Summary of physics and simulation

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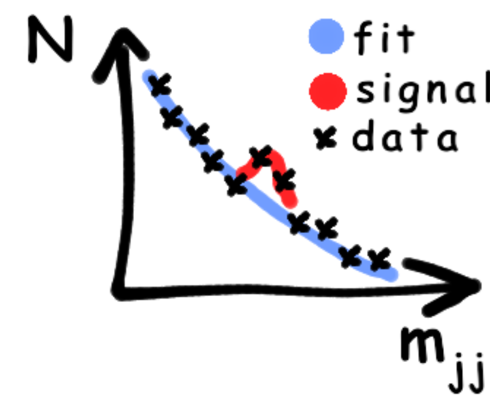
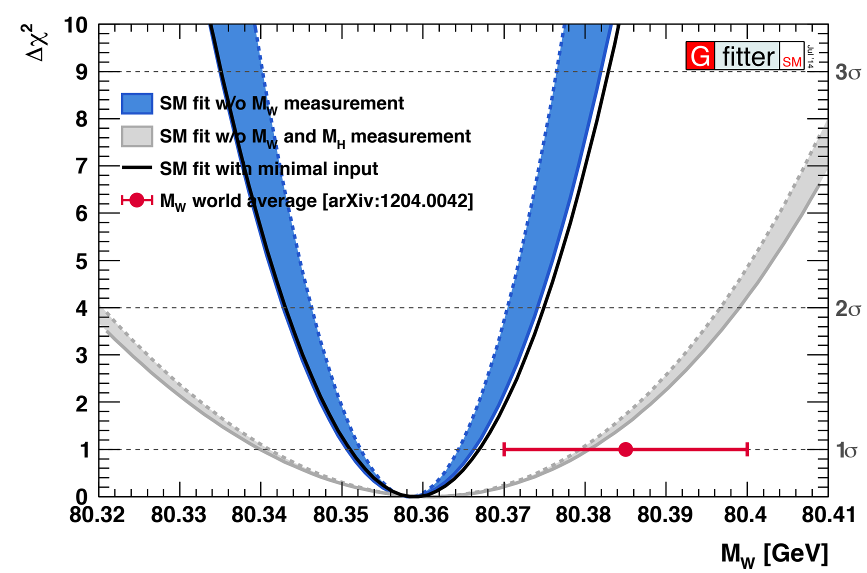
Workshop on the Circular Electron-Positron Collider - EU edition
Università degli Studi Roma Tre, May 24-26th, 2018

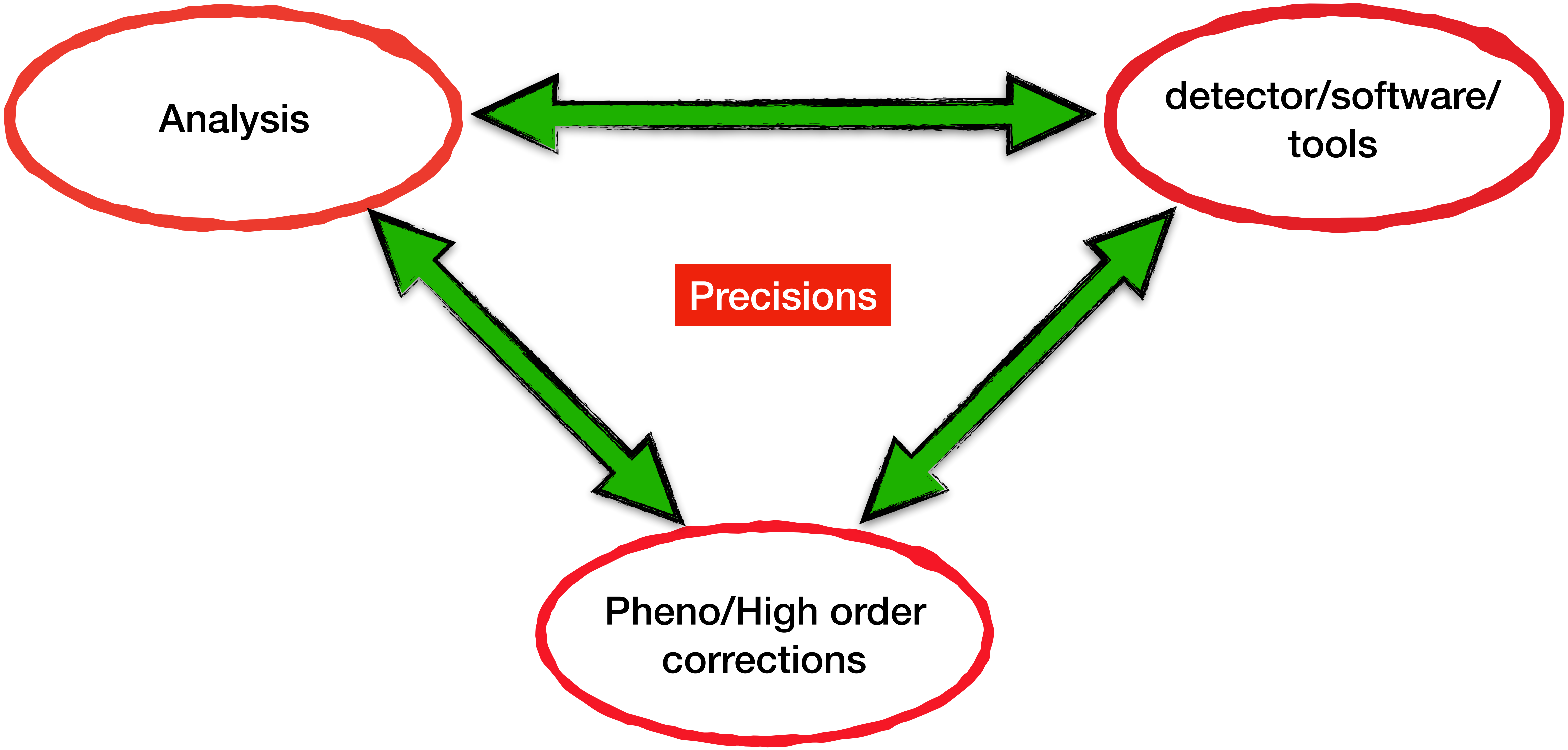
Precision as a tool to probe new physics

- Direct
  - Search for new particles or new phenomena
  - Examples： Higgs, Pc, …

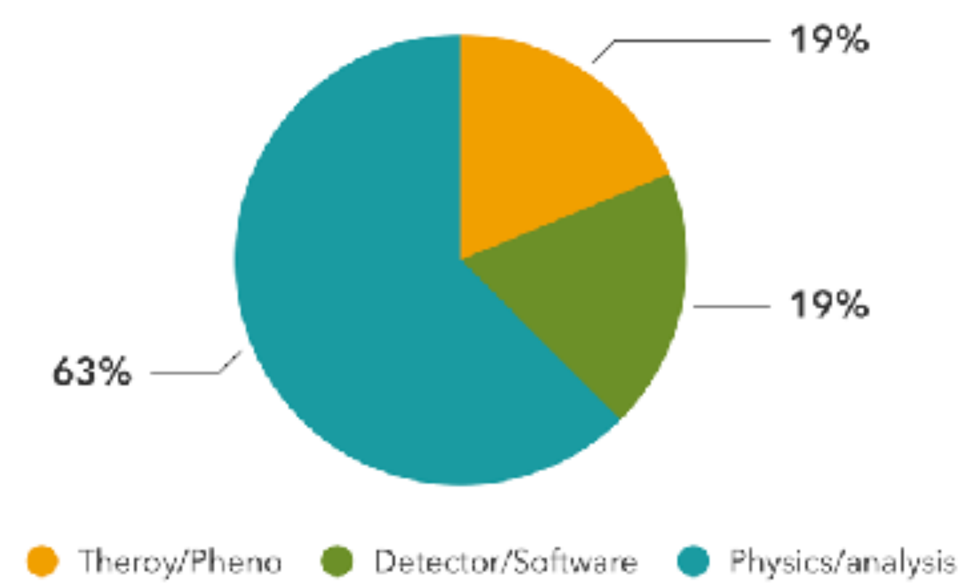


- Indirect
  - Precision measurements
  - Compared with theoretical prediction, the difference means something new
  - Examples： measure the H、W、Z, etc., precisely



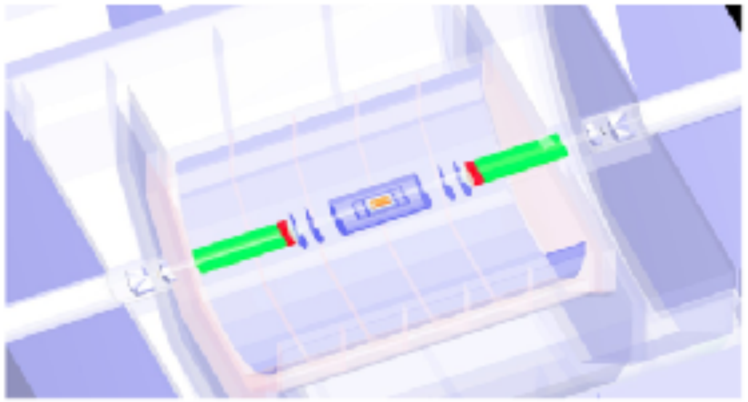


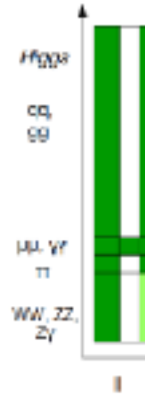
Four parallel sessions
16 talks
Fruitful discussions



Manqi

CEPC-v1, reference detector for the CEPC PreCDR studies





Supports most of the CEPC physics analysis till now;

Summarized into the CEPC PreCDR.

To be summarized in Higgs white paper, in final polishing stage

Feasibility & Optimized Parameters

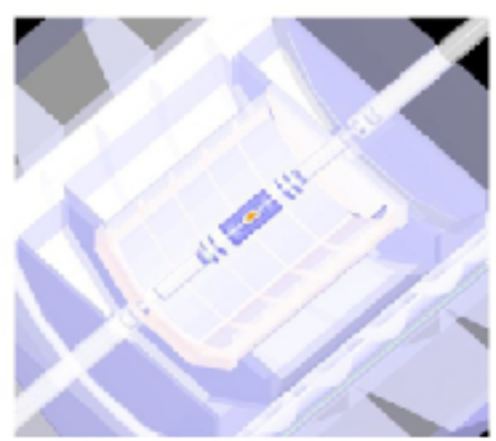
Feasibility analysis: TPC and Passive Cooling Calorimeter is valid for CEPC

	CEPC_v1 (~ ILD)	APODIS (Optimized)	Comments
Track Radius	1.8 m	>= 1.8 m	Requested by Br(H->di muon) measurement
B Field	**3.5 T**	**3 T**	**Requested by MDI**
ToF	**-**	**50 ps**	**Requested by pi-Kaon separation at Z pole**
ECAL Thickness	84 mm	84(90) mm	84 mm is optimized on Br(H->di photon) at 250 GeV; 90mm for bhabha event at 350 GeV
ECAL Cell Size	5 mm	10 mm	Passive cooling request ~ 20 mm. 10 mm should be highly appreciated for EW measurements – need further evaluation
ECAL NLayer	30	30	Depends on the Silicon Sensor thickness
HCAL Thickness	**1.3 m**	**1 m**	-
HCAL NLayer	**48**	**40**	Optimized on Higgs event at 250 GeV; Margin might be reserved for 350 GeV.

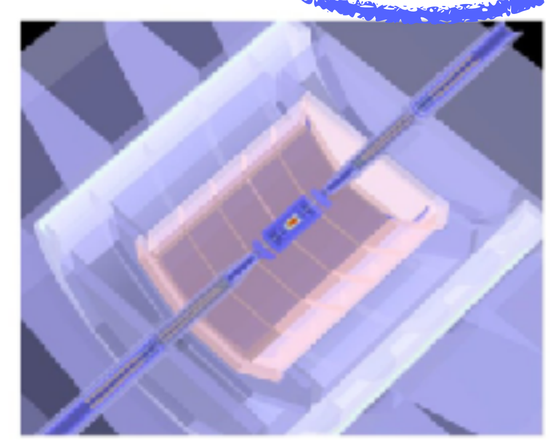
Benchmark detector for CDR: APODIS

(A PFA Oriented Detector for HIggS factory. a.k.a CEPC_v4)

- CEPC baseline detector being optimized and validated
- Software gets more mature
- Tutorials/documentations

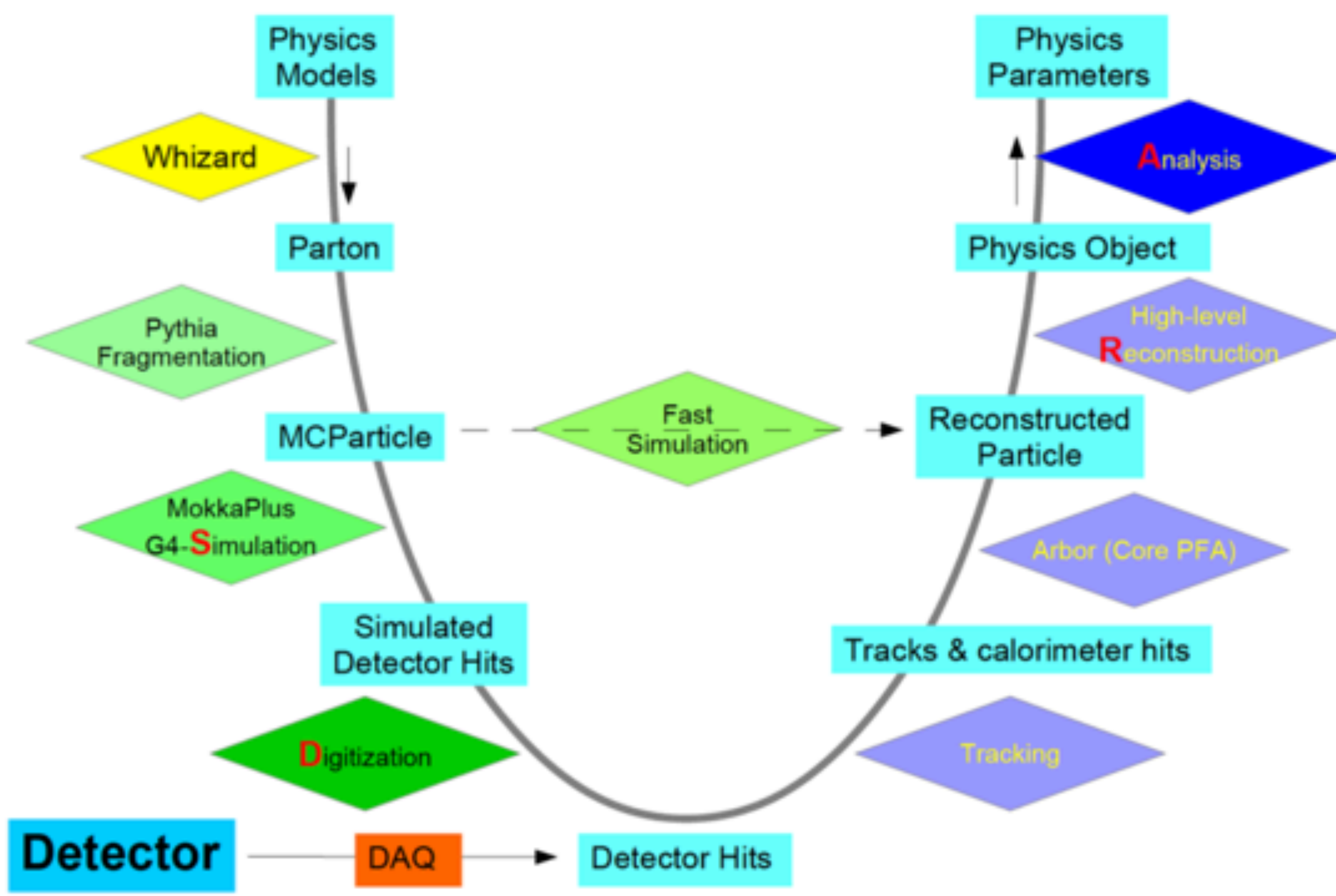


2015 PreCDR



2017 CDR

Software & Services



CEPC-SIMU-2017-001, CEPC-SIMU-2017-002,
(DocDB id-167, 168, 173)

25/05/2018 CEPC WS@Rome

- Generators (Whizard & Pythia)
- Data format & management (LCIO & Marlin)
- Simulation (MokkaC)
- Digitizations
- Tracking (Arbor tracking, conformal tracking)
- PFA (Arbor)
- Single Particle Physics Objects Finder (LICH)
- Composed object finder
- Tau finder
- Jet Clustering (FastJet)
- Jet Flavor Tagging (LCFIPLus)
- Event Display (Druid)
- General Analysis Framework (FSClasser)
- Fast Simulation (Delphes + FSClasser)

Tutorials: http://cepcsoft.ihep.ac.cn
Documentations: http://cepcdoc.ihep.ac.cn

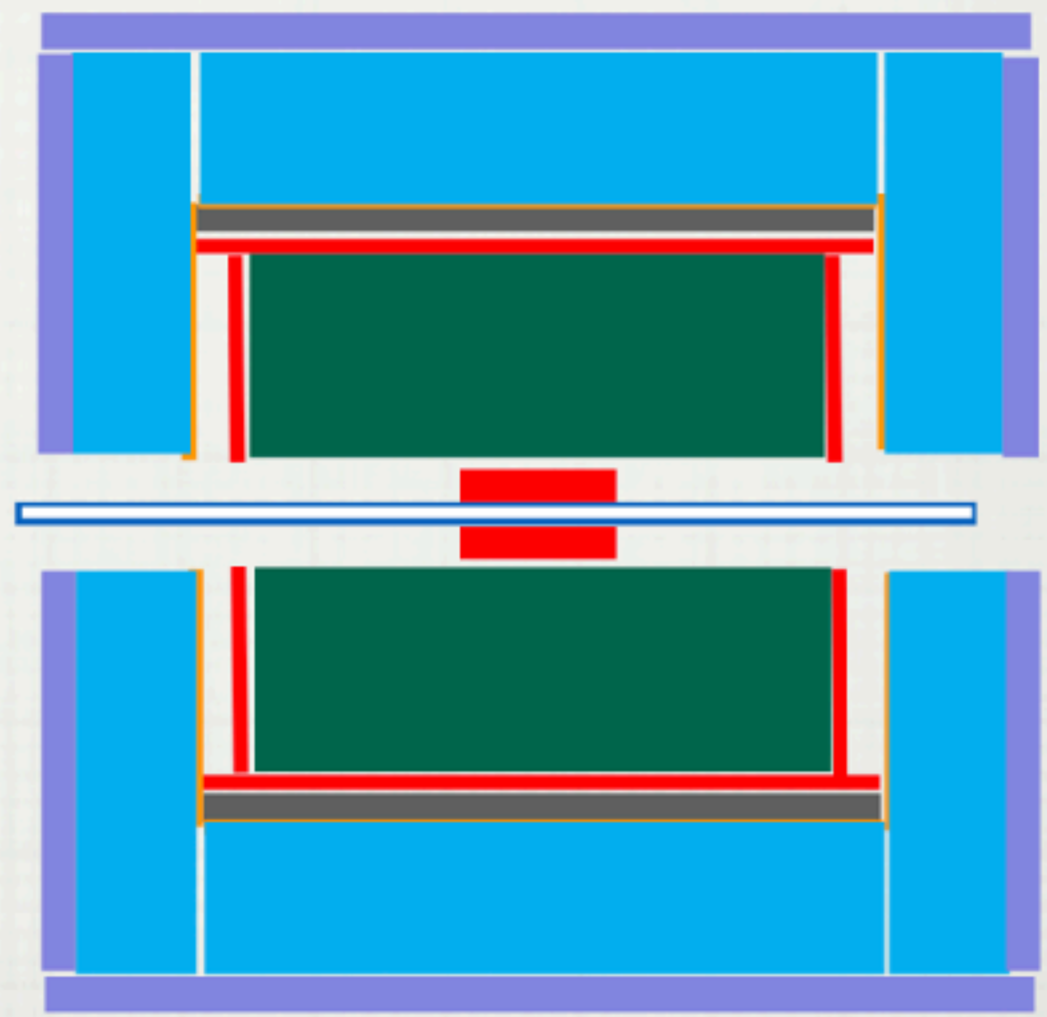
Alternative detector option : IDEA

Massimo

Detector Layout:

Drift chamber:
- strong&light
- Cluster timing
- PID

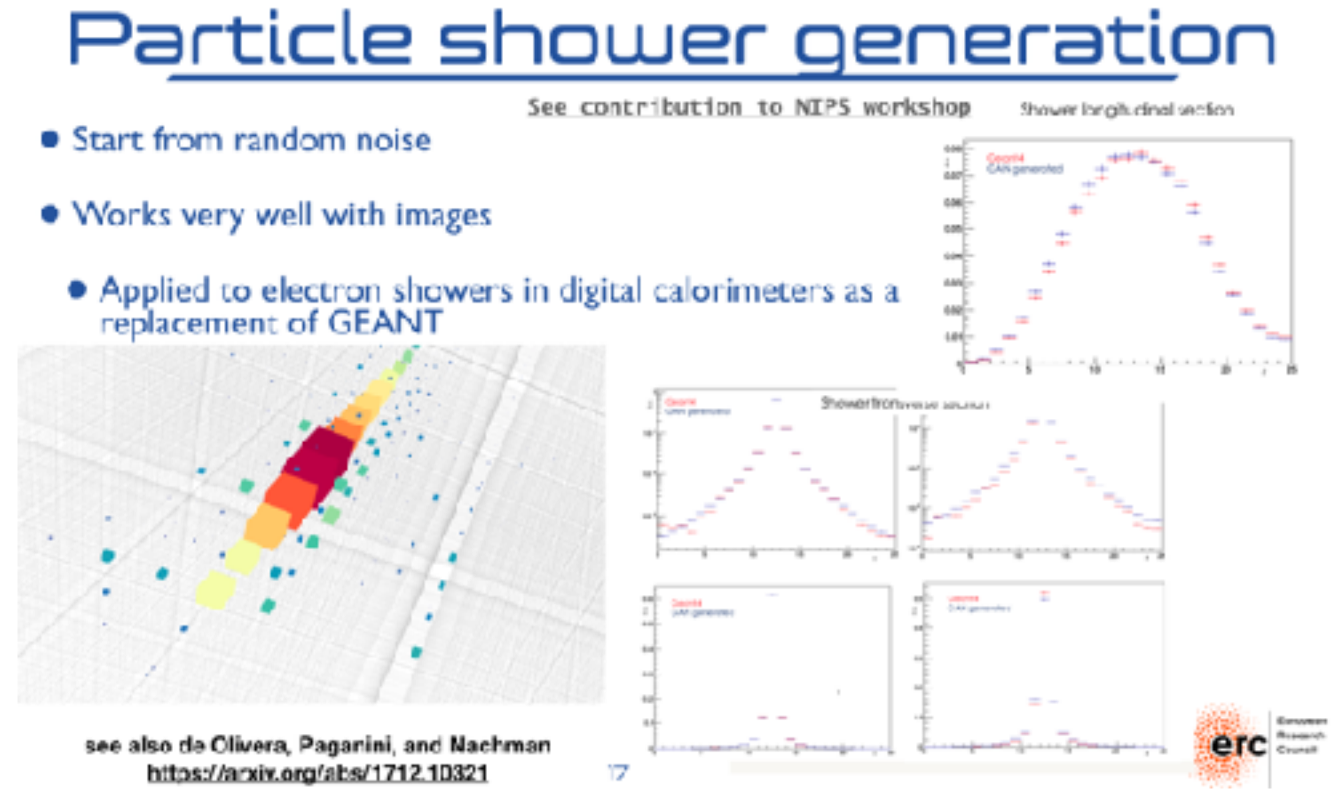
- Beam Pipe (≈1.5 cm radius)
- Vertex Detector (R ∈ [1.7; 34] cm)
- Drift Chamber (L = 400 cm, R ∈ [35; 200] cm)
- Outer Silicon Layer (strips)
- SC Coil (2T, ≈2.1m); THIN! 30 cm
  ($0.74 X_0$; 0.16 λ @90°)
- pre-shower (1-2 X_0)
- Dual Readout Calorimeter (2m, 7 λ)
- Yoke & Muon Chambers

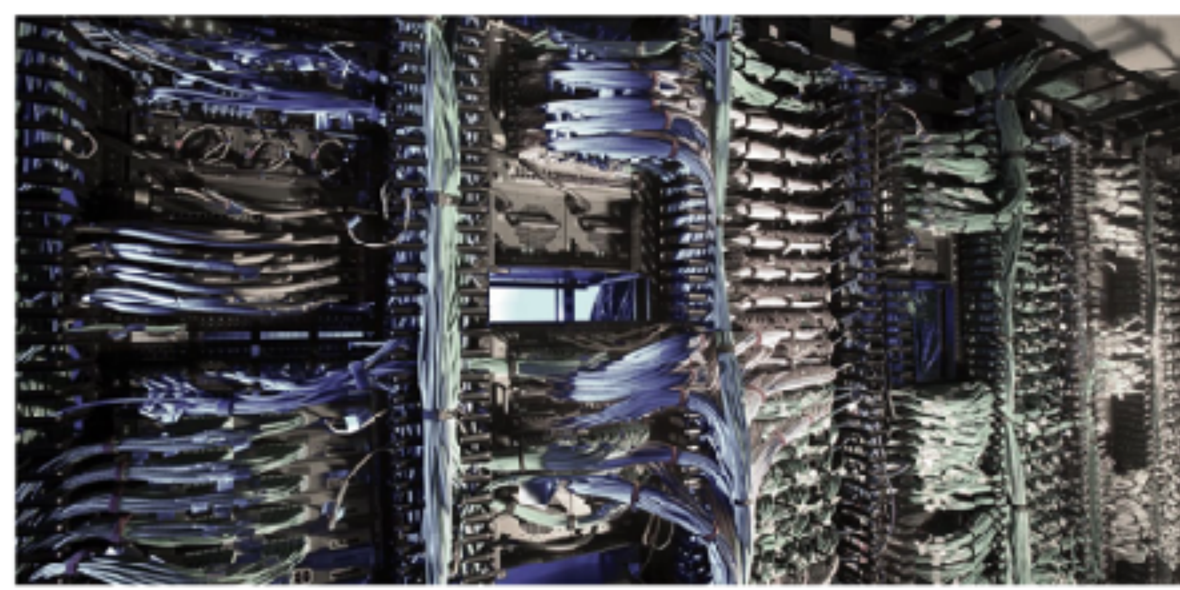


Machine Learning@future e+e-

- Can be used for almost everywhere: DAQ/trigger, reconstruction, PID/tagging, analysis, simulation, pheno. study, …
- Efficient 1: fast in application
- Efficient 2: less/no coding work
- Potential performance gain
- Benefits from industry developments

Work started, and a long way to go to meet very-high precision requirements of an intense e+e- collider





Machine Learning for trigger systems

Maurizio

Analysis and physics

Higgs combination

Kaili

	Current
$\sigma(ZH)$	0.50%
$\sigma(ZH) * Br(H \to bb)$	0.28%
$\sigma(ZH) * Br(H \to cc)$	3.5%
$\sigma(ZH) * Br(H \to gg)$	1.4%
$\sigma(ZH) * Br(H \to WW)$	1.0%
$\sigma(ZH) * Br(H \to ZZ)$	5.0%
$\sigma(ZH) * Br(H \to \tau\tau)$	0.8%
$\sigma(ZH) * Br(H \to \gamma\gamma)$	8.1%
$\sigma(ZH) * Br(H \to \mu\mu)$	16%
$\sigma(\nu\nu H) * Br(H \to bb)$	3.1%
$Br_{upper}(H \to inv.)$	0.42%
$\sigma(ZH) * Br(H \to Z\gamma)$	4σ(21%)

	10κ	7κ
κ_b	1.6%	1.0%
κ_c	2.3%	2.1%
κ_g	1.6%	1.2%
κ_γ	4.4%	4.3%
κ_τ	1.6%	1.1%
κ_Z	0.21%	0.17%
κ_W	1.4%	1.0%
κ_μ	8.1%	
Br_{inv}	0.42%	
Γ_H	3.2%	

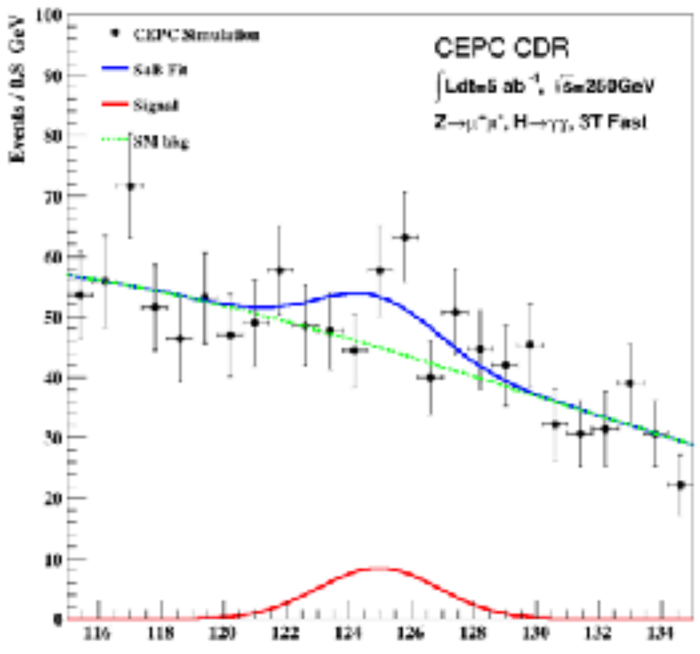
	10-parameter fit		7-parameter fit	
	CEPC	+HL-LHC	CEPC	+HL-LHC
Γ_h	3.2	2.5	–	–
κ_b	1.6	1.2	1.0	0.9
κ_c	2.3	2.0	2.1	1.9
κ_g	1.6	1.2	1.2	1.0
κ_W	1.4	1.1	1.0	0.9
κ_τ	1.6	1.2	1.1	1.0
κ_Z	0.21	0.21	0.17	0.16
κ_γ	4.4	1.7	4.3	1.7
κ_μ	8.1	4.9	–	–
BR_{inv}	0.31	0.31	–	–

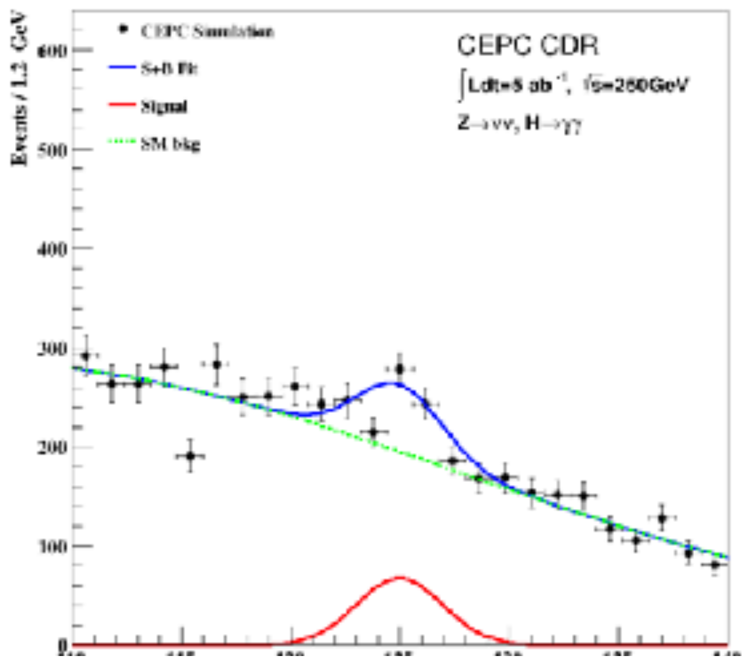
- Updated fit results of CEPC Higgs are shown.
- Correlations are taken in consideration in the simultaneous framework.
- To be used in the CDR and white paper.

Higgs->di-gamma

Fangyi

Repeat the former process in the other 2 sub-channels





Channel	$\mu \pm \delta(\mu)(stats)$
$ll\gamma\gamma$	$0.997^{+0.419}_{-0.404}$
$qq\gamma\gamma$	$0.996^{+0.104}_{-0.103}$
$\nu\nu\gamma\gamma$	$0.997^{+0.138}_{-0.135}$
combined	$0.996^{+0081}_{-0.081}$

Comparison due to different magnetic fields

Measurement precision in 3.5T
fast simulation by Feng Wang

Channel	$\delta(Br\times\sigma)/(Br\times\sigma)$
$ZH\to\mu\mu\gamma\gamma$	30.04%
$ZH\to\tau\tau\gamma\gamma$	32.14%
$ZH\to qq\gamma\gamma$	13.56%
$ZH\to\nu\nu\gamma\gamma$	14.26%
Total	9.0%

Measurement precision in 3.0T
fast simulation present

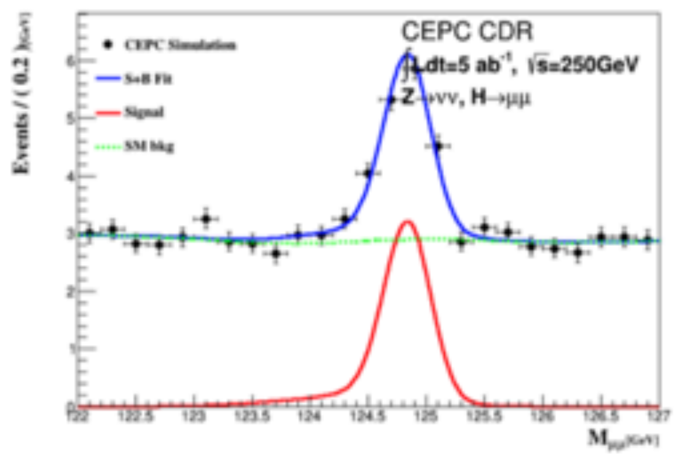
Channel	$\delta(Br\times\sigma)/(Br\times\sigma)$
$ZH\to\mu\mu\gamma\gamma$	41.11%
$ZH\to\tau\tau\gamma\gamma$	
$ZH\to qq\gamma\gamma$	10.35%
$ZH\to\nu\nu\gamma\gamma$	13.65%
Total	8.09%

Higgs->$\mu\mu$

Zhenwei&Kaili

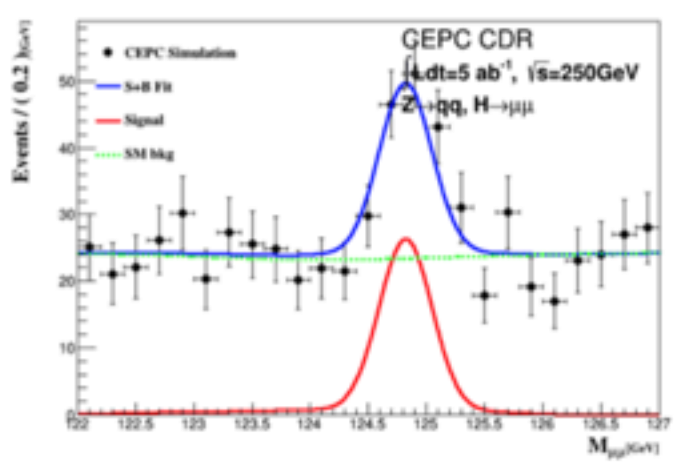
ZH→$\nu\nu\mu\mu, qq\mu\mu$

- Z->vv
  - 38%



Cutflow	signal	ZZ	WW	ZZorWW	SingleZ	2f
Init	41.7	34901	121952	489686	25619	1635887
$120 < M_{\mu^+\mu^-} < 130$	38.4	382	16677	56029	315	49490
MET¿8.5	37.9	291	16264	53740	305	8600
$89 < M_{reco}^{\mu^+\mu^-} < 94$	28.1	96	834	2034	79	184
$\cos\theta_{\mu_+} > 0, \cos\theta_{\mu_-} - 0$	9.1	22	11	86	17	9
efficiency	21.82%					

- Z->qq
  - 17%



Cutflow	signal	ZZ	WW	ZZorWW	SingleZ	2f
Init	156.3	390775	183751	463361	101164	63217
$120 < M_{\mu^+\mu^-} < 130$	141.6	3786	181	227	244	100
$M_{j1} > 4.2, M_{j2} > 2.8$	133.0	3216	111	0	9	60
$M_{jj} > 76.0$	127.5	2917	2	0	8	59
$89 < M_{reco}^{\mu^+\mu^-} < 94$	86.1	1106	0	0	0	0
efficiency	55.08%					

- Combined:15.9%
  - Considering the scheduled time, CEPC could be the first detector to see this process.

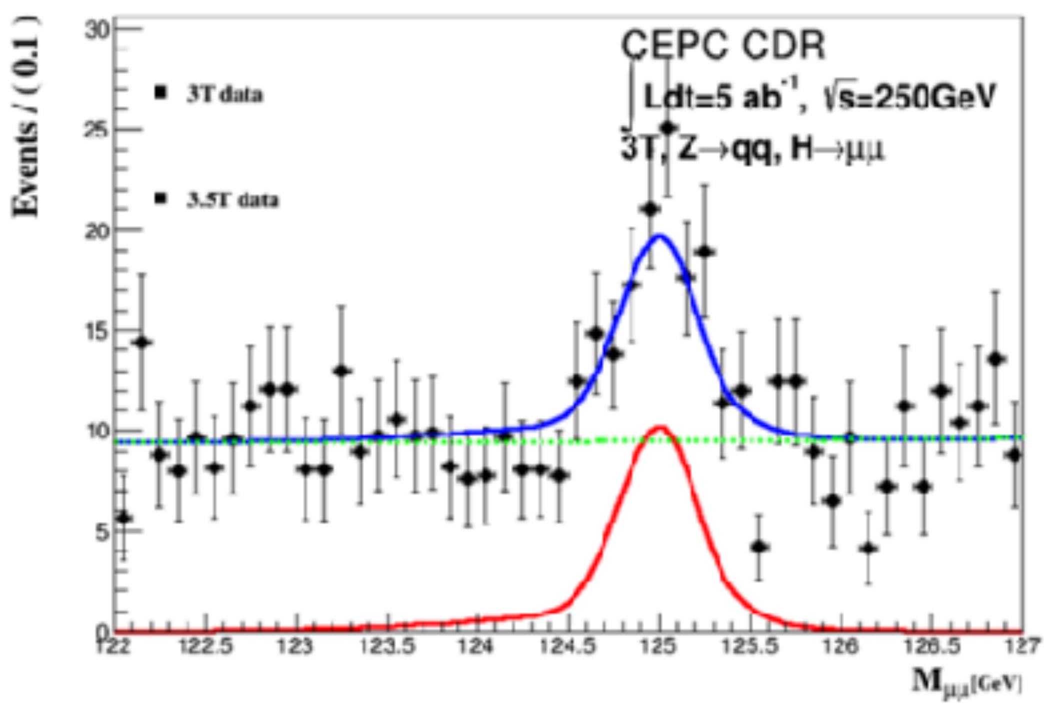
Main bkg: ZZ(sl)mu.down, ZZ(sl)mu.up

Higgs->$\mu\mu$

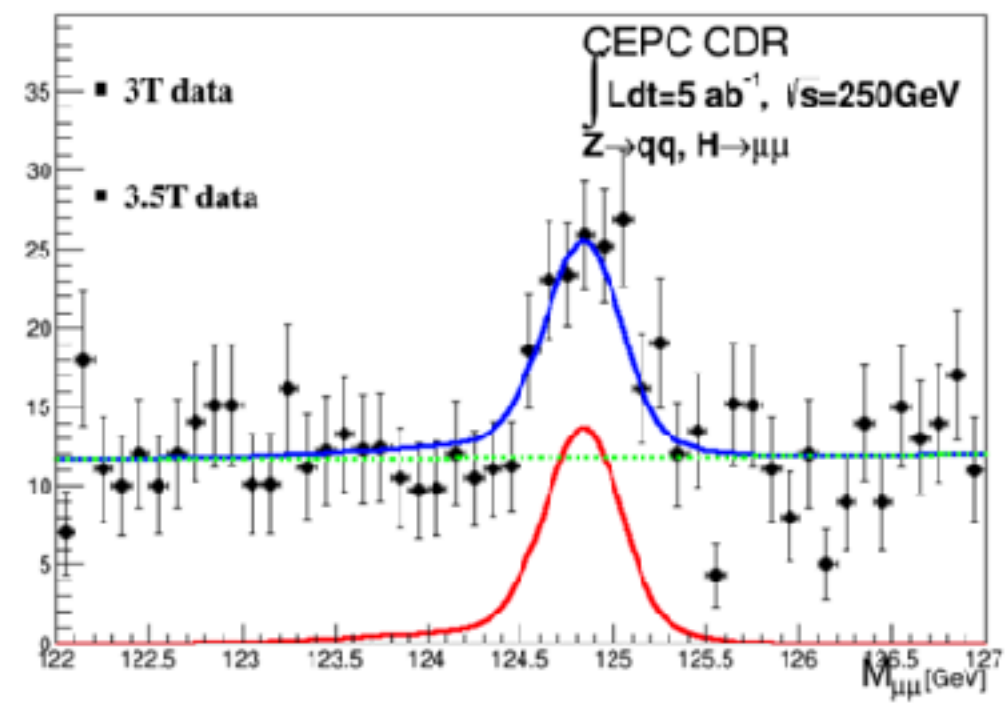
Zhenwei&Kaili

$Z \rightarrow qq,\ H \rightarrow \mu\mu$ Comparison

3T: 18.6%



3.5T: 17.4%

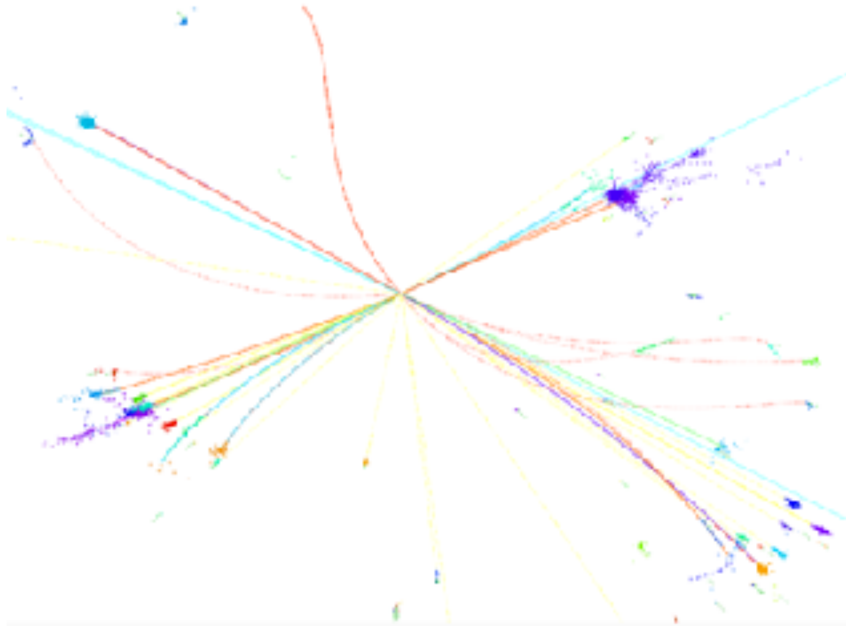


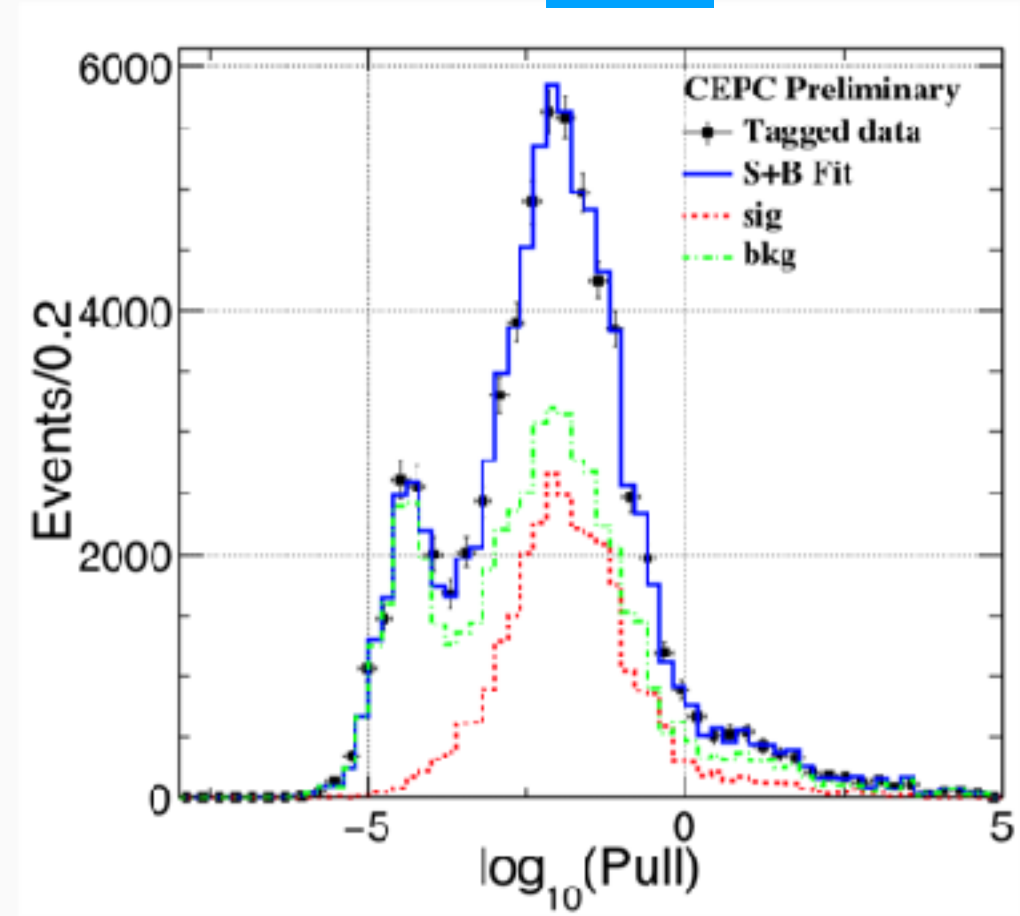
when the magnet field reduced,
2.8% signal, 4% bkg events would be lost in reconstruction.
3.1% signal, 4% bkg events would fail in preselection. (Good muon selection)
-> Signal: 81; Bkg: 1006;
Considering these, precision has reduced from 17.4% to 18.6%.
There is a slight performance downgrade from 3.5T to 3T.

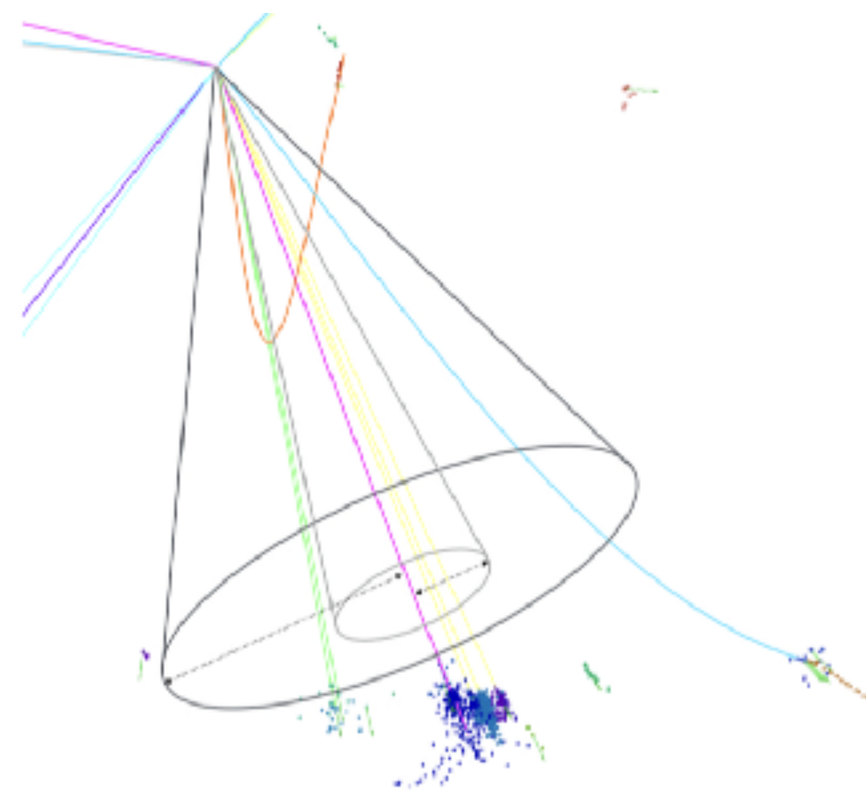
Dan

Higgs->tau tau

A. **Dedicated tau finder developed**
B. **Impact parameter plays important role**
C. **PFA oriented detector is essential**







Combined result for CEPC (5 ab^{-1})

	$\delta\ (\sigma\times$ BR $)/(\sigma\times$ BR$)$
$\mu\mu$H	2.26±0.05%
eeH(extrapolated)	2.72±0.05%
$\nu\nu$H	4.29±0.02%
qqH	0.93±0.01%
combined	0.81±0.01%

Higgs->WW*

Tong

Summary of the results

Category	Signal	Relative uncertainty	Efficiency of selection
$Z \to e^+e^-; H \to WW^* \to e\nu e\nu$	20±7	35.0%	21.1%
$Z \to e^+e^-; H \to WW^* \to \mu\nu\mu\nu$	44±8	18.2%	47.3%
$Z \to e^+e^-; H \to WW^* \to e\nu\mu\nu$	53±8	15.1%	28.2%
$Z \to e^+e^-; H \to WW^* \to e\nu qq$	435±23	5.3%	36.4%
$Z \to e^+e^-; H \to WW^* \to \mu\nu qq$	551±24	4.5%	46.4%
$Z \to \mu^+\mu^-; H \to WW^* \to e\nu e\nu$	23±5	21.7%	26.1%
$Z \to \mu^+\mu^-; H \to WW^* \to \mu\nu\mu\nu$	39±7	17.9%	44.8%
$Z \to \mu^+\mu^-; H \to WW^* \to e\nu\mu\nu$	93±10	10.7%	53.1%
$Z \to \mu^+\mu^-; H \to WW^* \to e\nu qq$	573±25	4.0%	51.5%
$Z \to \mu^+\mu^-; H \to WW^* \to \mu\nu qq$	756±30	4.4%	68.4%
$Z \to \mu^+\mu^-; H \to WW^* \to qqqq$	±	2.9%	
$Z \to \nu\bar{\nu}; H \to WW^* \to e\nu qq$	680±32	4.7%	9.0%
$Z \to \nu\bar{\nu}; H \to WW^* \to \mu\nu qq$	790±43	4.2%	10.5%
$Z \to \nu\bar{\nu}; H \to WW^* \to qqqq$	9022±224	2.5%	37.8%

WW fusion

Hao Liang

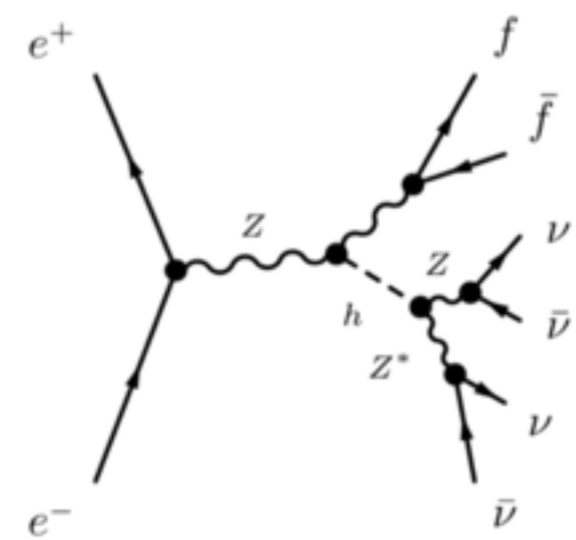
- WW fusion essential to Higgs width
- Fit to recoil mass of Higgs and/or cos theta to extract WW fusion signal $m_{\mathrm{recoil}} = \sqrt{(\sqrt{s} - E_H)^2 - p_H^2}$
- Improve mass resolution: E_H is replaced with $\sqrt{p_H^2 + m_H^2}$
- 2D fit doesn't improve much

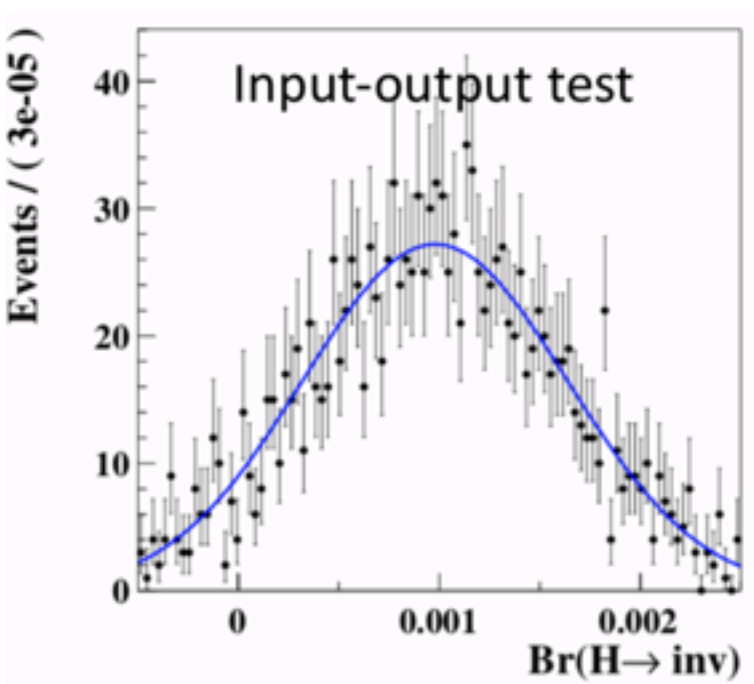
	Fit recoil mass	Fit recoil mass and θ
Approach 1	3.9%	3.8%
Approach 2	3.2%	3.1%

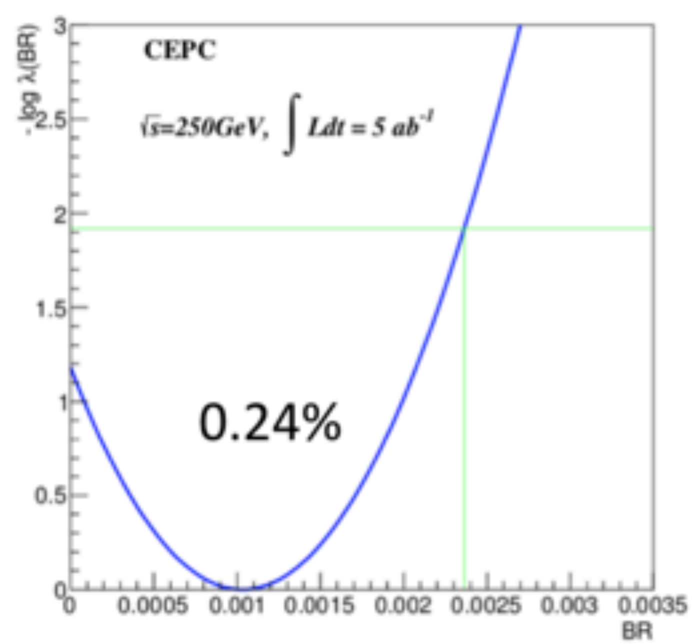
Higgs to invisible

Xin Shi

- Recoil method provides model independent way to explore Higgs invisible decay
- ATLAS/CMS UL >20%
- CEPC combines 3 channels
- CEPC: UL=0.24%







	$Z(e^+e^-)H(inv)$	$Z(\mu^+\mu^-)H(inv)$	$Z(q\bar{q})H(inv)$	Combined
Br	0.35±0.510%	0.350%±0.290%	0.094%±0.150%	0.103%±0.075%
95% CL upper limit	1.30%	0.90%	0.37%	0.24%

Higgs -> di-jet

Yu Bai

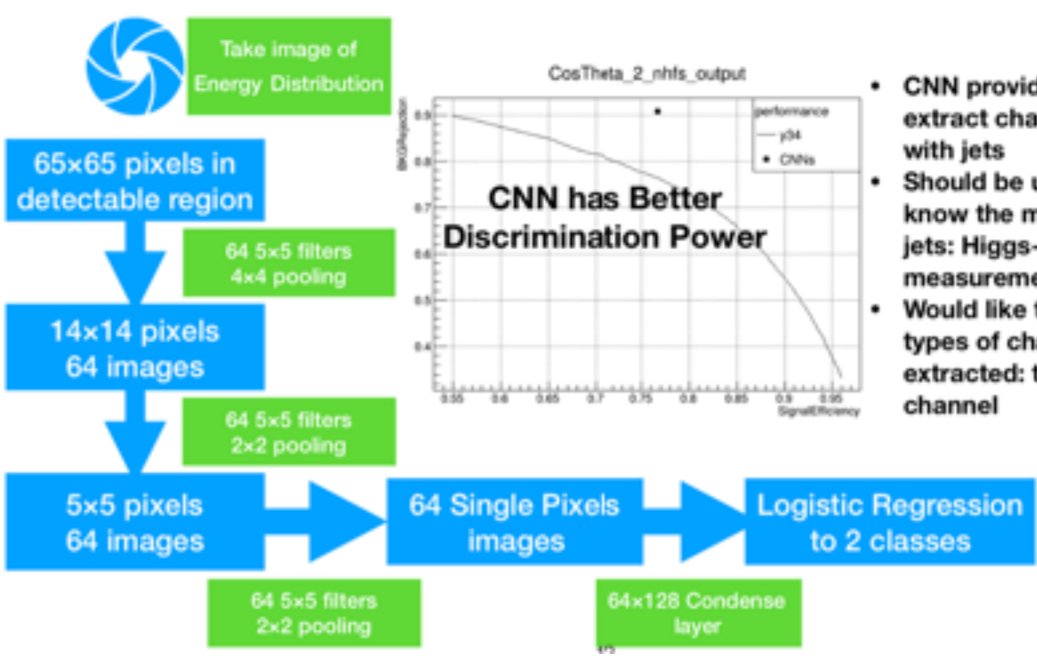
- **3D template fit used**
- **Systematics evaluated carefully**
- **Machine learning approach used to determined # of jets**
  —> help to reduce H->VV backgrounds

Table 6. Expected relative precision on $\sigma(ZH) \times \mathrm{BR}$ for the $H \to b\bar{b}$, $c\bar{c}$ a[…] CEPC dataset of 5 ab^{-1}.

Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.3%	14.1%	7.9%
$Z \to \mu^+\mu^-$	1.0%	10.5%	5.4%
$Z \to q\bar{q}$	0.4%	8.1%	5.4%
$Z \to \nu\bar{\nu}$	0.4%	3.8%	1.6%
Combined	0.3%	3.2%	1.5%

Technic development : Convolutional NN in Jets

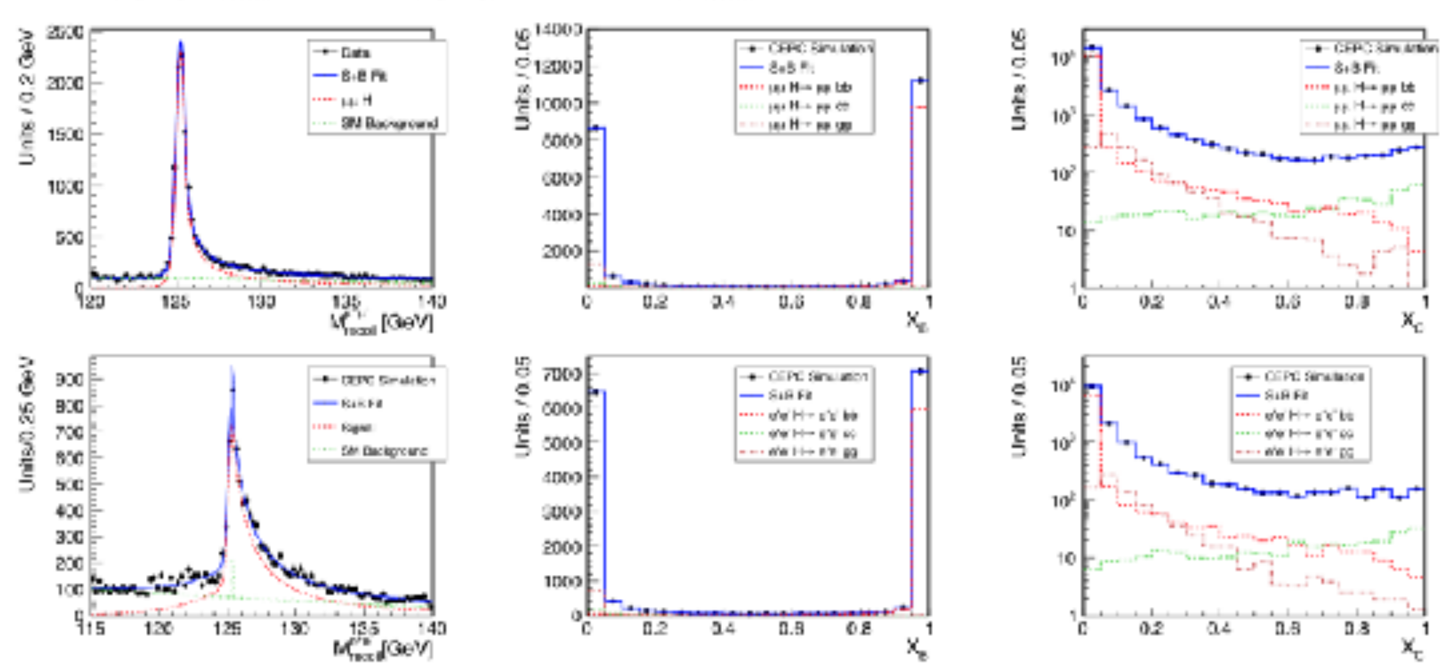
- We use CNN to separate H->qq and H-> ZZ*/WW*->qqqq



- **CNN provides new to extract character in event with jets**
- **Should be useful need to know the multiplicity of jets: Higgs->qq, QCD measurements etc.**
- **Would like to know other types of character can be extracted: try to use in qqH channel**

3D Fit

$$PDF^{3D}(X_B, X_C, M_{recoil}) = PDF^{flavor}(X_B, X_C) \times PDF^{recoil\_mass}(M_{recoil})$$



EW study

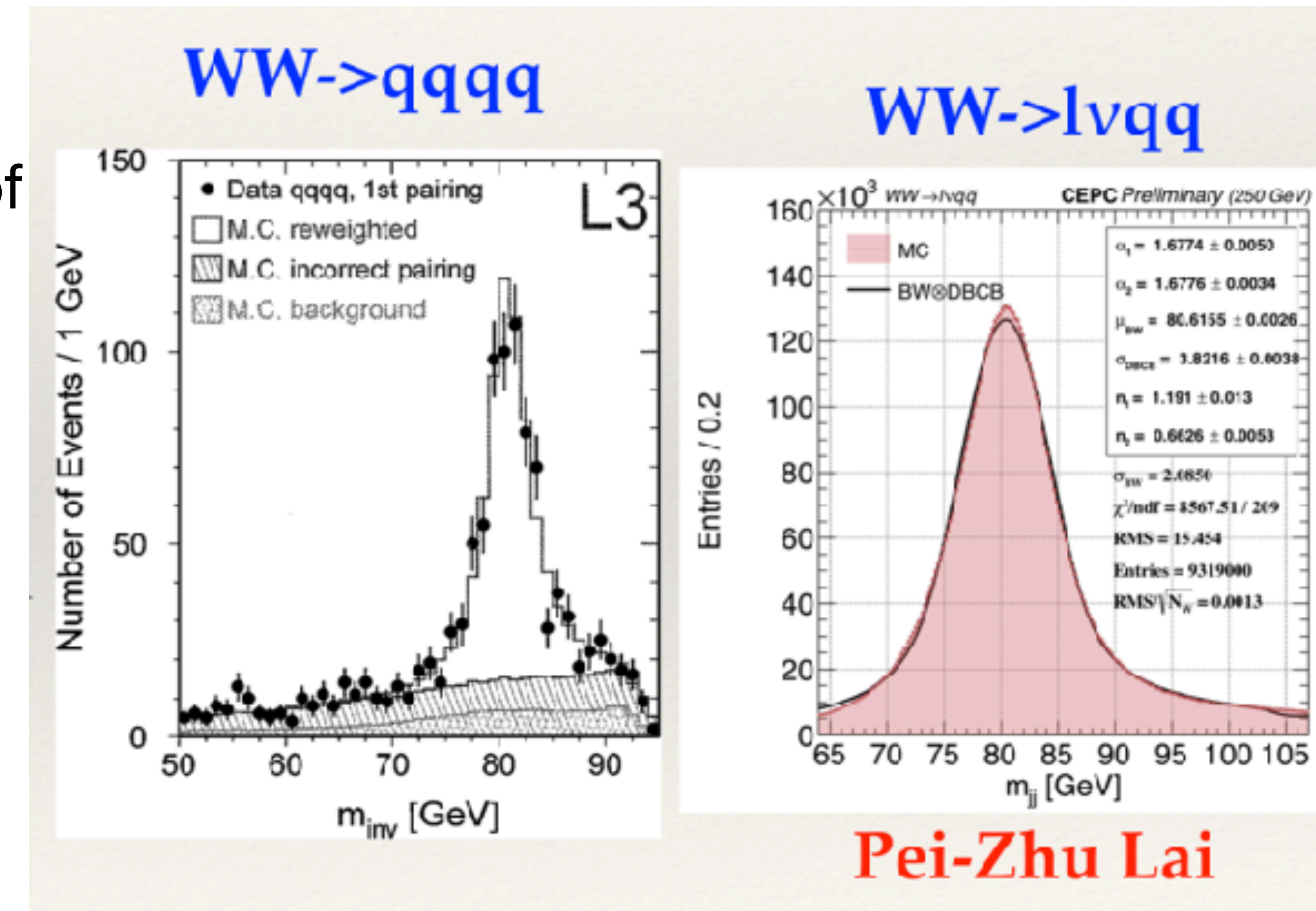
Zhijun

Zhijun summarized various topics and updates since preCDR
Mainly focus on systematics

Observable	LEP precision	CEPC precision	CEPC runs
m_Z	2 MeV	0.5 MeV	Z threshold scan
A_{FB}^b	1.7%	0.1%	Z threshold scan
$\sin^2\theta_W^{\rm eff}$	0.07%	0.002%	Z threshold scan
R_b	0.3%	0.02%	Z pole
R_μ	0.2%	0.01%	Z pole
N_ν	1.7%	0.05%	ZH runs
m_W	33 MeV	2-3 MeV	ZH runs
m_W	33 MeV	1 MeV	WW threshold

Two talks on W mass

- Hengne overview the status of direct and threshold scan approaches
- Possible techniques such as kinematic fit
- Systematics challenges: jet energy calibration, color reconnection, …



Hengne&Peixun

Two talks on W mass

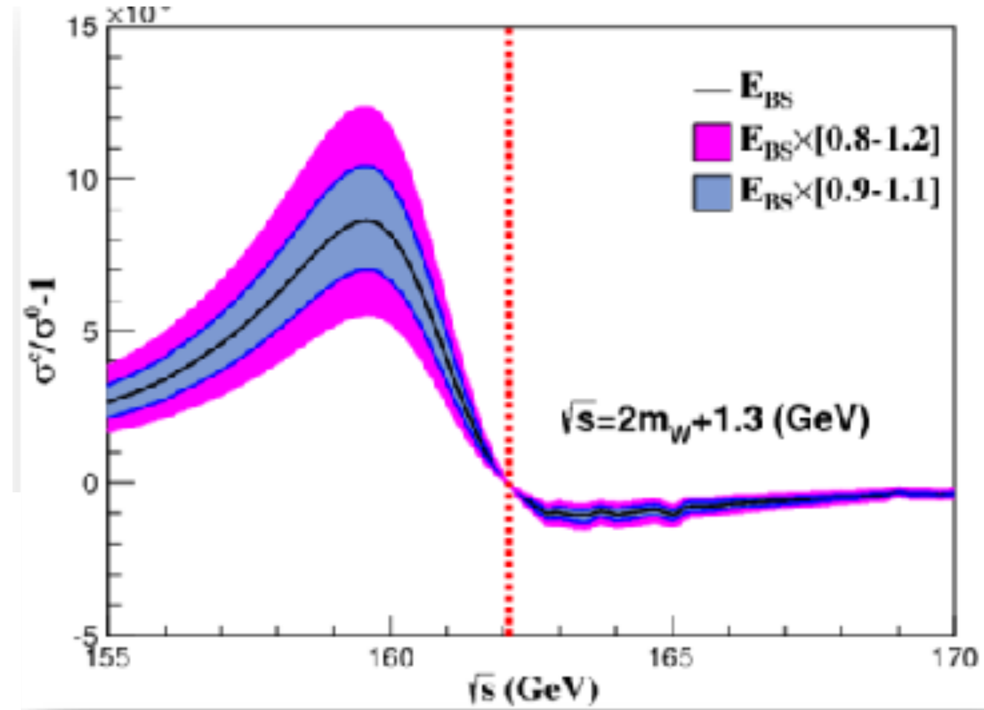
Considering statistics and systematic uncertainties
The preliminary study shows
CEPC can reach 1 MeV precision

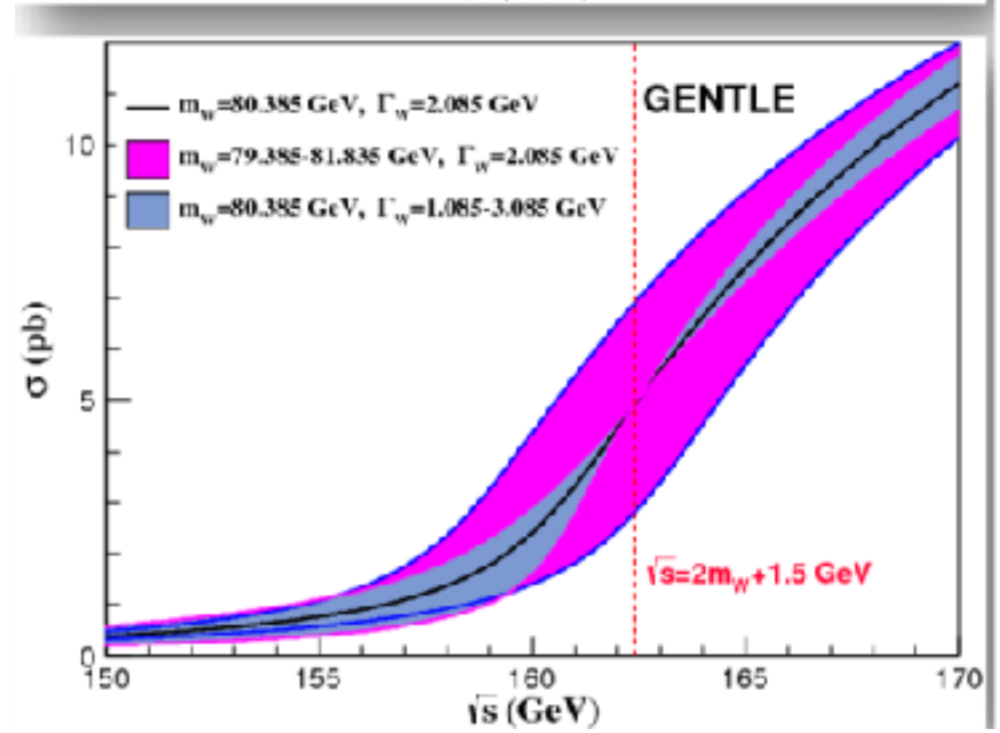
Results

$L = 3.2\ ab^{-1}, \epsilon P = 0.72\ , \sigma_{sys}^{corr} = 2\times10^{-4}$

ΔE=0.5 MeV, $E_{BS}=1.6\times10^{-3}$, $\Delta E_{BS}=0.01$

Data points	Δm_W (MeV)	$\Delta\Gamma_W$ (MeV)
1	0.9	-
2	1.0	2.9
3	1.0	2.8





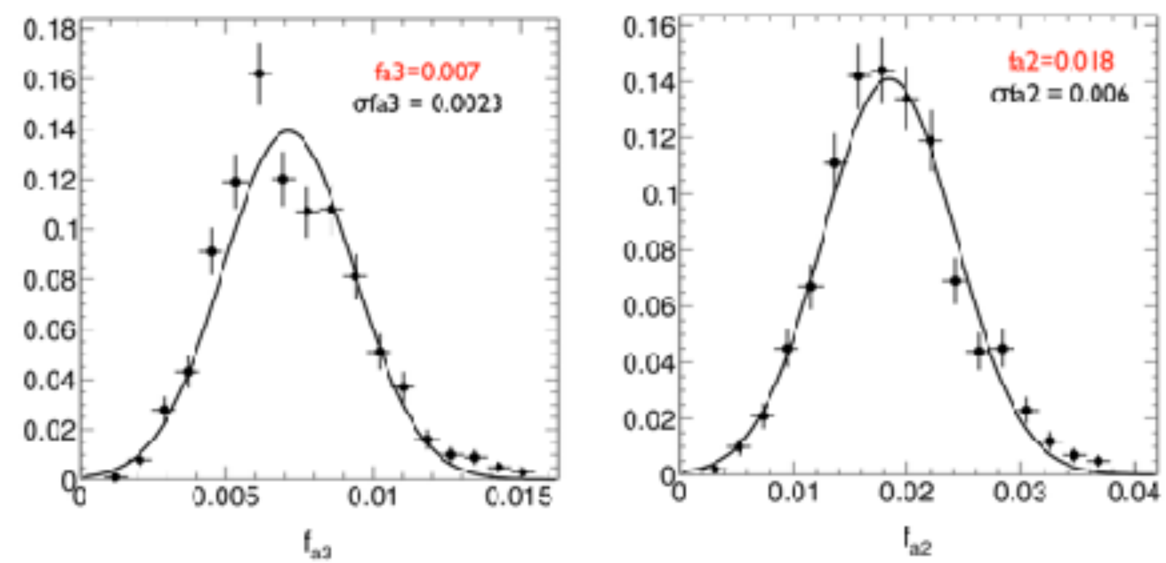
Some critical energy points not sensitive to some systematics

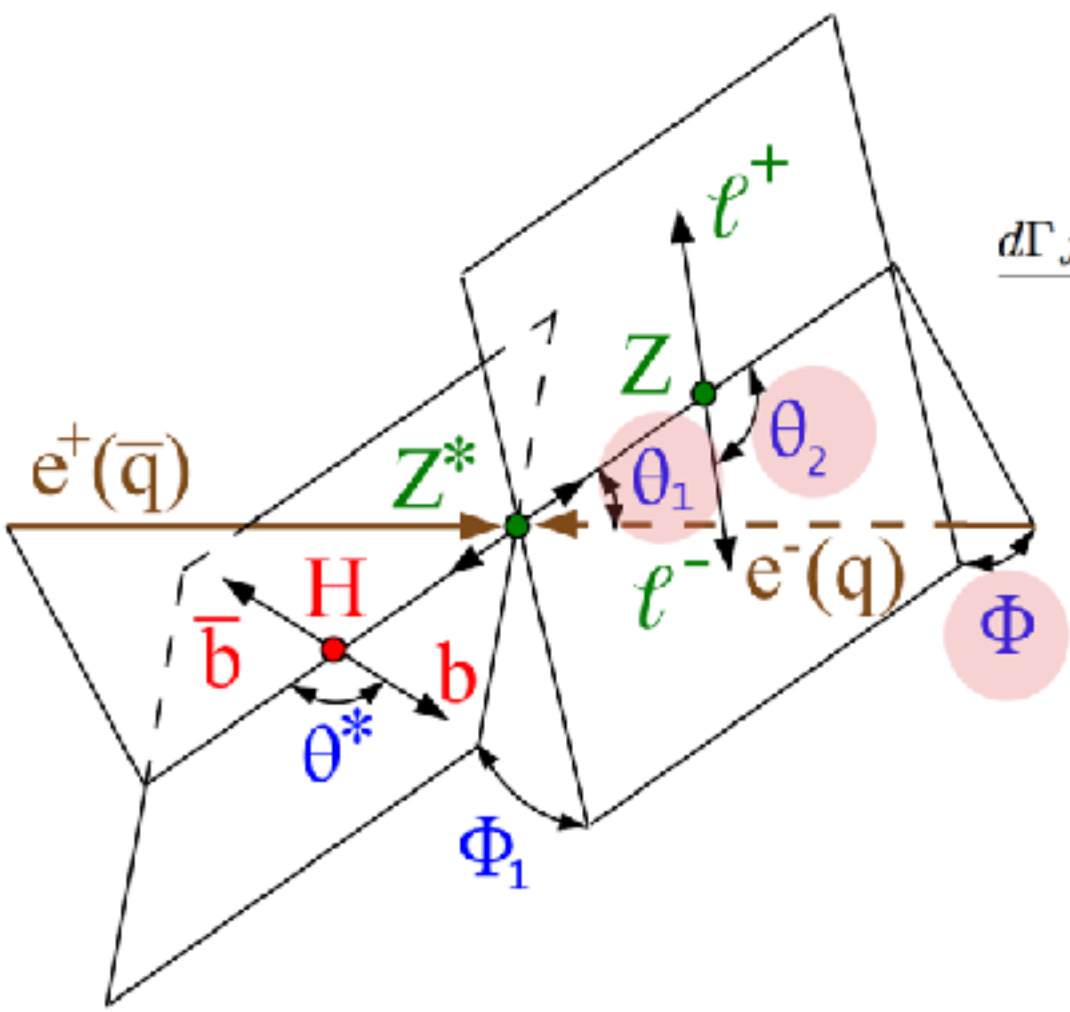
Yanyan

H->ZZ couplings

- Fit to multi-dimension differential distributions to extract SM and anomalous couplings

- Great precision



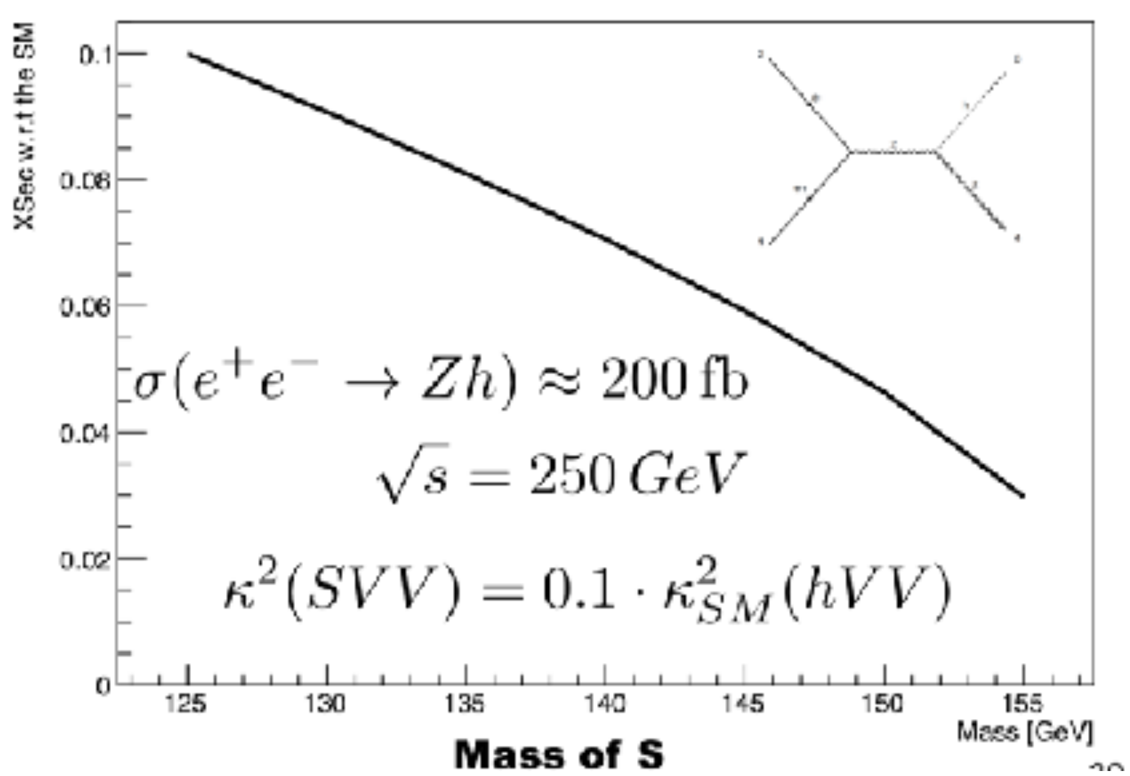


$$\frac{d\Gamma_{J=0}(s,\vec{\Omega})}{d\vec{\Omega}} \propto 4\,|A_{00}|^2 \sin^2\theta_1 \sin^2\theta_2$$
$$+\,|A_{+0}|^2\left(1-2R_1\cos\theta_1+\cos^2\theta_1\right)\left(1+2A_{f_2}\cos\theta_2+\cos^2\theta_2\right)$$
$$+\,|A_{-0}|^2\left(1+2R_1\cos\theta_1+\cos^2\theta_1\right)\left(1-2A_{f_2}\cos\theta_2+\cos^2\theta_2\right)$$
$$-\,4|A_{00}||A_{+0}|(R_1-\cos\theta_1)\sin\theta_1(A_{f_2}+\cos\theta_2)\sin\theta_2\cos(\Phi+\phi_{+0})$$
$$-\,4|A_{00}||A_{-0}|(R_1+\cos\theta_1)\sin\theta_1(A_{f_2}-\cos\theta_2)\sin\theta_2\cos(\Phi-\phi_{-0})$$
$$+\,2|A_{+0}||A_{-0}|\sin^2\theta_1\sin^2\theta_2\cos(2\Phi-\phi_{-0}+\phi_{+0})\,. \quad \text{(A2)}$$

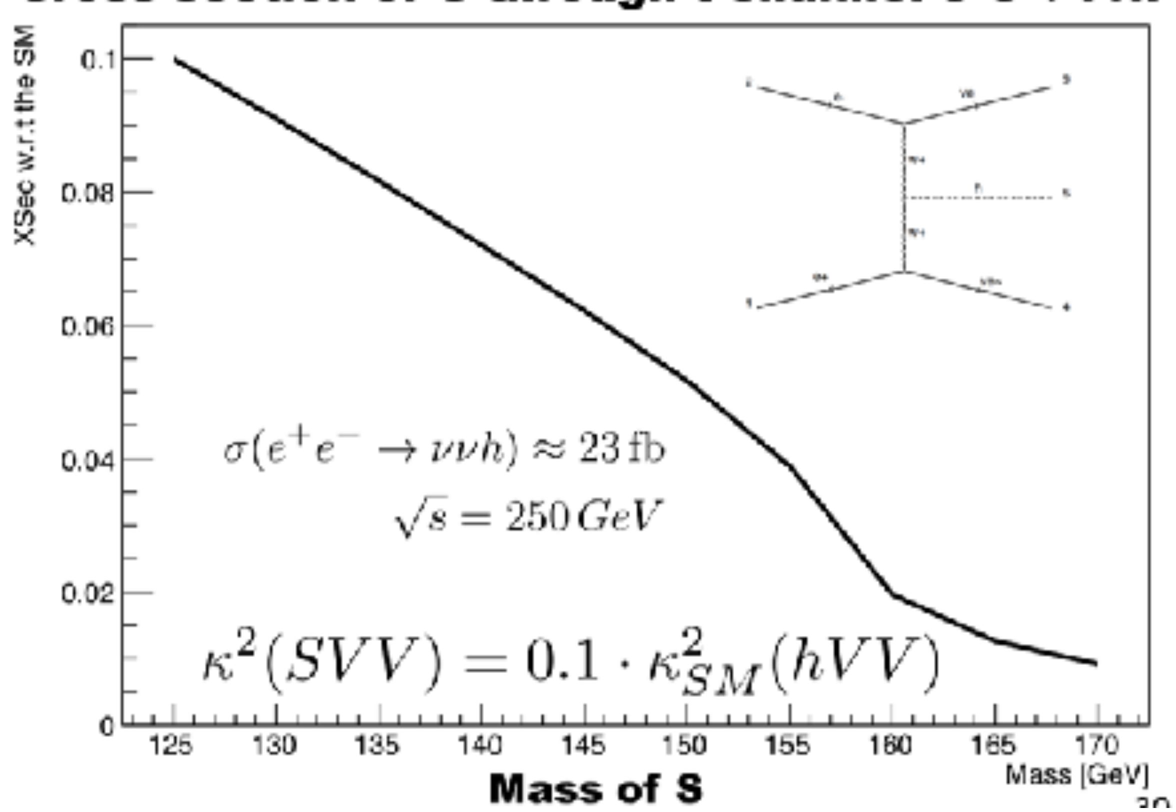
2HDM+S at ee

- Very nice results at LHC
- Impacts on the cross section of ee colliders

Cross-section of S through s-channel $e^+e^- \to Z^* \to Zh$



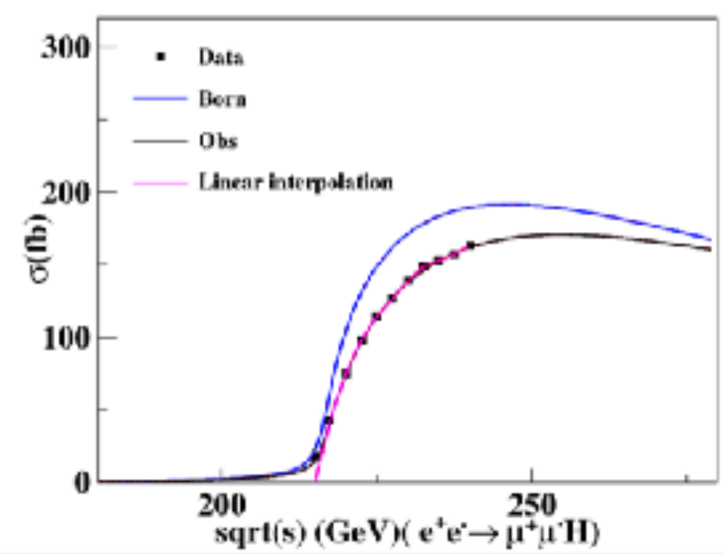
Cross-section of S through t-channel $e^+e^- \to \nu\nu h$



ISR correction at lepton collider

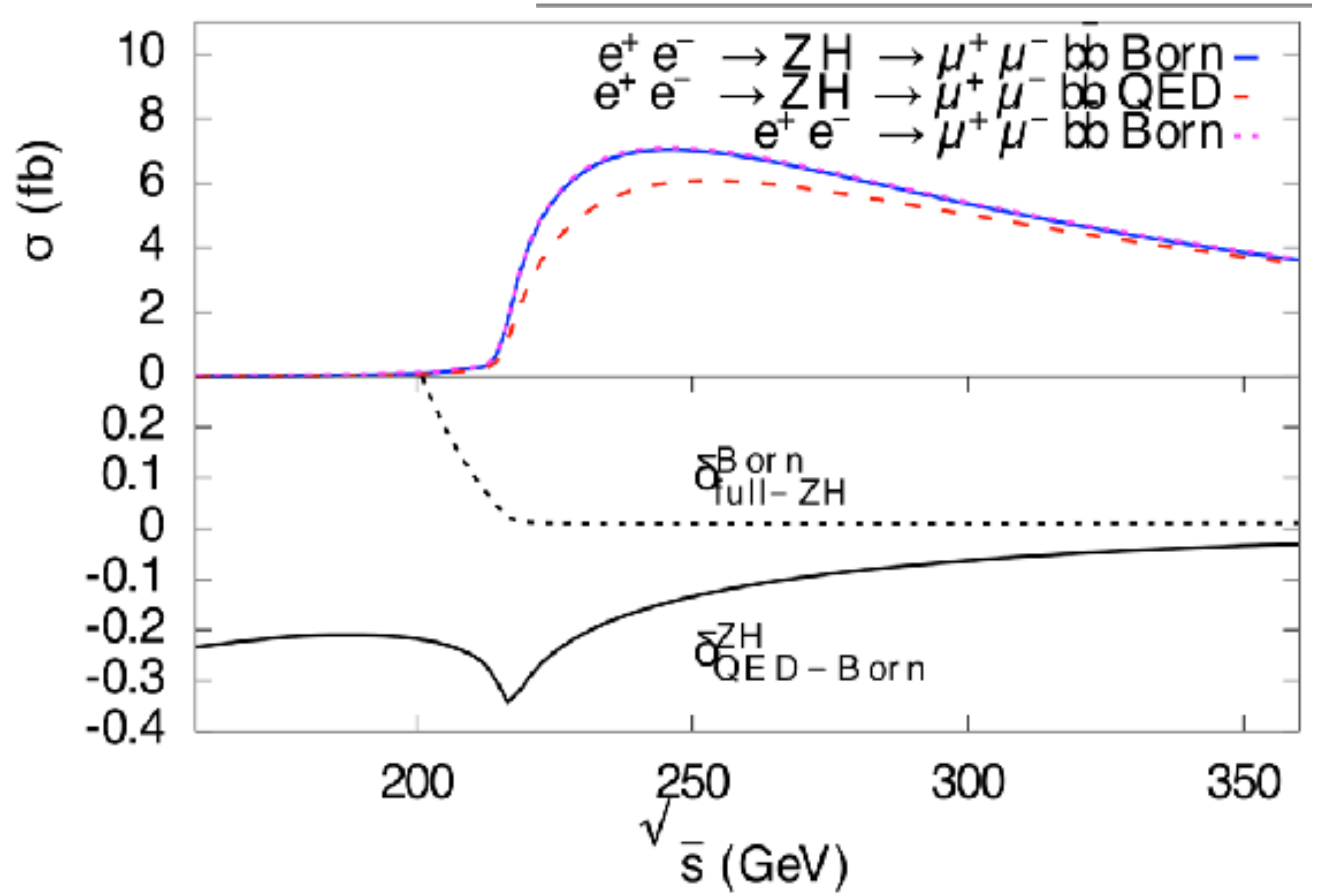
$$d\sigma(s) = \int dx_1 dx_2 D(x_1, s) D(x_2, s) d\sigma_0(x_1 x_2 s) \Theta(\text{cuts}).$$

Direct measurement



- ISR important for s-channel Higgs production
- And essential for model INDEPENDENT sigma(ZH) measurement at ee colliders, which changes Born cross section by 10-20%
- Additional data-taking is a must to determine the line-shape below 240GeV

Mario



Summary of summary

- CEPC detector optimization goes well: software, validation performance, and benchmark analyses
- Higgs, W and Z physics covered
- Differential distribution study produces interesting results
- High order correction being considered, pheno study
- New technology is making high energy experiment different
- Efforts of all three sides lay solid foundation for CEPC detector/physics study
- All high energy e+e- collider project can share common efforts