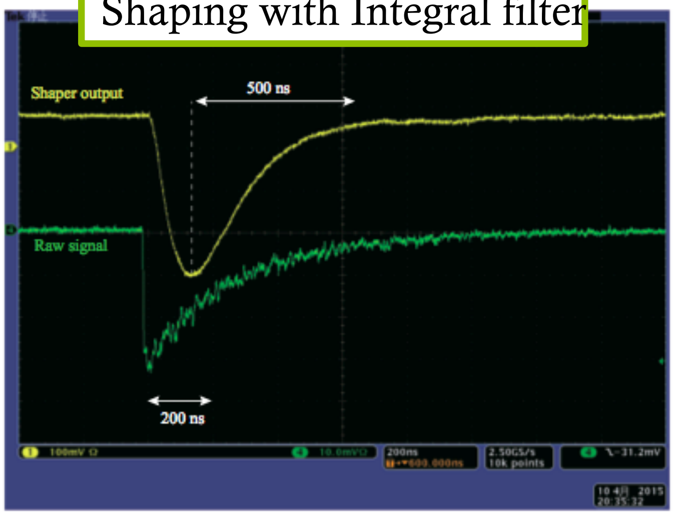
BGO calorimeter

- BGO
  - 24 BGO crystals (25 x 30 x 400 mm^3)
  - Requirement
    - Energy resolution better than 3 % for 80 MeV proton → OK
    - Keep this resolution under the expected single rate of 40 kHz (200 kHz w/ beam structure)
      - Flash ADC readout
    - Large acceptance for scattered proton
      - Re-design of BGO position

BGO waveform readout

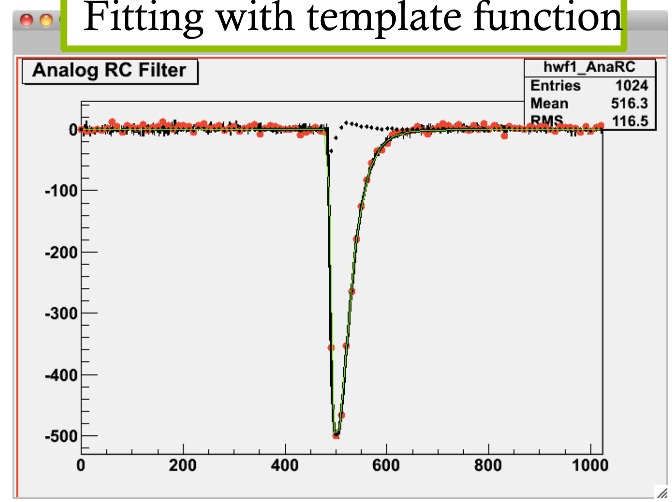
- Essential to separate the pile-up events under high rate condition
- Requirement
  - Keep the energy resolution of 1 % for 80 MeV proton
  - Reduce data size for reasonable DAQ efficiency

Shaping with Integral filter



30 ns sampling rate

Fitting with template function



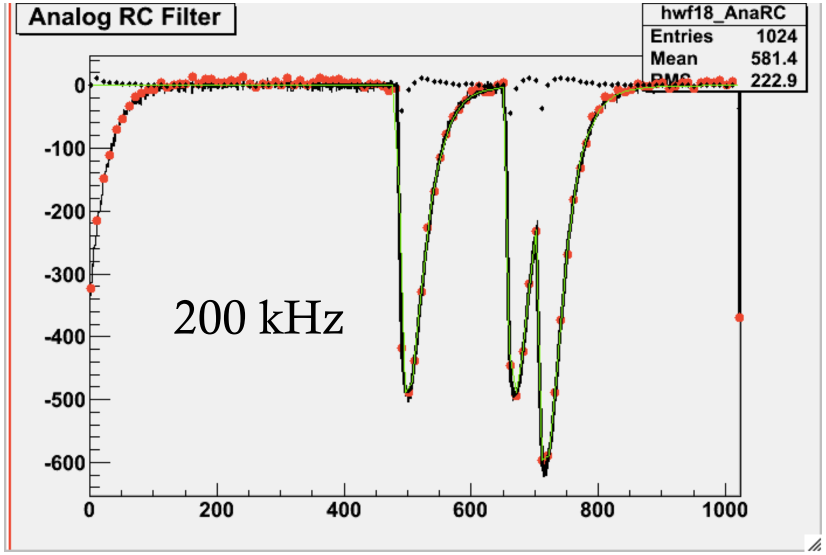
Achieve 1 % resolution with this method

Sampling data range : 2 μs → ~70 samples / channel
Even if NO pedestal suppression, 8 kHz DAQ is possible

BGO test w/ 80 MeV proton beam

- CYRICにて80 MeV proton beamをBGOに照射
- 2014 / 9

80 MeV 陽子に対しての波形



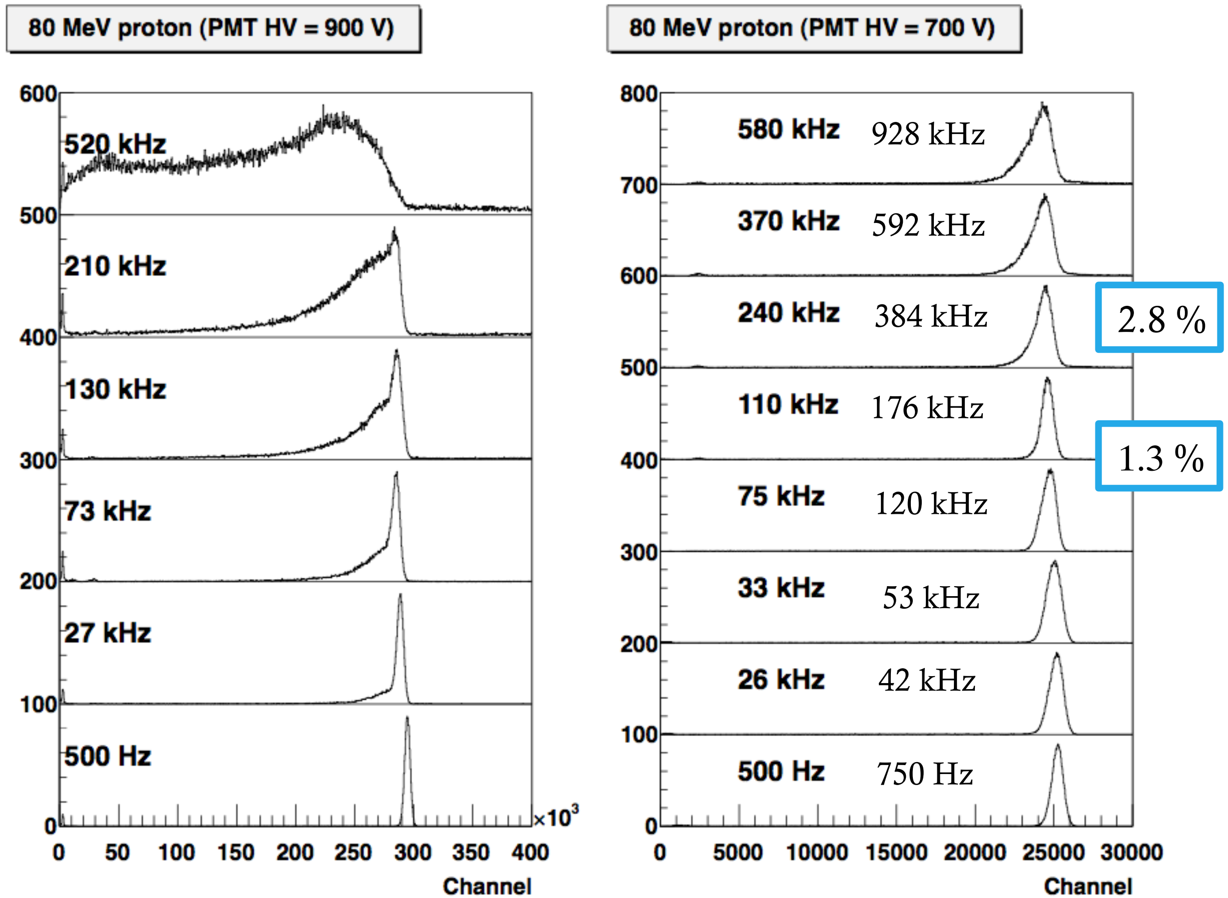
10 ns/ch

BGO performance test under high intensity conditions

- 80 MeV proton beam
  - Change beam intensity
    - 500 Hz ~ 500 kHz
- Operation voltage of PMT
  - 900 V (normal) : Gain drop due to high dynode current
  - 700 V : can suppress the gain drop.

Expected mean energy deposit @ E40 : 50 MeV

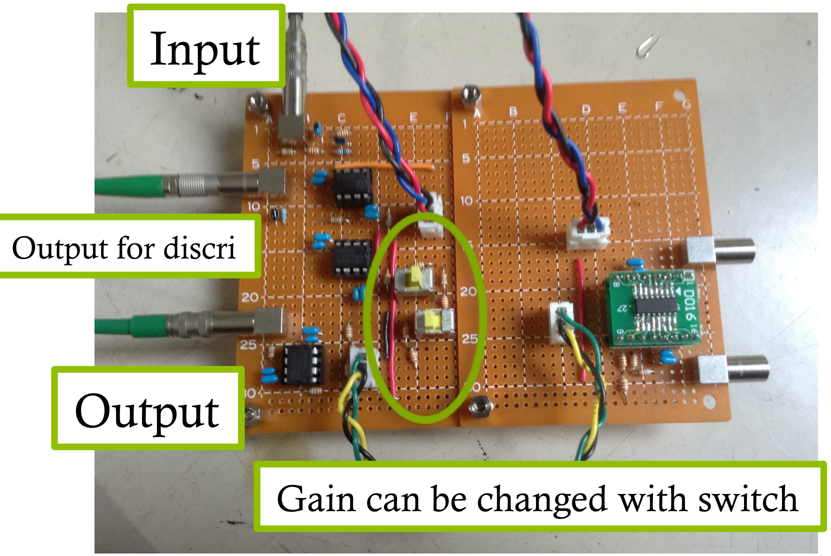
Correspond 1.6 times higher rate (in dynode current)

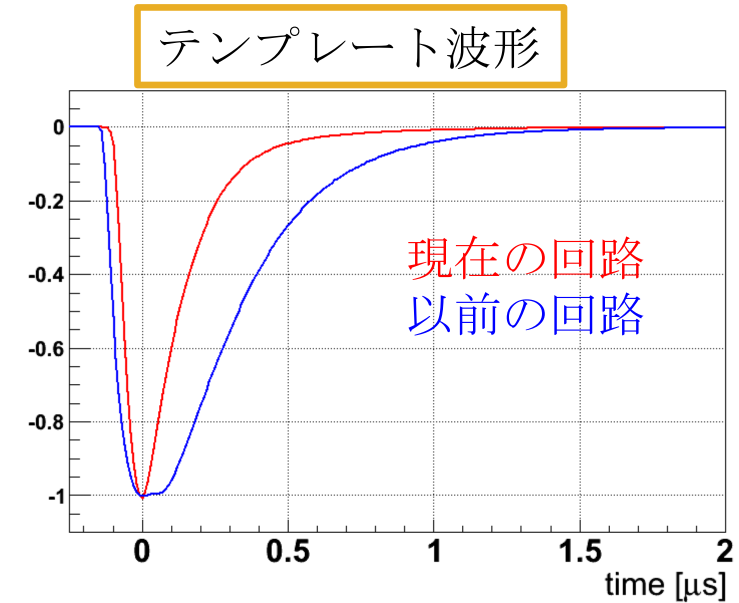


We can operate BGO by setting lower HV in the experimental condition
Now we are testing a amplifier circuit to improve S/N ratio and operate more lower voltage.

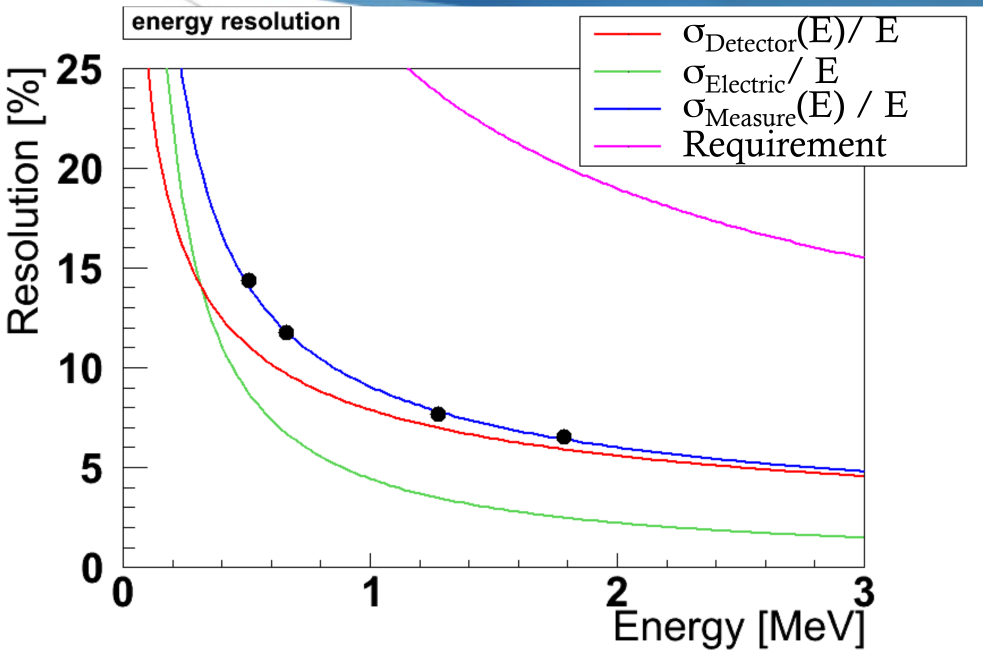
高計数率への新たな対策

- 増幅回路を追加
  - PMTでのゲインのロスをおぎなう。
- 整形回路の時定数を短く
  - 波形を短くし、波形分離能力を向上する。

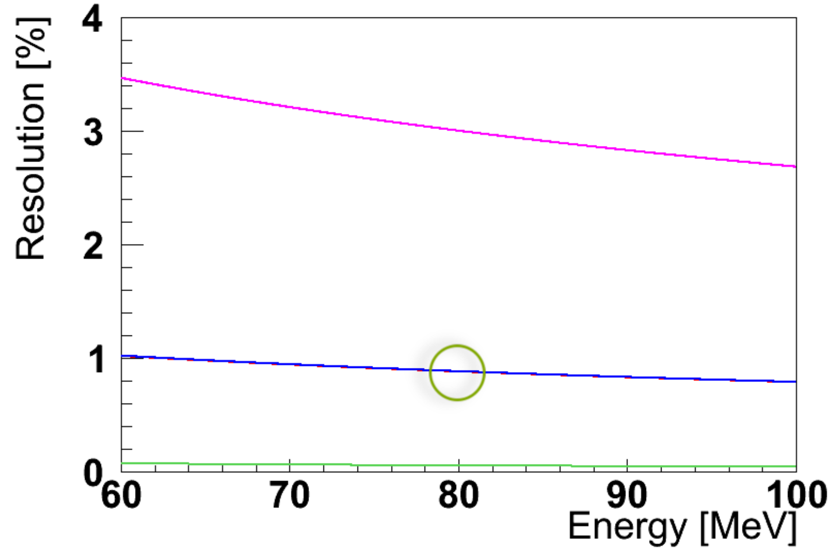




線源による分解能の確認



高エネルギー領域での分解能の予想



$$\sigma_{Measure}^2(E) = \sigma_{Detector}^2(E) + \sigma_{Electric}^2$$

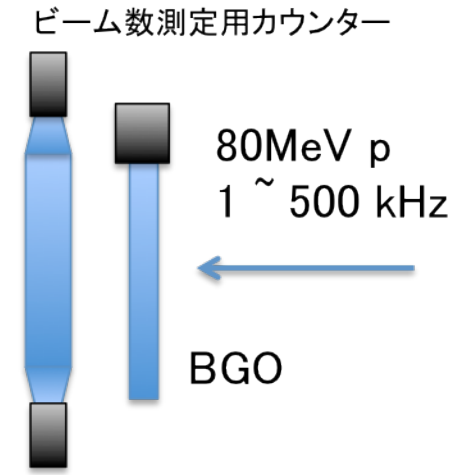
の関係で分解能のエネルギー依存性を良く再現

80 MeVのときでも
0.9 %と予想出来る

- 現在の回路でも分解能としては問題ないと予想出来る

今回申請の実験 (1)

- 陽子ビームの直接照射による高計数率下でのBGO検出器のテスト
  - 陽子のビームレート、PMTの電圧を変化させ分解能の確認
    - ビームレート : 1~ 500 kHz
    - PMT HV : 600, 650, 700 V
- エネルギー毎の波形の測定
  - dE/dxの異なるイベントに対してBGOの波形が同じであるかを調べる
    - degraderを用いて陽子ビームのエネルギーを変化させ波形を調べる



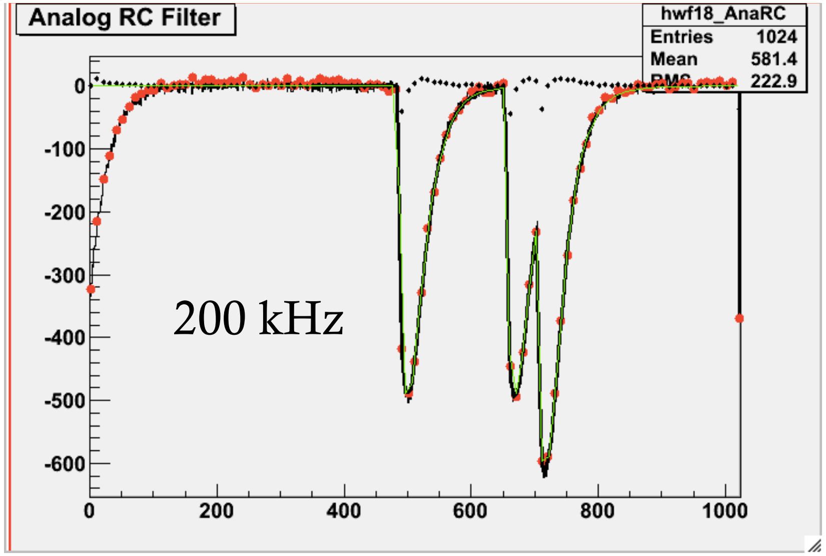
BGO readout under high singles rate

- BGO operation method under high singles rate
  - Wave form data w/ Flash ADC

    → Separation of piled-up events
  - Operation of PMT at lower HV

    → Stability of PMT gain

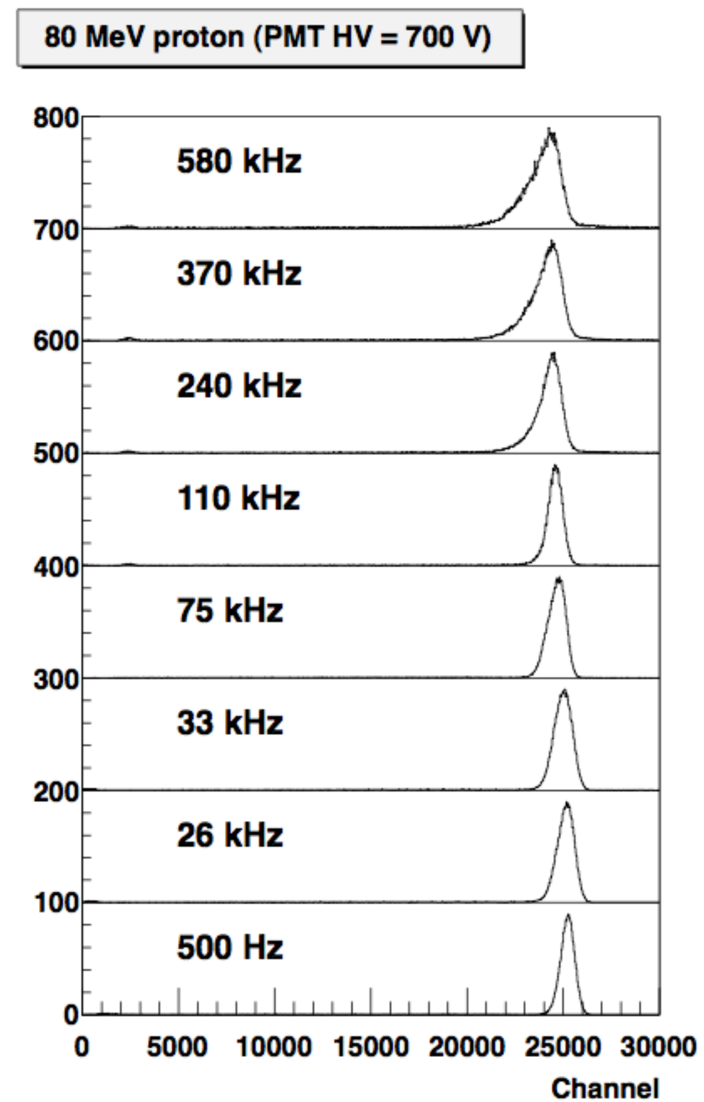
Waveform for 80 MeV proton



10 ns/ch

BGO readout under high singles rate

- BGO operation method under high singles rate
  - Wave form data w/ Flash ADC
    → Separation of piled-up events
  - Operation of PMT at lower HV
    → Stability of PMT gain



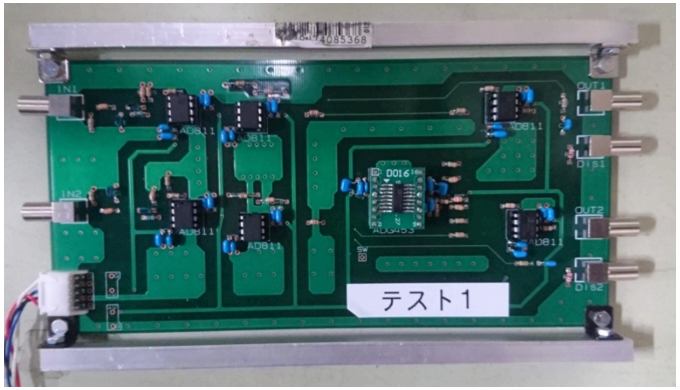
Beam test results in 2014

- Better resolution was obtained by operating at 700 V
- However, the performance was deteriorated with intensity
  -- Deterioration of resolution
  -- Peak shift

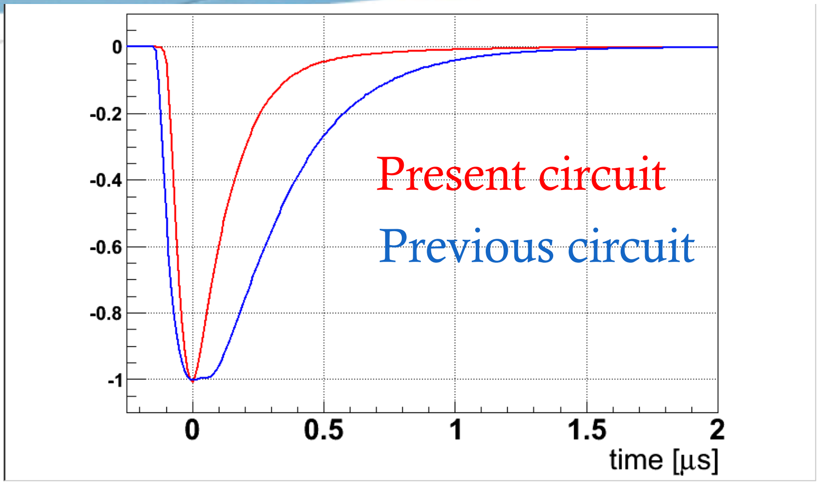
Operation at lower HV is essential

Development of Shaping Amplifier

- Add amplifier part to shaping circuit to compensate lower gain in lower HV operation
  - Operation in lower HV became possible.



Template waveform



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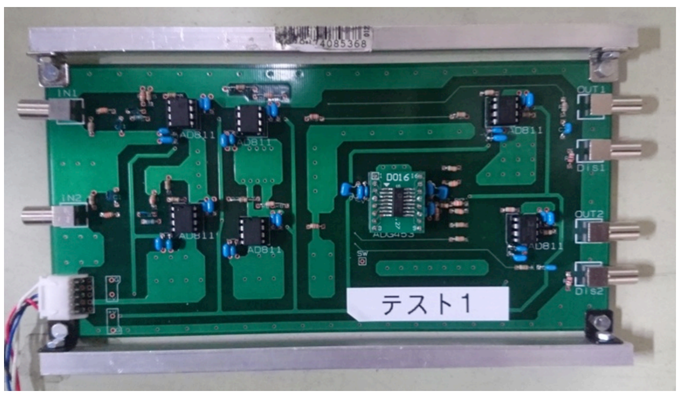
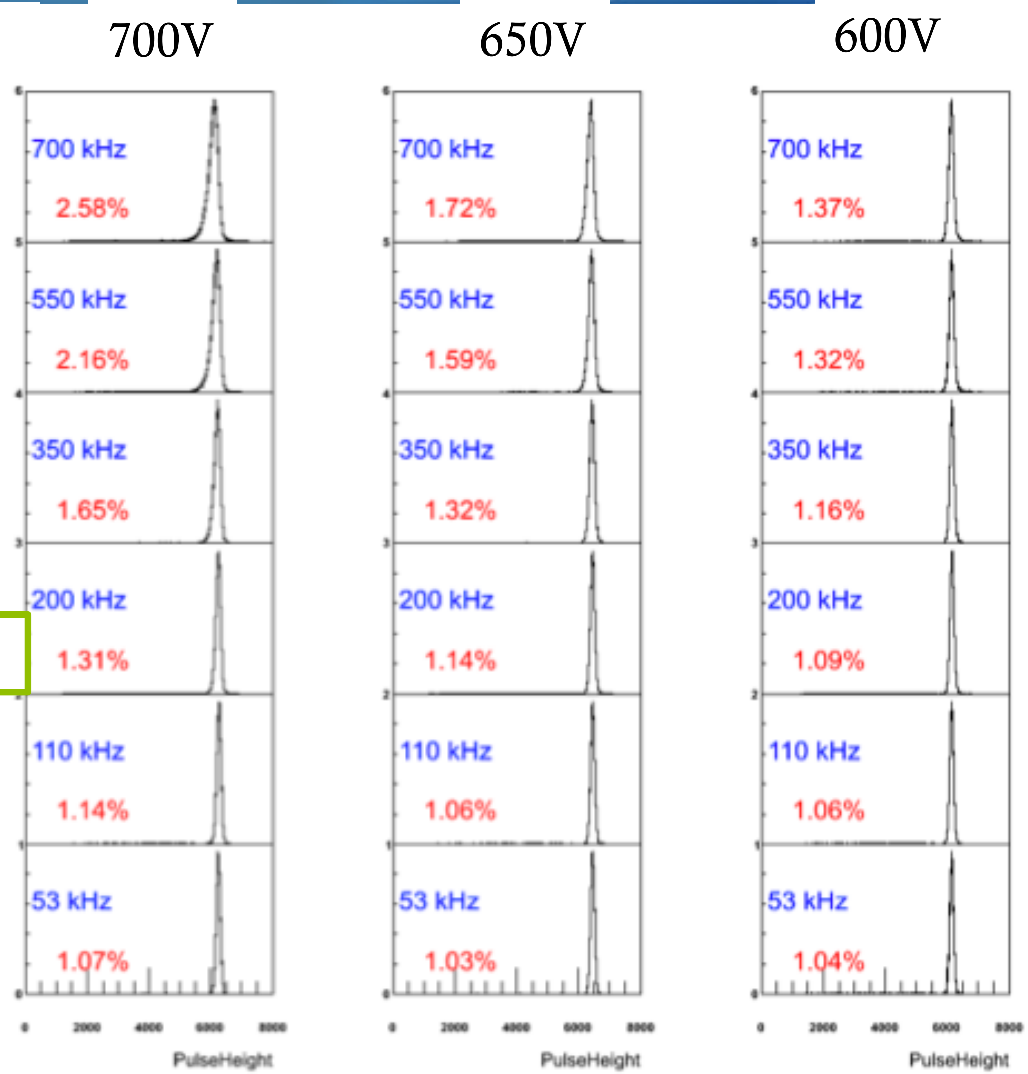




Test experiment w/ 80 MeV proton beam

Good result at 600 V

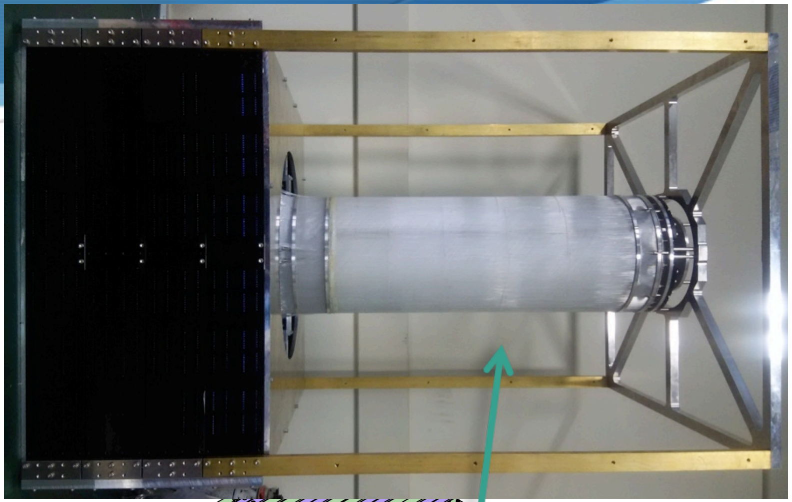
- Peak shift was not observed
- Resolution deterioration was very limited

Stable operation can be possible under J-PARC condition

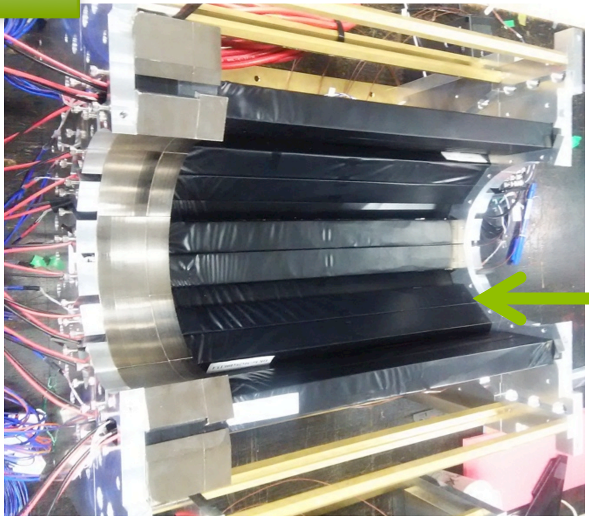
BGO systemの構築

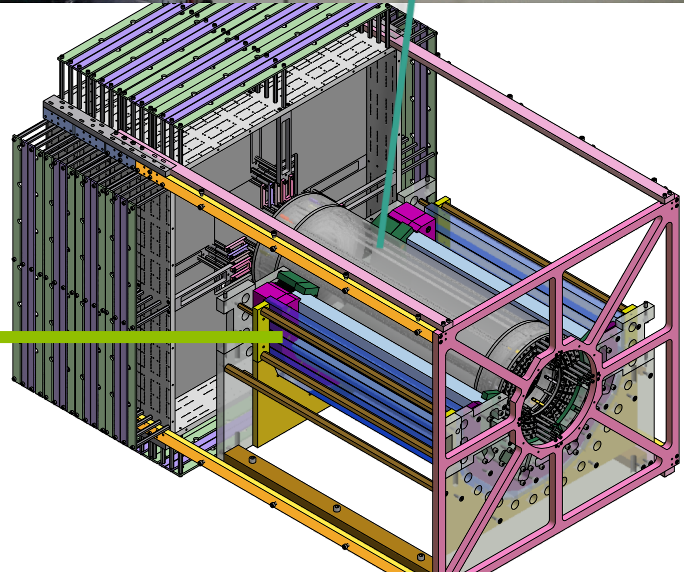
- CFT
  - All frame structures are combined into full system.
  - Operation voltages of all MPPCs were optimized.
- BGO
  - BGO counters are mounted to its frame structure
  - Readout system with 3 flash ADCs was constructed.

Cylindrical Fiber Tracker (CFT)



BGO calorimeter





CATCH systemの構築

Schedule

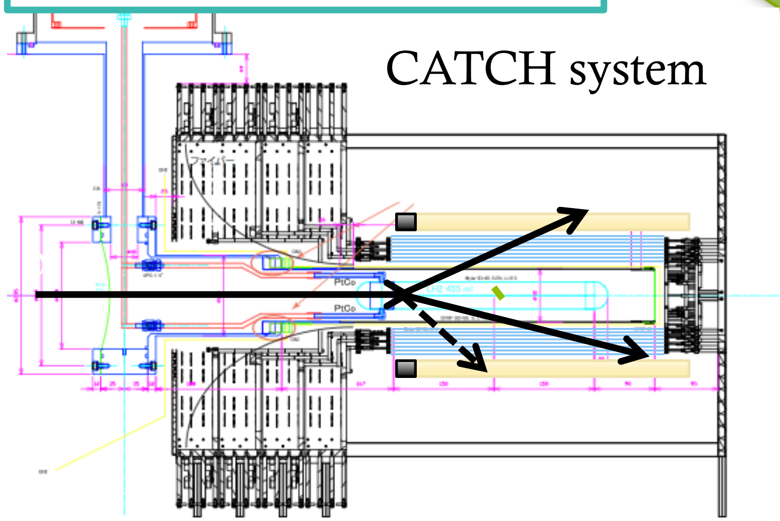
2016 Dec. Commissioning of CATCH system

2017 Jan. pp scattering experiment with CATCH system @ CYRIC

Measurement of pd → ppn breakup reaction to aim to extract 3N force

2017 Feb~Mar. Move CATCH system to J-PARC

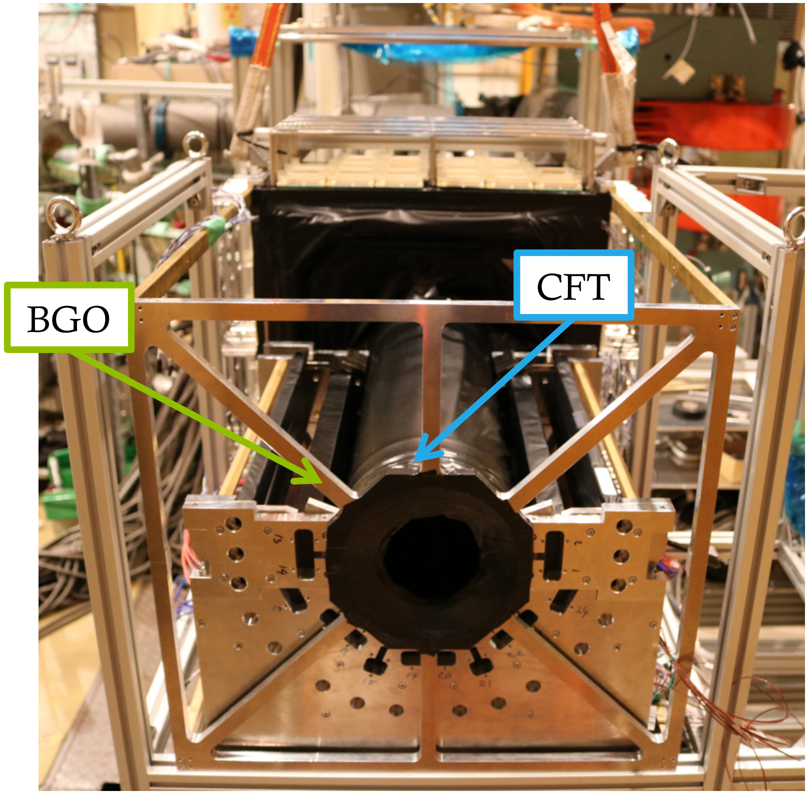
CATCH system

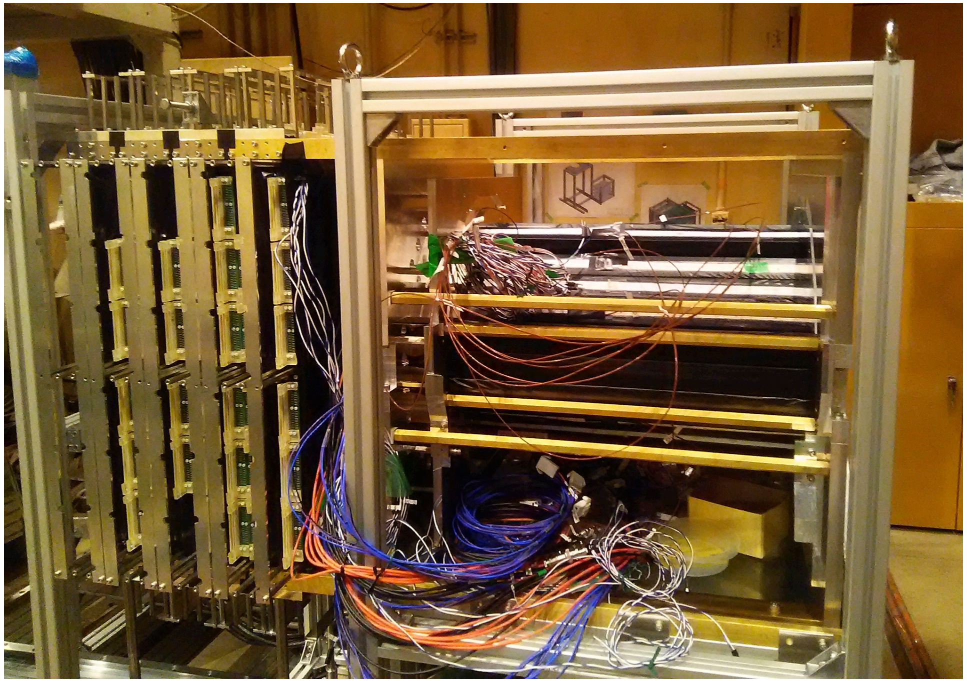


2017 Winter ~ 2018 Spring
Run E40 hopefully

Construction of CATCH

- Combining CFT and BGO

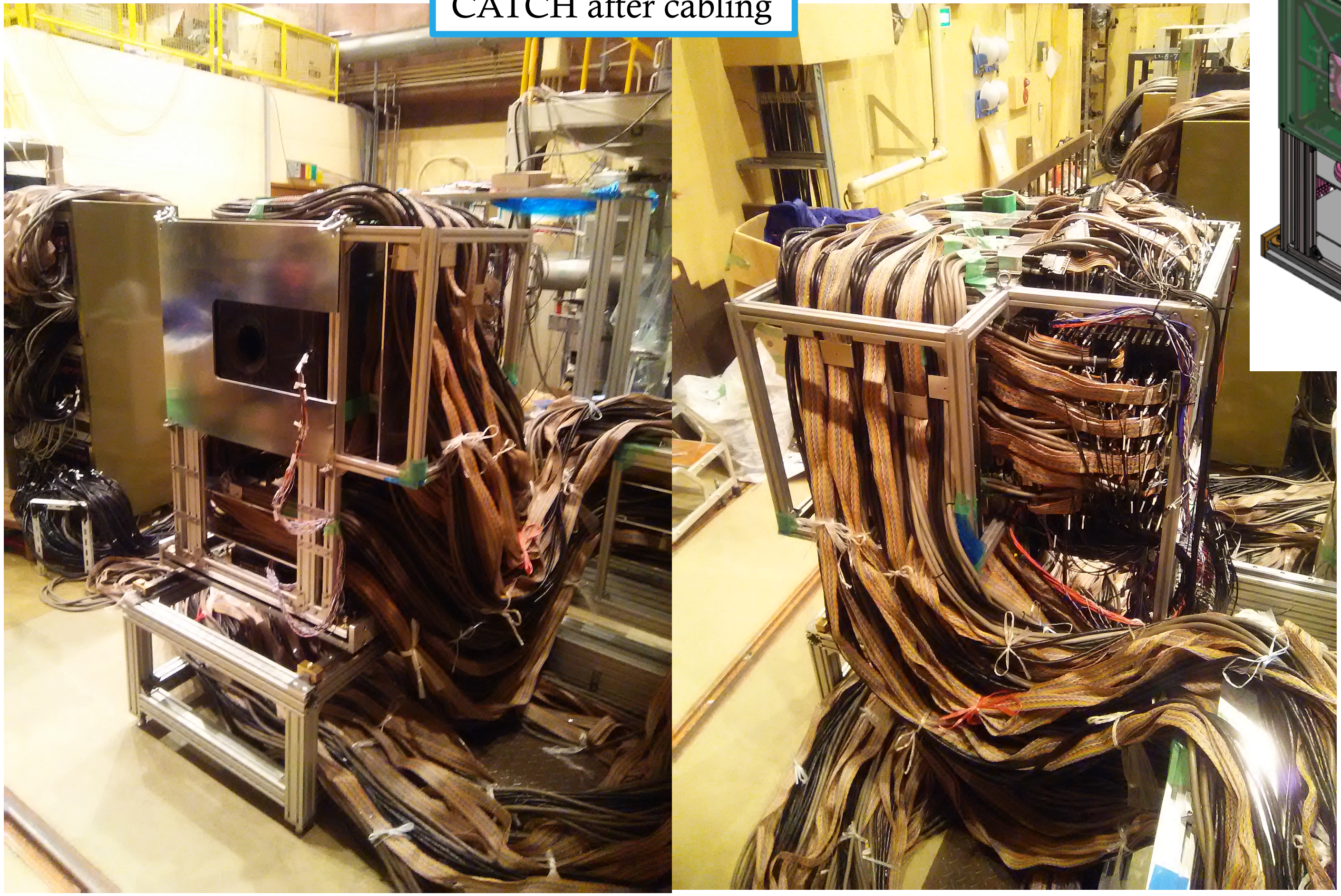




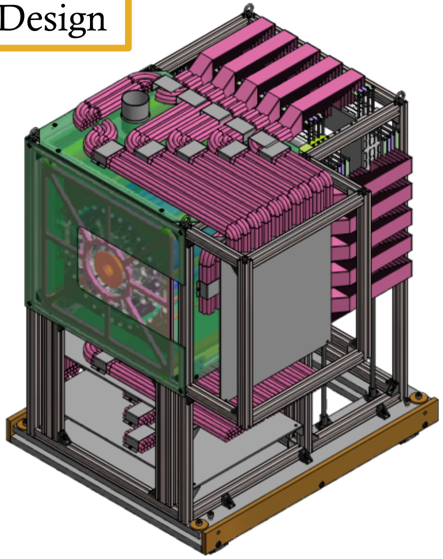
Construction of CATCH

- Cabling

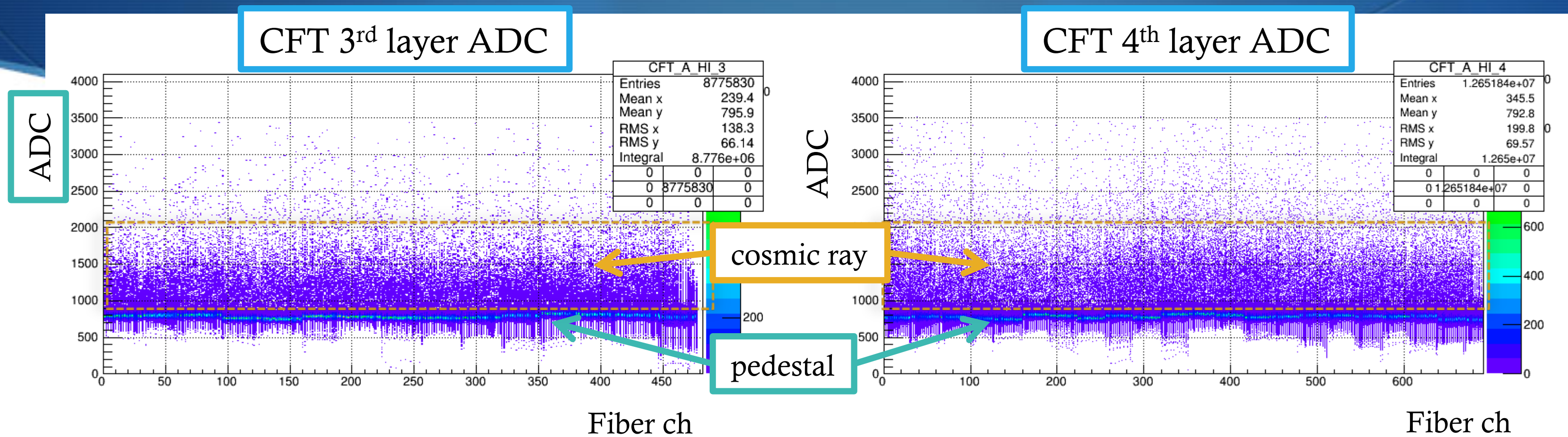
CATCH after cabling

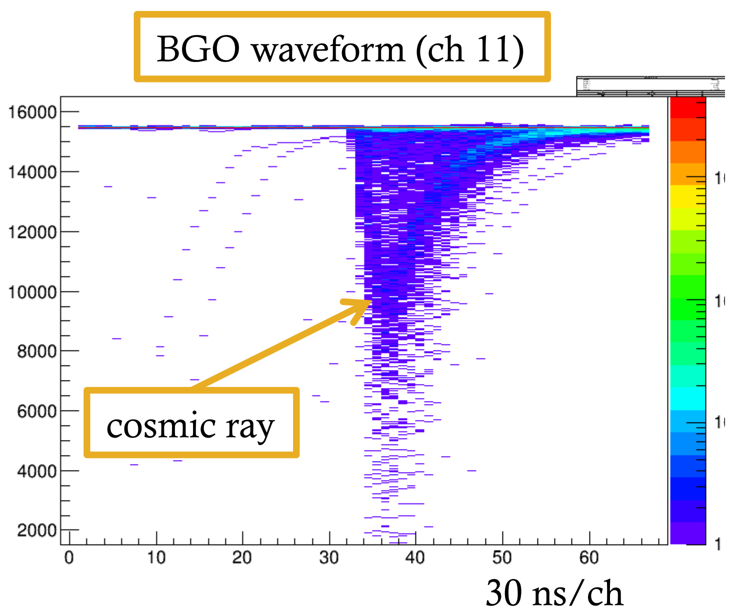


Design



CATCH readout for cosmic ray

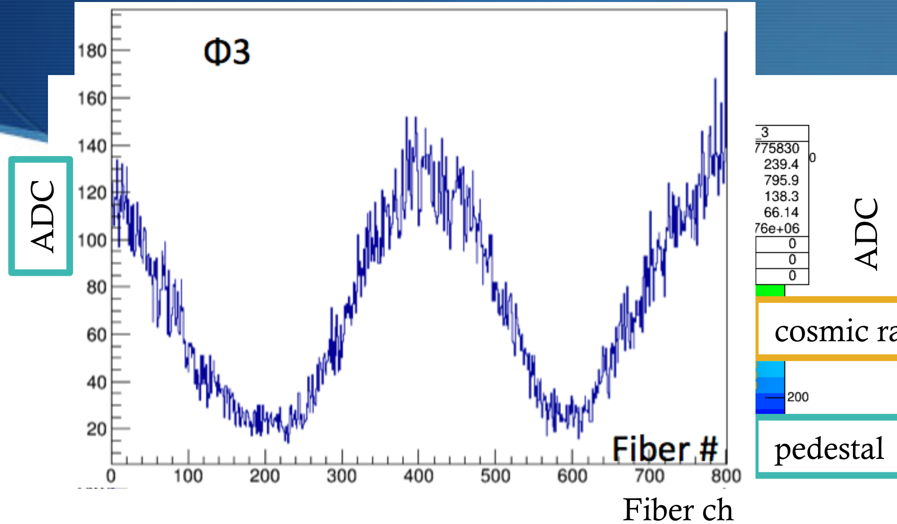


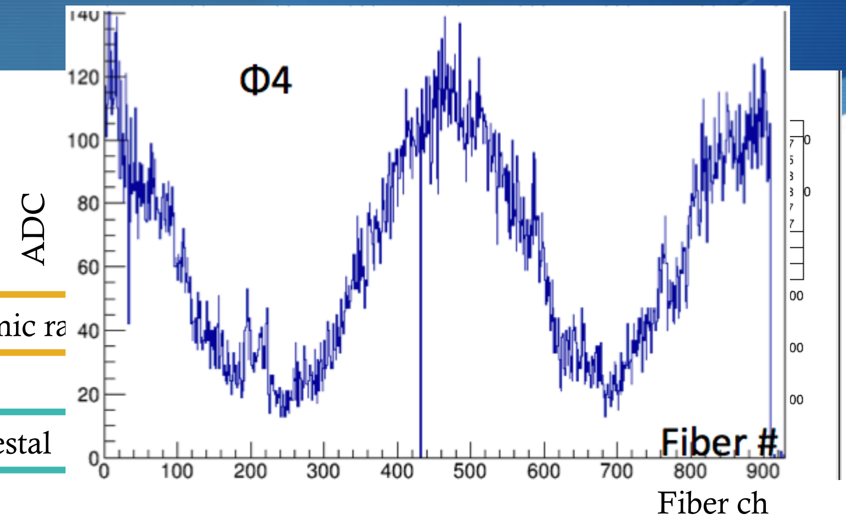


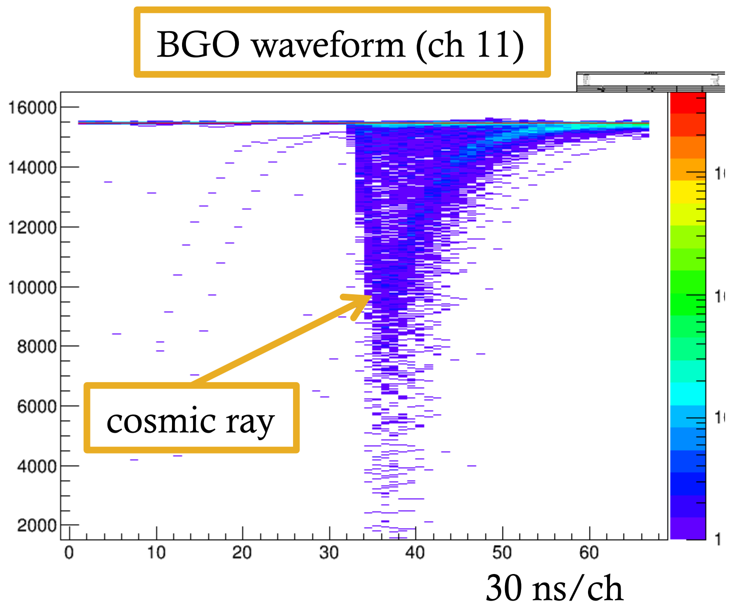
- Online histogram
  - CFT
    - Cosmic ray signal could be checked for almost all channels
  - BGO
    - Waveform data for all 24 ch could be checked.
- Readout speed
  - Expected rate for E40 : 1 kHz
  - Present performance of CATCH system
    - 90% for 6 kHz trigger

Enough margin for trigger rate

CATCH readout for cosmic ray







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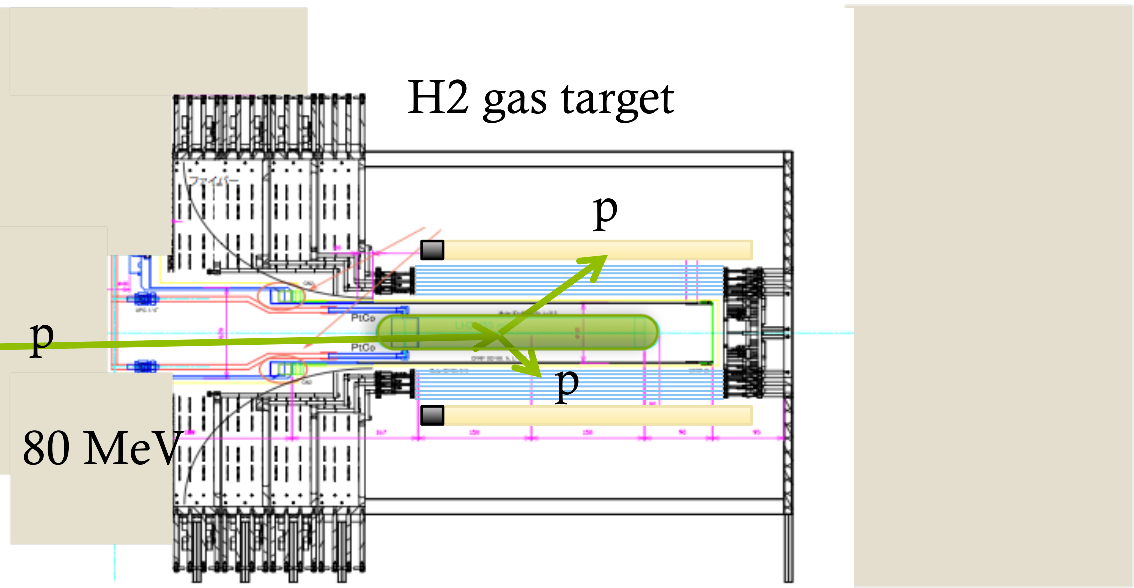
pp, pd scattering experiment at CYRIC

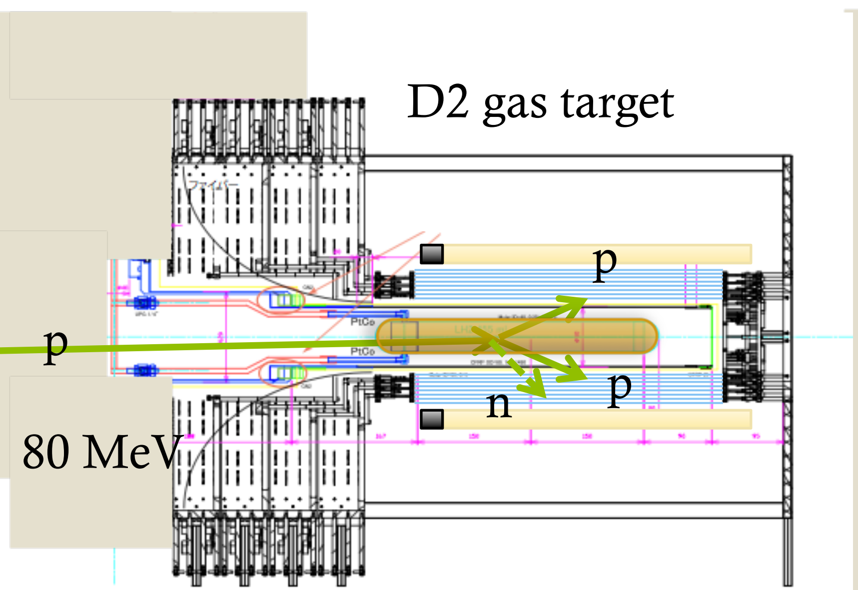
- Purpose
  - Commissioning and performance evaluation of CATCH system
    - pp and pC scattering w/ 80 MeV proton beam

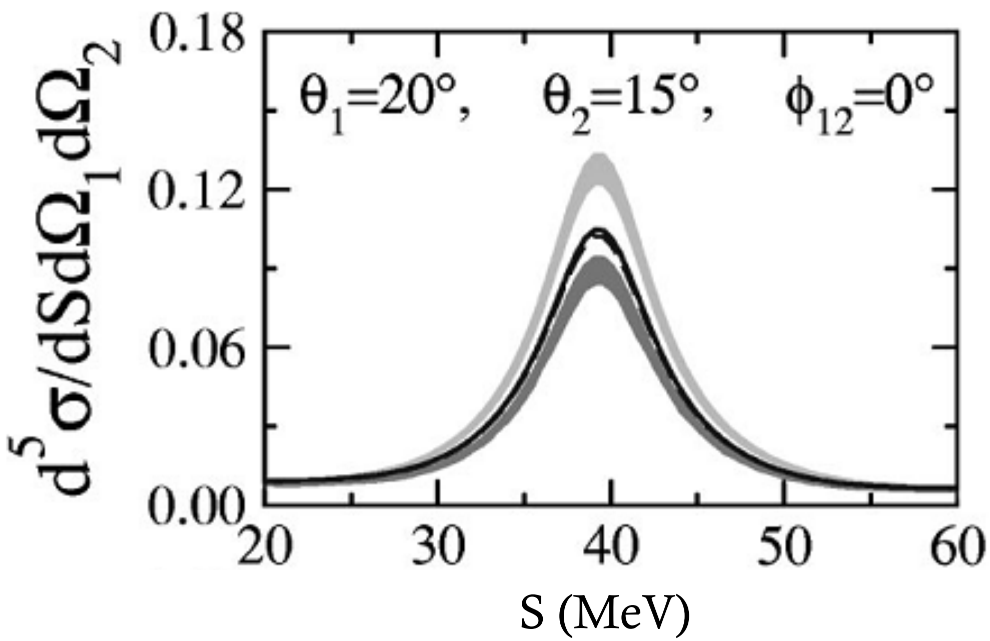


pp, pd scattering experiment at CYRIC

- Purpose
  - Commissioning and performance evaluation of CATCH system
    - pp and pC scattering w/ 80 MeV proton beam
  - Extraction of 3 body force from pd → ppn break up reaction
    - pd scattering w/ 80 MeV and 70 MeV

J. Kuroś-Żołnierczuk et al., PHYSICAL REVIEW C**66**, 024003 (2002)

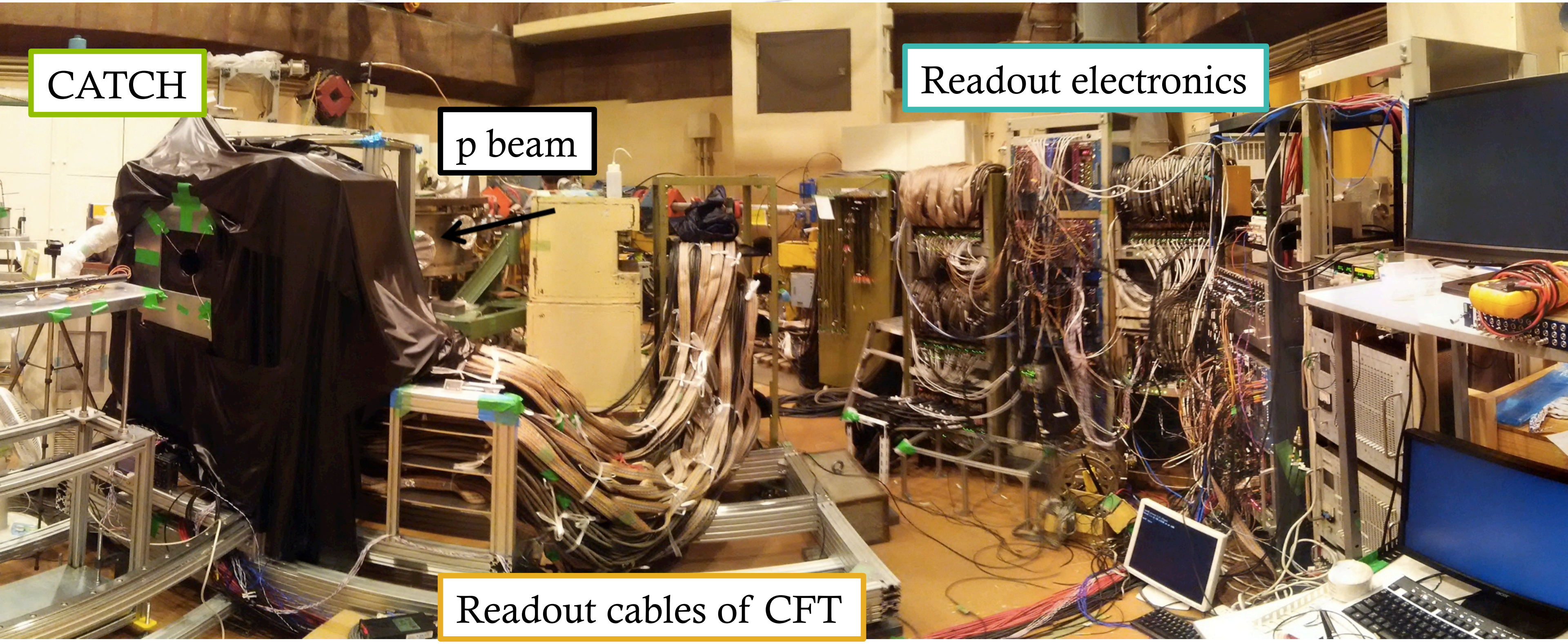




S : correlation between E1 and E2

Construction of CATCH at CYRIC

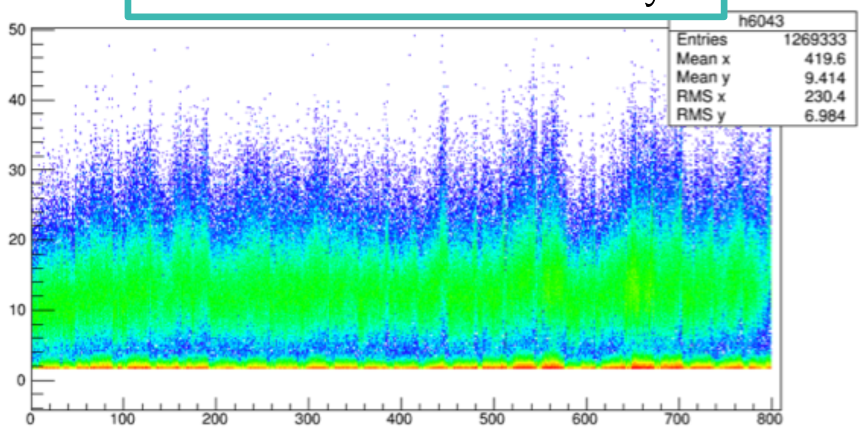
- Experimental period : 2017/1/23-26



Performance check

- All system worked well
  - We could learn the response of CFT for very large dE/dx events
    - Cross talk of signal in the par cable
  - DAQ performance
    - 88% @ 10 kHz
      - determined by 14 μs busy time of VME-EASIROC

Low Gain ADC of PHI3 layer



CH

Analysis is now on going

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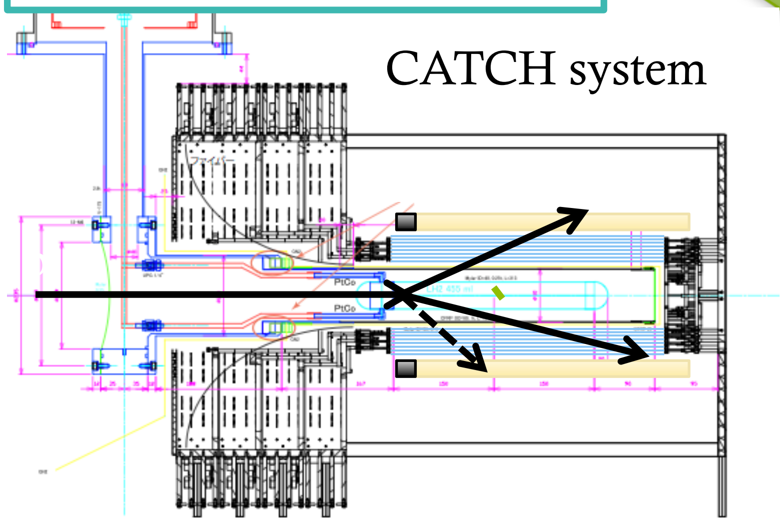
@ CYRIC

Measurement of
pd → ppn breakup reaction
to aim to extract 3N force

2017 Feb~Mar. Move CATCH system to J-PARC

3/6にJ-PARCへ運搬
J-PARCで本格的にコミッショニングを開始する



CATCH system

2017 Winter ~ 2018 Spring
Run E40 hopefully