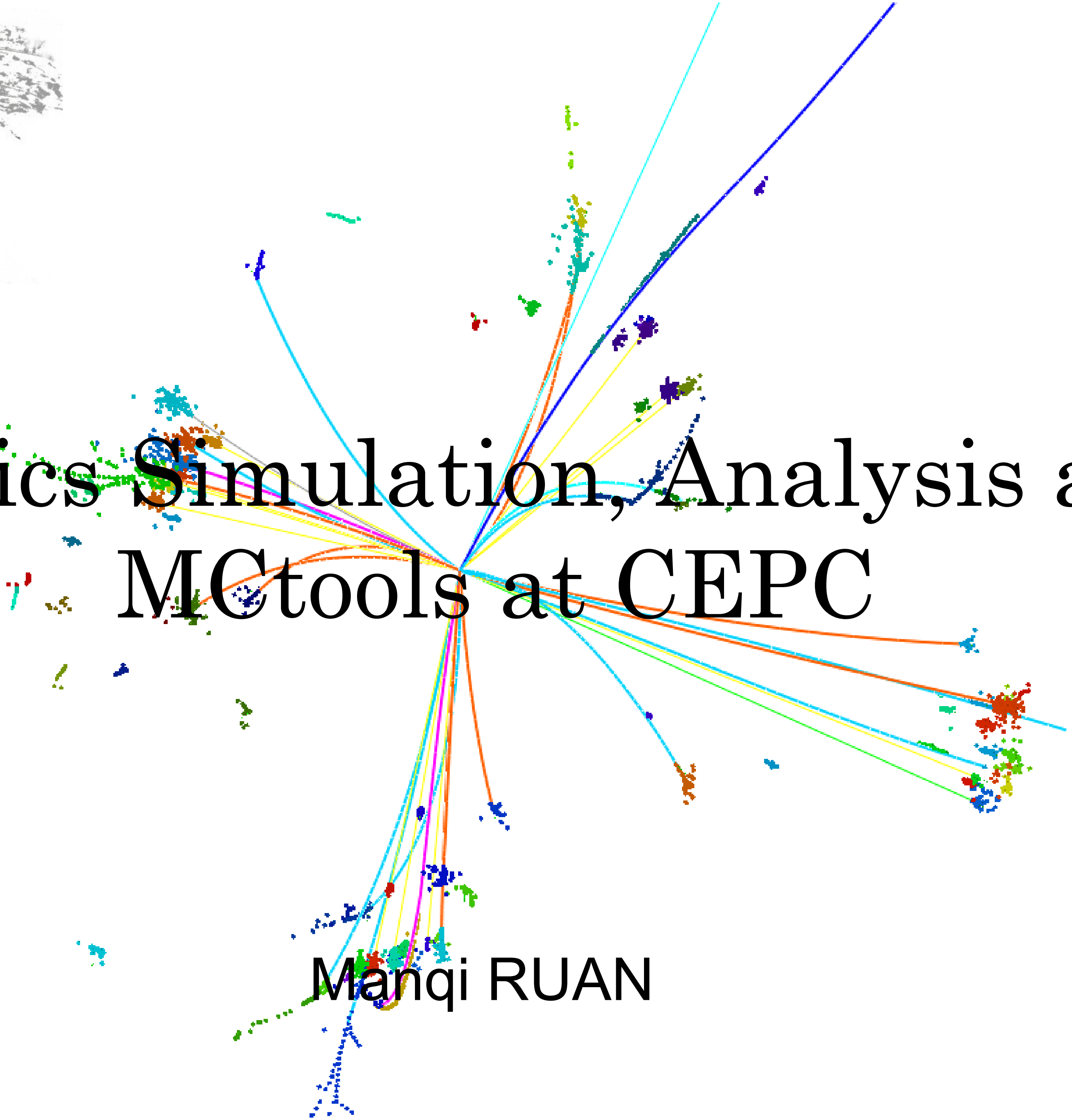
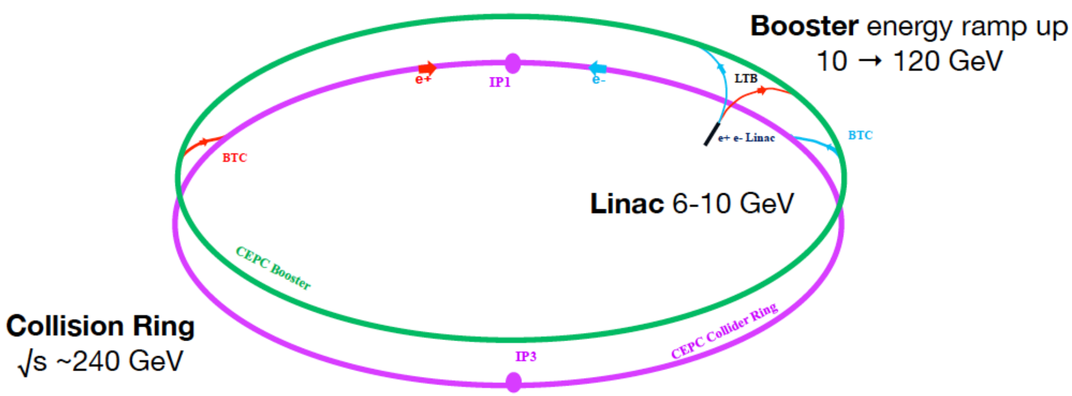
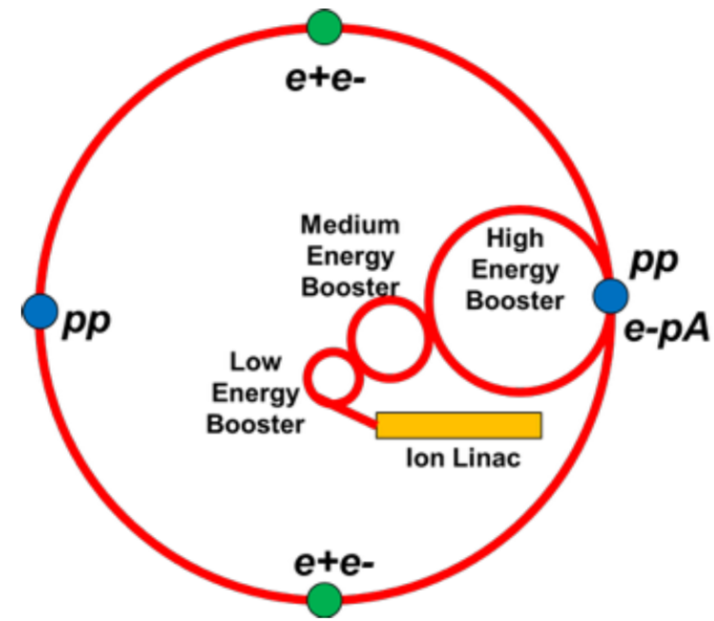


Physics Simulation, Analysis and MCtools at CEPC

Manqi RUAN

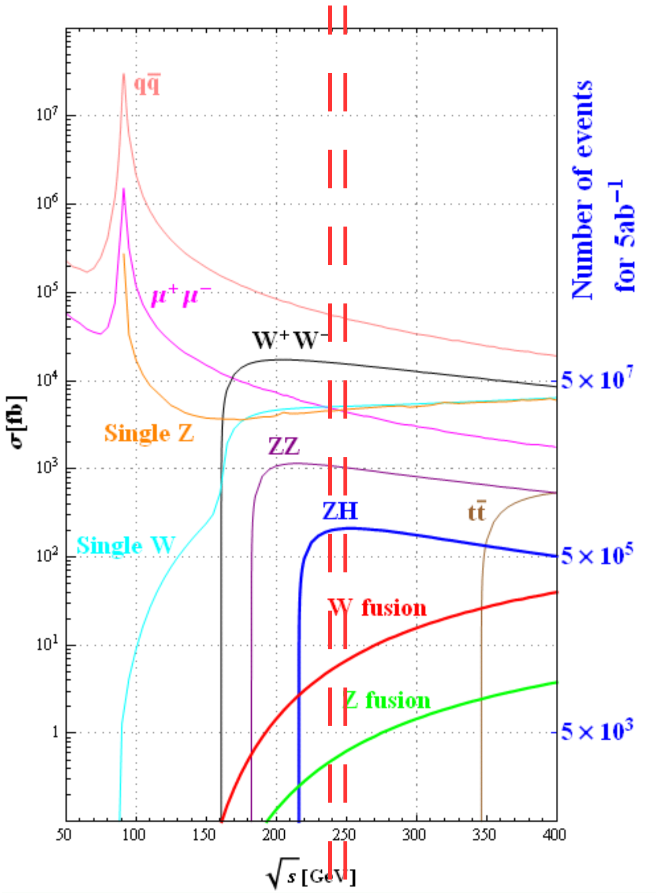
CEPC-SPPC

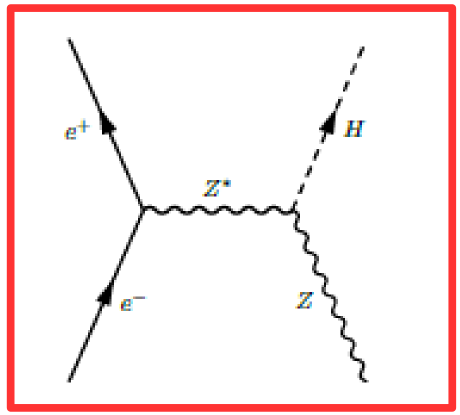


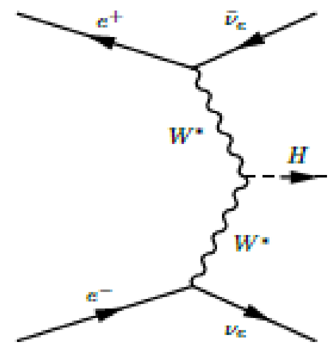


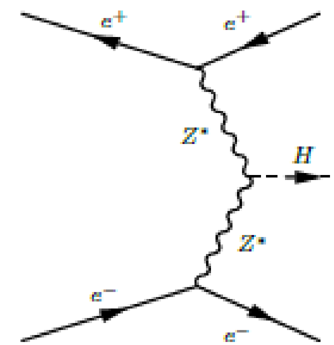
- Electron-positron collision phase
  - Higgs factory: collision at ~240 - 250 GeV center-of-mass energy, Instant luminosity ~ $2*10^{34}$ $cm^{-2}s^{-1}$, 1M clean Higgs event at 2 IP over 10 years
  - Z pole operation for precise EW measurement: 1E10 Z boson per year
- Proton-Proton collision phase
  - center-of-mass energy constrained by tunnel circumference and high-field dipole
  - Peak luminosity ~ $1*10^{35}$ $cm^{-2}s^{-1}$ (*ArXiv: 1504.06108, discussion on needed Luminosity*)
- Tunnel circumference: 54 km in the baseline design. Longer tunnel to be evaluated.

Higgs program at CEPC







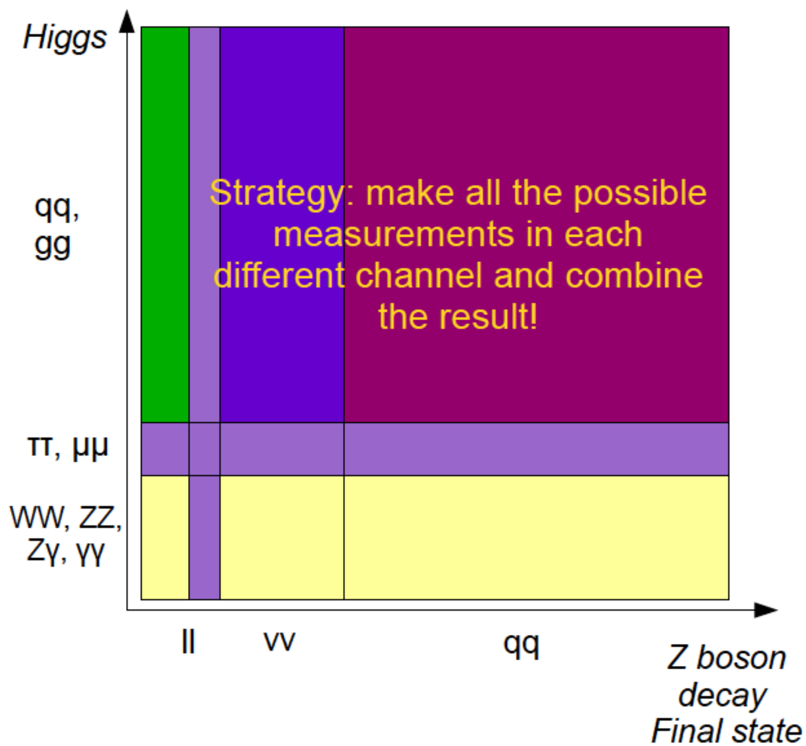


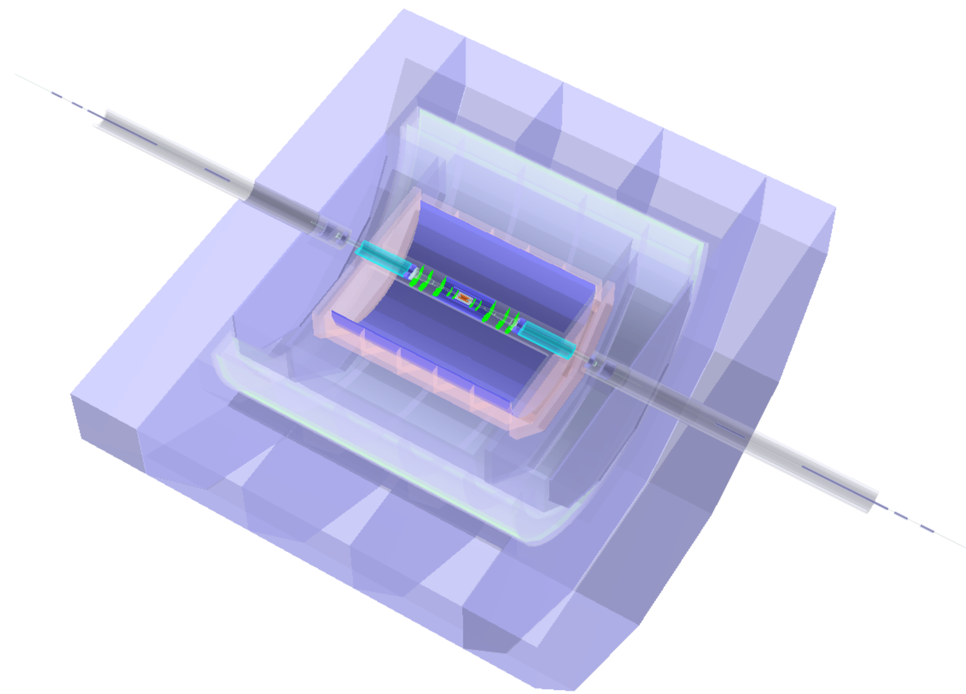
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

Observables: Higgs mass, CP, σ(ZH), event rates (σ(ZH, vvH)*Br(H->X))

Derive: Higgs width, branching ratios & absolute value of coupling constants

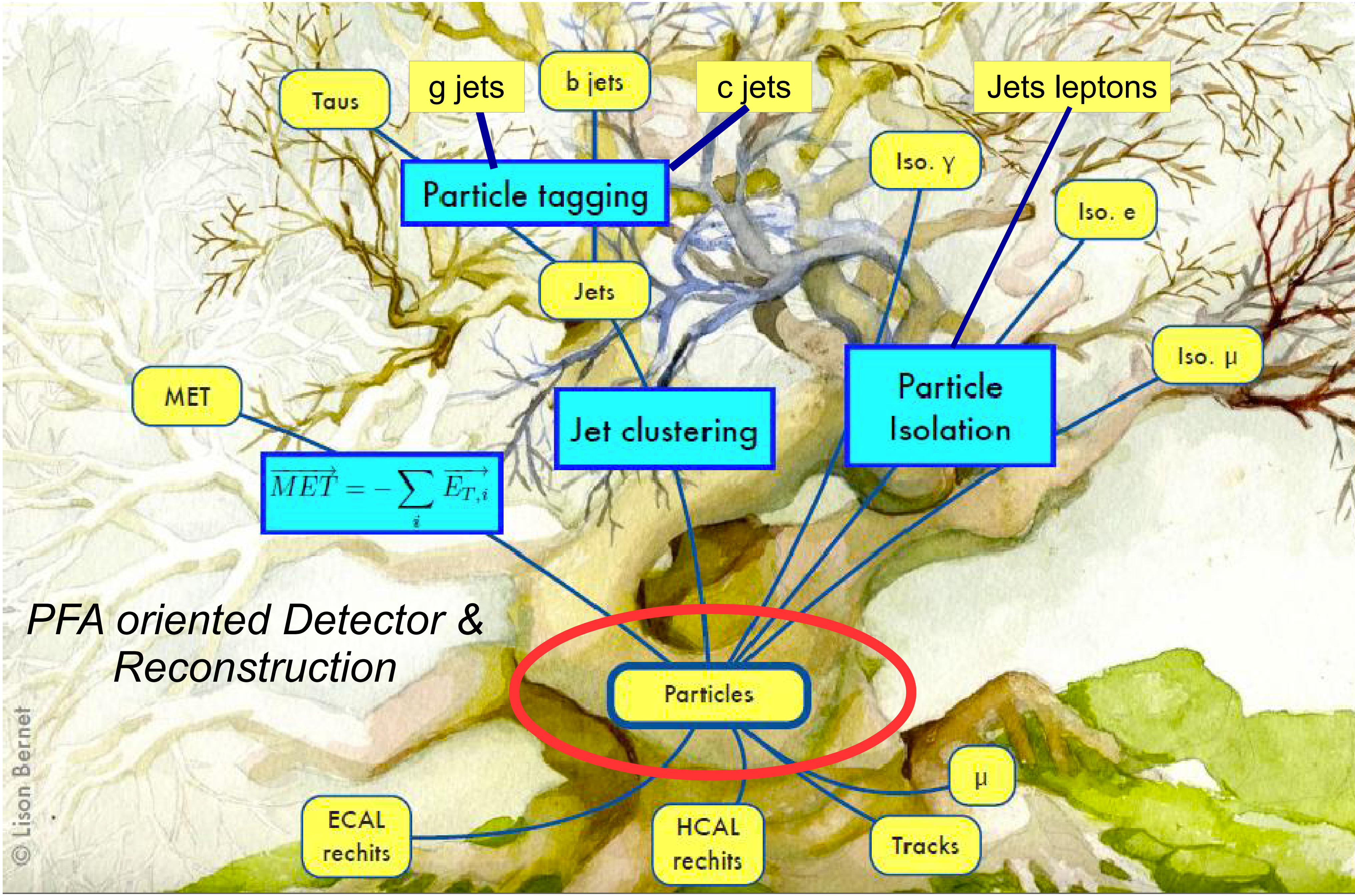
CEPC Conceptual detector, developed from ILD

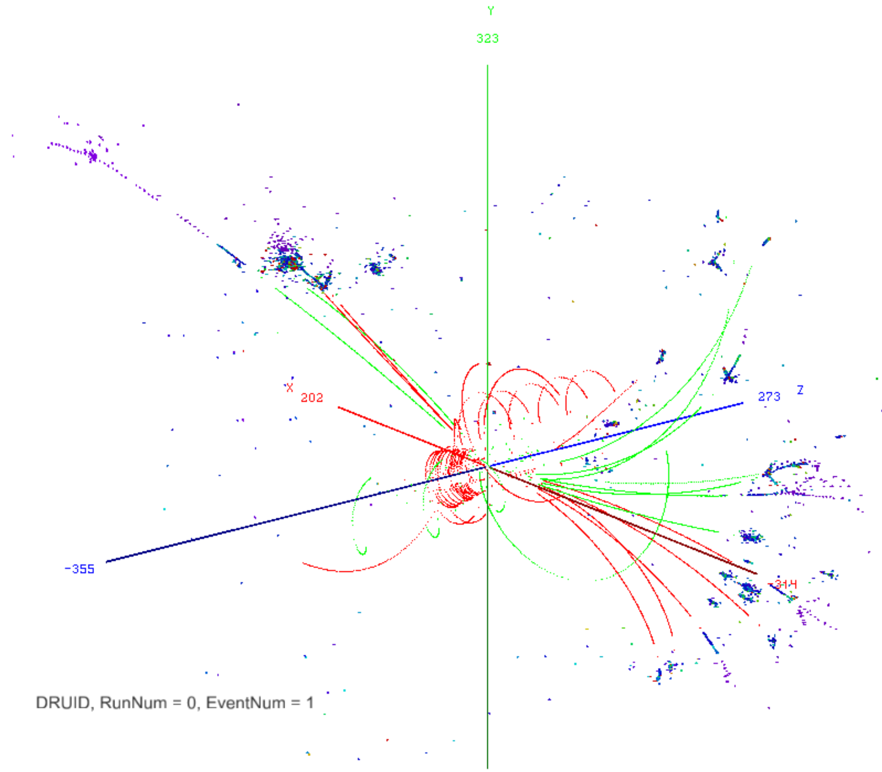


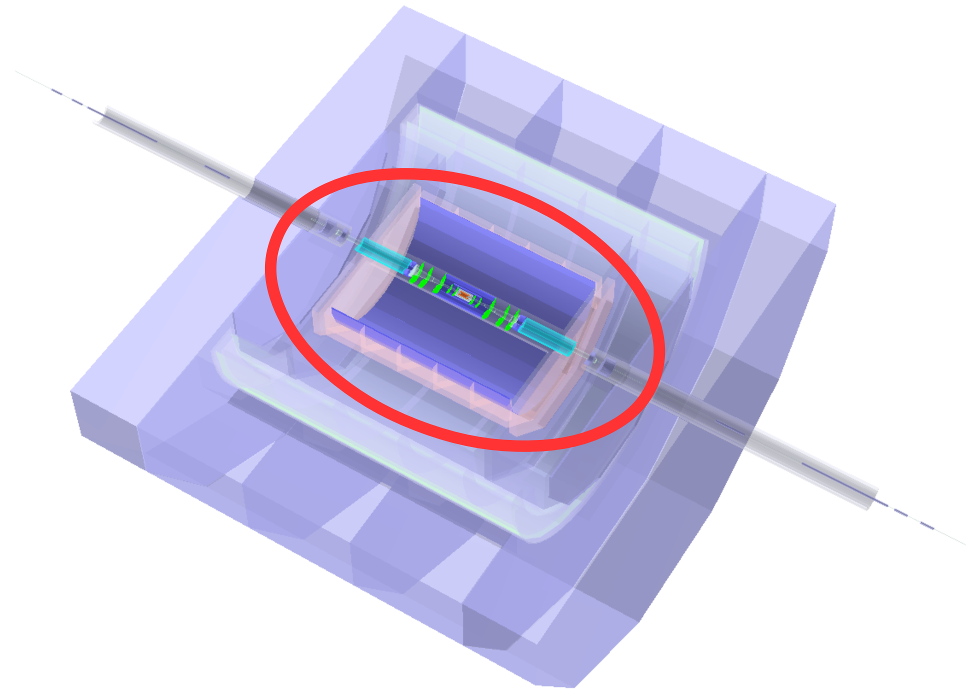


A detector reconstruct all the physics object (lepton, photon, tau, Jet, MET, ...) with high efficiency/precision

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

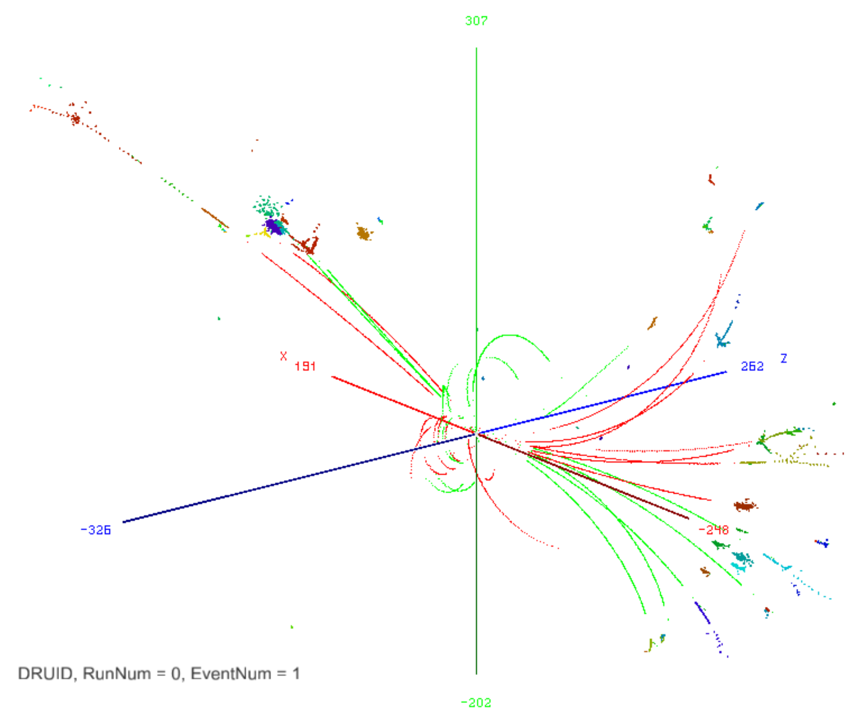

Taus
g jets
b jets
c jets
Jets leptons
Particle tagging
Iso. γ
Iso. e
Jets
Iso. μ
MET
Jet clustering
Particle Isolation
$\overrightarrow{MET} = -\sum_i \overrightarrow{E_{T,i}}$
PFA oriented Detector & Reconstruction
Particles
μ
ECAL rechits
HCAL rechits
Tracks
© Lison Bernet

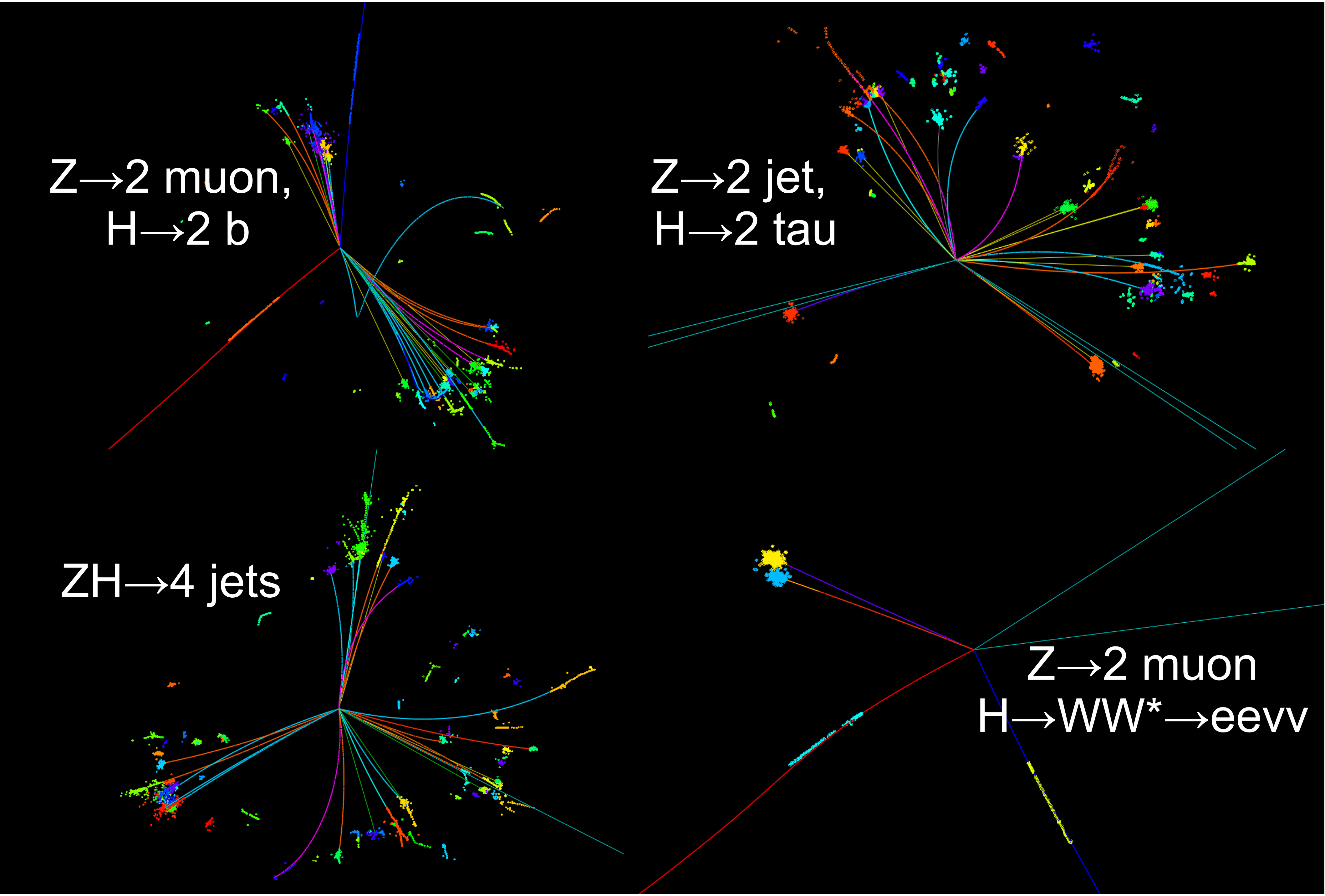


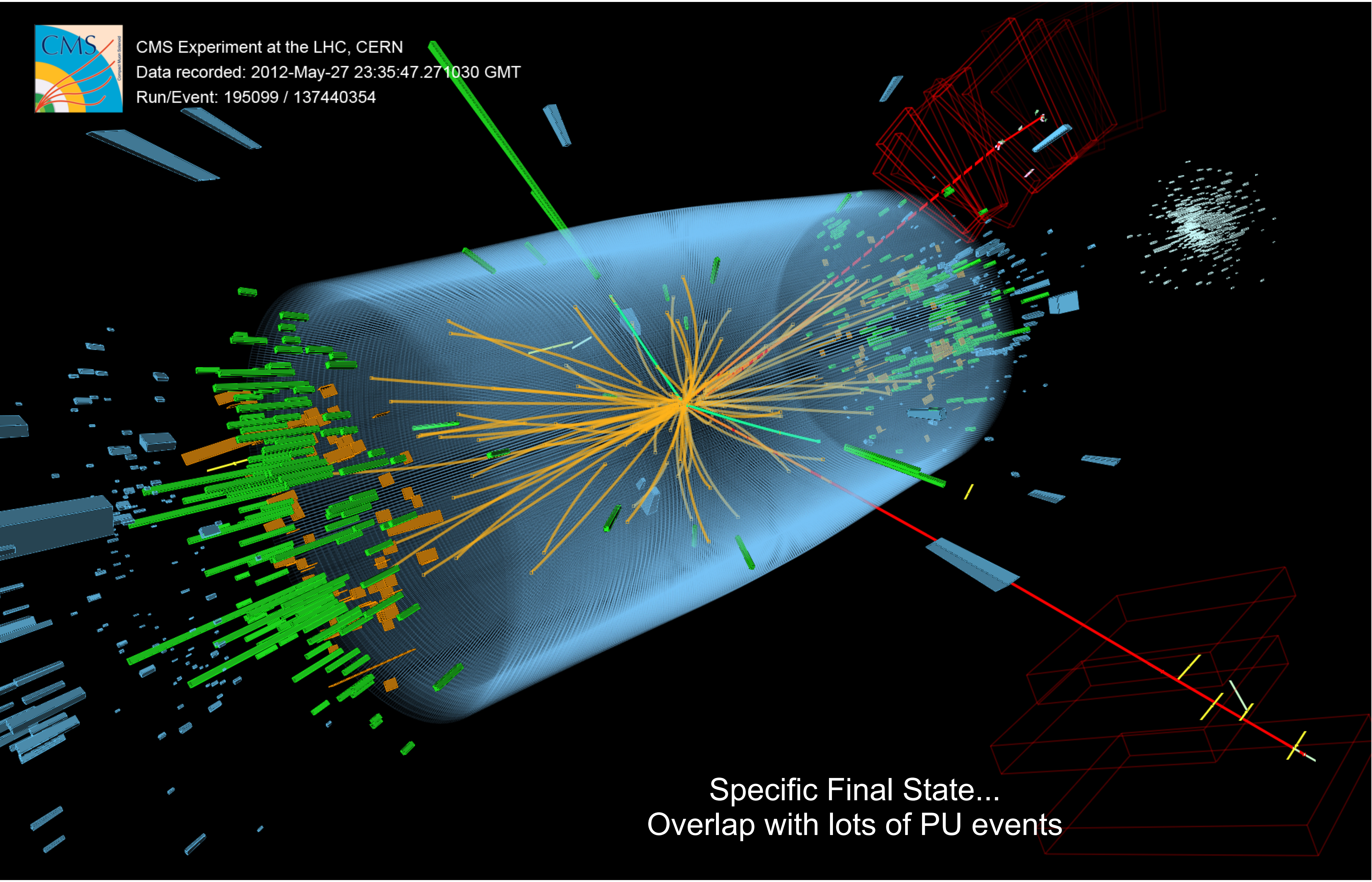


From Hits to Final State Particles

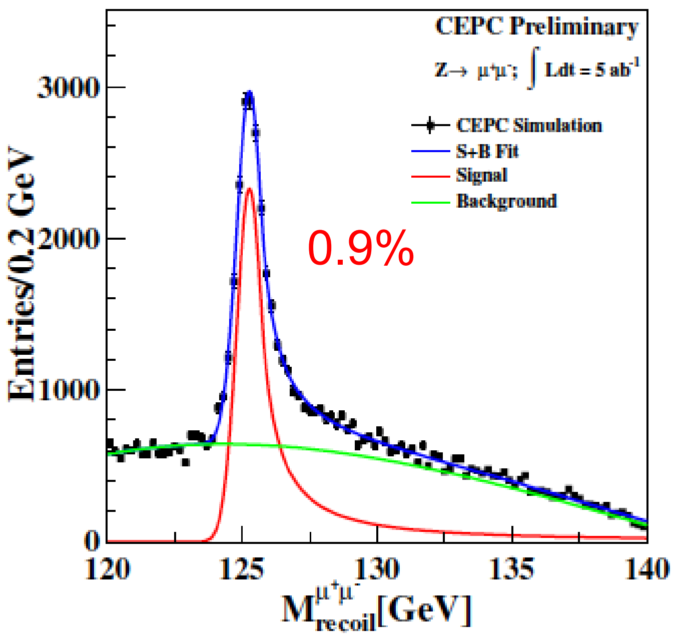
Goal: ... Access the origin o every detector hit ...

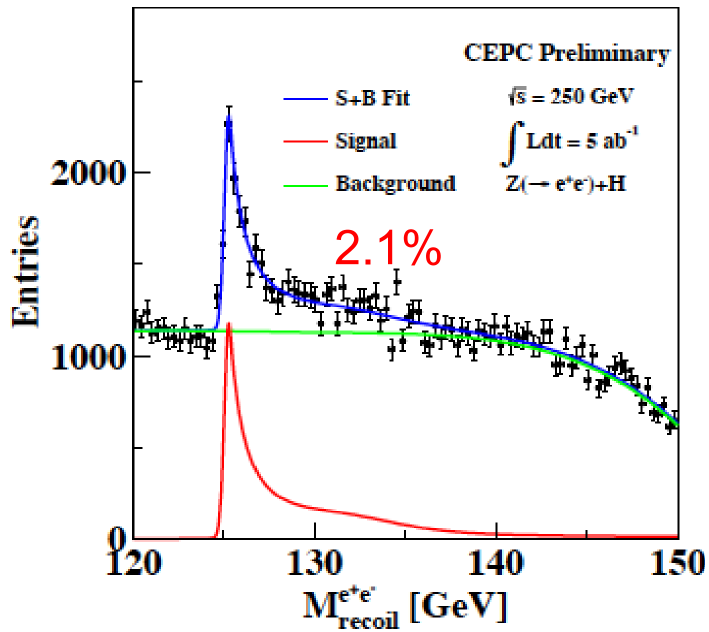


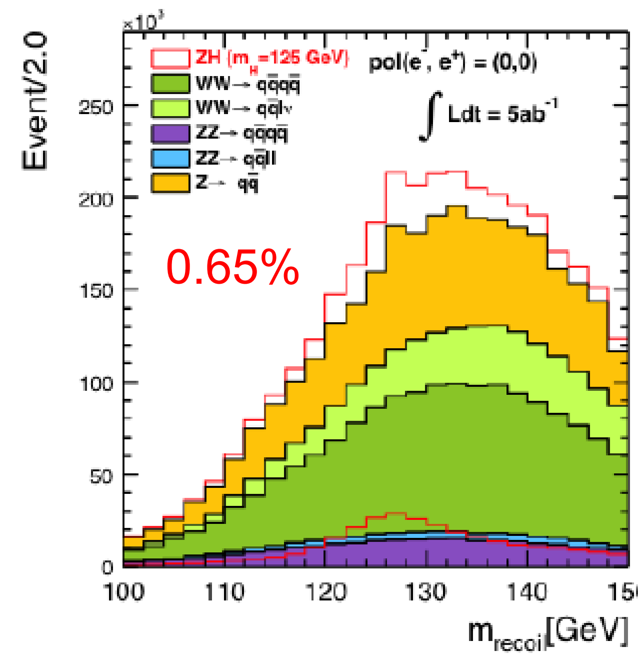

Z→2 muon,
H→2 b
Z→2 jet,
H→2 tau
ZH→4 jets
Z→2 muon
H→WW*→eevv


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-27 23:35:47.271030 GMT
Run/Event: 195099 / 137440354
Specific Final State...
Overlap with lots of PU events

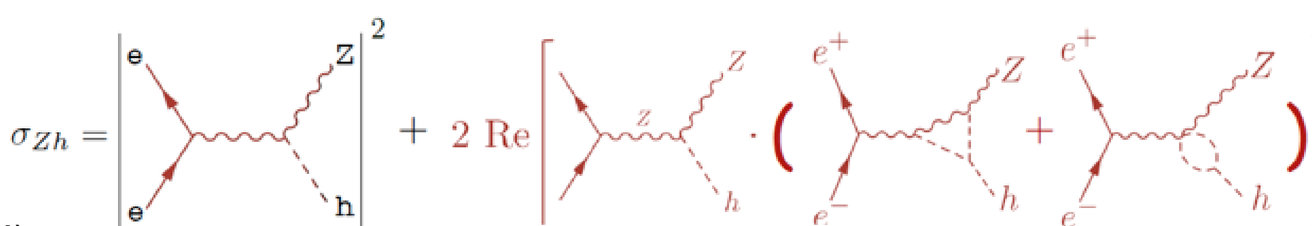
Model-independent measurement of σ(ZH)







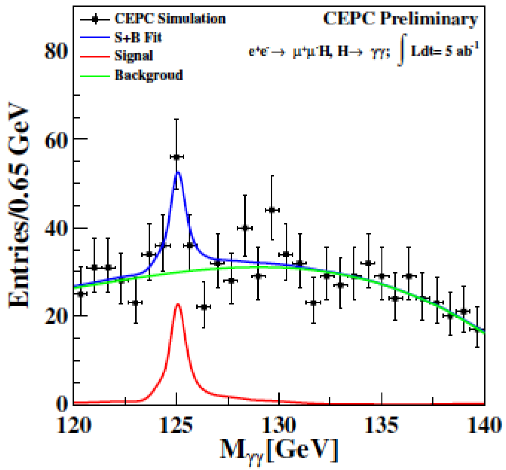
- Recoil mass method. Combined precision:
  δσ(ZH)/σ(ZH) = 0.5% -
  δg(HZZ)/g(HZZ) = 0.25%
- In-direct measurement on g(HHH)

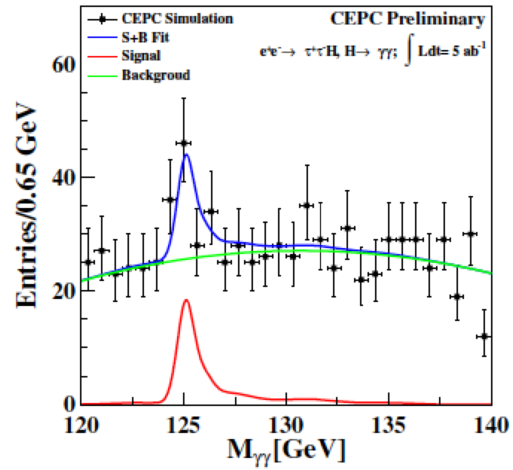


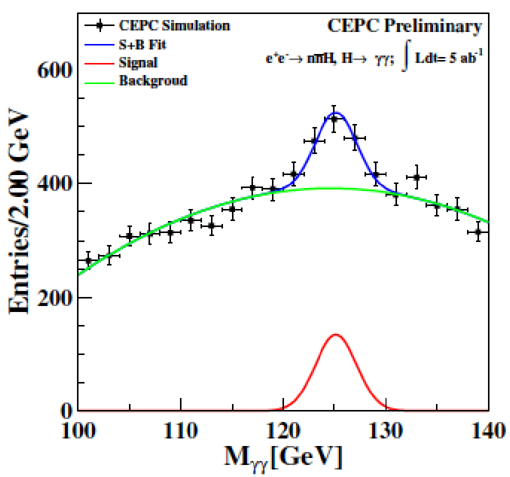
$$\delta_{\sigma}^{240} = 100\,(2\delta_Z + 0.014\delta_h)\,\%$$

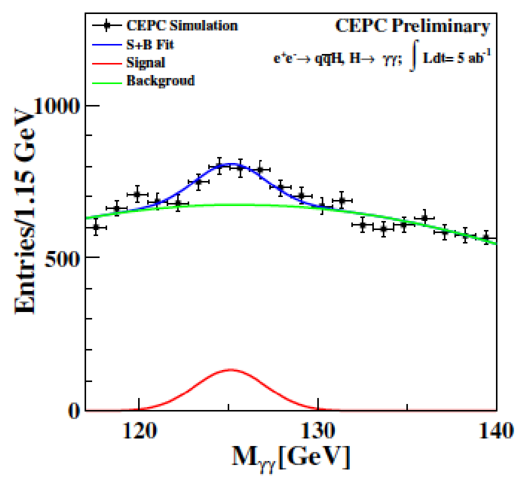
- *M. McCullough, 1312.3322*

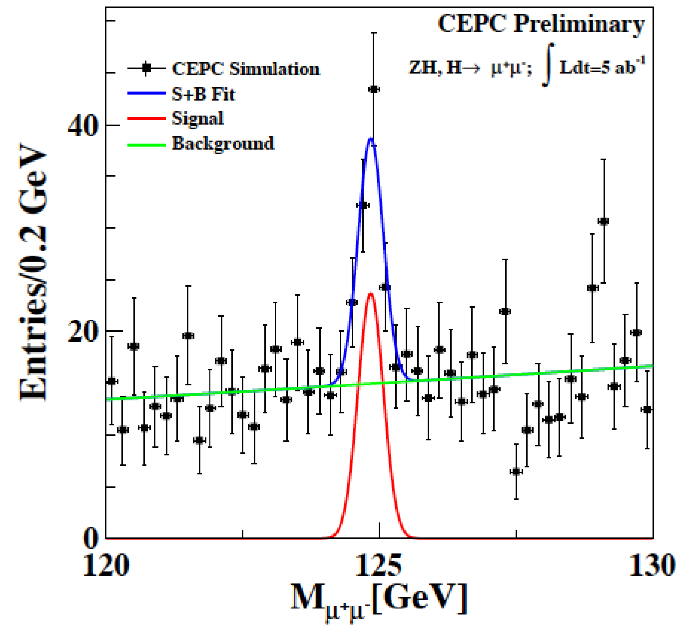
Higgs rare decay







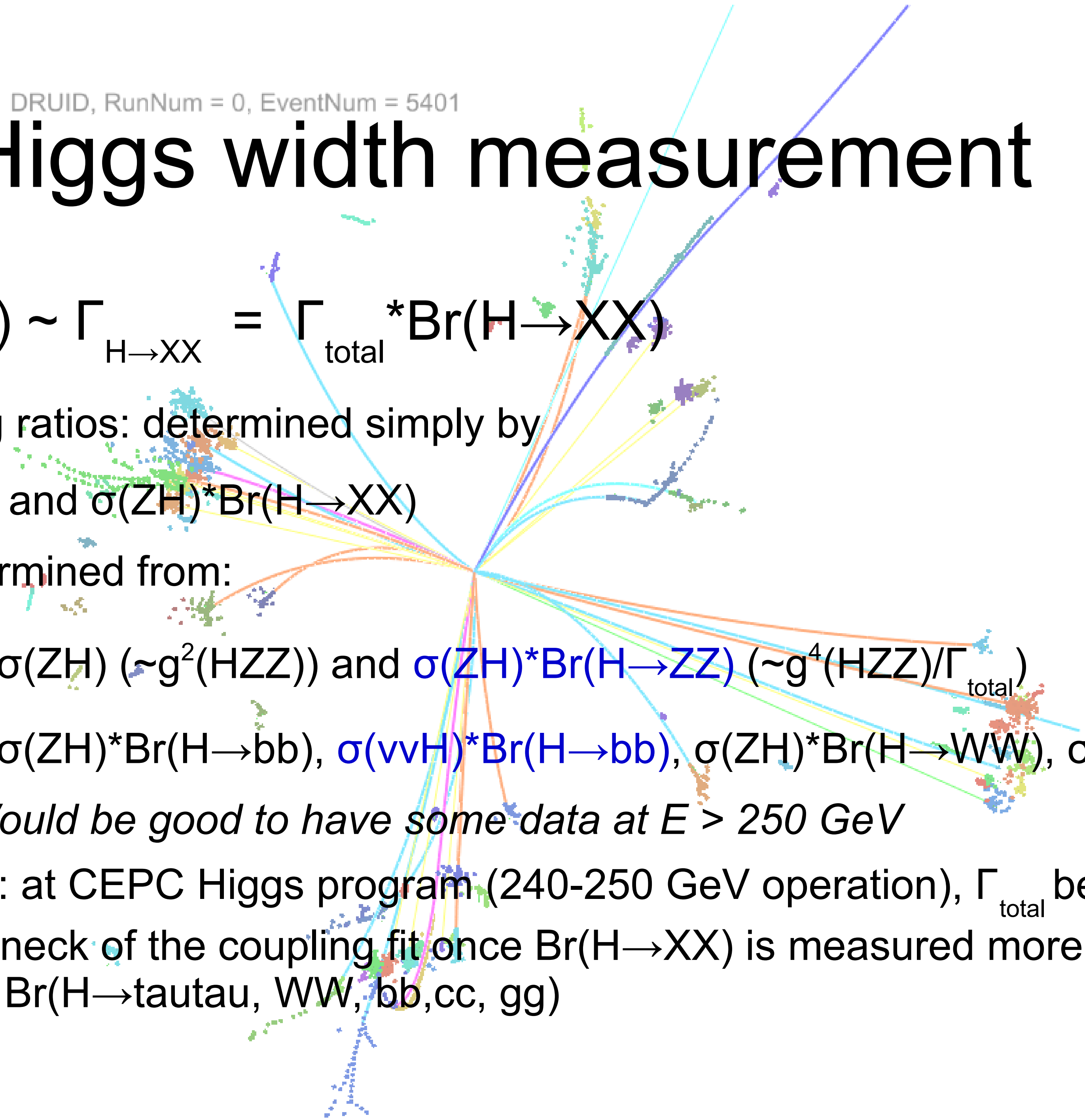




Br(H→γγ):
photon identification efficiency
& ECAL intrinsic resolution

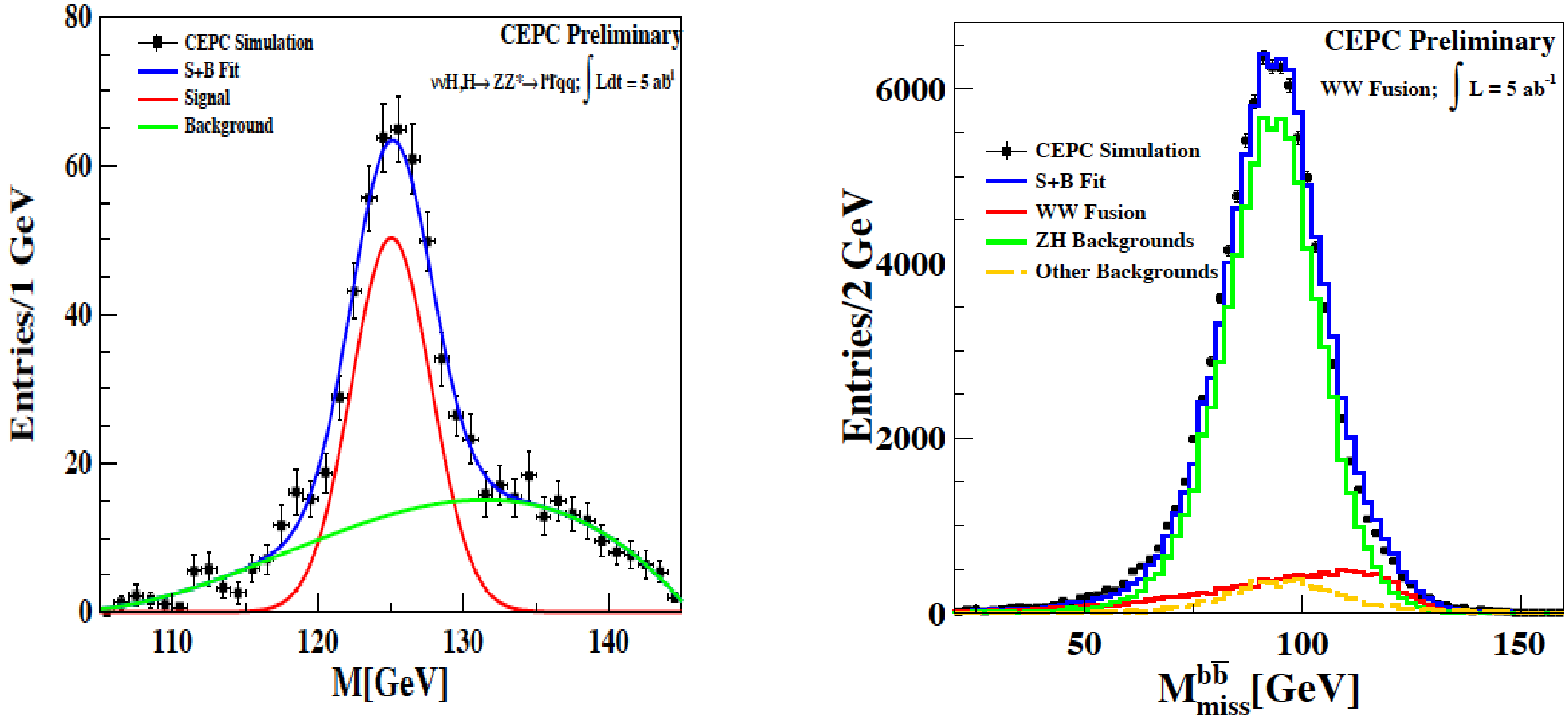
Br(H→μμ):
Muon identification & Track
Momentum resolution

Higgs width measurement



- $g^2(HXX) \sim \Gamma_{H\to XX} = \Gamma_{total} * Br(H\to XX)$
- Branching ratios: determined simply by
  - σ(ZH) and σ(ZH)*Br(H→XX)
- Γ_{total}: determined from:
  - From σ(ZH) ($\sim g^2(HZZ)$) and σ(ZH)*Br(H→ZZ) ($\sim g^4(HZZ)/\Gamma_{total}$)
  - From σ(ZH)*Br(H→bb), σ(vvH)*Br(H→bb), σ(ZH)*Br(H→WW), σ(ZH)
    - *Would be good to have some data at E > 250 GeV*
- Therefore: at CEPC Higgs program (240-250 GeV operation), Γ_{total} become the bottle neck of the coupling fit once Br(H→XX) is measured more precisely: Br(H→tautau, WW, bb,cc, gg)

Higgs width measurement



Br(H->ZZ): relative error of 6.9% achieved with ZH->ZZZ*->vv(Z)llqq(H) final states.
Extrapolation of TLEP result leads to 4.3% relative error

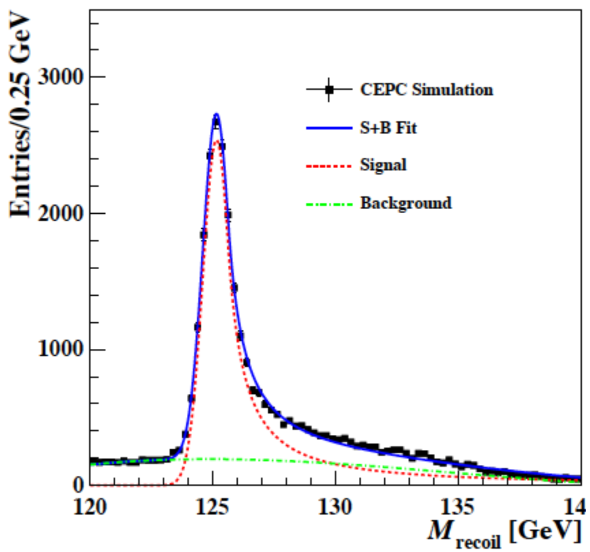
σ(vvH)*Br(H->bb): relative error of 2.8%

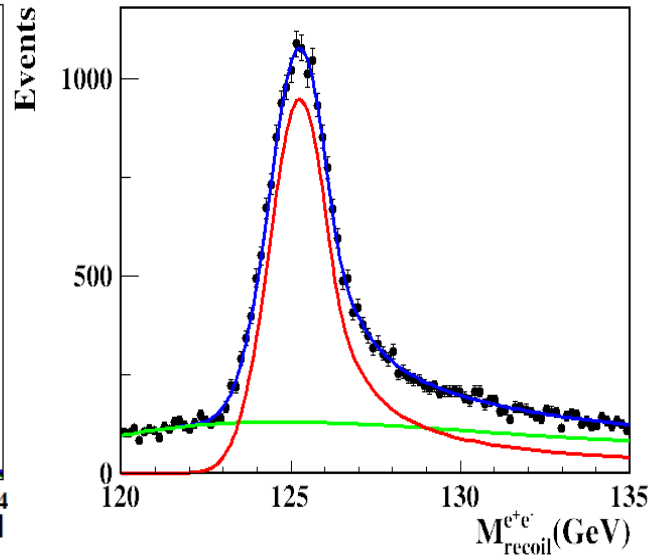
A combined accuracy of 2.8% for the Higgs total width measurements

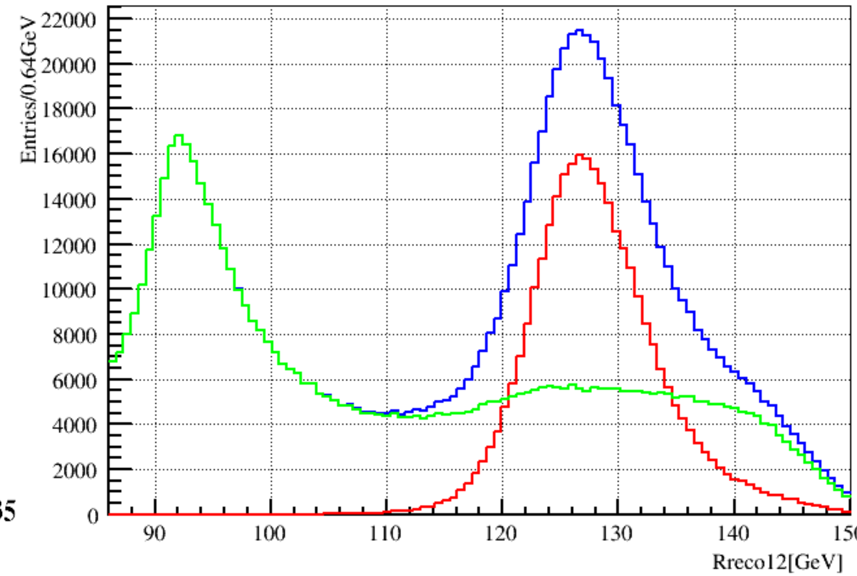
Higgs exotic

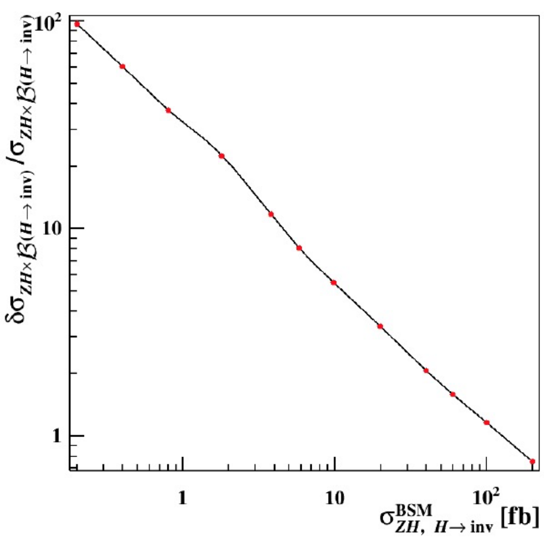
- Higgs → invisible via recoil mass spectrum
  - Di lepton channel: Zhenxing, Moxin (IHEP) & Kevin (Hongkong)
  - Di jet channel: Moxin
- Higgs → leptonic exotic mode
  - H → ee: Wanglei @ PKU
- Higgs → hadronic mode
  - H → Flavor changing quark pairs: samples ready, no analysis effort
    - H → tc, tu
    - H → bs, bd
  - H → semi invisible: Jiawei, Kevin (Hongkong) & Zhenxing

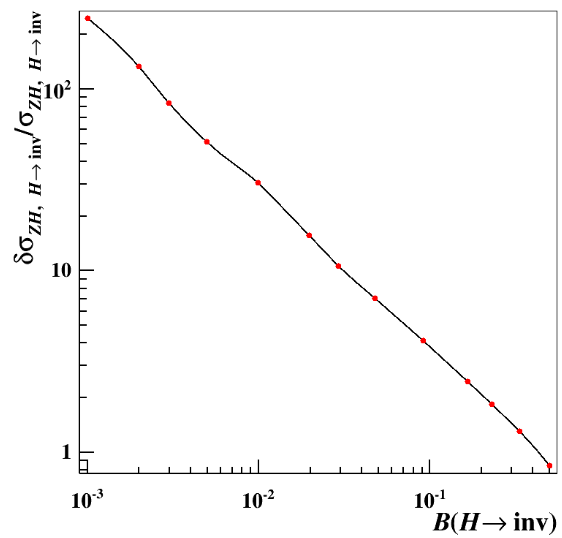
Higgs invisible decay





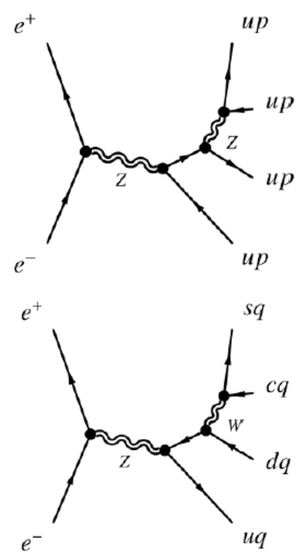




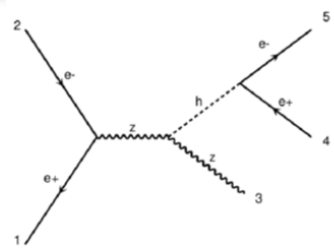


95%. C.L up limit:
0.14%

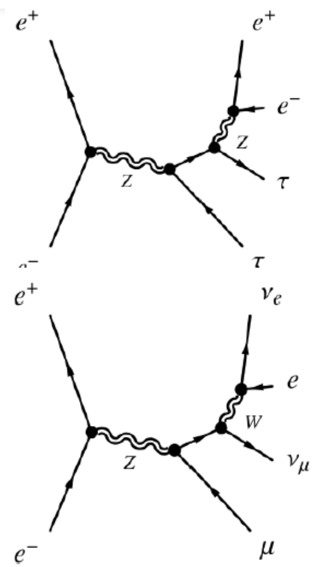
Higgs leptonic decay



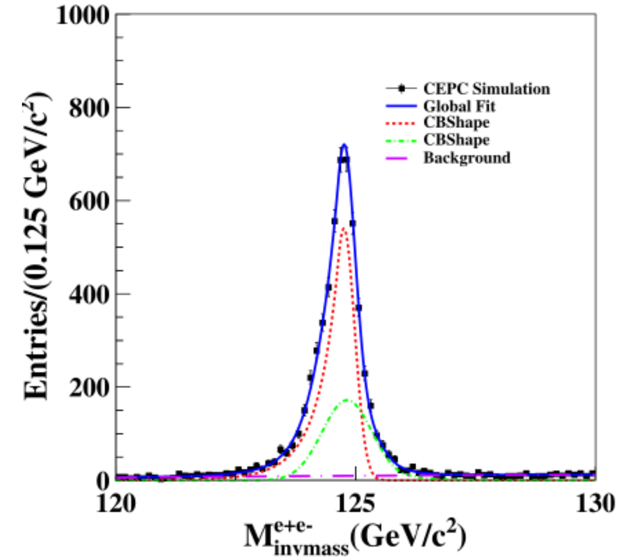
signal:Madgraph->Pythia->Mokka->Marlin



MC sample	parton level
signal sample	Madgraph
ZZ	Whizard
WW	Whizard
signal Z	Whizard
signal W	Whizard
single Z or W	Whizard
ZZ or WW	Whizard



bkg:Whizard->Pythia->Mokka->Marlin



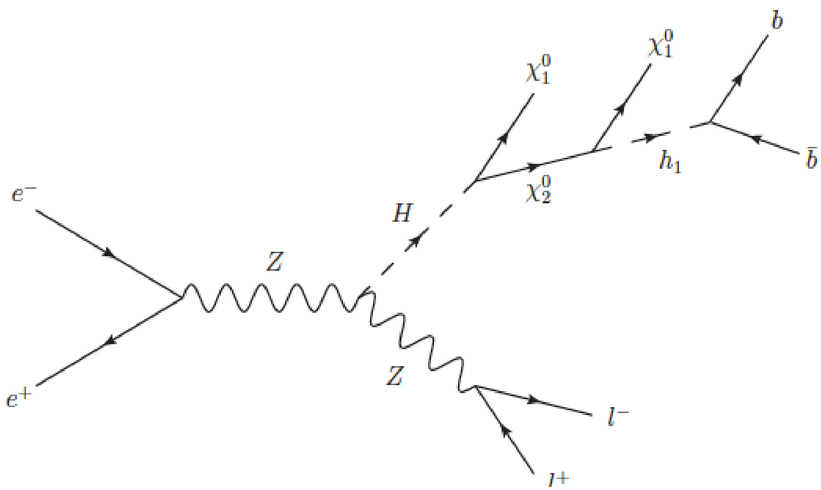
The limit results is 0.1665‰ at 95% confidence level

- $H \to ee$: SM Branching ratio ~ $o(10^{-9})$
- Uplimit at CEPC: one order of magnitude better than current LHC result
- To explore: $H \to e\mu$, $\mu\tau$

leptonic decay channel	BR upper limit at 95%	collaboration	Journal
h->ee	0.19%	CMS	Phys. Lett. B 744, 184
h->μμ	0.15%	CMS	Phys. Lett. B 744, 184
	0.16%	ATLAS	Phys. Lett. B 738, 68
h->eμ	0.036%	CMS	CMS-PAS-HIG-14-040
h->eτ	0.69%	CMS	CMS-PAS-HIG-14-040
	1.04%	ATLAS	unpublished
h->μτ	1.51%	CMS	Phys. Lett. B 749, 337
	1.43%	ATLAS	unpublished

http://indico.ihep.ac.cn/event/5592/contribution/12/material/slides/0.pdf

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)

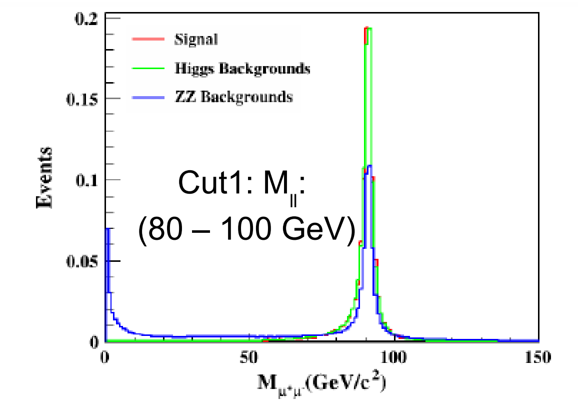
   10 GeV < $m_{\tilde{\chi}_2^0}$ < 125 GeV (20,40,60,80,100,120 GeV)

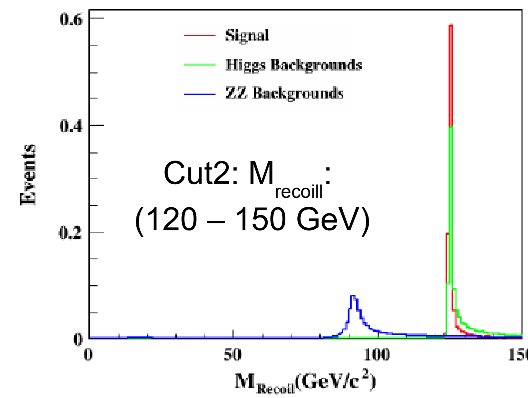
Suggested by prof. Liu

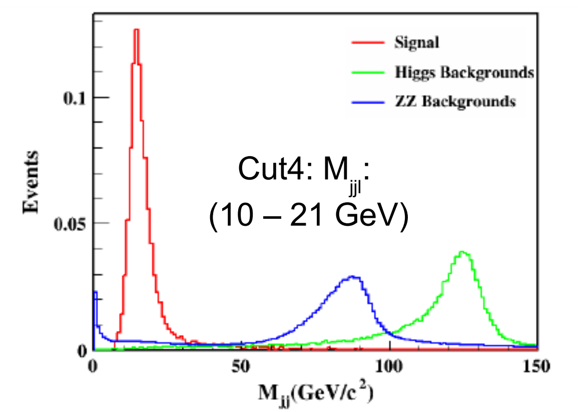
- Typical process at NMSSM & 2HDM...
- Joint efforts of Hongkong Cluster & IHEP: Main analyzers, Jiawei, Kevin & Zhenxing
  - Initialized at PreCDR, one parameter point explored with Fast Sim (Kevin)
  - Full Simulation exploration during IAS meeting (Zhenxing visited Hongkong)
  - Continue by Jiawei & Kevin (Jiawei stayed at IHEP for 3 weeks)

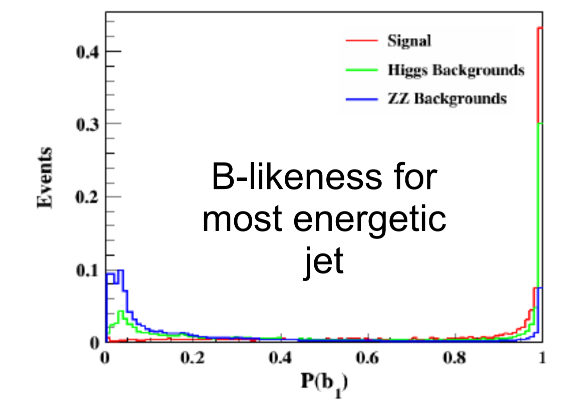
H→Exotic, hadronic

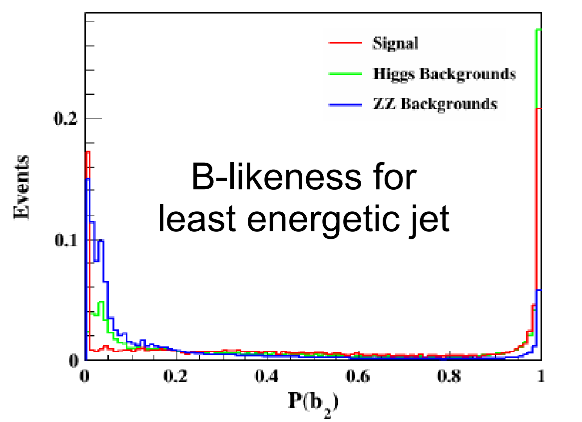
Para: M(LSP) = 0; M(h0) = 15 GeV; M(NLSP) = 20 GeV











	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

- Todo: a full scan over proposed parameter space

Differential distributions

- CEPC: reconstruct Higgs in a ultra-clean environment
- Physics object can be measured to a great precision: energy & direction
  - Leptons/Charged Particle: 1e-4 ~ 1e-5...
  - Photons: 1e-3 ~ 1e-4
  - Jets: 1e-3 in visible energy...
  - Highly depending on the detector design (Larger tracker & Smaller Calorimeter Cells)
- The direction information, represent the tensor form of Higgs operator...

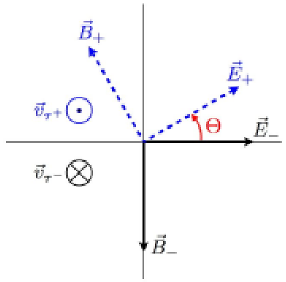
$$d\sigma/d\Theta$$

Higgs CP Phase in $h \to \tau^+\tau^-$ Decay

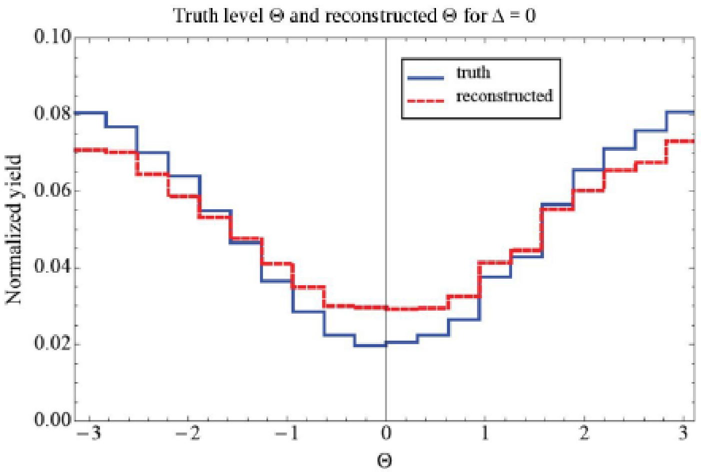
1308.1094

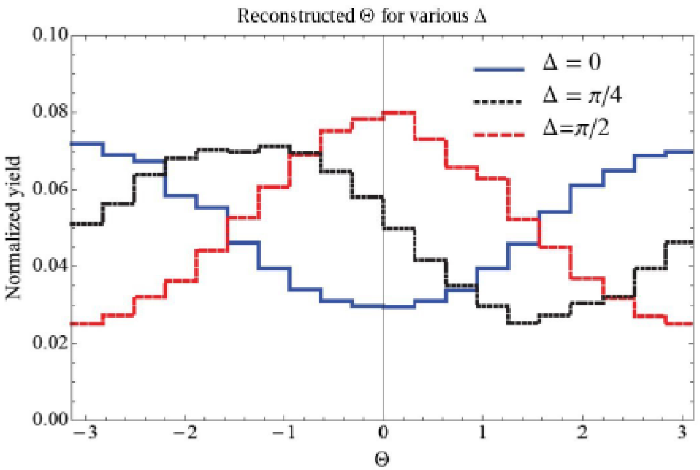
Θ Angle

$$\Theta \equiv \text{sgn}\left[\vec{v}_{\tau^+} \cdot (\vec{E}_- \times \vec{E}_+)\right] \arccos\left(\frac{\vec{E}_+ \cdot \vec{E}_-}{|\vec{E}_+||\vec{E}_-|}\right)$$



Differential Distribution

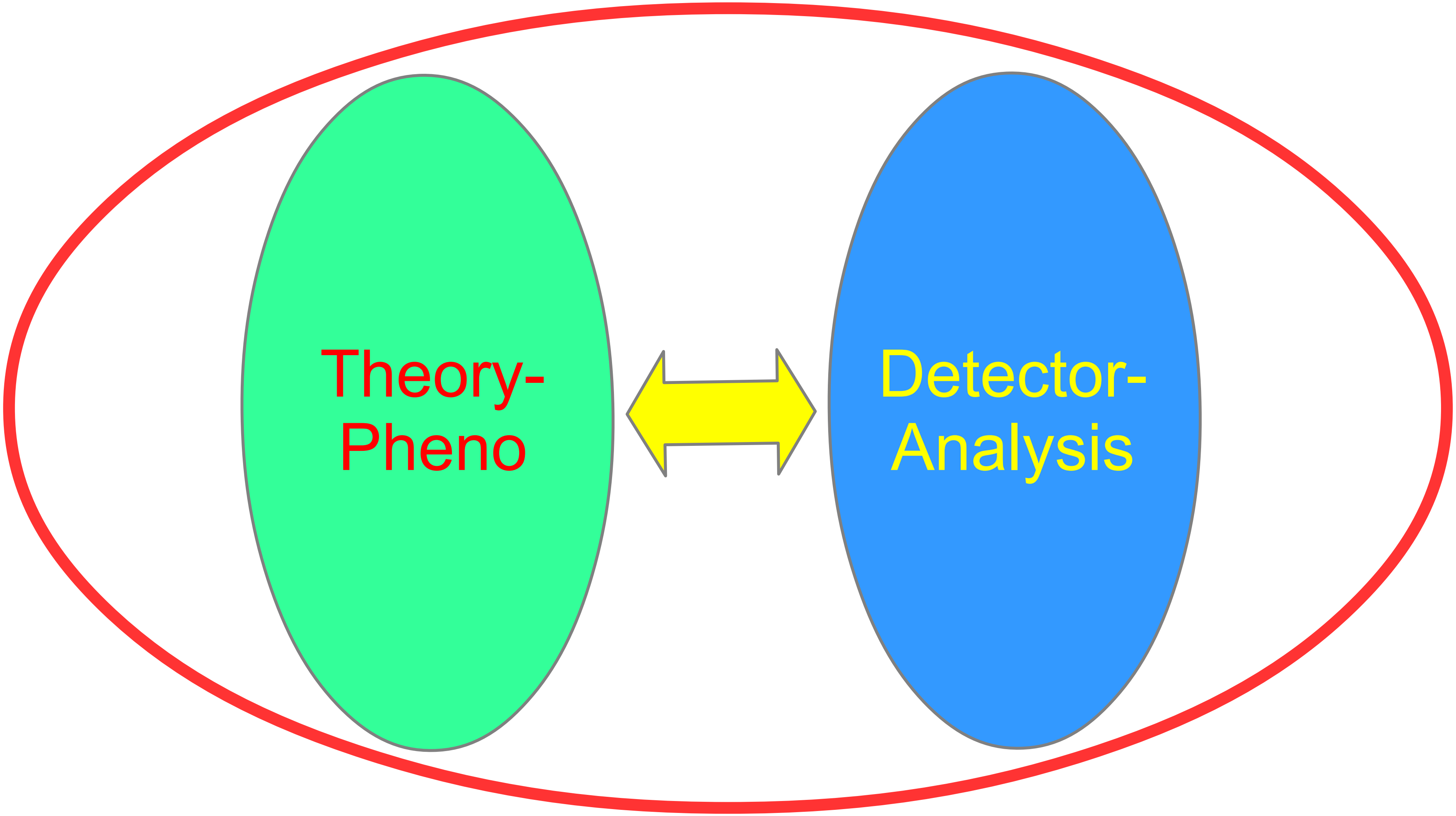


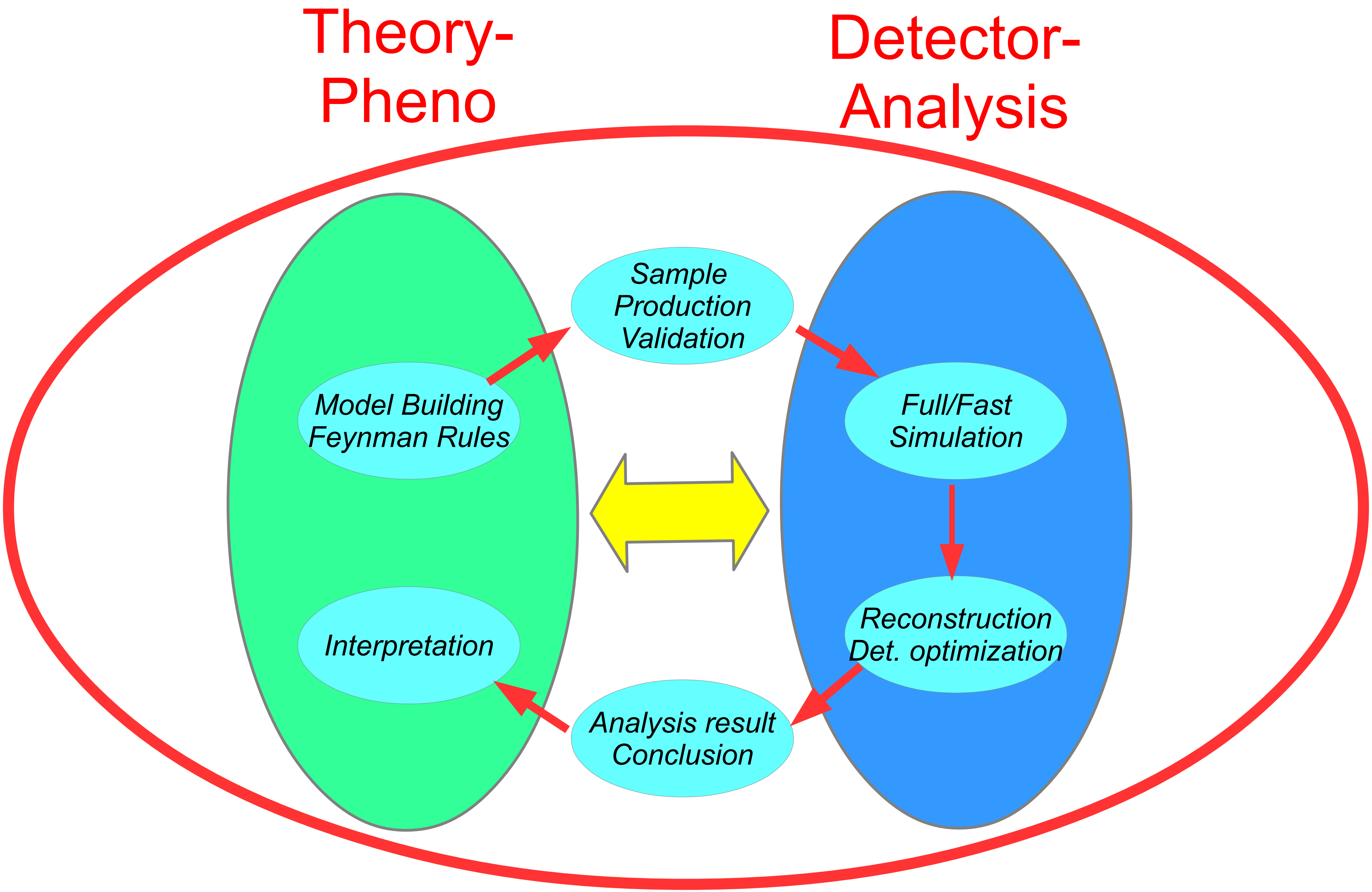


Precision Measurement @ CEPC

CEPC preCDR

Colliders	LHC	HL-LHC	CEPC1	CEPC5	CEPC10
Accuracy(1σ)	25°	8.0°	5.5°	2.5°	1.7°

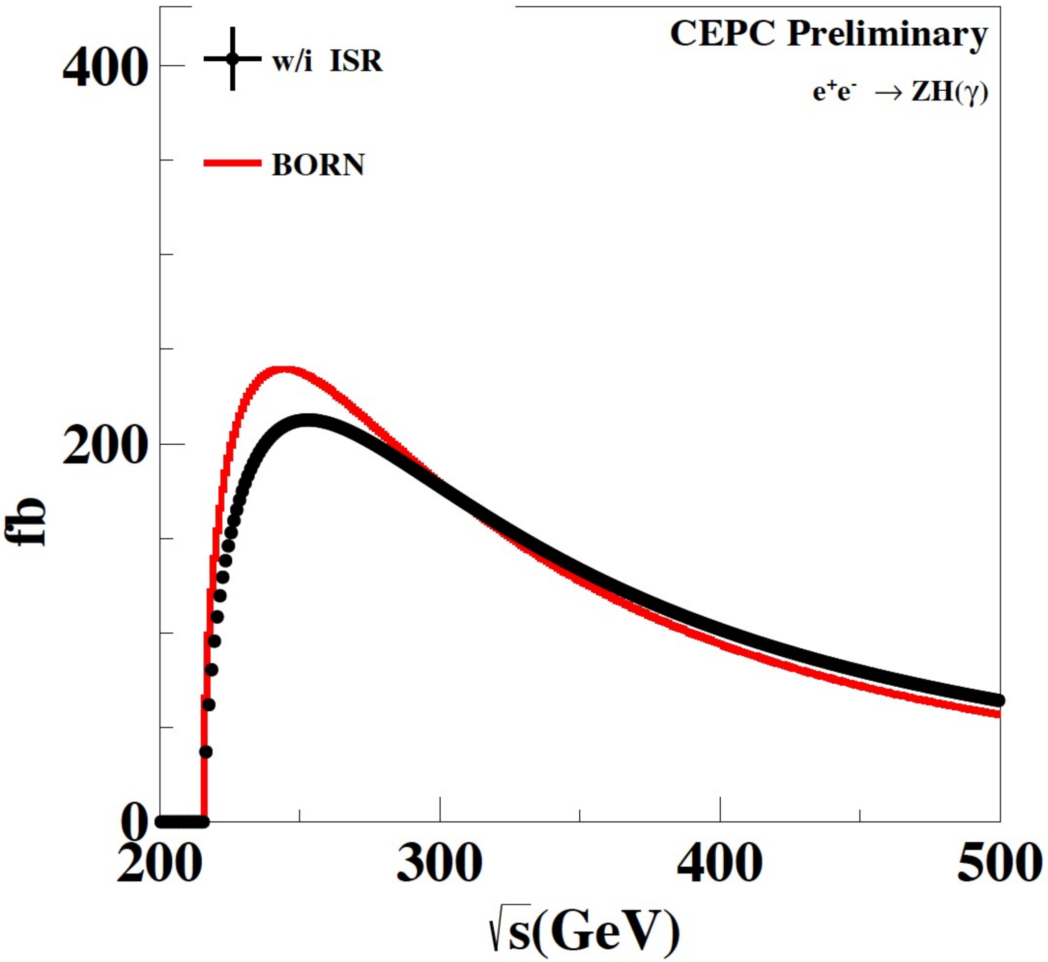

Theory-
Pheno
Detector-
Analysis



The Sim Group will provide the Full Set of SM Background, For any

High Precision Calculation

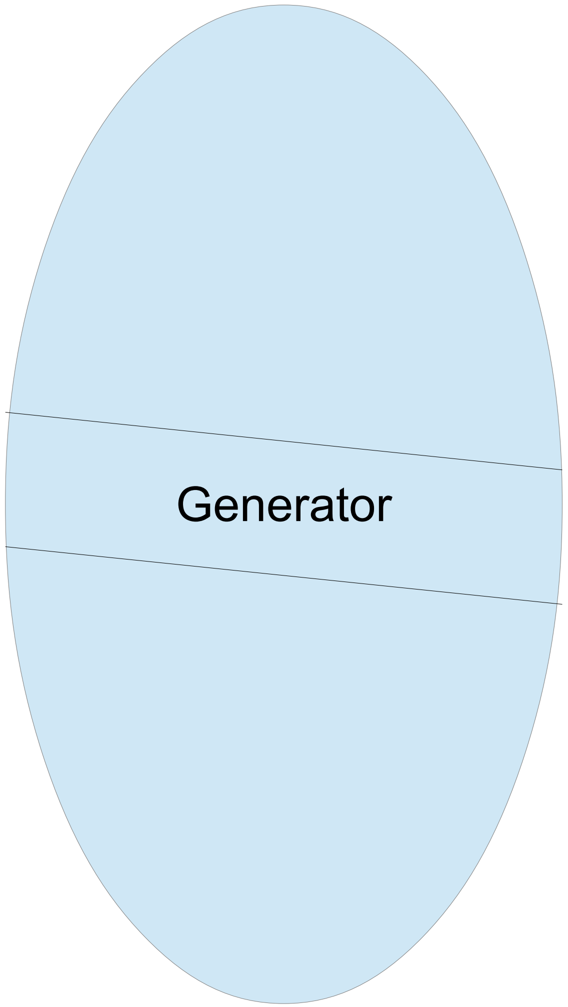
- CEPC is a very precise machine...
- Theoretical uncertainties for various measurement and Background sample validation is essential
- For example:
  - Radiation effects (ISR)
  - W line shape
  - Z line shape...



Generator Studies

- For any Pheno-expoloration, the Sim Group can provide **Full Set of SM Bkgrd** (on the same footing) & **more realistic detector simulation.**
- Generator: interface between Theory-Pheno And Detector Studies
- Cooperations Interactions with Madgraph & Whizard
  - Madgraph: ISR
  - Whizard 2.0: VTX position missing ...
  - MC4BSM WS
- Our own generator development is more than welcome
- Validation @ precision measurement
- **A fully operation chain**, still need lots of efforts

  MM → Feynman Rule → UFO → Samples → Validation→Sim/Reco/Analysis... → result & documentations.

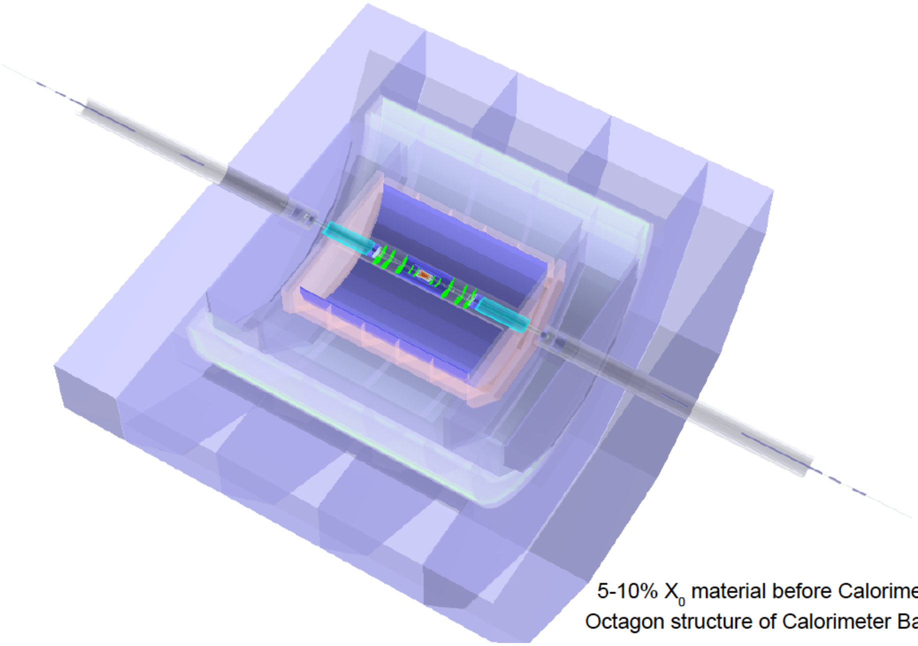


Theory-Pheno: Physics motivation

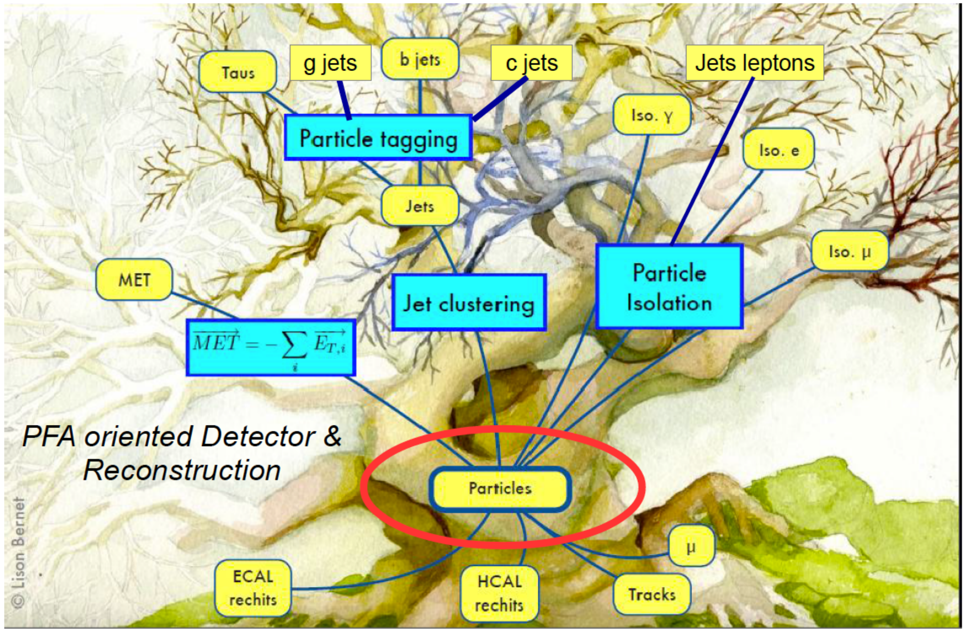
- Unique/distinguishable advantage of electron-positron Higgs factory
- Higgs:
  - Event Number Counting
    - Absolute Higgs measurements
      - Total generation Xsec
      - Higgs width, Decay branching ratio & absolute couplings
    - Exotic decay mode searching via recoil mass method
  - Differential distribution measurements
    - Higgs CP
    - O5, O6 Higgs interaction operators
- EW: Z pole observables, etc
- Any new observables?

Impact on detector design?

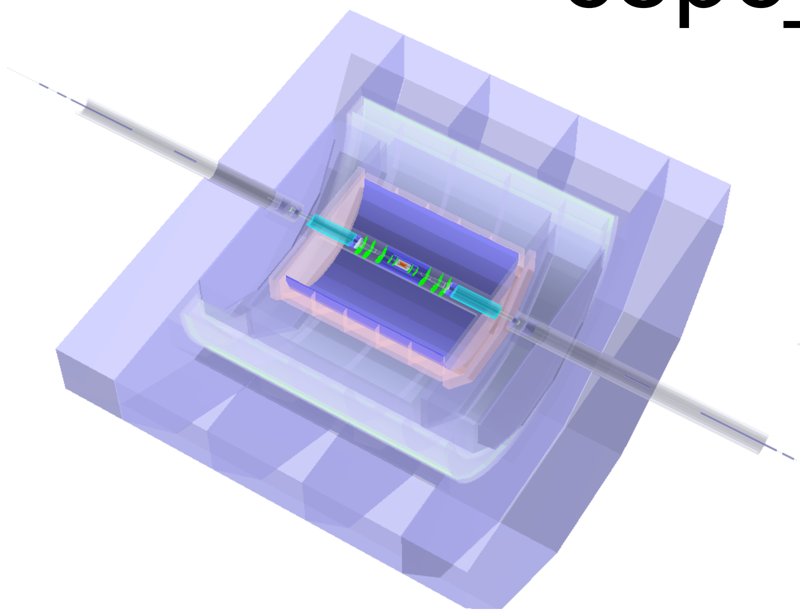
- Optimization on going – propose your favorite Detector model – OBJECT performance (solid angle coverage, finding efficiency & resolution...)
- For example: Muon chambers will enhance the sensitive region by one order of magnitude... would any physics model – such as these with long lived charged particle – appreciate it?

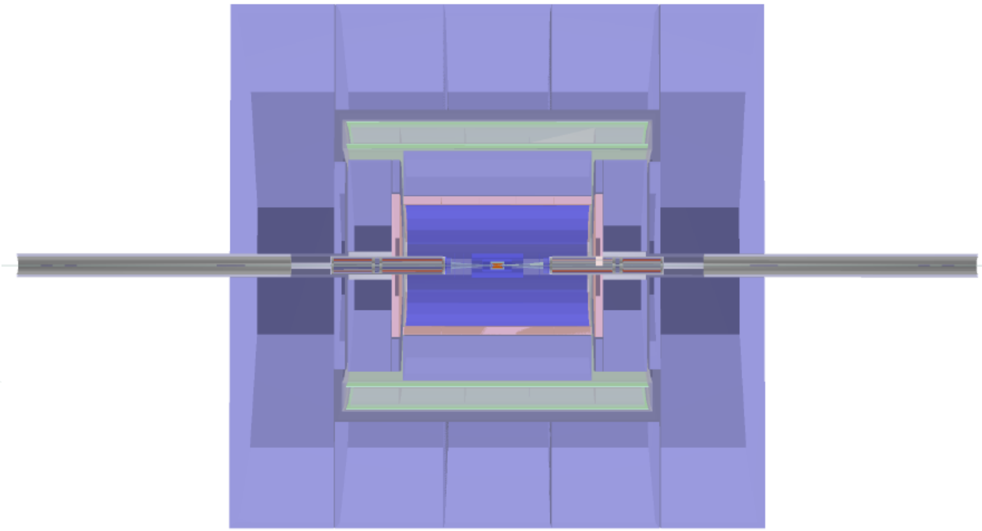


5-10% X_0 material before Calorimeter
Octagon structure of Calorimeter Barrel



Detector optimization: cepc_v1 -> cepc_o_v2



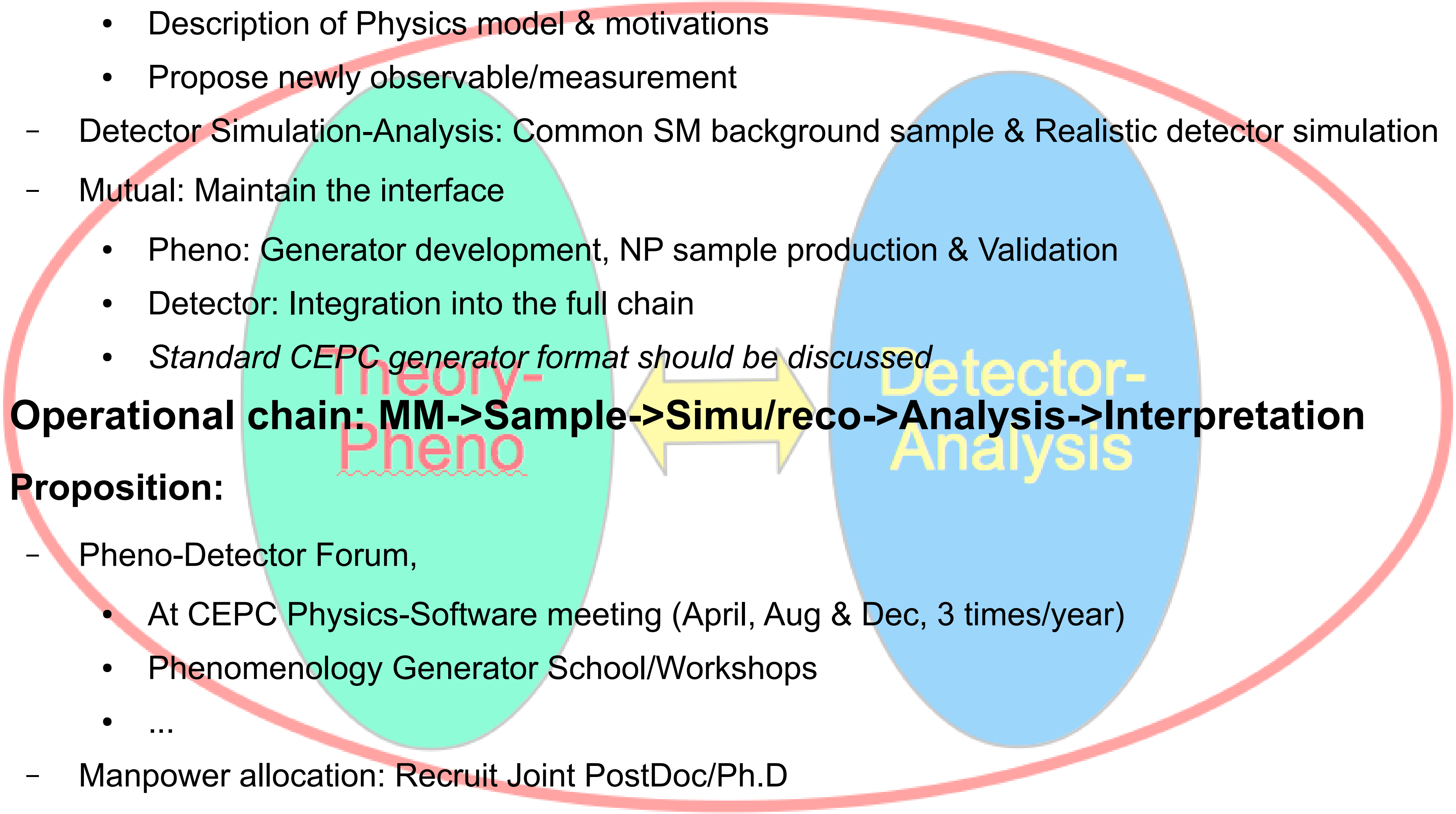


Parameter	CEPC_o_v2	CEPC_v1
LStar_zbegin	1150	1146.9
VXD_inner_radius	12	15
VXD_radius_r1	12	15
VXD_radius_r3	35	37
TPC_outer_radius	1500	1808
Hcal_nlayers	40	48
Ecal_cells_size	10	4.9
Field_nominal_value	3	3.5
Yoke Layers	2	3

Performance	adapted	optimized*
Tracking: D0, Z0	10% ↑ @ E < 20 GeV (VTX); 5% ↓ @ E > 20 GeV (B-Field);	
Theta, Phi	worse	-
Omega	worse	-
PFA:Clustering	Slightly worse	same
Matching	~10% ↓	~5% ↓
Separation	~10% ↓	~2% ↓
PID	3-5% ↓ @ E > 10 GeV; 10% ↓ @ E < 10 GeV;	~1%↓
JER	20% ↓	~10%↓
Flavor Tagging	Improved up to 5%↑	?

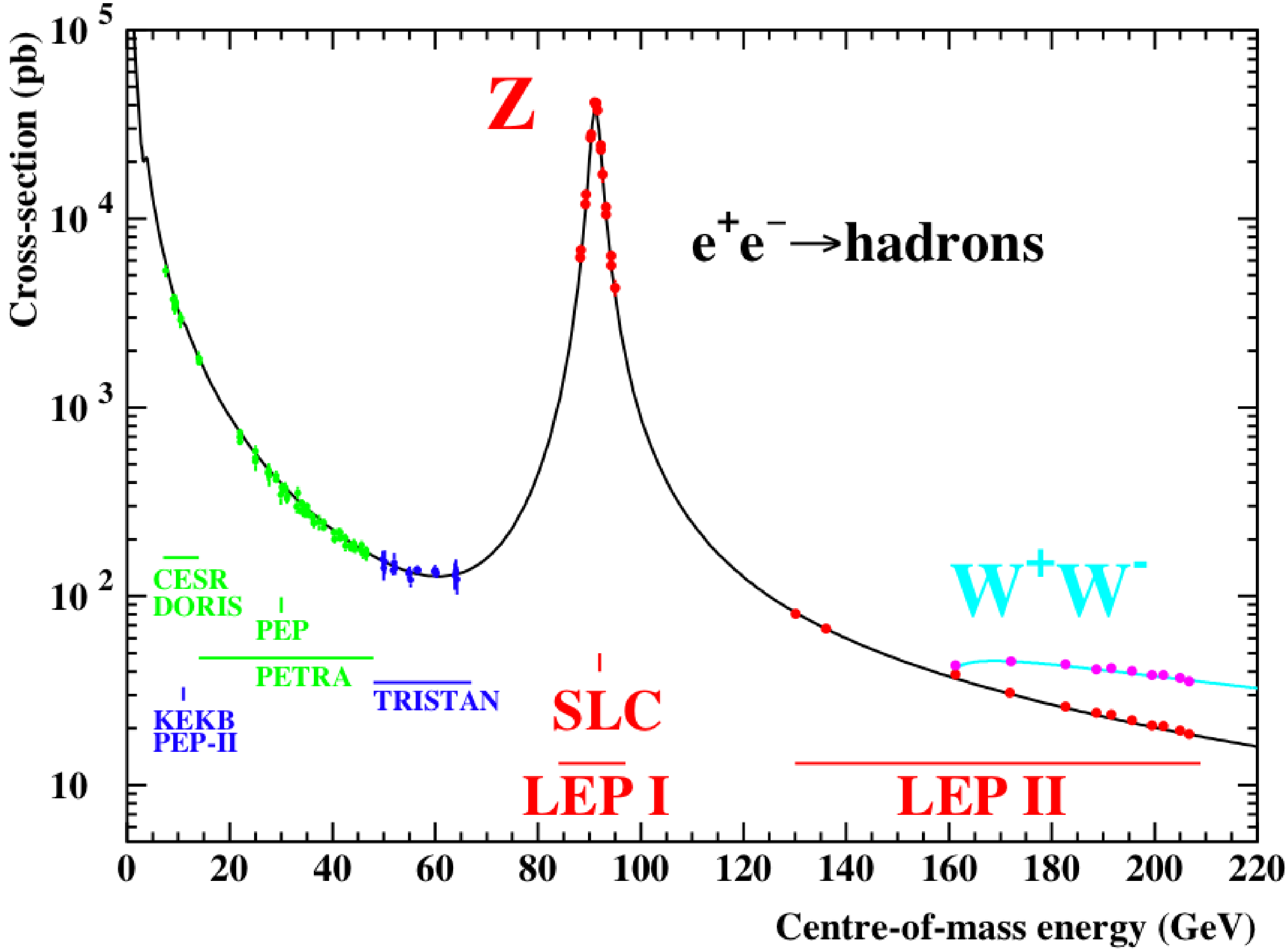
http://indico.ihep.ac.cn/event/5277/session/14/contribution/67/material/slides/0.pdf

- **Team work...**
  - Theory-Phenology: Model Building - Interpretation
    - Description of Physics model & motivations
    - Propose newly observable/measurement
  - Detector Simulation-Analysis: Common SM background sample & Realistic detector simulation
  - Mutual: Maintain the interface
    - Pheno: Generator development, NP sample production & Validation
    - Detector: Integration into the full chain
    - *Standard CEPC generator format should be discussed*

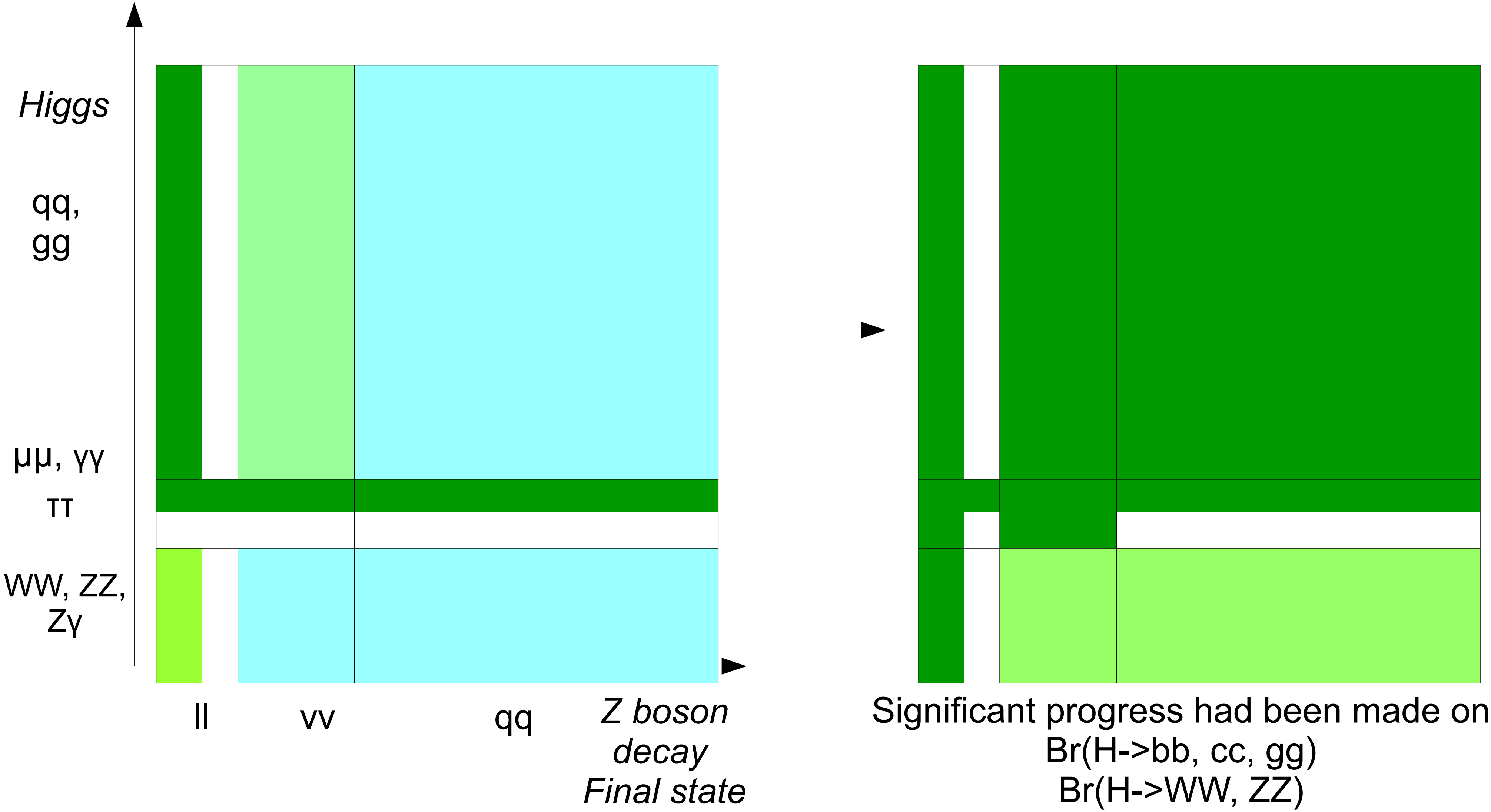


- **Operational chain: MM->Sample->Simu/reco->Analysis->Interpretation**
- **Proposition:**
  - Pheno-Detector Forum,
    - At CEPC Physics-Software meeting (April, Aug & Dec, 3 times/year)
    - Phenomenology Generator School/Workshops
    - ...
  - Manpower allocation: Recruit Joint PostDoc/Ph.D
  - Support relevant works: short term visit, travel, etc

Backup


Cross-section (pb)
10^5
10^4
10^3
10^2
10
Z
$e^+e^- \rightarrow$ hadrons
CESR
DORIS
PEP
PETRA
KEKB
PEP-II
TRISTAN
SLC
LEP I
LEP II
W^+W^-
0 20 40 60 80 100 120 140 160 180 200 220
Centre-of-mass energy (GeV)

Status: from PreCDR study to now...

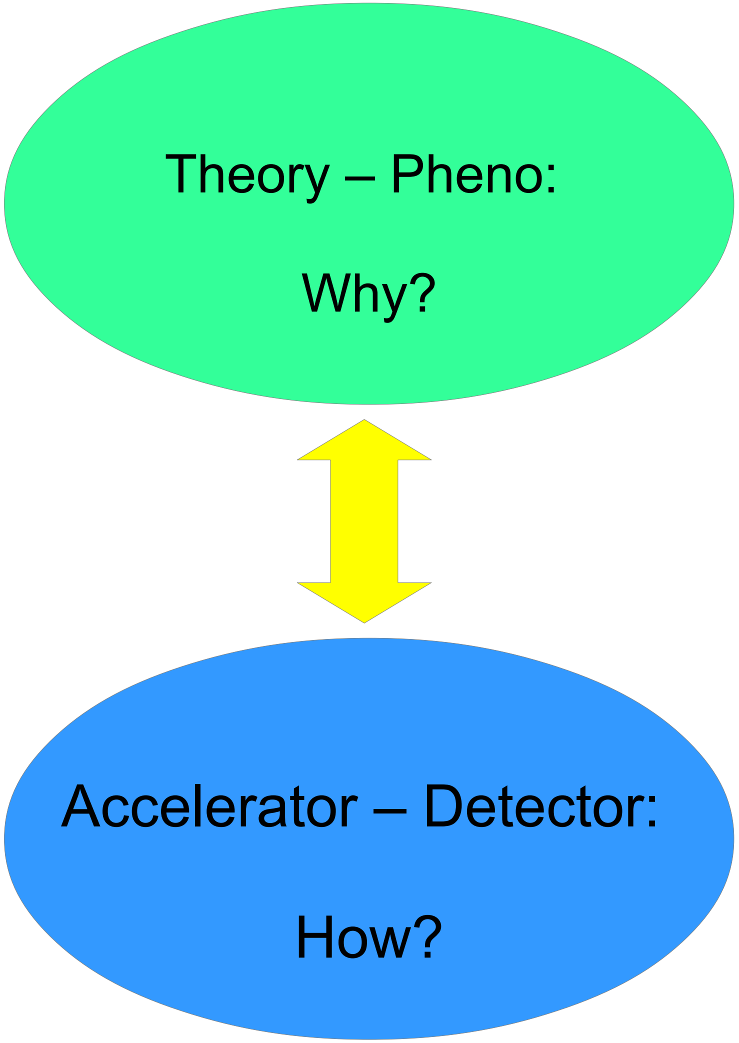


Significant progress had been made on
Br(H->bb, cc, gg)
Br(H->WW, ZZ)
Br(H->exotic)
Br(H->di tau, di muon)
Measurements

Outline

- Personal Perspective On Theory-Pheno
  - Interpretation of analysis result
  - Benchmark observable proposition:
    - Higgs exotic searches
    - Differential distributions
  - Generator Studies
    - Sample preparation & Validation

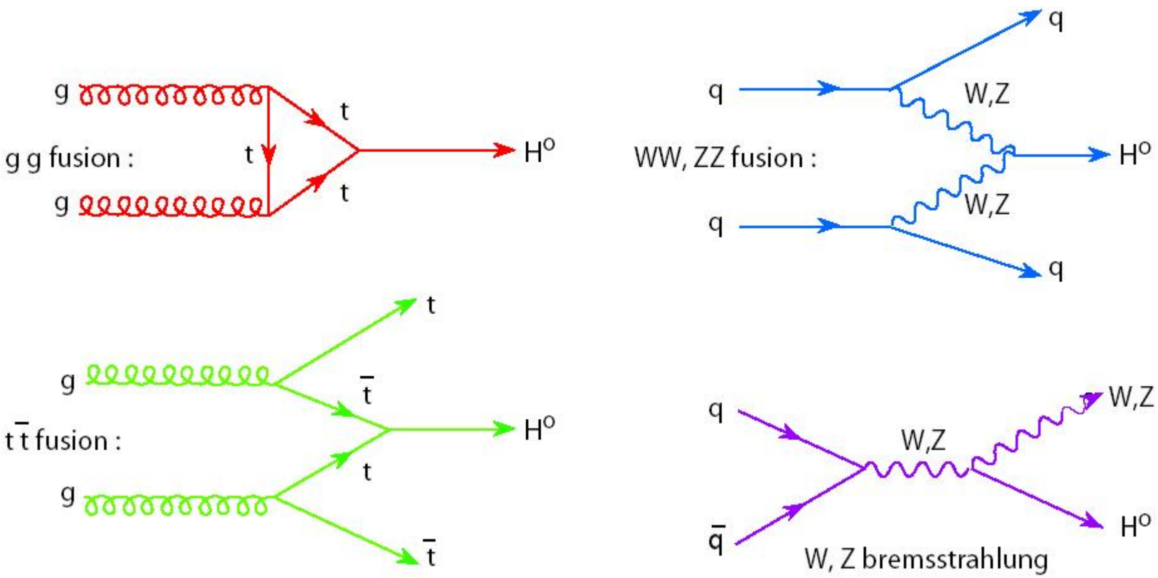
- This talk will also cover:
  - Fast Simulation: FSClasser & Delphes card
  - Outlook & proposition

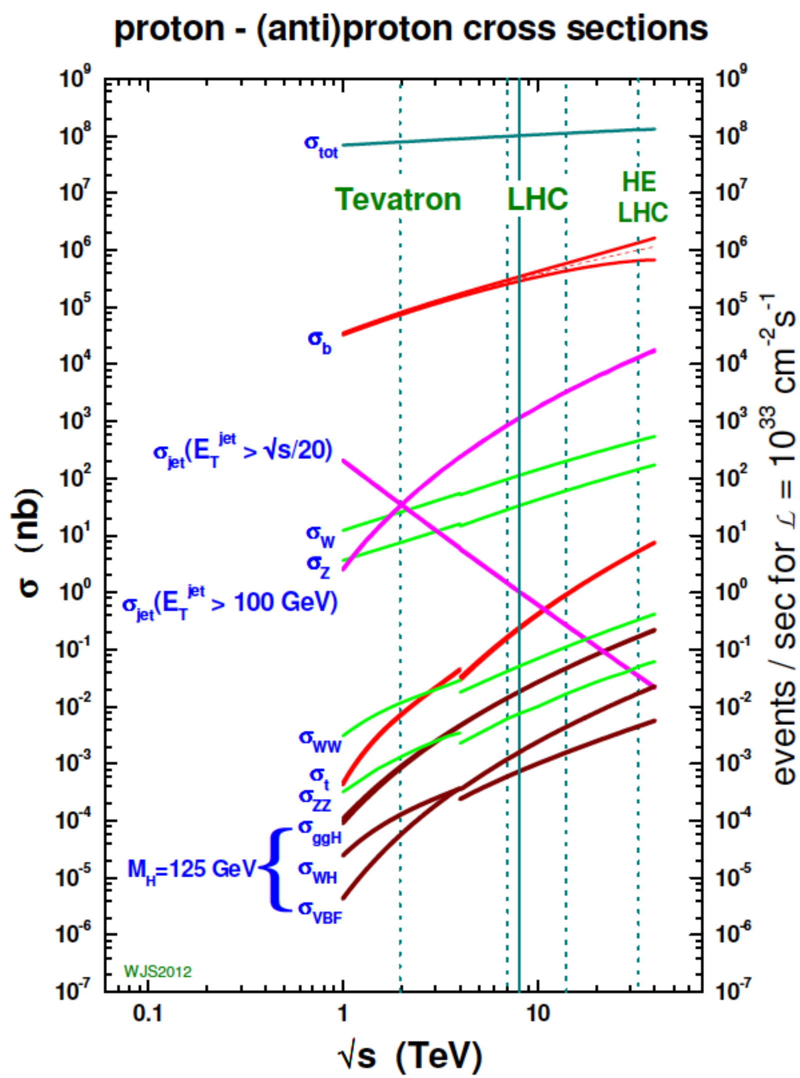


Core program: Absolute Higgs measurement

	PreCDR	Now
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%	1.7%
σ(ZH)*Br(H→WW)	1.5%	1.2%
σ(ZH)*Br(H→ZZ)	4.3%	4%
σ(ZH)*Br(H→ττ)	1.2%	1.0%
σ(ZH)*Br(H→γγ)	9.0%	9.0%
σ(ZH)*Br(H→μμ)	17%	17%
σ(vvH)*Br(H→Zγ)	-	-
σ(vvH)*Br(H→bb)	2.8%	2.8%
Higgs Mass/MeV	5.9	5.0
σ(ZH)*Br(H→inv)		
Br(H→ee)		
Br(H→bbχχ, 4b)	$<10^{-3}$	95%. CL = 3e-4

Higgs @ LHC



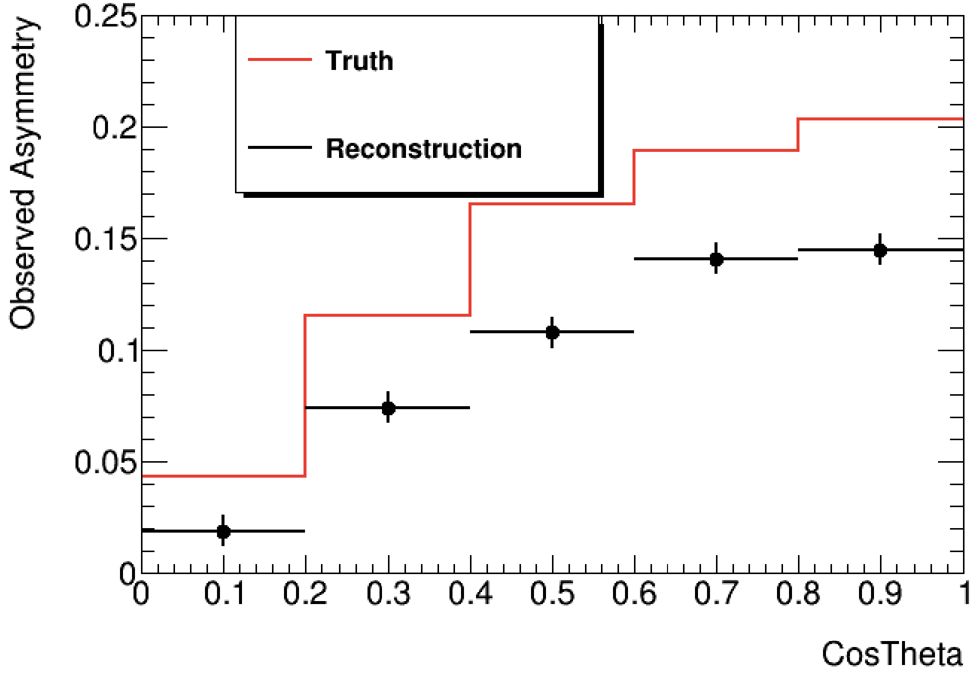


PP collider: High productivity but low finding efficiency
~already 10^6 Higgs in Run 1 data...

Higgs signal: found via the decay final states.

$$\sigma(AA \rightarrow H \rightarrow BB) \sim g^2(HAA)g^2(HBB)/\Gamma_{total}$$

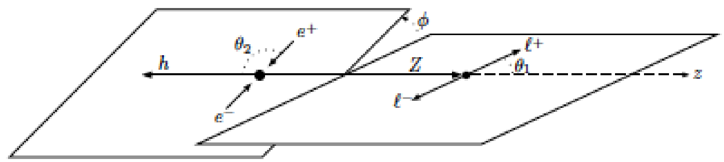
EW



- Afb(b) starts full sim analysis...
- More?

CP violating dim-6 operators

$$\mathcal{O}_{\Phi\Box} = (\Phi^\dagger\Phi)\Box(\Phi^\dagger\Phi) \qquad \mathcal{O}_{\Phi W} = (\Phi^\dagger\Phi)W^I_{\mu\nu}W^{I\mu\nu}$$
$$\mathcal{O}_{\Phi D} = (\Phi^\dagger D^\mu\Phi)^*(\Phi^\dagger D_\mu\Phi) \qquad \mathcal{O}_{\Phi B} = (\Phi^\dagger\Phi)B_{\mu\nu}B^{\mu\nu}$$
$$\mathcal{O}^{(1)}_{\Phi\ell} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar\ell\gamma^\mu\ell) \qquad \mathcal{O}_{\Phi WB} = (\Phi^\dagger\tau^I\Phi)W^I_{\mu\nu}B^{\mu\nu}$$
$$\mathcal{O}^{(3)}_{\Phi\ell} = (\Phi^\dagger i\overleftrightarrow{D}^I_\mu\Phi)(\bar\ell\gamma^\mu\tau^I\ell) \qquad \mathcal{O}_{\Phi\widetilde{W}} = (\Phi^\dagger\Phi)\widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$$
$$\mathcal{O}_{\Phi e} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar e\gamma^\mu e) \qquad \mathcal{O}_{\Phi\tilde{B}} = (\Phi^\dagger\Phi)\widetilde{B}_{\mu\nu}B^{\mu\nu}$$
$$\mathcal{O}_{4L} = (\bar\ell\gamma_\mu\ell)(\bar\ell\gamma^\mu\ell) \qquad \mathcal{O}_{\Phi\widetilde{W}B} = (\Phi^\dagger\tau^I\Phi)\widetilde{W}^I_{\mu\nu}B^{\mu\nu}$$



$$\frac{\mathrm{d}\sigma}{\mathrm{d}\phi\,\mathrm{d}\cos\theta_1\,\mathrm{d}\cos\theta_2}$$

Observables

$$\sigma(s) \qquad \mathcal{A}_{\theta_1} \equiv \frac{1}{\sigma}\int_{-1}^{1} d\cos\theta_1\,\mathrm{sgn}(\cos(2\theta_1))\,\frac{d\sigma}{d\cos\theta_1}$$

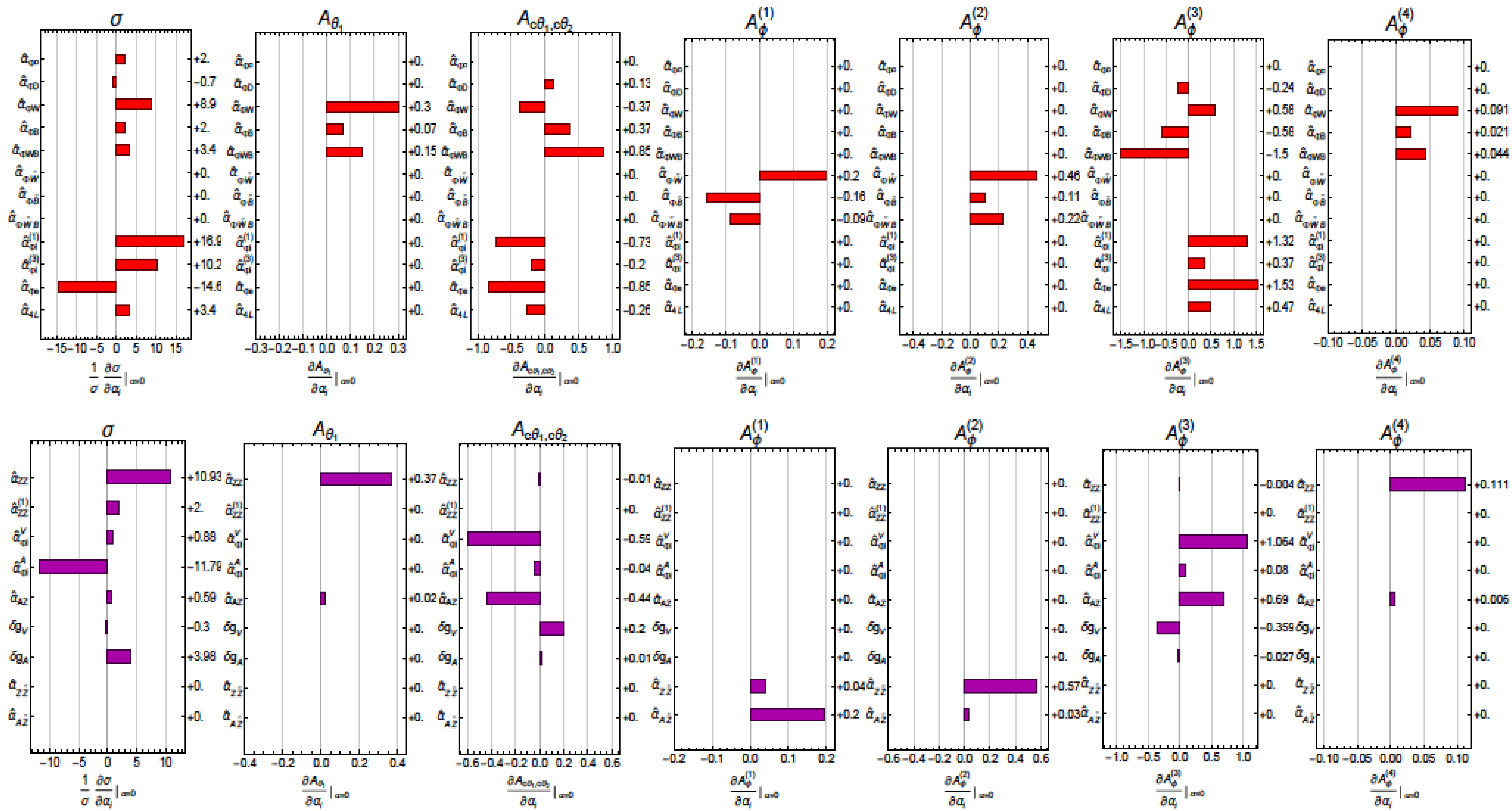
$$\mathcal{A}^{(1)}_{\phi} \equiv \frac{1}{\sigma}\int_0^{2\pi} d\phi\,\mathrm{sgn}(\sin\phi)\,\frac{d\sigma}{d\phi} \qquad \mathcal{A}^{(2)}_{\phi} \equiv \frac{1}{\sigma}\int_0^{2\pi} d\phi\,\mathrm{sgn}(\sin(2\phi))\,\frac{d\sigma}{d\phi}$$

$$\mathcal{A}^{(3)}_{\phi} \equiv \frac{1}{\sigma}\int_0^{2\pi} d\phi\,\mathrm{sgn}(\cos\phi) \qquad \mathcal{A}^{(4)}_{\phi} \equiv \frac{1}{\sigma}\int_0^{2\pi} d\phi\,\mathrm{sgn}(\cos(2\phi))\,\frac{d\sigma}{d\phi}$$

$$\mathcal{A}_{c\theta_1,c\theta_2} \equiv \frac{1}{\sigma}\int_{-1}^{1} d\cos\theta_1\mathrm{sgn}(\cos\theta_1)\int_{-1}^{1} d\cos\theta_2\mathrm{sgn}(\cos\theta_2)\frac{d^2\sigma}{d\cos\theta_1\,d\cos\theta_2}$$

Angular Observable in Higgsstrahlung

1512.06877

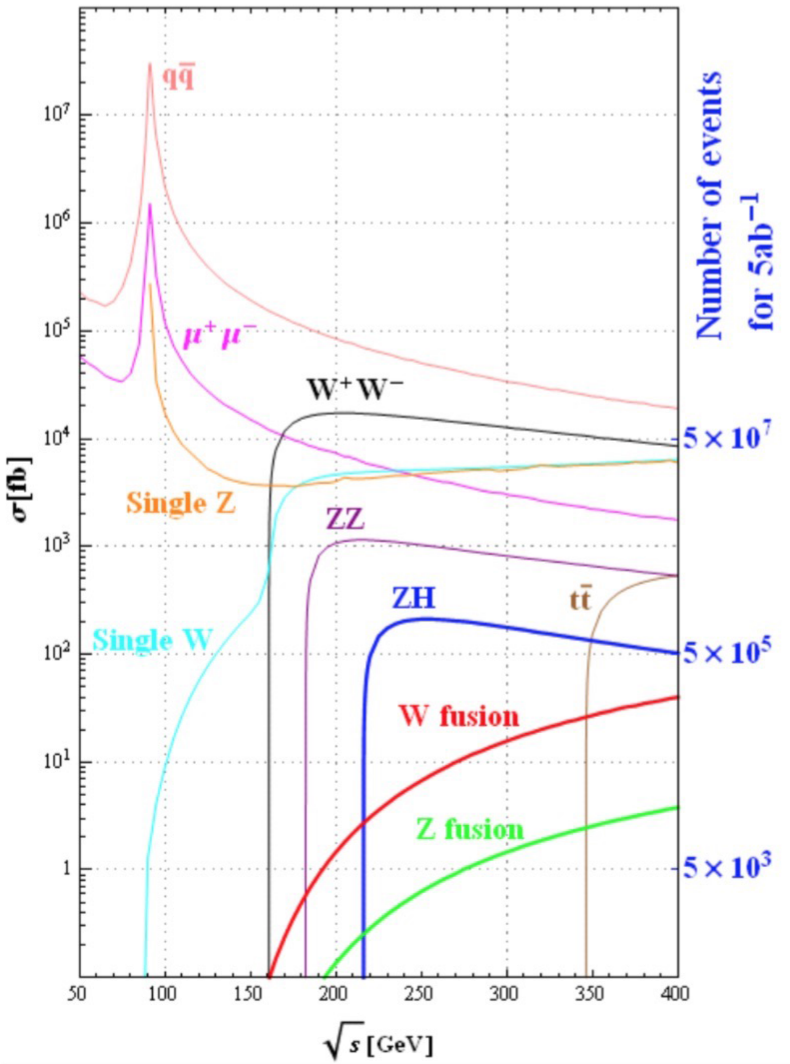


	$\widehat{\alpha}_{ZZ}$	$\widehat{\alpha}^{(1)}_{ZZ}$	$\widehat{\alpha}^{V}_{\Phi\ell}$	$\widehat{\alpha}^{A}_{\Phi\ell}$	$\widehat{\alpha}_{AZ}$	δg_V	δg_A	$\widehat{\alpha}_{Z\tilde{Z}}$	$\widehat{\alpha}_{A\tilde{Z}}$
rate	0.00064	0.0035	0.0079	0.00059	0.012	0.023	0.0018	∞	∞
angles	0.016	∞	0.0058	0.078	0.0087	0.017	0.23	0.012	0.036
total	0.00064	0.0035	0.0047	0.00059	0.0070	0.014	0.0018	0.012	0.036

At CEPC

- Higgs Run: 10 years, 1 M Higgs boson at 1 B physics events
- Z Pole Runs: 10 Billion Z boson in 1 year

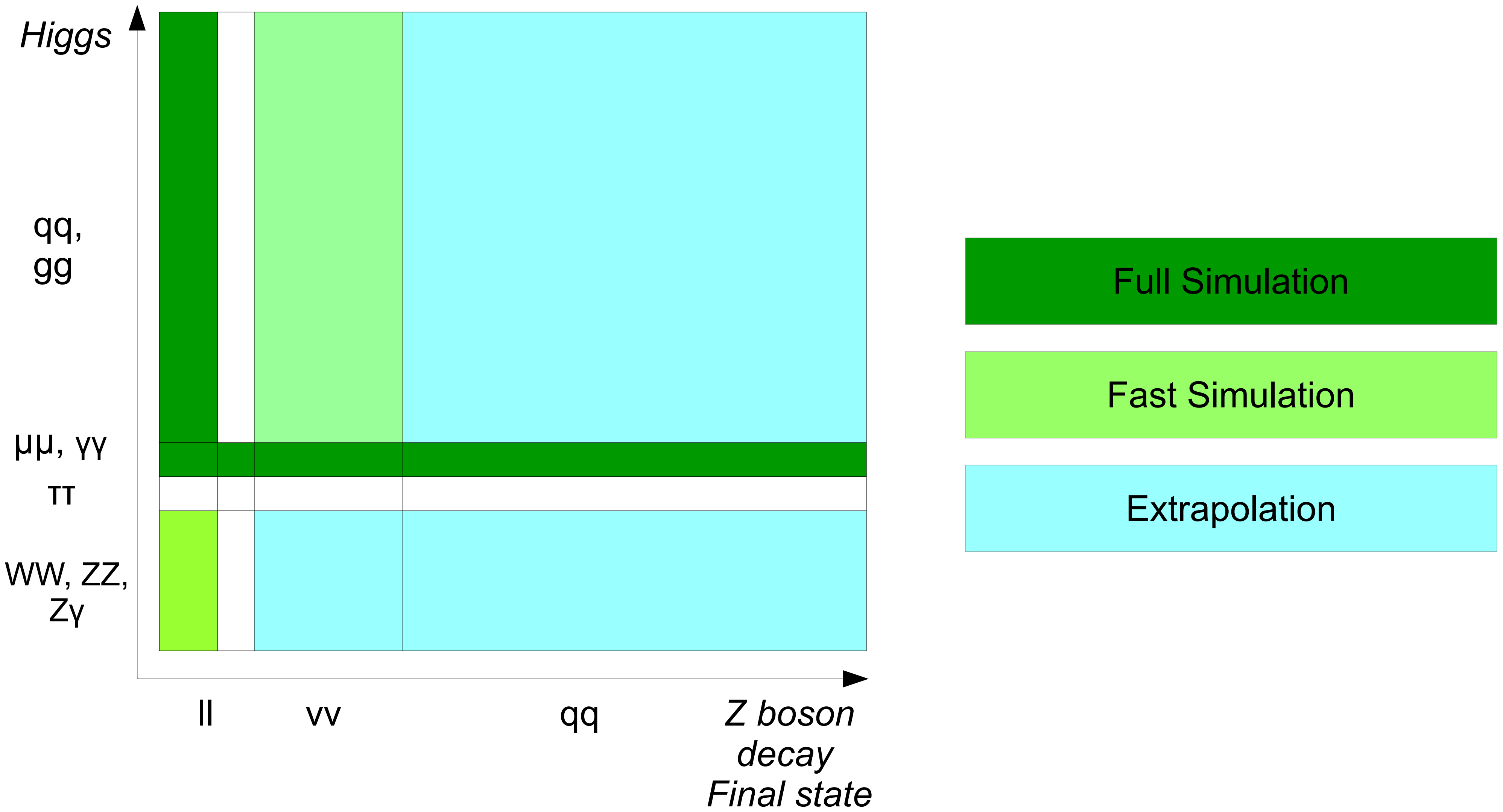
- Perfect understanding of the nature of Higgs boson, precise EW measurements, probe for NP...



Higgs program at CEPC

- **Absolute** Higgs measurements
- Benchmark measurements
  - sigma(ZH) determination
  - Higgs width measurement: Yuqian's talk
  - H->bb, cc, gg: see Baiyu's talk
  - Higgs exotic
    - Invisible
    - Hadronic state
    - Leptonic final state
- Next step:
  - Data driven method for sys. control?...
  - Differential distributions & loop hole at CEPC

Higgs analysis: Status at PreCDR



σ(ZH)*Br(H->bb, cc, gg)

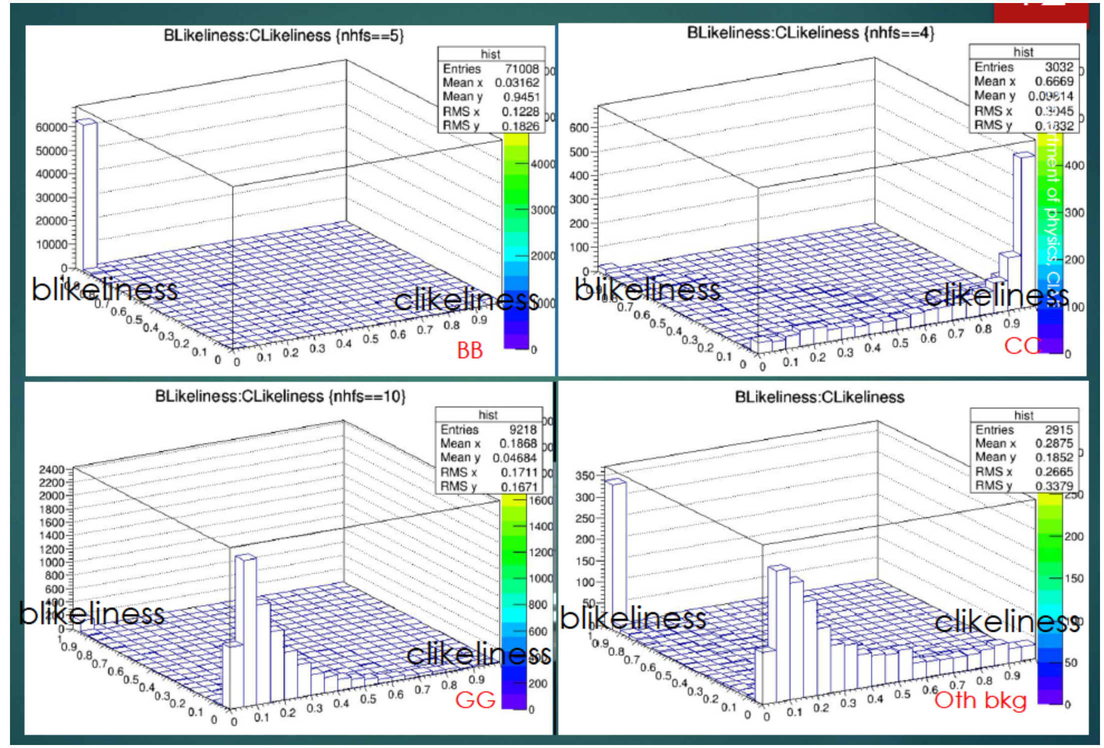
- Strategy: Event selection + Template fit on the b-likeness Vs c-likeness plane
- 4 independent channels: Signal & Key background are processed with Full Simulation

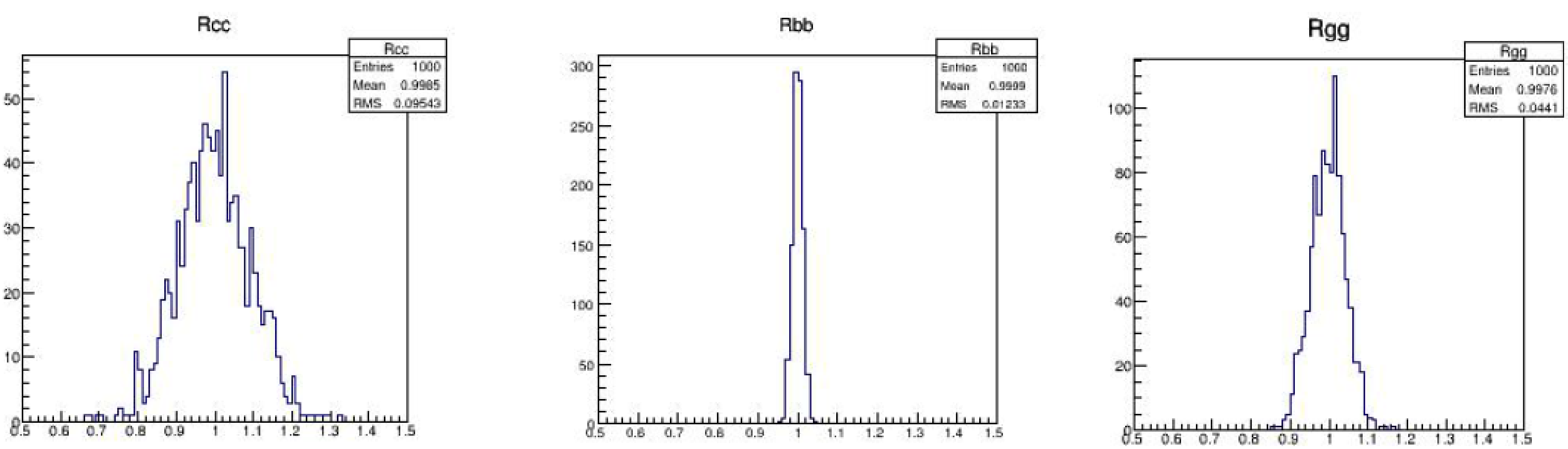
	Analyzer	bb	cc	gg	
mumuH	Zhenxing, etc	0.96%	13.5%	11.6%	
		0.96%	11.0%	8.73%	
eeH					
tautauH					
vvH	Lianghao, Yulei, Dikai	0.38%	3.5%	2.4%	Notes submitted
qqH	Baiyu, Boyang, etc	0.27%	4.4%	3.0%	Notes submitted
Comb. opti		0.21%	2.5%	1.7%	
Result at PreCDR		0.28%	2.2%	1.6%	

σ(ZH)*Br(H->bb, cc, gg)

- Key points
  - MumuH: different template fit technologies need to be compared and understood
  - qqH:
    - Complex analysis:
      - Jet clustering algorithm,
      - Hard gluon emission,
      - Matching
      - Systematic control
  - EeH & tautauH: to be covered
  - All channels: distinguish between H->gg events and H->WW/ZZ->4 jets events is still challenging!

Cut Definition	*Sig.*	*qq*	*qqnn*	*qqln*	*nnh*
Generated	16260	25M	183K	3681K	
FSClasser output	16768	25M	183K	3681K	7485
$N_{\mathrm{PFO}(E>0.4\mathrm{GeV})} > 20$	16748	23M	163K	3439K	4889
$110 < E_{\mathrm{total}} < 150$	14689	10M	126K	705K	3311
$P_T > 19$	13687	34K	116K	627K	3101
Isolation lepton veto	13429	33775	115K	327K	2537
$100 < M_{\mathrm{inv}} < 135$	12827	9506	10420	162K	2269
$70 < M_{\mathrm{rec}} < 125$	12166	7521	10045	110K	2260
$0.15 < y_{12} < 1$	12093	7405	9702	101K	2211
$y_{23} < 0.06$	10902	6644	8456	69313	1220
$y_{34} < 0.008$	10377	6504	7878	58532	519
$-0.98 < \cos(\theta^{(2\mathrm{jets})}_{\mathrm{included}}) < -0.4$	10284	5766	5454	34823	485
$BDT > 0.04$	8705	381	465	267	230
Significance	**84.92**				
Efficiency	**53.5%**				





Fitting result over truth for cc, bb, gg respectively

H -> WW* && H->ZZ*

- Various Final States! Any combination of leptons, missing E/P, jets...
- Processed with Full Simulation:
  - Final states with at most 2 jets
  - Lepton id, Isolate lepton finding and total momentum/energy resolution: key ingredient for these analysis
- WW*
  - Dedicated Isolation lepton finding algorithm has been developed, compared & tuned
- ZZ*
  - Tau related bakground could be largely suppressed once tau finder is more mature

H -> WW* && H->ZZ*

- Various Final States! Any combination of leptons, missing E/P, jets...
- Key measurement for achieving Higgs width
- Processed with Full Simulation:
  - Final states with leptons
    - Lepton ID & Detector coverage: intrinsic requirements
    - Isolation condition for letpons: compromise between Signal Efficiency & Bkgrd rejection rate
  - Libo, responsible for general isolation framework design & H->WW analysis
  - Yuqian, responsible for ZZ analysis

H -> WW*

Table 2.8 Expected precision of the $\sigma(ee \to ZH) \times \mathrm{BR}(H \to WW^*)$ measurement, assuming an integrated luminosity of 5 ab^{-1}.

Channel	Precision	Comment
$Z \to \mu\mu, H \to WW^* \to \ell\nu qq, \ell\ell\nu\nu$	4.9%	CEPC Full Simulation
$Z \to ee, H \to WW^* \to \ell\nu qq,\ \ell\ell\nu\nu$	7.0%	Estimated
$Z \to \nu\nu, H \to WW^* \to qqqq$	2.3%	Extrapolated from ILC result
$Z \to qq, H \to WW^* \to \ell\nu qq$	2.2%	Extrapolated from ILC result
Combined	1.5%	

Table from PreCDR

4.9% accuracy, should be updated to 4.2% at the CEPC note, which is composed Of 14.2% from llvv channel and 4.4% of lvqq channel.

Full Simulation analysis, performed by Libo, is applied on Z->dimuon, H->WW*->llvv channel
Clean signal, tiny fraction: 0.1% of all H->WW* events.

Category	Total	Signal	Background
$l_1 = e, l_2 = \mu$	105±10.2	105±10.2	0.0±0.0
$l = \mu$	58±7.6	52±7.2	6±2.4
$l = e$	40±6.3	36±6	4±2
WW^* full leptonic decay	203±14.2	193±13.9	10±3.2

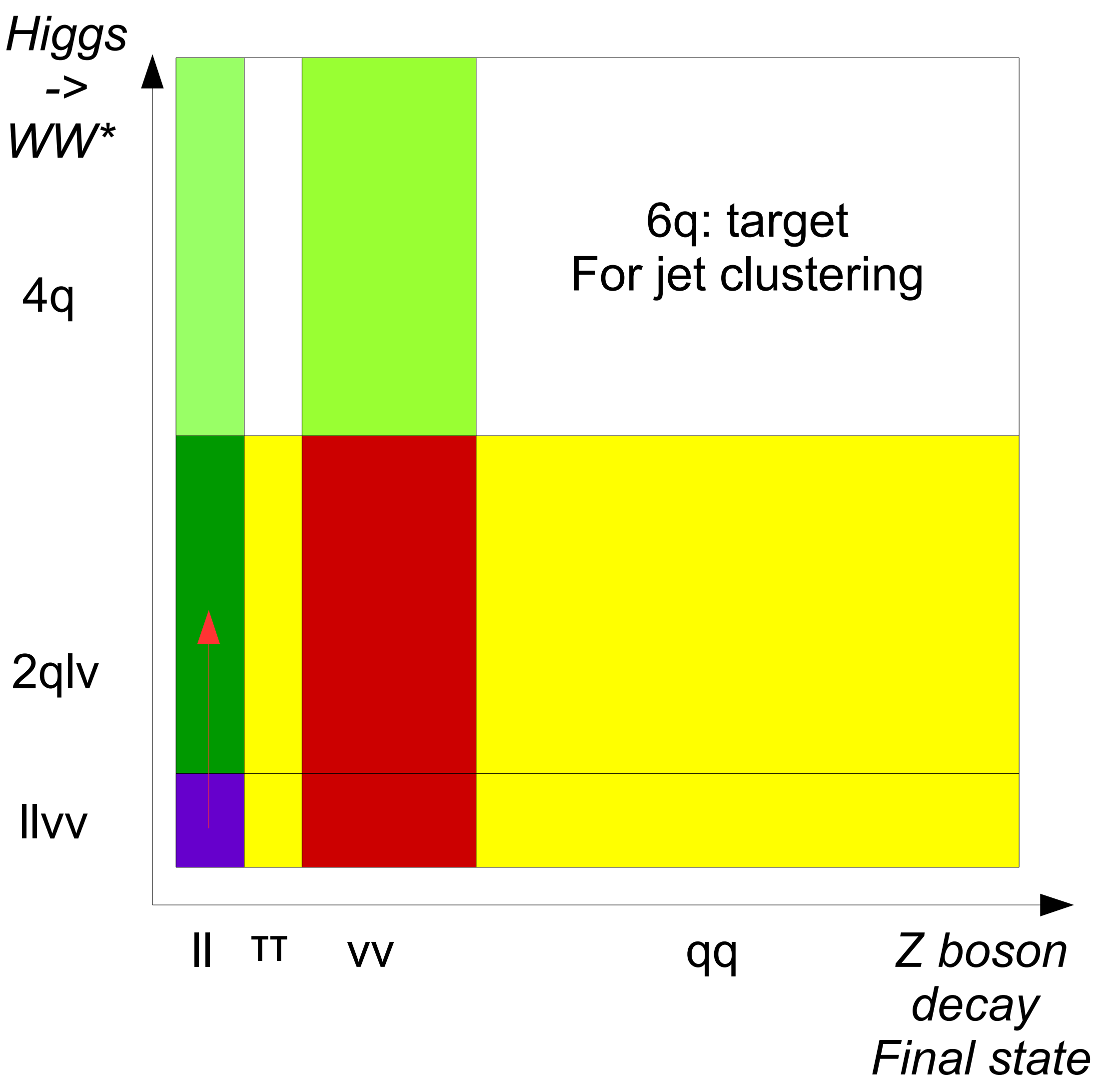
9.8%
14.6%
17.6%

In total:
7.4%

Table 4: Statistic error of different flavor final state and $H \to WW^* \to ll\nu\bar{\nu}(l = e, \mu)$

Improved by a factor of **2** comparing to PreCDR

H -> WW*



Suggested Priority:

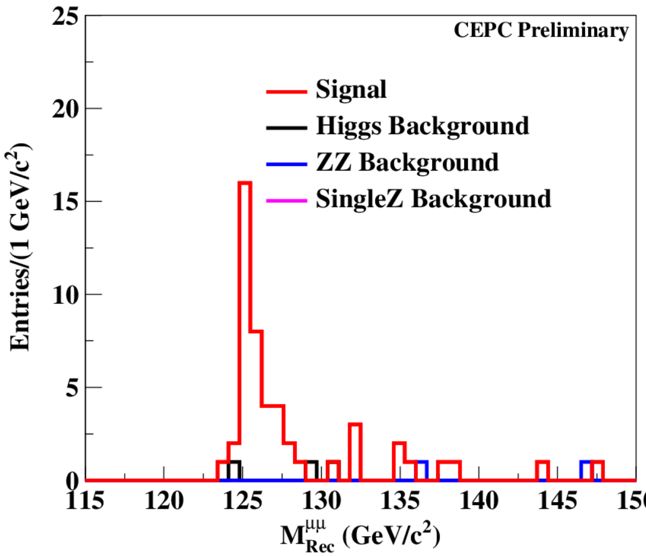
Repeat zhenxin's analysis

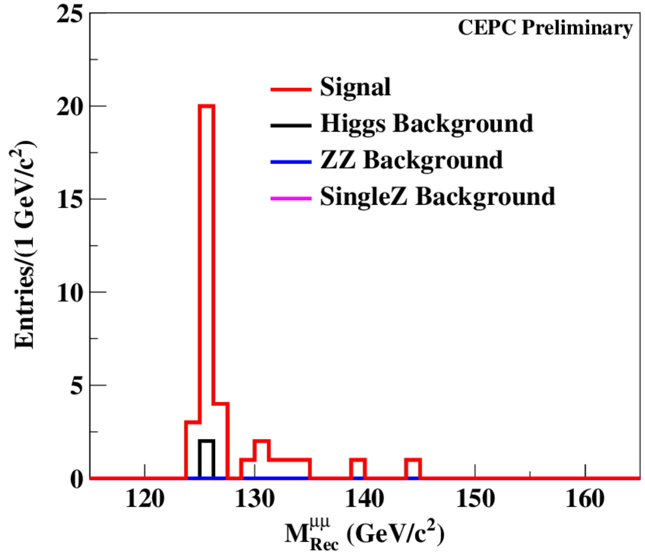
1: Z(vv) + H(llvv, 2qlv) (iso lepton)
(王峰 + 立波)
Di lepton: dR & mass, flavor classification,
Bkg: WW, ZZ, isrZ

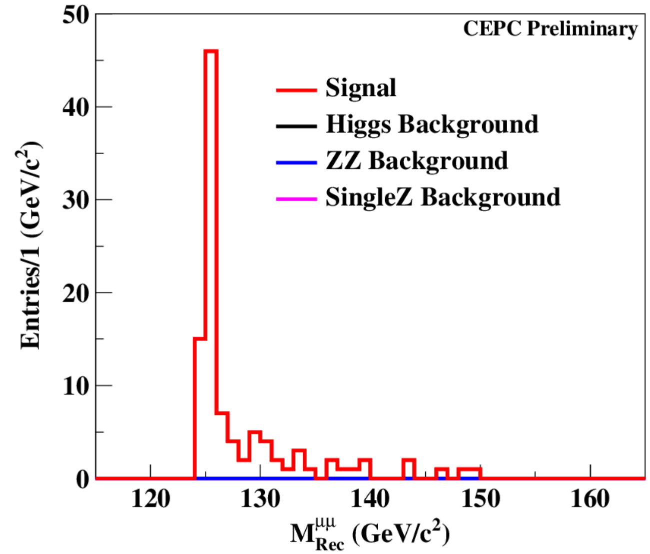
2: vv + 4q; ll + 4q
JER (peak at 125 GeV);
mixed with Higgs backgrounds
Z->vv/ll & H->2q, H->ZZ* -> 4q
B-tagging can be used to veto 40% of ZZ;
(+ 彧骞)
Bkg: Higgs noise

3: qq + 2qlv/llvv, Jet Clustering +
Iso lepton

H -> WW*







Category	Signal	*ZH*	*ZZ*	Single *Z*
Total	348	34624	5499688	7788916
$N_{ZPole}=2; N_{Isolep}=2; l=\mu$	77	129	5309	0
80 GeV $< M_{Inv}^{\mu^+\mu^-} <$ 100 GeV	73	124	4143	0
120 GeV $< M_{Rec}^{\mu^+\mu^-} <$ 150 GeV	66	118	2548	0
$N_{Remain} < 3$	66	56	2442	0
10 GeV $< M_{Inv}^{\mu^+\mu^-} <$ 65 GeV	58	46	411	0
40 GeV $< E_{Missing} <$ 100 GeV	55	26	231	0
$\sqrt{(\frac{D0}{sigD0})^2 + (\frac{Z0}{sigZ0})^2} < 5$	54	7	226	0
Total $P_T >$ 20 GeV	52	3	3	0

Table 2: Cut chain of $\mu\mu$ final state

Category	Signal	*ZH*	*ZZ*	Single *Z*
Total	348	34624	5499688	7788916
$N_{ZPole}=2; N_{Isolep}=2; l=e$	61	114	4	1807
80 GeV $< M_{Inv}^{\mu^+\mu^-} <$ 100 GeV	53	105	2	1165
120 GeV $< M_{Rec}^{\mu^+\mu^-} <$ 150 GeV	52	101	1	726
$N_{Remain} < 3$	51	60	0	692
10 GeV $< M_{Inv}^{e^+e^-} <$ 65 GeV	49	47	0	49
35 GeV $< E_{Missing} <$ 100 GeV	49	27	0	31
$\sqrt{(\frac{D0}{sigD0})^2 + (\frac{Z0}{sigZ0})^2} < 6$	39	4	0	24
Total $P_T >$ 20 GeV	36	4	0	0

Table 3: Cut chain of ee final state

Category	Signal	*ZH*	*ZZ*	Single *Z*
Total	348	34624	5499688	7788916
$N_{ZPole}=2; N_{Isolep}=2; l_1=e, l_2=\mu$	147	136	32	1
80 GeV $< M_{Inv}^{\mu^+\mu^-} <$ 100 GeV	134	119	21	0
120 GeV $< M_{Rec}^{\mu^+\mu^-} <$ 150 GeV	130	117	15	0
$N_{Remain} < 3$	130	89	3	0
10 GeV $< M_{Inv}^{e\mu} <$ 65 GeV	123	79	3	0
35 GeV $< E_{Missing} <$ 110 GeV	123	68	2	0
$\sqrt{(\frac{D0}{sigD0})^2 + (\frac{Z0}{sigZ0})^2} < 4$	105	0	0	0

Table 1: Cut chain of $e\mu$ final state

Obj Eff = 90%
Sig Eff = 60%

Obj Eff = 70%
Sig Eff = 41%

Obj Eff = 85%
Sig Eff = 60%

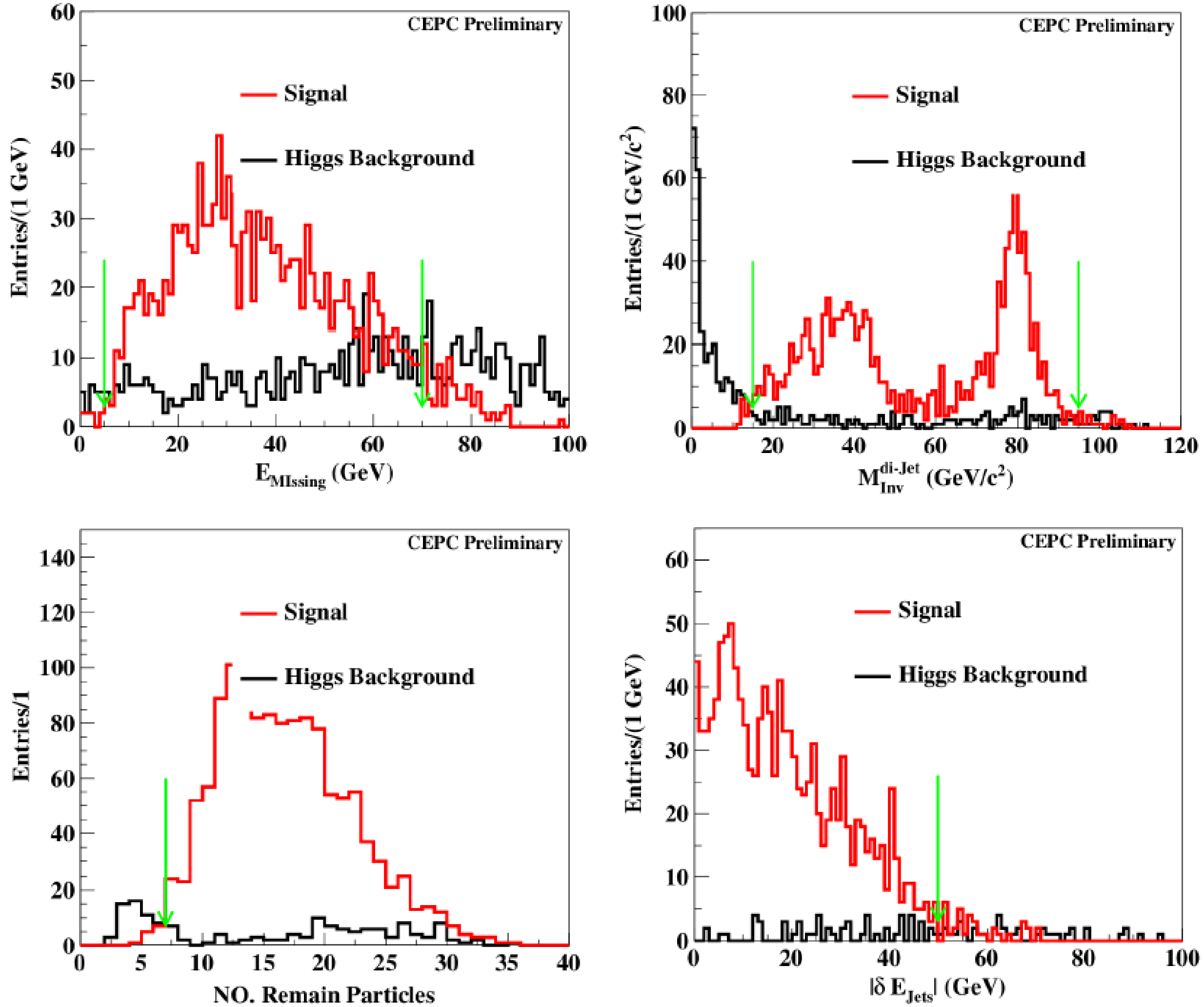
7% accuracy achieved with counting: improved by 2 times Comparing to Pre-CDR

Obj Eff: find 2 leptons from the Z pole and 2 isolated leptons.

H -> WW*

4 H->WW*->lvqq analysis

5GeV $< E_{Missing} <$ 70GeV
15GeV $< Mass_{Rec}^{di-jet} <$ 95GeV
No. Remain Particle >7
|E_jet1-E_Jet2|<50



2016/3/26

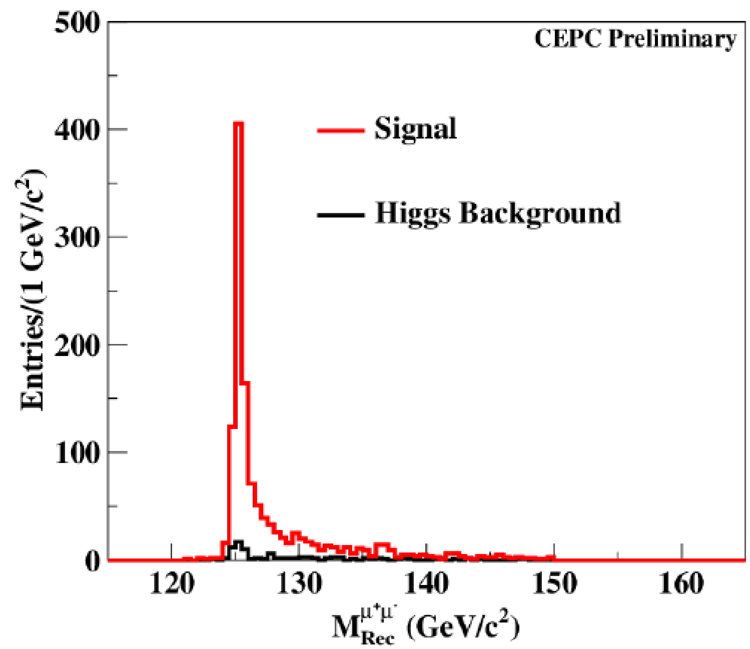
H -> WW*

4 H->WW->lvqq analysis*

Category	Signal	ZH
Total	2112	32291
$N_{ZPole} = 2; N_{Isolep} = 1; N_{Jets} = 2$	1853	2524
$80\ \mathrm{GeV} < M_{Inv}^{\mu^+\mu^-} < 100\ \mathrm{GeV}$	1665	2173
$120\ \mathrm{GeV} < M_{Rec}^{\mu^+\mu^-} < 150\ \mathrm{GeV}$	1610	2109
$(Y12 * y23)^2 < 0.005$	1601	1687
$E_{lepton} > 15\ \mathrm{GeV}$	1416	841
$5\ \mathrm{GeV} < E_{Missing} < 70\ \mathrm{GeV}$	1325	464
$15\ \mathrm{GeV} < M_{Rec}^{di-Jet} < 95\ \mathrm{GeV} < 6$	1289	156
$N_{Remain} > 7$	1252	96
$\lvert \delta E_{Jets} \rvert < 50\ \mathrm{GeV}$	1217	55

Table 4: Cut chain of semi leptonic decay of $H \rightarrow WW^*$

2016/3/26 CEPC Physics Software Meeting



Z Decay / W Decay	ll	vv	tau tau	qq
lvlv				
lvqq				
qqqq				
Tau+X				

Green: undone
Yellow: 25%
Orange: 50%

H->ZZ*

Yuqian's
Full simulation

	Z->ll	taus	vv	qq
ZZ*->4q	888	444	2.64k	9.24k
2v + 2q	508	254	1.51k	5.29k
2l + 2q	170	85	508	1778
4v	73	36	216	756
2l + 2v	49	24	145	508
4l	8	4	24	86
X + tau	120	60	356	1246

Yang Xuan's
Fast simulation

Priority 1: isolated leptons.

H->ZZ*

Resolution ~ 40-50%

ZZ*	ll	taus	vv	qq
4q	888	444	2.64k	9.24k
2v+2q	508	254	1.51k	5.29k
2l+2q	170	85	508	1778
4v	73	36	216	756
2l+2v	49	24	145	508
4l	8	4	24	86
X+tau	120	60	356	1246

S/B = 65/31 S/B = 94/21

ZZ*\IniZ	$\mu^+\mu^-$	e^+e^-
vvqq	126	126
qqvv	126	126

Result on cut base

Needs more optimise for better result

Difficult for now

ZZ*\IniZ	qq
μμvv	126
vvμμ	126
eevv	126
vvee	126

	vv
μμqq	126
qqμμ	126
eeqq	126
qqee	126

S/B = 97/18
S/B = 82/30
S/B = 54/67

Result from ini-Z to di-muon/electron: 15% comb 11.4% = 9.0%
Result from ini-Z to invisible: 11% comb 13% comb 20% = 7.7%;
including W fusion contribution, should increase the statistic by 18%; thus 7%
(comparing to 6.9% accuracy we achieved with Fast simulation at Pre-CDR)
In total: 5.5%

Reference Num at PreCDR: 4.3%
Next step: Including other channels with leptonic final states

H->di photon

- Feng & JianHuan
- Converted Photon recovery algorithm: proved to be efficient & save back ~ 10-15% of statistic: need further polishment
- Dedicated Photon Energy Estimator & Photon ID has been developed and adjusted to CEPC_v1 geometry

H->di muon

- Cui Zhenwei, (Wang Binlong)
- Test bed for event selection tuning
  - Cut based;
  - MVA-BDT based;
- Carefully designed BDT seems could largely improve the analysis result. Checking details

pre-section	217.7	10356245
124.2<Hmass<125.5	163.2	30050
90.7<Recoilmass<92.5	105.6	419
-55<Pzsum<52	93.3	290
29.2<Ptsum<62	88.5	269
-0.29<cosup<1	55.2	69
-1<cosum<0.20	47.5	48
0<arguu<178	46.5	42

pre-section	214.2	285346
32.3<(InvMass-RecMass)<34.2	98.4	7008
215.95<(InvMass+RecMass)<216.66	79.1	158
-0.88<(cosup+cosum)<0.87	78.9	157
-1.92<(cosup-cosum)<0.40	48.9	40
-62.1<pzsum<58.5	47.9	37
10.0<ptsum<62.4	47.6	37
0<Ptuu<178	46.5	34