应用于反应堆中微子TPC探测器研究进展

祁辉荣

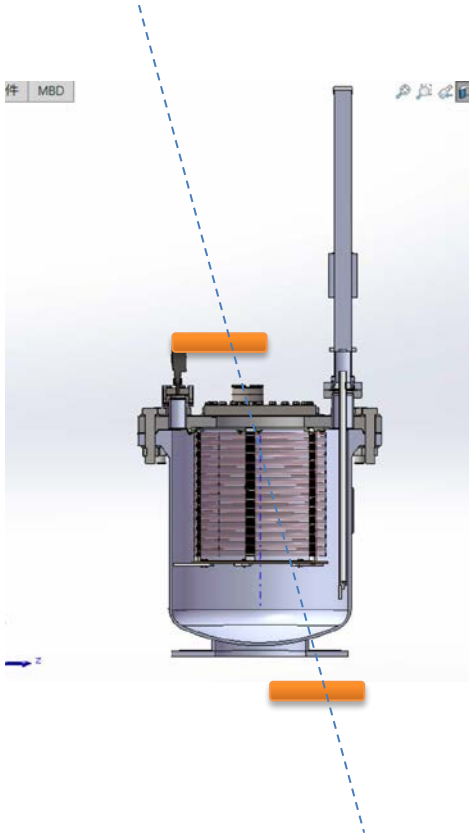
丁雪峰, 管宇铎, 文其林, 姚海峰, 佘信, 郭聪, 侯少静, 徐美杭, 魏夕杰

2025, 09, 26 IHEP

- 项目进展
  - 探测器测试进展
  - Gain fluctuations and test plan

进展1 – 探测器电子学连接测试

- 探测器进展
  - 探测器加装外部触发系统（<0.013Hz）
  - 调整上下100mm×100mm塑料闪烁体的位置 （使得入射Muon角度变的更大）

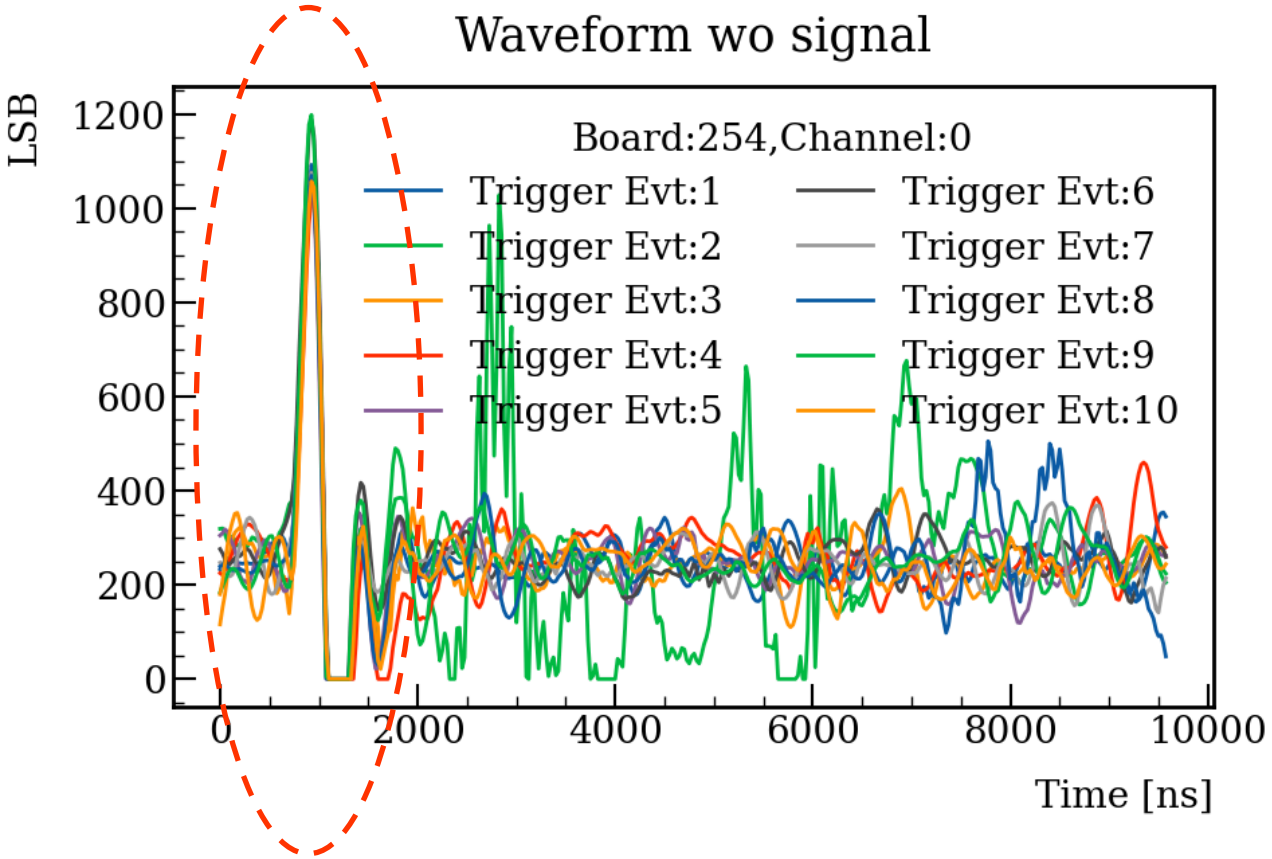


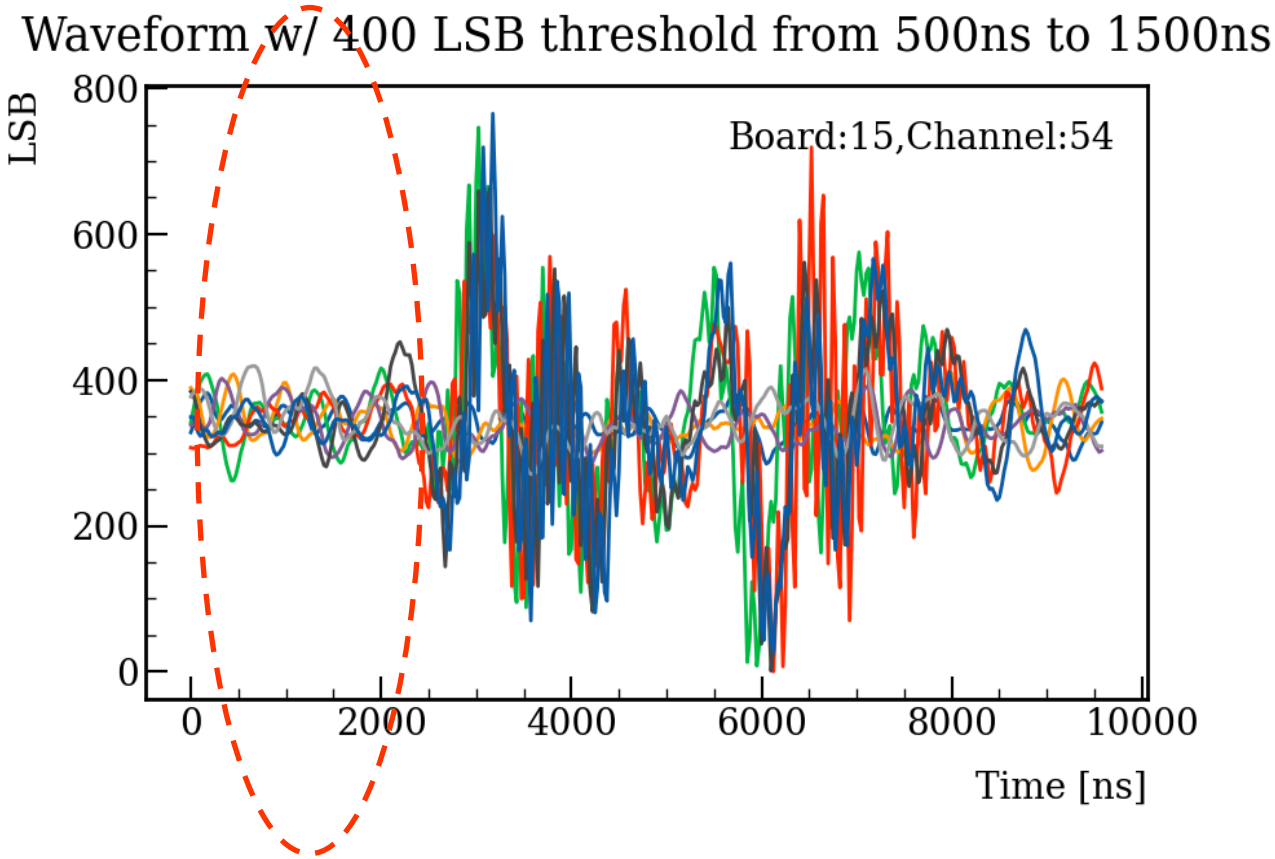
进展2 – 探测器数据采集

- Micromegas探测器数据采集
  - CF4压力（103kPa）
  - **每次取数20分钟（每组3-4次），**共四组数据
    - 15kV漂移高压+850V探测器高压； 15kV漂移高压+900V探测器高压
    - 11kV漂移高压+850V探测器高压； 11kV漂移高压+900V探测器高压

进展3 – 信号对比确认

- Micromegas探测器数据采集系统（文其林 + 管宇铎）
  - 探测器高压和漂移场高压均相同，Muon外触发系统修改为 → 信号发生器周期触发
  - 数据解码完成后，进行对比，**前端300ns底宽的有效信号消失，确定之前位置的就是muon信号**

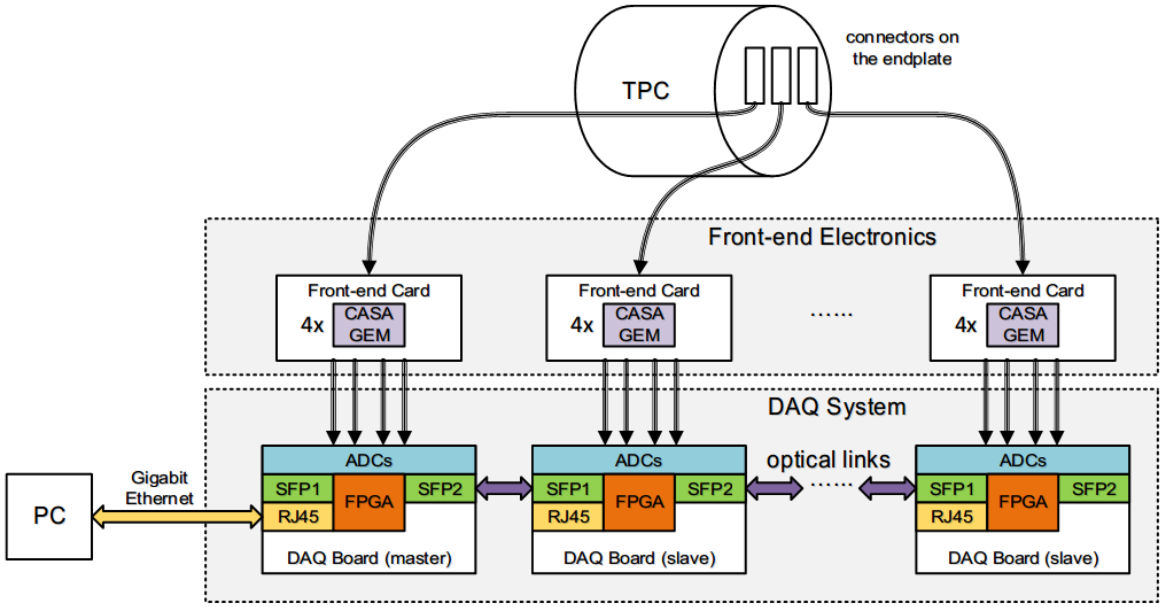


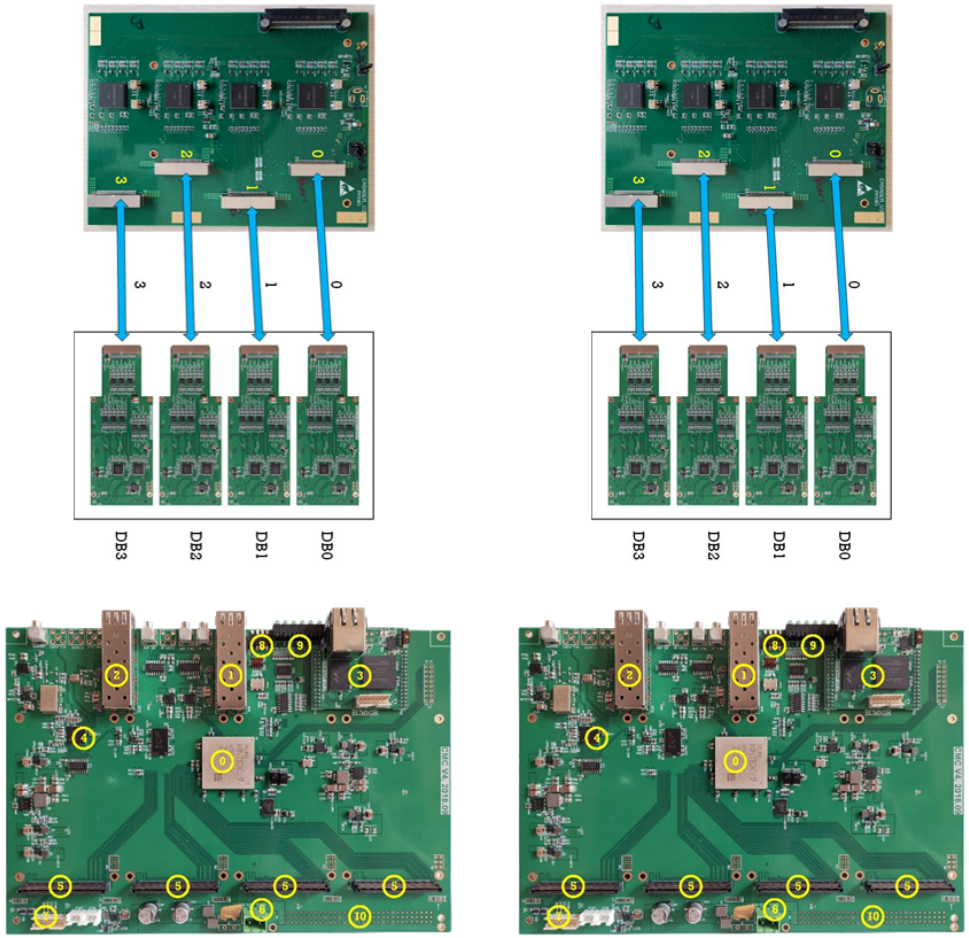


进展4 – 探测器数据采集系统数据分析

- Micromegas探测器数据采集系统（文其林 + 管宇铎）
  - 确认数据解包程序
  - 周二下午组织网络会议，与清华宫辉老师进行了时间信息的确认

CASA数据采集系统用于采集前端电路输出的模拟信号，系统由一块主板和若干块从板串行连接构成。上位机与主板通过以太网通信，主板与从板、从板与从板之间通过光纤通信。





Gain fluctuations and test plan

Motivations

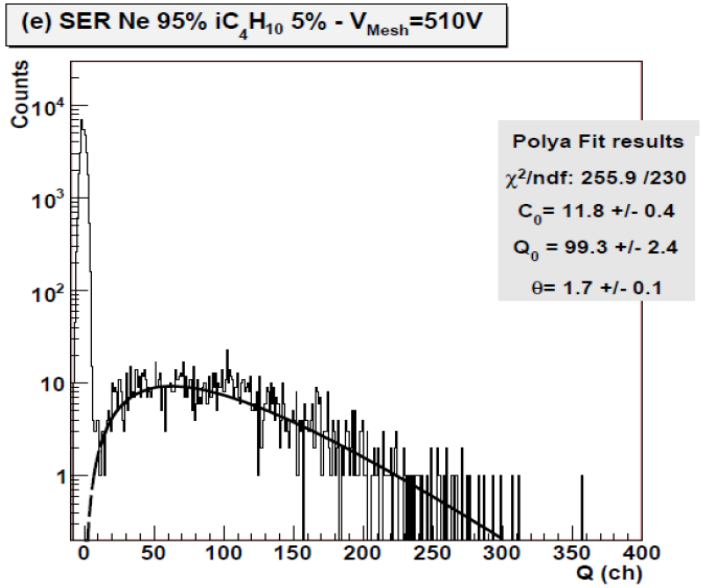
- Final avalanche size obeys a probability distribution Signal fluctuations impact on detector performance
  - Spatial resolution in a Micromegas
  - Energy resolution in amplification-based gas detectors
  - Minimum gain and ion backflow
  - Detection of single electrons with a pixel chip （**NEED the pixel readout**）

- What is the shape of the distribution ?
- How does it vary with gas, field, geometry…?

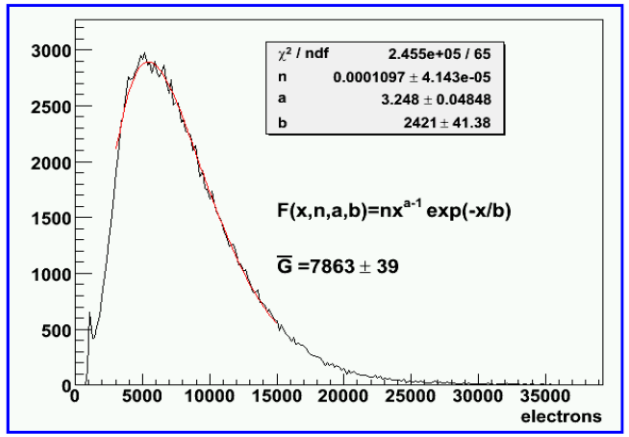
- The Polya distribution parameterized by Gas gain G and parameter m
  - Works well with Micromegas/ MWPC/ Thin GEM/ Single GEM
  - With GEM or Thin GEM, the distribution is more exponential

$$p_m(g) = \frac{m^m}{\Gamma(m)} \frac{1}{G} \left(\frac{g}{G}\right)^{m-1} \exp(-mg/G)$$

Micromegas, NIMA 461 (2001) 84

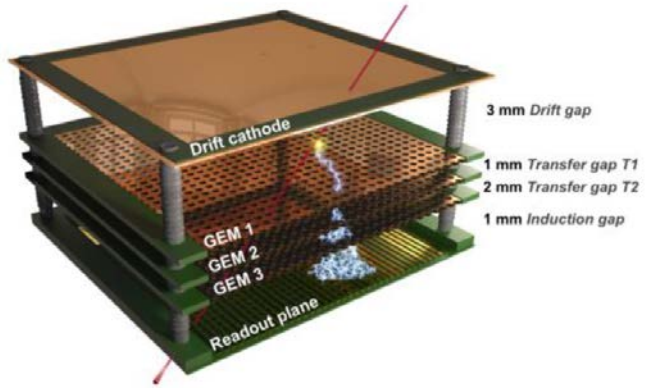


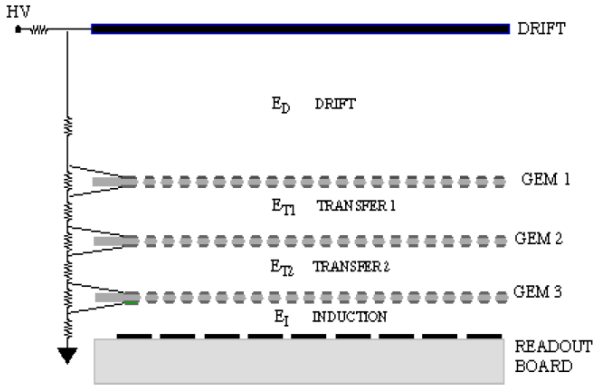
GEM, Bellazzini, IEEE 06, SanDiego

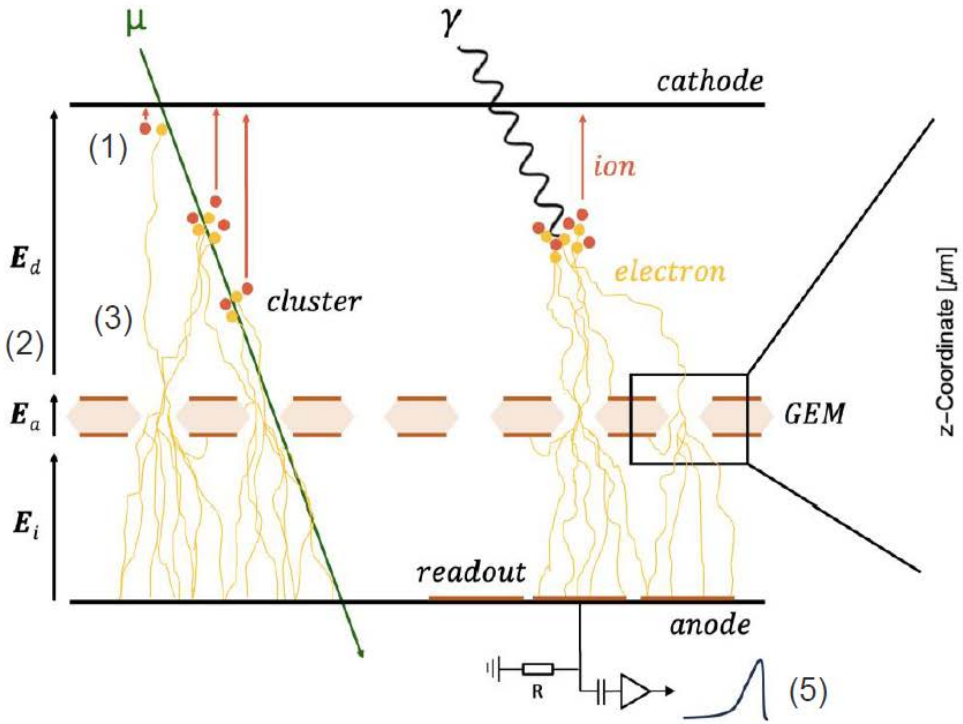


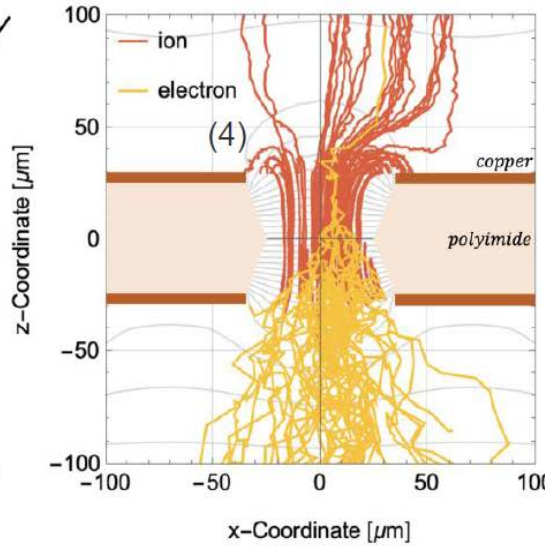
GEM and Micromegas

- GEM Detector
- 17%@5.9keV using 55Fe source









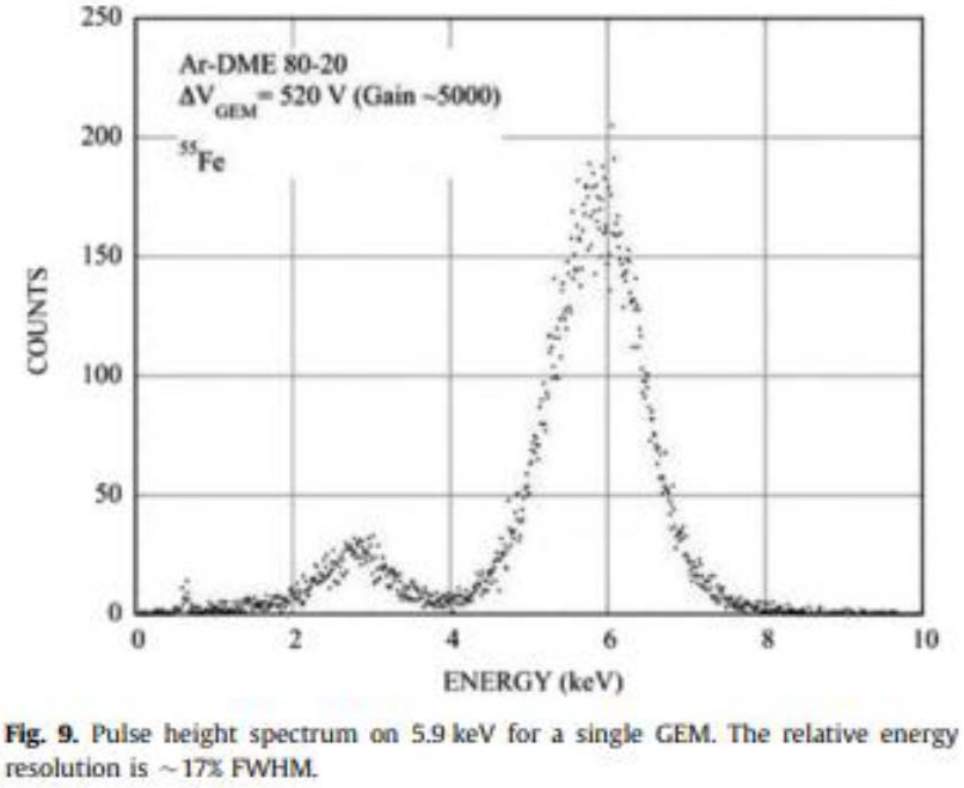


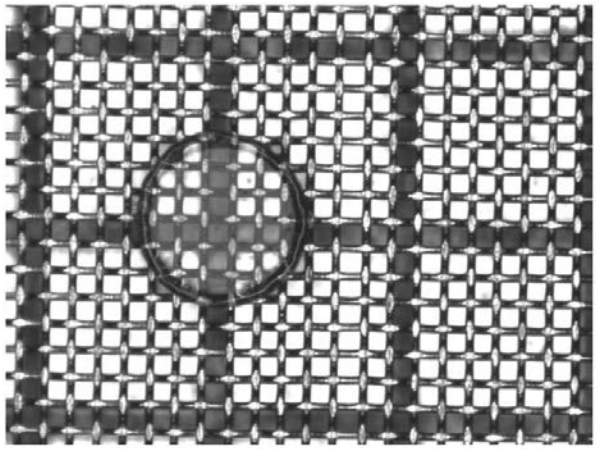
Fig. 9. Pulse height spectrum on 5.9 keV for a single GEM. The relative energy resolution is ~17% FWHM.

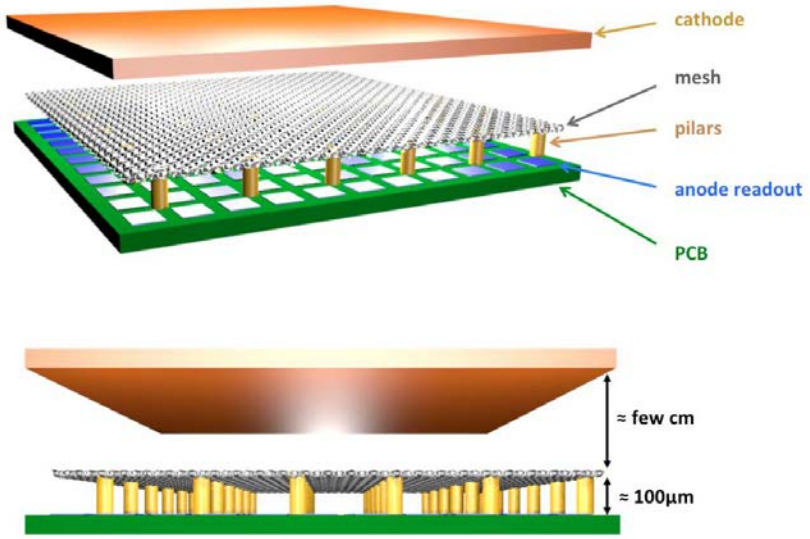
GEM and Micromegas

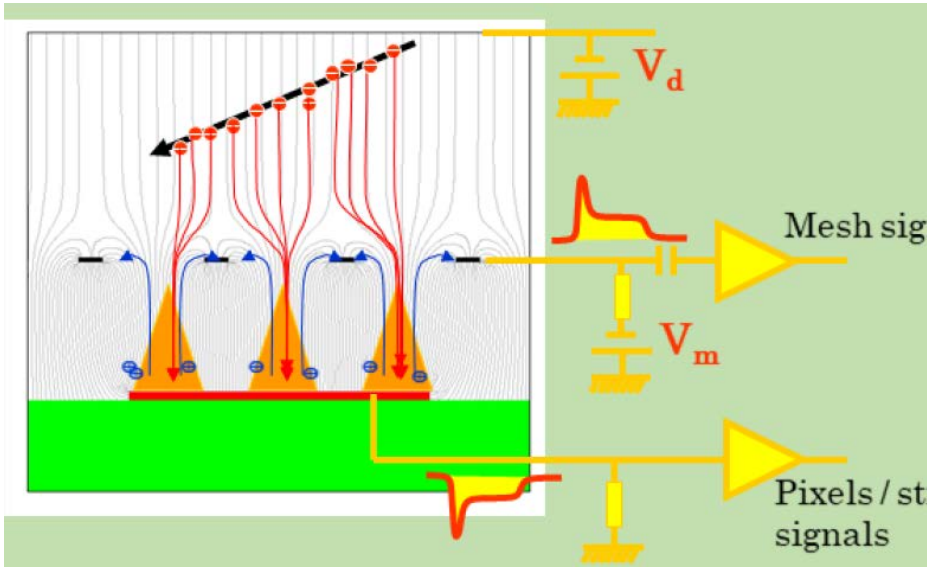
- Micromegas 探测器
- 11%@5.9keV using 55Fe source

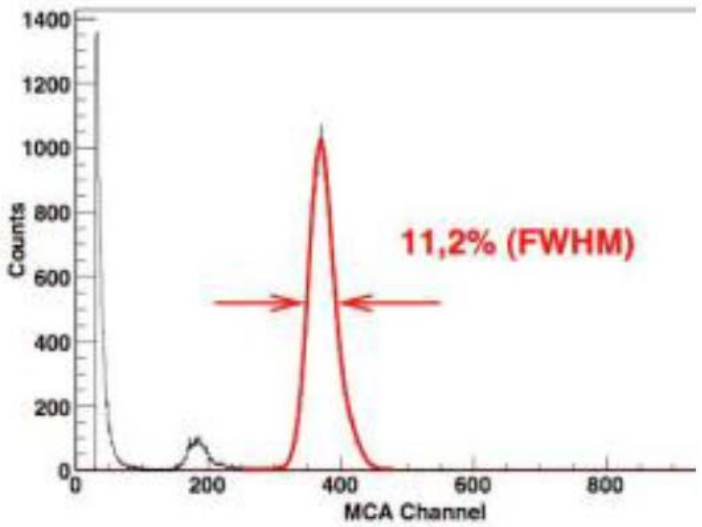
- Thin amplification gap
  - 50-150 μm□
- Small imperfections
  - → No gain variations

Bulk Micromegas





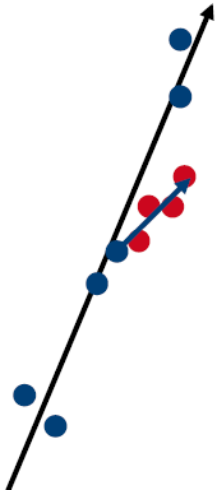




Ionization yield

- Ionization is a statistical process
- Poisson statistics at small gas layer (mm)
- Energy of ionized electrons with long tail (Landau distribution)
- High energy electrons can ionize further

- Leads to clustering of charges
  - 2-3 times less clusters than electrons
  - >50 % of cluster have one electron



E_x: First excitation energy
E_I: Ionisation energy
W_I: Average energy for creation of electron-ion pair
N_P: Primary number of electron-ion pairs
N_T: Total number of electron-ion pairs

$$N_T = \frac{dE/dx}{W_I}$$

Gas	Density, $mg\,cm^{-3}$	E_x eV	E_I eV	W_I eV	$dE/dx\|_{min}$ $keV\,cm^{-1}$	N_P cm^{-1}	N_T cm^{-1}
H_2	0.084	10.8	13.6	37	0.34	5.2	9.2
He	0.179	19.8	24.6	41.3	0.32	3.5	8
Ne	0.839	16.7	21.6	37	1.45	13	40
Ar	1.66	11.6	15.7	26	2.53	25	97
Xe	5.495	8.4	12.1	22	6.87	41	312
CH_4	0.667	8.8	12.6	30	1.61	28	54
C_2H_6	1.26	8.2	11.5	26	2.91	48	112
iC_4H_{10}	2.49	6.5	10.6	26	5.67	90	220
CO_2	1.84	7.0	13.8	34	3.35	35	100
CF_4	3.78	10.0	16.0	35-52	6.38	52-63	120

Measurement of gain fluctuation

- Experimental study plan
  - Direct measurement of the distribution:
    - High gains, low noise electronics, single electron source
  - Indirect measurements
    - Do not provide the shape but some moments (variance)
    - Assuming Polya - like fluctuations, one obtains the shape

- Energy resolution R and electron collection efficiency η
  - R decreases with the efficiency according to
  - $R^2 = F/N + b/\eta N + (1-\eta)/\eta N$
  - $R^2 = p_0 + p_1/\eta$

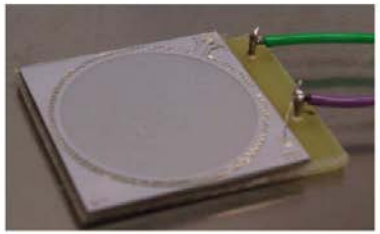
    $p_0 = (F-1)/N$

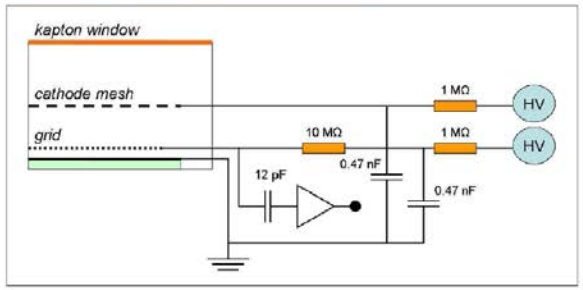
    $p_1 = (b+1)/N$

- Measure R(η) at e.g. 5.9 keV or stable source, fix F and N, b is $\sigma^2 = 1/m$
- But a certain number of primary e- and Fano factor have to be assumed

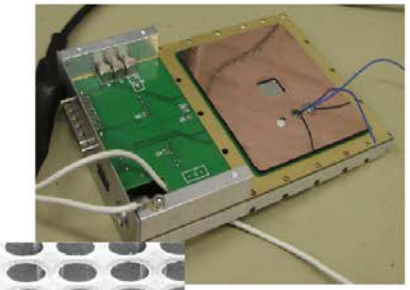
Experimental studies at NIKHEF

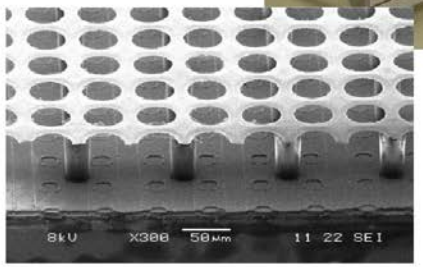
- Measure 1: *R(η)*
  - InGrid on bare wafer
  - Preamp/shaper/ADC
  - ^{55}Fe 5.9 keV X-ray source
  - Ar-based gas mixtures with iC_4H_{10} and CO_2





- Measure 2: *κ(G)*
  - InGrid on TimePix chip
  - Pixelman and ROOT
  - ^{55}Fe 5.9 keV X-ray source
  - Enough diffusion for counting
    - 10 cm drift gap
    - Ar 5% iC_4H_{10}



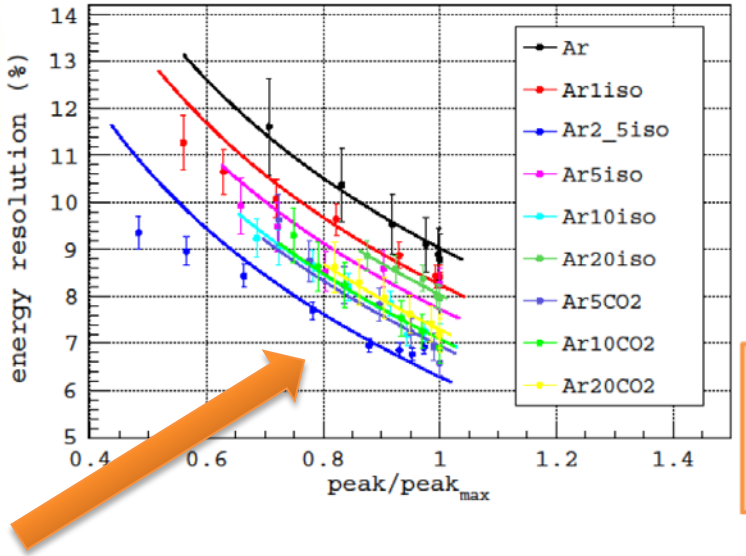


Energy resolution & collection

- Record ^{55}Fe spectra at various field ratios
  - Look at peak position VS field ratio
    define arbitrarily peak maximum as $\eta = 1$
  - Look at resolution VS collection
  - Fix *F* and *N*, adjust *b* on data points

Fit function:
$R = \sqrt{(p_0 + p_1/\eta)}$
$p_0 = (F-1)/N$
$p_1 = (b+1)/N$

$F = 0.2$ in all mix.
$N = 230$ in Ar/iso
$N = 220$ in Ar/CO2

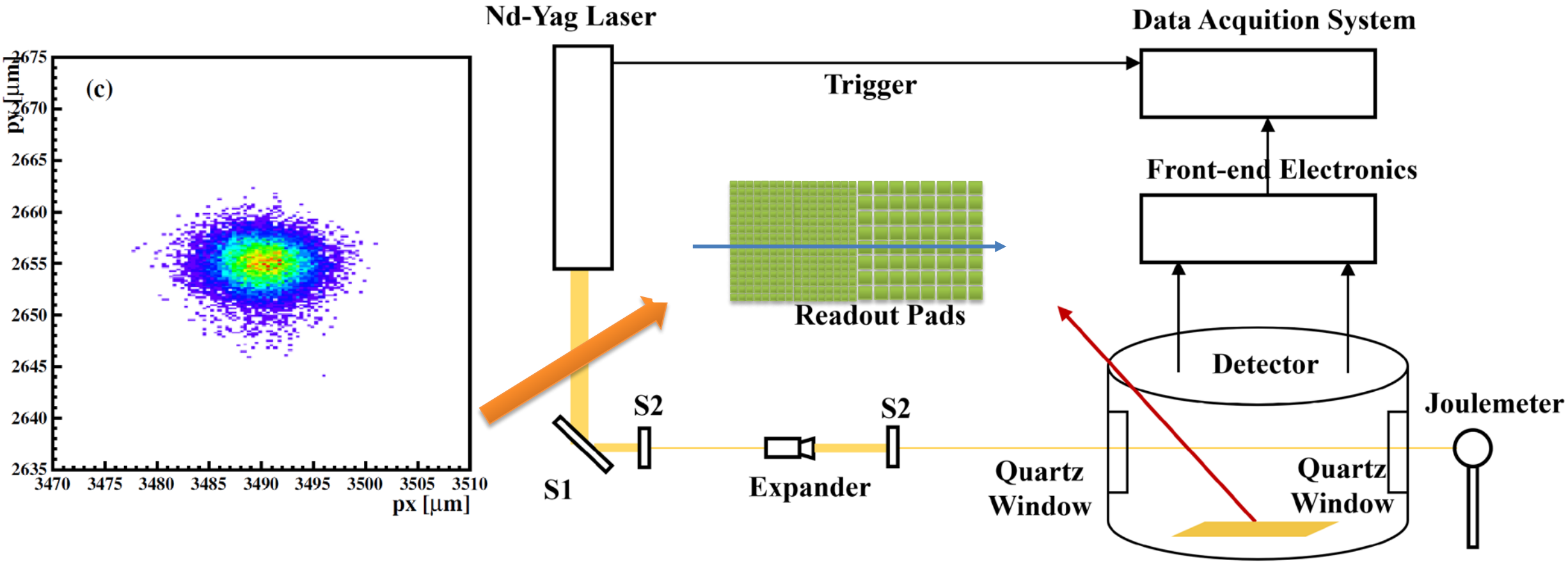


Gas	b	b_err	√b (%)	m=1/b
Ar	1,68	0,02	130	0,60
Ar1iso	1,37	0,01	117	0,73
Ar2_5iso	0,71	0,01	84	1,41
Ar5iso	1,18	0,02	109	0,85
Ar10iso	0,93	0,01	96	1,08
Ar20iso	1,29	0,01	114	0,78
Ar5CO2	0,86	0,02	93	1,16
Ar10CO2	0,91	0,02	95	1,10
Ar20CO2	0,97	0,02	98	1,03

- Rather low Polya parameter 0.6-1.4
  May be due to a poor grid quality
- Curves do not fit very well points
  Could let *F* or/and *N* free

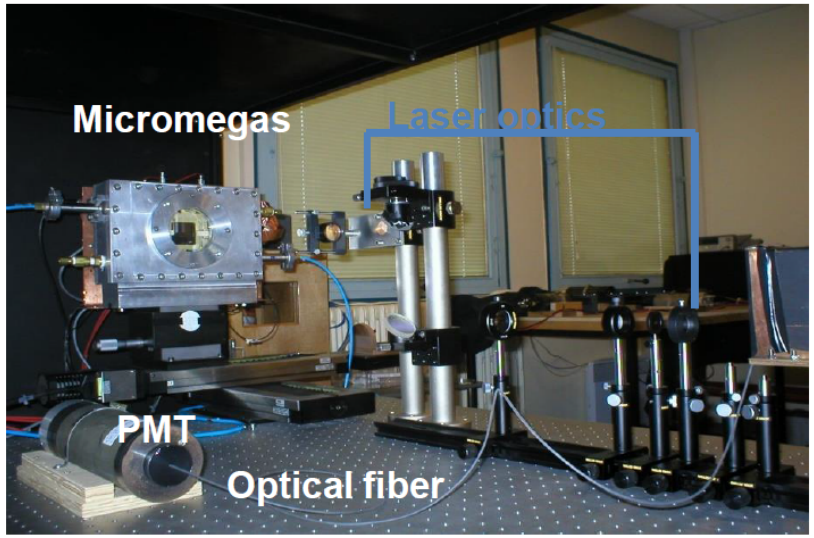
UV laser measurement at IHEP (Test Plan)

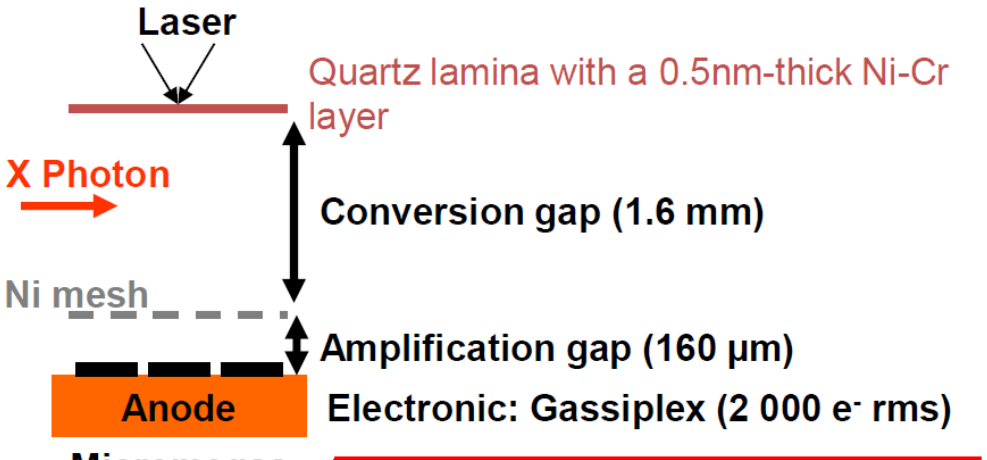
- 对激光衰减后的激光束进行了20分钟的能量连续监测
- 衰减后激光的平均能量为47.3 μJ， 能量稳定性优于3%
- 读出Pad设计为
  - 0.5mm×0.5mm ； 1mm×1mm； 1.5mm×1.5mm ； 2mm×2mm ； 2.5mm×2.5mm 不同尺寸大小



A Laser test bench for MPGD study

- MPGD characterization with a point-like electron source (<100 µm) of variable intensity produced by a 337nm UV laser.
- Study performed with a prototype for the ACTAR (ACTive TARget) project

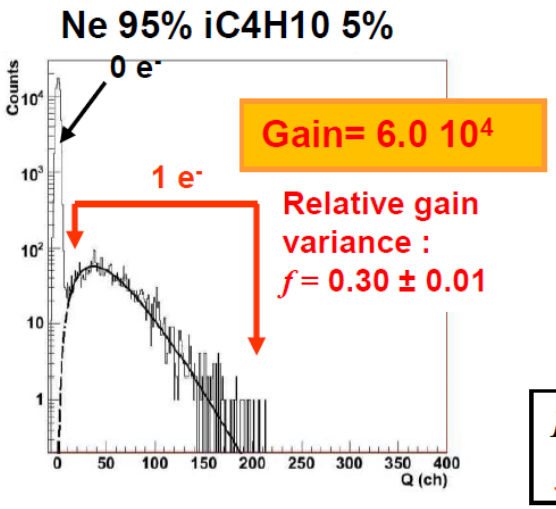




T. Zerguerras et al., NIM A 608 (2009) 397

1)

Single Electron Response

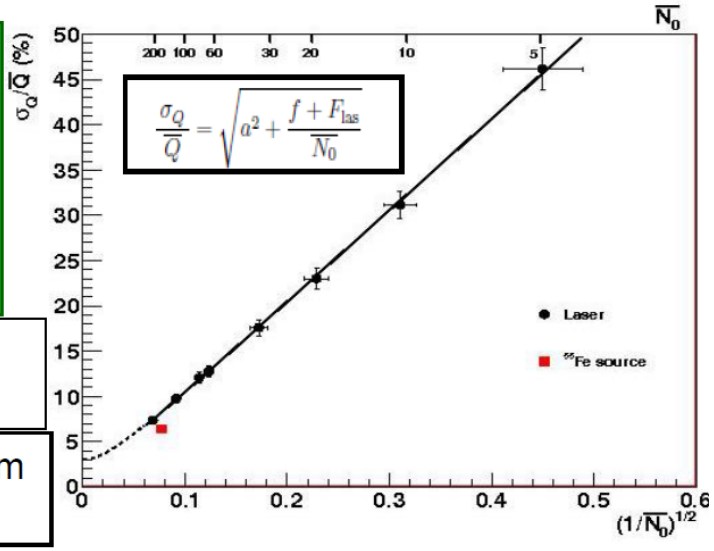


2)

Energy resolution following the number of primary electrons N_0

a :laser intrinsic constant

F_{las}: N_0 fluctuations from f and (f+F_{las})



Many thanks!