新学術領域「実験と観測で解き明かす中性子星の核物質」
第 3 回研究会 @ 熱川

J-PARC E40 実験の準備状況
The preparation status of J-PARC E40

2014.09.25

R. Honda (Tohoku Univ.)
for the E40 collaboration.

Contents

- Introduction
  - Physics motivation
  - Experimental method
- Preparation status
  - Cylindrical fiber tracker
  - BGO calorimeter
  - MPPC readout electronics
- Summary

Introduction – Overview -

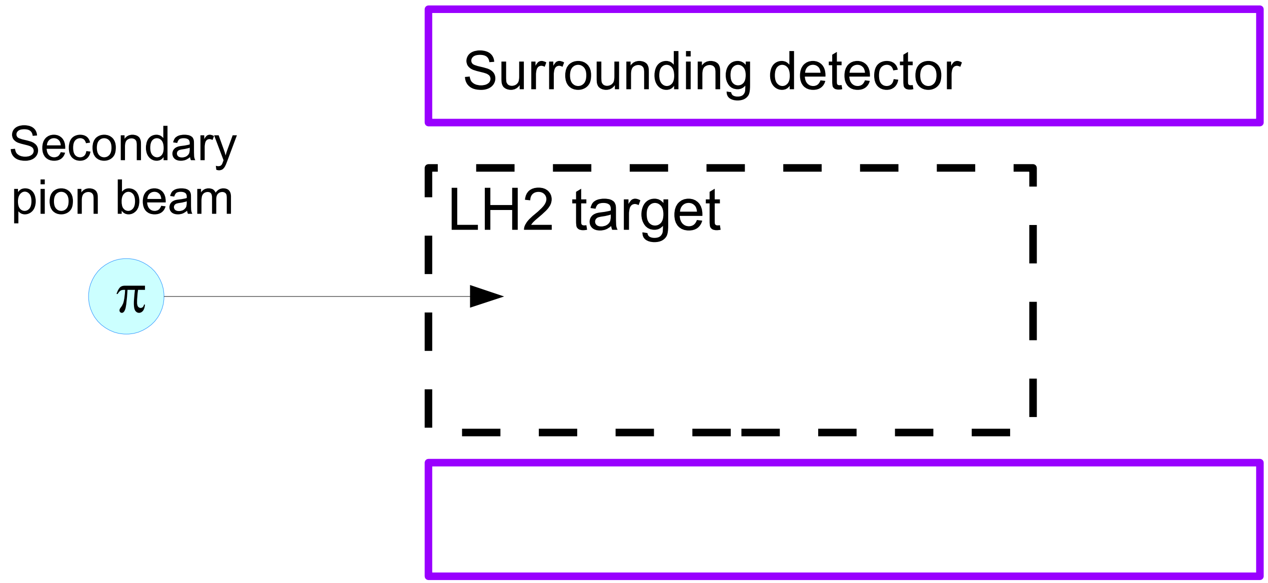
The J-PARC E40 experiment :

Measurement of the differential cross sections of

- Σ^+p elastic scattering,
- Σ^-p elastic scattering,
- $\Sigma^-p \rightarrow \Lambda N$ inelastic scattering.

with the high statistics (10^4 events for each channel.)

The results will be an quite important input data for the two-body interaction model in the flavor SU(3).



Introduction – Overview -

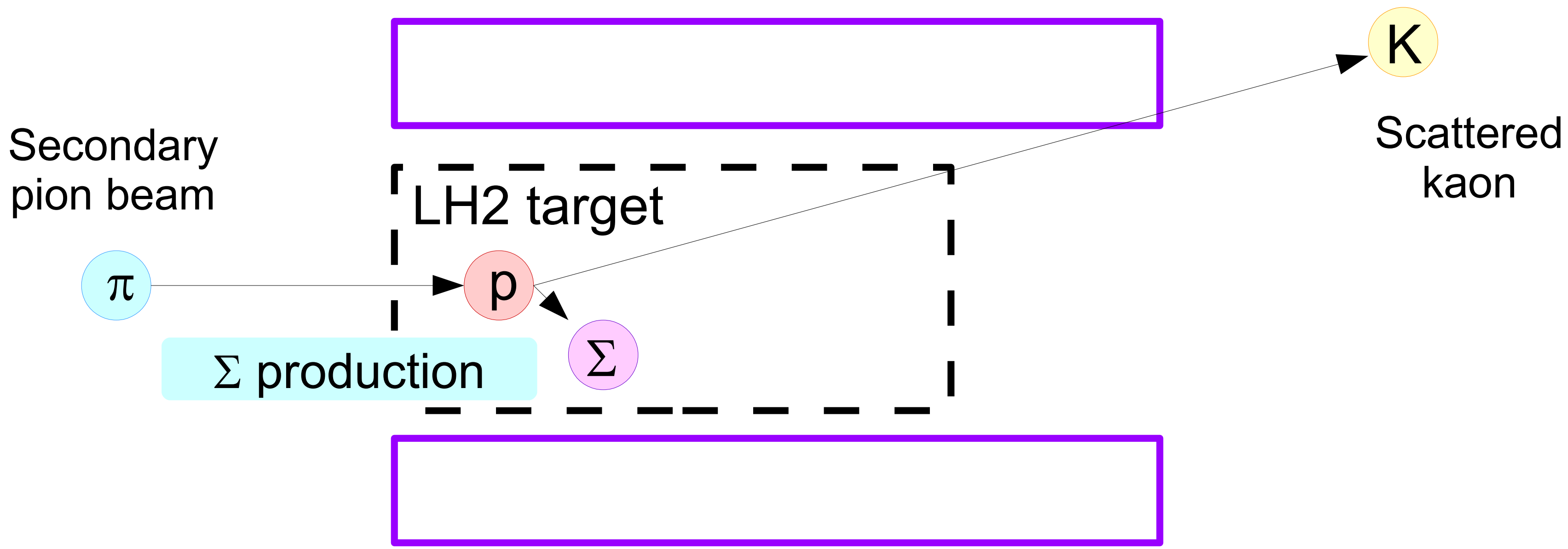
The J-PARC E40 experiment :

Measurement of the differential cross sections of

- $\Sigma^{+}p$ elastic scattering,
- $\Sigma^{-}p$ elastic scattering,
- $\Sigma^{-}p \rightarrow \Lambda N$ inelastic scattering.

with the high statistics (10^4 events for each channel.)

The results will be an quite important input data
for the two-body interaction model in the flavor SU(3).



Introduction – Overview -

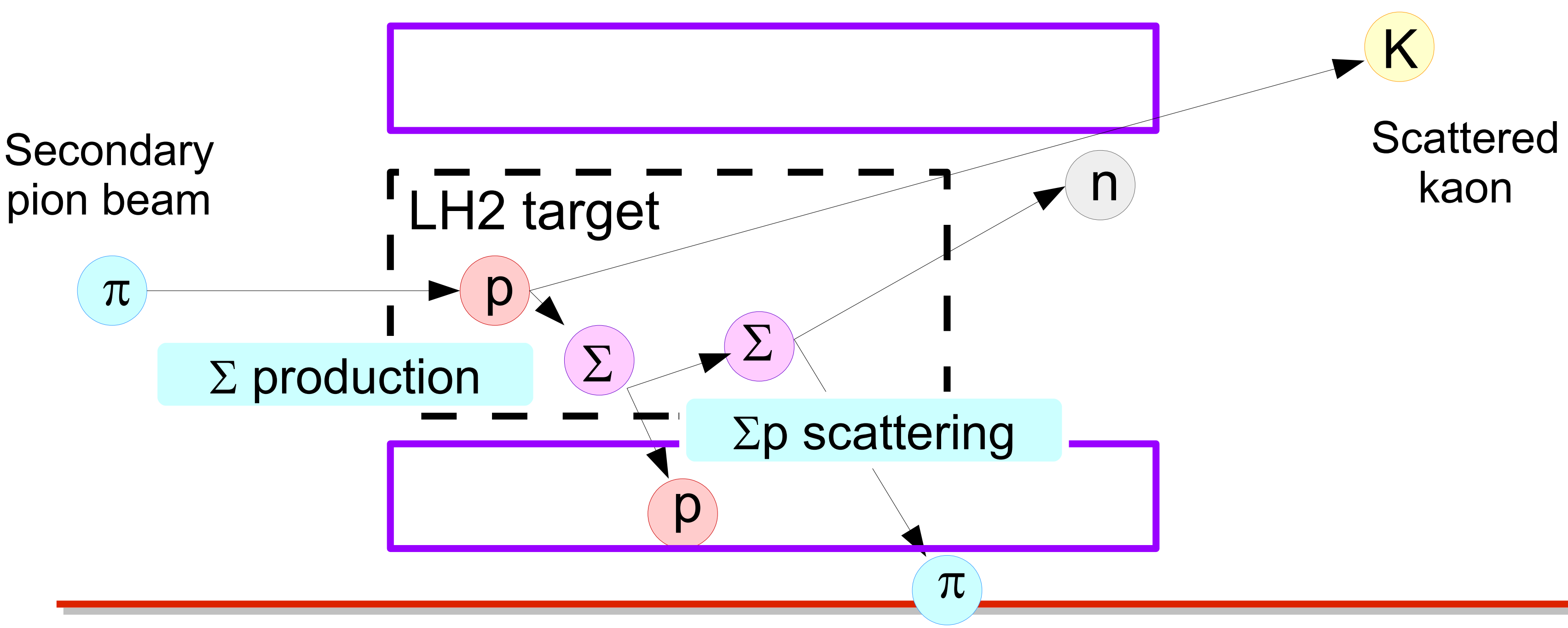
The J-PARC E40 experiment :

Measurement of the differential cross sections of

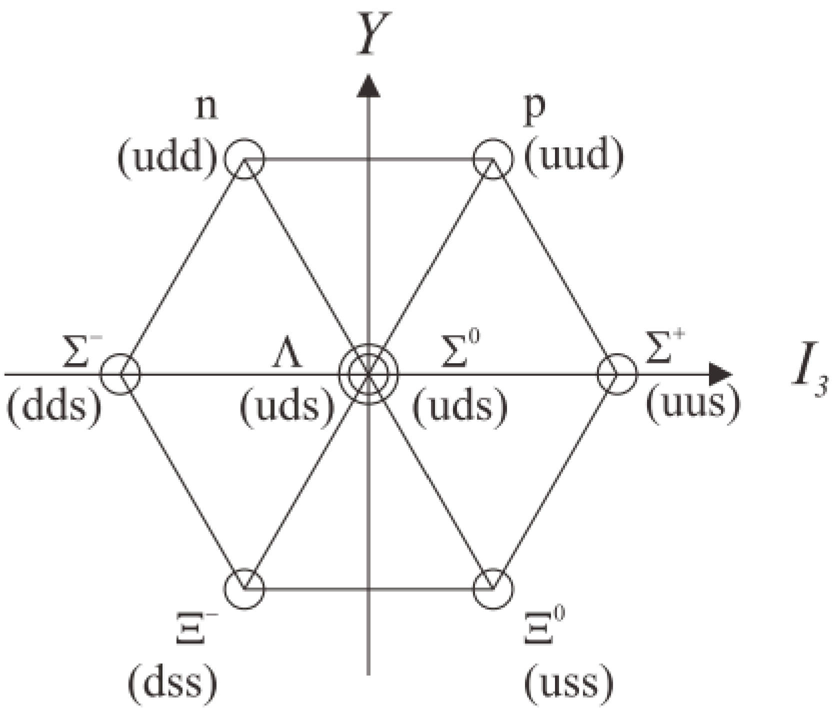
- Σ^+p elastic scattering,
- Σ^-p elastic scattering,
- $\Sigma^-p \rightarrow \Lambda N$ inelastic scattering.

with the high statistics (10^4 events for each channel.)

The results will be an quite important input data for the two-body interaction model in the flavor SU(3).



Introduction – Physics motivation -



Baryon octet with spin ½ in the $SU_f(3)$ symmetry.

The understanding of Nucleon-Nucleon (*NN*) interaction

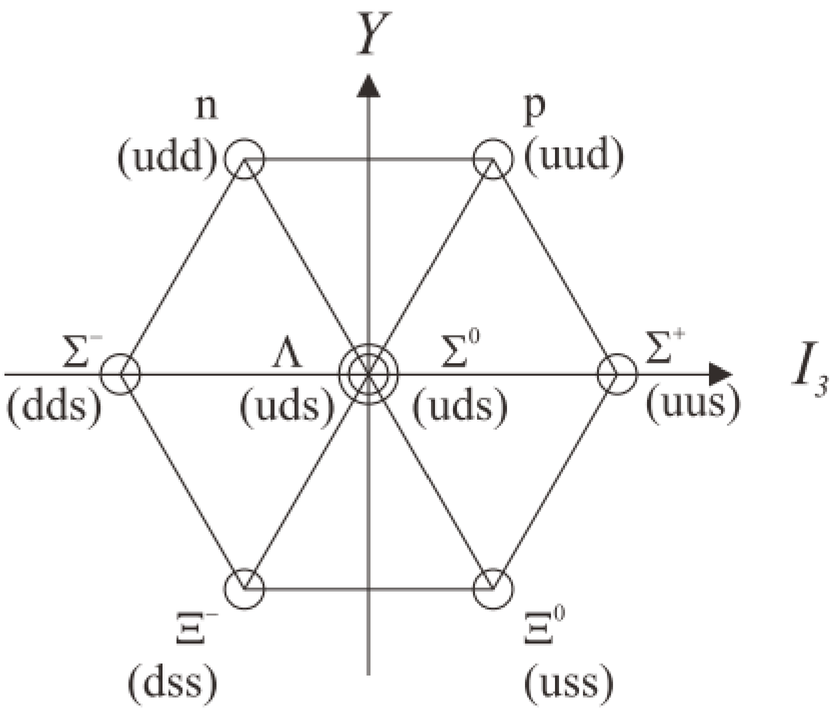
↓ Introduce *s* quark

Baryon-Baryon (*BB*) interaction

- Nucleon-Nucleon (NN)
- Hyperon-Nucleon (YN)
- Hyperon-Hyperon (YY)

Precise cross section data on *YN* scatterings are awaited to constrain parameters of two-body interaction models in $SU_f(3)$.

Introduction – Physics motivation -



Baryon octet with spin ½ in the $SU_f(3)$ symmetry.

The understanding of Nucleon-Nucleon (*NN*) interaction

A lot of experimental data on NN scatterings.

Introduce *s* quark

Baryon-Baryon (*BB*) interaction

- Nucleon-Nucleon (NN)
- Hyperon-Nucleon (YN)
- Hyperon-Hyperon (YY)

Lack of experimental data on YN scatterings.

Precise cross section data on *YN* scatterings are awaited to constrain parameters of two-body interaction models in $SU_f(3)$.

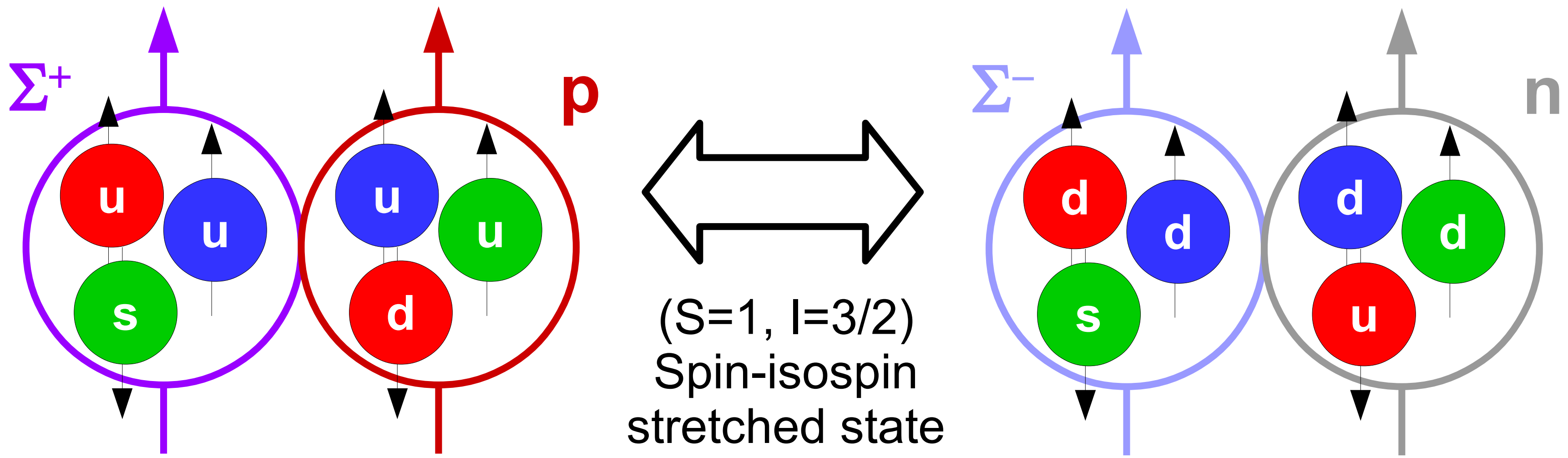
Introduction – Physics motivation -

For the investigation of the inner part of the neutron star.

Σ^+p channel

Probe the origin of the repulsive core.

The quite strong repulsive force due to the Pauli blocking in the quark level.



Σ^-p → ΛN conversion channel

Information on the Λ–Σ coupled channel.

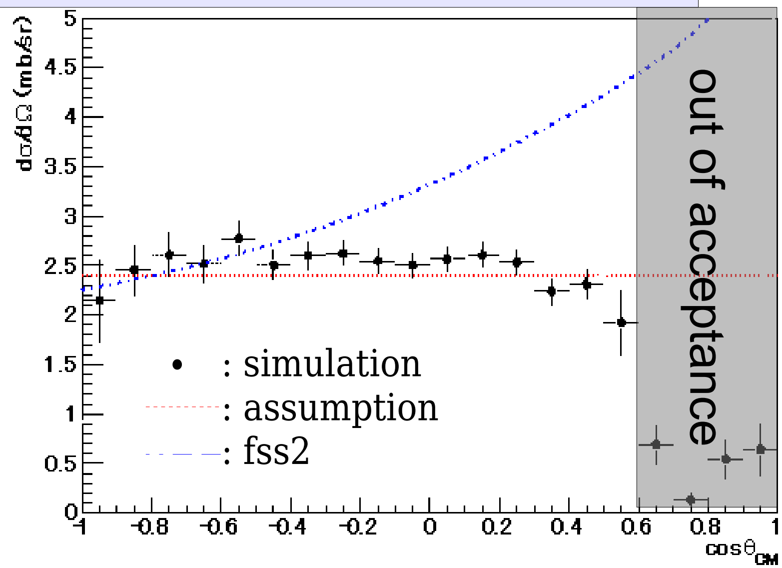
Σ mixing in the ΛN interaction in neutron stars.

Introduction – J-PARC E40 -

TOHOKU UNIVERSITY

Expected statistic errors

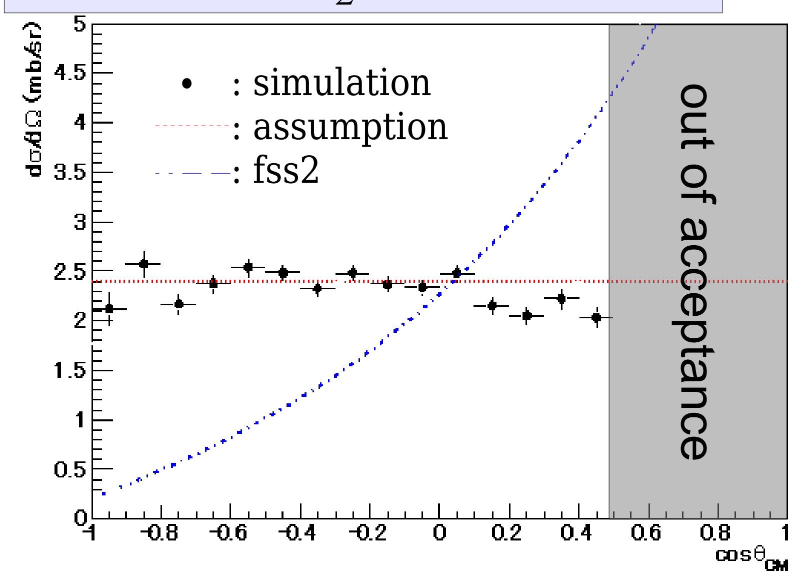
Σ^+p $d\sigma/d\Omega$ (p_Σ = 550 MeV/c)



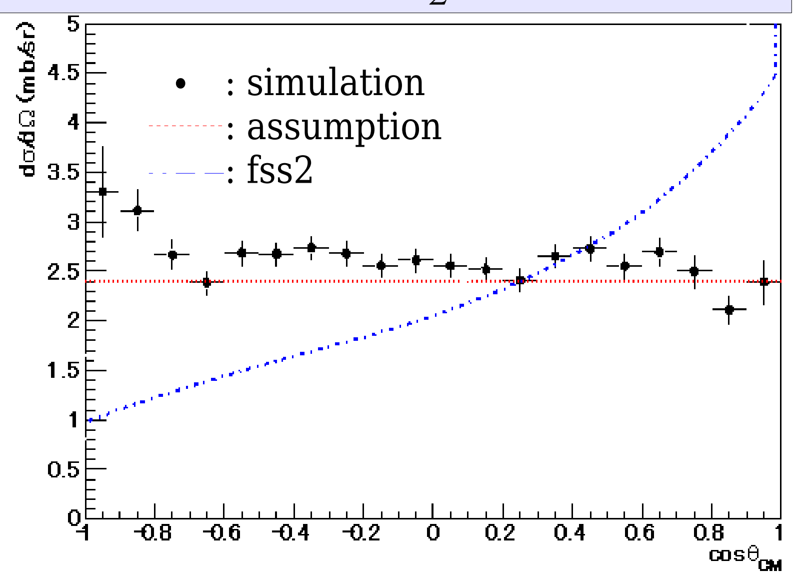
~20 days beam time
for Σ^- and Σ^+ each

($\Sigma^-p \rightarrow \Lambda n$ is by-product
of Σ^-p elastic scattering)

Σ^-p $d\sigma/d\Omega$ (p_Σ = 500 MeV/c)



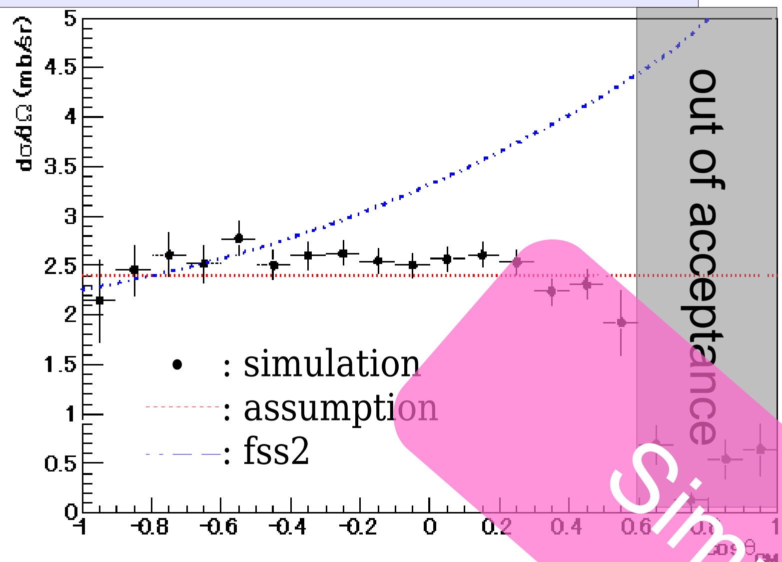
$\Sigma^-p \rightarrow \Lambda n$ $d\sigma/d\Omega$ (p_Σ = 500 MeV/c)



Introduction – J-PARC E40 -

Expected statistic errors

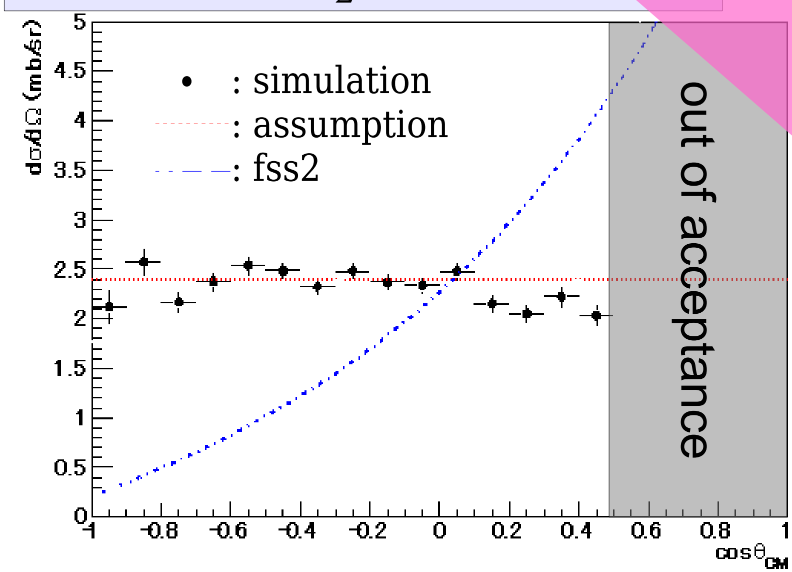
$\Sigma^+ p$ $d\sigma/d\Omega$ (p_Σ = 550 MeV/c)



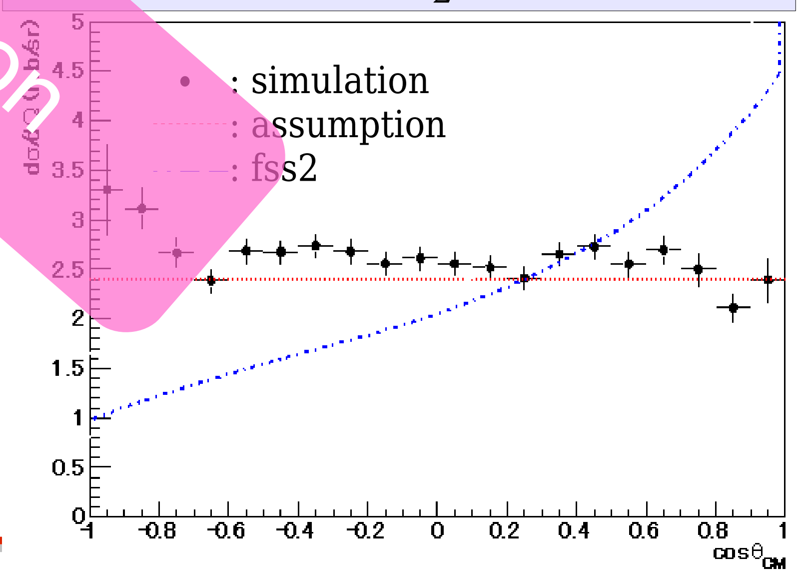
~20 days beam time
for Σ^- and Σ^+ each

($\Sigma^- p \rightarrow \Lambda n$ is by-product
of $\Sigma^- p$ elastic scattering)

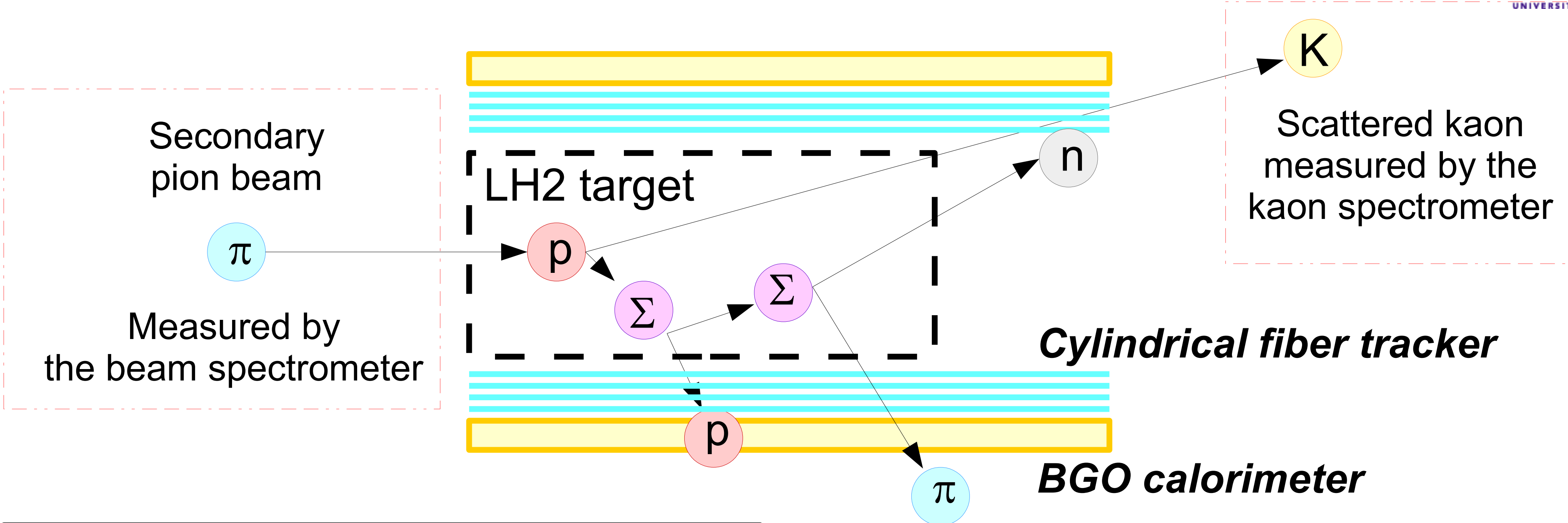
$\Sigma^- p$ $d\sigma/d\Omega$ (p_Σ = 500 MeV/c)



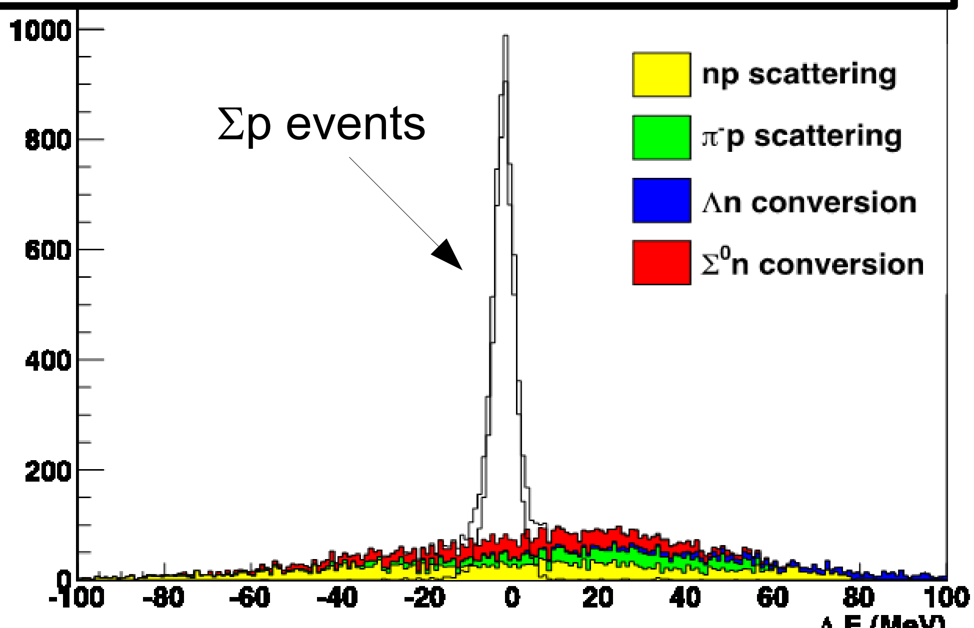
$\Sigma^- p \rightarrow \Lambda n$ $d\sigma/d\Omega$ (p_Σ = 500 MeV/c)

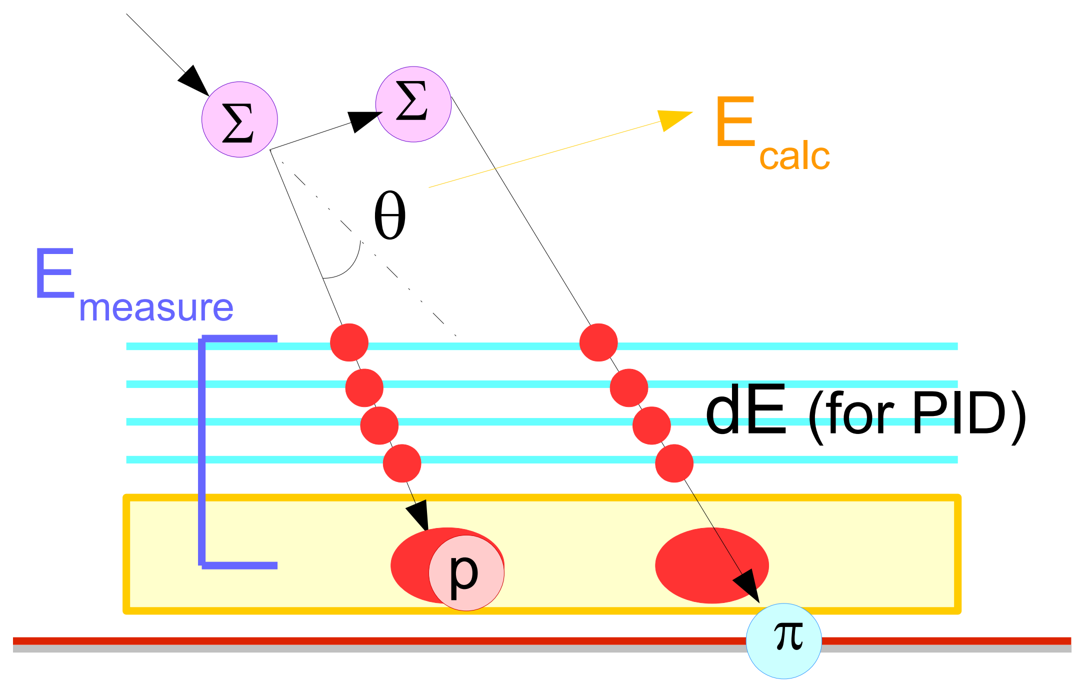


Introduction – Proton detection system -



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

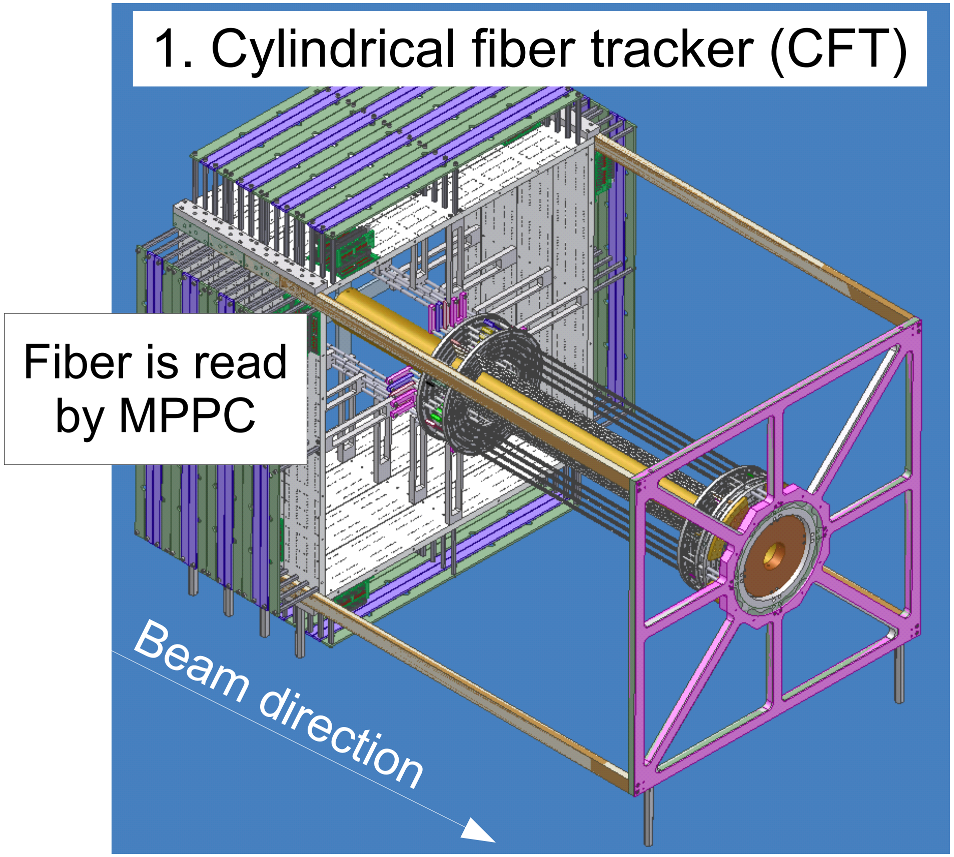


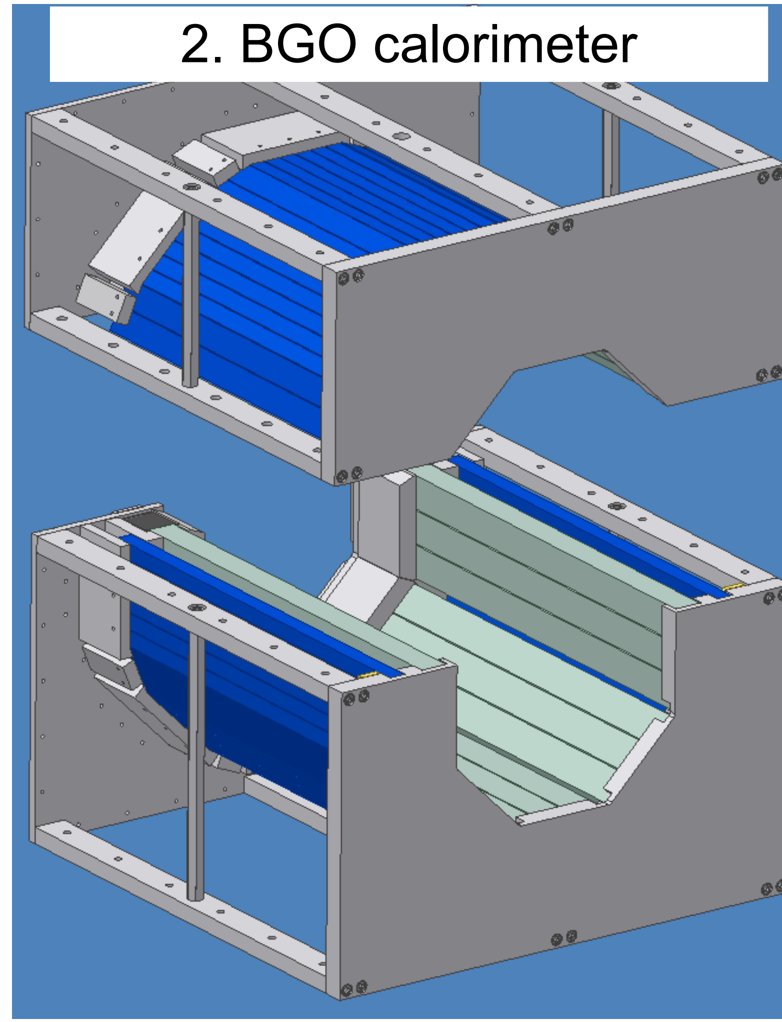


Preparation status

Preparation status

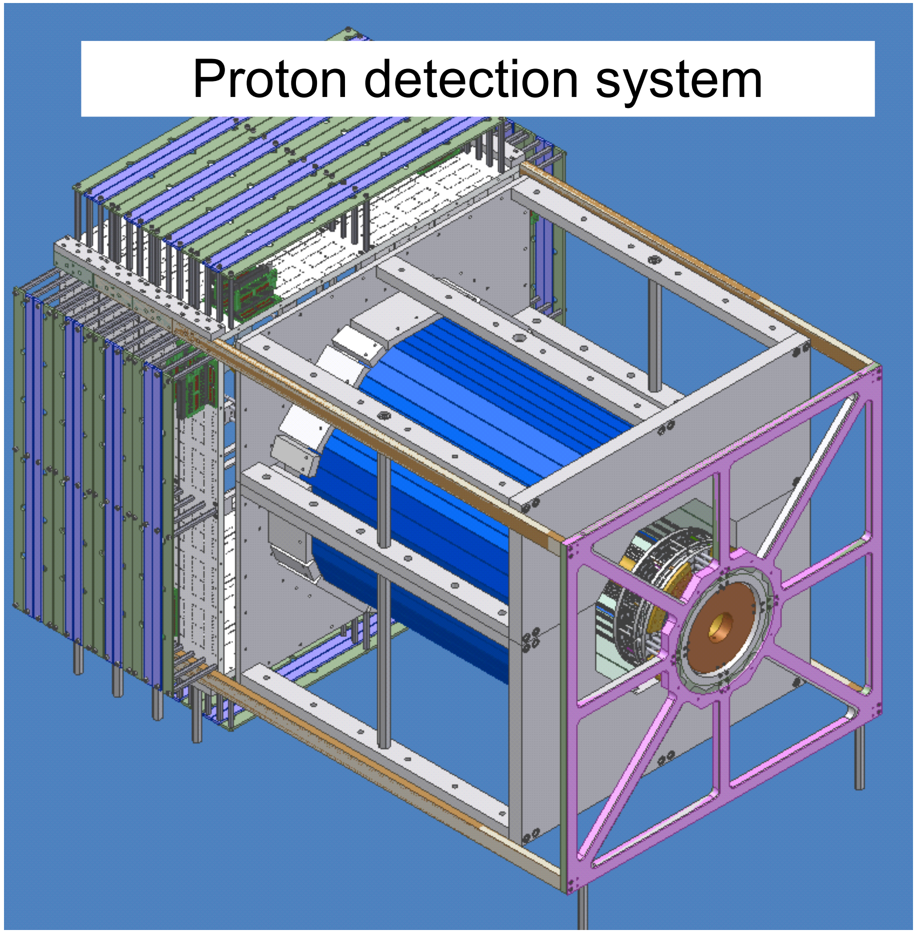
Actual design of the proton detection system.





3. Multi-MPPC readout electronics (VME-EASIROC)

Preparation status



- **CFT**
  - 8 layers configuration
  - r = 49 ~ 84 mm
  - ~5000 fibers
- **BGO calorimeter**
  - 24 crystals (25 x 30 x 400 mm^3)
- **VME-EASIROC**
  - 64 channels/board
  - ADC/MHTDC

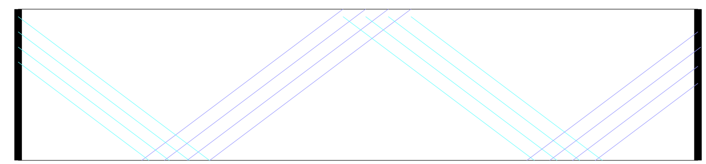
Preparation status
(CFT)

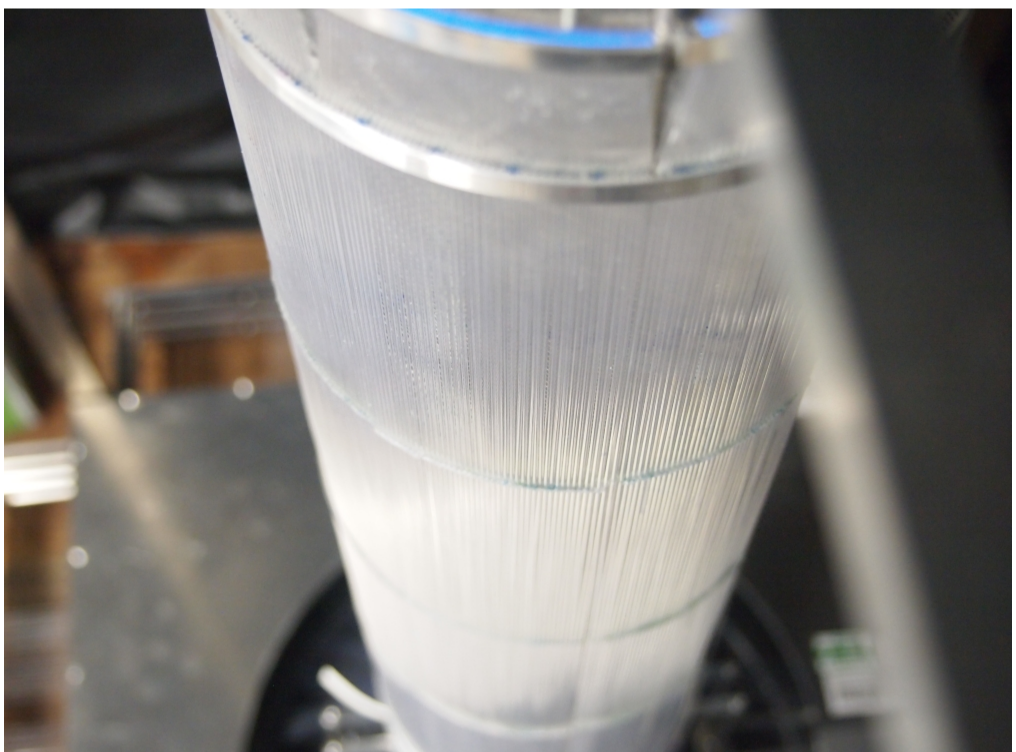
Preparation status - CFT -

CFT consists of the straight layer (Φ layer) and the spiral layer (uv layer) using Kuraray SCSF-78MJ with diameter of 0.75 mm.

Straight layer

Spiral layer

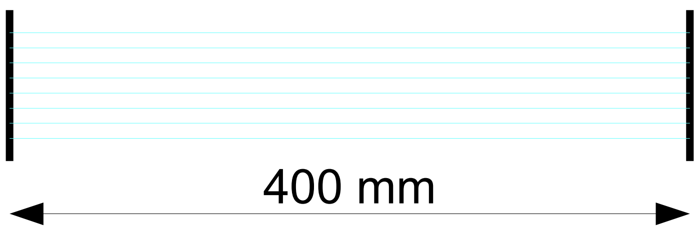


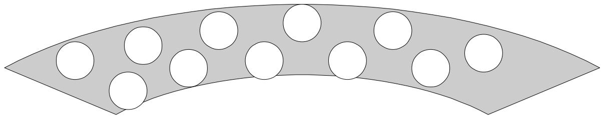


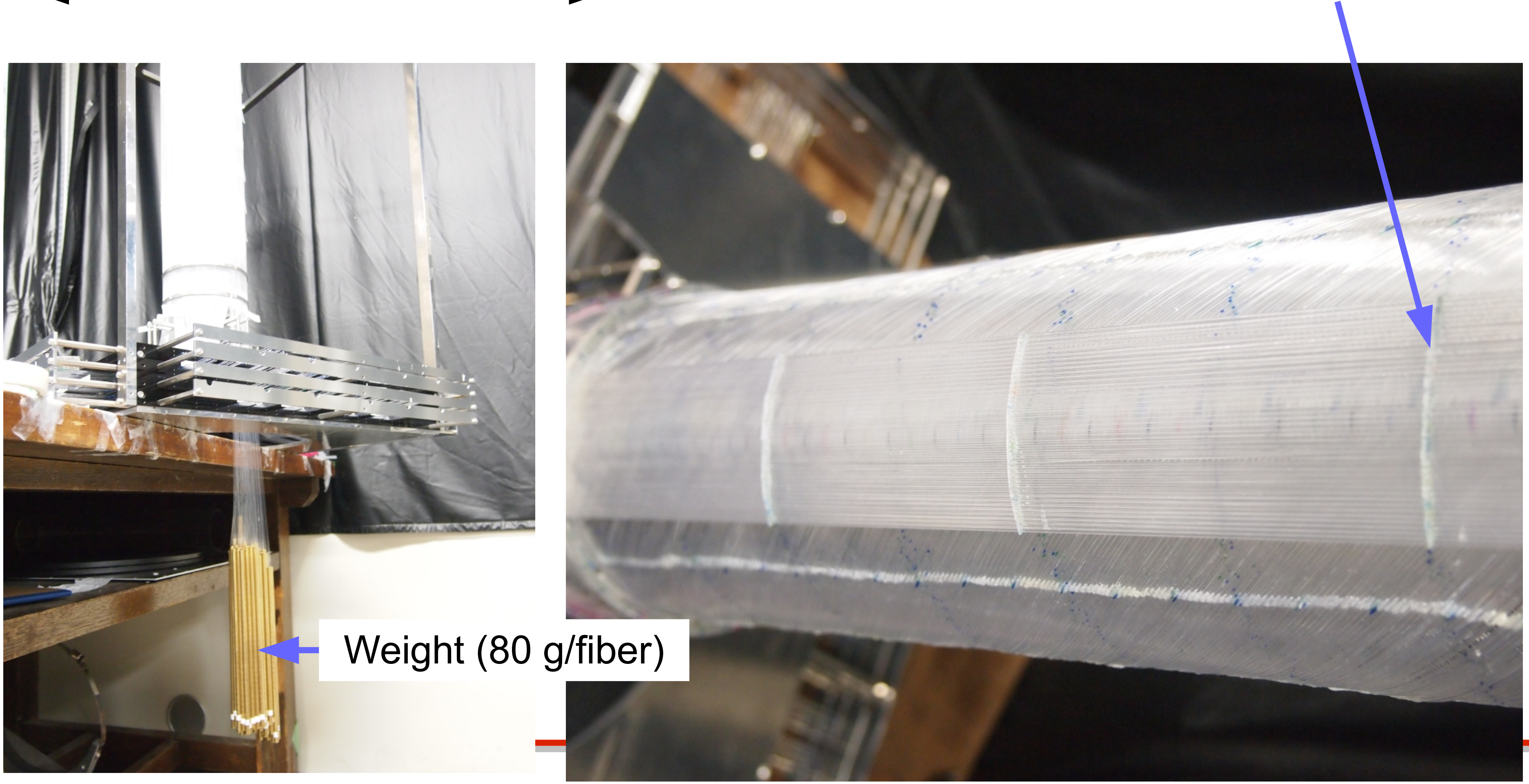
Preparation status - CFT -

CFT consists of the straight layer (Φ layer) and the spiral layer (uv layer) using Kuraray SCSF-78MJ with diameter of 0.75 mm.

Straight layer



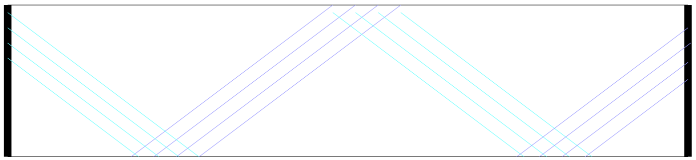


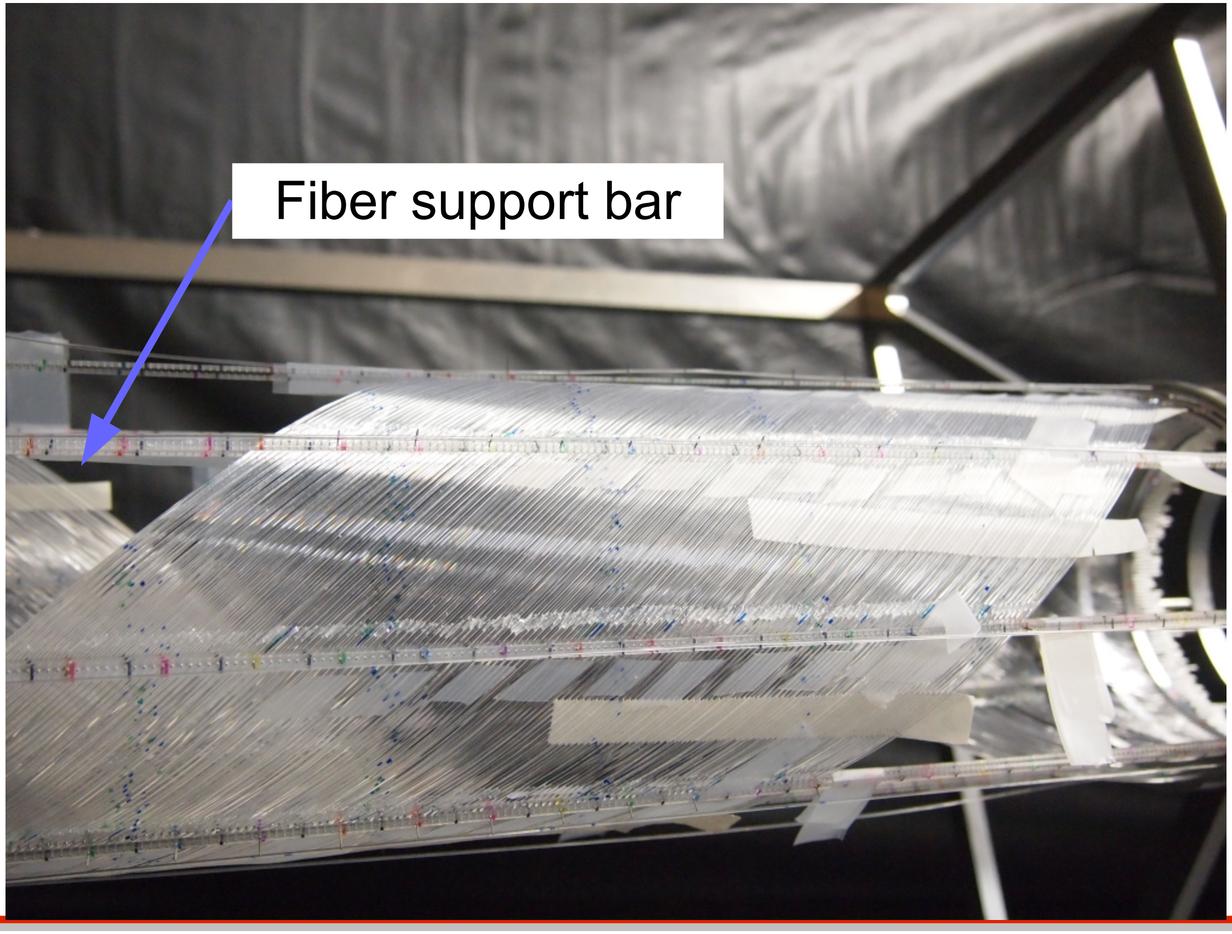


Preparation status - CFT -

CFT consists of the straight layer (Φ layer) and the spiral layer (uv layer) using Kuraray SCSF-78MJ with diameter of 0.75 mm.

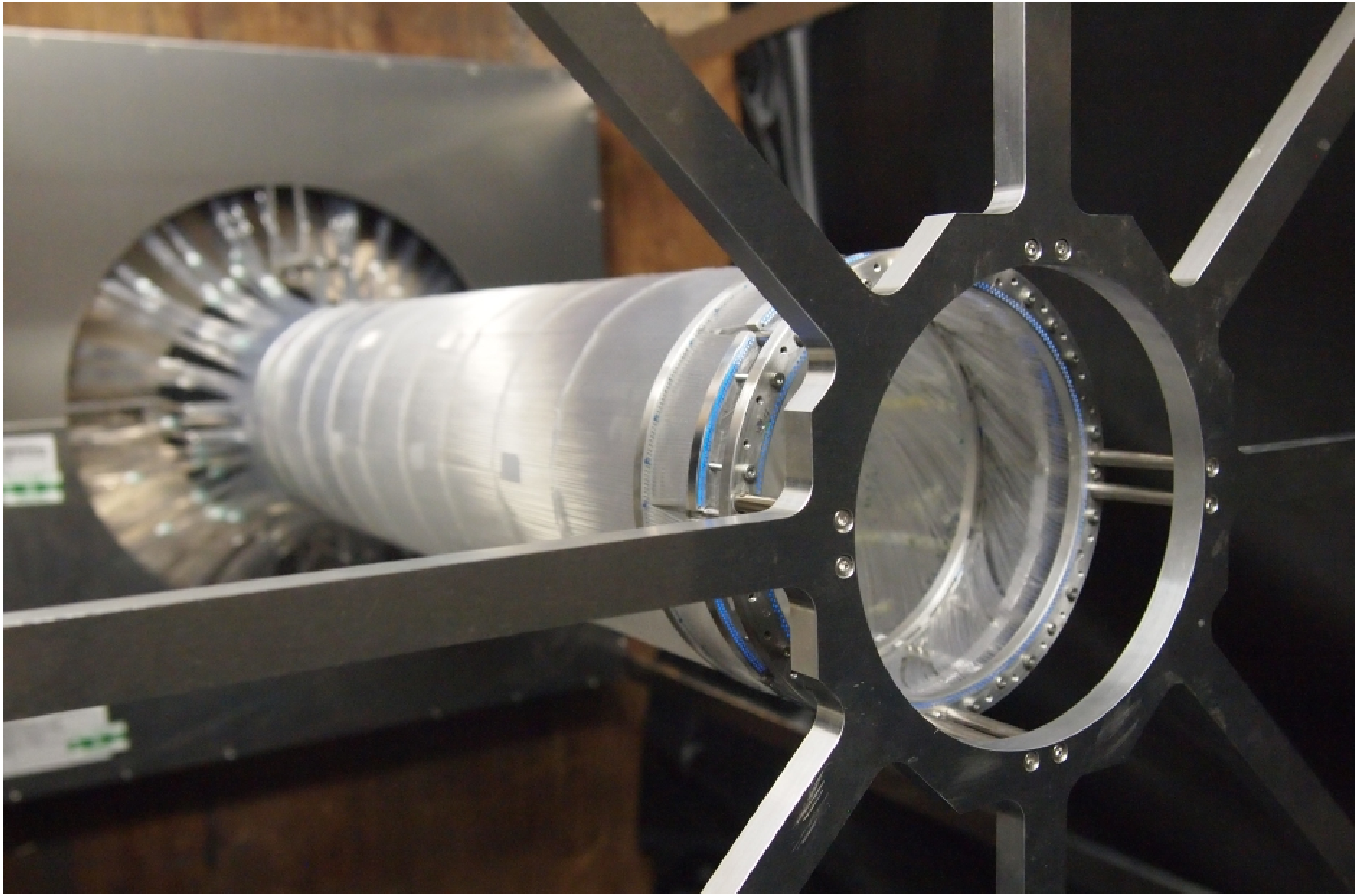
Spiral layer





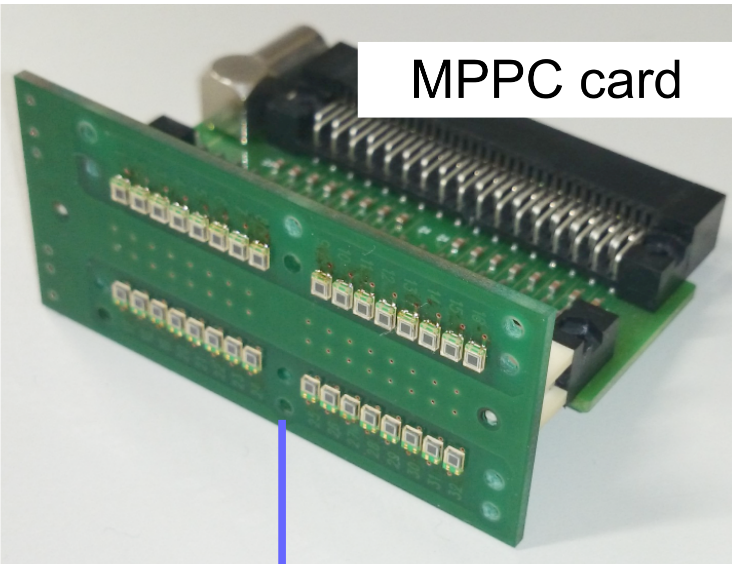
Preparation status - CFT -

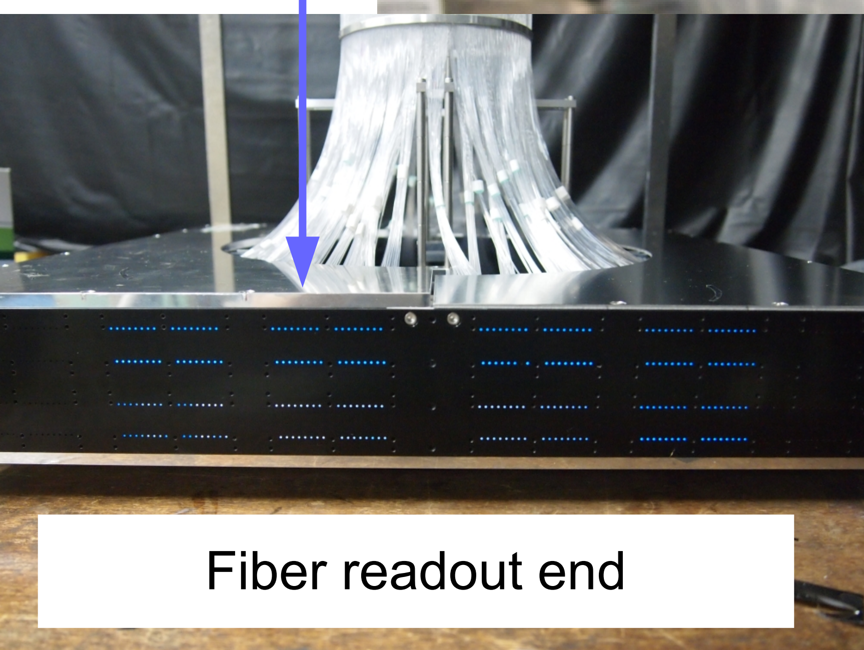
CFT consists of the straight layer (Φ layer) and the spiral layer (uv layer) using Kuraray SCSF-78MJ with diameter of 0.75 mm.

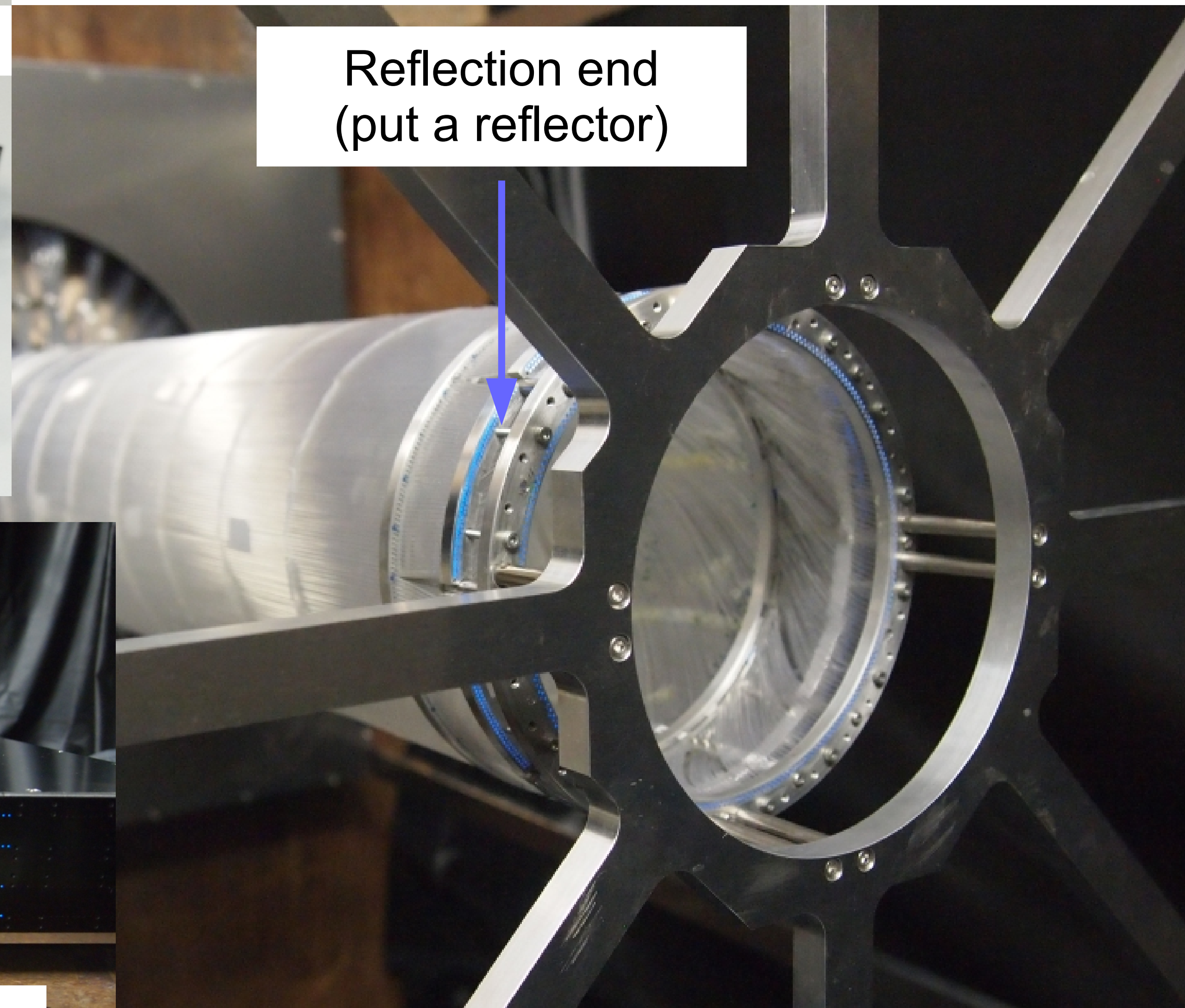


Preparation status - CFT -

CFT consists of the straight layer (Φ layer) and the spiral layer (uv layer) using Kuraray SCSF-78MJ with diameter of 0.75 mm.

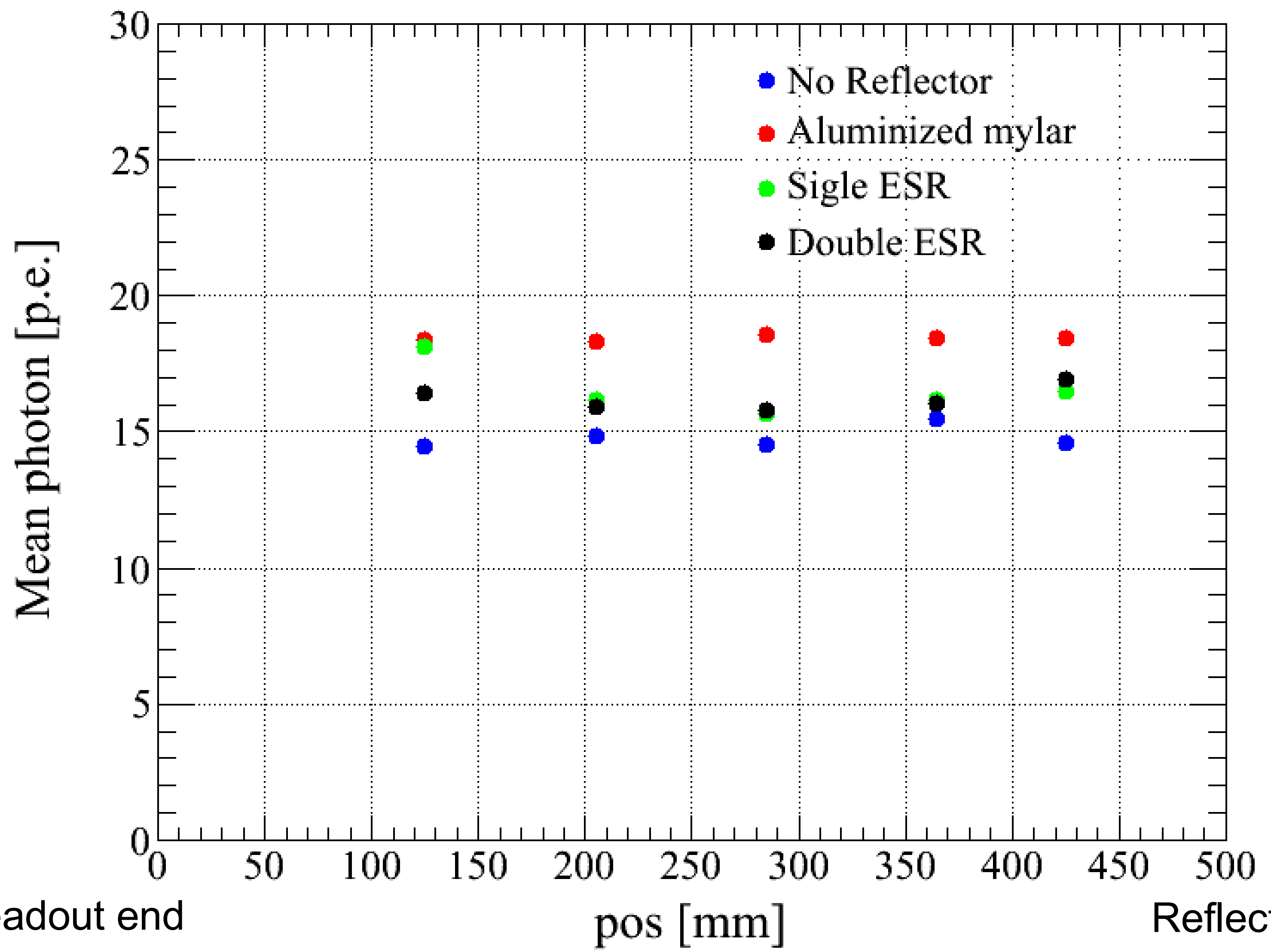






Preparation status - CFT -

The position dependence of the light yield for β ray
with several reflection materials.



Readout end

Reflection end

Preparation status - CFT -

Summary of CFT

- 2/8 layers were constructed.
  - One straight layer
  - One spiral layer

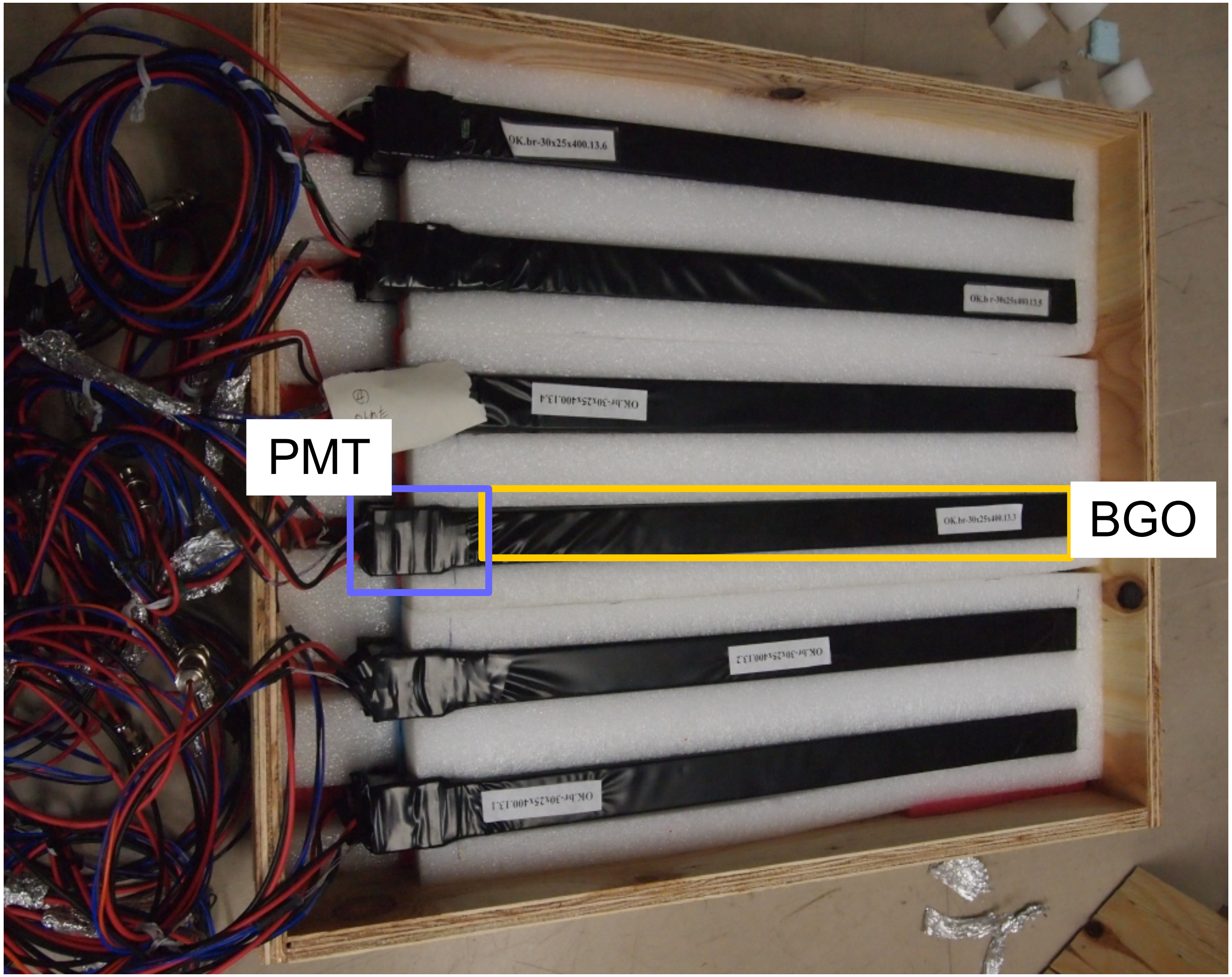
- The light yield and its uniformity is best when using aluminized mylar as a reflector.

- We are preparing the setup for the test beam in Tohoku.

Preparation status
(BGO calorimeter)

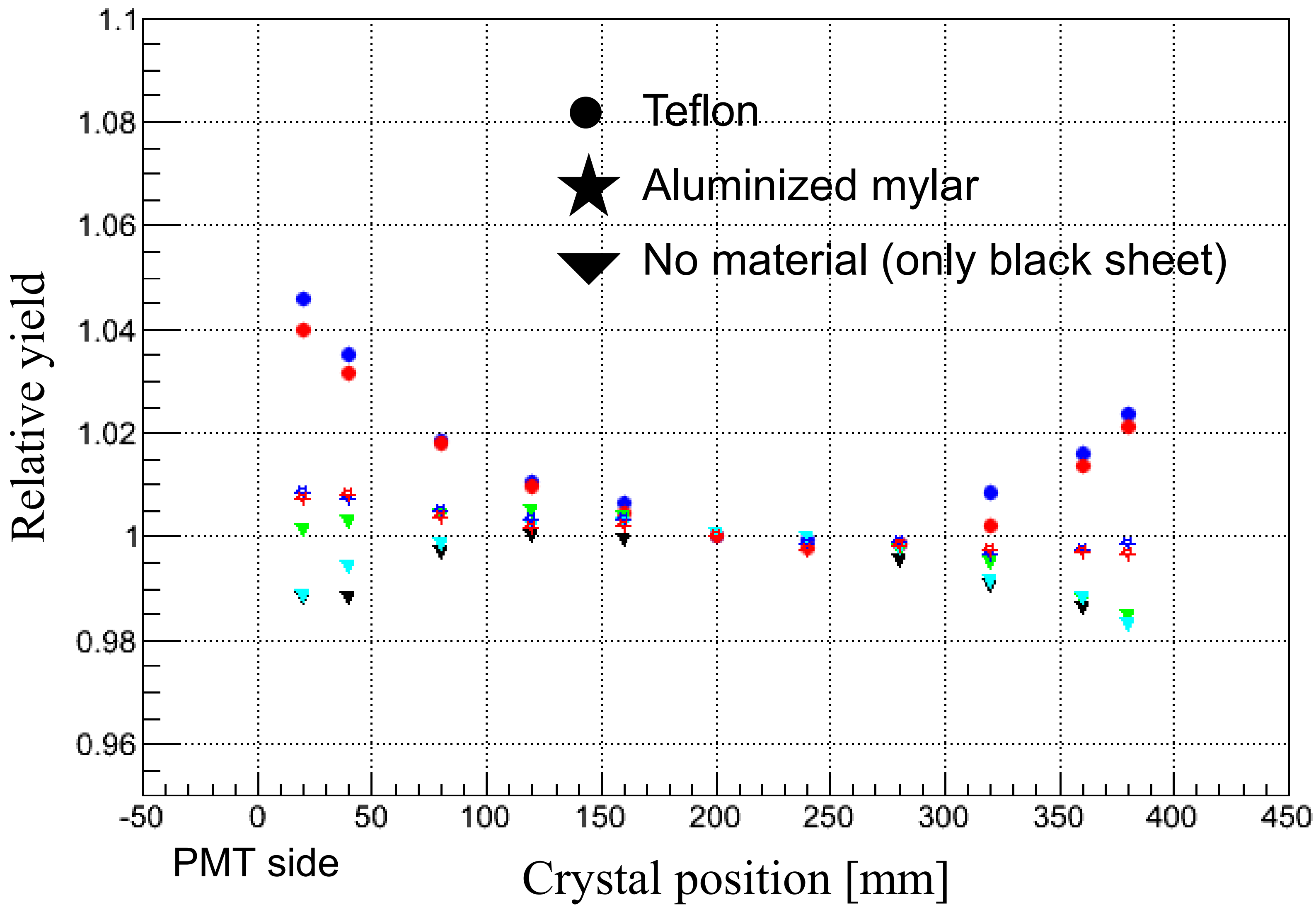
Preparation status – BGO calorimeter -

All the BGO crystals were already wrapped by single aluminized mylar.



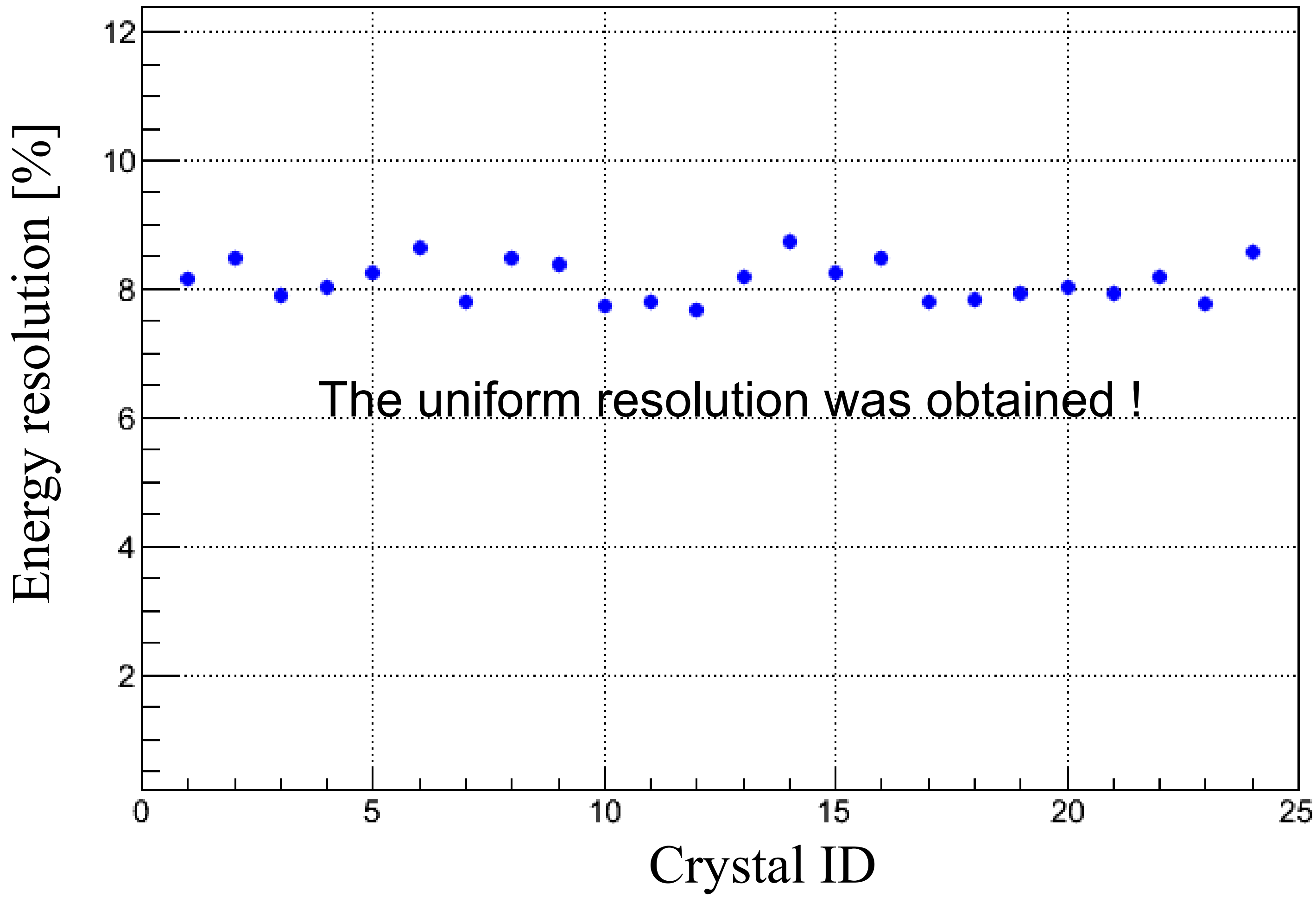
Preparation status – BGO calorimeter -

The position dependence of the light yield for γ ray (661 keV) with several wrapping materials.



Preparation status – BGO calorimeter -

The crystal dependence of the energy resolution for γ ray (661 keV) with aluminized mylar.



In addition, the energy resolution for proton @ 80 MeV was 1 %.
(Satisfy the requirement.)

Preparation status – BGO calorimeter -

Summary of BGO calorimeter

- All the crystals were wrapped with aluminized mylar.
- The energy resolution was
  - 8% @ 661 keV γ ray
  - 1% @ 80 MeV proton
- No crystal dependence of the resolution.

Preparation status
(VME-EASIROC)

Preparation status – VME-EASIROC -

TOHOKU UNIVERSITY

The electronics dedicated for the multi-MPPC readout using EASIROC.

EASIROC

An ASIC dedicated to read multi-MPPC
Front-end analog part of the board.

- 32 ch input/chip
- Double gain
- AMP
- Shaper
- Discriminator
- Slow control

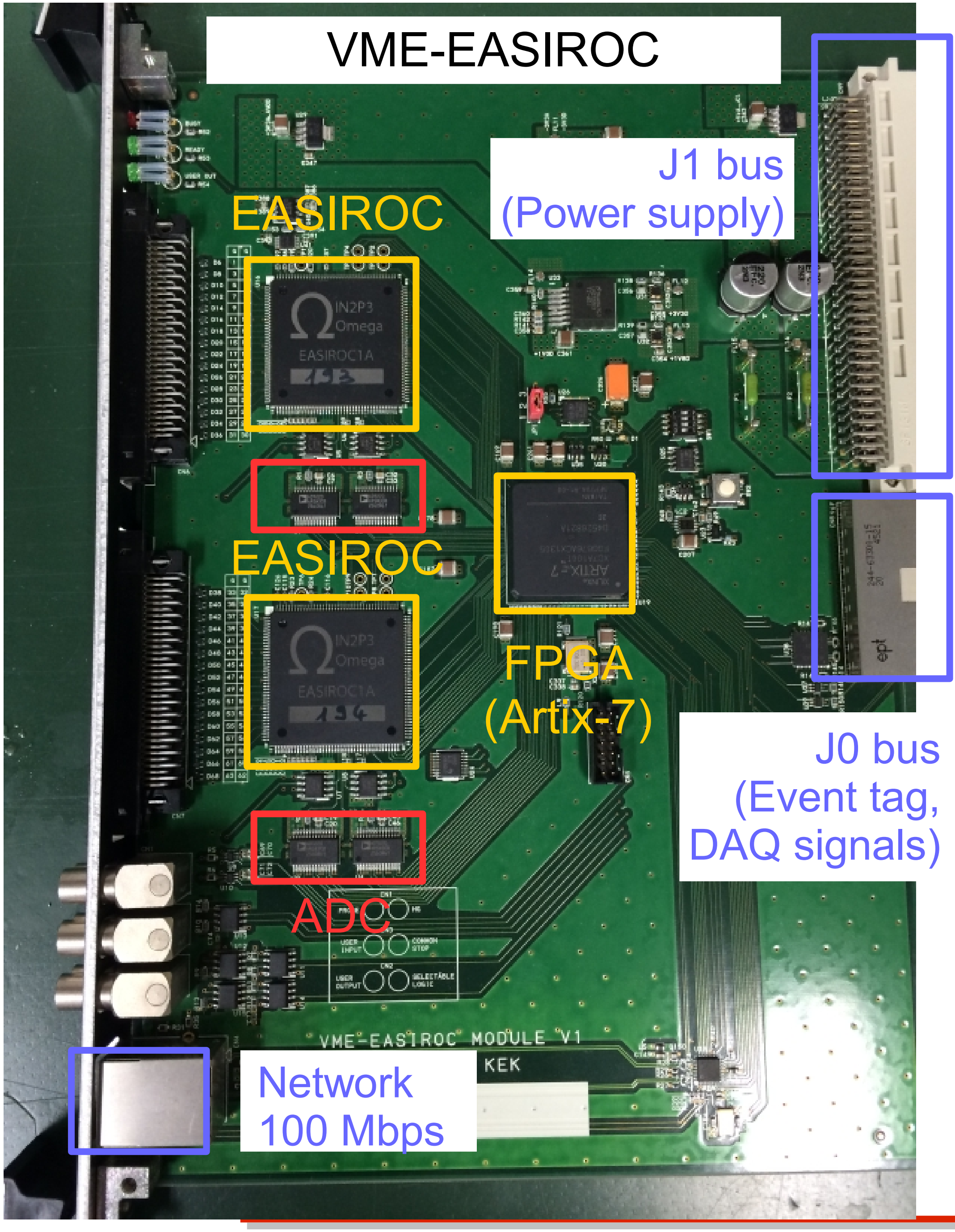
EASIROC electronics series

EASIROC evaluation board
(Developed by Open-It, Tohoku)

→ NIM-EASIROC
(Developed by Open-It, Osaka)

→ VME-EASIROC
(Developed by Open-It, Tohoku)

Preparation status – VME-EASIROC -



Specification

- 64 ch input/board
- ADC
  - Pulse height hold type
  - (Fast clear)
- MHTDC in FPGA
  - LSB = 1 ns
  - leading/trailing
  - Time window = 1 us
  - (Fast clear)
- DAQ
  - 100 Mbps SiTCP
  - Total dead time = 20 us
  - All DAQ signals and event tag are distributed from J0

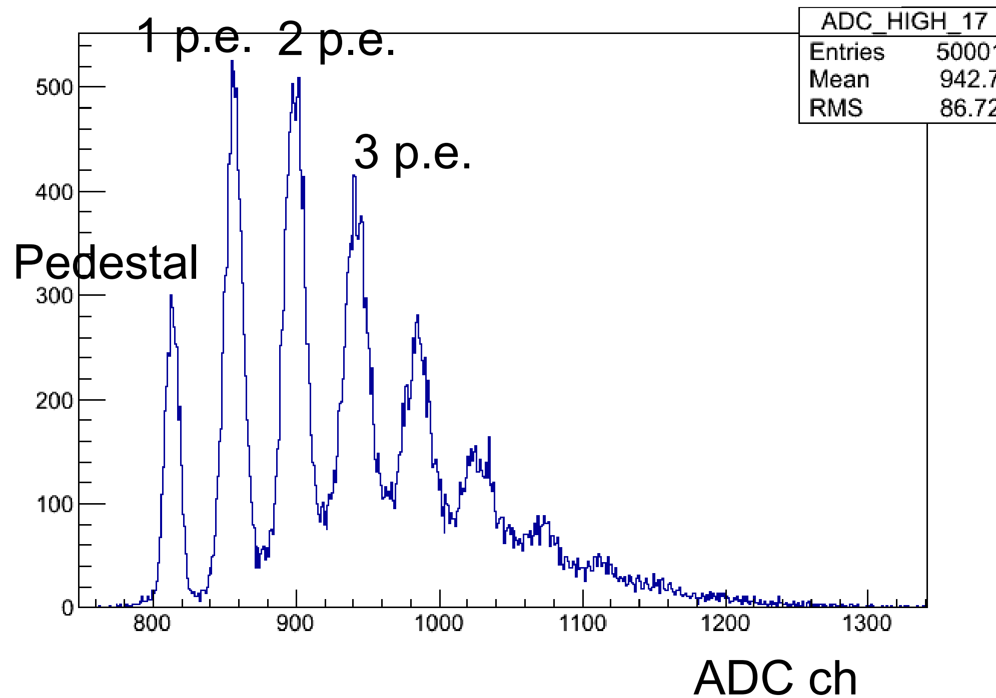
Preparation status – VME-EASIROC -

TOHOKU UNIVERSITY

Demonstration

Analog signal of MPPC
(Held at the peak position)

ADC distribution of MPPC
for LED light



MHTDC was also already implemented and worded well.

Preparation status – BGO calorimeter -

TOHOKU UNIVERSITY

Summary of VME-EASIROC

- 64 ch input Multi-MPPC readout electronics with EASIROC
- ADC/MHTDC on board
- Netword interface (100 Mbps TCP)
- Total dead time is 20 us.

To Do

CFT

- The test experiment in Tohoku using layers already constructed is planned for the performance evaluation.
- We will construct other layers of CFT in this fiscal year.

BGO calorimeter

- The waveform readout is under the development.

VME-EASIROC

- Mass production in this fiscal year.
- Implement fast clear.

Summary

- The J-PARC E40 experiment aims to measure the differential cross sections of Σp elastic and $\Sigma p \rightarrow \Lambda N$ inelastic scatterings.
  - Probe the repulsive force between $\Sigma^{-}n$ channel in the neutron star through the $\Sigma^{+}p$ scattering.

- The proton detection system comprised of CFT, BGO calorimeter, and VME-EASIROC is an essential detector system in E40 to identify the Σp scattering.

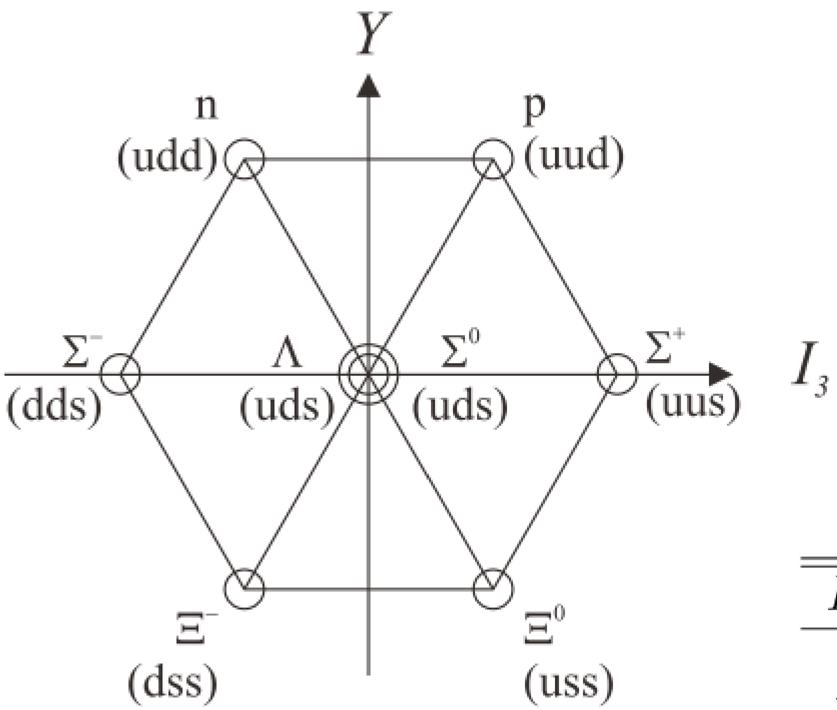
- For CFT, 2/8 layers (a straight layer and a spiral layer) were constructed.
  - The position dependence of the light yield was the most uniform when putting a aluminized mylar as a reflector.

- The 24 BGO crystals were wrapped by single aluminized mylar.
  - Its energy resolution were 1% for 80 MeV proton and 8% for 661 keV γ ray.

- VME-EASIROC was developed and its firmware including MHTDC was implemented.

Backup

Baryon-Baryon interaction in the flavor SU(3) symmetry.



Baryon octet with spin ½ in the $SU_f(3)$ symmetry.

The interaction between baryon octet is labeled by irreducible representations.

$$(11) \otimes (11) = (22) \oplus (11)_s \oplus (00) \oplus (03) \oplus (30) \oplus (11)_a .$$

flavor symmetric — flavor anti-symmetric

NN, ΛN, and ΣN potential using irreducible representation.

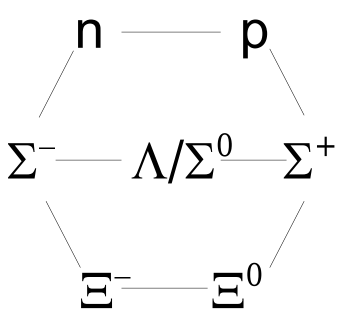
$BB(t)$	flavor symmetric	flavor anti-symmetric
$NN(t=0)$	-	(03)
$NN(t=1)$	(22)	-
$\Lambda N(t=1/2)$	$\frac{1}{\sqrt{10}}((11)_s + 3(22))$	$\frac{1}{\sqrt{2}}(-(11)_a + (03))$
$\Sigma N(t=1/2)$	$\frac{1}{\sqrt{10}}(3(11)_s - (22))$	$\frac{1}{\sqrt{2}}((11)_a + (03))$
$\Sigma N(t=3/2)$	(22)	(30)

Repulsive force originated from the Pauli principle in the quark level.

[M. Oka, et al., PTPS 137(2000)1.]

Introduction -Baryon-baryon interaction in SU(3)-

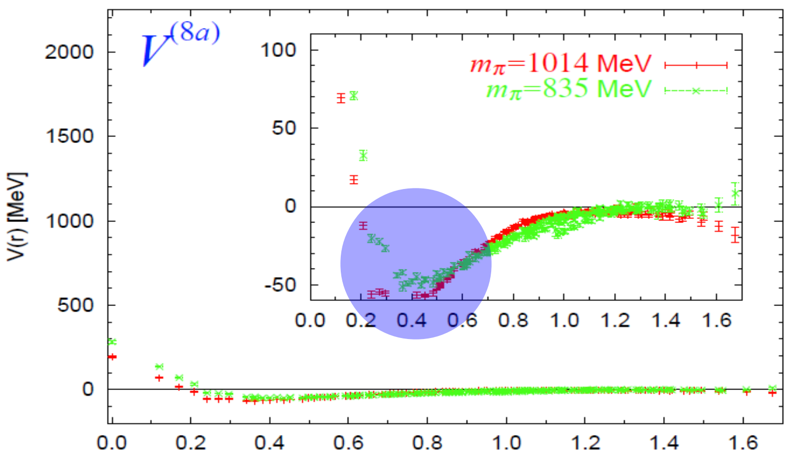
Baryon octet

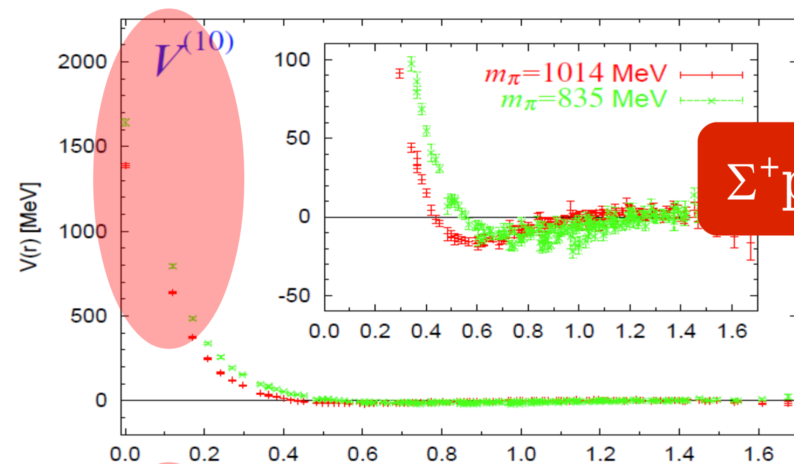


6 independent flavor basis interaction in SU(3) limit

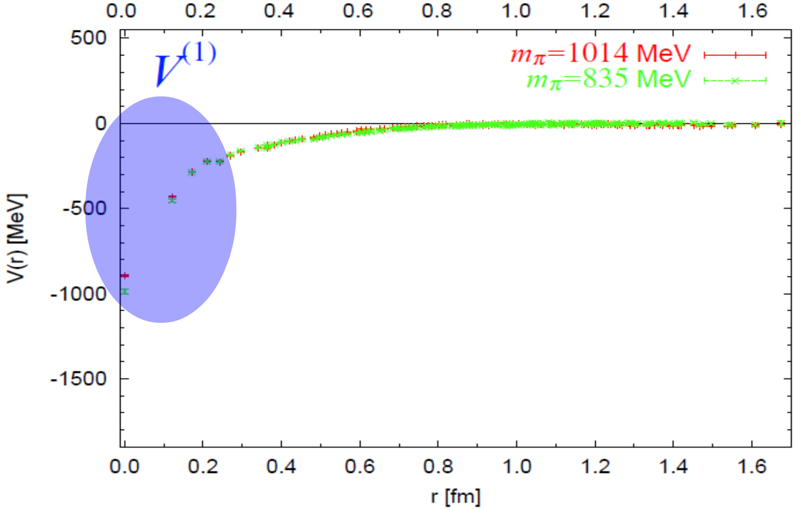
$$8 \otimes 8 = 27 \oplus 10^* \oplus 10 \oplus 8_s \oplus 8_a \oplus 1$$

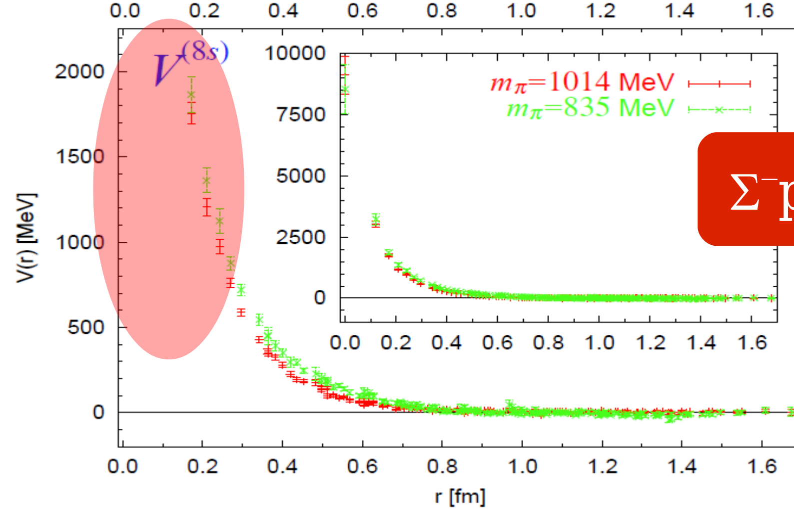
Lattice QCD, T. Inoue et al.
arXiv:1007:3559 [hep-lat]





$\Sigma^+ p$ $(S = 1, I = 3/2)$





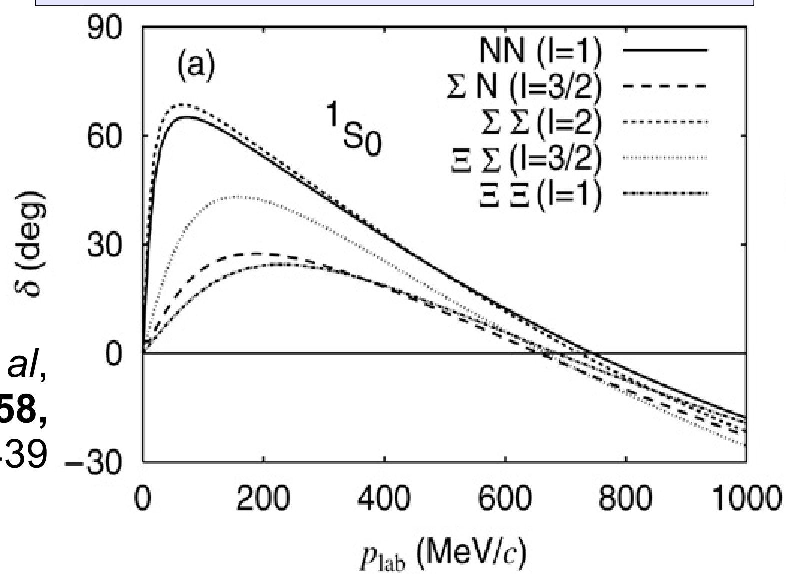
$\Sigma^- p$ $(S = 0, I = 1/2)$

J-PARC E40 -Physics motivation of E40-

ΣN (I = 3/2)	Spin Singlet ($^1S_0$)	Spin Triplet ($^3S_1$)
Σ^+p	**27** (same as NN (I = 1))	**10** (almost Pauli forbidden)

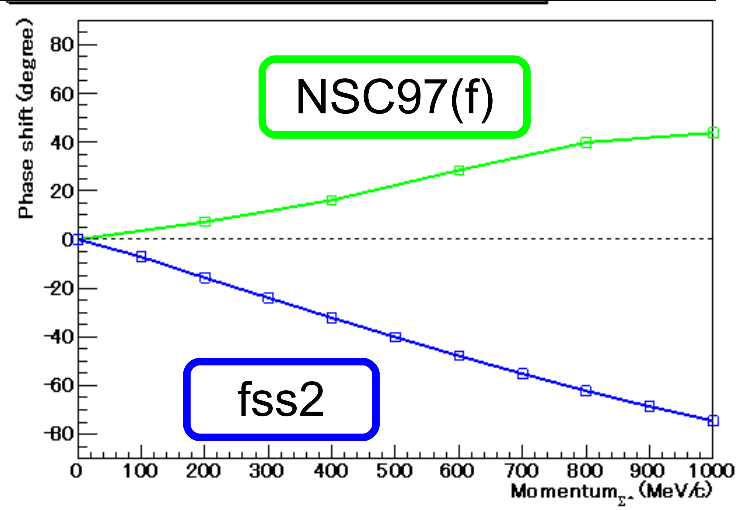
In SU(3) limit.

Phase shift of $^1S_0$ for **27** component



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

Phase shift of $^3S_1$ for Σ^+p scattering



Thanks to SU(3) symmetry, behavior of $^1S_0$ for Σ^+p is similar to NN interaction.

Storngly repulsive with quark picture.

TOHOKU UNIVERSITY

The method to obtain phase shift without phase-shift analysis.

→ Extract contribution from S-wave

→ $^{1}S_{0}$ state can be ignored

$$\frac{d\sigma}{d\Omega} = \frac{1}{k^2}\left|\sum_{l=0}^{\infty}(2l+1)e^{i\delta_l}\sin^2(\delta_l)P_l(\cos(\theta))\right|^2$$

$P_l(0) = 0$, for $l = 1,3,...$

→ S-wave is extracted

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

$^{1}S_{0}$ channel — $^{3}S_{1}$ channel

→ $^{1}S_{0}$ is negligibly small

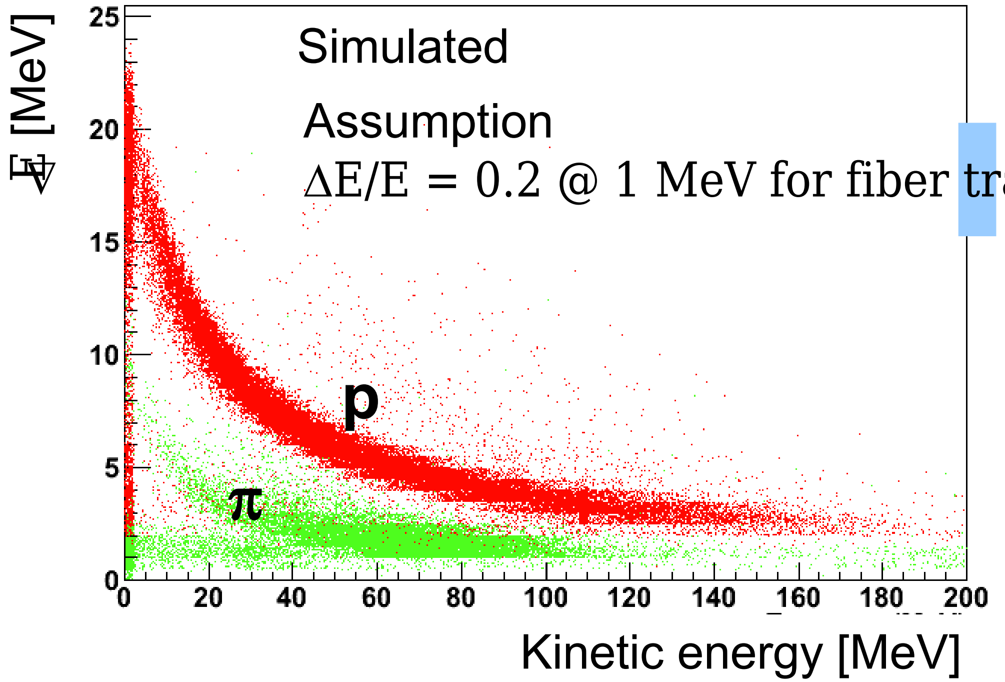
$$\frac{d\sigma}{d\Omega}(90°) \approx \frac{3}{4}\frac{1}{k^2}\sin^2(\delta_{3S1}) + (higher\ \ wave, etc...)$$

$^{3}S_{1}$ channel

Sensitive to $^{3}S_{1}$ channel

J-PARC E40 -Role of proton detection system-

Particle ID



Measurements

- ΔE (energy deposit in a fiber)
- Scattering angle (by tracking)
- Kinetic energy

Requirements

Tracker part

Energy resolution : 20 % @ 1 MeV

Angle resolution : σ = 1 degree

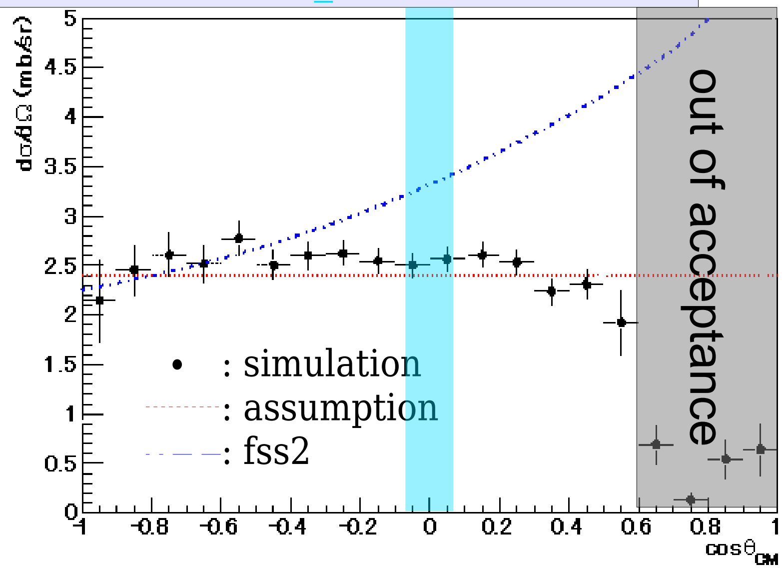
Calorimeter part

Energy resolution : 4 % @ 70 MeV

TOHOKU UNIVERSITY

Expected results

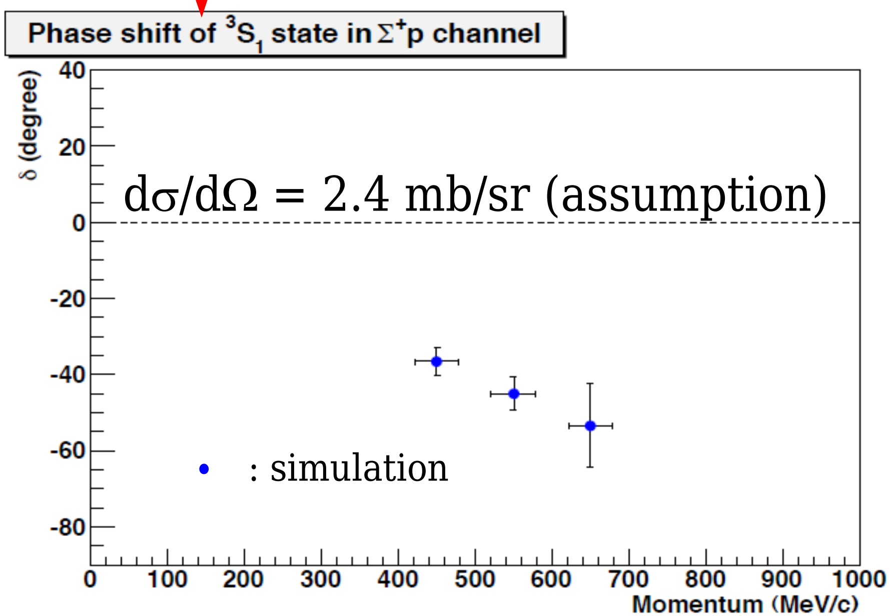
Σ^+p $d\sigma/d\Omega$ (p_Σ = 550 MeV/c)



Extract δ_{3S1} from cross section for various momentum range

$$\frac{3}{4}\frac{1}{k^2}\sin^2(\delta_{3S1}) = \frac{d\sigma}{d\Omega}(90^\circ) - (higher\ \ wave, etc...)$$

Model dependent



Possible to obtain δ_{3S1} with 20 % accuracy including uncertainty of models