The CEPC Muon detector

Xiaolong Wang
Fudan University

Joint Workshop of the CEPC Physics, Software and New Detector Concept

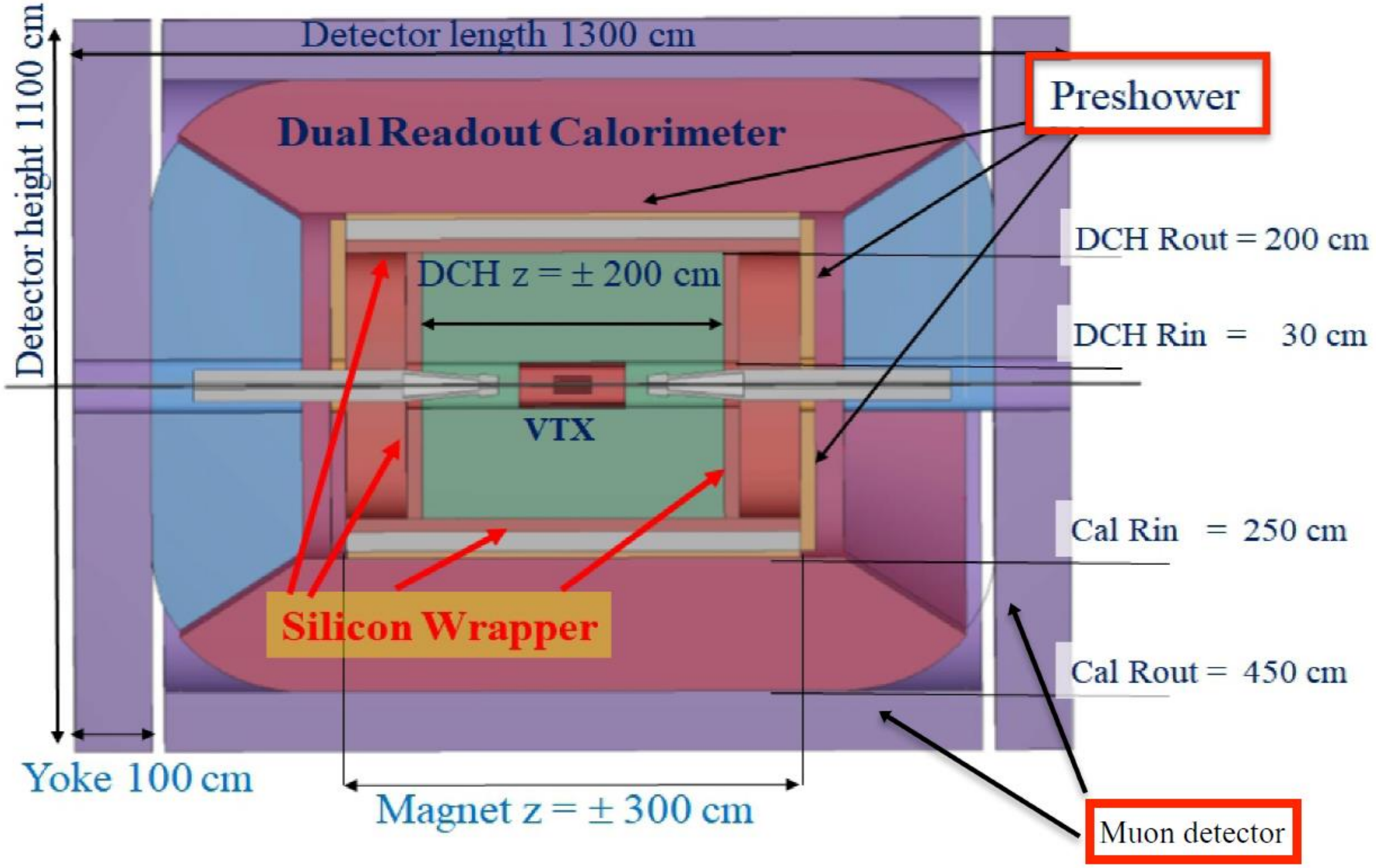
扬州，April 15, 2021

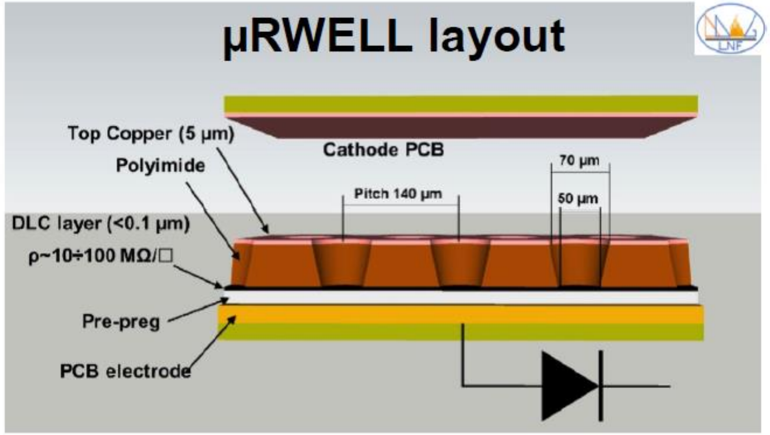
Ongoing R&D

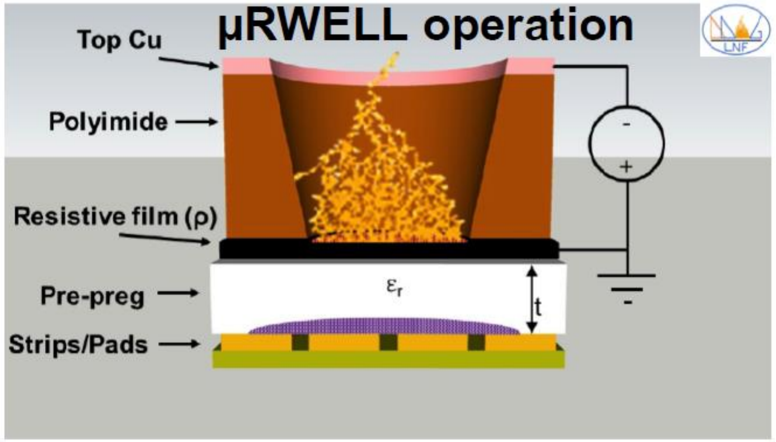
- 4.1 Scintillator-based muon detector
- 4.2 μRWELL-based muon and pre-shower detectors
    - Many slides from Paolo and Riccardo.
    - Many may be missed in this talk.

IDEA detector layout

IDEA detector is a general purpose detector designed for experiments at future e+e- colliders such as CEPC





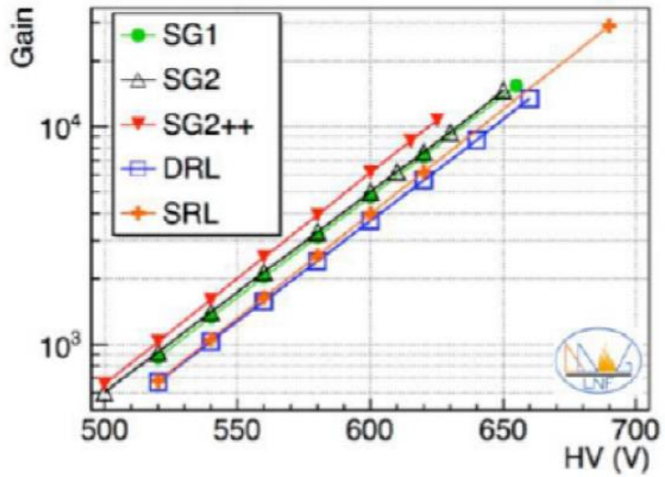


Pre-shower and the Muon Systems are designed with the μRWELL technology

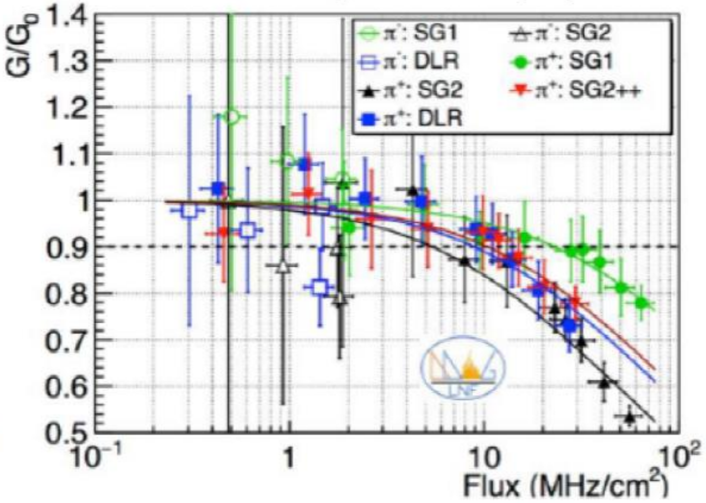
G. Bencivenni et al., JINST 10(2015)P02008

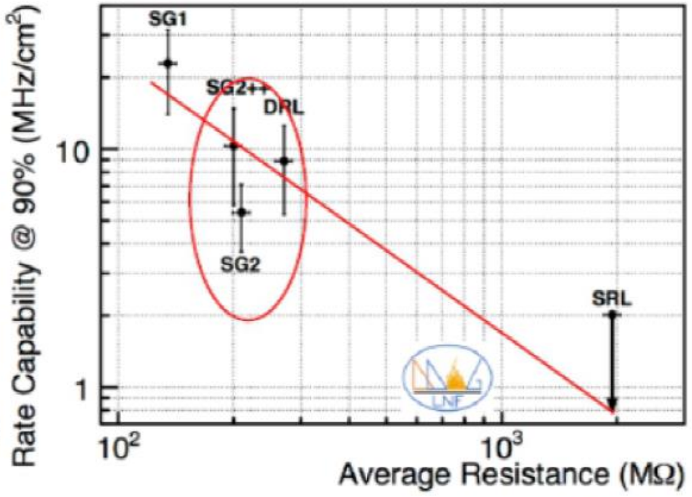
Current state of art of µRWELL

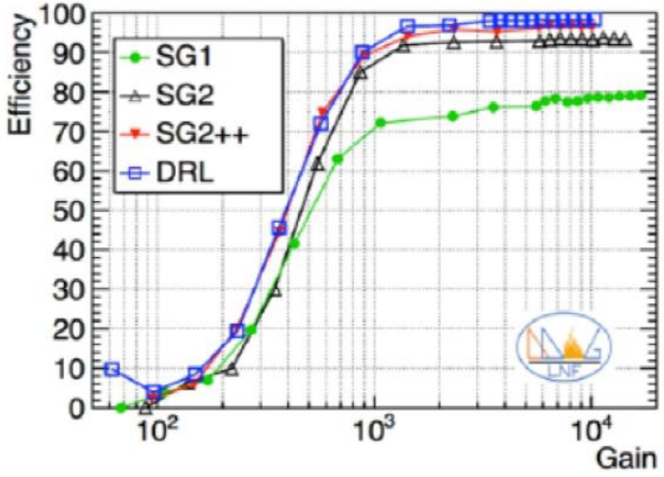
Gain up to ~ 10^4

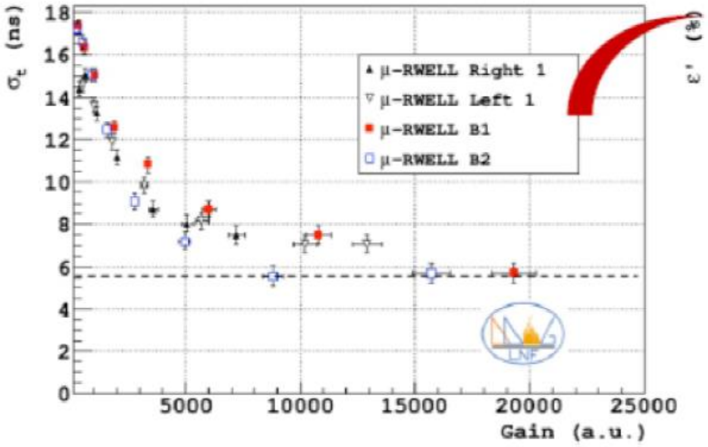


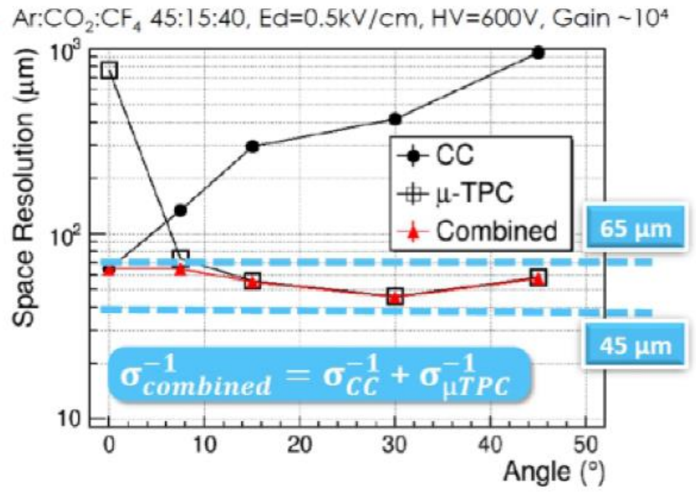
Rate capability (@ G = 5000) ~ 5-10 MHz/cm^2









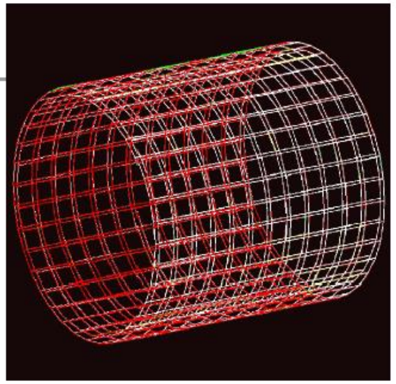


Efficiency ~ 98%

σ_t ~ 5-6 ns

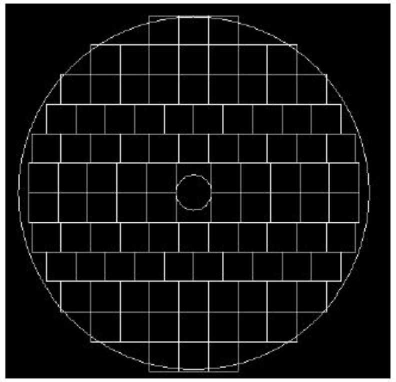
Space resolution in u-TPC-mode

IDEA pre-shower detector dimensions



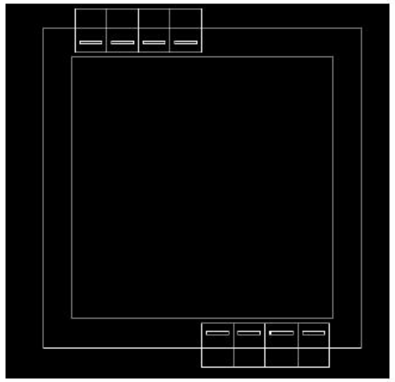
Barrel

R [mm]	Length [mm]	Thickness [mm]	pixel size [mm]	area [cm^2]	# of channels
2460	±2480	20	0.4×500	768K	384K



Endcap

R_{in} [mm]	R_{out} [mm]	z [mm]	Thickness [mm]	pixel size [mm]	area [cm^2]	# of channels
248	2440	±2460	20	0.4×500	370K	185K



IDEA's Pre-Shower detector would have in total:

~ **225 m2 total**

~ **1.5 M channel in total**

Tiles: 50x50 cm^2 with X-Y readout
Strip Length: 50 cm
Strip pitch: 0.4 mm
Input FEE capacity (Cap_{inp})~70 pF

IDEA Muon detector dimensions

Barrel

Layer	R [mm]	Length [mm]	Thickness [mm]	int. length	pixel size [mm]	area [cm^2]	# of channels
μRwell	4520	±4500	20		1.5×500	2.6M	341K
iron	4560	±4500	300	1.5			
μRwell	4880	±4500	20		1.5×500	2.8M	368K
iron	4920	±4500	300	1.5			
μRwell	5240	±5260	20		1.5×500	3.5M	462K

Endcap

Disk	R_{in} [mm]	R_{out} [mm]	z [mm]	Thickness [mm]	int. length	pixel size [mm]	area [cm^2]	# of channels
μRwell	454	5220	±4520	20		1.5×500	1.7M	227K
iron	454	5220	±4560	300	1.5			
μRwell	454	5220	±4880	20		1.5×500	1.7M	227K
iron	454	5220	±4920	300	1.5			
μRwell	454	5220	±5240	20		1.5×500	1.7M	227K

IDEA's Muon detector would have in total:

~ **2800 m2 total**

~ **4M channels in total**

~ **3 stations**

Tiles: 50x50 cm^2 with X-Y readout
Strip Length: 50 cm
Strip pitch: 1.5 mm
Input FEE capacity (Cap_{inp}) ~270 pF

Questions to solve

- How to optimize the detector design to the CEPC physics program?
- How to reduce the input FEE capacity in the muon system?
- How to build more than $3000\ m^2$ of µRWELL detector?

Activities on 2021

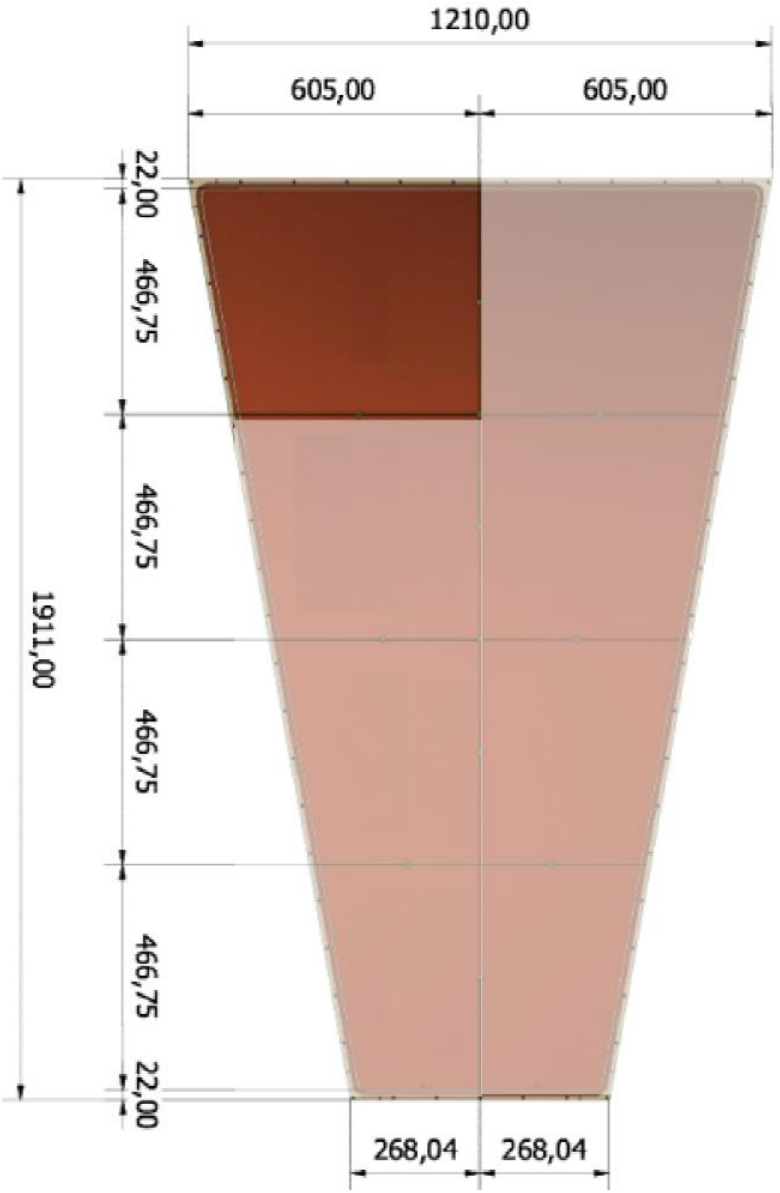
- The four main activities:
  1. Desgin and construction
  2. Simulation and reconstruction software
  3. Development of FEE
  4. Test and integration
- Hardware activities:
  1. Test of large size µRWELLs with TIGER-GEMROC readout
  2. Construction of a large size µRWELL at ELTOS (TT)
  3. Optimization studies on DLC resistivity and pitch size
- Software activities: …

Built and test a large area μRWELL

A first large area μRWELL has been built at CERN in Rui's workshop

Size: 606.5 x 498.5 x 1 mm
Active area: 559.6 - 480 (w) x 450 (h) mm
373 radial strips
strip pitch 1.29 - 1.5 mm
strip length ~ 22 cm

This first detector will tested with a cosmic-ray stand and readout with TIGER-GEMROC technology developed by INFN within the CGEM-IT BESIII frame.

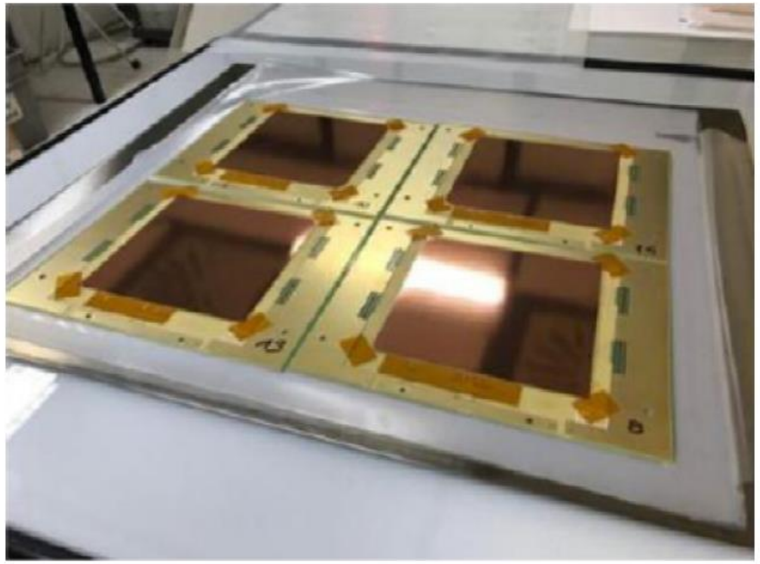


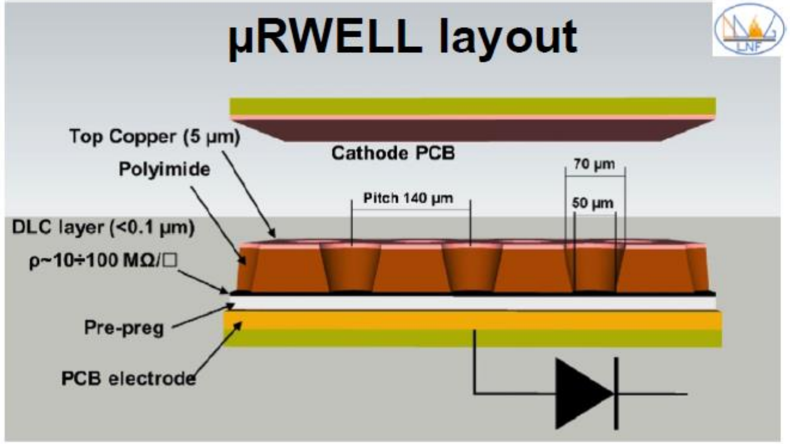
Built a second large area µRWELL: technological transfer

A second large area µRWELL of 500 x 500 mm2 will be developed together with ELTOS, an Italian industry that performs the coupling of the DLC-foil with the PCB (only for low rate layout)

The max size of the µRWELL-PCB that can be produced by ELTOS is about 600x700 mm2.

Up to 8 PCBs of such a size can be manufactured at the same time. The manufacturing procedure is slightly different from the one used by Rui but works fine. The etching is done at CERN.

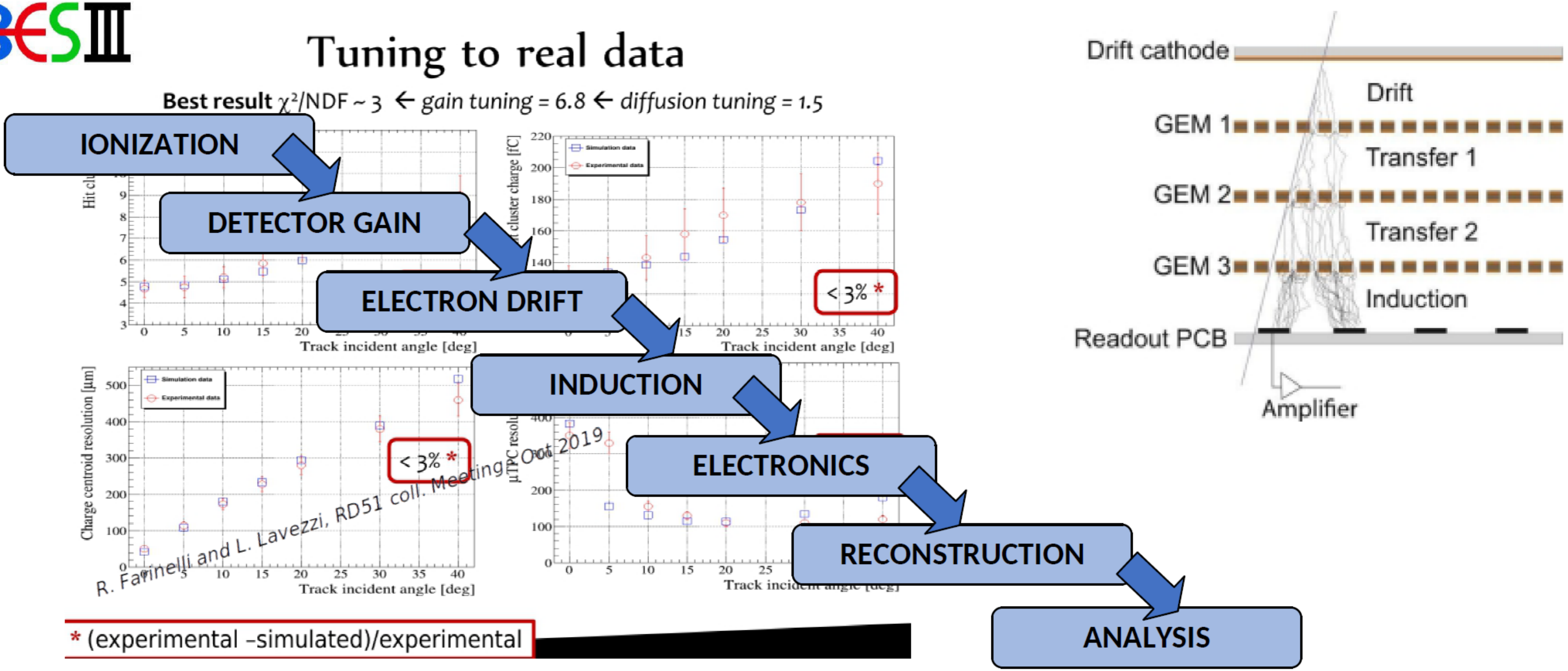




Software activities on 2021

- The 2021 program is centered mainly on the following activities:
  1. Development of a μRWELL detailed simulation
  2. Description of the IDEA pre-shower and muon system in the DD4HEP framework within the Key4HEP environment.
- These tasks are needed for futher software studies:
  3. Development of ML algorithms for the μRWELL signal reconstruction
  4. Performance studies with pre-shower and muon system (design optimization, Long Living Particles "case studies")

Detailed μRWELL simulation: the triple-GEM experience



A triple-GEM parametric simulation which take into account diffusion, transparency, gain, induction and readout electronics has been developed within the CGEM-IT BESIII frame. The simulated data has been tuned to the experimental results of charge, multiplicity and spatial resolution (CoG and μTPC)

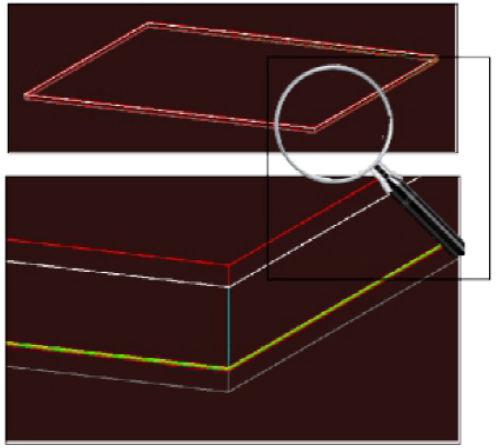
IDEA pre-shower and muon system simulation

The detailed simulation of a μRWELL will be implemented with the DD4HEP framework using Geant4

The simulation has to run with Key4HEP and to use it in the CEPC software

Once the full IDEA detector will be simulated, it will be possible to optimize the detector geometry (strip size, spatial resolution, etc...) as a function of the CEPC physics program.

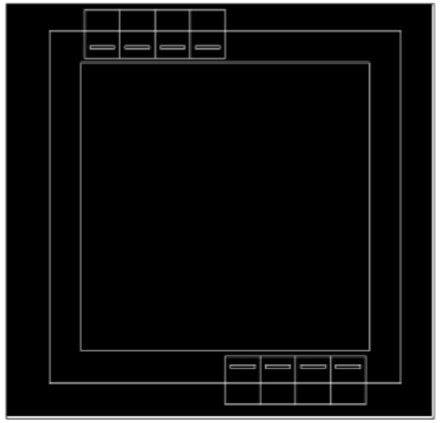
A high spatial resolution muon system impact can be studied system New Physics researches, such as the detection of Long Lived Particles

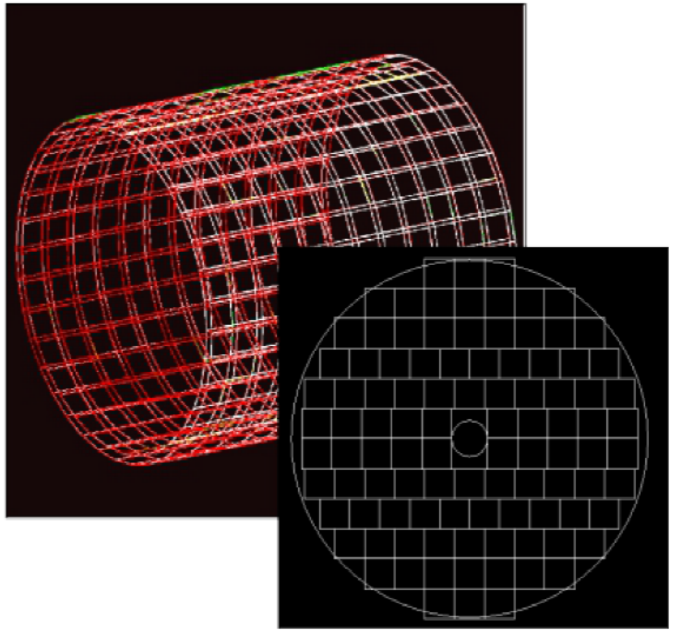


Chamber thickness: 9.4601mm
- Cathode thickness: 1.635mm
- Driftgap: 6mm
  - μ-RWELL+readout thickness: 1.8251mm

The cathode points to the IP

First considered chamber size:
500 mm x 500 mm





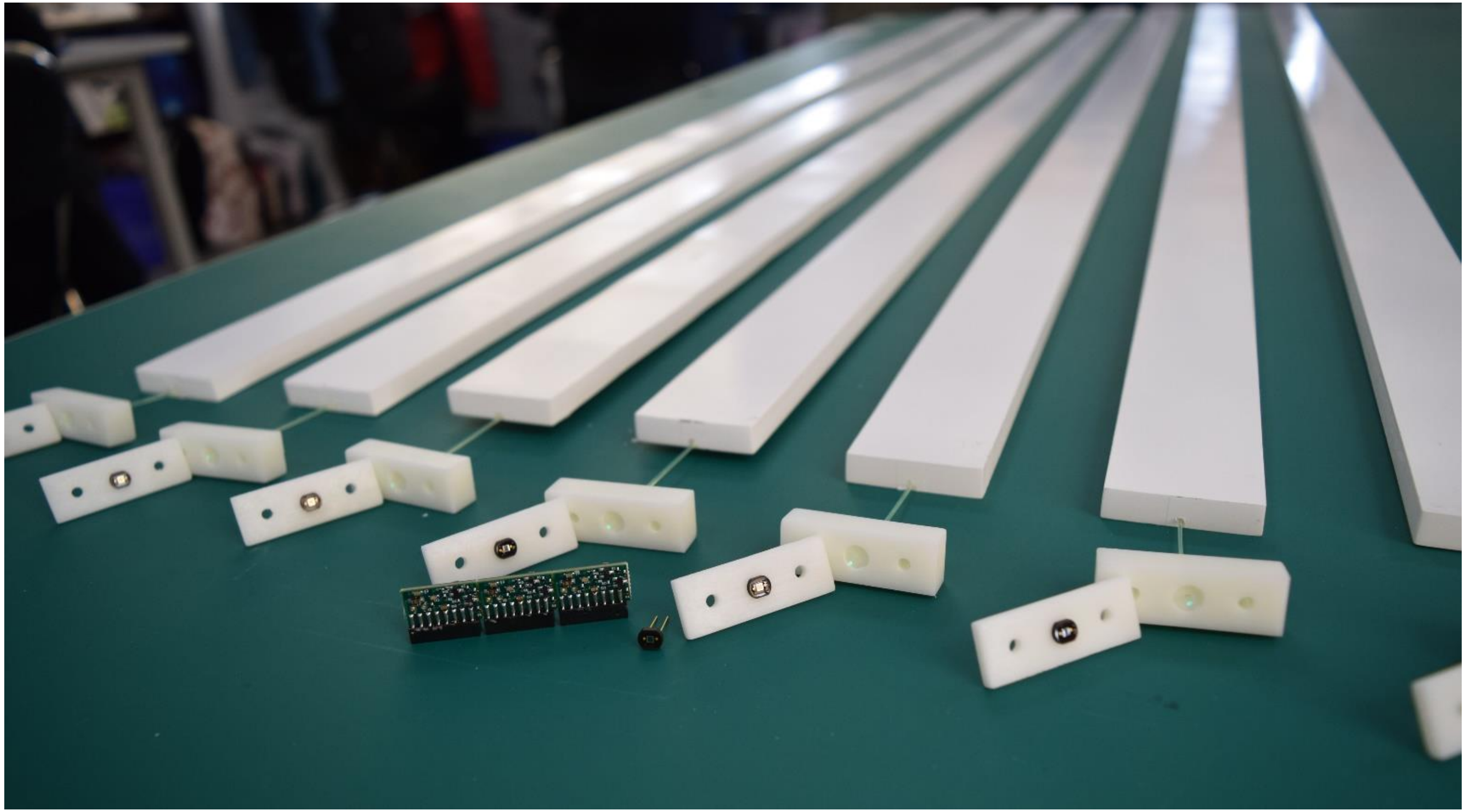
2022-2024 program on the µRWELL

- Define the best resistivity of the DLC for both µRWELL fundamental tiles and build the $50 \times 50\ cm^2$ prototypes for the pre-shower and muon systems.
- Optimize the engineering mass construction process together with the ELTOS industry.
- Develop a custom-made ASIC for the µRWELL with the experience obtained from the TIGER chip and to test the µRWELL prototypes.
- Develop a new reconstruction algorithm, ML-based, to improve the resolution of µRWELL.
- Simulation of the CEPC decay channels of interest to optimize the detector design with special emphasis on Long Lived Particles to show the impact of a performing tracked in the muon system instead of a tagger.

Conclusion for μRWELL-based detector

- The test of resistivity/pitch size relationship will optimize the detector and will provide information for the μRWELL detector simulation.
- The pre-shower and muon system simulation will be developed to describe the full IDEA detector in the CEPC software.
- A roadmap up to 2024 is defined starting from the construction, simulation and test activities ongoing. An international cooperation would boost these activities.

Scintillator-based detector

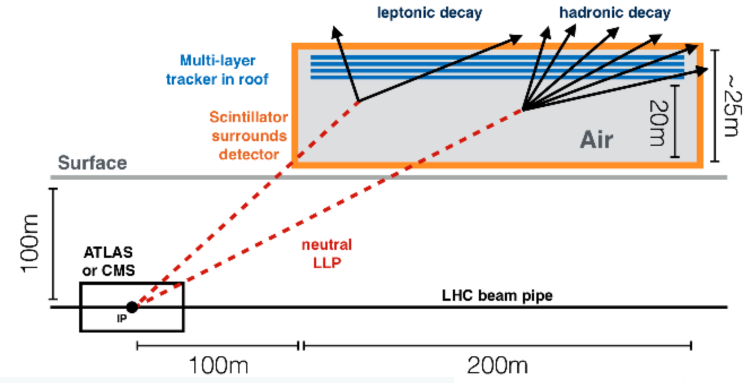


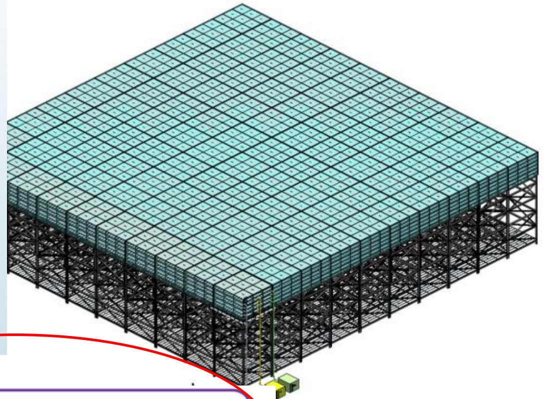
Hongyu will talk about time resolution study on the Young Scientist Forum.

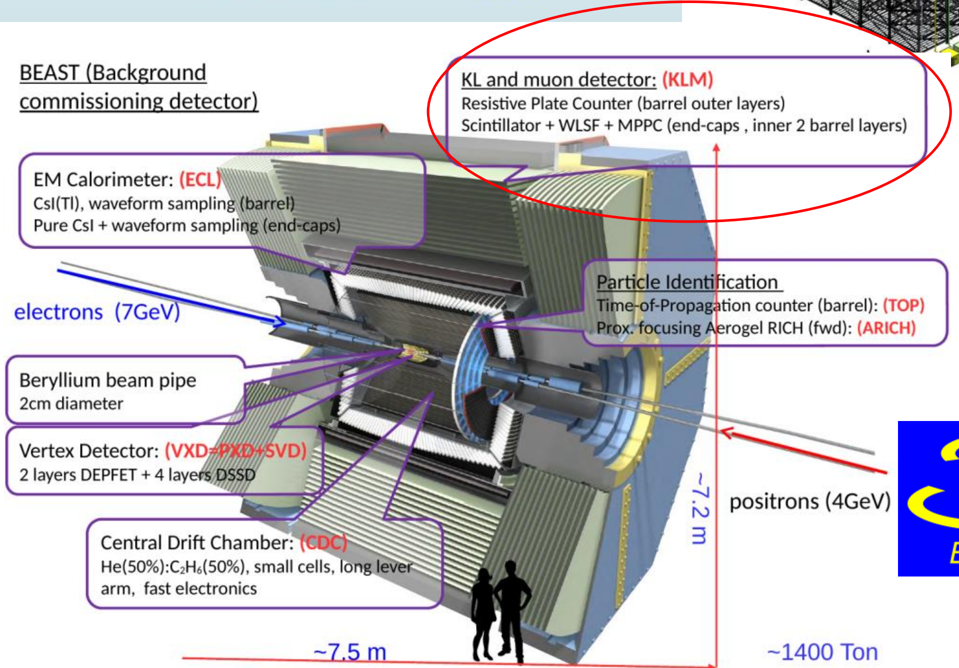
For reference

Scinti + SiPM

- MUTHUSLA experiment
  - Large size detector based on scintillator to search for long-live particle
  - Institutions: SLAC, Fermilab…
- Belle II experiment: L = 10^{36} $cm^{-2}s^{-1}$
  - Belle II started physics running on 11/3/2019
  - Endcap and inner 2 barrel layers: RPC → Scintillator
  - Good performance achieved
  - Belle II is considering the upgrade: all the barrel RPC → scintillator; new readout system
  - Institutions: Fudan U., U of Hawaii, Virginia Tech, …
- Helpful for R&D, testing, production, price…
- SiPM is becoming popular



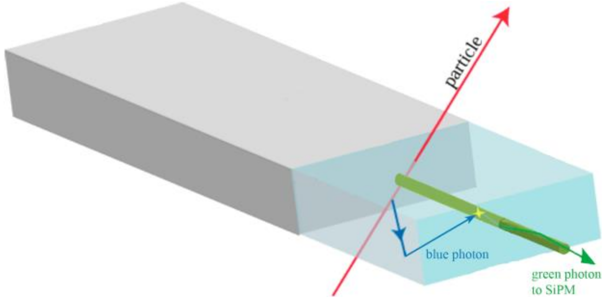


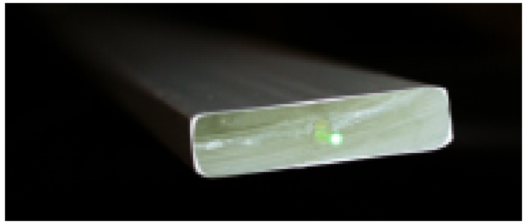


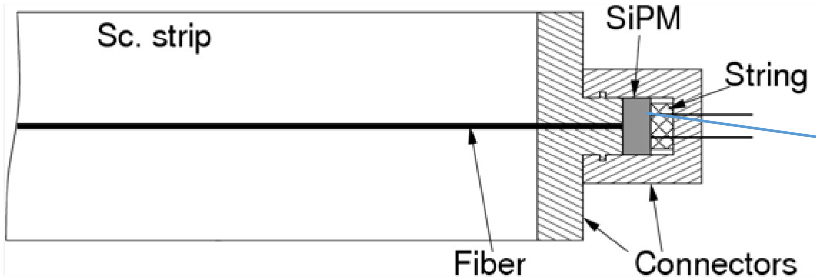
Belle II

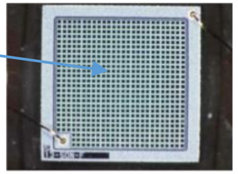
Structure

- Scintillator shape is flexible, easy to get good spatial resolution:
    - $\sigma = \text{Width}/\sqrt{12}$
- Wave length shift (WLS) fiber inside scintillator to collect photons and guide them to SiPM.
- Use SiPM at one or both ends, small size, low cost and can work at high magnetic field.









Belle II KLM

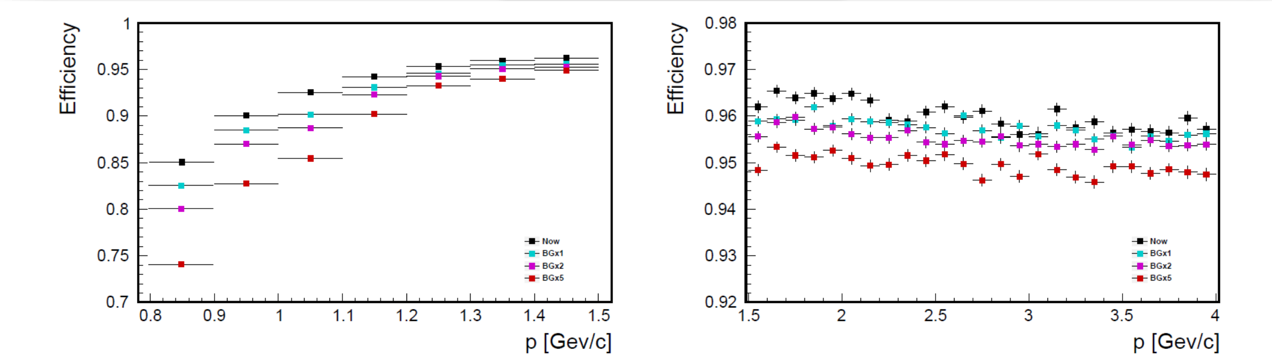
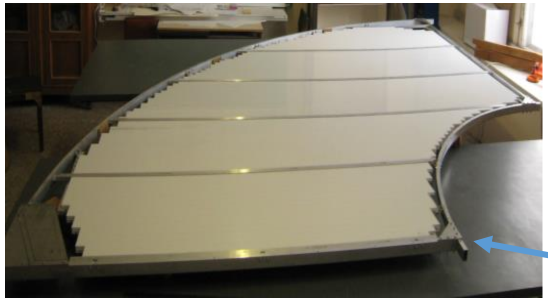
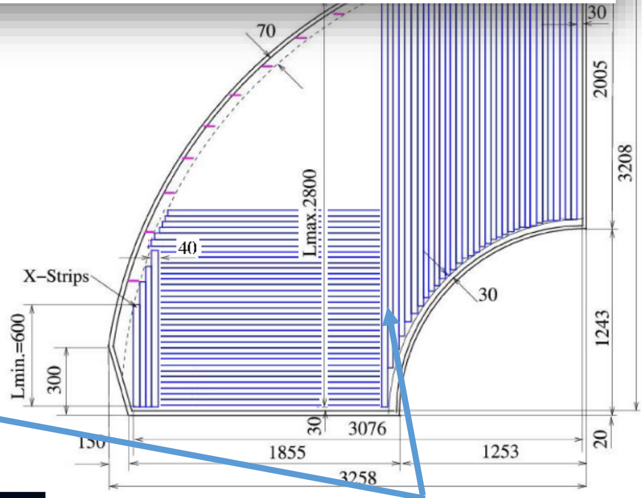
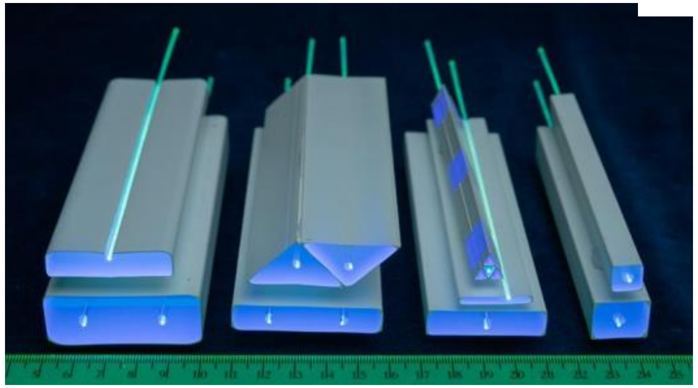


Figure 4: *Muon identification efficiency after the requirement muonID > 0.9 in the three considered scenarios for tracks with* $0.8 < p < 1.5$ *GeV/c (on the left) and for tracks with* $1.5 < p < 4.9$ *GeV/c (on the right).*





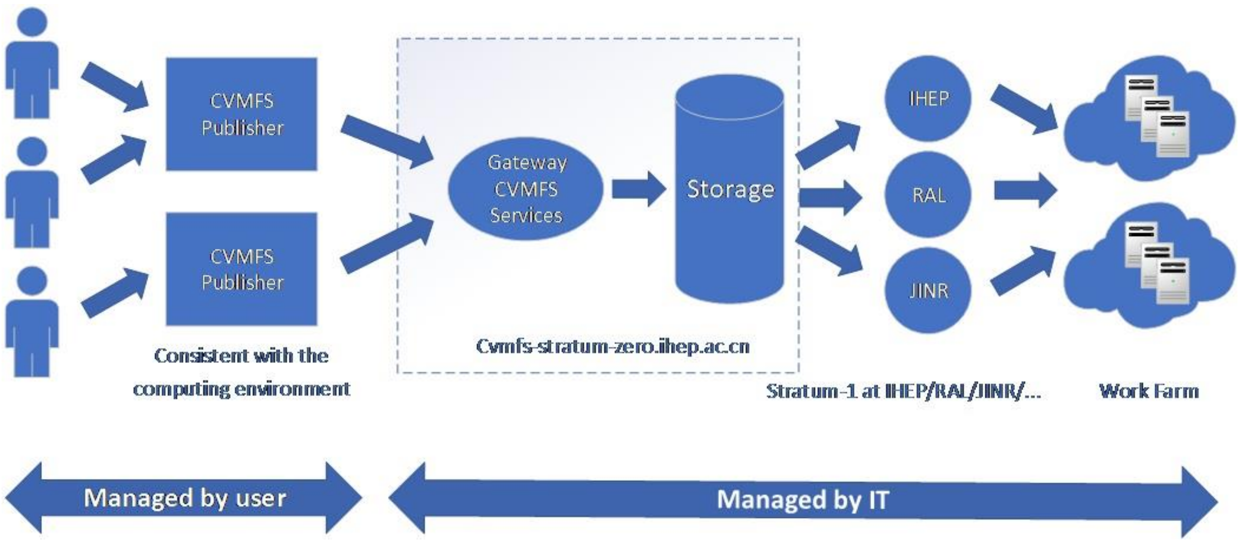


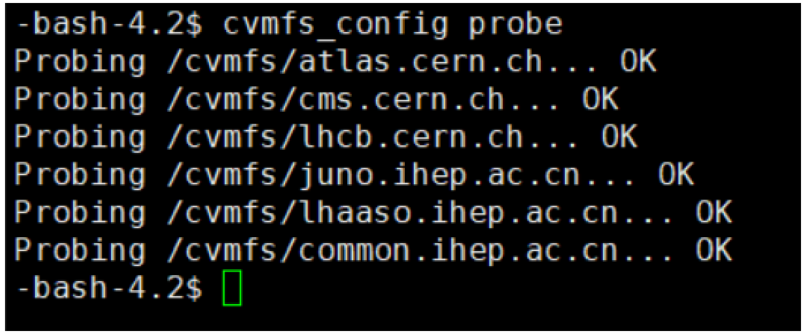
Superlayer for good 2-D resolution

Detector simulation

- The detector simulation using Geant4 started in the early 2021.
- CEPCSW installed, but G4 simulation has not been implemented yet.
- The next step is testing with a high energy muon track.

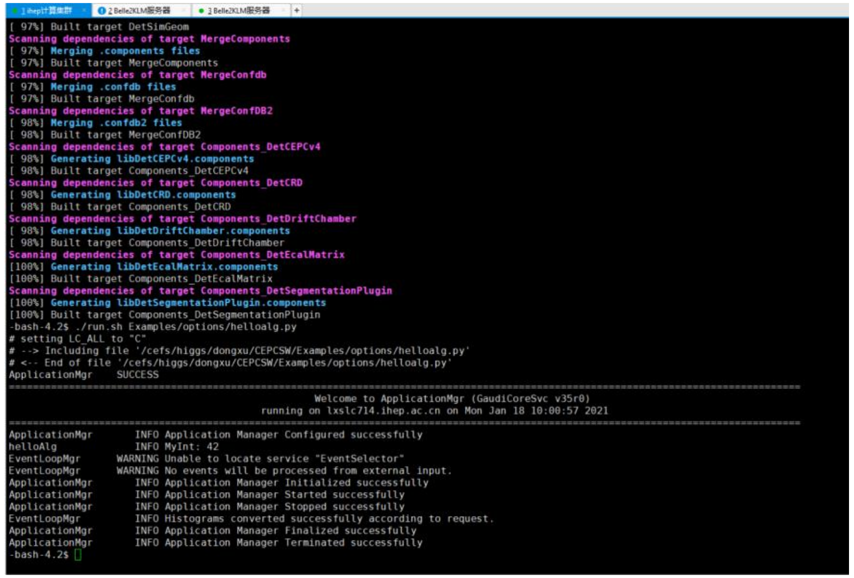
CEPCSW on cluster



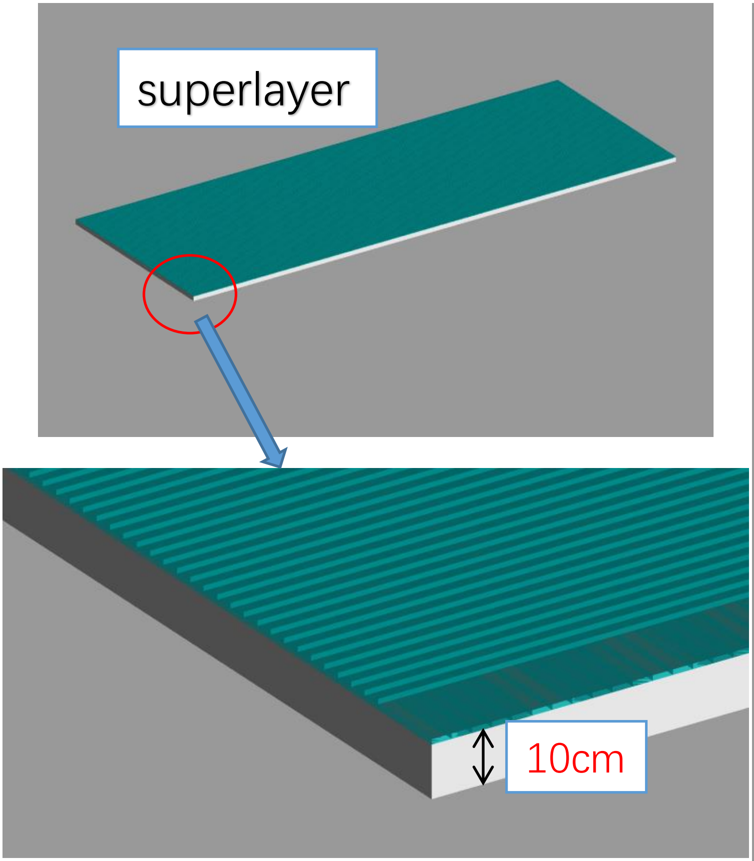


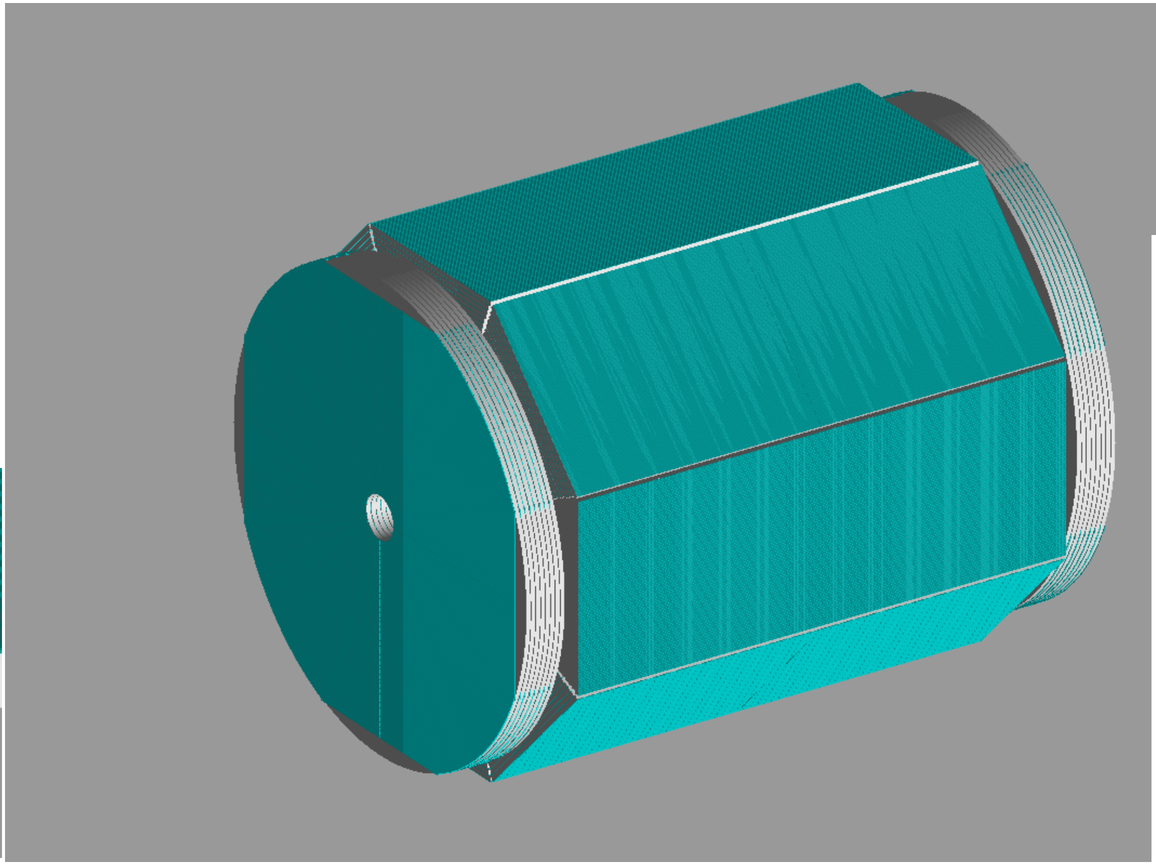
check CVMFS

```
$ git clone git@github.com:cepc/CEPCSW.git
$ cd CEPCSW
$ git checkout master # branch name
$ source setup.sh
$ ./build.sh
$ ./run.sh Examples/options/helloalg.py
```



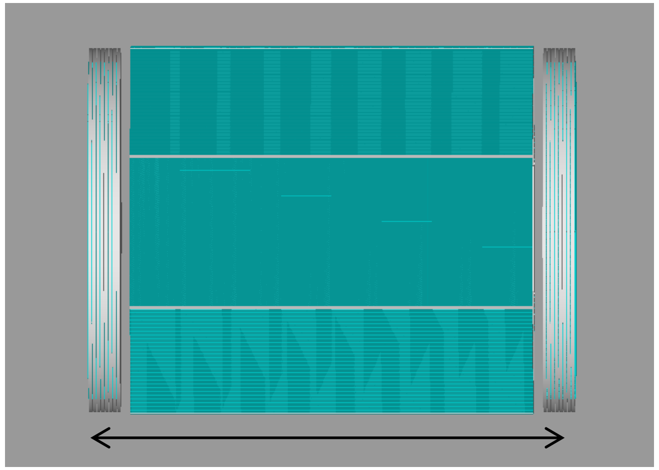
CEPCSW installed



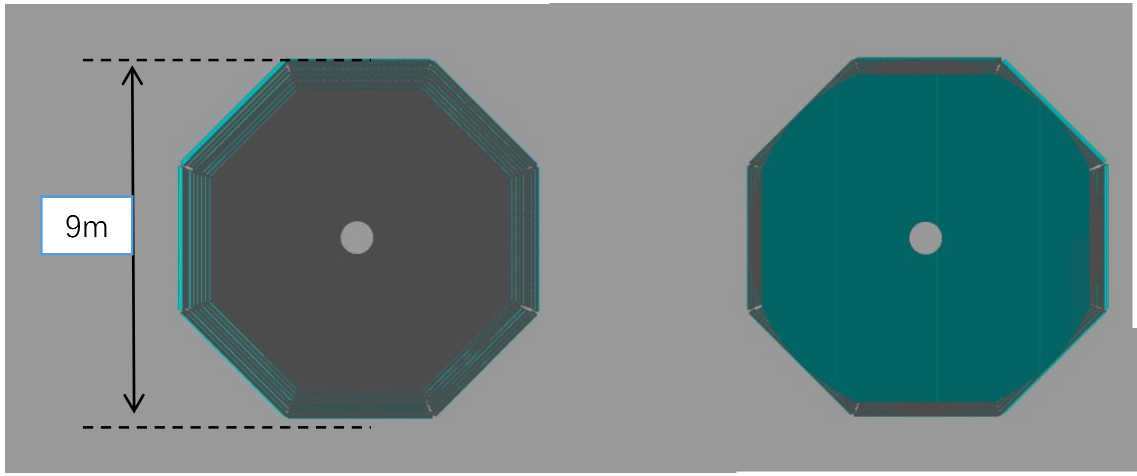


CEPC CDR 2018

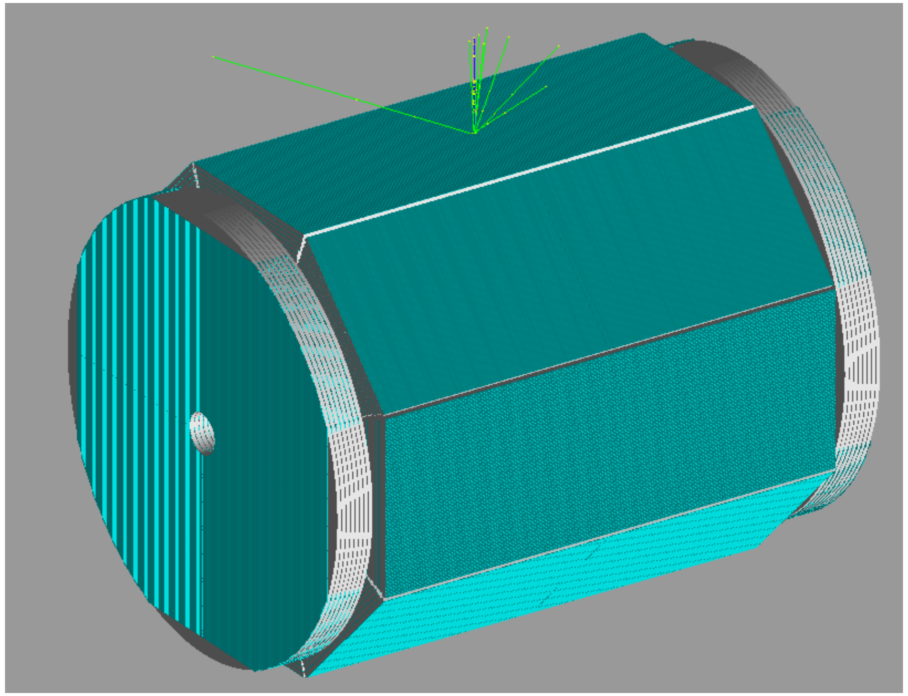
Parameter	Baseline
$L_b/2$ [m]	4.14
R_{in} [m]	4.40
R_{out} [m]	6.08
L_e [m]	1.72
R_e [m]	0.50
Segmentation in ϕ	12
Number of layers	8
Total thickness of iron (λ = 16.77 cm)	6.7λ (112 cm) (8/8/12/12/16/16/20/20) cm
Solid angle coverage	0.98 $\times 4\pi$
Position resolution [cm]	$\sigma_{r\phi}$: 2 σ_z : 1.5
Time resolution [ns]	1 – 2
Detection efficiency ($P_\mu > 5$ GeV)	$> 95\%$
Fake($\pi \to \mu$)@30GeV	$< 1\%$
Rate capability [Hz/cm^2]	$\sim$60
Technology	RPC (super module, 1 layer readout, 2 layers of RPC)
Total area [m^2]	Barrel: $\sim$4450 Endcap: $\sim$4150 Total: $\sim$8600

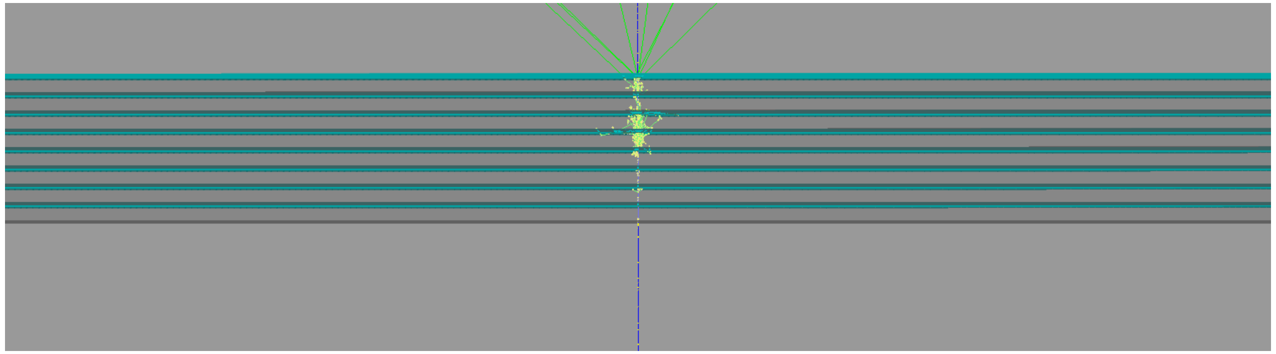


12m



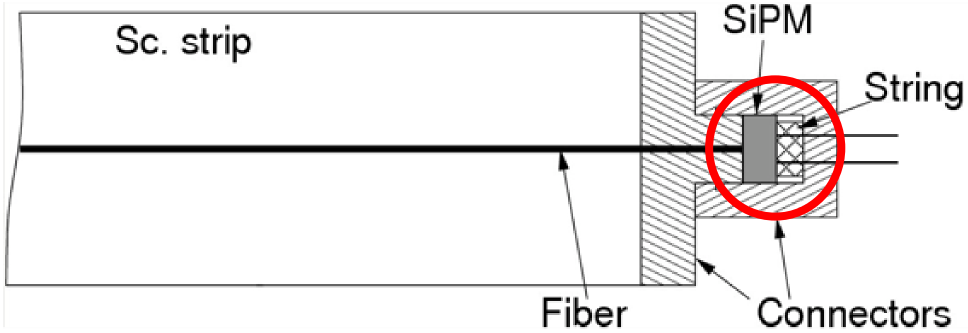
$40\ \mathrm{GeV}\ \mu^{\pm}$ hits

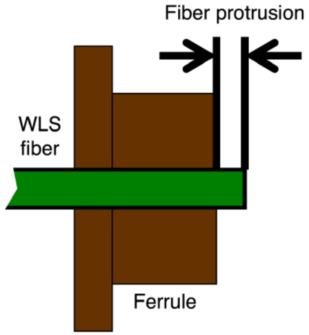




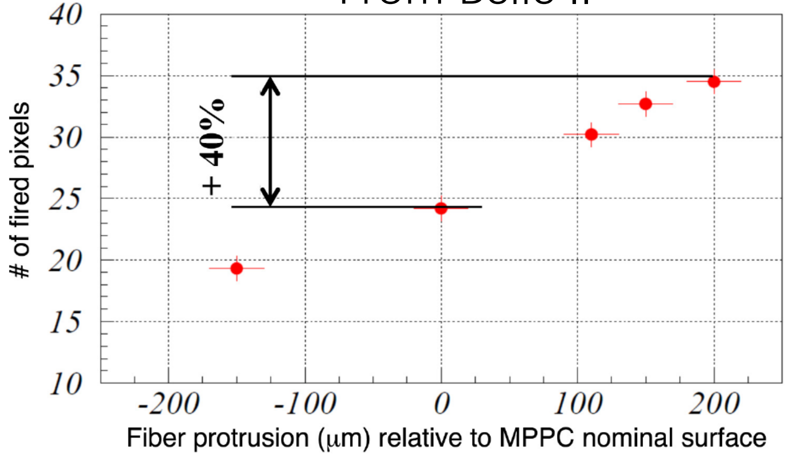
- Fast testing with $40\ \mathrm{GeV}\ \mu^{\pm}$ is performed.
- WLS fibre and SiPMs are not included yet.
- Plan:
  - A complete description of the scintillator-based muon detector.
  - Implementation into the CEPCSW.
  - Optimization according to CEPC physics goals.

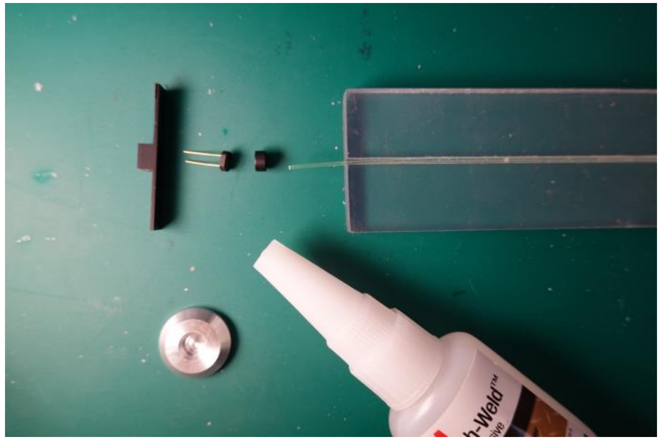
Optical coupling

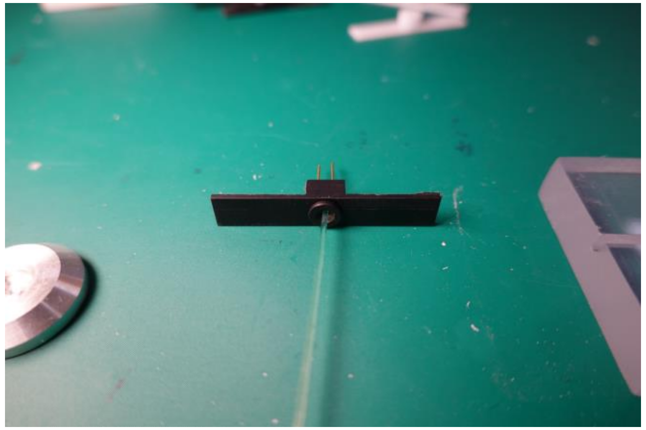




From Belle II







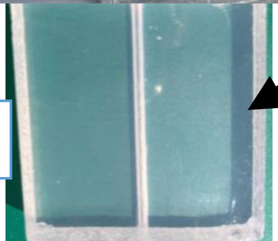
- ➢ Get closer to improve the light collection.
- ➢ Firm coupling to avoid the damage on the MPPC sensor surface.
- ➢ Studying the coupling between scintillator strip and fibre with optical glue.

Attenuation length of Scintillator

- Add scintillator between LED and MPPC

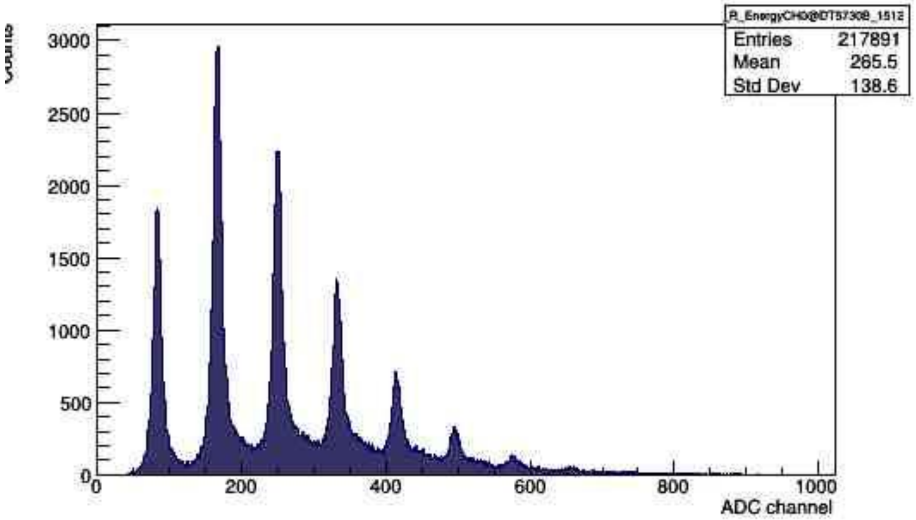
Pulse generator → LED light → scintillator (light) → MPPC → oscilloscope / Digital analyzer

DT5725



Smooth surface

Trigger:
2 channel coincidence
reduce dark count

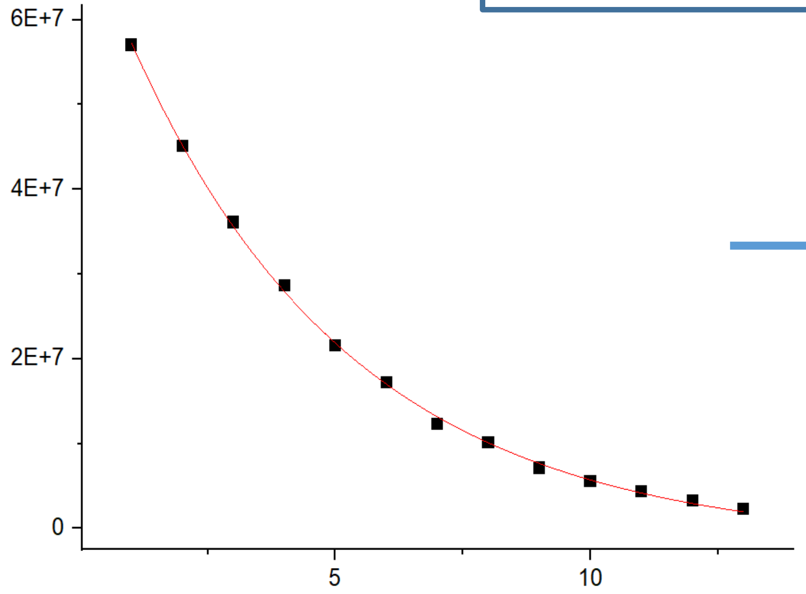


Multiphoton spectrum from MPPC

Attenuation length

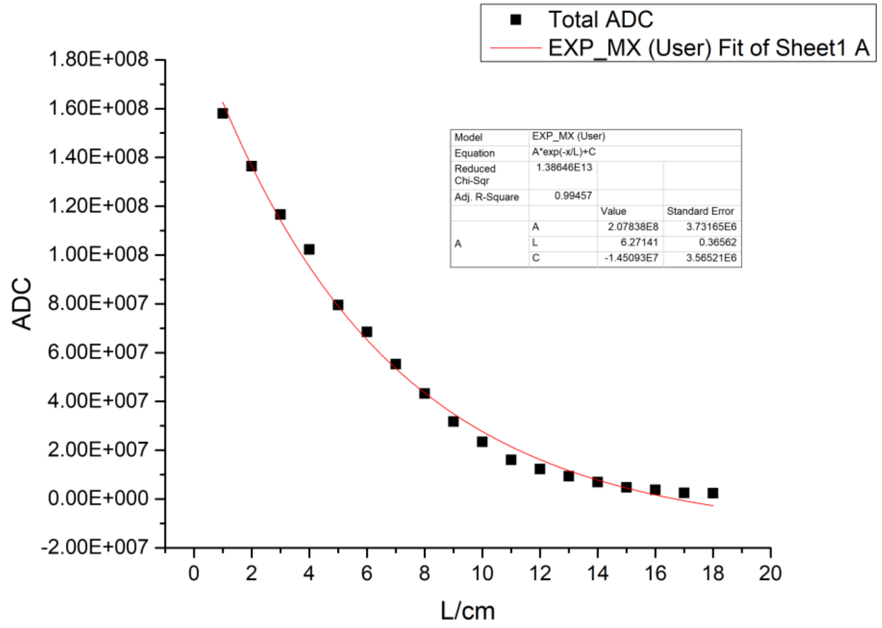
Attenuation formula :

$$y = A_0 e^{\frac{-x}{L}} + y_0$$



$L = (4.37 \pm 0.11)$ cm

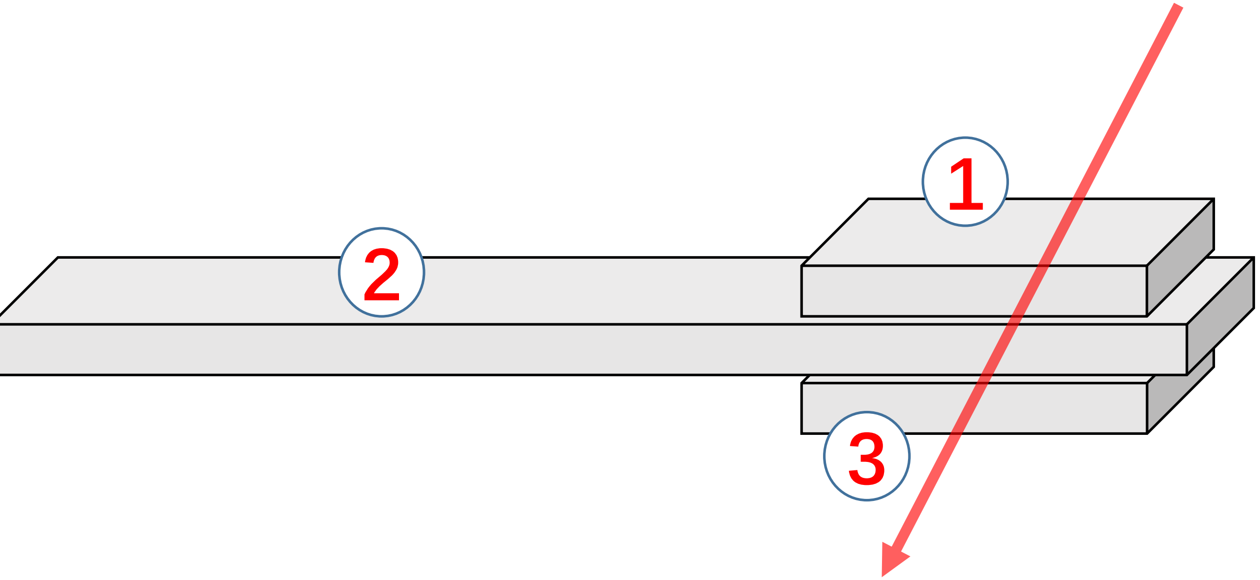
With optical glue between blocks



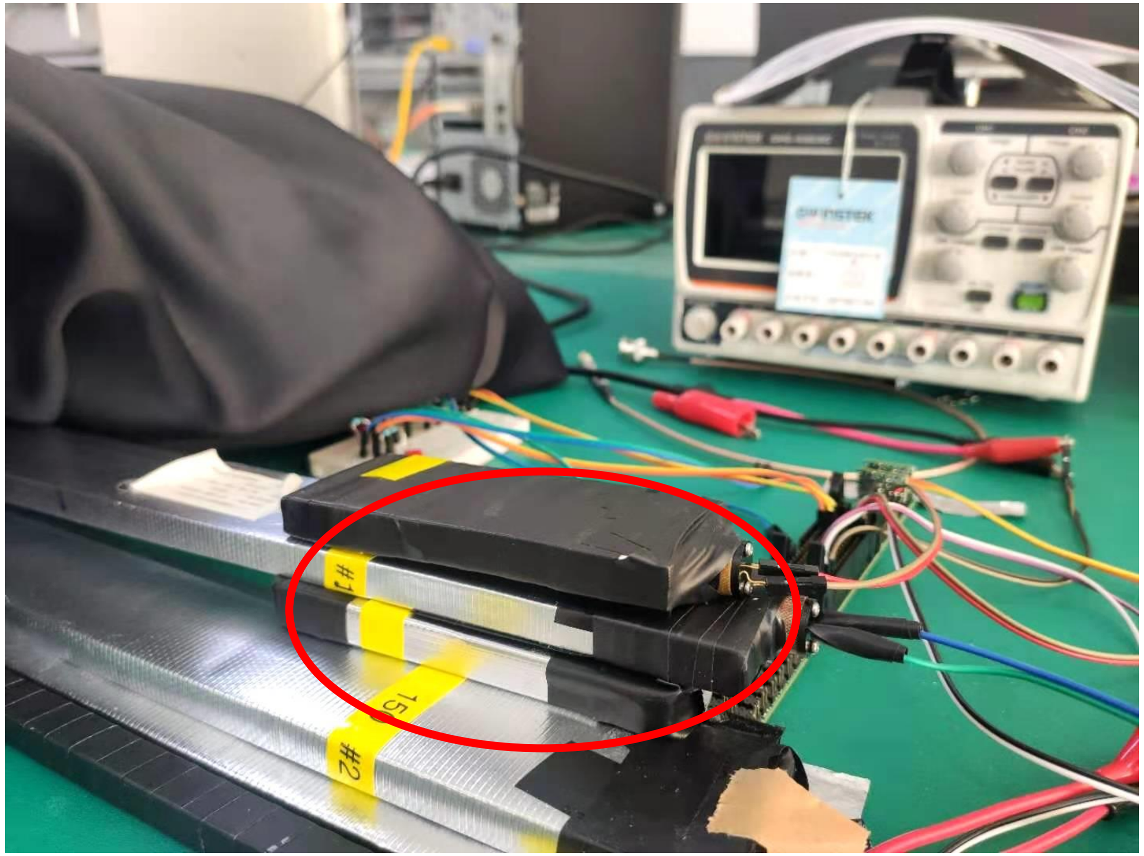
$L = 6.27$ cm

Attenuation length should be optimized at the production.

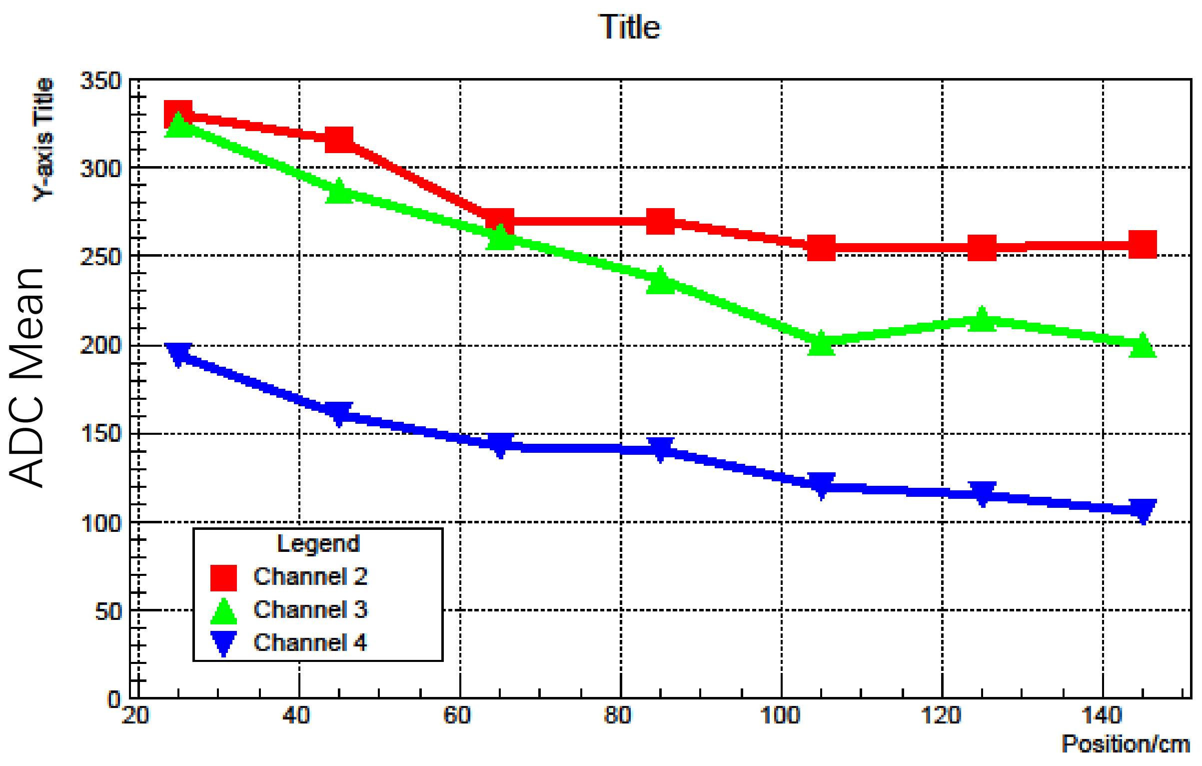
Photon collection and efficiency vs. length



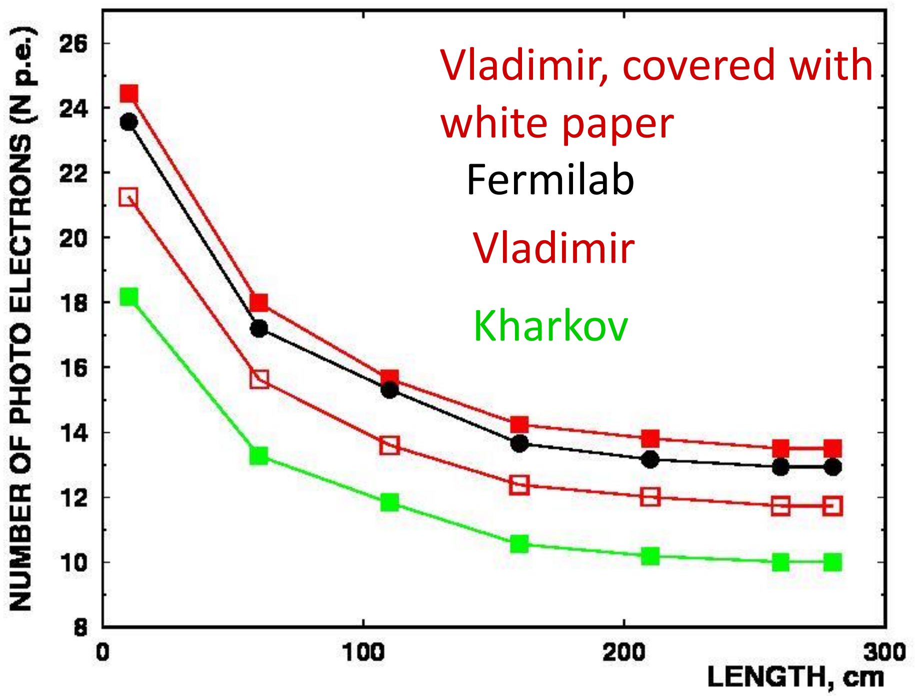
- Small strips for cosmic ray trigger: $4cm \times 10cm$.
- A good spatial resolution.



Photon collection

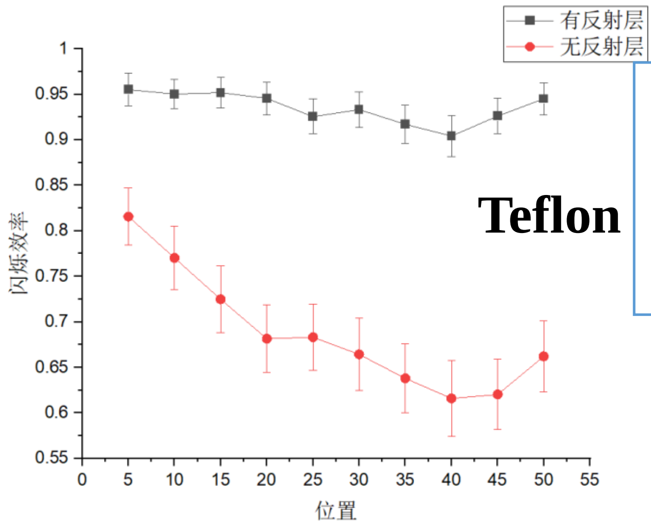


From Belle II



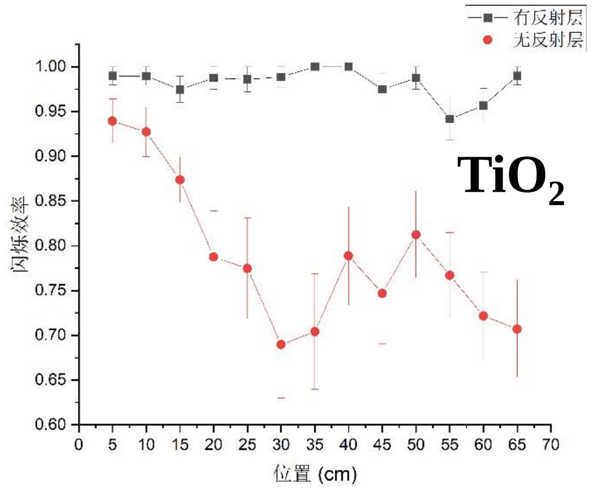
- ➢ With WLS fibre.
- ➢ They have different pedestals.

Efficiencies



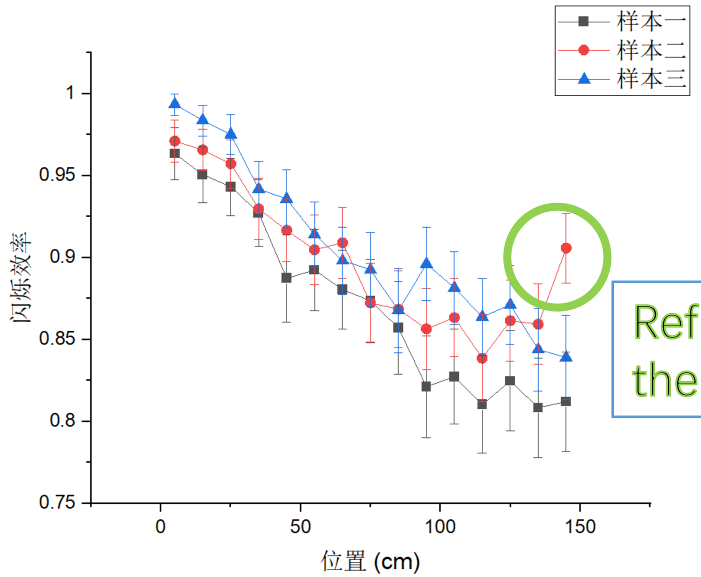
Teflon

- Diameter of fibre is $1.0\ mm$.
- $1.0\ mm$ fibre has been purchased, and will be tested soon.



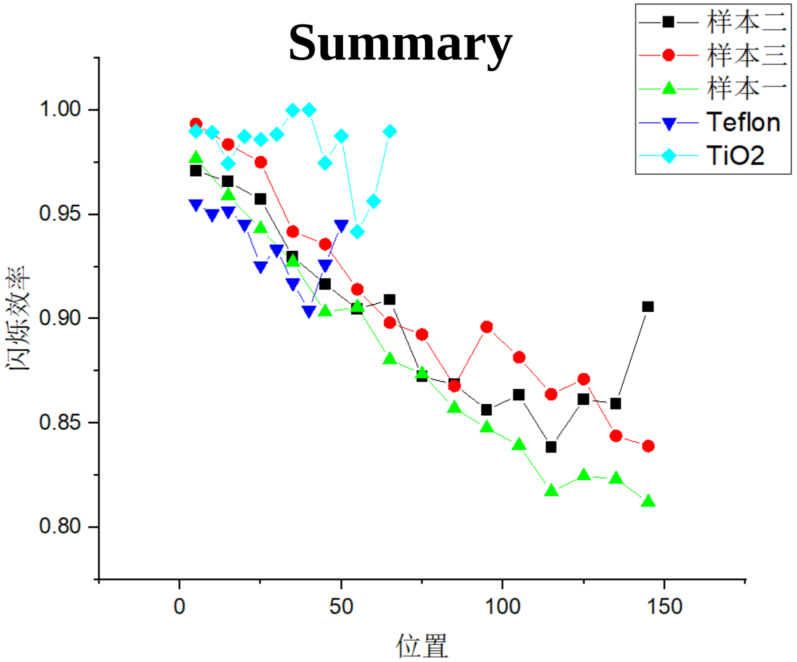
TiO_2

TiO_2 is a bit better, but the manufacture takes more time.



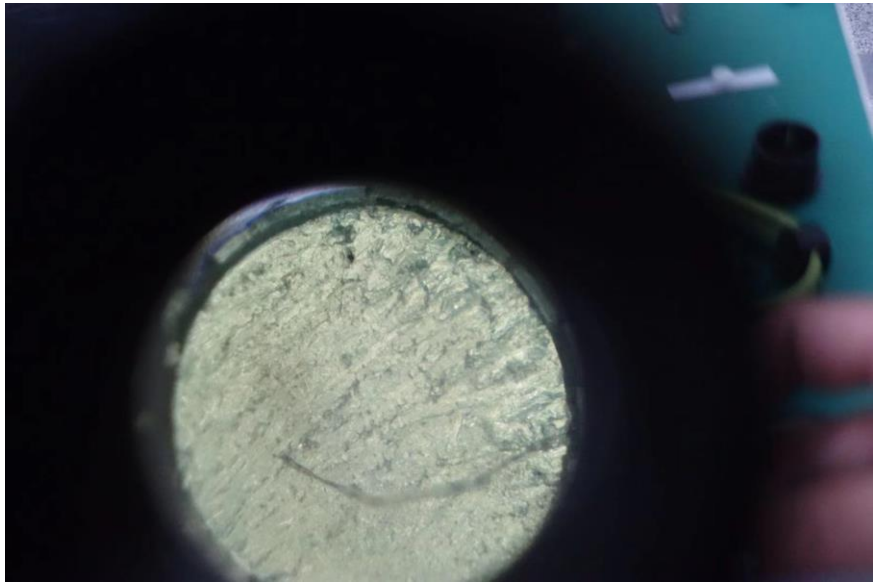
Reflection at the far end

Summary

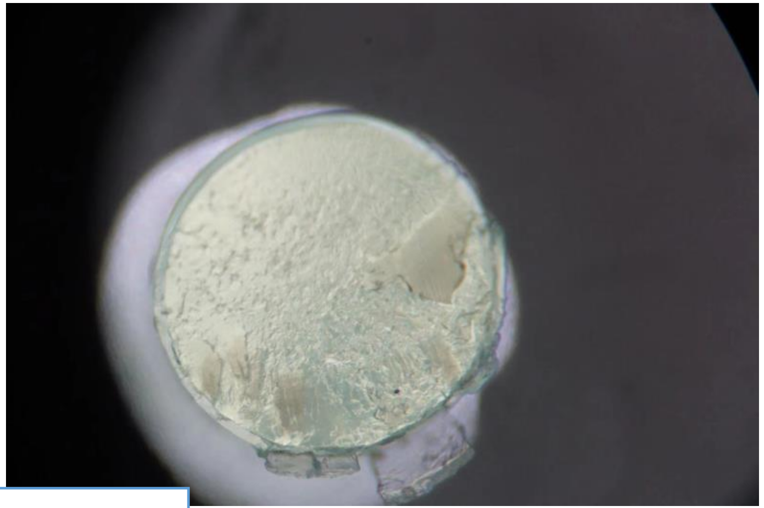


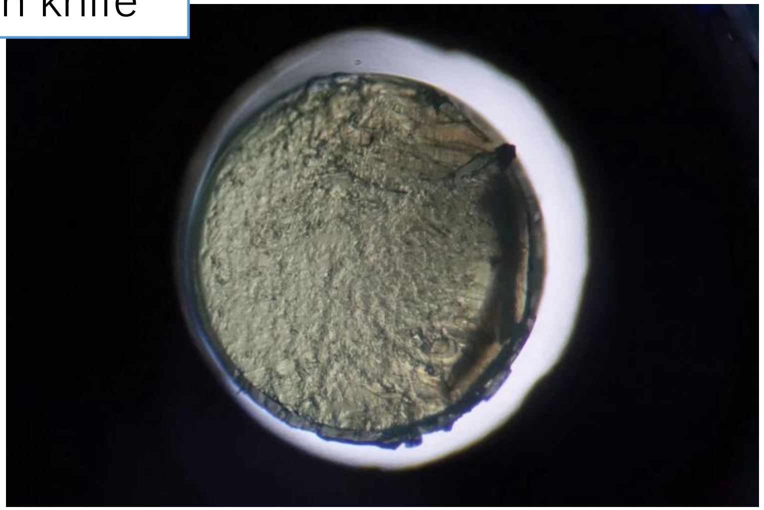
WLS fibre section

After surface grinding



Cut with knife



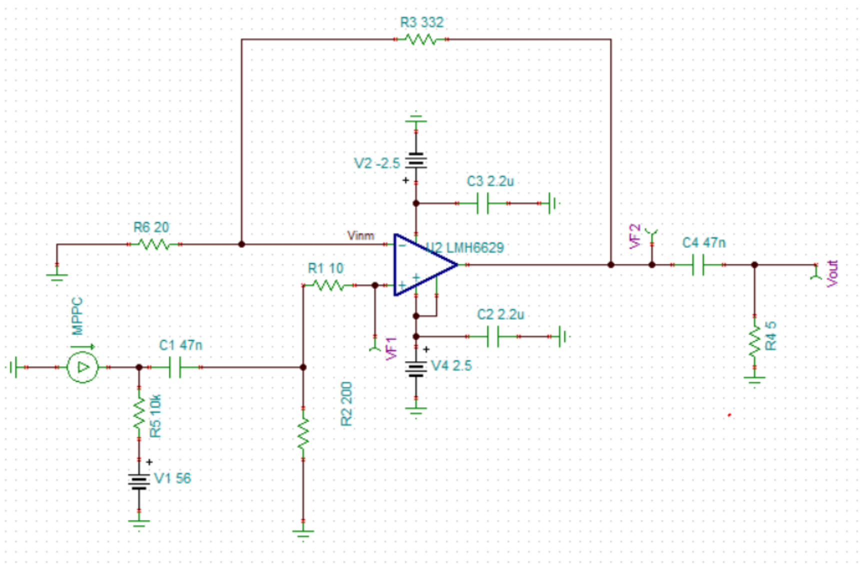


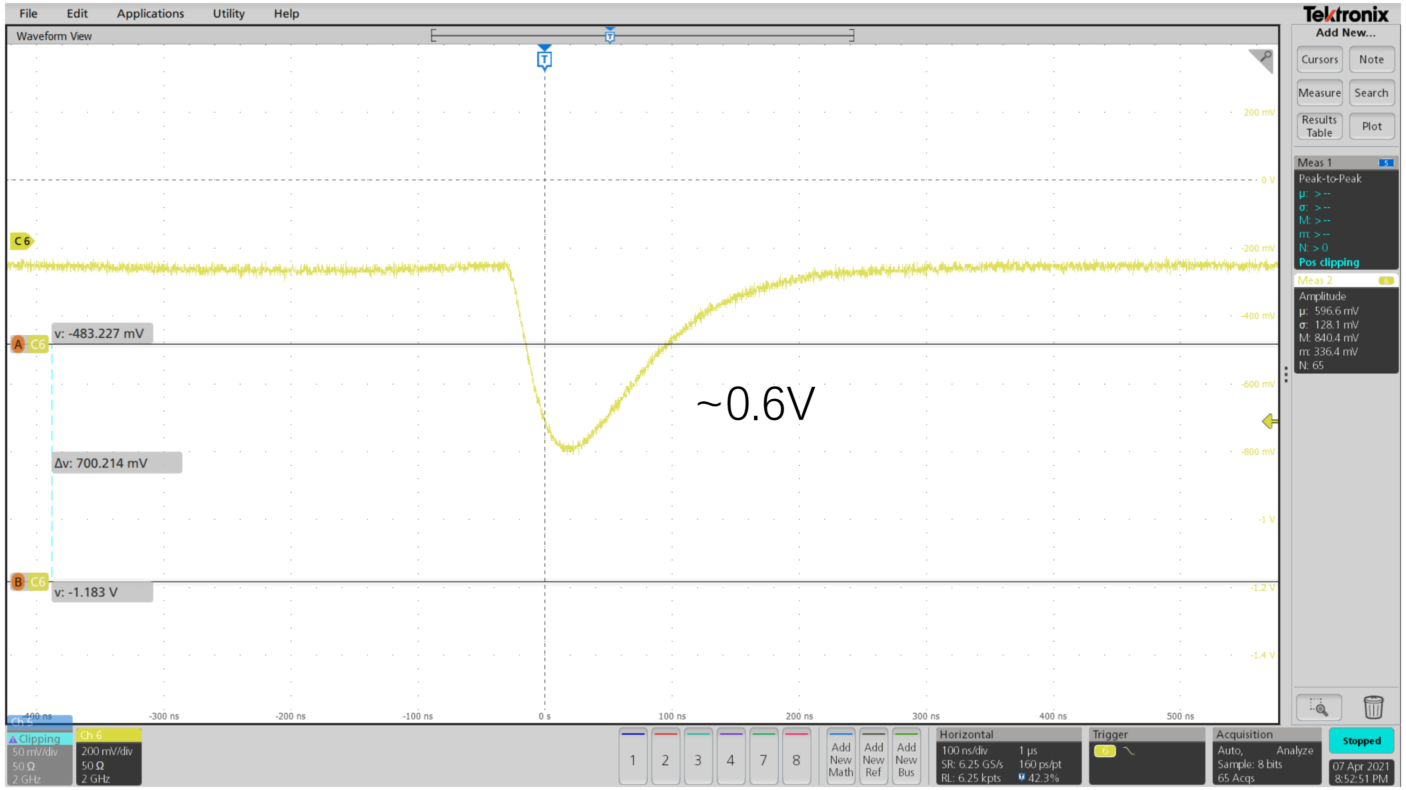
Random quality…

Need improvement on surface grinding for WLS fibre.

Pream study

- The pream design from Belle II KLM is used for MPPCs. Gain ~10 for long cables.
- Study on new pream is ongoing. More choices.





Much larger signal!

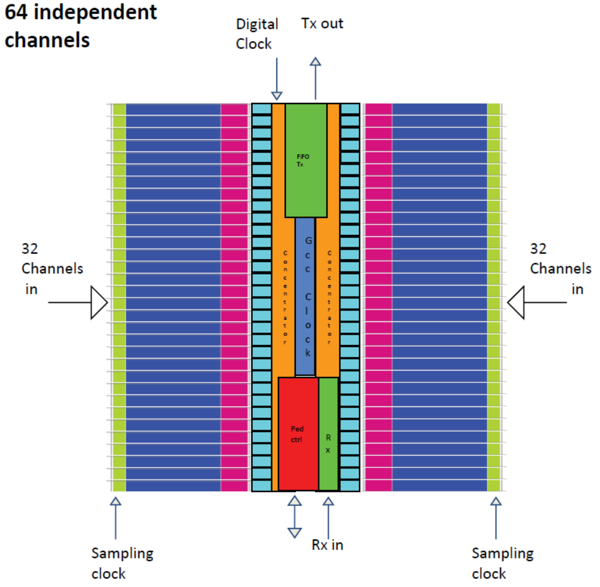
Waveform of a MPPC signal after new pream.

KLM readout upgrade at Belle II

Nalu Scientific
Data Acquisition Systems

TARGET ASIC upgrade

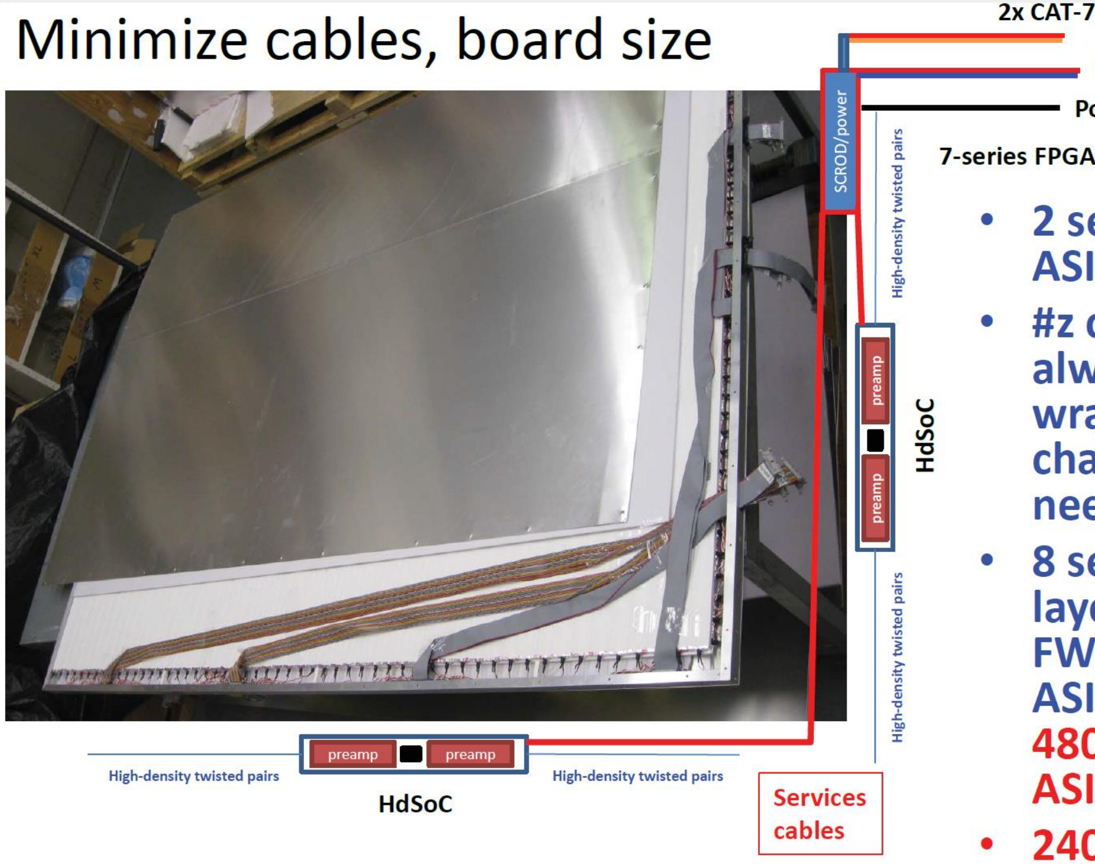
HdSoC Floorplan: 64 independent channels



Parameter	Specification
Channel no.	64
Sample rate	1-2 GSa/s
Bandwidth	1 GHz
No. bits	12
Supply Voltage	2.5V
Input noise	1mV
Gain stages	TBD -
Analog buffer length/channel	2048
Power/channel	20-40mW
Integration	SoC

- 4x integration
- Compact power/signal cabling to SCROD
- System on Chip (signal processing), reduce SCROD processing load
- “Data push” possible (reduces need for depth since don’t wait for L1 trigger)
- Possibility to integrate amplification, Si-PM overbias adjustment
- Prototypes available early 2021

Minimize cables, board size



7-series FPGA (Zynq?)

- 2 separate ASIC cards
- #z channels always same; wrap phi channels as needed
- 8 sectors * 15 layers * 2 FW/BW * 2 ASICs = 480 ASICs, ASIC cards
- 240 SCROD

Estimation on KLM upgrade cost

Item		L0-1 cost (2012)	L2-14 / L0-1 scale factor	L2-14 cost (2012)	Inflation 13 years (1.03/yr)	Estimate (2025)
Scintillator strips	Fermilab	$50,650	7.60	$384,940	1.47	565,862
WLS fiber	Kuraray Y11(200)M	$36,564	7.60	$277,886	1.47	408,493
Photosensors	Hamamatsu	$85,658	7.60	$651,001	1.47	956,971
Aluminum frames, HDPE, etc	Vendors	$49,507	7.60	$376,253	1.47	553,092
Shipping to KEK	Nittsu	$16,800	7.60	$127,680	1.47	187,690
Photosensor HV modules	CAEN A 1510 (12ch)	$20,672	6.67	$137,816	1.47	202,590
Photosensor HV mainframes	CAEN SY 2527	$37,801	0.33	$12,600	1.47	18,522
Subtotal				$1,968,177		**2,893,220**
Contingency (20%)				$393,635		578,644
				$2,361,812		**$2,893,220**
Labor	Universities	$178,754	5.00	$893,770	1.47	**1,313,842**

More than 26k channels with average length about 2m.

CEPC muon detector has about 80k channesl, 8600 m^2.

- $2.9M for detector material
- $1.3M for detector-construction labor
- $1.4-1.8M for readout electronics (including labor)
- $5.4-5.6M total project cost

With large potential on reducing the cost: Laber, scintillator, new fibre/SiPM in China.

Summary on scintillator-based detector

- Detector simulation is ongoing, and will be implemented into CEPCSW.
- Attenuation of scintillator, efficiency and photon collection have been studied.
- Large potential to improve the performance and reduce the cost.

Thank you!