Multi-layer THGEM (M-THGEM) for hadron calorimeter and muon system

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Outline

- HCAL and Muon system of CEPC
- THGEM development
- M-THGEM
- Summary

HCAL and Muon system of CEPC

CEPC

A high-luminosity circular e^+e^- collider and clean Higgs and/or Z factory proposed in China.

Center-of-mass energy: $\sqrt{s} \sim 240$ GeV

Luminosity: $L \sim 2 \times 10^{34}$ $cm^{-2}s^{-1}$

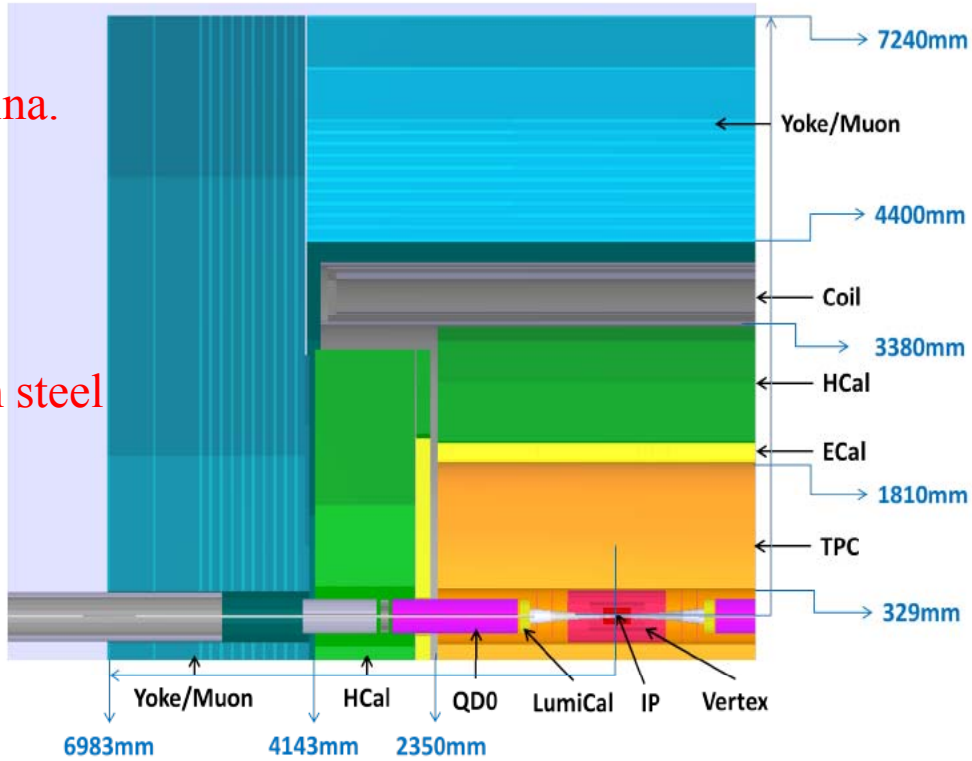
HCAL

A high-granularity sampling calorimeter with steel as the absorber and sensitive devices, such as scintillator tiles or gaseous detectors .

Energy resolution: $50\%\sqrt{E(GeV)}$

Jet energy resolution, ECAL+HCAL+PFA:

$\sigma E/E$ 3 – 4%, or $30\%\sqrt{E(GeV)}$ @100GeV



CEPC detector overview (baseline)

Muon system

A high-efficiency and low-cost tracking detector with steel as the absorber and sensitive devices, such as scintillator tiles or gaseous detectors

Reconstruction efficiency: 94%

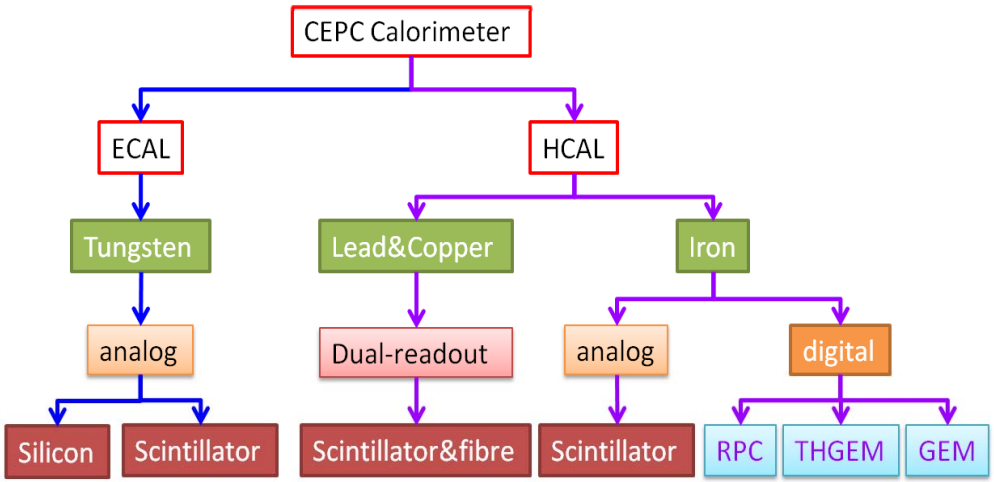
$P(\pi \rightarrow \mu)$@30 GeV: $<1\%$

The HCAL and Muon system have similar options for sensitive detector, and one detection technology may be adopted for both systems!

Hadronic calorimeter

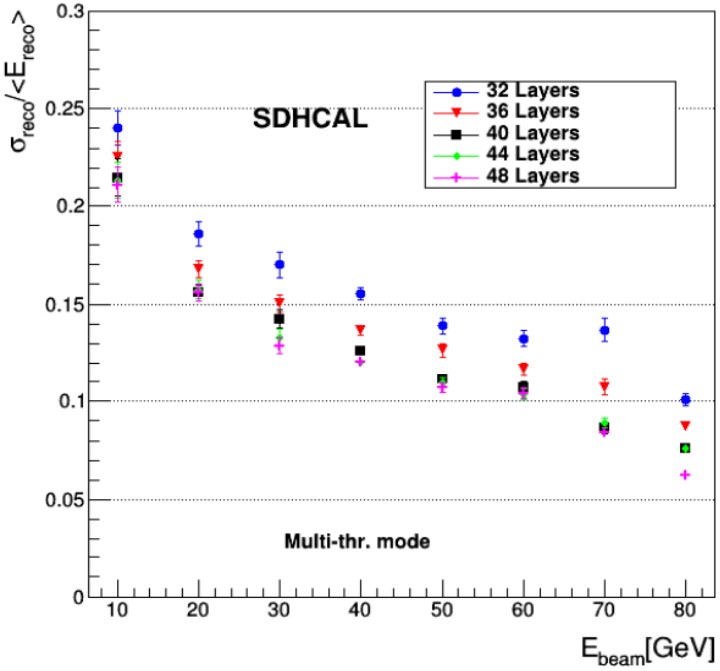
Options

Analog HCAL
Digital HCAL
Semi-digital HCAL
Dual-readout HCAL



Detector requirements

Granularity: 1 ×1 cm^2 or 3 ×3 cm^2
Readout channel density: ~ 4 ×10^5 /m^3
Total volume: 100 m^3
Layers: ~40
Thickness/layer: ~6mm
High rate: >1kHz/cm^2
High performance-price ratio



Technologies

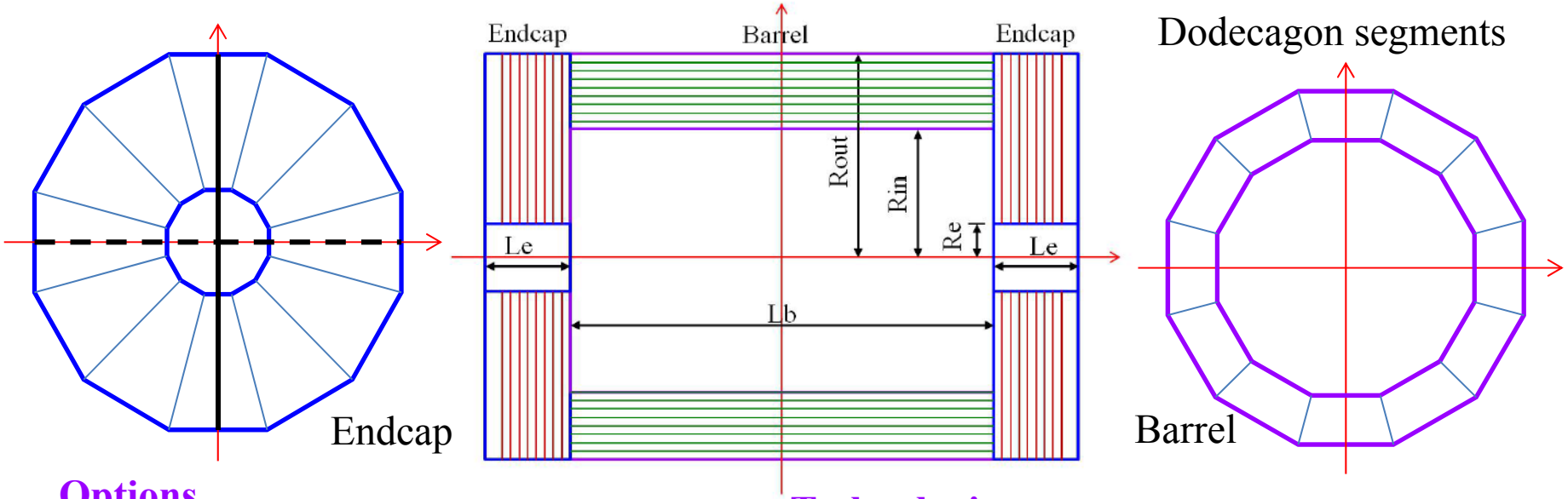
Scintillator detector

Plastic scintillator + SiPM

Gas detector

RPC (Glass RPC, Bakelite RPC)
GEM (CERN type GEM)
THGEM (new structure THGEMs) …

Muon system



Options

No dependent muon system

Good muon system

Detector requirements

Spatial resolution: <=2 cm

Detection efficience: 95%

Layers: ~8

Thickness/layer: <4cm

High rate: >60 Hz/cm^2

Total area: ~9000 m^2

Low cost, good stability, long-lived, easy mass production

Technologies

Scintillator detector

Scintillator strip + SiPM (1cm-thick)

Gas detector

RPC (Glass RPC, Bakelite RPC)

μRWell

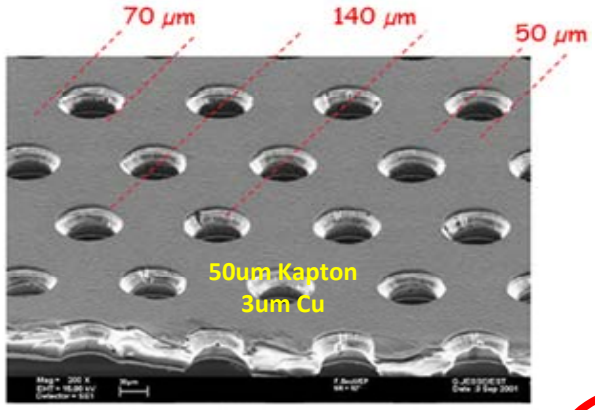
THGEM (new structure THGEMs)

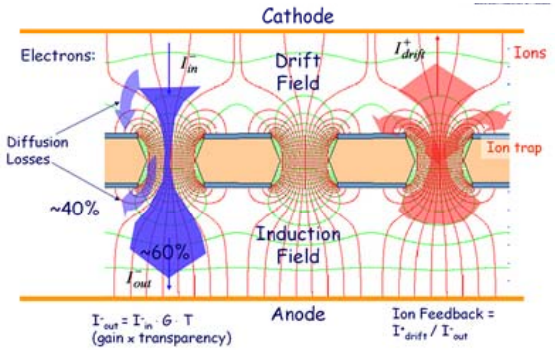
…

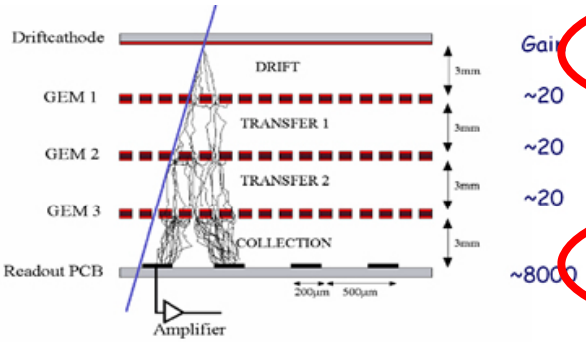
THGEM is a good candidate technology for both HCAL and muon system.

THGEM development

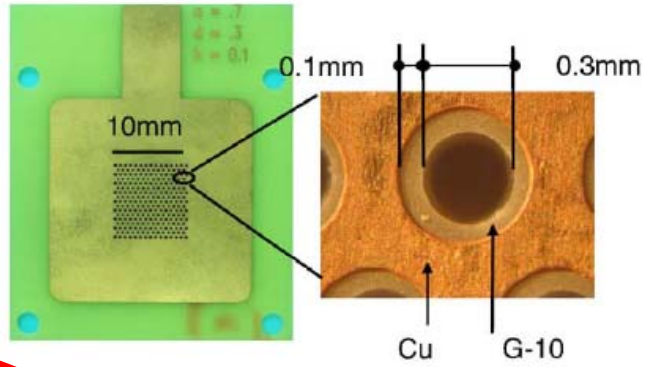
GEM(**Gas Electron Multiplier**), 1997 by F. Sauli） ⇨ THGEM(Thick **GEM**), 2004 by A. Breskin

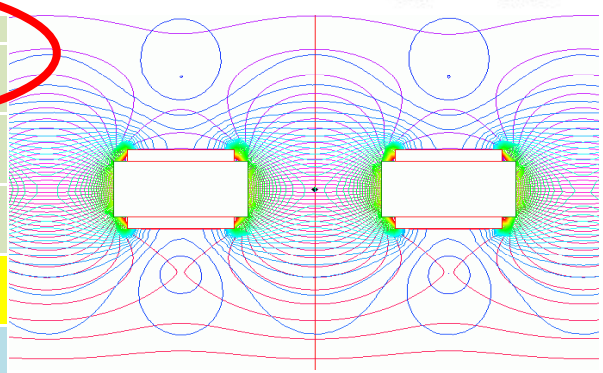


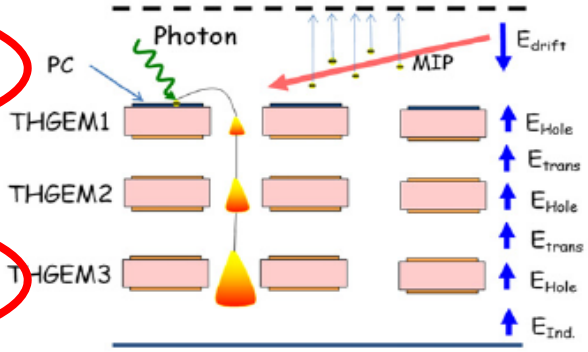




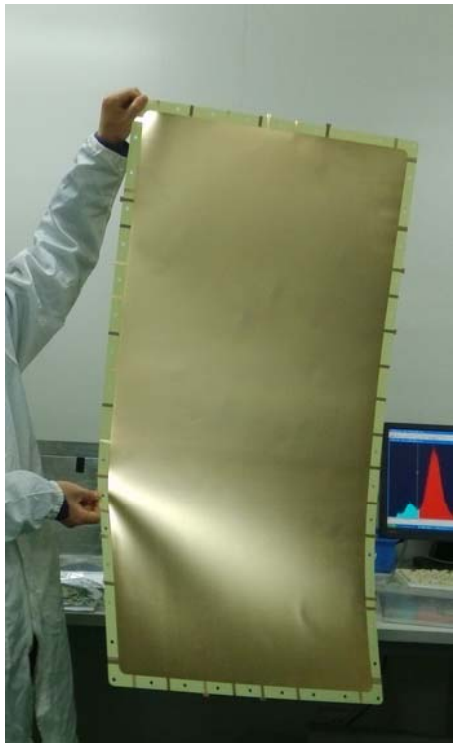
GEM	项目	THGEM
50	T/um	>=200
70	D/um	>=200
140	P/um	>=500
10	Rim/u	>=20
~10^3	GainS	>=10^4
~10^4	GainD	>=10^5
<20%	σE(FWHM)S	~20%
~25%	σE(FWHM)D	~30%
<100u	**σx**	**<500u**
High	Tech	Normal
High	Cost	Low
Fragile	Durability	Robust
Good	Stability	+++
Kapton	Substrates	FR-4, PTFE, Ceramic , Kapton



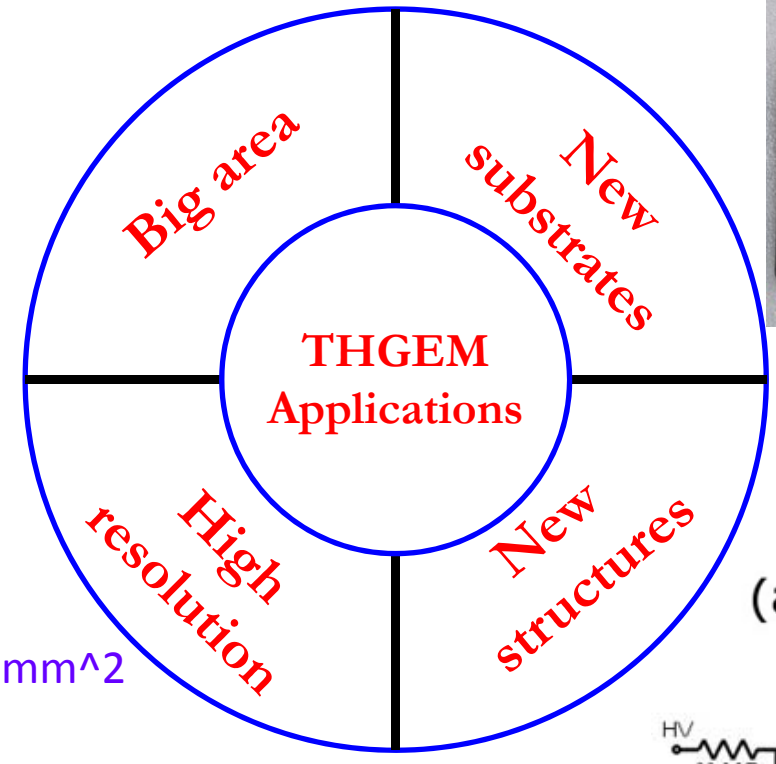


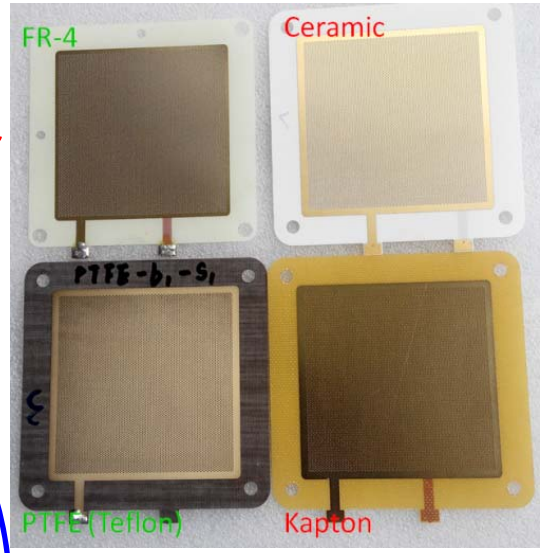


Developed by IHEP and KingBrother Co. Ltd. in China

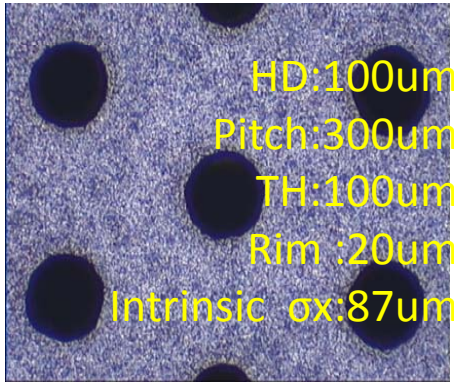


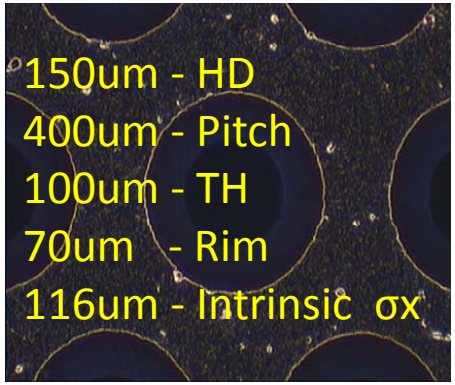
100×100 200×200
300×300 400×400
500×500 500×1000 mm^2

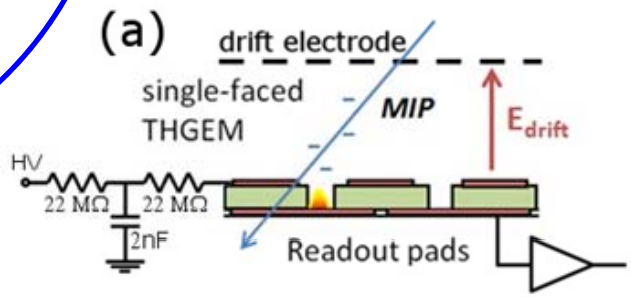




Low neutron absorption and scattering
Low radioactivity



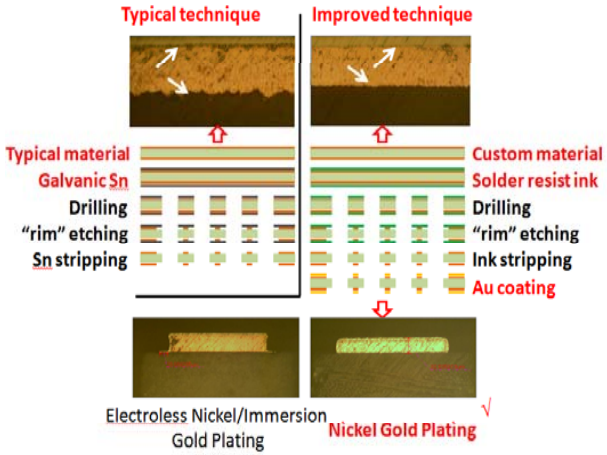




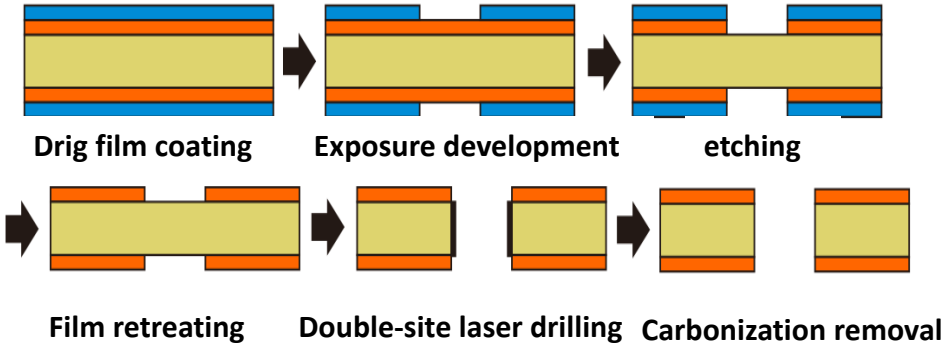
Resistive THGEM
Well THGEM
Groove THGEM
Multi-layer THGEM
…

Production and performance

Mechanical drilling



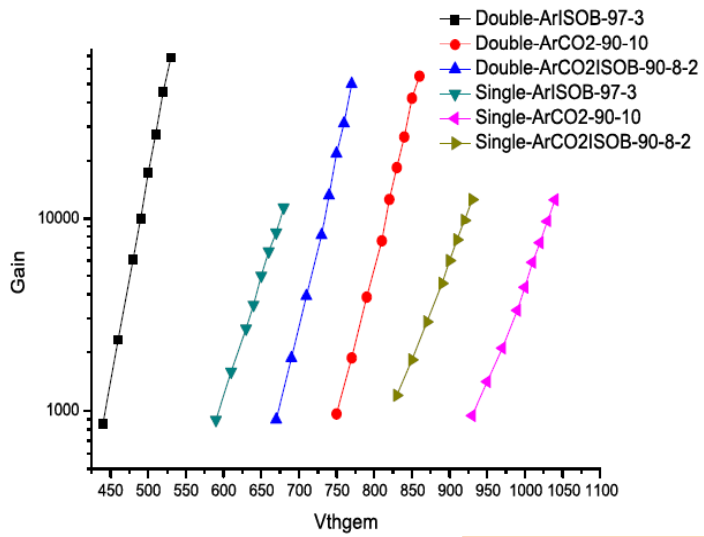
Laser drilling



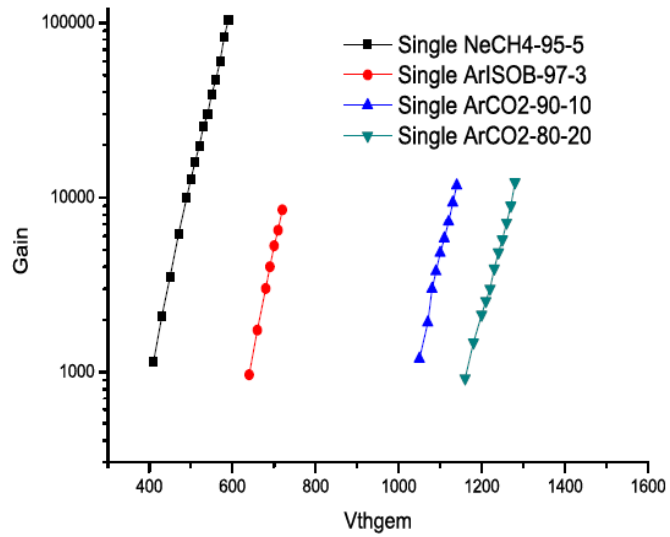
Substrate	FR-4	Ceramic	PTFE (Teflon)	Kapton (PI)
Mechanical properties	rigid & tough	fragible	tough, flexible	toughn, flexible
Cost	Cheap	High	High	High
Regular performance: Ar+IsoB: 97-3, 120h test				
Withstand voltage (in air) /V	1400	1200	1800	1600
Gain of single layer	8000	5000	10000	10000
Stability	Good	normal	Good	Good
Big-area detector/m^2	OK	-	OK	OK

Substrate	S-Area/m^2	HD/mm	Pitch/mm	TH/mm	Delivery/day
FR-4	<=0.5*1.0	0.10~0.5(0.2)	>=0.3 (0.6)	0.1~0.3(0.2)	20
Kapton	<=0.5*1.0	0.10~0.5(0.2)	>=0.3 (0.6)	0.05~0.3(0.2)	30
Ceramic	<=0.5*0.5	0.15~0.5(0.2)	>=0.4 (0.6)	0.1~0.3(0.2)	30
PTFE (Teflon)	<=0.5*1.0	0.15~0.5(0.2)	>=0.4 (0.6)	0.1~0.3(0.2)	30

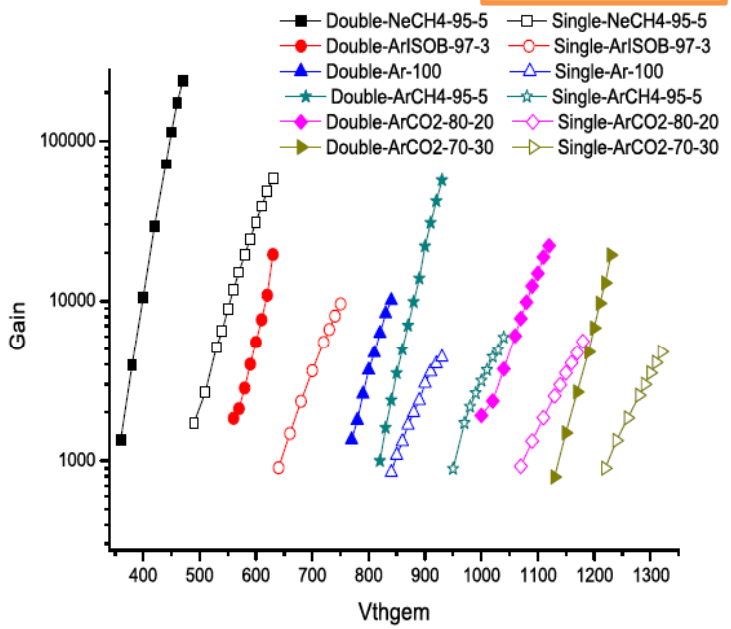
FR-4



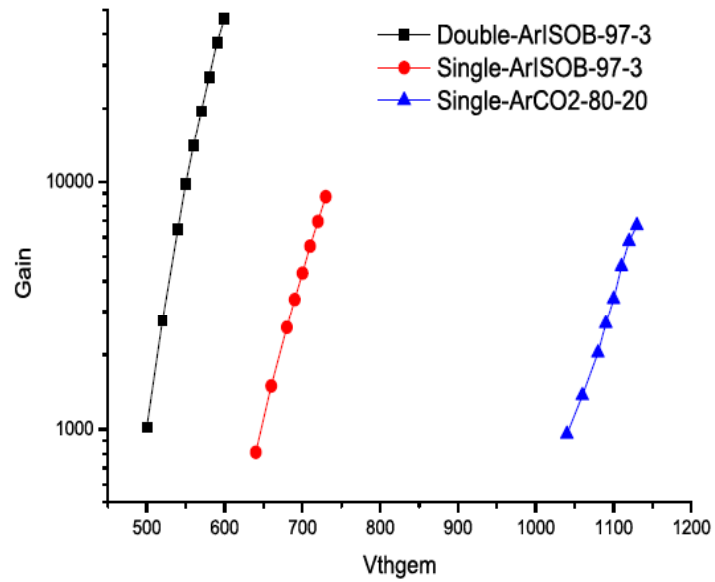
Ceramic



PTFE

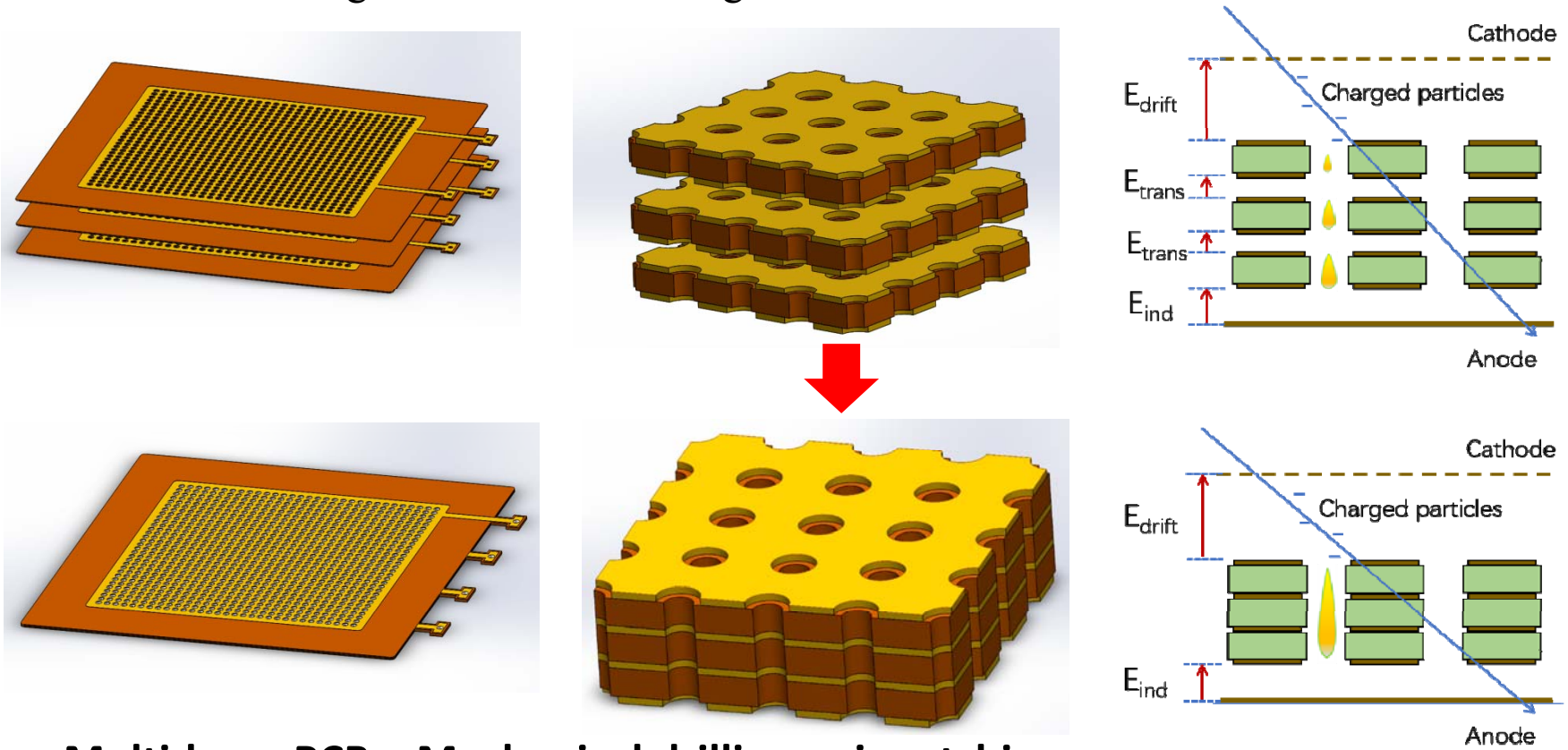


Kapton



M-THGEM: a novel structure

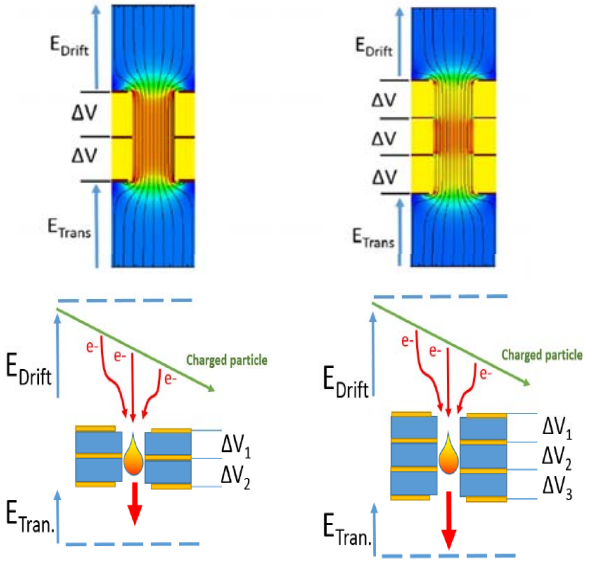
Multi-layer THGEM (M-THGEM) was proposed by M. Cortesi in Ref[1]. It is a new structure to reach smaller thickness, more compact structure, better performance and stability. M-THGEM is produced based on the multi-layer PCB technology by mechanical drilling and chemical etching.



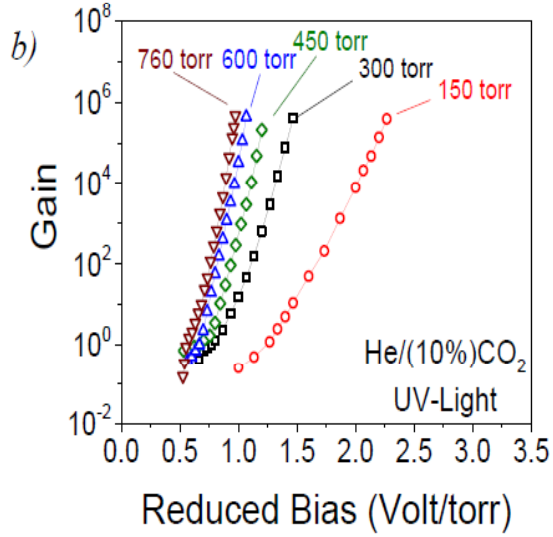
Multi-layer PCB + Mechanical drilling + rim etching

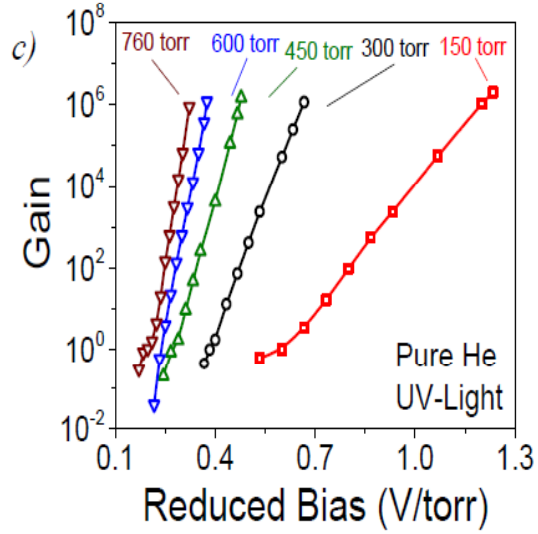
Ref .1 M. Cortesi et al., arXiv:1606.07314 [physics.ins-det]

Advantages



2-layer THGEM 3-layer THGEM





Structure:

- Single film, multi-layer successive avalanche, no transfer gaps;
- No parallelism problem for layers and no concentricity problem for holes;
- The thickness and types of substrate are selectable, 0.2, 0.25, 0.3, 0.4/layer ; FR4, PI, Ceramic and PTFE, all substrate can be chosen for M-THGEM.

Production:

At least a half of mechanical drilling time is saved, very important for mass production.

Performance:

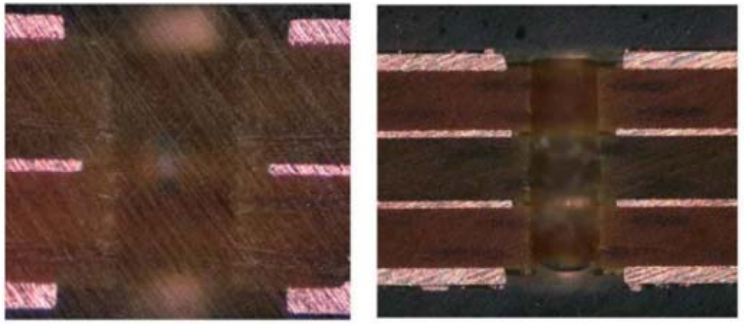
High gain, more stable

Stable operation in various gas mixtures even pure noble gas (He/Ne/Ar/Xe)

Good gain character in a wide range of gas pressures (150~760 torr)

Development

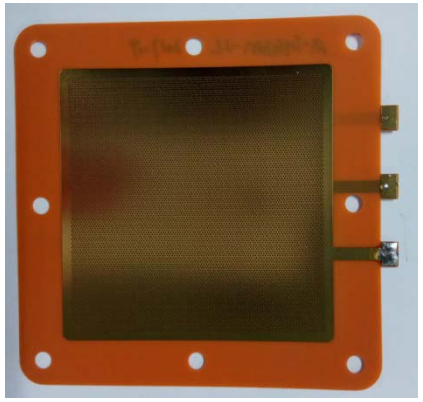
Based on the mature THGEM production techniques developed by IHEP and KingBrother Co. Ltd., M-THGEMs with various substrates, layers and dimensions were produced.



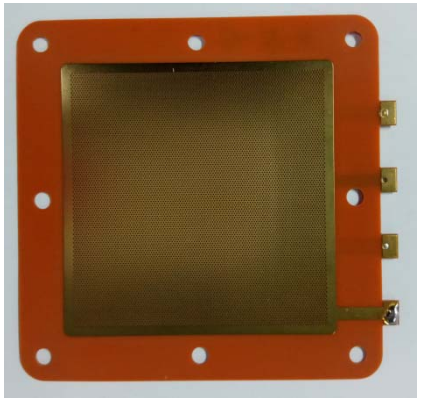
Cross sections of 2L(left) and 3L(right)M-THGEMs

HD: 200μm Pitch: 600μm Rim: 80μm	Total thickness: 2L: 300μm 3L: 500μm

FR-4 and PI, 60×60 mm²

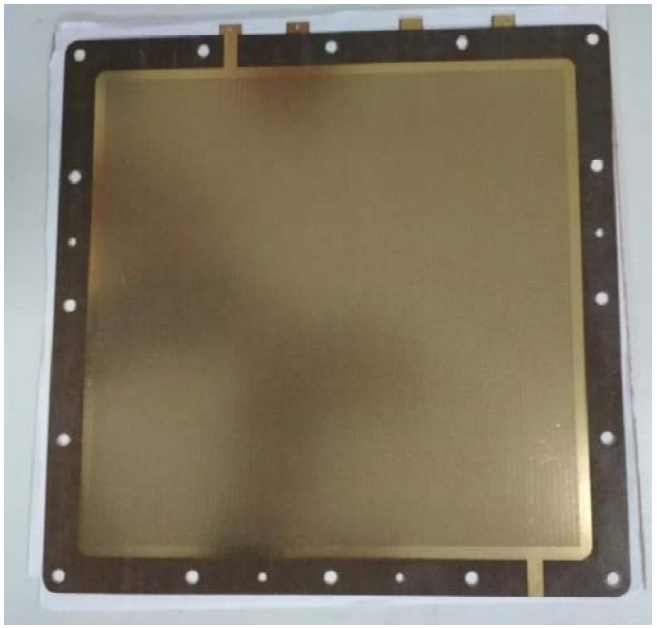


2-layer M-THGEM



3-layer M-THGEM

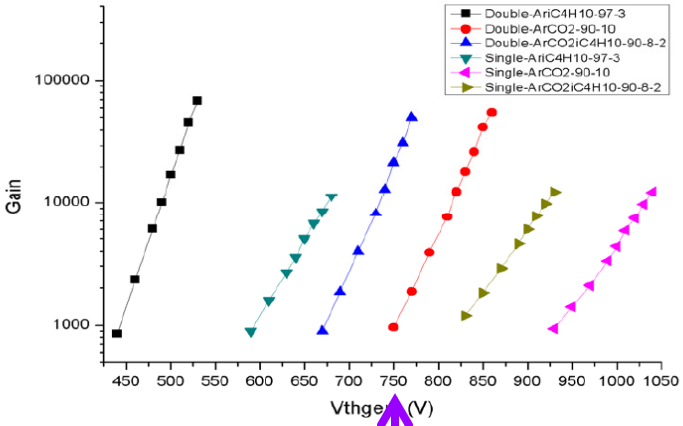
PTFE, 200×200 mm²

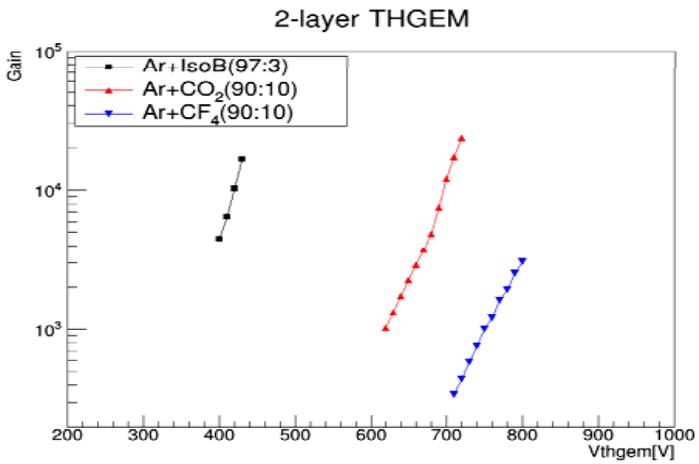


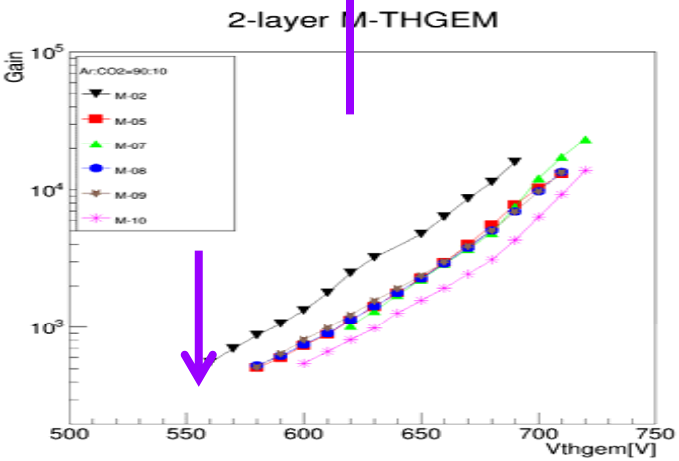
3-layer M-THGEM

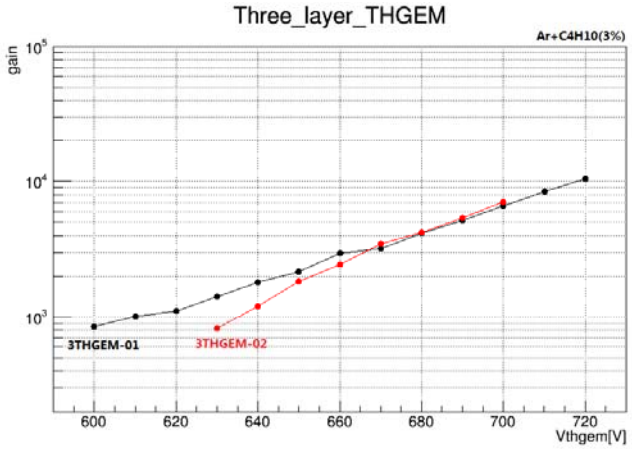
Ceramic M-THGEMs were also produced and provided for users in USA and Italy.

Performance

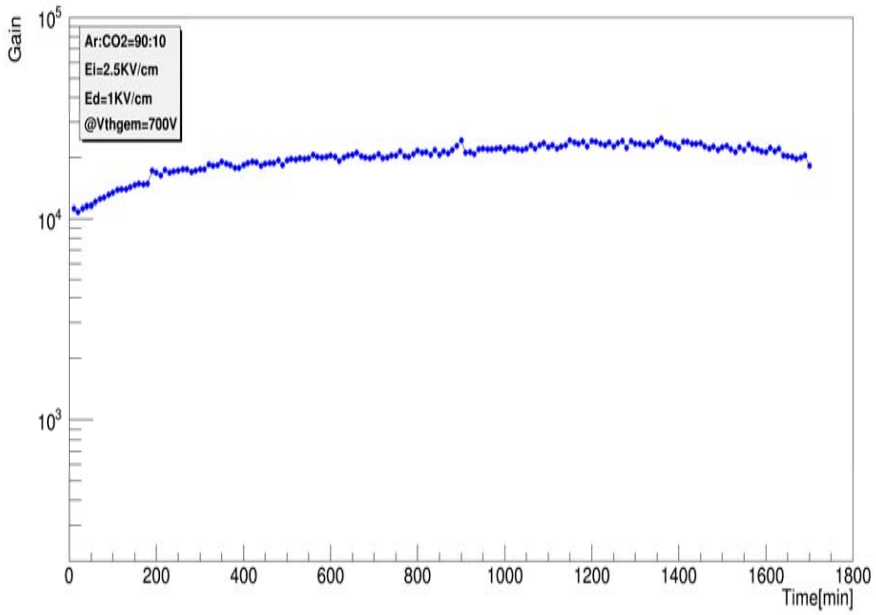


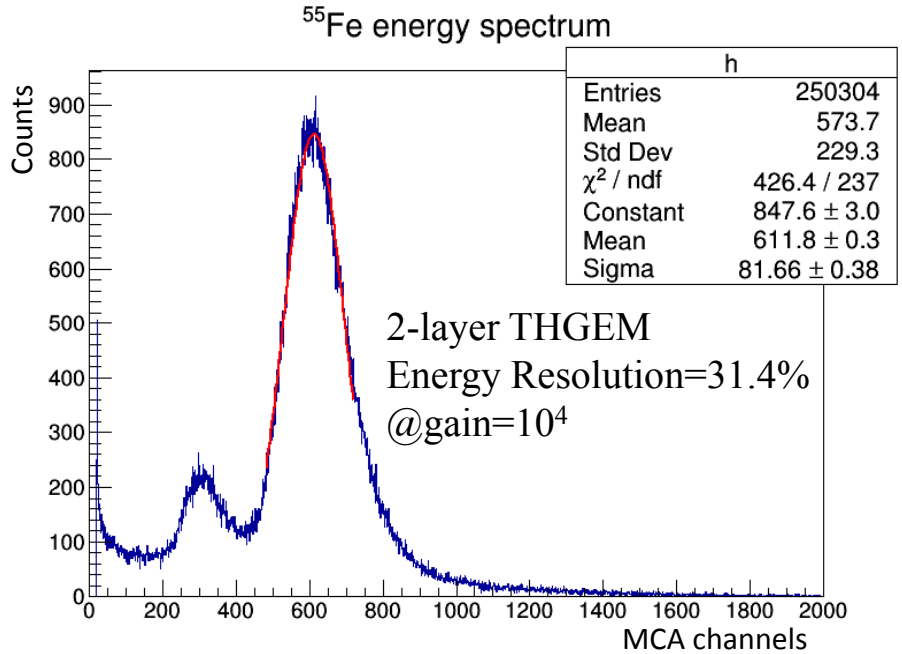






- Up to 1×10^4 high gain in typical gas mixtures, such as $Ar+CO_2$, $Ar+iC_4H_{10}$, and about 5000 in $Ar+CF_4$(carbon tetrafluoride).
- Lower operating voltage than the same number of layers cascade structure, about 150V.
- Three-layer M-THGEM shows similar gain level in 760 torr with two-layer M-THGEM, so it indicates that tow-layer M-THGEM is a better choice for normal applications. Three-layer M-THGEM has advantages in case of low gas pressure.

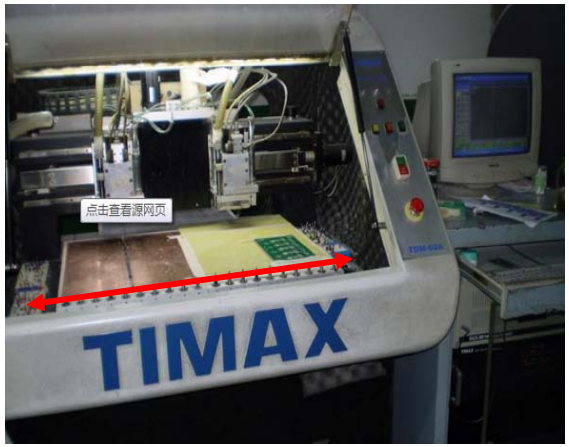


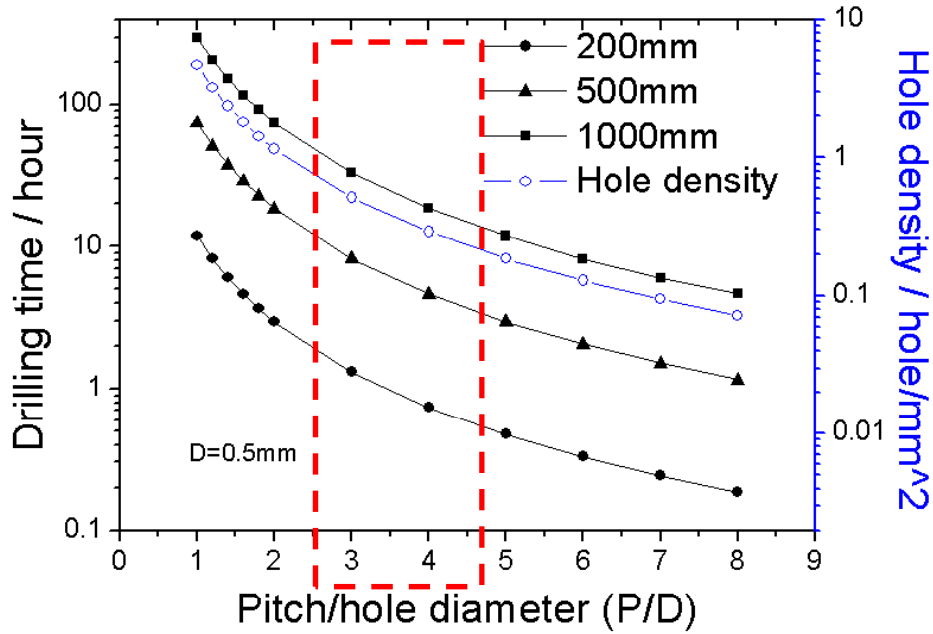


Good gain stability: 12% @ $2X10^4$, energy resolution is about 31%@ gain= $1X10^4$ （Ar/CO_2=90:10） and will be better at lower gain.

Big area

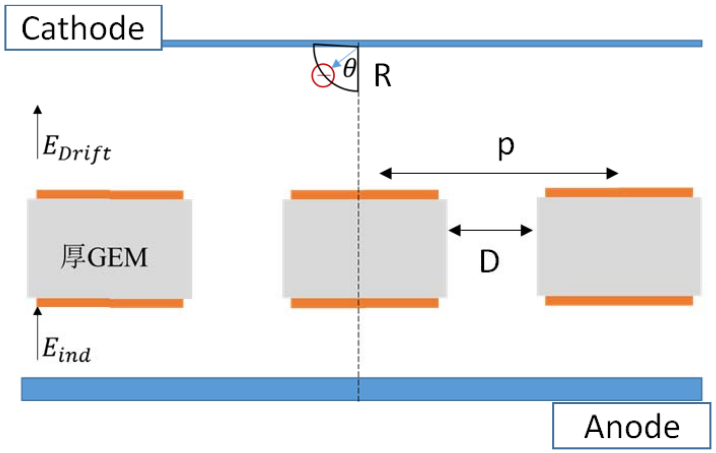
Besides the performance, the big area and mass production are two key factors for THGEM applications in HCAL and muon system. So far, mechanical driling is still the only mature way to produce big area THGEM, therefore the size of THGEM is limited by the width of PCB production line and the dimension of the numerical control drilling machine. Reachable max size is 1.2*0.5m^2。 In fact, the greatest difficulty of THGEM mass production is the huge time-consuming hole drilling.

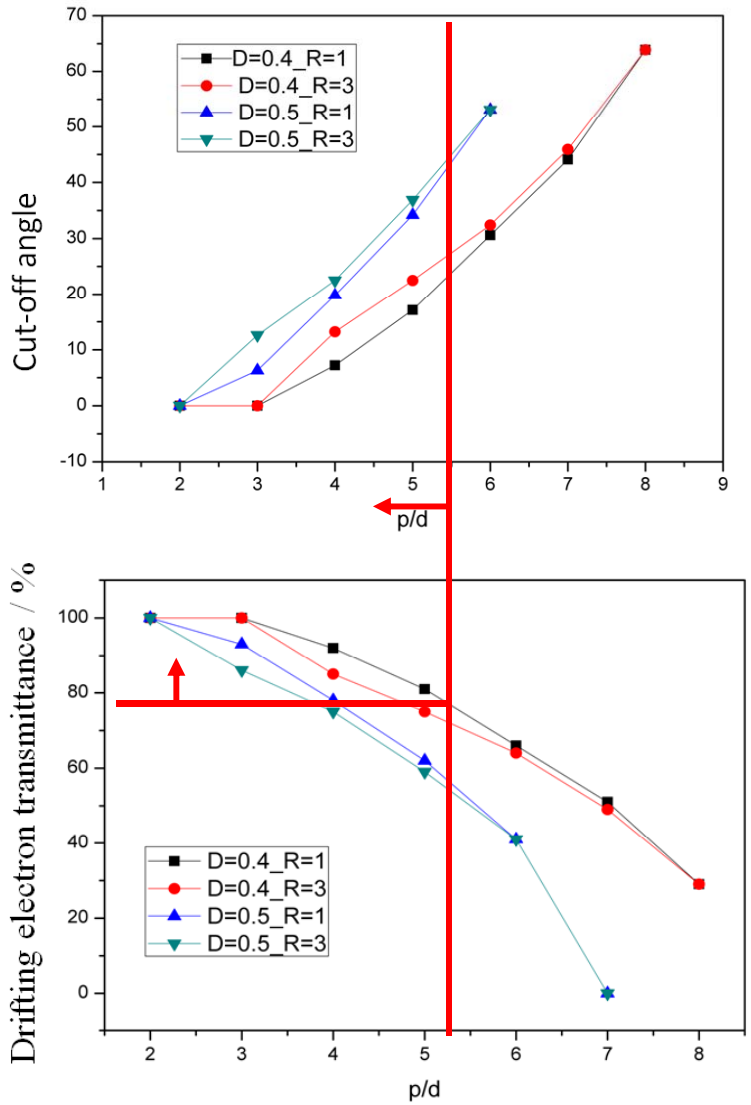




One of the effective way to reach big area for mechanical drilling is to reduce the total hole number, i.e., the hole density. The required spatial resolution for HCAL and muon system is about 1mm, which allows a larger hole pitch, and so lower hole density.

P/D optimization (Garfield++)



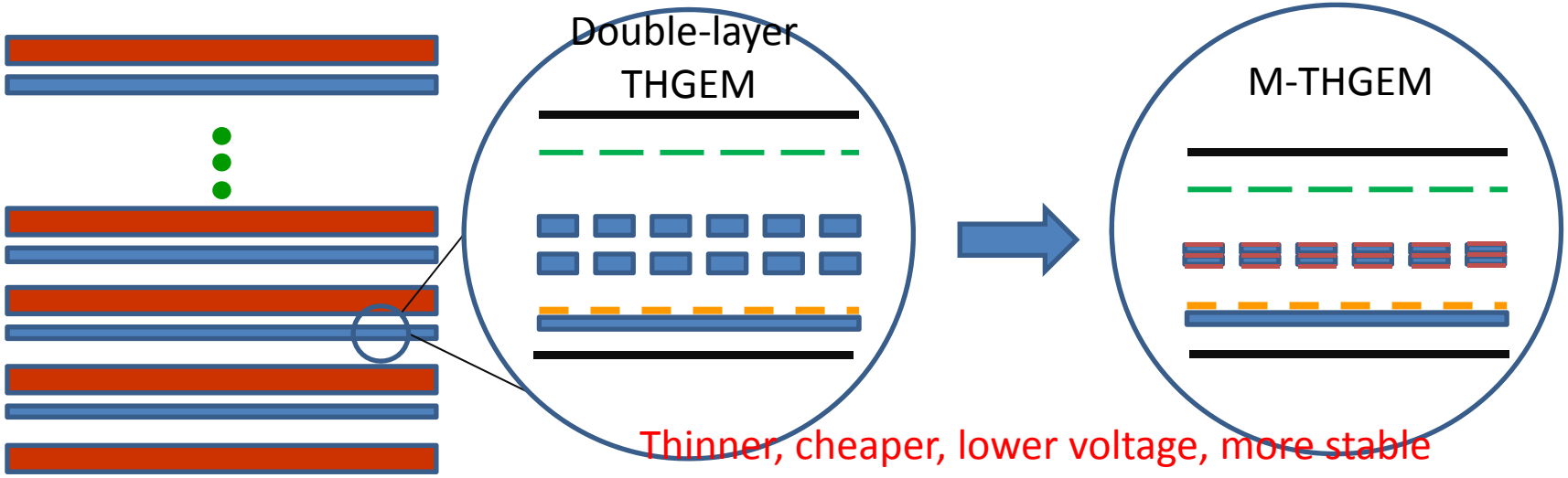


P/D: hole pitch over hole diameter;
Cut-off angle: the minimum ejection angle for electron drifting into hole. Zero is vertical to the THGEM.
Drifting electron transmittance: the ratio of electrons drifting over going into hole

For D=0.4mm, the largest P/D could be accepted is 5, and for D=0.5mm, P/D is <=4; So the maximum pitch must be <=2.0mm. In this case, it takes about 18 hours to drill holes of a 1.0m^2 M-THGEM.

A prototype design for DHCAL and muon chamber

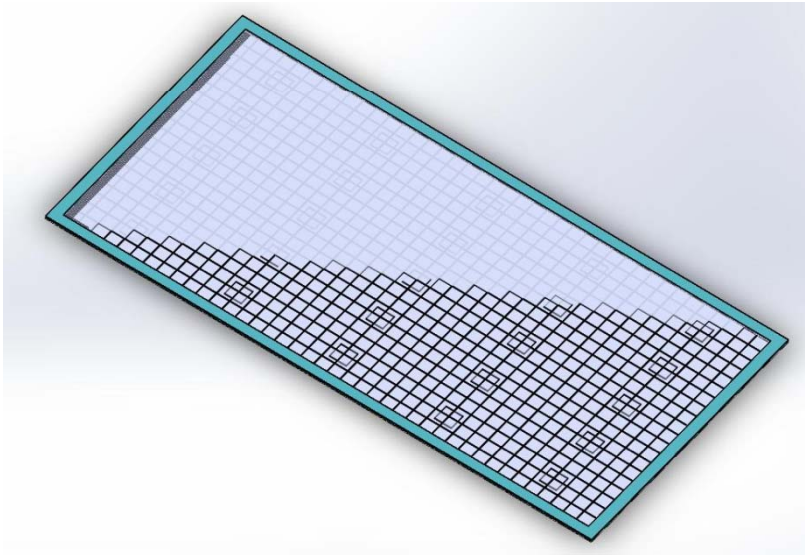
DHCAL/Muon system

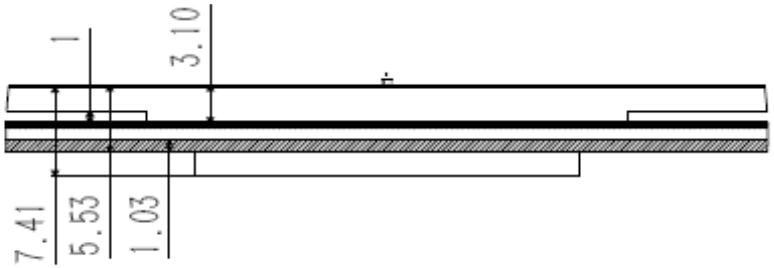


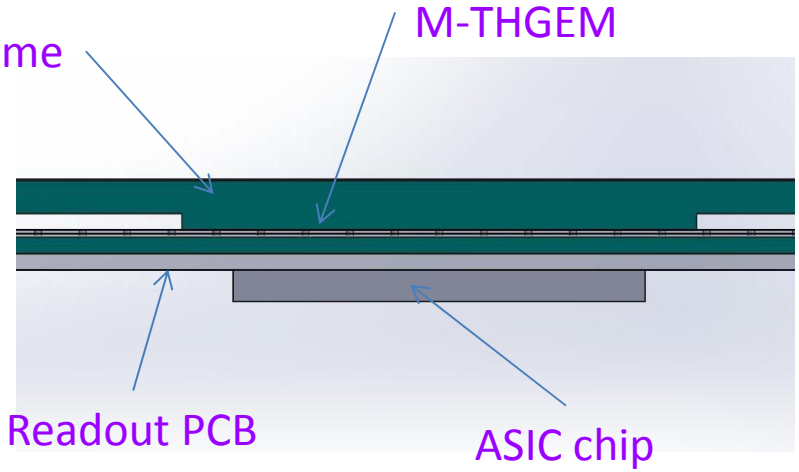
Thinner, cheaper, lower voltage, more stable

The modules of both DHCAL and muon system could have the similar structure, the main difference is the readout, one is PAD, and the other is strip.

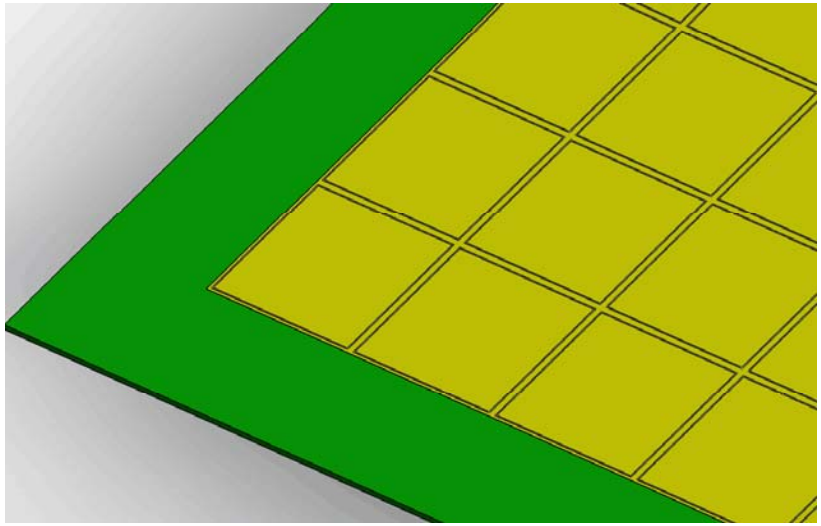
A example of a 1.0*0.5 m^2 module with 2.5-cm cell size

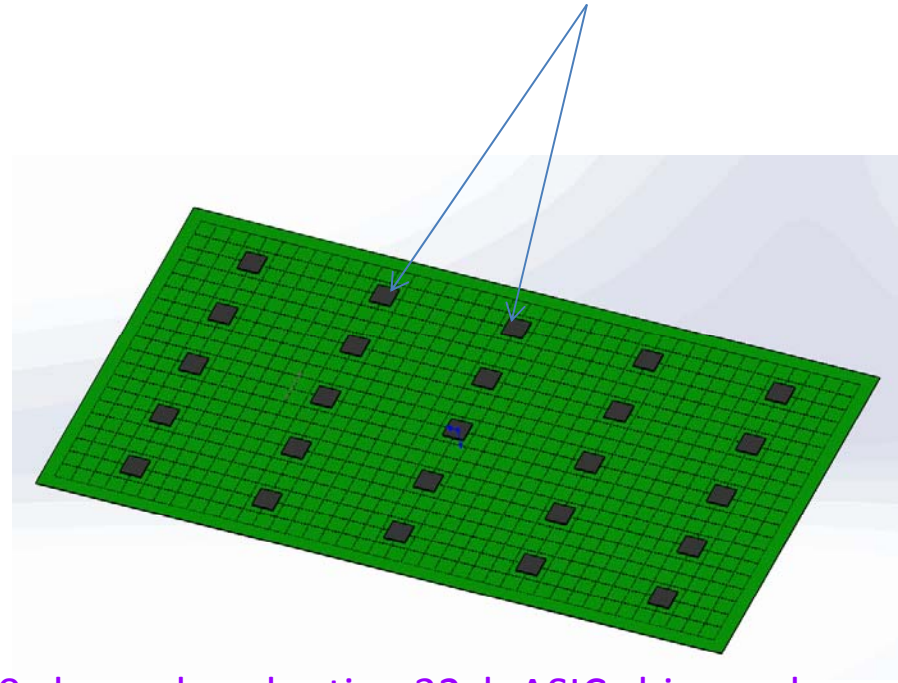






3-mm drifting gas gap, 1-mm inducing gap,
1.5-mm thick readout PCB board,
2-mm ASIC chip and electronic component.

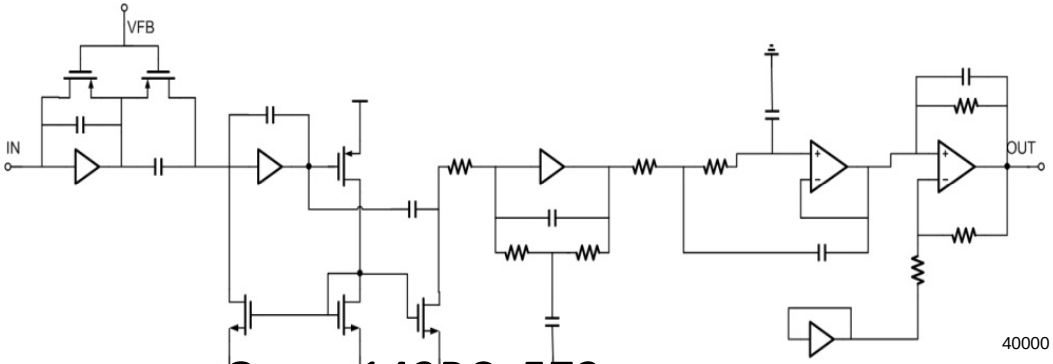


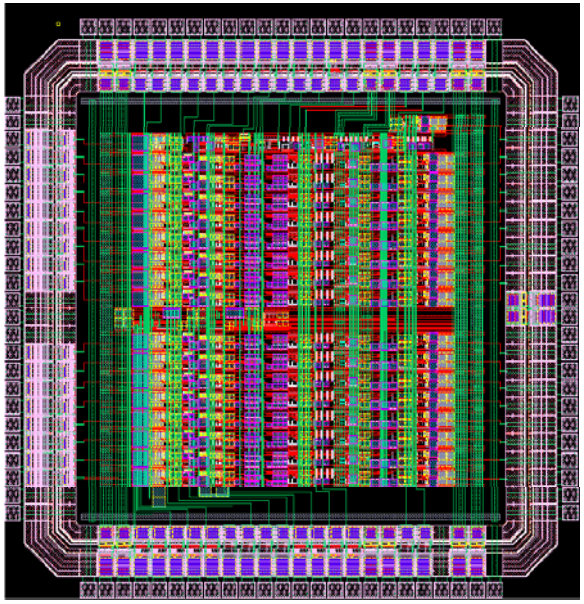


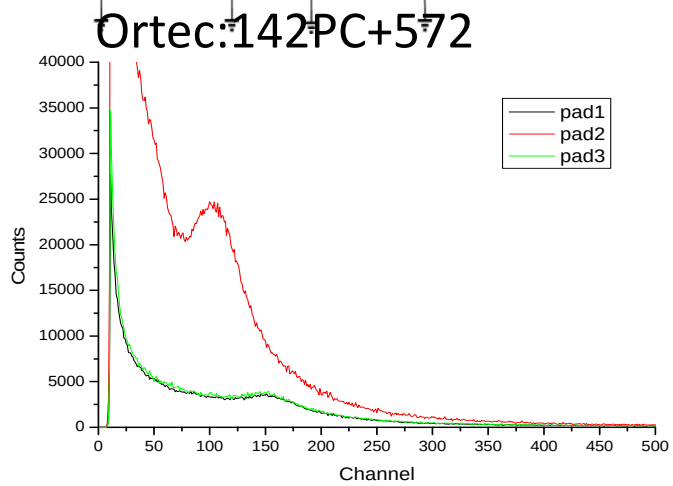
For HCAL, 2.5 mm readout PAD, 40*20 = 800 channels, adopting 32ch ASIC chip, each 8*4 cell array as an ASIC chip readout, 25 chips / module. For muon system, 40+20-60 channels /module, 2chips/module.

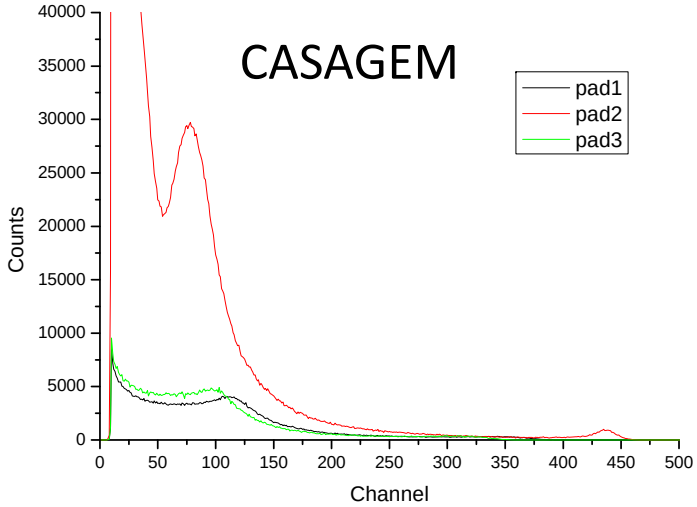
Front-end electronics

- **Front-end electronics, homemade ASIC chips CASAGEM, Tsinghua University, 32ch/chip version**
  - Structure： preAmp + 5 trends shaping
  - Gain： 2mV/fC, 4mV/fC, 20mV/fC, 40mV/fC
  - Shaping time： 20ns、40ns、60ns、80ns
  - Channel： 32+1(1 trigger)
  - Output： Single-ended parallel output









Summary

1. Various types of THGEMs had been developed in IHEP, CAS, Beijing China. Around THGEM applications, some achievements had been made, including: new substrate THGEMs, high spatial resolution THGEMs, big-area THGEMs, and new structure M-THGEM, etc.
2. M-THGEM is a new structure and promising THGEM and a high-rate, robust, compact and economical candidate for HCAL and muon system.
3. One way to reach big area and reduce huge time-consuming in hole drilling is to choose larger P/D, which could ensure the required spatial resolution and also the electron transmittance.
4. A prototype design is proposed for the modules of HCAL and muon ystem, module of 1.0*0.5m^2 with 2.5-cm cell size, 25 ASIC chips and 800-channel PAD readout or 60-channel stirp readout is recommended .
5. An electronics solution based on self-develop ASIC chip is also proposed for further development.

Thank you for attention!