

CEPC 触发研究

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探测器模拟更新

- **CEPCSW**探测器：
 - 模拟的配置文件： `Detector/DetCRD/scripts/TDR_o1_v01/sim(track/calodigi).py`
 - 最新的版本号为 `tdr24.10.0`
 - Muon Barrel 更改为 6 层，加了数字化部分；还没有 Endcap 数字化
 - TPC 发现了 bug，丢失了 10MeV 以下的 track
 - 除了 OTK 端盖外，各子探测器都有模拟结果
- 本底样本计划等 bug 解决后才产生，现有的为 `tdr24.9.0`（9月底的版本）

触发： L1

- L1：量能器 + Muon 探测器 + (ITK?)
- 量能器：40x40 作用触发单元，计算能量及质心位置
 - 挑选能量过阈，质心靠近探测器对撞点的事例
 - 用机器学习（决策树）挑选信号事例
- Muon 探测器：
 - 数击中个数，桶部可行，端盖有大量来自本底的击中
 - 等探测器加石蜡作为挡板
 - 重建出 Muon 径迹
- ITK 径迹重建

触发： HLT

- 加入 TPC 做径迹重建
 - 需要等软件组解决 bug
- 计划使用离线重建软件
- 量能器有可能不需要 HLT

量能器触发方案 1

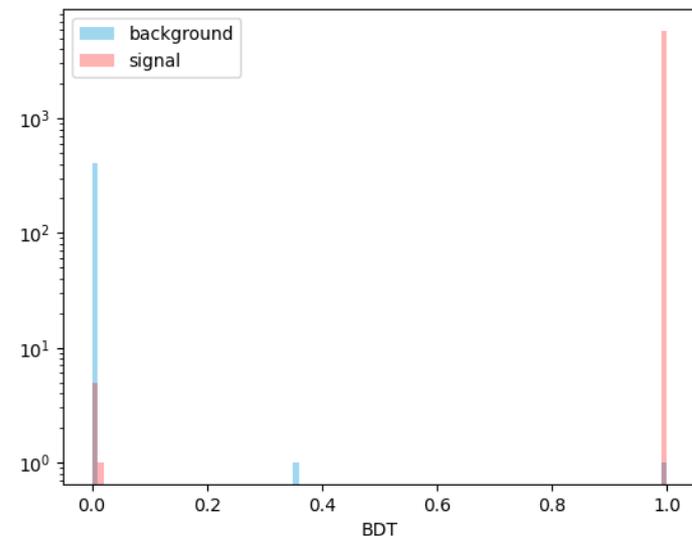
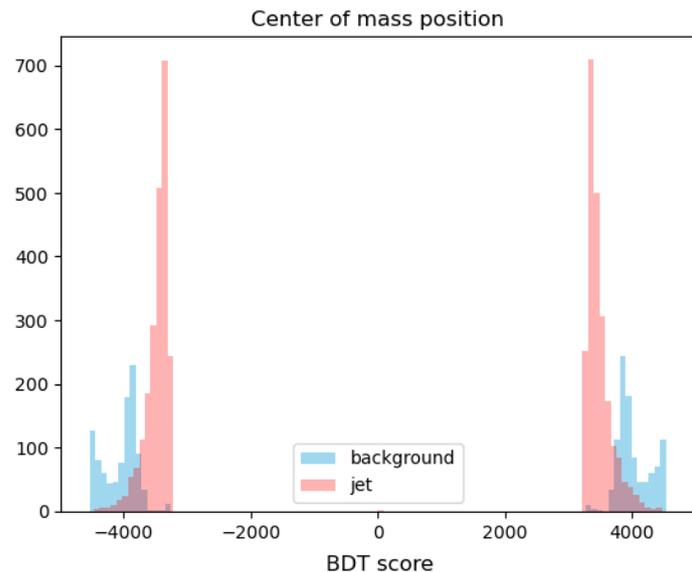
- 挑选能量最大的 40x40 的触发单元，判断是否过阈
- 束流本底压缩到 5% 以下，物理过程基本在 95% 以上

Sub-detector	Energy threshold
ECal Barrel	>0.5 GeV
or HCal Barrel	>0.5 GeV
or ECal Endcap	>5 GeV
or HCal Endcap	>50 GeV

Higgs decay channel	Efficiency
$Z(\nu\nu)H(\gamma\gamma)$	100%
$Z(\nu\nu)H(bb)$	100%
$Z(\nu\nu)H(Z\gamma)$	99.7%
$Z(\nu\nu)H(\tau\tau)$	96.7%
$Z(\nu\nu)H(WW)$	99.1%
$Z(\nu\nu)H(ZZ)$	95.8%
Beam background	4.8%

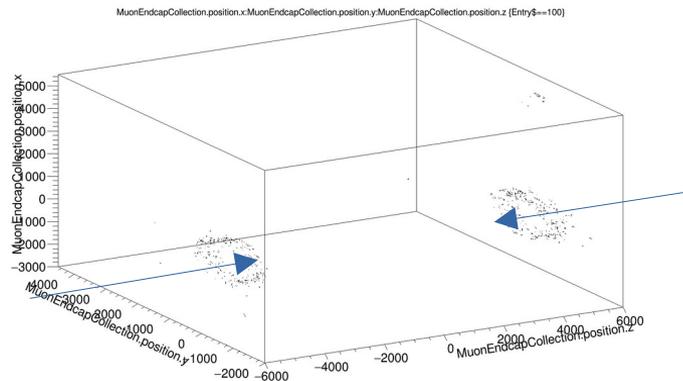
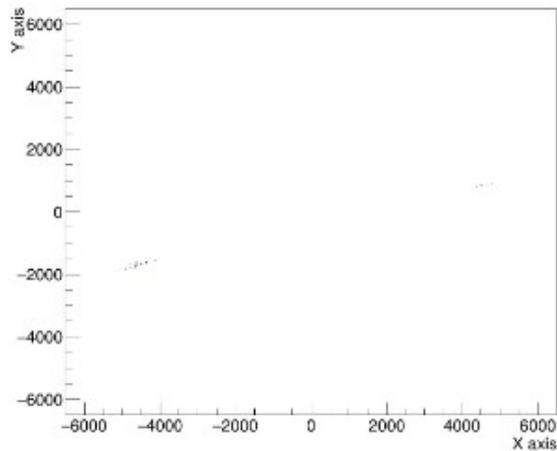
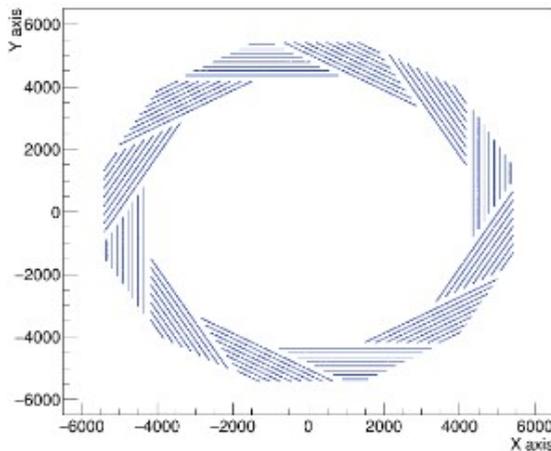
量能器触发方案 2

- 计算质心位置
 - 本底靠近外部，信号靠近内部，右上图为 HCal 端盖
- 用机器学习（BDT），以能量及质心位置作为输入，训练出 BDT 值
 - ECal/HCal，桶部 / 端盖，能量最大的两个 cluster 的能量及质心位置，总共 16 个参数作为输入
- signal 包括上一页提到的 Higgs 的所有过程
- 选择 BDT 阈值为 0.9，总的信号效率为 99.9%，本底为 0.25%
- Higgs：1.34MHz->3.4kHz
- 以后产生更多本底事例后能进一步改进



ITK/Muon

- 只考虑能量较高的粒子的径迹
- 径迹几乎为一条直线，用直线拟合
- 拟合后对照 ITK 及 Muon 的结果挑选出产生了 muon 子的事例
- Muon 端盖（下图）：等探测器更新，加入挡板



gamma-gamma 事例

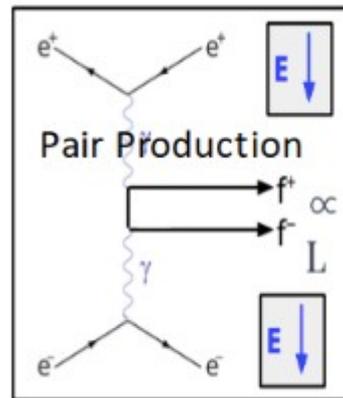
- IDRC 评审：双光子碰撞
- 束流本底中 pair production

Comments

The detailed (bottom-up) design of the TDAQ must await further details on the subdetector design.

Work on the trigger primitives is needed to bring the rate down to an acceptable input for the second-level trigger, and to inform further planning for the processing farms in the DAQ design. Should it be needed, a track trigger could provide a powerful additional primitive.

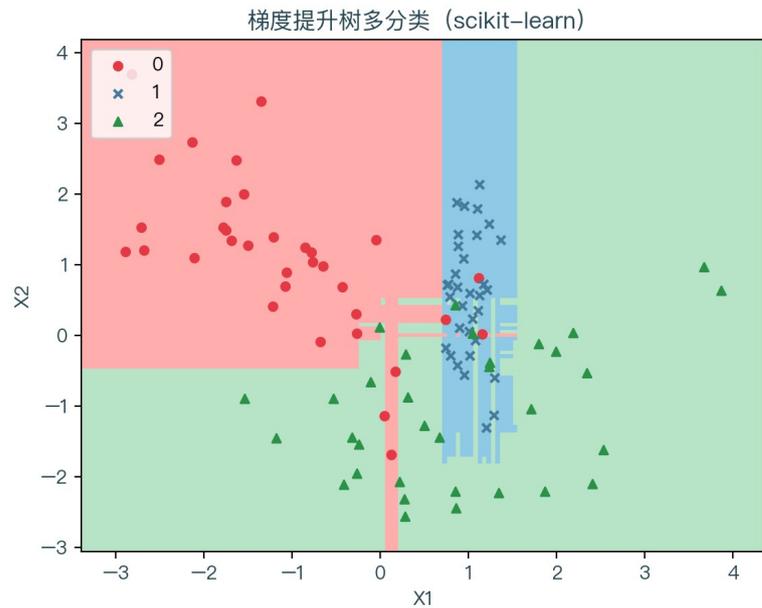
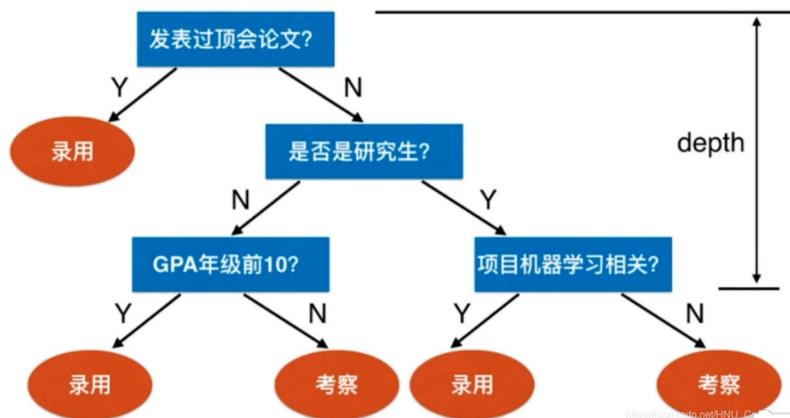
High-level triggering will also need to weigh the physics-versus-bandwidth tradeoff for lower-energy events, e.g. from [gamma-gamma collisions](#).



backup

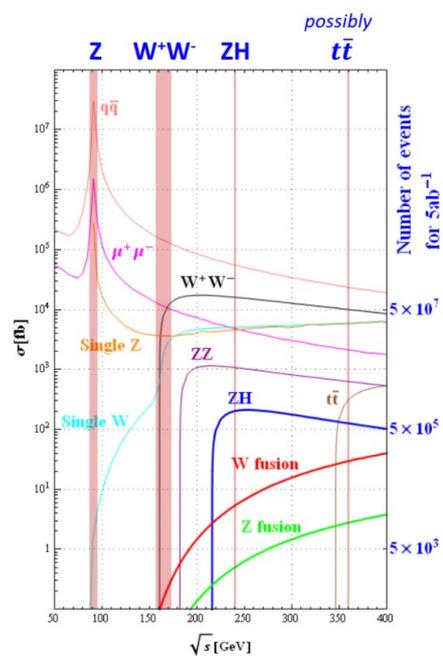
决策树 (BDT) 模型

招聘机器学习
算法工程师



CEPC 物理过程 / 事例率

- 四个模式，对应四个质心能量（50MW）
 - Z(91GeV, 23ns, 192E34), ~83kHz
 - Higgs(240 GeV, 346ns, 8.3E34)： Higgs 粒子的产生频率：
~0.02*Hz；所有物理过程共 ~8Hz
 - W(160 GeV, 139ns, 27E34)； tt(360 GeV, 2700ns, 0.8E34)
- 一级触发
 - 量能器 + Muon 探测器
- 高级触发
 - 全探测器信息



Operation mode		ZH	Z	W+W-	tt
\sqrt{s} [GeV]		~240	~91	~160	~360
Run Time [years]		10	2	1	5
30 MW	L / IP [$\times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	5.0	115	16	0.5
	$\int L dt$ [ab^{-1} , 2 IPs]	13	60	4.2	0.65
	Event yields [2 IPs]	2.6×10^6	2.5×10^{12}	1.3×10^8	4×10^5
50 MW	L / IP [$\times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	8.3	192	26.7	0.8
	$\int L dt$ [ab^{-1} , 2 IPs]	21.6	100	6.9	1
	Event yields [2 IPs]	4.3×10^6	4.1×10^{12}	2.1×10^8	6×10^5

CEPC accelerator TDR (Xiv:2312.14363)

强子量能器

- Link

- 能量到 MIP 的转换

- 瓷砖非均匀性

- SiPM 饱和效应

- 模拟到数字转换

- MIP 到能量

- 能量校准

```
150     if(!_UseRelDigi){
151         // -- Scintillation (Energy -> MIP -> Np.e.)
152         int sPix = gRandom->Poisson(Ehit / _MIPCalI * (_MIPADC / _PeADCMean));
153         Npe_scint = sPix;
154         // -- Tile non-uniformity
155         sPix = sPix * (1.0 + gRandom->Uniform(-_TileRes, _TileRes));
156         // -- SiPM Saturation (Np.e. -> Npixel)
157         sPix = std::round(_Pixel * (1.0 - TMath::Exp(-sPix * 1.0 / _Pixel)));
158         Npe_SiPM = sPix;
159         // -- ADC response (Npixel -> ADC)
160         double sChargeMean = sPix * _PeADCMean;
161         double sChargeSigma = sqrt(sPix * _PeADCSigma * _PeADCSigma);
162         sChargeOut = gRandom->Gaus(sChargeMean, sChargeSigma);
163         // -- (ADC->MIP)
164         sChargeOutHG = sChargeOut + gRandom->Gaus(_BaselineHG, _BaselineSigmaHG);
165         sChargeOutLG = sChargeOut / _HLRatio + gRandom->Gaus(_BaselineLG, _BaselineSigmaLG);
166         sChargeOutHG = std::round(gRandom->Gaus(sChargeOutHG, sChargeOutHG * _ADCErr));
167         sChargeOutLG = std::round(gRandom->Gaus(sChargeOutLG, sChargeOutLG * _ADCErr));
168         if (sChargeOutLG > _ADCLimit)
169             sChargeOutLG = _ADCLimit;
170         Double_t sMIP = 0;
171         if (sChargeOutHG > _ADCSwitch)
172             {
173                 sMIP = (sChargeOutLG - _BaselineLG) * _HLRatio / _MIPADC;
174                 sChargeOutHG = _ADCSwitch;
175             }
176         else
177             {
178                 sMIP = (sChargeOutHG - _BaselineHG) / _MIPADC;
179             }
180         Ehit = sMIP * _MIPCalI;
181     }
182     if(Ehit < _MIPCalI*_Eth_Mip) continue;
183
184     //Global calibration.
185     //TODO: add more digitization terms here.
186     double Ehit_calI = Ehit*_r_calI;
```

电磁量能器

- [Link](#)
- 时间数字化
- 计算两侧的累积电荷 $thQ1$ 和 $thQ2$
- 当累积电荷超过这个阈值时，认为已经达到了信号的显著部分，作为信号的时间

```
//if(_Debug>=2) std::cout<<"Time Digitalize: time at Q "<<_Qthfrac<<"*totQ"<<std::endl;
std::sort(DigiLvec.begin(), DigiLvec.end());
std::sort(DigiRvec.begin(), DigiRvec.end());
double thQ1=0;
double thQ2=0;
double thT1, thT2;
for(int iCont=0;iCont<DigiLvec.size();iCont++){
    thQ1 += DigiLvec[iCont].getQ();
    if(thQ1>totQ1*_Qthfrac){
        thT1 = DigiLvec[iCont].getT();
        if(_Debug>=3) std::cout<<"Get T1 at index: "<<iCont<<std::endl;
        break;
    }
}
for(int iCont=0;iCont<DigiRvec.size();iCont++){
    thQ2 += DigiRvec[iCont].getQ();
    if(thQ2>totQ2*_Qthfrac){
        thT2 = DigiRvec[iCont].getT();
        if(_Debug>=3) std::cout<<"Get T2 at index: "<<iCont<<std::endl;
        break;
    }
}
```

电磁量能器

• Link

• 能量数字化

• 能量到 MIP 的转换

• 模拟到数字转换

- 高斯分布模拟 ADC 的噪声
- 根据信号的大小选择合适的增益阶段进行转换
- 函数最终返回数字化后的能量值

```
if(fUseDigiScint)
    ScinGen = std::round(gRandom->Poisson((totQ1_Truth+totQ2_Truth)*1000 / fEcalMIPEnergy * sEcalCryMipLY));

// ##### ADC Digitization #####
// #####

Bool_t Use_G1 = kFALSE;
Bool_t Use_G2 = kFALSE;
Bool_t Use_G3 = kFALSE;

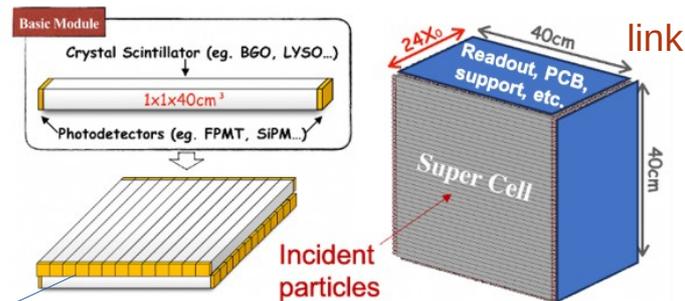
Double_t sADCMean = sPix * fEcalChargeADCMean;
Double_t sADCSigma = std::sqrt(sPix * fEcalChargeADCSigma * fEcalChargeADCSigma + fEcalNoiseADCSigma * fEcalNoiseADCSigma);
Int_t sADC = -1;
if(fUseDigiADC){
    sADC = std::round(gRandom->Gaus(sADCMean, sADCSigma));
}
if(sADC <= fADCSwitch){
    Use_G1 = kTRUE;
    sADC = std::round(gRandom->Gaus(sADC, fEcalADCErrror * sADC));
    Double_t sMIP = sADC / fEcalChargeADCMean / sEcalCryMipLY;
    if(sMIP < fEcalMIP_Thre) return 0;
    return sMIP * fEcalMIPEnergy;
}
else if(sADC > fADCSwitch && int(sADC/fGainRatio_12) <= fADCSwitch){
    Use_G2 = kTRUE;
    sADCMean = sPix * fEcalChargeADCMean / fGainRatio_12;
    sADCSigma = std::sqrt(sPix * fEcalChargeADCSigma / fGainRatio_12 * fEcalChargeADCSigma / fGainRatio_12 + fEcalNoiseADCSigma * fEcalNoiseADCSigma);
    sADC = std::round(gRandom->Gaus(sADCMean, sADCSigma));
    sADC = std::round(gRandom->Gaus(sADC, fEcalADCErrror * sADC));
    Double_t sMIP = sADC / fEcalChargeADCMean * fGainRatio_12 / sEcalCryMipLY;
    if(sMIP < fEcalMIP_Thre) return 0;
    return sMIP * fEcalMIPEnergy;
}
else if(int(sADC/fGainRatio_12) > fADCSwitch){
    Use_G3 = kTRUE;
    sADCMean = sPix * fEcalChargeADCMean / fGainRatio_12 / fGainRatio_23;
    sADCSigma = std::sqrt(sPix * fEcalChargeADCSigma / fGainRatio_12 / fGainRatio_23 * fEcalChargeADCSigma / fGainRatio_12 / fGainRatio_23 + fEcalNoiseADCSigma * fEcalNoiseADCSigma);
    sADC = std::round(gRandom->Gaus(sADCMean, sADCSigma));
    sADC = std::round(gRandom->Gaus(sADC, fEcalADCErrror * sADC));
    if (sADC > fADC-1) sADC = fADC-1;
    Double_t sMIP = sADC / fEcalChargeADCMean * fGainRatio_12 * fGainRatio_23 / sEcalCryMipLY;
    if(sMIP < fEcalMIP_Thre) return 0;
    return sMIP * fEcalMIPEnergy;
}
}
```

束流本底

- 50MW 束流本底：
 - 石老师已经产生了 2000 个 Higgs 束流本底，包括 single 和 pair ，可以用于触发研究
- Higgs 同步辐射及 Z 的束流本底还在跑
- 下次本底讨论在这周六（10月12号）早上9点

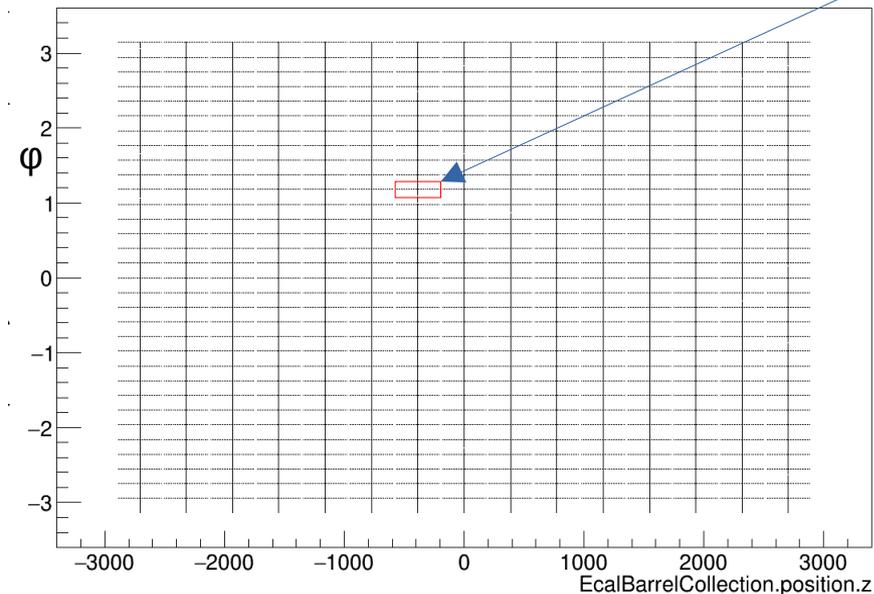
电磁量能器

- 左下图： barrel 圆心角 φ vs z ；右下图： endcap x vs y
- “线”与“线”之间距离约为 40cm；相邻两“点”之间距离约为 1cm
- 右上：电磁量能器模块示意图

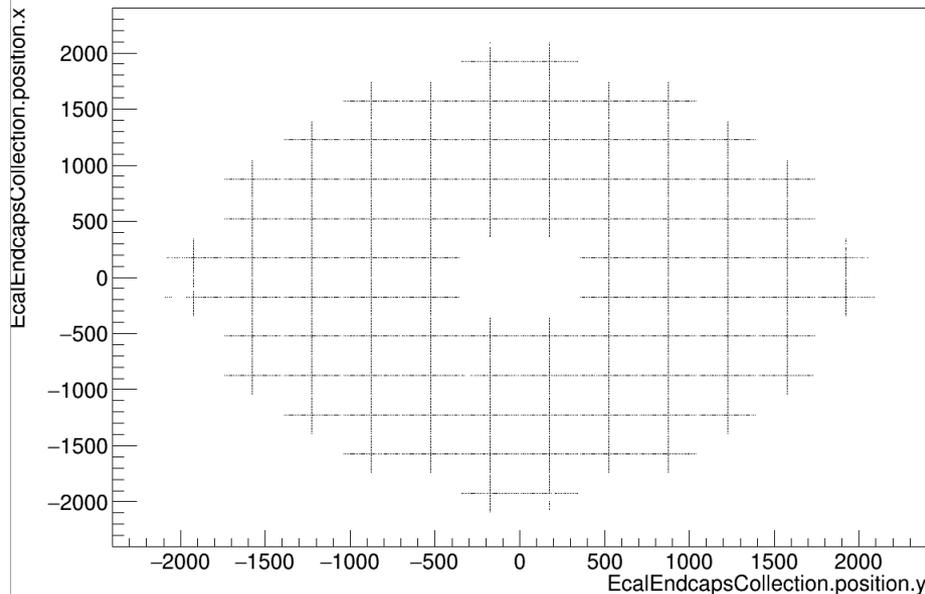


- **BGO bars in $1 \times 1 \times \sim 40 \text{ cm}^3$**
- **Effective granularity $1 \times 1 \times 2 \text{ cm}^3$**
- **Modules with cracks not pointing to IP (with an inclined angle of 12 degrees)**

atan2(EcalBarrelCollection.position.y,EcalBarrelCollection.position.x):EcalBarrelCollection.position.z



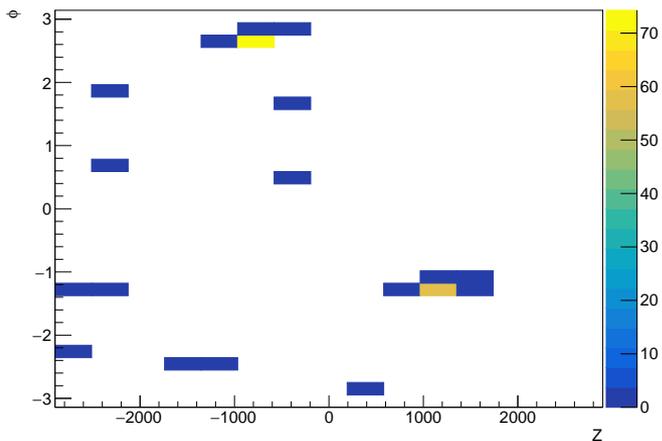
EcalEndcapsCollection.position.x:EcalEndcapsCollection.position.y



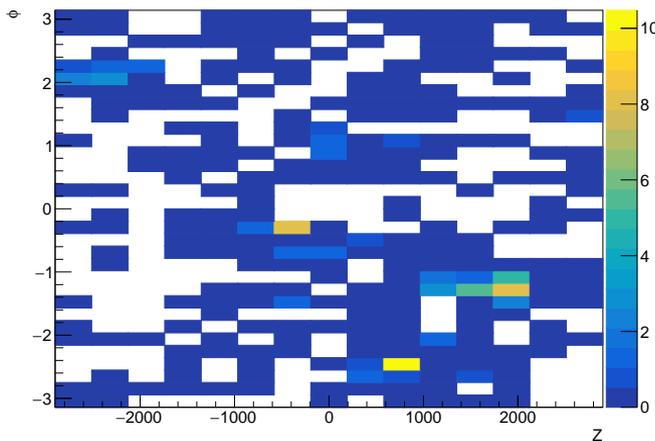
ECal barrel 能量分布

- 左: $nn\Upsilon\Upsilon$; 中: $nnbb$; 右: 束流本底
- 对物理过程, 在量能器上能量沉积比较大且集中
- 可以挑选能量最高的两个 cluster 来做判别

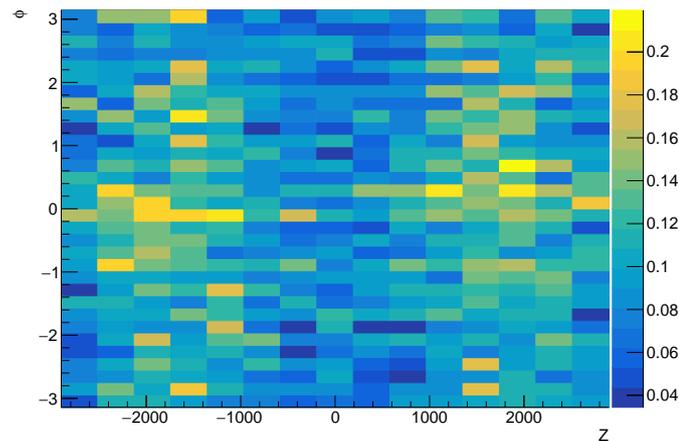
Photon ECal Barrel



Jet ECal Barrel



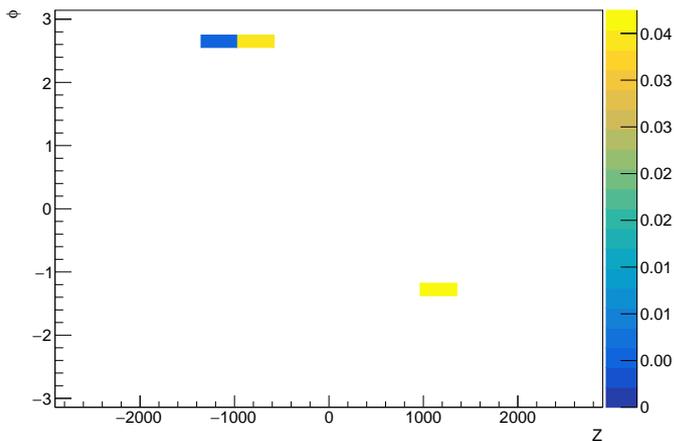
Beam bkg ECal Barrel



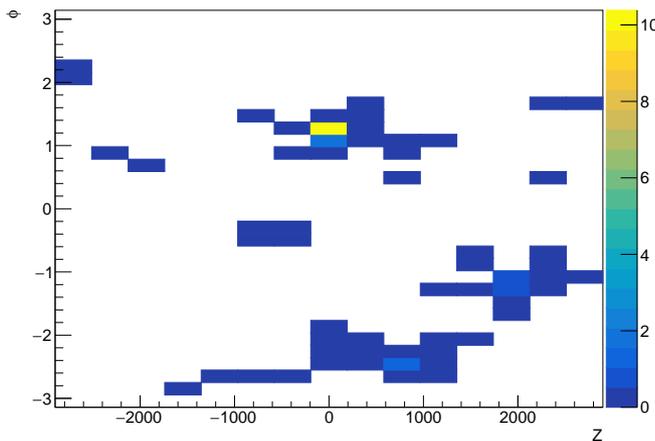
HCal barrel 能量分布

- 左: $n\gamma\gamma$; 中: nbb ; 右: 束流本底

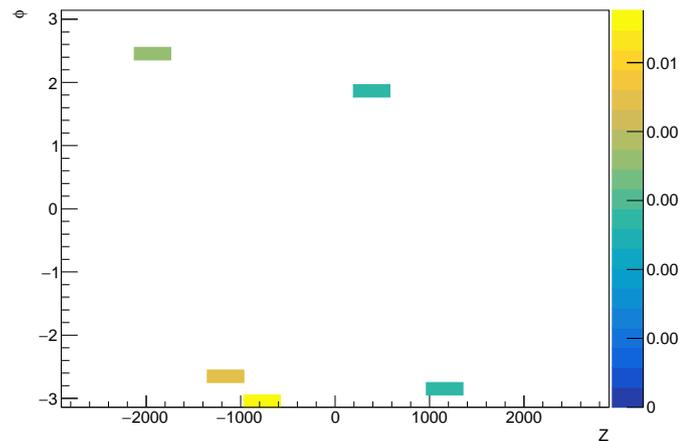
Photon HCal Barrel



Jet HCal Barrel



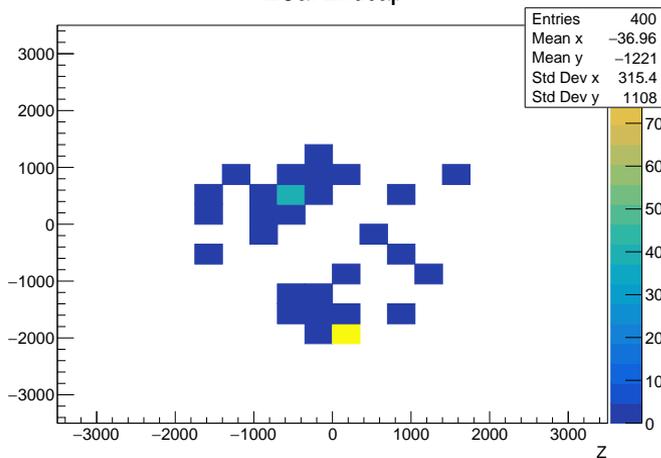
Beam bkg HCal Barrel



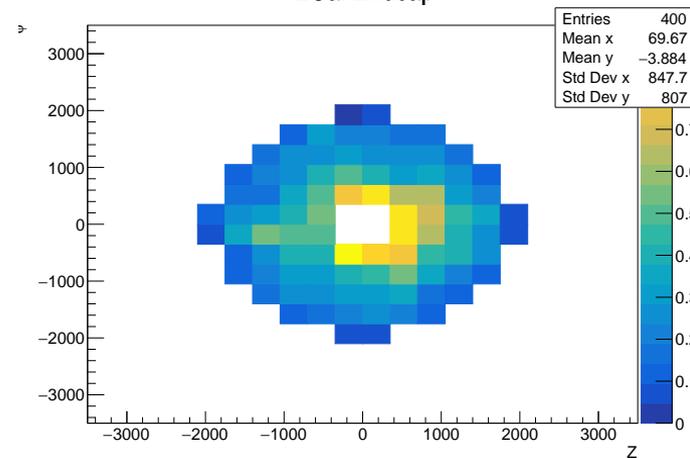
ECal endcap 能量分布

- 左: $nn\Upsilon$; 中: $nnbb$; 右: 束流本底
- 对物理过程, 在量能器上能量沉积比较大且集中
- 可以挑选能量最高的两个 cluster 来做判别

ECal Endcap

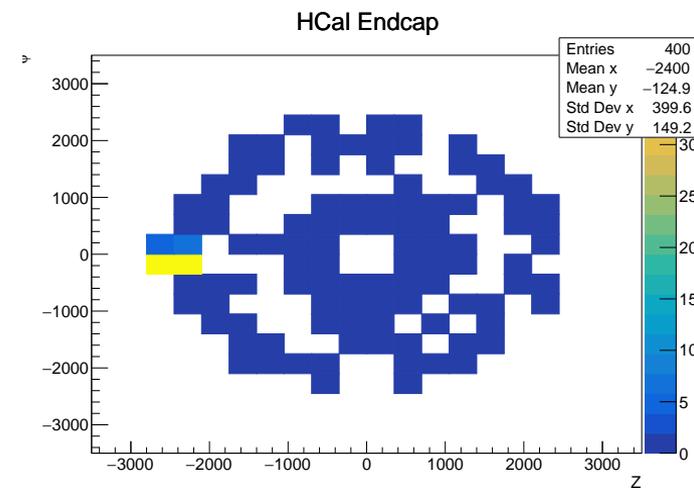
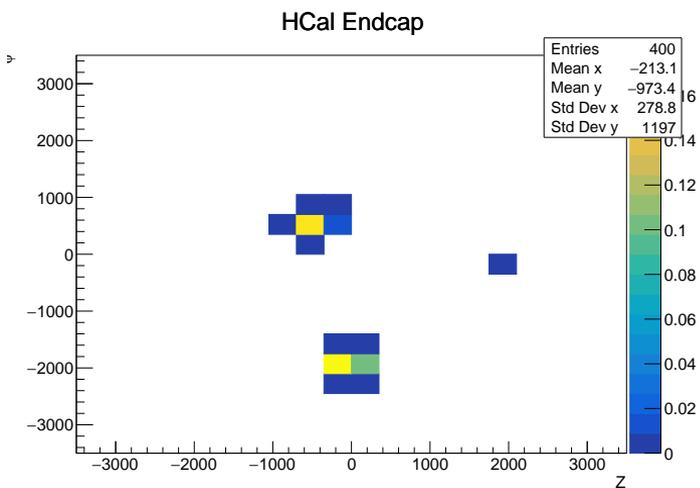


ECal Endcap



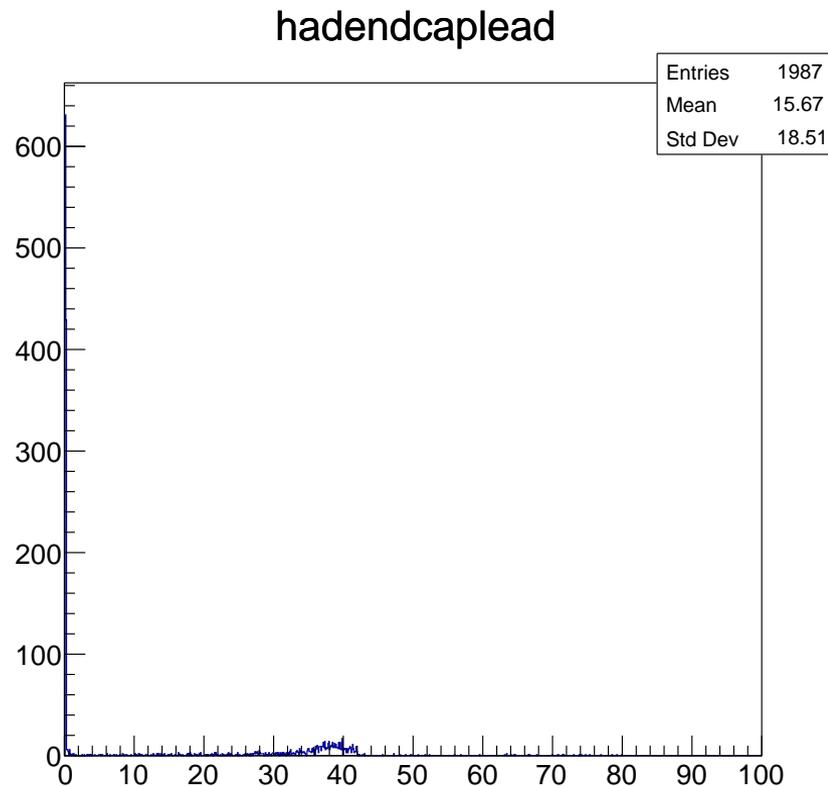
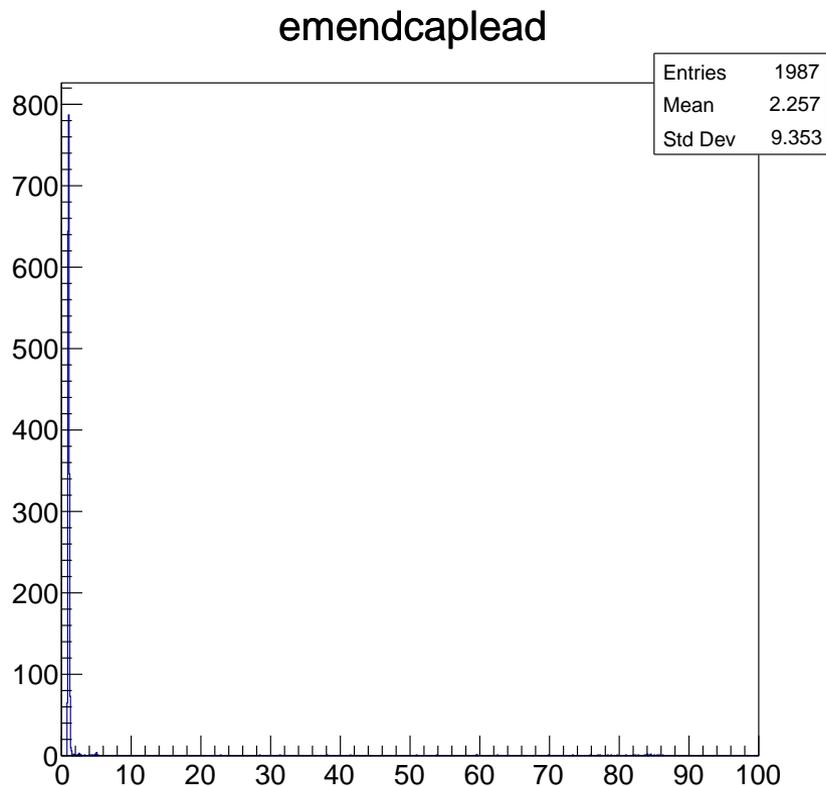
HCal endcap 能量分布

- 左: $nn\Upsilon\Upsilon$; 中: $nnbb$; 右: 束流本底



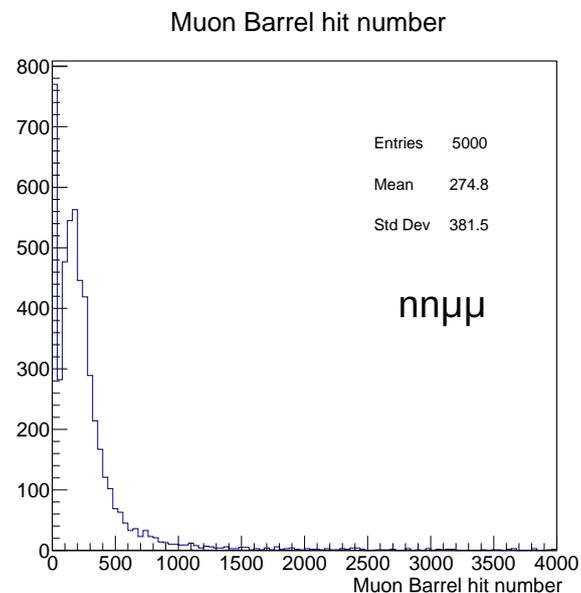
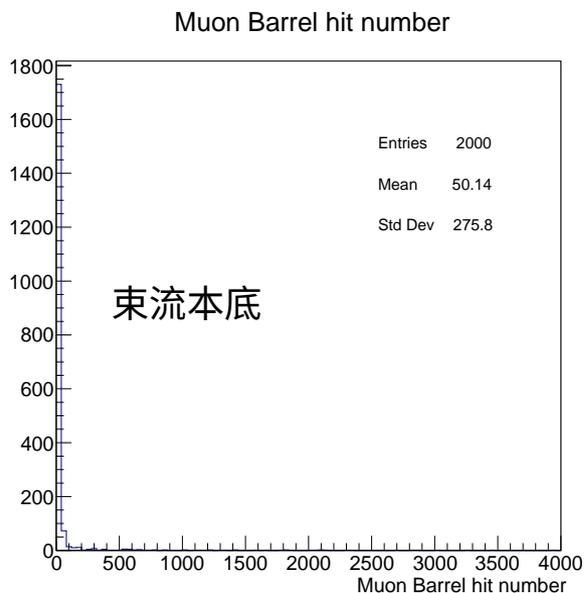
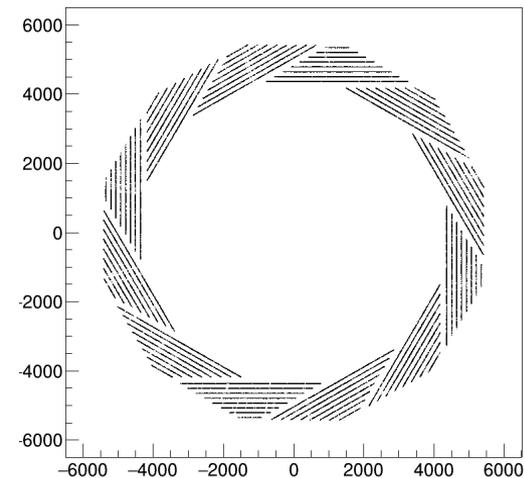
HCal endcap 能量分布

- 左: ECal; 右: Hcal



Muon Barrel hit

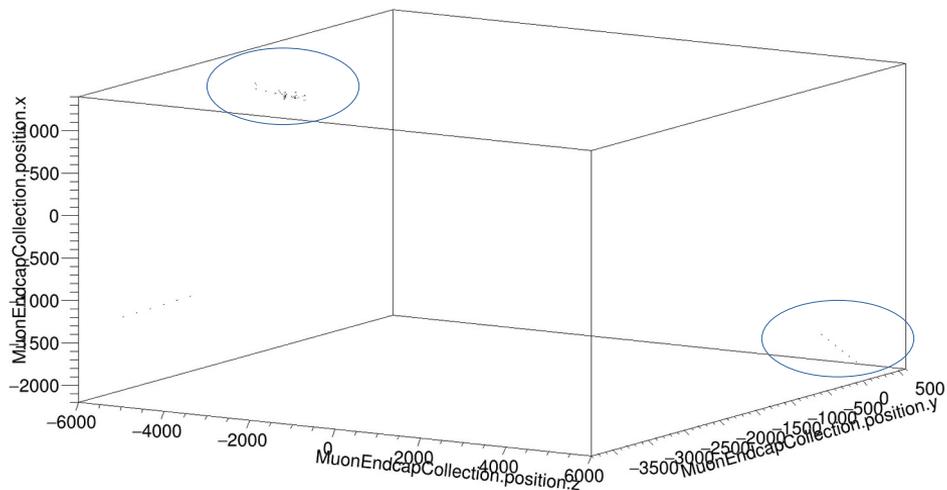
- 大部分本底过程的 hit 的个数非常小
- 左： 2000 个束流本底； 右： 1000 个 $ZH \rightarrow n\mu\mu$ ；
- $N_{hit} > 10$ 效率； $n\mu\mu$: 95% ； higgs 束流本底本底 24%



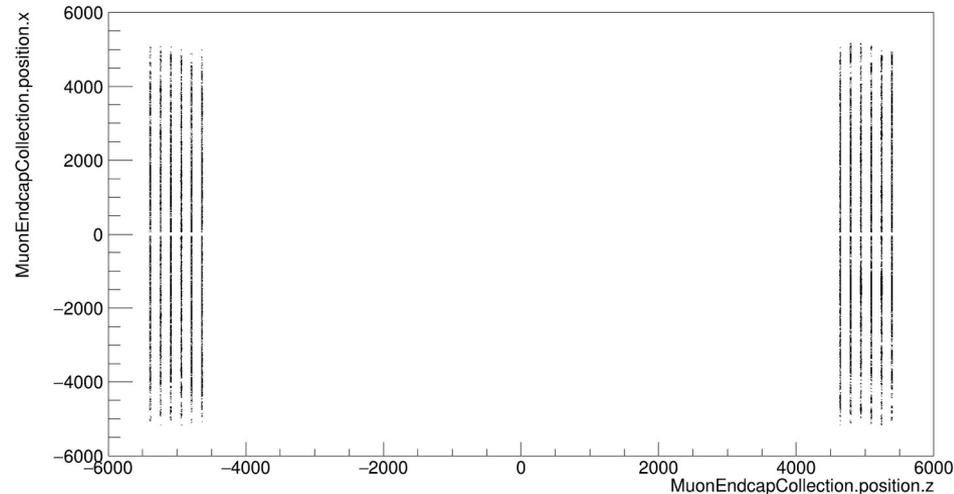
Muon Endcap

- 1000 个 $ZH \rightarrow n\mu\mu$ 事例
 - 右上: xz 平面
 - 右下: 3D 分布
- 左下: 单个 $n\mu\mu$ 事例

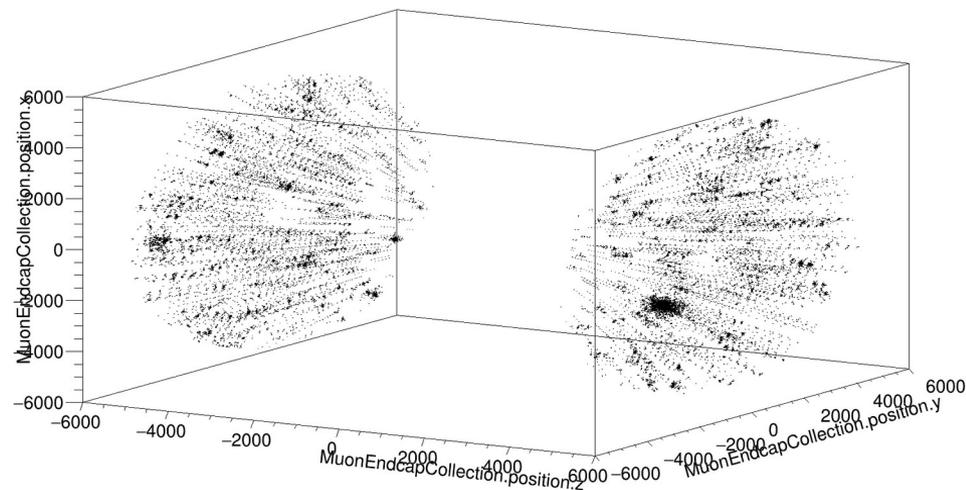
MuonEndcapCollection.position.x:MuonEndcapCollection.position.y:MuonEndcapCollection.position.z (Entry\$==100)



MuonEndcapCollection.position.x:MuonEndcapCollection.position.z

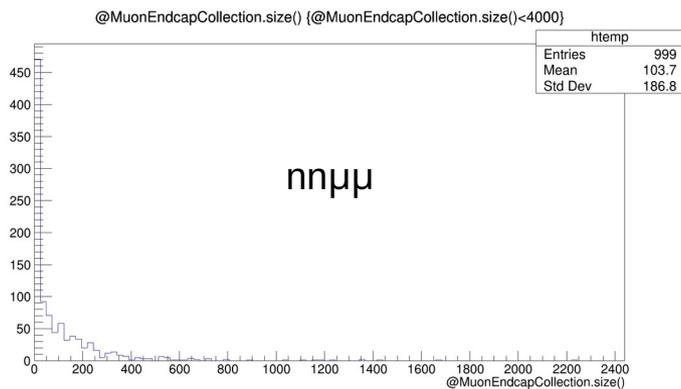
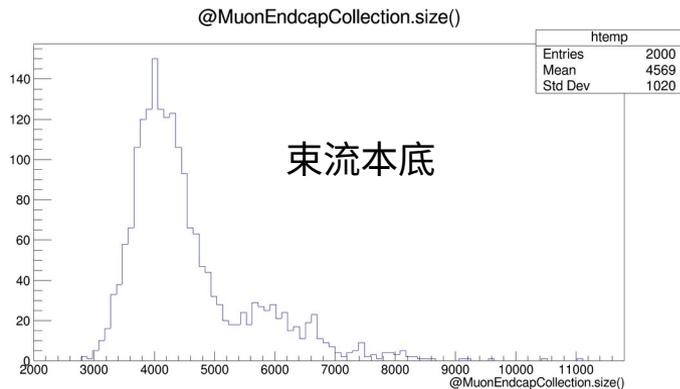
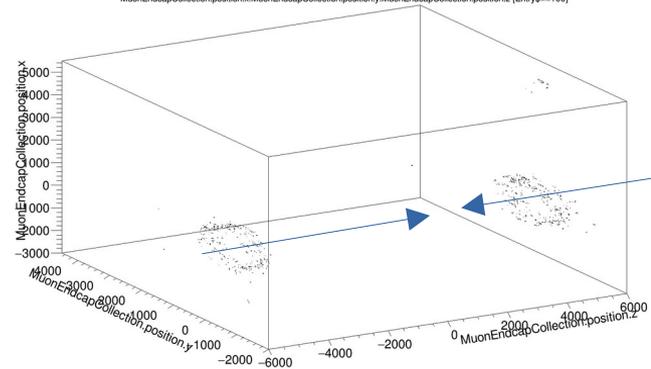
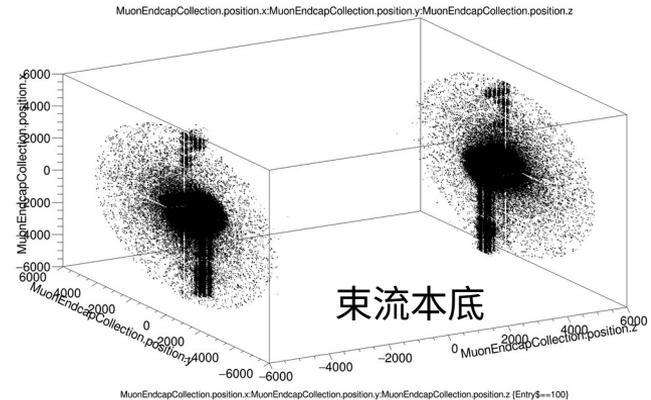


MuonEndcapCollection.position.x:MuonEndcapCollection.position.y:MuonEndcapCollection.position.z



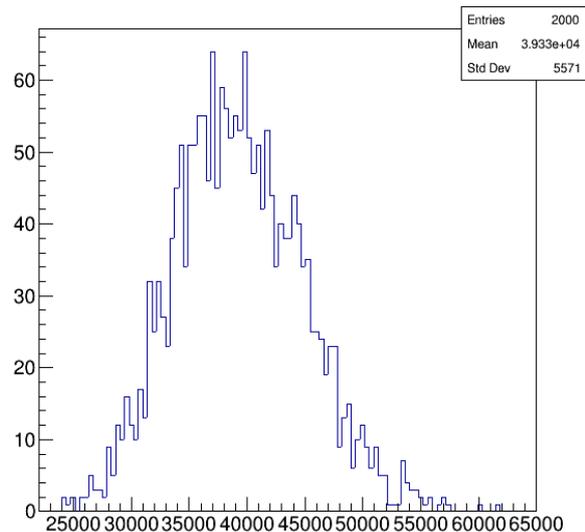
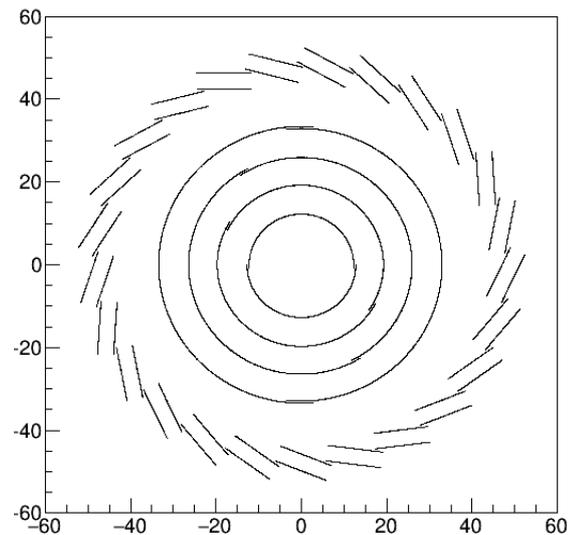
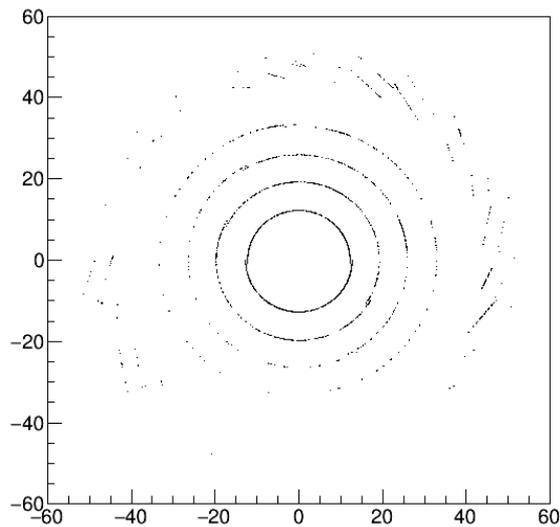
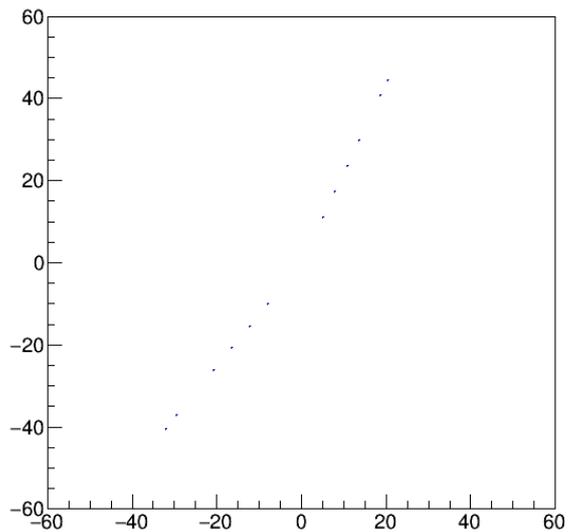
Muon Endcap

- 右图：束流本底 3D 分布，箭头为正负电子方向
 - 上：2000 个束流本底；下：单个本底事例，接近 4000 个 hit
- 下图：hit 的个数分布
 - 左：2000 个束流本底；右：1000 个 $ZH \rightarrow n\mu\mu$
- 束流本底在 endcap 上有大量的 hit
- 在 Muon Endcap 上做触发非常困难



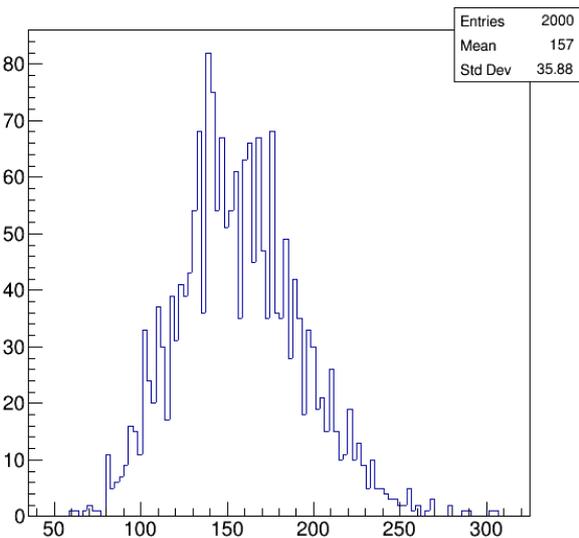
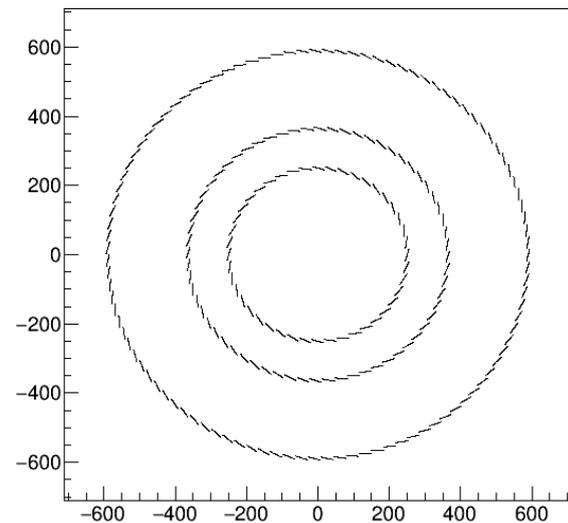
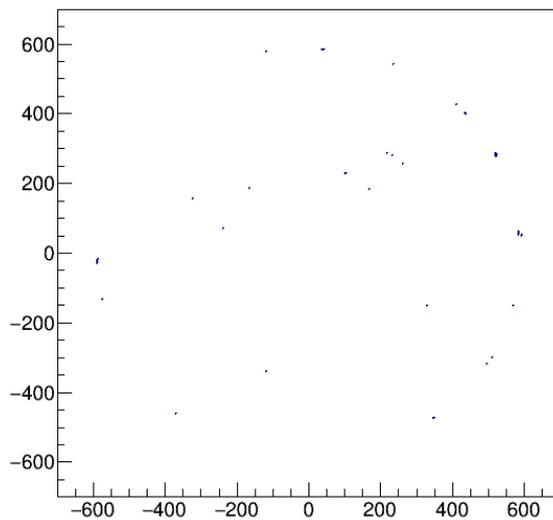
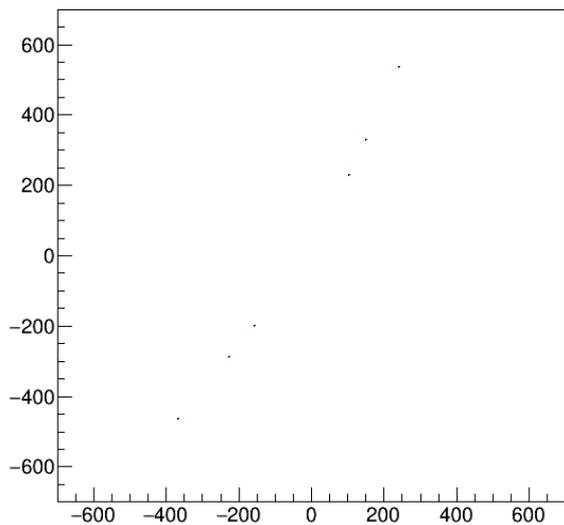
Vertex

- 左：单个 $ZH \rightarrow n\mu\mu$ 事例
- 中：单个束流本底事例
- 右：束流本底 Vertex hit 数量分布



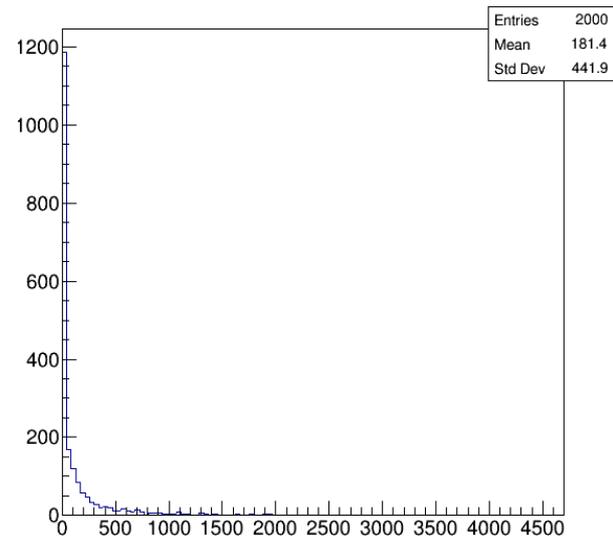
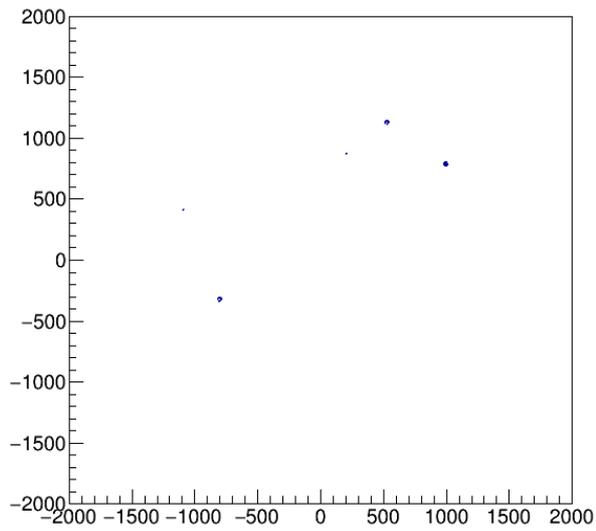
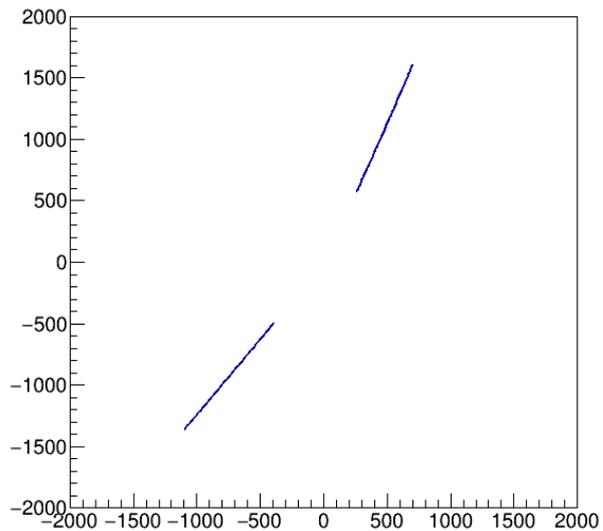
ITK

- 左：单个 $ZH \rightarrow nn\mu\mu$ 事例
- 中：单个束流本底事例
- 右：束流本底 Vertex hit 数量分布



TPC

- 左：单个 $ZH \rightarrow nn\mu\mu$ 事例
- 中：单个束流本底事例
- 右：束流本底 Vertex hit 数量分布



OTK

- 左：单个 $ZH \rightarrow nn\mu\mu$ 事例
- 中：单个束流本底事例
- 右：束流本底 Vertex hit 数量分布

