



科技部重点研发项目 课题三、探测器和物理研究汇报

Manqi RUAN

年度任务

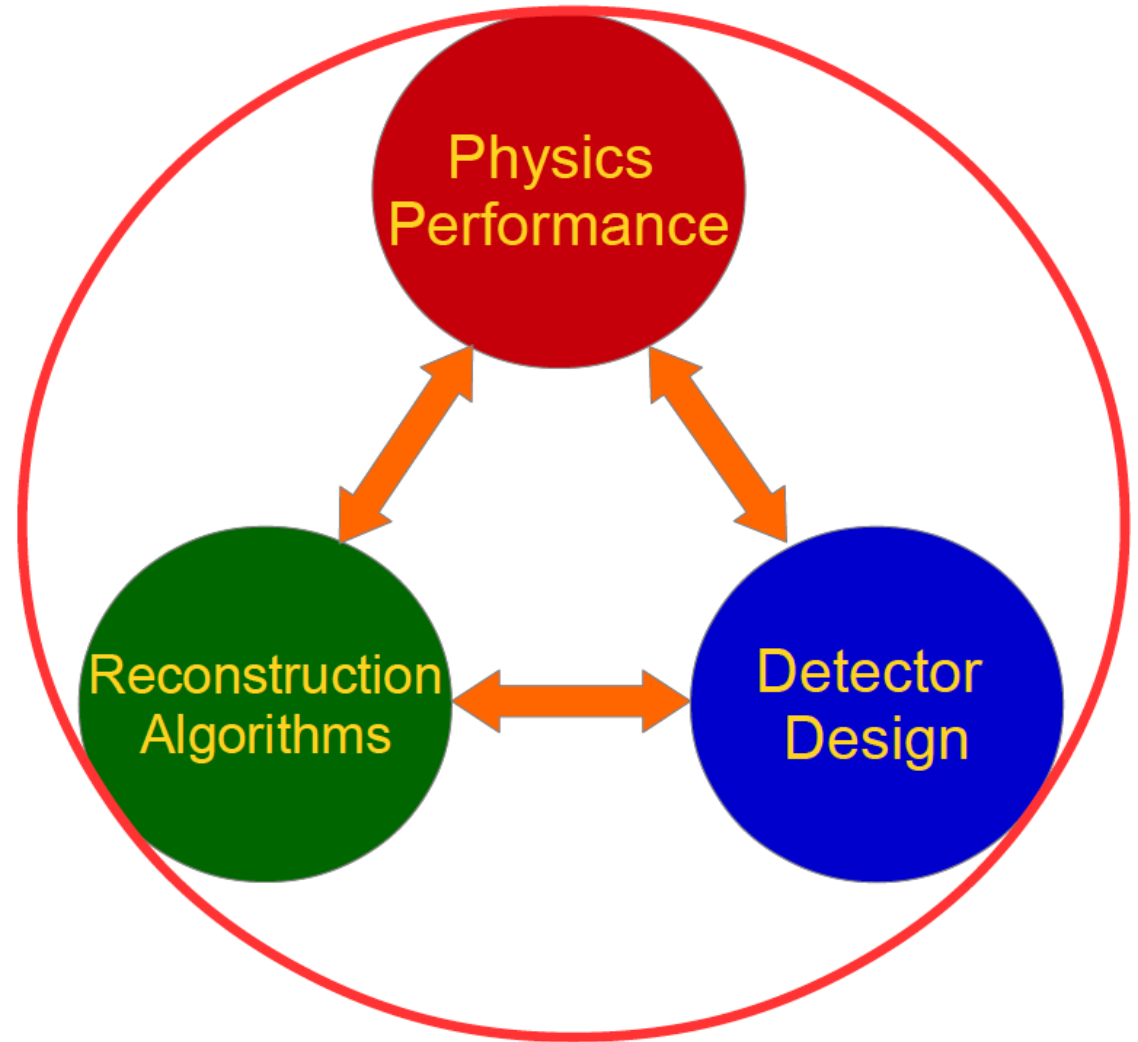
年度	任务	考核指标	成果形式	18年 7月 19年 6月	开始基准探测器几何下的软件开发和重建算法优化。深入理解子探测器系统的物理性能同其几何的依赖关系；确定基准探测器几何。	可用的基准探测器几何下重建算法；探测器物理性能和几何设计的依赖关系；探测器基准设计方案。	一系列探测器软件测试报告和2篇探测器设计文章。
16年 7月 17年 6月	进一步理解和整合现有软件工具。进行基于CEPC概念探测器的全模拟分析。设计开始设计新探测器几何，给出若干探测器设计方案。	2-3个初步的探测器设计几何，待优化。	2-3套探测器设计方案，模拟软件的设计手册和说明	19年 7月 20年 6月	经过若干迭代，完成探测器几何下重建算法的优化。开始基准探测器几何下的标志性物理测量分析。	优化的重建算法优化；部分预定的物理分析结果。	重建算法的测试报告和物理分析的内部报告。
17年 7月 18年 6月	开发CEPC的专用重建算法，进行重建算法在CEPC概念探测器上的优化；研究子探测器系统物理标的物的重建效率和精度同其几何的关系。深化测试性探测器几何的设计和验证；完成《CEPC概念设计报告》的探测器卷。	可用的重建软件；得到物理目标的重建效率和探测器几何的变化关系；完成《CEPC概念设计报告》。	重建软件的设计报告和说明文档；完成《CEPC概念设计报告》和国际评审。	20年 7月 21年 6月	发表文章，总结课题，完成评审和结题。	探测设计方案、优化的软件和物理分析成果	一系列国际会议报告和技术及5-6篇物理分析文章。

除 **2020-2021 年度任务、5-6 篇物理分析文章外**（目前有 **1 篇成稿、1 篇待投**），均已完成。

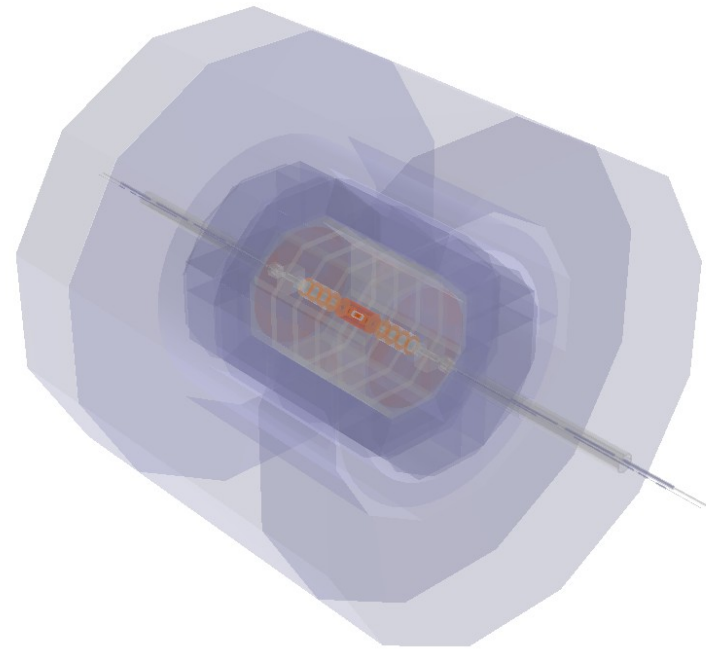
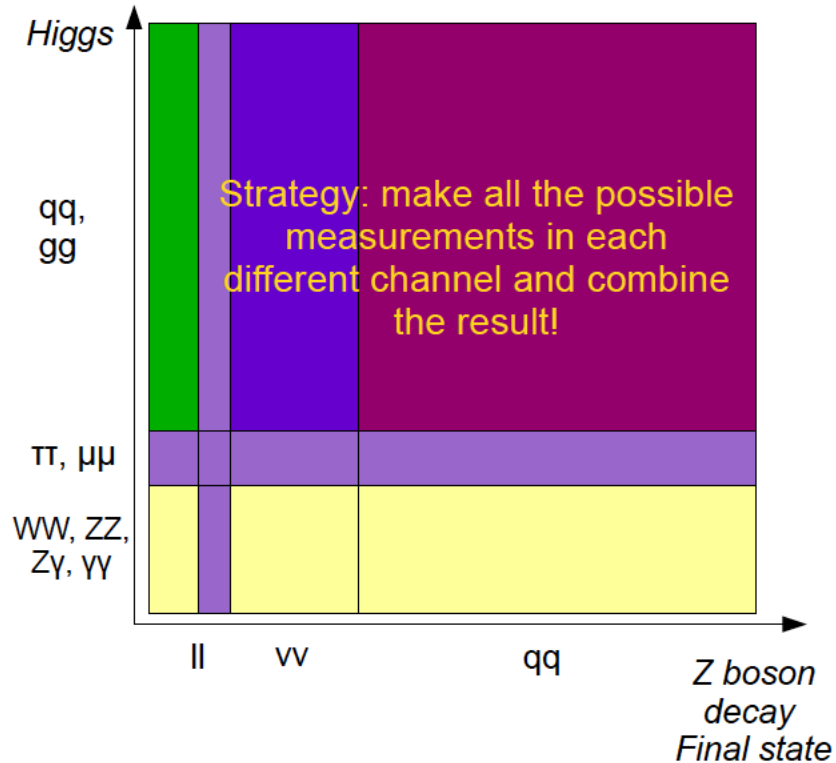
目标：概念设计完成

- 基线探测器几何；
- 基线重建软件工具；
- 全面系统的物理性能分析。

- 科技部课题侧重探测器优化设计及物理性能分析。和所创新课题共同支撑了上述工作。



CEPC 模拟的出发点： ILC 相关研究

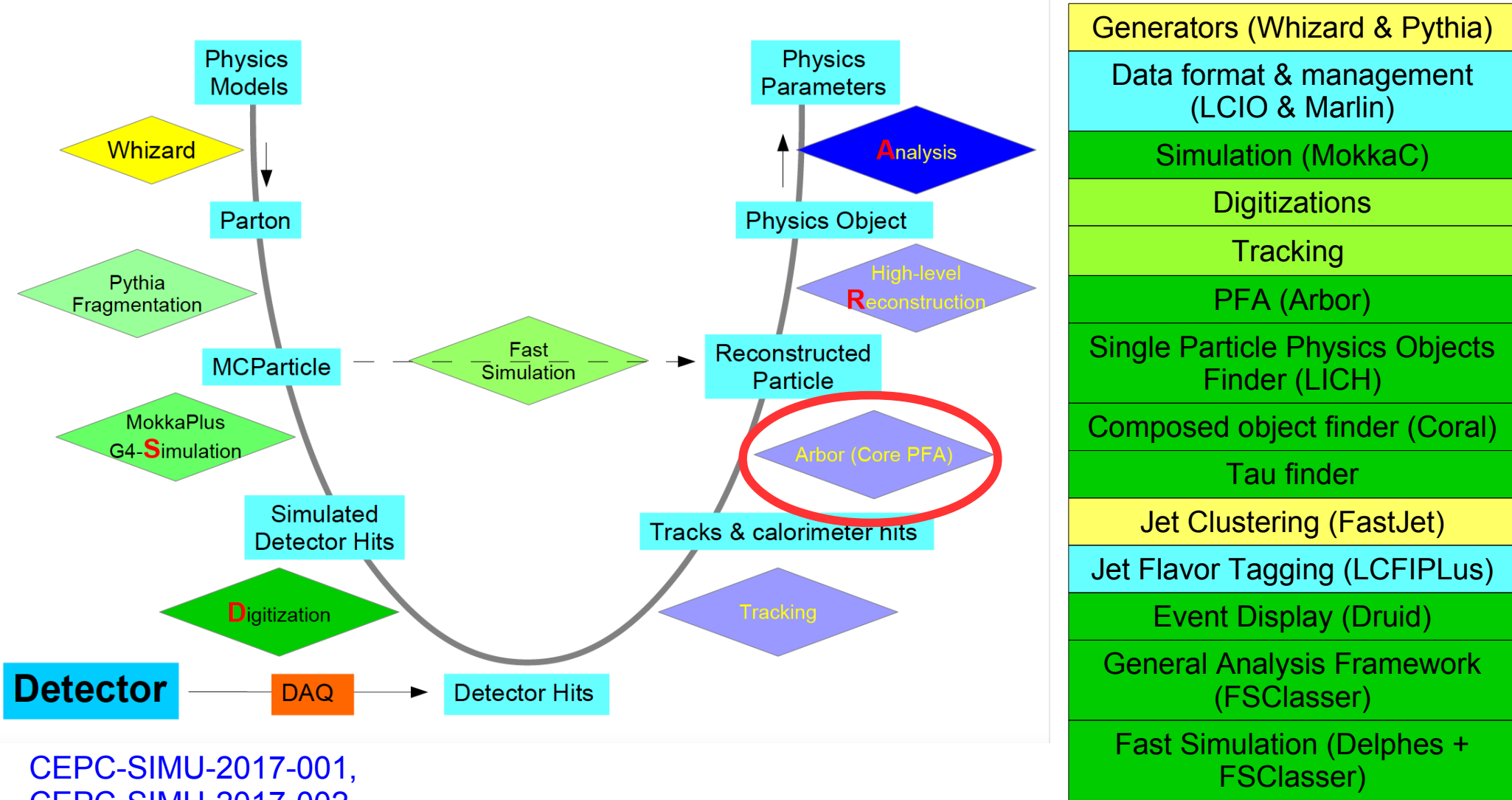


ILD 探测器拥有高精度的径迹系统及顶点重建。

作为粒子流导向的探测器，ILD 量能器系统的电子学道数在 1 亿量级，确保粒子簇射的有效分离，以及喷注能量的准确重建。

目标 1: 软件框架构建

CEPC Baseline Software



CEPC-SIMU-2017-001,
CEPC-SIMU-2017-002,
(DocDB id-167, 168, 173)

24/12/2018

General Software

ILCSoft

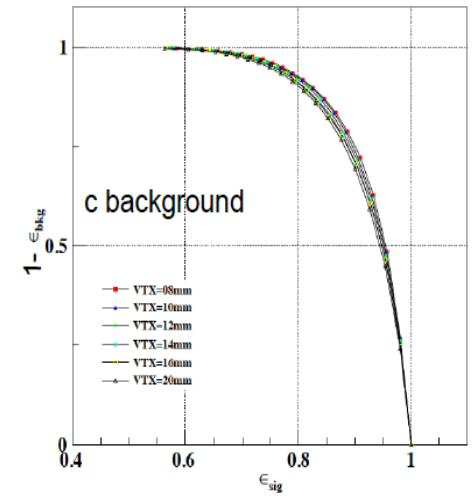
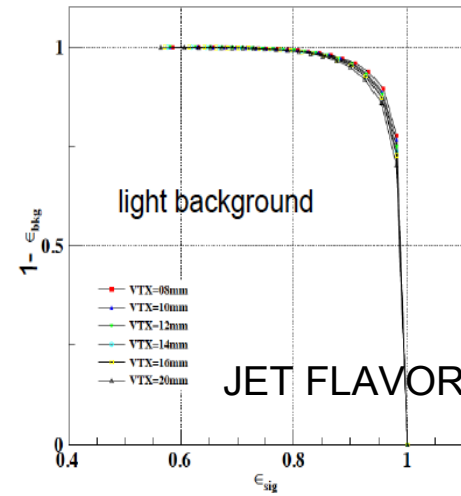
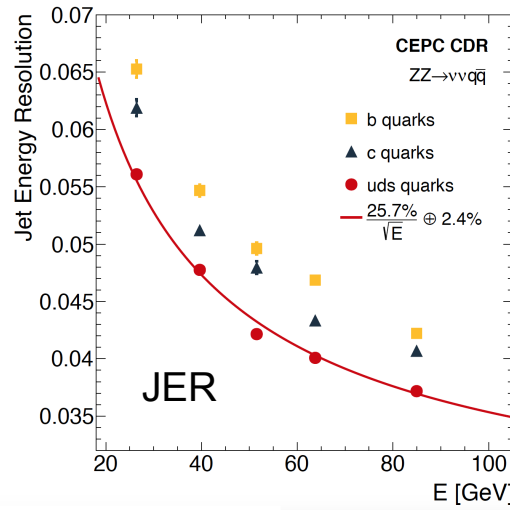
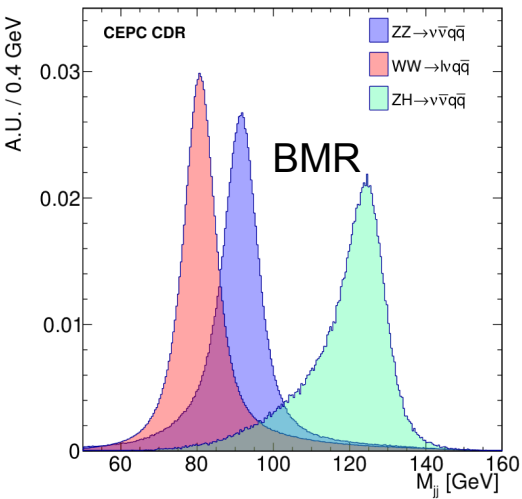
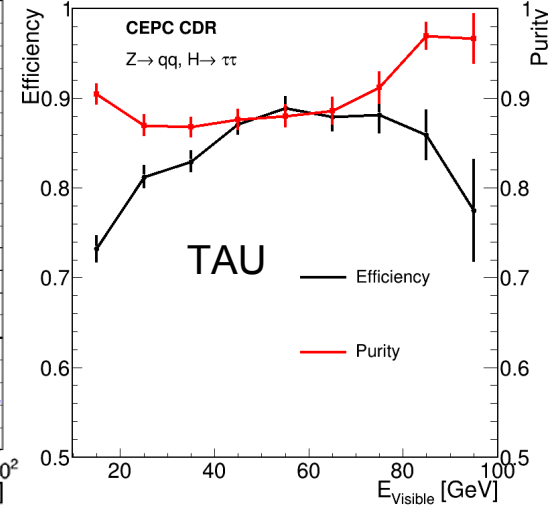
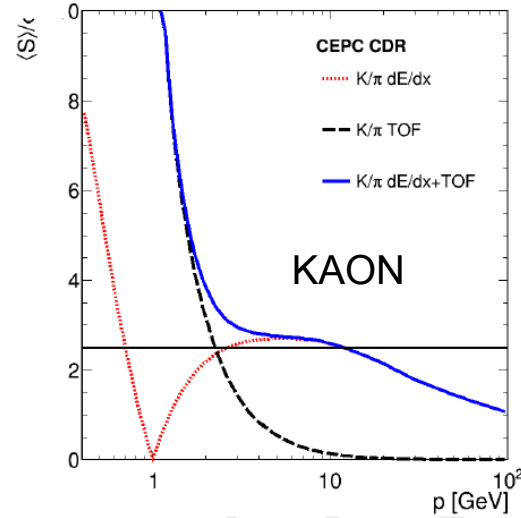
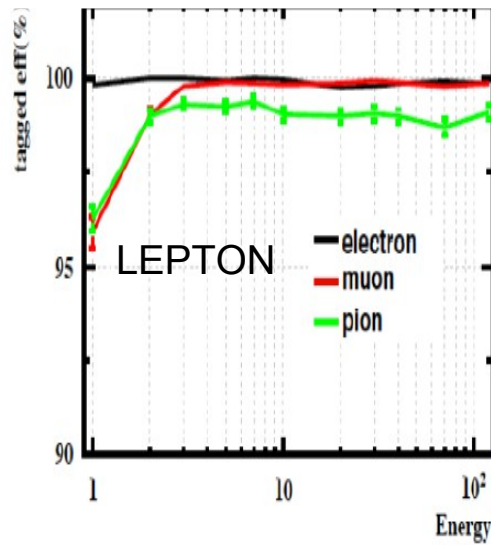
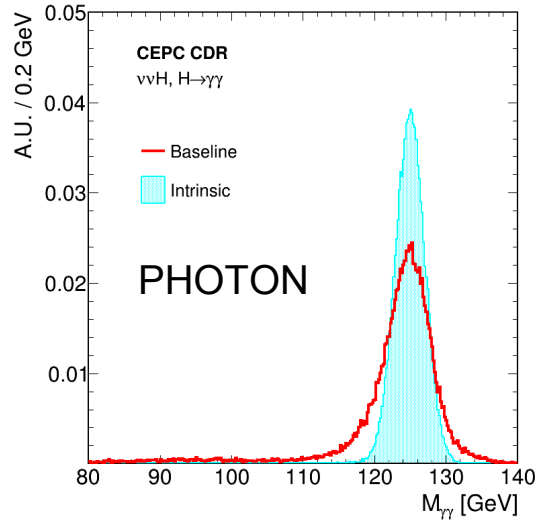
ILCSoft +
Development

Developments

核心物理性能分析

Eur. Phys. J. C (2017) 77: 591

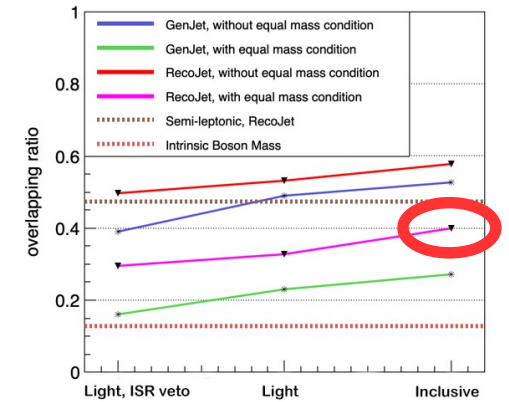
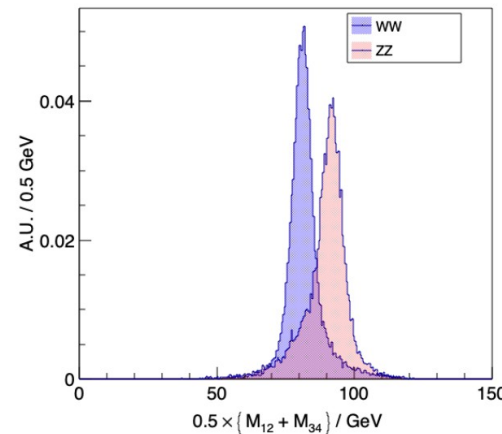
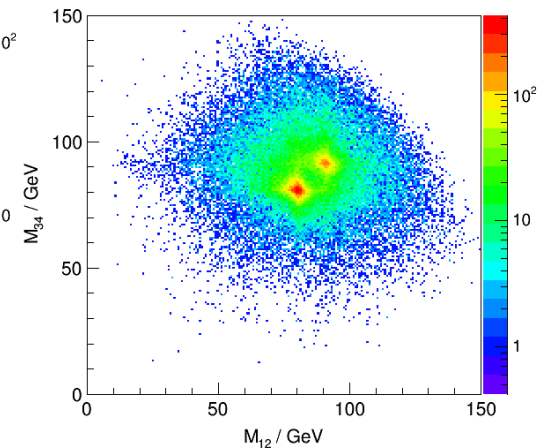
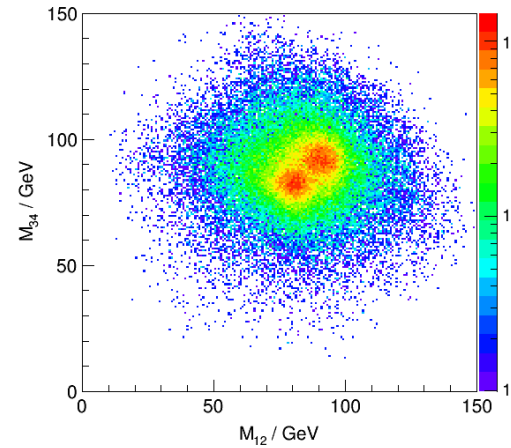
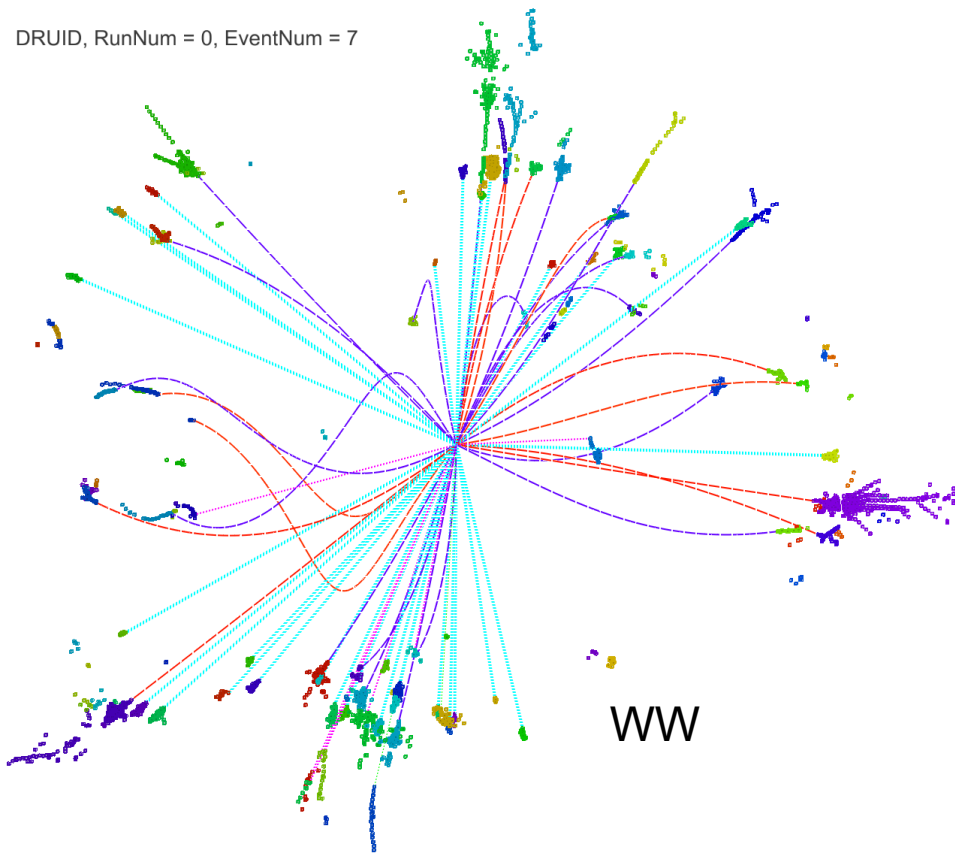
Eur. Phys. J. C (2018) 78:464



Eur. Phys. J. C (2018) 78: 426

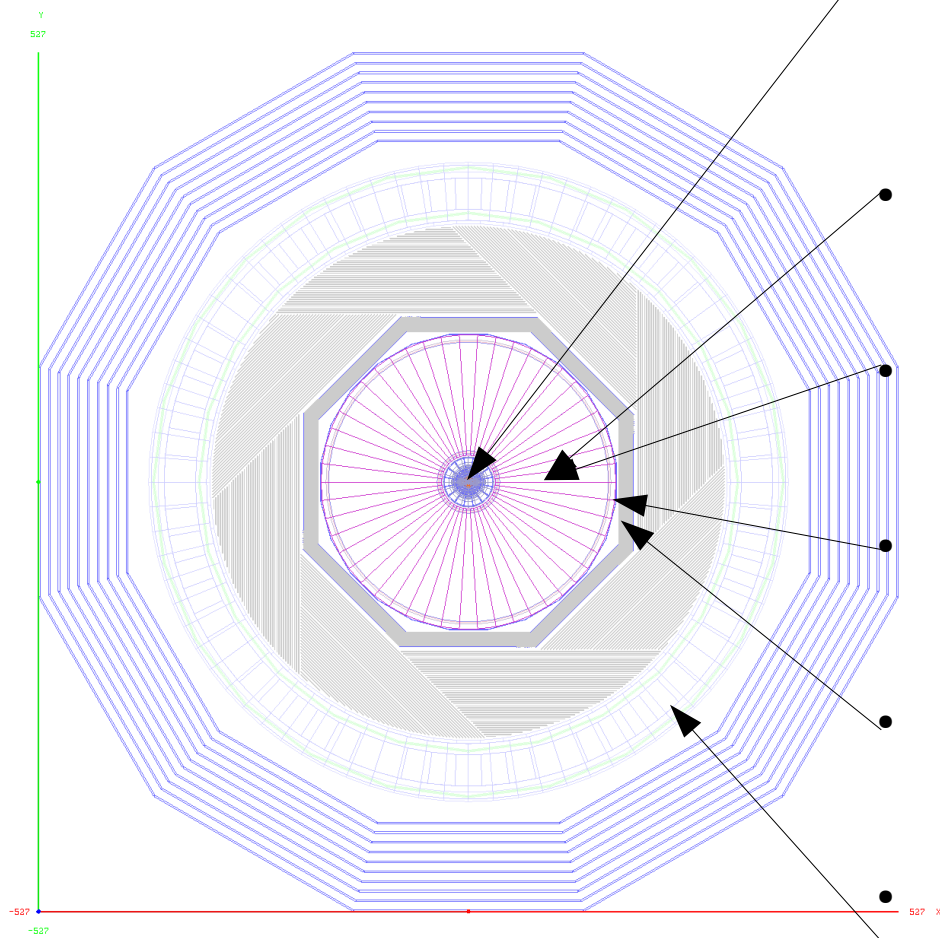
Separation of full hadronic WW-ZZ event

DRUID, RunNum = 0, EventNum = 7



A benchmark... not only for the detector & particle flow, but also for the Jet Clustering - pairing, or equivalently the color singlet reconstruction.

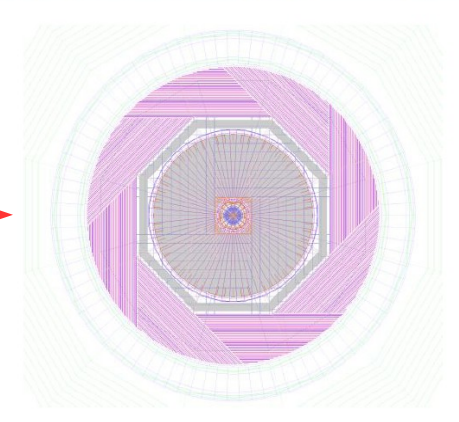
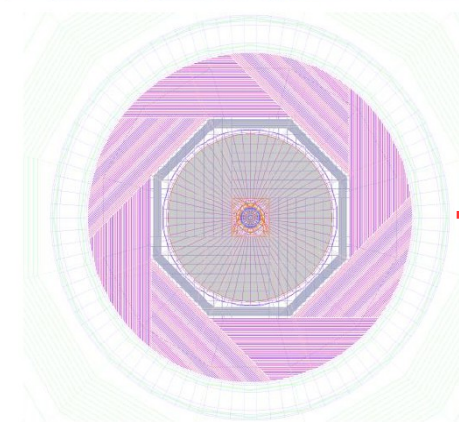
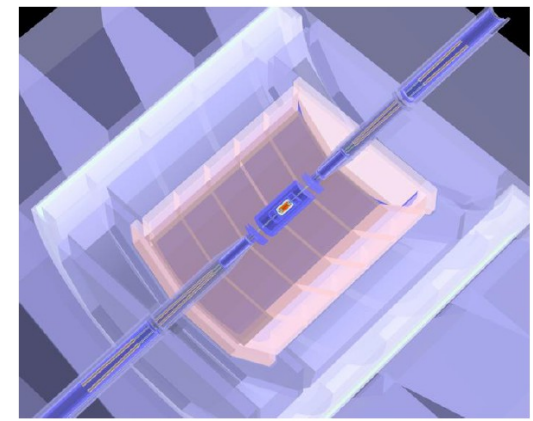
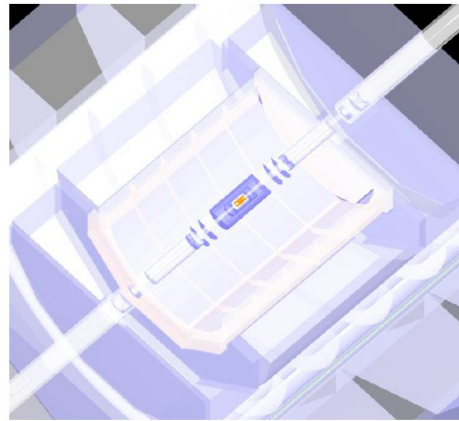
An PFA oriented detector for the CEPC



- Different collision environments/rates :
 - MDI design & simu: [CEPC-SIMU-2017-001](#)
 - [VTX Optimization: JINST-12-T09002 \(2018\)](#)
- The CEPC Event rate & charged kaon id
 - TPC Feasibility: [JINST-12-P07005 \(2017\)](#)
- Rich Flavor Program
 - Pid Potential: [Eur. Phys. J. C \(2018\) 78:464](#)
- Impact of SET:
 - CEPC Note in preparation
- No power pulsing at CEPC detector
 - Calo optimization: [JINST-13-P03010 \(2018\)](#)
- 3 Tesla Solenoid: required by the MDI
- Thiner Yoke: CEPC Note in preparation

CDR 基线探测器 **APODIS** (**CEPC-v4**)

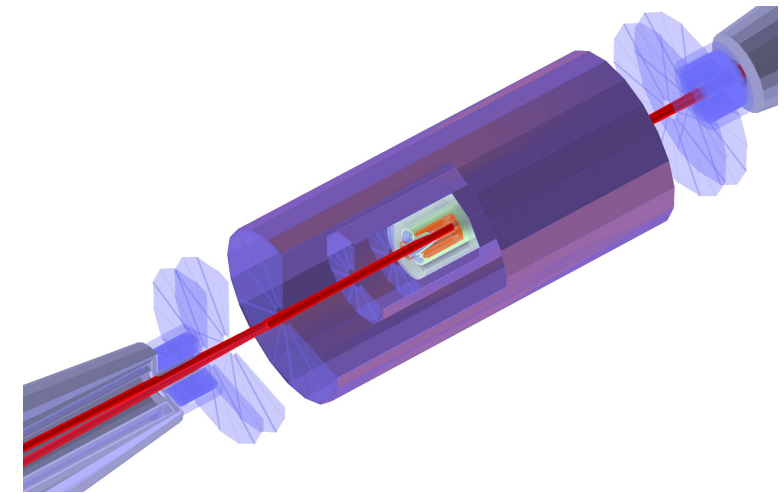
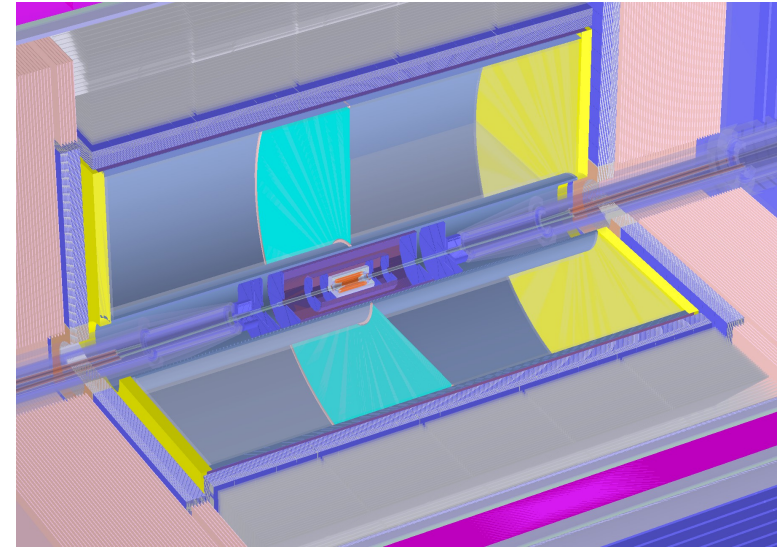
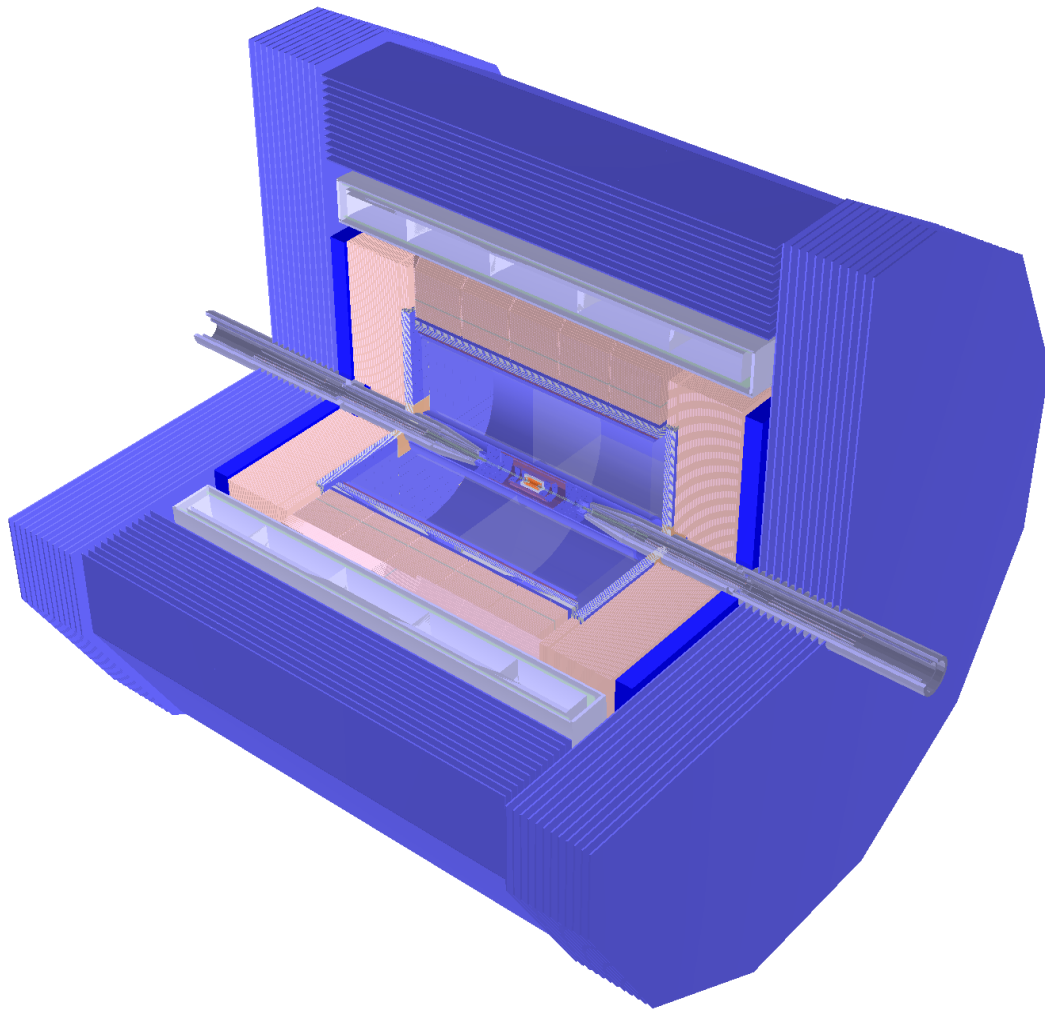
- 在概念上确认可适用于 CEPC 环境，通过标志性测量对各子探测器参数进行优化
- 相对 LHC 实验
 - 径迹精度提高一个量级
 - 喷注精度提高 3-4 倍 (Arbor)
 - 光子测量精度降低 30-50%
- 相对 ILD (CEPC-v1)
 - 在 Higgs 测量方面性能基本一致
 - 大大增强了 Kaon id 性能
- 功耗、造价、重量大幅下降
 - 电磁量能器功耗削减 75 - 80%
 - 轭铁重量下降削减 60 - 80%
 - 造价削减 30%



2015 PreCDR

2017 CDR

Baseline detector Geometry



论文发表、国际会议

- 2017.6 – 今：
 - 发表论文 7 + 1 篇
 - 完成 CEPC Note 约 10 篇
 - 完成博士学位论文 1 篇、硕士论文两篇
- 经过 2015-16 年的努力，核心软件工具完成。近期文章发表呈显著增长态势
 - CPC (submitted): Precision **Higgs Physics** at CEPC
 - CPC (accepted): The **Higgs signature** at the CEPC
 - JINST (2018.8): Study of **Vertex Optimization** at the CEPC CDR Baseline
 - EPJC (2018.5): Reconstruction of physics objects at the CEPC with **Arbor**
 - EPJC (2018.5): Performance study of **Pid** at CEPC using TPC dEdx and ToF
 - JINST (2018.3): PFA Oriented **ECAL Optimization** for the CEPC
 - EPJC (2017.8): **Lepton identification** of a PFA oriented detector for the future e+e- factory
 - JINST (2017.7): **Feasibility study of TPC** at electron positron collider at Z pole operation
- 多次参加国际会议，进行报告。

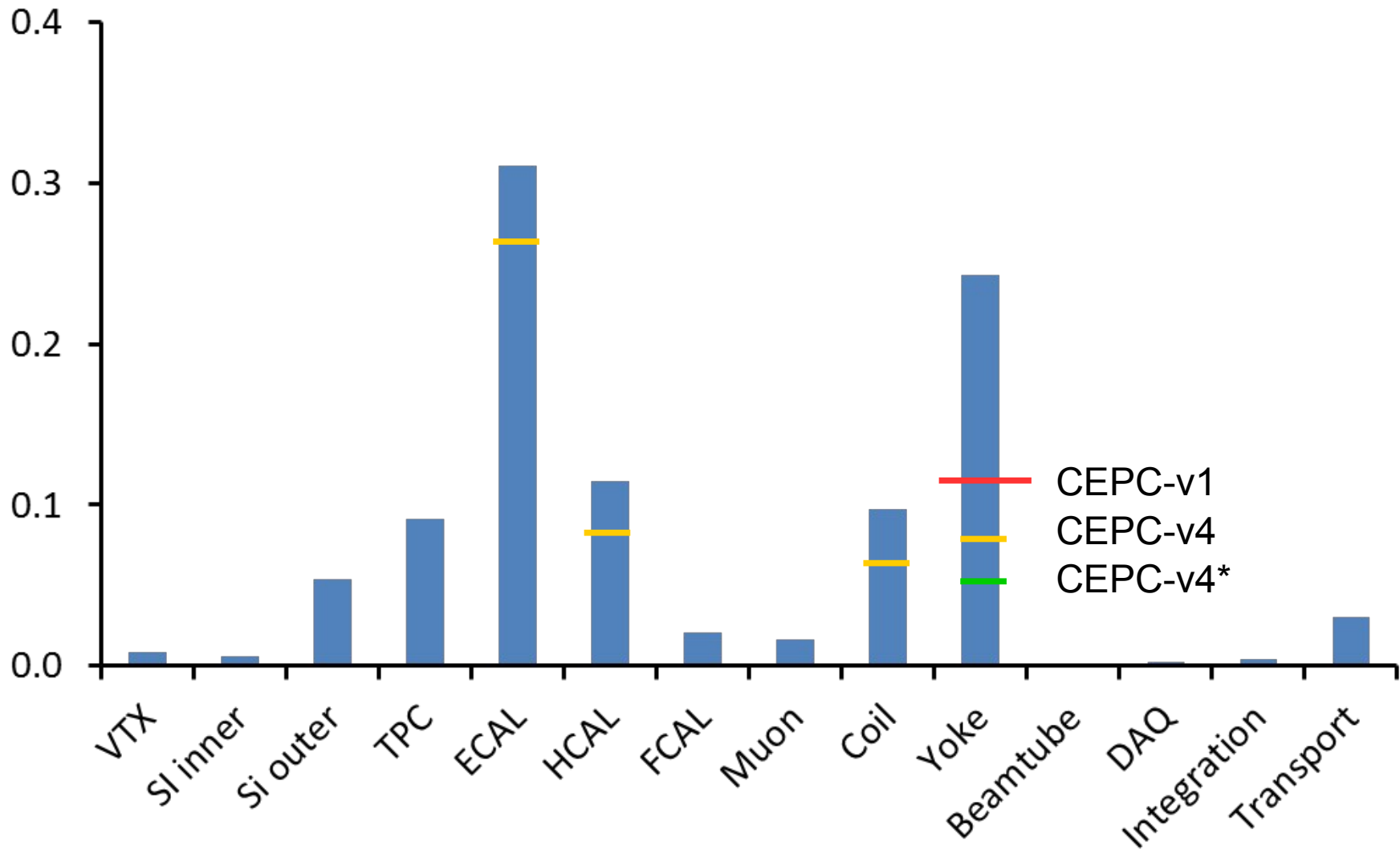
结论及展望

- 粒子流导向的基线探测器 - 重建算法在物理标的物重建上表现出优良的性能，能够满足、并充分发挥 **CEPC** 的物理潜力。其中，自主开发的 **Arbor** 算法起到了核心作用。
- 基线探测器的子探测器选型值得重点研究。在下一步研究中，需要：
 - 加强同子探测设计的交流、互动；确保相关 **TDR** 研究进展；
 - 进行进一步优化设计工作；
 - 加强国际合作；
 - 进行整合研究。
- 基线探测器 - 重建
 - 为物理潜力分析提供了可信的参考；
 - 为子探测器设计提供了性能、性价比上的参考；
 - 为整合等研究提供了可信的出发点。

Backup

ILD 原始造价: 400 MILCU = 4 亿美元 = 28 亿 CNY

按 CEPC-v4 几何, Scaling 至 22 亿 CNY; 进一步的优化应该可以控制到约 20 亿 CNY



进一步的优化需解决的问题

- 物理方面
 - Benchmark for PiD & Low Energy Photon
 - White papers
- 重建：
 - VTX 及 Flavor Tagging
 - Color Singlet Identification
 - PFA towards extreme (varying granularity)
- 探测器
 - TPC Distortion Correction
 - HCAL Optimization
 - Radius Scan
 - 机械， MDI 整合

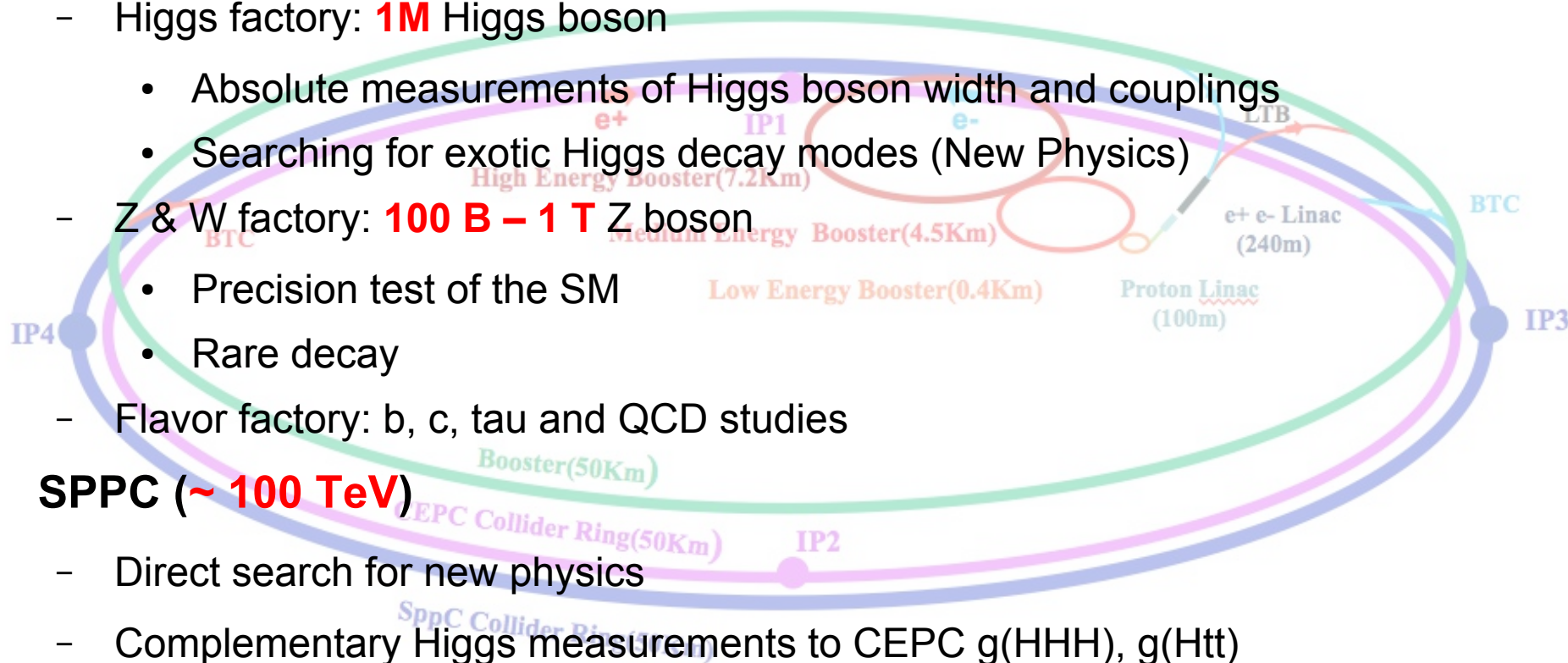
CEPC 探测器优化主要结论

Feasibility analysis: TPC is valid for CEPC

	CEPC_v1 (~ ILD)	APODIS (Optimized)	Comments
Track Radius	1.8 m	≥ 1.8 m	Requested by Br(H \rightarrow 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 \rightarrow di photon) at 250 GeV; 90mm for bhabha event at 350 GeV
ECAL Cell Size	5 mm	10 mm	Passive cooling request ~ 20 mm. 10 mm should be highly appreciated for EW measurements – need further evaluation
ECAL NLayer	30	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.

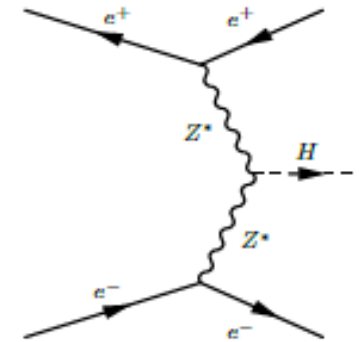
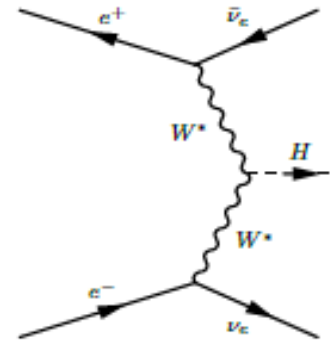
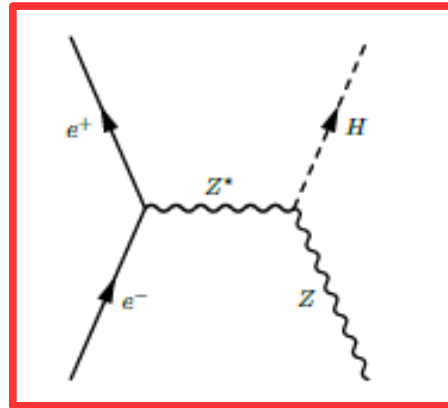
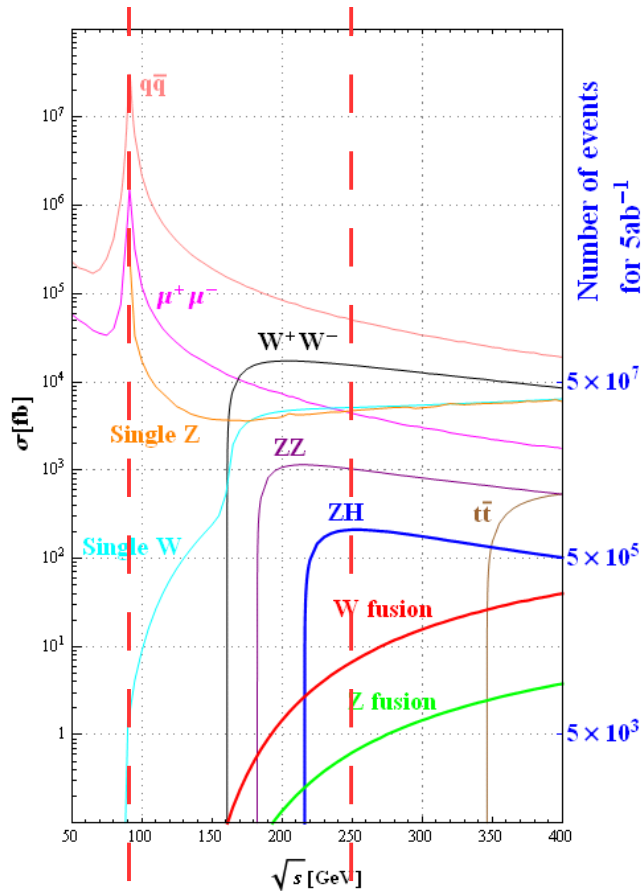
Science at CEPC-SPPC

- 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: **100 B – 1 T** 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 $g(\text{HHH})$, $g(\text{Htt})$
 - ...
- **Heavy ion, e-p collision...**



Complementary

CEPC: 1M Higgs & 100B -1T Z



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

Observables: EW Precision, tau physics, Flavor Physics...

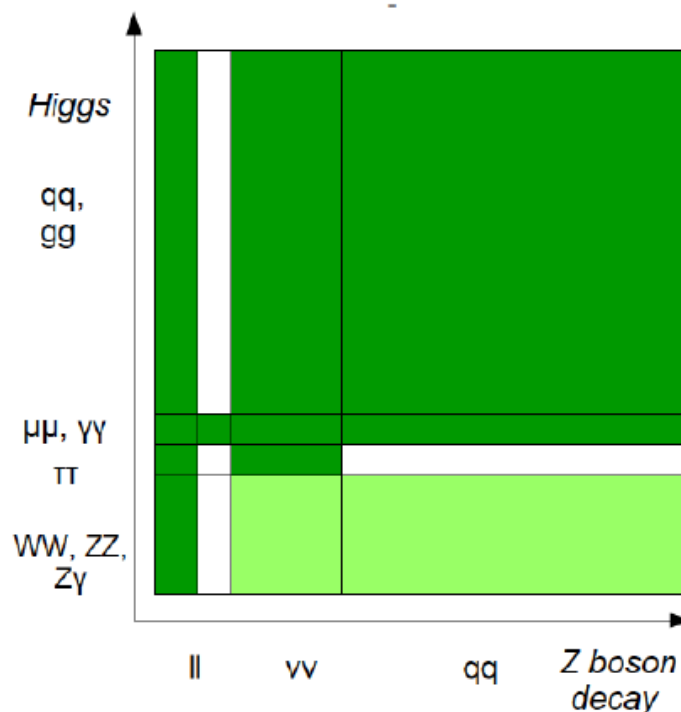
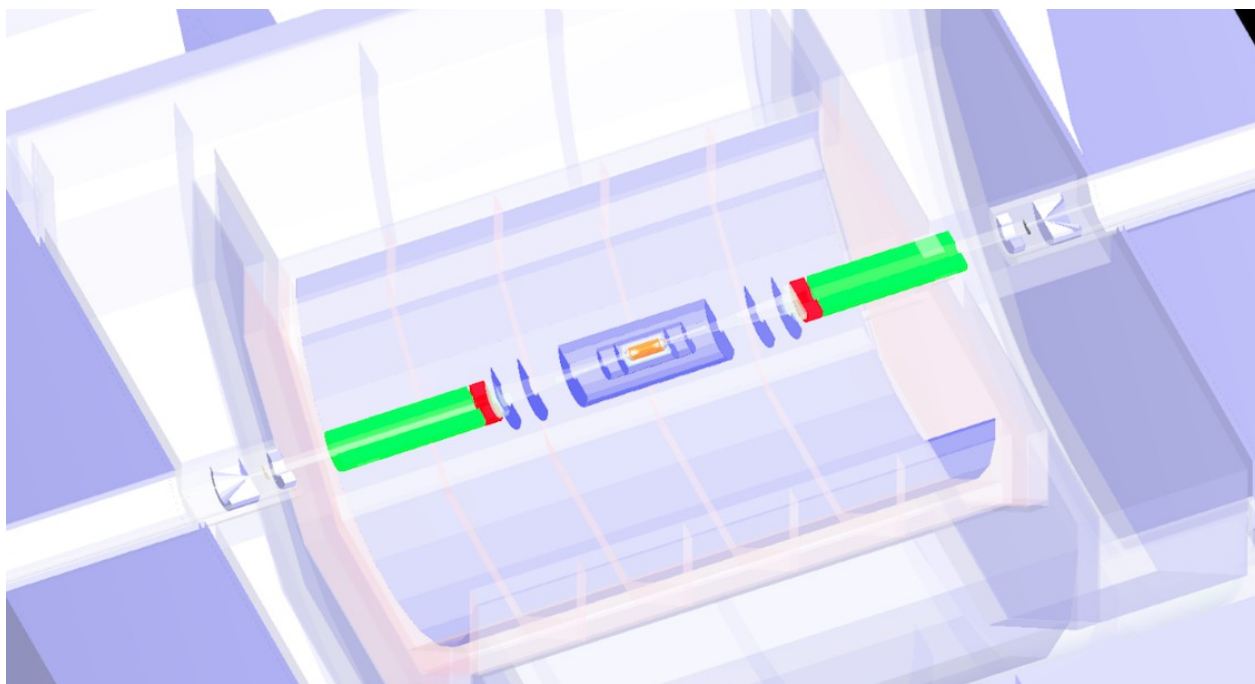
Higgs mass, CP, $\sigma(ZH)$, event rates ($\sigma(ZH, \nu\nu H) \cdot \text{Br}(H \rightarrow X)$), Diff. distributions

探测器几何

- 粒子流导向探测器类型
 - CEPC_v1 (PreCDR 基线探测器)
 - CEPC_o_v2 (“小”探测器：径迹系统缩小)
 - Simplified Geometry (用来进行几何死区、几何缺陷影响的比较研究)
 - CEPC_v4 (CEPC CDR 基线探测器)
 - CEPCSIDv6 (全硅探测器系统)

- 双读出系统探测器

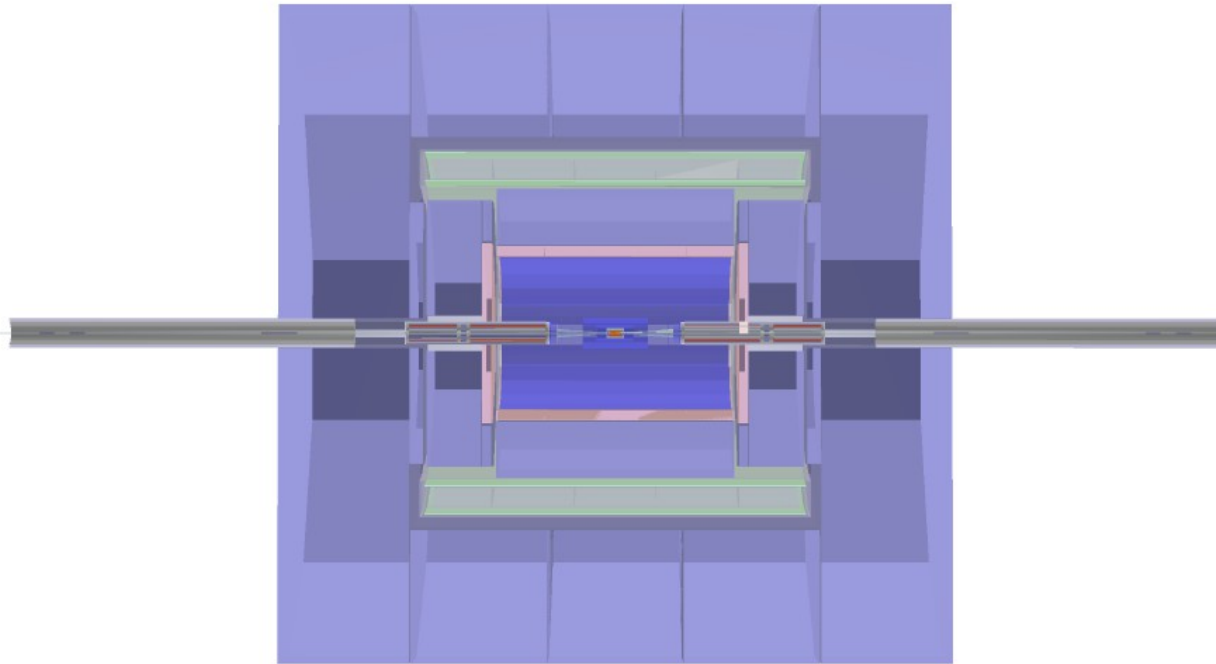
CEPC-v1, CEPC PreCDR 参考探测器



将 ILD 几何应用于 CEPC 环境中得出的“最小更改版本”（更改了 MDI 及 Yoke），支持了大量的 CEPC 物理研究

主要结论将被总结在 CEPC Higgs White Paper

CEPC_o_v2



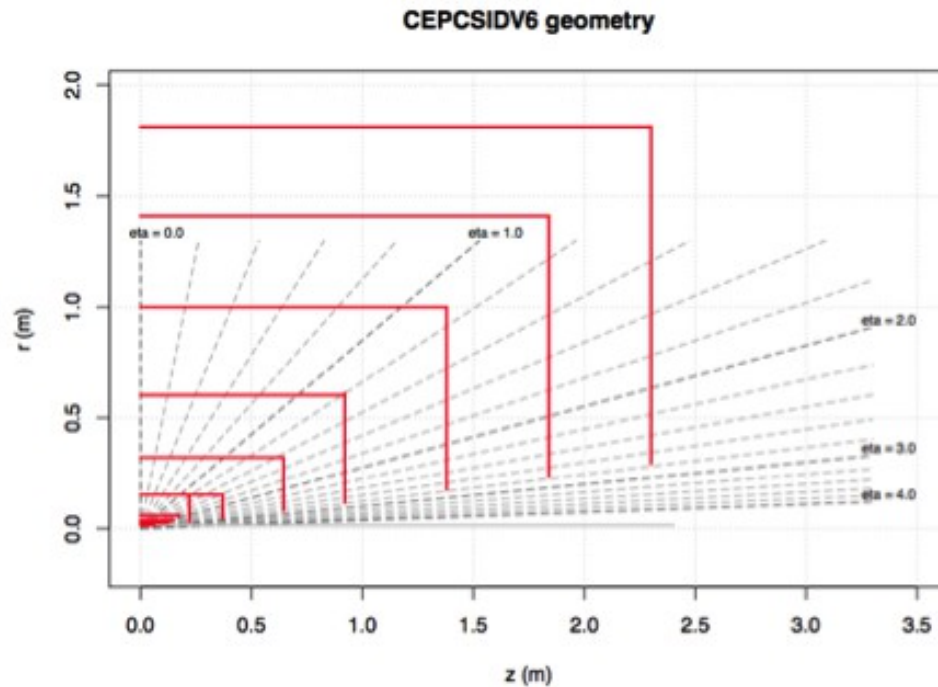
Parameter	CEPC_o_v2	CEPC_v1
LStar_zbegin	1150	1146.9
VXD_inner_radius	12	15
VXD_radius_r1	12	15
VXD_radius_r3	35	37
TPC_outer_radius	1500	1808
Hcal_nlayers	40	48
Ecal_cells_size	10	4.9
Field_nominal_value	3	3.5
Yoke Layers	2	3

在 CEPC-v1 基础上，主要参数削减 20% 得到的版本。

用来调试及测试 CEPC 重建软件在几何更改下的性能，其性能同预期基本相符。

自此，CEPC 软件可支持粒子流导向的探测器几何的优化和更改。

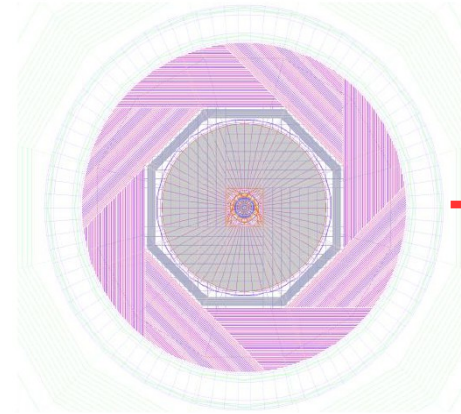
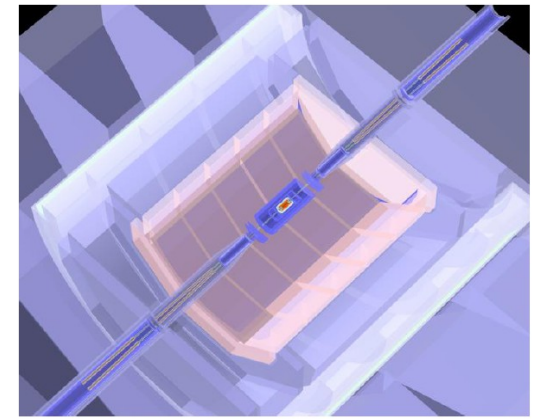
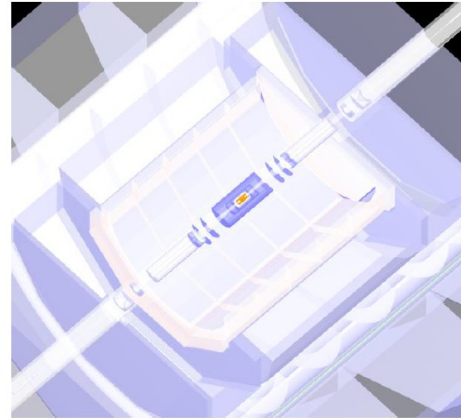
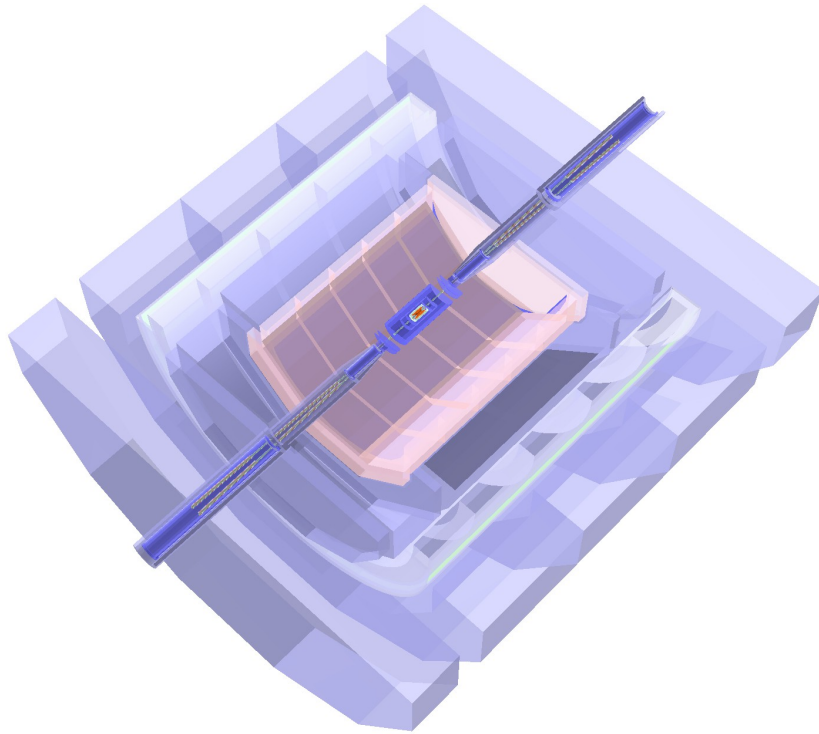
全硅径迹探测器系统



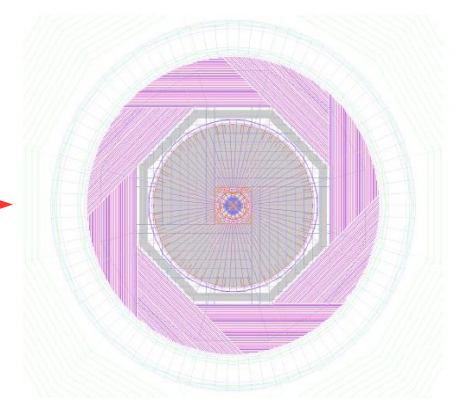
为全硅径迹系统应用于 CEPC 进行了模拟工具准备。

得到了初步物理性能分析结果，其性能（径迹重建效率、精度）同预期基本一致。

CEPC-v4, CDR 基线探测器



2015 PreCDR



2017 CDR

经过一系列可行性分析及探测器参数优化研究，得出 CDR 基线探测器。
初步解决了粒子流探测器应用于 CEPC 环境的适用性问题，以及几何优化问题。
是 CDR 上物理分析、物理潜力讨论的基础。

IDEA Simulation & Validation



CEPC NOTE

CEPC_TLS_SIM_2018_001

March 27, 2018



Figure 4: SVX

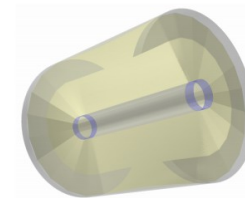


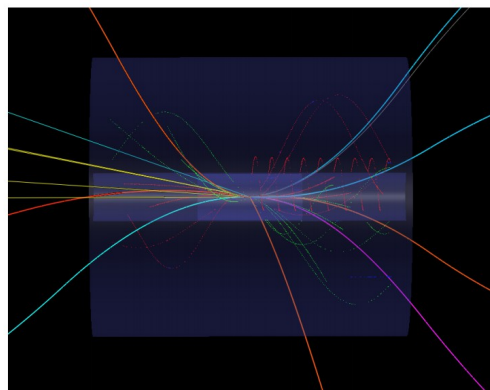
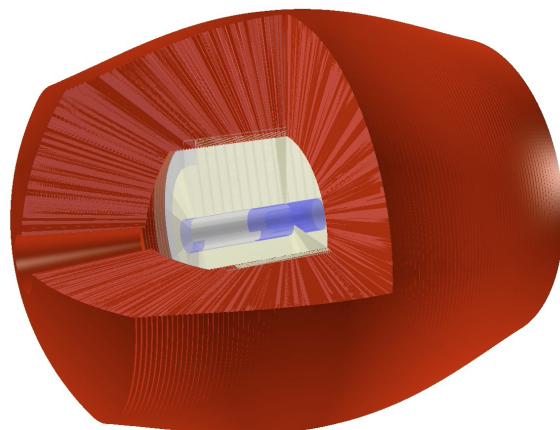
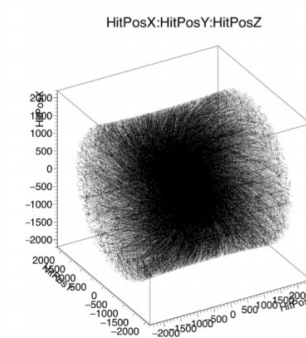
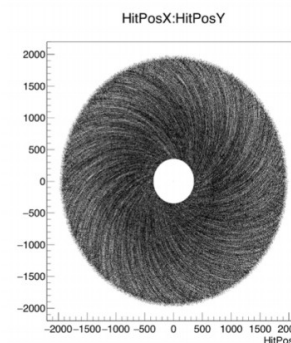
Figure 5: CDCH

Detector Geometry in Model CEPC-IDEA

Yin Xu

Abstract

Geant4 Based full simulation is indispensable for the CEPC physics analyses and detector optimization studies. So we integrated IDEA detector geometry into the simulation framework – Mokka [1]. This note introduces the IDEA model and how to develop with Mokka, some simple examples are also given.



IDEA Concept 是 CEPC 探测器的
备选设计方案
(Alternative Concept)

本工作为其模拟提供了相应工具。

软件：ILCSoft 应用于 CEPC 的主要挑战及应对

- 探测器几何支撑不足
 - 无法支持探测器几何的自由更改
 - 解决方案：Mokka - MokkaPlus 升级（成栋、徐音）
 - 支持任意几何更改，目前支持粒子流导向探测器，全硅径迹系统、IDEA 探测器几何、简化量能器几何等等
- 重建软件极为复杂，在新几何下调试困难
 - 粒子流重建需全面诠释探测器信号、极端依赖精准的模式识别
 - 原始 ILC 软件过于复杂，自由调试的工作量极大
 - 解决方案：
 - 完成 Arbor 重建算法的开发及优化。该算法从簇射树状结构出发，拥有高精度的模式识别以及簇射分离性能。继而为所有物理标的物的重建提供了坚实基础。
 - 发表于 Eur. Phys. J. C (2018) 78:426

软件：ILCSoft 应用于 CEPC 的主要挑战及应对

- 软件性能不足
 - Lepton identification 性能显著低于预期（ $\text{eff} < 95\%$, $\text{purity} \sim 90\%$ ），对探测器性能及对撞机物理潜力评估出现显著偏差
 - 解决方案：开发 LICH 算法系统解决 Lepton ID 问题。其性能趋近物理极限，高能孤立轻子甄别效率 $\sim 99.9\%$ ，较之 LEP 实验，强子 \rightarrow 轻子误判率压低 3 倍。
 - 发表于 Eur. Phys. J. C (2017) 77:591，被 ILCSoft 吸收为官方软件
 - Composite Object Finder 缺失：
 - 无法进行 Converted Photon, Bremsstrahlung photon, Kshort, Pi0, Lambda 的重建
 - 开发 Coral 算法（调试中），Converted Photon 重建效率达 80%。
 - Tau Finder 算法缺失：
 - 依据 $H \rightarrow \tau\tau$ 物理分析开发相关算法。完成于于丹的博士论文
- 缺乏全面、细致的物理性能分析。探测器性能同探测器几何的依赖不明，性能的具体瓶颈不明

软件：ILCSoft 应用于 CEPC 的主要挑战及应对

- 整体解决方案：以 Arbor 为基石，完成从 A-Z 的 CEPC 软件工具开发。
 - 原创性地开发了 Arbor 算法
 - 开发、补足了 ILCSoft 中缺失的功能模块，其中 Lepton identification, Display 等模块被 ILCSoft 吸收。
 - 进行了全面、细致的探测器性能分析，为 CEPC 优化提供了坚实基础
 - 以 CEPC-v4 为例，系统分析了物理标的物级别、Higgs 粒子信号级别，以及标志性物理学道级别的探测器性能
 - 总结于 CEPC CDR 及 CEPC Notes (CEPC DocDB-doc-174, 175)
 - 确保 CEPC 上的探测器性能的精准描述，有力支持 CEPC 物理分析工作。
 - 为方便相关研究，初步建立了 CEPC 软件文档及网页服务。

模拟 / 重建软件的设计手册和说明



CEPC NOTE

CEPC-SIMU-2017-001

October 20, 2017



CEPC NOTE

CEPC-SIMU-2017-002

October 27, 2017



Full Simulation Software at CEPC

CEPC Software Group

Manual of the CEPC software

CEPC Simulation Group

Abstract

The detector optimisation and physical analysis are being performed through full detector simulation at CEPC. As quick starting, a ILD-used simulation framework is selected. According the progress of CEPC, this simulation tool is also developed as a new version. This note will introduce the framework and its usage. And the development will also be described.

Abstract

This note is the manual of the CEPC software. It mainly covers the simulation tools of CEPC R&D study, as well as all the reconstruction and analysis algorithms.

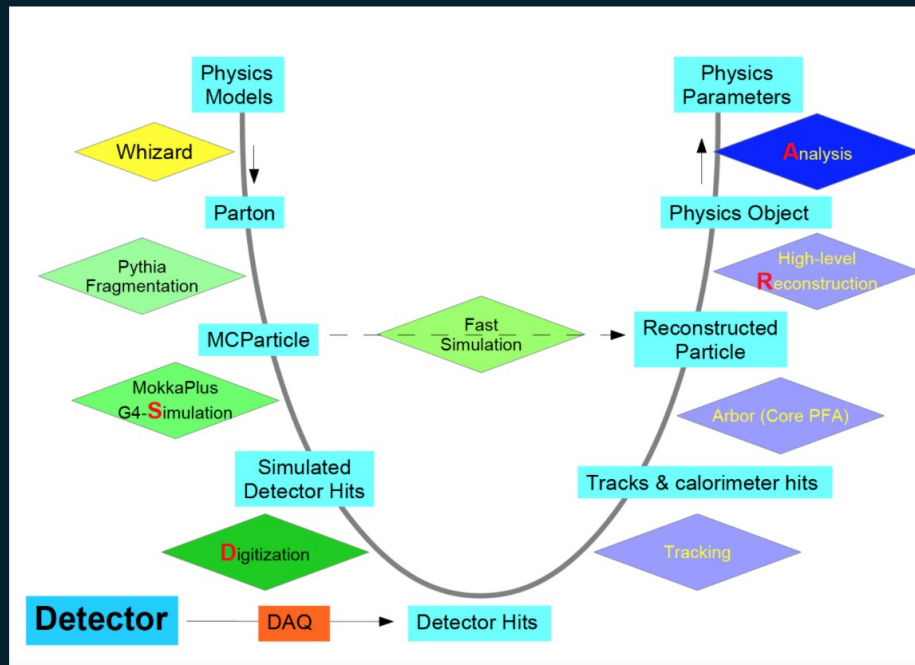
完成 CEPC 软件工具构建
完成设计手册及使用说明
初步构建了 CEPC 软件网站及软件服务

Quick Start

The HEP software consists of SDRAM (Simulation, Digitization, Reconstruction, Analysis) Chain and the DAQ software. The Software Chain is mainly focus on the SDRAM.

Try the full installation, generation, simulation, reconstruction and analysis process following the documentation.

Get Started



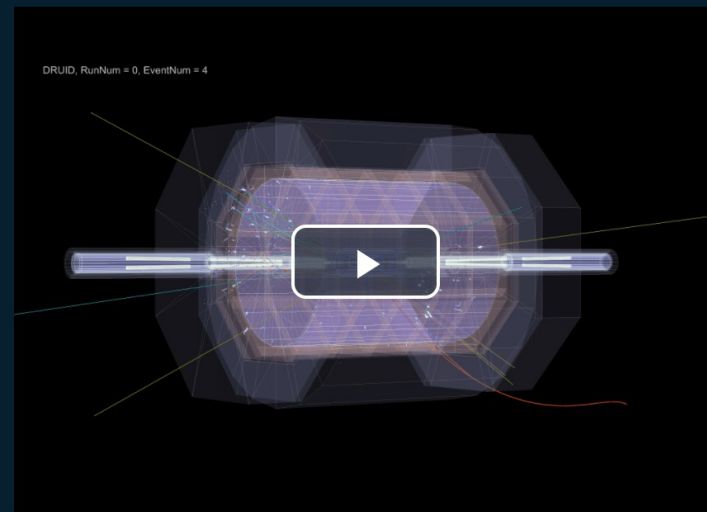
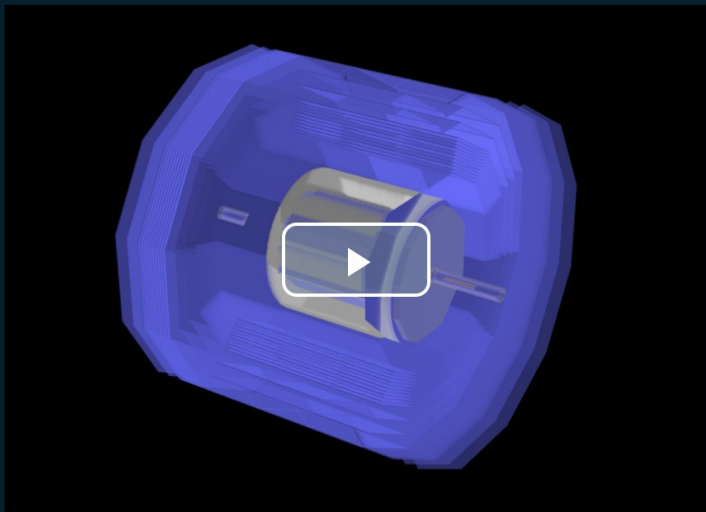
News

- 2018-02-26 Version 0.1.0-rc8 Released

Activities

- 2018-02-26 CEPC Software Discussion

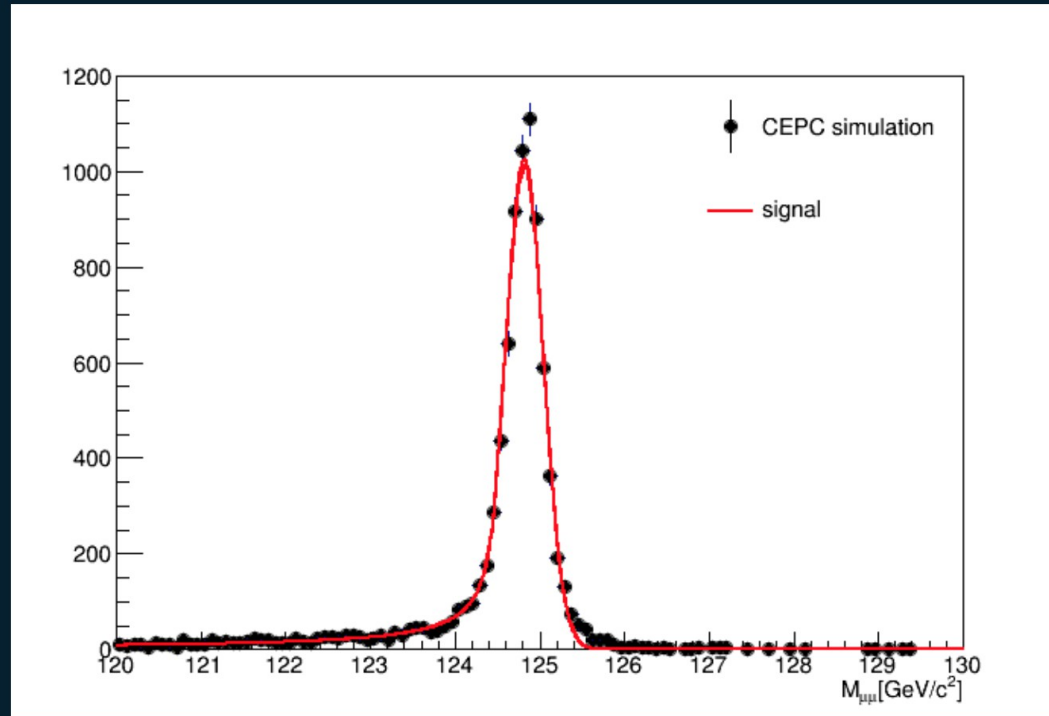
Event Display



then the invariant mass is calculated by

$$M_{\mu\mu} = \sqrt{(E_{\mu^-} + E_{\mu^+})^2 - (p_{\mu^-} + p_{\mu^+})^2}$$

Result



vvH, H->di muon Analysis

Estimated reading time: 1 minute

- You may find the project at <http://cepcgit.ihep.ac.cn/lihawl/vvHmumu>. The website is open to register. When you can access the project, use `git clone git@cepcgit.ihep.ac.cn:lihawl/vvHmumu.git` to have a local copy of this project.

Introduction

In this example, we will draw a plot of invariant mass of di-muon, which come from H , for the channel of vvH .

Edit this page

Request docs changes

Issues in GitLab

Content on this page:

Introduction

Event selection

Result

Edit this page

Request docs changes

Issues in GitLab

Content on this page:

Introduction

Event selection

Result

Introduction

Installation and Quick Start

SDRAM (Sim-Rec Software Chain)

Software Architecture

Performance

Analysis Examples

Introduction

vvH, H->di muon Analysis

vvH, H->di photon Analysis

vvH, H->di W Analysis

Recoil Mass of Leptons from Z

W/Z classification

DAQ & Prototype Test

Computing

About Web

Introduction

Installation and Quick Start

SDRAM (Sim-Rec Software Chain)

Software Architecture

Performance

Analysis Examples

Introduction

vvH, H->di muon Analysis

vvH, H->di photon Analysis

探测器优化研究主要结论


- 顶点系统（吴志刚）
 - 明晰 $H \rightarrow \tau\tau$, $H \rightarrow bb$, cc 测量精度同顶点几何的依赖关系（CEPC NOTE）
- 时间投影室（赵明锐、安芬芬）
 - 适用性研究（发表于 JINST）：在硬件设计支持下，TPC 可安全应用于 CEPC 环境
 - Kaon 甄别（发表于 EPJC）：CEPC-v4 可实现效率 / 纯度均高于 95% 的 Charged Kaon 甄别，为味物理研究提供了基础
 - 几何优化研究
- 电磁量能器：
 - 物质量、读出单元几何进行了系统优化，道数削减 75-80%（赵航，发表于 JINST）。
- 强子量能器、磁场：
 - 强子量能器厚度削减 20%，磁场削减至 3 Tesla 时，对喷注能量重建无明显影响（于丹，博士论文）

Jinst PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB
RECEIVED: May 12, 2017
REVISED: June 10, 2017
ACCEPTED: June 21, 2017
PUBLISHED: July 4, 2017

Feasibility study of TPC at electron positron colliders at Z pole operation

M. Zhao,^{a,b} M. Ruan,^{c,1} H. Qi,^{c,d} and Y. Gao^d

Eur. Phys. J. C _____
<https://doi.org/10.1140/epjc/s10052-018-5803-3>

THE EUROPEAN PHYSICAL JOURNAL C 

Regular Article - Experimental Physics

Monte Carlo study of particle identification at the CEPC using TPC dE/dx information

F. An^{1,2,4}, S. Prell², C. Chen², J. Cochran², X. Lou^{1,3,4}, M. Ruan^{1,b}

¹ Institute of High Energy Physics, Chinese Academy of Science, Beijing, China
² Department of Physics and Astronomy, Iowa State University, Ames, IA, USA
³ Physics Department, University of Texas at Dallas, Richardson, TX, USA
⁴ University of Chinese Academy of Science (UCAS), Beijing, China

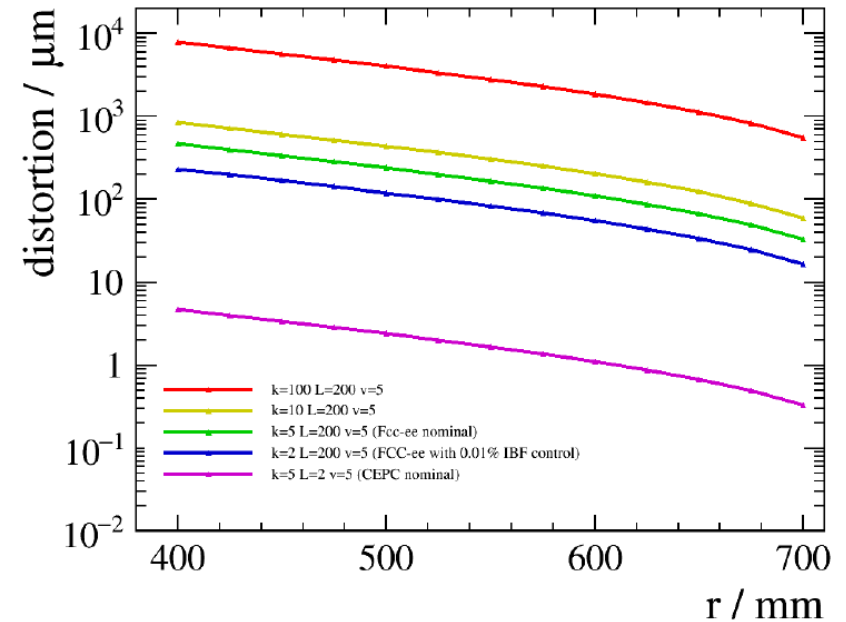
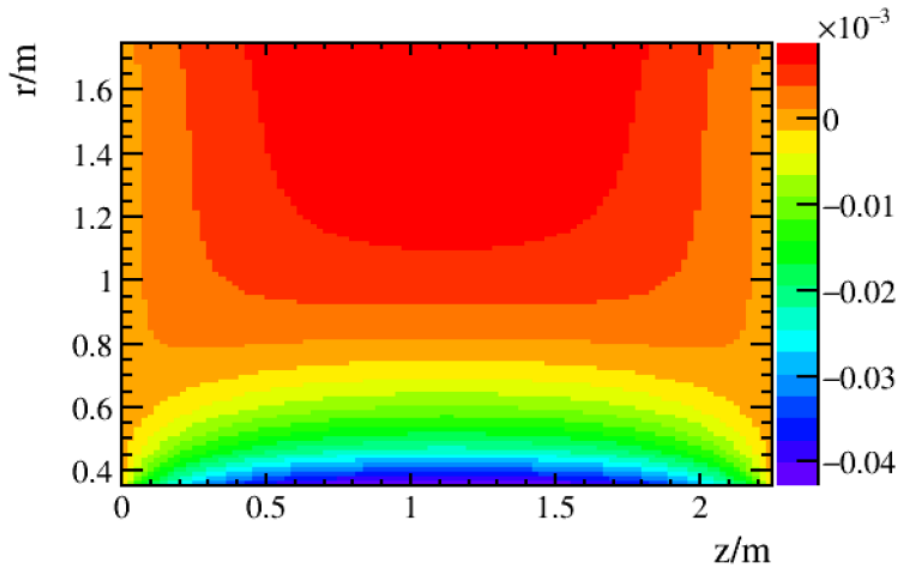
Received: 14 March 2018 / Accepted: 12 April 2018
© The Author(s) 2018

Journal of Instrumentation

Particle flow oriented electromagnetic calorimeter optimization for the circular electron positron collider

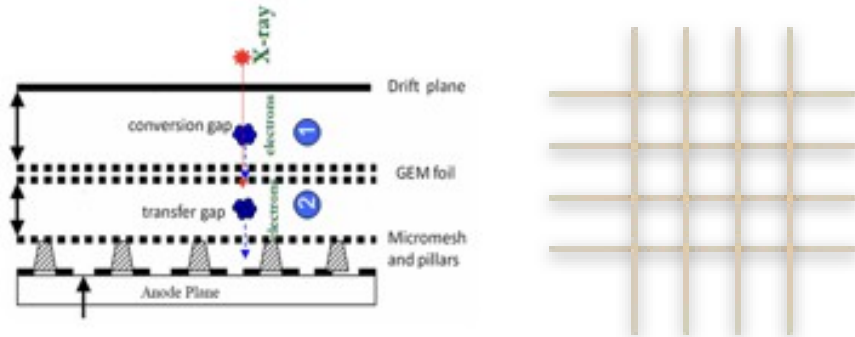
H. Zhao^{a,b,c}, C. Fu^a, D. Yu^{d,e}, Z. Wang^a, T. Hu^a and M. Ruan^a
Published 15 March 2018 • © 2018 IOP Publishing Ltd and Sissa Medialab
[Journal of Instrumentation, Volume 13, March 2018](https://doi.org/10.1088/1748-0227/13/03/030101)

TPC 适用性研究



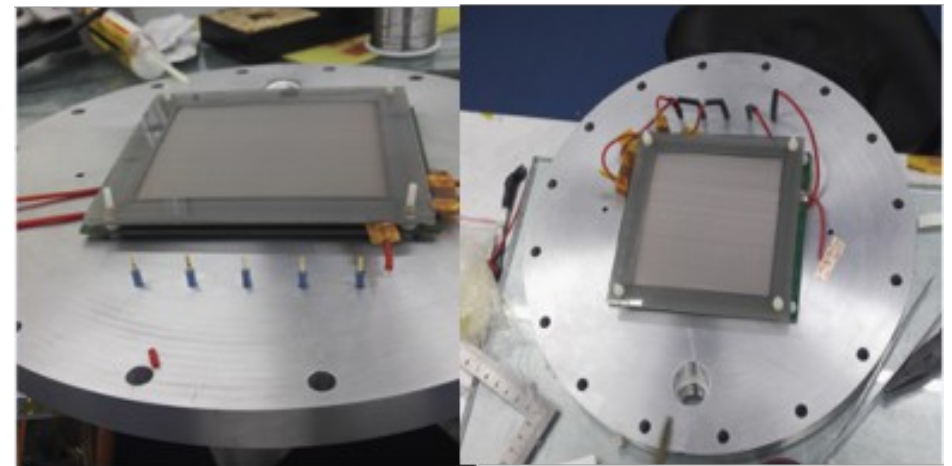
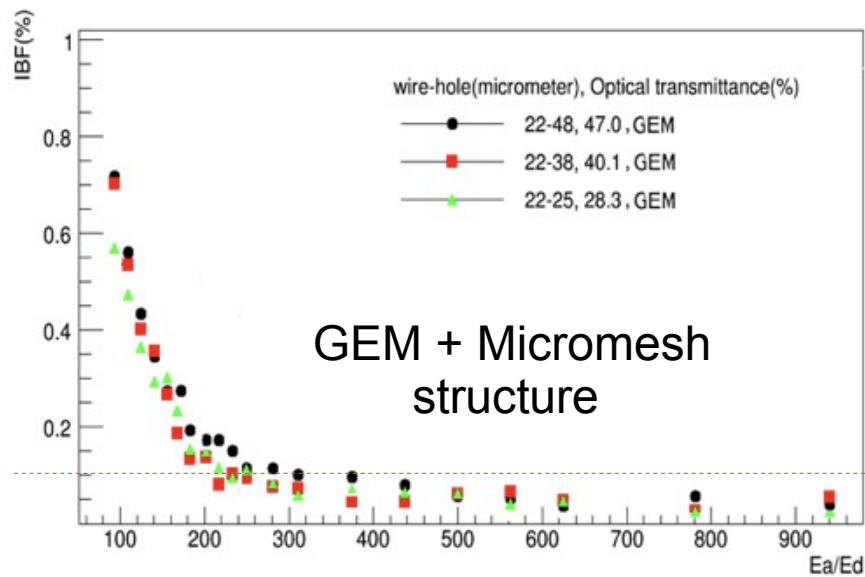
- Conclusion ([JINST_12_P07005](#), [CEPC-DocDB-id-147](#)):
 - Voxel occupancy $\sim (10^{-4} - 10^{-6})$ level, safe
 - **Safe for CEPC if the ion back flow be controlled to per mille level ($k = 5$) -**
适用性研究：要求粒子返流被控制到千分之一水平

粒子返流硬件设计及测试：达到千分之一水平



Micromegas(Saclay)

GEM(CERN)



Cathode with mesh

GEM-MM Detector

顶点系统优化研究

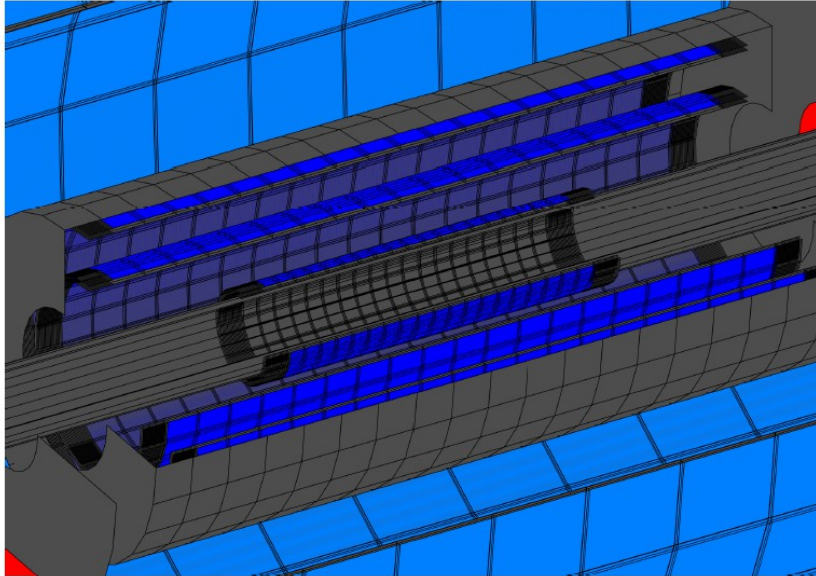


Table 1. Design parameters of the CEPC vertex system.

	R(mm)	Z (mm)	$\sigma(\mu m)$	material budget
Layer 1	16	62.5	2.8	0.15%/X ₀
Layer 2	18	62.5	6	0.15%/X ₀
Layer 3	37	125.0	4	0.15%/X ₀
Layer 4	39	125.0	4	0.15%/X ₀
Layer 5	58	125.0	4	0.15%/X ₀
Layer 6	60	125.0	4	0.15%/X ₀

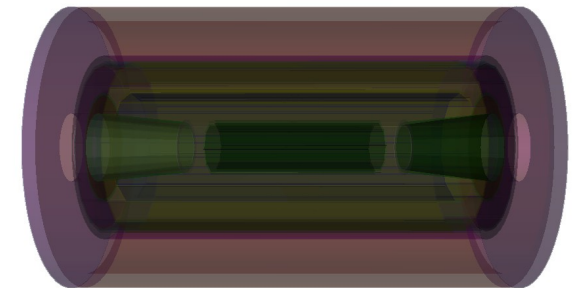


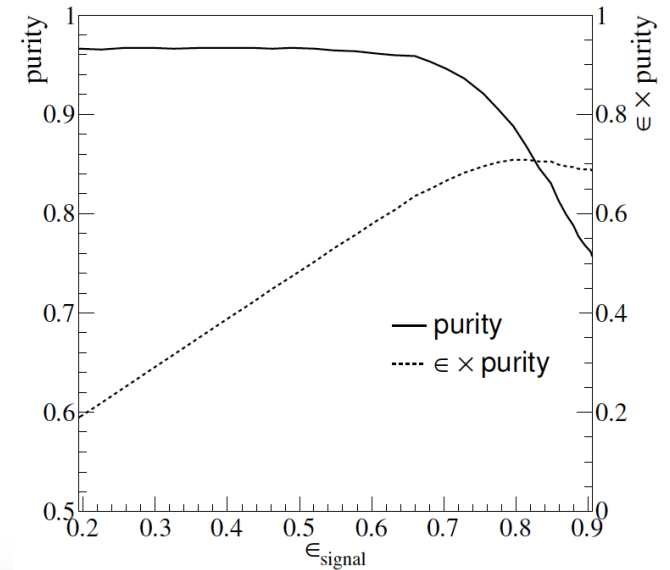
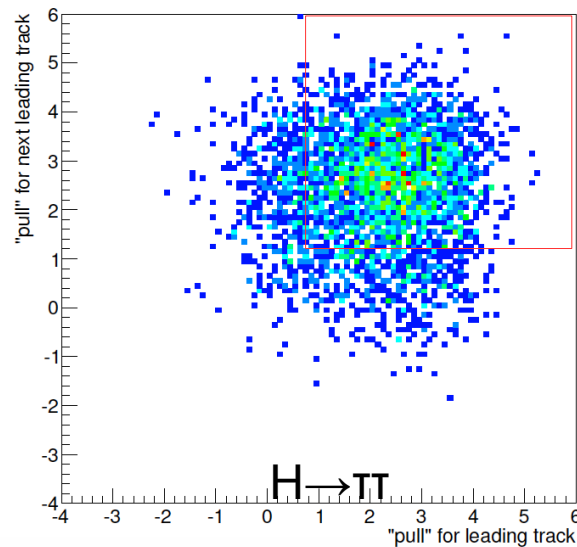
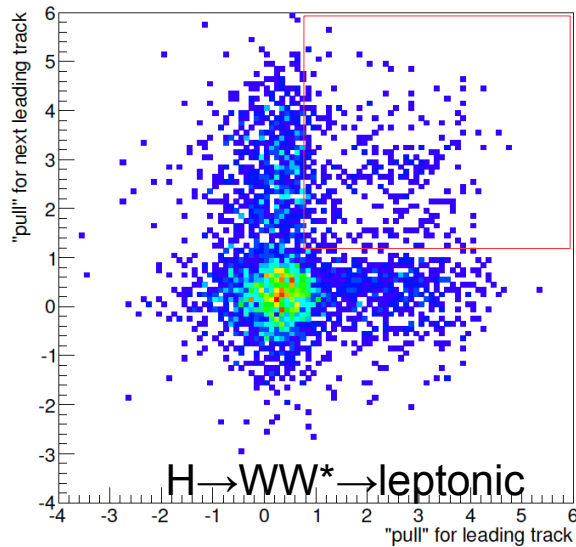
Figure 1. The vertex system schematic at the CEPC.

Table 2. Reference geometries

	Scenario A (Aggressive)	Scenario B (Baseline)	Scenario C (Conservative)
Material per layer/X ₀	0.075	0.15	0.3
Spatial resolution/ μm	1.4 - 3	2.8 - 6	5 - 10
R_{in}/mm	8	16	23

顶点系统优化研究: $g(H\tau\tau)$ 测量

	$\mu\mu H\tau\tau$	$\mu\mu H$ inclusive bkg	ZZ	WW	singleW	singleZ	$2f$
total generated	2292	33557	5711445	44180832	15361538	7809747	418595861
after preselection	2246	32894	122674	223691	0	86568	1075886
$N_{Trk}(A/B) < 6$ & $N_{ph}(A/B) < 7$	2219	1039	2559	352	0	9397	25583
BDT > 0.78	2135	885	484	24	0	157	161
efficiency	93.15%	2.63%	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%

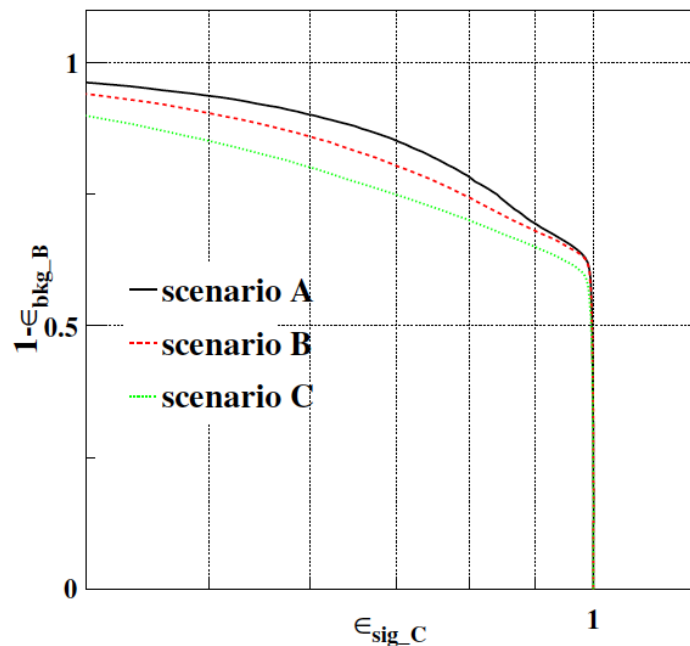


situations	best	baseline	worst
$\epsilon \cdot \text{purity}$	0.77 ± 0.01	0.71 ± 0.01	0.68 ± 0.01

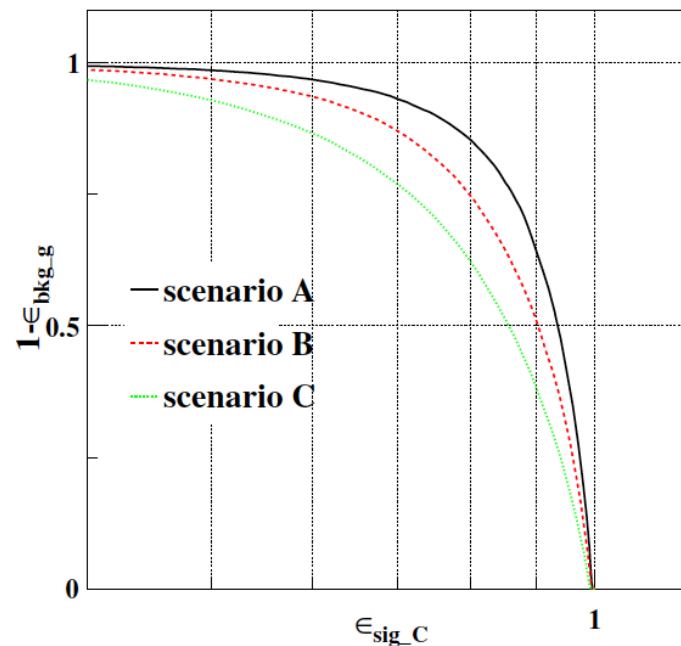
Worst: ALICE ITS parameter
Best: 2 times more aggressive w.r.t baseline
In inner Radius, Material & resolution

Conclusion: in this benchmark channel, VTX is sensitive but not crucial

顶点系统优化研究： Flavor Tagging 以及 $g(Hbb)$, $g(Hcc)$ 测量



(a) b background



(b) g background

Table 2. Reference geometries

	Scenario A (Aggressive)	Scenario B (Baseline)	Scenario C (Conservative)
Material per layer/ X_0	0.075	0.15	0.3
Spatial resolution/ μm	1.4 - 3	2.8 - 6	5 - 10.7
R_{in}/mm	8	16	23

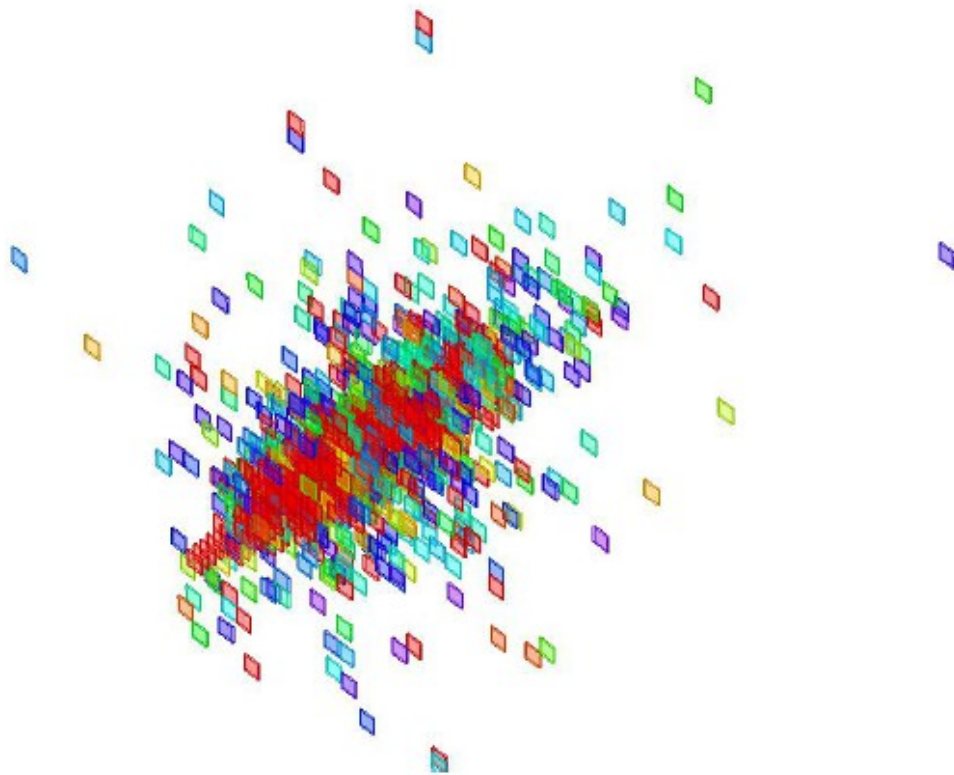
Table 6. $\epsilon \cdot p$ comparison for all three benchmarks.

Benchmark	Scenario A	Scenario B	Scenario C
$Br(H \rightarrow c\bar{c})$	0.133 ± 0.002	0.095 ± 0.001	0.078 ± 0.001
$Br(H \rightarrow b\bar{b})$	0.925 ± 0.001	0.914 ± 0.001	0.900 ± 0.001
$Br(H \rightarrow \tau^+\tau^-)$	0.77 ± 0.01	0.71 ± 0.01	0.68 ± 0.01

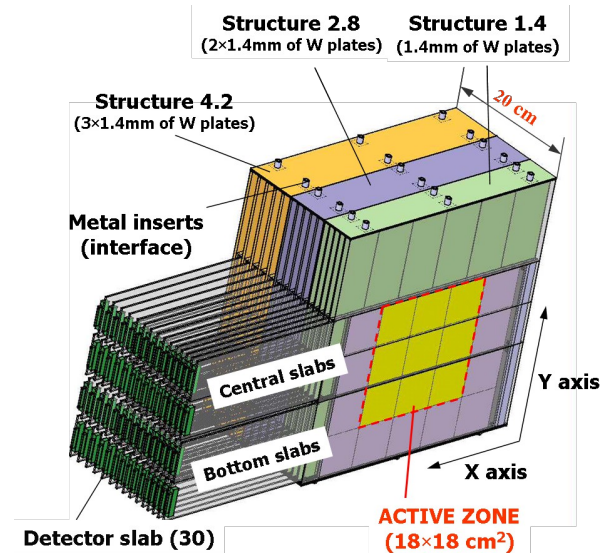
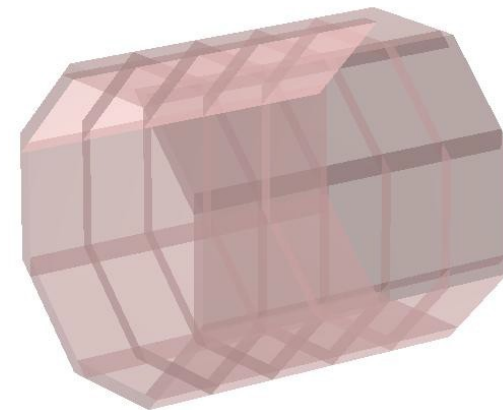
Calorimeter Optimization

- No Power Pulsing: Feasibility study of Passive Cooling
 - Number of channels need to reduced by more than 1 orders of magnitudes, test Geometries implemented (10-20 mm ECAL/HCAL Cell + reduced layers)
 - Performance on objects & Higgs Benchmarks
 - Photon & H->photons
 - Lepton & Higgs recoil
 - Jets & H->gluons
 - Cooperation with In2p3-LLR (MoU signed) & CALICE
- Determination of the geometry parameters for the calorimeter
 - HCAL Thickness
 - ECAL Thickness, Number of Layers & Cell Size

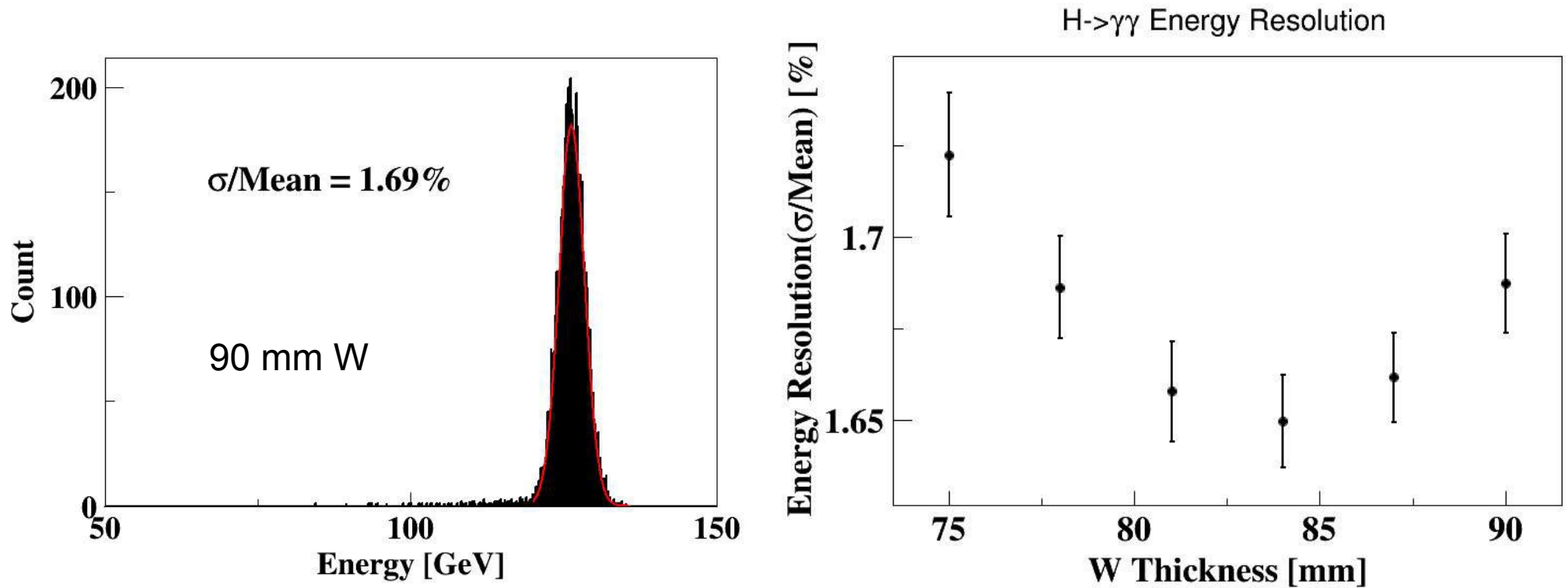
ECAL Saturation/Linear Range Study



50 GeV Photon Cluster
at ECAL with 10 mm Cell Size



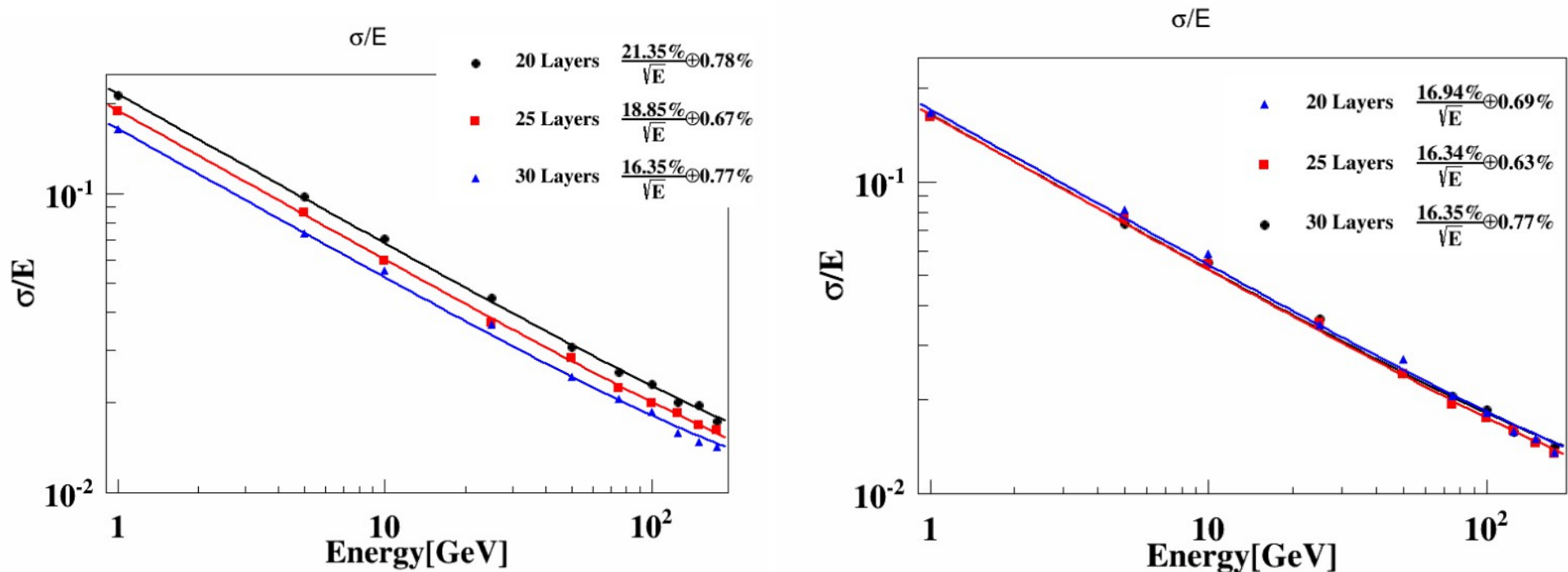
H->di photon Vs W thickness



30 Layers, each layer with 0.5 mm Si + 2 mm PCB
ECAL only performance

Optimization on the in-homogeneous longitudinal structure (i.e.,
Absorber thickness at different layer) not applied

Photon energy measurement Vs Longitudinal structure: #Layer & Si Thickness



Performance @ Photon with $E > 1$ GeV:

Energy Resolution is comparable at:

20 * 1.5 mm Si + 4.5 mm W

25 * 1 mm Si + 3.6 mm W

30 * 0.5 mm Si + 3 mm W

What's the maximal viable silicon wafer thickness?

Separation performance

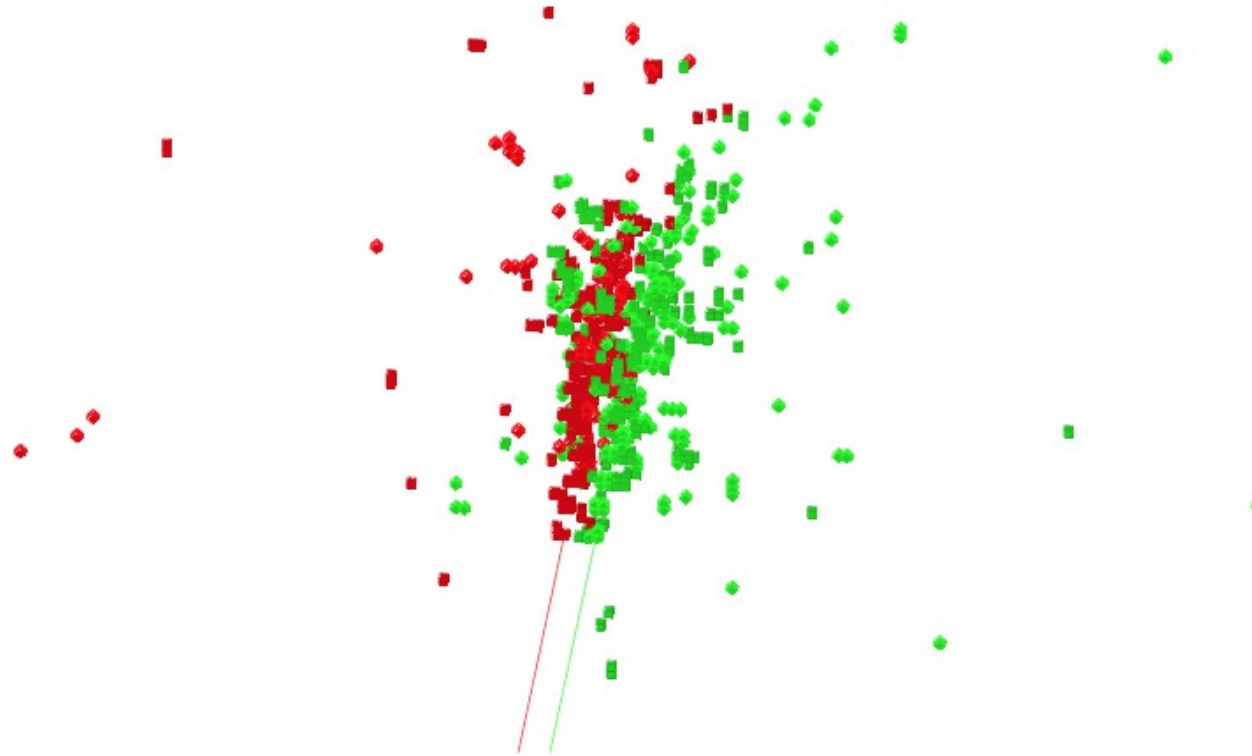
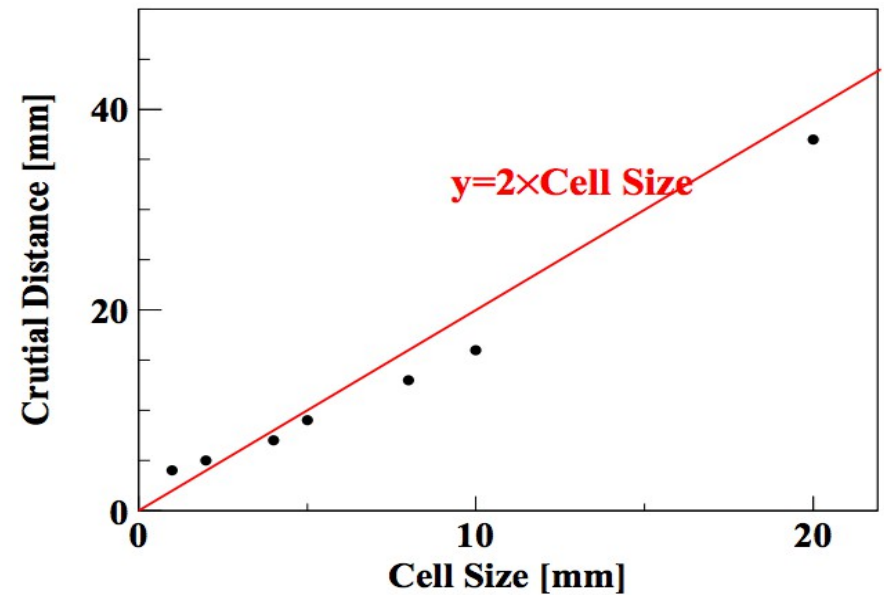
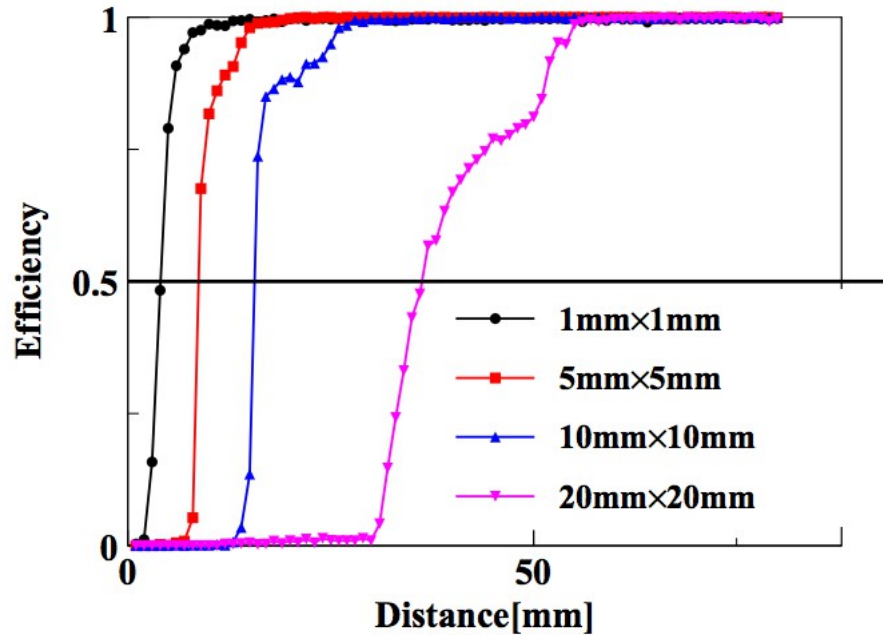


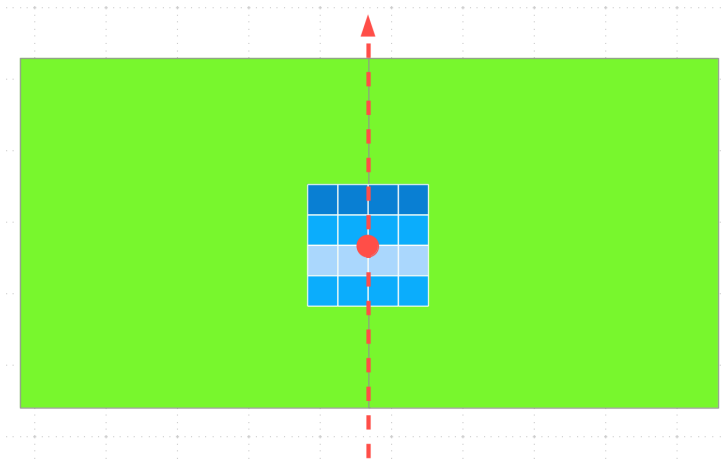
Figure 11. Event display of reconstructed di-photon.

Critical distance: $\sim 2 \times \text{Cell Size}$

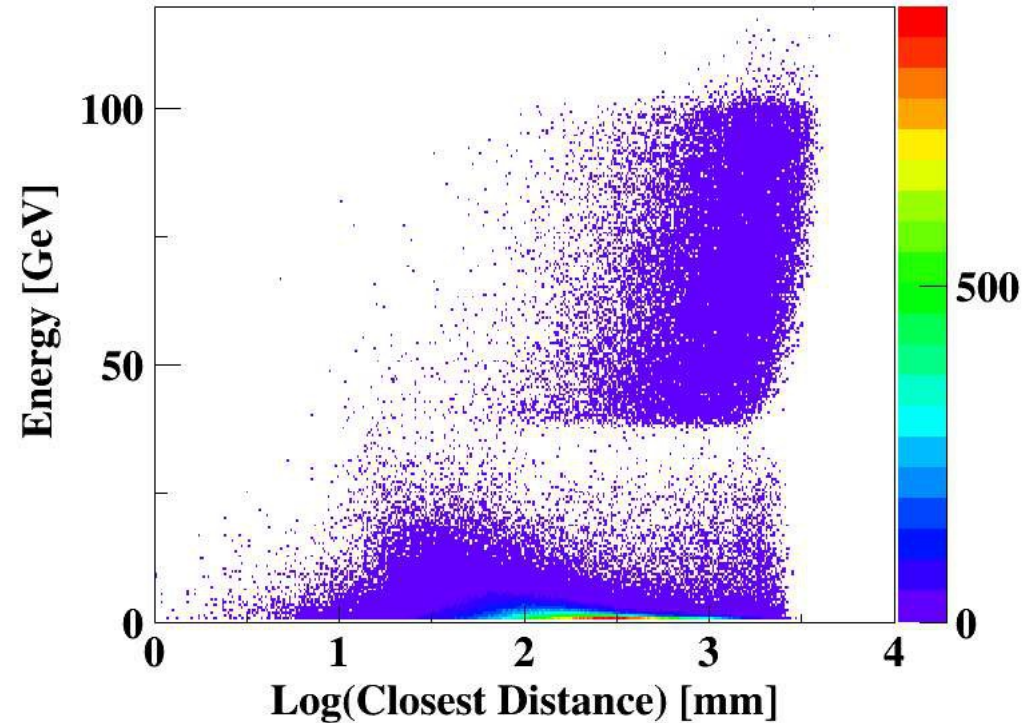
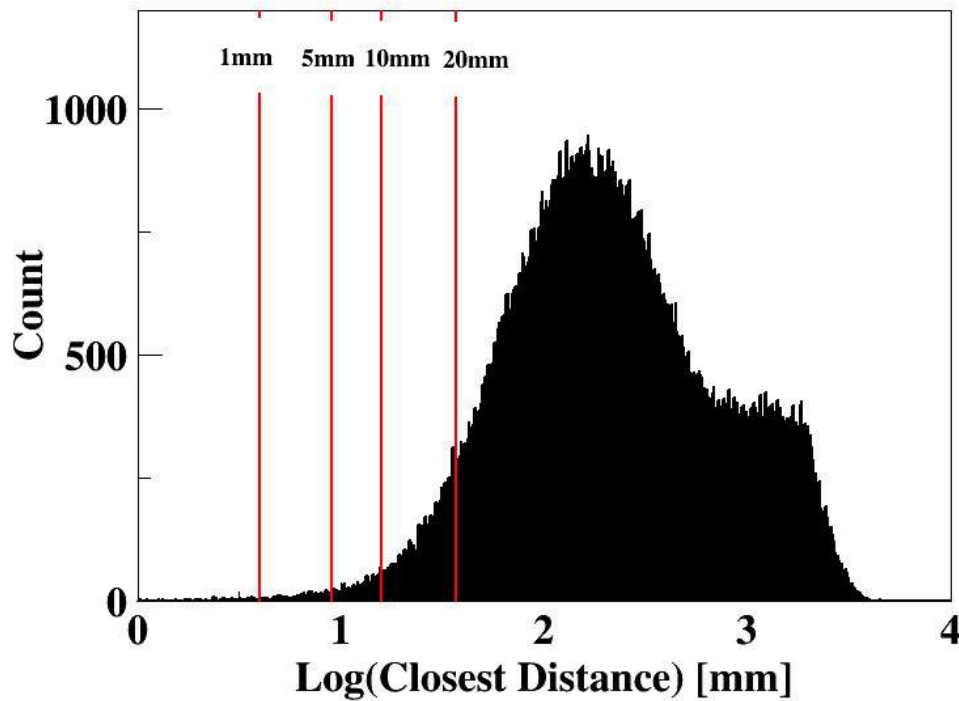


Simulation at 1 mm Cell & Digitized
To large cell size

Scan step = 1 mm

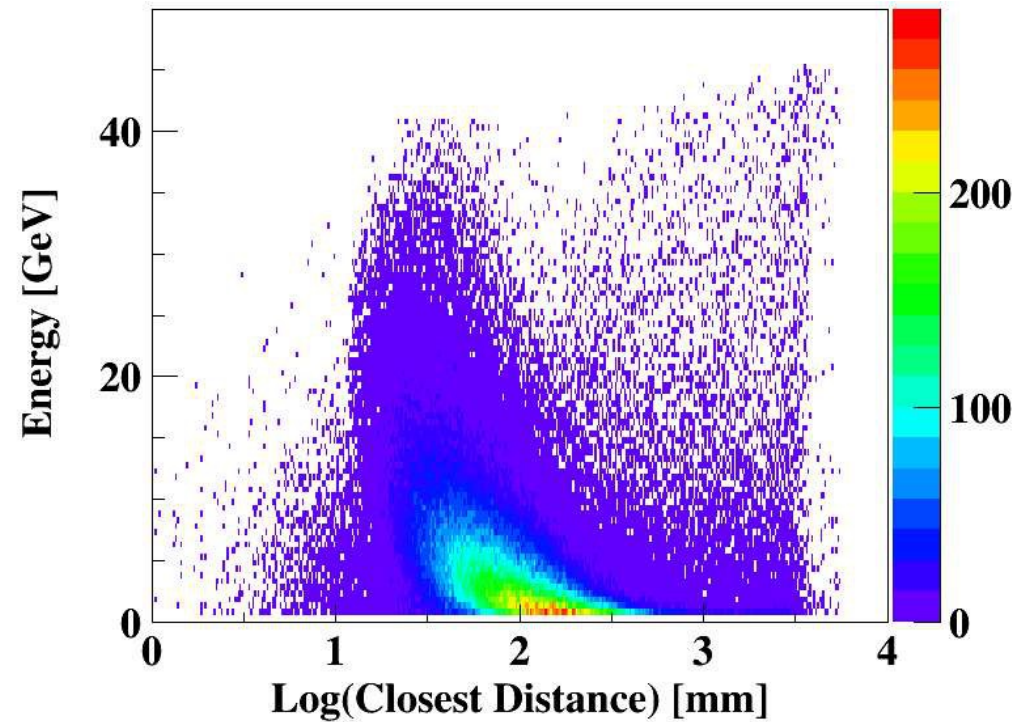
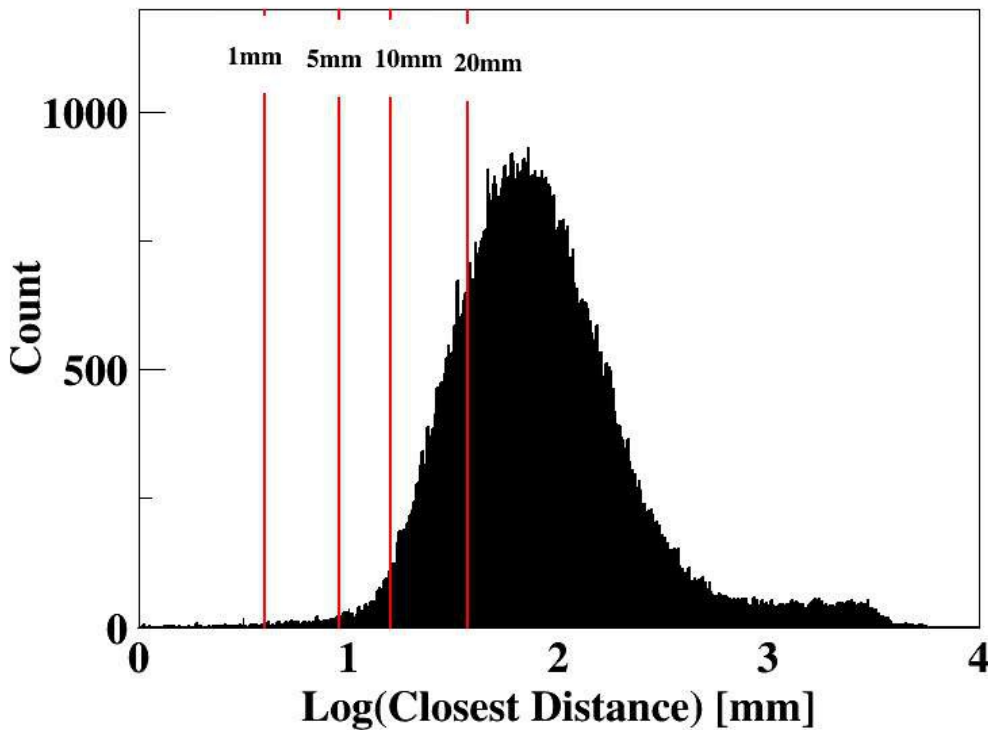


Impact of Separation: qqH, H- \rightarrow $\gamma\gamma$ @ 250 GeV



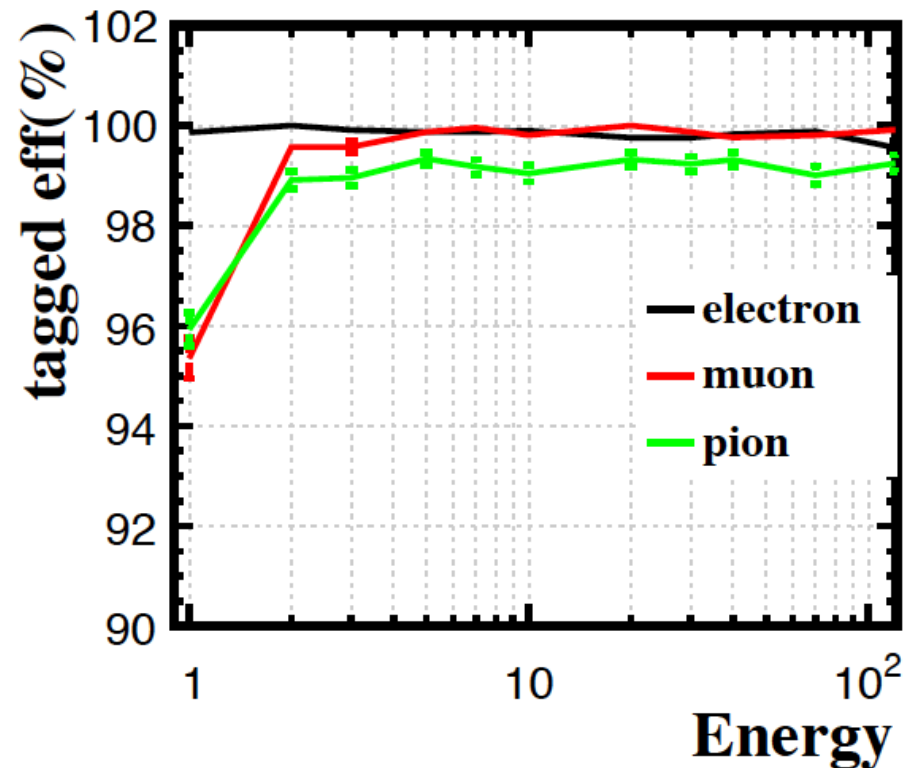
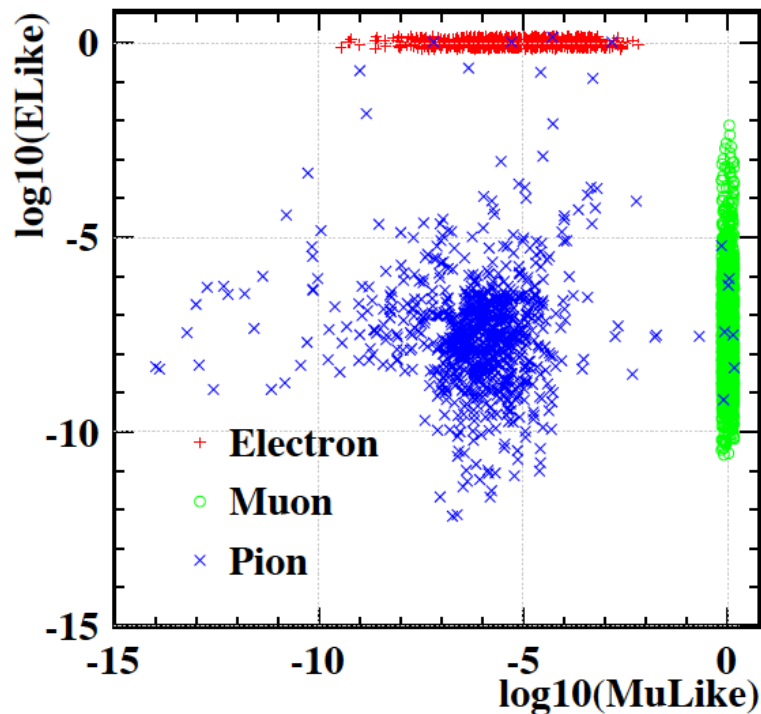
Cell Size/mm	1	5	10	20
Crucial Dis/mm	4	9	16	37
Percentage of potentially overlap photon: E > 30 GeV	0%	0%	0.1%	0.4%
E < 30GeV	0.1%	0.35%	1.1%	6.4%

Impact of Separation: Z->tau tau @ Z pole



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%

Dan: general Lepton ID for Calorimeter with High granularity (LICH)



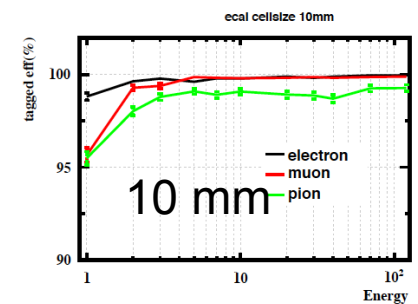
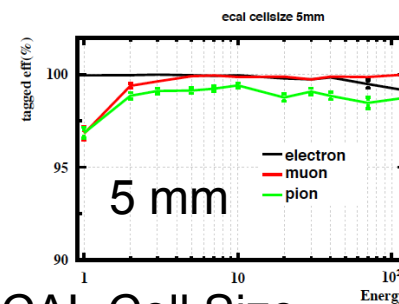
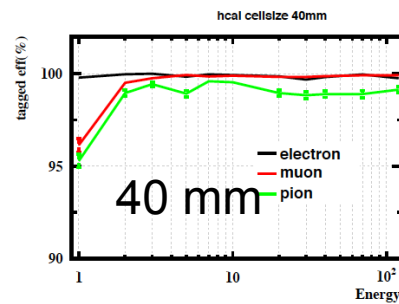
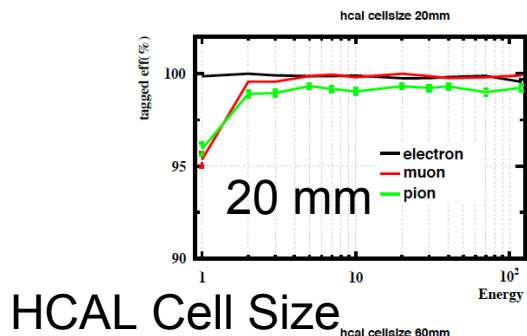
BDT method using 4 classes of 24 input discrimination variables.

Test performance by requesting

Electron = $E_likeness > 0.5$; Muon = $Mu_likeness > 0.5$

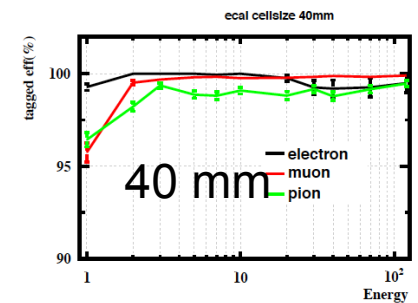
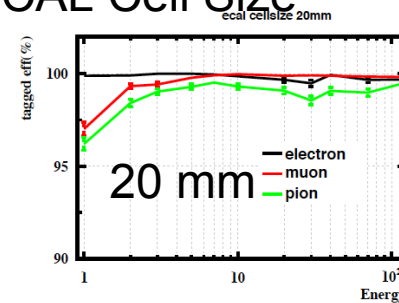
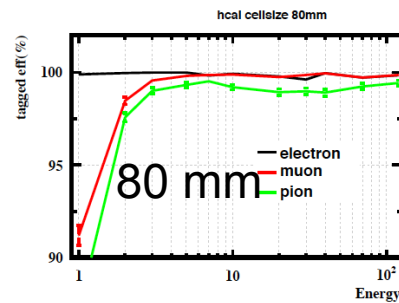
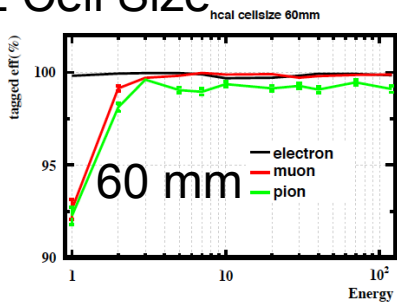
Single charged reconstructed particle, for $E > 2$ GeV: lepton efficiency $> 99.5\%$ && Pion mis id rate $\sim 1\%$

Vary the granularity



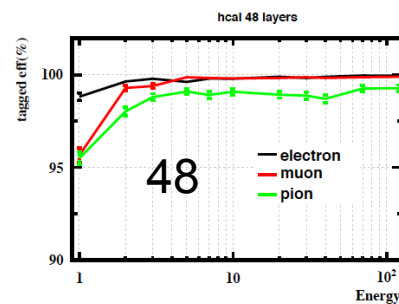
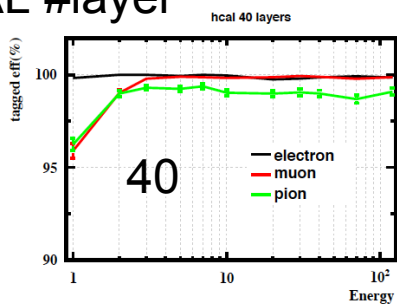
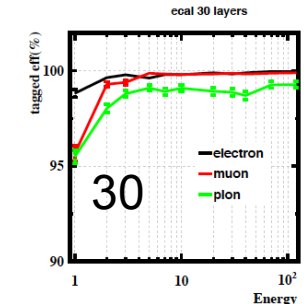
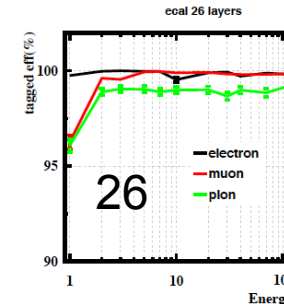
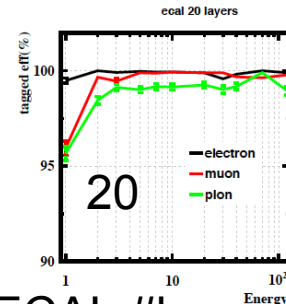
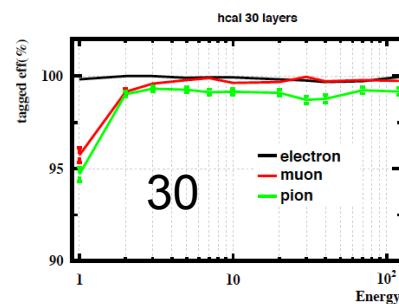
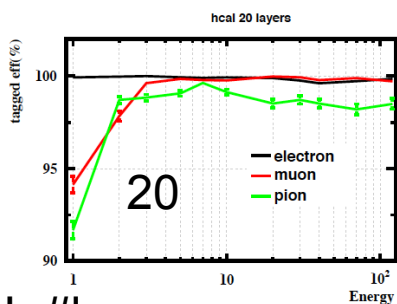
HCAL Cell Size

ECAL Cell Size



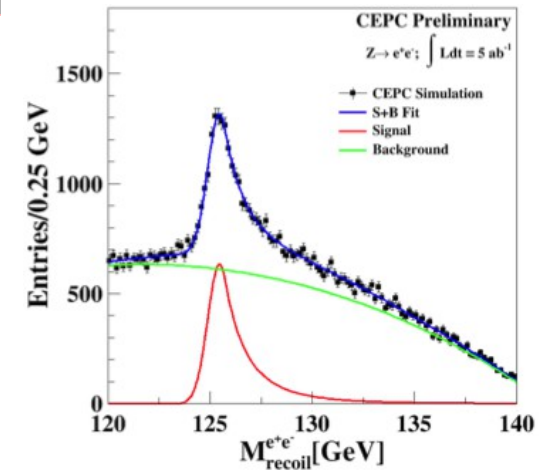
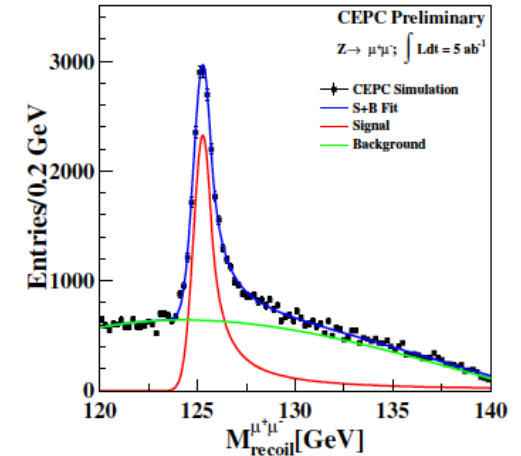
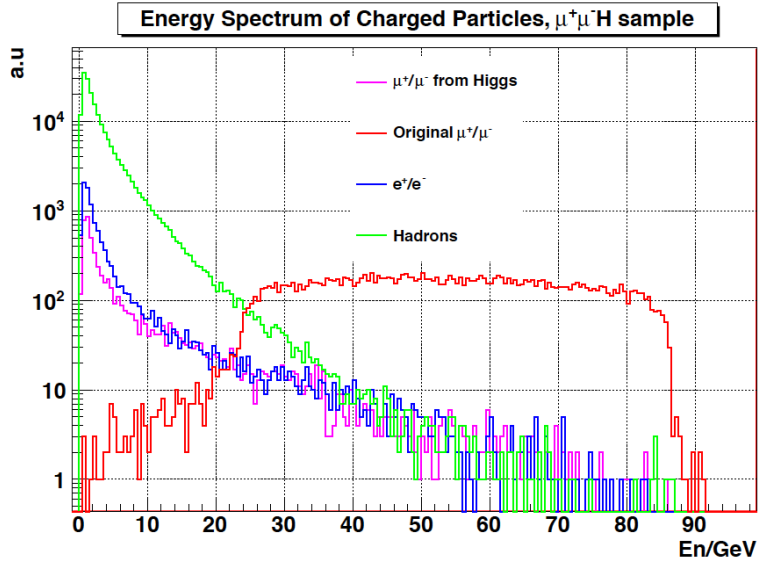
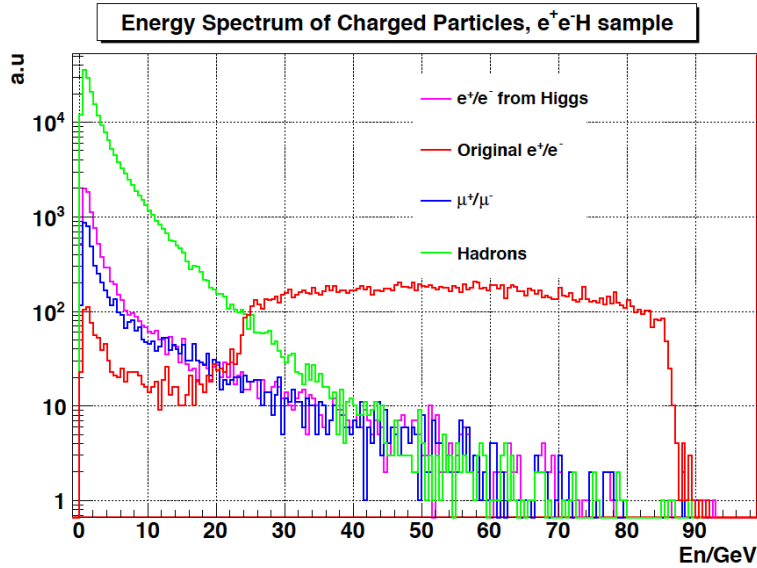
HCAL #layer

ECAL #layer



No Significant effect for $E > 2$ GeV charged Particles

Lepton id @ Higgs recoil



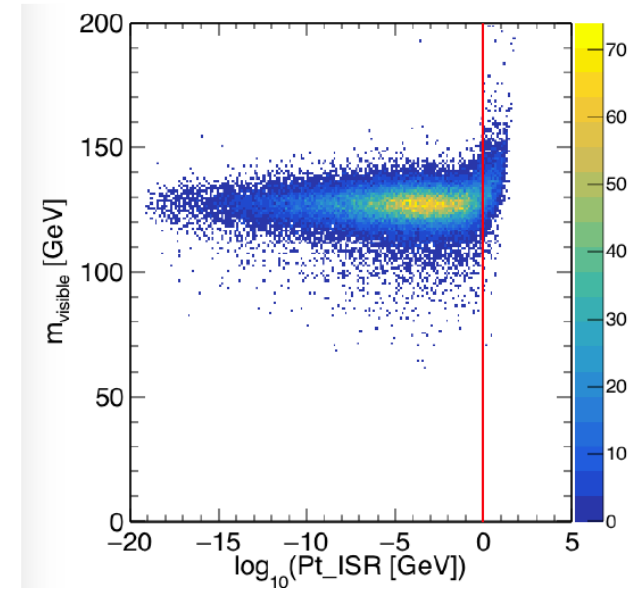
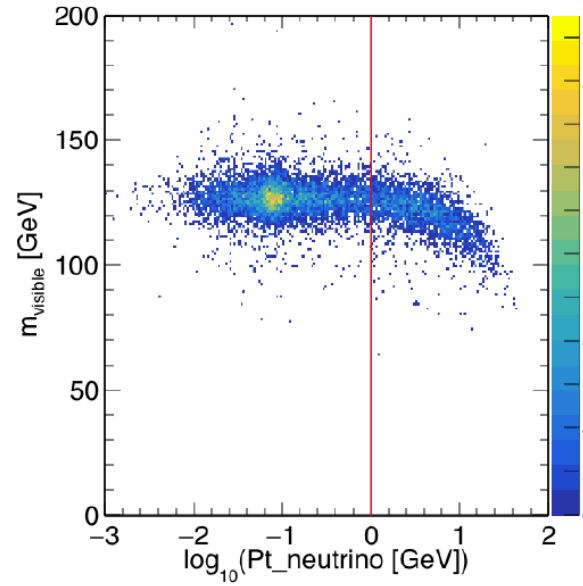
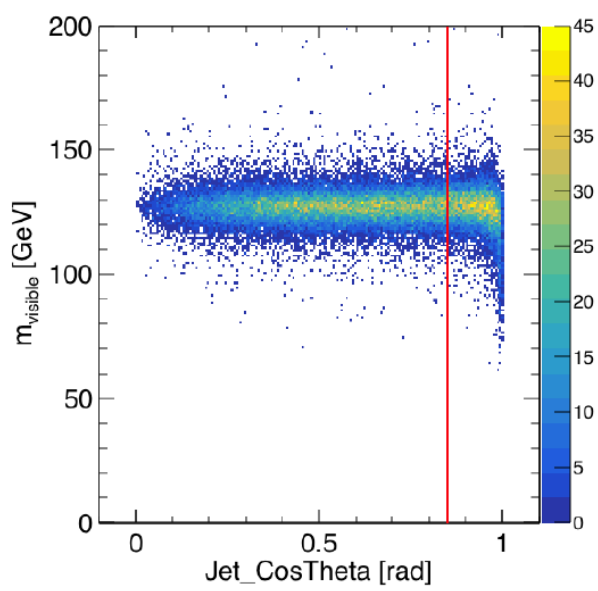
	Geom 1		Geom 2	
	$\mu\mu H$	eeH	$\mu\mu H$	eeH
Cut_μ	0.1	0.1	0.1	0.1
Cut_e	0.01	0.001	0.01	0.001
ϵ_E	93.41 ± 0.92	98.64 ± 0.08	91.60 ± 1.02	97.89 ± 0.11
η_E	92.02 ± 1.00	99.74 ± 0.04	89.89 ± 1.10	99.67 ± 0.04
ϵ_μ	99.54 ± 0.05	95.53 ± 0.76	99.19 ± 0.06	86.48 ± 1.26
η_μ	99.60 ± 0.04	96.31 ± 0.70	99.83 ± 0.03	95.38 ± 0.81
ϵ_{event}	98.53 ± 0.13	97.06 ± 0.19	97.24 ± 0.18	95.40 ± 0.24

Geom 1/2: 10 (20) mm ECAL/HCAL Cell

Initial Leptons identified at satisfactory efficiency & purity (limited by separation power)

More stringent requirement arises from jet leptons...

H to gluons: total visible mass



Reconstructed Higgs Mass from wH event, wi/wo cleaning

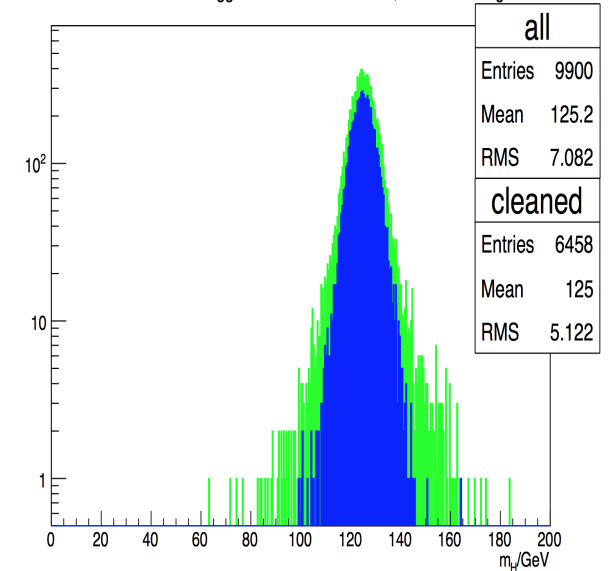
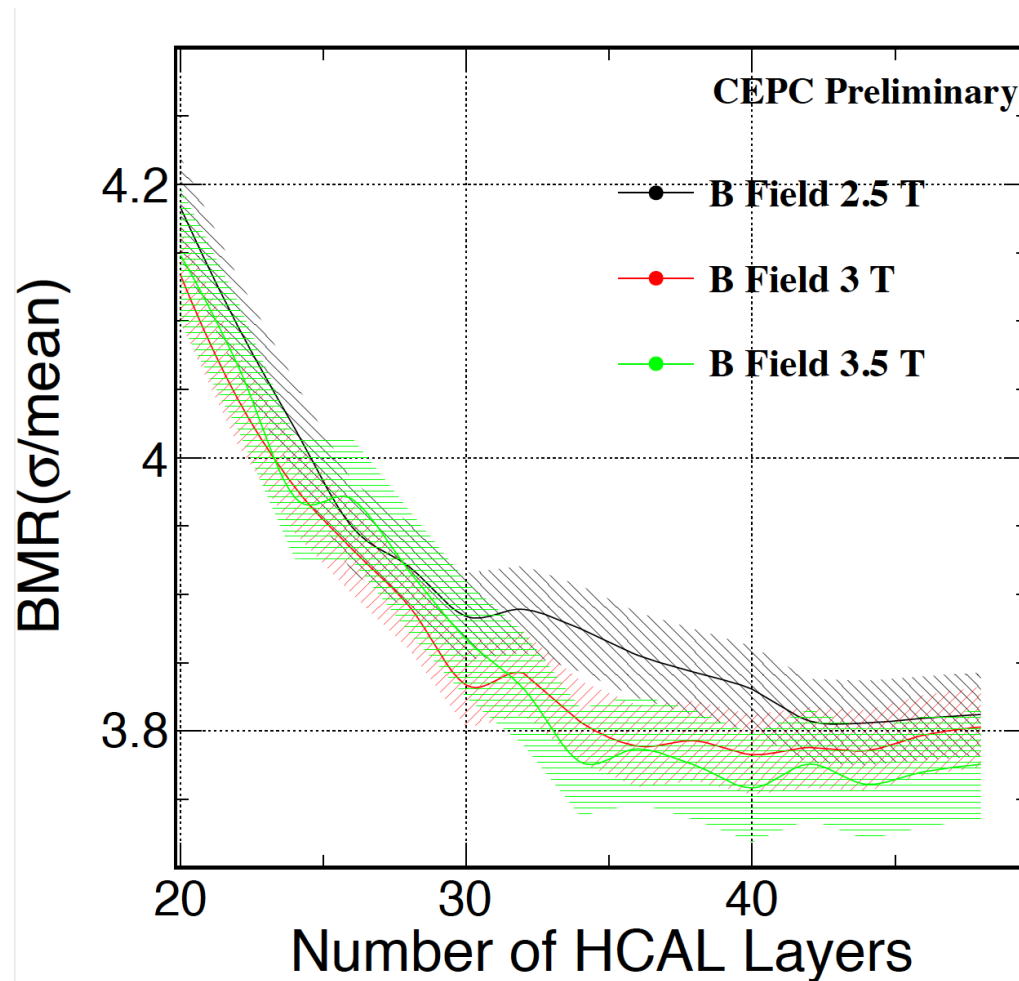


Table 1. Event selection efficiency for Higgs boson exclusive decay at CEPC with $\sqrt{s} = 240$ GeV.

	$\mu\mu$	$\gamma\gamma$	<i>di_gluon</i>	bb	cc	WW*	ZZ*
Total	45000	48000	48000	45000	46000	47000.	45000
$Pt_{ISR} < 1GeV$	-	95.52%	95.14%	95.37%	95.27%	95.19%	95.22%
$Pt_{neutrino} < 1GeV$	-	-	89.35%	39.00%	66.30%	37.41%	41.42%
$ costheta < 0.85$	-	-	67.27%	28.58%	49.23%	37.03%	40.91%

Boson Mass Resolution



Number of HCAL Layers: 48- \rightarrow 40;
No Significant effect on B-Field reduction from 3.5 \rightarrow # Tesla

实现高精度的 Higgs 信号重建

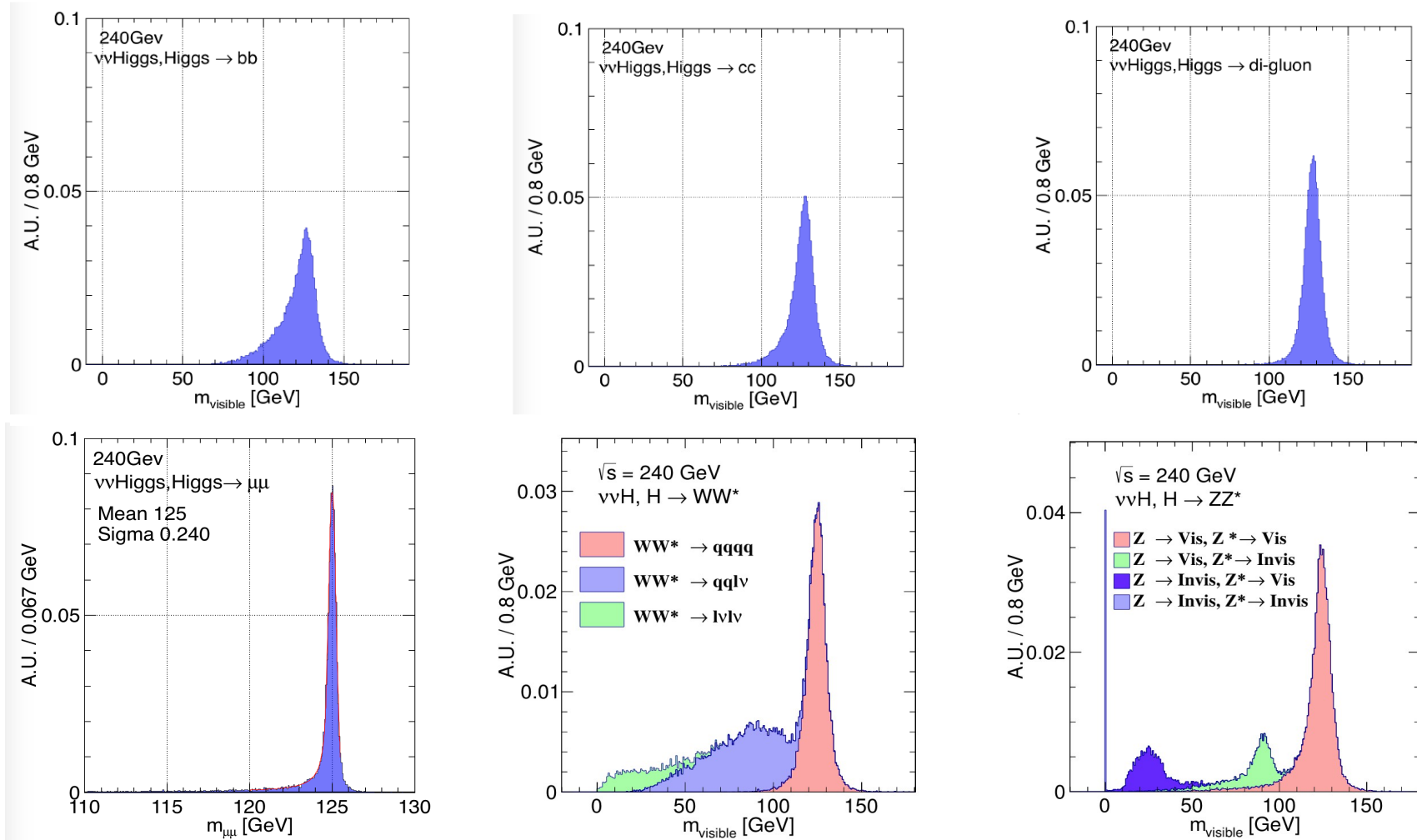


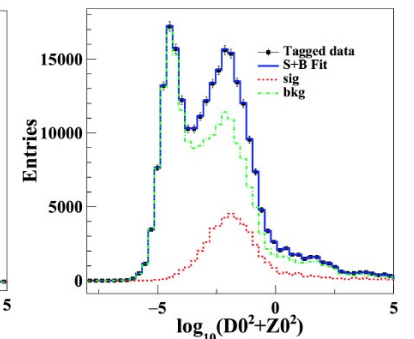
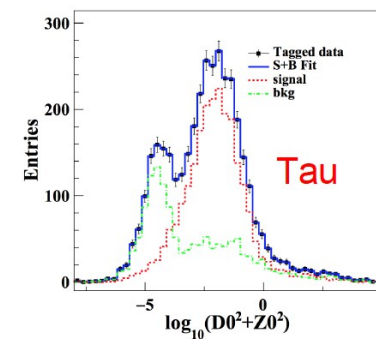
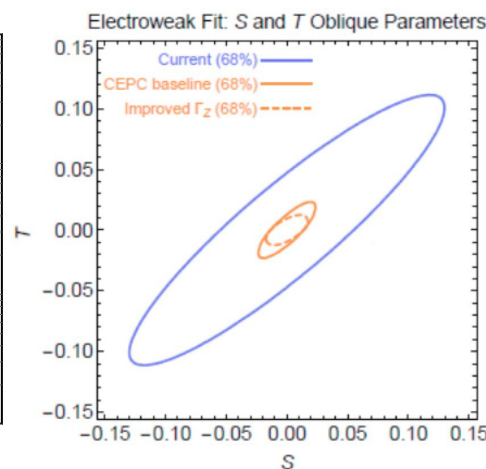
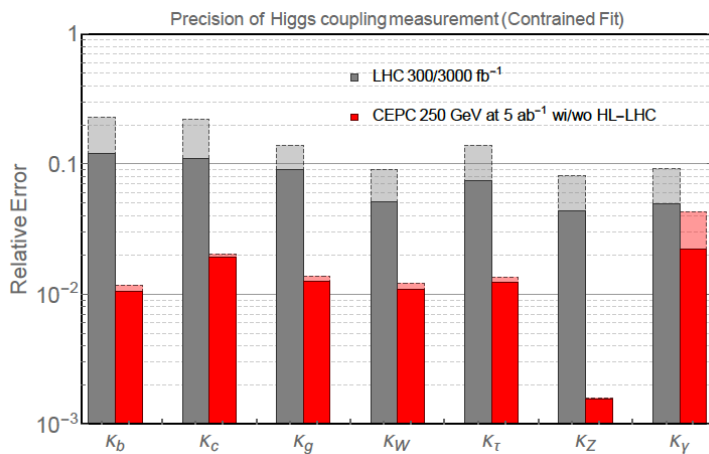
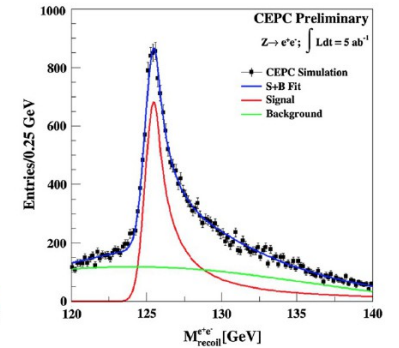
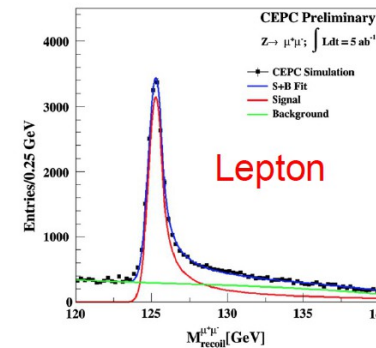
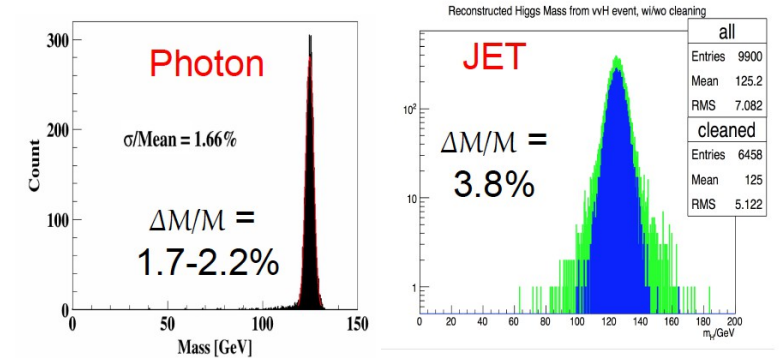
Table 2. Benchmark resolutions ($\sigma/Mean$) of reconstructed Higgs boson mass, comparing to LHC results.

	Higgs $\rightarrow \mu\mu$	Higgs $\rightarrow \gamma\gamma$.	Higgs $\rightarrow bb$
CEPC (APODIS)	0.20%	2.59% ¹	3.63%
LHC (CMS, ATLAS)	$\sim 2\%$ [19, 20]	$\sim 1.5\%$ [21, 22]	$\sim 10\%$ [23, 24]

¹ primary result without geometry based correction and fine-tuned calibration. <https://arxiv.org/abs/1806.04992>

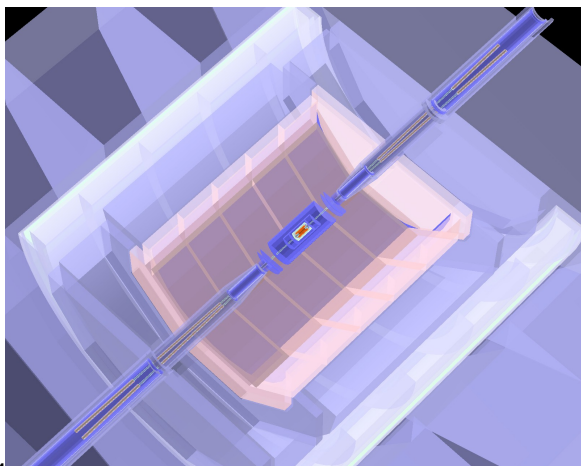
深入理解 CEPC 的物理潜力

- 分析表明，CEPC 基线探测器及重建算法可准确区分、测量不同物理事例，保证了 Higgs 粒子和电弱可观测量的测量精度
 - Higgs 粒子测量：精度在 HL-LHC 水平上提升一个量级
 - 电弱测量精度在现有水平上至少提升一个量级

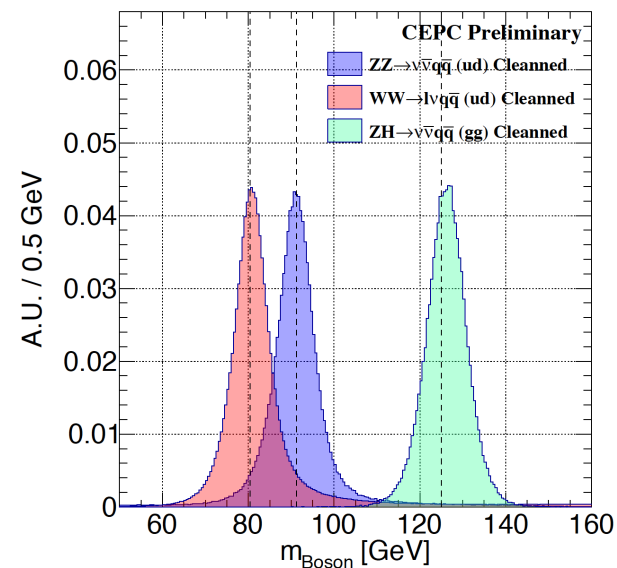
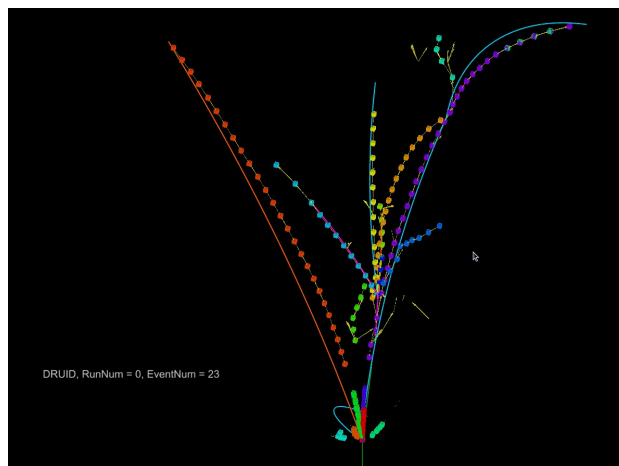


基线探测器设计及 Arbor 粒子流算法

- 完成了 CEPC 基线探测器设计和优化
 - 采取 ILD-like geometry，性能与 ILD 一致，加强了其 Flavor Physics 方面性能
 - 造价、功耗、总重显著优化 (30%/80%/30%)
- 开发了 Arbor 算法，可高效、准确重建所有关键物理标的物
 - 具有目前正负电子 Higgs 工厂 (ILC, FCC, CLIC, CEPC) 上最好的轻子鉴别性能。效率达 99.5% 以上，对比 ALEPH，误判率下降了 3-5 倍
 - 世界领先的喷注重建性能，可通过喷注不变质量区分 W, Z, Higgs 粒子，喷注能量分辨率 3-5%，较之 LEP、LHC 实验提高 3-4 倍



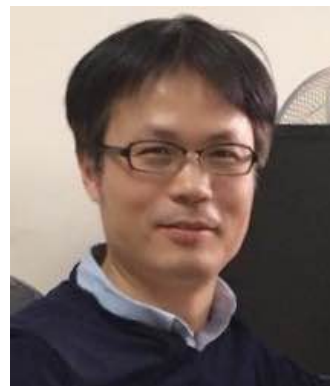
24/12/2018



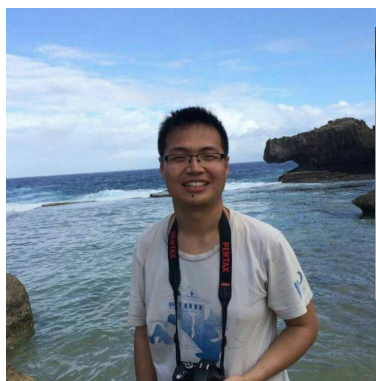
未来工作计划

- 推动 TDR 阶段研究
 - 基线探测器：
 - 强化同子探测器组合作
 - 研究整合（ **Integration** ）
 - 探测器系统误差分析及控制
 - 新型探测器：积极探索新思路、新设计
 - 加强国际合作（ **LCTPC** ， **CALICE** ， **RD...** ）。推动组内学生、博后走上国际舞台
 - 坚持、强化同加速器、理论的沟通合作
- 进一步研究重建软件、算法，加强同已有实验及硬件研究的合作

人员队伍： 软件 / 模拟



成栋：几何及寻迹



新人：赵祥虎
软件 - 计算



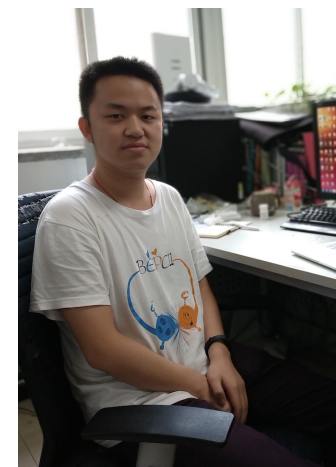
于丹：轻子甄别
PFA, tau
(赵忠尧 Fellow, 晨光杯二等奖)



新人：赖培筑
喷注



新人：安芬芬
Pid, 软件



吴志刚
顶点优化



徐音：几何



赵明锐：寻迹，
软件



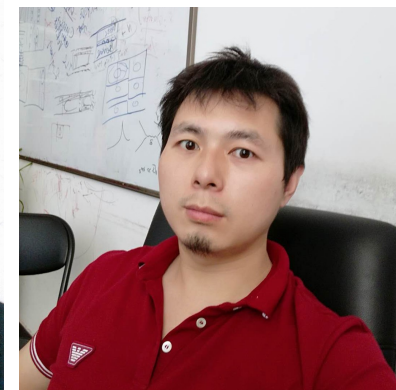
李刚：产生子，
喷注味道甄别



赵航：PFA，
量能器优化
(赵忠尧 Fellow)



李亮：轻子



曼奇：探测器设计，
软件，分析

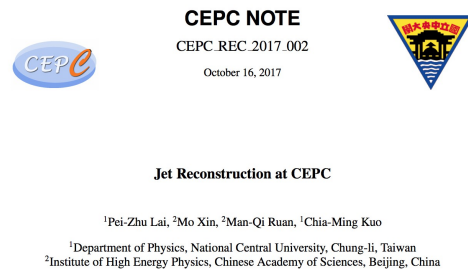
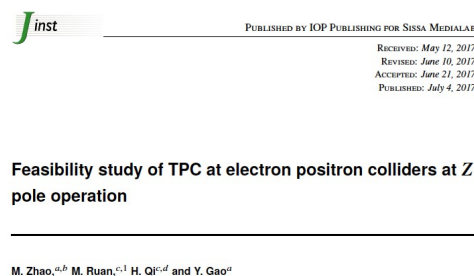
24/12/2018

人才培养

- 目前指导博士后 4 人（合作 1 人），学生 4 人（合作 4 人）。
- 三名博士后已出站、6 名学生毕业。发表论文、Note 多篇。
- 博士后
 - 赵航：2017 进站，赵忠尧奖学金，JINST 1 篇，CPC 已投 1 篇。
 - 于丹：中法联培博士，2018 进站，赵忠尧奖学金，晨光杯二等奖，EPJC 1 篇。
 - 安芬芬：2017 进站，中美联培博士后，EPJC 1 篇
 - 赵祥虎：2018 进站，搭建 CEPC 软件服务
 - 唐光毅：于 CEPC 能量标定研究展开合作研究
- 学生
 - 赖培筑：同台湾中央大学联合指导，CEPC Note 2 篇，参与 EPJC 文章 1 篇
 - 吴志刚：同 CEPC VTX 组联合指导，CEPC Note 1 篇，1 篇 JINST 待投
 - 赵明锐：同原子能所联合指导，JINST 1 篇
 - 郑太范：同南大联合培养，CEPC Note 1 篇
 - 梁浩、朱永峰、王心怡、崔翰化：Proceeding 1 篇，CEPC Note 若干

关键合作

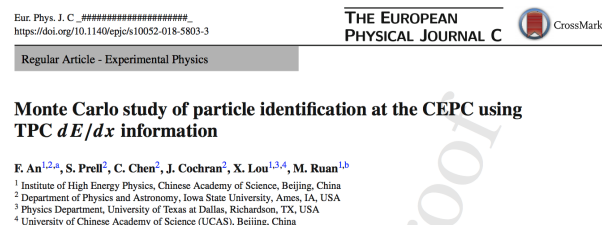
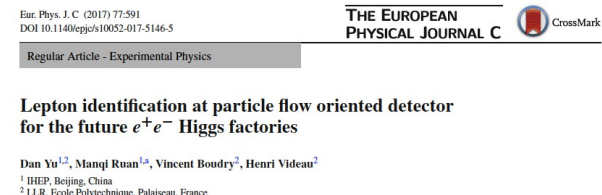
- 同法国 LLR、IPNL 以及 CALICE
 - 合作指导联合培养博士论文
 - 完成了电磁量能器优化研究
 - 积极参与高粒度量能器预研
- 同美国 Iowa State University 进行 dEdx, Pid 研究
- 同 LCTPC 合作组进行 TPC 适用性研究
- 同 CERN 进行快速模拟、粒子流算法、物理潜力合作研究
- 同 Whizard 合作组进行产生子合作研究
- 同台湾中研院及中央大学
 - 进行高粒度量能器研究
 - 完成喷注重建性能研究
- 同塞尔维亚 Vinca 研究所进行物理分析合作研究



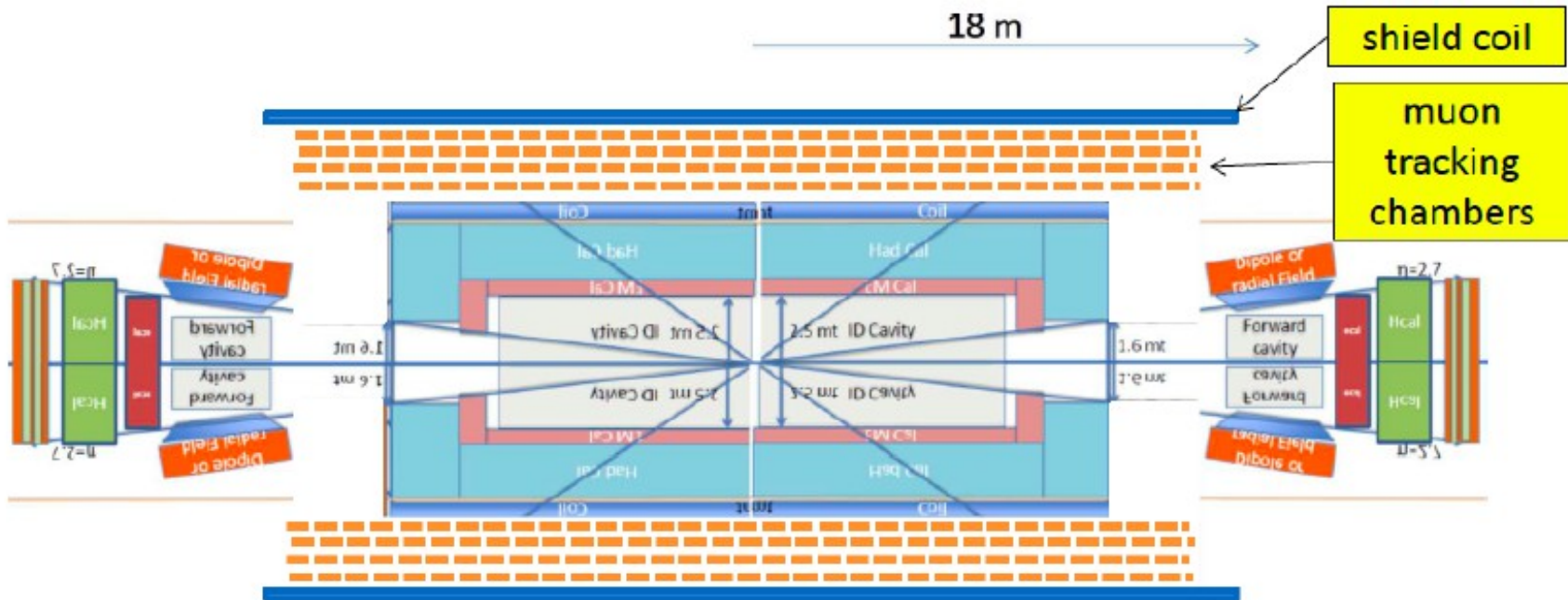
Journal of Instrumentation

Particle flow oriented electromagnetic calorimeter optimization for the circular electron positron collider

H. Zhao^{a,b,c}, C. Fu^a, D. Yu^{d,e}, Z. Wang^a, T. Hu^a and M. Ruan^a
Published 15 March 2018 • © 2018 IOP Publishing Ltd and Sissa Medialab
[Journal of Instrumentation, Volume 13, March 2018](#)

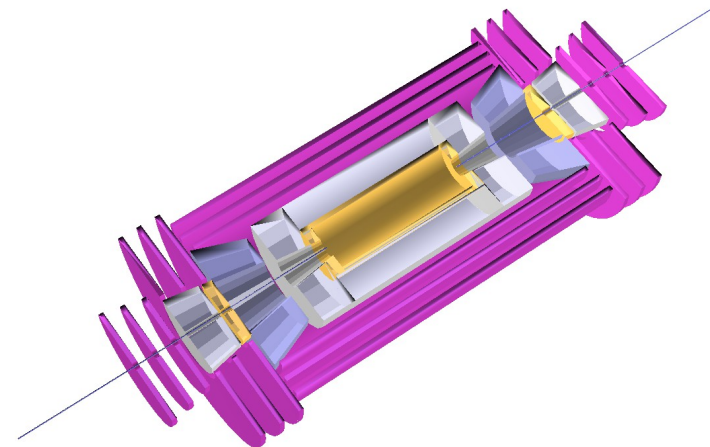


SPPC Conceptual detector



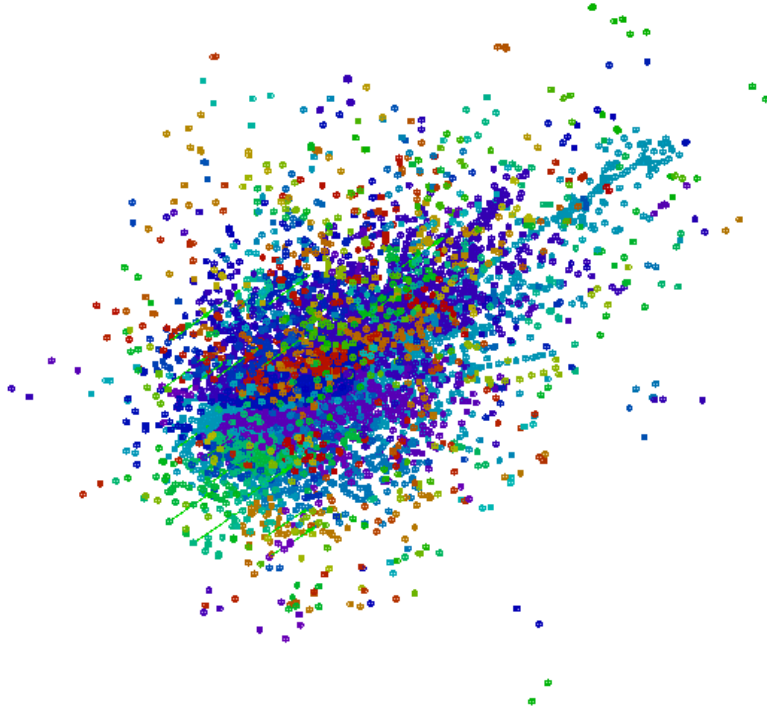
C. Young

Solenoid + dipole pairs



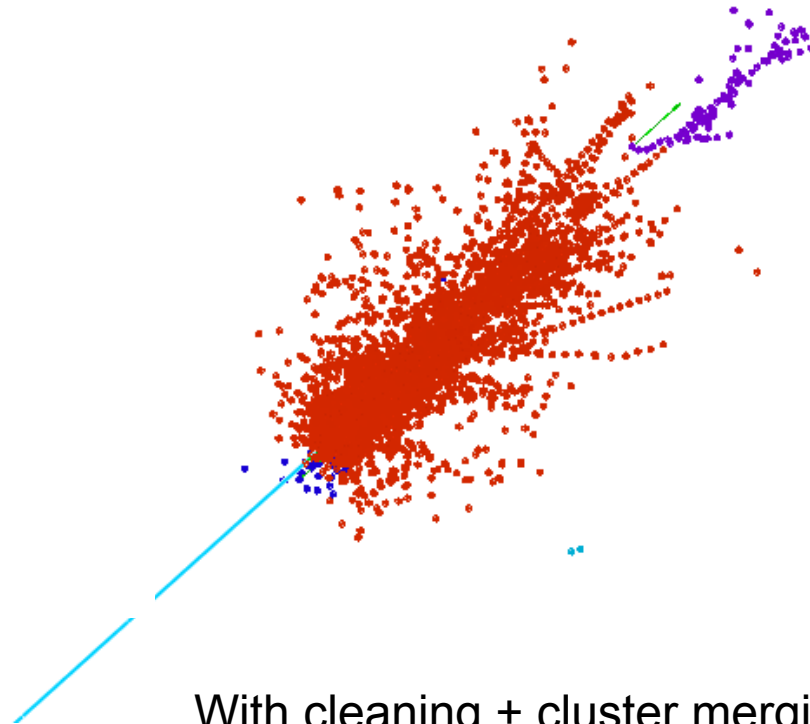
1 TeV pion reconstruction

DRUID, RunNum = 0, EventNum = 1



Original Version

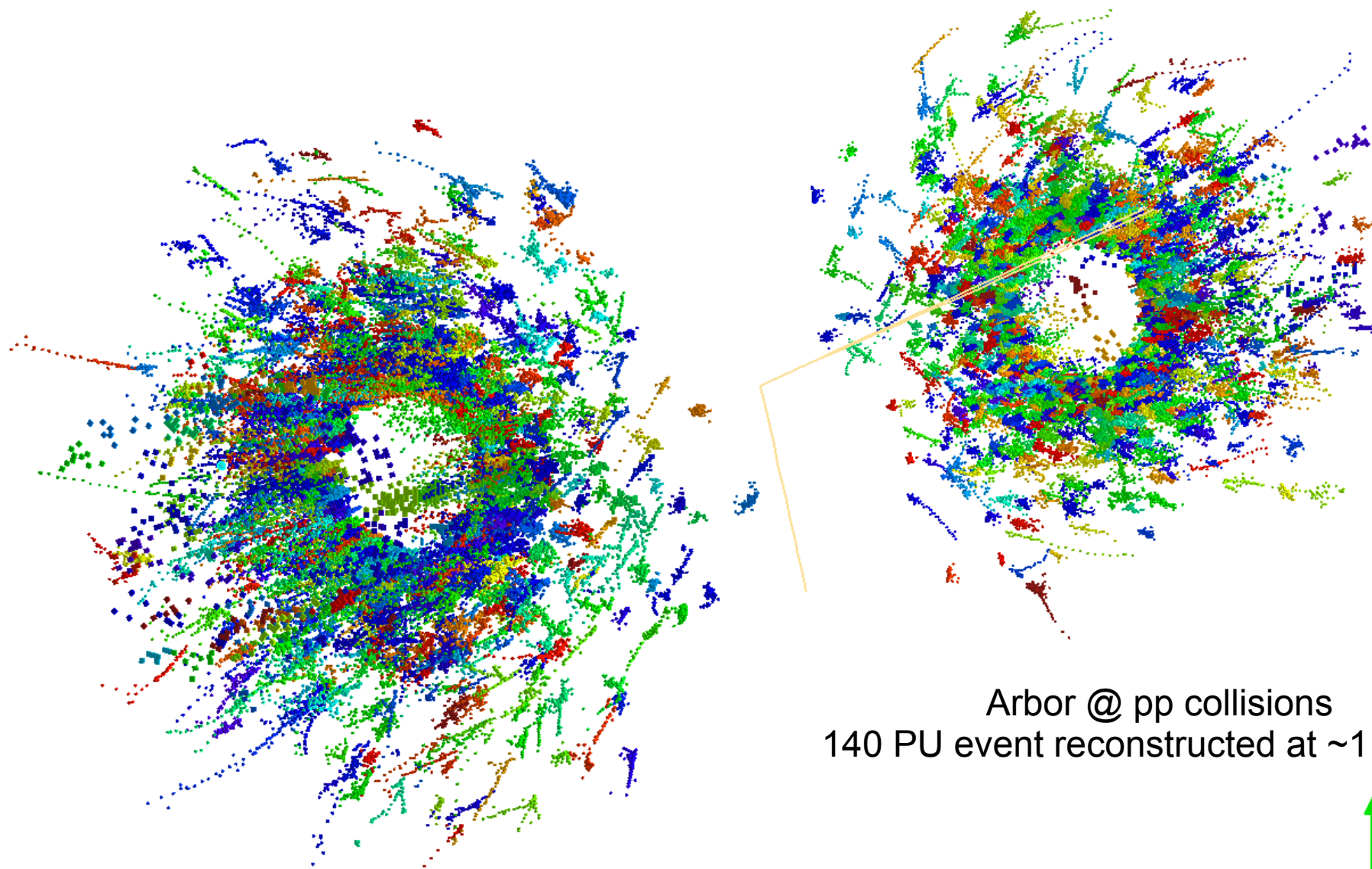
EventNum = 1



With cleaning + cluster merging



CMS Experiment at LHC, CERN
Data recorded: Thu Jan 1 01:00:00 1970 CEST
Run/Event: 1 / 1201
Lumi section: 13



Arbor @ pp collisions
140 PU event reconstructed at ~1 min/evt

