CHLOE: updates

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Outline

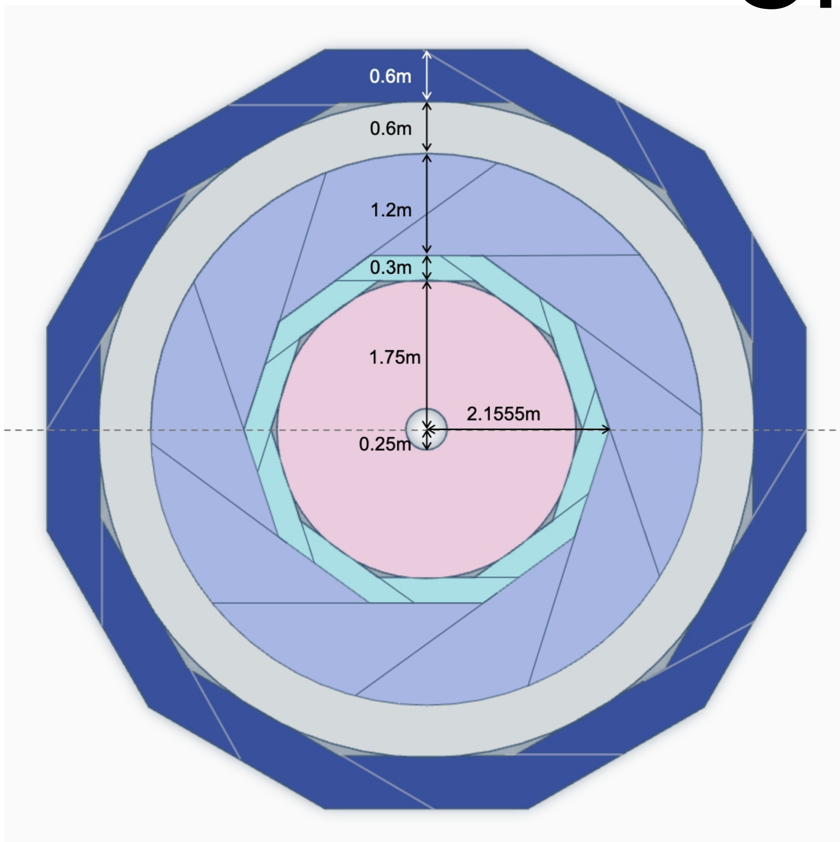
- Requirements
- CHLOE Concept: briefing
- Anticipated Performance & Cost
- Update: Glass ECAL + jet origin id
- Summary

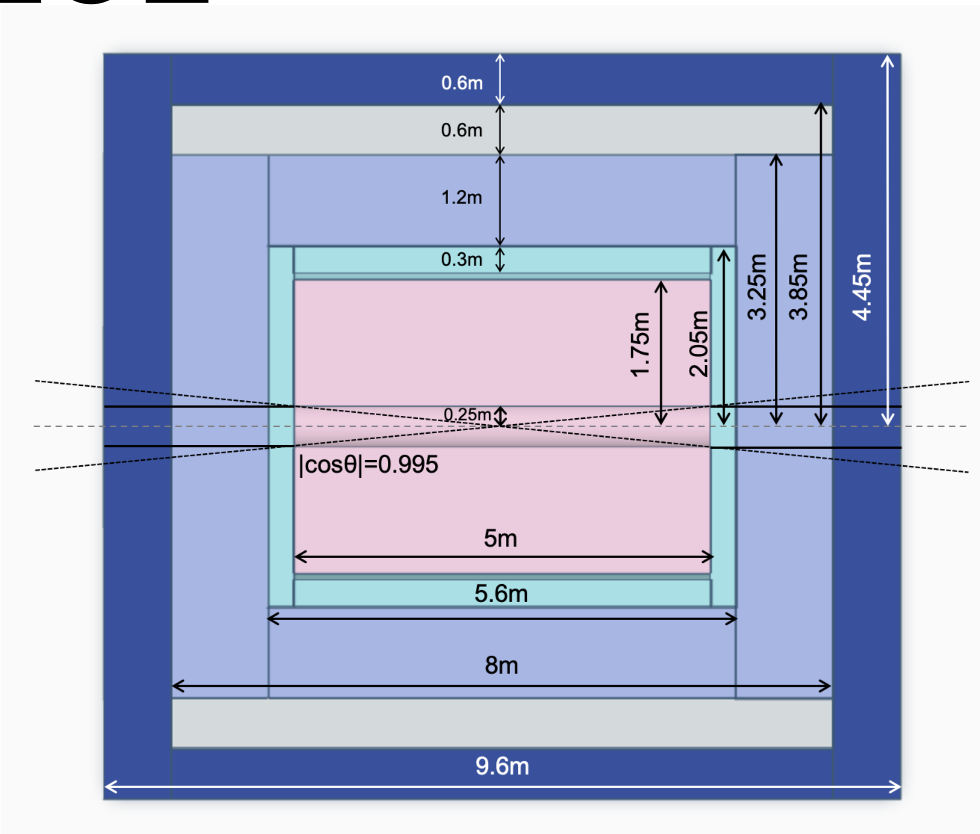
Extreme detector requirements

- Suited to the collision environment, especially beam background/MDI
- Trigger-less equivalent: Trigger system works as Trigger-less
- Extremely stable
- Large acceptance: polar angle, energy, time
- **PFA compatible (in SpaceTime): final state particle separation – pursue 1-1 correspondence**
  - Physics Objects Identification: Isolated, inside jets & jets
    - Single particle objects: Leptons, photons, Charged hadron
    - Composited objects: Pi-0, K-short, Lambda, Phi, Tau, D/B hadron, ..., Jets
  - Improving the E/M resolution for composited objects, especially jets
- **BMR (Boson Mass Resolution)**
  - **< 4% for Higgs measurements, ~3% for NP tagging & Flavor Physics Measurements**
- Pid: Pion & Kaon separation > 3σ (Kaon finding at incl. Z->qq : eff/purity > 95%)
- Jet origin identification: Flavor Tagging, Charge Reconstruction, s-tagging...
- Excellent intrinsic resolution E/M/position: per mille level for track, percentage level for EM...

+with acceptable price: To be addressed by innovative detector design + key tech R&D

CHLOE

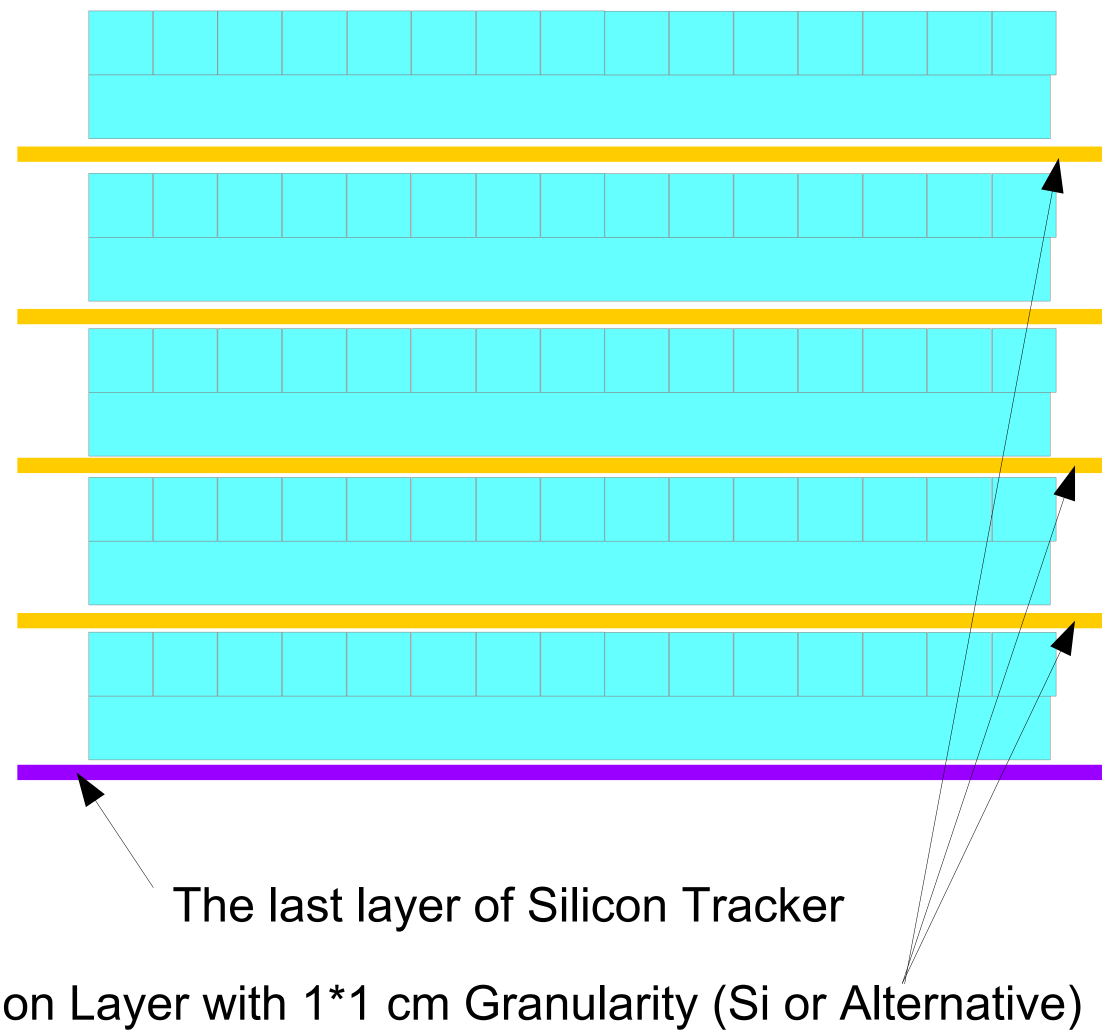




- Main features:
  - Aggressive VTX + Large volume Gaseous Chamber for Tracker
  - ECAL + HCAL: Xstal/Glass ECAL + Glass HCAL with Positioning & Timing
  - 12-side polygon Calo

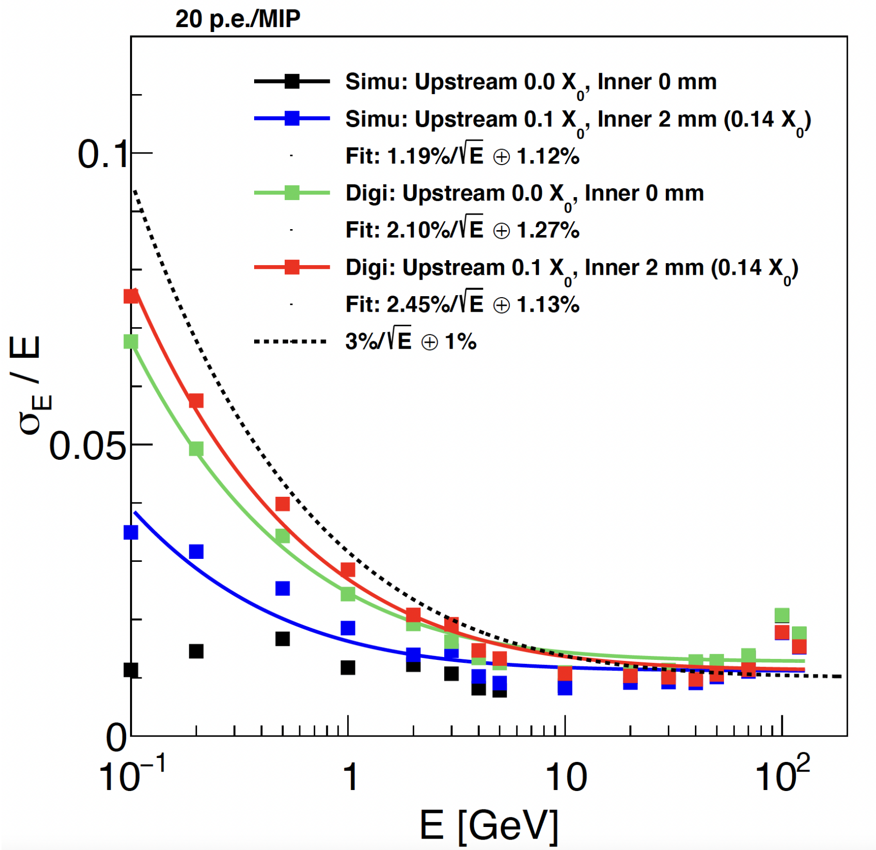
ECAL: Crystal + Position/timing layer

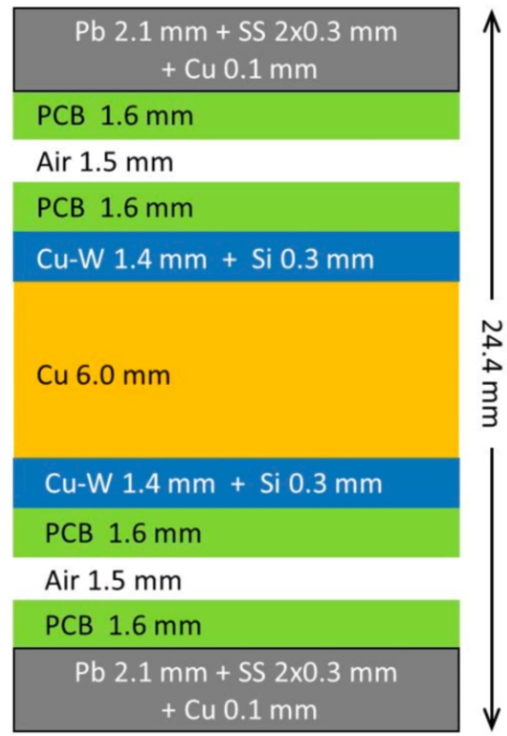
- Geometry
  - Total Crystal Volume: 23.3 m^3
  - Single Crystal Bar Dimension: 2.67cm * 2.67cm * 40cm = 291 cc, In total 80k bars
  - Inner Area: 80 m^2
  - Total Readout Channel:
    - 80000*2 = 160k (Crystal)
    - 800000*4 = 3.2 M (Si)
- Performance
  - EM resolution
  - Anticipated BMR
  - Timing



*Compared to 1*1*40 cm crystal bars*
With in total 570 k bars and 1.14 M readout

EM resolution





CMS HGC Project:

600 m^2 Si + 300 m^2 Sci

Total cost:
69 M CHF ~ 500 M CNY

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CEPC:

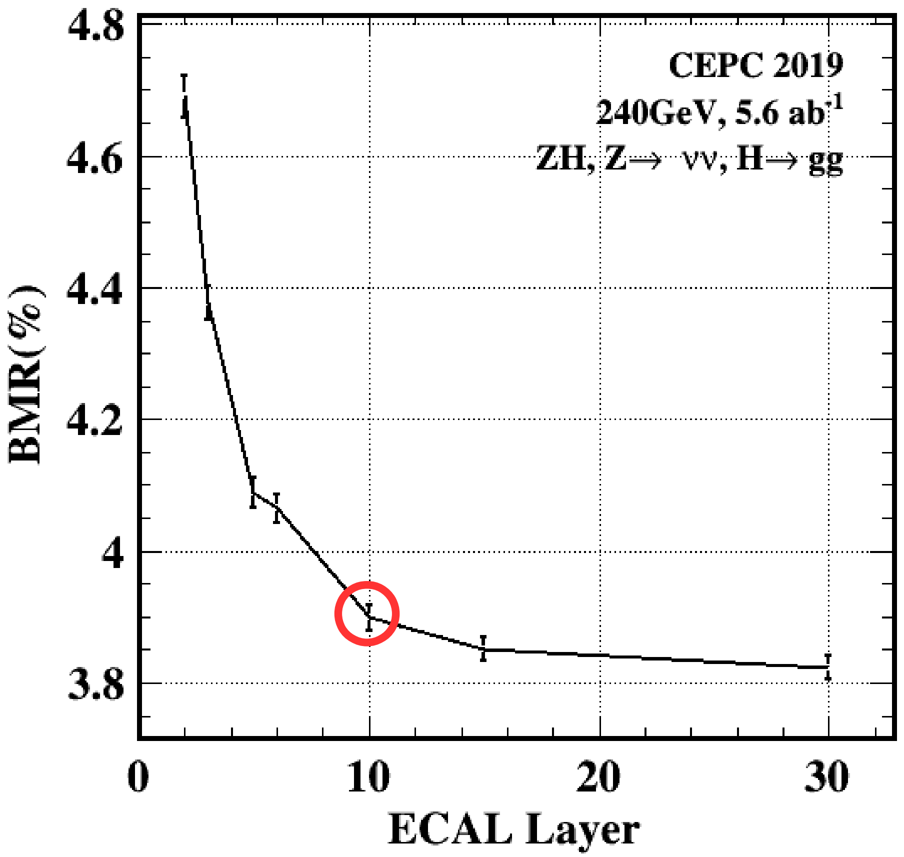
~ 300 m^2 Positioning Layer

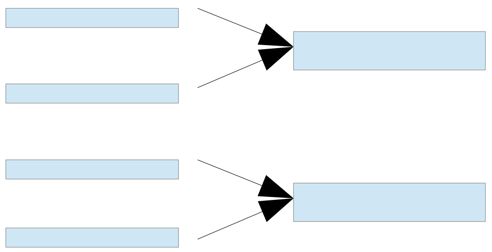
~ o(100) M CNY

- Positioning layer: material budget of ~ 0.2 X0 (3 mm Cu), fraction < 3%
- Compatible with CMS HGC Silicon layer wi cooling; which has much higher data rate & requirement on energy reco. -> further optimization is possible

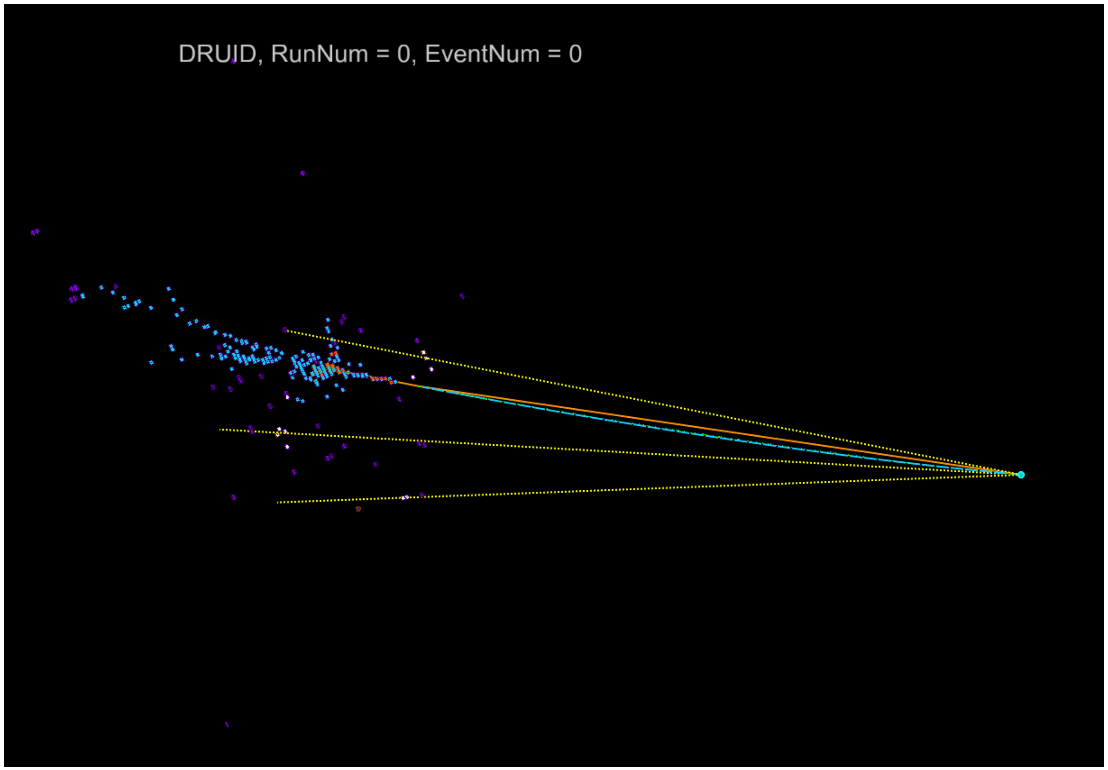
BMR

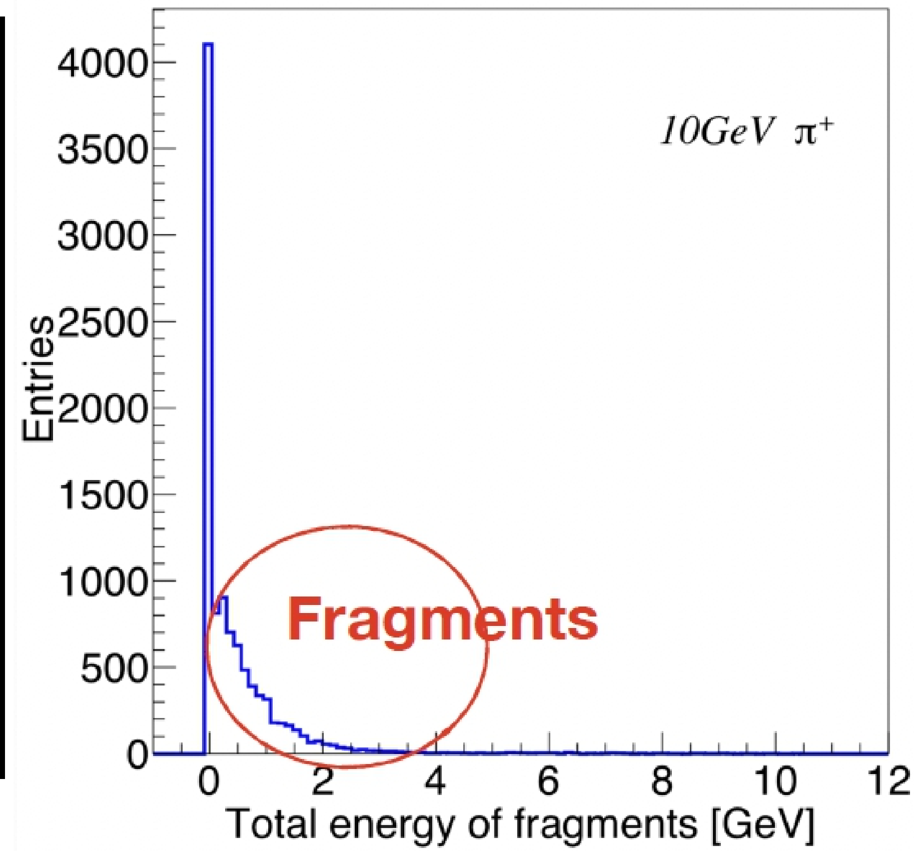
- Optimization study at Baseline – Merge Hits of neighboring layers in longitudinal direction. Compared to 30 Si-W layers, 10 layers has a relative degrading of 2% (3.82 → 3.9)
- 5 double-layers + 4 silicon sensors + advanced algorithm shall comparable to 10 layers... if not better
- Better EM resolution of Xstal ECAL has positive impact on BMR
- BMR shall be comparable to baseline



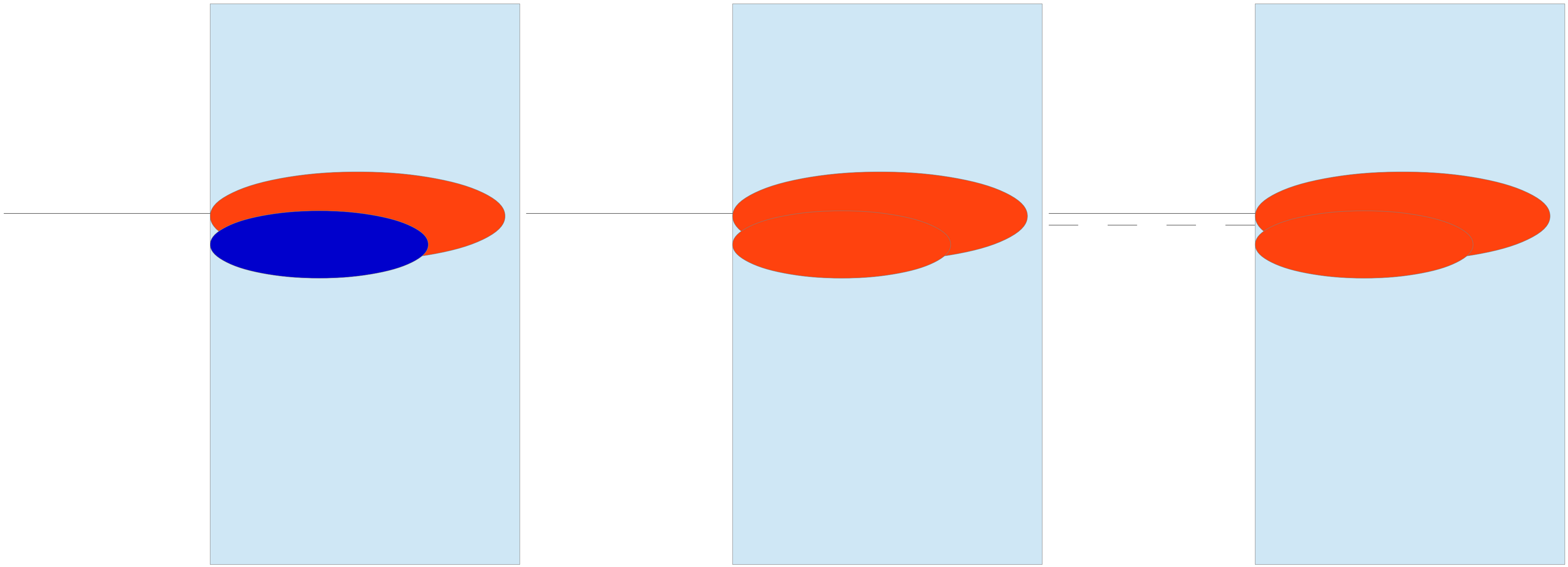


Confusion-1: charged fragments





Confusion-2: Merged neutral PFO



- If Cluster Energy be significantly larger than associated track (E >> P): reconstructed as a Charged PFO with E = P, and a Neutral one with energy of E-P
- However due to the failure and uncertainty of tracking, ... exist mis-id

Touch base study using MCTruth

Baseline (SiWECAL + SDHCAL)

0: BMR ~3.70%, original

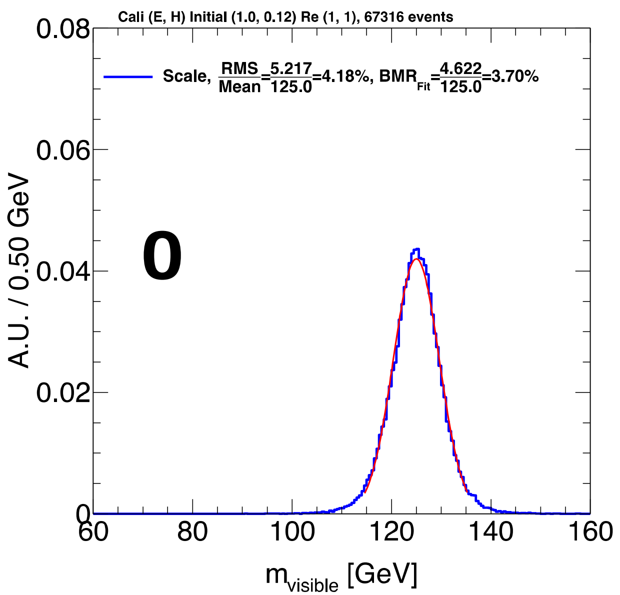
1: BMR ~3.33%, remove charged fragments

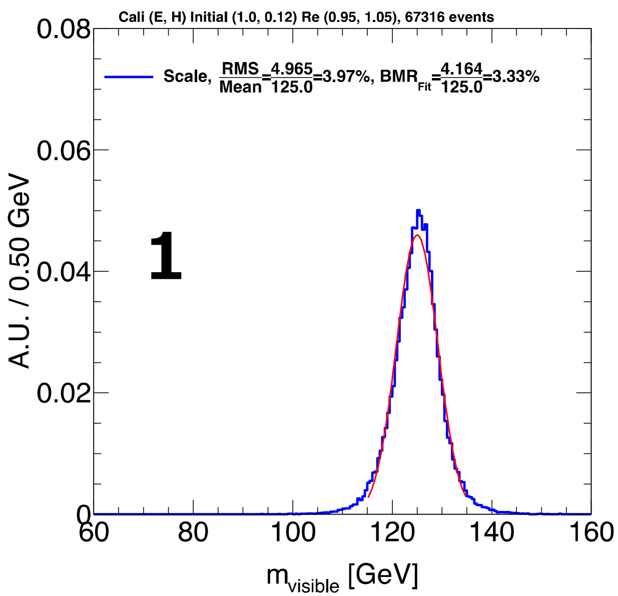
2: BMR ~3.09%, remove charged fragments + “Null MCP” event cut

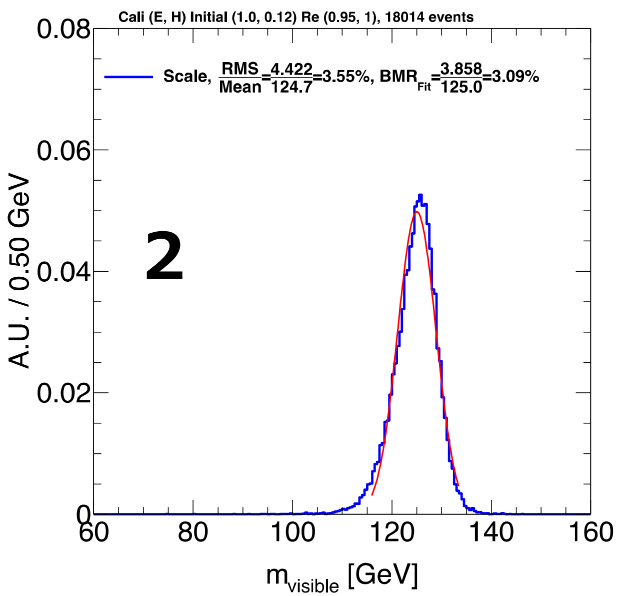
PS: Two cases of “Null MCP” (fail to link to MCTruth Particle)

- PFO reconstructed by Energy Flow
- PFO caused by LumiCal Hits

Null MCP Cut eff ~ 25%







Perf & Cost Comparison: 2 scenarios

Parameters	Default Setting	~~Optimal~~ Setting Preferable-1
Boson Mass Resolution	3.59%	3.36%
Number of Layers	40	40
Layer Thickness	$0.125\,\lambda$ 10 mm GS + 13.85 mm Steel	$0.15\,\lambda$ 15 mm GS + 14.5 mm Steel
Total Thickness	$5\,\lambda$	$6\,\lambda$
Transverse Cell Size	$4 \times 4\,\mathrm{cm}^2$	$2 \times 2\,\mathrm{cm}^2$
Scintillator Density	$6\,\mathrm{g/cm}^3$	$6\,\mathrm{g/cm}^3$
Readout Threshold	0.1 MIP	0.1 MIP
Total HCAL/GS Volume	$109/46\ \mathrm{m}^3$	$157/80\ \mathrm{m}^3$
HCAL External Radius	3020 mm	3269 mm
Total Readout Channels	2.86×10^6	1.33×10^7

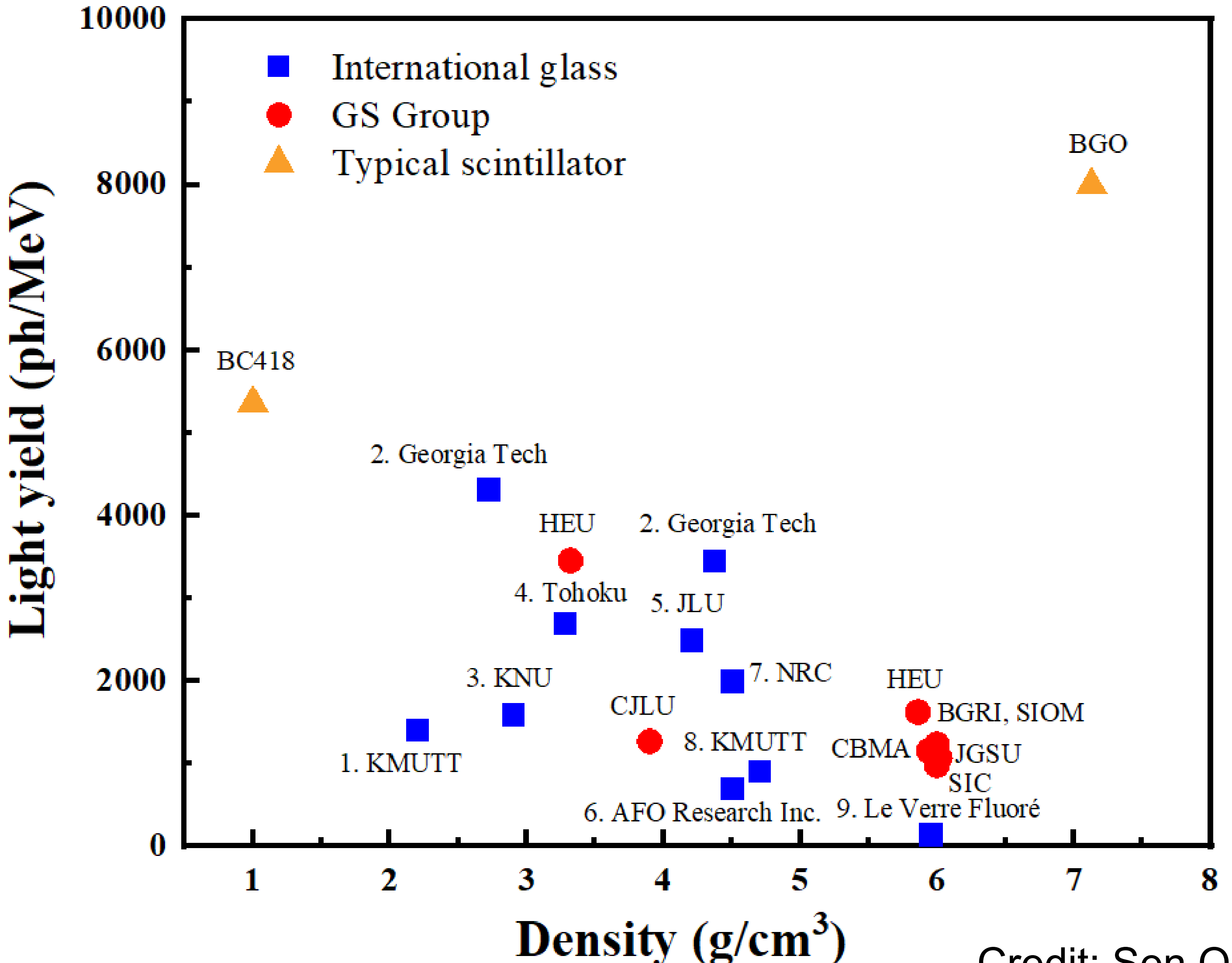
- Balance between Perf. & Cost.

Anticipated BMRs

	Current	Leading confusion solved (Fragment & Merging)
CDR Baseline	3.7%	3.1%
GSHCAL (default)	3.6%	2.9%
GSHCAL (Preferable)	3.3%	2.7%
CHLOE expectation	3.4%	2.8%

- Achievable BMR estimate: ~ 3.0%
  - Better energy estimation tech. potentially improve the BMR by 0.2 – 0.3%
  - Realistic pattern recognition may not match ideal level (granularity, space/time resolution, etc): degrade BMR by 0.2%
  - Realistic digitization to account the homogeneity effects: degrade BMR by 0.2%
  - ...

Glass ECAL: is it an option?



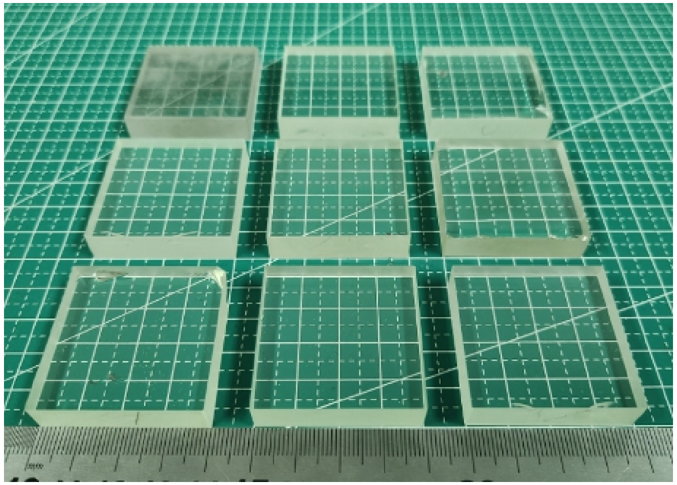
Credit: Sen Qian

Cost Estimation

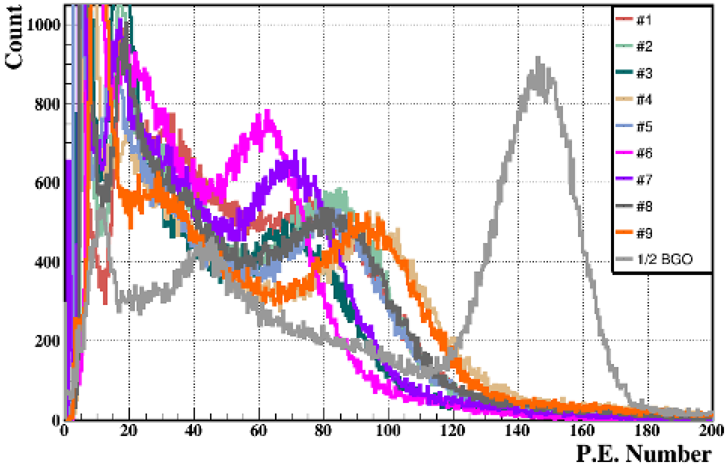
子探测器	总价（亿 CNY）	总价（亿 CNY）
MDI	0.3	0.3
Vertex + Si Tracker	5.6	3.4 (LGAD...)
TPC/DC	1.8/1.2	1.8/1.2
ECAL	16.8	9.5 (Crystal Price Halves)
HCAL	4.0	4.0
Solenoid	1.8	1.8
Yoke + Muon	0.2 + 1.3	0.2 + 1.3
Mechanics	0.8	0.8
Online	2.0	2.0
Transportation	1.0	1.0
Total	35.6/35.0	26.1/25.5

27 cubic meter BGO with price ~ 3.5/7 USD/cc ~ 7.5/15 亿 CNY
Glass: order of magnitude smaller.
By using the Glass ECAL... we could save ~ 6.5 – 13 亿 CNY

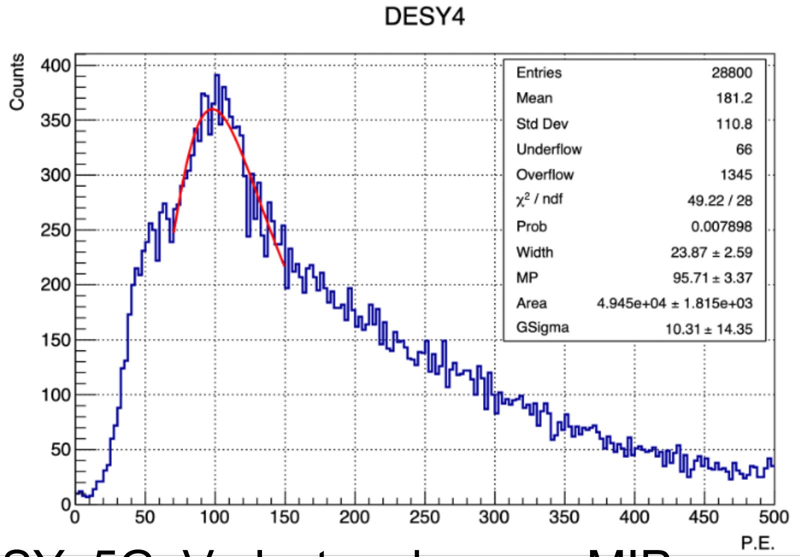
Glass ECAL: is it an option?



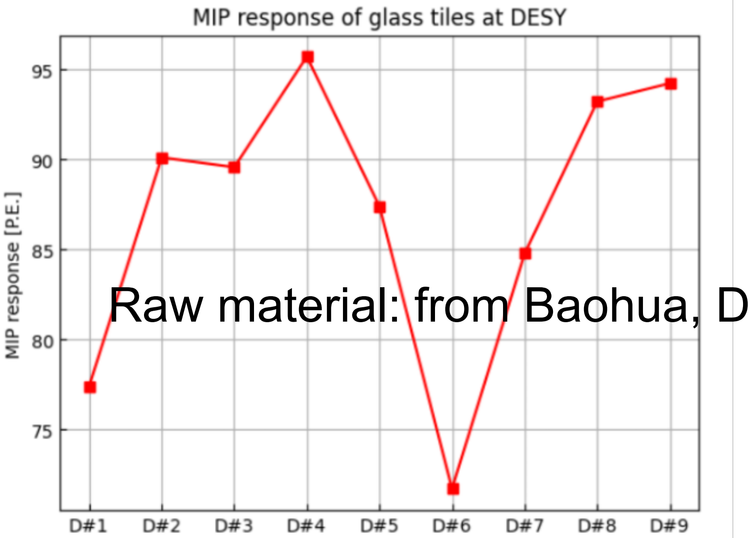
Density ~ 6 g/cc, Cell Size ~ 4*4*1 cm^3



Full energy peak of Ce137 662 keV gamma



DESY: 5GeV electron beam ~ MIP

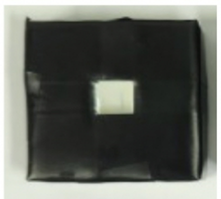


Raw material: from Baohua, Dejing, etc

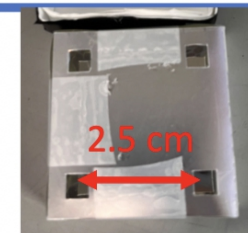
MPV with beam targeting the very center ~ SiPM position

Position dependence of the acquired light

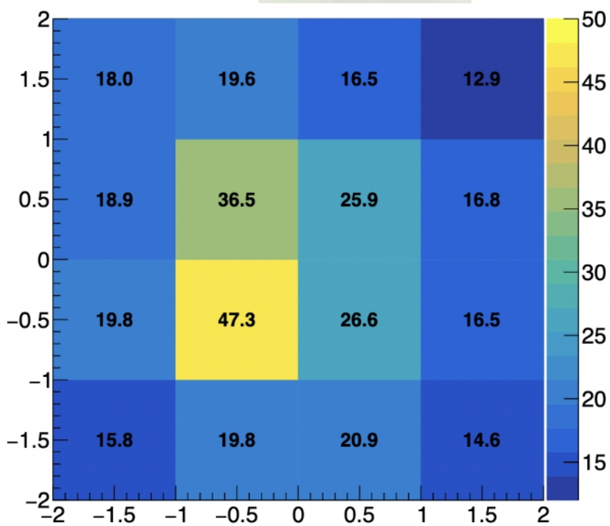
Beamtest results at DESY: uniformity



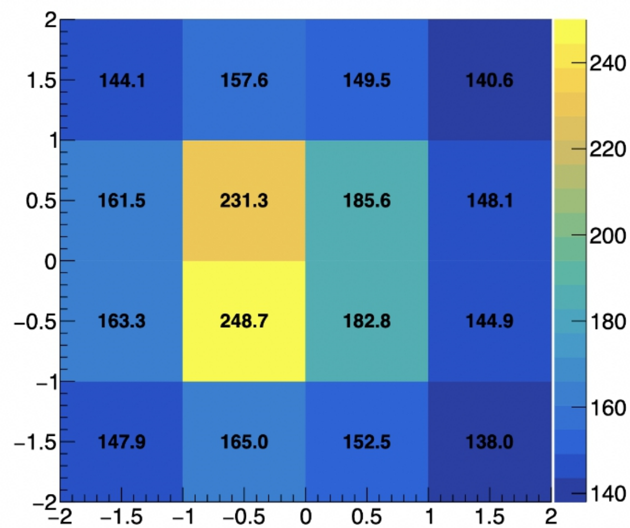
Tile coupled with one SiPM: cavity not yet implemented for better response uniformity



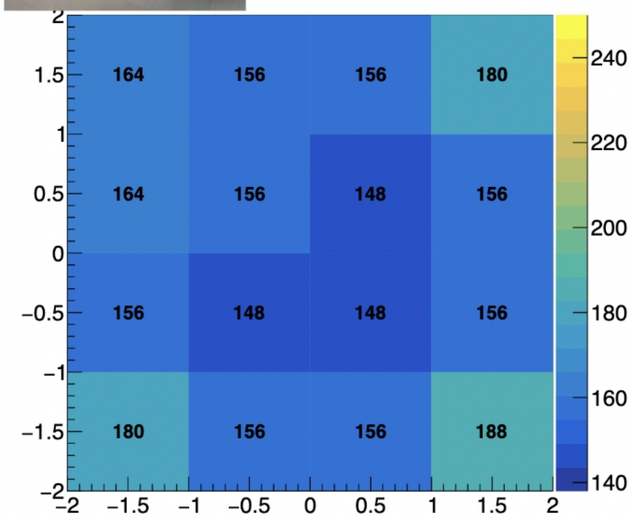
Tile coupled with 4 SiPMs



Glass (DESY#4) with 1 SiPM: 6×6 mm^3
Average = 21.6



Plastic scintillator with 1 SiPM: 6×6 mm^3
Average = 166.4

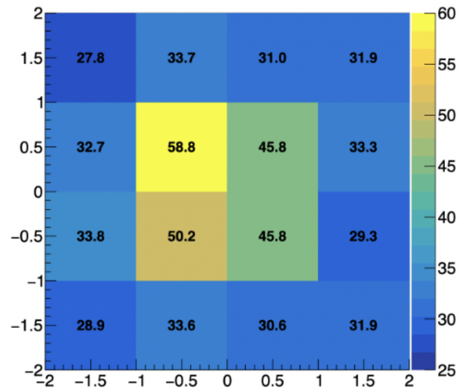


Plastic scintillator with 4 SiPMs: 3×3 mm^3
Average = 160.5

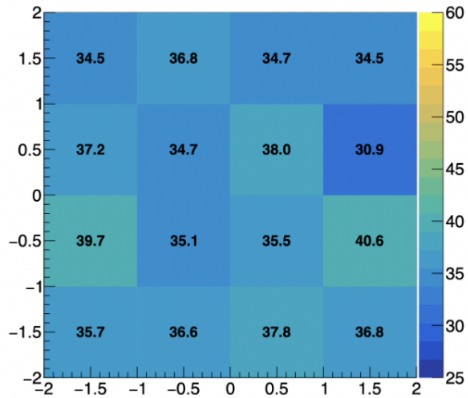
Optical simulation

Geant4 full optical simulation: uniformity

Glass Scintillator

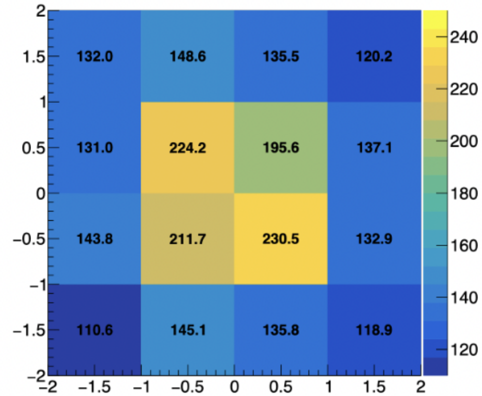


average = 36.2

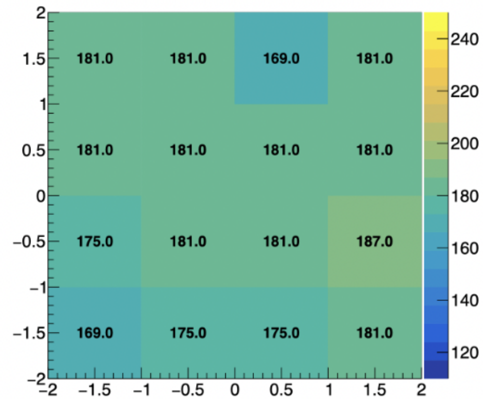


average = 36.2

Plastic Scintillator

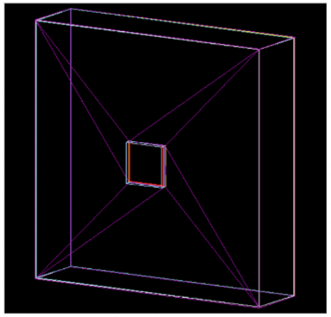


average = 153.3

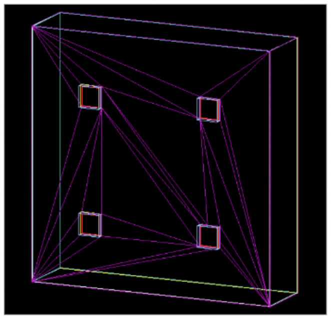


average = 178.6

1 SiPM: 6×6 mm^3



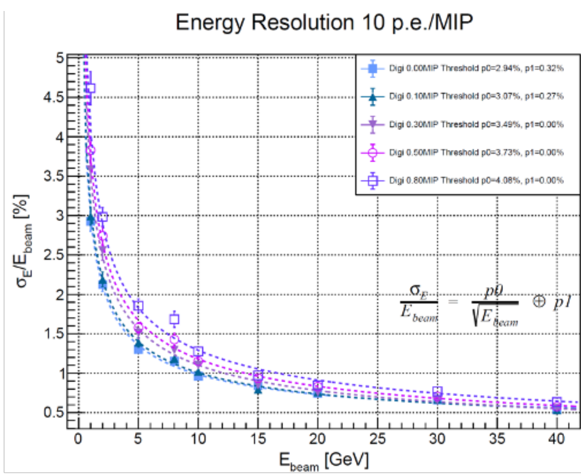
4 SiPMs 3×3 mm^3

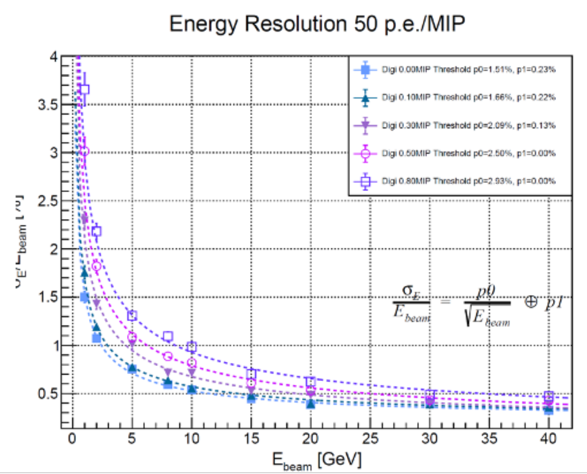


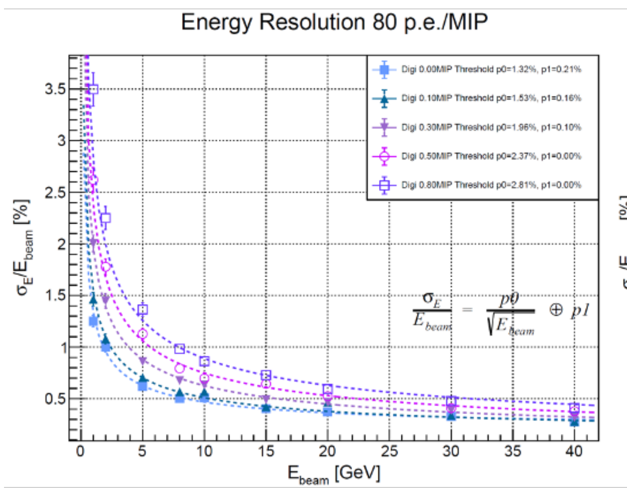
➢ Ongoing studies with G4 simulation: optimisation for better uniformity

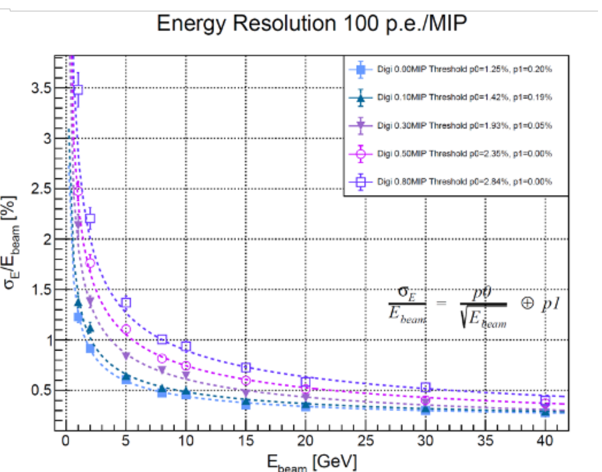
- Need simulation & beam test to understand its property, requirements & design optimization w.r.t. SiPM, coupling, coating, size, etc.

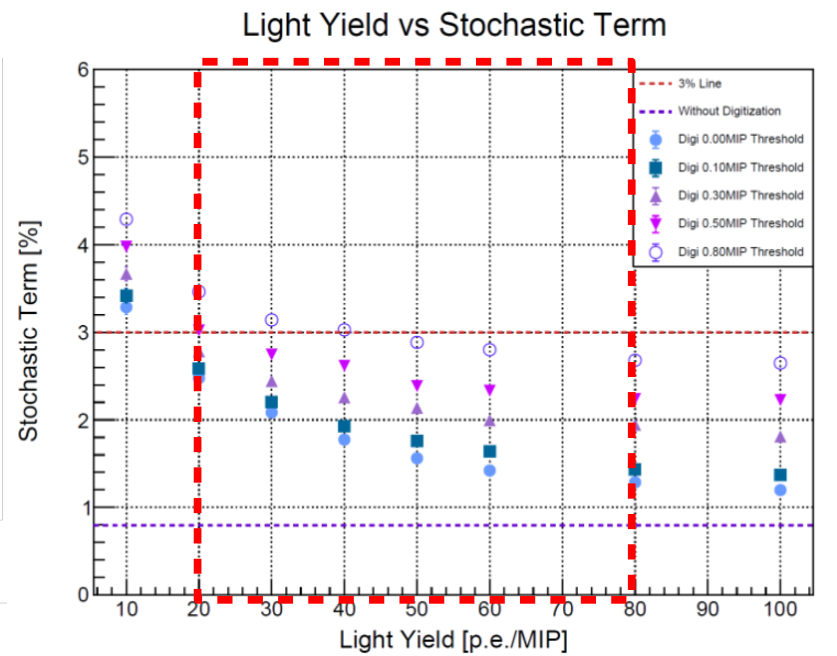
Stochastic: 1%-3%, depends on Threshold









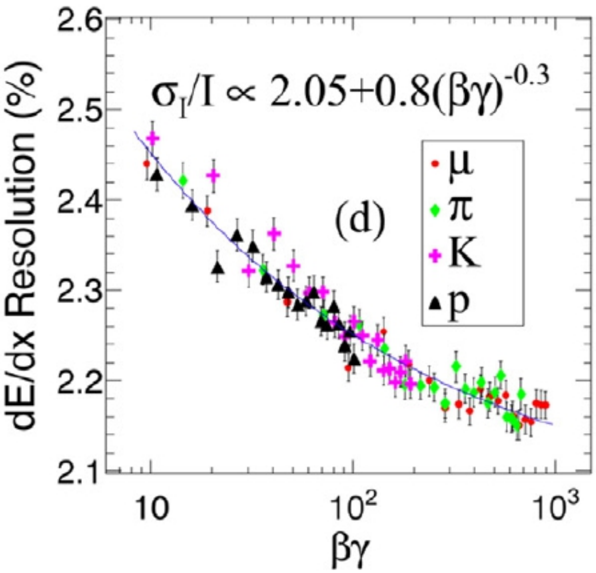


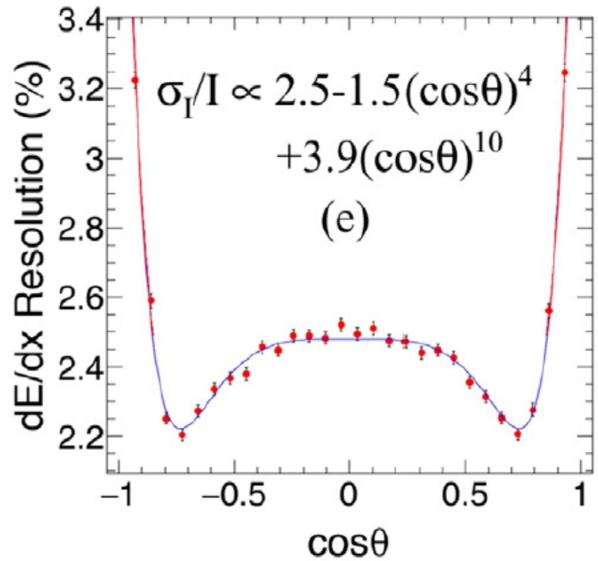
1) Stochastic term reaches plateau if LY > 80 p.e./MIP
2) Energy threshold could achieve 0.1 MIP (> 8 p.e.)

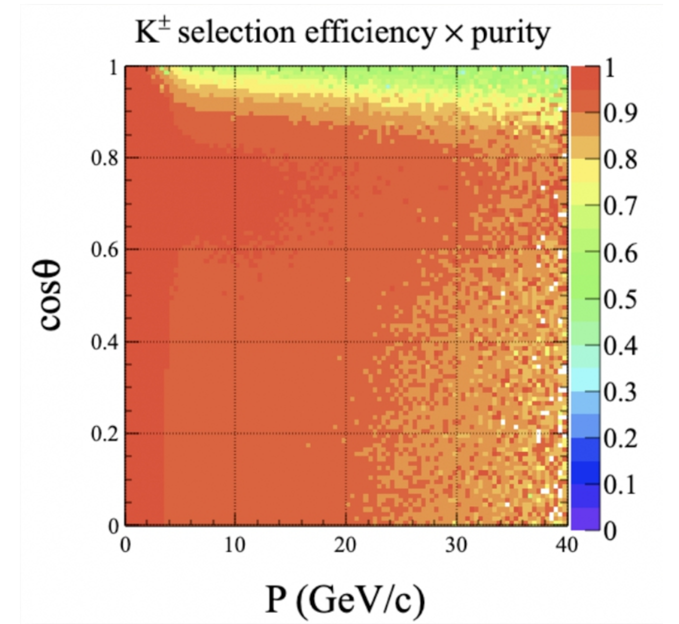
- For 3×3 mm^2 NDL 6μm SiPM noise: 276 kHz/mm^2
- ~2.5 single p.e. noise within 1μs, over 8 p.e. cases ~0.1%

Physics requirement: 3% stochastic, 0.3 – 0.5% constant: homogeneity as main challenge

Tracker: Pid







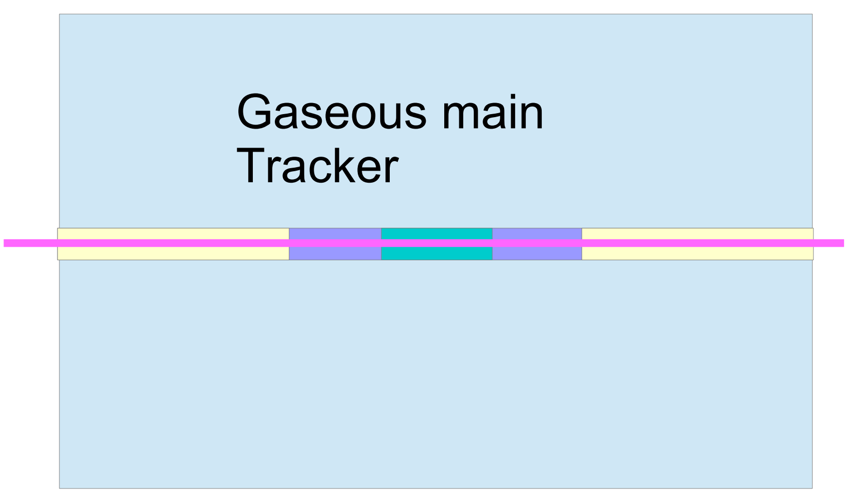
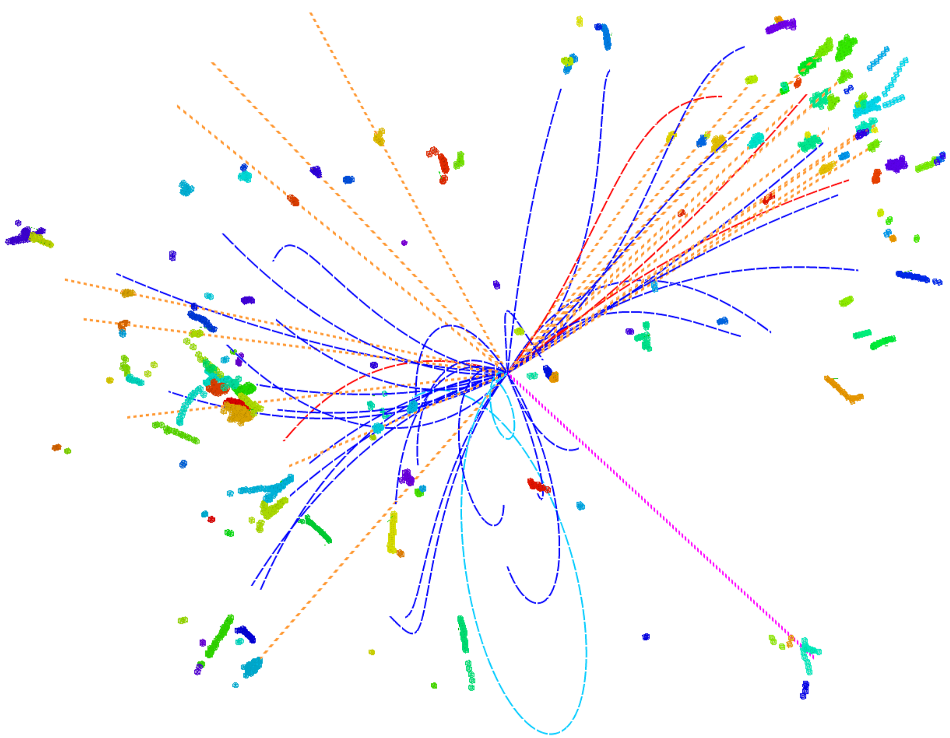


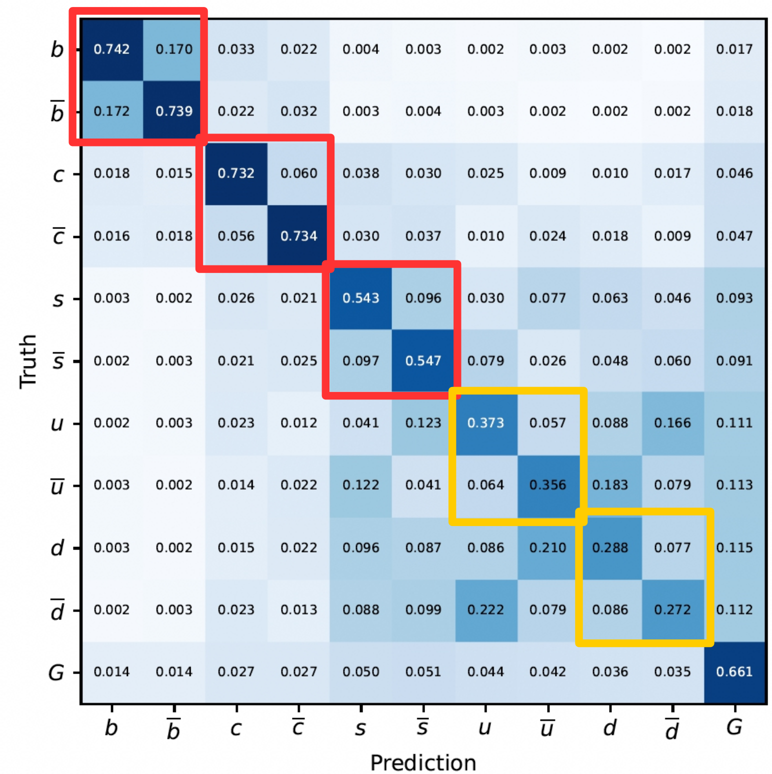
Table 3
The $K^{\pm}$ identification performance with different factors, $\sigma_{actual} = factor \cdot \sigma_{intrinsic}$, with/without combination of TOF information at the Z-pole.

	Factor	1.	1.2	1.5	2.
dE/dx	ϵ_K (%)	95.97	94.09	91.19	87.09
	$purity_K$ (%)	81.56	78.17	71.85	61.28
dE/dx & TOF	ϵ_K (%)	98.43	97.41	95.52	92.3
	$purity_K$ (%)	97.89	96.31	93.25	87.33

- Pid via dEdx or dNdx: better than 3% in barrel region for GeV level hadron
- Inner radius of TPC in baseline: 30 cm
- Reducing inner radius is strongly favored in fwd region

Jet Origin Identification



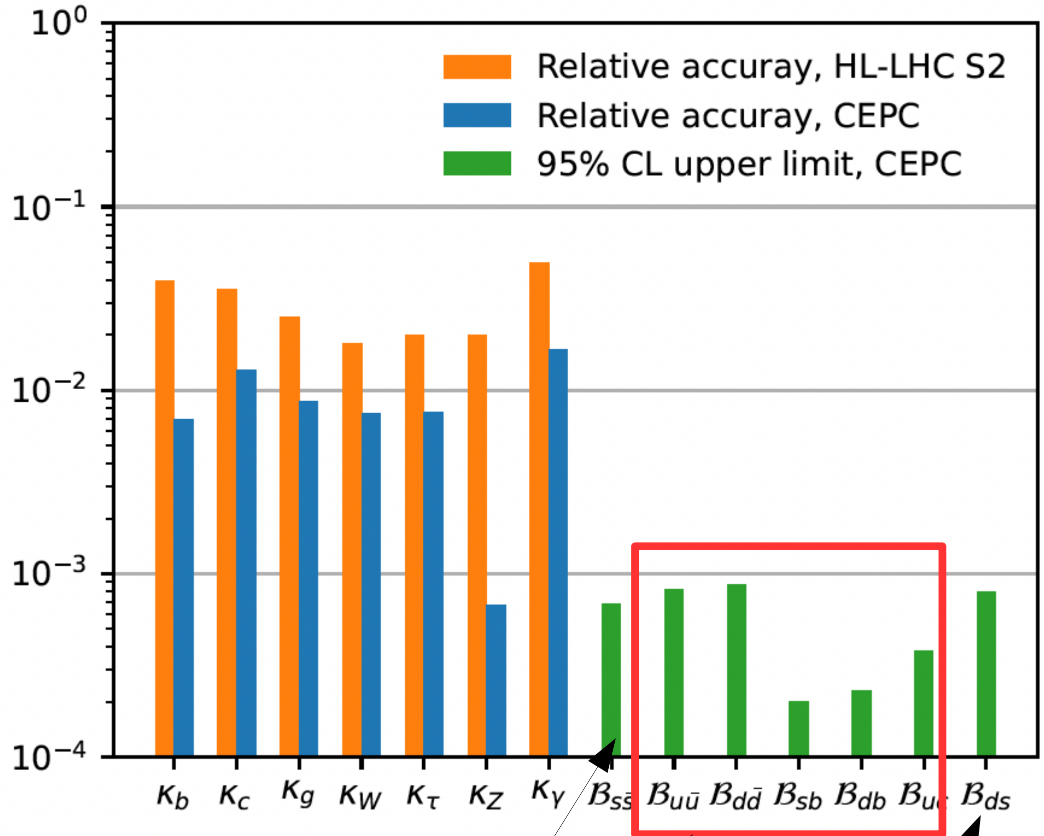


- **Jet origin identification: 11 categories (5 quarks + 5 anti quarks + gluon)**
  - Jet Flavor Tagging + Jet Charge measurements + s-tagging + gluon tagging...
- Full Simulated vvH, Higgs to two jets sample at CEPC baseline configuration: CEPC-v4 detector, reconstructed with **Arbor + ParticleNet (Deep Learning Tech.)**

https://arxiv.org/abs/2310.03440

https://arxiv.org/abs/2309.13231

Benchmark analyses using Jet origin ID



Improved by ~3 times

Improved by 1-2 orders of magnitudes

Presumably... firstly quantified

TABLE I: Summary of background events of $H \to b\bar{b}/c\bar{c}/gg$, Z, and W prior to flavor-based event selection, along with the expected upper limits on Higgs decay branching ratios at 95% CL. Expectations are derived based on the background-only hypothesis.

	Bkg. (10^3)			Upper limit (10^{-3})						
	H	Z	W	$s\bar{s}$	$u\bar{u}$	$d\bar{d}$	sb	db	uc	ds
$\nu\bar{\nu}H$	151	20	2.1	0.81	0.95	0.99	0.26	0.27	0.46	0.93
$\mu^+\mu^-H$	50	25	0	2.6	3.0	3.2	0.5	0.6	1.0	3.0
e^+e^-H	26	16	0	4.1	4.6	4.8	0.7	0.9	1.6	4.3
Comb.	-	-	-	0.75	0.91	0.95	0.22	0.23	0.39	0.86

[28] J. Duarte-Campderros, G. Perez, M. Schlaffer, and A. Soffer. Probing the Higgs–strange-quark coupling at e^+e^- colliders using light-jet flavor tagging. *Phys. Rev. D*, 101(11):115005, 2020.

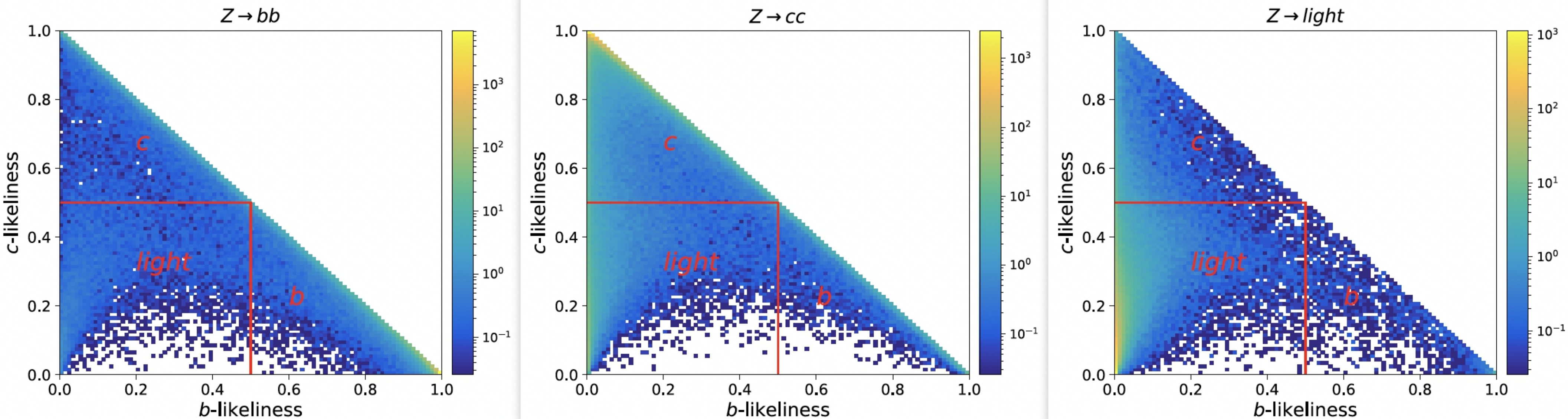
[50] Alexander Albert et al. Strange quark as a probe for new physics in the Higgs sector. In *Snowmass 2021*, 3 2022.

[59] J. de Blas et al. Higgs Boson Studies at Future Particle Colliders. *JHEP*, 01:139, 2020.

[60] Jorge De Blas, Gauthier Durieux, Christophe Grojean, Jiayin Gu, and Ayan Paul. On the future of Higgs, electroweak and diboson measurements at lepton colliders. *JHEP*, 12:117, 2019.

For H->bb, cc, gg: results in 20 – 40% improvement in relative accuracies (preliminary)...

Three categories: b, c, & light



Hadronic Z pole sample

1 M Z→bb, cc, (uds) each

60/20/20% for training/validating/testing.

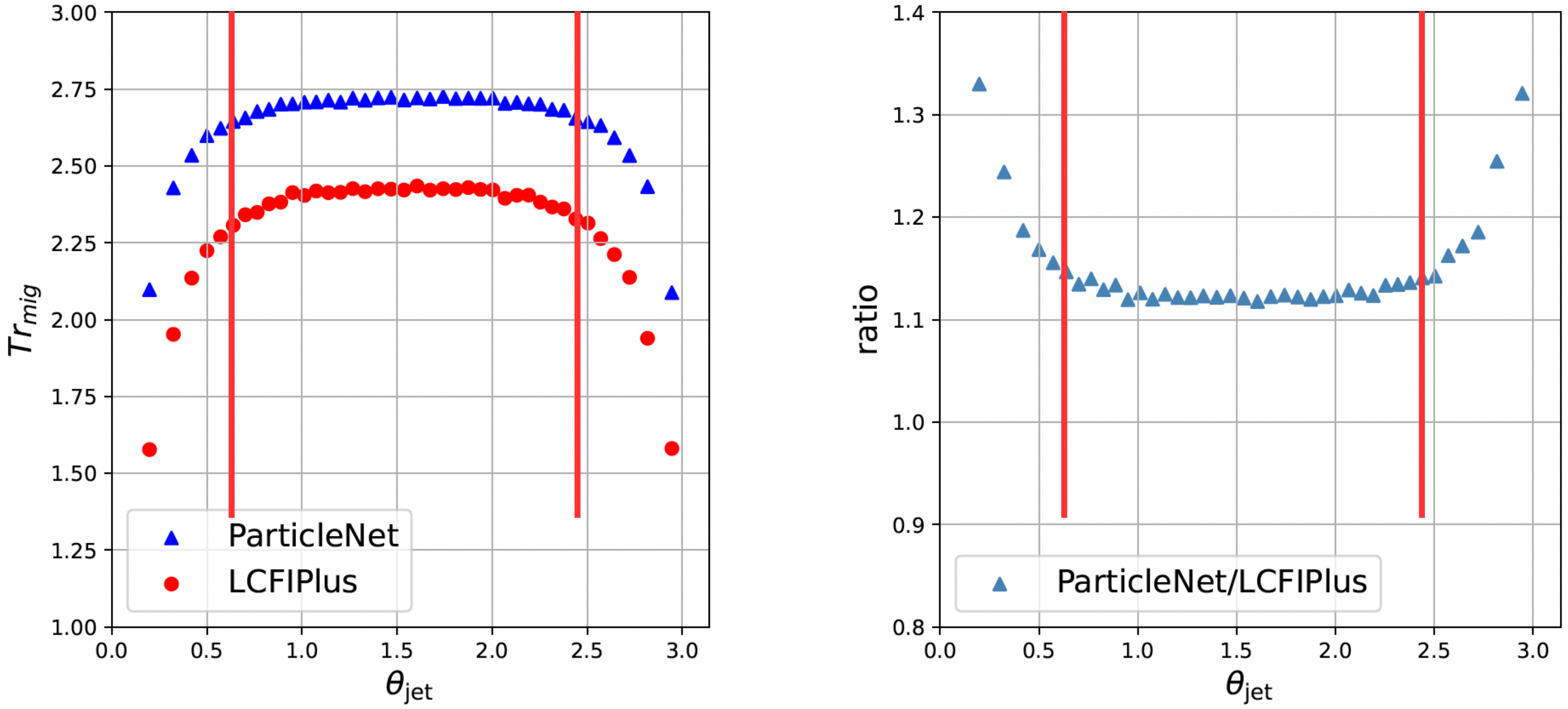
Result on Testing sample

truth \ predicted	b	c	uds
b	0.911	0.059	0.031
c	0.039	0.784	0.177
uds	0.005	0.051	0.944

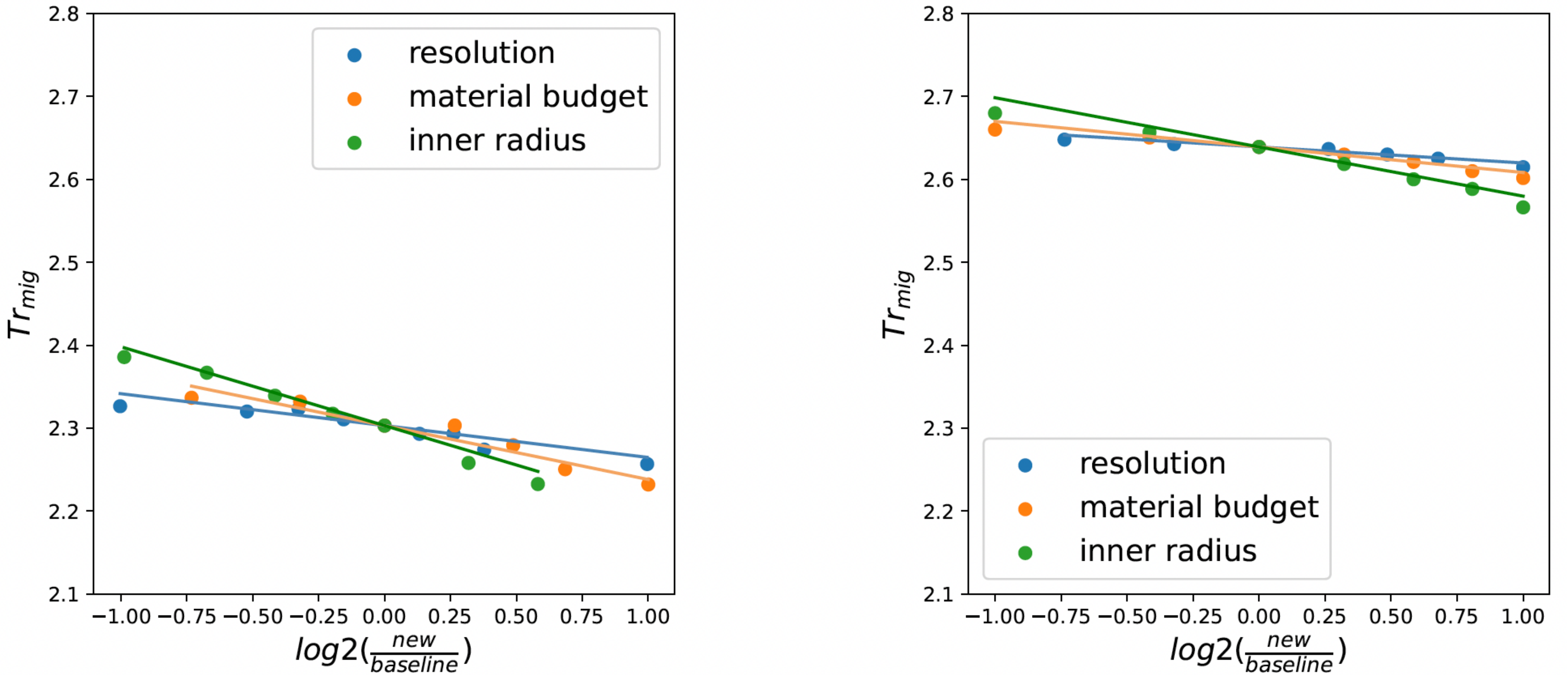
truth \ predicted	b	c	uds
b	0.789	0.126	0.085
c	0.084	0.582	0.334
uds	0.008	0.06	0.933

Figure 7. The migration matrix of ParticleNet (left) and LCFIPlus (right) at the CEPC.

Dependence on polar angle



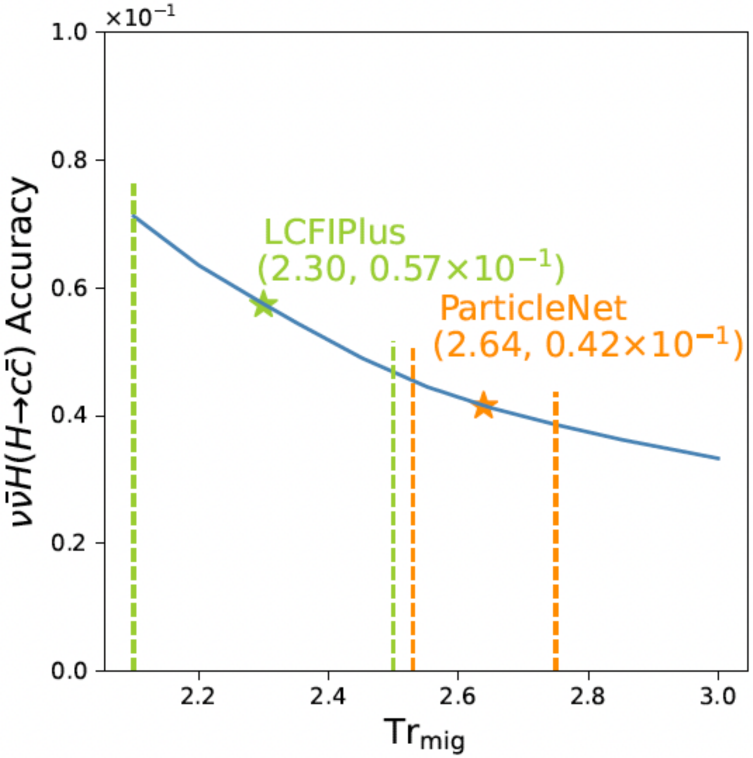
Comparison on Det. Optimization

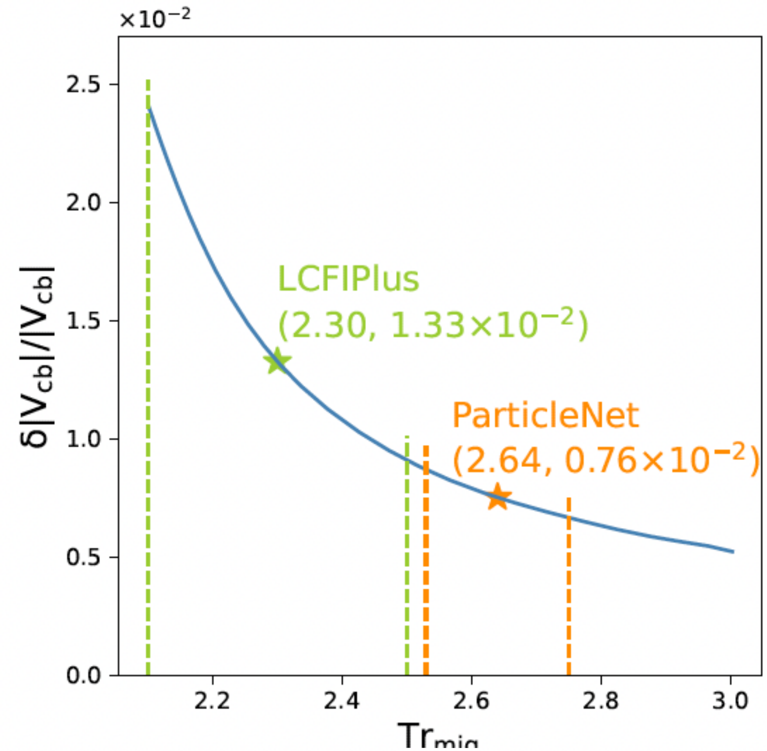


$$Tr_{mig} = 2.30 + 0.06 \cdot log_2 \frac{R^0_{material}}{R_{material}} + 0.04 \cdot log_2 \frac{R^0_{resolution}}{R_{resolution}} + 0.10 \cdot log_2 \frac{R^0_{radius}}{R_{radius}} \quad (4.1)$$

$$Tr_{mig} = 2.64 + 0.03 \cdot log_2 \frac{R^0_{material}}{R_{material}} + 0.02 \cdot log_2 \frac{R^0_{resolution}}{R_{resolution}} + 0.06 \cdot log_2 \frac{R^0_{radius}}{R_{radius}} \quad (4.2)$$

Impact on physics benchmarks





Conservative/Aggressive:

all three parameters 2/0.5*Baseline

		conservative	baseline	optimal
$\nu\nu Hc\bar{c}$	LCFIPlus	0.071	0.057	0.047
	ParticleNet	0.045	0.042	0.038
	$\frac{\text{LCFIPlus}}{\text{ParticleNet}}$	1.58	1.38	1.26
$\lvert V_{cb}\rvert$	LCFIPlus	0.0241	0.0133	0.0091
	ParticleNet	0.0086	0.0076	0.0067
	$\frac{\text{LCFIPlus}}{\text{ParticleNet}}$	2.80	1.75	1.36

Summary

- CHLOE:
  - Anticipated BMR ~ 3 + excellent jet origin-id
  - Glass ECAL: promising & much cheaper (cost – save to 0.7 B CNY)

- Requirements:
  - Excellent pattern reco. especially separation of final state particle + great intrinsic resolution of Cluster energy
  - Multiple Para. to be optimized
    - Material Budget
    - E/HCAL Cell Size, # Layer, Materials
    - Z->tautau study has tension with 1*1 cm^2 cells

Critical question & Studies

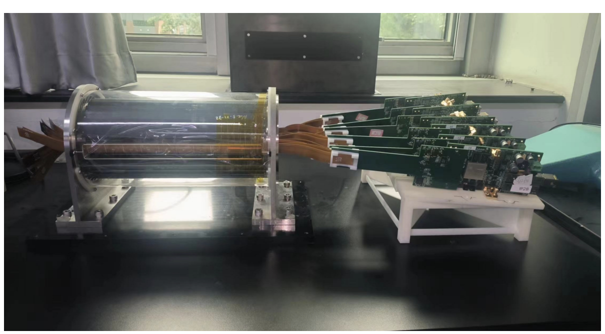
- MDI & Beam background
  - Determines the Geometric Configuration (inner R, Z) of Gaseous tracker & Silicon vertex/inner tracker: which shall have the smallest inner radius & large acceptance

- Calo. Positioning & Timing layer design: granularity, power, material, cooling & integration

- Glass Feasibility at ECAL, etc:
  - **Density, Light Yield, Homogeneity, Transparency..**
  - Light Accumulation dependence: SiPM coupling, Size, Positioning Dependence (signifiant at large cell: center/corner Light Yields can be different by > 3 times at 4*4*1 cm cell!)
  - SiPM properties,
    - Noise level,
    - #Pixel, Saturation & correction
    - Dependence to external conditions (Temp. pressure, B-Field)
  - **Need a platform to perform intensive & standardized tests + Simulation studies**

Proposition

- Algo. developments
  - Event Building in Space Time (intrinsic time/space resolution of sub-D)
  - Advanced 5D PFA: multi-stage PFA using time/energy info. + Shower Energy Estimation
  - Jet origin id & iteration with MDI – Det esp. VTX design
- Joint work hardware, software & algorithms: Discussion at Monday + Software training today...
- Construct ECAL Prototype using Glas
- Joint test of multi sub-D prototypes: Scintillator Tiles + Silicon Vertex
  - Key performance: Light Yield (efficiency) as a function of Position/angle.
  - To explore the best local design & To quantify the requirements (SiPM/DAQ coupling, transparency, density, refractivity, coating...)
  - Is it possible to have a dedicated Test Site at BEPC Synchrotron Lines?



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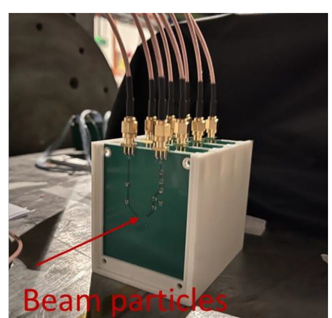

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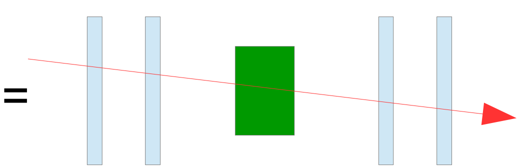
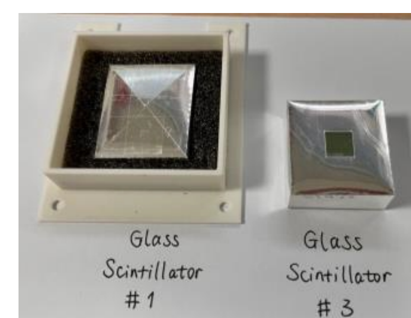




Backup

Glass ECAL: is it an option?

Glass Light Yield: 1/6 of the BGO; density ~ BGO

Simulation setup: 1×1×4 cm3 glass bar with ESR reflector

•40×40×40 cm3 supercell, 10 layers of glass bars for ~24X0

•1~40 GeV electron for EM resolution study

Digitization setup

•Photon statistics, SiPM gain uncertainty, ADC uncertainty,…

Key parameters

•Light yields: number of detected photons per MIP (~7.126 MeV in 1 cm glass)

•Threshold: energy cut per cell

Energy resolution: stochastic term < 3%

•Moderately high light yield → dynamic range

•Low energy threshold → noise level

Avalanche @ gaseous detector

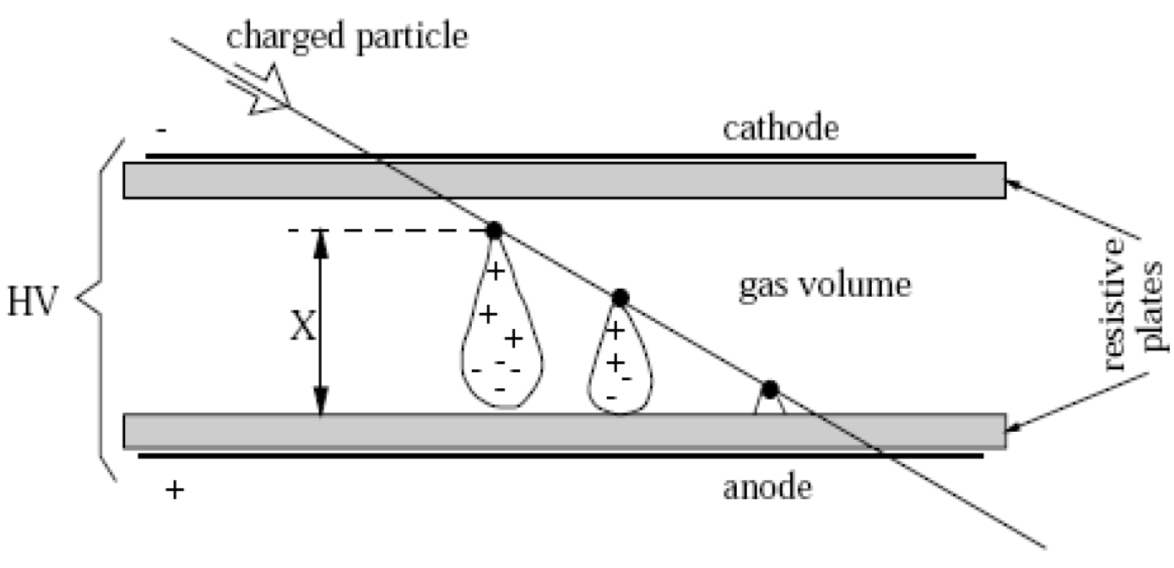
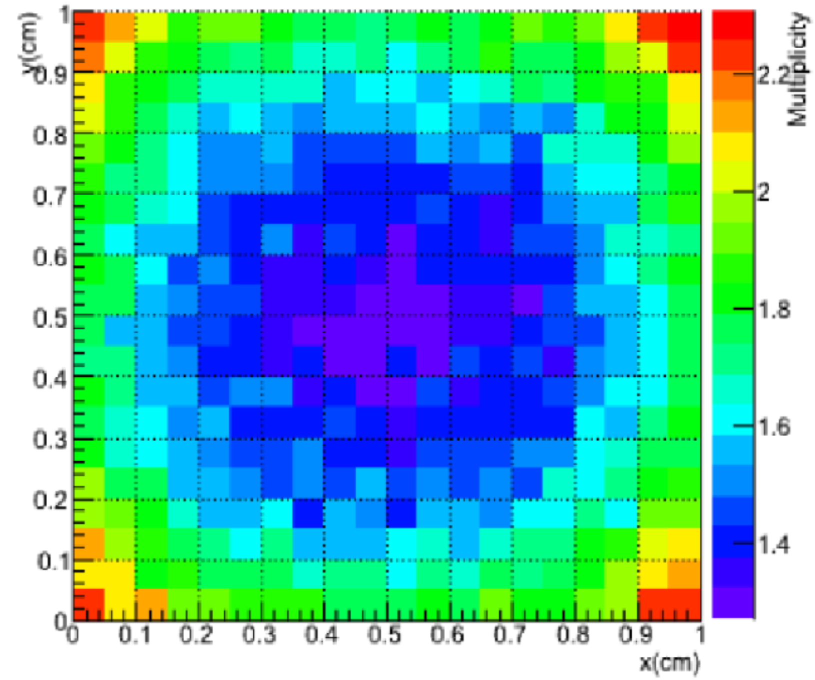
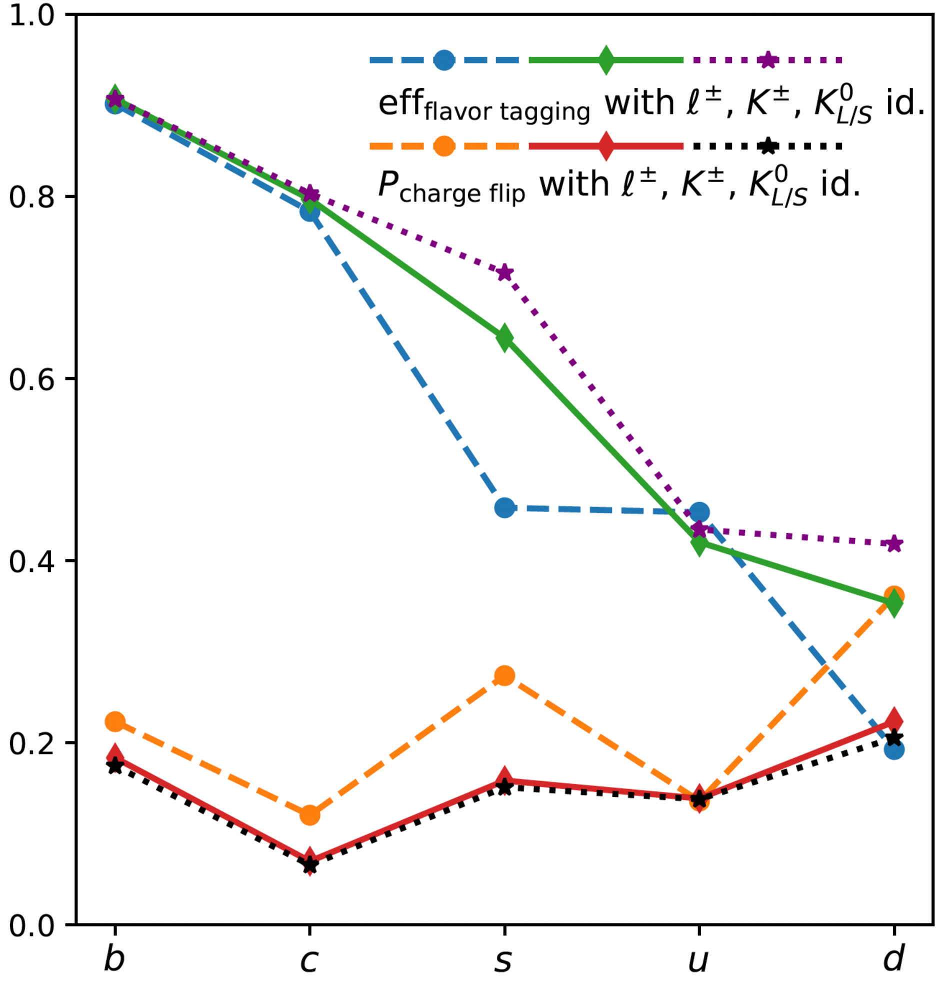


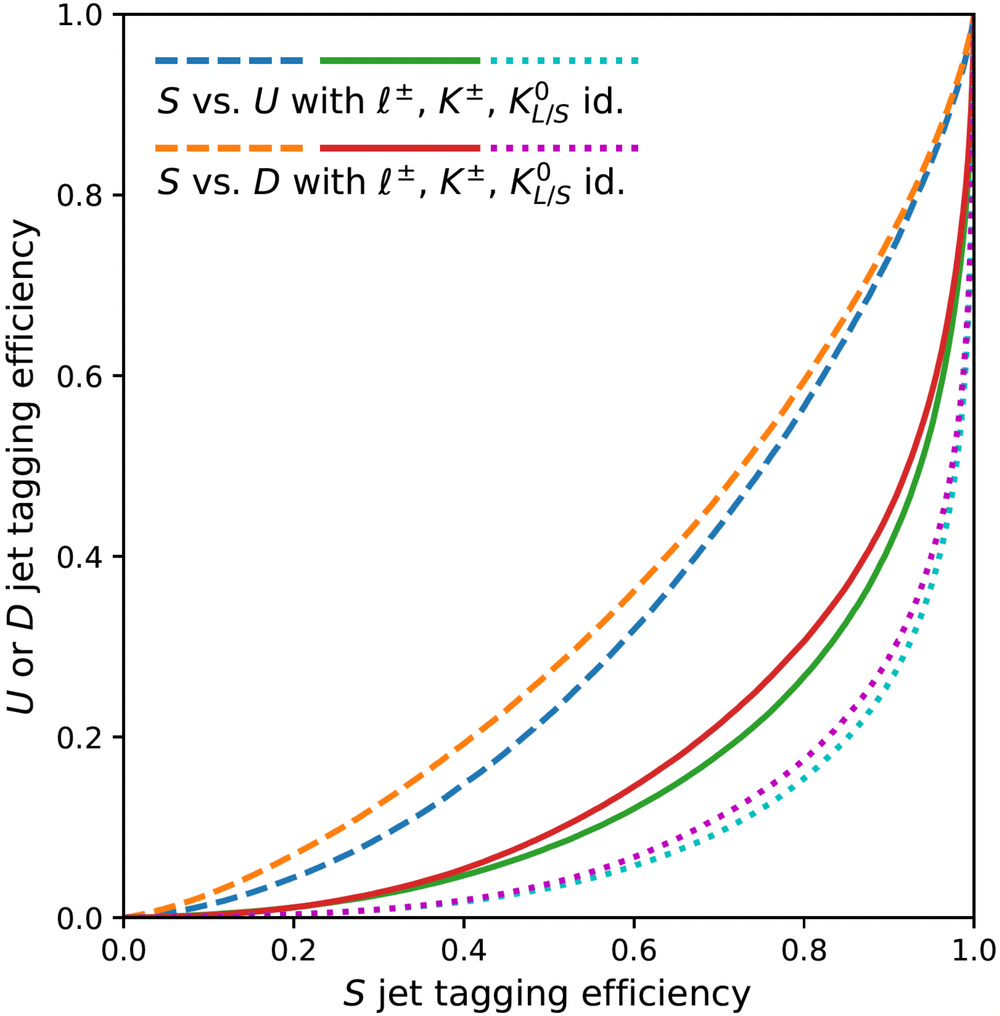
Fig. 1. Sketch of RPC gap.



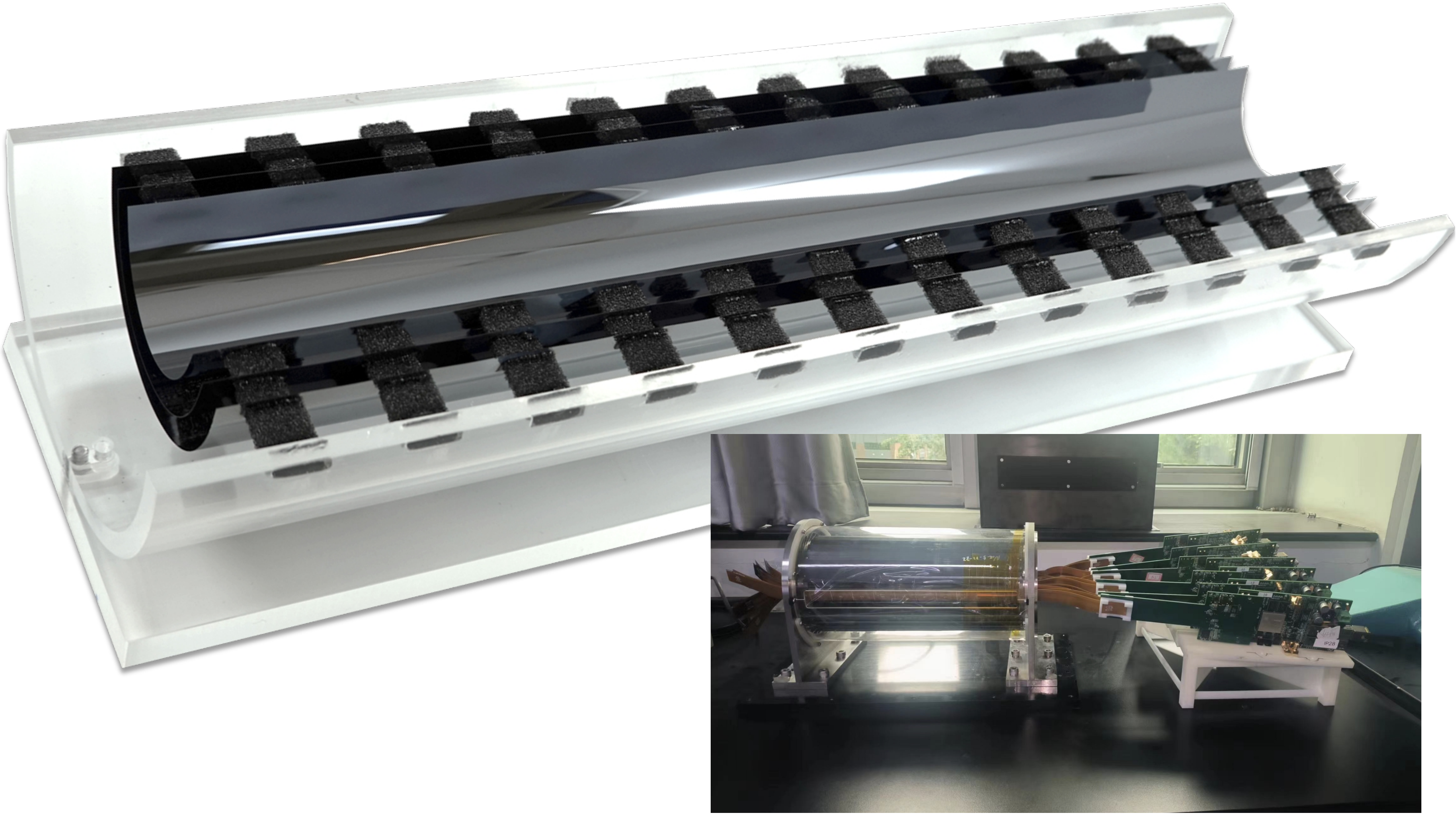
- Once one charged particle sailing though the RPC:
  - Efficiency: chance to create a hit (~ Induced charge > Threshold)
  - Multiplicity: number of hits in one lighted layer ~ number of cells with Induced charge > Threshold
    - Typical value ~ 1.4 – 1.8 at GRPC, ~ 1.1 at MicroMegas
    - Charge Image scale ~ 1mm (depending on resistive plates thickness)

Performance with different PID scenarios

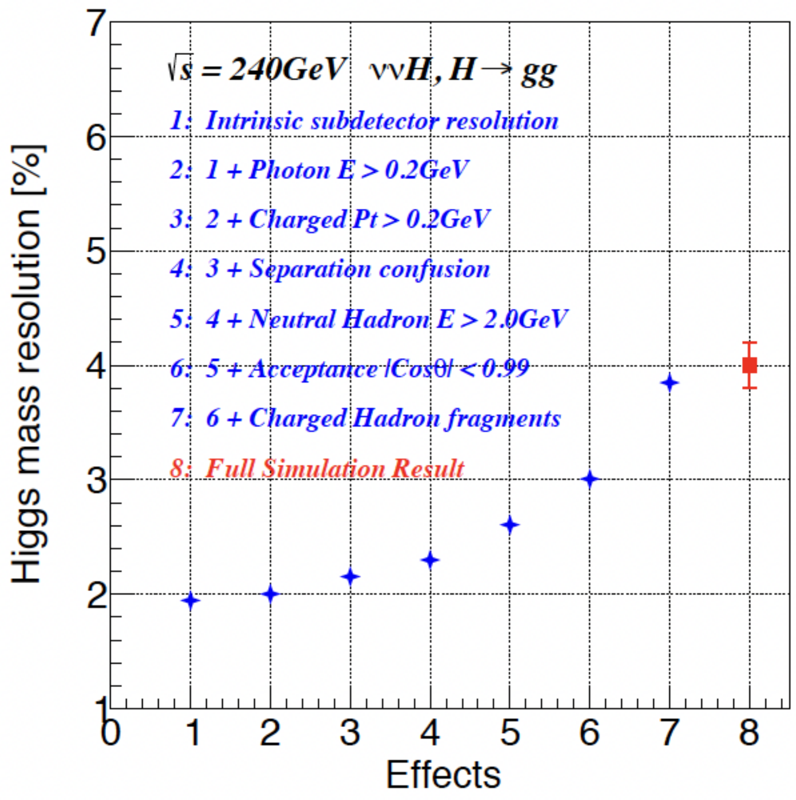


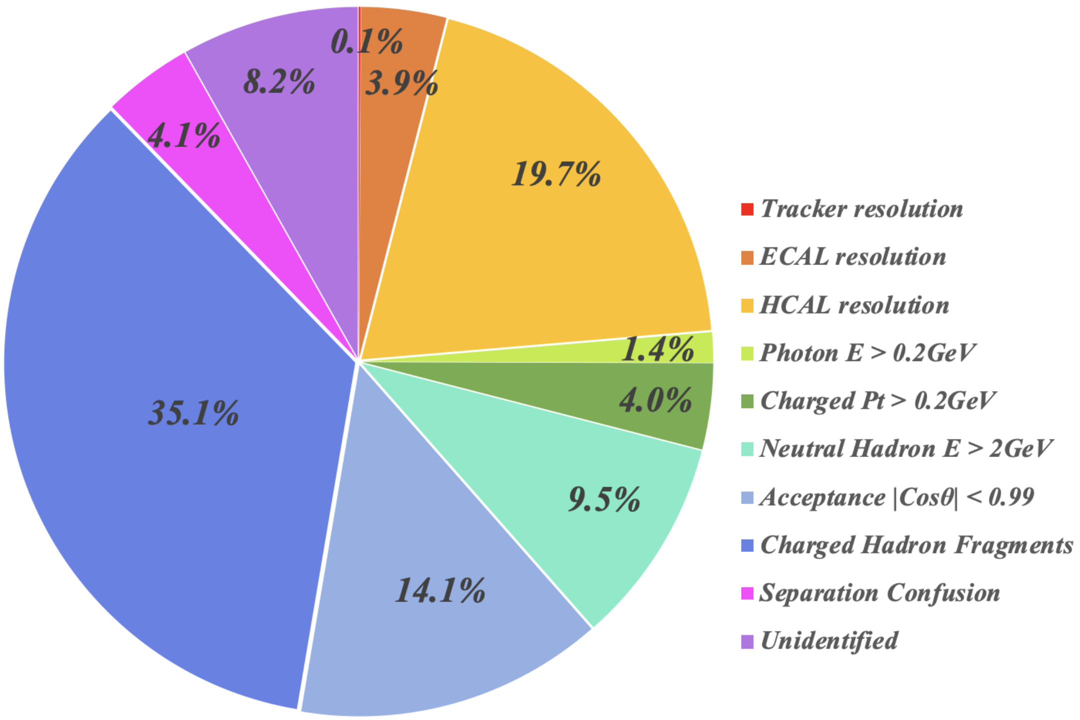


...ALICE ITS3...

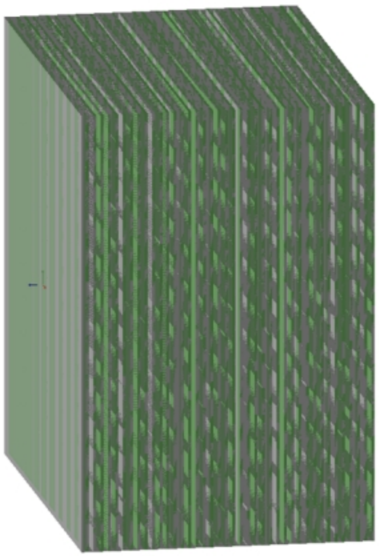


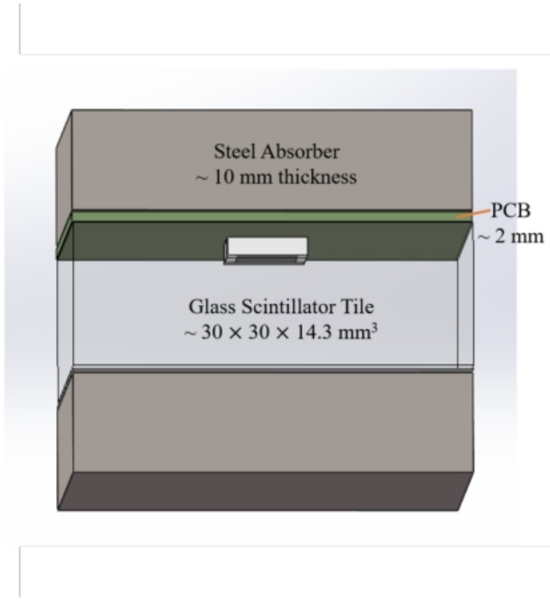
BMR: decomposition

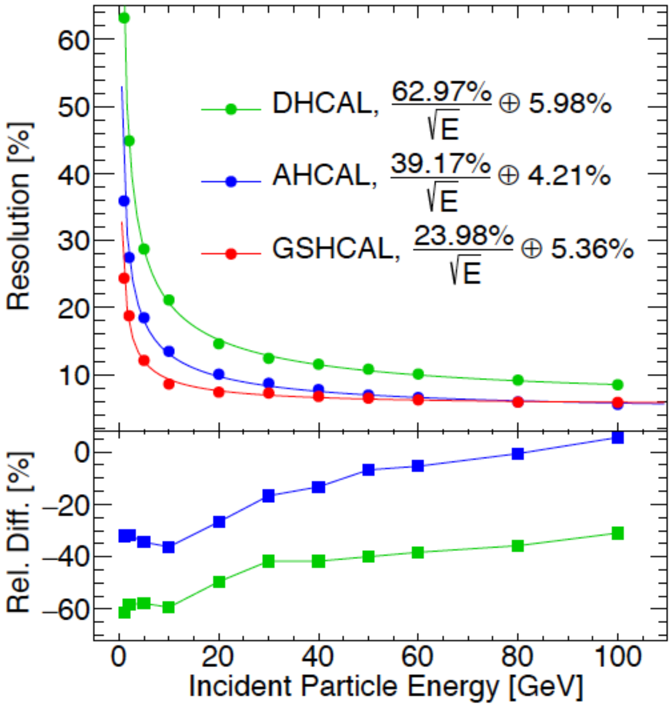




GSHCAL



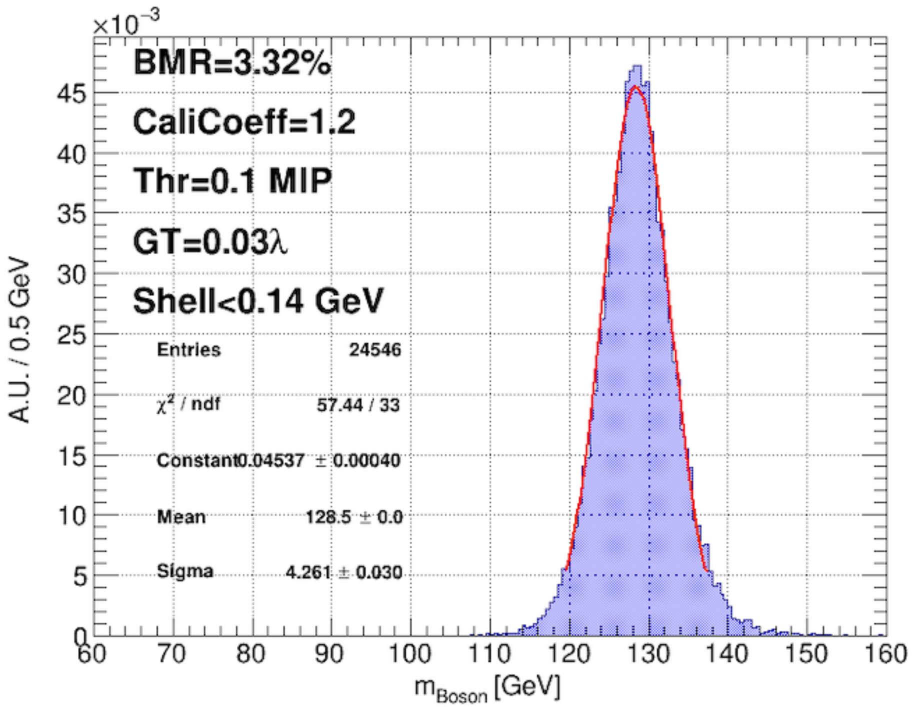


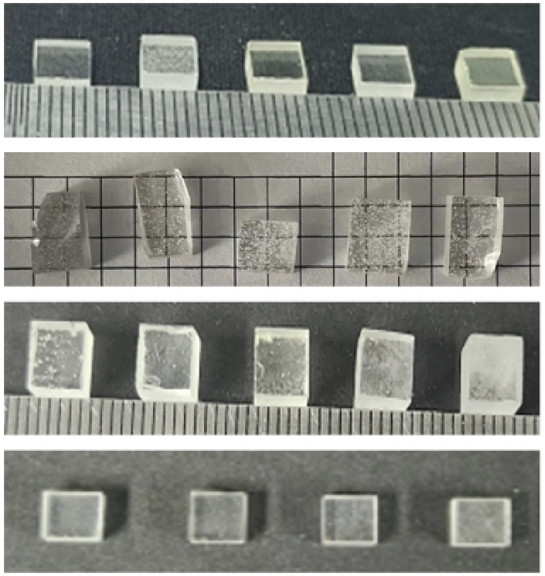


- Substantial improvement at Hadronic Energy resolution with relevant energy...

BMR wi GSHCAL

P. Hu & YX. Wang





2021.11
Density ~4.5 g/cm³

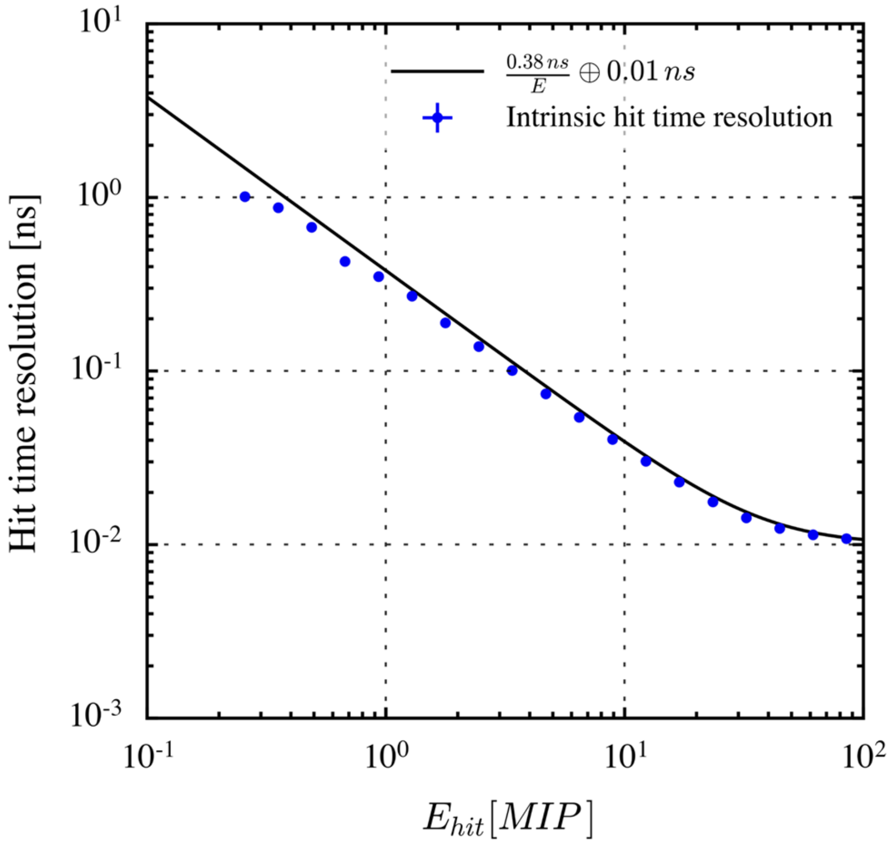
2021.11
Density ~4.0 g/cm³

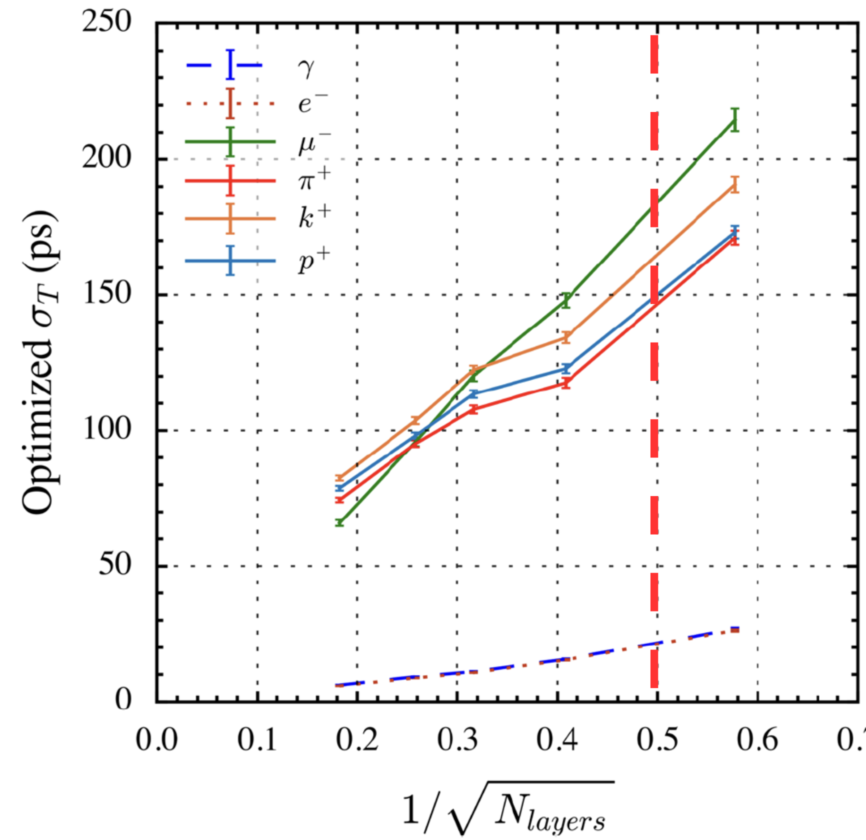
2022.06
Density ~6.0 g/cm³

2023.02
Density ~6.0 g/cm³

- Baseline + replace DHCAL to GSHCAL + Simple para. optimization
- ~ o(10)% improvement w.r.t. DHCAL

Timing





4 CMS HGC layers: time resolution for 10-15 GeV particles:

- 150-160 ps for hadron shower
- 20 ps for EM shower

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THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Experimental Physics

Cluster time measurement with CEPC calorimeter

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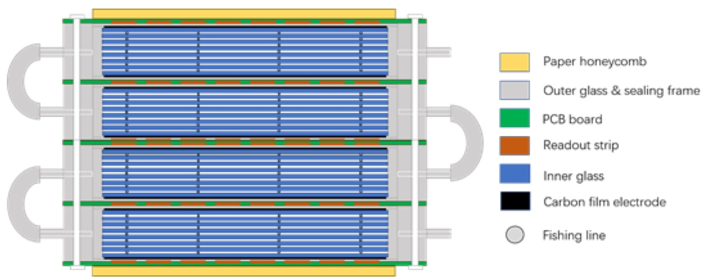
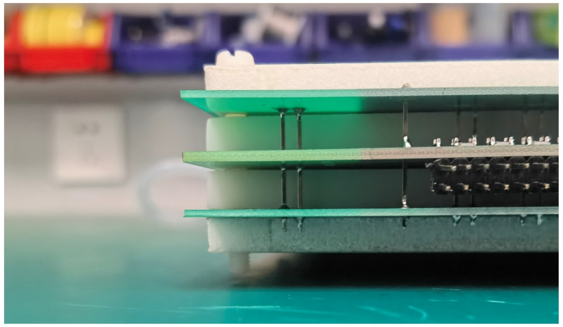
Precision Cluster timing is critical to dealing with in time leakage & Off time pileup effects

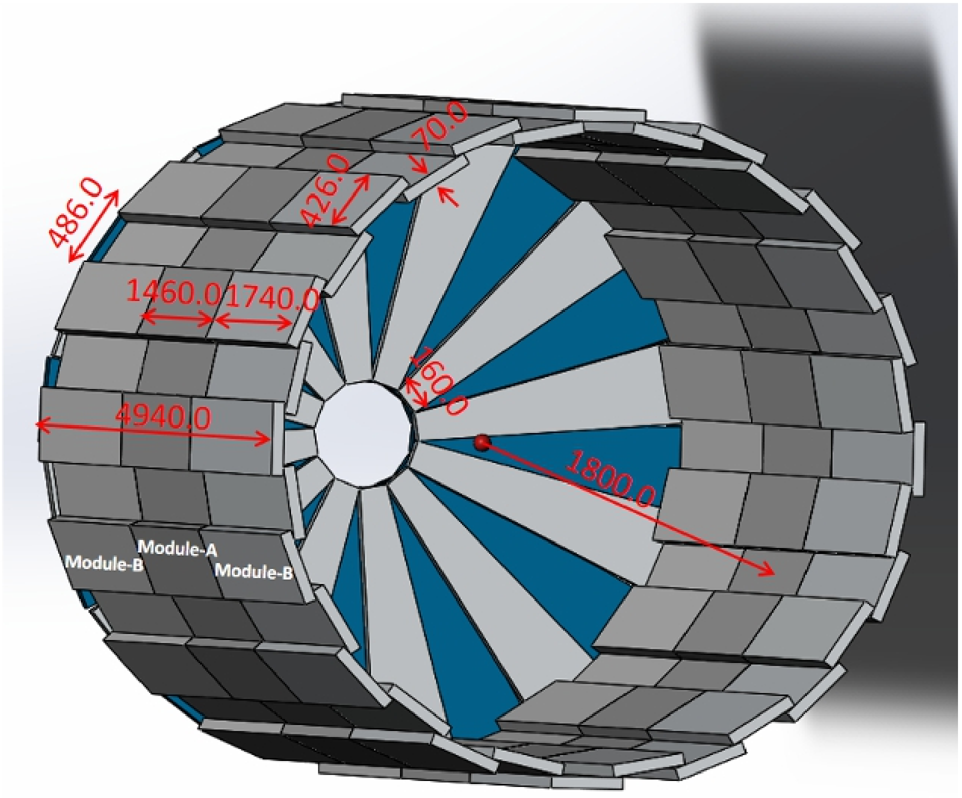
Alternative choice of positioning layer



(a) Structure of sealed MRPC.



(b) Sealed MRPC in kind.

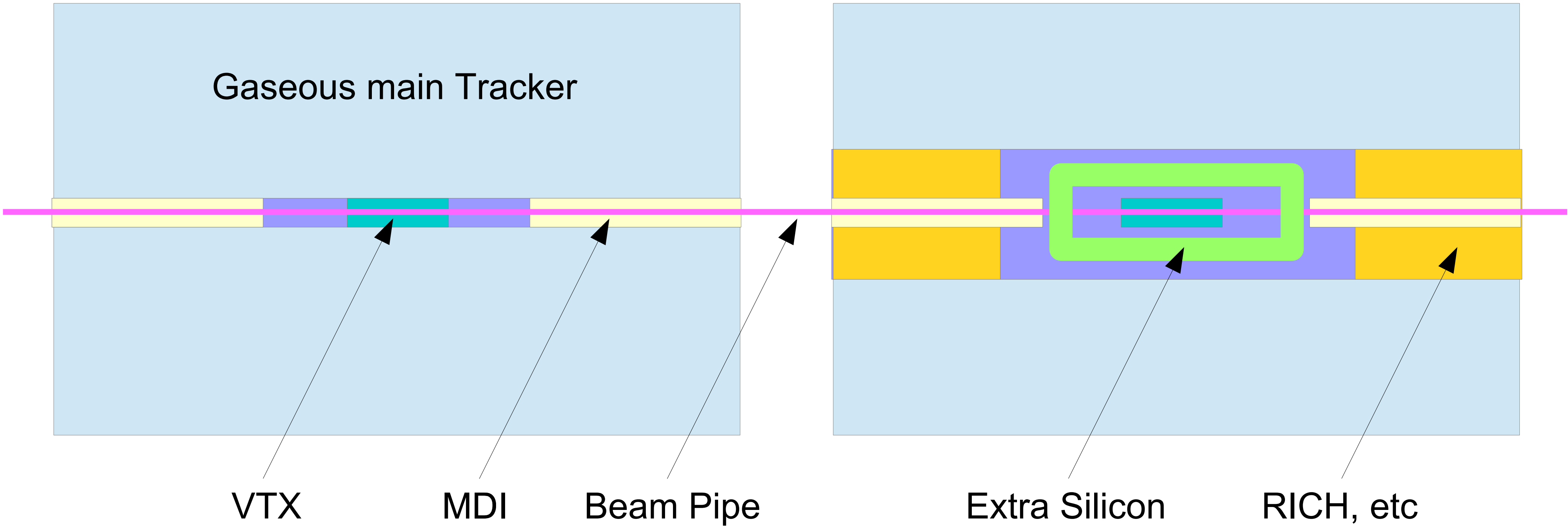


- MRPC: 35 M CNY for 1 layer, with 35 ps time resolution & area ~ 80 m^2
- Geo. & Readout need to be optimized, to integrate with ECAL.

Tracker & Vertex

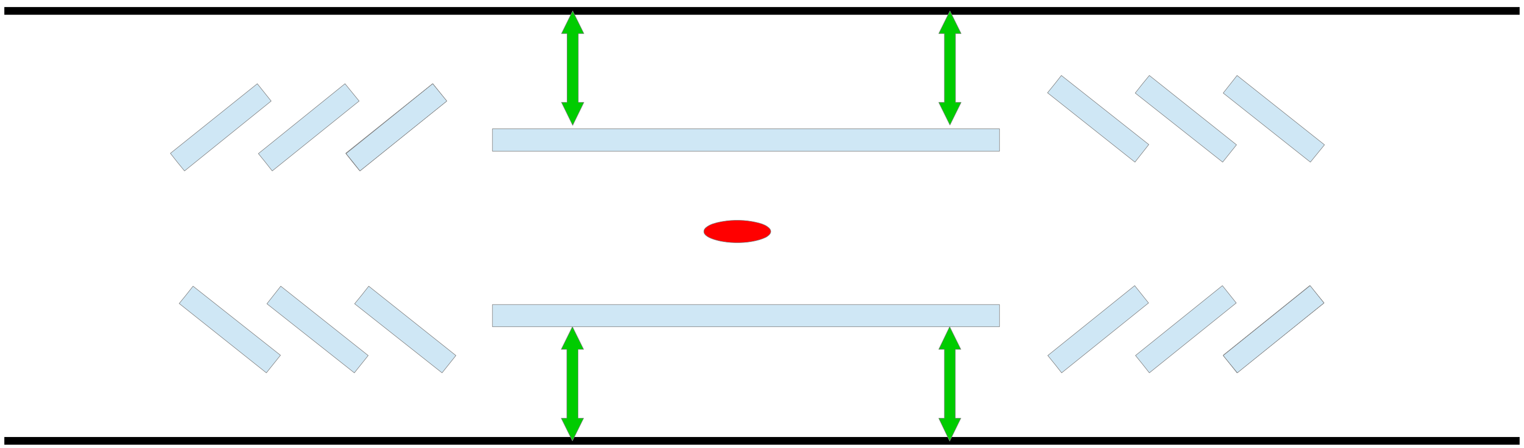
- Performance always requires:
  - Smaller R_{in} : limited by Beam background/Beamstrahlung & MDI
    - Large acceptance
    - VTX: ~ better 2nd Vertex & Flavor tagging
    - Tracker: better differential Pid (especially fwd), lower Pt threshold
  - Large R_{out} : limited by cost
    - Better momentum resolution,
    - Better Pid,
    - Better separation, better BMR

2.5 Tracker Scenarios

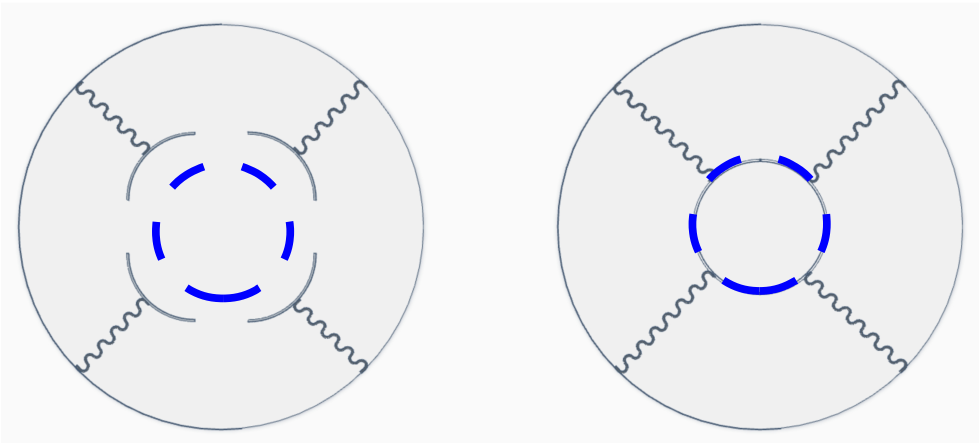


- Our understanding to Beam background & MDI design not fully converged
  - Beamstrahlung background seems to be very challenge to gaseous tracker
- I will discuss mainly the 1st scenario (Left)：
  - Tracker inner radius of 25 cm to have good Pid in fwd region
- The 2.5 scenario: Silicon Tracker with Pid (like AMS, with much better precision...): *impossible??*

Vin portable



- Challenge, but attractive
  - Pursue minimal inner radius
  - Tuning with feedback to beam background monitoring (BPM, Lumi-CAL, etc)
  - No multiple scattering from beam pipe, critical for pp collider experiments
  - Very challenge for the mechanics & HOM...

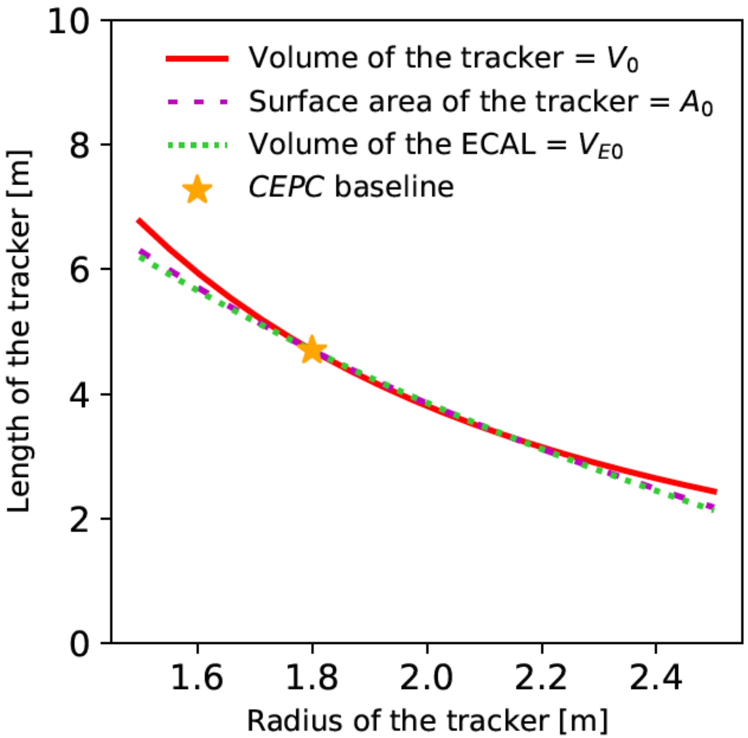


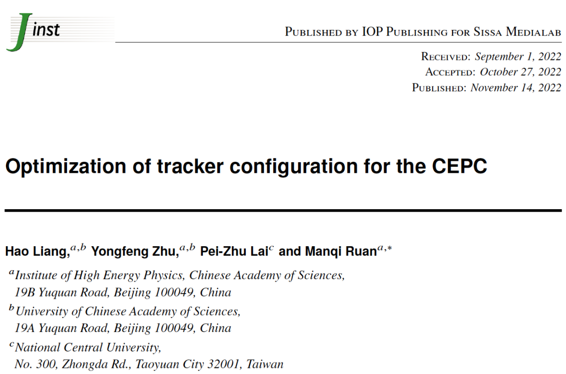
Global Geometry

- Tracker: R&Z

- Calorimeter:
  - ECAL: Polygon sides?
  - Mechanic: Patel or Vortex?

Tracker: R/Z ratio

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Optimization of tracker configuration for the CEPC

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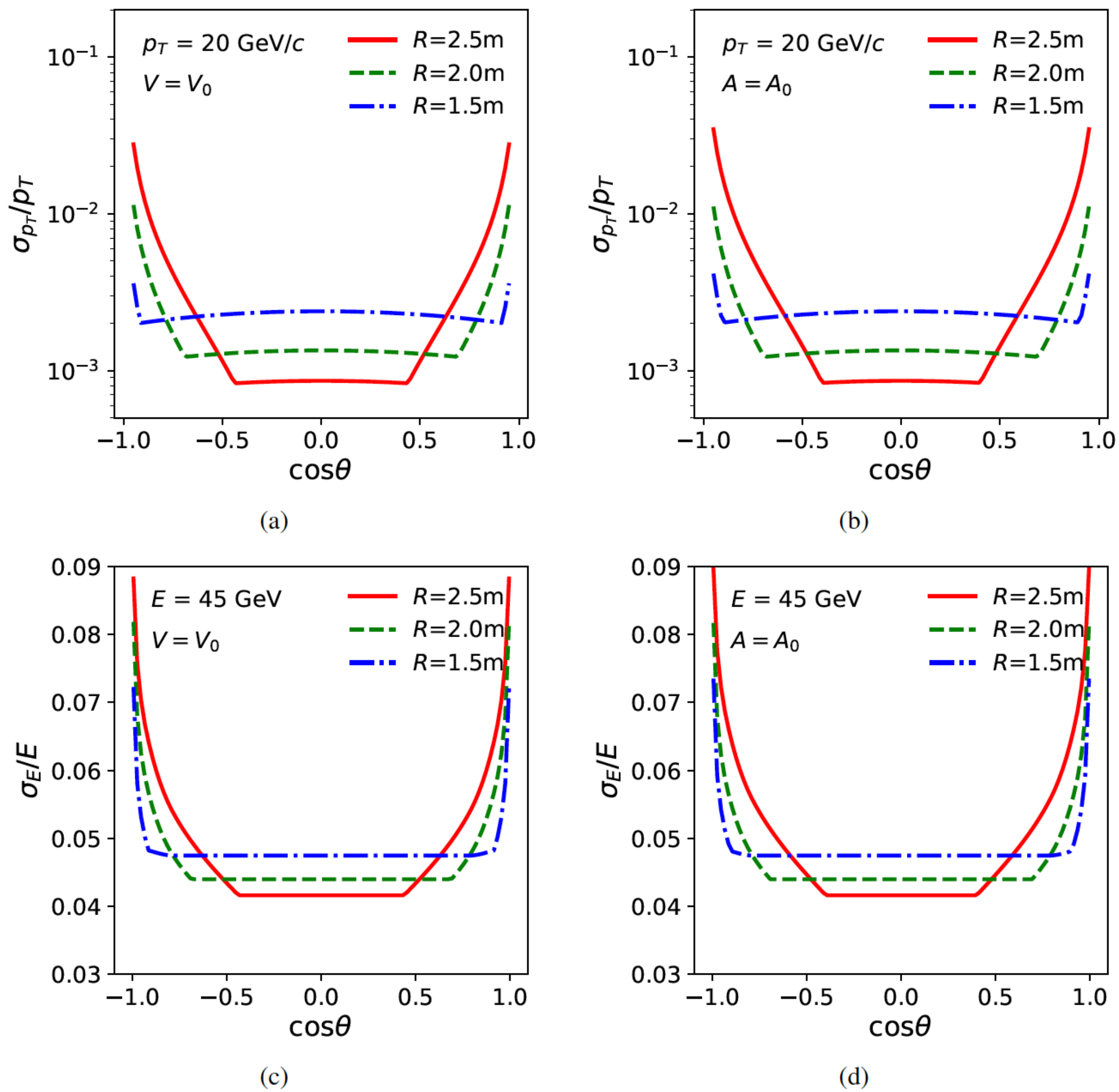
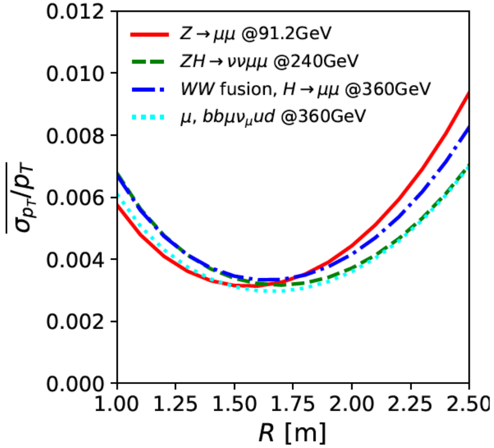
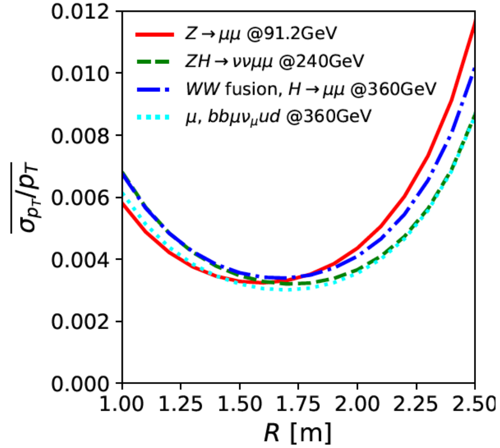


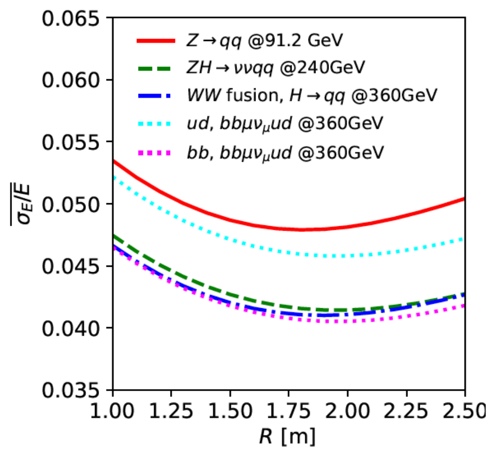
Tracker: R/Z ratio



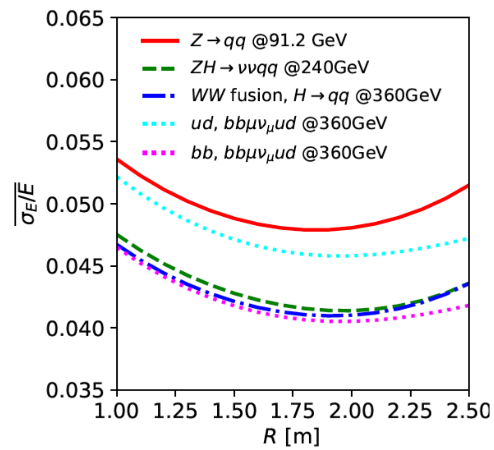
(a)



(b)



(c)



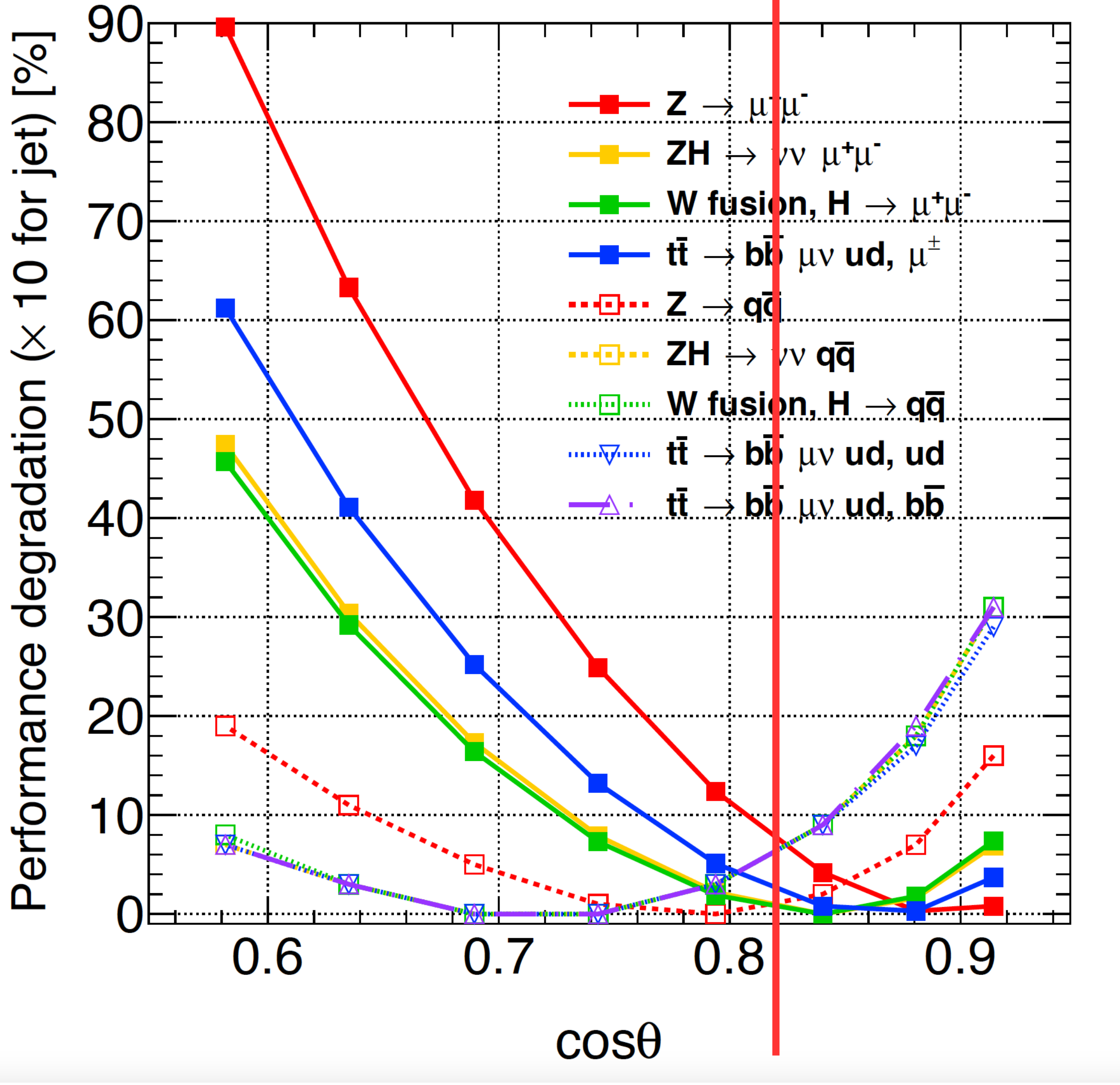
(d)

Table 3. The performance degradations for different tracker radii compared to the optimal resolution of each benchmark channel. The box shows the minimum number of each row.

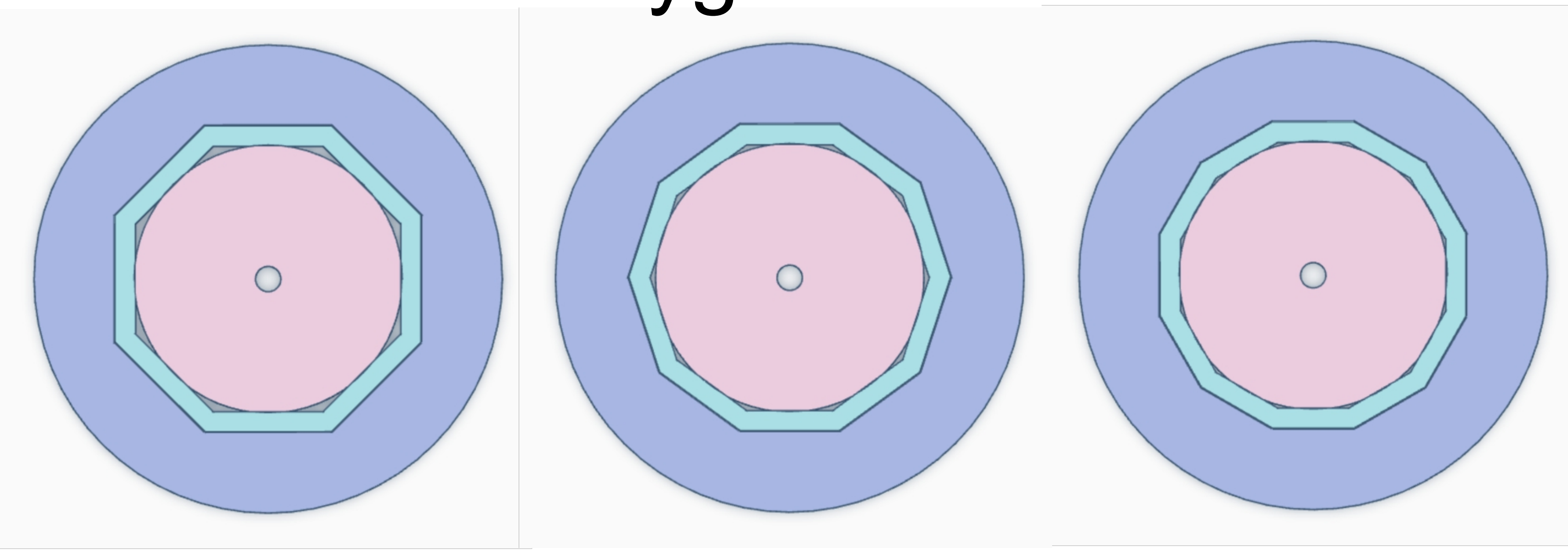
Benchmark	Cost estimator	Degradations (%) vs. radii (m)							
		1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2
$Z \to \mu^-\mu^+$	volume	0.8	**0.3**	4.2	12.4	24.9	41.8	63.3	89.6
$\sqrt{s} = 91.2$ GeV	surface area	1.4	**0.0**	2.3	8.5	19.0	34.6	56.3	86.1
$Z \to q\bar{q}$	volume	1.6	0.7	0.2	**0.0**	0.1	0.5	1.1	1.9
$\sqrt{s} = 91.2$ GeV	surface area	2.0	1.0	0.4	**0.0**	0.0	0.4	1.1	2.1
$ZH \to \nu\nu\mu^-\mu^+$	volume	6.9	1.6	**0.0**	2.2	7.9	17.3	30.4	47.4
$\sqrt{s} = 240$ GeV	surface area	8.5	2.5	**0.1**	1.1	5.7	14.4	28.0	47.9
$ZH \to \nu\nu q\bar{q}$	volume	3.1	1.8	0.9	0.3	0.0	**0.0**	0.3	0.7
$\sqrt{s} = 240$ GeV	surface area	3.4	2.1	1.1	0.4	0.1	**0.0**	0.3	1.0
W fusion, $H \to \mu^-\mu^+$	volume	7.4	1.8	**0.0**	1.9	7.3	16.4	29.2	45.7
$\sqrt{s} = 360$ GeV	surface area	9.0	2.9	**0.1**	0.9	5.2	13.6	27.0	46.4
W fusion, $H \to q\bar{q}$	volume	3.1	1.8	0.9	0.3	**0.0**	0.0	0.3	0.8
$\sqrt{s} = 360$ GeV	surface area	3.4	2.1	1.1	0.4	0.1	**0.0**	0.3	1.0
$\mu^\pm$, $b\bar{b}\mu\nu_\mu ud$	volume	3.7	**0.3**	0.8	5.1	13.2	25.2	41.1	61.2
$\sqrt{s} = 360$ GeV	surface area	5.0	0.8	**0.2**	3.1	9.8	20.9	37.3	60.5
ud, $b\bar{b}\mu\nu_\mu ud$	volume	2.9	1.7	0.9	0.3	0.0	**0.0**	0.3	0.7
$\sqrt{s} = 360$ GeV	surface area	3.2	2.0	1.1	0.4	0.1	**0.0**	0.3	0.9
$b\bar{b}$, $b\bar{b}\mu\nu_\mu ud$	volume	3.1	1.9	0.9	0.3	0.0	**0.0**	0.3	0.7
$\sqrt{s} = 360$ GeV	surface area	3.4	2.1	1.1	0.4	0.1	**0.0**	0.3	1.0

Track Jet

R/Z: 1.75/5 meter

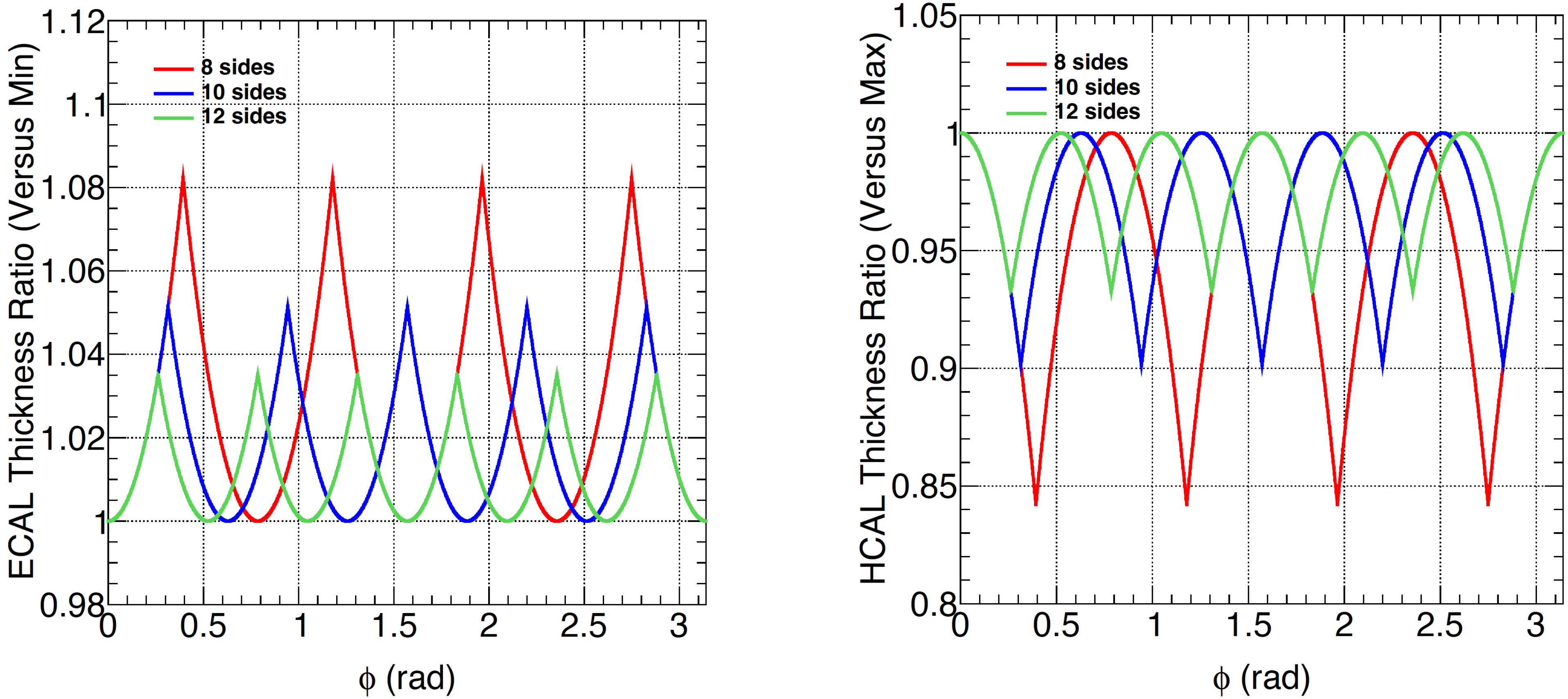


Polygon sides



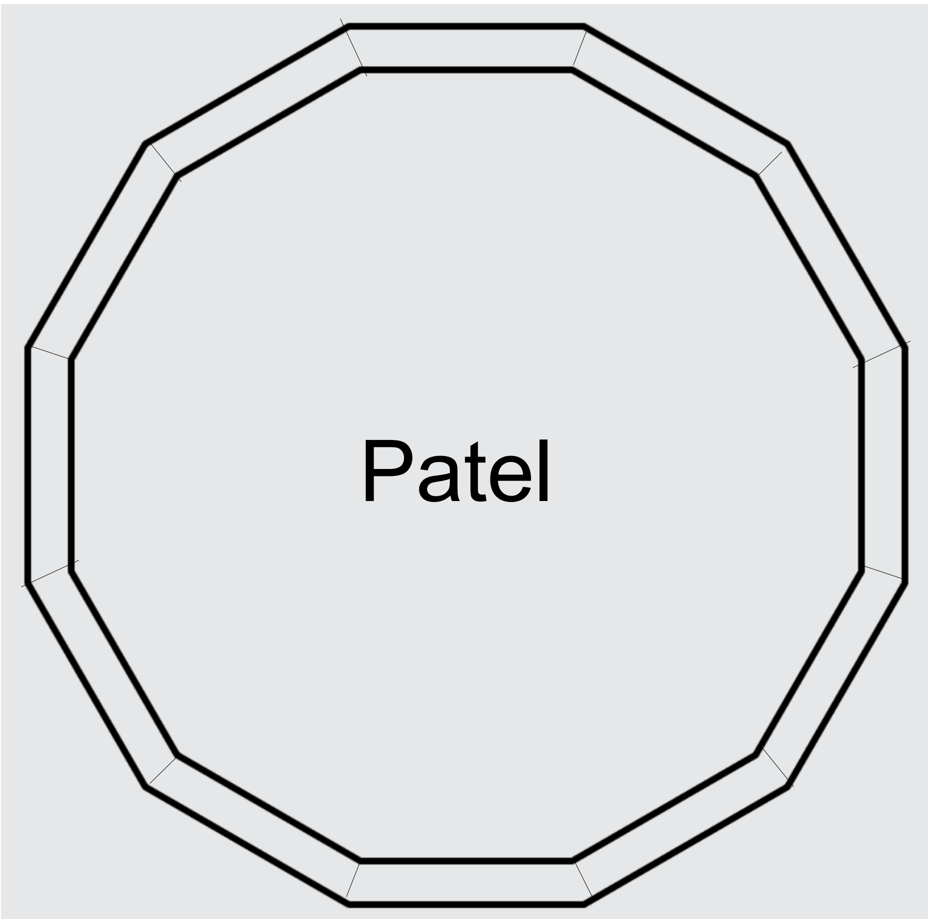
ECAL		HCAL (45 layers)					
Polygon	V (m³)	Sampling Fraction	Thickness Endcap (mm)	Thickness Barrel (mm)	Glass thickness ratio	Total V (m³)	Glass V (m³)
8	31.8911	1:1	1161	1200	0.604651	206.709	124.987
10	31.2703					208.62	126.142
12	30.9449					209.622	126.748
8	31.8911	1:6	987.498	1000	0.203314	160.99	32.7315
10	31.2703					162.901	33.1201
12	30.9449					163.903	33.3237

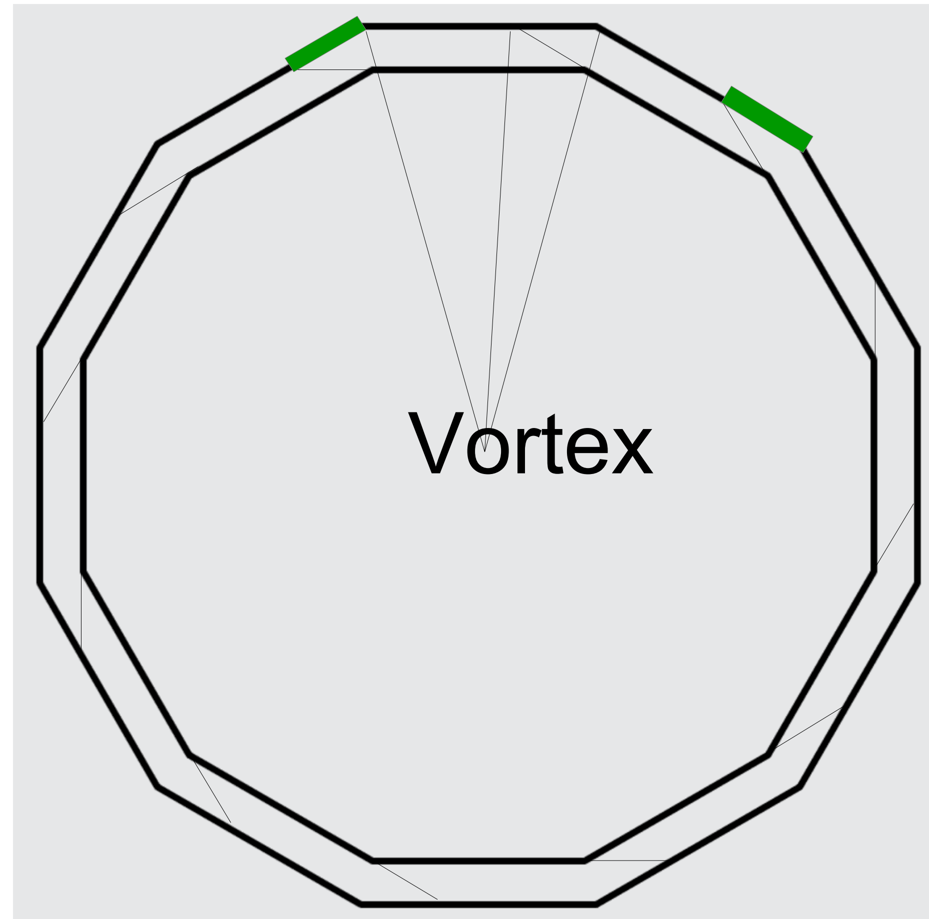
...Inhomogeneity in Φ...



Material budget variation smaller than 10% → Polygon sides >= 10

Polygon mechanic



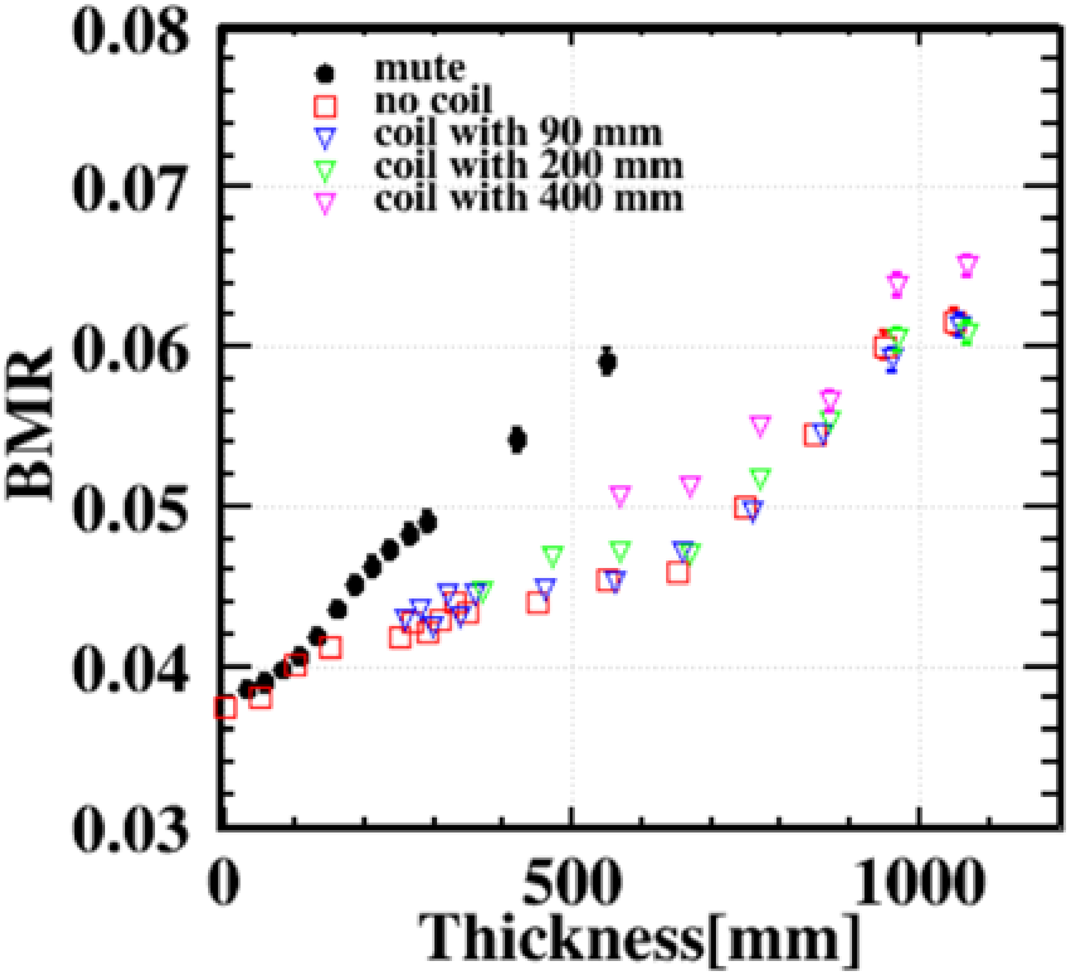


Vortex: Pro: Dead zone not aligned with IP;
Self-supporting structure;
Easier Access to PCB/electronics from external;
Con: Large fraction of overlapping region: need dedicated correction
Need to cut Xstal to fit the obtuse shape.

Summary

- We propose CHLOE, using
  - GSHCAL
  - Xbar ECAL + Position/timing layer of
    - **Silicon**
    - MGPRC
  - 2.5 Tracker Scenarios:
    - **Gas Tracker $R_{in/out}$ ~ 25/175 cm, Z ~ 500 cm**
    - Improved 4th: Fwd RHIC
    - Full Silicon with Pid (dE/dx ~ 3%...)
  - 3 VTX Scenarios
    - Rin ~ 10 mm
    - **Vin**
    - Vin Portable
- Anticipated Performance
  - Acceptance: cos(θ)~0.995
  - **BMR ~ 3%**
  - **EM resolution 3%/sqrt(E), const. term < 1%**
  - Timing resolution ~ o(50) ps
  - dP/P ~ 0.1% in the barrel
  - Pid: **eff/purity > 96%** for charged Kaon at hadronic Z event
  - Jet Flavor Tagging:
    - Tr(Mig): from ~2.4 to ~2.7
    - Enhance the g(Hcc) and |Vcb| measurements by 60% - 100%...
  - Fulfill the requirements of not only Higgs, but also Flavor & New Physics

Impact on BMR

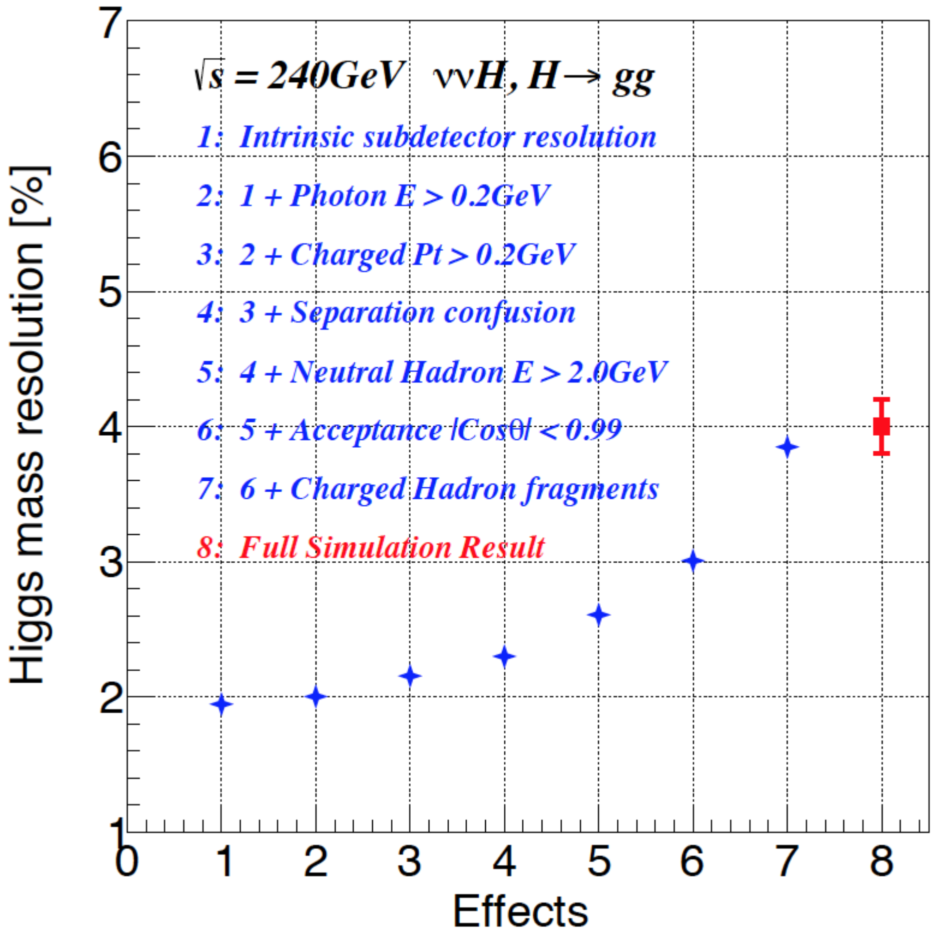


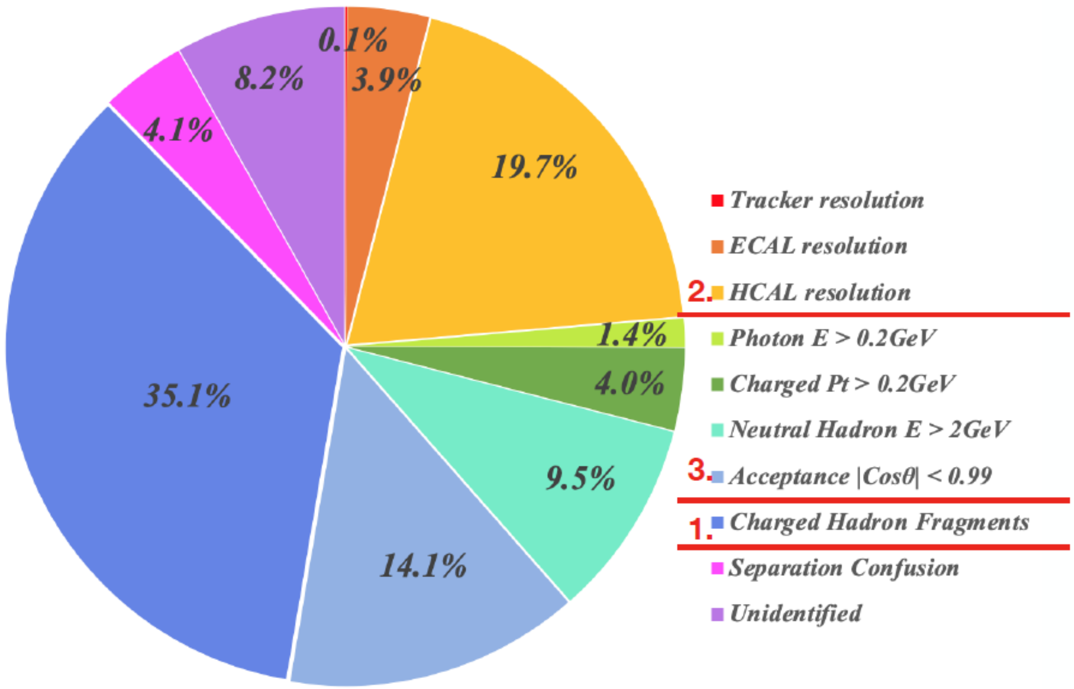
- BMR is sensitive to Both space & material
- A minimal space of

  R*(1(cos(pi/n)) – 1)

  is required to put a 0-thickness circle between parallel polygons. A 169 mm gap is required at baseline octagon structure, leads to a BMR degrading of 8% (3.8% -> 4.1%), whose gap is 30 mm.
- Solenoid material, BMR degrades for
  - 1X0 (of Al) & 260 mm Gap: 10%
  - 2.2X0 & 370 mm Gap: 15%.
  - 4.4X0 & 570 mm Gap: 32%.

PFA Fast simulation



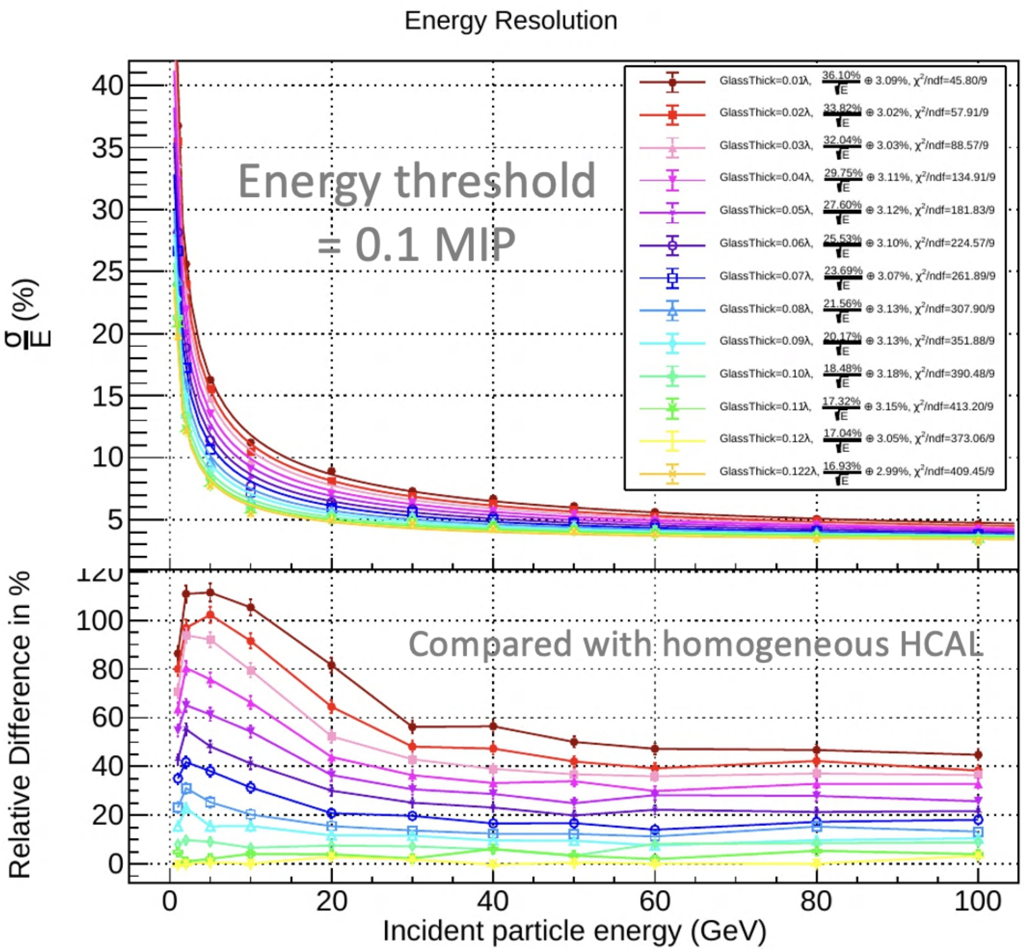


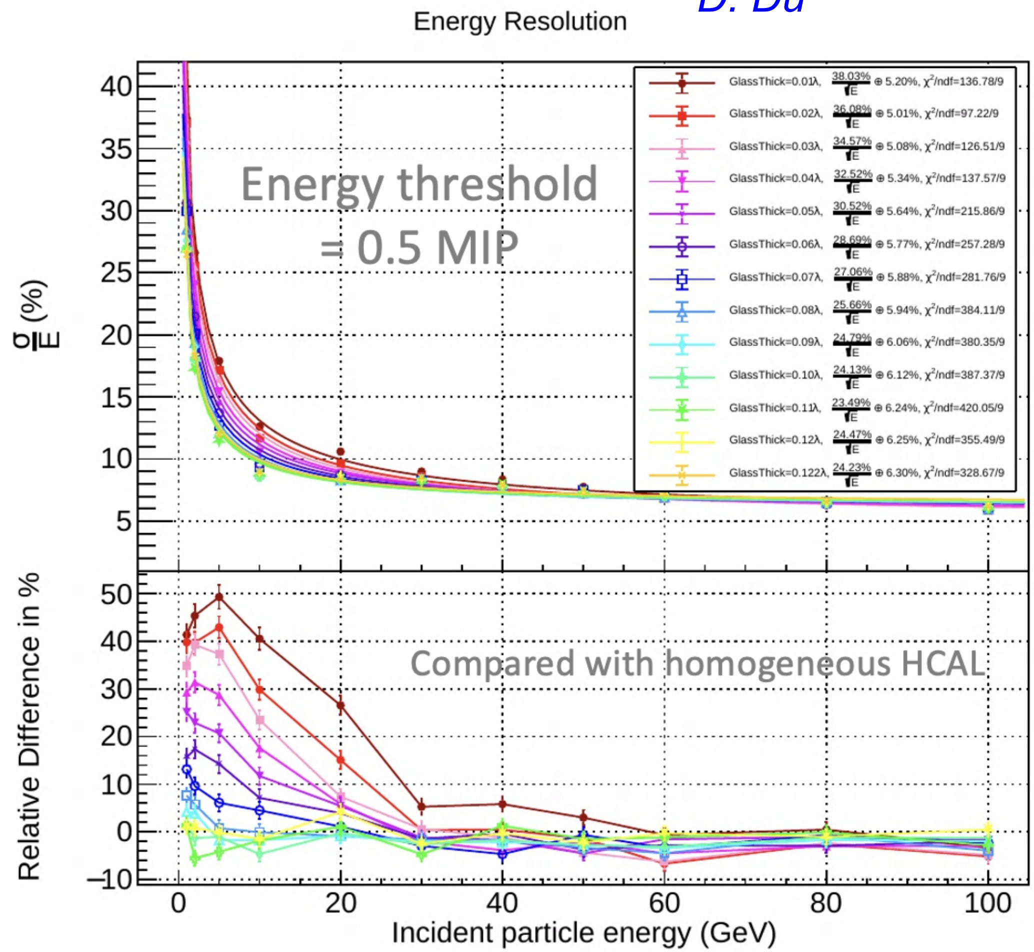
YX. Wang

Fast simulation reproduces the full simulation results, factorize/quantifies different impacts

HCAL

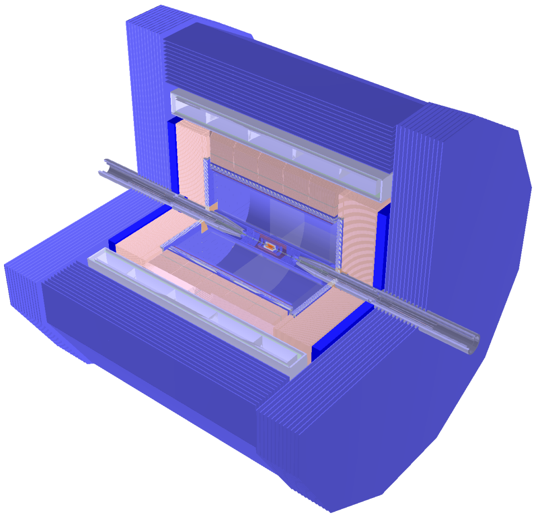
D. Du



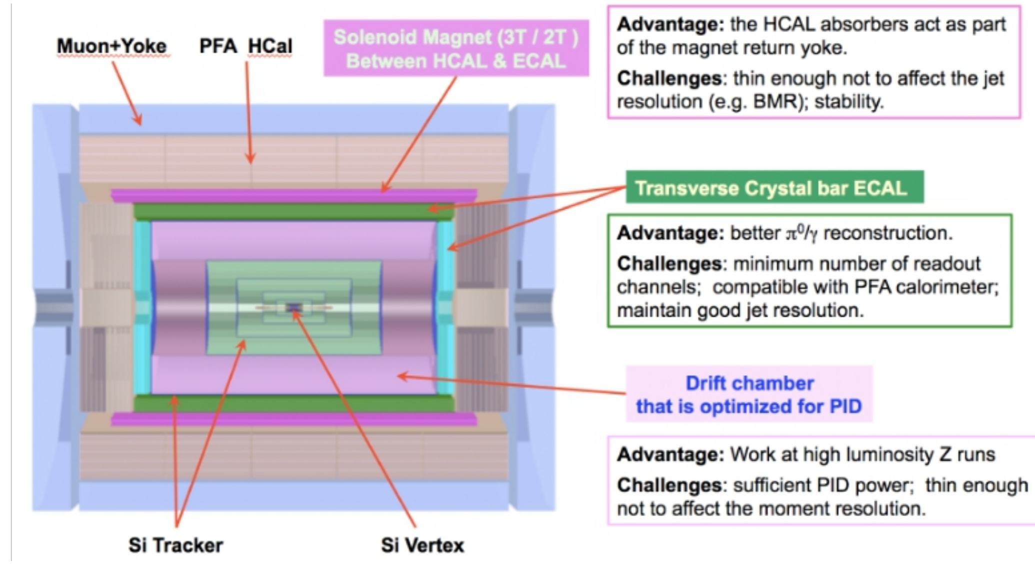


- In an ideal case - ideal Geometry ~ semi infinite...
- HCAL resolution significantly w.r.t. Baseline, at single particle level

From Baseline to 4th



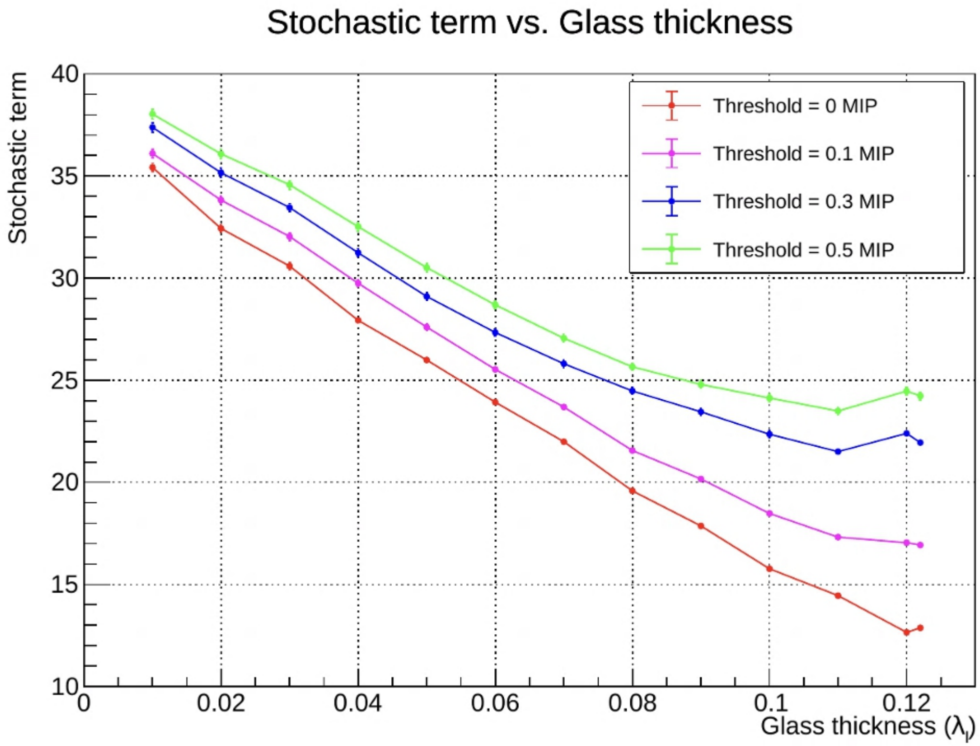
→

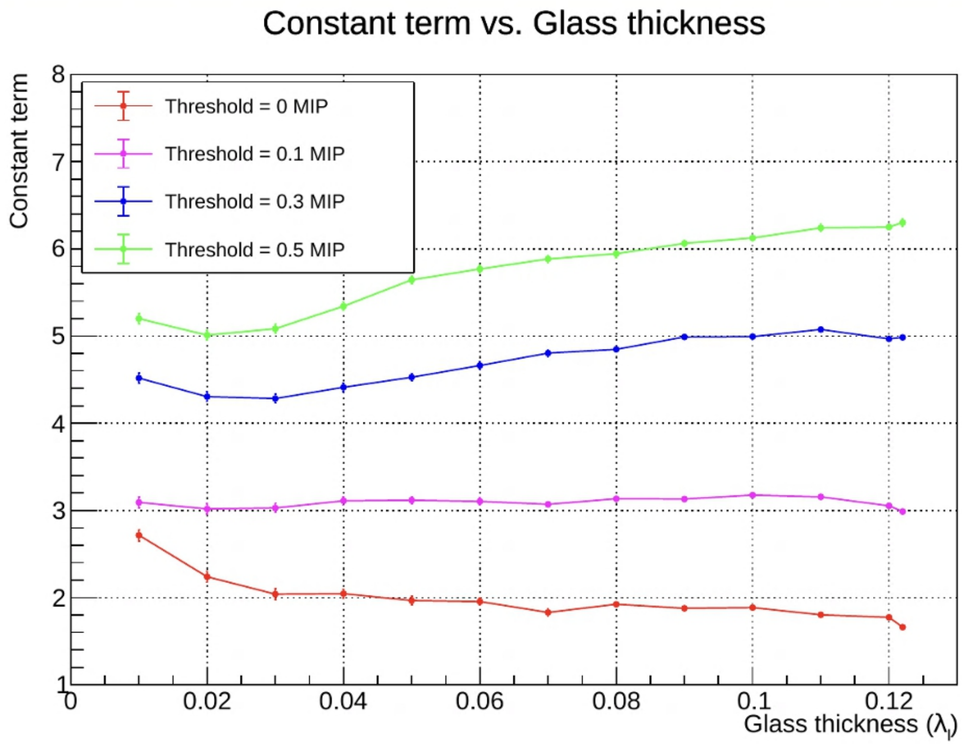


- Tracker: TPC + Silicon → Drift Chamber + Silicon
- ECAL: Si+W → Xstal
- HCAL: GRPC + Iron → Glass + Iron
- Solenoid: Outside HCAL → Between ECAL & HCAL

Single Particle @ GS HCAL

D. Du

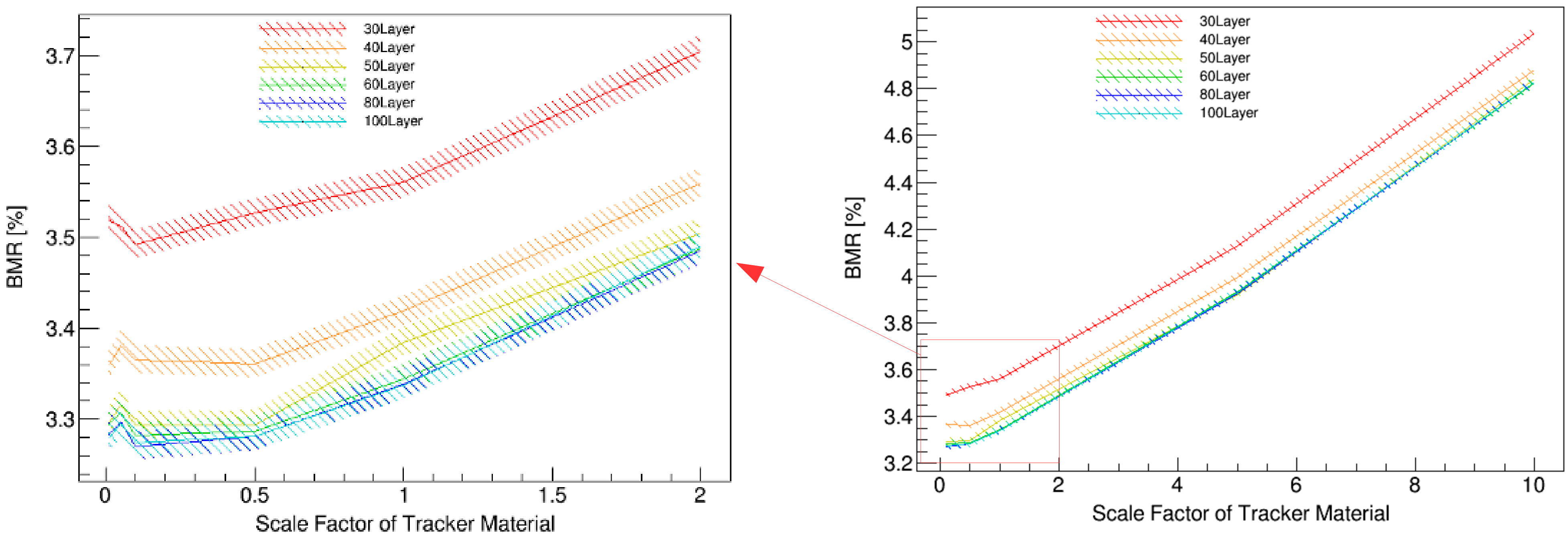




- Performance improves almost linearly at lower energy threshold, and larger sampling fraction

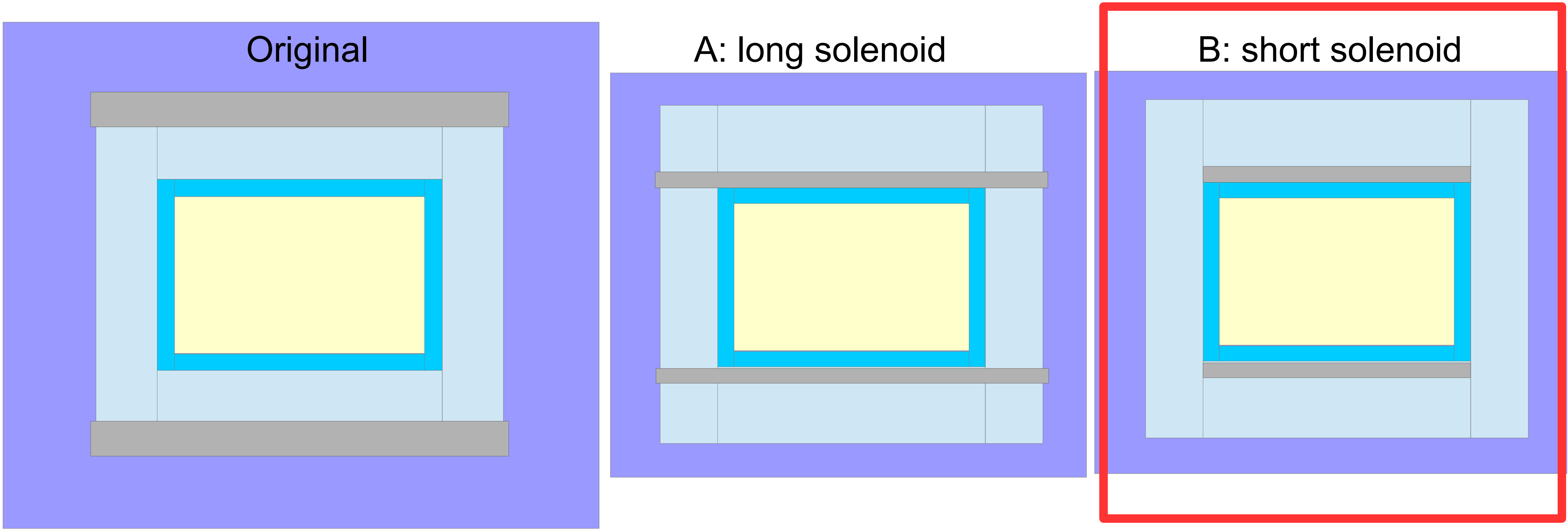
BMR VS upstream material

P. Hu, Preliminary



- Baseline: 10% X0 material in the barrel region.
- Would be great to half the upstream material.

Solenoid between E&HCAL

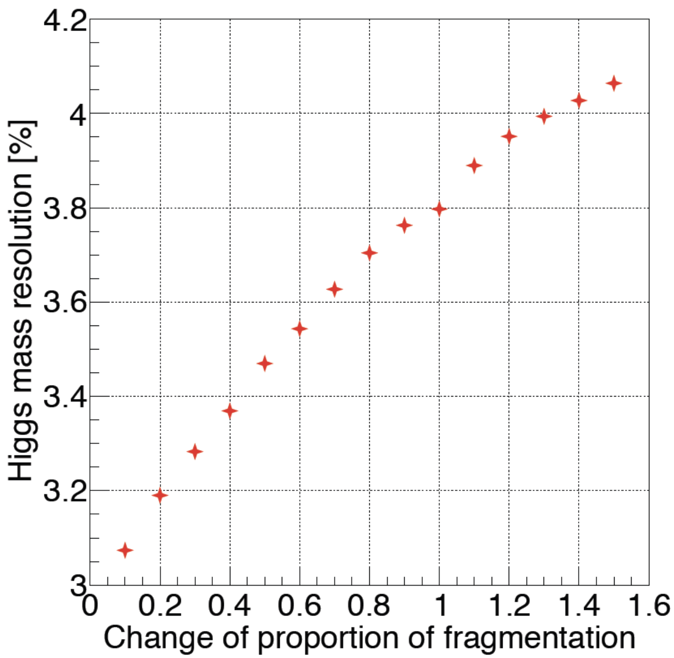


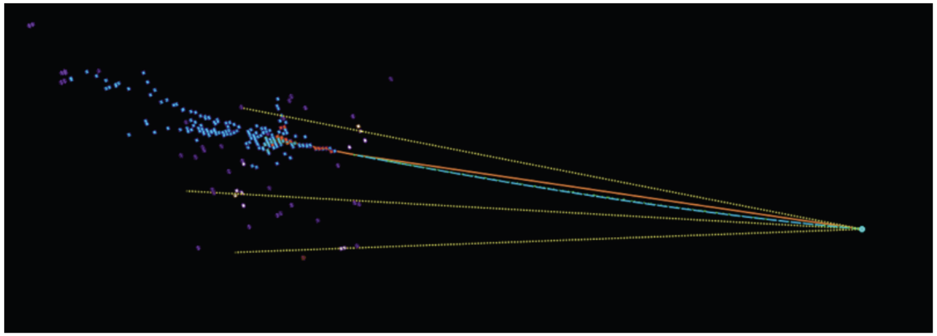
- Long/short solenoid between E/HCAL: saving cost on reduced solenoid & Yoke, while the HCAL cost increases (once ECAL/Tracker fixed)
- Performance comparison between long/short solenoid
  - Short solenoid has less dead materials & worse B-Field homogeneity
  - Assume B-Field difficulties can be solved, short solenoid has better performance, and implemented in Full sim (Thanks to ChengDong!)

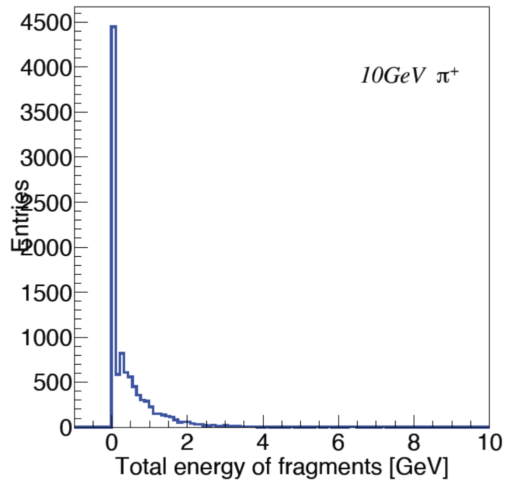
二、粒子流重建算法中误差源的拆解分析与模型构建

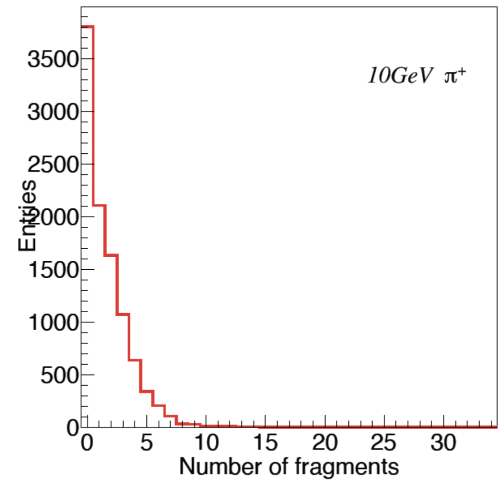
➢ 依赖关系分析——带电强子碎裂簇团

- ➢对 BMR 的影响最显著
- ➢若能完全消除：BMR ~3.8% → 3%
- ➢消除一半：BMR ~3.8% → 3.5%

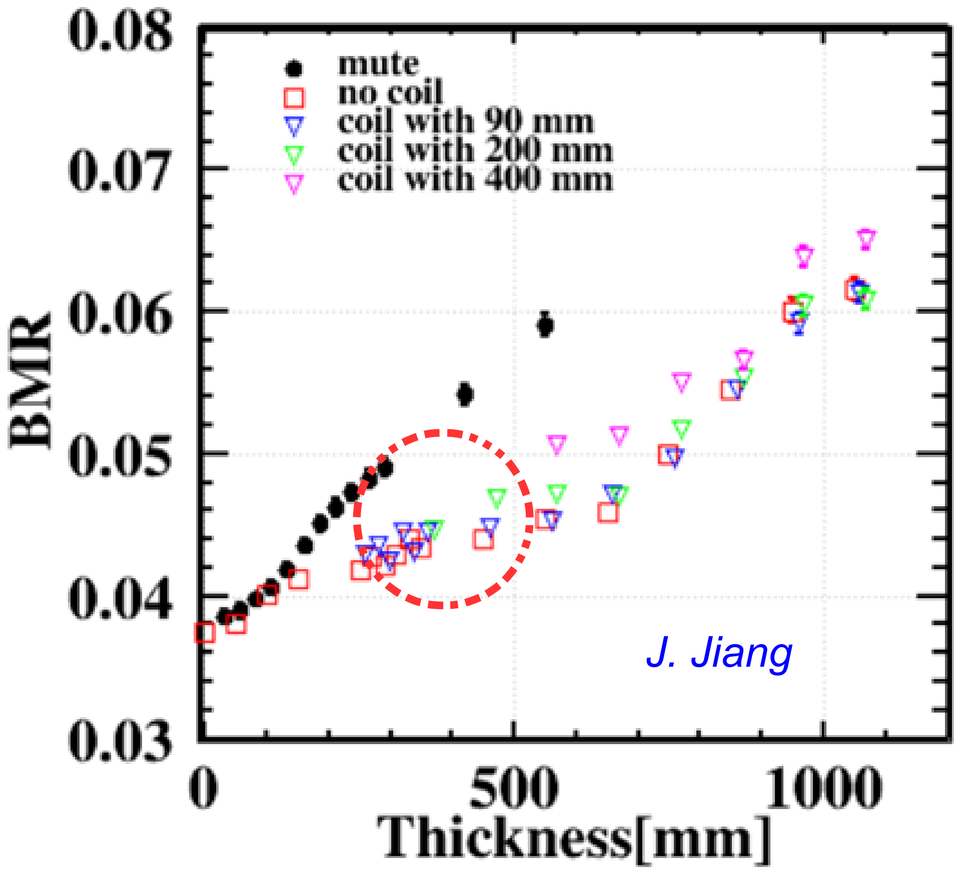


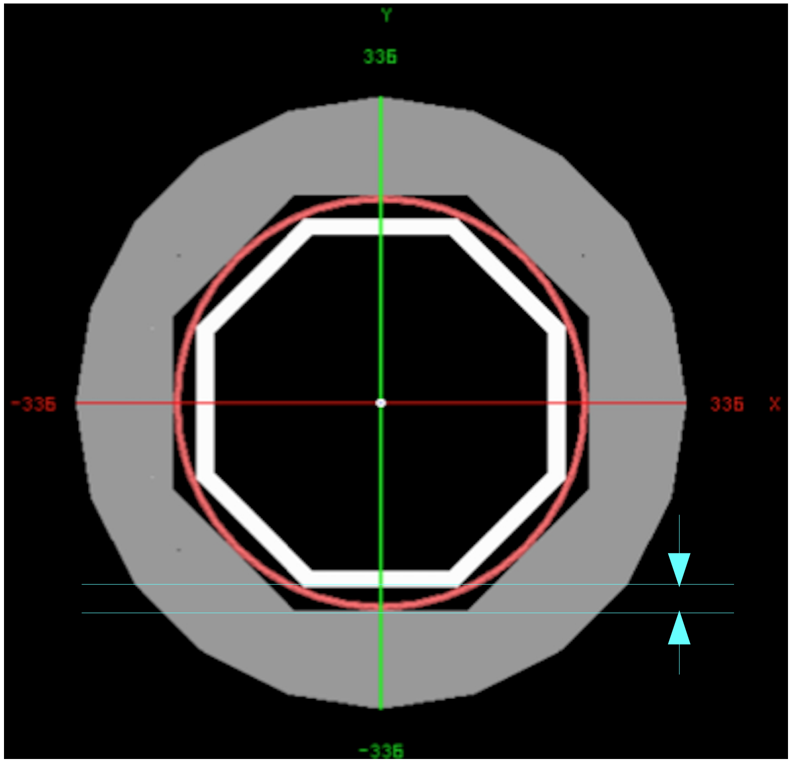






Smaller Solenoid Impact on BMR



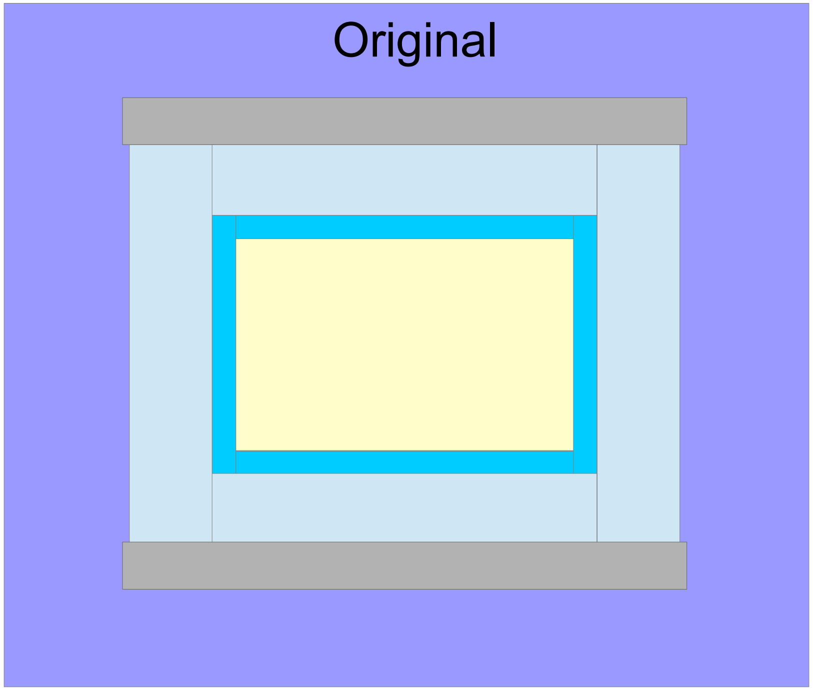


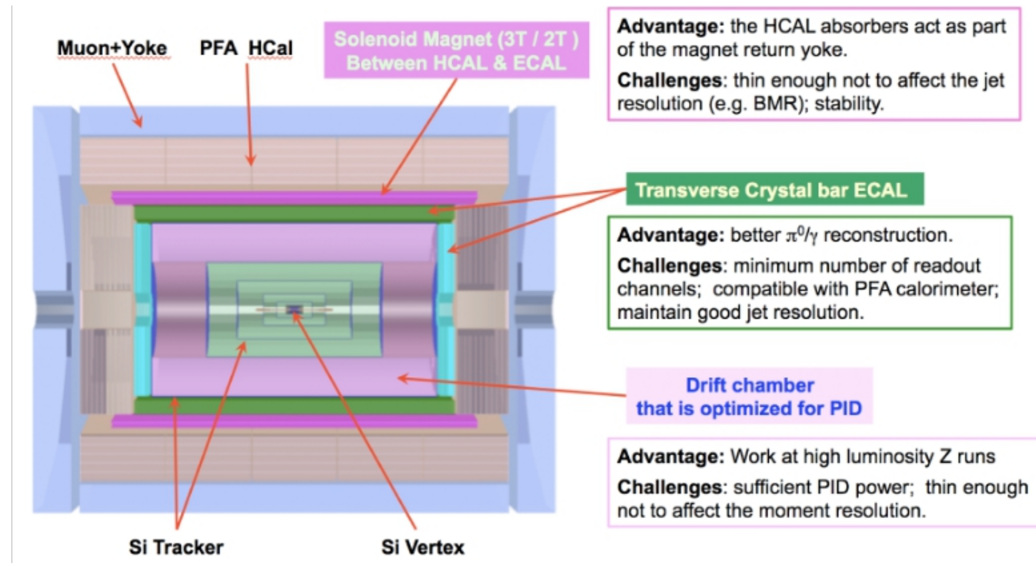
150 mm thick Cylinder Solenoid require at least 300 mm distances between ECAL/HCAL, Solenoid has Material Budget of at least 1 - 2 X_0

BMR Degrades from 3.8% to ~4.4%.

Valve, Dead-zone, etc, will induce further inhomogeneity and degrades the performances.

Difference in cost



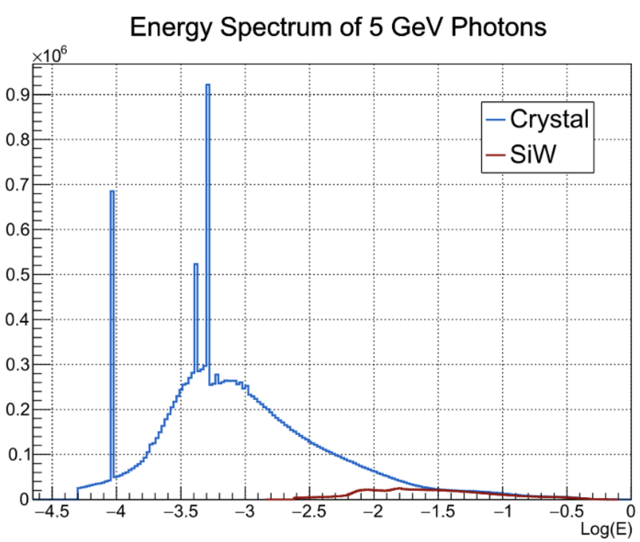


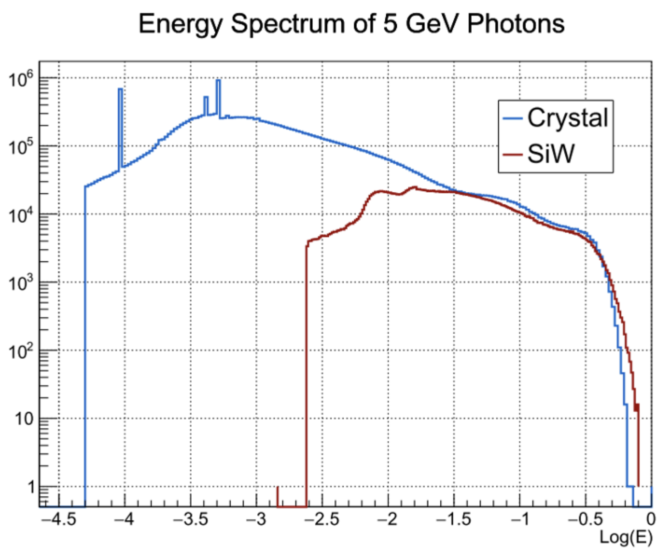
	Inside	Outside
Solenoid (LTS)	10900 w	14706 w
Yoke	? (~ 1000 w)	~ 6000 w
Solenoid (HTS)	14500 – 15400 w	22000 – 23800 w

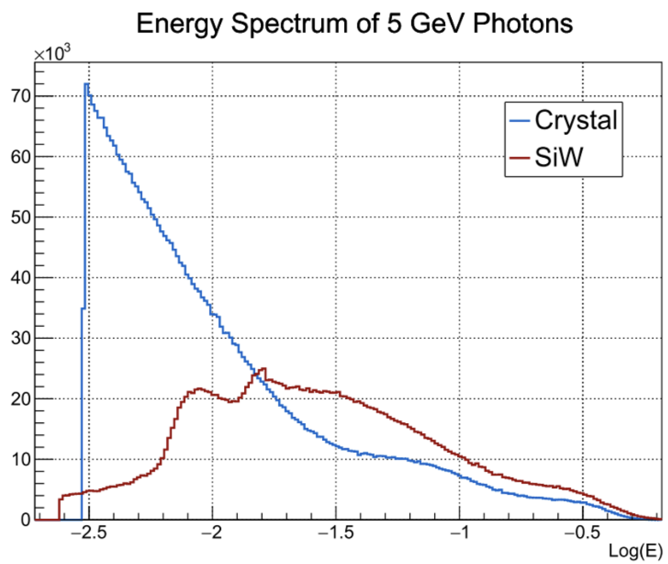
LTS (NiTi): Cost difference ~ 100 M.
HTS(YBCO): Cost difference < 150 M.

Summary

- Tracker: TPC + Silicon → Drift Chamber + Silicon:
  - Almost irrelevant if the Tracker is good enough;
  - BMR: Small margin from Pid, require upstream material in the barrel < 10%, if possible, 5%.
- ECAL: Si+W → Xstal
  - Crystal improves EM resolution, and induces much more hits
  - Small impact on BMR if separation power is ensured.
- HCAL: GRPC + Iron → Glass + Iron
  - Promising
    - Single Particle level improved up to 2 times
    - 10% improvement on BMR (3.3%)
- Solenoid: Outside HCAL → Between ECAL & HCAL
  - BMR degrading to at least 4.4! Strongly disfavor
- Vertex, or VTX + MDI: Lots of margin & need intensive effort





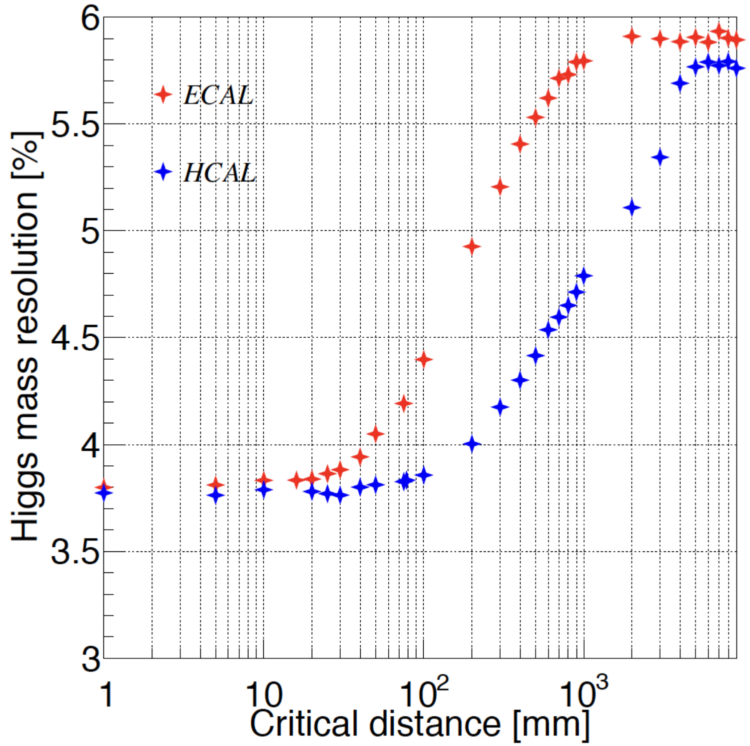


- Original energy spectrum, 10k events, threshold 50 keV
- A large number of low energy hits in crystal ECAL

- Threshold (0.3 MIP): SiW 50 keV, crystal 3 MeV

二、粒子流重建算法中误差源的拆解分析与模型构建

- 依赖关系分析——临近粒子分离能力
  - 分离能力越差，BMR 越大，最终趋于强子能量分辨
  - 左侧拐点
    - 电磁簇射 < 20mm
    - 强子簇射 < 100mm
  - 基线临界分离距离
    - 电磁簇射 ~16mm
    - 强子簇射 ~78mm
    - 基本满足需求



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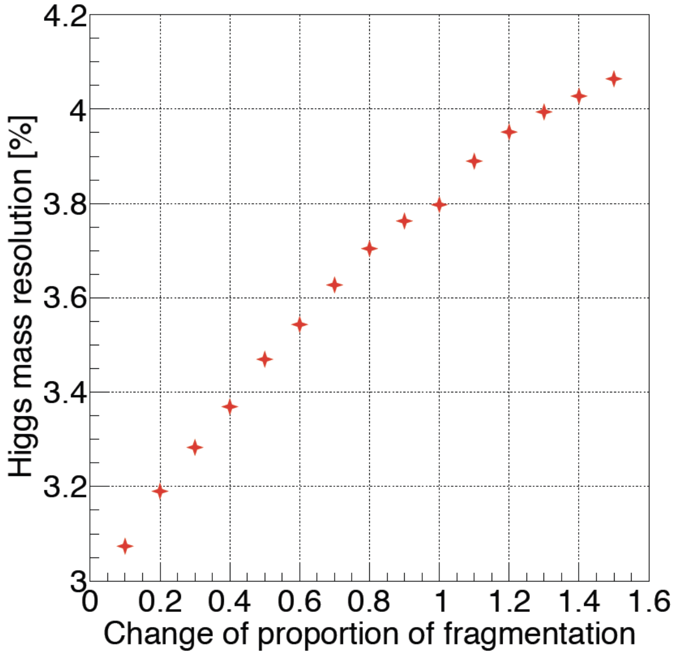
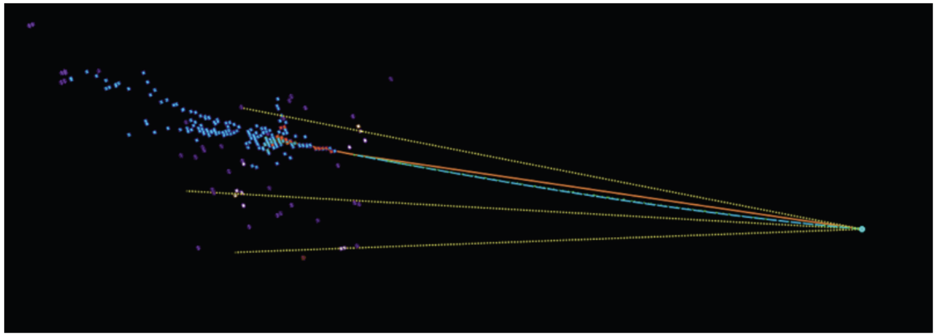
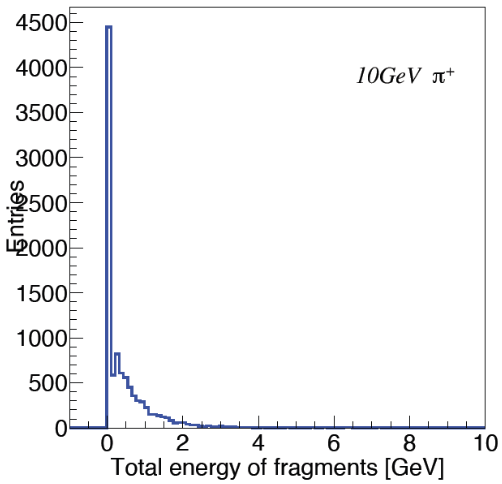
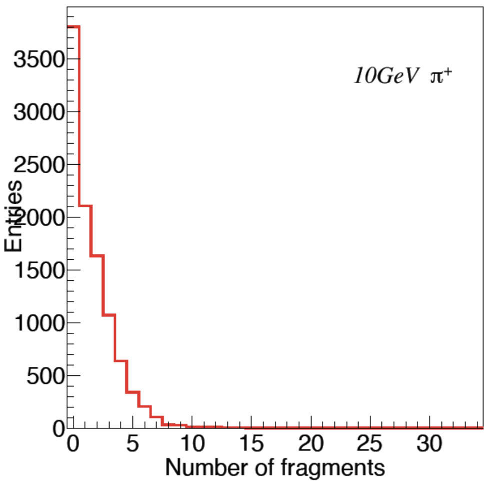


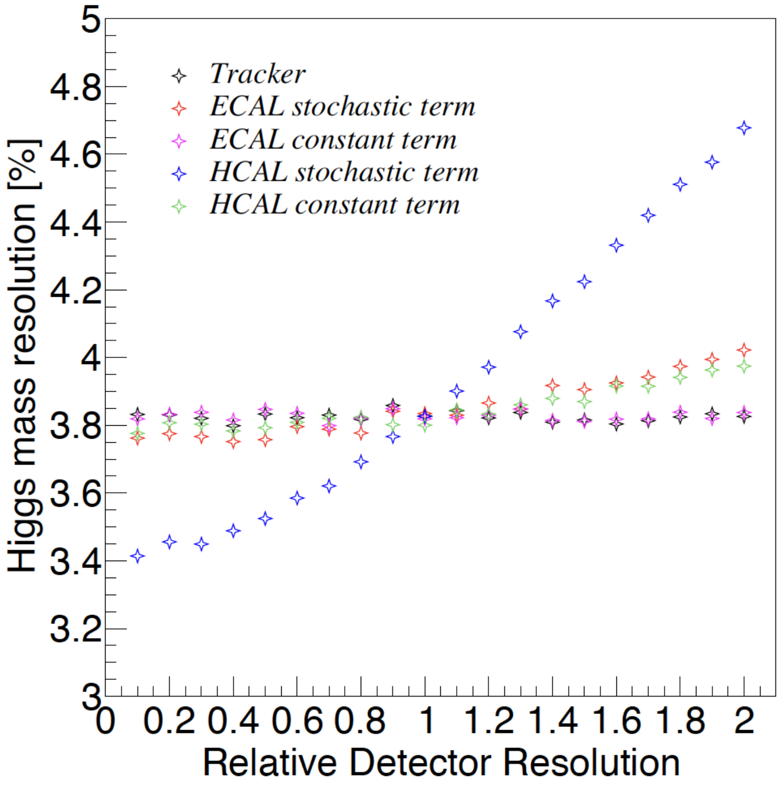






二、粒子流重建算法中误差源的拆解分析与模型构建

- 依赖关系分析——探测器本征分辨率
  - 基线性能（基准点1）
    - 径迹动量分辨率 ~0.1%
    - 电磁能量分辨率 $17\%/\sqrt{E} \oplus 1\%$
    - 强子能量分辨率 $59.2\%/\sqrt{E} \oplus 6.3\%$
  - 依赖关系
    - 对强子能量分辨率统计项最敏感
      - $59.2\%/\sqrt{E} \rightarrow 40\%/\sqrt{E}$
      - BMR 3.8% → 3.6%
    - 电磁统计项和强子常数项的影响次之
    - 电磁常数项和径迹动量分辨率影响最弱



低温超导方案（不包括轭铁）

		Inside（万元）	Outside（万元）
超导线圈	超导电缆	3050	5760
	线圈加工测试	1500	1885
磁体内部低温	阀箱、吊挂、冷却结构、恒温器	1500	2215
制冷系统	低温系统，管道及支架、低温控制	2000	2000
真空系统	机械泵、分子泵、质谱仪等	310	310
电源及失超保护	电源、失超保护系统、母排	2000	2000
控制系统	检测及联锁控制	160	160
磁测系统	测磁机安装设计制造	376	376
总额		10,896	14,706