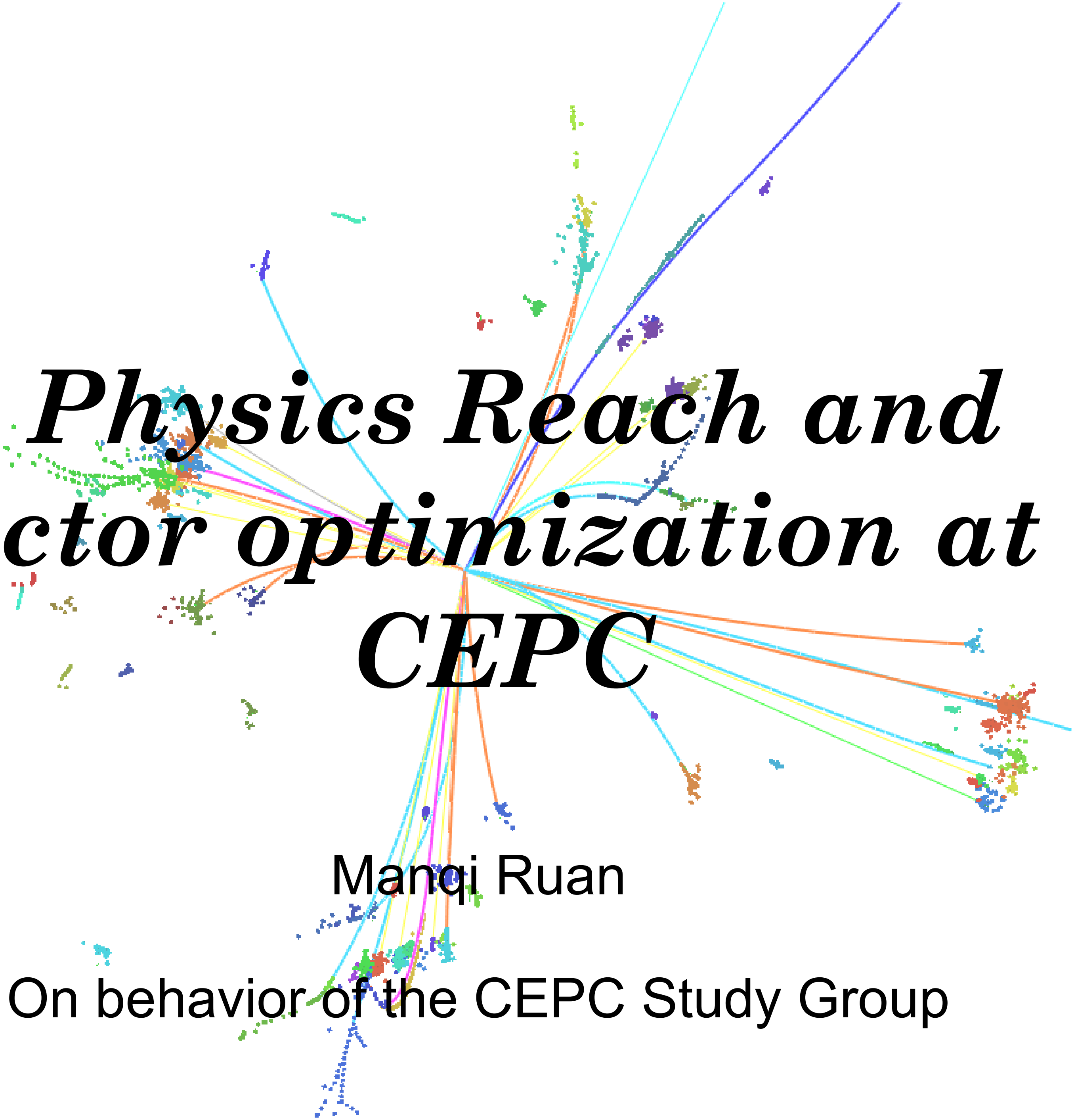
Physics Reach and Detector optimization at the CEPC

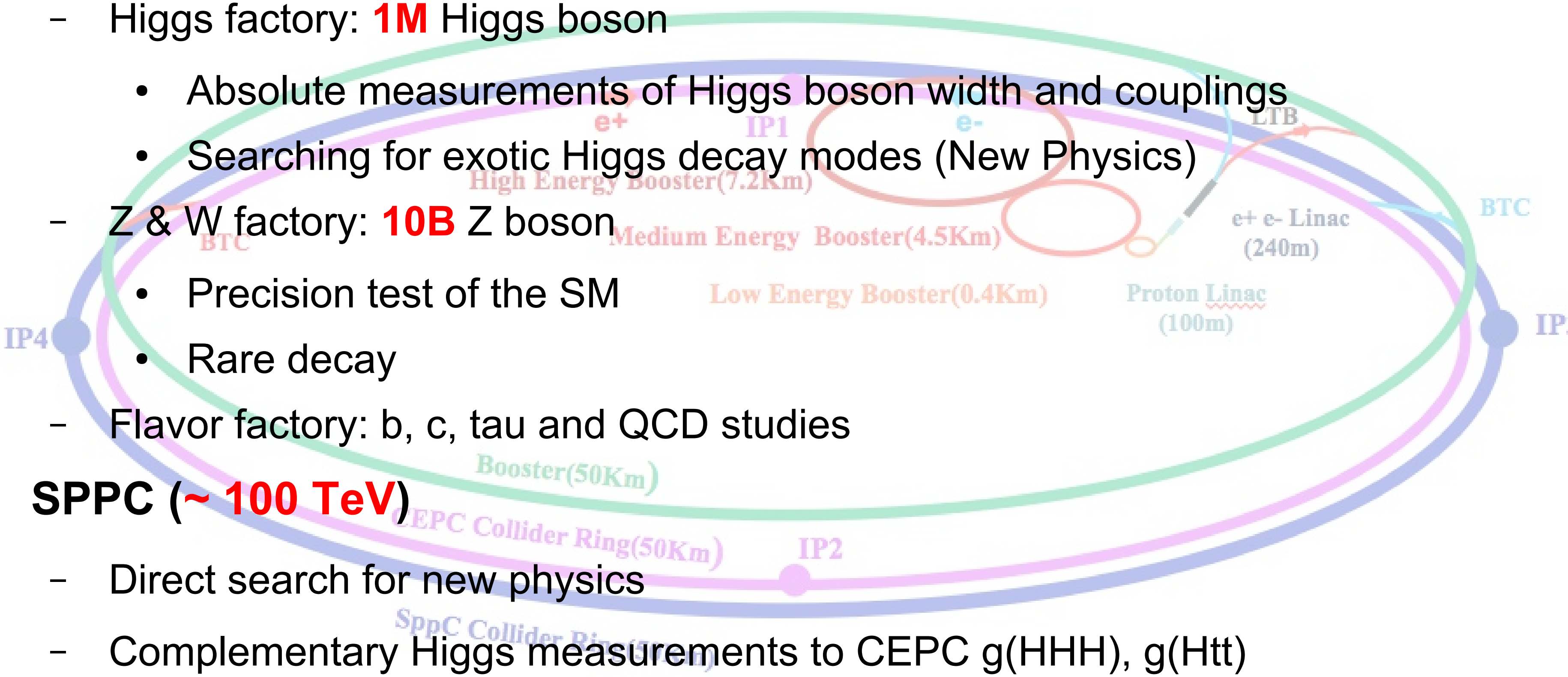


Manqi Ruan

On behavior of the CEPC Study Group

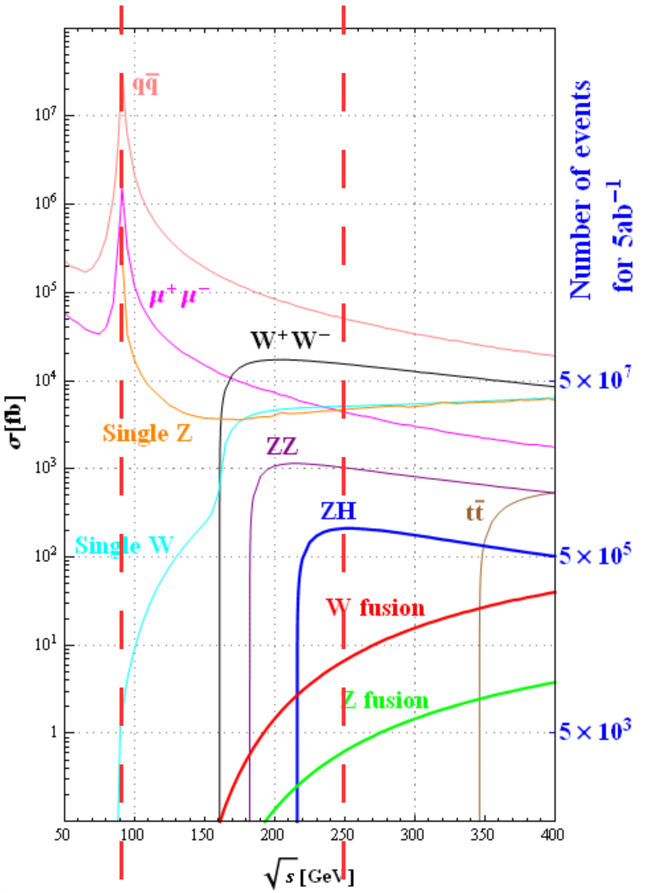
Science at CEPC-SPPC

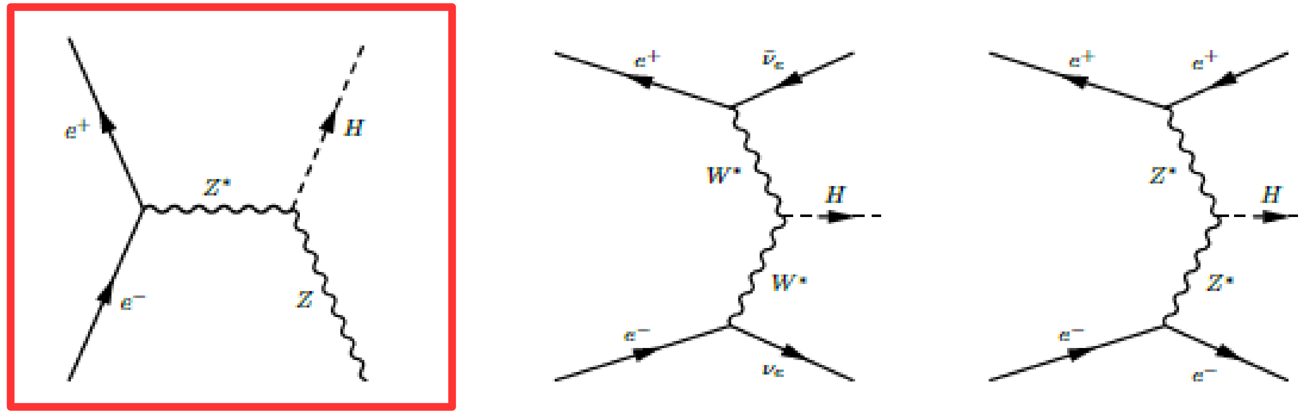
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **10B** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor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





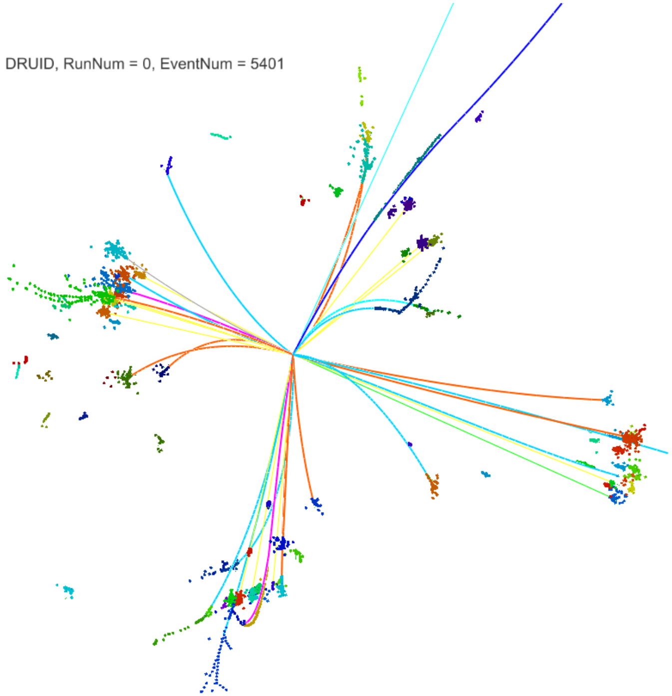
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

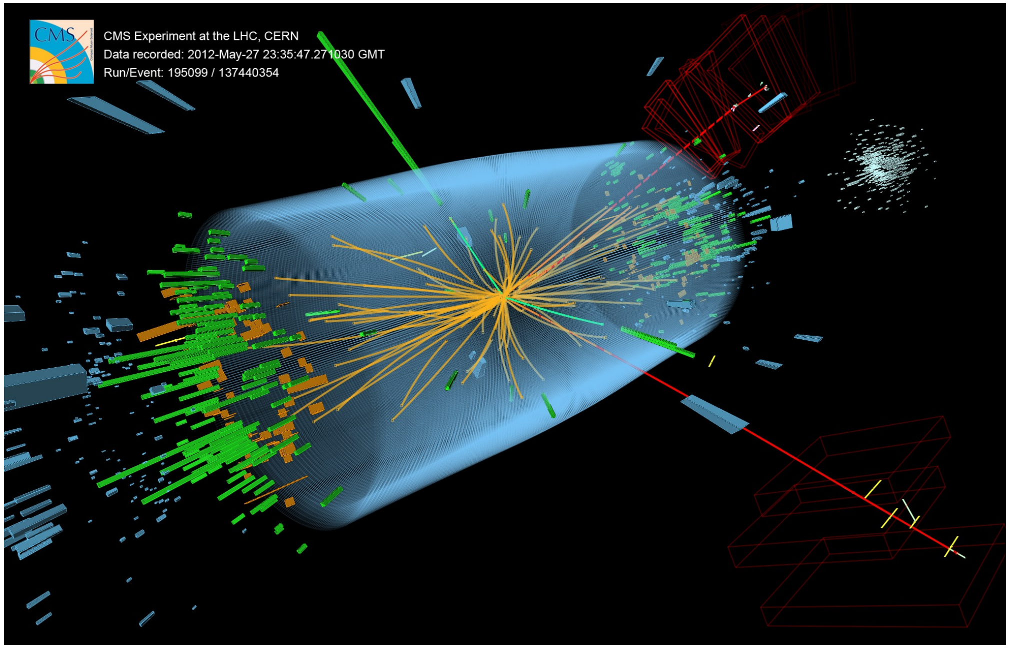
Observables: EW Precision, tau physics, Flavor Physics...

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

Derive: Absolute Higgs width, branching ratios, couplings

Higgs measurement at e+e- & pp

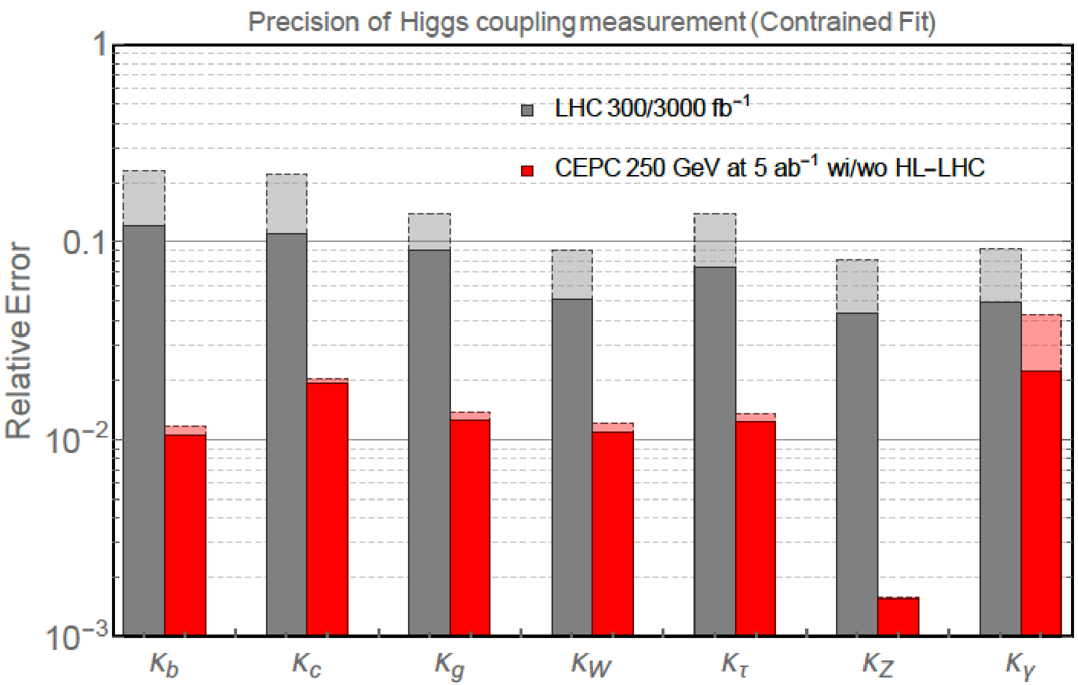


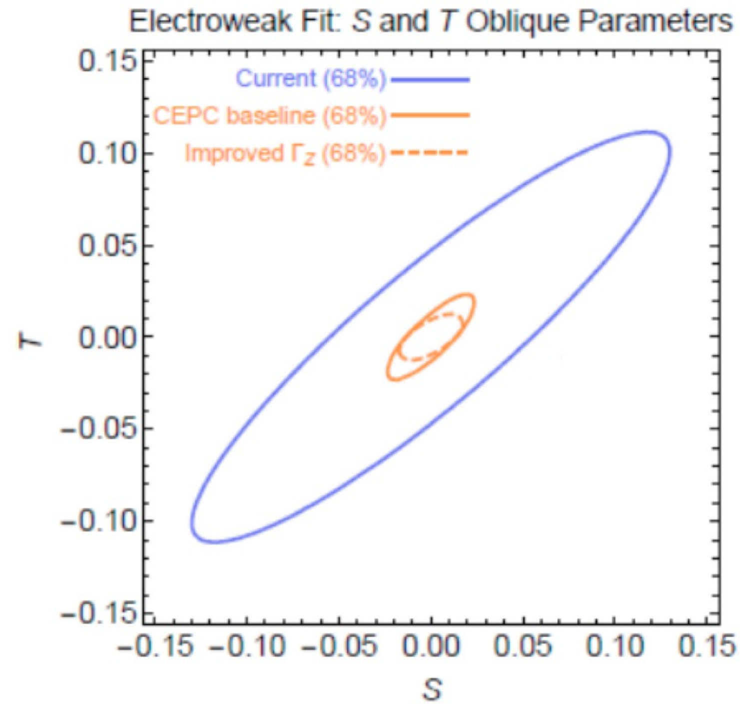


	Yield	efficiency	Comments
LHC	Run 1: 10^6 Run 2/HL: 10^{7-8}	$\sim o(10^{-3})$	High Productivity & High background, Relative Measurements, Limited access to width, exotic ratio, etc, Direct access to g(ttH), and even g(HHH)
CEPC	10^6	$\sim o(1)$	Clean environment & Absolute measurement, Percentage level accuracy of Higgs width & Couplings

Complementary

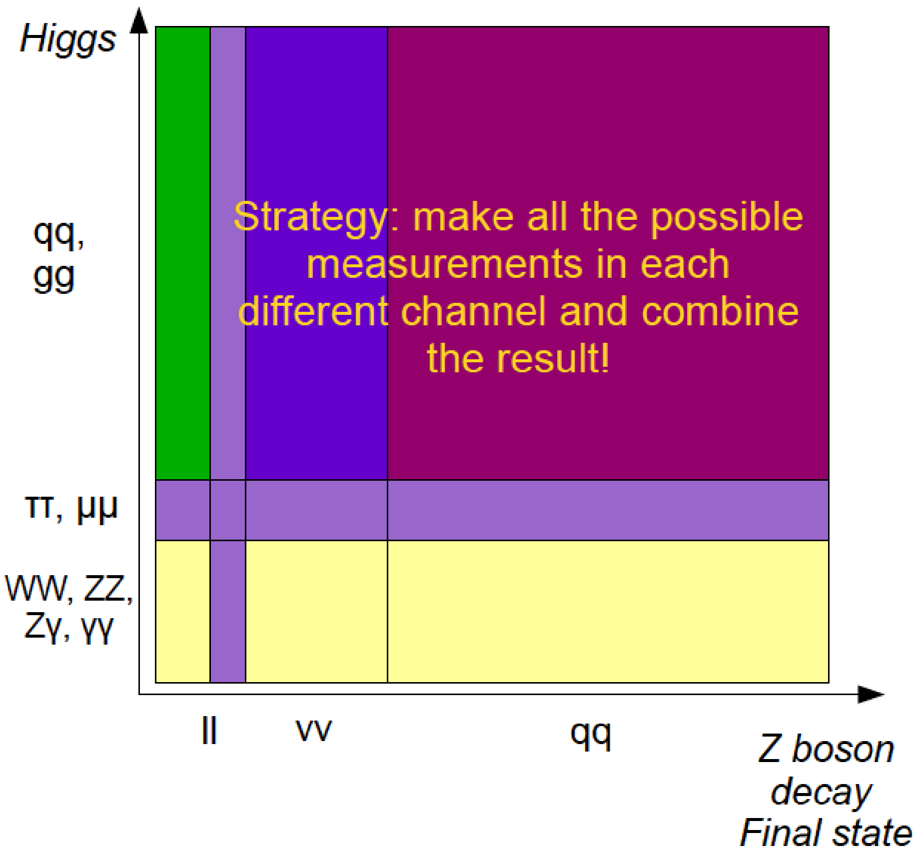
Key science

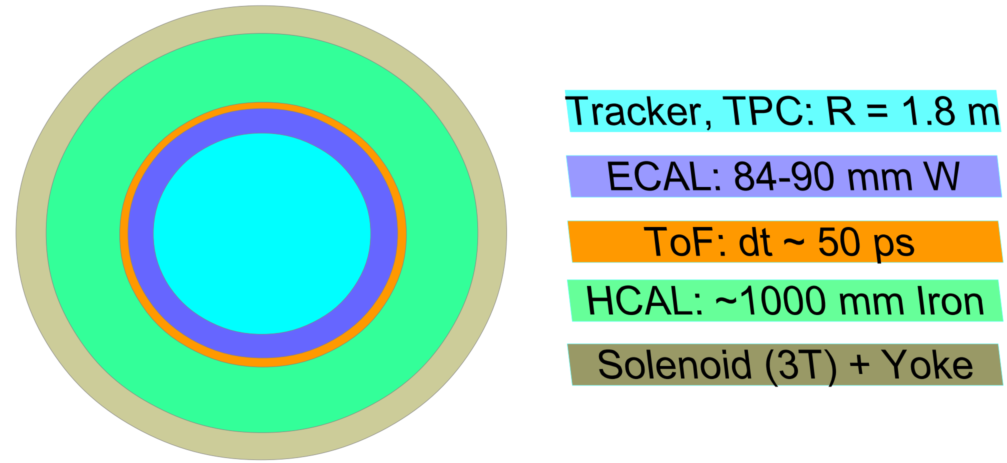




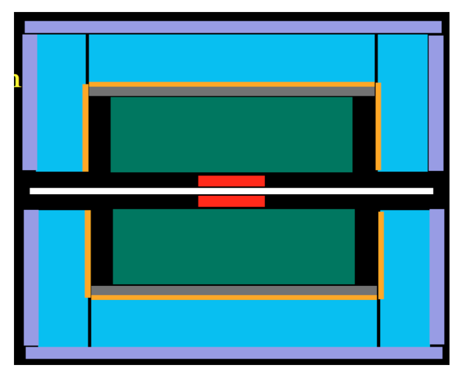
- The nature of Higgs boson & EWSB, + flavor physics...
  - Higgs signal strengths (In kappa framework): expected accuracy roughly 1 order of magnitude better than HL-LHC
  - Absolute measurement to the Higgs boson: 2-3% level accuracy of Higgs boson width, 10^{-3} - 10^{-5} up limit to Higgs invisible/exotic decay modes (improved by at least 2 orders of magnitude comparing to HL-LHC)
  - Improve EW measurement precision by also 1 order of magnitude

Detector Designs



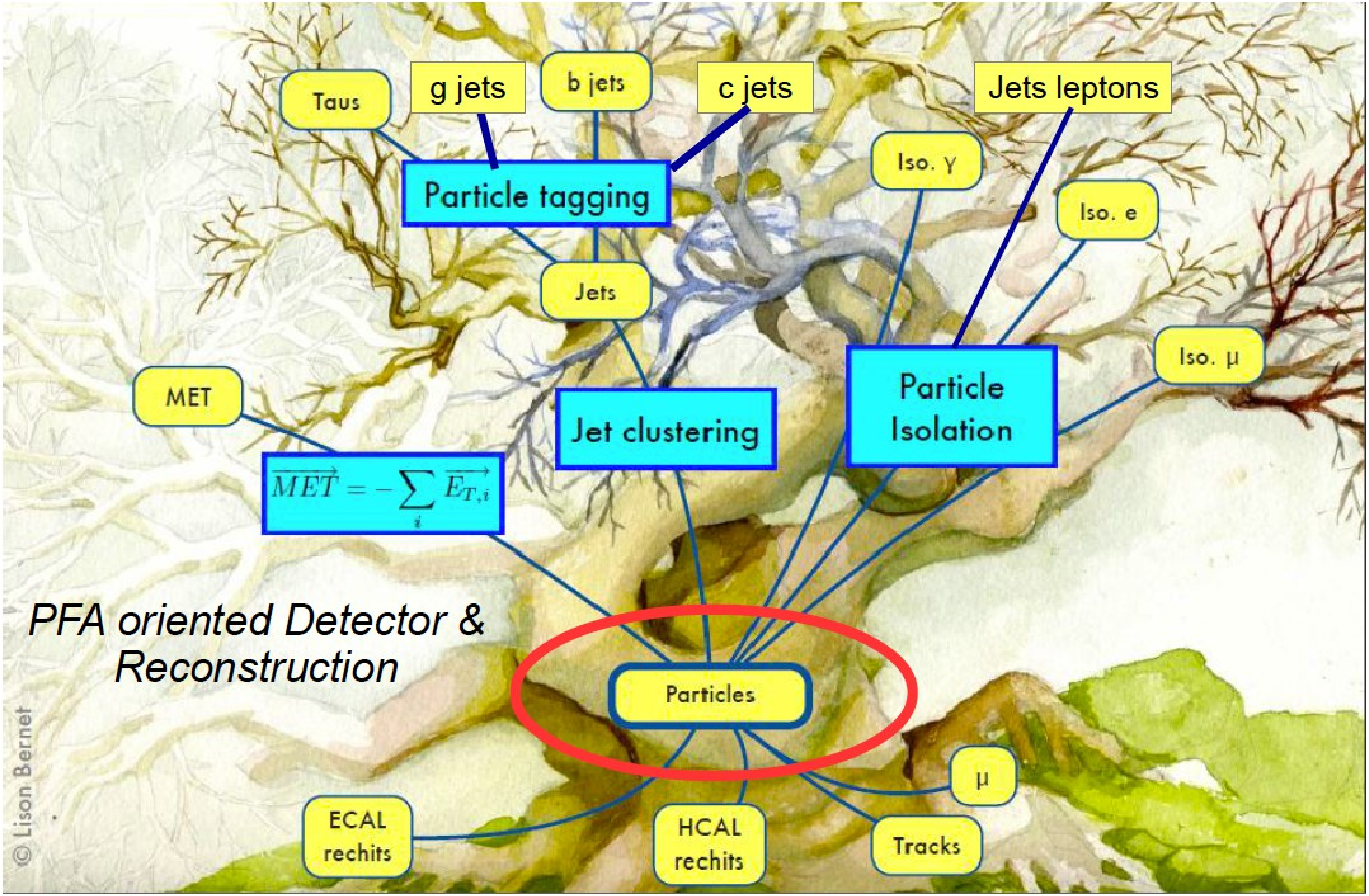


PFA Oriented:
TPC/Silicon + High Granularity Calorimeter



- 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

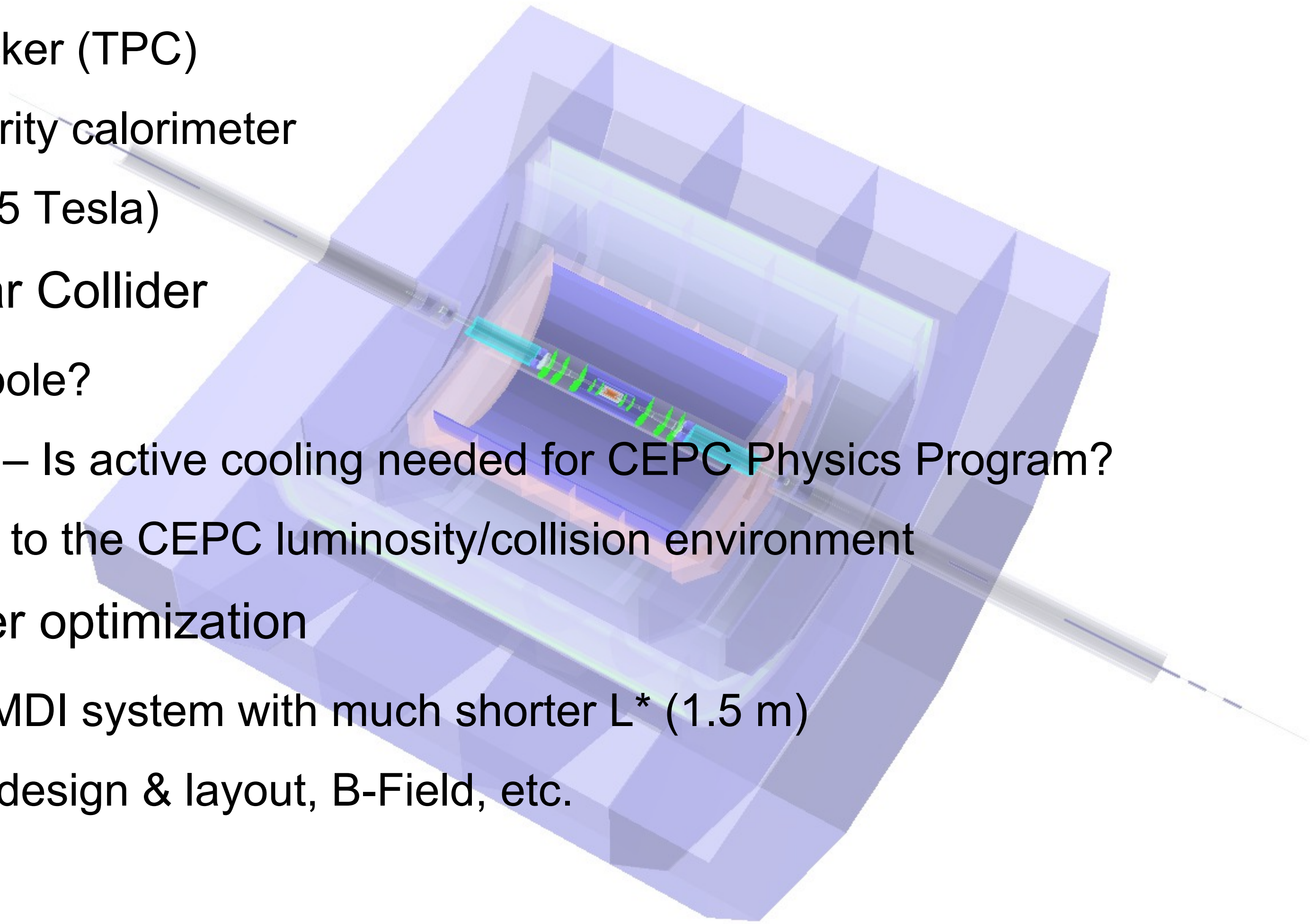
IDEA:
Wire Chamber + Dual Readout Calorimeter



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

PFA Oriented: reference & key questions

- Reference Detector Concept: **ILD**, SiD, ALEPH...
  - Light material tracker (TPC)
  - Ultra high granularity calorimeter
  - Strong B-Field (3.5 Tesla)
- Feasibility at Circular Collider
  - TPC @ CEPC Z pole?
  - No power pulsing – Is active cooling needed for CEPC Physics Program?
  - BDS/MDI suitable to the CEPC luminosity/collision environment
- Geometry/Parameter optimization
  - Re-design of the MDI system with much shorter L* (1.5 m)
  - Sub system size, design & layout, B-Field, etc.

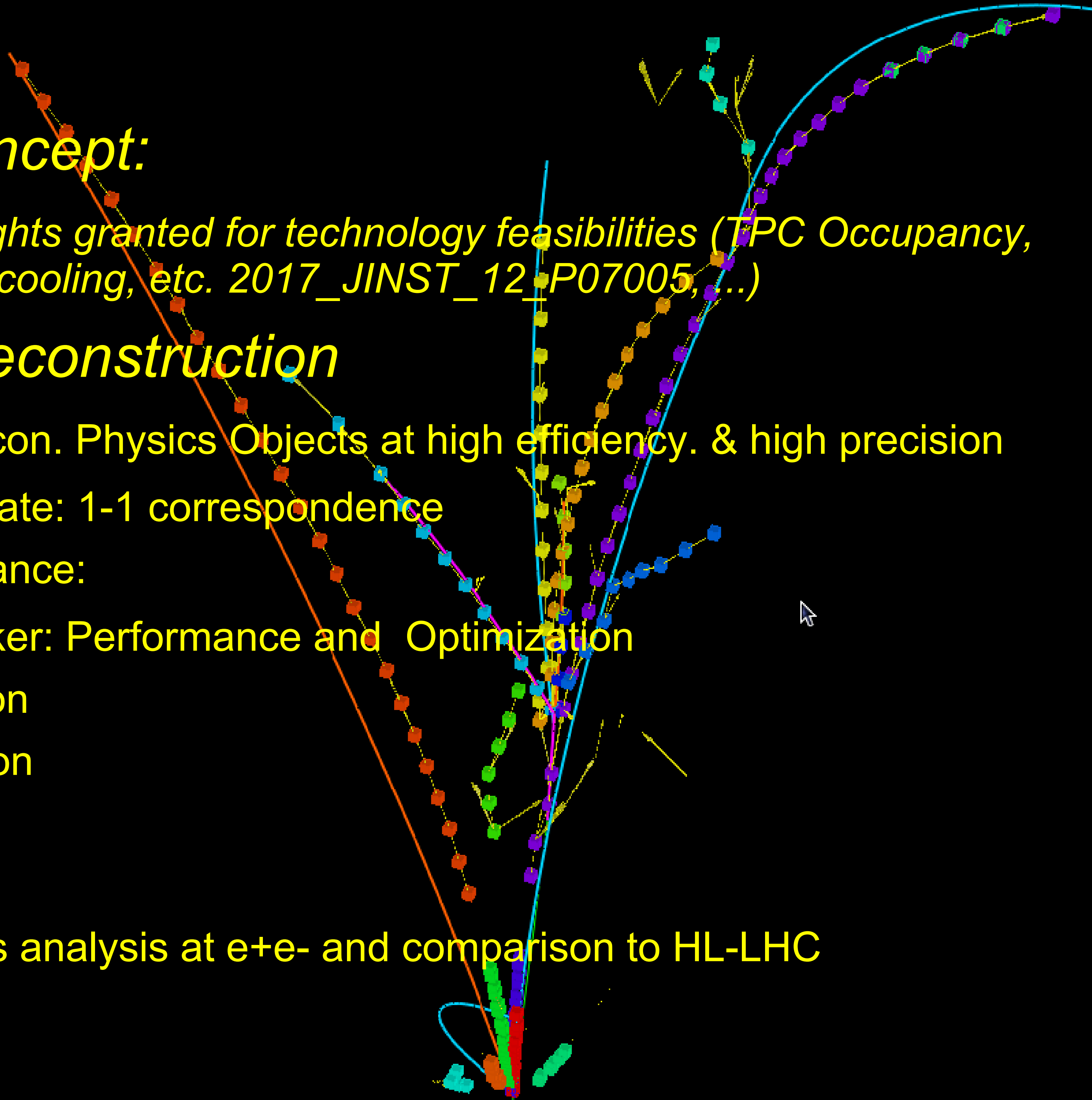


PFA Concept:

Green lights granted for technology feasibilities (TPC Occupancy, Passive cooling, etc. 2017_JINST_12_P07005, ...)

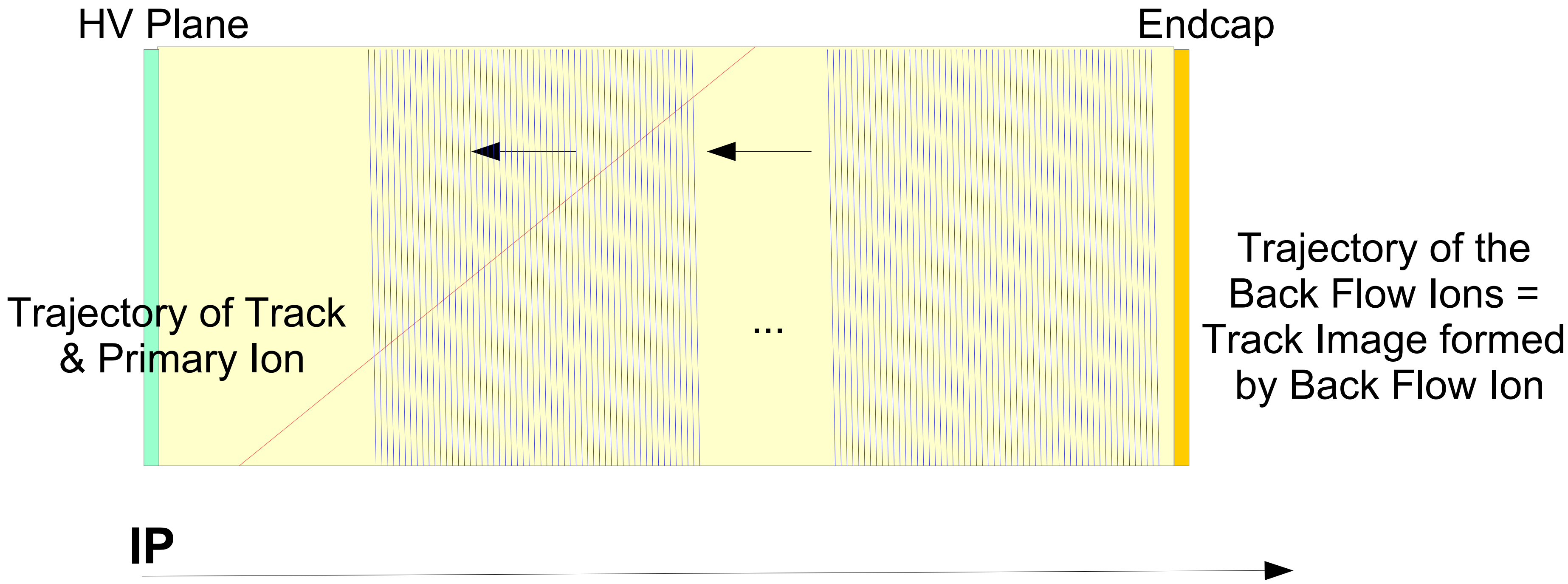
Arbor Reconstruction

- Goal: recon. Physics Objects at high efficiency. & high precision
  - Ultimate: 1-1 correspondence
- Performance:
  - Tracker: Performance and Optimization
  - Lepton
  - Photon
  - Jets
  - Taus
  - Higgs analysis at e+e- and comparison to HL-LHC

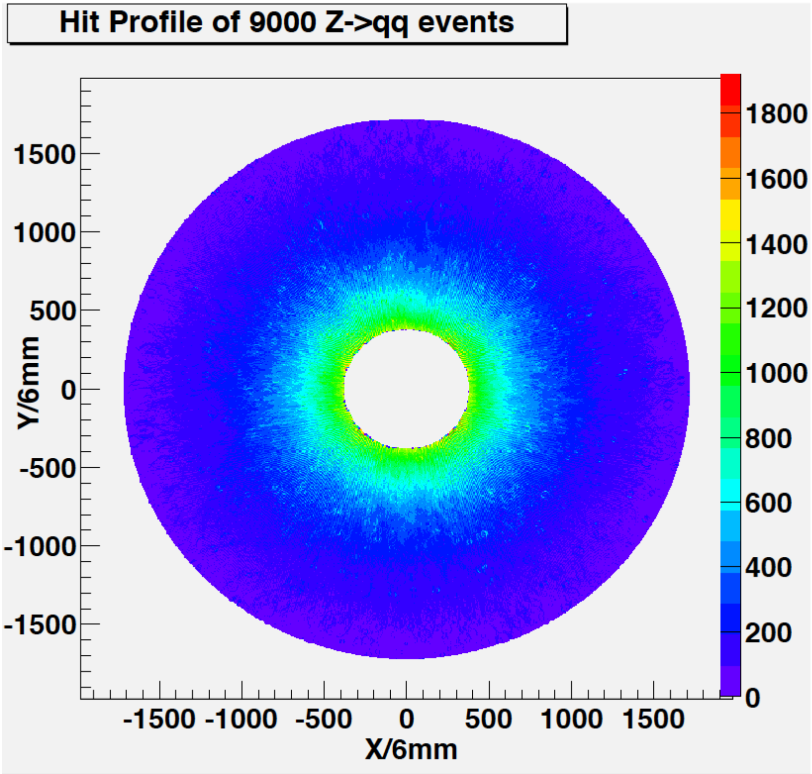


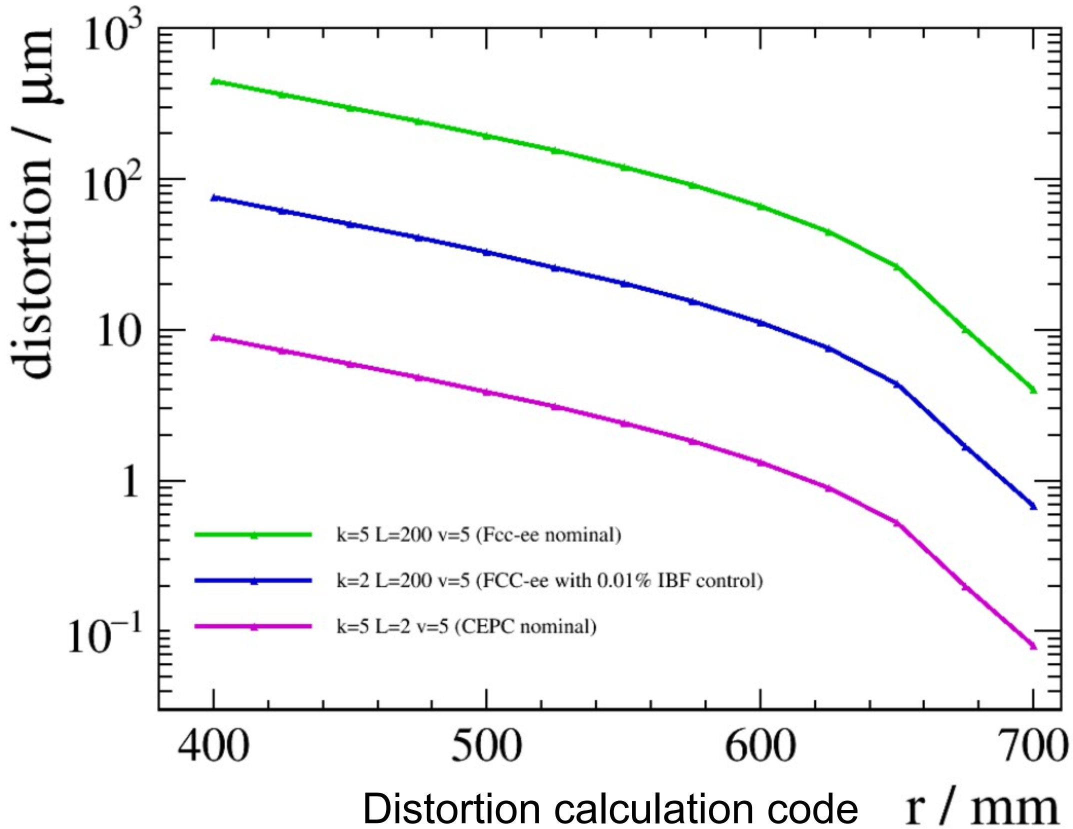
Feasibility of TPC at Z pole

- 600 Ion Disks induced from Z->qq events at 2E34$cm^{-2}s^{-1}$
- Voxel occupancy & Charge distortion from **Ion Back Flow** (IBF)



TPC Feasibility (Preliminary)

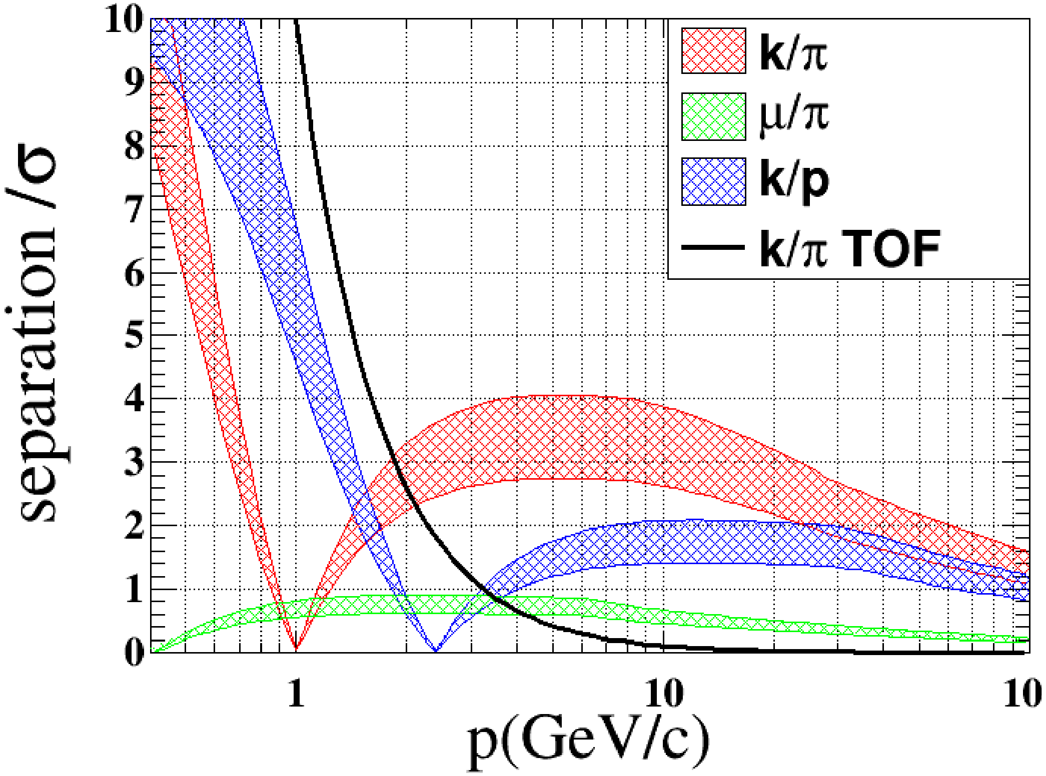


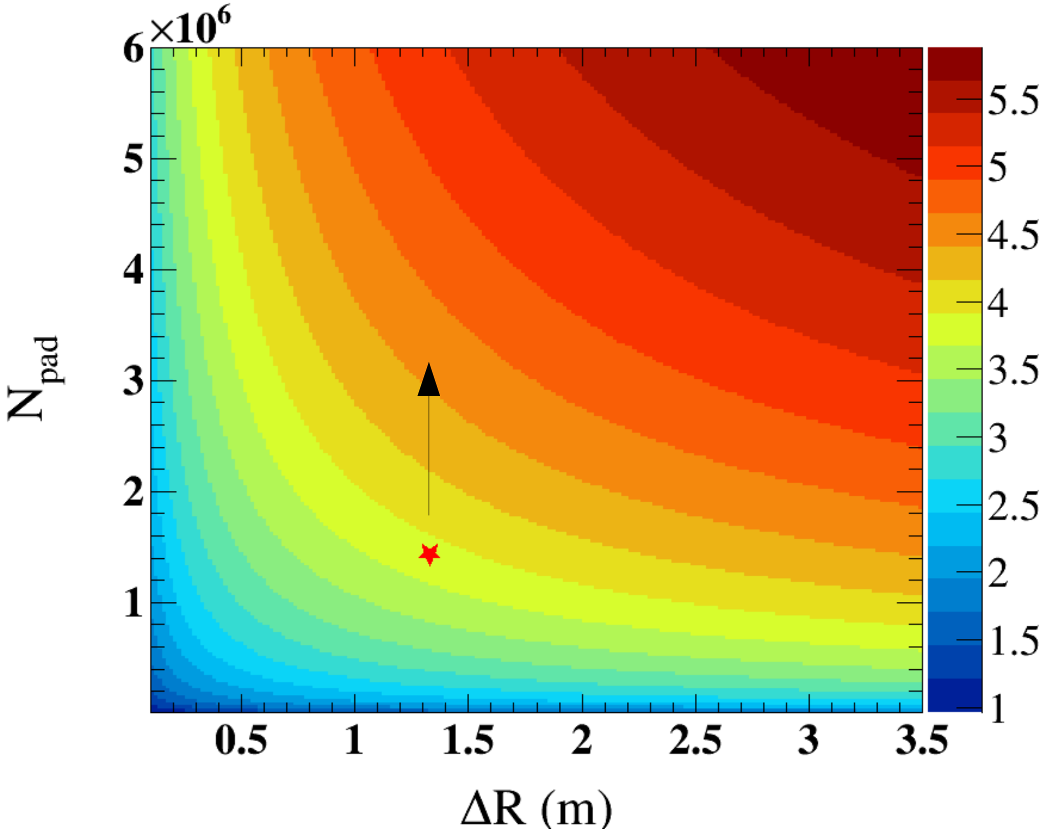


Distortion calculation code provided by KEK

- Conclusion:
  - Voxel occupancy ~ (10^-4 – 10^-6) level, safe
  - **Safe for CEPC If the ion back flow be controlled to per mille level (IBF*Gain = k ~ 5)** - The charge distortion at ILD TPC would be one order of magnitude then the intrinsic resolution (L = 2E34 $cm^{-2}s^{-1}$)

TPC dEdx & future optimizations

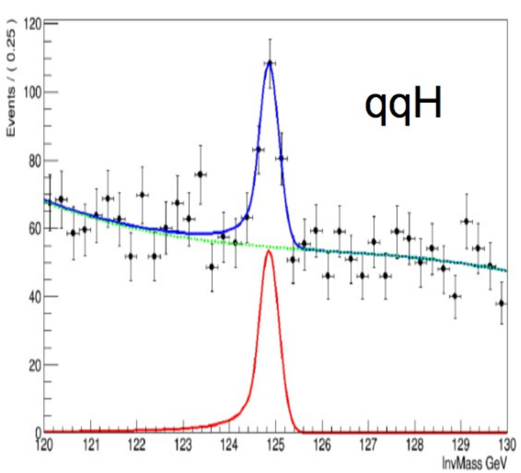


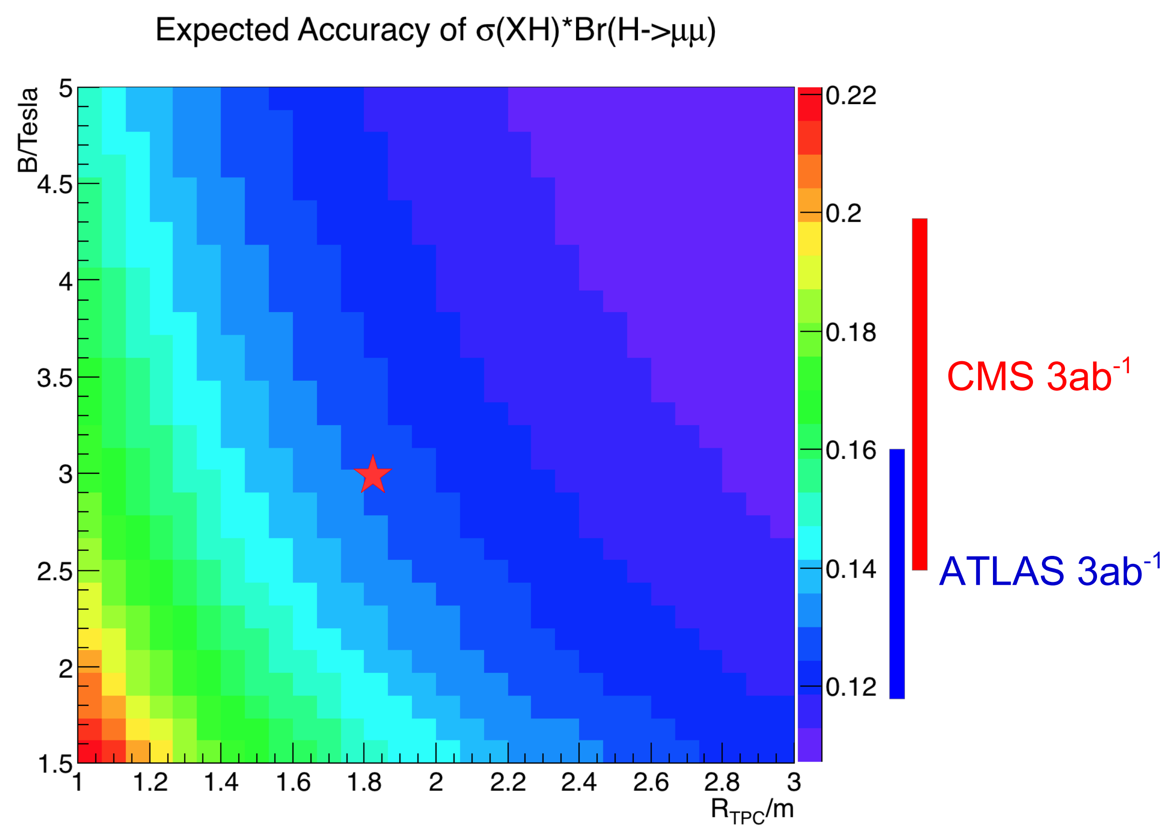


- TPC dEdx + ToF at dt ~ 50 ps: pi-kaon separation of 3-4σ at Z pole (E < 20 GeV)
- Be iterate with hardware study & Test beam: Quantify the hardware requirements
- TPC in general:
  - Stability & Homogeneity requirement
  - Radiation Background, Gas optimization (Neutron Flux, Delta/Gamma Ray)

Tracker Radius

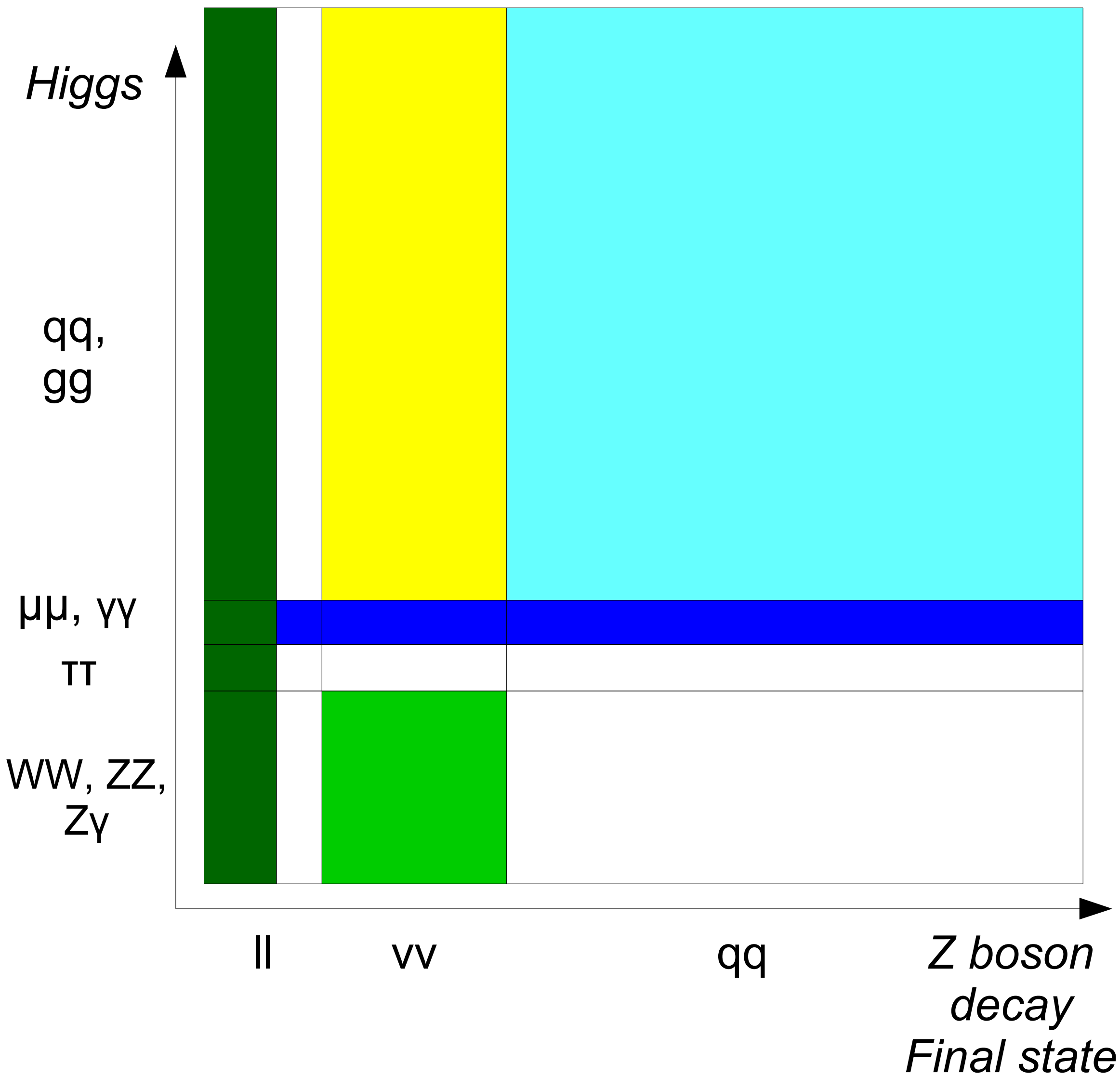
- Recommend CEPC TPC radius >= 1.8m:
  - **Better H→μμ measurement**
  - Better separation & JER
  - Better dEdx





★ *Reference TPC Setting: B = 3 T & R_{out} = 1.8*

Optimization Benchmarks



Lepton & Momentum resolution: Br = 6.7%

Flavor Tagging & JER: Br = 14%

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

Jet Clustering: Br = 50%

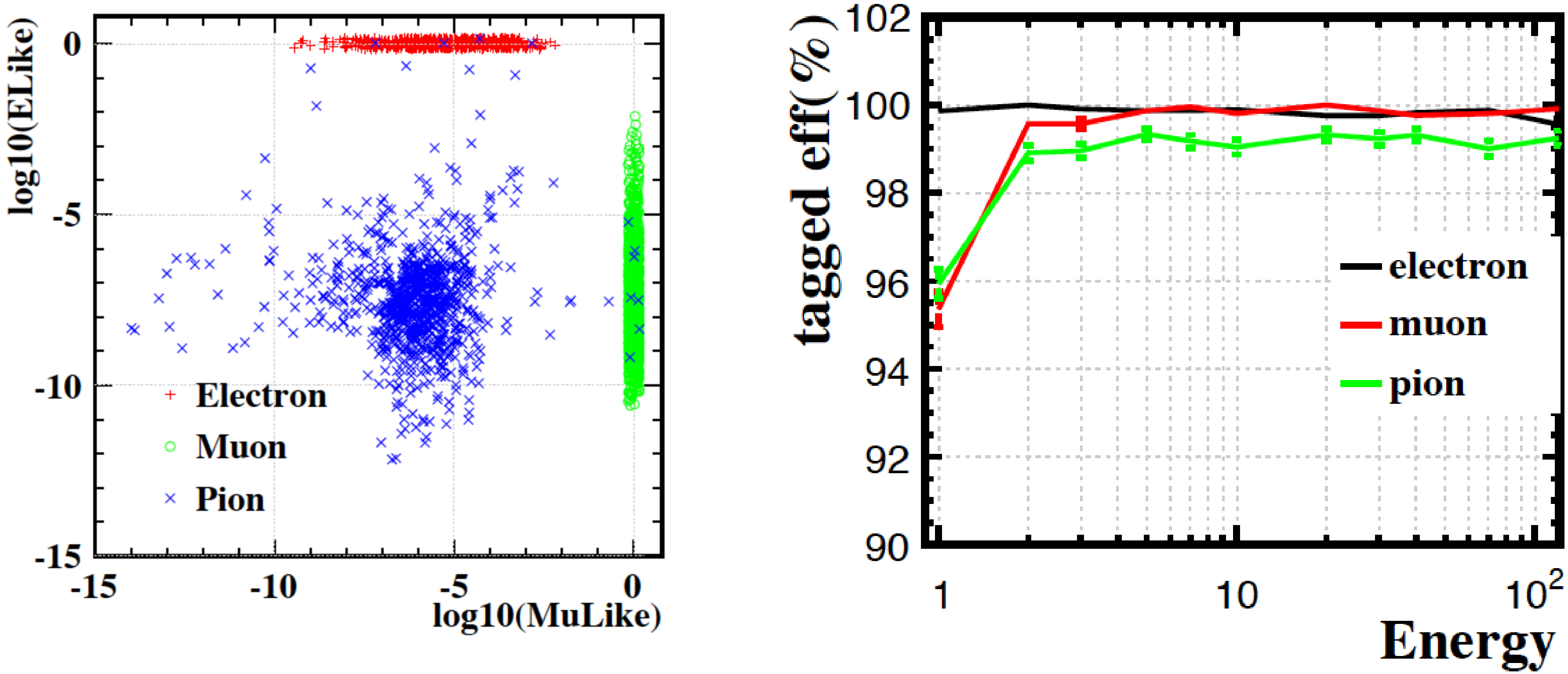
Photon/ECAL: Br = 0.2%

Tracking: H→μμ, Br = 0.02%

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

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

Leptons: identified by LICH: Lepton ID for Calorimeter with High granularity



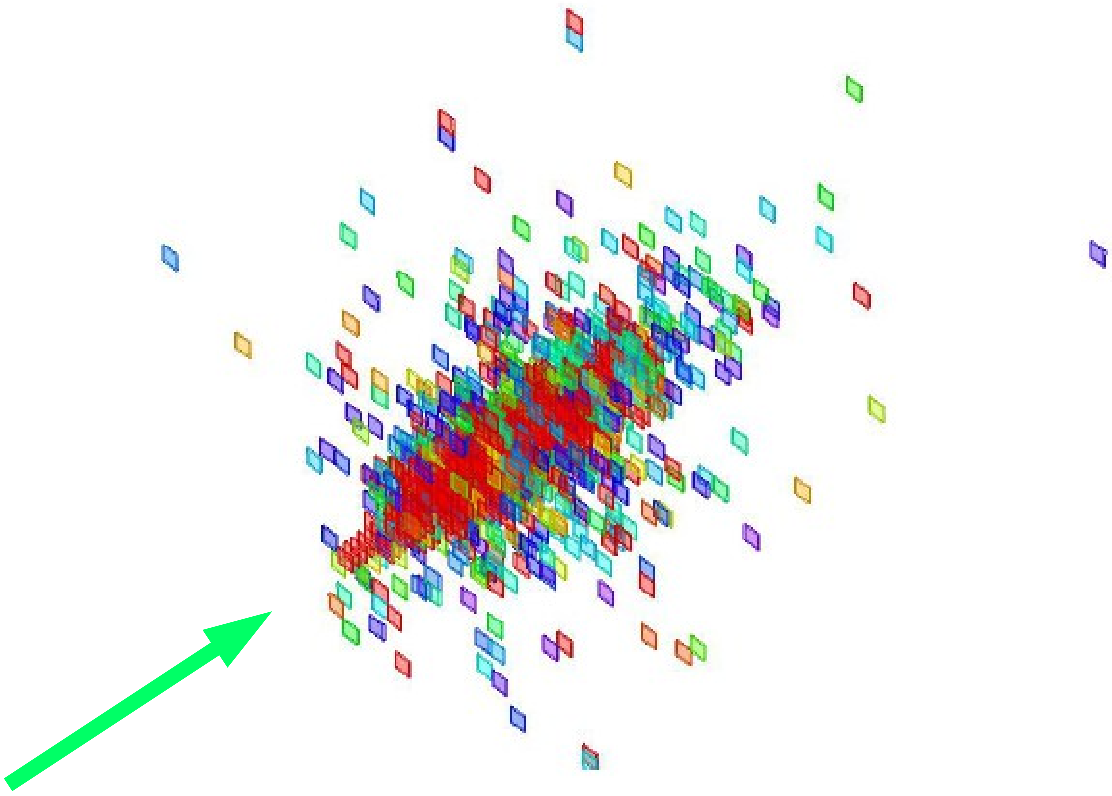
BDT method using 4 classes of 24 input discrimination variables.

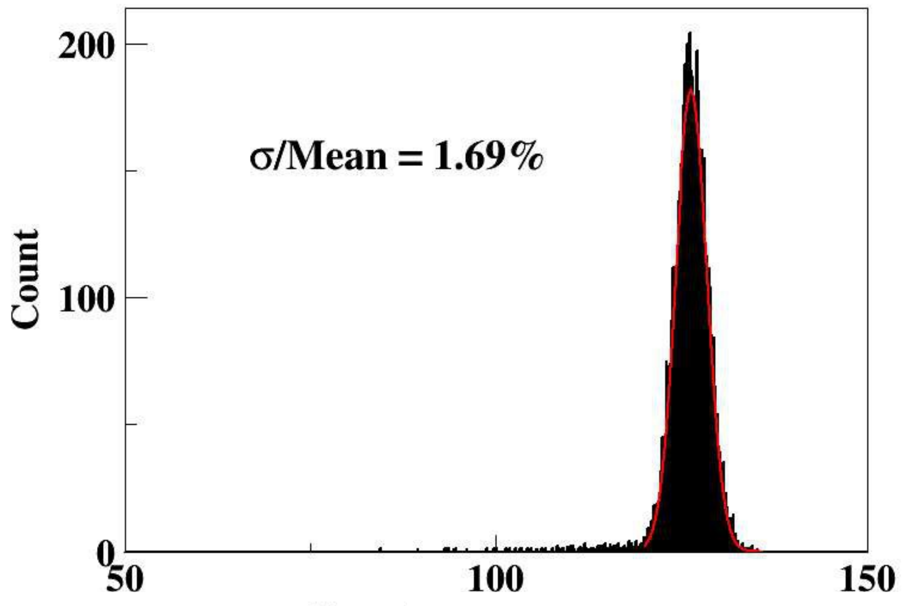
Test performance by requesting

Electron = E_likeness > 0.5 ; Muon = Mu_likeness > 0.5

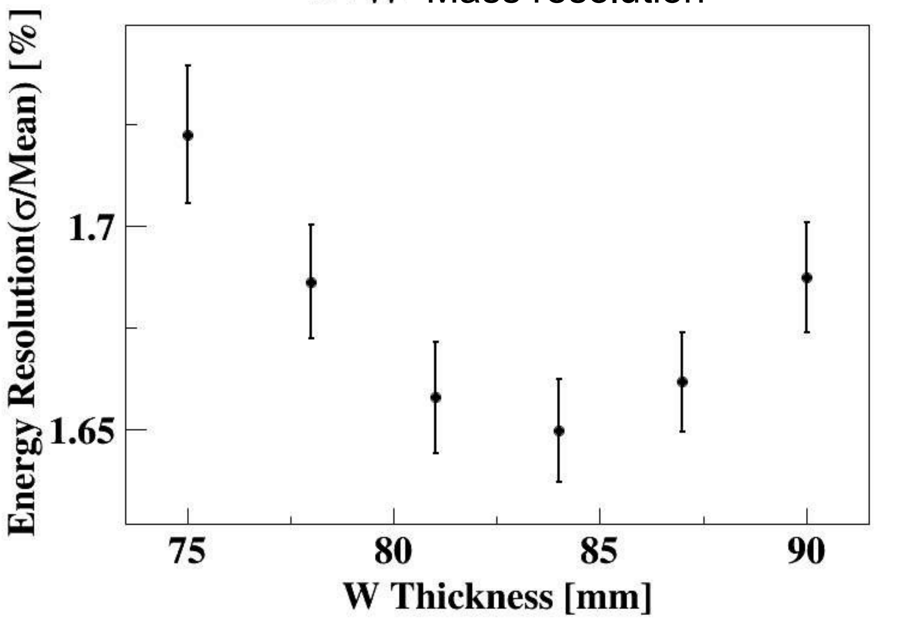
Single charged reconstructed particle, for E > 2 GeV: lepton efficiency > 99.5% && Pion mis id rate ~ 1%

Photons & Br(H→γγ) measurement



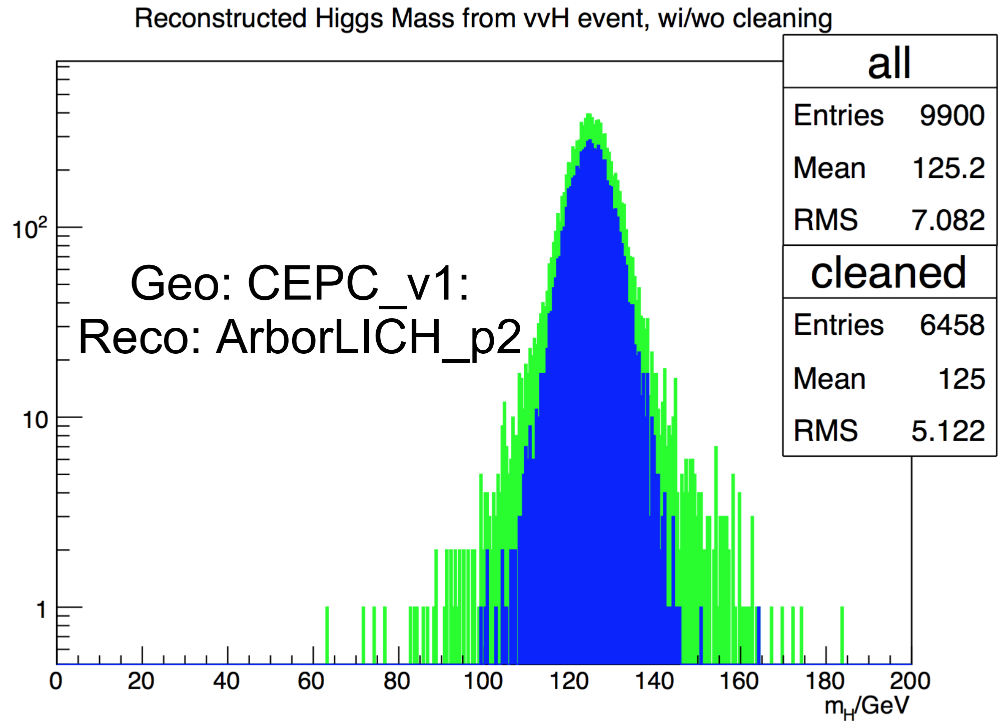


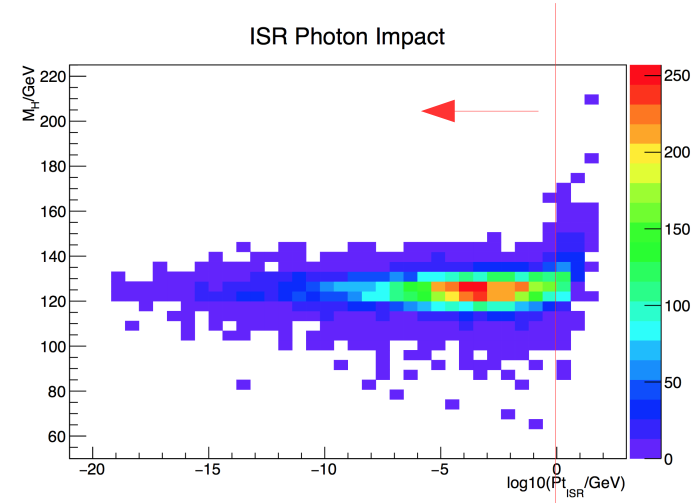
H->γγ Mass resolution

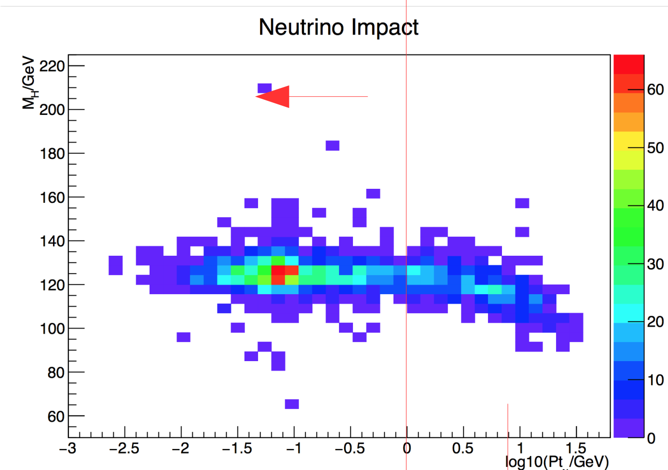


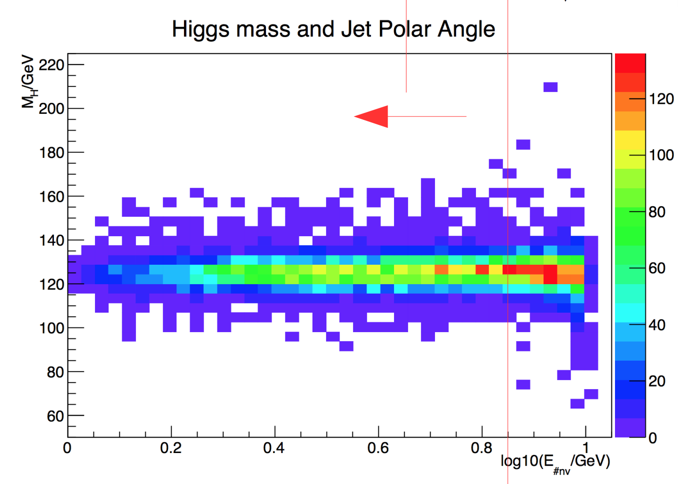
30 Layers, each layer with
0.5 mm Si + 2 mm PCB
ECAL only performance

Jets @ vvH, H→gluons



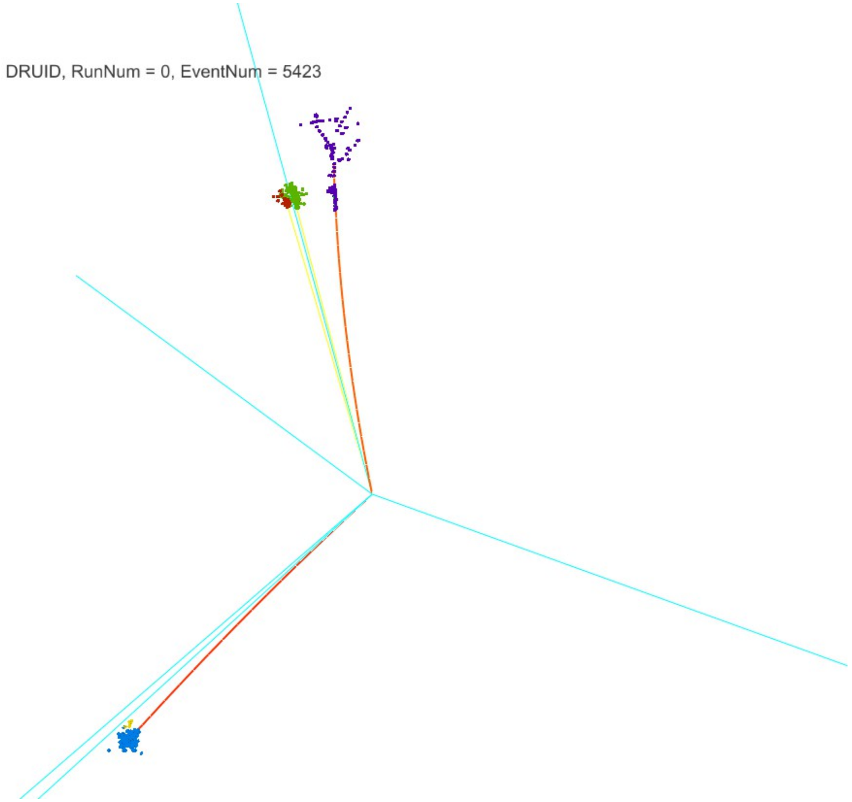


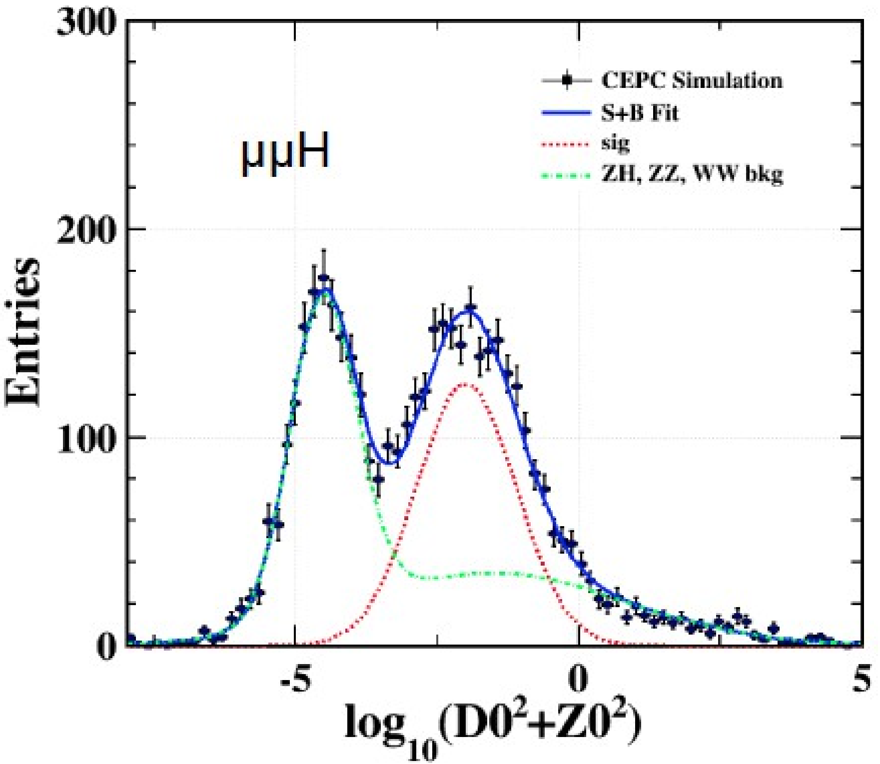




All	9900
ISRPt < 1 GeV	9335
ISRPt < 1 && N3Pt < 1	8766
ISRPt < 1&& N3Pt < 1&& |cos(Theat)| < 0.85	6458

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 ννH final state. The remaining bkgrds are irreducible: H→WW/ZZ→leptonic/tau final state
  - In μμH channel: δN/N = 3%

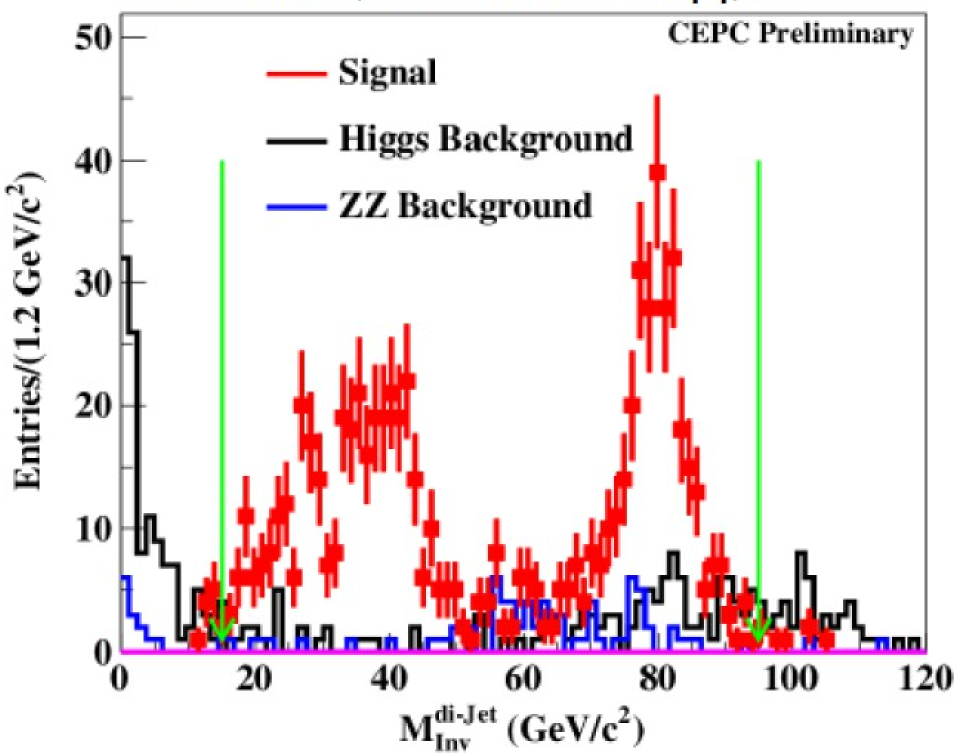
Detector Power consumption

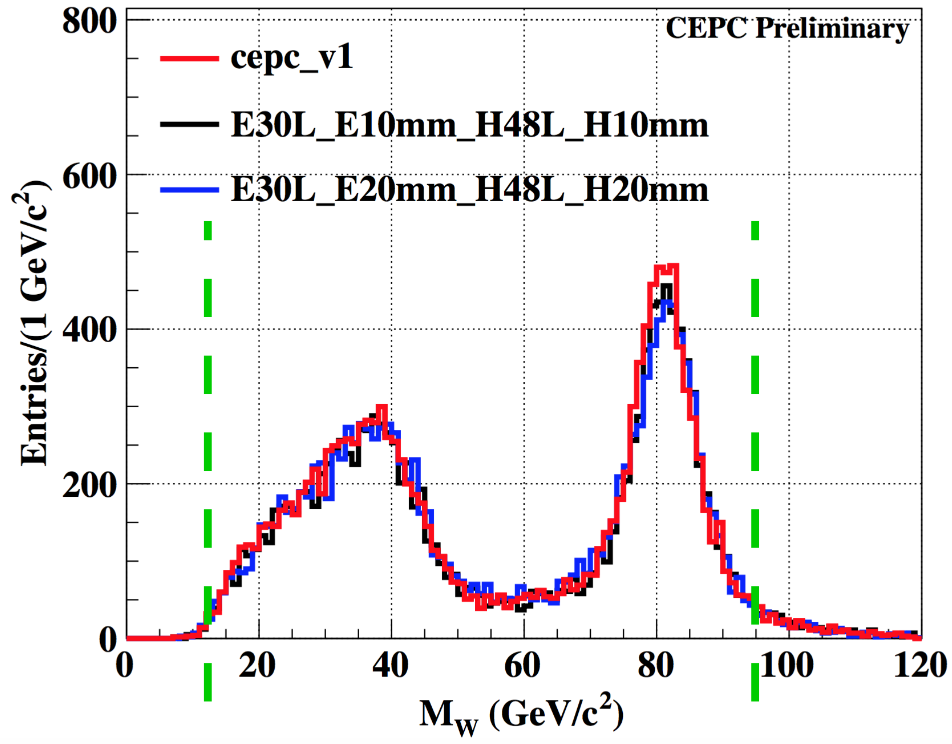
- Power pulsing
  - Reduce the power consumption by 2 orders of magnitude
  - Not applicable at Circular collider: the original design consumes ~o(MW) power @ CEPC
- Solution
  - Reduce the number of readout channels;

    Or
  - Implement dedicated cooling system;
- Passive cooling geometry: Readout channels reduced by 10 times
  - Object reconstruction efficiency: no significant impact
  - Event reconstruction efficiency (Defined as the efficiency of identify all the physics objects) Slightly (~1-2%) degrading in Higgs events

Br(H→WW) @ 10mm/20mm Cell size

Liao libo, H→WW*→lvqq, Z→ll



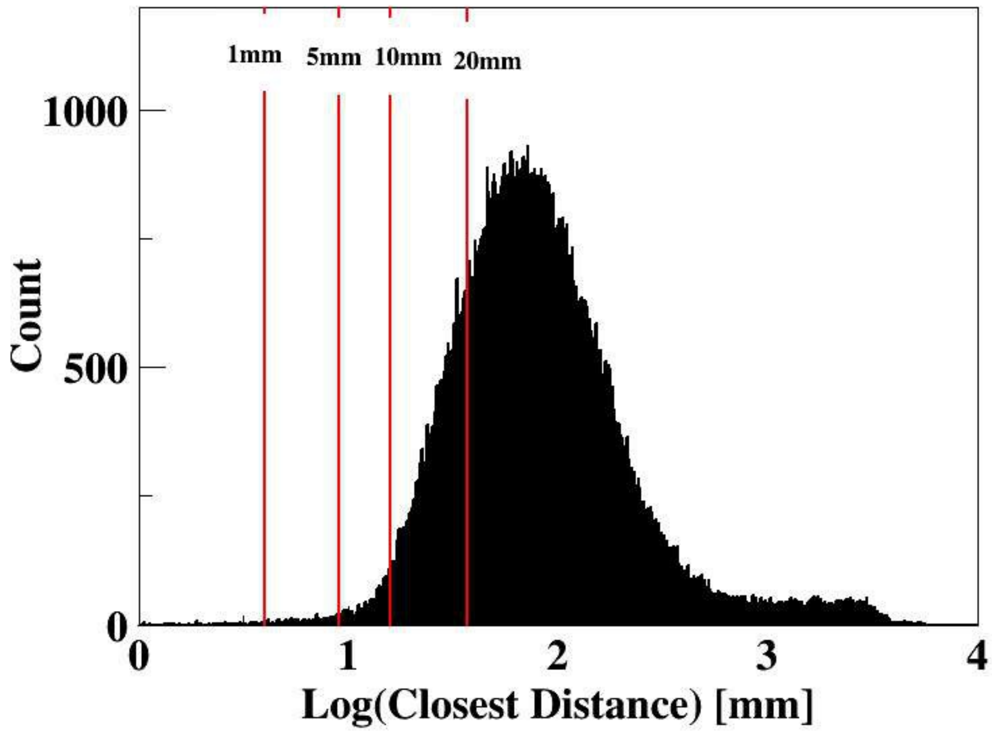


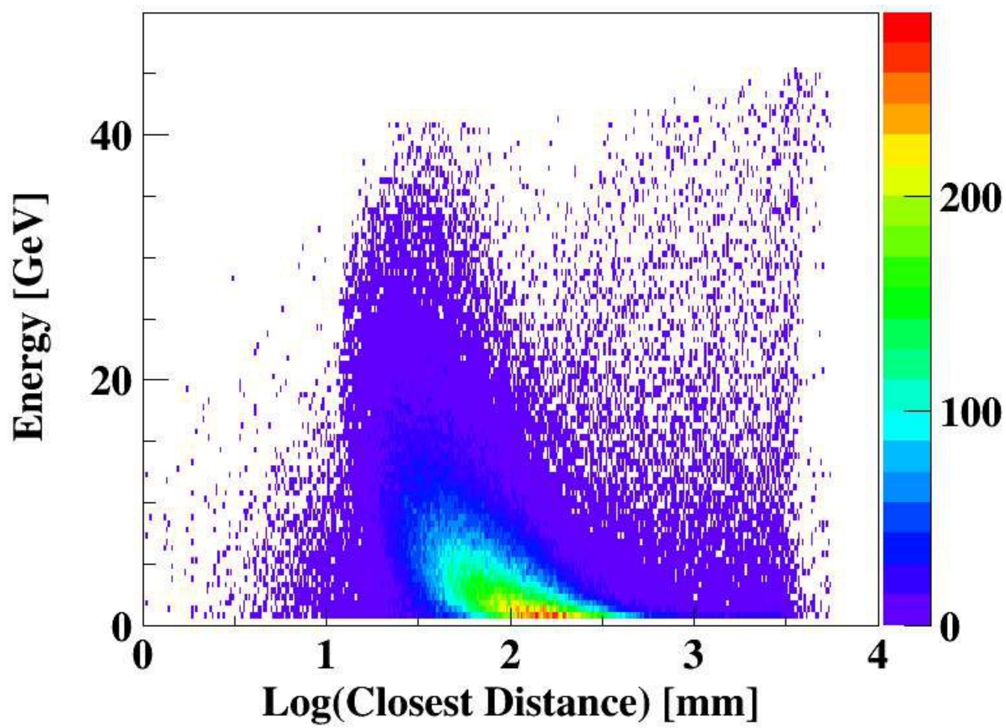
Br(H→WW) via vvH, H→WW*→lvqq

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

Over all: event reco. efficiency varies ~1%

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%

Feasibility & Optimized Parameters

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

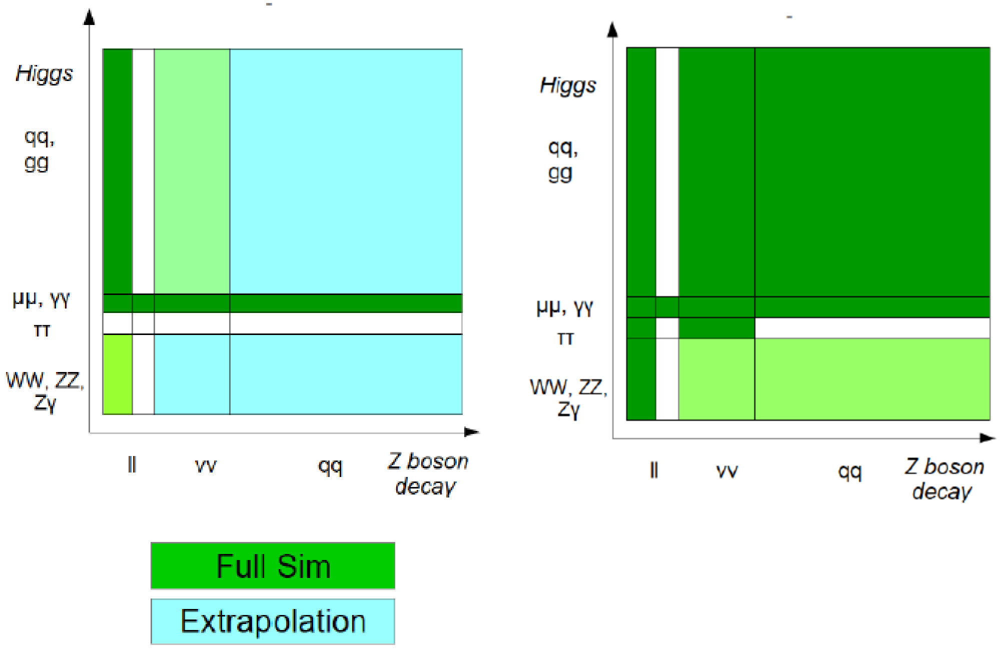
	CEPC_v1 (~ ILD)	Optimized (Preliminary)	Comments
Track Radius	1.8 m	>= 1.8 m	Requested by Br(H->di muon) measurement
B Field	**3.5 T**	**3 T**	**Requested by MDI**
ToF	**-**	**50 ps**	**Requested by pi-Kaon separation at Z pole**
ECAL Thickness	84 mm	84(90) mm	84 mm is optimized on Br(H->di photon) at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

PFA Oriented Detector: Performance

- Solid Angle Coverage : $|\cos(\theta)| < 0.99$
- Lepton id : eff > 99.5%, mis id < 1%
- Calorimeter Shower Separation : 9 – 16 mm
- Tracking: $\delta(1/P_t) \sim 2\text{e-}5\ \text{GeV}^{-1}$, 1 order of magnitude better than current status
- C-tagging is feasible
- Photon Energy resolution: σ/Mean ~ 1.7 – 2.4% for $H \to \gamma\gamma$ events
- Jet Energy resolution: σ/Mean ~ 4% for H->gg events
- Pi-Kaon Separation: at 3-4 sigma level with E < 20 GeV

- Systematic control : ~ 1 order of magnitude better
  - Beam energy monitoring, Calibration, Alignments...

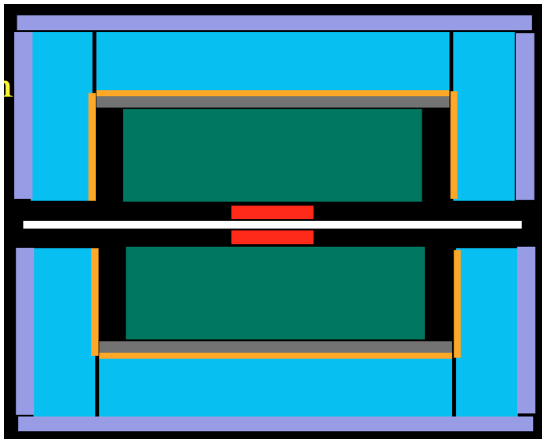
Applied to CEPC Higgs analysis

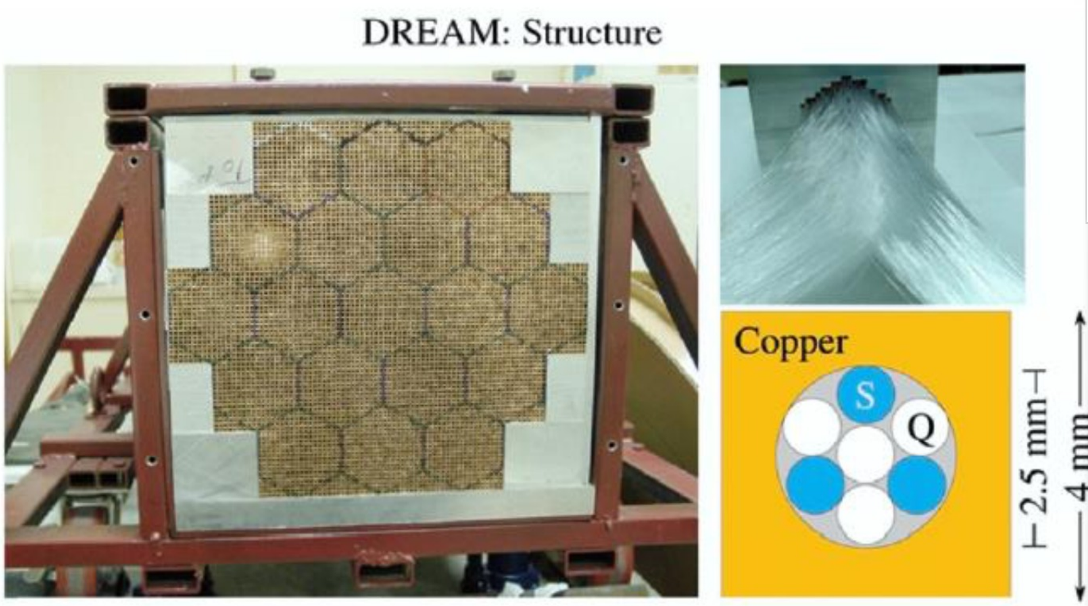


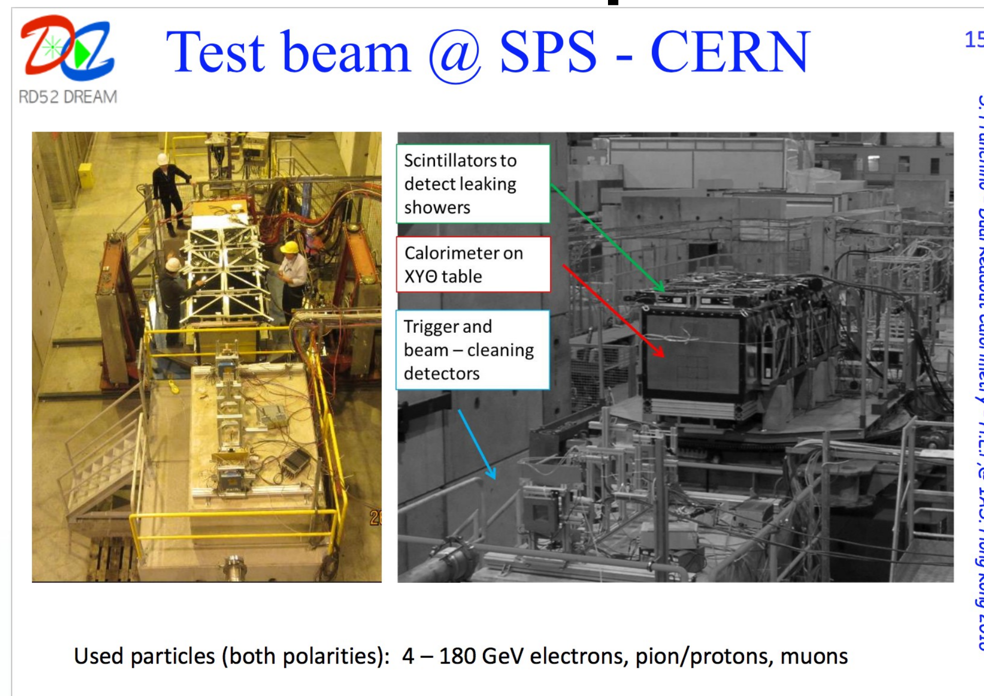
	PreCDR (Jan 2015)	Now (Aug 2016)
σ(ZH)	0.51%	0.50%
σ(ZH)*Br(H→bb)	0.28%	0.21%
σ(ZH)*Br(H→cc)	2.1%	2.5%
σ(ZH)*Br(H→gg)	1.6%	1.2%
σ(ZH)*Br(H→WW)	1.5%	1.0%
σ(ZH)*Br(H→ZZ)	4.3%	4.3%
σ(ZH)*Br(H→ττ)	1.2%	1.0%
σ(ZH)*Br(H→γγ)	9.0%	9.0%
σ(ZH)*Br(H→Zγ)	-	~4 σ
σ(ZH)*Br(H→μμ)	17%	12%
σ(ννH)*Br(H→bb)	2.8%	2.8%
Higgs 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

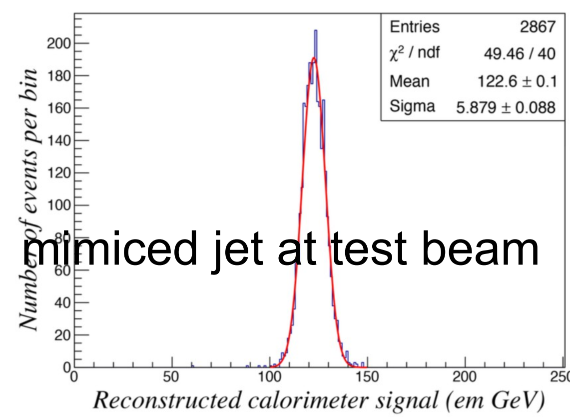
Now: ~50 independent analyses at Full Simulation level

The “IDEA” detector concept







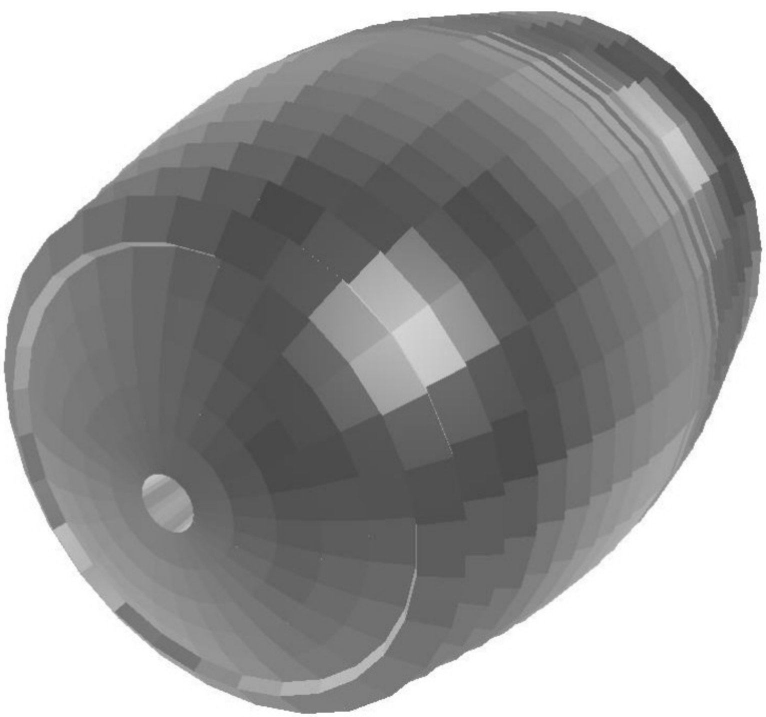


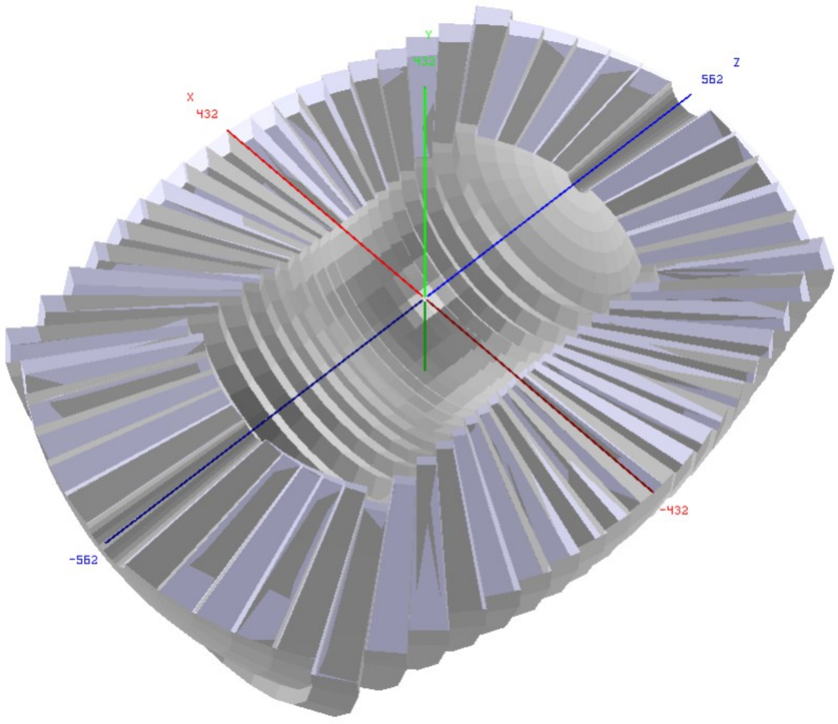
mimiced jet at test beam

Fig. 18. Signal distribution for 125 GeV multiparticle events obtained with the rotation method described in the text. The energy scale is set by electrons showering in this detector.

Simulation initialized

- $N\phi = 28$
- Nbarrel = 10
- Nencap = 5
- $\delta\theta = 0.1$





Summary

- CEPC:
  - A tremendous Higgs/EW factory, Boost the precision of Higgs/EW measurement by more than 1 order of magnitude
    - Higgs performance well understood;
    - Systematic study/controls would be essential for the EW measurement
  - Request detector(s) that can successfully reconstruct all kinds of physics objects: Photons, Leptons, Jets, Tau, MET
- CEPC Detectors: PFA Oriented Concept & IDEA
  - PFA Oriented Concept: TPC + HGC
    - Green light granted for technology feasibilities
    - Fully established in simulation/reconstruction, dedicated Reconstruction algorithm that reconstruct every physics objects
    - Optimized w.r.t Set of Benchmark Physics Performance/Processes
  - IDEA Concept: Dual Readout Calorimeter + Wire Chamber. Detector concept in implementation, much to be explored.
- New ideas & your participation is more than welcome!

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- Accommodation
- Transportation

The International Workshop on the CEPC aims at gathering scientists around the world to study the Circular Electron Positron Collider (CEPC) as a Higgs factory. The focuses will be the measurement of the Higgs properties with high precision, probing new physics through the Higgs boson, to study the full spectrum of the physics cases, to report on the conceptual design of the CEPC accelerator and the detector, as well as the simulation studies and the R&D of critical technologies. The possible upgrade path of the CEPC, including a high energy Super proton-proton Collider (SppC), will be explored.

One main purpose of the workshop is to make the CEPC study much more international by having broad participation and contributions globally, and to elevate the CEPC study group to an international organization.

Thanks

Timeline

Milestones

1st, PreCDR (end of 2014)

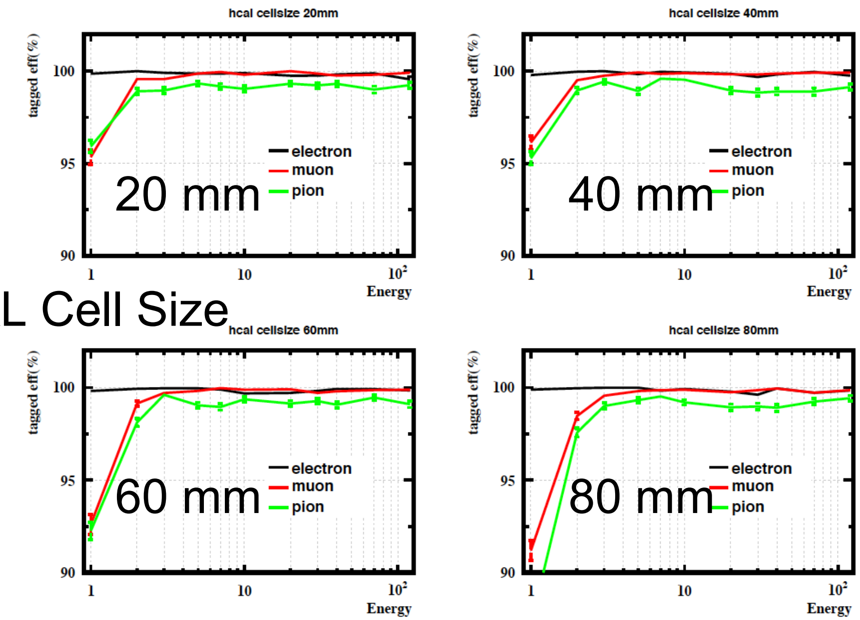
2nd, R&D funding from MOST (Middle 2016, 35 M CNY/5yr for the 1st phase)

3rd, CDR (end of 2017)

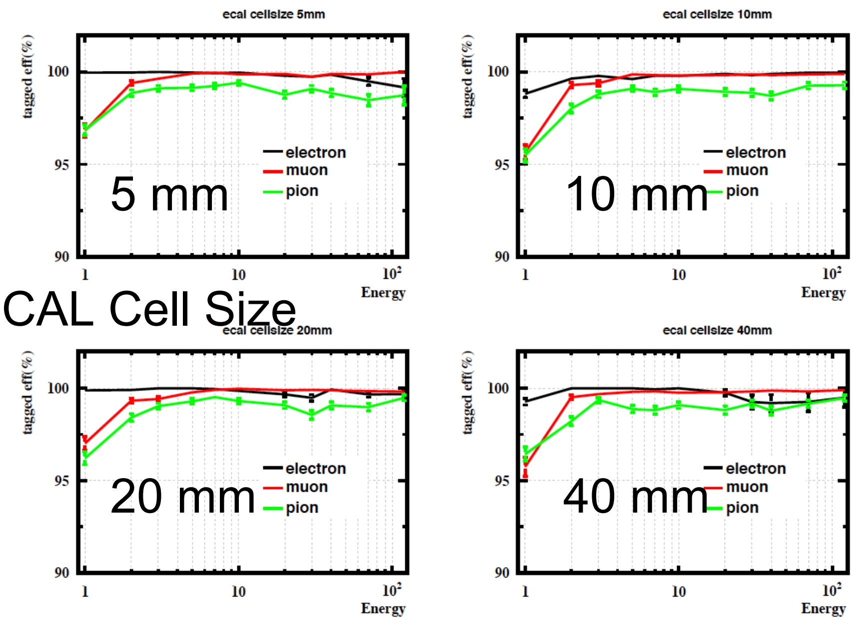
...

Vary the granularity

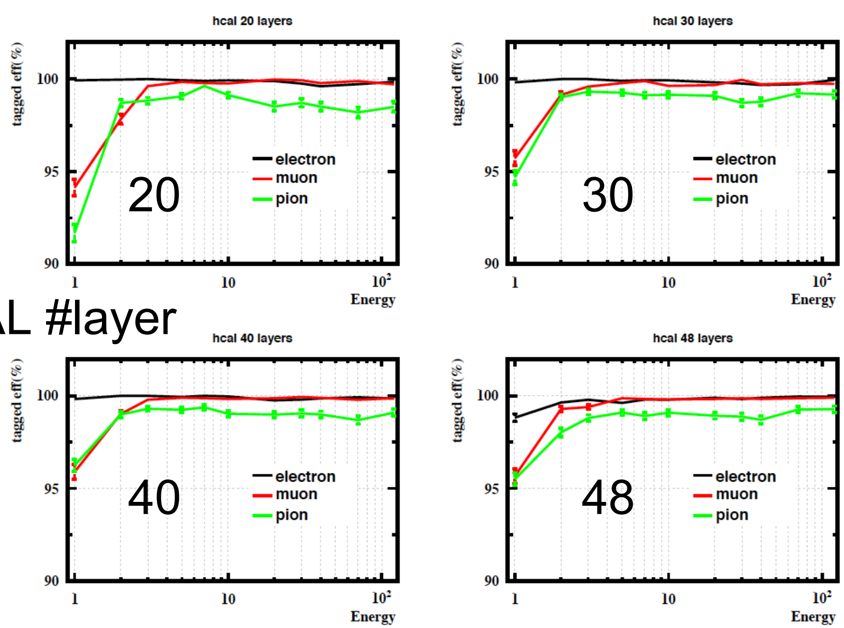
HCAL Cell Size



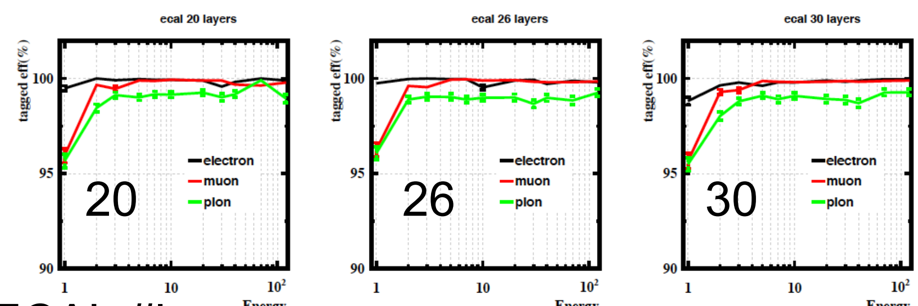
ECAL Cell Size



HCAL #layer

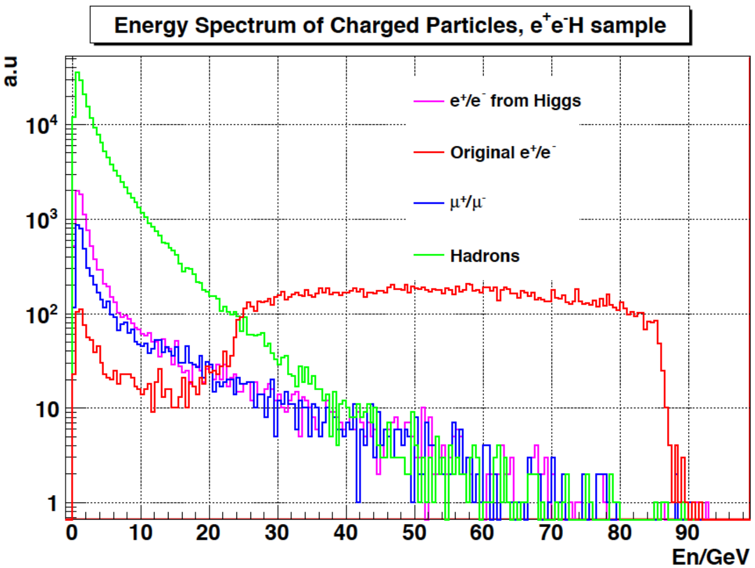


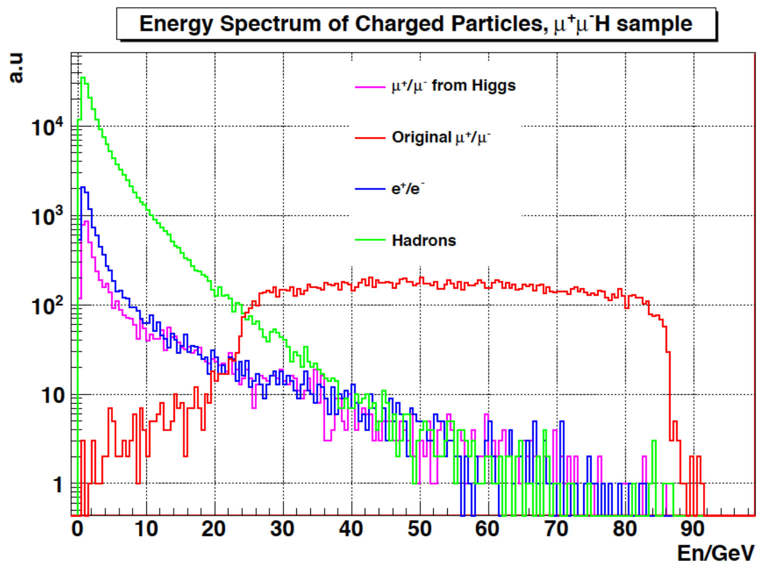
ECAL #layer

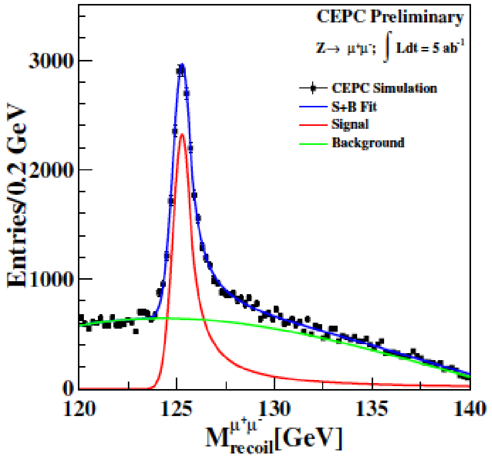


No Significant effect for E > 2 GeV charged Particles

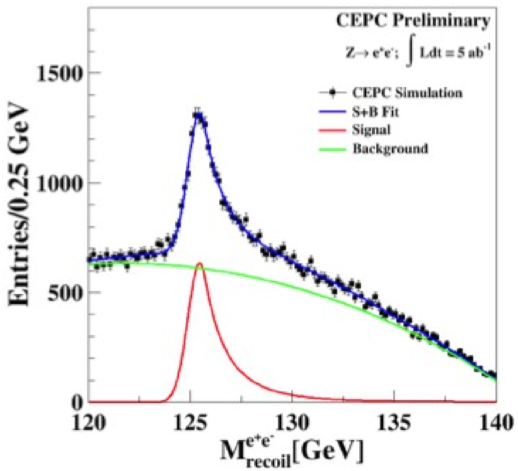
LICH @ llH events







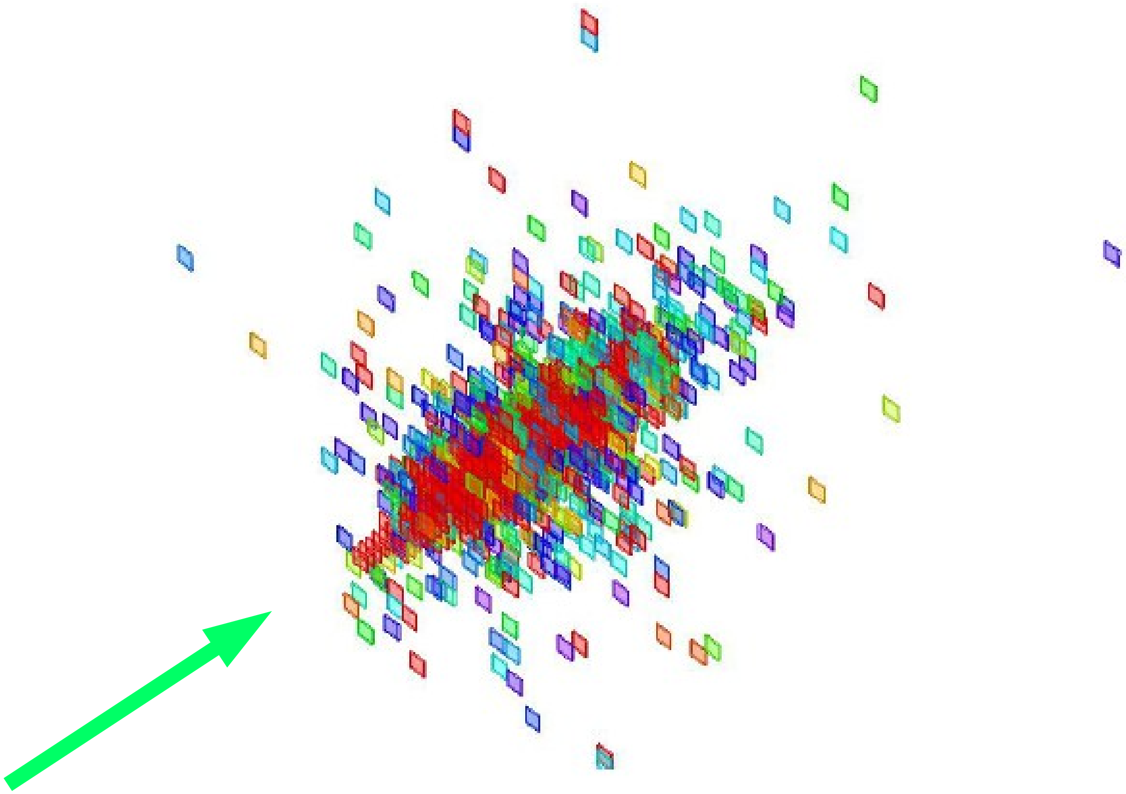
	Geom 1		Geom 2	
	$\mu\mu$H	eeH	$\mu\mu$H	eeH
Cut$_\mu$	0.1	0.1	0.1	0.1
Cut$_e$	0.01	0.001	0.01	0.001
ε_E	93.41 ± 0.92	**98.64 ± 0.08**	91.60 ± 1.02	**97.89 ± 0.11**
η_E	92.02 ± 1.00	**99.74 ± 0.04**	89.89 ± 1.10	**99.67 ± 0.04**
ε_μ	**99.54 ± 0.05**	95.53 ± 0.76	**99.19 ± 0.06**	86.48 ± 1.26
η_μ	**99.60 ± 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

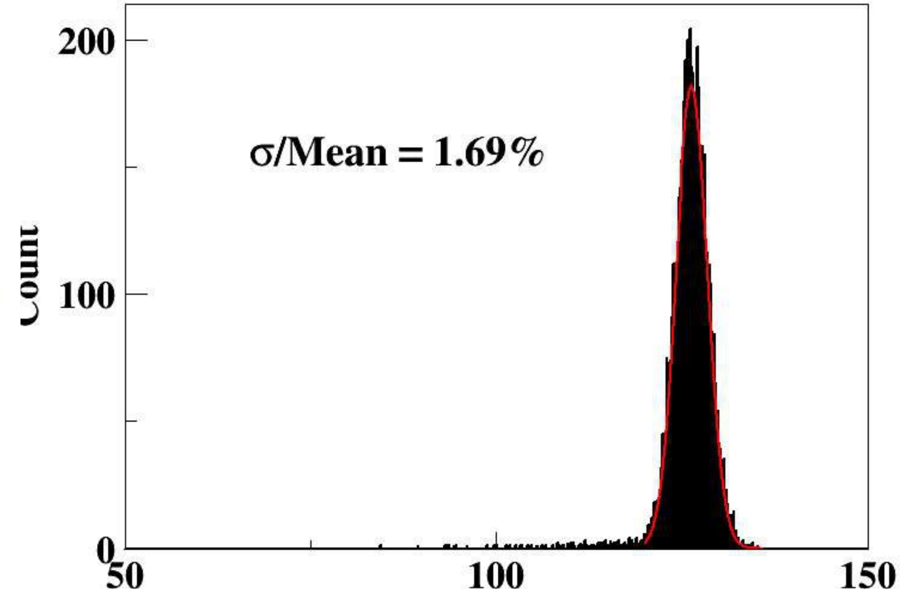


Geom 1/2: 10 (20) mm ECAL/HCAL Cell
Initial Leptons identified at satisfactory efficiency & purity (limited by separation power)
More stringent requirement arrises from jet leptons...

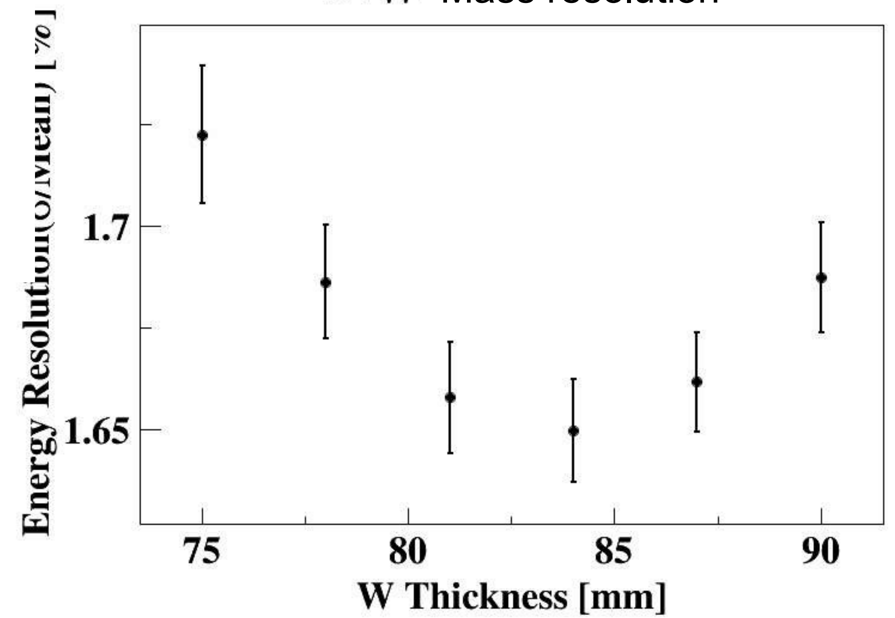
https://arxiv.org/abs/1701.07542

Photons & Br(H→γγ) measurement





H->γγ Mass resolution



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

Separation

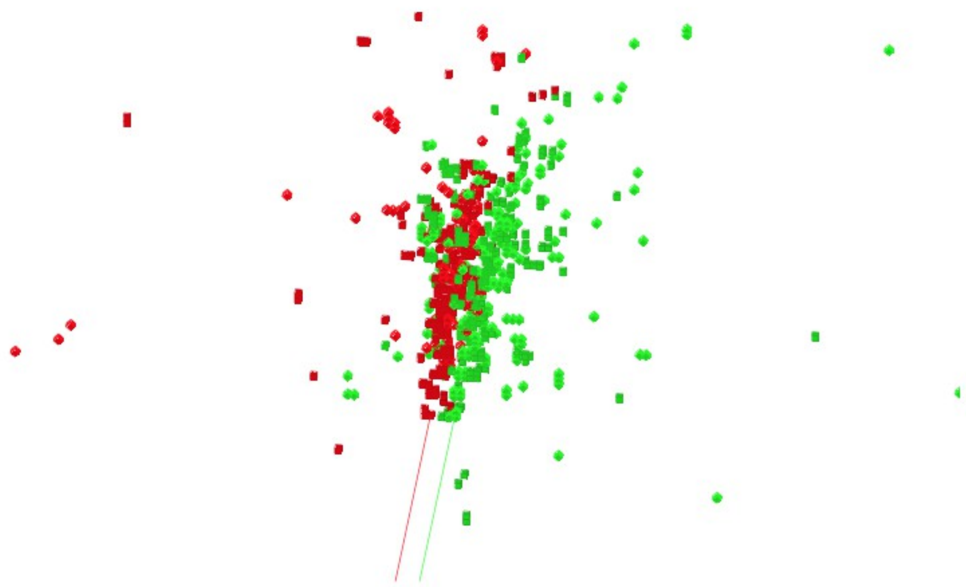
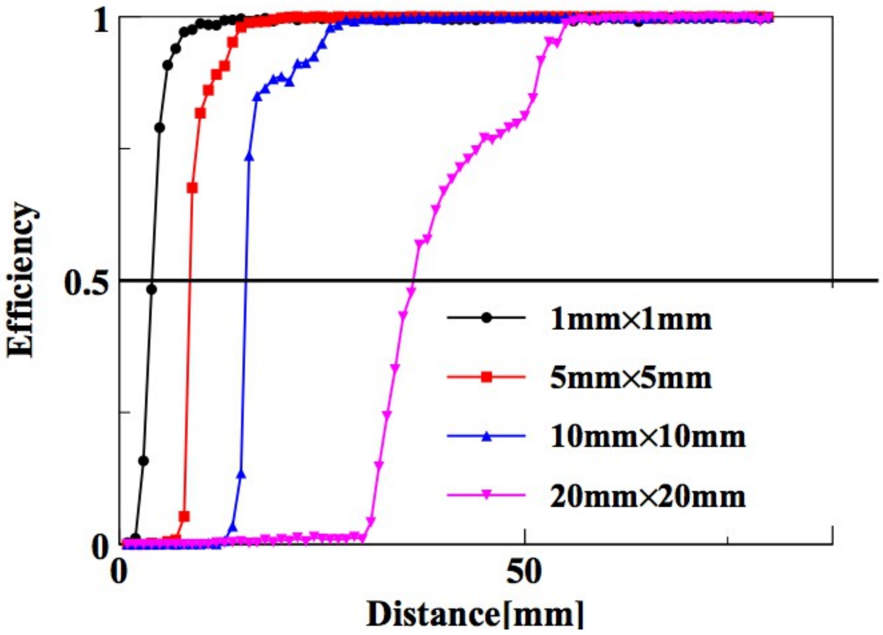
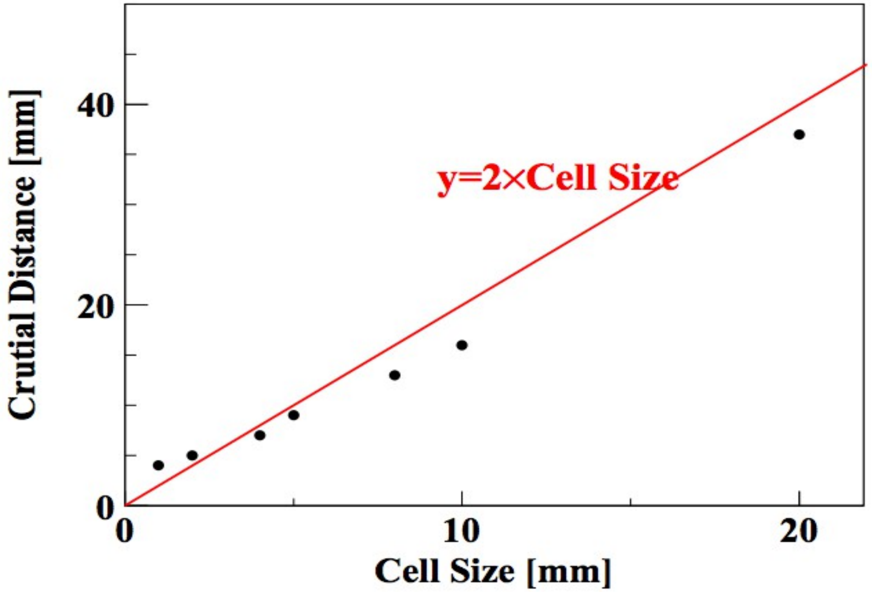


Figure 11. Event display of reconstructed di-photon.

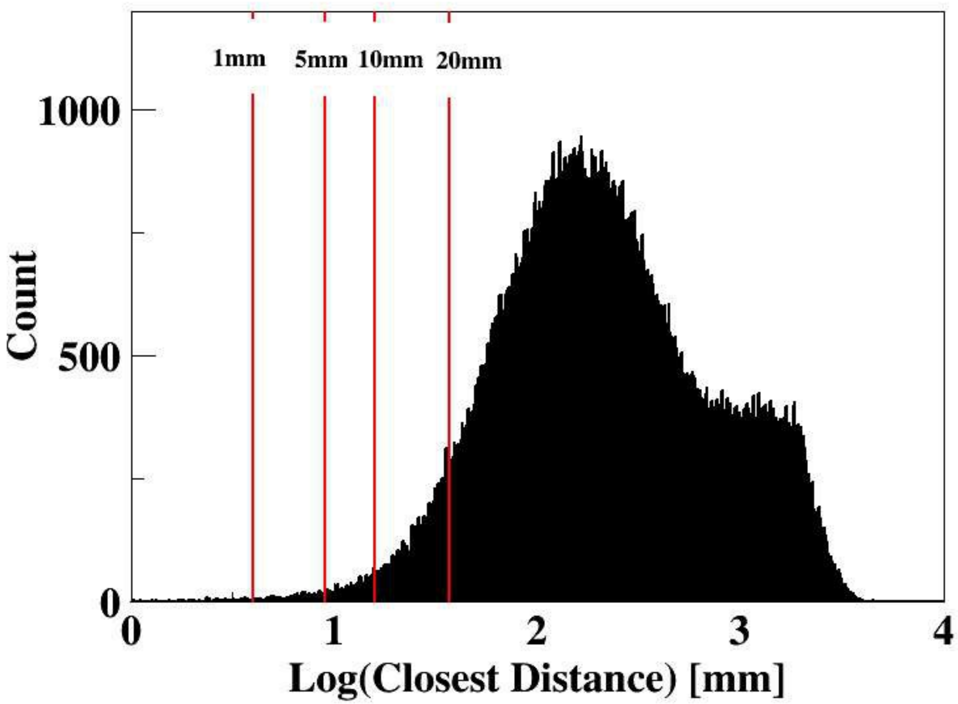


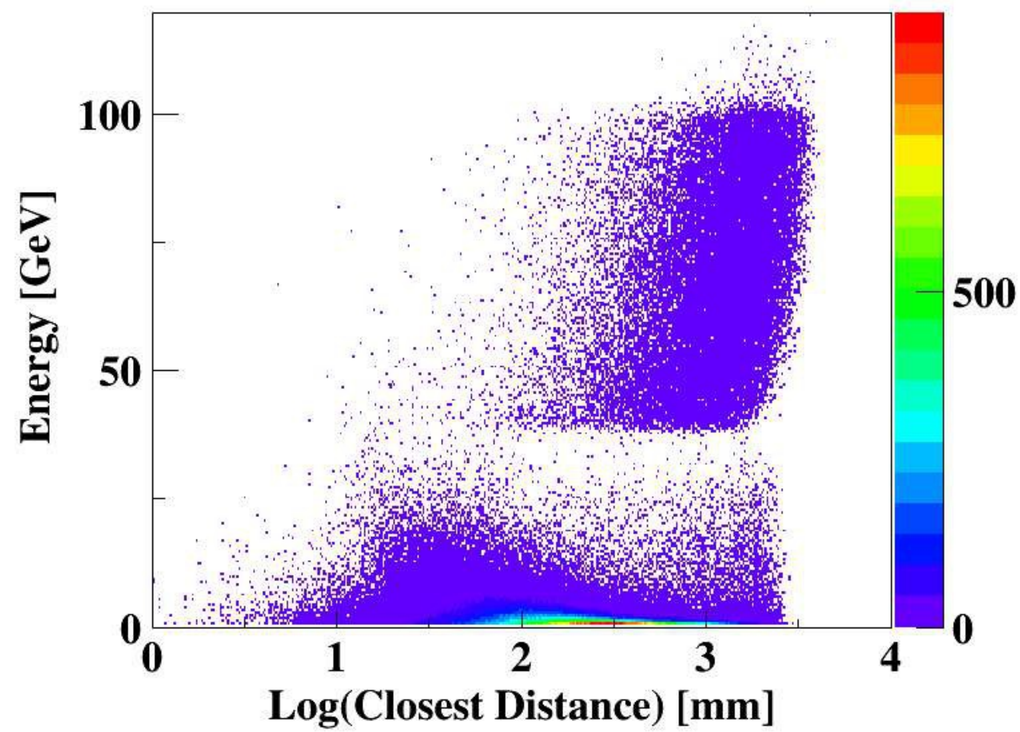


Critical Distance:

~ 2 * Cell Size if Cell Size < Moliere Radius
~ Cell Size if Cell Size >> Moliere Radius

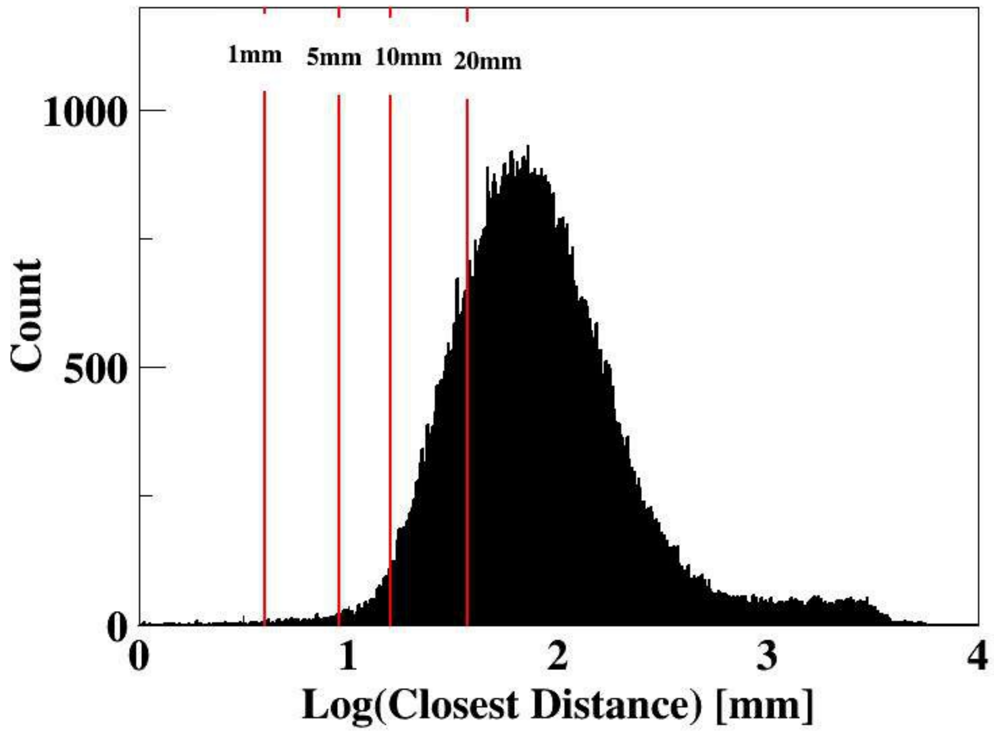
Impact of Separation: qqH, H->γγ @ 250 GeV

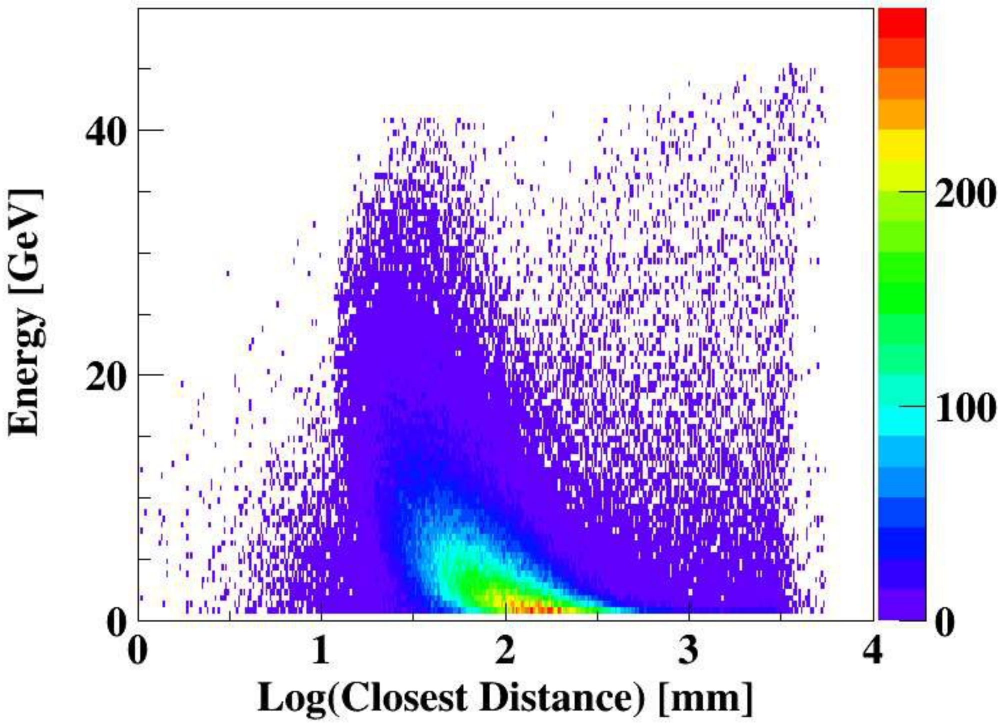




Cell Size/mm	1	5	10	20
Crucial Dis/mm	4	9	16	37
Percentage of potentially overlap photon: E > 30 GeV	0%	0%	0.1%	0.4%
E < 30GeV	0.1%	0.35%	1.1%	6.4%

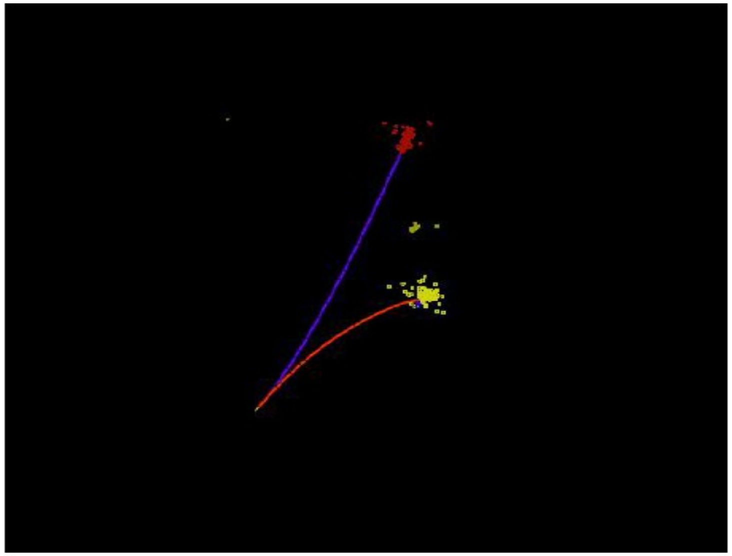
Impact of Separation: Z->tau tau @ Z pole

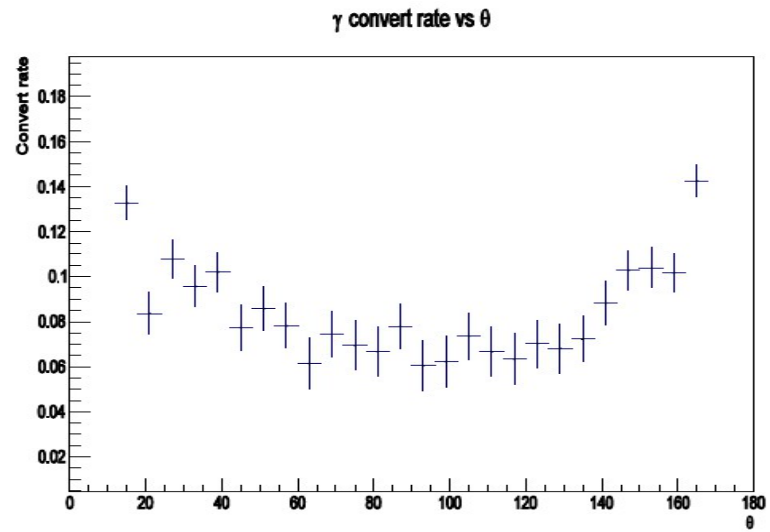


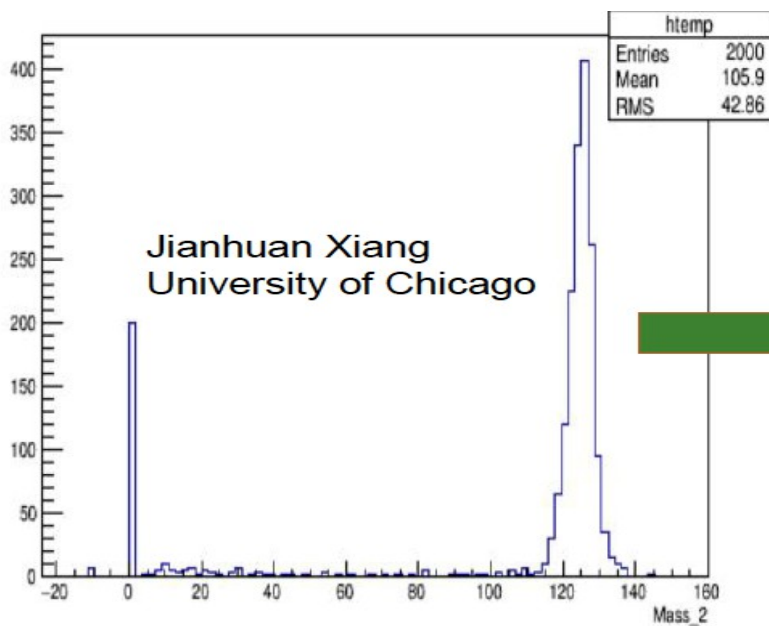


Cell Size/mm	1	5	10	20
Crucial Dis/mm	4	9	16	37
Percentage of potentially overlap photon	0.07%	0.4%	1.7%	18.6%

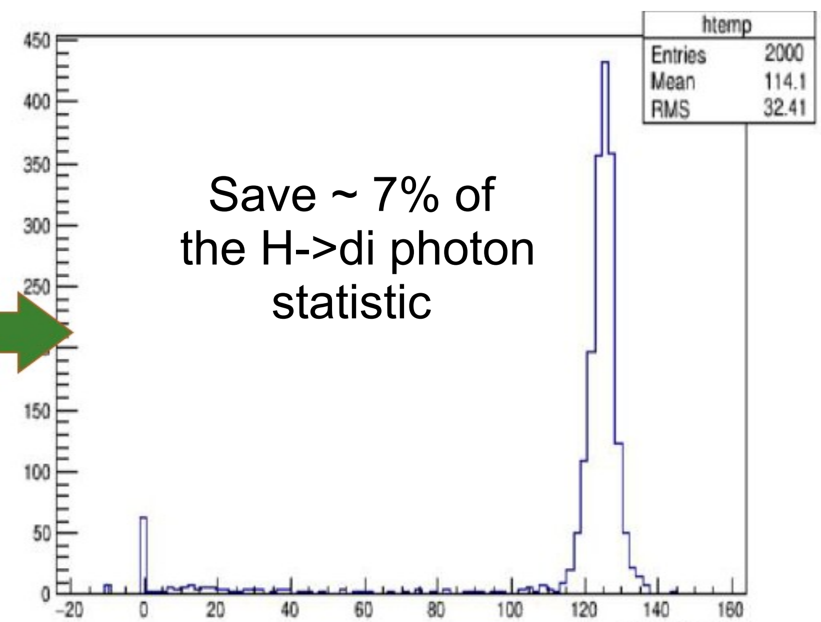
Composed object: converted photon





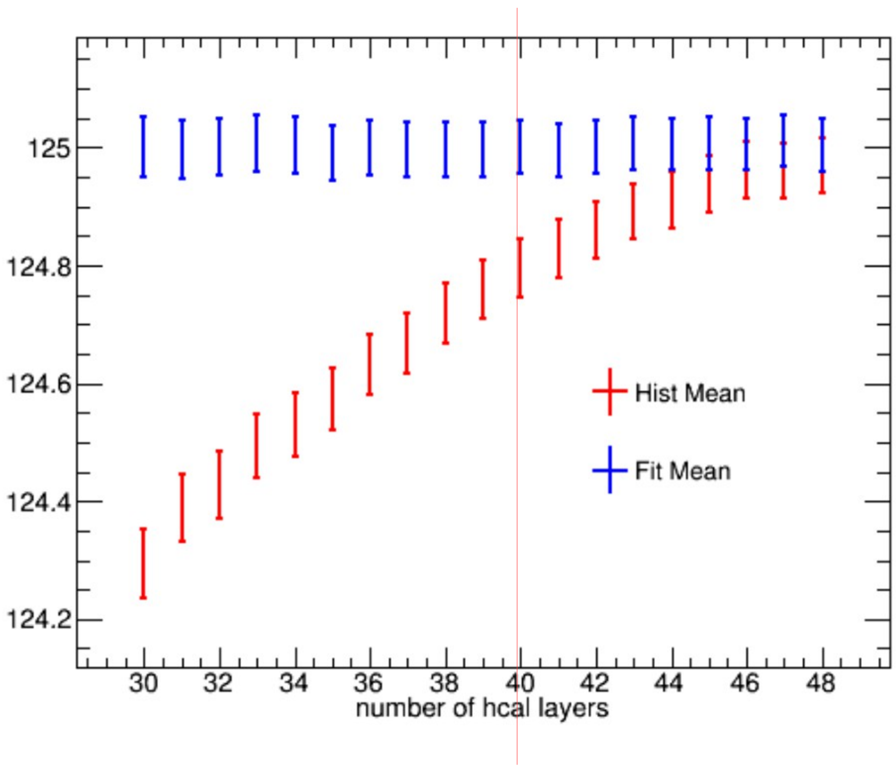


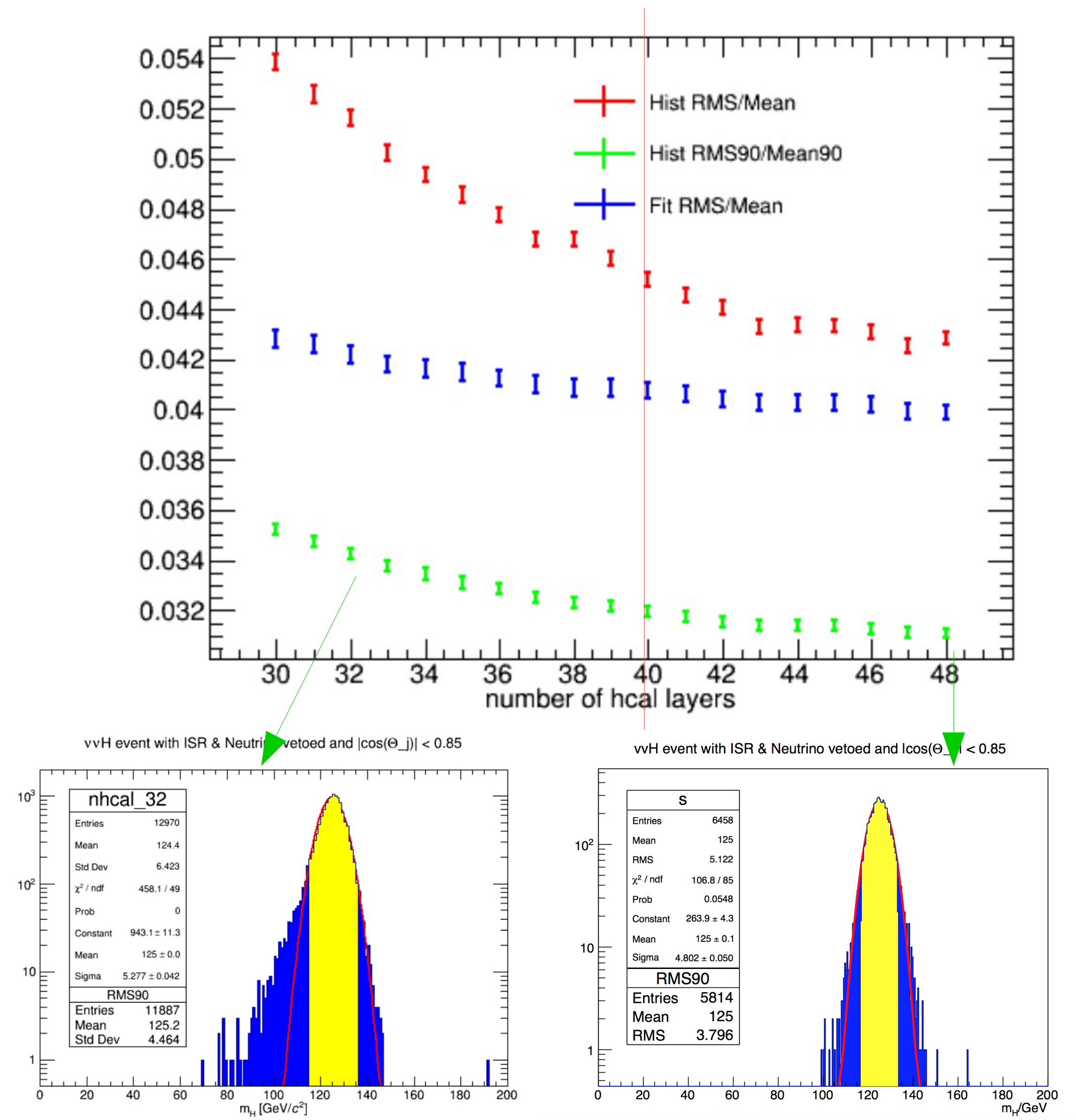
Jianhuan Xiang
University of Chicago



Save ~ 7% of
the H->di photon
statistic

JER Vs #Layer (Preliminary)

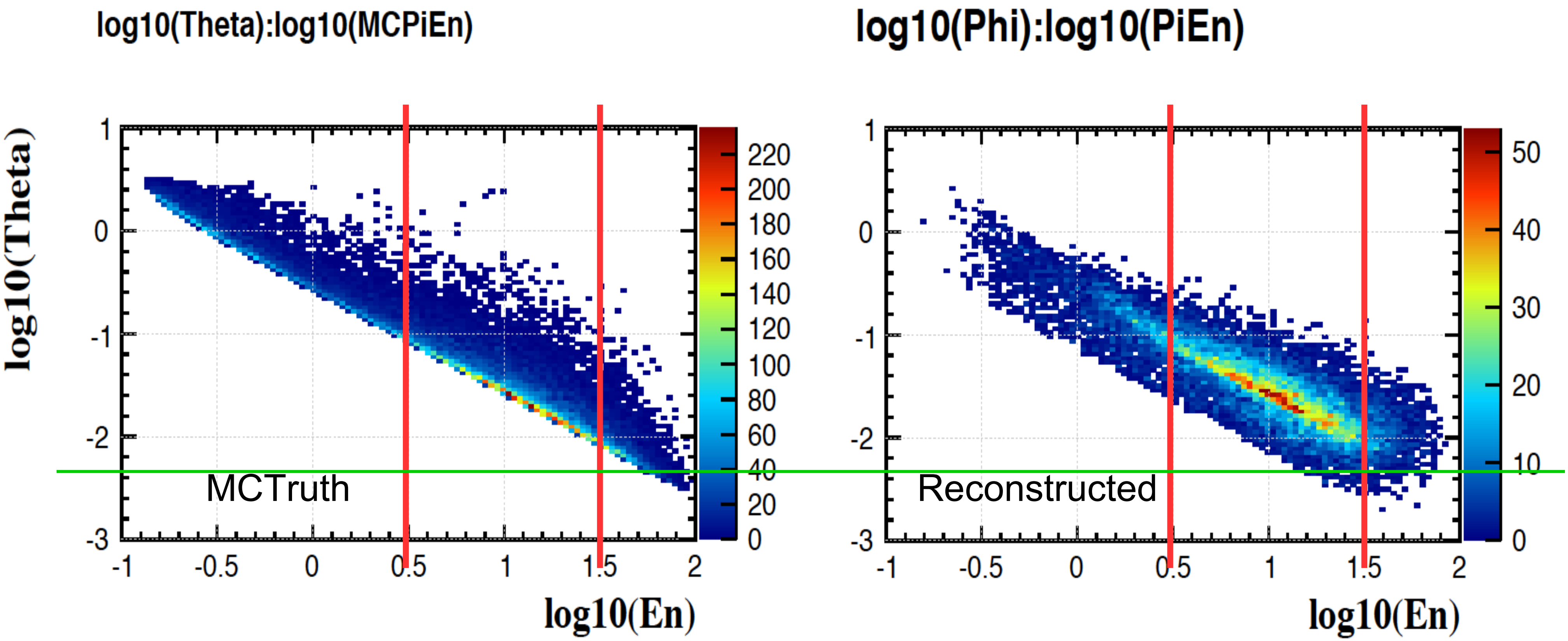




Reducing the #Layers from 48 -> 40
(same layer thickness)
A degrading of 2% (relative) in JER

Performance depends on the version...

Composed object: π_0 (Preliminary)

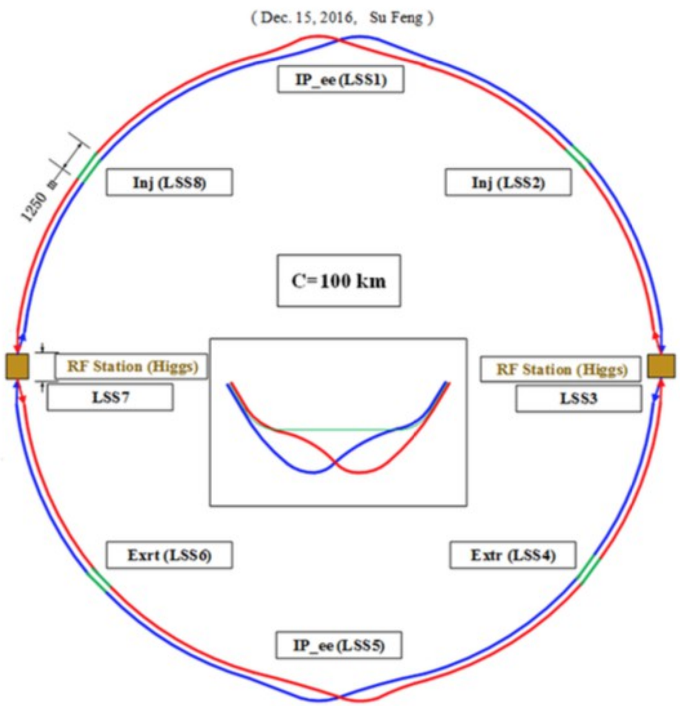


Testing on Higgs to di tau events. Tau inclusive decay
(X axis, Energy of Pi0, Y axis, Angle between two photons decayed from pi0)

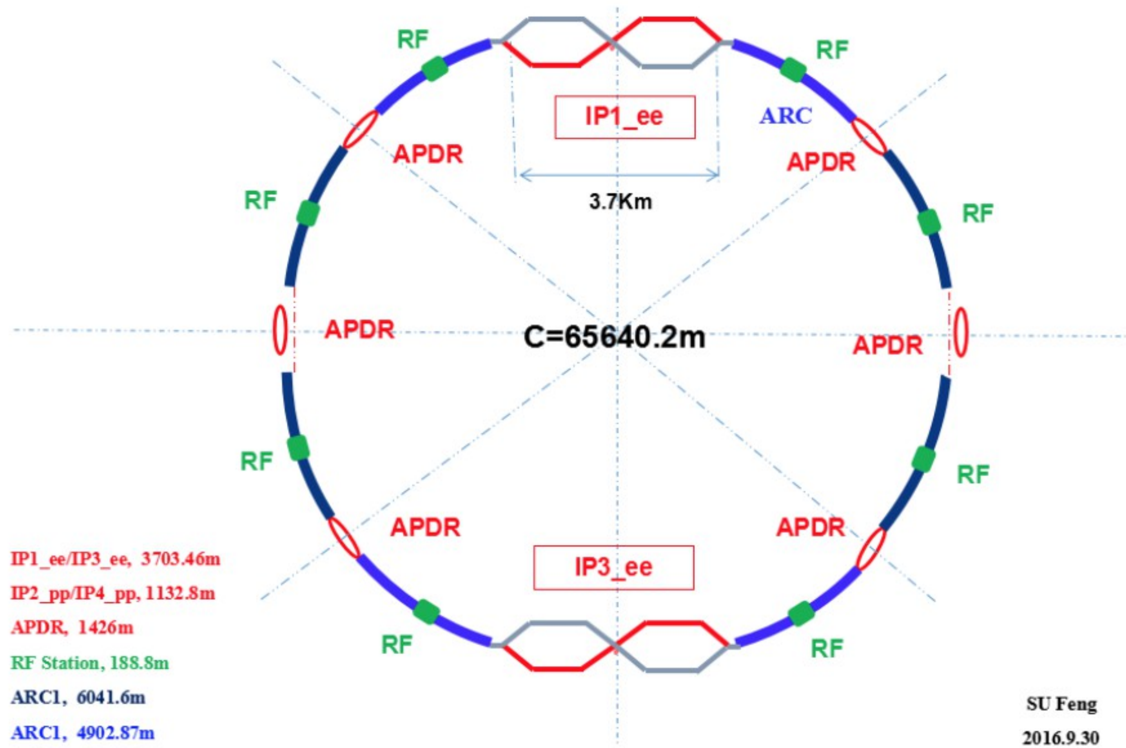
For pi0 with En > 3 GeV && En < 30 GeV, Reconstruction efficiency ~ 65%..
Horizontal line corresponding to 9 mm separation at ECAL.

CEPC two shcemes towards CDR

Jie Gao



CEPC Advanced Partial Double Ring Option II



CEPC Baseline Design

Better performance for Higgs and Z compared with alternative scheme, without bottle neck problems, but with higher cost

CEPC Alternative Design

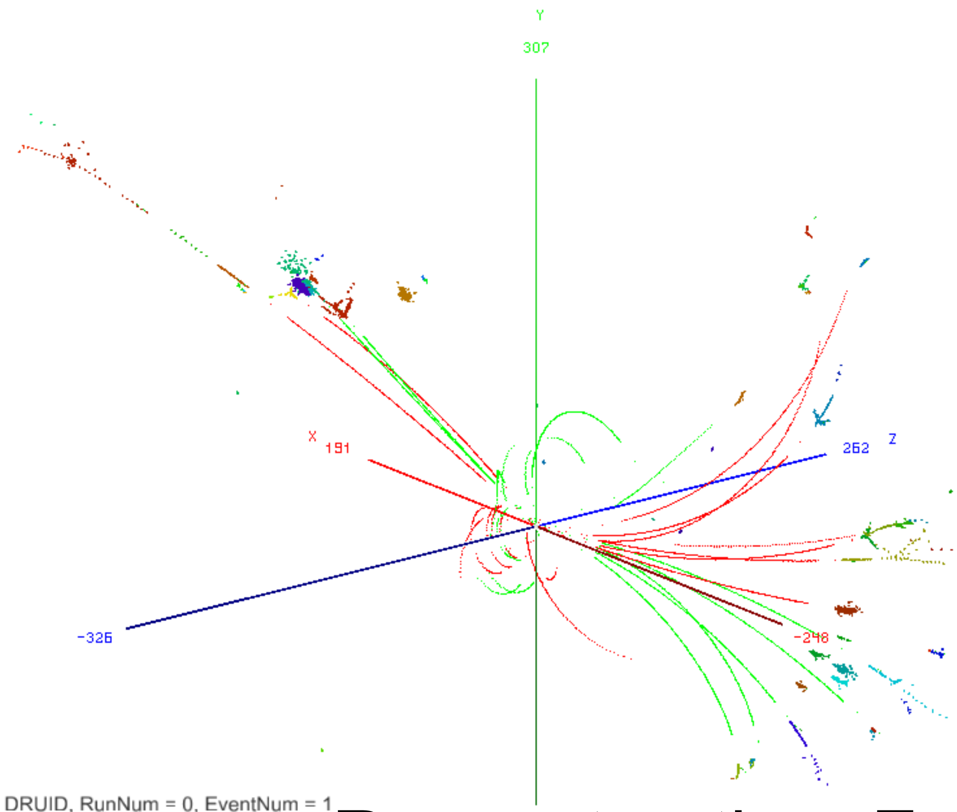
Lower cost and reaching the fundamental requirement for Higgs and Z luminosities, under the condition that sawtooth and beam loading effects be solved

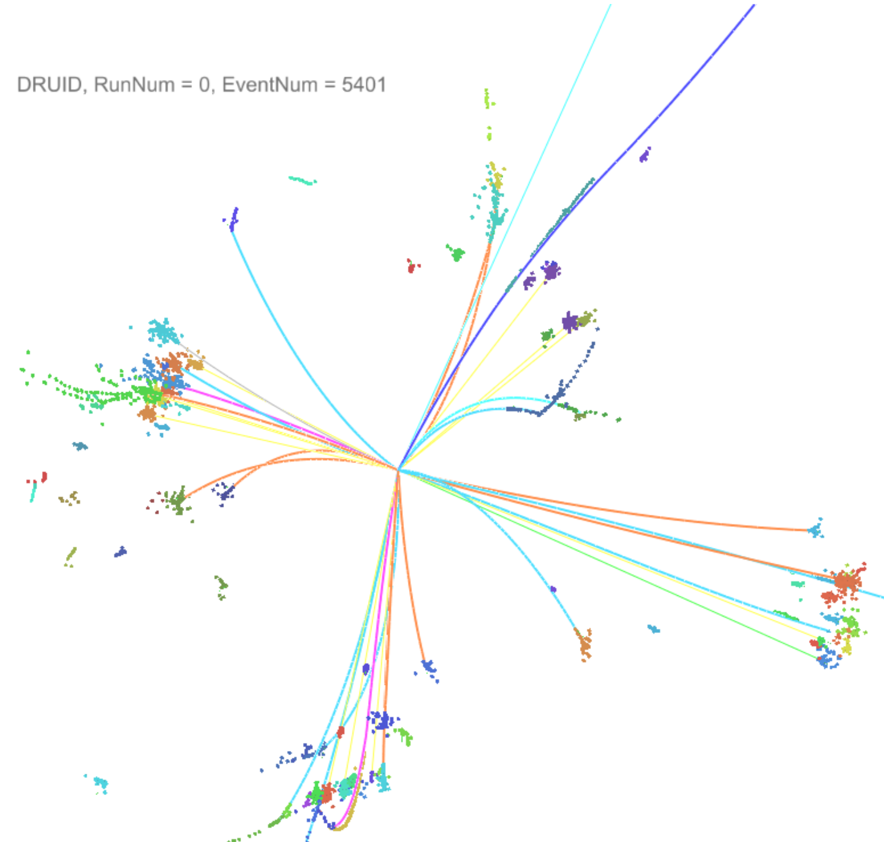
Parameters of CEPC Double ring

Chenghui Yu

	Higgs	*W*	*Z*
Number of IPs	2	2	2
Energy (GeV)	120	80	45.5
SR loss/turn (GeV)	1.67	0.33	0.034
Half crossing angle (mrad)	16.5	16.5	16.5
Piwinski angle	3.19	5.69	4.29
N_e/bunch (10^{11})	0.968	0.365	0.455
Bunch number	**412**	**5534**	**21300**
Beam current (mA)	19.2	97.1	465.8
SR power /beam (MW)	**32**	**32**	**16.1**
Bending radius (km)	11	11	11
Momentum compaction (10^{-5})	1.14	1.14	4.49
β_{IP} x/y (m)	0.171/0.002	0.171 /0.002	0.16/0.002
Emittance x/y (nm)	1.31/0.004	0.57/0.0017	1.48/0.0078
Transverse σ_{IP} (um)	15.0/0.089	9.9/0.059	15.4/0.125
ξ_x/ξ_y/IP	0.013/0.083	0.0055/0.062	0.008/0.054
RF Phase (degree)	128	126.9	165.3
V_{RF} (GV)	2.1	0.41	0.14
f_{RF} (MHz) (harmonic)	650	650 (217800)	650 (217800)
Nature σ_z (mm)	2.72	3.37	3.97
Total σ_z (mm)	2.9	3.4	4.0
HOM power/cavity (kw)	0.41(2cell)	0.36(2cell)	1.99(2cell)
Energy spread (%)	0.098	0.065	0.037
Energy acceptance (%)	1.5		
Energy acceptance by RF (%)	2.1	1.1	1.1
n_γ	0.26	0.15	0.12
Life time due to beamstrahlung (min)	52		
F (hour glass)	0.96	0.98	0.96
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	**2.0**	**5.15**	**11.9**

Sim Higgs @ CEPC

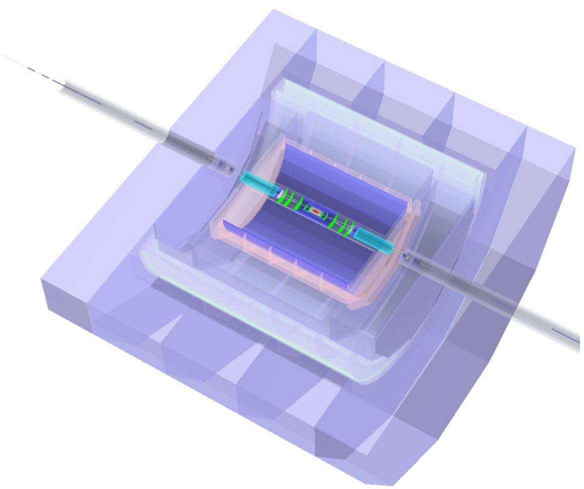


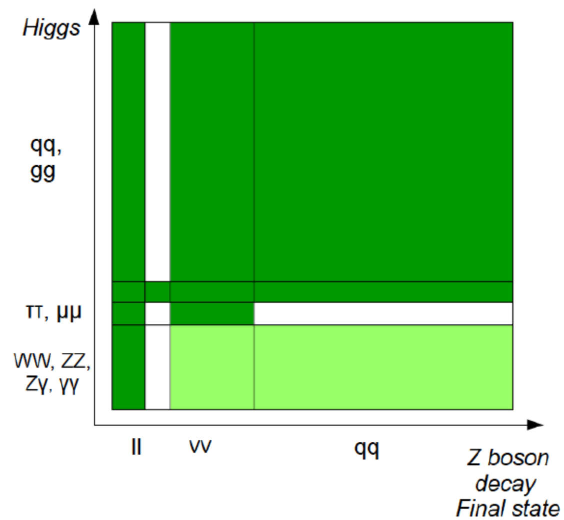


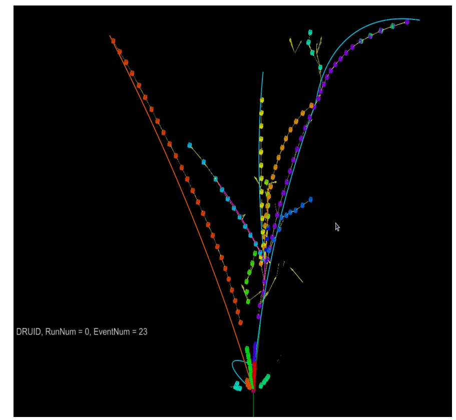
Reconstruction: From Hits to Objects...

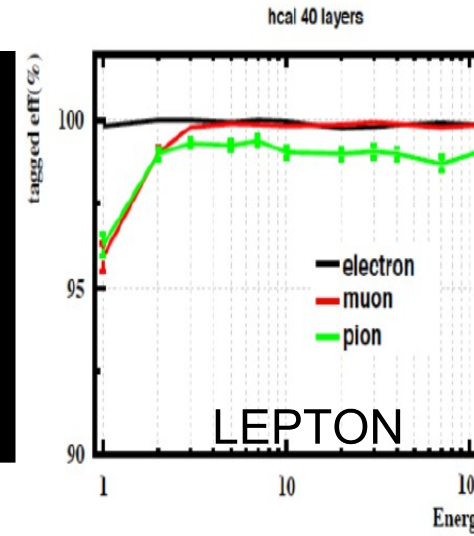
Optimization: Performance at different geometries with adequate Reconstruction

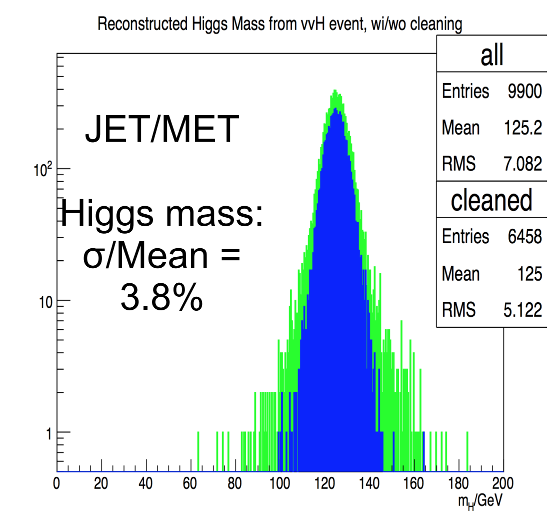
Reconstruction

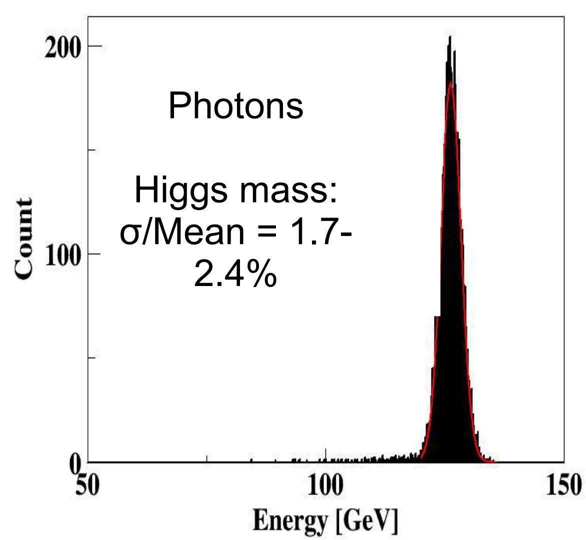




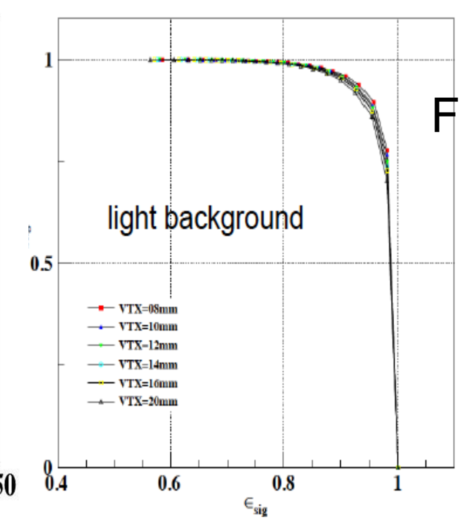


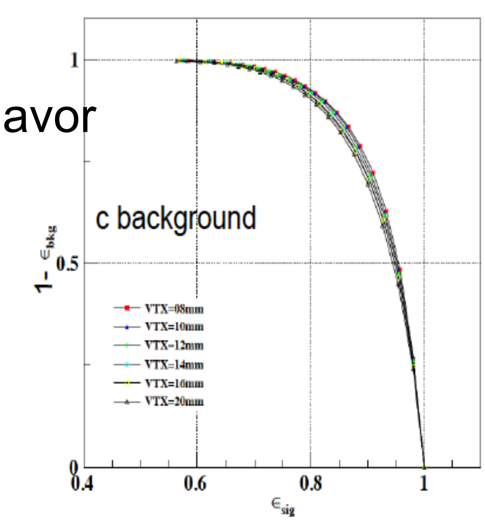




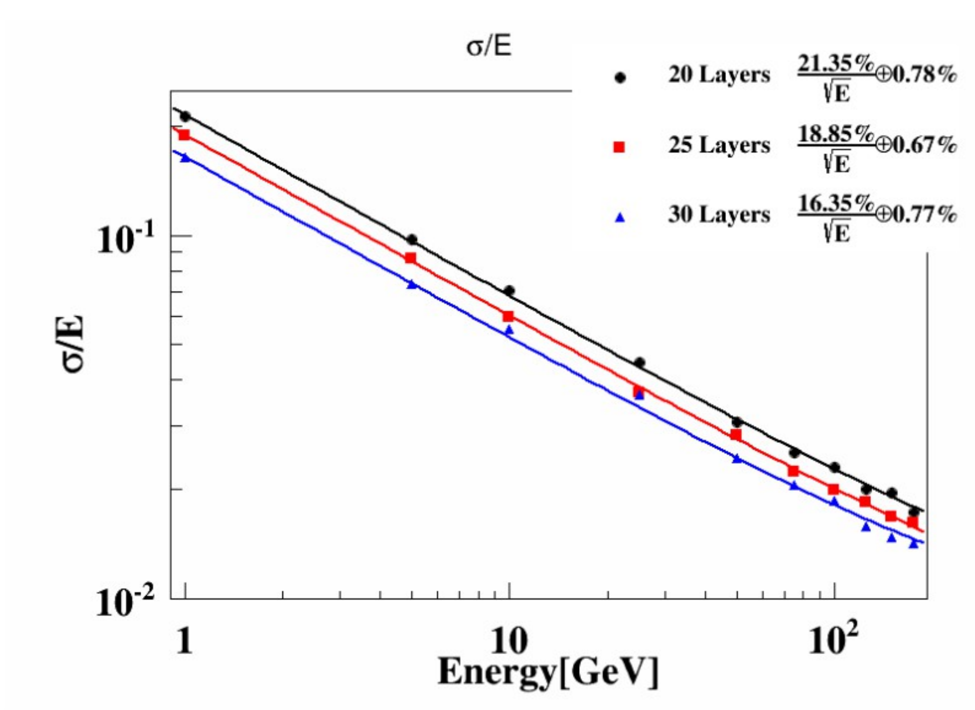


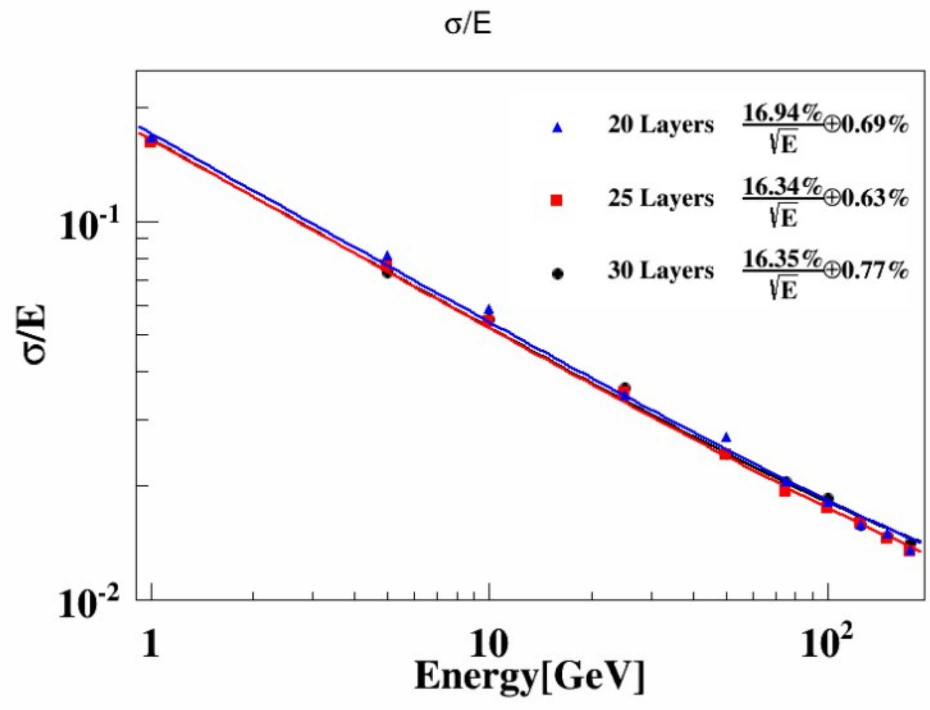
Flavor





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?