Development of a tracking detector system with multichannel scintillation fibers and PPD

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Contents

Introduction

Σp scattering experiment at J-PARC

scintillation fibers and PPD tracker

Test experiment with a prototype fiber detector

- Energy resolution of a scintillation fiber

Development of new readout electronics for multi-MPPC

EASIROC and SiTCP

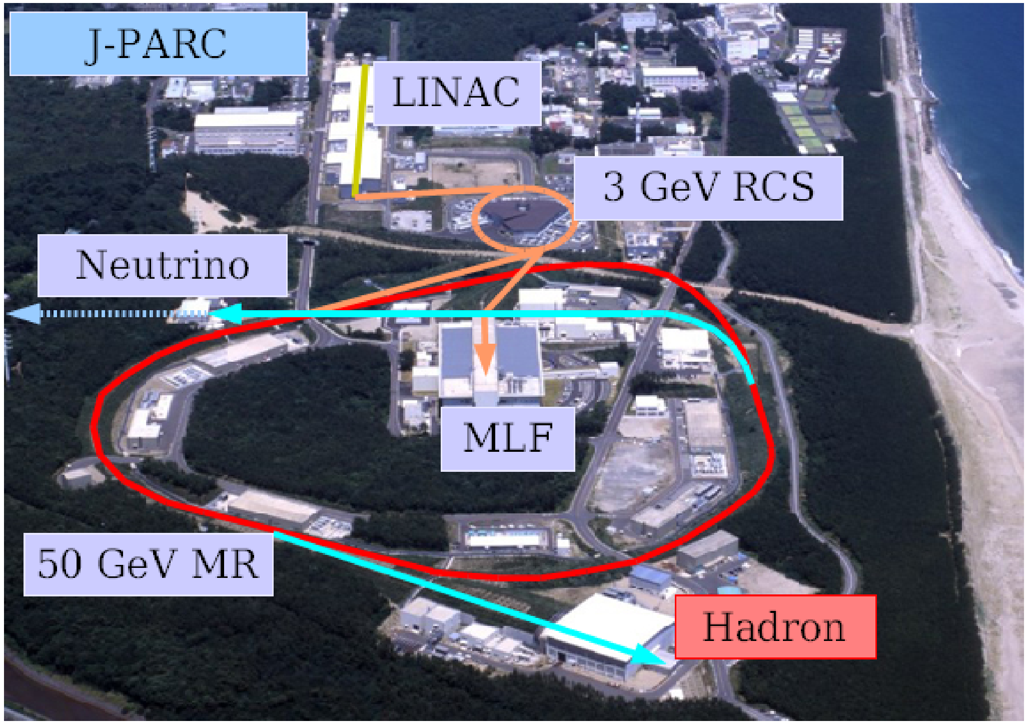
Test measurement with new electronics

- ADC spectrum of a fiber for β ray
- Time resolution of a scintillation fiber

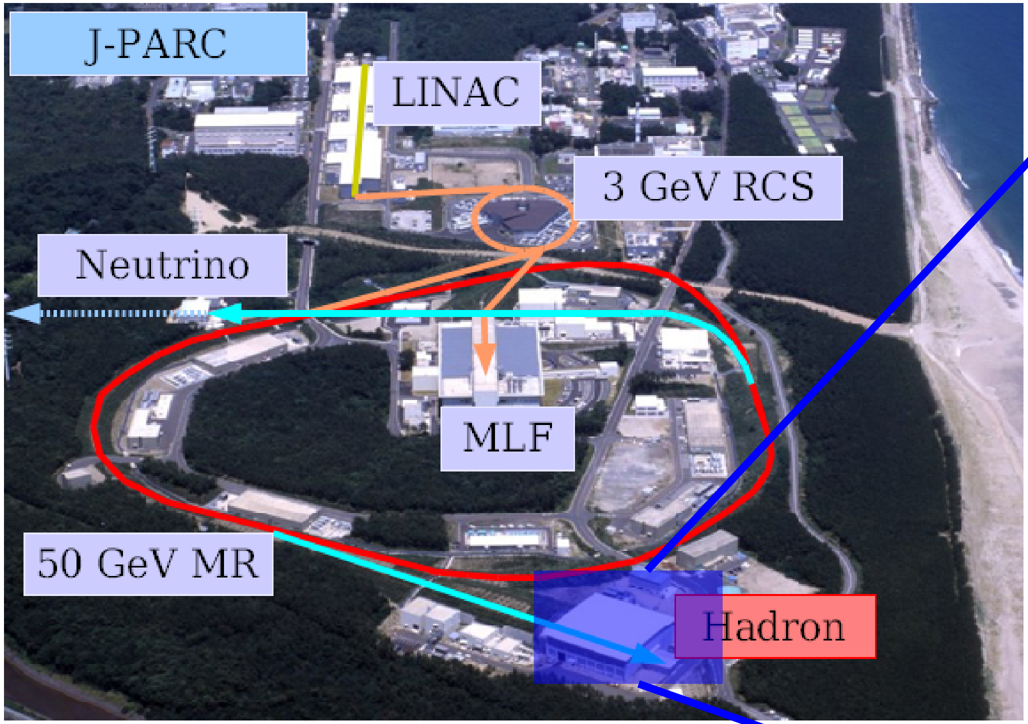
Summary

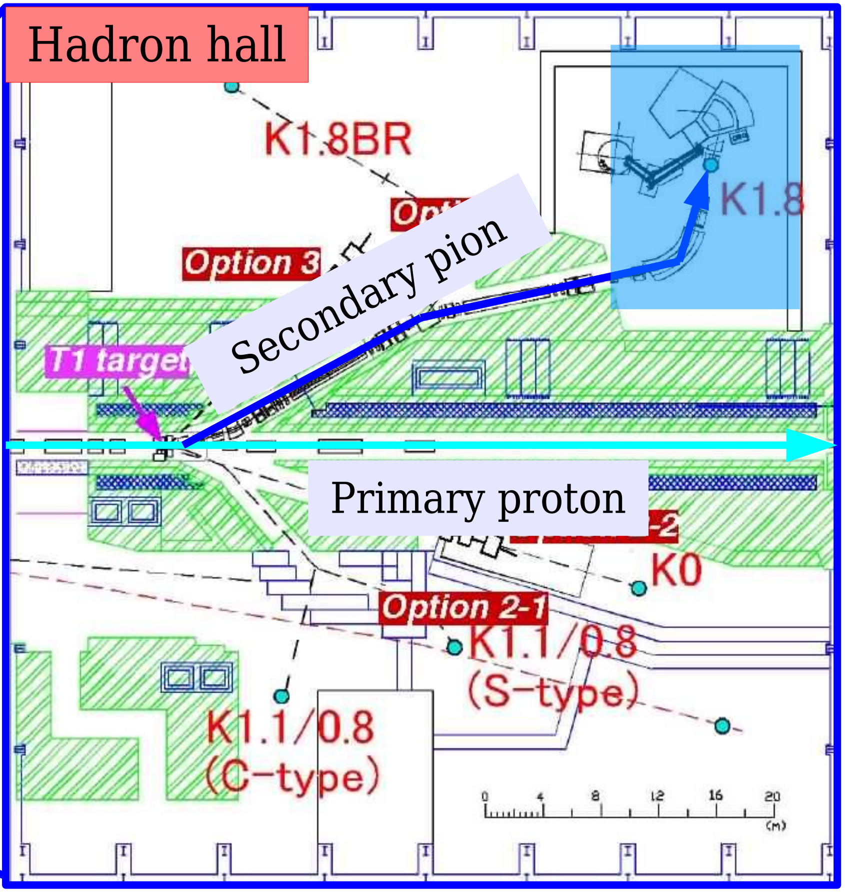
Introduction

A Σp scattering experiment at J-PARC with fiber trackers.



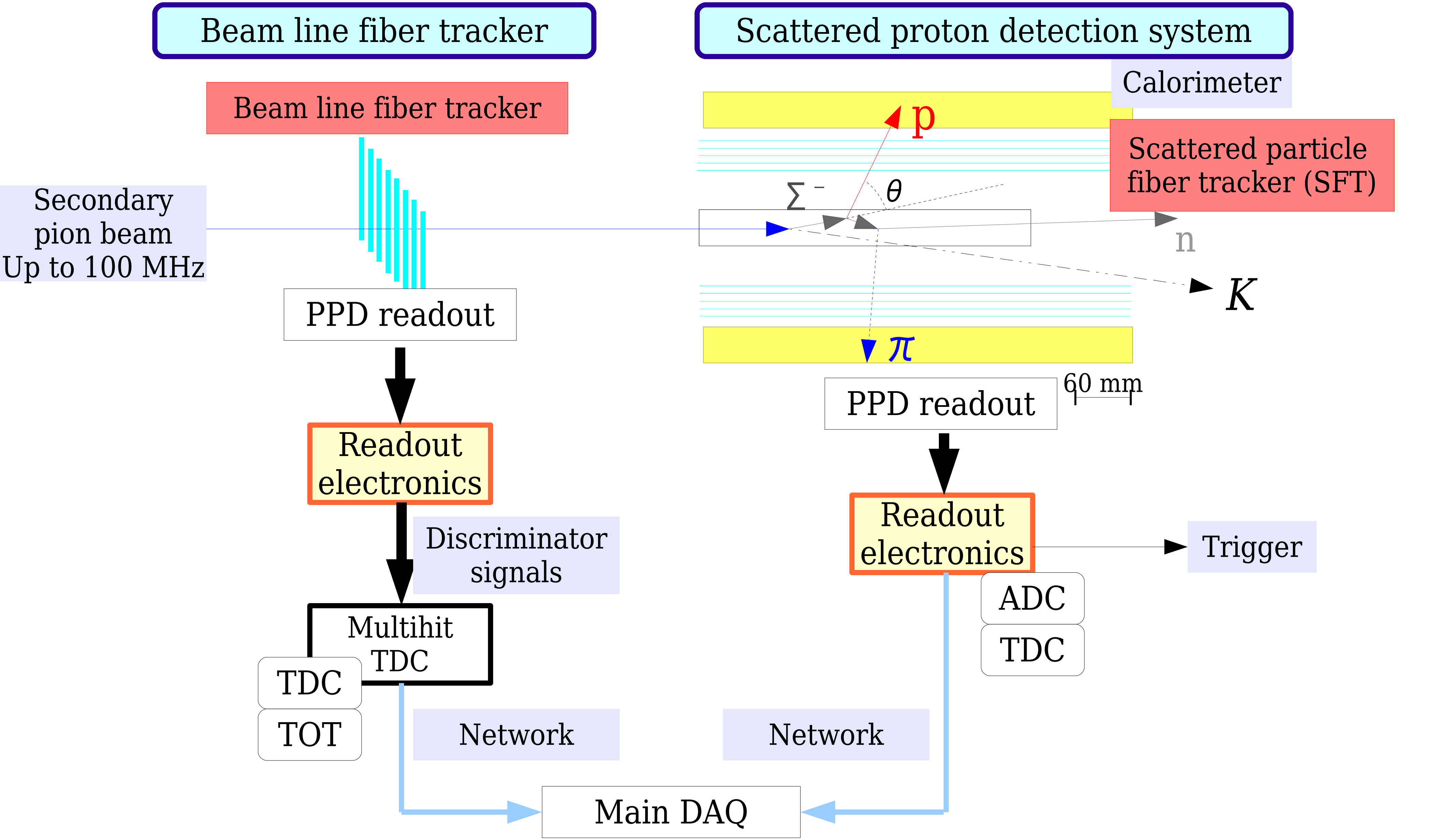
A Σp scattering experiment at J-PARC with fiber trackers.





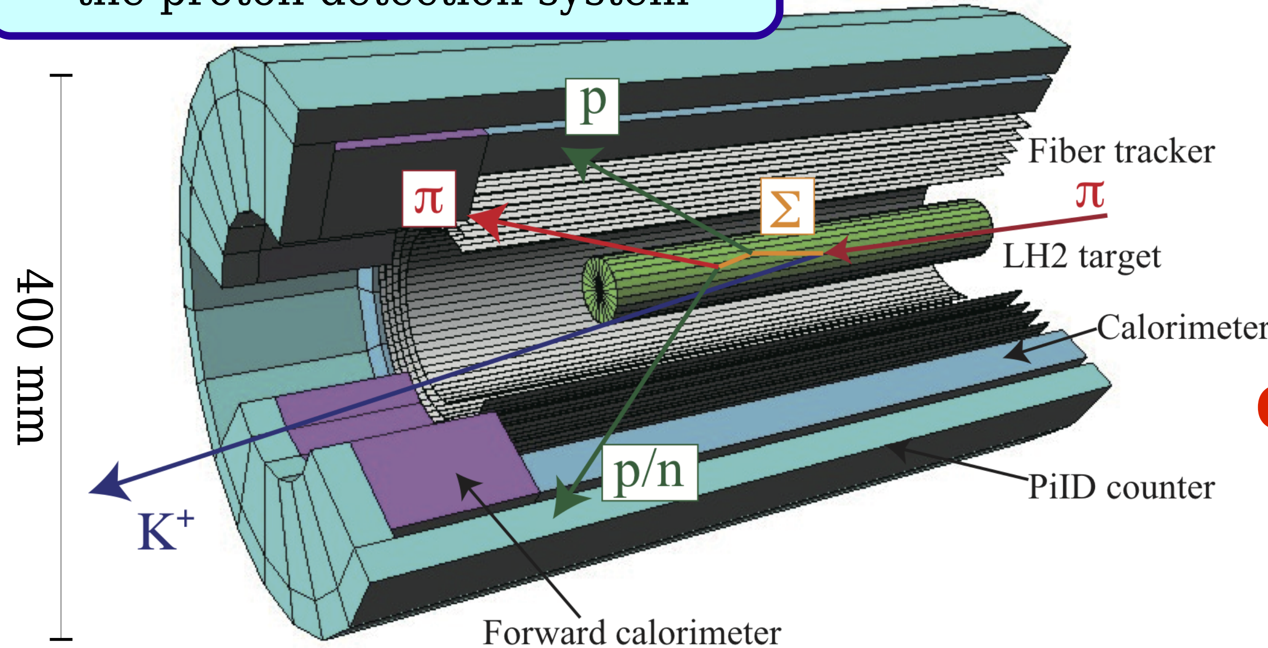
Introduction - a Σp scattering experiment -

A Σp scattering experiment at J-PARC with fiber trackers.



Introduction – MPPC to readout fibers -

Conceptual image of
the proton detection system



Large acceptance

↕

Compact and fine detector

PPD	Gain	Response	Magnet field	Bias voltage	Area
	$\sim 10^6$	Very Fast	**Not Influenced**	Low	**Small**

Possible to construct a very fine and small detector near by a magnet with MPPC.

Introduction – Requirements -

Scattered proton detection system

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

Requirements

Tracker part

Energy resolution	: 20 % @ 1 MeV
Position resolution	: 500 μm
Angle resolution	: σ = 1 degree

Calorimeter part

Energy resolution	: 4 % @ 70 MeV

Beam line fiber tracker

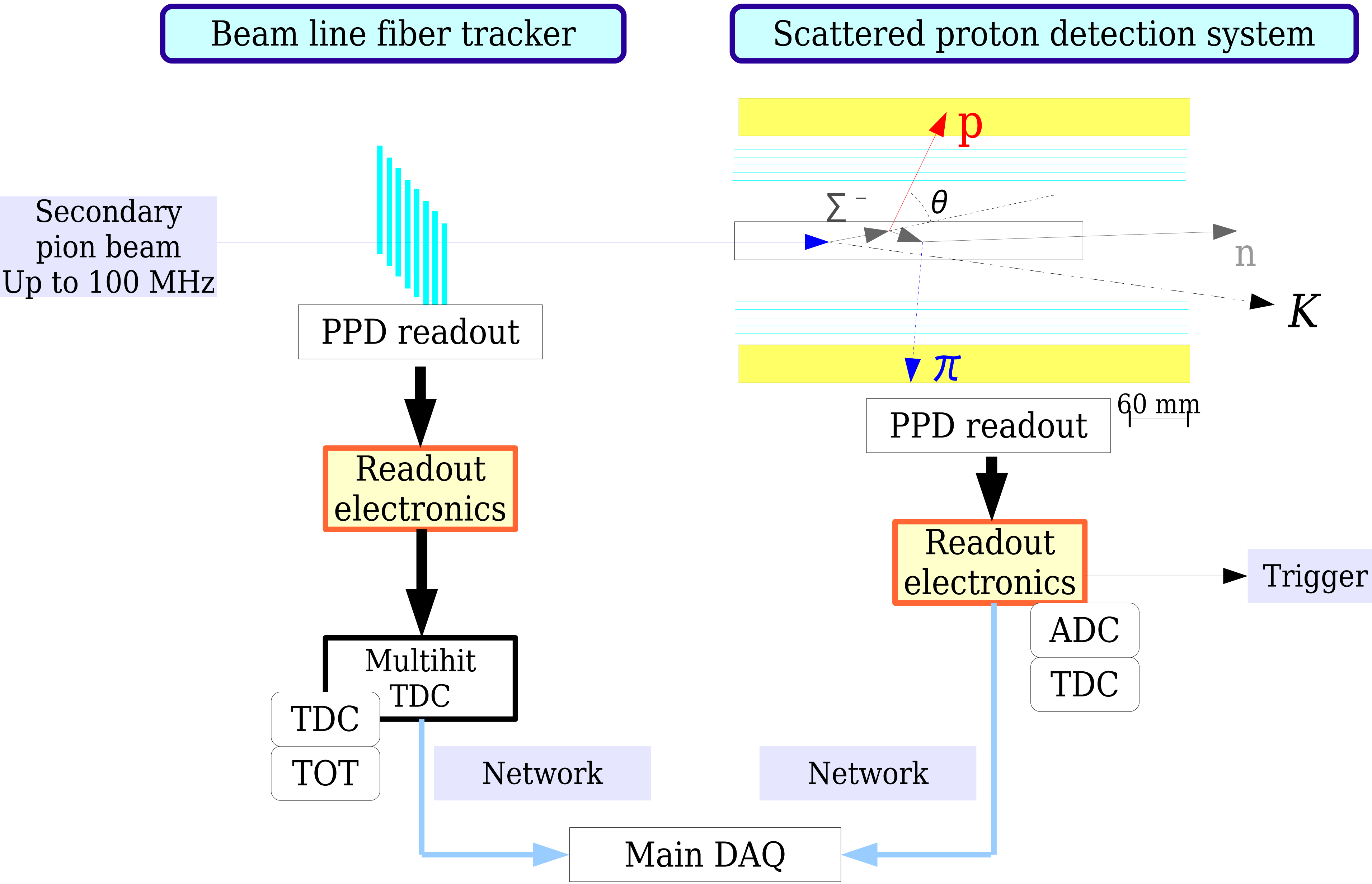
Measurements
- Timing
- Position (Horizontal axis)

Requirements

Time resolution	: 0.8 ns
Position resolution	: 1 mm

My contents

A Σp scattering experiment at J-PARC with fiber trackers.



My contents

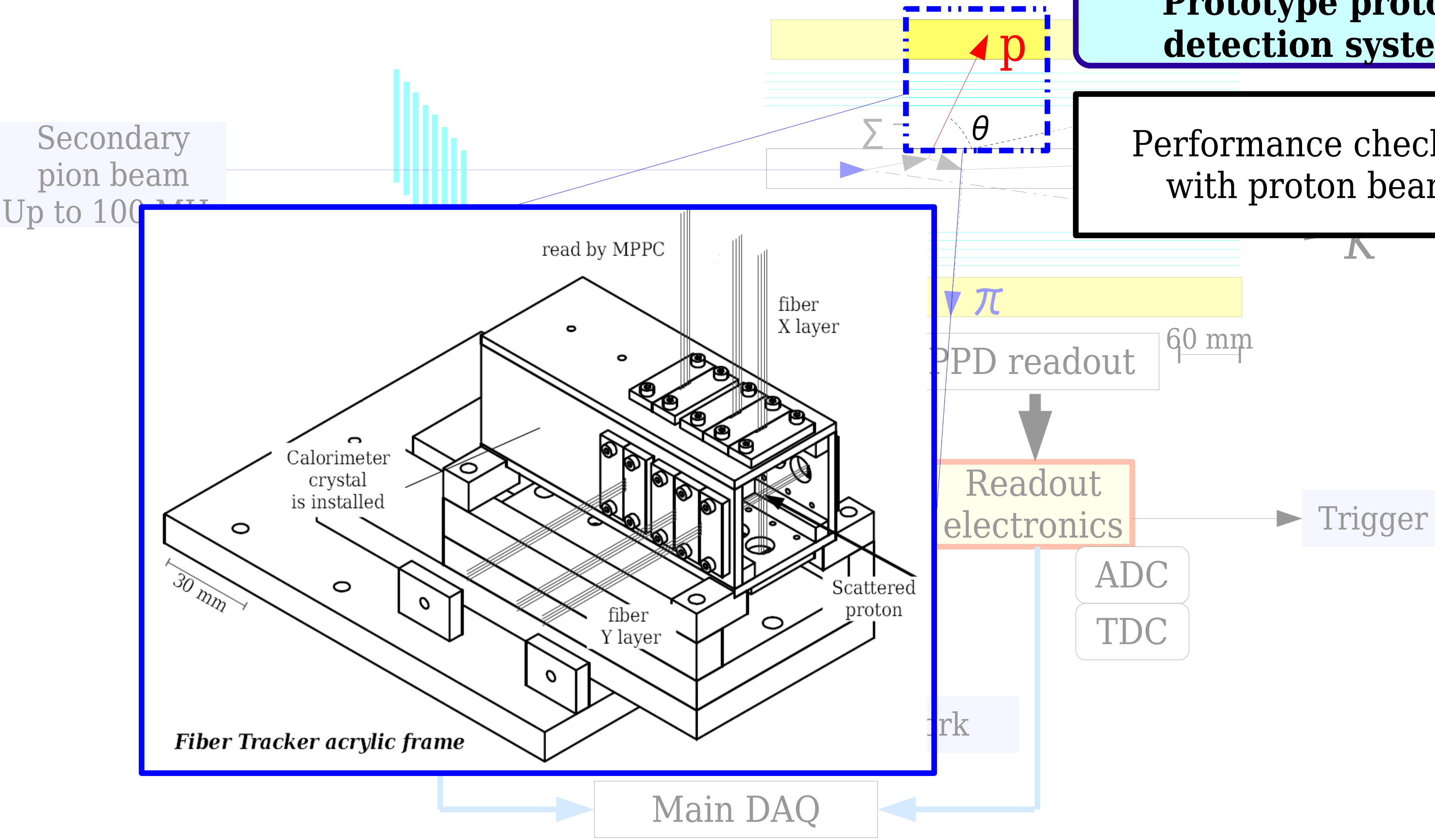
A Σp scattering experiment at J-PARC with **fiber trackers.**

Beam line fiber tracker

Scattered proton detection system

Prototype proton detection system

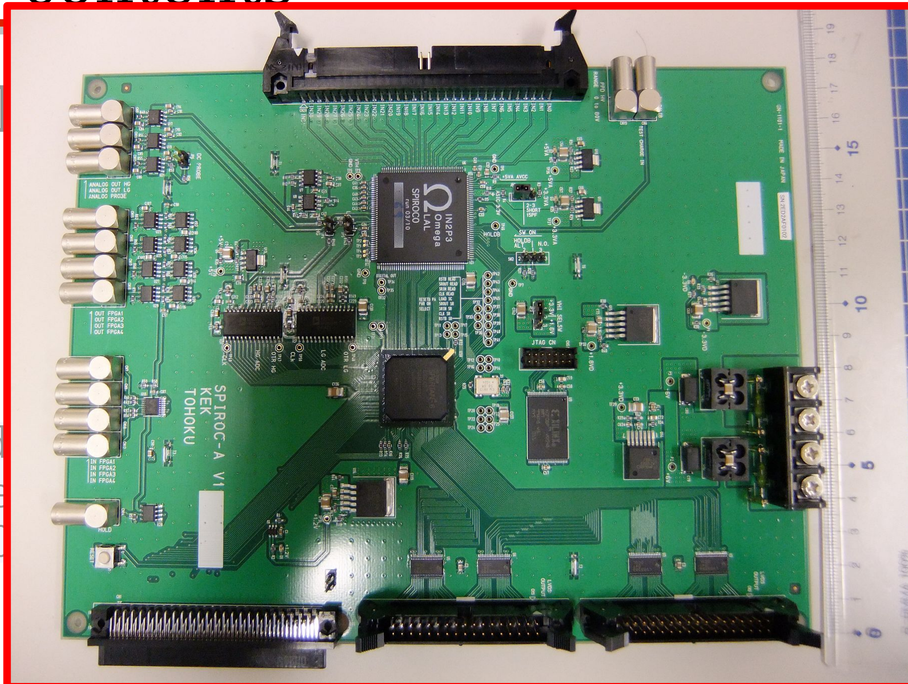
Performance checking with proton beam.



My contents

A Σ[...]-PARC with **fiber trackers.**

[...]cattered proton detection system



Prototype proton detection system

p

θ

Σ

π

K

Performance checking with proton beam.

Second[...]
pion be[...]
Up to 100[...]

PPD read[...]

Readout electronics with EASIROC and SiTCP

Readout electronics

Readout electronics

Trigger

ADC

ADC
Data transfer rate
via TCP/Ethernet

Multihit TDC

TDC

TOT

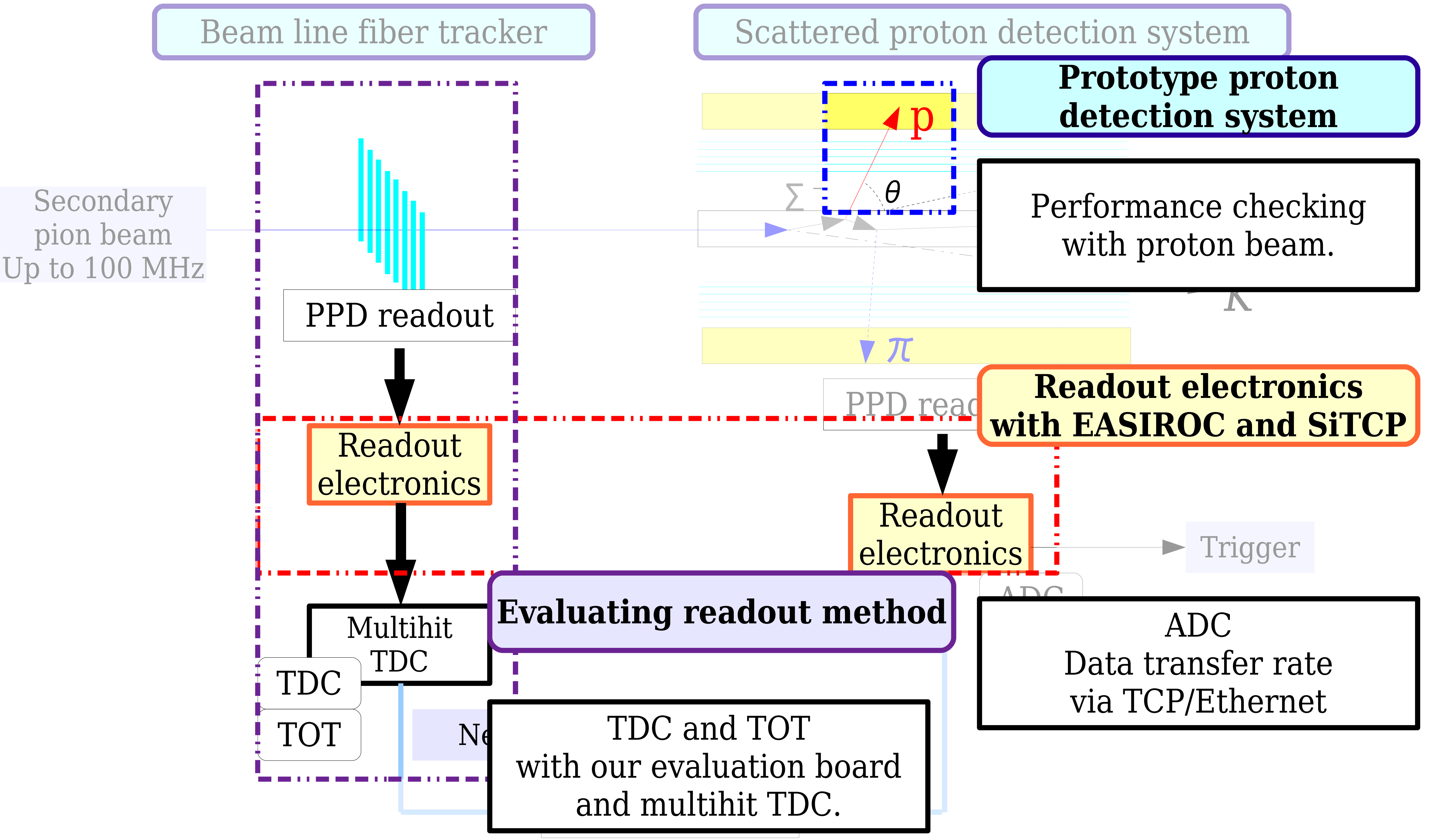
Network

Network

Main DAQ

My contents

A Σp scattering experiment at J-PARC with fiber trackers.



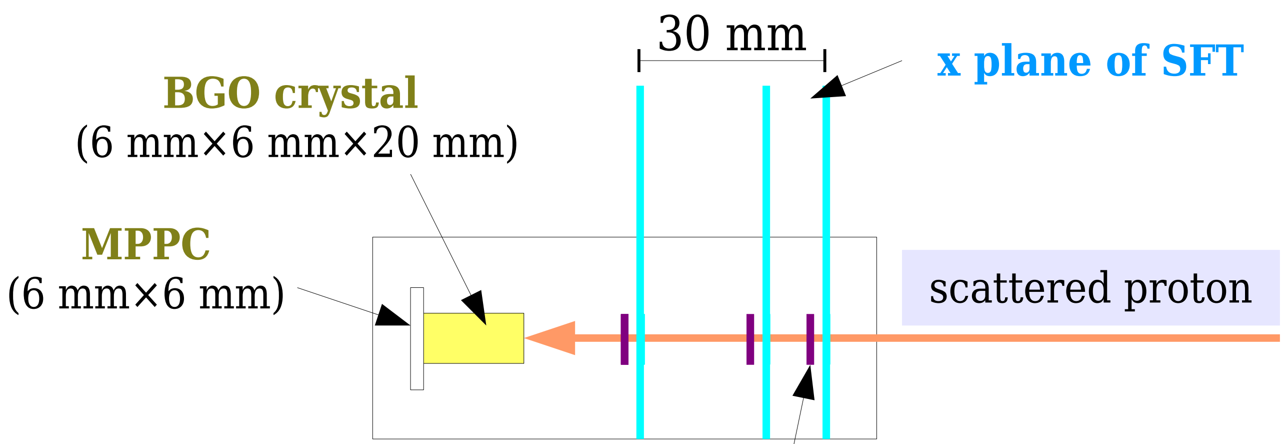
The prototype proton detection system

The prototype proton detection system

Image of the prototype detector

Component of the prototype SFT

- 500 µm square type fiber
  (Kurary SCSF-81, Emission peak 437 nm)
- MPPC 400 pixel (S10362-11-050C)
- Total 6 layers, 24 channels

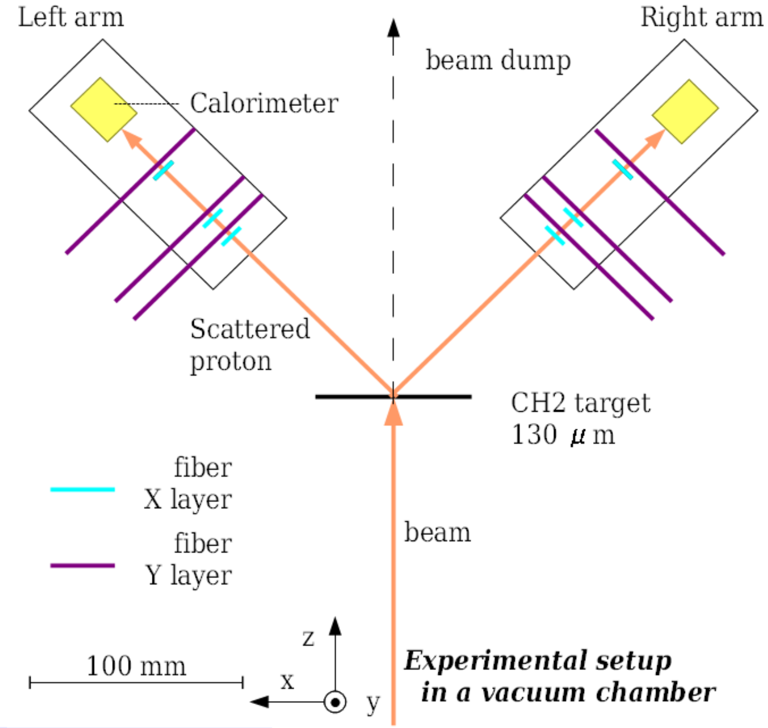


Component of the calorimeter

- BGO crystal (6 mm×6 mm×20 mm)
- MPPC 6 mm×6 mm array type (S10985-025C)

Readout method with NIM, VME modules
PMT AMP (20 times) for MPPC (SFT)
ADC : CAEN v795, charge integrating type VME ADC

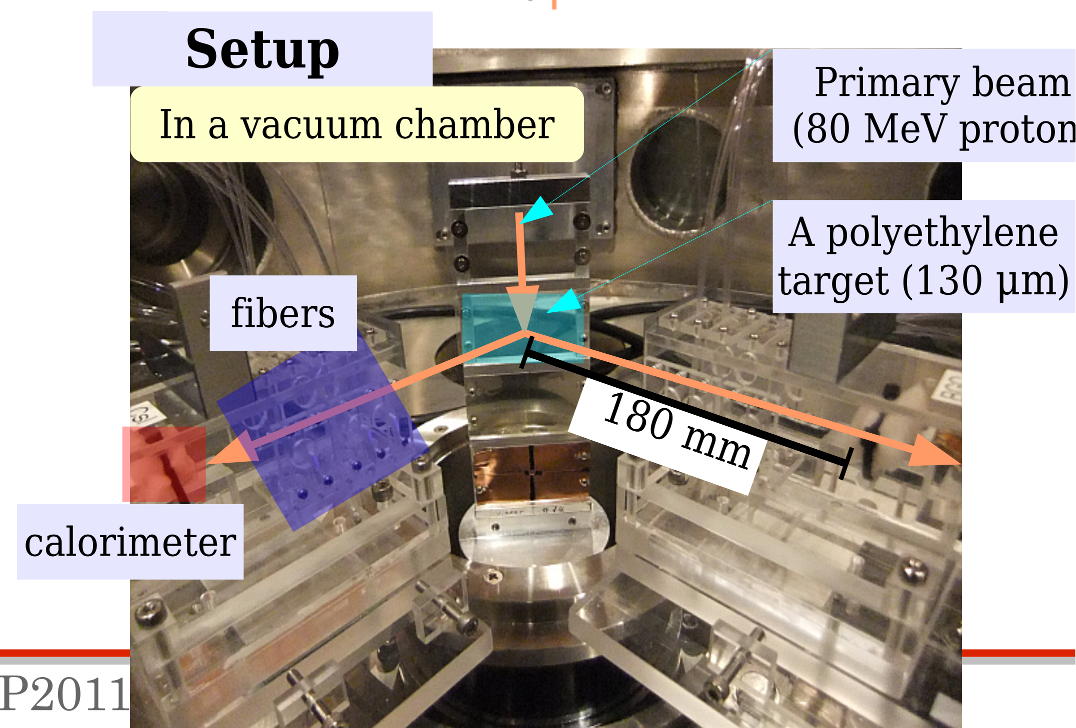
The prototype proton detection system



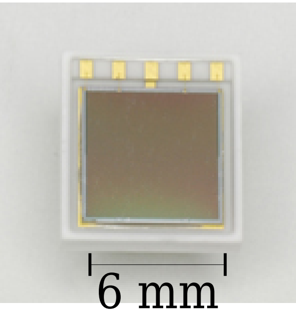
Test experiment
A test experiment in a cyclotron facility in Tohoku University
Detector performance check by scattered proton
proton-proton (pp) scattering
proton-carbon (pC) scattering

Performance study

- **Energy resolution (# of photo electron)**
- ΔE-E distribution (PID ability)
- Detection efficiency
- Angle resolution
- Differential cross section

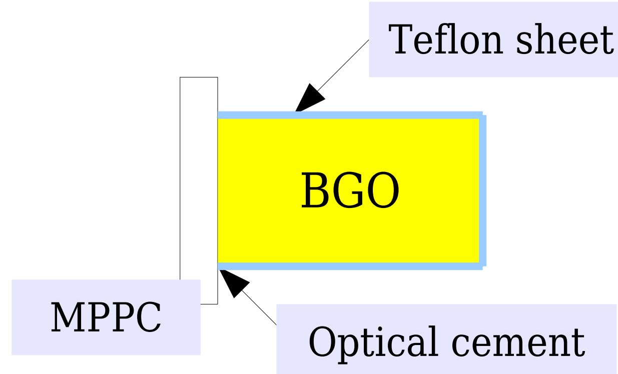


Result -BGO calorimeter-

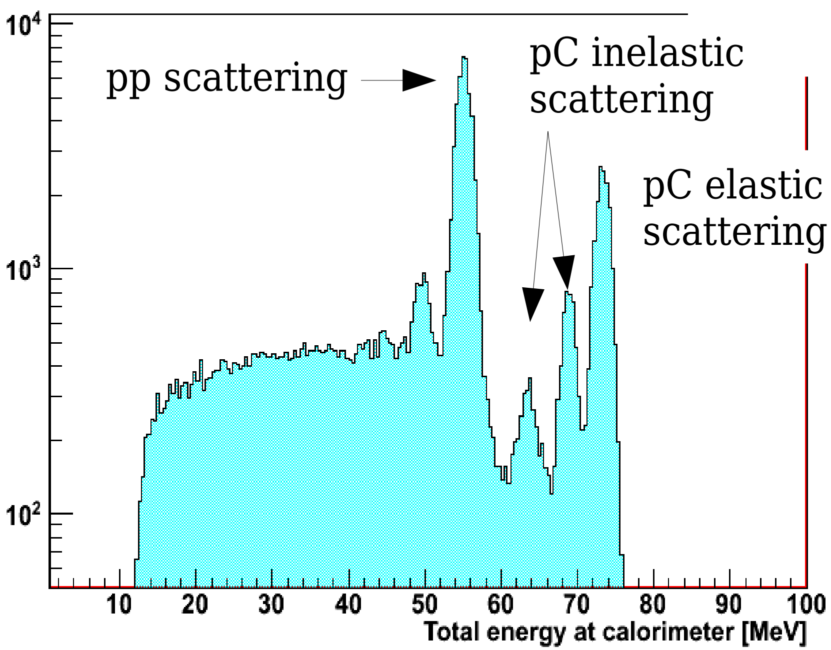


MPPC (S10985-025C)

pixel size : 25 µm
sensitive area : 6 mm×6 mm
# of pixels : 57600
gain : 2.75×10^5



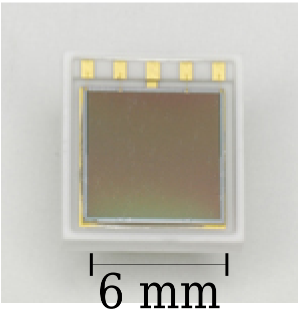
Energy distribution of the calorimeter



Energy resolution : **1.0 % @70 MeV**

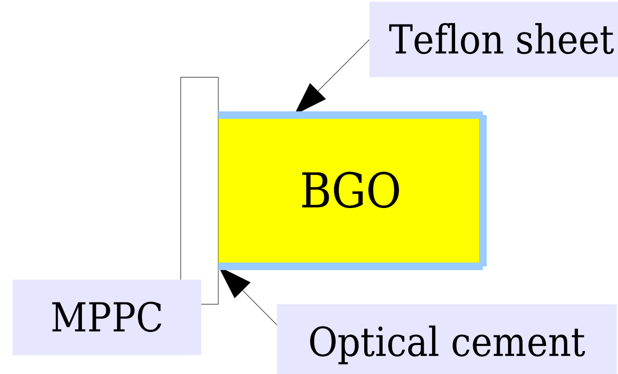
*Linearity is OK.

Result -BGO calorimeter-

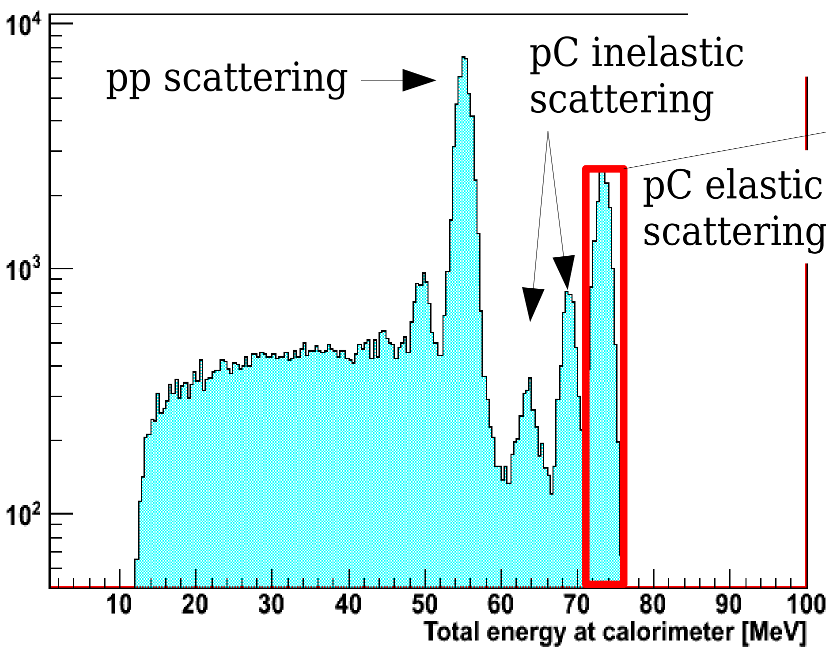


MPPC (S10985-025C)

pixel size : 25 µm
sensitive area : 6 mm×6 mm
# of pixels : 57600
gain : 2.75×10^{5}



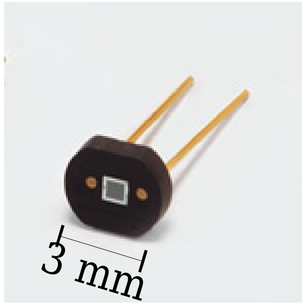
Energy distribution of the calorimeter



Energy resolution : **1.0 % @70 MeV**

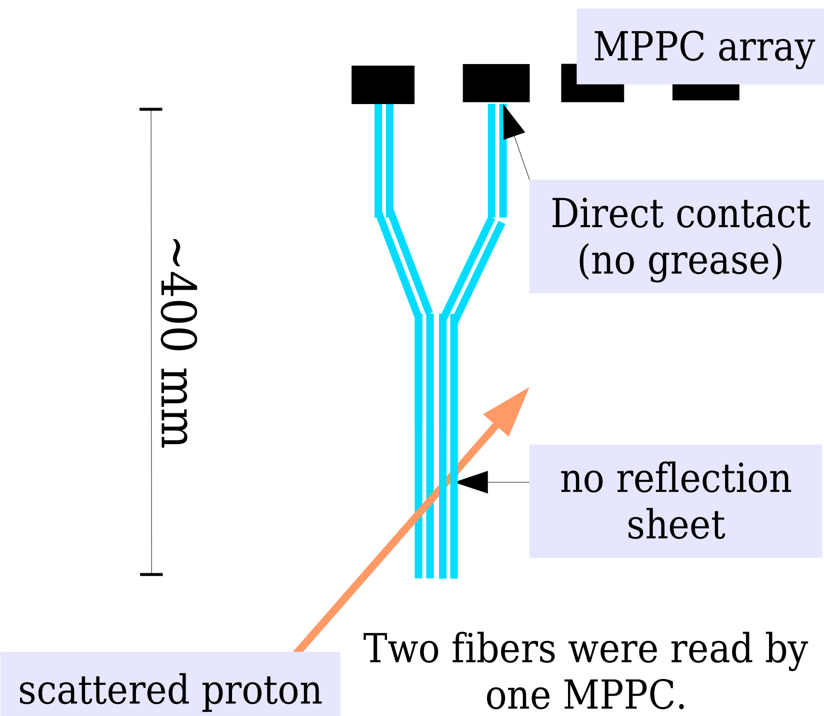
*Linearity is OK.

Result -the SFT-



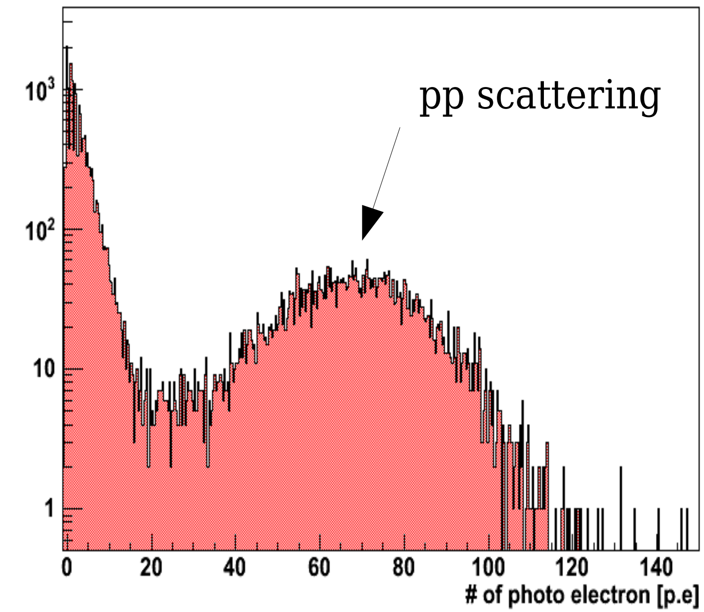
MPPC (S10362-11-050C)

pixel size : 500 μm
sensitive area : 1 mm×1 mm
# of pixels : 400
gain : 7.5×10^5



Two fibers were read by one MPPC.

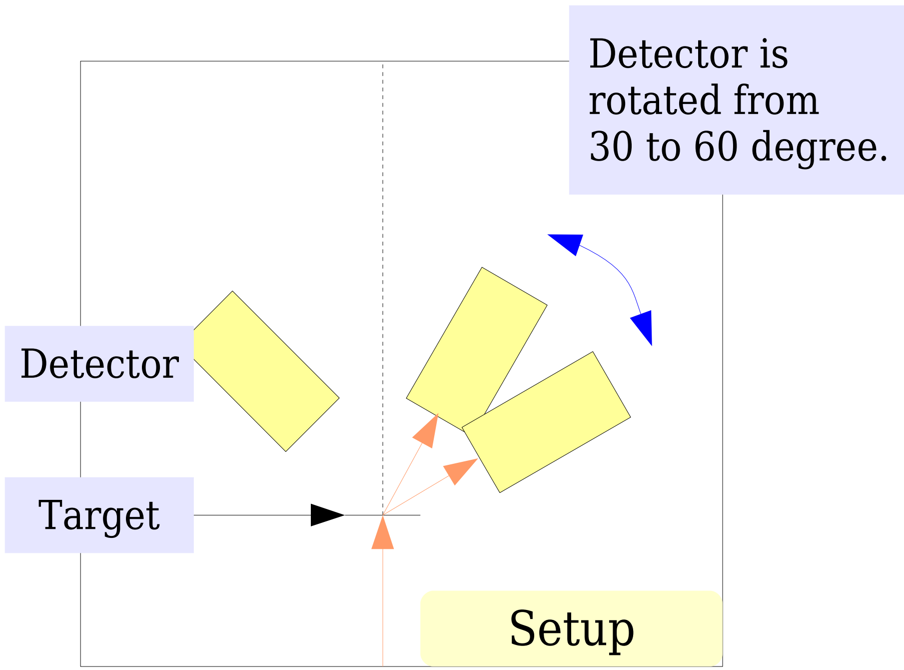
p.e distribution for one fiber @ 50 deg

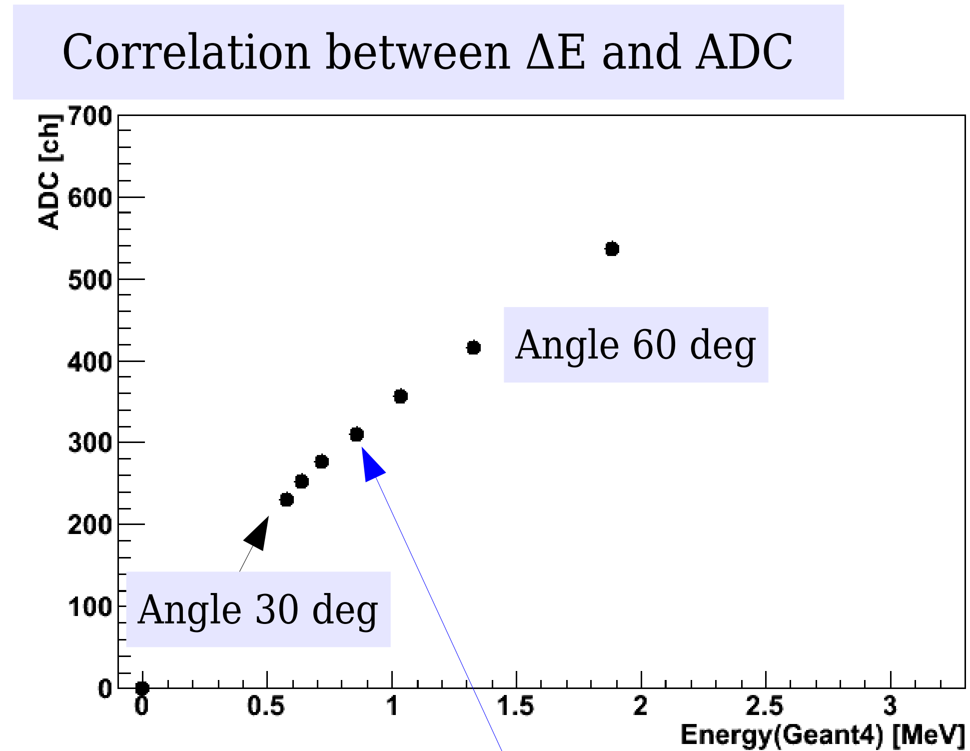


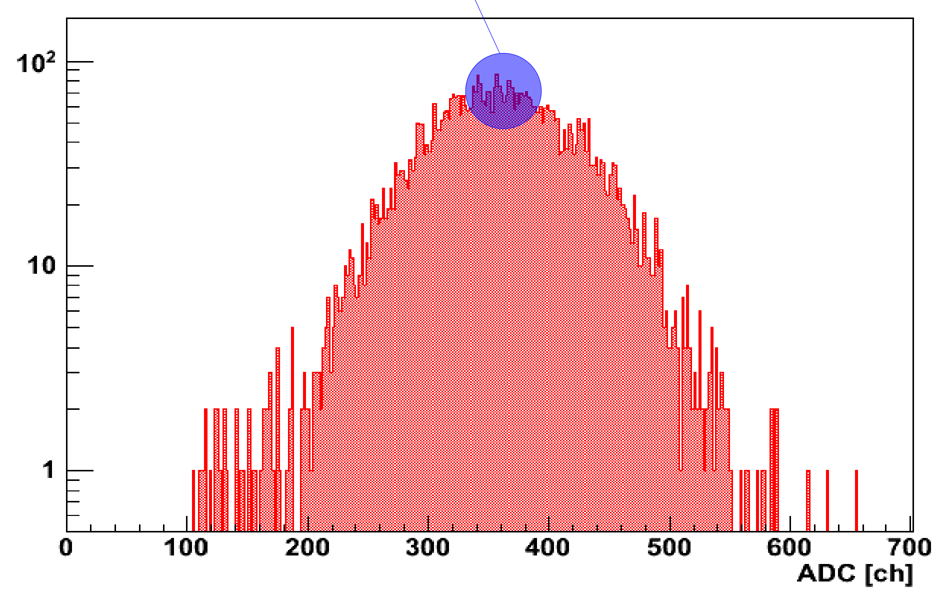
Mean # of p.e : **67 p.e @ ΔE=1 MeV**
σ/Mean : 20.9 %

Expected σ/Mean : = 14.9 % = $\sqrt{\sigma^2_{\Delta E}+\sigma^2_{p.e}}$
(Obtained by Geant4 simulation)

Result -Energy calibration of fiber-







Energy of scattered proton can
be determined by detector orientation.

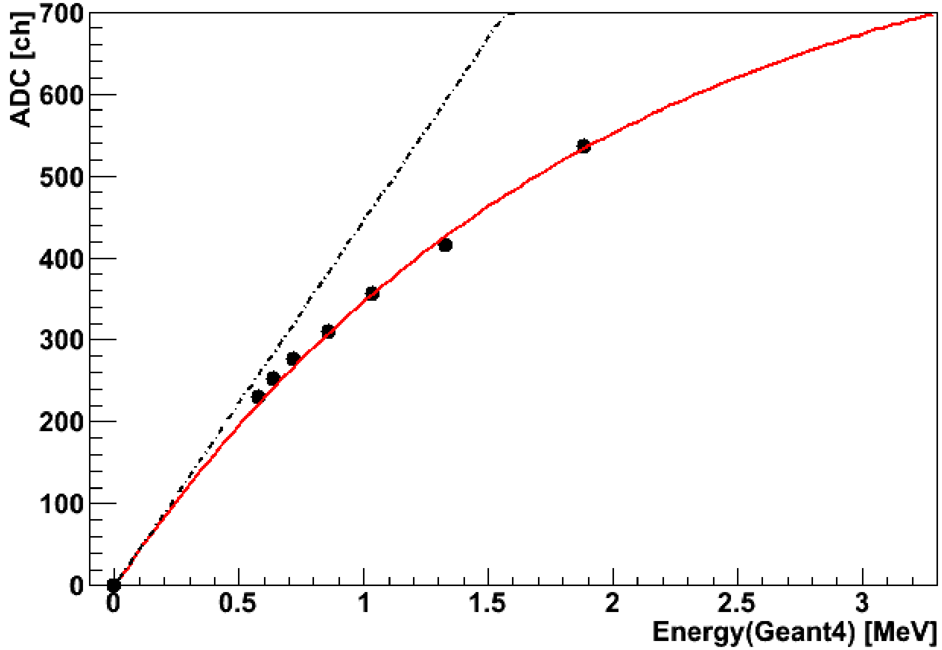
Correlation diagram between
simulated ΔE and ADC.

Result -Energy calibration of fiber-

Saturation of MPPC is seen in the figure.
Basic response function is following

$$ADC(energy) = A \times (1 - \exp(\frac{-B \times energy}{A})) \quad - (1)$$

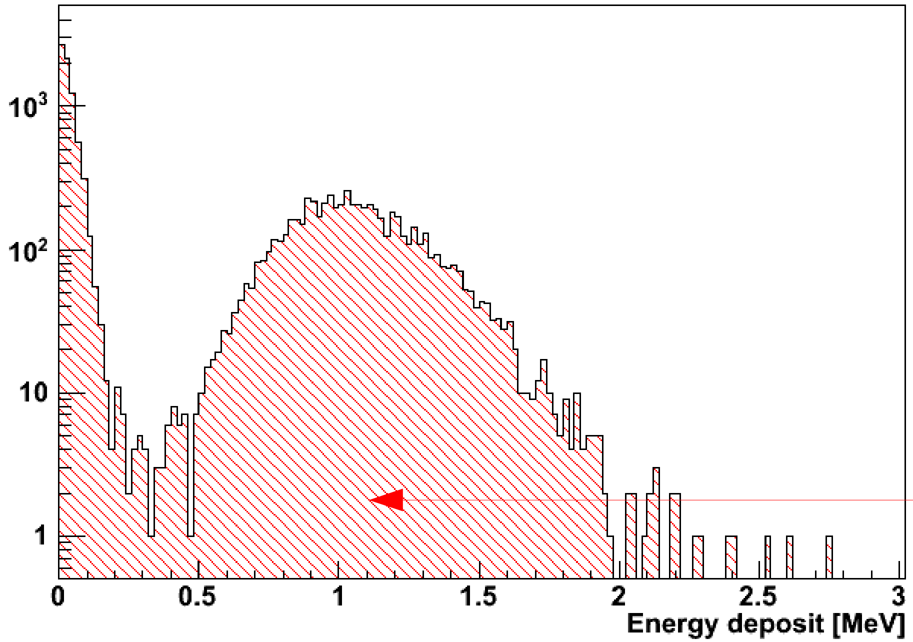
Fitting result



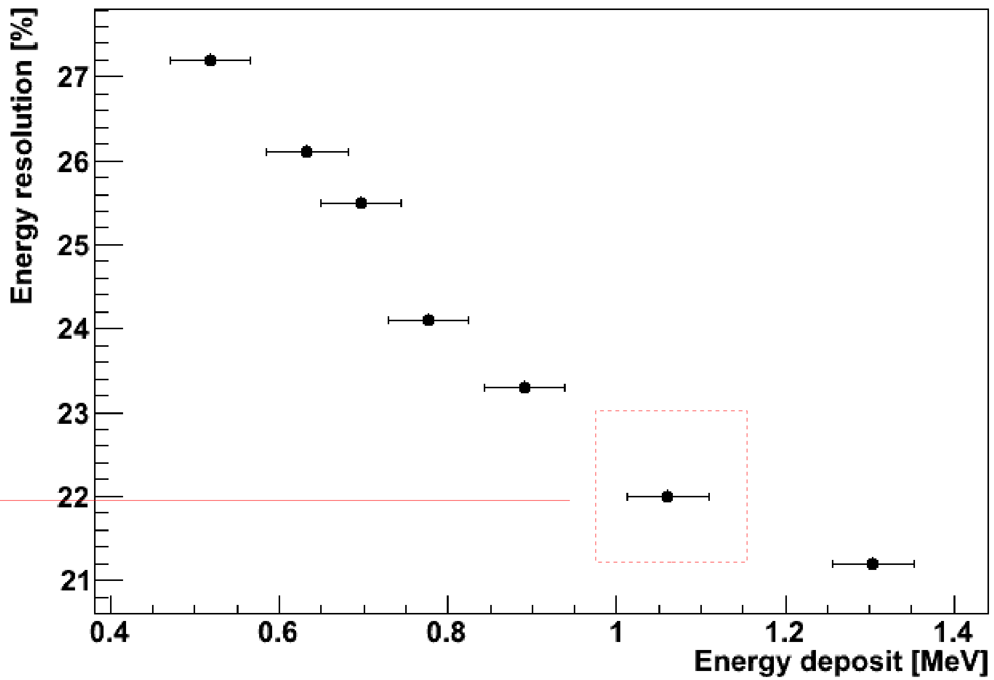
Result -Energy calibration of fiber-

Calibration result
Energy resolution : **22.0 % @ 1 MeV** Requirement : 20 %

Energy loss distribution for proton
(one fiber @ 50 deg)



Energy resolution vs energy deposit



Improvement is necessary.

Readout electronics with EASIROC and SiTCP

Readout electronics for multi-MPPC

Concepts

Asynchronous operation
Data transfer via network

Requirements

On board ADC and TDC	: For the scattered particle detection system.
Discriminator bus outputs	: For the beam line fiber tracker.
Data transfer rate above 3 kHz	: Maximum speed of our DAQ is 3 kHz
	(Data size will be 250 bytes/event by pedestal suppression)

EASIROC

Developed by Omega IN2P3.
- 32 channels inputs
- HV adjustment (4.5 V, 8 bit)
- Amp, shaper, discriminator
- Analog (serial) , discriminator (parallel) outputs.

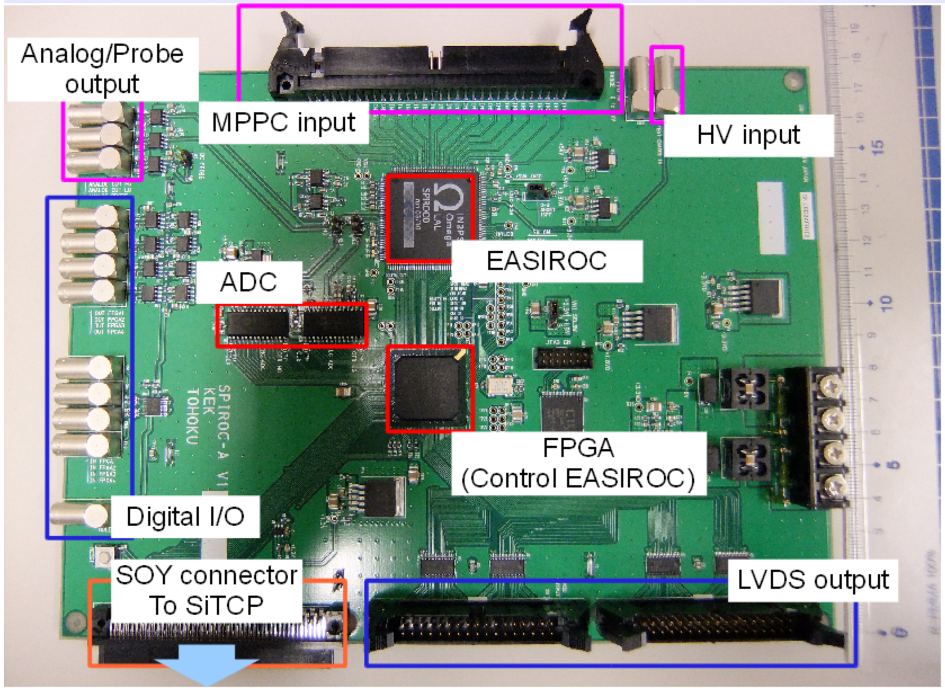
SiTCP

TCP/IP which is implemented with hardware.
Developed by Dr.Uchida in KEK.
- Easy to use TCP/Ethernet
- Up to 1 Gbps with low frequency clock

New electronics for our experiment

Readout electronics for multi-MPPC

Our evaluation board with EASIROC and SiTCP

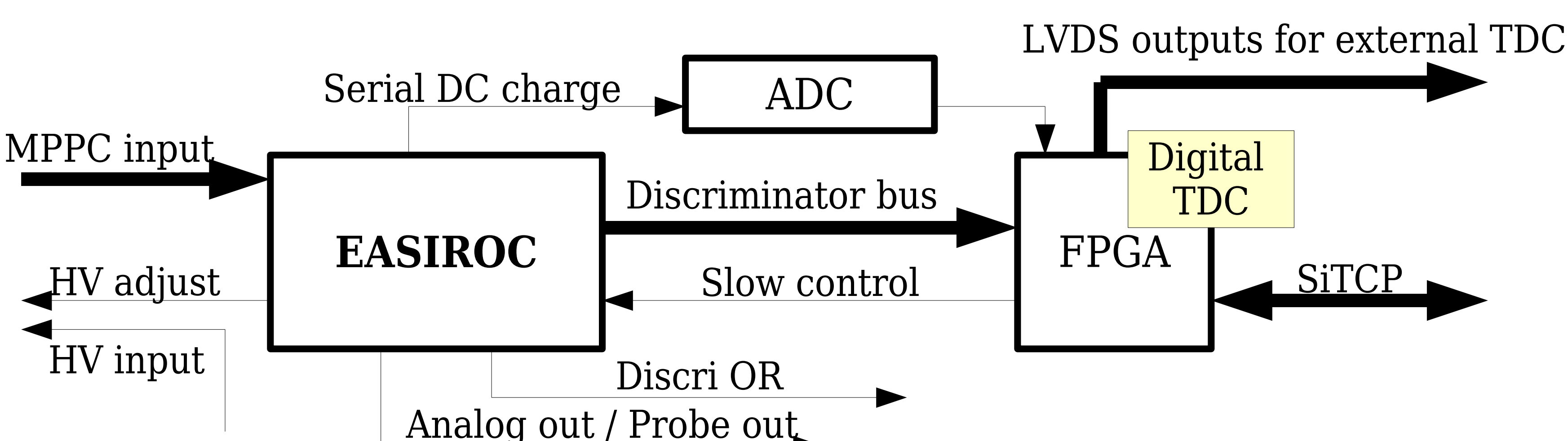


I/O components

Analog I/O
- MPPC input (32 ch)
- HV input
- Analog signal output / probe output

Digital I/O
- NIM level input x5 (400 Mbps)
- NIM level output x4 (~ 1Gbps)
- LVDS output (640Mbps)
- SiTCP (SOY)

*Using a general purpose SiTCP board (SOY) to communicate DAQ computer. We are able to implement SiTCP in one board.



Test measurement with prototype board

Test condition

fiber : **SCSF-78MJ**

(1 mm in diameter multi-clad, Emission peak 450 ns)

MPPC : **S10362-11-100C**

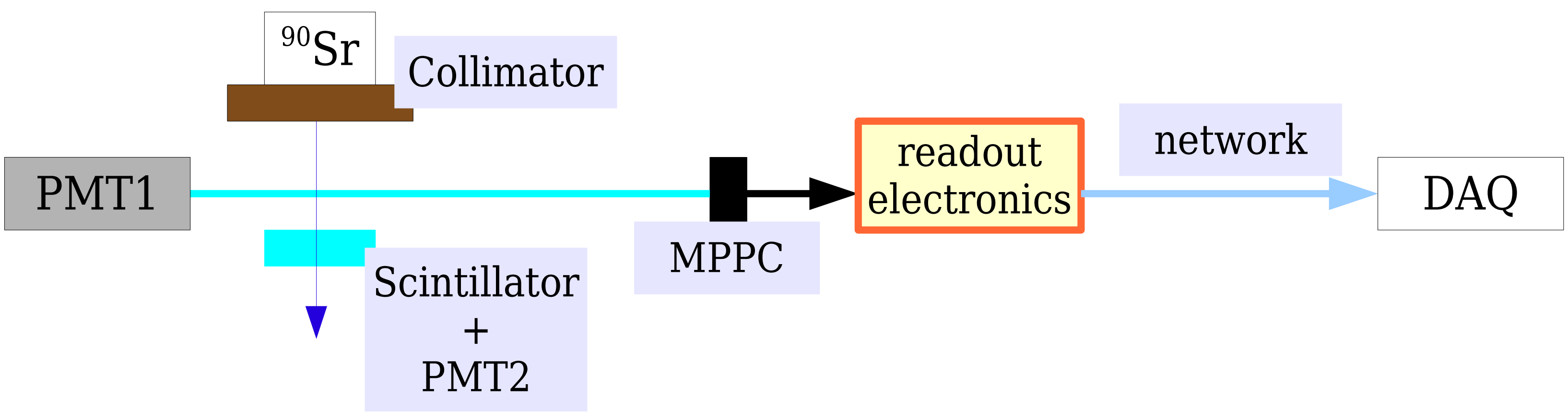
ADC : AD9220 (On board)

Trigger : PMT1⊗PMT2

Evaluation

- ADC
- Data transfer rate

Setup

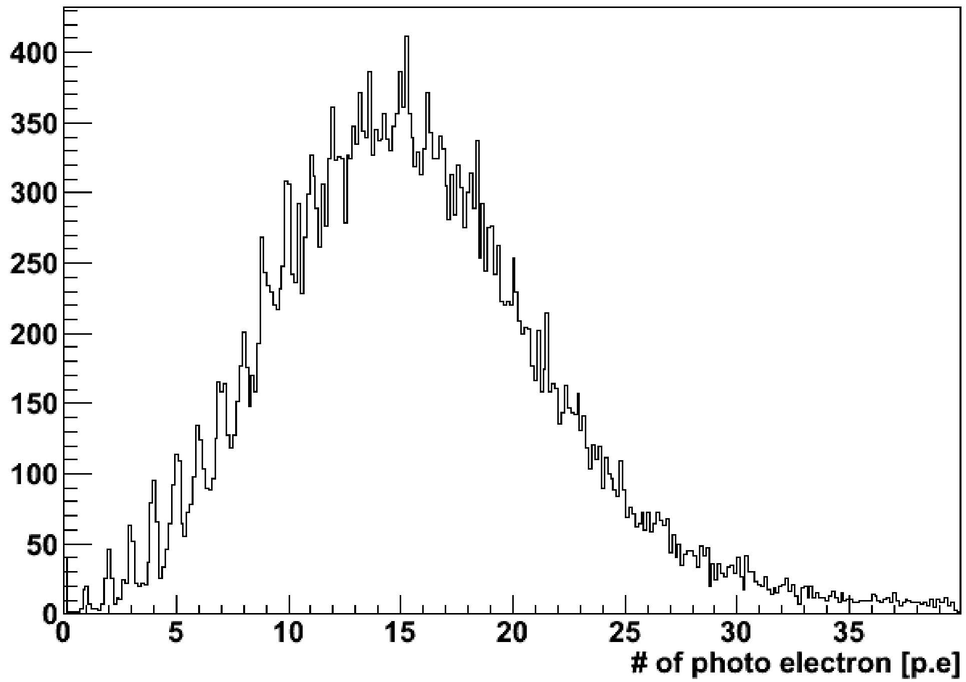


Test measurement with prototype board

Result of ADC

Mean # of p.e	: 14.7 p.e
ADC readout speed	: **14 kHz** (64 byte/event)
Bias voltage	: 70.3 V (Rated voltage)
Obtained gain	: $\sim 3\times10^6$

ADC spectrum for β ray



Required transfer rate was achieved

Evaluating readout method for the beam line fiber tracker

Test measurement for the beam line fiber tracker

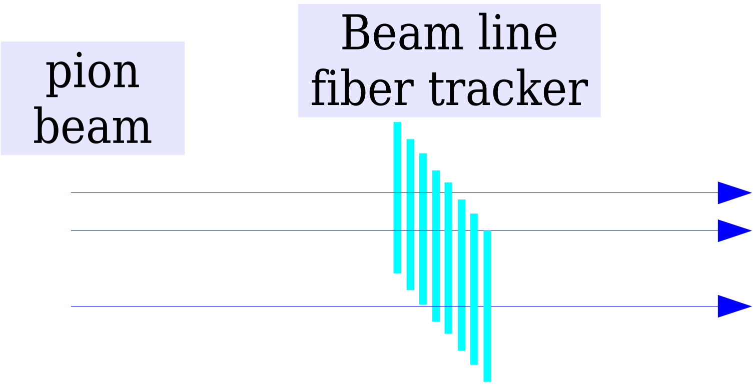
Beam line fiber tracker

Measurements

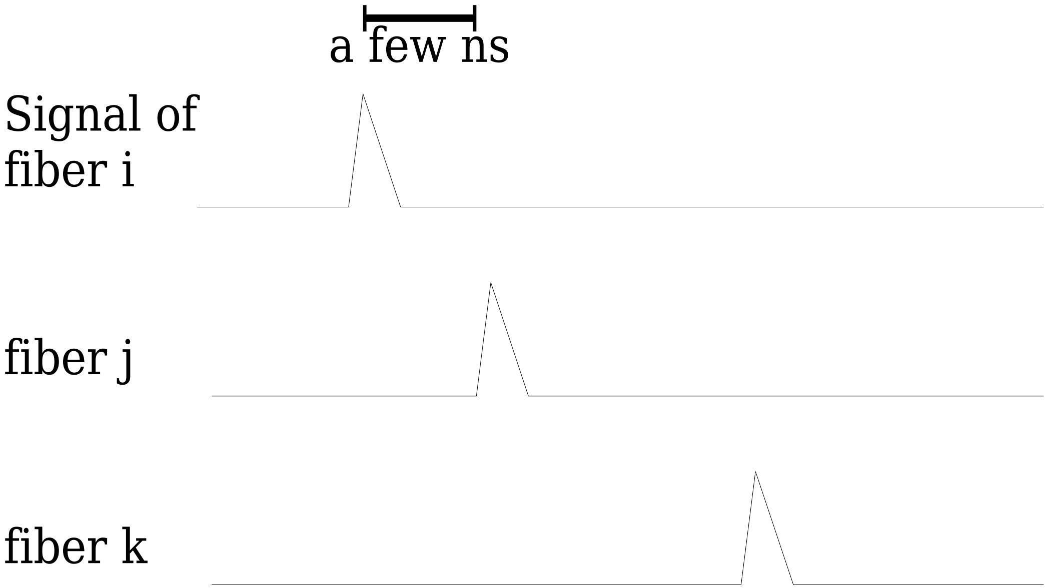
- Timing
- Position (Horizontal axis)

Requirements

Time resolution	: 0.8 ns
Position resolution	: 1 mm



Multi track event



Instantaneous rate will be up to **100 MHz**

Test measurement for the beam line fiber tracker

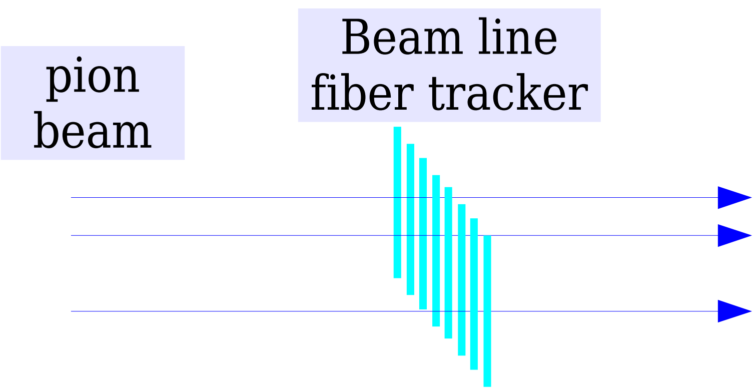
Beam line fiber tracker

Measurements

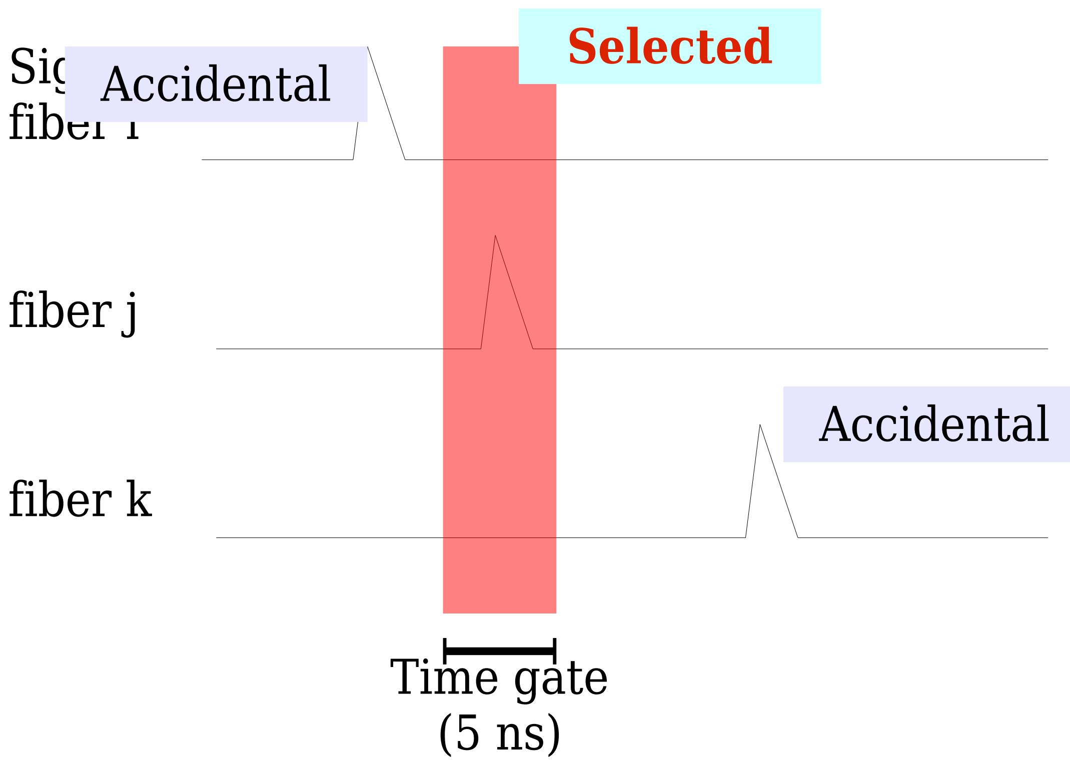
- Timing
- Position (Horizontal axis)

Requirements

Time resolution	: 0.8 ns
Position resolution	: 1 mm



Multi track event



Accidental events < 5 % => 5 ns time gate => **σ = 0.8 ns**

Test measurement for the beam line fiber tracker

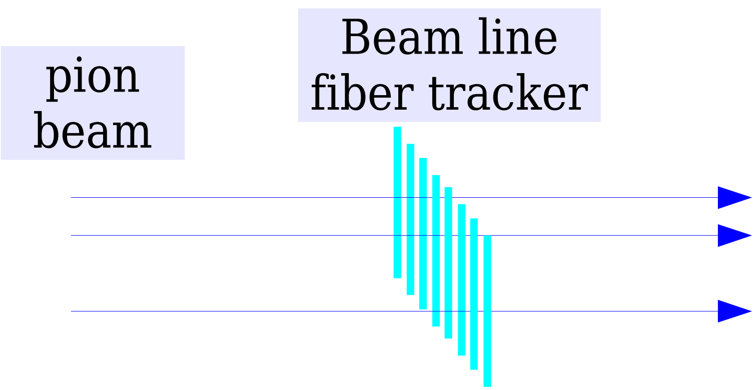
Beam line fiber tracker

Measurements

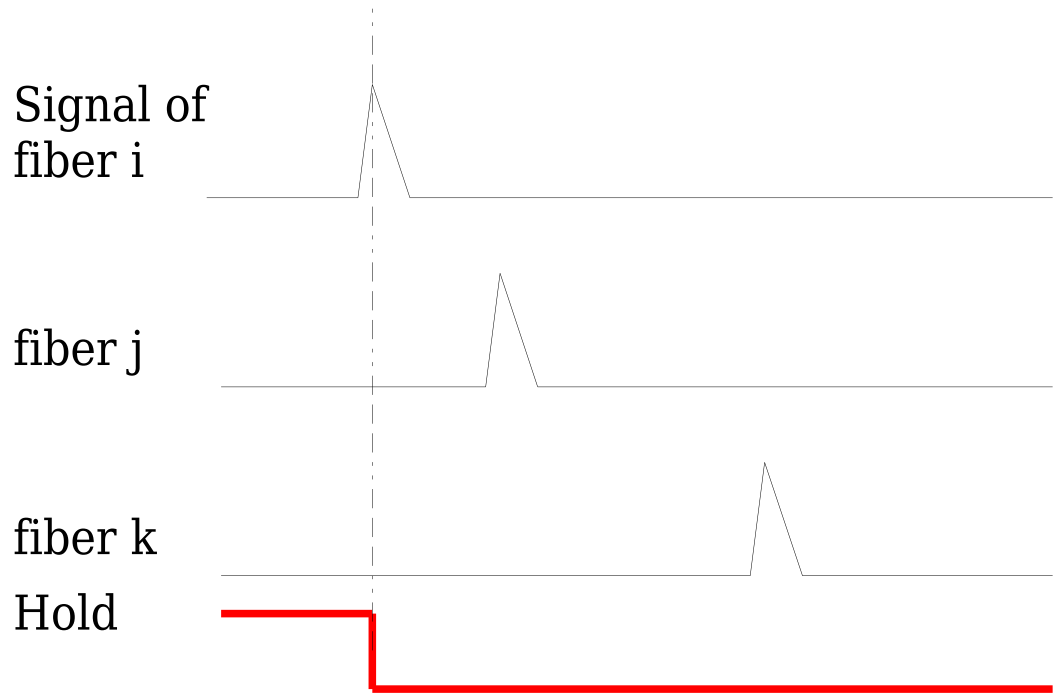
- Timing
- Position (Horizontal axis)

Requirements

Time resolution : 0.8 ns
Position resolution : 1 mm



Multi track event



Peak hold type charge measurement with common signal

Hard to use on board ADC

Test measurement for the beam line fiber tracker

Beam line fiber tracker

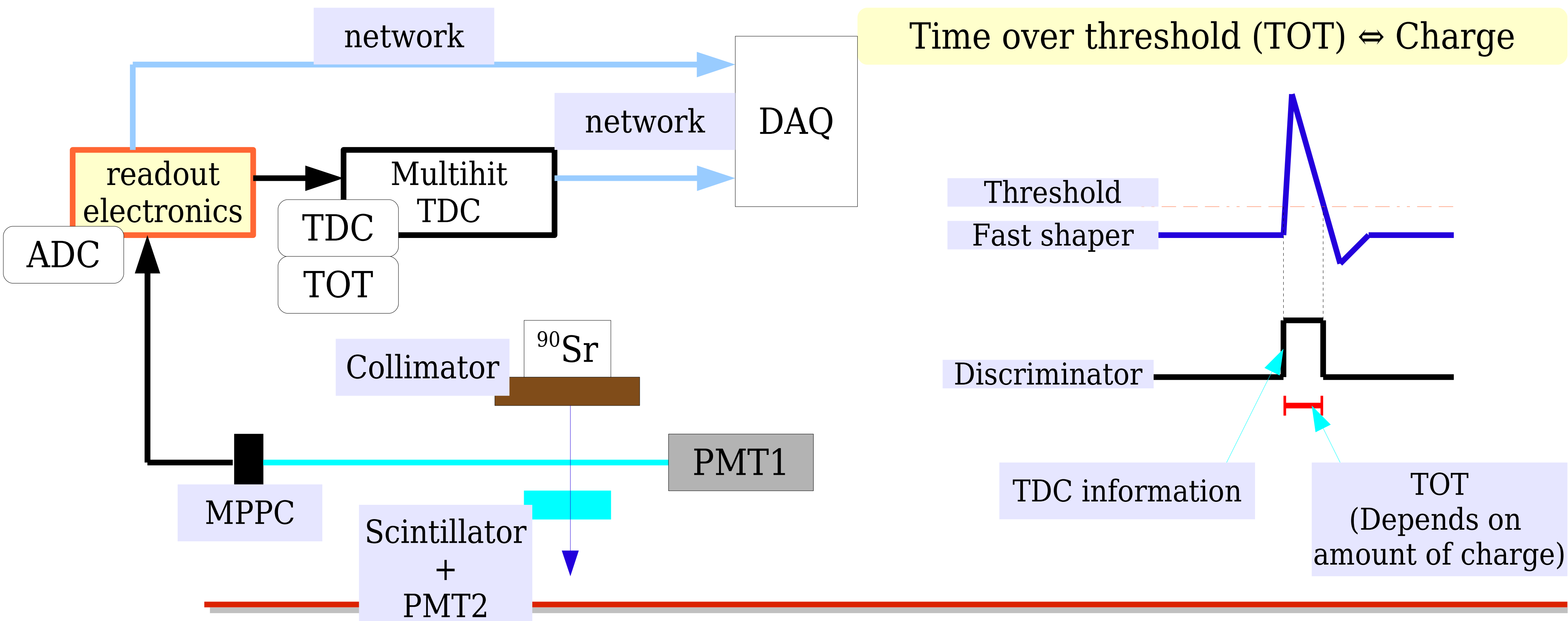
Measurements
- Timing
- Position (Horizontal axis)

Requirements

Time resolution : 0.8 ns
Position resolution : 1 mm

Slewing correction with TOT information

Time resolution is important for the beam line tracker. Slewing correction is necessary.

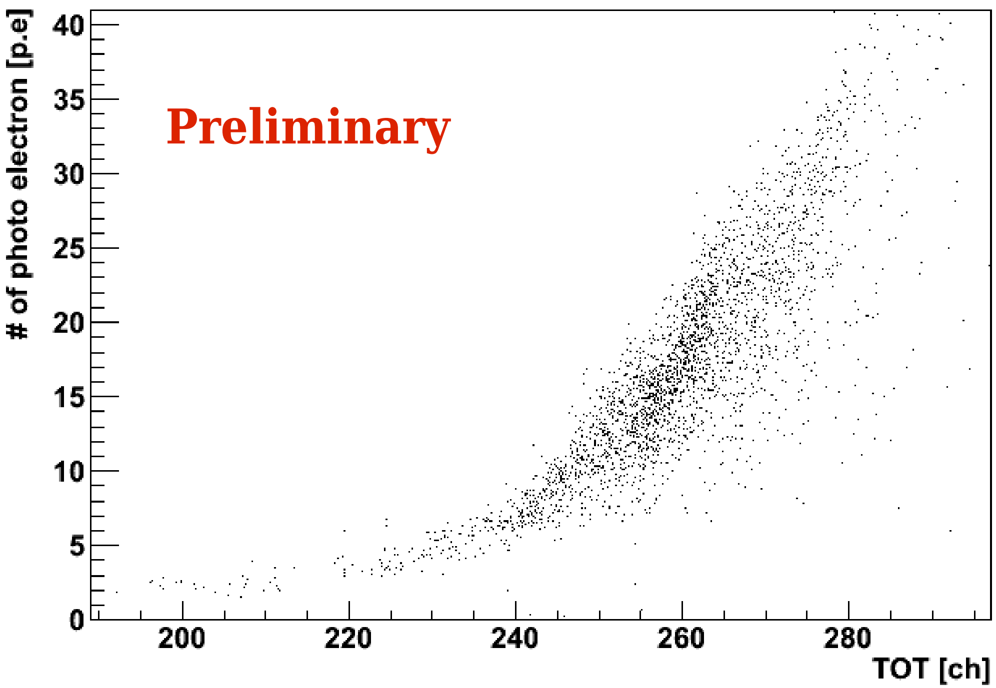


Test measurement for the beam line fiber tracker

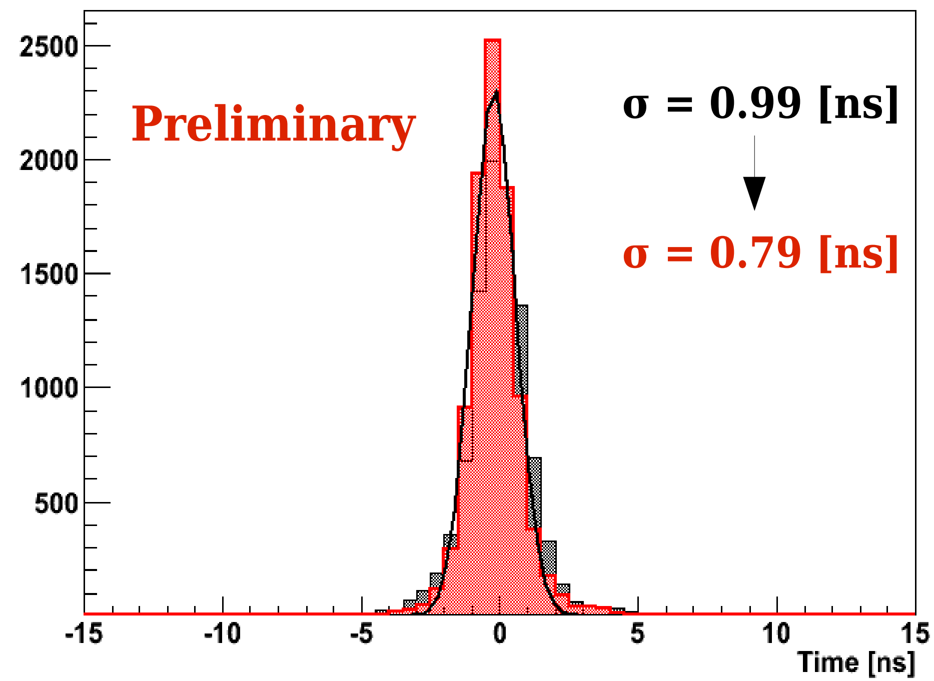
Result of TDC measurement

Time resolution	: **σ = 0.79 ns (After correction with TOT)**
Threshold	: above 1.5 p.e
Bias voltage	: 70.7 V
TDC	: CAMAC TDC (Model 3377)

Correlation between ADC and TOT



Time resolution



Timing resolution is sufficient
We confirmed that readout method for the beam line fiber tracker works well.

Summary

Σp scattering with the fiber trackers at J-PARC.

- Beam line fiber tracer
- Proton detection system
- Readout electronics for multi-MPPC

Developments

- Prototype proton detection system
- New readout board with EASIROC and SiTCP

Performance evaluation

For prototype proton detection system with proton beam

Energy resolution : **1.0 % @ 70 MeV** (BGO calorimeter)
: **22.0 % @ 1 MeV** (Fiber tracker)

For new readout electronics with β ray

Data transfer rate : **14 kHz** (64 byte/event)

Evaluating readout method for the beam line fiber tracker.

Time resolution : **0.79 ns (After slewing correction with TOT)**

Back up

Back up

Why 500 μm size scintillation fiber ?

Angle resolution of the SFT is most important in our experiment.

↓

We cannot increase material between the target and the calorimeter

Redundancy
at least 10 plane

⇔

Energy resolution

↓

500 μm size scintillation fiber

Back up

Prototype calorimeter

Energy resolution : 1 % with 6 mm * 6 mm * 20 mm length crystal

Production version calorimeter

25 m * 25 mm * 450 mm length BGO crystal

Assumption
Correction efficiency is 1/10

↓

Energy resolution : 3.1 %

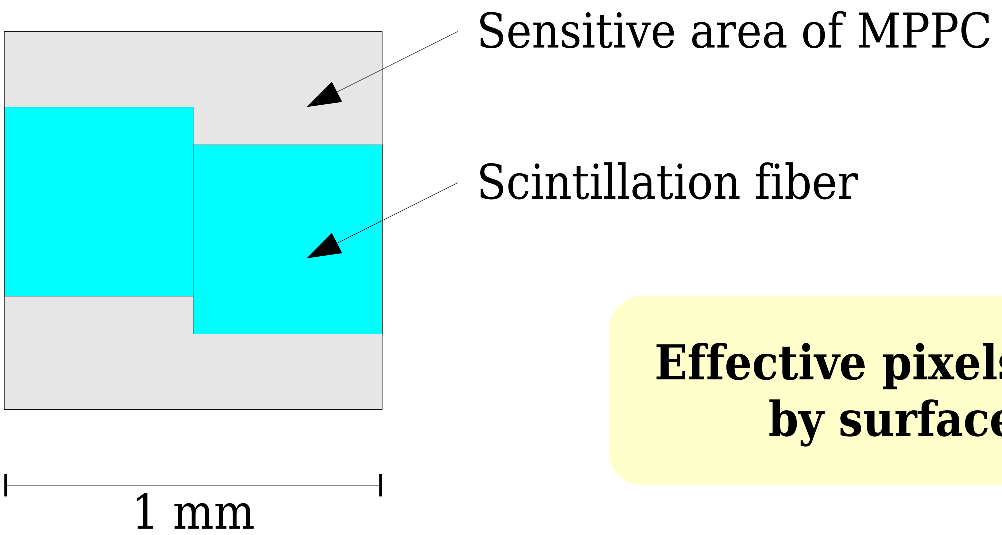
Another experiments is needed
with realistic setup...

Back up

Effective pixels

Effective pixels => ~ 100 pixel

Why ? Total # of pixels of S10362-11-050C is 400 pixels.
=> Surface size between fibers and sensitive area of MPPC are different.



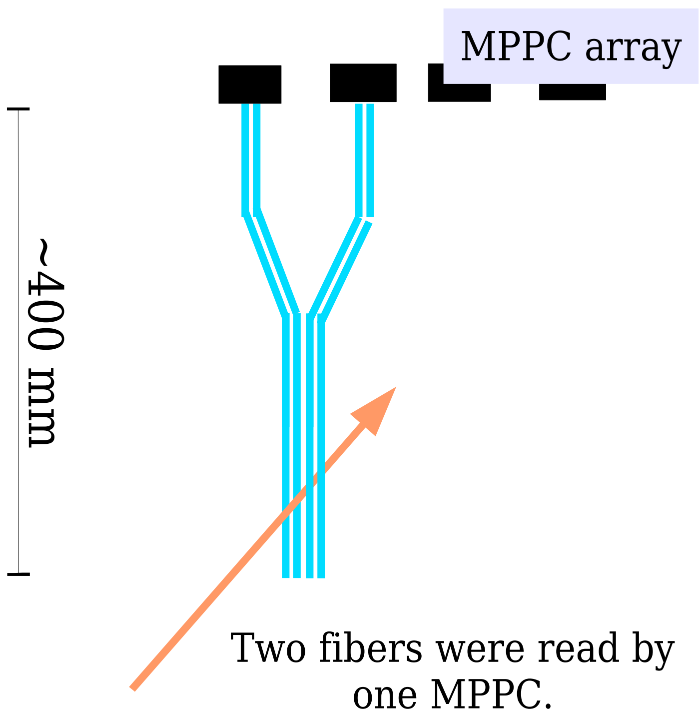
Effective pixels is limited to ~ 1/4 by surface size of fibers.

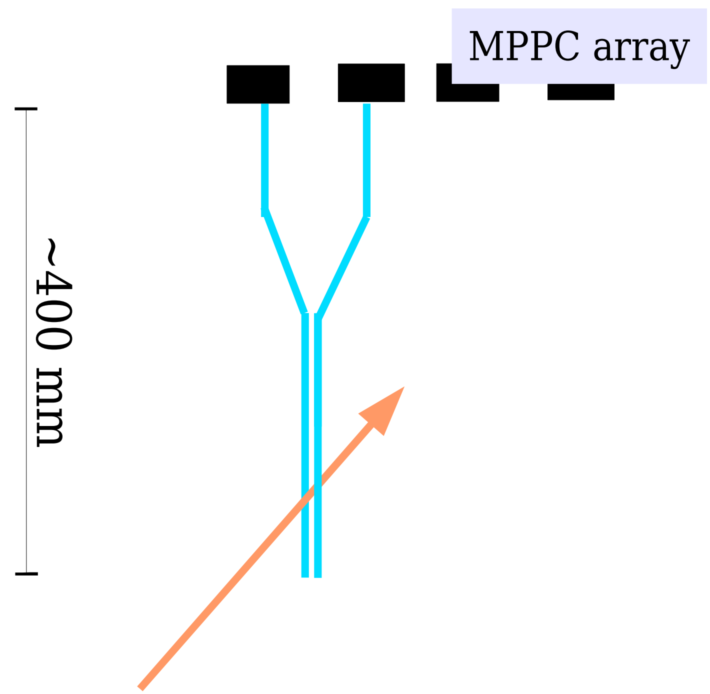
Improvement

Possible improvement

In this test experiment, two fibers were read by one MPPC.
Light yield is very sensitive for light contact.

Two fiber reading → **fiber by fiber**



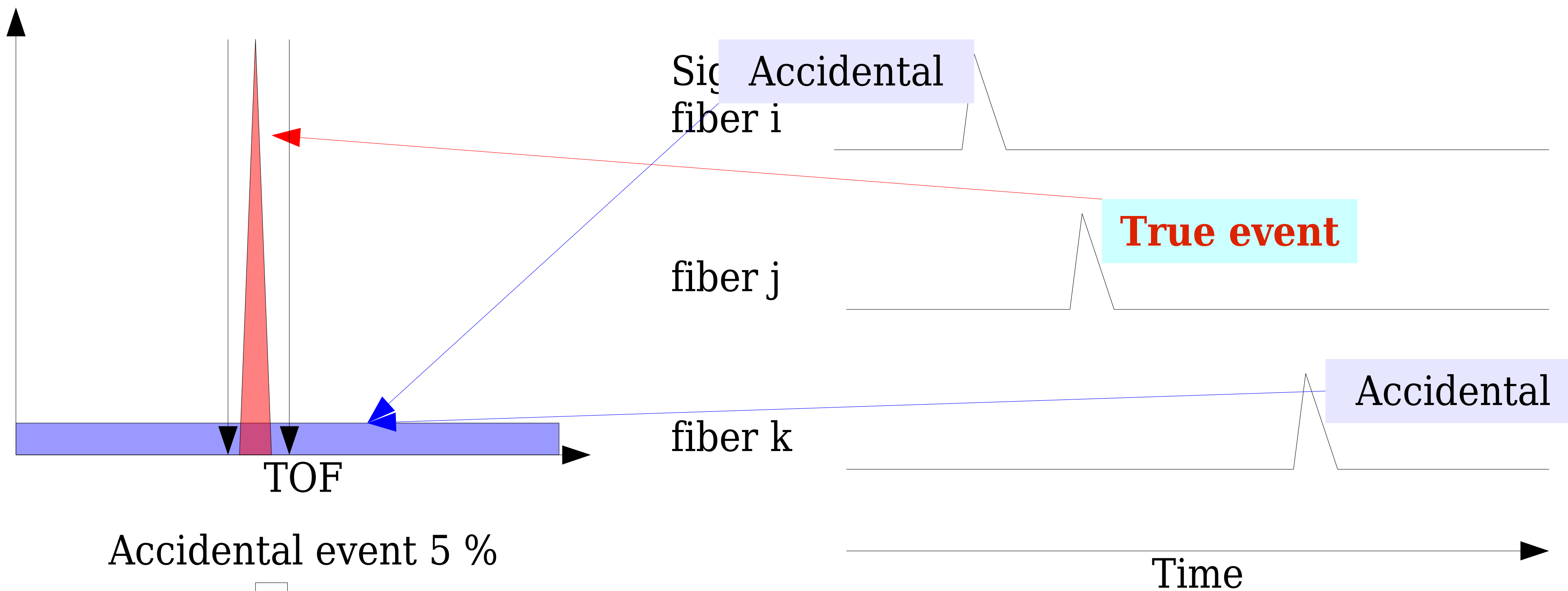


Light contact might be different between two fibers...

Back up

Time gate of the BFT

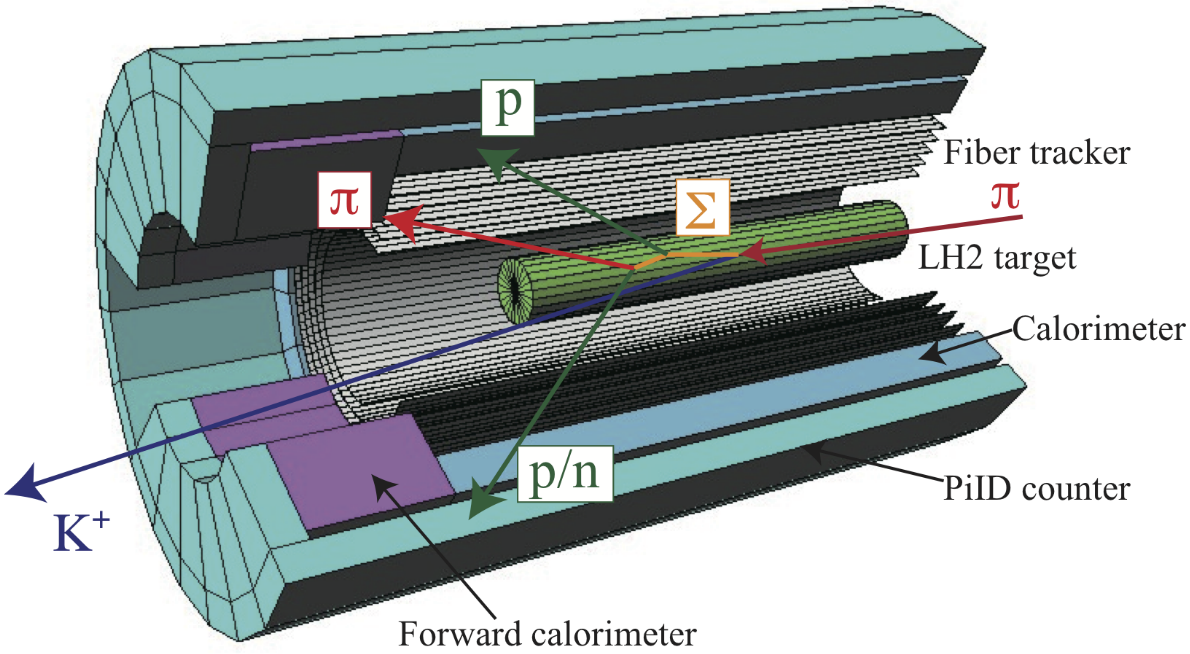
Time of Flight (TOF) between BFT and other timing counter (**σ = 0.1 ns**)



Accidental event 5 %

5 ns time gate

Time resolution of BFT
σ = 0.8 ns



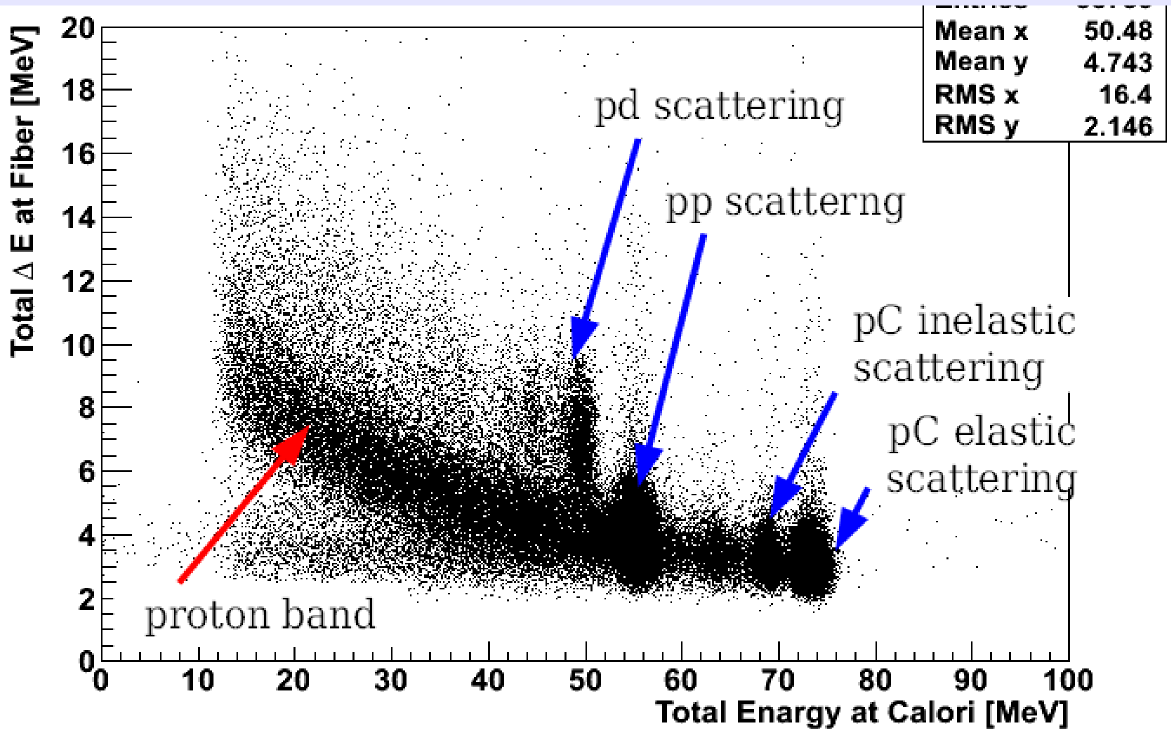
Design of SFT
Fiber : 500 μm in diameter scintillation fiber.
Detector : MPPC (S10931-050P)
Each fiber is read by MPPC.
10 layers (XUV plane)

Design of BFT
Fiber : 1 mm square type scintillation fiber
Detector : MPPC (S10931-100P)
Each fiber is read by MPPC.
2 layers (x-x')

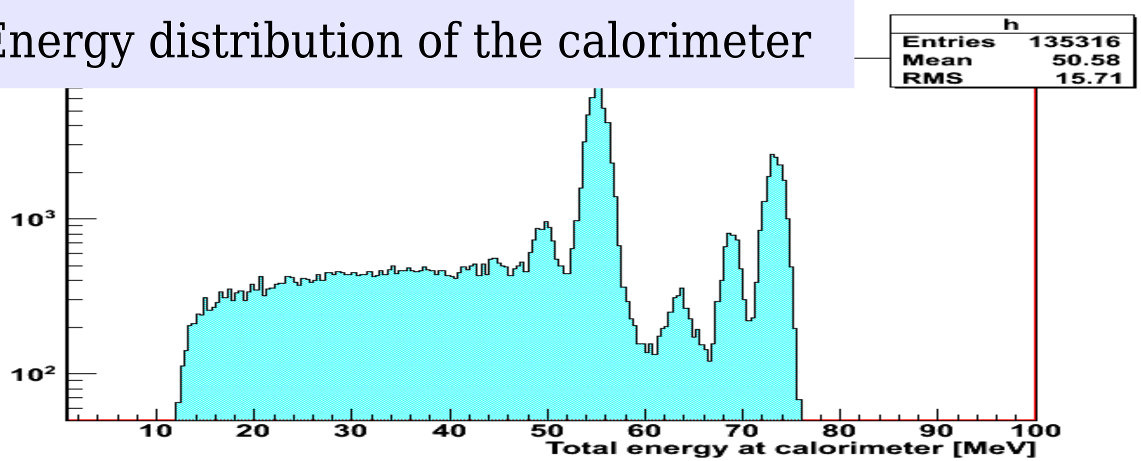
Design of the calorimeter part
Scintillator : BGO crystal
(25 mm thickness, 450 mm length)
Detector : MPPC

Result -the ΔE-E distribution-

ΔE-E distribution at scattering angle 30 deg



Energy distribution of the calorimeter



ΔE-E distribution

Correlation between sum of ΔE in each fiber and energy at the calorimeter.

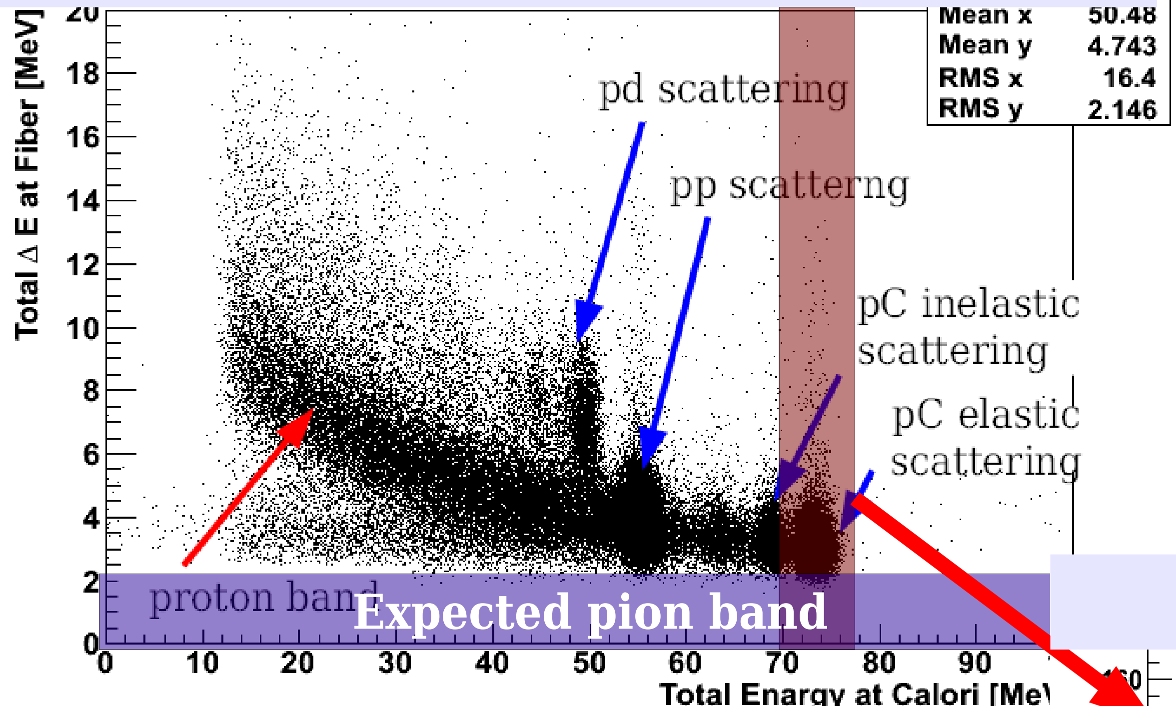
In the left figure, we can see a proton and deuteron band.

The energy resolution of the SFT

resolution : **14.7 % @ 5.5 MeV**
(pp scattering @ 45 deg)
resolution : **15.1 % @ 3.1 MeV**
(pC elastic scattering)

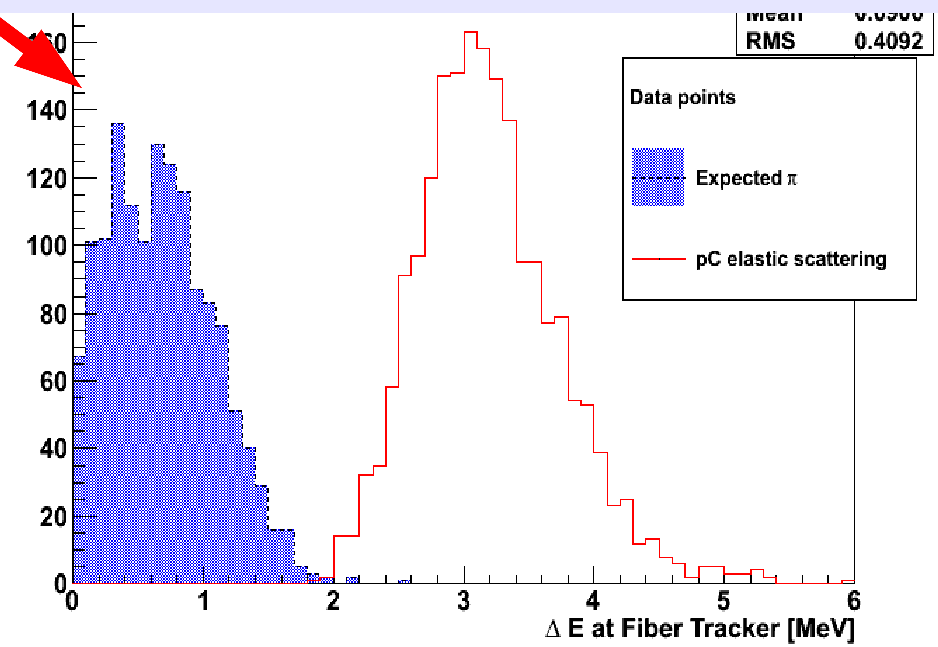
Result -the ΔE-E distribution-

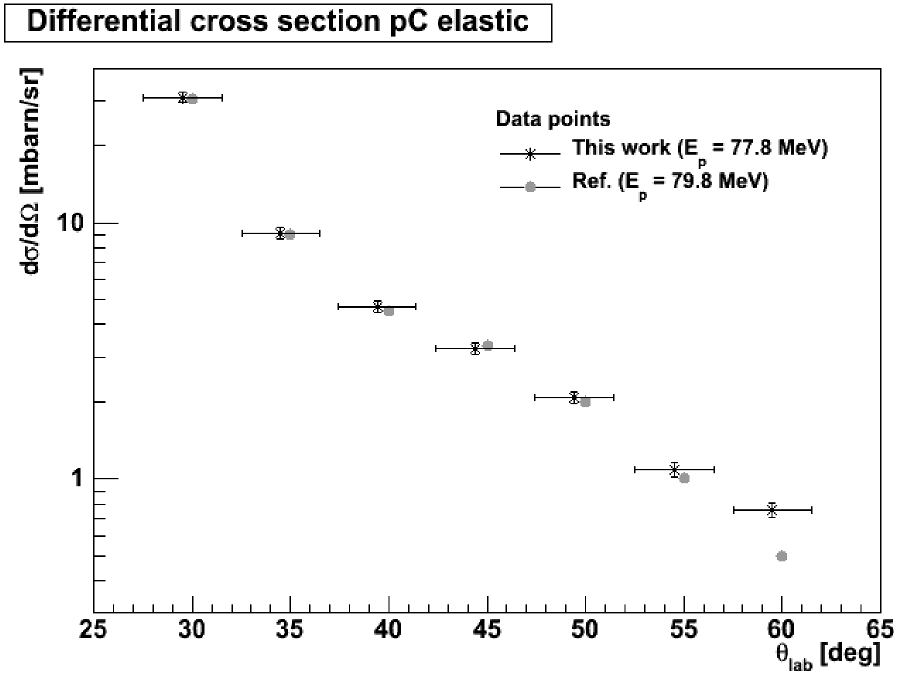
ΔE-E distribution at scattering angle 30 deg

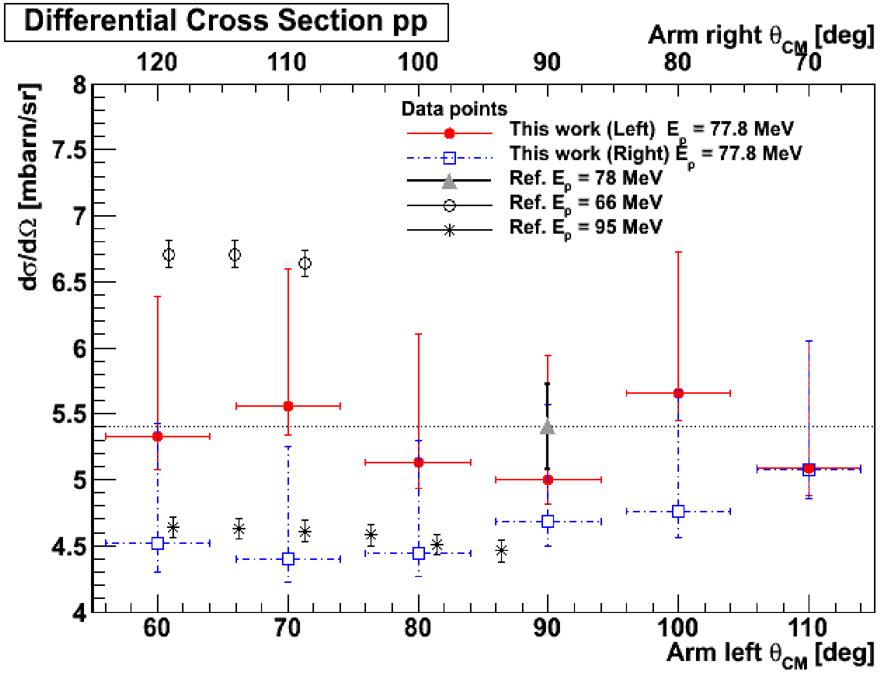


pion / proton separation
Blue peak in the figure below is expected pion peak. Number of events of two peak is same.
Separation of pion and proton is prospected **2.6σ**.
Requirement separation for this system is **5.0σ. Improvement is necessary.**

Projection red region to y axis




Differential cross section pC elastic
Data points
This work (E_p = 77.8 MeV)
Ref. (E_p = 79.8 MeV)
dσ/dΩ [mbarn/sr]
10
1
25
30
35
40
45
50
55
60
65
θ_lab [deg]


Differential Cross Section pp
Arm right θ_CM [deg]
120
110
100
90
80
70
Data points
This work (Left) E_p = 77.8 MeV
This work (Right) E_p = 77.8 MeV
Ref. E_p = 78 MeV
Ref. E_p = 66 MeV
Ref. E_p = 95 MeV
dσ/dΩ [mbarn/sr]
8
7.5
7
6.5
6
5.5
5
4.5
4
60
70
80
90
100
110
Arm left θ_CM [deg]