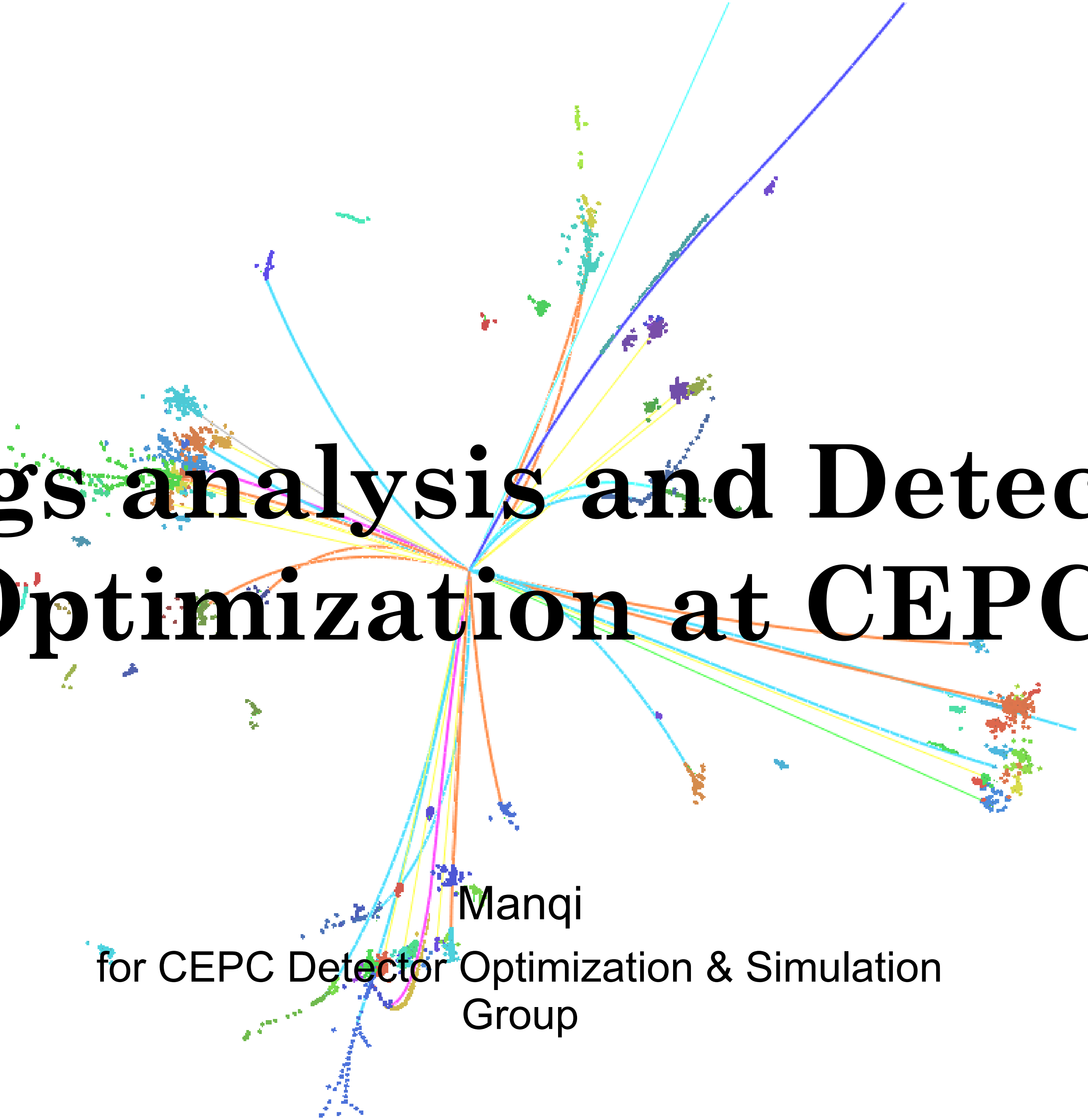
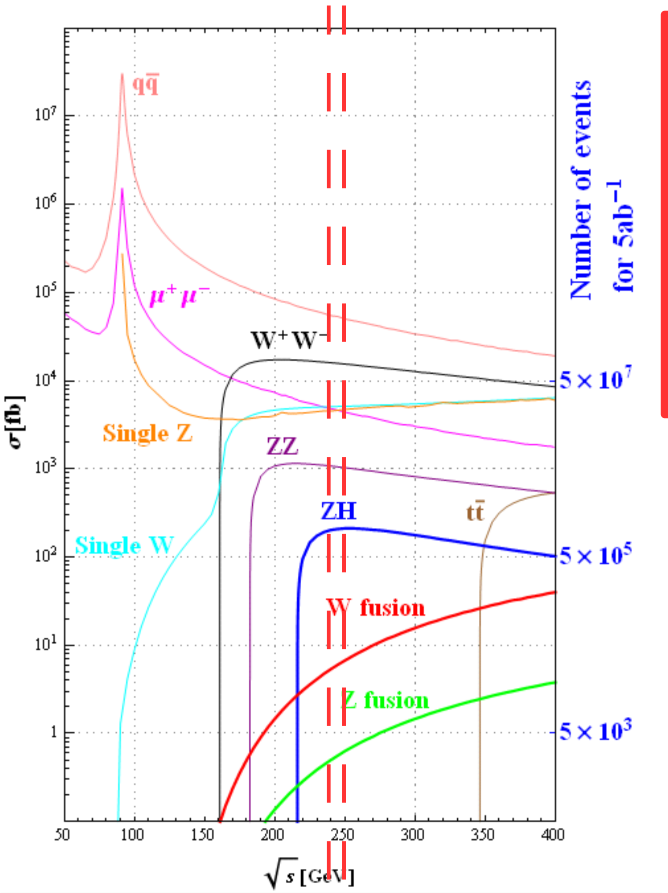
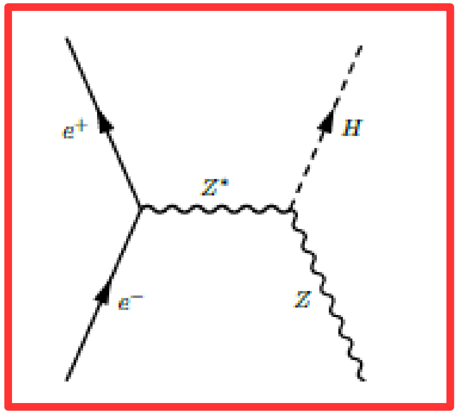


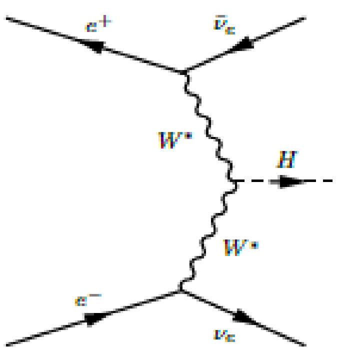
Higgs analysis and Detector Optimization at CEPC

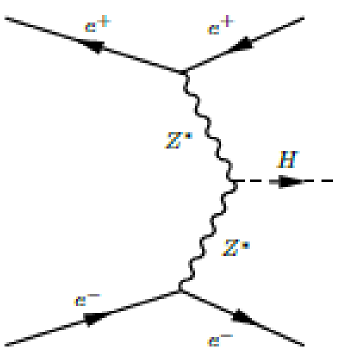
Manqi
for CEPC Detector Optimization & Simulation Group

Higgs @ CEPC







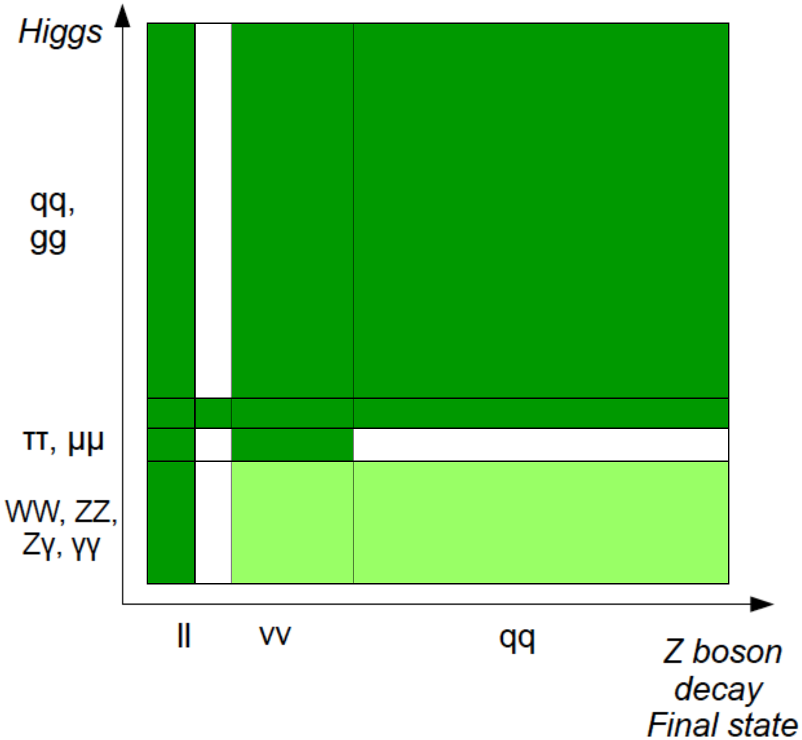


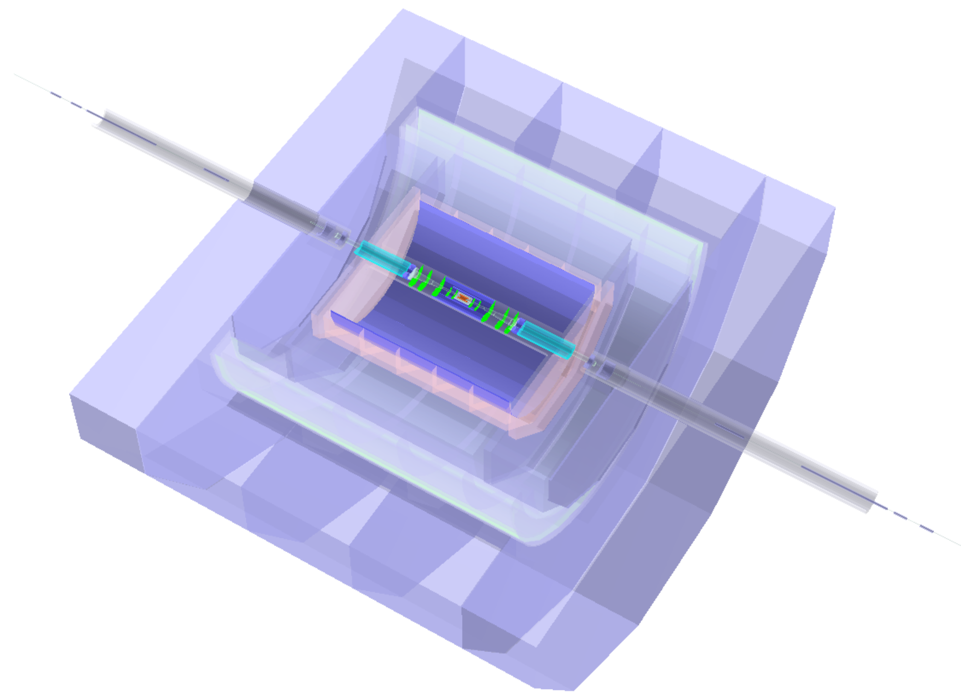
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

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

Derive: Absolute Higgs width, branching ratios, couplings

Higgs analysis & conceptual detector





~o(50) independent analyses, mostly studied Full Simulation level

Reconstruct all the physics objects (lepton, γ, tau, Jet, MET, ...) with high efficiency/precision

To be covered:

- Tau finding in jet environments
- Br(H→WW/ZZ) in multi-jet events

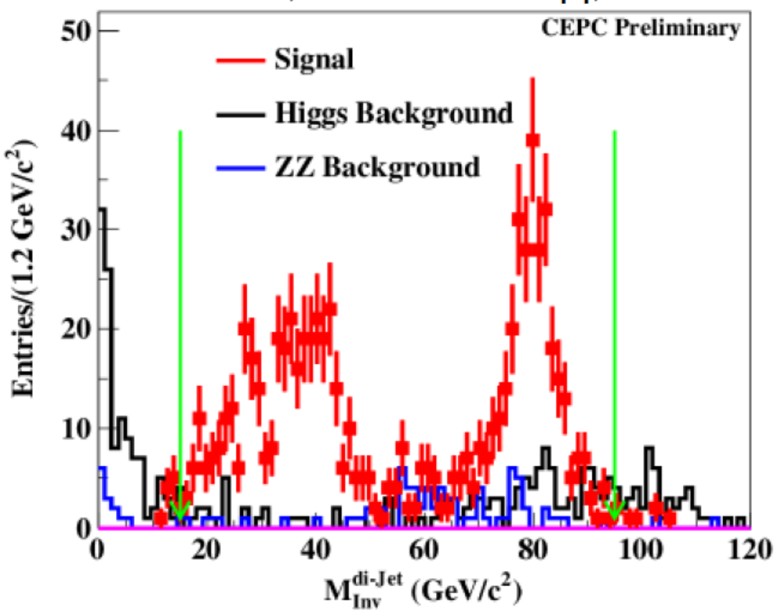
High Precision VTX close to IP: b, c, tau tagging
High Precision Tracking system: δ(1/Pt) ~ $2*10^{-5}$(GeV^{-1})
***PFA** oriented Calorimeter System (~o(10^8) channels):*
Tagging, ID, Jet energy resolution, etc

CEPC_v1, MDI/Yoke changed w.r.t ILD

Br(H→WW)

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

Liao libo, H→WW*→lvqq, Z→ll



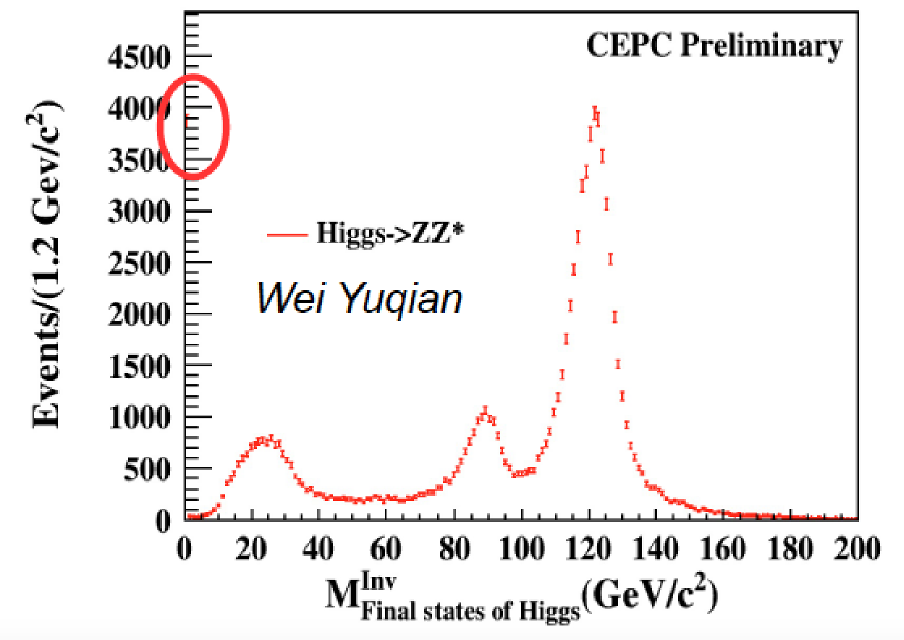
Expected Number of events with different objects

	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

Legend (cell colours):
- 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)
- High efficiency in event reconstruction (finding all physics objects: efficiency 80-90%)

Br(H→ZZ)



Expected Number of events with different objects

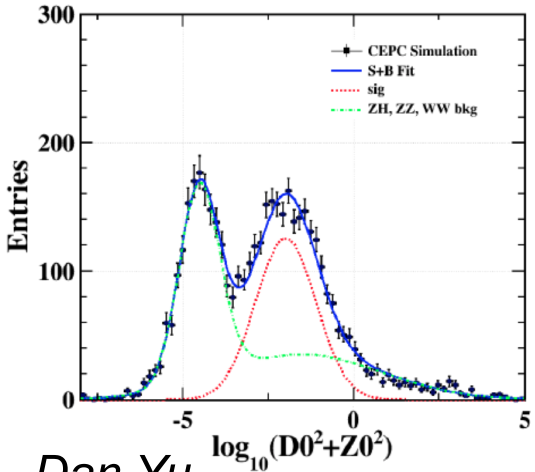
	Z→ll	tautau	vv	qq
H→ZZ*→4q	888	444	3.10k	9.24k
2v + 2q	508	254	1.77k	5.29k
2l + 2q	170	85	596	1.8k
4v	73	36	254	756
2l + 2v	49	24	170	508
4l	8	4	28	86
X + tau	120	60	418	1246

Purple	More than 2 jets, Await for sophisticated Jet Clustering
Cyan	Await for tau finder
Pink	limited accuracy ~ > 50%
Yellow	Explored by H->invisible analysis -> Accuracy ~ 40%
Green	Promising channels
White	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)
- High efficiency in event reconstruction

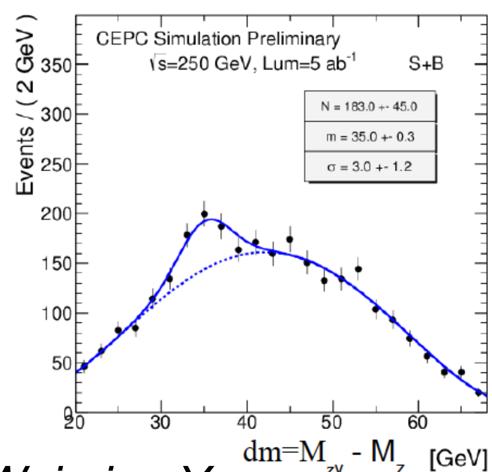
Status

Br(H→ττ) via Z to ll



Dan Yu

- Initial study of zH → zzγ → qqννγ is promising to be 4 σ with 5 ab^{-1}.



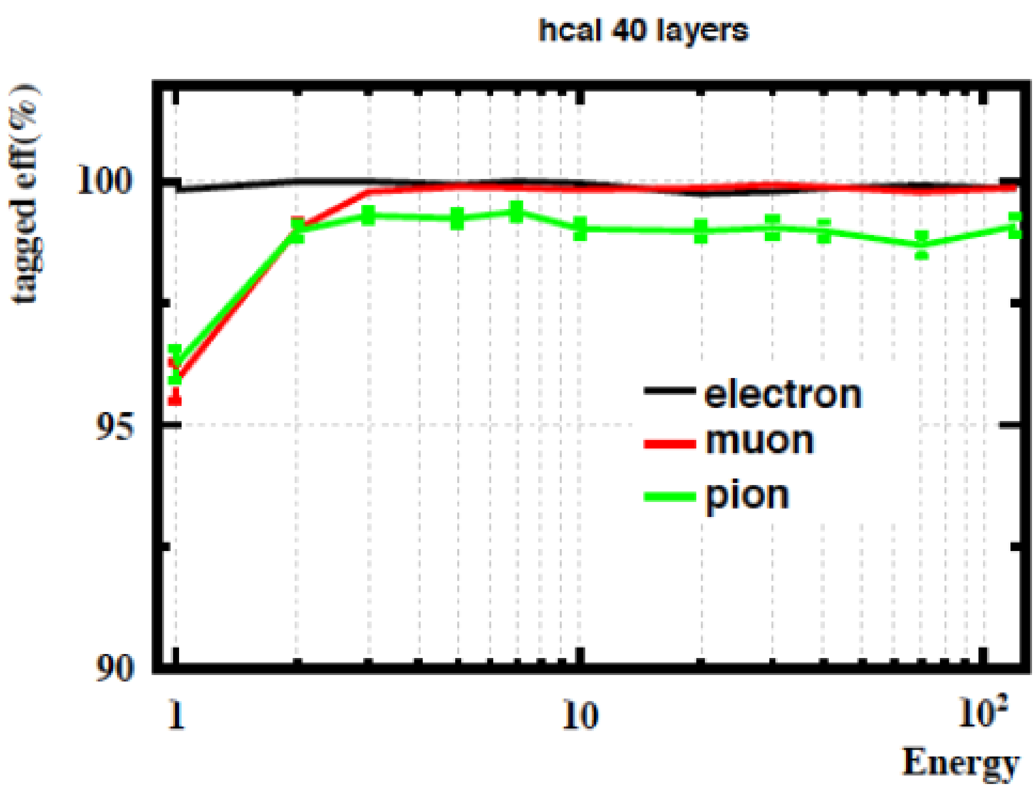
Weiming Yao

	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(vvH)*Br(H→bb)	2.8%	2.8%
Higgs Mass/MeV	5.9	5.0
σ(ZH)*Br(H→inv)	95%. CL = 1.4e-3	1.4e-3
Br(H→ee/emu)	-	1.7e-4/1.2e-4
Br(H→bbχχ)	$<10^{-3}$	3.0e-4

Optimization: Calorimeter

- Granularity: Wi/wo active cooling
  - Geometry in ILD (ild_o2_v05):
    - *ECAL, 5 mm Cell Size & 30 layers, 5 kw with power pulsing*
    - *HCAL, 10 mm Cell Size & 48 layers.*
  - @ CEPC:
    - *Wi Active cooling: + 2mm thick cooper per active layer, in progressing*
    - **Wo Active cooling: reduce the granularity by ~ 1 order of magnitude (in considering Electronics/Sensor progress...)**
  - Performance:
    - Lepton ID
    - Physics benchmarks:
      - *Z→di lepton, Higgs to inc;*
      - *Z→νν; H→WW→lνqq;*
      - *Z→νν; H→ZZ→llqq;*
- ECAL Saturation studies on H→γγ measurements

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



Scanned Settings:

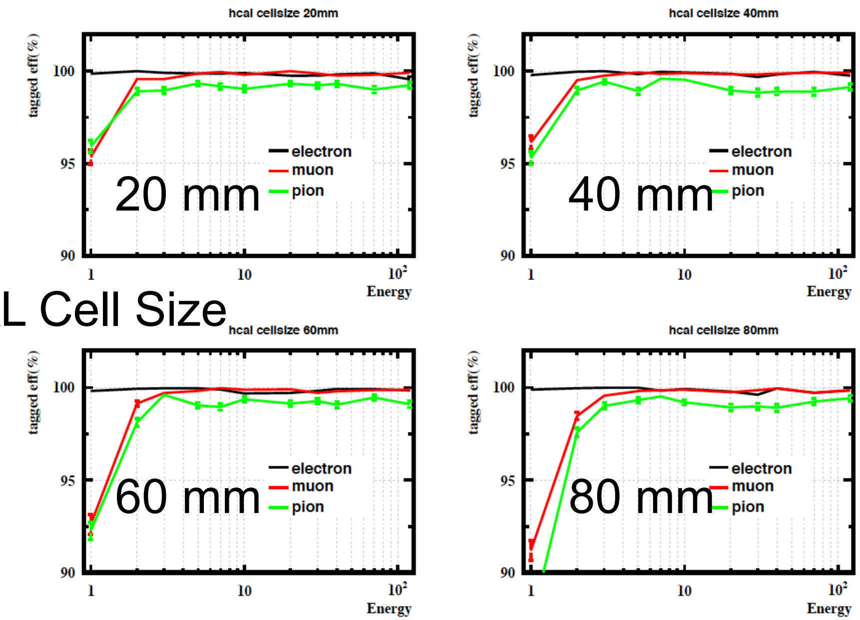
- ECAL Cell Size: 5 - 40 mm
- HCAL Cell Size: 10 - 80 mm
- ECAL N Layer: 30 - 20
- HCAL N Layer: 48 - 20

BDT method using 4 classes of 24 input discrimination variables.

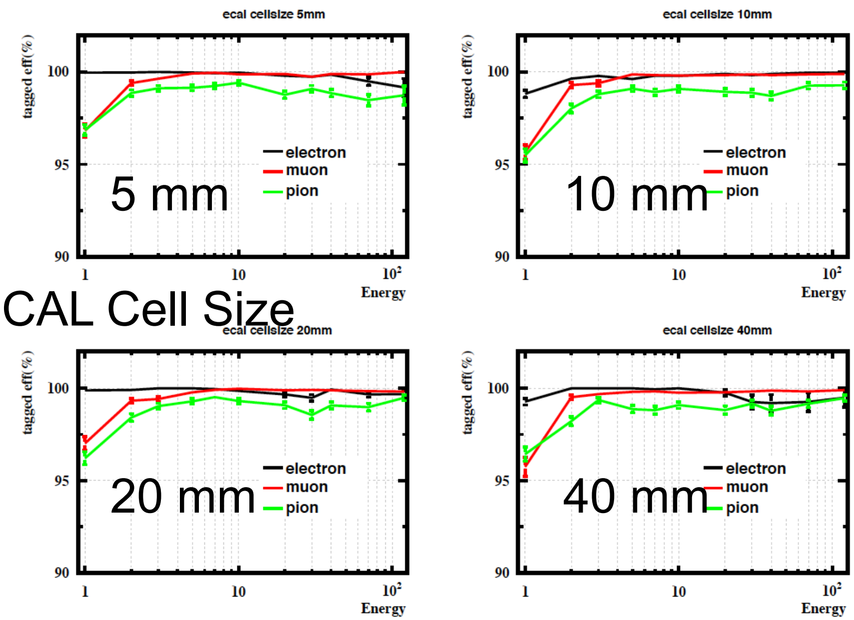
At Single Particle level, for E > 2 GeV charged reconstructed particle:
lepton efficiency > 99.5% && Pion mis id rate < 2%

Vary the granularity

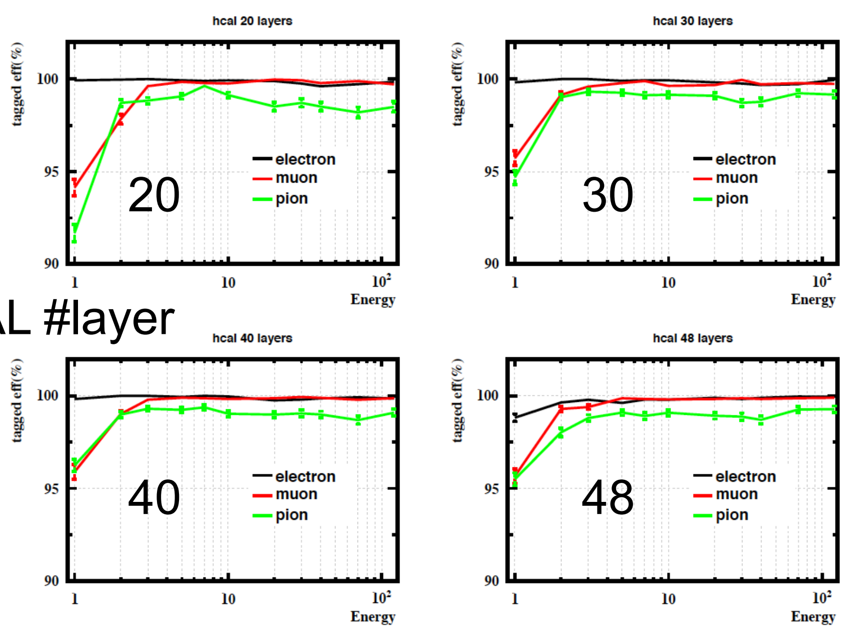
HCAL Cell Size



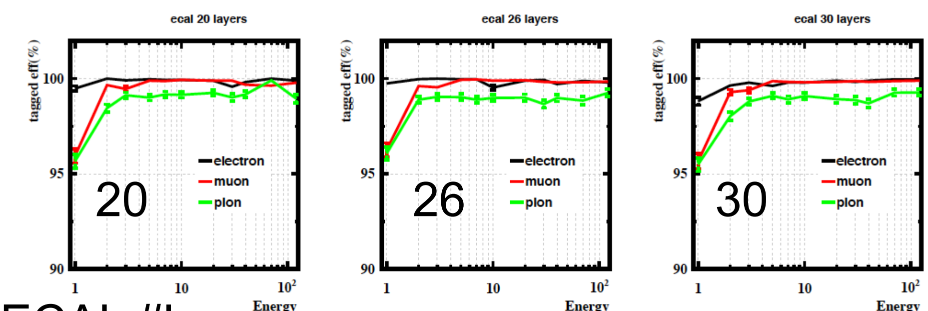
ECAL Cell Size



HCAL #layer

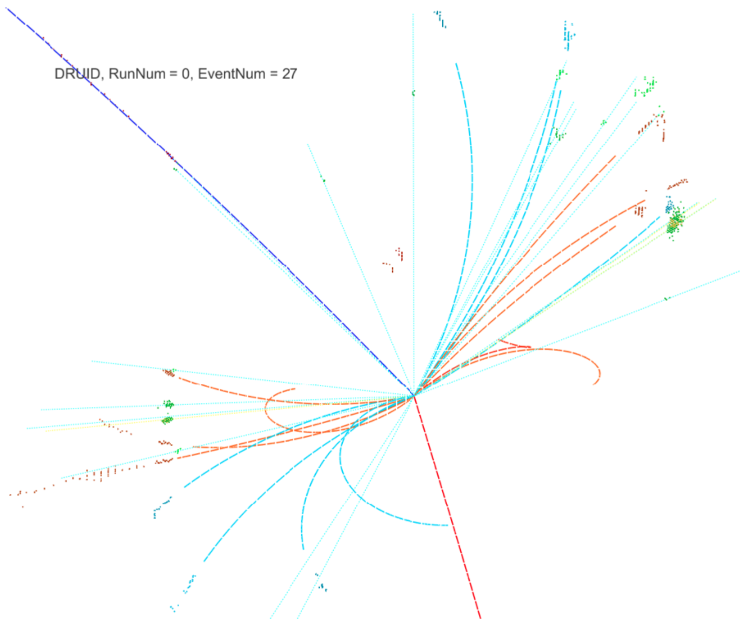


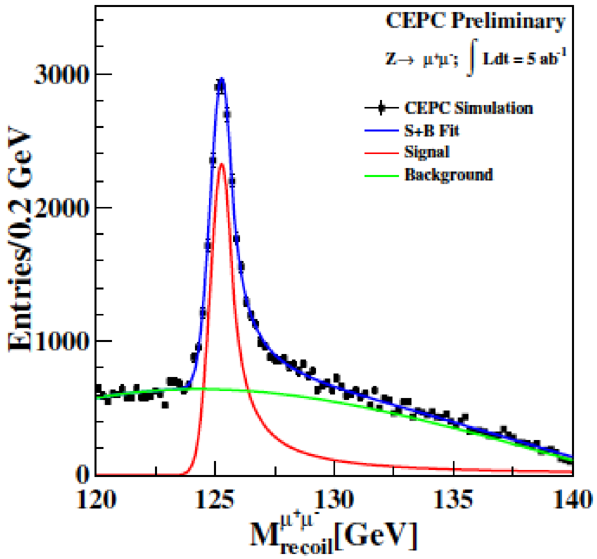
ECAL #layer

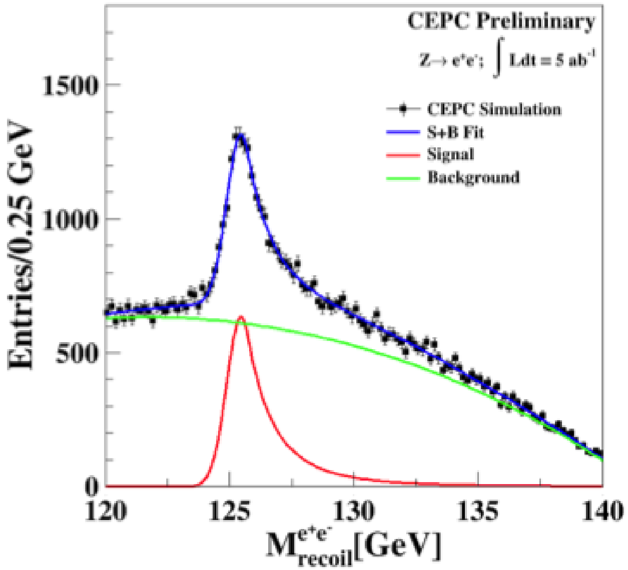


No Significant effect for E > 2 GeV charged Particles

Lepton: Higgs recoil via ZH, Z→ll







		CEPC_v1, ILD	Test Geo 1	**TG 2**	**TG 3**
ECAL	Cell Size/mm	5	10	20	20
	# Layers	30	30	30	20
HCAL	Cell Size/mm	10	10	20	20
	# Layers	48	48	48	20
Ratio of Channels (X/ILD)	ECAL	1	1/4	1/16	1/24
	HCAL	1	1	1/4	1/10
Event Recon. Efficiency	$\mu\mu$H	**95.7%***	**98.0%**	**96.5%**	**95.2%**
	eeH	**91.1%***	**89.6%**	**89.1%**	**74.5%(???)**

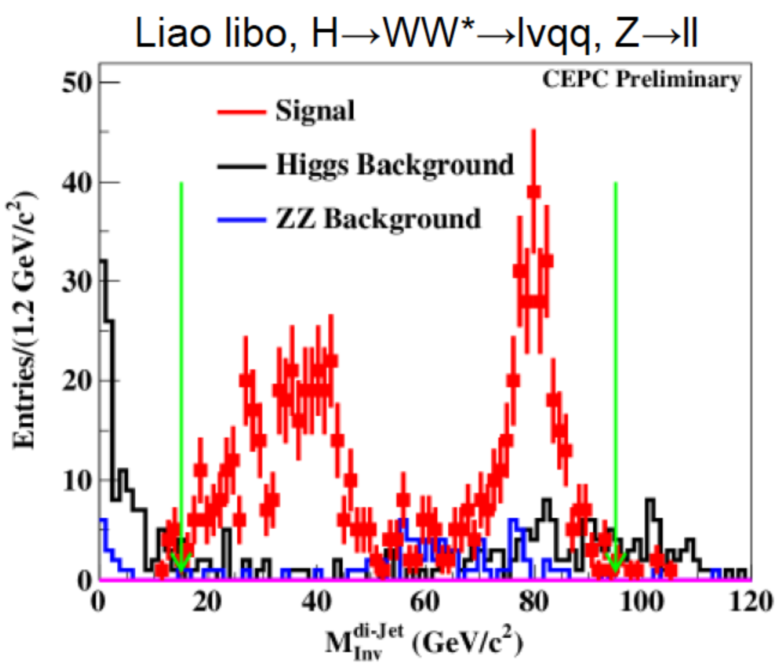
TG2/3: active cooling free...

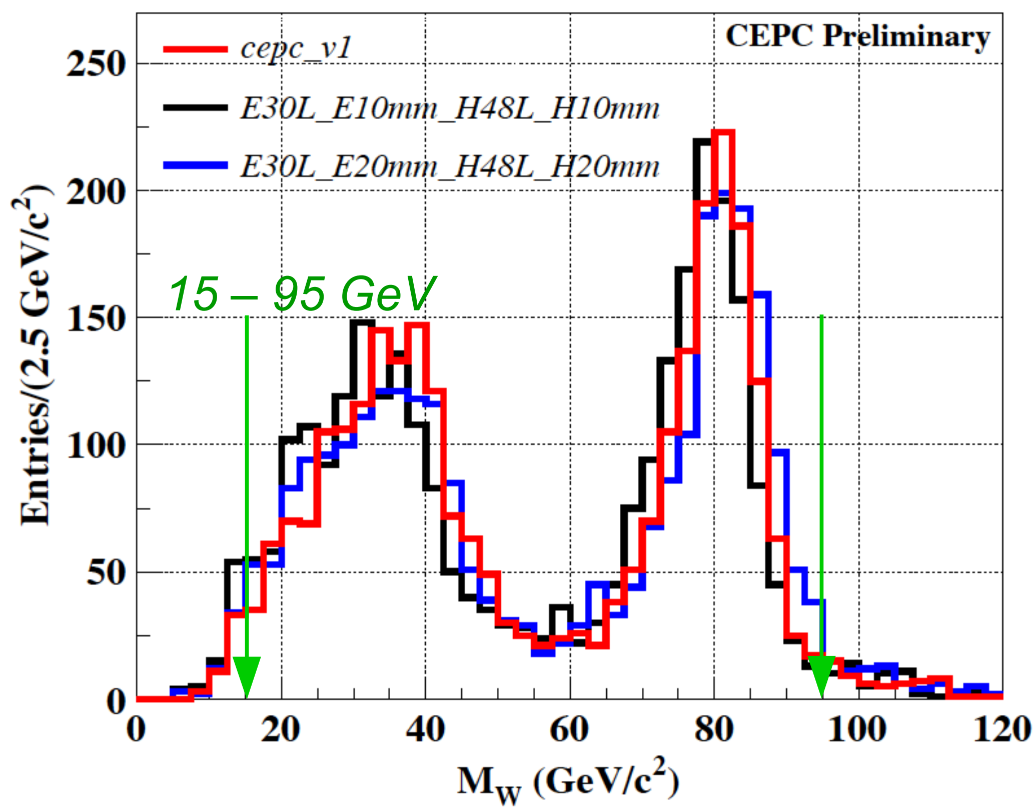
Lepton id efficiency slightly reduced, presumably due to separation power degrading (shower overlap)

Electron id stay to be tuned

CEPC_v1 reconstructions uses old lepton id; Test Geometry models uses LICH
Sample statistic 35k (corresponding to 5 ab^{-1} integrated luminosity)

Lepton + Jets: Br(H→WW)





Br(H→WW) via vvH, H→WW*→lvqq

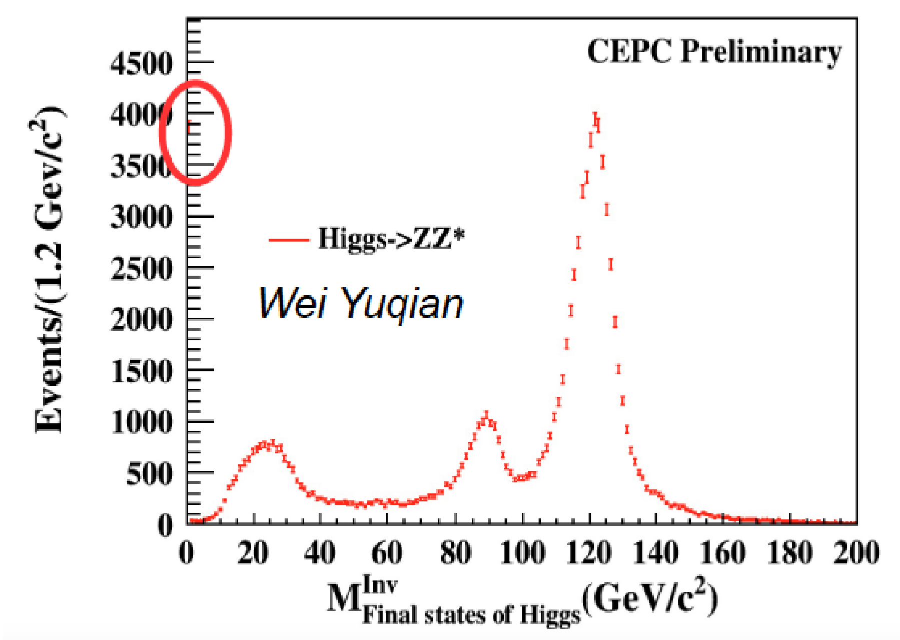
No lose in the object level efficiency;
JER slightly degraded, ~ 5/10% at 10/20 mm
(*ill. behaviors: stay to be tuned*)

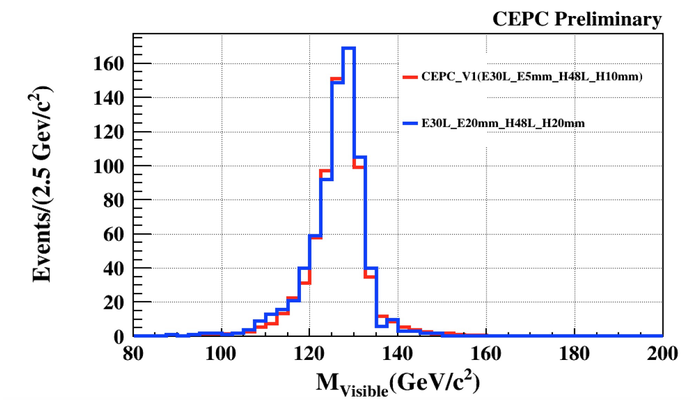
Over all: event reco. efficiency varies ~1%

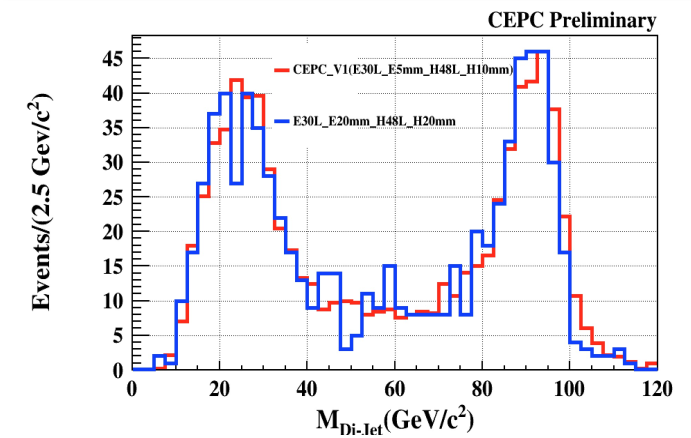
	Simu.	Recon.	Efficiency
CEPC_v1	2885	2783	96.5%
TG1	2878	2814	97.8%
TG2	2878	2807	97.5%

TG1: E30L_H48L_10mm, TG2: E30L_H48L_20mm

Lepton + Jets: Br(H→ZZ)



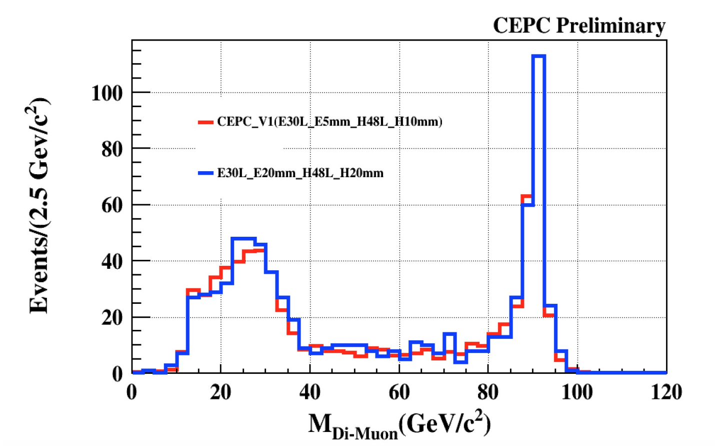




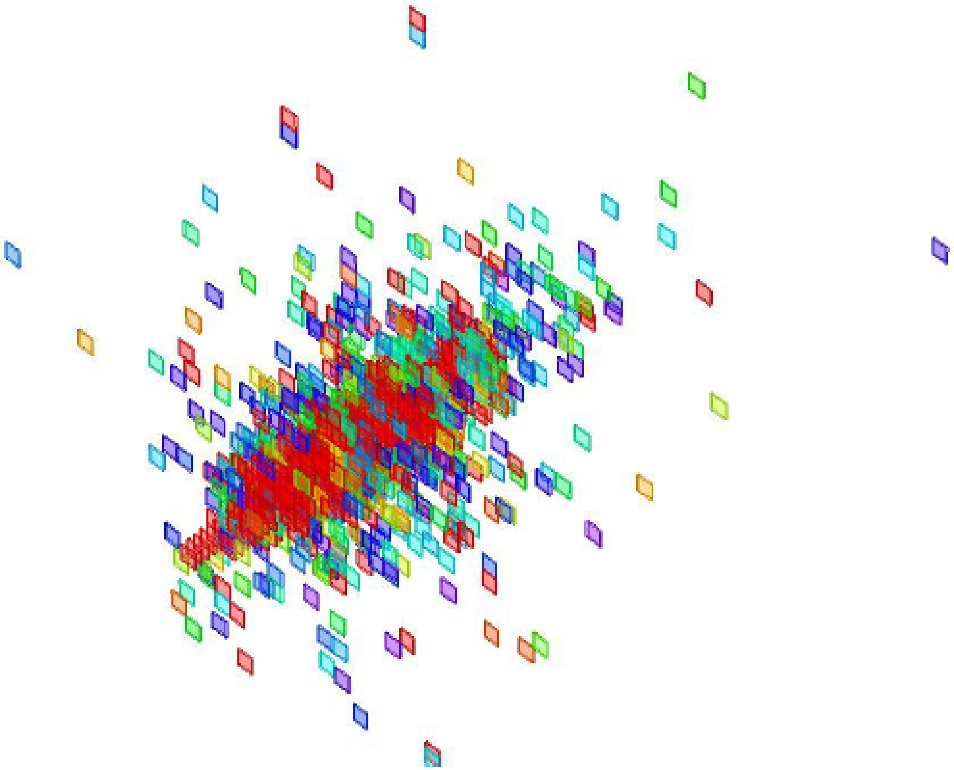
Br(H→ZZ) via vvH, H→ZZ*→llqq

Over all event reco. efficiency reduced ~2%

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

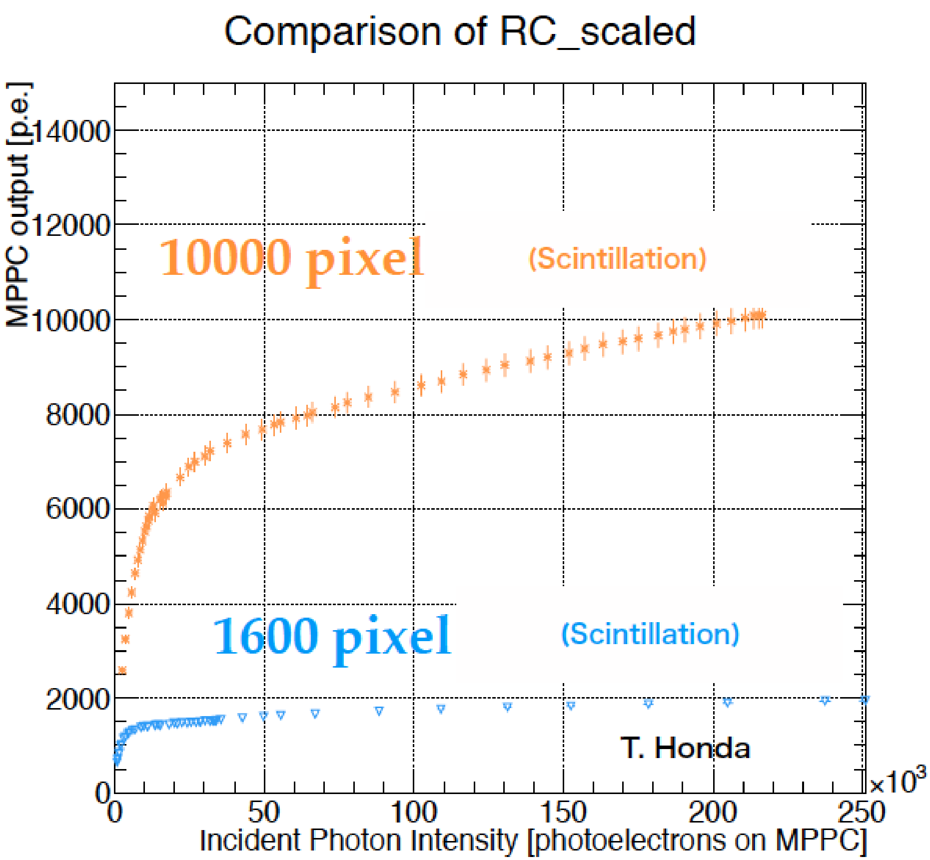


ECAL Saturation/Linear Range Study



50 GeV Photon Cluster
at ECAL with 10 mm Cell Size

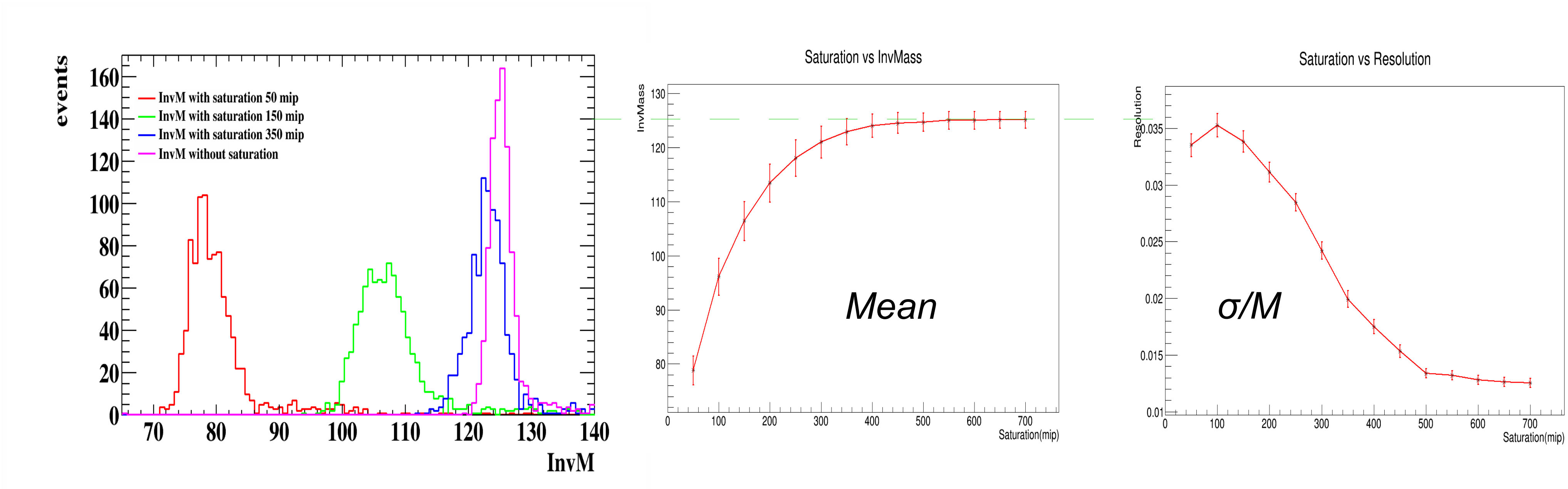
~o(1k) hits, hottest hit with E ~ 1k MIP.



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)

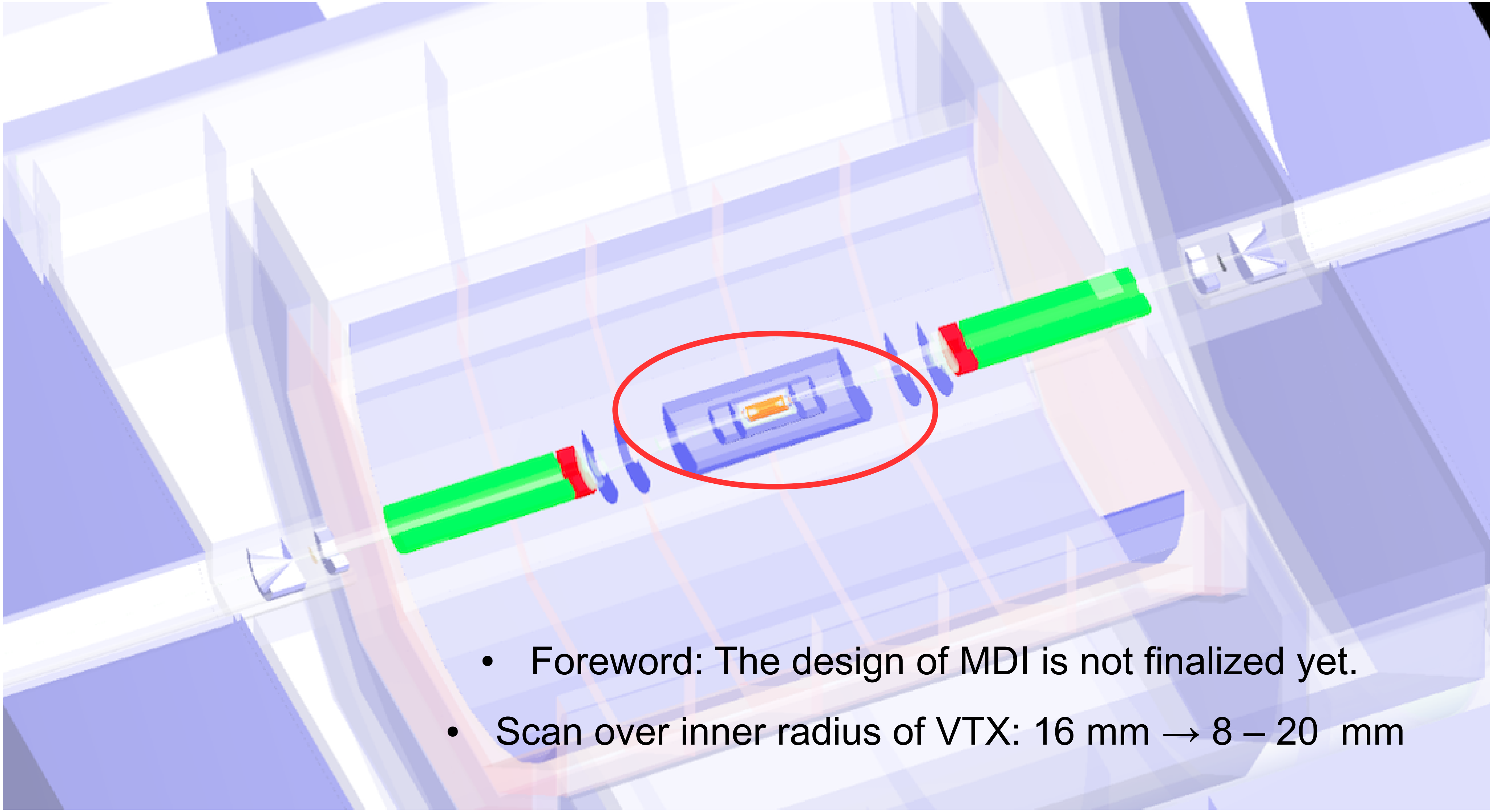
Empirical formula on needed ranger of a single photon:

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

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

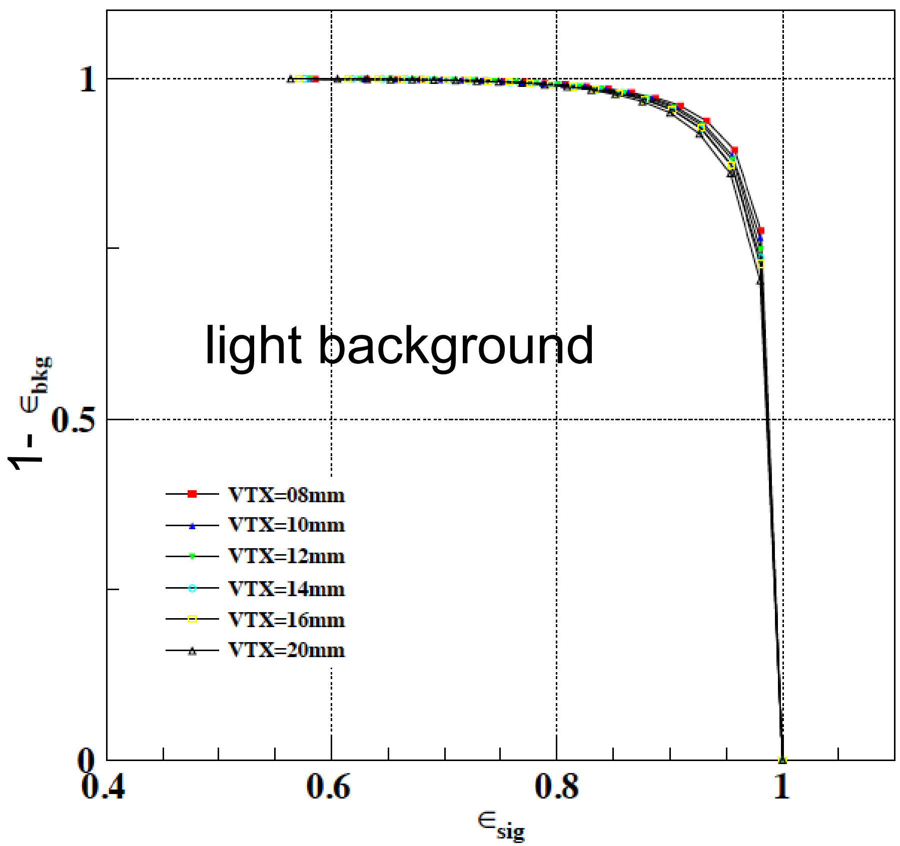
Shuzheng Wang

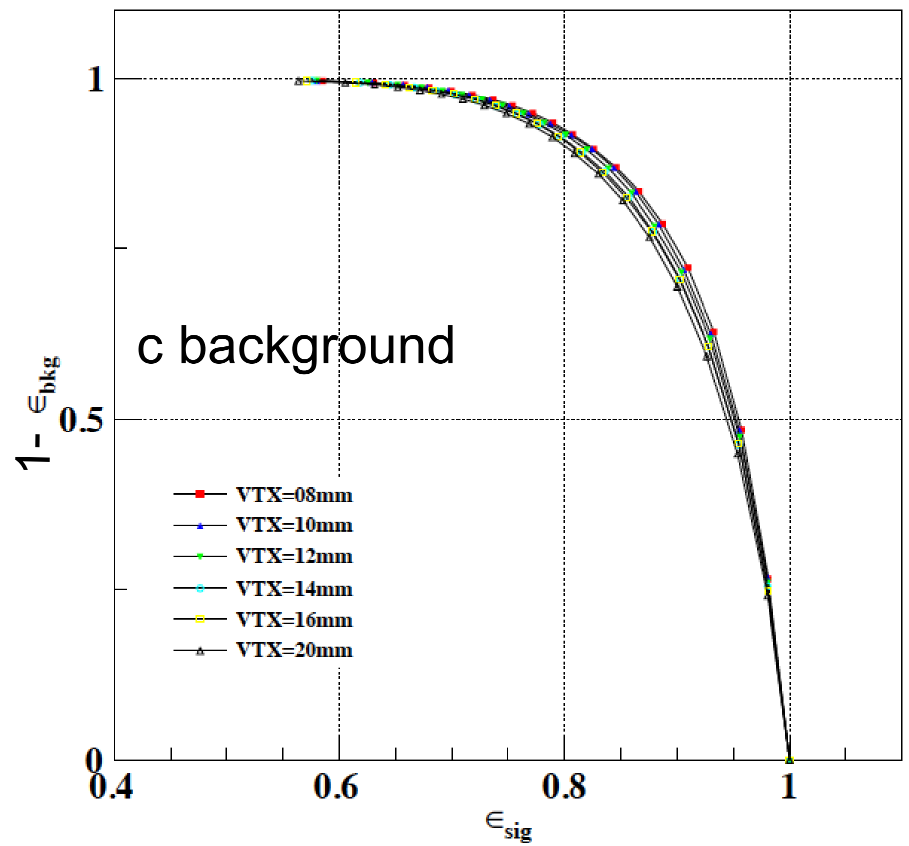
Vary the VTX inner Radius



- Foreword: The design of MDI is not finalized yet.
- Scan over inner radius of VTX: 16 mm → 8 – 20 mm

B-tagging @ different radius

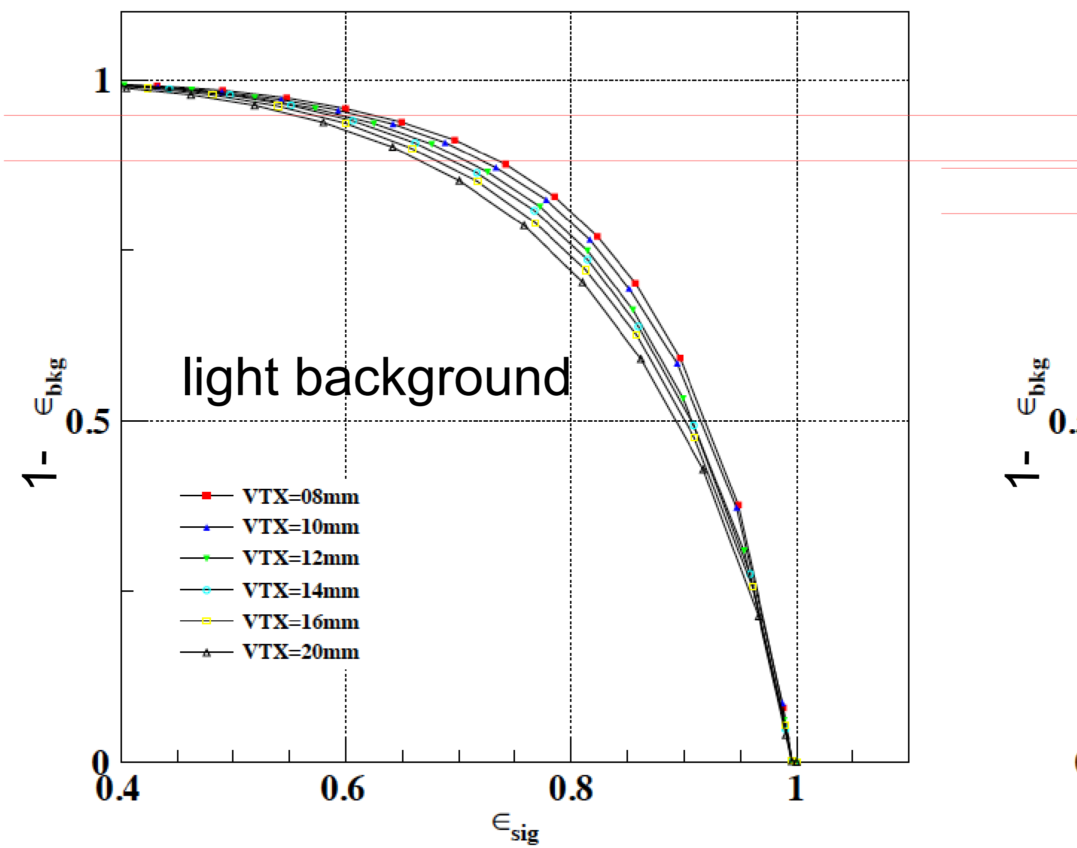


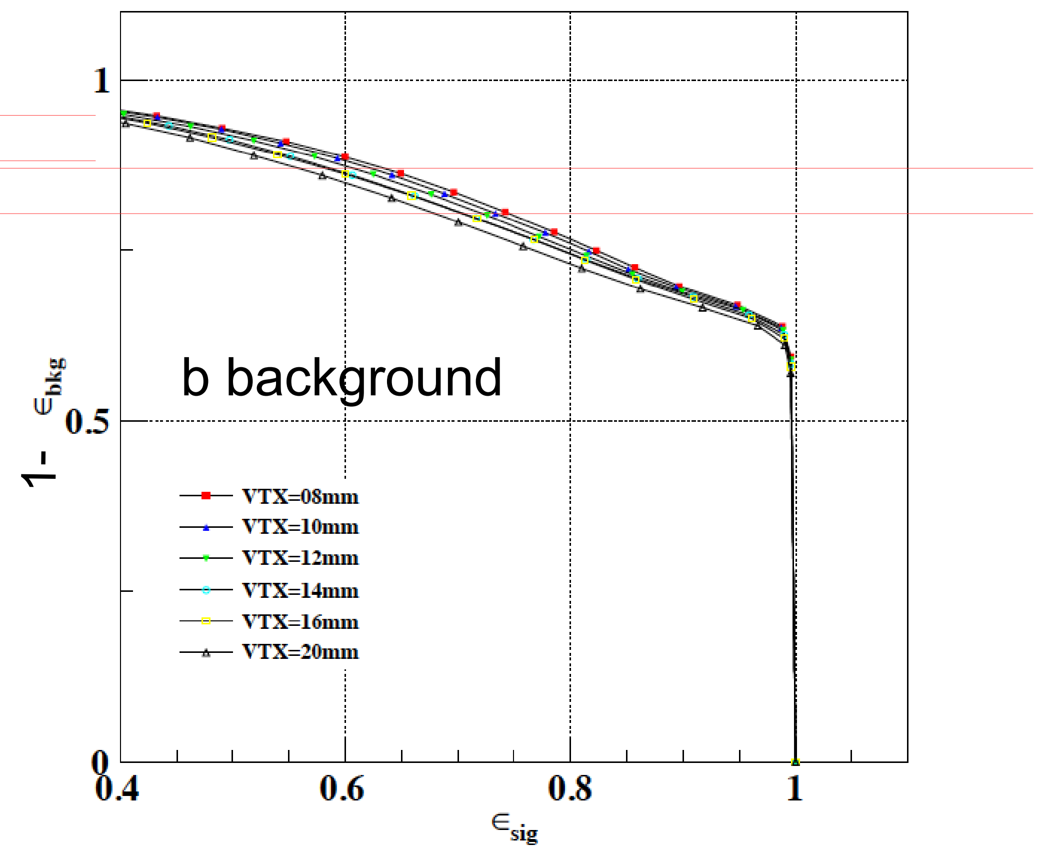


Gang Li

- *With 8 – 20 mm VTX Inner radius, very good b-tagging*
  - *At efficiency ~ 80%: almost reject all the light background & only 8-10% c-jets misidentified as b-jets (Purity ~93-96% at Z to qq events).*

C-tagging @ different radius



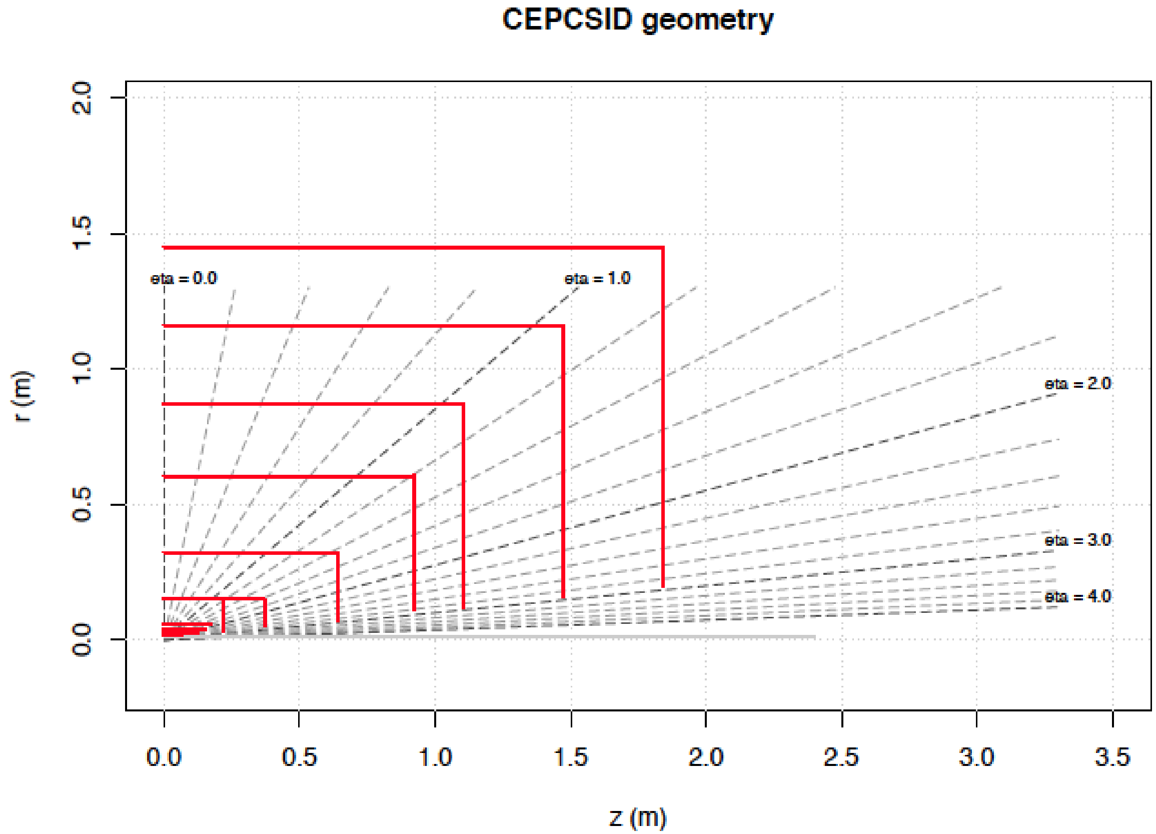


- At the same purity: C-tagging efficiency could be improved by ~ 10% by reducing the inner radius from 20 mm to 8 mm...

Full Silicon Tracker Concept for CEPC*

*http://cepc.ihep.ac.cn/ cepc/cepc_twiki/index.php/Pure_Silicon_Detector

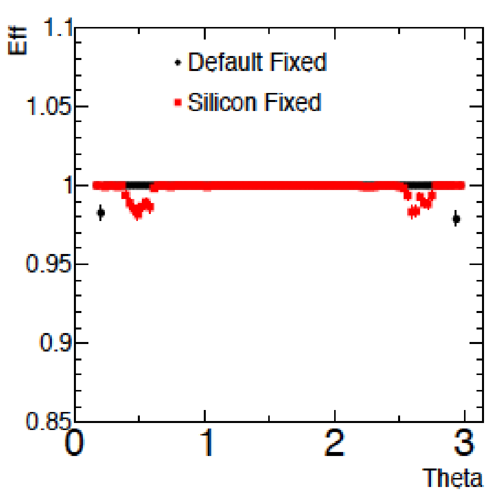
- CEPC full silicon has been implemented in Mokka.
- Based on CEPC V1 silicon tracker, we replace TPC with additional SIT layers and FTD endcaps.
- The advantage is to recycle CEPC silicon tracking.



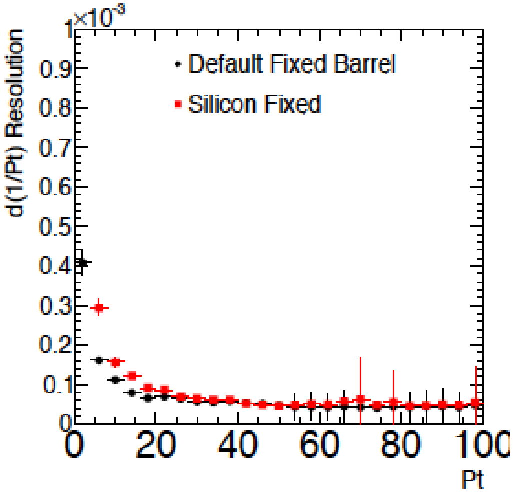
Prof. Weiming Yao

Full Detector Simulation and Reconstruction

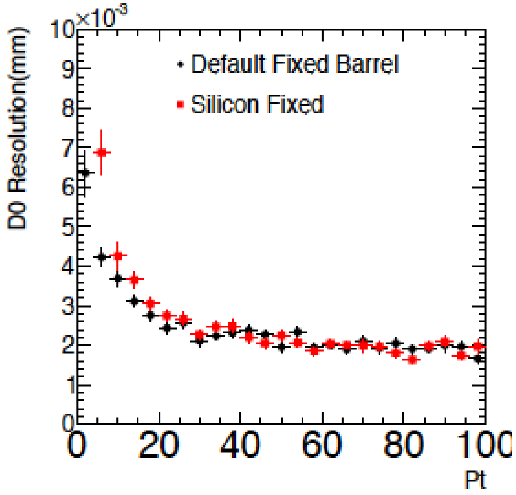
- Generated single muon with CEPC full silicon
- Reconstructed using Marlin Silicon only.
- The performance is comparable to CEPC V1.



(a) Eff vs theta

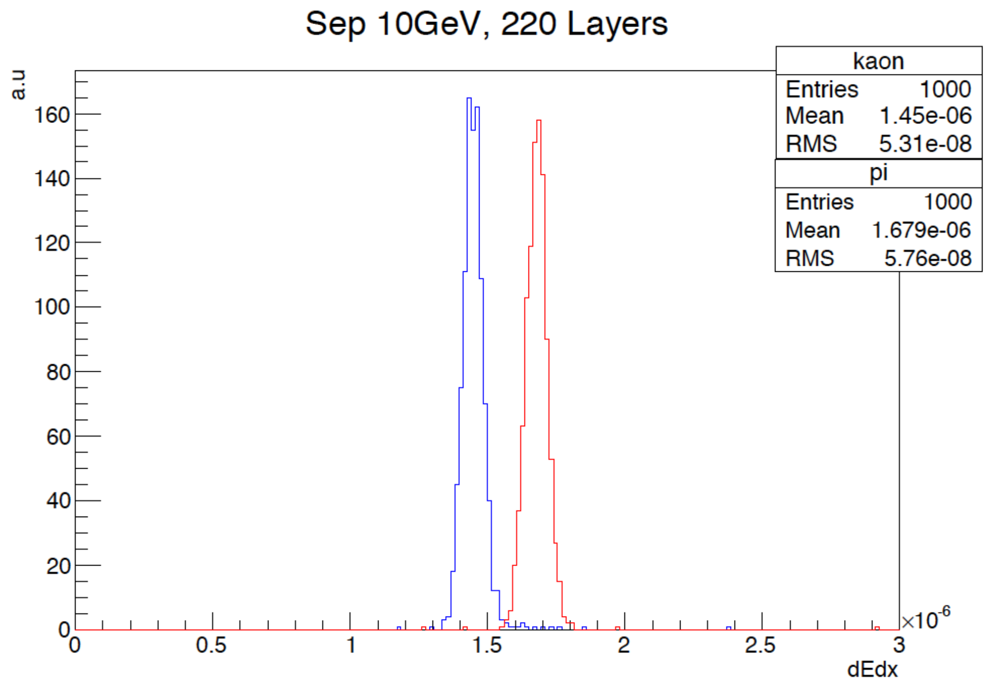


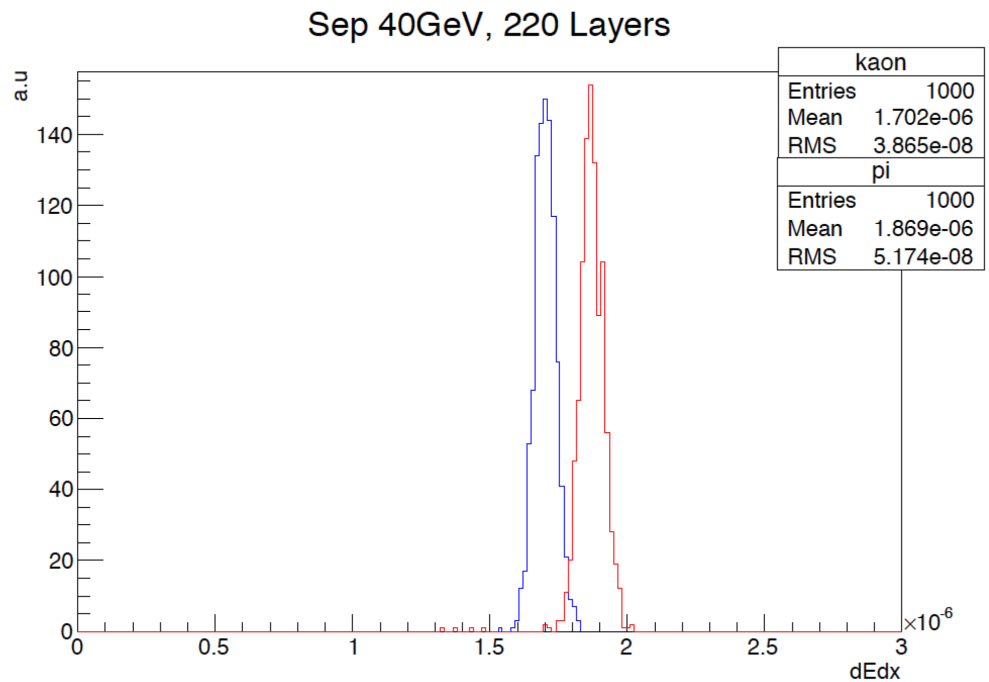
(b) sigma(1/pt) vs Pt



(c) sigma(D0) vs Pt

TPC





dEdx, GeV per Hit (6 mm wide)

dE/dx, clear pi-K separation at E up to 40 GeV...

1.8/0.3 m TPC outer/inner radius, Half Z 2.35m, > 200 layers,
layer thickness 6 mm, T2K Gas, Ar : CF4 : iC4H10 = 95 : 3 : 2

Key question: How to faithfully extract the dEdx information?

ILD Reference:
https://agenda.linearcollider.org/event/7020/contributions/34830/attachments/30307/45306/Top.pdf

Summary

- Higgs analyses:
  - Mostly covered at full simulation level & results slightly varied from preCDR
  - Significant progress on H→VV and H→Exotic decay measurements
  - To do: Higgs analyses with tau/multi-jets final states: need dedicated tau finder & jet clustering algorithm
- Optimization: Calorimeter
  - **WO active cooling:**
    - Lepton ID at single particle level solved (in various of granularities). Electron id at full physics event still need to be tuned (brems photon flag...)
    - JER reduced by 5/10% (10/20 mm Cell) comparing to ILD (5 mm Cell)
    - **Event reconstruction efficiency reduced by ~ 1-2%** in Higgs recoil analysis via lepton channel, Br(H→WW→μvqq), Br(H→ZZ→llqq) channels
    - **Need to investigate other observables**
  - ECAL Linear Range: 1k/1.8k MIP at 10/20 mm Cell Size. Very challenge to Scintillator + SiPM readout option
  - Many optimization studies at Hit/PFA//**Digitization** level: See calorimeter section (Qian Liu's presentation)

Summary

- Optimization, VTX:
  - Impact of VTX radius on Flavor tagging performance: quantized
  - **Further input from MDI is needed**

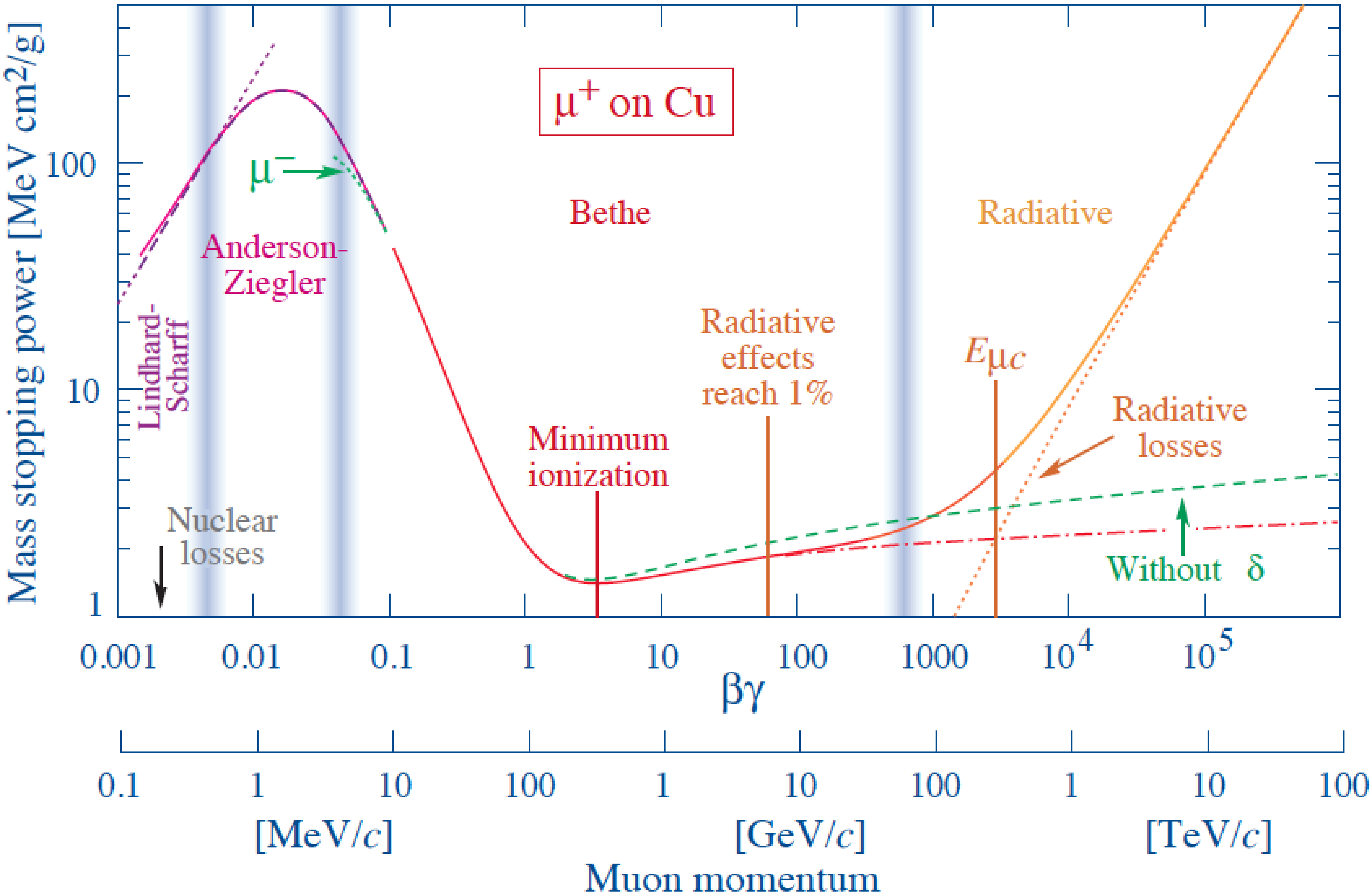
- Optimization: Tracker
  - **Significant progress on full Silicon tracking**: see Weiming's presentation
    - Validated – optimization at Fast Simulation
    - Geometry implemented to G4
    - Different sets of reconstruction implemented & compared

  - **TPC: dE/dx, pi-K separation up to 40 GeV?**

- *For more information, slides at the 2nd CEPC Physics-Software workshop: http://indico.ihep.ac.cn/event/6253/*

Thanks

Back up



μ+ on Cu
Mass stopping power [MeV cm2/g]
100
10
1
μ−
Bethe
Radiative
Anderson-
Ziegler
Lindhard-
Scharff
Radiative
effects
reach 1%
Eμc
Radiative
losses
Minimum
ionization
Nuclear
losses
Without δ
0.001
0.01
0.1
1
10
100
1000
10^4
10^5
βγ
0.1
1
10
100
1
10
100
1
10
100
[MeV/c]
[GeV/c]
[TeV/c]
Muon momentum

Br(H→ZZ)

ZZZ*	Yield	Object reconstructed	Signal Efficiency(%)	Main Background	Accuracy (%)	Comments
μμννqq	128	118	63.3	h->ww&zz_sl	**12.9**	Tau finder would be highly appreciated Reconstructed efficiency of electron need to be improved
μμqqνν	128	125	-	h->bb&zz_sl	>25	
eeννqq	132	91	53.8	h->ww&sze_sl	**15.8**	
eeqqνν	132	88	-	h->bb&zz_sl	>25	
ννμμqq	158	144	61.4	h->t,w&zz_sl	**11.0**	
ννqqμμ	158	149	51.9	h->w,b&zz_sl	**12.9**	
ννeeqq	151	118	43.1	h->w&sze_sl	**21.3**	
ννqqee	151	134	-	h->bb&sze_sl	>25	
qqμμνν	135	115	-	h->tt&zz_sl	>25	Compare to ll recoil, qq recoil mass has much worse distinguishing power to SM background
qqννμμ	135	122	-	h->t,w&zz_sl	>25	
qqeeνν	127	107	-	h->tt&sze_sl	>25	
qqννee	127	123	-	h->t,w&sze_sl	>25	
μμμμqq/qqμμ	43	39	69.8	h->tt&zz_sl	**19.9**	Tau finder & Electron Reconstruction
μμeeqq/qqee	43	39	60.5	h->tt&zz_sl	**21.2**	
eeeeqq/eeqqee	43	33	-	h->tt&sze_sl	>25	
eeμμqq/eeqqμμ	43	41	58.2	h->tt&sze_sl	**19.9**	

Full Simulation analysis performed on 16 independent channels.
8 Channels acquire accuracy better than 25%.

Combined accuracy: **5.4%**

If electron id efficiency ~ muon id: ***4.8%***

If tau finder (used for veto) is mature: ??

TLEP extrapolation**: 4.3%**

Br(H→WW)

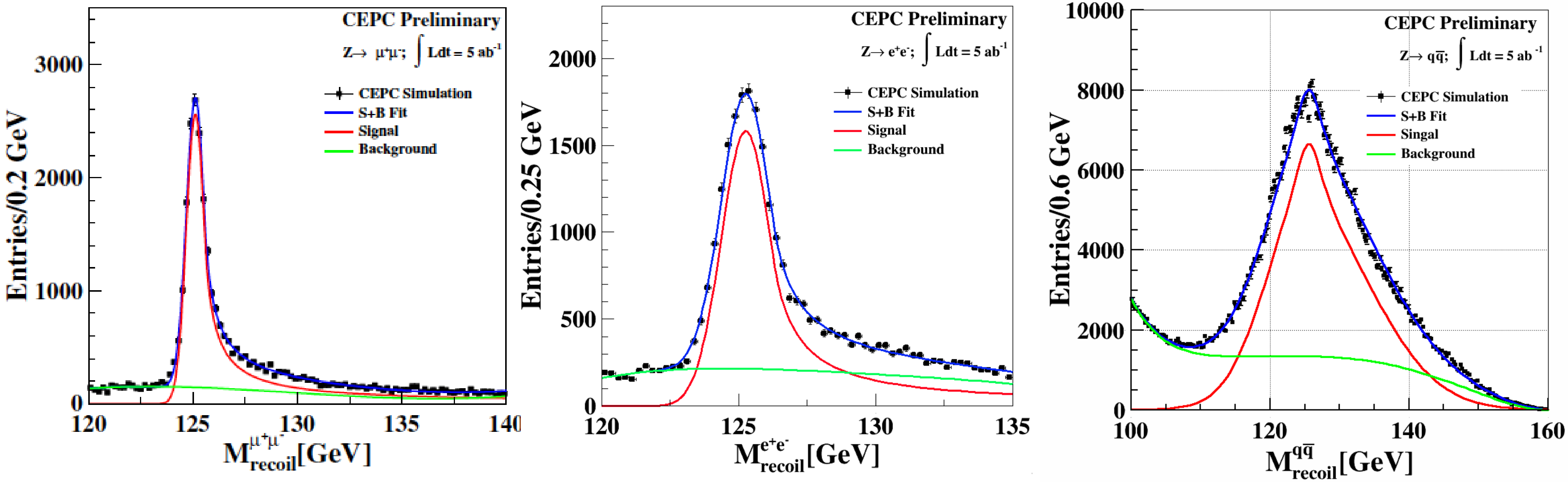
ZH, H->WW*	Yield	Object reconstructed	Isolation	Signal Efficiency	Main Background	Accuracy	Combined
Z(μμ)H(evev)	88	76(86.36%)	61(80.26%)	36(40.91%)	4(ZH)	17.57%	
Z(μμ)H(μvμv)	89	80(89.89%)	77(96.25%)	52(58.43%)	6(ZH&ZZ)	14.65%	
Z(μμ)H(evμv)	174	157(90.23%)	147(93.63%)	105(60.34%)	0	9.76%	2.68%
Z(μμ)H(evqq)	1105	1042(94.30%)	864(82.92%)	663(60.00%)	45(ZH)	4.02%	
Z(μμ)H(μvqq)	1110	1056(95.14%)	988(93.56%)	717(64.59%)	159(ZH&ZZ)	4.13%	
Z(μμ)H(qqqq)	Preliminary						3.0%
Z(ee)H(evev)	91	62(68.13%)	60(96.77%)	22(24.16%)	16(SZ)	28.02%	
Z(ee)H(μvμv)	82	63(76.83%)	63(100%)	44(53.66%)	24(SZ)	18.74%	
Z(ee)H(evμv)	178	132(74.16%)	124(93.94%)	82(46.07%)	25(ZH&SZ)	12.61%	2.87%
Z(ee)H(evqq)	1182	1041(88.07%)	916(87.99%)	621(51.78%)	188(SZ&ZH)	4.62%	
Z(ee)H(μvqq)	1221	1194(97.79%)	1048(87.77%)	684(56.02%)	49(ZH&SZ)	3.96%	
Z(ee)H(qqqq)	Preliminary estimation						3.2%

- Full Simulation on 12 independent channels
  - Very high object reconstruction efficiency
  - Combined result: 1.45%
- Extrapolation from other ILC channels: 1.59%
- Combined: 1.07%

	Z→ll	tautau	vv	qq
H→WW*→4q		3.45k	2.3%	69.1k
μvqq		1.14k	6.47k	2.2%
evqq		1.14k	6.47k	
eevv	1.45%	93	527	1.9k
μμvv		93	527	1.9k
eμvv		186	1154	3.7k
X + tau	3.2k	1.6k	9.14k	32.0k

Higgs invisible decays

*Assuming sigma(ZH)*Br(H->inv) = 200 fb*

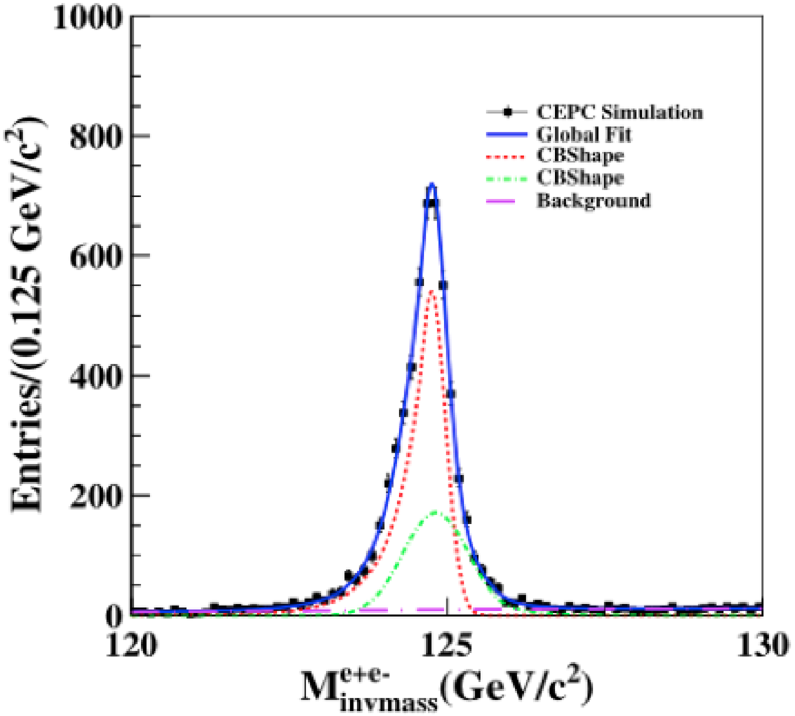


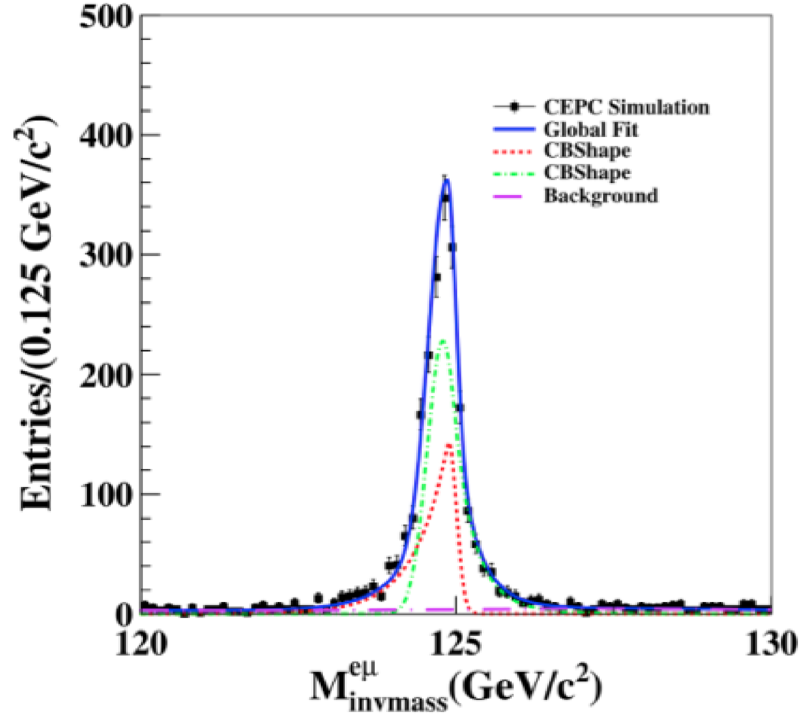
Invisible up limit at CEPC: 0.14% at 95% C.L

Up limit of Br(H→ee) & Br(H→eμ)

Lei Wang

*Assuming sigma(ZH)*Br(H->ee/eμ) = 200 fb*

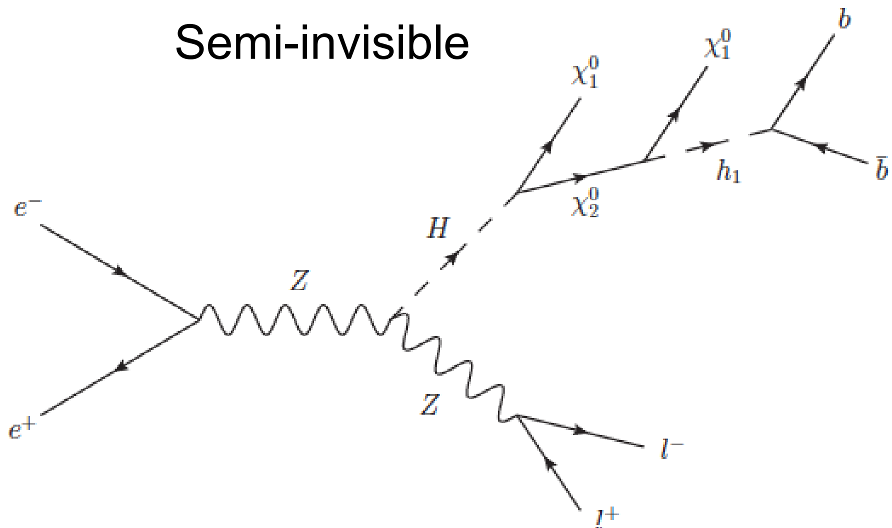




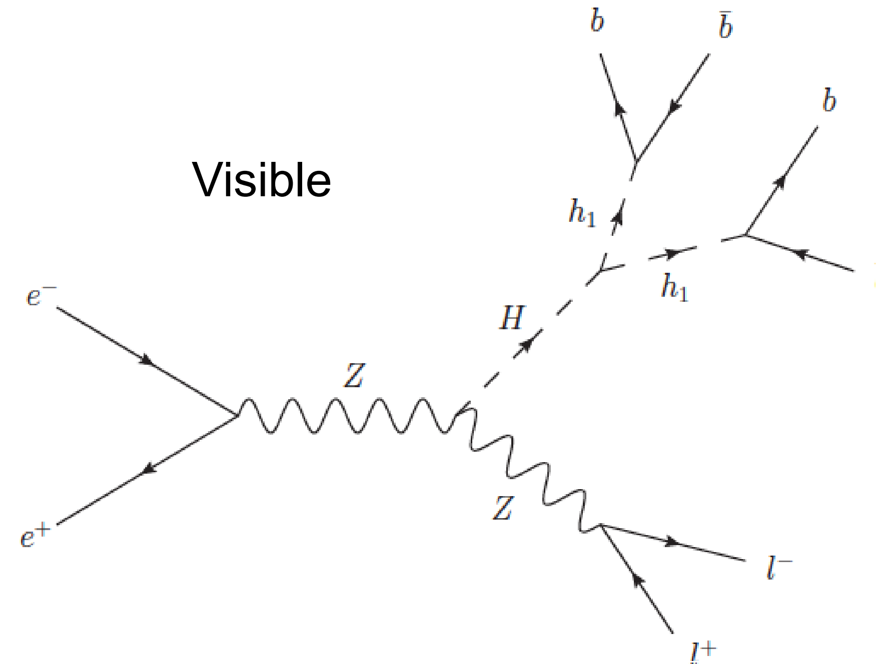
95% up limit: Br(H->ee) = 1.7e-4;
Br(H->emu) = 1.2e-4;

H→Exotic, Hadronic

Semi-invisible



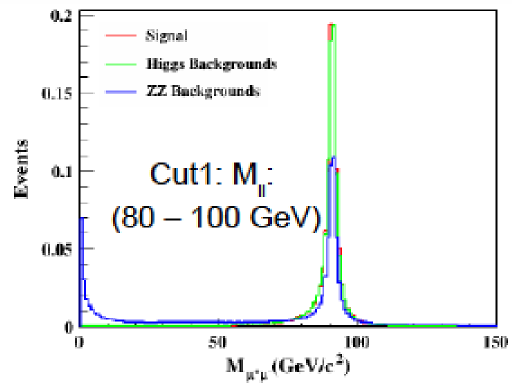
Visible

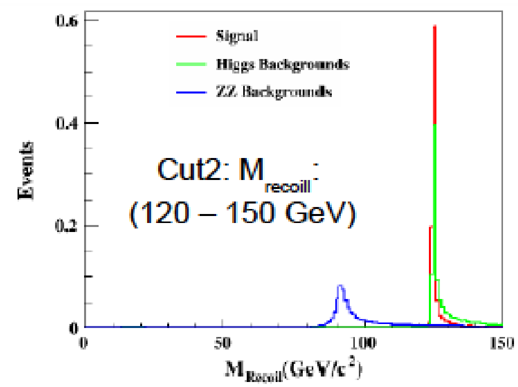


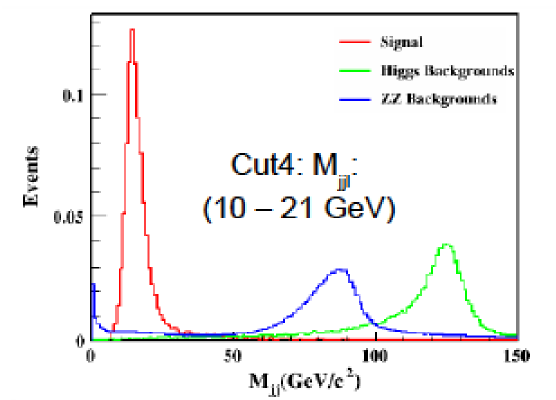
- Typical processes in 2HDM & NMSSM
- Joint efforts by HK Cluster and IHEP
  - Study proposed by T. Liu
  - Main analyzer, Jiawei Wang, Kevin & Zhenxing Chen
- 95% CL up limit ~o(10^{-4}).

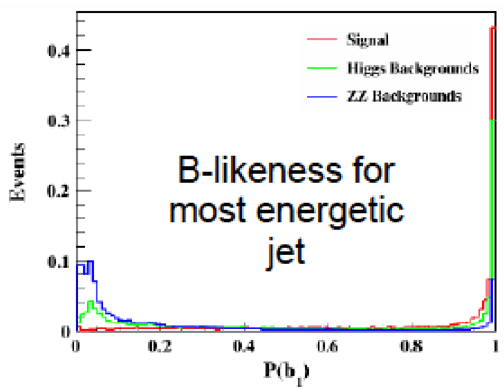
H->Exotic, hadronic

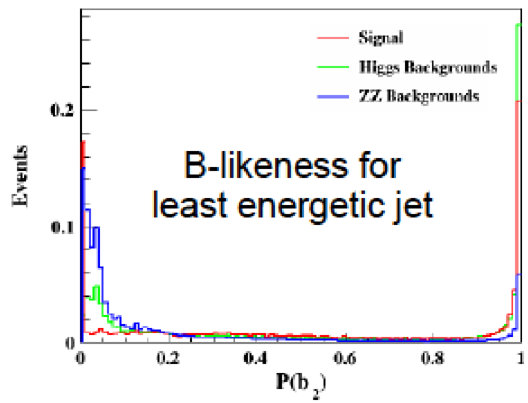
Para: M(LSP) = 0; M(h0) = 15 GeV; M(NLSP) = 20 GeV









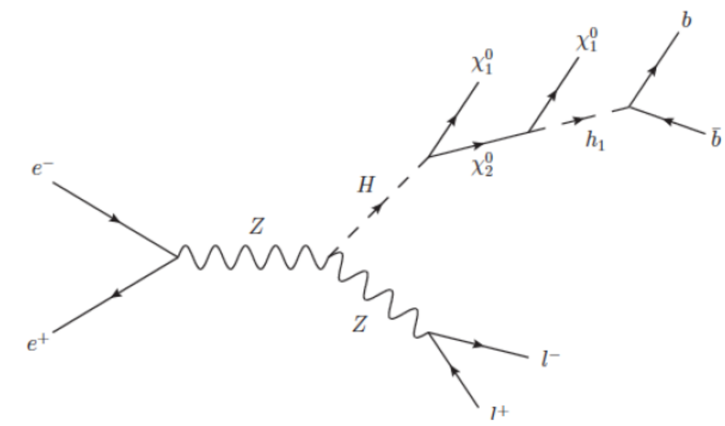


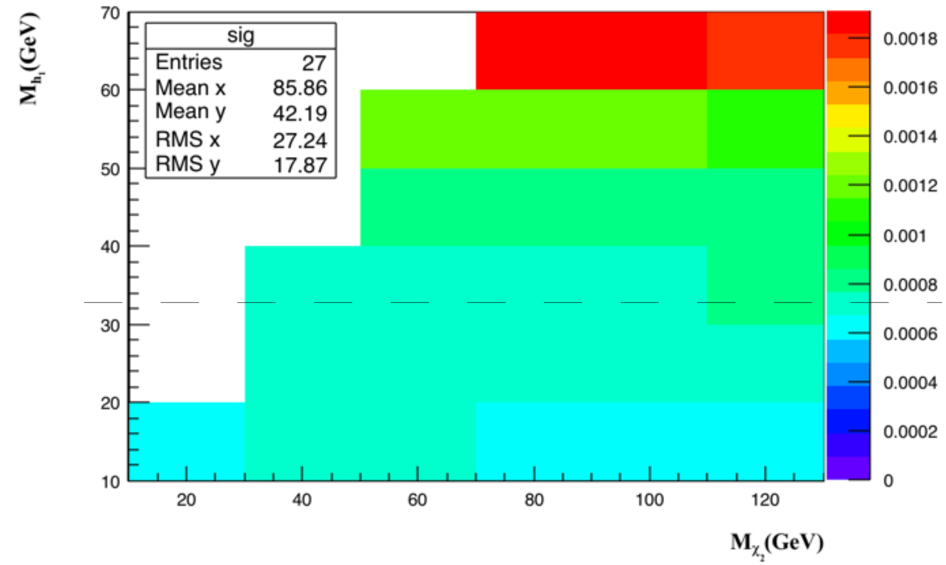
	Object found	Cut 1 m_{ll}	Cut 2 m_{rec}	Cut 3 b likeness	Cut 4 m_{jj}
Signal	17	15	15	12	10
ZH BGs	34093	30732	30030	16026	4
ZZ BGs	538790	281198	30825	4274	20

Cut3: sum(B-likeness) > 0.9

- 95% CL. Uplimt set to be 5E-4; will be significantly improved by including di-electron/tau channel...
- ISR effect not included in the Signal sample. sigma(ZH) refered to SM Xsec of 200 fb. Effect on uplimit setting could be ignored

H→Exotic, Hadronic





Benchmark Points

Scan over the parameter space for sensitivity:

1. Fix $m_{\tilde{\chi}_1^0} = 0$ GeV and make exclusion contours on the m_{h^0} and $m_{\tilde{\chi}_2^0}$ plane with the range:

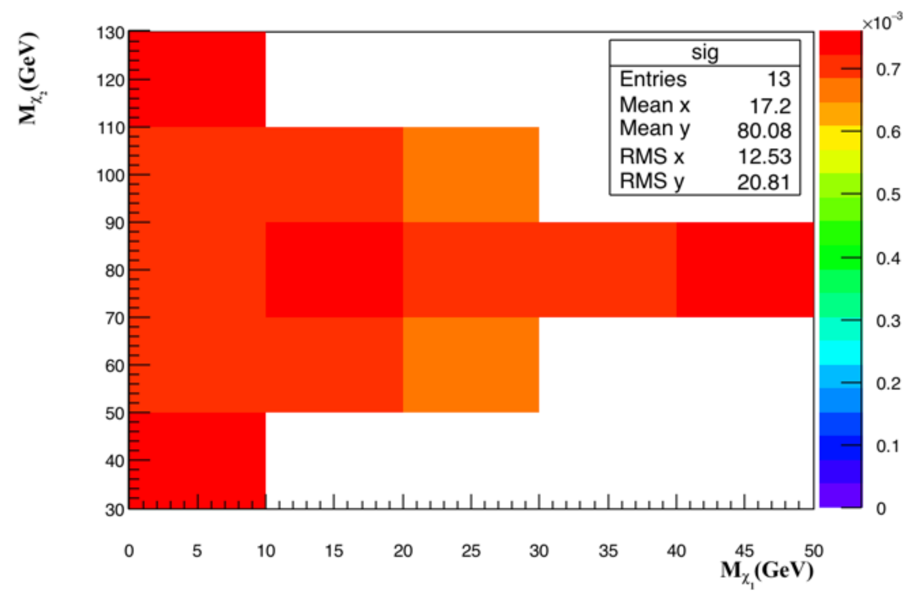
   10 GeV < m_{h^0} < 60 GeV (15,25,35,45,55 GeV)

   10 GeV < $m_{\tilde{\chi}_2^0}$ < 125 GeV (20,40,60,80,100,120 GeV)

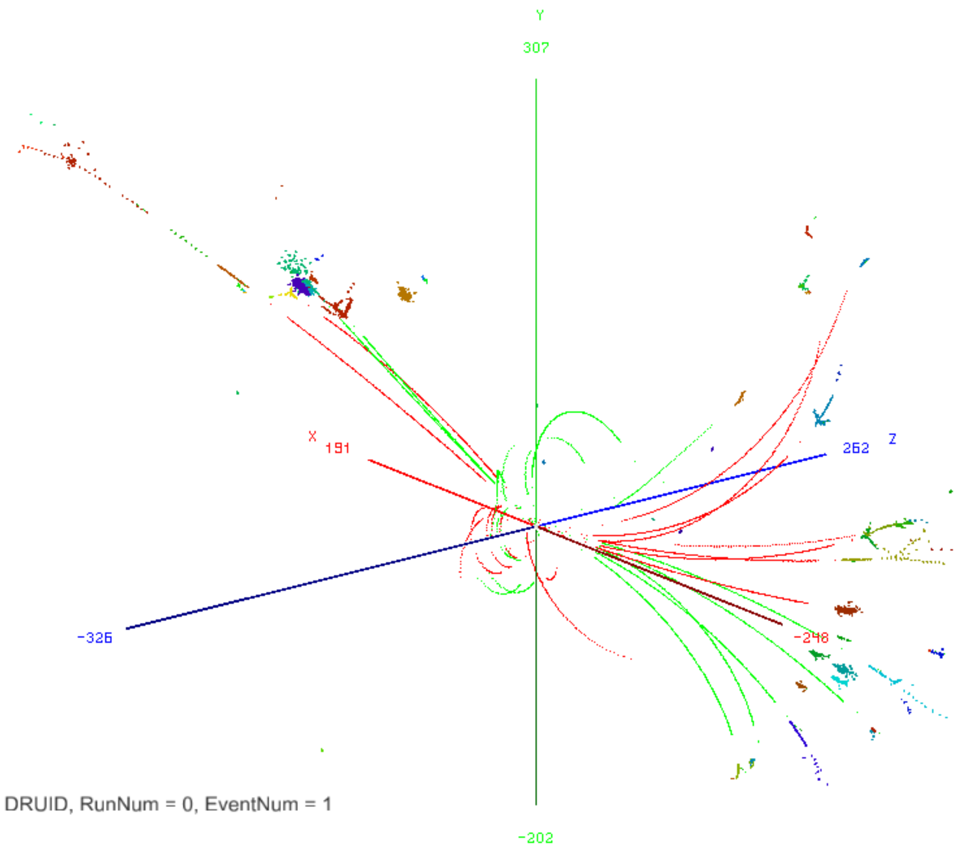
2. Fix $m_{h^0} = 30$ GeV and make exclusion contours on the $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0}$ plane, with the range:

   0 GeV < $m_{\tilde{\chi}_1^0}$ < 60 GeV (5,15,25,35,45,55 GeV)
   10 GeV < $m_{\tilde{\chi}_2^0}$ < 125 GeV (20,40,60,80,100,120 GeV)

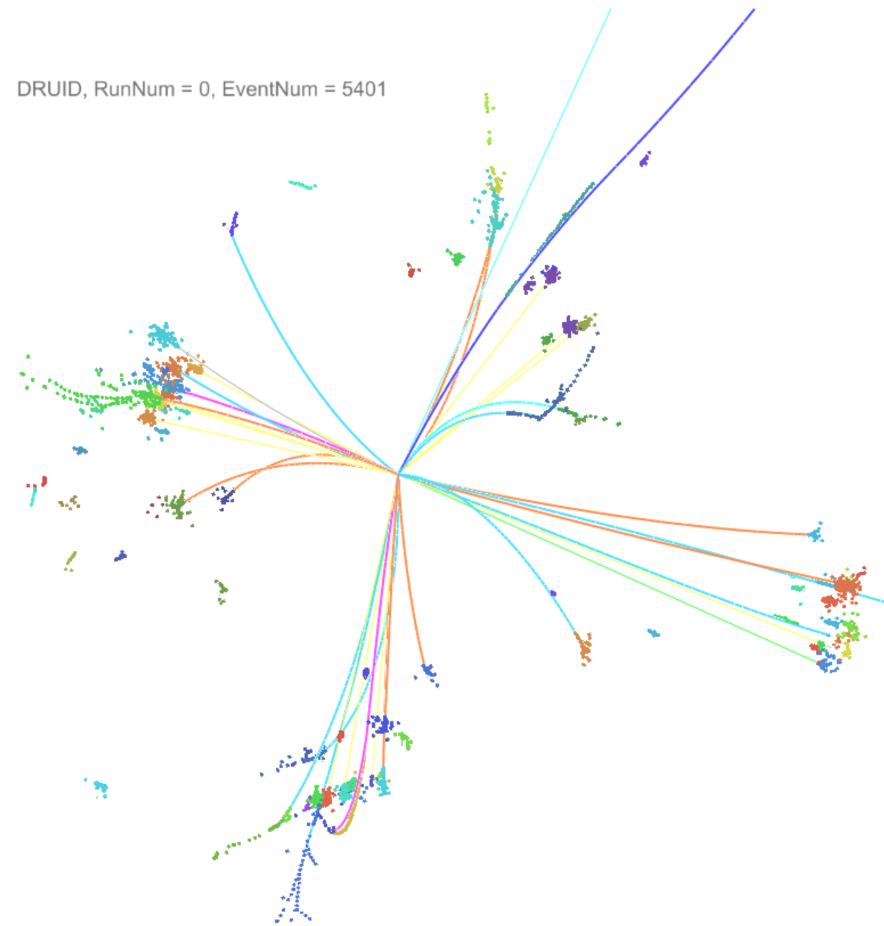
Suggested by prof. Liu



Simulated Higgs Event @ CEPC

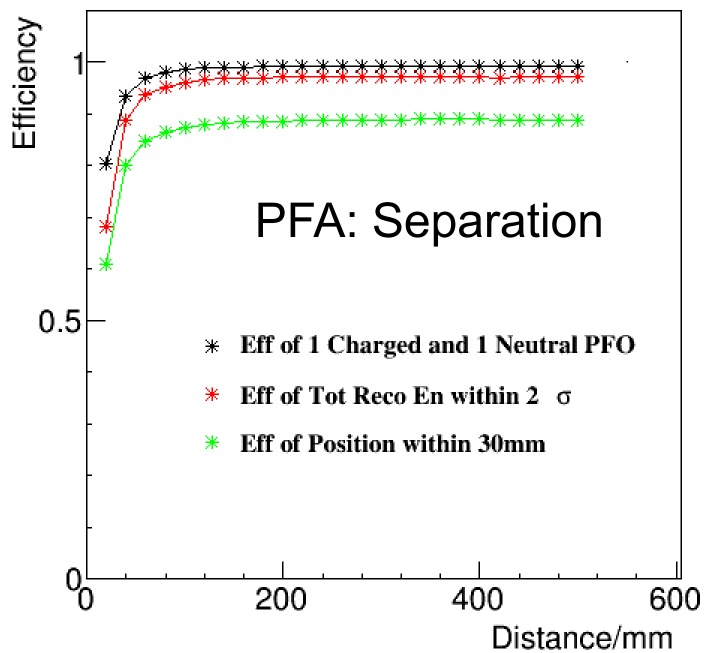


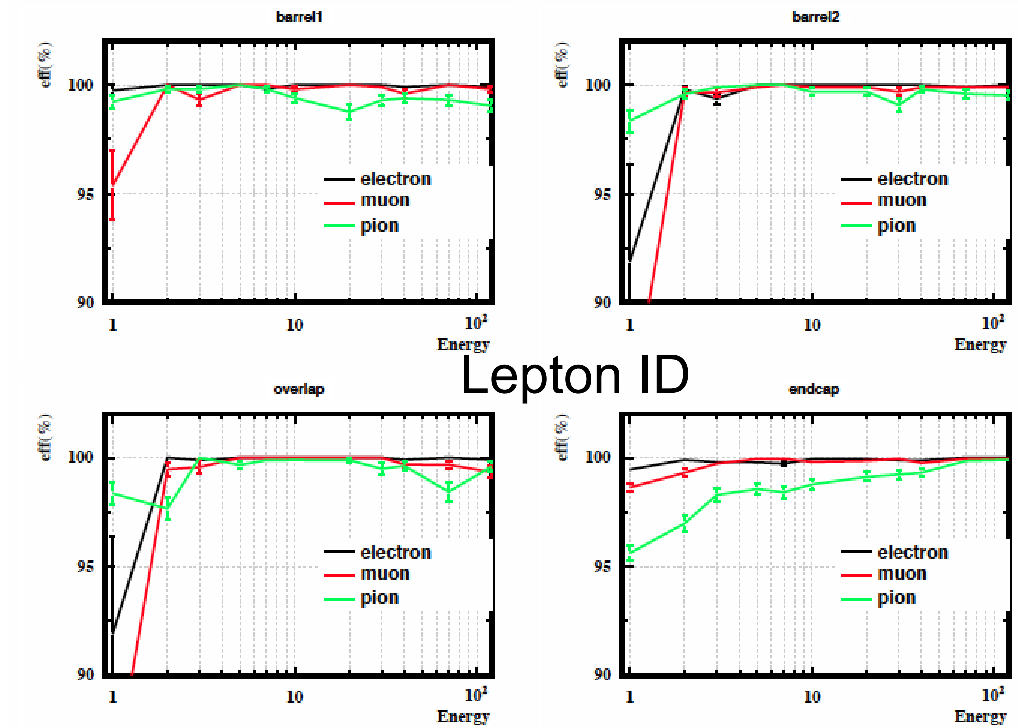
~25% of Higgs events

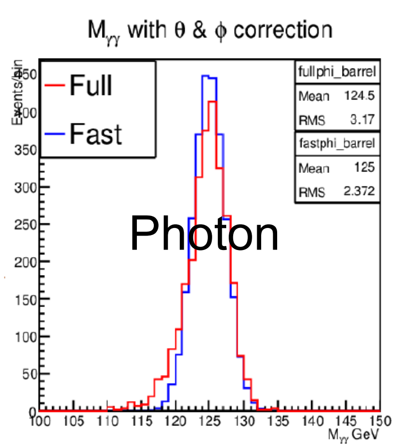


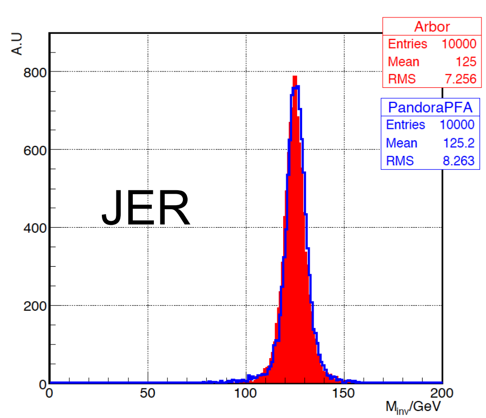
~50% of Higgs events

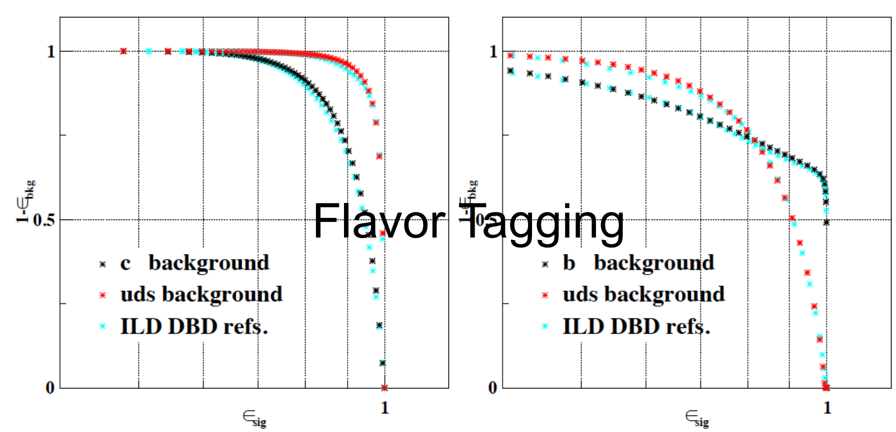
Reconstructions



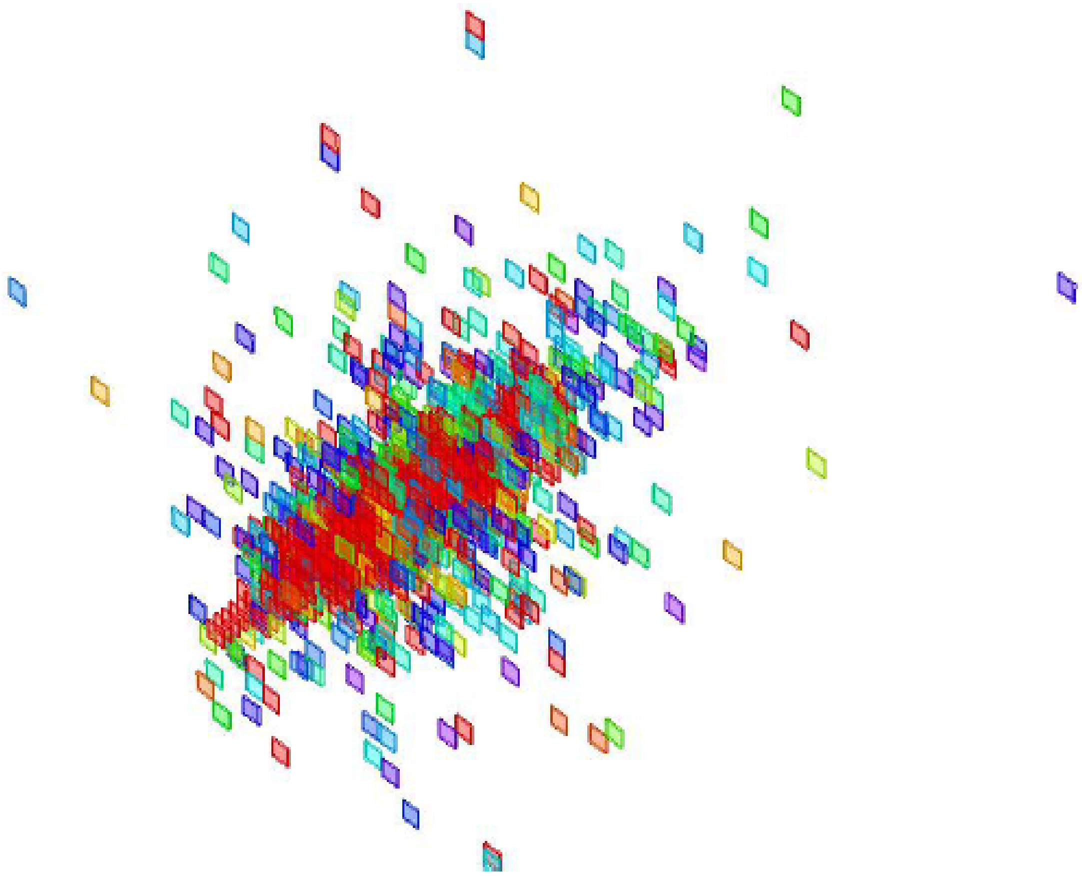








ECAL Saturation/Linear Range Study



50 GeV Photon Cluster
at ECAL with 10 mm Cell Size