Study of Micromegas in several noble gas and mixtures for potential application of dark matter detection

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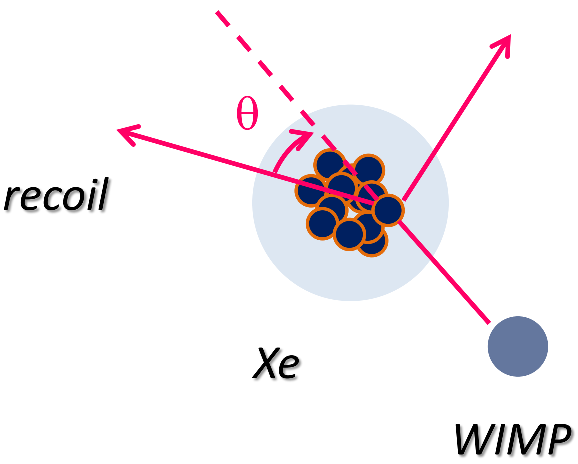
Outline

- Introduction
- Design & Fabrication of Micromegas readout panel
- Characteristic of Micromegas in Ar and Ne based mixtures
- Micromegas in TPC filled with gaseous XENON
- Summary and discussion

Direct detection of WIMPs

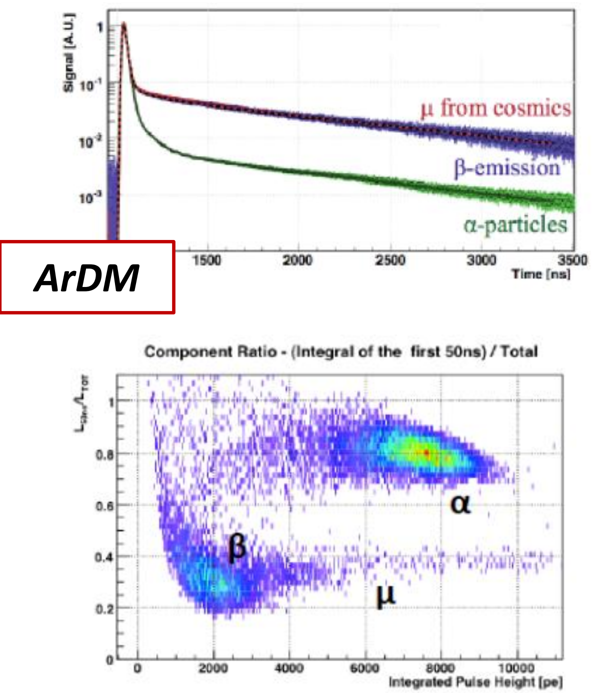


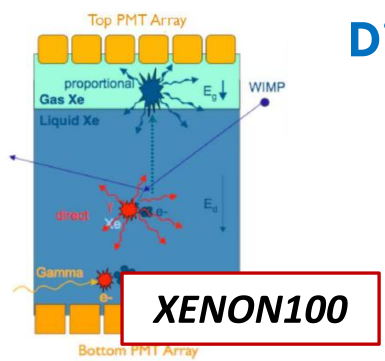
- Direct detection of WIMPs can be via elastic scattering from nuclei where slowly moving recoils can be detected
- Recoil energy from non-relativistic kinematics:

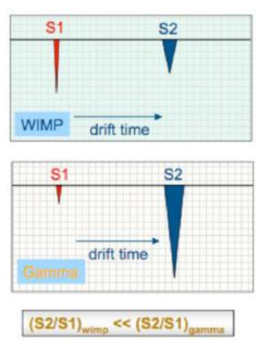
$$E_{recoil} = \frac{4M_\chi M_{recoil}}{(M_\chi + M_{recoil})^2} E_\chi \cos^2\theta$$

Typical: 1-100 keV if WIMPs mass in the range 10GeV-10TeV

- Detect recoils via ionization, scintillation etc.







Direct Dark Matter detector with noble liquids and gases

Particle identification

» Pulse shape discrimination

» Charge/light ratio

Advantages

✓ Large masses , Scalable

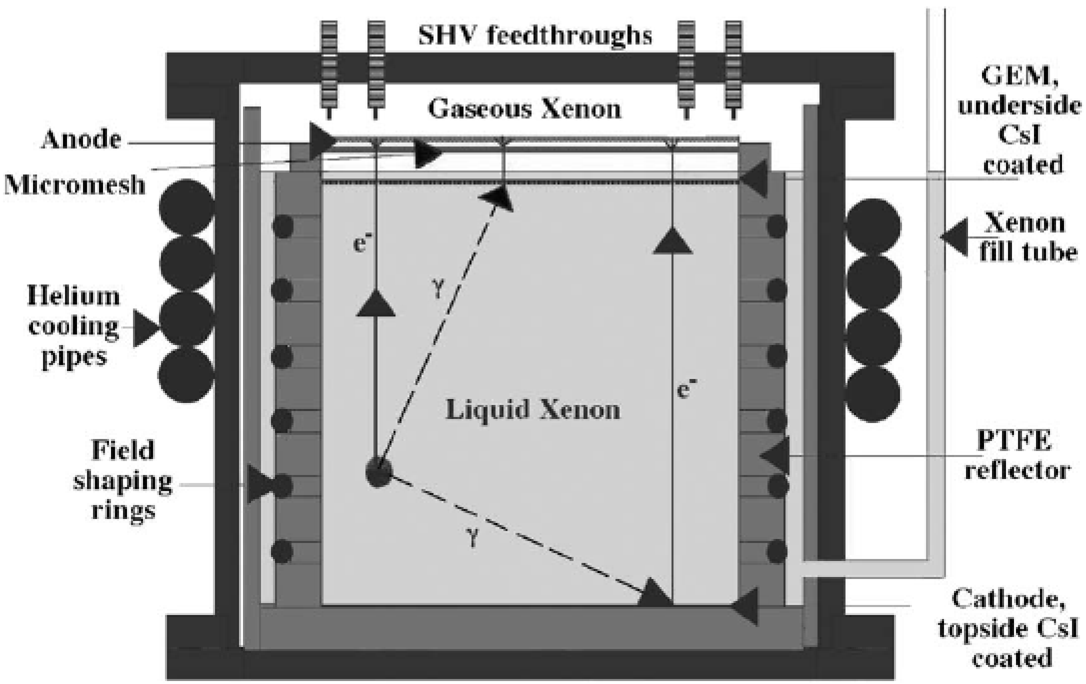
✓ Scintillation & ionization (dual-phase)

✓ Self Shielding, background reduction

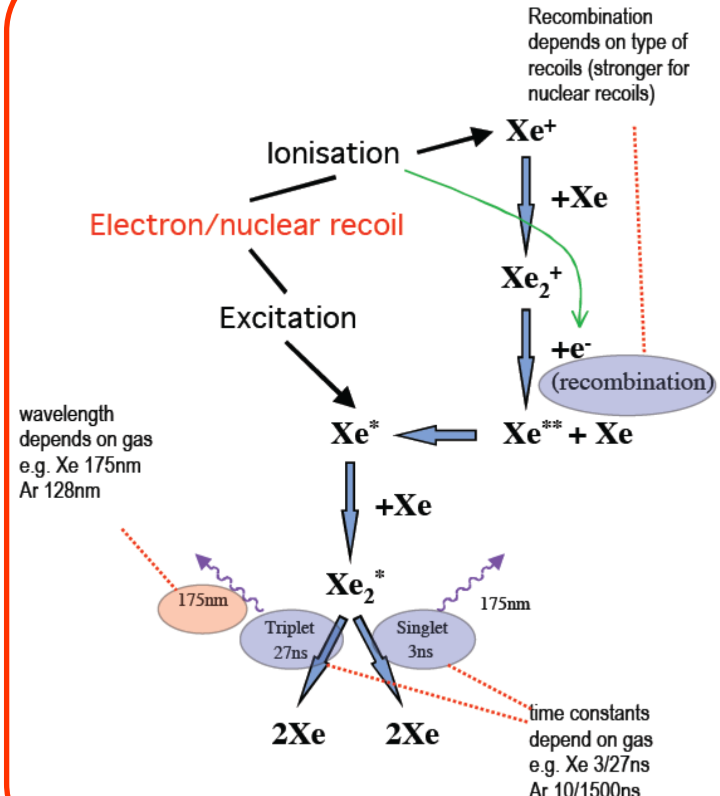
✓ Operation in TPC (3D reconstruction)

Dual-Phase DM detector Layout

Possible Layout DM Detector with dual-phase Xenon



P.K. Lightfoot et al. NIM A 554(2005)



Nigel Smith, RAL

→ *Micromegas could be used as charge readout (with multiplication) device in GXe (collect and amplify ionization electrons extracted from LXe)*

Why Micro-pattern as charge r/o device?

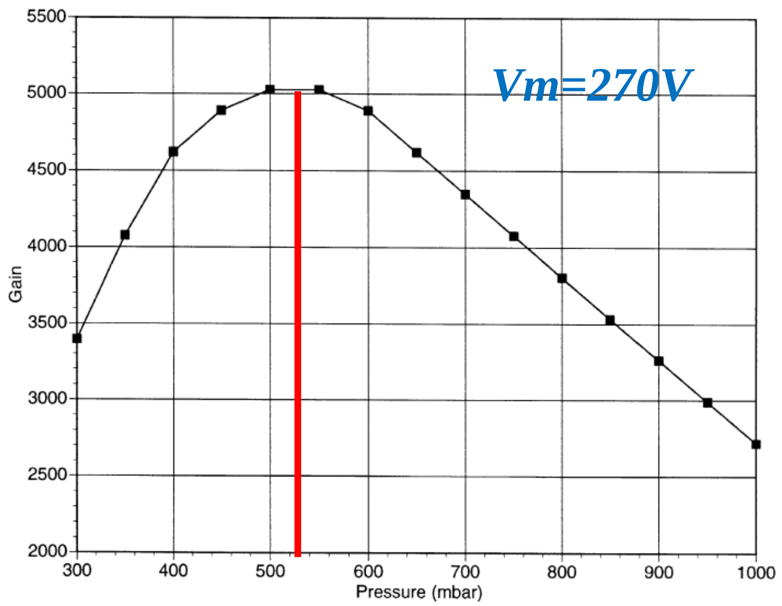
Micro-pattern gaseous detector (GEM, Micromegas) are suitable to be used as charge r/o device in DM detection for the reason that:

- *Good spatial resolution (GEM, Micromegas)*
- *Good energy resolution for low energy x-rays (Micromegas)*
- *Flexible readout pattern*
- *Low material budget and high radiopurity*

In addition, micromegas (high gain, robust) are especially promising to operate at high pressure compared with conventional parallel mesh chamber

$$G = e^{\alpha d}\left(\alpha = Ape^{-\frac{Bpd}{V}}\right) \Rightarrow \frac{\partial G}{\partial p} = G\alpha d\left(\frac{1}{p} - \frac{Bd}{V}\right)$$

Ar+7% cyclohexane for 50 μm amplification gap



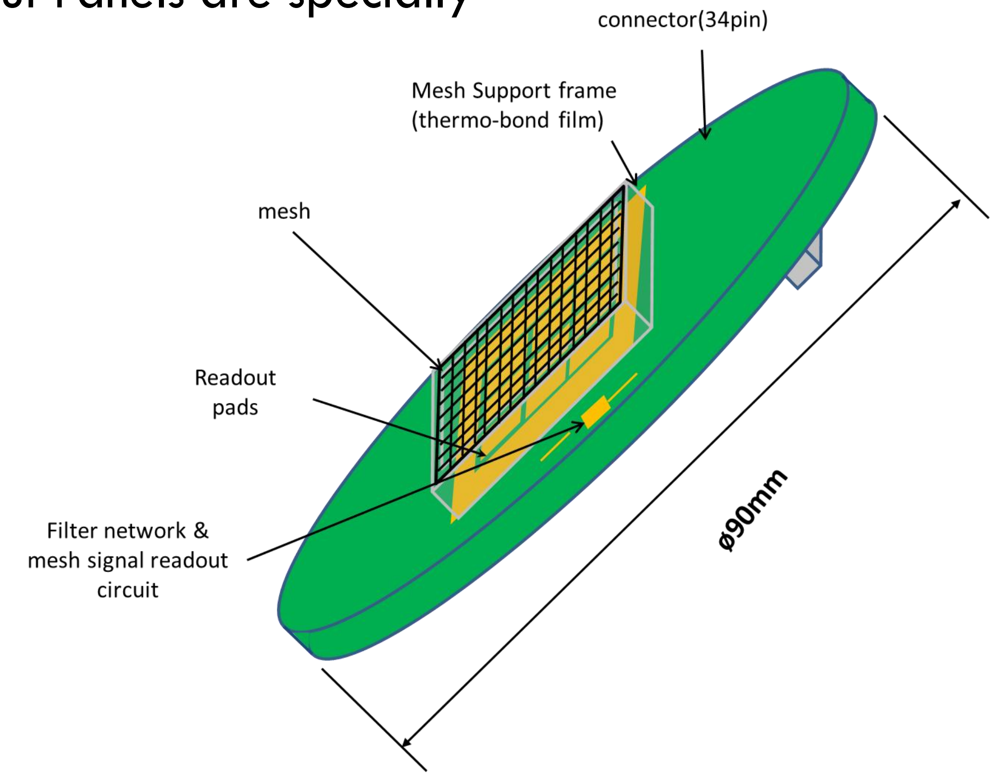
Y. Giomataris. NIM A 419 (1998)

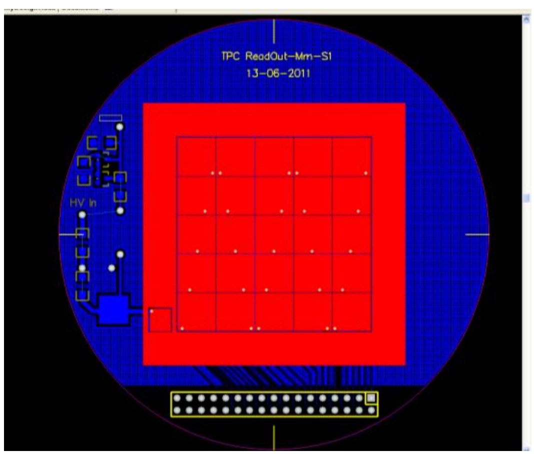
Motivation of this work:

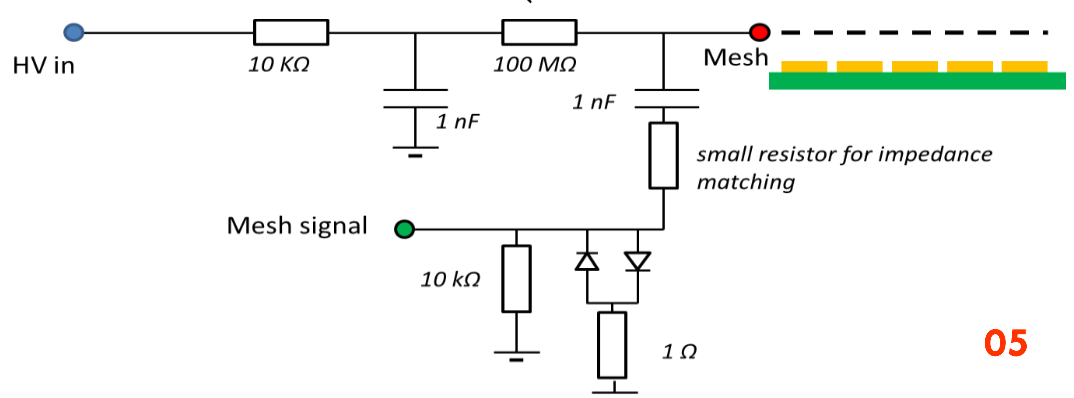
- *Micromegas with a novel thermo-bond film separator is developed in USTC since 2010*
- *Study of Characteristics of such micromegas In Ar, Ne, Xe for potential DM detection*

Mmegas Readout Panel

- Some prototype Micromegas Readout Panels are specially designed for the experiment
- General feature
- 30 mm × 30 mm active area
- ~100 μm avalanche gap achieved by using thermal-bond film
- Filter network integrated
- Mesh signal readout circuit for trigger, spark counting

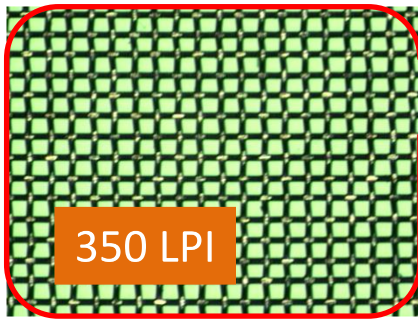






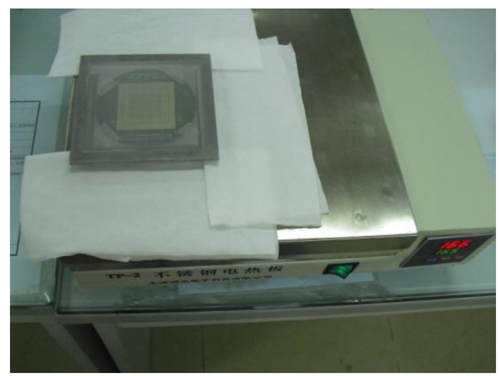
- Fabrication

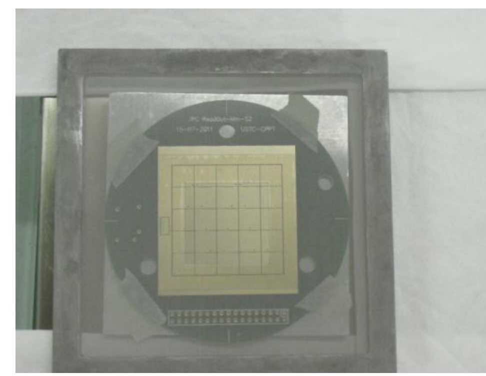
Mesh stretching & conditioning



Tension: 17-19N/cm

Thermal attaching





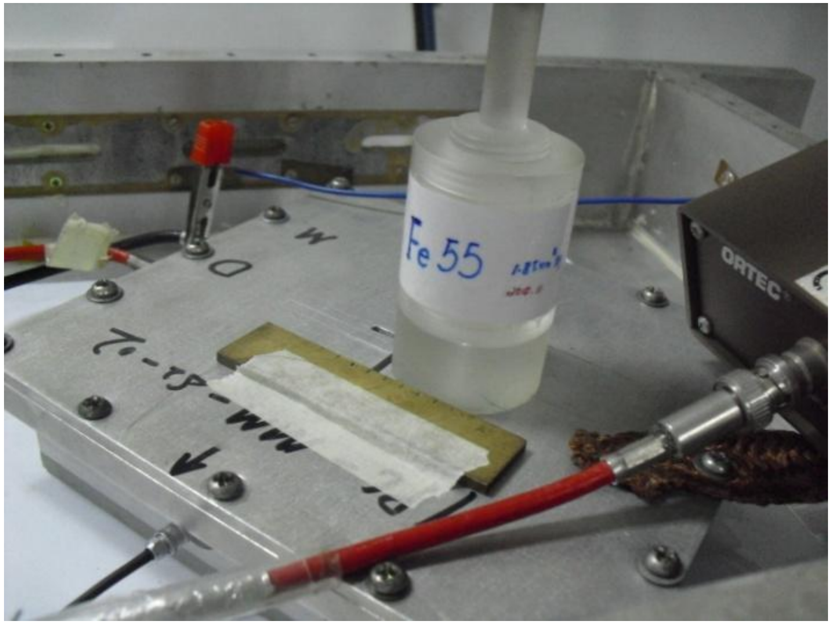
HV test and assemble

- 350 LPI woven stainless steel mesh (pitch/wire diameter 70/22 μm)
- Mesh Tension: measured by tensometer, well controlled
- Mesh conditioning: alcohol cleaning and compressed nitrogen gas blowing

Characteristics of Mmegas in Ar and Ne based mixtures

- Lab tests setup

X-ray gun (Cu target) exposure

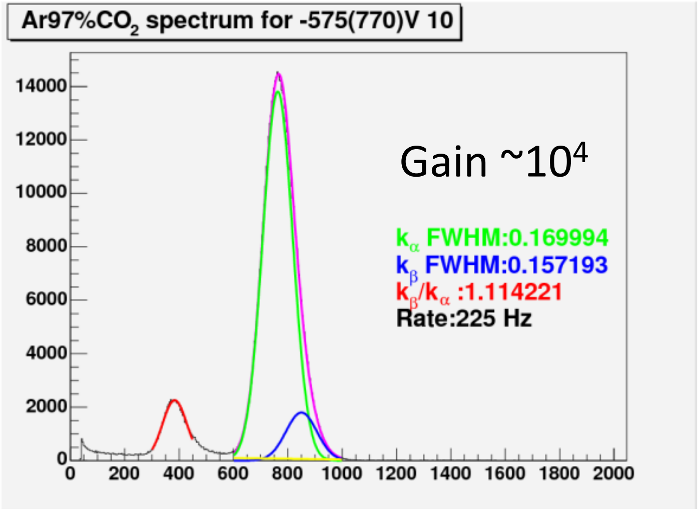


Fe-55 test

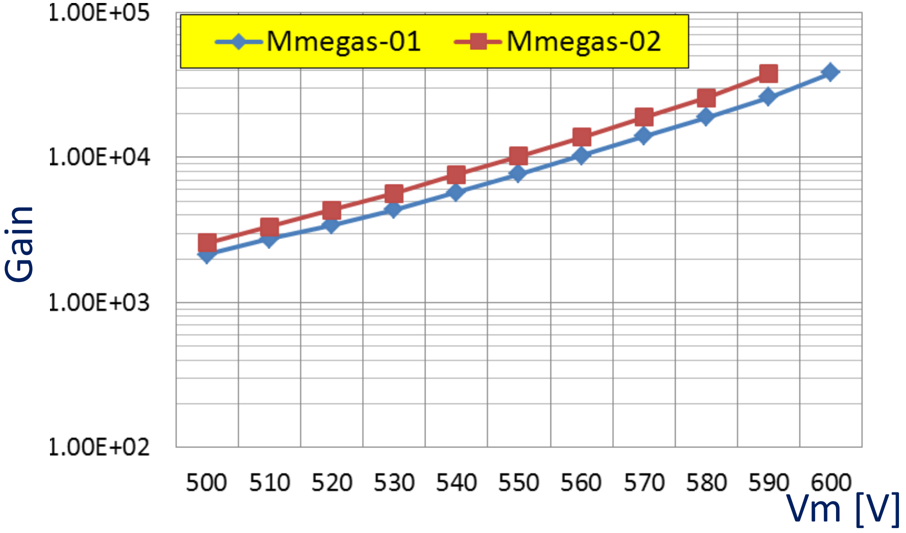
- Exposure in intense copper characteristic (8 KeV) X-rays or illuminate by Fe-55 source
- Single channel r/o through electronic chain with Preamp and Main Amplifier
- Charge info. registered into MCA, pulse shape recorded by Digital Oscilloscope

Characteristics of Mmegas in Argon based mixture Ar/CO_2 93:7

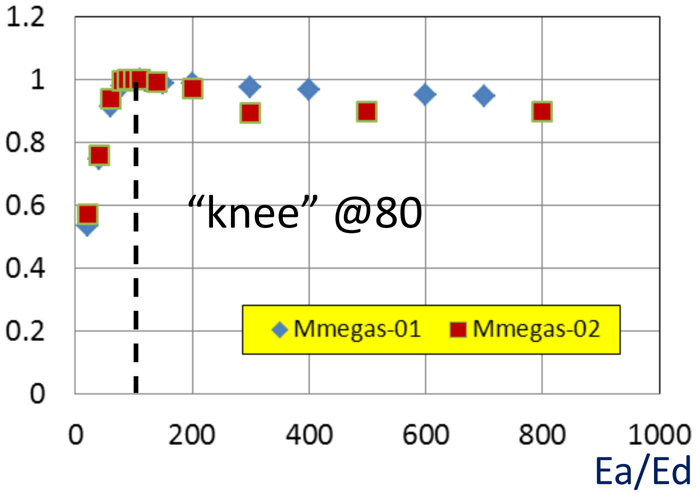
- Typical Fe-55 spectrum



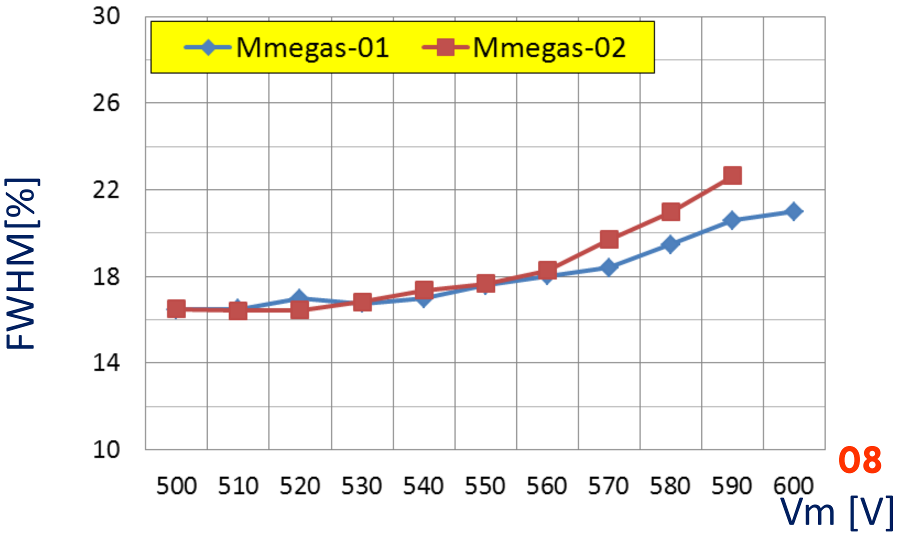
- Gas Gain



- Electron transparency



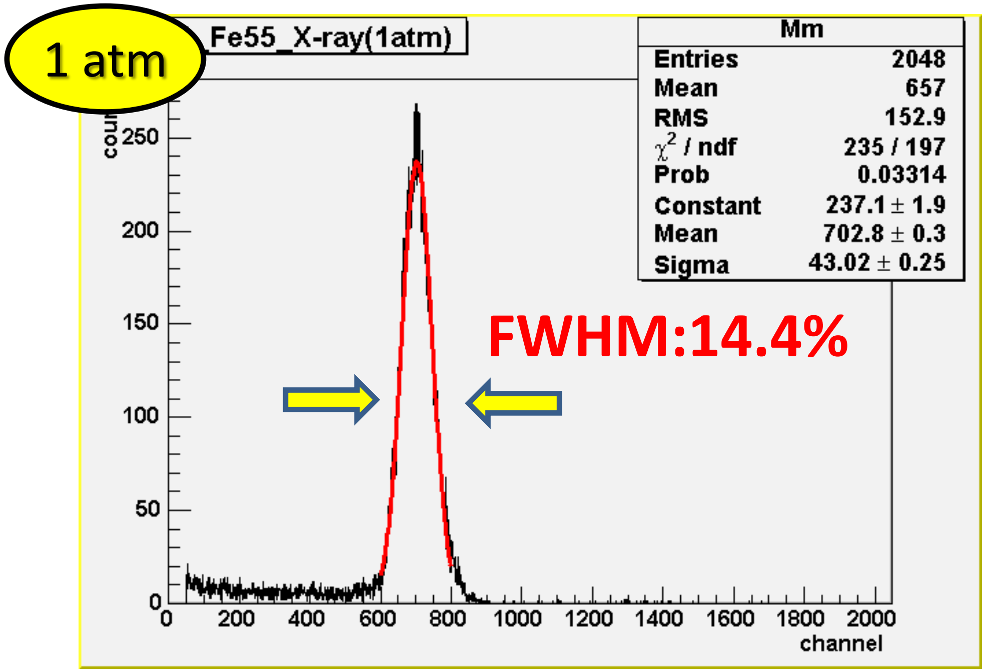
- (Fe-55) Energy resolution vs. Gain



Characteristics of Mmegas in Neon based mixture Neon/CF_4 95:5

- Motivation of using Neon mixtures: increase operational gain close to Raether limit (~10^7-10^8 electrons) → increase sensitivity in sub-keV region in DM detection

- Typical Fe-55 spectrum

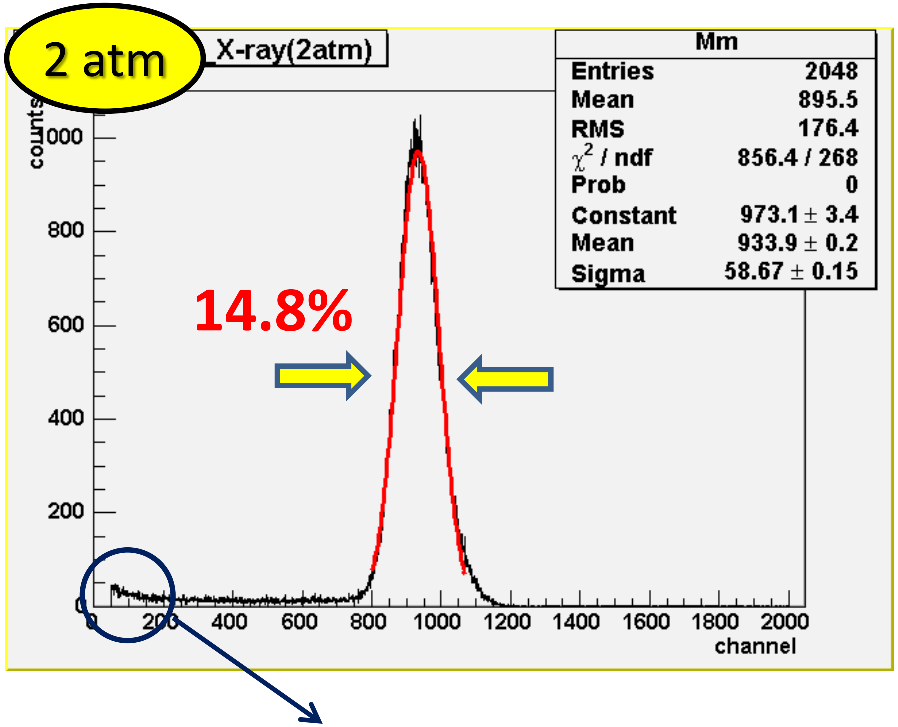


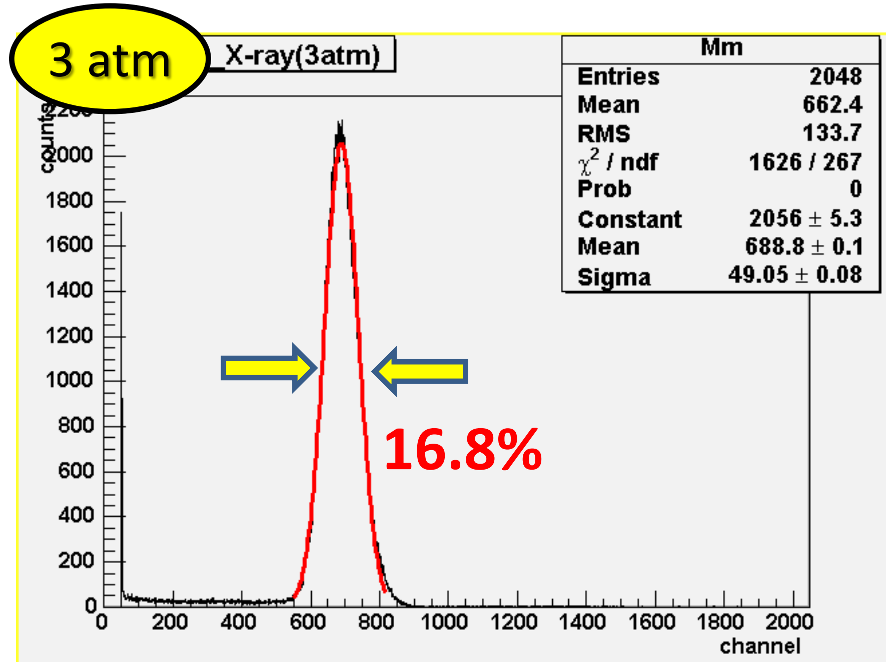
(ε_{Ne}~36eV, ε_{Ar}~26eV)

- Less electron-ion pairs liberated in Neon based mixture than in argon based ones
- but better ER achieved in Neon based mixture due to high ionization yield and less avalanche fluctuations *H.Schindler et al., Nucl. Instrum. Meth. A 624 (2010) 78*
- similar ER behavior for micro-bulk micromegas *F.J. Iguaz, Proceedings of the TIPP2011 conference*

Characteristics of Mmegas in Neon based mixture Neon/CF_4 95:5

- Typical Fe-55 spectrum at high pressure

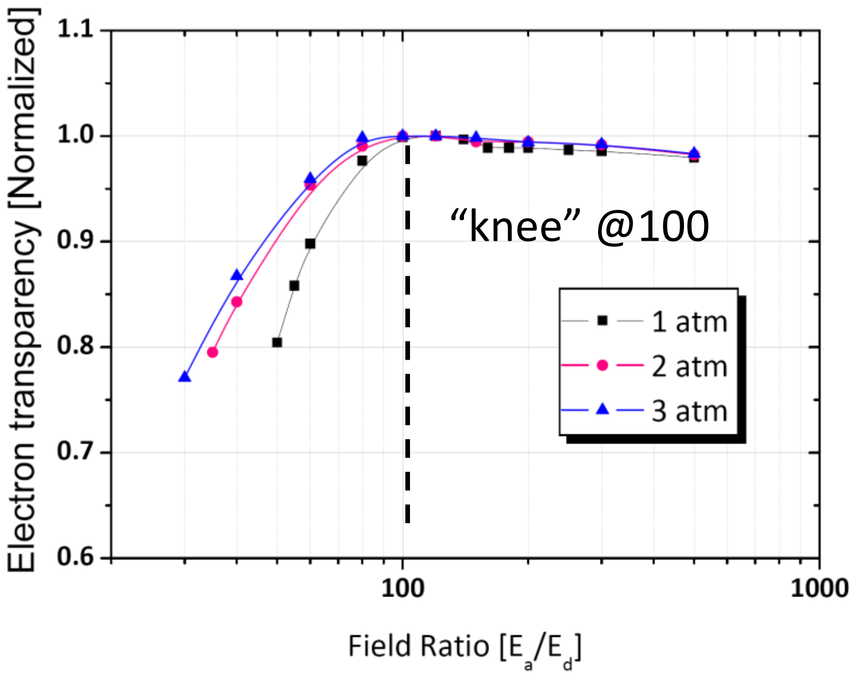




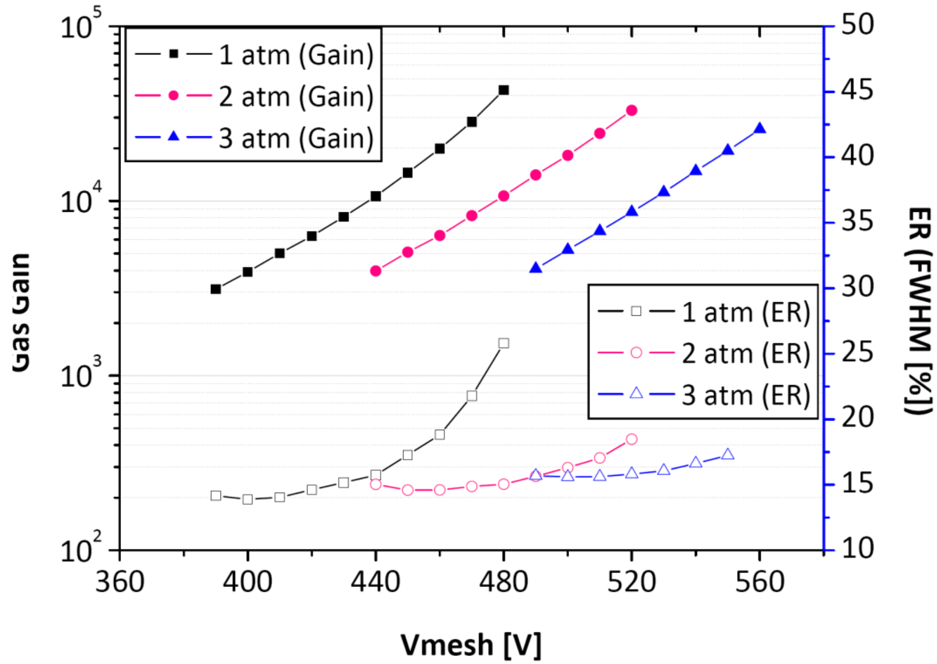
Threshold down to 400 eV is possible with high gain

Characteristics of Mmegas in Neon based mixture Neon/CF_4 95:5

- Electron transparency



- Gas gain

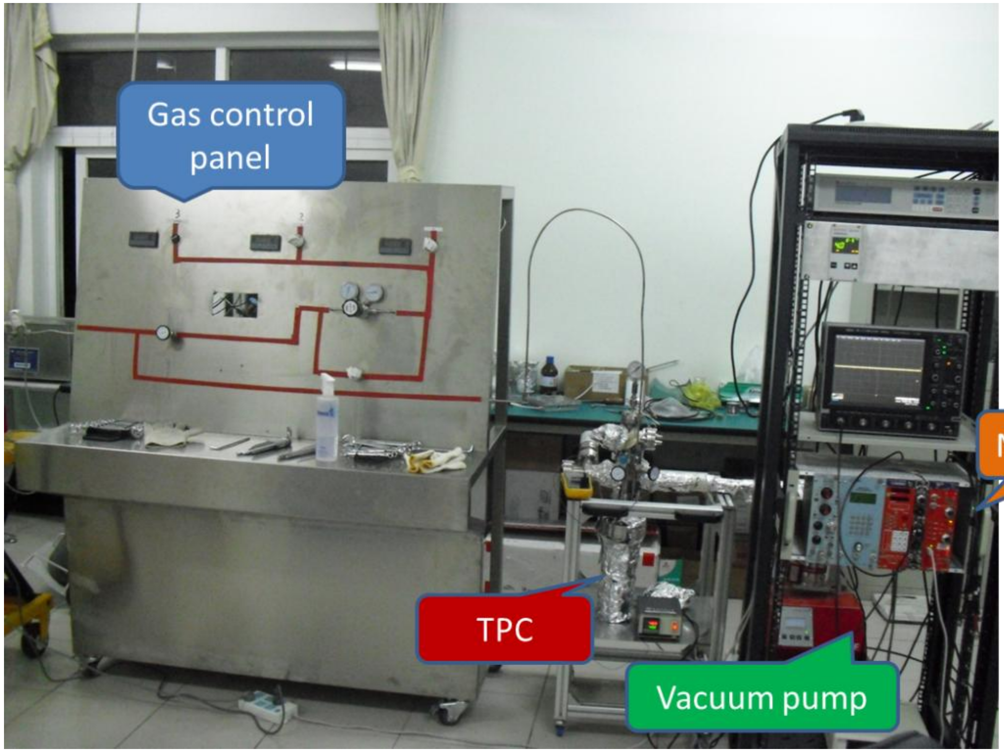


Gas gain >2*10^4 for pressure up to 3 atm with promising energy resolution

Gain could be further increased to the level suit for single photon detection with MM+THGEM hybrid ⇨ See Zhiyong's next presentation

Mmegas study in Xe filled TPC

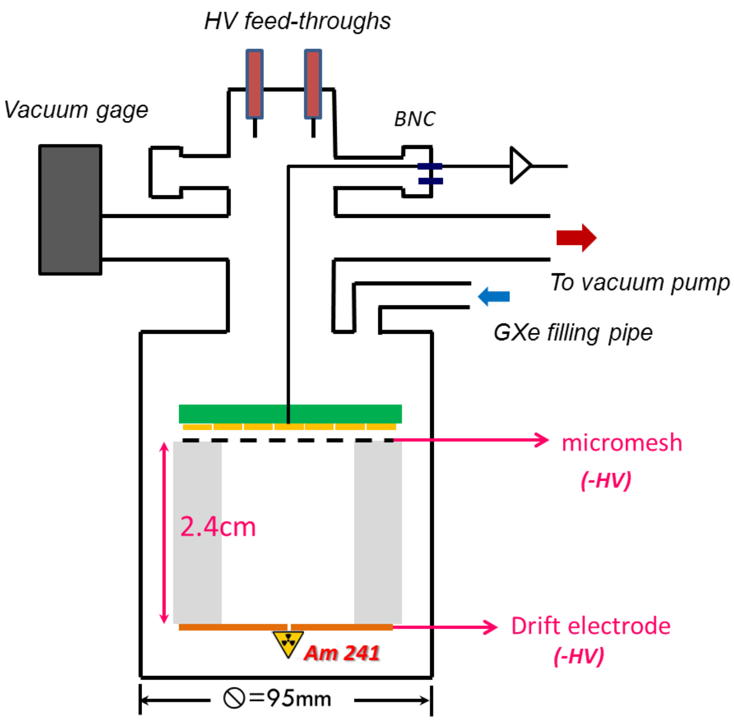
- Test Setup

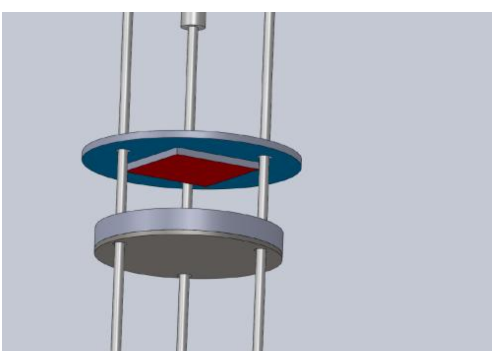


- Micromegas placed in the prototype TPC (Ø95mm)
- ^{241}Am (~33KBq) attached to the Drift electrode (0.3mm thick) made of thin copper layer covered epoxy plate
- Small hole(ø=1mm) in the center of drift electrode blocks most of the alphas (rate limited to ~100Hz).

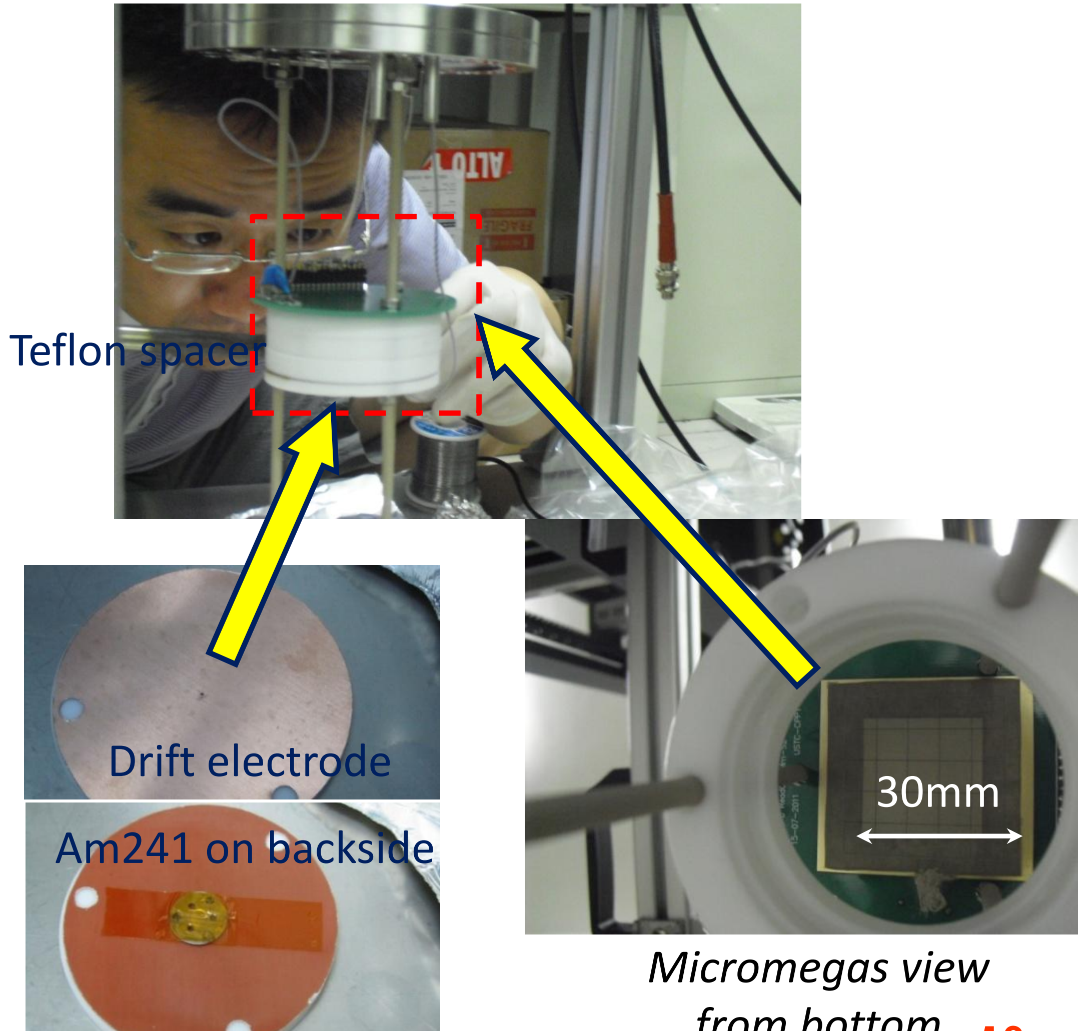
Mmegas study in Xe filled TPC

- Test Setup





- Installation



Micromegas view from bottom

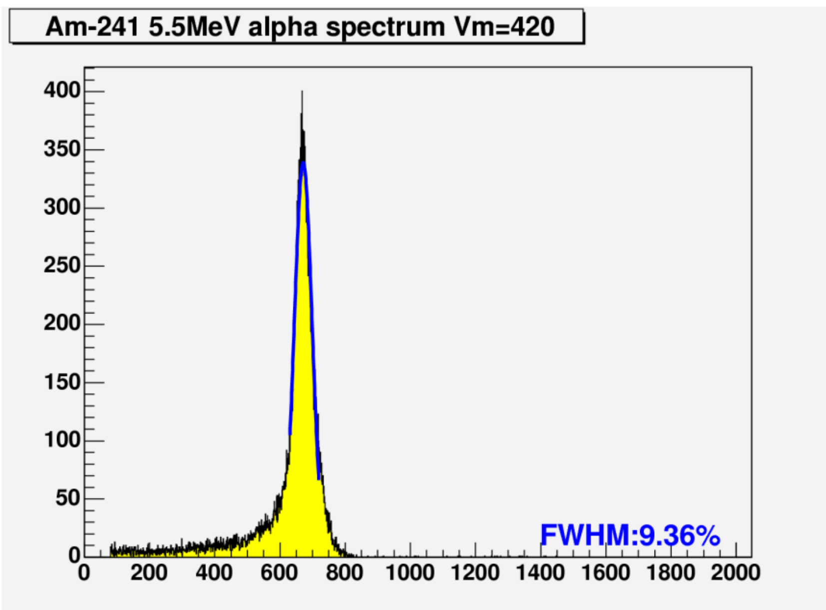
source placed 0.7mm from drift electrode

Mmegas study in Xe filled TPC

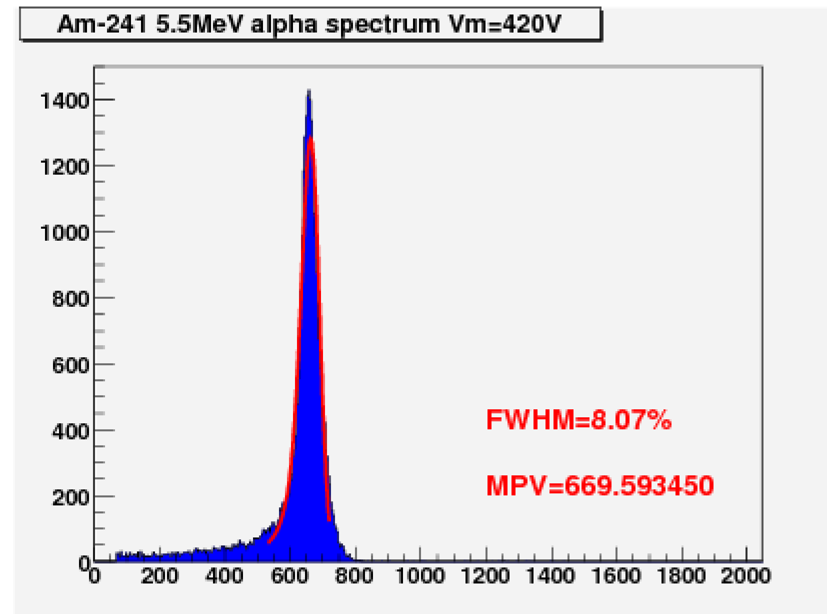
- Alpha response (Am 241)

p=1atm

Simple *Gaussian* fit



Inverse Landau ⊗ Gaussian



- Fitting strategy: resolution for alphas are deconvoluted from inverse convolution of landau and gaussian functions

$$S(x) = \frac{p[2]}{\sqrt{2\pi}\cdot p[0]\cdot p[3]} \times \int L\left(\frac{-x-p[1]}{p[0]}\right) \exp[\frac{(-x-y)^2}{2(p[3])^2}]\, dy$$

p[0]: Landau scale parameter

p[1]: Landau location parameter

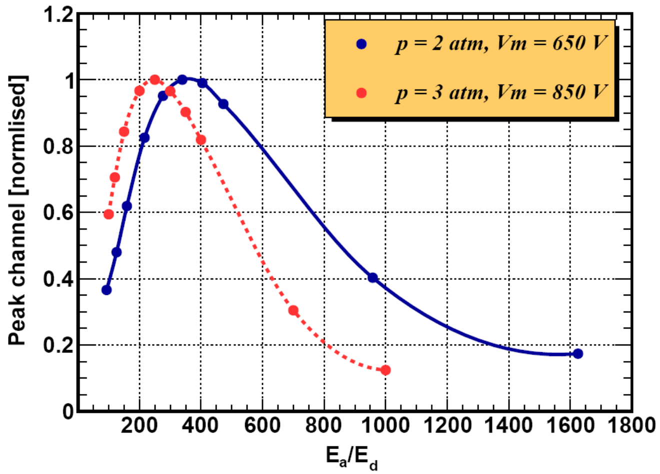
p[2]: Total area (normalization factor)

p[3]: Gaussian sigma

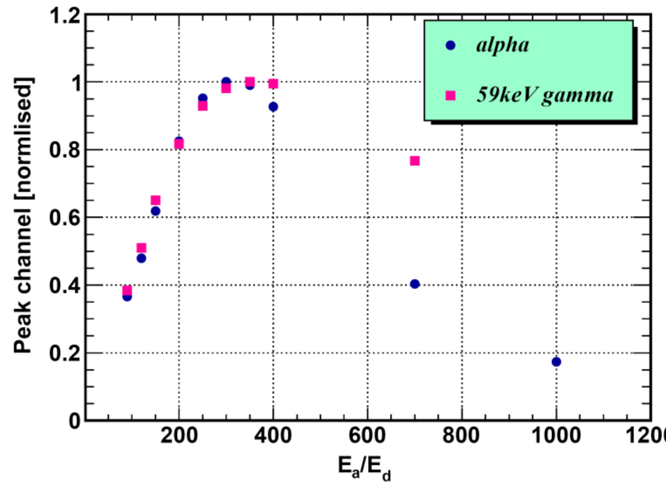
*MPV=p[1]-0.22278298*p[0]*

Mmegas study in Xe filled TPC

- Transparency

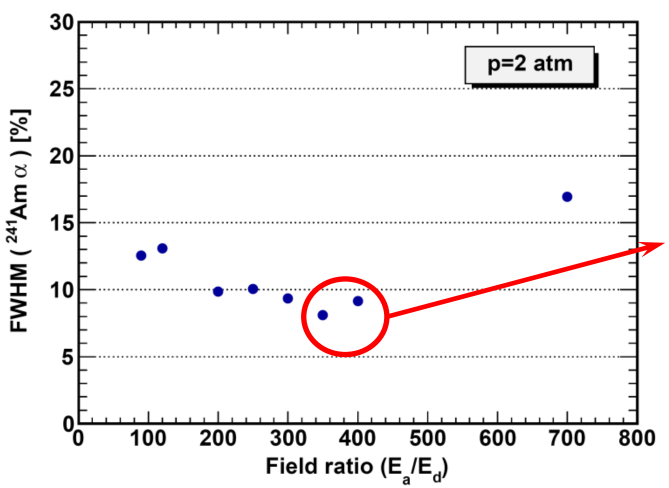


Alpha peak position vs. field ratio



Compassion of transparency measurement with α and 59KeV γ (2 atm)

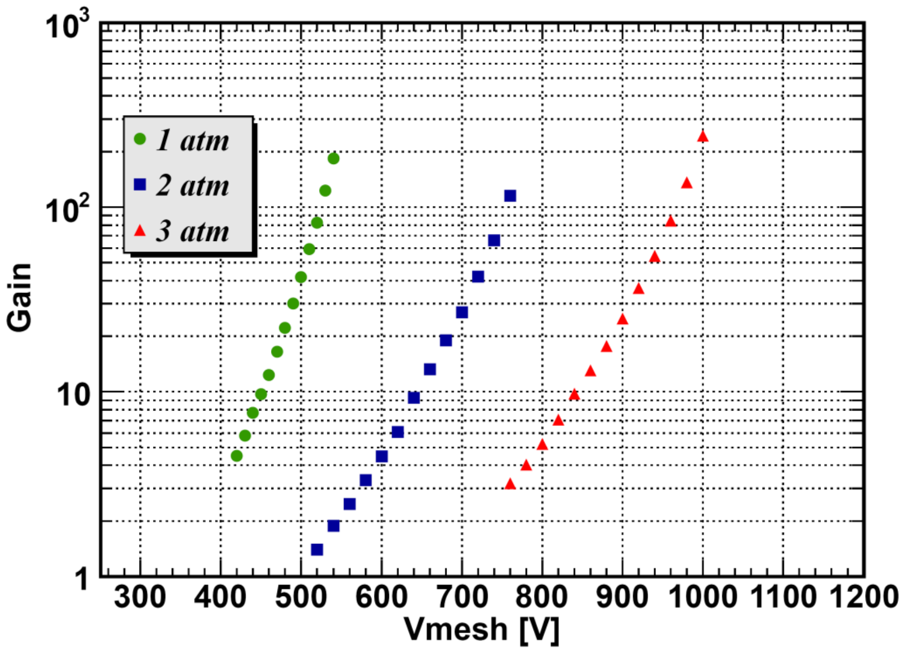
α Energy resolution (FWHM) vs. field ratio



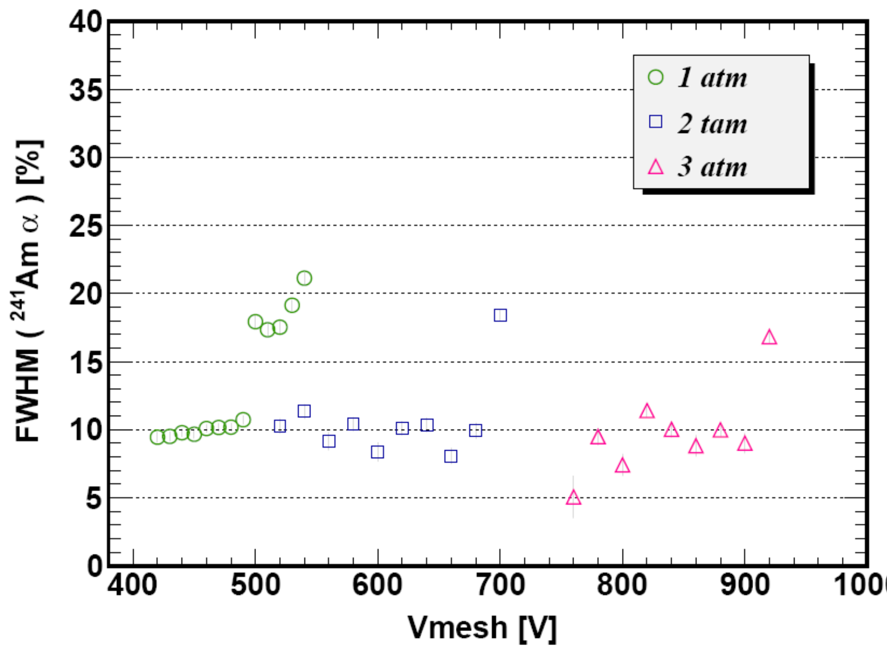
Best FWHM obtained@ Ea/Ed~ 350
(maximum electron transparency)

Mmegas study in Xe filled TPC

- Gas Gain



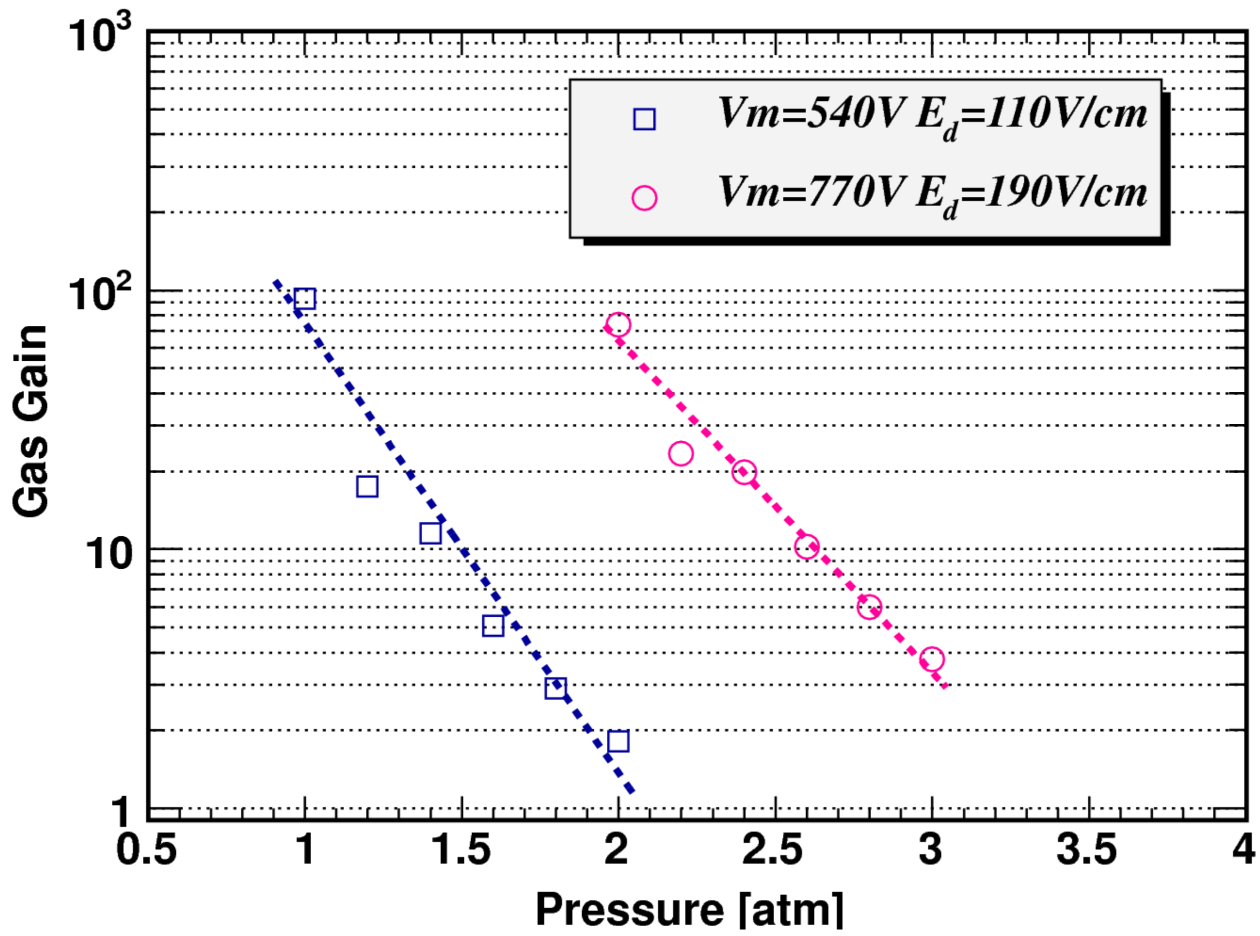
- Alpha resolution



- Due to the saturation of readout electronic chain, highest points in the gain plot are not the limit of gain
- sparks occur at mesh voltage 10-30 V higher than the values correspond to highest gain in the plot

Mmegas study in Xe filled TPC

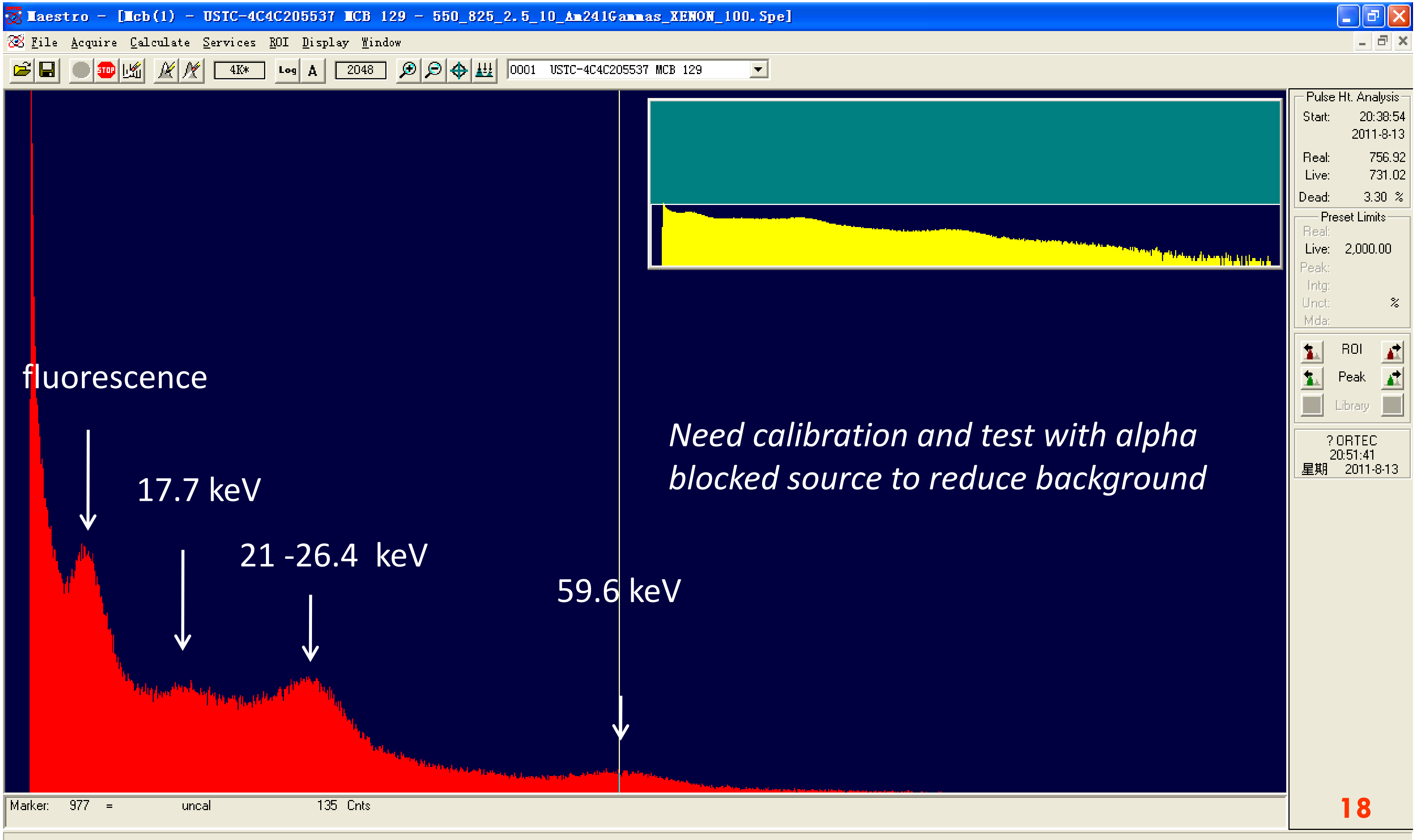
- Gas Gain vs. Pressure



Mmegas study in Xe filled TPC

- gamma lines (Am 241)

Vm= 550 V   p= 1 atm



Mmegas study in Xe filled TPC

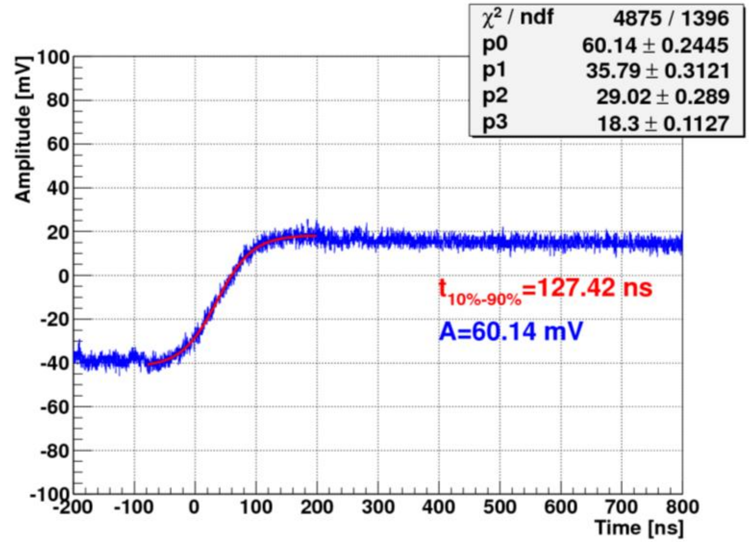
- Pulse Shape Analysis
  - Signals from preAmp are digitized and recorded through Digital Oscilloscope for offline analysis
  - Pulse shapes are fitted (range: 2~3*rise time) with sigmoid function:

$$A(t) = -\frac{p[0]}{1 + e^{\frac{t-p[1]}{p[2]}}} + p[3]$$

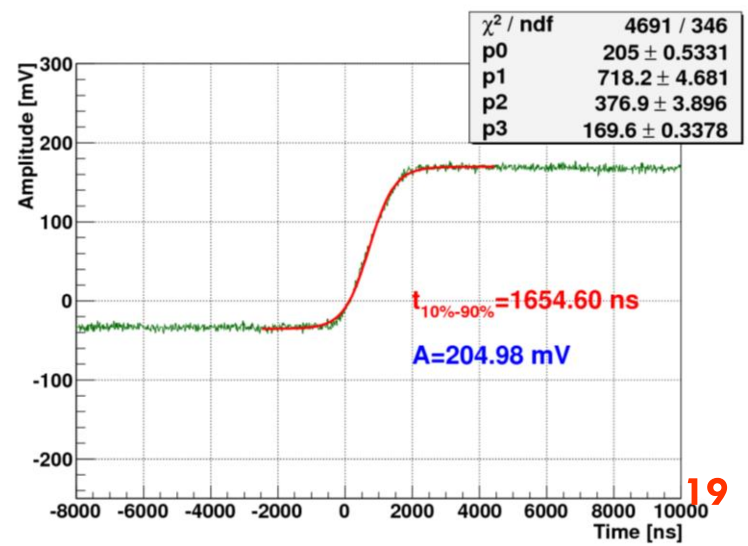
  - Signal Amplitude and Rise time are extracted from the fitted function.
  - Rise time: $T_{10\%-90\%} = 4.39 * p[2]$
  - Long rise time for alpha

→ long electron drift path & low drift velocity in Xe gas

X-ray in Ar/CO2 97:3



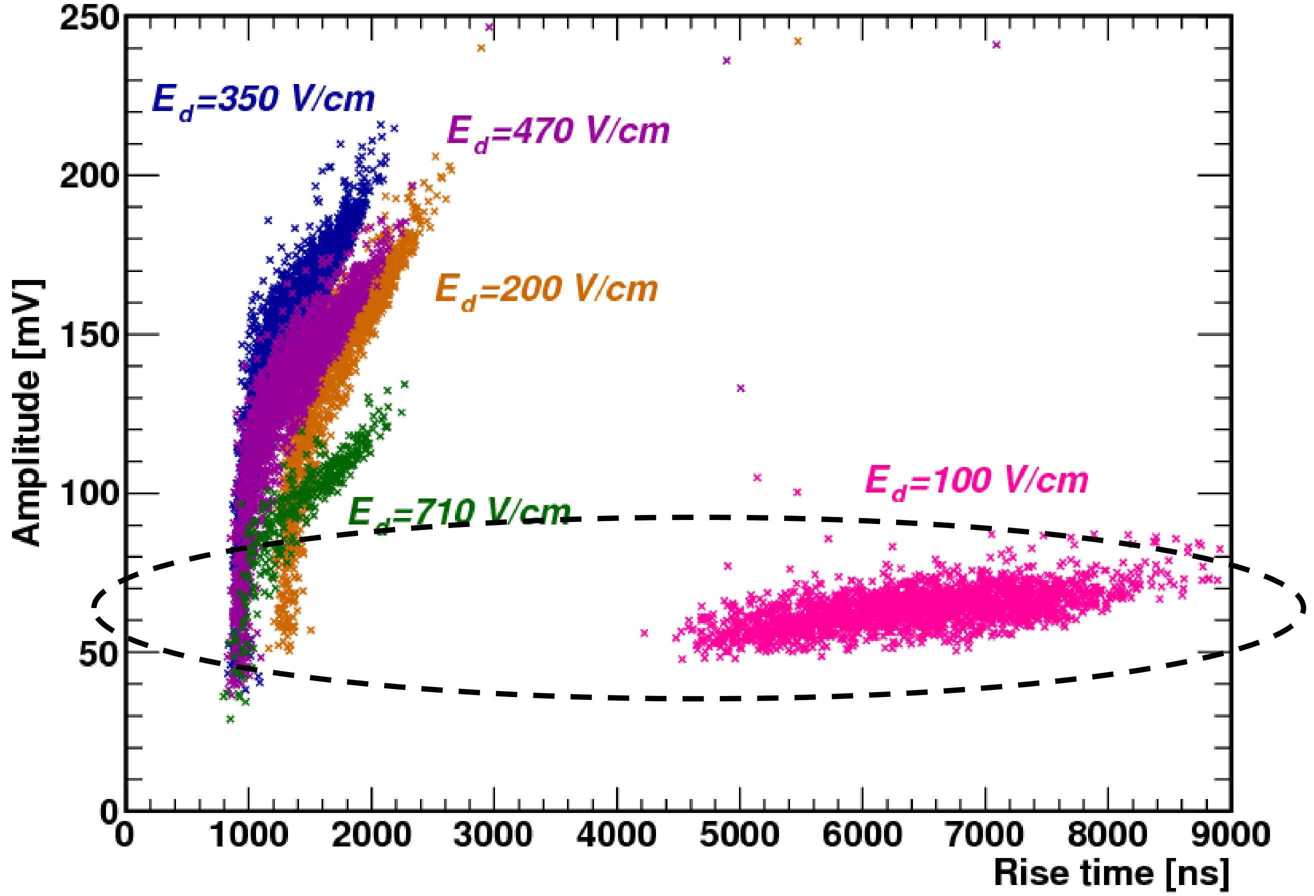
Alpha in Xenon



Mmegas study in Xe filled TPC

- Pulse Shape Analysis

T-A relation during transparency scan | *Vm= 850 V p= 3 atm*



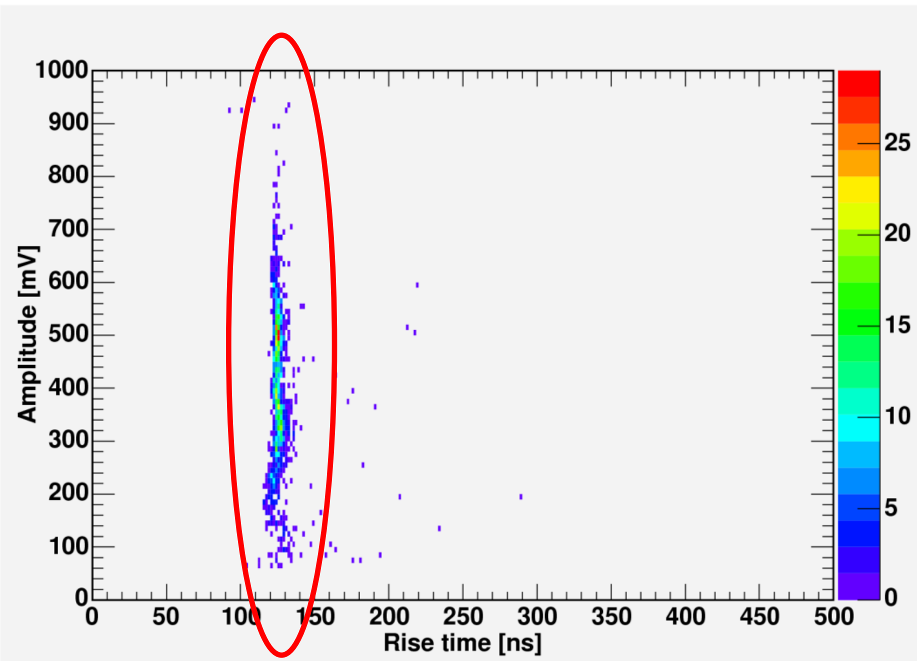
Small amplitude, large T-A variation @ low drift electric field

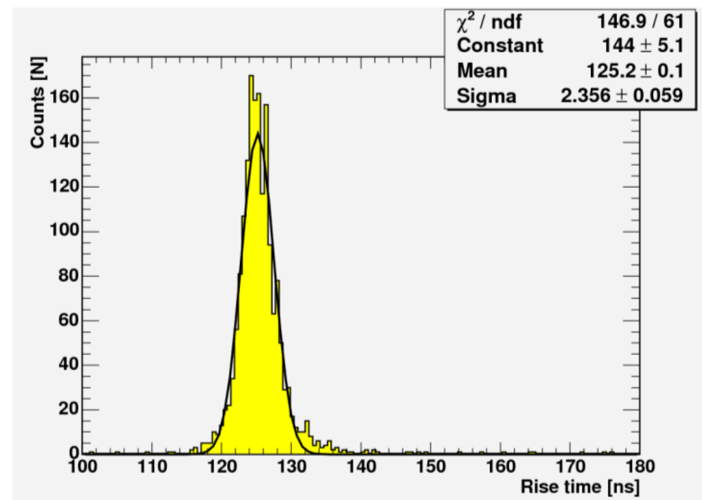
→ ***Indication of Attachment and Recombination!***

Mmegas study in Xe filled TPC

- Pulse Shape Analysis

1. X-ray (8KeV)





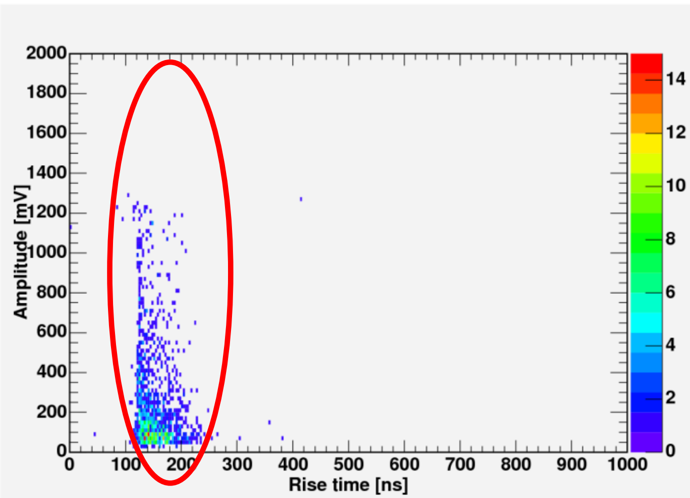
Rise time spectrum

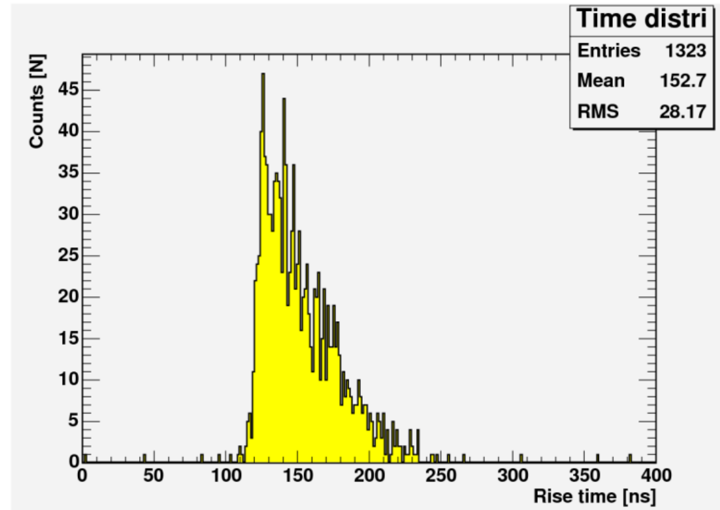
Vm=600V in Ar:CO_2 93/7

Mmegas study in Xe filled TPC

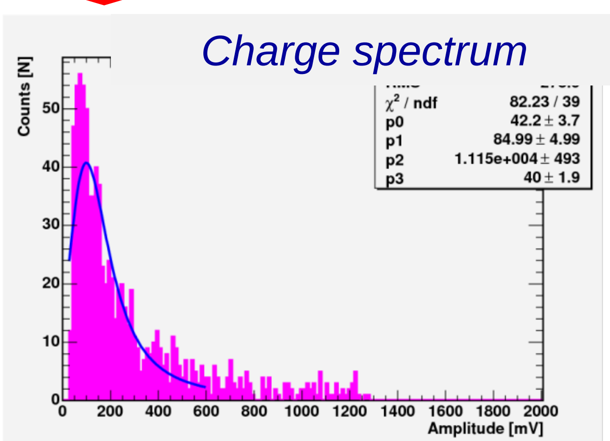
- Pulse Shape Analysis

2. Cosmic ray





Rise time spectrum



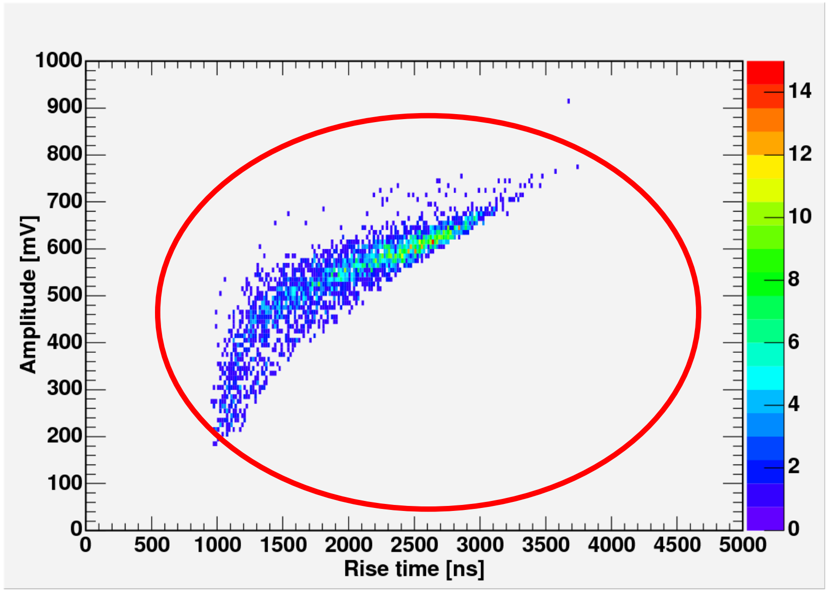
Charge spectrum

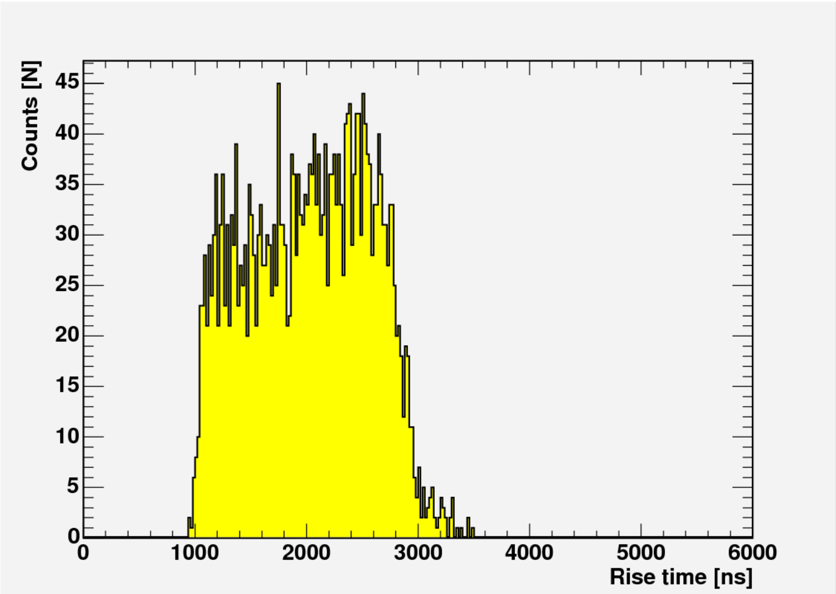
Vm=600V in Ar:CO_2 93/7

Mmegas study in Xe filled TPC

- Pulse Shape Analysis

3. Alpha





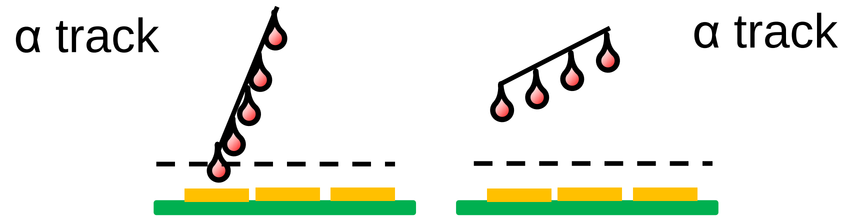
Rise time spectrum

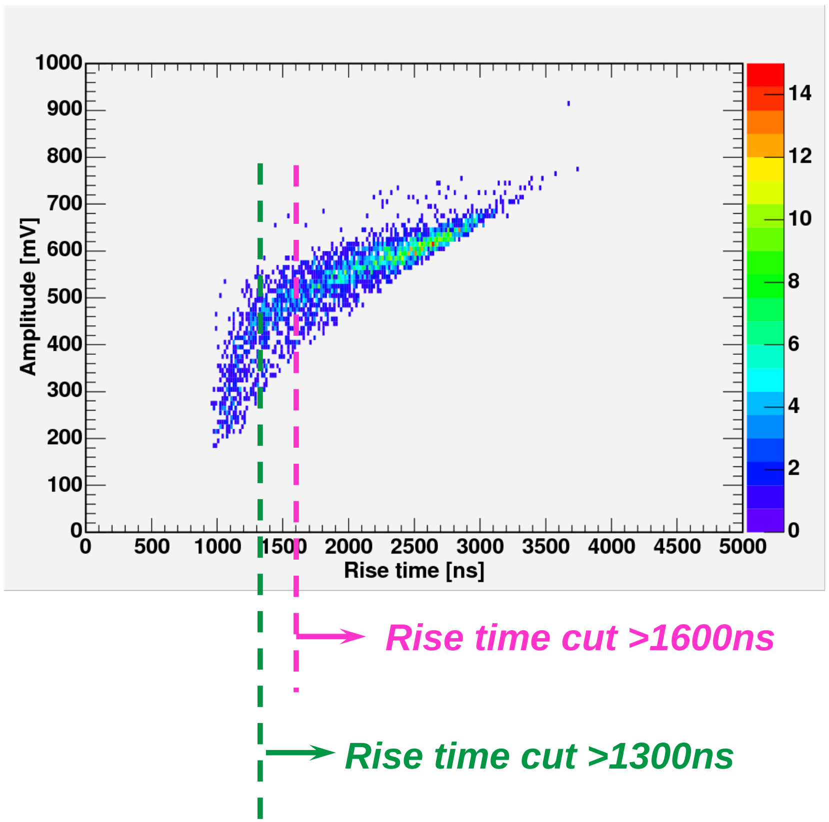
Vm=720V in XENON (2 atm)

Mmegas study in Xe filled TPC

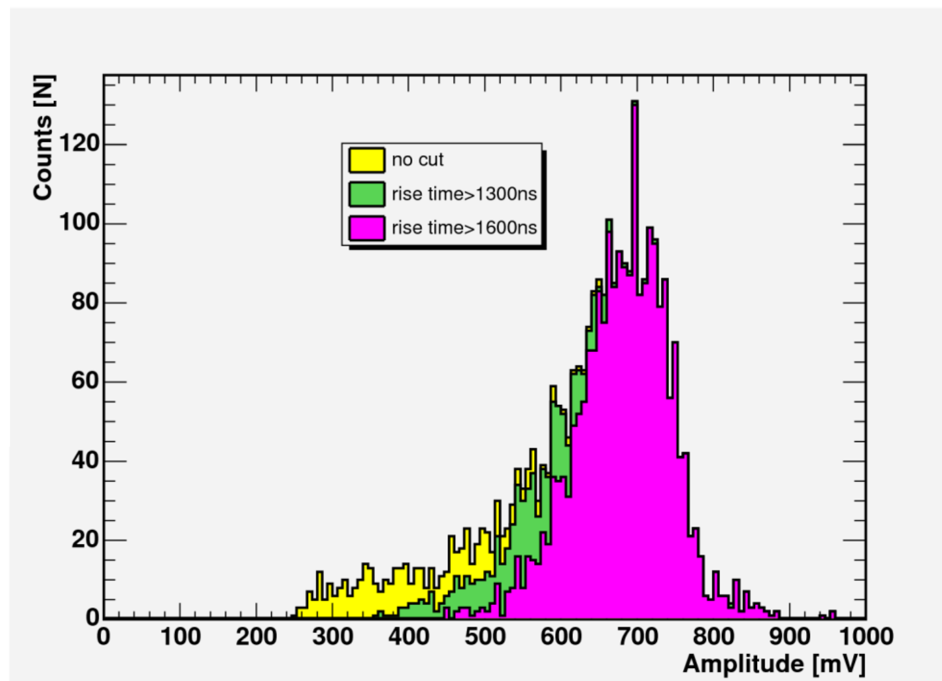
- Pulse Shape Analysis

3. Alpha





Charge spectrum



» Evidence of attachment in Xe gas

» Better energy resolution after removal of event with possible attachment

Vm=720V in XENON (2 atm)

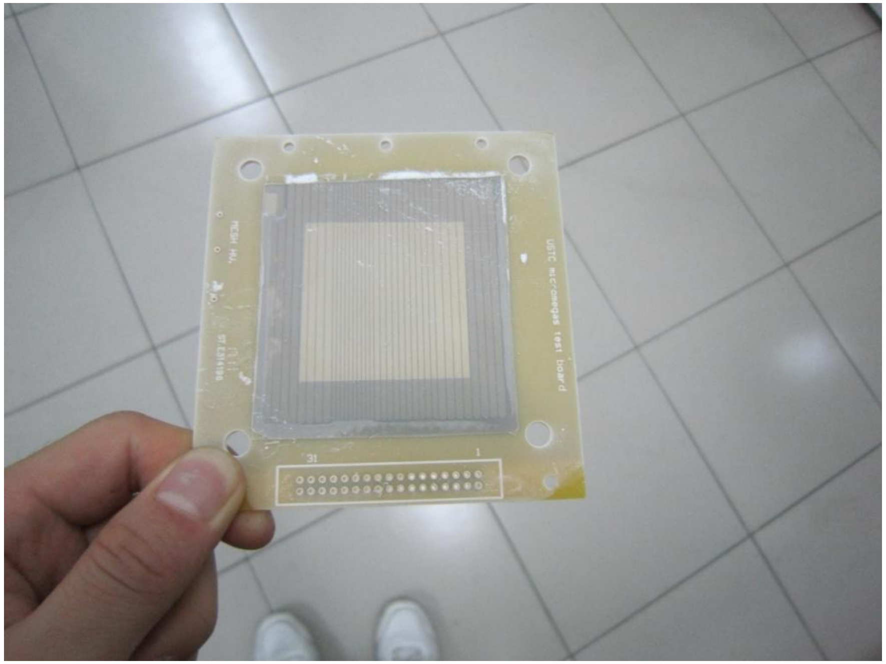
Mmegas study in Xe filled TPC

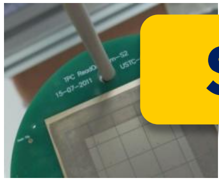
- Ionization quenching
  - Dense ionization from alpha tracks are more likely to suffer electron-ion pairs recombination. The equivalent ionization energy deviate from the value for gammas generate considerable low ionization density due to such ionization quenching.
  - Quenching effect can be investigated by comparing measured and theoretically calculated alpha/gamma full-energy peak ratio

Vm [V]	Ed [V/cm]	Alpha/gamma peak ratio (measur.)	Alpha/gamma peak ratio (Theor.)
960	320	66.9	$\frac{5100KeV(\alpha)}{59keV(\gamma)} = 86$
970	323 600	66.4 70	
980	327	67.8	
990	330	67	

- Quenching is apparently observed:
  - » Almost unity with different mesh voltages, slightly improved when drift field strengthened
  - » Large (~20%) quenching fraction

Mmegas with thermo-bond film separator in low temperature





Summary and discussion

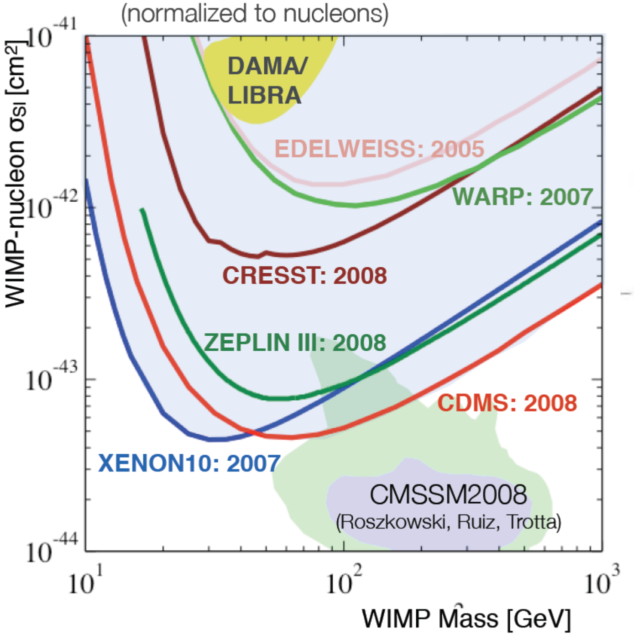
- *Micromegas has the potential of application in dual-phase DM detectors and this motivates us to study the performance of micromegas with thermo-bond film separators in noble gas based mixtures*
- *Prototype Micromegas readout panels using thermo-bond film separator are designed and fabricated in USTC. Energy resolution (FWHM) can be better than 17% for 5.9 KeV X-ray in Ar/CO_2 93:7 also in Neon/CF4 95:5 (1-3 atm) and gain up to 10^4 can be easily achieved. These tests would give reference to MM+GEM hybrid for GPM development.*
- *Micromegas panel is also tested in TPC filled with pure Xenon gas by using Am241*
- *Gas gain for alphas greater than 150 are measured (Not the limit, Constrained by r/o saturation). Best energy resolution (FWHM) < 8% for alphas. Limited partially by fluctuation of energy deposition in drift gap, gain non-uniformity, attachment etc.*
- *Pulse Shape analyses show degradation of energy resolution due to possible attachment during the long time of ionized electrons drift (Importance of purification)*
- *Quenching effect in dense ionization is observed in XENON but not fully understood*
- *Preliminary test of such Micromegas shows its capability to withstand the cryogenic environment*

Thank you for your attention!

SPARES

- Event rate: $\frac{dR}{dE_{recoil}} = N_T \frac{\rho_\chi}{M_\chi} \langle \sigma_{\chi-N} \rangle$
- $\langle \sigma_{\chi-N} \rangle$ depends on the interaction involves scalar coupling(spin-independent) or axial coupling (spin-dependent)

Spin-independent cross section
(normalized to nucleons)



Spin-dependent cross section