CEPC preview

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Outline

★Introduction

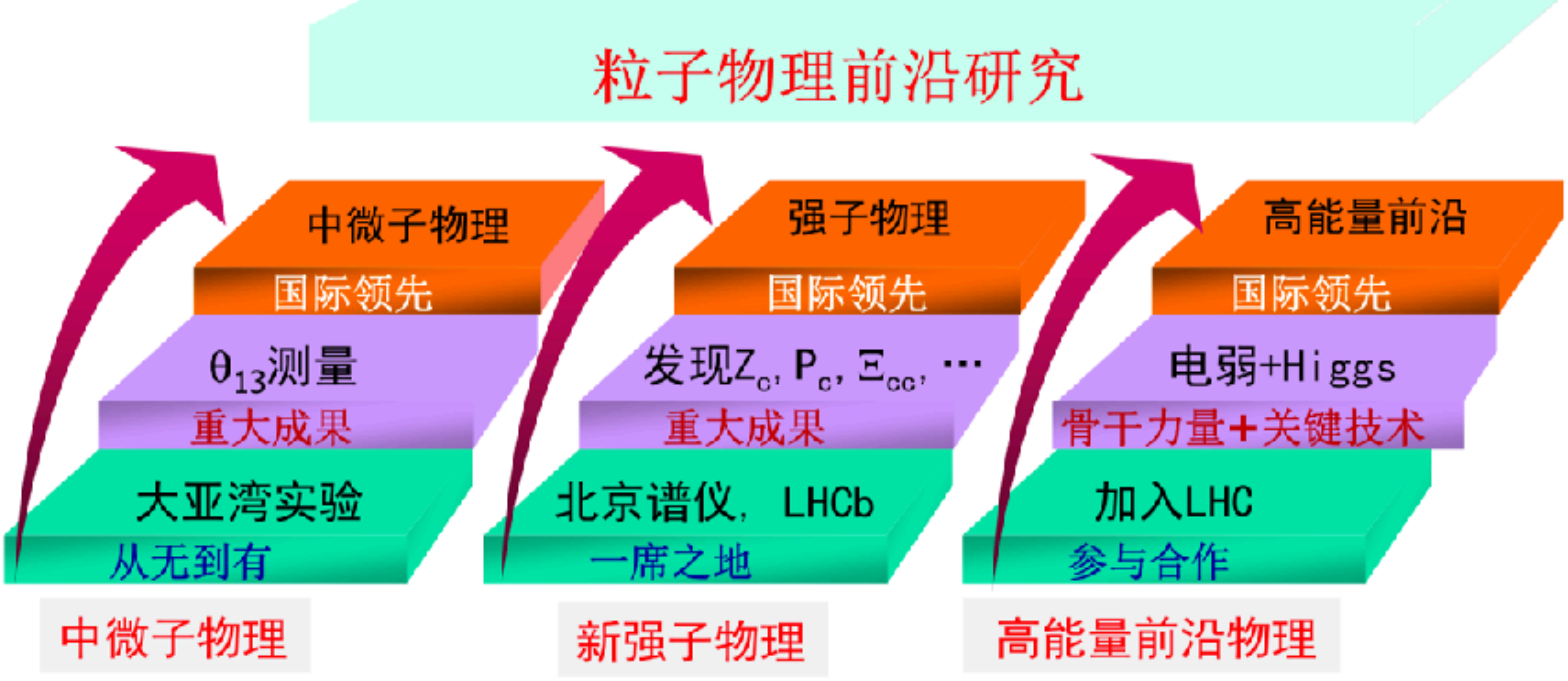
✓Precision

✓CEPC+SppC

★CEPC detector and software

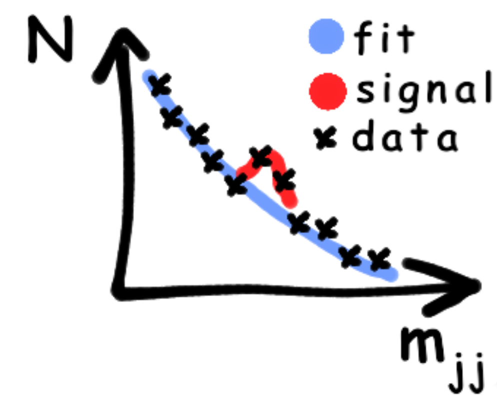
★CEPC physics analysis

★Summary

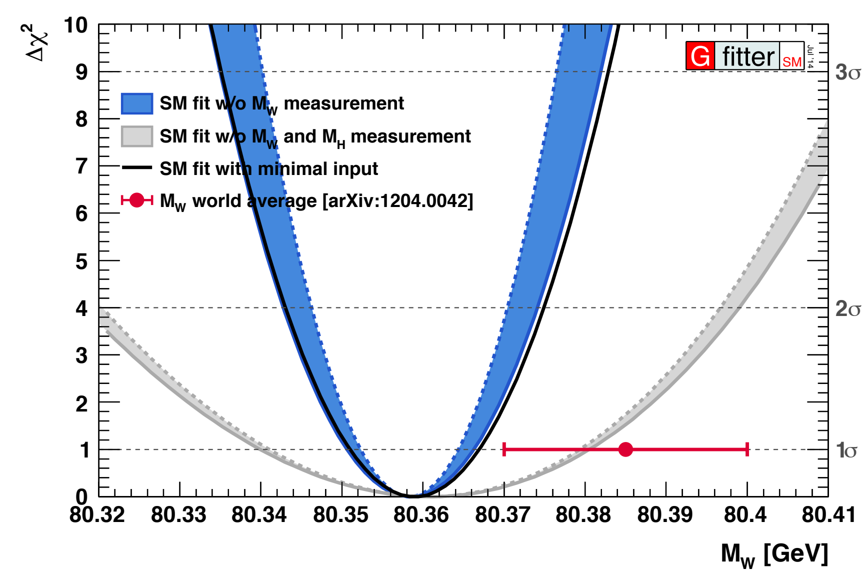

粒子物理前沿研究
中微子物理
国际领先
θ13测量
重大成果
大亚湾实验
从无到有
强子物理
国际领先
发现Zc, Pc, Ξcc, …
重大成果
北京谱仪, LHCb
一席之地
高能量前沿
国际领先
电弱+Higgs
骨干力量+关键技术
加入LHC
参与合作
中微子物理
新强子物理
高能量前沿物理

如何寻找新物理——精确测量也可以

- 直接方法:
  - 寻找与已知不同的粒子或者现象
  - 例子：Higgs, Zc, Pc的发现



- 间接
  - 精确测量
  - 比较差别，而差别可能就来自我们不知道的物理原理
  - 例子：精确测量 H、W、Z 粒子的质量



为什么需要CEPC

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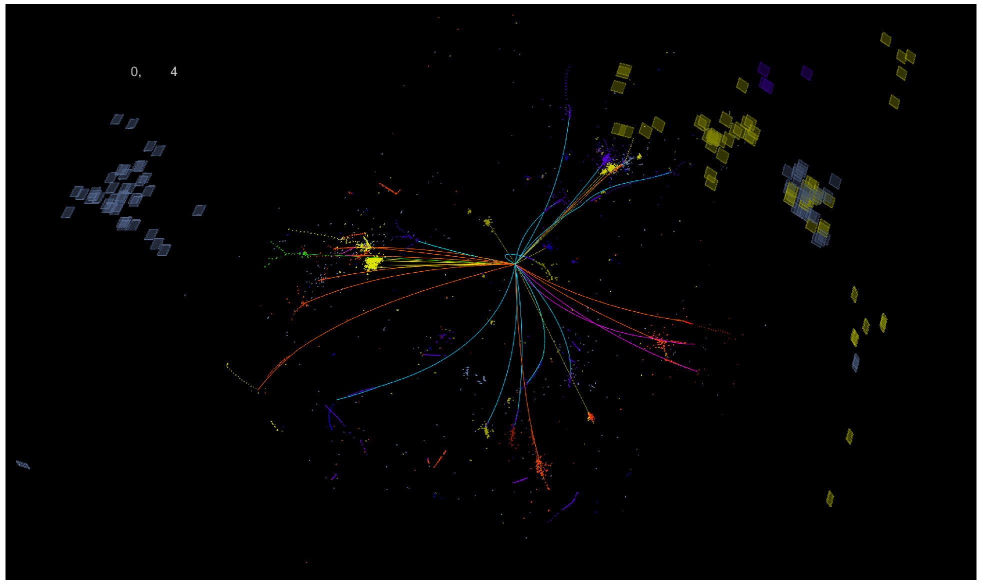


The properties of Higgs boson Higgs

Precision test of SM

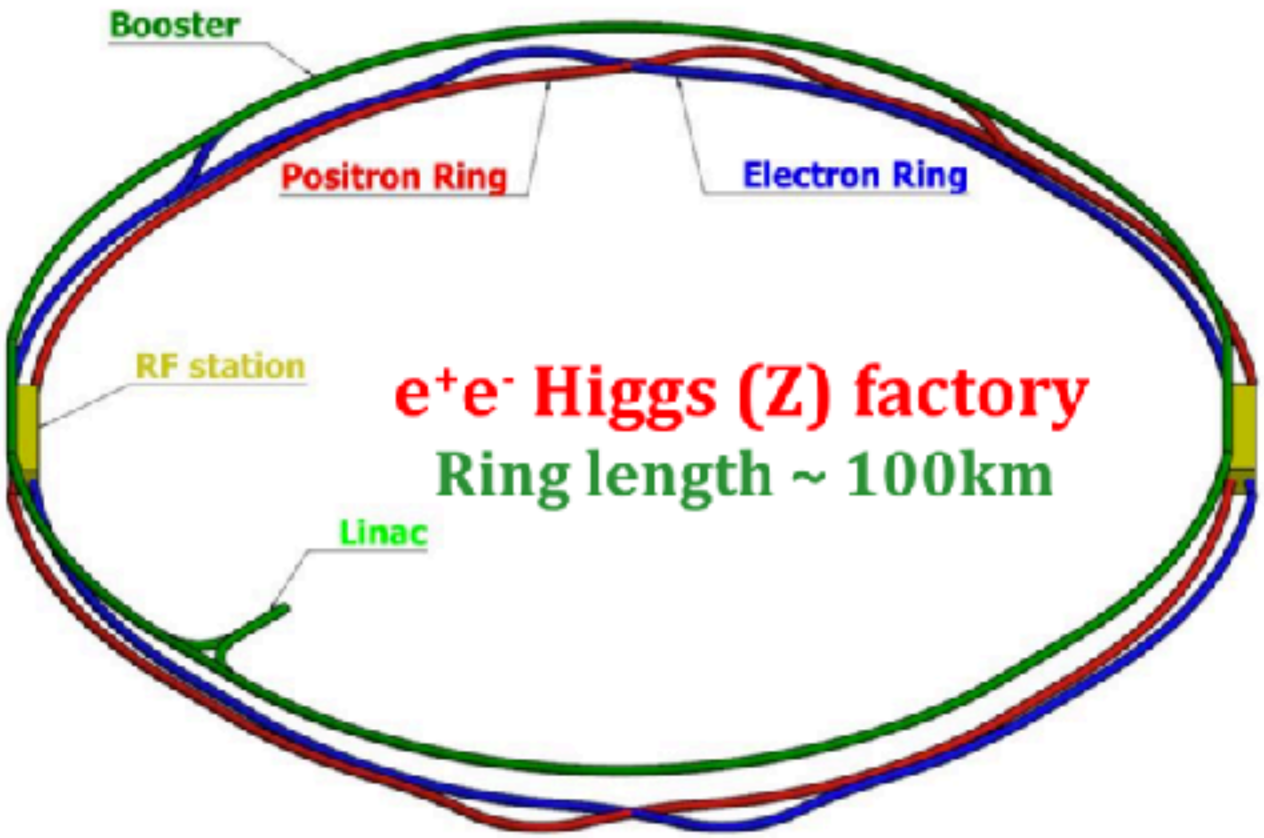
What are dark matter and dark energy?

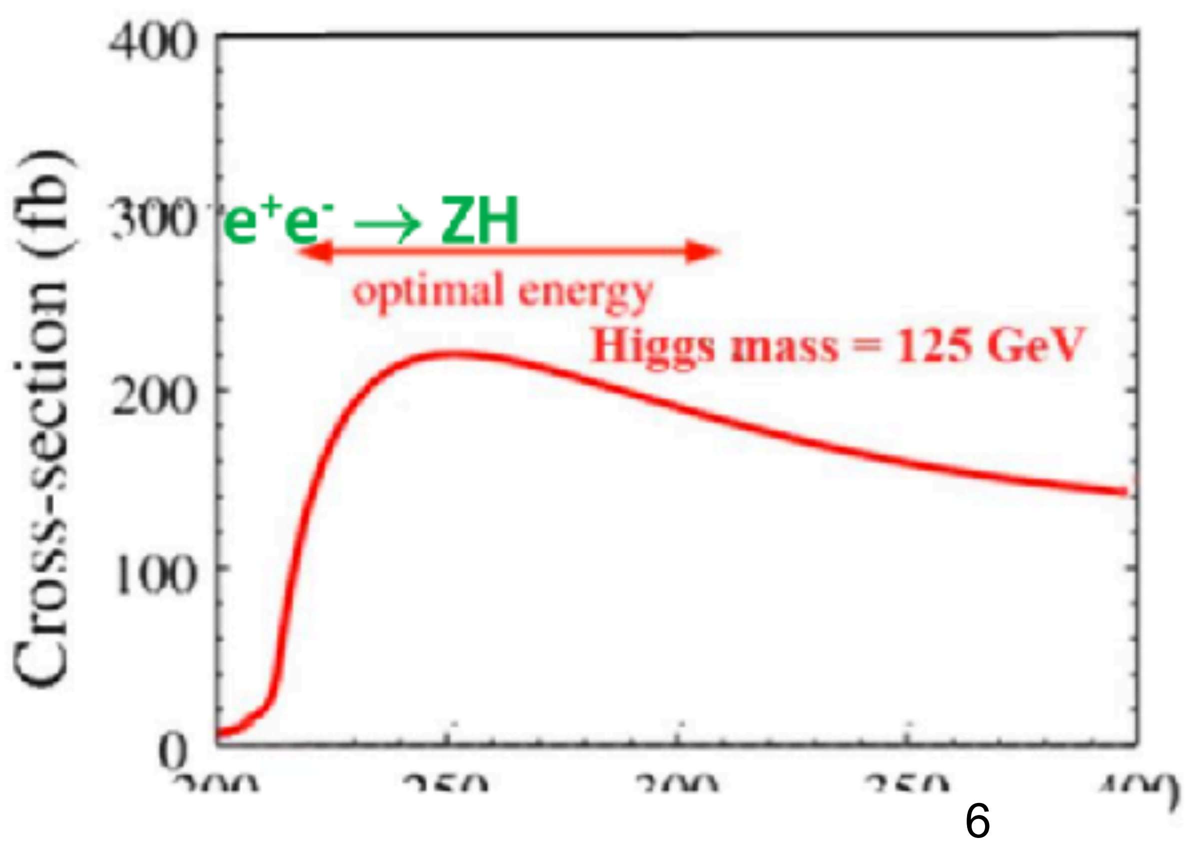
Supersymmetric particles

Why is there more matter then antimatter

Symmetry breaking

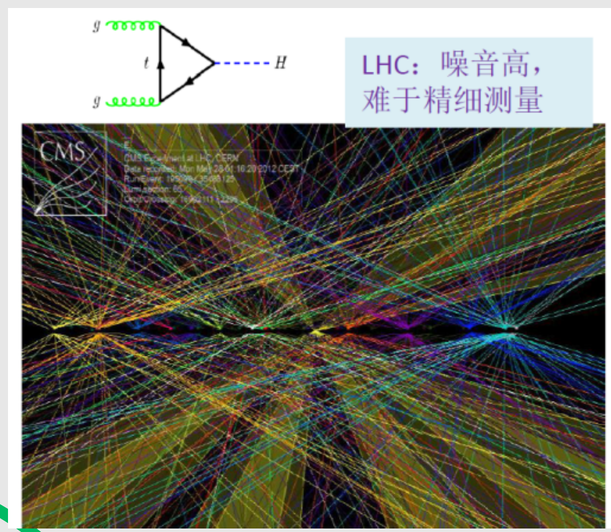
… …

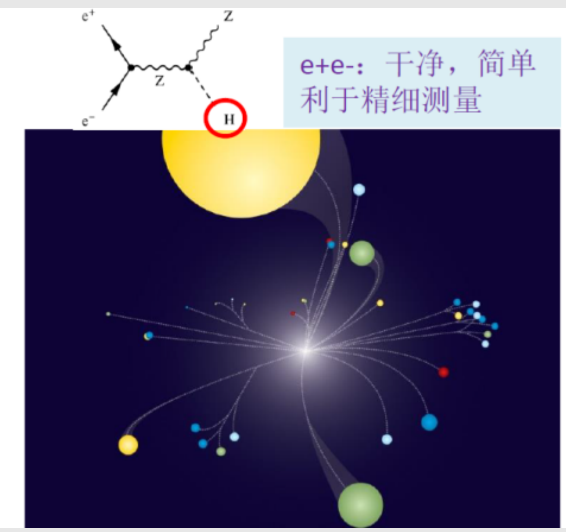


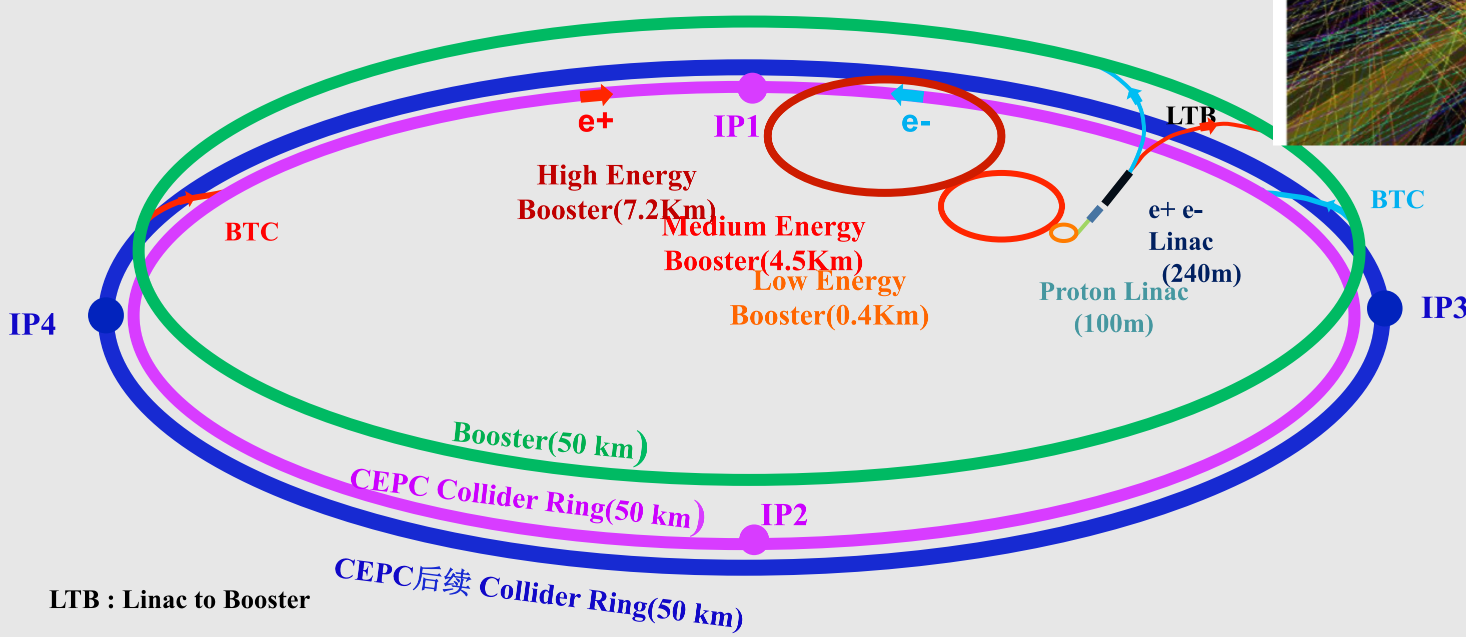


高能环形正负电子对撞机方案

- **建设一个100 公里周长的 环形正负电子对撞机(CEPC)， 高精度研究Higgs（Z）粒子，并寻找新物理**
- **CEPC的升级可能：在同一隧道中建设 pp/AA对撞机，也可以建设ep/eA 对撞机，或其它可能性**







LTB : Linac to Booster

BTC : Booster to Collider Ring

加速器参数设计

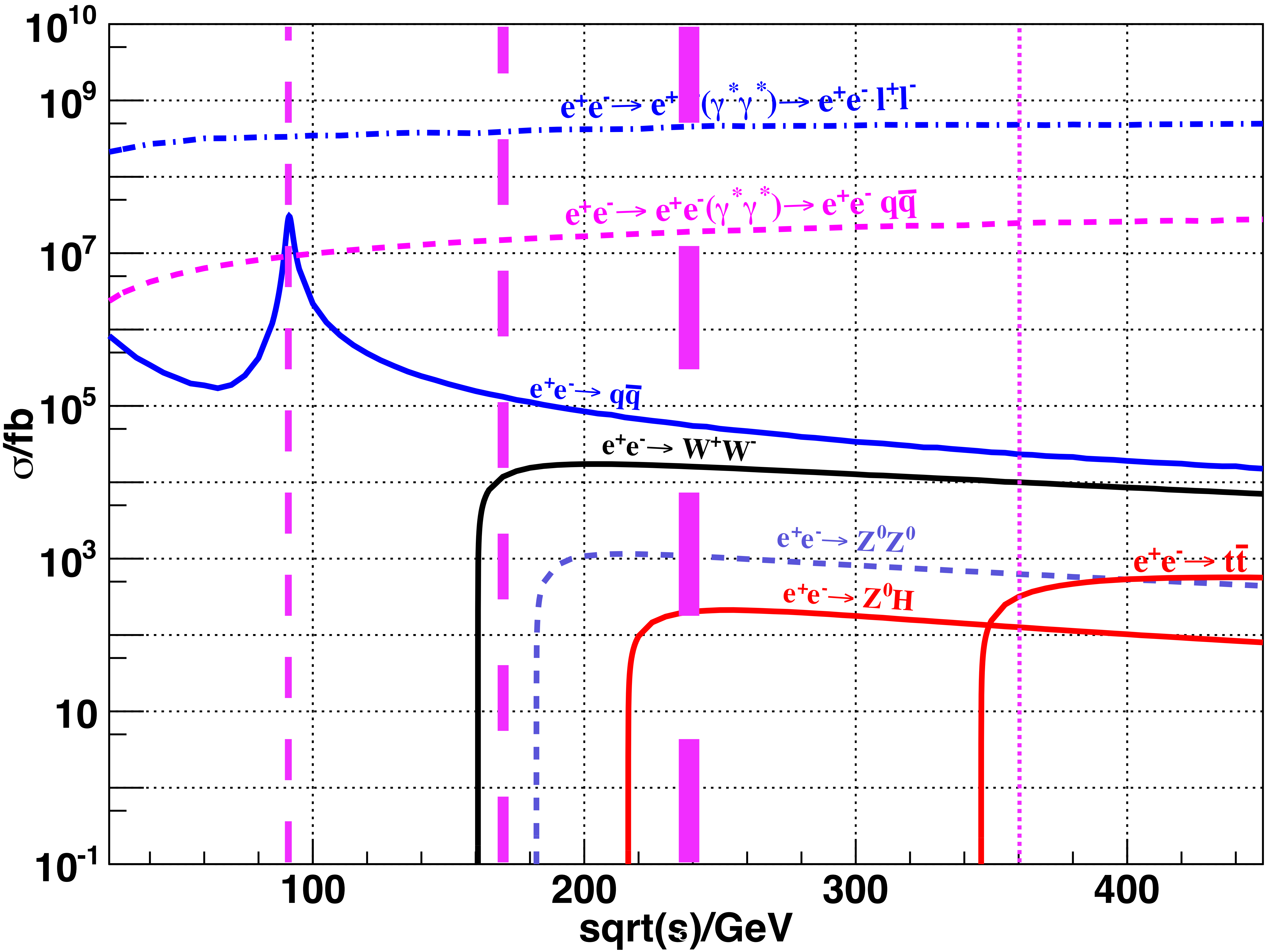
	Higgs	*W*	*Z*
Number of IPs	2		
Energy (GeV)	120	80	45.5
Circumference (km)	100		
SR loss/turn (GeV)	1.73	0.34	0.036
Half crossing angle (mrad)	16.5		
Piwinski angle	2.58	7.74	23.8
N_e/bunch (10^{10})	15	15	8.0
Bunch number (bunch spacing)	242 (0.68us)	1220 (0.27us)	12000 (25ns+10%gap)
Beam current (mA)	17.4	87.9	461
SR power /beam (MW)	30	30	16.5
Bending radius (km)	10.6		
Momentum compaction (10^{-5})	1.11		
β_{IP} x/y (m)	0.36/0.0015	0.36/0.0015	0.2/0.0015
Emittance x/y (nm)	1.21/0.0031	0.54/0.0016	0.17/0.004
Transverse σ_{IP} (um)	20.9/0.068	13.9/0.049	5.9/0.078
ξ_x/ξ_y/IP	0.031/0.109	0.013/0.12	0.0041/0.056
V_{RF} (GV)	2.17	0.47	0.1
f_{RF} (MHz) (harmonic)	650 (216816)		
Nature bunch length σ_z (mm)	2.72	2.98	2.42
Bunch length σ_z (mm)	3.26	6.53	8.5
HOM power/cavity (kw)	0.54 (2cell)	0.87(2cell)	1.94(2cell)
Energy spread (%)	0.1	0.066	0.038
Energy acceptance requirement (%)	1.35		
Energy acceptance by RF (%)	2.06	1.47	1.7
Photon number due to beamstrahlung	0.29	0.44	0.55
Lifetime _simulation (min)	100		
Lifetime (hour)	0.67 (40 min)	2	4
F (hour glass)	0.89	0.94	0.99
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.93	11.5	16.6

3T→2T

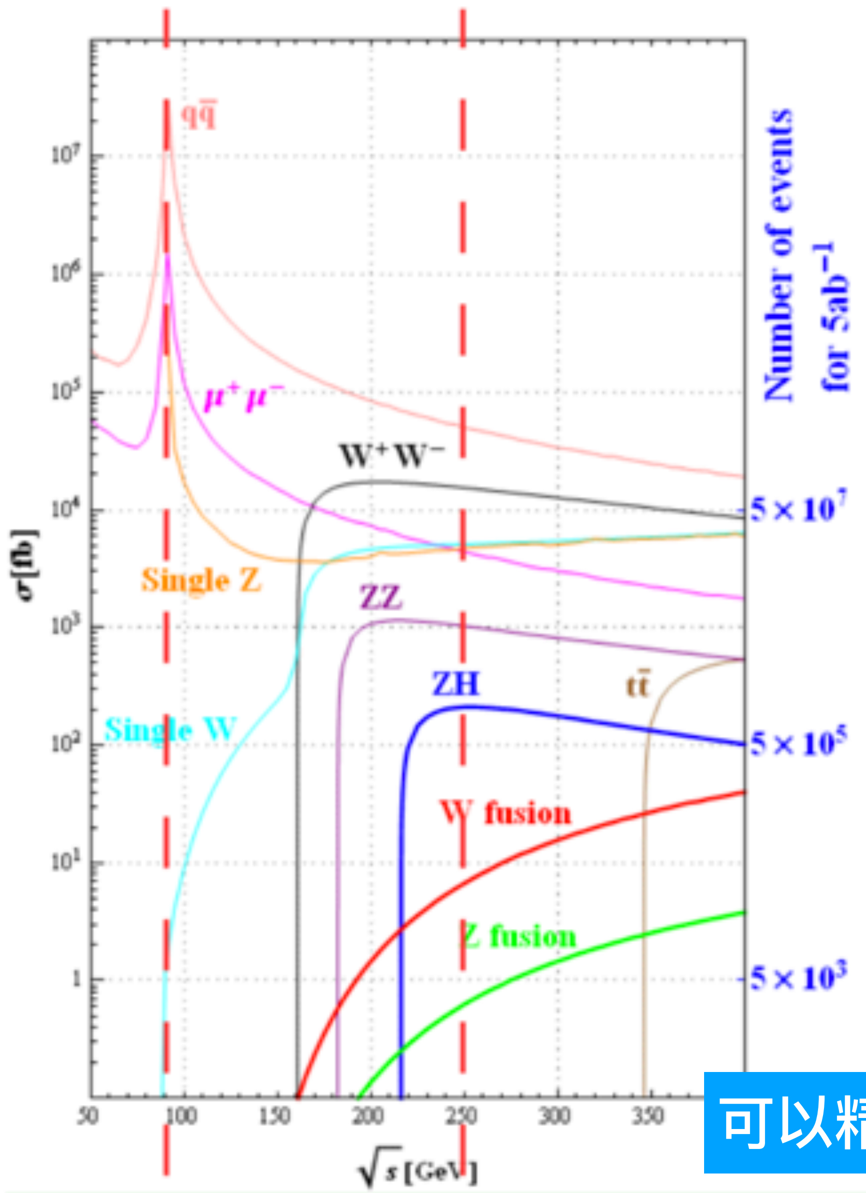
0.2/0.001

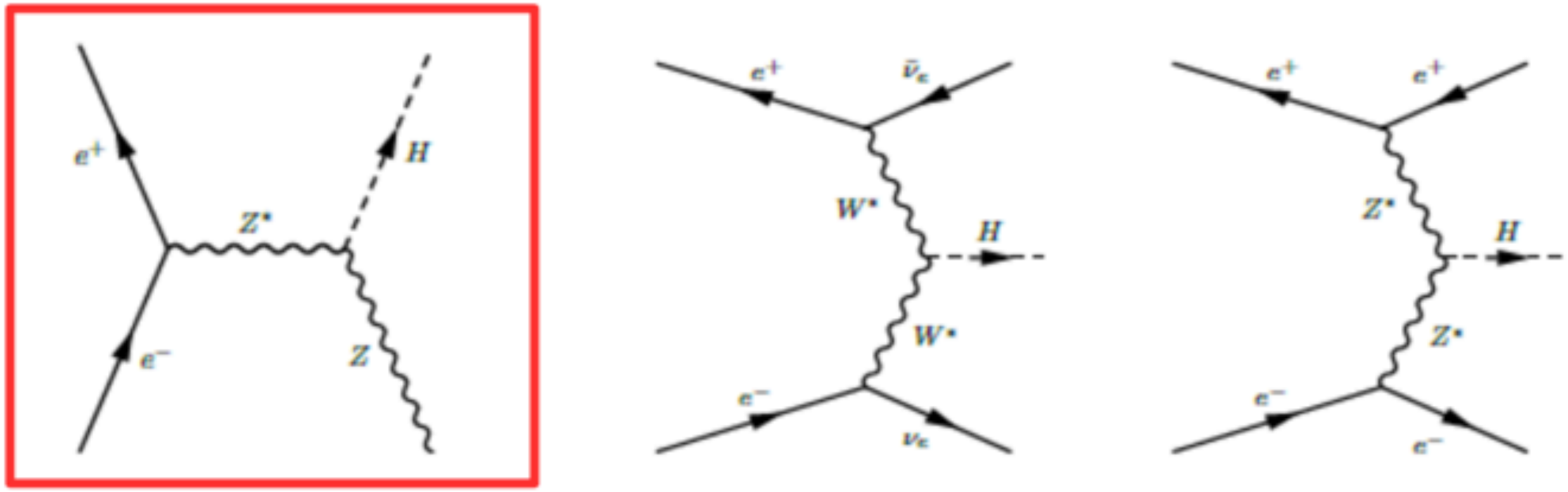
0.17/0.0015

32



σ/fb
sqrt(s)/GeV
e+e-→ e+e-(γ*γ*)→ e+e- l+l-
e+e-→ e+e-(γ*γ*)→ e+e- qq̄
e+e-→ qq̄
e+e-→ W+W-
e+e-→ Z0Z0
e+e-→ tt̄
e+e-→ Z0H





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

可以精确测量除了 Higgs 自耦合以外的所有性质，精度比 LHC 高一个量级

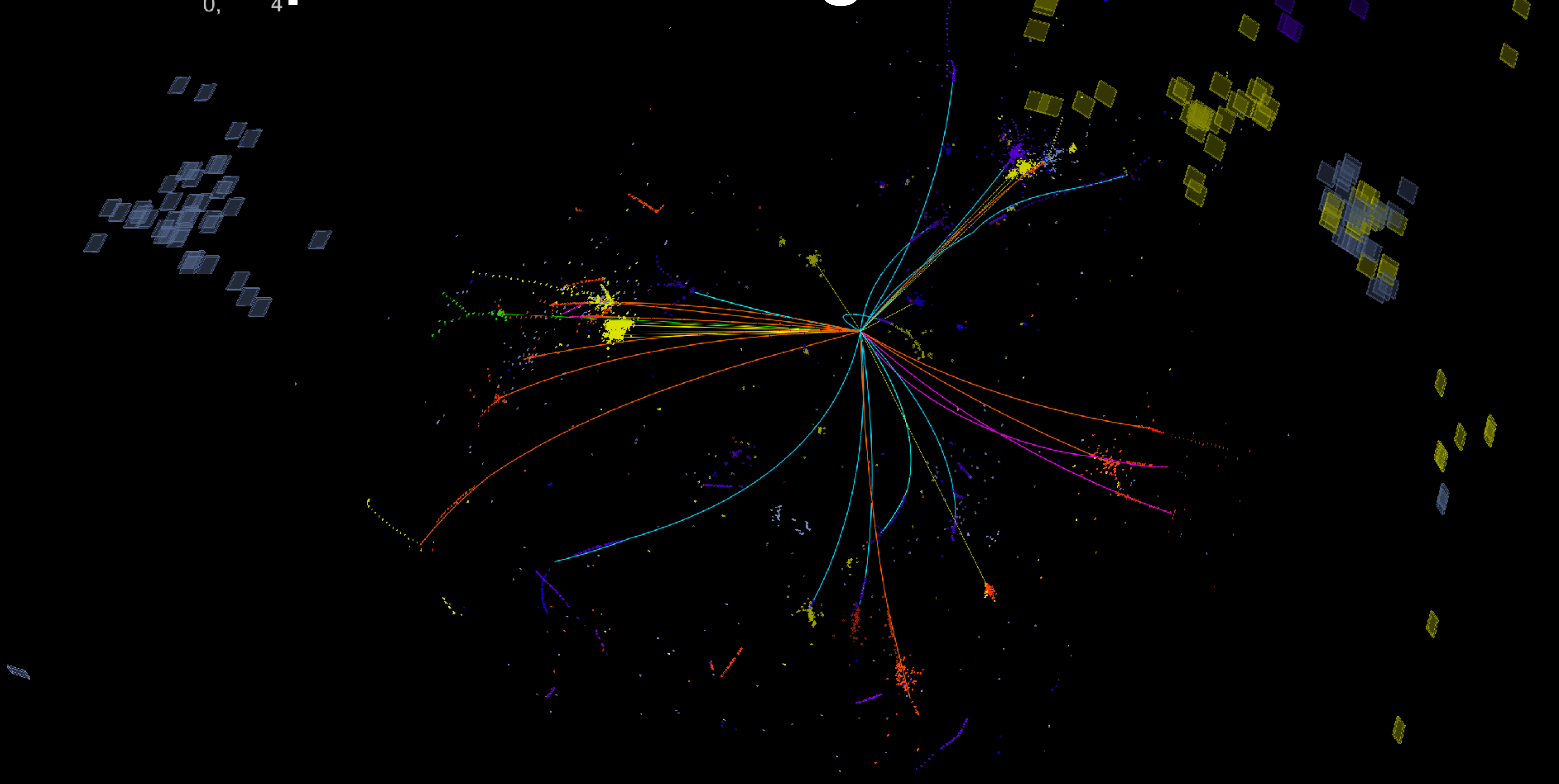
CEPC: 1M Higgs events、10B+ Z boson

精确测量几乎所有 Higgs 性质，精度提高一个量级

标准模型关键参数的测量精度有望超过一个量级

Flavor physics at Z pole + 双光子对撞

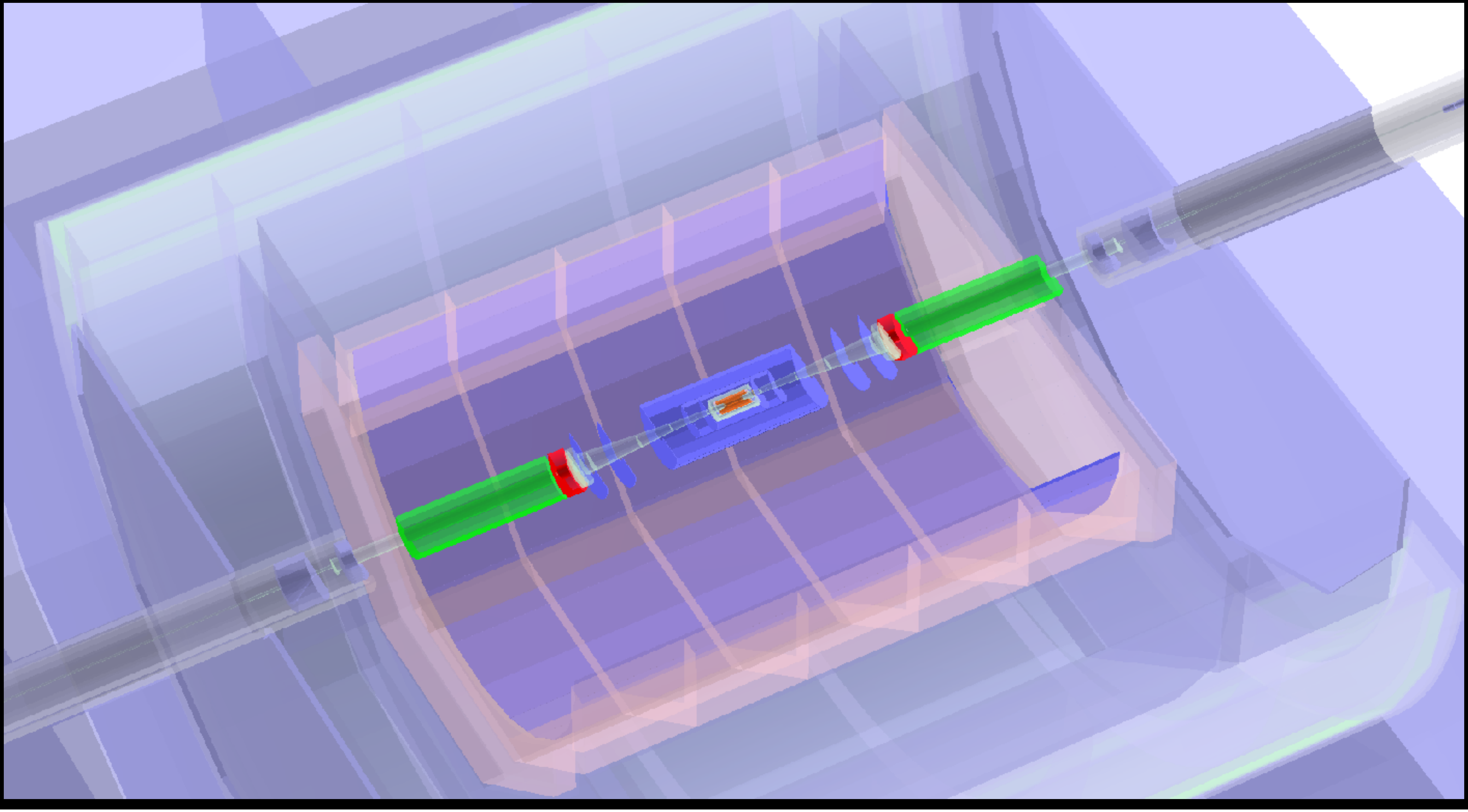
PFA： particle flow algorithm



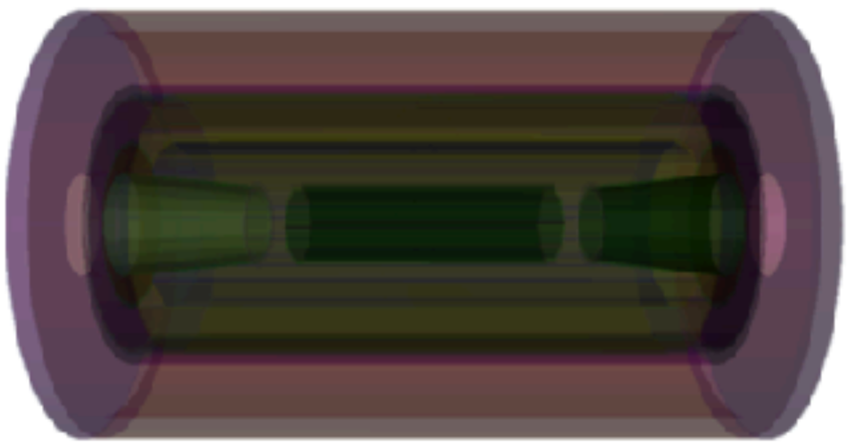
高能量、高亮度、高粒度

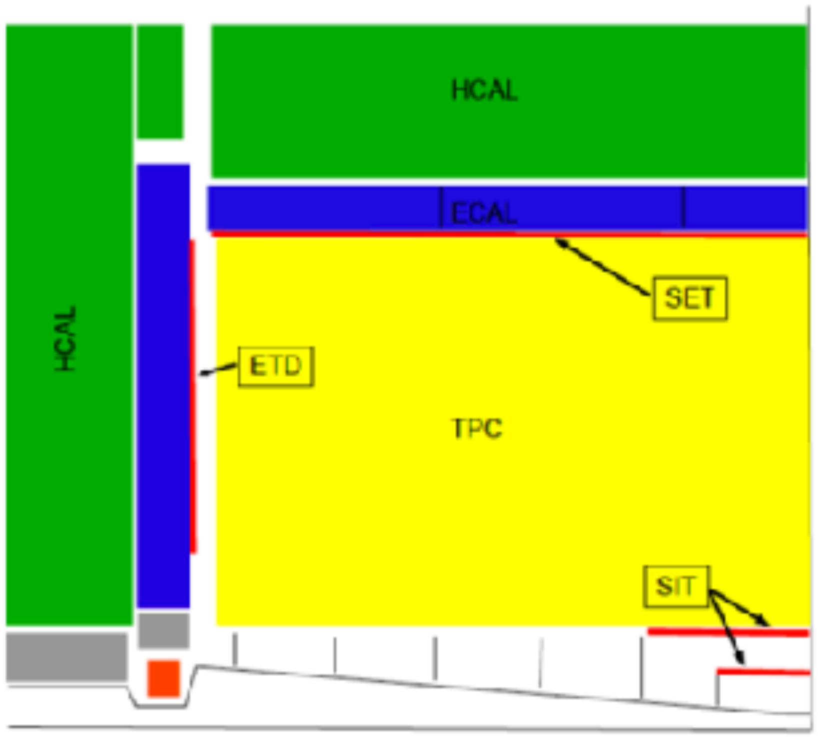
—— PFA detector+大数据+机器学习 ➡ 物理结果

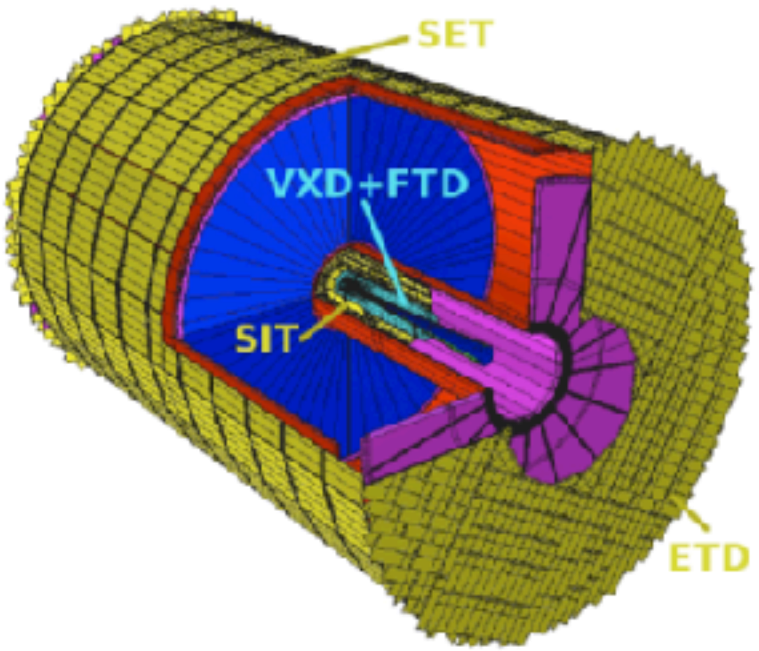
CEPC detector



- A detector reconstruct 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: $\delta(1/Pt) \sim 2*10^{-5}(GeV^{-1})$
- PFA oriented Calorimeter System (~$o(10^{8})$ channels): ID, Jet energy resolution, etc





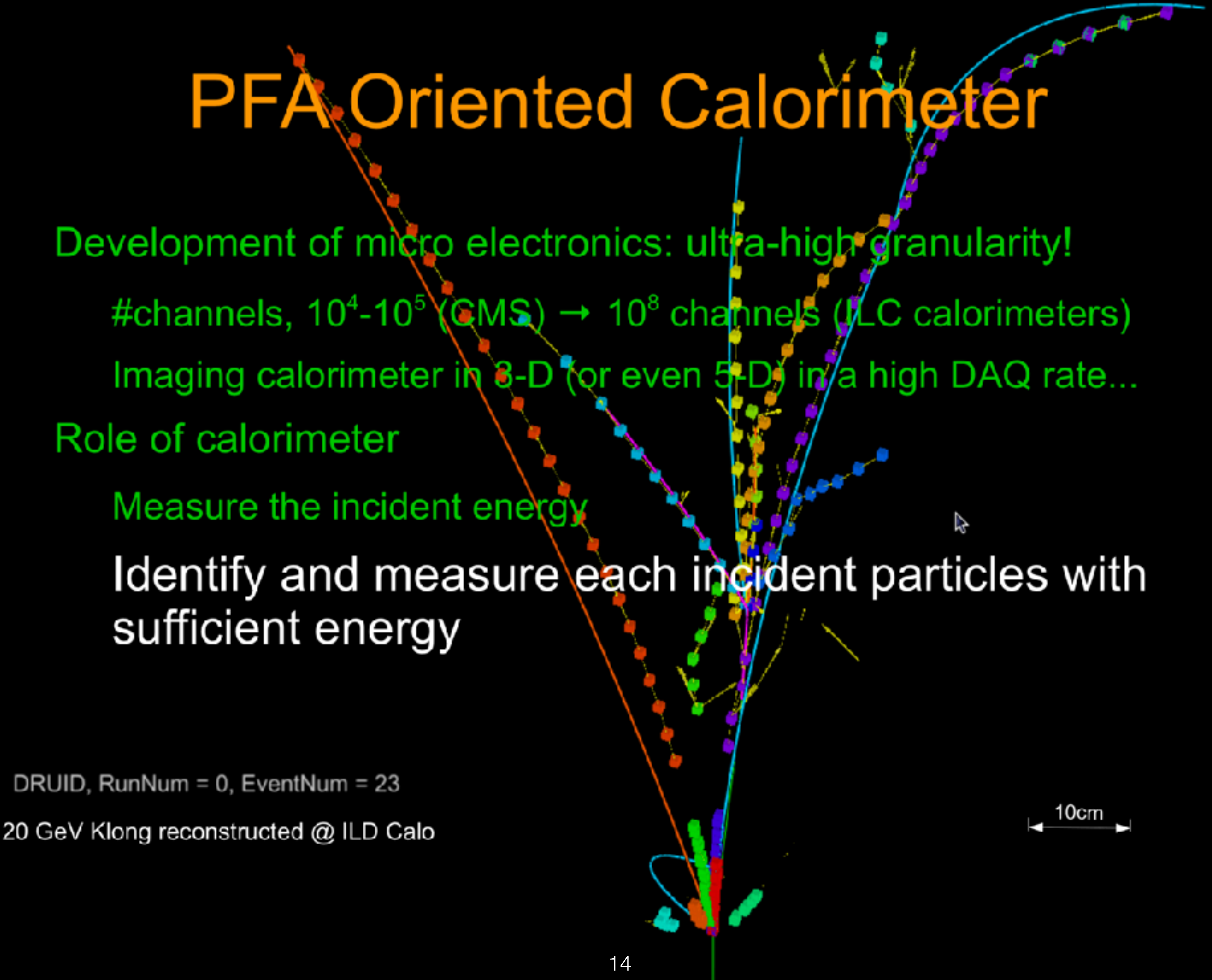


Vertex & Silicon Tracking system

- VTX: Inner most layer Radius: ~16 mm, Spatial resolution: 3~5 μm
- Massive usage of silicon pixel/strips in the tracking system & VTX: ensures good accuracy in Impact parameter & momentum measurement

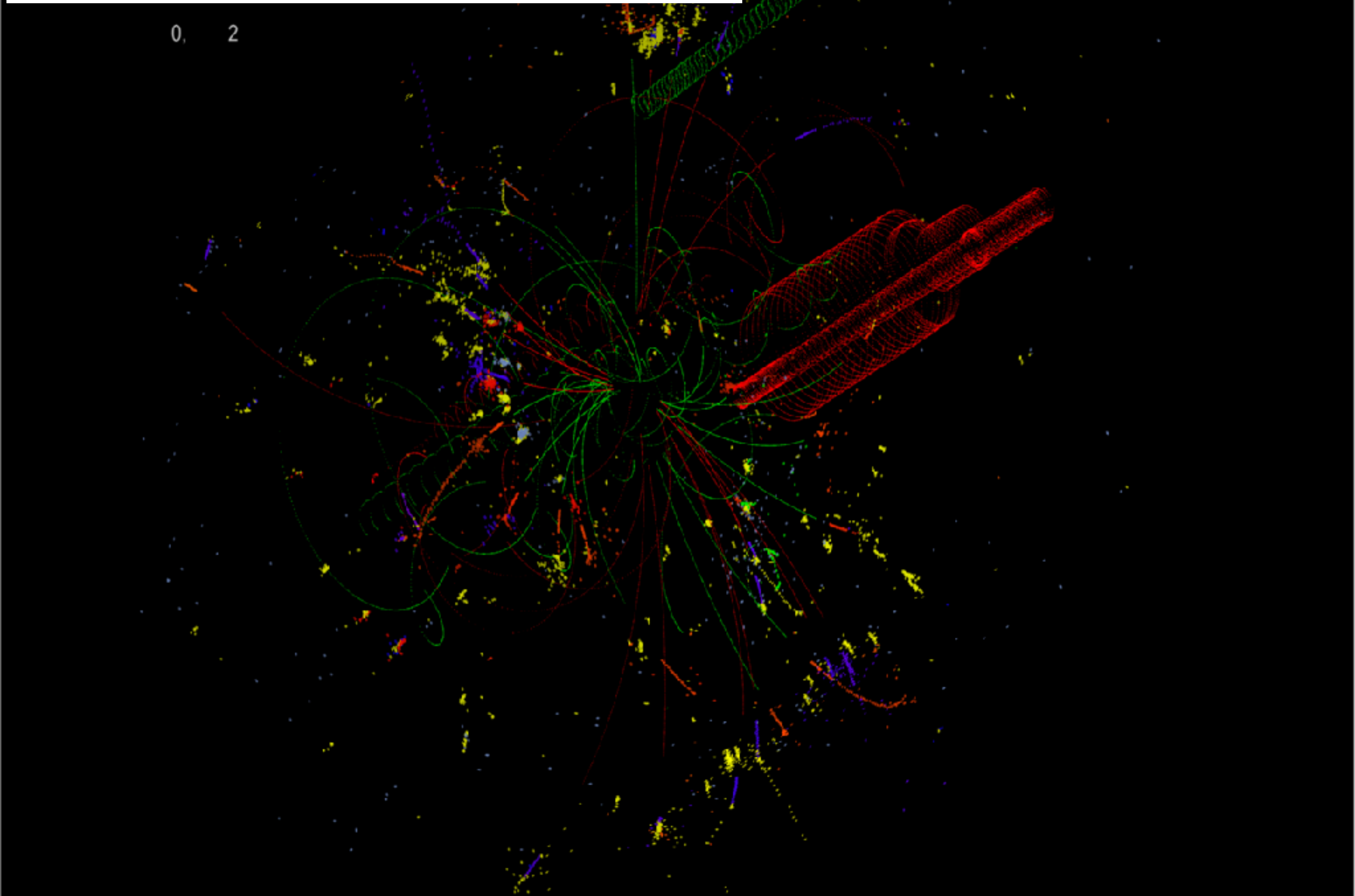
PFA Oriented Calorimeter

- Development of micro electronics: ultra-high granularity!
  - #channels, 10^4-10^5 (CMS) → 10^8 channels (ILC calorimeters)
  - Imaging calorimeter in 3-D (or even 5-D) in a high DAQ rate...
- Role of calorimeter
  - Measure the incident energy
  - Identify and measure each incident particles with sufficient energy



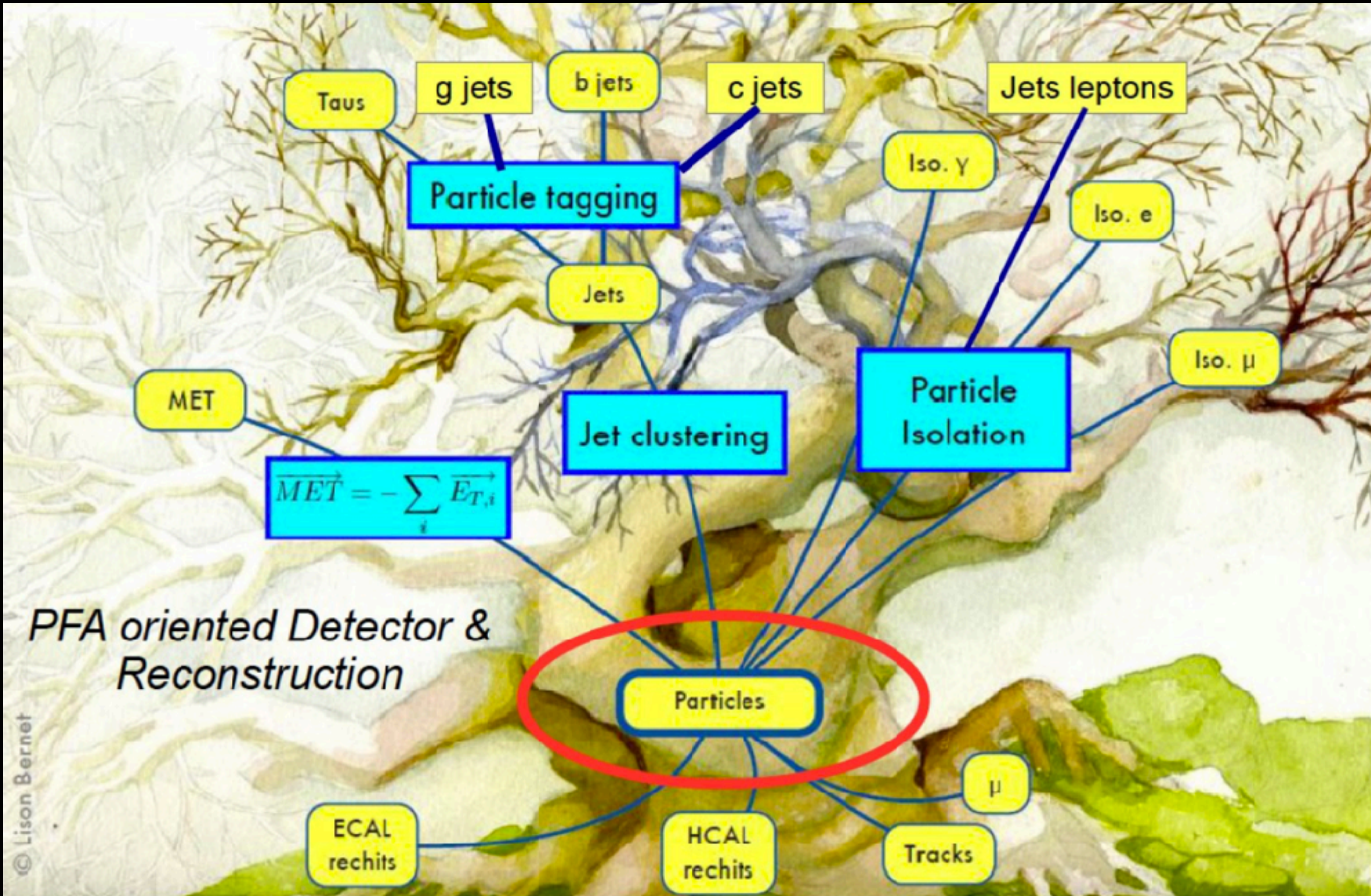
20 GeV Klong reconstructed @ ILD Calo

From Hits to Final State Particles



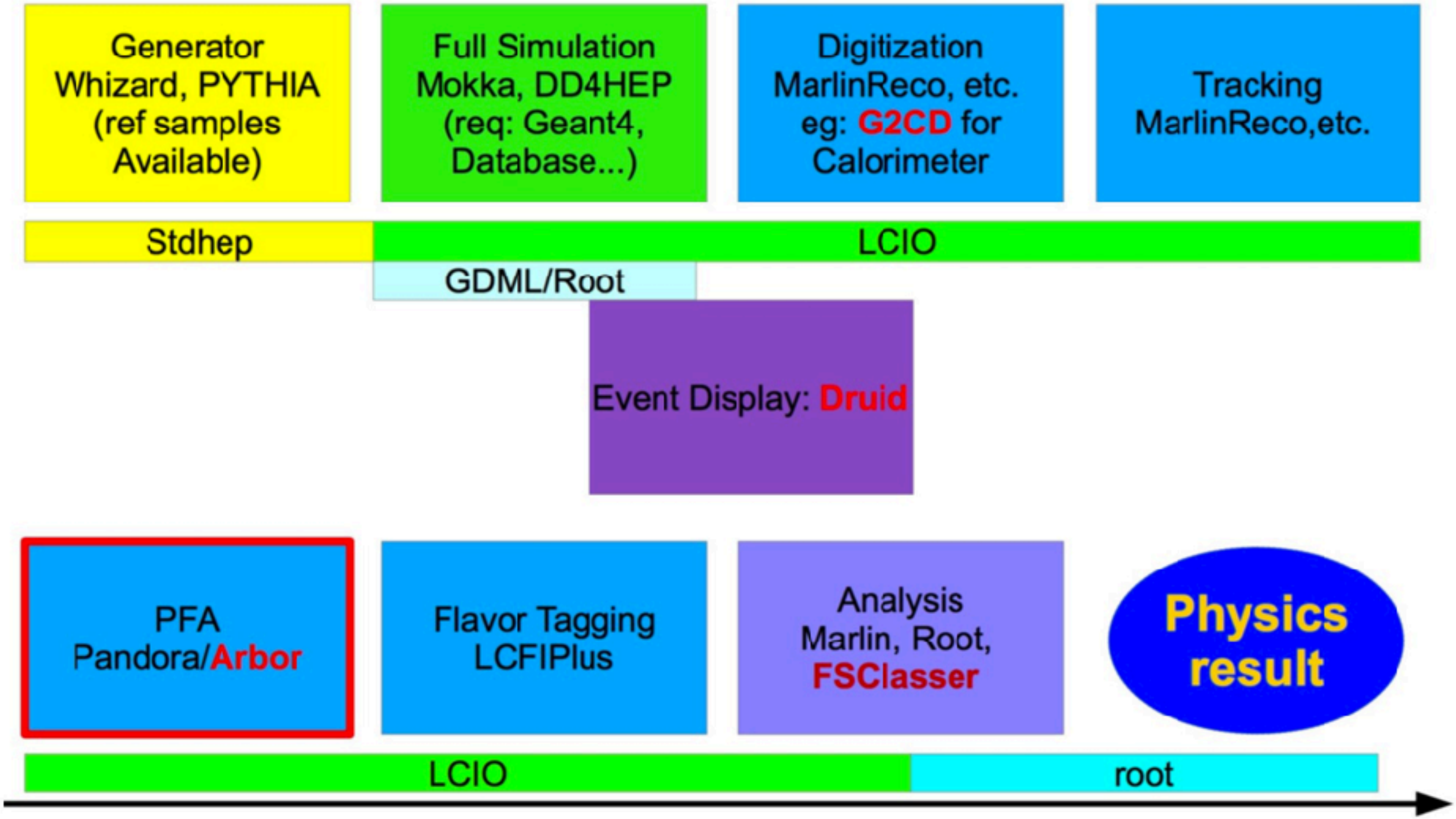
CEPC software

- ☐ Generators
- ☐ Simulation
- ☐ Reconstruction
- ☐ Calibration
- ☐ Analysis

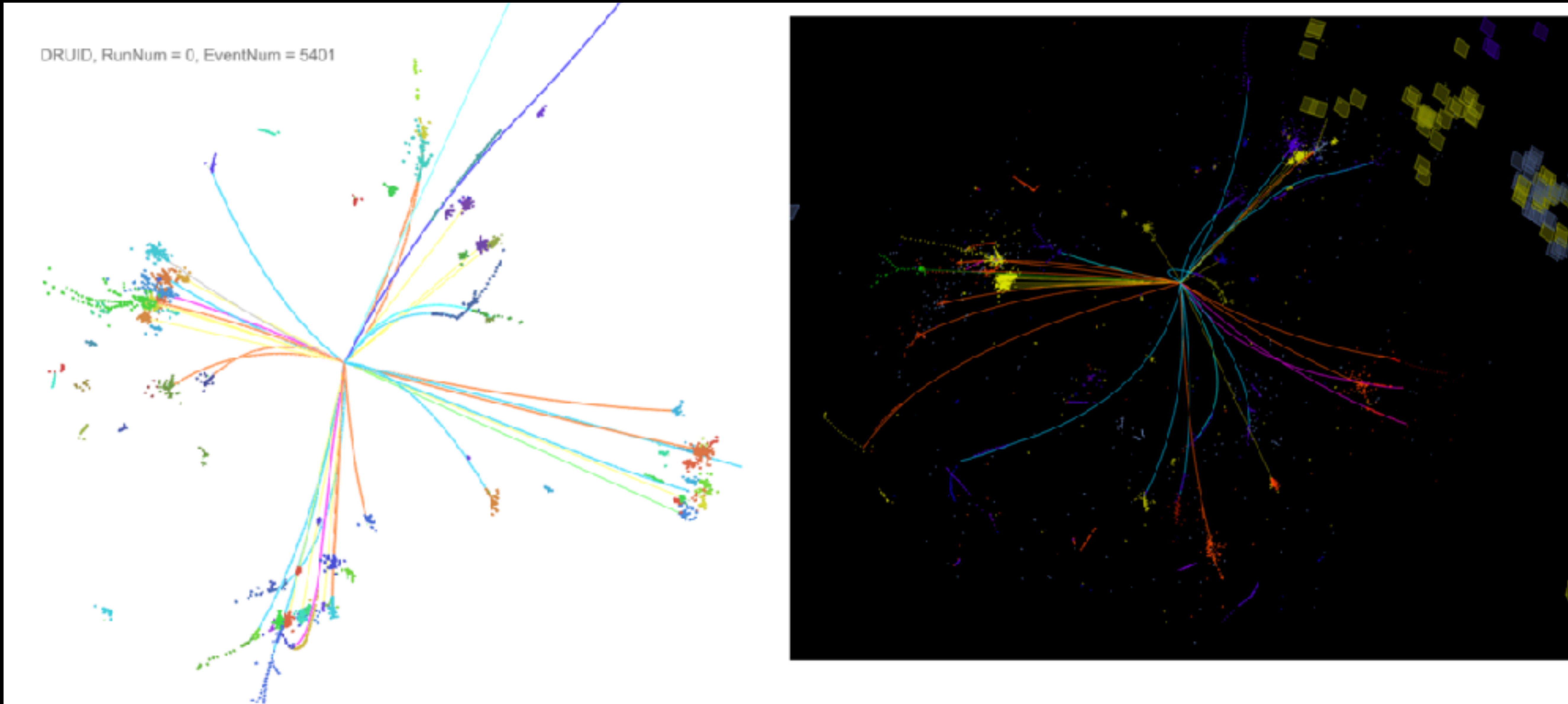


高精度的挑战之一是：高效、精准地记录、重建每种关键物理对象

SCRAC



完整的的工具链



重建的第一步：径迹重建

径迹寻找+径迹拟合

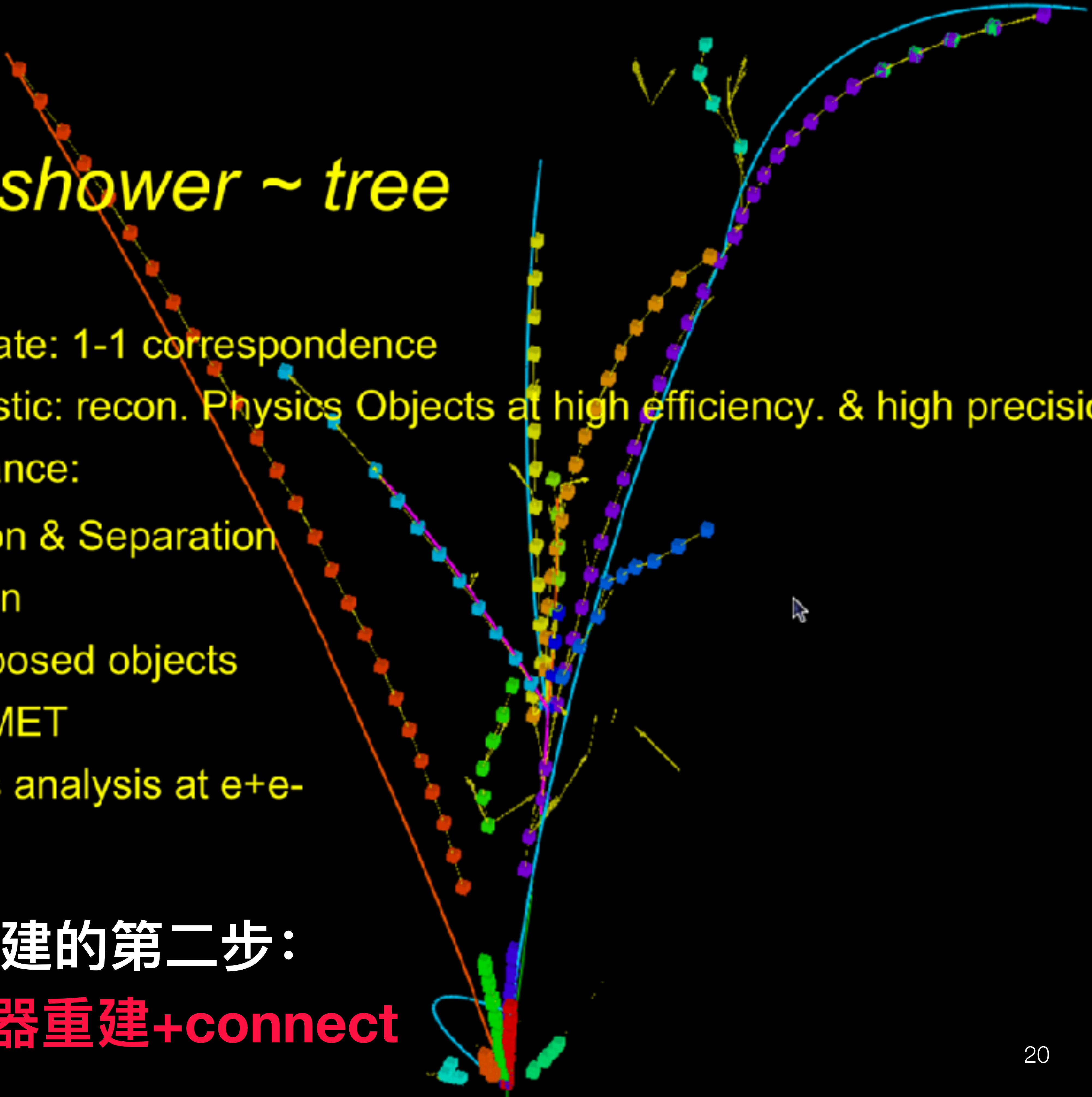
Arbor: shower ~ tree

Goal:

- Ultimate: 1-1 correspondence
- Realistic: recon. Physics Objects at high efficiency. & high precision

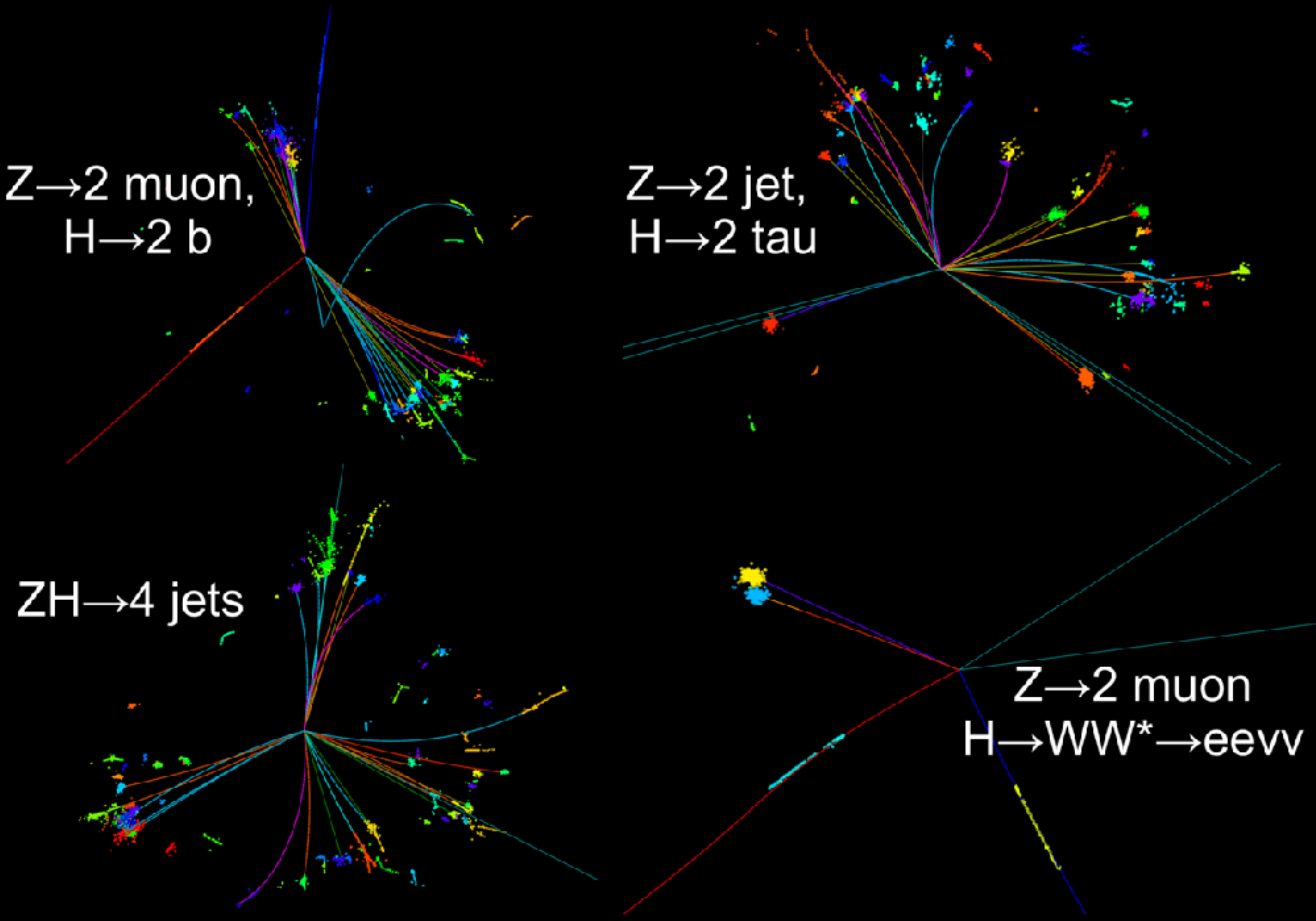
Performance:

- Photon & Separation
- Lepton
- Composed objects
- JET/MET
- Higgs analysis at e+e-



重建的第二步：

量能器重建+connect

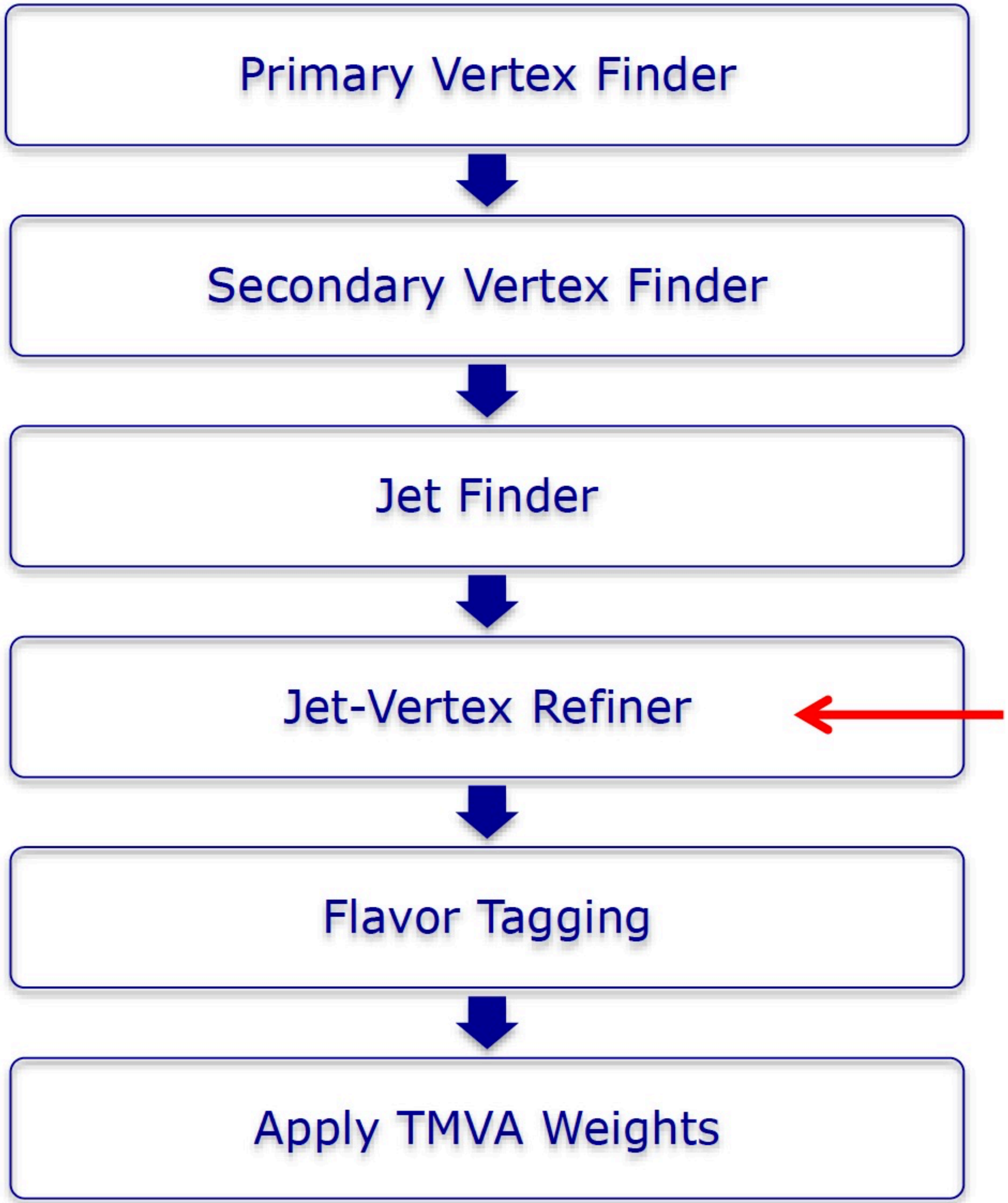


Z→2 muon,
H→2 b
Z→2 jet,
H→2 tau
ZH→4 jets
Z→2 muon
H→WW*→eeνν

第三步：jet（tau）

- Jet-clustering
- Jet-substructure
- Jet-flavor-tagging， gluon ID

Reconstruction Flow

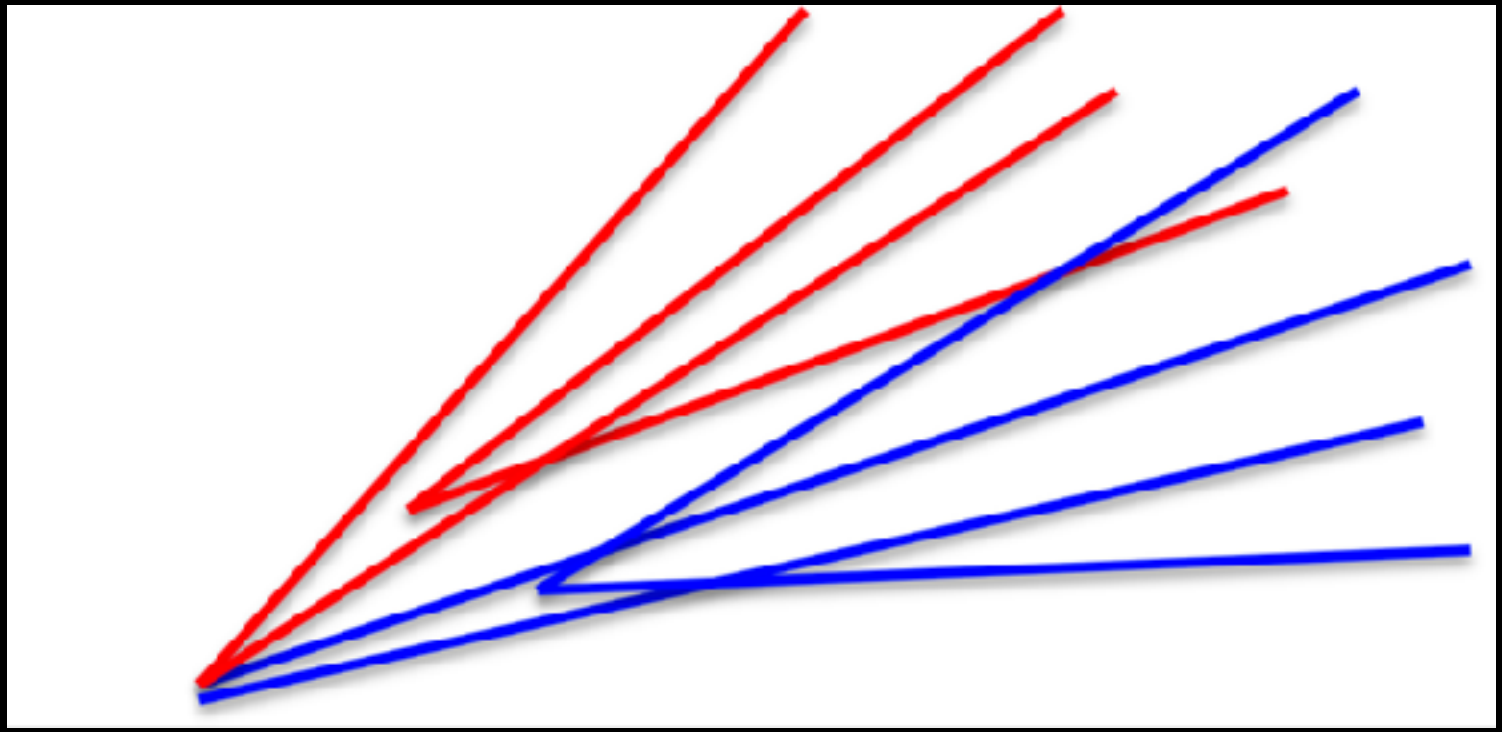


Vertex finding first,
Jet finding second

Vertex charge optimization could go here

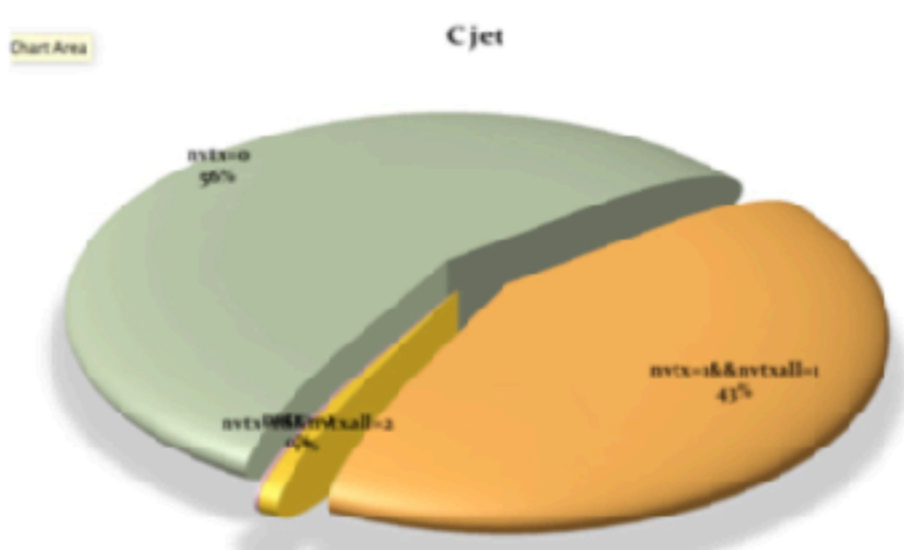
Current procedure

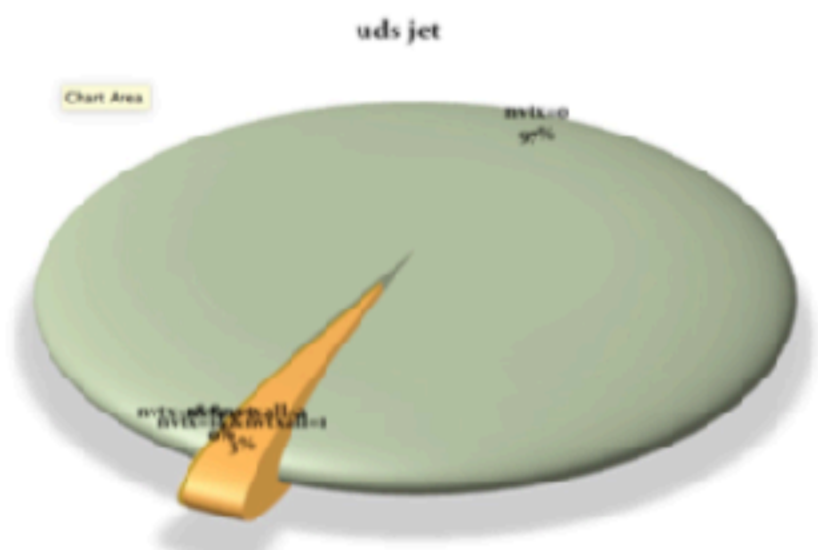
鉴别的硬件基础：< 5微米的顶点测量精度



最重要的特征

	Total	nvtx==0	nvtx=1&& Nvtxall==1	nvtx==1&& nvtxall==2	Nvtx>=2
B	395567	83099	156094	76239	80135
C	396692	223238	169400	3392	662
uds	393310	382522	10511	171	106

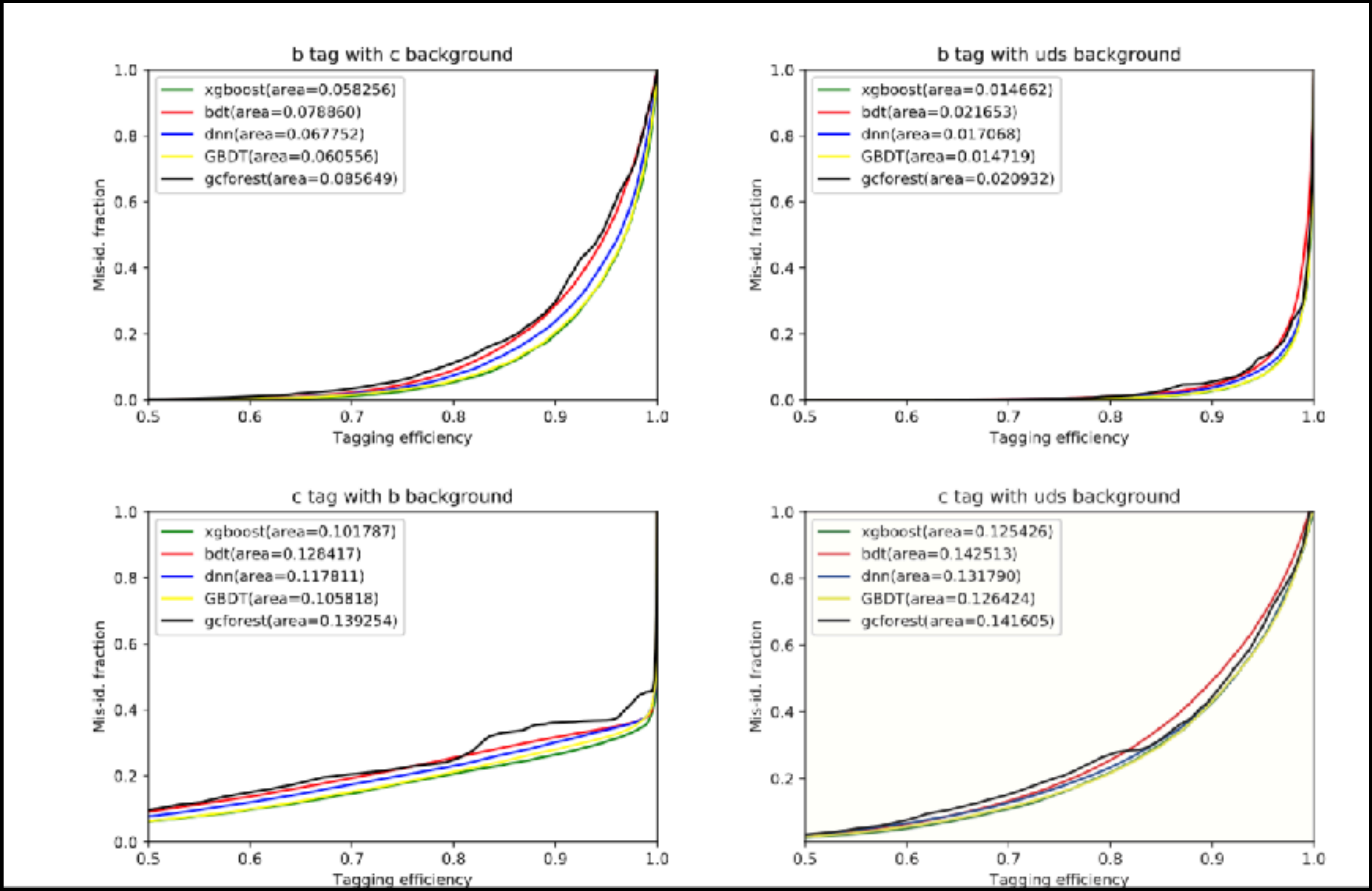




机器学习

nvtx=0	trk1d0sig trk2d0sig trk1z0sig trk2z0sig trk1pt_jete trk2pt_jete jprobr5sigma jprobz5sigma d0bprob d0cprob d0qprob z0bprob z0cprob z0qprob nmuon nelectron trkmass(17)
nvtx=1&& nvtxall=1	trk1d0sig trk2d0sig trk1z0sig trk2z0sig trk1pt_jete trk2pt_jete jprobr jprobz vtxlen1_jete vtxsig1_jete vtxdirang1_jete vtxmom1_jete vtxmass1 vtxmult1 vtxmasspc vtxprob d0bprob d0cprob d0qprob z0bprob z0cprob z0qprob trkmass nelectron nmuon(25)
nvtx=1&& nvtxall=2	trk1d0sig trk2d0sig trk1z0sig trk2z0sig trk1pt_jete trk2pt_jete jprobr jprobz vtxlen1_jete vtxsig1_jete vtxdirang1_jete vtxmom1_jete vtxmass1 vtxmult1 vtxmasspc vtxprob 1vtxprob vtxlen12all_jete vtxmassall (19)
Nvtx>=2	trk1d0sig trk2d0sig trk1z0sig trk2z0sig trk1pt_jete trk2pt_jete jprobr jprobz vtxlen1_jete vtxsig1_jete vtxdirang1_jete vtxmom1_jete vtxmass1 vtxmult1 vtxmasspc vtxprob vtxlen2_jete vtxsig2_jete vtxdirang2_jete vtxmom2_jete vtxmass2 vtxmult2 vtxlen12_jete vtxsig12_jete vtxdirang12_jete vtxmom_jete vtxmass vtxmult 1vtxprob(29)

鉴别效率和误判

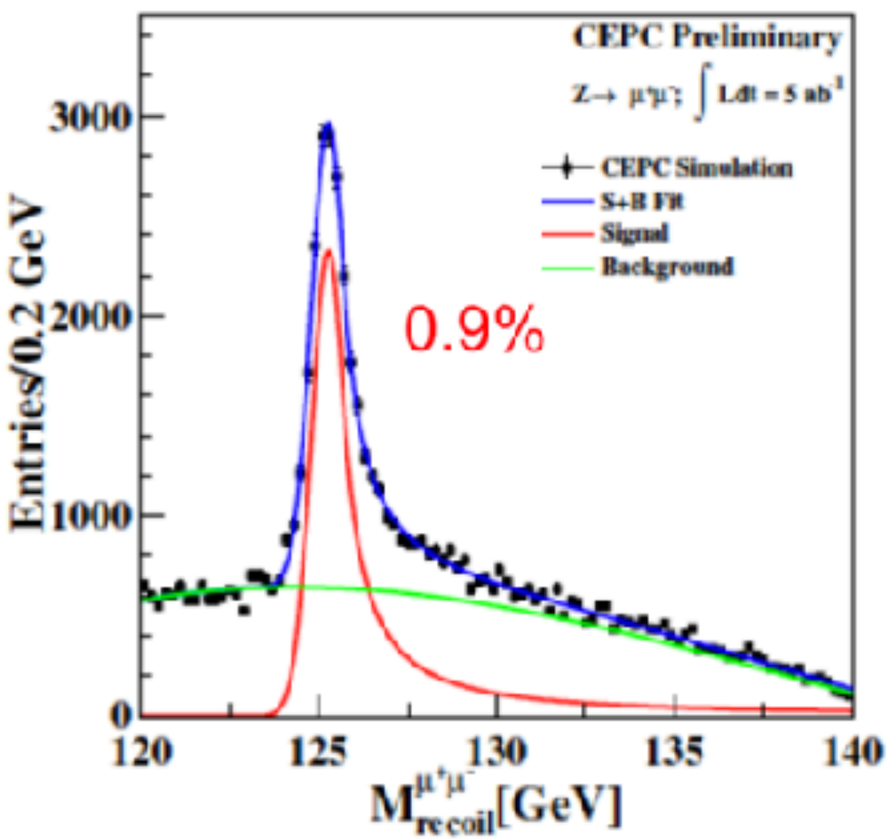


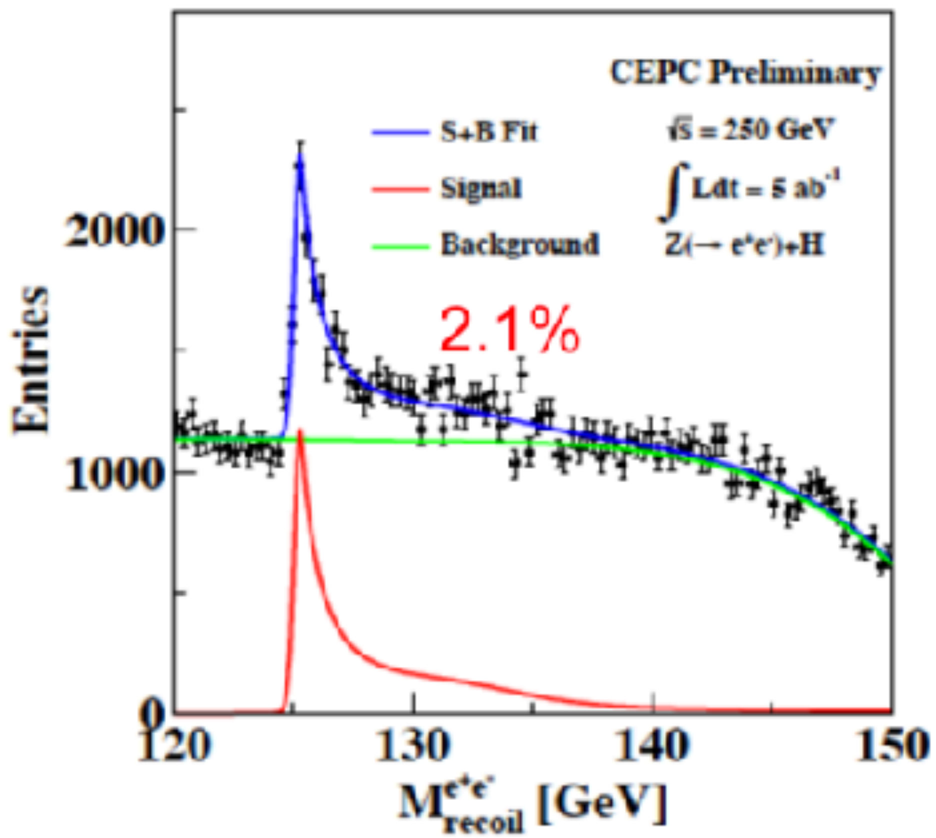
b tag with c background
xgboost(area=0.058256)
bdt(area=0.078860)
dnn(area=0.067752)
GBDT(area=0.060556)
gcforest(area=0.085649)
Mis-id. fraction
Tagging efficiency
b tag with uds background
xgboost(area=0.014662)
bdt(area=0.021653)
dnn(area=0.017068)
GBDT(area=0.014719)
gcforest(area=0.020932)
Mis-id. fraction
Tagging efficiency
c tag with b background
xgboost(area=0.101787)
bdt(area=0.128417)
dnn(area=0.117811)
GBDT(area=0.105818)
gcforest(area=0.139254)
Mis-id. fraction
Tagging efficiency
c tag with uds background
xgboost(area=0.125426)
bdt(area=0.142513)
dnn(area=0.131790)
GBDT(area=0.126424)
gcforest(area=0.141605)
Mis-id. fraction
Tagging efficiency

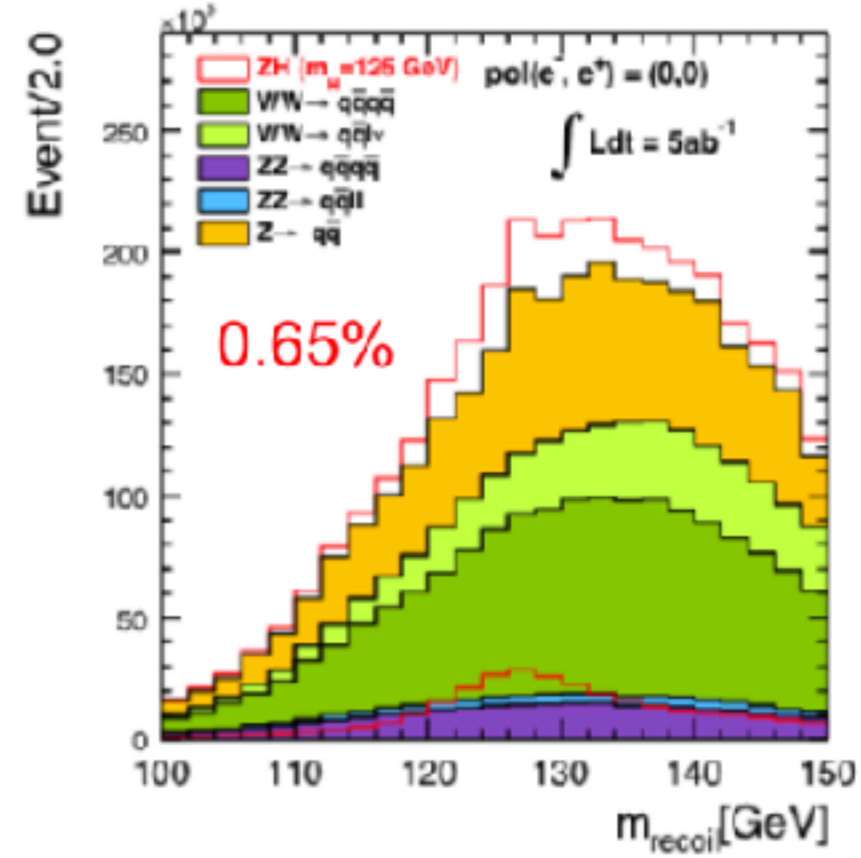
CEPC physics

Higgs
W
Z&flavor
Top

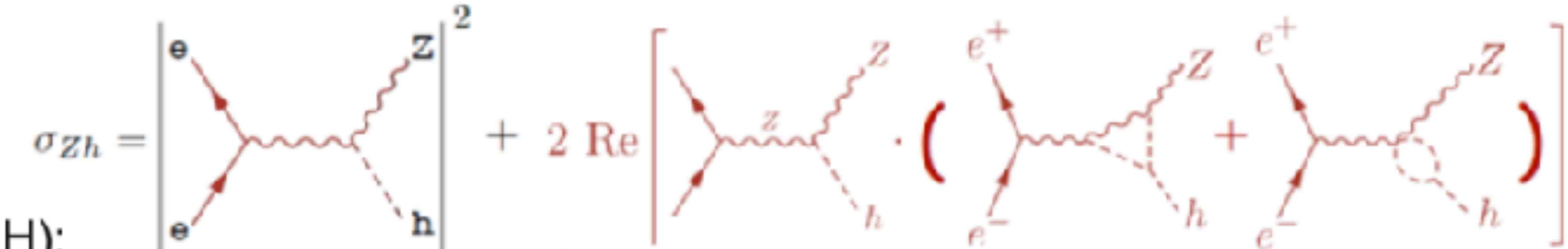
Model-independent measurement of σ(ZH)





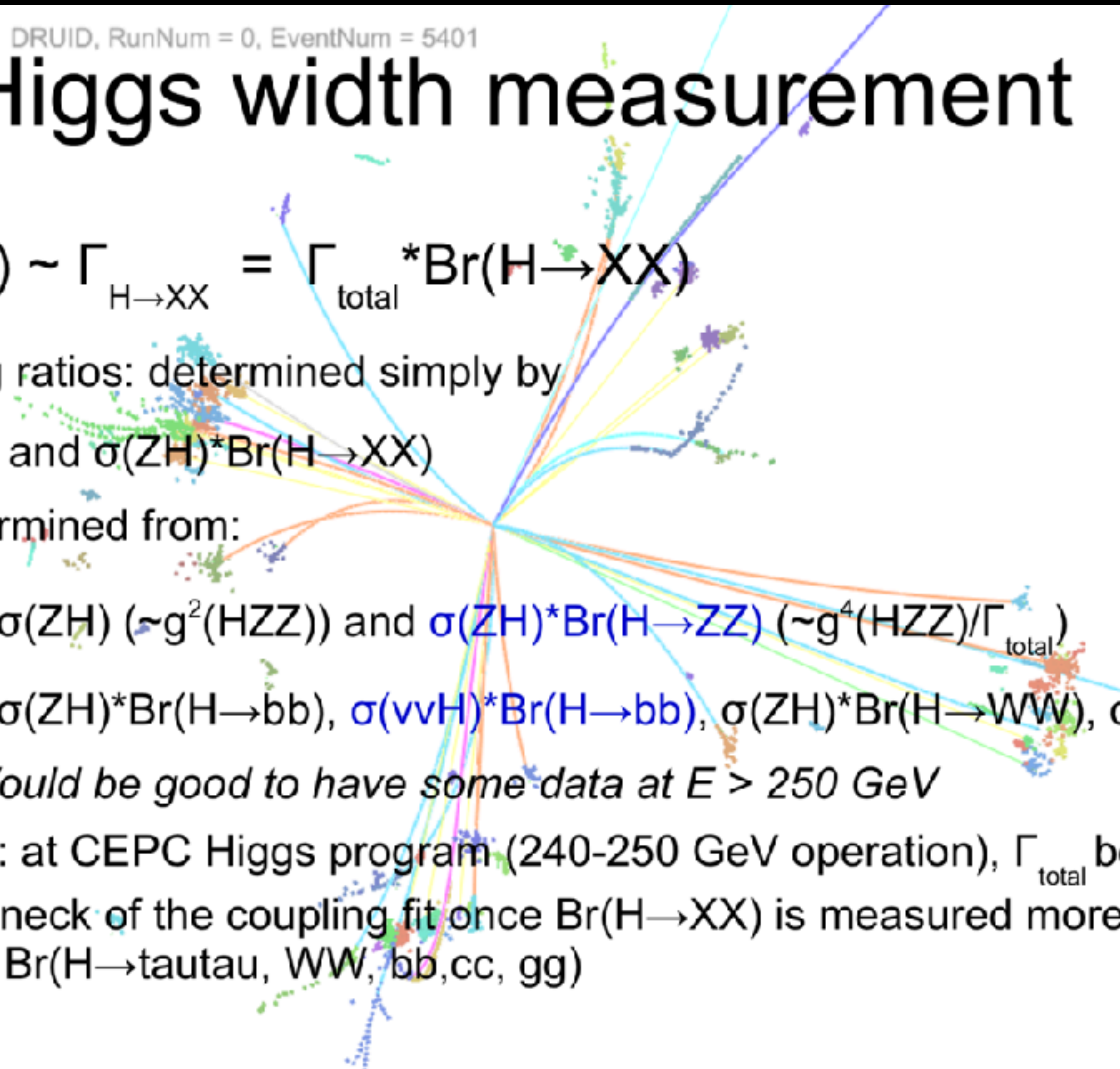


- Recoil mass method. Combined precision:
  δσ(ZH)/σ(ZH) = 0.5% -
  δg(HZZ)/g(HZZ) = 0.25%
- In-direct measurement on g(HHH): ~60% in 7 para fit and ~ 70% in 10 para fit



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

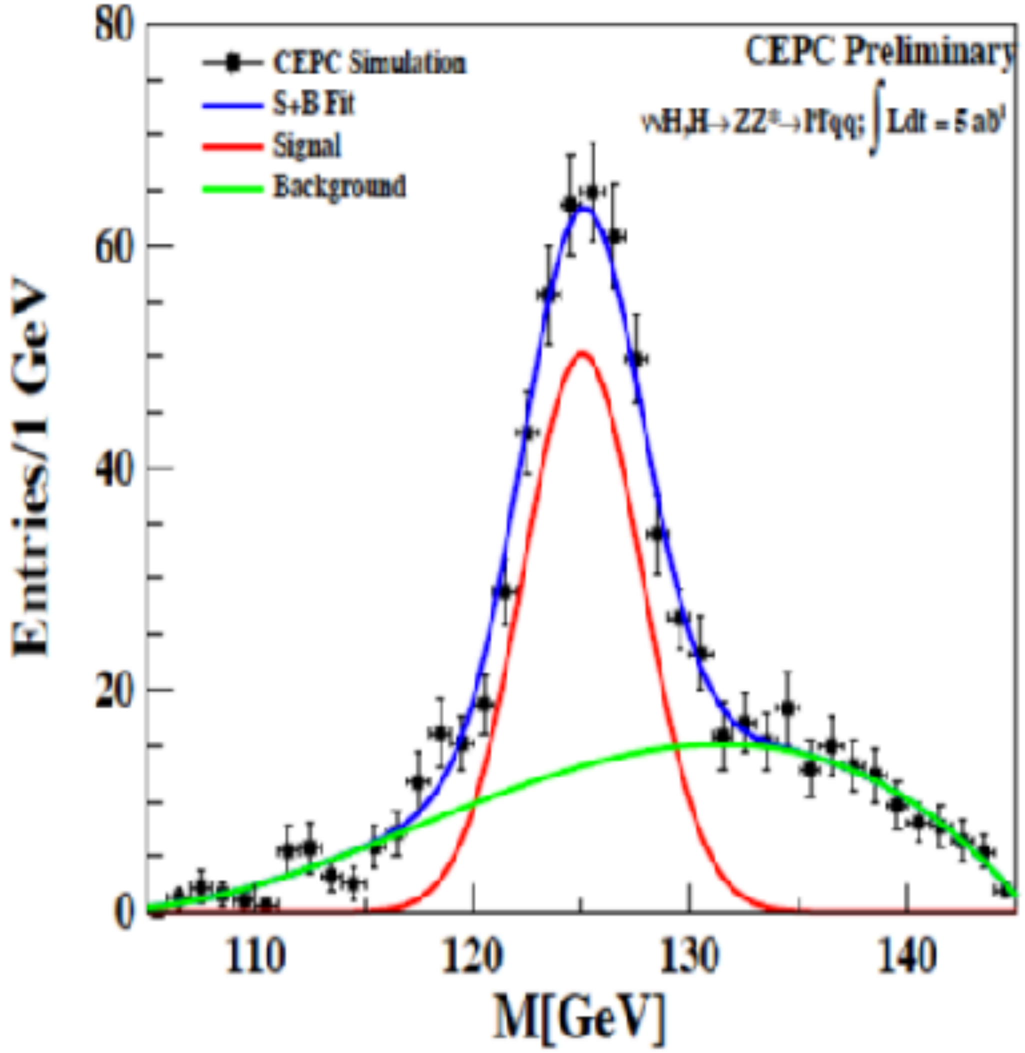
- *M. McCullough, 1312.3322*

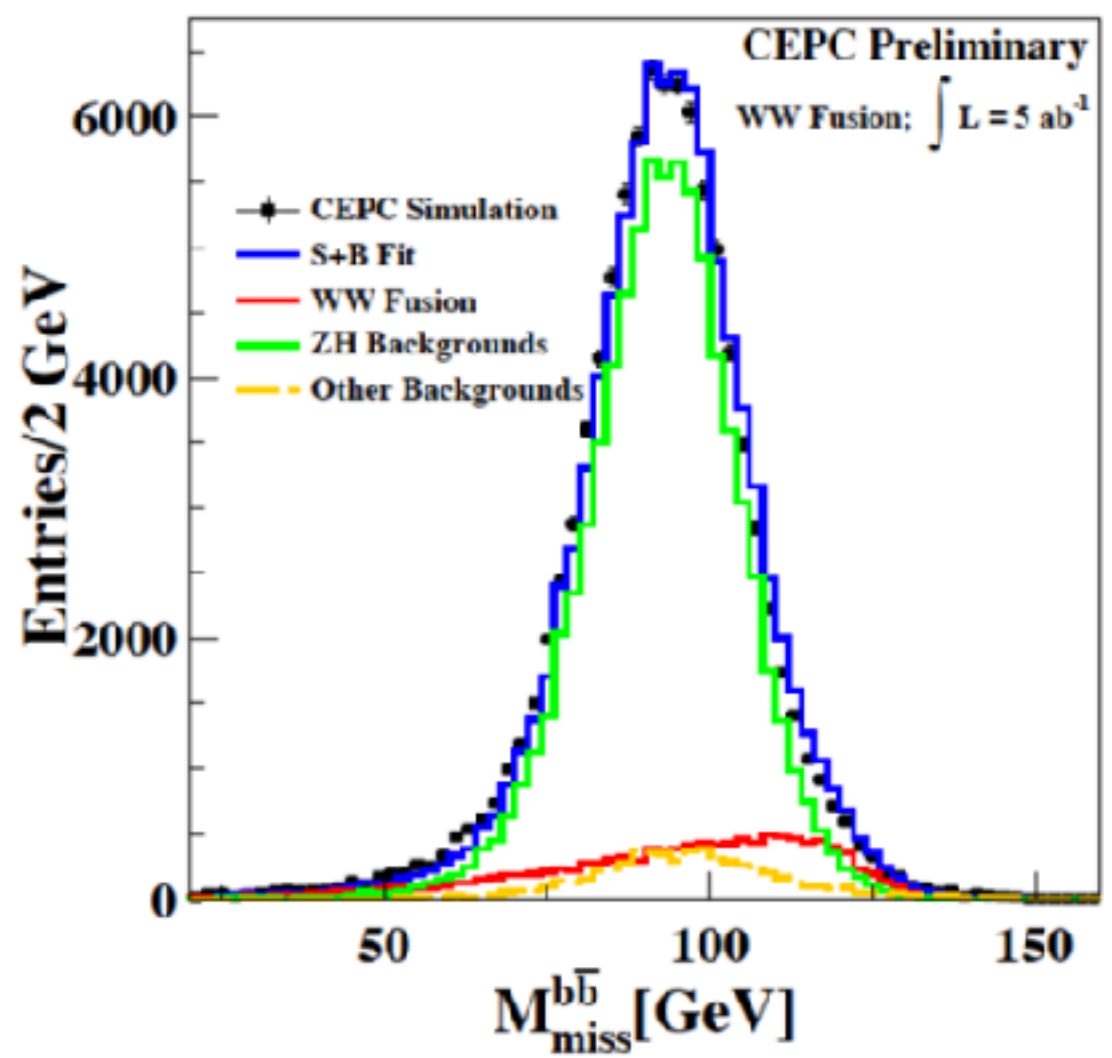


Higgs width measurement

- $g^2(HXX) \sim \Gamma_{H\to XX} = \Gamma_{total}{*}Br(H\to XX)$
- Branching ratios: determined simply by
  - $\sigma(ZH)$ and $\sigma(ZH){*}Br(H\to XX)$
- Γ_{total} : determined from:
  - From $\sigma(ZH)$ ($\sim g^2(HZZ)$) and $\sigma(ZH){*}Br(H\to ZZ)$ ($\sim g^4(HZZ)/\Gamma_{total}$)
  - From $\sigma(ZH){*}Br(H\to bb)$, $\sigma(\nu\nu H){*}Br(H\to bb)$, $\sigma(ZH){*}Br(H\to WW)$, $\sigma(ZH)$
    - *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 $Br(H\to XX)$ is measured more precisely: $Br(H\to$ 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

Event rate & Branching ratio measurements

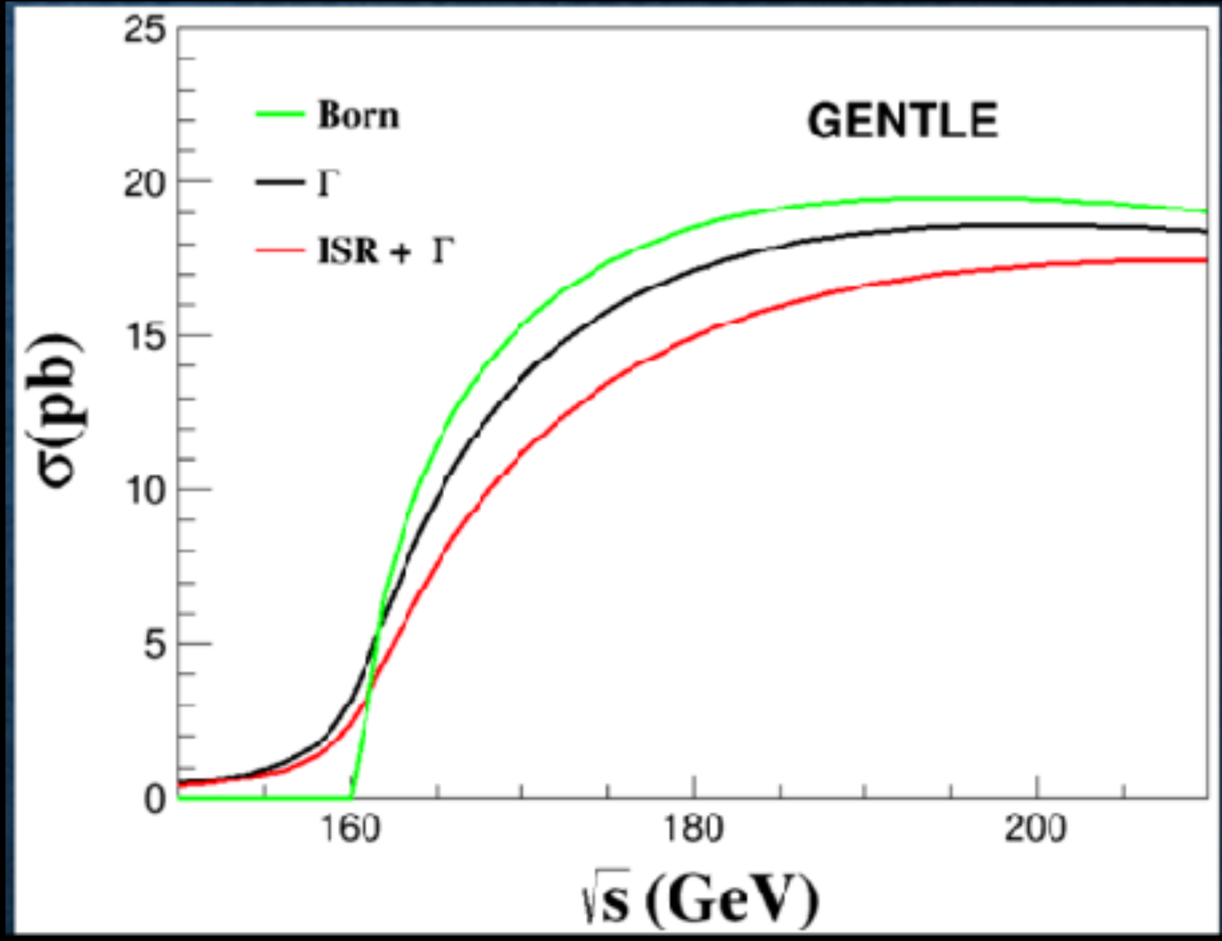
Table 3.12 Estimated precisions of Higgs boson property measurements at the CEPC. All the numbers refer to relative precision except for M_H and $\mathrm{BR}(H \to \mathrm{inv})$ for which ΔM_H and 95% CL upper limit are quoted respectively.

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%

W mass scan

Theoretical uncertainty still missing



With the configurations :

$$L = 3.2\ ab^{-1}, \epsilon P = 0.72\ , \sigma_{sys}^{corr} = 2 \times 10^{-4}$$

$$\Delta E = 0.5\ \text{MeV},\ E_{BS} = 1.6 \times 10^{-3},\ \Delta E_{BS} = 0.01$$

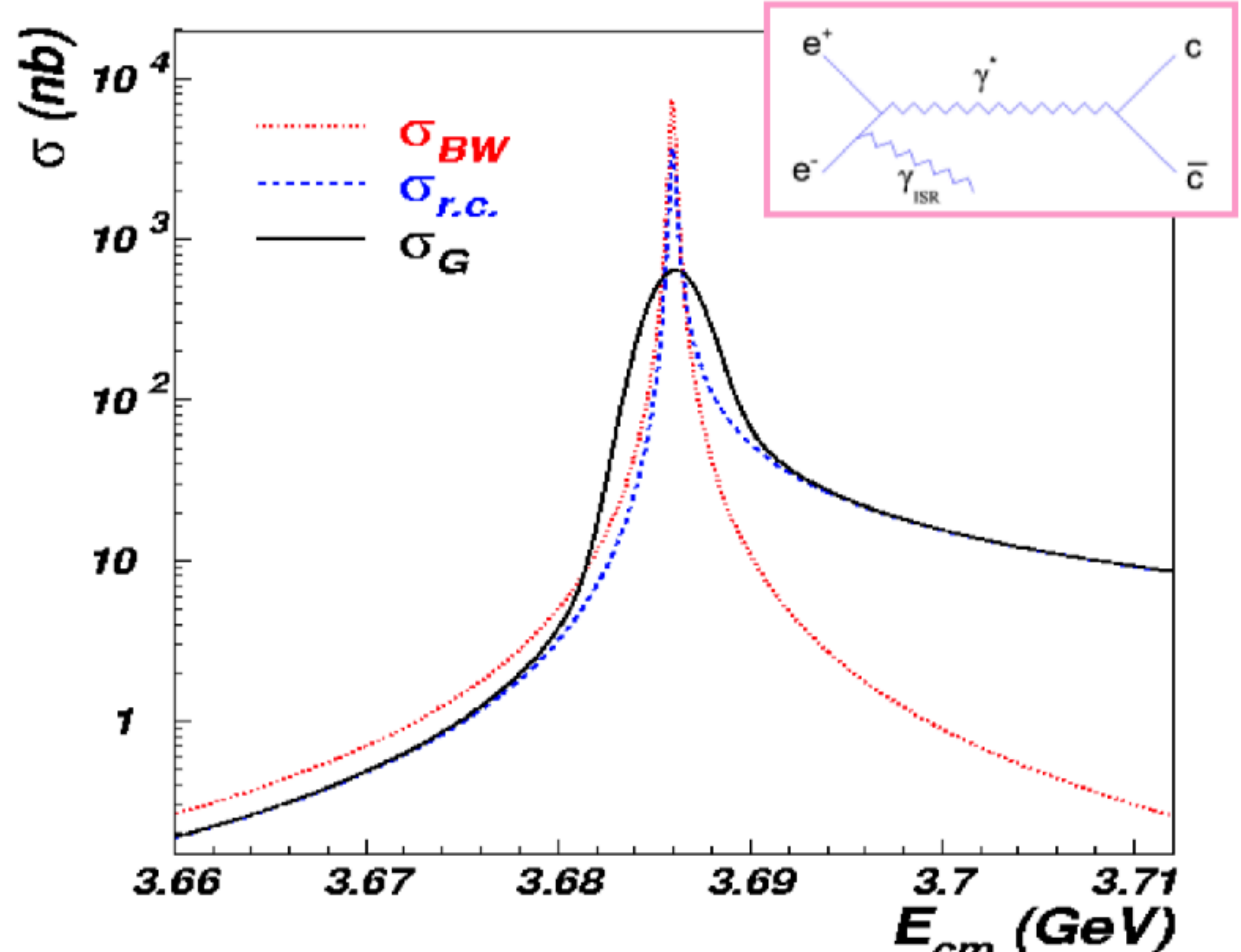
If we taking data at:

A. One points: $\Delta m_W \sim 0.9$ MeV (162.5 GeV)

B. Two points: $\Delta m_W \sim 1.0$ MeV, $\Delta\Gamma_W \sim 2.9$ MeV (E_1=157.5, E_2=162.5GeV, F_1=0.3)

C. Three points: $\Delta m_W \sim 1.0$ MeV, $\Delta\Gamma_W \sim 2.8$ MeV (E_1=157.5, E_2=162.5, E_3=161.5GeV, F_1=0.3, F_2=0.9)

The initial state radiation in e⁺ e⁻ collider



The ISR correction factor

1. The experimental observed cross section:

$$\sigma^{\mathrm{obs}}(s) = \int_0^{x_{\mathrm{m}}} F(x,s)\sigma^{\mathrm{dre}}(s(1-x))\ \mathrm{d}x \qquad (1)$$

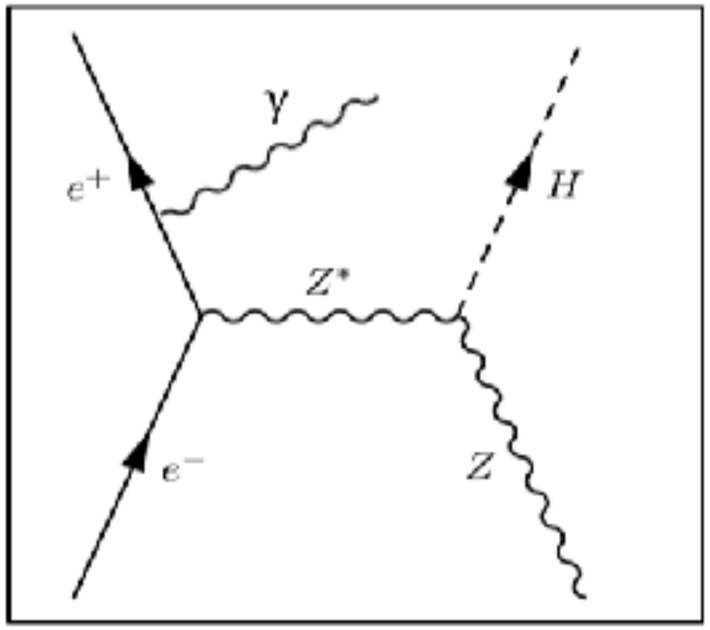
$$= \int_0^{x_{\mathrm{m}}} F(x,s)\frac{\sigma^{\mathrm{B}}(s(1-x))}{|1-\Pi(s(1-x))|^2}\ \mathrm{d}x, \qquad (2)$$

2. The ISR correction factor is defined:

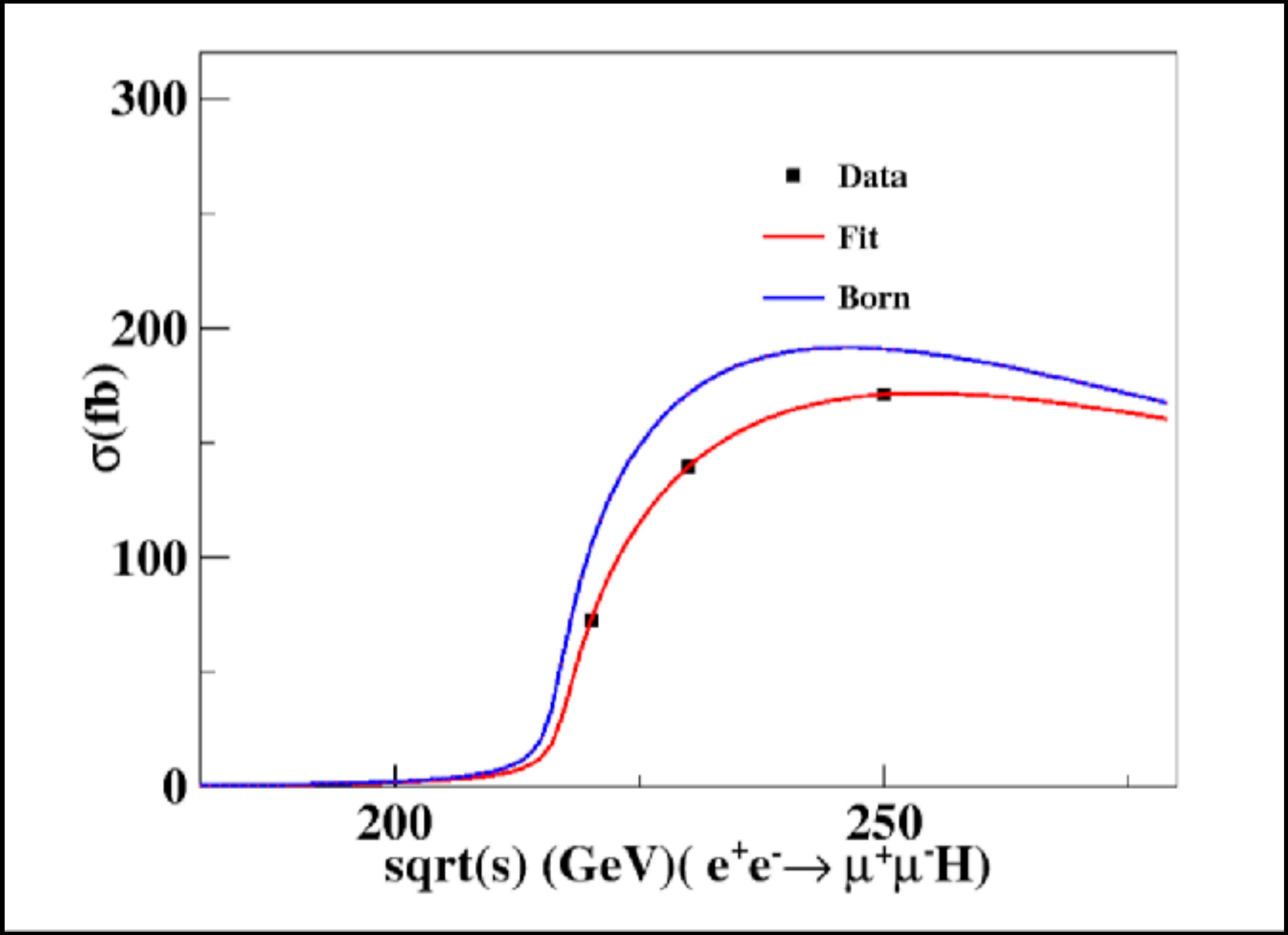
$$1+\delta(s) = \sigma^{\mathrm{dre}}(s)/\sigma^{\mathrm{obs}}(s)$$

3. The factorized born cross section:

$$\sigma^{\mathrm{B}}(s) = (1+\delta(s))\frac{\sigma^{\mathrm{obs}}(s)}{1/|1-\Pi(s)|^2}$$

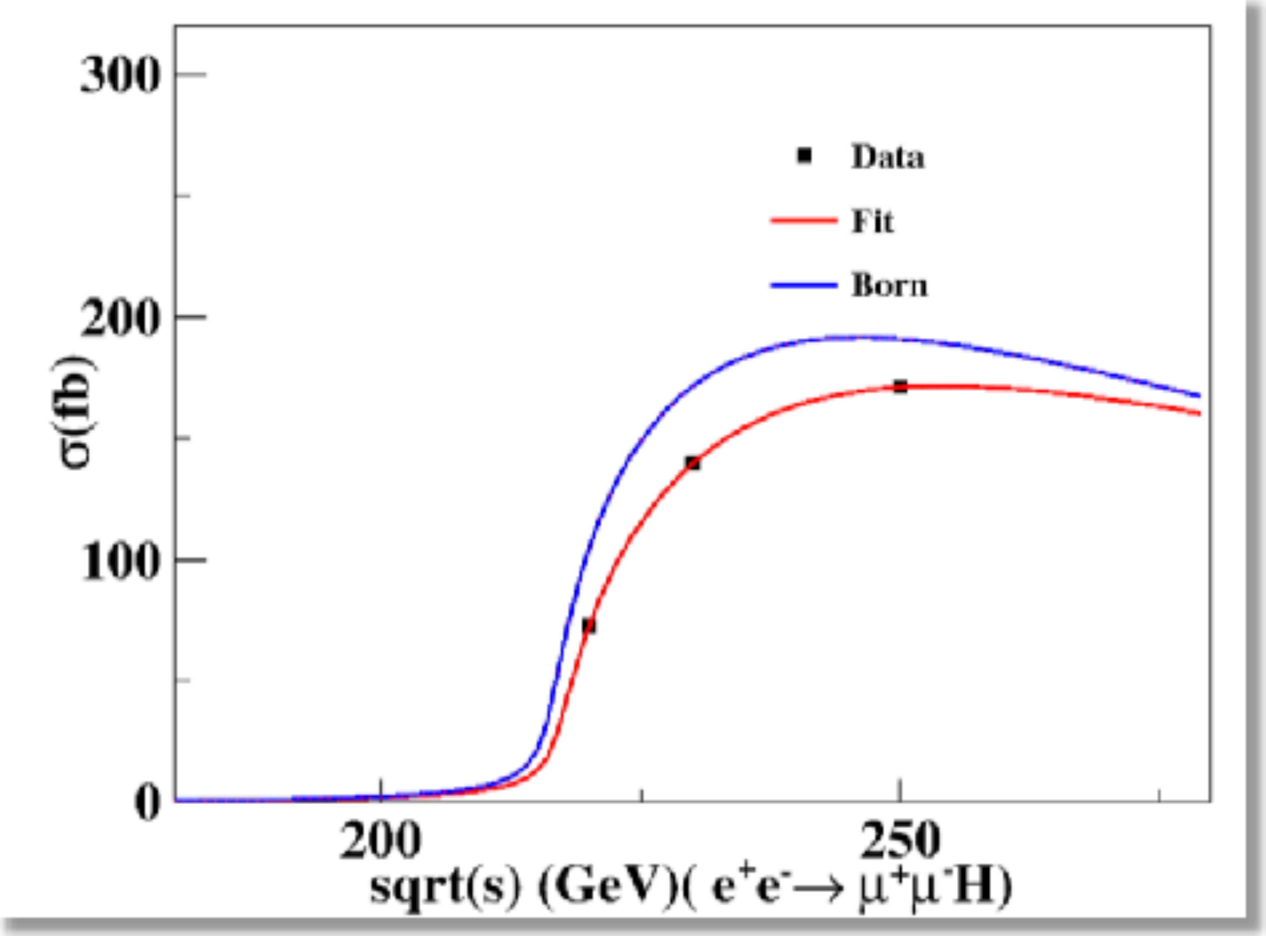


The line shape of $\sigma(e^+ e^- \to Z H)$



Model dependent fit

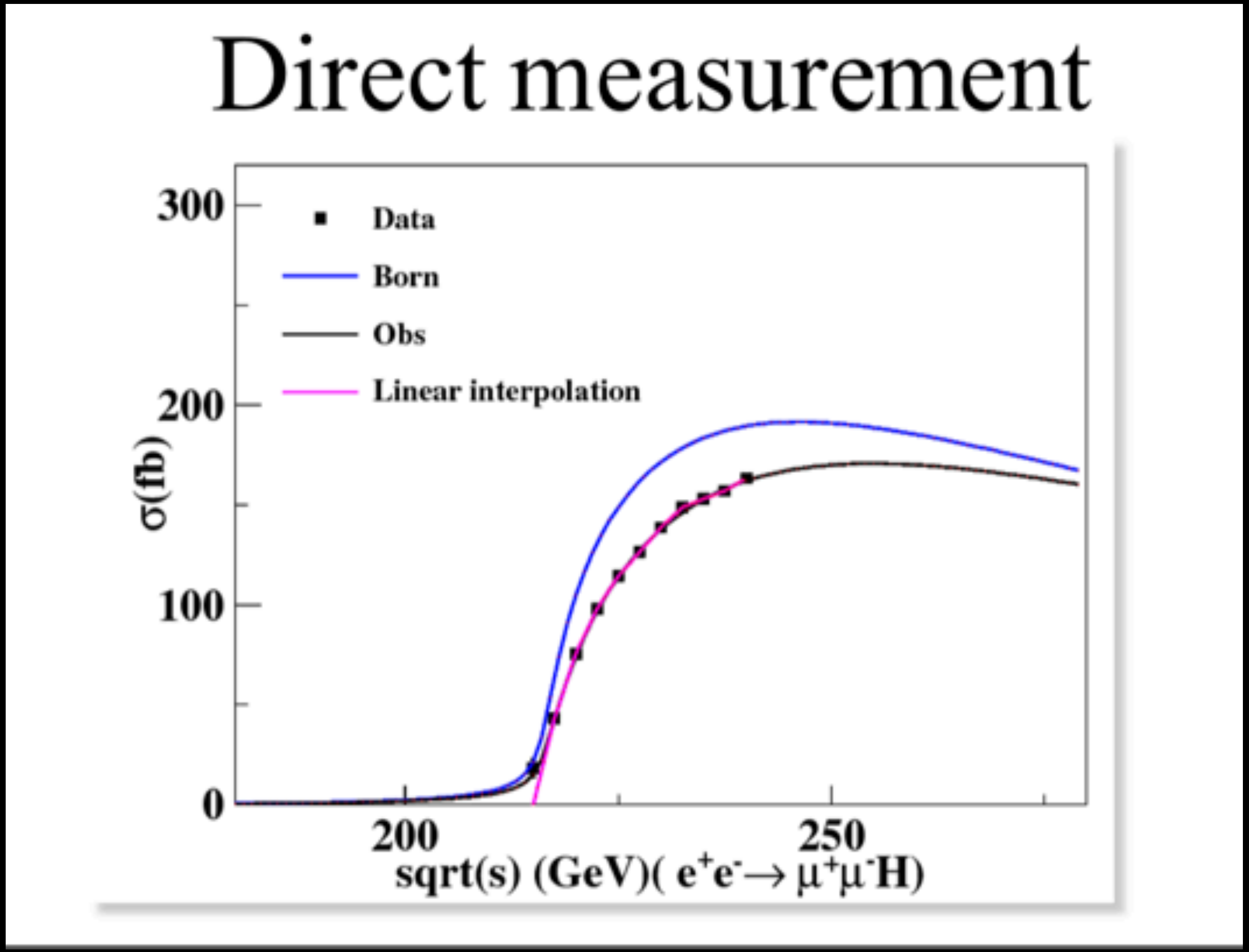
1. The parameters in the formula are Z mass, Z width, higgs mass and the weak mixing angle θ_w
2. The four parameters are float in the fit to propagate the uncertainties of the observed cross section.
3. Fit result shows that by collecting data sets list on the right table, the uncertainty of $1+\sigma$ is 0.5%



Scan data above ZH threshold			
$\sqrt{s}$ (GeV)	220	230	250
L (fb^{-1})	50	50	500

Measure the line shape is an issue

- Line shape from data necessary
- Scan from threshold
- It needs a lots of data-taking



Summary

- CEPC is a very challenge project for theory, experiment, and politics
- Higgs simulation in good shape
- EW has only a few simulation studies
- Flavor physics missing at present
- Precision calculations are more than appreciated