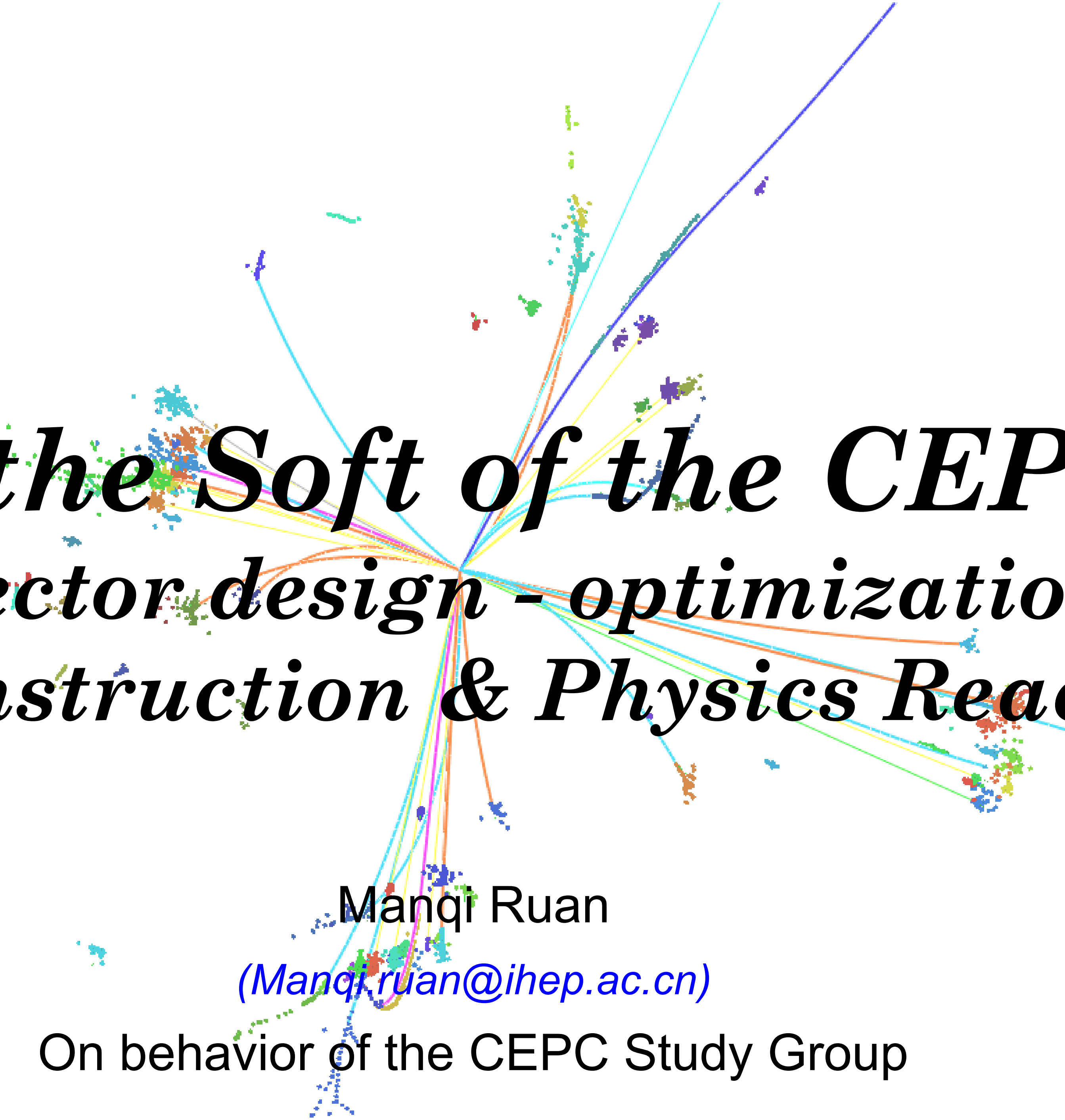


On the Soft of the CEPC:
Detector design - optimization, Reconstruction & Physics Reaches

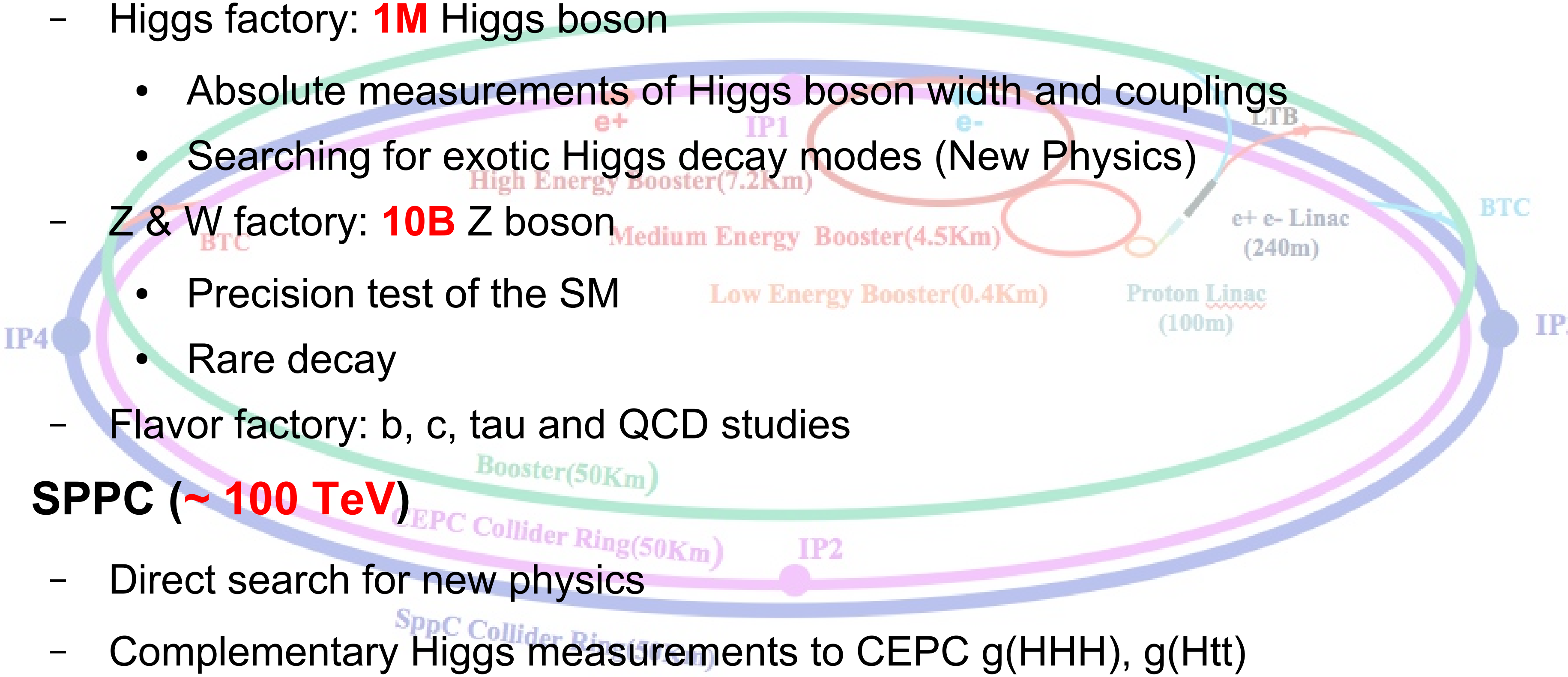
Manqi Ruan

(Manqi.ruan@ihep.ac.cn)

On behavior of the CEPC Study Group

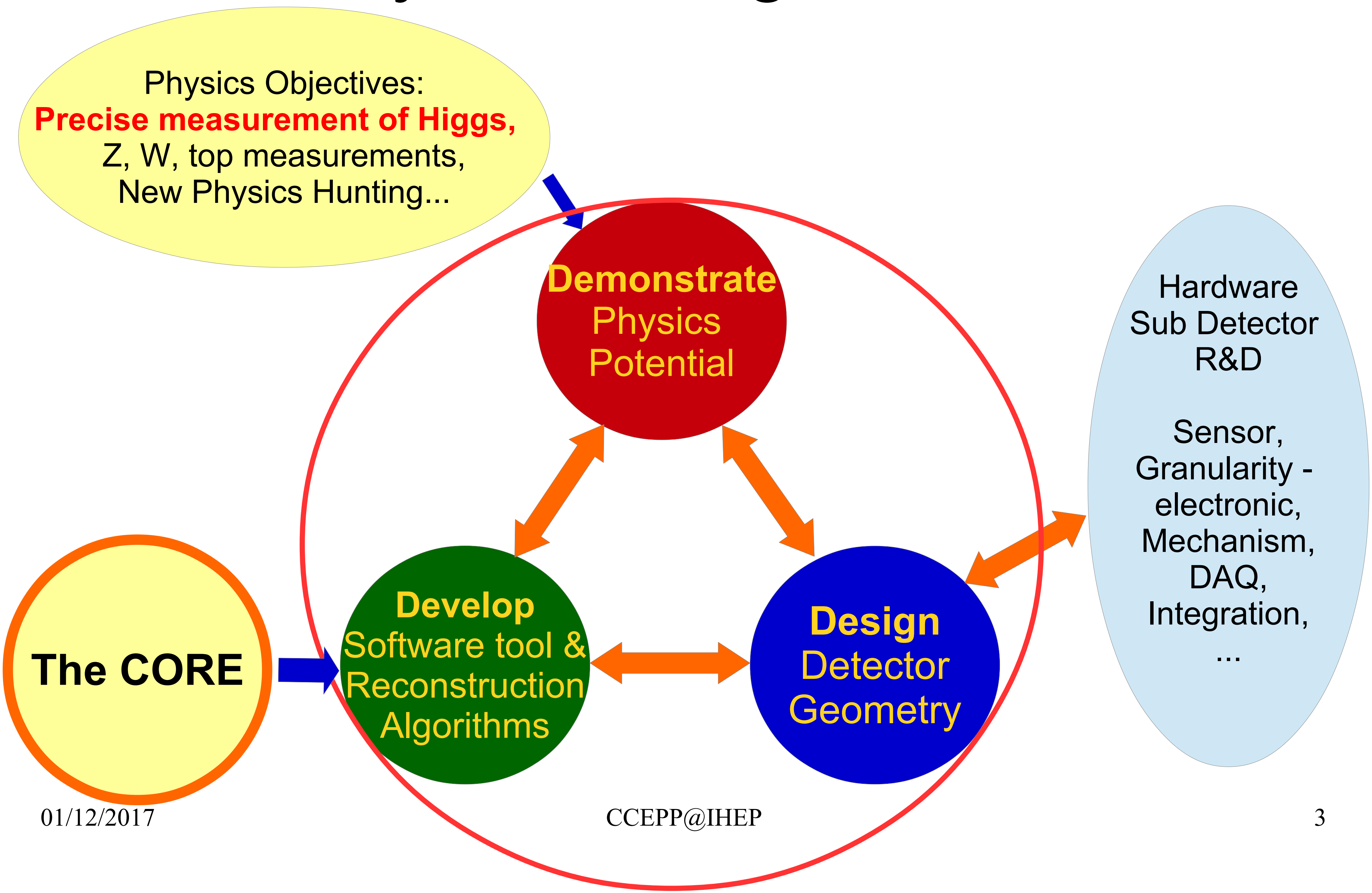
Science at CEPC-SPPC

- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **10B** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**



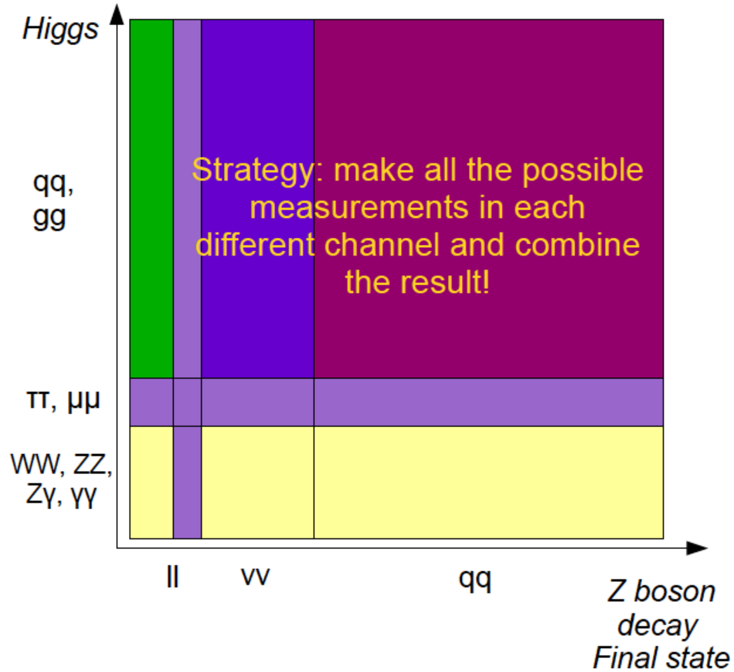
Complementary

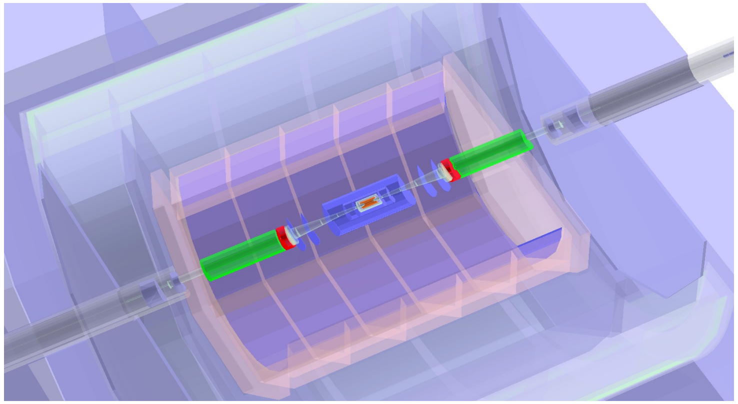
Key SOFT ingredients



Requirements & Detector reference

- Requirements:
  - Be adequate
  - High Hermetic
  - **Objects**
    - Excellent Lepton ID
    - Charged Kaon ID
    - High Eff/Precision Photon Reco
    - Excellent Tau Performance
    - Good Jet(MET) Reconstruction
    - Flavor Tagging (b, c, light, gluon)
- Reference Detector
  - CEPC_v1, designed for PreCDR





Modified from ILD geometry (L*, Yoke, etc)

Arbor Reconstruction

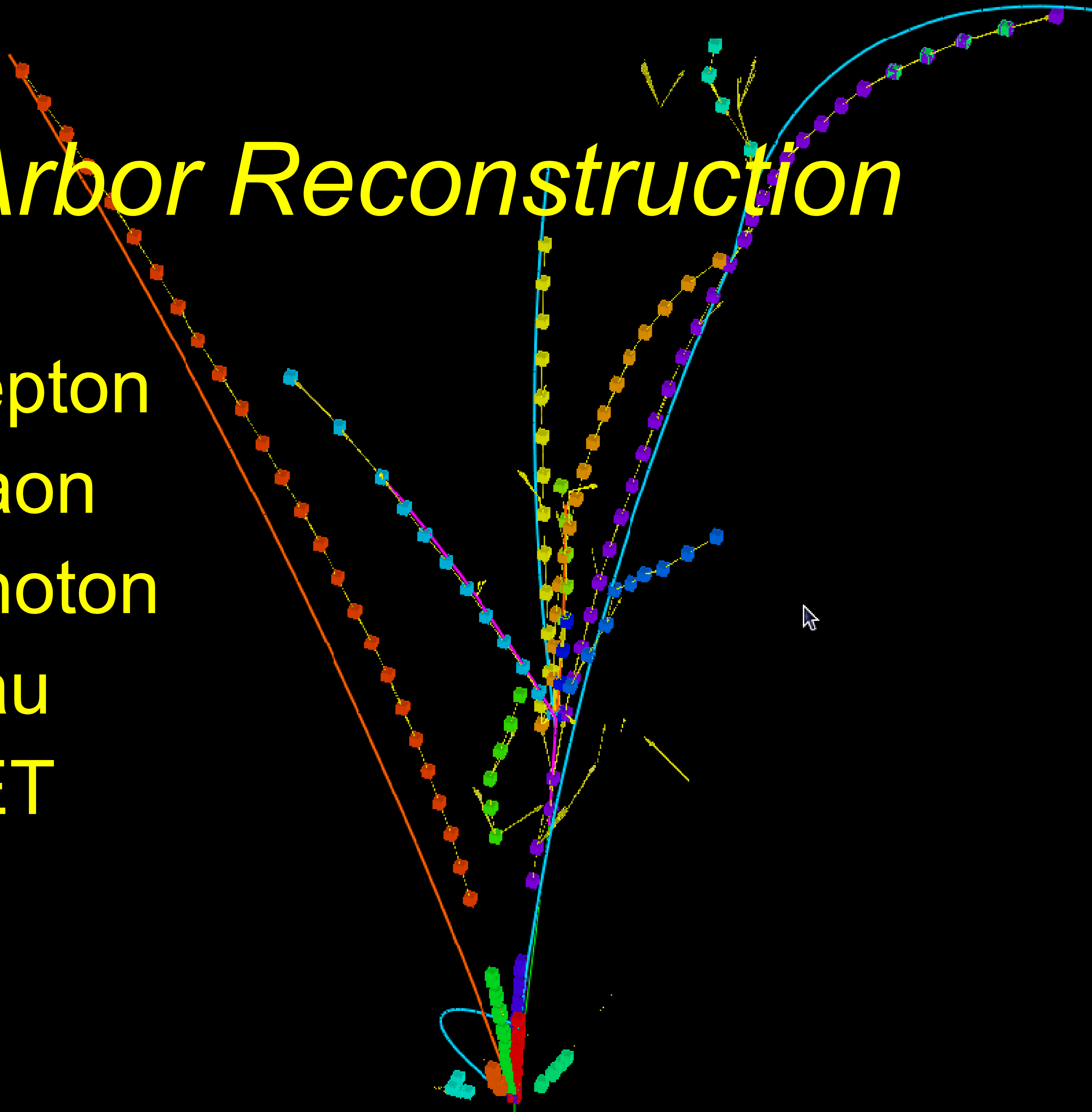
Lepton

Kaon

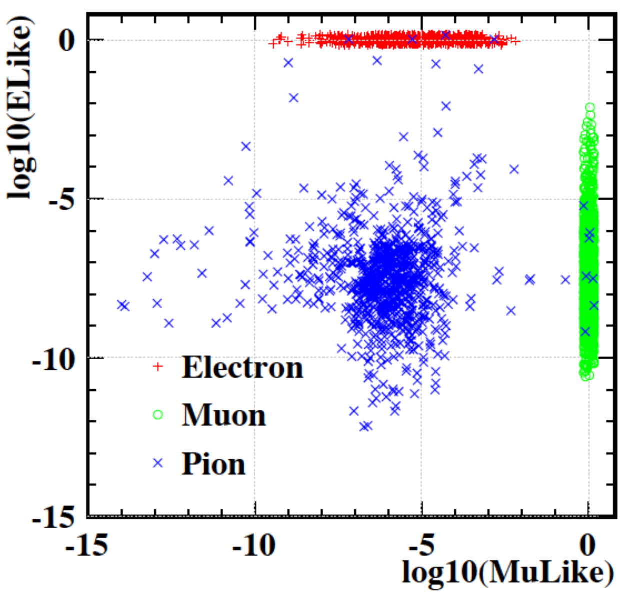
Photon

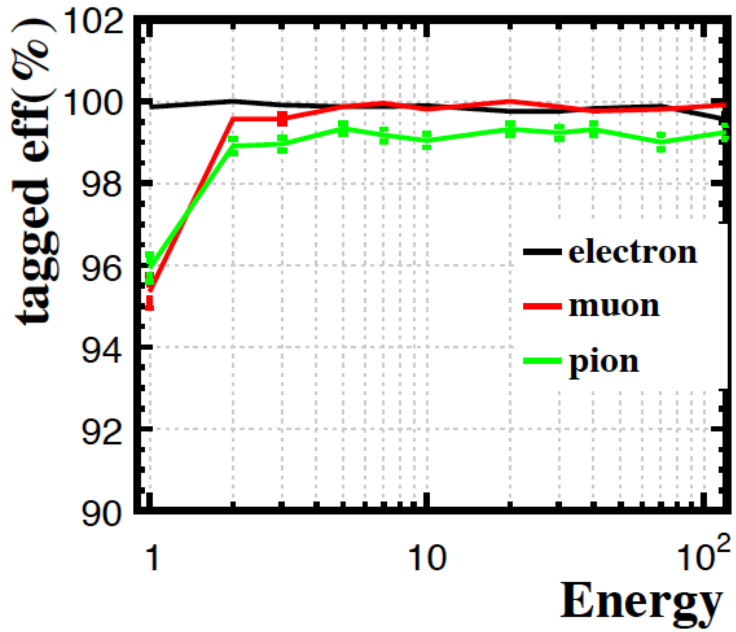
Tau

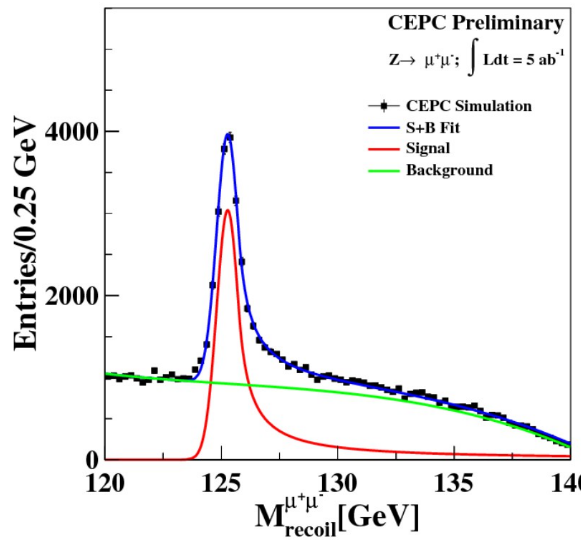
JET

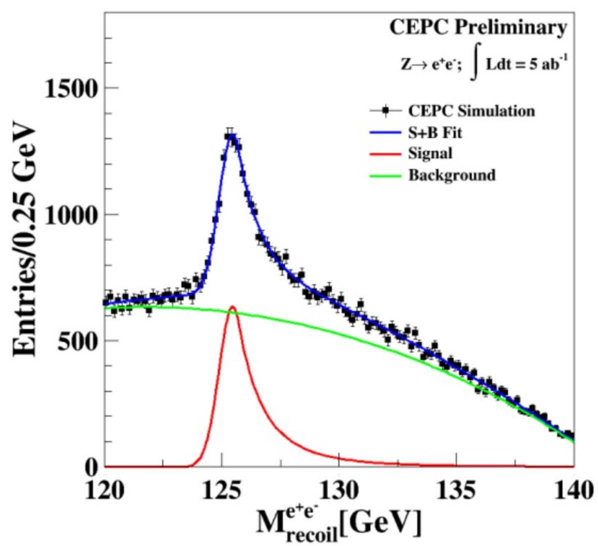


Lepton







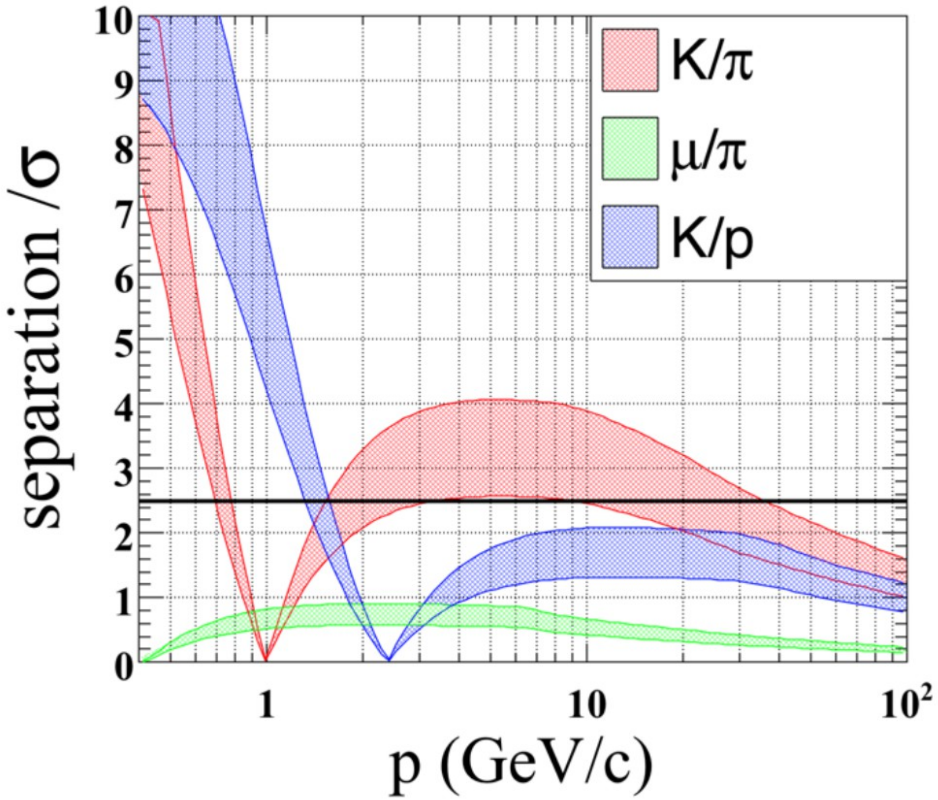


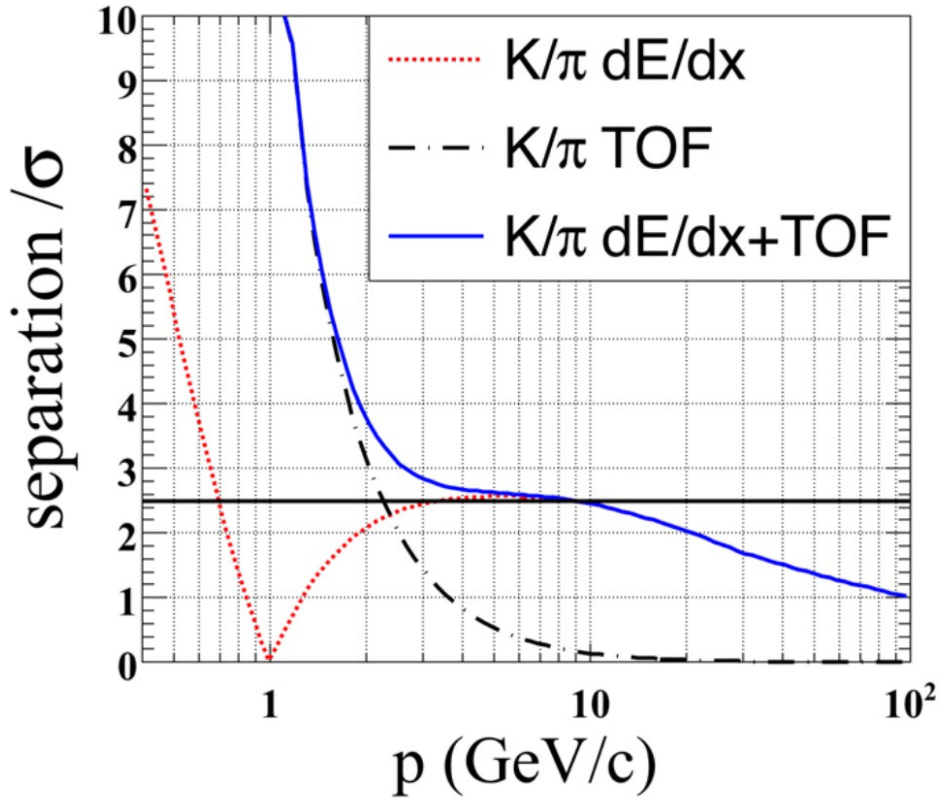
BDT method using 4 classes of 24 input discrimination variables.

Test performance at: Electron = E_likeness > 0.5 ;
Muon = Mu_likeness > 0.5
Single charged reconstructed particle, for E > 2 GeV:
lepton efficiency > 99.5% && Pion mis id rate ~ 1%

https://link.springer.com/article/10.1140/epjc/s10052-017-5146-5

Kaon





Highly appreciated in flavor physics @ CEPC Z pole

TPC dEdx + ToF of 50 ps

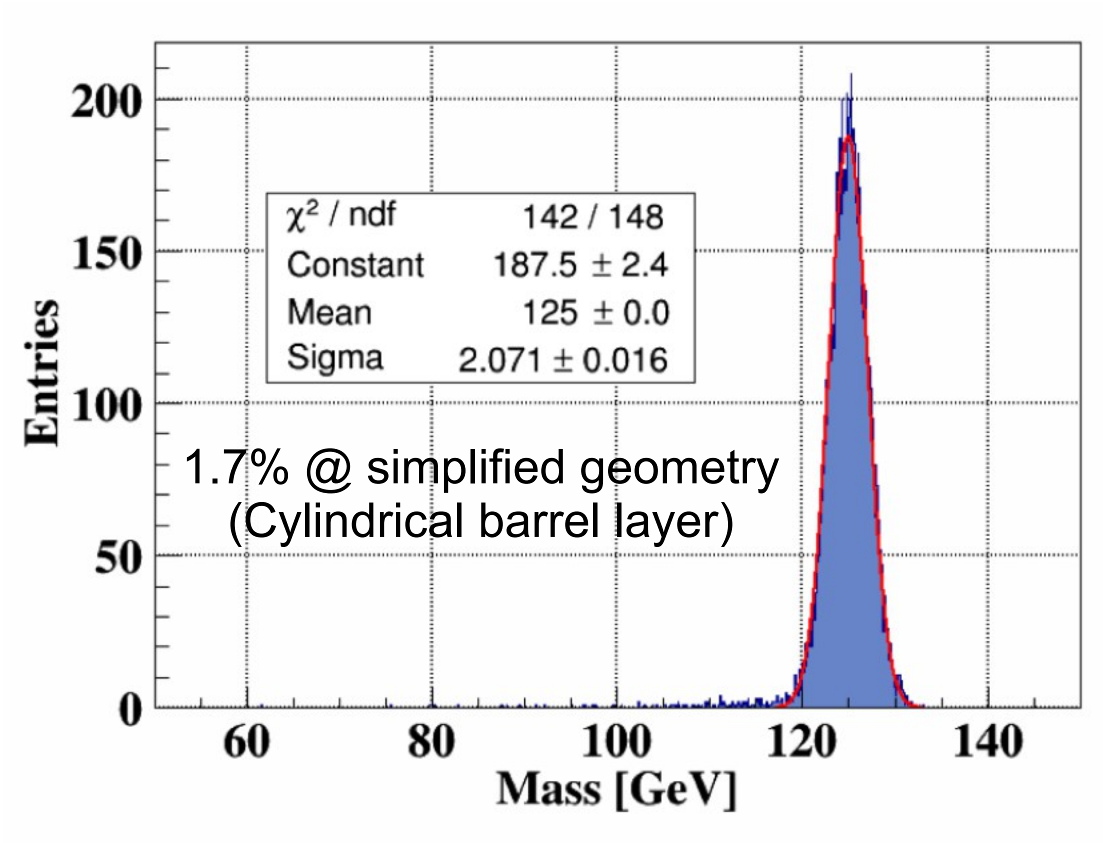
At inclusive Z pole sample:

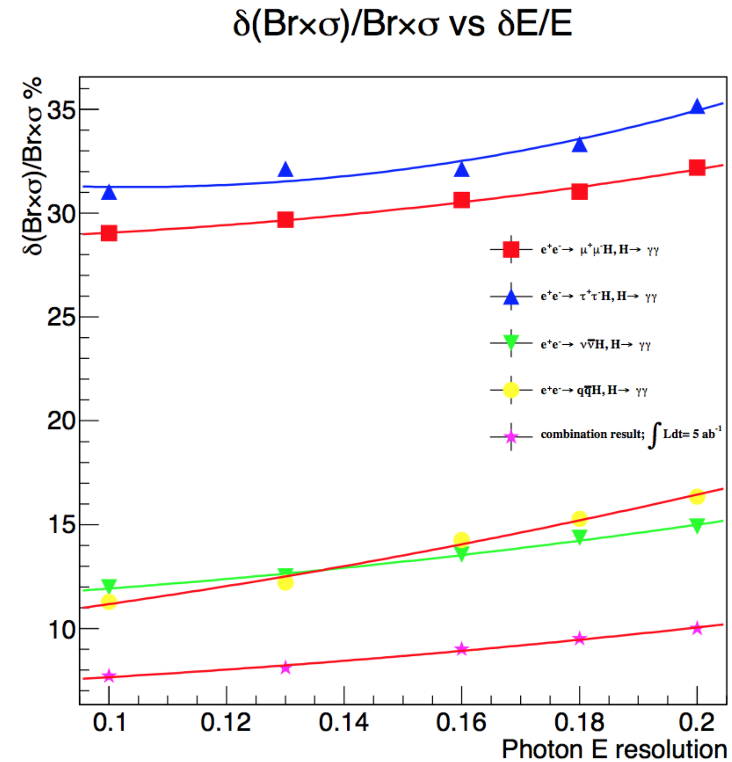
Conservative estimation: efficiency/purity of **91%/94%** (2-20 GeV, 50% degrading +50 ps ToF)

Could be improved to **96%/96%** at 20% degrading + 50 ps ToF

More detail in S. Porell's Talk:
http://indico.ihep.ac.cn/event/6618/session/10/contribution/85/material/slides/0.pdf

Photon

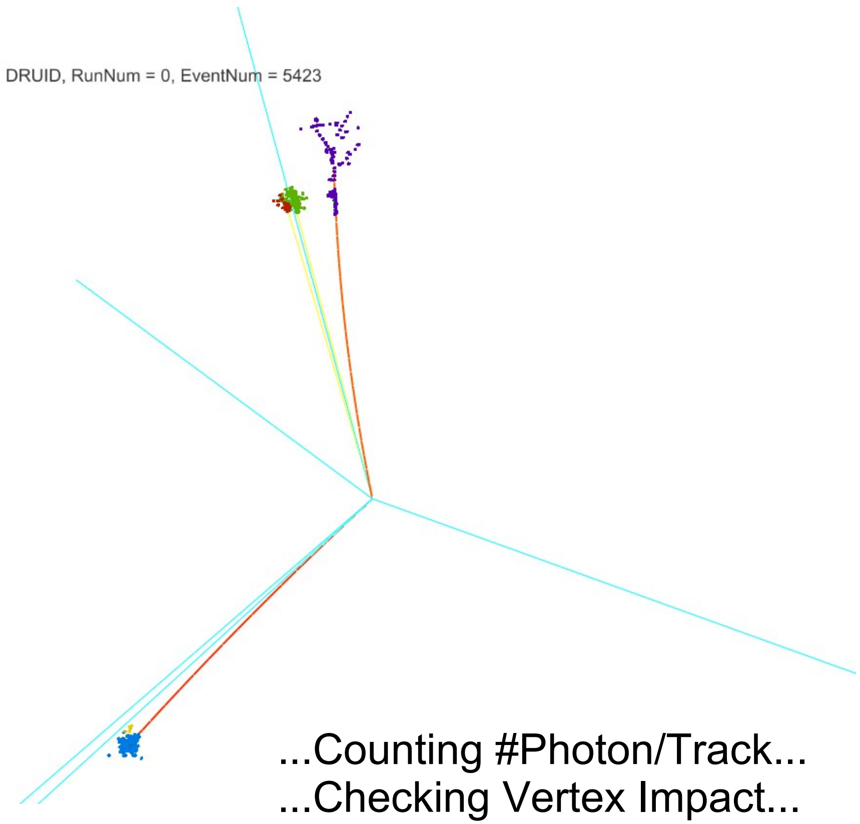




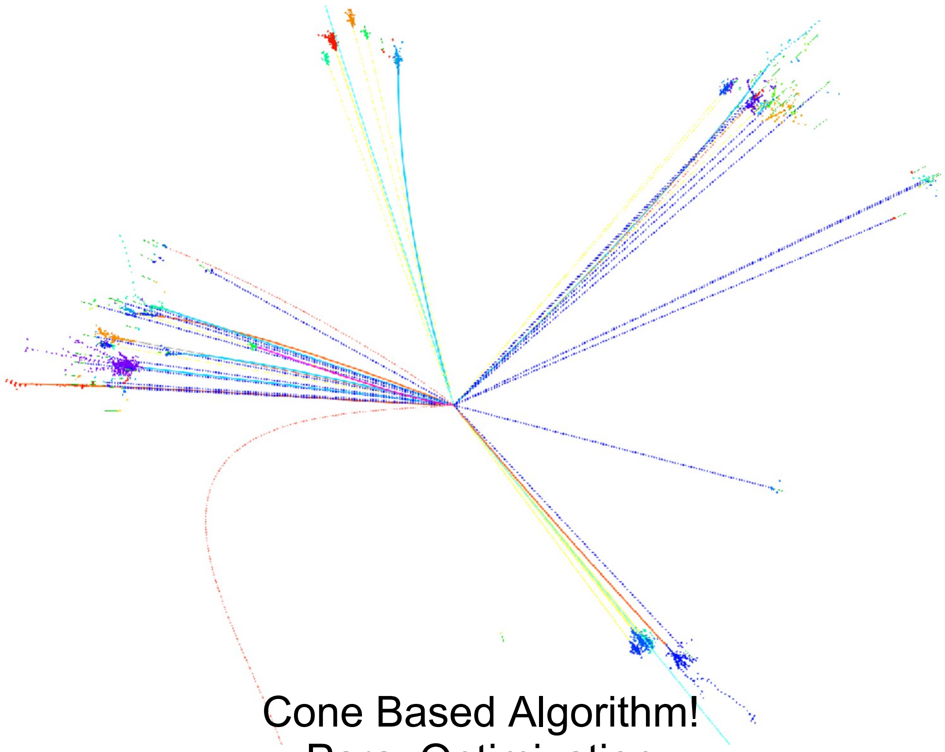
Relative Accuracy: ~ 8.5%

Inhomogeneity degrades the resolution significantly.
Physics requirement: constant term < 1%
Detector geometry defects degrades the mass resolution to **2.2%** (after correction);

Tau



...Counting #Photon/Track...
...Checking Vertex Impact...

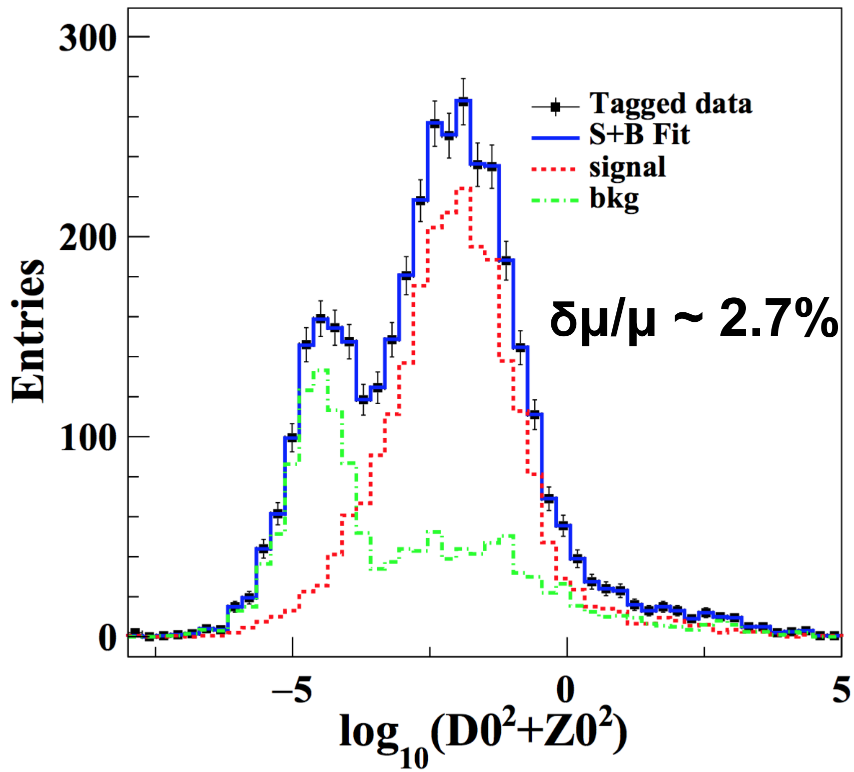


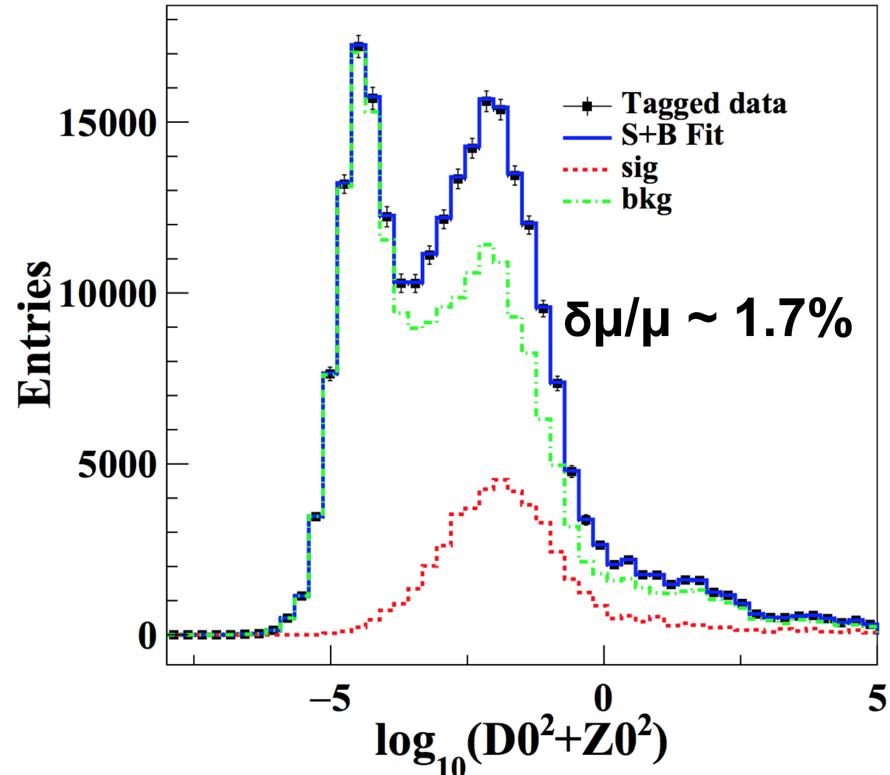
Cone Based Algorithm!
Para. Optimization

- Two catalogues:
  - Leptonic environments: i.e, llττ(ZZ/ZH), ννττ(ZZ/ZH/WW), Z→ττ;
  - Jet environments: i.e, ZZ/ZH→qqττ, WW→qqντ;

See Dan's presentation for more details
https://agenda.linearcollider.org/event/7645/contributions/40070/

g(Hττ) measurement: preliminary





- ZH→μμττ
- Extremely Efficient Event Selection
- Signal efficiency of 93% - entire SM background reduced by 5 orders of magnitude

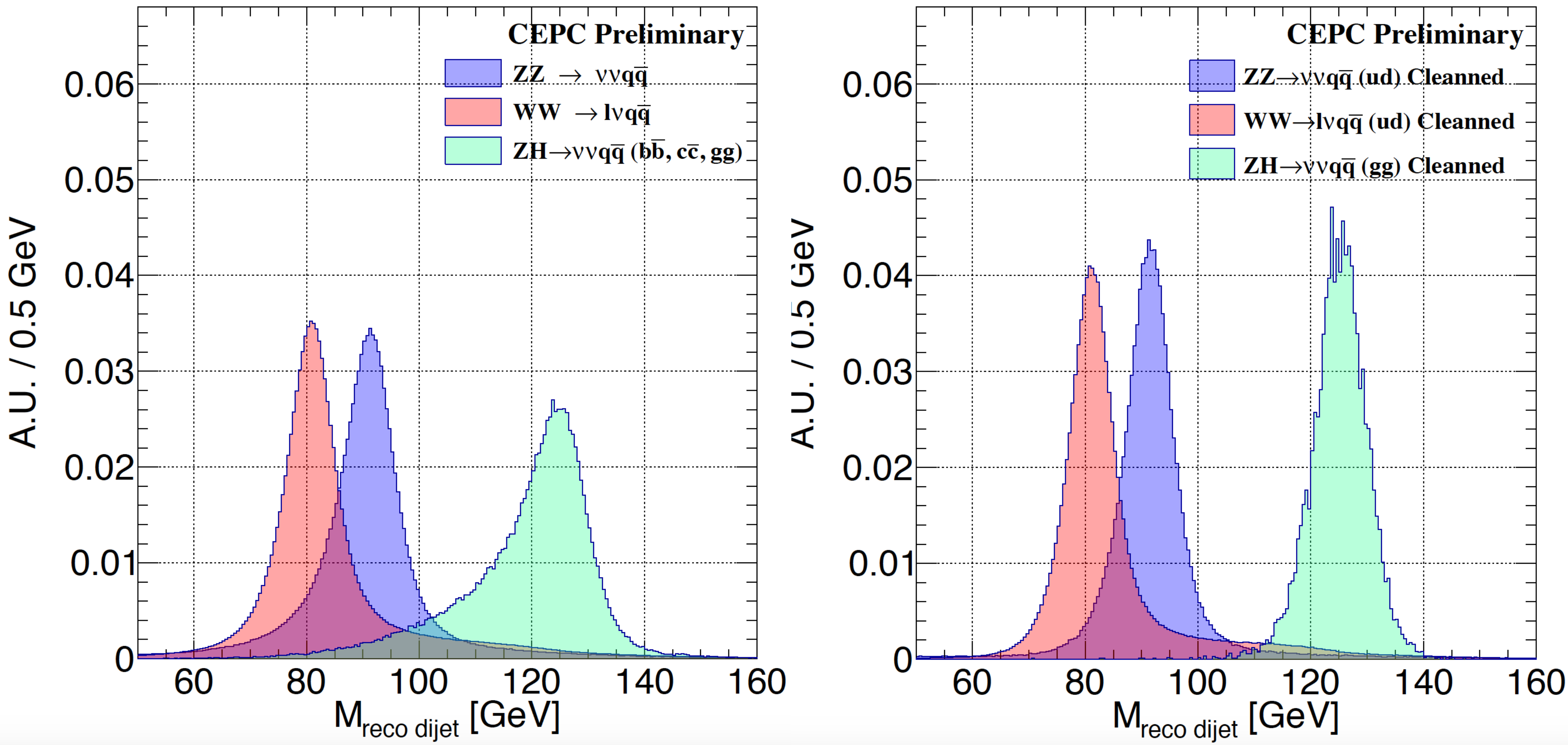
- ZH→qqττ
- Cone based tau finding algorithm, Compromise the efficiency & purity
- Signal efficiency of 51%

VTX system, and the understanding of background, is also crucial for this measurement

Jets

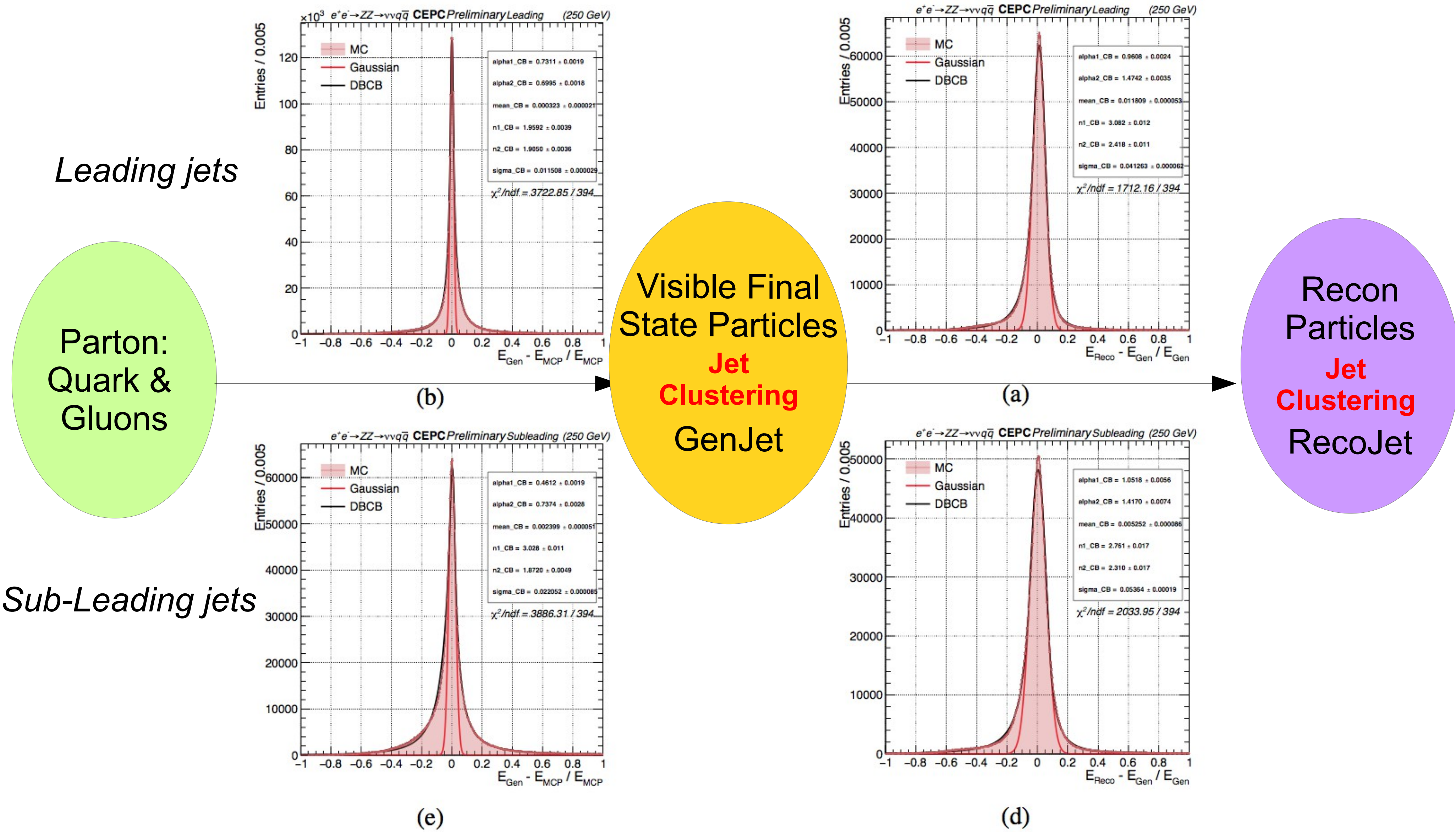
- Boson Mass Resolution (BMR): Separate W, Z and Higgs in hadronic decays
  - Essential for Higgs measurement
    - Separate Higgs from Z/W (relatively easy)
    - Separate H→ZZ/WW events (challenging)
  - Appreciated in Triplet Gauge Boson Coupling measurements
    - Separate WW (Signal) from ZZ, ISR return Z, etc.
  - ...
- Single jet response & Jet Clustering
  - Jet Clustering May dominants the uncertainty in physics analysis, i.e, at Higgs coupling measurement at ZH->4 jets
  - Search for the most suited jet clustering algorithm (Presumably channel dependent) – Understand the Corresponding Systematic
  - ...

BMR



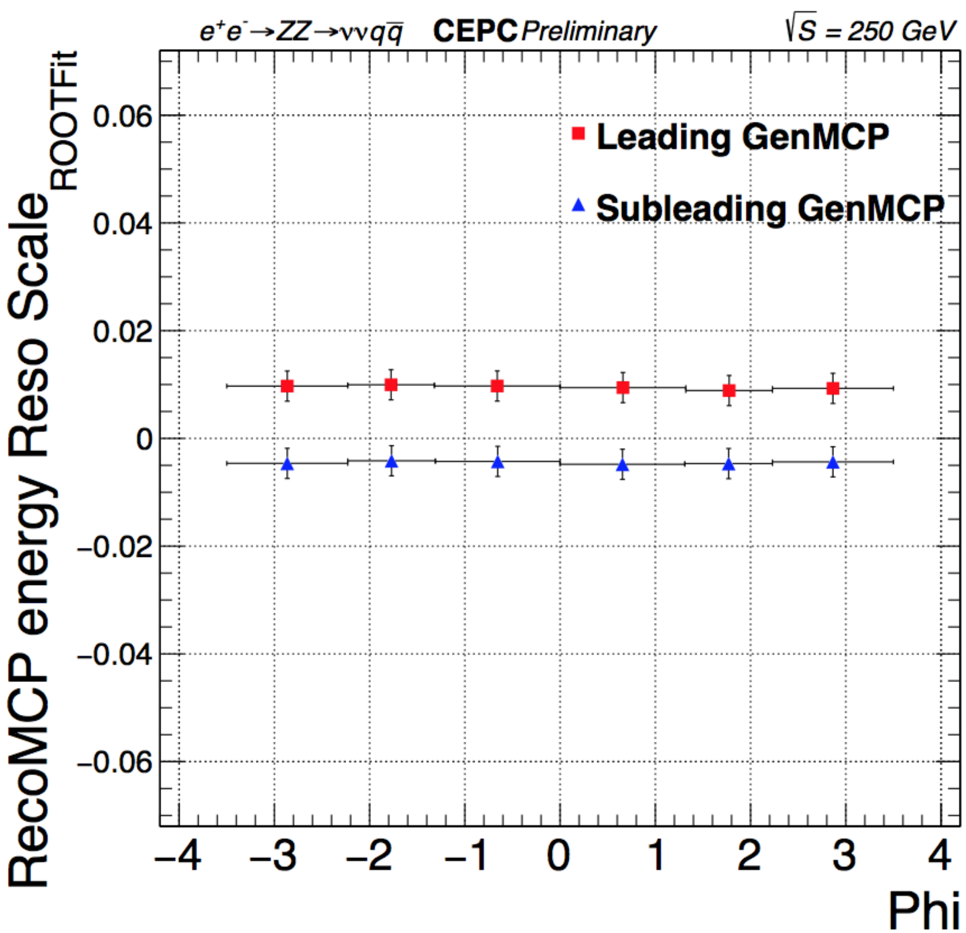
Cleaned: Veto events with heavy flavor jet, visible ISR photon, signifiant neutrino Component generated in jet cascade & jet direction towards beam pile hole (eff at H->gg ~ 65%)

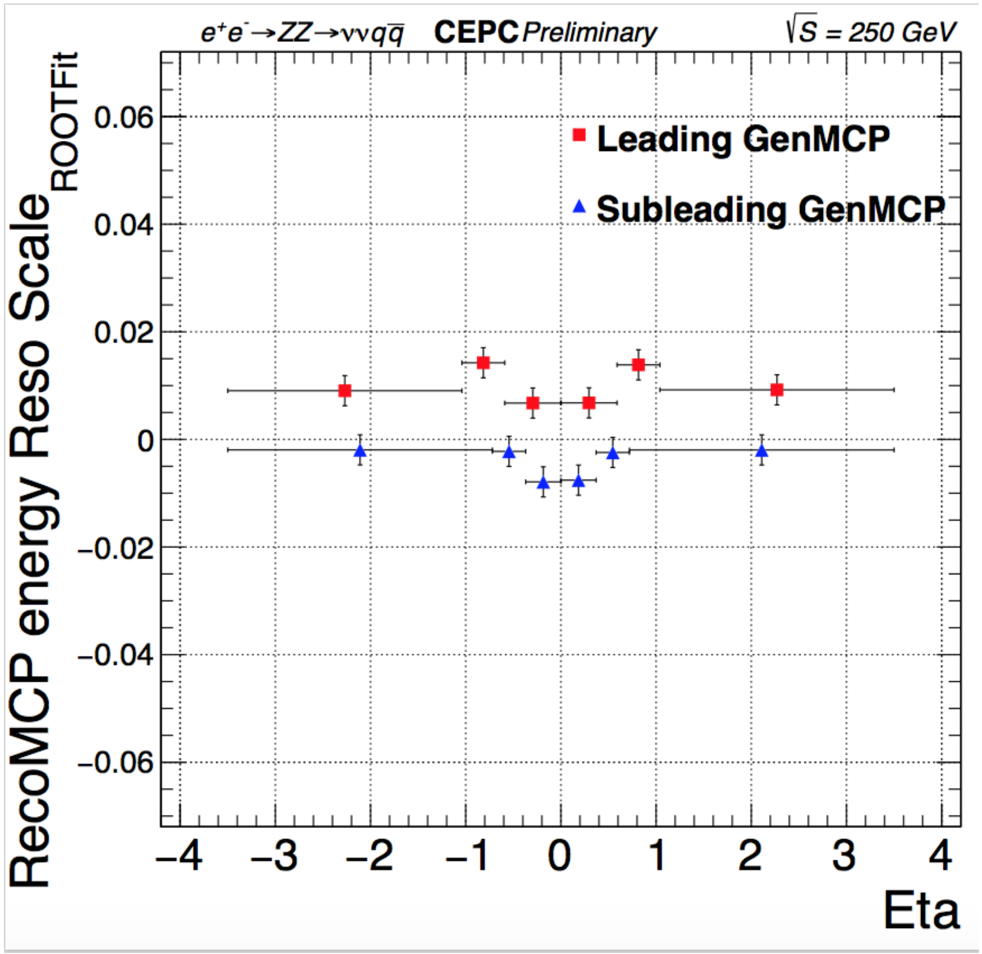
Individual Jet Response & Jet Clustering



Jet Clustering is Mainly responsible for the tails

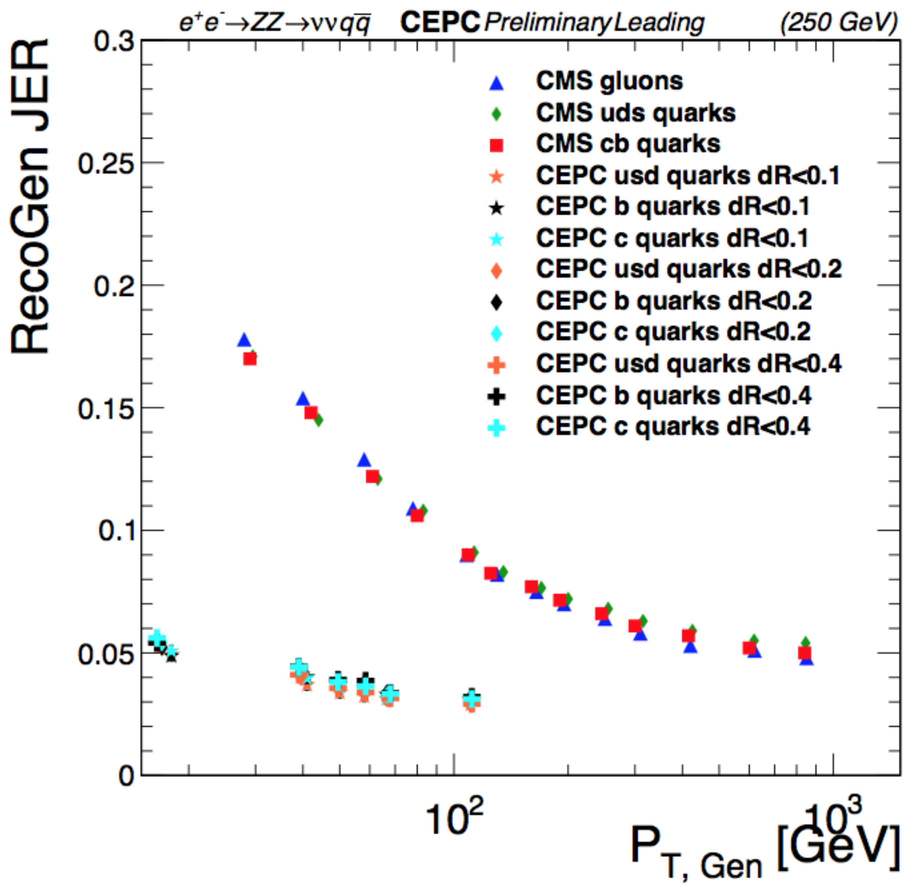
Jet energy Scale

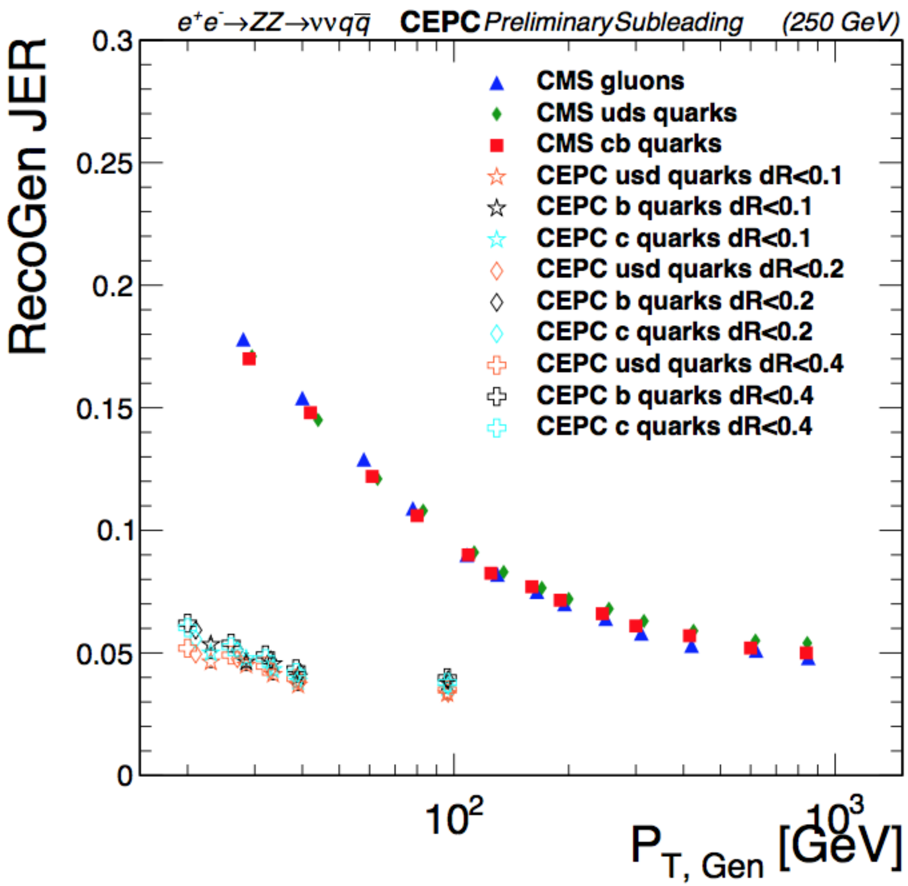




Amplitude ~ 1%
Large JES observed at Leading Jet (Correlated), and at overlap region (Increasing of Splitting)

Jet Energy Resolution



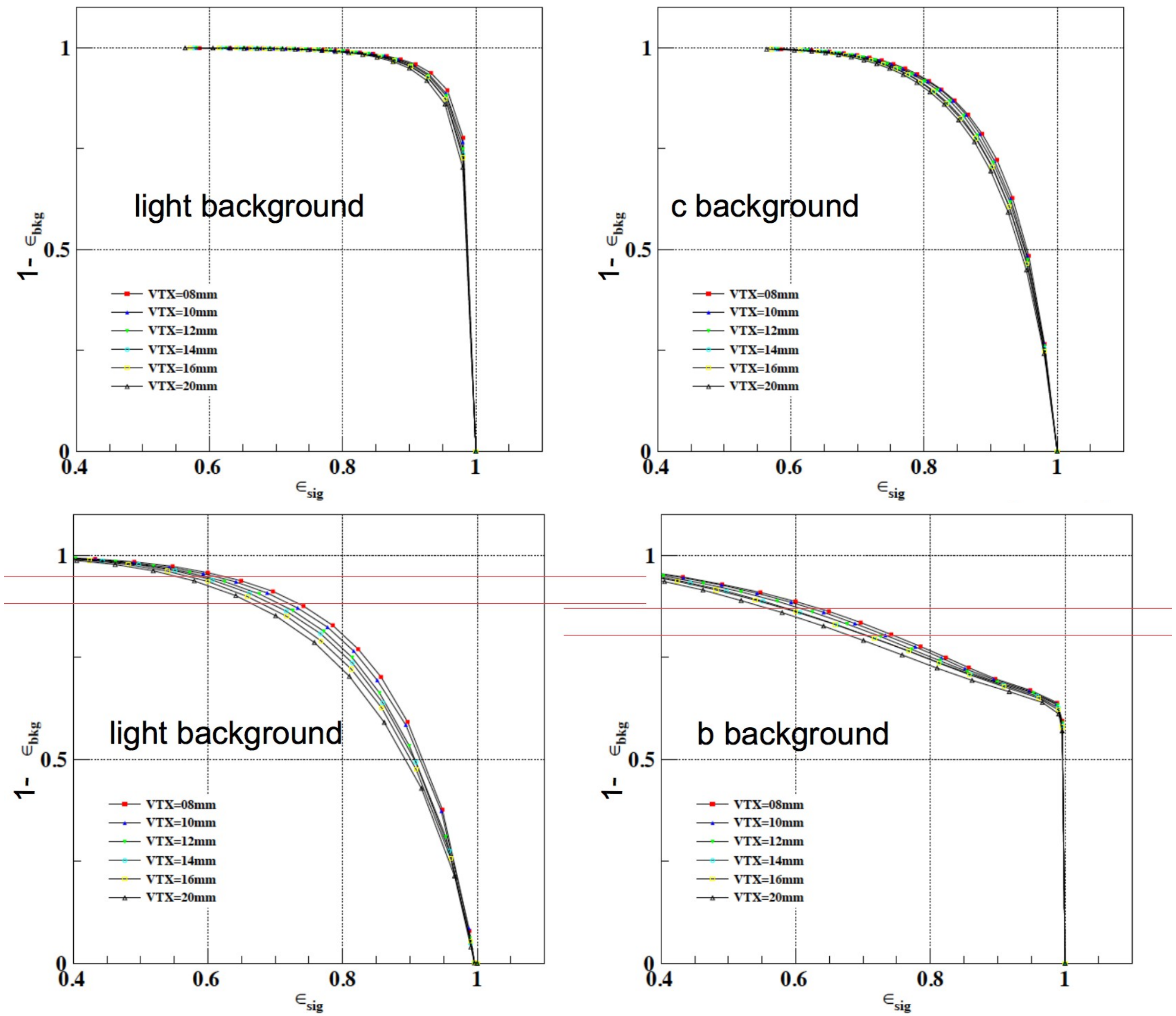


CMS Reference: CMS-JME-13-004,

Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV

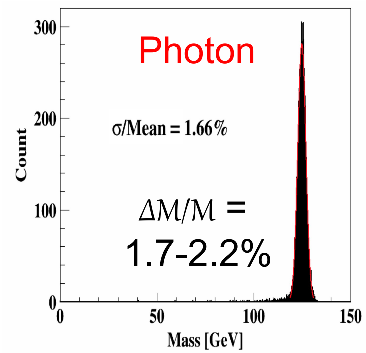
Flavor Tagging

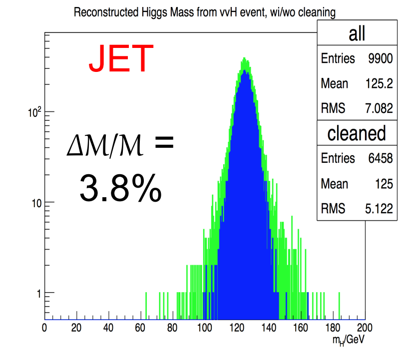
- LCFIPlus Package
- Typical Performance at Z pole sample:
  - *B-tagging: eff/purity = 80%/90%*
  - *C-tagging: eff/purity = 60%/60%*
- Geometry Dependence of the Performance evaluated

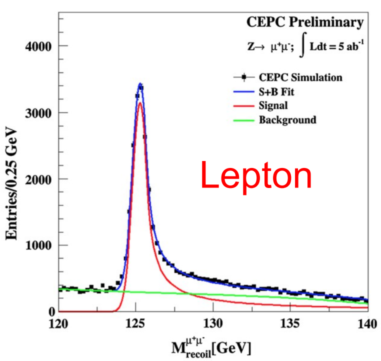


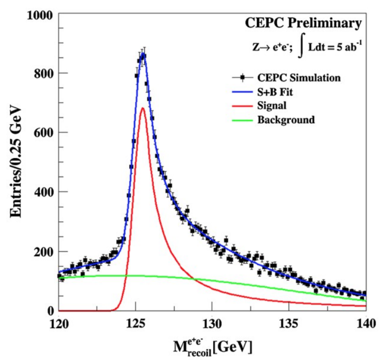
See G. Li's presentation for more details
https://agenda.linearcollider.org/event/7645/contributions/40124/

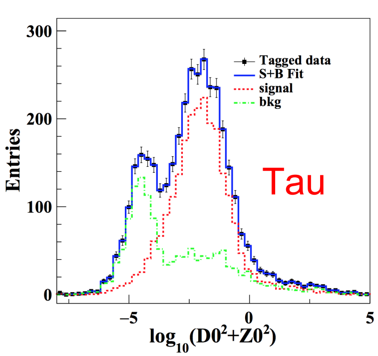
PFA Oriented Reconstruction

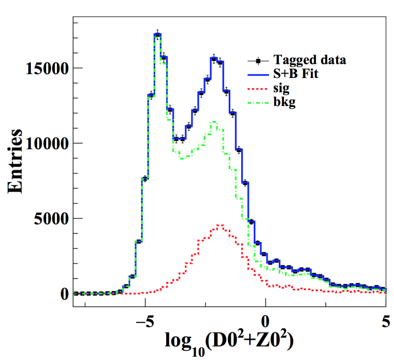










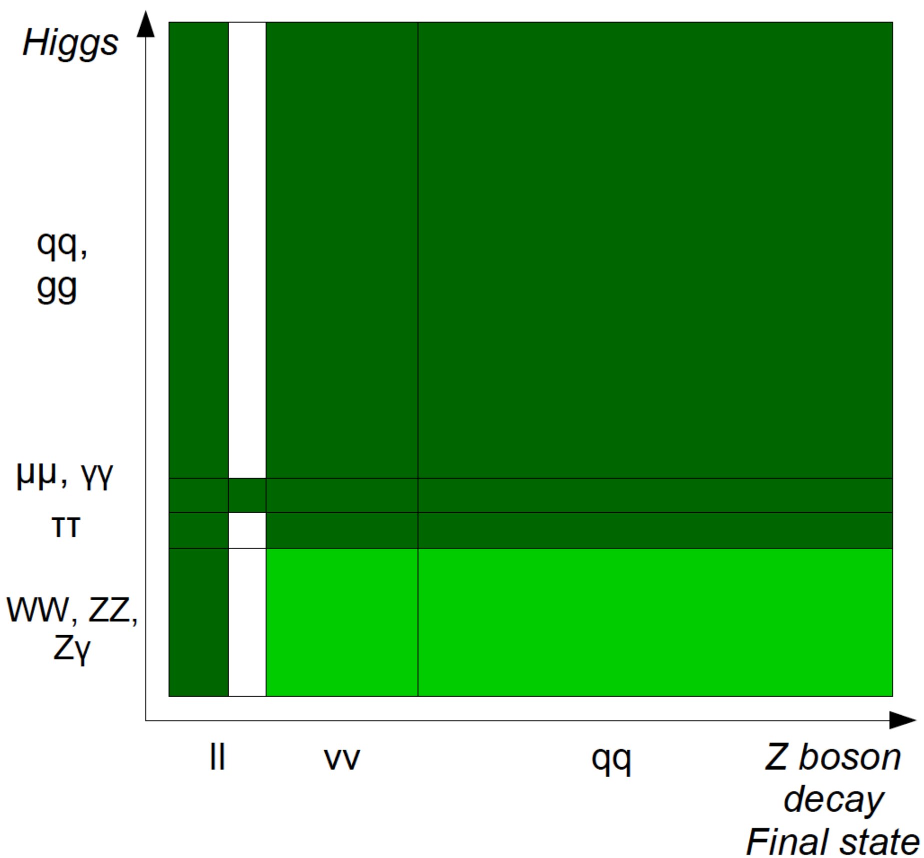


Example Working Points & Performance for Object identification (Preliminary)

	Efficiency	Purity	Mis-id Probability from Main Background
Leptons	99.5 – 99.9%	99.5 – 99.9% at Higgs Runs(c.m.s = 240 GeV), Energy dependent	$P(\pi^{\pm} \to leptons) < 1\%$
Photons*	99.3 – 99.9%	99.5 – 99.9% at Higgs Runs Energy Dependent	$P(\text{Neutron} \to \gamma) = 1\text{-}5\%$
Charged Kaons**	86 – 99%	90 – 99% at Z pole Runs (c.m.s = 91.2GeV, Track Momentum 2- 20 GeV)	$P(\pi^{\pm} \to K^{\pm}) = 0.3 - 1.1\%$
b-jets	80%	90% at Z pole runs $(Z \to qq)$	P(uds → b) = 1% P(c → b) = 10%
c-jets	60%	60% at Z pole runs	P(uds → c) = 5% P(b → c) = 15%

Photon: only considering neutron background and using ToF information*
*Kaon**: Performance Highly depend on DAQ & Geometry*

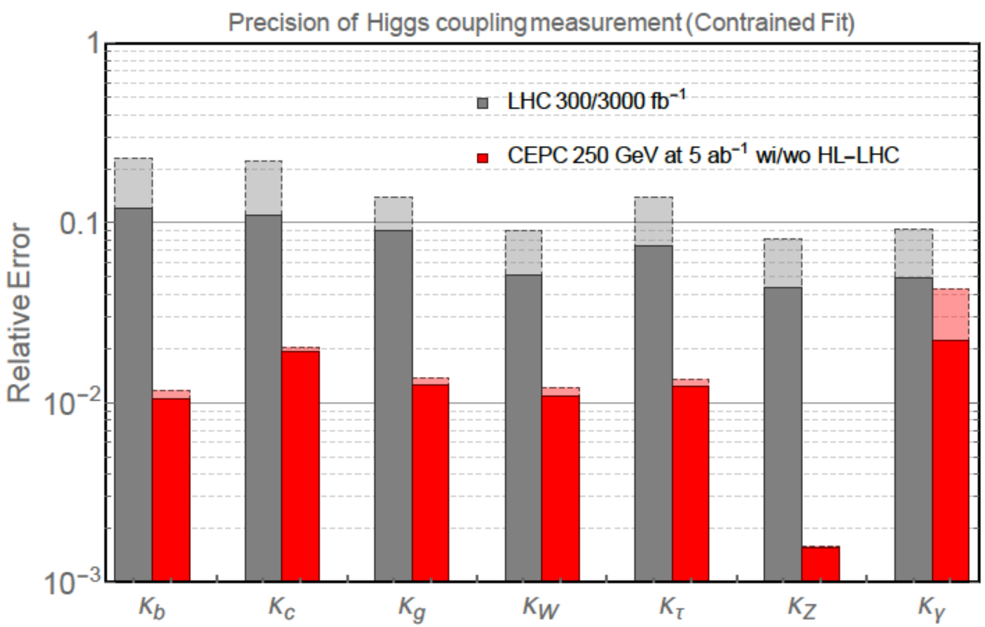
CEPC Higgs Analyses

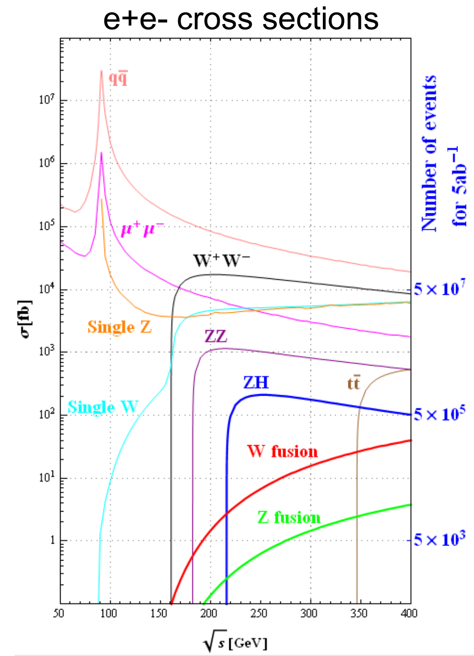


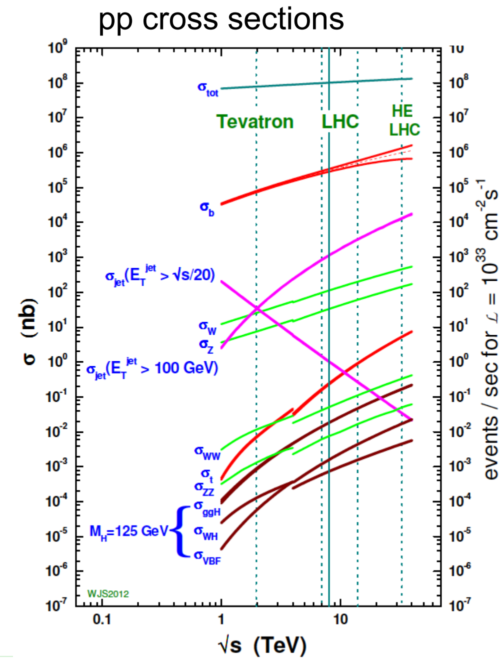
	PreCDR (Jan 2015)	Now (Aug 2016)
σ(ZH)	0.51%	0.50%
σ(ZH)*Br(H→bb)	0.28%	0.21%
σ(ZH)*Br(H→cc)	2.1%	2.5%
σ(ZH)*Br(H→gg)	1.6%	1.3%
σ(ZH)*Br(H→WW)	1.5%	1.0%
σ(ZH)*Br(H→ZZ)	4.3%	4.3%
σ(ZH)*Br(H→ττ)	1.2%	1.0%
σ(ZH)*Br(H→γγ)	9.0%	9.0%
σ(ZH)*Br(H→Zγ)	-	~4 σ
σ(ZH)*Br(H→μμ)	17%	17%
σ(ννH)*Br(H→bb)	2.8%	2.8%
Higgs Mass/MeV	5.9	5.0
σ(ZH)*Br(H→inv)	95%. CL = 1.4e-3	1.4e-3
Br(H→ee/emu)	-	1.7e-4/1.2e-4
Br(H→bbχχ)	$<10^{-3}$	3.0e-4

Higgs Physics @ CEPC-v1: event rate measurements almost fully covered
(*mostly with* ***old*** *reconstruction...*)

Higgs measurement at e+e- & pp

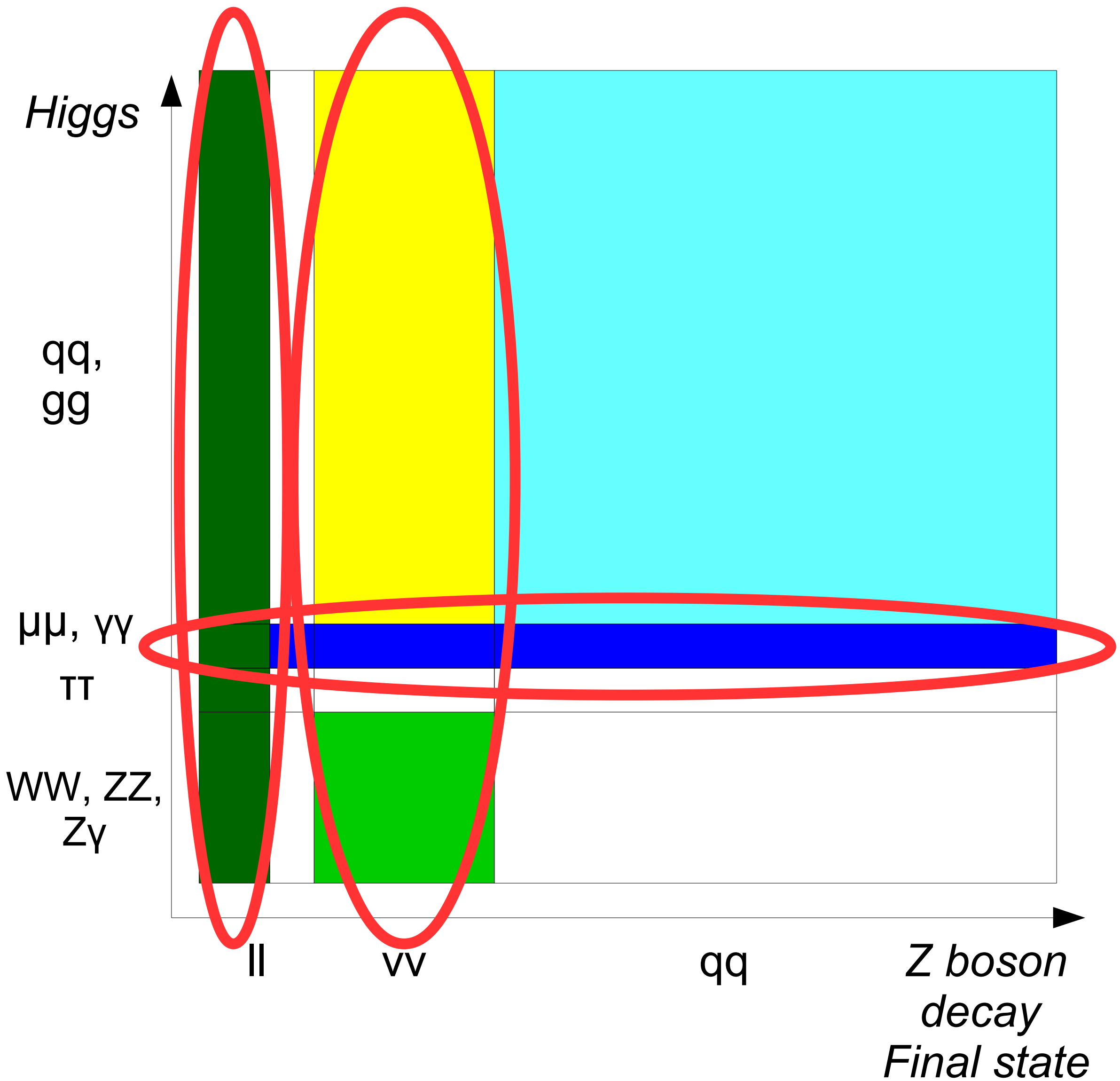






	Yield	efficiency	Comments
LHC	Run 1: 10^6 Run 2/HL: 10^{7-8}	~o(10^{-3})	High Productivity & High background, Relative Measurements, Limited access to width, exotic ratio, etc, Direct access to g(ttH), and even g(HHH)
CEPC	10^6	**~o(1)**	Clean environment & Absolute measurement, Percentage level accuracy of Higgs width & Couplings

Benchmark measurements



Lepton & Momentum resolution: Br = 6.7%

Flavor Tagging & JER: Br = 14%

Composition of Jet/MET, lepton: Br = 4%

Jet Clustering: Br = 50%

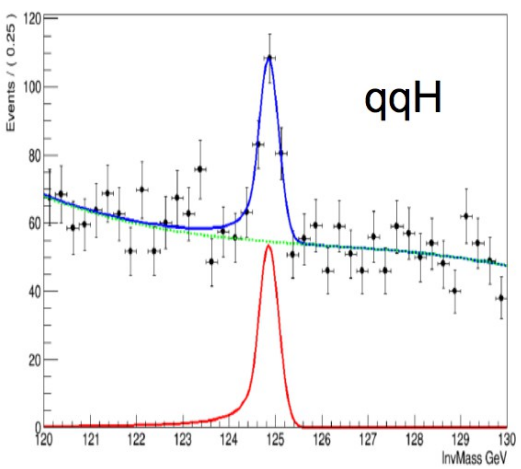
Photon/ECAL: Br = 0.2%

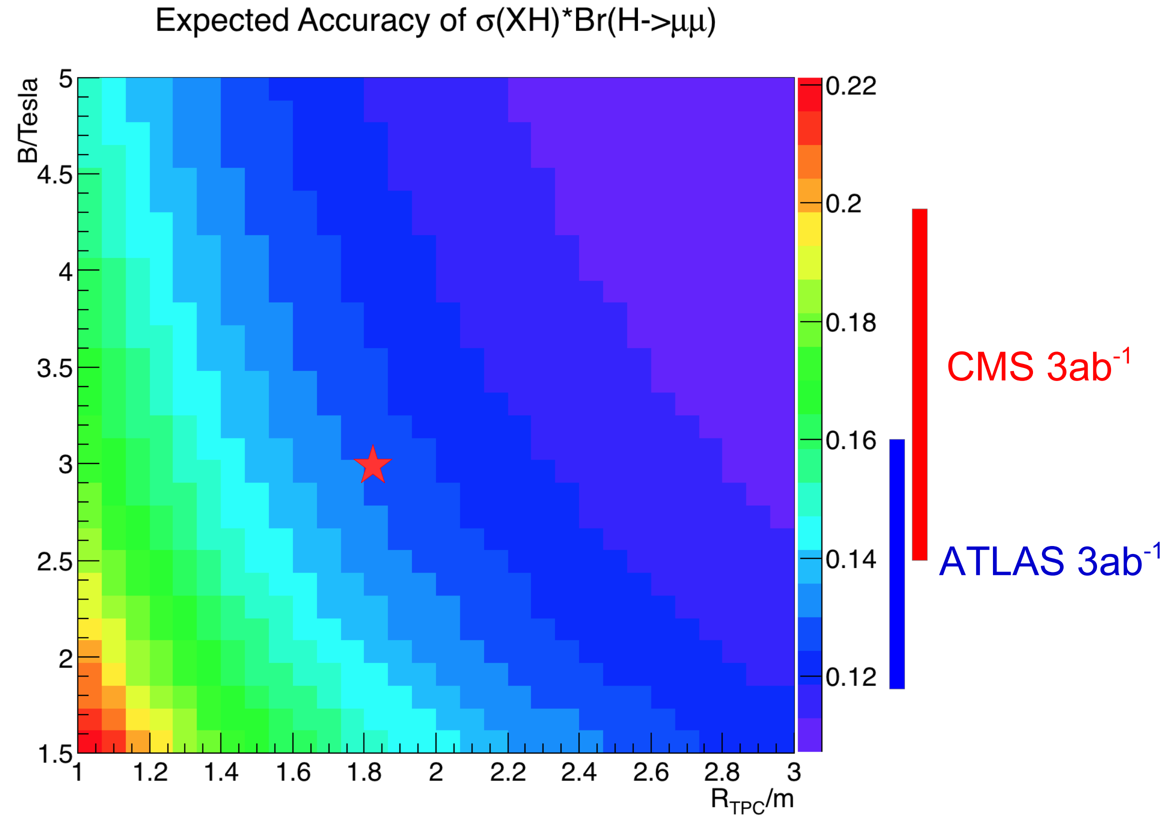
qqH, H->inv. MET & NP: SM Br = 0.1%

EW, Br(tau->X) @ Z pole: Separation

TPC Radius & B-Field

- TPC is Feasible at CEPC Z pole operation (2017 JINST 12 P07005)
- Detector cost is sensitive to tracker radius, recommended Value >= 1.8m:
  - Better separation & JER
  - **Better (H->di muon) measurement**

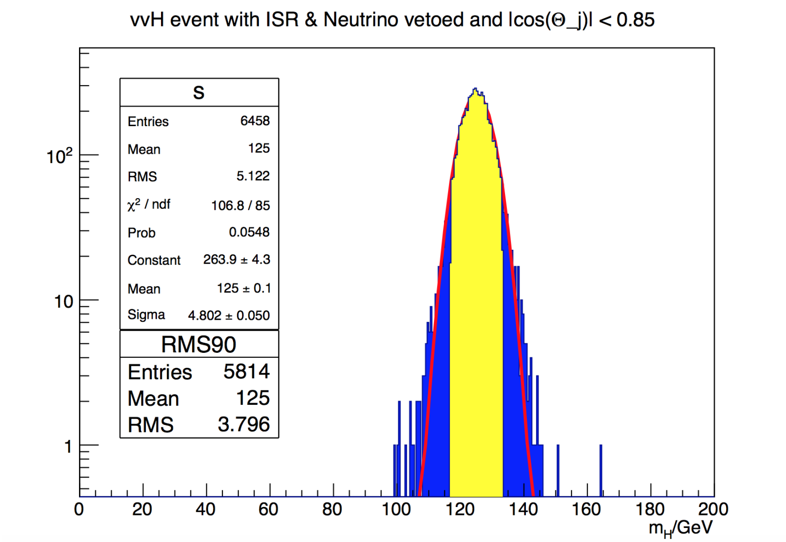




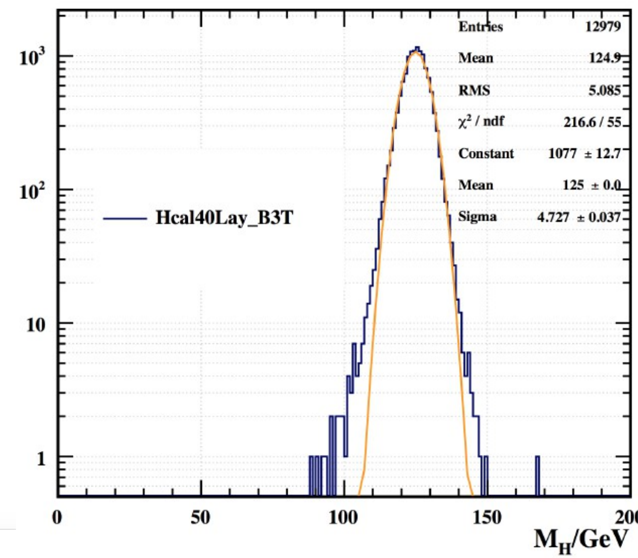
★ *Default TPC Setting: B = 3 T & R_{out} = 1.8*

JER VS **B-Field & NLayer**

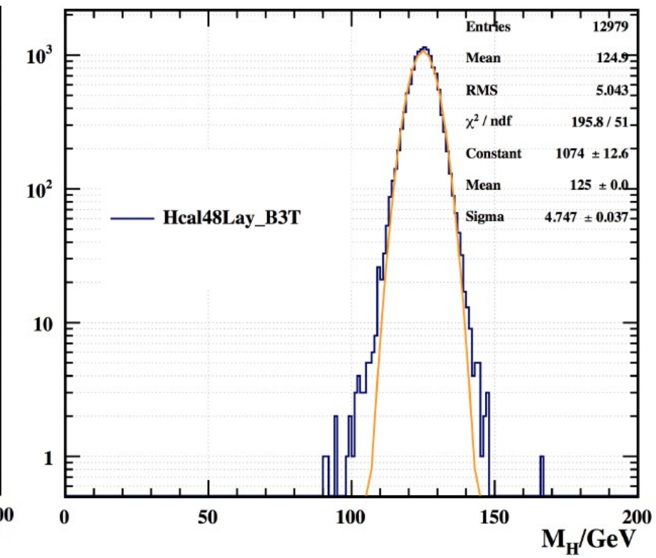
3.5T & 48 Layers



3T & 40 Layers



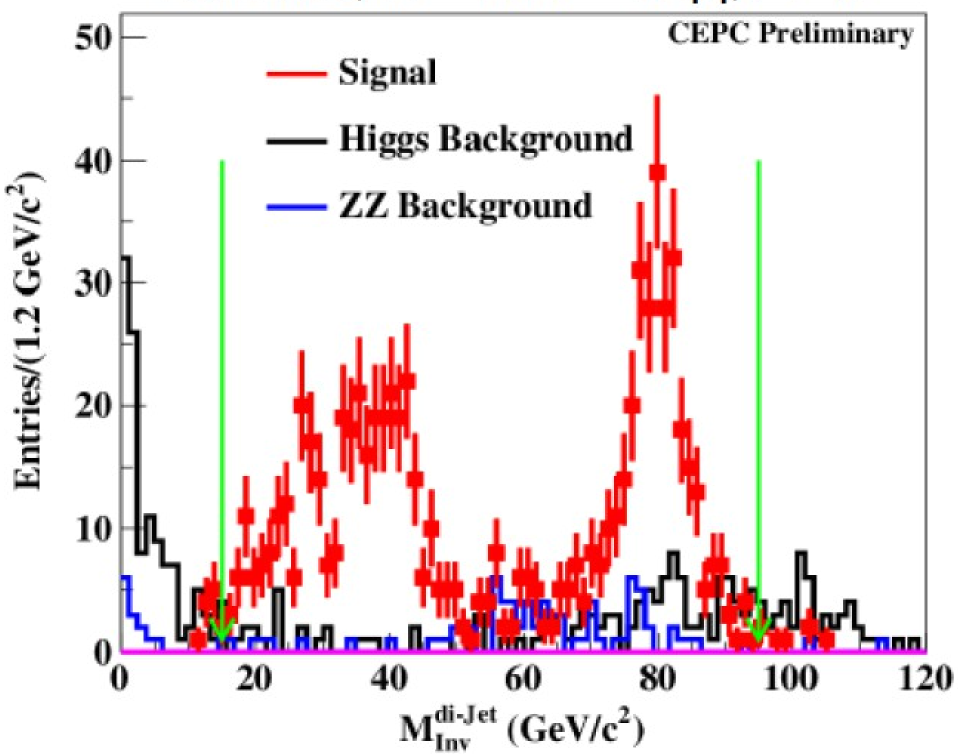
3T & 48 Layers

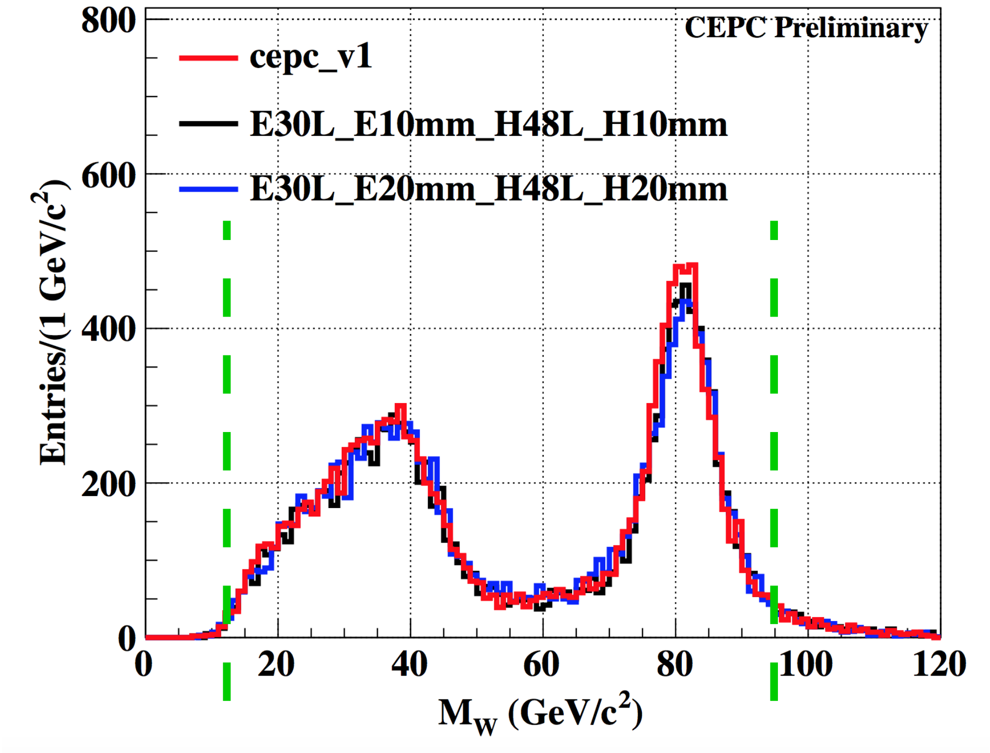


- Marginal Impact on JER (from 3.5T -> 3T)
- *3 Tesla even turns out to be better than 3.5 Tesla (~only 1 sigma)*

Br(H→WW) Vs **Cell size**

Liao libo, H→WW*→lvqq, Z→ll



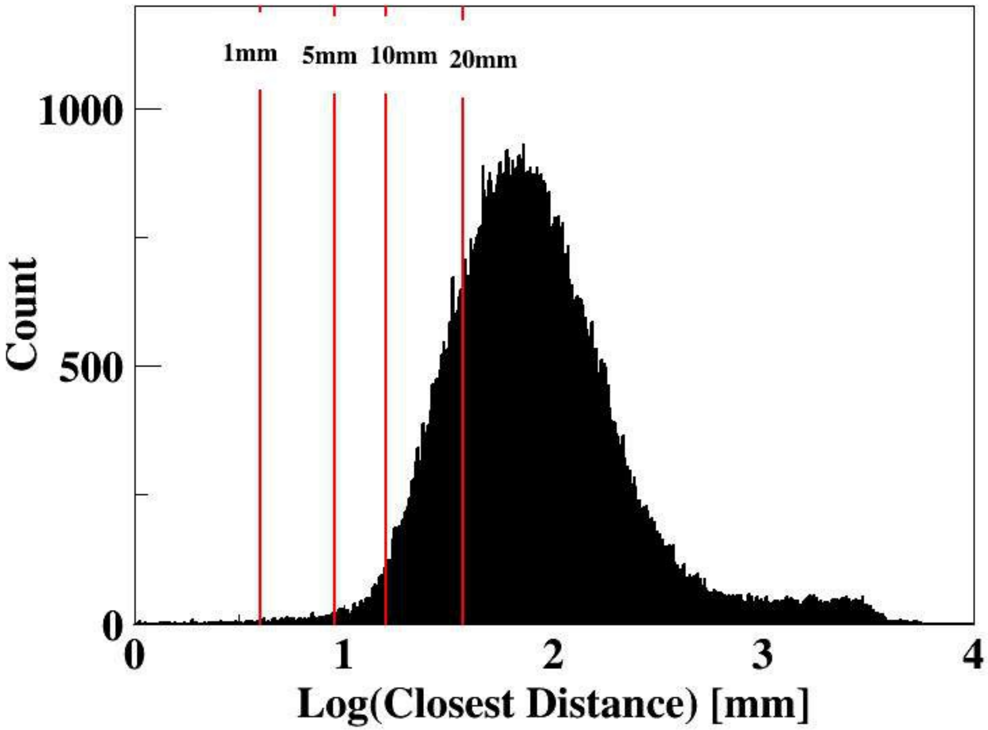


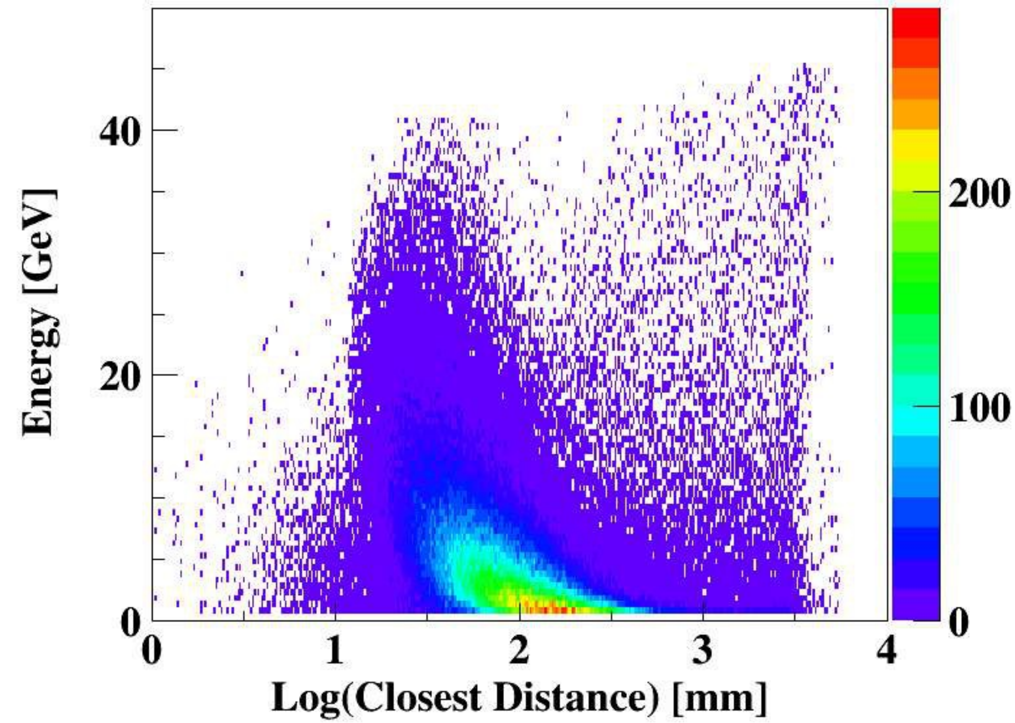
Br(H→WW) via vvH, H→WW*→lvqq

No lose in the object level efficiency: JER degraded, ~ 5/10% at 10/20 mm

Over all: event reco. efficiency varies ~1%

Z->tau tau @ Z pole VS **Cell Size**





Cell Size/mm	1	5	10	20
Crucial Dis/mm	4	9	16	37
Percentage of potentially overlap photon	0.07%	0.4%	1.7%	18.6%

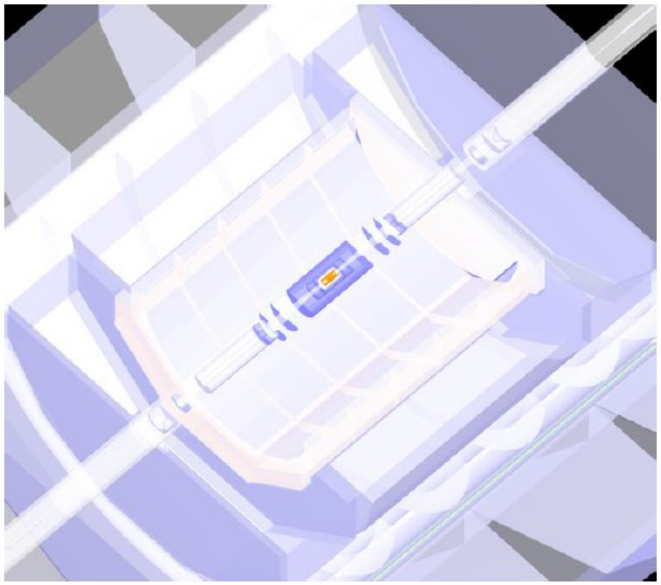
5 → 20 mm: May severe degrade Tau physics performance
→ to be investigated

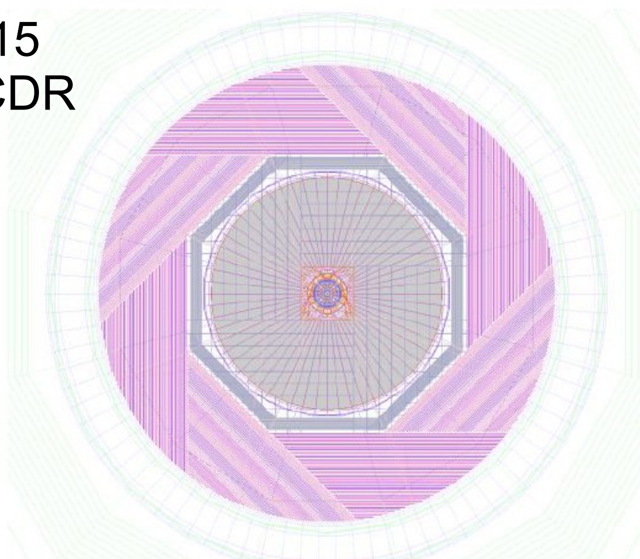
Optimized Parameters

	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 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 (5) mm	Passive cooling request ~ 20 mm. < 10 mm is appreciated for EW measurements – need further evaluation
ECAL NLayer	30	30 (20)	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.

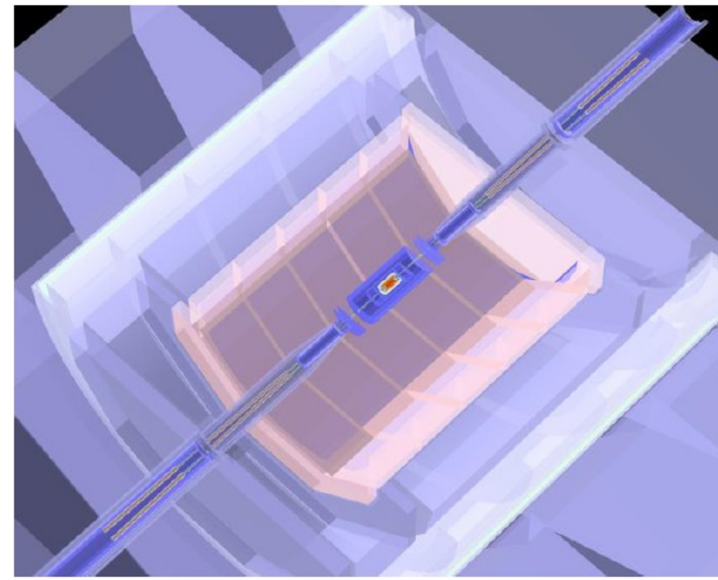
Benchmark detector for CDR: **APODIS**

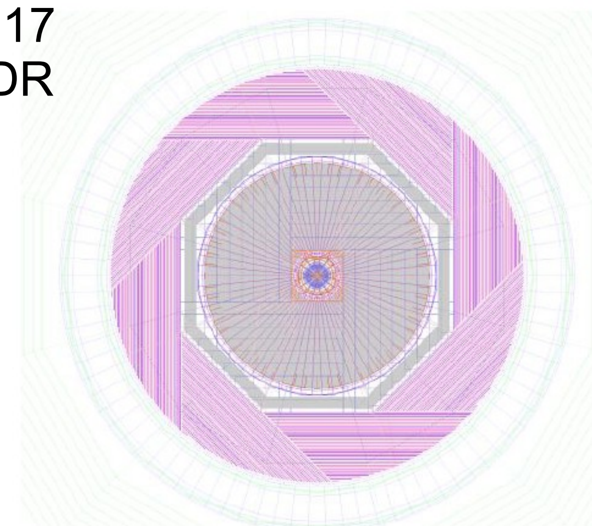
(A PFA Oriented Detector for HIggS factory. a.k.a CEPC_v4)





2015
PreCDR

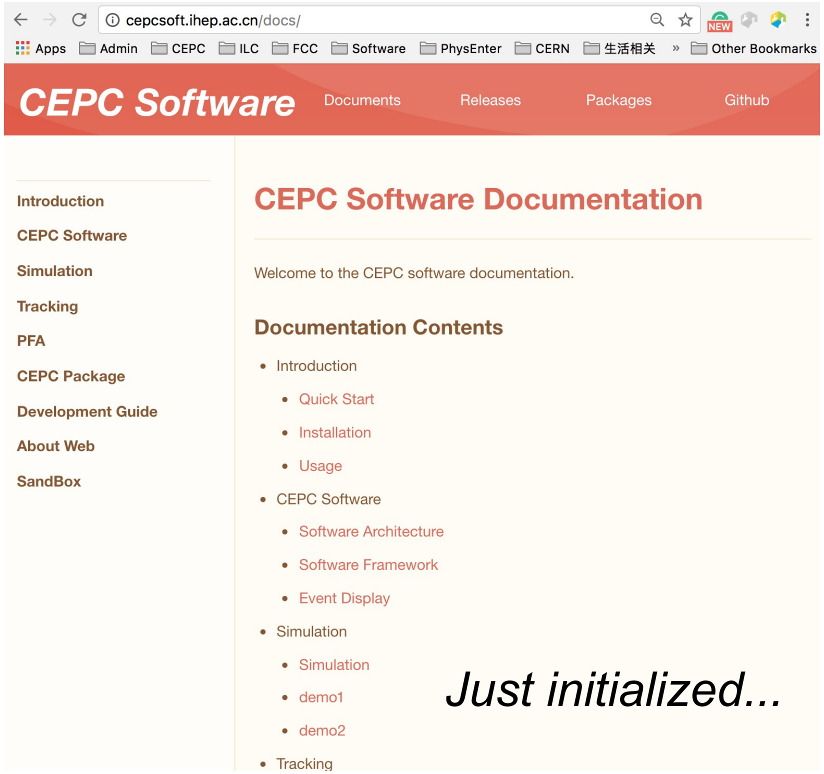




2017
CDR

Todo: from conceptual to engineering

- **Software Team: Common Sample & Software Services**
- **Benchmark analyses at APODIS**
- Novel Reco. & Pattern Recognition Algorithms
- Systematic control study
  - Sub-detector digitizers, test beam - validation
  - Requirement analyses
  - In-situ Monitoring
  - Data driven methods
- DAQ design & further optimization
- Global Integration



Publications, Notes & International cooperations @ 2017

- Documentation
  - 3 Papers (JINST, EPJC, JPhysG)
  - ~o(10) CEPC Notes
- Talks at International Conference
  - 4 Talks at CHEF (Calorimeter for High Energy Frontier), Lyon, France
  - 4 Talks at LCWS (Linear Collider Workshop), Strasburg, France
  - 1 Invited talk at FCAL Workshop, Vinca, Serbia
  - 1 Talk at DPF, Fermi Lab, US
  - 1 Talk at CALICE Workshop
  - ~10 talks at CEPC Workshop
- Visiting & Cooperation with KEK, Vinca, In2p3, Iowa, Michigan, etc

困难 & 解决方案

- **人力和计算资源方面的巨大缺口**
- 人力
  - 课题的深度和难度大为增加
  - 已有学生、博士后较为稚嫩，难以独立承担科研课题。能够独立完成科研任务的博士后， Staff 级别人力急缺
  - 以学生为主的，在 PreCDR 阶段训练成熟的分析队伍人员流失严重
- 计算资源 ～400 CPU
  - Massive Production 的产额仅仅达到最低要求（单探测器、单重建版本下的一份 SM 样本）的 1/10 。已成为制约我们国际合作的瓶颈
  - 需支持探测器整体优化、重建算法优化调试、子探测器模拟和 Digitization 开发、物理分析等繁多工作

- **加大投入**
- 人力
  - 寻找优秀博士、博士后
  - 招募百人 / 青千级的 Staff
  - 加强合作
    - 整理清晰我们的软件、样本服务，减低合作者合作的技术难度
    - 制定明晰的合作课题和合作计划
  - 鼓励高能所员工参加
    - 给予足够的 Credit
- 计算资源
  - 强烈建议建立一个 1k CPU 量级的、 CEPC 计算资源池

Conclusion

- PFA oriented detector + Arbor: **Decent performance fulfills the requirements**
  - High efficiency & purity for Lepton, Kaon, Photon reconstruction
  - The Jet energy resolution
    - BMR: efficiently separate W, Z & Higgs
    - Jet level: |JES| < 1%, JER ~ 3-6% (Jet Clustering has significant impact)
  - Well established Higgs Signal in Physics benchmarks

- **APODIS: Benchmark Geometry for CDR**
  - Similar Higgs performance w.r.t CEPC_v1 (degrading < 1% anticipated)
  - Adequate to CEPC Collision environment
  - ECAL #Channel reduced to 1/4 (1/6); HCAL Size/#Channel reduced to 80%

- Many interesting/important topics to be explored

Backup

Systematics requirements

- Luminosity
  - 10^{-3} for Higgs Run
  - 10^{-4} for Z pole operation
- Beam energy measurement
  - o(1-10) MeV for Higgs
  - o(0.1 – 1) MeV for Z
- Detector Requirements
  - Alignments
    - ~o(micrometer) accuracy for LumiCal
  - Homogeneity
    - ~o(10%) for Scintillator Calorimeter
  - Stability

Common topics

- Beam energy monitoring
  - 1 MeV accuracy is conditionally accessible (Very demanding) – Needs more careful study
- Deep learning in Flavor Tagging
  - Significant Impact observed
    - At Z pole: B-tagging purity improved from 89%->93% (eff = 80%)
    - At Higgs Sample: C-tagging purity improved by ~50% (eff = 60%)
  - Much to be explore
- Computing:
  - Appreciation to Dirac, IHEPCC, BES, QMUL, IPAS...
  - Short in Computing Power: Only covers 1/10 of SM Background in 1 geometry set
- DAQ
  - By giving some of the present examples, I am trying to give a hint on how the future DAQ system would move, but it is hard to predict new technology more than 10 year ahead
  - We need our own thoughts like xTCA
  - We need development from Industry
    - New FPGA, high IO
    - Powerful CPUs,PPUs
  - We should not wait, but keep working/improving

G. TANG

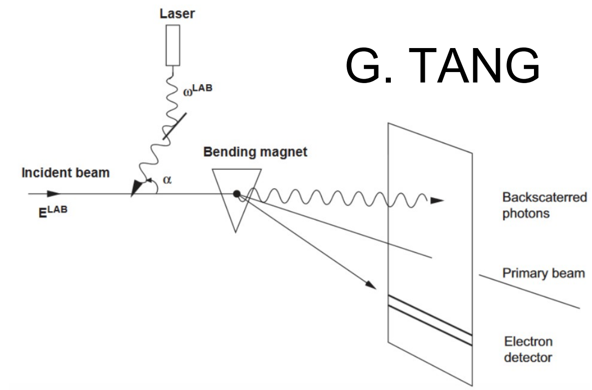
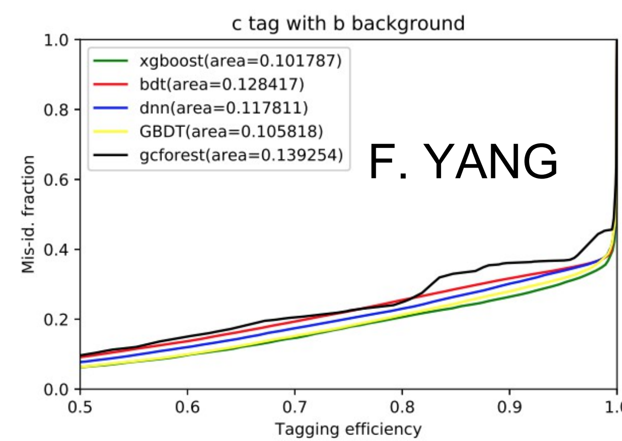


Fig. 8. Scheme of the proposed energy spectrometer based on Compton backscattering.



F. YANG

14:40 **Beam Energy monitoring via Compton Scattering** *20'*
Speaker: Mr. Guangyi Tang (高能所)
Material: Slides

15:00 **Computing at CEPC** *20'*
Speaker: Mr. Xianghu ZHAO (IHEP)
Material: Slides

15:20 **Machine Learning at CEPC** *20'*
Speaker: Prof. Fan Yang (XMU)
Material: Slides

18:10 **Advanced DAQ systems for current and future colliders** *20'*
Speaker: Prof. Zhen An LIU (IHEP)
Material: Slides

To Machine

16:30 - 18:15 **MDI (joint detector and accelerator) I: Parallel Session V**

Conveners: Dr. Suen Hou (SINICA), Prof. Michael Sullivan (SLAC National Accelerator

Location: C305

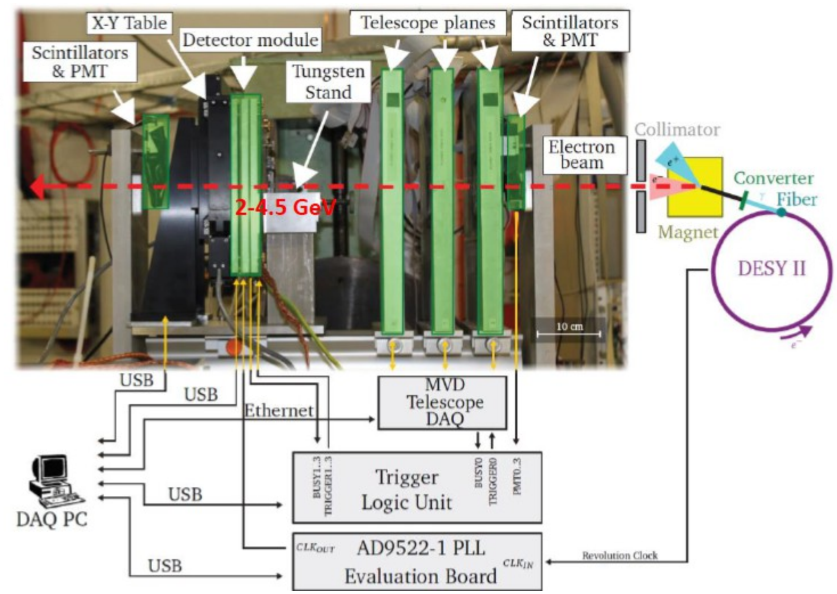
16:30 **Introduction (interaction region, magnets, etc.)** *25'*
Speaker: Mr. Chenghui Yu (Institute of High Energy Physics)
Material: Slides

16:55 **Radiation backgrounds at CEPC** *20'*
Speaker: Dr. Hongbo ZHU (IHEP)
Material: Slides

17:15 **MDI at SuperKEKB** *20'*
Speaker: Mr. Peter Lewis (Hawaii U.)
Material: Slides

17:35 **Overview of LC FCAL** *20'*
Speaker: Prof. Ivanka Bozovic (VINCA)
Material: Slides

17:55 **LumiCal at CEPC** *20'*
Speaker: Dr. Suen Hou (SINICA)
Material: Slides



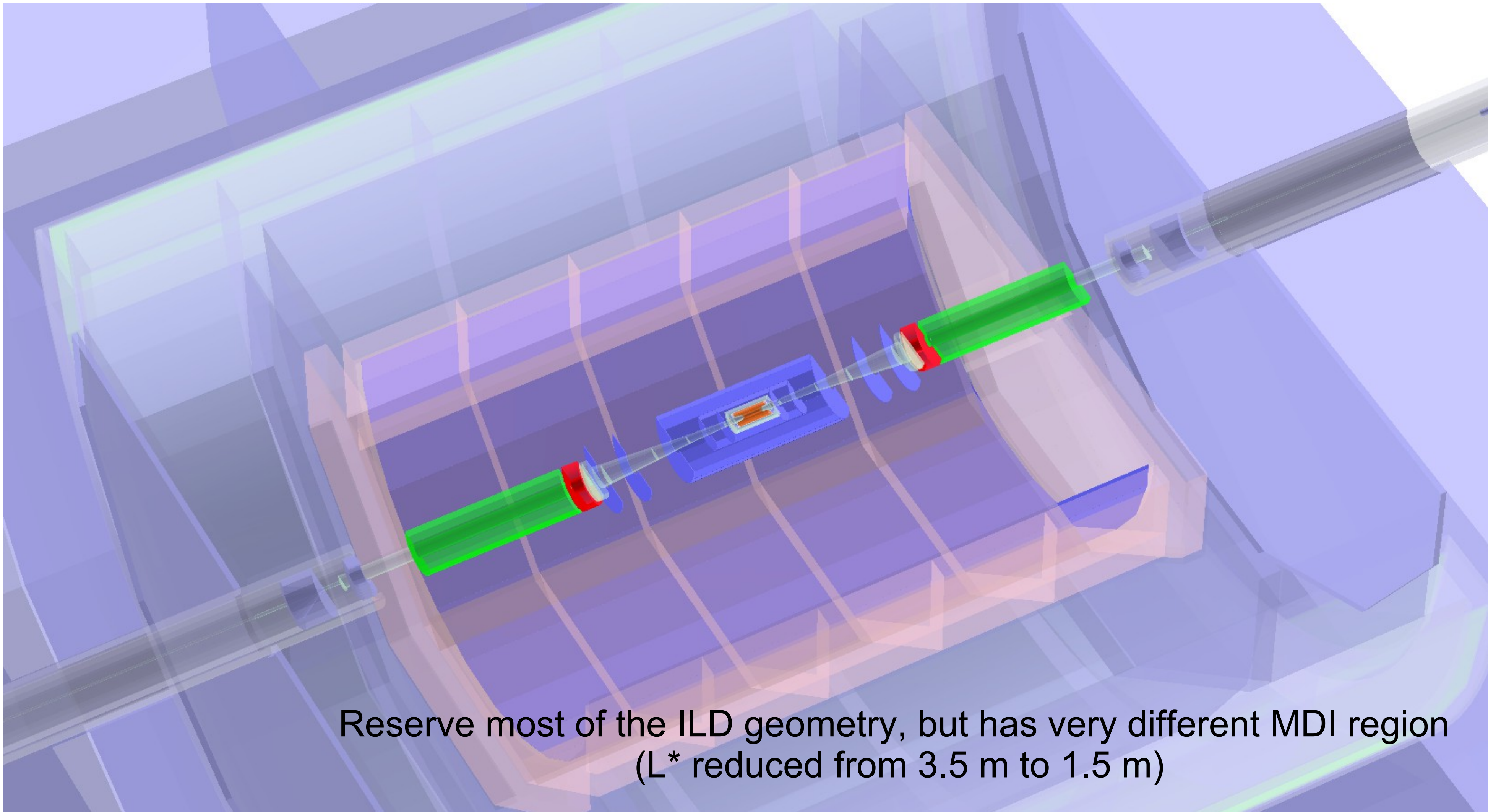
MDI: Challenges everywhere!

1. Luminosity of Bhabha counting is demanded to ***δL/L ~ 0.1%*** wtih Si Strip to reach $\boldsymbol{r_{inner}}$ to resolution ***<10 μm***

   A "floating LumiCal" has unknown systematics on $\boldsymbol{r_{inner}}$

   By adding electron tracking to calibrate "mean of $\boldsymbol{r_{inner}}$" to ***1 μm → to reach δL/L ~ 0.01%***

Conceptual Detector for PreCDR Study: CEPC_v1



近期目标 & 愿景

- 建立完整、专业的 CEPC 软件队伍，提供相关服务
  - Manual, Feedback, Webpage, Documentation
  - Validation & Release
  - Test sample & Full SM Samples
  - 对人力的需求极大（至少 2 名 FTE ）
- 继续进行子探测器性能研究和模拟
  - 目前的基线探测器中电磁量能器采用了 Si-W 方案，而国内的硬件研究集中在闪烁体方案中。后者的应用、性能评估、建模尚处于早期阶段。严格说来，对于后者的适用性和优化还有大量重要问题需要回答。
- 完善基线探测器下的物理模拟、分析：填补 EW 分析性能的空白
- 深入研究探测器的整合问题（ Integration ）
- 深入国际合作

Key performance: Separation

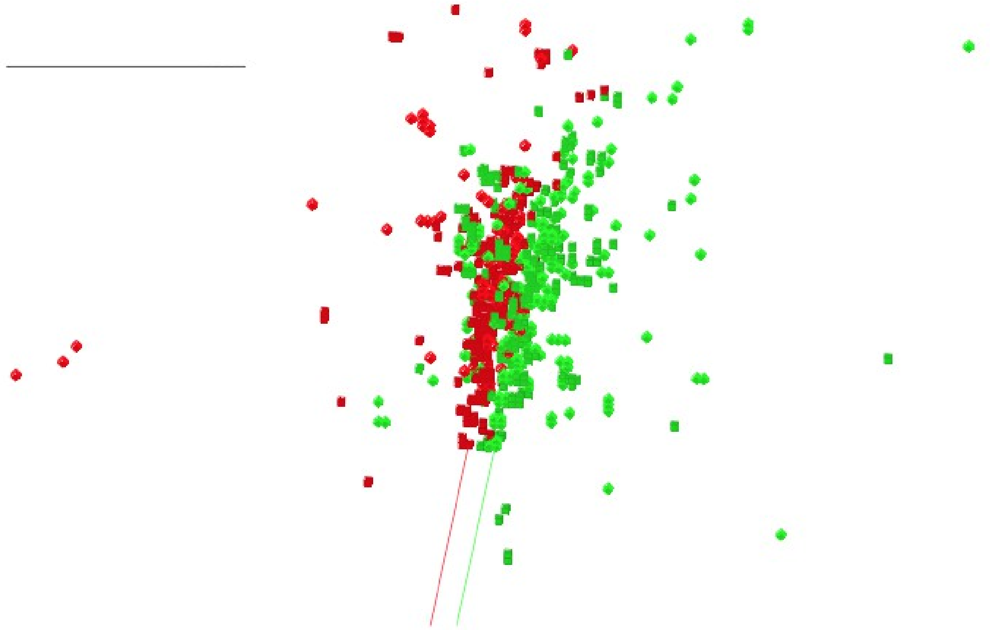
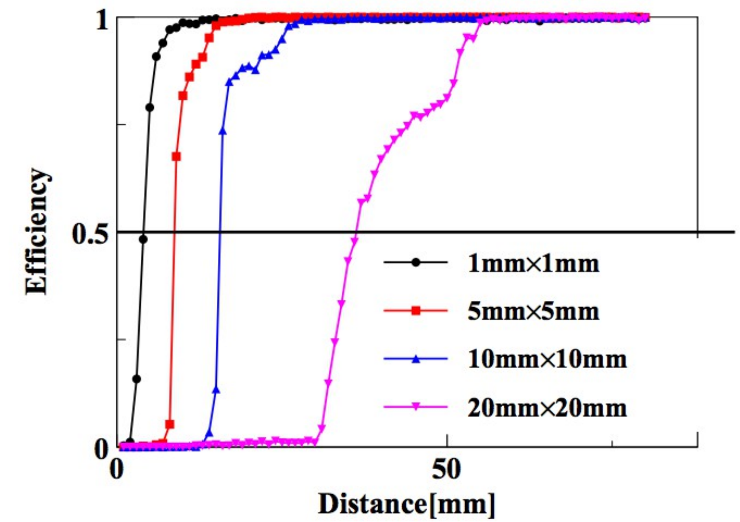
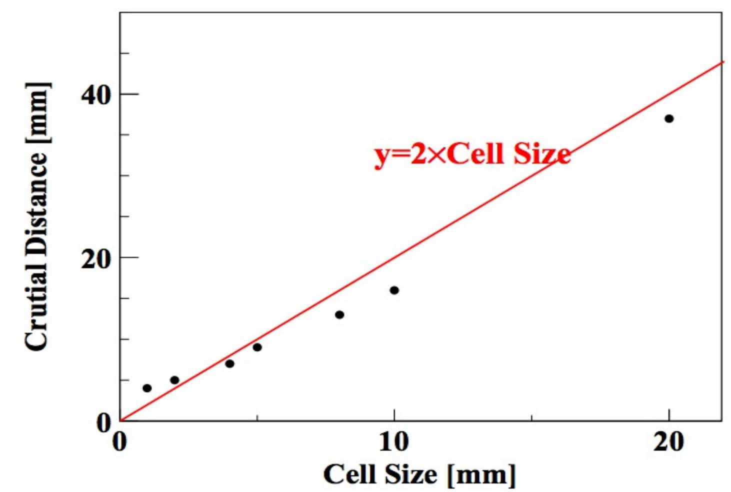


Figure 11. Event display of reconstructed di-photon.

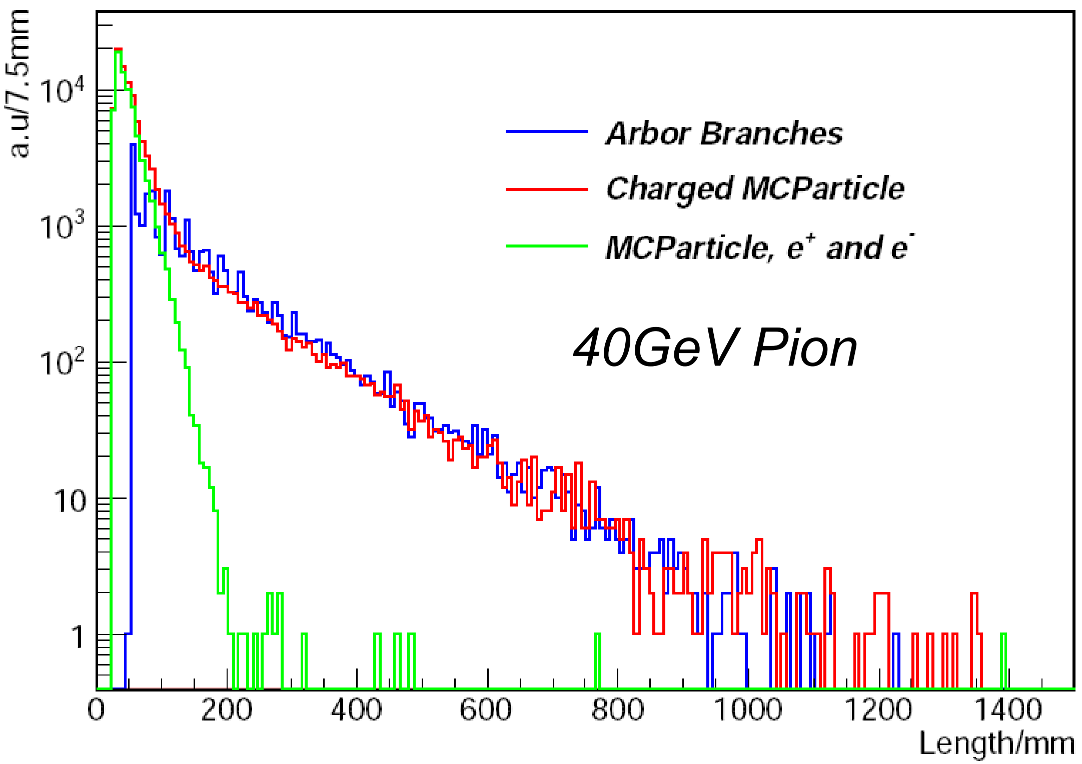


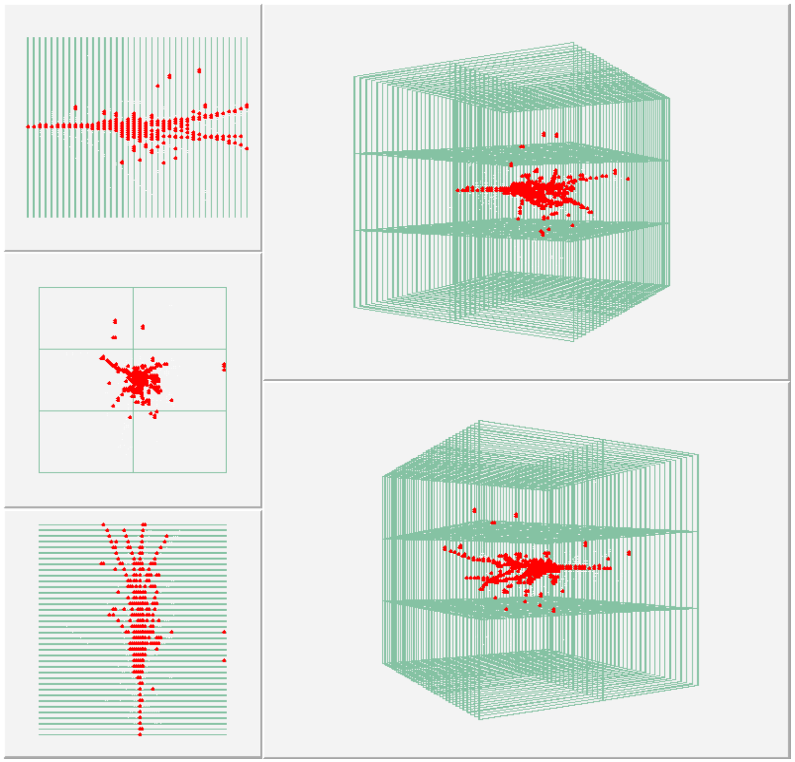


Separation power/Crucial Distance:

- ~ 2*Cell with Cell Size <= Moliere Radius;
- ~ 1 Cell with Cell Size > 1 Moliere Radius.

Validation: Arbor Branch Length





Arbor: successfully tag sub-shower structure

Samples: Particle gun event at ILD HCAL (readout granularity 1cm^2 & layer thickness 2.65cm)
Length:
Charged MCParticle: spatial distance between generation/end points
Arbor branch: sum of distance between neighbor hits