

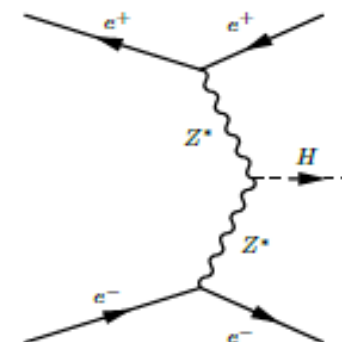
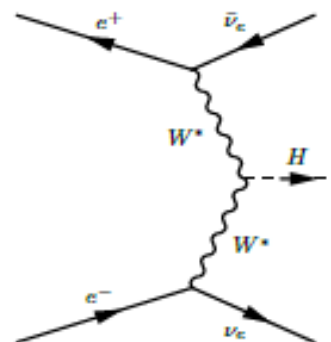
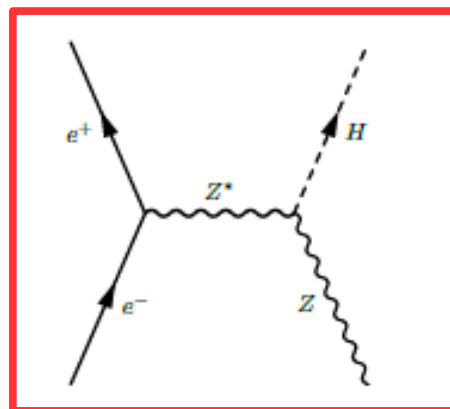
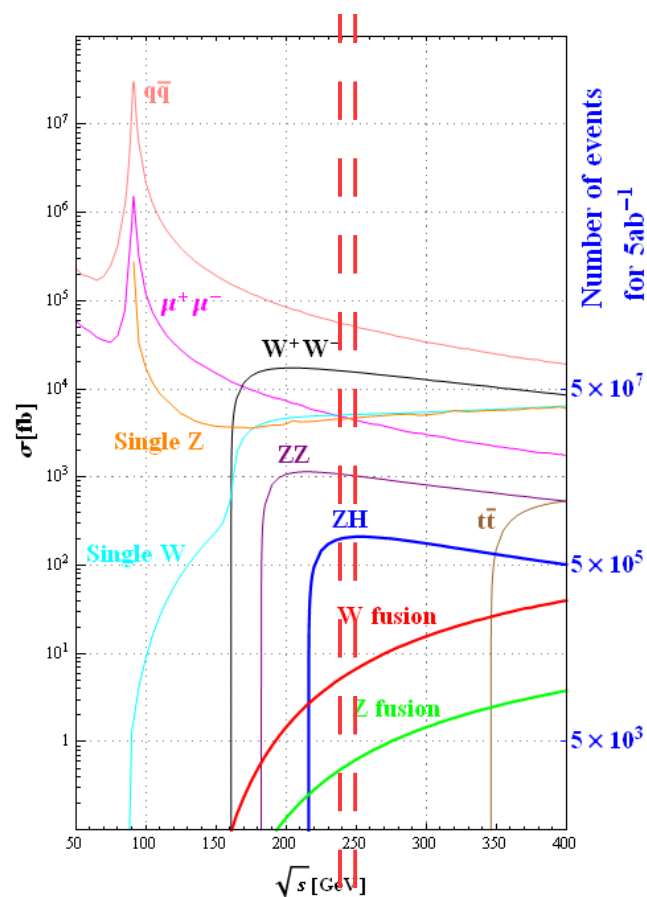


Higgs analysis and Detector Optimization at CEPC

Manqi

for CEPC Detector Optimization & Simulation Group

Higgs @ CEPC

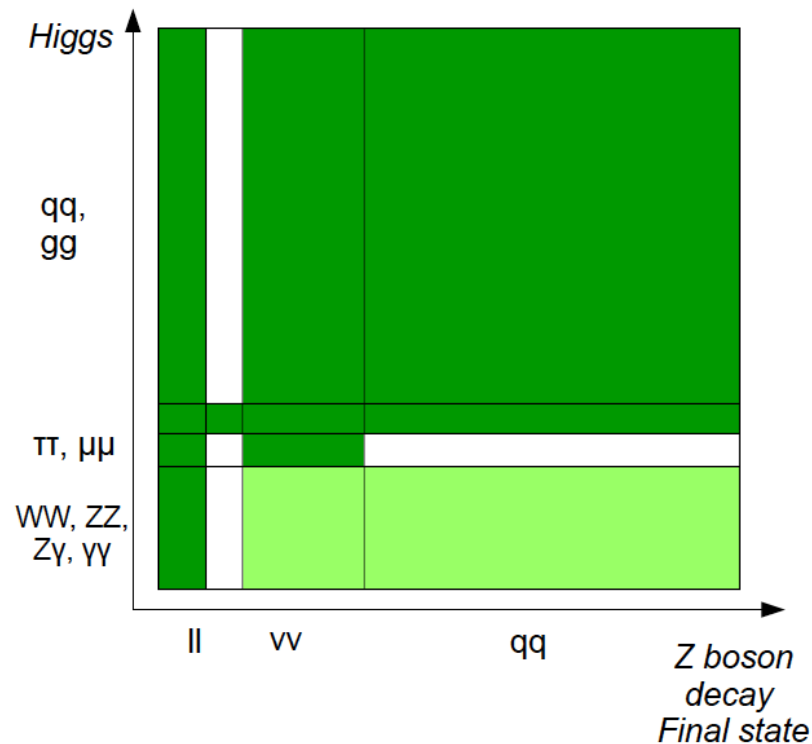


Process	Cross section	Events in 5 ab ⁻¹
Higgs boson production, cross section in fb		
$e^+e^- \rightarrow ZH$	212	1.06×10^6
$e^+e^- \rightarrow \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \rightarrow e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

Observables: Higgs mass, CP, $\sigma(ZH)$, event rates ($\sigma(ZH, \nu\nu H) \cdot \text{Br}(H \rightarrow X)$), Diff. distributions

Derive: **Absolute** Higgs width, branching ratios, **couplings**

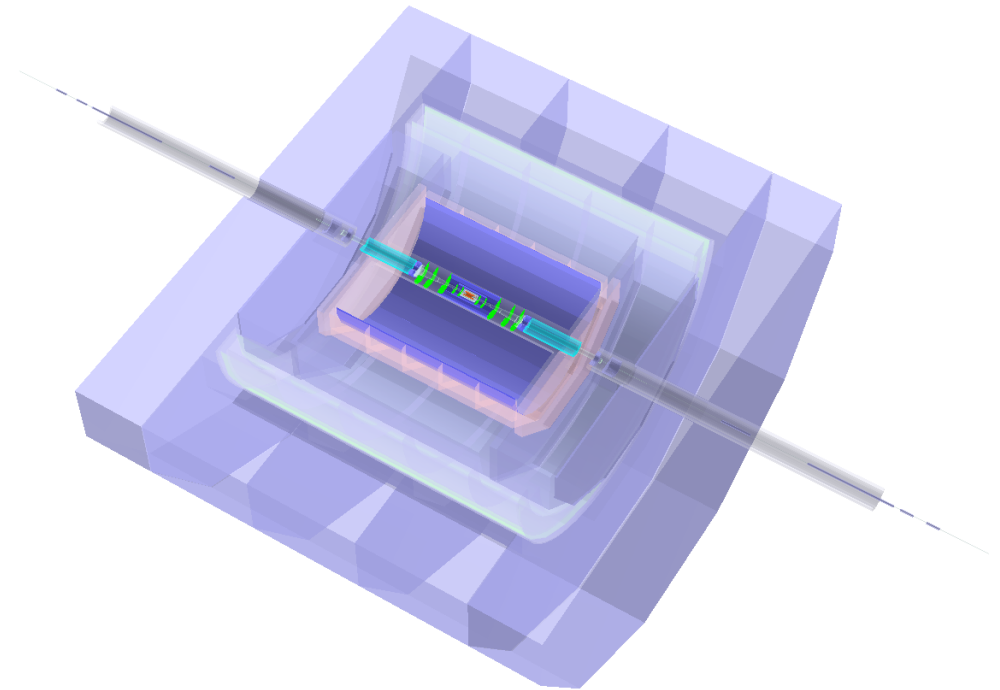
Higgs analysis & conceptual detector



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

To be covered:

Tau finding in jet environments
 $\text{Br}(H \rightarrow WW/ZZ)$ in multi-jet events

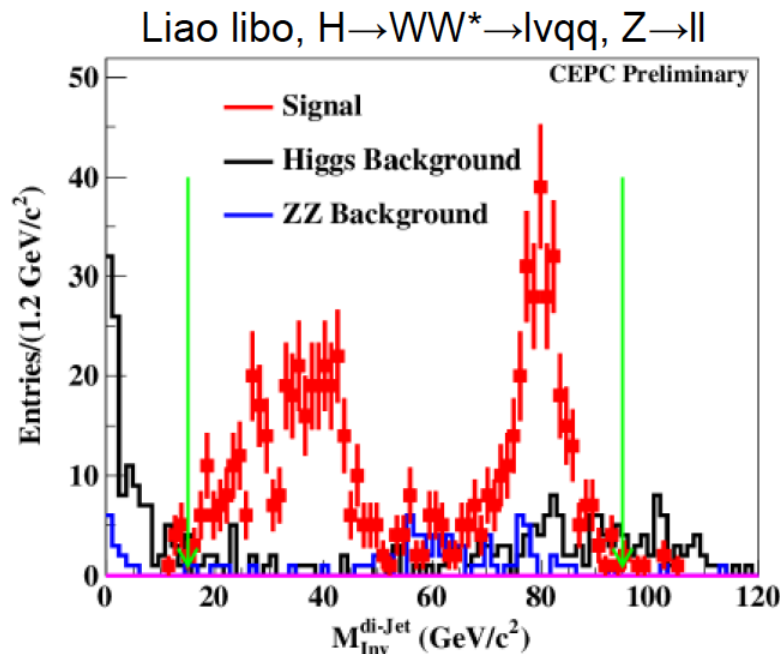


Reconstruct all the physics objects (lepton, γ , tau, Jet, MET, ...) with high efficiency/precision

High Precision VTX close to IP: b, c, τ tagging
High Precision Tracking system: $\delta(1/P_t) \sim 2 \cdot 10^{-5} (\text{GeV}^{-1})$
PFA oriented Calorimeter System ($\sim o(10^8)$ channels):
Tagging, ID, Jet energy resolution, etc

Br(H→WW)

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



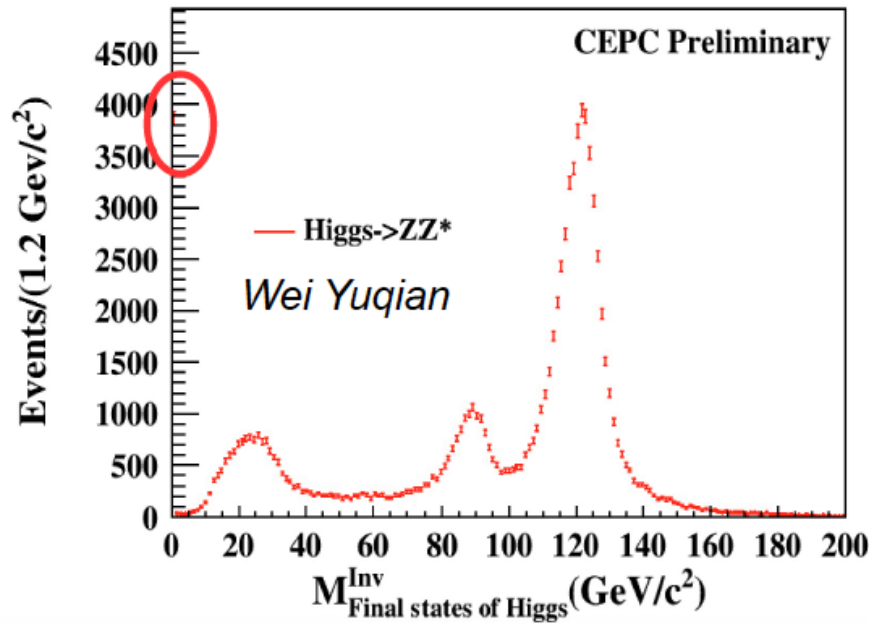
Expected Number of events with different objects

	Z→ll	tautau	vv	qq
H→WW*→4q	6.91k	3.45k	19.74k	69.1k
μνqq	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)
- High efficiency in event reconstruction (finding all physics objects: efficiency 80-90%)

Br(H→ZZ)



Expected Number of events with different objects

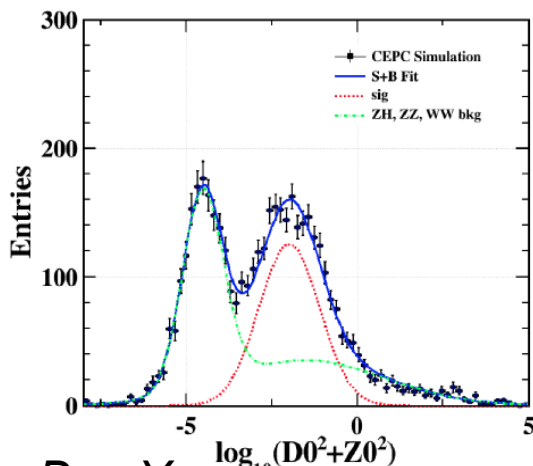
	Z→ll	tautau	vv	qq
H→ZZ*→4q	888	444	3.10k	9.24k
2v + 2q	508	254	1.77k	5.29k
2l + 2q	170	85	596	1.8k
4v	73	36	254	756
2l + 2v	49	24	170	508
4l	8	4	28	86
X + tau	120	60	418	1246

	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)
- High efficiency in event reconstruction

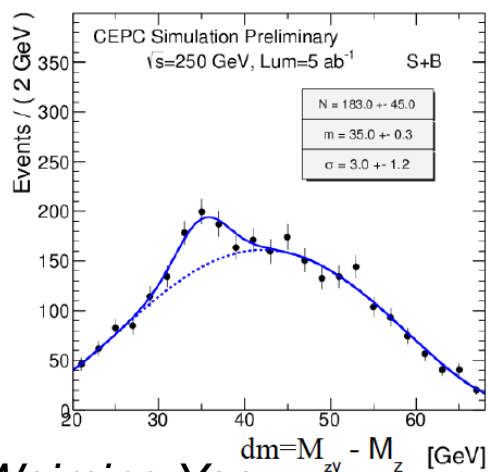
Status

Br(H→ττ) via Z to ll



Dan Yu

- Initial study of $zH \rightarrow z\gamma \rightarrow qq\nu\nu\gamma$ is promising to be 4σ with 5 ab^{-1} .



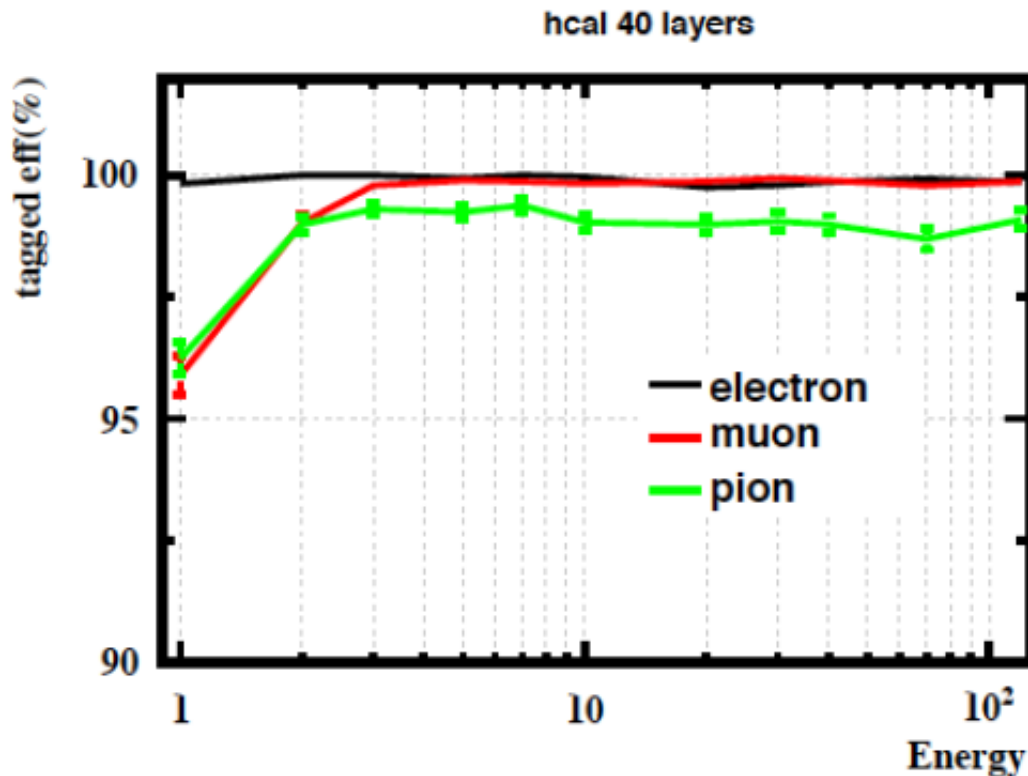
Weiming Yao

	PreCDR (Jan 2015)	Now (Aug 2016)
$\sigma(\text{ZH})$	0.51%	0.50%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{bb})$	0.28%	0.21%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{cc})$	2.1%	2.5%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{gg})$	1.6%	1.3%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{WW})$	1.5%	1.0%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{ZZ})$	4.3%	4.3%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \tau\tau)$	1.2%	1.0%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \gamma\gamma)$	9.0%	9.0%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{Z}\gamma)$	-	$\sim 4\sigma$
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \mu\mu)$	17%	17%
$\sigma(\text{v}\nu\text{H}) \cdot \text{Br}(\text{H} \rightarrow \text{bb})$	2.8%	2.8%
Higgs Mass/MeV	5.9	5.0
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{inv})$	95%. CL = $1.4\text{e-}3$	$1.4\text{e-}3$
$\text{Br}(\text{H} \rightarrow \text{ee}/\text{emu})$	-	$1.7\text{e-}4/1.2\text{e-}4$
$\text{Br}(\text{H} \rightarrow \text{bb}\chi\chi)$	$<10^{-3}$	$3.0\text{e-}4$

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:
 - *$Z \rightarrow di$ lepton, Higgs to inc;*
 - *$Z \rightarrow \nu\nu$; $H \rightarrow WW \rightarrow l\nu qq$;*
 - *$Z \rightarrow \nu\nu$; $H \rightarrow ZZ \rightarrow ll qq$;*
- ECAL Saturation studies on $H \rightarrow \gamma\gamma$ measurements

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



Scanned Settings:

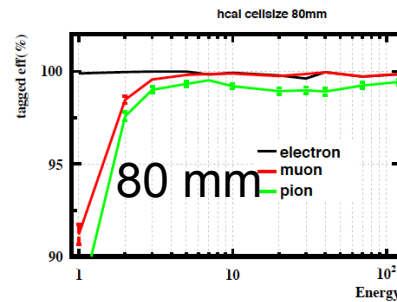
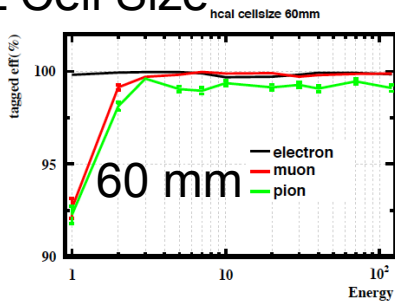
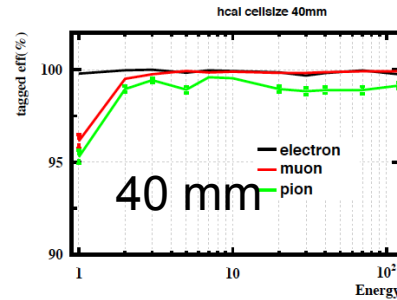
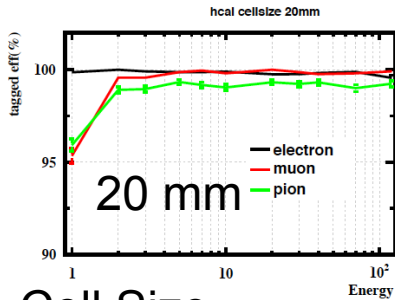
- ECAL Cell Size: 5 - 40 mm
- HCAL Cell Size: 10 - 80 mm
- ECAL N Layer: 30 - 20
- HCAL N Layer: 48 - 20

BDT method using 4 classes of 24 input discrimination variables.

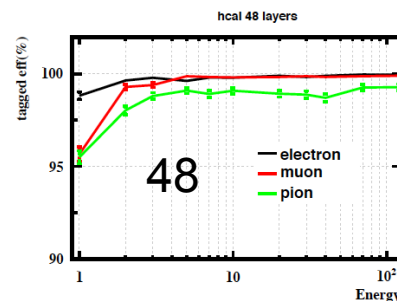
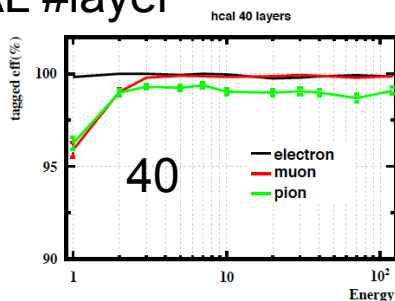
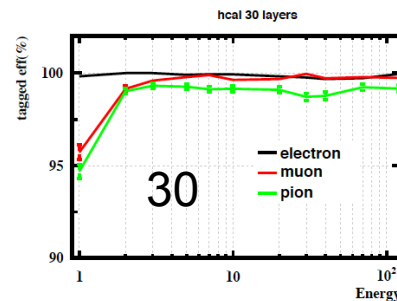
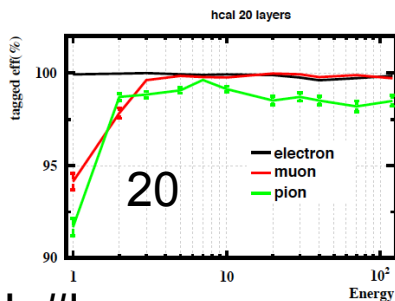
At Single Particle level, for $E > 2$ GeV charged reconstructed particle:
lepton efficiency $> 99.5\%$ && Pion mis id rate $< 2\%$

Vary the granularity

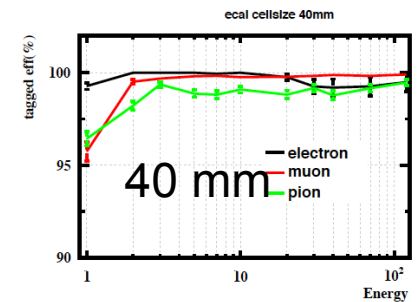
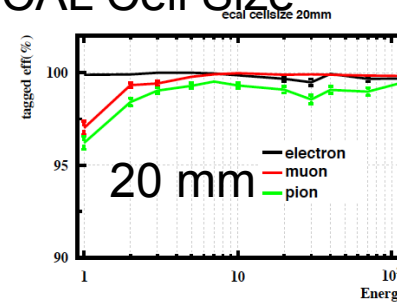
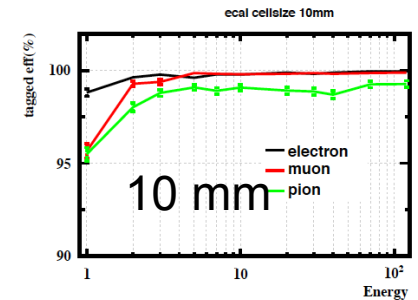
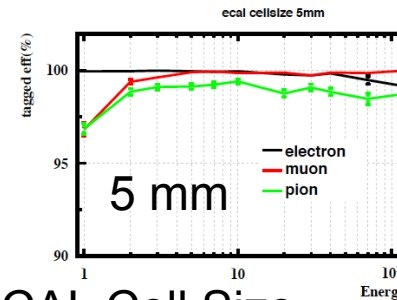
HCAL Cell Size



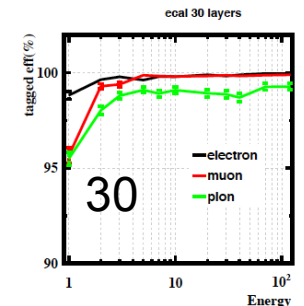
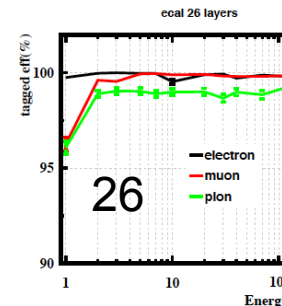
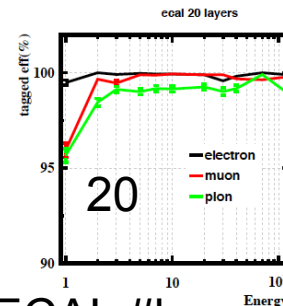
HCAL #layer



ECAL Cell Size

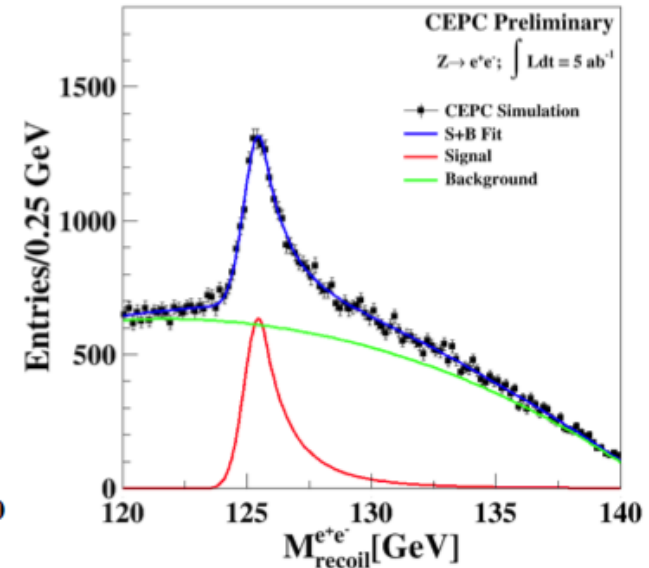
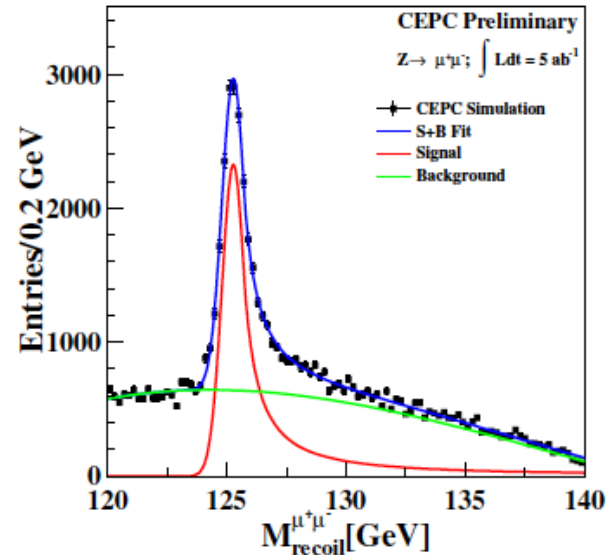
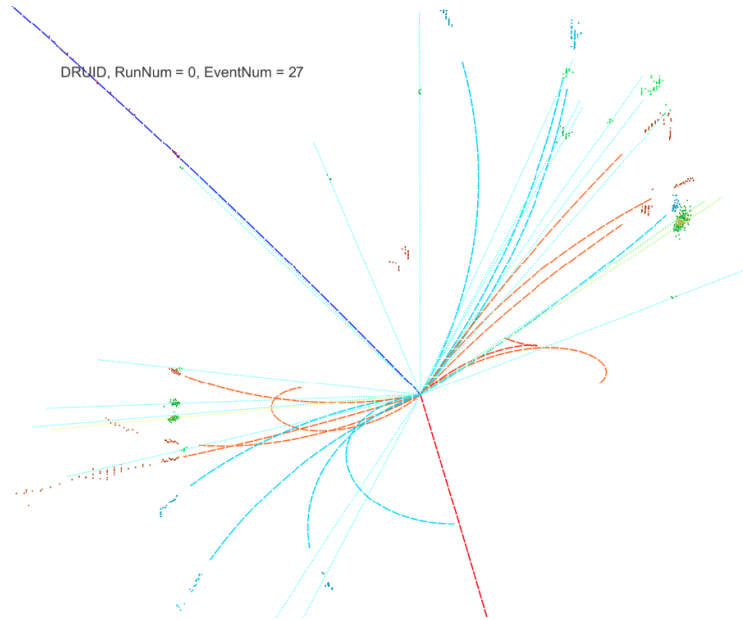


ECAL #layer



No Significant effect for $E > 2$ GeV charged Particles

Lepton: Higgs recoil via ZH , $Z \rightarrow ll$



		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%(???)

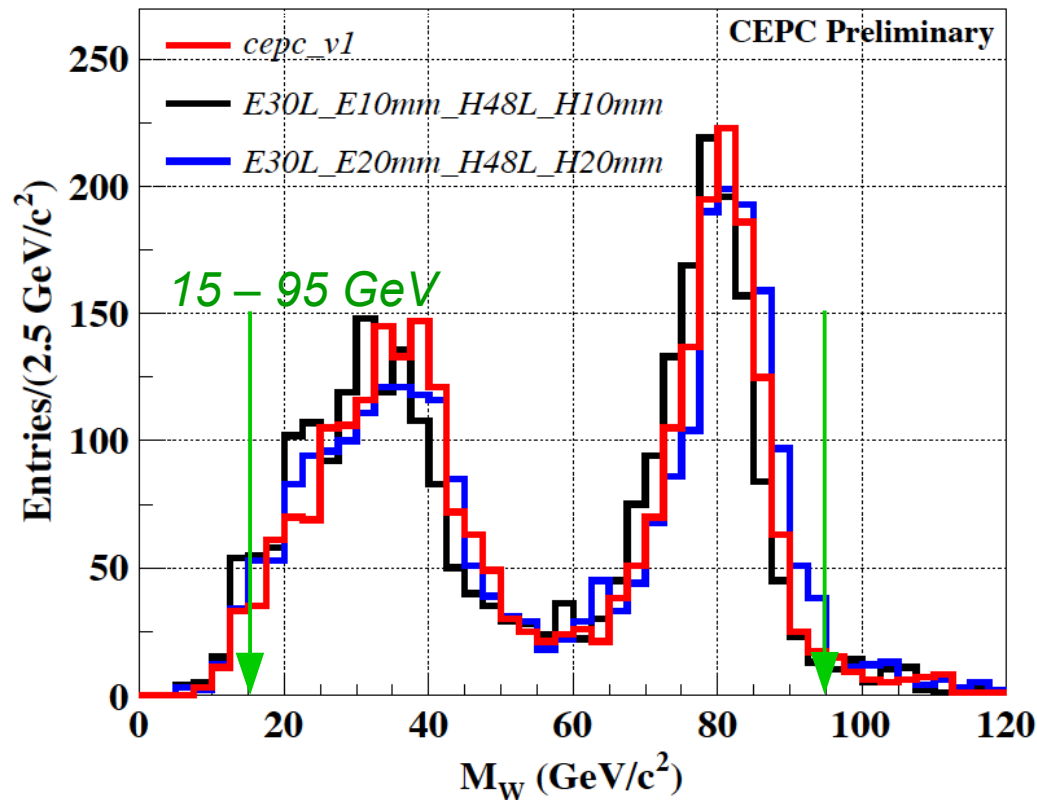
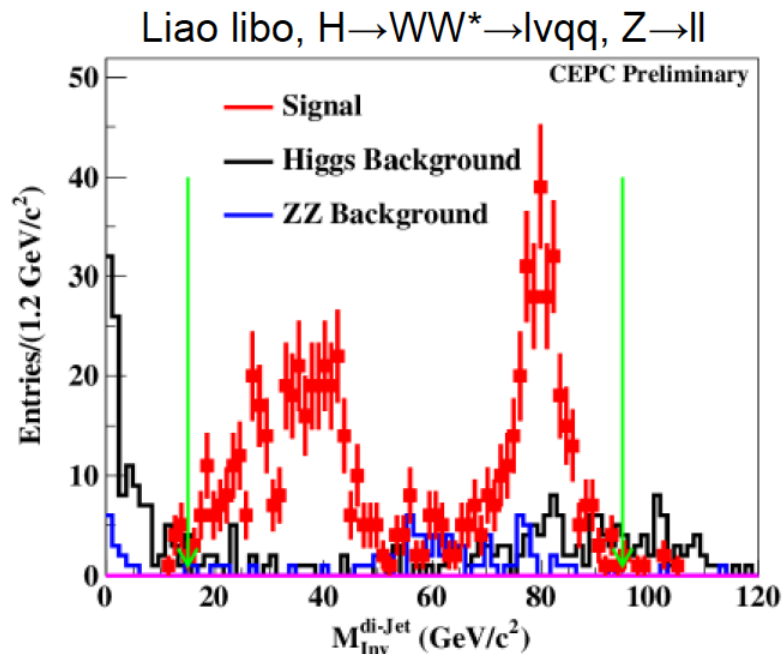
TG2/3: active cooling free...

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: $\text{Br}(H \rightarrow WW)$



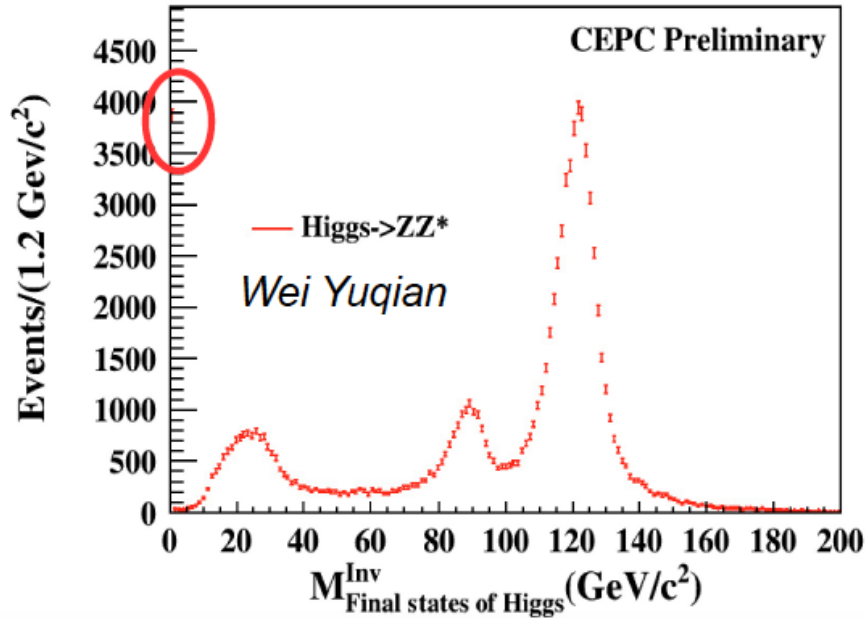
$\text{Br}(H \rightarrow WW)$ via vvH , $H \rightarrow WW^* \rightarrow lvqq$

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

Over all: event reco. efficiency varies $\sim 1\%$

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

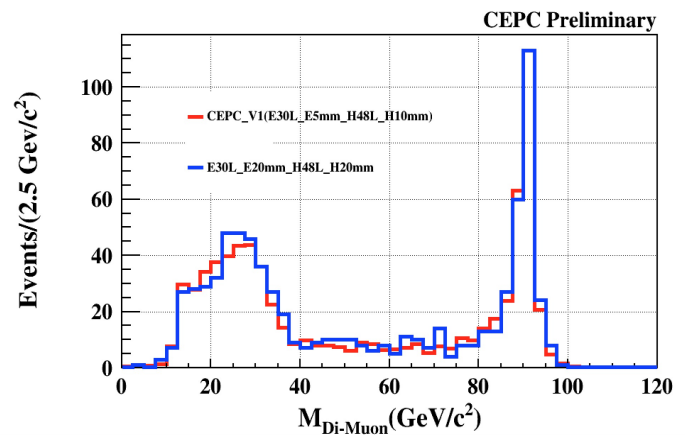
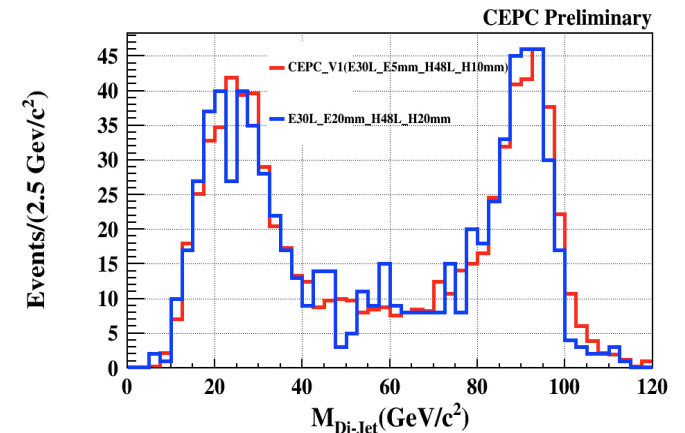
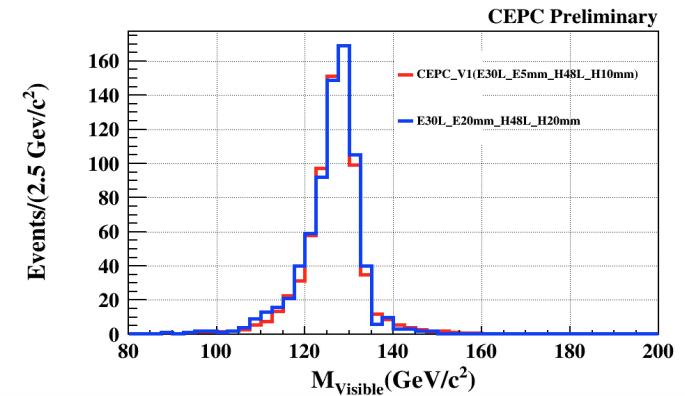
Lepton + Jets: $\text{Br}(\text{H} \rightarrow \text{ZZ})$



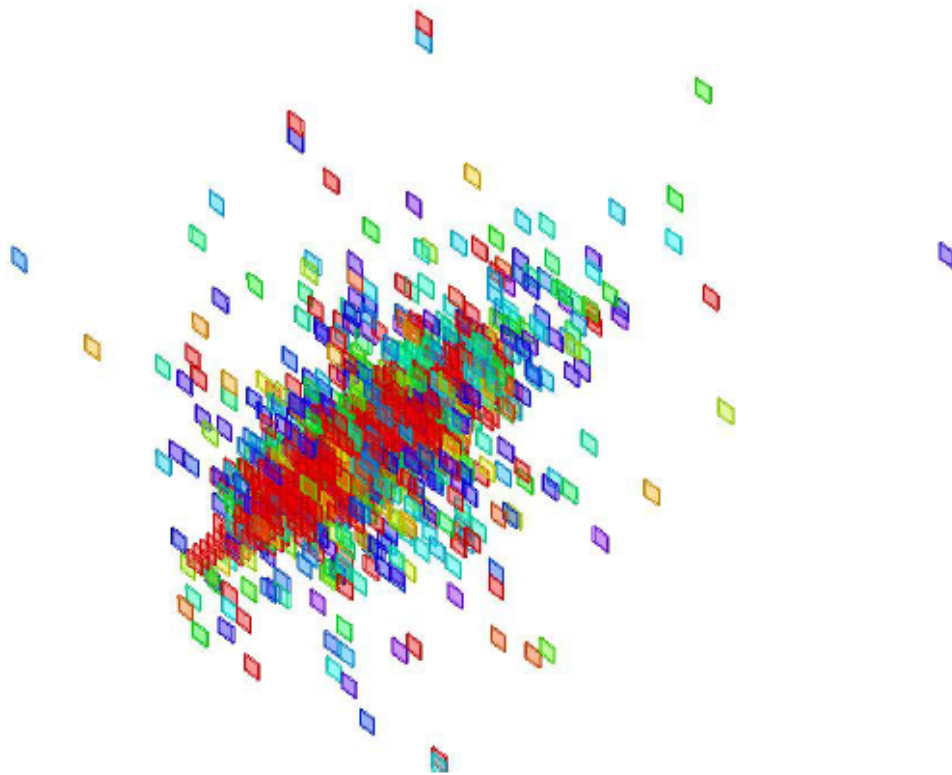
$\text{Br}(\text{H} \rightarrow \text{ZZ})$ via vvH , $\text{H} \rightarrow \text{ZZ}^* \rightarrow \text{llqq}$

Over all event reco. efficiency reduced $\sim 2\%$

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

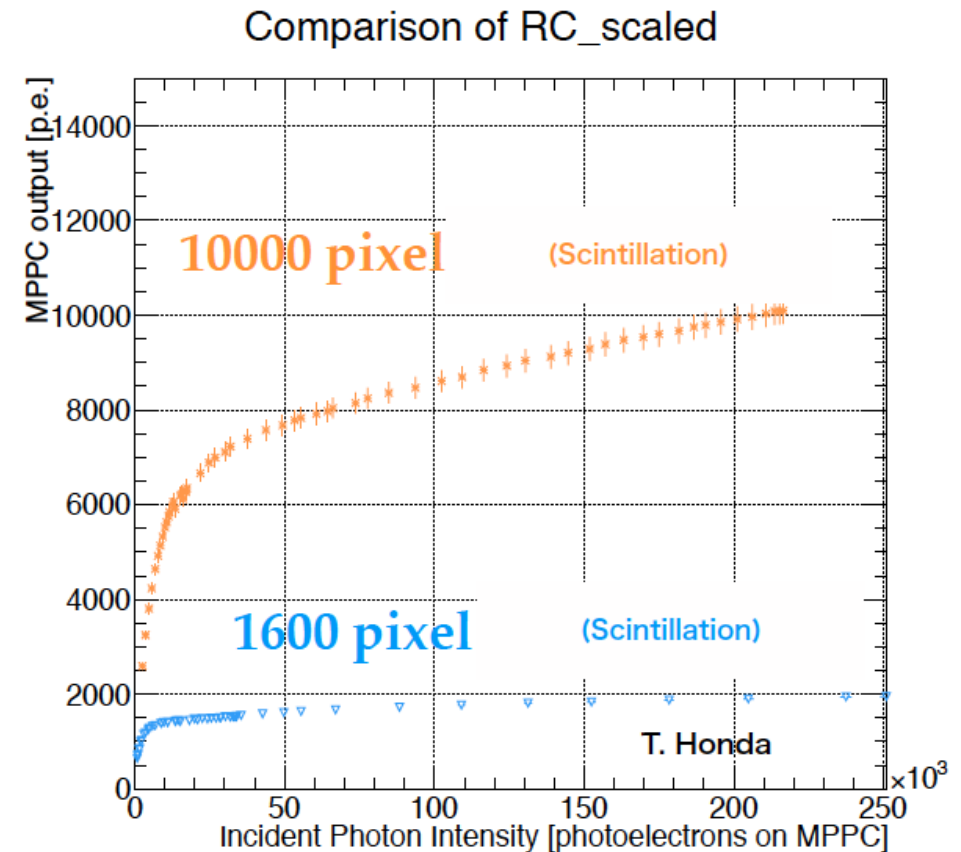


ECAL Saturation/Linear Range Study



50 GeV Photon Cluster
at ECAL with 10 mm Cell Size

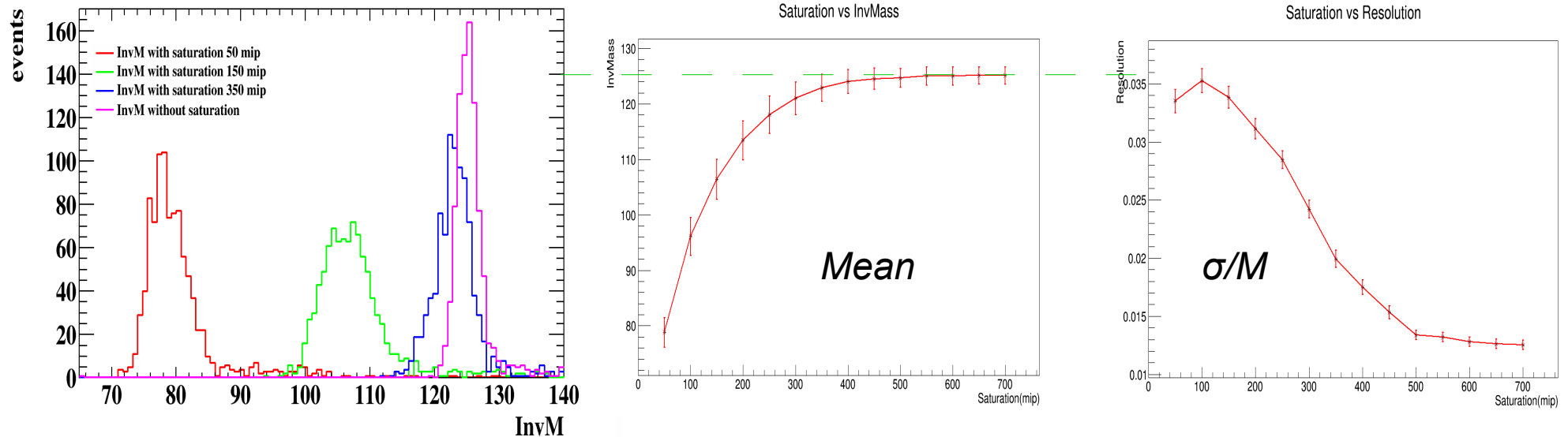
~o(1k) hits, hottest hit with $E \sim 1k$ MIP.



T.Takeshita, ILDDDET@KEK

Scintillator: $MIP \rightarrow Photon \rightarrow P.E$

Impact on $H \rightarrow \gamma\gamma$ measurement



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

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

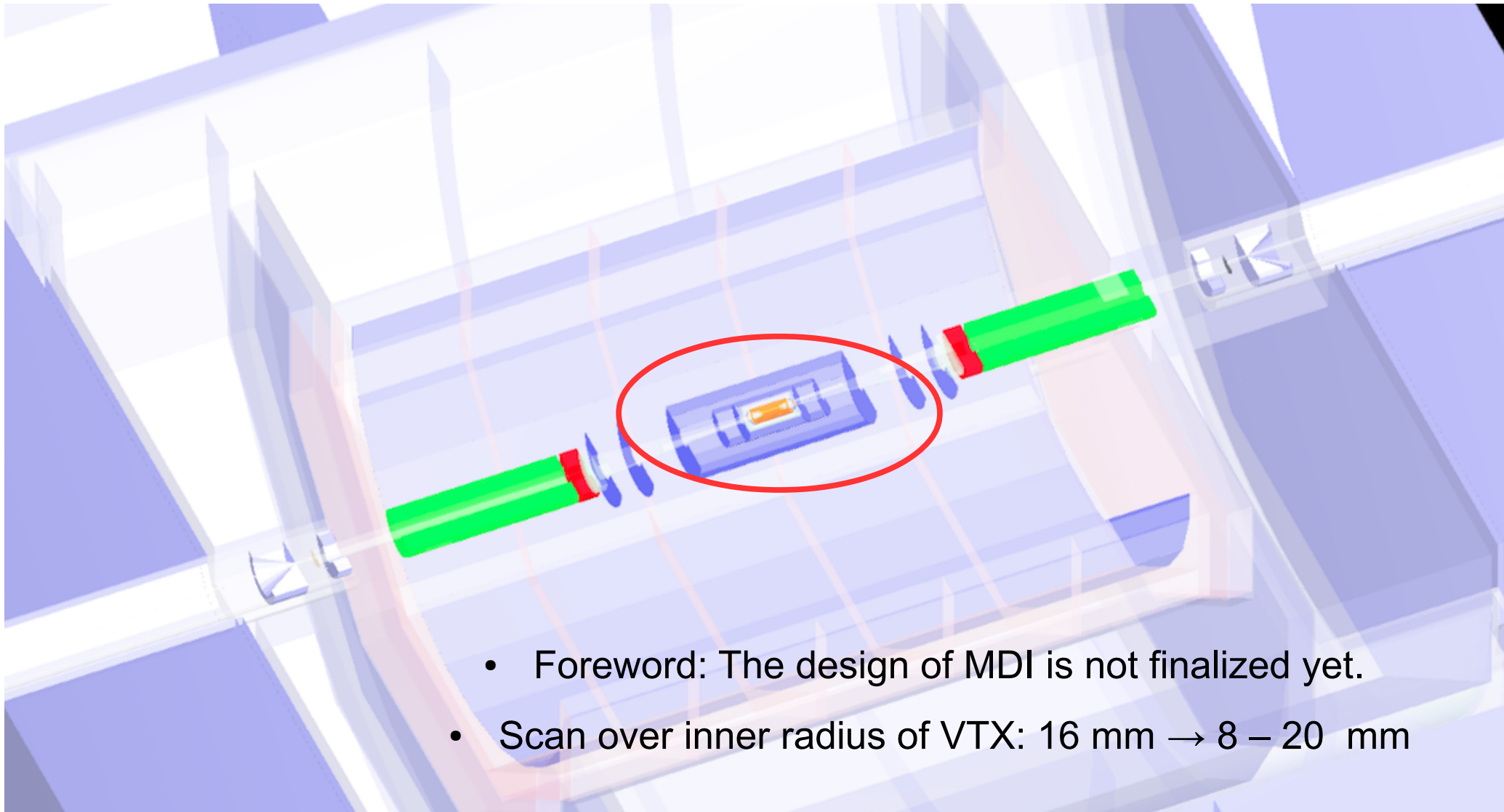
Empirical formula on needed ranger of a single photon:

$$\log_{10}(\text{Ranger}) = 0.87 \cdot x + 0.97 \cdot y - 0.24 \cdot y^2 + 1.26$$

$x = \log_{10}(E)$, $y = \log_{10}(\text{Cell Size/cm})$

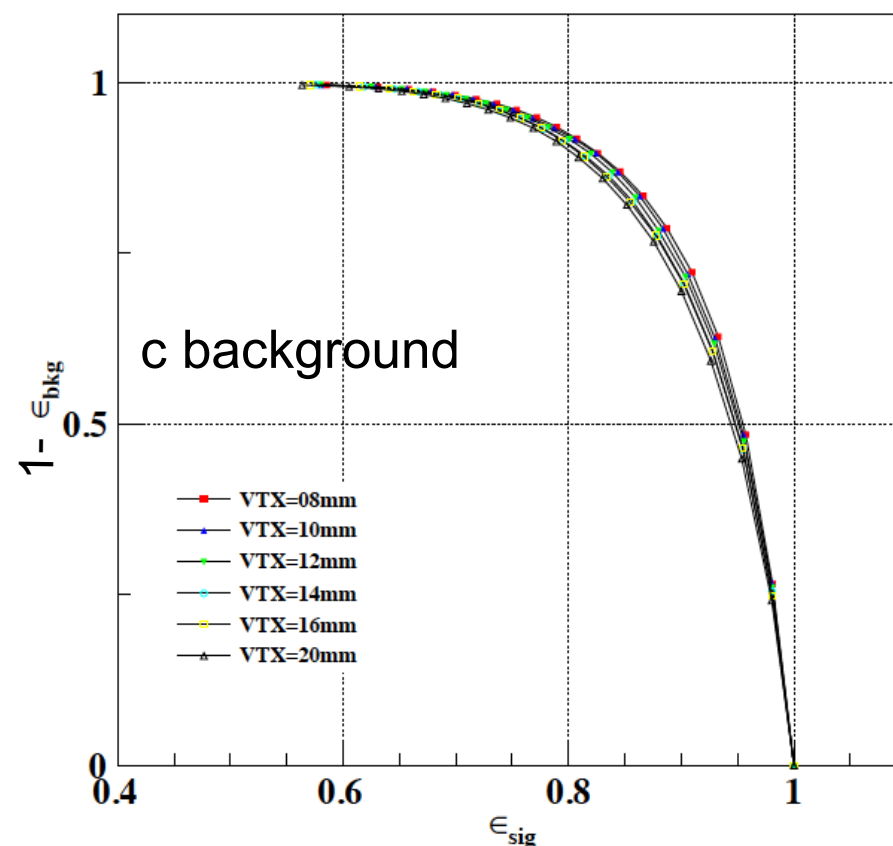
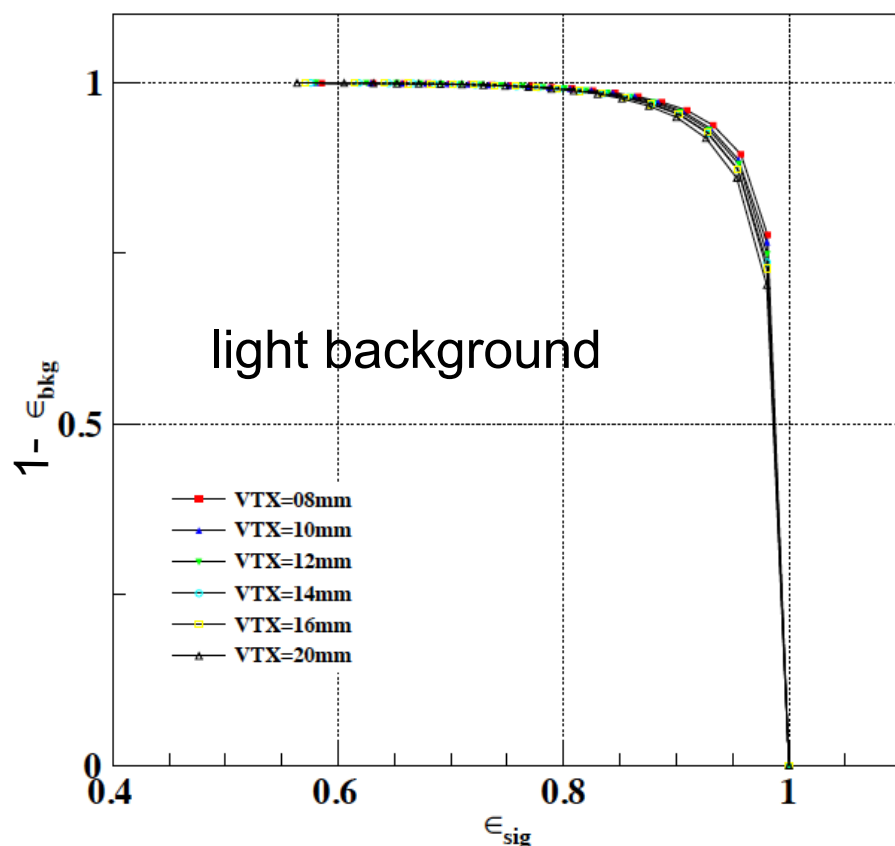
Shuzheng Wang

Vary the VTX inner Radius



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

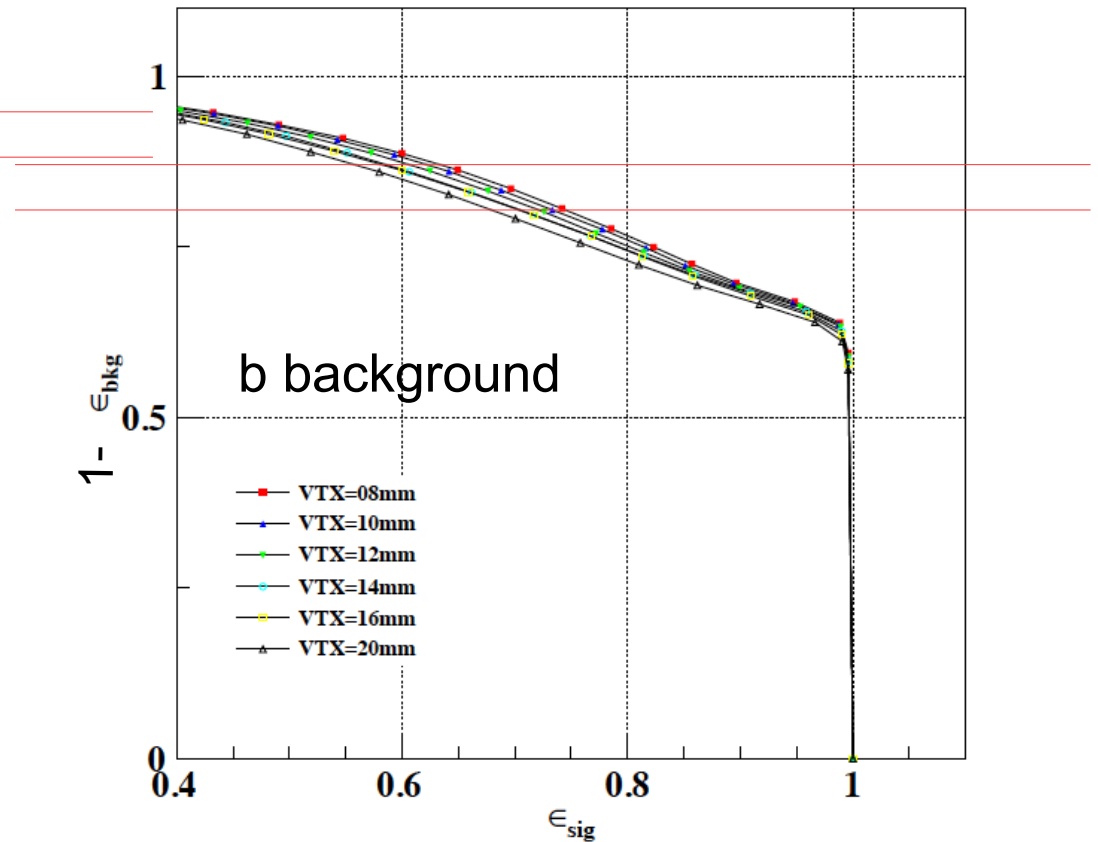
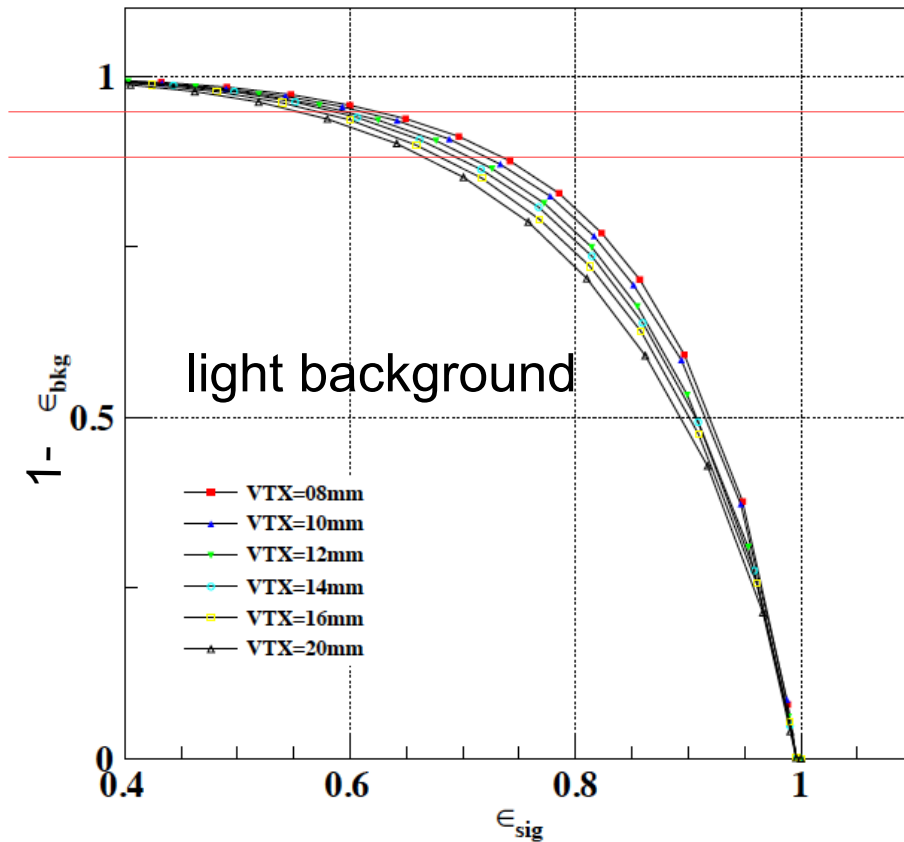
B-tagging @ different radius



Gang Li

- With 8 – 20 mm VTX Inner radius, very good *b*-tagging
 - At efficiency $\sim 80\%$: 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

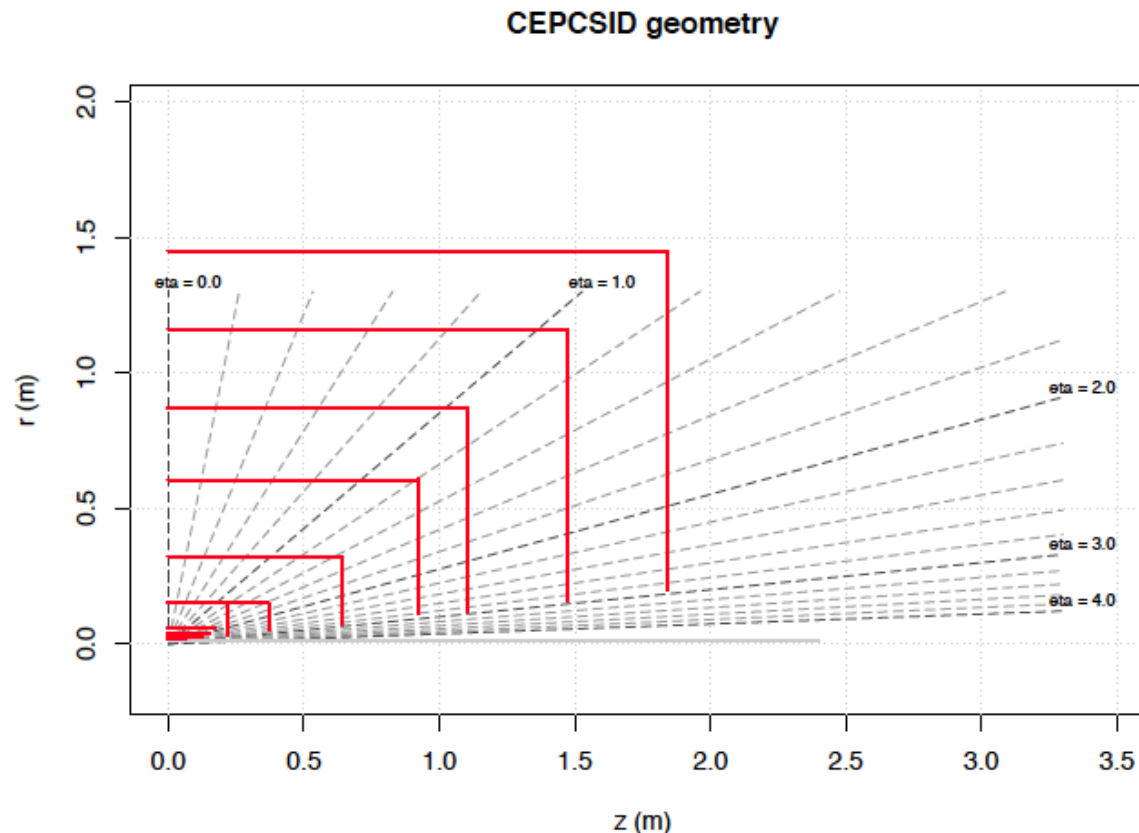


- At the same purity: C-tagging efficiency could be improved by $\sim 10\%$ by reducing the inner radius from 20 mm to 8 mm...

Full Silicon Tracker Concept for CEPC*

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

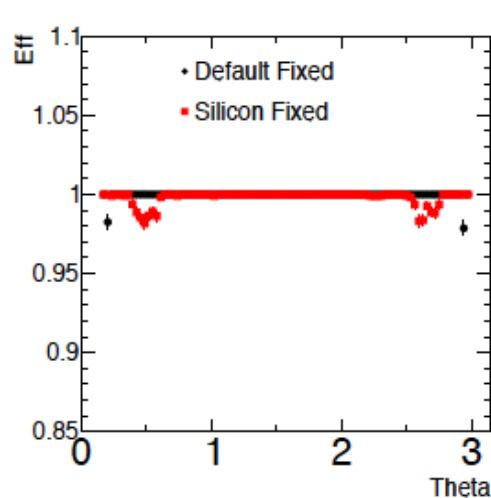
- CEPC full silicon has been implemented in Mokka.
- Based on CEPC V1 silicon tracker, we replace TPC with additional SIT layers and FTD endcaps.
- The advantage is to recycle CEPC silicon tracking.



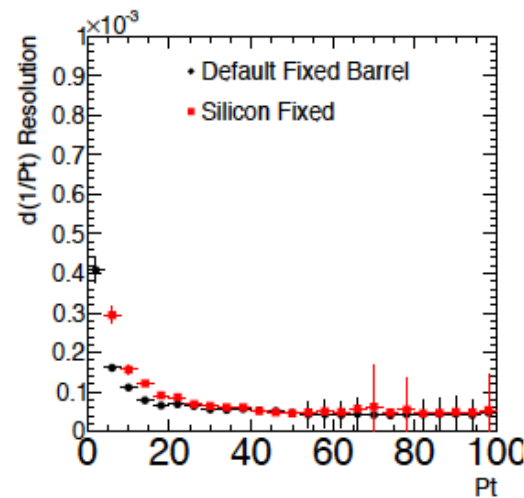
**Prof.
Weiming Yao**

Full Detector Simulation and Reconstruction

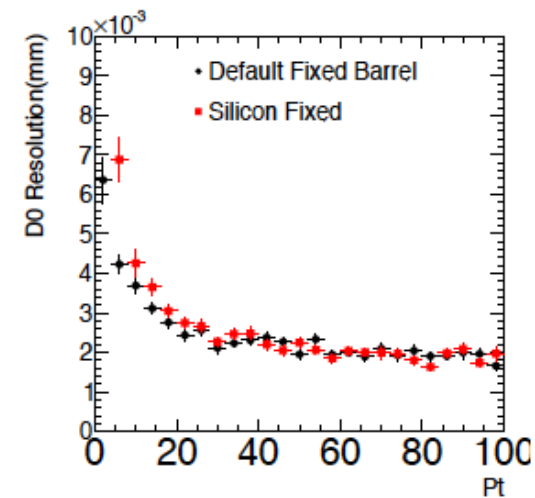
- Generated single muon with CEPC full silicon
- Reconstructed using Marlin Silicon only.
- The performance is comparable to CEPC V1.



(a) Eff vs theta



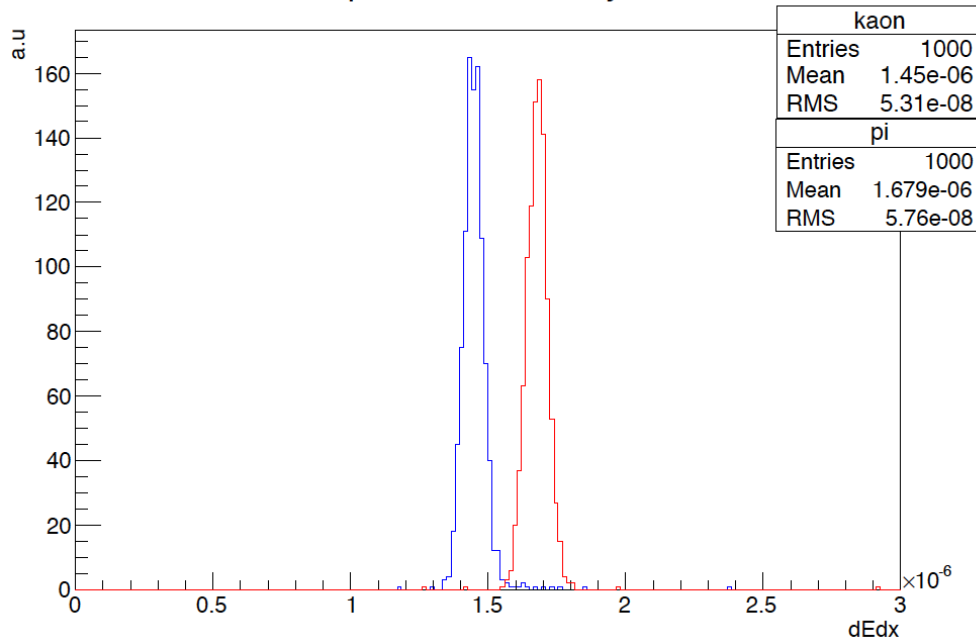
(b) $\sigma(1/pt)$ vs Pt



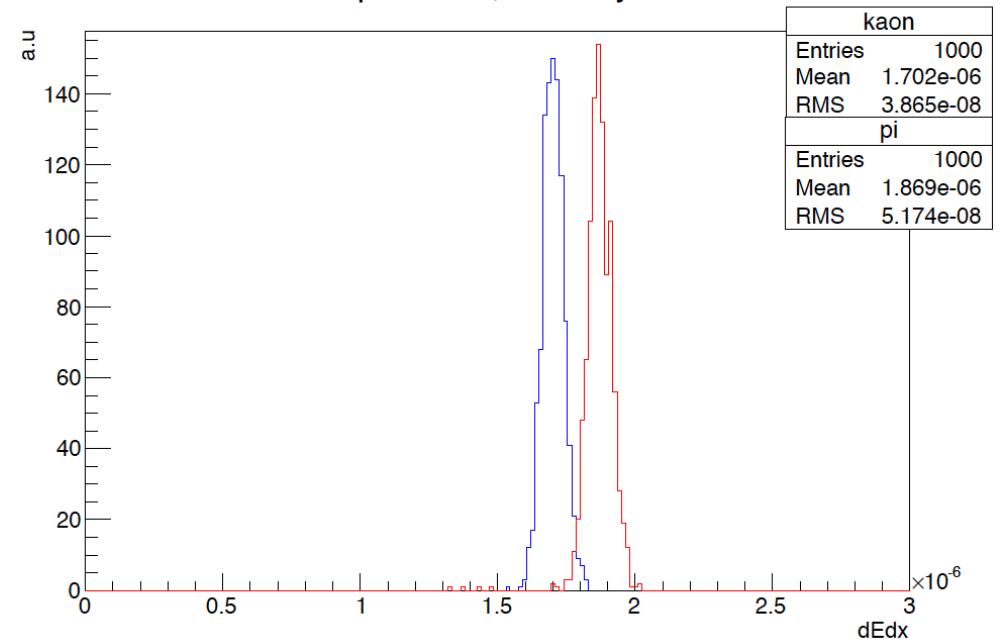
(c) $\sigma(D0)$ vs Pt

TPC

Sep 10GeV, 220 Layers



Sep 40GeV, 220 Layers



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

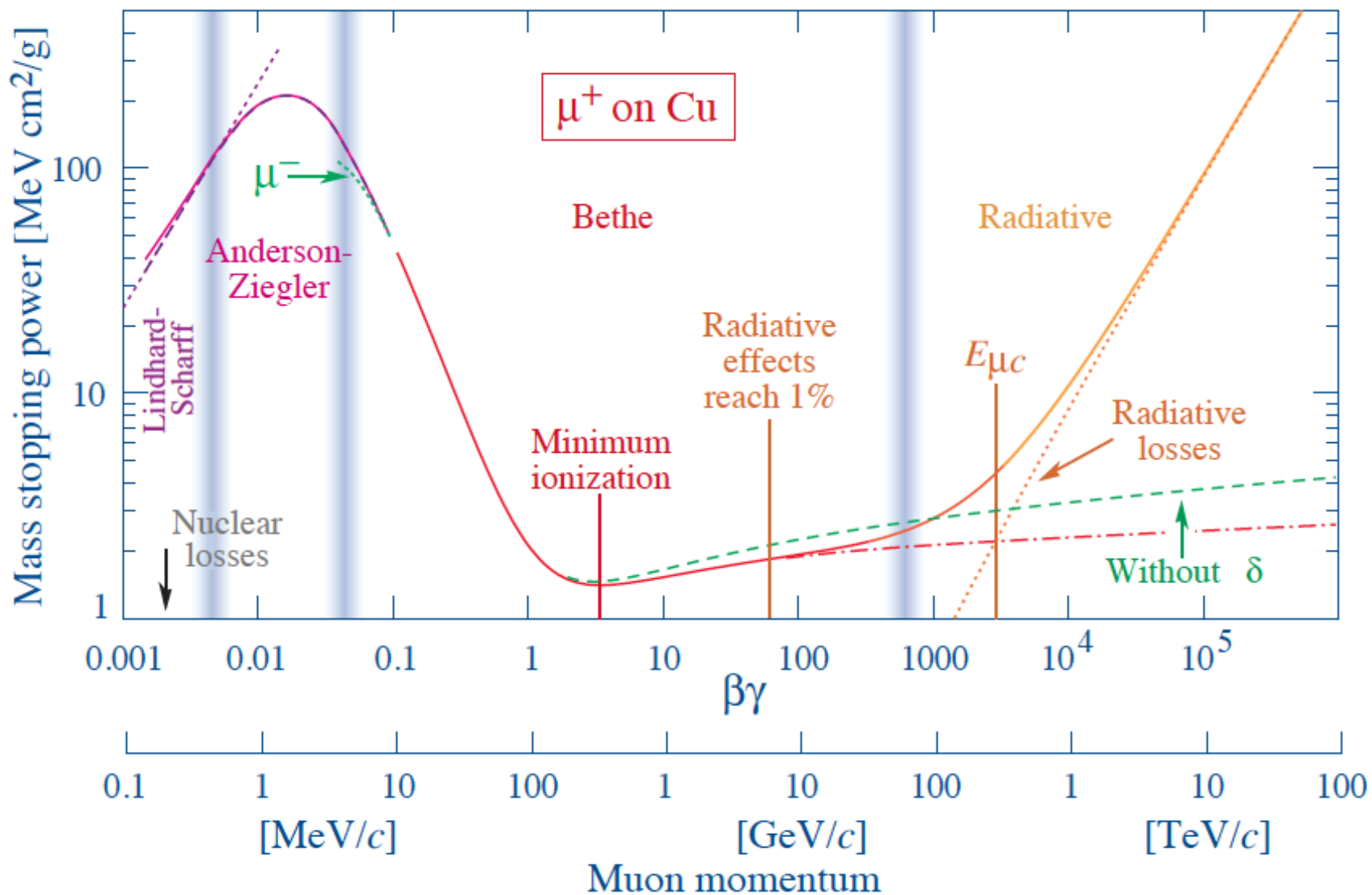
- Higgs analyses:
 - Mostly covered at full simulation level & results slightly varied from preCDR
 - Significant progress on $H \rightarrow VV$ and $H \rightarrow \text{Exotic}$ decay measurements
 - To do: Higgs analyses with tau/multi-jets final states: need dedicated tau finder & jet clustering algorithm
- 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 $\sim 1\text{-}2\%$** in Higgs recoil analysis via lepton channel, $\text{Br}(H \rightarrow WW \rightarrow \mu\nu qq)$, $\text{Br}(H \rightarrow ZZ \rightarrow ll qq)$ 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



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
μμεeqq/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)

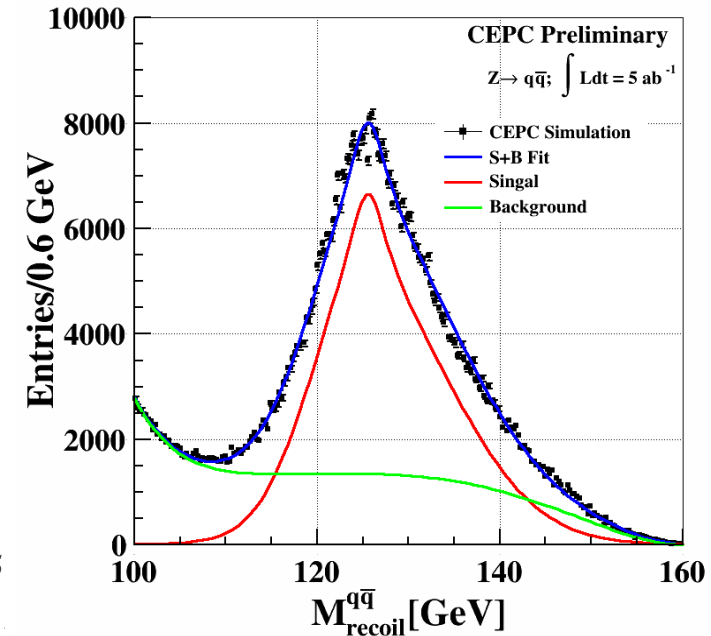
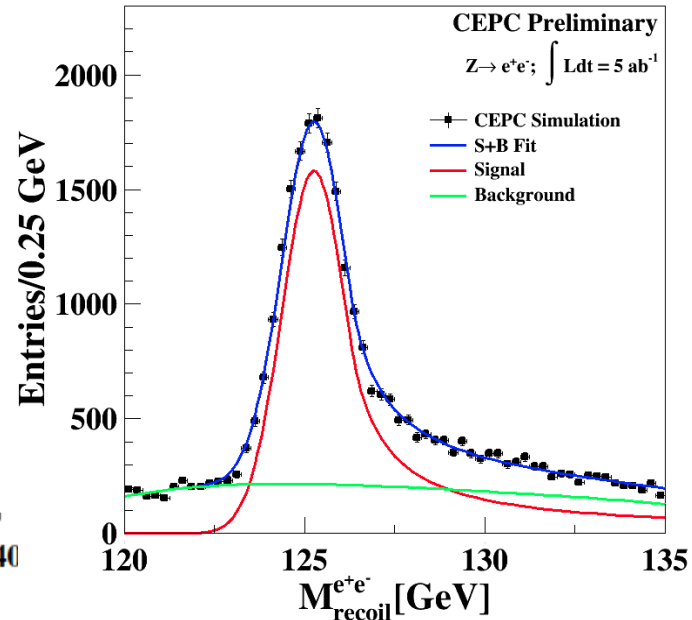
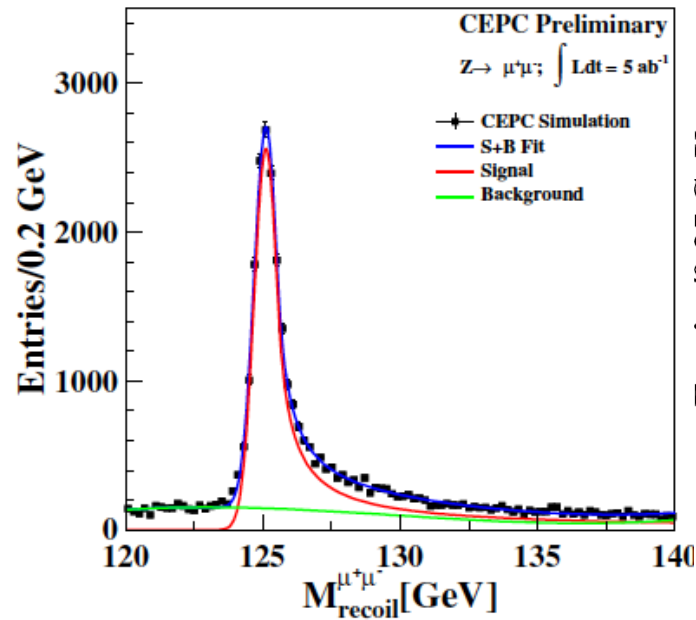
ZH, H→WW*	Yield	Object reconstructed	Isolation	Signal Efficiency	Main Background	Accuracy	Combined
Z($\mu\mu$)H(evev)	88	76(86.36%)	61(80.26%)	36(40.91%)	4(ZH)	17.57%	2.68%
Z($\mu\mu$)H($\mu\nu\mu\nu$)	89	80(89.89%)	77(96.25%)	52(58.43%)	6(ZH&ZZ)	14.65%	
Z($\mu\mu$)H(ev $\mu\nu$)	174	157(90.23%)	147(93.63%)	105(60.34%)	0	9.76%	
Z($\mu\mu$)H(evqq)	1105	1042(94.30%)	864(82.92%)	663(60.00%)	45(ZH)	4.02%	
Z($\mu\mu$)H($\mu\nu$ qq)	1110	1056(95.14%)	988(93.56%)	717(64.59%)	159(ZH&ZZ)	4.13%	
Z($\mu\mu$)H(qqqq)	Preliminary						3.0%
Z(ee)H(evev)	91	62(68.13%)	60(96.77%)	22(24.16%)	16(SZ)	28.02%	2.87%
Z(ee)H($\mu\nu\mu\nu$)	82	63(76.83%)	63(100%)	44(53.66%)	24(SZ)	18.74%	
Z(ee)H(ev $\mu\nu$)	178	132(74.16%)	124(93.94%)	82(46.07%)	25(ZH&SZ)	12.61%	
Z(ee)H(evqq)	1182	1041(88.07%)	916(87.99%)	621(51.78%)	188(SZ&ZH)	4.62%	
Z(ee)H($\mu\nu$ qq)	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	1.45%	3.45k	2.3%	69.1k
$\mu\nu$ qq		1.14k	6.47k	2.2%
evqq		1.14k	6.47k	
eev		93	527	1.9k
$\mu\nu\nu$		93	527	1.9k
e $\mu\nu$		186	1154	3.7k
X + tau	3.2k	1.6k	9.14k	32.0k

Higgs invisible decays

Assuming $\sigma(ZH) \cdot \text{Br}(H \rightarrow \text{inv}) = 200 \text{ fb}$

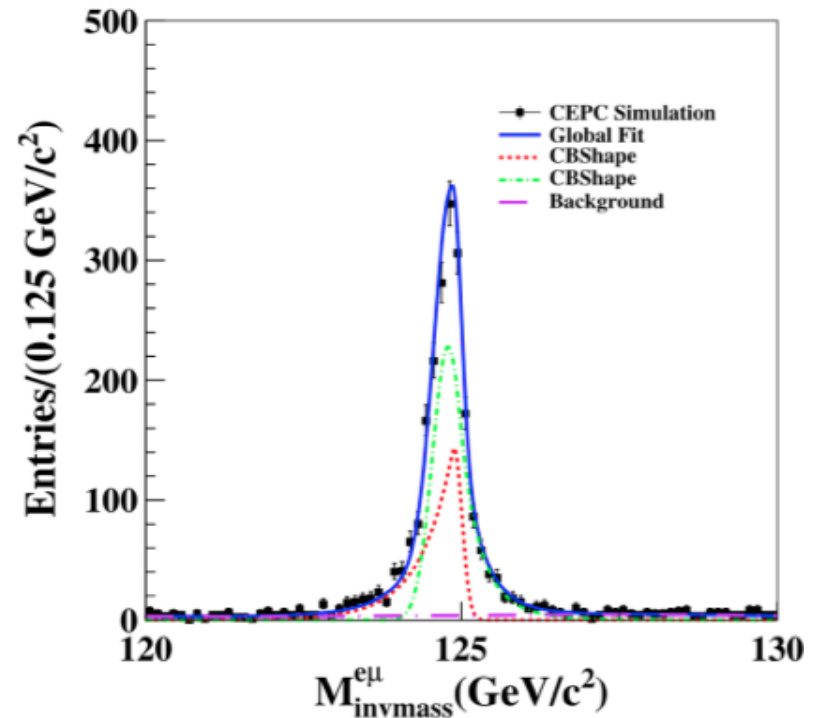
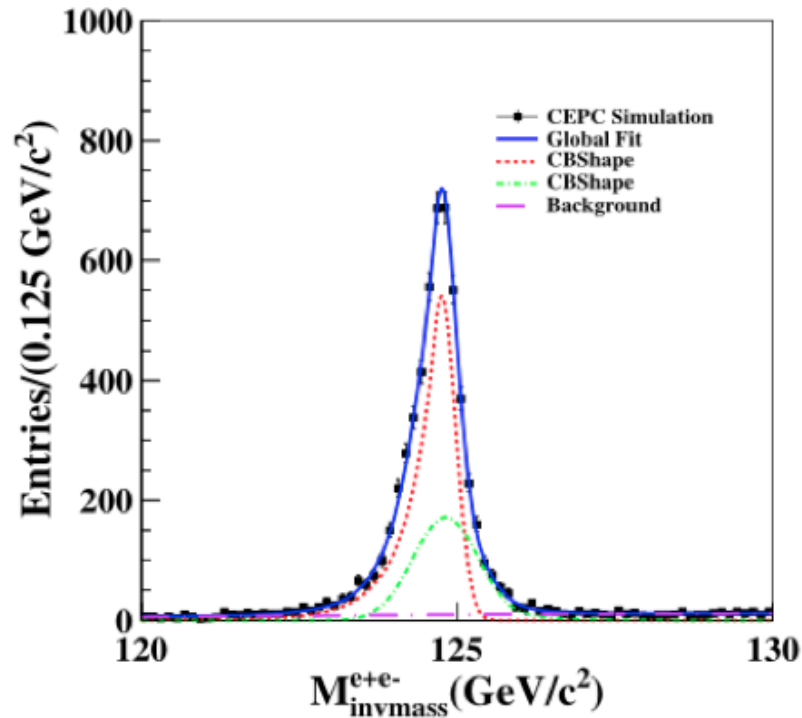


Invisible up limit at CEPC: 0.14% at 95% C.L

Up limit of $\text{Br}(H \rightarrow ee)$ & $\text{Br}(H \rightarrow e\mu)$

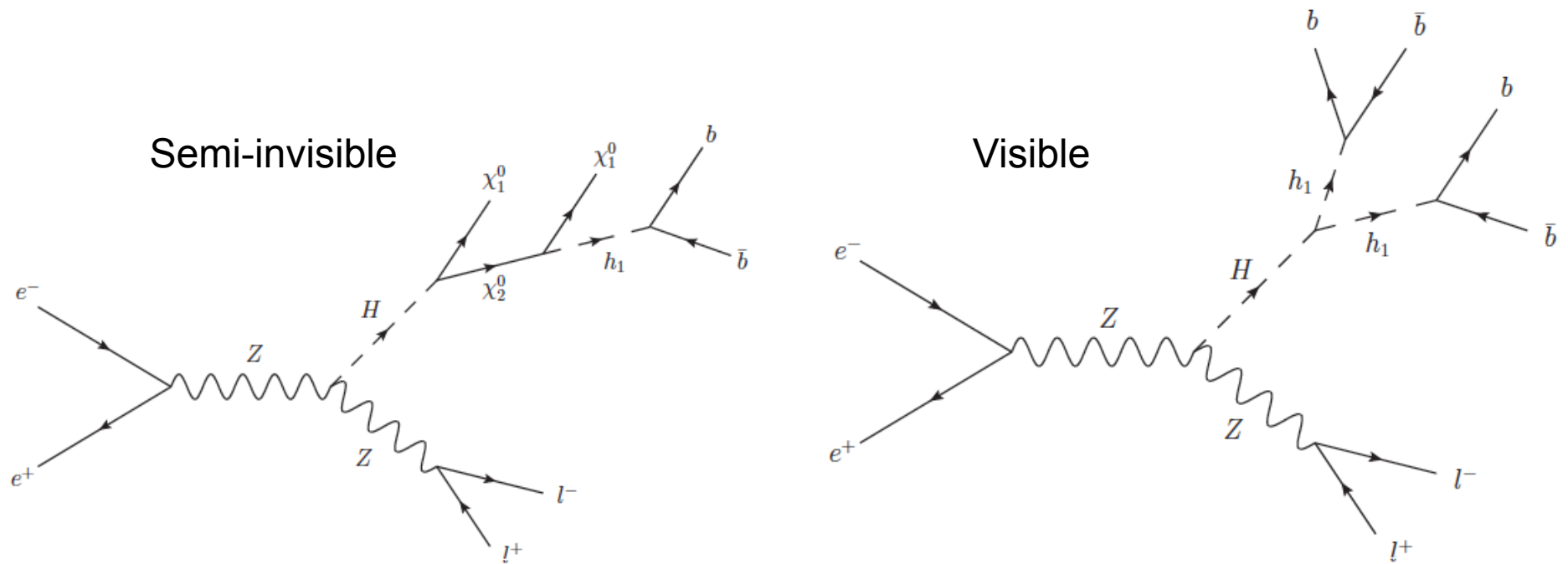
Lei Wang

Assuming $\sigma(\text{ZH}) \cdot \text{Br}(H \rightarrow ee/e\mu) = 200 \text{ fb}$



95% up limit: $\text{Br}(H \rightarrow ee) = 1.7\text{e-}4$;
 $\text{Br}(H \rightarrow e\mu) = 1.2\text{e-}4$;

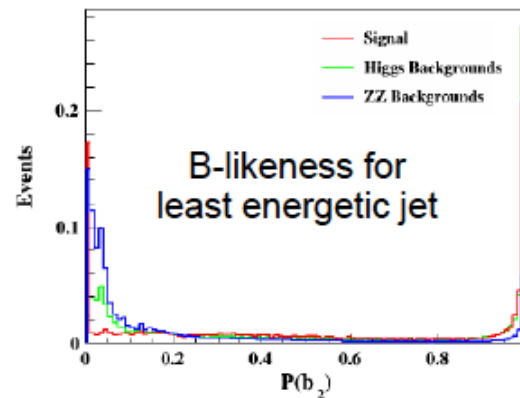
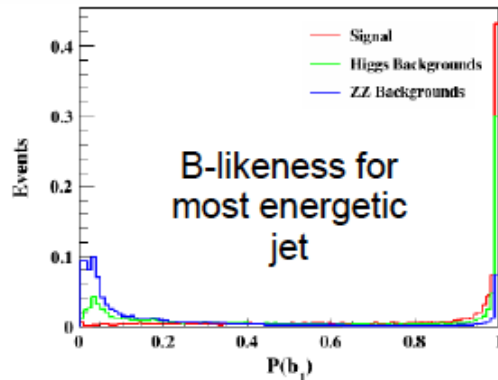
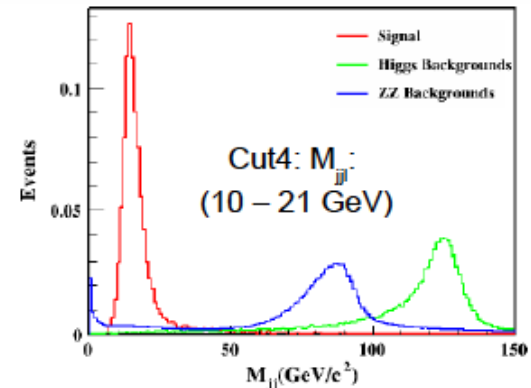
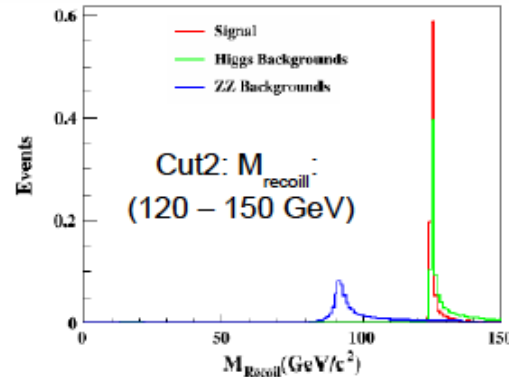
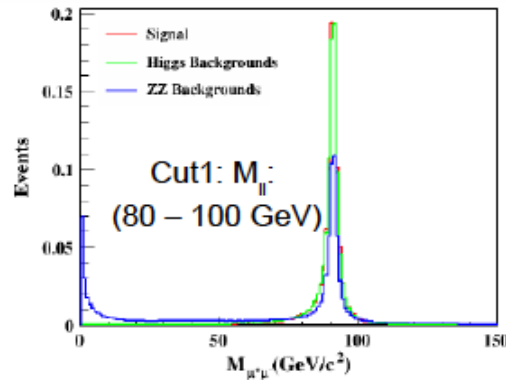
$H \rightarrow \text{Exotic, Hadronic}$



- 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 $\sim \mathcal{O}(10^{-4})$.

H->Exotic, hadronic

Para: $M(\text{LSP}) = 0$; $M(h_0) = 15 \text{ GeV}$; $M(\text{NLSP}) = 20 \text{ GeV}$

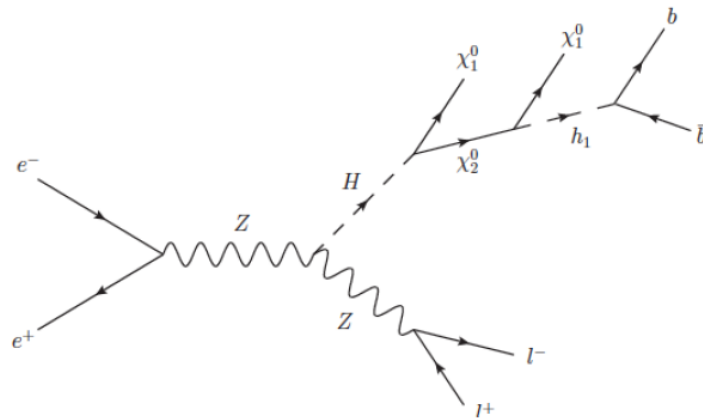


Object found	Cut 1 $m_{\mu\mu}$	Cut 2 m_{rec}	Cut 3 b likeness	Cut 4 m_{jj}
Signal	17	15	12	10
ZH BGs	34093	30732	30030	16026
ZZ BGs	538790	281198	30825	4274

Cut3: $\text{sum}(\text{B-likeness}) > 0.9$

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

H → Exotic, Hadronic

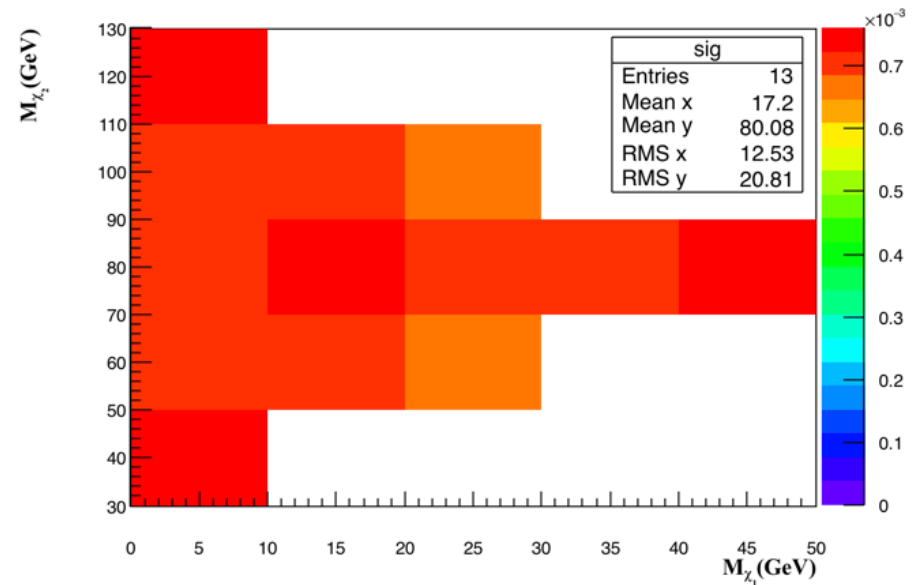
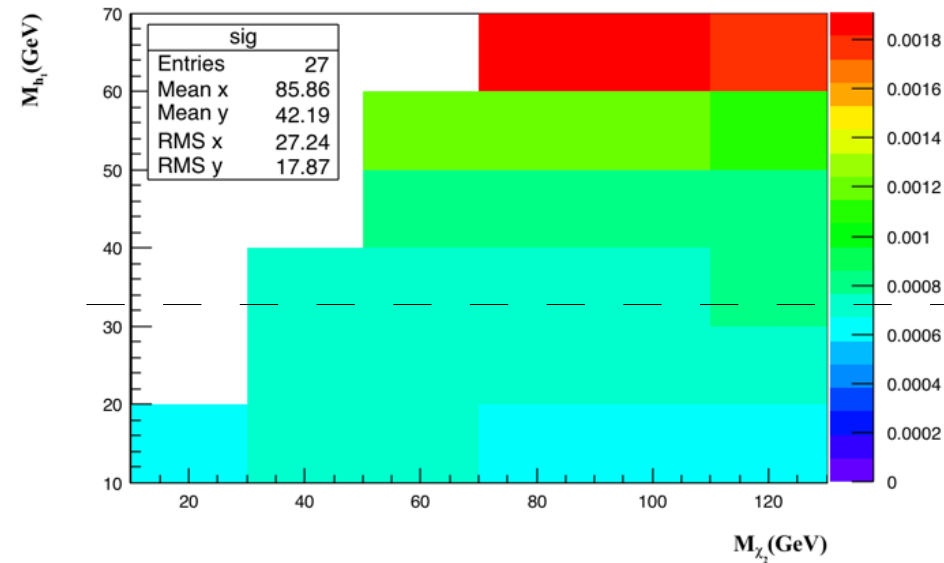


Benchmark Points

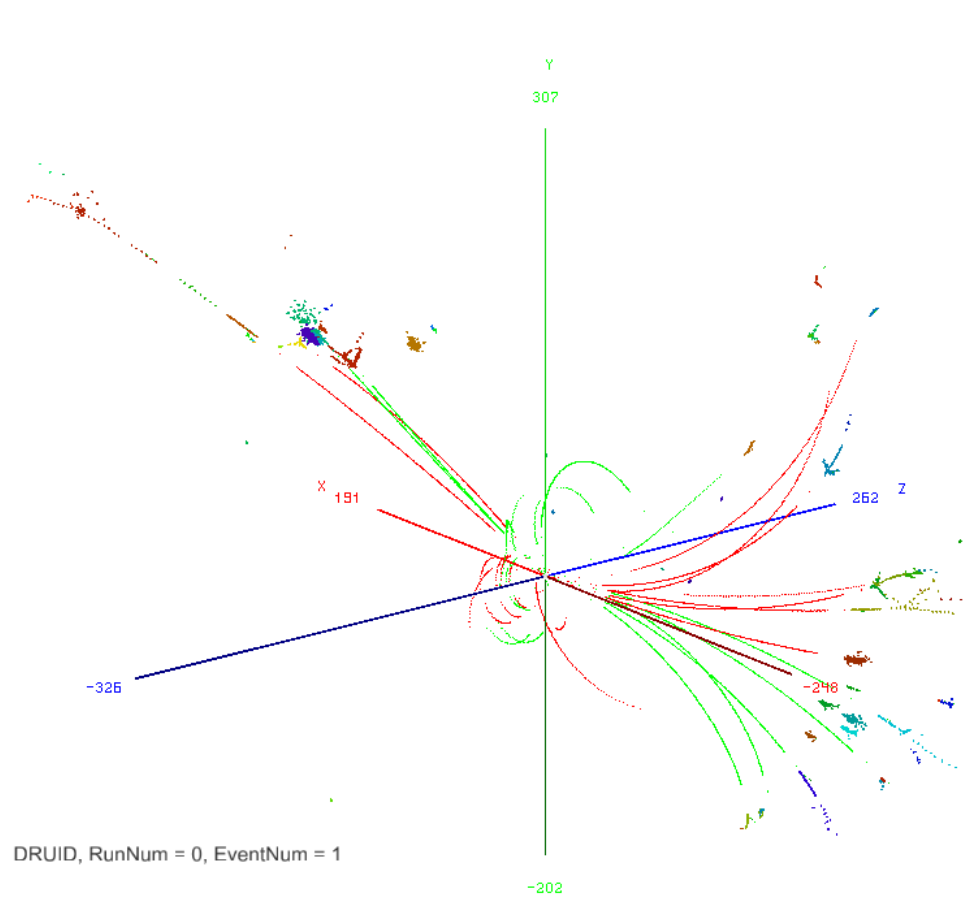
Scan over the parameter space for sensitivity:

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

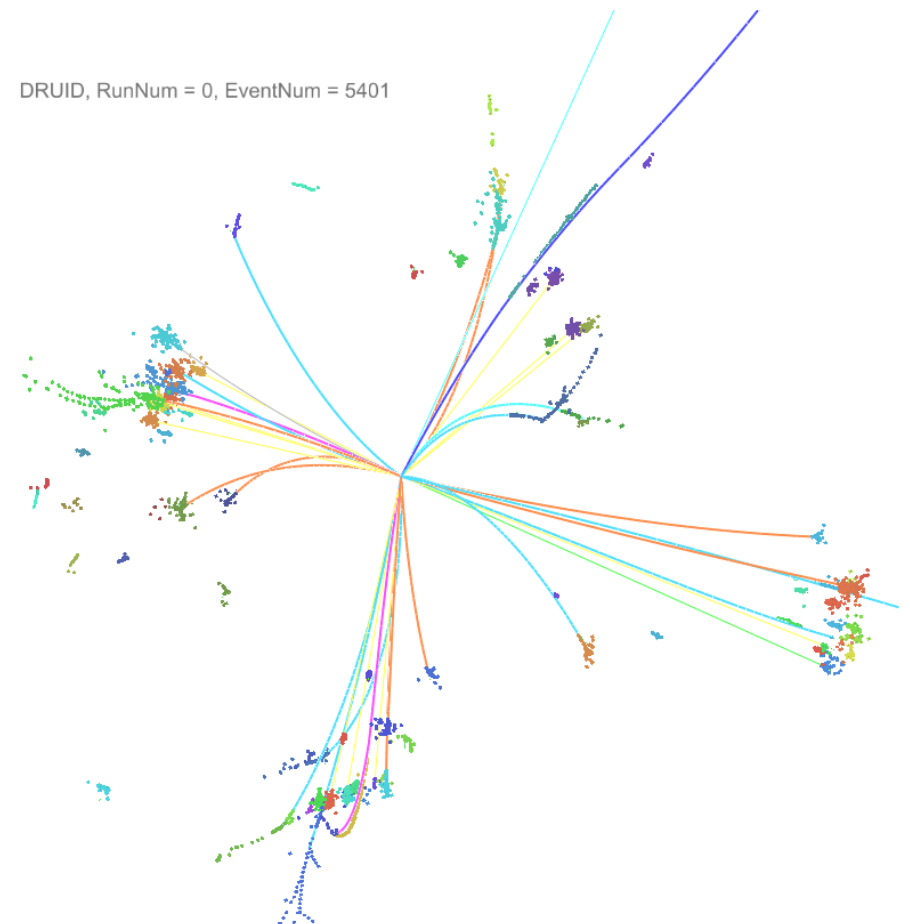
Suggested by prof. Liu



Simulated Higgs Event @ CEPC

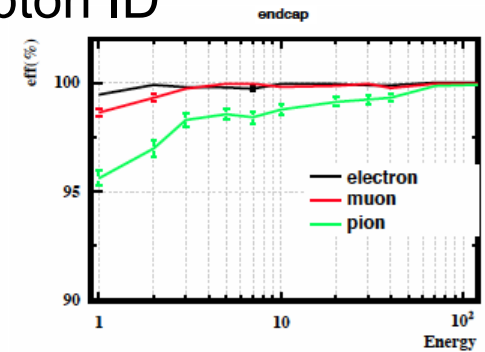
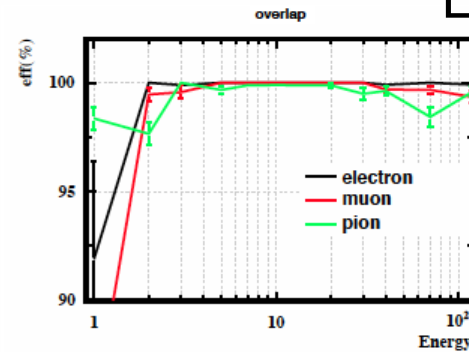
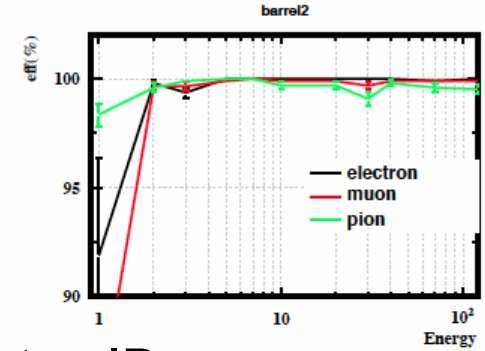
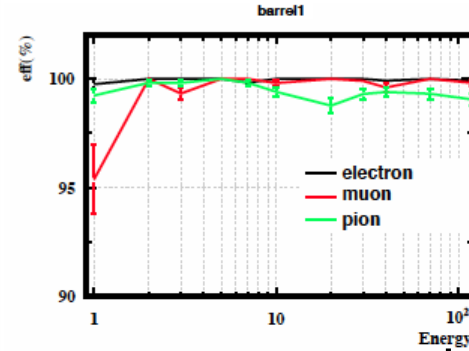
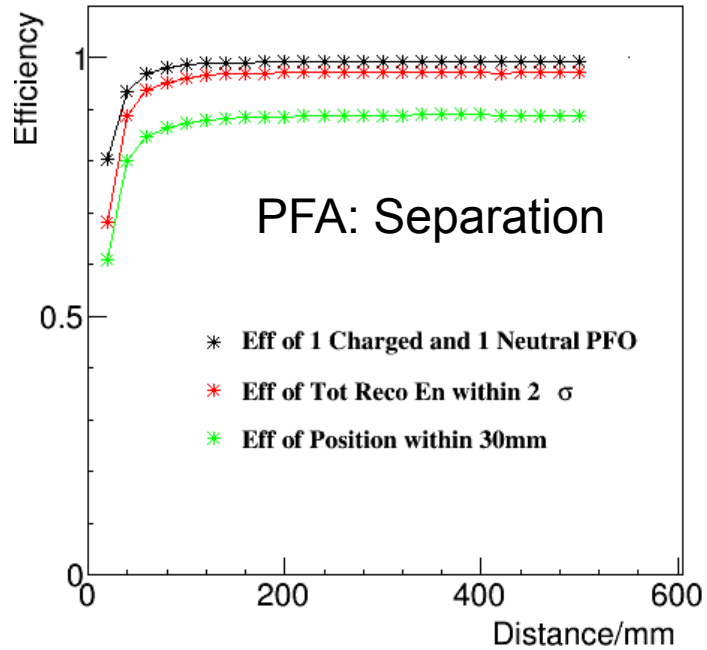


~25% of Higgs events

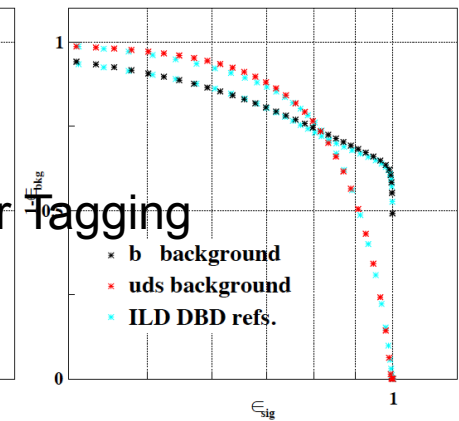
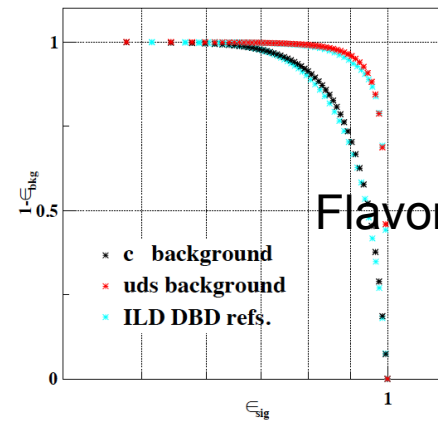
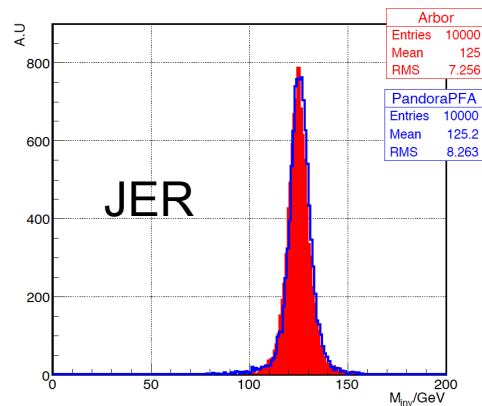
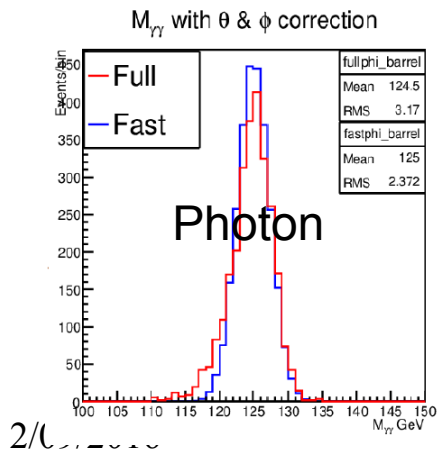


~50% of Higgs events

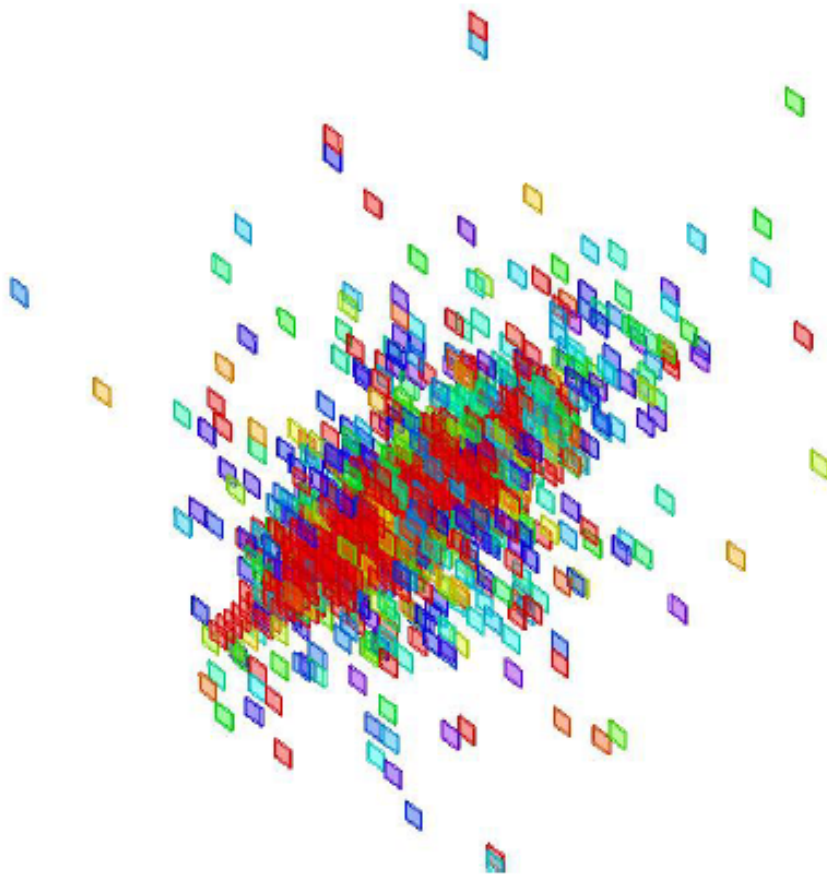
Reconstructions



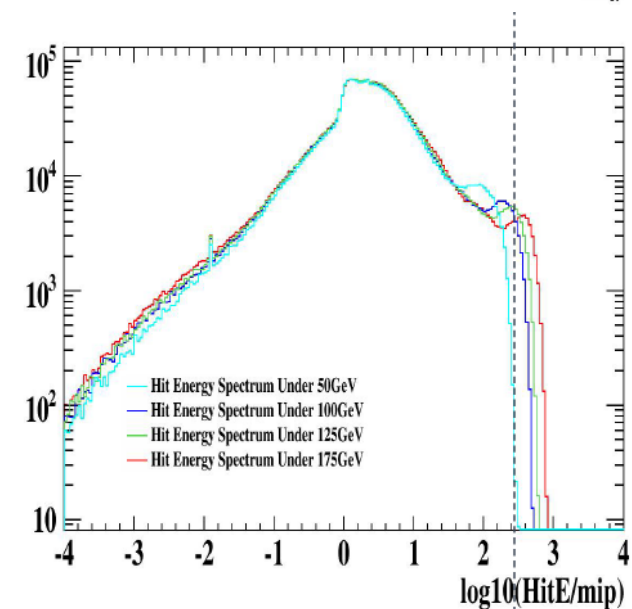
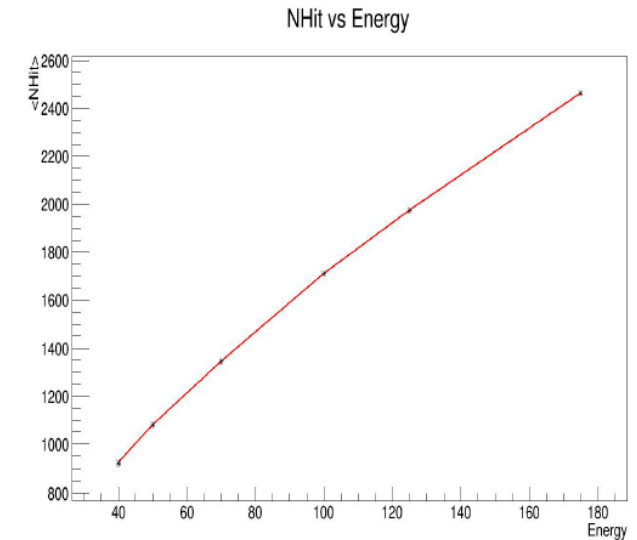
Lepton ID



ECAL Saturation/Linear Range Study



50 GeV Photon Cluster
at ECAL with 10 mm Cell Size



JER, $\text{Br}(H \rightarrow \text{inv})$ via ZH , $Z \rightarrow qq$