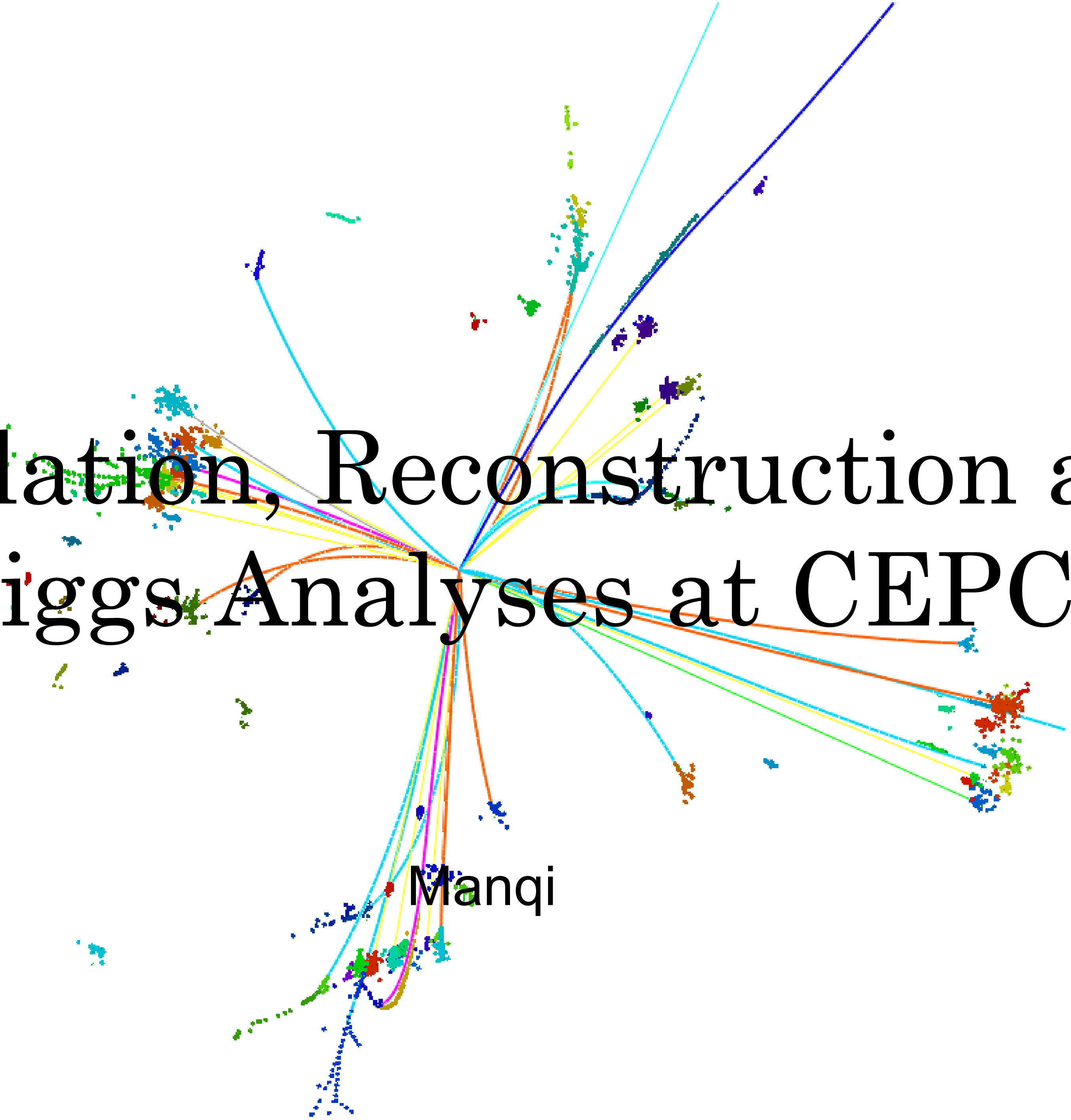
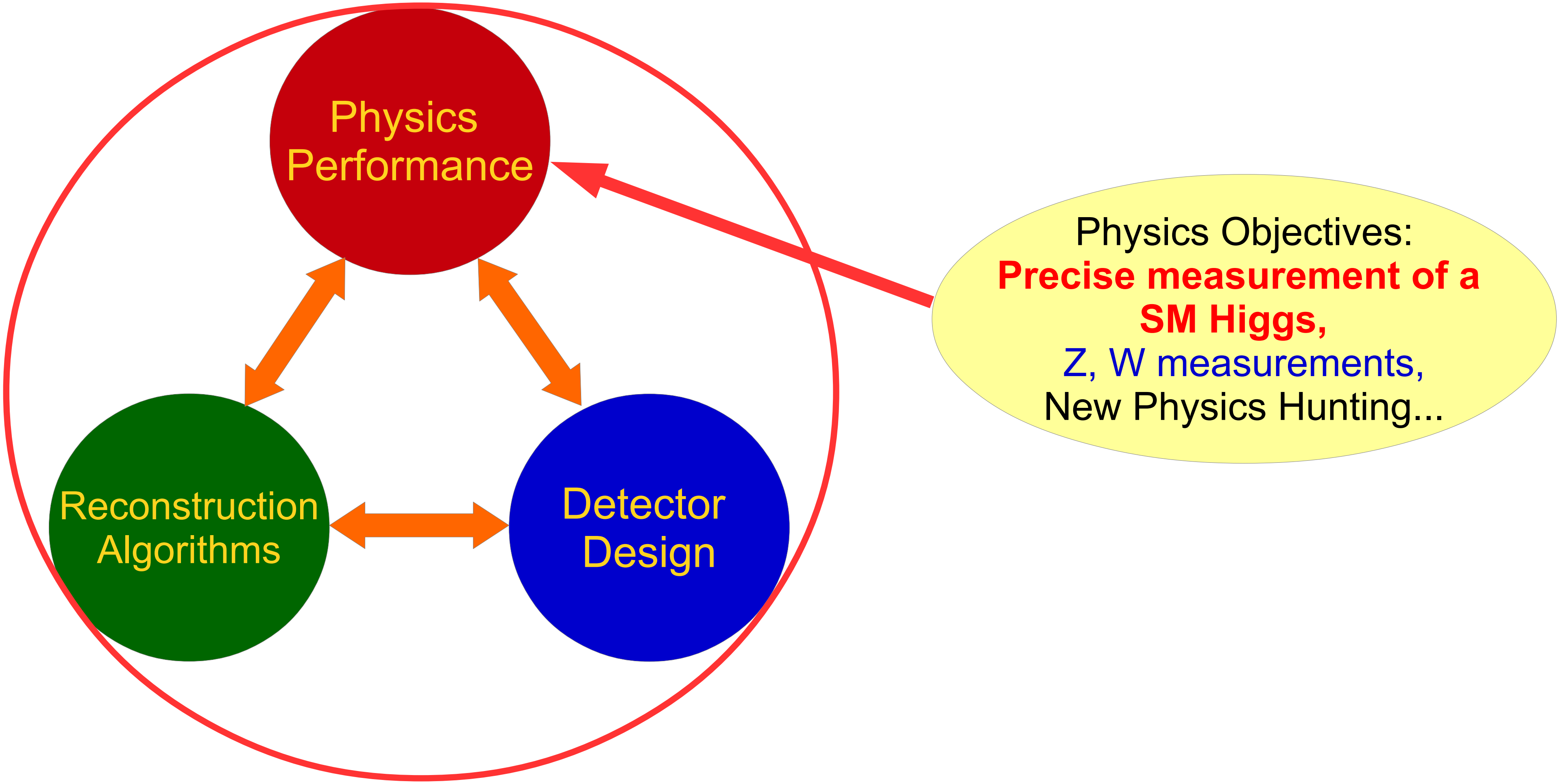
Simulation, Reconstruction and Higgs Analyses at CEPC



Manqi

Simulation, key ingredients

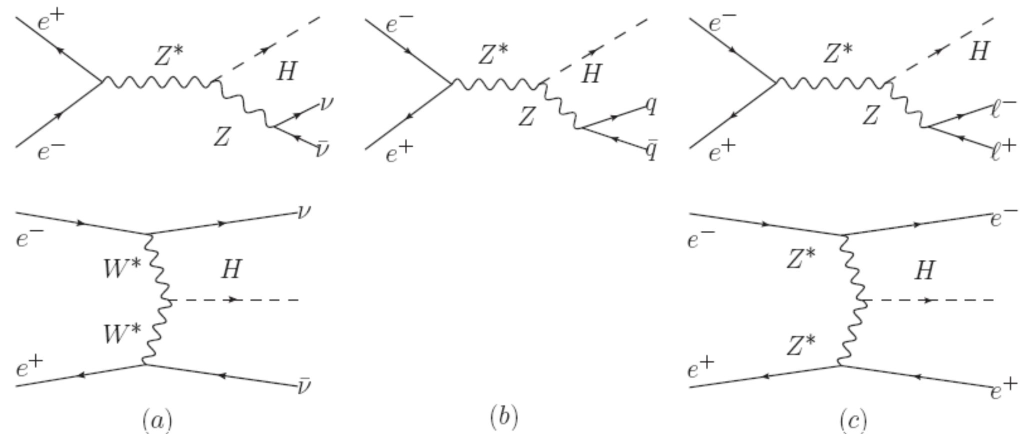


SM Higgs observables

- From 1M Higgs: Direct measurements
  - Mass, spin, σ(ZH)
  - Branching ratios (b, c, τ, g, W, Z)
  - Branching ratios (gamma, mu)

    +

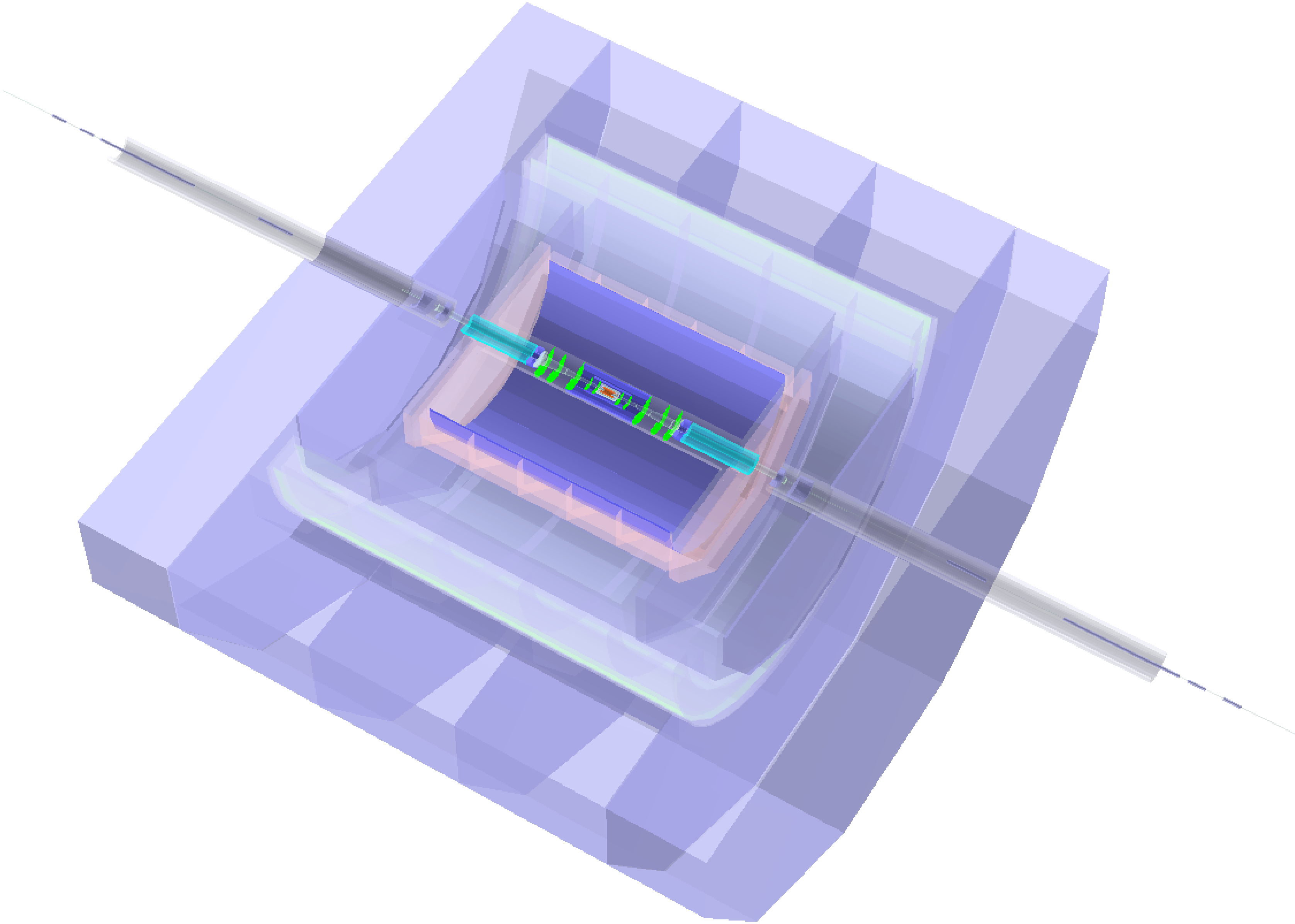
  - Invisible Branching ratio
  - σ(ννH)*Br(H→bb)
- Derived: width and couplings



Mode	$b\bar{b}$	$c\bar{c}$	gg	WW^*	$\mu^+\mu^-$	$\tau^+\tau^-$	ZZ^*	$\gamma\gamma$	$Z\gamma$
BR (%)	57.8	2.7	8.6	21.6	0.02	6.4	2.7	0.23	0.16

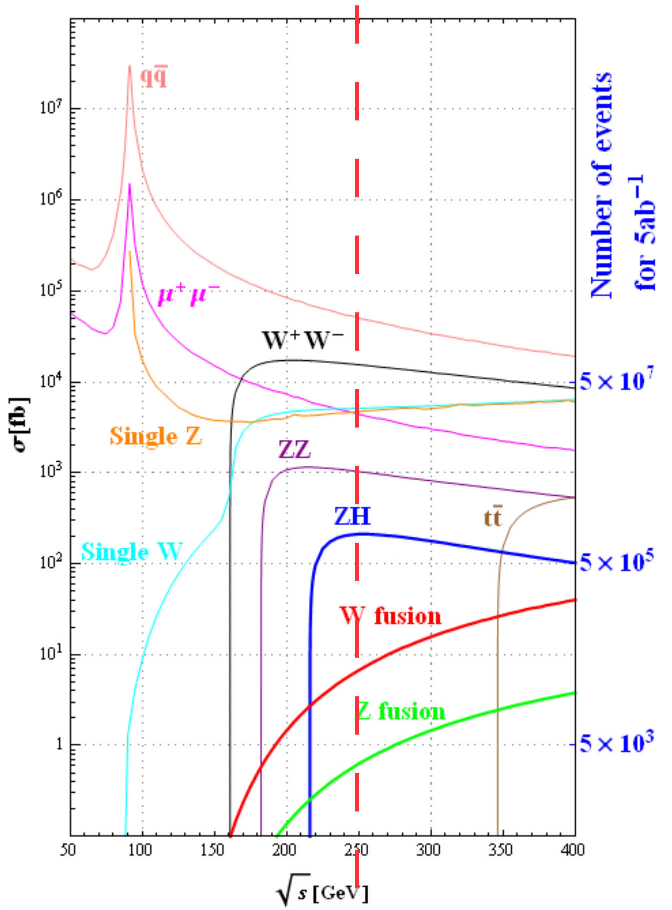
g(Hbb), g(Hcc), g(Htt), g(HWW)/Γ_H, g(Hμμ), g(Hττ), g(HZZ)/Γ_H, g(HWW)/g(Htt)

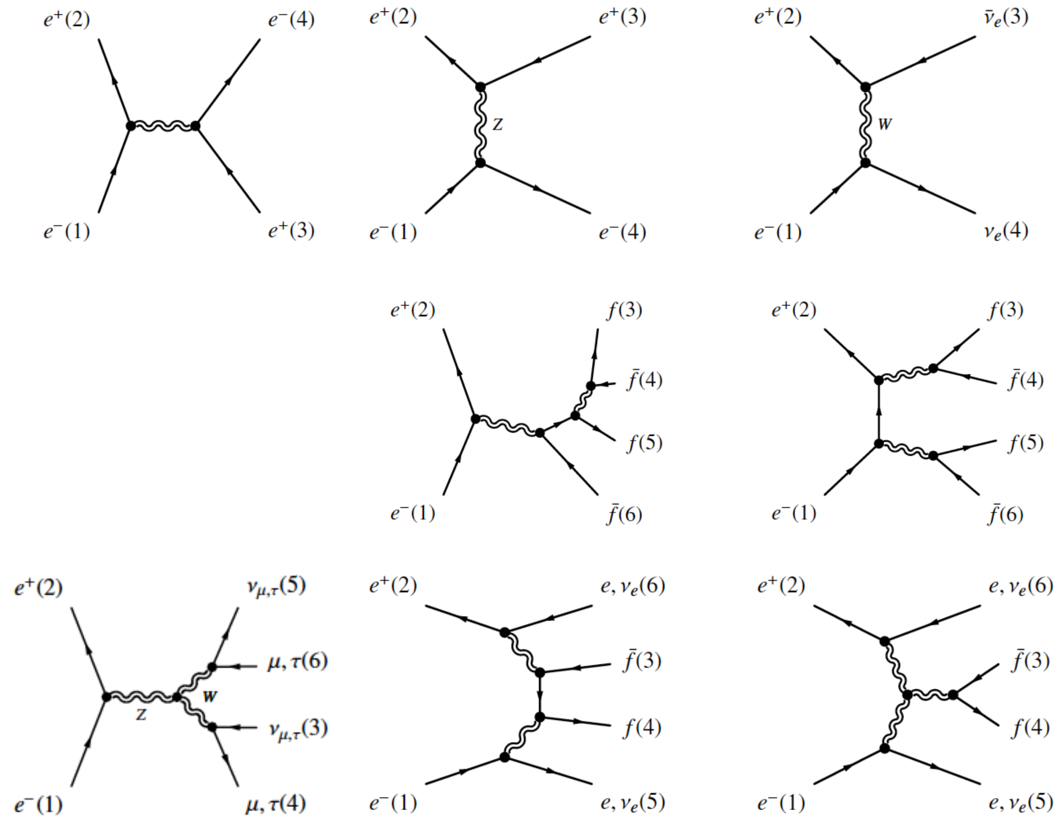
Conceptual detector design



MDI - Forward tracking system changed w.r.t ILD

Generators





- Whizard: SM Higgs signal & background (2 fermion, 4 fermion including radiation corrections), Supported by Whizard team
- Madgraph: BSM models (FCNC, exotic Higgs decay, etc.)

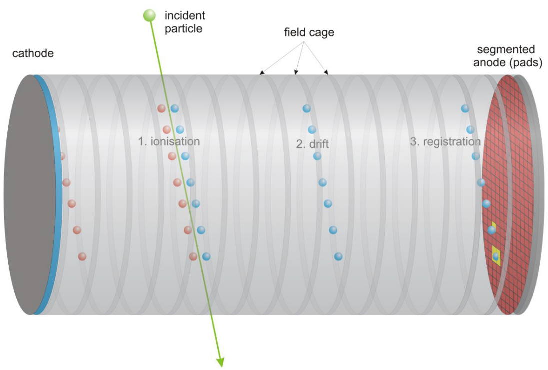
Reconstruction

Table 3.4 Expected performance of CEPC detector at object level (within geometry acceptance). For the flavor tagging, the b/c tagging efficiency should preserve a purity of 80% at Z pole sample with hadronic final states

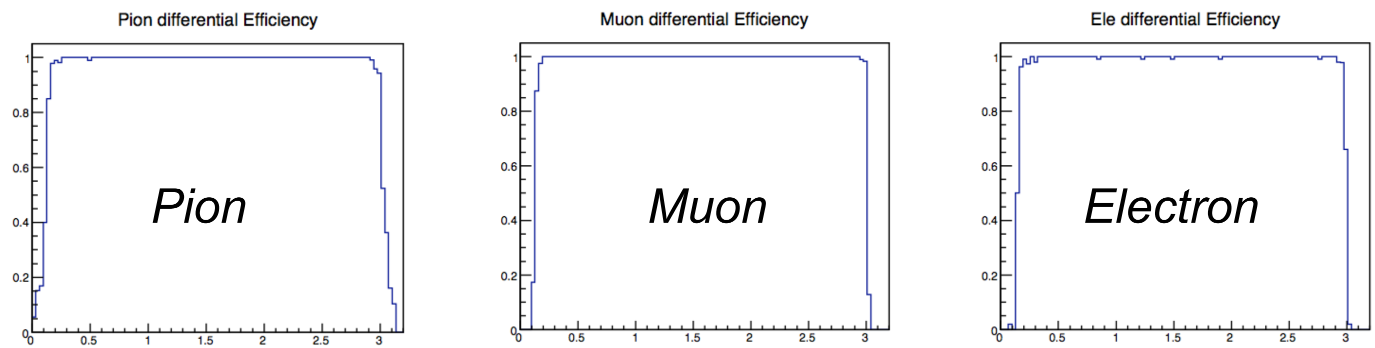
Tool	Object	Expected	Achieved
Tracking: Kalman Fitter based Clupatra (ILC tool)	Charged particle tagging efficiency ($E > 10$ GeV)	99.5%	>99%
Arbor	Muon identification efficiency ($E > 10$ GeV)	98.5%	99%
	Electron identification efficiency ($E > 10$ GeV)	99.5%	99%
	Photon tagging efficiency ($E > 1$ GeV)	95%	99% for E>5GeV γ
	Neutral Hadron tagging efficiency ($E > 5$ GeV)	90%	NAN
	Jet Energy resolution	3 - 4%	4%
Flavor tagging: LCFIPlus (ILC tool)	b-tagging efficiency	90%	87%
	c-tagging efficiency	60%	40%

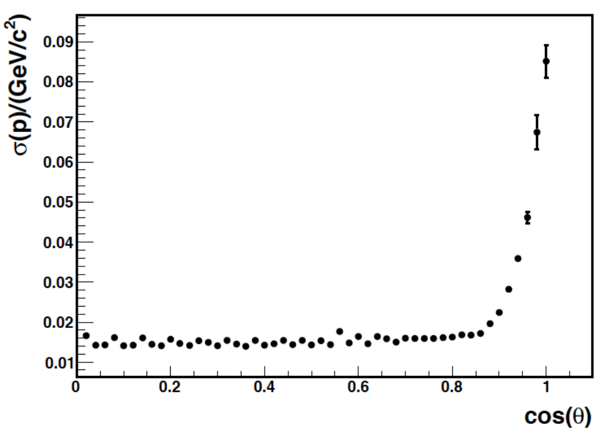
- Fully validated reconstruction chain
- PFA oriented: object finding efficiency & Jet Energy Resolution

Tracking



Reconstruction Efficiency of Charged Particles





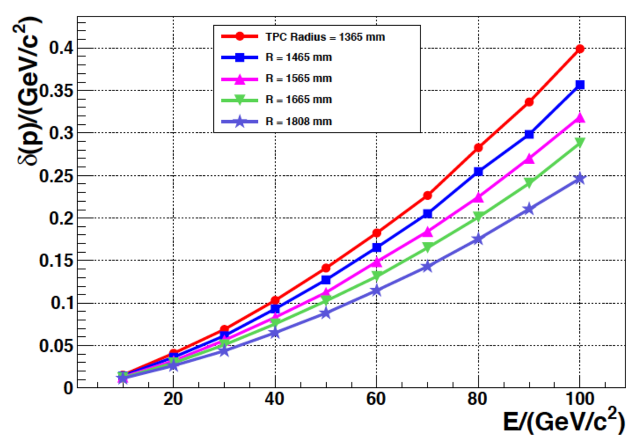


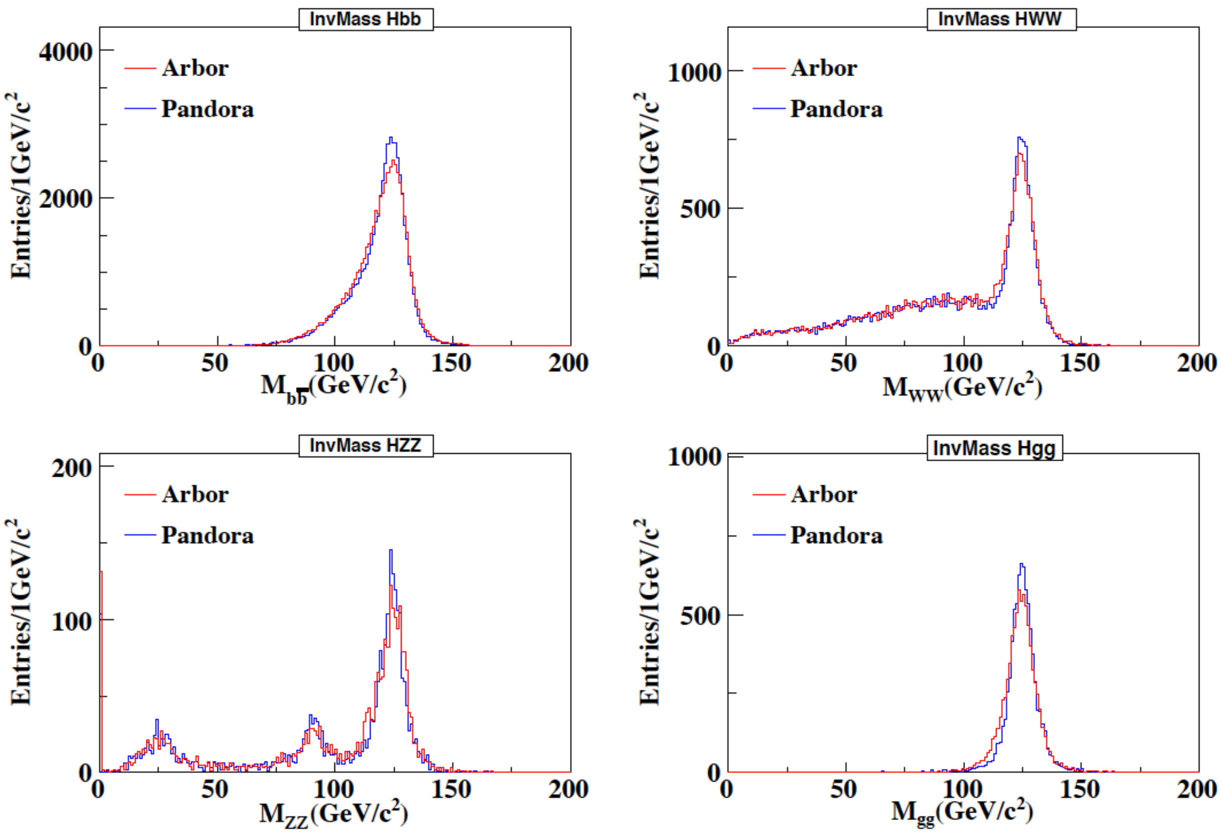
Fig. 4. Tracker Performance at different Polar angle

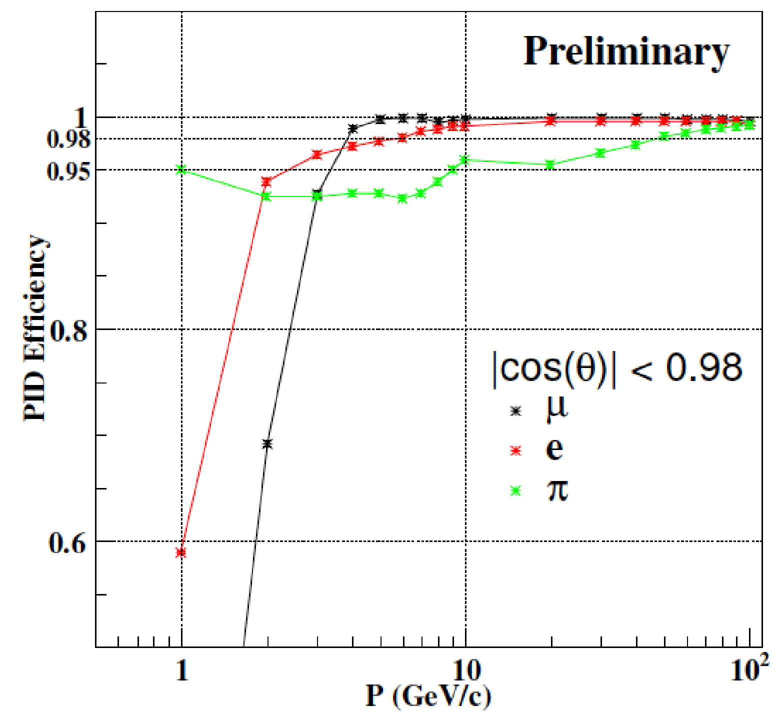
Fig. 6. Tracker Performance at different TPC Radius

Reproduced the performance at ILD

PFA: Jet Energy Resolution & Lepton ID

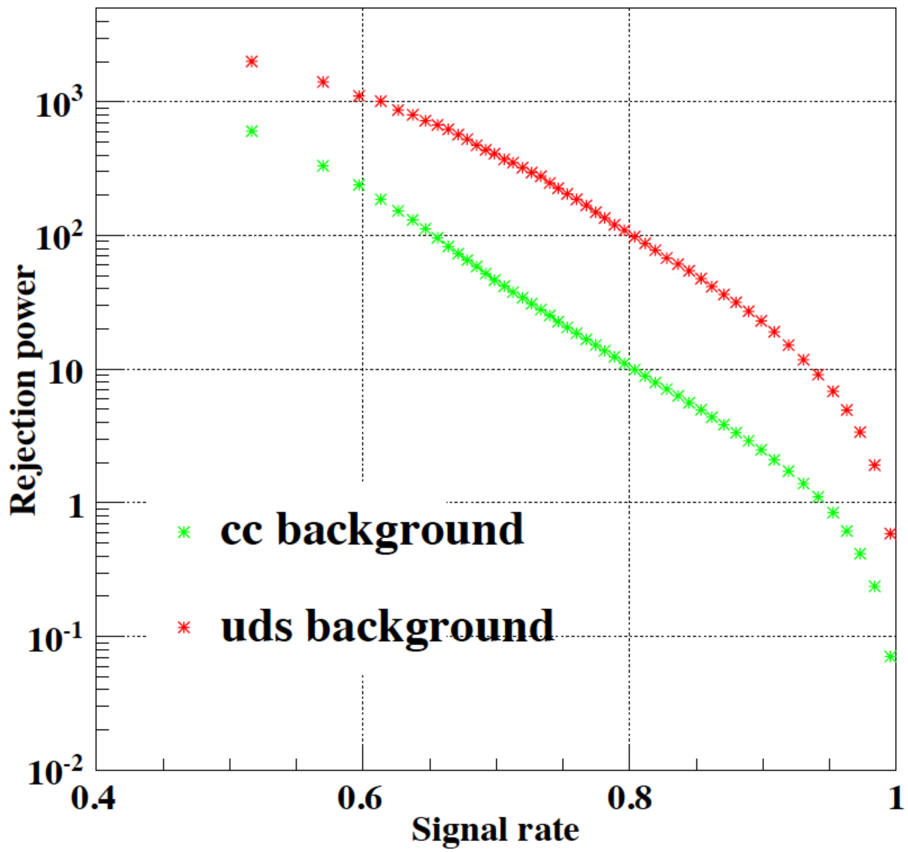
Invariant mass of vvH events: Still tuning...

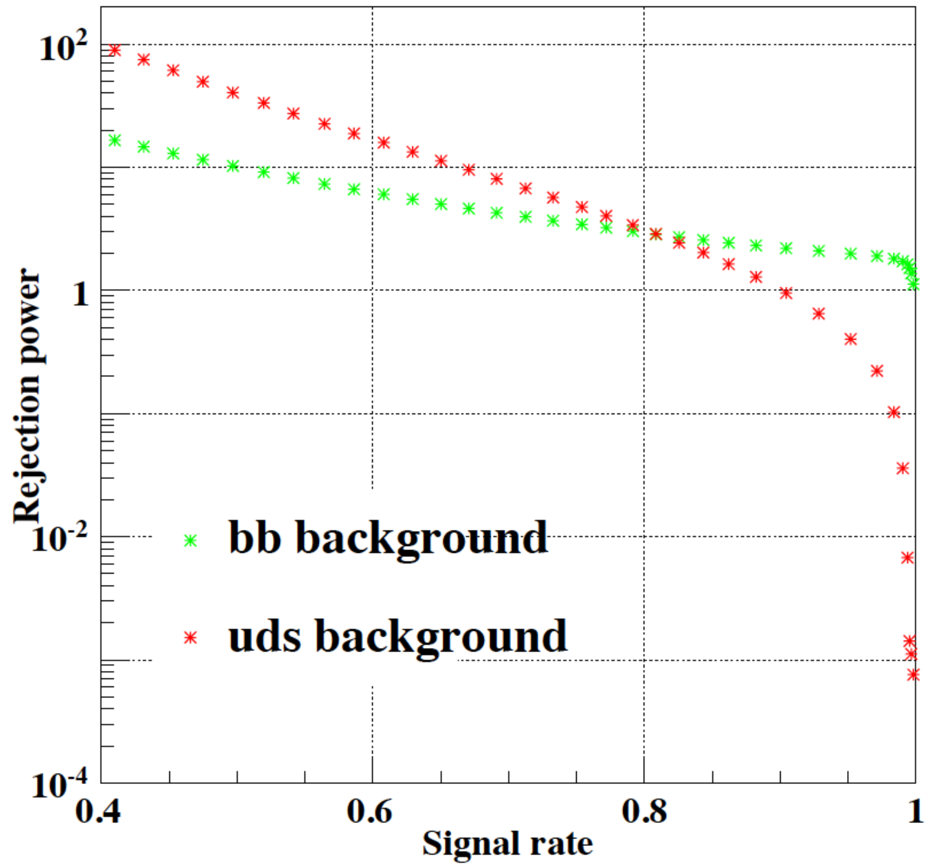




- PFA at CEPC: **physics object finding**
  - *Ultimate goal: 1-1 correspondence between incident - reconstructed particle*

Flavor tagging

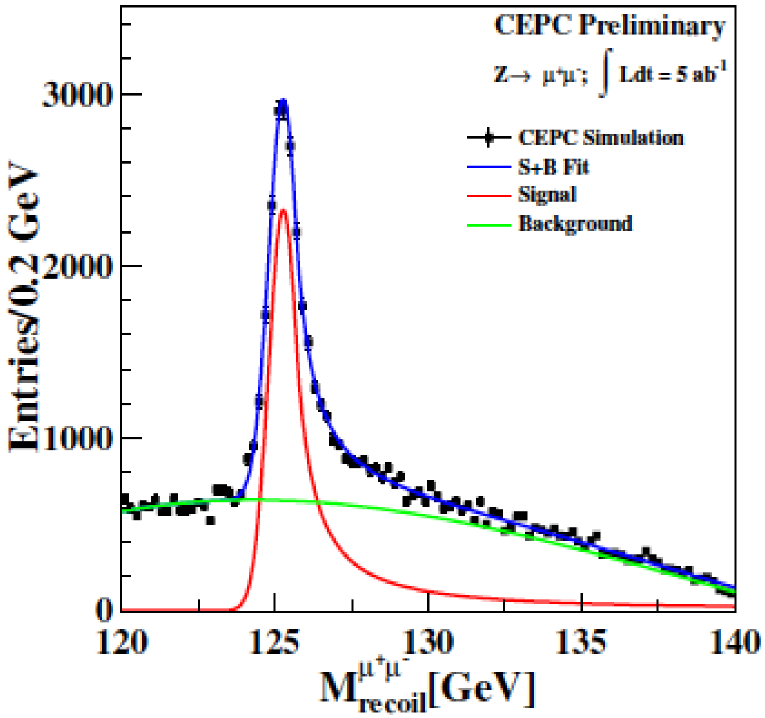


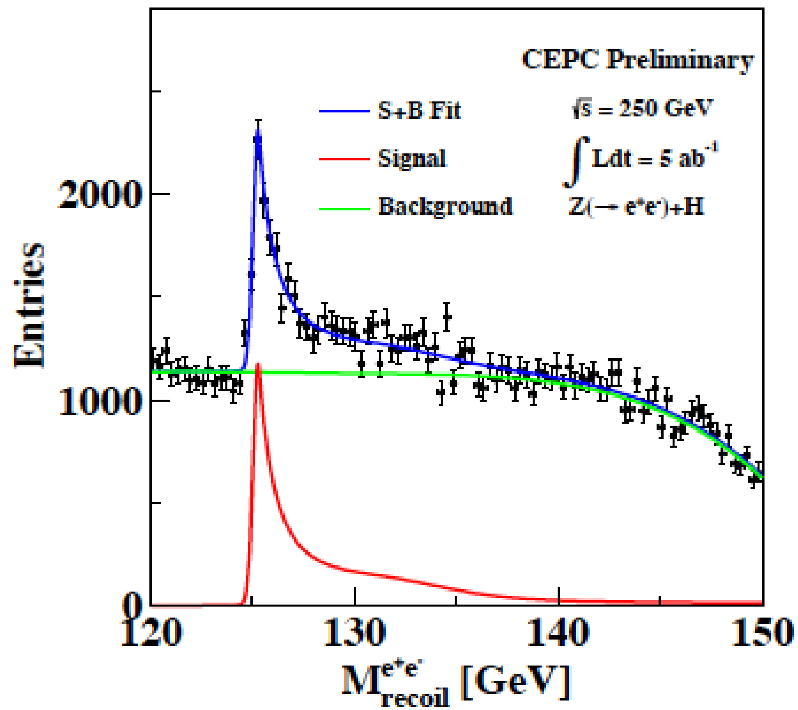


B-tagging almost reach the required performance;
C-tagging performance is lower than required, tuning on going;

Rejection power: define as 1/ε – 1 for background

Higgs tagging via Z→di lepton





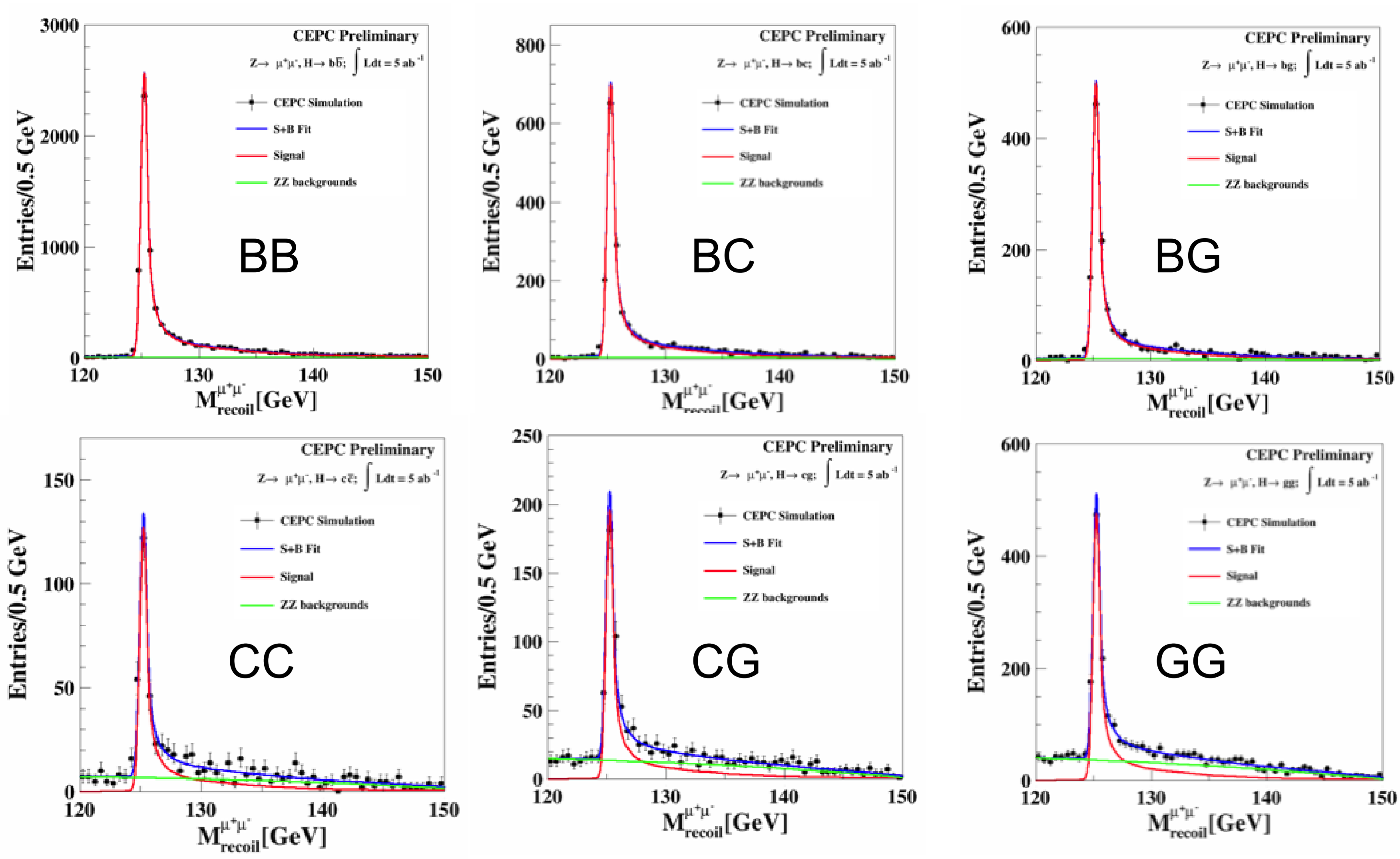
Recoil mass: clean signal, portal to exotic decay, etc

Key ingredients: Lepton identification efficiency & Track momentum resolution;
Bremstrhalung photon recovery for di-electron channel

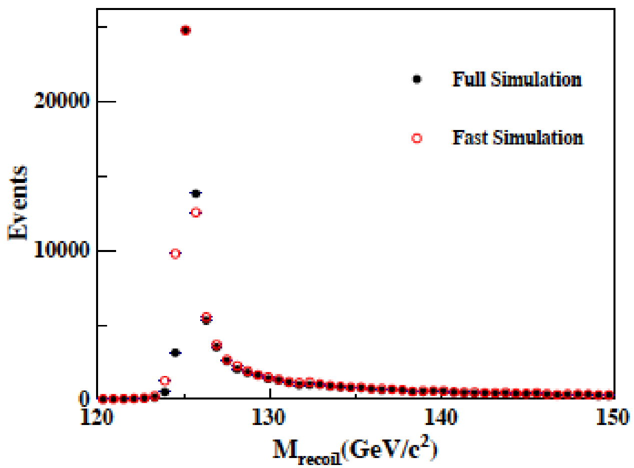
Strictly Model independent analyses with full simulation
Full set of SM background (processed with CEPC Fast Simulation tool)
Beam energy spread considered for the di-muon channel.

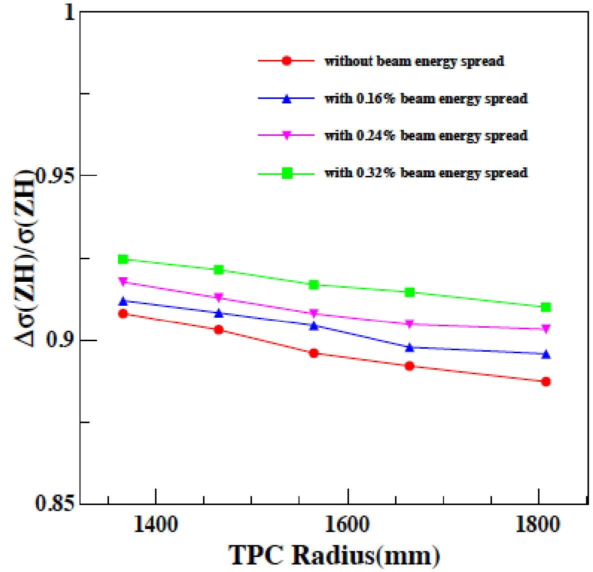
Br(H→bb, cc, gg) via Z→μμ

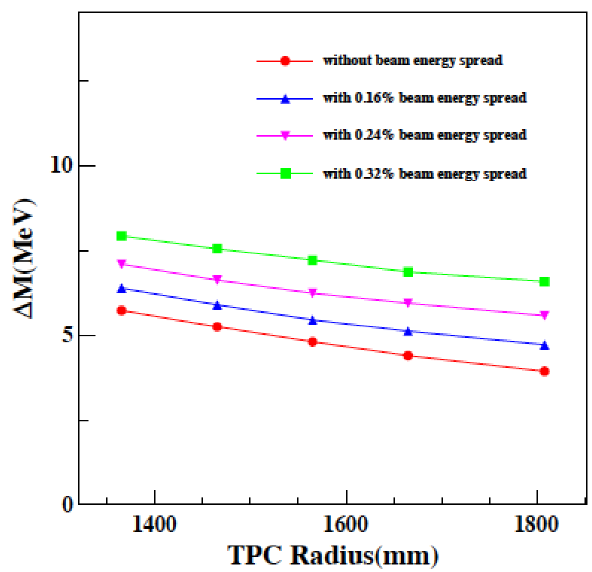
Jet Flavor tagging



Fast simulation - geometry optimization







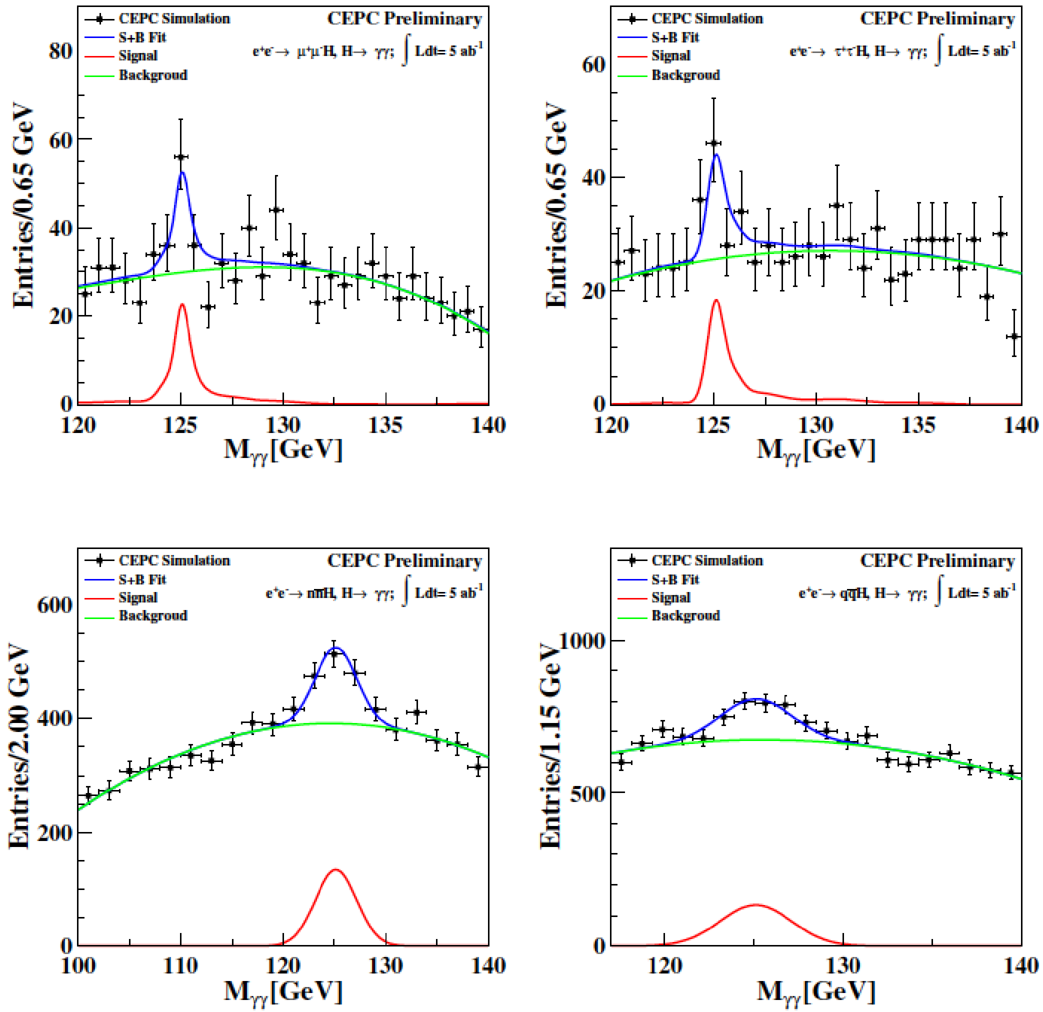
PFA based, including reconstruction efficiencies (polar angle/energy dependent), resolution for different types of particles

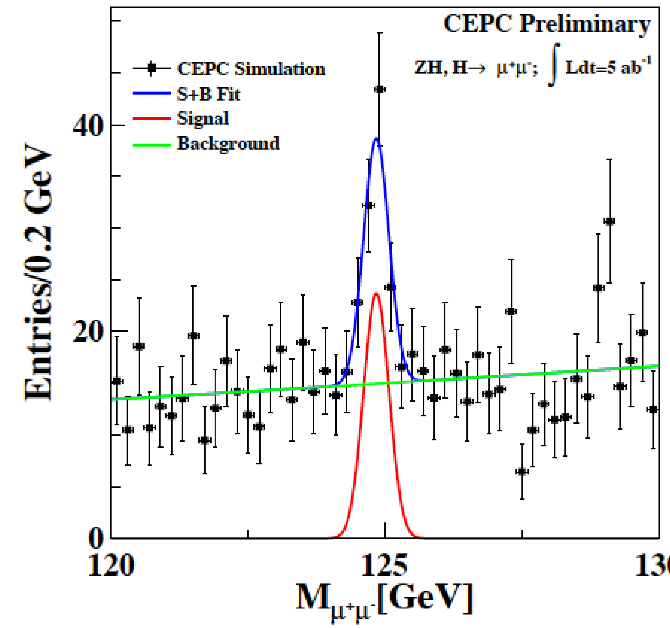
Applied to all background samples

Additional parametrization for different tracker sizes: for optimization

Left plot: Validation of Fast simulation on Higgs recoil mass spectrum
Right plot: Mass and Xsec resolution with 500 fb^{-1} integration luminosity via di-muon channel

Higgs rare decays





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

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

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(ννH)*Br(H→bb)	-	-		-
Br(H→invisible)			-	
Br(H→exotic)				

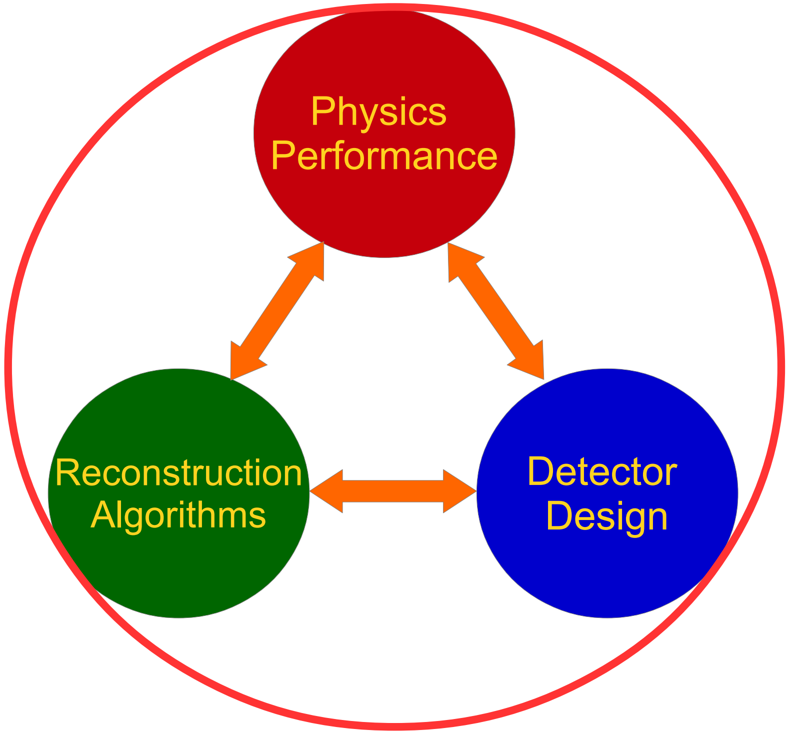
Signal with CEPC Full Simulation, Bkgrd with Fast Simulation

CEPC Fast Simulation

Extrapolated from ILC/FCC-ee results

Toward CDR

- Simulation:
  - 1 - 2 benchmark detector model(s)
  - Key parameter optimization: B field, Tracker layout, Size, Granularity, etc
- Reconstruction:
  - Adjust to new geometries
  - Optimization & developments
- Analysis:
  - Cover Higgs Analyses & SM measurement at full simulation level



Example topics

- TPC Related:
  - Feasibility study at Z pole
  - Geometry re-design & optimization, reconstruction chain adjustment
  - Systematic study: B-Field in-homogeneity & monitoring
- Physics Analysis:
  - Higgs:
    - SM
    - Exotic decay measurements with recoil mass method
  - Z pole & SM
    - Neutrino generation (first use free samples at Higgs run...)
    - ...

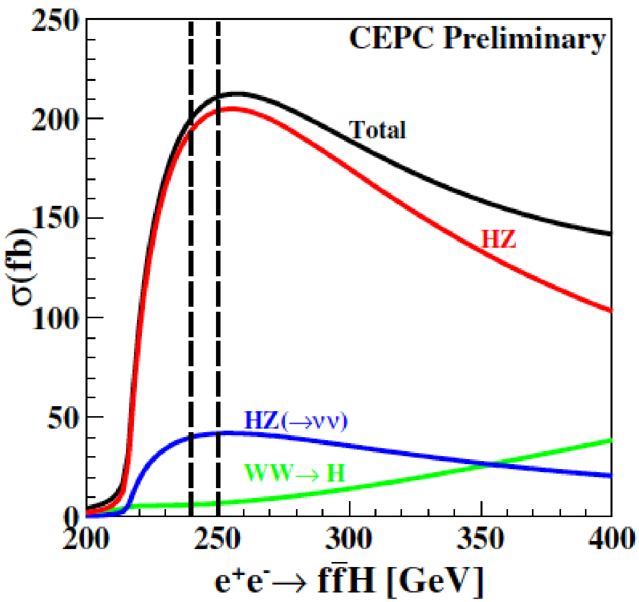
Summary

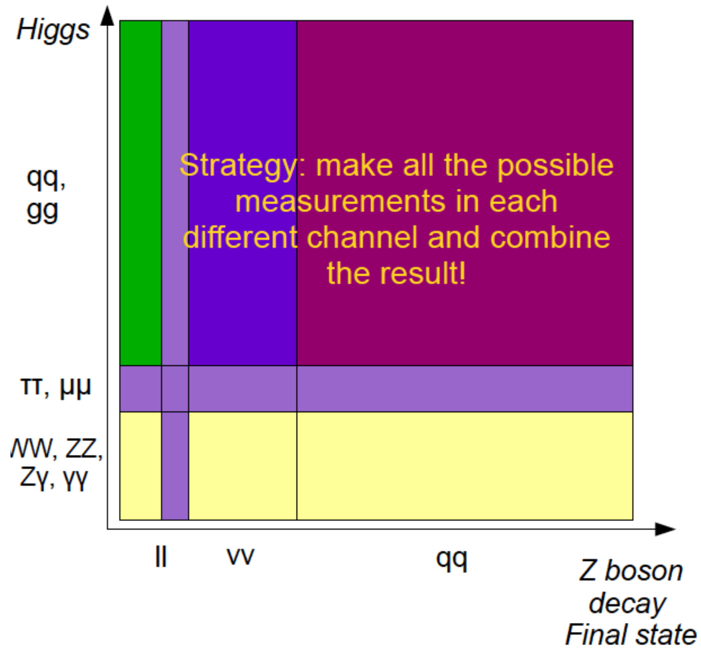
- Fully validated simulation – reconstruction chain: thanks to ILC/ILD!
  - Ongoing efforts
    - Flavor tagging
    - Jet Clustering & Jet Energy Resolution
    - Fast simulation toolkit for Z pole physics
  - Iterating until converge to an optimized design
- Higgs measurements at CEPC:
  - Benchmark measurements explored
- Toward CDR
  - Many interesting tasks ahead
  - Weekly Simulation-Analysis Meeting (Monday 9 am Paris Time)

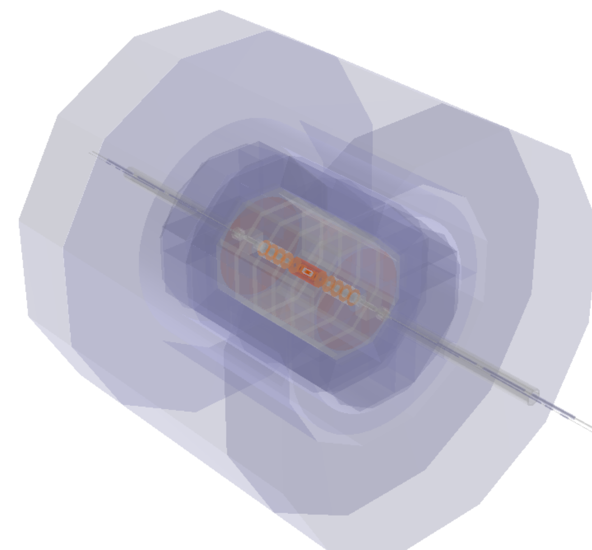
Thanks

Backup

ILD, the starting point of CEPC detector







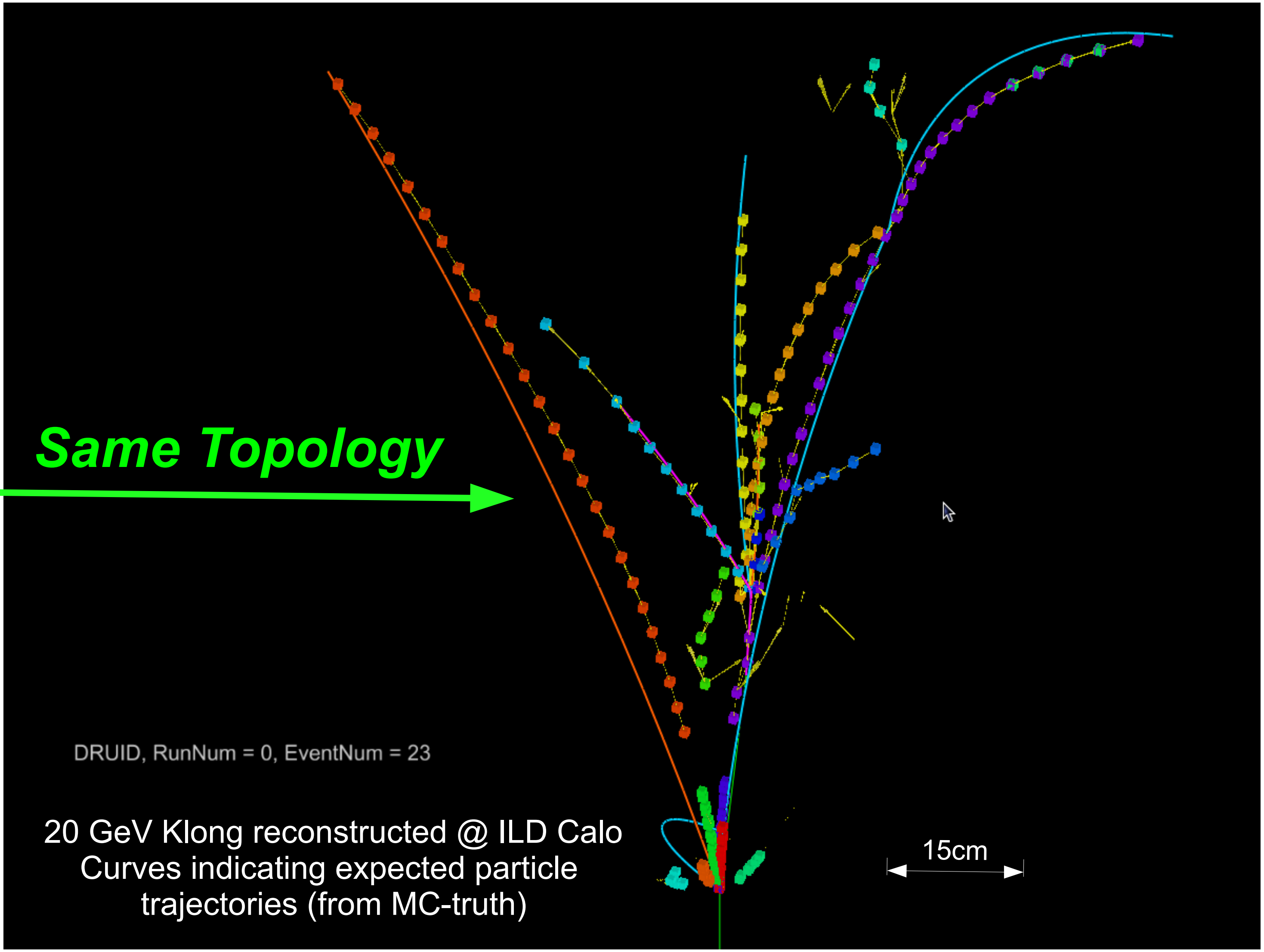
A detector measures all the physics objects (lepton, photon, tau, Jet, MET, ...) with high efficiency/precision

High precision VTX located close to IP: b, c, tau tagging

High precision tracking system

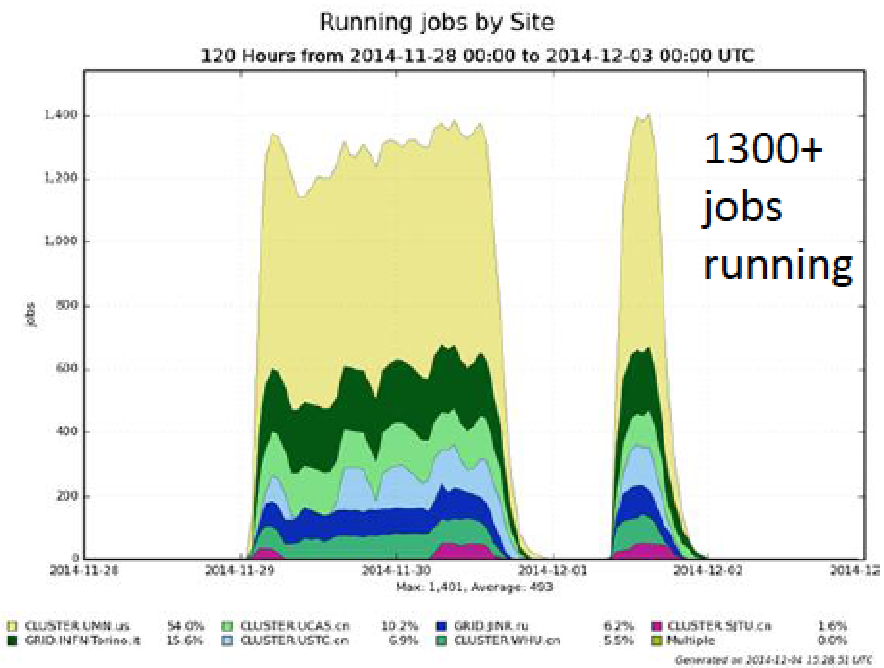
PFA oriented calorimetry system (~o(10^8) channels): PID, jet energy resolution, etc.

Arbor PFA, principle



- Original idea from Henri Videau, in the ALEPH studies

Computing



#	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: Centralized Farm + Distributed Computing

Goal: fully simulated Higgs signal samples (done) + SM background samples (on going)

Thus, we reached...

Table 3.12 Estimated precisions of Higgs boson property measurements at the CEPC. All the numbers refer to relative precision except for M_H and BR($H \to$ inv) for which ΔM_H and 95% CL upper limit are quoted respectively.

ΔM_H	Γ_H	$\sigma(ZH)$	$\sigma(\nu\nu H) \times \mathrm{BR}(H \to bb)$
5.9 MeV	2.8%	0.51%	2.8%

Decay mode	$\sigma(ZH) \times \mathrm{BR}$	BR
$H \to bb$	0.28%	0.57%
$H \to cc$	2.2%	2.3%
$H \to gg$	1.6%	1.7%
$H \to \tau\tau$	1.2%	1.3%
$H \to WW$	1.5%	1.6%
$H \to ZZ$	4.3%	4.3%
$H \to \gamma\gamma$	9.0%	9.0%
$H \to \mu\mu$	17%	17%
$H \to \mathrm{inv}$	–	0.28%

Outline

- Introduction: Physics at CEPC
- Status: Simulation Studies at CEPC Pre-CDR
  - Generator
  - Simulation
  - Reconstruction
  - Computing & Generation
  - Analysis: Status & High light
- Summary

Team members

- Generator: X. Mo (IHEP)
- Simulation:
  - Fast Simulation: B. Liu, Z. Chen (IHEP)
  - Full Simulation: Y Xu (NanKai University), etc.
- Reconstruction:
  - Tracking: B. Li (Tsinghua University)
  - Particle Flow
    - M. Ruan, B. Ma, D. Yu (IHEP & LLR), etc: Arbor framework
  - Flavor tagging: G. Li (IHEP): LCFIPlus
- Analysis:
  - FTEs with students from IHEP, Peking University, Wuhan University, Shandong University, USTC, UCAS, HongKong University, etc
- Computing: T. Yan, etc

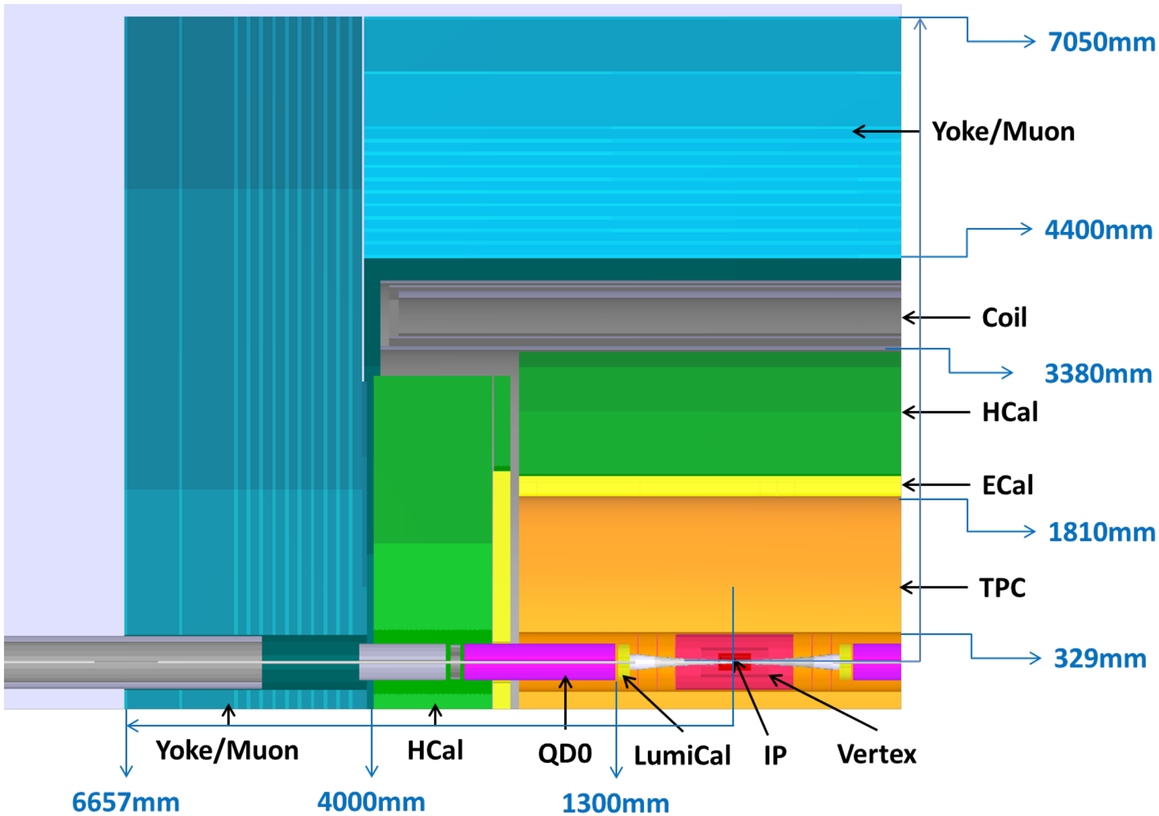
FTE taking care of the core technologies…

A group of o(10) analyzers.

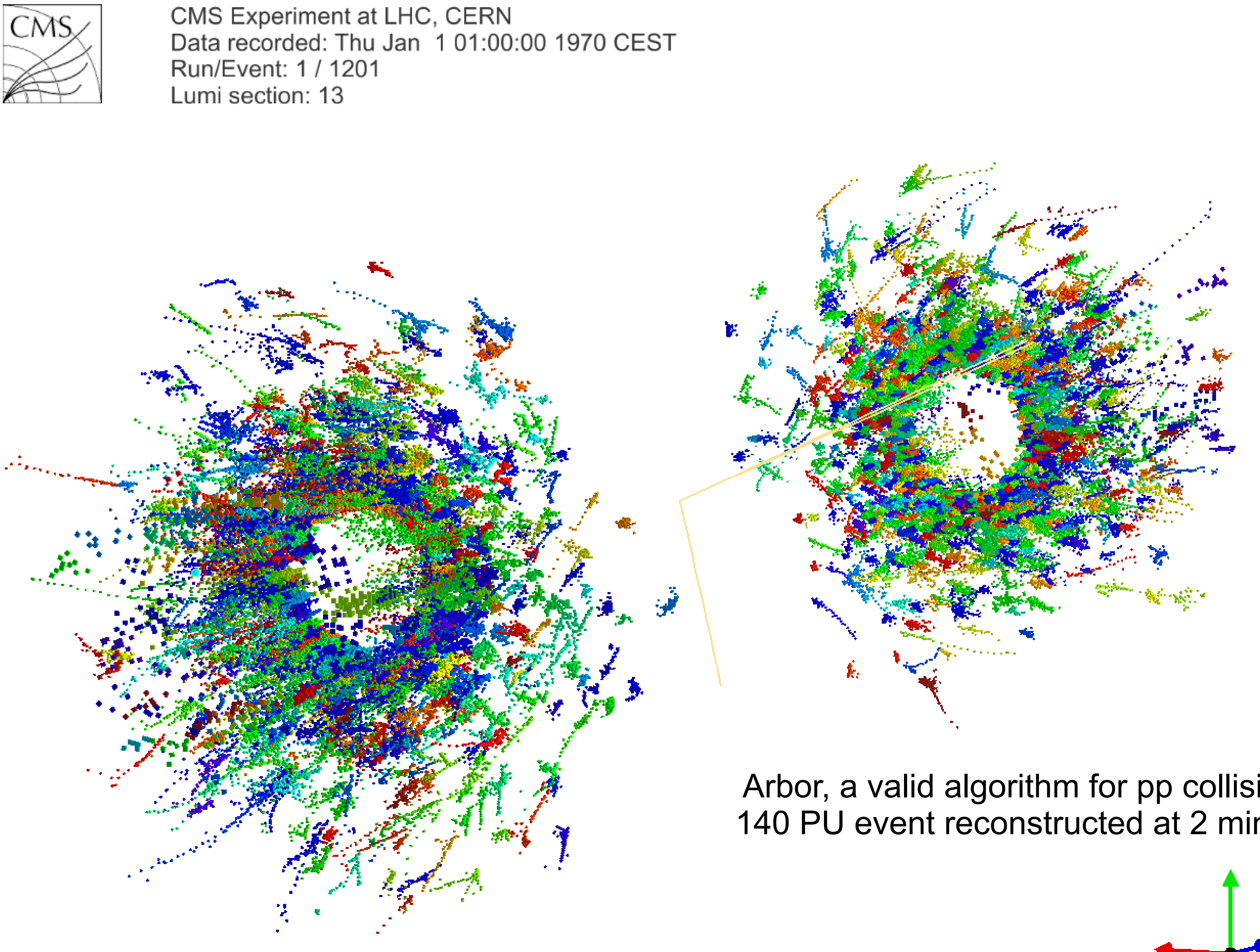
Br(H→bb, cc, gg)

- Key ingredients: Lepton tagging, Jet Clustering & Jet Flavor tagging
- Analysis status
  - Fully simulated Higgs signal & Fast simulated llqq background
  - Method:
    - Force everything besides two leading leptons into 2 jets
    - Event selection on leptons and jets kinematics
    - Flavor tagging: classify selected events into all possible flavor combination (bb, cc, gg, bc, bg, cg)
    - Resolve back the signal and background yields (only bb, cc, gg numbers)
  - C-tagging efficiency: need to be improved.

CEPC Simulation



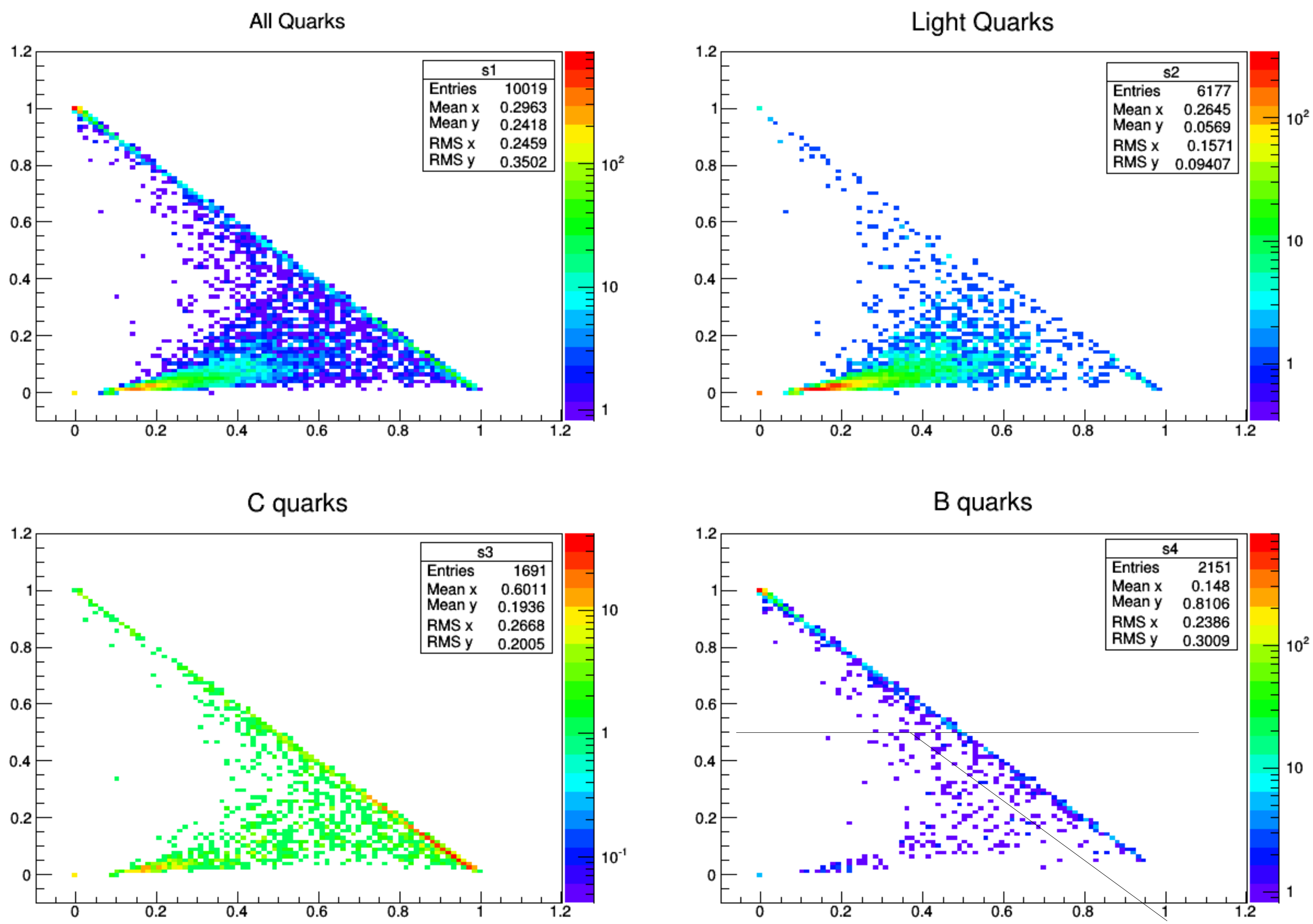
Geant 4 Simulation team: Y. Xu (NanKai U) etc
Full access to geometry editing/validation.



Arbor, a valid algorithm for pp collisions
140 PU event reconstructed at 2 min/evt

Flavor tagging

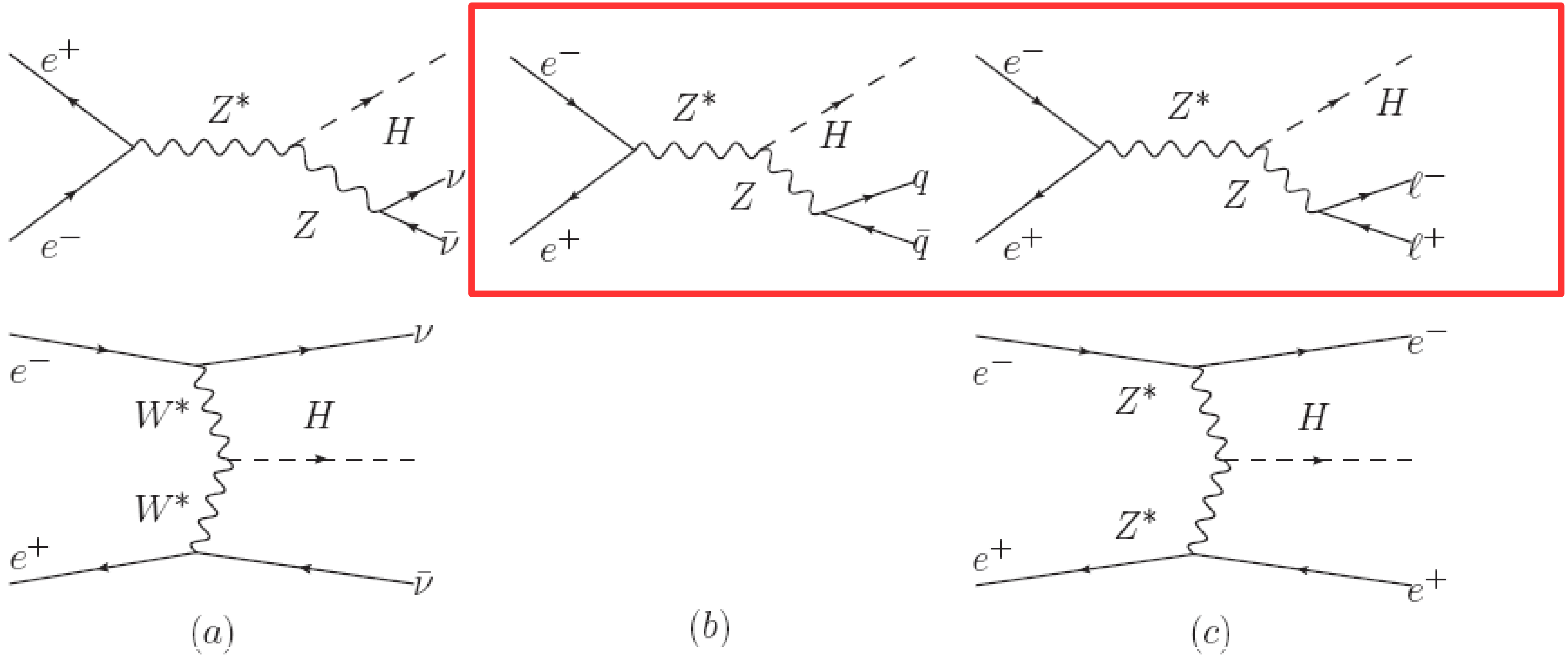
- Gang: LCFI is working now – need to see if it works as expected
- Jet Clustering is also an issue...



An example non-loss Migration Matrix

	b	c	udsg
b	81.8%	9.3%	8.9%
c	9.0%	50.2%	40.7%
udsg	0.96%	1.9%	97.2%

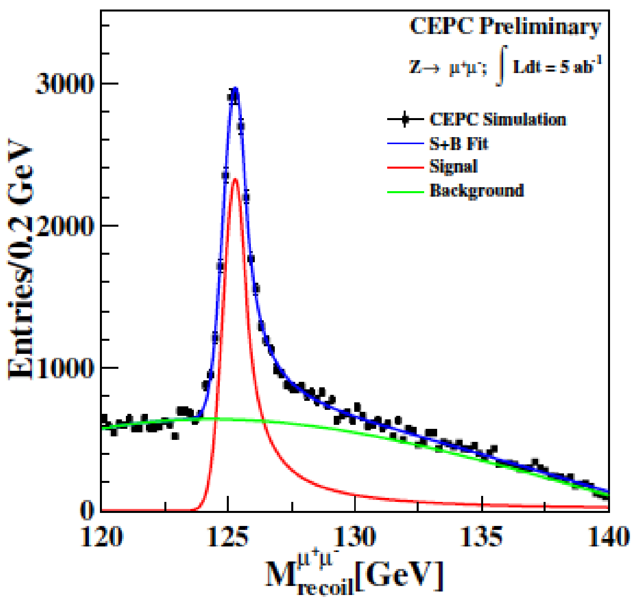
Higgs analysis: Model independent tagging of Higgs boson

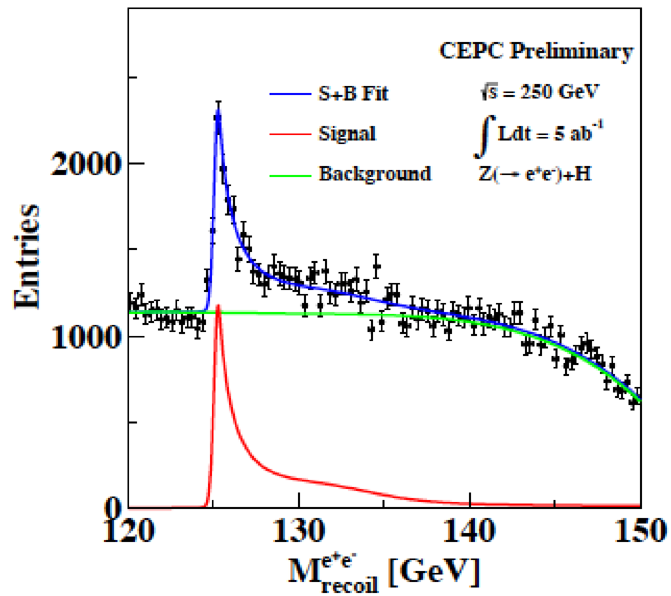


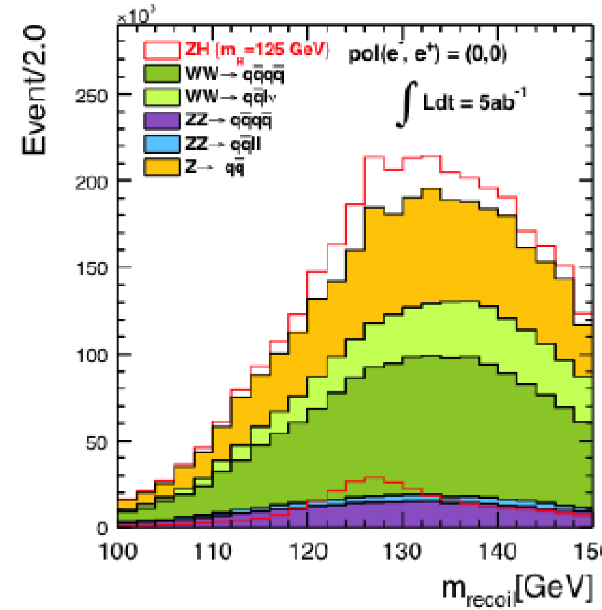
Higgsstrahlung event with Z decays into visible final state:
Absolute tagging of Higgs signal without measuring Higgs decay final state: Inclusive sigma(ZH) measurement

Anchor for all the absolute Higgs measurements

Higgs tagging via Z→visible channel







Di lepton channel:

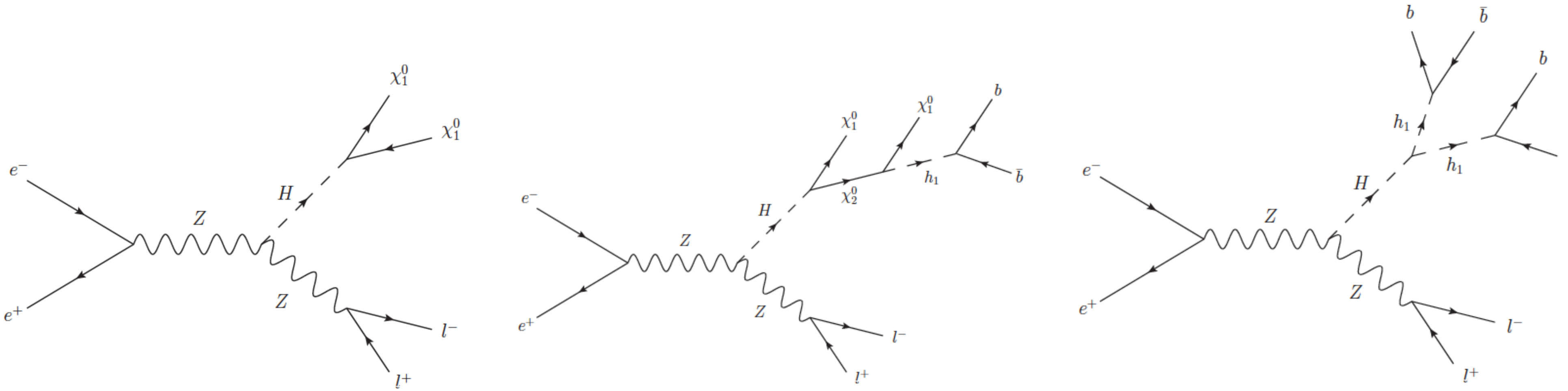
- Strictly Model independent analysis
- Full set of SM background (processed with CEPC Fast Simulation tool)
- Beam energy spread considered for the di-muon channel.

Z decay mode	ΔM_H (MeV)	$\Delta\sigma(ZH)/\sigma(ZH)$	$\Delta g(HZZ)/g(HZZ)$
ee	13	2.1%	
$\mu\mu$	6.6	0.9%	
$ee+\mu\mu$	5.9	0.8%	0.4%
qq		0.65%	0.32%
$ee+\mu\mu+qq$		0.51%	0.25%

Di jet channel:

- Fast simulation
- Systematic control would be an key issue.

Higgs tagging via Z→di lepton: Higgs exotic decays

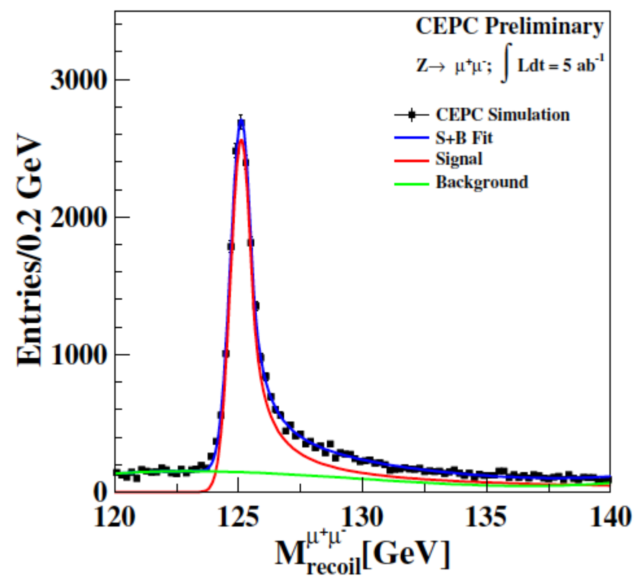


Limit from Higgs total width: 2.8%

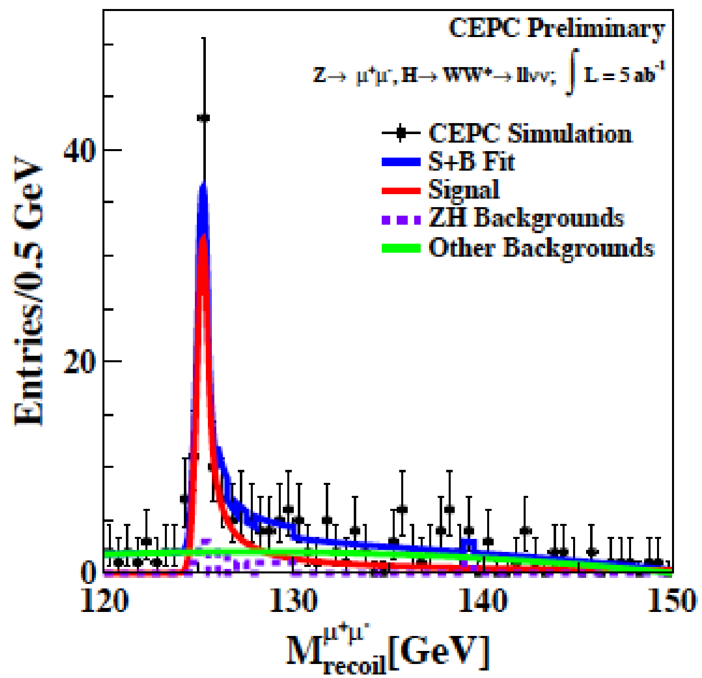
Specify Higgs decay final state would leads to significantly better result.

Test a set of benchmark Higgs exotic decay (H->invisible, H->bb + MET, H->bbbb):

5 sigma deviation expected with Br(H→exo) ~ 0.1%



Br(H→WW)



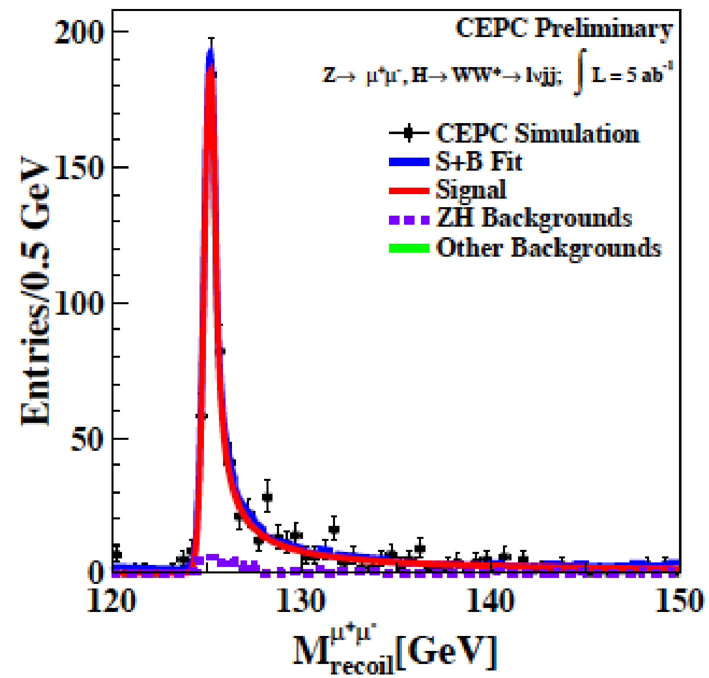
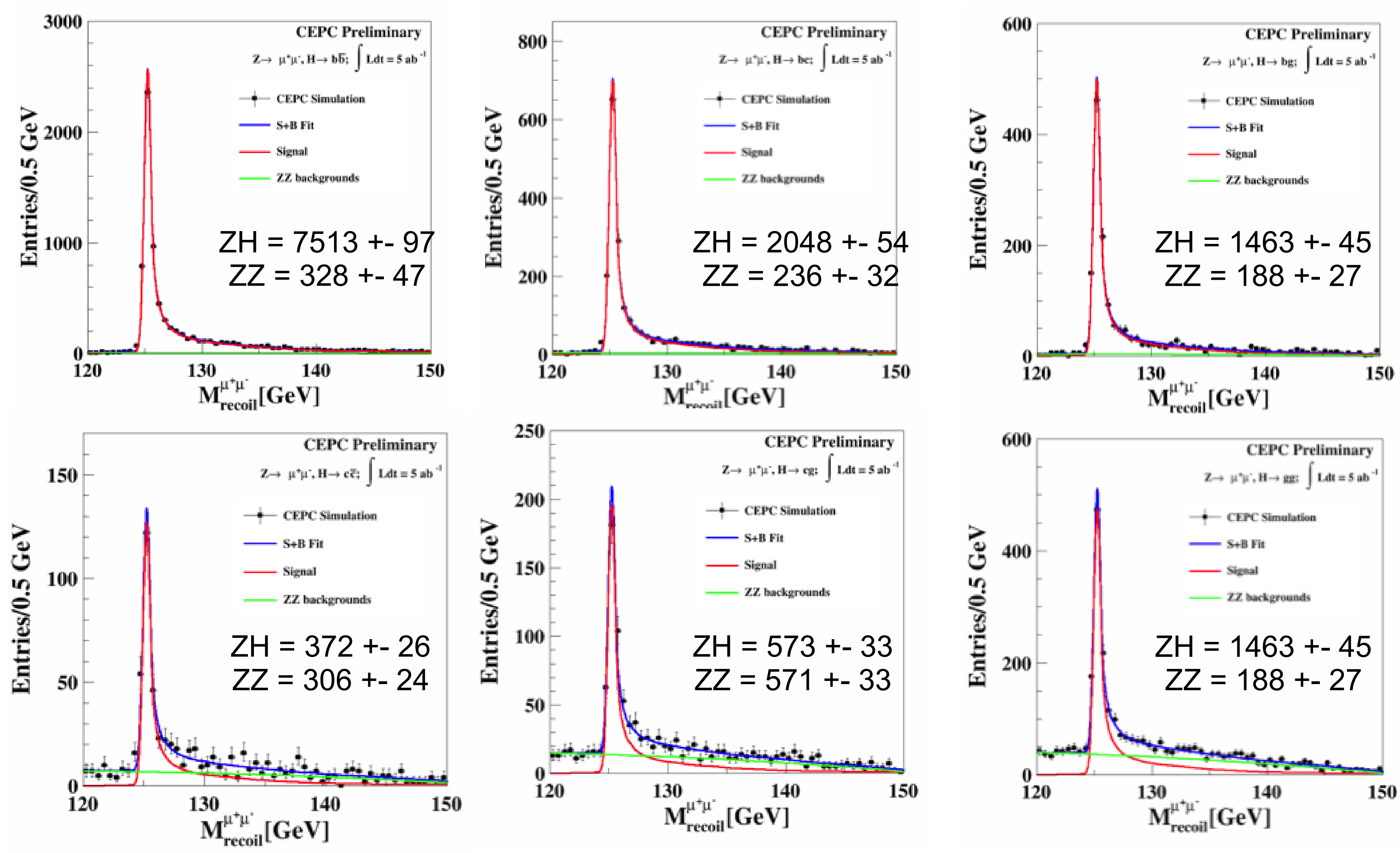


Table 3.8 Expected precision of the $\sigma(ee \to ZH) \times \mathrm{BR}(H \to WW^*)$ measurement, assuming an integrated luminosity of 5 ab^{-1}.

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%	

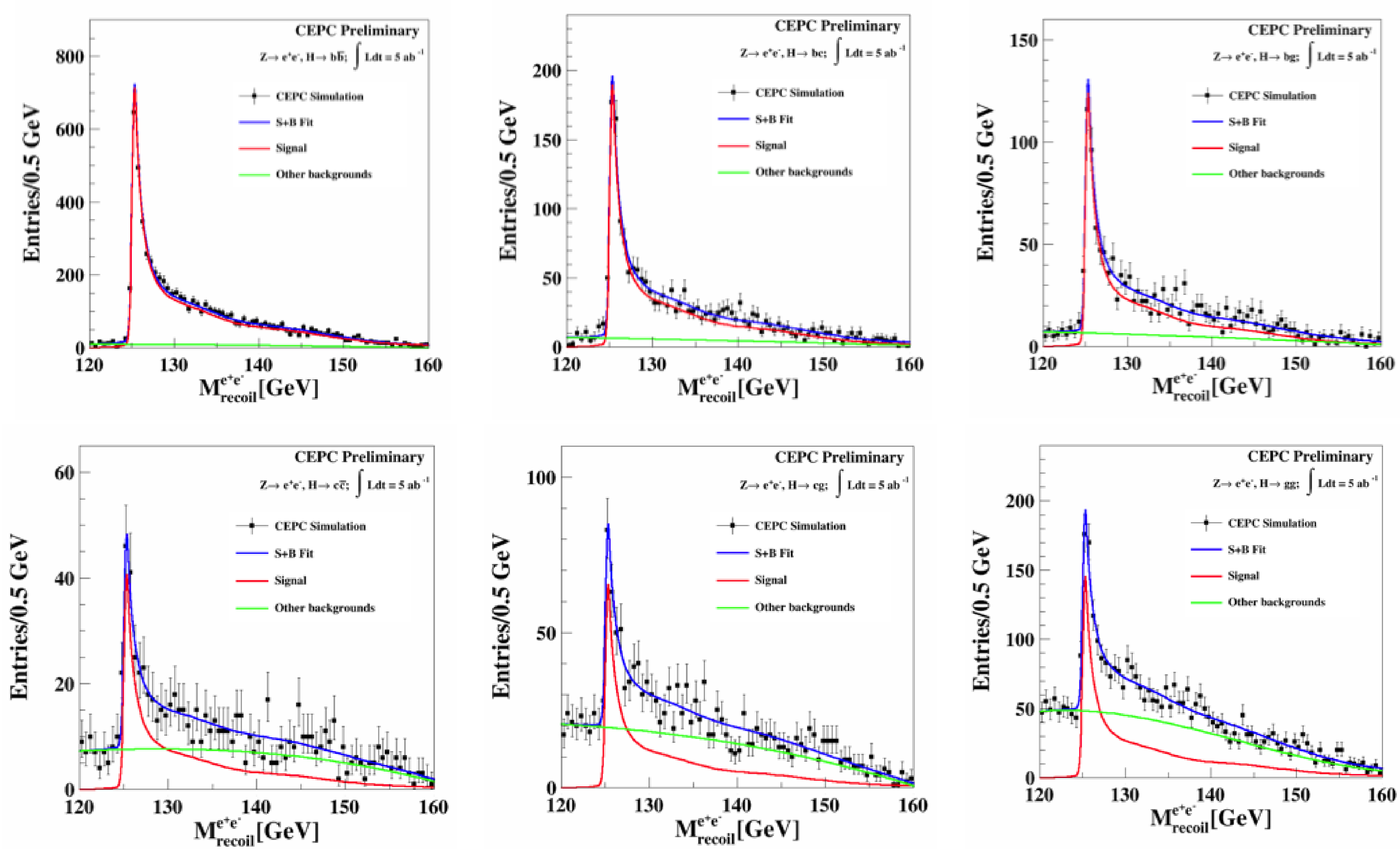
From the recoil mass spectrum: tagging decay final states → Higgs decay branching ratios

Br(H→bb, cc, gg) via Z→μμ

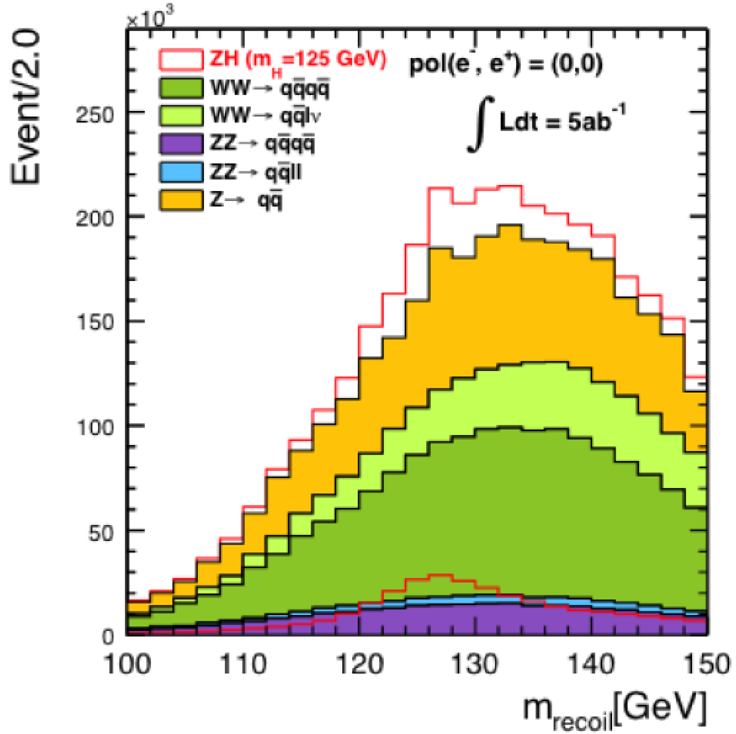


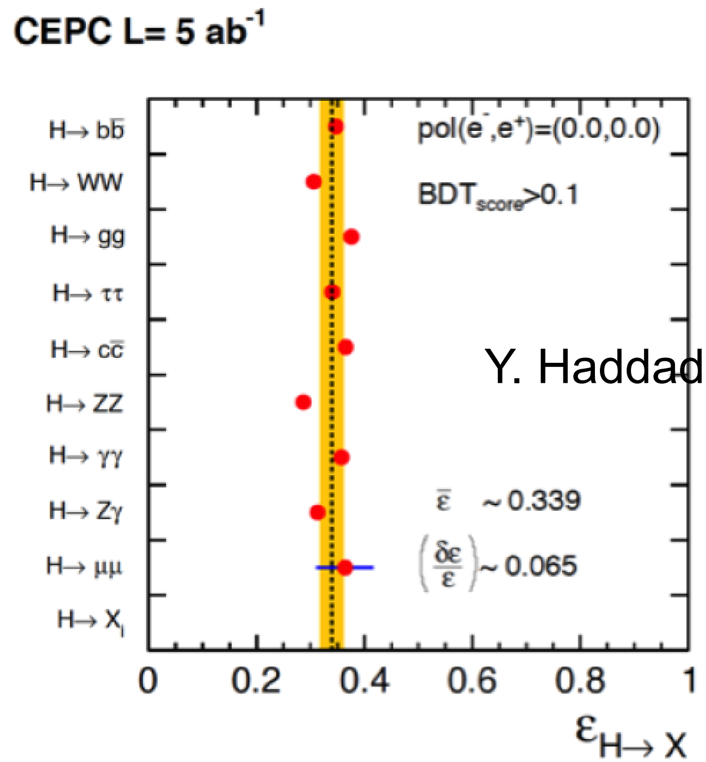
- Key ingredients: Lepton tagging, Jet Clustering & Jet Flavor tagging

Di-electron channel



Higgs tagging via Z→di jet channel, Fast simulation





Control of the systematic (on in-homogeneity of the efficiency for different Higgs decay final State) is essential: a key task for future analysis

Z decay mode	ΔM_H (MeV)	$\Delta\sigma(ZH)/\sigma(ZH)$	$\Delta g(HZZ)/g(HZZ)$
ee	13	2.1%	
$\mu\mu$	6.6	0.9%	
$ee+\mu\mu$	5.9	0.8%	0.4%
qq		0.65%	0.32%
$ee+\mu\mu+qq$		0.51%	0.25%

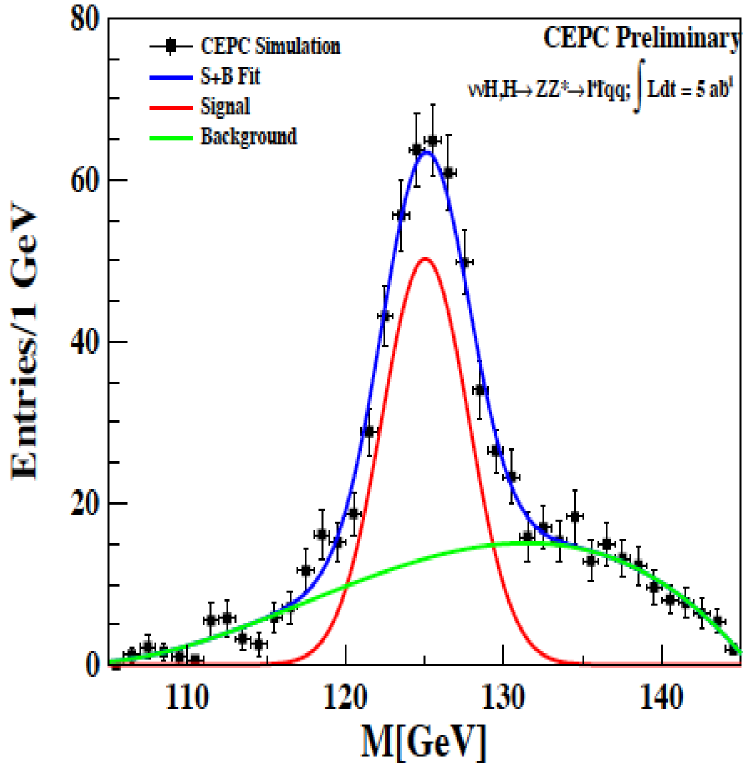
Table 3.10 Expected yields for signal and backgrounds in $H \to \gamma\gamma$ channel, normalized to 5 ab^{-1}.

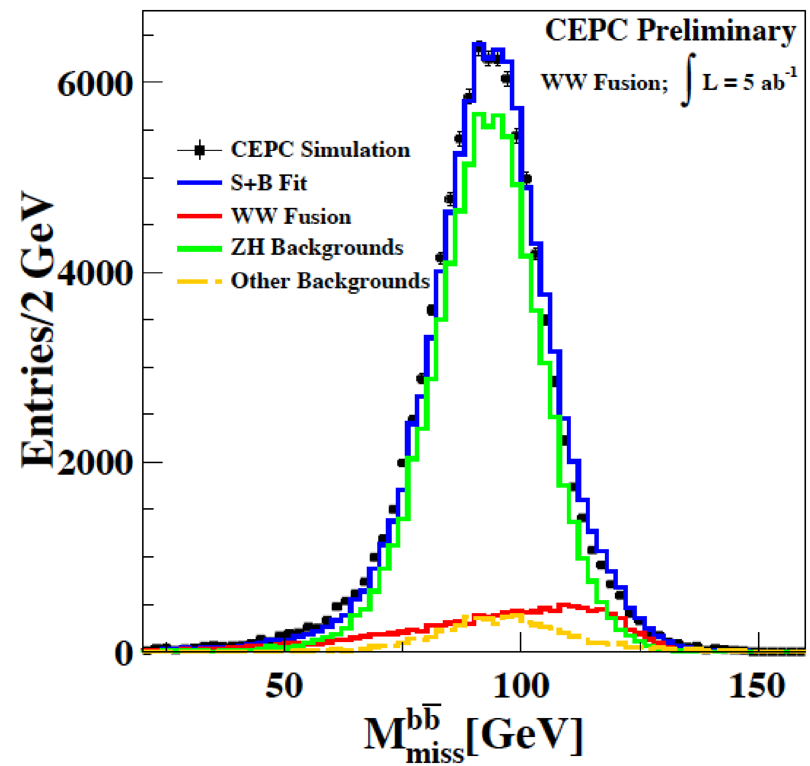
Channel		Resolution assumption: $\frac{\delta E}{E} = \frac{R}{\sqrt{E}} \oplus 1\%$		
		$R = 10\%$	$R = 16\%$	$R = 20\%$
$Z \to \mu^+\mu^-$	Signal/efficiency	62 ± 18/42.2%	62 ± 19	59 ± 19
	Background	832 ± 33	831 ± 34	826 ± 33
	$\Delta(\sigma \times BR)/\sigma \times BR$	29.0%	30.6%	32.2%
$Z \to \tau^+\tau^-$	Signal/efficiency	58 ± 18/41.9%	56 ± 18	54 ± 19
	Background	760 ± 32	757 ± 32	762 ± 32
	$\Delta(\sigma \times BR)/\sigma \times BR$	31.0%	32.1%	35.2%
$Z \to \nu\nu$	Signal	334 ± 40/57.5%	339 ± 46	342 ± 51
	Background	7059 ± 91	7053 ± 94	7047 ± 96
	$\Delta(\sigma \times BR)/\sigma \times BR$	12.0%	13.6%	14.9%
$Z \to qq$	Signal	594 ± 67/34.3%	582 ± 83	575 ± 94
	Background	13053 ± 130	12831 ± 138	12566 ± 144
	$\Delta(\sigma \times BR)/\sigma \times BR$	11.3%	14.3%	16.4%
Combined	$\Delta(\sigma \times BR)/\sigma \times BR$	7.7%	9.0%	10.0%

Higgs width measurement

- Higgs total width:
  - Indispensable for determine the absolute couplings between Higgs & its decay final state particle
    - $g^2(HXX) \sim \Gamma_{H\to XX} = \Gamma_{total} * Br(H\to XX)$
  - Limit to any partial width contributed from any exotic decay
- Two alternative methods at 250 GeV electron-positron collision
  - H→ZZ channel:
    - Inclusive Xsec measurement ($\sigma(ZH) \sim g^2(HZZ)$)
    - $\sigma(ZH)*Br(H\to ZZ) \sim g^4(HZZ)/\Gamma_{total}$
  - W fusion channel:
    - $\sigma(ZH) \sim g^2(HZZ)$
    - $\sigma(ZH)*Br(H\to bb) \sim g^2(HZZ)*g^2(Hbb)/\Gamma_{total}$
    - $\sigma(ZH)*Br(H\to WW) \sim g^2(HZZ)*g^2(HWW)/\Gamma_{total}$
    - $\sigma(vvH)*Br(H\to bb) \sim g^2(HWW)*g^2(Hbb)/\Gamma_{total}$

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