CEPC and MC Simulation
$\mathbf{H} \rightarrow ee, \mu\mu$

Qiang Li

Based on arXiv:1705.04486, 1711.06807, and 1804.00125

Outline

- **CEPC**
- **CEPC Samples**
- **ISR and Beamstrahlung**
- **Whizard**
- **ISR within MadGraph**
- $\mathbf{H} \rightarrow \boldsymbol{ee}$
- $\mathbf{H} \rightarrow \boldsymbol{\mu\mu}$
- **Outlook**

CEPC

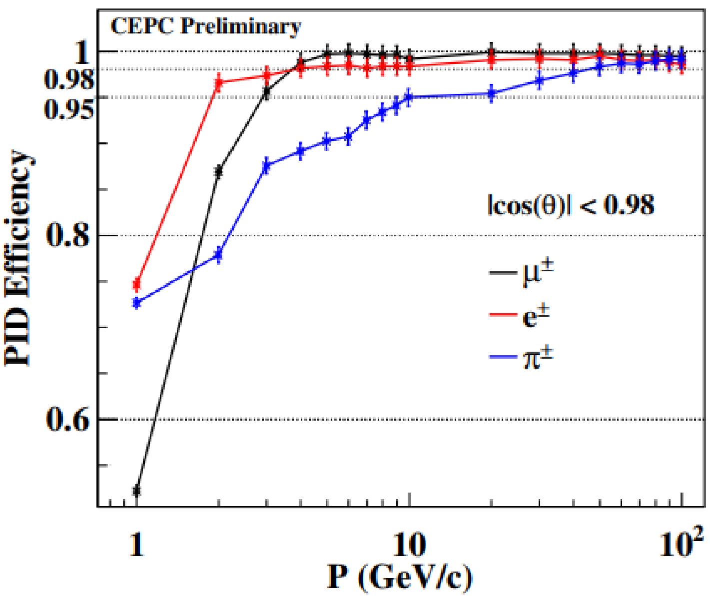
- **Circular electron-positron collider**
- **240-250 GeV**
- **10 years Luminosity: 5 ab-1**

Signal part

Background part

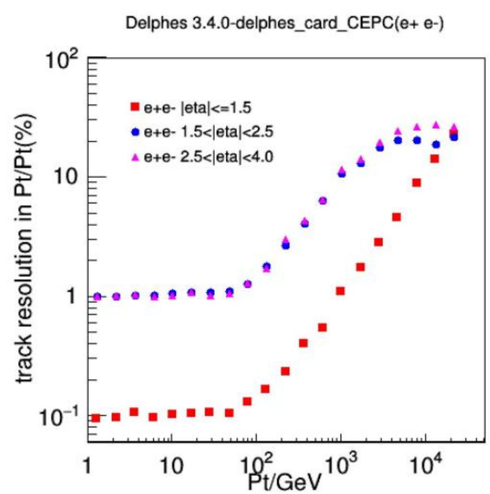
- 2 fermions
- 4 fermions

Pre-CDR



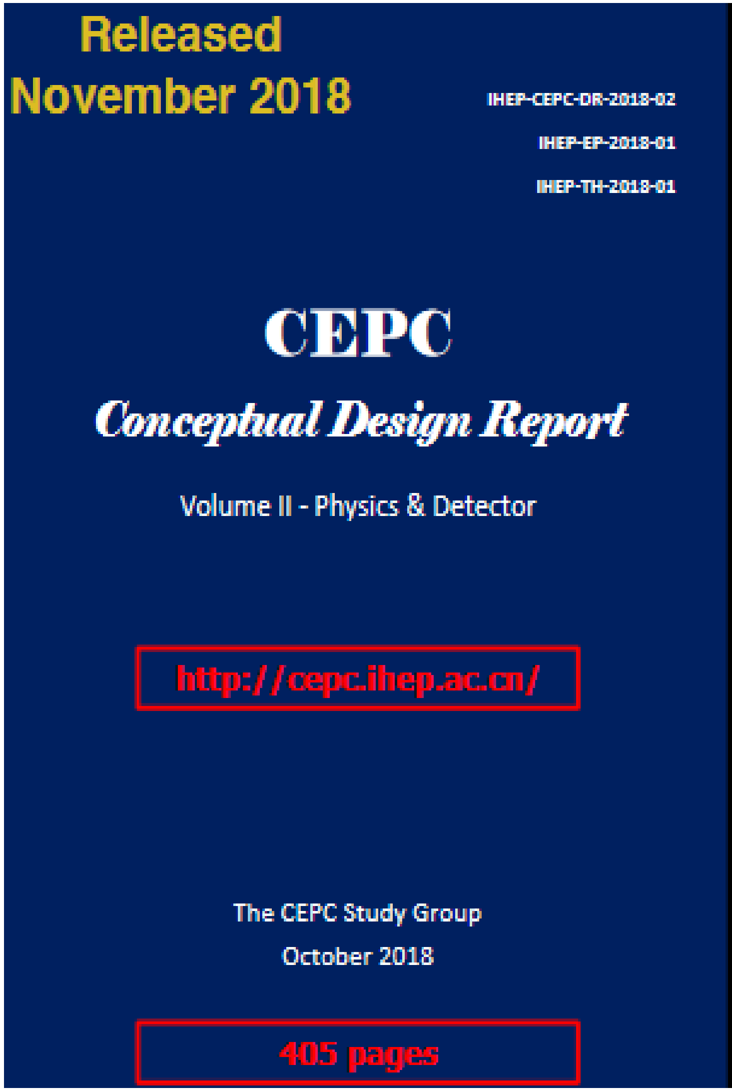
Improved recently by Dan Yu et.al. with MVA technique

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_T) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$BR(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_T \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$BR(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu m$
$H \to q\bar{q},\ VV$	$BR(H \to q\bar{q},\ VV)$	ECAL, HCAL	$\sigma_E^{jet}/E \sim 3-4\%$
$H \to \gamma\gamma$	$BR(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)



Tracker resolution verified in Delphes by Chen Cheng et.al.

CEPC-CDR


Released
November 2018

IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

CEPC
Conceptual Design Report
Volume II - Physics & Detector

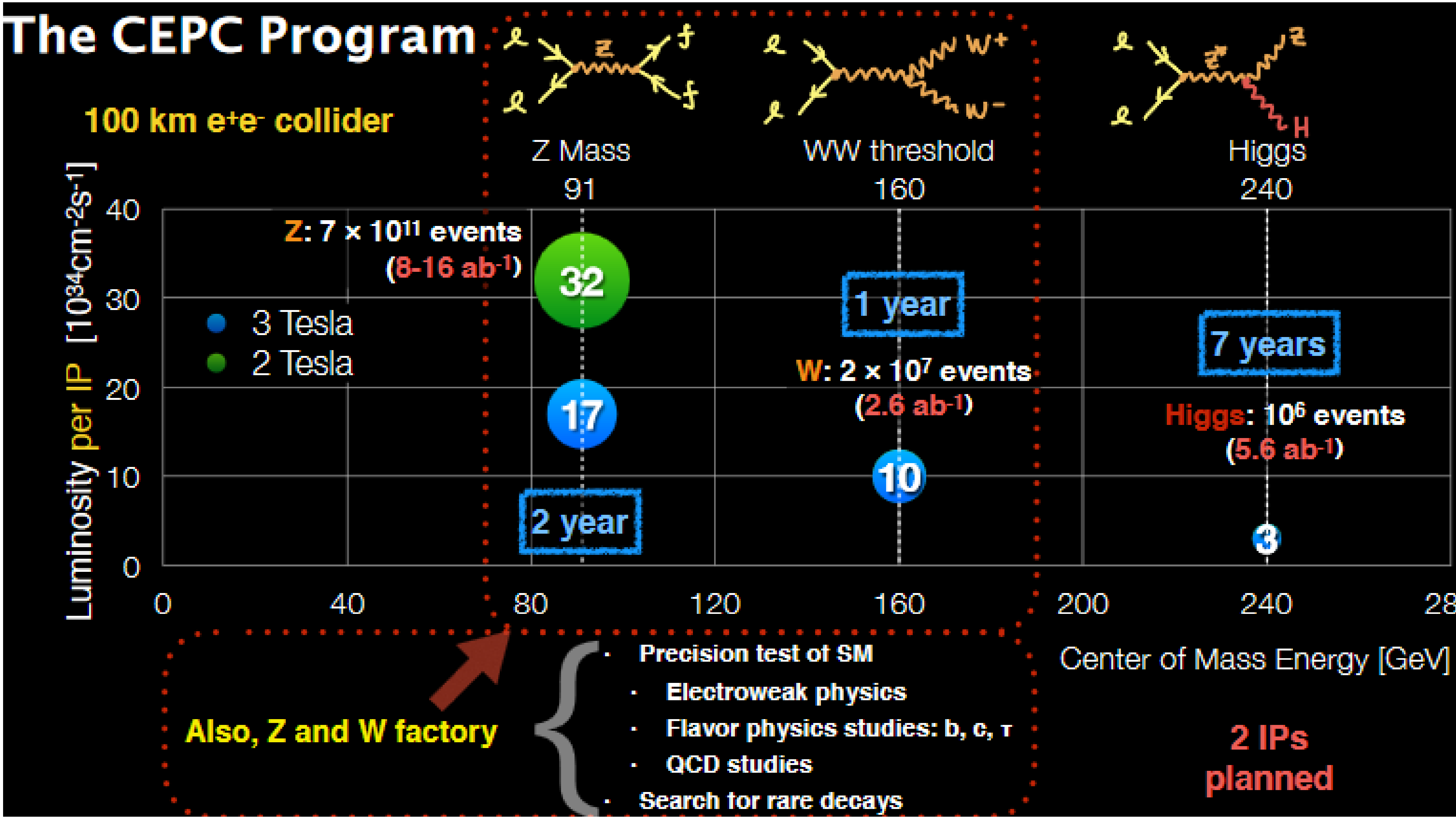
http://cepc.ihep.ac.cn/

The CEPC Study Group
October 2018

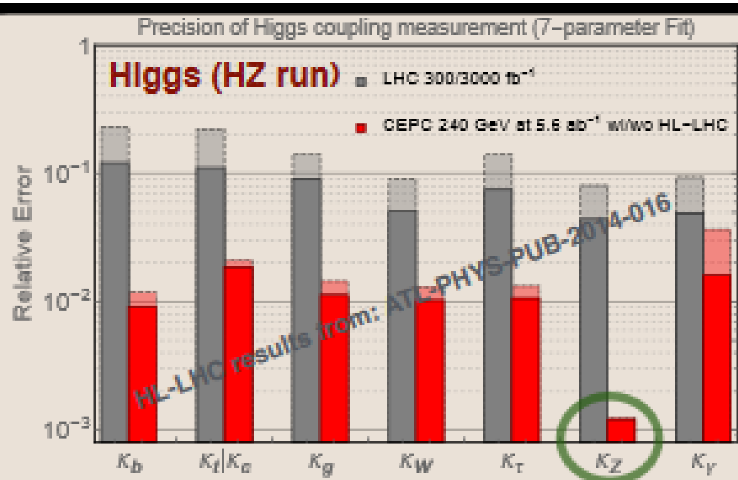
405 pages

CEPC CDR, Vol. 2 — Physics and Detector

CEPC Plan


The CEPC Program
100 km e+e- collider
Z Mass
91
WW threshold
160
Higgs
240
Luminosity per IP [10^34cm-2s-1]
Z: 7 × 10^11 events
(8-16 ab-1)
32
17
2 year
3 Tesla
2 Tesla
1 year
W: 2 × 10^7 events
(2.6 ab-1)
10
7 years
Higgs: 10^6 events
(5.6 ab-1)
3
Center of Mass Energy [GeV]
Also, Z and W factory
Precision test of SM
Electroweak physics
Flavor physics studies: b, c, τ
QCD studies
Search for rare decays
2 IPs planned

CEPC: Higgs Factory

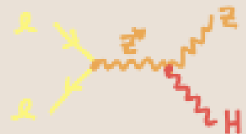


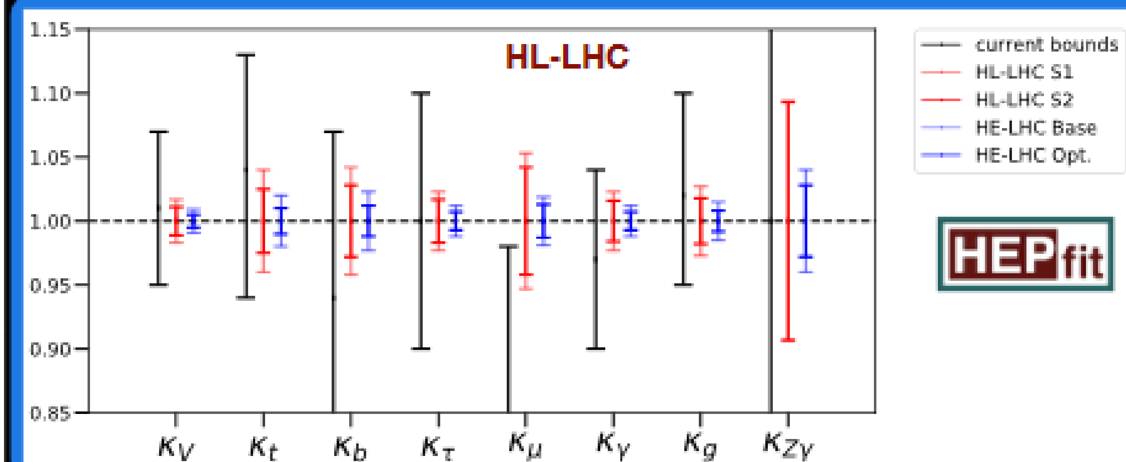
Including detector performance

$$\kappa_f = \frac{g(hff)}{g(hff;\mathrm{SM})},\ \kappa_V = \frac{g(hVV)}{g(hVV;\mathrm{SM})}$$

CEPC K_x ~1% uncertainty

K_Z ~ 0.13 %





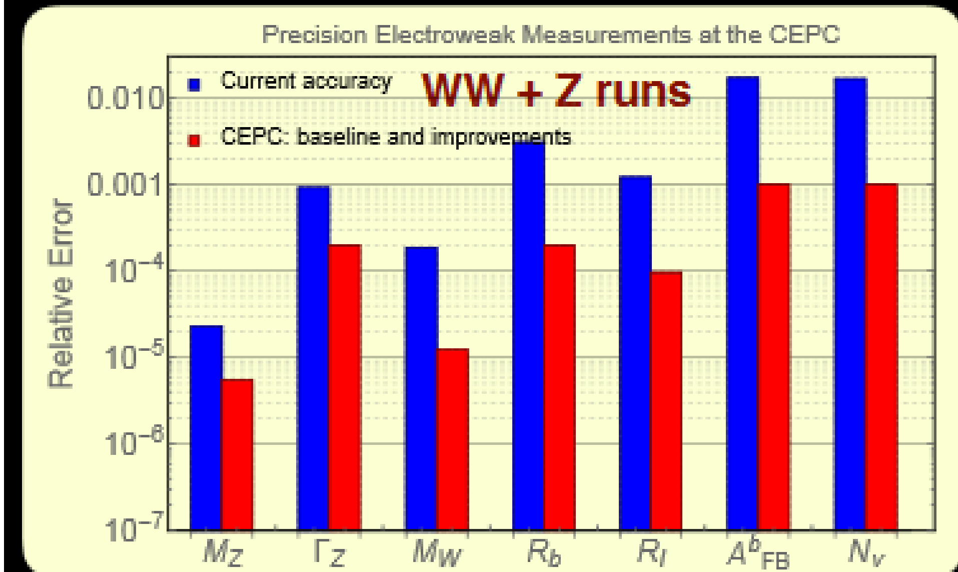
Updated HL-LHC results

arXiv: 1902.00134v2, March 2019

Higgs couplings uncertainties
HL-LHC ~ 2-5%

Global analysis scheme at CEPC proposed to improved the precision of Higgs decay branching ratios

CEPC: EWK Precision

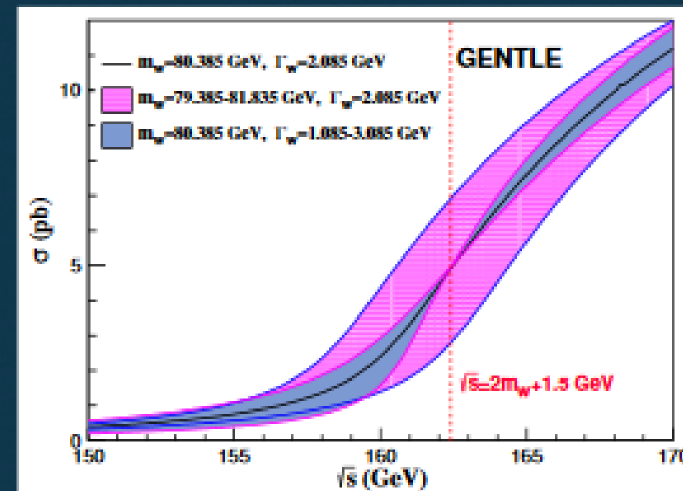


Including detector performance

Assumes: 2-year run at Z-pole and
1-year run at WW threshold

Today
2 pm Session

W Mass from Threshold Scan



Similar to LEP technique

Use 3 √s points: 157.5, 161.5 and 162.5 GeV

Beam energy spread: 0.13-0.1%

E_{CM} uncertainty: 0.5 MeV

$L = 2.6\ ab^{-1} \rightarrow \Delta M_W \sim 1$ MeV

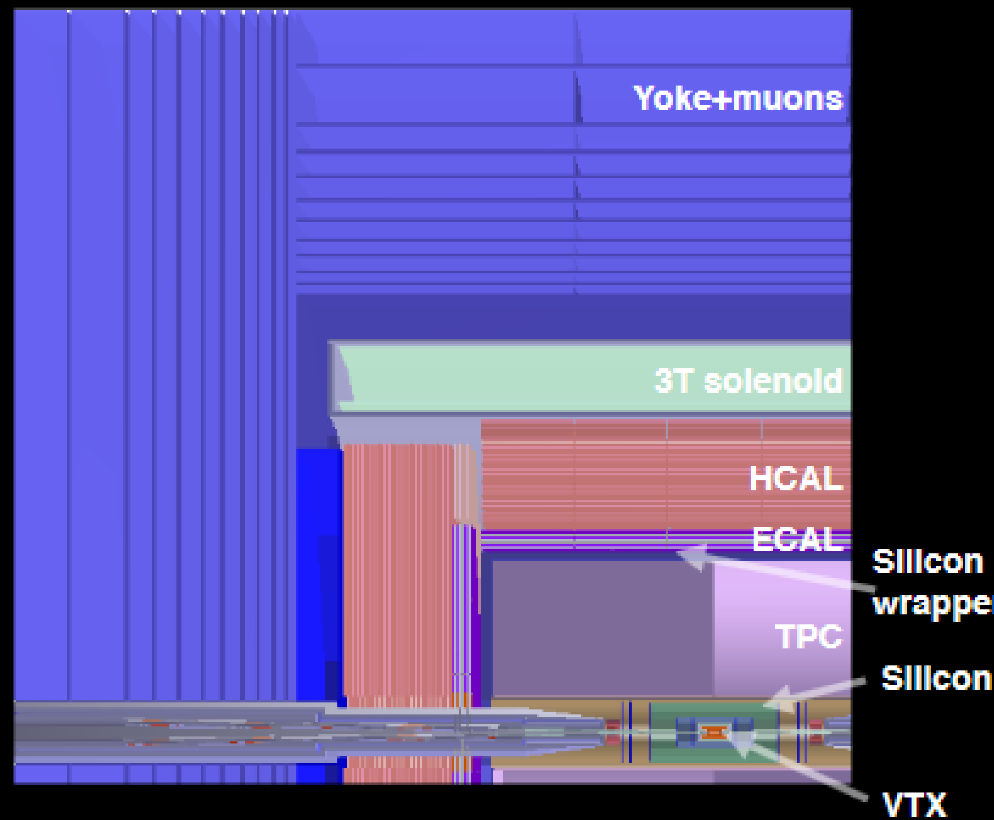
Working on publication together with FCC-ee (Paolo Azzurri)

CEPC Detector

CEPC CDR: Particle Flow Conceptual Detector

Major concerns being addressed

1. MDI region highly constrained
   L* = 2.2 m
   Compensating magnets
2. Low-material Inner Tracker design
3. TPC as tracker in high-luminosity Z-pole scenario
4. ECAL/HCAL granularity needs
   Passive versus active cooling
   Electromagnetic resolution



Magnetic Field: 3 Tesla

CEPC Software

Simulation Software

Based on standard tools

Root data format
DD4hep
Geant4

New hit-based Fast Simulation

FATRAS
(Fast ATLAS TRAck Simulation)

Reconstruction Software

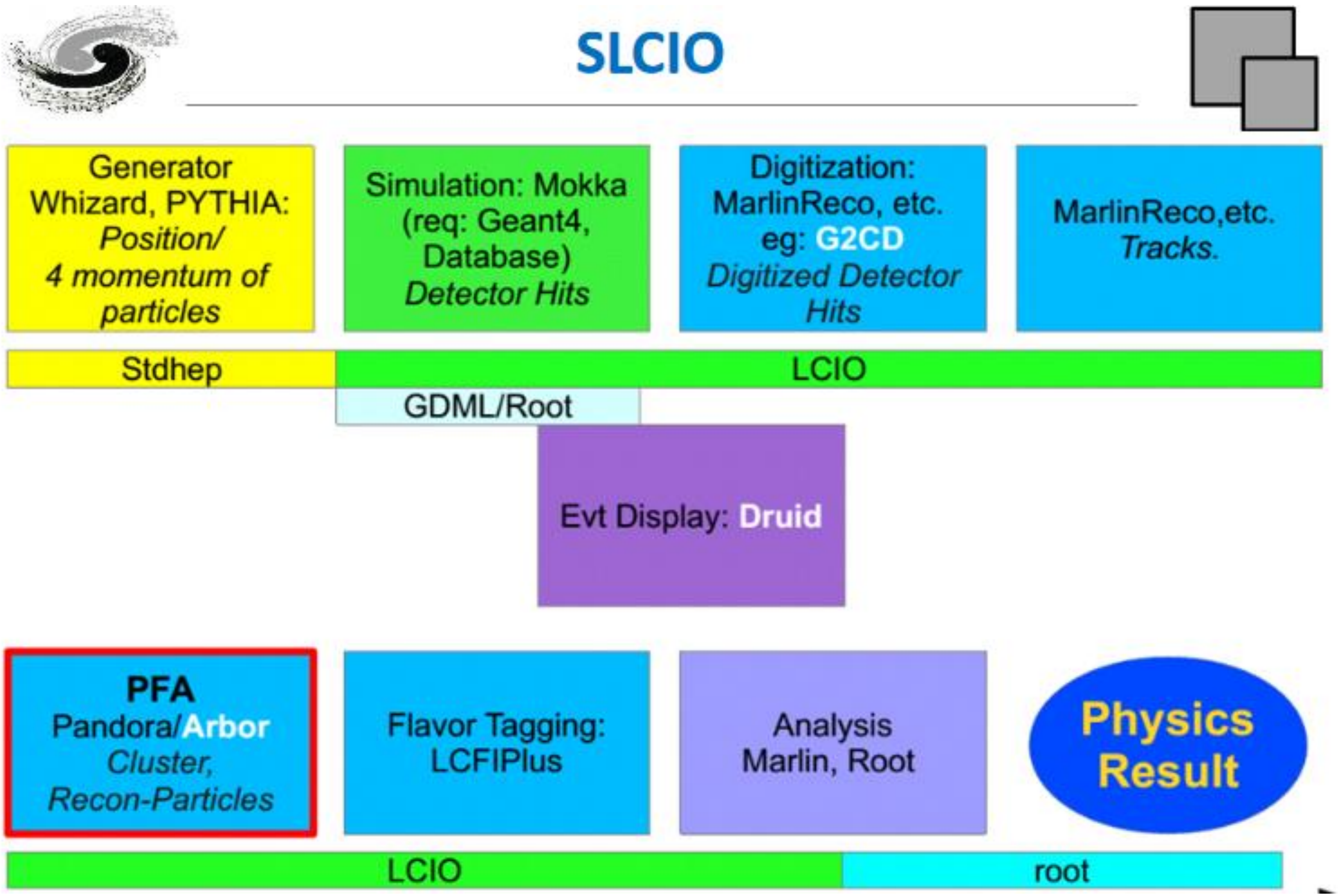
Considering new tracking tool

ACTS
(A Common Tracking Software)

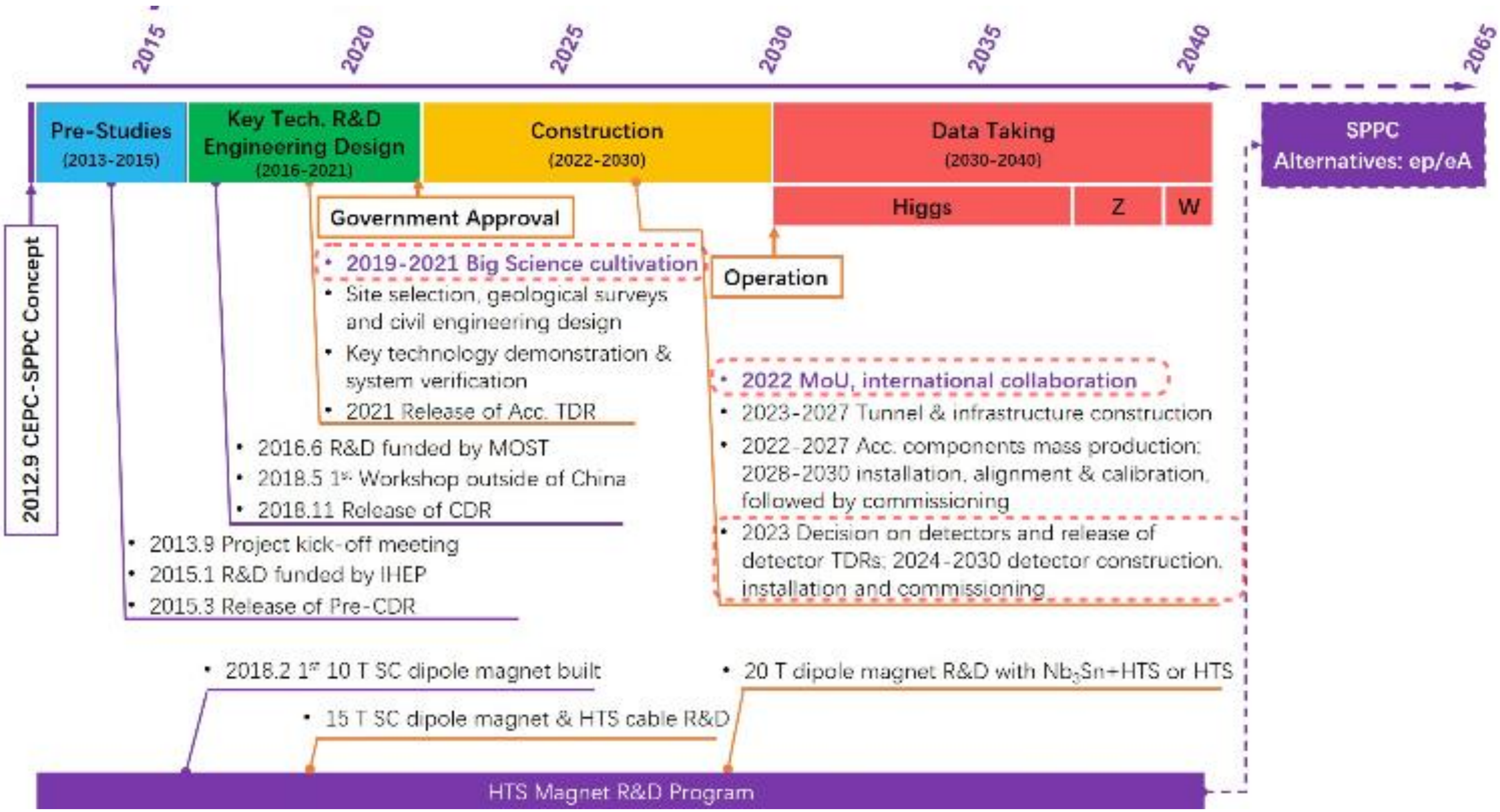
Porting of PFA tools:
Pandora and Arbor

Developing other algorithms:
vertex, long-lived charged particles,
particle identification in jets

CEPC Software

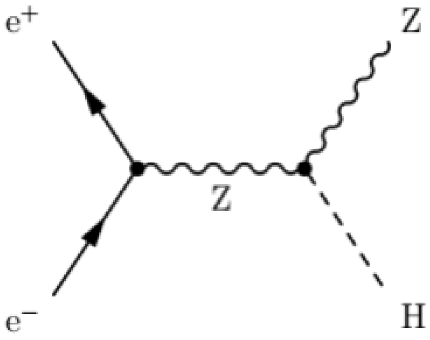


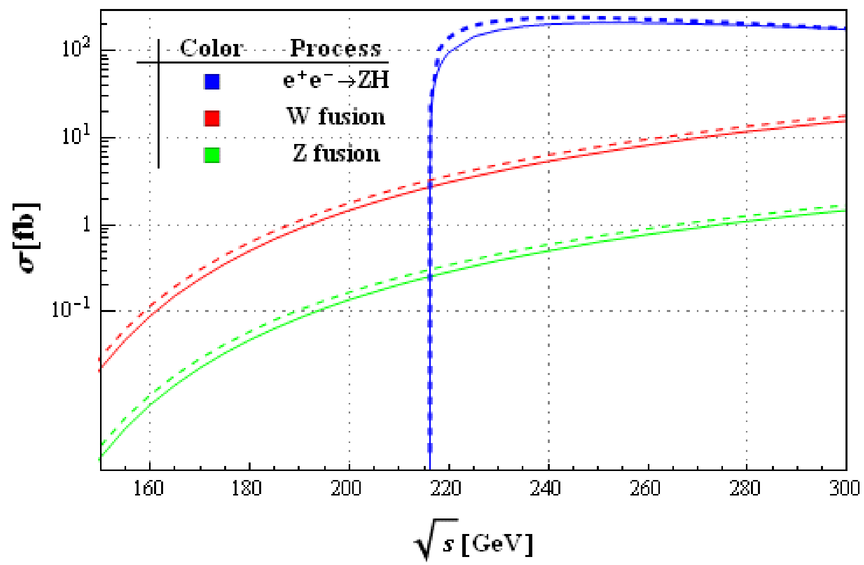
CEPC timeline



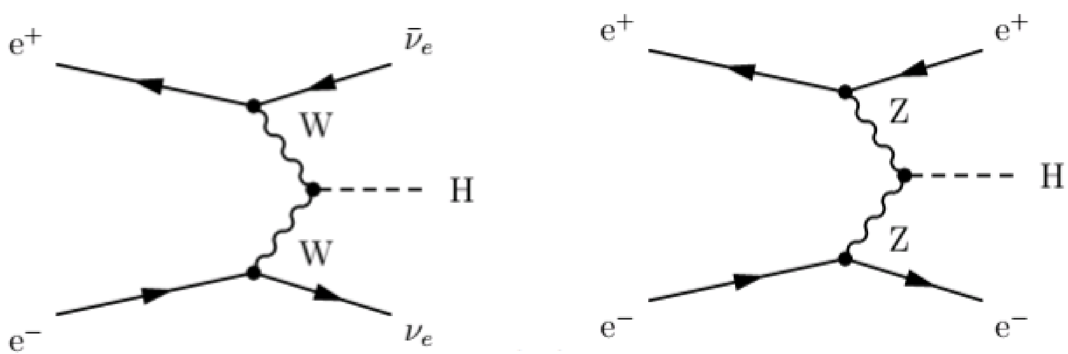
Higgs Signal

Higgs-strahlung





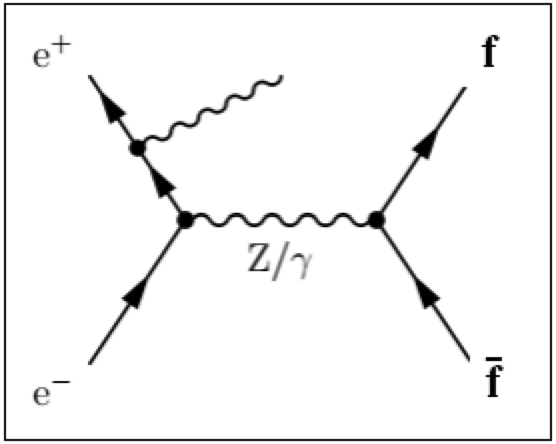
Vector boson fusion



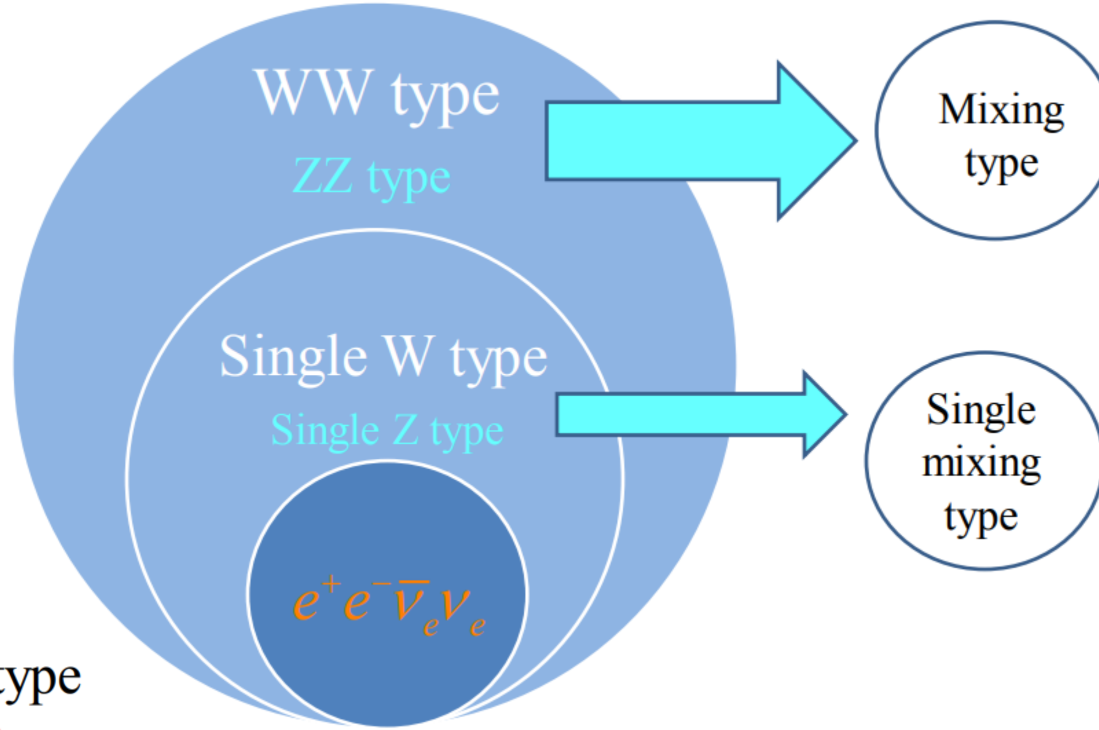
Dashed: w/o ISR
Solid: w/ ISR

Xin Mo et.al

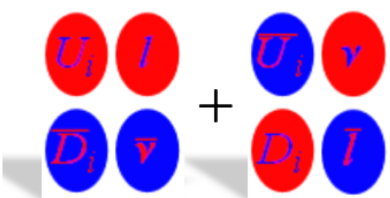
Background



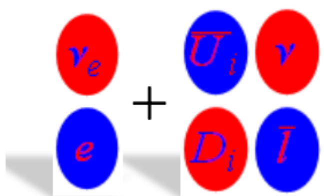
Classification of 4 fermions



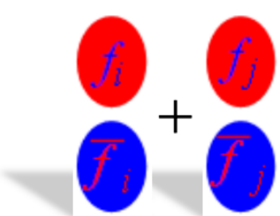
- WW type



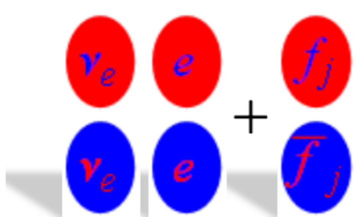
- Single W type



- ZZ type



- Single Z type

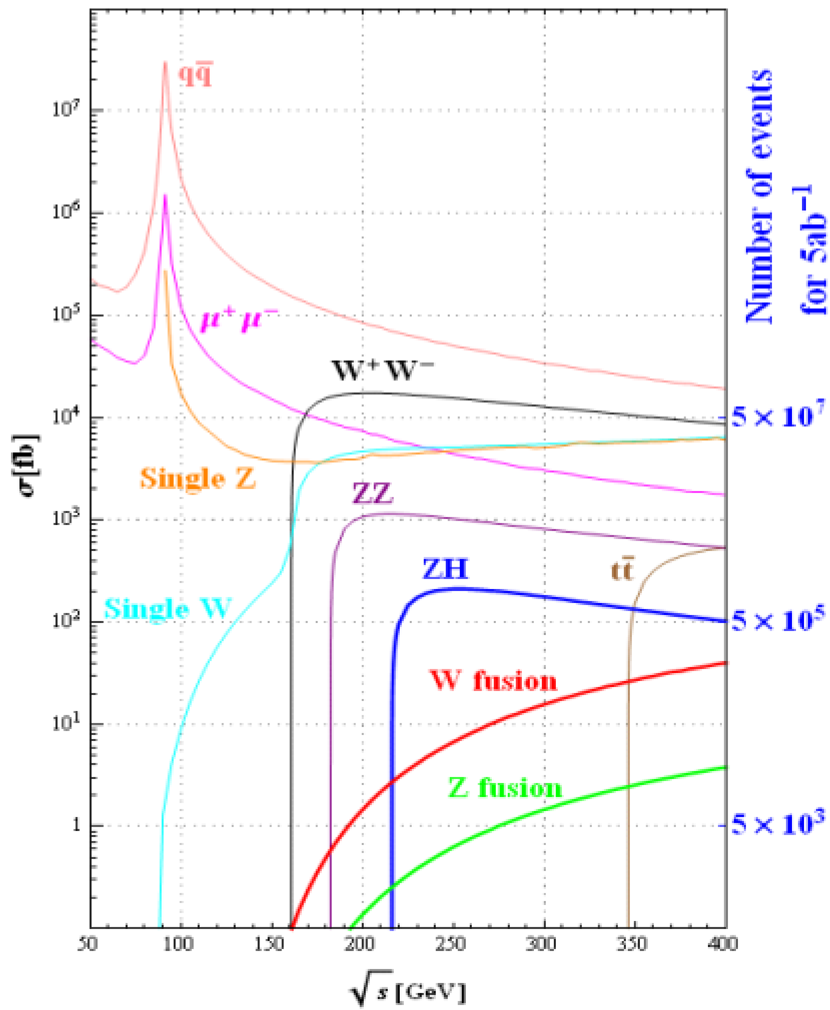


LEP Convention:
See more details in slides from Dr. Xin Mo

Summary Table

Cross sections [fb]

	240GeV	250GeV
qq	54662	50216
$\mu^+\mu^-$	4685	4405
single Z	4538	4734
single W	5086	5144
W^+W^-	16004	15484
ZZ	1079	1033
ZH	203	212
W fusion	5.36	6.72
Z fusion	0.50	0.63



Summary Table

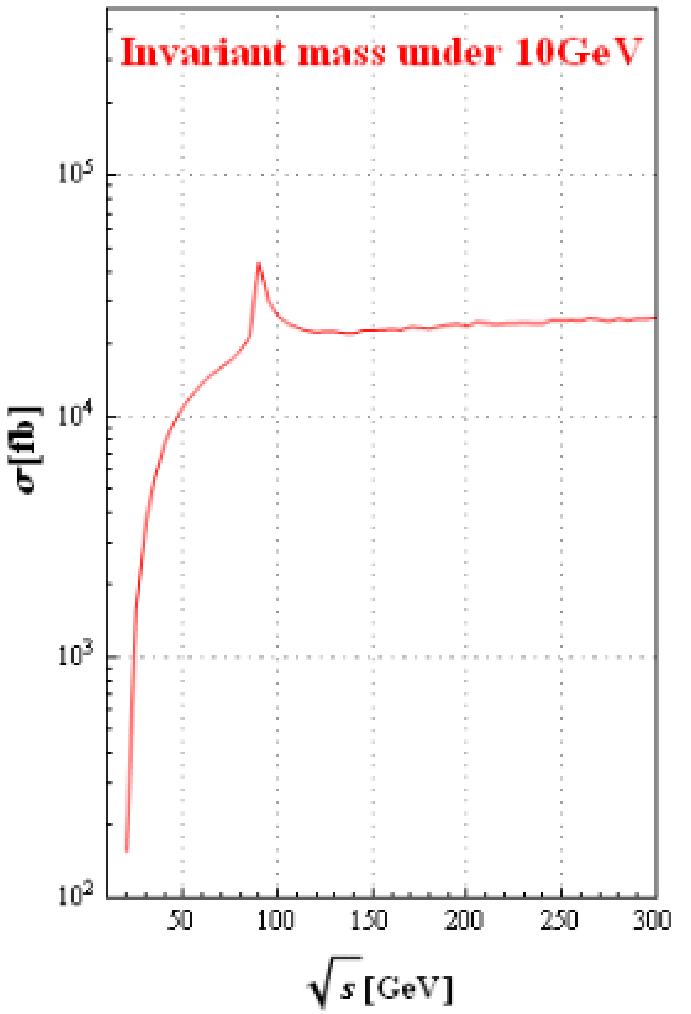
Process	Cross section	Nevents in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6
Background processes, cross section in pb		
$e^+e^- \to e^+e^-$ (Bhabha)	25.1	1.3×10^8
$e^+e^- \to qq$	50.2	2.5×10^8
$e^+e^- \to \mu\mu$ (or $\tau\tau$)	4.40	2.2×10^7
$e^+e^- \to WW$	15.4	7.7×10^7
$e^+e^- \to ZZ$	1.03	5.2×10^6
$e^+e^- \to eeZ$	4.73	2.4×10^7
$e^+e^- \to e\nu W$	5.14	2.6×10^7

Bhabha

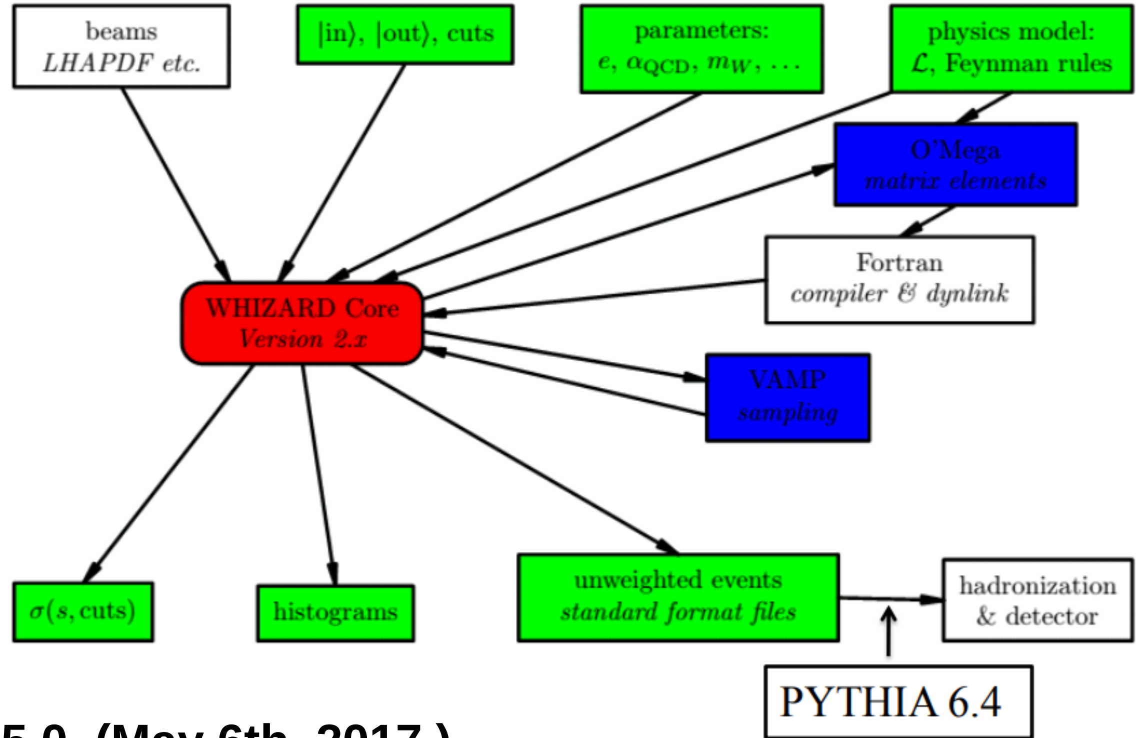
The Bhabha process

- Leading background
- Measurements for luminosity

Cut	σ [fb]	Error [fb]
10GeV	2705545	$O(10^4)$
5GeV	11062568	$O(10^4)$
1GeV	276518660	$O(10^6)$
0.5GeV	1077946300	$O(10^7)$



Whizard



The official version is 2.5.0. (May 6th, 2017.)

The WHIZARD Event Generator

The Generator of Monte Carlo Event Generators for Tevatron, LHC, ILC, CLIC, CEPC, FCC-ee, FCC-hh, SppC and other High Energy Physics Experiments

W,HIggs,Z And Respective Decays

Whizard

Slide from J. Reuter

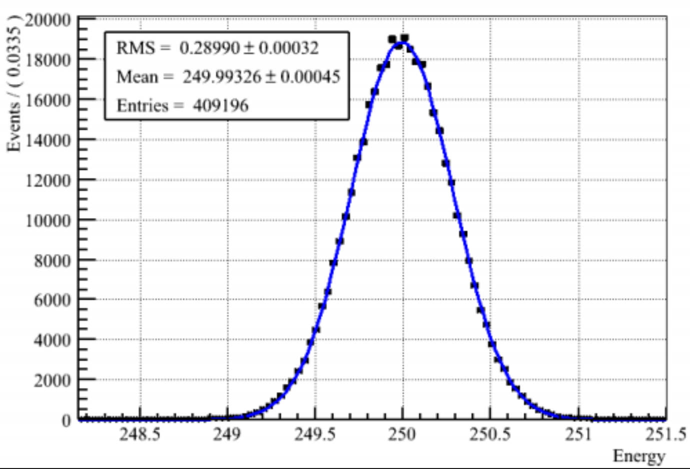
Structured Beams

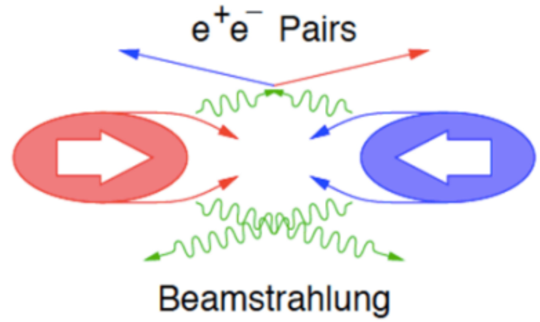
- **Hadron Colliders structured beams**
  - LHAPDF interface
  - CERN-/PDFLIB support no longer available
  - Most prominent PDFs directly included
  - ISR and FSR (two different own implementations, interface to PYTHIA) (cf. Talk S. Schmidt)
  - Matching matrix elements/showers (MLM) (cf. Talk S. Schmidt)
  - Underlying event/multiple interactions (cf. Talk H. Boschmann)
- **Lepton Colliders structured beams**
  - ISR (implemented: Skrzypek/Jadach, Kuraev/Fadin, incl. p_T distributions)
  - arbitrarily polarized beams (density matrices)
  - Beamstrahlung (CIRCE module)
  - Photon collider spectra (CIRCE2 module)
  - external beam spectra can be read in (files/generating code)
  - FSR (e.g. YFS) not (yet) implemented (charged mesons/hadrons)
- **Hadronic events/hadronic decays**
  - through PYTHIA interface (or HERWIG or Sherpa)

Beamstrahlung

Generator of Unwanted Interactions for Numerical Experiment Analysis Program Interfaced to GEANT

- GuineaPig
- Beam energy spectral





- Whizard version 1
  GuineaPig→lumilinker→user.f90
- Whizard version 2
  - Circe2
  - Internal CEPC spectral

Macroscopic em interactions.

One bunch bent by the field of the other bunch. There will be special kind of synchrotron radiation

At CEPC, this effect is small

	ISR [fb]	ISR & Beamstrahlung [fb]
$\sigma(e^+e^- \to ZH)$	212	211
$\sigma(e^+e^- \to \nu\bar{\nu}H)$	6.72	6.72
$\sigma(e^+e^- \to e^+e^-H)$	0.63	0.63
$\sigma(e^+e^- \to q\bar{q})$	50216	50416
$\sigma(e^+e^- \to W^+W^-)$	15484	15440
$\sigma(e^+e^- \to ZZ)$	1033	1030

Qinglei Xiu, Hongbo Zhu, Xinchou Lou

Xin Mo, Gang Li, Manqi Ruan, Xinchou Lou

Whizard cepc

Parameters	Symbol	LEP2	CEPC	ILC250	ILC500
Center of mass energy	E_{cm} [GeV]	209	240	250	500
Bunch population	N [$\times 10^{10}$]	58	37.1	2	2
Horizontal beam size at IP	σ_x [nm]	270000	73700	729	474
Vertical beam size at IP	σ_y [nm]	3500	160	7.7	5.9
Bunch length	σ_z [μm]	16000	2260	300	300
Horizontal beta function at IP	β_x [mm]	1500	800	13	11
Vertical beta function at IP	β_y [mm]	50	1.2	0.41	0.48
Normalized horizontal emittance at IP	$\gamma\epsilon_x$ [mm · mrad]	9.81	1594.5	10	10
Normalized vertical emittance at IP	$\gamma\epsilon_y$ [mm · mrad]	0.051	4.79	0.035	0.035
Luminosity	L [10^{34} cm^{-2}s^{-1}]	0.013	1.8	0.75	1.8
Beamstrahlung parameter	Υ_{av} [$\times 10^{-4}$]	**0.25**	**4.7**	**200**	**620**

Qinglei Xiu, Hongbo Zhu, Xinchou Lou

The beamstrahlung is usually characterised by the beamstrahlung parameter Υ :

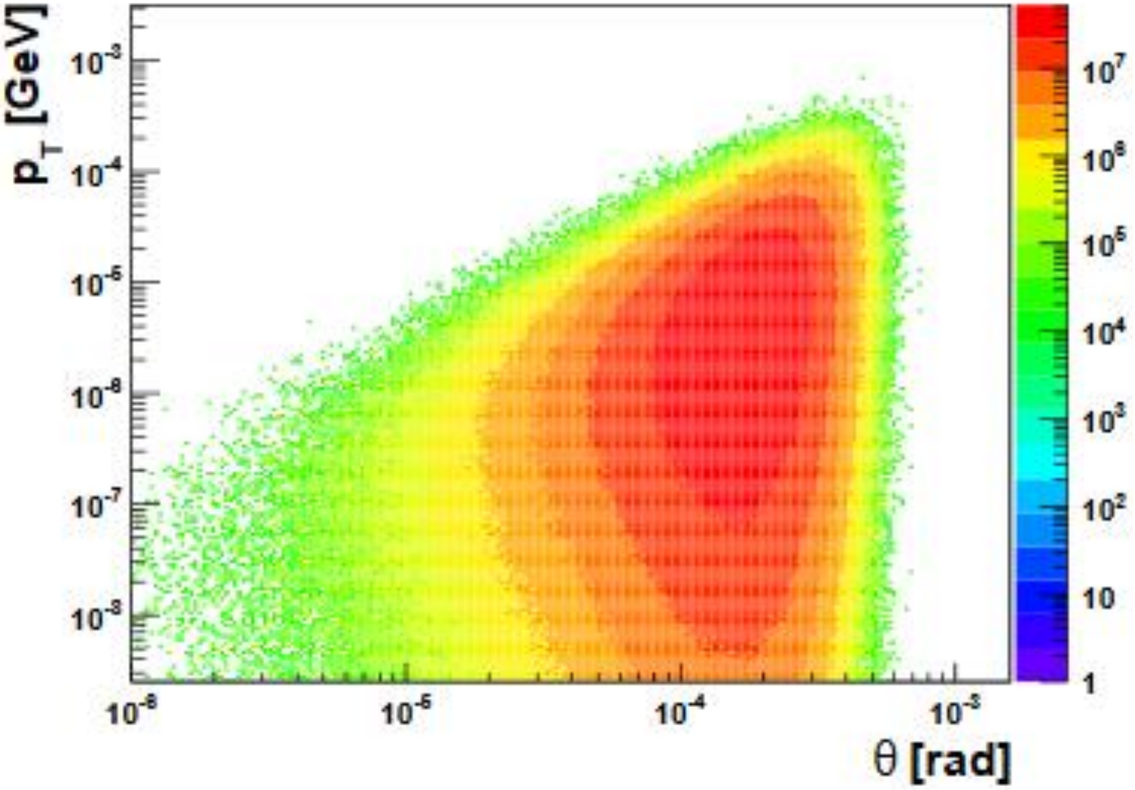
$$\Upsilon = \frac{2}{3}\frac{h\omega_c}{E}$$

where $\omega_c = \frac{3}{2}\gamma^3 c/\rho$ denotes the critical energy of synchrotron radiation, ρ the bending radius of the particle trajectory and E the beam particle energy before radiation. The higher the Υ, the more beamstrahlung photons with higher energies will be emitted. Assuming Gaussian charge distributions for the colliding beams, the average Υ can be estimated with the following formula:

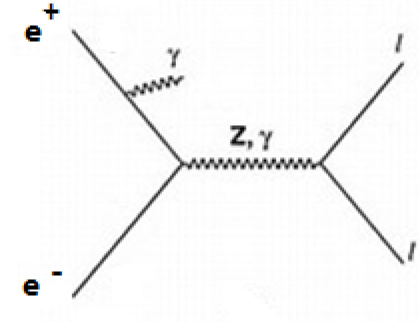
$$\Upsilon_{av} \approx \frac{5}{6}\frac{N r_e^2 \gamma}{\alpha(\sigma_x + \sigma_y)\sigma_z}$$

where r_e is the classical electron radius, γ the Lorentz factor of the beam particles, α the fine structure constant, σ_x/σ_y the transverse size of the bunch and σ_z the bunch length.

The beam-beam interactions have been simulated with Guinea-Pig++ (Generator of Unwanted Interac-tions for Numerical Experiment Analysis Program Interfaced to GEANT), which allows detailed studies of the emission of the beamstrahlung photons, the incoherent pair production and the hadronic events



Initial State Radiation



lepton-collider processes are strongly affected by electromagnetic initial-state radiation (ISR).

WHIZARD implements ISR in a standard structure function formalism that resum the corrections from infrared (leading) and collinear (3rd order) radiation and implements them in kinematics and dynamics, if requested.

$$f_0(x) = \epsilon(1-x)^{-1+\epsilon}$$

$$f_1(x) = g_1(\epsilon)\, f_0(x) - \frac{\epsilon}{2}(1+x)$$

$$f_2(x) = g_2(\epsilon)\, f_0(x) - \frac{\epsilon}{2}(1+x) - \frac{\epsilon^2}{8}\left(\frac{1+3x^2}{1-x}\ln x + 4(1+x)\ln(1-x) + 5 + x\right)$$

$$f_3(x) = g_3(\epsilon)\, f_0(x) - \frac{\epsilon}{2}(1+x) - \frac{\epsilon^2}{8}\left(\frac{1+3x^2}{1-x}\ln x + 4(1+x)\ln(1-x) + 5 + x\right) - \frac{\epsilon^3}{48}\left((1+x)\left[6\,\mathrm{Li}_2(x) + 12\ln^2(1-x) - 3\pi^2\right] + 6(x+5)\ln(1-x) + \frac{1}{1-x}\left[\frac{3}{2}(1+8x+3x^2)\ln x + 12(1+x^2)\ln x\ln(1-x) - \frac{1}{2}(1+7x^2)\ln^2 x + \frac{1}{4}(39-24x-15x^2)\right]\right)$$

$$g(\epsilon) = \frac{\exp\left(\epsilon(-\gamma_E + \frac{3}{4})\right)}{\Gamma(1+\epsilon)}$$

Parameter	Default	Meaning
isr_alpha	0/intrinsic	value of α_{QED} for ISR
isr_order	3	max. order of hard-collinear photon emission
isr_mass	0/intrinsic	mass of the radiating lepton
isr_q_max	$0/\sqrt{s}$	upper cutoff for ISR
?isr_recoil	false	flag to switch on recoil/p_T
?isr_keep_energy	false	recoil flag to conserve energy in splitting

$$x = 1 - (1 - x')^{1/\epsilon}$$

MC Mapping to avoid inefficiency
See more in Sec.15.6 in Whizard Manual

Initial State Radiation

./bin/whizard zh.sin

```
process proc = "e+", "e-" => "Z", "H"
compile
sqrts = 250 GeV
beams = "e+", "e-" => isr
integrate(proc)
simulate (proc) {
n_events = 2000
$sample = "my_events"
sample_format = lhef
}
```

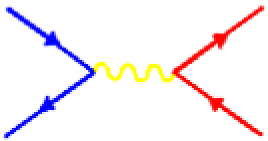
```
Initializing integration for process proc:
 Beam structure: e+, e-
 Beam data (collision):
   e+  (mass = 5.1099700E-04 GeV)
   e-  (mass = 5.1099700E-04 GeV)
   sqrts = 2.500000000000E+02 GeV
------------------------------------------------------------
Process [scattering]: 'proc'
  Library name  = 'default_lib'
  Process index = 1
  Process components:
    1: 'proc_i1':   e+, e- => Z, H [omega]
============================================================
 It      Calls  Integral[fb]  Error[fb]   Err[%]    Acc  Eff[%]
============================================================
 VAMP: parameter mismatch, discarding grid file 'proc_m1.vg'
  1        800  2.4007857E+02  5.62E-02    0.02    0.01*  93.68
  2        800  2.4016919E+02  4.74E-02    0.02    0.01*  50.86
  3        800  2.4018463E+02  4.98E-02    0.02    0.01   65.36
------------------------------------------------------------
  3       2400  2.4014992E+02  2.93E-02    0.01    0.01   65.36
------------------------------------------------------------
  4       9984  2.4015210E+02  4.29E-03    0.00    0.00*  65.35
  5       9984  2.4015829E+02  4.25E-03    0.00    0.00*  65.35
  6       9984  2.4015343E+02  4.24E-03    0.00    0.00*  65.35
------------------------------------------------------------
  6      29952  2.4015462E+02  2.46E-03    0.00    0.00   65.35
============================================================
```

```
Initializing integration for process proc:
Beam structure: e+, e- => isr
Beam data (collision):
  e+  (mass = 5.1099700E-04 GeV)
  e-  (mass = 5.1099700E-04 GeV)
  sqrts = 2.500000000000E+02 GeV
------------------------------------------------------------
Process [scattering]: 'proc'
  Library name  = 'default_lib'
  Process index = 1
  Process components:
    1: 'proc_i1':   e+, e- => Z, H [omega]
============================================================
 It      Calls  Integral[fb]  Error[fb]   Err[%]    Acc  Eff[%]
============================================================
 VAMP: using grids and results from file 'proc_m1.vg'
  1       1000  2.1561167E+02  3.04E+00    1.41    0.45*  45.91
  2       1000  2.1558059E+02  1.98E+00    0.92    0.29*  27.42
  3       1000  2.1076954E+02  1.59E+00    0.75    0.24*  51.51
------------------------------------------------------------
  3       3000  2.1306671E+02  1.15E+00    0.54    0.29   51.51
------------------------------------------------------------
 VAMP: using grids and results from file 'proc_m1.vg'
  4      10000  2.1186554E+02  5.10E-01    0.24    0.24   49.07
  5      10000  2.1033709E+02  5.27E-01    0.25    0.25   48.71
  6      10000  2.1245617E+02  4.96E-01    0.23    0.23*  45.38
```

No ISR: ~240fb

With ISR: ~212fb

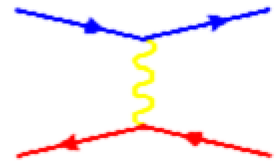
MadGraph for CEPC



The MadGraph5_aMC@NLO homepage

UCL UIUC Launchpad

by the MG/ME Development team



Generate Process | Register | Tools | My Database | Cluster Status | Downloads (needs account) | Wiki | Answers | Bug reports

User friendly

High precision simulation

Advanced for pp colliders

Event.hep (MadGraph+ pythia) → **convertStdHep** → Event.hepmc (intermediate step) → **HepMCToHEPEvt** → Event.HEPevt (Input for CEPC)

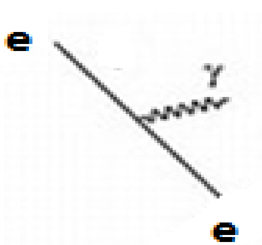
Note: stdhep package should be adjusted to match CEPC framework

MadGraph for CEPC

Effective Photon approximation
Source/PDF/PhotonFlux.f

Improving the Weizsäcker-Williams Approximation in Electron-Proton Collisions
hep-ph/9310350

$$f_\gamma^{(e)}(y) = \frac{\alpha_{\rm em}}{2\pi}\left[2m_e^2 y\left(\frac{1}{q_{max}^2} - \frac{1}{q_{min}^2}\right) + \frac{1+(1-y)^2}{y}\log\frac{q_{min}^2}{q_{max}^2}\right]$$



If Naïvely starting from here, and change y to 1-x,
-> Large instability!
Singular when x -> 1

$$f_e(x)dx = \frac{\alpha}{2\pi}\left[\frac{1+x^2}{1-x}\right]\log\frac{Q}{m_e}\,dx$$

arXiv:1002.0204

PhotonFlux.f ×

```
c/* ********************************************************* */
c/*  Equivalent photon approximation structure function.   * */
c/*     Improved Weizsaecker-Williams formula              * */
c/*   V.M.Budnev et al., Phys.Rep. 15C (1975) 181          * */
c/* ********************************************************* */
c    provided by Tomasz Pierzchala - UCL

      real*8 function epa_electron(x,q2max)
      integer i
      real*8 x,phi_f
      real*8 xin
      real*8 alpha
      real*8 f, q2min,q2max
      real*8 PI
      data PI/3.14159265358979323846/

      data xin/0.511d-3/ !electron mass in GeV

      alpha = .0072992701

C     // x = omega/E = (E-E')/E
      if (x.lt.1) then
         q2min= xin*xin*x*x/(1-x)
         if(q2min.lt.q2max) then
            f = alpha/2d0/PI*
     &           (2d0*xin*xin*x*(-1/q2min+1/q2max)+
     &           (2-2d0*x+x*x)/x*dlog(q2max/q2min))

         else
           f = 0.
         endif
      else
         f= 0.
      endif
c      write (*,*) x,dsqrt(q2min),dsqrt(q2max),f
      if (f .lt. 0) f = 0
      epa_electron= f

      end
```

MadGraph for CEPC

Singular when x -> 1, -> ISR structure function as in Whizard

15.6.1 Physics

Whizard Manual

The ISR structure function is in the most crude approximation (LLA without α corrections, i.e. ϵ^0)

$$f_0(x) = \epsilon(1-x)^{-1+\epsilon} \qquad \text{with} \qquad \epsilon = \frac{\alpha}{\pi} q_e^2 \ln\frac{s}{m^2}, \tag{15.27}$$

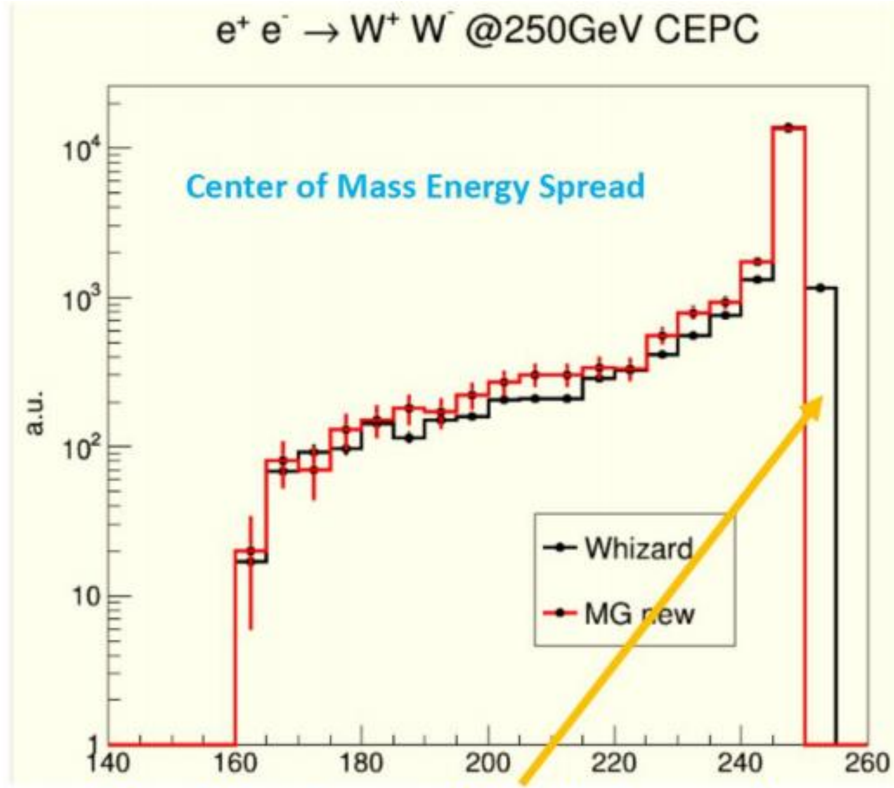
Including ϵ, ϵ^2, and ϵ^3 corrections, the successive approximation of the ISR structure function read

$$f_0(x) = \epsilon(1-x)^{-1+\epsilon} \tag{15.33}$$

$$f_1(x) = g_1(\epsilon)\, f_0(x) - \frac{\epsilon}{2}(1+x) \tag{15.34}$$

$$f_2(x) = g_2(\epsilon)\, f_0(x) - \frac{\epsilon}{2}(1+x) - \frac{\epsilon^2}{8}\left(\frac{1+3x^2}{1-x}\ln x + 4(1+x)\ln(1-x) + 5 + x\right) \tag{15.35}$$

$$\begin{aligned} f_3(x) = {} & g_3(\epsilon)\, f_0(x) - \frac{\epsilon}{2}(1+x) \\ & - \frac{\epsilon^2}{8}\left(\frac{1+3x^2}{1-x}\ln x + 4(1+x)\ln(1-x) + 5 + x\right) \\ & - \frac{\epsilon^3}{48}\Bigg((1+x)\left[6\,\mathrm{Li}_2(x) + 12\ln^2(1-x) - 3\pi^2\right] + 6(x+5)\ln(1-x) \\ & \quad + \frac{1}{1-x}\left[\frac{3}{2}(1+8x+3x^2)\ln x + 12(1+x^2)\ln x \ln(1-x) \right. \\ & \quad \left. - \frac{1}{2}(1+7x^2)\ln^2 x + \frac{1}{4}(39-24x-15x^2)\right]\Bigg) \end{aligned} \tag{15.36}$$



'Singular' region near X~1, to be improved more with Monte-Carlo Mapping

-> Improved by MC mapping,
should adjust the phase space generating code

ISR with MG

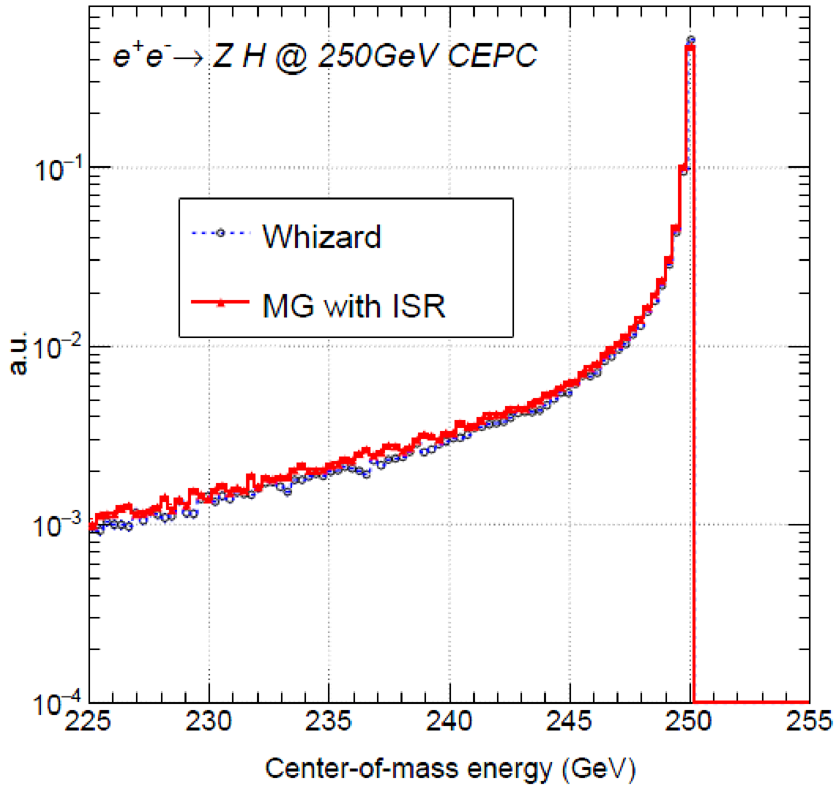
https://github.com/qliphy/MGISR/tree/mg262

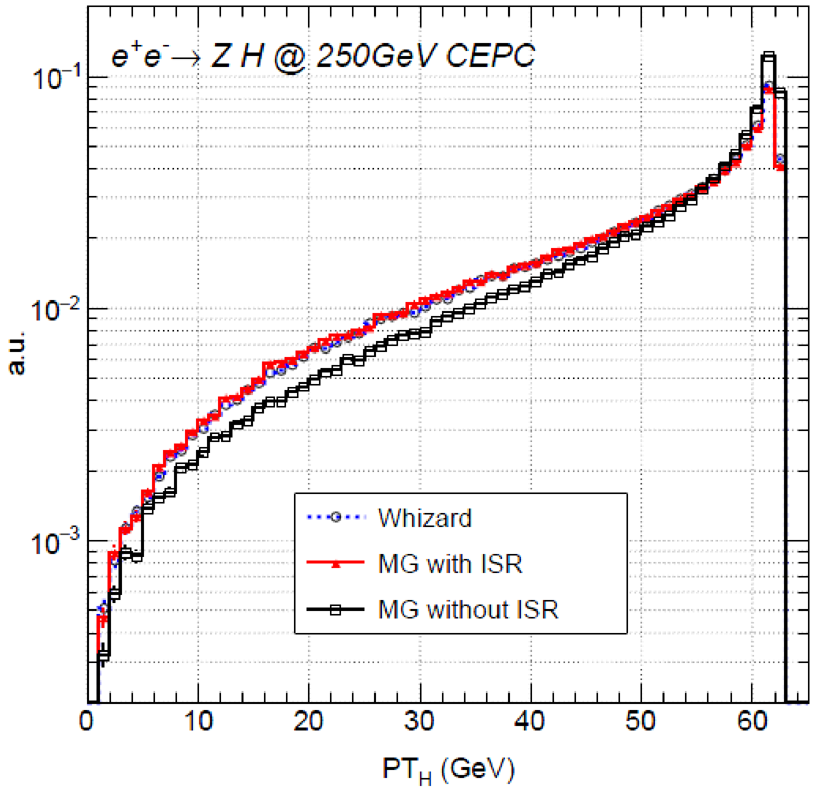
LICENSE	Create LICENSE	a year ago
README.md	Update README.md	6 months ago
__init__.py	for mg262	6 months ago
genps.f	Update genps.f	6 months ago
pdg2pdf.f	for mg262	6 months ago
reweight.f	for mg262	6 months ago

A plugin for MGV26 to include Initial State Radiation
Put it under MG/Plugin.
After generating a process, output to a directory:
output EE_ISR YourDirectory
The only difference from nominal way is "EE_ISR" added above

Note: Master branch is being developed; Branch mg262 is frozen and can work with MG262

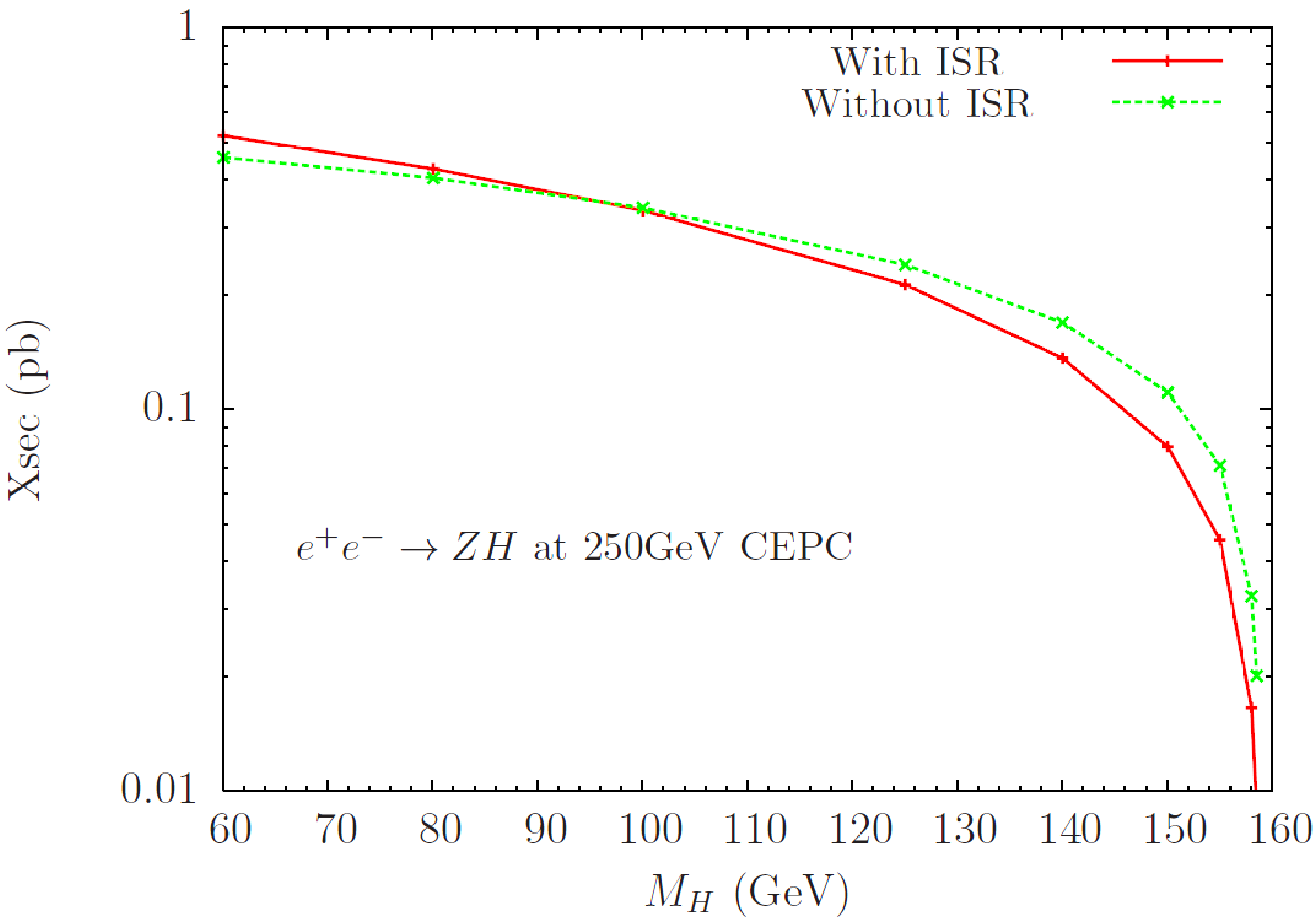
Validation



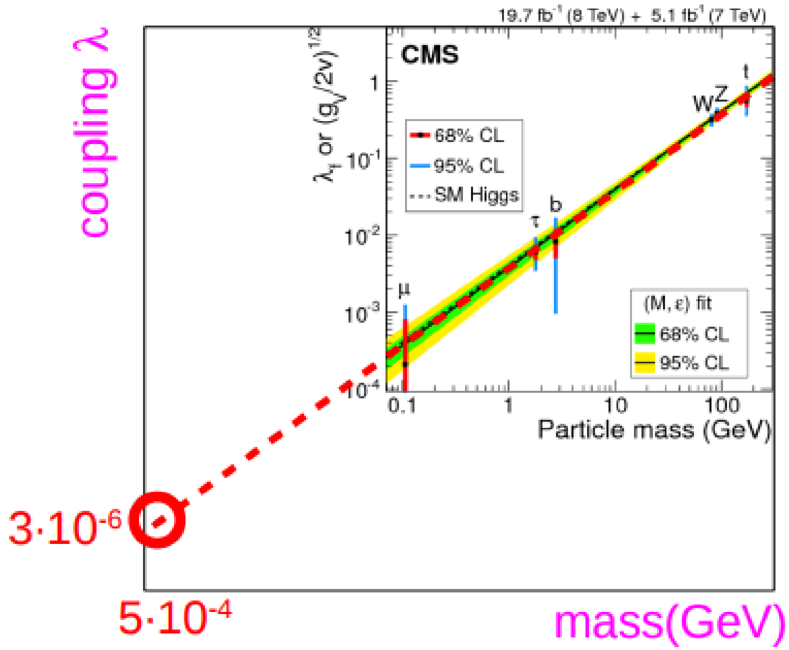


Similar checks have also been done for other processes including $e^+e^- \to W^+W^-, W^+W^-Z$

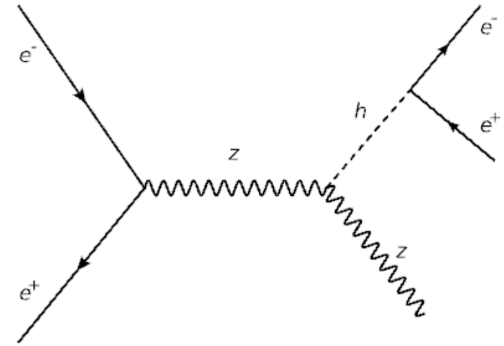
Non-Standard Higgs



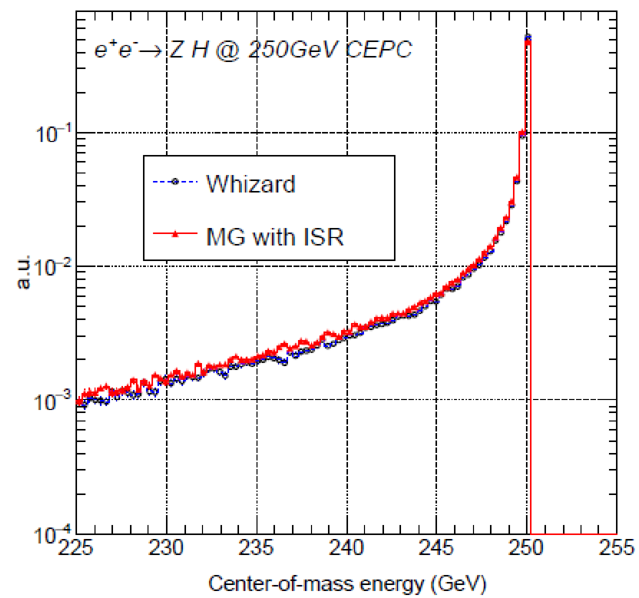
$H \rightarrow ee$



FCC-ee Phys. Workshop, CERN, Feb'16



$$m^2_{recoil} = s + m^2_H - 2 \cdot E_H \cdot \sqrt{s}$$

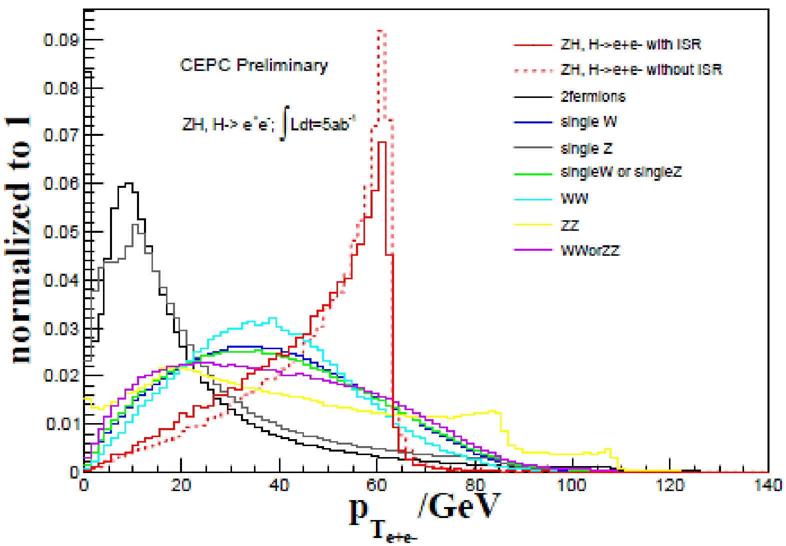


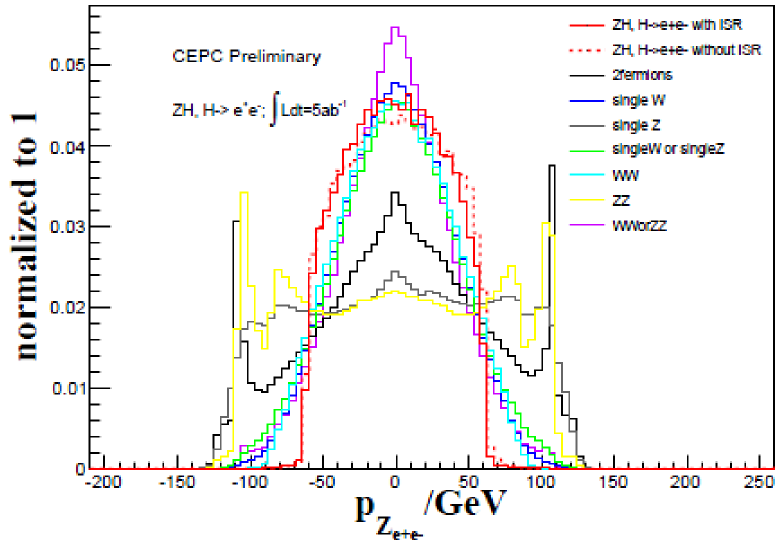
CMS Run1: 95% CL upper limit as 0.19%
FCC-ee: resonant s-channel can be sensitive to around 2 times SM prediction, but depends much on beam energy control

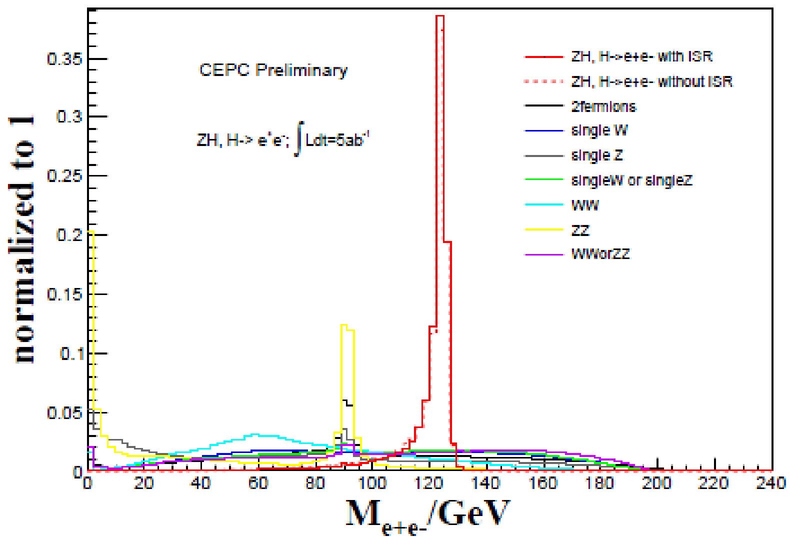
Signal Samples from MG;
Bkg samples from CEPC official productions

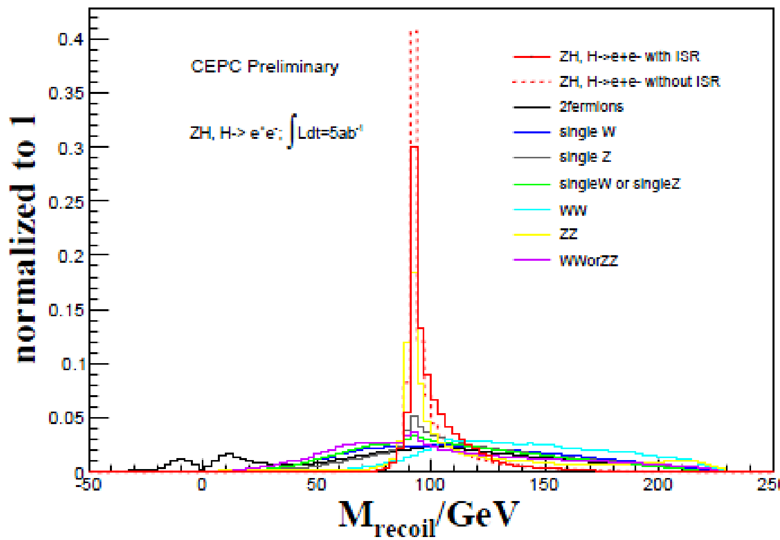
$H \to ee$

Distributions of $p_{\mathrm{T}e^+e^-}$, $p_{\mathrm{Z}e^+e^-}$, $M_{e^+e^-}$ and M_{recoil} for signals and backgrounds.









$H \to ee$

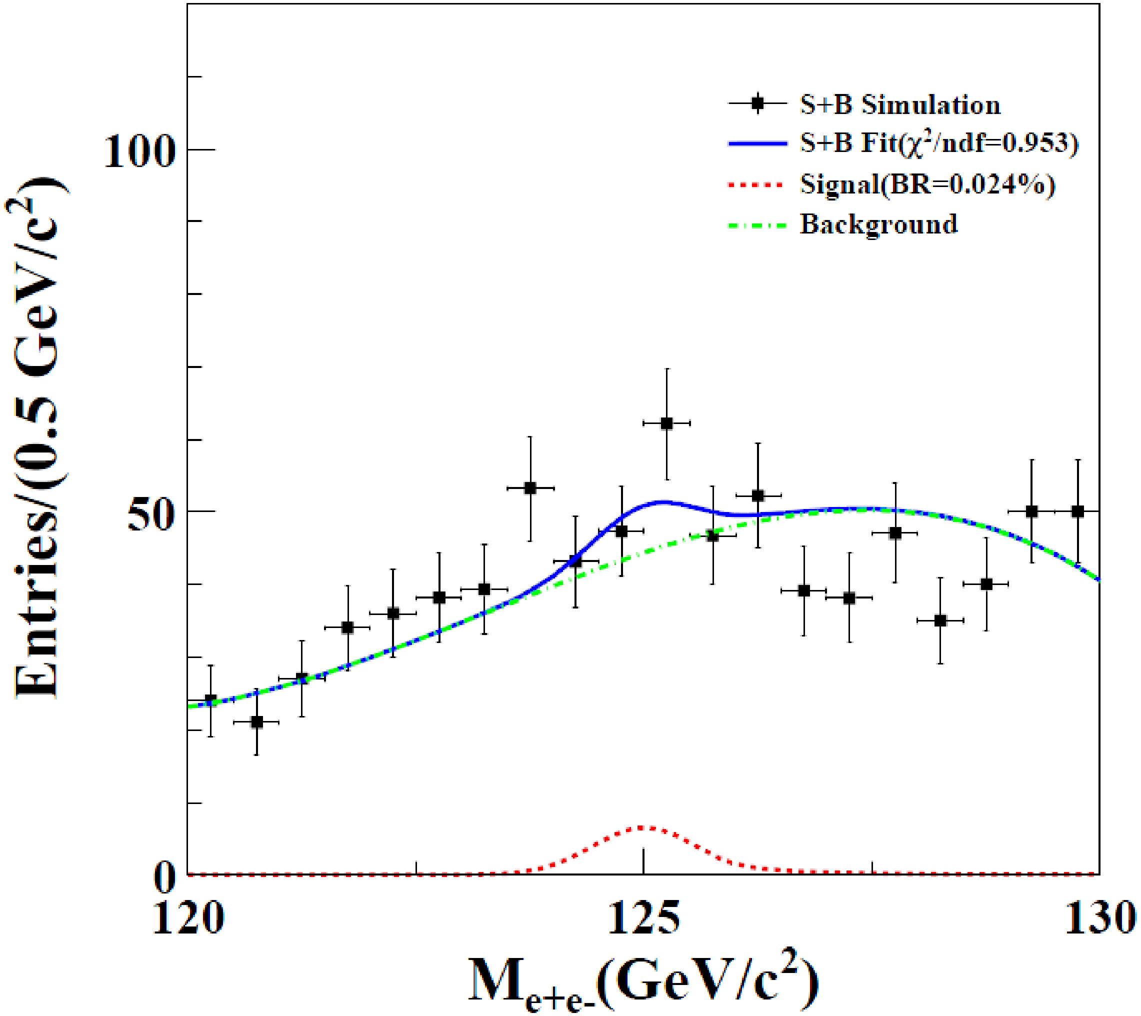
CEPC with $\sqrt{s} = 250$ GeV and integrated luminosity of 5000 fb^{-1}

Category	signal	2fermions	single ZorW	single Z	single W
total	50000	418194802	1259165	7913405	17190655
$N_{e^+} \geq 1$, $N_{e^-} \geq 1$	47418	36822471	978594	3480494	2260761
120 GeV $< M_{e^+e^-} <$ 130 GeV	34463	1954192	71193	126094	151950
90 GeV $< M_{recoil} <$ 93 GeV	12362	61089	3564	6954	7255
46 GeV $< p_{\mathrm{T}e^+e^-} <$ 63 GeV	8582	6816	1863	1861	3652
-42 GeV $< p_{\mathrm{Z}e^+e^-} <$ 41 GeV	8511	6372	1783	1750	3468
$\Delta\phi < 166°$	7404	5131	1696	1651	3233
$cos_{e^+} \geq$ -0.07, $cos_{e^-} \leq$ 0.14	3564	241	86	48	161

Category	WW	ZZ	WWorZZ	total background
total	49115769	4967152	21902983	520543931
$N_{e^+} \geq 1$, $N_{e^-} \geq 1$	640839	758732	814608	45756499
120 GeV $< M_{e^+e^-} <$ 130 GeV	26731	7593	55196	2392949
90 GeV $< M_{recoil} <$ 93 GeV	1783	1464	2434	84543
46 GeV $< p_{\mathrm{T}e^+e^-} <$ 63 GeV	868	682	1297	17039
-42 GeV $< p_{\mathrm{Z}e^+e^-} <$ 41 GeV	837	647	1247	16104
$\Delta\phi > 166°$	702	566	1182	14161
$cos_{e^+} \geq$ -0.07, $cos_{e^-} \leq$ 0.14	20	178	70	804

Signal Efficiency: 10.4% wo ISR; 7.1% w ISR

$H \to ee$



95% CL upper limit on Br($H \to ee$):

0.017% wo ISR
0.024% w ISR

The invariant mass spectrum of e +e − in the inclusive analysis. The dots with error bars represent data from CEPC simulation. The solid (blue) line indicates the fit. The dashed (red) shows the signal (assuming B(H −→ e +e −)=0.024%) and the long-dashed (green) line is the background.

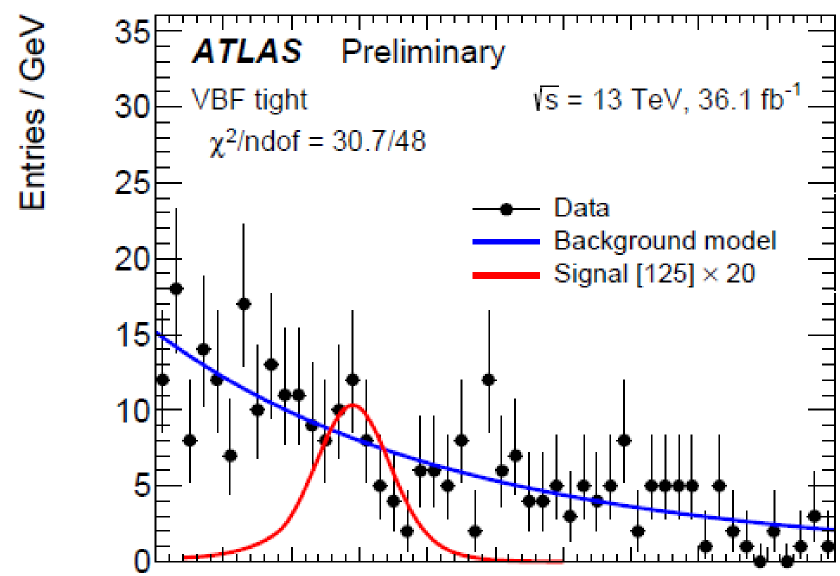
H → μμ

Detector	Signal	luminosity(fb^{-1})	$\sqrt{s}$ (TeV)	Significance or Precision
ILC *arXiv:1603.04718* *arXiv:0911.0006*	ννH	500	1	2.75
	qqH	250	0.25	1.1
	ννH	250	0.25	1.8

ATL-PHYS-PUB-2013-014
CMS NOTE-13-002

		μ-hat error	
	$\mathscr{L}$ (fb^{-1})	Scenario 1	Scenario 2
ATLAS	300	± 0.39	± 0.38
CMS	300	± 0.42	± 0.40
ATLAS	3000	± 0.16	± 0.12
CMS	3000	± 0.20	± 0.14

ATLAS scenarios: 1- full sys 2- no theory sys
CMS scenarios: 1- run-1 sys 2- reduced sys



The observed (expected) upper limit is 2.8(2.9) times the Standard Model prediction. ATLAS-CONF-2017-14

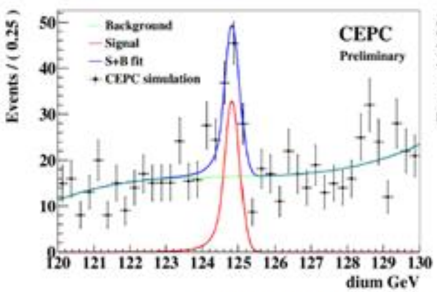
$H \to \mu\mu$

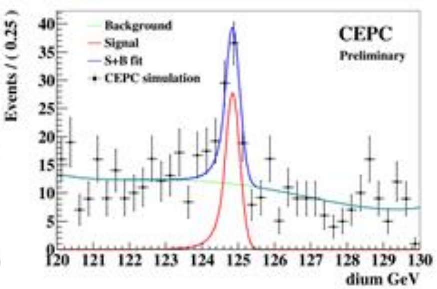
•Inclusive analysis

• Cut-based

Category	signal	ZZ	WW	ZZorWW	SingleZ	2f
Preselection	207.3	311312	129869	501590	63658	1740371
120<dium<130	189.7	5479	17126	57405	1868	52525
90.8<recoilu<93.4	118.4	1207	868	2115	164	1157
25<diupt<62.4	109.5	951	697	1675	121	439
-55.2<diupz<55.2	107.1	897	647	1613	112	391
cosum<0.28	69.7	480	55	277	55	164
cosup>-0.28	58.3	348	29	142	44	116
puu>-0.996	58.0	346	27	142	43	70
efficiency	28.0%					

• MVA(BDTG) :muon momentum and angles





Fit result with cut-based(left) and MVA(right)

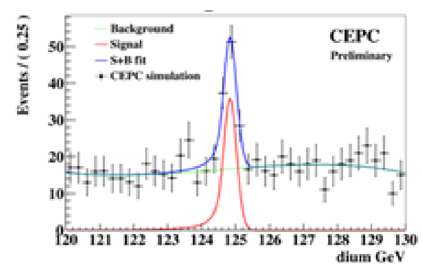
•ZqqHuu analysis

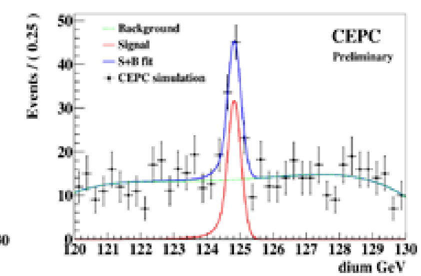
• Cut-based

Category	signal	ZZ	WW	ZZorWW	SingleZ	2f
Preselection	207.3	390775	183751	463361	101164	0
120<invariant mass<130	141.6	3786	181	227	244	0
jet1m<4.2 jet2m<2.8	133.0	3216	111	0	9	0
dijm>76.0	127.5	2917	2	0	8	0
90.9<recoilu<93.5	78.7	893	0	0	0	0
20<diupt<62.3	74.9	743	0	0	0	0
-58<diupz<58	74.2	714	0	0	0	0
cosup>-0.94	73.0	691	0	0	0	0
cosum<0.94	71.6	665	0	0	0	0
efficiency	50.6%					

• TMVA step1 (MLP): jet1m,jet2m,dijm,recoil

step2 (BDTG): cosum, cosup, upZ, umZ, diupz,dijpz, j1H, j2H, cosj1,cosj2





Fit result of cut-based (left) and MVA(right)

Significance (σ)			
	Inclusive	**$Z \to qq$**	**$Z \to \nu\nu$**
MVA	7.37	8.17	2.62
Cut	7.67	8.12	1.91

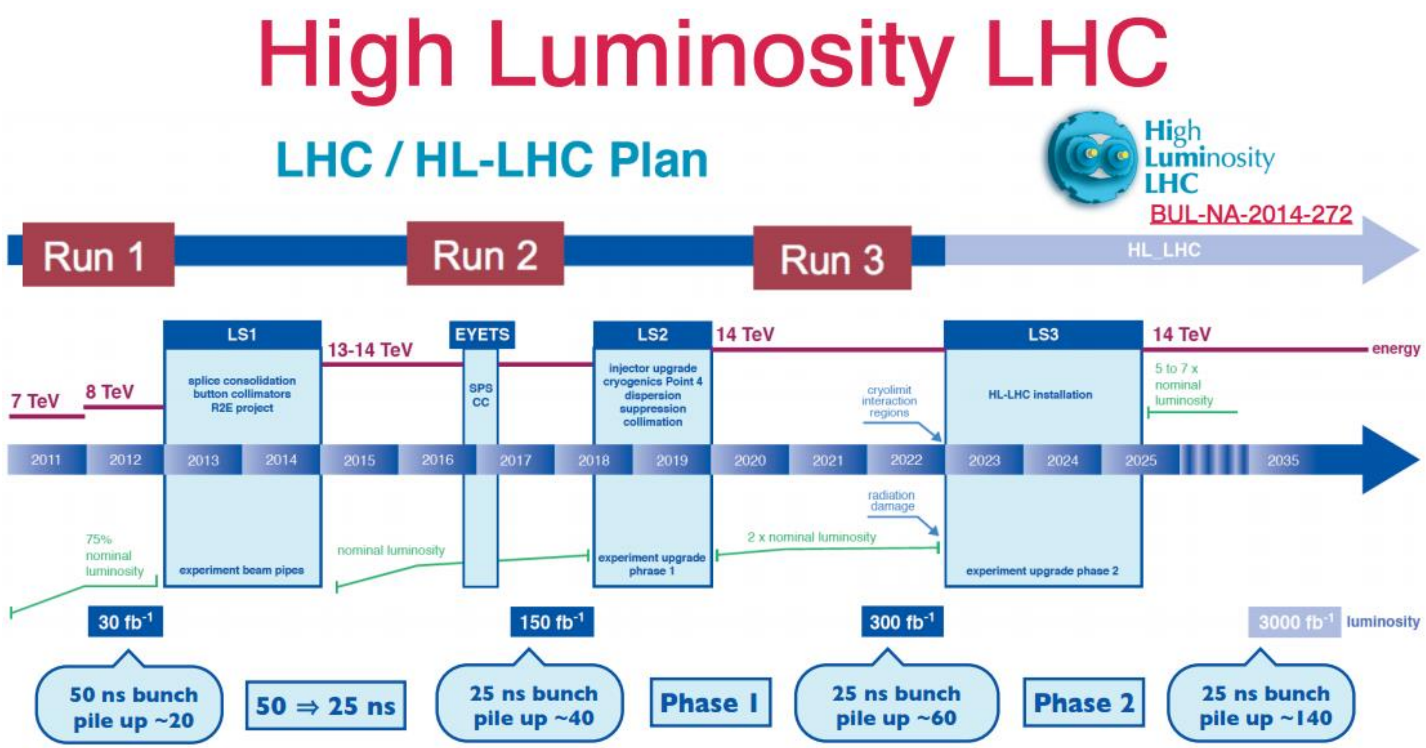
Together with optimization results on tracker size and magnetic field in CDR

$1.04^{+0.13}_{-0.13}$ **Improved from +-17% in pre-CDR**

HL – LHC

The HL-LHC project started as an international endeavour involving 29 institutes from 13 countries. It began in November 2011 and two years later was identified as one of the main priorities of the European Strategy for Particle Physics, before the project **was formally approved by the CERN Council in June 2016**.

‘The High-Luminosity LHC will extend the LHC’s reach beyond its initial mission, bringing new opportunities for discovery, measuring the properties of particles such as the Higgs boson with greater precision, and exploring the fundamental constituents of the universe ever more profoundly,’ said CERN Director-General Fabiola Gianotti.



Backup

Feasibility & Optimized Parameters

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

	CEPC_v1 (~ ILD)	Optimized (Preliminary)	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 – 20 mm	Passive cooling request ~ 20 mm. 10 mm should be highly appreciated for EW measurements – need further evaluation
ECAL NLayer	30	20 – 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.

Manqi Ruan