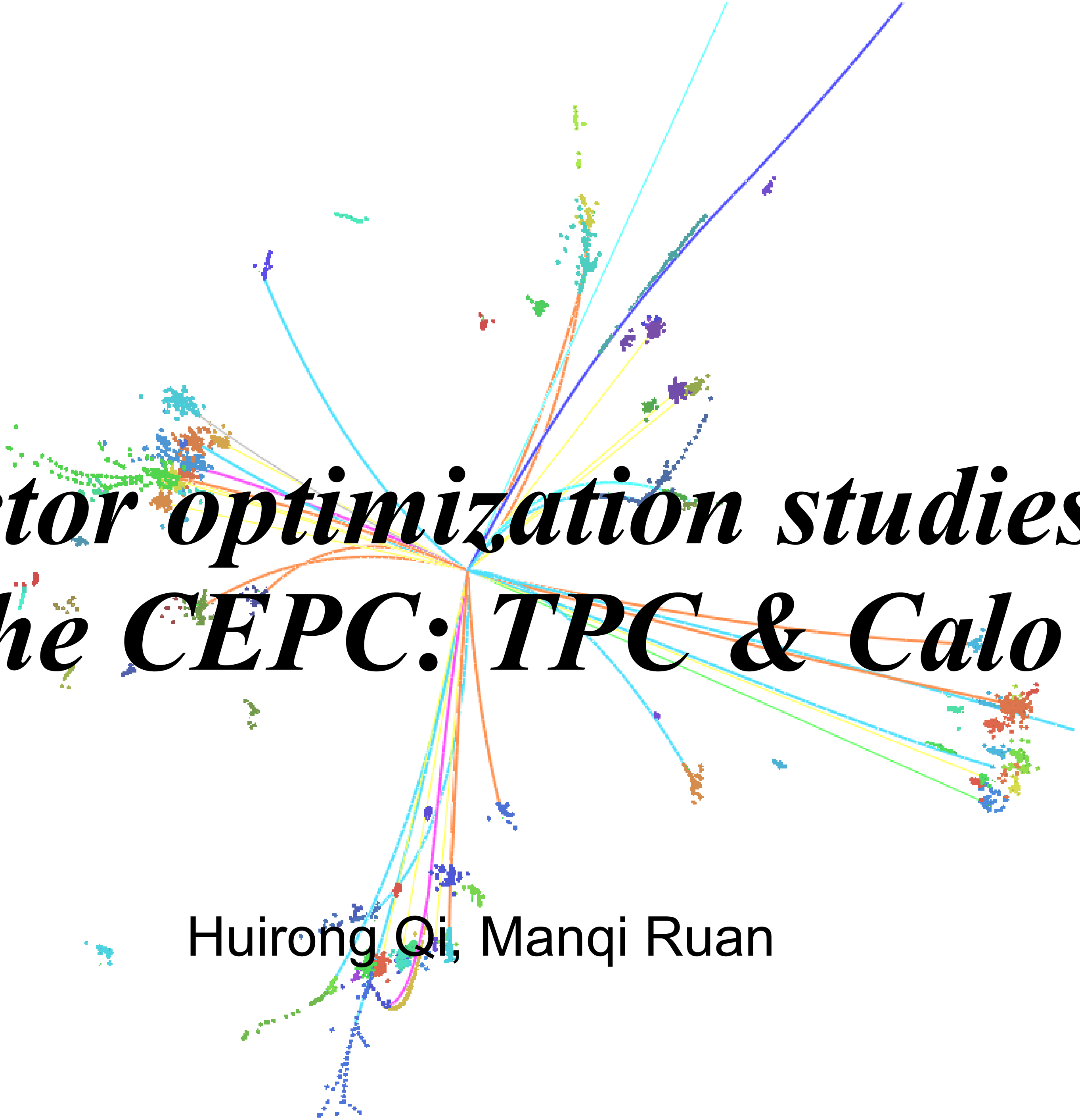
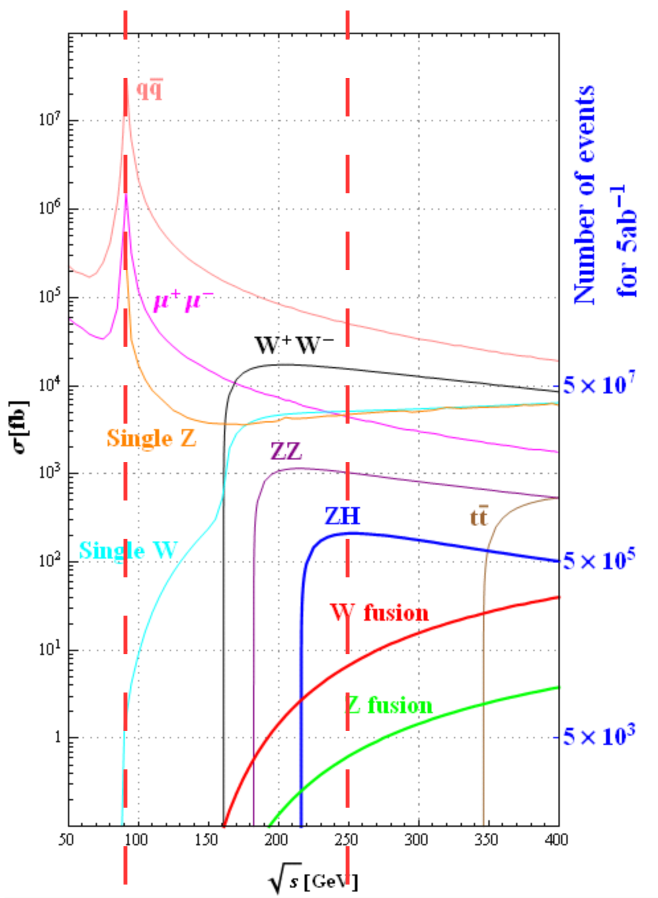
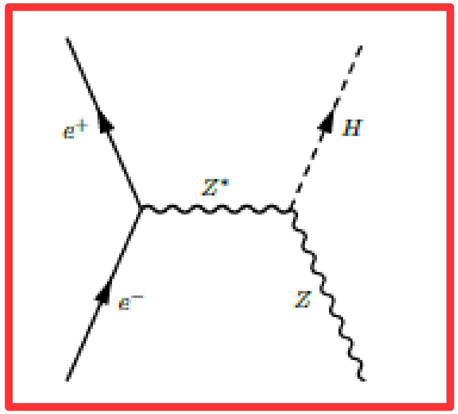


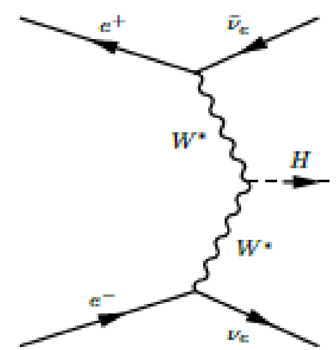
Detector optimization studies for the CEPC: TPC & Calo

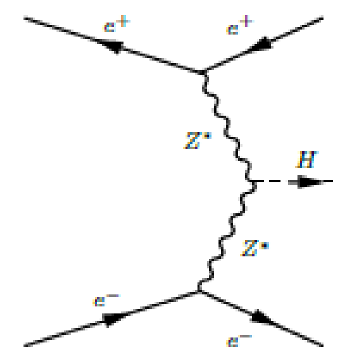
Huirong Qi, Manqi Ruan

CEPC: 1M Higgs & 10-100 B Z









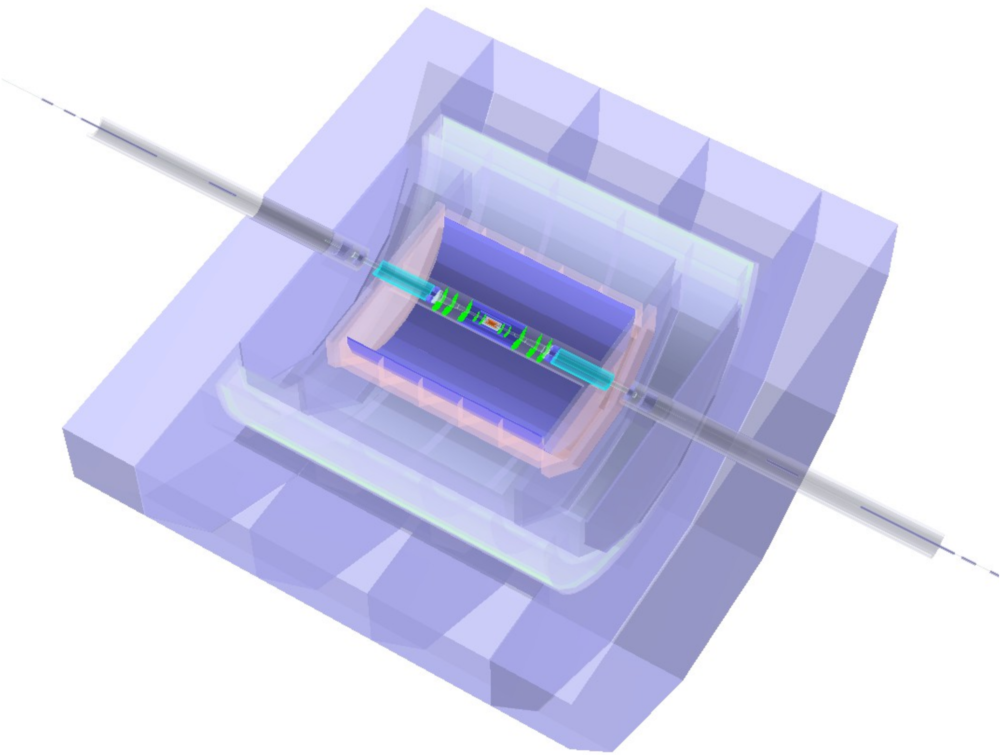
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

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

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

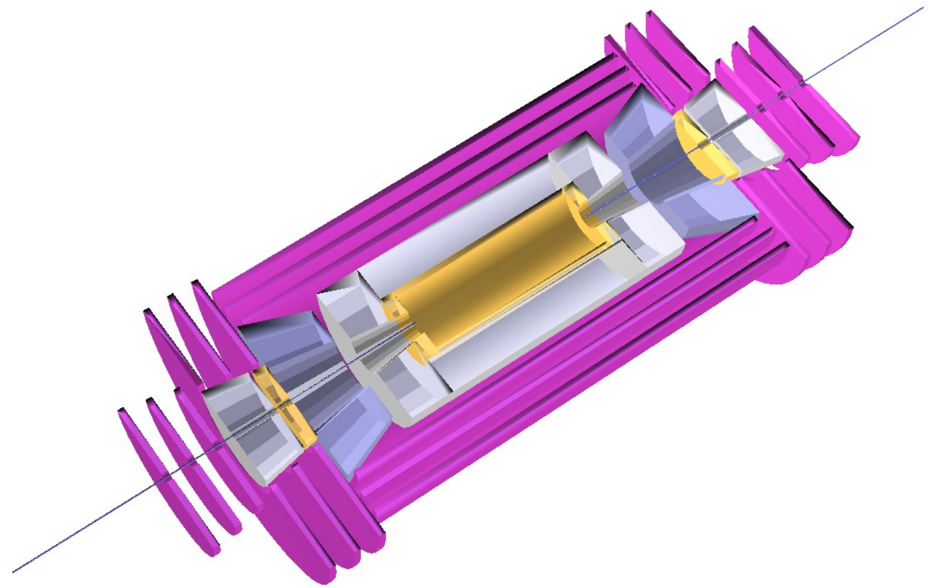
Derive: Absolute Higgs width, branching ratios, couplings

Geometries



CEPC_v1
Forward Region & Yoke Thickness
Modified w.r.t ild_o2_v05

Used for CEPC Higgs analysis

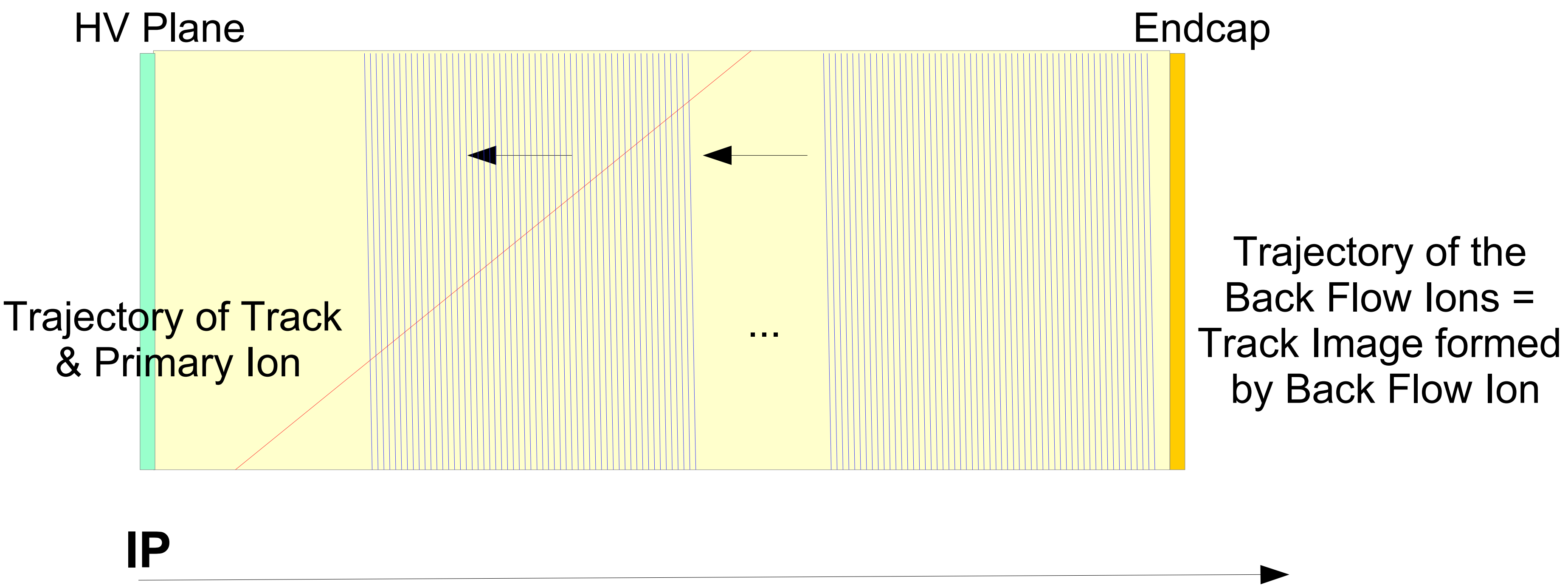


Simplified, Defect free geometry...
Cylinder like calorimeter layers,
& Silicon tracker (Optional)

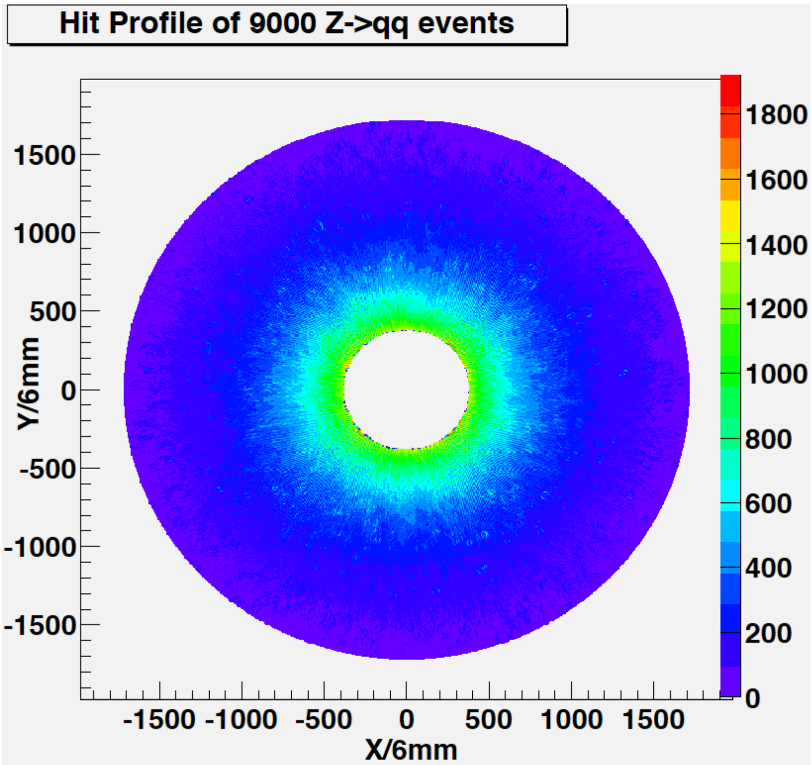
Used for Arbor tuning, Calorimeter optimization & Conceptual SPPC Detector study...

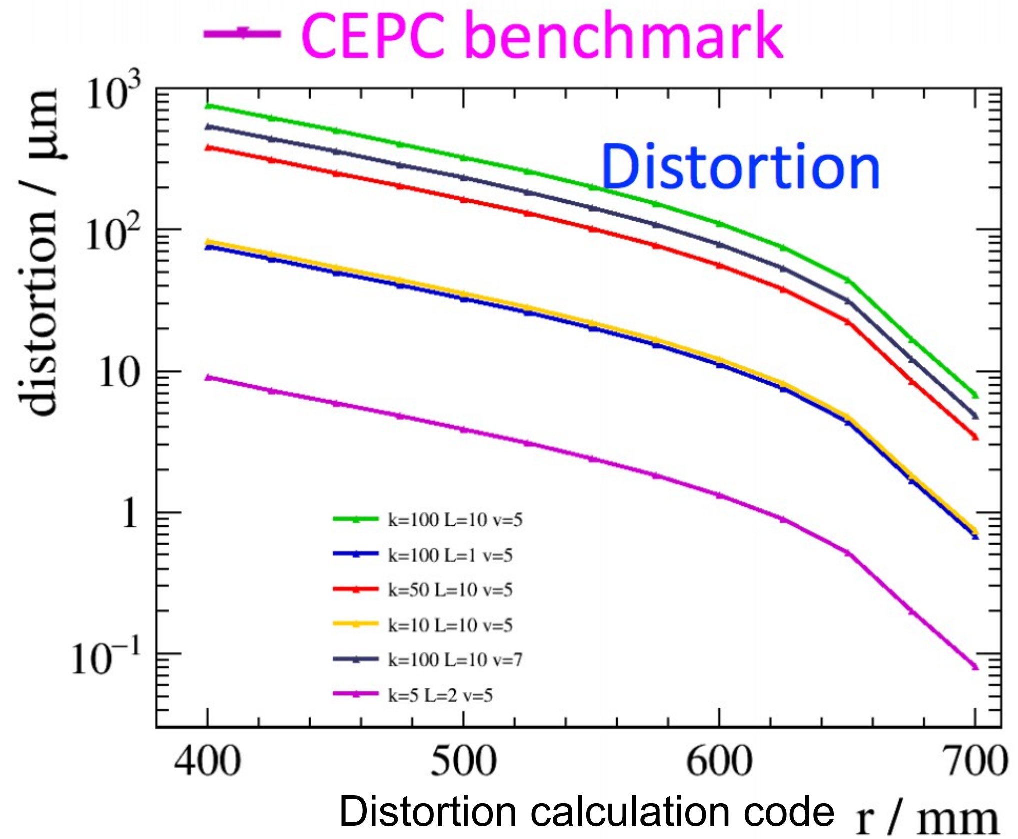
Feasibility of TPC at CEPC

- 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)

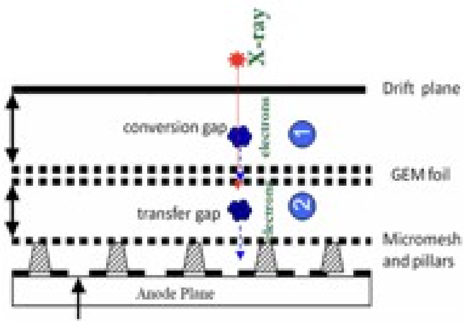


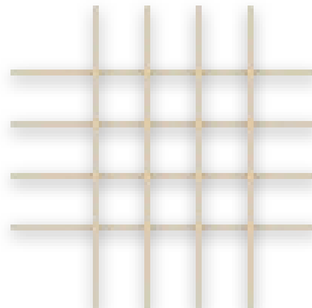


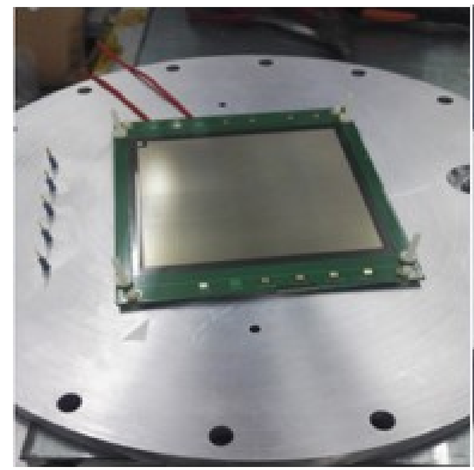
Distortion calculation code provided by KEK

- 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 $cm^{-2}s^{-1}$)

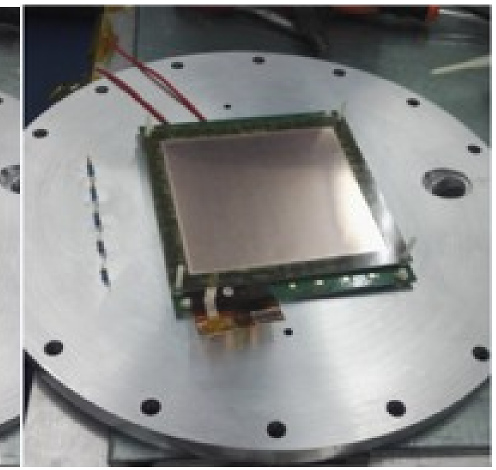
R&D on the IBF control



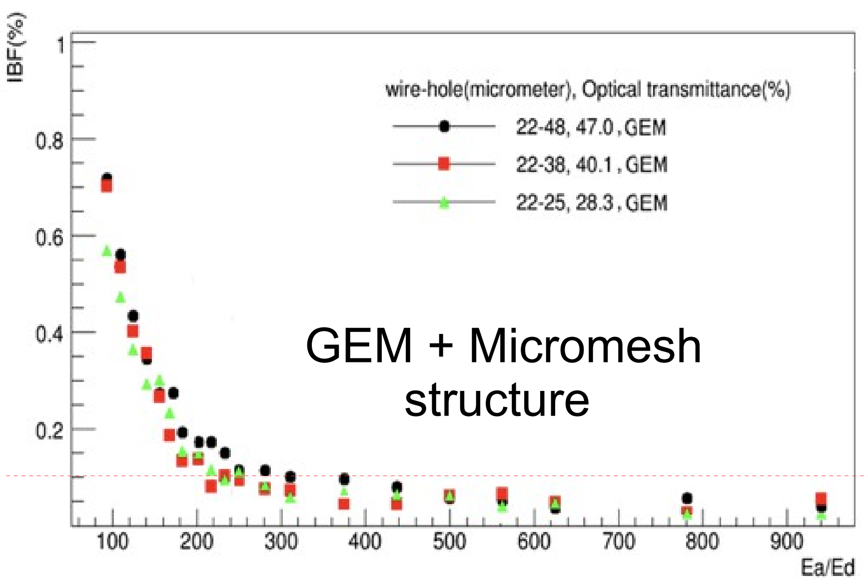




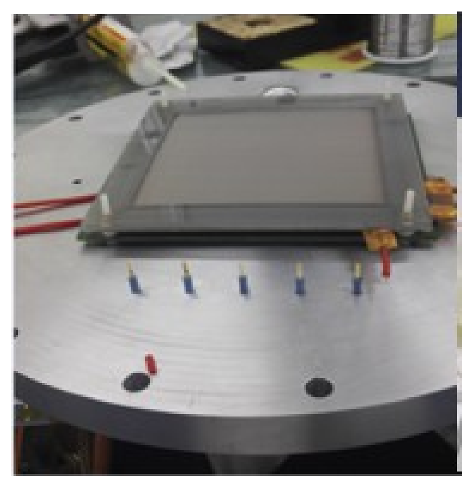
Micromegas(Saclay)



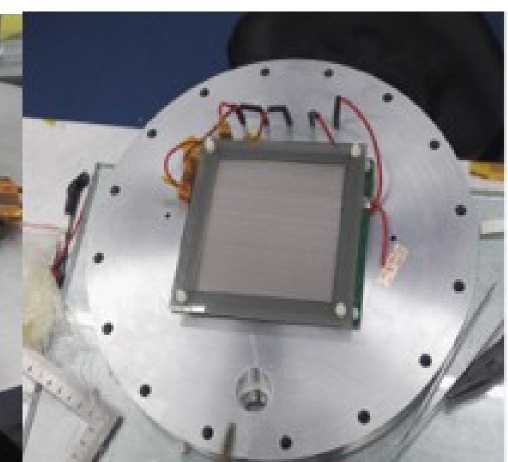
GEM(CERN)



GEM + Micromesh structure



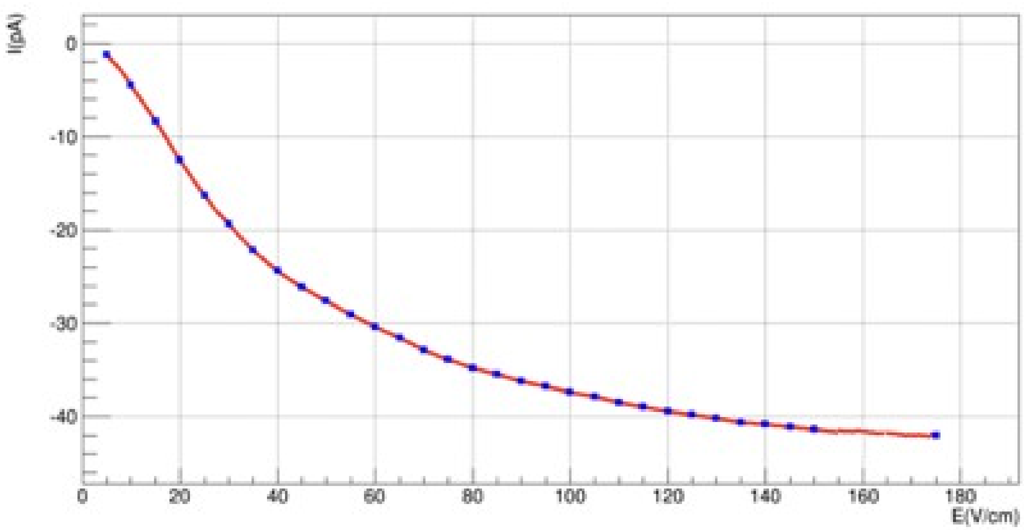
Cathode with mesh



GEM-MM Detector

UV test -first step

- UV lamp measurement
  - pA current meter from Keithley
  - First step test about the current in mesh
  - E_drift: 10~175V/cm
  - ~43pA@175V/cm
  - Stable current with UV light
  - ~200V/cm@T2K operation gas



Electrons by photoelectric effect with Edrift

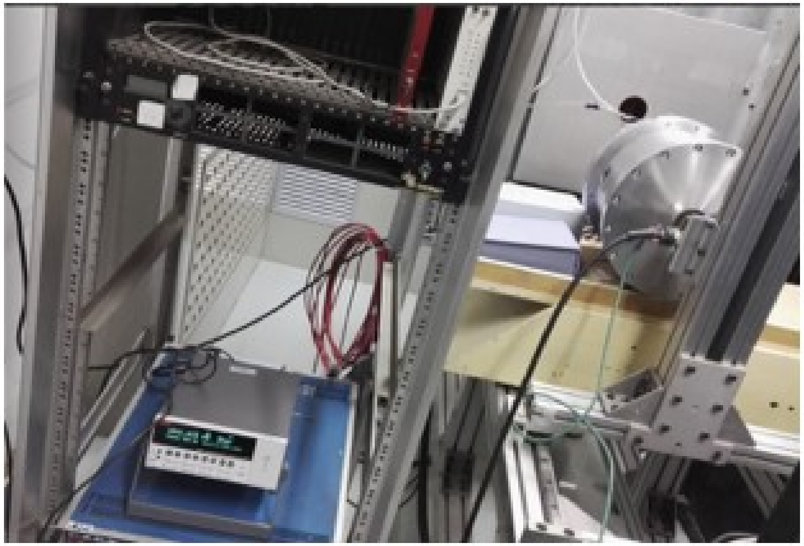
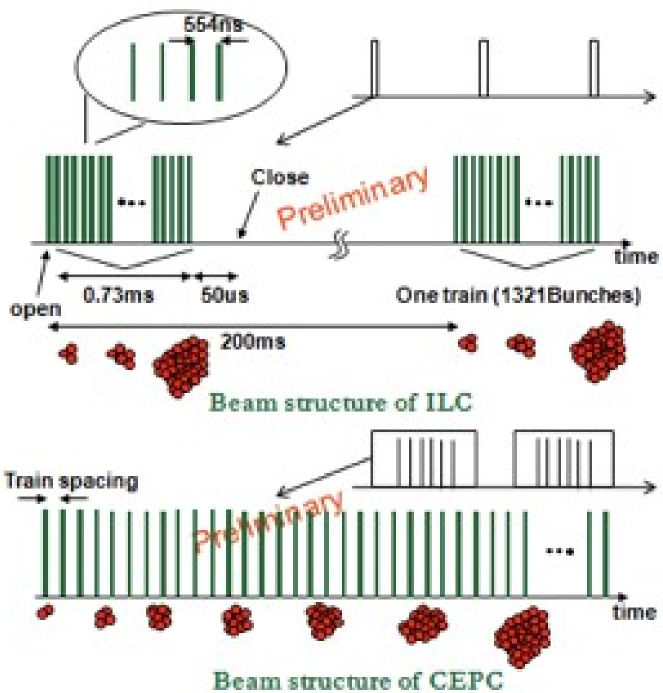


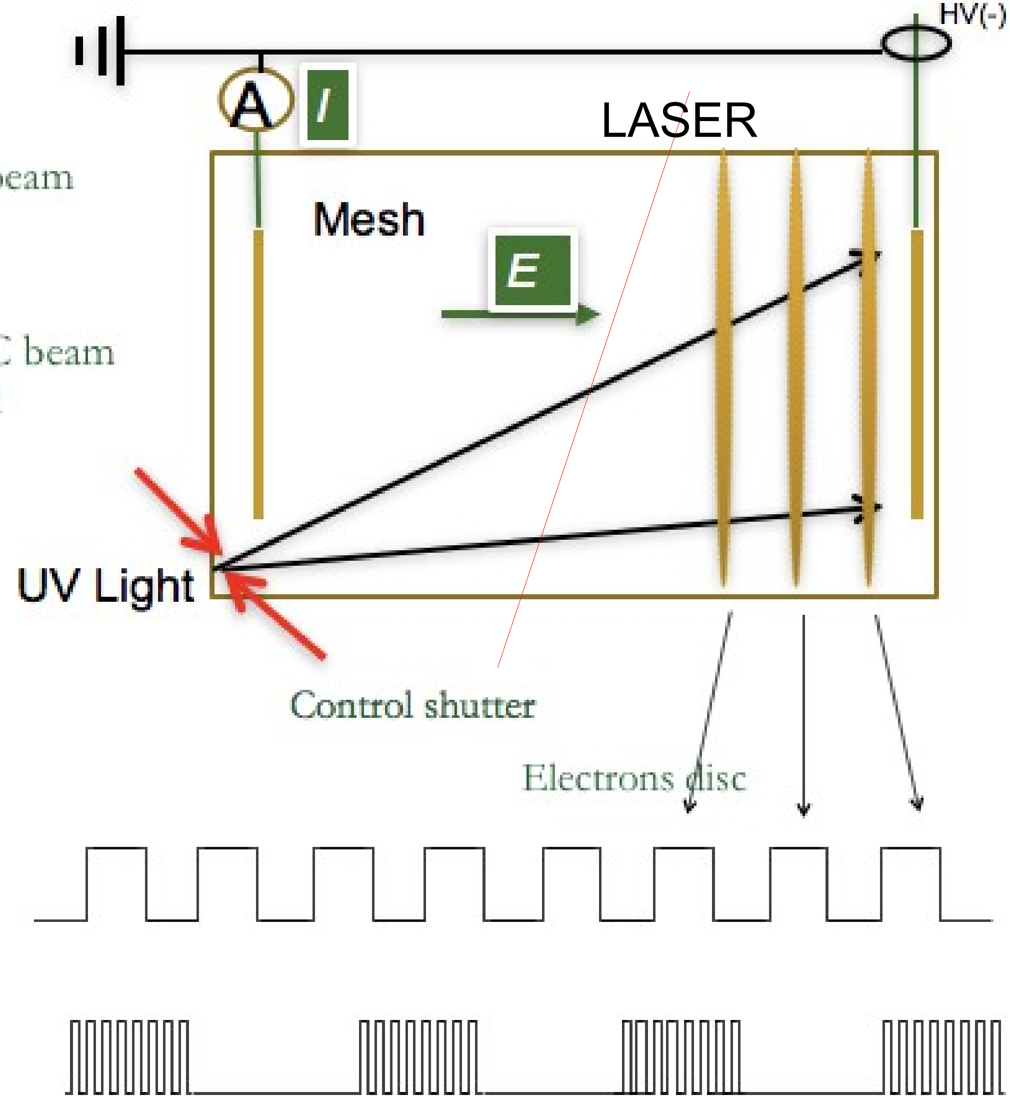
Photo of the new module in lab

X

UV test - next step

- In the case of ILD-TPC
  - Bunch-train structure of the ILC beam (one ~1ms train every 200 ms)
- In the case of CEPC-TPC
  - Bunch-train structure of the CEPC beam (one bunch every ~90μs) or partial double ring
- Gating and IBF test





Shutter time similar to ILC and CEPC beam structure

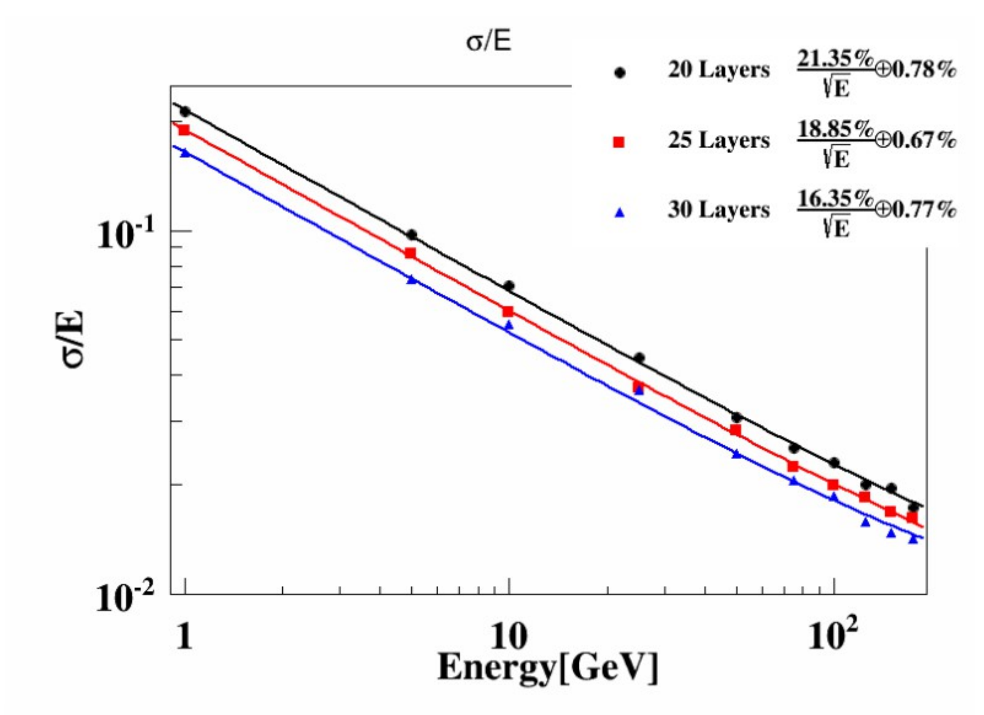
To Mimic the bunch structure & the Ion Distortion with track induced by Laser beam

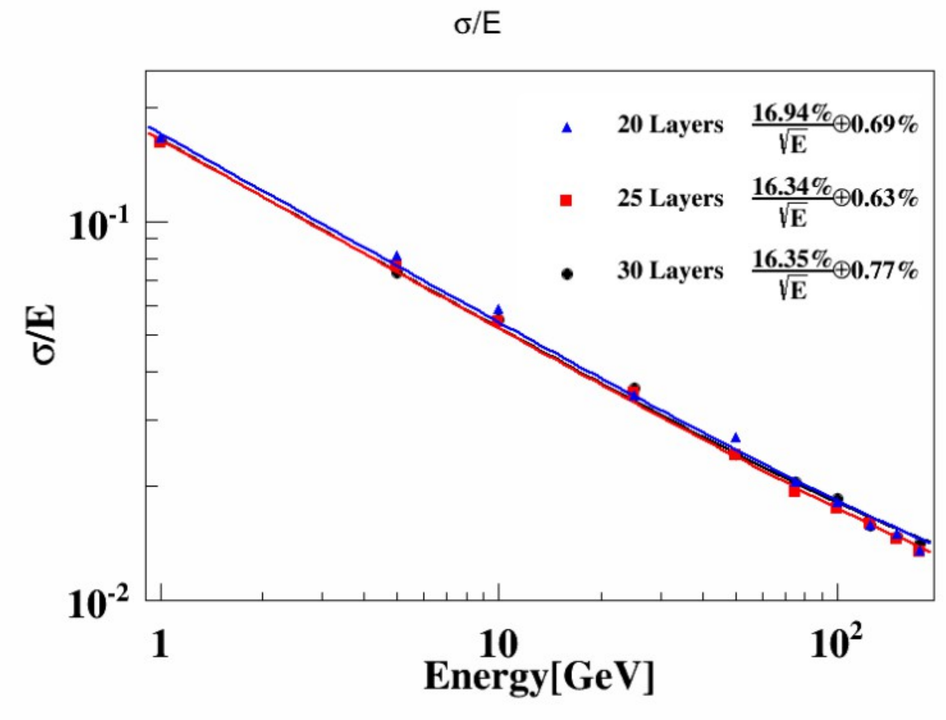
Calo Optimization at CEPC

- Feasibility study of Passive Cooling without Power Pulsing
  - 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, Lepton & Jet
    - H->gluons, H->di photon, Higgs recoil & 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

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



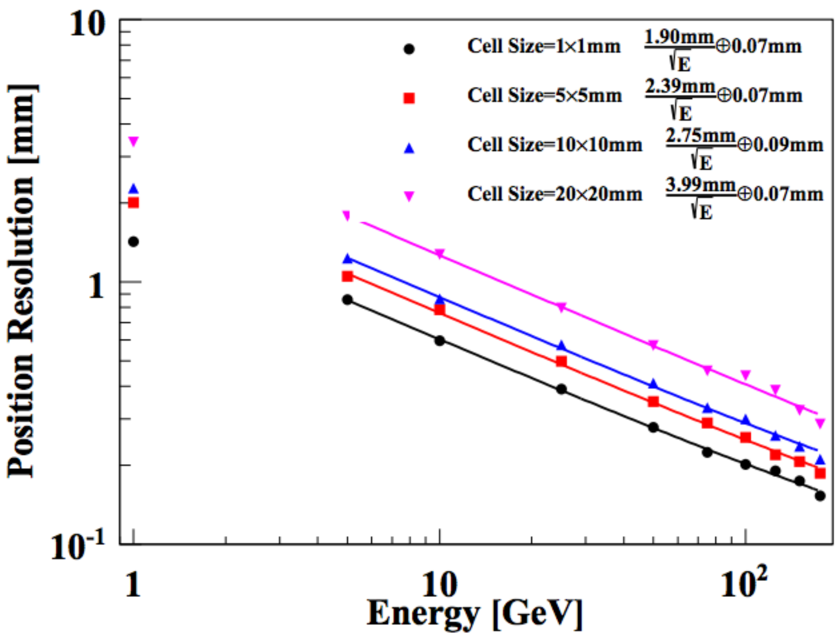


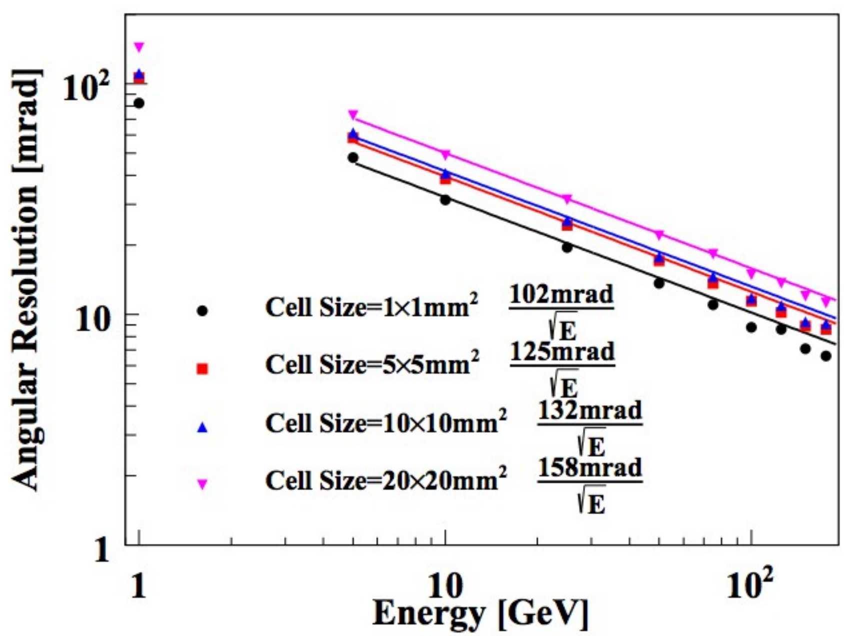
Performance @ Photon with E > 1 GeV:

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?

Cell Size: Position/Angular





Key performance: Separation

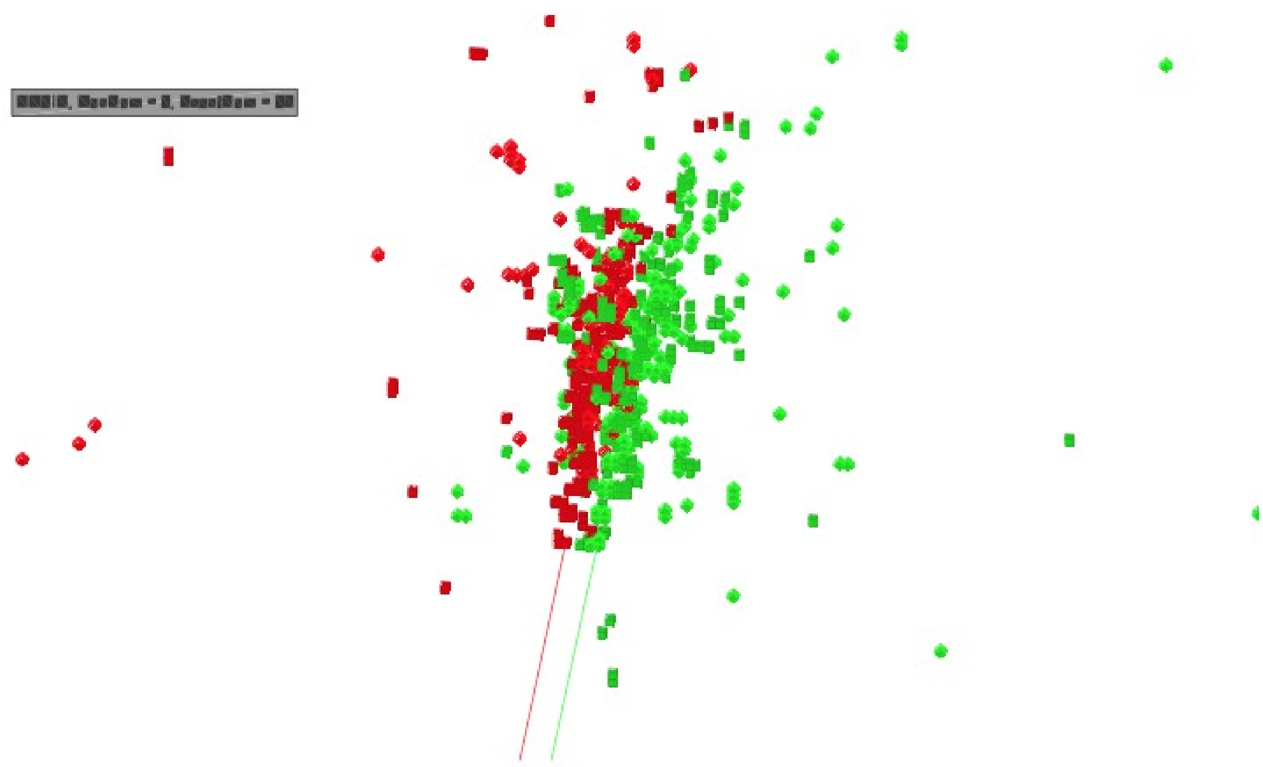
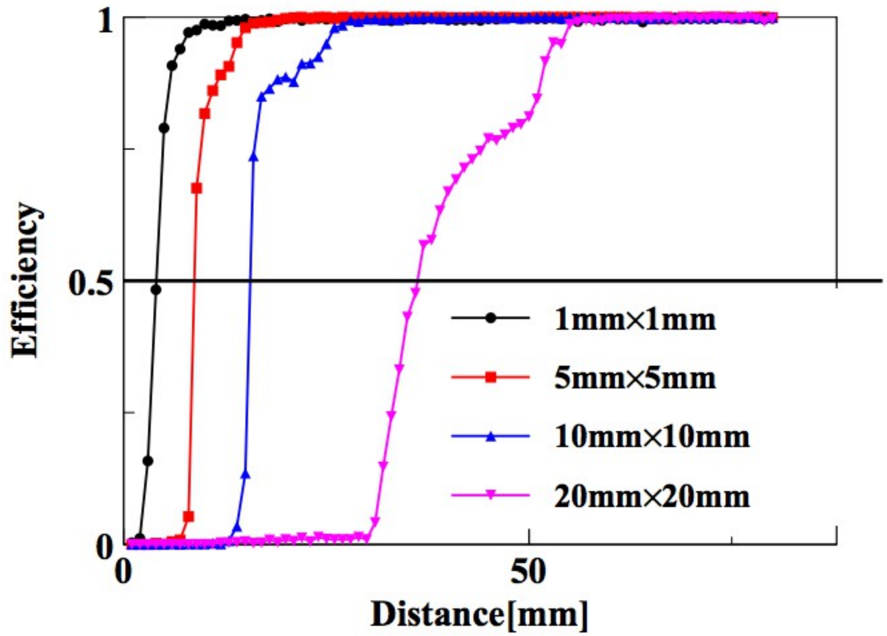
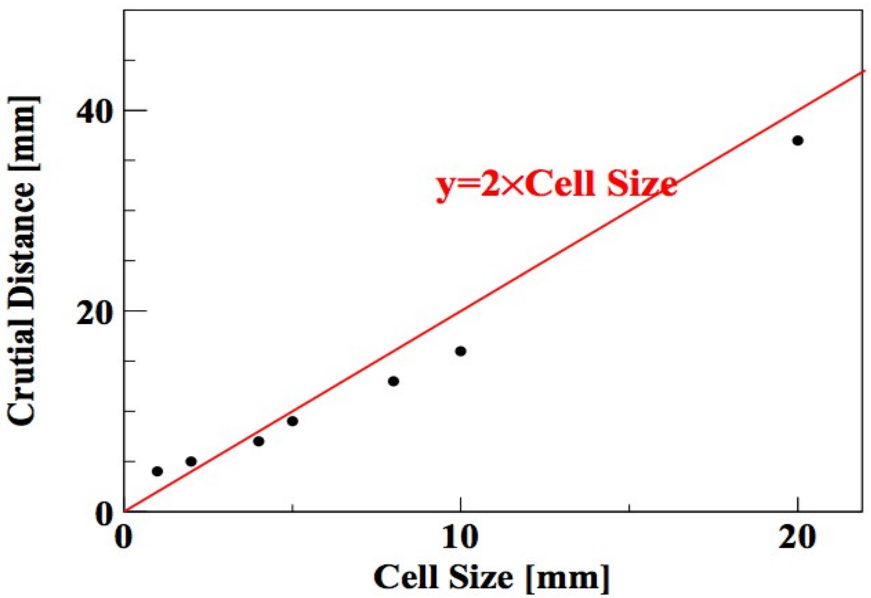


Figure 11. Event display of reconstructed di-photon.

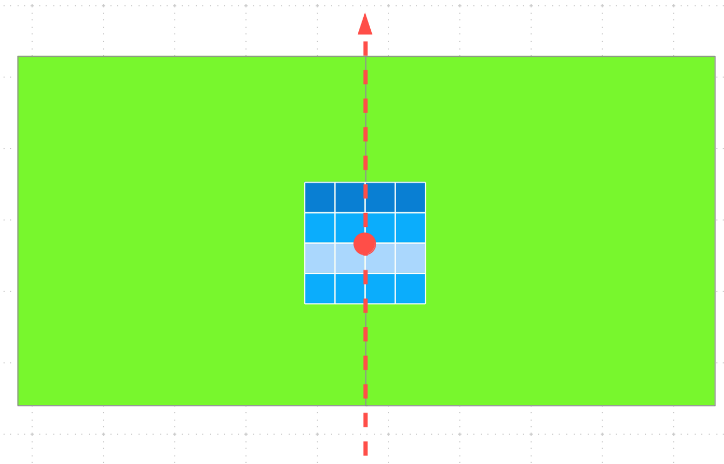
Critical distance: ~ 2*Cell Size



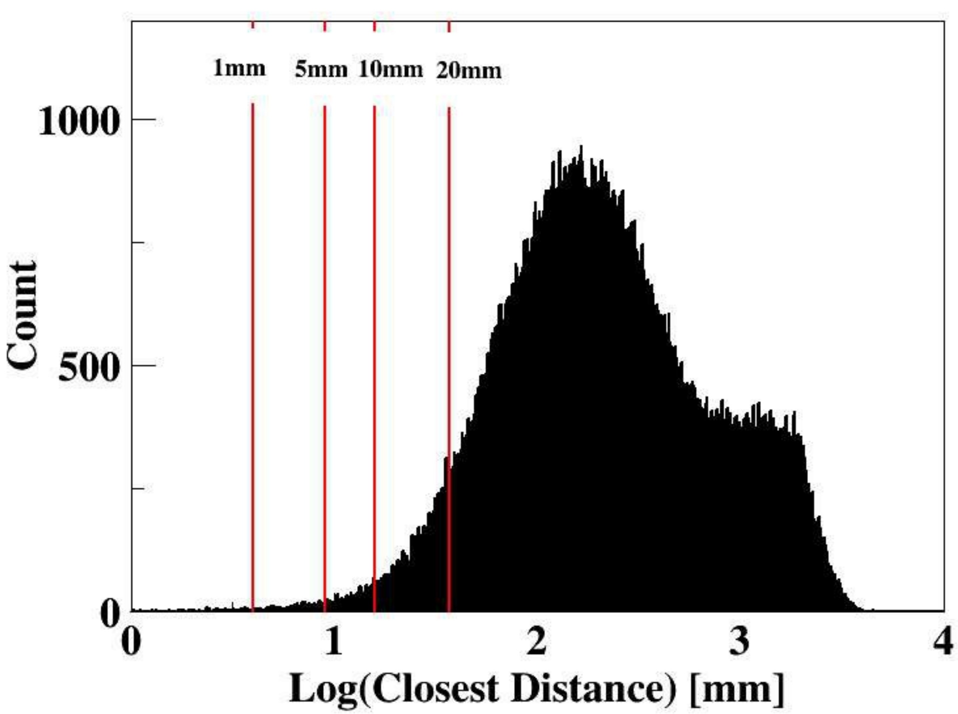


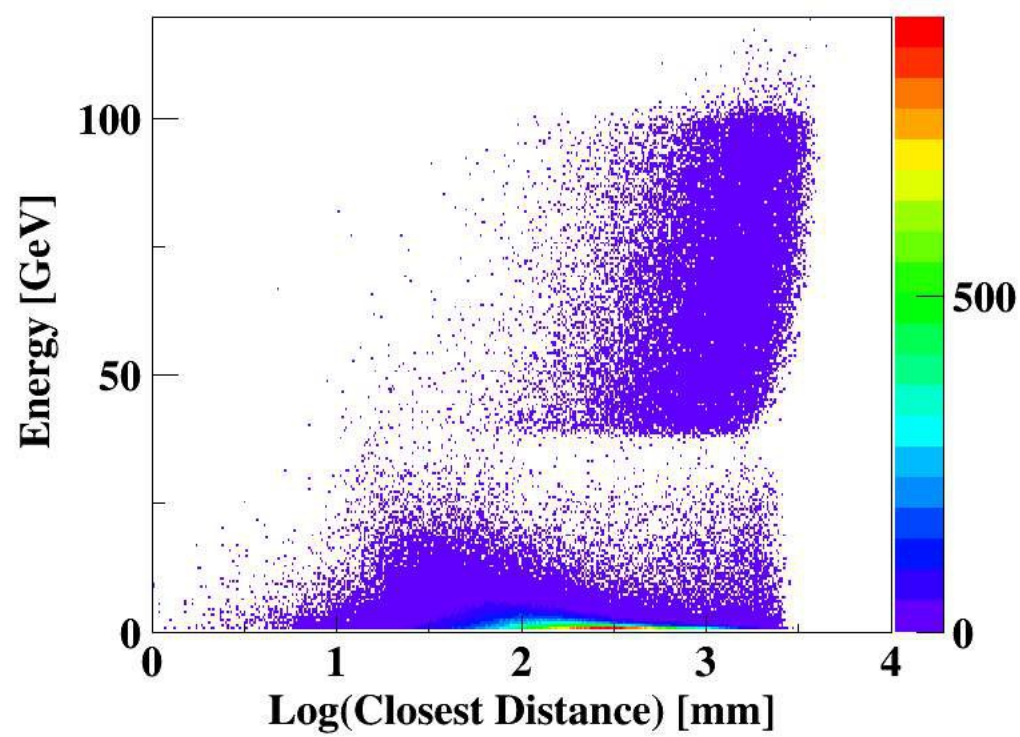
Simulation at 1 mm Cell & Digitized
To large cell size

Scan step = 1 mm



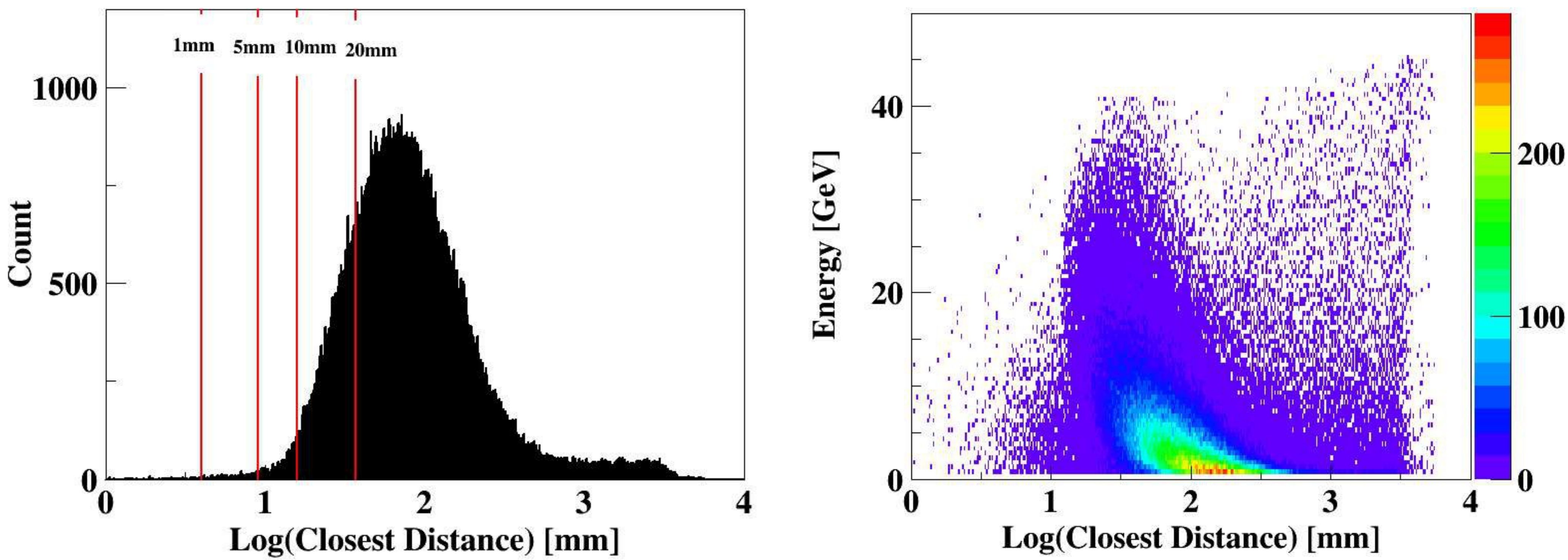
Impact of Separation: qqH, H->γγ @ 250 GeV





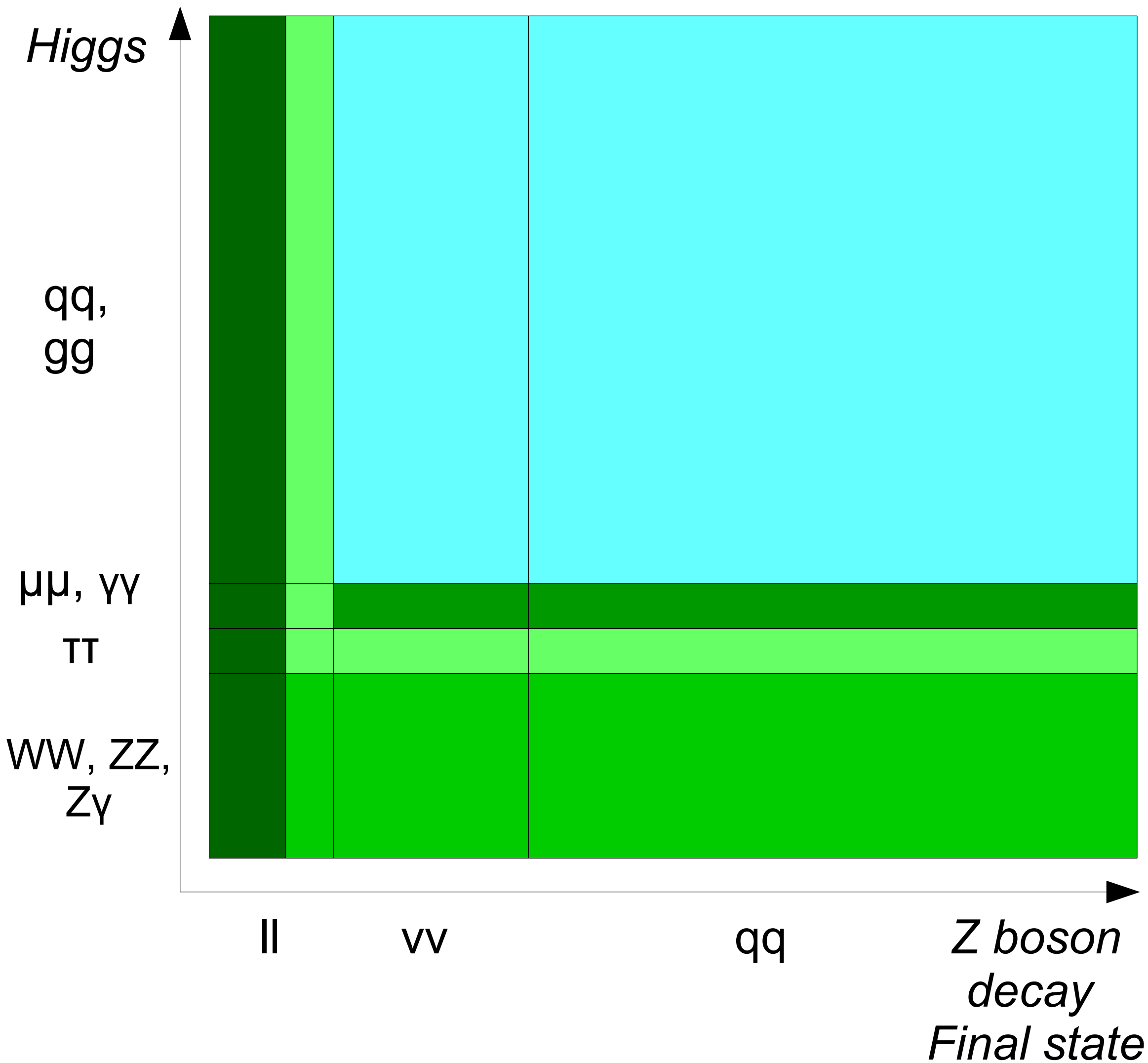
Cell Size/mm	1	5	10	20
Crucial Dis/mm	4	9	16	37
Percentage of potentially overlap photon: E > 30 GeV	0%	0%	0.1%	0.4%
E < 30GeV	0.1%	0.35%	1.1%	6.4%

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



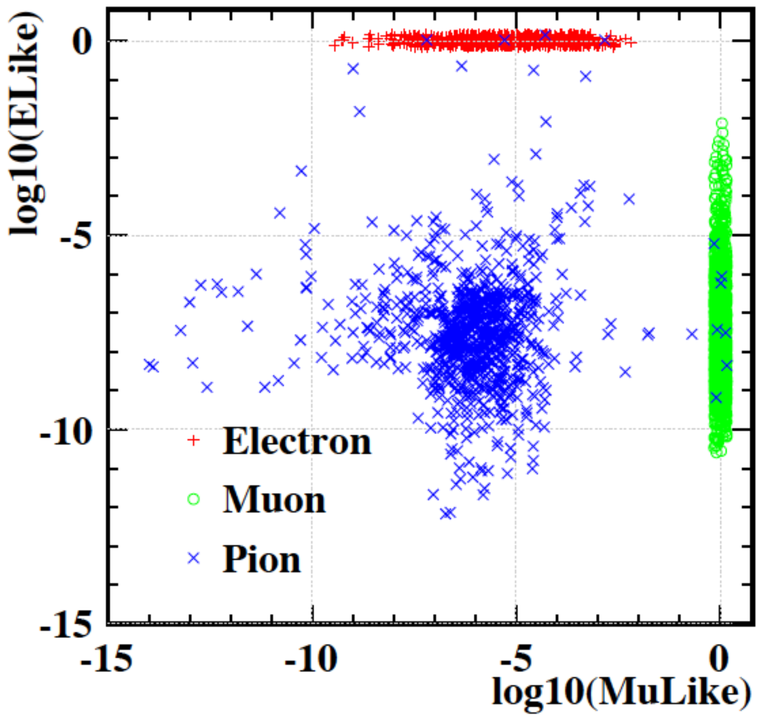
Cell Size/mm	1	5	10	20
Crucial Dis/mm	4	9	16	37
Percentage of potentially overlap photon	0.07%	0.4%	1.7%	18.6%

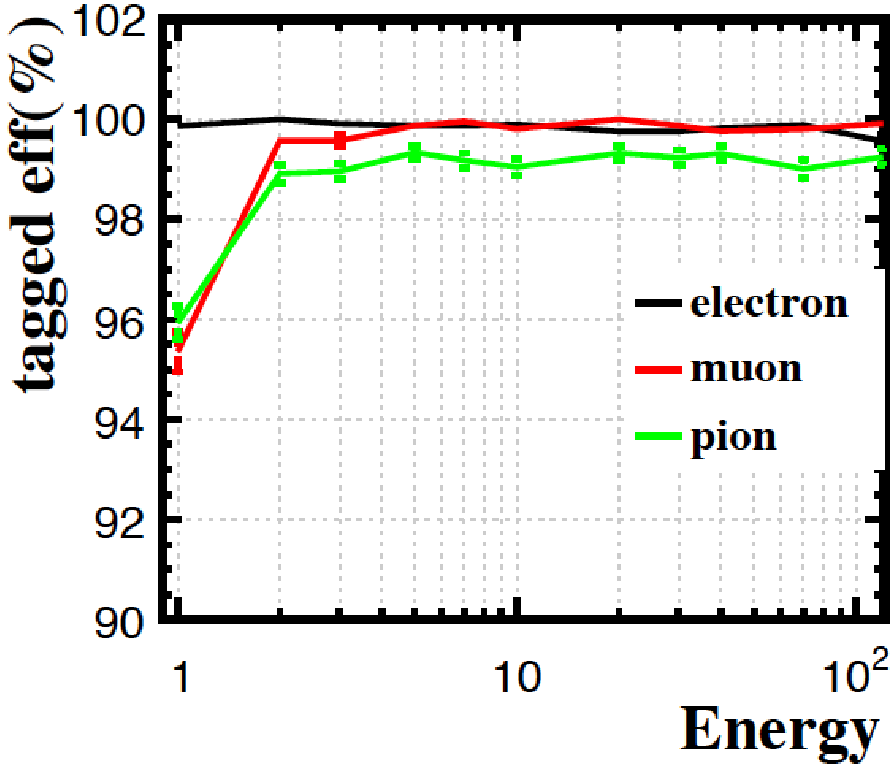
Leptons: key to Higgs program



- Key objective: Identify the initial leptons
  - Leptons generated in Z decays in ZH events
  - Electrons in Z fusions
- Secondary: leptons generated in Higgs decay
  - H->WW/ZZ/tautau/μμ
  - H->bb, cc->leptonic decay
  - Hadron decays

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





BDT method using 4 classes of 24 input discrimination variables.

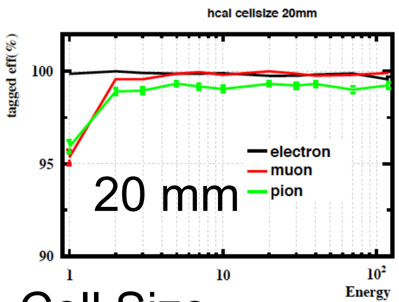
Test performance by requesting

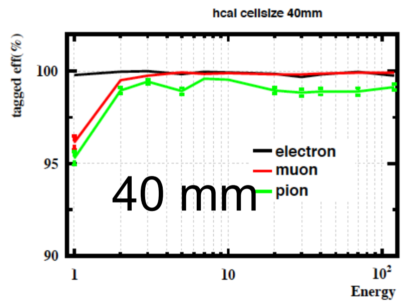
Electron = E_likeness > 0.5 ; Muon = Mu_likeness > 0.5

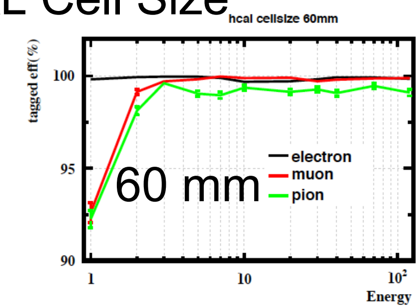
Single charged reconstructed particle, for E > 2 GeV: lepton efficiency > 99.5% && Pion mis id rate ~ 1%

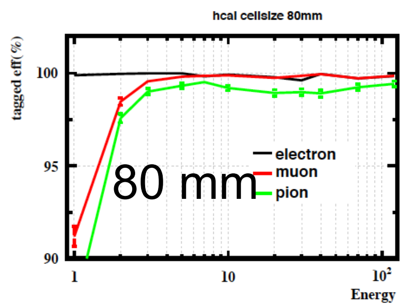
Vary the granularity

HCAL Cell Size

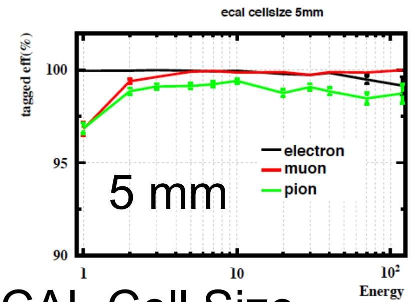


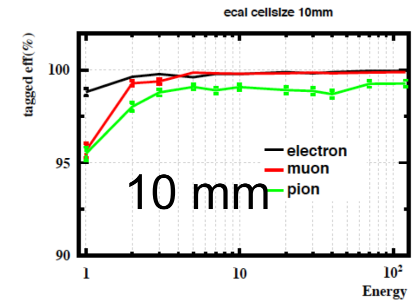


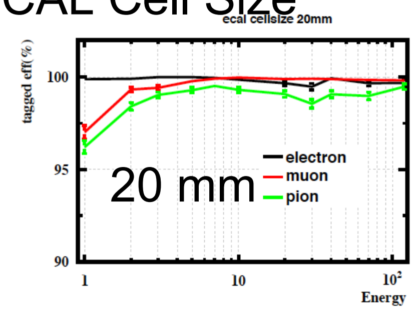


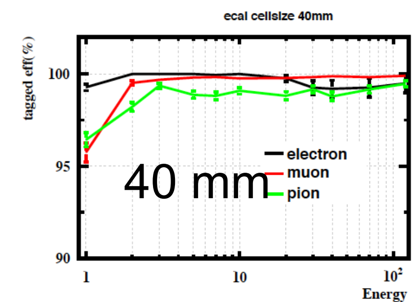


ECAL Cell Size

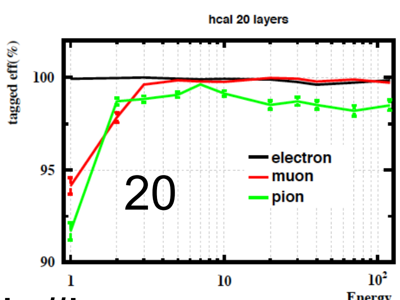


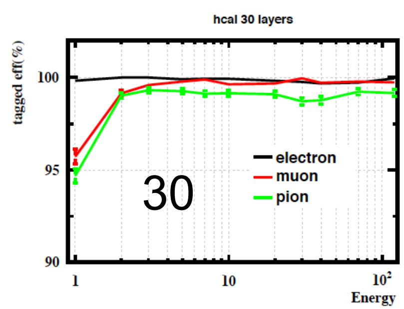


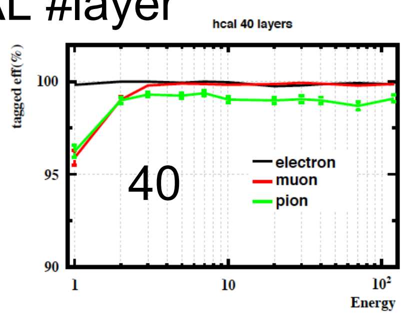


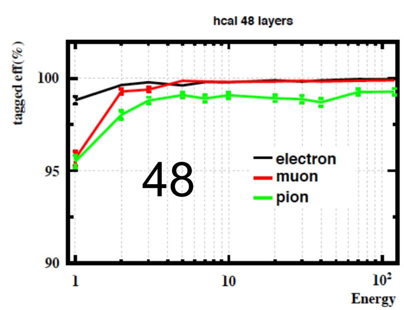


HCAL #layer

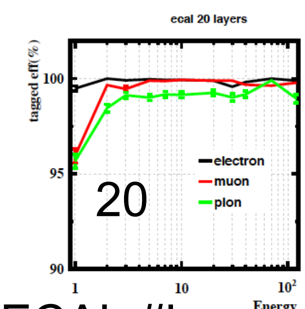


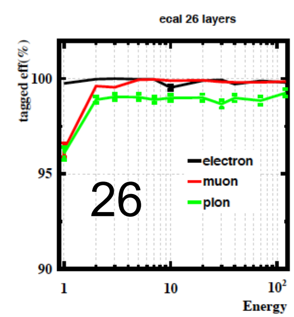


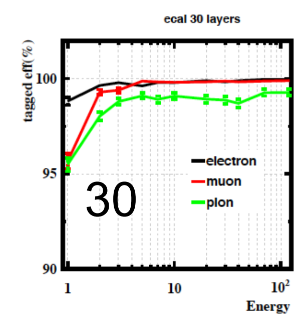




ECAL #layer

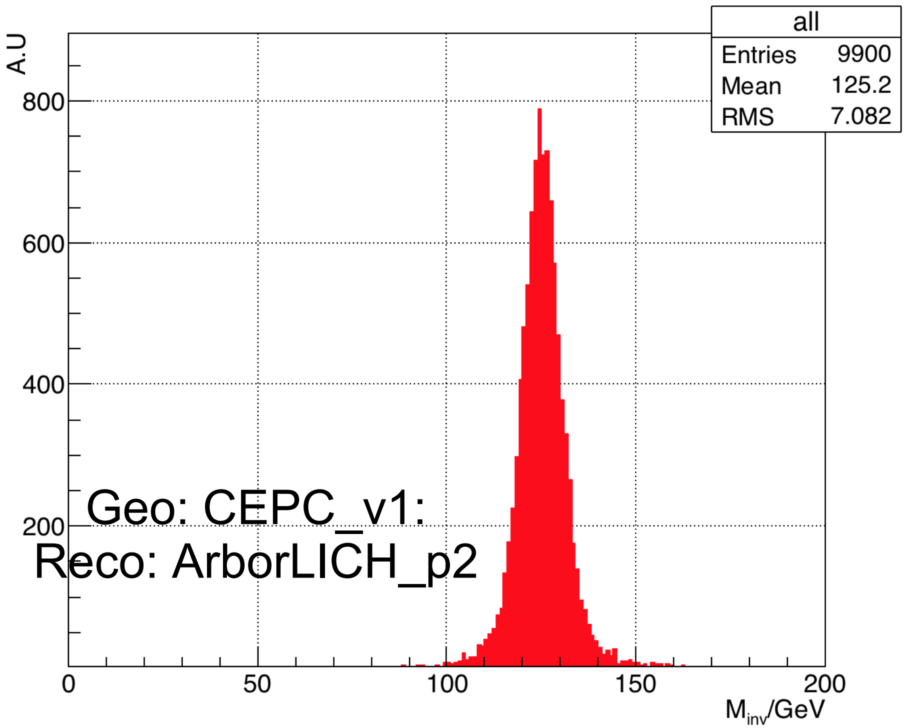




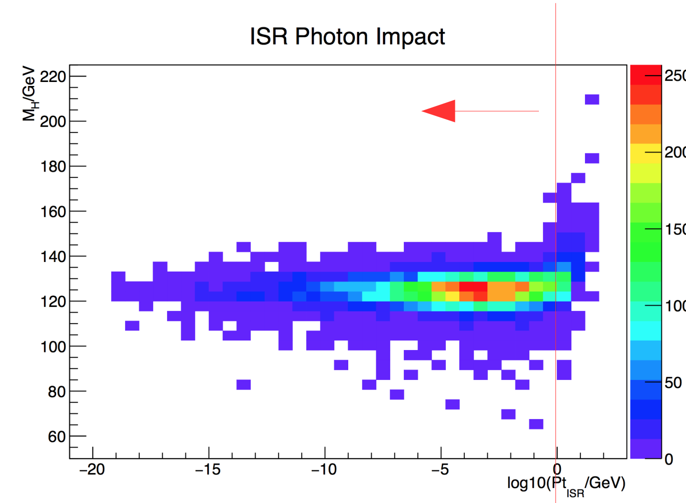


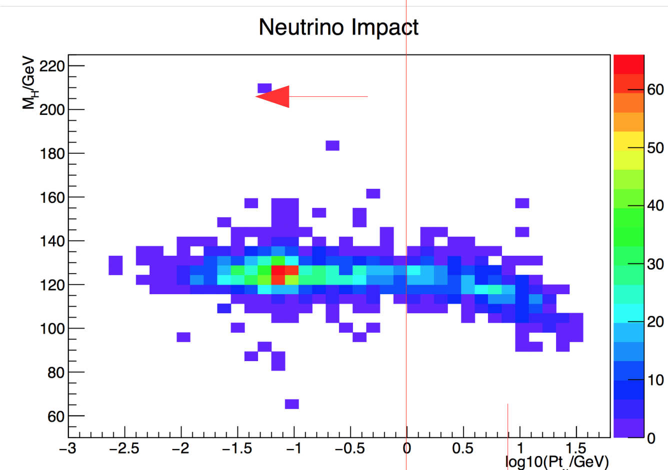
No Significant effect for E > 2 GeV charged Particles

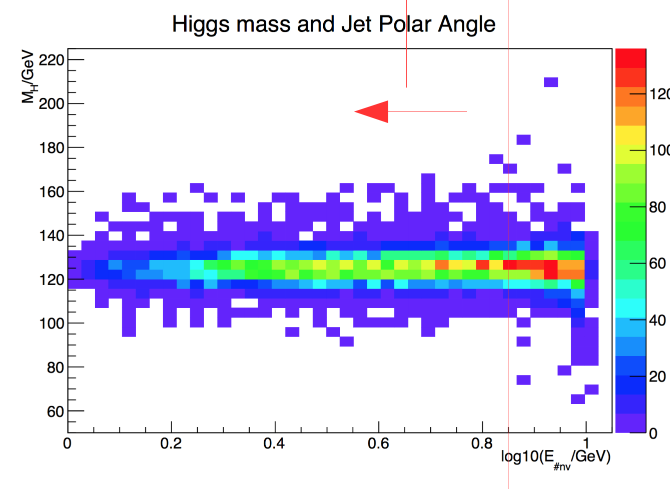
Jets @ vvH, H->gluons

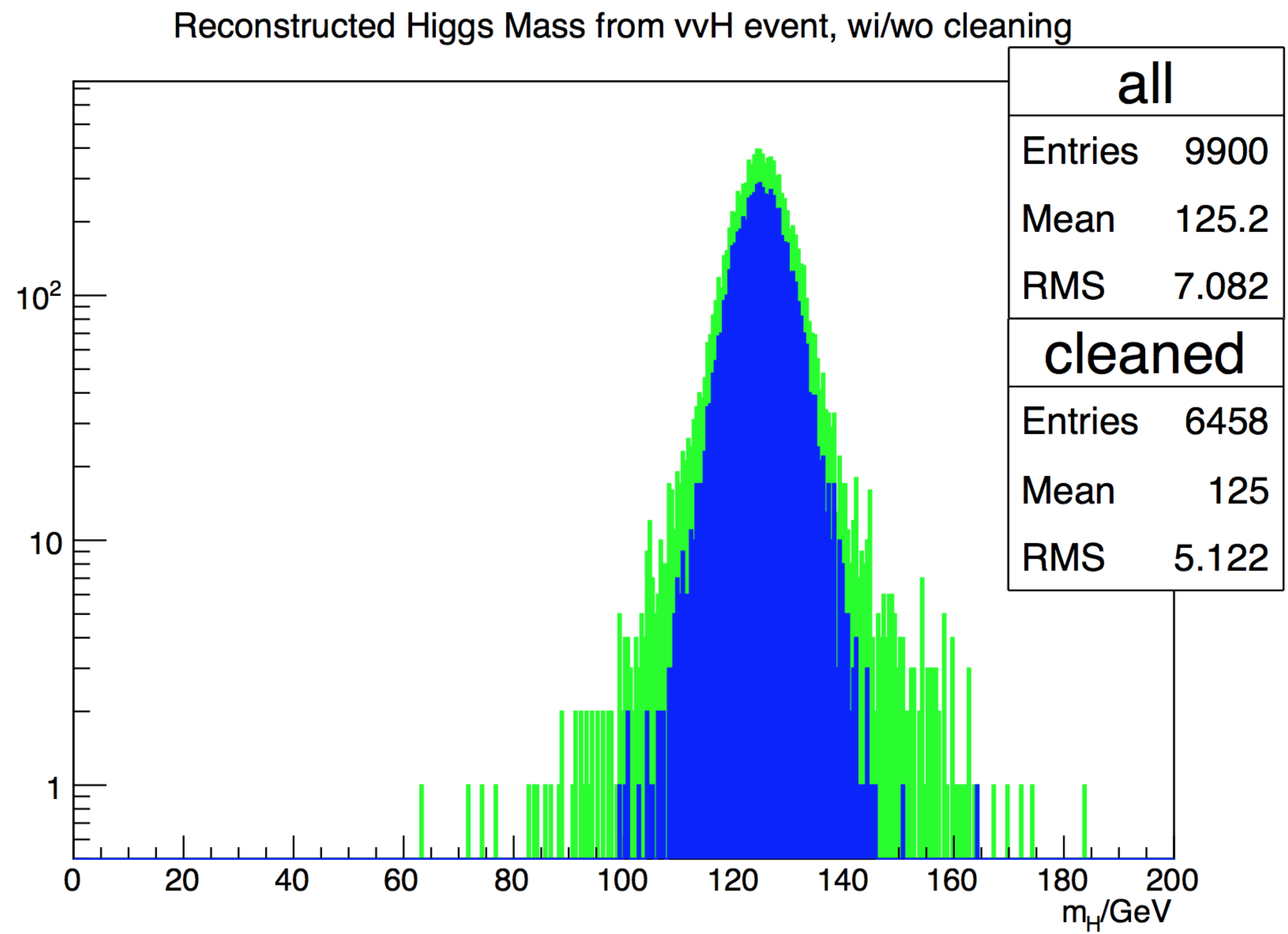


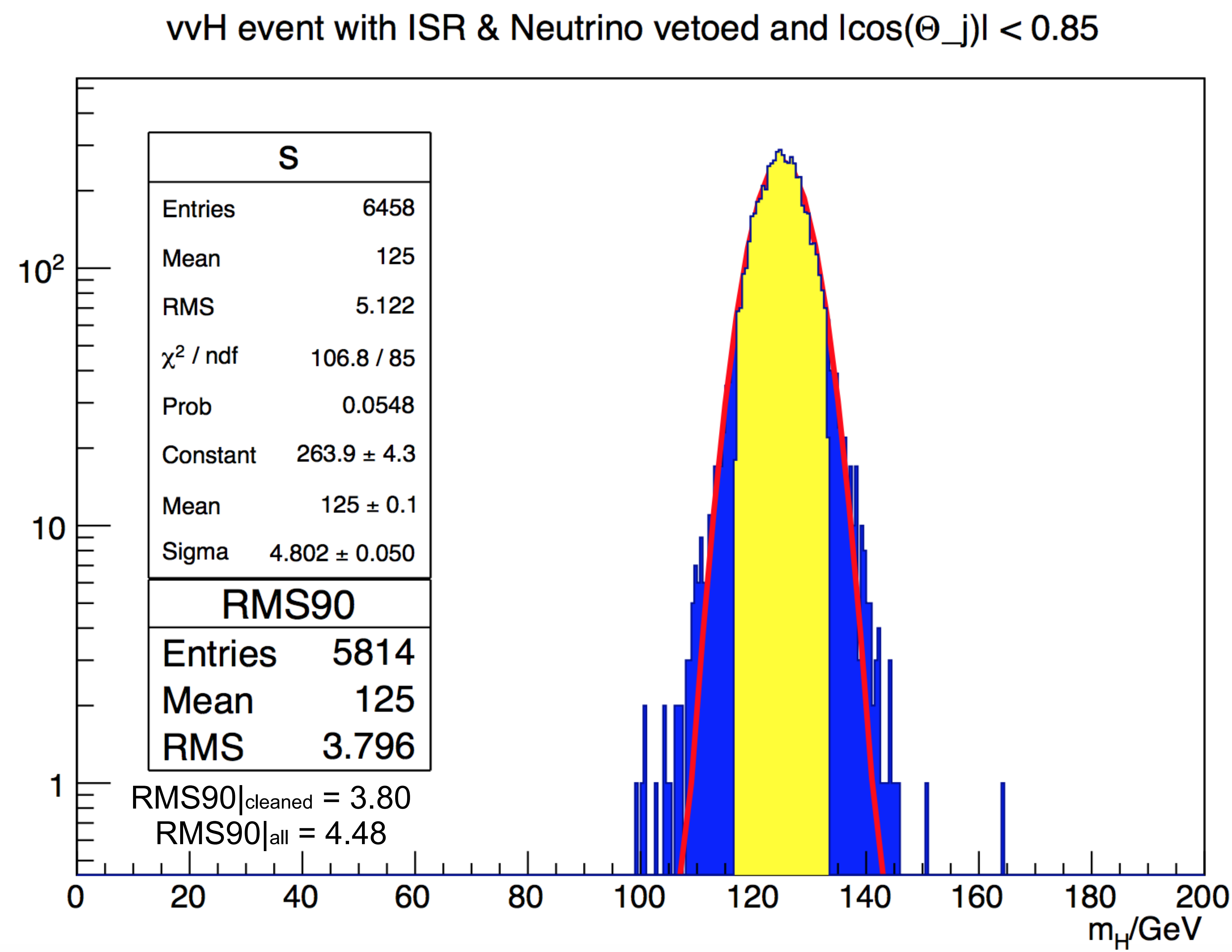
All	9900
ISRPt < 1 GeV	9335
ISRPt < 1 && N3Pt < 1	8766
ISRPt < 1&& N3Pt < 1&& |cos(Theat)| < 0.85	6458



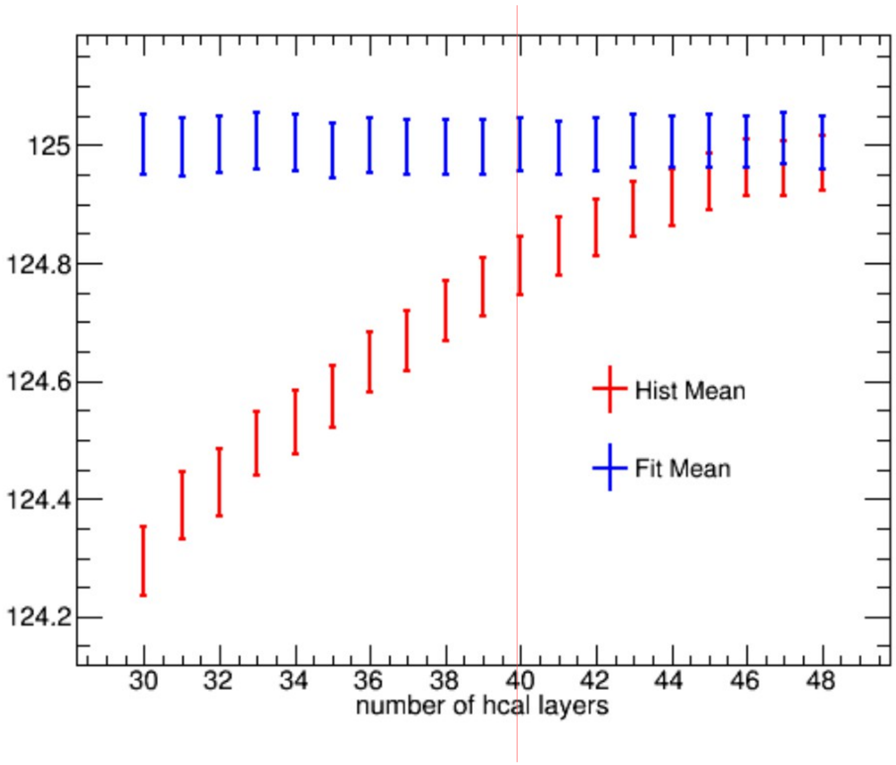


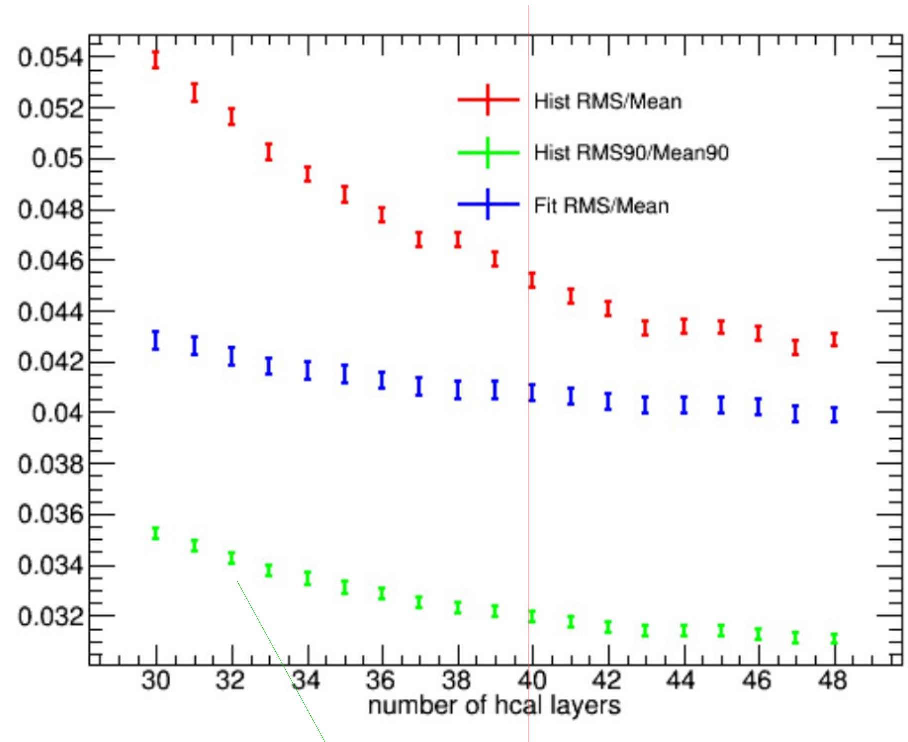



Reconstructed Higgs Mass from vvH event, wi/wo cleaning
all
Entries 9900
Mean 125.2
RMS 7.082
cleaned
Entries 6458
Mean 125
RMS 5.122
10^2
10
1
0
20
40
60
80
100
120
140
160
180
200
m_H/GeV


vvH event with ISR & Neutrino vetoed and |cos(Θ_j)| < 0.85
S
Entries 6458
Mean 125
RMS 5.122
χ2 / ndf 106.8 / 85
Prob 0.0548
Constant 263.9 ± 4.3
Mean 125 ± 0.1
Sigma 4.802 ± 0.050
RMS90
Entries 5814
Mean 125
RMS 3.796
RMS90|cleaned = 3.80
RMS90|all = 4.48
mH/GeV

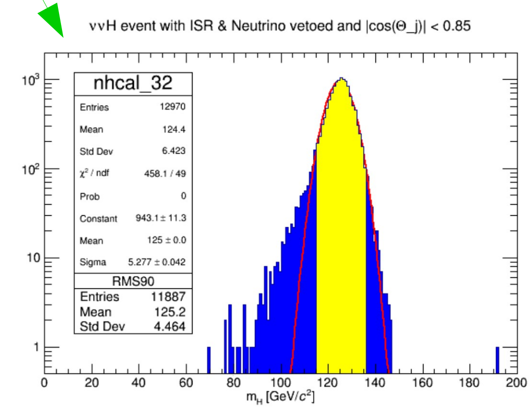
JER Vs #Layer (Preliminary)



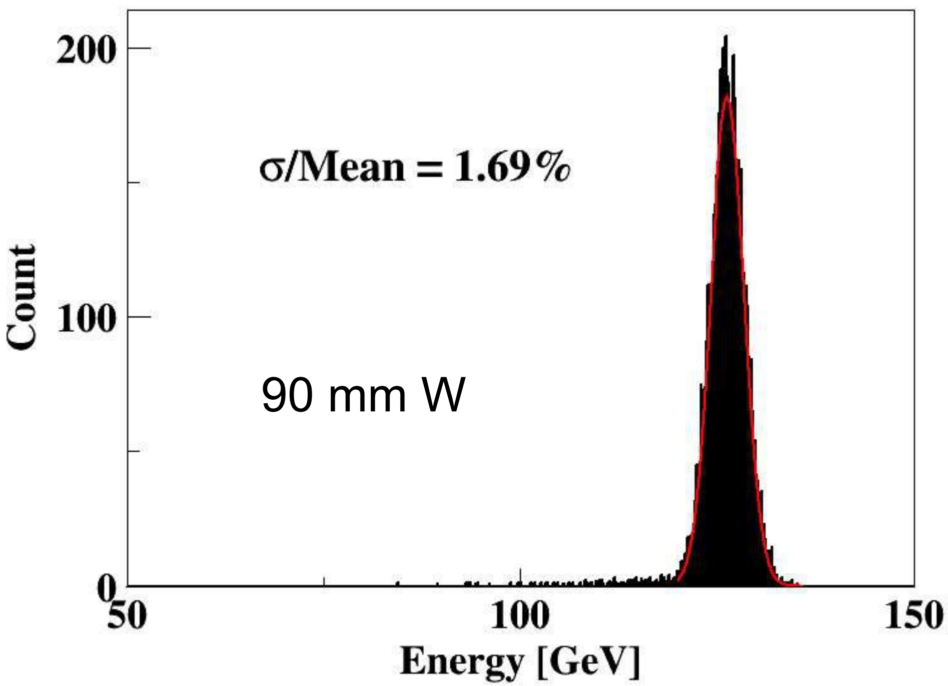


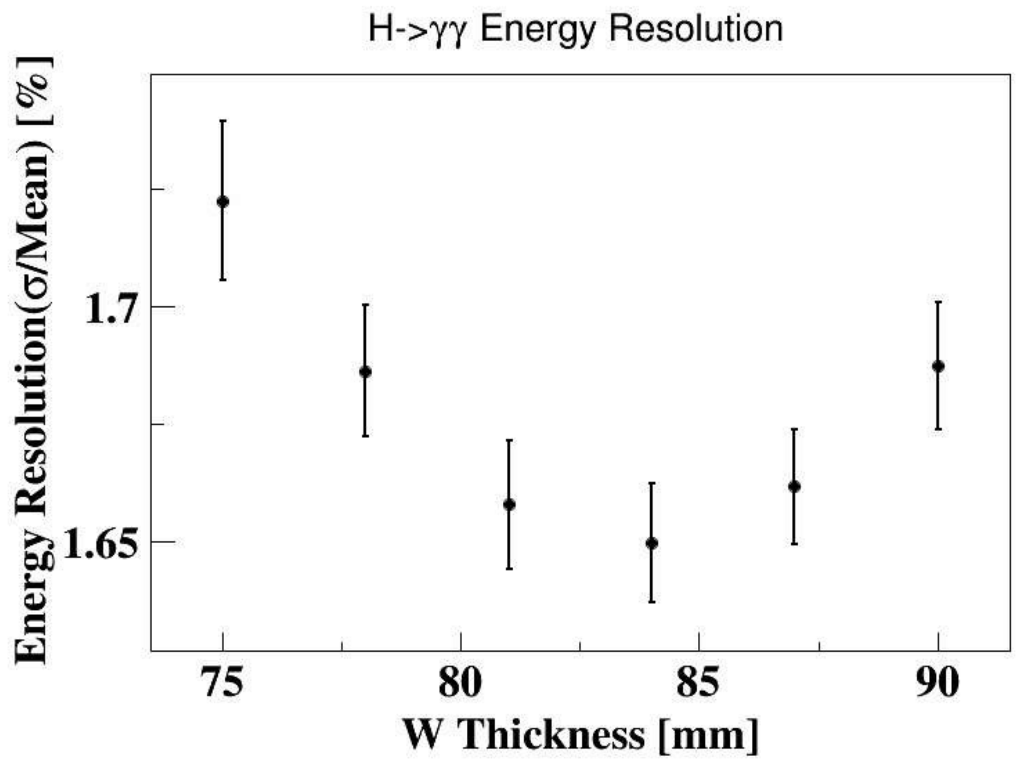
Reducing the #Layers from 48 -> 40 (same layer thickness)
A degrading of 2% (relative) in JER

Performance depends on the version...



H->di photon Vs W thickness

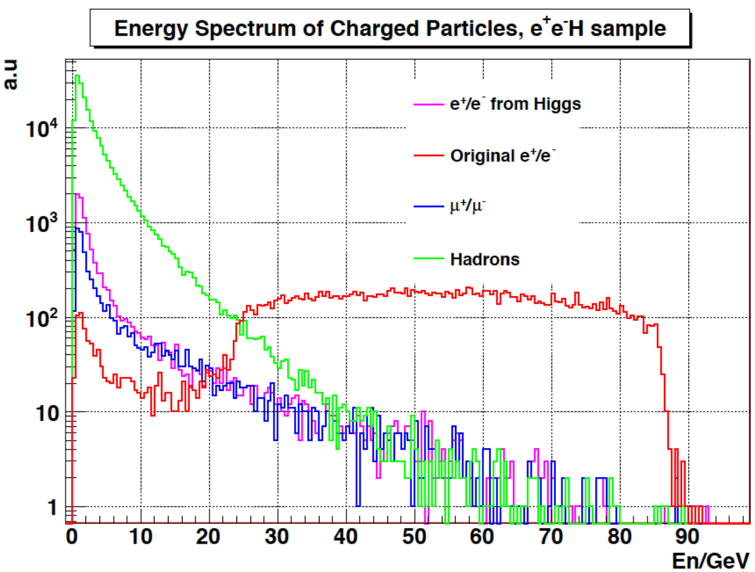


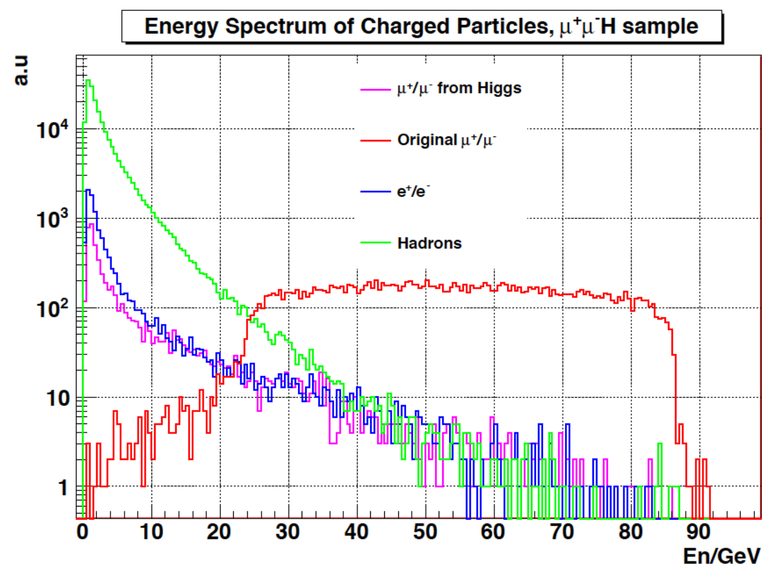


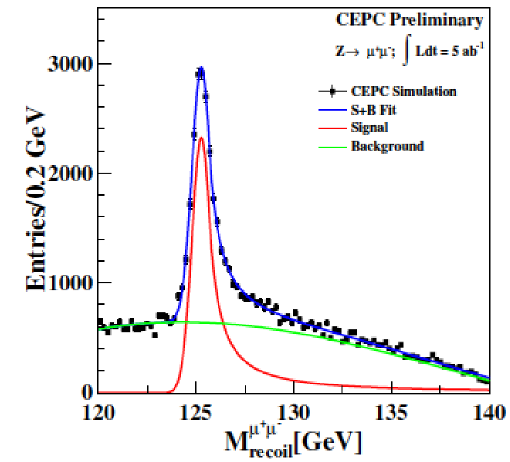
30 Layers, each layer with 0.5 mm Si + 2 mm PCB
ECAL only performance

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

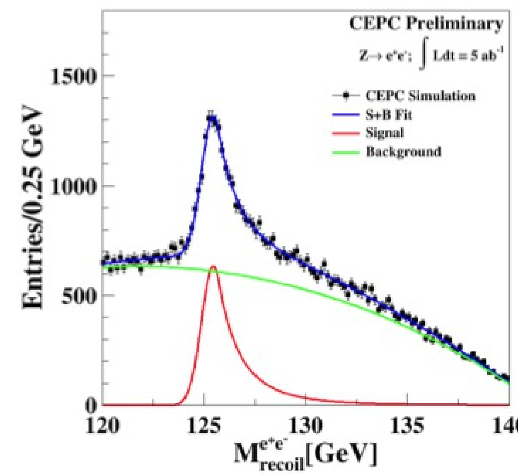
Lepton id @ Higgs recoil







	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

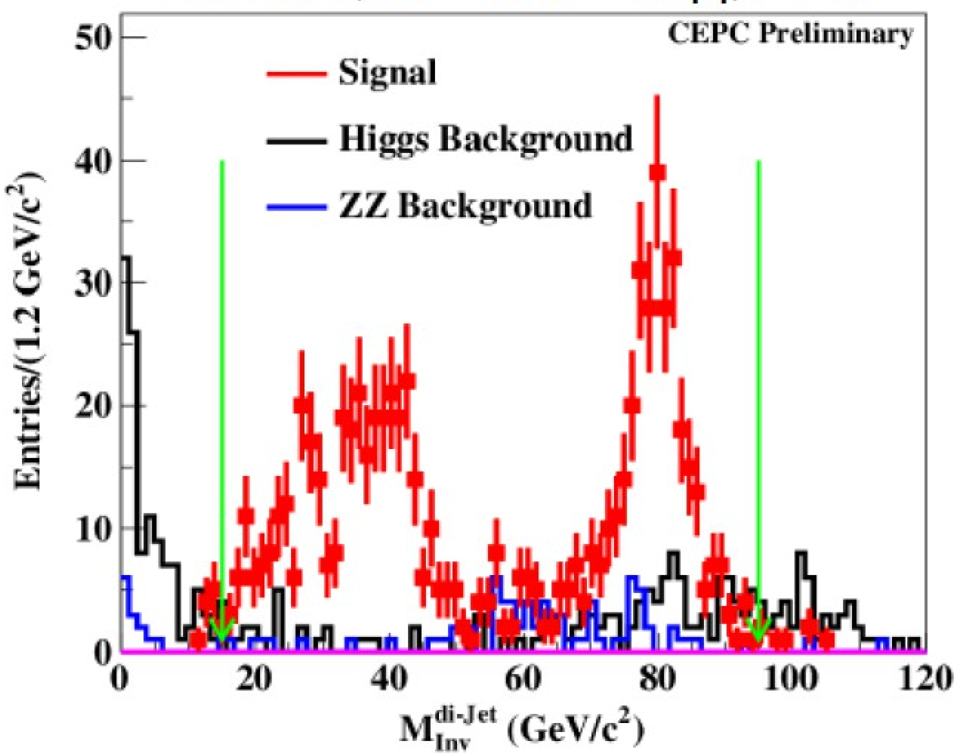
Initial Leptons identified at satisfactory efficiency & purity (limited by separation power)

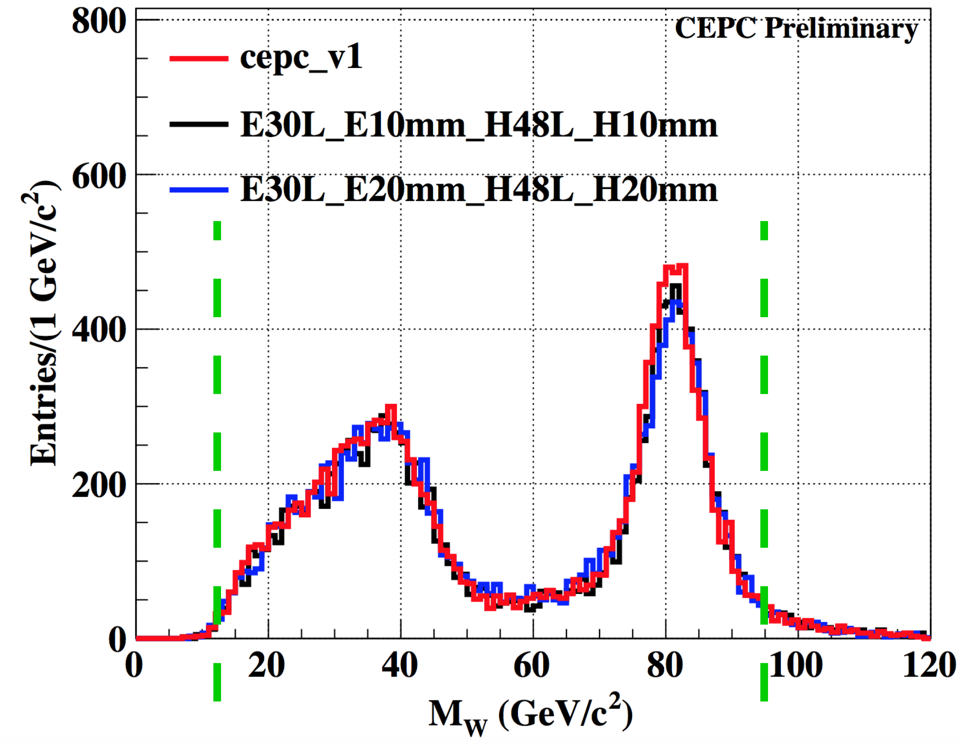
More stringent requirement arrises from jet leptons...

https://arxiv.org/abs/1701.07542

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%

Summary

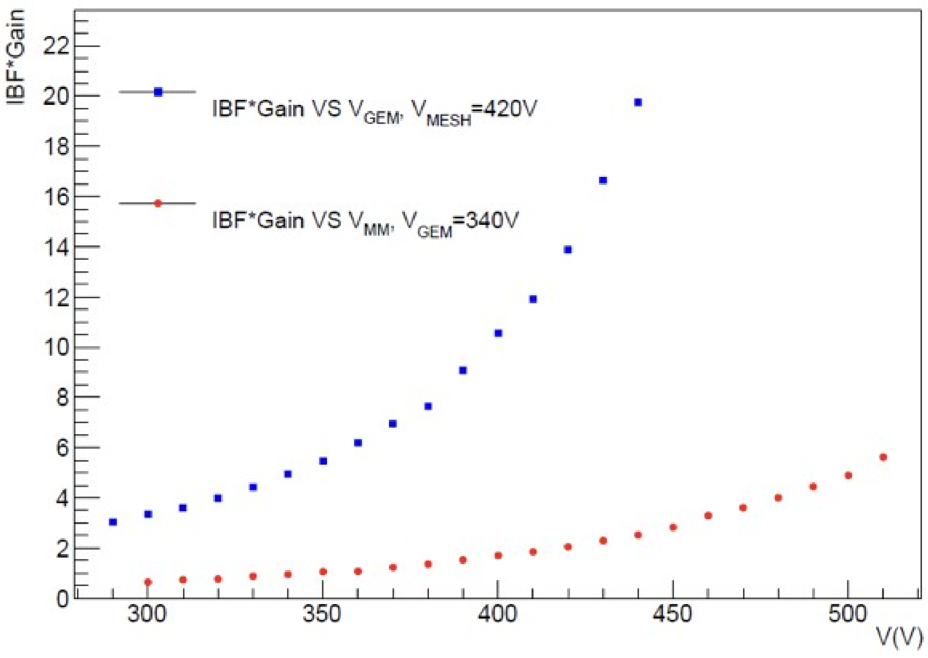
- PFA oriented CEPC detector optimization is supported with full Sim-Analysis
- Feasibility:
  - TPC: Yes if IBF is controlled to per mille level;
  - Passive cooling for Calorimeter
    - No Impact on Well Isolated Particle;
    - Percentage level degrade for Higgs event measurement (0 - 1%)
    - May Severely degrade Tau physics: Dedicated Analyses will be followed.
- Optimization:
  - General Geometry Parameters
    - ECAL: ~ 84 mm Tungsten, divided to 20-30 layers (vary with Si thickness)
    - HCAL: ~ 1.1 meter Iron, divided to less than 40 layers
  - Evaluation of Impacts from Geometry defects, detector inhomogeneities, etc. evaluated

Future Plan

- Converge to an Benchmark geometry & get Physics Benchmarks analyzed
- Closer cooperation with Detector designs, to have validated digitization towards different technology & options

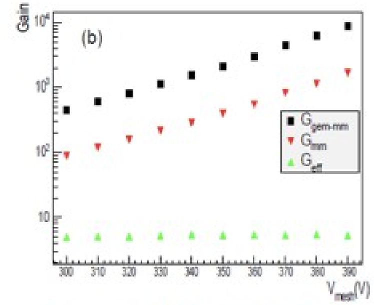
	Object	Key Performance	$\sigma/M\vert m_H$	maturity
H->di photon	photon	Intrinsic ECAL Energy resolution	1.7% - 2.4%	90%
Higgs recoil	lepton	Lepton id & Track Momenta accuracy	-	~ 100%
vvH, H->gluons	Jet	JER	4%	60%
qqH, H->inv	MET	JER	-	10%
vvH, llH, H->WW*->lvqq	lepton+Jet+ MET	Composition	-	80%
ZH->4 jet	Jets	Jet clustering & JER	-	10%
Br(tau->X) @ Z pole	Tau	Photon & Pi0	-	5%

Thanks

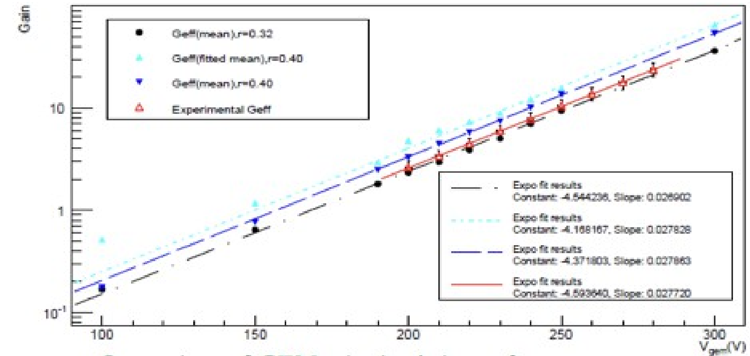


Gain of GEM-MM module

- Gain of the GEM-MM
  - Gain simulation by Garfield++
  - Gain test with GEM-MM detector
  - Optimization operation high voltage
  - V_{GEM}=240V/V_{MM} from 300V to 400V
  - Good fit the value with simulation and measurement
  - Gain of GEM: 3~23
  - Gain of GEM-MM: 100~10000



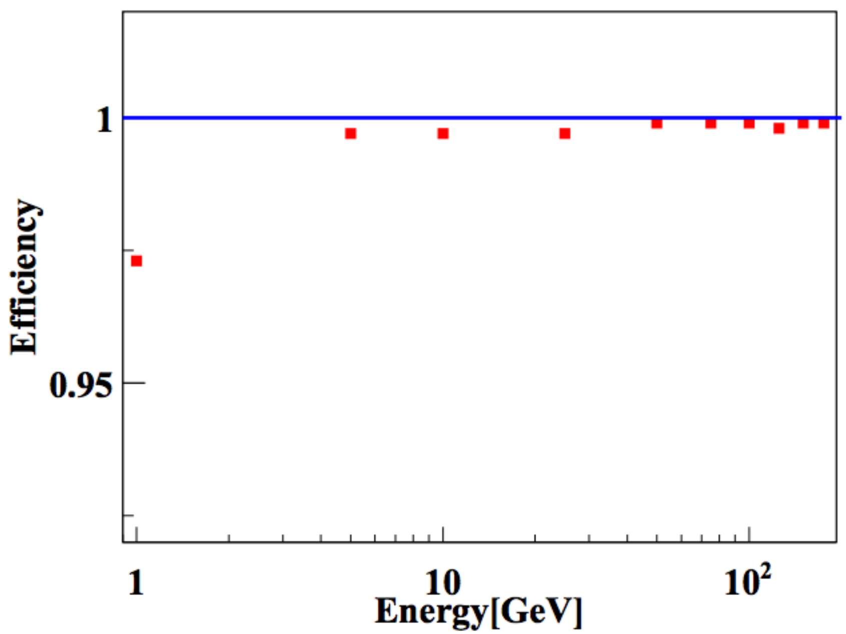
Gain with MM at VGEM=240V

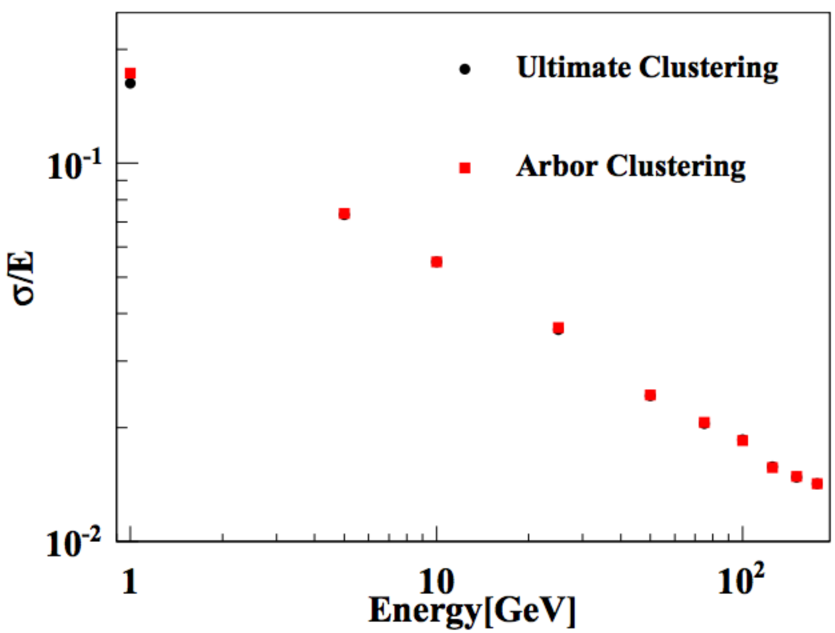


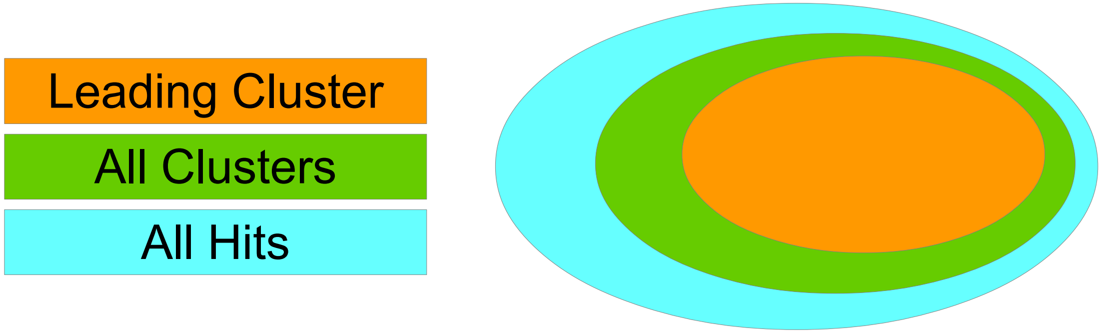
Comparison of GEM gain simulation and measurement

X

Photon: Ideal & Realistic Clustering







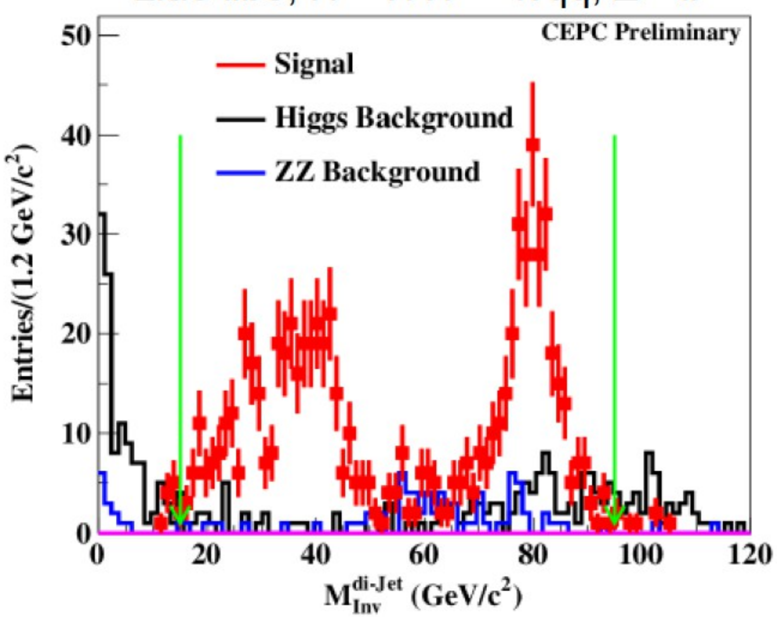
Efficiency
= LC Energy/total hit energy

@ 5 mm Cell Size

@Br(H→WW)

H→WW/ZZ: Portal to Higgs width & perfect test bed for detector/reconstruction performance...

Liao libo, H→WW*→lvqq, Z→ll



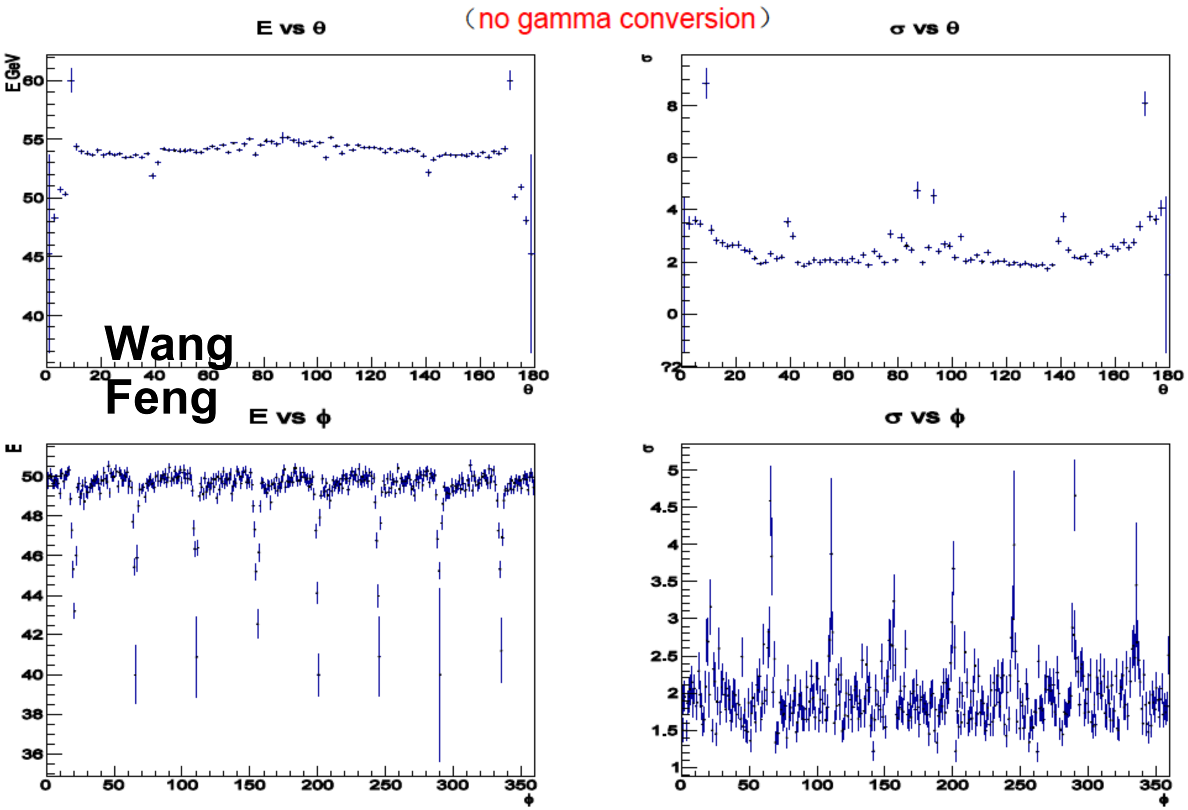
Expected Number of events with different objects

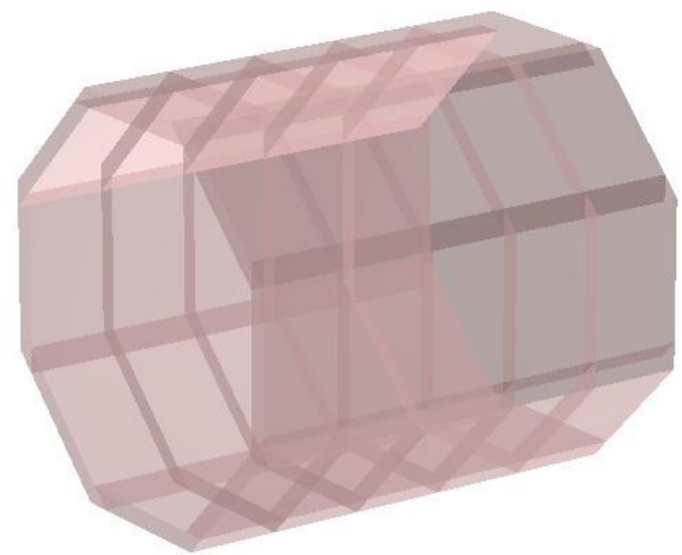
	Z→ll	tautau	vv	qq
H→WW*→4q	6.91k	3.45k	19.74k	69.1k
μvqq	2.27k	1.14k	6.47k	22.7k
evqq	2.27k	1.14k	6.47k	22.7k
eevv	186	93	527	1.9k
μμvv	186	93	527	1.9k
eμvv	372	186	1154	3.7k
X + tau	3.2k	1.6k	9.14k	32.0k

Extrapolated from ILC results
Await for tau finder
Await for the SM Background simulation
Full Simulation
Preliminary result acquired
Unexplored

- Br(H→WW), Combined accuracy ~ 1.0% from 13 independent full simulation analyses
  - 1.45% at llH, H→WW*→ inc channels, 12 independent channels.
  - *~ 1.7% at vvH, H→WW*→ 4q channel (Preliminary. ILC extrapolation = 2.3%)*
  - 2.3% at qqH, H→WW*→ 2qlv channel (extrapolated from ILC full simulation)
  - Combined: 1.0%

PFA: photon reconstruction

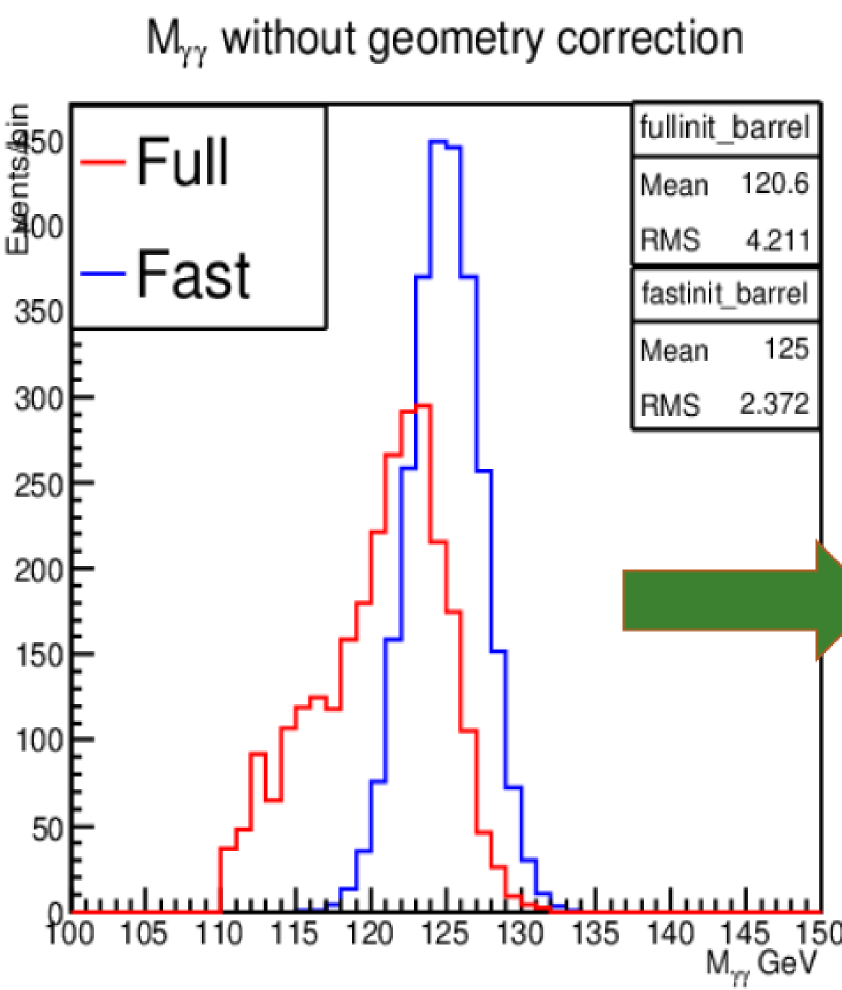


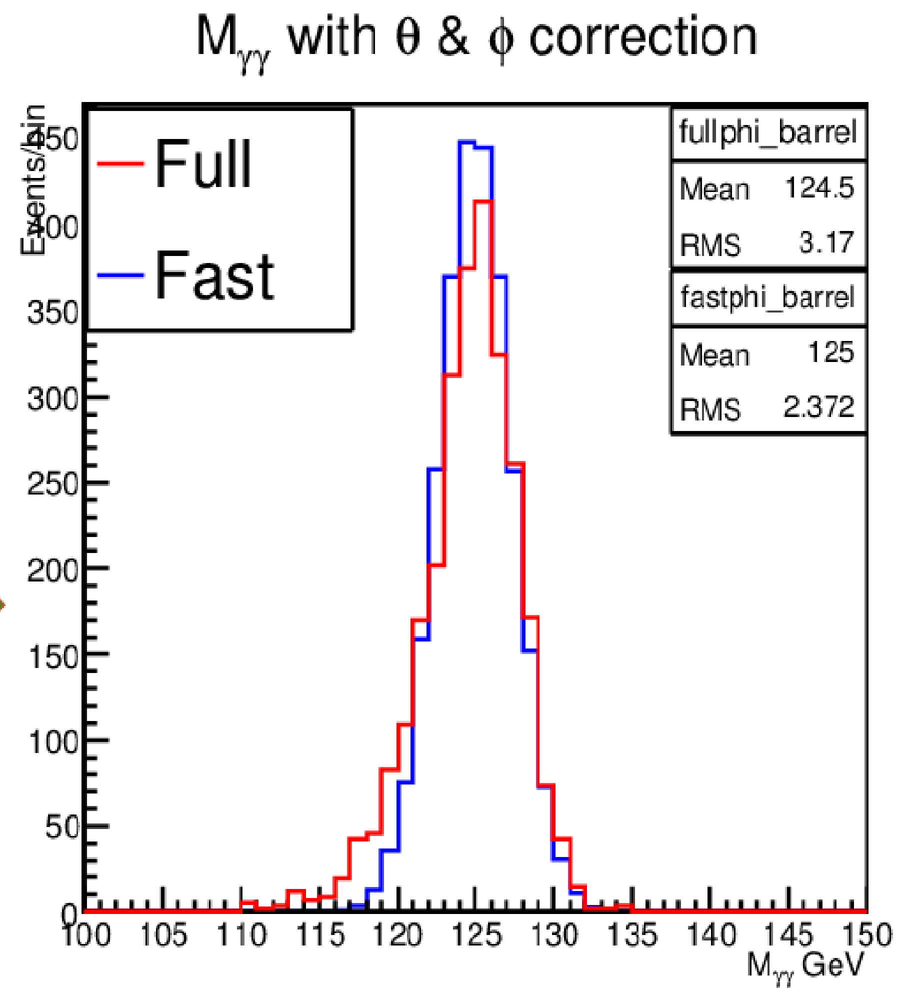


ECAL Barrel of ILD/CEPC_v1

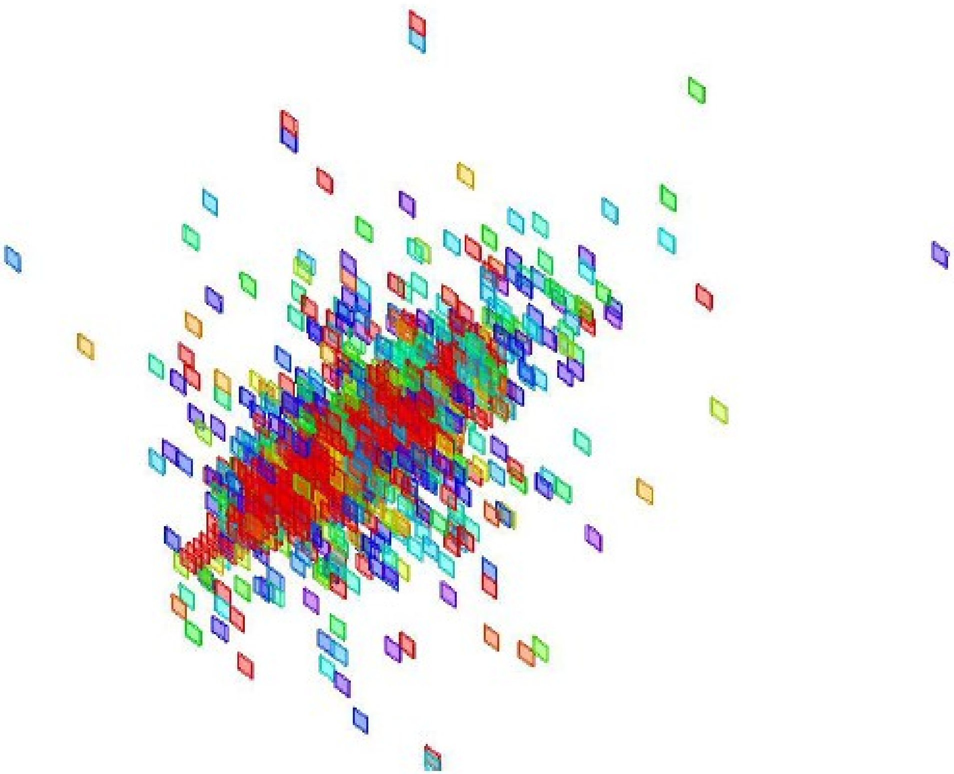
Angular Correlation of EM Shower energy response

PFA: photon reconstruction



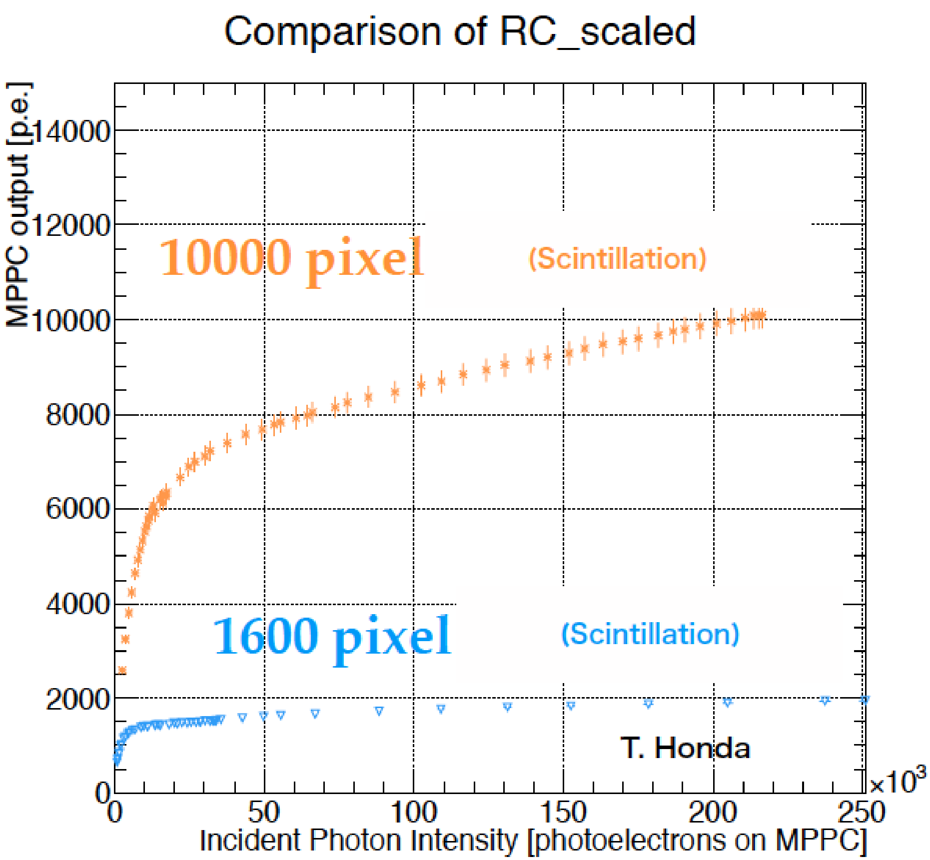


ECAL Saturation/Linear Range Study



50 GeV Photon Cluster
at ECAL with 10 mm Cell Size

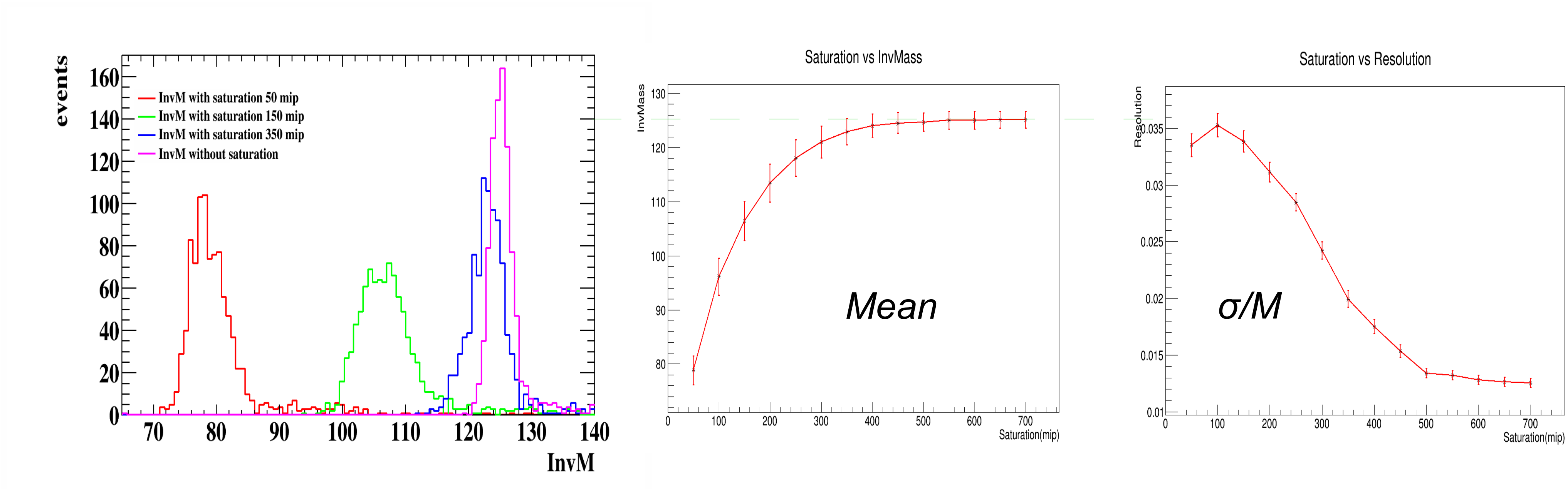
~o(1k) hits, hottest hit with E ~ 1k MIP.



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:

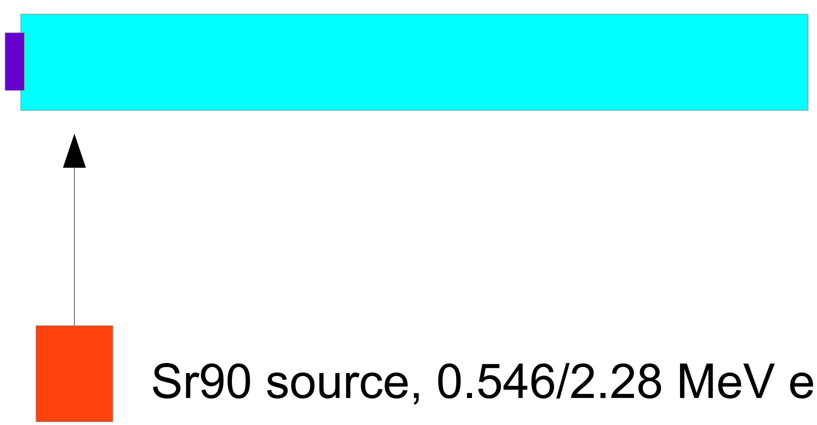
$$\log10(\text{Ranger}) = 0.87*x + 0.97*y - 0.24*y^2 + 1.26$$

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

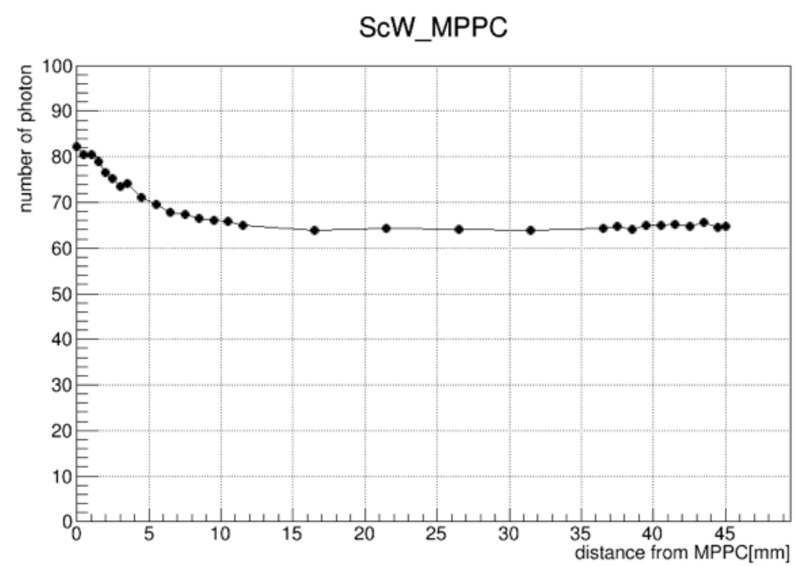
Shuzheng Wang

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%**

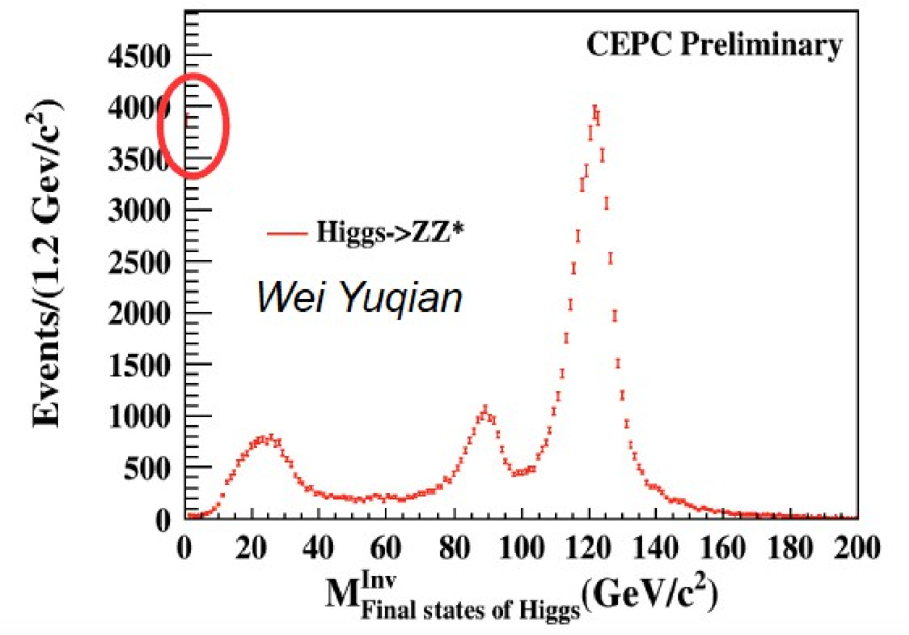


Sr90 source, 0.546/2.28 MeV electron



#pixel with different hit position

@Br(H→ZZ)



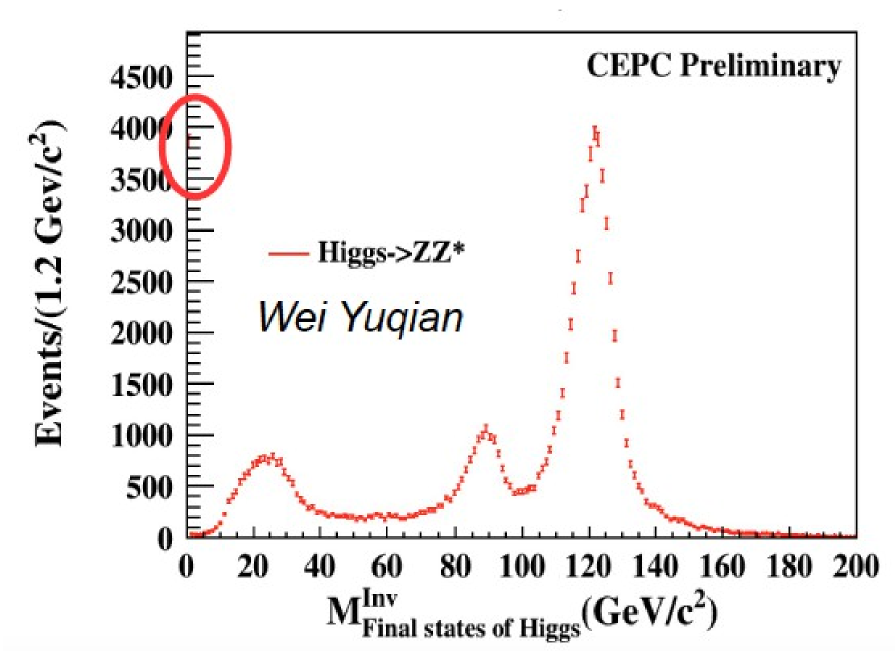
Expected Number of events with different objects

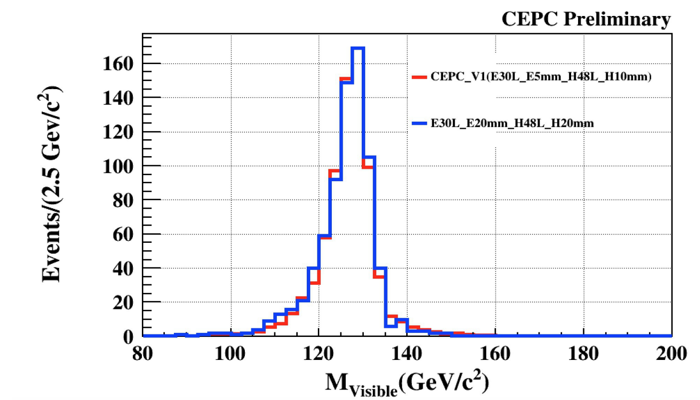
	Z→ll	tautau	vv	qq
H→ZZ*→4q	888	444	3.10k	9.24k
2v + 2q	508	254	1.77k	5.29k
2l + 2q	170	85	596	1.8k
4v	73	36	254	756
2l + 2v	49	24	170	508
4l	8	4	28	86
X + tau	120	60	418	1246

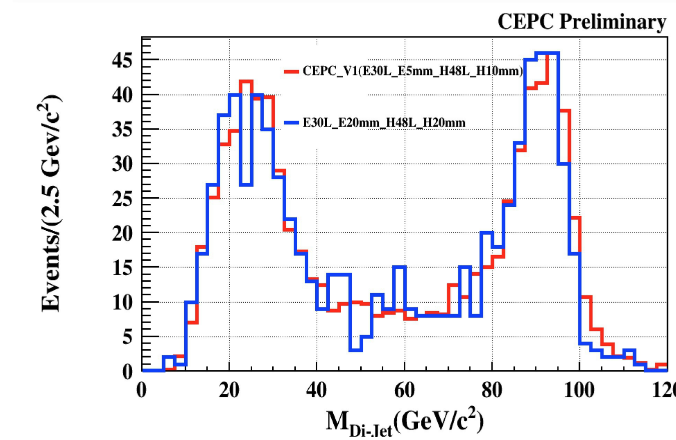
- More than 2 jets, Await for sophisticated Jet Clustering
- Await for tau finder
- limited accuracy ~ > 50%
- Explored by H->invisible analysis -> Accuracy ~ 40%
- Promising channels
- Unexplored

- Br(H→ZZ), explored at 18 different channels with full simulation (llvvqq, 4lqq, ll4q, 2l4v)
  - 8 Channels has individual accuracy better than 25%: Combined accuracy **~ 5.4%**
  - 8 with accuracy worse than 25 - 50%
  - 2 with accuracy worse than 50% (llH, H→ZZ→4q and vvH, H→ZZ→llvv)
  - *If electron id efficiency ~ muon id:* ***4.8%***
  - ***If tau finder (used for veto) is mature: ??***
  - TLEP extrapolation: **4.3%**

Br(H→ZZ) @ 20mm Cell size



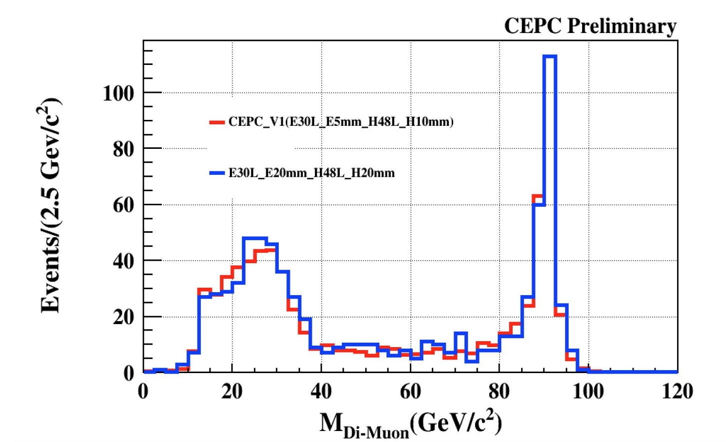




Br(H→ZZ) via vvH, H→ZZ*→llqq

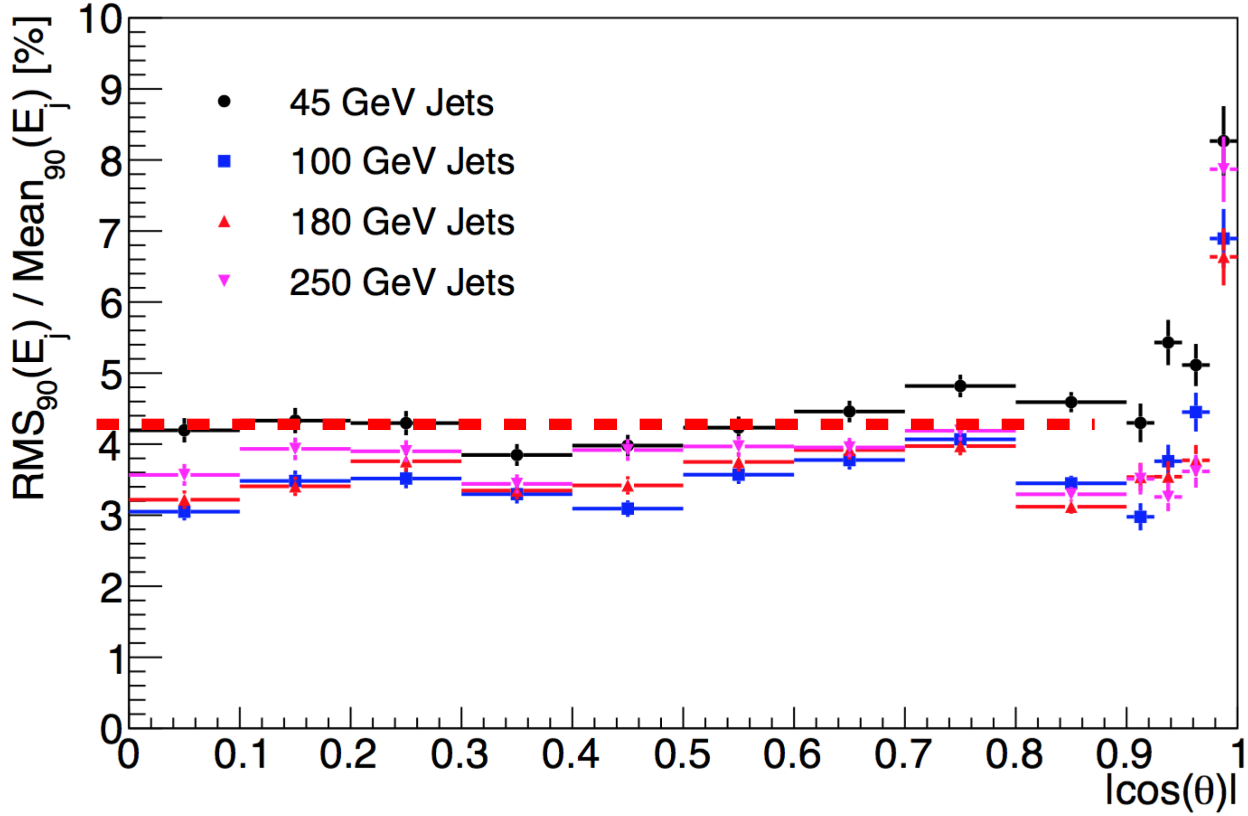
Over all event reco. efficiency reduced ~2%

	Events	Recon.	Efficiency
CEPC_v1	4143	3957	95.5%
TG2	808	754	93.3%



Arbor @ CEPC_v1 with DHCAL
For vvH event (Jet Energy = 30 – 100 GeV)
RMS90/Mean * sqrt(2) = 3.8/125 * 1.414 = 4.3%

PandoraPFA
avec
le SDHCAL



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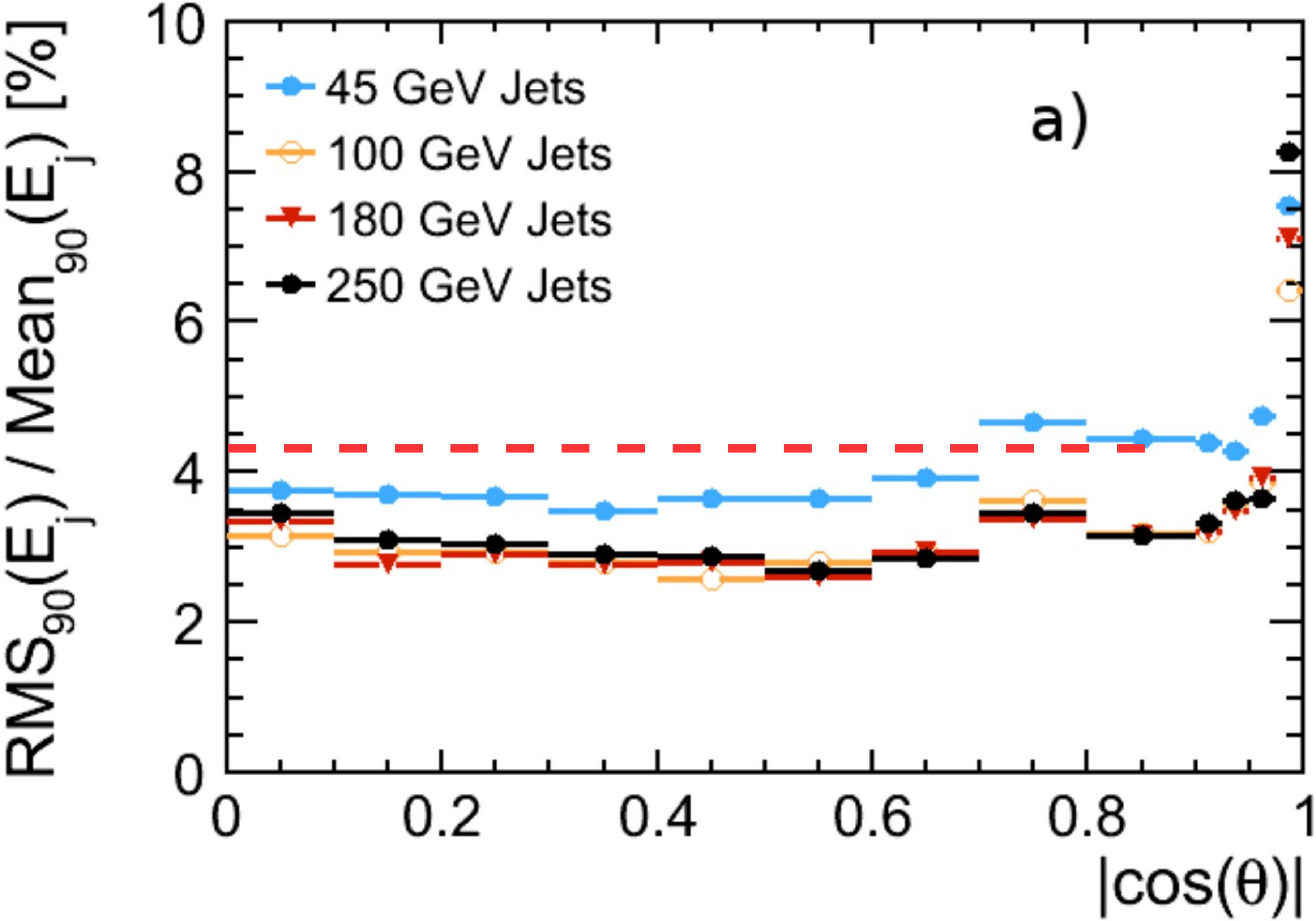
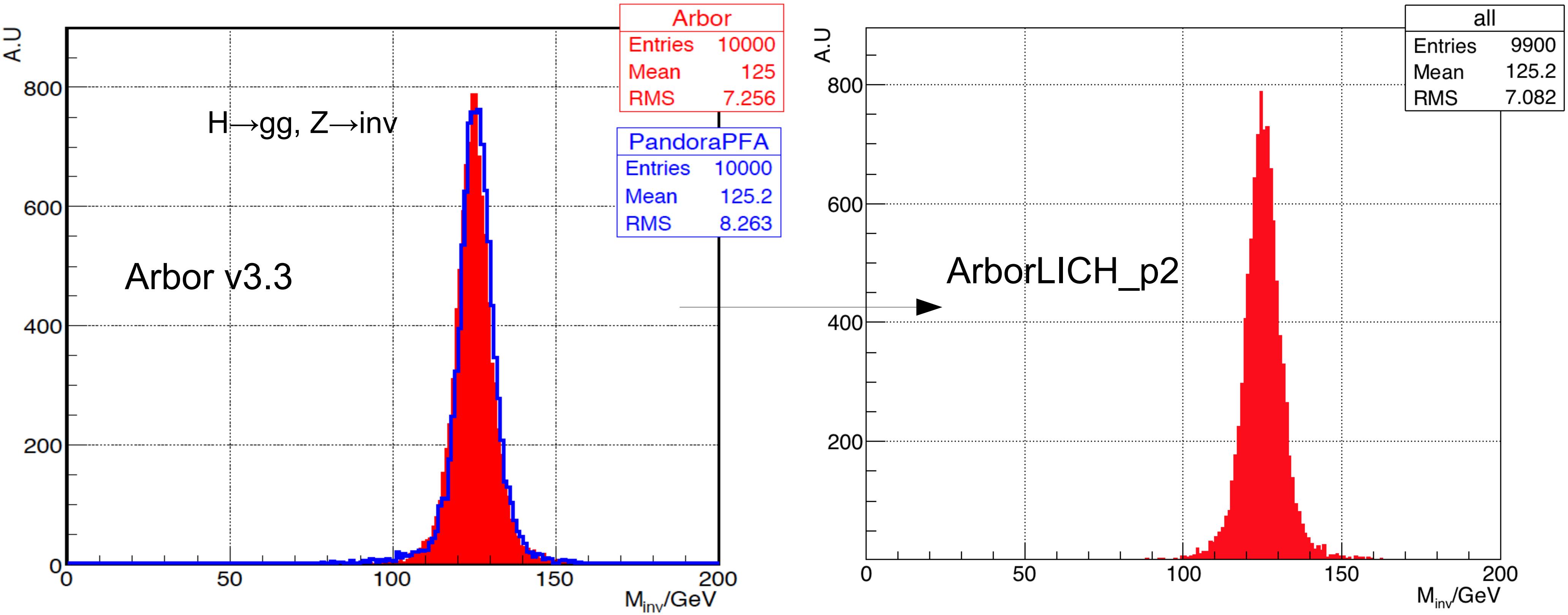


45 GeV Jets
100 GeV Jets
180 GeV Jets
250 GeV Jets
a)
RMS$_{90}$(E$_j$) / Mean$_{90}$(E$_j$) [%]
|cos(θ)|
0
2
4
6
8
10
0
0.2
0.4
0.6
0.8
1

JER on vvH event at CEPC_v1



- Digital HCAL mode: Energy Estimated as k*NHit for HCAL Cluster, Calibration Constant (k) optimized for both Pandora & Arbor via Scan
- Jet: Highly depending on Jet clustering if #Jet > 2...

Longitudinal: total thickness

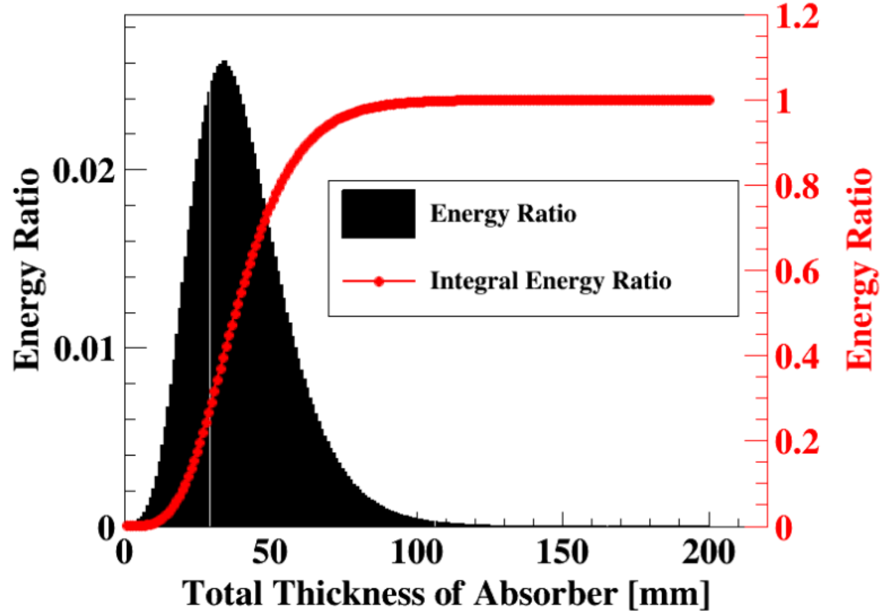
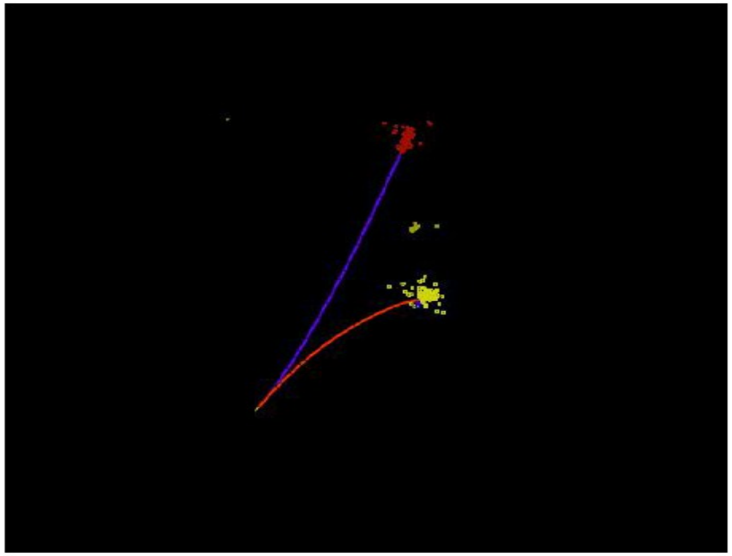


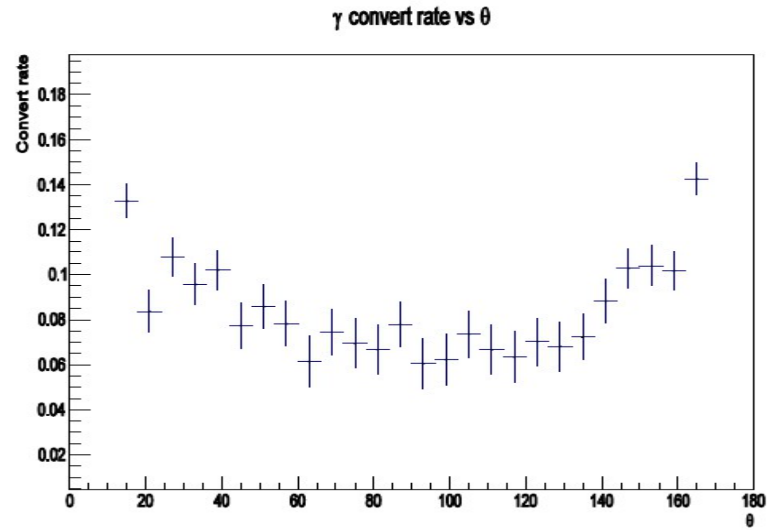
Figure 3. Deposit energy ratio of 120GeV photon shower by the depth in tungsten, and the integrated result.

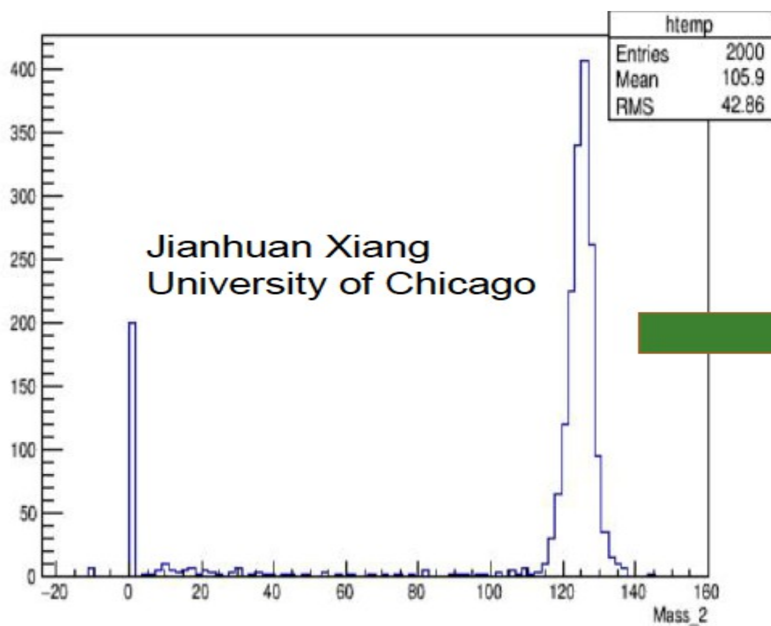
Table 1. Percentage of EM showers energy deposit in 80mm-95mm tungsten

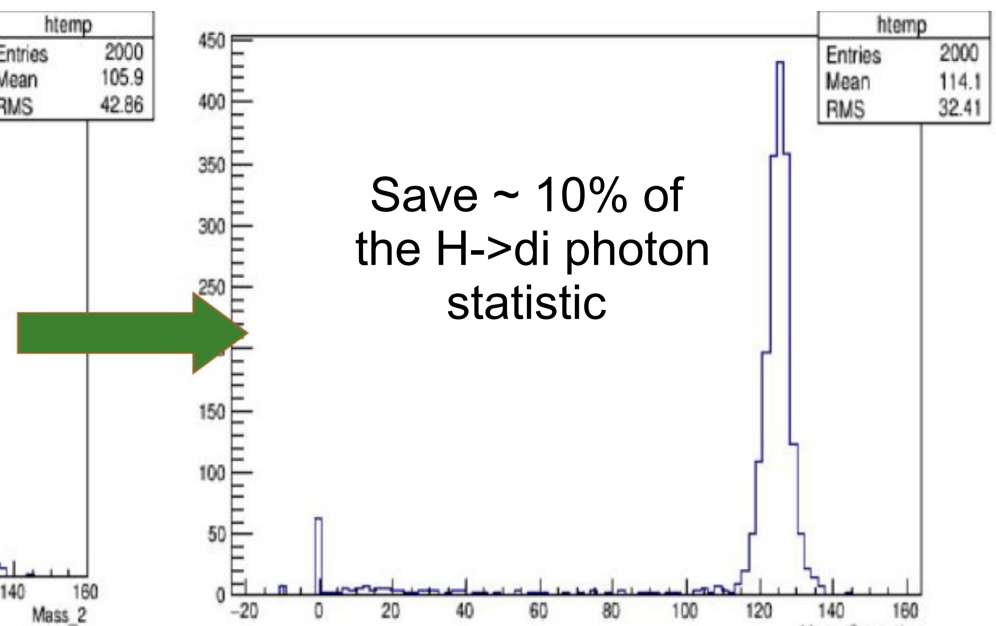
Photon Energy	95mm W	90mm W	85mm W	80mm W
175GeV	99.0%	98.6%	97.9%	96.9%
120GeV	99.2%	98.8%	98.2%	97.3%
75GeV	99.4%	99.1%	98.7%	98.1%

Photon conversion & recovery

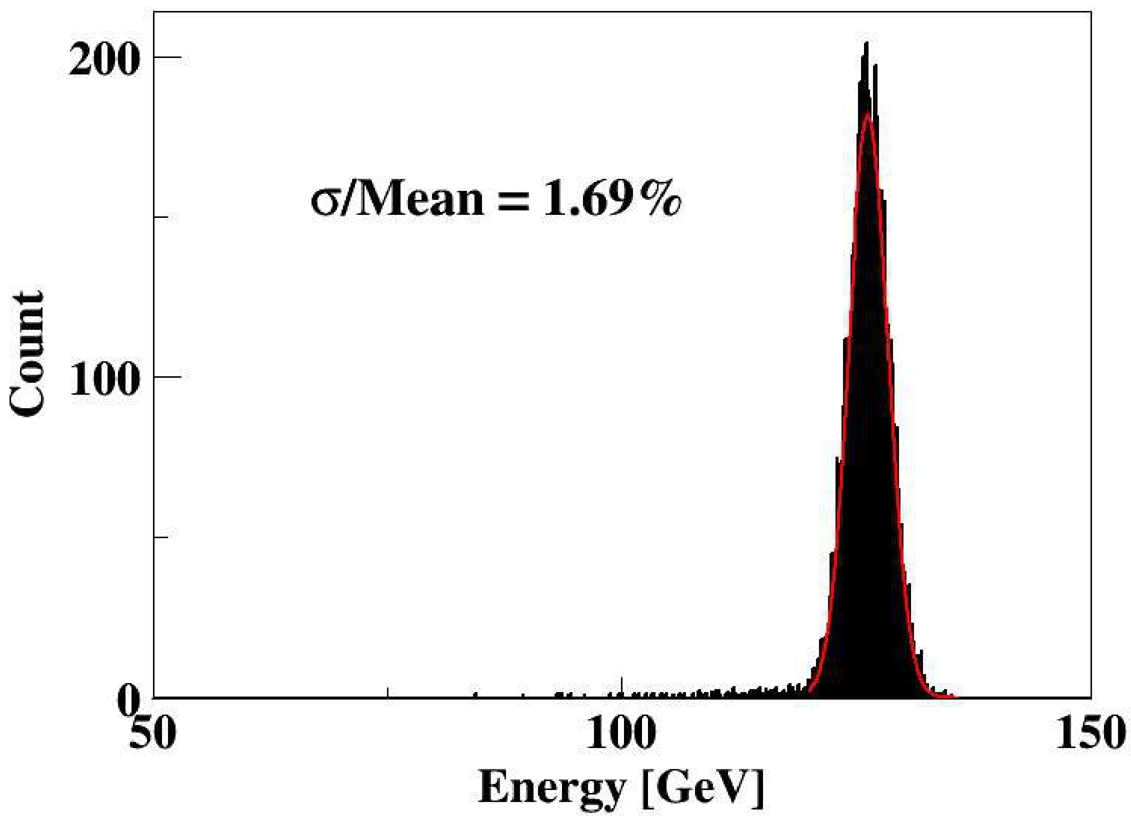


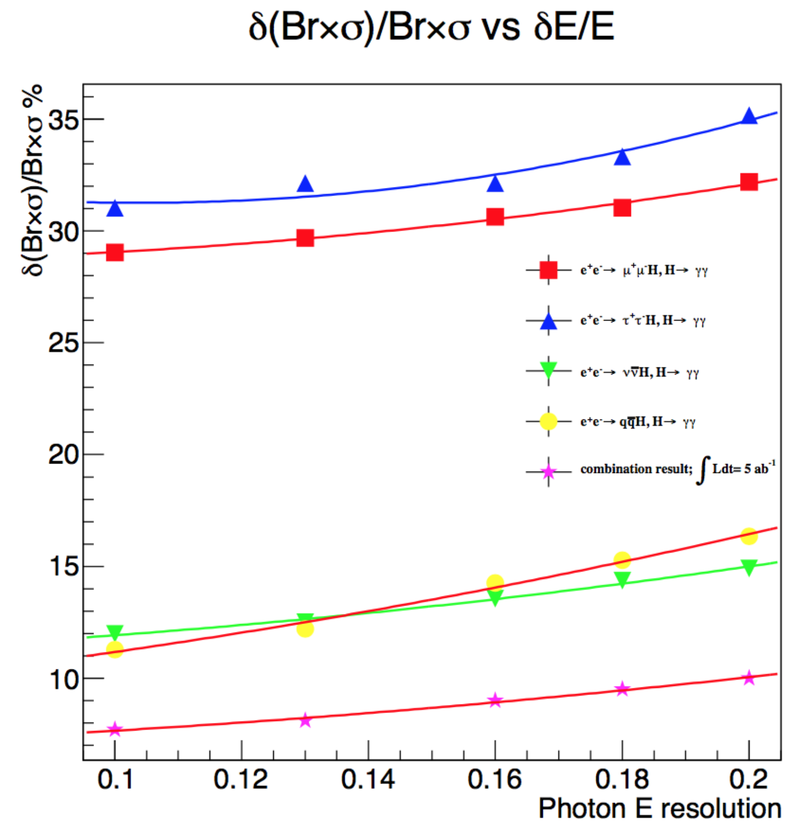






@ H->di photon





Relative Accuracy on sigma*Br: ~ 8.5%