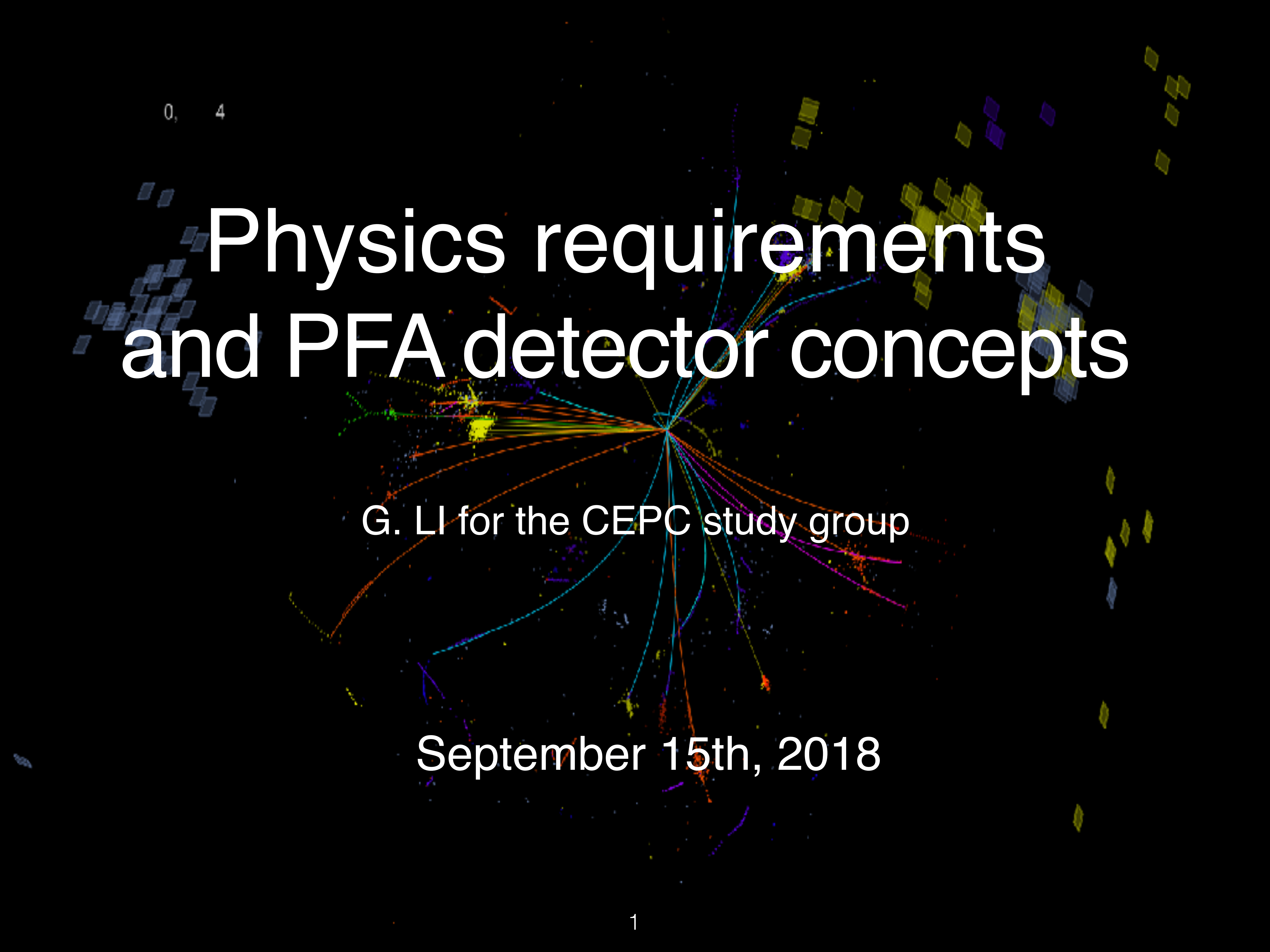
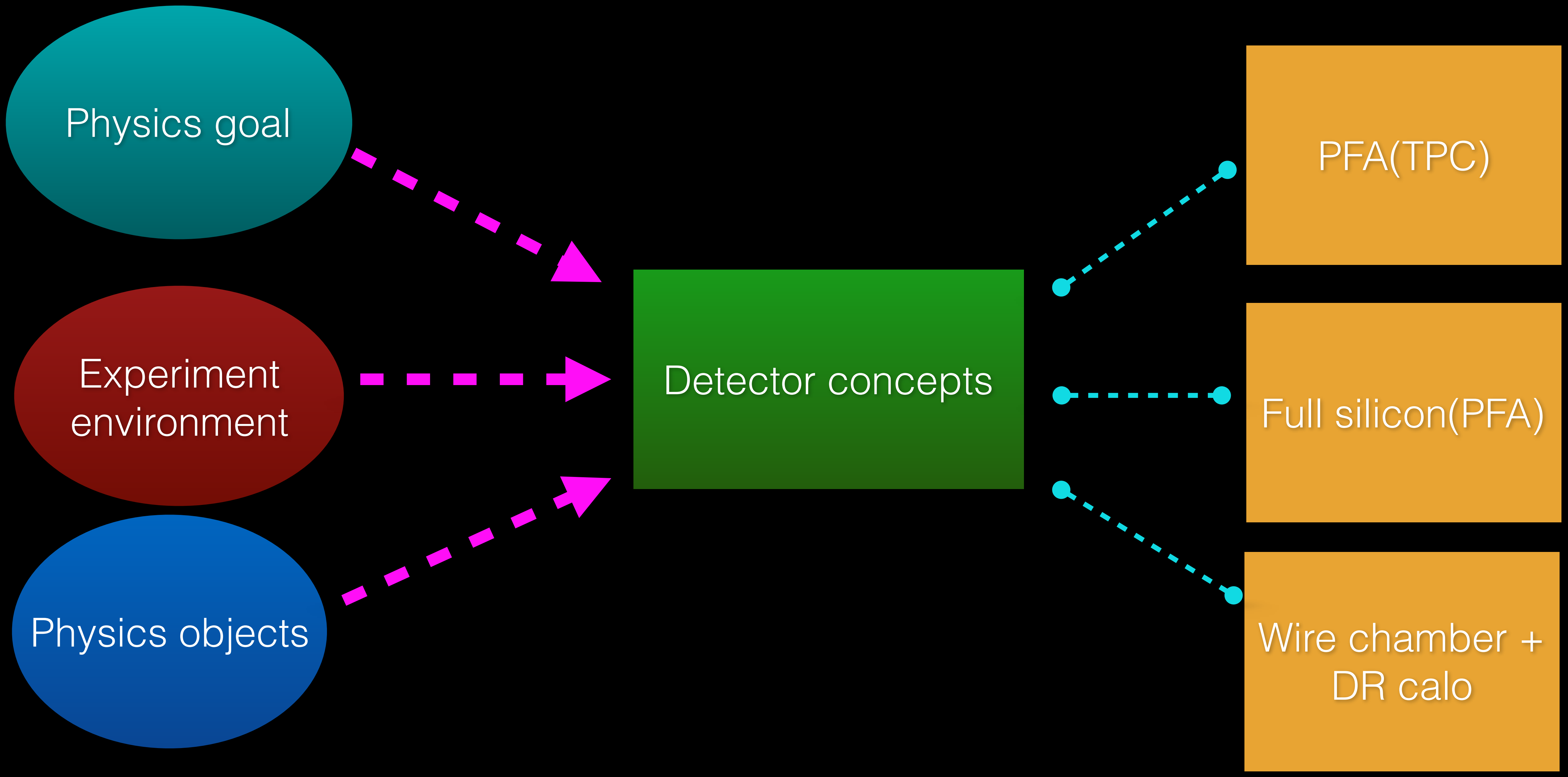


Physics requirements and PFA detector concepts

G. LI for the CEPC study group

September 15th, 2018

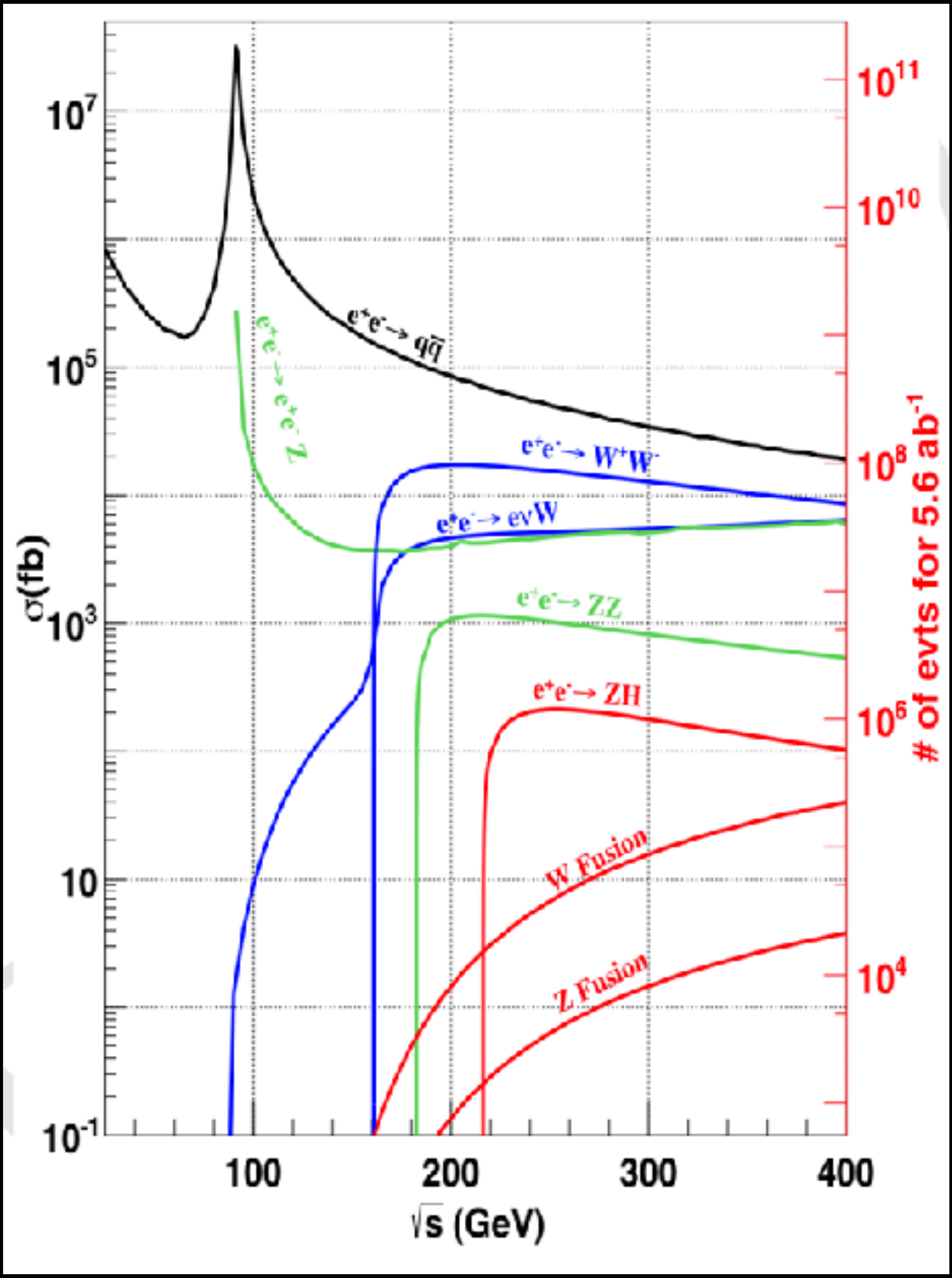
Schema


Physics goal
Experiment environment
Physics objects
Detector concepts
PFA(TPC)
Full silicon(PFA)
Wire chamber + DR calo

Physics of Z, W, and Higgs

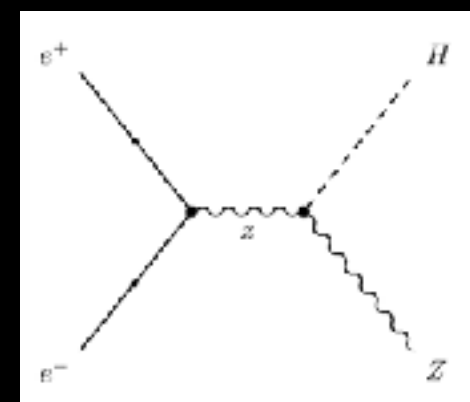
- ✓CEPC dedicated to Higgs physics, as well as EW physics of W & Z
- ✓1M Higgs events expected, still limited by statistics ~O(0.01), but
- ✓W&Z physics extremely depends on the systematic uncertainty control

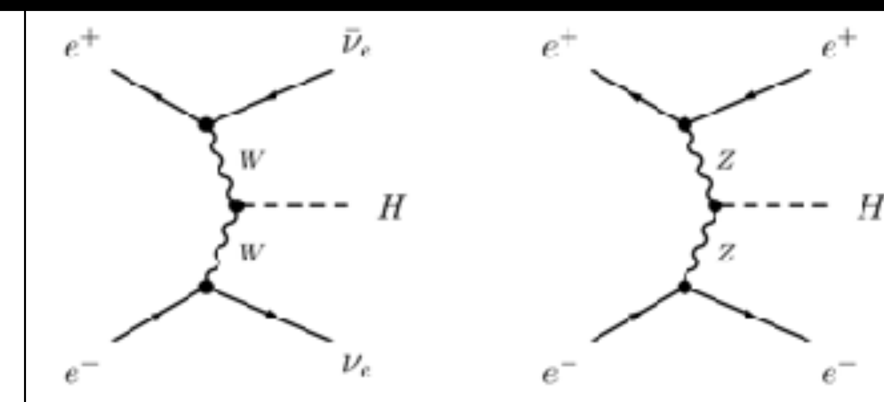
Operation mode	Z factory	W threshold scan	Higgs factory
$\sqrt{s}$ (GeV)	91.2	158 - 172	240
L (10^{34}cm^{-2}s^{-1})	16-32	10	3
Running time (years)	2	1	7
Integrated Luminosity (ab^{-1})	8 - 16	2.6	5.6
Higgs yield	-	-	10^6
W yield	-	10^7	10^8
Z yield	10^{11-12}	10^9	10^9



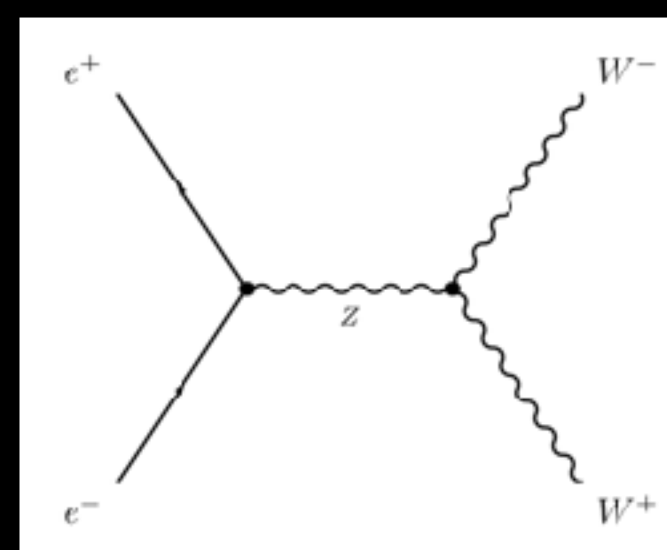
Two ways to go beyond SM
Precision measurements and direct searches

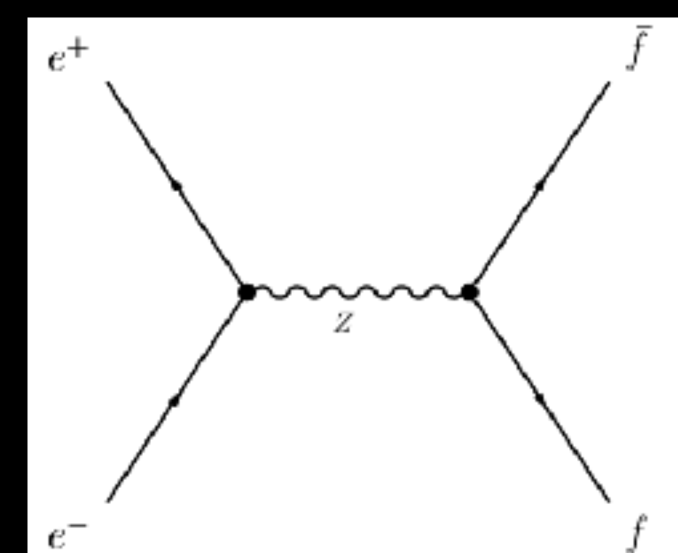
- Higgs : precision measurement the Higgs properties of its mass, width, production, decay couplings





- W: mass, width, and TGC
- Z: Rb, Afb, …
- Flavor physics





See Jianming, and Zhijun's talks

Physics requirements

- Robustness and efficiency : record all physics events/objects in a noisy environment
- Ultimate goal: trace the whole cascade topology of an physics events, for example jet substructure!
- Excellent resolution and efficiency to reconstruction physics objects: better resolutions can compensate statistics
- Luminosity/beam energy calibration to meet physics goal
  - Luminosity: ~ 0.1% at 240 GeV and ~0.01% at 91 GeV
- Highly hermetic coverage: better use of advantage of e+e- collider — initial state precisely defined.
- PID: lepton/jet/hadron identification with high efficiency and rejection power
  - Lepton: identification efficiency of 99% and a misidentification rate smaller than 2% for (p > 5GeV)
  - Jet: b-jet identification efficiency/purity better than 80%, and c-jet efficiency/purity 60% (Z pole)
  - pi/K separation: up to 20GeV for flavor physics

Benchmarks for performance

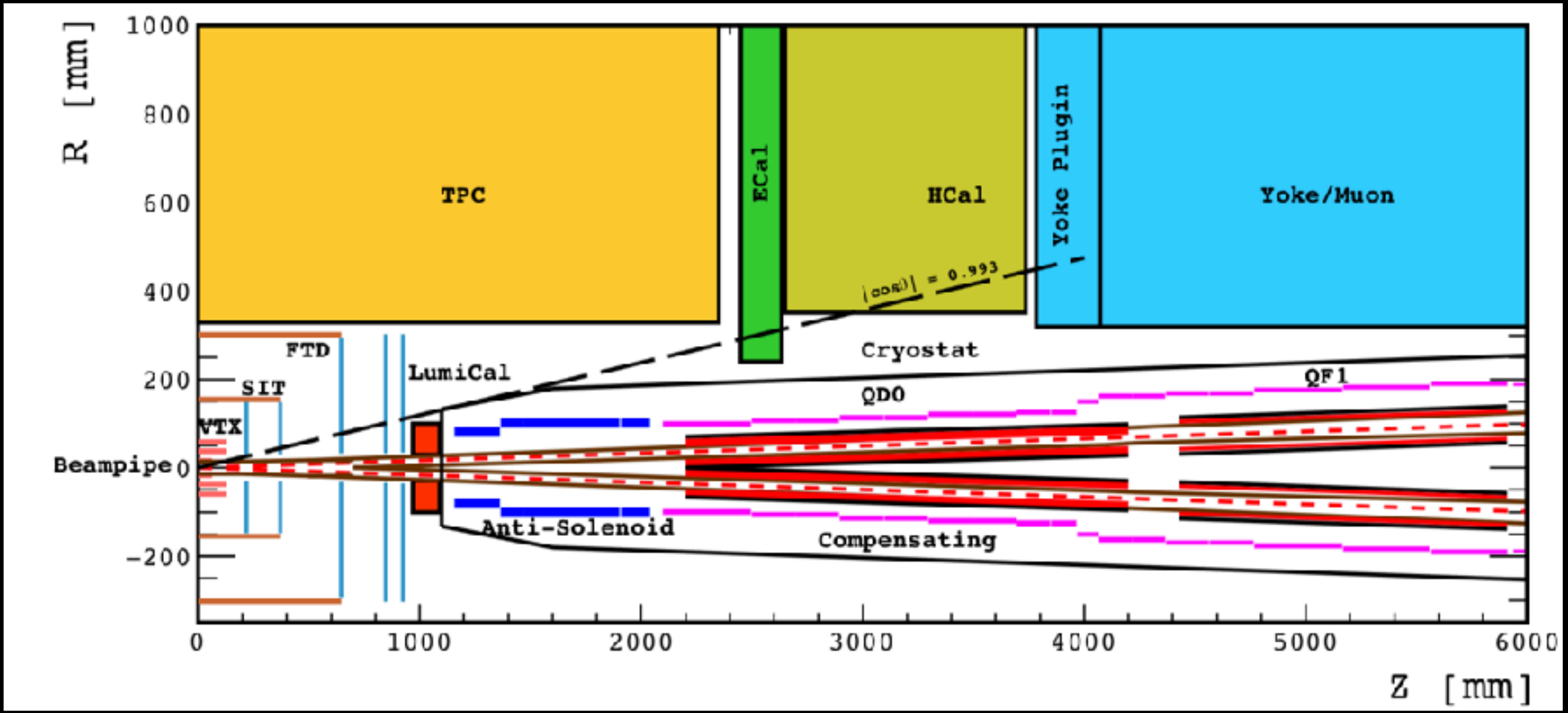
Physics process	Measurands	Critical detector	Required performance
$ZH \to l^+l^-X$	m_H, σ_{ZH}	Tracker	$\Delta(1/P_T) = 2\times10^{-5} \oplus \frac{0.001}{P(\mathrm{GeV})\sin^{\frac{3}{2}}\theta}$
$H \to \mu^+\mu^-$	$B(H \to \mu^+\mu^-)$		
$H \to b\bar{b}, c\bar{c}, gg$	$B(H \to b\bar{b}, c\bar{c}, gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV})\sin^{3/2}\theta}(\mu\mathrm{m})$
$H \to q\bar{q}, W^+W^-, ZZ$	$B(H \to q\bar{q}, W^+W^-, ZZ)$	ECAL, HCAL	$\sigma_E^{jet} = 3 \sim 4\,\%$ at 100GeV
$H \to \gamma\gamma$	$B(H \to \gamma\gamma)$	ECAL	$\frac{\Delta E}{E} = \frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

Experiment conditions

- CEPC design supposed to deliver more luminosities at all energies
- Baseline design of accelerator
  - double ring
  - cross angle: 33 mrad
  - L* = 2.2 m, QD0, QF1 inside detector
  - Backgrounds : pair production & off-beam particles
  - Luminosity measurement very challenge
- Stringent requirements on detector design

More details in Hongbo's talk

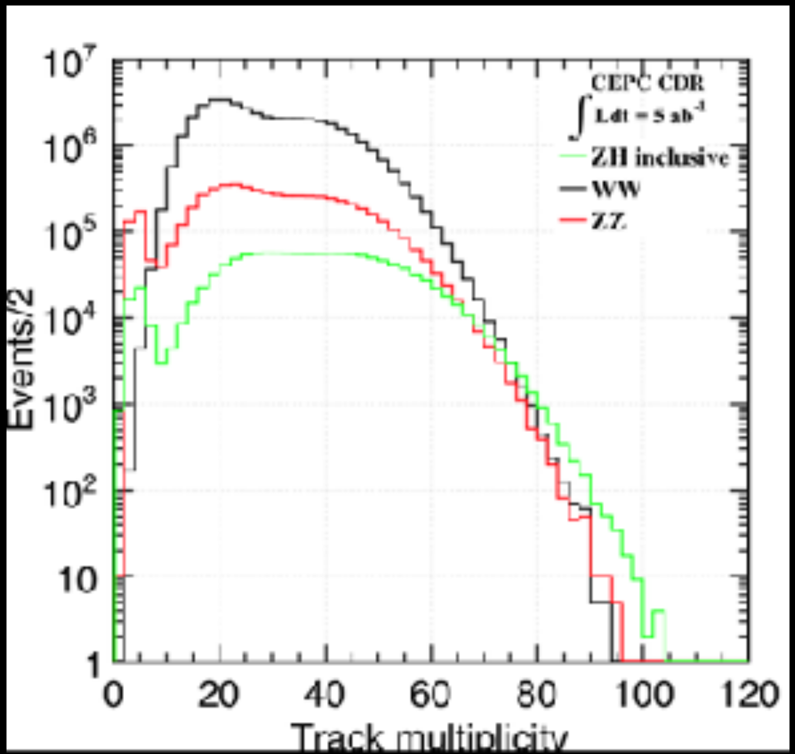
	H (240)	W (160)	Z (91)
Hit Density [hits/cm^2·BX]	2.4	2.3	0.25
TID [MRad/year]	0.93	2.9	3.4
NIEL [10^{12} 1 MeV n_{eq}/cm^2·year]	2.1	5.5	6.2

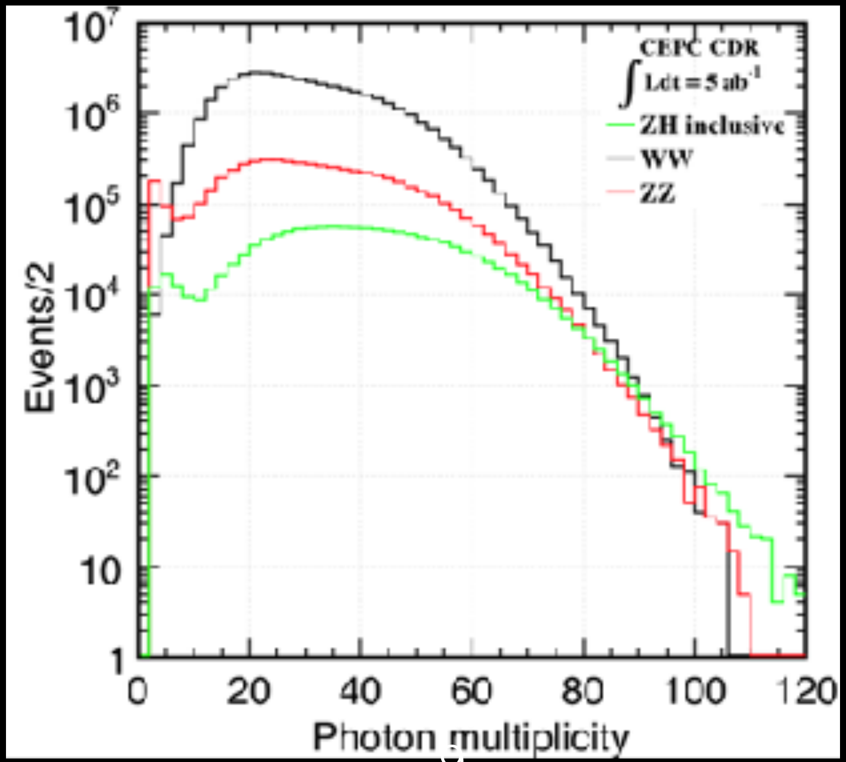


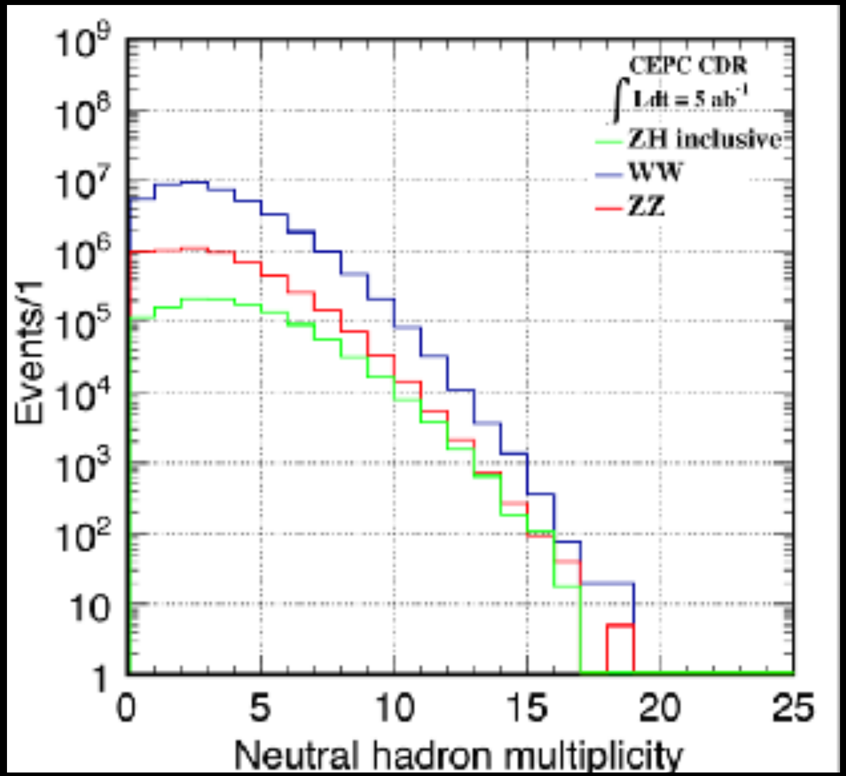
Physics objects:
leptons, photons, jets,
missing energy, $\cdots$

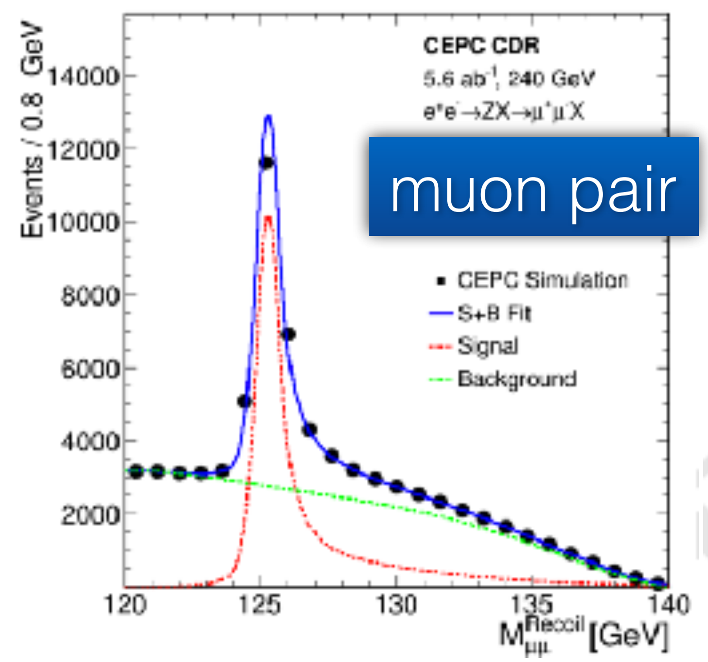
Multiplicities of typical events

- Averaged multiplicities of the charged tracks and photons ~ 30, but the maximum to 100, which carry most of the energy of an events
- Neutral hadrons ~ 10% of the energy
- Dedicated detectors are combined together to measure and separate them precisely and efficiently

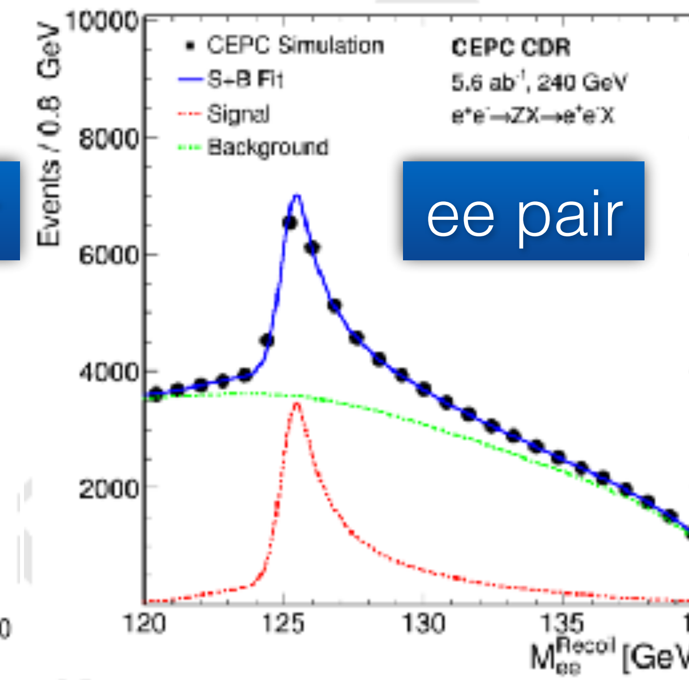




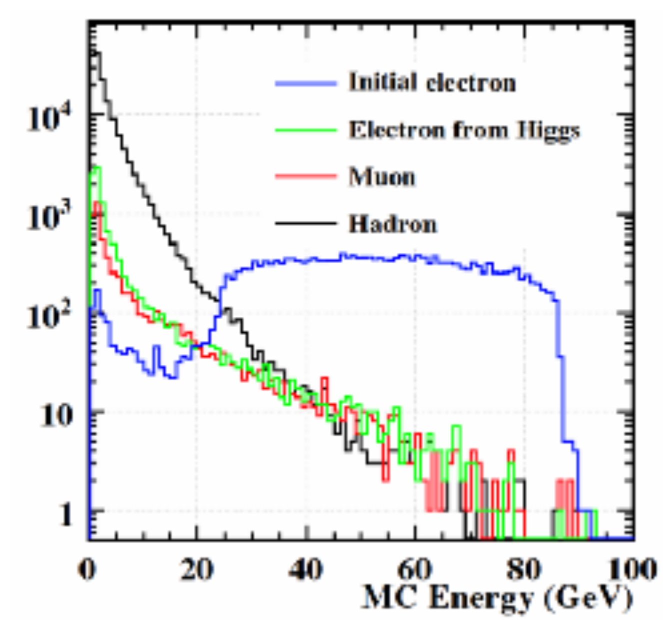




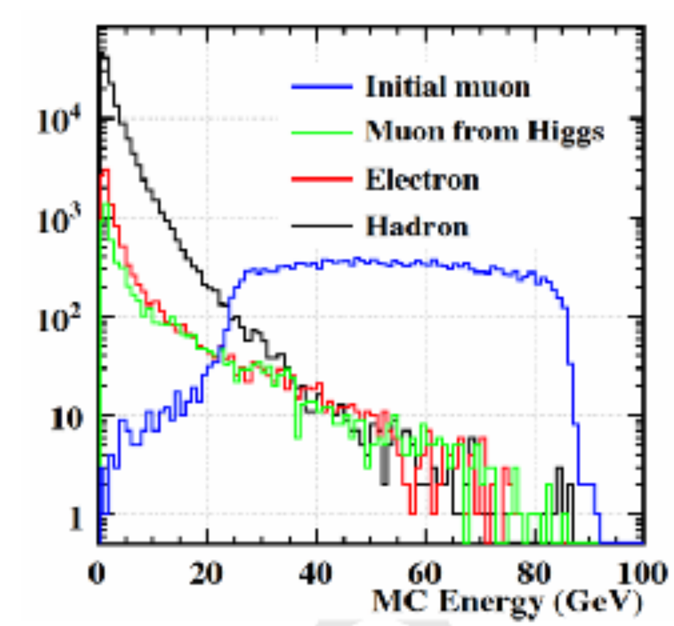
CEPC CDR
5.6 ab-1, 240 GeV
e+e-→ZX→μ+μ-X
muon pair
CEPC Simulation
S+B Fit
Signal
Background
Events / 0.8 GeV
M_μμ^Recoil [GeV]



CEPC Simulation
S+B Fit
Signal
Background
CEPC CDR
5.6 ab-1, 240 GeV
e+e-→ZX→e+e-X
ee pair
Events / 0.8 GeV
M_ee^Recoil [GeV]



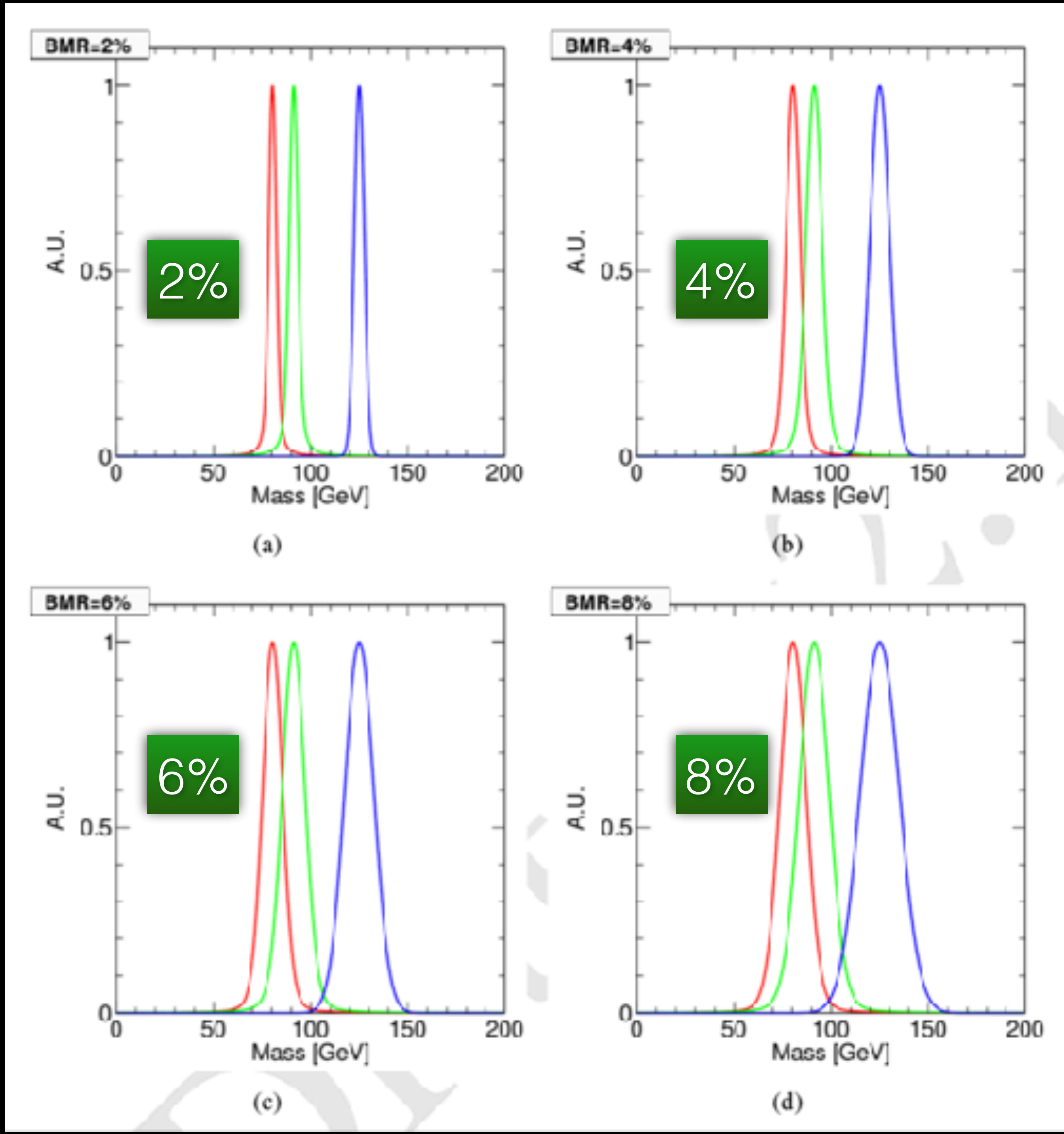
Initial electron
Electron from Higgs
Muon
Hadron
MC Energy (GeV)



Initial muon
Muon from Higgs
Electron
Hadron
MC Energy (GeV)

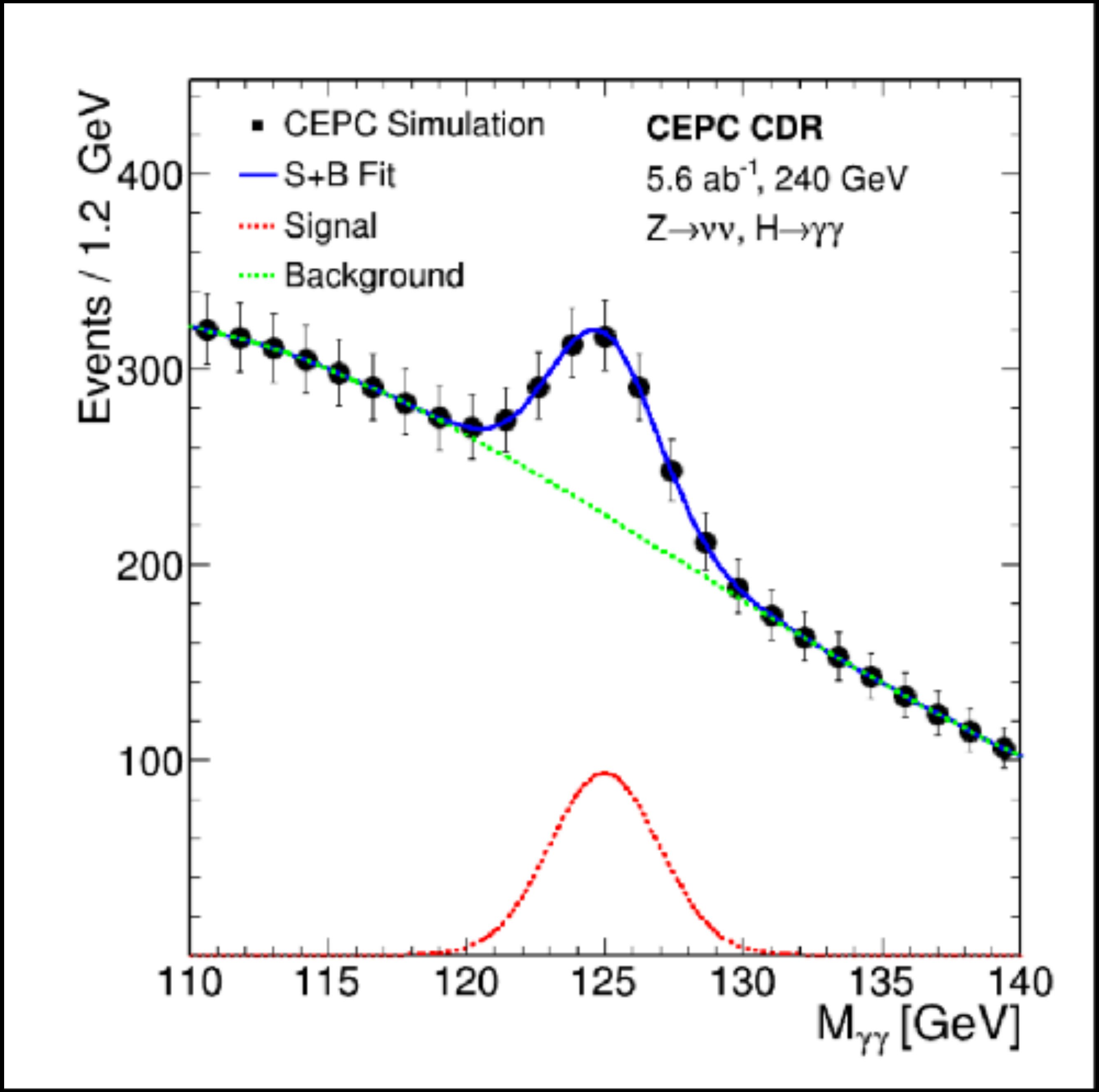
Jet energy resolution

- Jet energy resolution (JER) is essential for boson reconstruction, left plots demonstrate the importance of boson mass resolution
- 4% is minimum requirement for W&Z boson separation



Photons

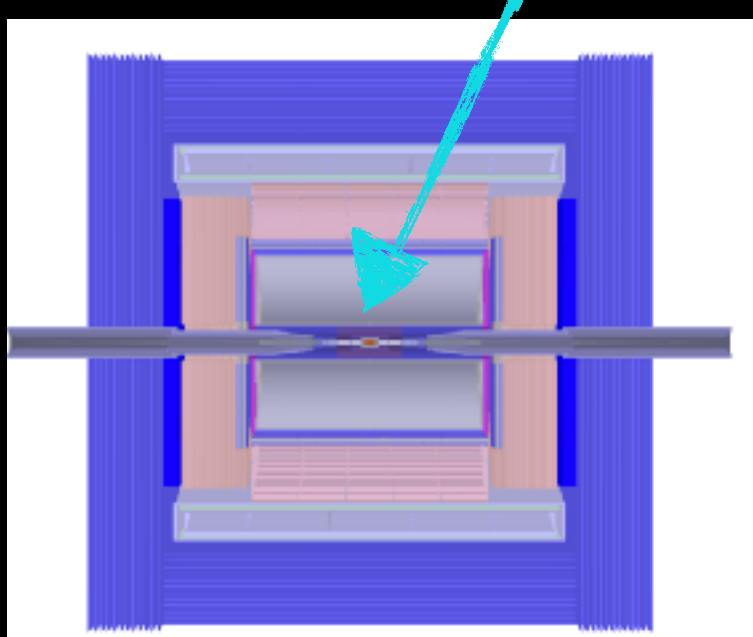
- Photon energy resolution is key issue for Higgs di-photon measurement, as well as π^0 and ISR photon tagging
- Simulation shows $20\%/E^{1/2}$ is minimum requirement for Higgs to di-photon study.



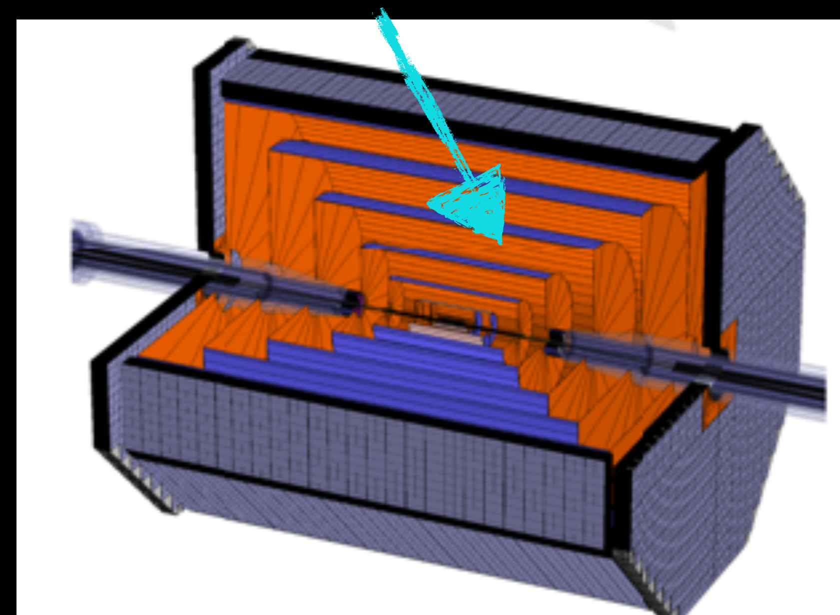
CEPC detector concepts

- Three detector concepts proposed
  - silicon+TPC+PFA calo - used for full simulation performance study
  - full silicon+PFA calo - more details in Chendong's talk
  - silicon+DC+DR calo - Franco's talk

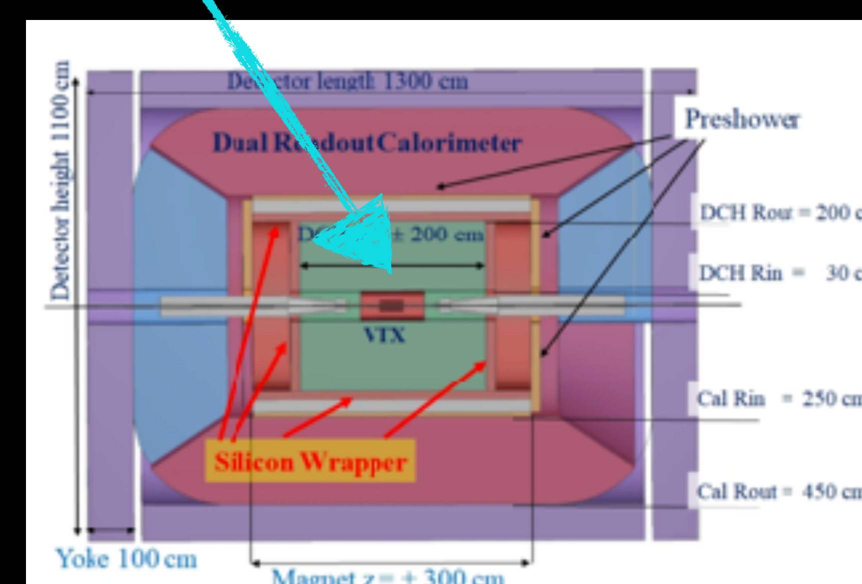
TPC



Silicon



Drift chamber



CEPC baseline detector concept

silicon+TPC+PFA calo

Particle flow: make use of the optimal sub-detector information in reconstruction and a high granularity calorimetry system

Baseline design

Concept	ILD	CEPC baseline
Tracker	TPC/Silicon	TPC/Silicon or FST
Solenoid B-Field (T)	3.5	3
Solenoid Inner Radius (m)	3.4	3.2
Solenoid Length (m)	8.0	7.8
L* (m)	3.5	2.2
VTX Inner Radius (mm)	16	16
Tracker Outer Radius (m)	1.81	1.81
Calorimeter	PFA	PFA
Calorimeter λ_I	6.6	5.6
ECAL Cell Size (mm)	5	10
ECAL Time resolution (ps)	-	200
ECAL X_0	24	24
HCAL Layer Number	48	40
HCAL Absorber	Fe	Fe
HCAL λ_I	5.9	4.9
DRCAL Cell Size (mm)	-	-
DRCAL Time resolution (ps)	-	-
DRCAL Absorber	-	-
Overall Height (m)	14.0	14.5
Overall Length (m)	13.2	14.0

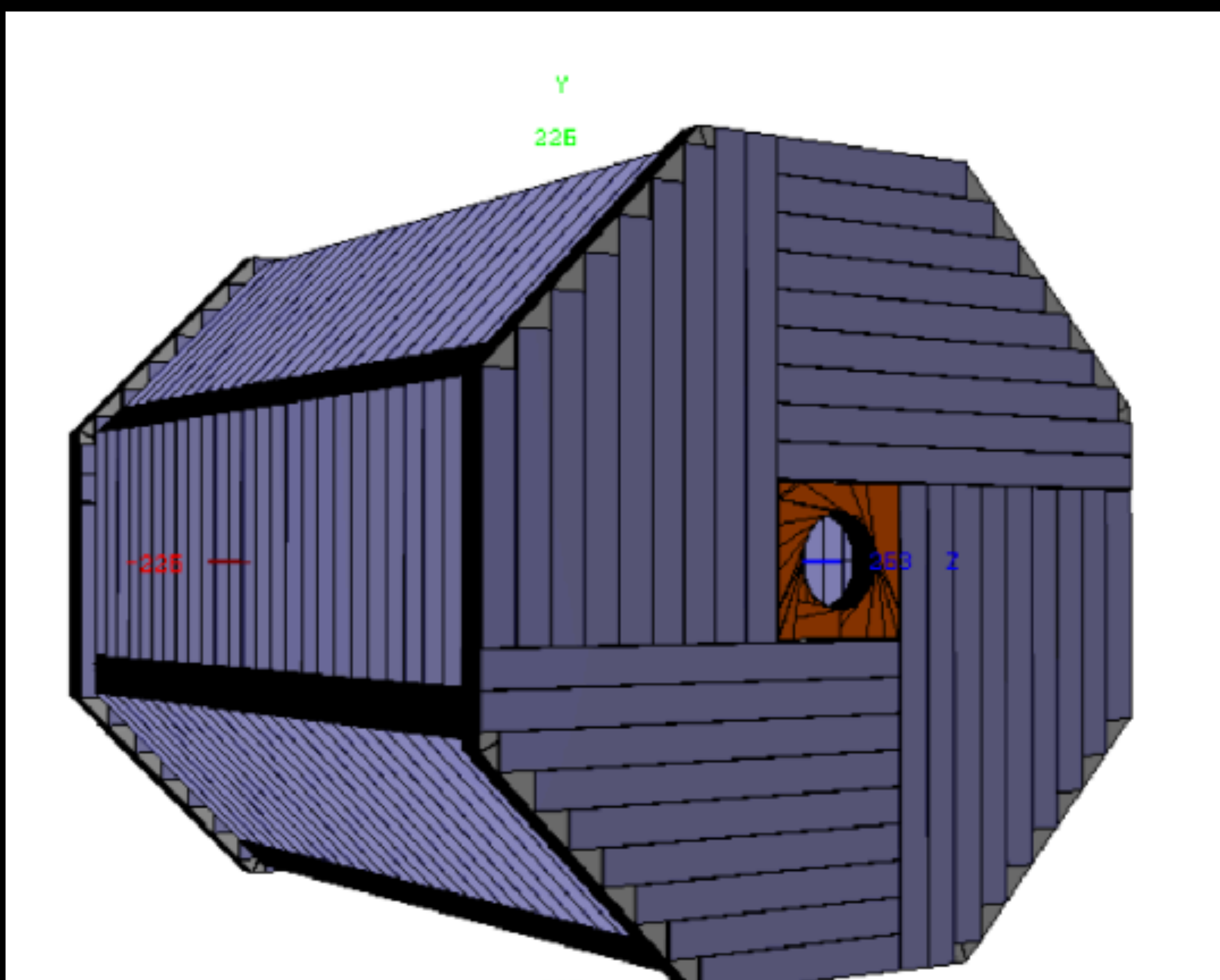
- L*: 2.2 m, required by accelerator final focusing
- Magnet field: 3 Tesla to achieve higher luminosity
- Excellent impact parameter resolution:

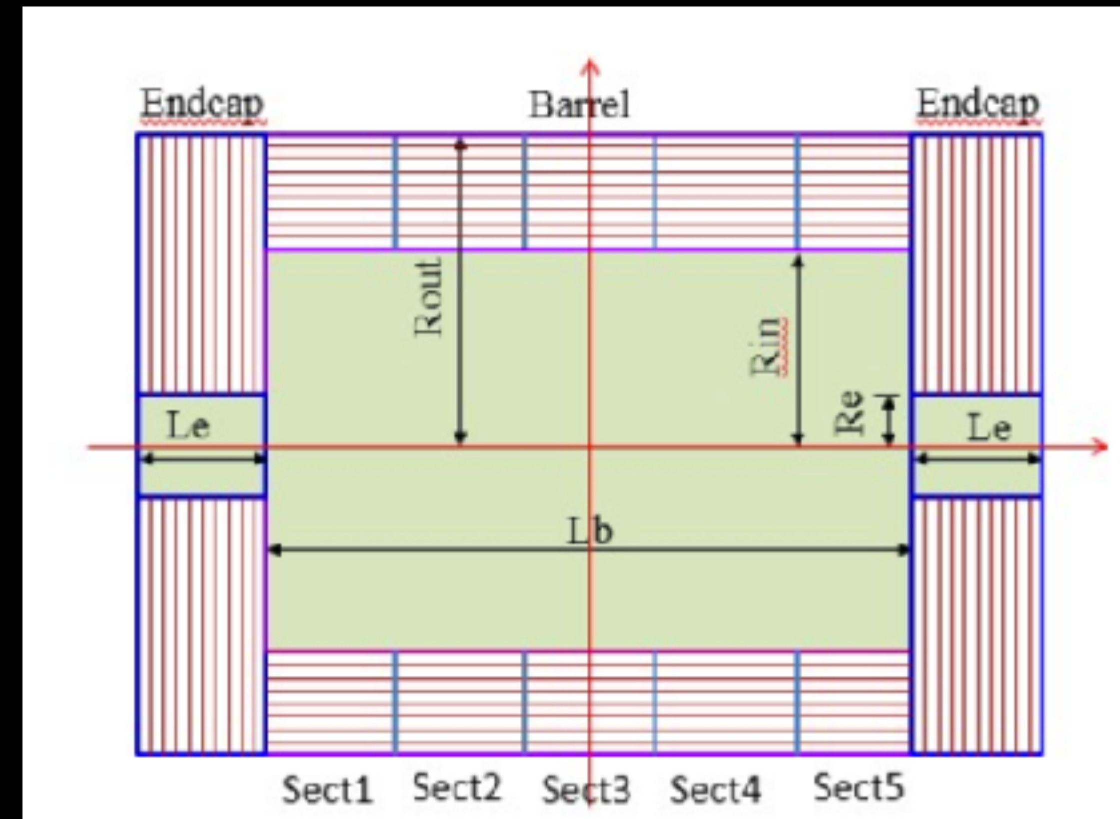
$$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV})\sin^{3/2}\theta}$$

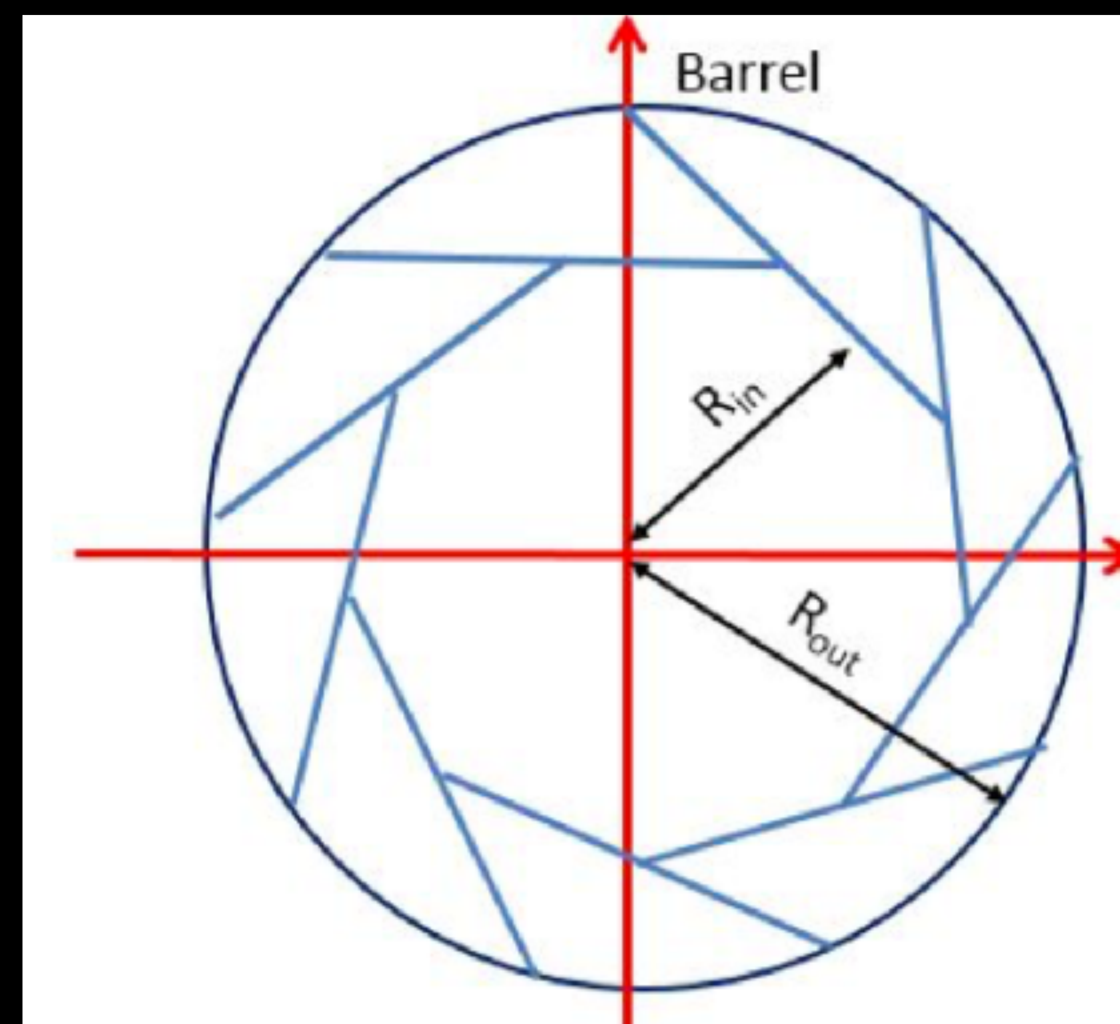
- Momentum resolution : $\Delta(1/P_T) \sim 2 \times 10^{-5}\ \mathrm{GeV}^{-1}$
- A double amplification layer technique for TPC for the Z pole high events rate environment
- Good performance on pi/K separation with TPC dE/dx and time information in ECAL
- Calorimetry system, see next page …

Key of PFA concept

- Ecal baseline
  - 30 layers
  - Cell size: $1 \times 1\mathrm{cm}^2$
  - 24 X_0
- Hcal baseline
  - 40 layers
  - $\lambda_I = 4.9$







Summary

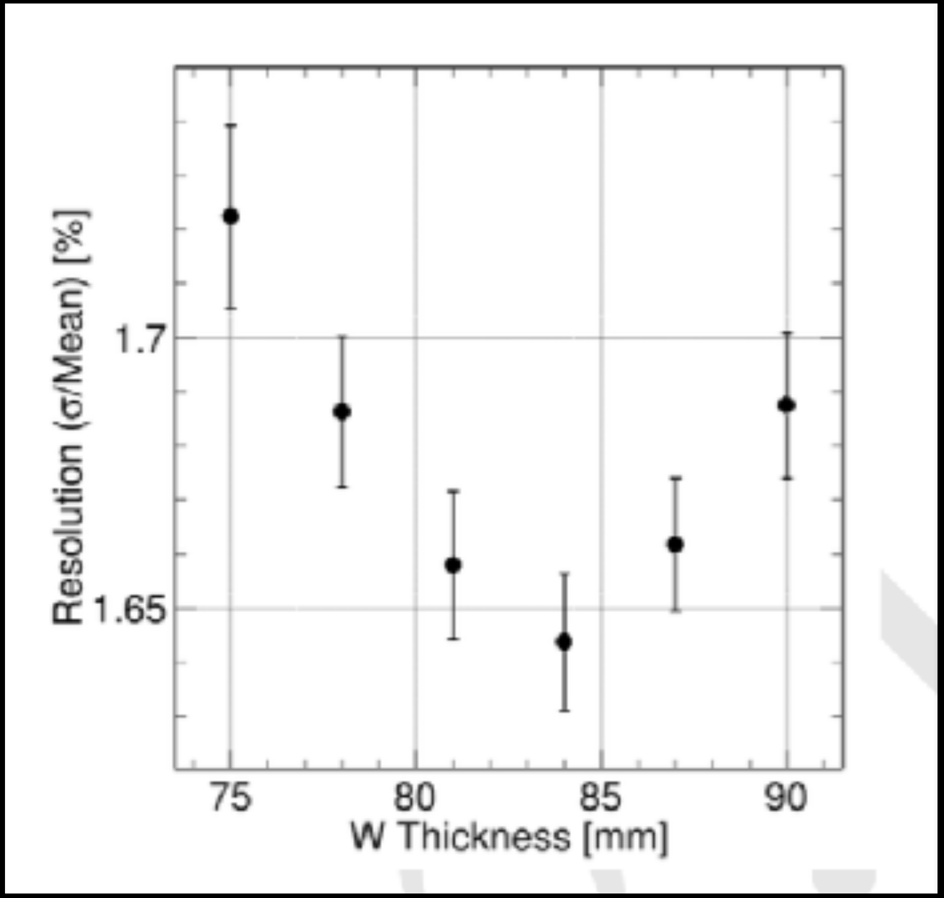
- CEPC focus on Higgs, EW precision and flavor physics also its physics goal
- MDI and physics program put stringent requirements on detector design
- Three detector concept are developed for CEPC physics
- TPC+PFA detector concept is study with full simulation, shows good performance for CEPC Higgs study.

Extras

Calorimetry optimizations

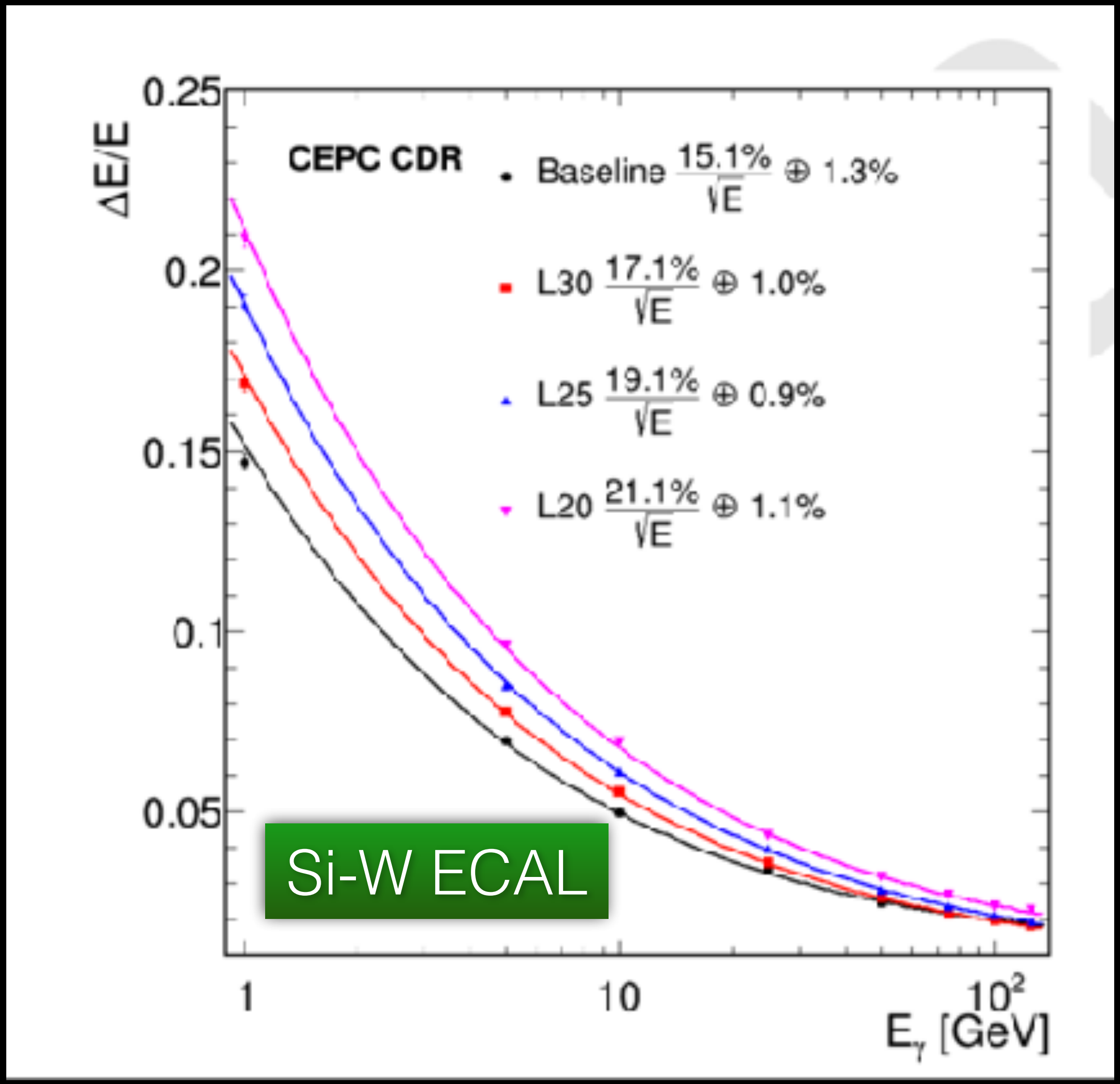
- High granularity calorimetry system suffers from cooling problem, but CEPC is not going to operate with push-pull mode
- The cell size and number of layers optimized with full simulation study, which is active-cooling free but with 5% resolution degrading.
- Optimized results
  - ECAL cell size: of 10x10 mm^2
  - ECAL absorber: 84 mm
  - HCAL #of layers: 40
  - Cost/weight/thickness reduced

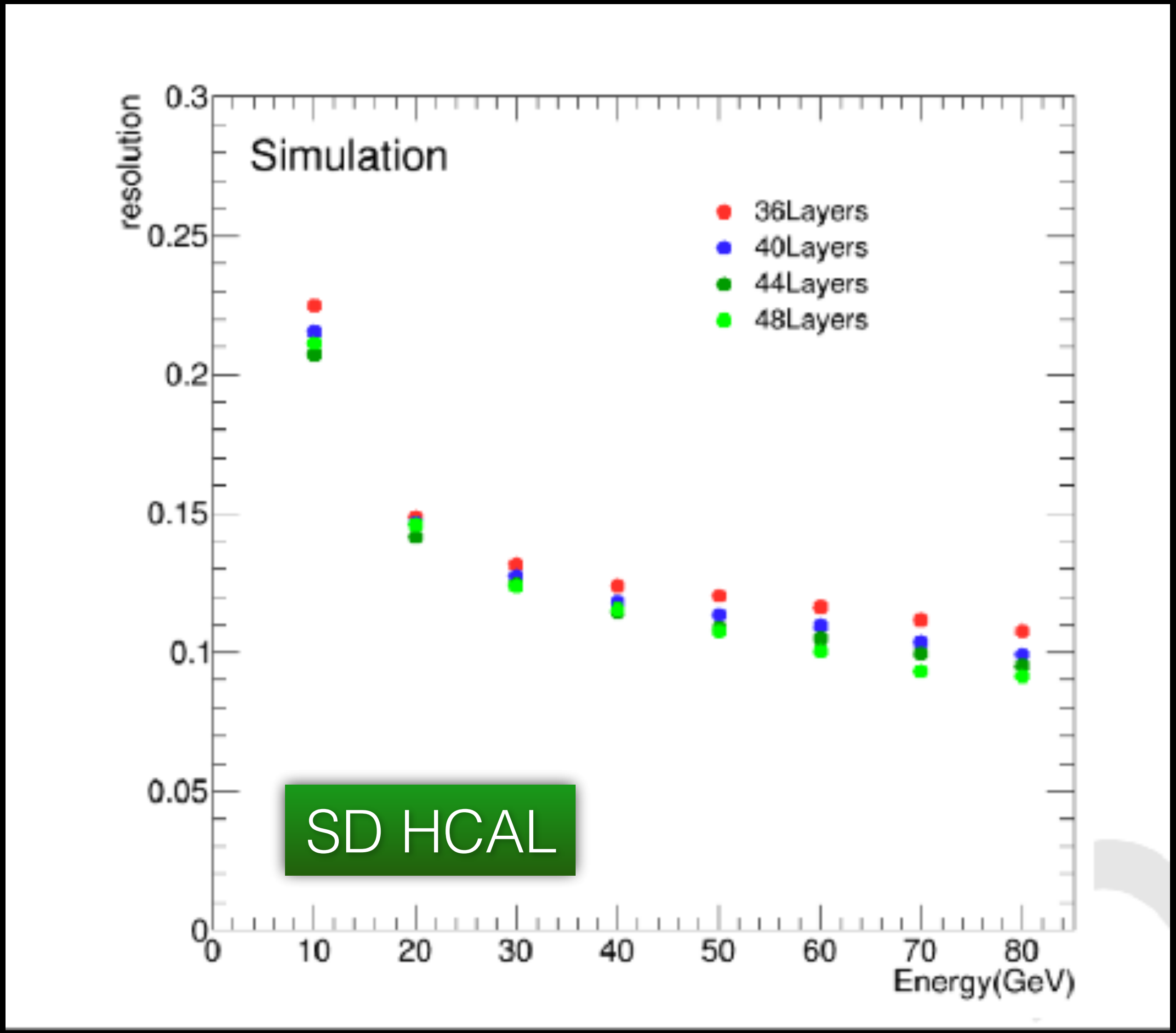
    25%/50%/20%



Calorimetry optimizations

- Number of layers vs. energy resolutions





Other issues

- Photon energy resolution optimized for Higgs study and satisfiys the CEPC requirement
- Muon detector provides good ID efficiency and rejection power, combine it with calorimetry system
- More details please refer to Manqi’s performance talk

The requirements
high tracking efficiency
Excellent tracking resolution
Jet energy (boson mass) resolution
Good separation power: pi0, tau, jets, …

Generally
High granularity means high efficiency
Potential application of modern development of machine learning/deep learning