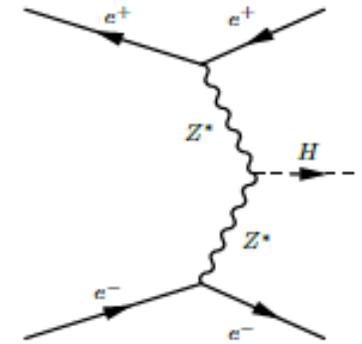
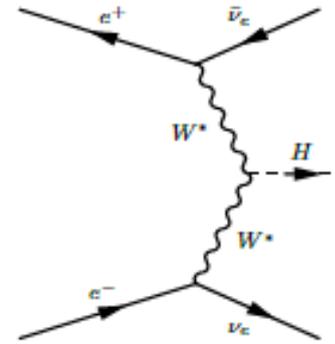
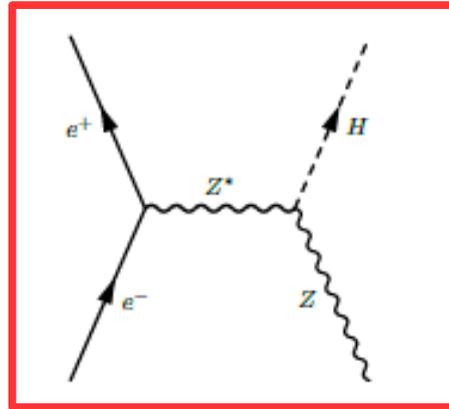
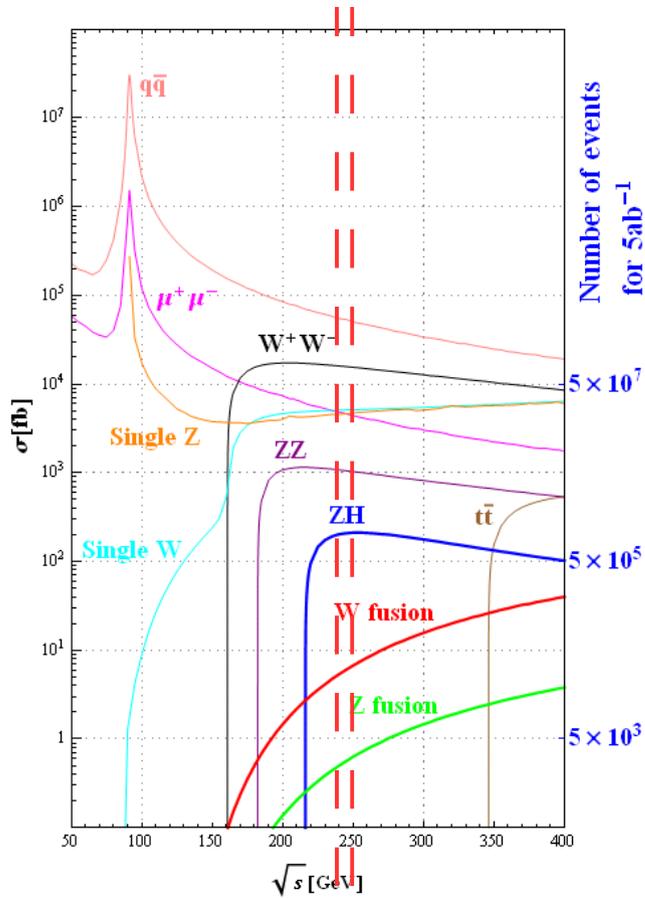


# Higgs analysis and Detector Optimization at CEPC

Manqi

for CEPC Detector Optimization & Simulation Group

# Higgs @ CEPC

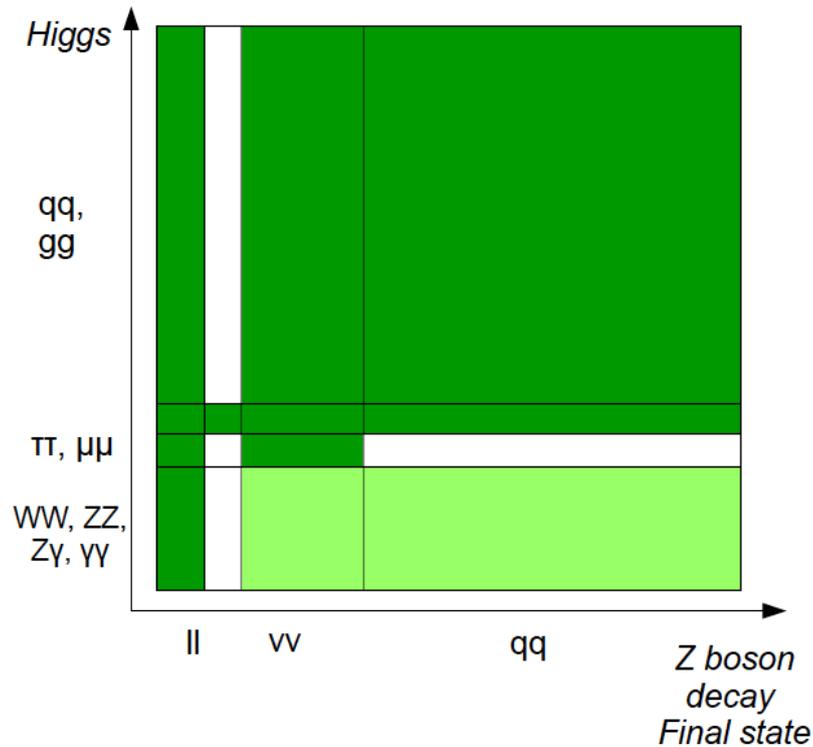


Process	Cross section	Events in 5 ab <sup>-1</sup>
Higgs boson production, cross section in fb		
$e^+e^- \rightarrow ZH$	212	$1.06 \times 10^6$
$e^+e^- \rightarrow \nu\bar{\nu}H$	6.72	$3.36 \times 10^4$
$e^+e^- \rightarrow e^+e^-H$	0.63	$3.15 \times 10^3$
Total	219	$1.10 \times 10^6$

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**

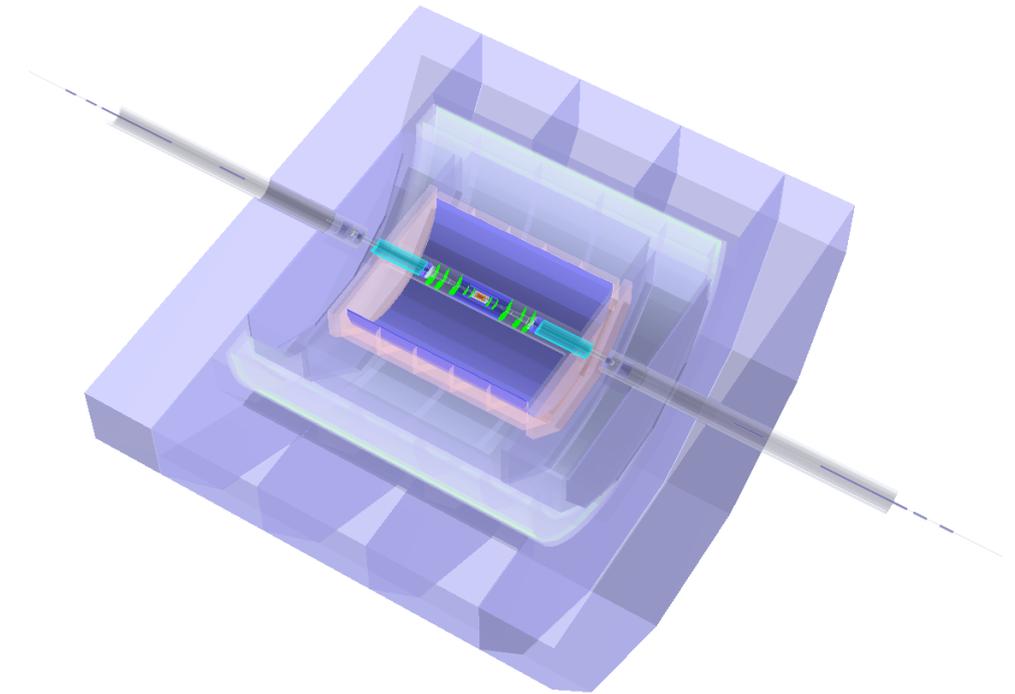
# Higgs analysis & conceptual detector



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

To be covered:

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

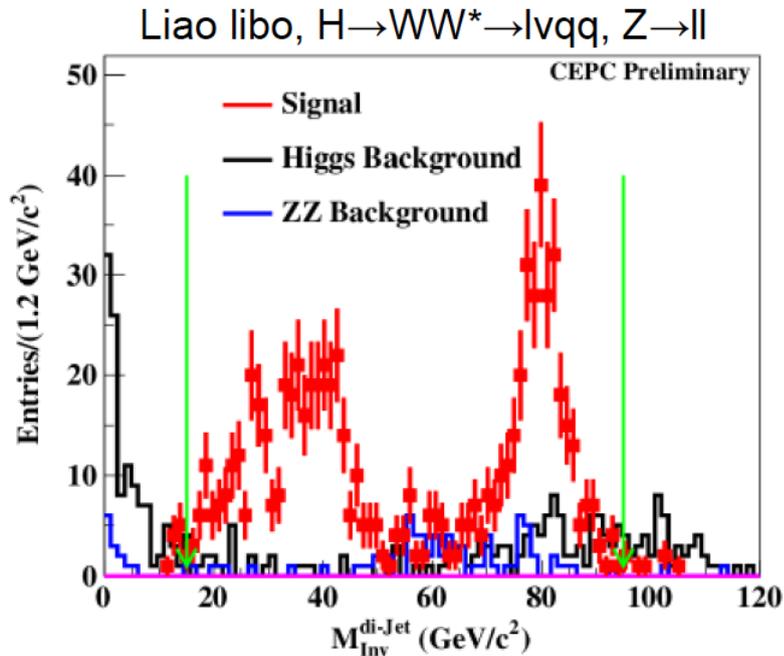


Reconstruct all the physics objects (lepton,  $\gamma$ , tau, Jet, MET, ...) with high efficiency/precision

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

# Br(H→WW)

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



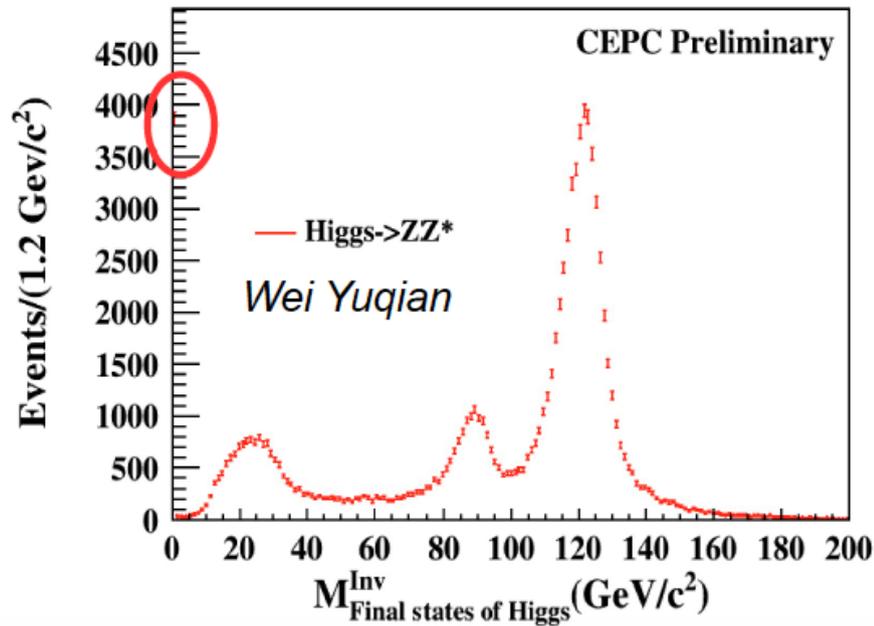
Expected Number of events with different objects

	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
μμνν	186	93	527	1.9k
eμνν	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,  $H \rightarrow WW^* \rightarrow$  inc channels, 12 independent channels.
  - ~ 1.7% at vvH,  $H \rightarrow WW^* \rightarrow 4q$  channel (Preliminary. ILC extrapolation = 2.3%)
  - 2.3% at qqH,  $H \rightarrow WW^* \rightarrow 2ql\nu$  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

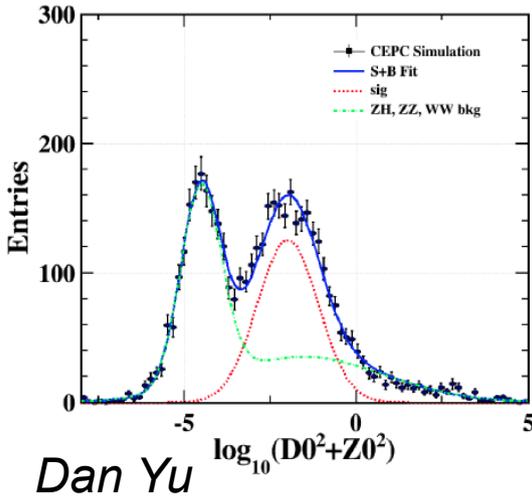
	Z→ll	tautau	vv	qq
H→ZZ*→4q	888	444	3.10k	9.24k
2v + 2q	508	254	1.77k	5.29k
2l + 2q	170	85	596	1.8k
4v	73	36	254	756
2l + 2v	49	24	170	508
4l	8	4	28	86
X + tau	120	60	418	1246

	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

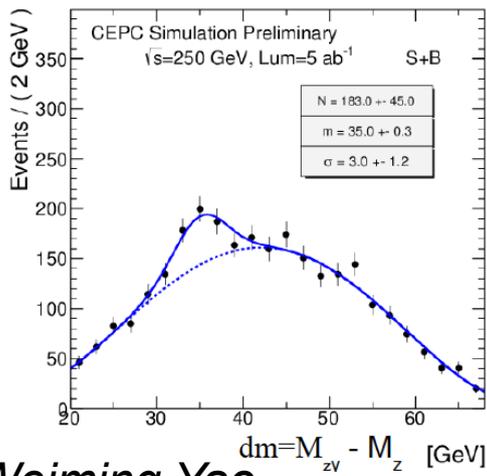
- Br(H→ZZ), explored at 18 different channels with full simulation (llvvqq, 4lqq, ll4q, 2l4v)
  - 8 Channels has individual accuracy better than 25%: Combined accuracy ~ **5.4%**
  - 8 with accuracy worse than 25 - 50%
  - 2 with accuracy worse than 50% (llH, H→ZZ→4q and vvH, H→ZZ→llvv)
- High efficiency in event reconstruction

# Status

Br(H→ττ) via Z to ll



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

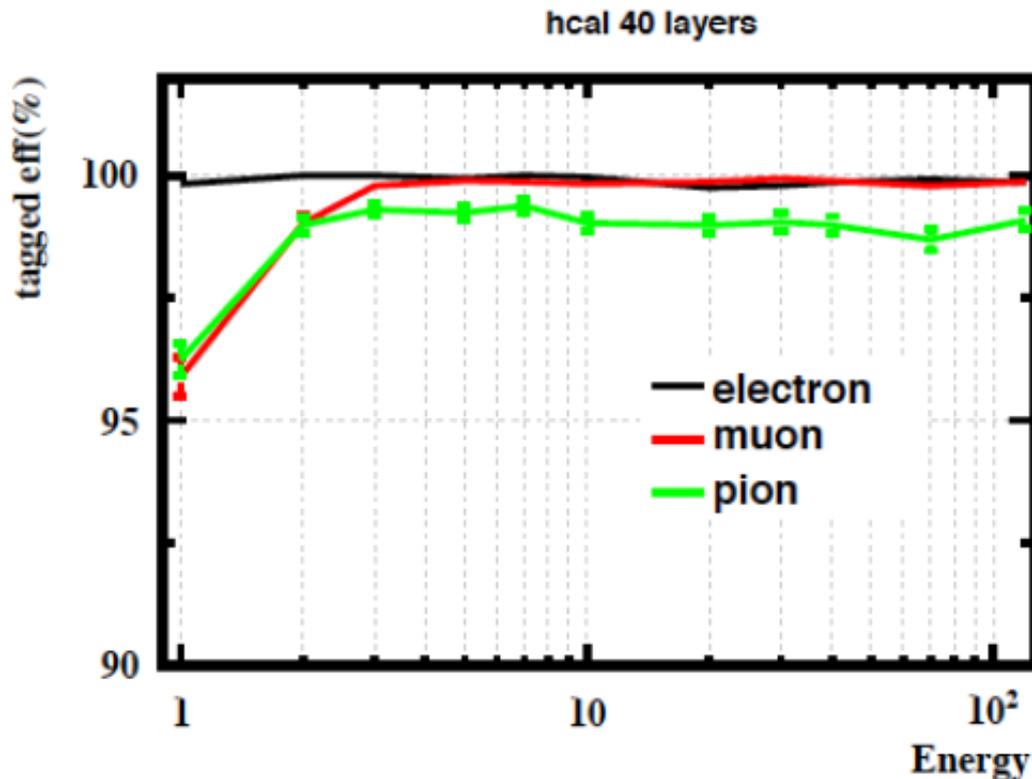


	PreCDR (Jan 2015)	Now (Aug 2016)
$\sigma(\text{ZH})$	0.51%	0.50%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{bb})$	0.28%	0.21%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{cc})$	2.1%	2.5%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{gg})$	1.6%	1.3%
$\sigma(\text{ZH}) \cdot \text{Br}(\text{H} \rightarrow \text{WW})$	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→di lepton, Higgs to inc;*
      - *Z→vv; H→WW→lvqq;*
      - *Z→vv; H→ZZ→llqq;*
- ECAL Saturation studies on H→γγ measurements

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



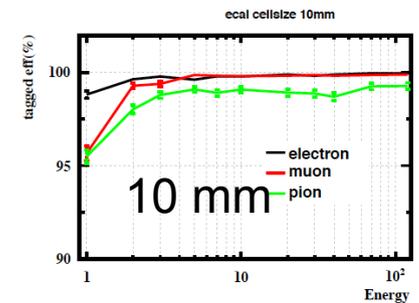
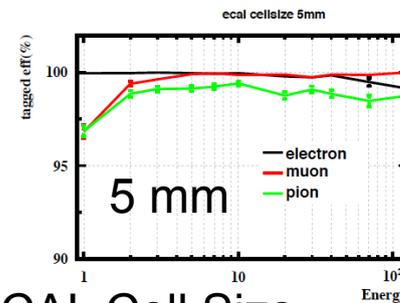
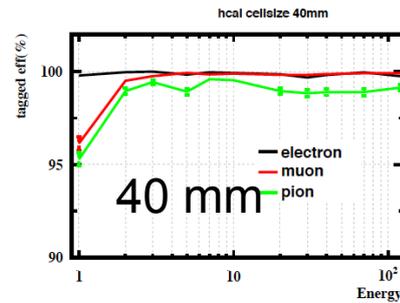
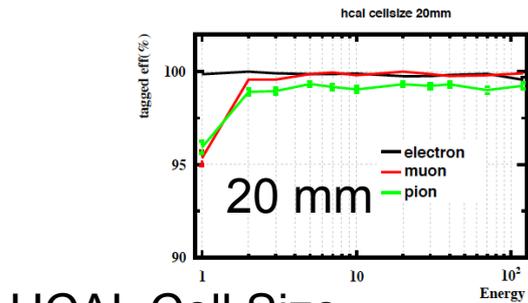
Scanned Settings:

- 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.*

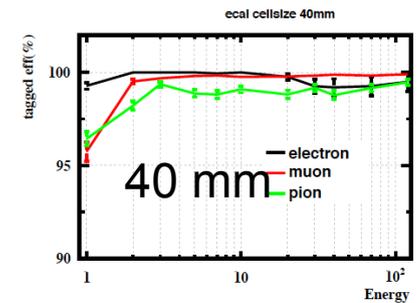
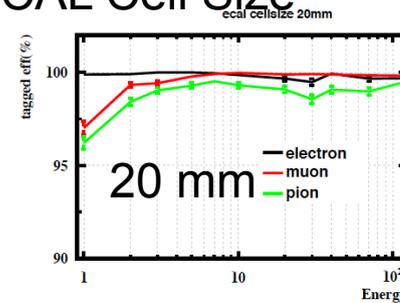
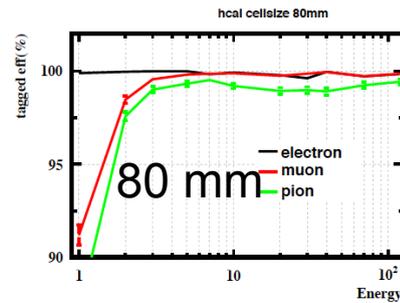
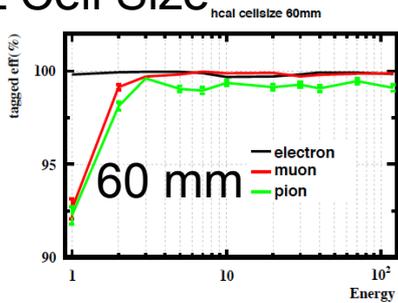
At Single Particle level, for  $E > 2$  GeV charged reconstructed particle:  
lepton efficiency  $> 99.5\%$  && Pion mis id rate  $< 2\%$

# Vary the granularity



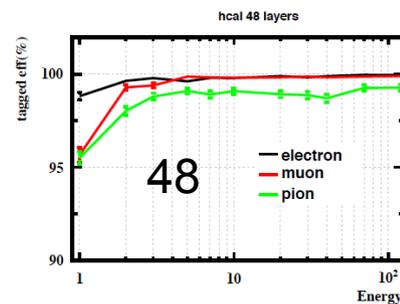
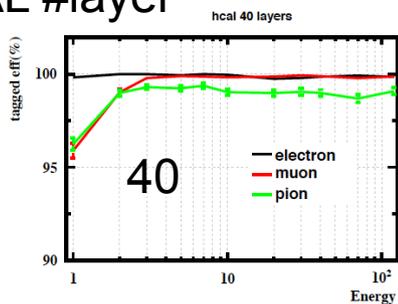
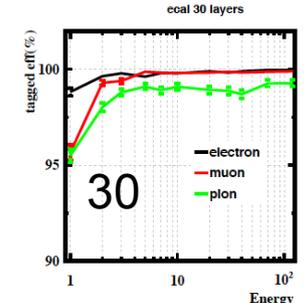
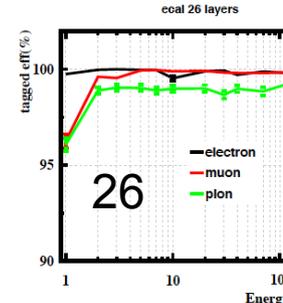
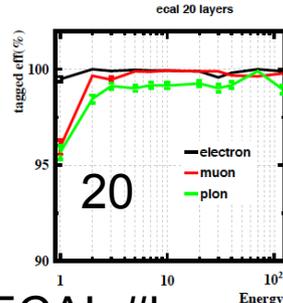
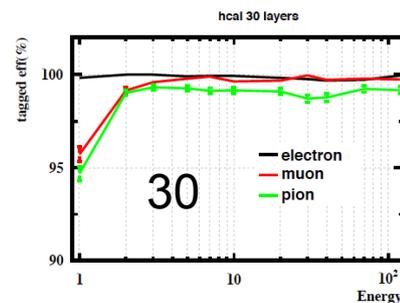
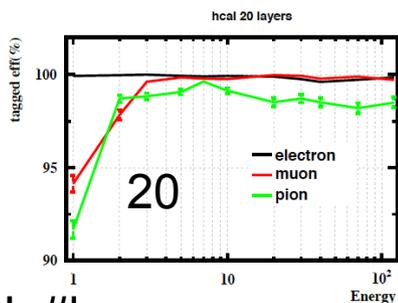
HCAL Cell Size

ECAL Cell Size



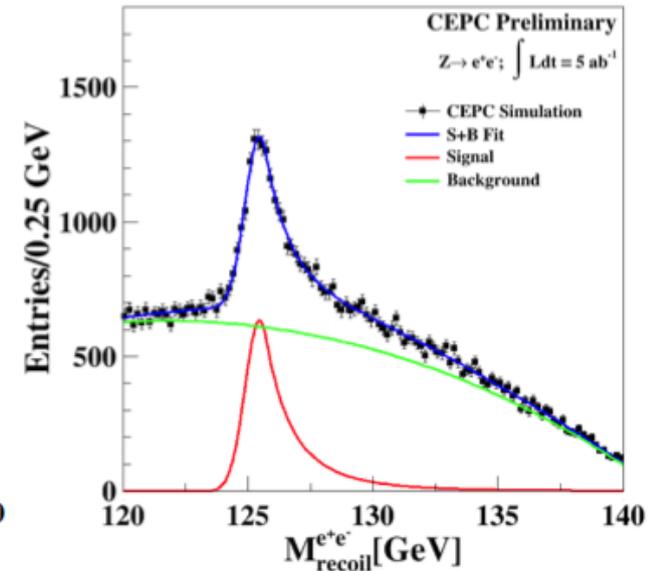
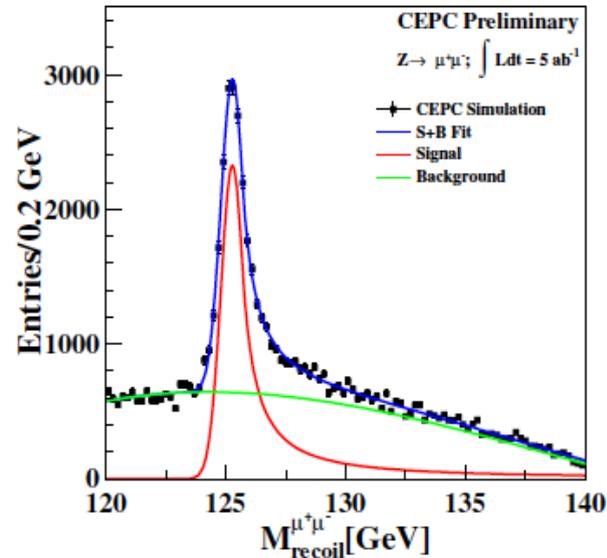
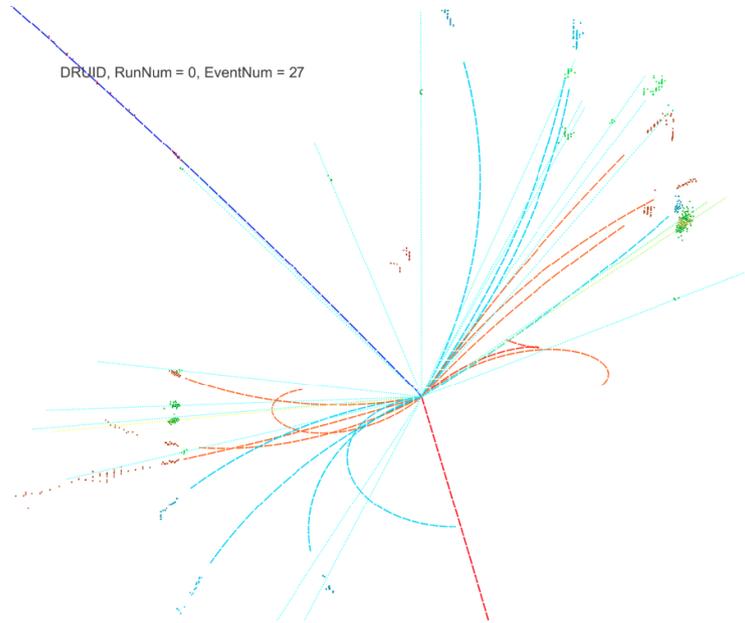
HCAL #layer

ECAL #layer



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

# Lepton: Higgs recoil via ZH, Z→ll



		CEPC_v1, ILD	Test Geo 1	<b>TG 2</b>	<b>TG 3</b>
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	<b>95.7%*</b>	<b>98.0%</b>	<b>96.5%</b>	<b>95.2%</b>
	eeH	<b>91.1%*</b>	<b>89.6%</b>	<b>89.1%</b>	<b>74.5%(???)</b>

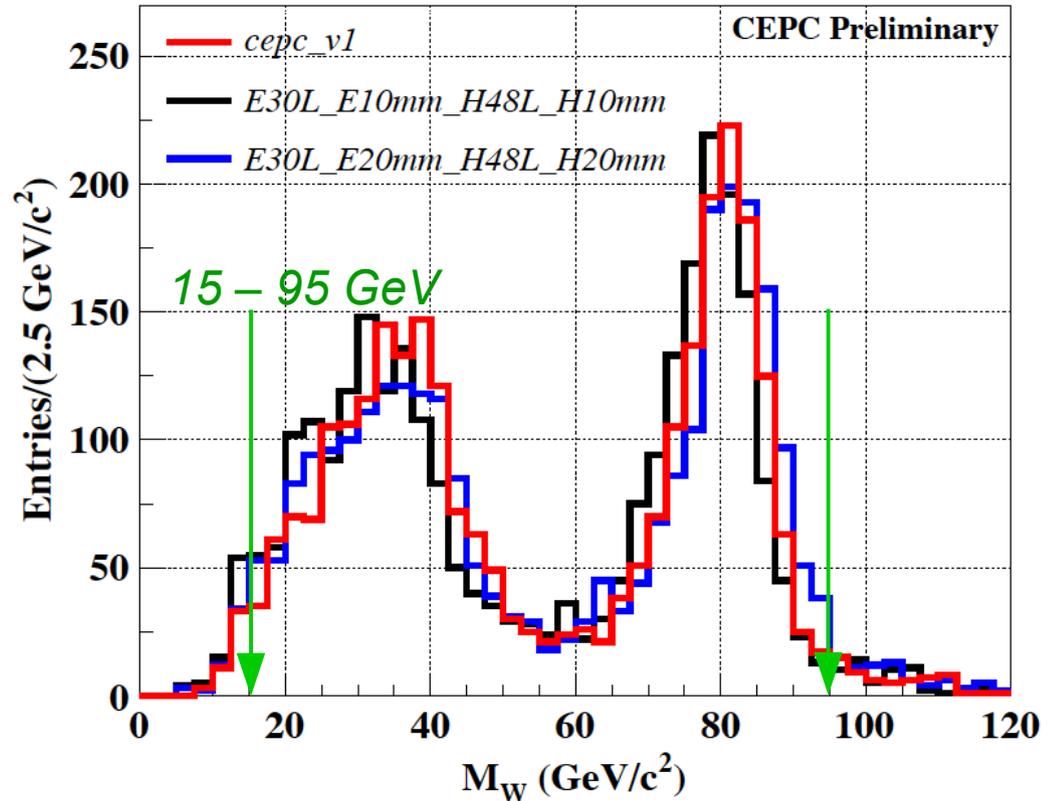
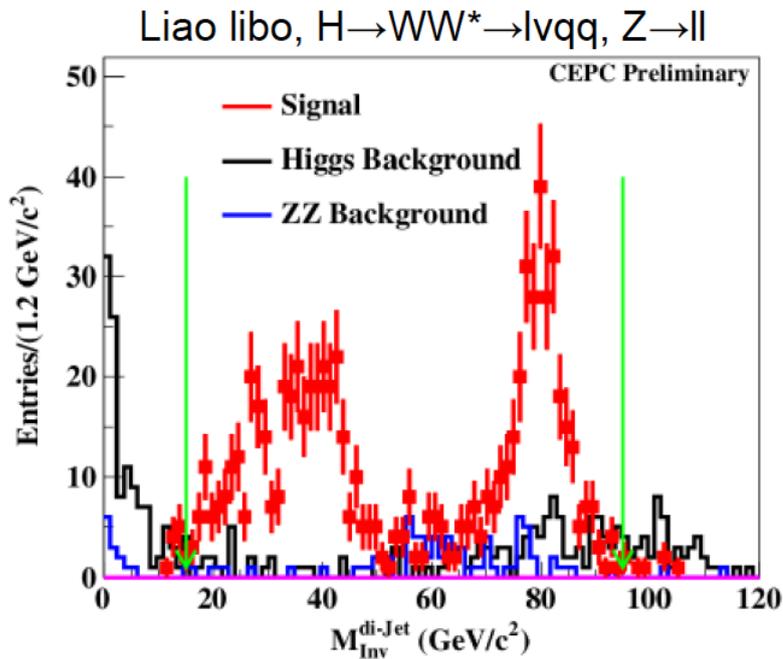
**TG2/3: active cooling free...**

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

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



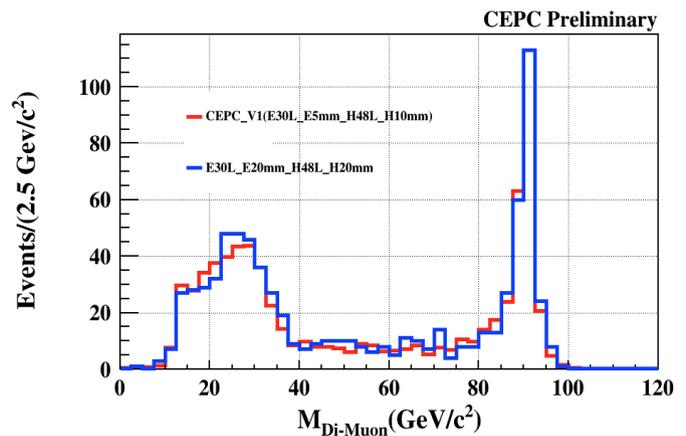
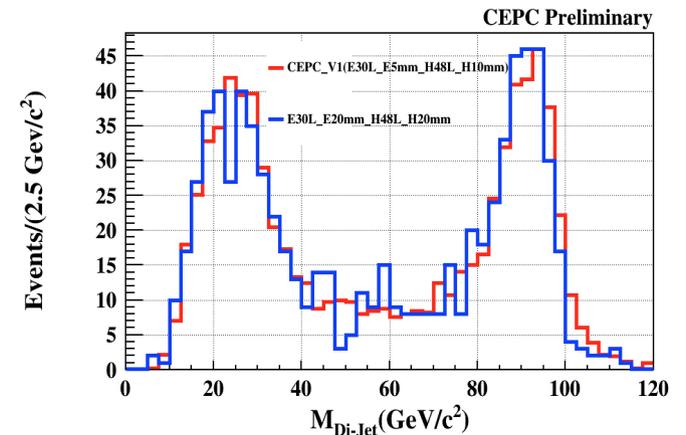
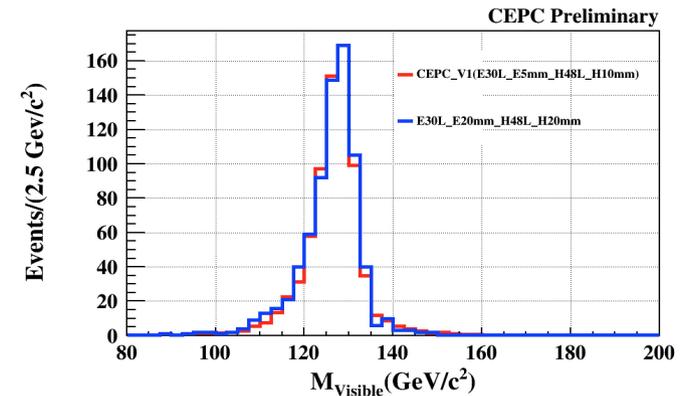
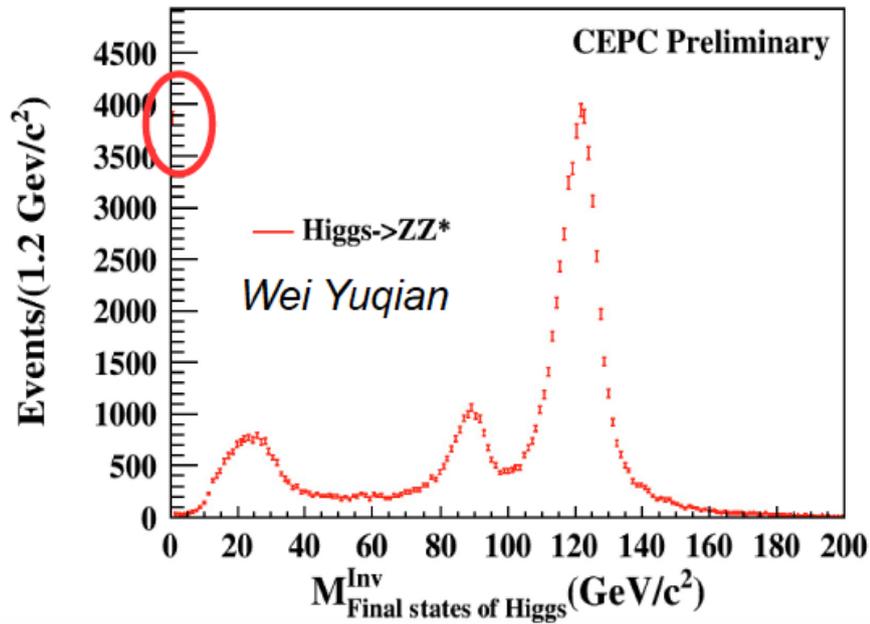
$\text{Br}(H \rightarrow WW)$  via  $\nu\nu H$ ,  $H \rightarrow WW^* \rightarrow lvqq$

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%
<b>TG2</b>	2878	2807	97.5%

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

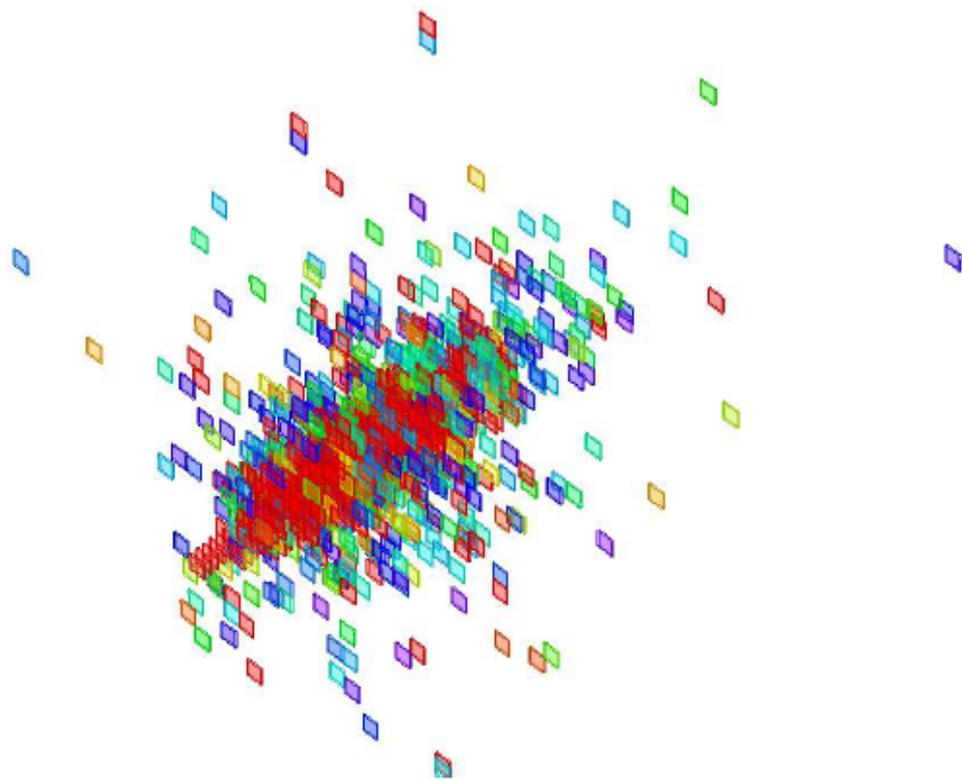


$\text{Br}(H \rightarrow ZZ)$  via  $\nu\nu H$ ,  $H \rightarrow ZZ^* \rightarrow llqq$

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

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

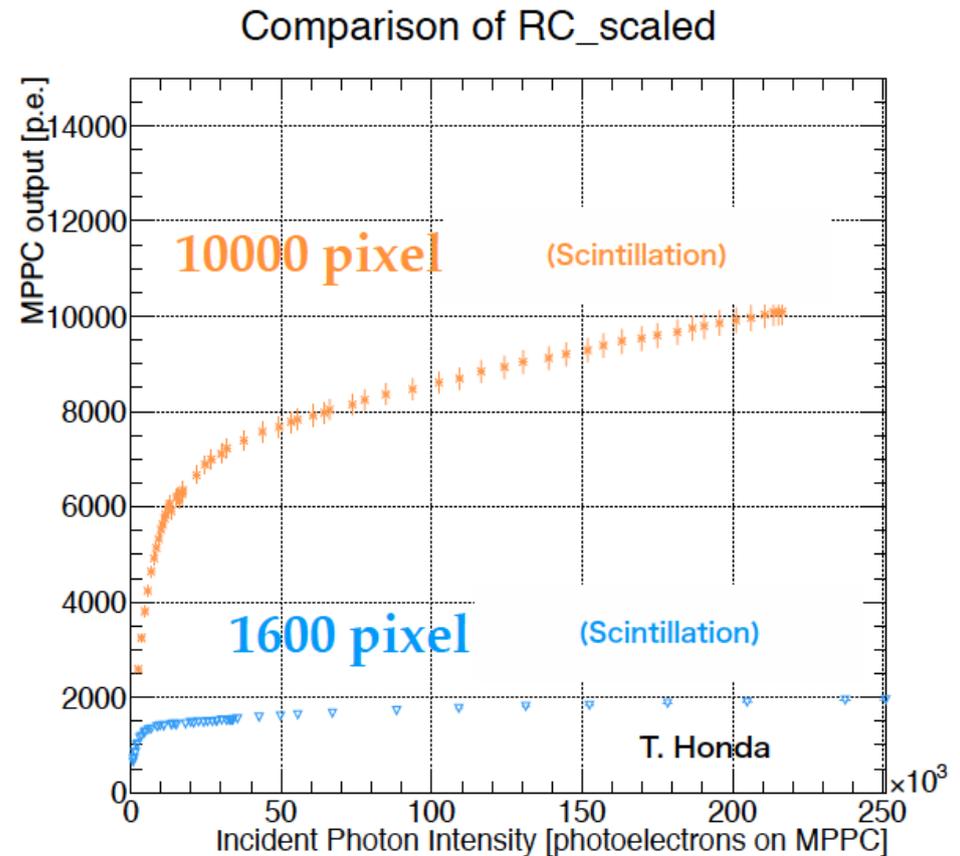
# ECAL Saturation/Linear Range Study



50 GeV Photon Cluster  
at ECAL with 10 mm Cell Size

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

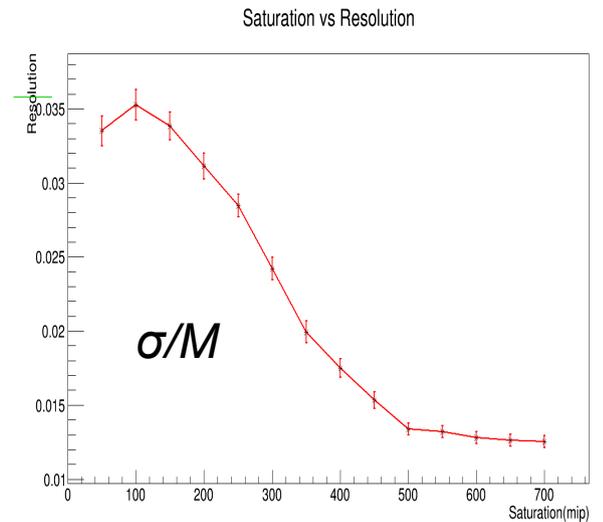
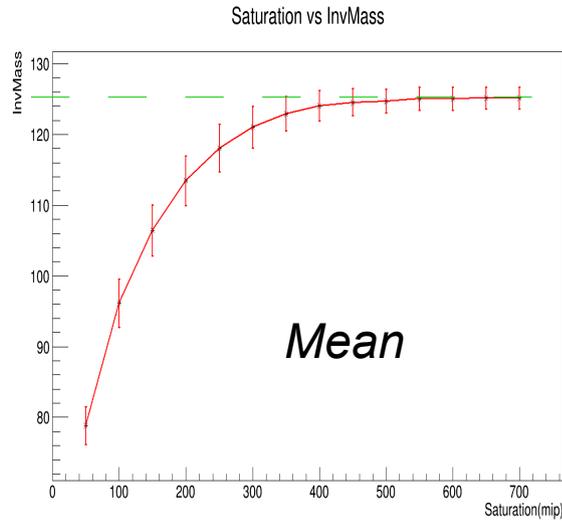
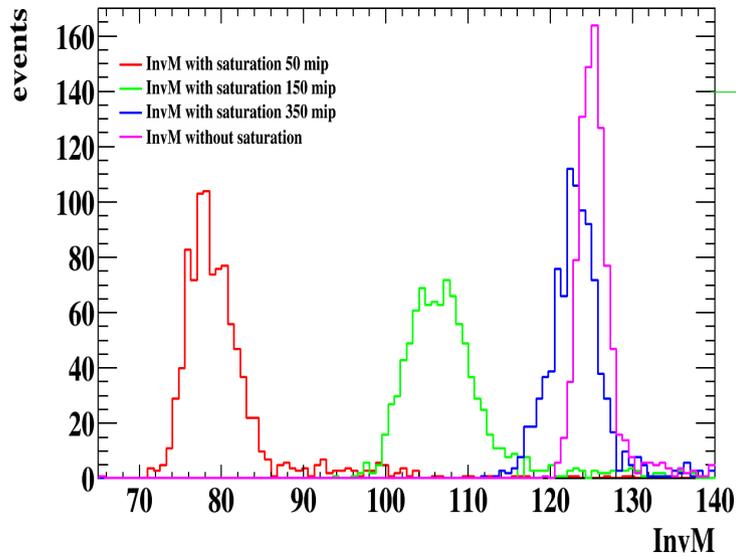
2/09/2016



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)

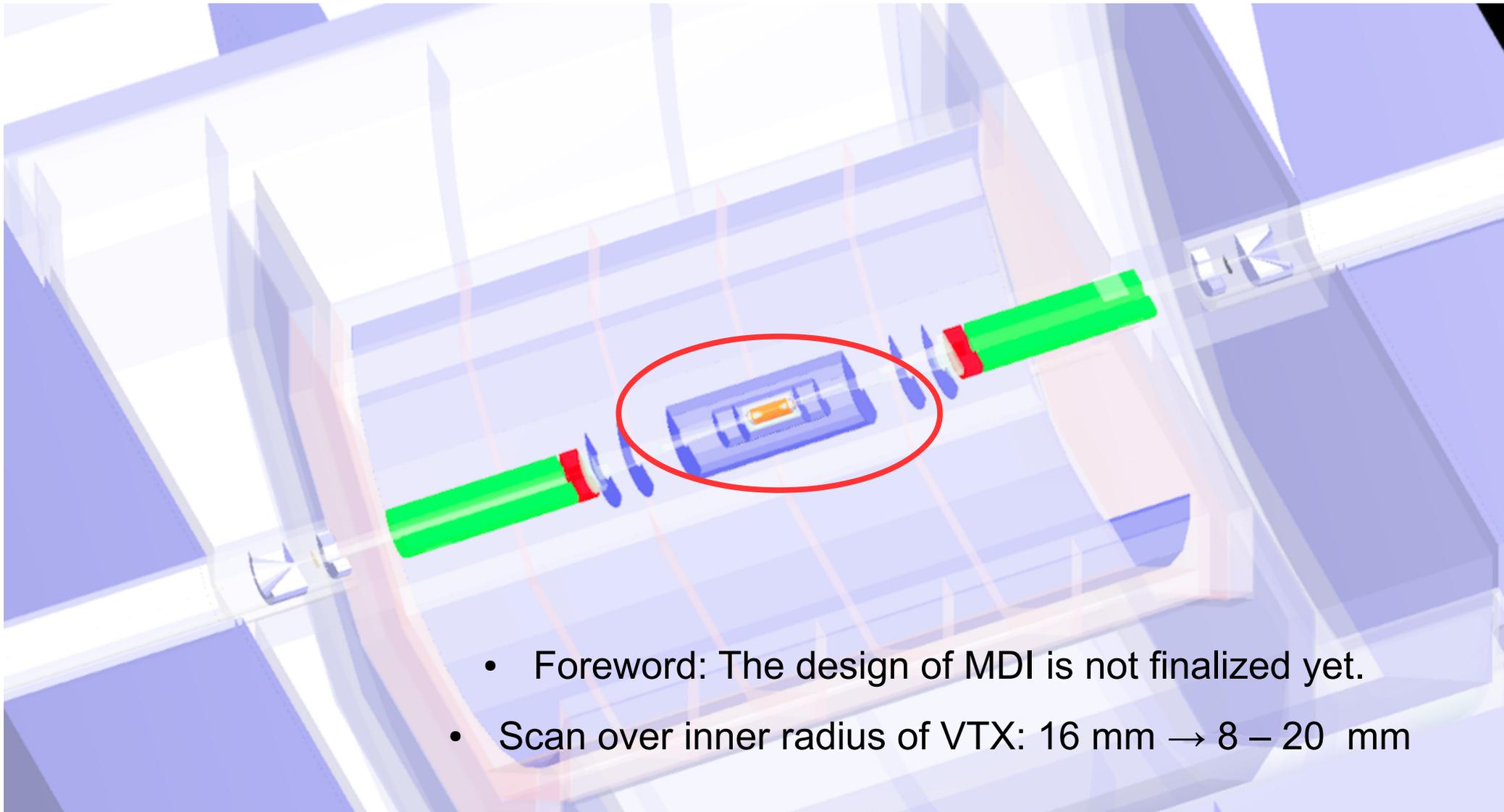
Empirical formula on needed ranger of a single photon:

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

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

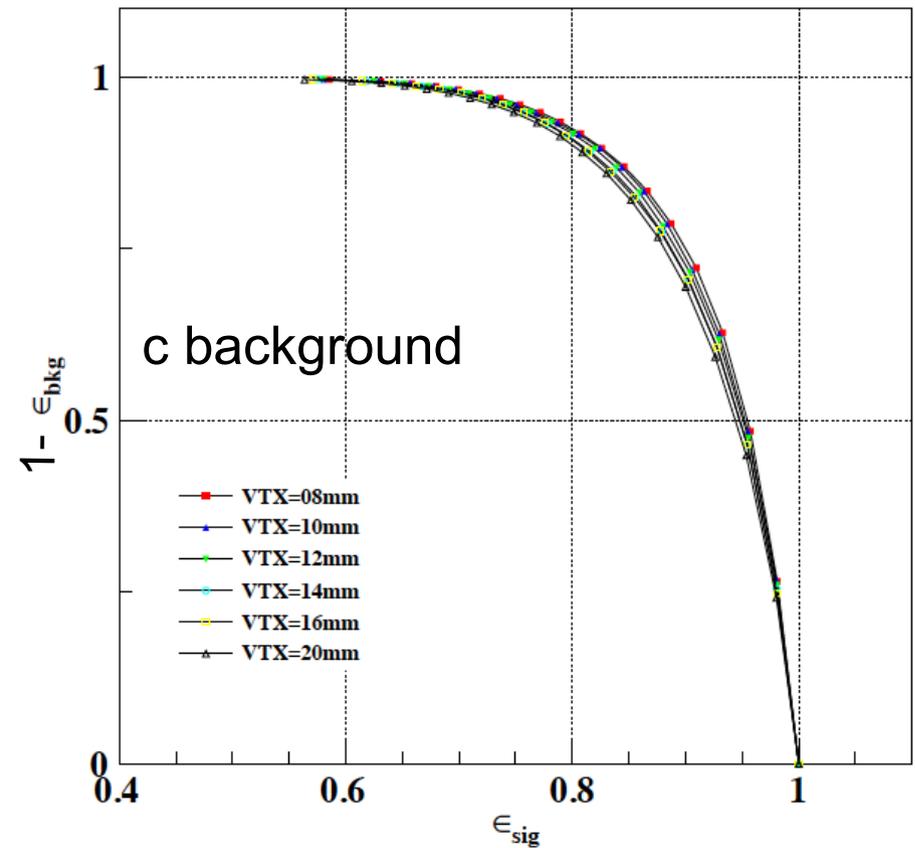
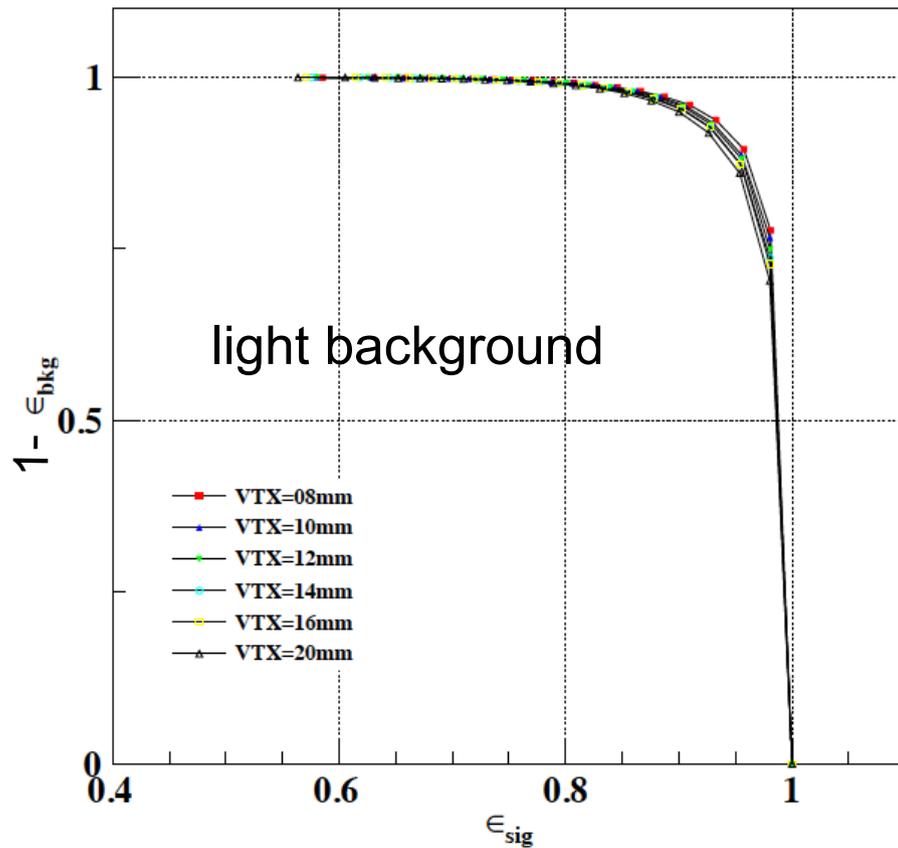
**Shuzheng Wang**

# Vary the VTX inner Radius



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

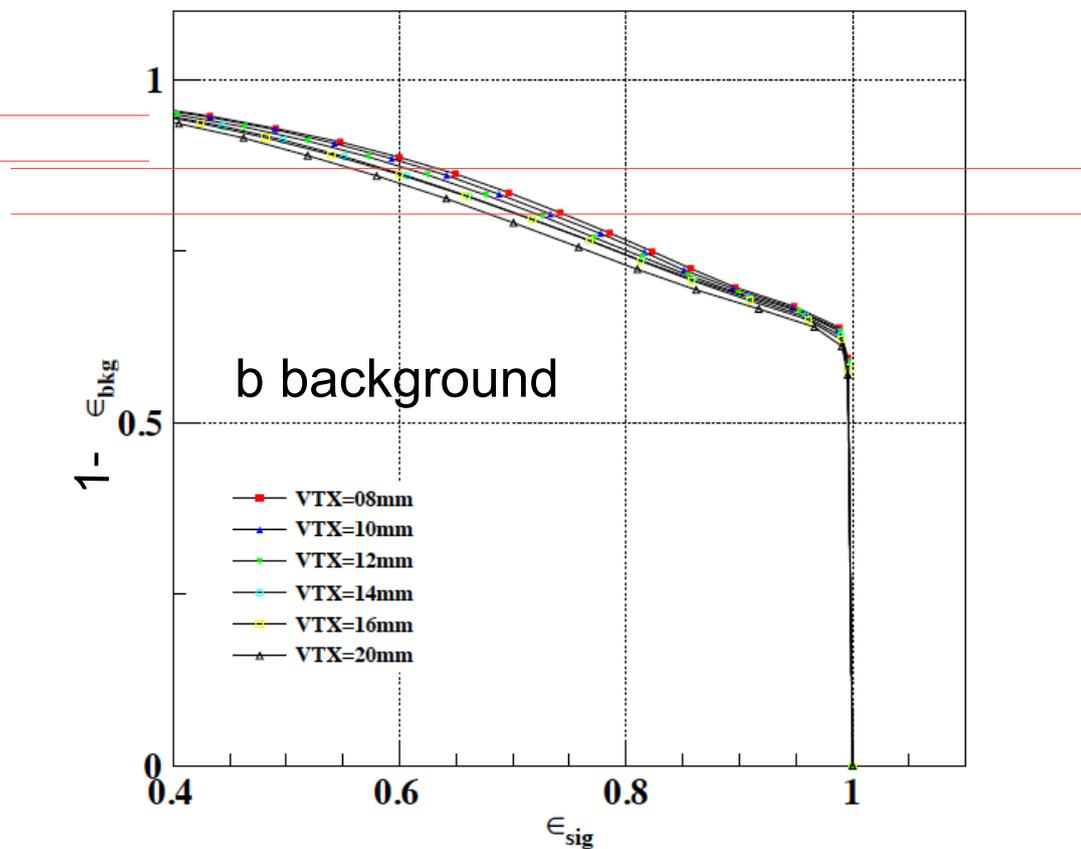
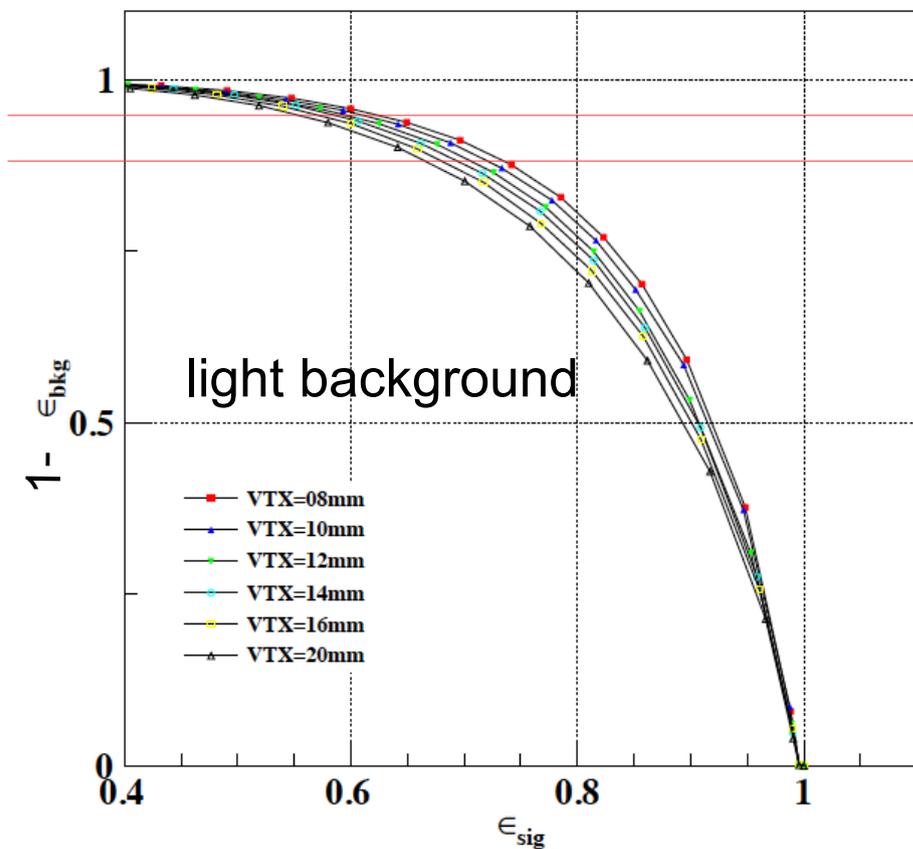
# B-tagging @ different radius



**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  $\sim 93-96\%$  at Z to qq events).*

# C-tagging @ different radius

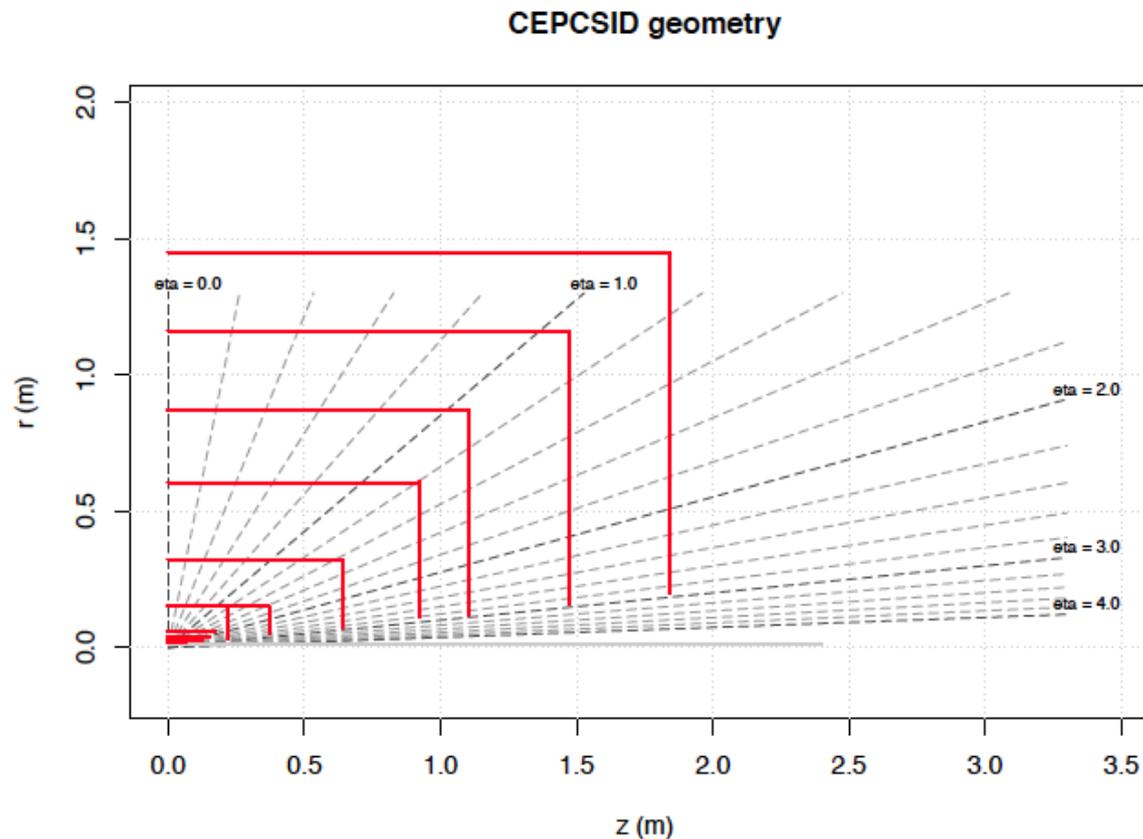


- At the same purity: C-tagging efficiency could be improved by ~ 10% by reducing the inner radius from 20 mm to 8 mm...

# Full Silicon Tracker Concept for CEPC\*

\* [http://cepc.ihep.ac.cn/cepc/cepc-twiki/index.php/Pure\\_Silicon\\_Detector](http://cepc.ihep.ac.cn/cepc/cepc-twiki/index.php/Pure_Silicon_Detector)

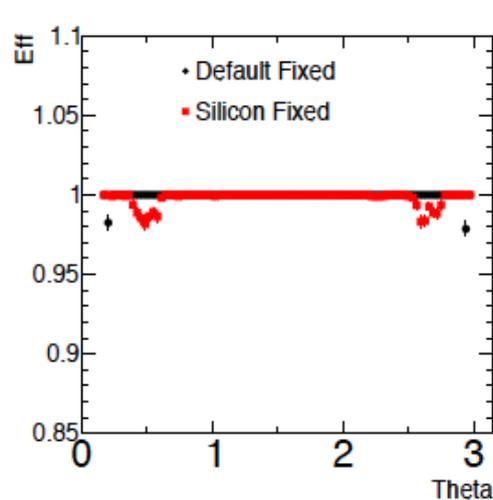
- CEPC full silicon has been implemented in Mokka.
- Based on CEPC V1 silicon tracker, we replace TPC with additional SIT layers and FTD endcaps.
- The advantage is to recycle CEPC silicon tracking.



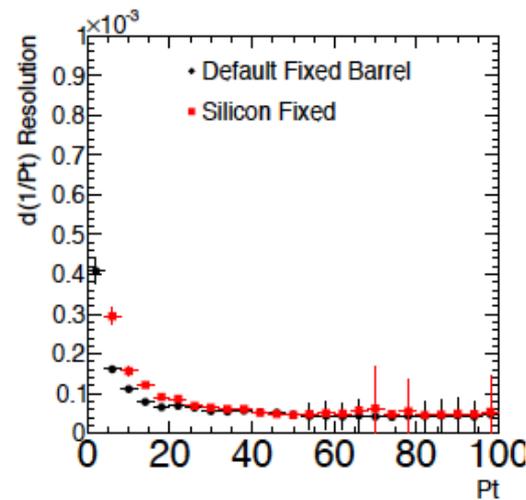
**Prof.  
Weiming Yao**

# Full Detector Simulation and Reconstruction

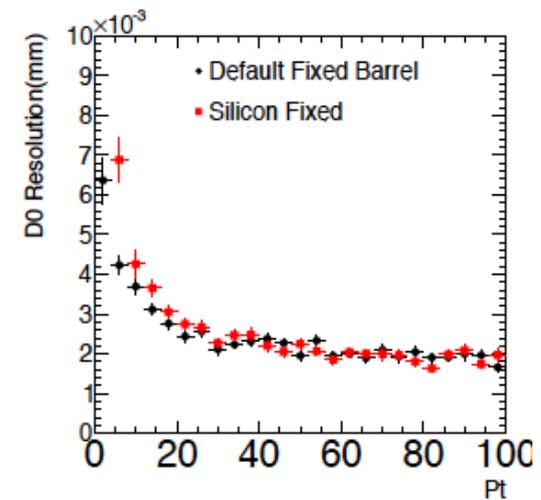
- Generated single muon with CEPC full silicon
- Reconstructed using Marlin Silicon only.
- The performance is comparable to CEPC V1.



(a) Eff vs theta



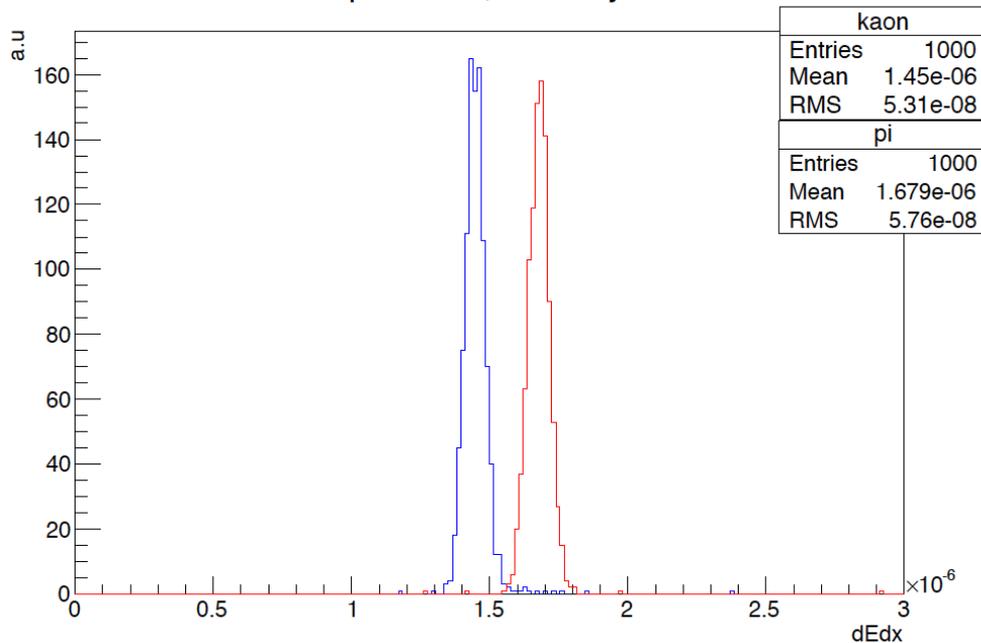
(b)  $\sigma(1/pt)$  vs Pt



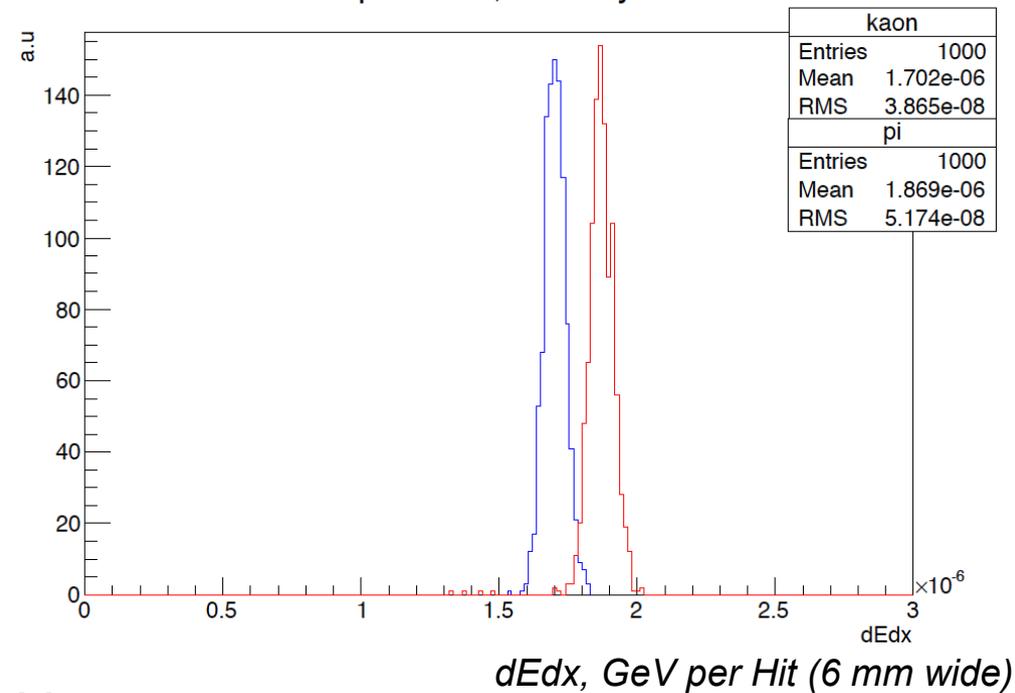
(c)  $\sigma(D0)$  vs Pt

# 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

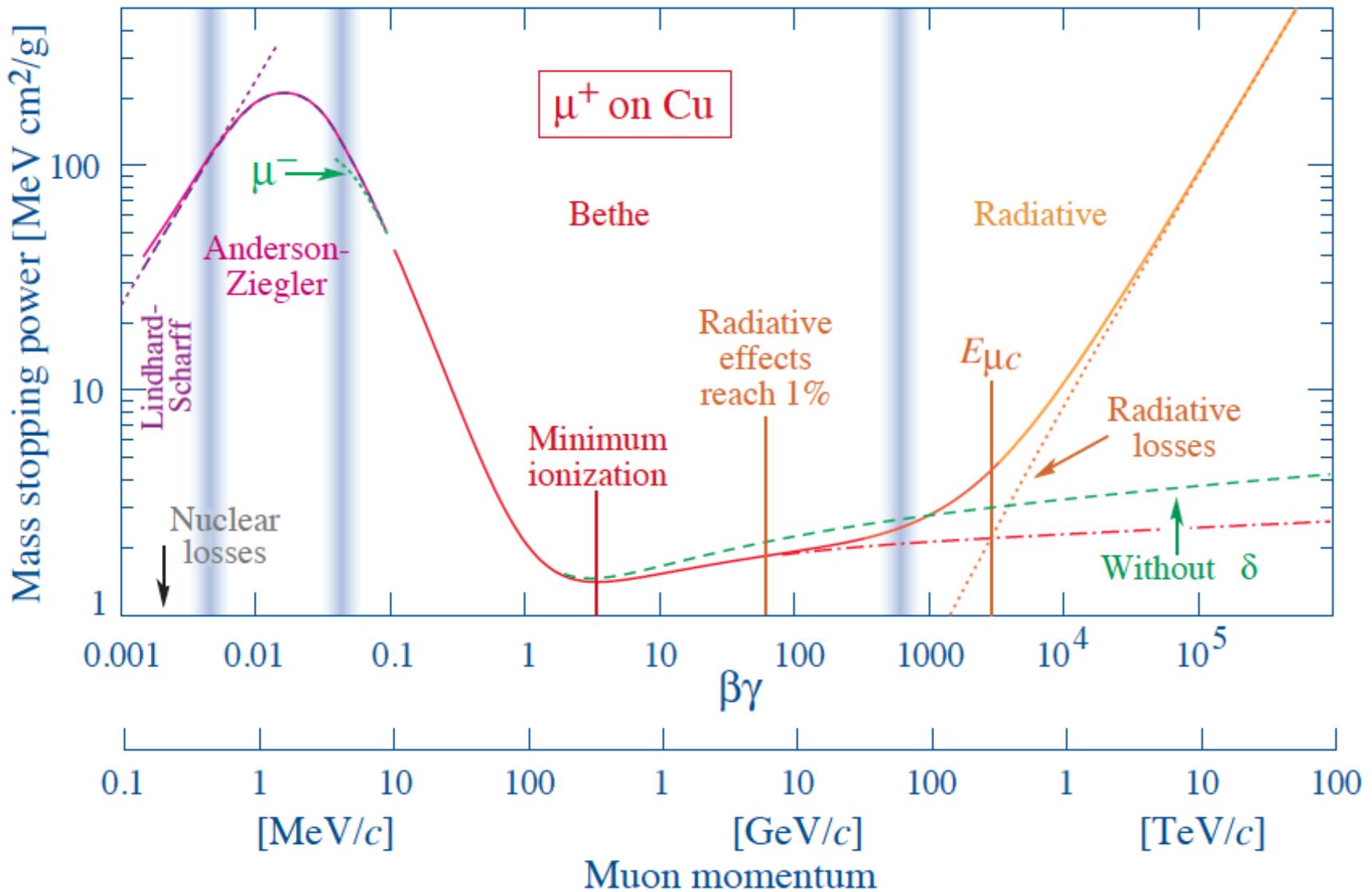
- Higgs analyses:
  - Mostly covered at full simulation level & results slightly varied from preCDR
  - Significant progress on  $H \rightarrow VV$  and  $H \rightarrow \text{Exotic}$  decay measurements
  - To do: Higgs analyses with tau/multi-jets final states: need dedicated tau finder & jet clustering 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 ~ 1-2%** in Higgs recoil analysis via lepton channel,  $\text{Br}(H \rightarrow WW \rightarrow \mu\nu qq)$ ,  $\text{Br}(H \rightarrow ZZ \rightarrow llqq)$  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 2<sup>nd</sup> 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	<b>12.9</b>	Tau finder would be highly appreciated
μμqqνν	128	125	-	h->bb&zz_sl	>25	
eeννqq	132	91	53.8	h->ww&sze_sl	<b>15.8</b>	Reconstructed efficiency of electron need to be improved
eeqqνν	132	88	-	h->bb&zz_sl	>25	
ννμμqq	158	144	61.4	h->t,w&zz_sl	<b>11.0</b>	
ννqqμμ	158	149	51.9	h->w,b&zz_sl	<b>12.9</b>	
ννeeqq	151	118	43.1	h->w&sze_sl	<b>21.3</b>	
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	<b>19.9</b>	Tau finder & Electron Reconstruction
μμeeqq/qqee	43	39	60.5	h->tt&zz_sl	<b>21.2</b>	
eeeeqq/eeqqee	43	33	-	h->tt&sze_sl	>25	
eeμμqq/eeqqμμ	43	41	58.2	h->tt&sze_sl	<b>19.9</b>	

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)

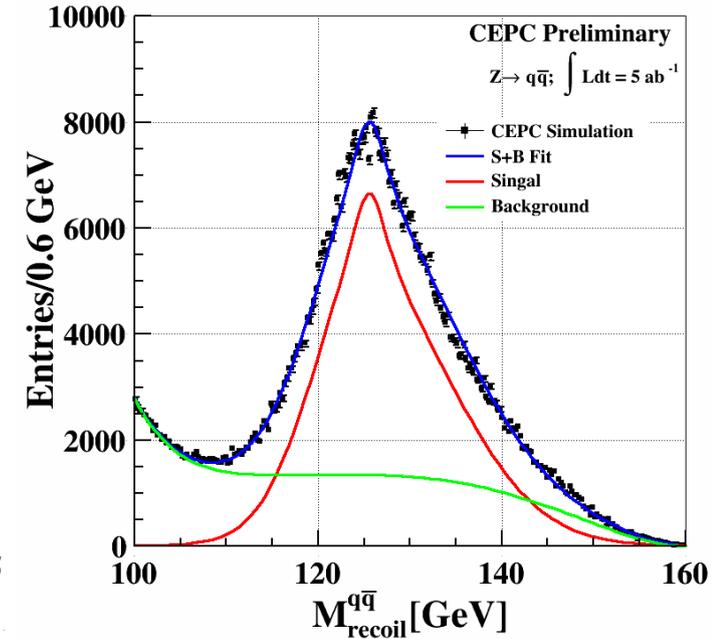
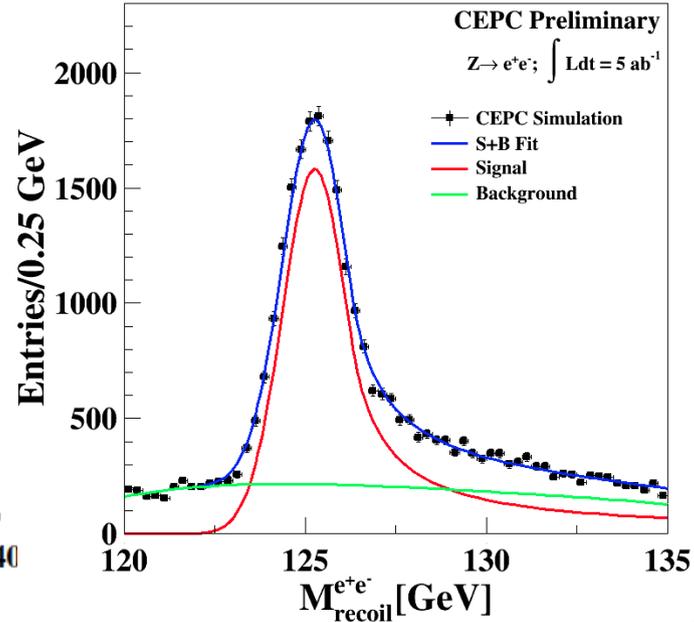
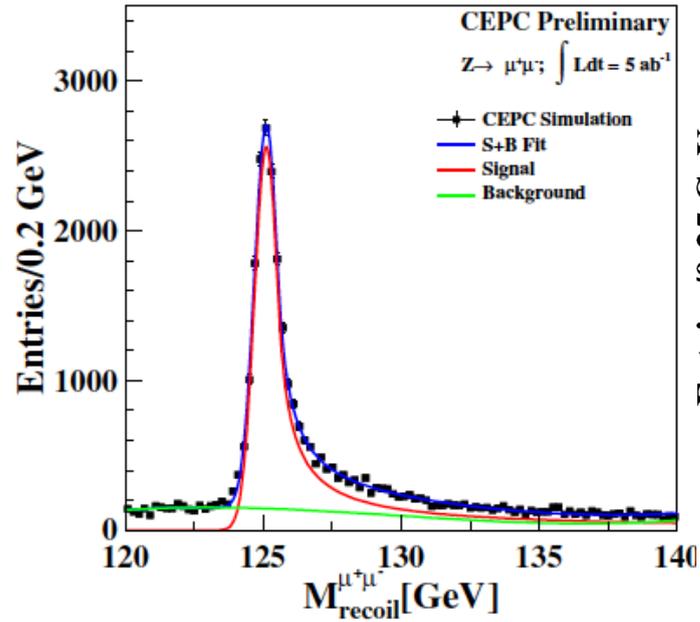
ZH, H → WW*	Yield	Object reconstructed	Isolation	Signal Efficiency	Main Background	Accuracy	Combined
Z(μμ)H(eνeν)	88	76(86.36%)	61(80.26%)	36(40.91%)	4(ZH)	17.57%	2.68%
Z(μμ)H(μνμν)	89	80(89.89%)	77(96.25%)	52(58.43%)	6(ZH&ZZ)	14.65%	
Z(μμ)H(eνμν)	174	157(90.23%)	147(93.63%)	105(60.34%)	0	9.76%	
Z(μμ)H(eνqq)	1105	1042(94.30%)	864(82.92%)	663(60.00%)	45(ZH)	4.02%	
Z(μμ)H(μνqq)	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(eνeν)	91	62(68.13%)	60(96.77%)	22(24.16%)	16(SZ)	28.02%	2.87%
Z(ee)H(μνμν)	82	63(76.83%)	63(100%)	44(53.66%)	24(SZ)	18.74%	
Z(ee)H(eνμν)	178	132(74.16%)	124(93.94%)	82(46.07%)	25(ZH&SZ)	12.61%	
Z(ee)H(eνqq)	1182	1041(88.07%)	916(87.99%)	621(51.78%)	188(SZ&ZH)	4.62%	
Z(ee)H(μνqq)	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	νν	qq
H → WW* → 4q	1.45%	3.45k	2.3%	69.1k
μνqq		1.14k	6.47k	2.2%
eνqq		1.14k	6.47k	
eeνν		93	527	1.9k
μμνν		93	527	1.9k
eμνν		186	1154	3.7k
X + tau		3.2k	1.6k	9.14k

# Higgs invisible decays

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

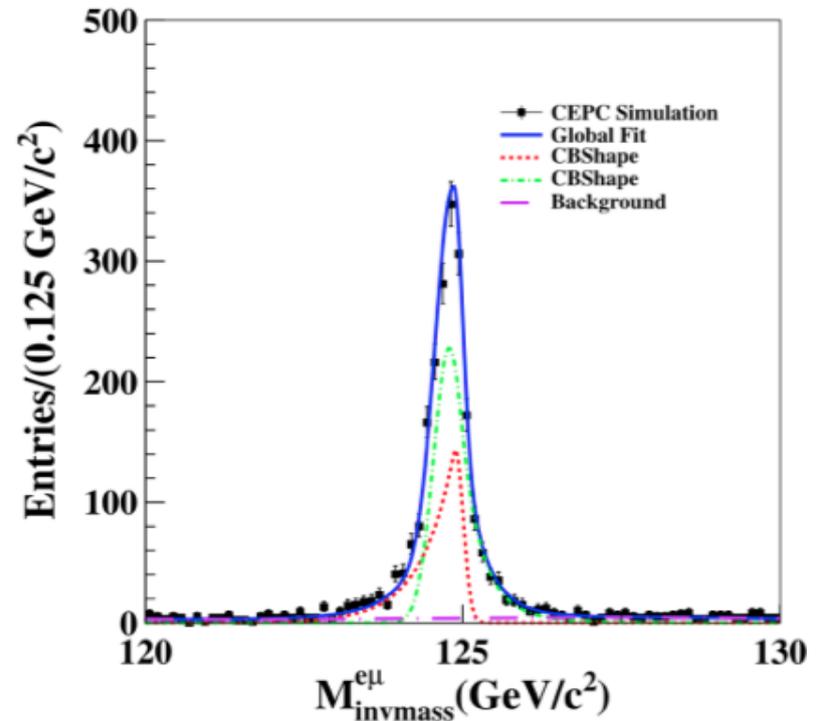
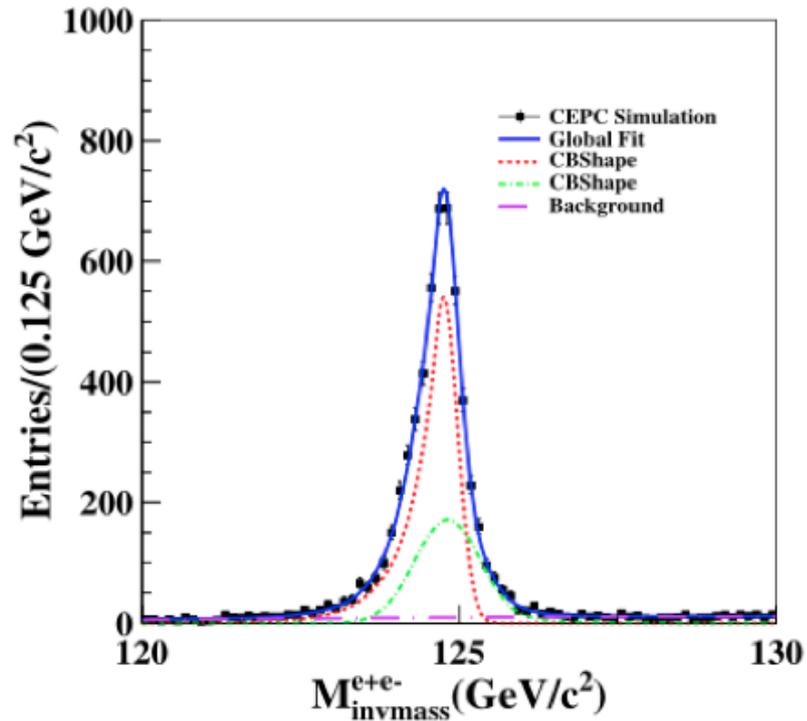


Invisible up limit at CEPC: 0.14% at 95% C.L

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

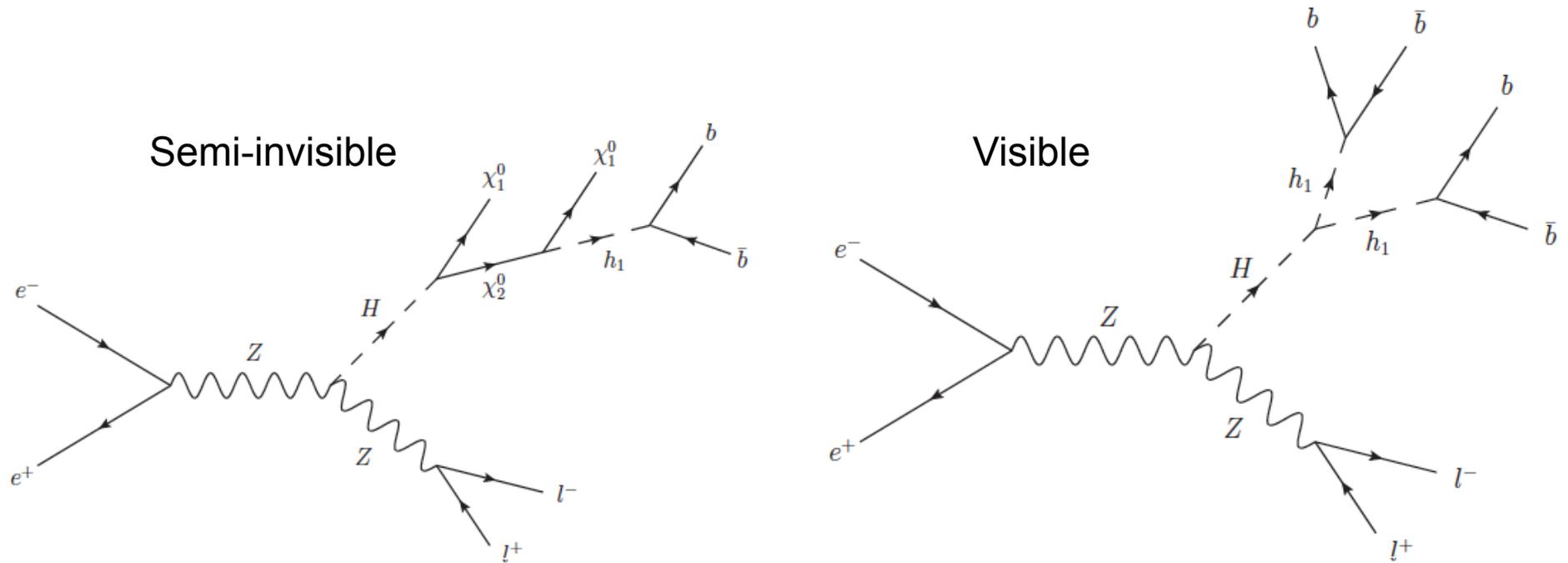
Lei Wang

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



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

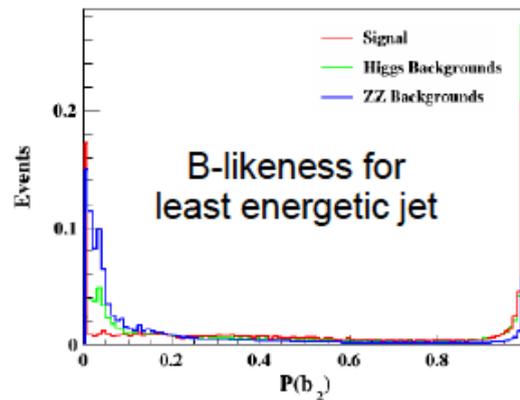
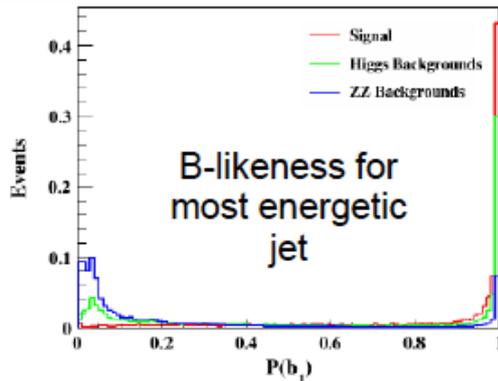
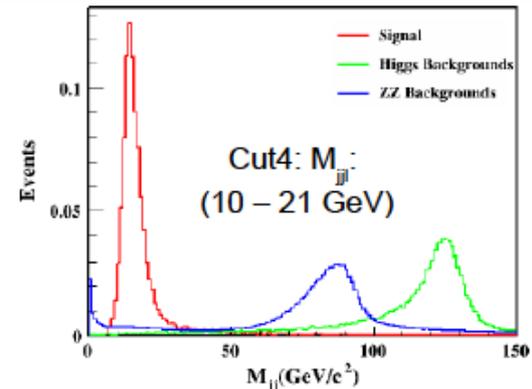
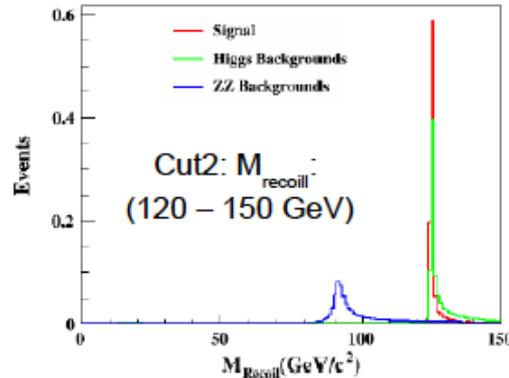
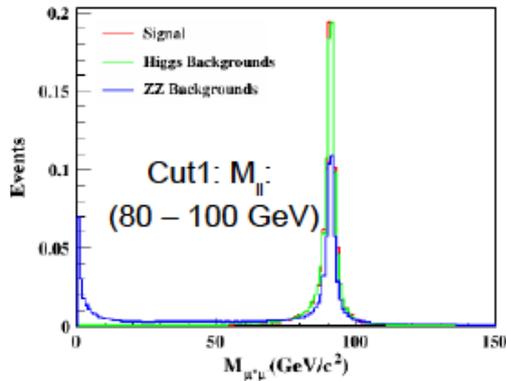
# H → Exotic, Hadronic



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

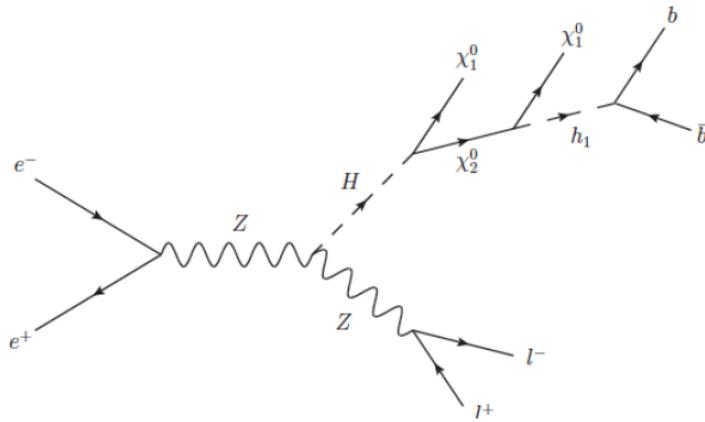


Object found	Cut 1 $m_{\mu\mu}$	Cut 2 $m_{rec}$	Cut 3 b likeness	Cut 4 $m_{jj}$
Signal	17	15	12	10
ZH BGs	34093	30732	16026	4
ZZ BGs	538790	281198	30825	20

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

- 95% CL. Uplimit set to be  $5E-4$ ; 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

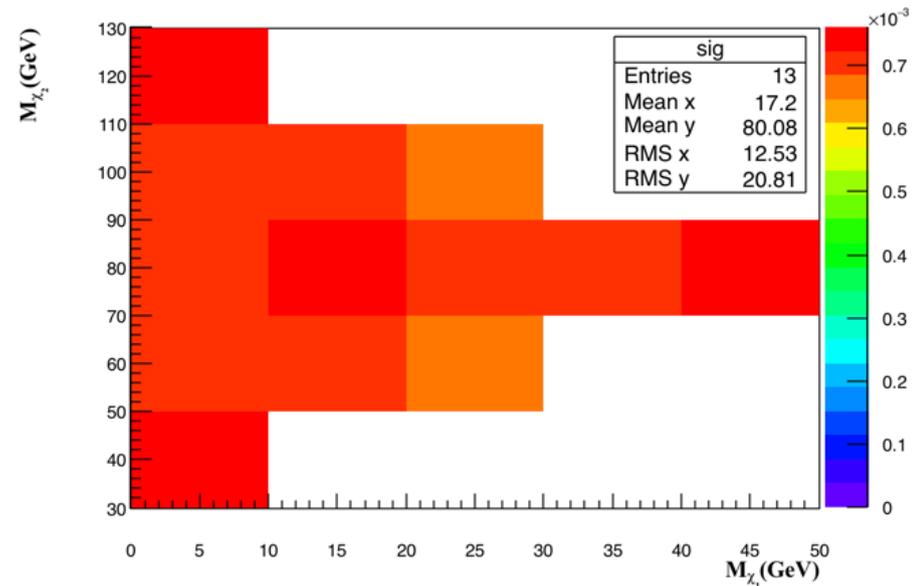
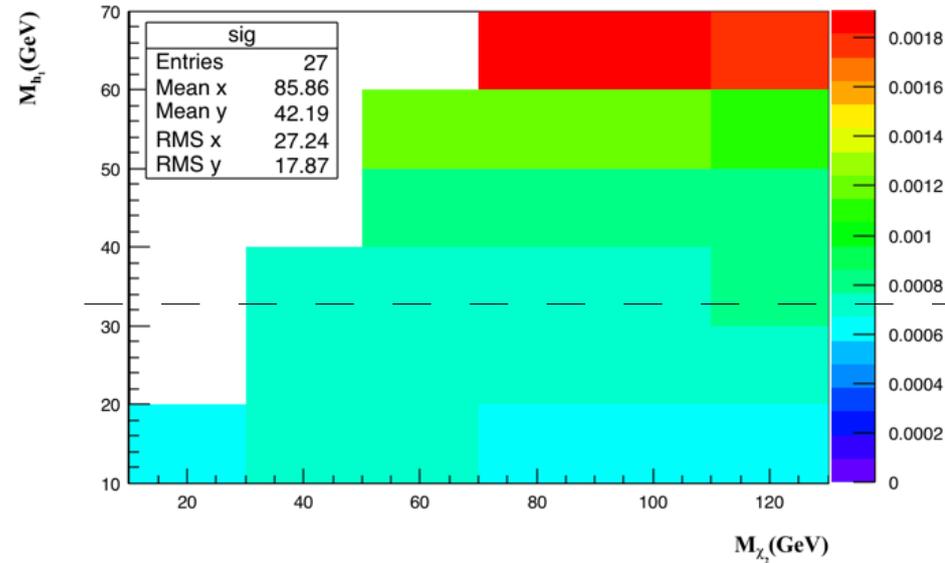


## Benchmark Points

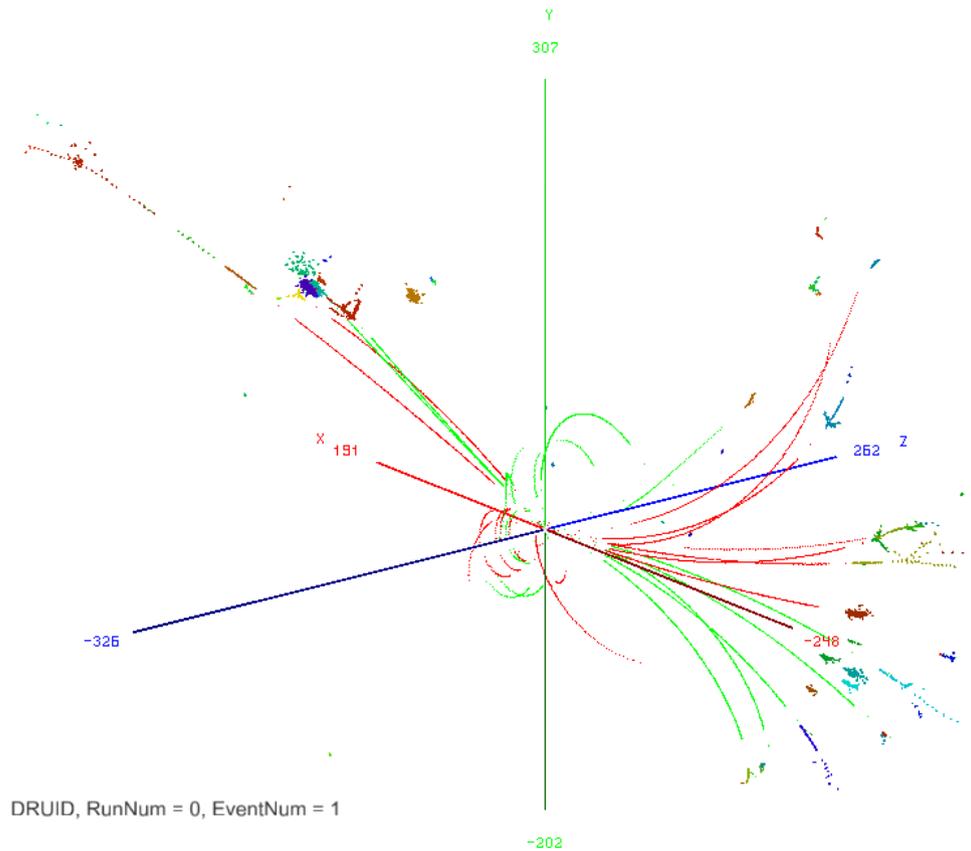
Scan over the parameter space for sensitivity:

- 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)
- 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)

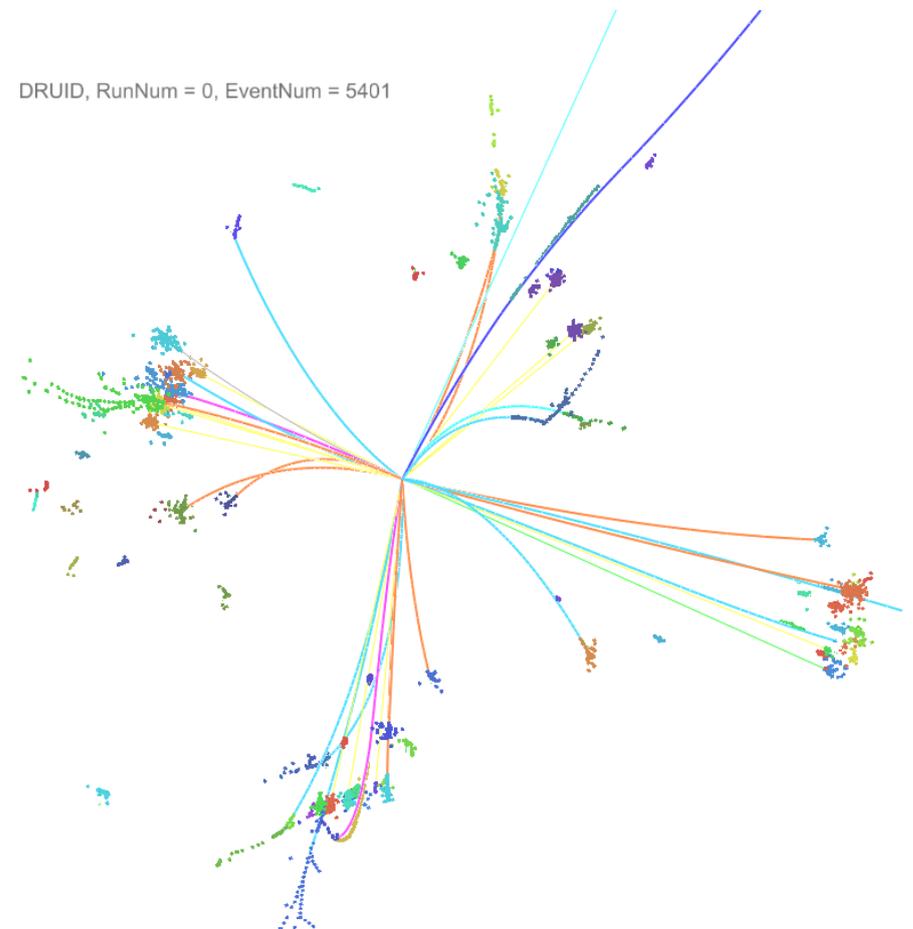
Suggested by prof. Liu



# Simulated Higgs Event @ CEPC

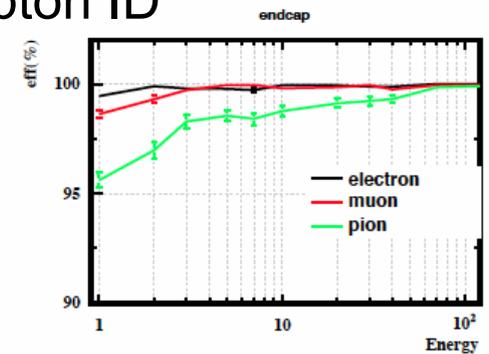
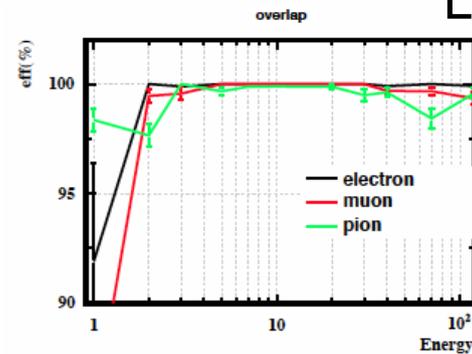
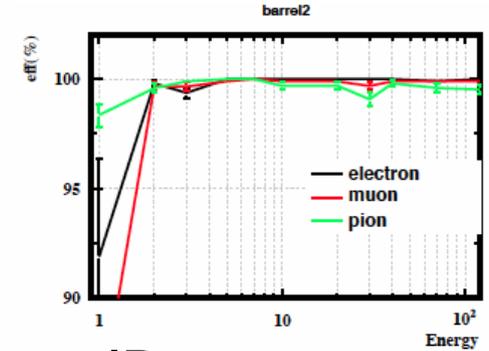
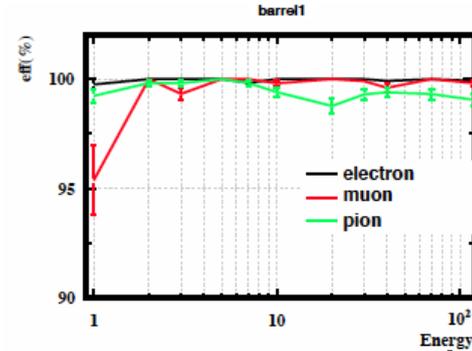
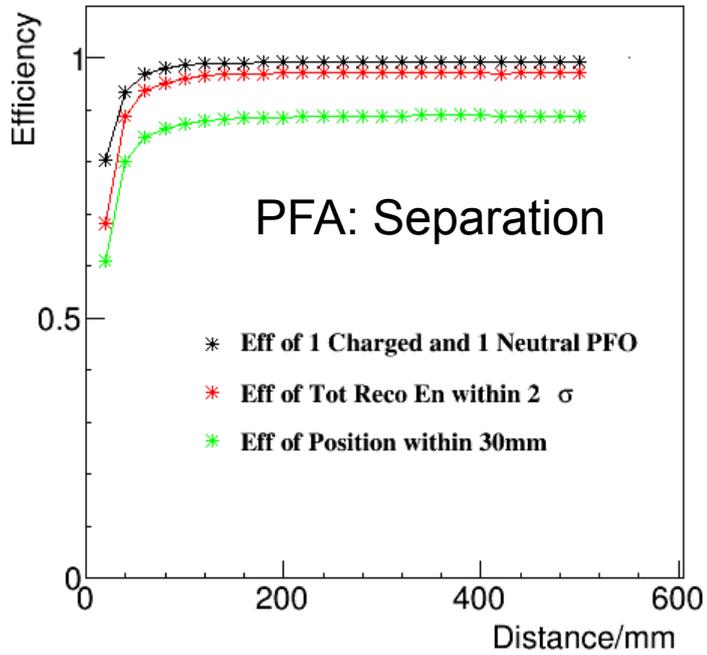


*~25% of Higgs events*

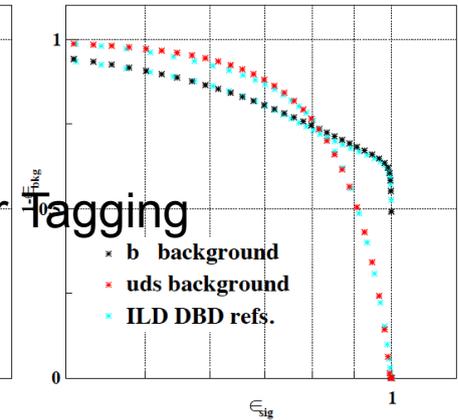
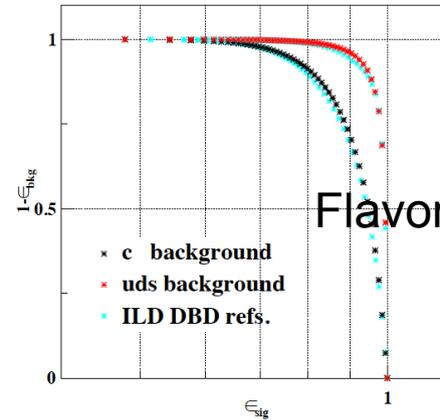
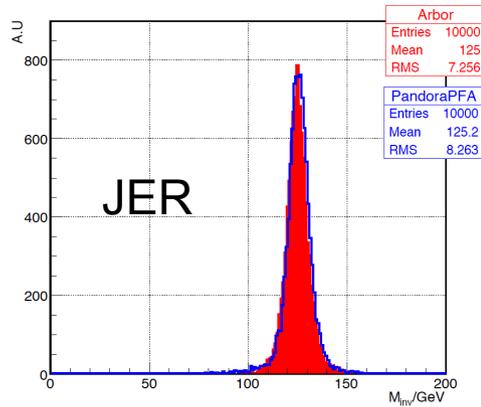
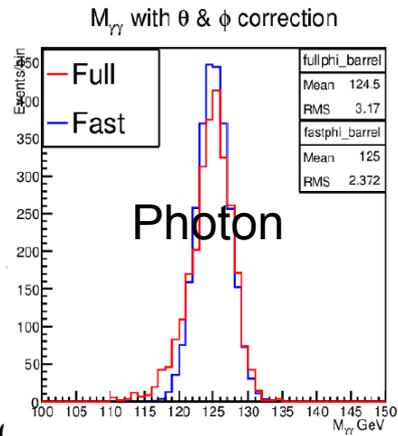


*~50% of Higgs events*

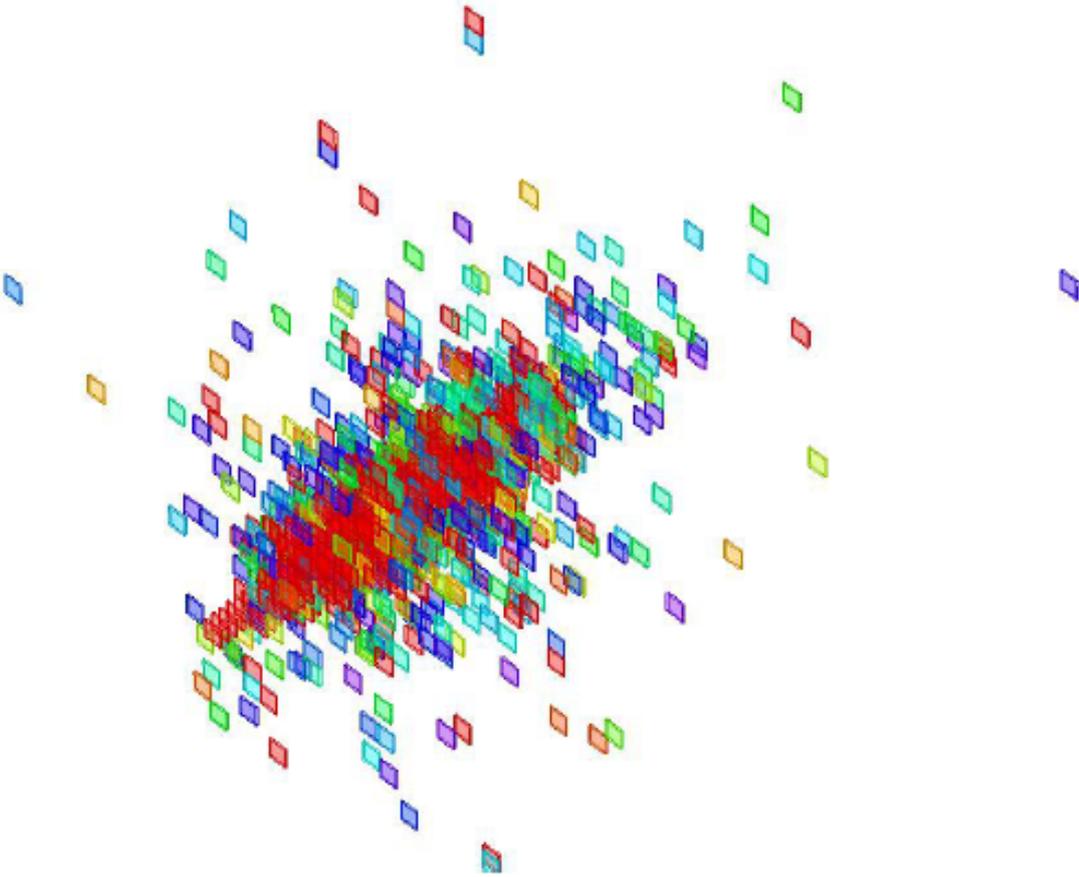
# Reconstructions



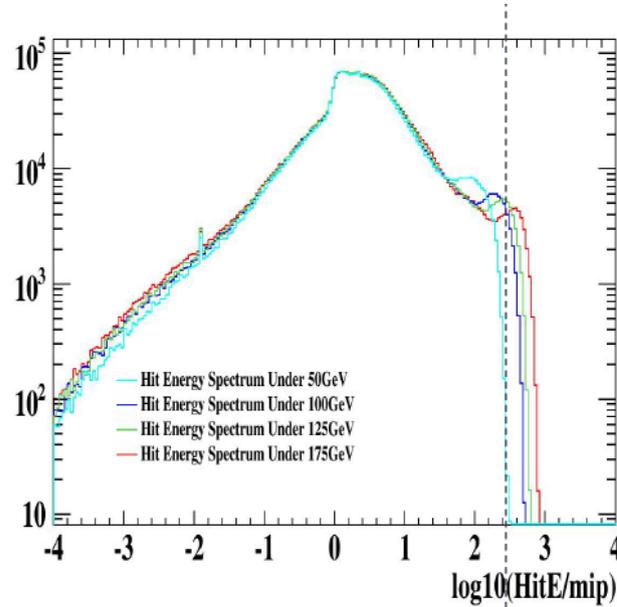
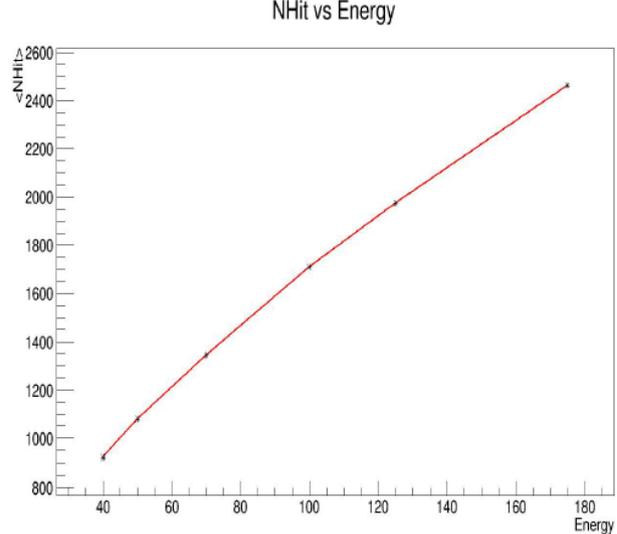
Lepton ID



# ECAL Saturation/Linear Range Study



50 GeV Photon Cluster  
at ECAL with 10 mm Cell Size



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