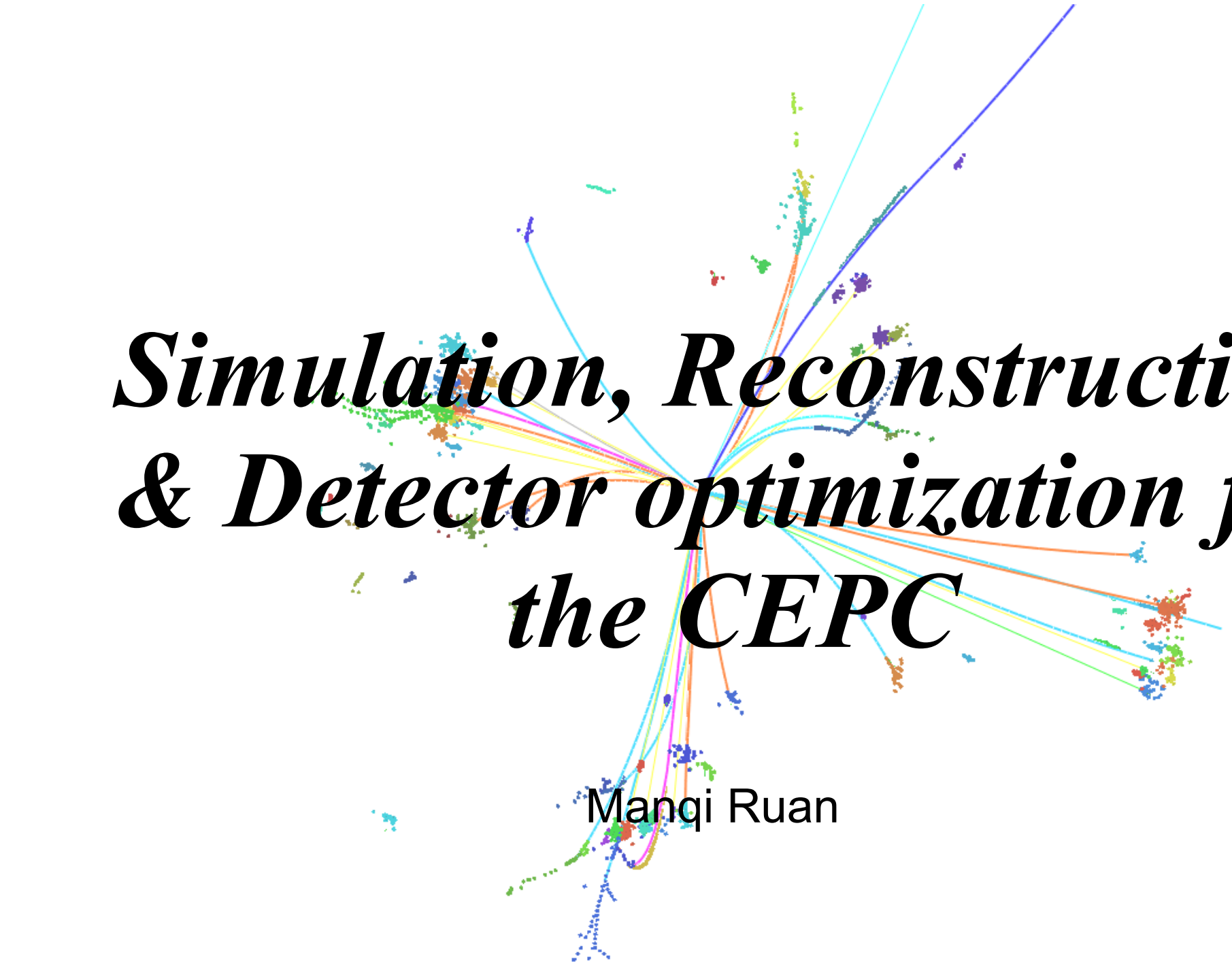
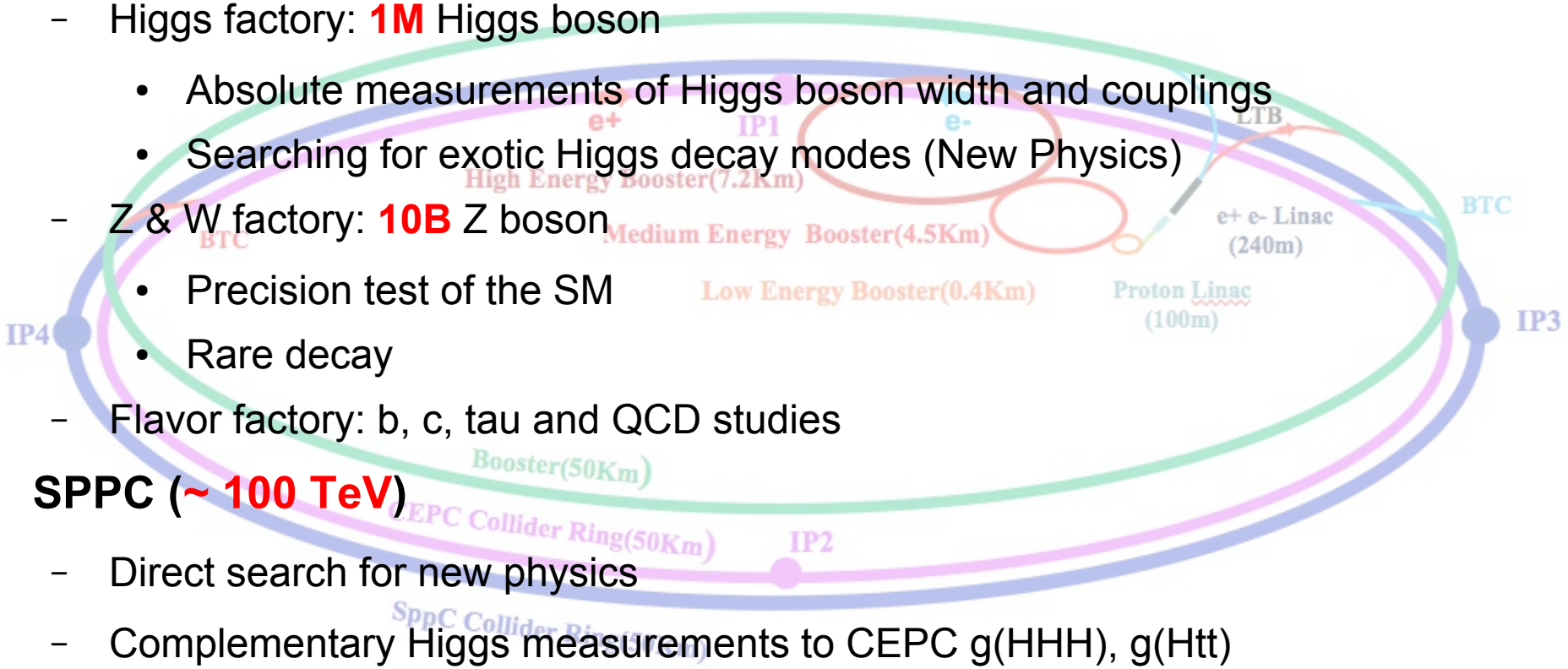


Simulation, Reconstruction & Detector optimization for the CEPC

Manqi Ruan

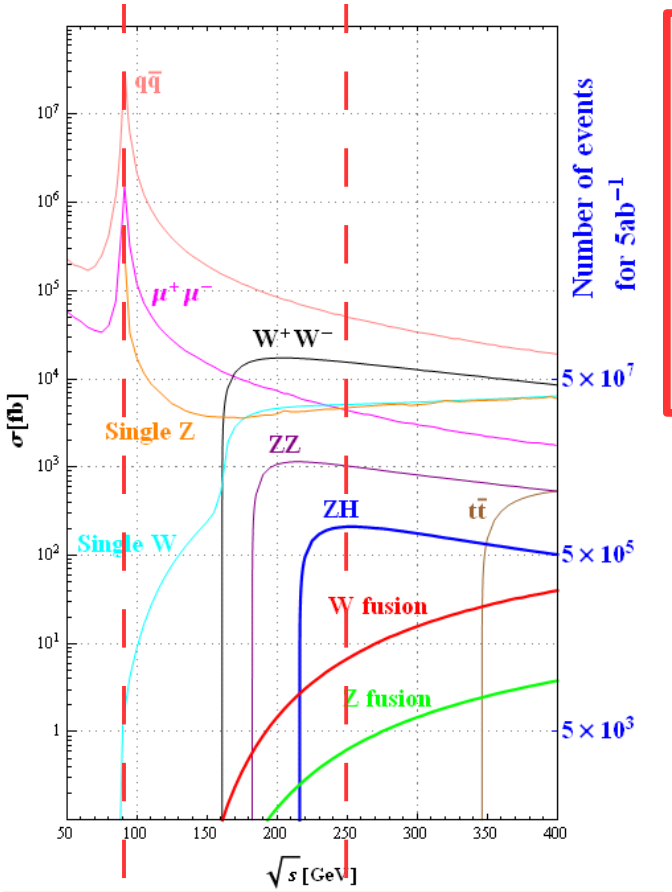
Science at CEPC-SPPC

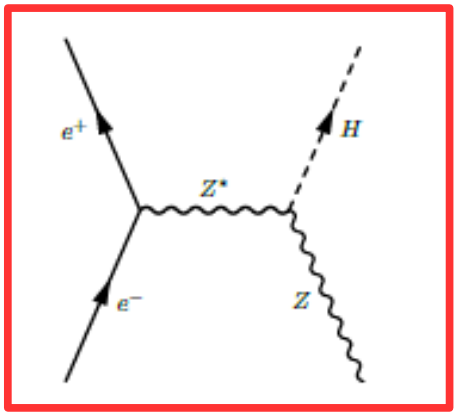
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **10B** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor 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...**

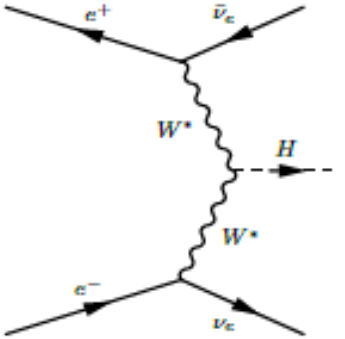


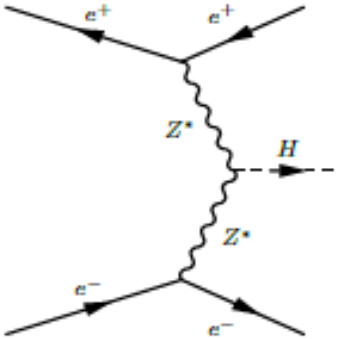
Complementary

CEPC: 1M Higgs & 10-100 B Z









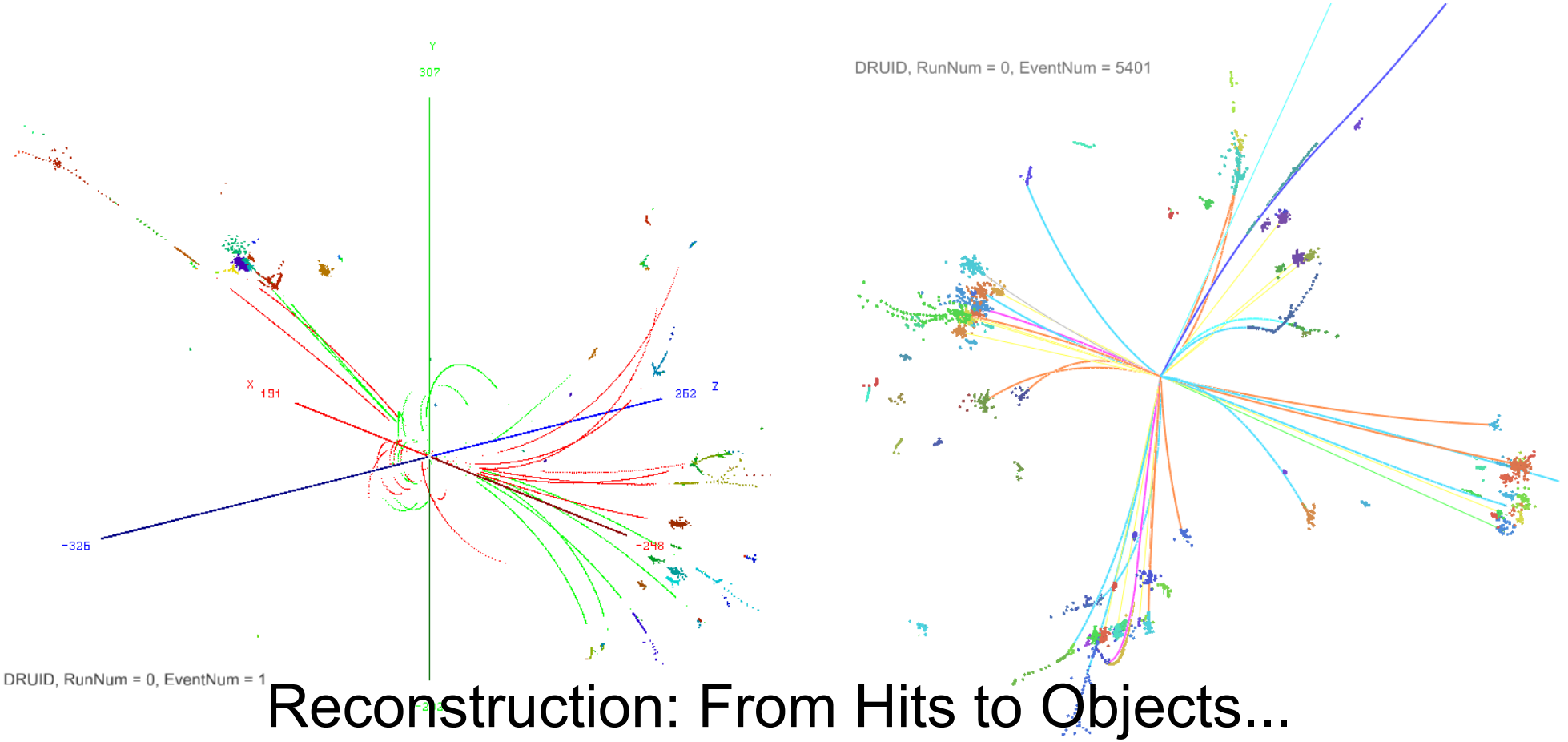
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

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

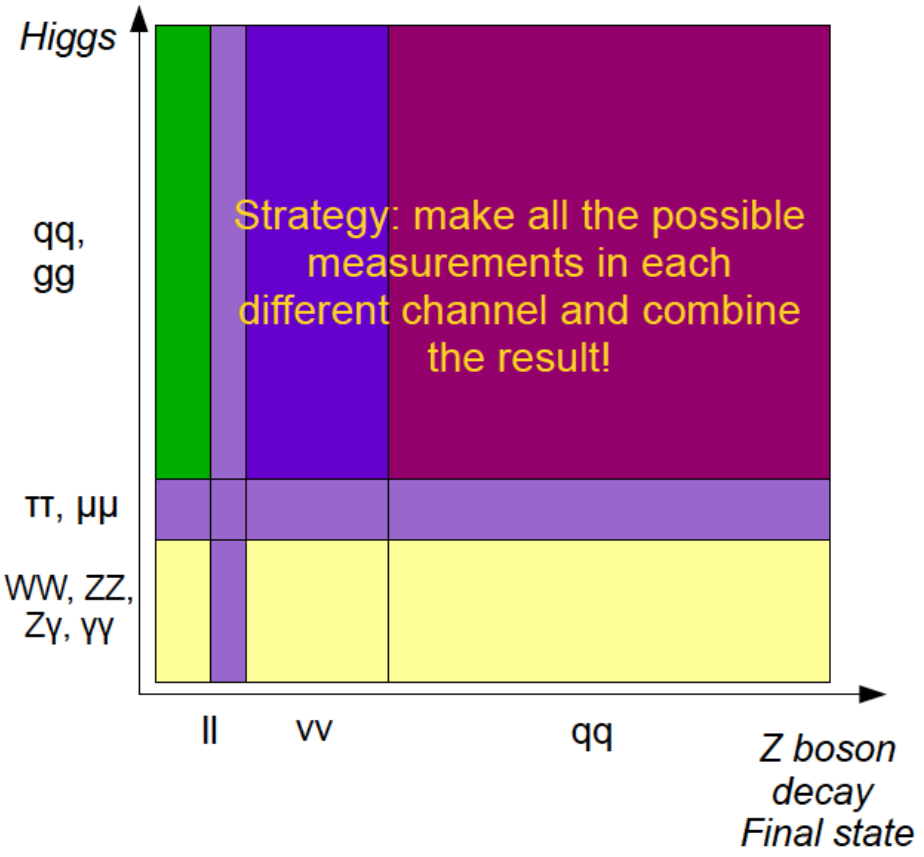
Sim Higgs @ CEPC

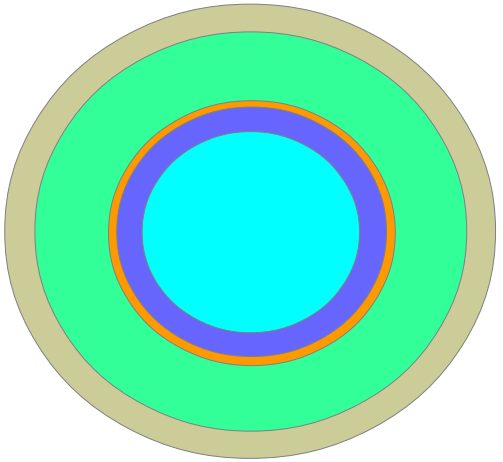


Reconstruction: From Hits to Objects...

Optimization: Performance at different geometries with adequate Reconstruction

Detector Designs





Tracker, TPC: R = 1.8 m

ECAL: 84-90 mm W

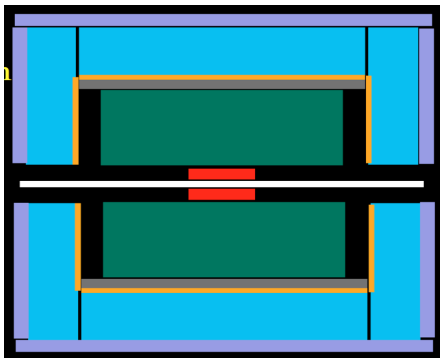
ToF: dt ~ 50 ps

HCAL: ~1000 mm Iron

Solenoid (3T) + Yoke

PFA Oriented:

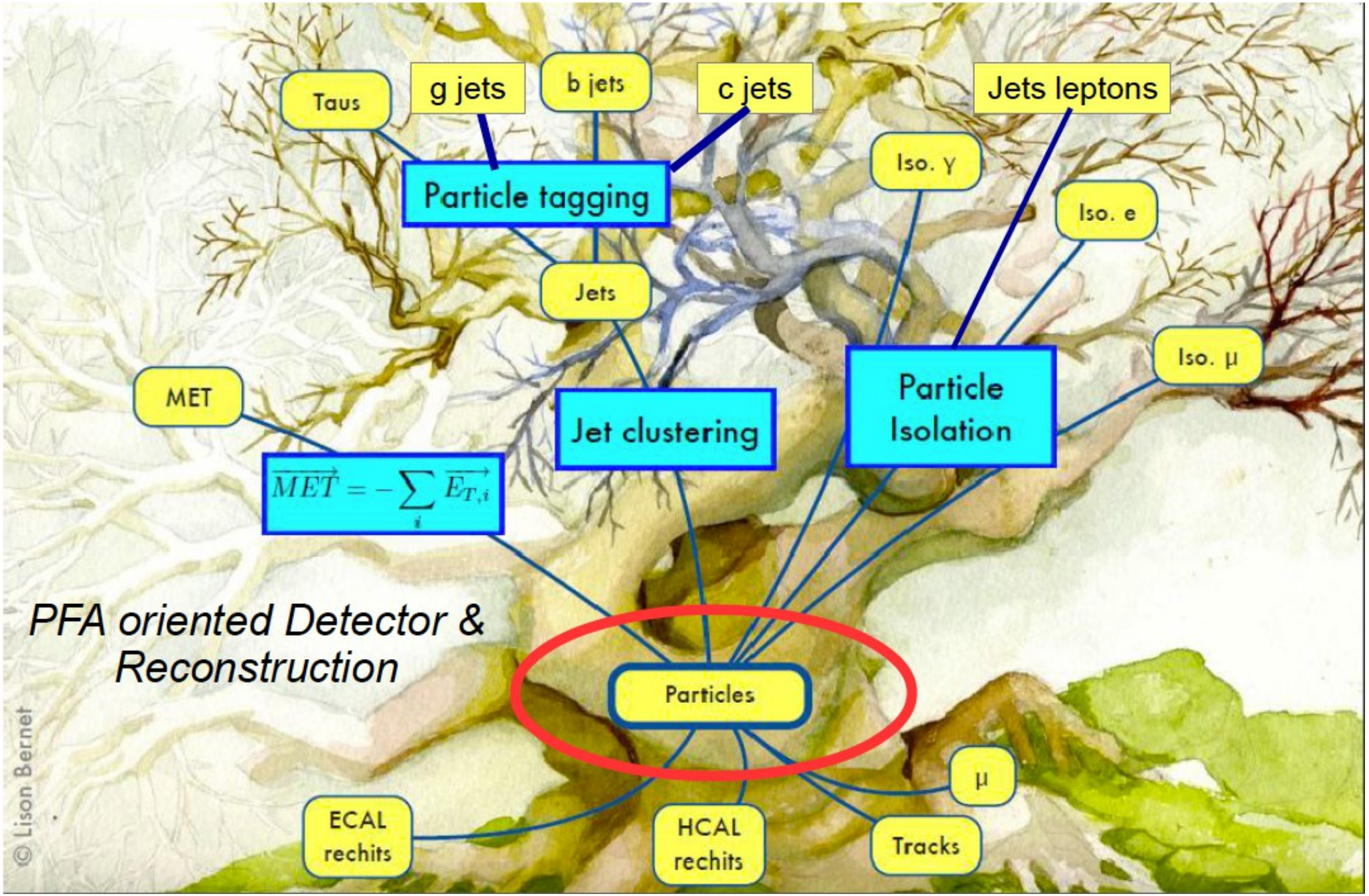
TPC/Silicon + High Granularity Calorimeter



- 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

Alternative:

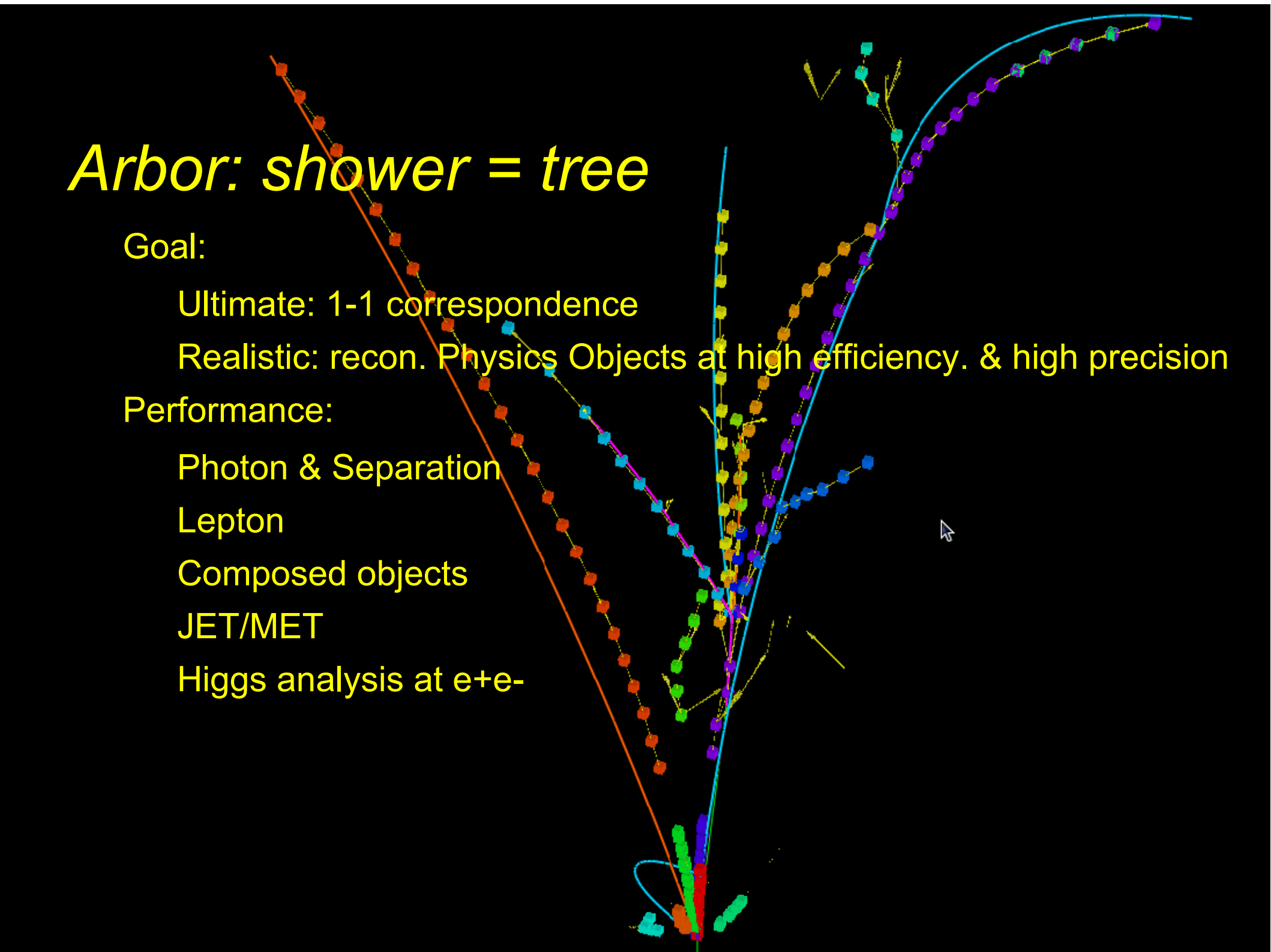
Wire Chamber + Dual Readout Calorimeter


Taus
g jets
b jets
c jets
Jets leptons
Particle tagging
Iso. γ
Iso. e
Jets
Iso. μ
MET
Jet clustering
Particle Isolation
$\overrightarrow{MET} = -\sum_i \overrightarrow{E_{T,i}}$
PFA oriented Detector & Reconstruction
Particles
μ
ECAL rechits
HCAL rechits
Tracks
© Lison Bernet

PFA Oriented Detector: Performance

- 探测器需准确重建、测量所有的物理标的物，以完成 Higgs, EW 等的精确测量
  - 大空间角覆盖：$|\cos(\theta)| < 0.99$
  - 轻子鉴别： eff > 99.5%, mis id < 1% 优于现有最高水平
  - 末态粒子量能器簇射分离：远优于目前最好水平
  - 径迹重建及带电粒子动量测量： $\delta(1/Pt) \sim 2e\text{-}5\ GeV^{-1}$, 10 倍于目前最好水平
  - 区别 b, c 和轻夸克喷注：要求高精度顶点系统，首次实现 c 夸克喷注的区分
  - 喷注能量测量： 1.5 – 2 倍于目前最好水平，以在 Higgs 衰变相关末态中准确重建 Higgs 粒子质量 (σ/Mean ~ 4% for H->gg events)
  - 系统误差控制： 10 倍于目前最好水平
    - 束流能量、亮度的监测、测量，准直和刻度。

Arbor: shower = tree



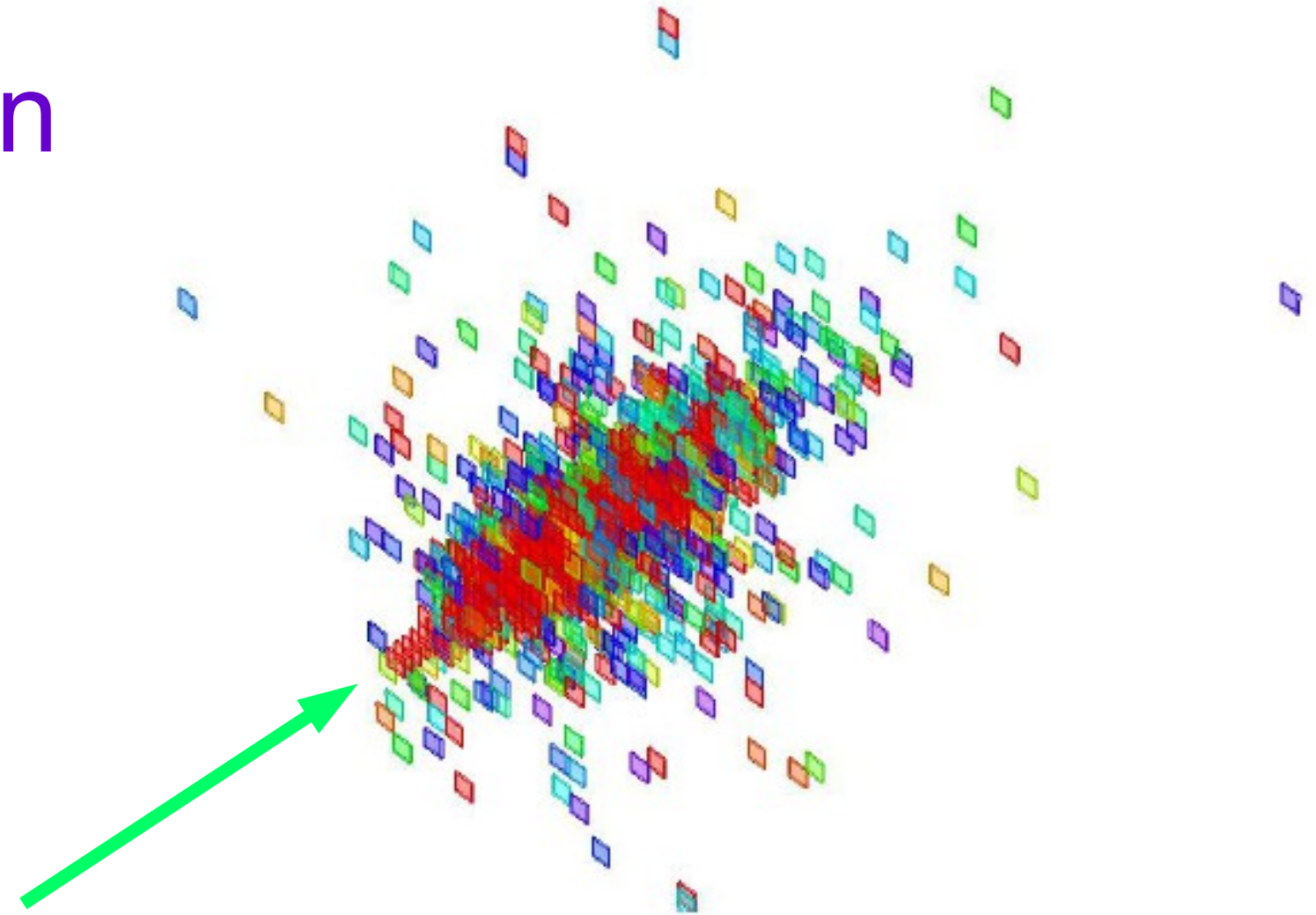
Goal:

- Ultimate: 1-1 correspondence
- Realistic: recon. Physics Objects at high efficiency. & high precision

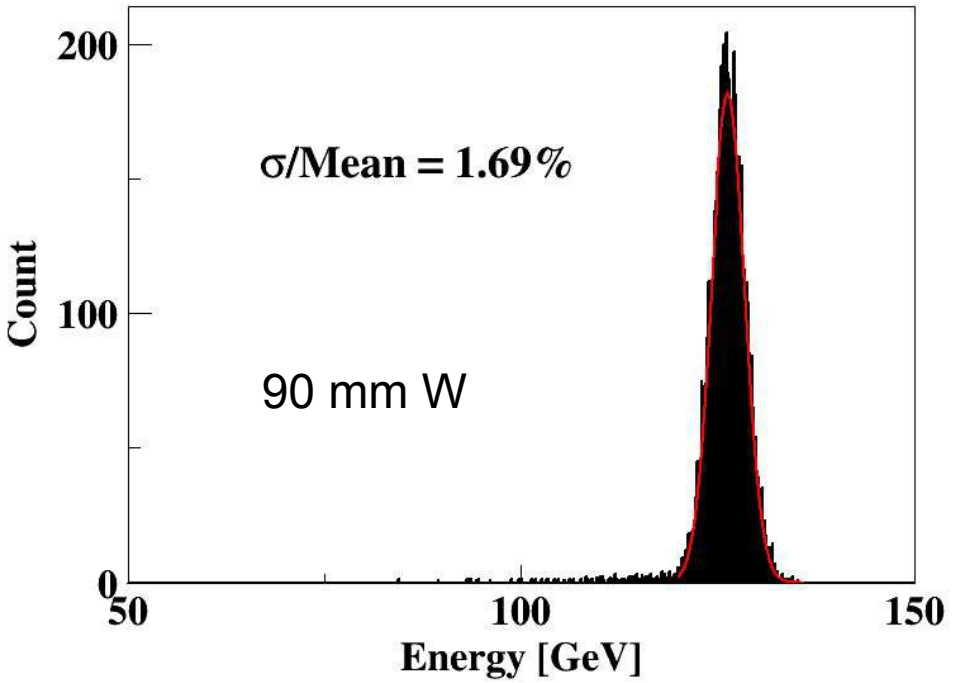
Performance:

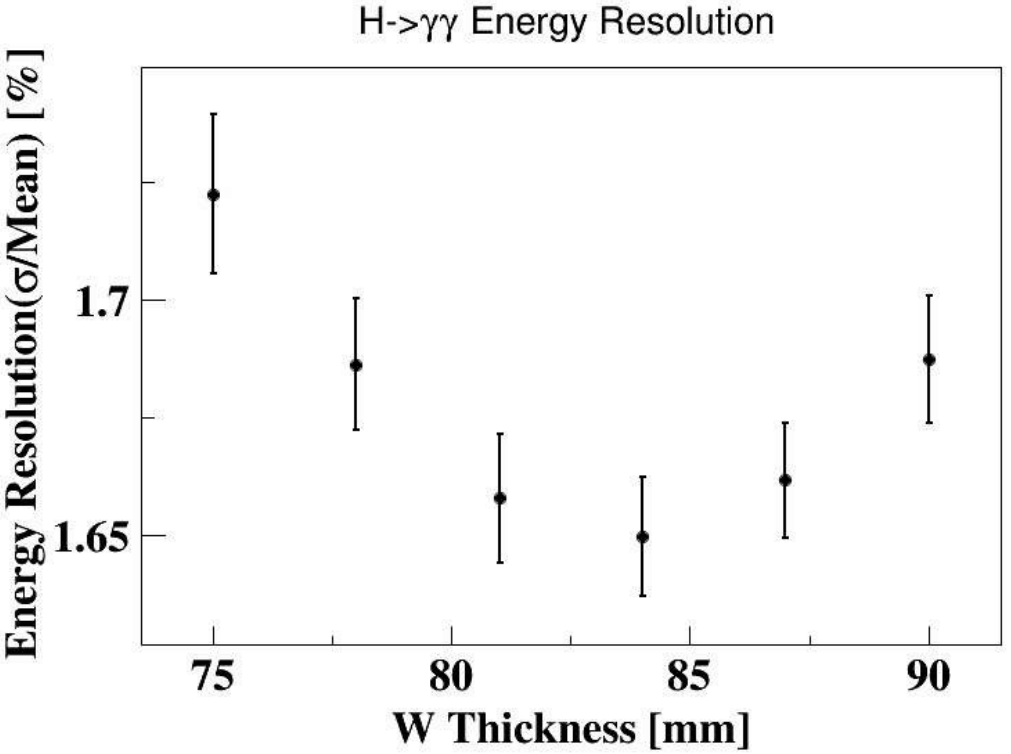
- Photon & Separation
- Lepton
- Composed objects
- JET/MET
- Higgs analysis at e+e-

Photon



H->di photon Vs W thickness

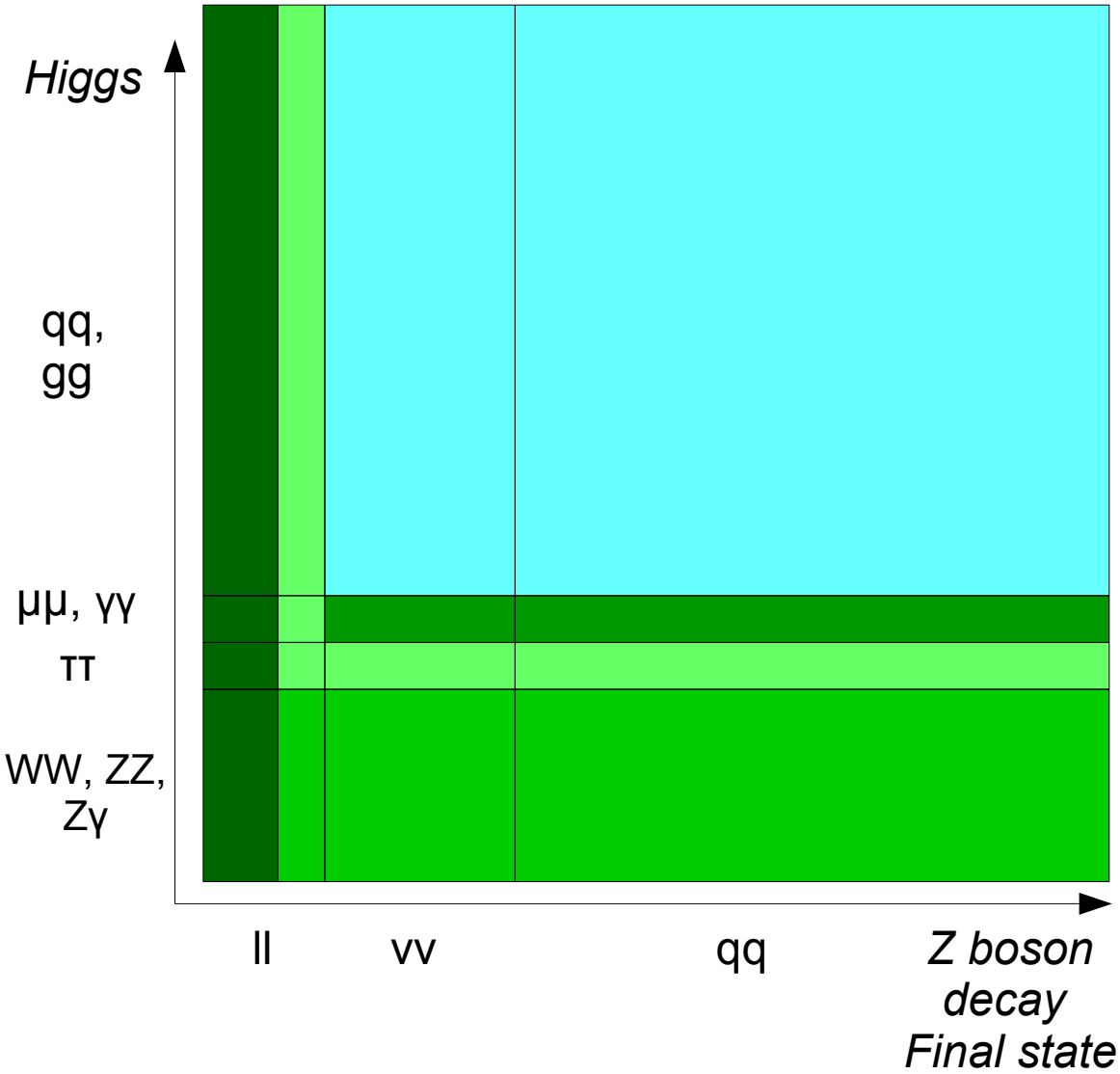




30 Layers, each layer with 0.5 mm Si + 2 mm PCB
ECAL only performance

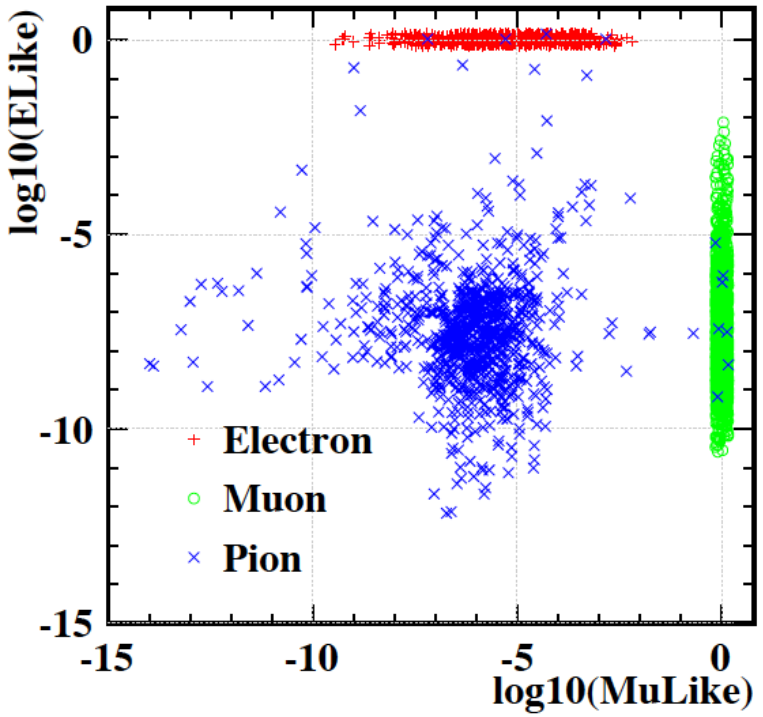
Optimization on the in-homogeneous longitudinal structure (i.e, Absorber thickness at different layer) not applied

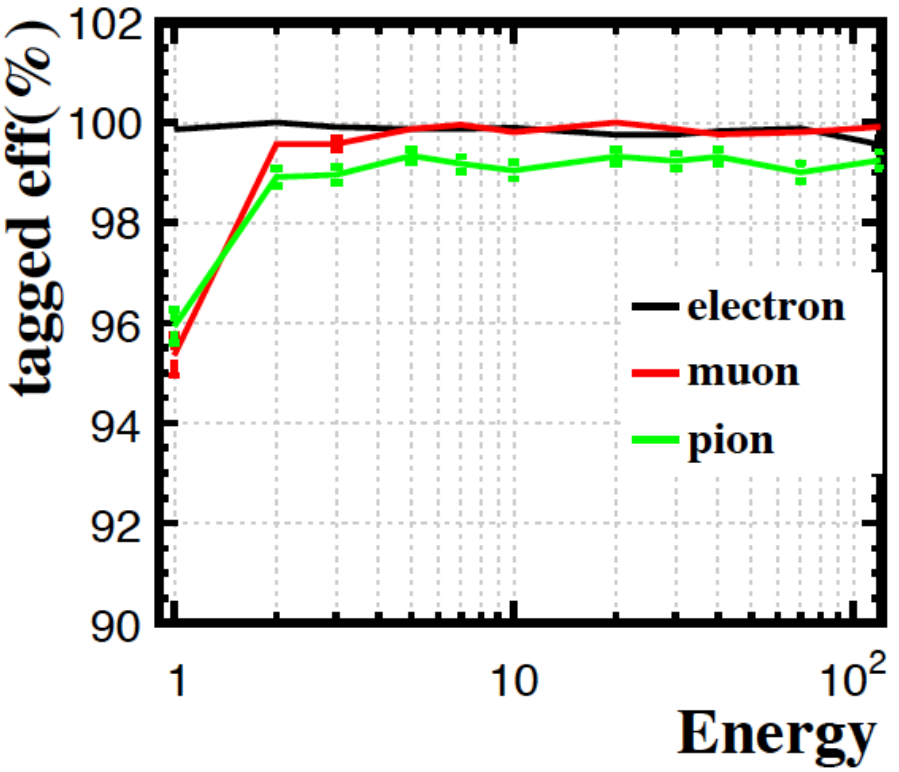
Leptons: essential for Higgs program



- 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 Yu: general **L**epton **I**D for **C**alorimeter with **H**igh granularity (LICH)



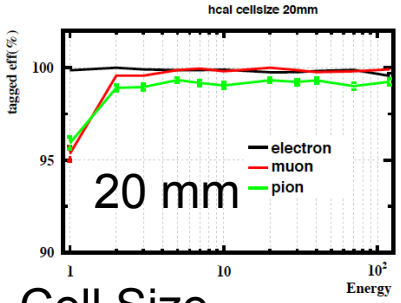


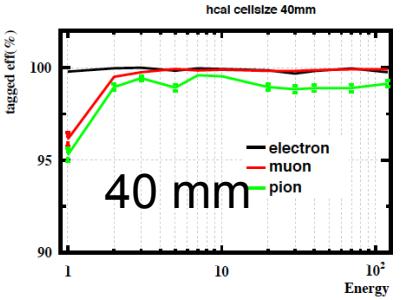
BDT method using 4 classes of 24 input discrimination variables.

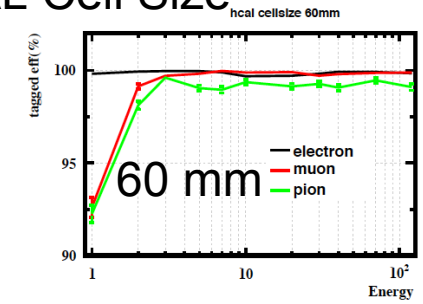
Test performance by requesting
Electron = E_likeness > 0.5 ; Muon = Mu_likeness > 0.5
Single charged reconstructed particle, for E > 2 GeV: lepton efficiency > 99.5% && Pion mis id rate ~ 1%

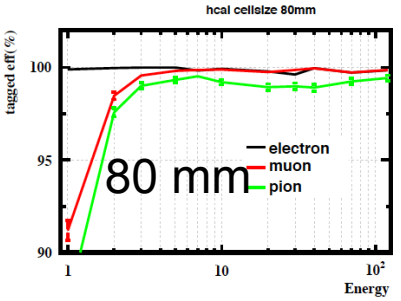
Vary the granularity

HCAL Cell Size

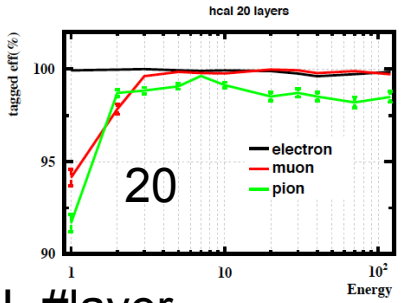


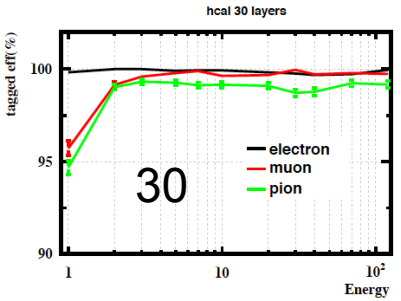


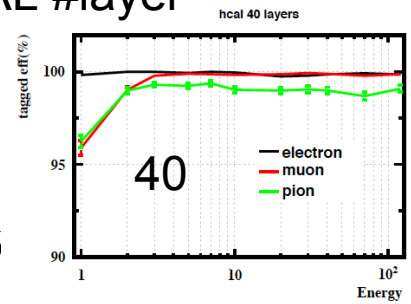


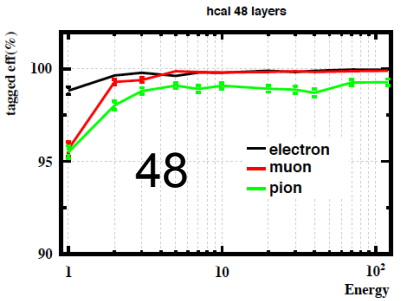


HCAL #layer

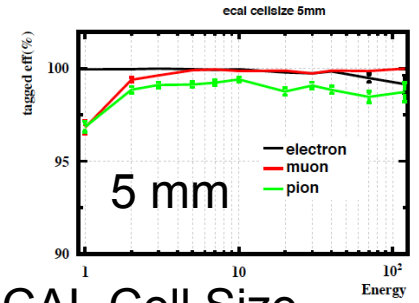


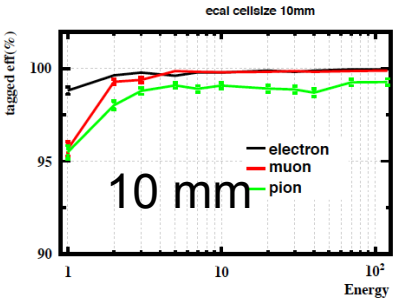


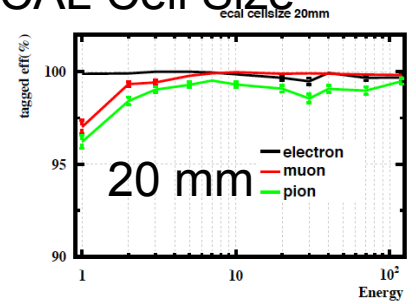


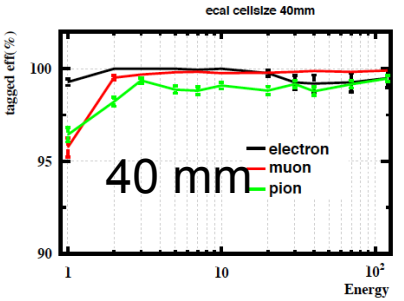


ECAL Cell Size

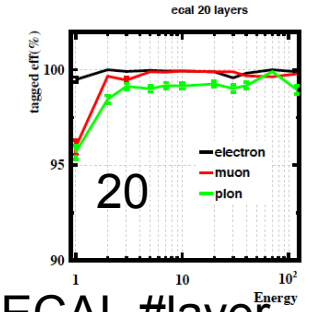


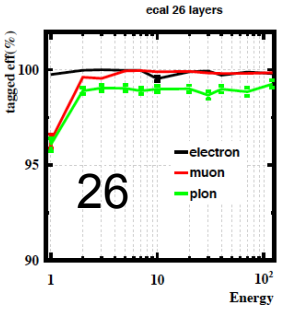


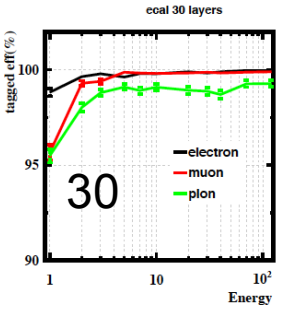




ECAL #layer

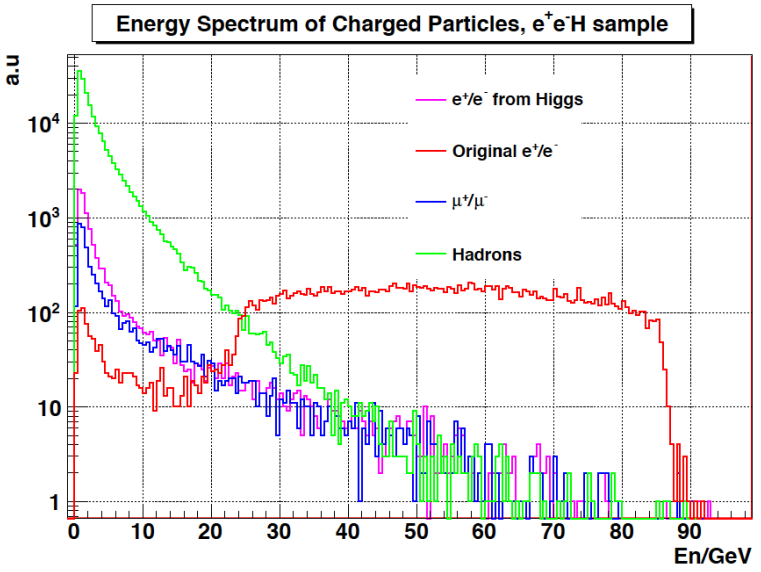


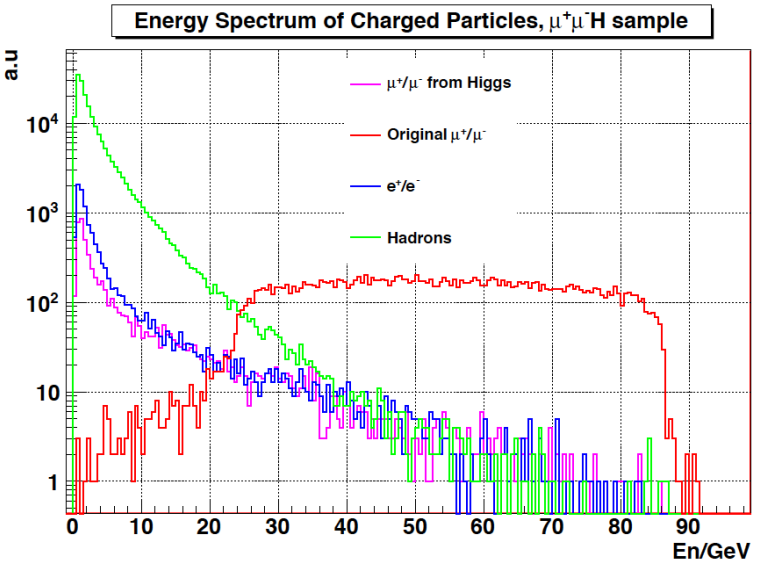


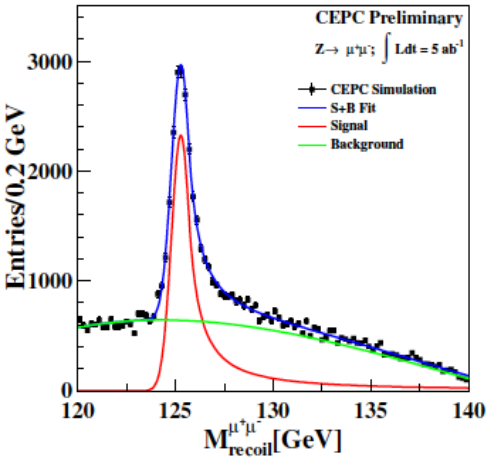


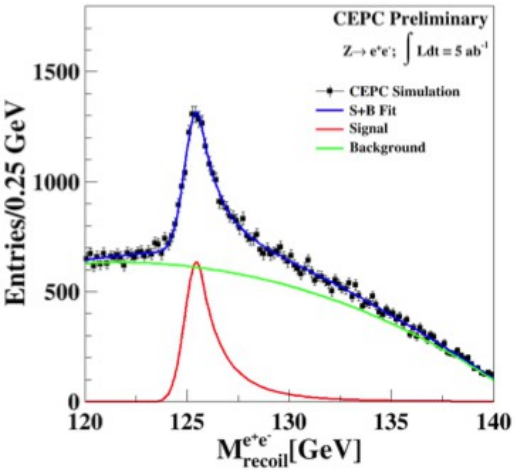
No Significant effect for E > 2 GeV charged Particles

LICH @ llH events









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

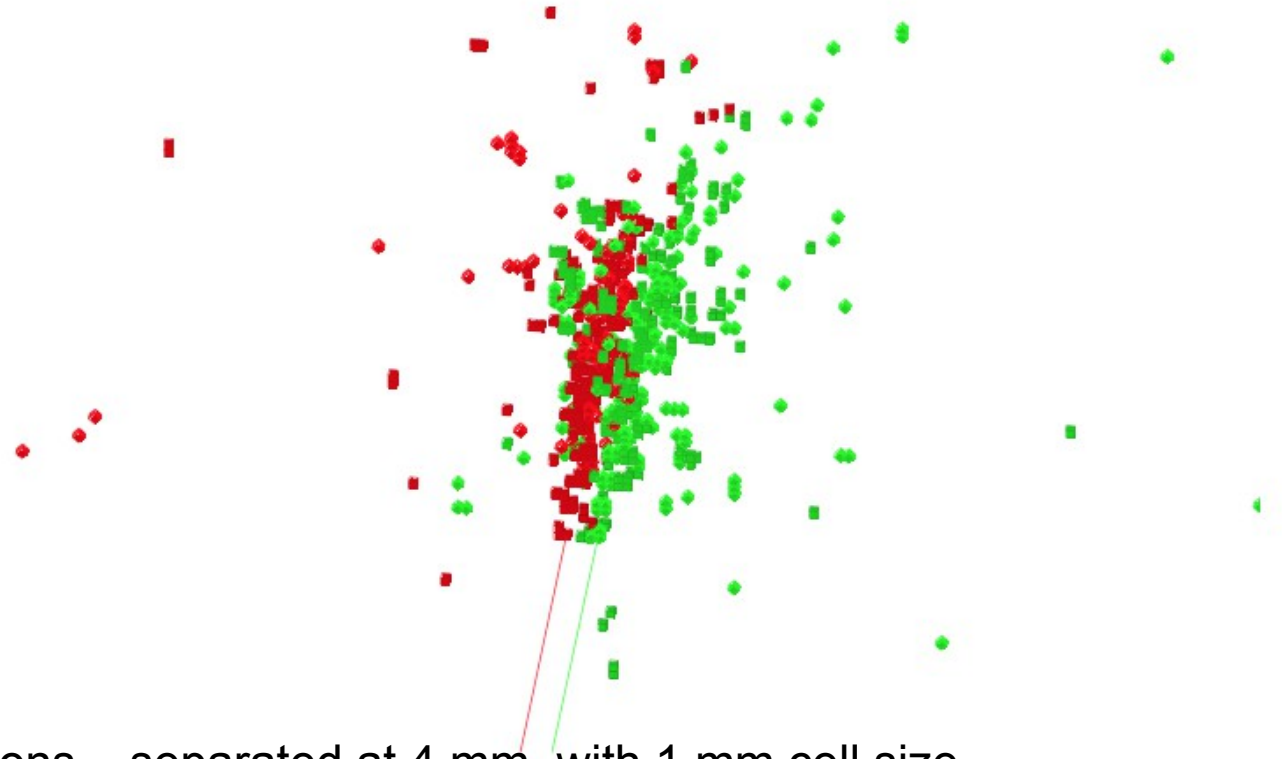
Geom 1/2: 10 (20) mm ECAL/HCAL Cell

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

More stringent requirement arrises from jet leptons...

https://arxiv.org/abs/1701.07542

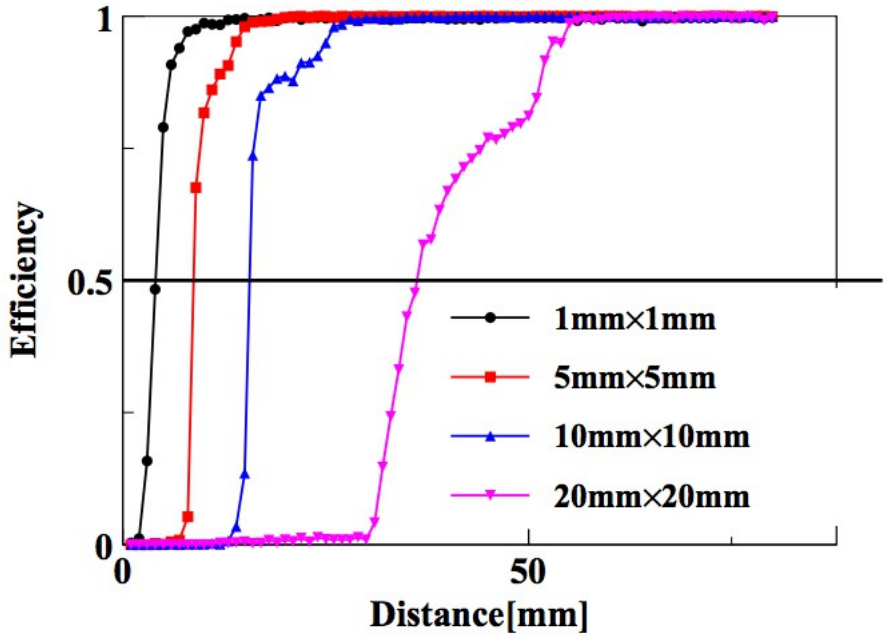
Separation

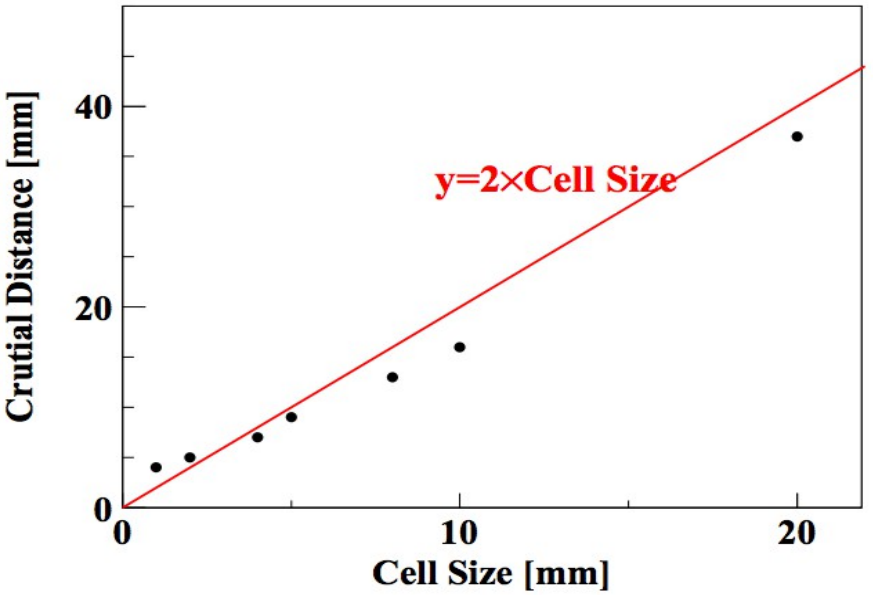


Two 5 GeV photons – separated at 4 mm, with 1 mm cell size

Figure 11. Event display of reconstructed di-photon.

Critical distance: ~ 2*Cell Size

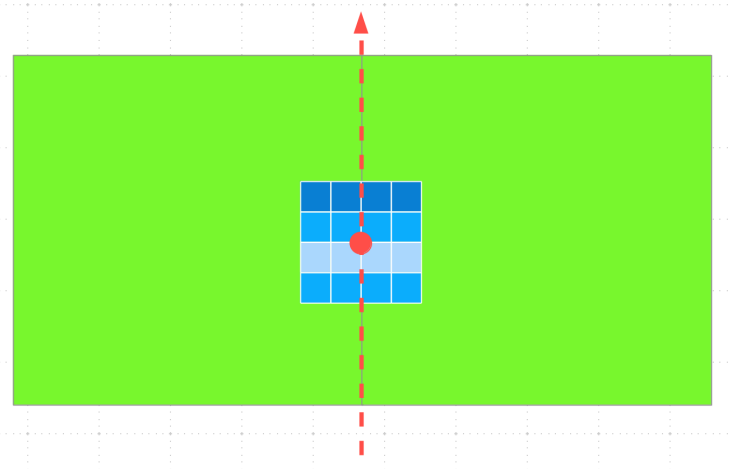




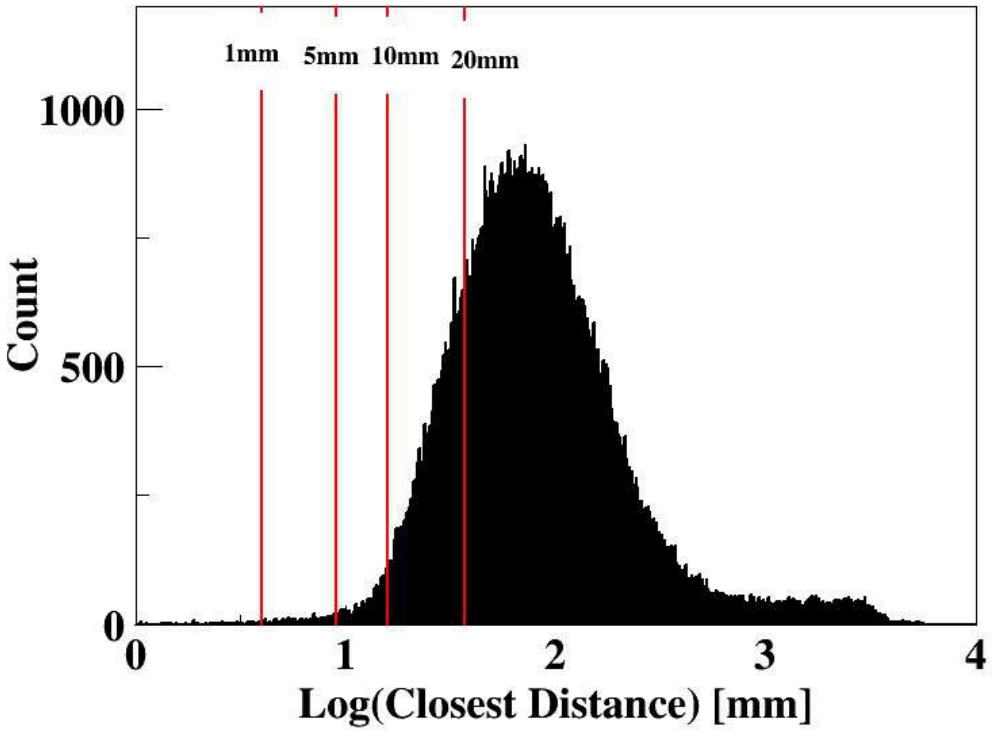
Efficiency: successfully reconstruct 2 Photons with $1/3 < E/E_{total} < 2/3$

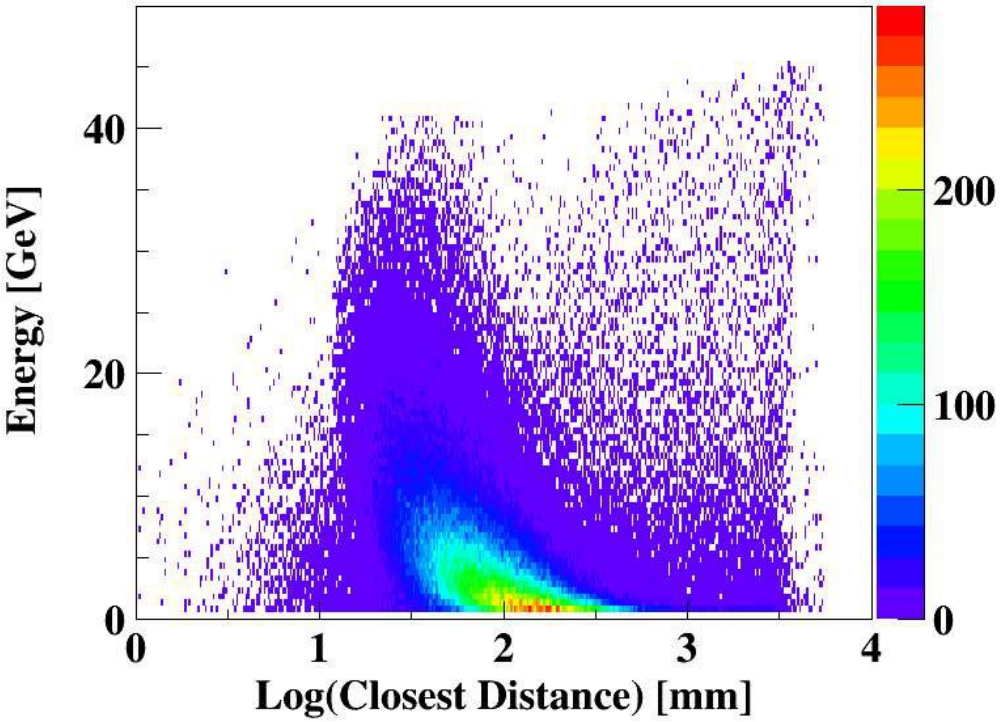
Simulation at 1 mm Cell & Digitized To large cell size

Scan step = 1 mm



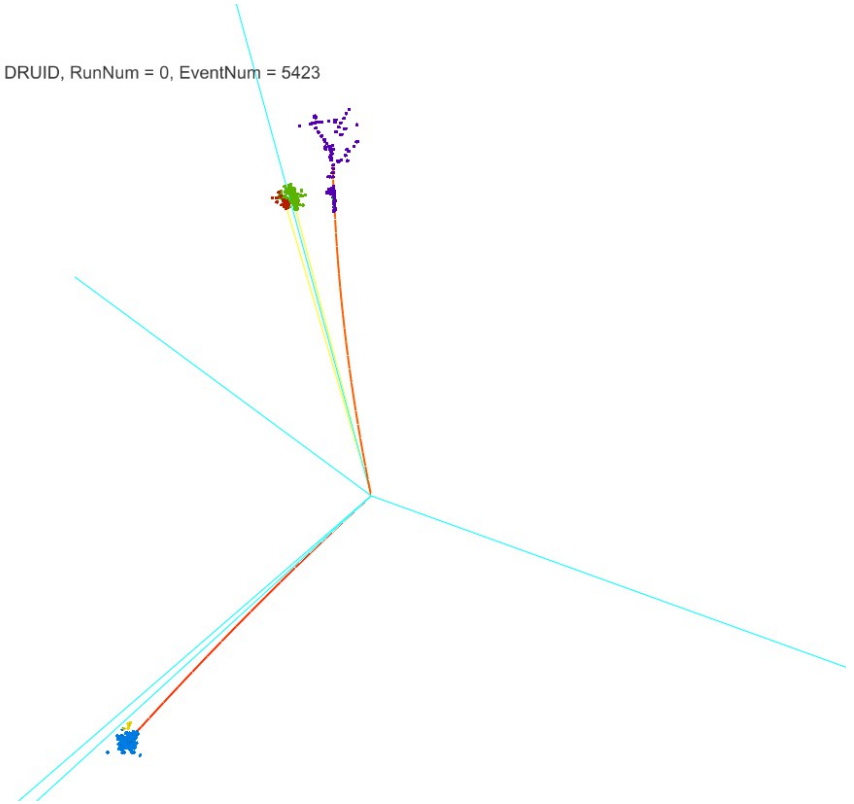
Impact of Separation: Z->tau tau @ Z pole

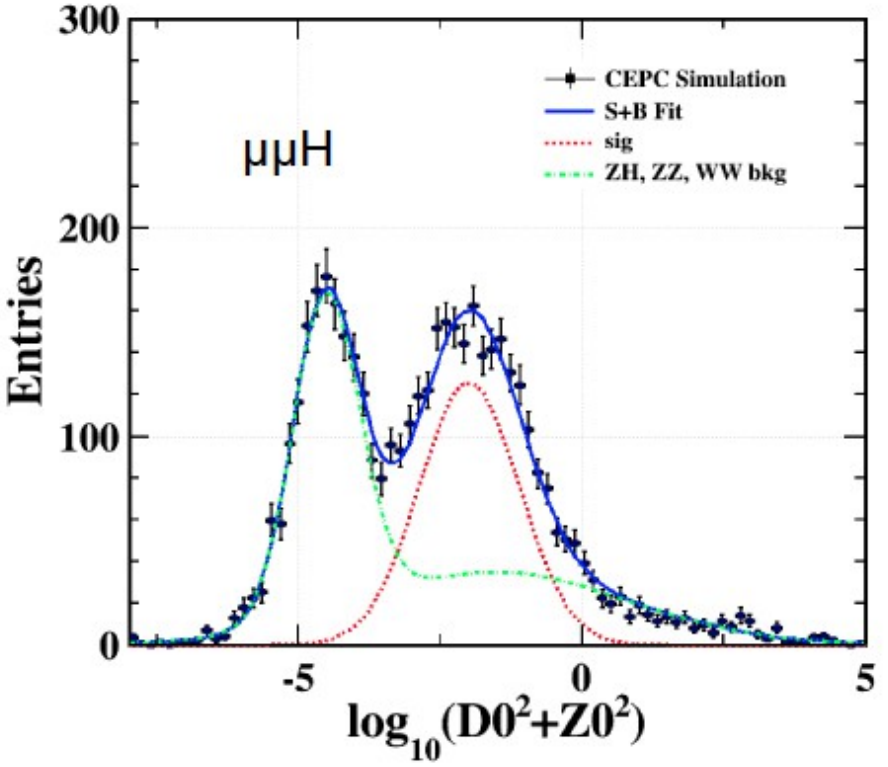




Cell Size/mm	1	5	10	20
Crucial Dis/mm	4	9	16	37
Percentage of potentially overlap photon	0.07%	0.4%	1.7%	18.6%

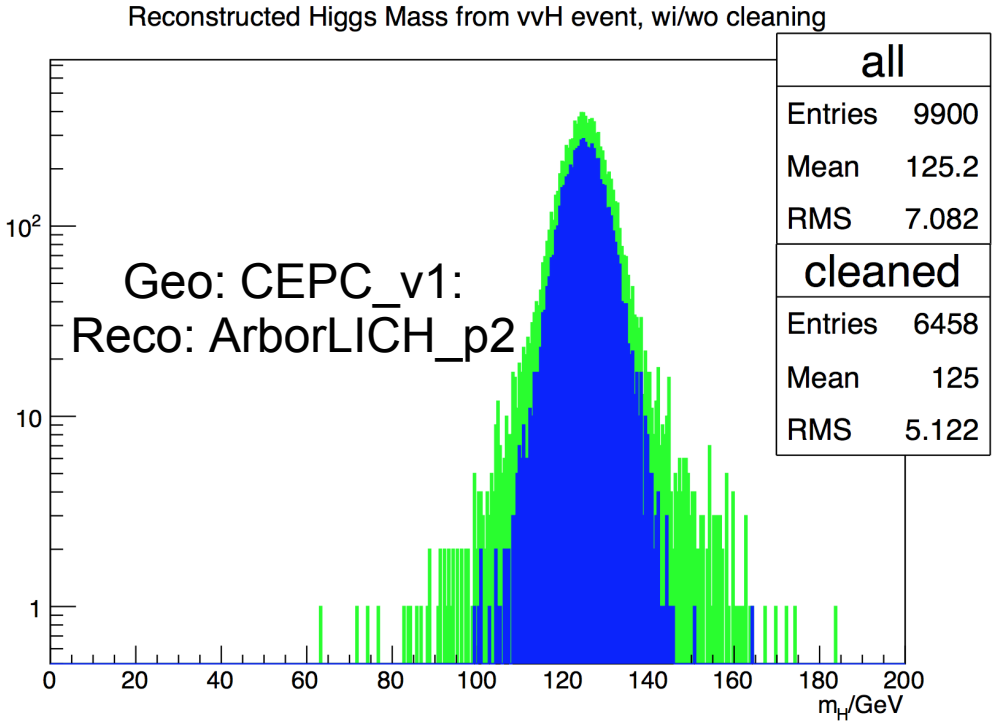
Tau reconstruction



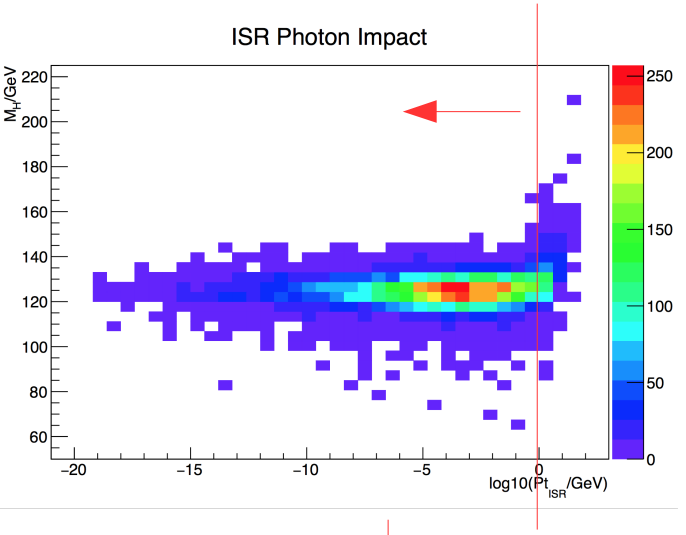


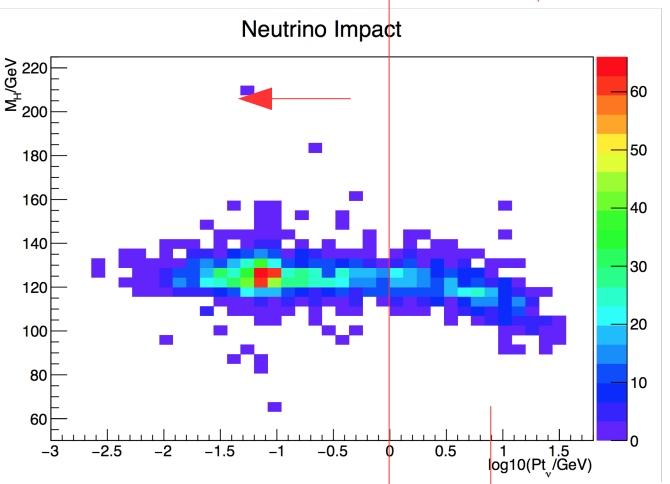
- In no-jet environment: counting number of charged particle – (pions & leptons), photons (pi0s) + restrict impact parameters leads to very high efficiency in Tau finding:
  - At inclusive Higgs decay sample: Efficiency ~ 98% for of H→ττ event finding, with llH and vvH final state. The remaining bkgrds are irreducible: H→WW/ZZ→leptonic/tau final state
  - In μμH channel: δN/N = 3%

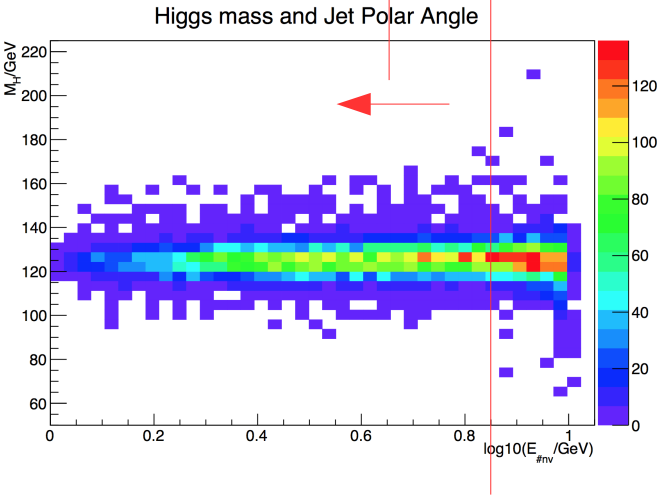
Jets @ vvH, H->gluons



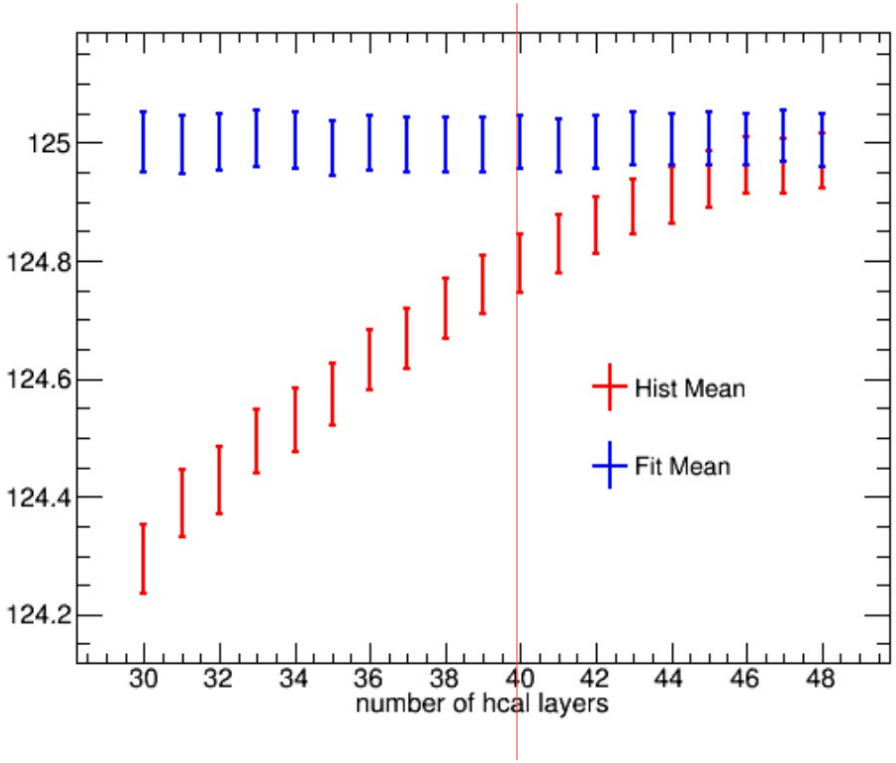
All	9900
ISRPt < 1 GeV	9335
ISRPt < 1 && N3Pt < 1	8766
ISRPt < 1&& N3Pt < 1&& |cos(Theat)| < 0.85	6458

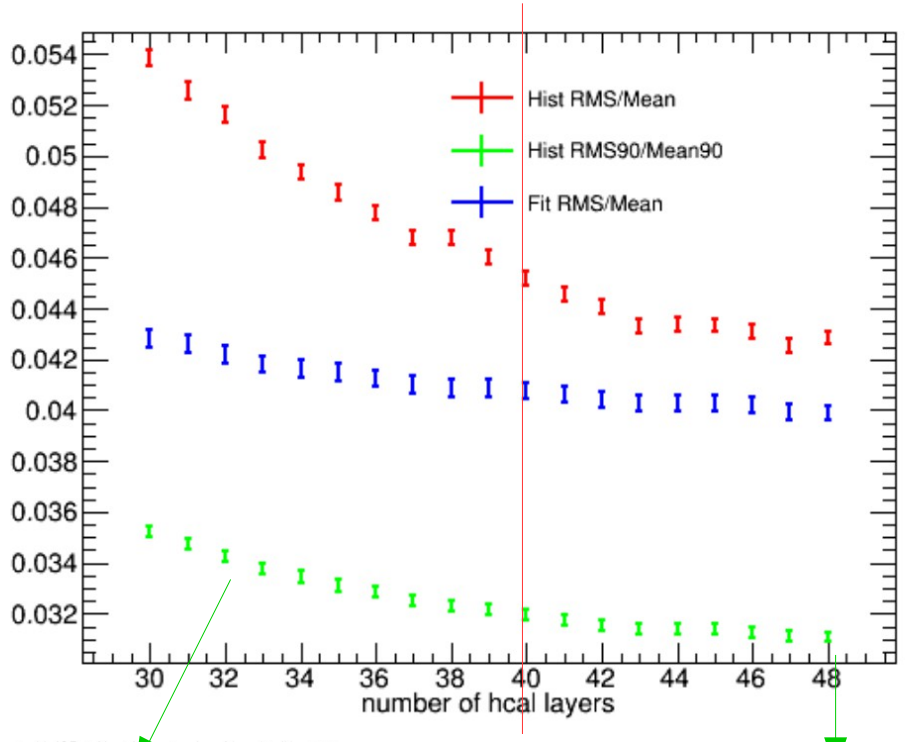


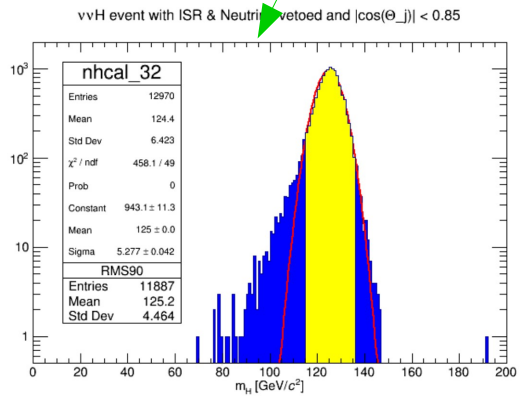


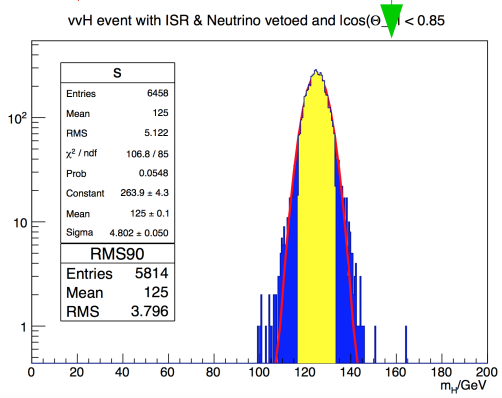


JER Vs #Layer (Preliminary)





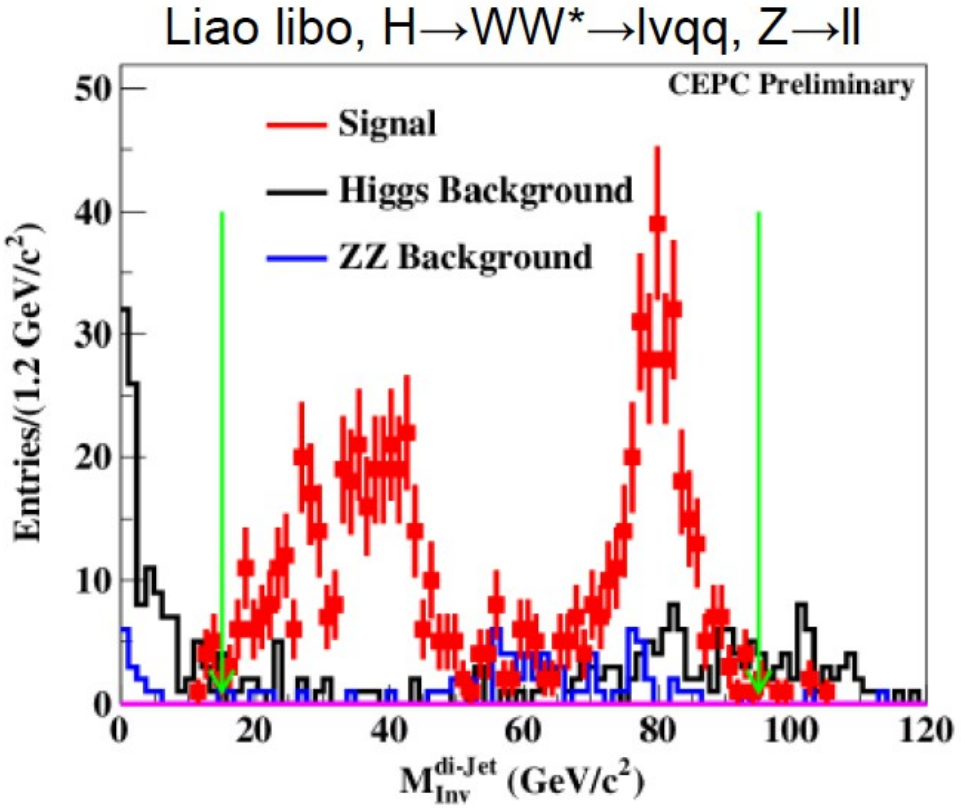


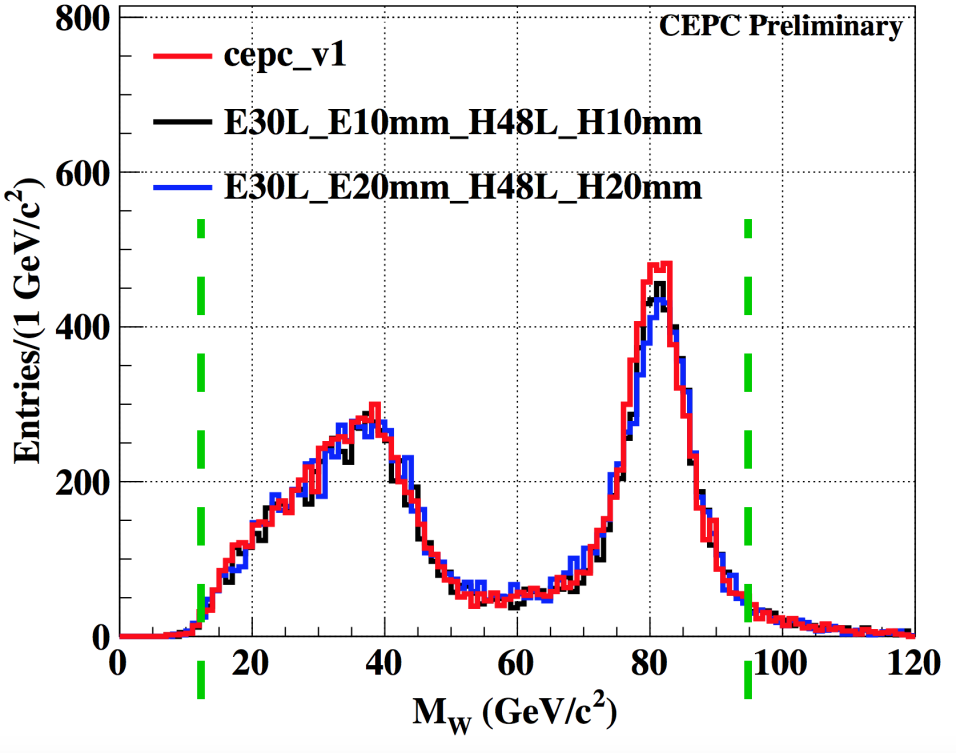


Reducing the #Layers from 48 -> 40 (same layer thickness)
A degrading of 2% (relative) in JER

Performance depends on the version...

Composite & Passive cooling:
Br(H→WW) @ 10mm/20mm Cell size



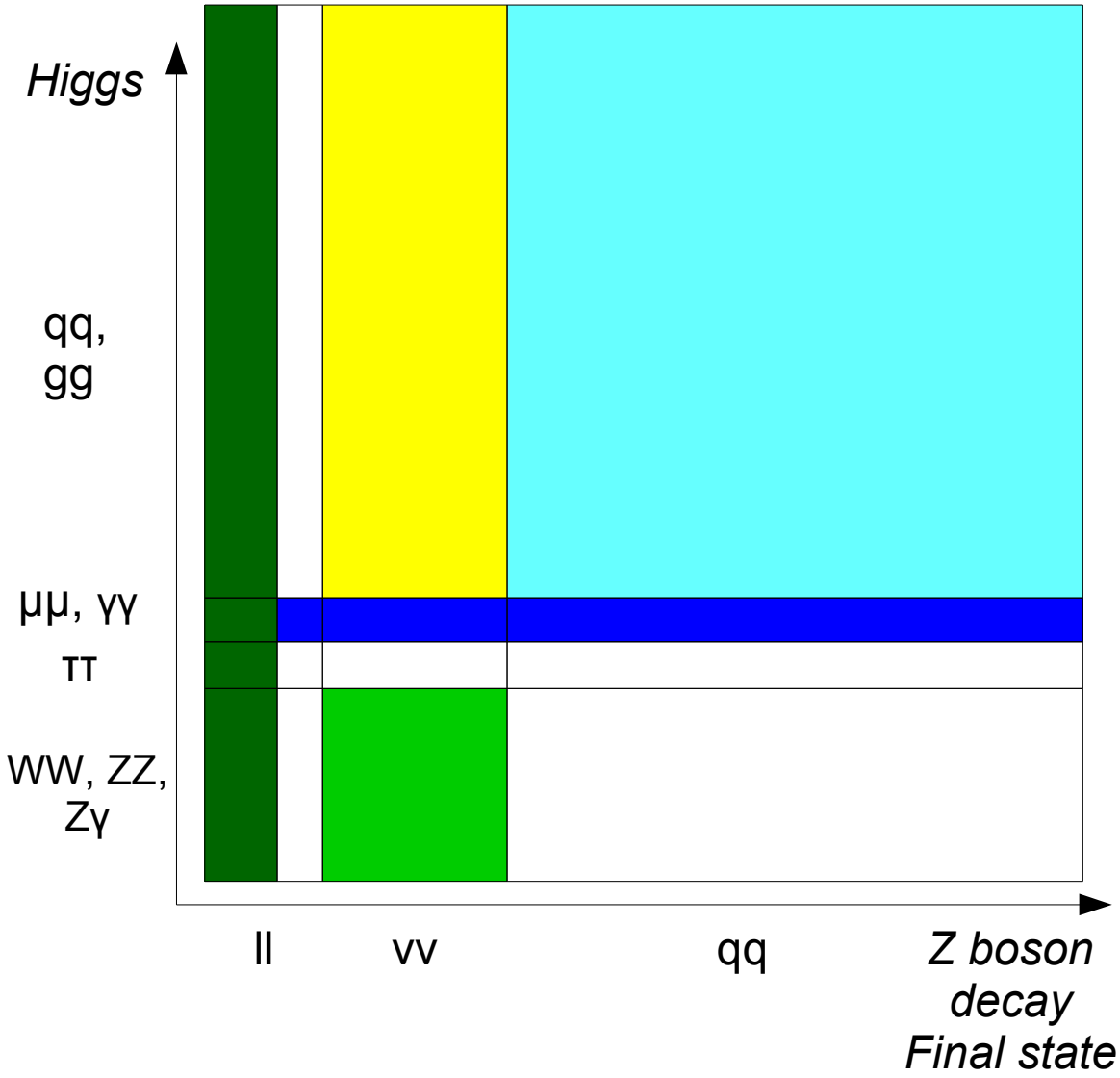


Br(H→WW) via vvH, H→WW*→lvqq

No lose in the object level efficiency: JER slightly degraded, ~ 5/10% at 10/20 mm

Over all: event reco. efficiency varies ~1%

Optimization Benchmarks



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

Feasibility & Optimized Parameters

Feasibility analysis: TPC and Passive Cooling Calorimeter is valid for CEPC

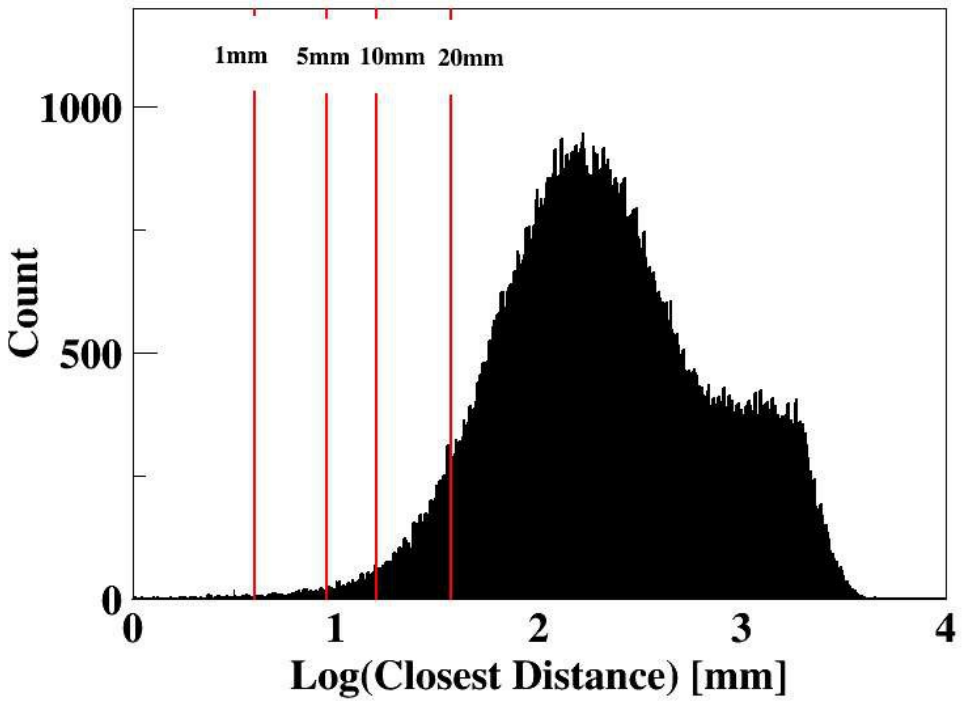
	CEPC_v1 (~ ILD)	Optimized (Preliminary)	Comments
Track Radius	1.8 m	>= 1.8 m	Requested by Br(H->di muon) measurement
B Field	**3.5 T**	**3 T**	**Requested by MDI**
ToF	**-**	**50 ps**	**Requested by pi-Kaon separation at Z pole**
ECAL Thickness	84 mm	84(90) mm	84 mm is optimized on Br(H->di photon) at 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.

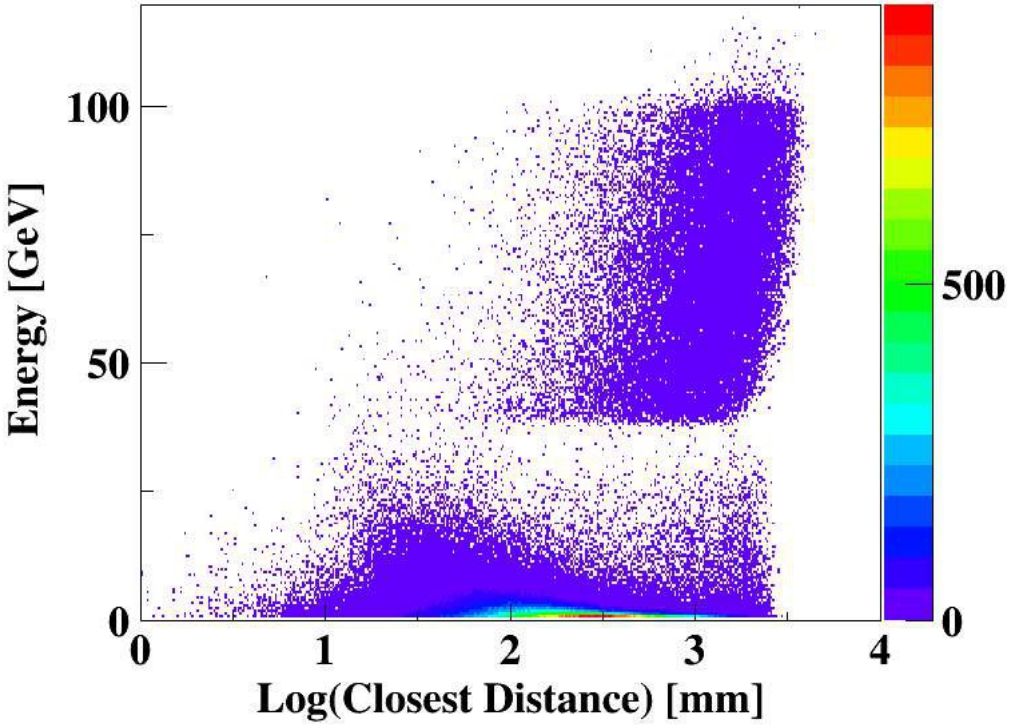
Summary

- CEPC: a tremendous Higgs/EW factory, request detector(s) that can successfully reconstruct all key physics objects
  - Photons, Leptons, Jets, Tau, MET
- CEPC Detectors: PFA Oriented Concept & Alternative
- PFA Oriented Concept: TPC + HGC
  - Fully established in simulation/reconstruction, dedicated Reconstruction algorithm that reconstruct every physics objects
  - Feasibility:
    - TPC is not limited at CEPC by the voxel occupancy & charge distortion
    - Passive cooling HGC: marginal impact at CEPC Higgs program
  - Optimized w.r.t Set of Benchmark Physics Processes: each challenge a combination of key performance

Thanks

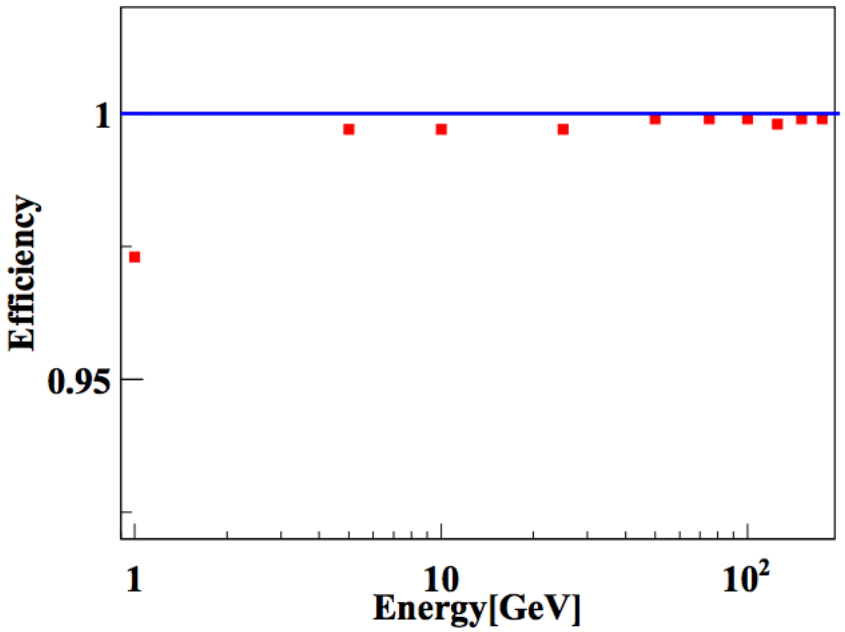
Impact of Separation: qqH, H->γγ @ 250 GeV

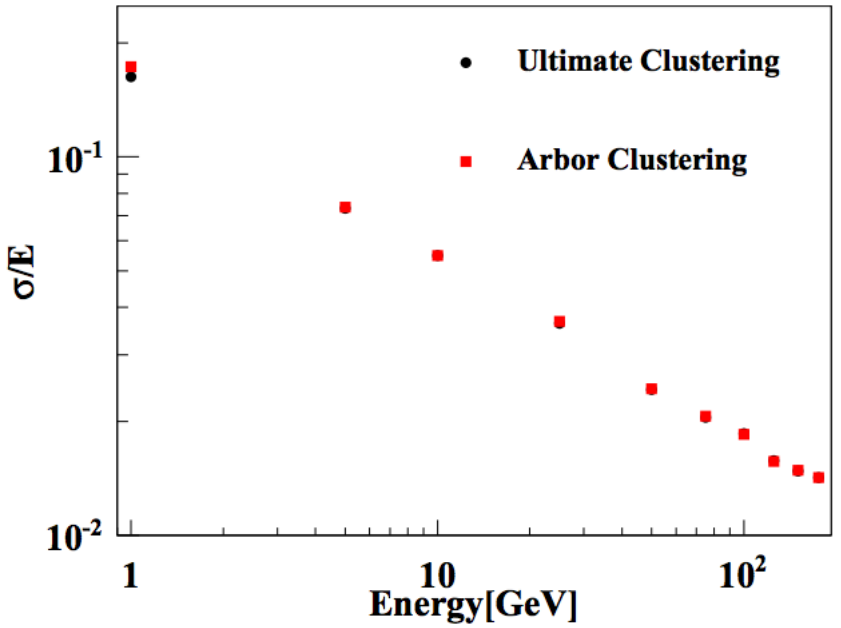




Cell Size/mm	1	5	10	20
Crucial Dis/mm	4	9	16	37
Percentage of potentially overlap photon: E > 30 GeV	0%	0%	0.1%	0.4%
E < 30GeV	0.1%	0.35%	1.1%	6.4%

Clustering: Ideal Vs Realistic

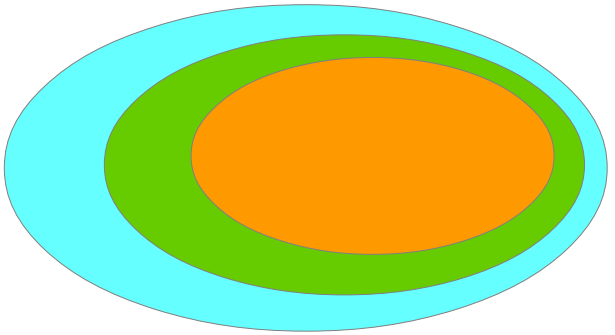




Leading Cluster

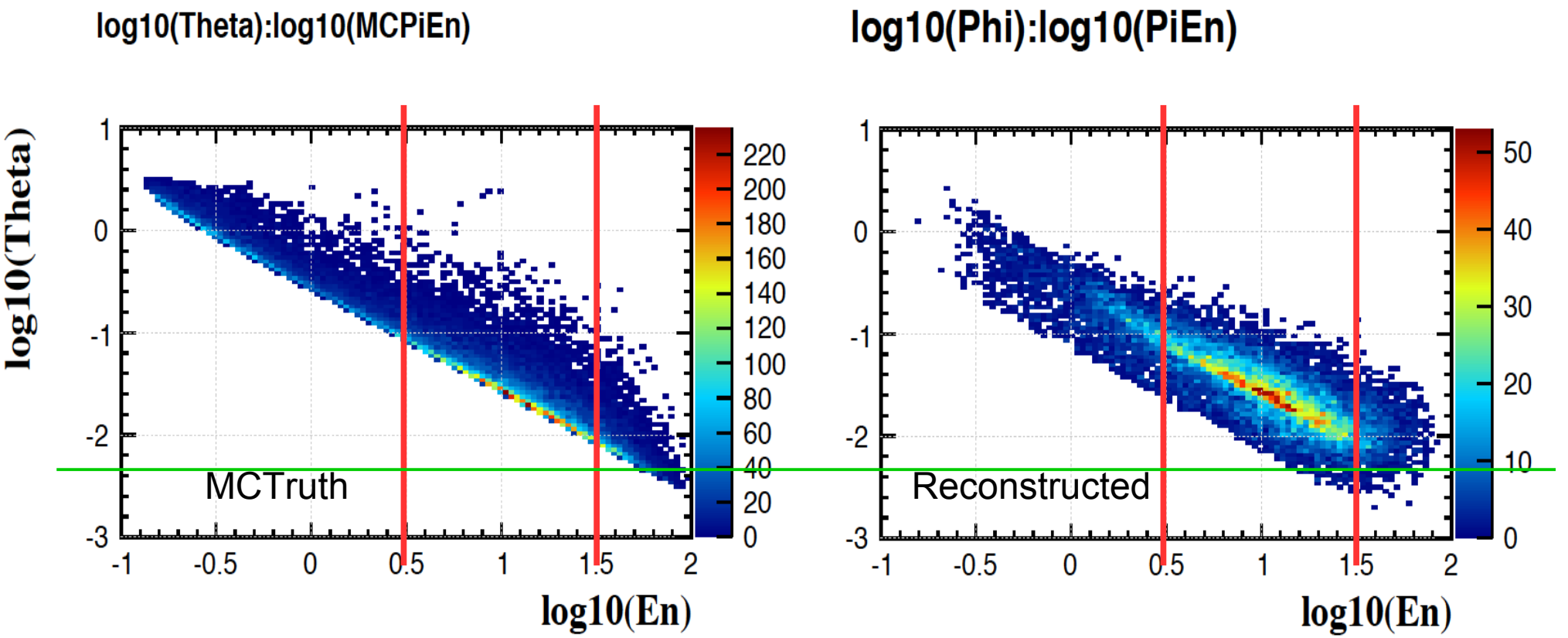
All Clusters

All Hits



Efficiency
= LC Energy/total hit energy

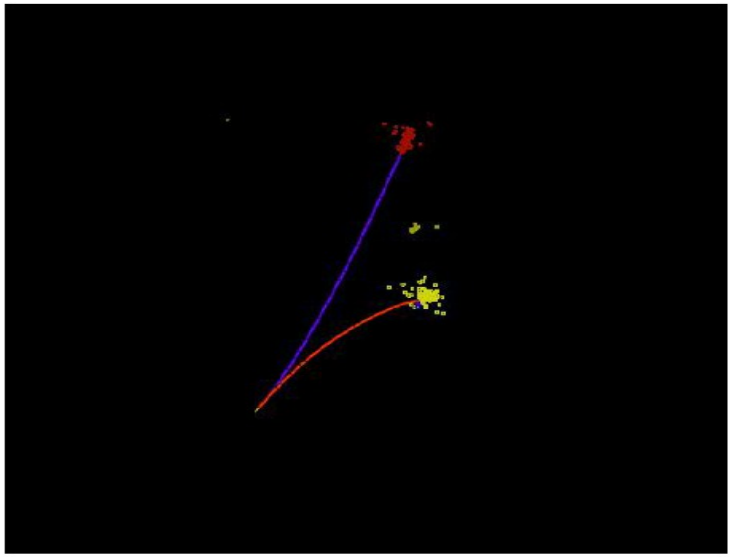
Composed object: π_0 (Preliminary)

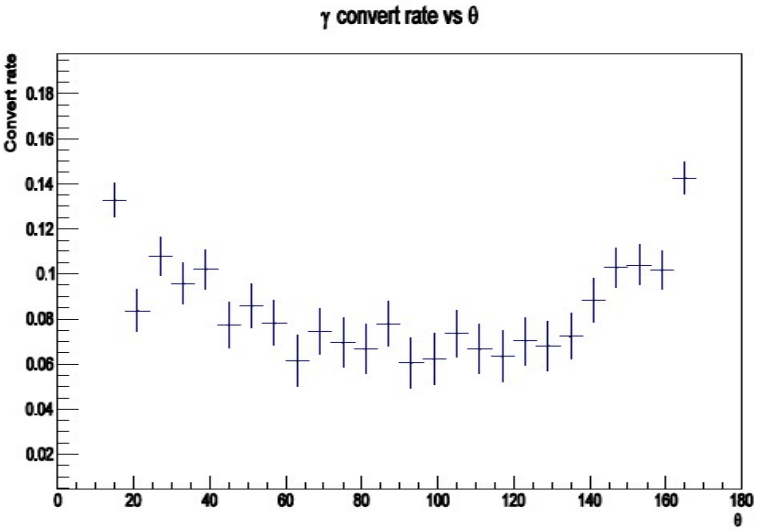


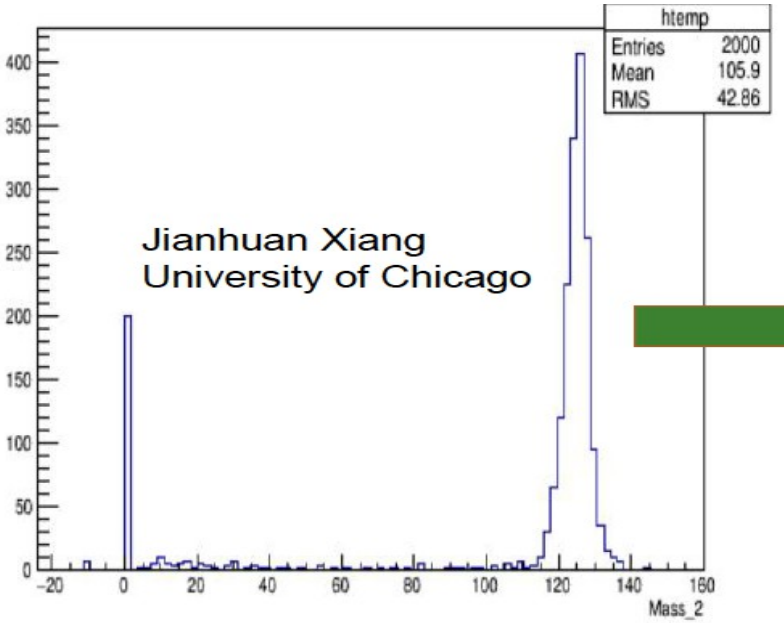
Testing on Higgs to di tau events. Tau inclusive decay
(X axis, Energy of Pi0, Y axis, Angle between two photons decayed from pi0)

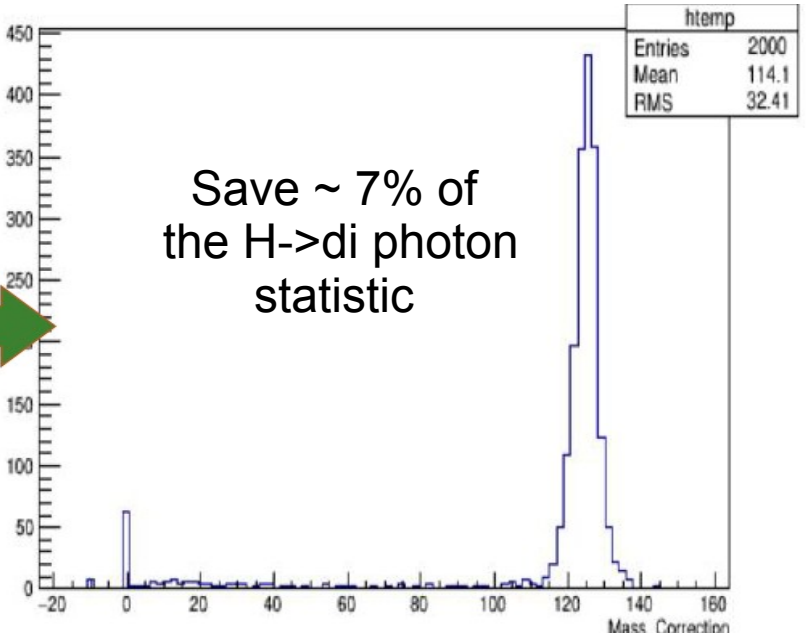
For pi0 with En > 3 GeV && En < 30 GeV, Reconstruction efficiency ~ 65%..
Horizontal line corresponding to 9 mm separation at ECAL.

Composed object: converted photon

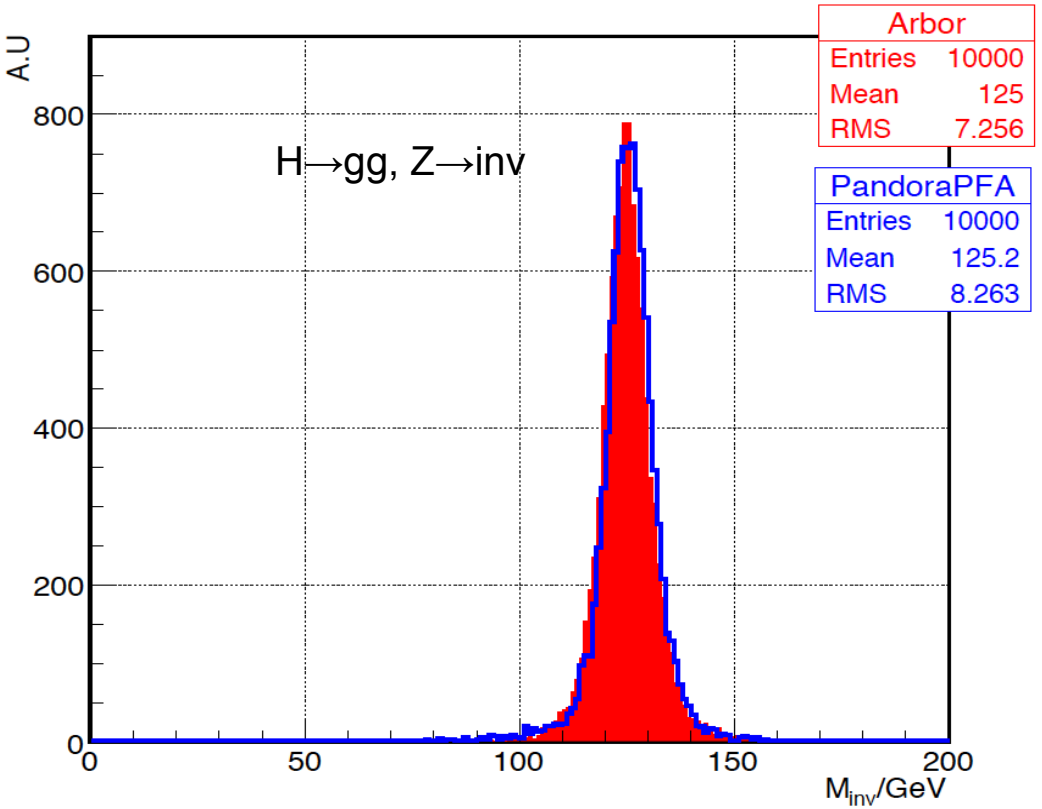


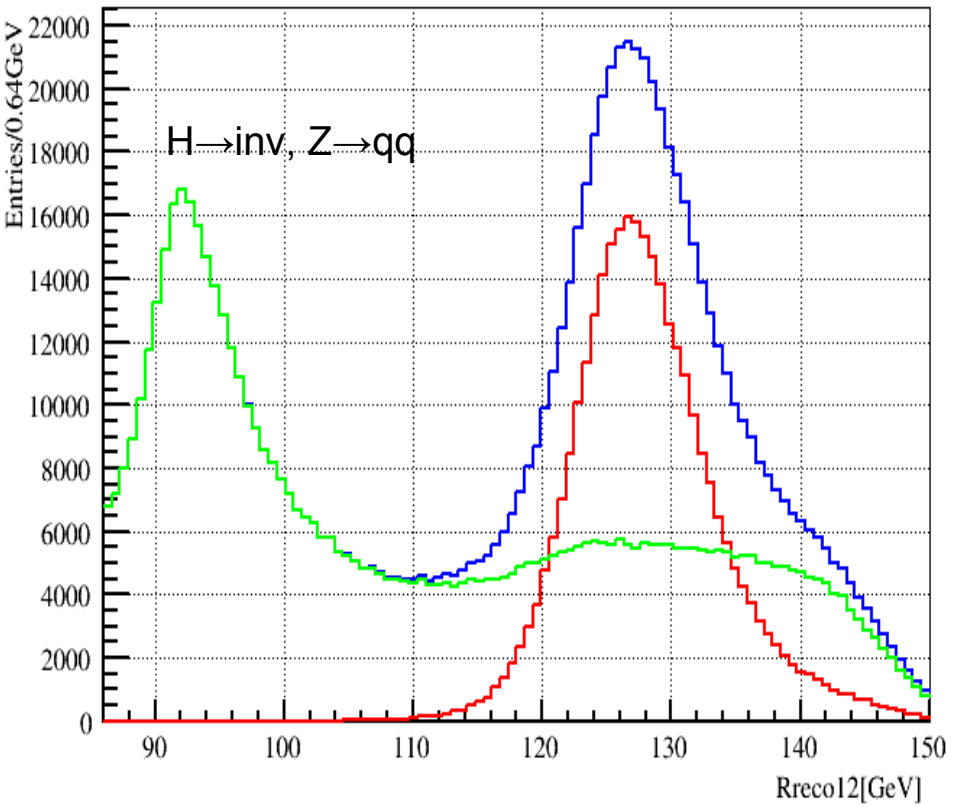






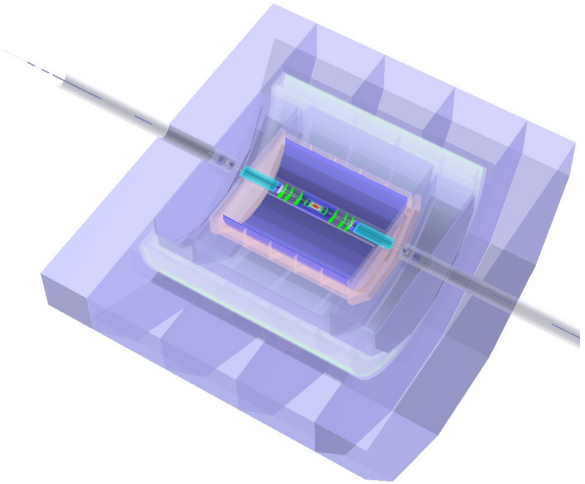
JER/MET

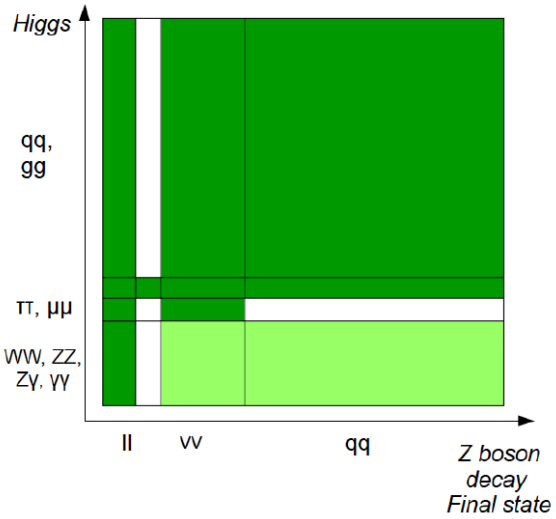


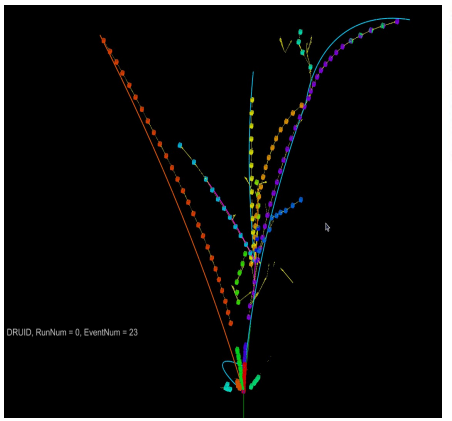


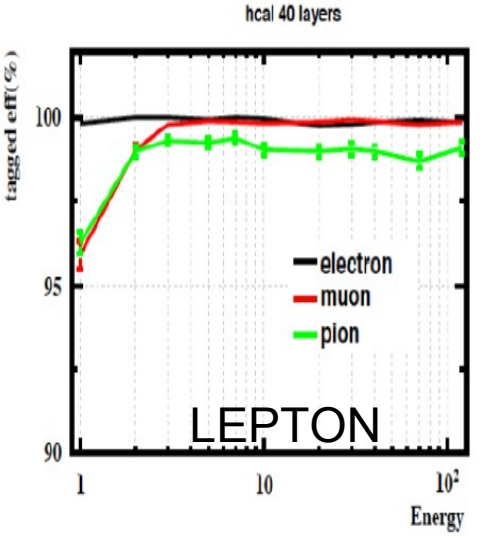
- Digital ECAL mode: Energy Estimated as k*NHit for HCAL Cluster, Calibration Constant (k) optimized for both Pandora & Arbor via Scan
- MET: usually no ambiguity;
- Jet: Highly depending on Jet clustering if #Jet > 2...

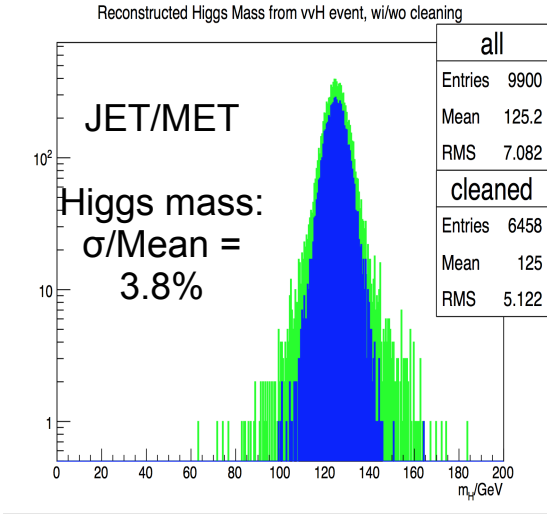
Reconstruction

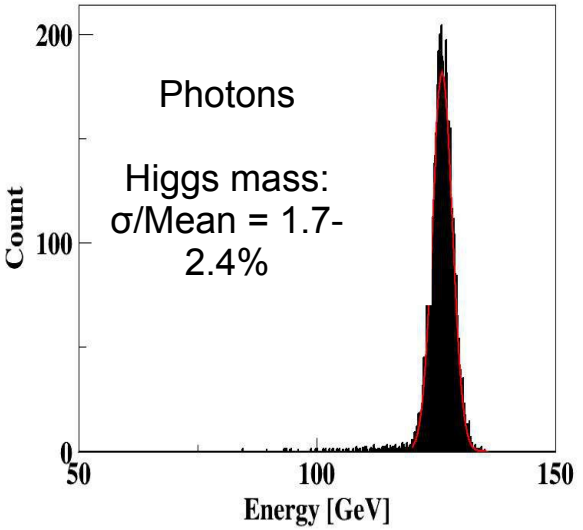


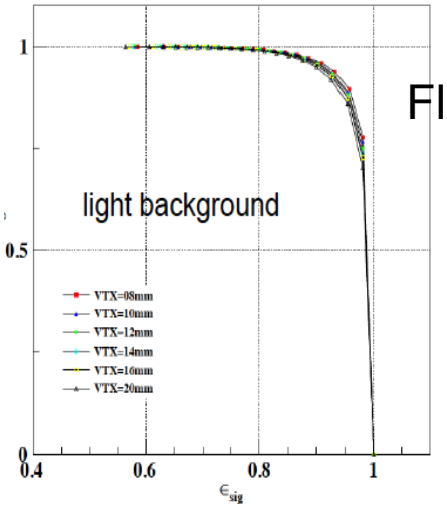


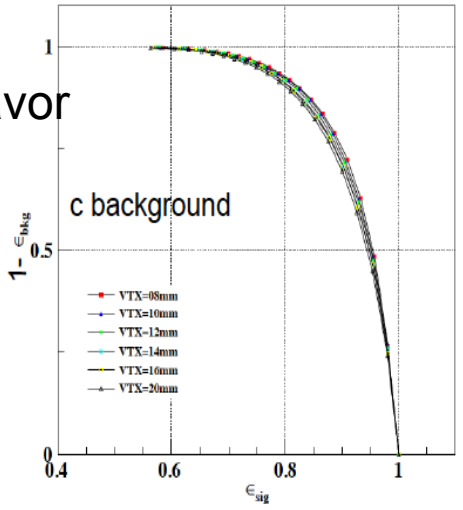




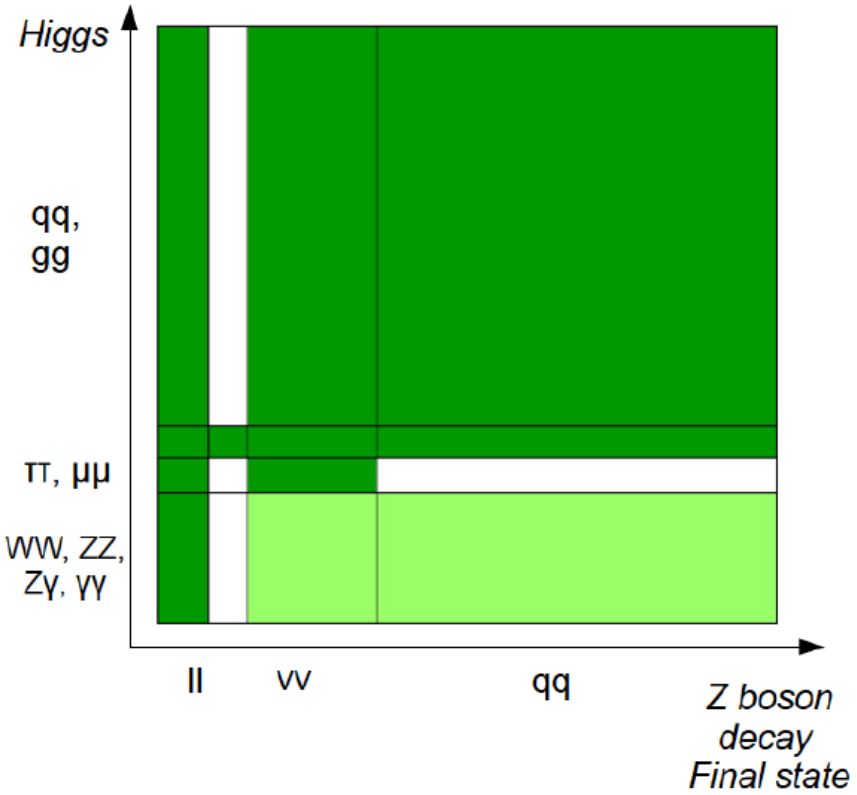






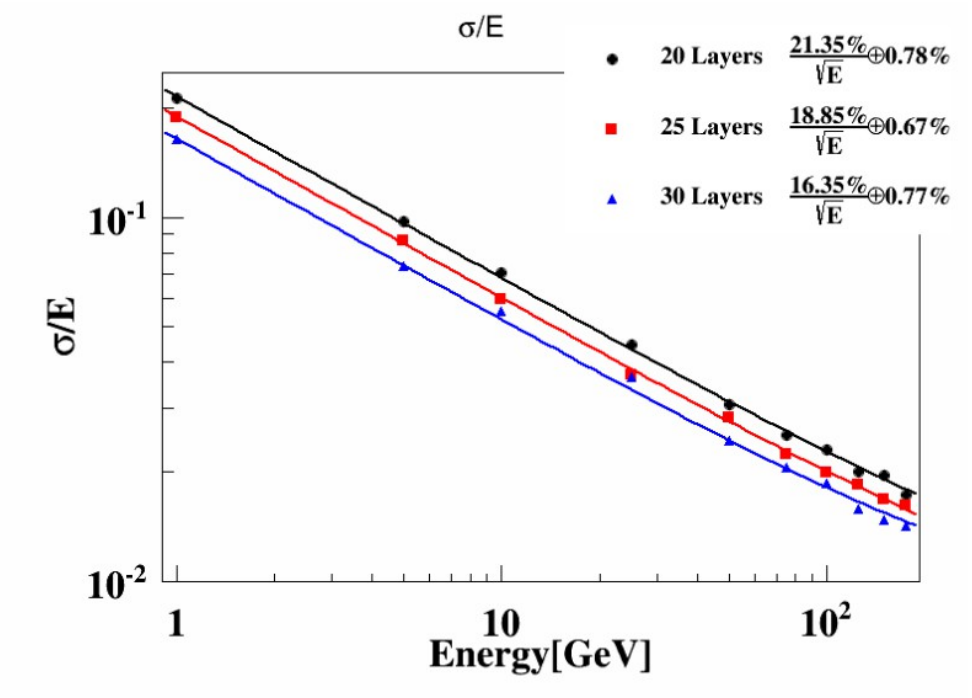


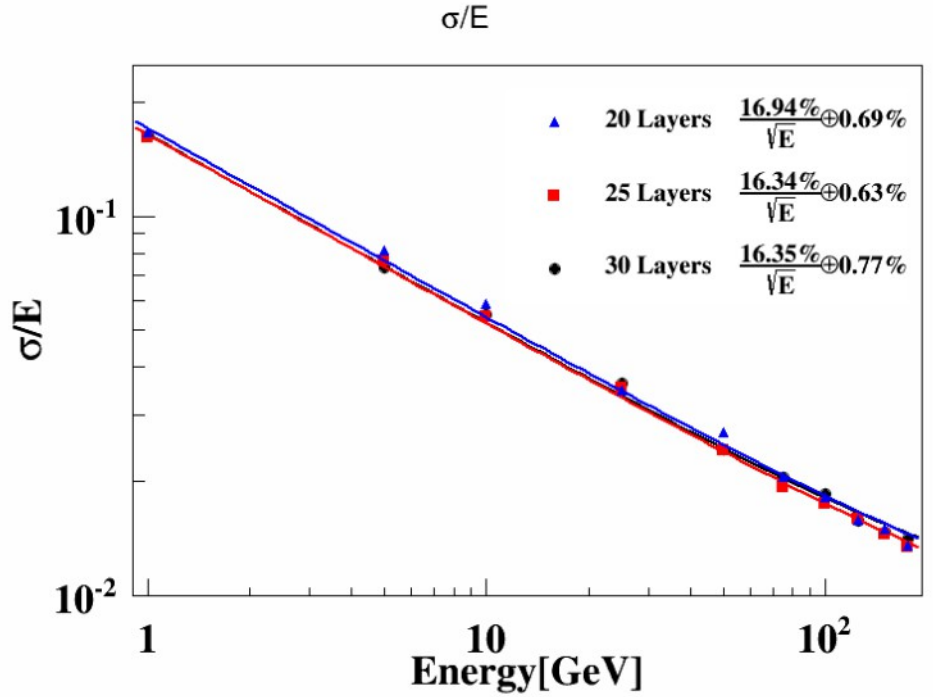
CEPC: Simulation Studies



	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

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





Performance @ Photon with E > 1 GeV:

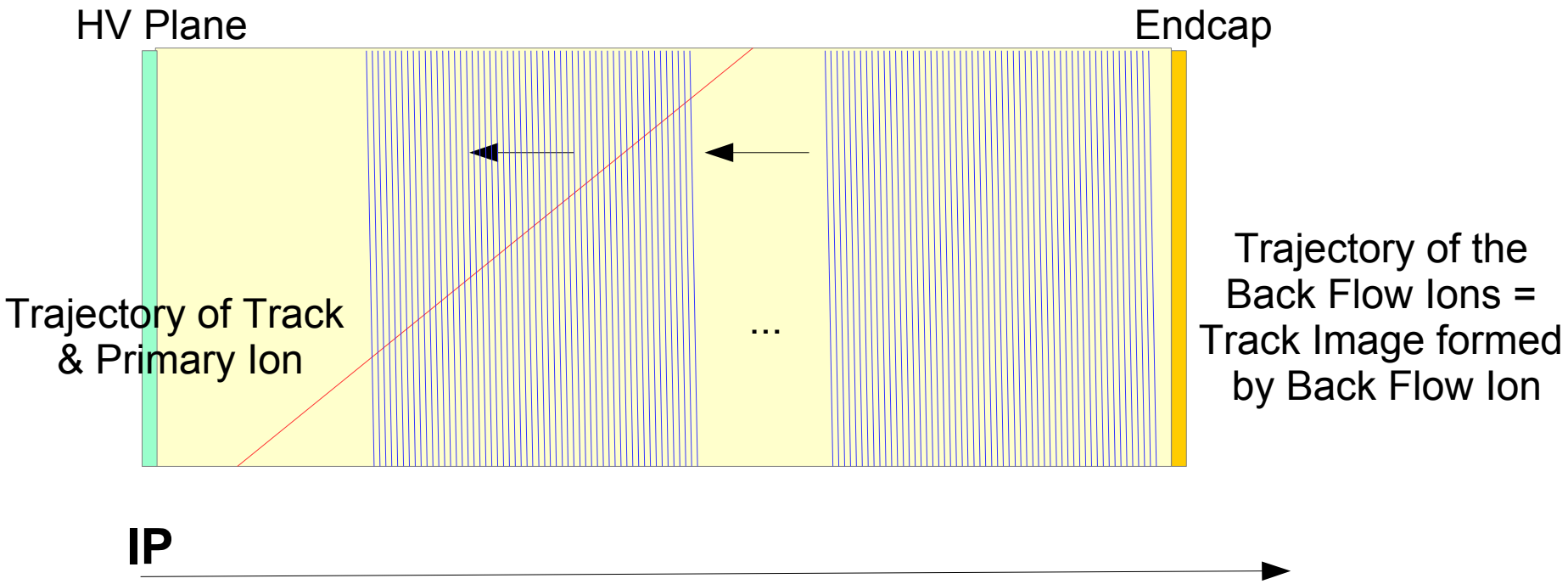
Energy Resolution is comparable at:

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

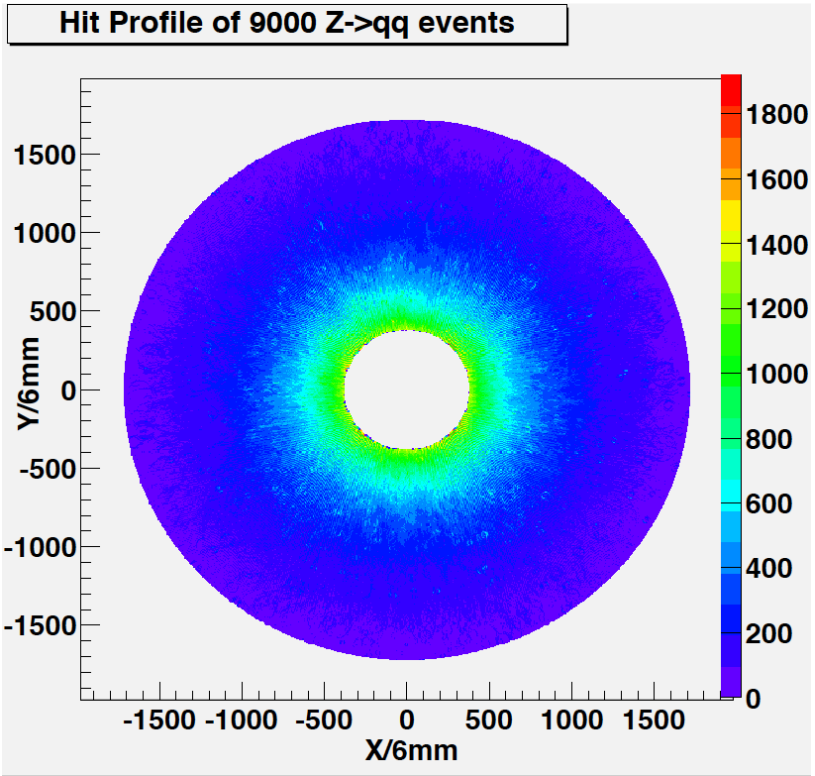
What's the maximal viable silicon wafer thickness?

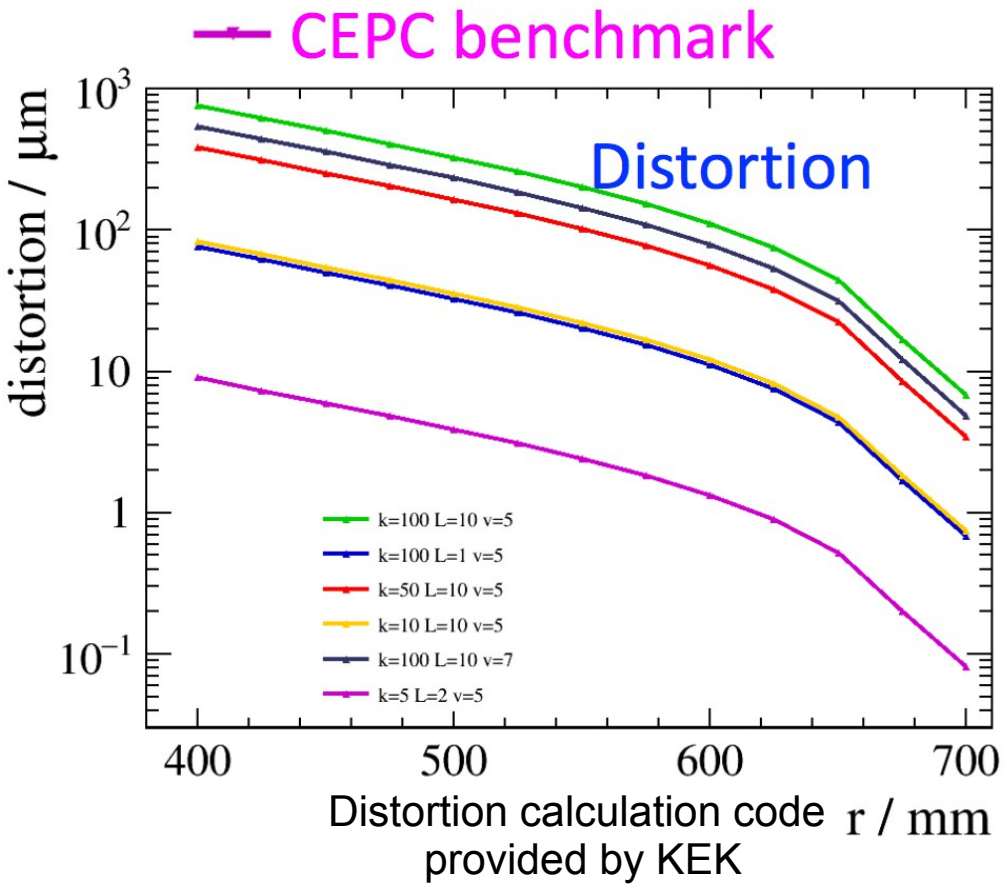
Feasibility of TPC at Z pole

- 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^-4 – 10^-6) 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 $cm^{-2}s^{-1}$)