Drift chamber towards CEPC Reference TDR

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On behalf of DC group

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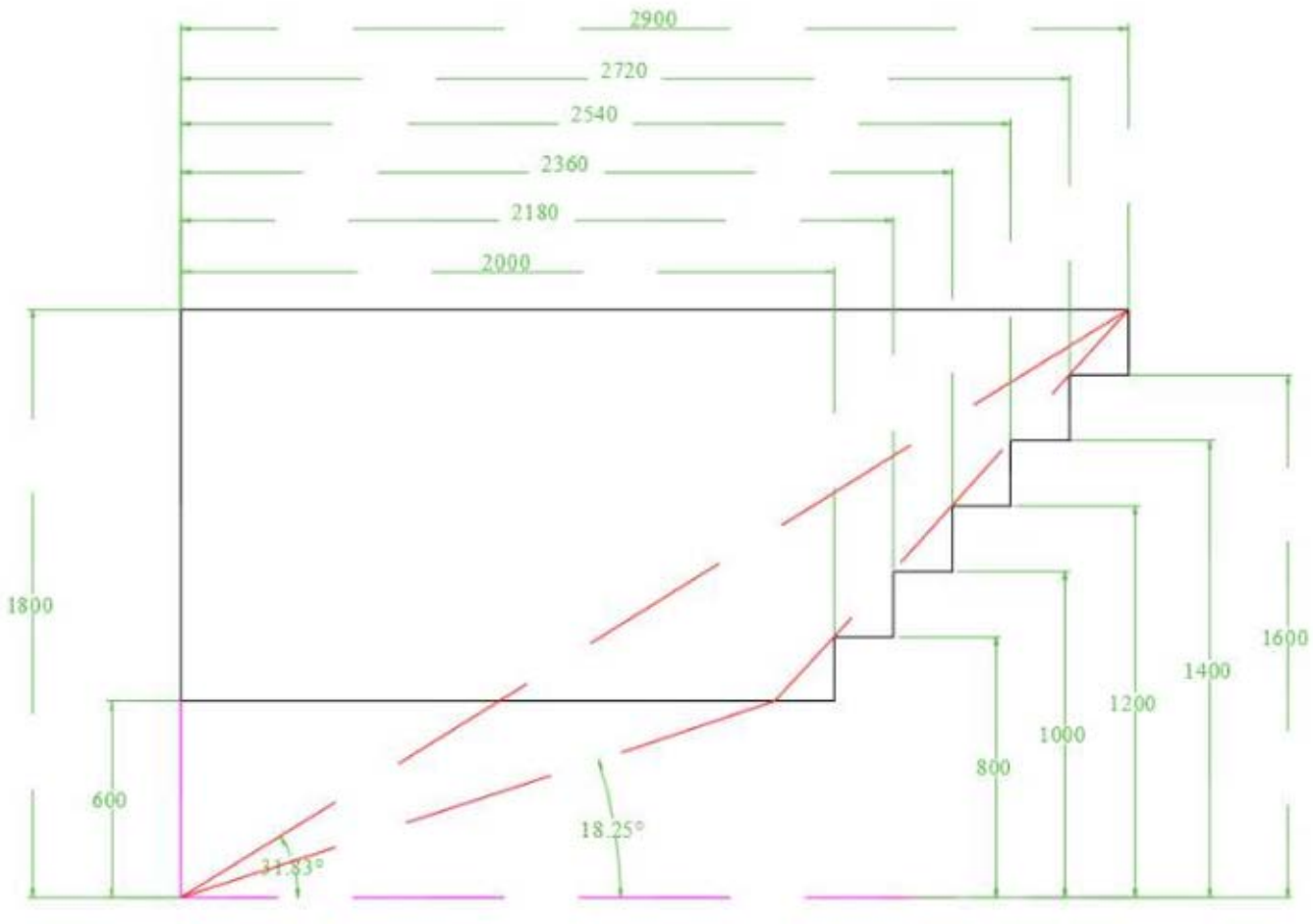
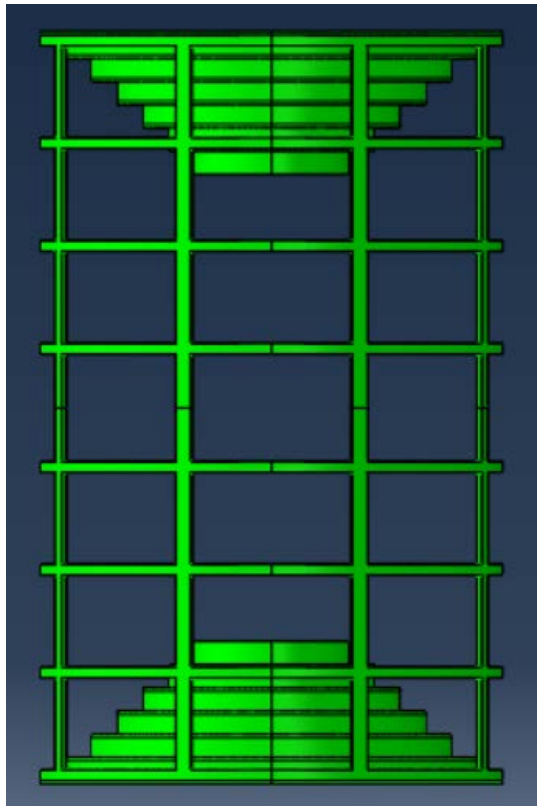
Outline

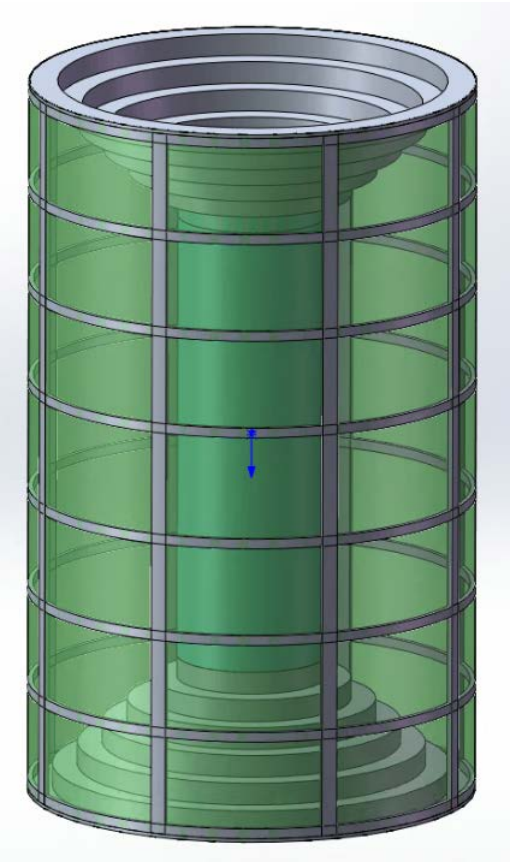
- **Mechanical design and FEA**
- **Electronics scheme**
- **Performance study and prototype test**

Mechanical design and FEA

Overall Design







CF Frame structure： 8 longitudinal hollow beams + 8 annular hollow beams + inner CF cylinder and outer CF cylinder

- Length : 5800mm
- Outer diameter: 3600mm， Inner Diameter: 1200mm；
- Thickness of each end plate: 25mm， weight :1100kg

Wire tension

	cell number /step	length	single sense wire tension(g)	Single field wire tension(g)	total tension /step (kg)
	2684	4000	43.29	66.52	651.78
	3452	4360	51.43	79.03	995.95
	4220	4720	60.28	92.62	1426.88
	4988	5080	69.82	107.29	1953.63
	5756	5440	80.07	123.03	2585.27
	6524	5800	91.02	139.85	3330.85
total	27623				10944

Diameter of field wire (Al coated with Au) : 60μm
Diameter of sense wire (W coated with Au): 20μm
Sag = 280 μm

Meet requirements of stability condition:

$$T > (\frac{VLC}{d})^2/(4\pi\varepsilon_0)$$

Loads

Wire Tension

	cell number/step	length	Sense wire tension(g) /cell	Field wire tension(g) /cell	Sense wire tension (kg)	Field wire tension (kg)	total tension(kg) /step
	2684	4000	43.29	66.52	116.19	535.59	651.78
	3452	4360	51.43	79.03	177.55	818.41	995.95
	4220	4720	60.28	92.62	254.37	1172.51	1426.88
	4988	5080	69.82	107.29	348.27	1605.36	1953.63
	5756	5440	80.07	123.03	460.87	2124.39	2585.27
	6524	5800	91.02	139.85	593.79	2737.07	3330.85
total	27623				1951	8993	10944

yield strength of 7075 aluminum:505MPa

	Young's Modulus	Poisson's Ratio
1	71700000000	0.33

Density of CF 1.6

Data

	E1	E2	Nu12	G12	G13	G23
1	320000000000	7000000000	0.29	4200000000	4200000000	2700000000

CF parameter

Data

	Ten Stress Fiber Dir	Com Stress Fiber Dir	Ten Stress Transv Dir	Com Stress Transv Dir	Shear Strength	Cross-Prod Term Coeff	Stress Limit
1	2000000000	600000000	22000000	100000000	50000000	0	0

Carbon Fiber Material parameter

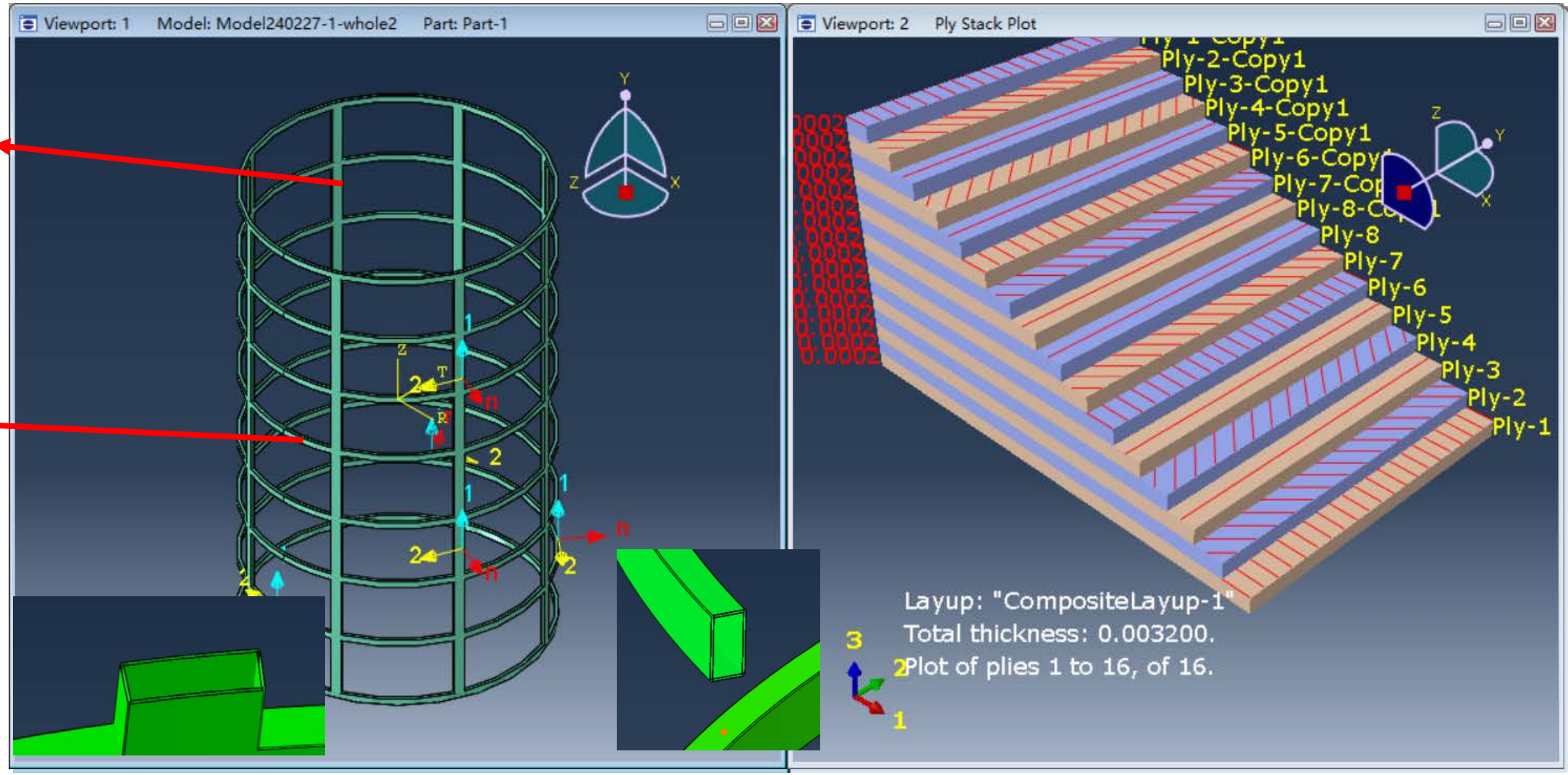
性能	东丽M55J复合材料	测试标准
	室温	
0度拉伸强度，Mpa	2000	ASTM D3039
0度拉伸模量，GPa	320	
泊松比	0.29	
90度拉伸强度，Mpa	22	
90度拉伸模量，GPa	7.0	
弯曲强度，Mpa	1000	ASTM D7264
弯曲模量，GPa	230	
0度压缩强度，Mpa	600	ASTM D6641
0度压缩模量，GPa	300	
90度压缩强度，Mpa	100	
90度压缩模量，GPa	6.5	
ILSS，Mpa	50	ASTM D2344
面内剪切强度，Mpa	50	ASTM D3518
面内剪切模量，GPa	4.2	

M55J CF

FEA

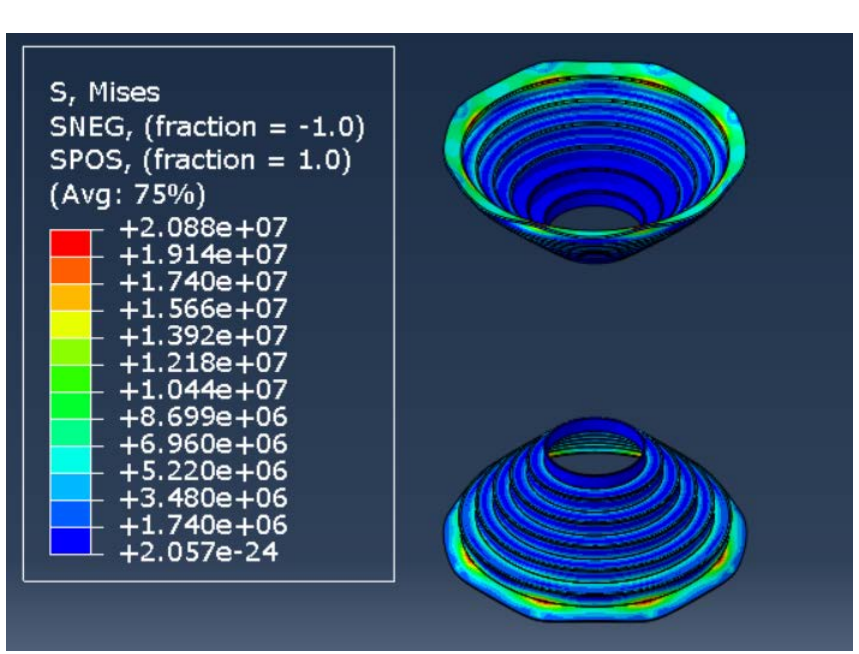
Cross section of longitudinal HB：125mm*40mm，thickness: 3.2mm
weight： 78kg

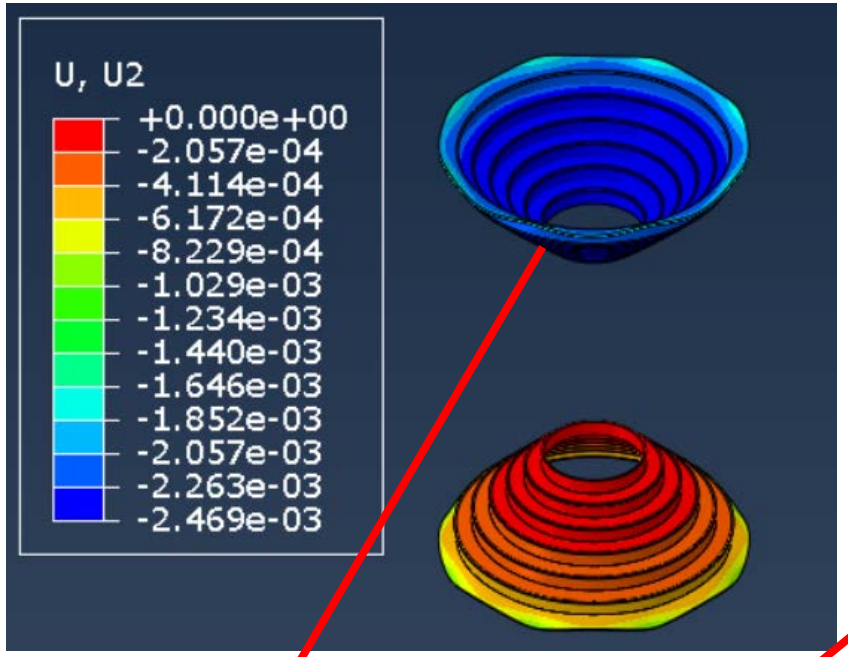
Cross section of annular HB：80*40mm
Thickness: 3.2mm
weight： 111kg

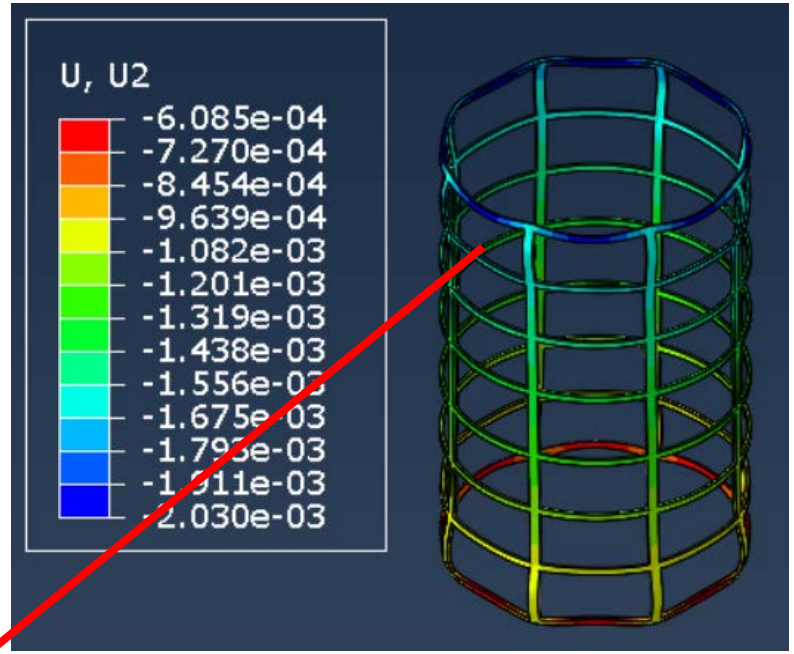


Thickness of CF wall: 3.2mm， including 16 composite layers. Thickness of each composite layer: 200μm

Loads: Wire tension+ Axial self weight：

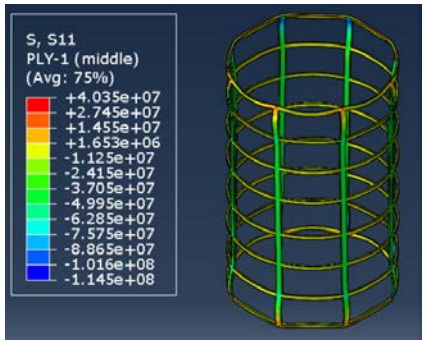


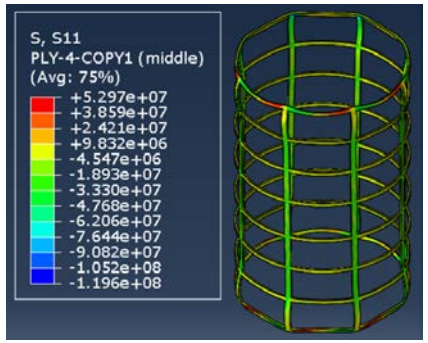


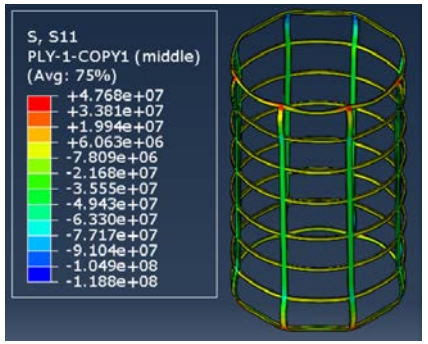


Stress 20.9MPa,
endplate deformation 2.5mm,
CF frame deformation 1.4mm

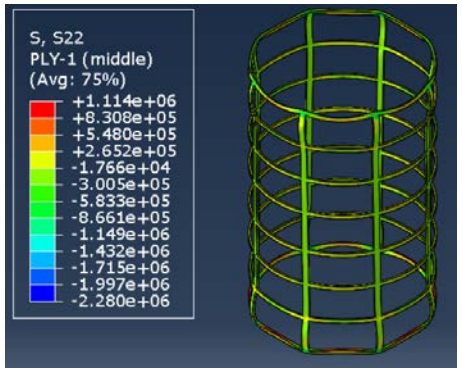
Loads: Wire tension+ Axial self weight：

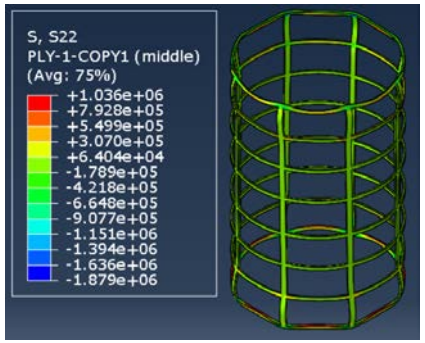




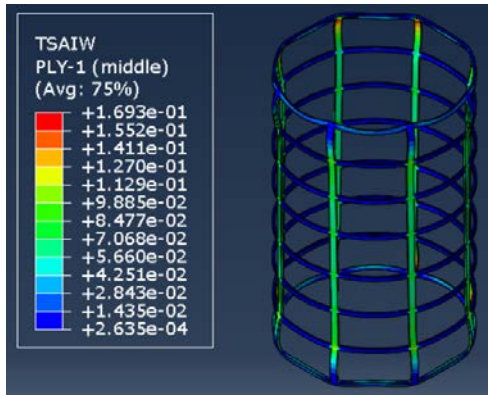


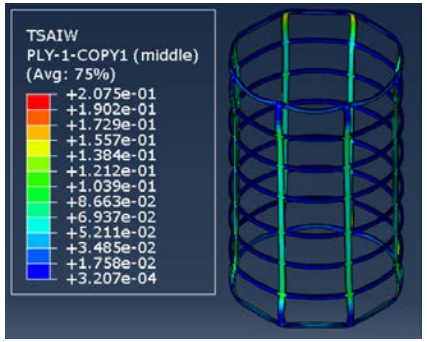
The maximum stress in the 0 degree direction of CF is 53MPa, located in the -4th layer





The maximum stress in the 90 degree direction of CF is 1.1 MPa, located in the first layer

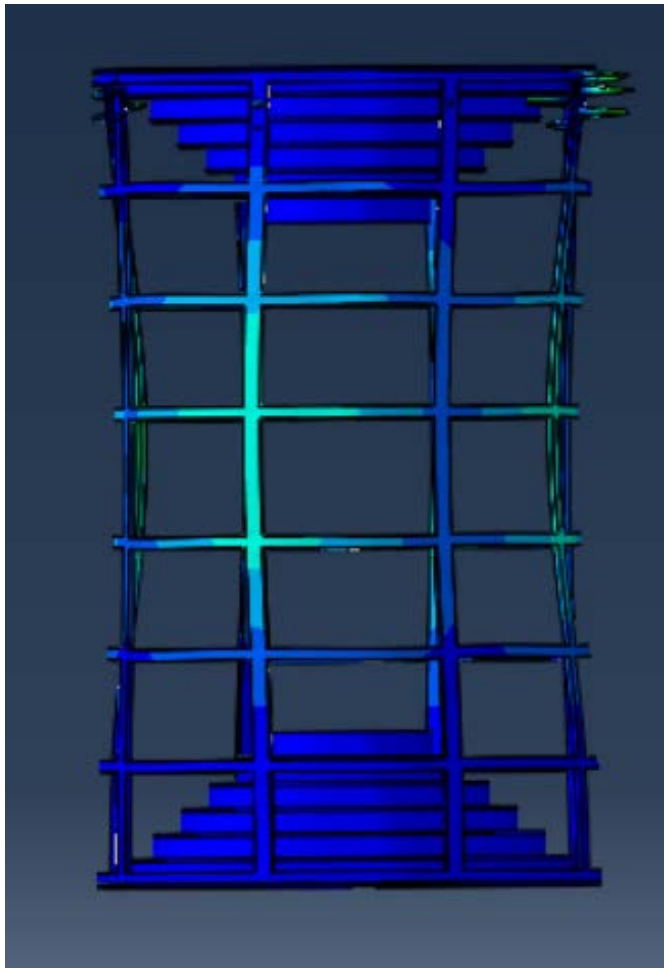




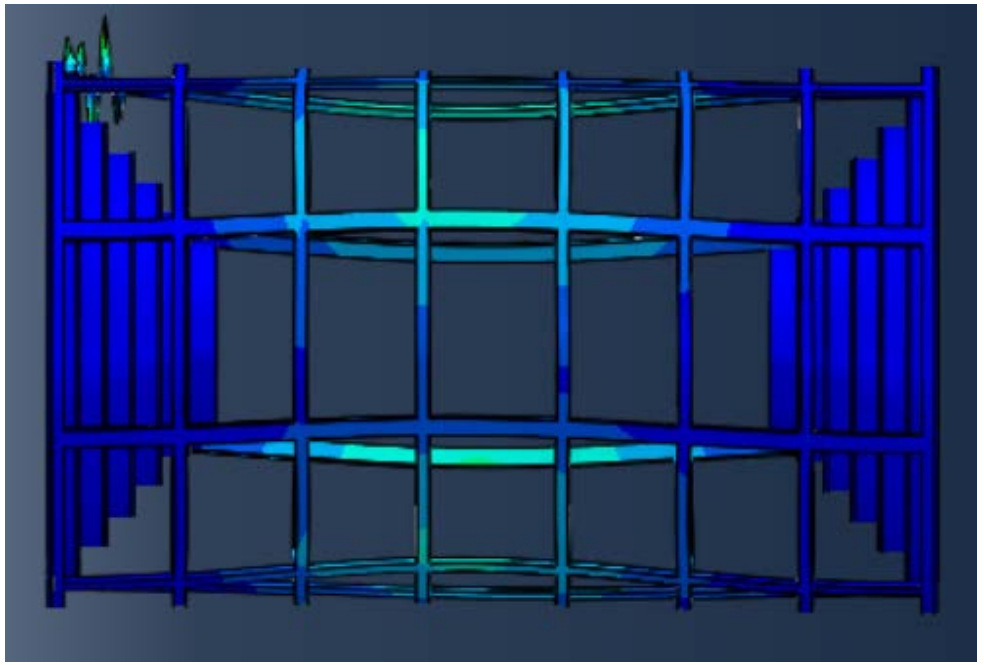
TSAIW： 0.21， located in the sixteenth layer

safety factor：~5

Loads: Wire tension+ Axial self weight :



Vertical self weight
Buckling coefficient : ~12



Horizontal self weight
Buckling coefficient : ~14

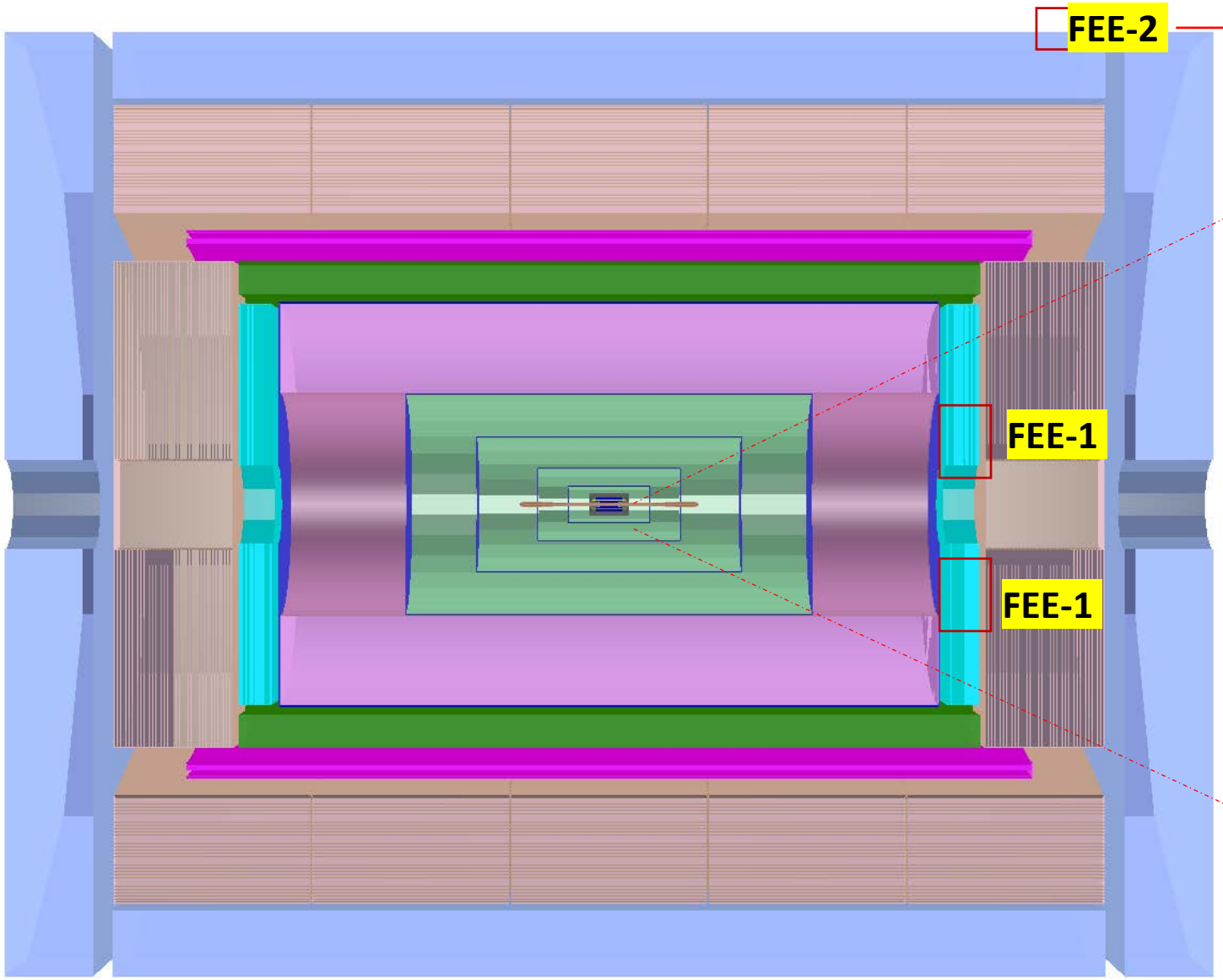
The structure is stable

Updated design parameters

R extension	600-1800mm
Length of outermost wires（cosθ=0.85）	5800mm
Thickness of inner CF cylinder： (for gas tightness, no load)	200μm (0.08% X_0)
Thickness of outer CF cylinder： (for gas tightness, no load)	300μm (0.13% X_0)
Outer CF frame structure：	Equivalent CF thickness: 1.8 mm (0.77% X_0)
Thickness of end Al plate:	25mm (28% X_0)
Material budget of cables at end plate	~ 1.8% X_0
Cell size:	~ 18 mm × 18 mm
Cell number	27623
Diameter of field wire (Al coated with Au)	60μm
Diameter of sense wire (W coated with Au)	20μm
Ratio of field wires to sense wires	3:1
Gas mixture	He/iC_4H_{10}=90:10
Gas + wire material	0.16% X_0

Electronics

Global design for DC Elec-TDAQ system



To BEE

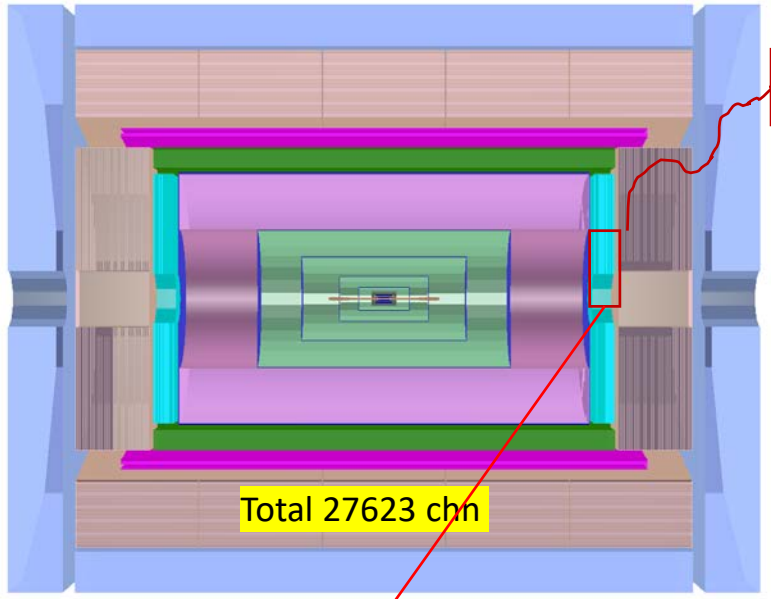
Considering : radiation hardness
Power consumption,
Material budget

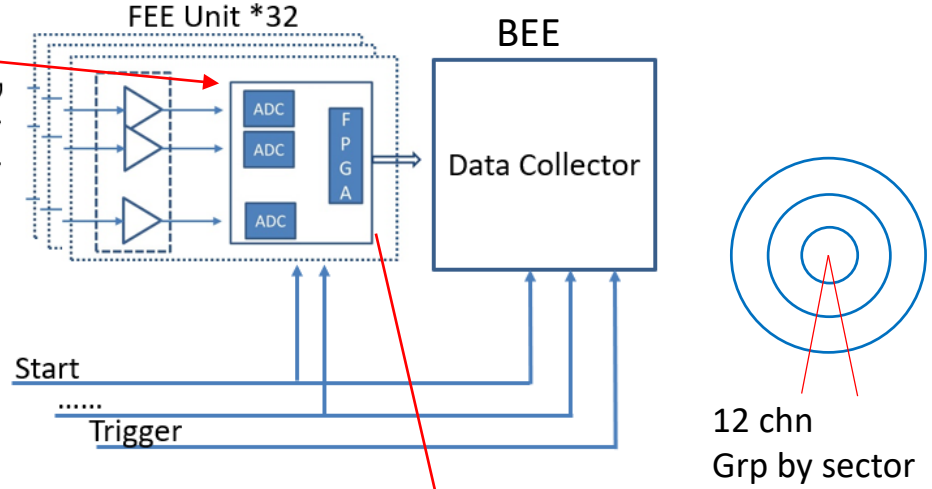
FEE-1:
A rad-hard (analog) FEE (preamp)

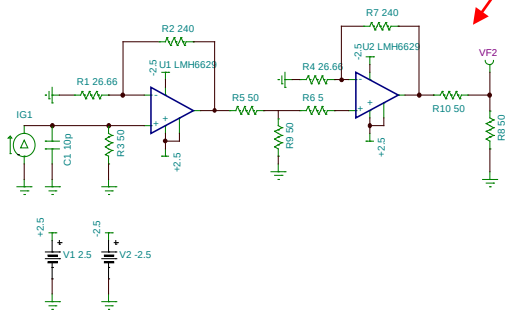
FEE-2:
Non rad-hard FEE for data buffering, in low dose region (ADC and FPGA)

To BEE

Preliminary readout scheme of Drift Chamber

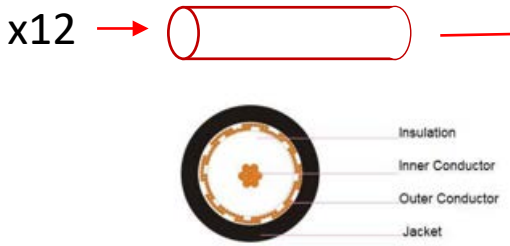




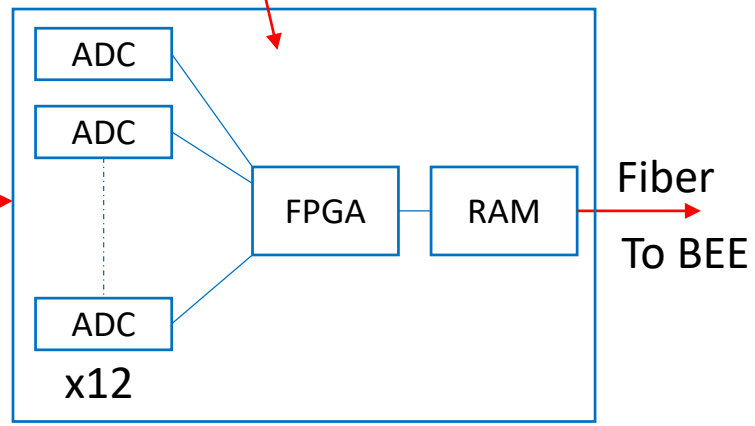


High Bandwidth Preamp
100mW/ch -> 2.7kW in total

1.4kW for each end plate, air cooling is OK
no additional material bufget



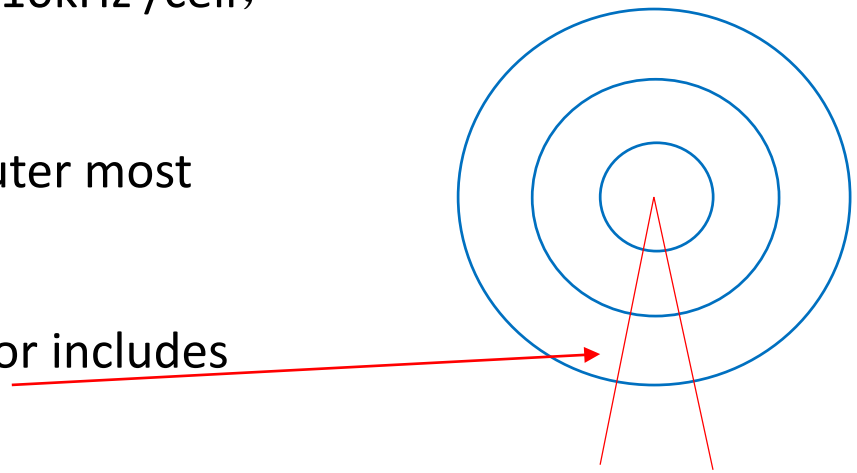
Analog signal on Cable
2.8mm per co-ax
12 signals + 1 Power
3dB attenuation @ 280MHz



ADC @1.3Gsps 12bit

Data size estimation

- ADC sampling rate : 1.3Gsps, 12bit, sampling window: 1.5 μ s, data size/single hit: 2k×2Byte
- Hit rate of the inner most layer: ~ 70kHz/cell， outer most layer: 10kHz /cell，average hit rate: ~30kHz/ cell
- Average Occupancy: 5% (10.5% for inner most layer, 1.2% for outer most layer)
- Each digital board corresponds to 12 preamplifier channels (sector includes inner to outer layers)
- Data size estimation：
  - 0.5Gbps/12 channels-- compatible with calibration requirement and overall readout scheme of the detector

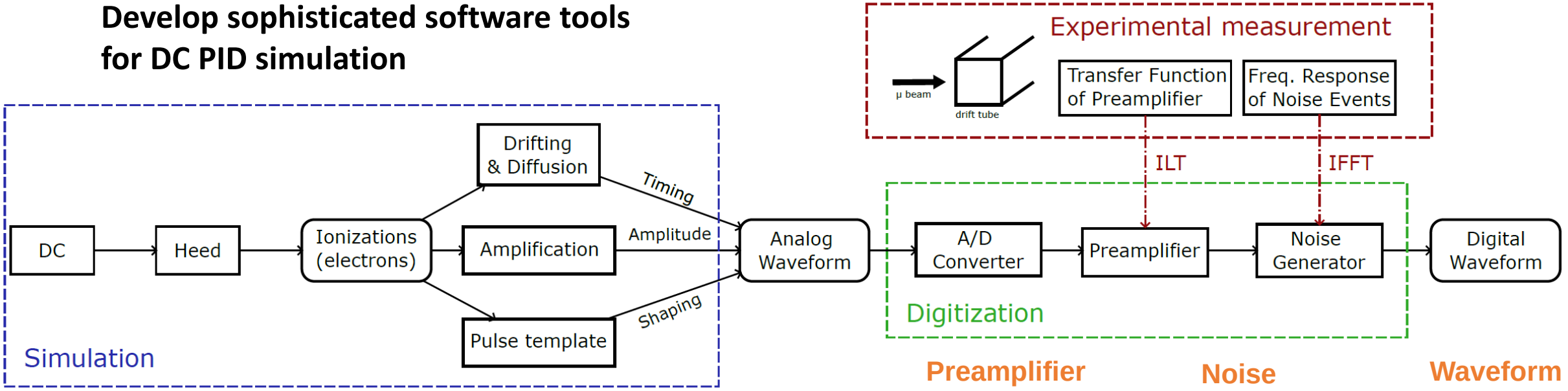


12 chn
Grp by sector

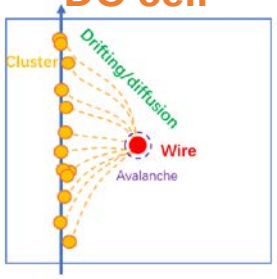
Performance

Waveform-based full simulation

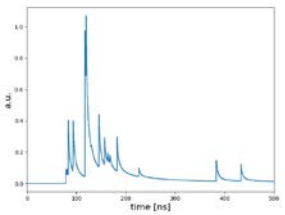
Develop sophisticated software tools for DC PID simulation



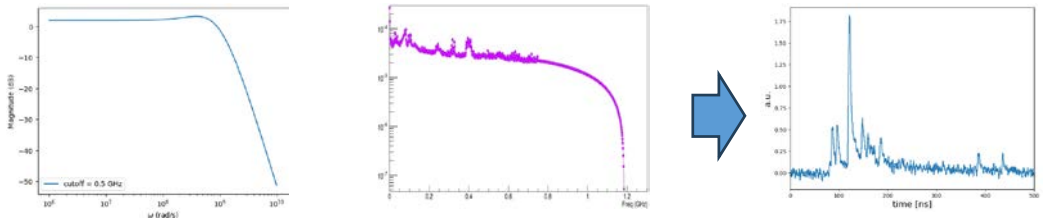
DC cell



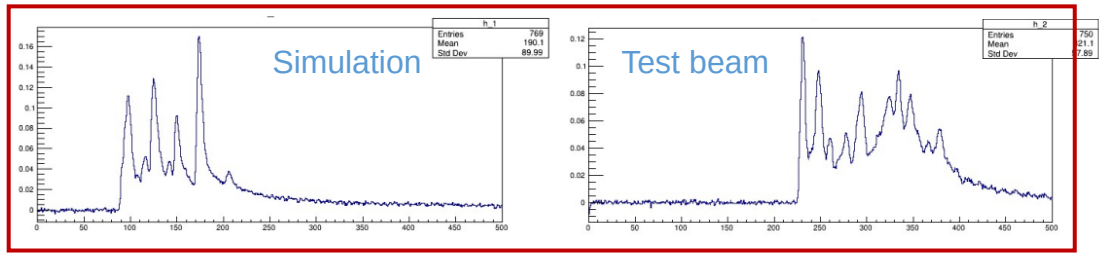
Induced signal



Preamplifier **Noise** **Waveform**

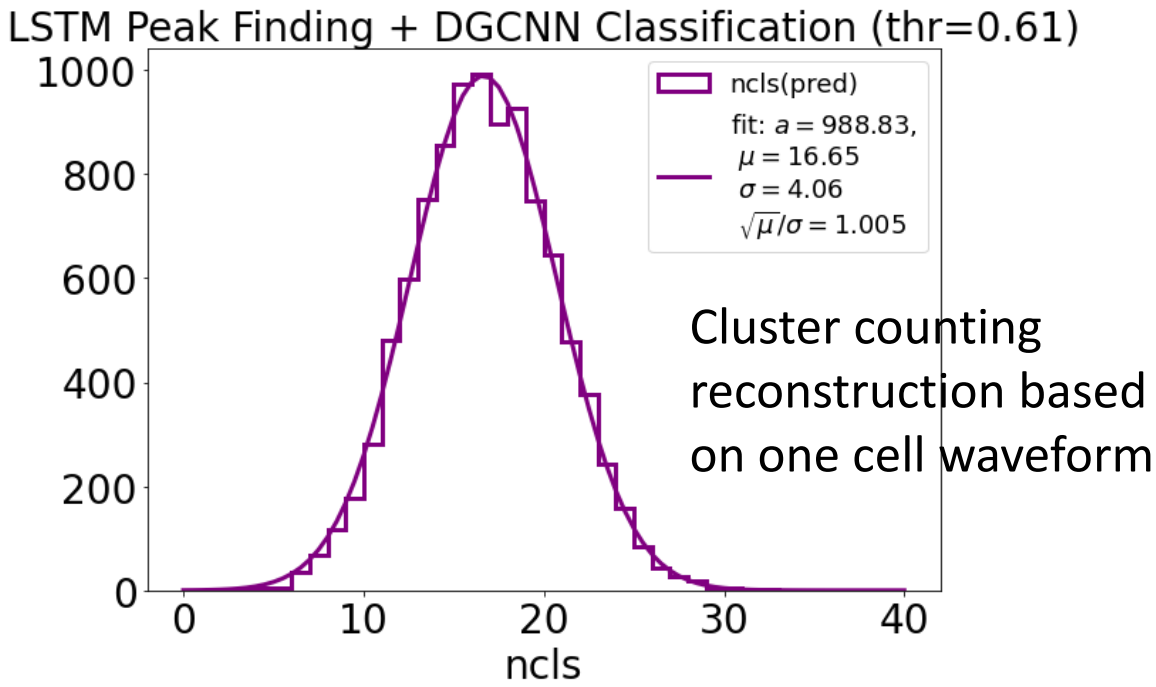


Tuned MC is comparable to data



Machine learning reconstruction

- Supervised model for MC simulation
  - Full labels in MC
  - Model structure
    - LSTM-based peak finding
    - DGCNN-based clusterization
- Semi-supervised model for data
  - Lack of labels in data
  - Domain adaptation to map data to MC sample

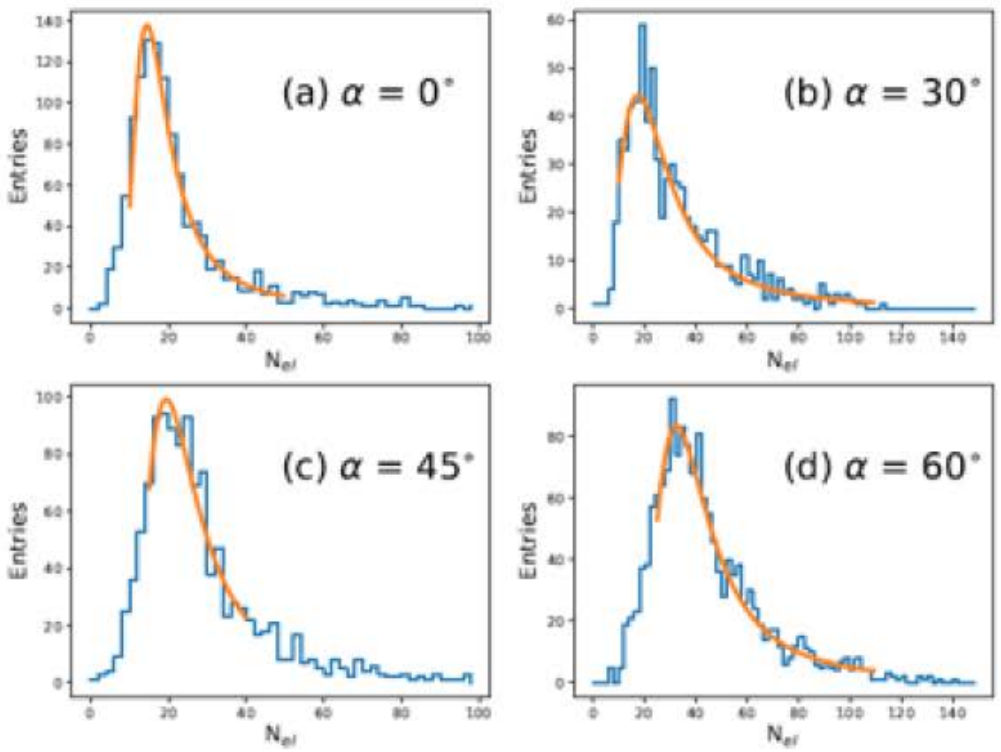


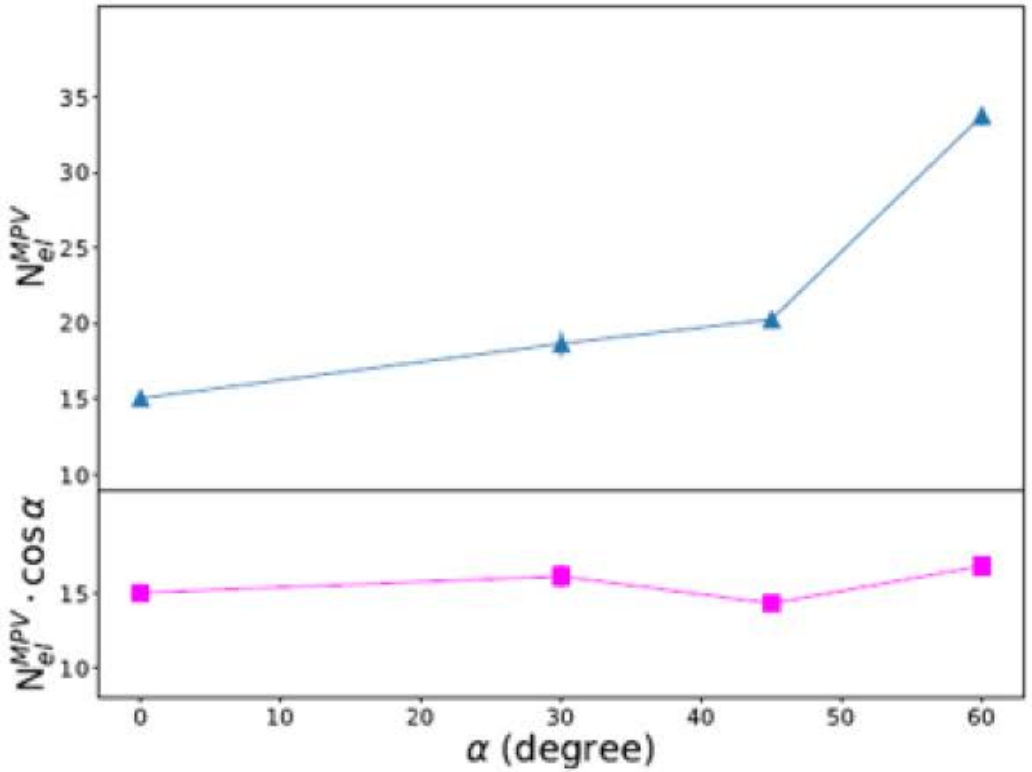
Cluster counting reconstruction based on one cell waveform

Clusterization Method	μ	σ	σ/μ
MC truth	**16.53**	**3.93**	**23.8%**
Classical algorithm	18.67	4.60	24.6%
Deep learning	16.65	4.06	24.4%

- Closer to MC truth N_{cls} distribution
- ~10% improvement with ML (equivalent to a detector with 20% larger radius)

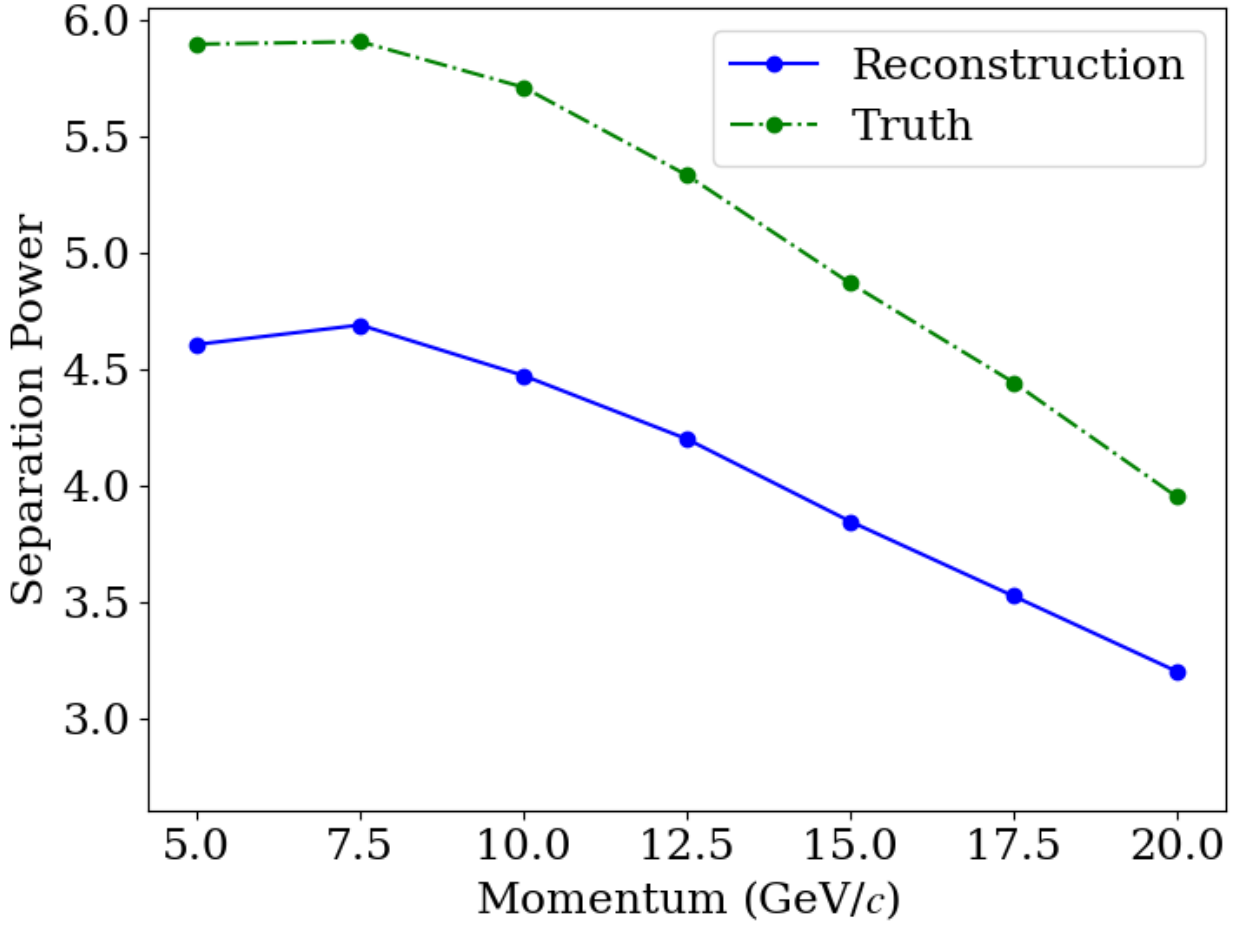
Data analysis with ML reconstruction





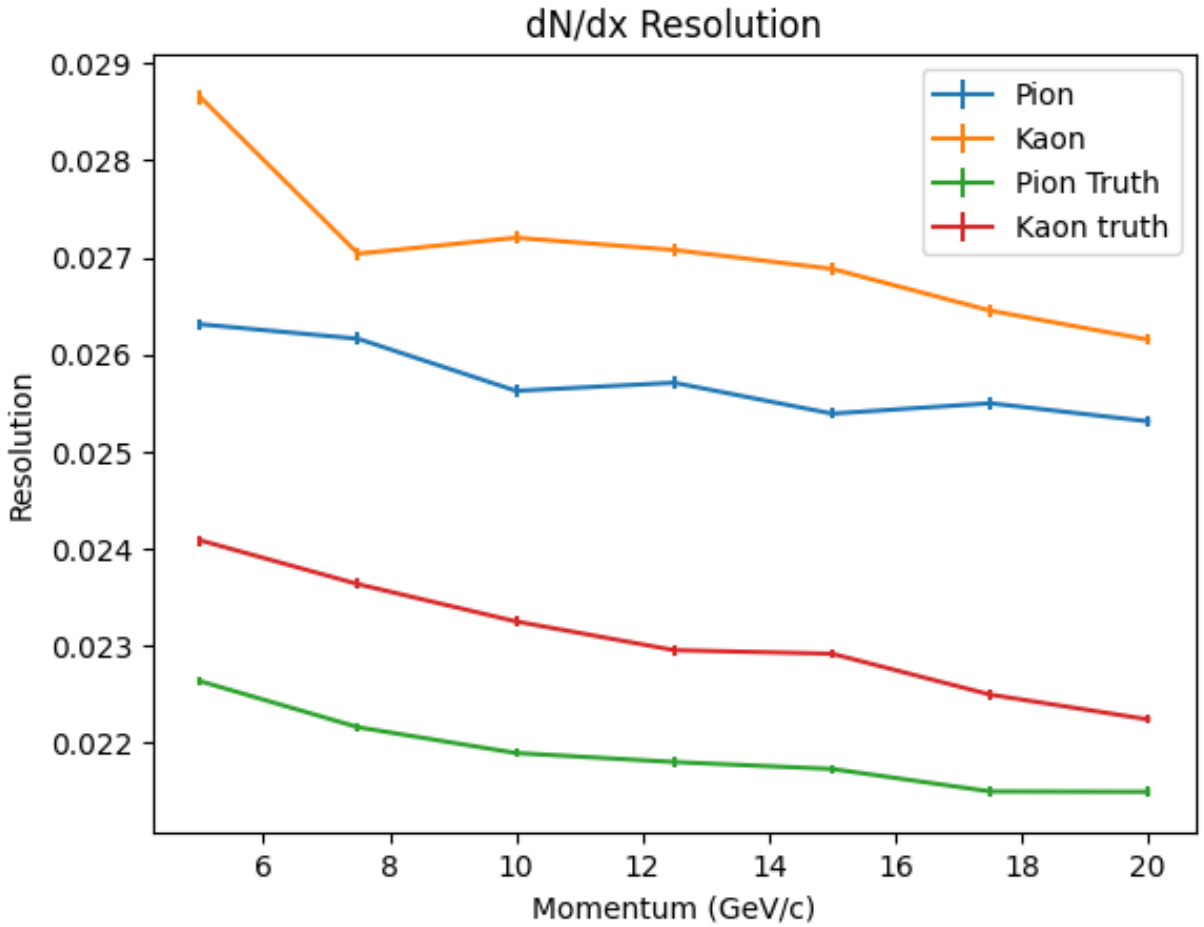
- Multi-waveform results for samples in different angles
- The algorithm is stable w.r.t. track length

PID performance



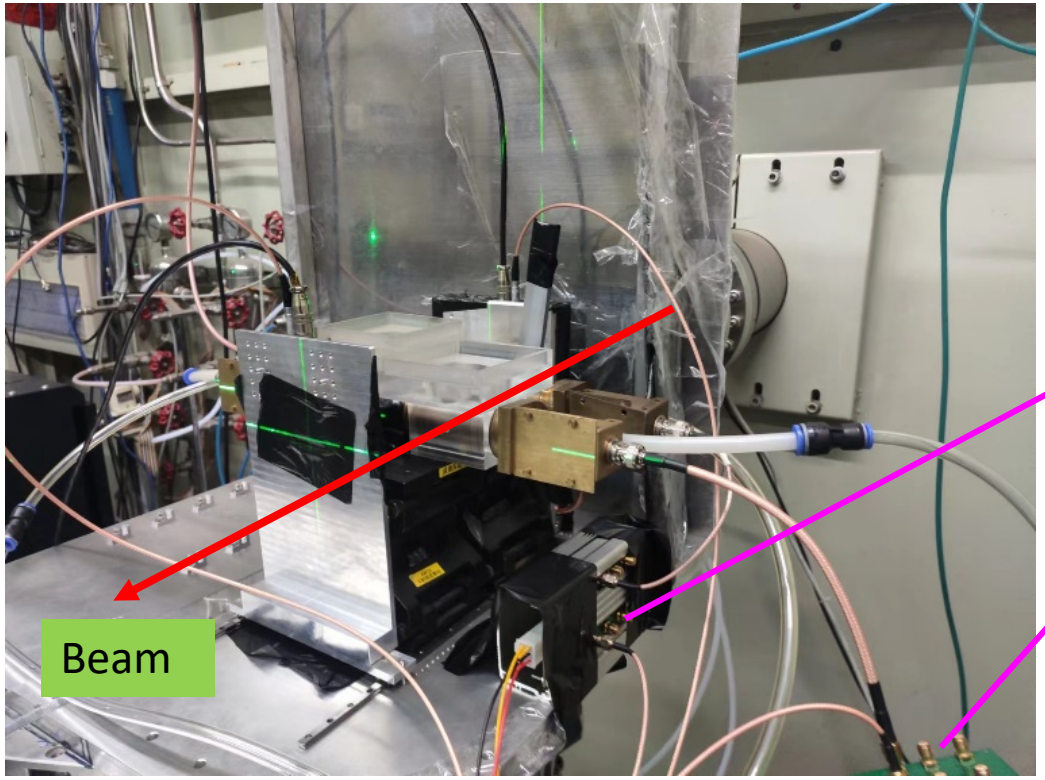
- 1.2 m track length
- For 20 GeV/c K/π,
- Separation power: 3.1σ

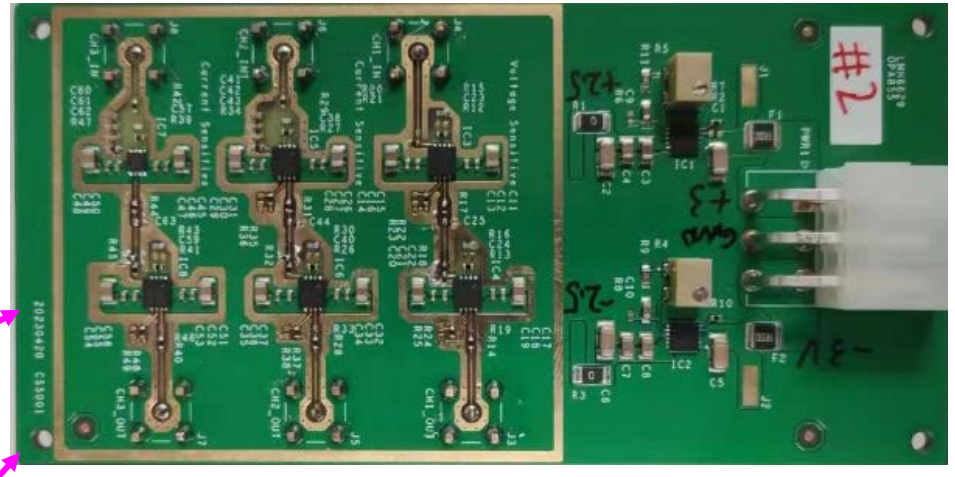
dN/dx Resolution

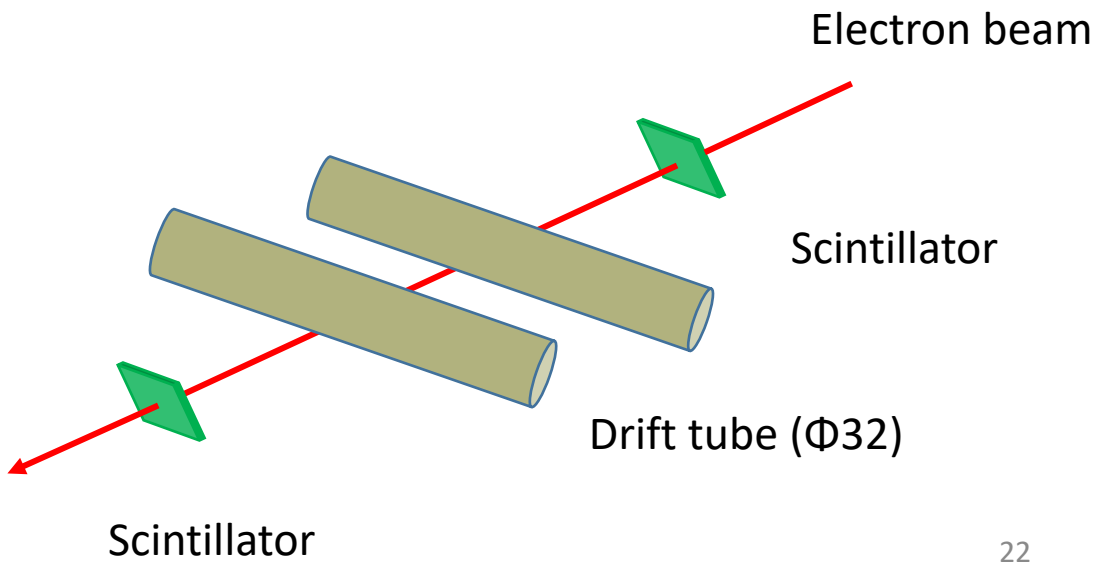


- dN/dx resolution: 2.5%-2.6% for pion
- 2.6%-2.7% for Kaon

Beam test with detector prototype (IHEP)



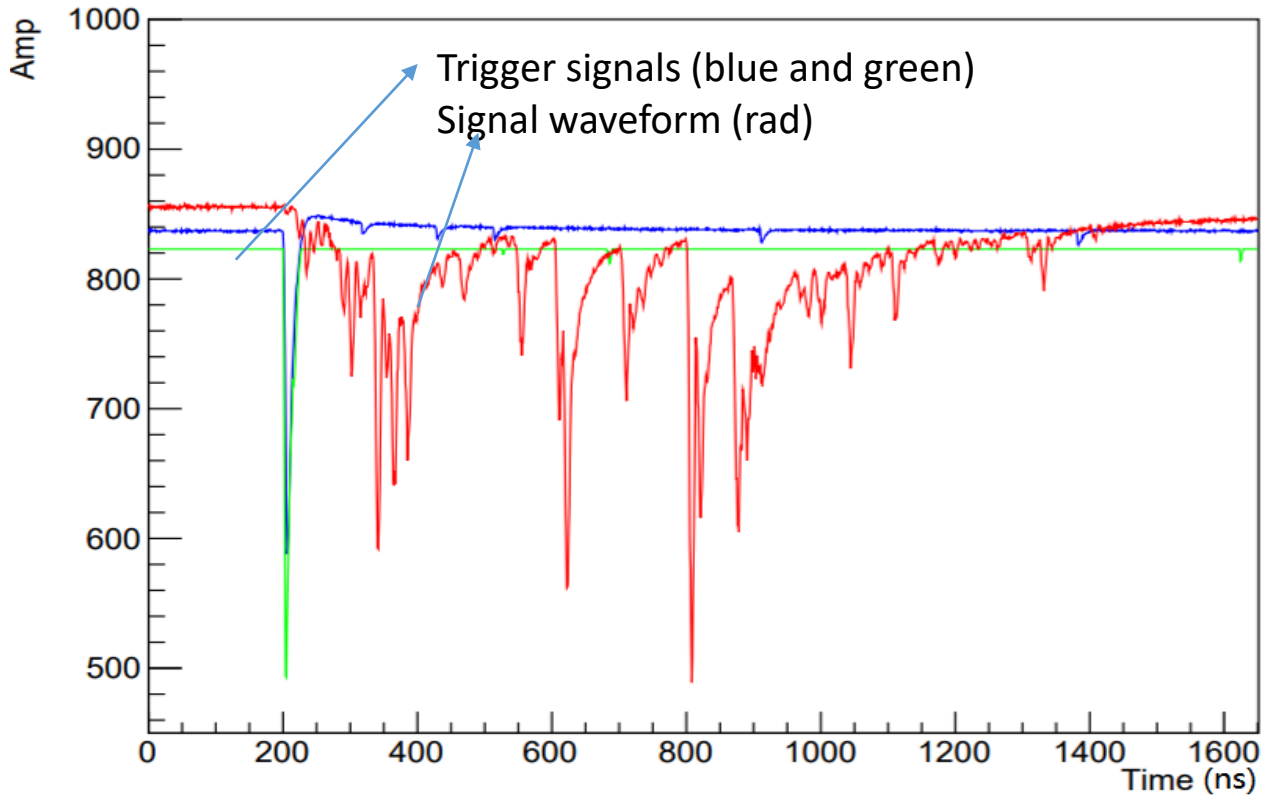




- Two drift tubes + preamps + ADC (1GHz)
- The system was tested with electron beam at IHEP

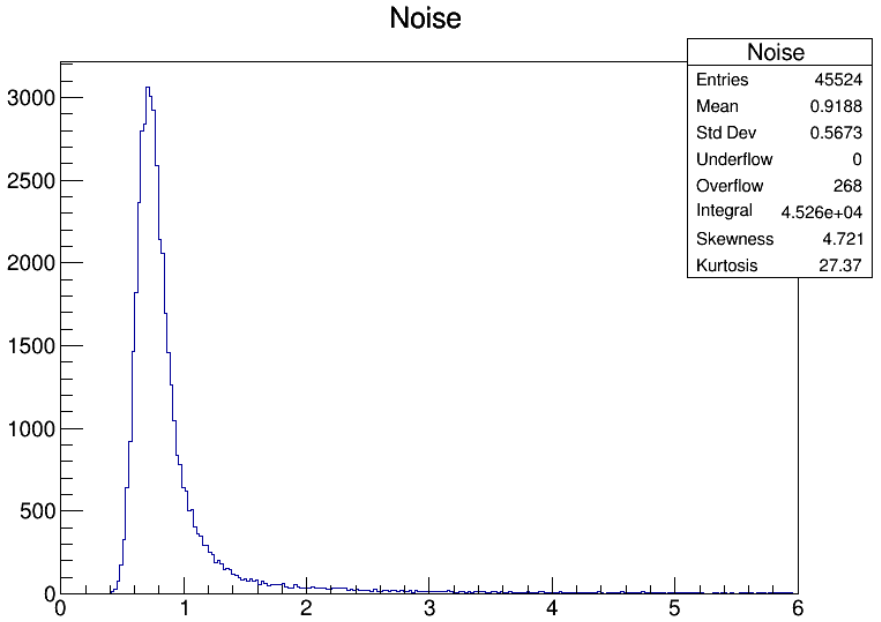
Typical Waveform

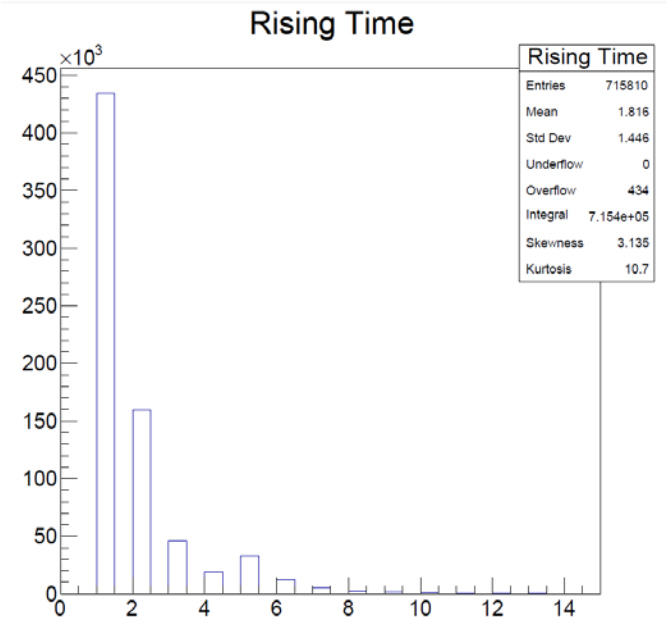
- He: iC4H10 = 90 : 10
- Digitizer: DT5751
  - Sampling rate: 1GHz
  - Four channels, two for scintillators, two for drift tubes

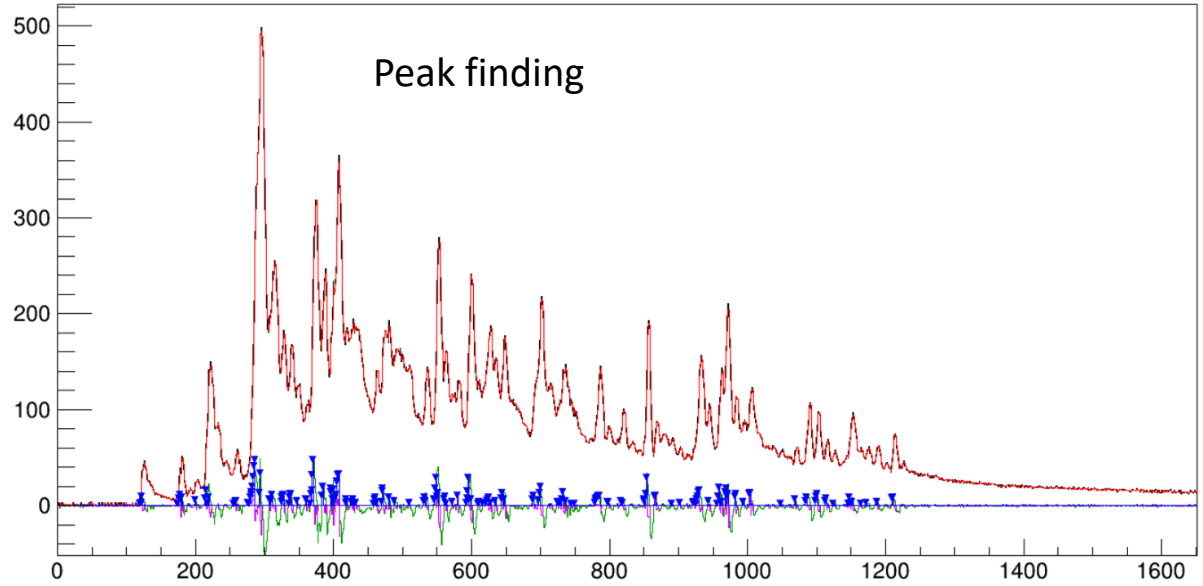


Preliminary analysis

- Low noise and high bandwidth preamplifiers
- Rise time : ~ ns
- Clear peaks







Question and discussion

- Is it possible to construct so big(long) drift chamber? (wire length, wire tension, difficulty for wiring …, need prototyping)
- Does the wire length (5.8m) (input capacitance) impact on the waveform test ?(need tests)
- Wire layout: all stereo, or axial and stereo (based on requirement of Z resolution)?
- Wire Sag = 280 μm , is it reasonable, impact on the spatial resolution?
- Any problem for DC operation under 3T magnetic field