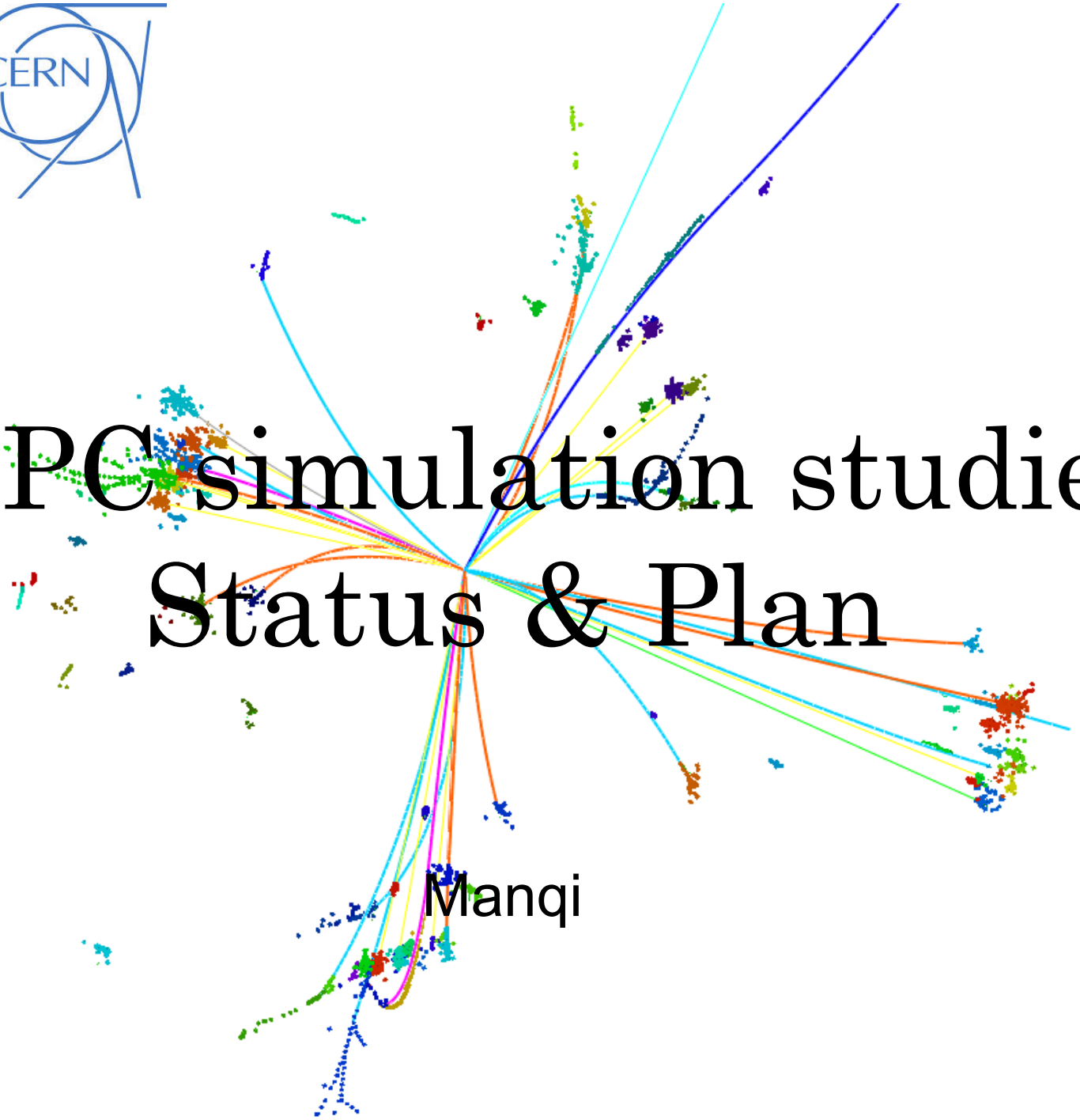
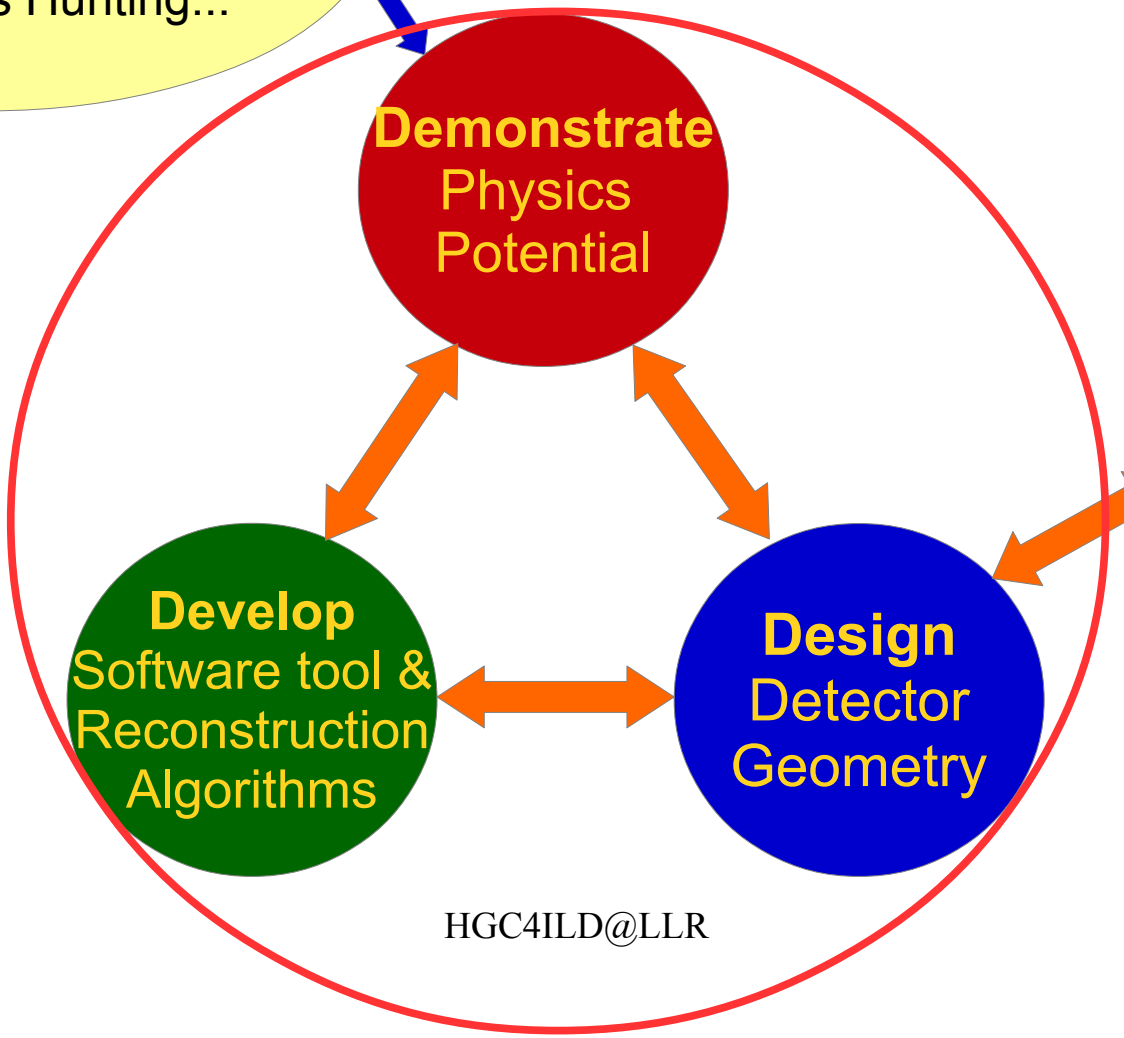
CEPC simulation studies, Status & Plan



Manqi

Simulation study: key ingredients

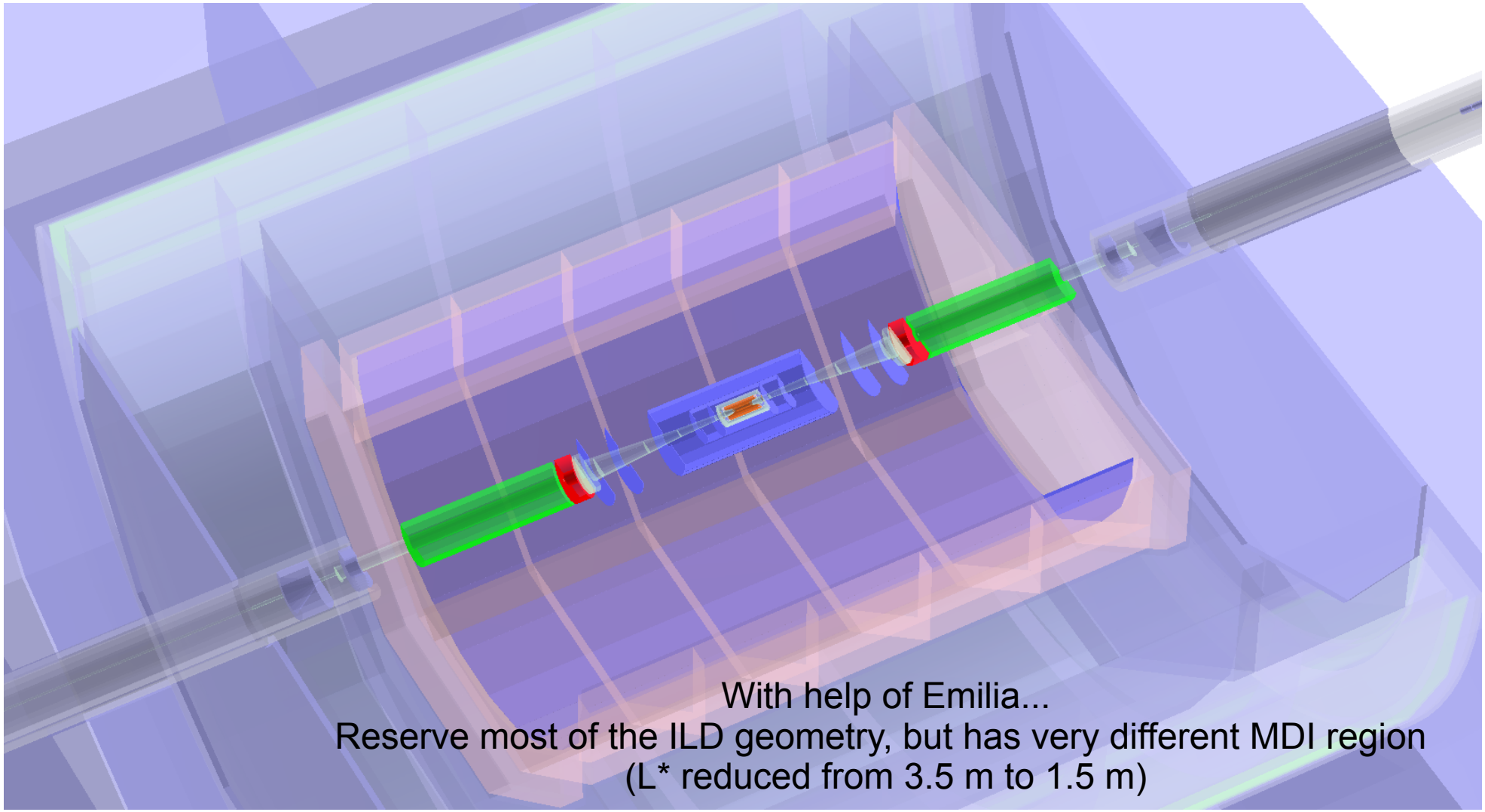
Physics Objectives:
Precise measurement of Higgs,
Z, W, top measurements,
New Physics Hunting...



Hardware
Sub Detector
R&D

Sensor,
Granularity -
electronic,
Mechanism,
DAQ,
Integration,
...

Conceptual CEPC Detector: modified from ILD



With help of Emilia...
Reserve most of the ILD geometry, but has very different MDI region
(L* reduced from 3.5 m to 1.5 m)

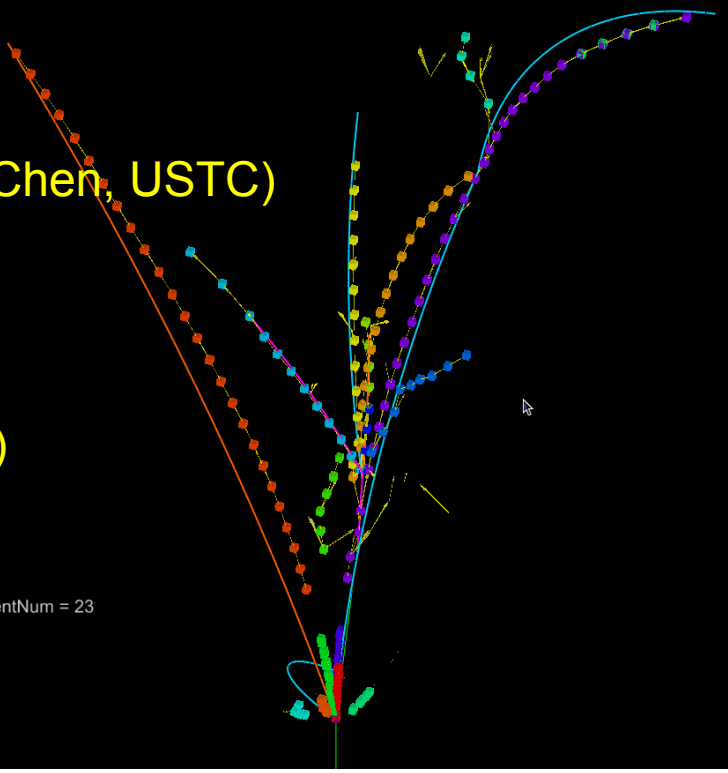
Simulation & Reconstruction Software

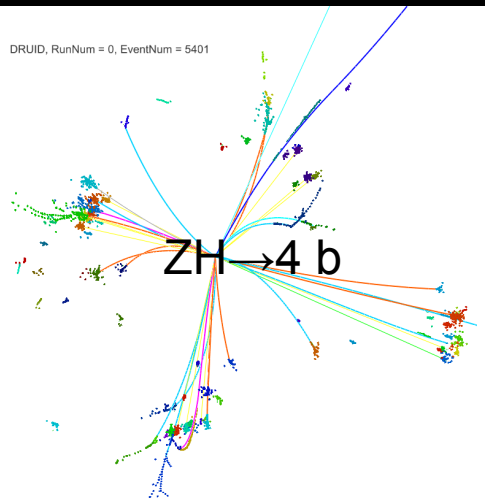
Geant 4 Full Simulation:

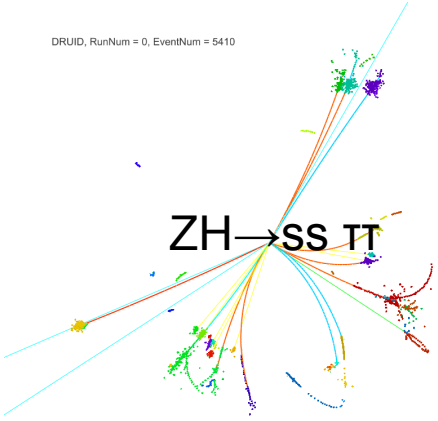
- Geometry can be edited freely (Y. Xu, NKU & X. Chen, USTC)
- Series of geometries has been generated

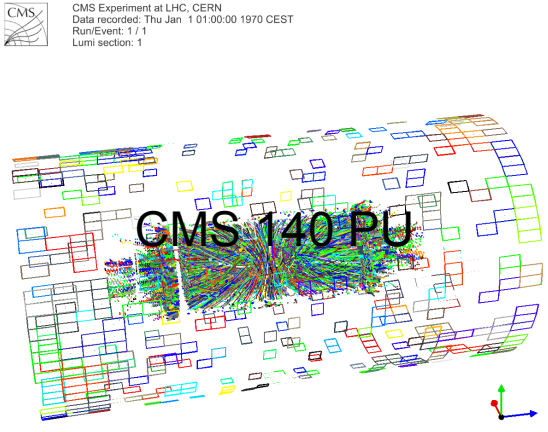
Reconstruction Chain

- Tracking: Clupatra & ILD tracking (B. Li, etc THU)
- PFA: Arbor (M. Ruan, etc, IHEP)
- Flavor Tagging: LFCIPlus (G. Li, etc, IHEP)





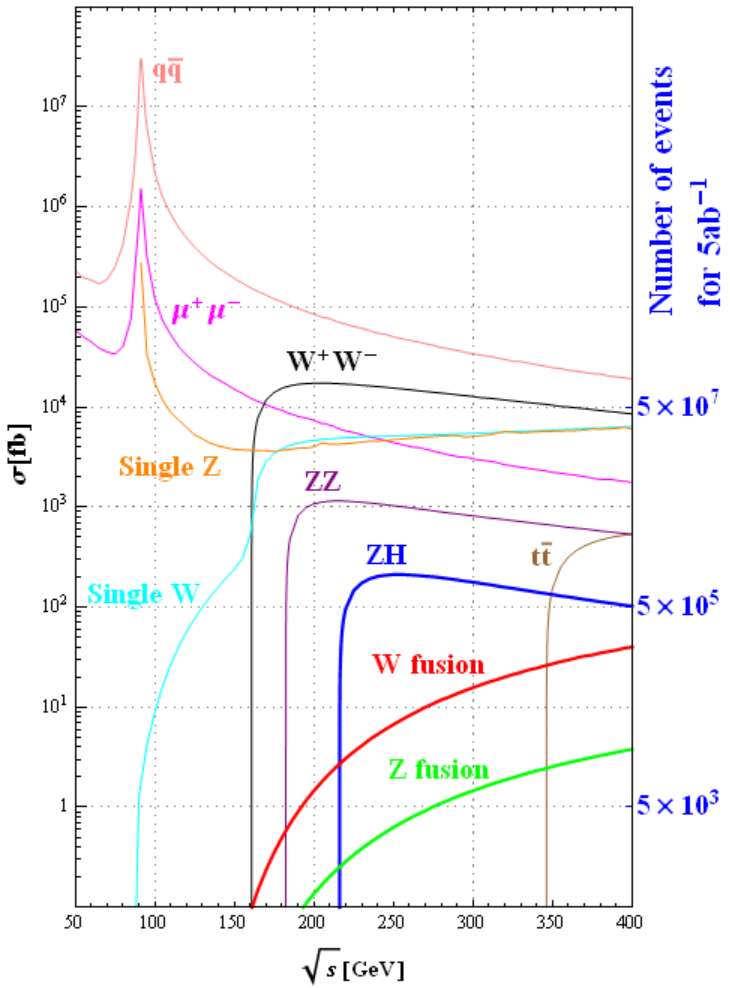




Samples & Computing

- Sample

  Generators: Full SM sample (Moxin) + Several BSM Signals



T. Yan @ IHEP

Resources Status

#	Site Name	CPU Cores	OS	Status	Shared by VO
1	CLOUD.IHEP-OPENSTACK.cn	144	SL 6.5	Active	bes,cepc,juno
2	CLOUD.IHEP-OPENNEBULA.cn	120	SL 6.5	Active	bes,cepc,juno
3	CLUSTER.WHU.cn	100	SL 6.4	Active	cepc,bes,juno
4	CLUSTER.SJTU.cn	100	SL 6.5	Active	cepc,bes
5	CLUSTER.GXU.cn	50	CentOS 5.10	Active	cepc
6	CLUSTER.BUAA.cn	50	SL 5.8	Testing	bes,cepc
7	CLUSTER.PKU.cn	64	SL 5.10	Testing	bes,cepc
8	CLUSTER.SDU-MLL.cn	150	SL 6.6	Testing	bes,cepc
9	CLUSTER.SDU-HXT.cn	100		Preparing	bes,cepc
10	CLOUD.WHU.cn	120	SL 6.6	Preparing	cepc,bes,juno
11	CLOUD.IHEP-PUBLIC.cn	10+	SL 6.6	Preparing	cepc,bes,juno
	Total (Active + Testing)	**778**			

- Computing: resource is not ideal (1 - 2k CPU + 2 – 3 PB storage), but sufficient for us to carry on lots of studies already
- Distributed computing is needed

CEPC Higgs Analysis: Status

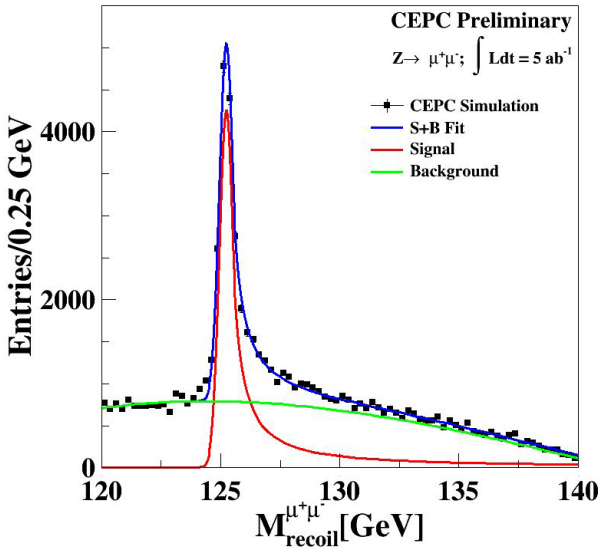
	di-muon	di-electron	di-neutrino	di-jets
σ(ZH)			-	
M_H				
σ(ZH)*Br(H→bb)				
σ(ZH)*Br(H→cc)				
σ(ZH)*Br(H→gg)				
σ(ZH)*Br(H→WW)				
σ(ZH)*Br(H→ZZ)				
σ(ZH)*Br(H→ττ)				
σ(ZH)*Br(H→γγ)				
σ(ZH)*Br(H→μμ)				
σ(vvH)*Br(H→bb)	-	-		-
Br(H→invisible)			-	
Br(H→exotic)				

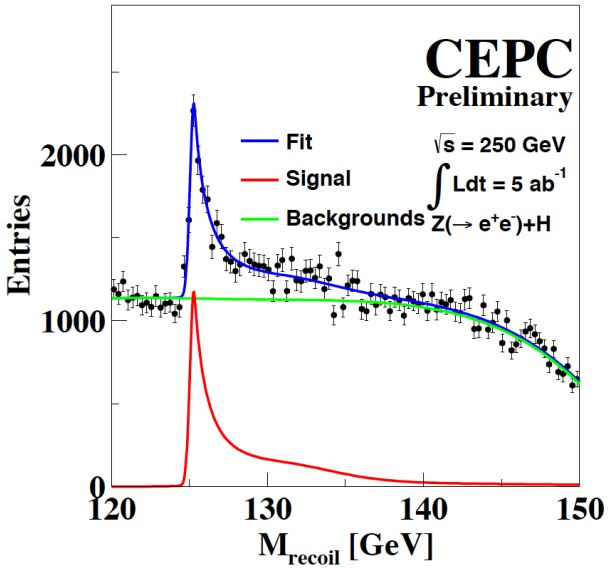
Signal with CEPC Full Simulation, Bkgrd with Fast Simulation

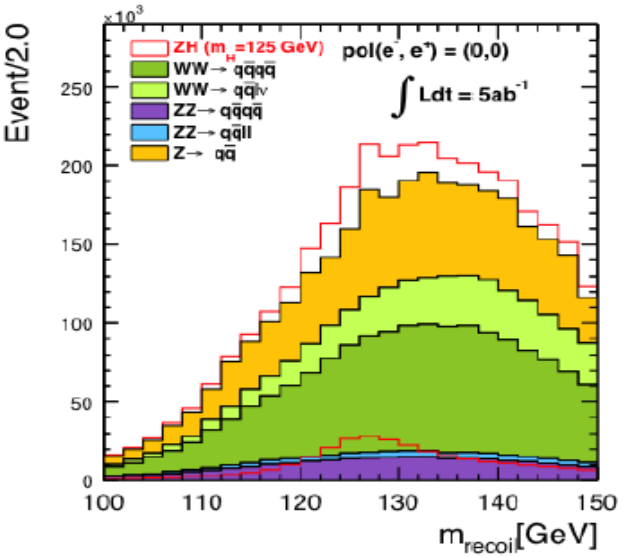
CEPC Fast Simulation

Extrapolated from ILC/FCC-ee results

Higgs Analysis: Higgs mass & σ(ZH)







Mass measurement:
5.0 MeV from di-muon channel &
17 MeV from di-electron channel

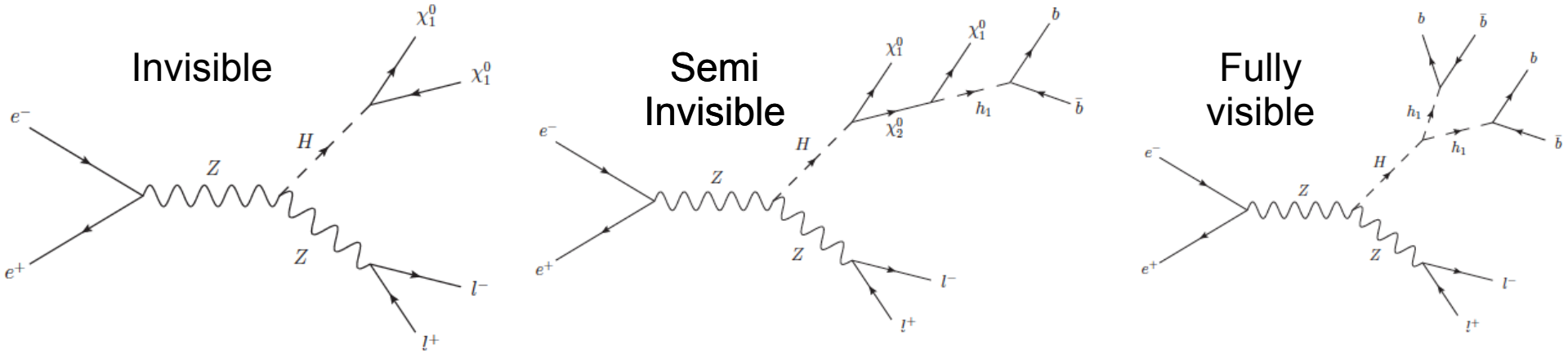
Xsec measurement:
0.9% from di-muon, 2.1% from di-electron, 0.65% from di-jet

Analyzer:

Z.X Chen (PKU & IHEP)
L.Yuan (Kobe University, Japan)
Y. Haddad (LLR, France & Imperial University, UK)

0.5% accuracy on σ(ZH), the **anchor** of absolute Higgs measurements,
0.25% accuracy on g(HZZ), an extremely sensitive probe to NP

Higgs→ Exotics



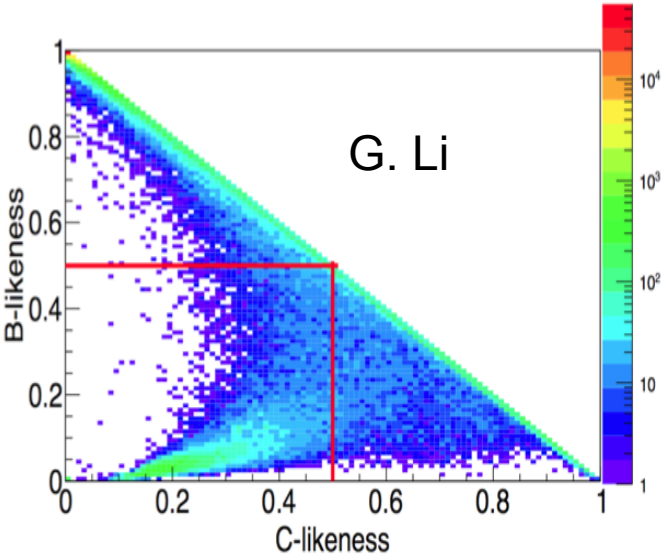
Model independent tagging of Higgs boson (though recoil mass spectrum)
Make CEPC extremely sensitive to BSM Higgs decay...

Benchmark tests:

Br(H→inv) can measured to **0.14%** accuracy with Br = 100%
Br(H→bb + MET) will induce 9.4σ deviation with Br = 0.2%
Br(H→bbbb) will induce 8.4σ sigma deviation with Br = 0.04%

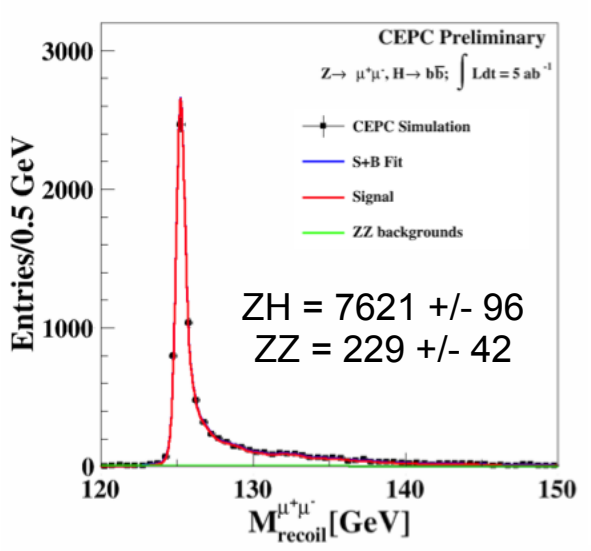
Z→μμ/ee, H→bb, cc, gg

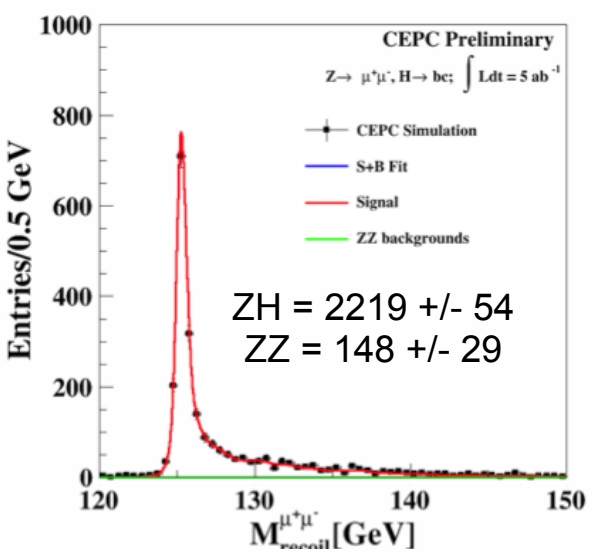
- Preliminary analysis
  - With fully simulated Higgs signal
  - Only consider μμ/eeqq background. Ignore other SM background and Higgs backgrounds
- Method:
  - Force everything besides two leading leptons into 2 jets
  - Event selection on leptons and jets kinematics
  - Flavor tagging: classify selected events into possible flavor combination (bb, cc, gg, bc, bg, cg)
  - Resolve back the signal and background yields (only bb, cc, gg numbers)

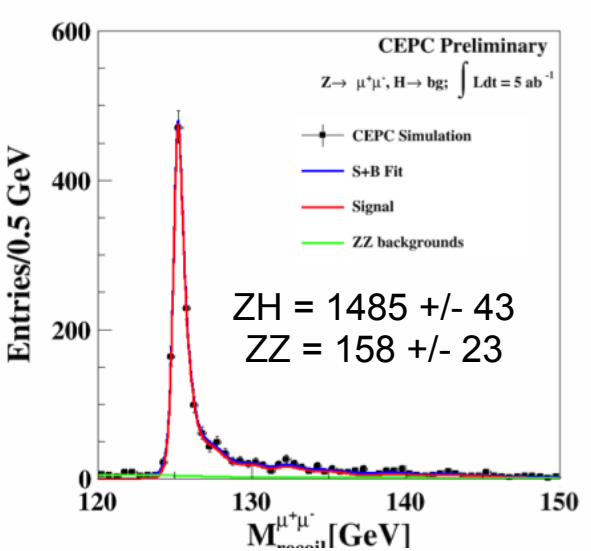


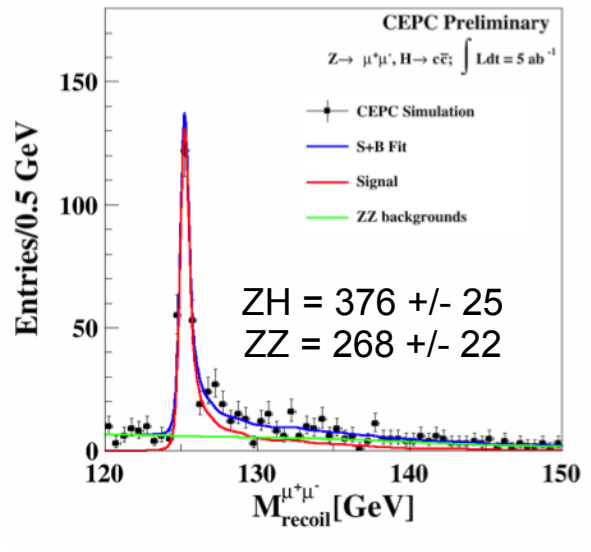

```
migrate matrix w/o eff.
 83.65%, 10.36%,  5.99%
  9.48%, 61.19%, 29.33%
  3.50%,  9.01%, 87.49%
```

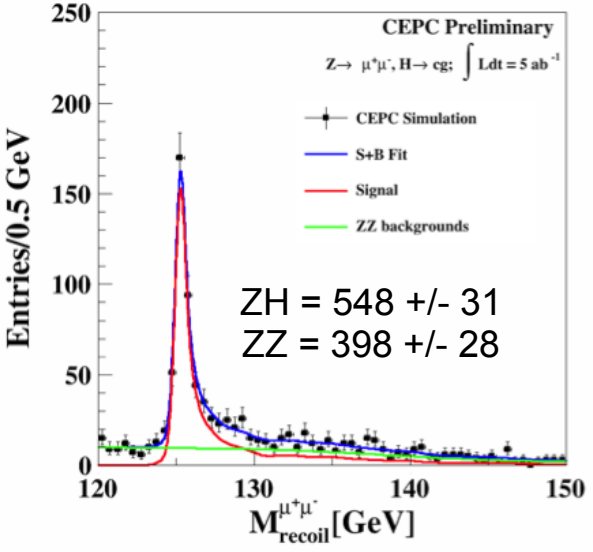
Z→μμ, H→bb, cc, gg

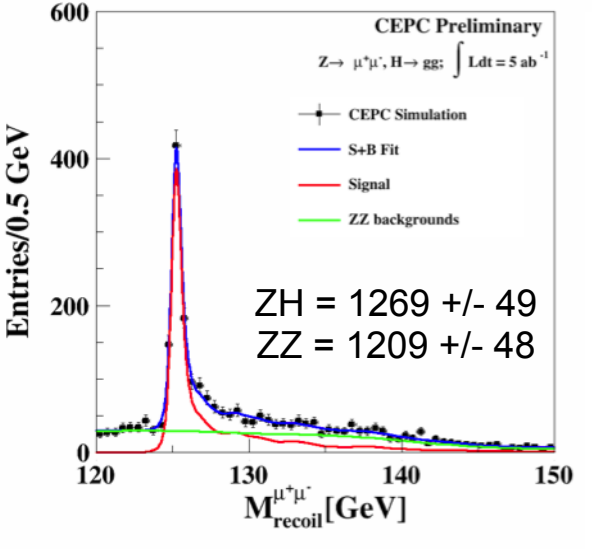

CEPC Preliminary
Z→ μ⁺μ⁻, H→ bb̄; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
ZZ backgrounds
ZH = 7621 +/- 96
ZZ = 229 +/- 42
Entries/0.5 GeV
M^{μ⁺μ⁻}_{recoil}[GeV]


CEPC Preliminary
Z→ μ⁺μ⁻, H→ bc; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
ZZ backgrounds
ZH = 2219 +/- 54
ZZ = 148 +/- 29
Entries/0.5 GeV
M^{μ⁺μ⁻}_{recoil}[GeV]

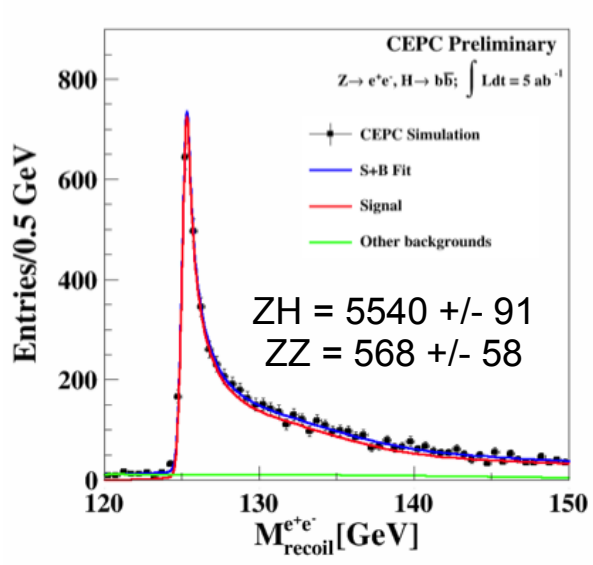

CEPC Preliminary
Z→ μ⁺μ⁻, H→ bg; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
ZZ backgrounds
ZH = 1485 +/- 43
ZZ = 158 +/- 23
Entries/0.5 GeV
M^{μ⁺μ⁻}_{recoil}[GeV]

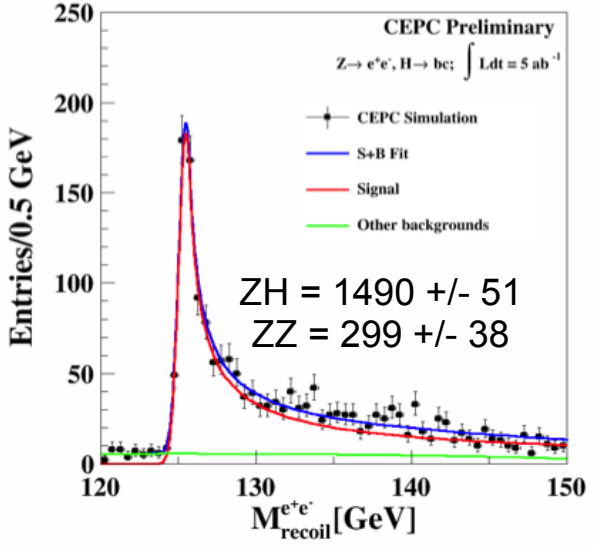

CEPC Preliminary
Z→ μ⁺μ⁻, H→ cc̄; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
ZZ backgrounds
ZH = 376 +/- 25
ZZ = 268 +/- 22
Entries/0.5 GeV
M^{μ⁺μ⁻}_{recoil}[GeV]

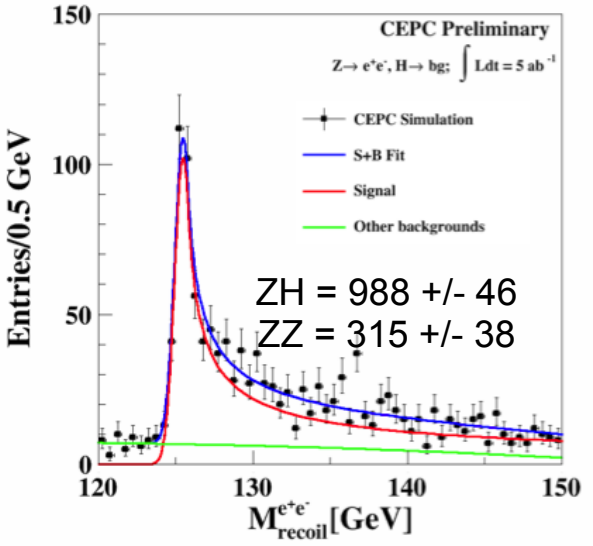

CEPC Preliminary
Z→ μ⁺μ⁻, H→ cg; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
ZZ backgrounds
ZH = 548 +/- 31
ZZ = 398 +/- 28
Entries/0.5 GeV
M^{μ⁺μ⁻}_{recoil}[GeV]

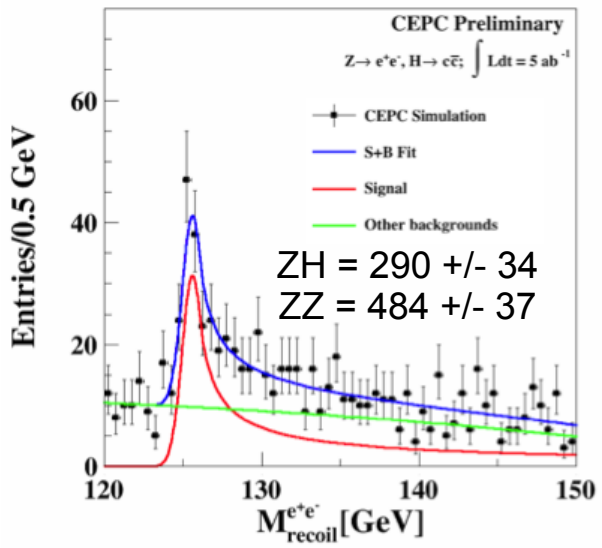

CEPC Preliminary
Z→ μ⁺μ⁻, H→ gg; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
ZZ backgrounds
ZH = 1269 +/- 49
ZZ = 1209 +/- 48
Entries/0.5 GeV
M^{μ⁺μ⁻}_{recoil}[GeV]

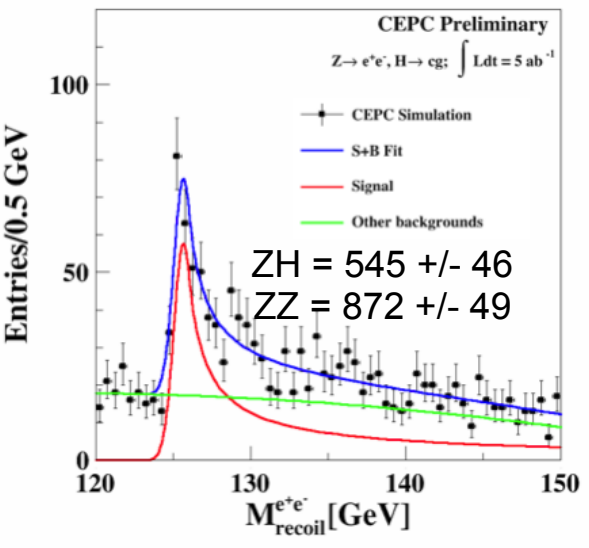
Z→ee, H→bb, cc, gg

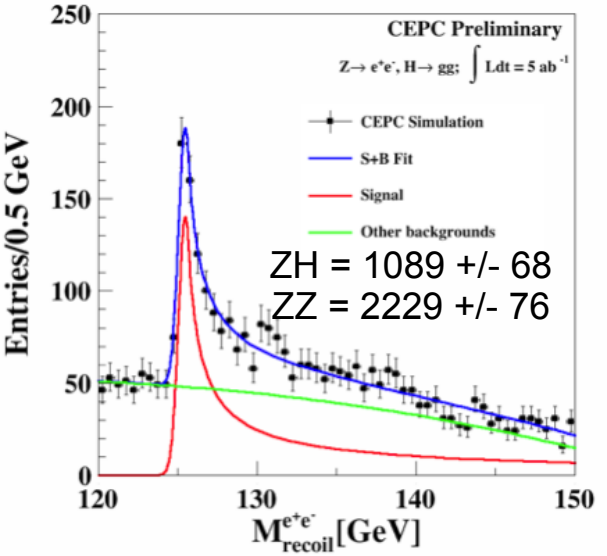

CEPC Preliminary
Z→ e⁺e⁻, H→ bb̄; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
Other backgrounds
ZH = 5540 +/- 91
ZZ = 568 +/- 58
Entries/0.5 GeV
M^{e⁺e⁻}_{recoil}[GeV]


CEPC Preliminary
Z→ e⁺e⁻, H→ bc; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
Other backgrounds
ZH = 1490 +/- 51
ZZ = 299 +/- 38
Entries/0.5 GeV
M^{e⁺e⁻}_{recoil}[GeV]


CEPC Preliminary
Z→ e⁺e⁻, H→ bg; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
Other backgrounds
ZH = 988 +/- 46
ZZ = 315 +/- 38
Entries/0.5 GeV
M^{e⁺e⁻}_{recoil}[GeV]


CEPC Preliminary
Z→ e⁺e⁻, H→ cc̄; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
Other backgrounds
ZH = 290 +/- 34
ZZ = 484 +/- 37
Entries/0.5 GeV
M^{e⁺e⁻}_{recoil}[GeV]


CEPC Preliminary
Z→ e⁺e⁻, H→ cg; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
Other backgrounds
ZH = 545 +/- 46
ZZ = 872 +/- 49
Entries/0.5 GeV
M^{e⁺e⁻}_{recoil}[GeV]


CEPC Preliminary
Z→ e⁺e⁻, H→ gg; ∫ Ldt = 5 ab⁻¹
CEPC Simulation
S+B Fit
Signal
Other backgrounds
ZH = 1089 +/- 68
ZZ = 2229 +/- 76
Entries/0.5 GeV
M^{e⁺e⁻}_{recoil}[GeV]

Measurements

Di-muon channel

ZH

Expected events	Solution	Error
11416	11485	0.85%
562	523	10.00%
1494	1522	3.96%

ZZ

Expected events	Solution	Error
343	344	14.88%
618	565	7.98%
1498	1495	3.68%

ILC result

bb 1.0%
cc 8.0%
gg 4.8%

Di-electron channel

ZH

Expected events	Solution	Error
8154	8123	1.25%
399	412	19.05%
1408	1409	6.33%

ZZ

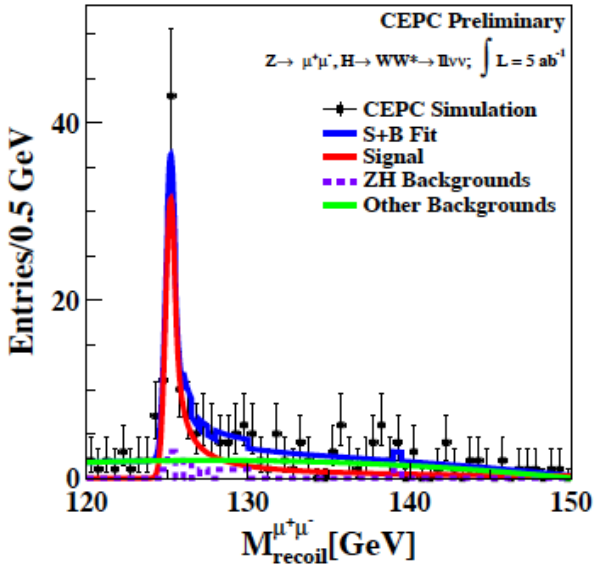
Expected events	Solution	Error
679	767	9.53%
1205	1083	7.63%
2864	2905	3.28%

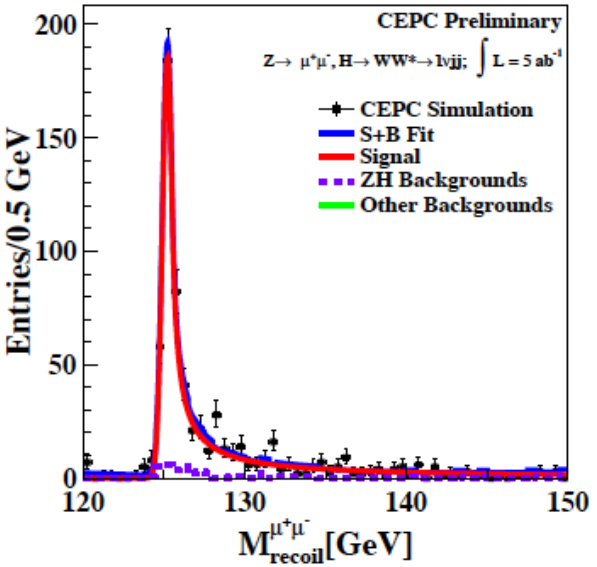
ILC result

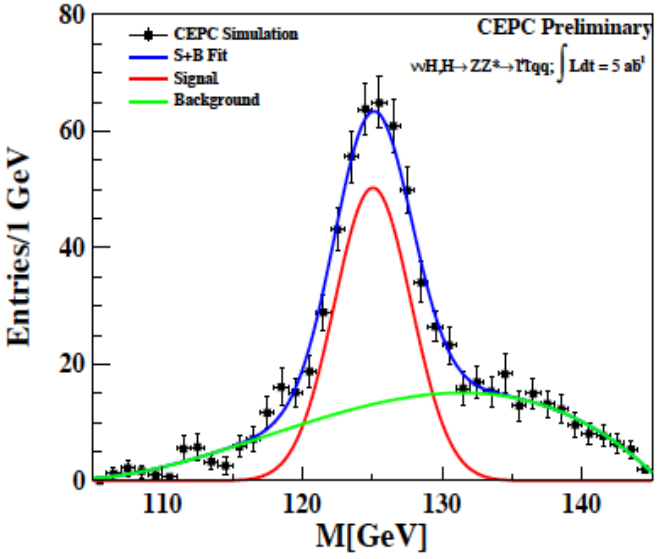
bb 1.1%
cc 6.5%
gg 4.8%

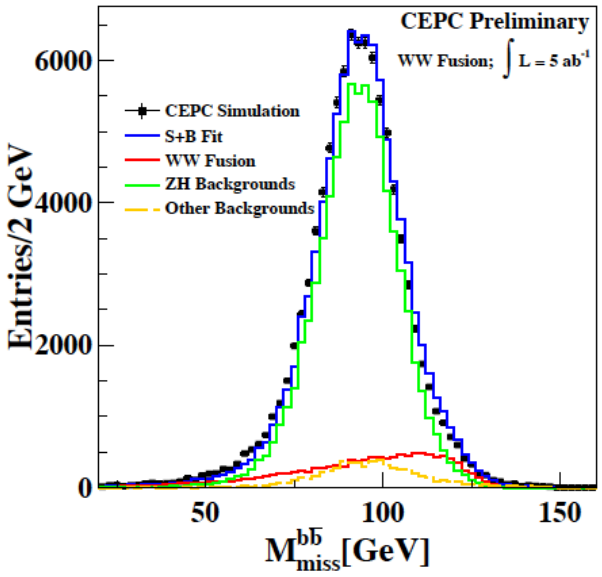
Electron channel significantly worse than muon for:
1, electron tagging efficiency & 2, larger background

Higgs Analysis: Br(H→WW*, ZZ*) & σ(vvH)*Br(H→bb)







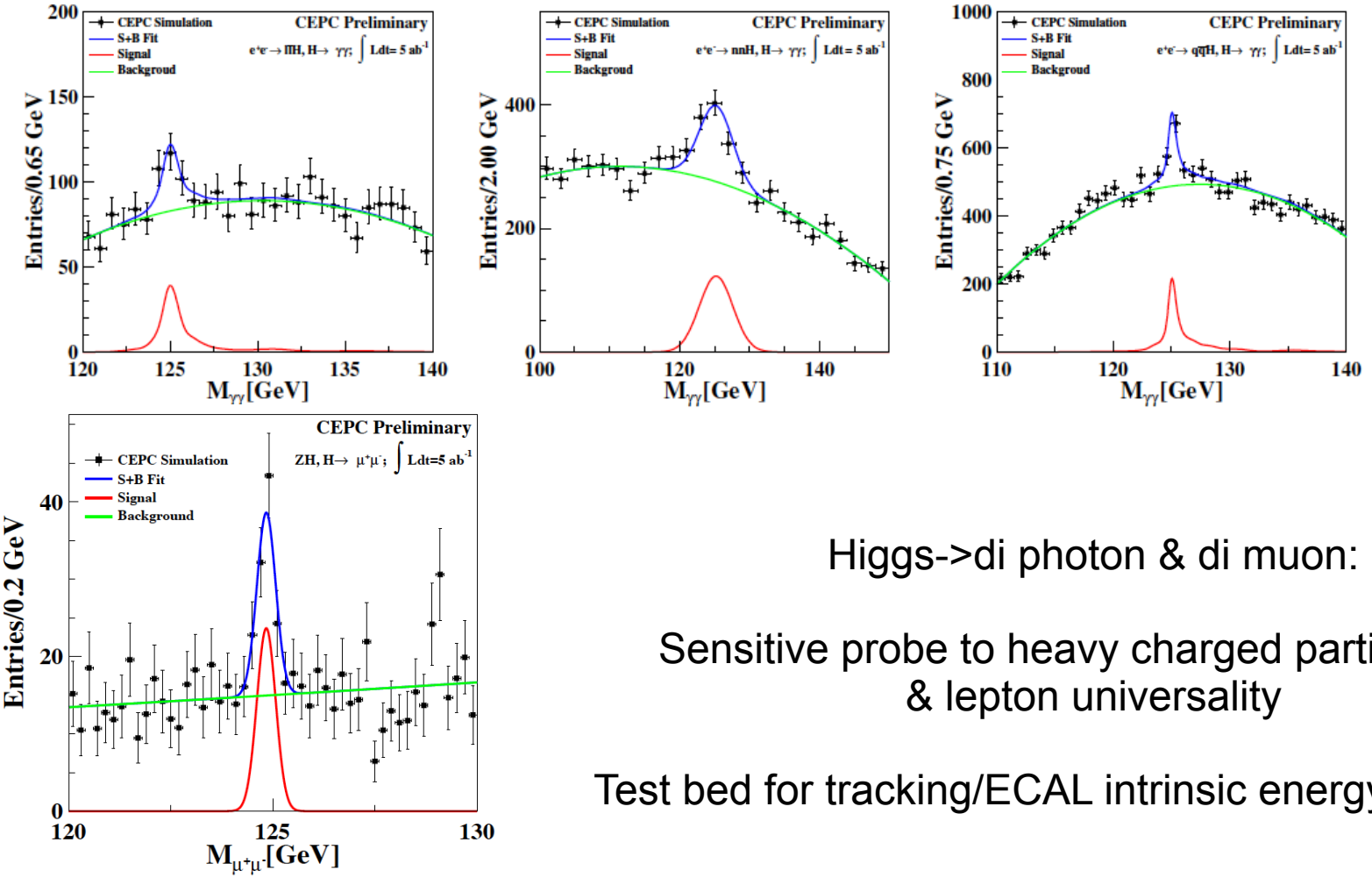


Essential Input to determine Higgs total width and g(HWW)

H→VV*: Complicate decay final states, partial explored

Higgs Rare Decays

Figure 3.14 $\sigma(ZH, \nu\nu H) \times Br(H \to \gamma\gamma)$ measured from $llH, \nu\nu H$ and qqH channels with different modelling of ECAL energy resolutions.



Higgs->di photon & di muon:

Sensitive probe to heavy charged particle (NP) & lepton universality

Test bed for tracking/ECAL intrinsic energy resolution

Comparison to ILC/FCC-ee

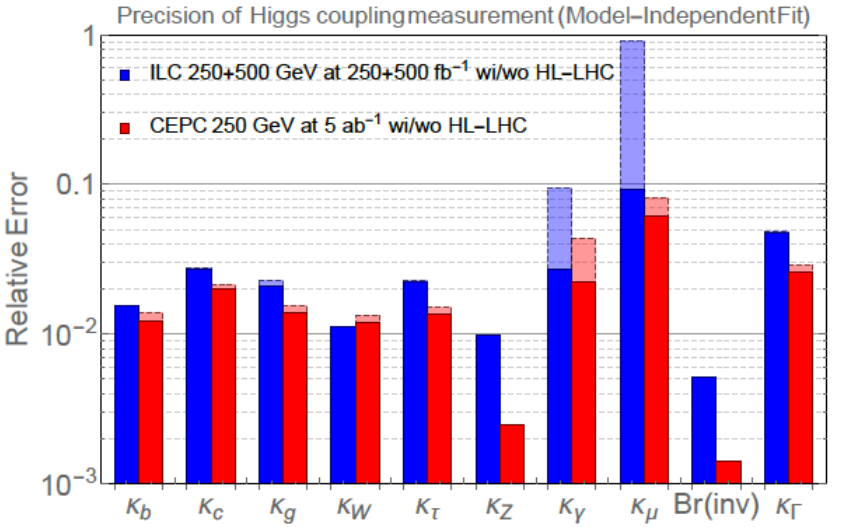
	ILC Extrapolation	FCC-ee Extrapolation	CEPC Simu
mH (Model Independent)	8 MeV		4.7 MeV
σ(ZH)	0.7 %	0.55%	0.5%
Higgs CP			
Δ(σ*Br)/(σ*Br)			
ZH, H→bb	0.4%	0.27%	0.24%
H→cc	2.1%	1.6%	2.6%
H→gg	1.8%	1.9%	1.3%
H→WW*	1.3%	1.2%	1.5%
H→ττ	1.2%	1.0%	1.2%
H→ZZ*	5.1%	4.3%	4.3%
H→γγ	8%	4.1%	8.2%
H→μμ	-	18%	17%
H→Inv.	0.14%	-	0.14%
vvH, H→bb	3.8%	2.9%	2.6%

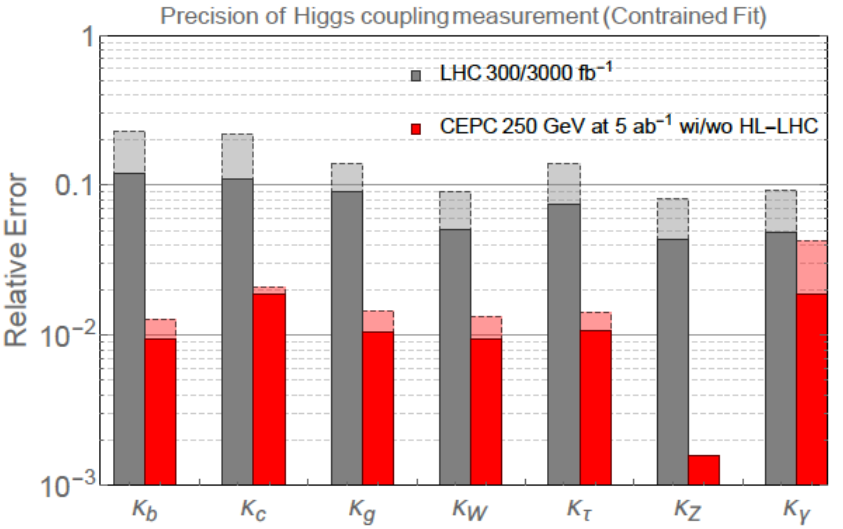
Normalize to same Higgs Yields at 3 facilities...
FCC-ee at 240 GeV (sigma(ZH) = 197 fb, sigma(vvH) = 6.1 fb),
ILC/CEPC at 250 GeV (sigma(ZH) = 209 fb, sigma(vvH) = 6.8 fb)
Number in blue, recent update.

From measurements to couplings

Δm_H	Γ_H	$\sigma(ZH)$	$\sigma(\nu\nu H) \times BR(h \to bb)$
5.5 MeV	2.9%	0.5%	2.6%

Decay mode	$\sigma(ZH) \times BR$	Branching Ratio $BR(h \to XX)$
$h \to bb$	0.25%	0.56%
$h \to cc$	3.2%	3.2%
$h \to gg$	1.3%	1.4%
$h \to \tau\tau$	1.2%	1.3%
$h \to WW$	1.5%	1.6%
$h \to ZZ$	4.3%	4.3%
$h \to \gamma\gamma$	8.2%	8.2%
$h \to \mu\mu$	16%	16%
$h \to inv$	0.14%	0.5%





Combination group: (Y. Fang, Z. Liu, etc)

Model independent result compared to ILC
&
Model dependent result compare to LHC
(LHC: very limited access to model Independent measurement)

Higgs measurements at CEPC: roughly understood

Z pole: EW & Flavor

07/05/14 9

Summary

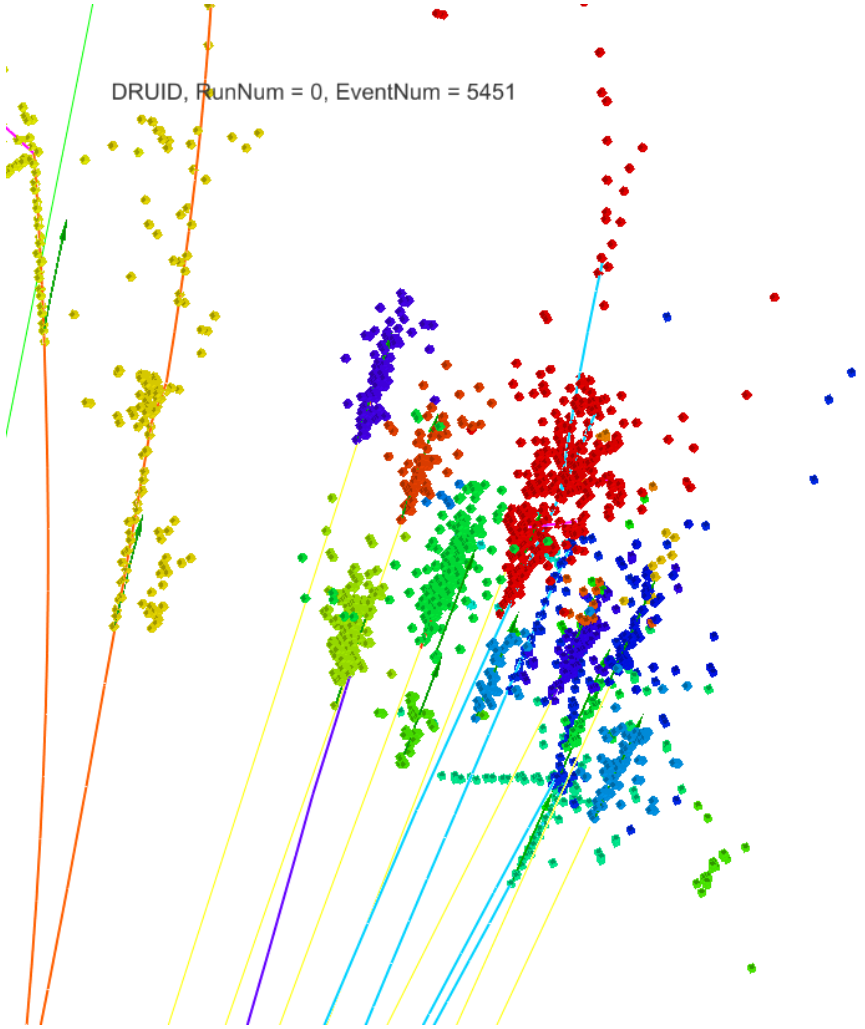
- Writing a note on CEPC Z-pole physics
  - 30% written
  - More measurements to be covered
    - Z mass/width measurement
    - QCD alpha_S measurement
    - ……

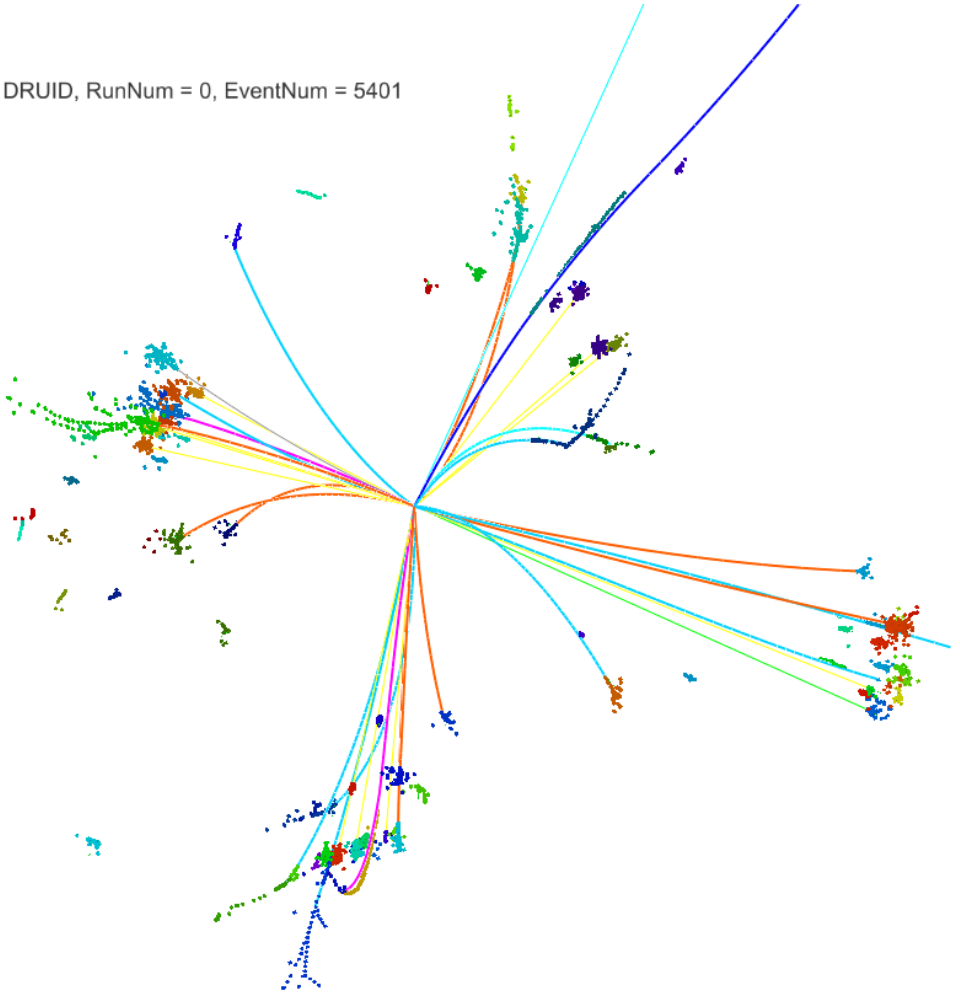
Observable	LEP precision	CEPC precis
$A_{FB\,(b)}$	1.7%	0.15%
$Sin^2\theta_W$	0.1%	0.01%
R^b	~0.3%	0.08%
N_v (direct measurement)	1.7%	0.18%
R^{mu}	0.2%	0.05%
R^{tau}	0.2%	0.05%

Z. Liang at USCD

- 2.1 Higgs Factory as excellent `early' Z0 Factory about Beauty, Charm Hadrons & Dynamics
  - 2.1.1 Introduction
  - 2.1.2 Tools
  - 2.1.3 Beauty transitions
  - 2.1.4 Charm mesons & baryons transitions
  - 2.1.5 Very rare decays
  - 2.1.6 Production of beauty & charm hadrons
  - 2.1.7 CPV in decays and production
  - 2.1.8 Charged Lepton Flavor Violation
  - 2.1.9 Summary
- References

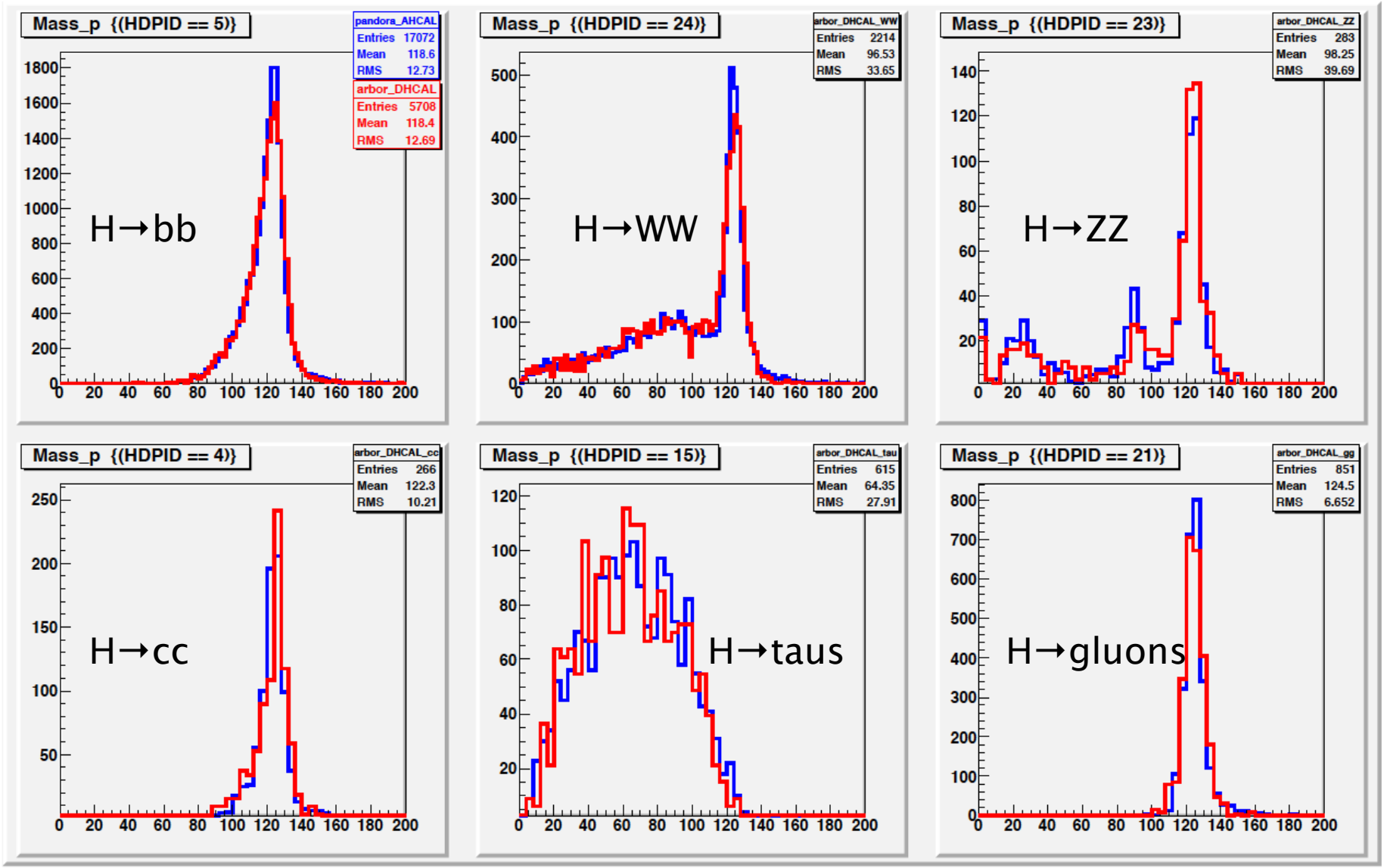
Reconstruction: a closer look





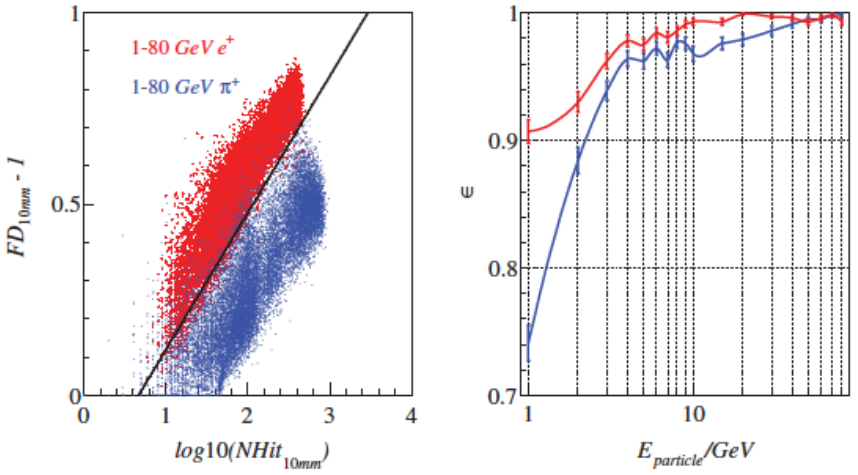
Separation: Key for PFA

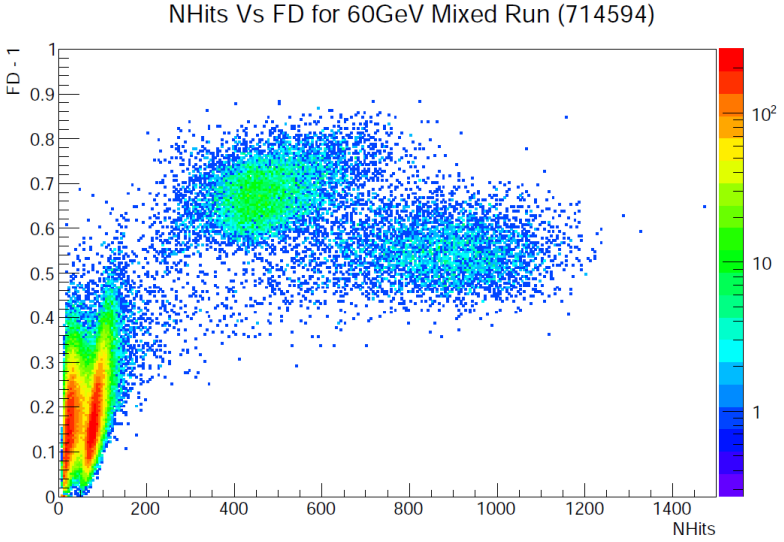
At Higgs invariant mass



Arbor Uses GRPC Hadron Calorimeter, whose intrinsic resolution – based on current energy estimator is worse than that Pandora Used (Scintillator Tile Analogy HCAL).

Lepton identification (Preliminary)





10GeV	P_PID_e(%)	P_PID_mu(%)	P_PID_pi(%)
e	99.02	0.09	0.89
mu	0.02	98.24	1.74
pi	5.34	4.14	90.66

20GeV	P_PID_e(%)	P_PID_mu(%)	P_PID_pi(%)
e	99.47	0.06	0.47
mu	0.09	99.11	0.80
pi	5.56	1.99	92.45

30GeV	P_PID_e(%)	P_PID_mu(%)	P_PID_pi(%)
e	99.47	0.03	0.50
mu	0.06	99.20	0.74
pi	5.28	1.84	92.88

40GeV	P_PID_e(%)	P_PID_mu(%)	P_PID_pi(%)
e	99.43	0.13	0.44
mu	0.13	99.45	0.41
pi	5.38	1.71	92.91

50GeV	P_PID_e(%)	P_PID_mu(%)	P_PID_pi(%)
e	99.70	0.09	0.21
mu	0.20	99.35	0.45
pi	6.28	1.37	92.35

60GeV	P_PID_e(%)	P_PID_mu(%)	P_PID_pi(%)
e	99.71	0.09	0.20
mu	0.24	99.56	0.20
pi	5.84	1.63	92.53

70GeV	P_PID_e(%)	P_PID_mu(%)	P_PID_pi(%)
e	99.62	0.09	0.29
mu	0.25	99.58	0.17
pi	5.06	1.78	93.26

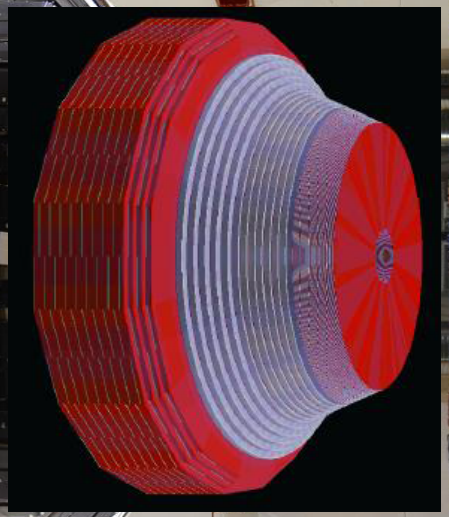
80GeV	P_PID_e(%)	P_PID_mu(%)	P_PID_pi(%)
e	99.47	0.09	0.44
mu	0.22	99.68	0.10
pi	5.00	2.49	92.51

90GeV	P_PID_e(%)	P_PID_mu(%)	P_PID_pi(%)
e	99.46	0.05	0.49
mu	0.25	99.69	0.06
pi	5.00	2.34	92.76

100GeV	P_PID_e(%)	P_PID_mu(%)	P_PID_pi(%)
e	99.28	0.03	0.69
mu	0.43	99.56	0.01
pi	4.24	2.59	93.17

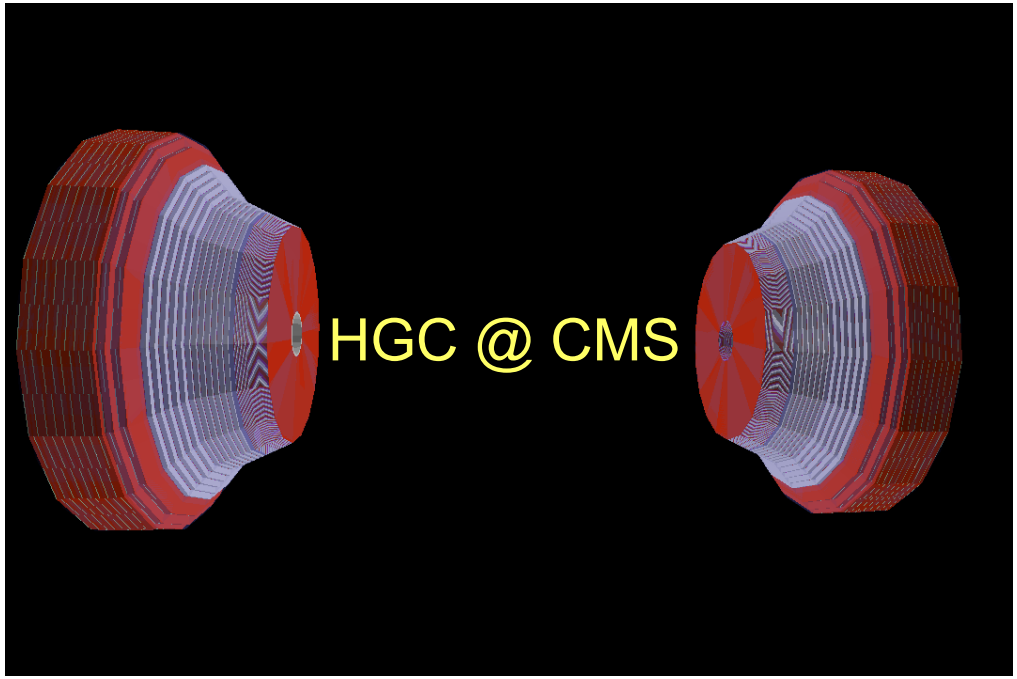
Binsong MA @ IHEP: Arbor Clusters:
Efficiency > 99% is achieved for muon/electron:
On going activity: understand the pion mis-id case...
Push to low energy cases

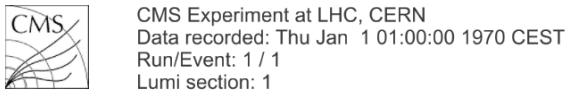
A Silicon based High luminosity Calorimeter for HL-LHC...

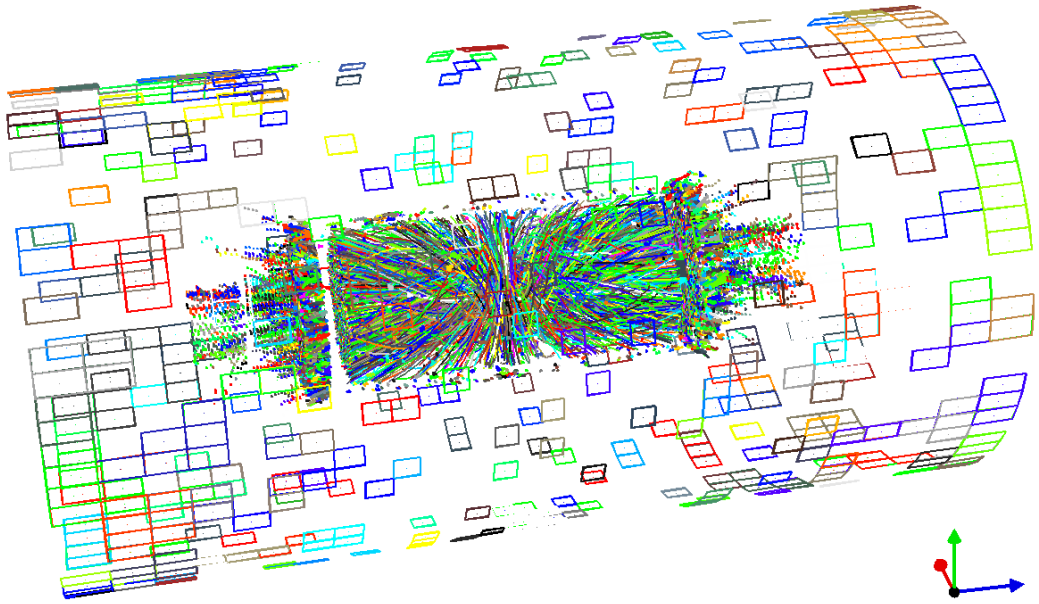


...Pile ups...

140 PU: 100 k hits ~ o(100 TeV) energy deposition at each EndCap...

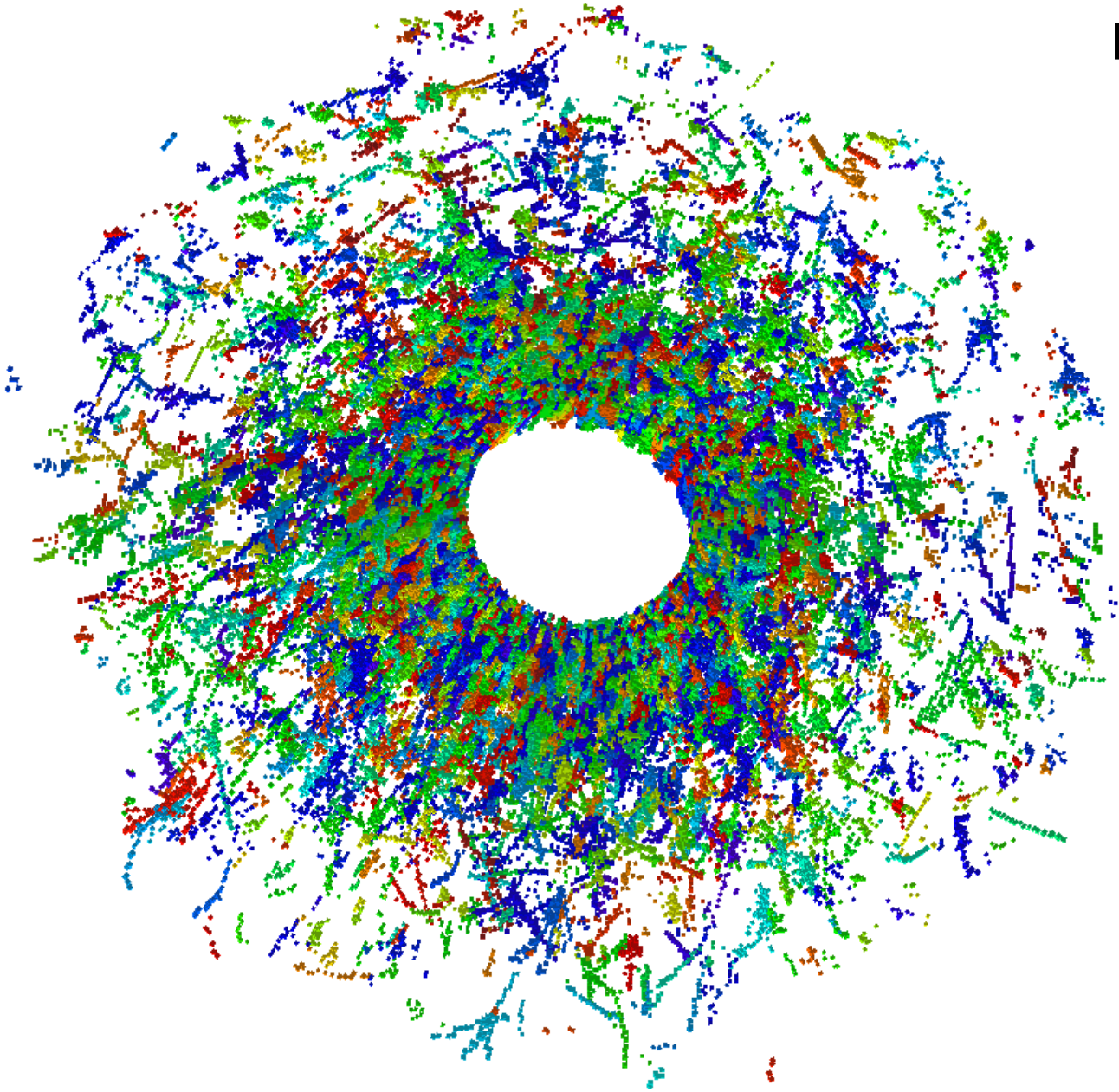






CMS Experiment at LHC, CERN
Data recorded: Thu Jan 1 01:00:00 1970 CEST
Run/Event: 1 / 1
Lumi section: 1

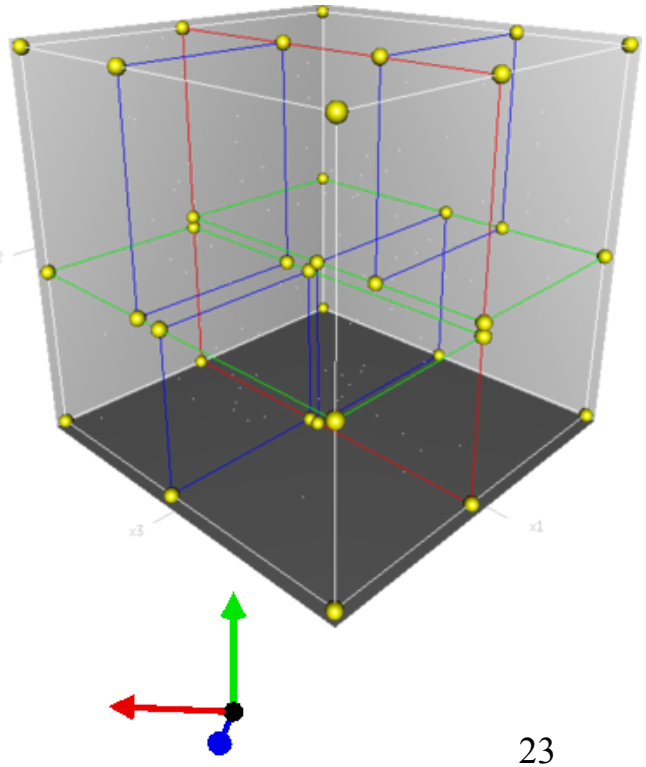
Lindsey Gray



KD-Tree implemented:

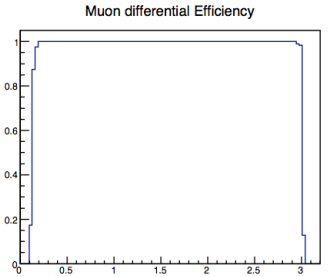
$N^2 \rightarrow N\log(N)$

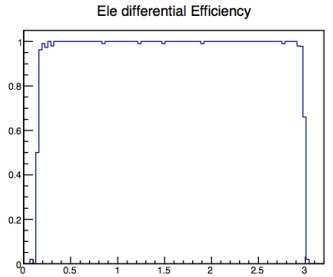
One event ~ 40 sec...

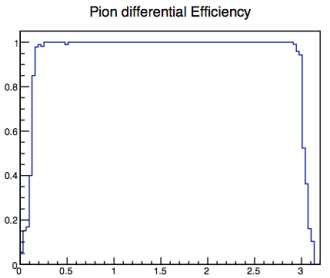


Reconstruction: next steps

- Tracking
  - TPC?
  - Tagging of pre interaction, kink, etc...
- PFA
  - Arbor development:
    - Efficiency orientated
    - Photon energy reconstruction
    - Neutral Hadron energy measurement
    - Bremsstrahlung photon tagging & electron id
- FlavorTagging
  - Identification between quark jets/gluon jets?
  - Optimization with Inner detector design







Arbor-v2: on going

Toward the CDR: CEPC

- Physics @ CEPC
  - Higgs measurement simulated (Fast/Full)
    - SM
    - BSM
  - Z pole
    - Flavor physics
    - EW measurements
- ILD based, Conceptual detector model(s) realized at Full Simulation level
- Workable software chain, optimization stage
- MDI: preliminary design

1 – 2 years

- Physics @ CEPC
  - Higgs
    - Analysis converged to Full simulation level
  - Z pole
    - EW (& flavor?): dedicated Fast simulation tool to be developed
- Iterate with sub-detector studies, and converged to 1 - 2 benchmark detectors
- Develop/Optimize reconstruction algorithm/software by iteration with physics analysis
- MDI: iterate with acc. Group to fix the design...

Toward the CDR: SPPC

- Physics potential
  - SM: Higgs (g(HHH), g(Htt), rare generation/decay)
  - SM: Non-Higgs
  - BSM: representative NP models
- Detector design
  - Understand the correlation between object reconstruction & performance...
  - Constrains: High eta region layout
- Software:
  - Fast simulation tool: support Potential Demonstration & Detector Design
  - Full-sim/reco validation & preparations
- Design of experimental area, interference with 2 beam lines (electron-positron & proton-proton)...

Lots of interesting/well-defined tasks...

Team Building & trainings



Training

Go t

August 2014

11 Aug - 15 Aug Detector Simulation and Geometry editing

October 2013

19 Oct - 20 Oct CEPC Training: Physics Analysis, Detector Optimization and Software tools

International Summer school on TeV Experimental Physics (iSTEP)

20-29 August 2014
IHEP
Asia/Shanghai timezone

Overview

Continuous efforts + dedicated training

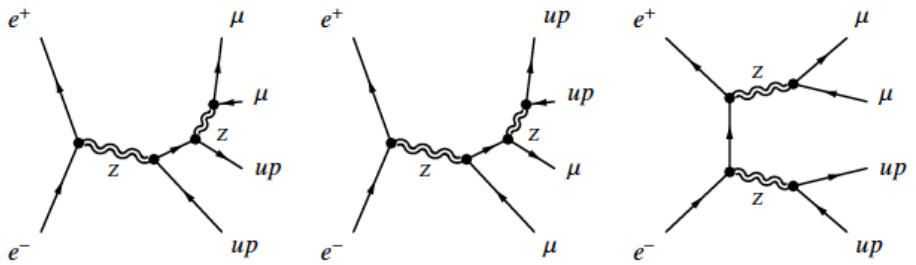
A small group of analyzers trained...

Summary

- Pre-CDR phase: Finalizing...
  - Workable simulation reconstruction chain
  - Higgs analysis covered by Simulation study (50% at Full simulation level)
- Lots of interesting tasks in the coming two years
  - Optimize detector geometries/adequate reconstruction for CEPC
  - Get conceptual detector design for pp collision phase
- Arbor PFA
  - Promising at both ee & pp collision...
  - Arbor v2 under development: efficiency & tagging oriented
- Team building
  - A small group of analyzers
  - Full simulation analysis chain
  - ...

Backup

183 **6.7 zz_sl0mu_up**



207 **6.31 sze_sl0uu**