

TPC探测器的软件开发和数据分析

Yankun Sun (孙艳坤)

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*Institute of High energy physics, CAS, China
China Spallation Neutron Source (CSNS)*



中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

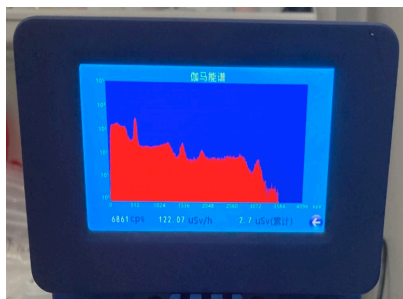
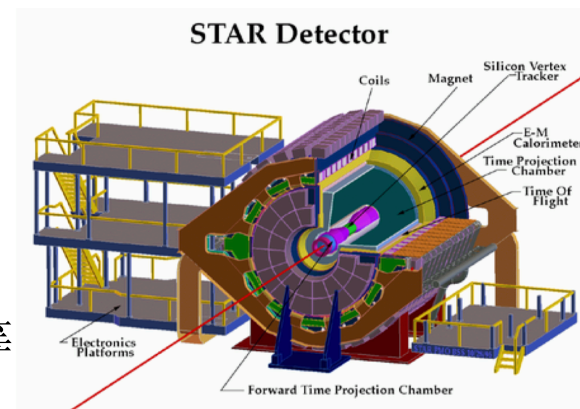


中国散裂中子源
China Spallation Neutron Source

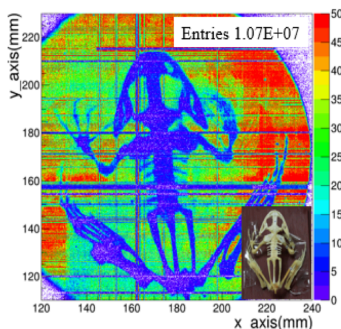
时间投影室

✓ 时间投影室（TPC）

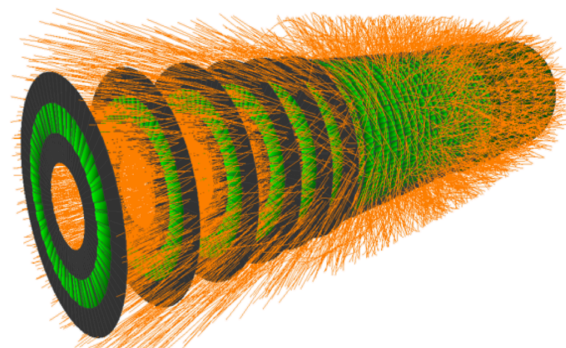
- 目前最先进的气体探测器，可以高精度的重建粒子的三维径迹
- 探测器优点
 - 接近 4π 几何接受度
 - 可以探测低能到高能带电粒子
- 应用领域
 - 高能粒子物理：STAR TPC探测器
 - 核物理：核截面数据，核结构的测量等
 - 核天体物理：元素的合成



一维-能谱



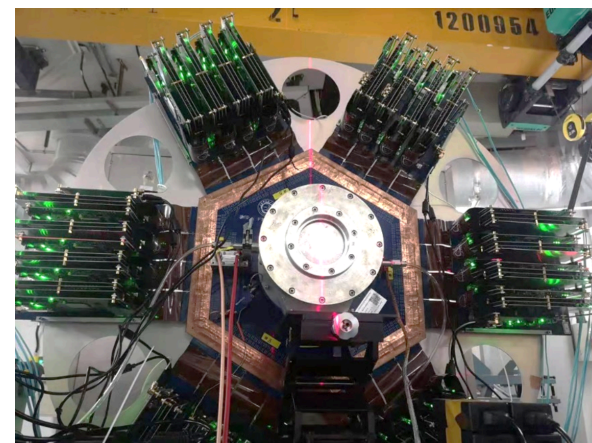
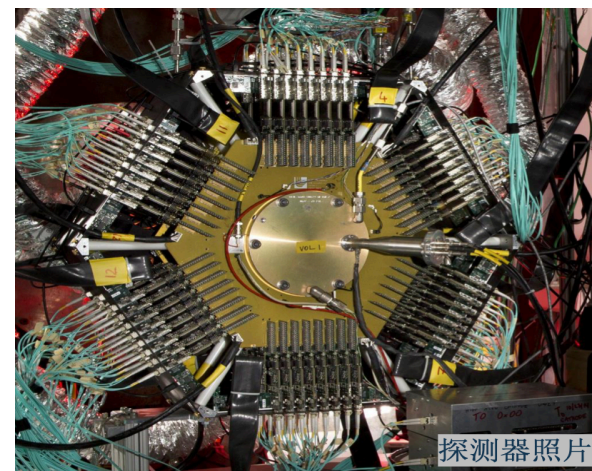
二维-图像



三维-空间径迹

时间投影室

- ✓ 美国洛斯阿拉莫斯中子科学中心
 - 建成了国际上第一台核数据测量TPC
 - 武器研究机构
 - NIFFTE合作组成员主要来自美国本土
- ✓ 散裂中子源
 - 国内上第一台核数据测量TPC
 - 项目挑战
 - 庞大的电子学读出：
 1. 当前：1519通道数
 2. 未来：近万通道数
 - 复杂的数据分析：
 1. 数据质量检查、刻度
 2. 径迹重建算法
 3. 粒子鉴别算法
 4. 物理参数测量
 5. 系统误差分析



时间投影室

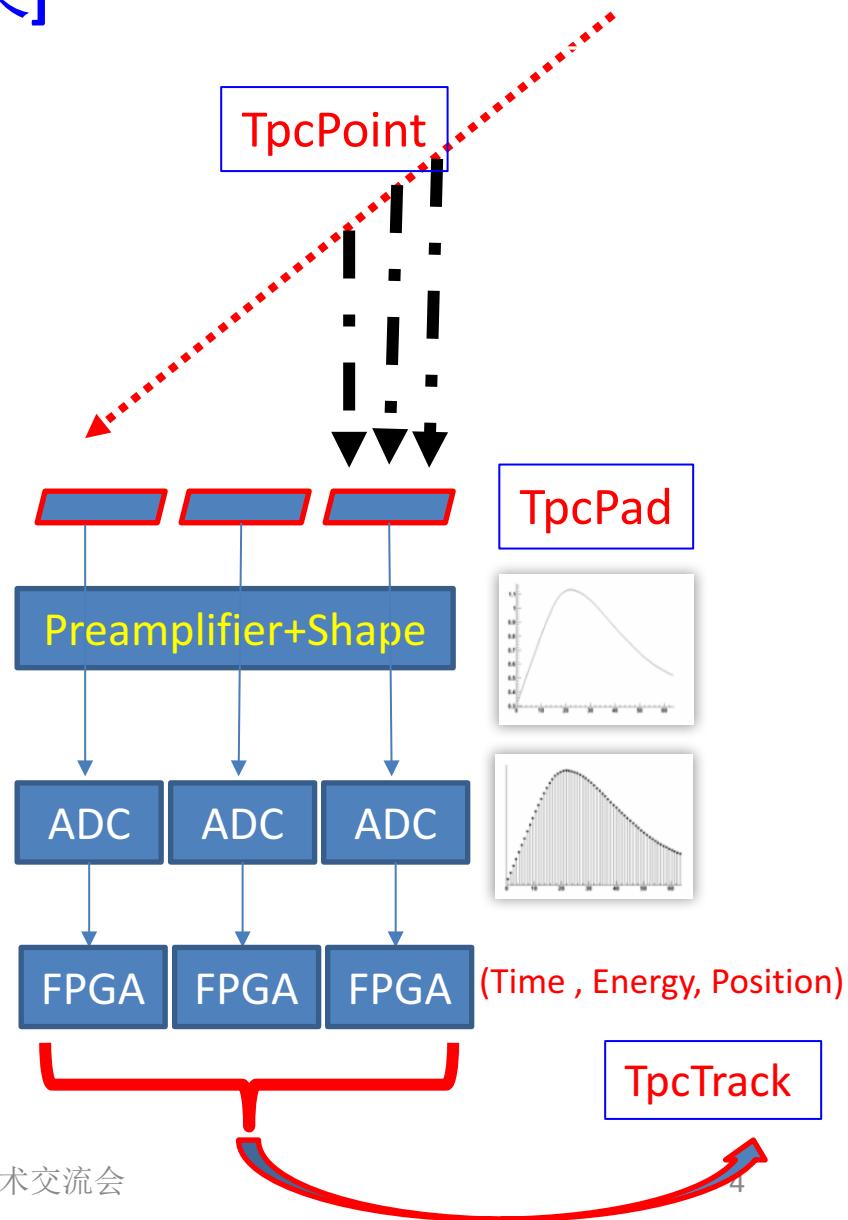
[软件框架]

✓ 软件分析框架

- 蒙卡模拟
 - 产生子
 - 电子漂移雪崩
 - 电荷感应扩散
 - 电子学积分成形

- 数据分析
 - 数据解码
 - 波形分析
 - 径迹重建
 - 粒子甄别

- 在线事例显示



时间投影室

[软件框架]

✓ 软件分析框架

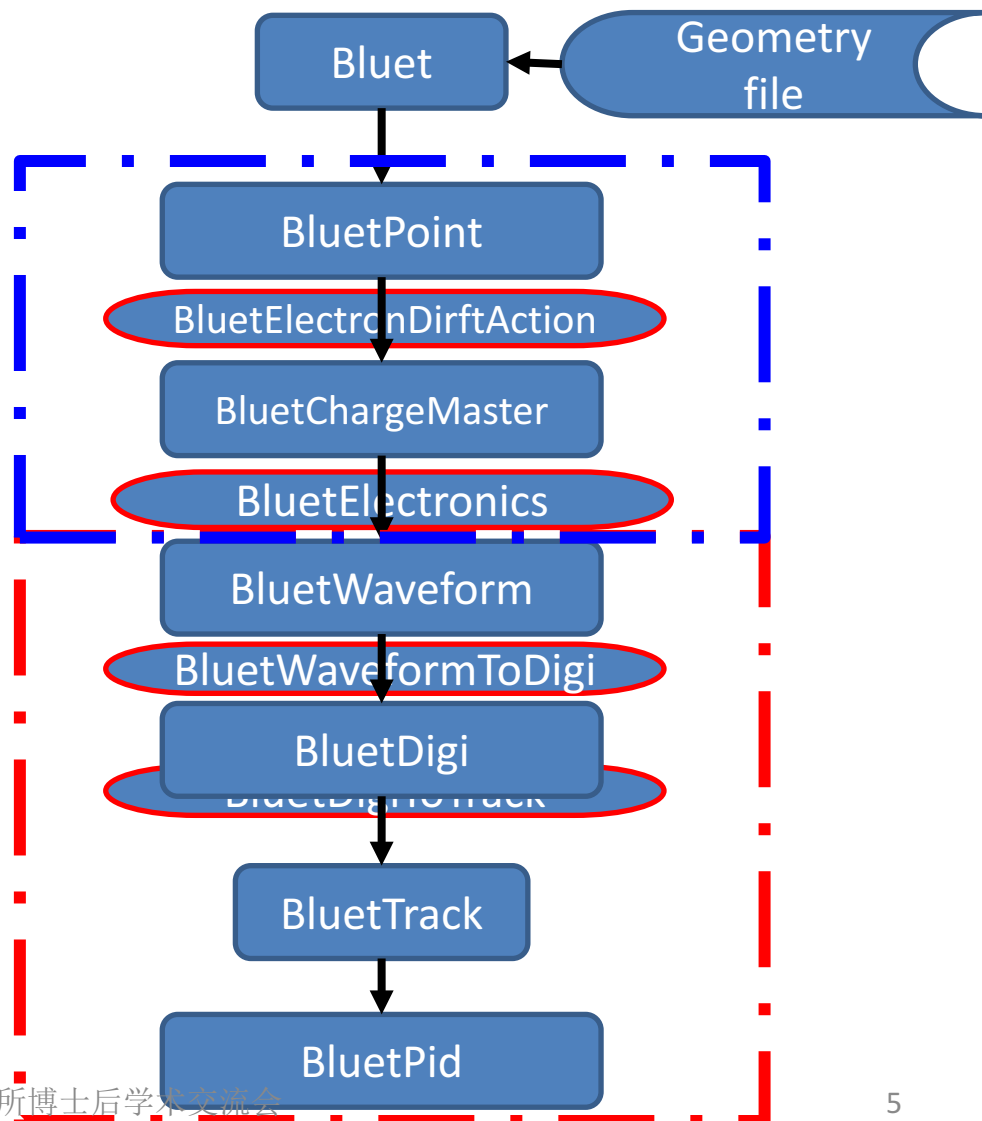
➤ 蒙卡模拟

- 物理产生子
- 电子漂移雪崩
- 电荷感应扩散
- 电子学积分成形

➤ 数据分析

- 数据解码
- 波形分析
- 径迹重建
- 粒子甄别

➤ 在线事例显示



时间投影室

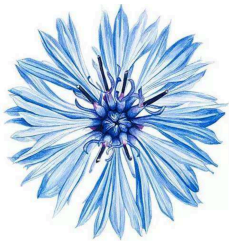
[软件框架]

✓ Dependent libs of Compile of Bluet

- Gcc 4.8.5
- Cmake-3.14.0-Linux-x86_64
- Geant4.10.05.p01
- ROOT 6.22/02
- Eigen – 3.3.9

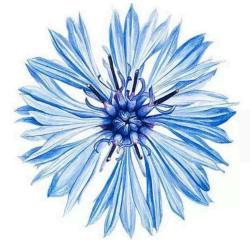
✓ Path of Softwares @wnsana01

- /usr/bin/gcc
- /wns_ana/bagshare/geant4/bin/geant4.sh
- /wns_ana/bagshare/root/bin/thisroot.sh
- /datafs/software/cmake-3.14.0-Linux-x86_64/bin
- /cvmfs/software.csns.ihep.ac.cn/software/eigen3/include/eigen3



时间投影室

[软件框架]



✓ Bluet-2.0 [矢车菊-Bluet]

➤ BluetSim

- BluetGarfield
- BluetGeant4

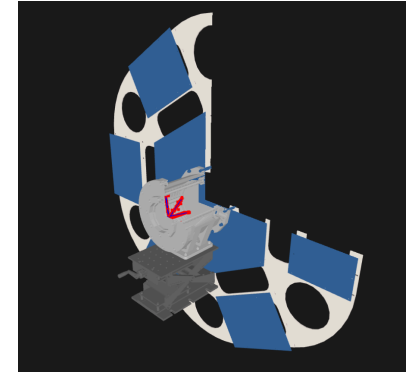
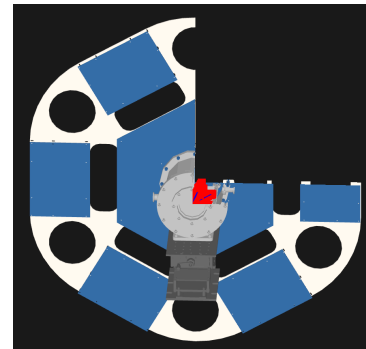
➤ BluetAna

- BluetRawToRoot
- BluetWaveformToDigi
- BluetDigiToTrack
- BluetPID
- ...

➤ Main function

- runBluet.C

```
BluetConfig.h
BluetDigi.h
BluetDigiToTrack.h
BluetFourierFilter.h
BluetHough.h
BluetHough3D.h
BluetModule.h
BluetPID.h
BluetPadMaster.h
BluetPointCloud.h
BluetRawToWaveform.h
BluetSphere.h
BluetTrack.h
BluetTrackMaster.h
BluetVector3d.h
BluetWaveFit.h
BluetWaveform.h
BluetWaveformToDigi.h
```

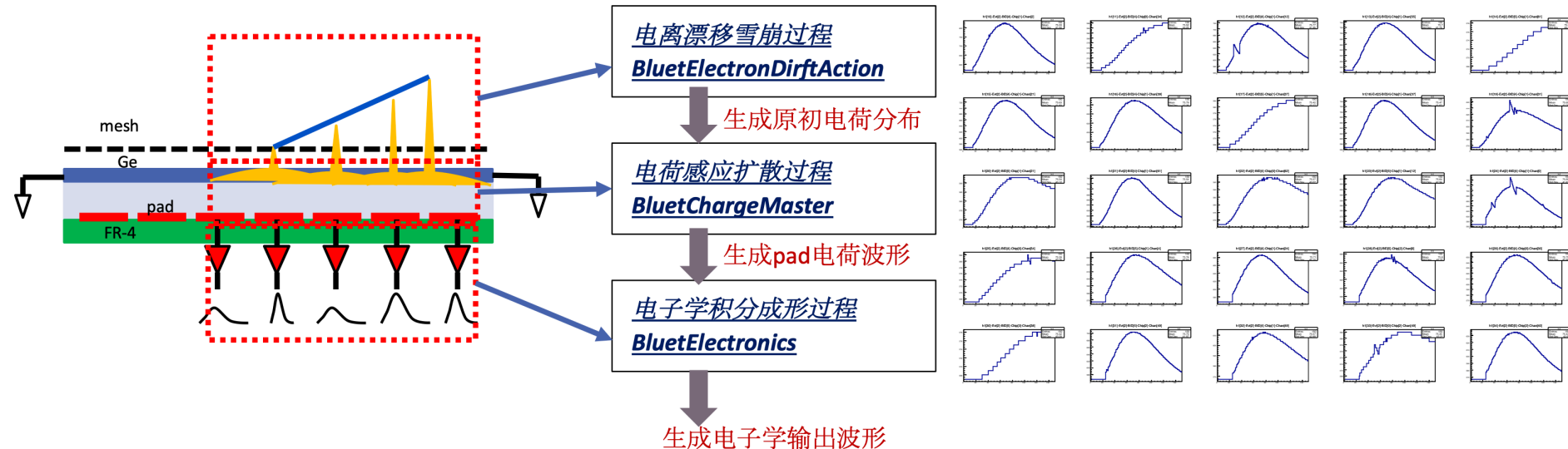
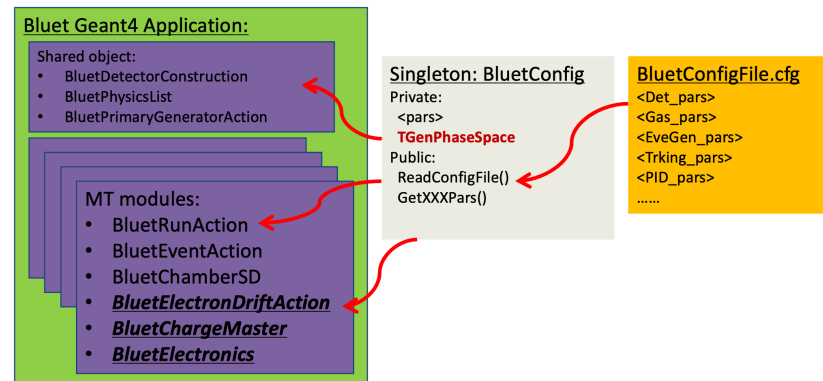


```
BluetConfig.cc
BluetDigi.cc
BluetDigiToTrack.cc
BluetFourierFilter.cc
BluetHough.cc
BluetHough3D.cc
BluetPID.cc
BluetPadMaster.cc
BluetPointCloud.cc
BluetRawToWaveform.cc
BluetSphere.cc
BluetTrack.cc
BluetTrackMaster.cc
BluetVector3d.cc
BluetWaveFit.cc
BluetWaveform.cc
BluetWaveformToDigi.cc
```

时间投影室

[BluetSim]

- ✓ BluetSim
 - BluetGarfield
 - BluetGeant



时间投影室

[BluetGarfield]

✓ 气体参数

- Ar[0.97] + CO2[0.03]
- GasPressure = 1 atm
- GasTemperature = 298.15

✓ 物理参数

- 漂移速度
- 扩散系数

>>> >>>

$E[\text{V/cm}] = 145$

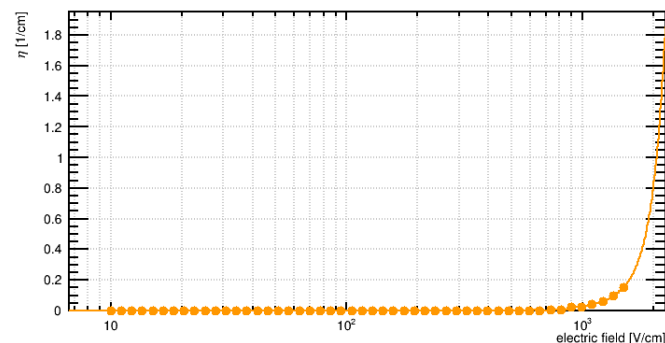
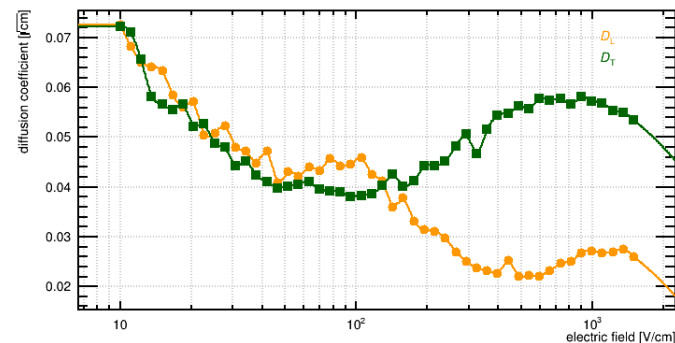
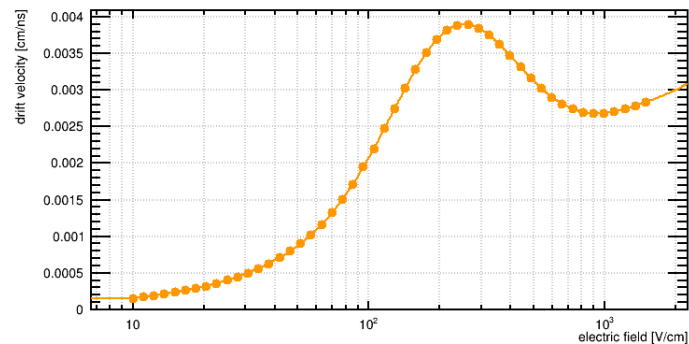
$v_{\text{Drift}}[\text{cm/ns}] = 0.00306479$

$\text{diffuT}[\text{sqrt(cm)}] = 0.0422245$

$\text{diffuL}[\text{sqrt(cm)}] = 0.0361902$

$\text{diffuL}[\text{ns/sqrt(cm)}] = 11.8084$

$\text{Attachment}[1/\text{cm}] = 0$



时间投影室

[BluetGeant4]

✓ 放射源模式

- 源半径大小
- 固定靶模式
- 活化靶模式
- 源种类
- 源能量

BluetConfigFile.cfg

```
<GeneratorType> RadioactiveSource
<BeamRadius> 0.05 [mm]
<TargetType> FixedTarget
#<TargetType> ActiveTarget
<SourceName> alpha
#<SourceName> e+
#<SourceName> e-
#<SourceName> gamma
<SourceEnergy> 5.805 [MeV]
```

✓ 核反应模式

- 束流半径
- 固定靶
- 活化靶
- 末态核子数
- 初态粒子设置
- 末态粒子设置

```
# -----
# G4 event generator parameters
# -----
#<GeneratorType> NuclearReaction
#<TargetType> ActiveTarget
#<PrimaryEnergy> 15.0 0.0 [MeV]
#<BeamRadius> 15.0 [mm]
#<ReactionID> 1
#<NumberOfDaughterNucleus> 2
#<PDGCodePrimary> 2112 1000060120
#<PDGCodeDaughter> 2212 1000050120
#<NumberOfDaughterNucleus> 4
#<PDGCodePrimary> 2112 1000060120
#<PDGCodeDaughter> 2112 1000020040 1000020040 1000020040
```

时间投影室

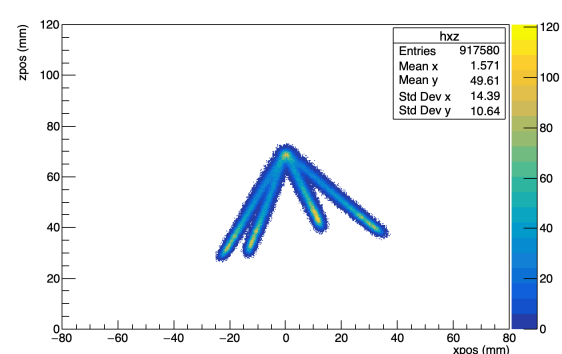
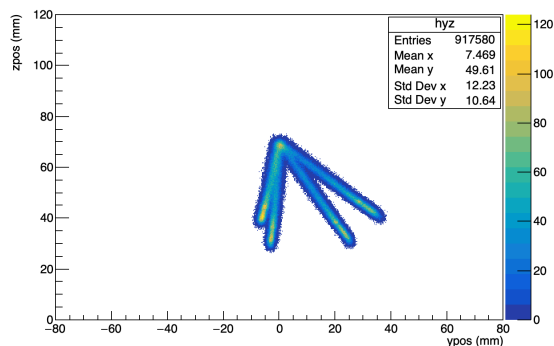
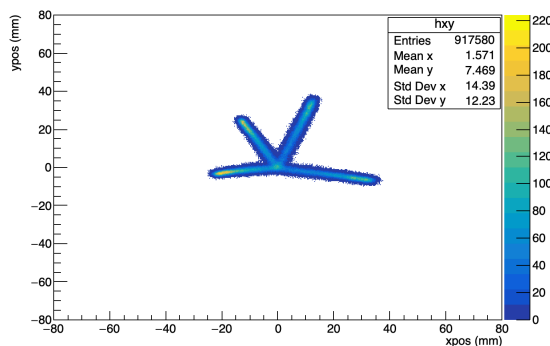
[BluetGeant4]

✓ 放射源模式

- 源半径=0.05mm
- 固定靶模式
- 源=alpha
- 源能量 =5.805 MeV
- 电场=145 V/cm
- 气体=Ar[0.97] + CO2[0.03]
- 气压=1.0 atm
- 温度=298.15 K

✓ 径迹投影

- 四事例 `Bluet_G4run_20210908_112807_t1.root`



时间投影室

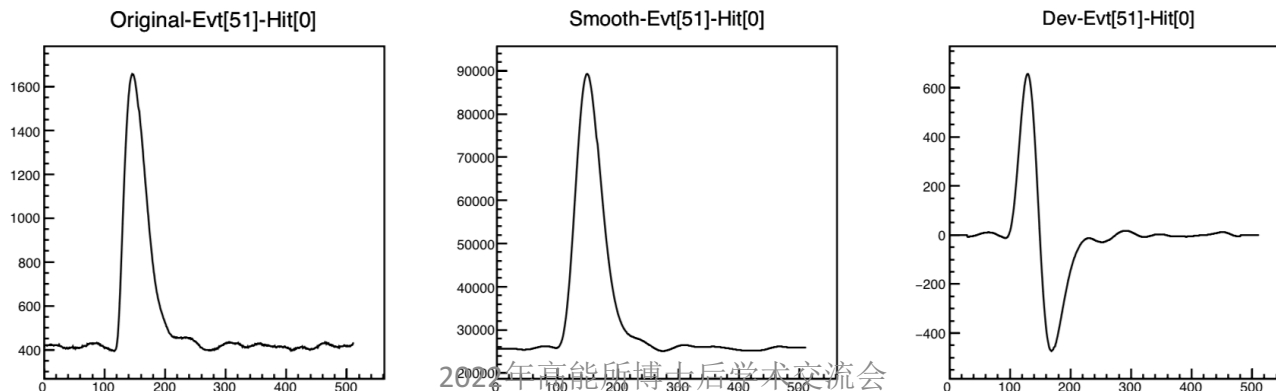
[BluetAna]

✓ `class` BluetWaveformToDigi

```
void WaveformToDigi();  
void WaveformToFilterDigi();  
void PlotWaveformFilter(int NumEvent, int NumHit);
```

✓ How to plot waveform of smooth and dev?

```
#####  
///Plot smooth and dev waveform based on FFT method  
#####  
int iEvent = 51;  
int iHit = 0;  
waveform2Digi->PlotWaveformFilter(iEvent, iHit);
```



时间投影室

[BluetAna]

✓ `class` BluetDigiToTrack

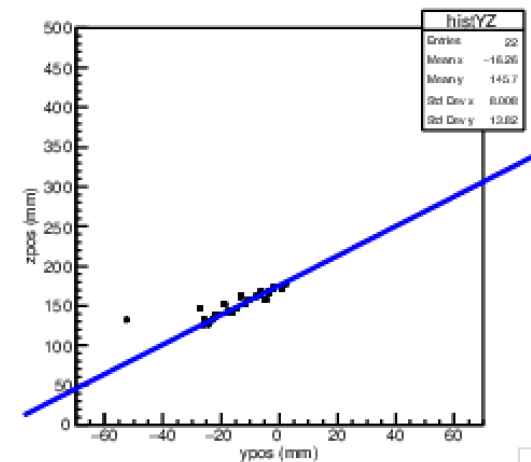
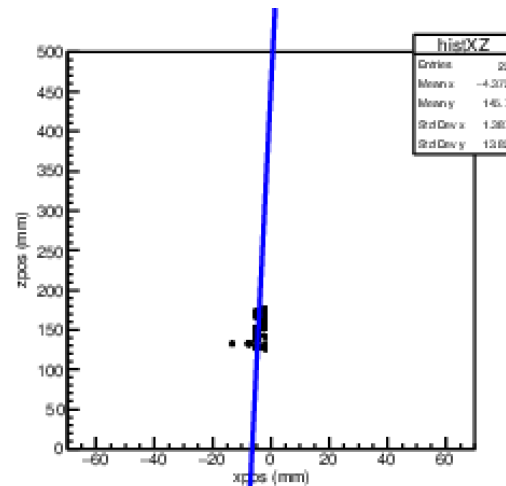
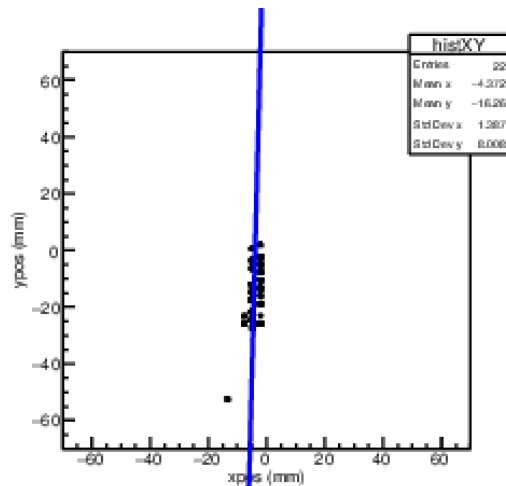
```
void DigiToTrackParameters(int startEvent, int stopEvent);
```

```
void DigiToTrack(int NumEvent);
```

```
void DigiToPlotRawTrack(int startEvent, int stopEvent);
```

```
void DigiToPlotFitTrack(int startEvent, int stopEvent);
```

✓ How to fit to track?



时间投影室

[BluetAna]

✓ `class` BluetDigiToTrack

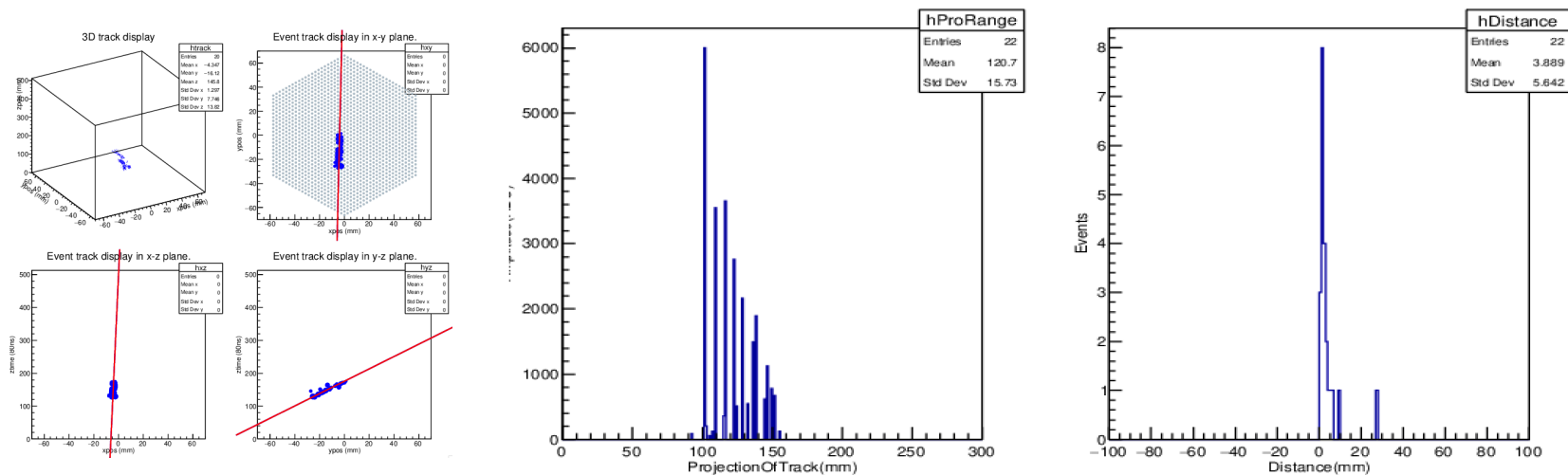
`void` DigiToTrackParameters(int startEvent, int stopEvent);

`void` DigiToTrack(int NumEvent);

`void` DigiToPlotRawTrack(int startEvent, int stopEvent);

`void` DigiToPlotFitTrack(int startEvent, int stopEvent);

✓ How to obtain projection of track-direction?



时间投影室

[BluetPID]

✓ 传统方法粒子鉴别

➤ 粒子径迹重建

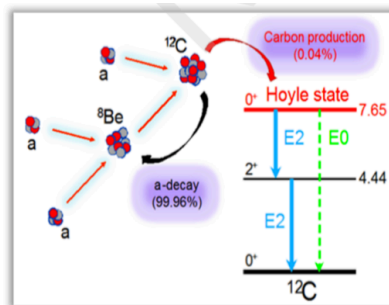
- 霍夫变换
- 卡尔曼滤波

➤ 提取径迹参数

✓ 引入新方法的必要性

➤ 图像模式识别

- 神经网络



$$\alpha + \alpha \rightarrow {}^8\text{Be} \quad (1)$$

$${}^8\text{Be} + \alpha \rightarrow {}^{12}\text{C}^* \quad (2)$$

$${}^{12}\text{C}^* \rightarrow {}^8\text{Be} + \alpha \rightarrow \alpha + \alpha + \alpha \quad (3)$$

$${}^{12}\text{C}^* \rightarrow \alpha + \alpha + \alpha \quad (4)$$

$${}^{12}\text{C}^* \rightarrow {}^{12}\text{C} + \gamma + \gamma \quad (5)$$

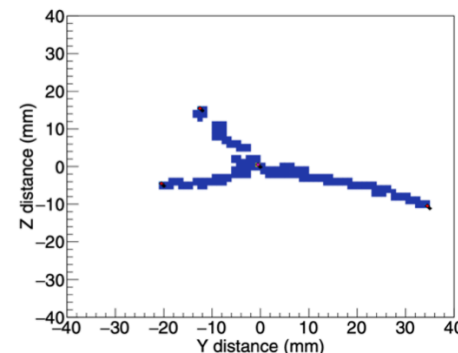
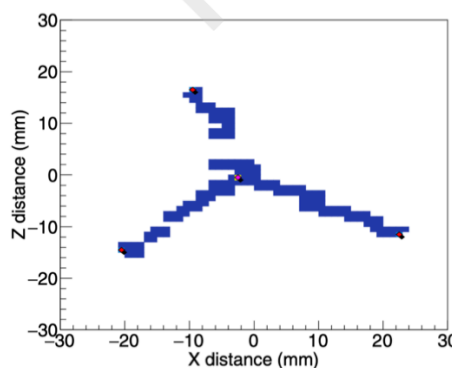
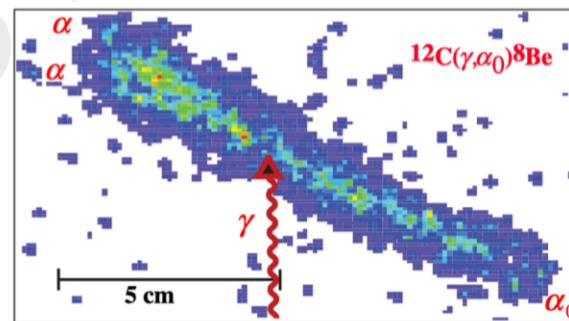


表 1 ImageNet 图像分类大赛中相应算法及其 Top-5 错误率

年份	2011	2012	2014	2015	2017
算法类型	传统算法	AlexNet	VGG	ResNet	SENet
网络层数		8	19	152	252
Top-5 错误率	25.8%	16.4%	7.3%	3.57%	2.25%



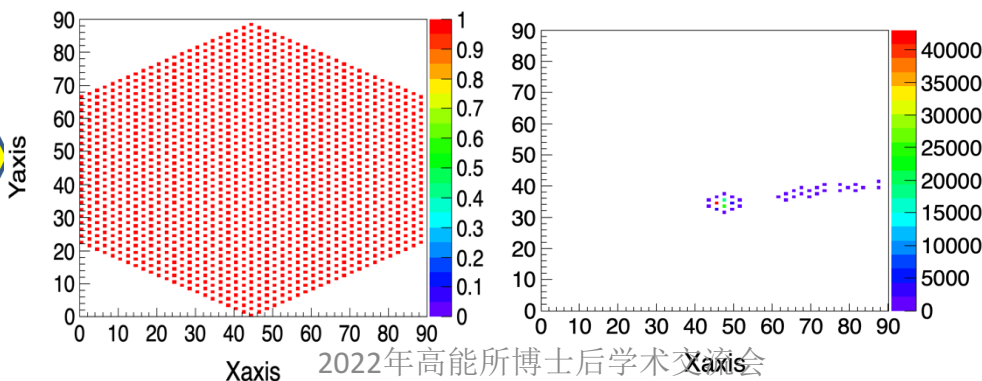
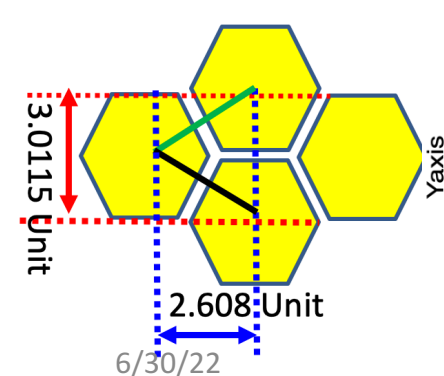
时间投影室

[BluetPID]

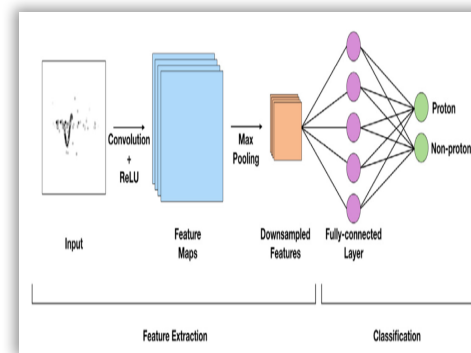
- ✓ 反应道甄别
 - 模拟数据
 - C/Ar/O (n, p)反应
- ✓ 神经网络方法
 - 数据预处理
 - 卷积网络模型
 - 数据训练
 - 模型迁移

靶核类型	反应道编号	事例数	输入参数
氩 (^{40}Ar)	0	14999	[X,Y,Z, ΔE , En]
碳 (^{12}C)	1	13751	[X,Y,Z, ΔE , En]
氧 (^{16}O)	2	14999	[X,Y,Z, ΔE , En]

标签值/预测值	^{40}Ar	^{12}C	^{16}O
^{40}Ar	93.4%	1.8%	4.8%
^{12}C	0.5%	91.2%	8.3%
^{16}O	1.2%	4.3%	94.5%



2022年高能所博士后学术交流会



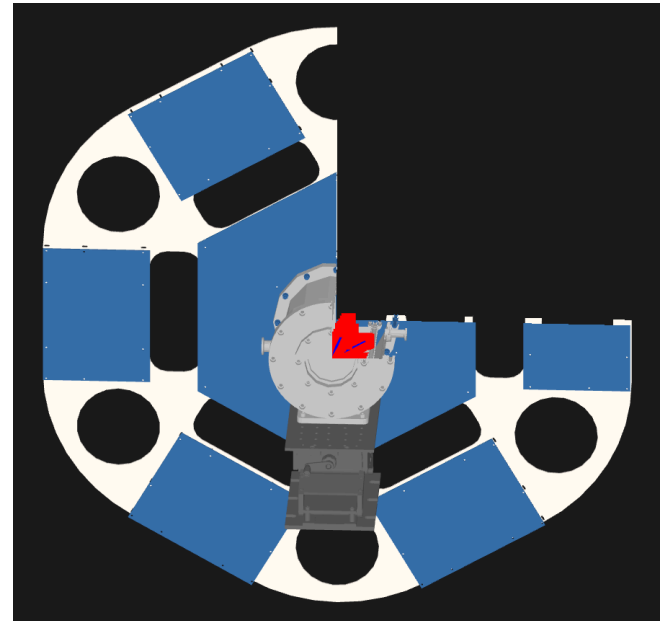
时间投影室

[EventDisplay]

✓ 事例在线显示网址

➤ <http://10.1.252.103:8080/#/bluet>

✓ TPC探测器几何交互式操作



时间投影室

[GitHub]

✓ 远程代码库

CSNS Back-n TPC > BLUET-v2.0



BLUET-v2.0

Project ID: 719



★ Star 0

🍴 Fork 0

🔗 39 Commits 1 Branch 0 Tags 28.3 MB Files 28.3 MB Storage

BLUET-v2.0 code for CSNS Back-n TPC simulation and data analysis.

master

bluet-v2.0 /

+

History

Find file

Web IDE



Clone

✓ 远程代码同步



git clone

git@code.ihep.ac.cn:csns
-backn-tpc/bluet-v2.0.git

Members with access to CSNS Back-n TPC				
	Search	2FA	Everyone	Sort by Name, ascending
	chenyonghao@ihep.ac.cn @chenyonghao	Owner	2030-05-07	
Given access 6 days ago · Expires in almost 10 years				
	fanrr@ihep.ac.cn @fanrr	Owner	2030-05-07	
Given access 6 days ago · Expires in almost 10 years				
	jiangwei@ihep.ac.cn @jiangwei	Owner	2030-05-07	
Given access 6 days ago · Expires in almost 10 years				
	sunyankun @sunyankun It's you	Owner		Leave
Given access 6 days ago · Expires in almost 10 years				
	yangli@ihep.ac.cn @yangli	Owner	2030-05-07	
Given access 6 days ago · Expires in almost 10 years				
	yih@ihep.ac.cn @yih	Owner	Expiration date	
Given access 6 days ago				

时间投影室

[MC数据分析]

✓ 四组分标准alpha源

➤ $E = 5.805 \text{ MeV}$

➤ $E = 4.775 \text{ MeV}$

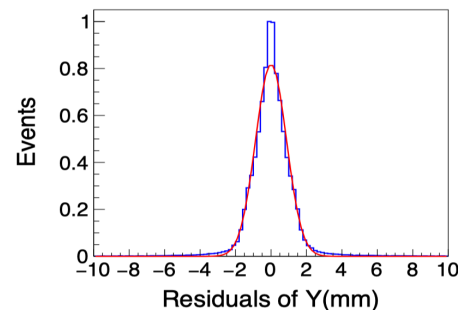
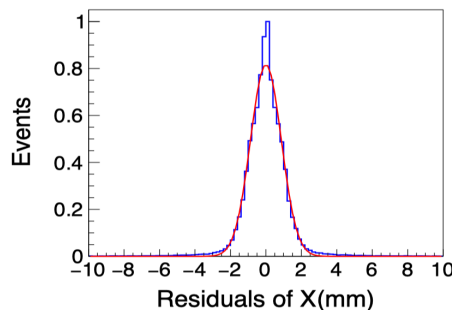
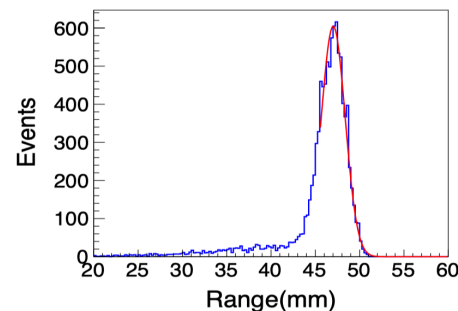
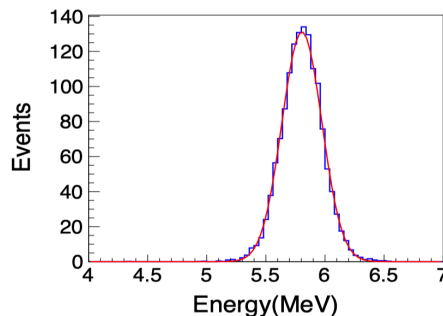
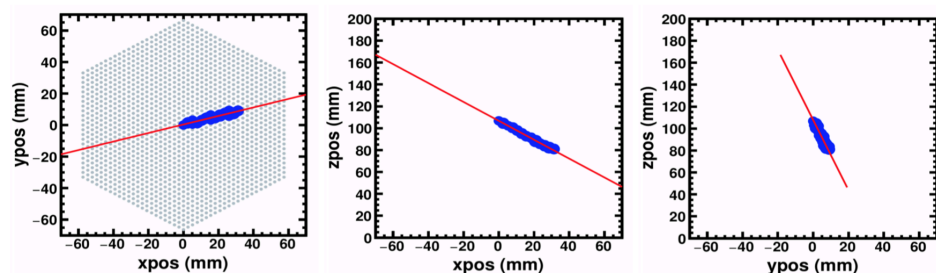
➤ $E = 5.115 \text{ MeV}$

➤ $E = 5.499 \text{ MeV}$

✓ 径迹二维投影与拟合

✓ 粒子参数分布

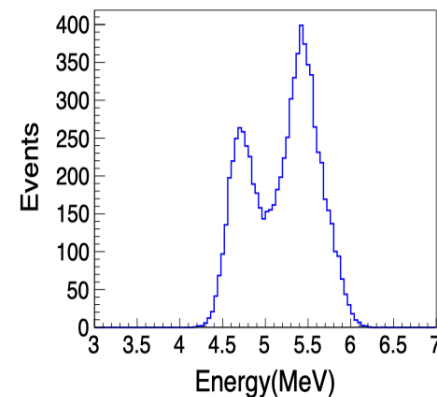
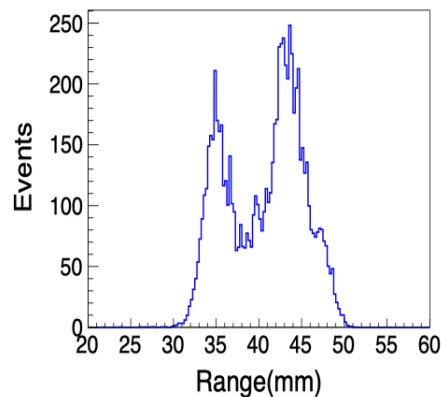
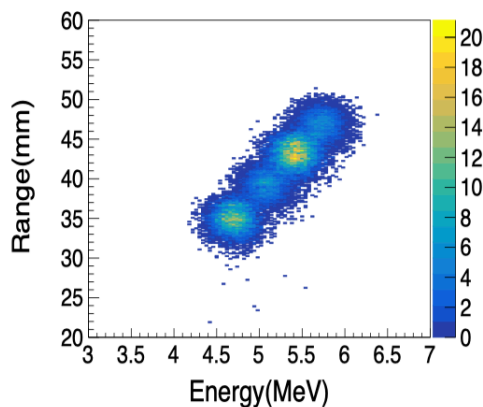
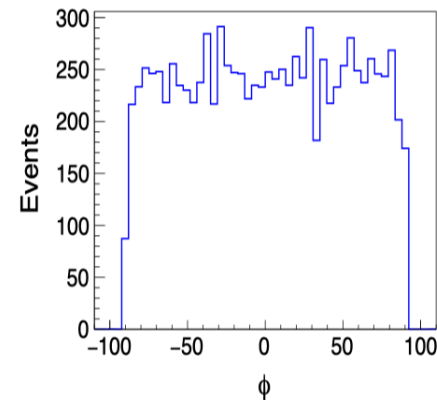
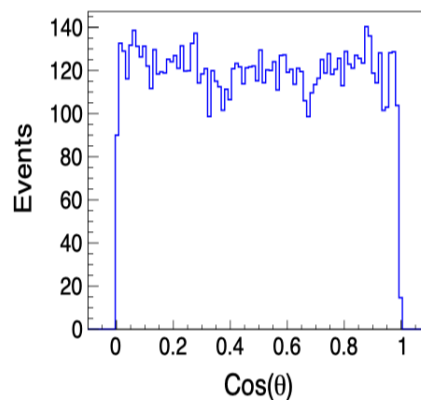
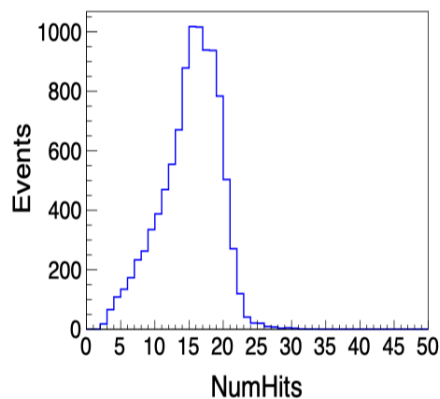
1. 能量分布
2. 径迹长度分布
3. 残差分布



时间投影室

[MC数据分析]

- ✓ 实验结果：径迹参数分布
 - 击中数目 && 角分布 && 能量和射程

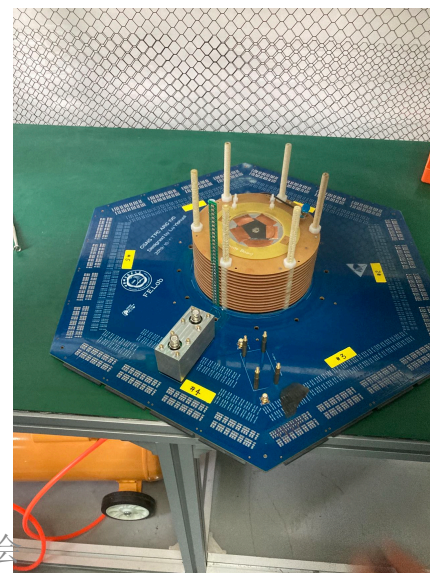


时间投影室

[alpha源数据分析]

✓ 实验测试及其参数

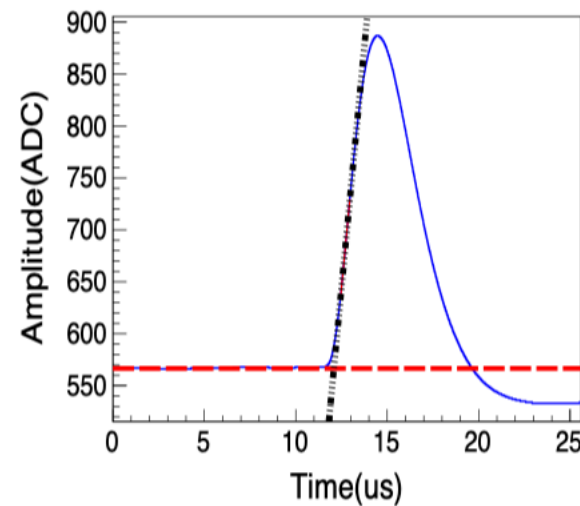
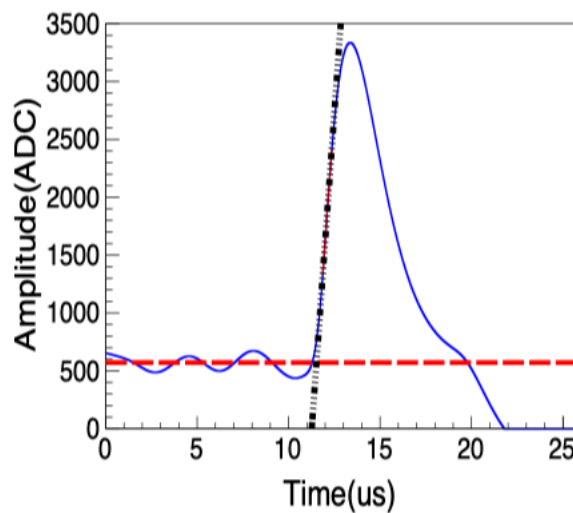
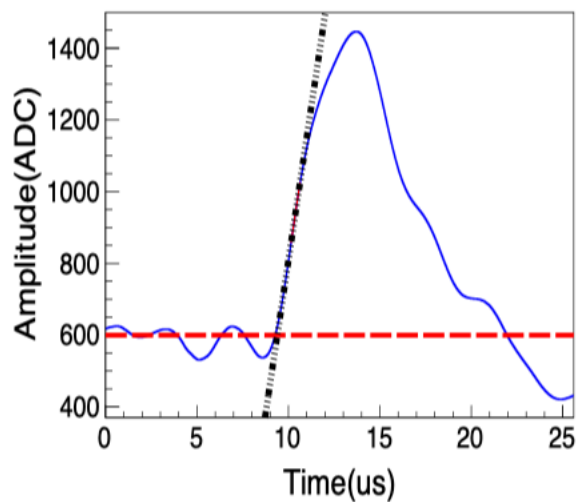
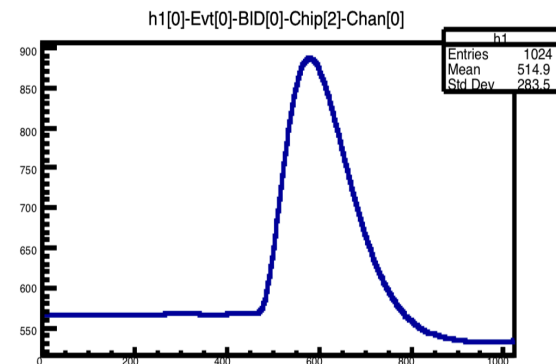
- 气体组分: Ar+CO₂
- 电压: $V_{\text{mesh}} = 400 \text{ V}$, $V_{\text{cathode}} = 1800 \text{ V}$
- 漂移速度: 0.02086 mm/ns
- 放射源: 四组分alpha源
- 电子学: $\text{sample}/25 \text{ ns}$, $\text{range} = 1024 * 25 \text{ ns} = 25.6 \mu \text{s}$
- 探测器相关参数: Cathod-ID : 0-2-27 ; Mesh-ID : 3-3-38



时间投影室

[alpha源数据分析]

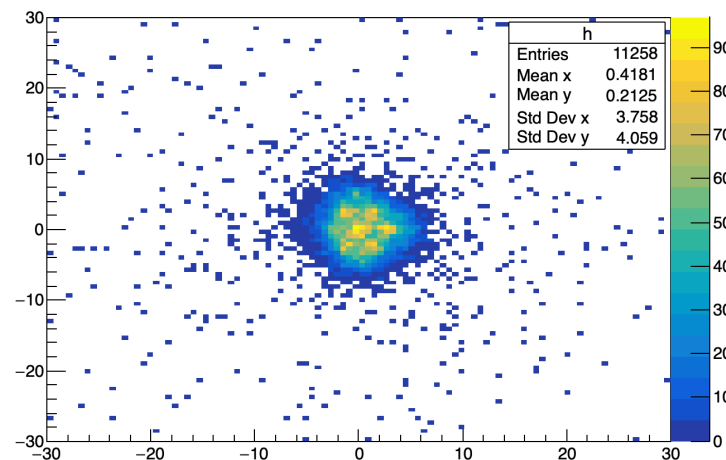
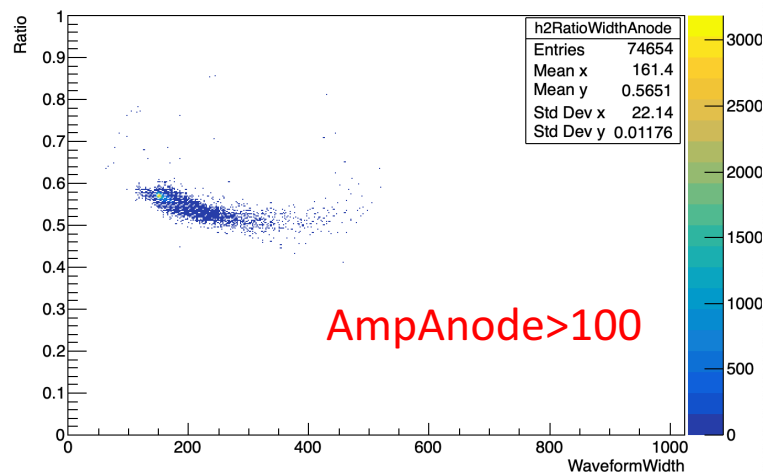
- ✓ 事例集
 - Daq.run.20211101215012.001-dat.root
- ✓ 定时方法：前沿拟合
 - 单事例：Evt = 0, NumHit = 0
- ✓ 信号幅度：最大值法



时间投影室

[alpha源数据分析]

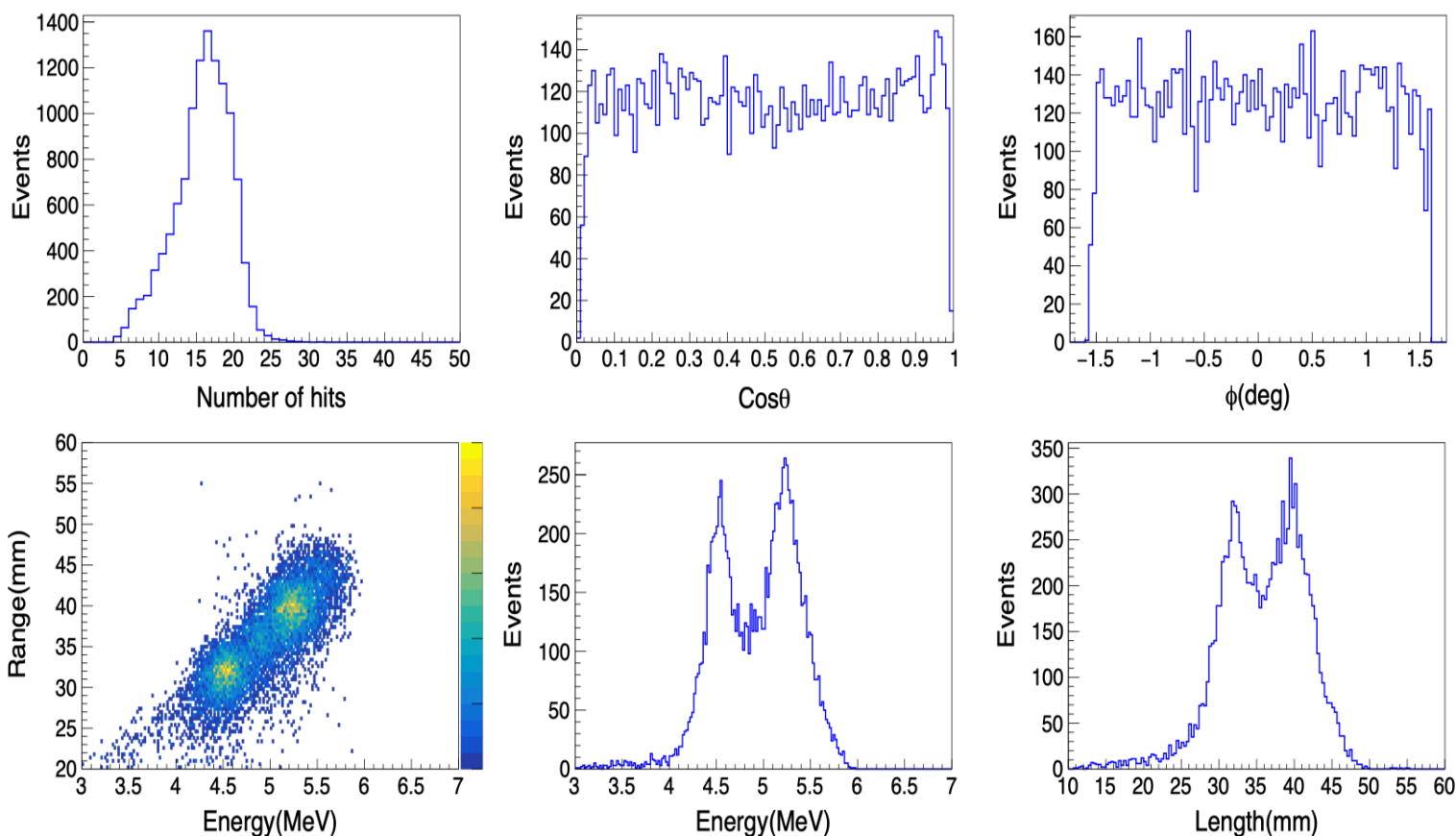
- ✓ 事例选择条件
- Raw-NumHit>5
 - T0Cathode>0
 - T0Mesh>0
 - AmpCathode = [700,1500]
 - AmpMesh = [2500, 3000]
 - AmpAnode>100
 - WidthAnode<200
 - RatioAnode=[0.5, 0.7]
 - PosX = [-30, 30]mm
 - PosY = [-30, 30] mm



时间投影室

[alpha源数据分析]

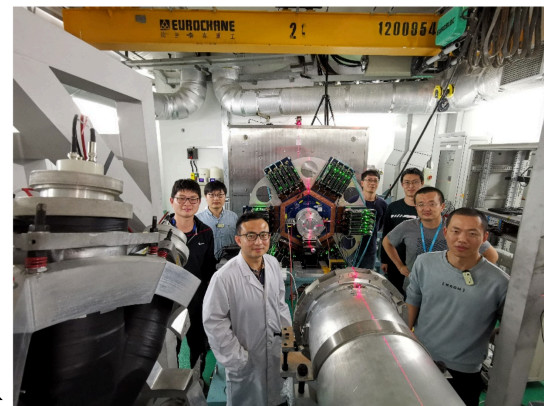
- ✓ 实验结果：径迹参数分布
 - 击中数目 && 角分布 && 能量和射程



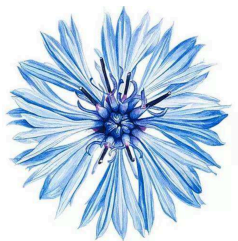
时间投影室

[alpha源数据分析]

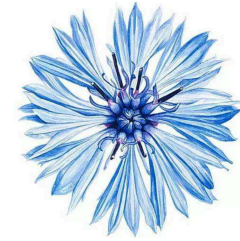
- ✓ 标准alpha源实验测试
 - 实验数据和MC模拟结果基本一致
 - TPC探测器性能得到了实验验证
 - 中子核物理实验研究奠定了良好基础
- ✓ 研究工作得到了国家自然科学基金的支持



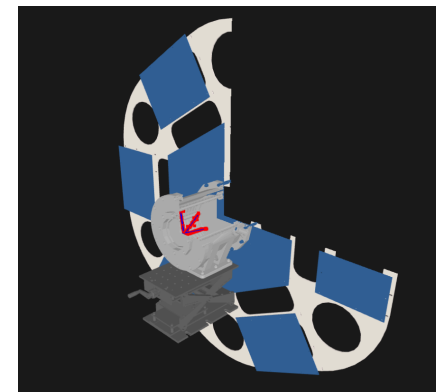
起止年月	项目名称	项目来源	经费	主持/参与
22.01-24.12	神经网络方法在霍伊尔态研究中的应用	国家自然科学基金 青年科学基金项目	30万	主持
22.01-24.12	基于时间投影室的中子-质子散射截面测量	国家自然科学基金 面上项目	61万	参与
22-10-25-10	核数据测量时间投影室实验及数据分析方法研究	区域联合基金-重点项目	100万	参与



总结



- ✓ 初步完成了TPC软件开发
 - 蒙卡模拟
 - 物理产生子
 - 电子学信号模拟
 - 数据分析
 1. 数据质量检查、刻度
 2. 径迹重建算法、粒子鉴别算法
 3. 物理参数测量、系统误差分析
 - TPC升级-软件也需要更新和迭代
- ✓ TPC探测器的初步测试
 - 进行了标准阿尔法源测试
 - 完成了MC样本和实验数据分析



Backup

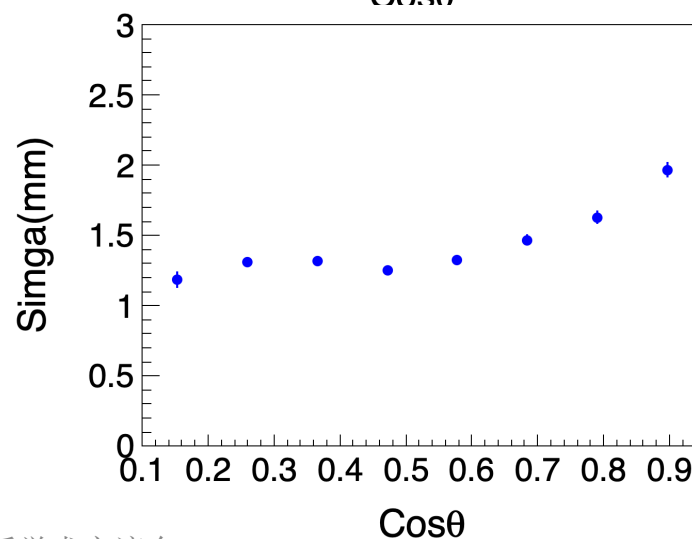
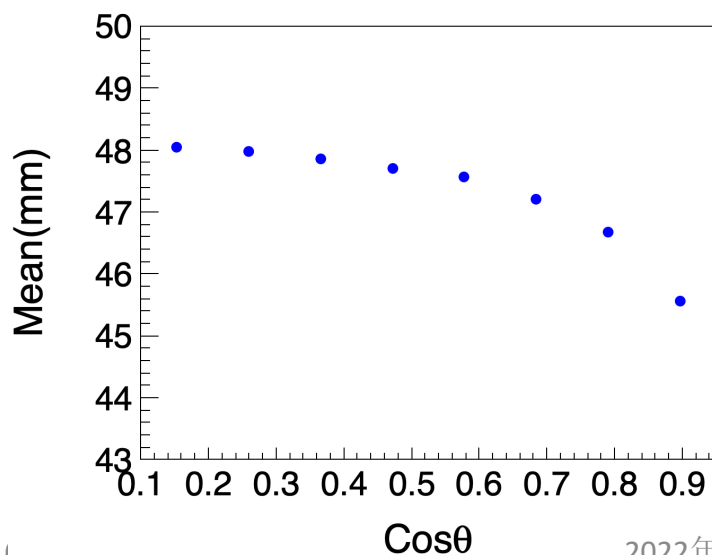
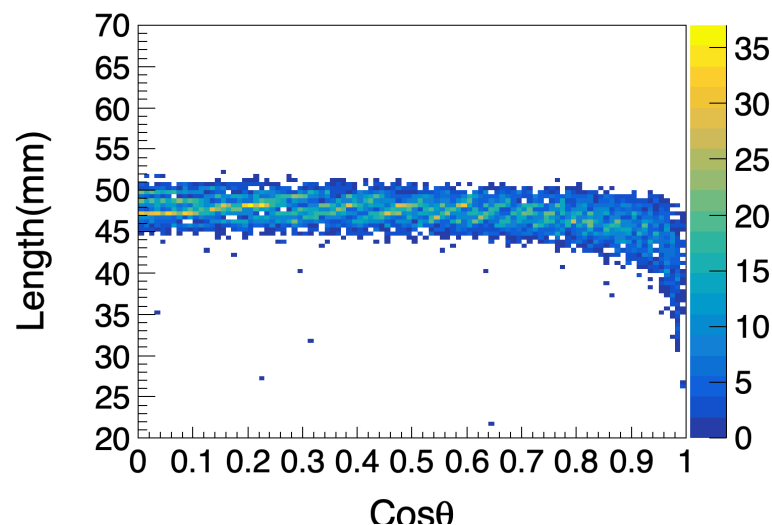
总结与讨论

✓ TPC developer

- Management of Framework : *Sun Yankun*
- Event generator : *Yi Han, Jiang Wei*
- Simulation: *Yi Han, Fan Ruirui, Bai Haofan*
- Waveform analysis: *Chen Yonghao, Yi Han, Yankun Sun*
- Reconstructed Tracks : *Li Yang*
- Event display: *Li Yang*
- PID : *Yi Han and Sun Yankun*

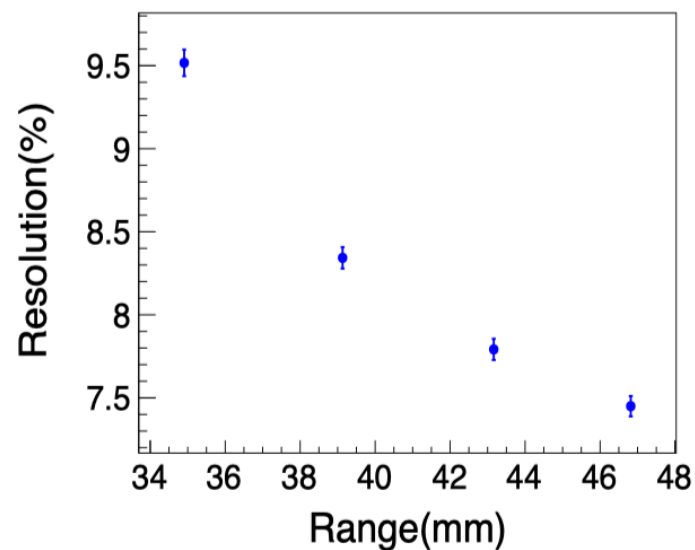
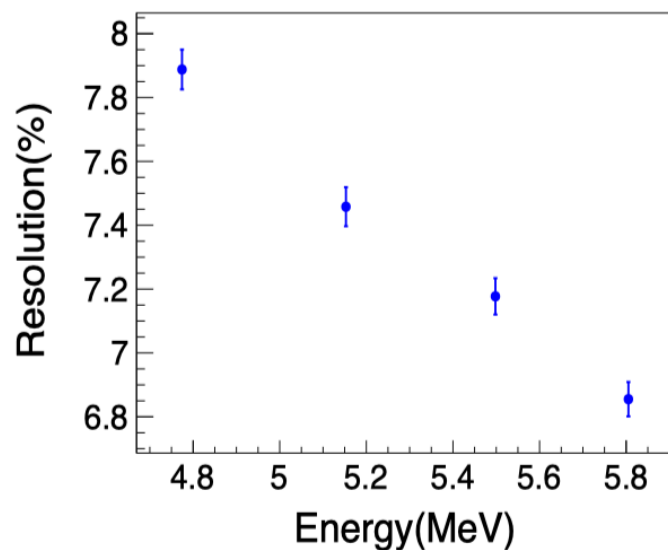
角分布

- ✓ 角度分布
 - Costheta vs Length
 - Mean and sigam
- ✓ alpha源参数
 - Point-like
 - $E = 5.805 \text{ MeV}$



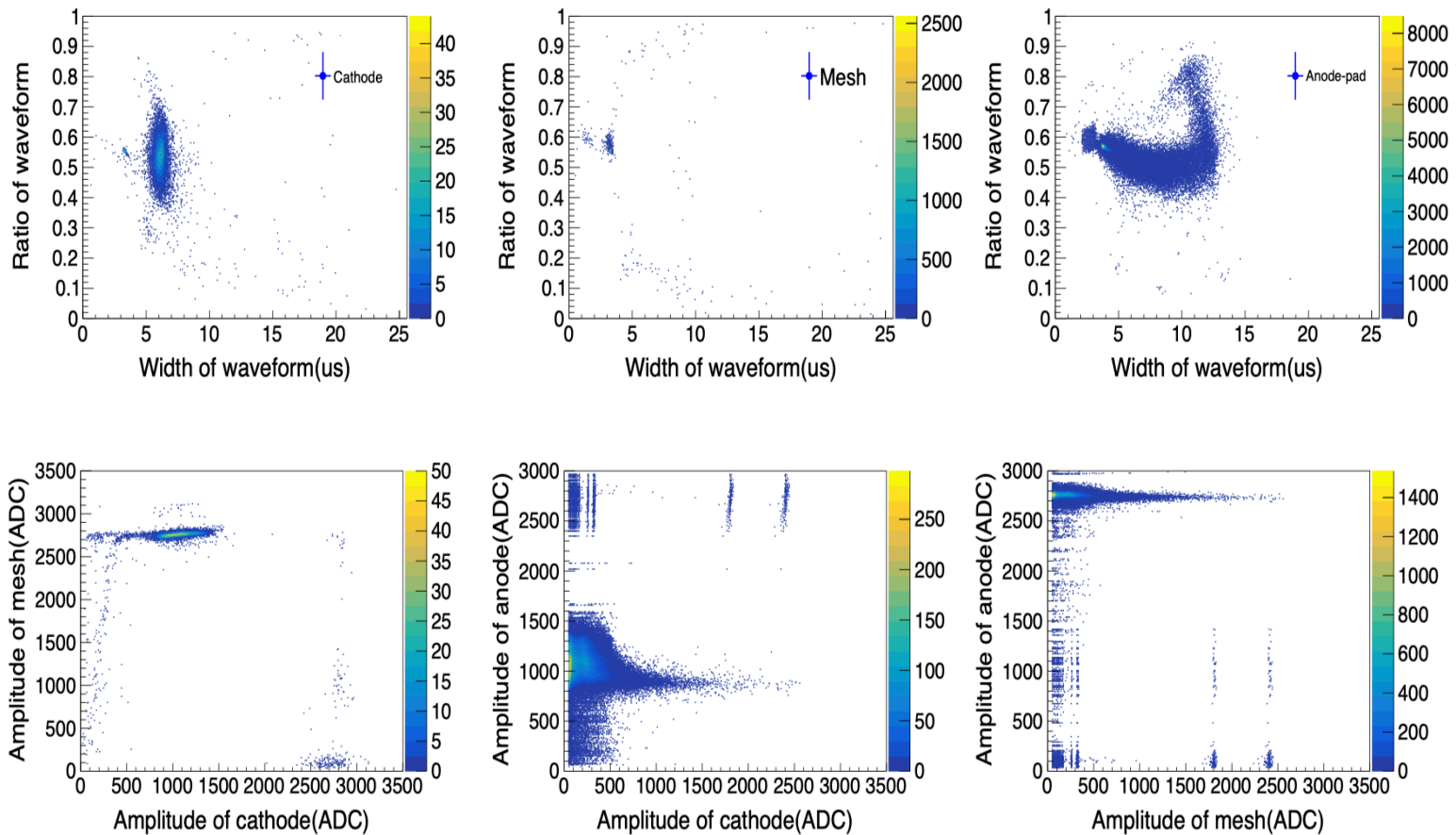
实验数据分析

- ✓ 能量分辨和径迹长度分辨随着粒子能量的变化



实验数据分析

✓ 事例选择条件：脉冲波形筛选&&幅度约束



时间投影室

[alpha源数据分析]

✓标准alpha源实验测试

- 实验数据和MC模拟结果符合很好
- TPC探测器性能得到了实验验证
- 为了后期核物理实验的数据处理奠定了良好基础

