高能所所创新基金支持

Progress on CEPC Simulations

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for the CEPC Simulation group

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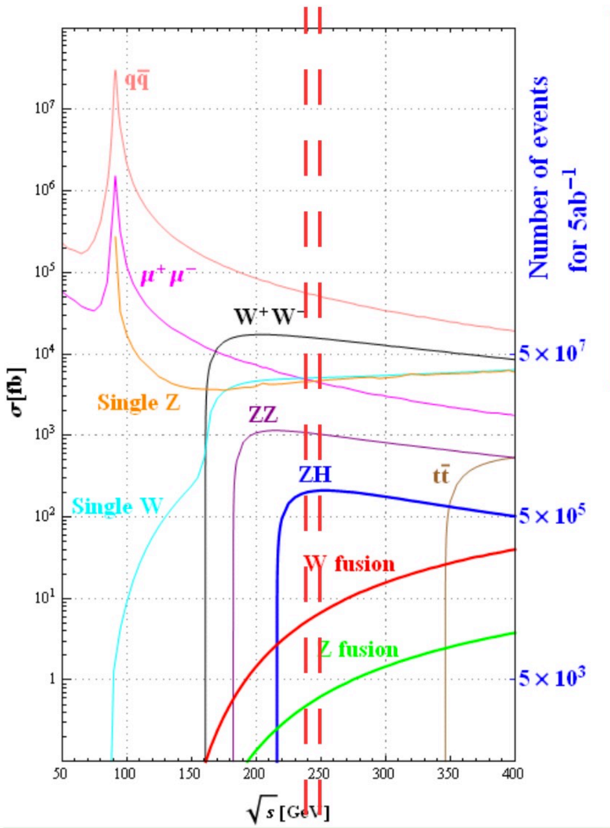
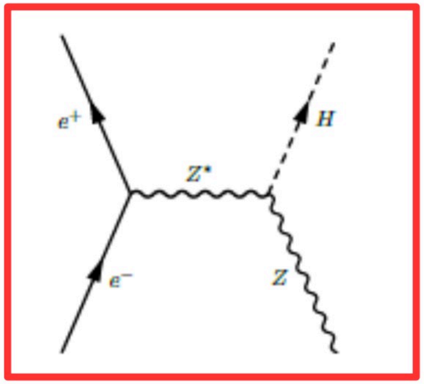
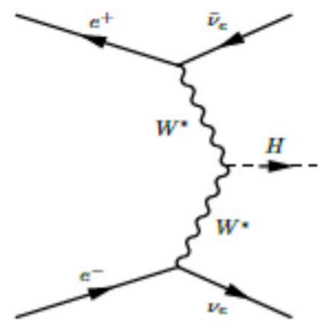
Outline

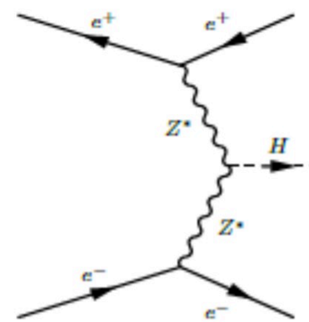
- ✓ Introduction
- ✓ Software developments
  - ➢ Simulation
  - ➢ Reconstruction
  - ➢ Analysis
- ✓ Detector optimization
  - ➢ VTX
  - ➢ Tracker
  - ➢ Calorimeter
- ✓ Summary

Higgs physics at CEPC







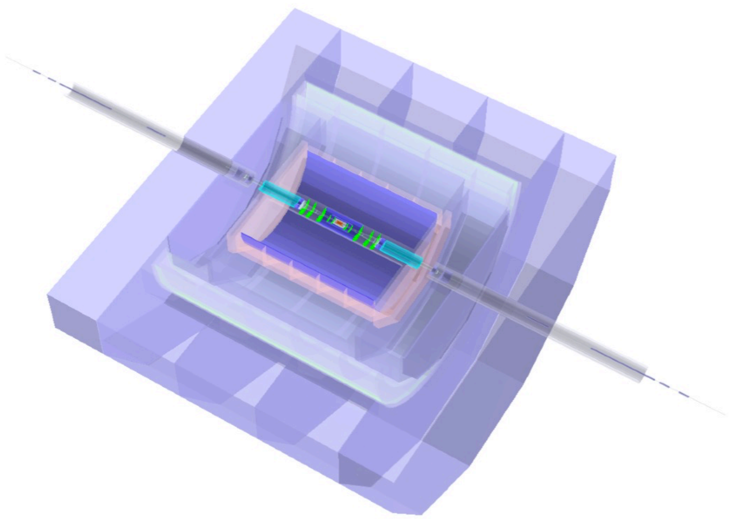


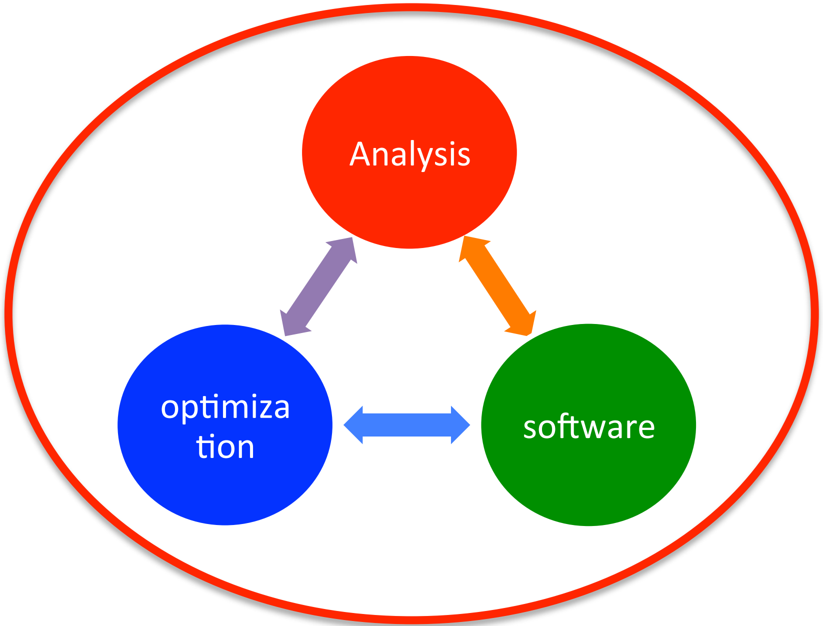
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

Observables: Higgs mass, σ(ZH), production rates (σ(ZH, nnH)×B(H→X)), distributions

Derive: Absolute Higgs width, branching ratios, couplings

Higgs physics at CEPC

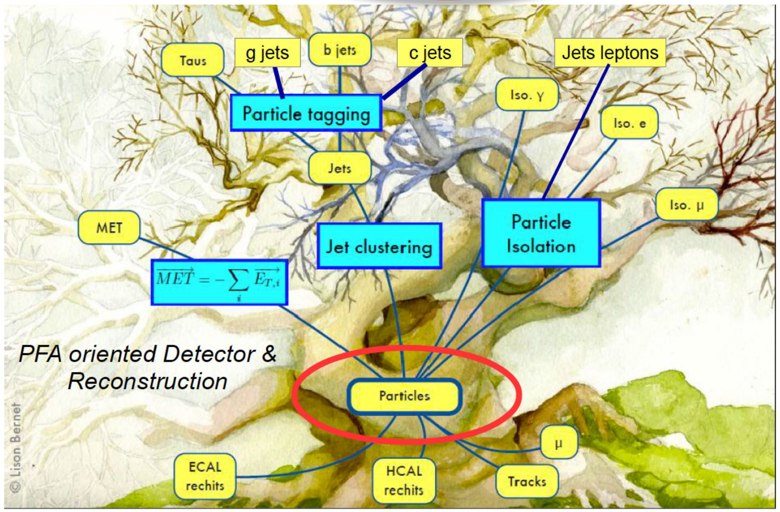




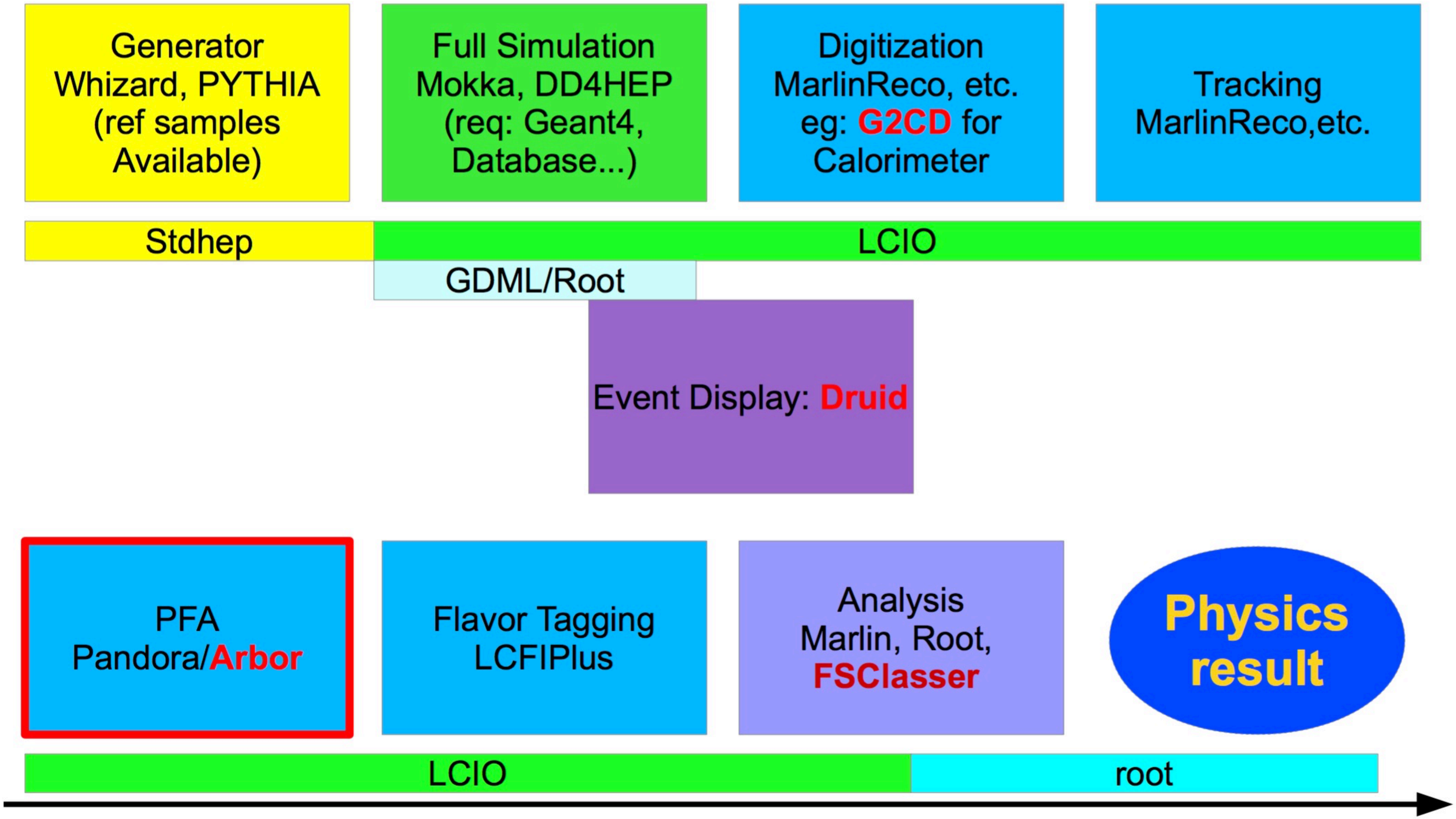
Reconstruct all the physics objects (e, μ, τ, γ, Jet, MET, ...)

Excellent VTX: b, c, tau tagging
Excellent Tracker: δ(1/Pt) ~ 2*10-5(GeV^{-1})

PFA oriented Calorimeter (~o(10^8) channels): Pid, Jet energy resolution, etc



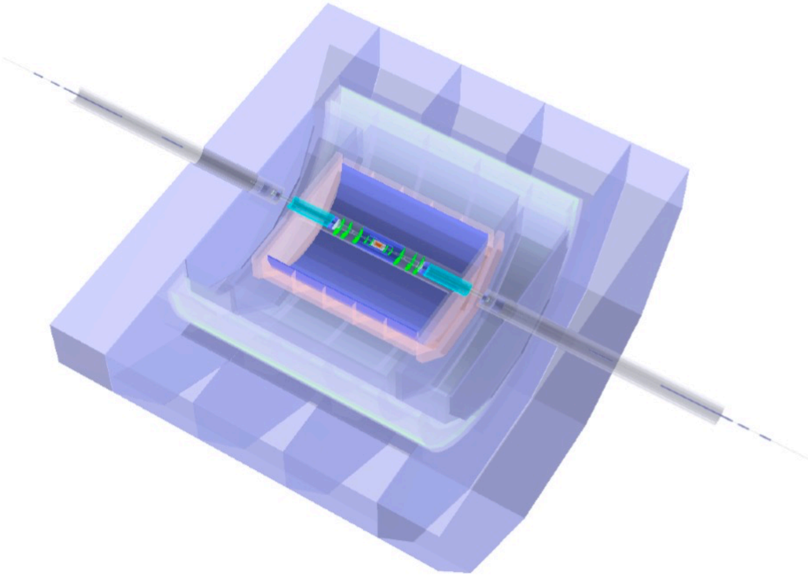
SCRAC

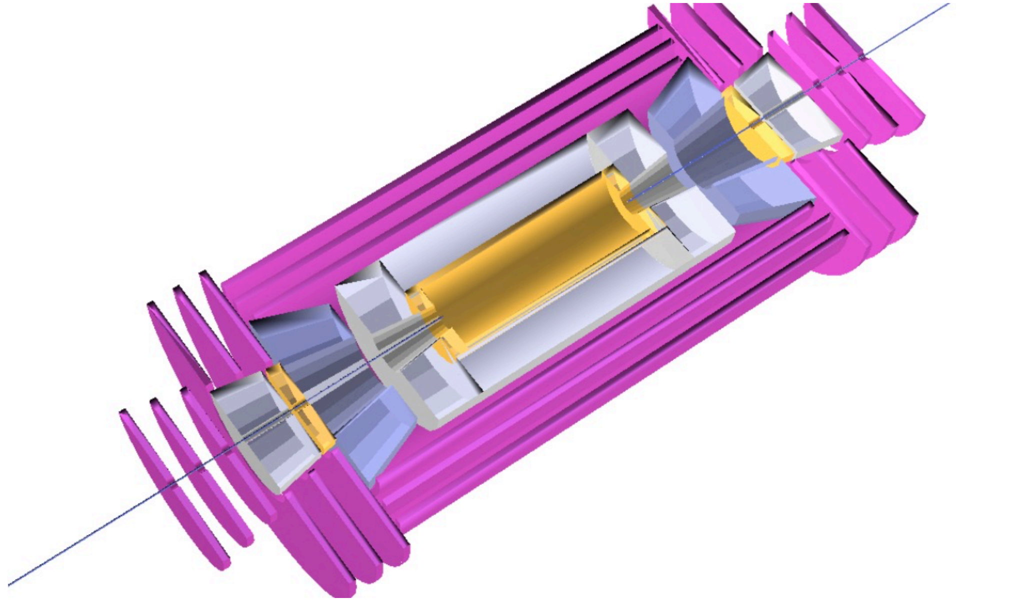

Generator
Whizard, PYTHIA
(ref samples
Available)
Full Simulation
Mokka, DD4HEP
(req: Geant4,
Database...)
Digitization
MarlinReco, etc.
eg: G2CD for
Calorimeter
Tracking
MarlinReco,etc.
Stdhep
LCIO
GDML/Root
Event Display: Druid
PFA
Pandora/Arbor
Flavor Tagging
LCFIPlus
Analysis
Marlin, Root,
FSClasser
Physics
result
LCIO
root

Simulation tools

Developed from Mokka

applied to both CEPC & SPPC Detector design   2 Staffs: Chengdong Fu & Yin Xu

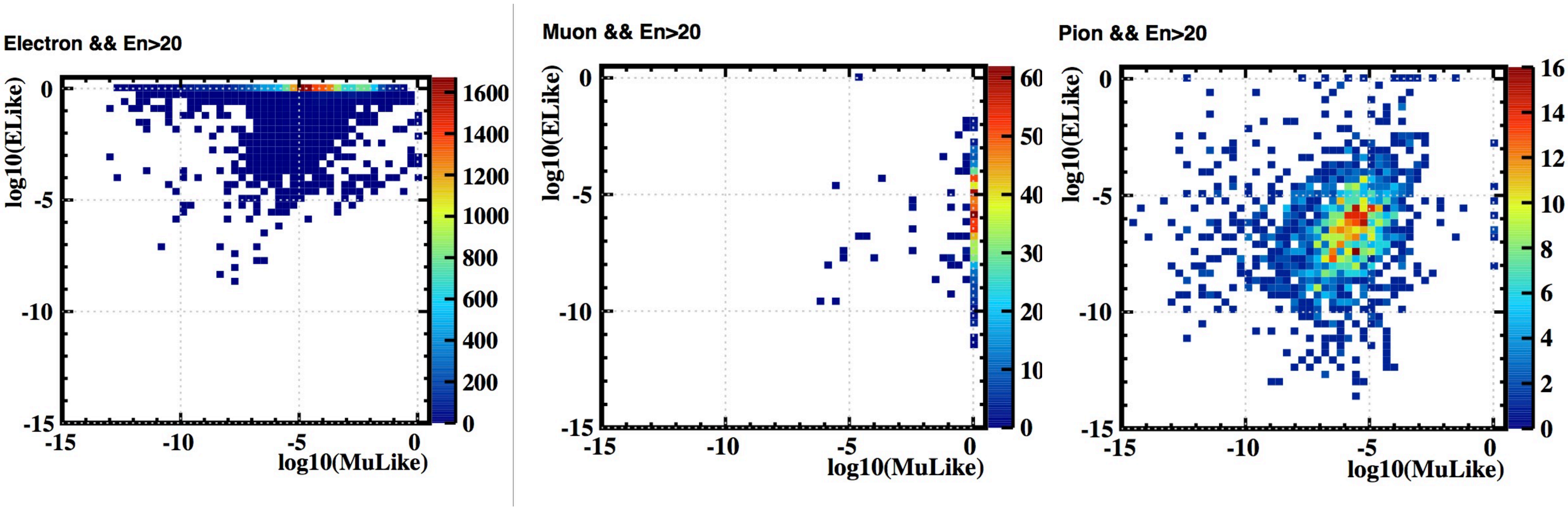




More functions, more detector drivers …

Edit geometry, B-field, sub-detector study …

A general **L**epton **I**D for **C**alorimeter with **H**igh granularity (LICH) by Dan Yu



Based on Arbor and BDT, using 4 classed of 24 input discrimination variables

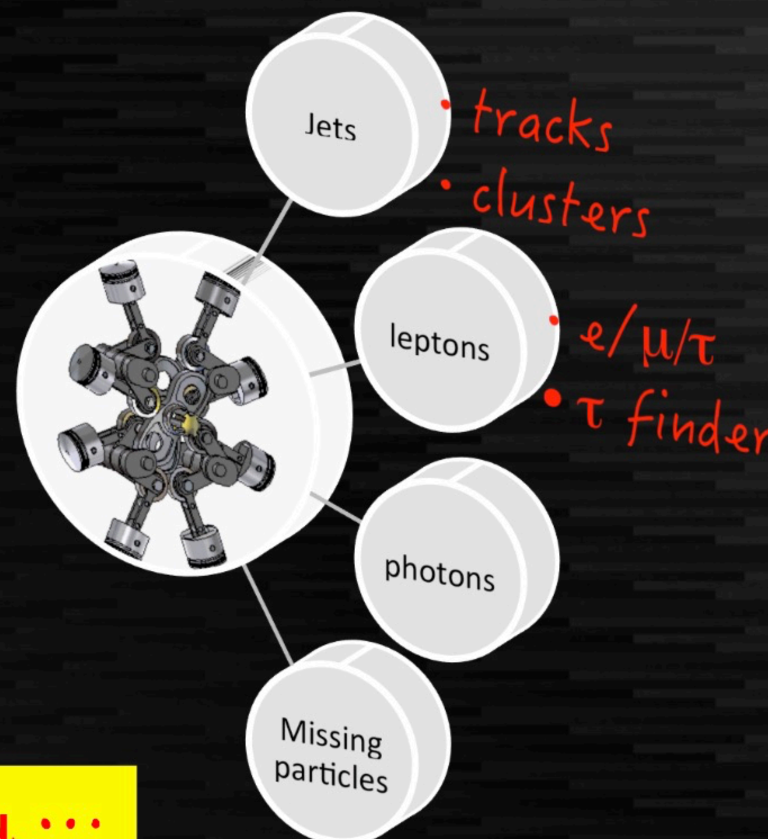
Performance test by requiring : Max [(e_likeness, μ_likeness), e_likeness > 0.5 && μ_likeness > 0.5)

Single charged particle with E > 2 GeV: lepton efficiency > 99.5% && Pion mis id < 2%

A dedicated analysis framework

Novices can start from root …

Feed all types of particle object to the **combination engine** for further processing



$ee+X$, $\mu\mu+X$, $jj+ee$, $jj+\mu\mu$ …

Data → ntupes → plots

Detector Optimization

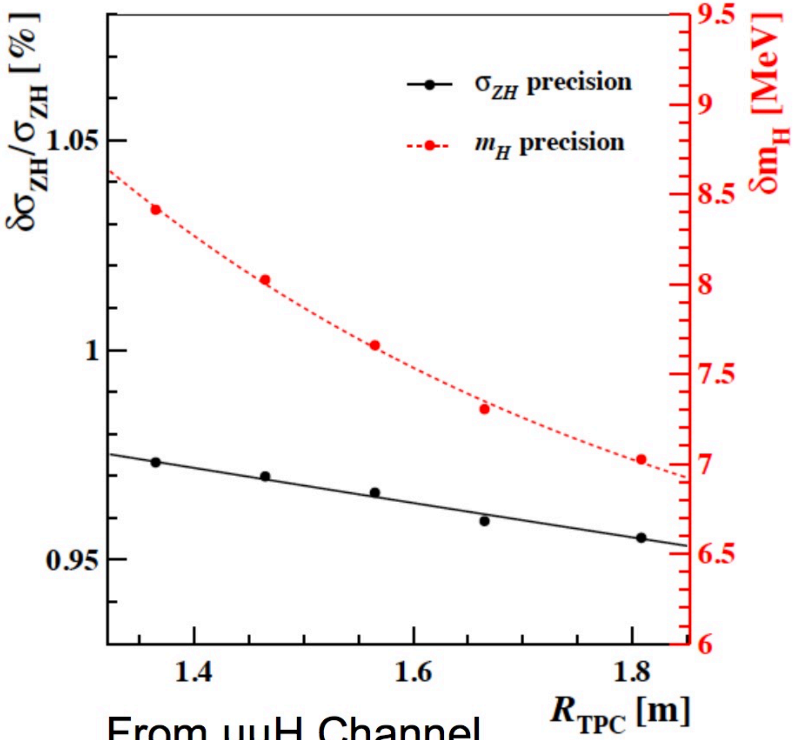
- ✓ **Goal:**
  - ✧ Deepen understanding on the physics requirement & performance: **Set up physics benchmarks**
  - ✧ More realistic - Precise modeling of hardware response: **Cooperate with sub detector group studies, develop, validate and integrate dedicated Digitization**
- ✓ **Software Tools**
  - ✧ Implementation of Detector Geometry: **Mature**
  - ✧ Adjust/Optimize reconstruction algorithm: **current focus (always a shortage in manpower)**
- ✓ **Main actions**
  - ✧ April 2016, CEPC_v1→CEPC_o_v2: test of software readiness
  - ✧ April–now: Sub-detector level optimizations/explorations

Physics Benchmarks

Benchmarks	Main observables	Key performances	Status
llH, H->X	Higgs recoil spectrum	Lepton Id efficiency, Tracker intrinsic momentum resolution	Well understood
H+X, H->di photon	Event reconstruction efficiency, Higgs invariant mass peak width	Tracker Material, Intrinsic ECAL energy Resolution	
ZH->4 jets,	Br(H->bb, cc, gg)	Jet clustering, PFA: Jet Energy Resolution, Jet Flavor Tagging	Studied at CEPC conceptual Detector (CEPC_v1)
vvH, H->di tau	Efficiency of Tau reconstruction with different tau decay mode	PFA separation, Impact parameter resolution	
qqH, H->invisible	Higgs recoil spectrum	PFA: Jet Energy Resolution	
vvH, H->WW->lvqq	Event Reconstruction Efficiency di-jet mass distribution	PFA, Simultaneous reconstruction of Lepton, Jets and Missing Energy	Studied at different Calorimeter Granularity
H+X, H->di muon	Event reconstruction efficiency, Higgs invariant mass peak width	Lepton Id efficiency, Tracker intrinsic momentum resolution	Studied at CEPC conceptual Detector
vvH, H->2 jets	Br(H->bb, cc, gg)	Jet Energy Resolution & Flavor Tagging	
WW->lvqq	W mass	Jet Energy resolution & Systematic controls	Full simulation analysis not accomplished yet

Each analysis to be redone at different geometry, full simulated Higgs signal sample, (and potentially WW sample)

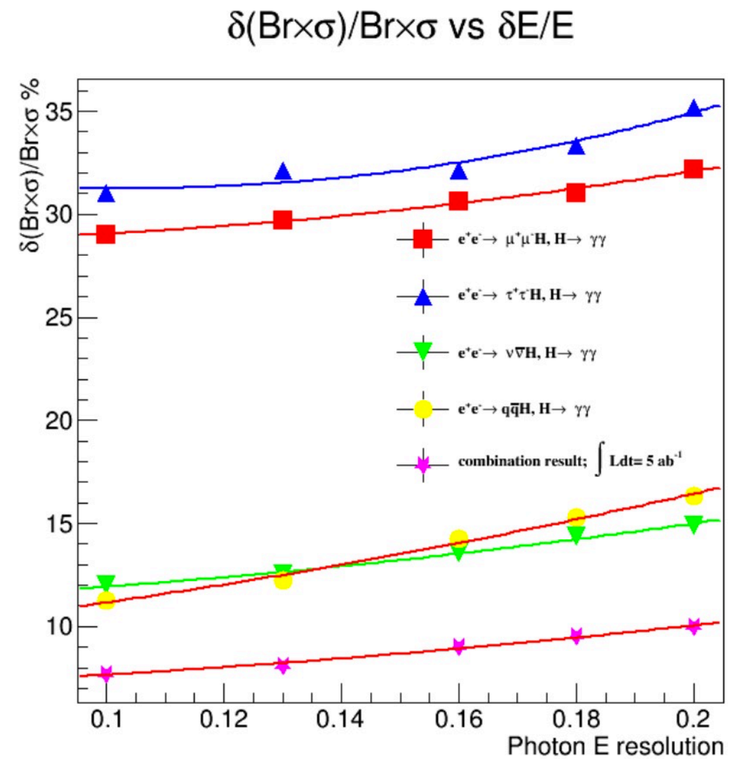
TPC Radius & ECAL resolution



From μμH Channel

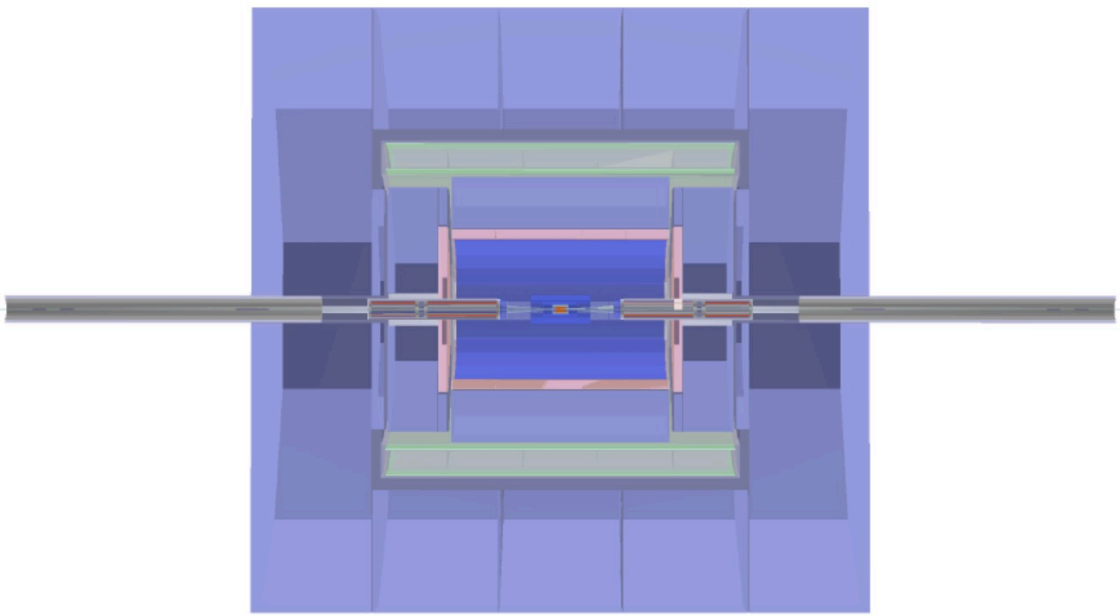
$$\delta m_H = 5.848 \times (1 + 5.192 \times e^{-1.808 \cdot R_{TPC}})\ \mathrm{MeV}$$

$$\frac{\delta\sigma_{ZH}}{\sigma_{ZH}} = 0.517 \times (1 + e^{-0.093 \cdot R_{TPC}})$$



H->di photon branching ratio
Measurement
Many detailed analysis followed

CEPC_o_v2: readiness test of reconstruction chain



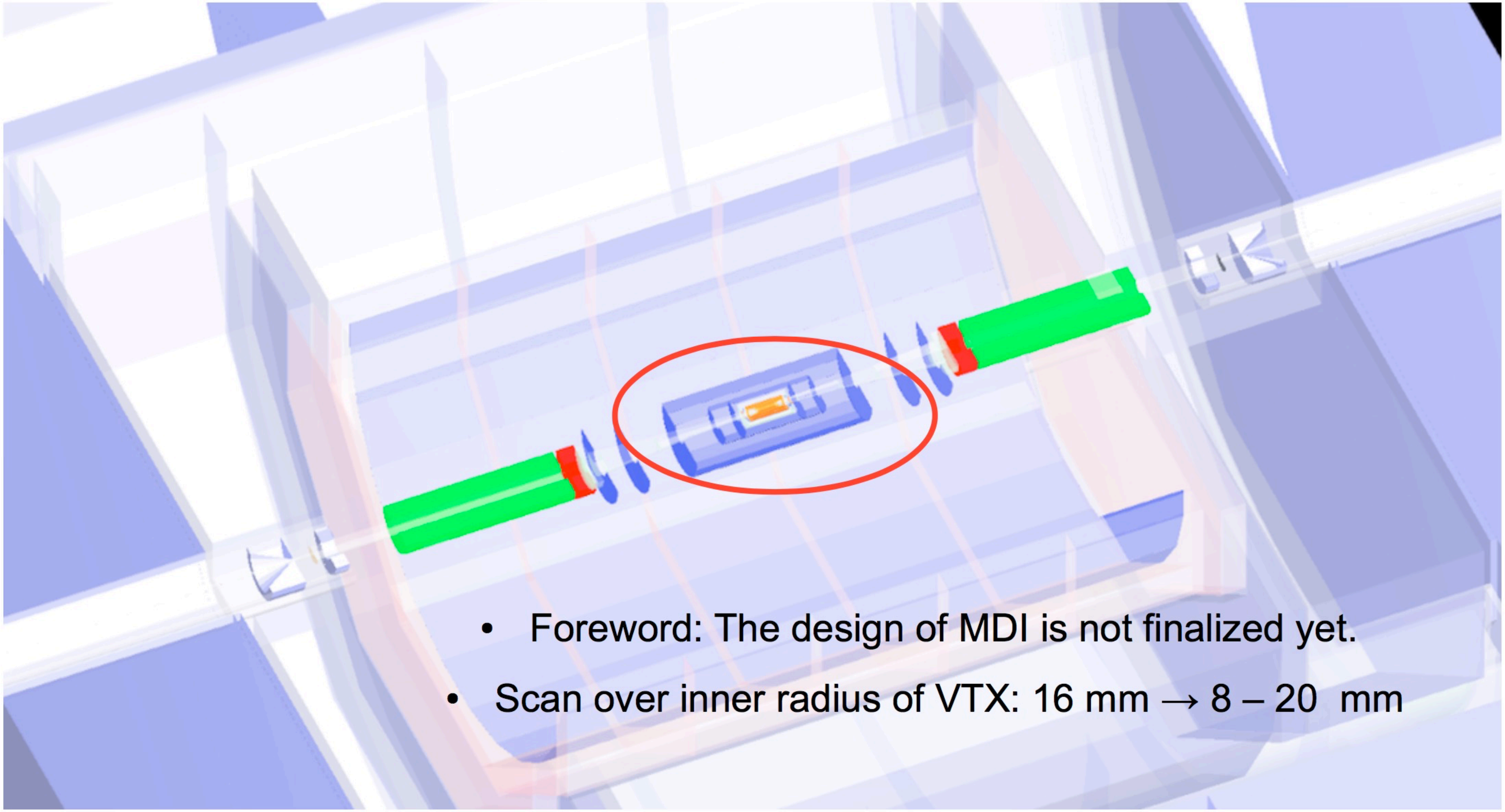
Parameter	CEPC_o_v2	CEPC_v1
LStar_zbegin	1150	1146.9
VXD_inner_radius	12	15
VXD_radius_r1	12	15
VXD_radius_r3	35	37
TPC_outer_radius	1500	1808
Hcal_nlayers	40	48
Ecal_cells_size	10	4.9
Field_nominal_value	3	3.5
Yoke Layers	2	3

Parameter put by hand, motivated by:
- Saving the cost.
- Closer VTX inner layer, better flavor tagging?

Reconstruction: be aware of TPC boundary & B-Field Strength

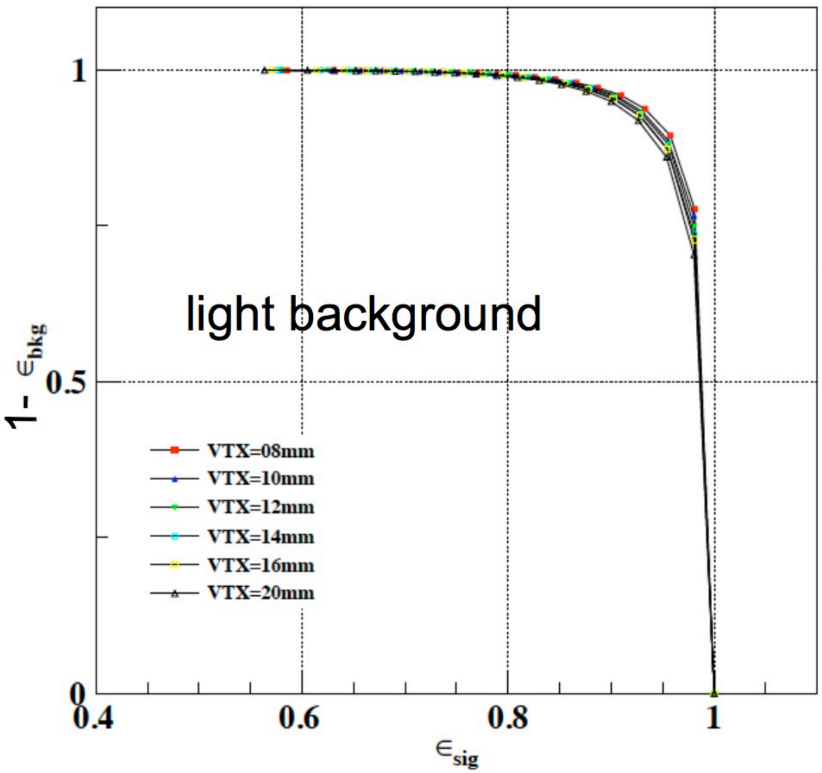
Geometry Implemented by Xuyin (NanKai U)

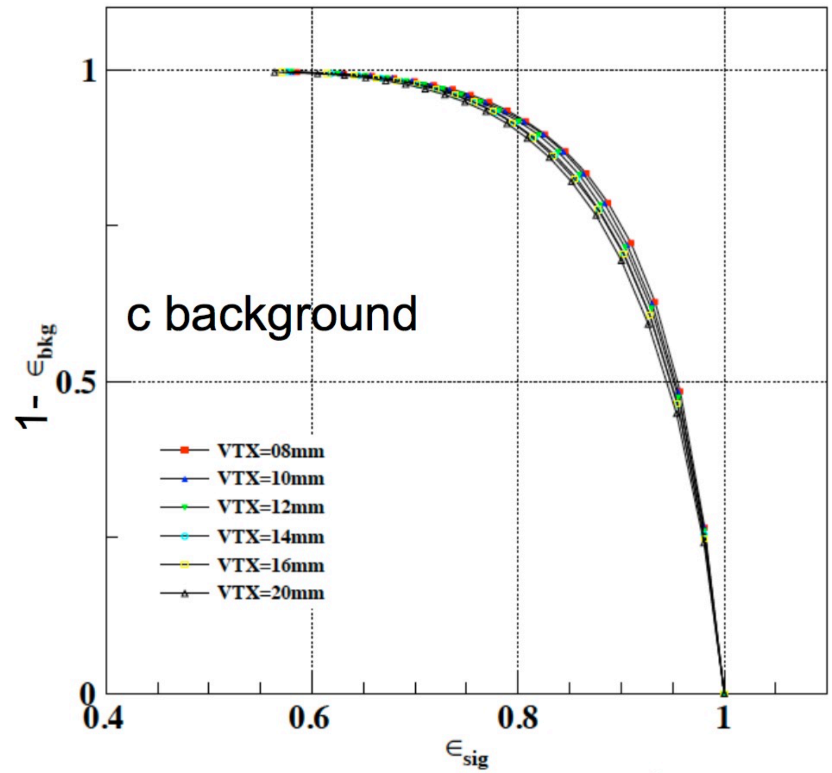
Optimization @ Vertex, vary the inner Radius



- Foreword: The design of MDI is not finalized yet.
- Scan over inner radius of VTX: 16 mm → 8 – 20 mm

B-tagging @ different radius

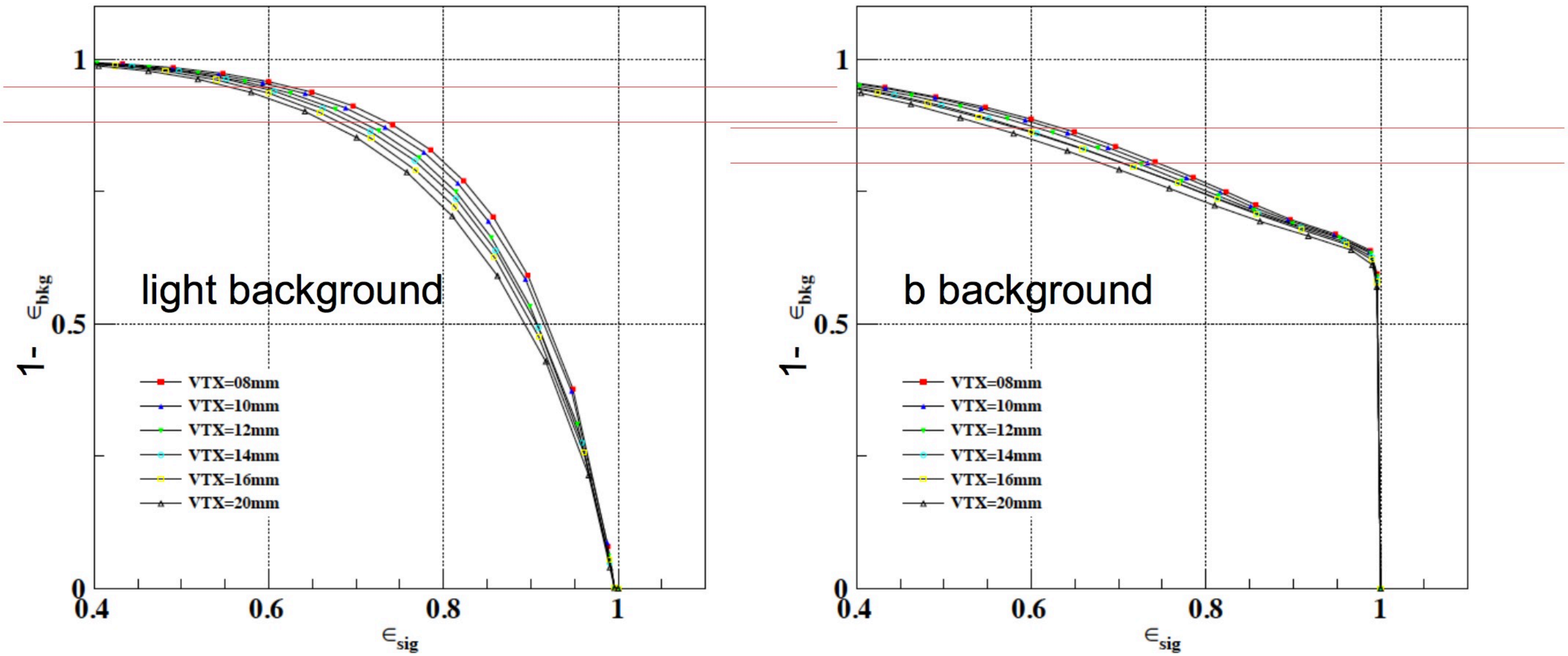




Gang Li

- *With 8 – 20 mm VTX Inner radius, very good b-tagging*
  - *At efficiency ~ 80%: almost reject all the light background & only 8-10% c-jets misidentified as b-jets (Purity ~93-96% at Z to qq events).*

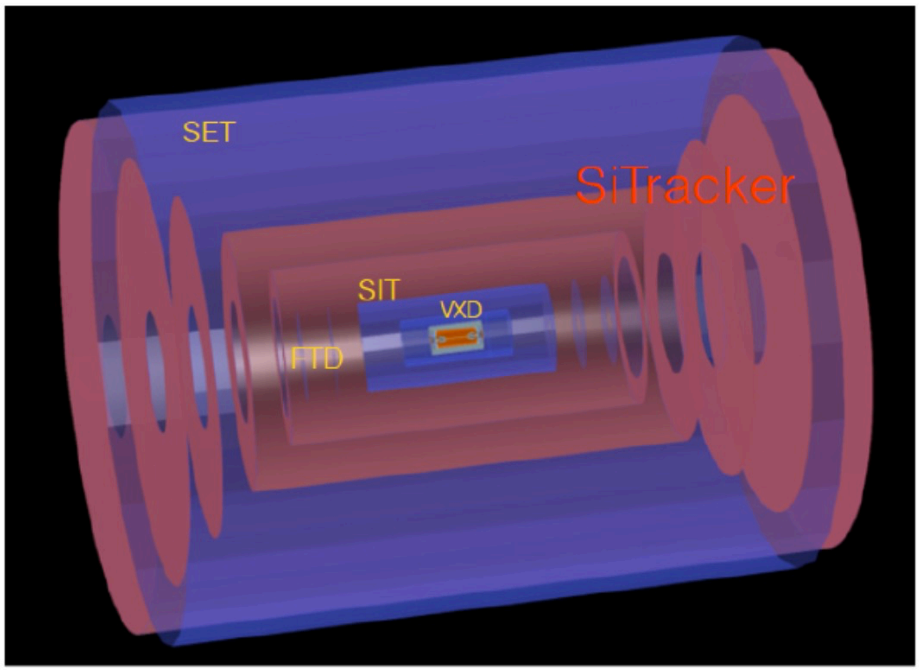
C-tagging @ different radius

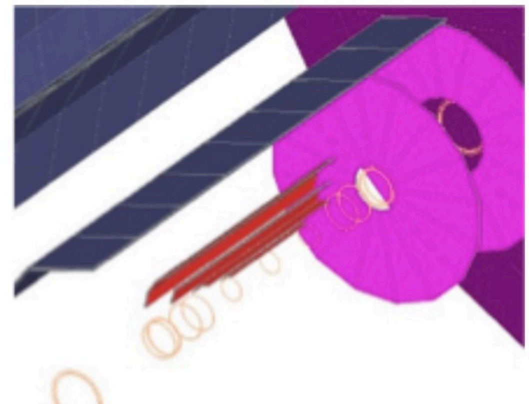


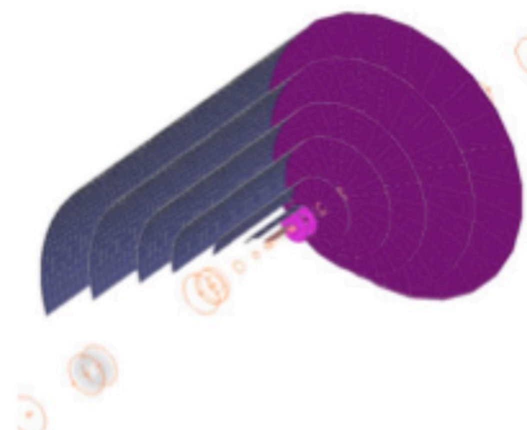
- At the same purity: C-tagging efficiency could be improved by ~ 10% by reducing the inner radius from 20 mm to 8 mm...

Optimization @ Tracker: Silicon Tracking & Digitization

Prof. Weiming Yao, Chengdong Fu, Bo Li, Yao Zhang, etc





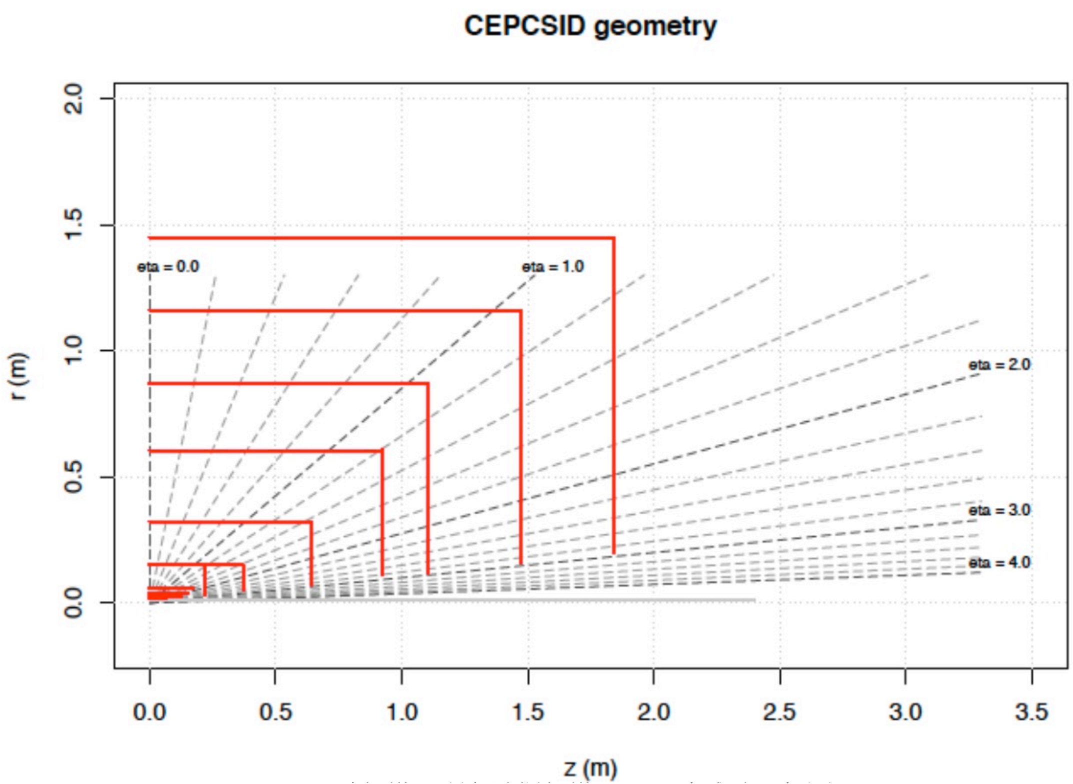


- Digitization
  - Original ones: Hit position smeared by resolution
  - Implemented: Center of pixel with hits merging

Full Silicon Tracker Concept for CEPC*

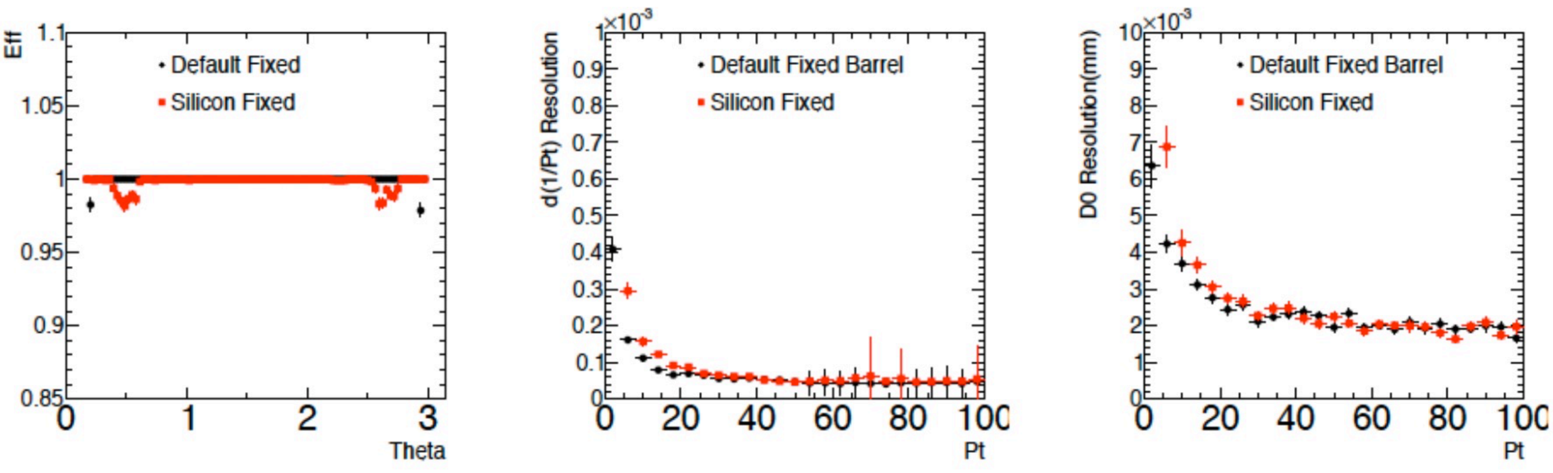
*http://cepc.ihep.ac.cn/ cepc/cepc_twiki/index.php/Pure_Silicon_Detector

- CEPC full silicon has been implemented in Mokka.
- Based on CEPC V1 silicon tracker, we replace TPC with additional SIT layers and FTD endcaps.
- The advantage is to recycle CEPC silicon tracking.



Full Detector Simulation and Reconstruction

- Generated single muon with CEPC full silicon
- Reconstructed using Marlin Silicon only.
- The performance is comparable to CEPC V1.



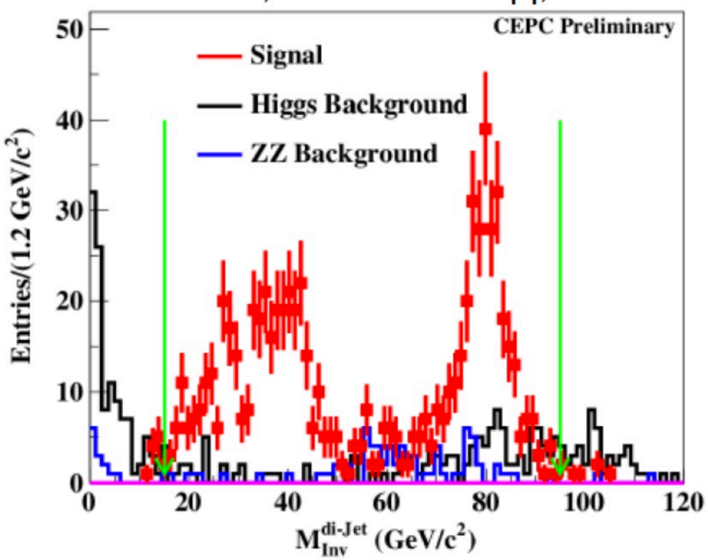
(a) Eff vs theta (b) sigma(1/pt) vs Pt (c) sigma(D0) vs Pt

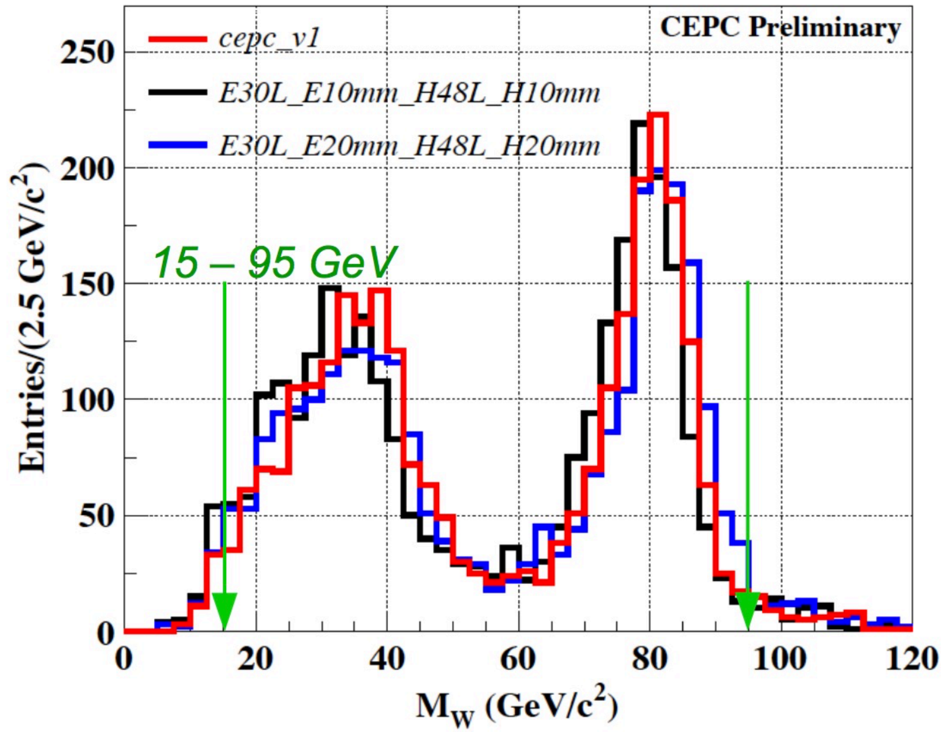
Optimization @ Calorimeter

- Granularity: Wi/wo active cooling
  - Geometry in ILD (ild_o2_v05):
    - *ECAL, 5 mm Cell Size & 30 layers, 5 kw with power pulsing*
    - *HCAL, 10 mm Cell Size & 48 layers.*
  - No Power Pulsing @ CEPC:
    - *Wi Active cooling: + 2mm thick cooper per active layer*
    - **Wo Active cooling: reduce the granularity by ~ 1 order of magnitude (in considering Electronics/Sensor progress...)**
  - Performance:
    - Lepton ID
    - Physics benchmarks:
      - *Z→di lepton, Higgs to inc;*
      - *Z→vv; H→WW→lvqq;*
      - *Z→vv; H→ZZ→llqq;*
- *ECAL Benchmark: H→γγ measurements*

Lepton + Jets: Br(H→WW)

Liao libo, H→WW*→lvqq, Z→ll





Br(H→WW) via vvH, H→WW*→lvqq

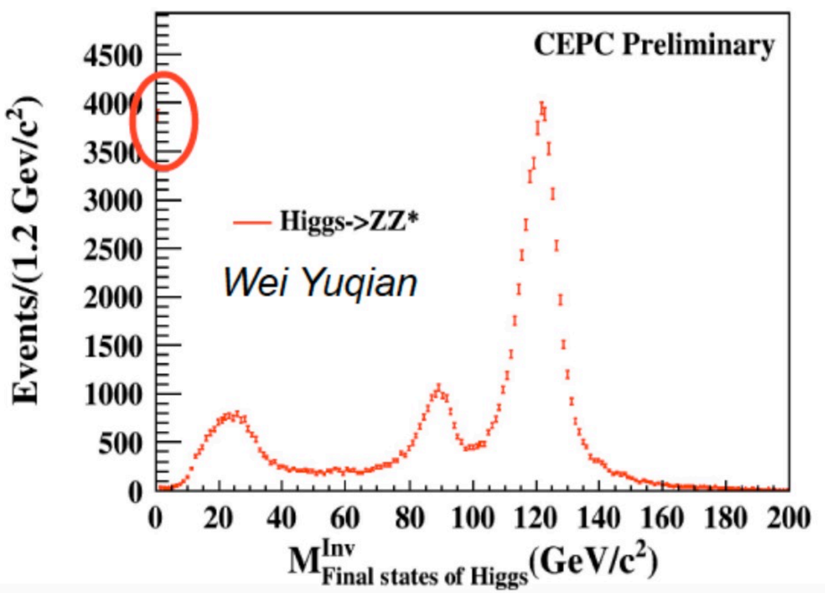
No lose in the object level efficiency;
JER slightly degraded, ~ 5/10% at 10/20 mm
(*ill. behaviors: stay to be tuned*)

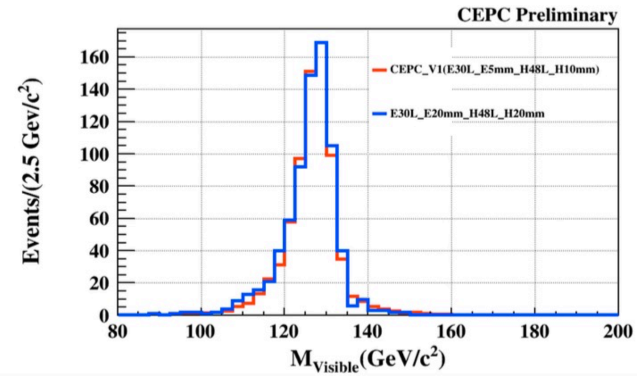
Over all: event reco. efficiency varies ~1%

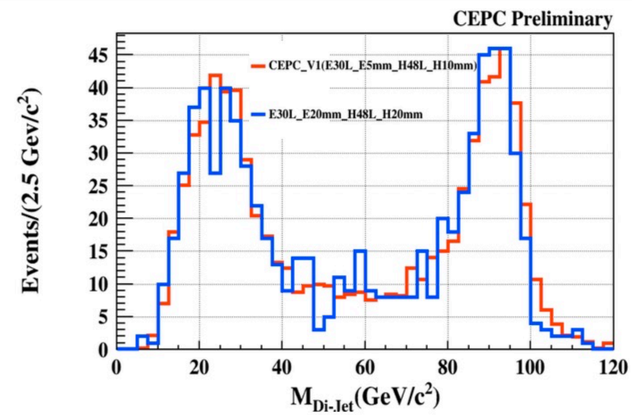
	Simu.	Recon.	Efficiency
CEPC_v1	2885	2783	96.5%
TG1	2878	2814	97.8%
TG2	2878	2807	97.5%

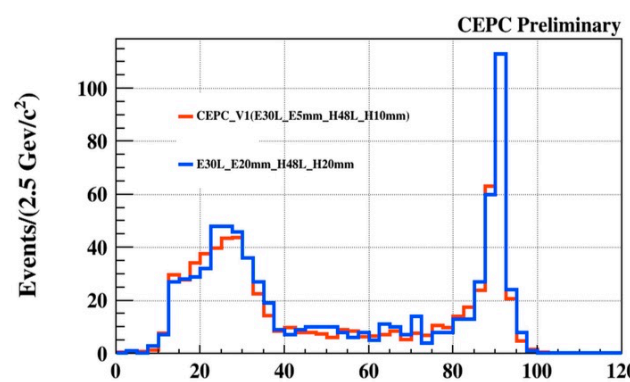
TG1: E30L_H48L_10mm, TG2: E30L_H48L_20mm

Lepton + Jets: Br(H→ZZ)









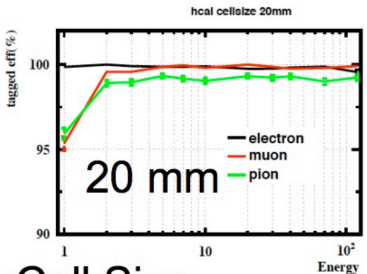
Br(H→ZZ) via vvH, H→ZZ*→llqq

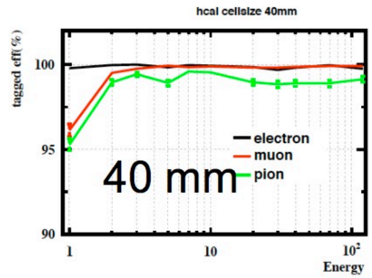
Over all event reco. efficiency reduced ~2%

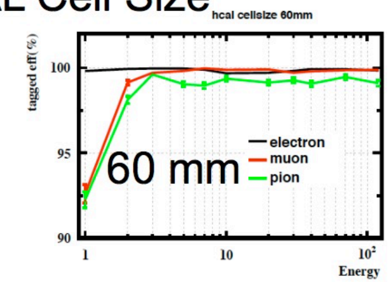
	Events	Recon.	Efficiency
CEPC_v1	4143	3957	95.5%
TG2	808	754	93.3%

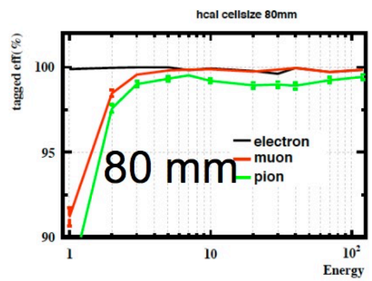
LICH @ different granularity

HCAL Cell Size

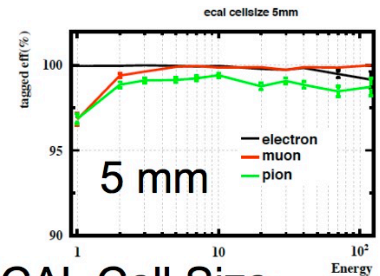


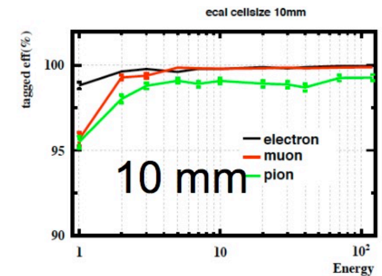


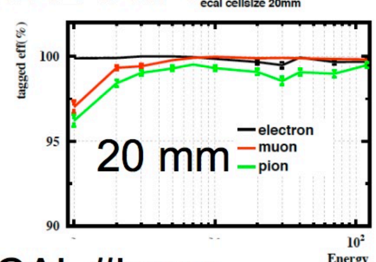


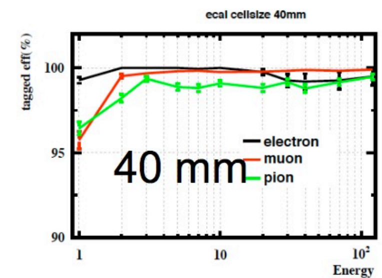


ECAL Cell Size

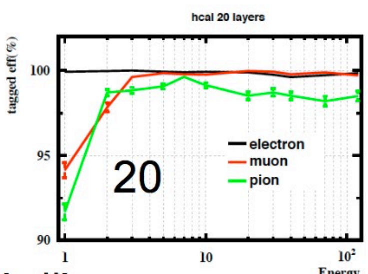


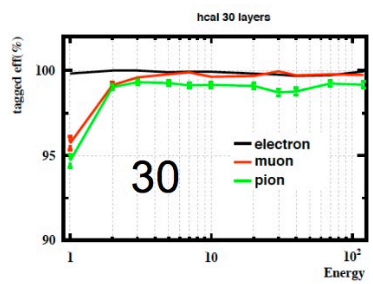


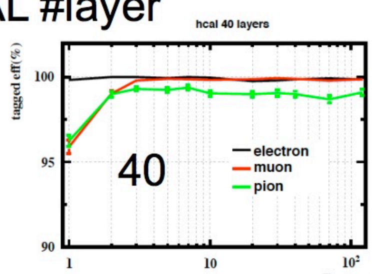


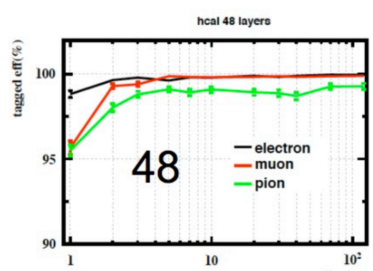


HCAL #layer

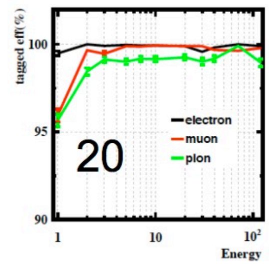


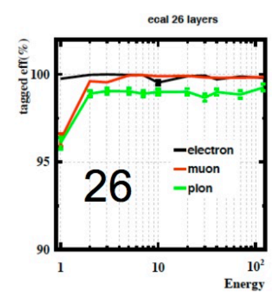


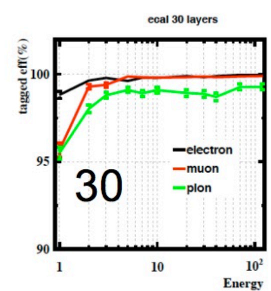




ECAL #layer







- Scanned geometries:
  - ECAL Cell Size: 5 - 40 mm
  - HCAL Cell Size: 10 - 80 mm
  - ECAL N Layer: 30 - 20
  - HCAL N Layer: 48 – 20
- No Significant effect for E > 2 GeV isolated charged particle

Lepton: Higgs recoil via ZH, Z→ll

		CEPC_v1	TG 1	TG2	TG3
ECAL	Cell Size/mm	5	10	20	20
	Layer Number	30	30	30	20
HCAL	Cell Size/mm	10	10	20	20
	Layer Number	48	48	48	20
Ratio of Channels (X/CEPC_v1)	ECAL	1	1/4	1/16	1/24
	HCAL	1	1	1/4	1/10
Muon ID, for Energy > 20 GeV $\mu\mu$H sample	Selection condition	$L\mu > 0.1$			
	Efficiency	-	99.5±0.1	99.2±0.1	98.8±0.1
	Purity	-	99.6±0.0	99.8±0.0	99.6±0.1
	Event Reco Efficiency	**95.7%±0.1**	**98.5±0.1**	**97.2±0.2**	**95.7±0.2**
Electron ID, for Energy > 20 GeV, eeH sample	Selection condition	$Le > 0.001$ && $L\mu < 0.1$			
	Efficiency	-	98.6±0.1	97.9±0.1	97.2±0.1
	Purity	-	99.7±0.0	99.7±0.0	98.7±0.1
	Event Reco Efficiency	**91.1%±0.1**	**97.1±0.2**	**95.4±0.2**	**93.9±0.3**

*Test Geometry: TG2, TG3 are **active cooling free** models*

Performance at CEPC_v1: using PID at Arbor_v2, TG1-3 using Arbor_v3 + LICH
Impact: limited to 2 – 3% for muon/electron channels
Could be further ameliorated by clustering, identification & analysis algorithms

Impact** on Leptons id @ Charged particle whose Energy < 20, and consequently b-tagging, tau reconstruction performances, **need further studies

CEPC_v1 → CEPC_o_v2

W.R.T CEPC_v1, Reduce:

Total cost ~ 20%;
ECAL power/FEE: 75%;
HCAL thickness/channels ~ 20%;
B-Field to 17% (3.5 → 3);
VTX inner radius: 25%;

Qualitatively: everything goes into the expected direction

Quantitatively: **big** uncertainty

Reconstruction: lots of effects needed for **OPTIMIZATION**

Optimized*: my personal perspective

Performance	adapted	optimized*
Tracking: D0, Z0	10% ↑ @ E < 20 GeV (VTX); 5% ↓ @ E > 20 GeV (B-Field);	
Theta, Phi	worse	-
Omega	worse	-
PFA:Clustering	Slightly worse	same
Matching	~10% ↓	~5% ↓
Separation	~10% ↓	~2% ↓
PID	3-5% ↓ @ E > 10 GeV; 10% ↓ @ E < 10 GeV;	~1%↓
JER	20% ↓	~10%↓
C-Tagging	Improved up to 5%↑	?

Software tool: ready

Optimization study at each sub-detector level is needed

Summary

- CEPC: flexible simulation, reconstruction, calibration and analysis software chain ready, sufficient for detector optimization.
- Full simulation of Benchmark analysis almost converged, ready for iteration for detector optimization
- Optimization already started to answer some key questions
- An alternative detector initialized.