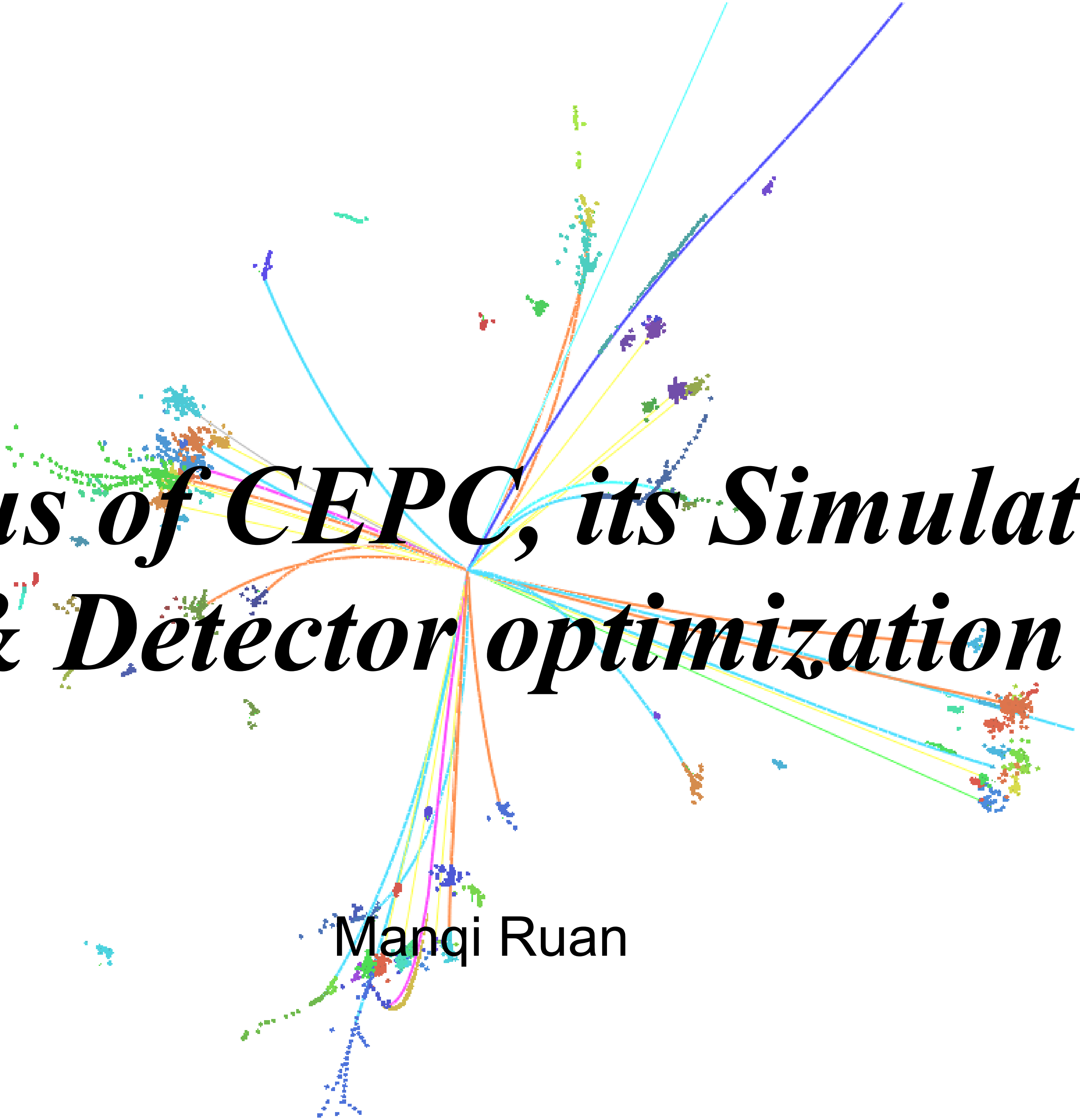
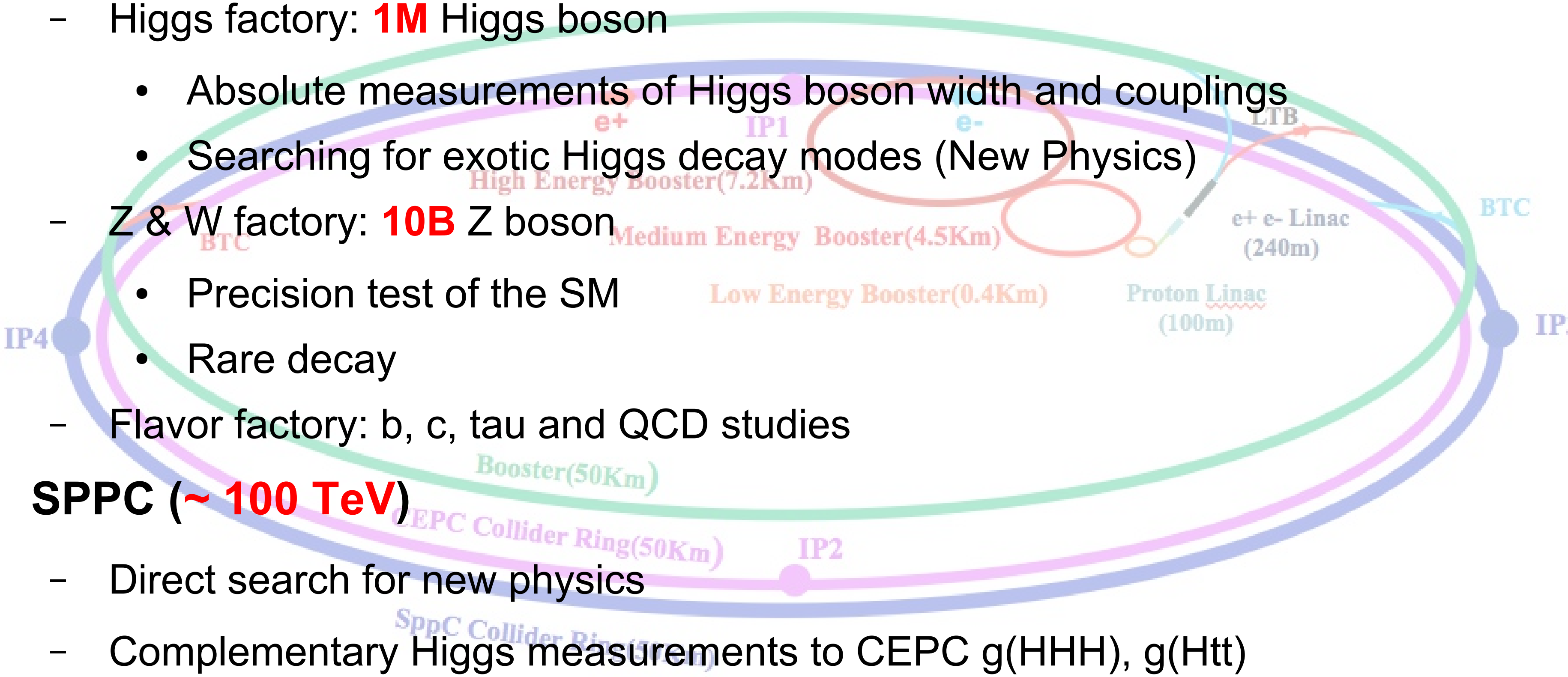


Status of CEPC, its Simulation & Detector optimization

Manqi Ruan

Science at CEPC-SPPC

- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **10B** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**



Complementary

Timeline

Milestones

1st, PreCDR (end of 2014)

2nd, R&D funding from MOST (Middle 2016, 35 M CNY/5yr for the 1st phase)

3rd, CDR (end of 2017)

...

IHEP-CEPC-DR-2015-01

IHEP-EP-2015-01

IHEP-TH-2015-01

Can be downloaded from

http://cepc.ihep.ac.cn/preCDR/volume.html

CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

403 pages, 480 authors

The CEPC-SPPC Study Group

March 2015

IHEP-CEPC-DR-2015-01

IHEP-AC-2015-01

CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

328 pages, 300 authors

The CEPC-SPPC Study Group

March 2015

Current Status and the Plan

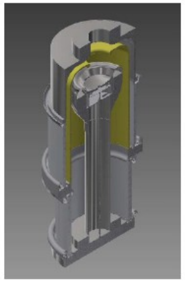
- Pre-CDR completed
  - No show-stoppers
  - Technical challenges identified ➔ R&D issues
  - Preliminary cost estimate
- Working towards CDR
  - A working machine on paper
  - Ready to be reviewed by government at any moment
- R&D issues identified and funding request underway
  - Seed money from IHEP: 12 M RMB/3 yrs
  - MOST: 36 M/5 yr approved, ~40 M to be asked next year
  - NSFC: ~12M RMB approved/4 yrs ➔ 6 M/yr to be approved
  - NCDR: ~0.8 B RMB/5 yr, failed in a voting process
  - CAS: ~ 8M/yr, more under discussion
  - CNSF: under discussion
  - Beijing Municipal Government: R&D platform

Key R&D issues

RF power source: Efficiency

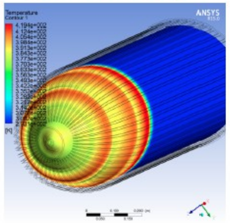
Key parameters of NEW klystron design

Parameters mode	Now	Future
Centre frequency (MHz)	650+/-0.5	650+/-0.5
Output power (kW)	800	800
Beam voltage (kV)	80	70
Beam current (A)	16	15
Efficiency (%)	65	80



Gun assembly

- ➢ Key factors for the cost and the power consumption
- ➢ Used by radar, radio and television broadcasting, …



Collector design

SRF System: three key issues

- Extremely high Q_0 cavities
  - New technology: N-doping to improve Q_0 by a factor ~4
- Efficient thermal power extraction
  - SR power
  - HOM power
- Mass production

- ➢ Largest SRF system next to ILC
- ➢ Technically challenge
- ➢ Used by all future acclerators
- ➢ Key factors for the cost

- High power Cryogenic system
- Beam Monitoring and Diagnostics
- High field SC magnets

  ...
- Site selection & Civil design

HTC Superconducting Cables

- Huge impact If magnet can be used at ~ 4.5K - 20 K
- Fe-based HTC cable
  - Metal, easy to process; Isotropic; Cheap in principle
- Background in CAS
  - World highest Tc Fe-based materials
  - World first ~ 115 m Fe-based SC cables: 12000 A/cm^2 @ 10 T
- A collaboration on “HTC SC materials” : Institute of Physics, USTC, Institute of electric engineering, IHEP, 3 SC cable companies in China
  - Iron based HTC cables
  - ReBCO & Bi-2212
  - Goal: ~ 3-5 $ /kA·m
    - Current density: × 10
    - Cost/m: ÷10

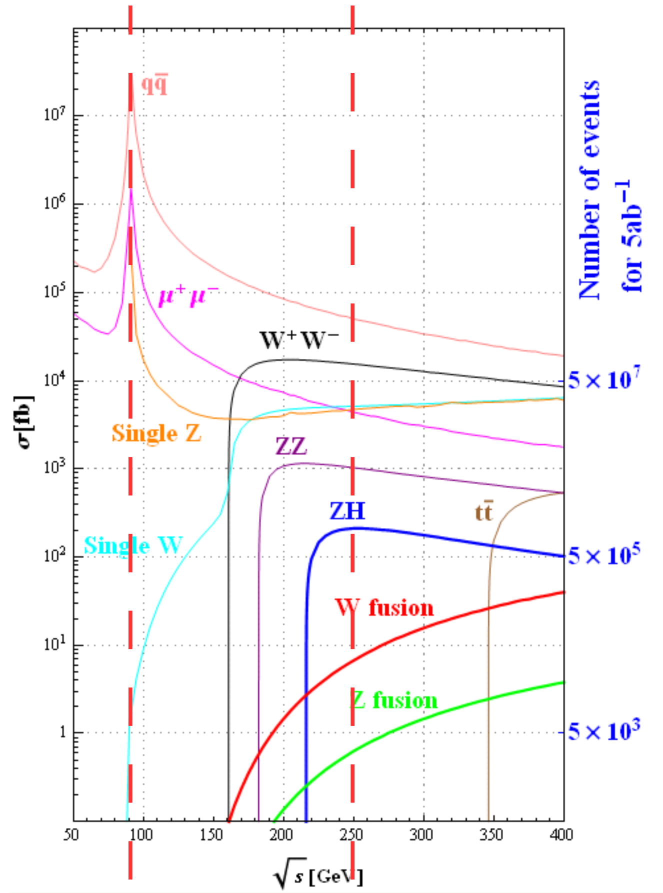
Common Issues with HEPS

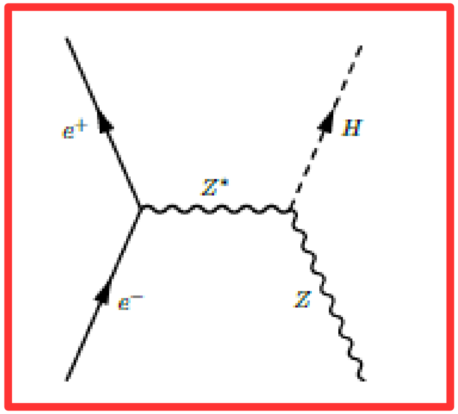
- HEPS-TF approved by NCDR
- HEPS(80 km from IHEP) to be approved in 2018 ?
- Applicable to CEPC: Beam diagnostics, vacuum, mechanics, …
- A large R&D platform for accelerators and detectors, supported by the Municipal Government of Beijing

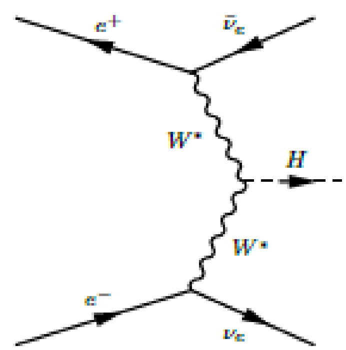
Beam Energy: 6 GeV
Beam Current: 200 mA
Circumference: 1300 m
Emittance: 0.06 nm·rad

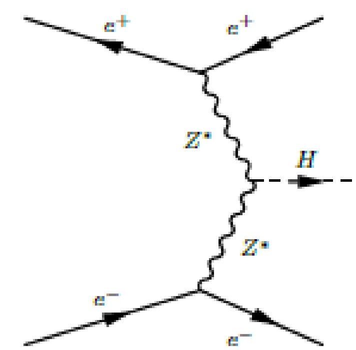
Requiring a factor of 10 better orbit precision, magnet precision & stability, etc.

CEPC: 1M Higgs & 10-100 B Z









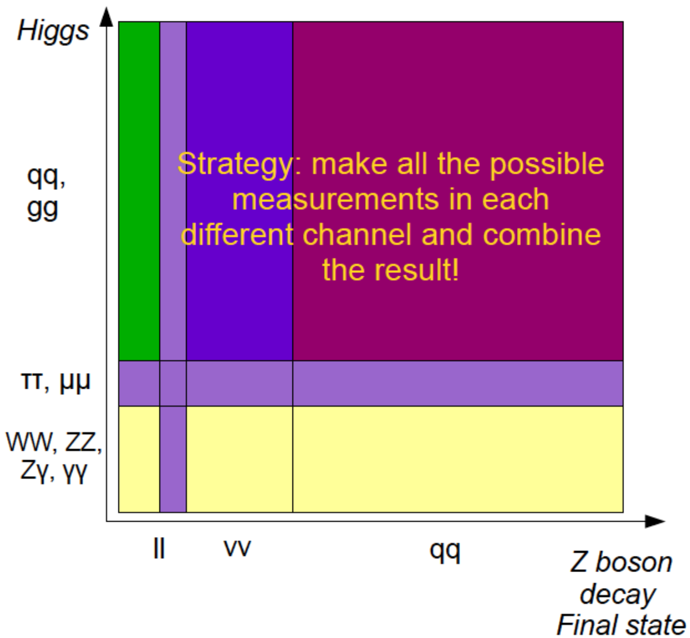
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

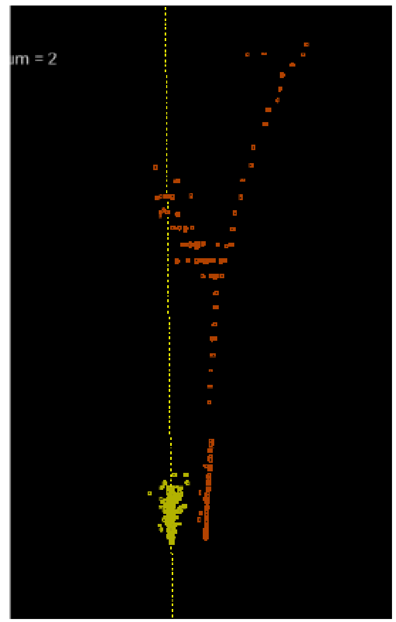
Observables: EW Precision, tau physics, Flavor Physics...

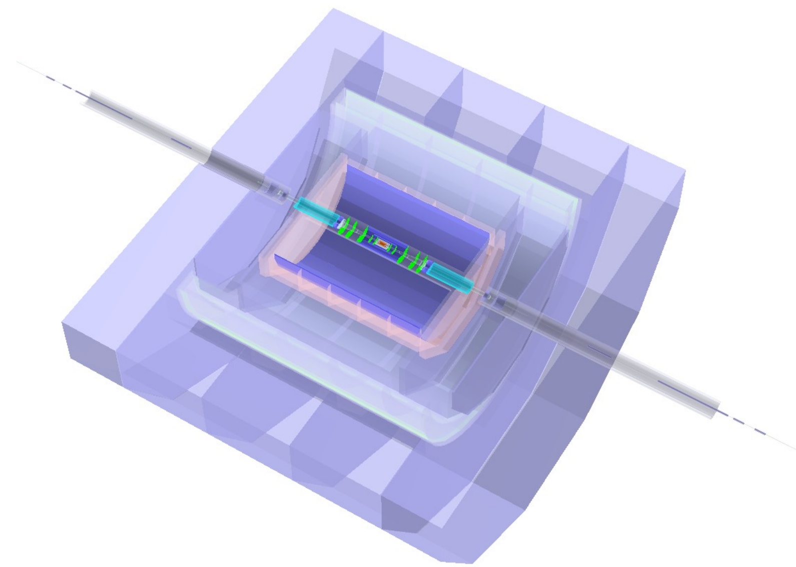
Higgs mass, CP, σ(ZH), event rates (σ(ZH, vvH)*Br(H→X)), Diff. distributions

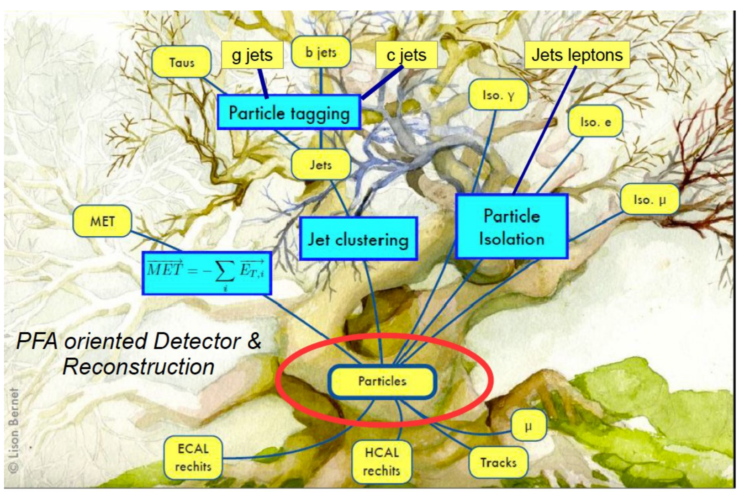
Derive: Absolute Higgs width, branching ratios, couplings

Detector performance



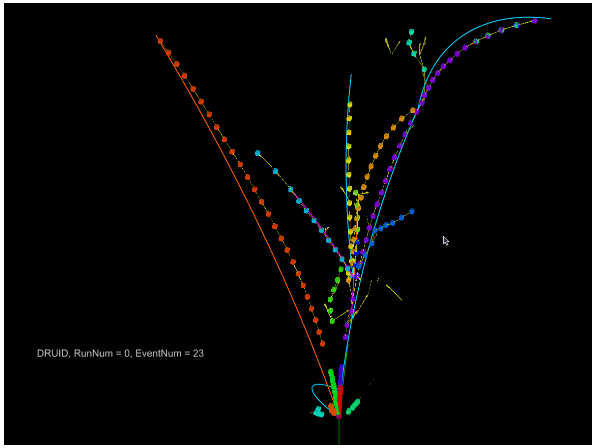


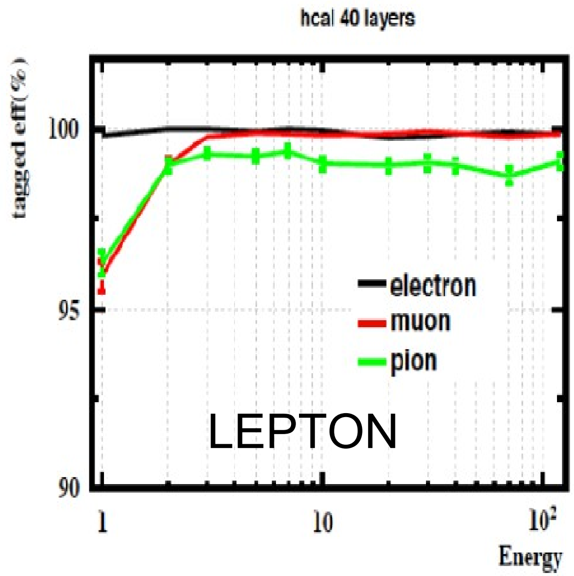


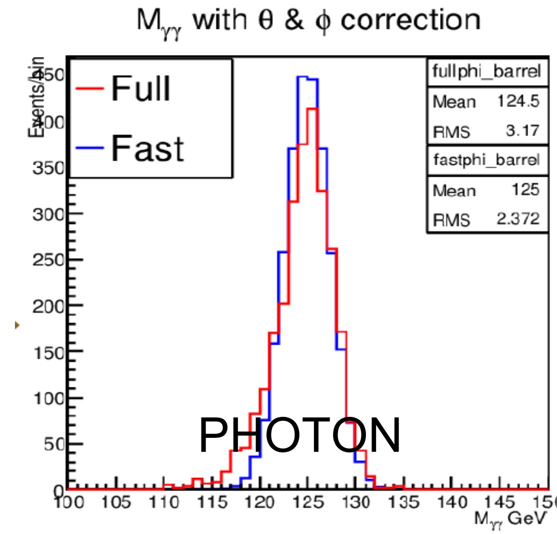


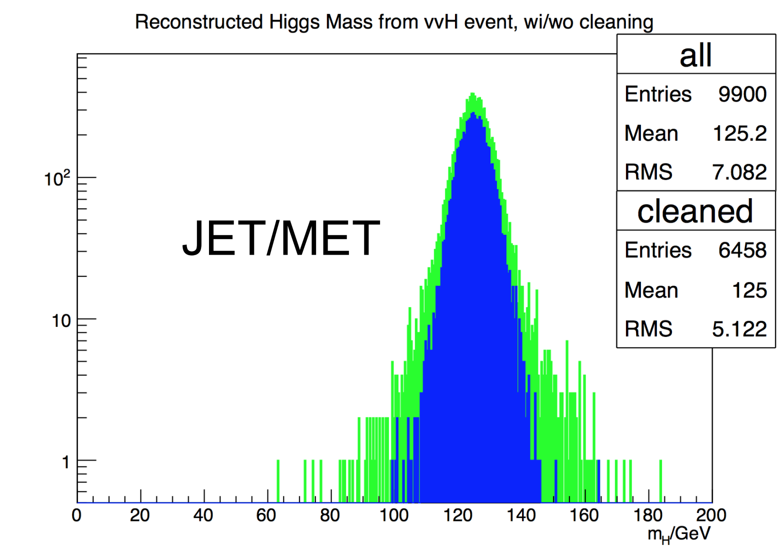
Acceptance	$\|\cos(\theta)\| < 0.995$ (from the inner radius of the outmost tracking disk)
Tracking Efficiency	For isolated charged particle with energy > 1GeV: ~100%
Photon Reconstruction Efficiency	For isolated photon with energy > 0.5 GeV: ~100%
Tracker resolution	$\delta(1/P_T) = 2*10^{-5}(\mathrm{GeV}^{-1})$
ECAL intrinsic resolution	$\delta E/E = 16\%/\sqrt{E/GeV} \oplus 0.5\%$
HCAL intrinsic resolution	$\delta E/E = 60\%/\sqrt{E/GeV} \oplus 1\%$
Jet energy resolution	$\delta E/E = 4\%$
Typical Distance for shower separation	< 3 cm
Lepton identification	For charged particle with Energy >2GeV: Lepton identification efficiency > 99.5%, P(hadron→muon)~P(hadron→electron): 1%
b-tagging	At Z pole samples & eff(b→b)) = 80%, P(uds→b) < 1%, P(c→b) ~ 10%
c-tagging	At Z pole samples & eff(c→c)) = 60%, P(uds→c) = 7%, P(b→c) = 12%

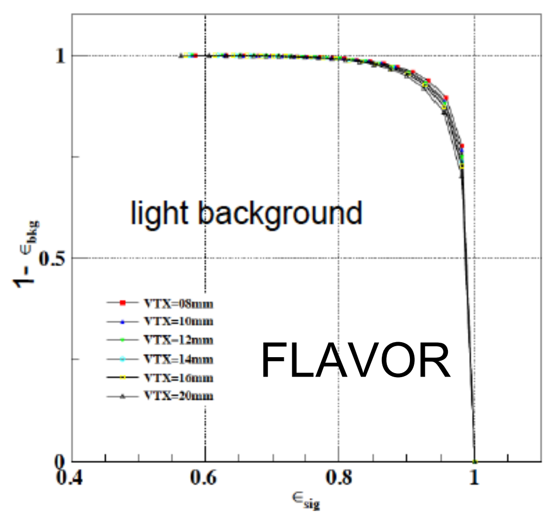
Reconstruction

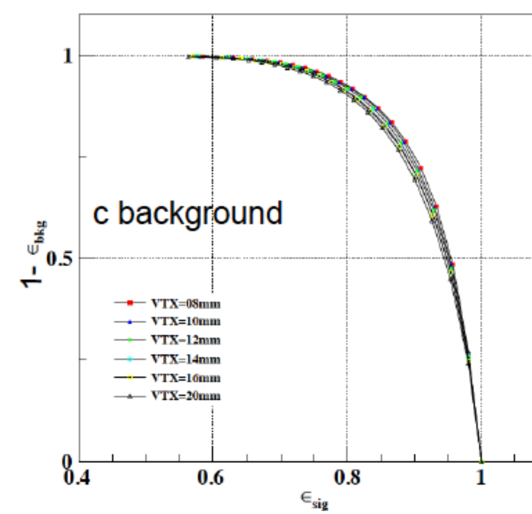




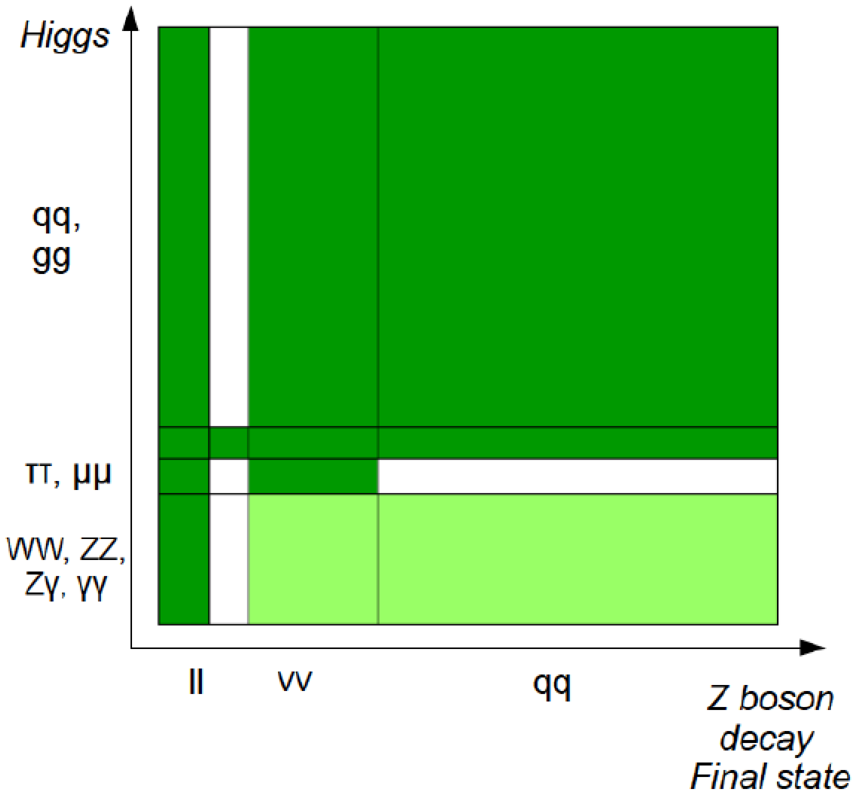






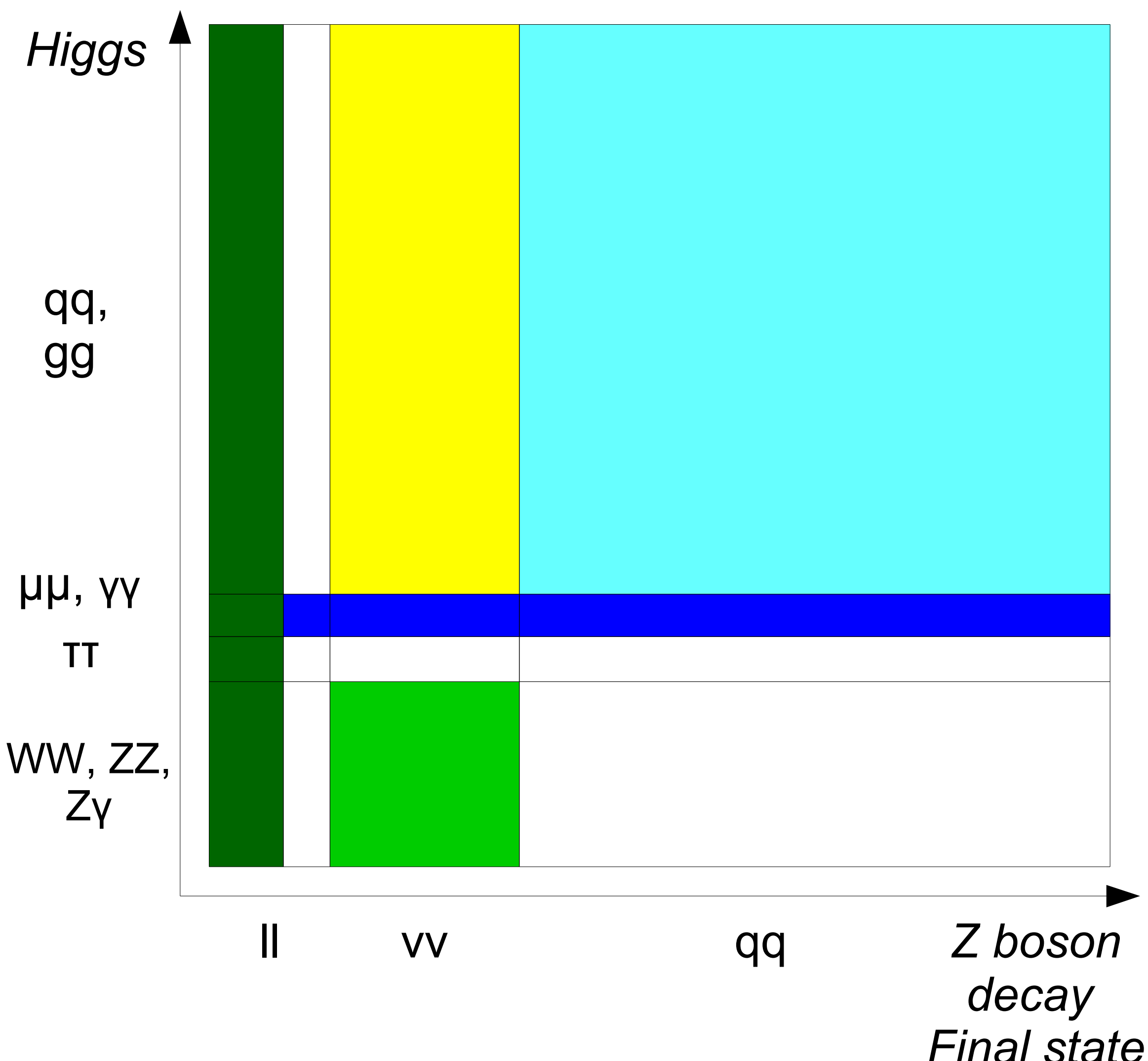


CEPC: Simulation Studies



	PreCDR (Jan 2015)	Now (Aug 2016)
σ(ZH)	0.51%	0.50%
σ(ZH)*Br(H→bb)	0.28%	0.21%
σ(ZH)*Br(H→cc)	2.1%	2.5%
σ(ZH)*Br(H→gg)	1.6%	1.3%
σ(ZH)*Br(H→WW)	1.5%	1.0%
σ(ZH)*Br(H→ZZ)	4.3%	4.3%
σ(ZH)*Br(H→ττ)	1.2%	1.0%
σ(ZH)*Br(H→γγ)	9.0%	9.0%
σ(ZH)*Br(H→Zγ)	-	~4 σ
σ(ZH)*Br(H→μμ)	17%	17%
σ(ννH)*Br(H→bb)	2.8%	2.8%
Higgs Mass/MeV	5.9	5.0
σ(ZH)*Br(H→inv)	95%. CL = 1.4e-3	1.4e-3
Br(H→ee/emu)	-	1.7e-4/1.2e-4
Br(H→bbχχ)	$<10^{-3}$	3.0e-4

Optimization: Feasibility of TPC & Passive cooling, etc + Performance @ Benchmark



Lepton & Momentum resolution: Br = 6.7%

Flavor Tagging & JER: Br = 14%

Composition of Jet/MET, lepton: Br = 4%

Jet Clustering: Br = 50%

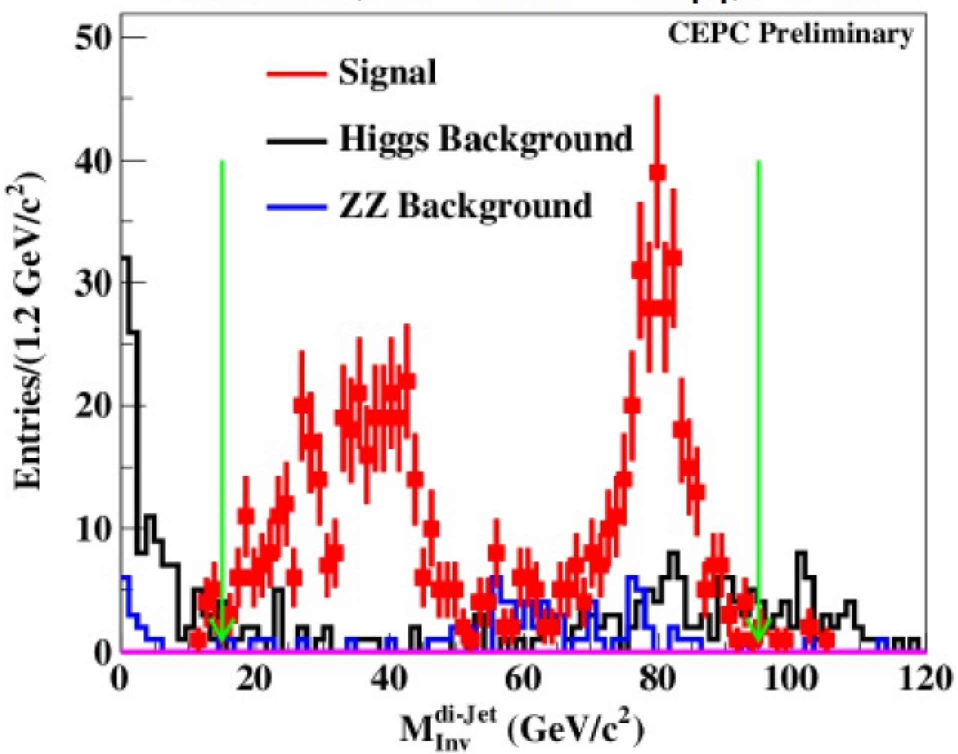
Photon/ECAL: Br = 0.2%

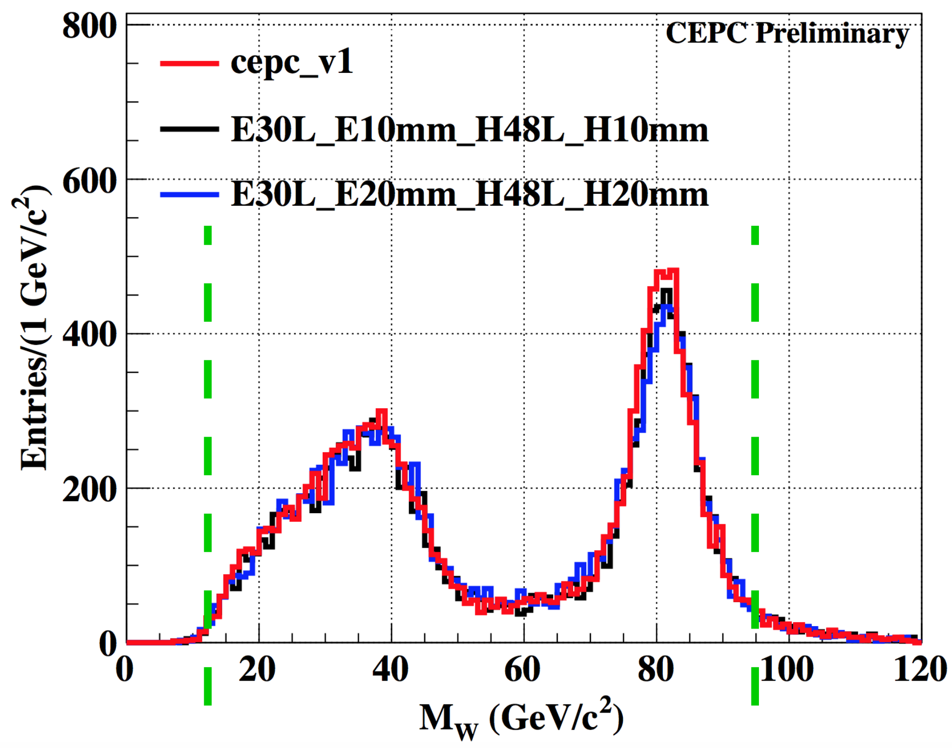
qqH, H->inv. MET & NP: SM Br = 0.1%

EW, Br(tau->X) @ Z pole: Separation

Br(H→WW) @ 10mm/20mm Cell size

Liao libo, H→WW*→lvqq, Z→ll

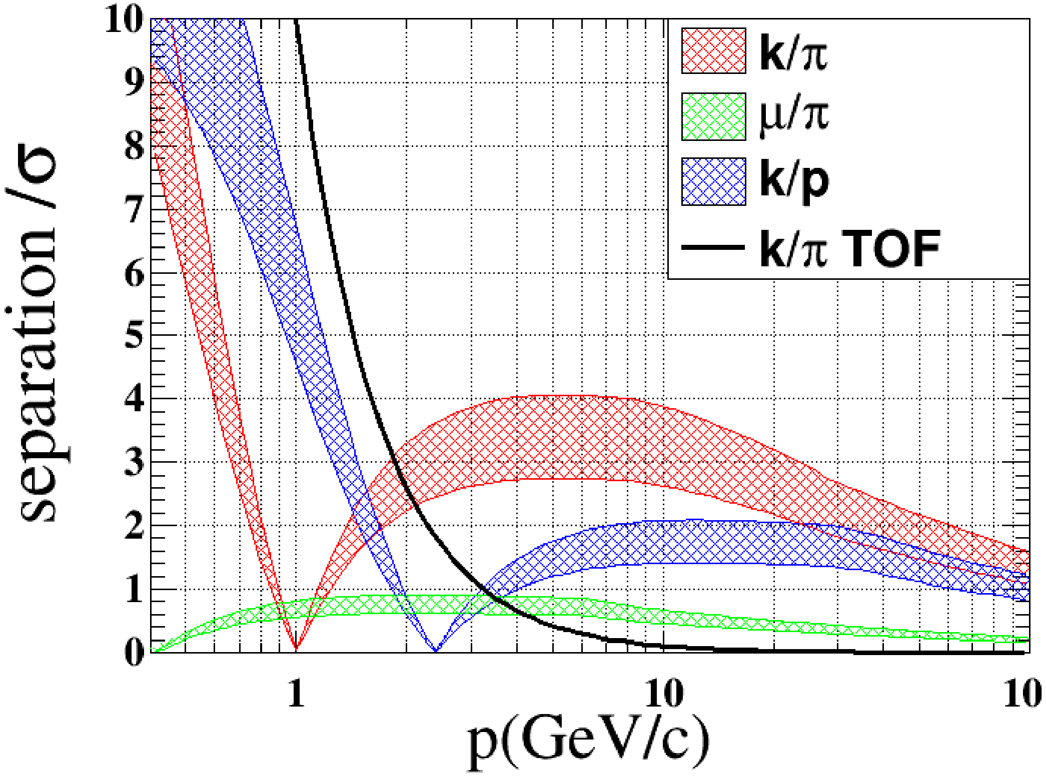


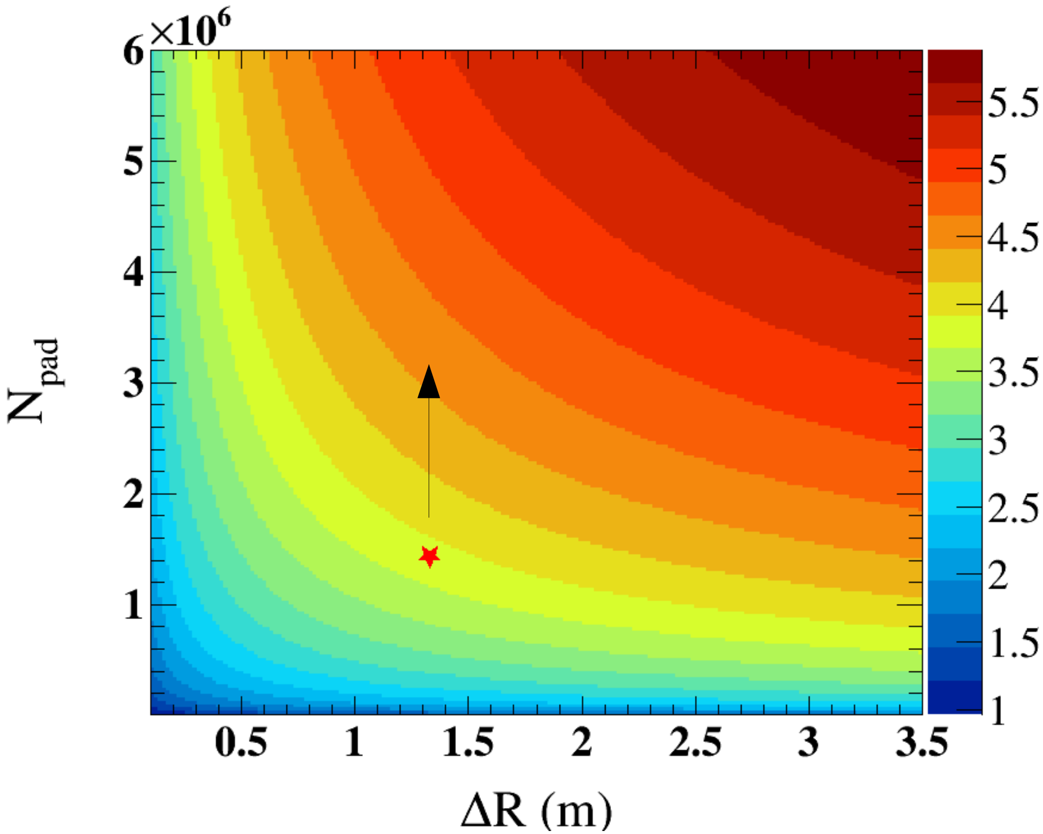


Br(H→WW) via vvH, H→WW*→lvqq
No lose in the object level efficiency: JER slightly degraded, ~ 5/10% at 10/20 mm
Over all: event reco. efficiency varies ~1%

PASSIVE COOLING Calo: Feasible for CEPC Higgs operation

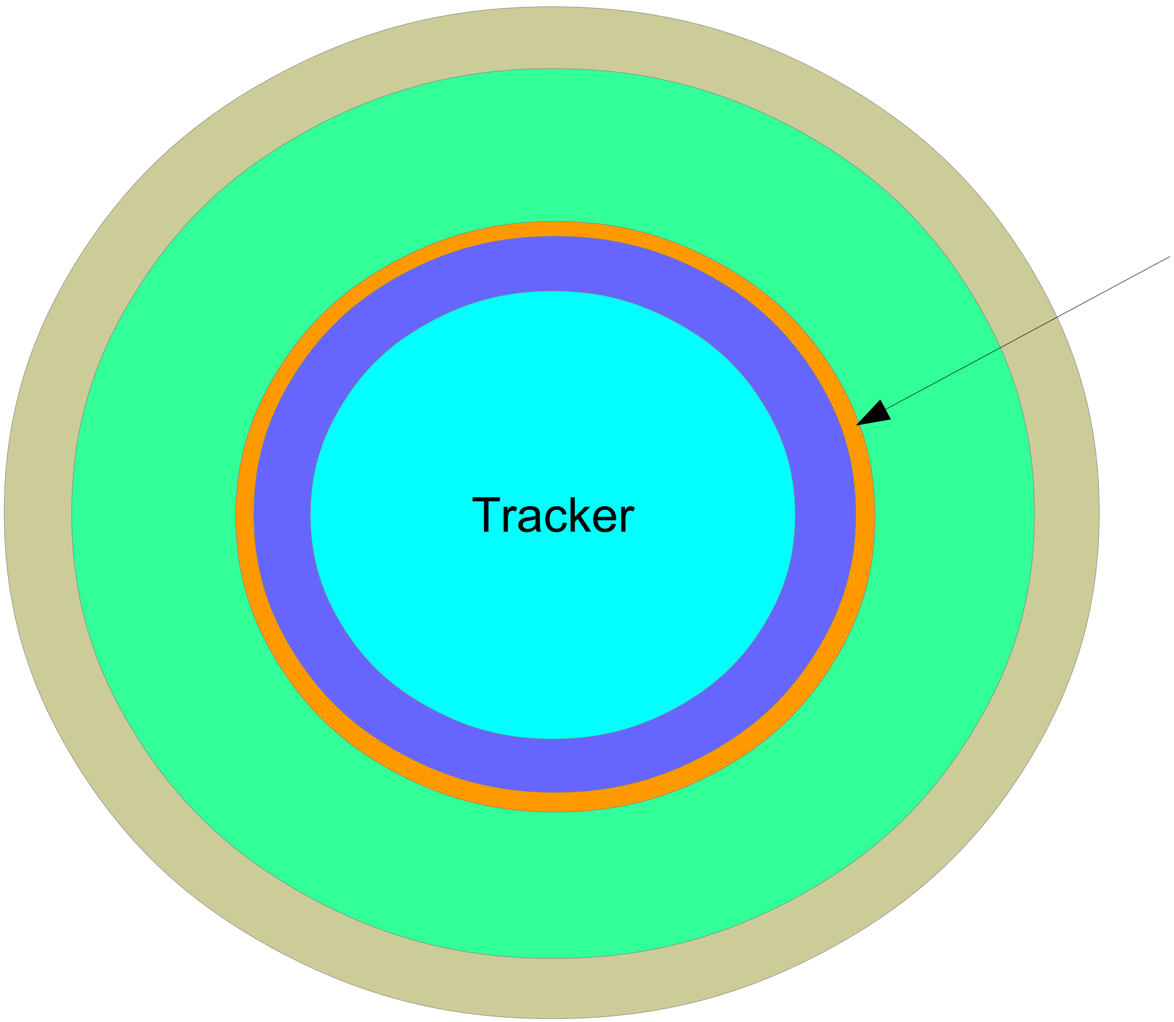
TPC dEdx & optimizations





- TPC dEdx + ToF at dt ~ 50 ps: a full range of pi-kaon separation (3-4σ) at Z pole
- Be iterate with hardware study & Test beam: Quantify the hardware requirements
- TPC in general:
  - Stability & Homogeneity requirement
  - Radiation Background, Gas optimization (Neutron Flux, Delta/Gamma Ray)

A preliminary design



Dedicated ToF
Or
ECAL Layer with TDC
Equipped Chips

delta(T) ~ 50 ps

To balance the efficiency & Purity of time measurement...

Tracker, TPC: R = 1.8 m

ECAL: 84-90 mm W

HCAL: 1000-1200 mm Iron

Solenoid (3T) + Yoke

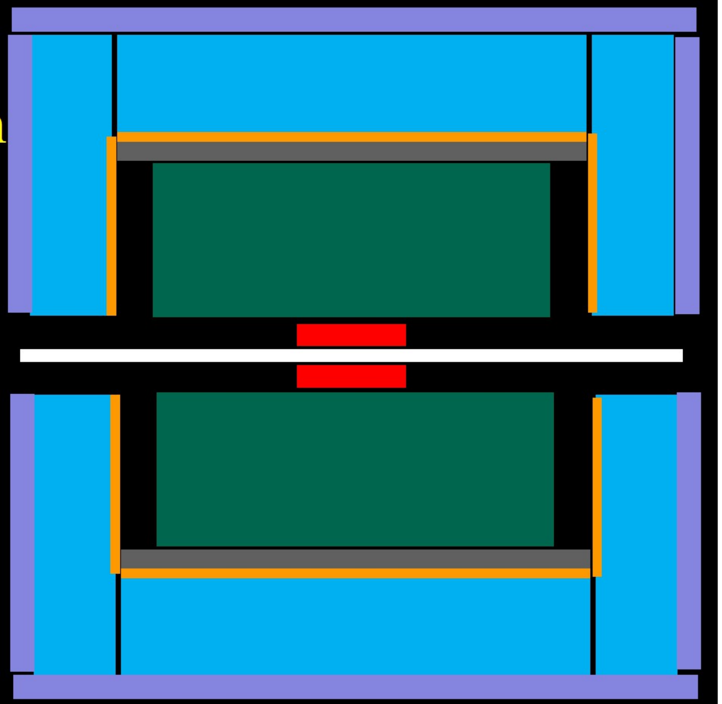
Parameter Optimization of the PFA oriented detector

	CEPC_v1 (~ ILD)	Optimized (Preliminary)	Comments
Track Radius	1.8 m	>= 1.8 m	Requested by Br(H->di muon) measurement
B Field	**3.5 T**	**3 T**	**Requested by MDI**
ToF	**-**	**50 ps**	**Requested by pi-Kaon separation at Z pole**
ECAL Thickness	84 mm	84(90) mm	84 mm is optimized on Br(H->di photon) at 250 GeV; 90mm for bhabha event at 350 GeV
ECAL Cell Size	5 mm	10 – 20 mm	Passive cooling request ~ 20 mm. 10 mm should be highly appreciated for EW measurements – need further evaluation
ECAL NLayer	30	20 – 30	Depends on the Silicon Sensor thickness
HCAL Thickness	**1.3 m**	**1 m**	-
HCAL NLayer	**48**	**40**	Optimized on Higgs event at 250 GeV; Margin might be reserved for 350 GeV.

Another concept

Summarizing ....

- Beam pipe (R~2 cm)
- VTX: 4-7 MAPS layers
- DCH: 4 m long, R 40-200 cm
- 2 T, R~2 m SC Coil
- Preshower (1-2 X_0)
- DR calorimeter (2 m/8 λ_{int})
- (yoke) muon chambers



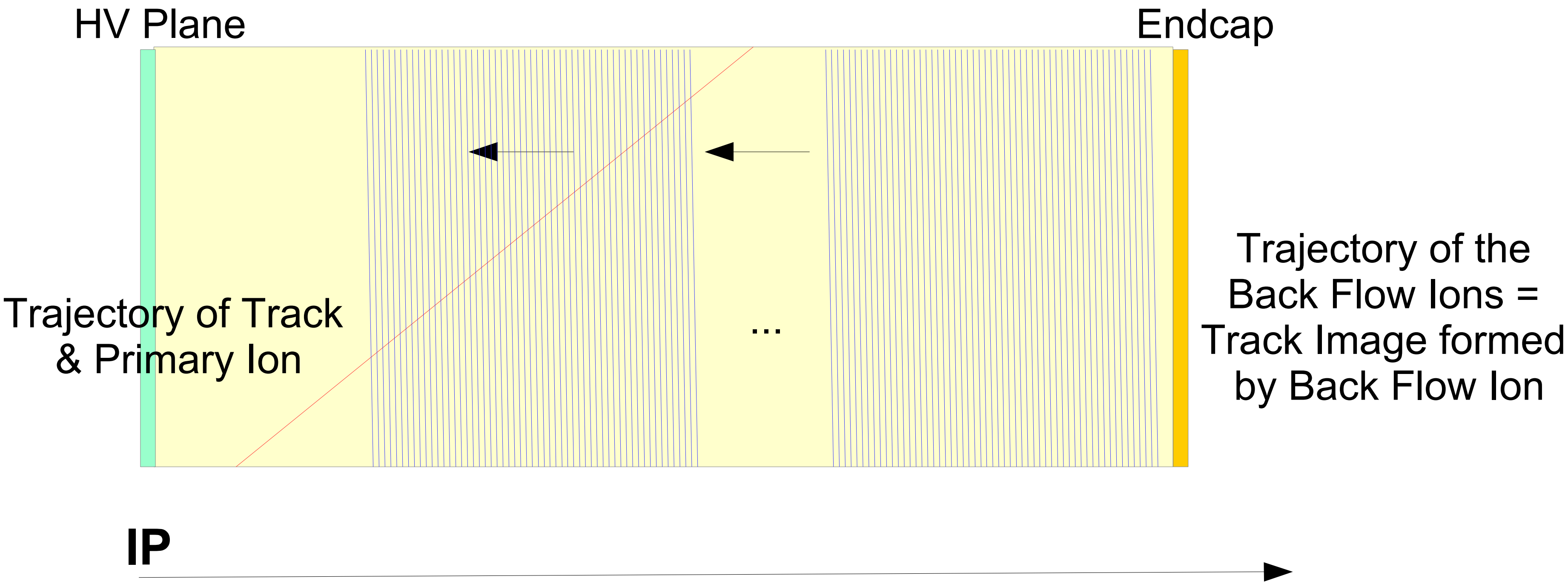
http://ias.ust.hk/program/shared_doc/2017/201701hep/HEP_20170125_Franco_Bedeschi.pdf

Tasks ahead

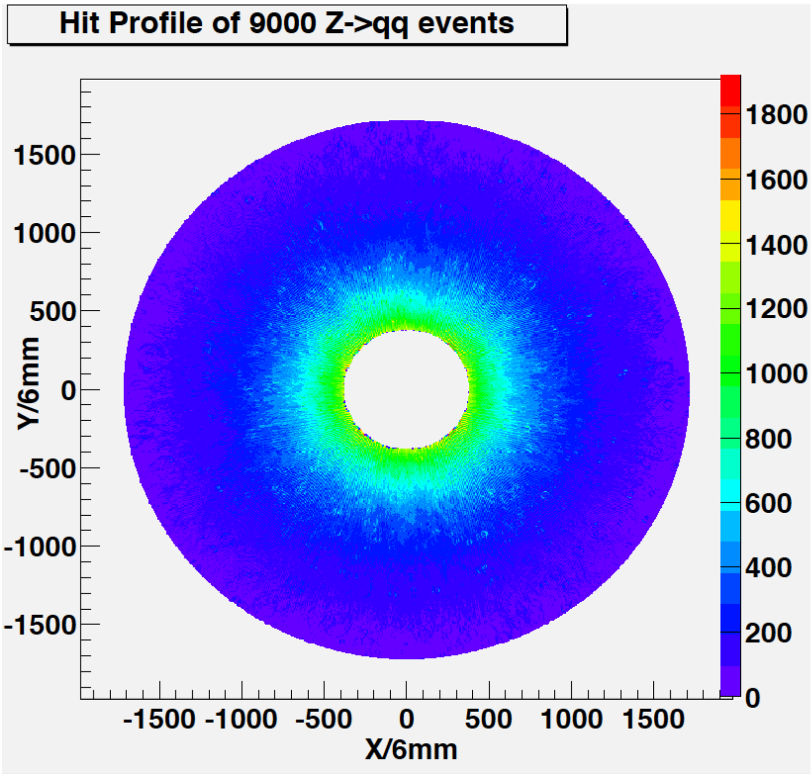
- Software & reconstruction: maintenance, Development and optimization
- Optimization:
  - Simulation study at physics benchmarks
  - Iteration with hardware study & Quantify the physics requirement
- Further exploration of Physics potential
  - I.e, EW analysis & New Physics analysis
- Get prepared: From CDR to TDR
  - Sub Detector, design, prototype and integration

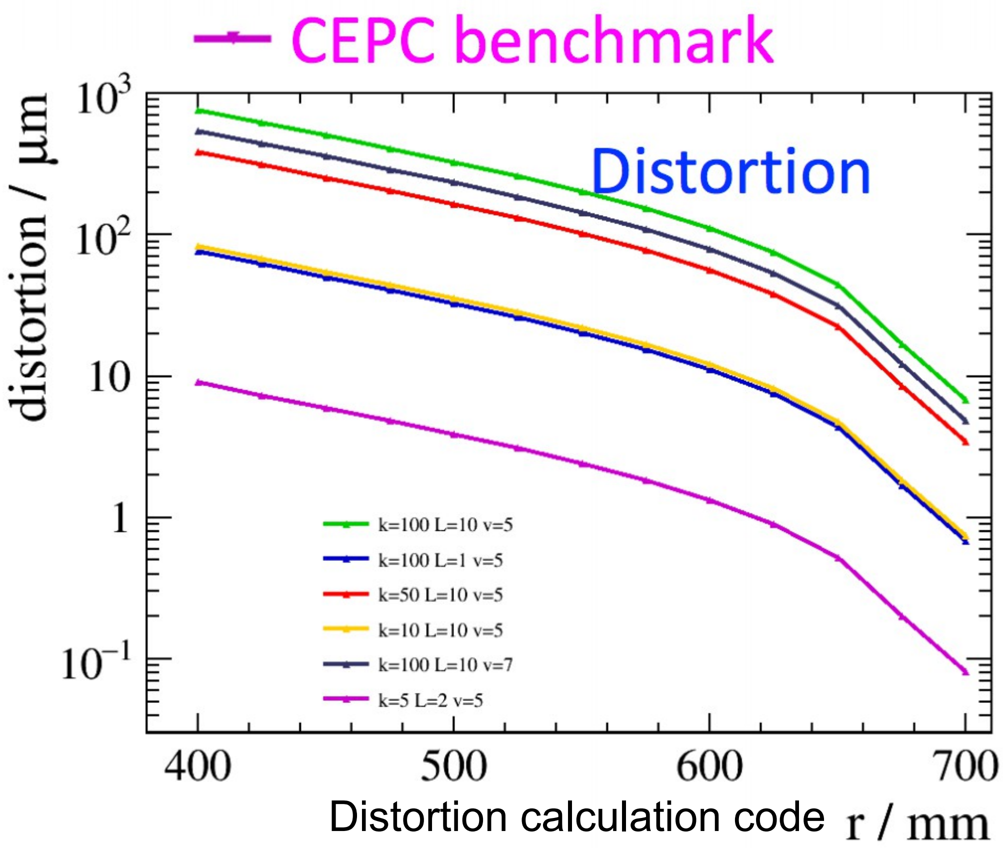
Feasibility of TPC at Z pole

- 600 Ion Disks induced from Z->qq events at 2E34cm^{-2}s^{-1}
- Voxel occupancy & Charge distortion from **Ion Back Flow** (IBF)
- Cooperation with CEA & LCTPC



TPC Feasibility (Preliminary)

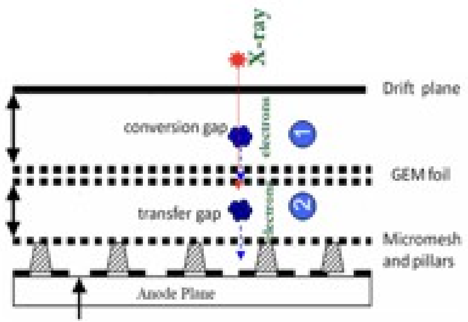


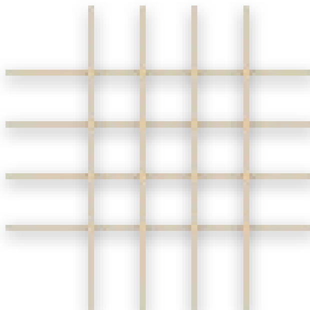


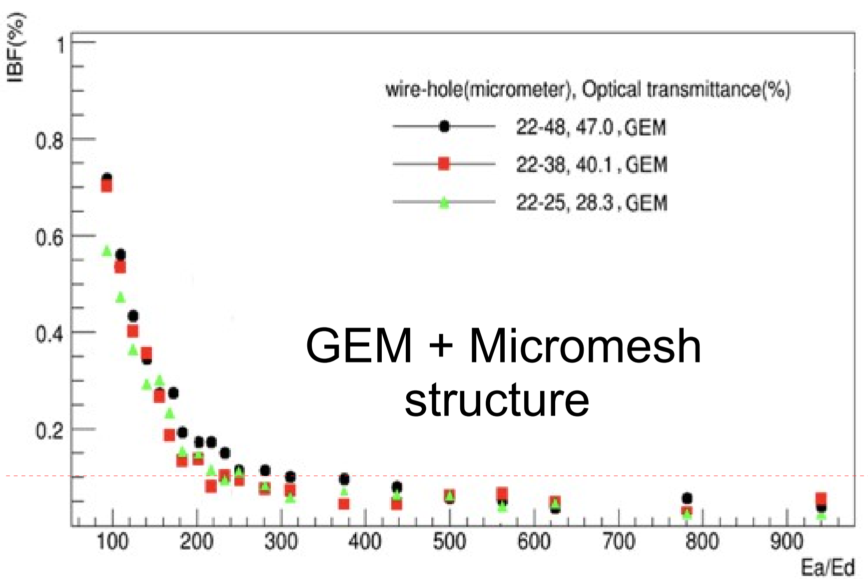
Distortion calculation code provided by KEK

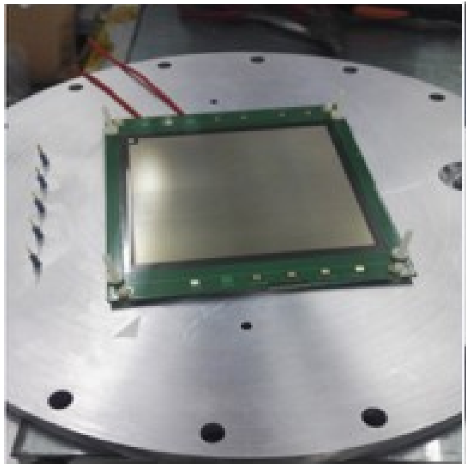
- Conclusion:
  - Voxel occupancy ~ (10^-5 – 10^-7) level, safe
  - **Safe for CEPC If the ion back flow be controlled to per mille level** - The charge distortion at ILD TPC would be one order of magnitude then the intrinsic resolution (L = 2E34 $cm^{-2}s^{-1}$)

R&D on the IBF control

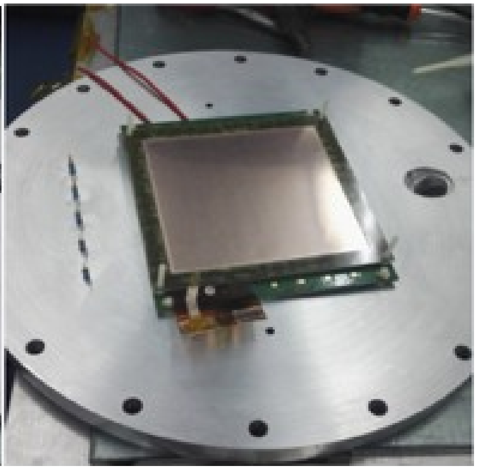




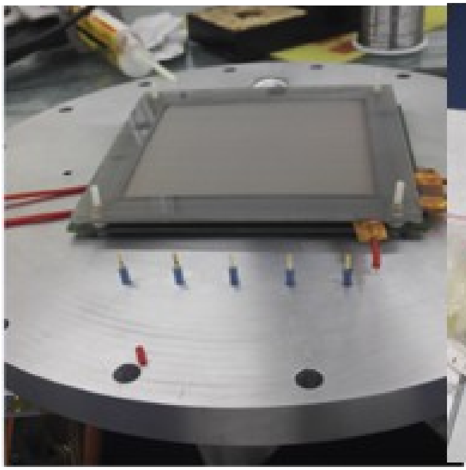




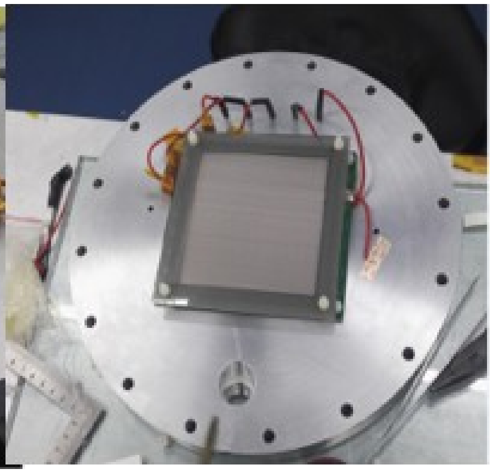
Micromegas(Saclay)



GEM(CERN)

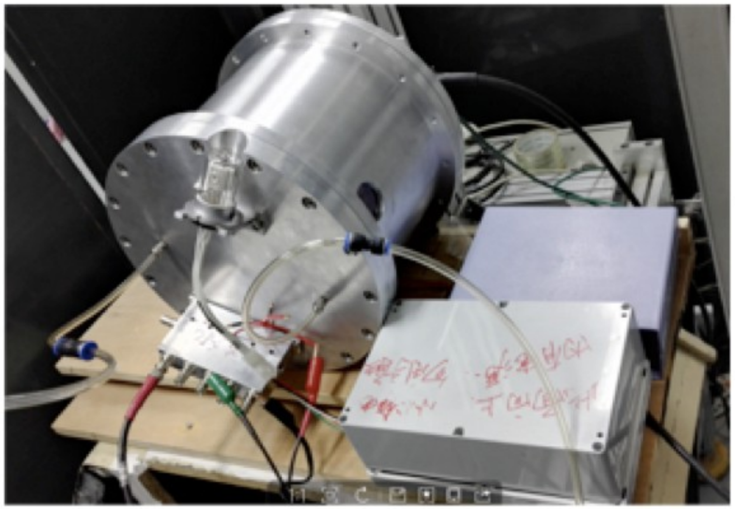


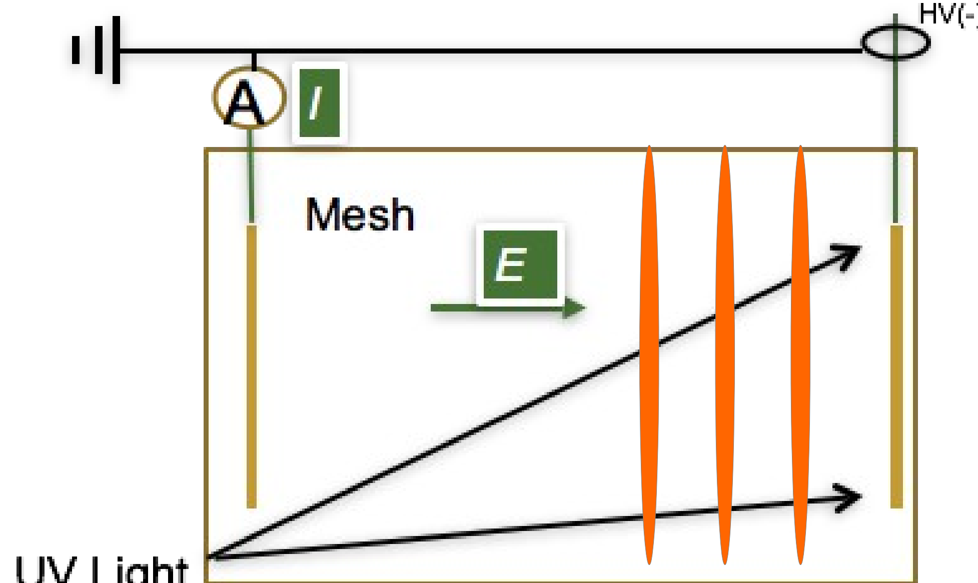
Cathode with mesh



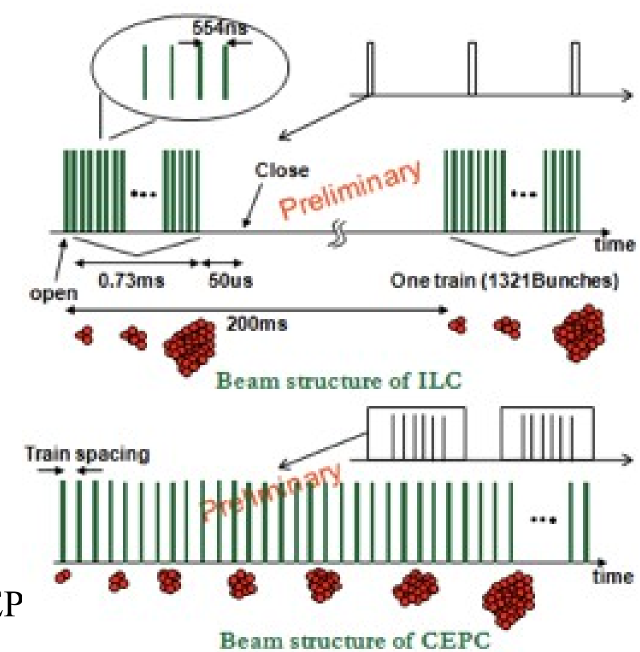
GEM-MM Detector

Next step: UV test to the IBF





To Mimic the bunch structure & the Ion Distortion with track induced by Laser beam

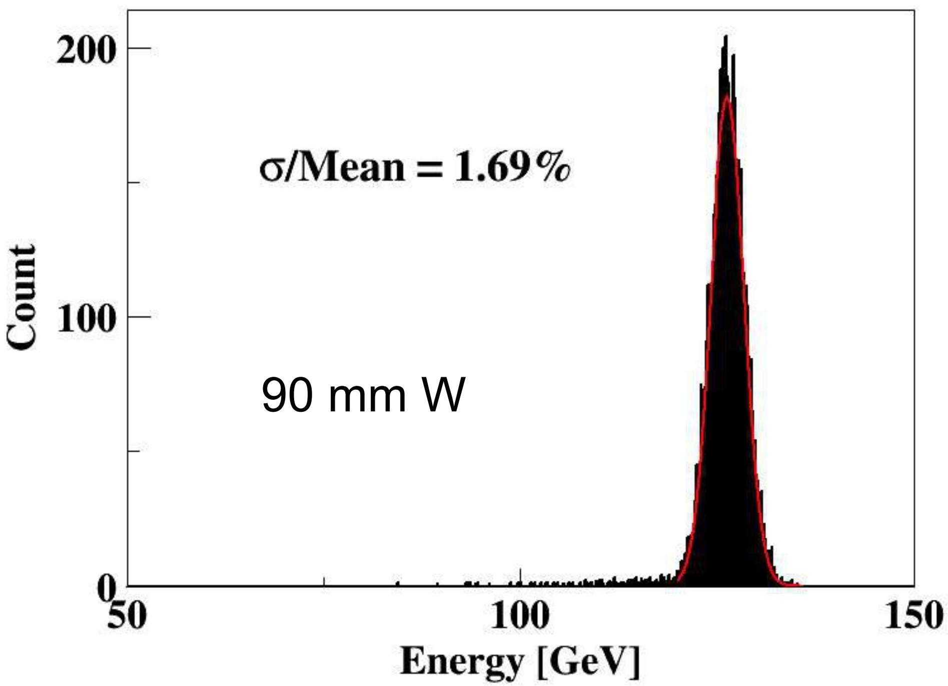


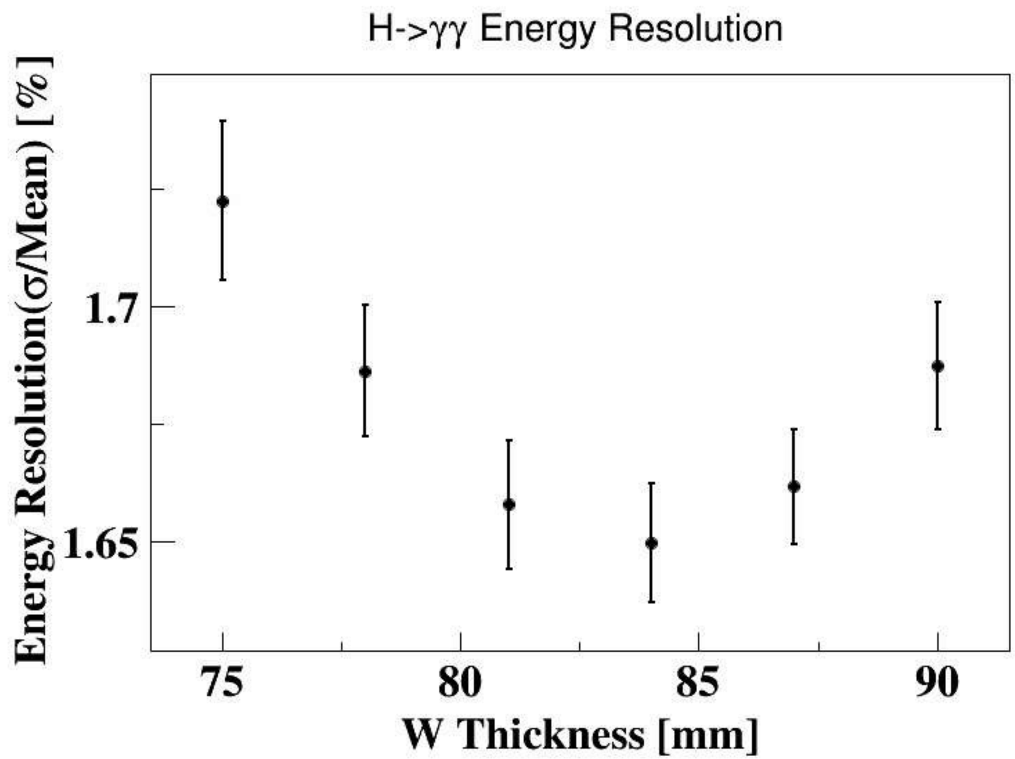
Calorimeter Optimization

- No Power Pulsing: Feasibility study of Passive Cooling
  - Number of channels need to reduced by more than 1 orders of magnitudes, test Geometries implemented (10-20 mm ECAL/HCAL Cell + reduced layers)
  - Performance on objects & Higgs Benchmarks
    - Photon & H->photons
    - Lepton & Higgs recoil
    - Jets & H->gluons, H->WW*
  - Cooperation with In2p3-LLR (MoU signed) & CALICE

- Determination of the geometry parameters for the calorimeter
  - HCAL Thickness
  - ECAL Thickness, Number of Layers & Cell Size

H->di photon Vs W thickness

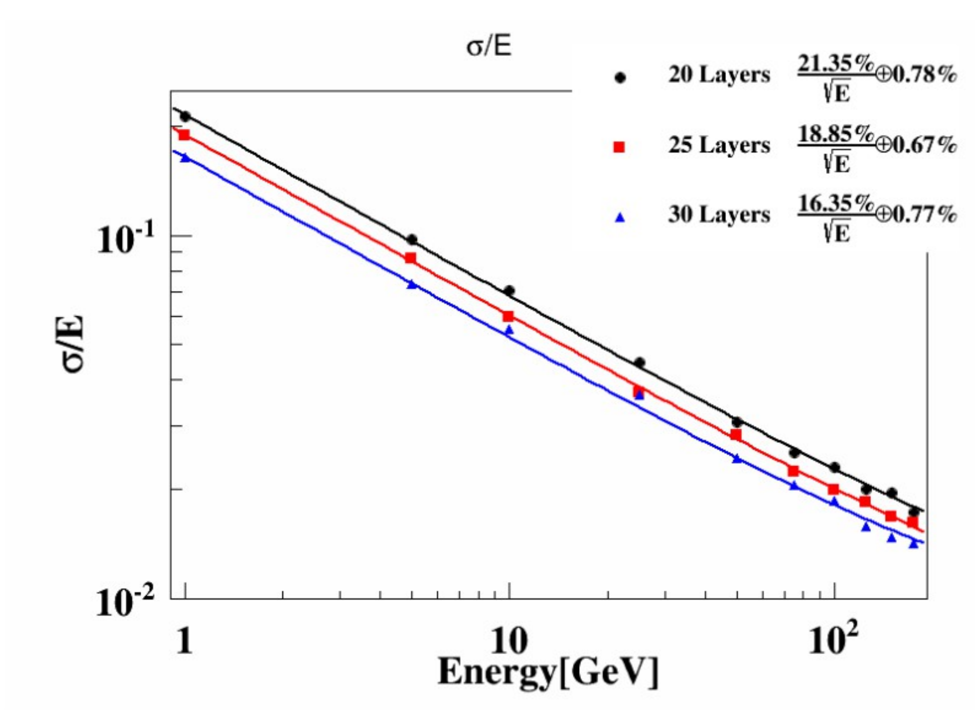


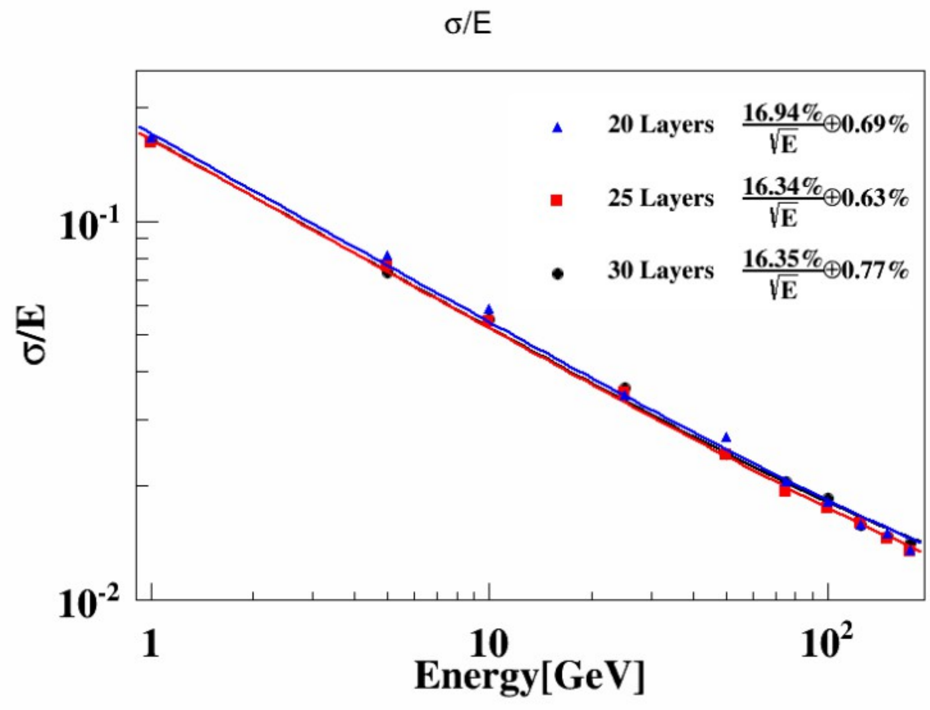


30 Layers, each layer with 0.5 mm Si + 2 mm PCB
ECAL only performance

Optimization on the in-homogeneous longitudinal structure (i.e, Absorber thickness at different layer) not applied

Photon energy measurement Vs Longitudinal structure: #Layer & Si Thickness





Performance @ Photon with E > 1 GeV:

Energy Resolution is comparable at:

20 * 1.5 mm Si + 4.5 mm W
25 * 1 mm Si + 3.6 mm W
30 * 0.5 mm Si + 3 mm W

What's the maximal viable silicon wafer thickness?

Key performance: Separation

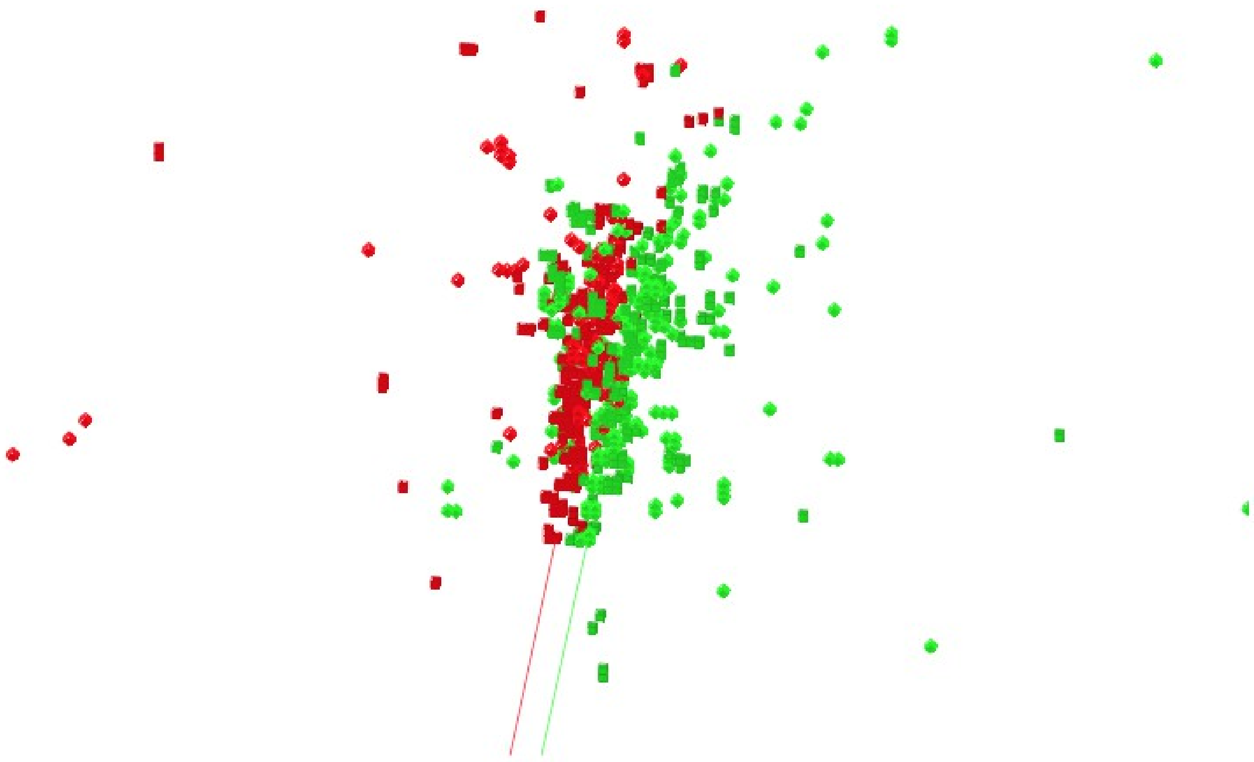
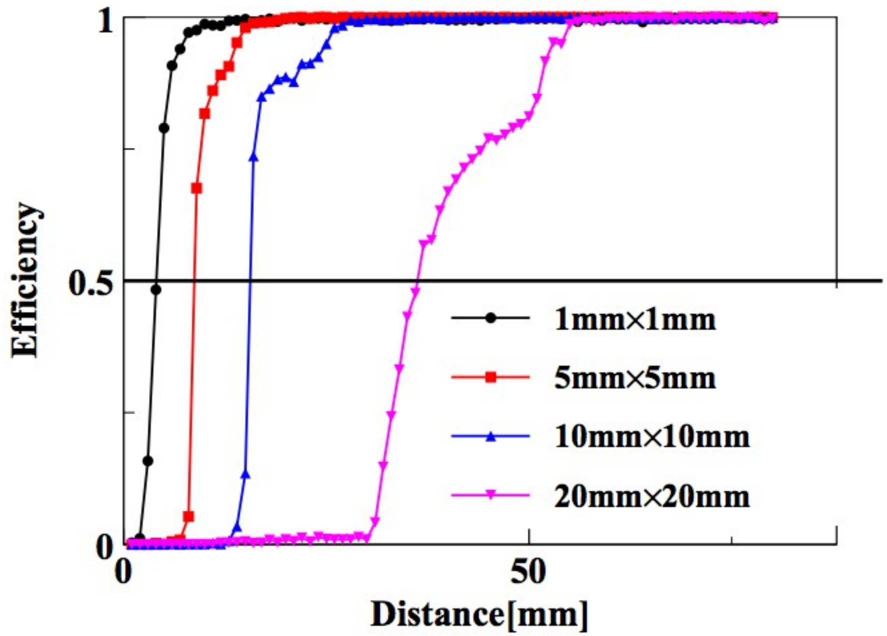
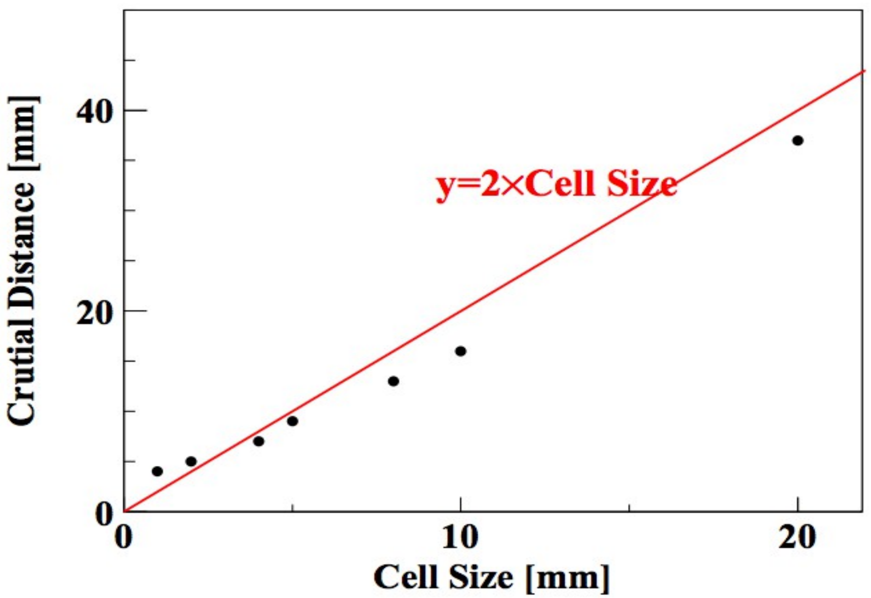


Figure 11. Event display of reconstructed di-photon.

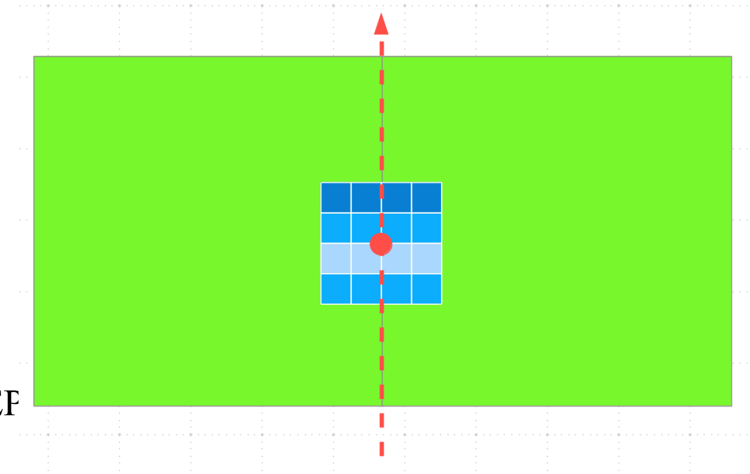
Critical distance: ~ 2*Cell Size



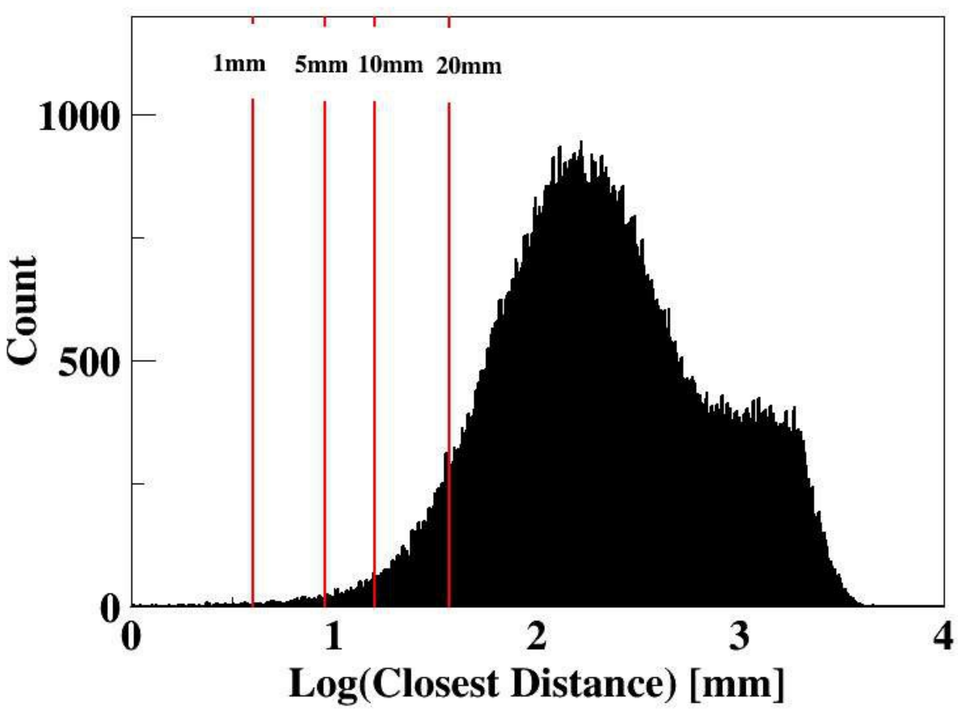


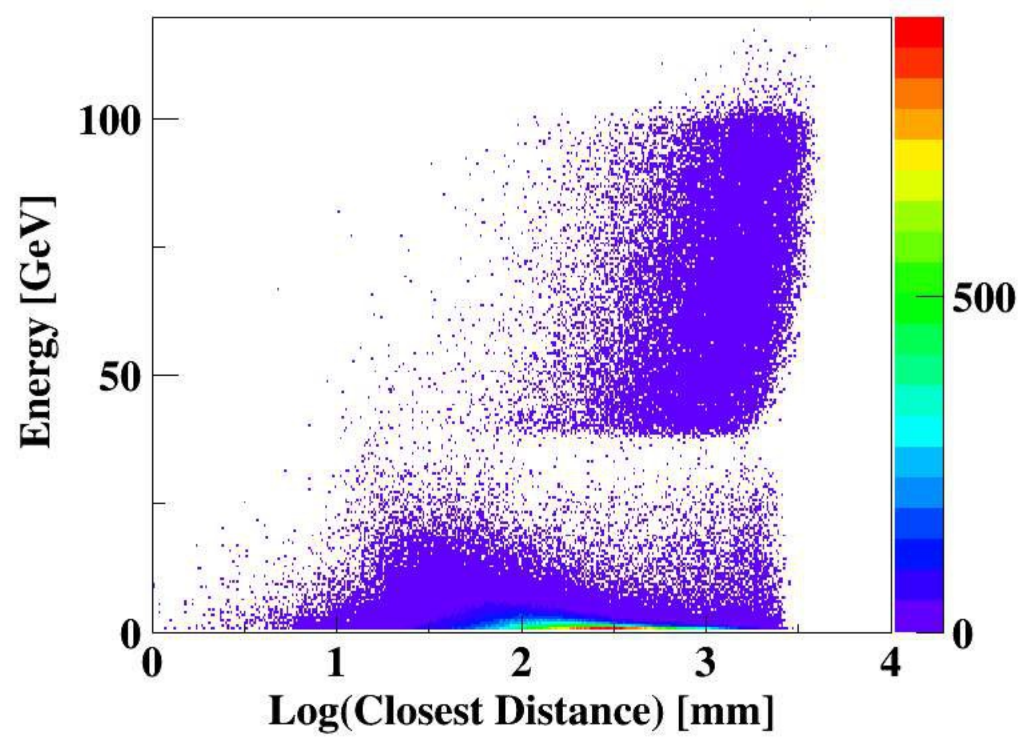
Simulation at 1 mm Cell & Digitized
To large cell size

Scan step = 1 mm



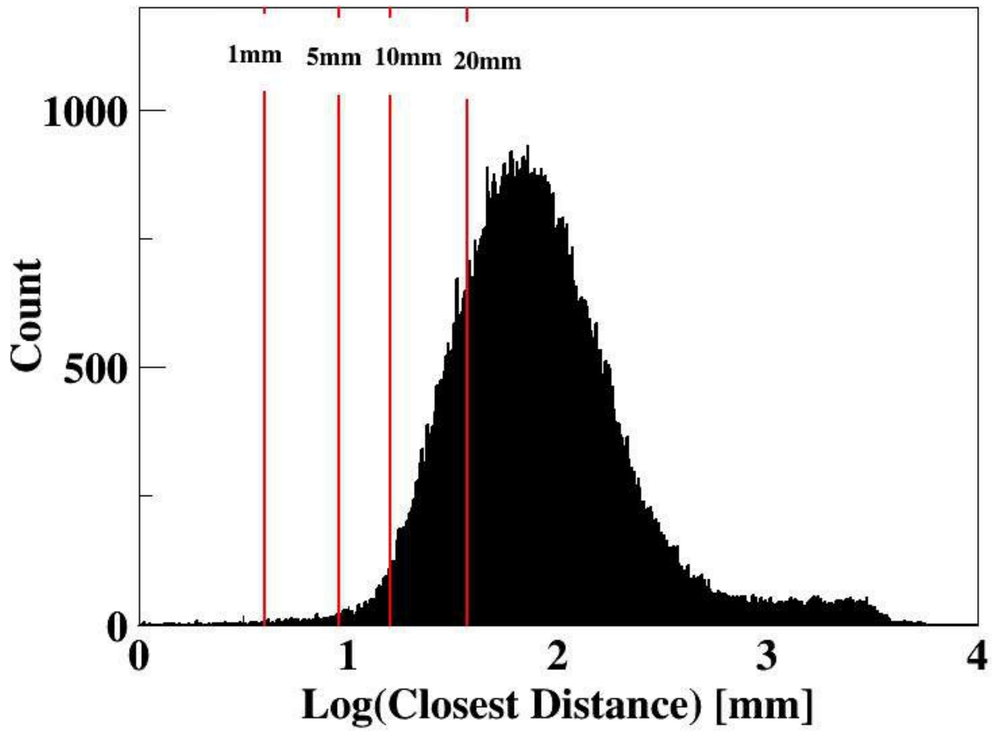
Impact of Separation: qqH, H->γγ @ 250 GeV

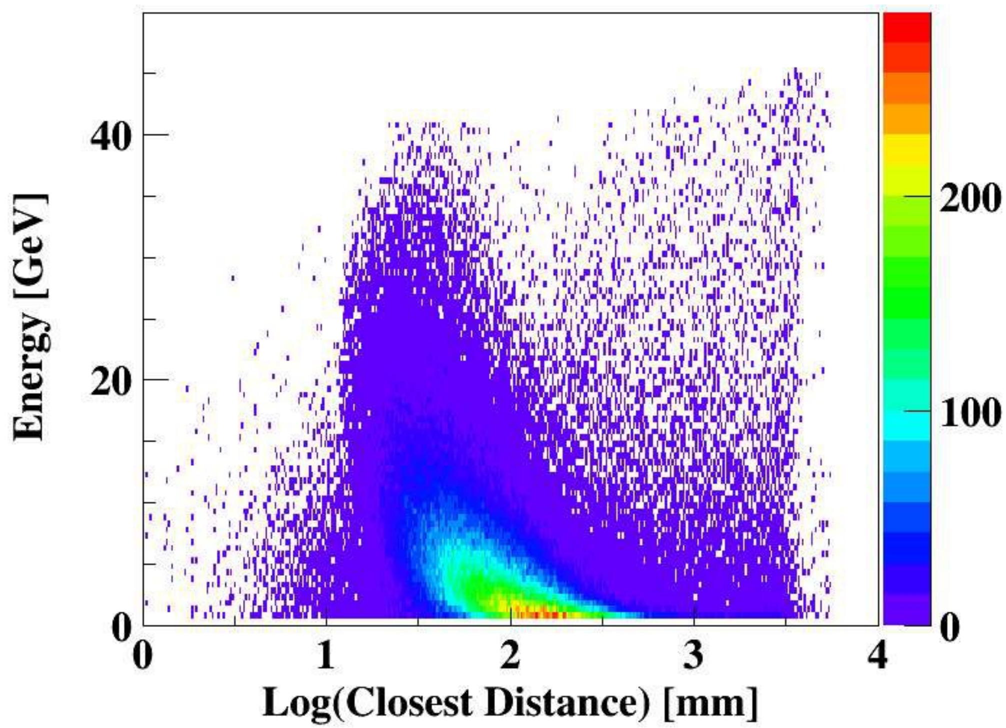




Cell Size/mm	1	5	10	20
Crucial Dis/mm	4	9	16	37
Percentage of potentially overlap photon: E > 30 GeV	0%	0%	0.1%	0.4%
E < 30GeV	0.1%	0.35%	1.1%	6.4%

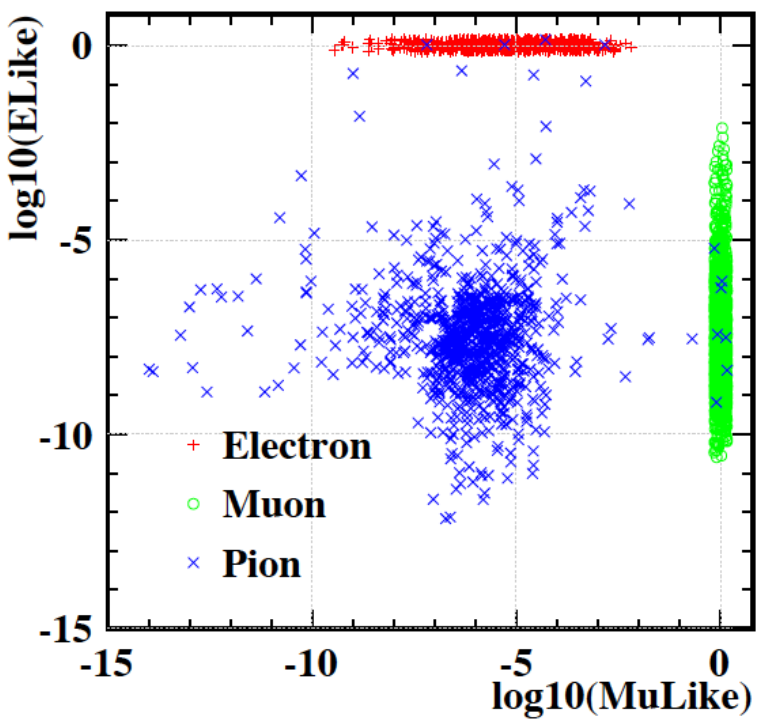
Impact of Separation: Z->tau tau @ Z pole

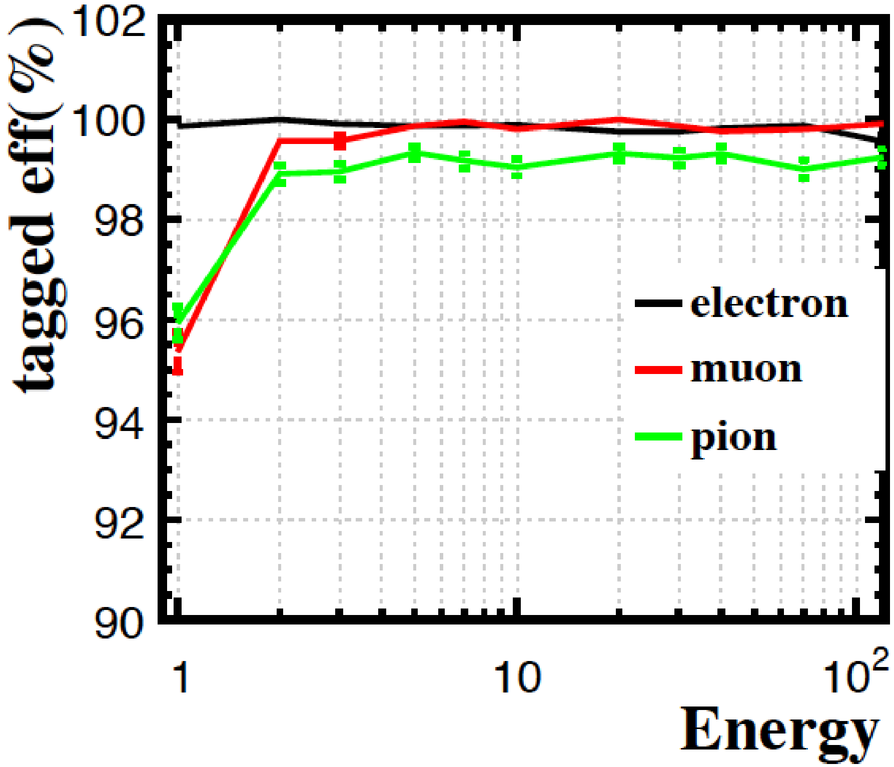




Cell Size/mm	1	5	10	20
Crucial Dis/mm	4	9	16	37
Percentage of potentially overlap photon	0.07%	0.4%	1.7%	18.6%

Dan: general Lepton ID for Calorimeter with High granularity (LICH)





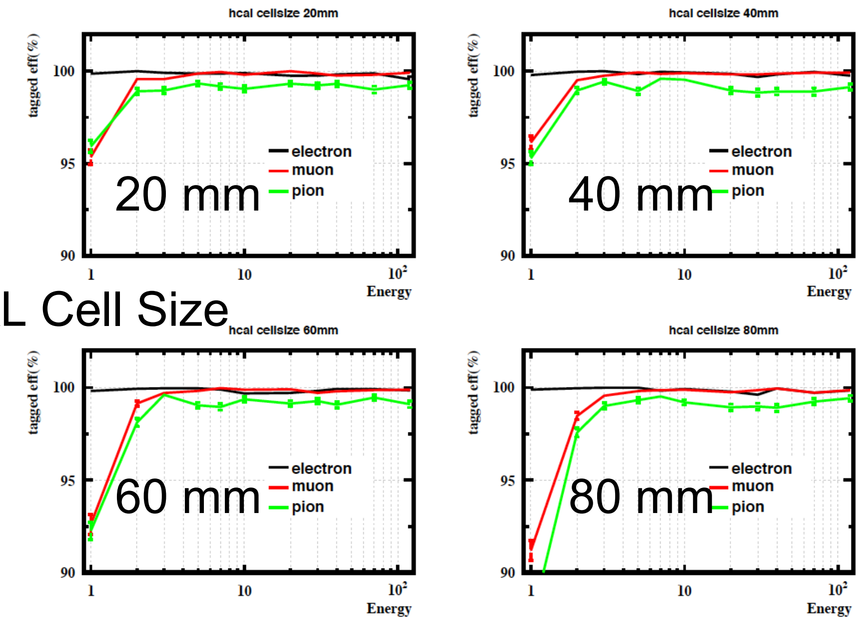
BDT method using 4 classes of 24 input discrimination variables.

Test performance by requesting
Electron = E_likeness > 0.5 ; Muon = Mu_likeness > 0.5
Single charged reconstructed particle, for E > 2 GeV: lepton efficiency > 99.5% && Pion mis id rate ~ 1%

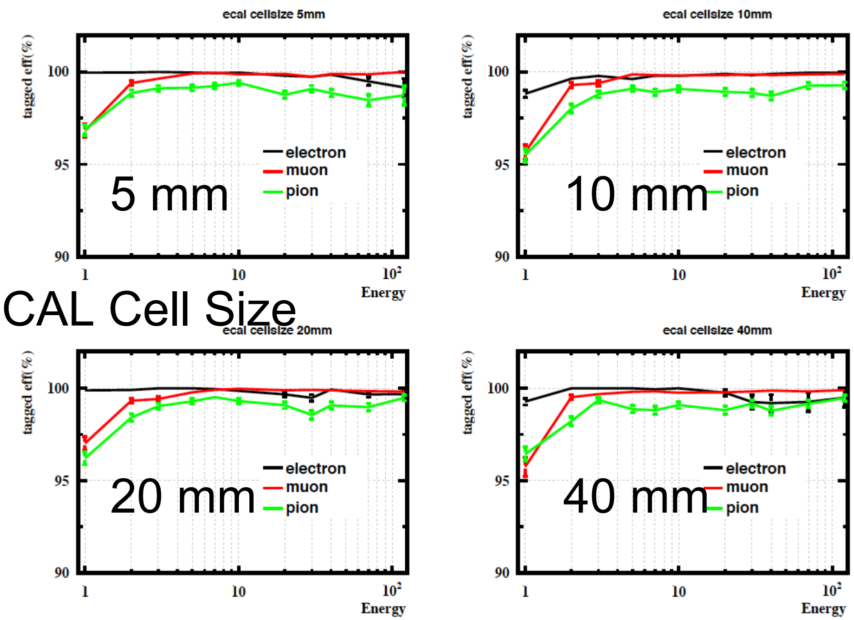
 https://arxiv.org/abs/1701.07542

Vary the granularity

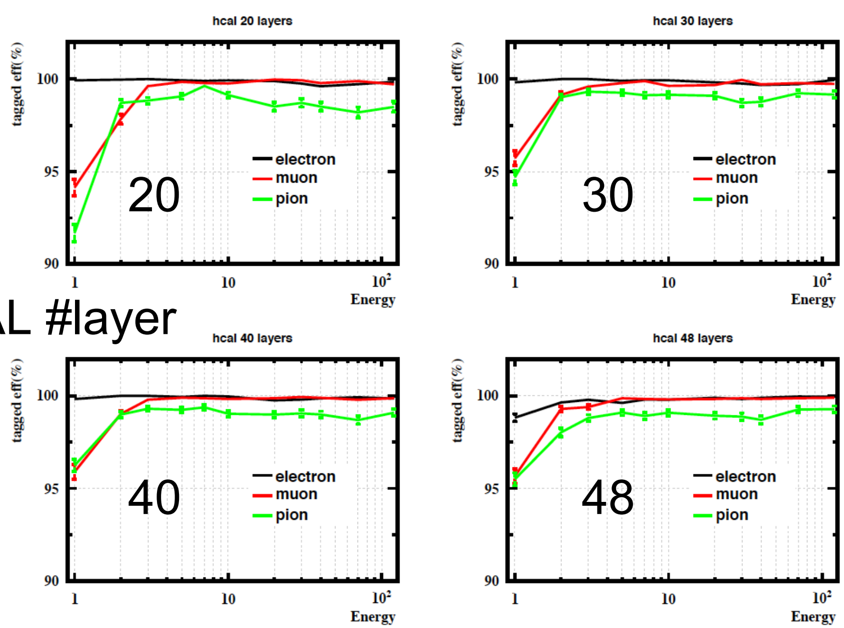
HCAL Cell Size



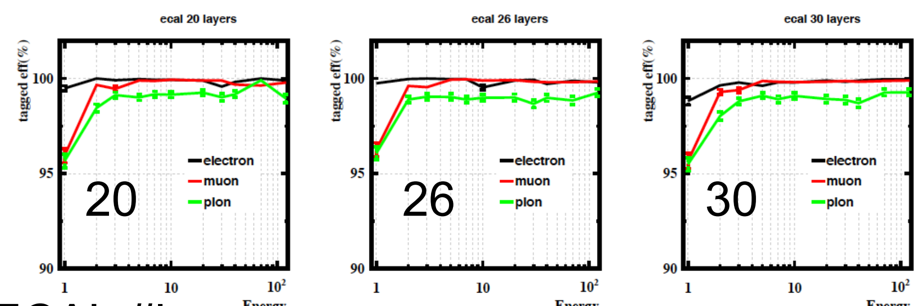
ECAL Cell Size



HCAL #layer

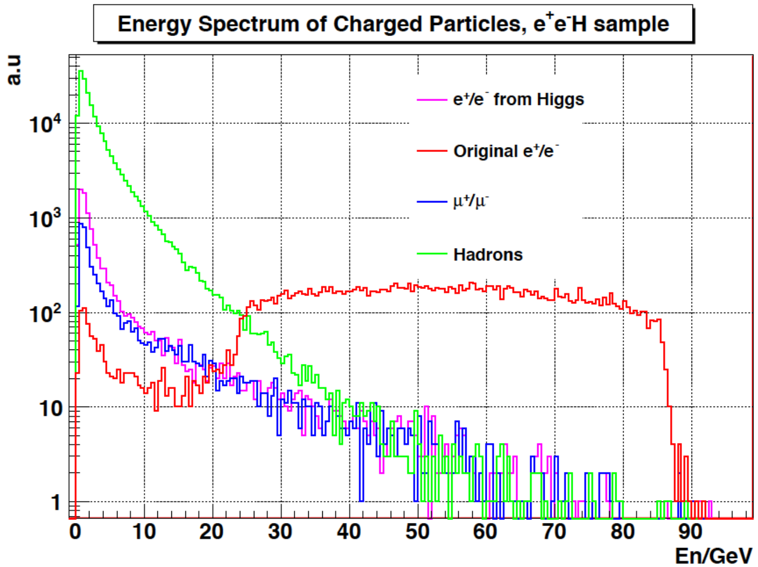


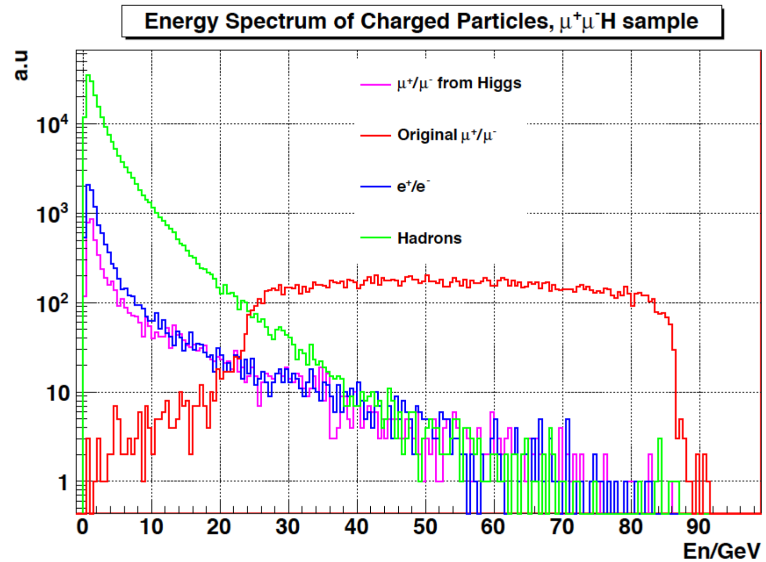
ECAL #layer

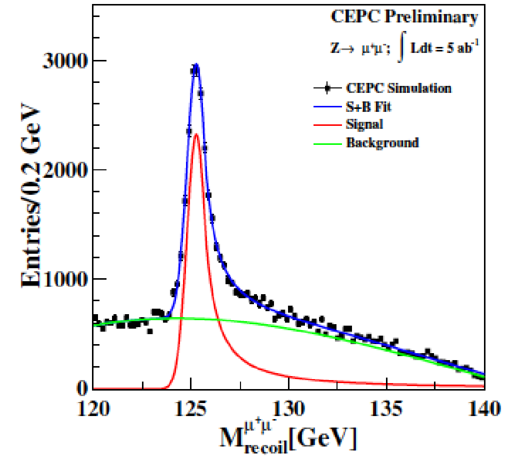


No Significant effect for E > 2 GeV charged Particles

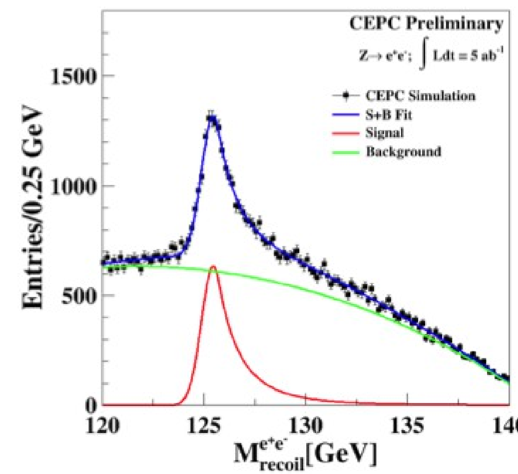
Lepton id @ Higgs recoil







	Geom 1		Geom 2	
	$\mu\mu$H	eeH	$\mu\mu$H	eeH
Cut$_\mu$	0.1	0.1	0.1	0.1
Cut$_e$	0.01	0.001	0.01	0.001
ε_E	93.41 ± 0.92	**98.64 ± 0.08**	91.60 ± 1.02	**97.89 ± 0.11**
η_E	92.02 ± 1.00	**99.74 ± 0.04**	89.89 ± 1.10	**99.67 ± 0.04**
ε_μ	**99.54 ± 0.05**	95.53 ± 0.76	**99.19 ± 0.06**	86.48 ± 1.26
η_μ	**99.60 ± 0.04**	96.31 ± 0.70	**99.83 ± 0.03**	95.38 ± 0.81
ε_{event}	98.53 ± 0.13	97.06 ± 0.19	97.24 ± 0.18	95.40 ± 0.24



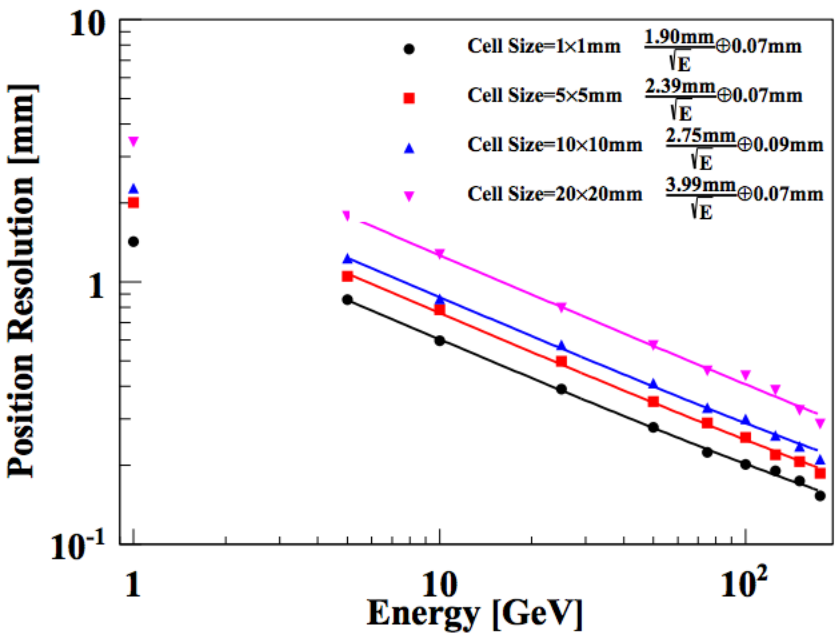
Geom 1/2: 10 (20) mm ECAL/HCAL Cell

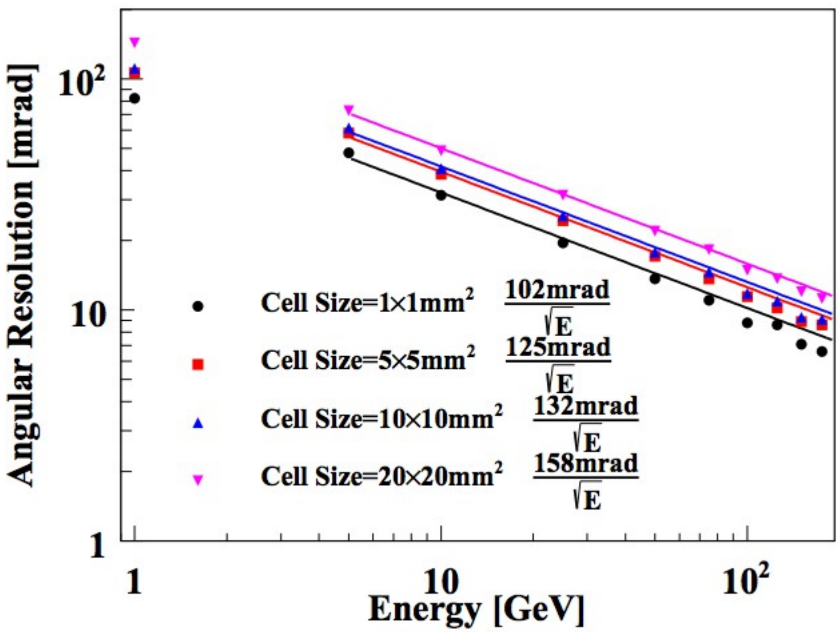
Initial Leptons identified at satisfactory efficiency & purity (limited by separation power)

More stringent requirement arrises from jet leptons...

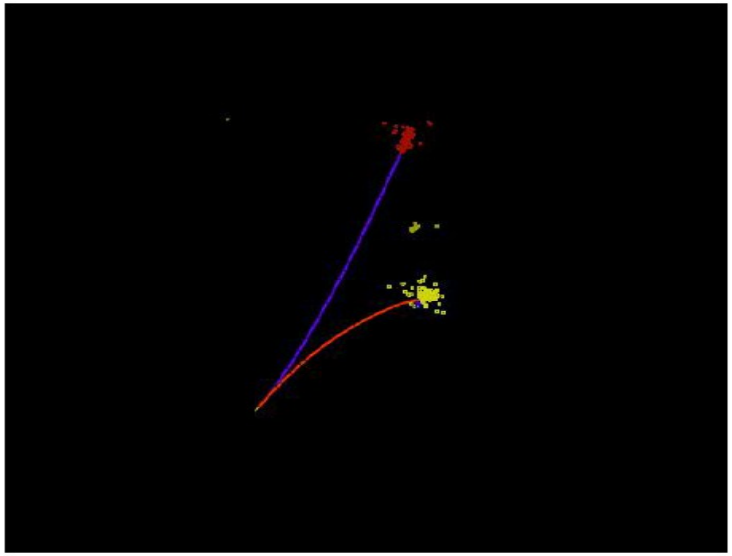
https://arxiv.org/abs/1701.07542

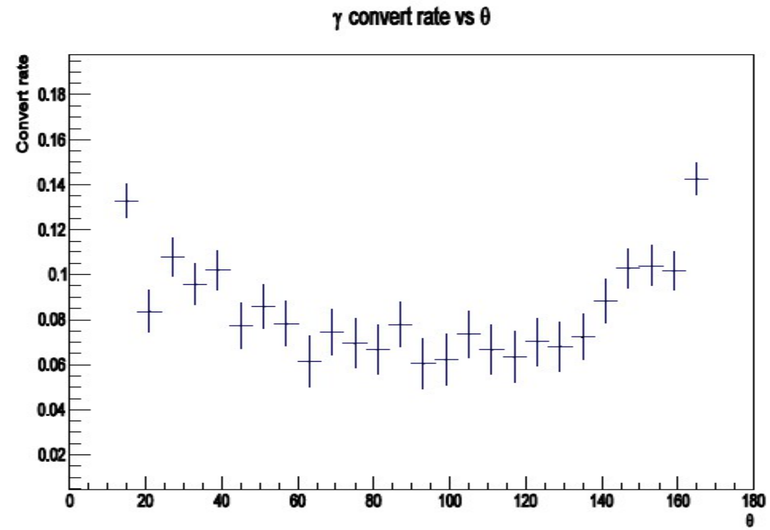
Cell Size: Position/Angular

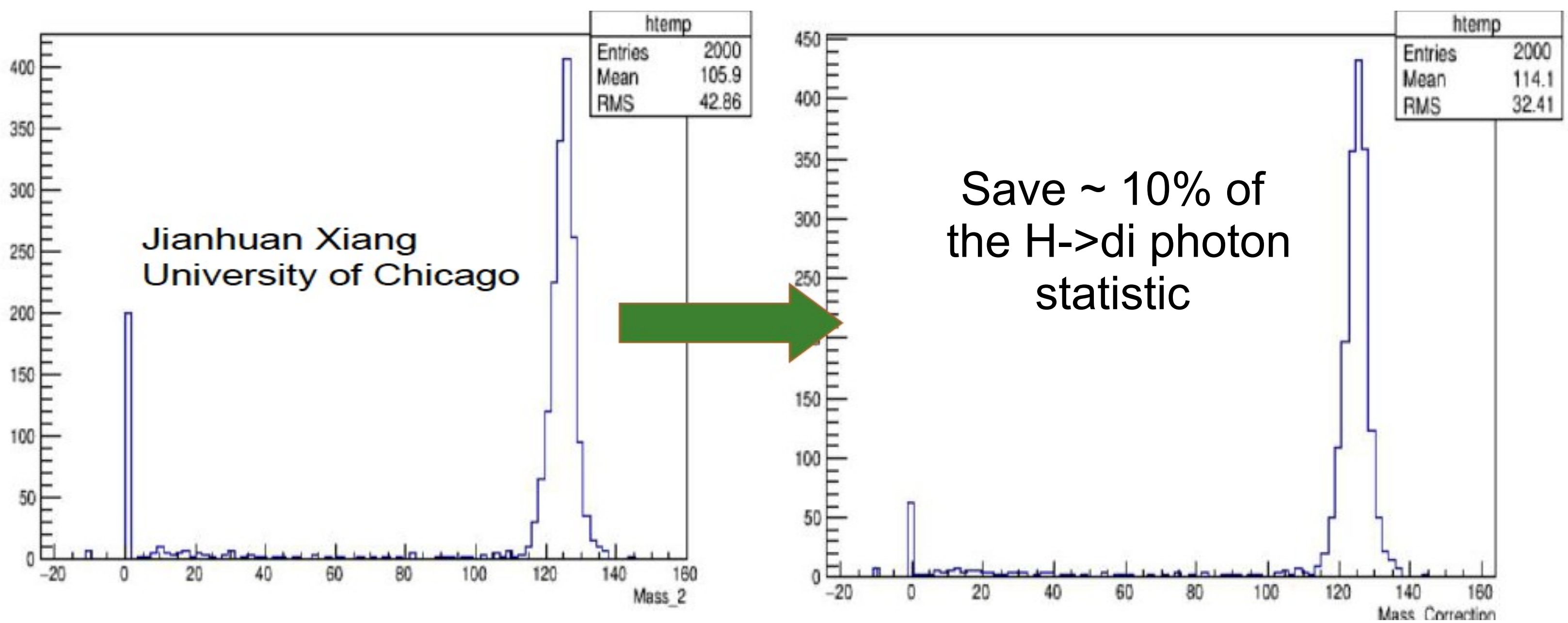




Photon conversion & recovery





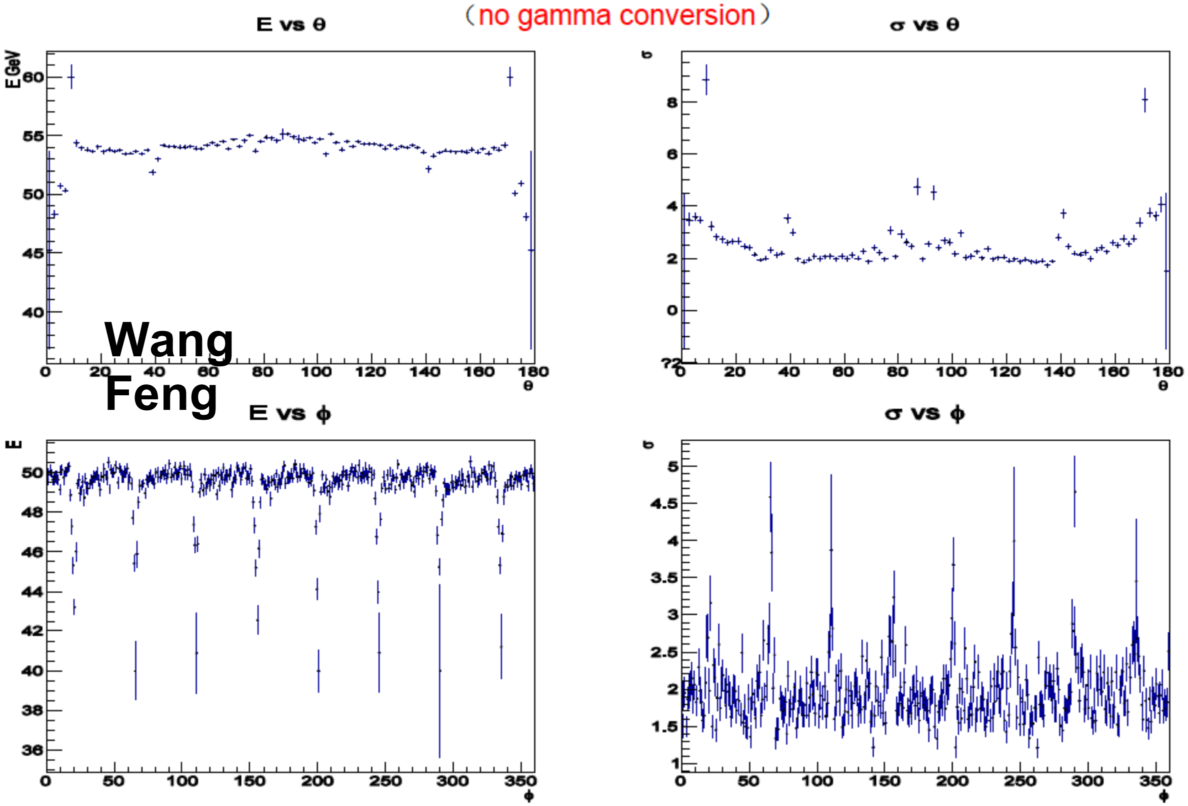


Jianhuan Xiang
University of Chicago

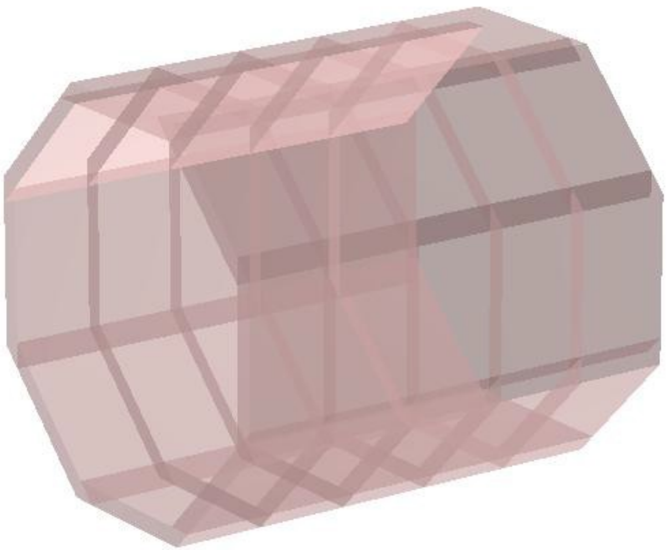
Save ~ 10% of
the H->di photon
statistic

PFA: photon reconstruction

(no gamma conversion)



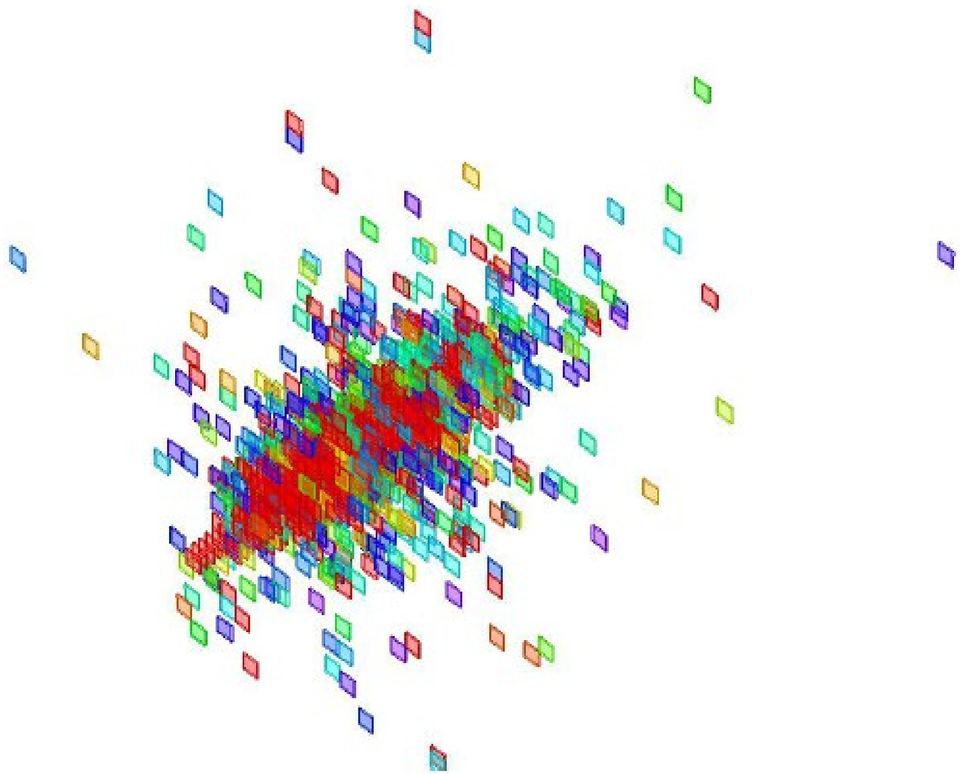
Wang Feng



ECAL Barrel of ILD/CEPC_v1

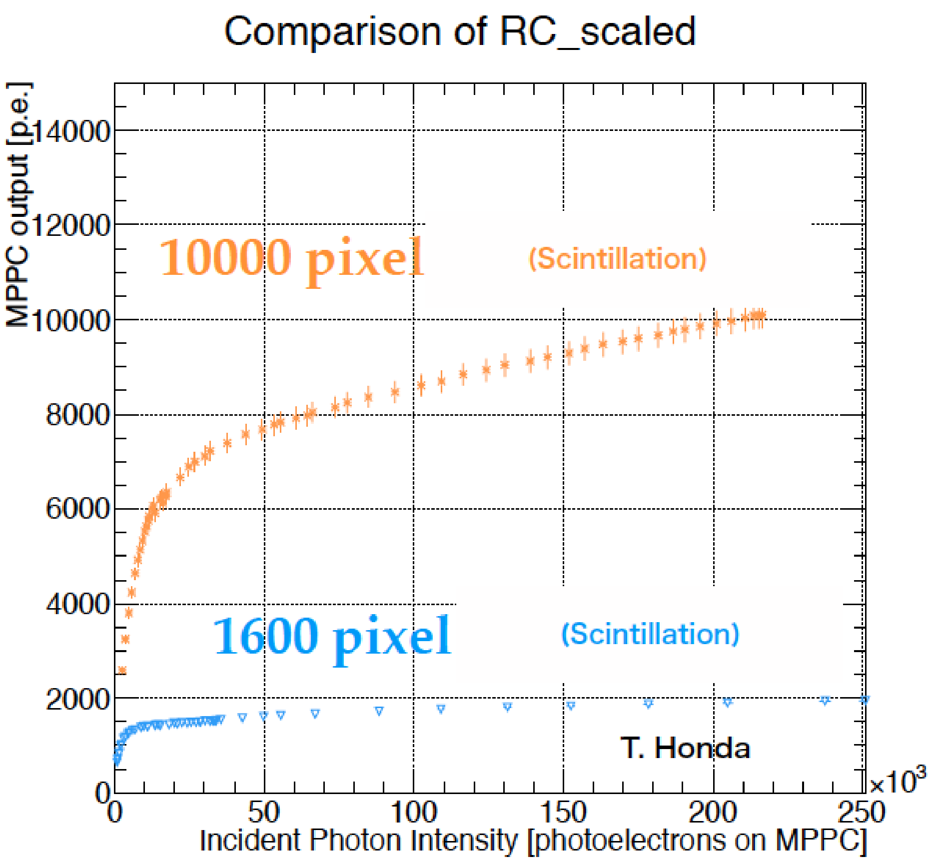
Angular Correlation of EM Shower energy response

ECAL Saturation/Linear Range Study



50 GeV Photon Cluster
at ECAL with 10 mm Cell Size

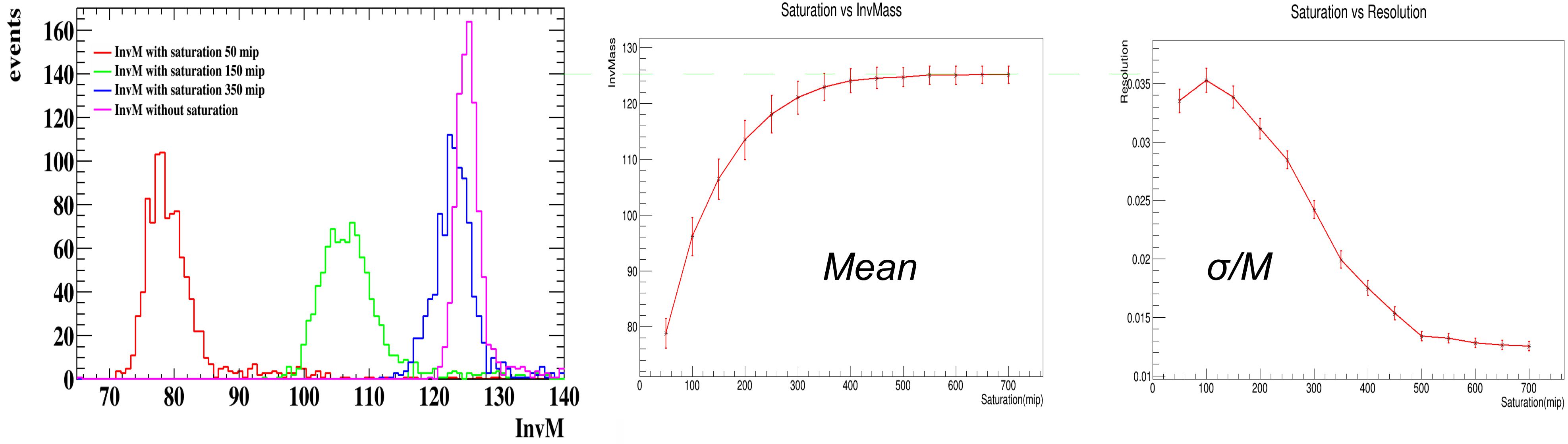
~o(1k) hits, hottest hit with E ~ 1k MIP.



T.Takeshita, ILDDET@KEK

Scintillator: MIP→Photon→P.E

Impact on H→γγ measurement



ECAL Linear Ranger: recommended to be >1k/1.8k MIP (for 10/20 mm Cell)

10k pixel SiPM readout is very challenging (If Photon generation > 10 per mip)

Empirical formula on needed ranger of a single photon:

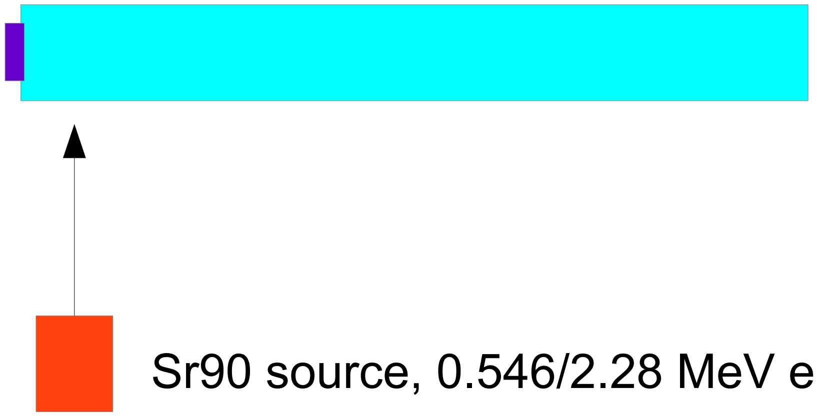
$$\log10(\text{Ranger}) = 0.87*x + 0.97*y - 0.24*y^2 + 1.26$$

$x = \log10(E)$, $y = \log10(\text{Cell Size/cm})$

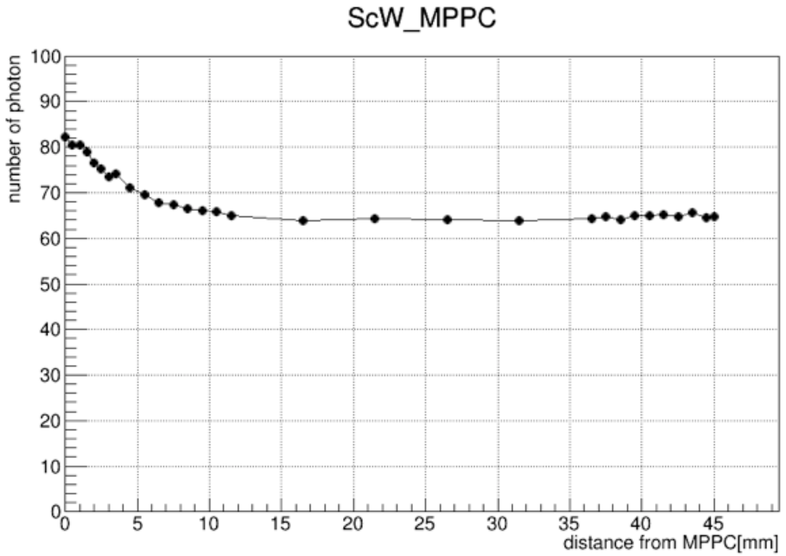
Shuzheng Wang

In-Homogeneity

- Performance degrades
  - Cracks: **20-30%** (σ/M ~ 2.4% @ CEPC_v1, with corrections)
  - By the photo yield in-homogenity (20% along the strip): **12%**
  - Local dead zone (1mm dead region along the strip of 5mm*45 mm): **8%**



Sr90 source, 0.546/2.28 MeV electron



#pixel with different hit position