

阵列型阻性阳极四角读出 重建算法研究

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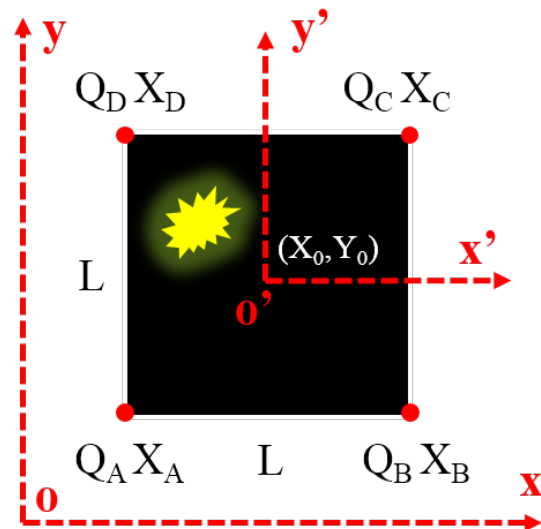
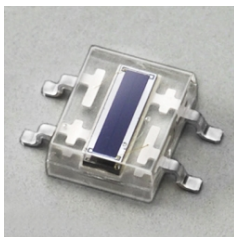
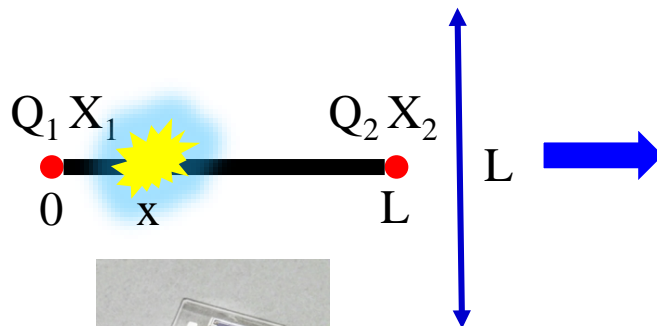
- 背景介绍
- 重建算法分析与改进
- 多次击中事例重建效果
- 总结

背景介绍

● 传统阻性阳极读出方法（四角读出结构）

■ 一维阻性条

$$\begin{aligned} x &= \frac{Q_2}{Q_1 + Q_2} L \\ &= \frac{Q_2}{Q_1 + Q_2} (x_2 - x_1) \\ &= \frac{x_1 Q_1 + x_2 Q_2}{Q_1 + Q_2} \end{aligned}$$



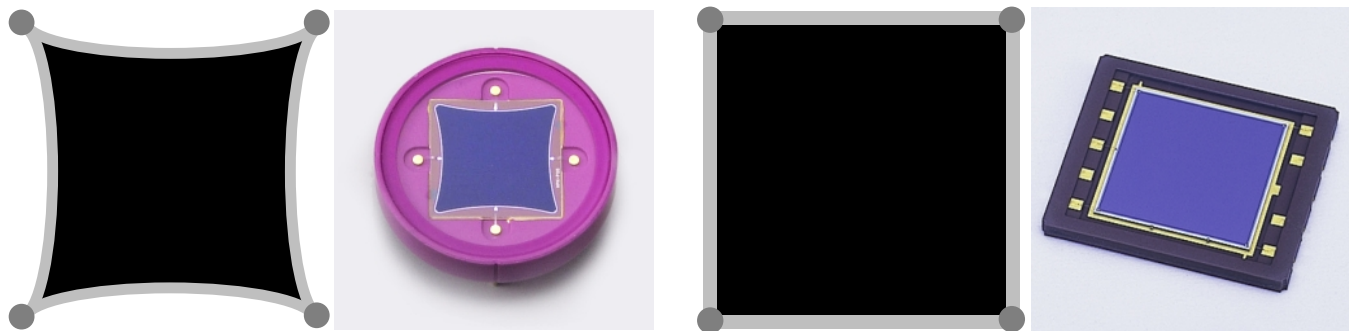
■ 二维阻性平面

$$\begin{aligned} x &= \frac{Q_2}{Q_1 + Q_2} L \\ &= \frac{Q_B + Q_C}{Q_A + Q_B + Q_C + Q_D} L \\ &= \frac{Q_B + Q_C}{Q_A + Q_B + Q_C + Q_D} L - \frac{L}{2} \\ &= \frac{(Q_B + Q_C) - (Q_A + Q_D) L}{Q_A + Q_B + Q_C + Q_D} \cdot \frac{1}{2} \\ &= \frac{Q_A x_A + Q_B x_B + Q_C x_C + Q_D x_D}{Q_A + Q_B + Q_C + Q_D} \end{aligned}$$

阻性阳极读出方法在微通道板（MCP）、半导体位置灵敏探测器（PSD）等探测器上得到广泛应用

■ 严重的枕形失真现象

- ◆ Gear-Type 结构
- ◆ Doke-Type 结构



背景介绍

● 阵列型阻性阳极读出方法

■ 适用于MicroMegas、GEM等的读出

- ◆ 保持位置分辨率的前提下节省电子学

■ 德国Siegen大学的Micro-CAT探测器

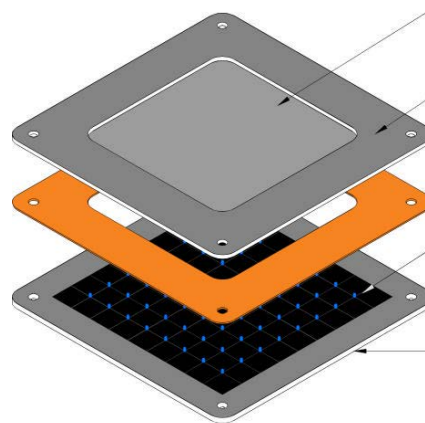
- ◆ $\sigma = 200 \sim 400 \mu\text{m}$
- ◆ 7×7 Cells, $8 \times 8 \text{ mm}^2$

● 我们的工作

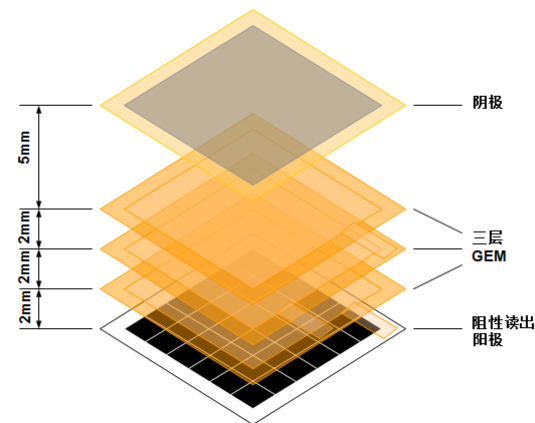
■ Resistive Anode GEM (RAGEM)

- ◆ $\sigma < 100 \mu\text{m}$ @ $8 \times 8 \text{ mm}^2$ Cell
- ◆ 11×11 Cells

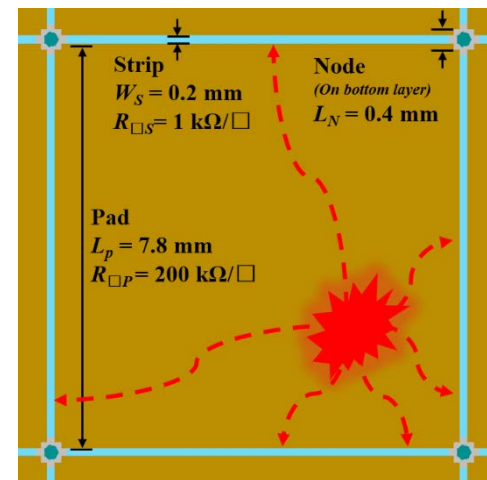
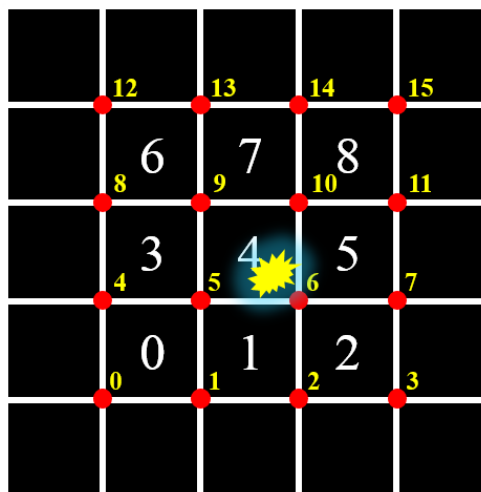
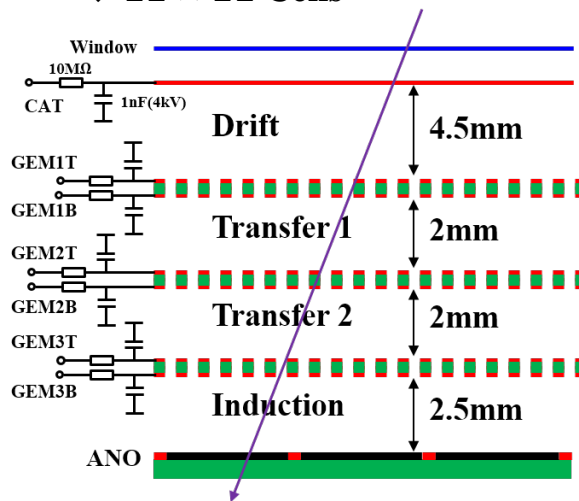
- Orthen et al. Nucl. Instrum. Meth., 478(2002) 200 - 204
- M. Y. Dong et al. Chin. Phys. C., 37:26002, 2013.



MicroCAT

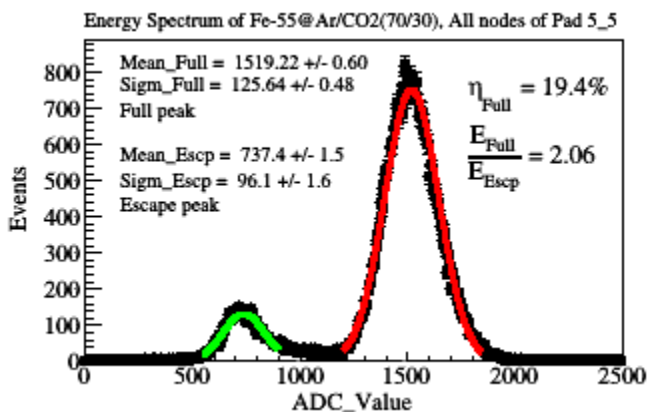


RAGEM

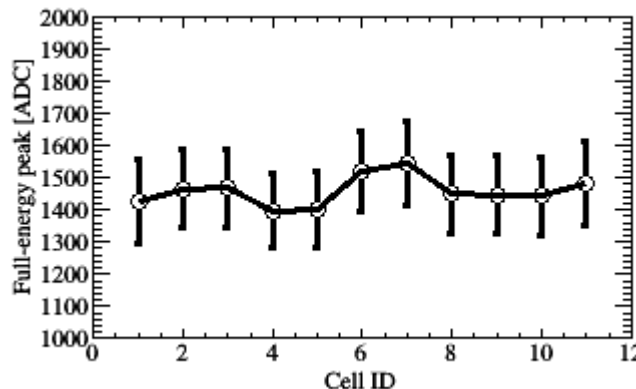


RAGEM测试性能

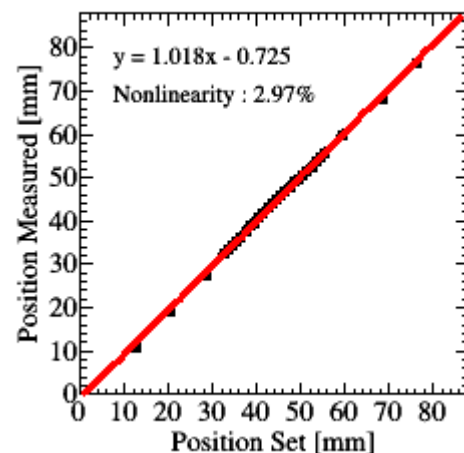
铁源能量分辨率 $\eta \approx 20\%$



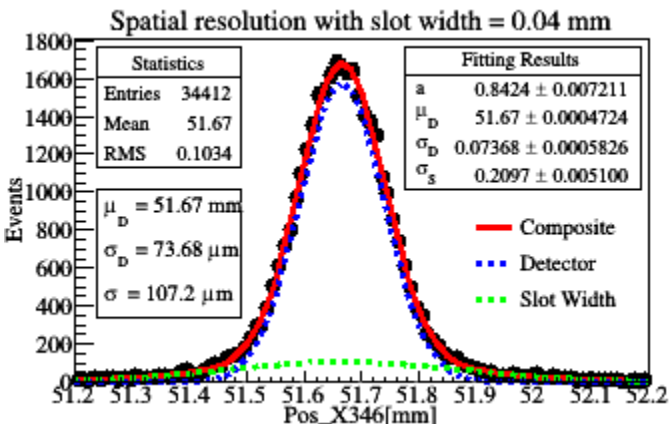
增益均匀性 $a < 7\%$



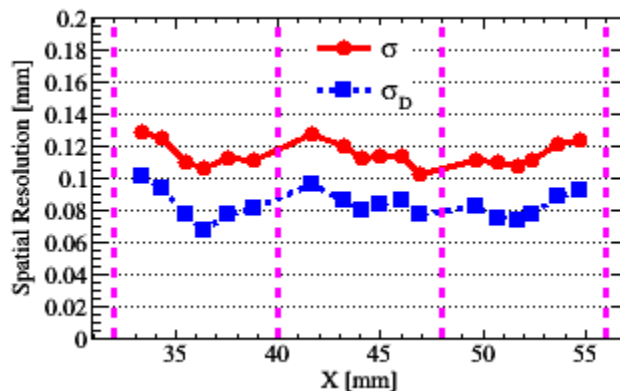
位置非线性（整体） $n < 3\%$



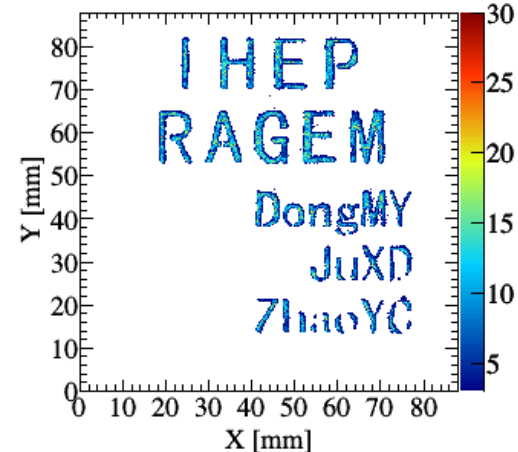
位置分辨率 $\sigma_D \approx 74 \mu\text{m}$



位置分辨率均匀性 $\sigma_D < 100 \mu\text{m}$



X光机对3D打印的Mask成像



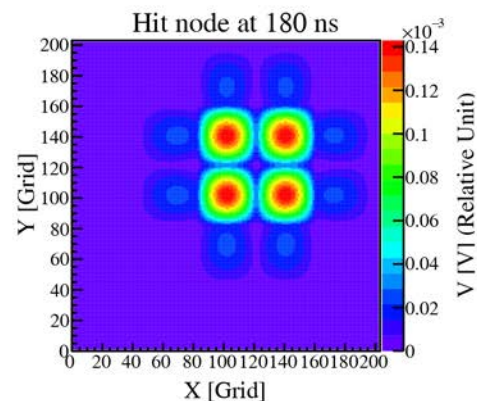
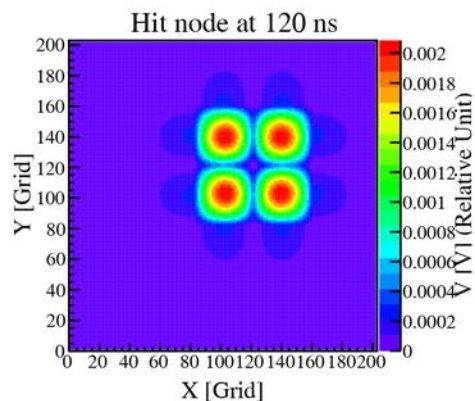
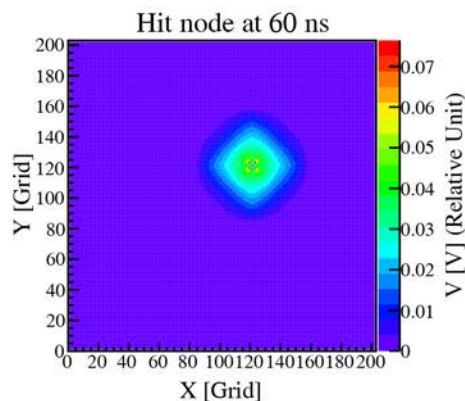
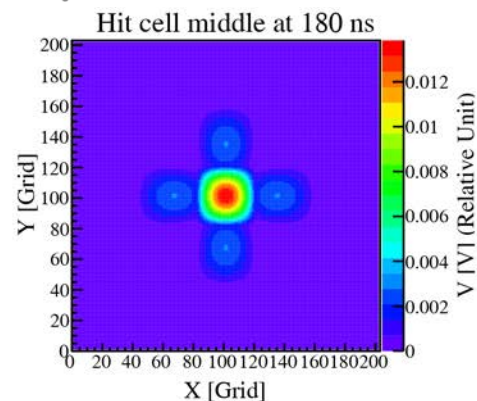
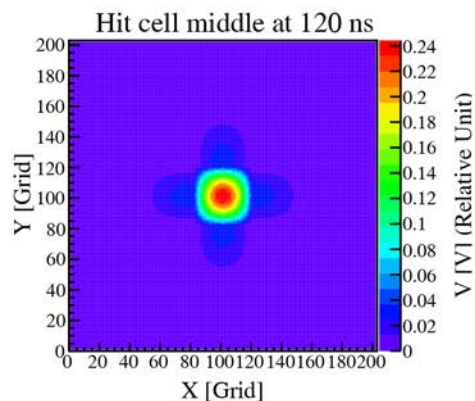
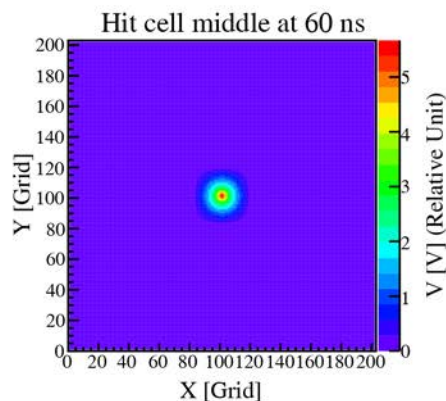
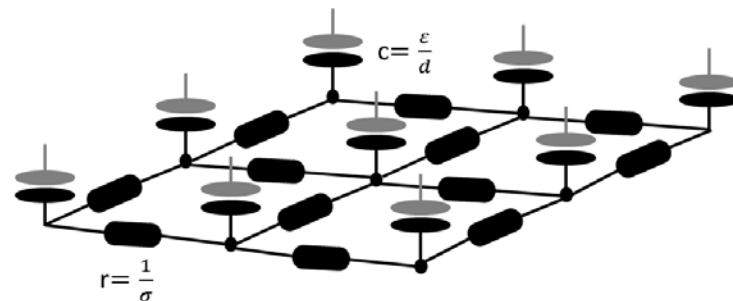
数学模型

- 雪崩电子云团的输运过程等效为电荷在一个二维RC网络的传输过程

- 进一步抽象为对一个二维含时偏微分方程的求解

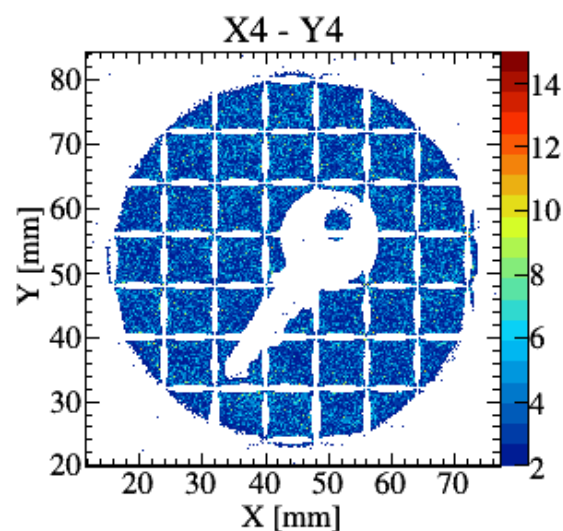
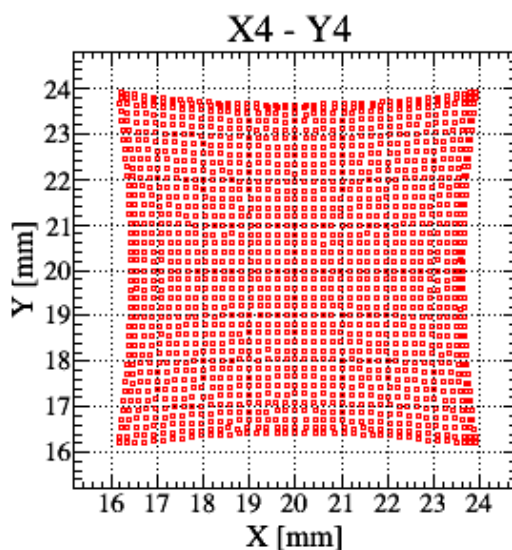
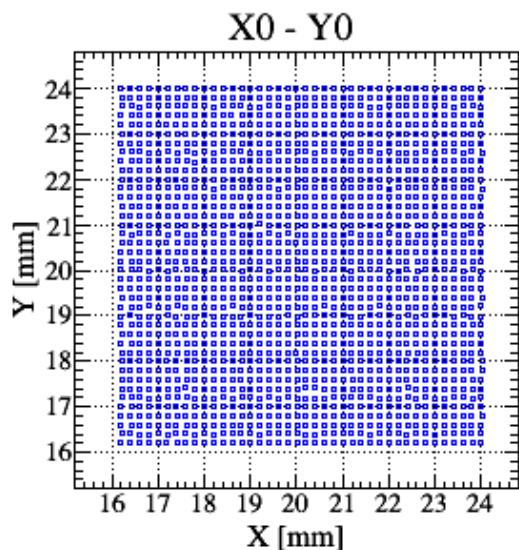
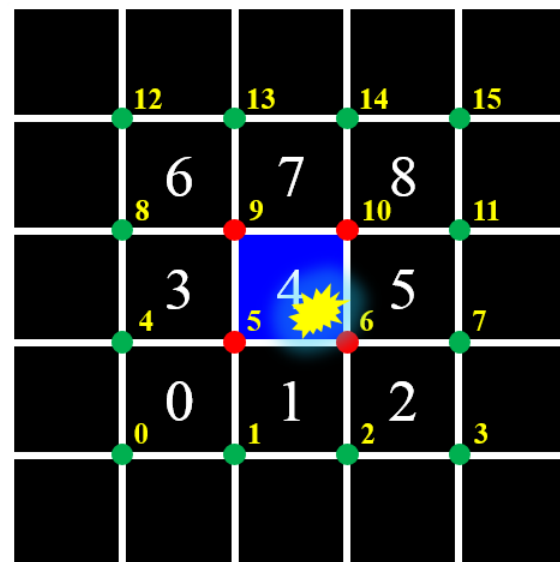
$$c \frac{\partial V(x, y, t)}{\partial t} - \nabla \cdot (\sigma(x, y) \nabla V(x, y, t)) = I(x, y, t)$$

- 读出节点处的电位为 0
- 有限差分法求解



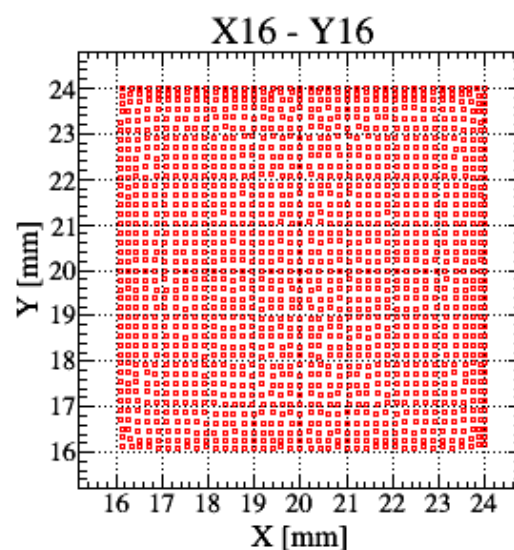
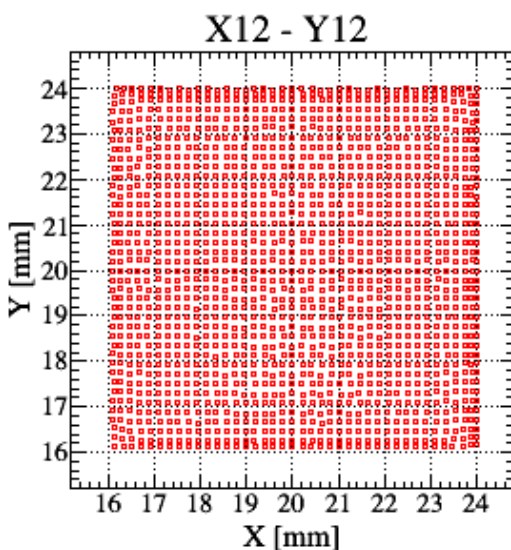
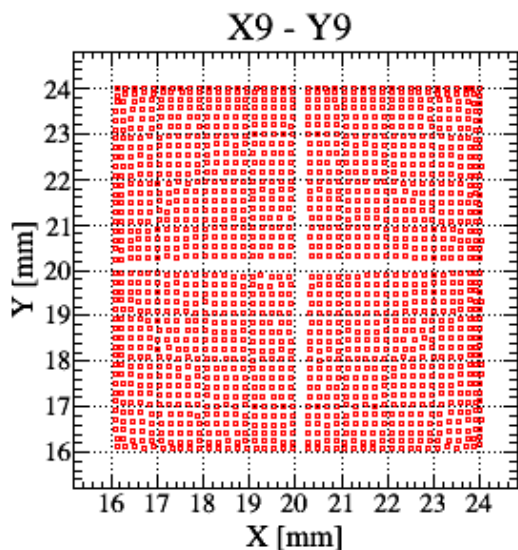
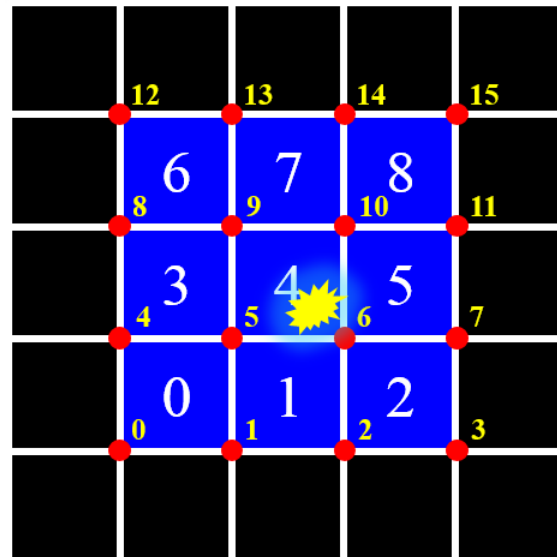
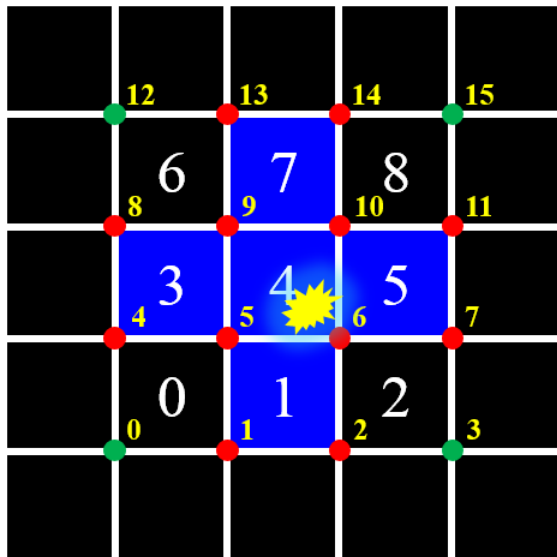
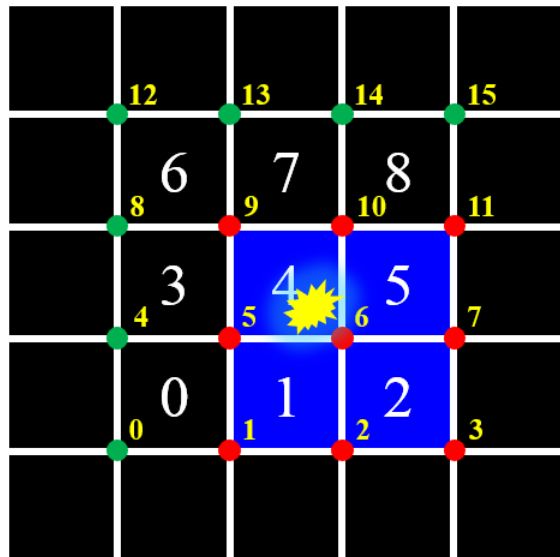
重建算法：四节点

- $X = \frac{(Q_B+Q_C)-(Q_A+Q_D)}{Q_A+Q_B+Q_C+Q_D} \frac{L}{2} = \frac{\sum_{i=1}^4 Q_i X_i}{\sum_{i=1}^4 Q_i}$ (电荷分配法 \Rightarrow 重心法)
- 模拟数据同时知道击中位置和重建位置，便于分析重建效果
- 成像畸变：枕形失真和收缩
 - ◆ 种子 Cell 边缘附近的电荷扩散到了邻近的 Cell，电荷损失率
- 传统单Cell型PSD，Cell尺寸较大，针孔阵列成像，查表法修正
 - ◆ 阵列型阻性阳极的Cell尺寸小，且数量多
 - ◆ 利用模拟数据进行查表法修正，但耗时多，且不方便



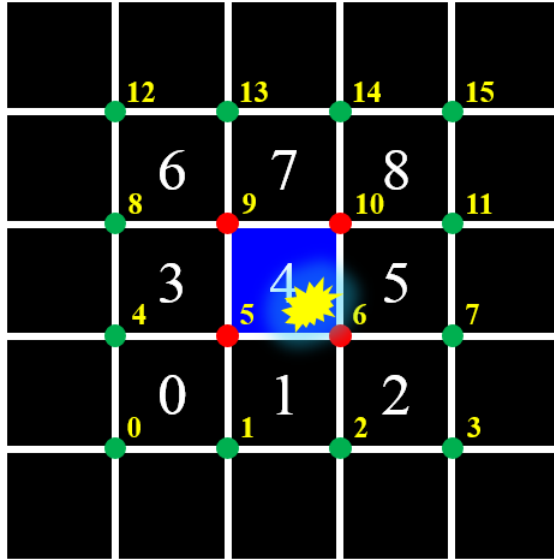
重建算法：多节点

- 有效修正Charge Sharing的影响；引入基线波动，不利于多次击中事例重建

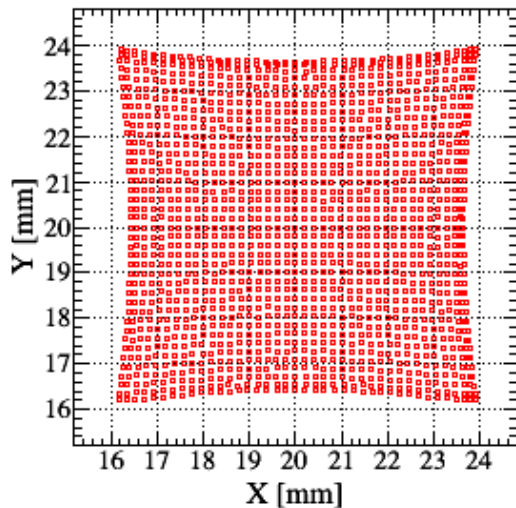


重建算法：节点加权

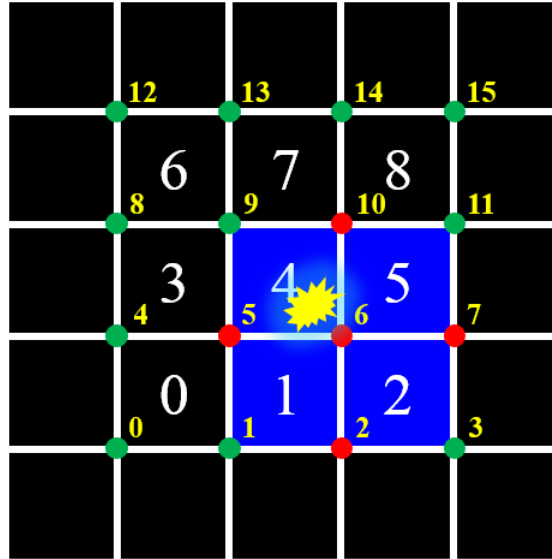
- $X_{346} = a_x X_4 + (1 - a_x)[b_x X_3 + (1 - b_x)X_6]$, 分区重建; 困难转移到了权重因子的确定; 迭代



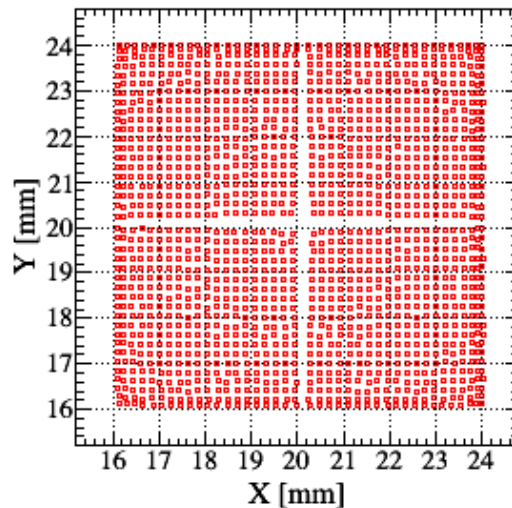
X4 - Y4



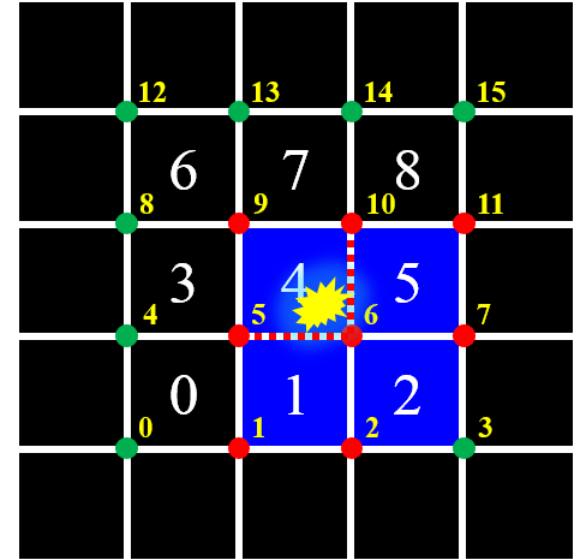
2017-11-12



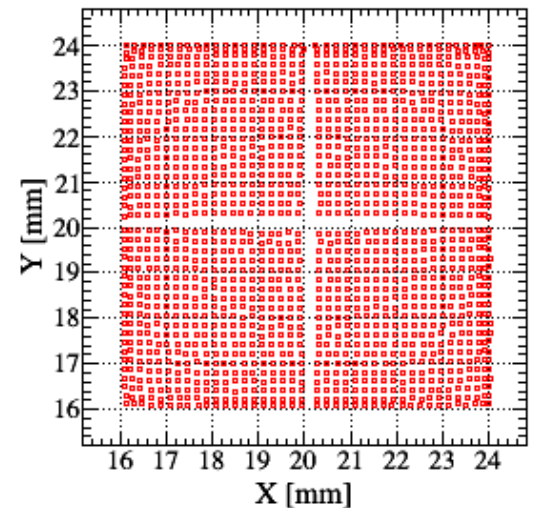
X3 - Y3



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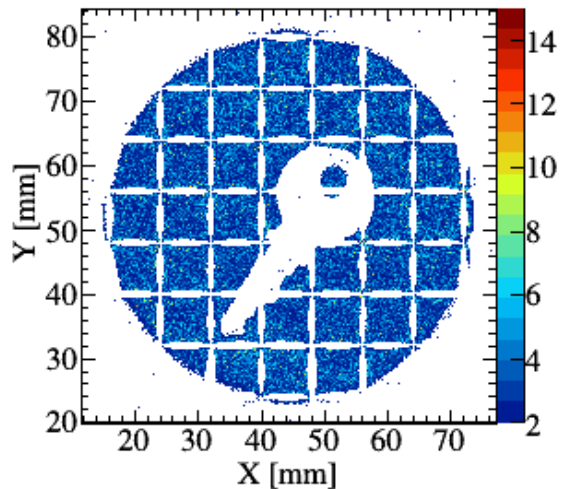


X6 - Y6

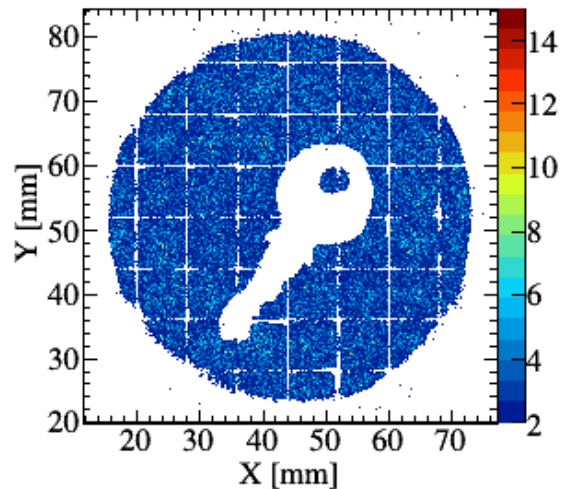


重建算法：实验数据对比

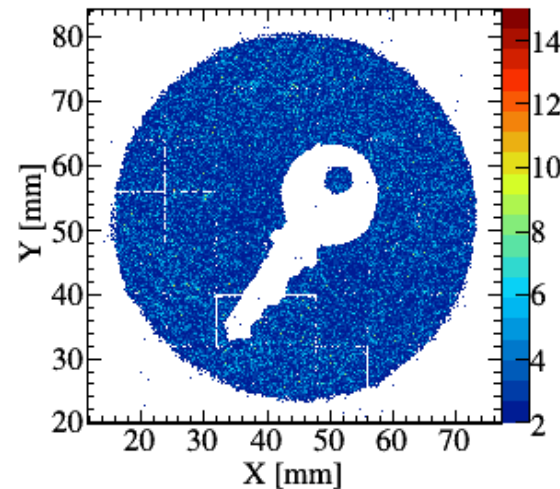
X4 - Y4



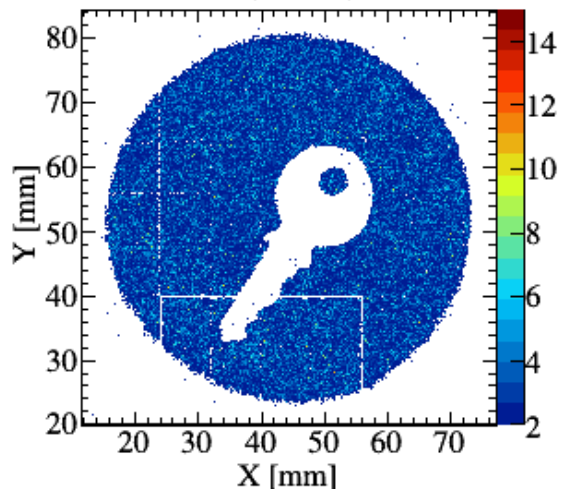
X3 - Y3



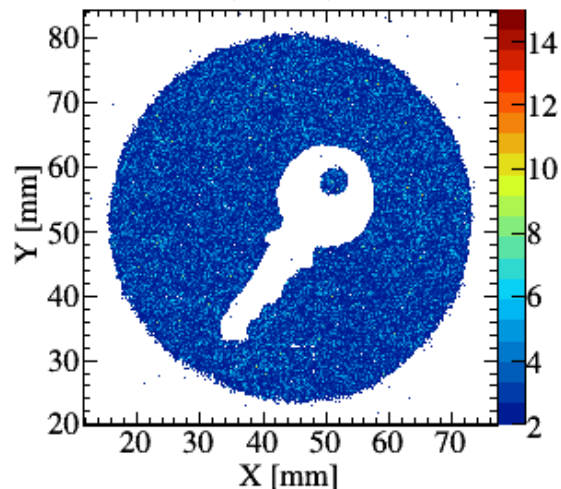
X12 - Y12



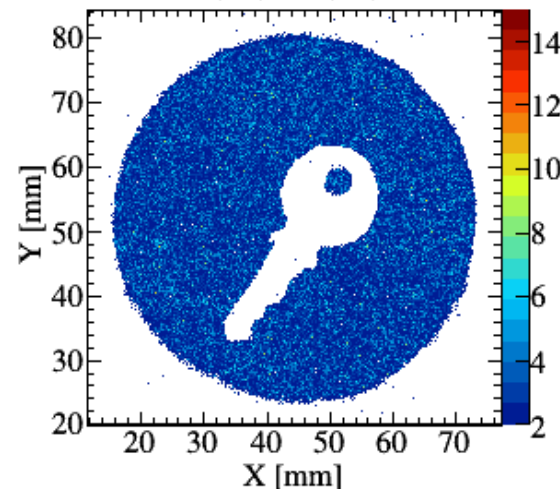
X16 - Y16



X34 - Y34

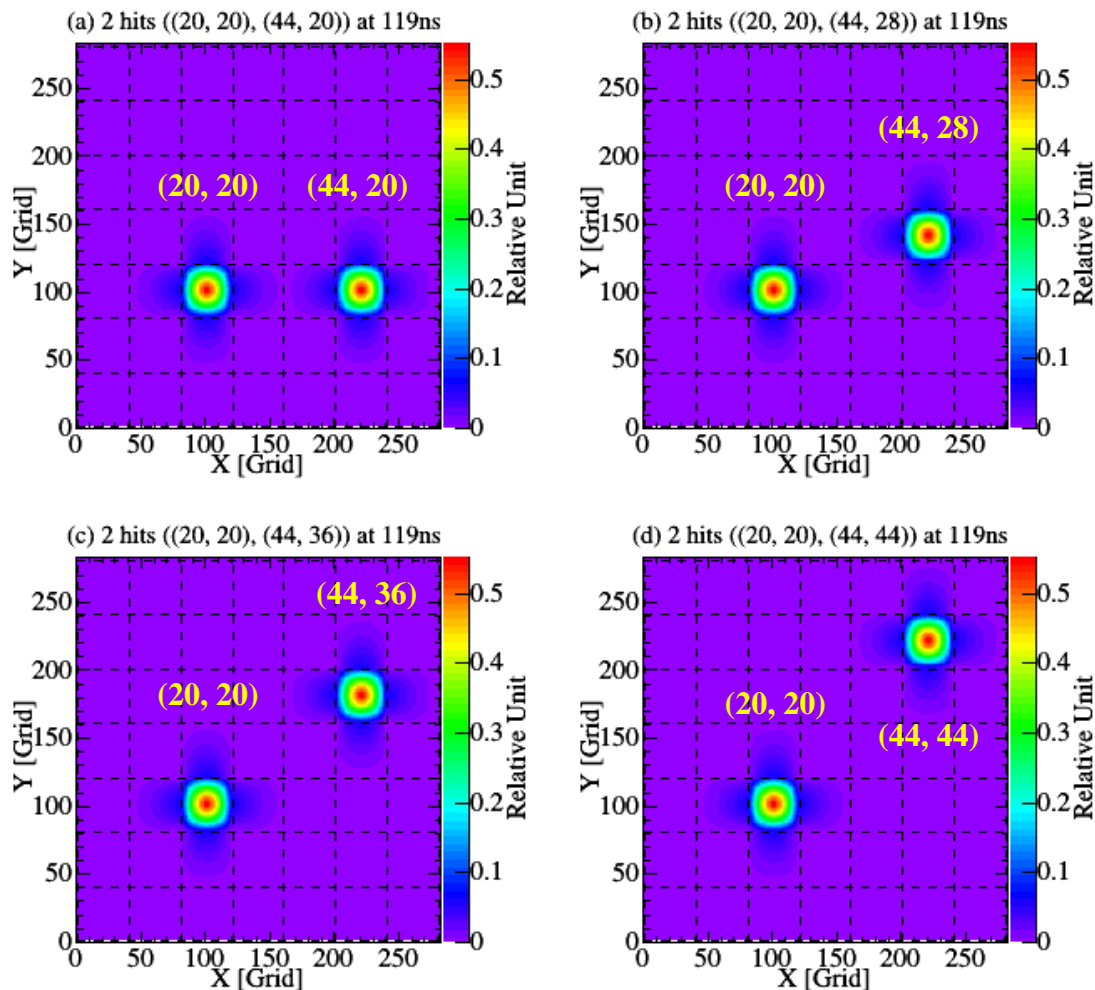


X346 - Y346



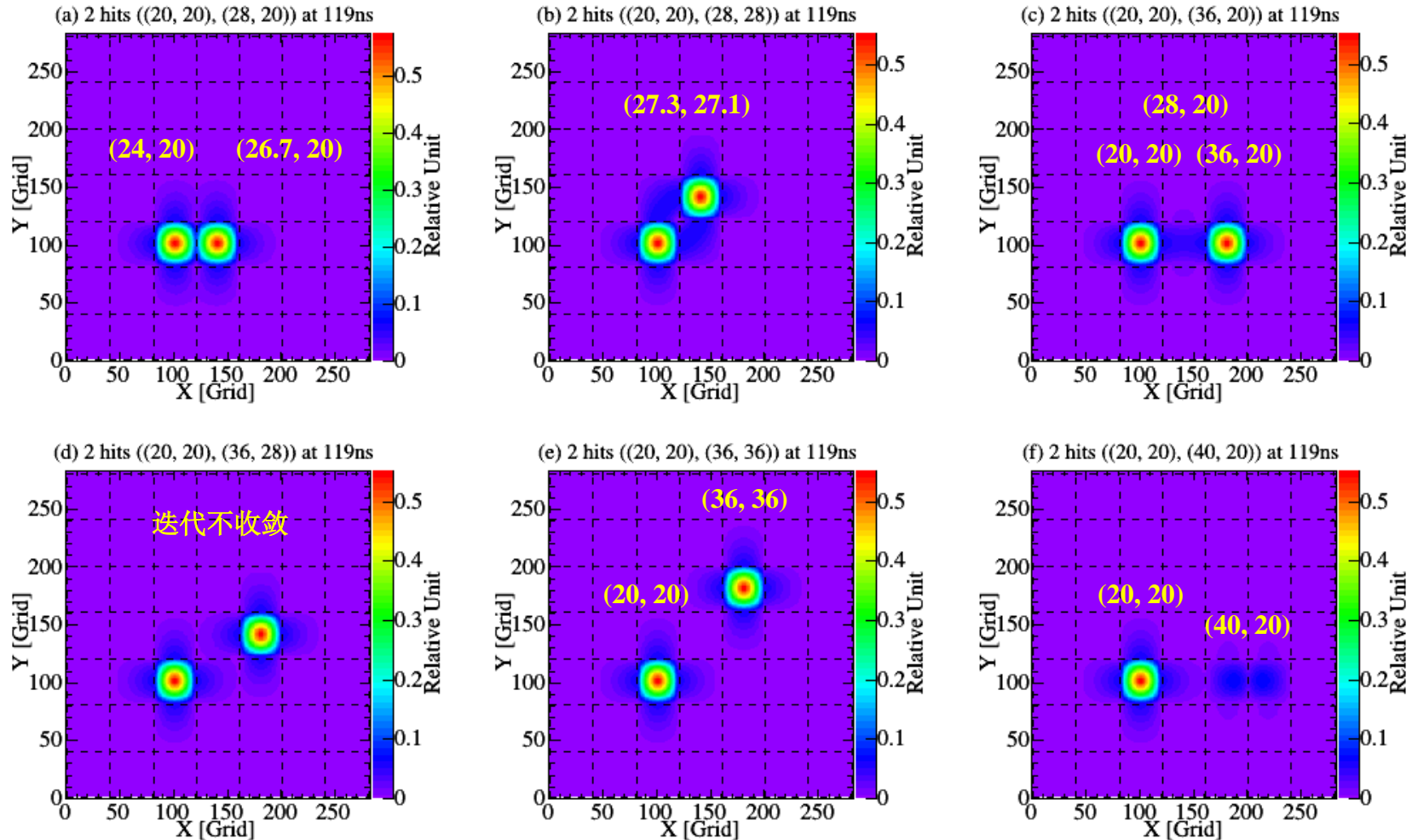
多次击中事例重建

- 主要考虑同时有两个事例击中情形
 - 第二个Hit位于 3×3 Cells 区间外，成功重建 2 个 Hit，重建精度好于 $1.0 \mu\text{m}$



多次击中事例重建

- 第二个Hit位于 3×3 Cells 区间之内，当两个Hit间隔2个Cell尺寸时，重建成功



重建算法对计数率的影响

多次击中估算

- Δt 时间内击中探测器有效面积 s 的粒子数服从泊松分布

- ◆ $P(X = k) = \frac{\lambda^k}{k!} e^{-\lambda}$, 其中, $\lambda = \epsilon \cdot \Delta t \cdot s \cdot I_0$

- ▶ λ : 单位时间内随机事件的平均发生率
- ▶ ϵ : 探测器的探测效率, 假设为 1
- ▶ Δt : 探测器采样时间窗, 默认为 $2 \mu\text{s}$
- ▶ s : 探测器有效面积, $3 \times 3 \times 8 \times 8 \text{ mm}^2$
- ▶ I_0 : 探测器单位面积上的入射流强

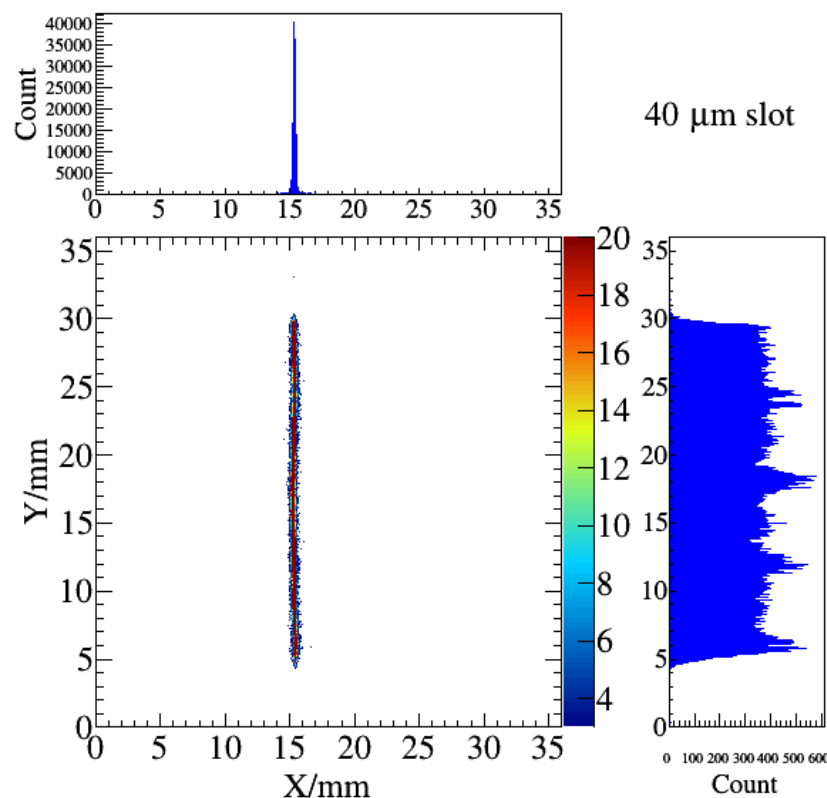
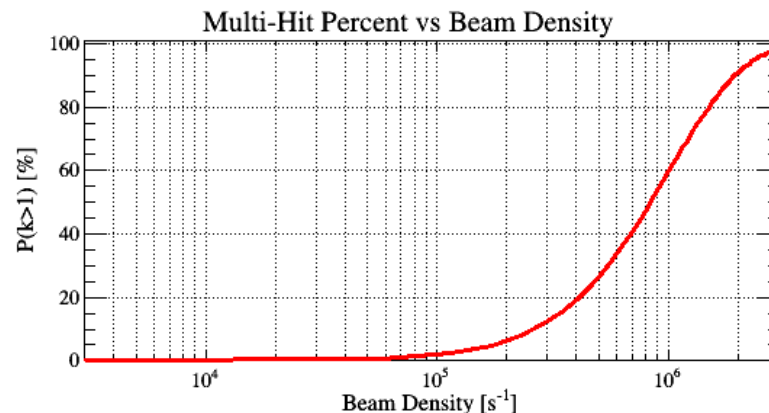
- 3×3 Cells, $P(k > 1) = 1.8\% @ 100 \text{ kHz}$

探测器现有实验数据的计数率估算

- X光机对狭缝成像, DAQ计时约40s内取数20万事例

- ◆ $\frac{197604}{40\text{s}} = 4.94 \text{ kHz}$

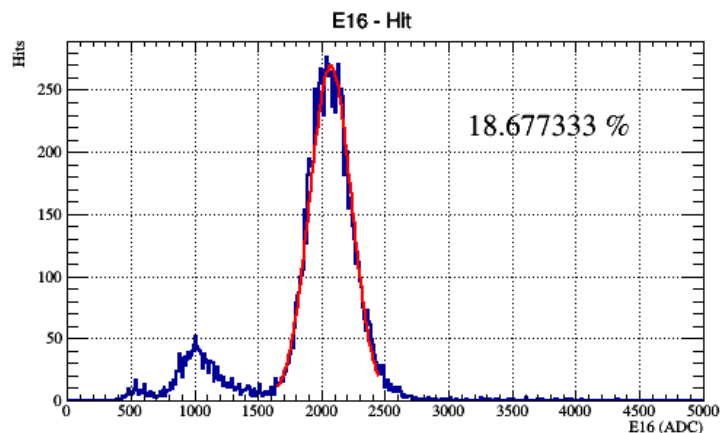
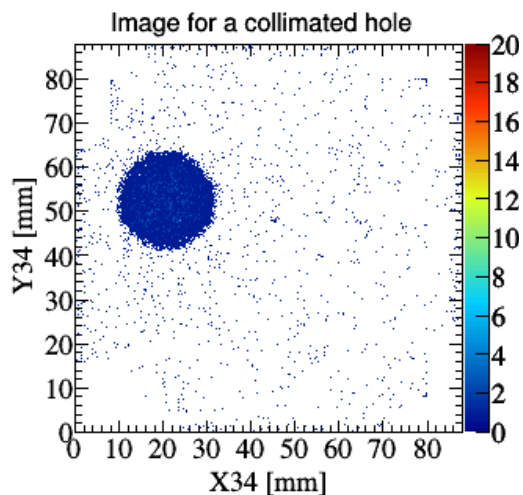
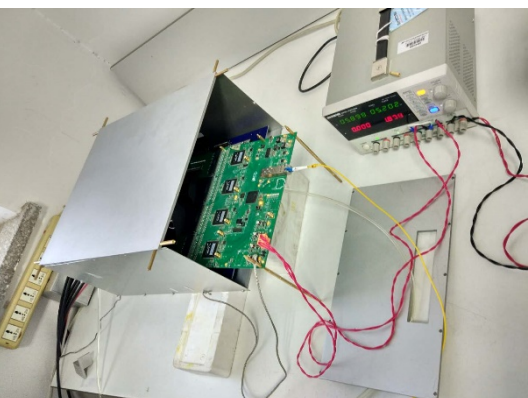
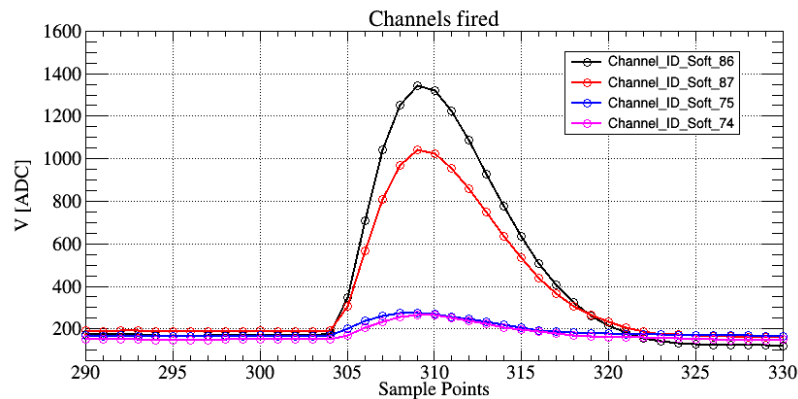
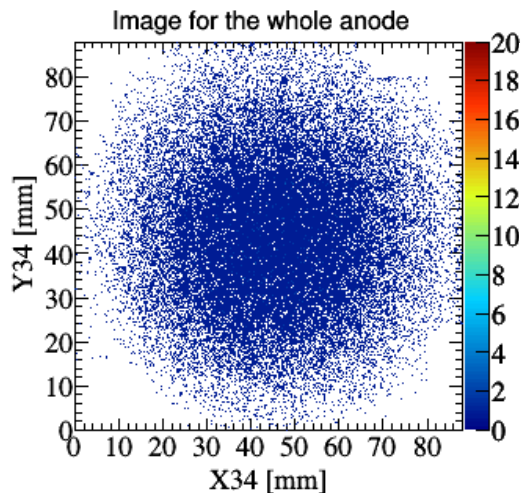
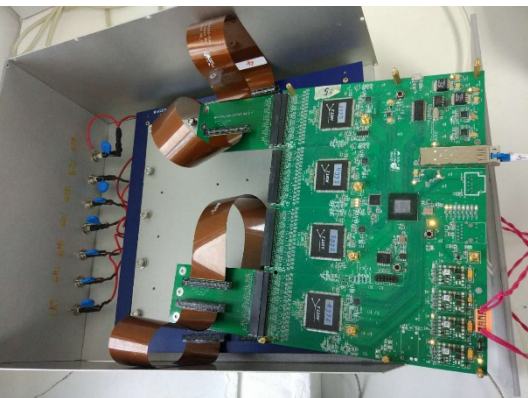
- ◆ $\frac{197604}{25\text{mm} \times 40\mu\text{m} \times 40\text{s}} = 494 \text{ kHz} \cdot \text{cm}^{-2}$



总结

- 阵列型阻性阳极读出方法在二维X射线成像GEM探测器上成功应用
- 阻性阳极读出内禀的枕形失真现象，优化重建算法减弱和消除这种畸变
 - 34节点加权重建算法使用最少的节点信息，获得良好的重建性能
- 探究了重建算法对多次击中事例的响应情况
 - 重建算法足以应对在 3×3 Cells单元之外的多次击中响应
 - 重建算法确保探测器可以在高于100 KHz的计数率下正常工作

AGET 电子学



感谢封常青、沈仲弢、朱丹阳、潘姜

谢谢

Two-dimensional imaging triple-GEM detector with resistive anode readout. JINST. (2017)

基于阻性阳极读出方法的GEM探测器二维成像性能研究。物理学报。(2017)

Design and optimization of resistive anode for a two-dimensional imaging GEM detector. CPC(2016)

多次击中事例重建

- 进一步分析两个Hit位于 3×3 Cell区间之内的情形

