STCF Main Drift CHamber R&D Progress

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Outline

1. **Progress of the Detector**
    - Detector Design Optimizations
    - Research on Detector Techniques (feedthroughs, wire stringing)
    - Research on Detector Prototype
2. **Progress of the Electronics**
    - Design of Prototype Readout Electronics with Discrete Components
    - Design of Prototype Preamp ASIC
3. **Summary**

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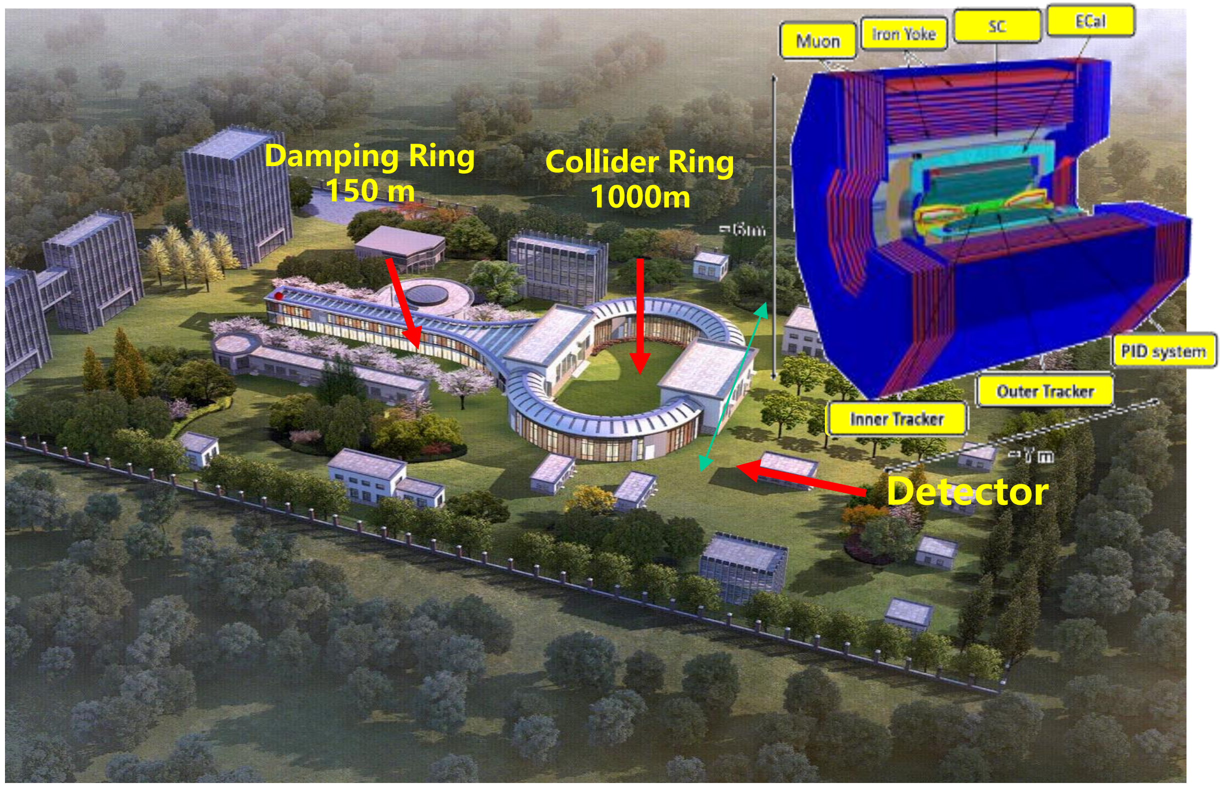
STCF-MDCH (Main Drift CHamber)

Goal: Measuring and reconstructing charged tracks with the inner tracker



STCF:

- Center-of-mass energy: 2~7 GeV
- Luminosity: > 0.5~1x10^{35} cm^{-2} s^{-1}

MDCH performance requirements:

- 93% solid angle acceptance (θ<20°)
- Tracking efficiency >90% @150 MeV/c
- Momentum resolution < 0.5% @1 GeV/c
- dE/dx resolution < 6%
- Low material budget (< 5%X0)
- Electronics for high count rate (200~400 kHz/ch)

Super Tau Charm Facility (STCF)

Main Drift Chamber (MDC)

Challenge:

High luminosity → high count rate → pileup

Original design:

- Innermost layers (~10 mm cells) count rate: ~400 kHz/ch
- Probability of events piling up: ~18% within a 500 ns time window

Requirements:

- Designing ultra-small drift cells (~5 mm)
- Developing electronics to handle high count rate

Table 6.2.1: The main parameters of the STCF MDC conceptual design.

Superlayer	Radius (mm)	Num. of Layers	Inclination (mrad)	Num. of Cells	Cell size (mm)
A	200.0	6	0	128	9.8 to 12.5
U	271.6	6	39.3 to 47.6	160	10.7 to 12.9
V	342.2	6	-41.2 to -48.4	192	11.2 to 13.2
A	419.2	6	0	224	11.7 to 13.5
U	499.8	6	50.0 to 56.4	256	12.3 to 13.8
V	578.1	6	-51.3 to -57.2	288	12.6 to 14.0
A	662.0	6	0	320	13.0 to 14.3
A	744.0	6	0	352	13.3 to 14.5
total	200 to 827.3	48		11520	

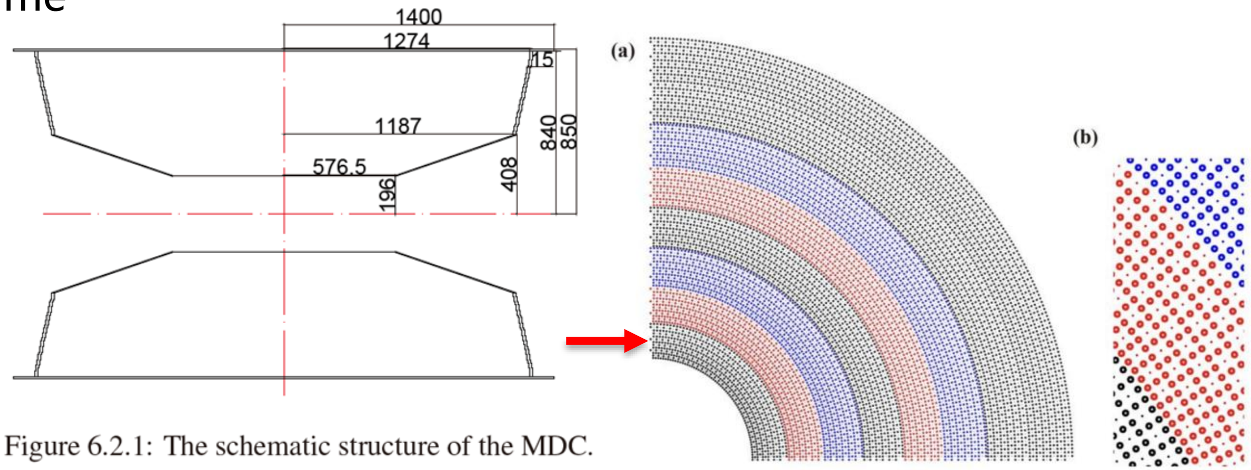
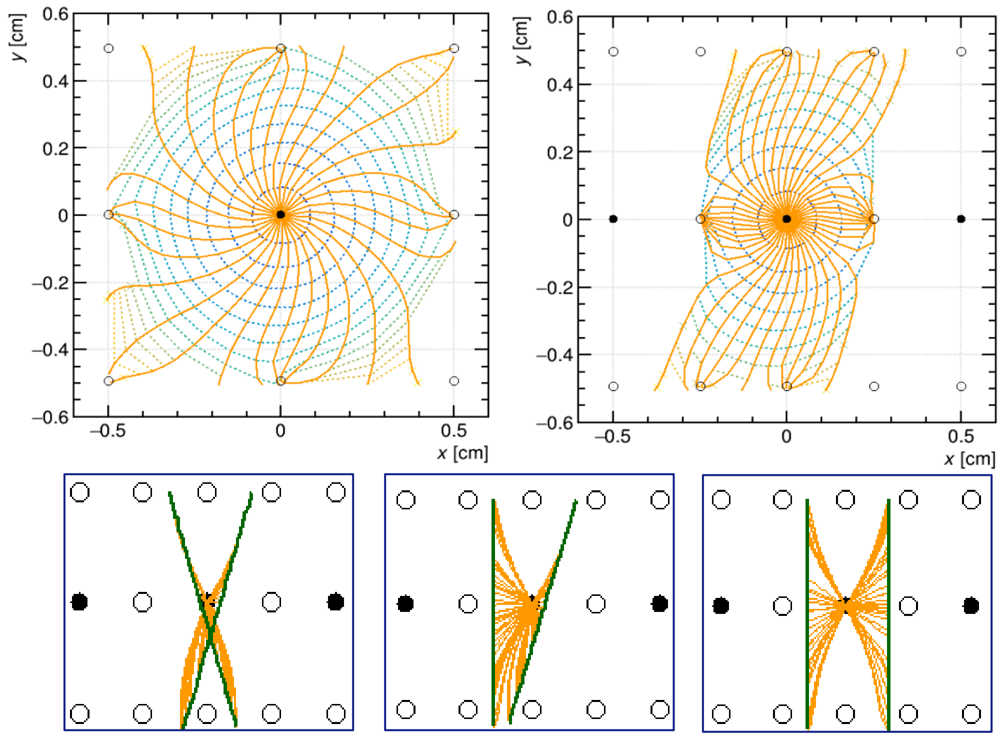


Figure 6.2.1: The schematic structure of the MDC.

MDC signal simulation

Simulation:

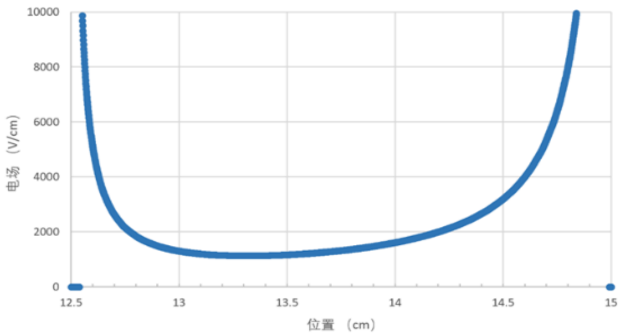
- Drift cell size: 10 mm
- Work gas: 60%He + 40%C3H8
- Operating voltage 1700V
- Time interval: 300ns



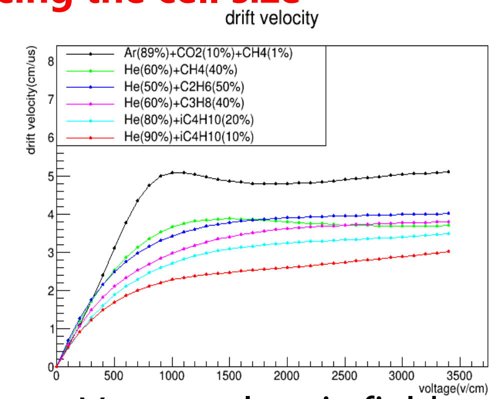
Electric field distribution & induced signals

Shortening drift time:

- Drift cells operated mostly in a low electric field
- Changing the cell size or voltage slightly affected drift velocity
- **The most effective way is reducing the cell size**

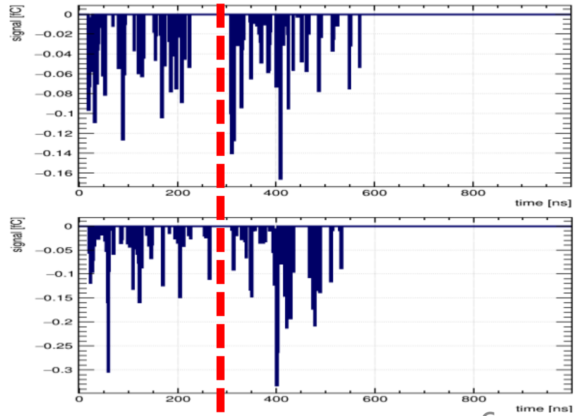


V_{drift} vs. cell size



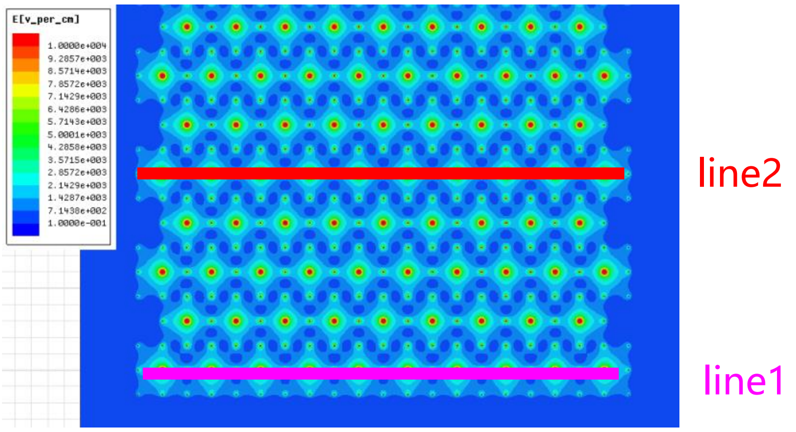
V_{drift} vs. electric field

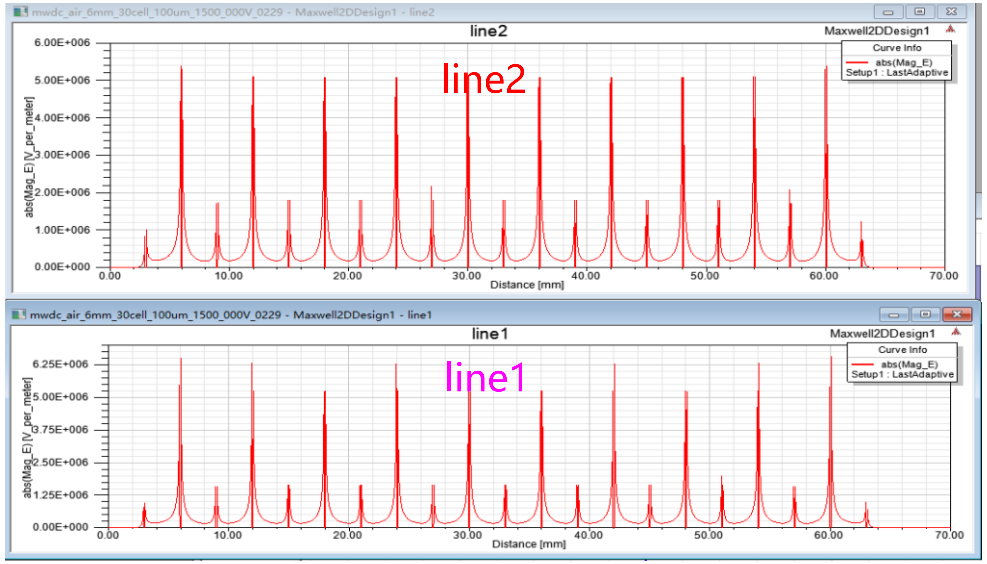
- Signals depended on track characteristics, some were difficult to separate



MDC electric field simulation

Simulation:





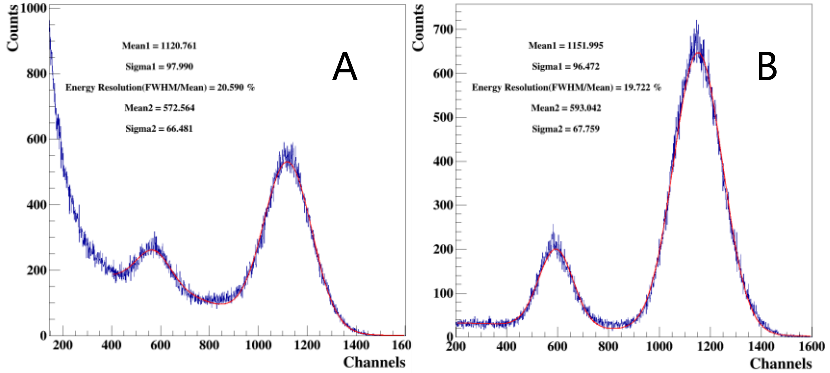
Optimization:

- Adding a compensation voltage to the outermost field wires to reduce edge effect (< 20 kV/cm)
- Energy resolution was improved

Parameter settings

A	B
6mm CELL 4 layer	6mm CELL 4 layer
Anode wire: 20um 1500V	Anode wire: 20um 1200V
Field wire: 100um 0V	Field wire: 100um -300V

Energy spectrum of Fe source test



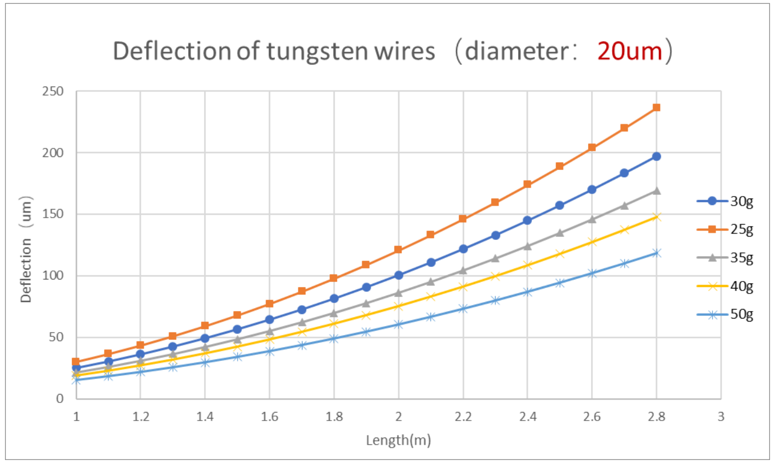
Wire tension optimization

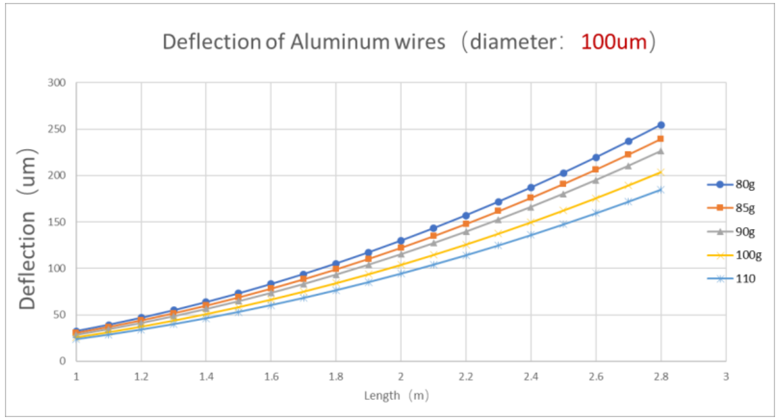
We chose **20μm gold-plated tungsten wire (30g) for anode wires, 100μm aluminum wire (80g) for field wires**

Design summary

	BES III (6796 cell) (Outer: 5024+16128=21152 Inner: 484+1612=2096 Steps: 1288+4144=5432 2096+5432+21152=28680)	MEGII (IDEA drift chamber Inner has 11904 wires; Outer 343968 wires	BELLEII CDC 14336 cells	STCF (CDR 11520 cells, 48448 wires) (Ultra-small cell 19488 cells, 84448 wires)
Size	Inner radius 182.5 mm Effective length 1102 mm Outer radius 810 mm Effective length 2306 mm	Total length 4 m Radius 35~200 cm Inner radius 17~30 cm Effective length 1.93 m	Inner radius 160 mm Outer radius 1130 mm Length 2325 mm	Inner radius 200 mm Outer radius 850 mm Effective length 1274*2mm
Wire layer design	Chamber: 25 μm Gold-plated tungsten wire 18g; 110um Aluminum wire 54g. Out Chamber: 25 um Gold-plated tungsten wire 50g; 110 um Aluminum wire 170g	Chamber: 20 μm Gold-plated tungsten wire 25g; 40um Aluminum wire 20g.	56 layers 30 um Gold-plated tungsten wire 50 g 126um Aluminum wire 80g	Preliminary confirmation: For Anode wire: Gold-plated tungsten wire(20μm 30g); For Field wire: Aluminum wire(100 μm 80g)
Cell size	Chamber 12 mm Out chamber 16 mm	Chamber 6 mm	Chamber 6.59~9.34 mm Out chamber 16.69 mm	Planed : 5~11mm

Gravitational deflection of wires

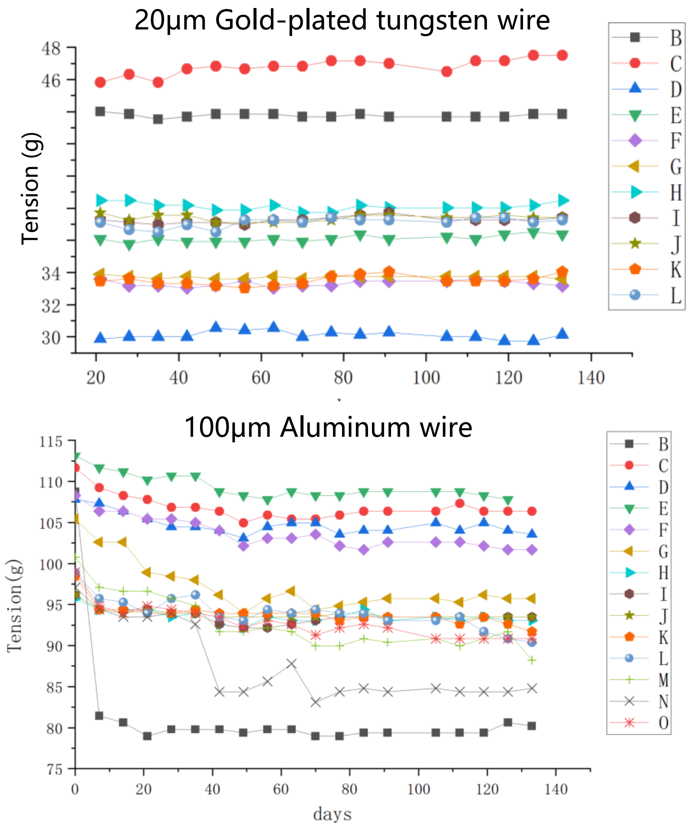




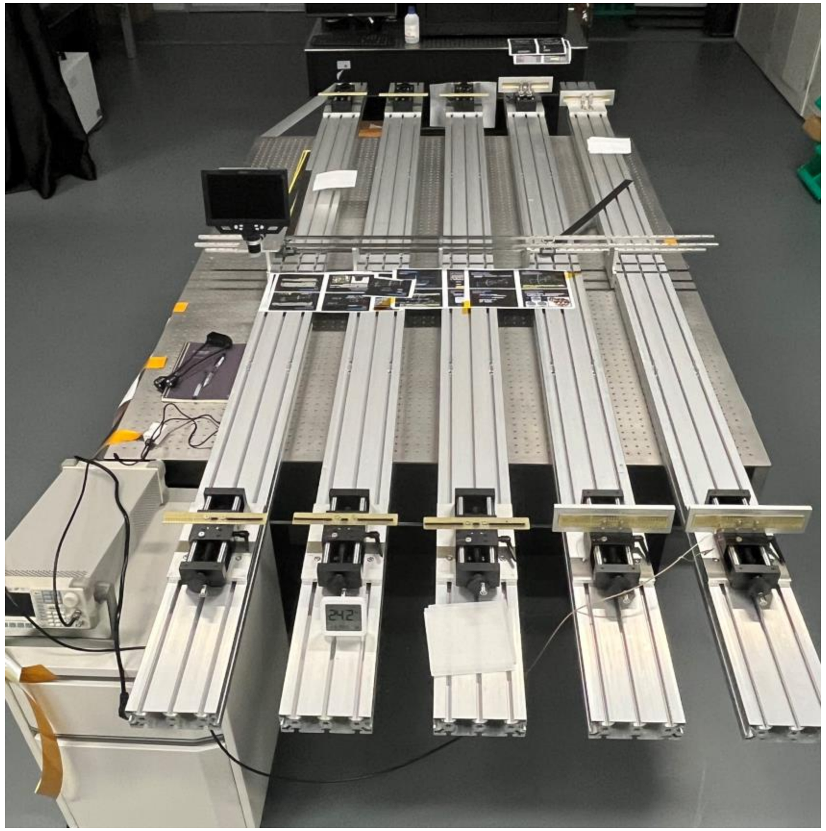
Wire tension detection system

We developed **a wire tension detection system** and evolved 3 versions

Results: gold-plated tungsten wires showed no noticeable creep, aluminum wires gradually lost some tension



Test results for 2.8-meter wires, ~130 days



New test platform

Wire layer distribution

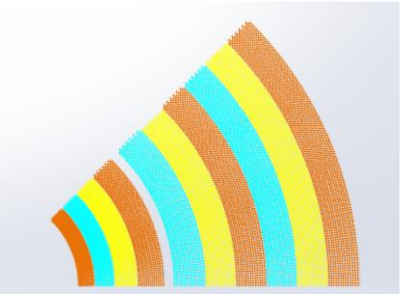
Design is based on ultra-small drift cells

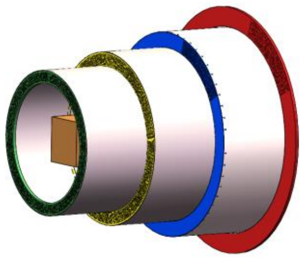
- **Advantages**
  - Simplifying the design of electronics (400kHz→200kHz)
  - Short drift distance
  - Short signal duration
  - Minimizing the Lorentz angle effect
- **Challenges**
  - Difficulty of wire stringing technique
  - Limited space
  - Higher material budget

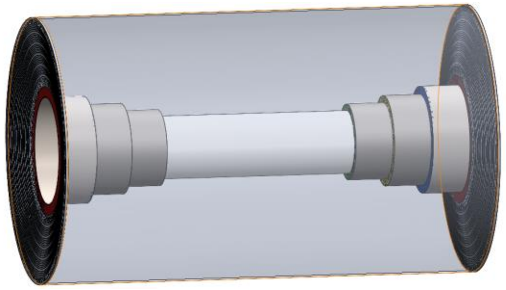
Key parameters

Index	Super layers	the Cell number of per super layer	Cell size	locate
A	6	256	5.09~5.76	205
U	6	256	6.05~6.84	
V	6	256	7.16~8.09	
A	6	256	8.45~9.55	
U	6	256	10.44~11.80	420
V	6	320	9.77~10.78	
A	6	352	10.09~11.03	
U	6	400	9.97~10.78	
V	6	432	10.22~10.99	
A	6	464	10.46~11.35	833

		wire num	Tension（g)	
In layer	Anode	6144	30	Chamber tension(kg)
	Field	20480	80	
	In Total	26624		1822.72
Out layer	Anode	13344	30	Out chamber tension (kg)
	Field	44480	80	
	Out total	57824		3958.72
Total	Total anode	19488	30	
	Total field	64960	80	
	Total	84448		5781.44





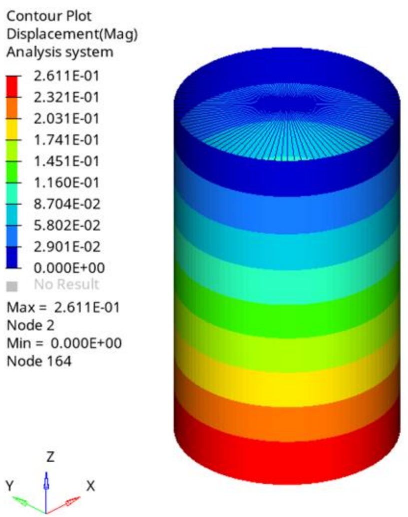


Carbon fiber outer barrel simulation

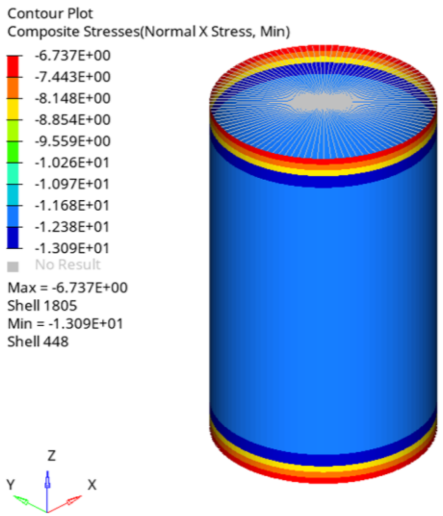
Simulation conditions:

- A cylinder with a 1700 mm diameter, 2800 mm length, made of T700 fiber, and an axial force of 20 T
- The two ends of the carbon fiber cylinder are connected by rigid body units, which restricts the bottom end, and the top end is loaded with an axial load of 20 T

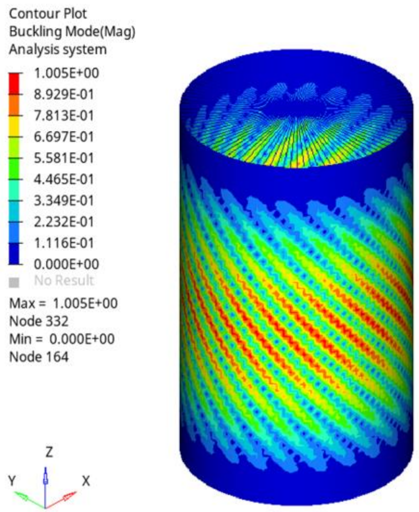
Results:



Maximum displacement: 0.26 mm



Maximum compressive stress: 13.1 MPa



Critical instability coefficient: 12.8

→ The structure is stable and resilient under high stress

Feedthroughs

Roles of feedthroughs:

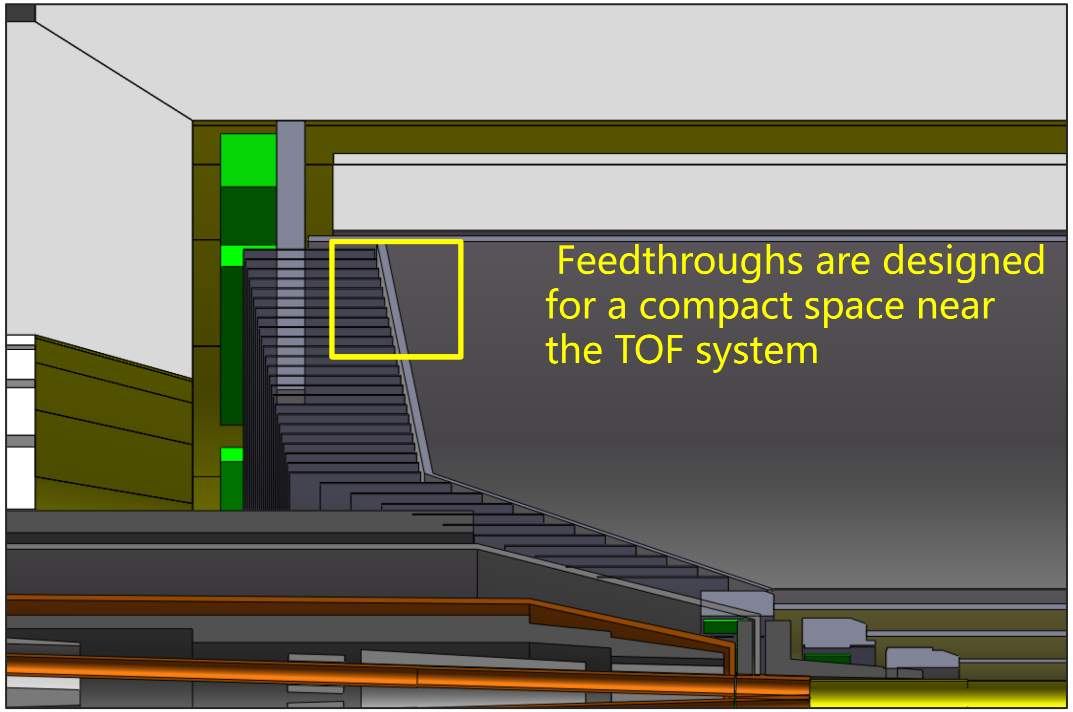
- Accurately locating and tensioning large numbers of fine wires
- Providing electrical insulation and gas sealing

Future STCF-MDCH:

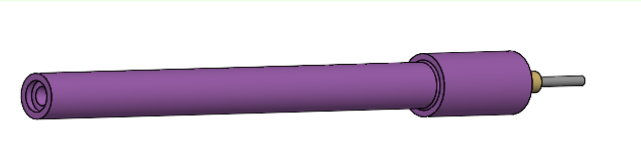
- The future STCF-MDCH will use aluminum for the endplate
- Feedthroughs must be insulated
- Insulated feedthroughs are difficult to produce

Prototype:

- The prototype used insulated PCB for the endplate
- Feedthroughs can be made of aluminum
- Injection molding technique is underway



Research on feedthroughs



BESⅢ feedthroughs

BELLEⅡ feedthroughs

STCF feedthrough V3

- Reduced size

STCF feedthrough V4

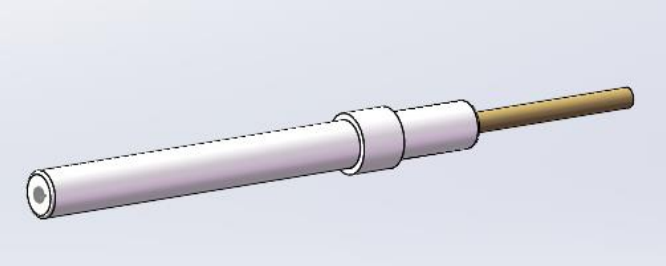
- Optimized signal connection

STCF feedthrough V1

- Copper tubes
- Tested discharging

STCF feedthrough V2

- Aluminum tubes
- Tested wire stringing



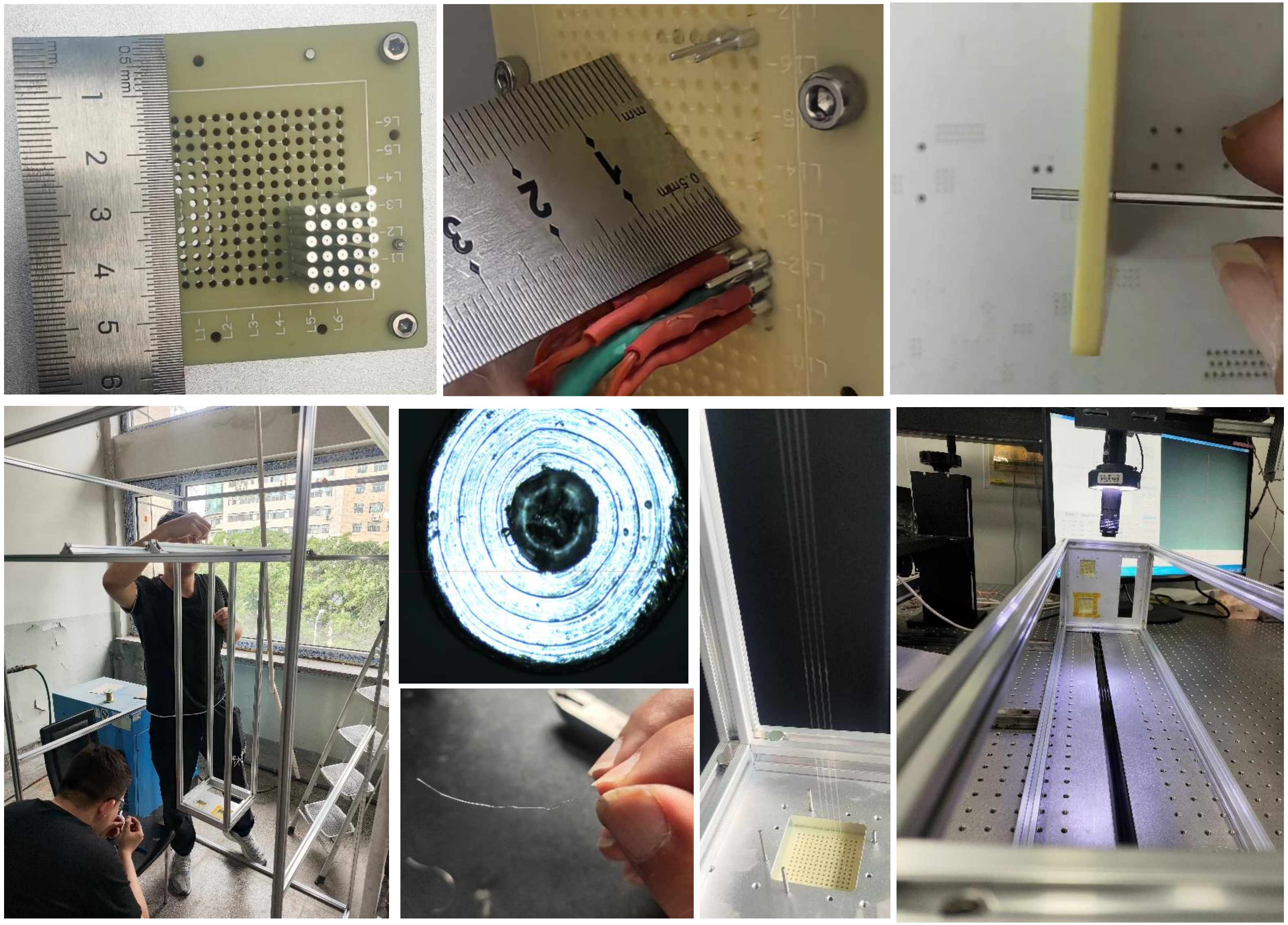
STCF feedthrough V5

- Insulated design
- Electrode connection

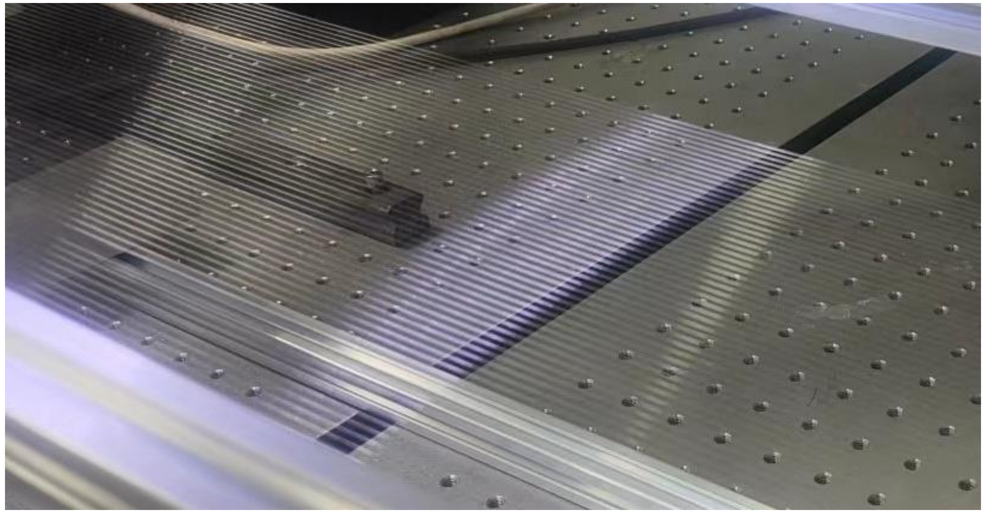
Wire stringing technique

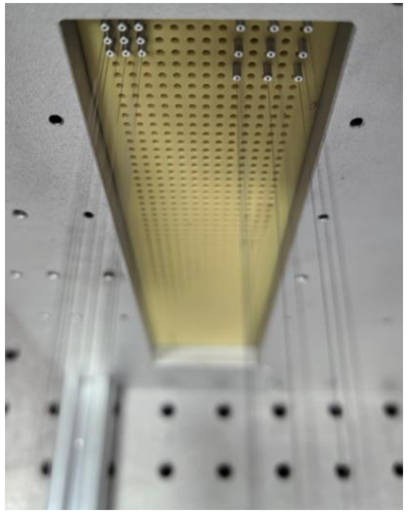
Ultra-small cell design is challenging for the stringing

- Feedthrough outer diameter: 1.6 mm
- Stringing point: 1.4 mm
- **Inner diameter of the field wire hole: 0.3 mm**



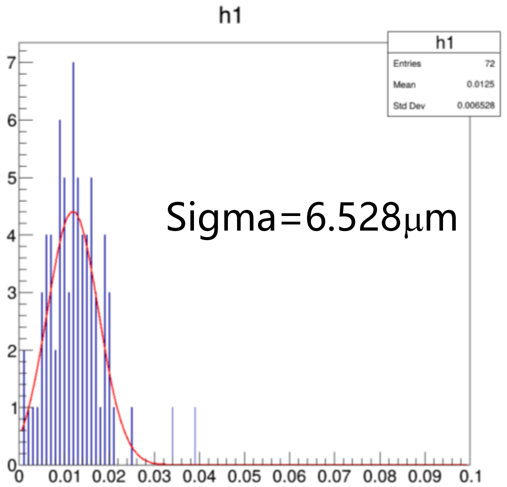
Positioning accuracy analysis



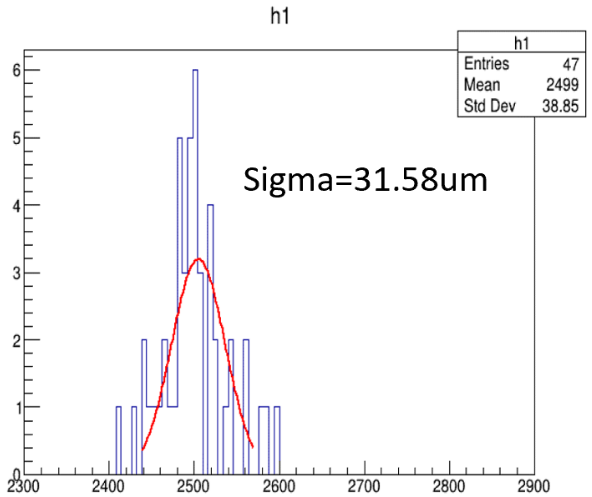


Results:

- **Concentricity**: standard deviation is 6.528μm
- **Uniformity**: for a 2.5mm pitch drift cell, the actual pitch mean value is 2.499mm with a standard deviation of 31.58μm

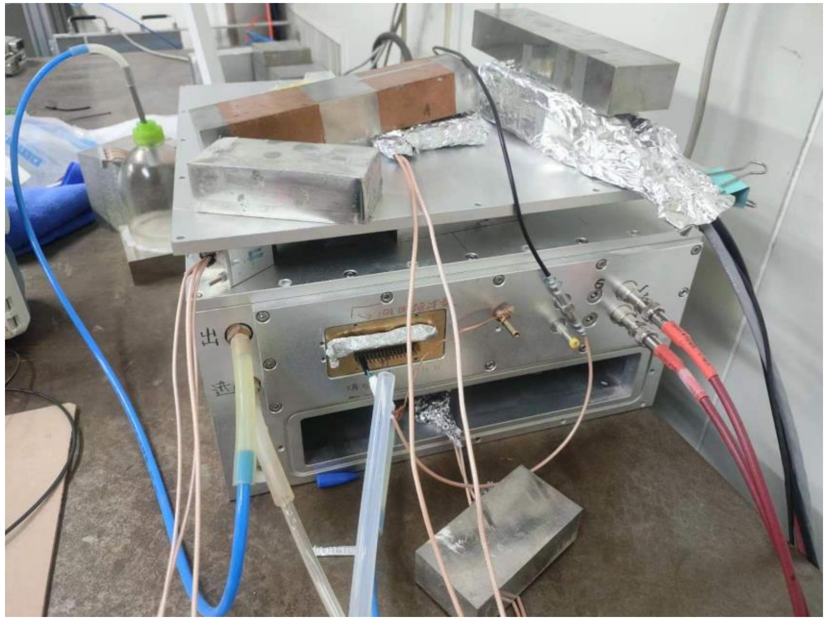


Concentricity of feedthroughs



Uniformity of the wire spacing

A small prototype of 10 mm drift cells

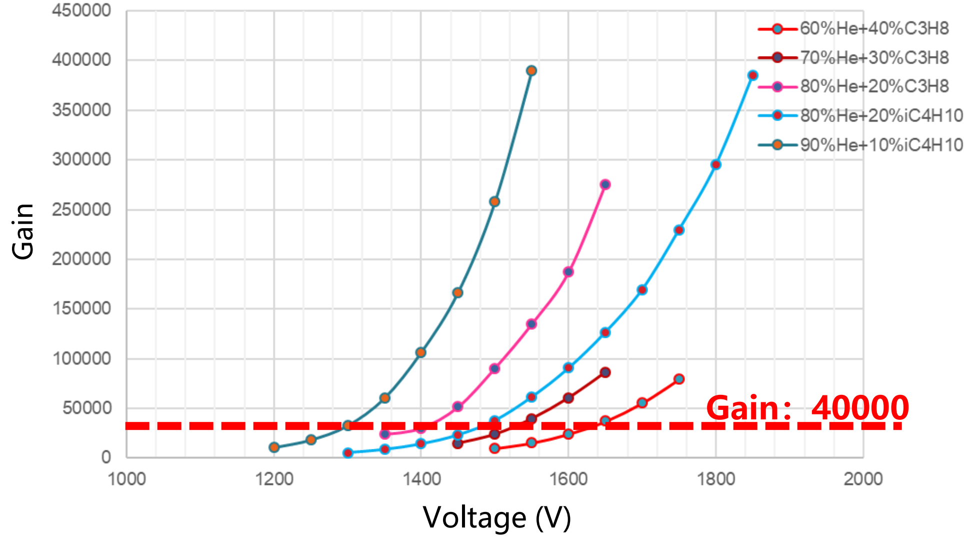


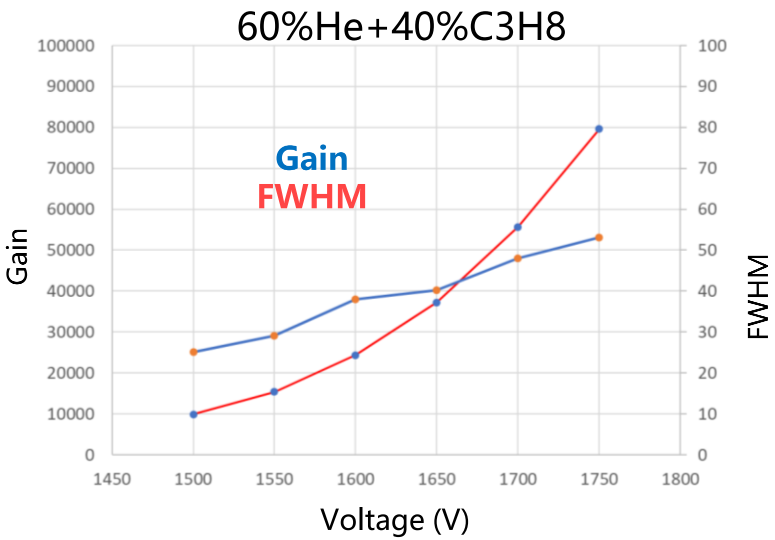
Electronics used in the test: 142A+572A+MCA

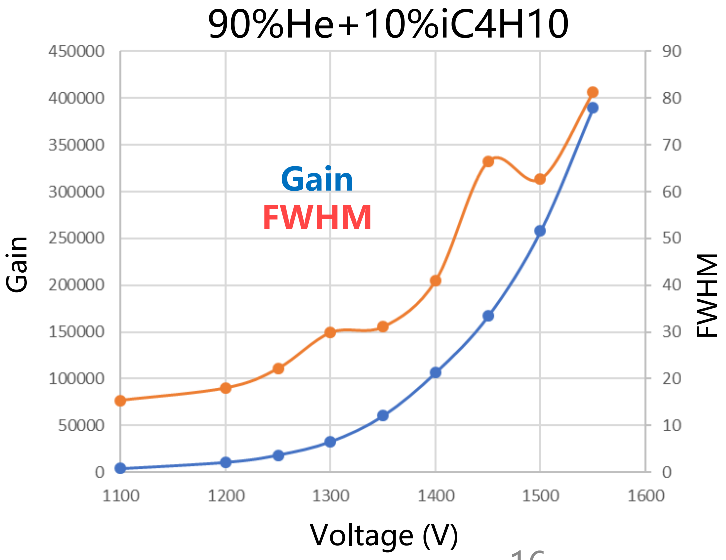
Conclusions:

- As gain increased, energy resolution was worse
- Balance gain with energy resolution and other constraints

Detector gain at different voltages and in different operating gases

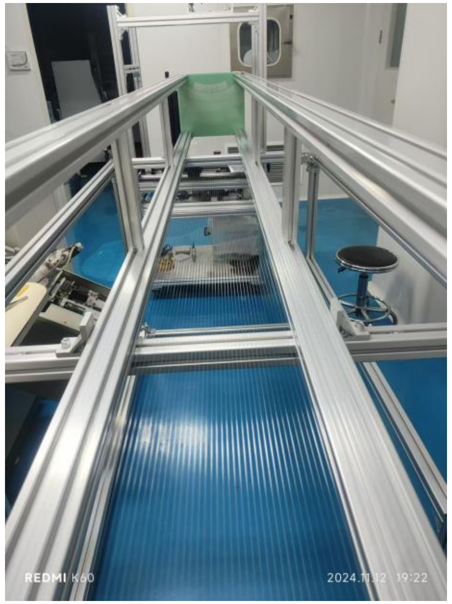


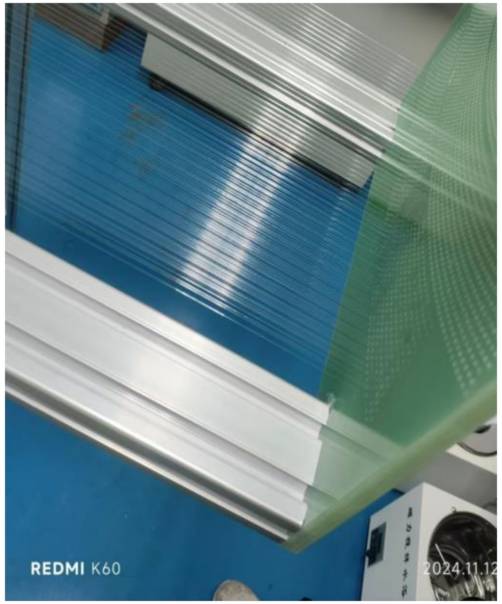


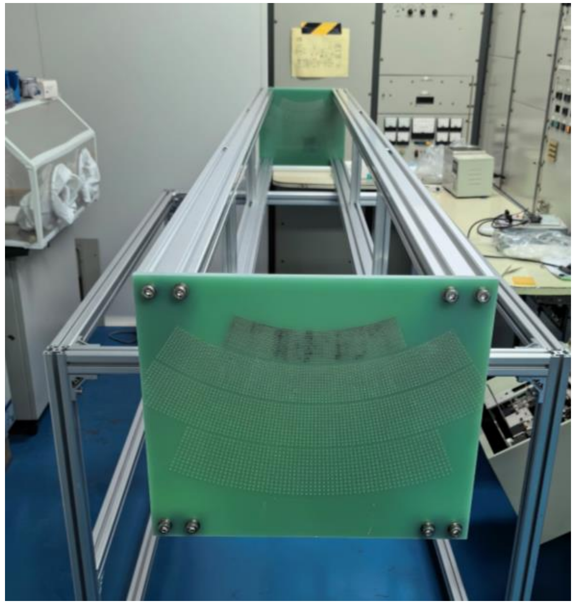


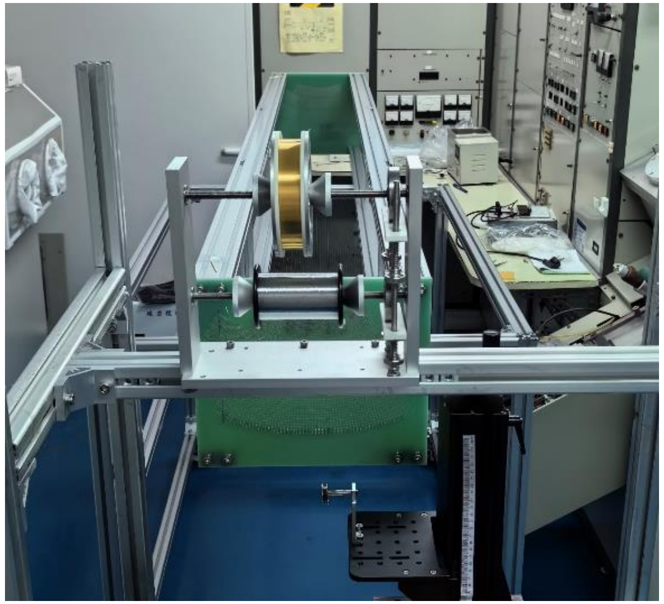
Fabrication of the full-length prototype

Design and fabrication of the full-length prototype:



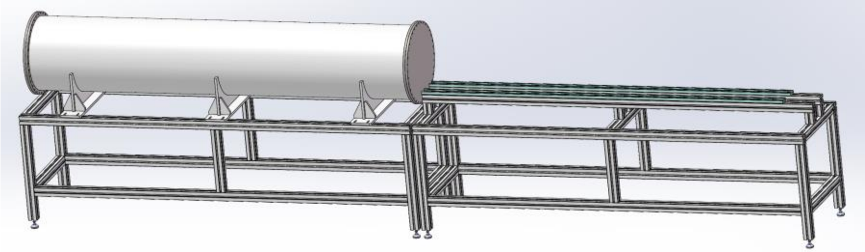




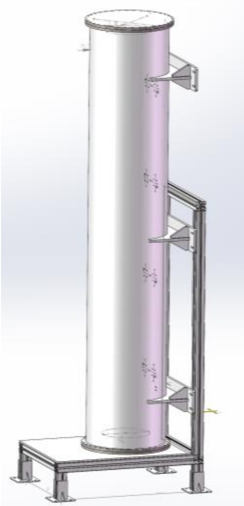


Two test schemes for the prototype：

Horizontal testing



Vertical testing



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3. Summary

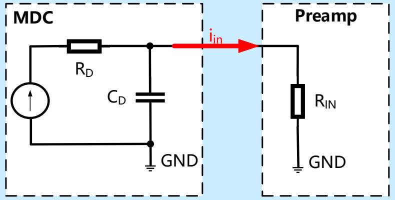
Research on readout electronics

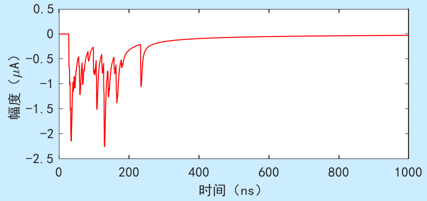
Review of existing MDC readout electronics

	BESⅢ	BelleⅡ	MEGⅡ
Preamp	TIA	CSA	Voltage Amplifier
Time measurement	HPTDC	FPGA-TDC	Extract time information of clusters from digitized waveforms
Charge measurement	Numerical integration	Numerical integration	-
Innermost layer unit size (mm)	14	7	6.6
Count rate	30 kHz	30 kHz	~40 kHz

For STCF-MDCH, count rate: 200~400kHz

Simulation & analysis of STCF-MDCH output signals





Signal characteristics:

- Pileup due to high count rate
- Long duration
- Multi-peak
- Large inconsistency

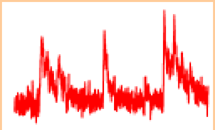
Key requirements:

- Charge accuracy < 8 fC RMS
- Time accuracy < 1 ns RMS
- Innermost layer detection efficiency > 95%

Ultra -small cells

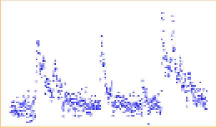
Readout scheme

STCF-MDCH output signals → **TIA**



No shaper or small shape time

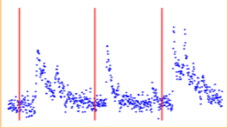
Waveform digitization



- SCA: large dead time
- **ADC**: low integration, high power consumption

Optimization: use ASICs Lower sampling rate

Waveform distinction algorithm



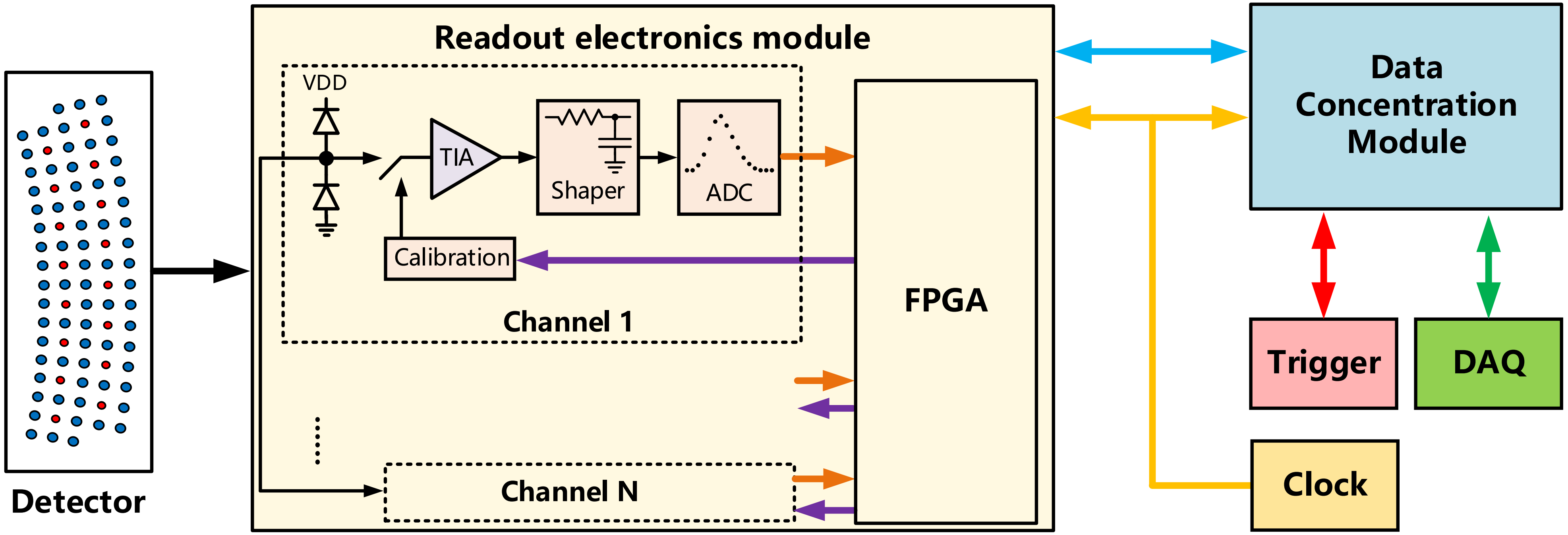
→ **Extract time and charge information** → **Modification algorithm**

Time and charge information of STCF-MDCH

Structure of MDC electronics

Tasks of MDC readout electronics:

- Readout the signals from the detector
- Framing data for trigger and DAQ
- Receiving the synchronous clock
- Receiving the trigger signal and DAQ commands

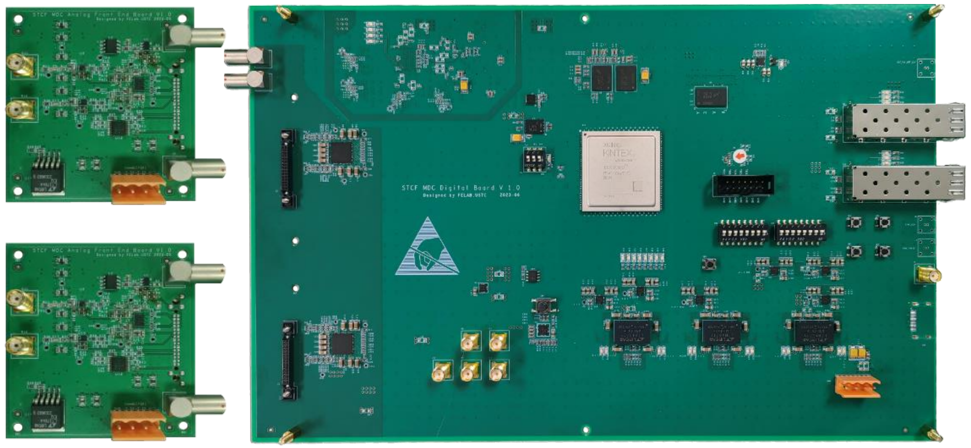


MDC detector – MDC readout electronics - backend electronics interconnection architecture

Prototype readout electronics

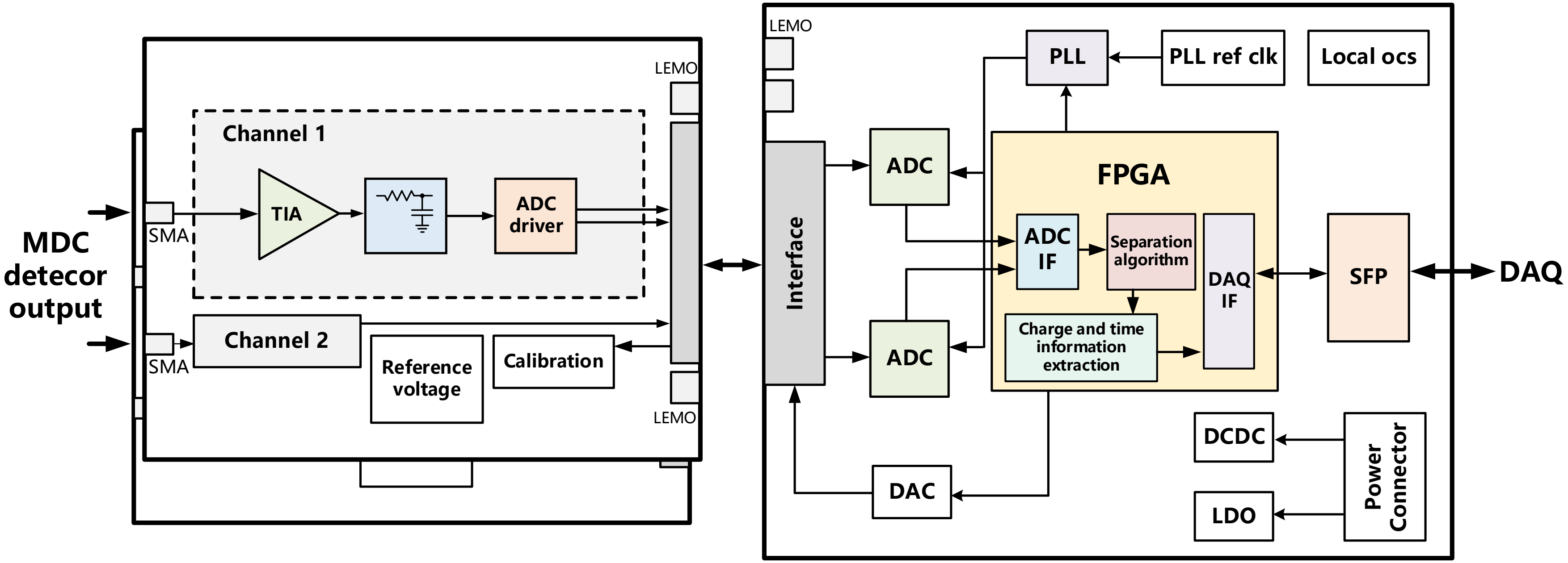
Prototype readout electronics with discrete components

- 2 daughterboards + 1 motherboard for 4 channels
- Extracting time and charge information based on waveform digitization
- Attempting to separate overlapping pulses at high count rate



Progress:

- Results in lab (210kHz):
  - Charge accuracy 4.6 fC RMS
  - Time accuracy 760 ps RMS
  - Detection efficiency 95.8%
- More practical tests are on the way
- Algorithms are being optimized
- More compact circuit is being developed



Prototype preamp ASIC

ASIC: 16-channel front-end amplifier

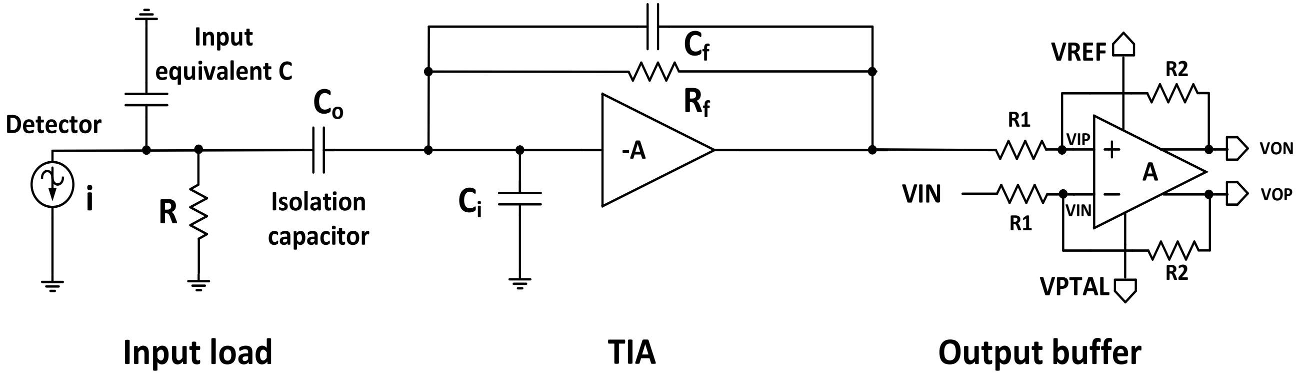
- Transimpedance amplifiers + output drivers
- High bandwidth, high gain, and low noise to handle the weak signals and high count rate of the STCF-MDCH

Progress:

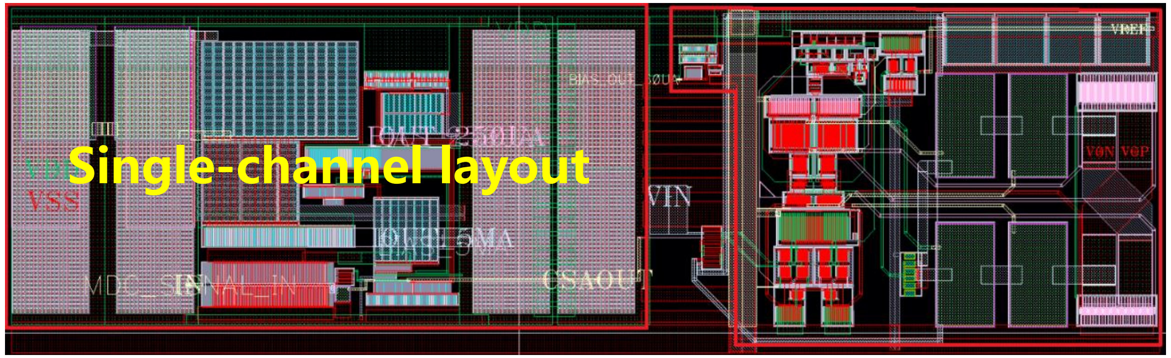
- Design is completed
- Simulation tests have passed
- Wafer is fabricated
- Packaging and testing will start soon

Single-channel design requirements and simulation results

Indicators	Requirements	Pre-simulation	Post-simulation
Gain	38 kΩ – 42 kΩ	38.11 kΩ	38.11 kΩ
Bandwidth	>80 MHz	80.96 MHz	85.47 MHz
Power/ch	<55 mW	48.73 mW	48.75 mW
Input charge noise	<6 fC	1.39 fC	1.65 fC
Timing accuracy	<300 ps	116.4 ps	127.8 ps



Circuit structure of the completed design of the ASIC

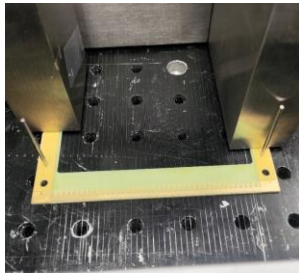


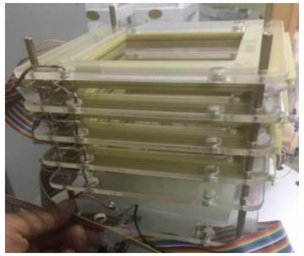
Outline

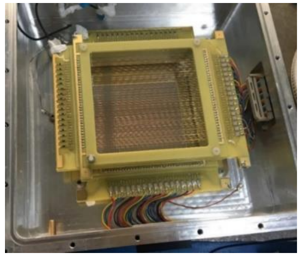
1. **Progress of the Detector**
   - Detector Design Optimizations
   - Research on Detector Techniques (feedthroughs, wire stringing)
   - Research on Detector Prototype
2. **Progress of the Electronics**
   - Design of Prototype Readout Electronics with Discrete Components
   - Design of Prototype Preamp ASIC
3. **Summary**

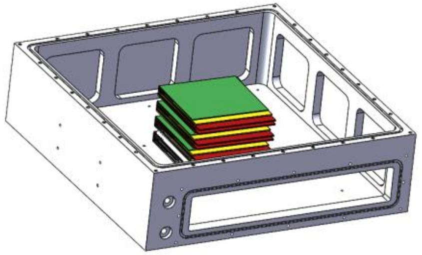
Summary

- **Detector**
  - **Progress**: designed ultra-small drift cells, optimized wire tension, researched feedthroughs, and built prototypes
  - **Future work**: test and refine wire stringing for the 2m prototype, improve positioning accuracy, optimize stress/layout, and assemble a 5mm cell prototype
- **Electronics**
  - **Progress**: developed a prototype based on discrete components and a 16-channel ASIC
  - **Future work**: optimize firmware, develop compact readout prototypes, test ASICs, and conduct joint testing of the detector and electronics









Thanks for your attention!