7th International Conference on
New Developments In Photodetection

" Development of a cylindrical tracking detector with multichannel scintillation fibers and PPD readout "

Yuya Akazawa

Tohoku University

for the J-PARC E40 collaboration

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Contents

- **Motivation for development**
  - Requirements
- **Construction of Cylindrical Fiber Tracker**
  - Fiber construction
  - PPD Read-out
- **Performance evaluation**
  - Response for cosmic ray and proton
  - Linearity
  - Energy resolution
- **Summary**

Σp scattering experiment

Σp scattering experiment @J-PARC , Japan

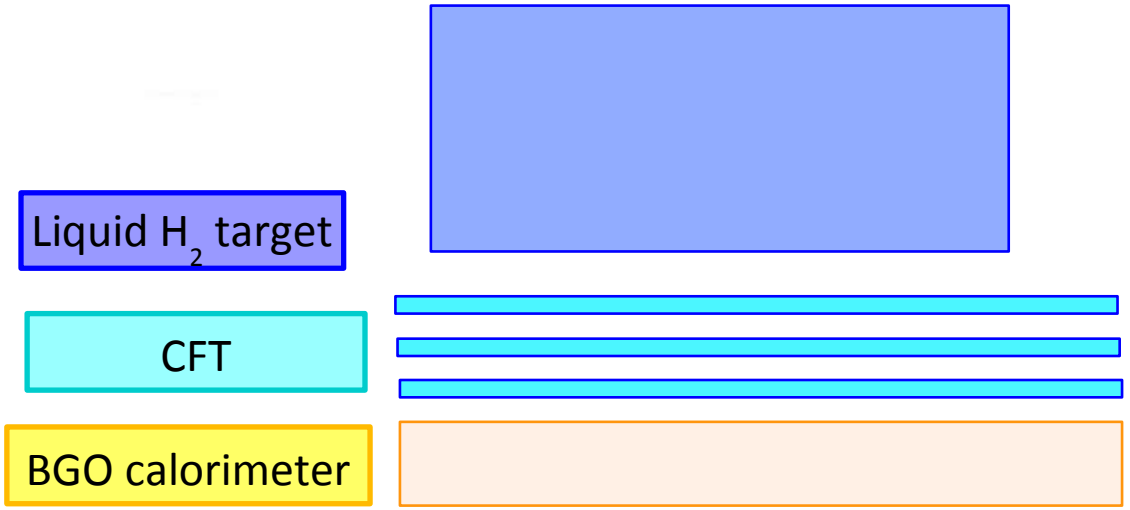
⇒⇒ ΣN interaction

Measurement of **dσ/dΩ of Σp scattering** with **high statistics**

※ It is difficult to use Σ as a target or a beam

∵ lifetime (~10^{-10}s)

⇒ **need to produce Σ in a target**



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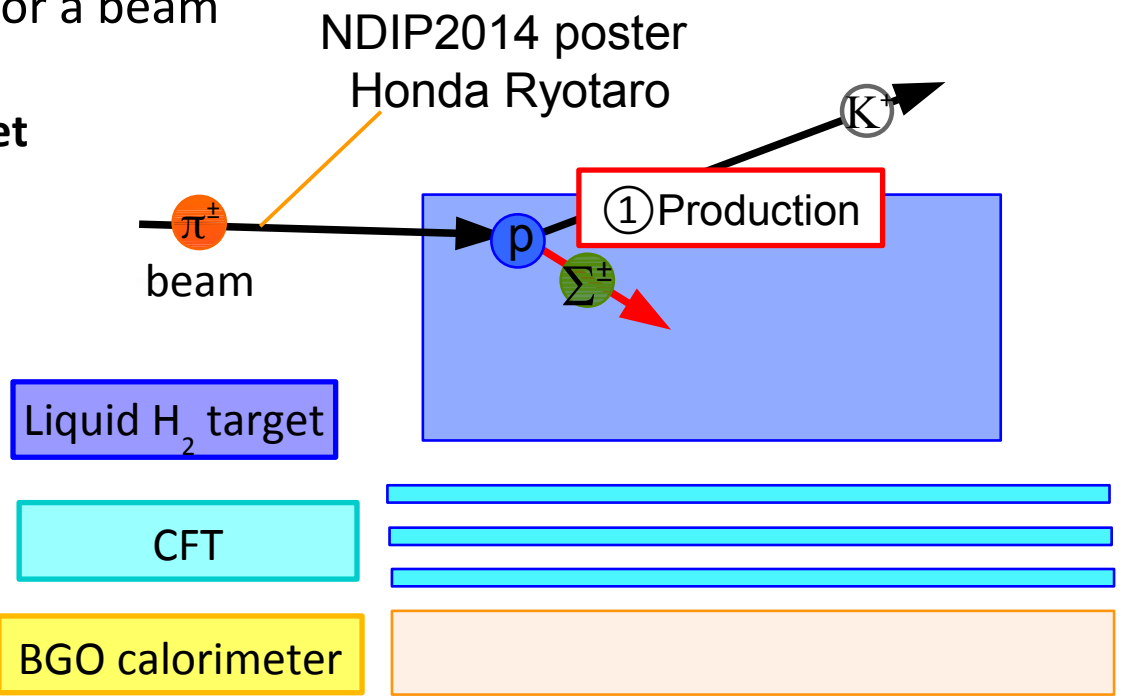

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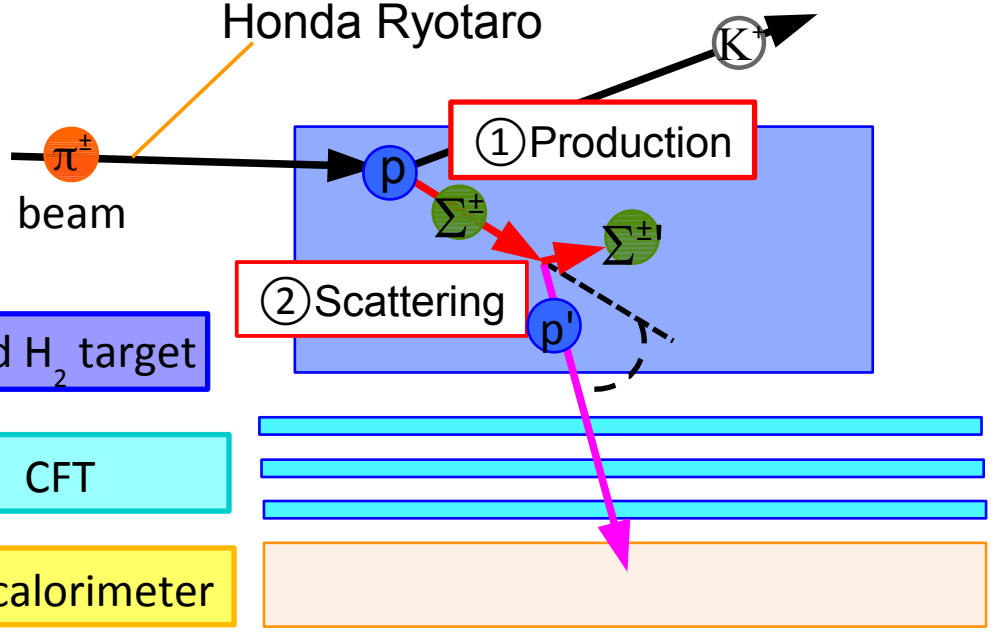
NDIP2014 poster
Honda Ryotaro



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②Scattering $\Sigma^{\pm} + p \rightarrow \Sigma^{\pm\prime} + p'$

Cylindrical Fiber Tracker(CFT)
- **Trajectory**
- **Energy deposit ⇒ PID**

BGO calorimeter
- **Kinetic Energy**

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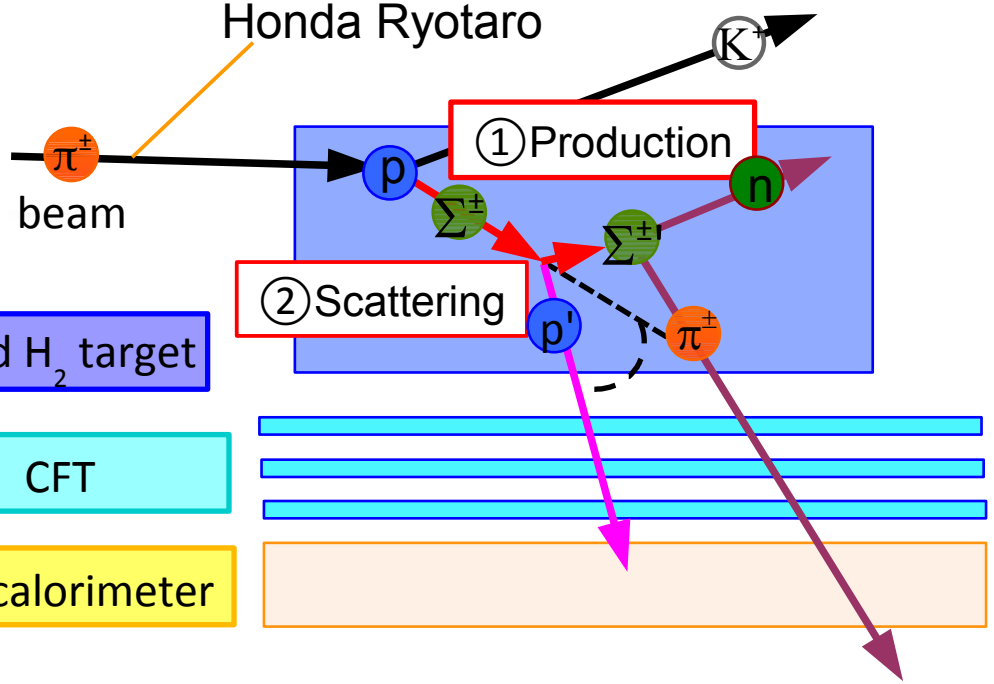

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Liquid H_2 target

CFT

BGO calorimeter

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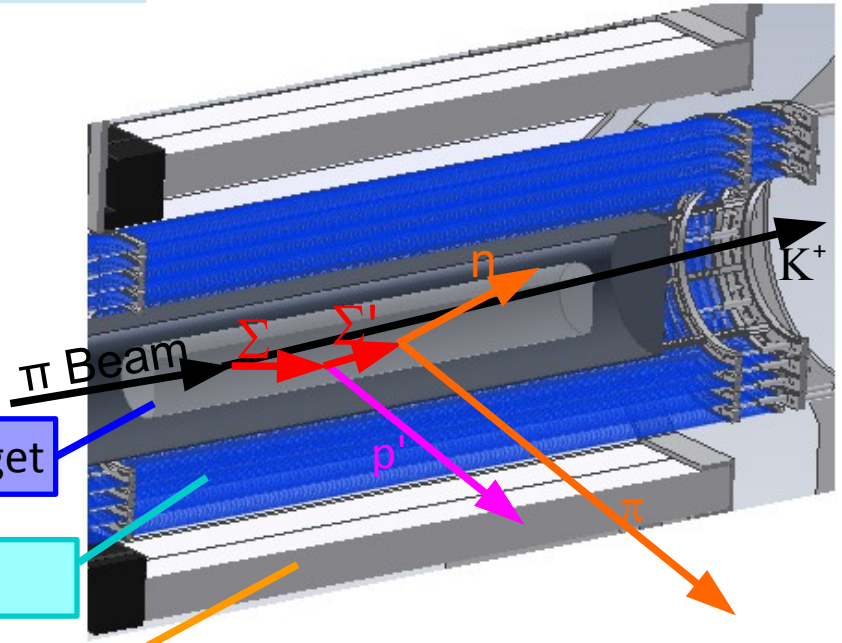

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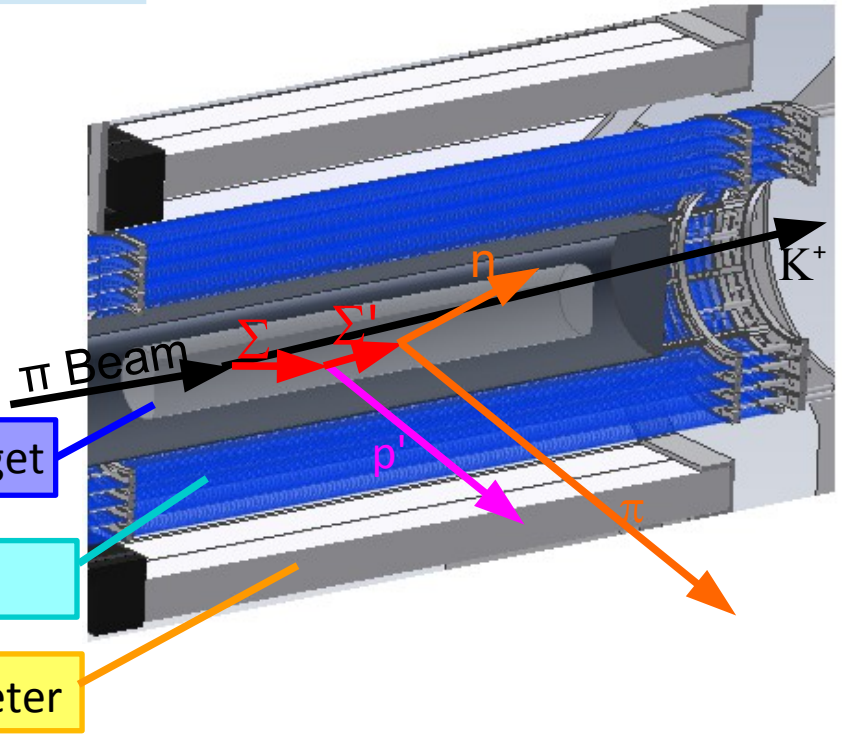


Cylindrical Fiber Tracker(CFT)
- **Trajectory**
- **Energy deposit ⇒ PID**

BGO calorimeter
- **Kinetic Energy**

Main topic ~development of CFT~

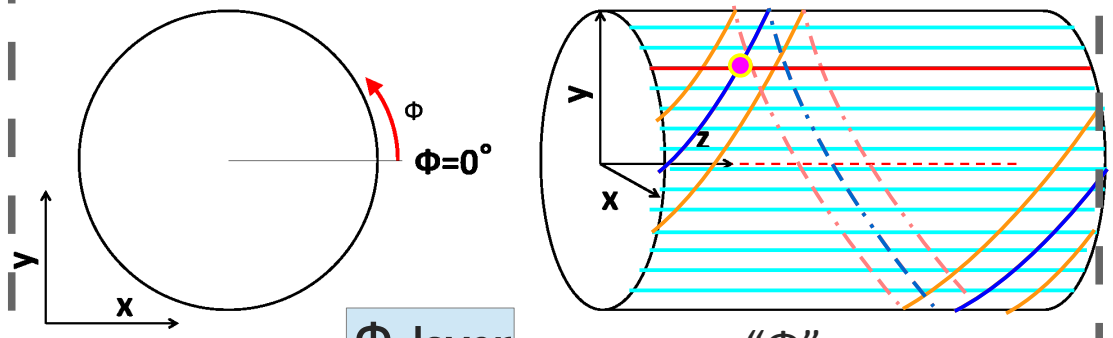
Measurement of **energy deposit** by CFT
with combination of **scintillation fibers** & **MPPCs**

Cylindrical Fiber Tracker

Requirements

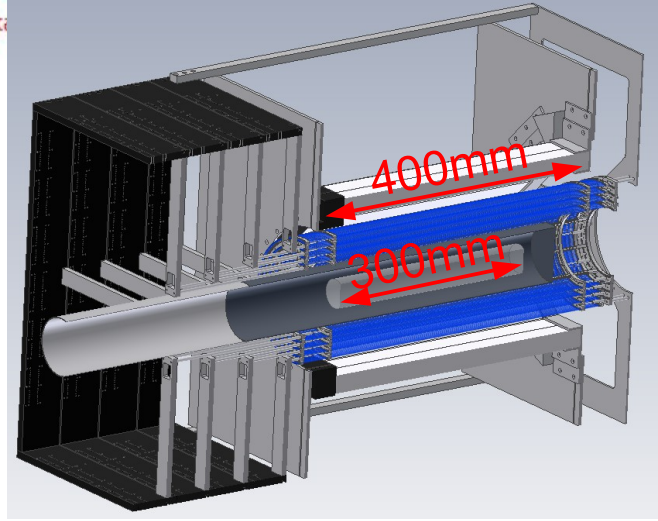
- Energy resolution
  - 35% for 70MeV proton for 1 layer
- Angular resolution : σ_θ=0.77deg
- Surround the target
  - Cylindrical shape
  - Long active region ・・・ **400mm**
- 2 types of fiber configurations

  ⇒⇒ Track finding 3 dimensionally
  - Φ layers (straight layer)
  - UV layers (spiral layer)



Φ layer measure "Φ"

U・V layer get **z** position using "Φ"



Energy deposit depends on the **Mass**

↓ ↓

Resolve **proton** and **π**

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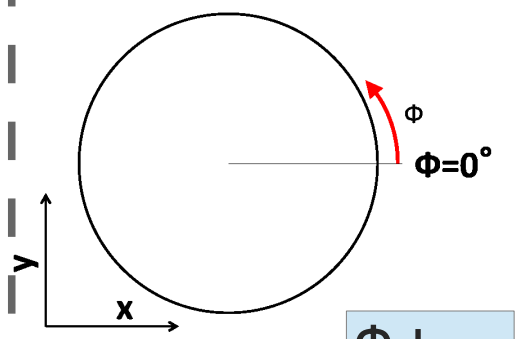

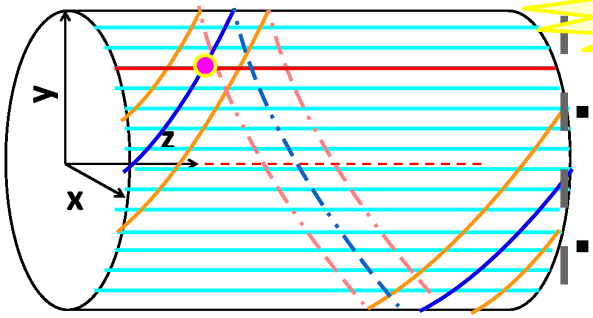

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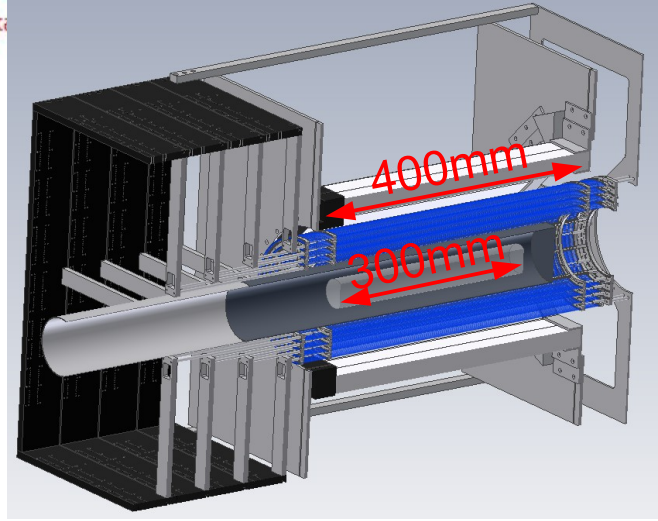

Energy deposit depends on the **Mass**

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Resolve **proton** and **π**

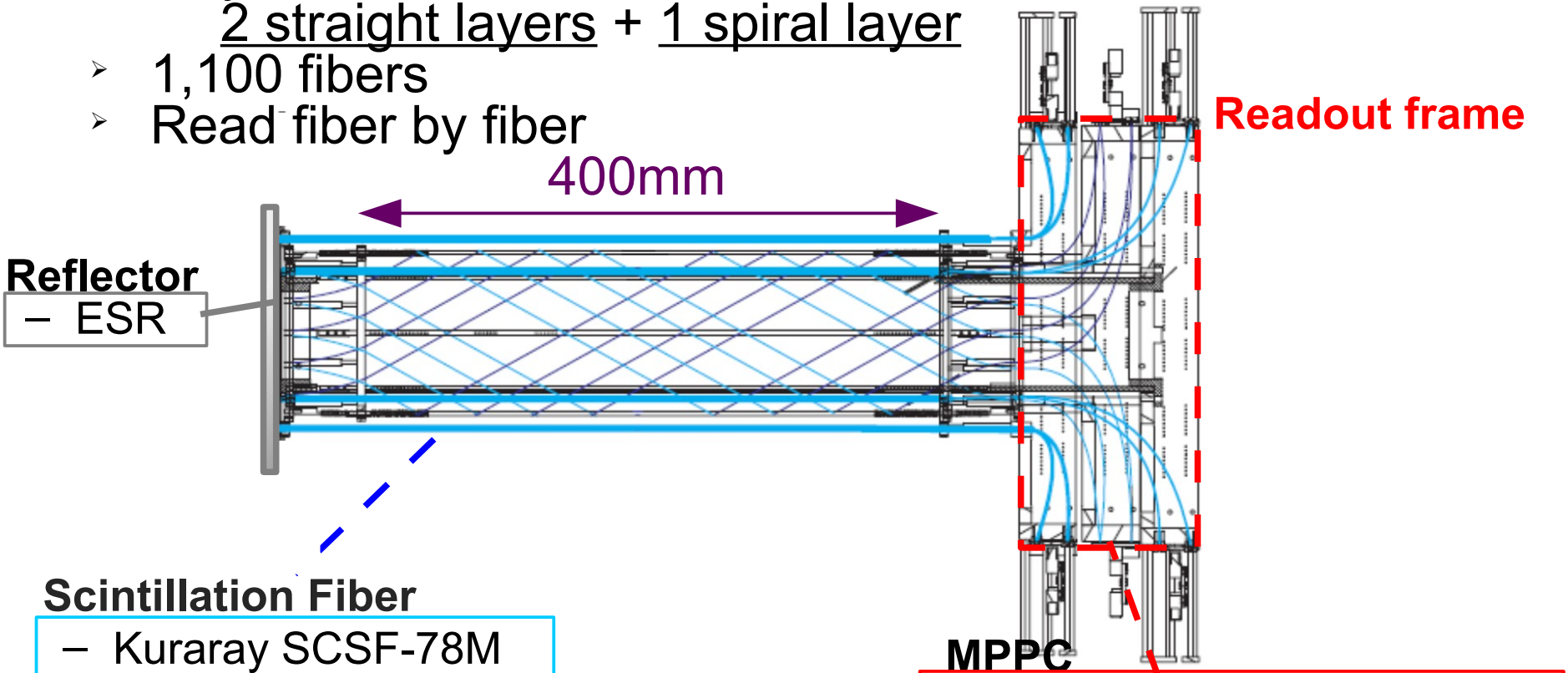
Some challenges to overcome for development of CFT

- **Fiber construction**
  - Special fiber configuration
- **Many channel operation**
  - Photon readout fiber by fiber

→ **Prototype**

CFT prototype

- 3layers
  2 straight layers + 1 spiral layer
- 1,100 fibers
- Read fiber by fiber



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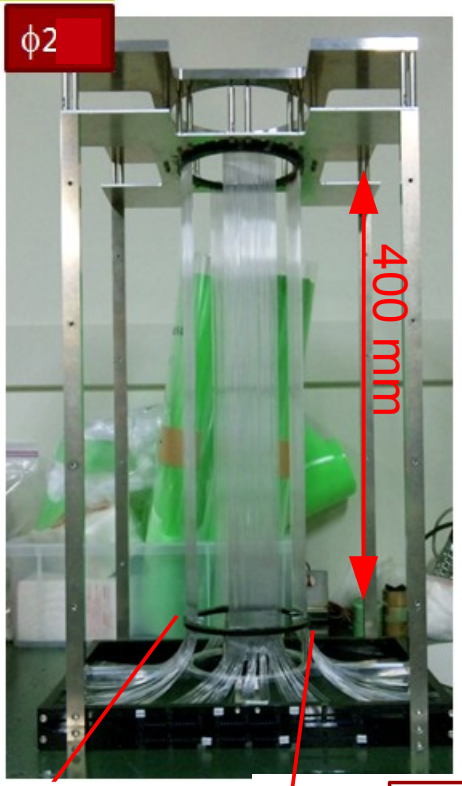
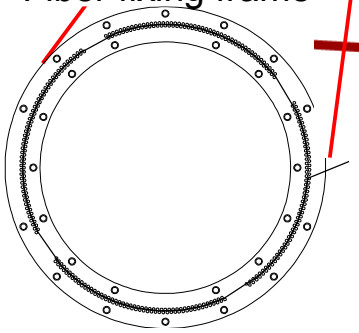
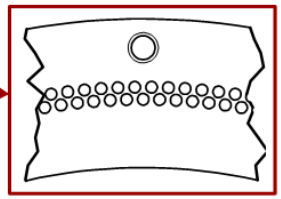
Construction of CFT prototype

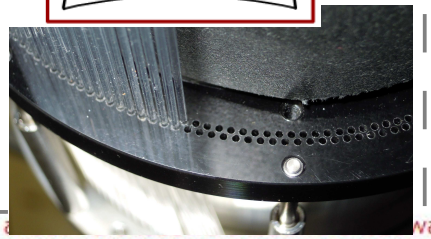
Straight layer



Fiber fixing frame

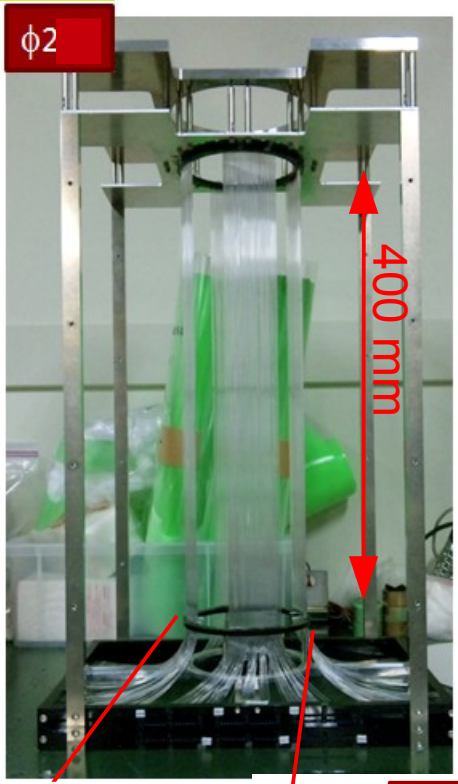






Construction of CFT prototype

Straight layer



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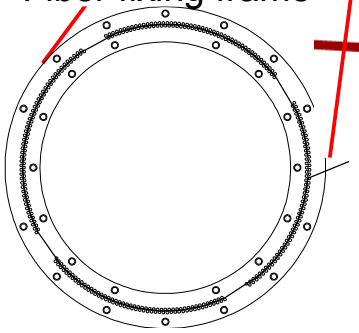
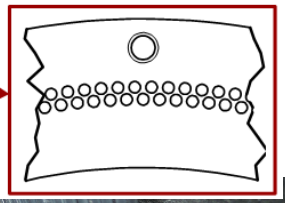
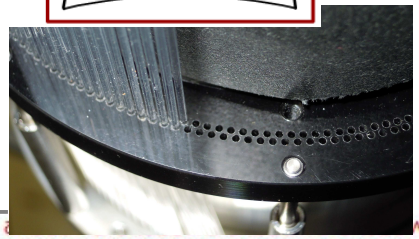
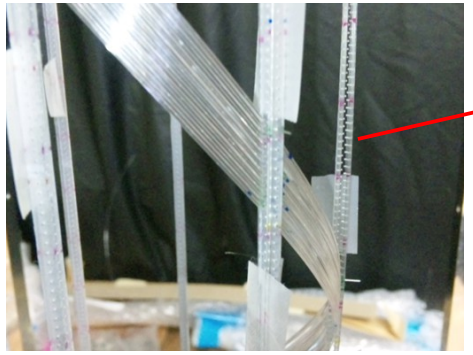


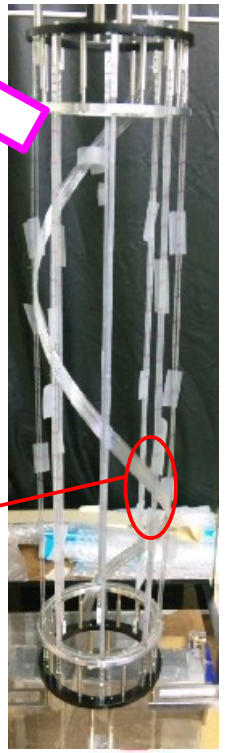




U

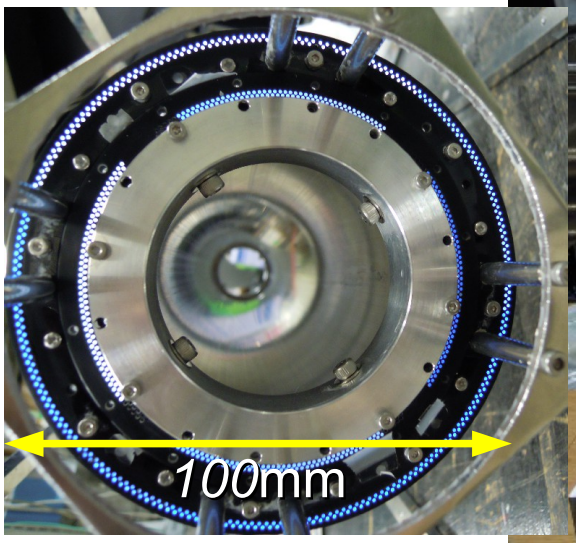
Spiral layer

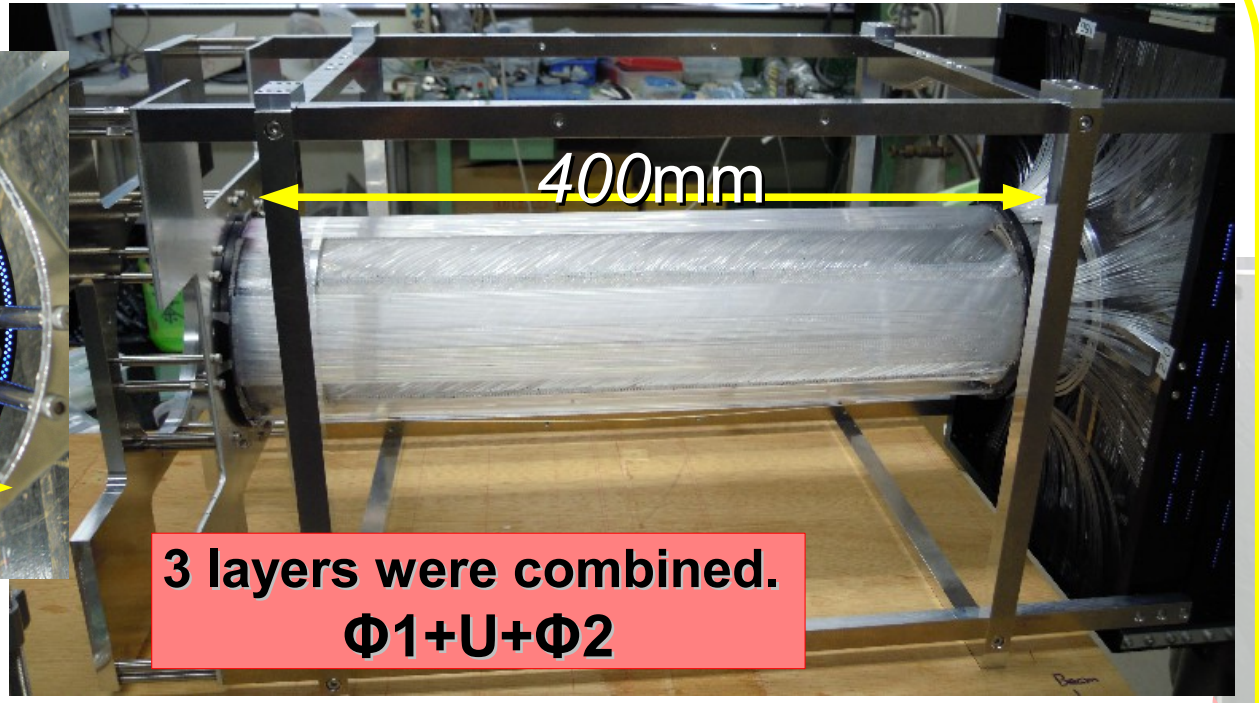




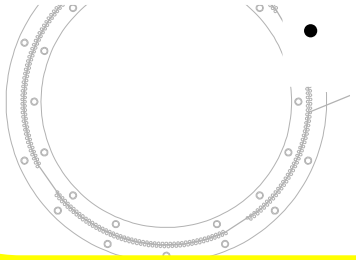
Construction of CFT prototype

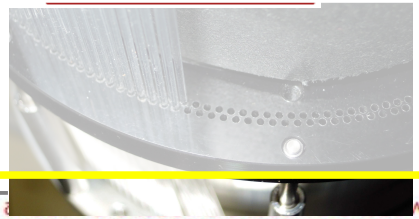
Straight layer ϕ2 U Spiral layer





- Number of fiber : ~1100 channels

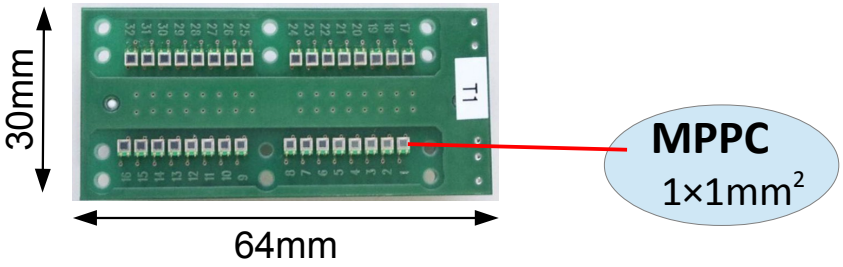




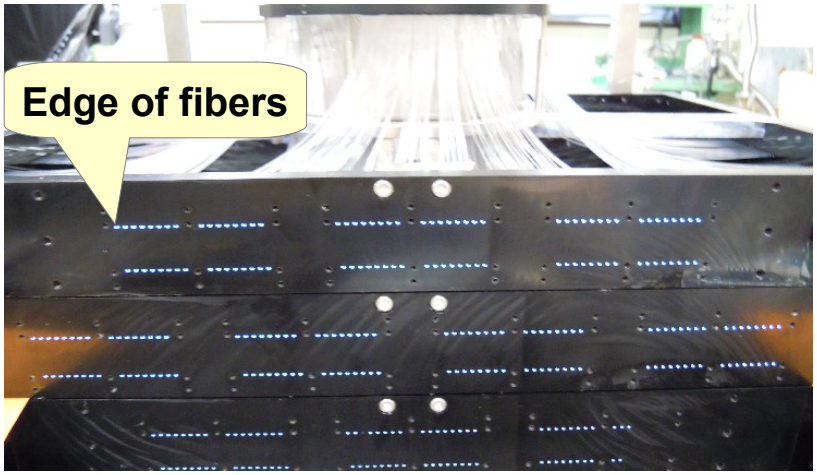
Readout ~photon sensor~

- Number of fiber : 1100 channel
- Photon sensor
  : MPPC fiber by fiber

A circuit mounting **32 MPPCs**



Readout frame



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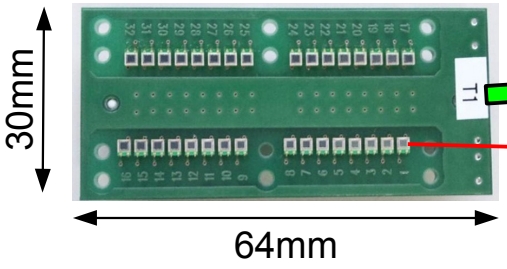
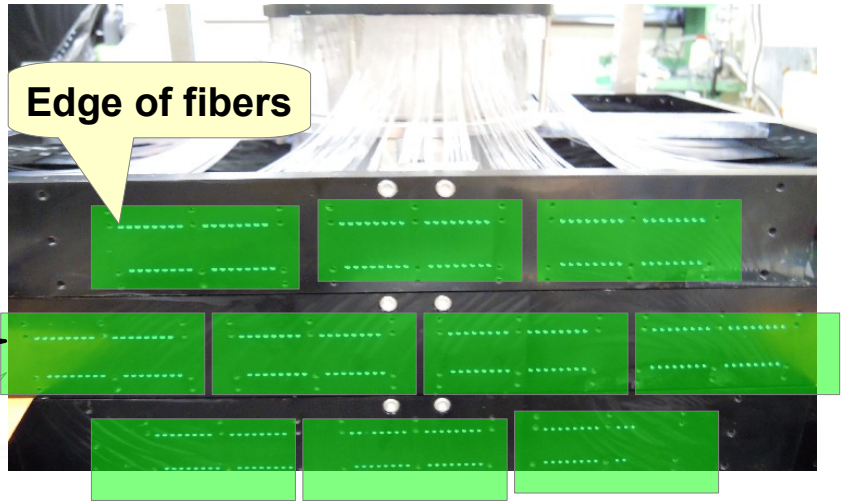
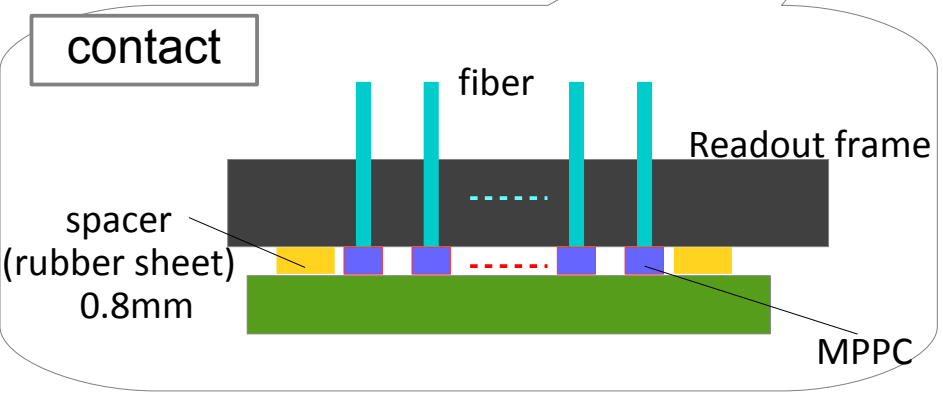


attach

MPPC
1×1mm^2

Readout frame





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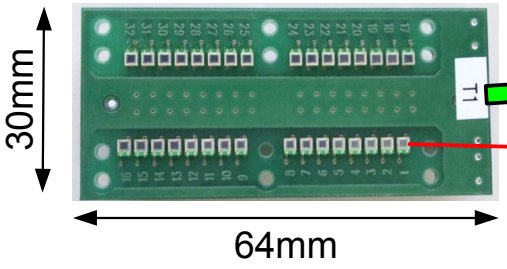

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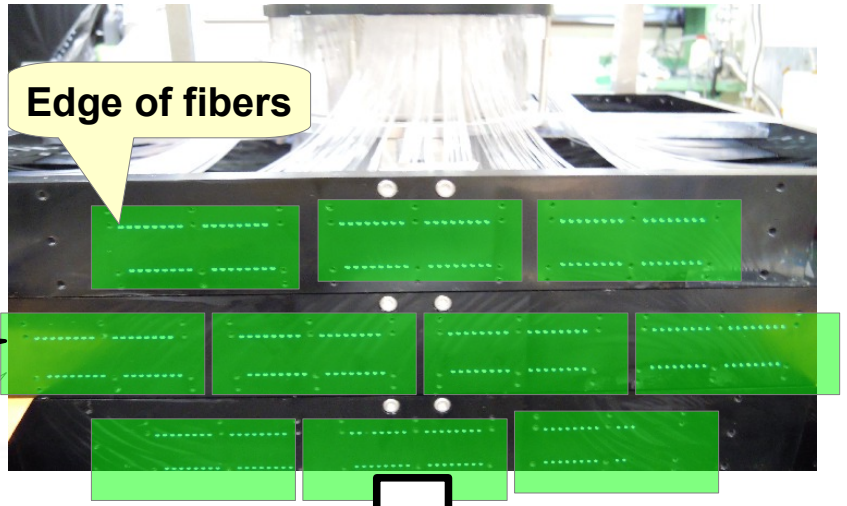
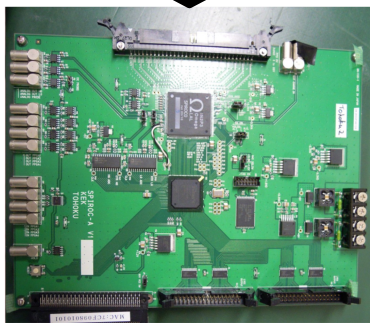
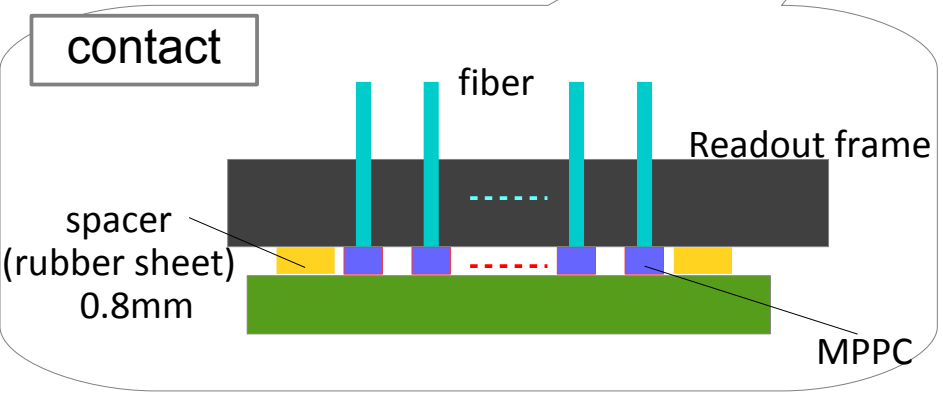


EASIROC board



ADC , TDC , bias adjustment etc...



Ref
EASIROC chip : proceedings of NDIP 2011 Omega/IN2P3
EASIROC board : R. Honda PD12

MPPC operation

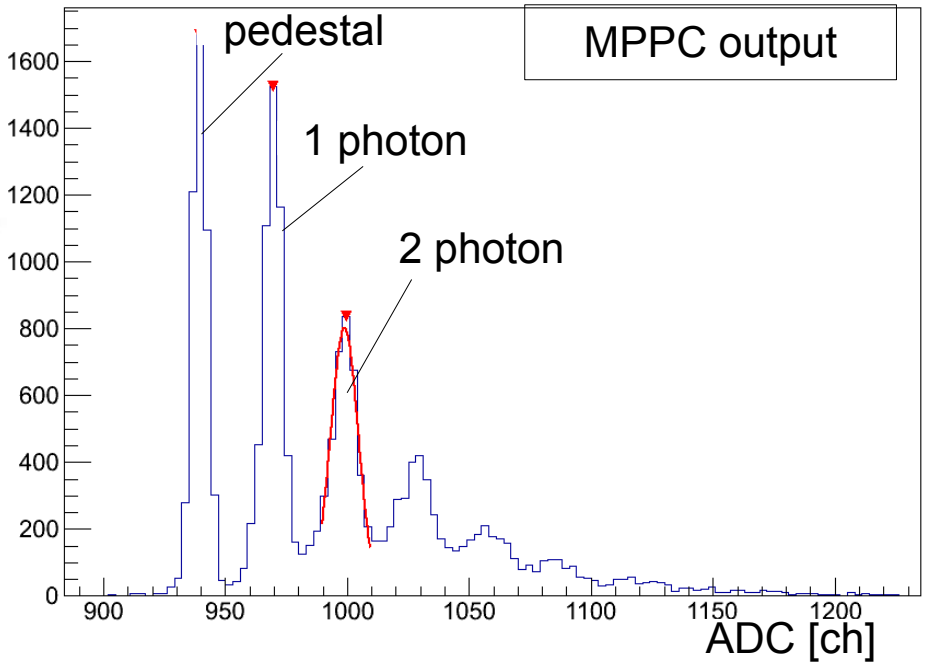
- For uniformity of MPPCs
  - Each MPPC's gain was adjusted by **changing bias voltage**.

EASIROC

20mV/bit, 0~4.5V

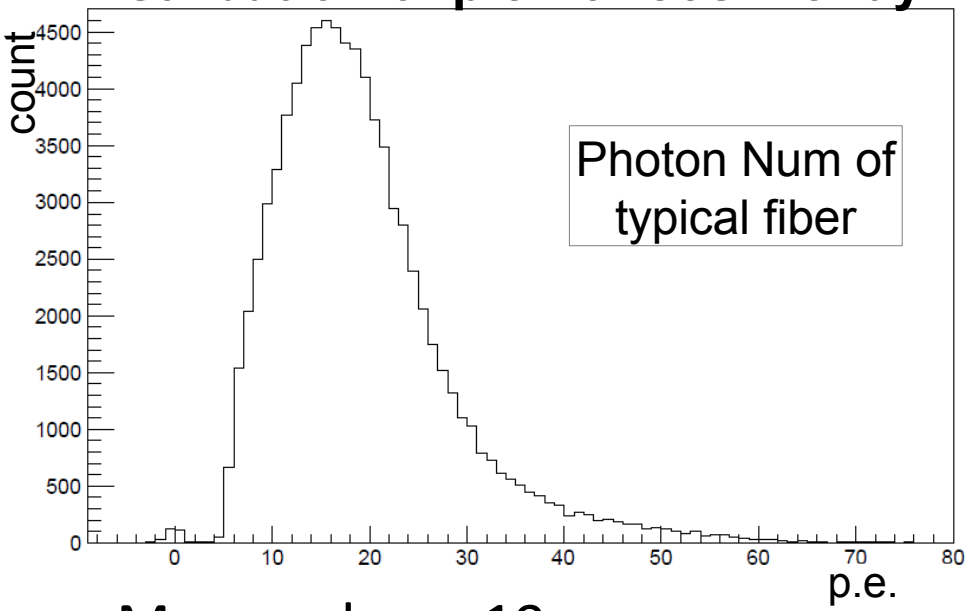
for each channel

  - 1,100 MPPCs were adjusted.
- Operation voltage
  - Over Voltage ≈ 1.4V



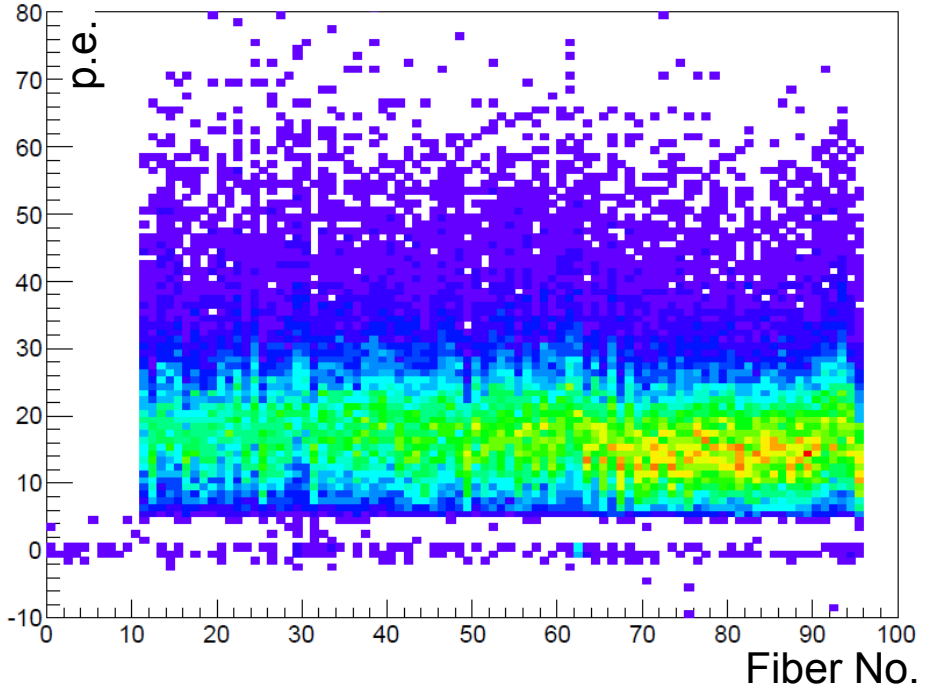
Measurement of cosmic ray

Distribution of p.e. for cosmic ray



- Mean value = 19 p.e.
  - sufficient to distinguish hit

Uniformity for all fibers



Light yield was almost uniform.

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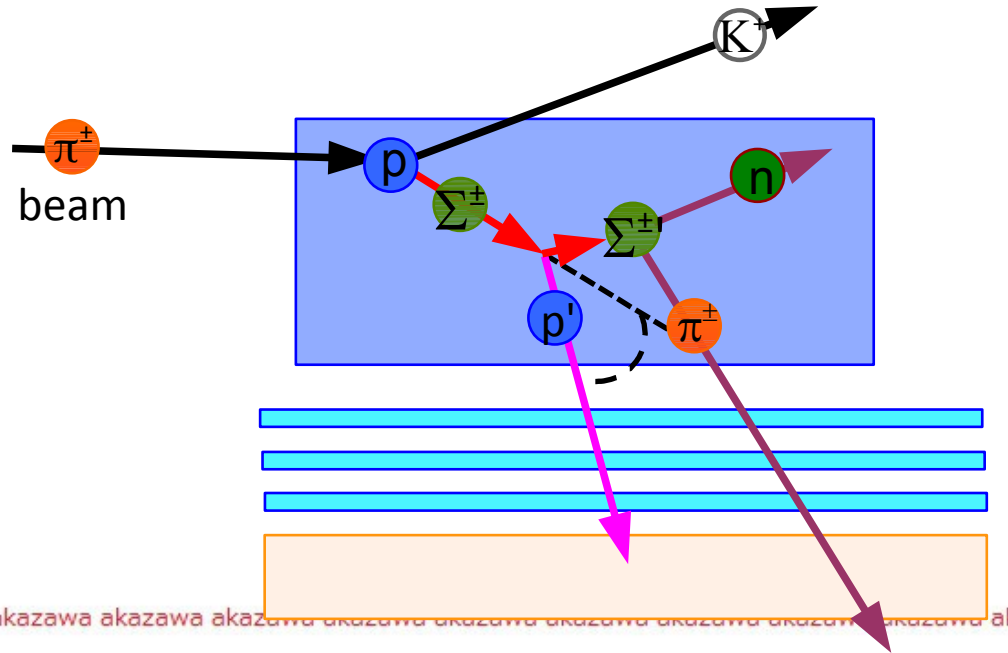
Performance evaluation

Measurement of energy deposit

- **Linearity**
  - Between **energy deposit** and **light yield**
- **Energy resolution**
  - Require **σ/Mean = 35%** for 70MeV proton for 1 layer in order to resolve **proton** and **pion** with 4σ



MIP particle

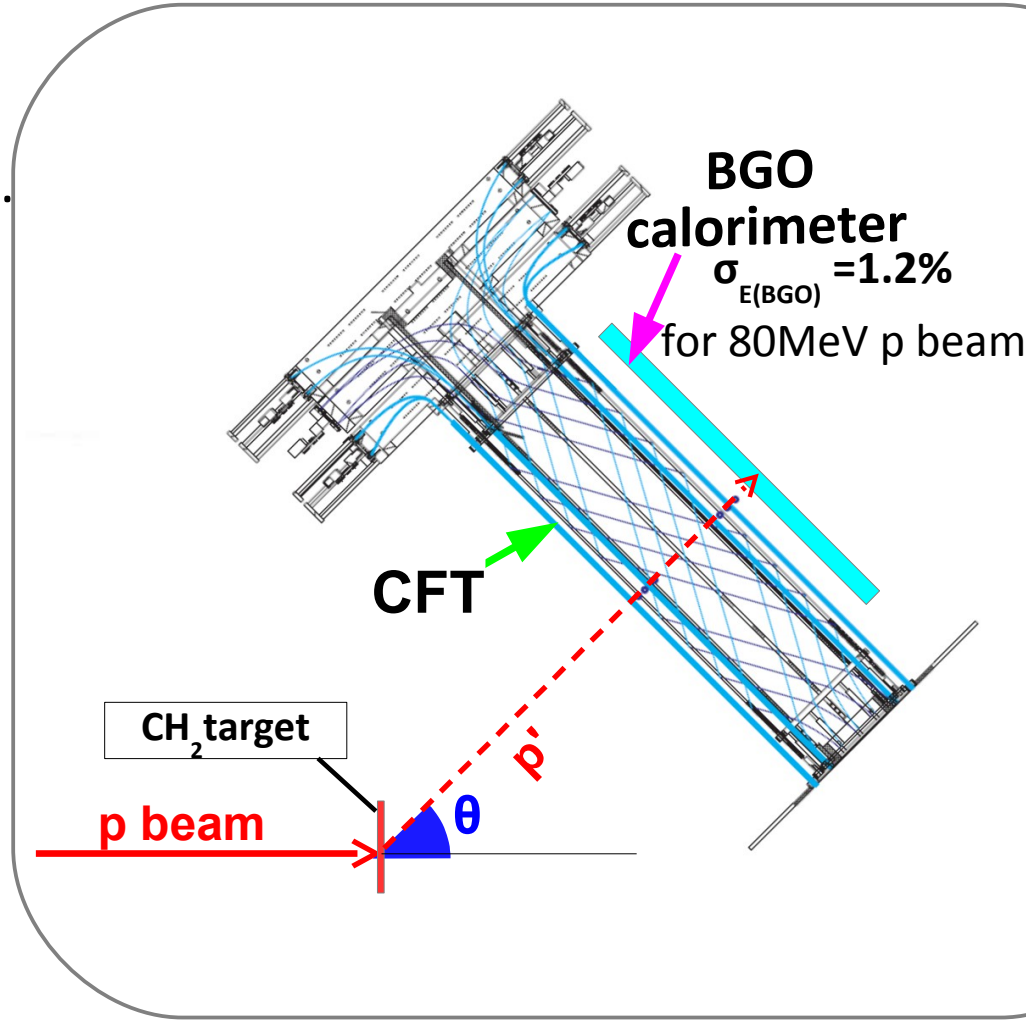
Σ decay product

cosmic ray

Performance evaluation for proton

Test experiment in CYRIC

- pp scattering experiment
  - **80MeV** proton beam from cyclotron @CYRIC in Tohoku Univ.



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Performance evaluation for proton

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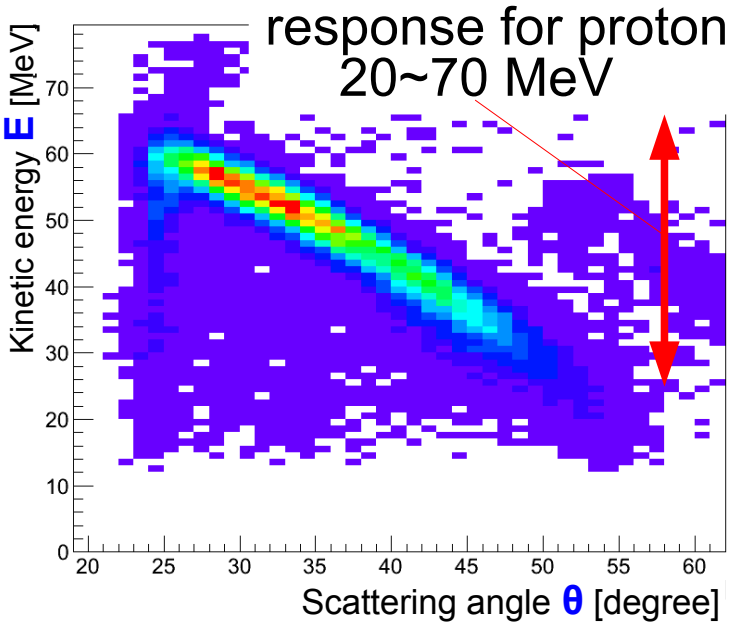
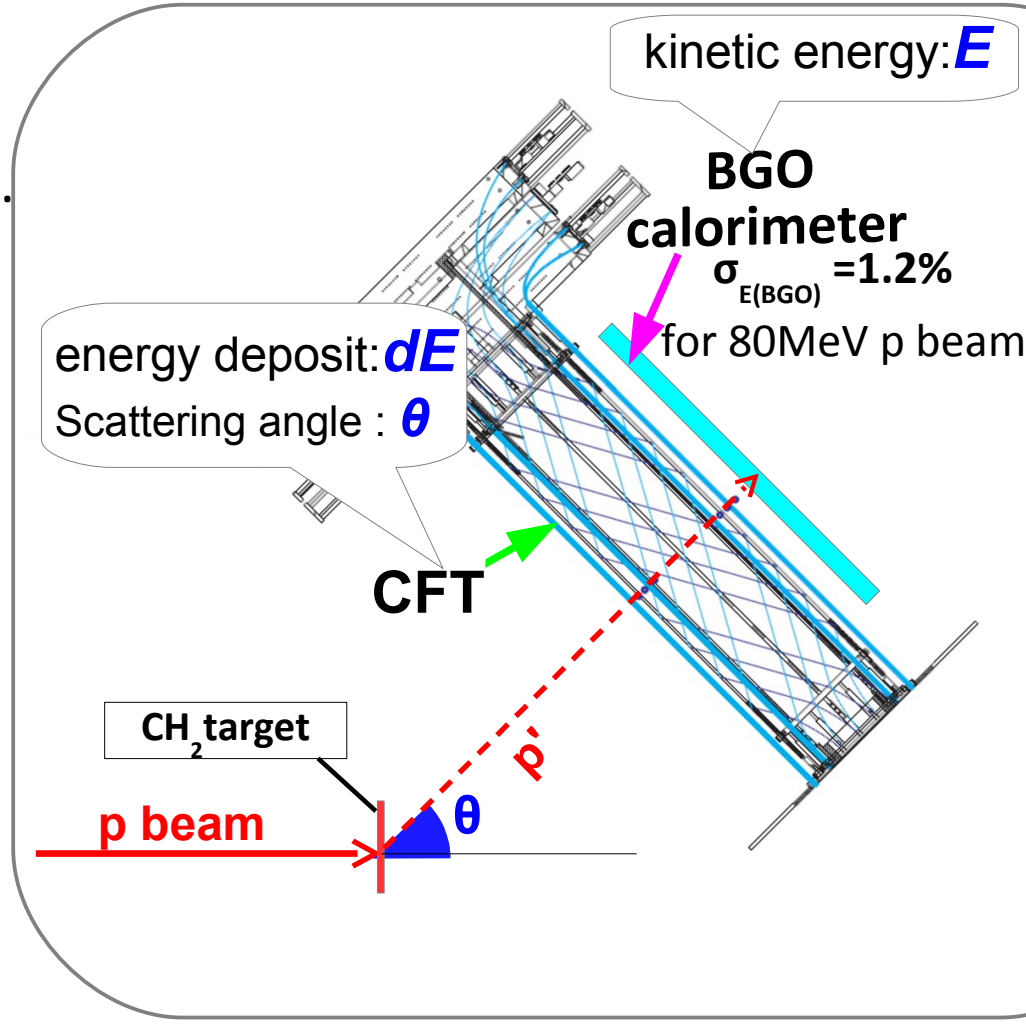
  - **80MeV** proton beam from cyclotron @CYRIC in Tohoku Univ.
  - **Ep** is selected by **θ**





Linearity of light yield

Experimental data
p.e.

compare

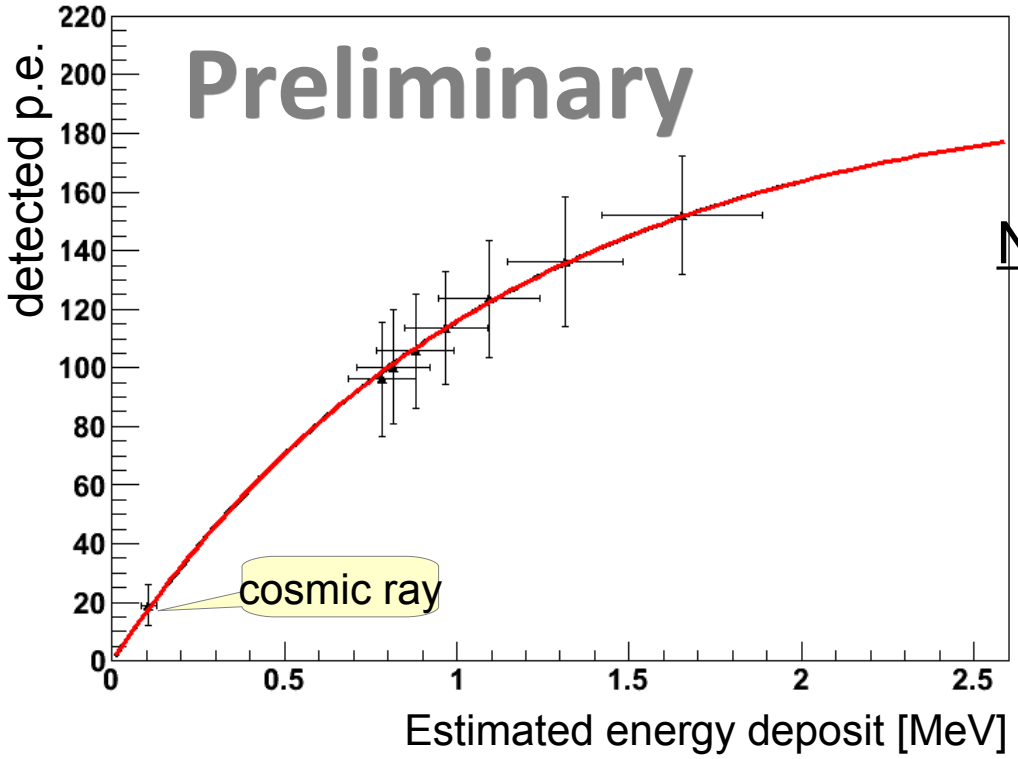
Simulation
Estimated energy deposit

Linearity of light yield

Experimental data
p.e.

compare

Simulation
Estimated energy deposit



※ For each layer

Response function

$N_{out} = N_{eff}*\{1- \exp(-B*dE/N_{eff})\}$

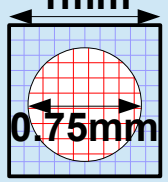
N_{eff} = effective pixel number of MPPC

= **197 pixels**

MPPC covering area to fiber

: 400pixel*(covering ratio)

≒ 180pixel

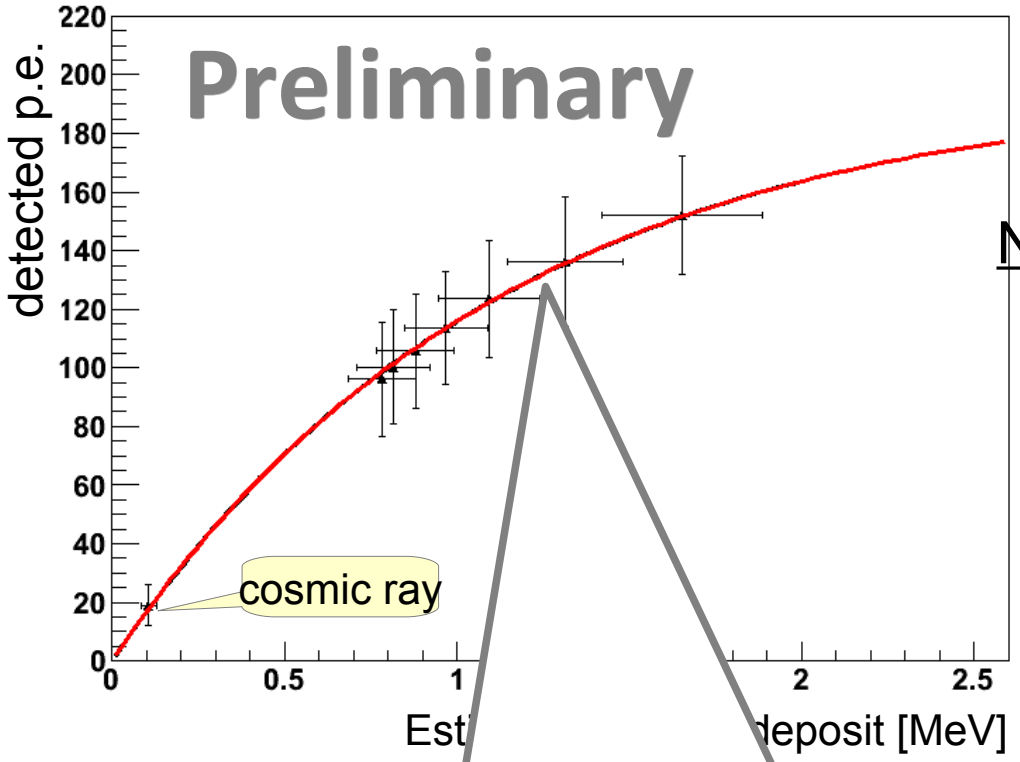


Linearity of light yield

Experimental data
p.e.

compare

Simulation
Estimated energy deposit



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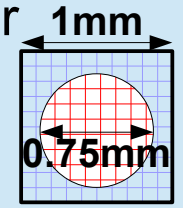
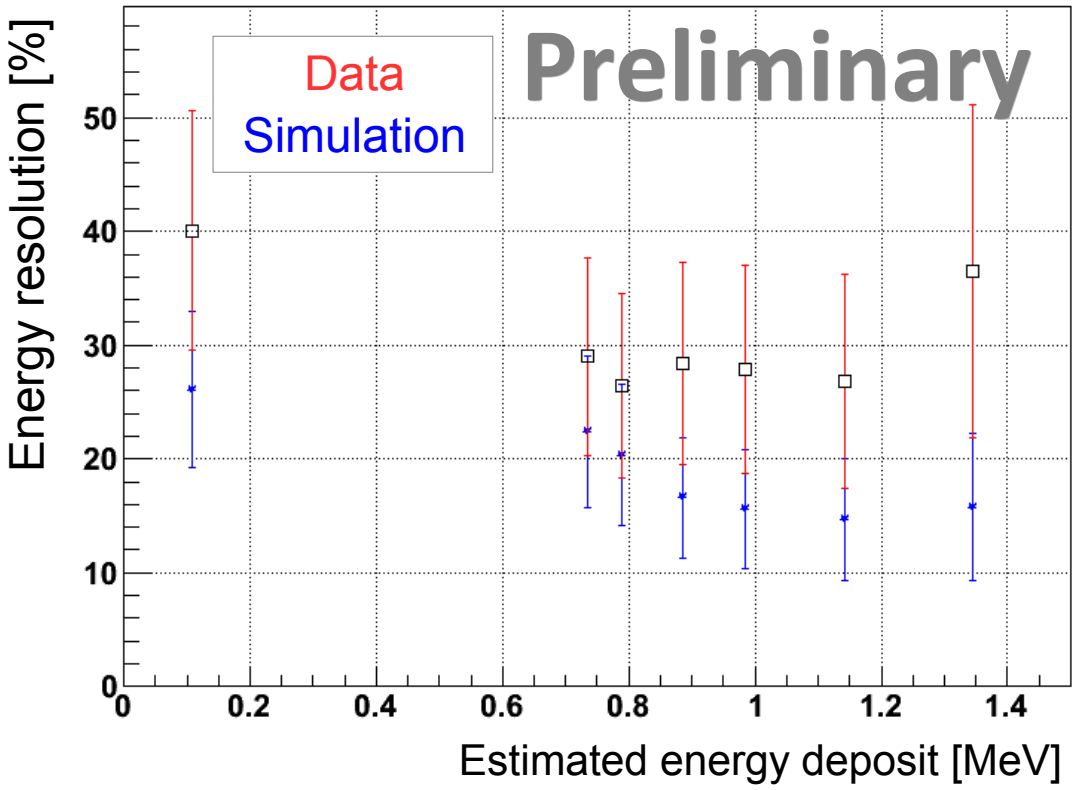


How much does non-linearity affect to energy resolution ?

Energy resolution

Energy resolution of one layer



- Simulation
  - Cylinder Shape of fiber
  - Fluctuation of Photon number
  - MPPC Saturation

suggests that resolution will become worse at high dE region.

- Resolution was worse than simulation. <-- to be calibrated for each channel
- Energy resolution of CFT = **28%** for 70MeV proton (dE = 0.7MeV)

satisfied our requirement (35% for 70MeV)

summary

- We plan to perform Σp scattering experiment at J-PARC
  CFT(Cylindrical Fiber Tracker) will measure the **trajectory** and the **energy deposit**

✓ Construction ― a Prototype consists of 3 layers
- Scintillation Fiber + MPPC
- 2 straight layers +1 spiral layer ≈ 1,100 fibers
- MPPCs which read each fiber were operated by EASIROC board

✓ Performance evaluation
- Measured cosmic ray and pp scattering
  - Cosmic-ray ・・・ Mean detected photon number = **19 p.e.**
- Linearity ・・・ MPPC saturated in high energy deposit region.
- Effective pixel number of MPPC = **197pixels**
  ⇔ consistent with fiber covering area
- Energy resolution
  - worse than that of simulation ← to be improved
  - **σ/Mean = 28% for 70MeV proton(dE=4.7MeV)**

satisfied our requirement

akazawa akazawa akazawa akazawa akazawa akazawa akazawa akazawa akazawa akazawa akazawa akawaza akazawa akazawa akazawa akazawa

Back up

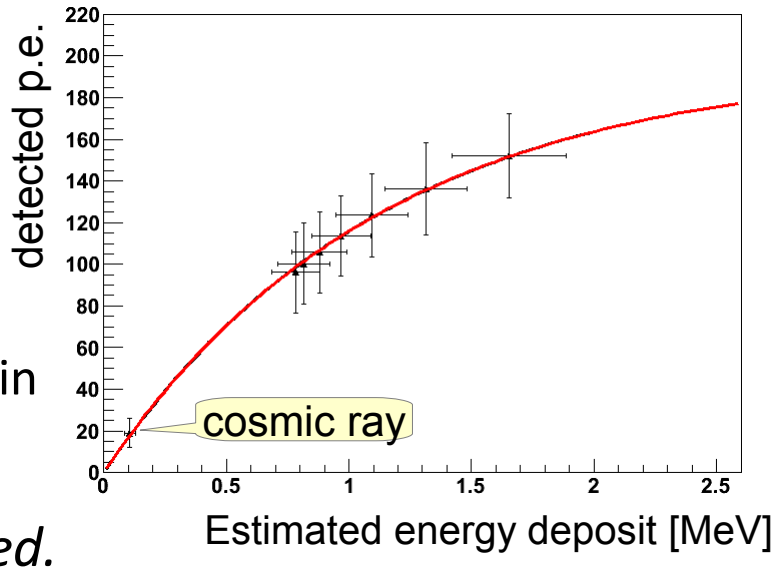
To improve the energy resolution

- Calibration method
  - Response function
    - **Layer by layer (now)**

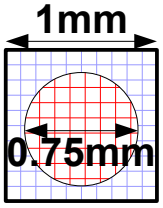
contain the effect of the deviation of MPPC' gain

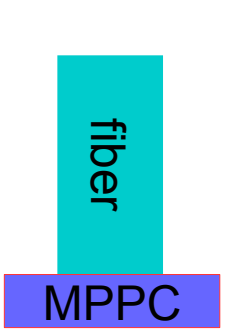
- ⇒⇒ **fiber by fiber**

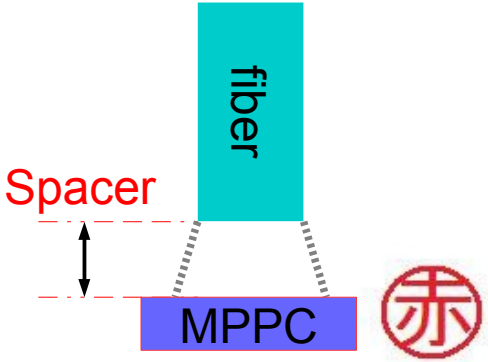
Energy resolution should be improved.



- Expand MPPC effective area
  - Inserting a spacer between fiber and MPPC
  - MPPC saturation will become weaker.
- etc...



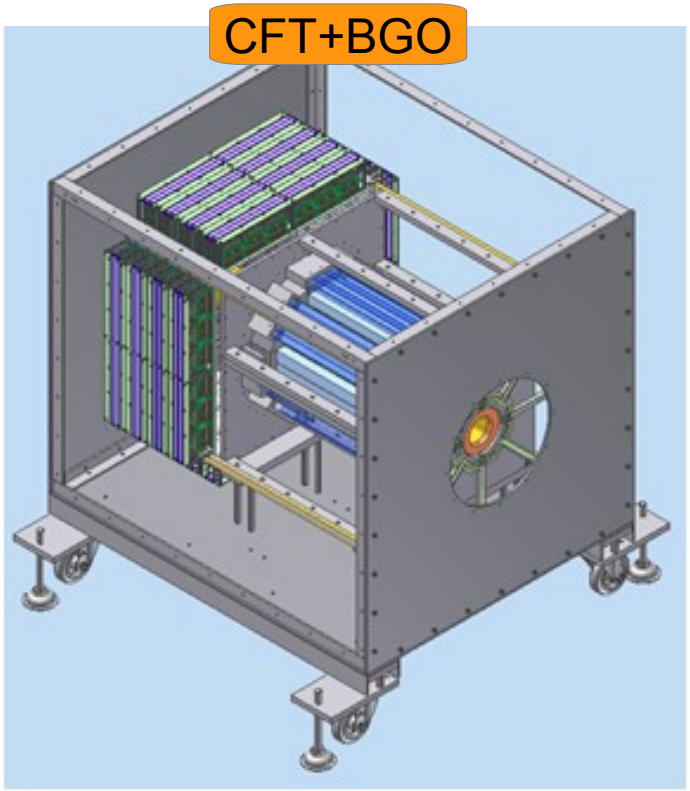


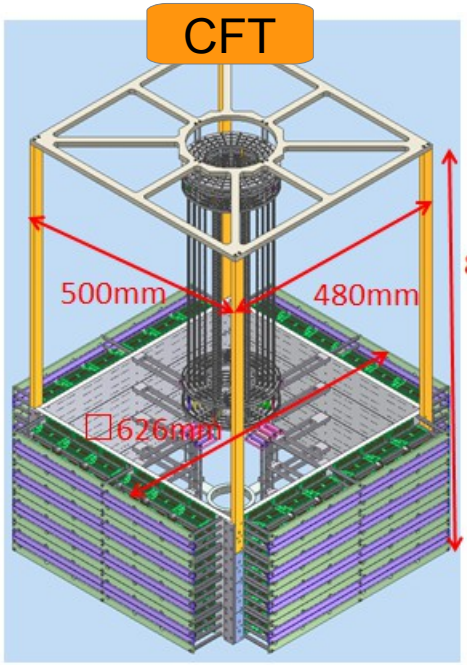


A design of actual type

Actual detectors

- The design have almost finished
- Just now constructing

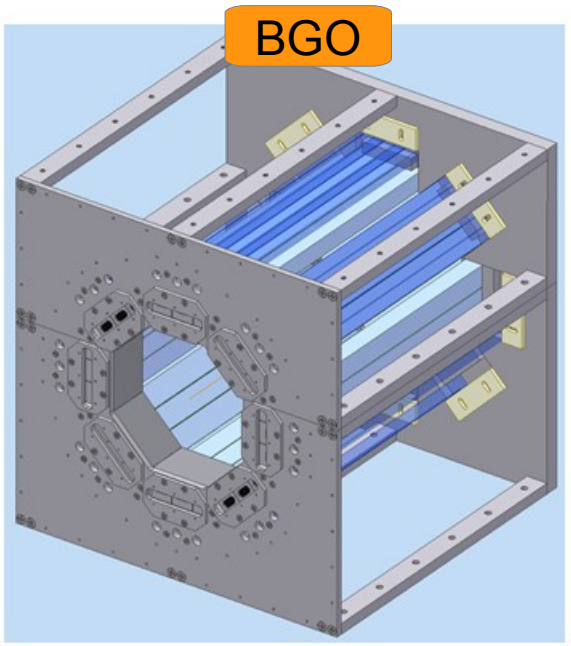




・CFT・・・

4 Φ layers,4 U・V layers

~5,000 fibers



・BGO calorimeter・・・

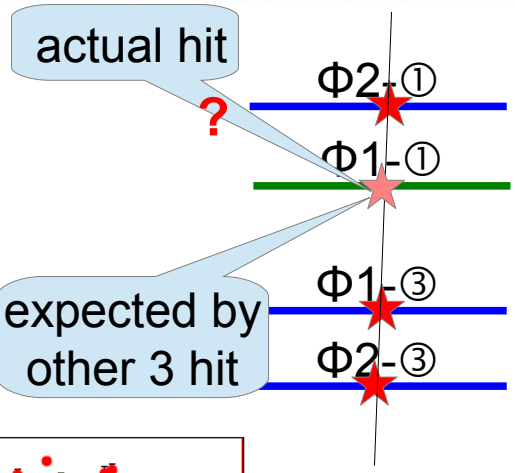
24 BGO(30×25×400mm^3)

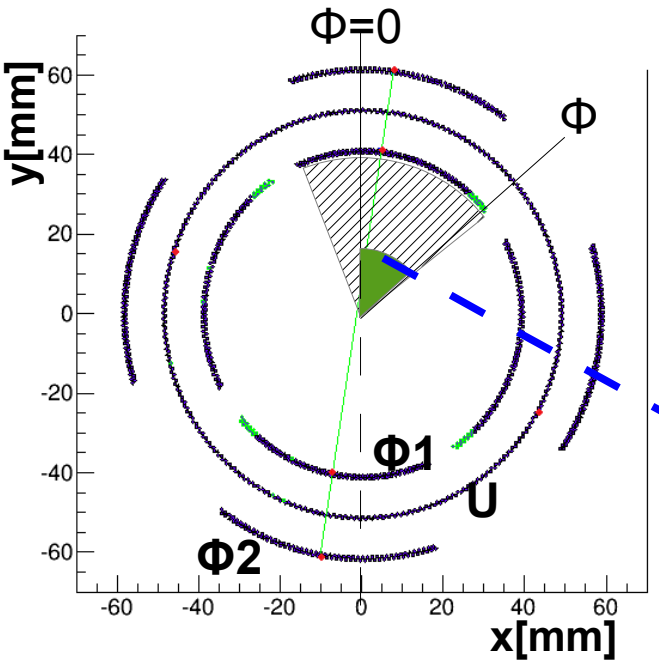
will be placed cylindrically

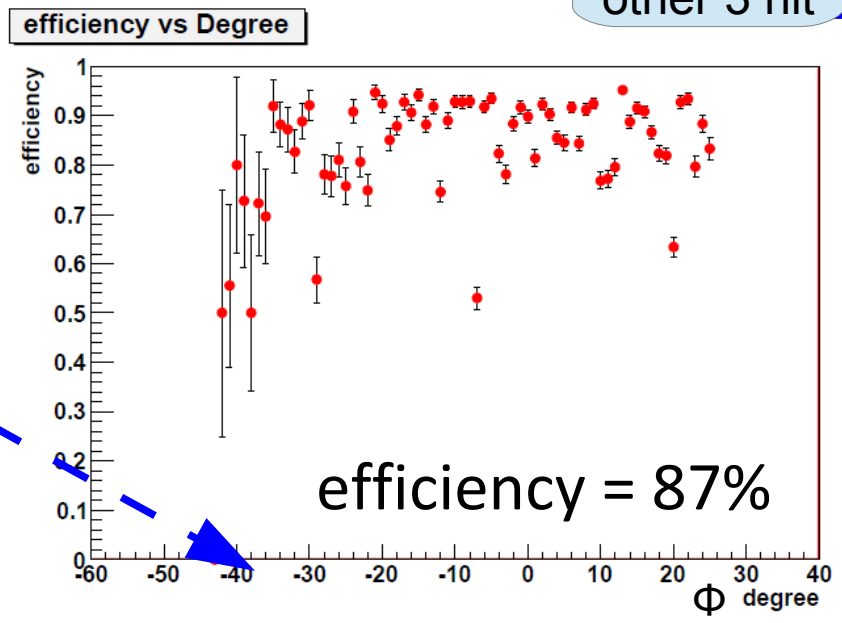
Efficiency

- Efficiency for Φ layer

  (actual hit) / (expected by other 3 hit track)







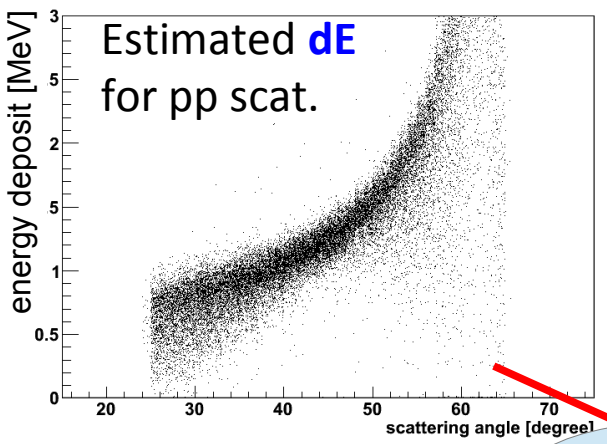
- Number of photon is sufficient
- Position dependence

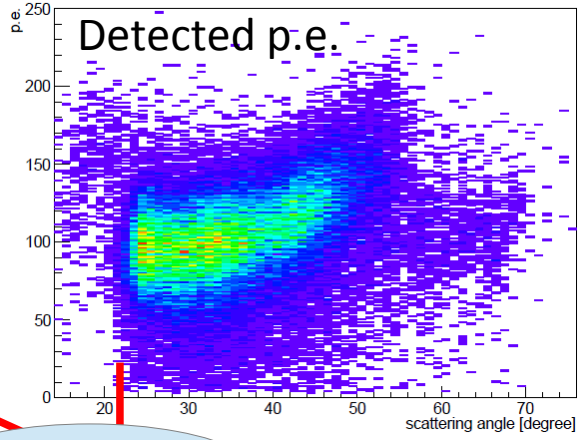
  ⇒ suggest that there were some space between some fibers

  – to be improved

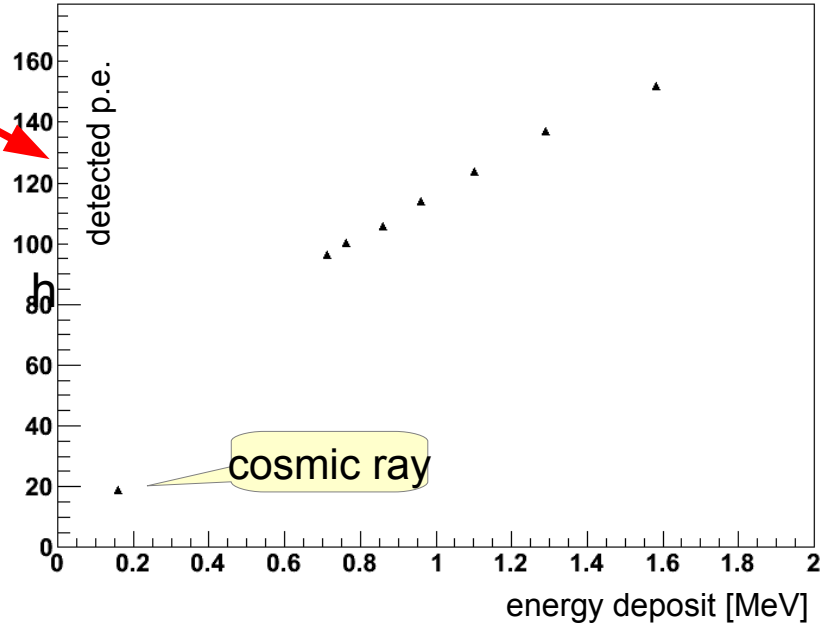
Linearity of light yield

- Linearity between energy deposit(simulation) and p.e.(actually detected)





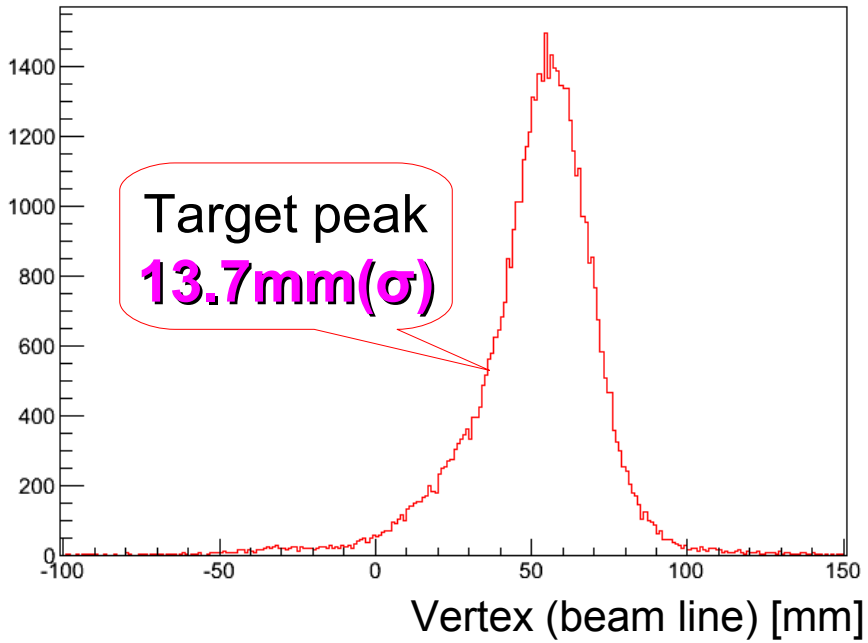
Compare
via scattering angle

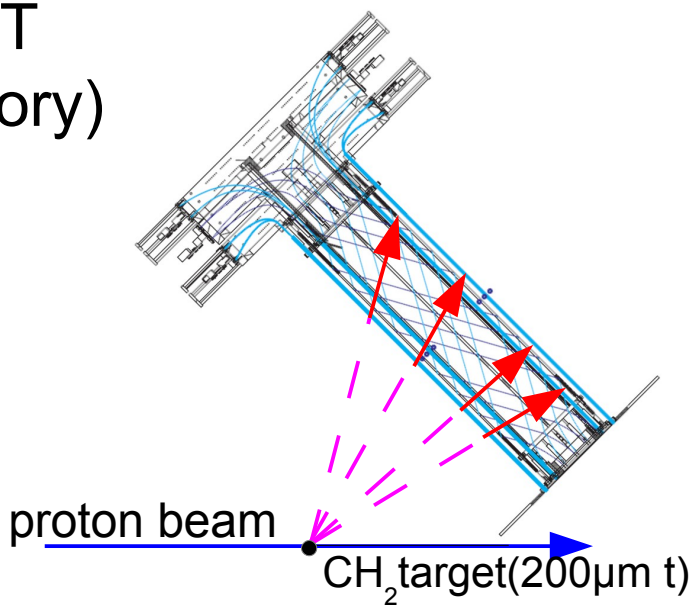


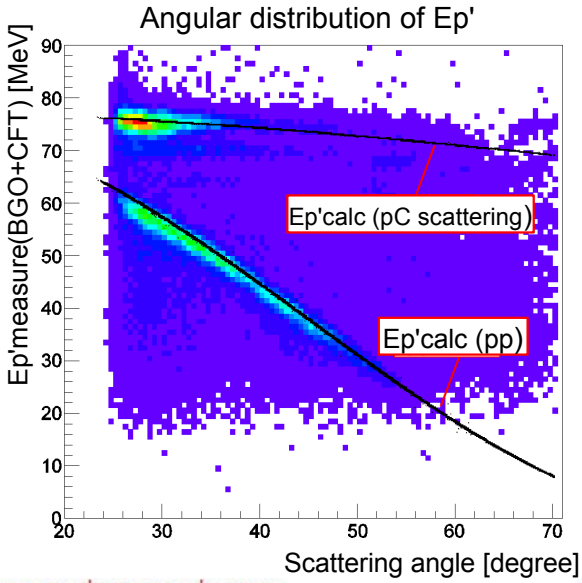
angular resolution

Trajectory was reconstructed by CFT

----> vertex (beam line × trajectory)







- estimated from σ_{vertex}=13.7mm

  $\sigma_{\Delta\theta}$=1.0°

- Ideal resolution (Geant4)

  $\sigma_{\Delta\theta}$=0.77° , σ_{vertex}=9.4mm

Prototype nearly realized the simulated performance

⇒ to be better by improving position precision