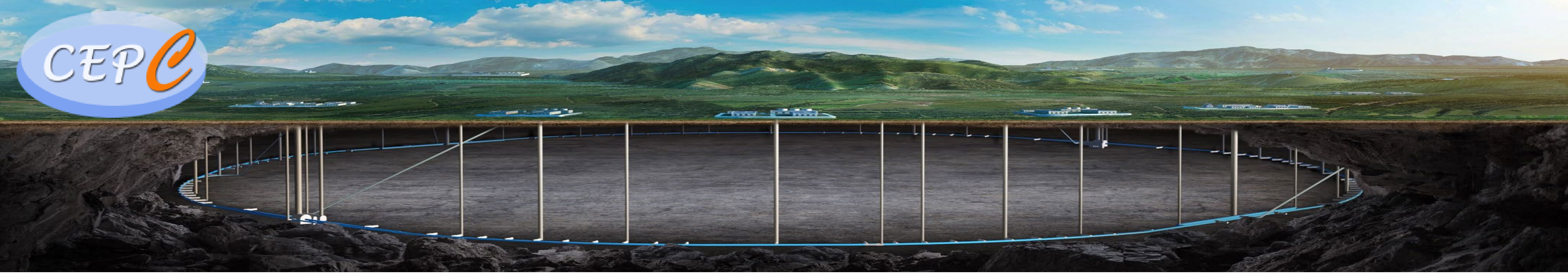

CEPC Muon Detector

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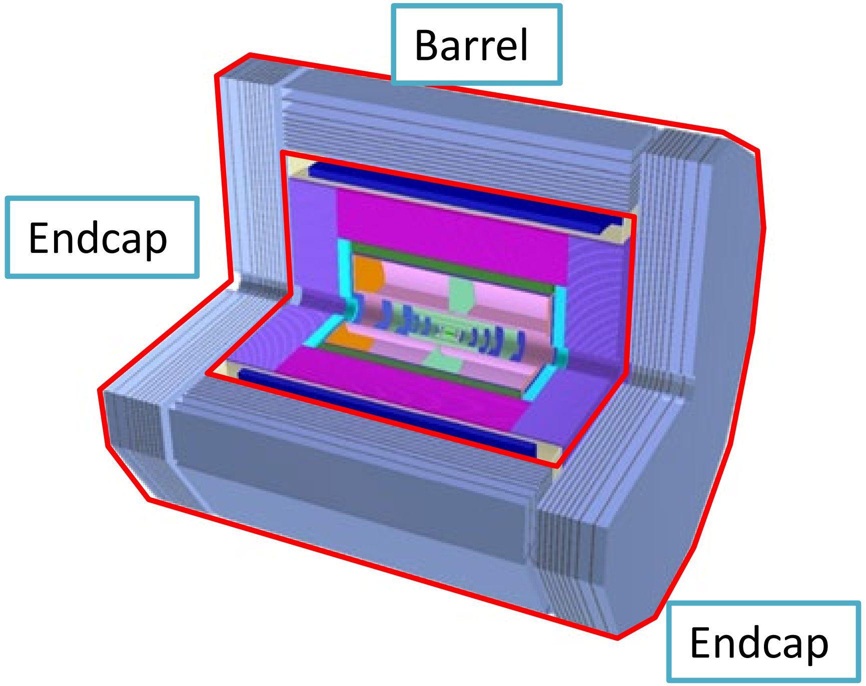
Content

Introduction

Muon detector, the outermost detector with the largest volume, clean environment.

- Production of Higgs: $e^+e^- \rightarrow ZH$, Higgs could be determined in the recoil of $Z \rightarrow \mu^+\mu^-$.
- Muons provide in many theoretical models a characteristic signature for new physics.
- Muon detector is designed for muon identification, but not limited to this. Benefits:
  - Could be used to detect the leakage of HCAL.
  - Can be used for trigger, like in ATLAS.
  - Can be used to search for Long-lived particles.
- Functions: muon ID, search for NP, leakage of HCAL, trigger and timing information.
- Furthermore, it must be robust and low cost.



Key requirements:
- **Muon ID**
- Track reconstruction

Requirements

- Solid angle coverage: $0.98 \times 4\pi$
- Detection efficiency ($p_\mu^T > 4.0$ GeV$/c$): $> 95\%$
- Fake ($\pi \rightarrow \mu$) @ 30 GeV$/c$: $< 1\%$
- Position resolution: $\sim 1\ cm$
- Time resolution: $\sim 1\ ns$
- Rate capability: ~ 60 Hz$/cm^2$

Solid angle coverage and detection efficiency → High efficiency

Fake rate → Low fake rate

Position resolution → Resolution due to the multiple scattering of muon

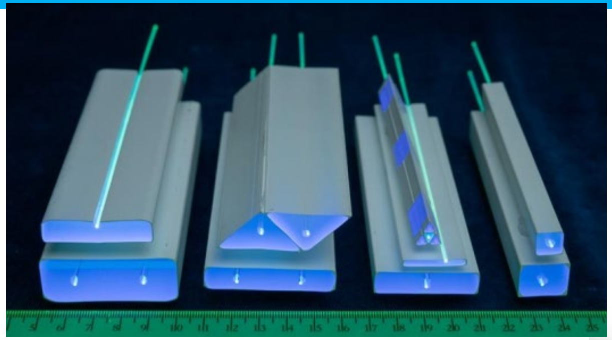
Time resolution → A typical time resolution of modern muon detector, and useful for trigger, T0 and background suppression.

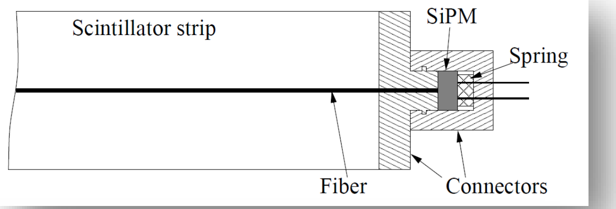
Rate capability → Compatible with the high luminosity operation

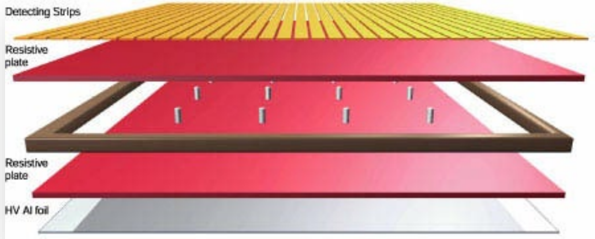
Technology survey and our choices

- Extruded plastic scintillator (PS) technology
  - Belle II, JUNO-TAO, MATHUSLA, LHAASO, sPHENIX, etc.
- RPC technology:
  - Belle, BESIII, Dayabay, ATLAS, CMS
- μ-RWELL (MGPD) technology
  - IDEA
- Experiments @ LHC
  - ATLAS: Thin Gap Chamber, RPC, Monitored Drift Tube, Small-Strip Thin-Gap Chamber, and Micromegas
  - LHCb: MWPC, RPC
  - CMS: Drift tube, Cathode Strip Chamber, RPC

Simple structure:
PS bar, fiber, SiPM





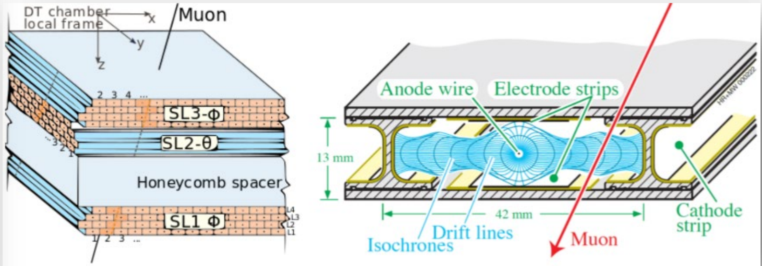


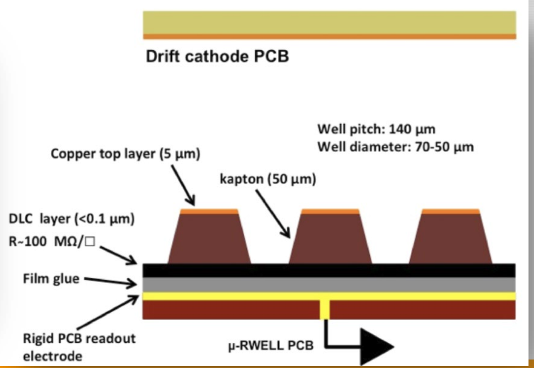
Summary of performance and technical requirements for different gaseous μ detectors

	MDT/DT	CSC	TGC	MRPC	RPC
Spatial resolution [μm]	150	100	5mm	15mm	15mm
Time resolution [ns]	40	7	4.3	0.075	2
Averaged efficiency [%]	98	98	99	95	95
Hit rate [Hz/cm^2]	200	500	1000	500	100
Eletronic dependence	A	A	B	A	C
Software dependence	B	A	B	C	C
Technology requirement	A	A	B	B	C
Cost per channel	H	H	M	M	L

A-C are in descending order of the requirements,H-High,M-Middling,L-low.

+PS





Comparisons

	Advantages	Disadvantage
PS(+SiPM)	Solid detector, structure simple, high rate capability, low operation voltage, use SiPM similar to HCAL, time resolution	DCR of SiPM
RPC	Cost, mature tech., time resolution	Fill gas, HV system
μ-RWELL	Spatial resolution, high rate capability	Structure, number of readout channels, time resolution, cost.

PS bar and RPC have similar cost.

Rate capability: $5\sim10\text{kHz}/cm^2$

Scintillator	base	density ϱ [g/cm^3]	τ_D [ns]	L_{ph}, N_{ph} [per MeV]	λ_{em} [nm]	$n(\lambda_{em})$
Anthracene		1.25	30	16 000	440	1.62
BC-408 (BICRON)	PVT	1.032	2.1	10 000	425	1.58
BC-418 (BICRON)	PVT	1.032	1.5	11 000	391	1.58
UPS-89 (AMCRYS-H)	PS	1.06	2.4	10 000	418	1.60
UPS-91F (AMCRYS-H)	PS	1.06	0.6	6 500	390	1.60

Our choice: PS(+SiPM) as the baseline option, RPC for comparison in R&D.

Technical Challenges

- Long detector module: $> 5m$, due to the large size of the muon detector.
- How to achieve the required efficiency and the time resolution from a long PS bar?
  - Kuraray fiber has an attenuation length of $6.8m$.
  - We got the effective attenuation length of $2.63m$ from lab testing on WLS fiber.

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- Requirements
- Technology survey and our choices
- Technical challenges
- R&D efforts and results
- Detailed design
- Performance from simulation
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R&D efforts and results

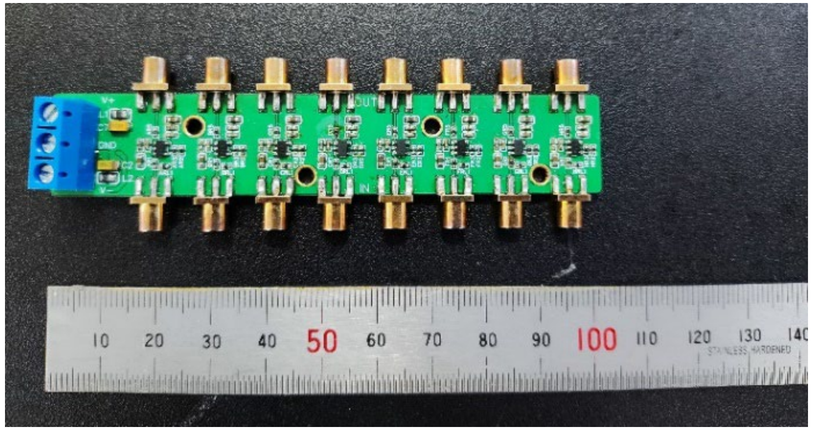
- Front-end electronics
- Performance of PS bars
- Simulation for improvements
- New R&D on PS bars
- Prototype and CR testing

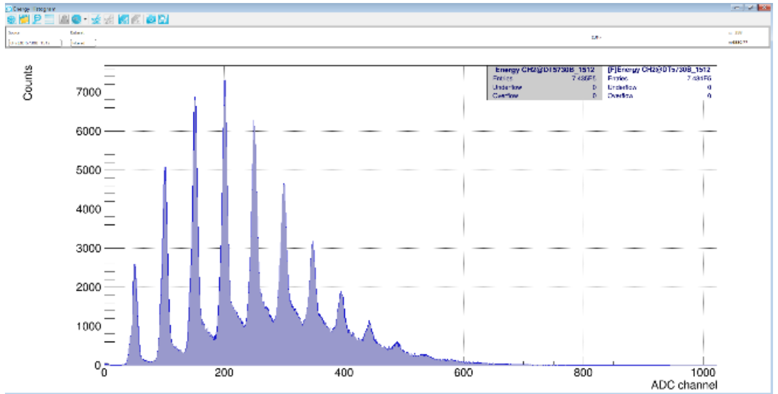
Published papers:

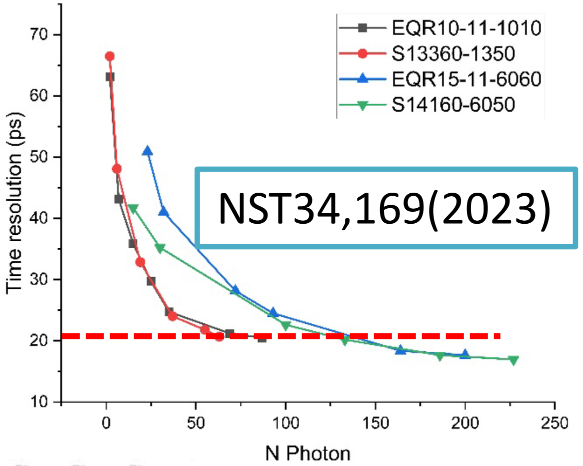
1. Design and performance of a high-speed and low-noise preamplifier for SiPM, Nucl. Sci. Tech. 34, 169(2023)
2. Design and test for the CEPC muon subdetector based on extruded scintillator and SiPM, JINST 19 P06020(2024)

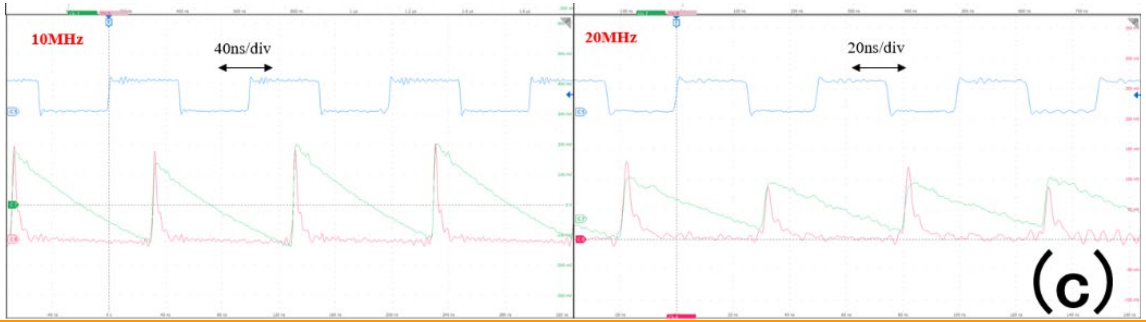
R&D for front-end electronics

- Many different kinds of preamps for SiPM have been designed and tested, such as:
  - Design high-speed and low-noise preamp for SiPM.
    - Baseline noise of 0.6 mV, bandwidth of 426 MHz, and time resolution of 20 ps.
    - Test with laser input at 20MHz.
    - Clear N_{pe} spectrum.





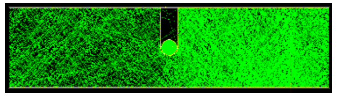




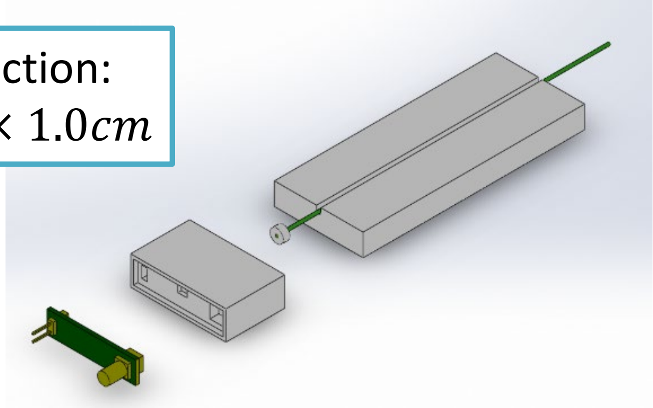
Performance of PS bars

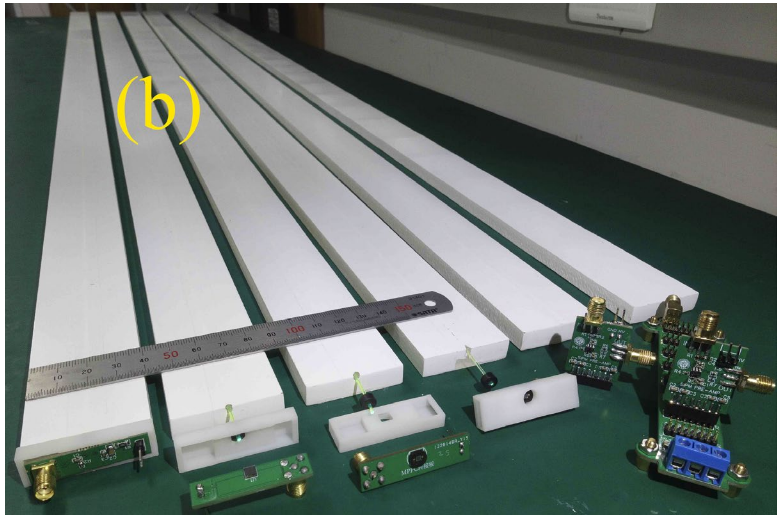
- PS bars made by GNKD company (Beijing)
  - Increase the light yield;
  - Develop/improve the reflection layer with Teflon;
  - Strip production, with a width of $4cm$.
- The quality of $1.5m$ bars has achieved the required performance, which will be described later.
- R&D on longer bar with hole has started

Samples with U groove



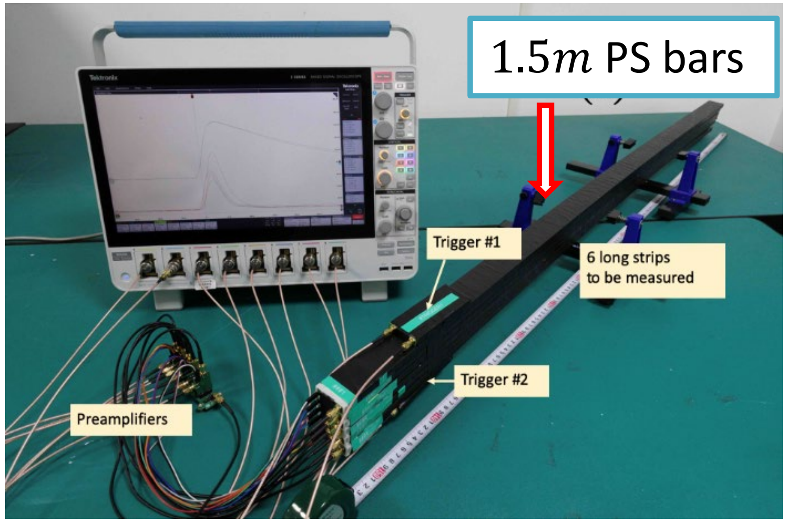
Cross section: $4.0cm \times 1.0cm$





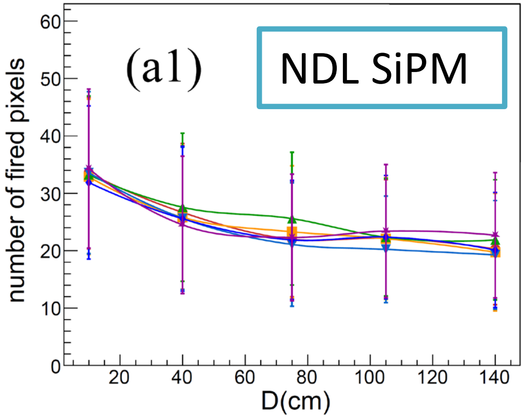
Prototype and CR test

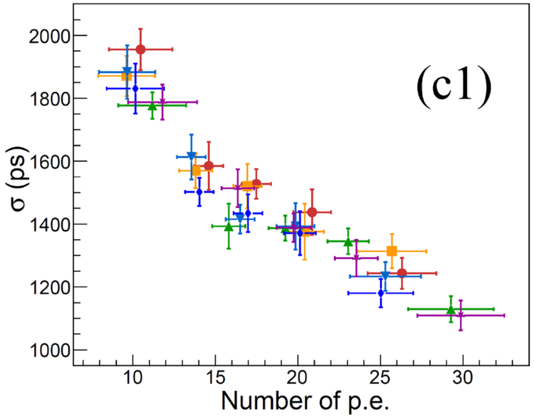
- Studies of SiPMs, WLS fibers
- Prototype:
  - $1.5m$ PS bar + WLS fiber $(1.2mm)$ + NDL SiPM/MPPC $(3.0mm/1.3mm)$
- Performance:
  - $\epsilon > 98\%$ can be obtained
  - Time resolution better than $1.5ns$

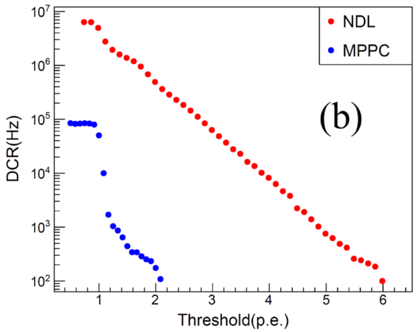


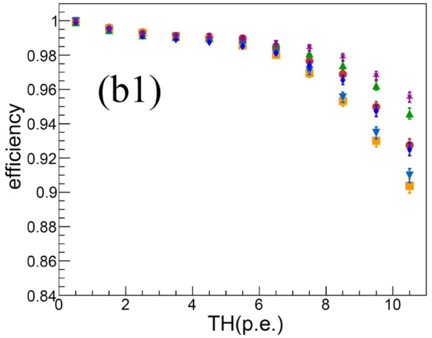
JINST 19 P06020(2024)

Effective attenuation length of fiber $L_{Att} = 2.63 \pm 0.37\ m$

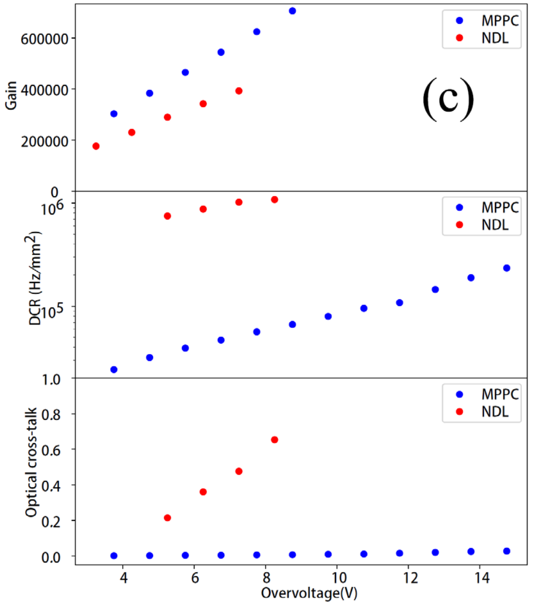


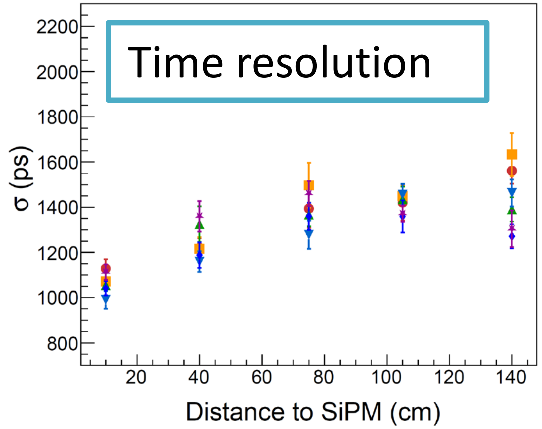






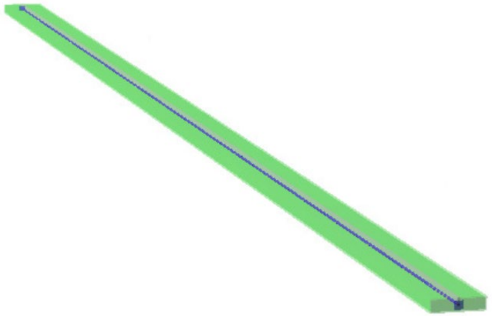
Properties of SiPMs

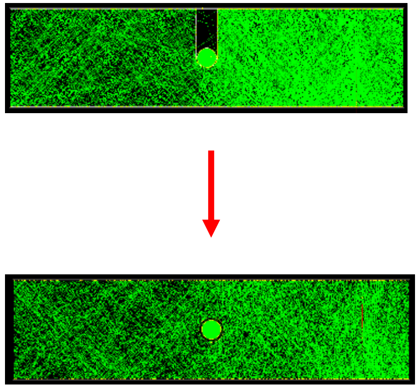




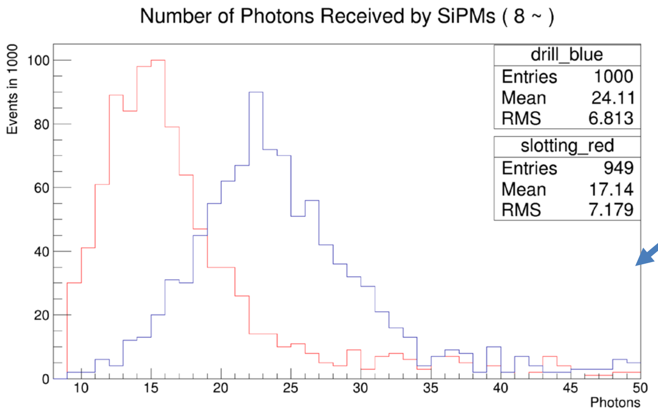
Standalone simulation

- Improving the performance of a single channel is to the key for a long detector module.
  - Light yield and light collection
- Simulation for single channel
  - Light collection and compared to lab test
  - Fiber embedding: Groove → hole, $N_{pe} \times 1.4$
  - Diameter: $1.2mm$ → $2.0mm$, $N_{pe} \times (2 - 2.8)$

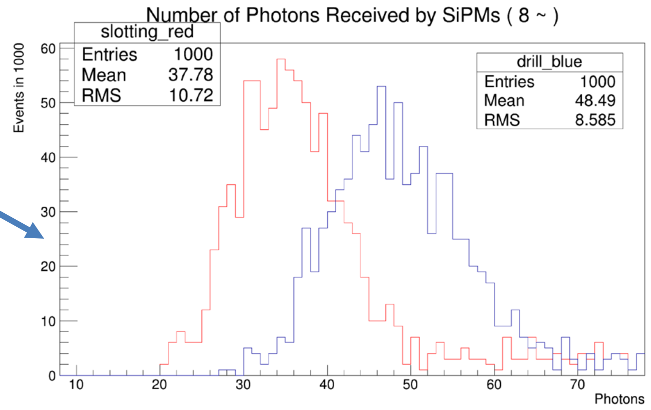


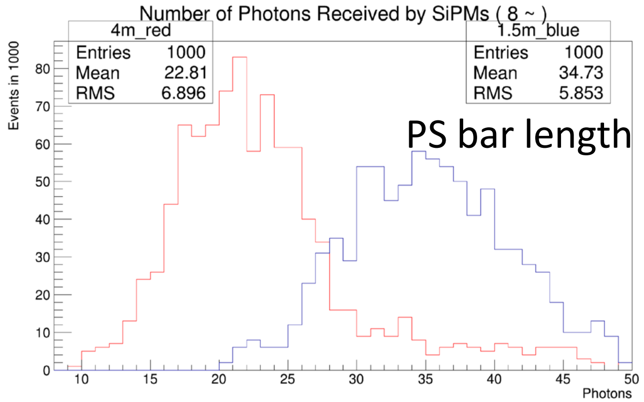


Simulation shows potential to increase the light yield by a factor of $(2.8 - 3.9)$, which is helpful for building long detector module.



Groove vs hole

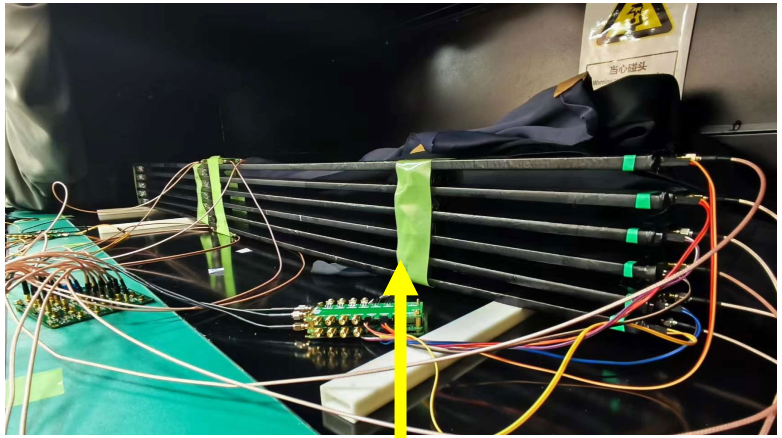




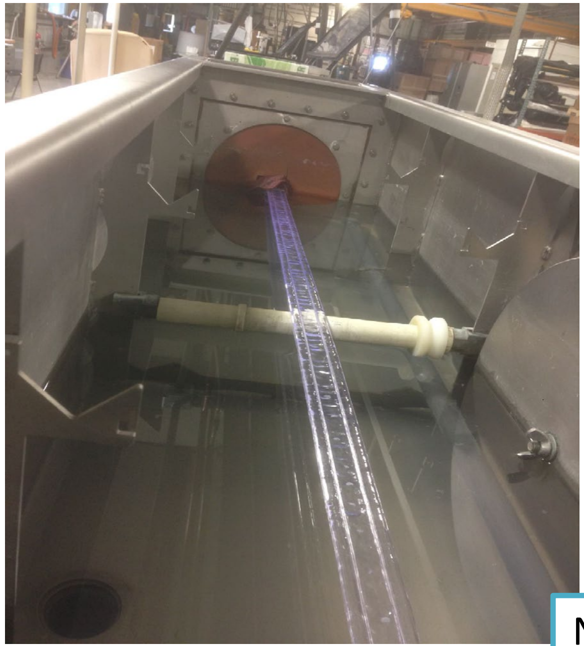
Improvements on the scint. strip

- Very new R&D in the past months, like the production in Fermi Lab.
- Fiber embedding: Groove → hole
- Diameter: no new fiber available yet, we use three 1.2mm fibers instead.

Use NDL EQR15 $3mm \times 3mm$



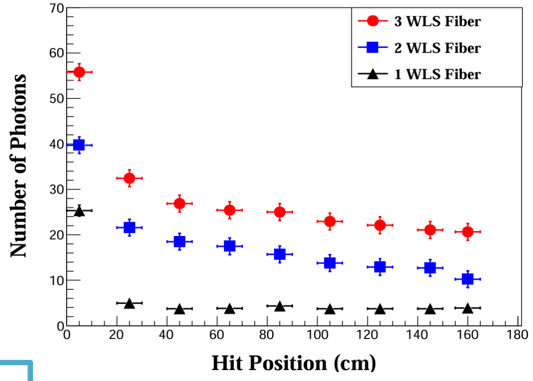
Trigger at middle

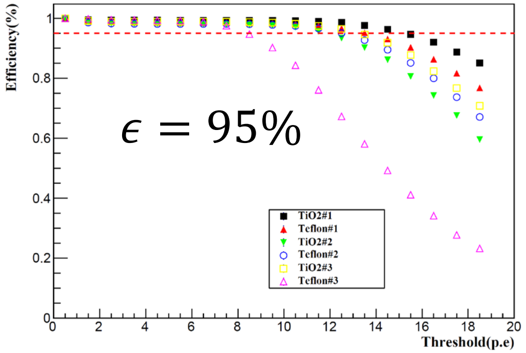


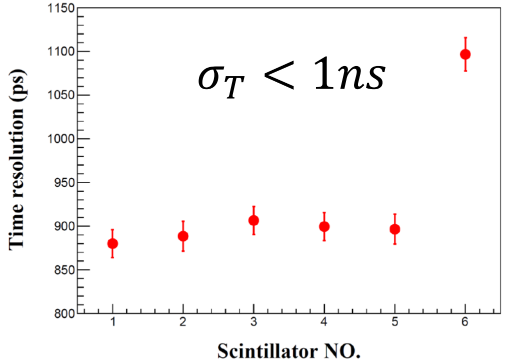
Scintillator production at Fermilab

New scintillator provided by GNKD, with our R&D!

1.65m new scint with 2.5mm diameter hole







Very positive to the design of long module (>4m).

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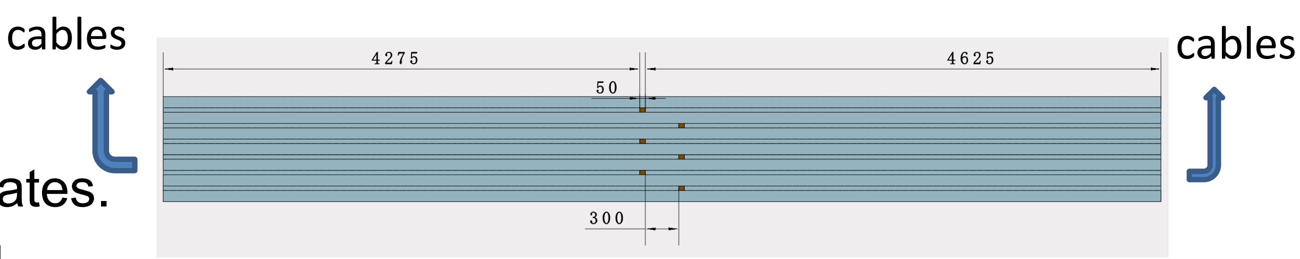
Detailed design

- Geometry: barrel and endcaps
- Detector channel elements and module
- Consideration on readout electronics

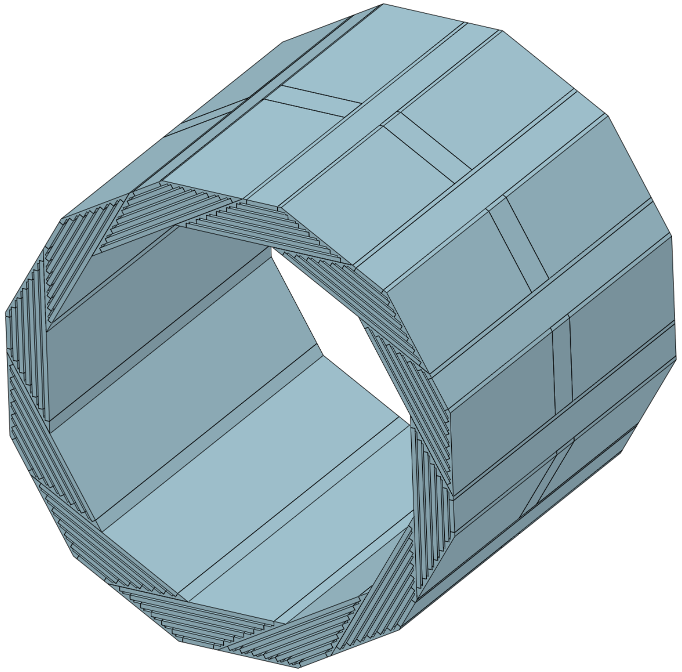
Detailed design - geometry

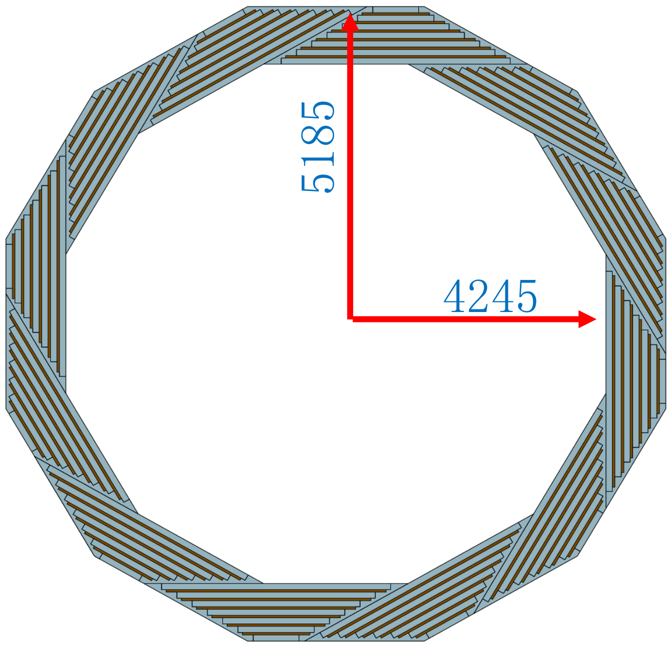
- Geometry: 6 superlayers, to cover the detection as much as possible
  - Barrel: Helix dodecagon sectors.
  - Rectangle modules inserted between iron plates.
  - Cable: towards the gaps between barrel and endcaps.

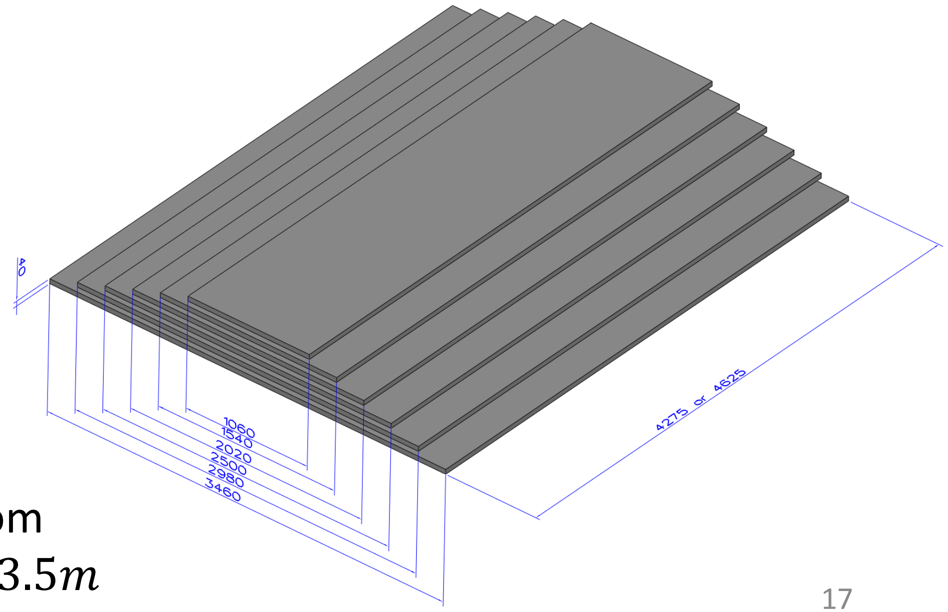
$L = 4.275m$ or $4.625m$



Vary the separation position to avoid dead zone in the middle of barrel.



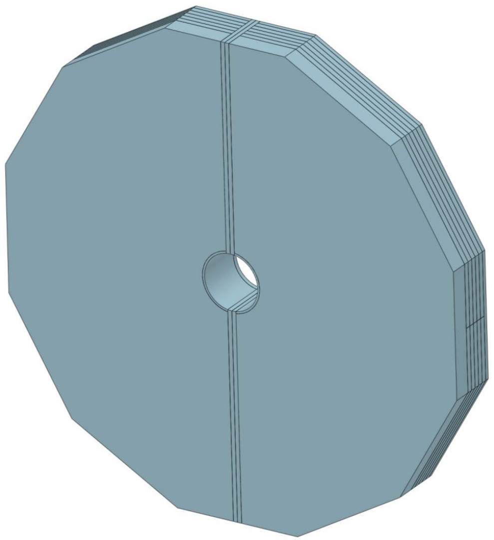


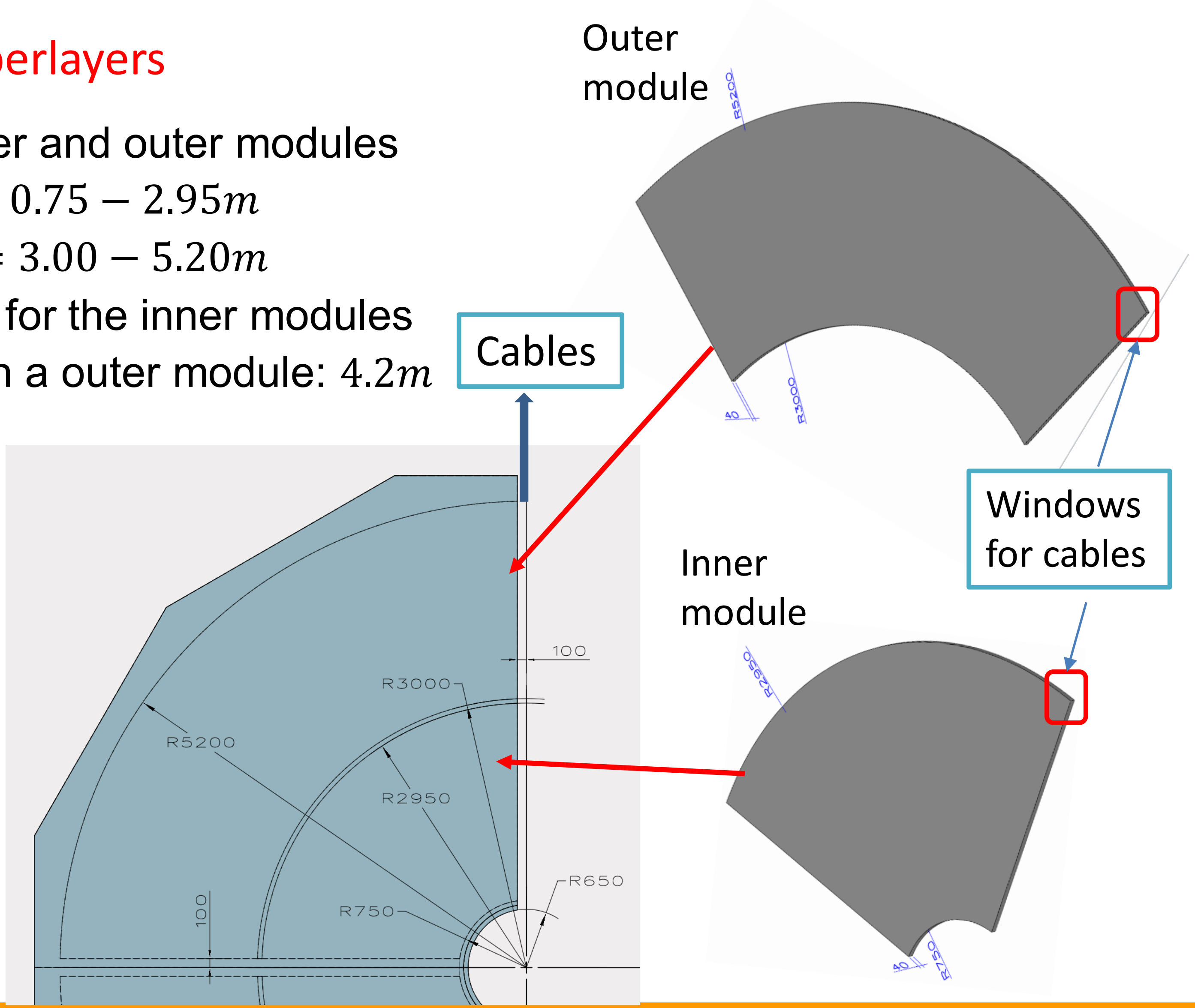


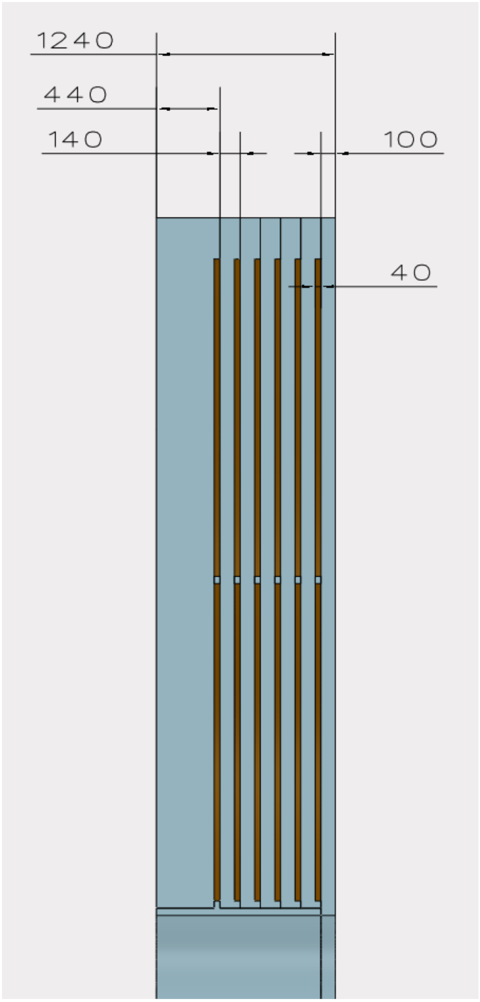
Width from 1.1 m to 3.5m

Detailed design - geometry

- Geometry: 6 superlayers
  - Endcaps: inner and outer modules
    - Inner: $R = 0.75 - 2.95m$
    - Outer: $R = 3.00 - 5.20m$
  - High hit rates for the inner modules
  - Longest bar in a outer module: $4.2m$



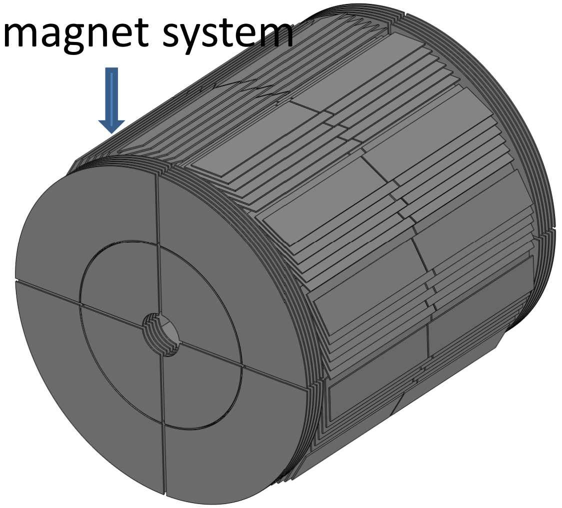


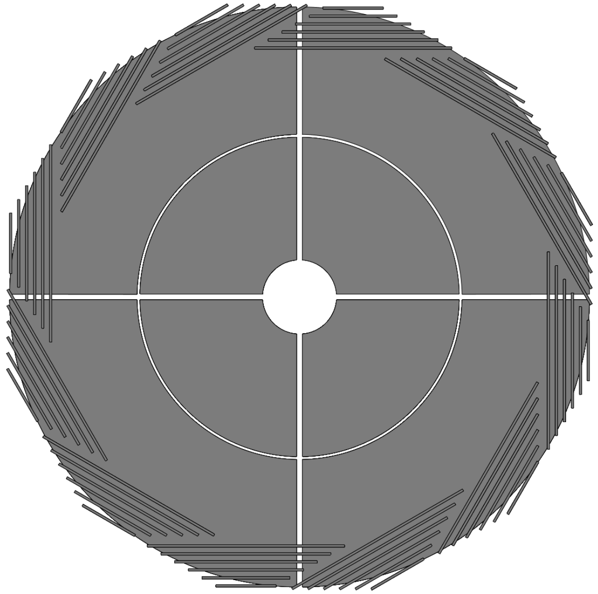


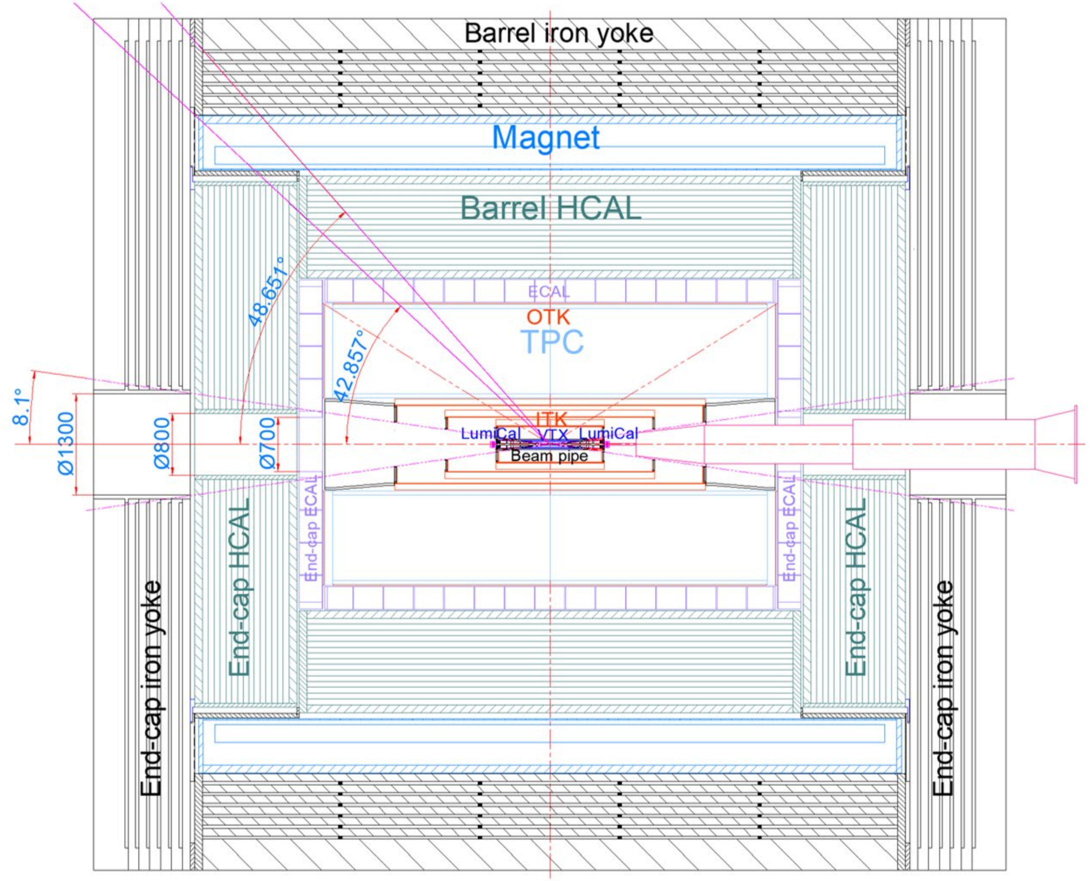
Overall of the design

- Number of channels: (288 modules) 43,176
  - Barrel: 144 modules, 23,976 ch
  - Inner endcaps: 48 modules, 6,912 ch
  - Outer endcaps: 48 modules, 12,288 ch
- Sensitive length: $119{,}563m$
  - Length for PS bar and WLS fiber
- Sensitive area: $4782m^2$

Chimney for magnet system





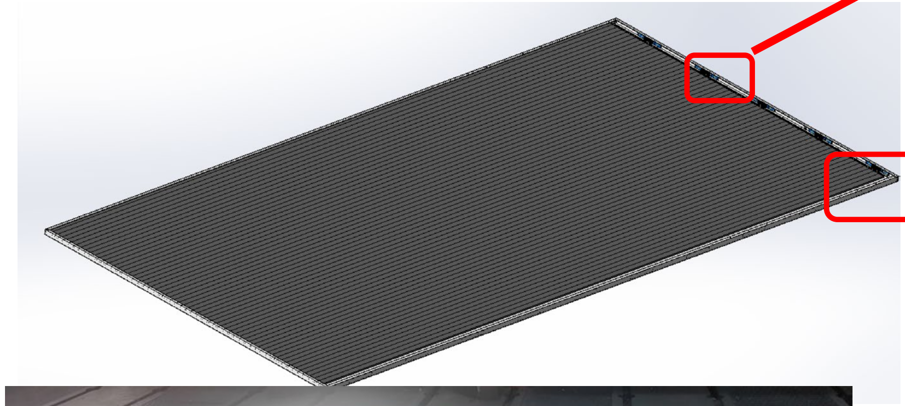


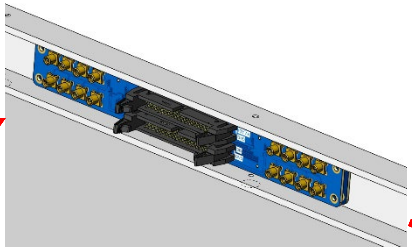
Detection dead area: $\sim 1.5\%$
0.04% due to chimneys in the barrel for magnet system, 0.07% from the cross in endcaps, and 1.4% due to the beampipe.

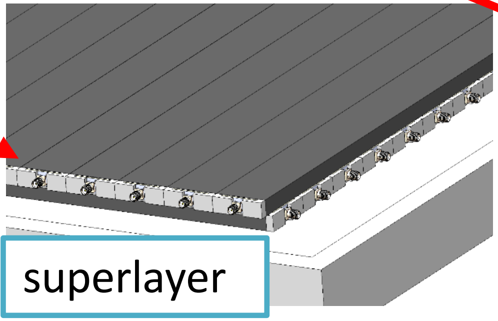
Detailed design of the channel and module

- Detector channel
  - PS bar: $4cm \times 1cm$ cross section
  - WLS fiber: $\phi = 2.0mm$
  - SiPM: $3mm \times 3mm$

- Detector module
  - Superlayer with perpendicular channels
  - Carriers for preamps held at the frame
  - Space between PS bars and aluminum layer is allowed for long cables.
- Mechanics
  - Aluminum frame, PS bars







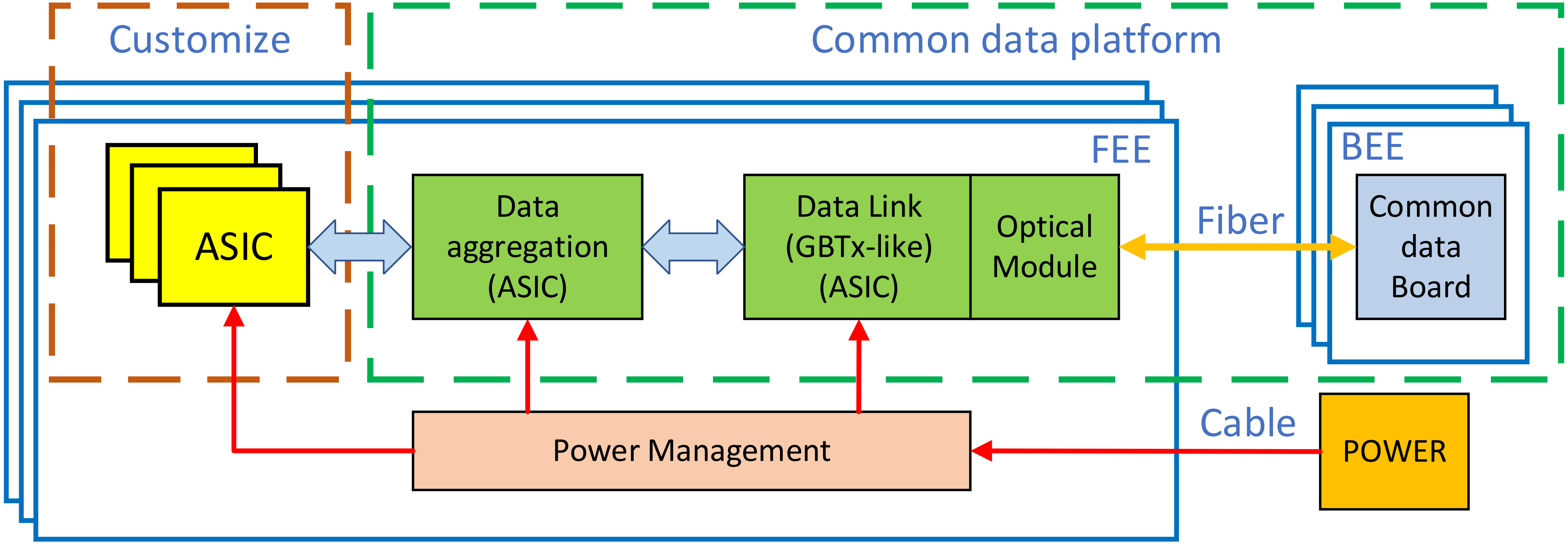
superlayer

To BEE with ribbon cables

First Al frame ($1.7m \times 1.7m$) is ready for module prototype.

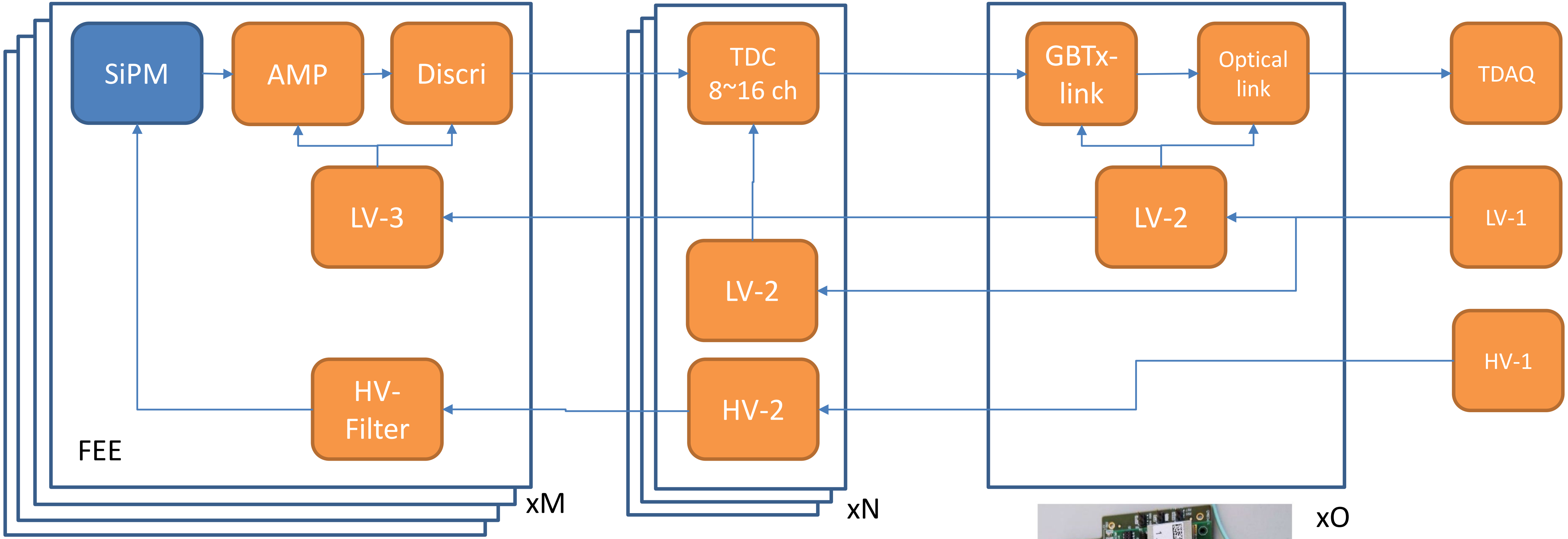
Carrier for the FEE, inside the module. Can be modified for the new electronics in the future.

Baseline for SiPM readout

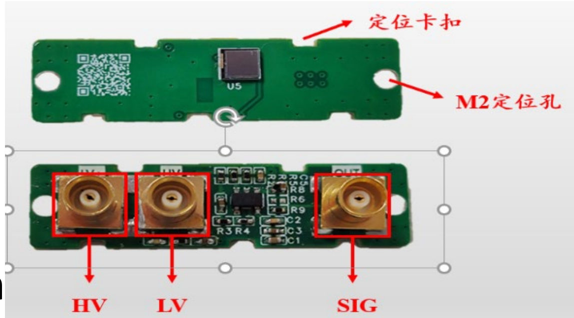


- Readout design for ECAL and HCAL covers the requirements of Muon detector: $N_{pe} < 100, \sigma_T < 0.5ns$
- Use the ASIC scheme from ECAL or HCAL, and customize the FEE based on ASIC.
- Revise according to the constraints from cooling and mechanical structure of the detector

Stage scheme



Example:



For each ch

For each module

For each sector

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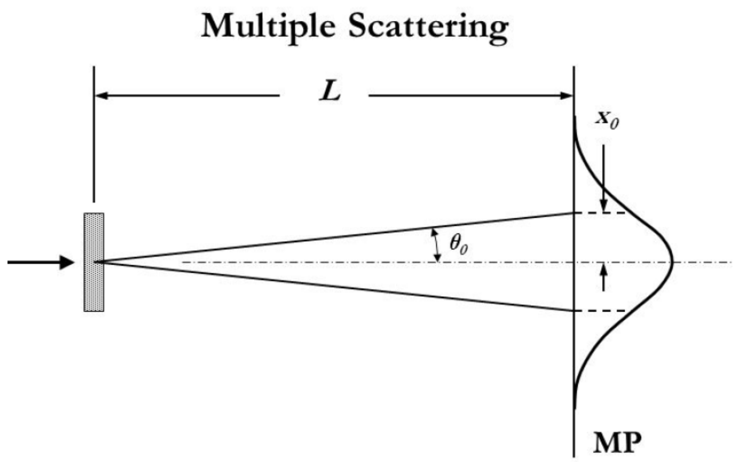
Geant4 simulation for performance

- Geometry and Geant4 simulation is implemented in CEPCSW, reconstruction and performance studies are ongoing:
  - Study of the Molière radius of muons originating at the interaction point and traversing the ECAL and HCAL. → Spatial resolution

Spatial resolution

- Spatial resolution due to the multiple scattering:

$$\Theta_{rms}^{proj.} = \sqrt{<\Theta^2>} = \frac{13.6\text{ MeV}}{\beta cp} z \frac{x}{X_0}[1 + 0.038\ln(x/X_0)]$$



- From the calculation: $\sim 1.3cm$
- Reference to Belle II (1cm):

  $L \times 2$, $p_{th} \times 4 \rightarrow \sigma_{scat} \sim 1cm$
- The higher momentum, the smaller σ_{scat}

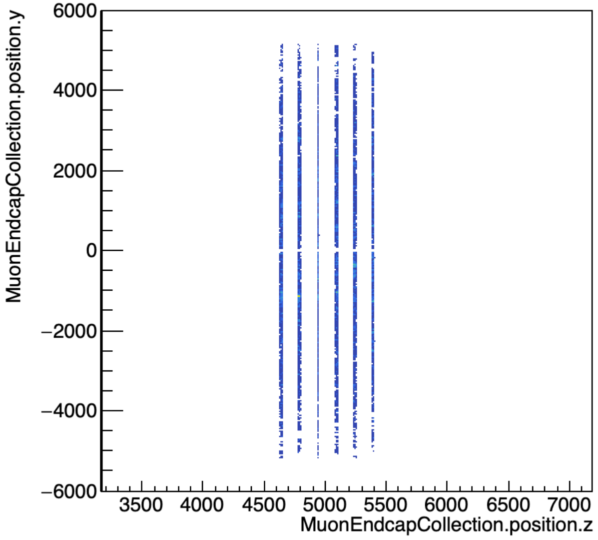
Spatial resolution of $1\ cm$ is required, i.e., keep the width of **$4\ cm$** for a PS bar.

Detector Simulation

- Everything based on CEPCSW framework.

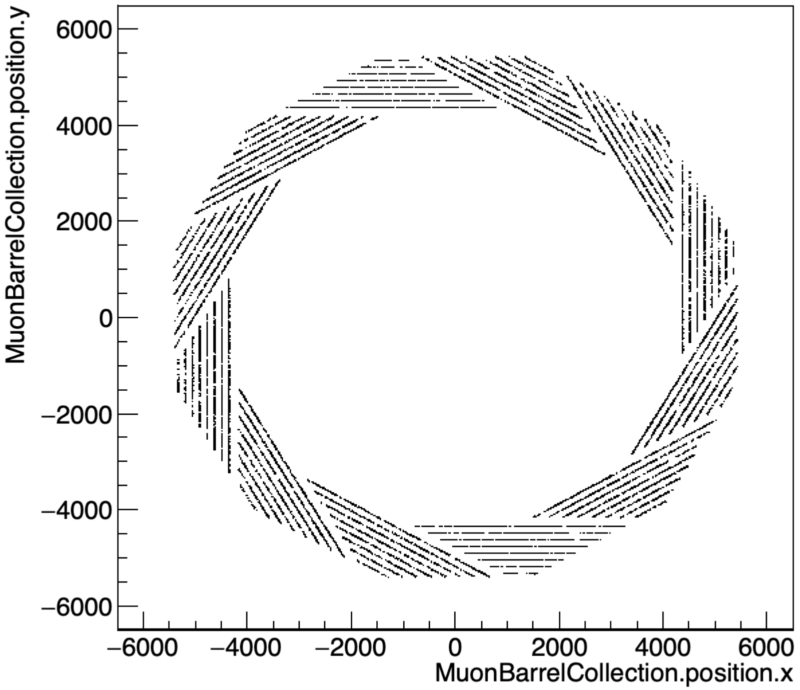
Muon Sim Hit positions

z-y position map in Endcap



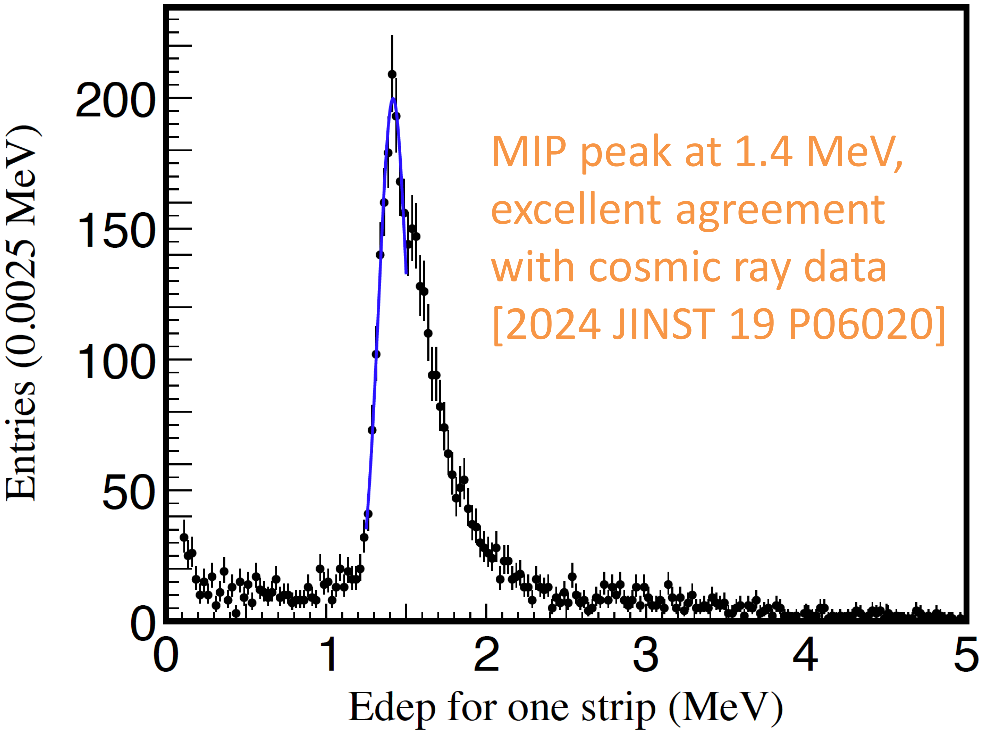
1k muons at 10 GeV muons

x-y position map in Barrel



Muon detector geometry is clearly visible!

Muon Sim Hit Energy deposition



MIP peak at 1.4 MeV, excellent agreement with cosmic ray data [2024 JINST 19 P06020]

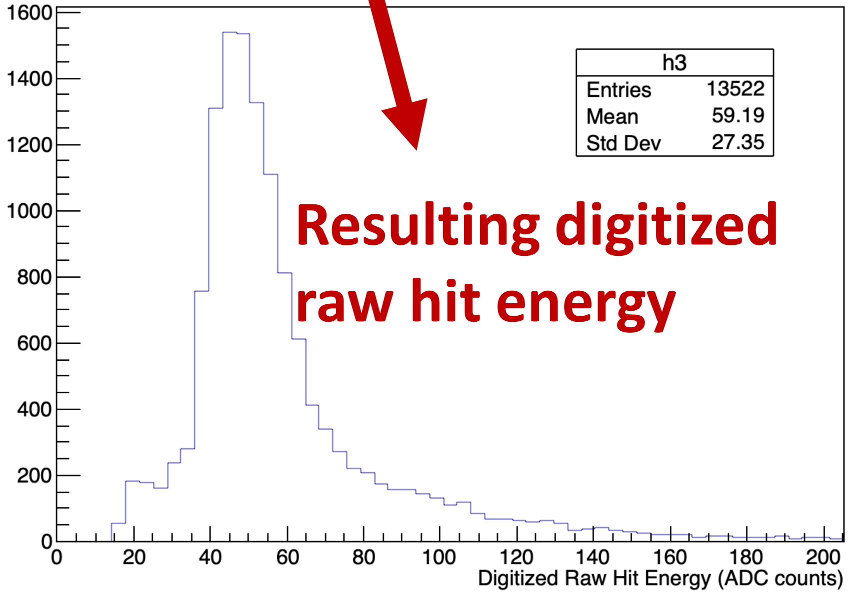
Detector Simulation

- Digitization from "Sim Hit" (deposited energy) to "Raw Hit" (ADC counts)
- A first experimental version implemented:
  - A simplified model from deposited energy to ADC counts.
  - Only for barrel at the moment.

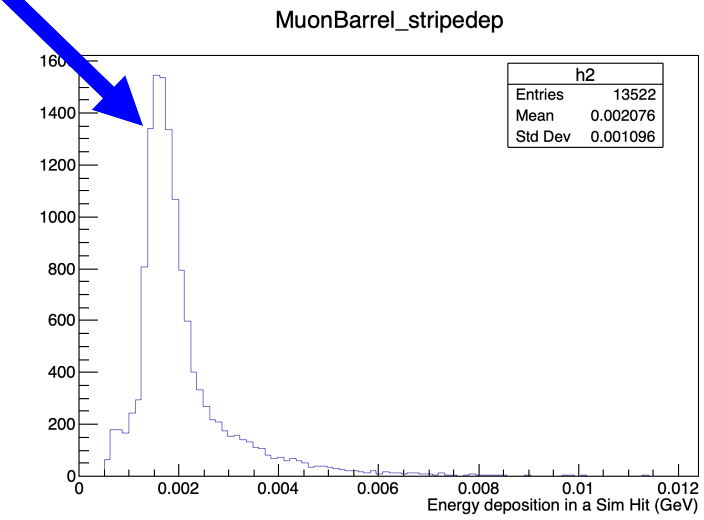
a MIP

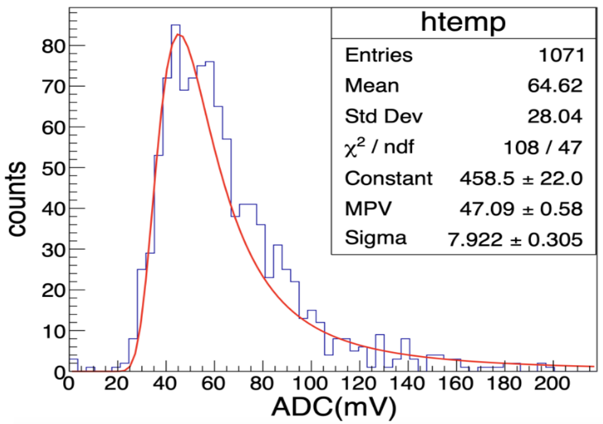
ADC distribution of MIPs from CR testing.

$$E_{dig}\ \text{(ADC counts)} = E_{sim}\ \text{(MeV)} \div 1.4\ \text{MeV} \otimes$$



Resulting digitized raw hit energy



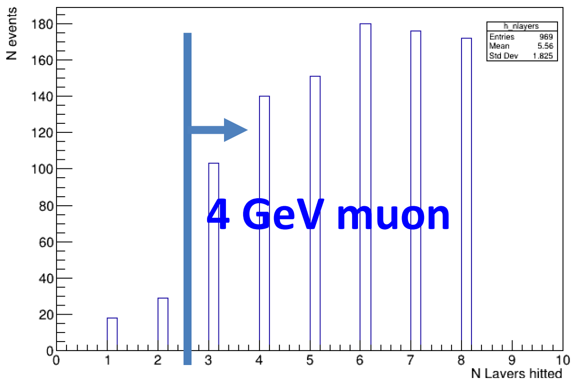


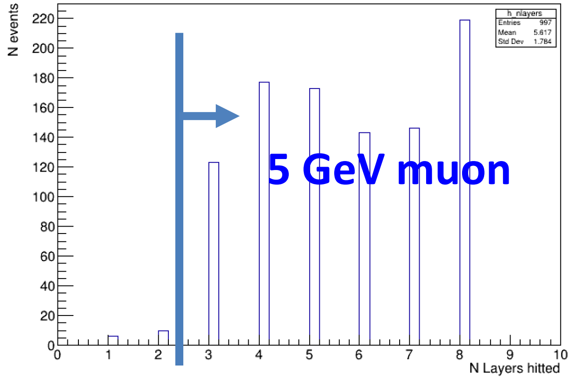
[2024 JINST 19 P06020]

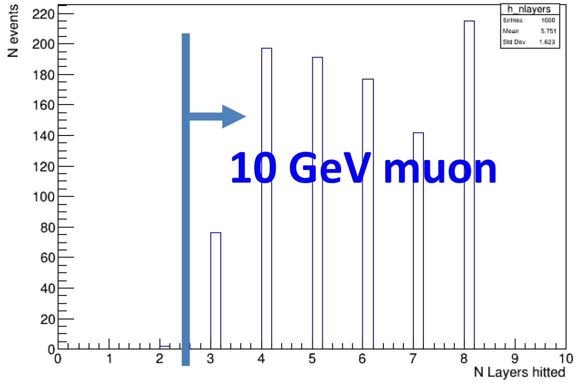
Muon ID from simulation

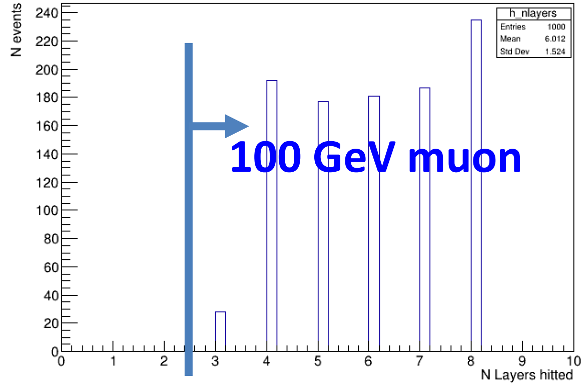
- Muon ID efficiency vs. momentum
- Define Muon ID:

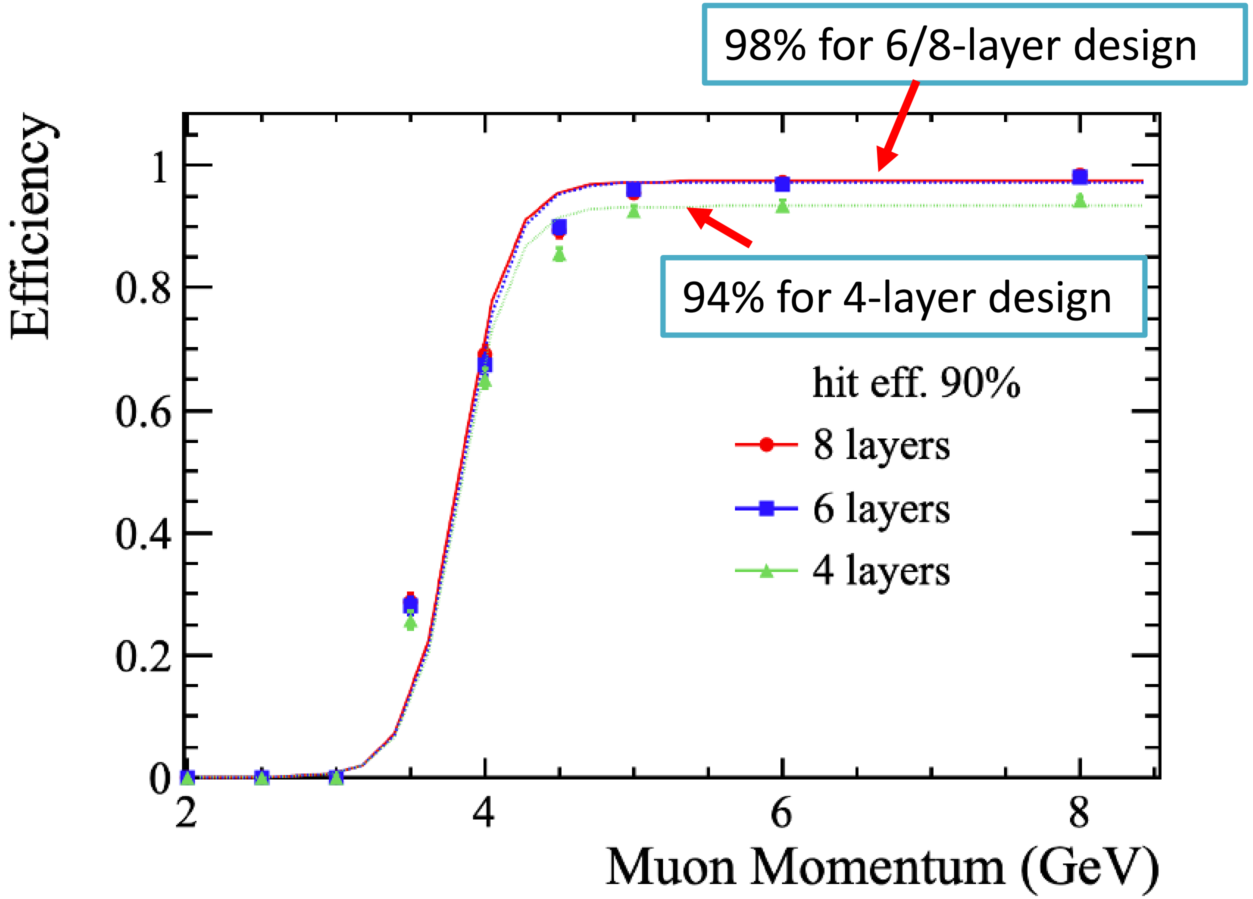
  If a muon candidate has 3 or more hits reconstructed in the muon detector, it is identified as a muon.









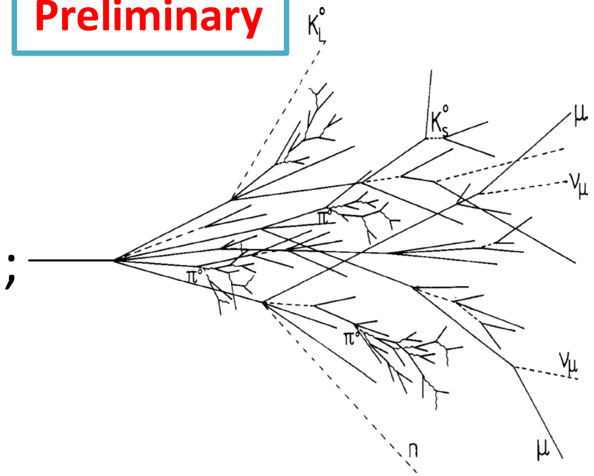


Muon ID efficiency of the barrel

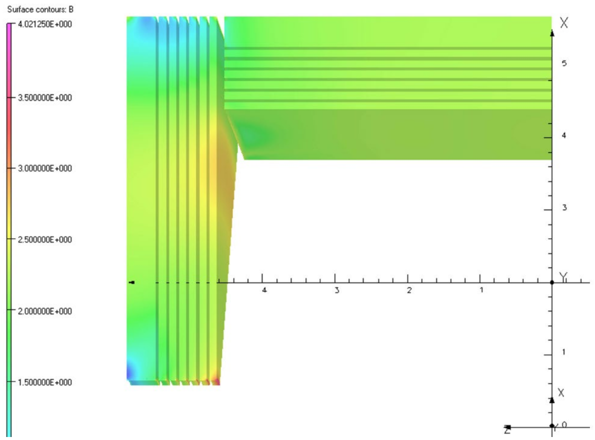
About track reconstruction

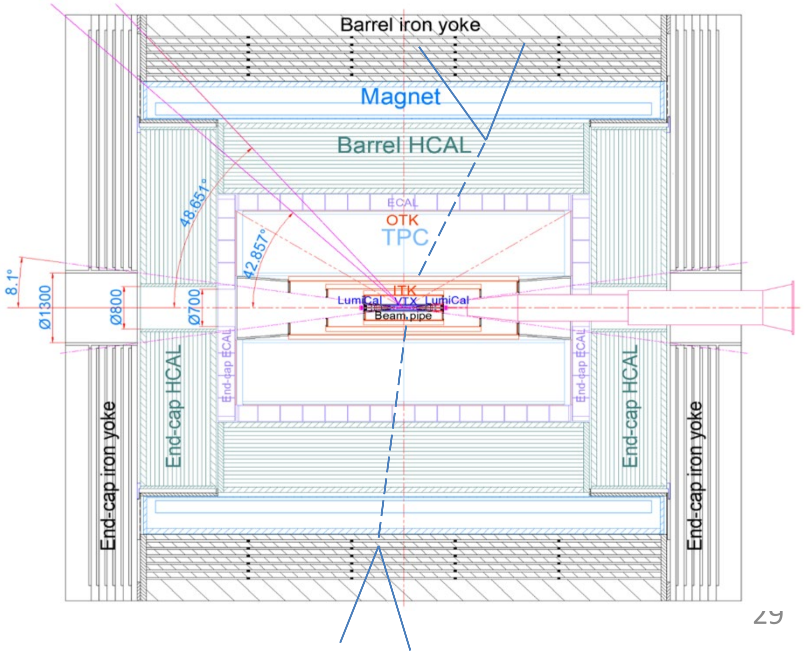
- Tracking in the muon detector may be used to rescue some energy leakage of HCAL:
  - Magnet field in the iron layers can be simulated;
  - Most charged particles in the tail of a hadronic shower are $\pi^{\pm}$ and $\mu^{\pm}$.
  - If we can reconstruct the momentum of these charged particles, or add their masses, at least.
  - K_L may be reconstructed from its decay to $\pi^+\pi^-\pi^0$.
- Tracking in the Muon detector can extend the search of LLP from $L < 3.5\ m$ to $L < 4.9m$.

Preliminary



Magnet field





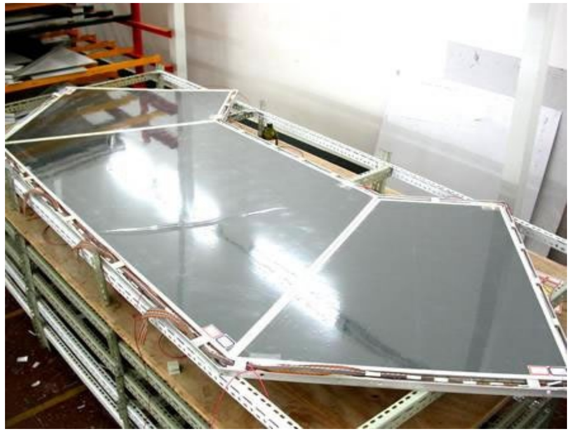
Content

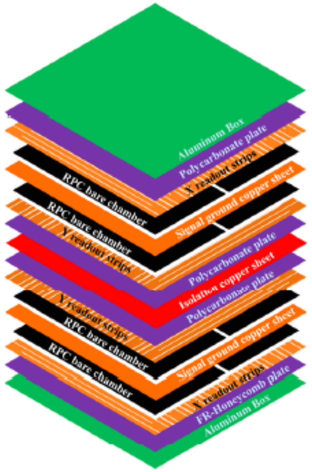
- Introduction
- Requirements
- Technology survey and our choices
- Technical challenges
- R&D efforts and results
- Detailed design
- Performance from simulation
- RPC related and testing
- Research team and working plan
- Summary

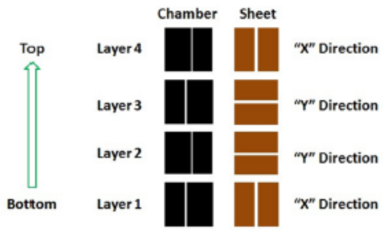
For the backup option

RPC technology used in China

	MUC@BESIII	CR veto@DYB
Bare RPCs	1,272 m^2	3,200 m^2
Box	136	195
Readout strip & insulation materials	636 m^2	3,200 m^2
Electronics	9,152ch	6,000 ch



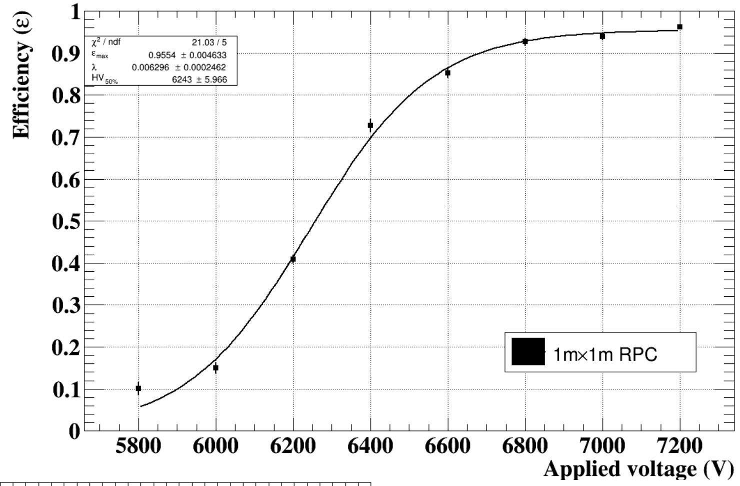




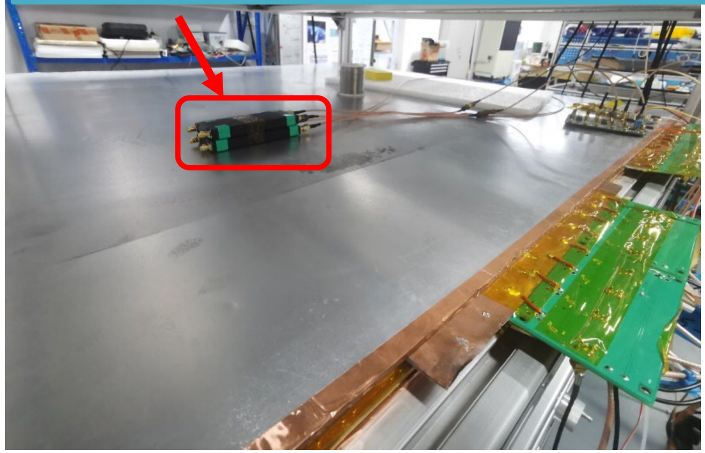
Ongoing R&D at SJTU

- A prototype from ATLAS (upgrade).
- Use R134a gas, 1.2 mm gas gap.
- Gain of preamp: 16
- Efficiency curve and time resolution determined from CR testing.

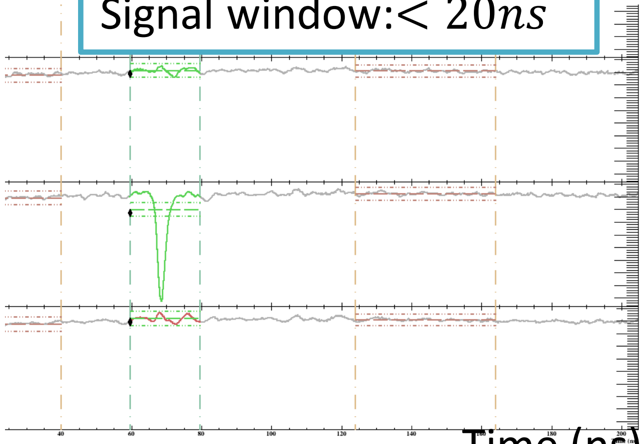
Fit to $\boldsymbol{\varepsilon} = \frac{\varepsilon_{max}}{1+e^{\lambda\times(HV_{50\%}-\boldsymbol{U})}}$

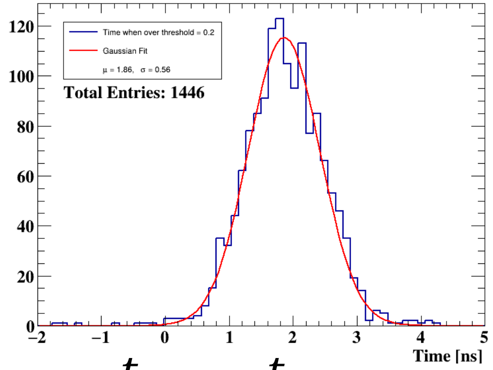


Trigger with time resolution < 0.1ns

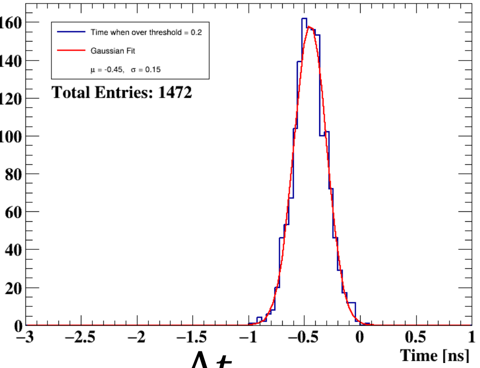


Signal window: $< 20ns$





$t_{RPC} - t_{trig}$



Δt_{trig}

For the backup option, we will perform the R&D focusing on glass with low resistance ($10^{10}\Omega m$), which is available in China.

$$\sigma_{RPC} = \sqrt{\sigma^2_{\Delta t_{RPC}} - \frac{\sigma^2_{\Delta t_{trig}}}{2}} \approx 550ps$$

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Research Team

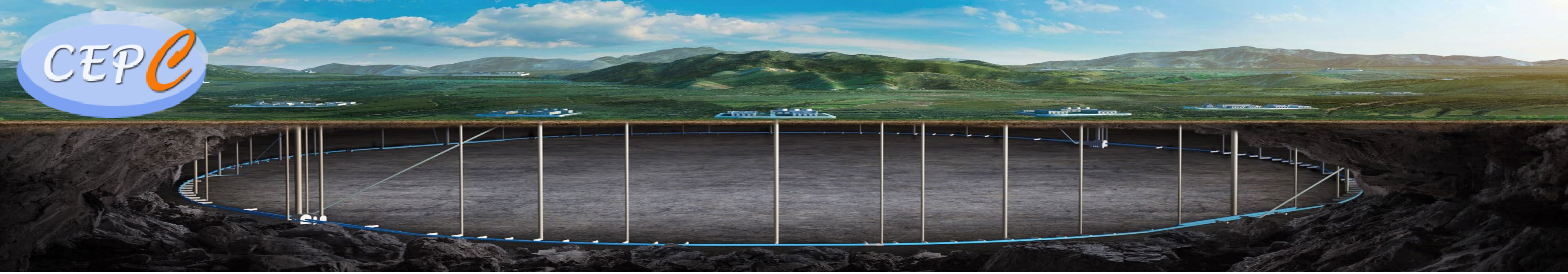
- Institutions (7) and faculties/staff (13)
  - Fudan University: Xiaolong Wang, Wanbing He, Weihu Ma
  - Shanghai Jiaotong University: Jun Guo, Liang Li
  - IHEP: Zhi Wu, Yuguang Xie, Jie Zhang
  - South China Normal University: Hengne Li
  - Nankai University: Minggang Zhao, Junhao Yin
  - LPI: Pasha Pakhalov
  - BINP: Alexander Barnyakov
- Graduate students: ~20
- Task board:
  - Overall: X.L. Wang
  - Software and simulation: H.N. Li, J.H. Yin, M.G. Zhao
  - R&D on PS scheme: X.L. Wang, Z. Wu, W.B. He, W.H. Ma
  - R&D on PRC scheme: J. Guo, Y.G. Xie
  - Production and testing: Z. Wu, Y.G. Xie
  - Electronics: J. Zhang
  - Radiation hardness test: W.H. Ma
  - LLP search: L. Li

Working plan

- Improvement and optimization of PS bars
- Build a prototype module and testing
  - The performance of a module with a length of $5m$: efficiency, time resolution
- Optimization of structure design
- Software and simulation
- Radiation hardness studies.

Summary

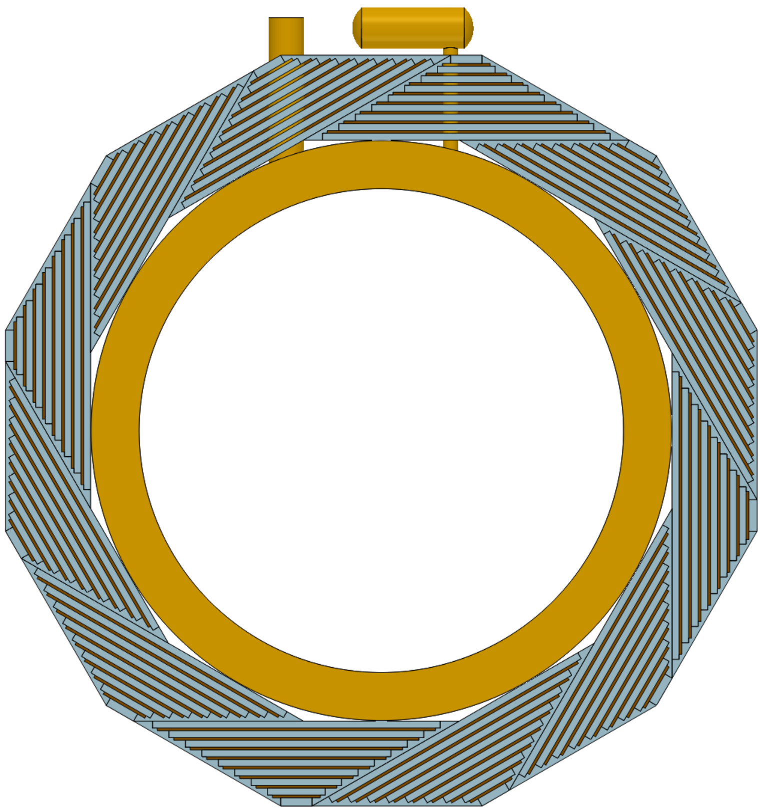
- Muon detector will be designed for muon ID, but not limited to this.
- Many R&D efforts have been performed: FEE, prototype, simulation, etc.
  - Performance of a $1.5m$ prototype: $\epsilon > 98\%$, $\sigma_T < 1.5\ ns$
  - R&D on new scintillator with hole shows very good performance.
- Detailed design:
  - Barrel: 6 layers, 2 long modules per layer, helix dodecagon
  - Endcaps: 6 layers, 4 sectors per layer, two modules (inner and outer) per sector
  - Large area modules with long PS bars.
  - $43{,}176$ channels, $4782\ m^2$ area, and $119{,}563\ m$ long fiber, in total.
- Work plan will focus on electronics, software and simulation for performance, prototype modules with long bars.

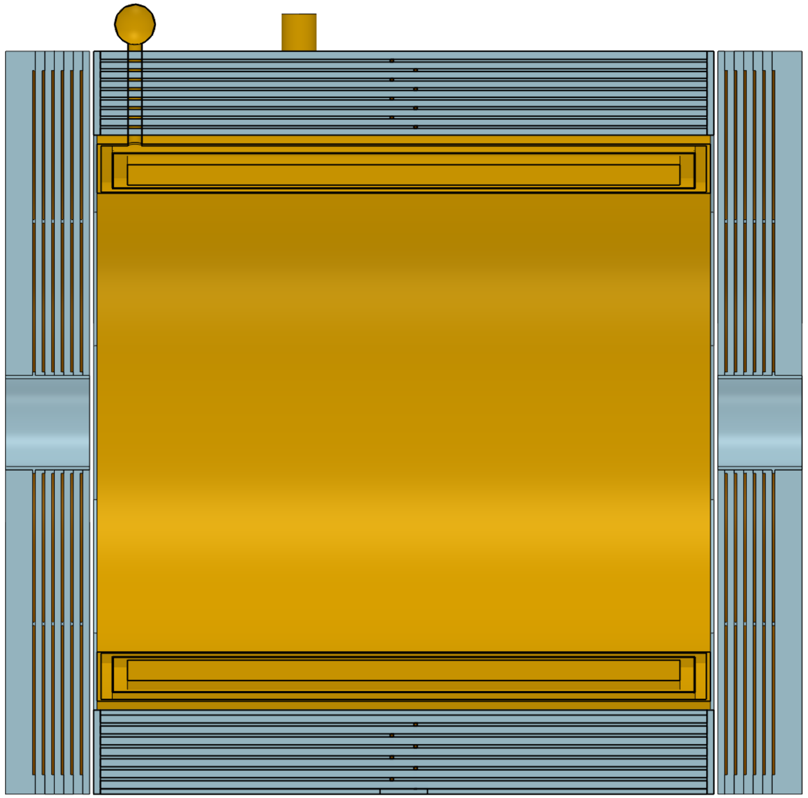


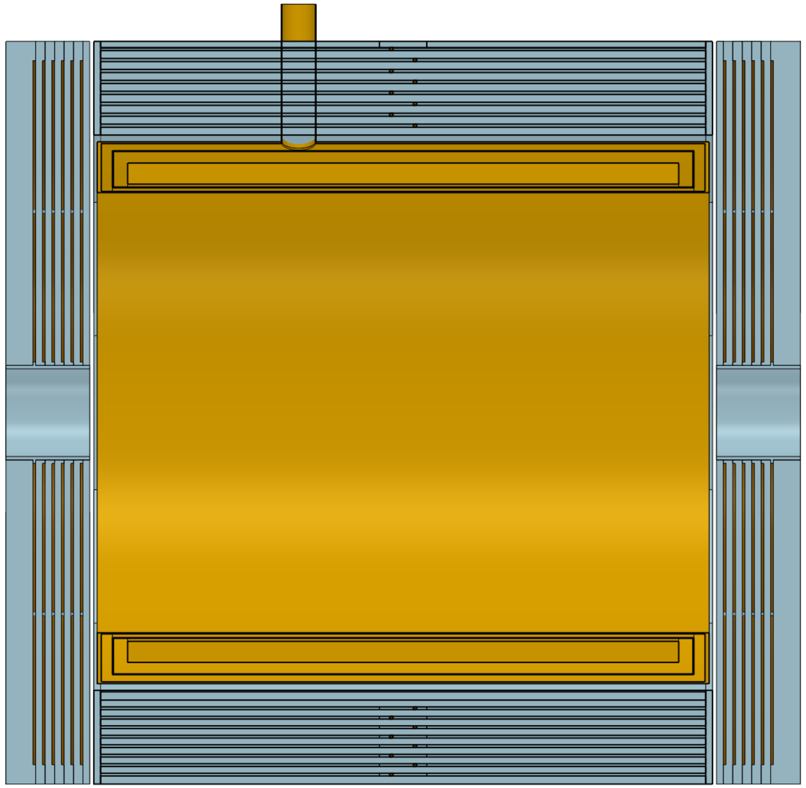
Thank you for your attention!

Add chimneys

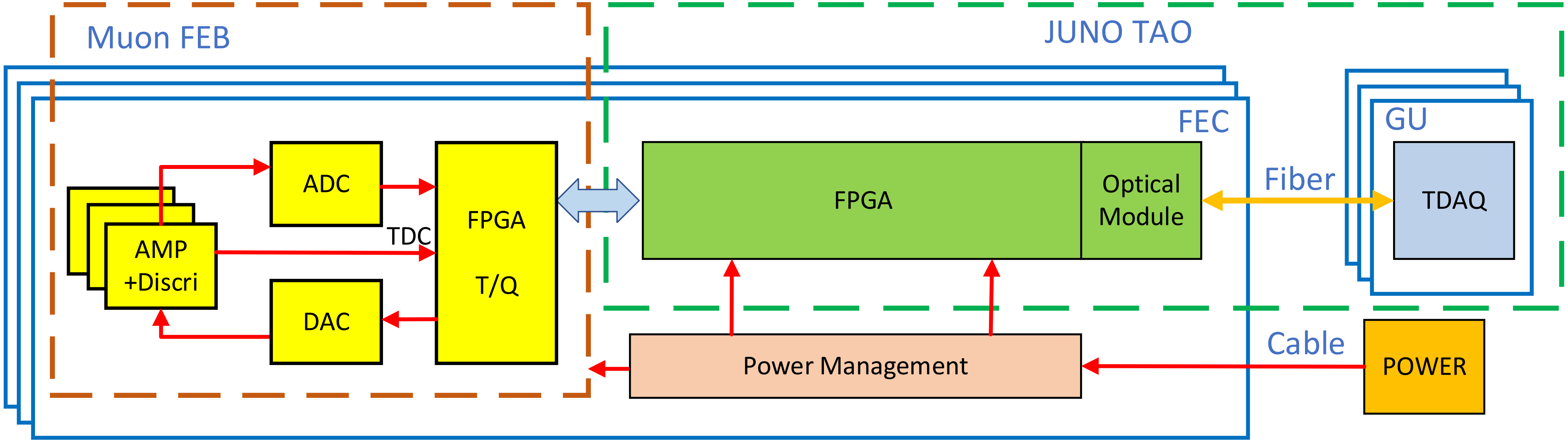
- Input the chimneys of the magnet system.
- It contributes a dead zone of <0.4%.





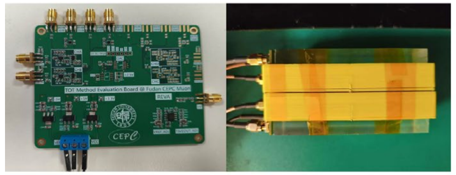


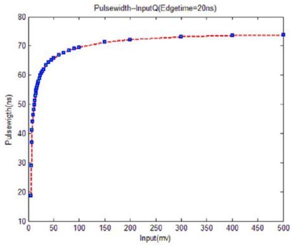
Near-term test environment

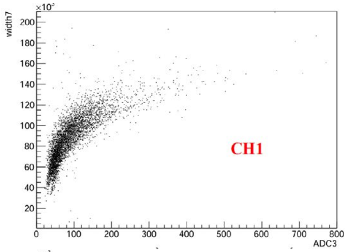


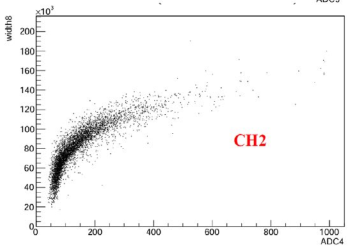
- FEB (Front-end Electronics Board)
  - Commercial chips with radiation tolerance based on past studies for particle physics experiments
  - FPGA based TDC for TOA and TOT measurement with ~1 ns time resolution
  - ADC for charge measurement or TOT calibration
  - DAC for threshold setting or SiPM bias voltage adjustment
- Reuse JUNO-TAO electronics for readout, clock synchronization and TDAQ
  - To accelerate the development schedule

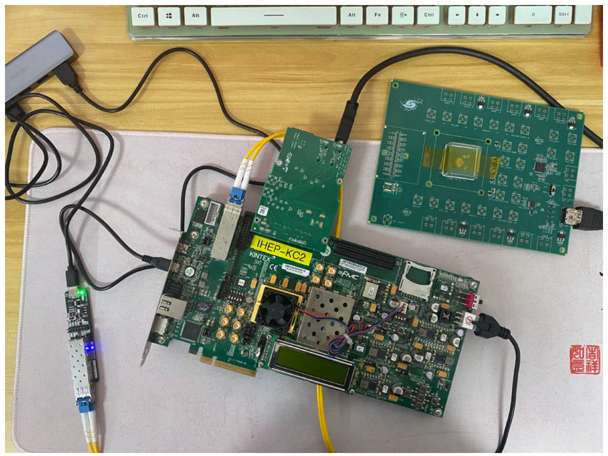
Test for TOT









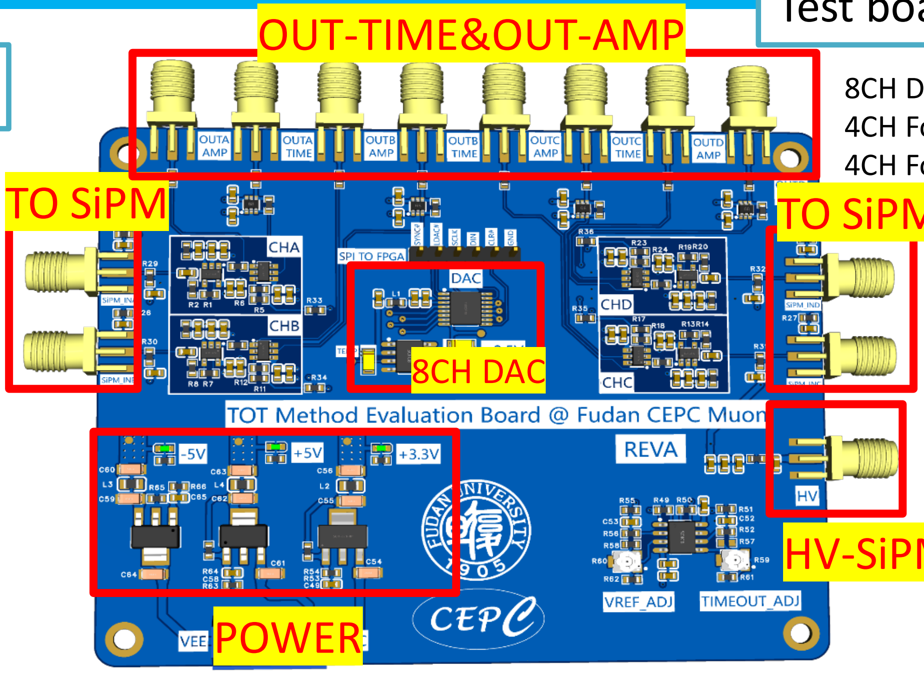


Readout electronics: Time-over-threshold (TOT) scheme

- Front-end electronics ready:
  - High time resolution preamp: $\sigma_T \approx 20\ ps$
  - High-speed discriminator shows $\sigma_T \approx 0.2\ ns$
- Implementation of TOT: operational amplifier + high-speed discriminator + TDC.
- FEE integrated DAC to adjust threshold and SiPM bias voltage.
- It's possible to get N_{pe} according to TOT.
- Investigating the possibility of integrating the BEE into the detector module: only power cable and signal fiber.

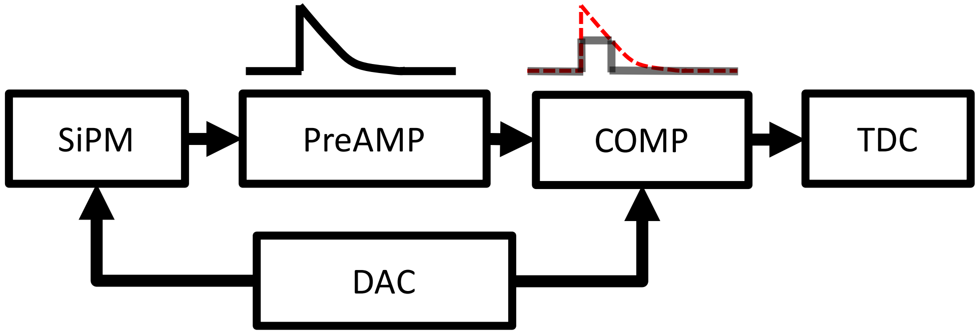
Long cables!

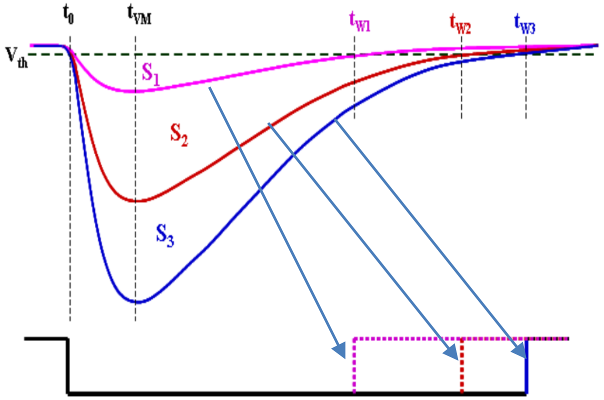
Test board

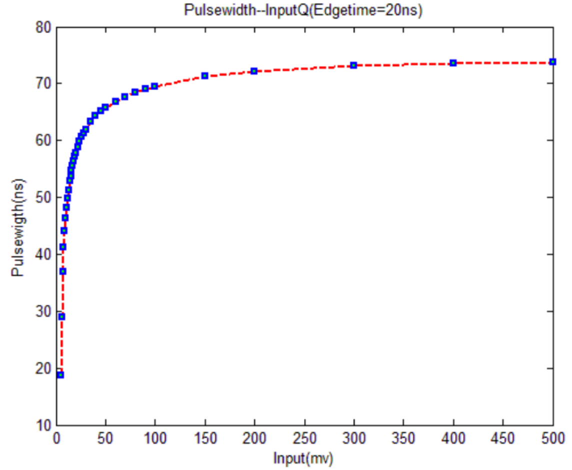


8CH DAC AD562
4CH For HV_ADJ
4CH For TH_ADJ

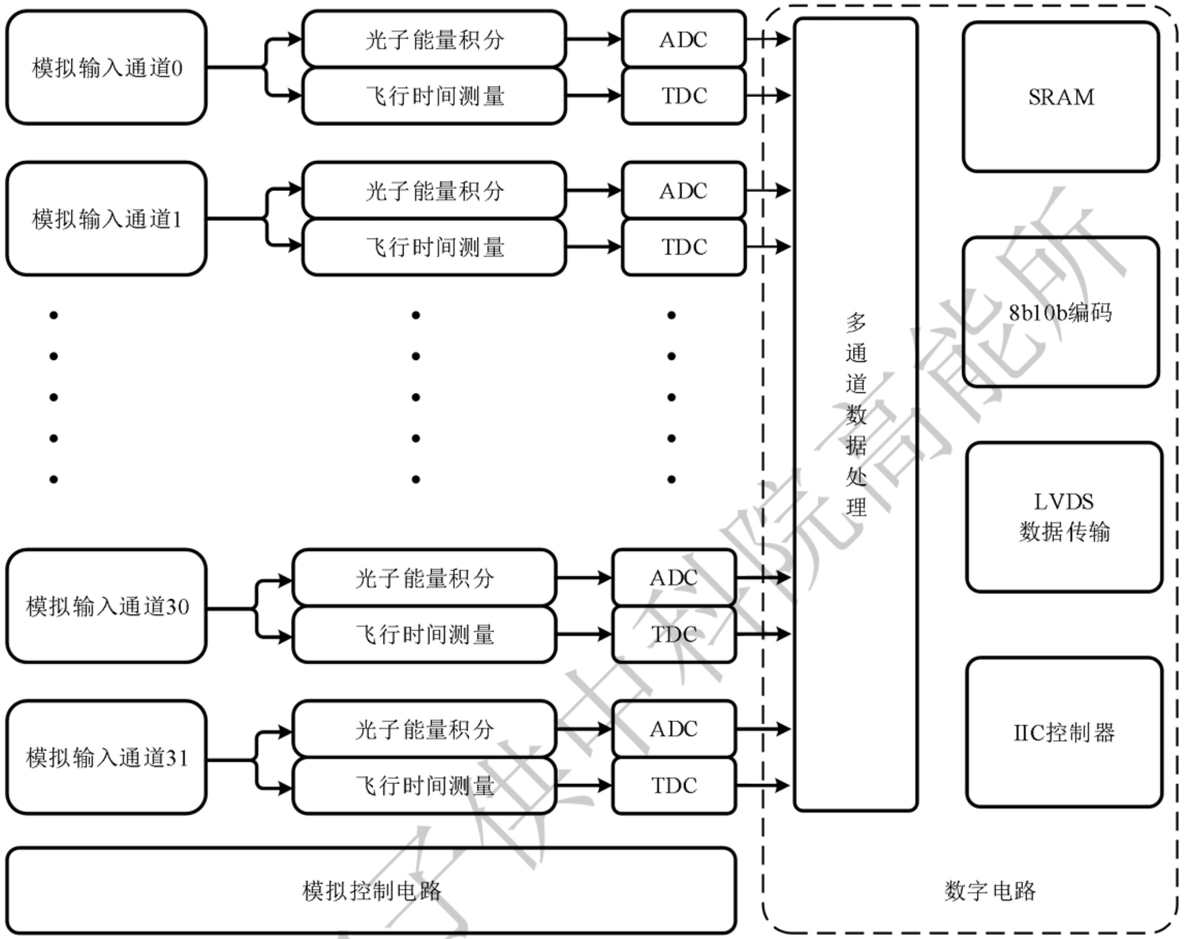
Temperature sensor will be included.

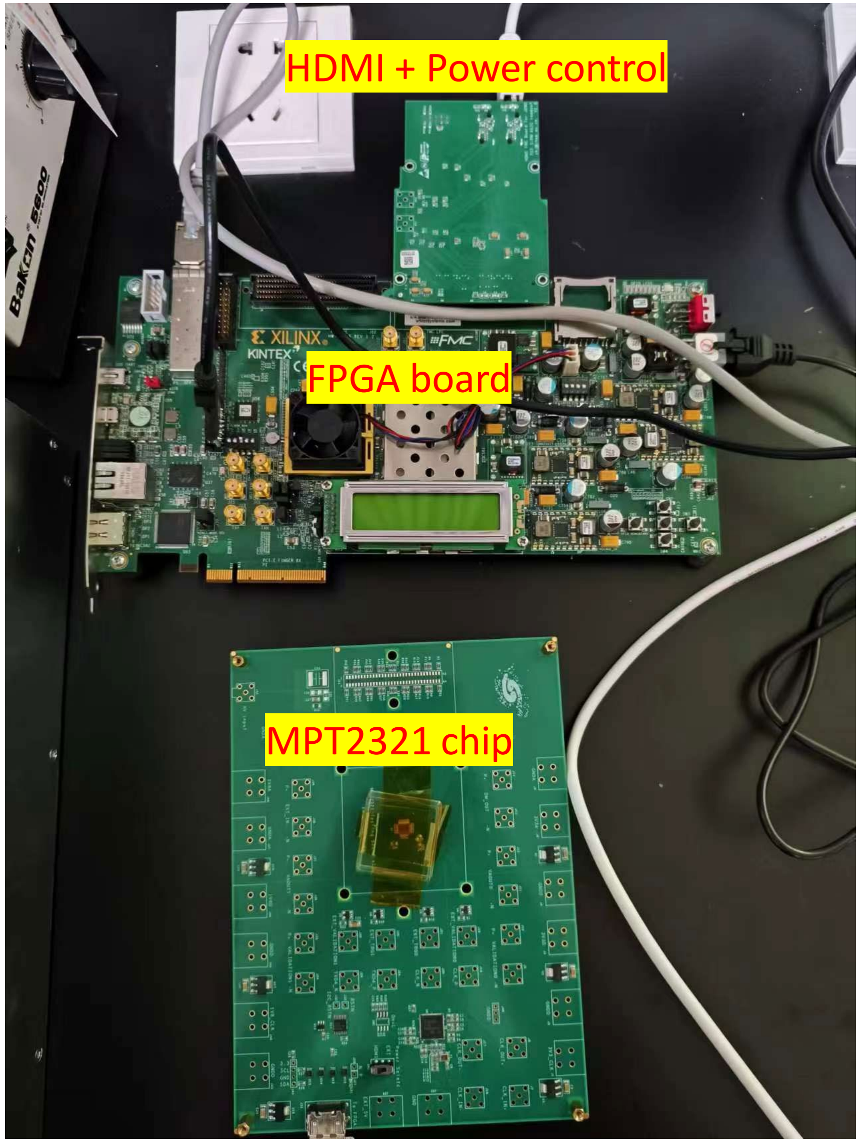






SiPM – ASIC MPT2321



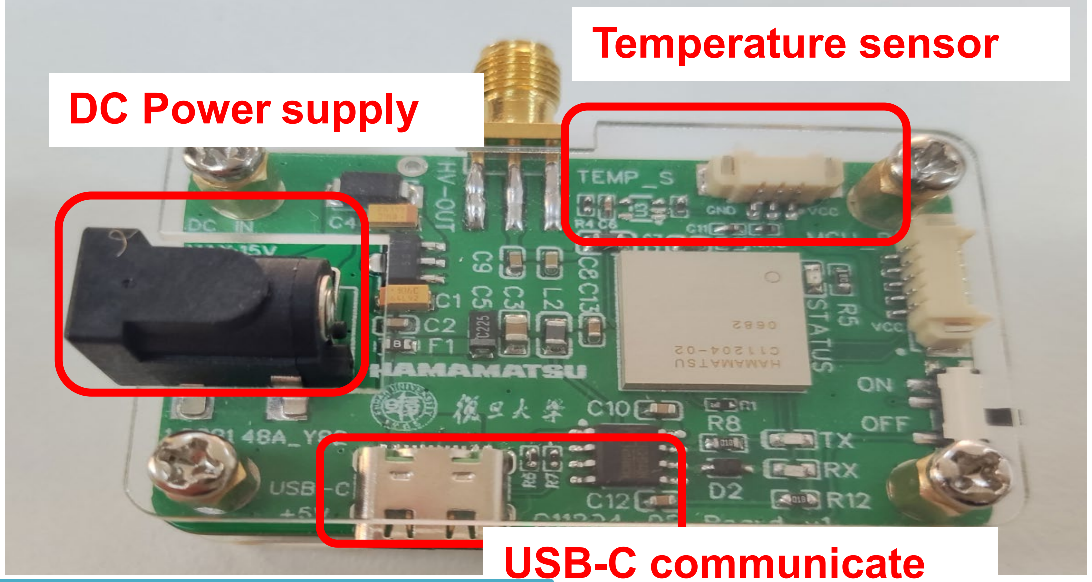


MPT2321, made in China

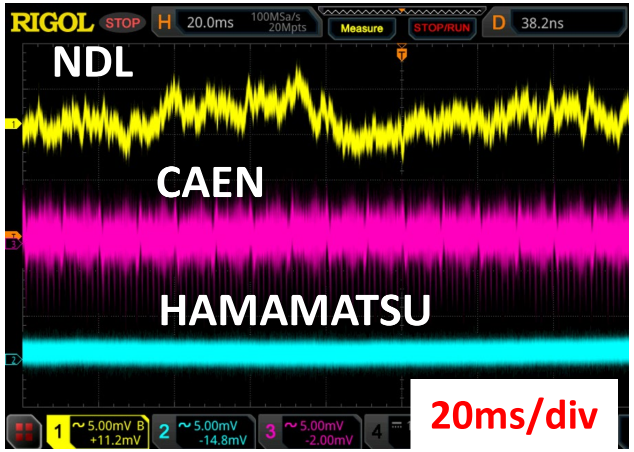
32CH ADC (12bit) + TDC(50ps)

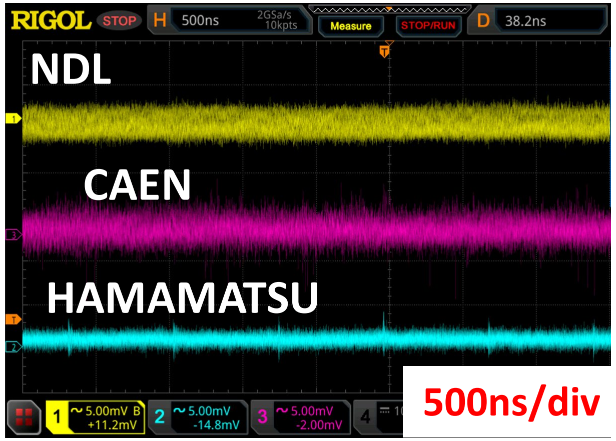
SiPM mini power

- Study on mini power to be integrated into the FEE.



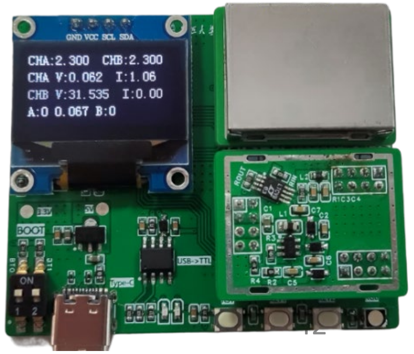
Ripple noise @ OUTPUT:45V





SiPM POWER	BIAS-2-14/70 @NDL	C14156 @Hamamatsu	MAX5026 @Fudan
Voltage (V) Output Range	14~70	0~80	0~71
Current (mA) Output Range	0.5	2	2
Number of SiPMs driven	100	400	400
Power consumption (mW)	250	100	200
Ripple noise (mV/Vpp)	5.2	0.1	2
Price (¥)	~2000	500	30

1$ = 7¥



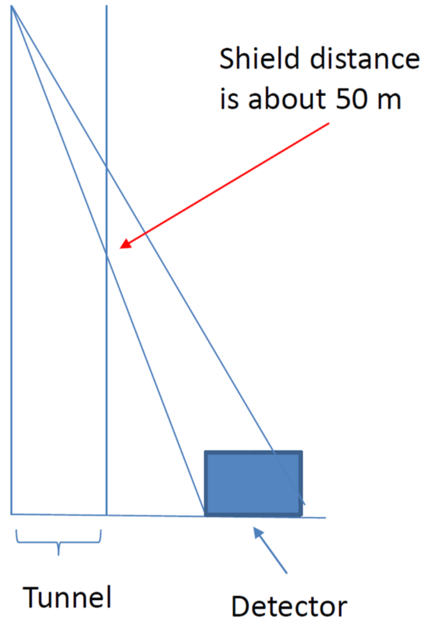
Considerations of the backgrounds

- Very low level of the CR backgrounds, with the earth shield of > 50m.
- Reference to the beam backgrounds in Belle II.

Barrel Layer	Expected Hit Rate (Hz/cm^2)	Expected RPC Efficiency	Bad-case Hit Rate (Hz/cm^2)	Bad-case RPC Efficiency	Worst-case Hit Rate (Hz/cm^2)	Worst-case RPC Efficiency
0	—scintillators—		—scintillators—		—scintillators—	
1	—scintillators—		—scintillators—		—scintillators—	
2	2.6	0.86	26	0.00	260	0.00
3	1.7	0.91	17	0.14	170	0.00
4	0.9	0.95	9	0.54	90	0.00
5	0.5	0.97	5	0.54	50	0.00
6	0.5	0.97	5	0.54	50	0.00
7	0.3	0.98	3	0.84	30	0.00
8	0.5	0.97	5	0.54	50	0.00
9	0.2	0.98	2	0.89	20	0.00
10	0.2	0.98	2	0.89	20	0.00
11	0.1	0.99	1	0.94	10	0.49
12	0.1	0.99	1	0.94	10	0.49
13	0.1	0.99	1	0.94	10	0.49
14	0.2	0.98	1	0.94	10	0.49

Table 2: Neutron flux, hit rate per unit area, and instantaneous efficiency in each layer of the barrel KLM from the late-2020 simulations of beam-induced neutron backgrounds at the SuperKEKB design luminosity of $6 \times 10^{35}\,cm^{-2}s^{-1}$. Here, the Belle II hybrid configuration replaces the RPCs in the two innermost layers with scintillators and neutron-absorbing polyethylene sheets.

For a 4m long bar, the hit rate might be 160Hz. For the 'bad-case', it would be 1.6kHz!



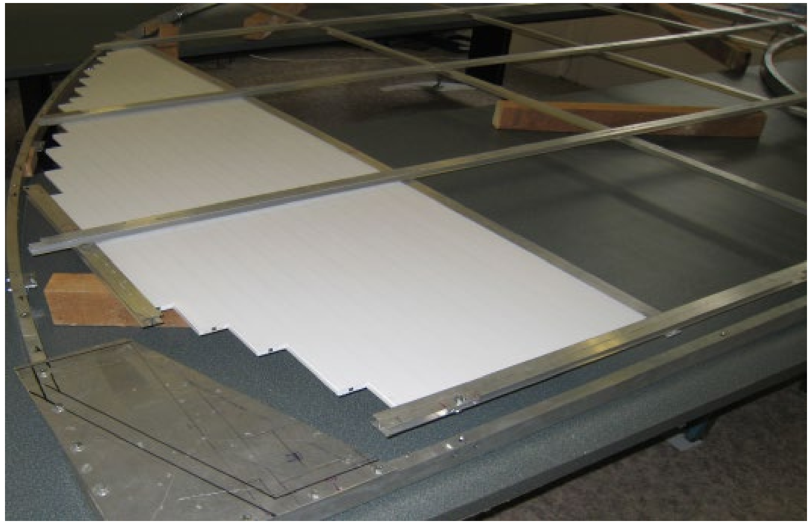
Bandwidth requirement

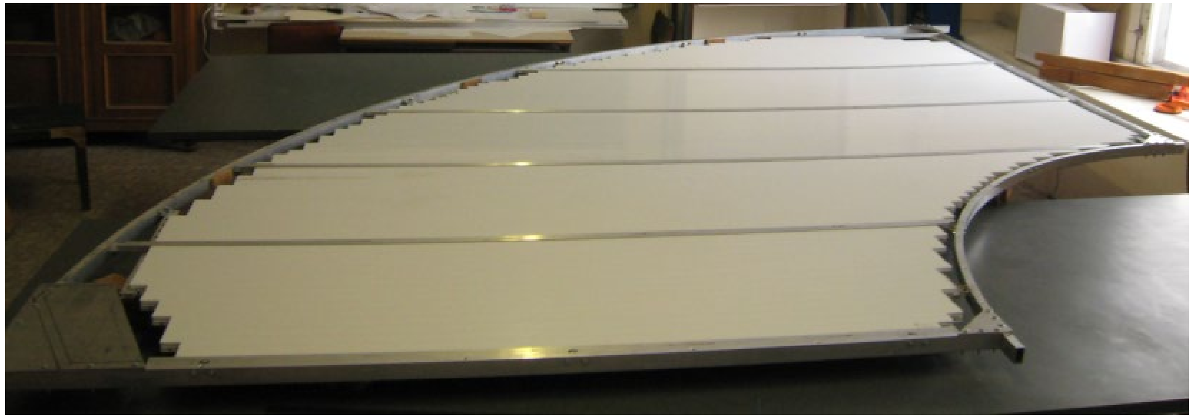
Muon	Module	Channel/Module	Readout Channel	Hit rate/Hz (worst case)	Data format	Raw data rate / Gbps
Barrel	192	169.5	32544	10 k	48bit (8b BX+ 10b ADC + 2b range + 9b TOT + 7b TOA+ 4b chn ID + 8b chip ID)	15.63
Inner endcaps	64	144	9216	10k~100 k, Average 20 k		8.85
Outer endcaps	64	256	16384	10 k		7.87
Total			~58.2 k			~32.4

- Very preliminary, conservative estimation according to data from Belle II experiment.
- We assigning a faculty to take care of this issue.

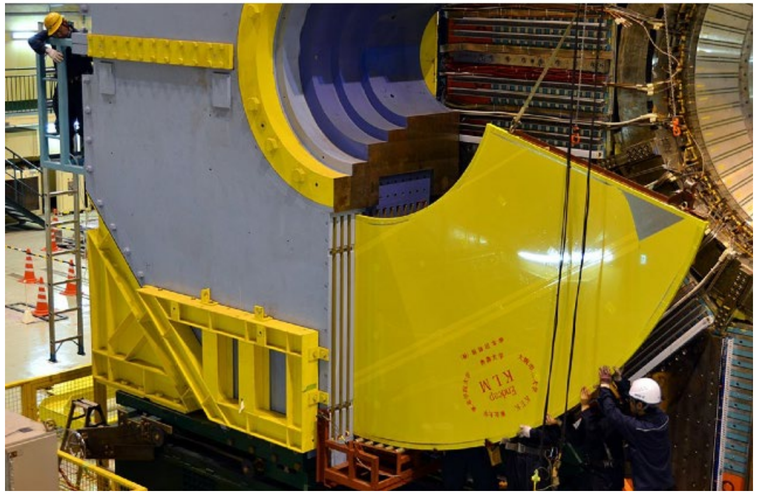
Reference for endcaps

- Structure of a module

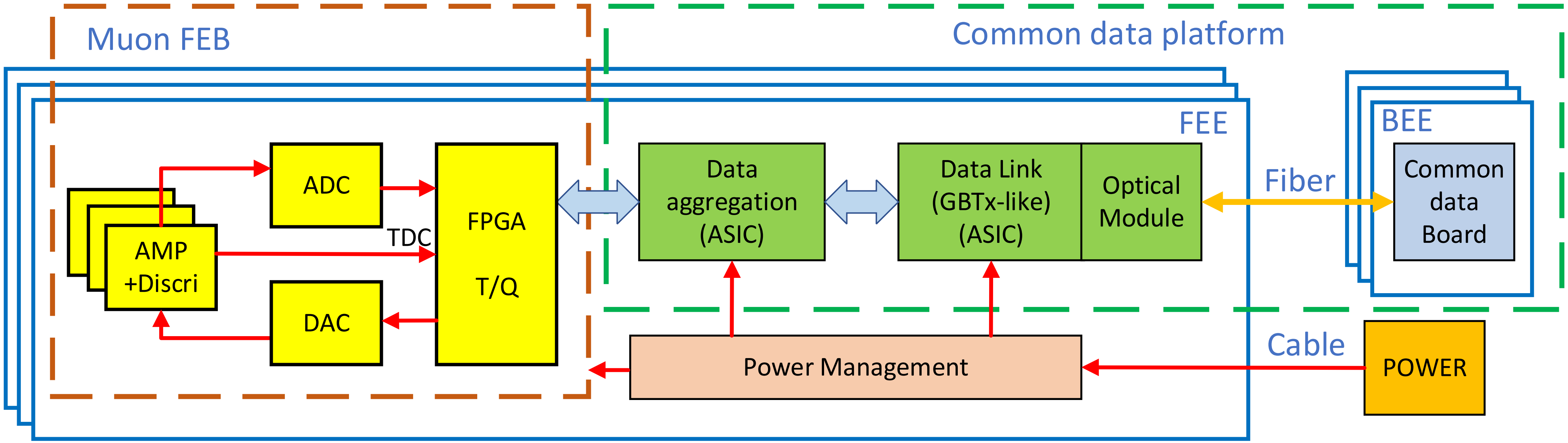




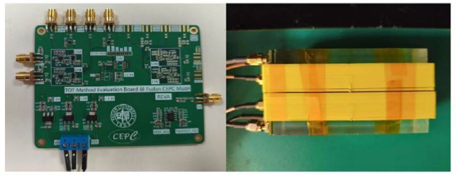
- Installation

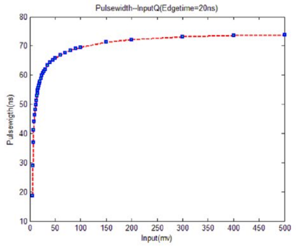


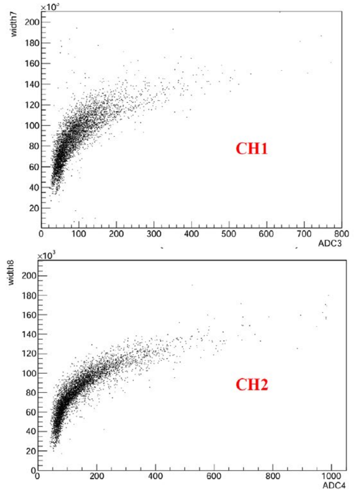
Alternative: discrete device scheme



Test for TOT







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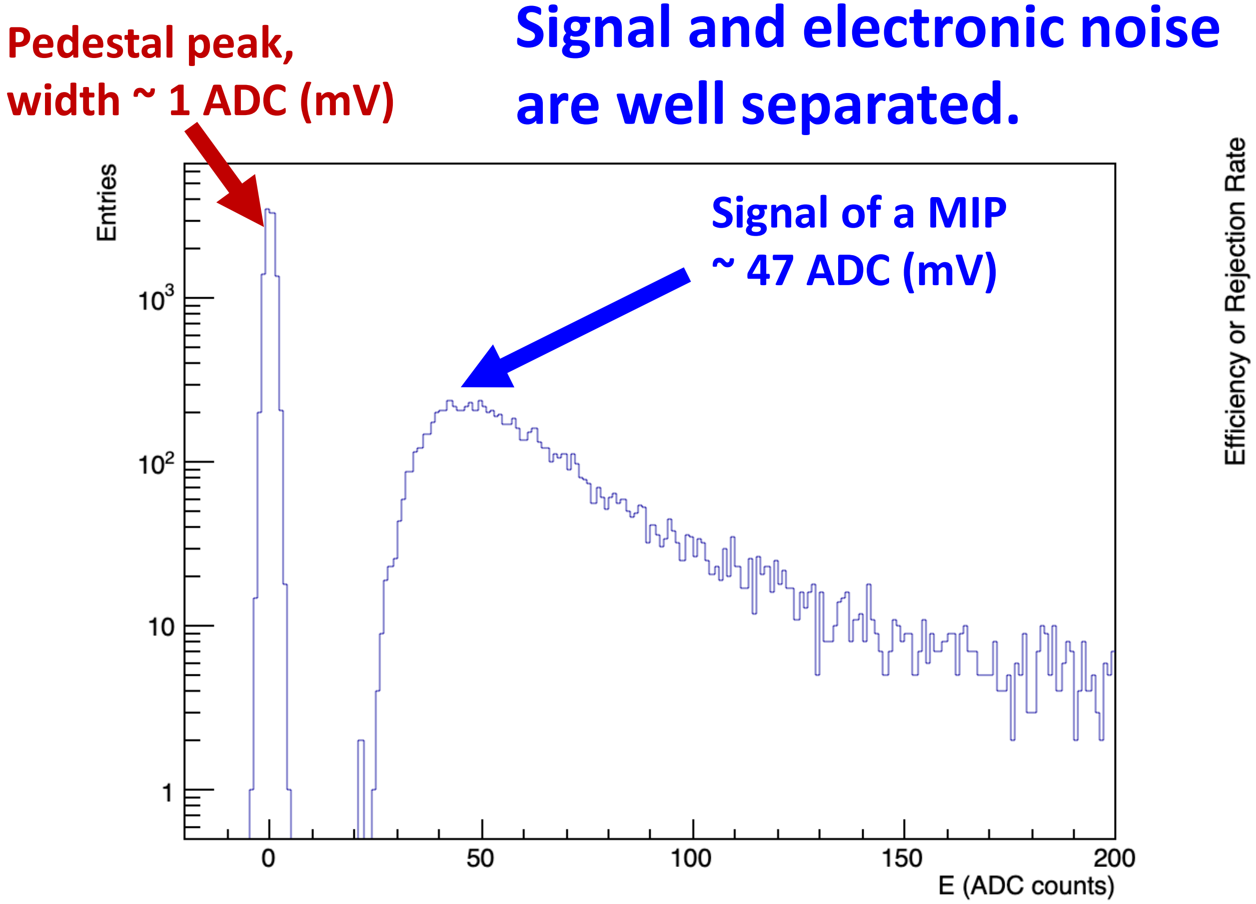
  - Commercial chips with radiation tolerance based on past studies for particle physics experiments
  - FPGA based TDC for TOA and TOT measurement with ~1 ns time resolution
  - ADC for charge measurement or TOT calibration
  - DAC for threshold setting or SiPM bias voltage adjustment

Detector Optimization

- The muon tracker hit vs. energy threshold:



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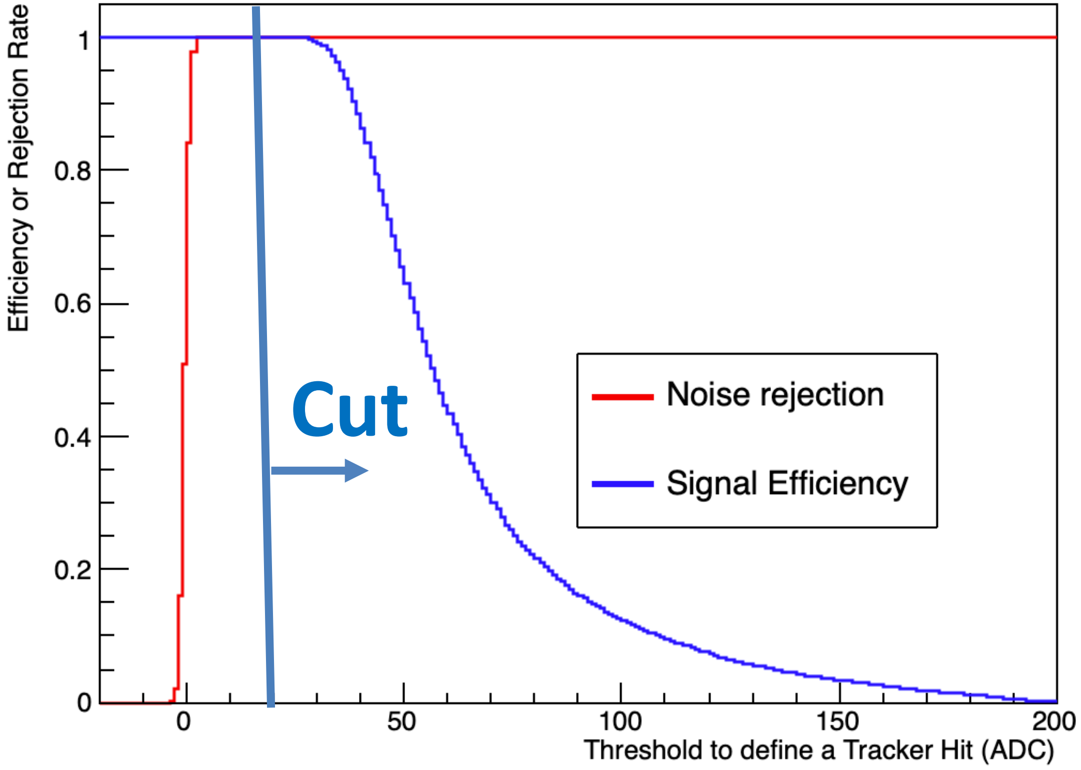
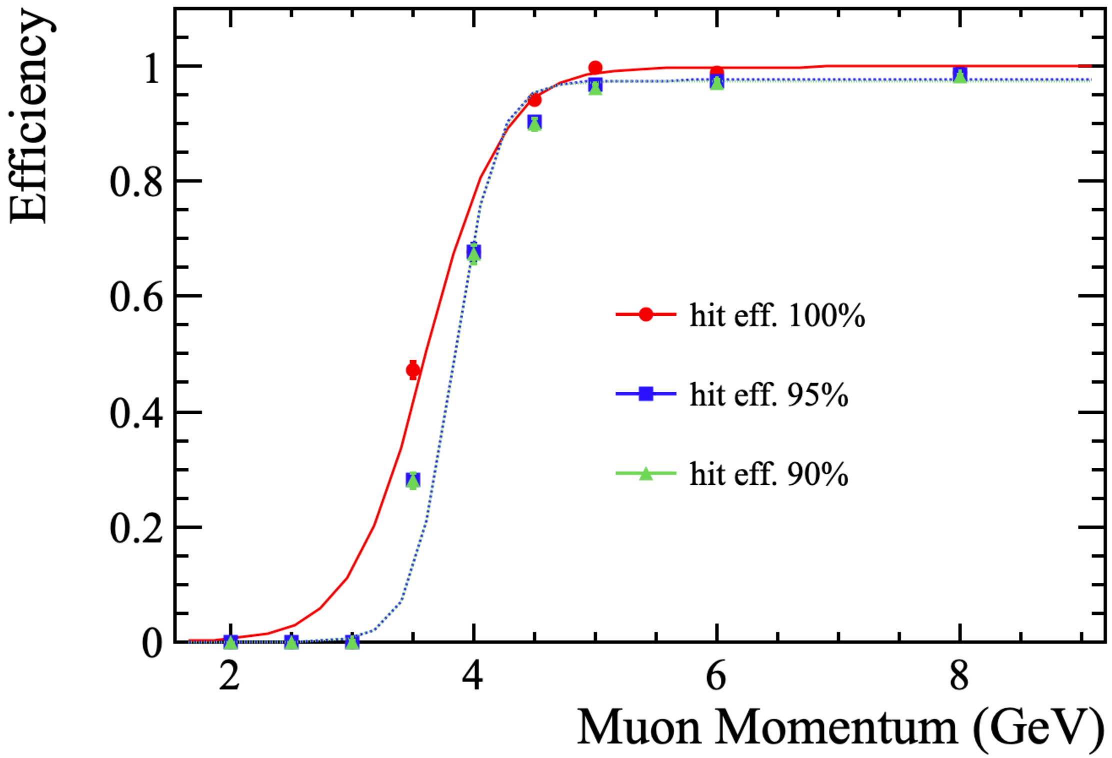


Assuming pedestal : signal = 1:1

Detector Optimization

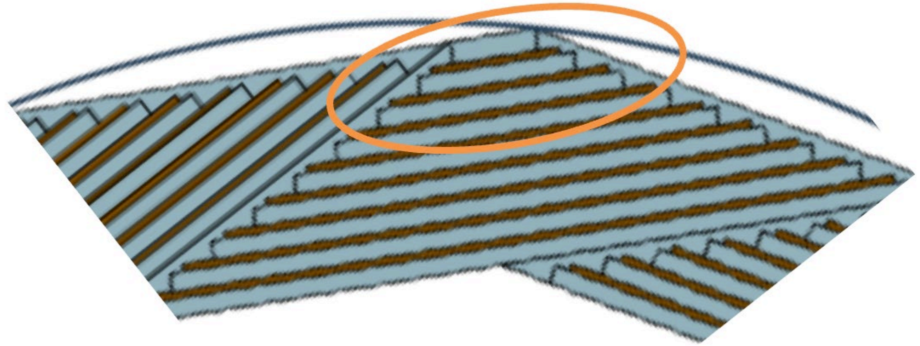
Muon ID efficiency vs efficiency of single channel



6-layer design of the barrel

What we learn from the simulations:

1. Efficiency of a single channel should $\geq 95\%$,
2. Number of superlayers should ≥ 6,
   while, layers #7,8 are not very helpful for the muon ID, due to the short ϕ-length
3. Threshold of momentum $> 4\ \mathrm{GeV}/c$, need help from HCAL for the lower momentum muon track.



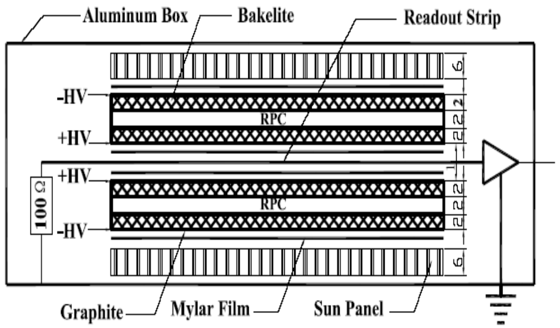
RPC technology – BESIII

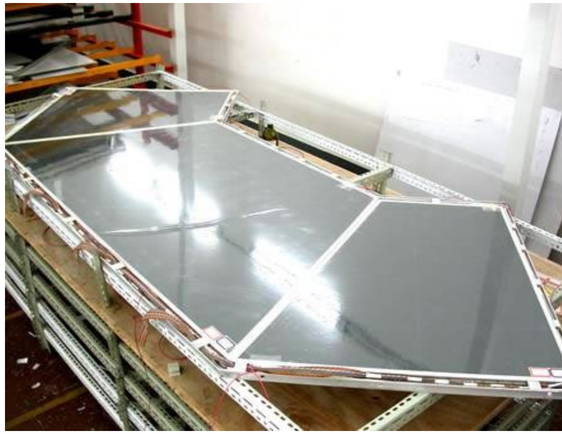
- Homemade Oil-free Bakelite RPC;
- Gas mixture: Ar:R134a:ISO-B=50:42:8
- First time successful mass production in China, bare chamber pass rate $> 90\%$;
- Good performance and keep running even now (>15years)!

Bare RPCs	$1{,}272\ m^2$
Box	136
Readout strip & insulation materials	$636\ m^2$
Electronics	9,152ch

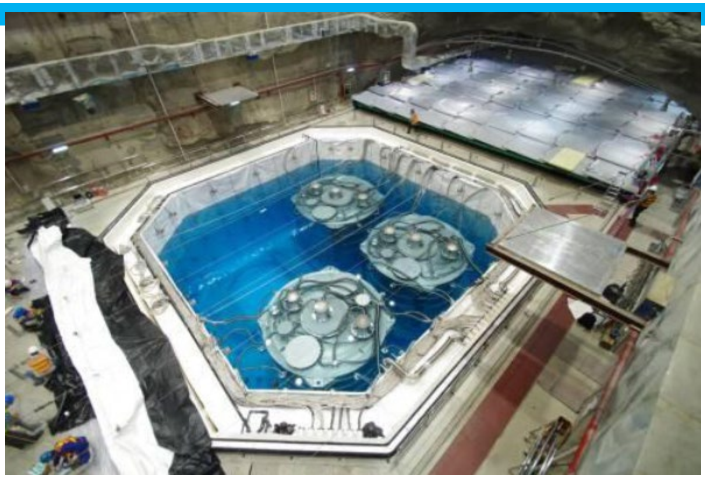
Table 2-4 BESIII Detector Performance

Parameters		Design Target	Real Performance			
			Cosmic Ray	Double μ	$\pi\pi J/\psi(\mu\mu)$	Total
Average Efficiency		95	94.7	95.11	95.17	93.6
Counting Rate		$< 0.1Hz/cm^2$	0.04 (Random Trigger)			
Spatial Resolution	$\sigma_{R\Phi}$	$< 20mm$	19	18	19	17.6
	σ_Z	$< 30mm$	23	21	22	22.5
$P(\pi \to \mu)@1GeV/c$		$< 5\%$	5.5% (MC)			



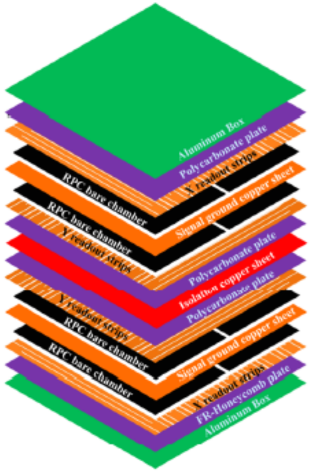


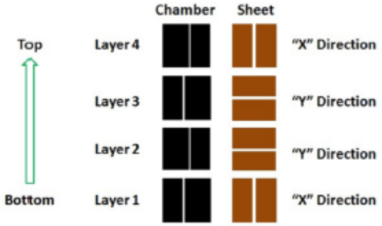
RPC technology – Dayabay



- Super module:
  - Two layers of 2-D readout
  - 4-layer RPCs
- Module size: $2.17m \times 2.20m \times 0.08m$
- Number of modules: 194
- Bare RPC sizes: $1.0m \times 2.10m$, $1.1m \times 2.1m$
- Bakelite plate size limitation: $2.4m \times 1.2m$!

Bare RPCs	$3{,}200\ m^2$
Box	195
Readout strip & insulation materials	$3{,}200\ m^2$
Electronics	6,000 ch





We have the tech. based on Bakelite ready.