Study of Columnar Recombination in Xe+trymethilamine Mixtures using a Micromegas-TPC

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Universidad de Zaragoza, Spain
in collaboration with Lawrence Berkeley Lab, USA

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2 – 6 June 2014 / Amsterdam, The Netherlands

"Instrumentation as enabler of Science"

Outline

1. Introduction
2. Experimental setup and procedure
3. Results: Electron life time
4. Results: Recombination

   4.1 Charge vs E_{drift}/P for α-particles and γ-rays

   4.2 Charge vs φ angle for α-particles
5. Conclusions and Outlook

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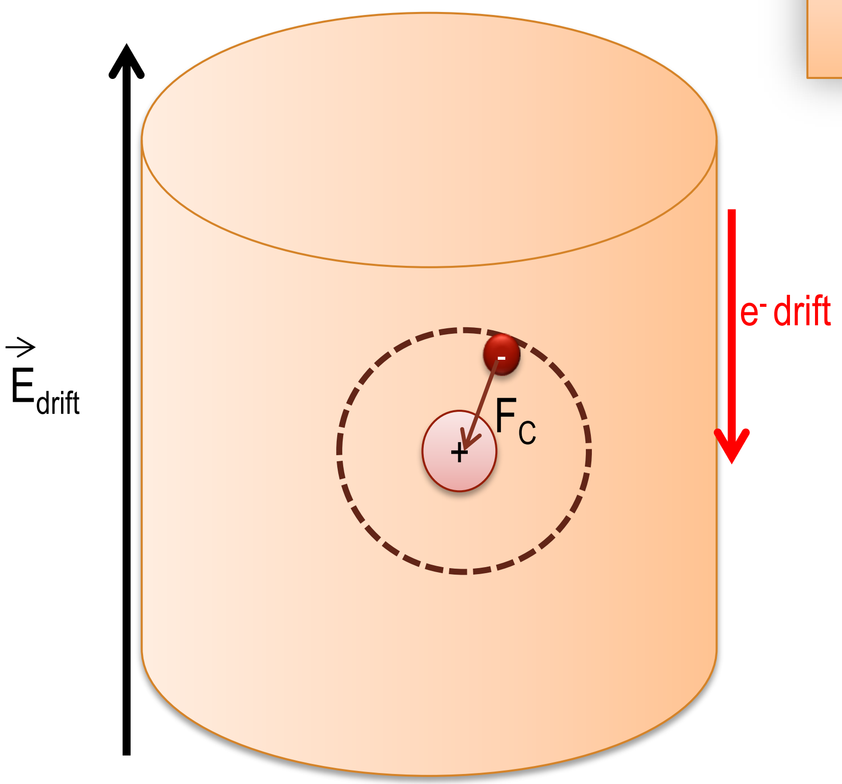
Introduction

Geminate or Initial recombination

Onsager theory explains [1]

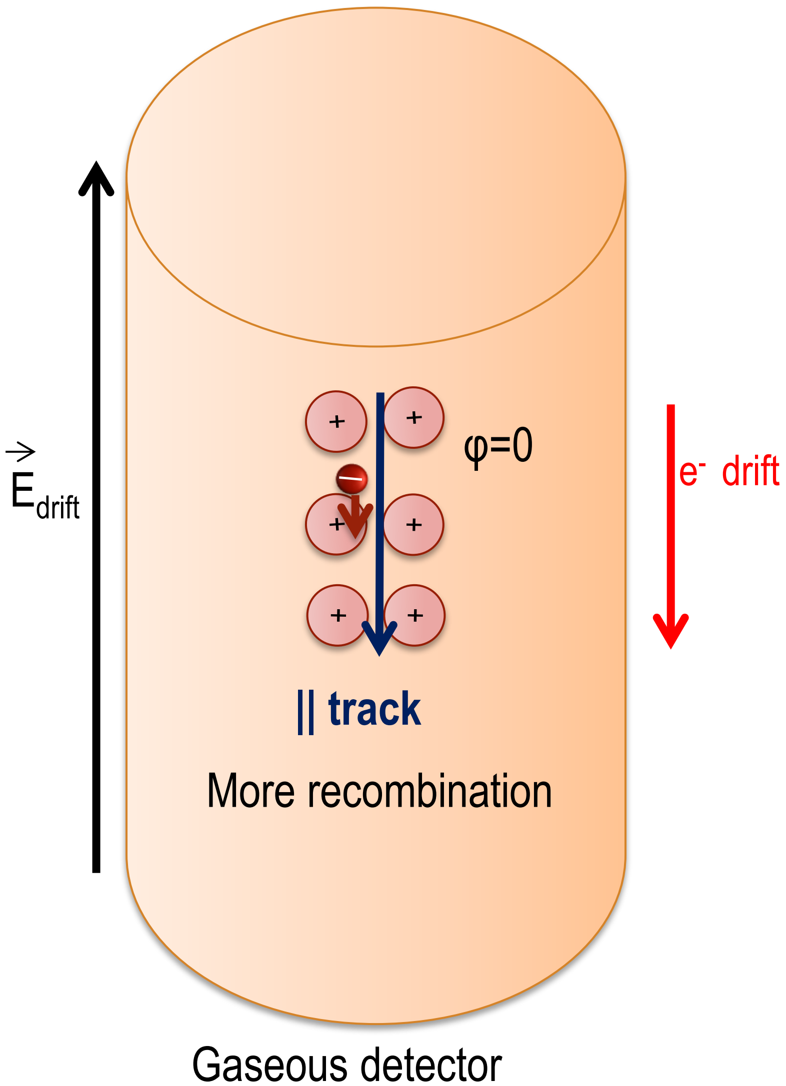
- Electron's Brownian motion under the action of an external field.

[1] L. Onsager, Phys. Rev. 54 (1938) 554



Gaseous detector

Introduction



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Columnar or volume recombination

Electrons that escapes to initial recombination can be captured by the effect of the random motion.

Jaffe Theory [2]

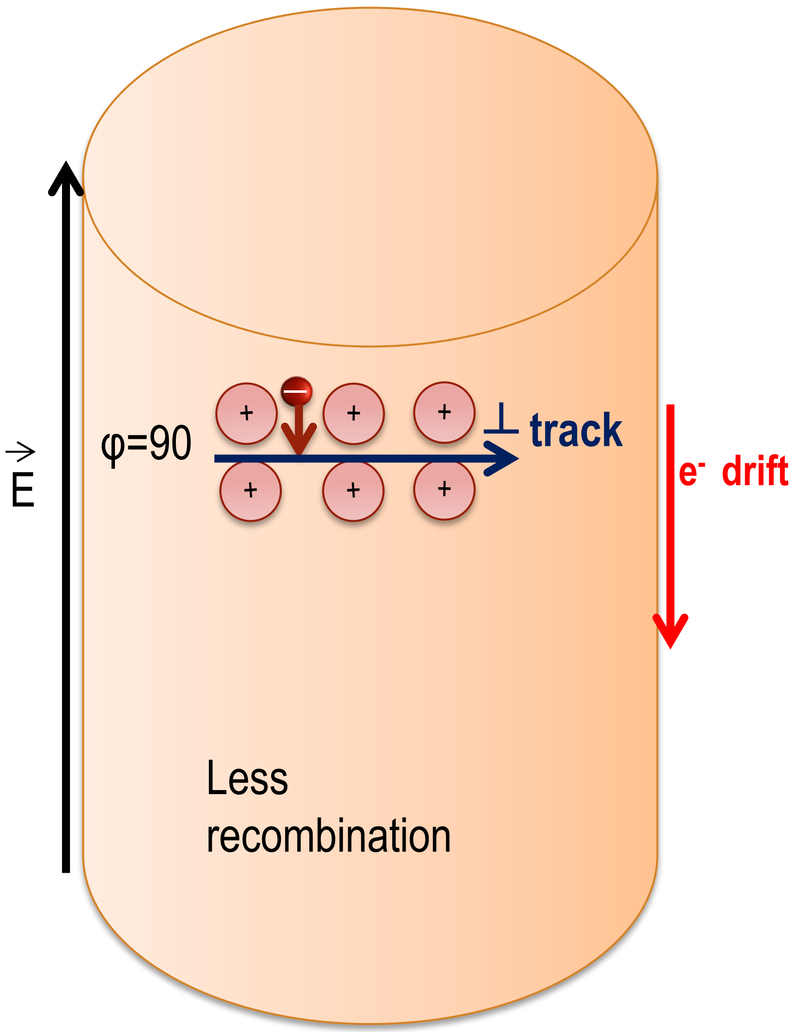
- Described by the electron continuity equation.

Columnar recombination depends on

- Ion density of the particle
- density of the gas
- $\vec{E}_{drift}$
- the ionizing track orientation with respect to $\vec{E}_{drift}$

[2]G. Jaffe, Ann, Phys. (Leipzig) **42** (1913).

Introduction



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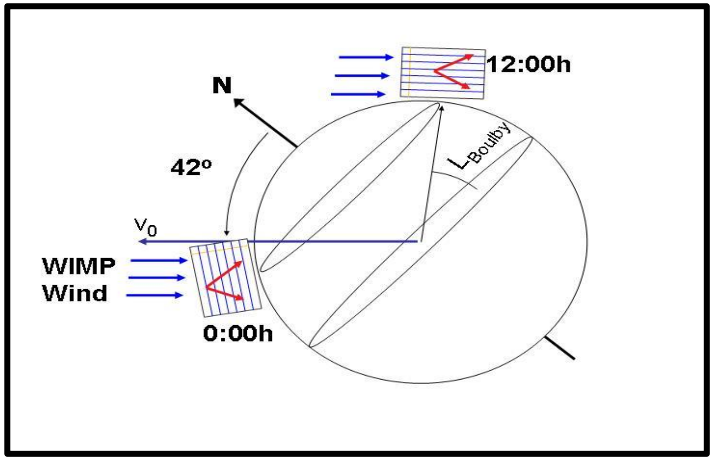
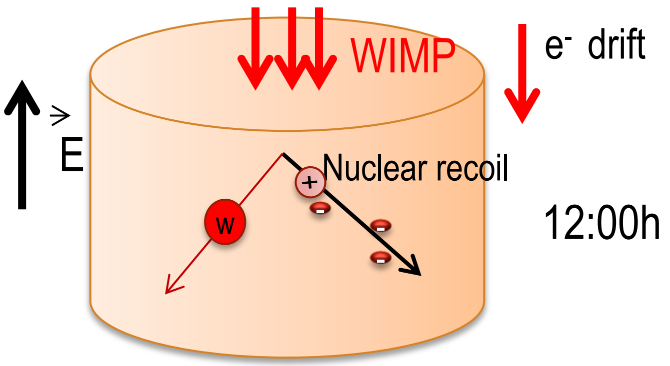
Introduction

New Concept:

Columnar recombination may be used to infer the directionality of dark matter [3,4].

- Daily Eath's rotation produces a daily oscillation in the mean direction of the WIMP





[3] D. Nygren, J. Phys. Conf. Ser. **309** (2011) 012006.
[4] A. Goldschmidt. Talk Symposium Berkeley, May 2014

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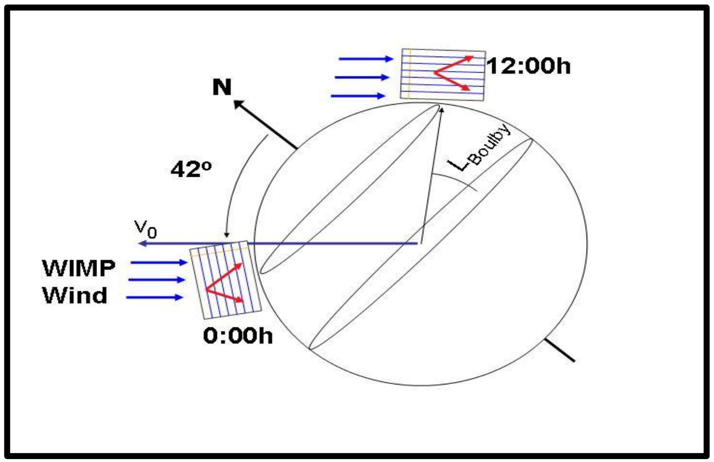
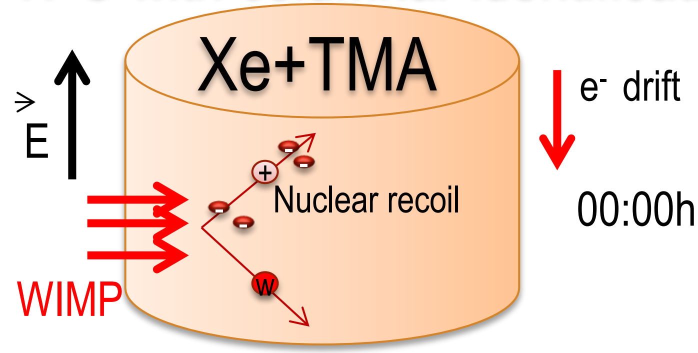


HP TPC with columnar identification



Day-night modulation, not known background

Xe+TMA Penning mixture

- ✓ Penning Mixture: Excitations of Xe transfer to TMA ionization by Penning effect. [5,6]
- ✓ Reduction of diffusion

Xe+TMA Mixture may enhance directionality

[3]] D. Nygren J Conf. Ser **460** (2013) 012006
[4]] A. Goldschmidt. Talk Symposium Berkeley, May 2014
[5] D. Nygren, J. Phys. Conf. Ser. **309** (2011) 012006.
[6] S. Cebrian, *Jinst* **8** (2013) P01012

Introduction

Objective

Study the electron-ion recombination in Xe+TMA mixtures at high pressure, focusing in the columnar recombination for α-particles

Methodology

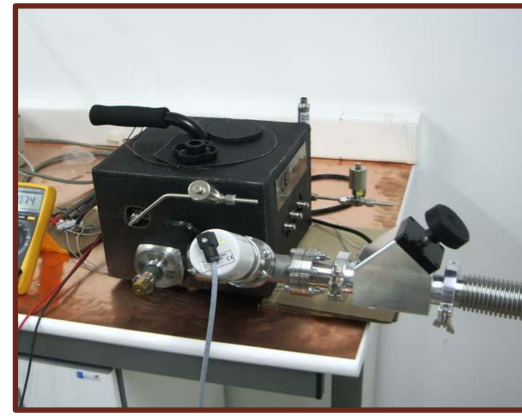
1. Charge (**Q**) versus electric field ($\mathbf{E}_{\mathbf{drift}}$) for α- particles and γ-rays
2. **Q** versus the track angle (φ) for α-particles

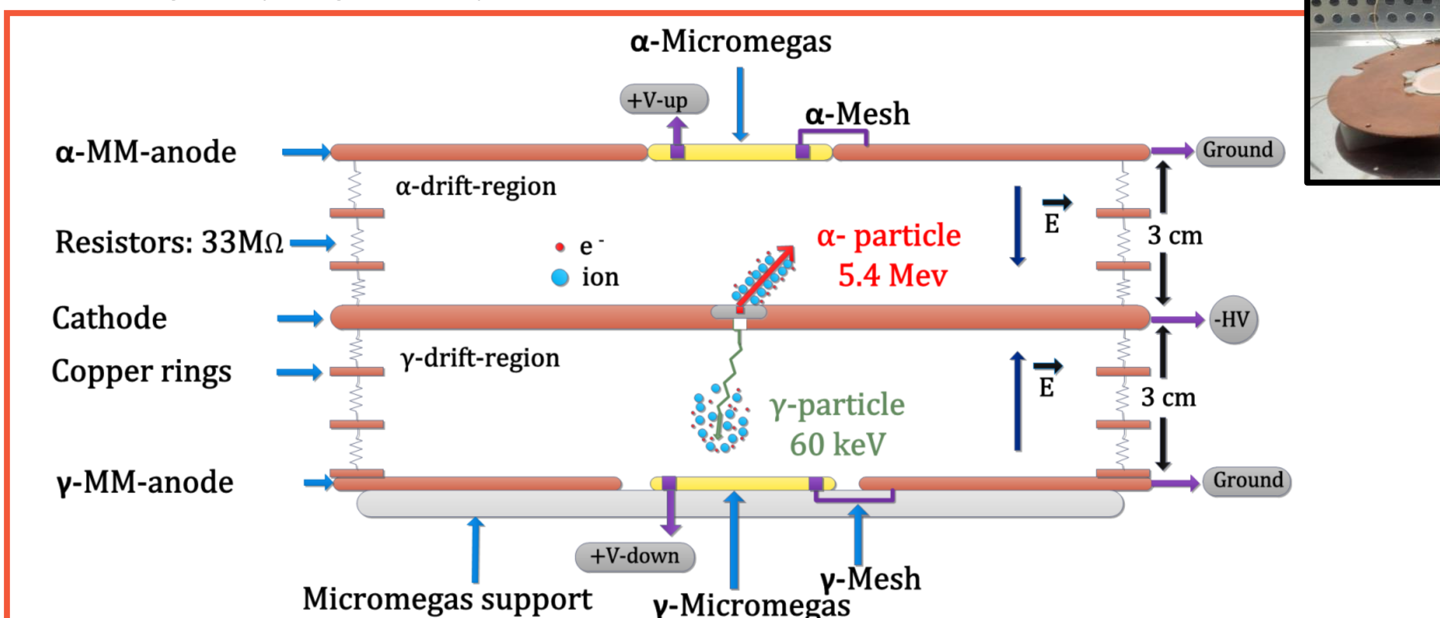
Outline

1. Introduction
2. Experimental setup and procedure
3. Results: Coincidence setup
4. Results: Recombination setup
   - **4.1** Charge vs E_{drift} α-particles and γ-rays
   - **4.2** Charge vs φ angle α-particles
5. Preliminary: comparison with Jaffé Model
6. Conclusions and Outlook

Experimental setup and procedure

- TPC of 2 l formed by two symmetric drift regions of 3 cm
- An ^{241}Am radioactive source that emits α-particles and γ-rays in coincidence is placed on the cathode.
- Two microbulk Micromegas (MM) (35 mm in diameter) are used to detect the signal, which are placed one in each anode
- α –particles → α- MM
  γ-rays → γ- MM
- Xe+TMA mixture is constantly recirculating by SAES filter, allowing very high purify of the mixture





Experimental setup and procedure

1

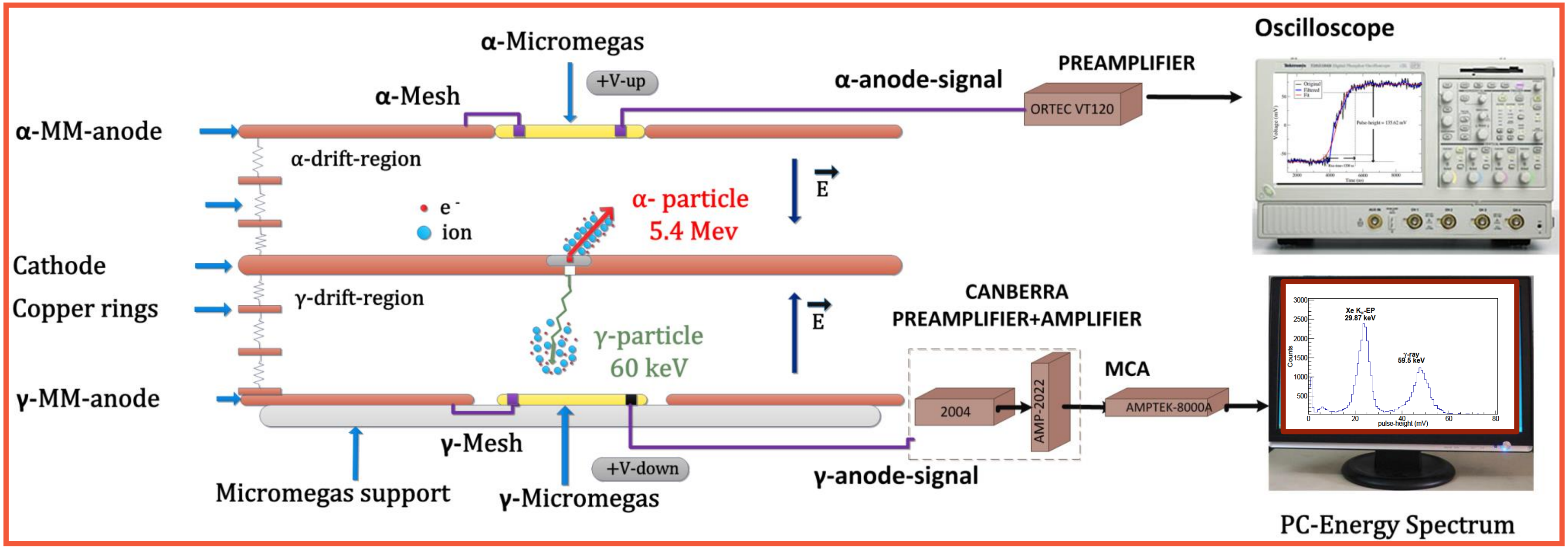
Two configurations

Recombination

1. Q versus E_{drift} for α- particles and γ-rays
2. Q versus φ angle for α- particles

Rate= 130 Hz

Measurements:
From 3 to 8 bar with 2,2%TMA
At 5 bar 1,2% TMA
At 6 bar 1,5% TMA
Scanning the E_{drift}/P from 10 to 350 V/cm/bar



Experimental setup and procedure

Two configurations

2

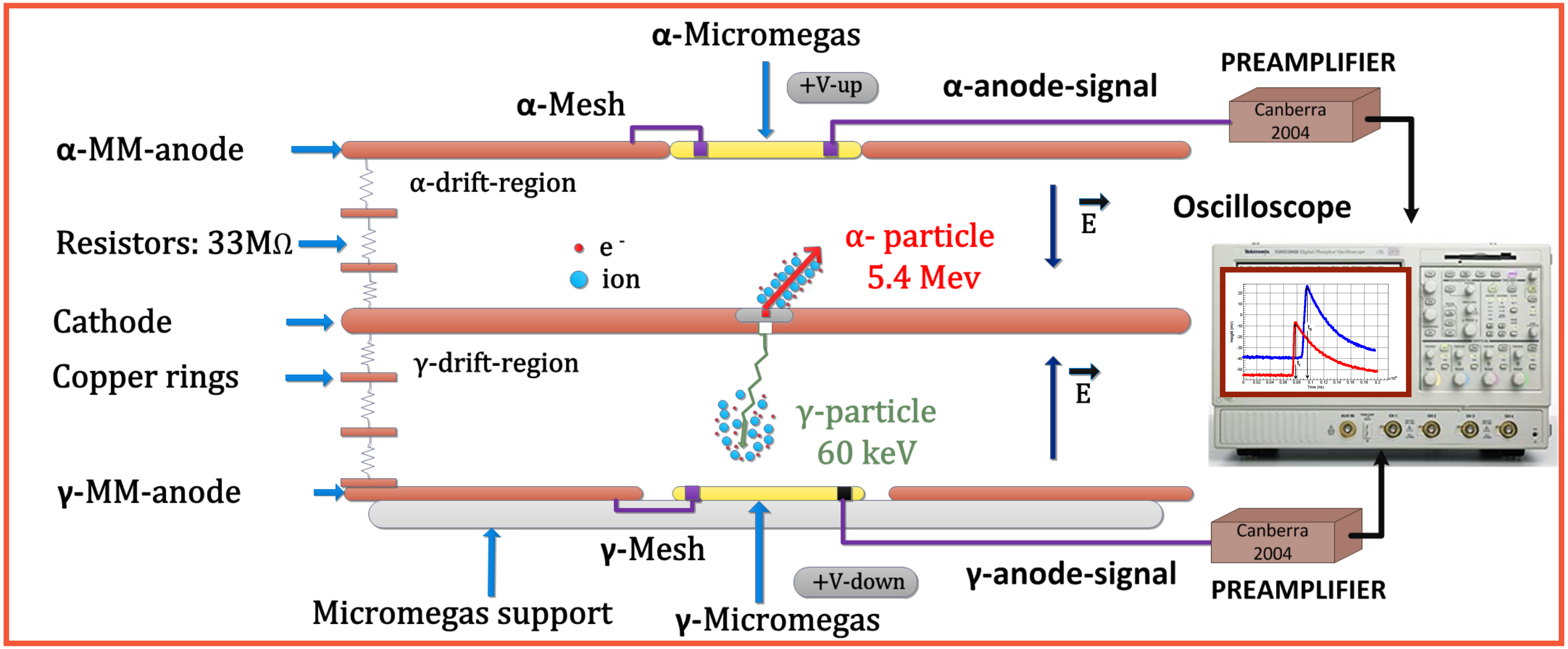
Attachment

Measurements:

- From 3 to 6 bar at low E_{drift}/P (<60V/cm/bar)
- To monitor the level of purity of the gas

1. Electron life time at different E_{drift}

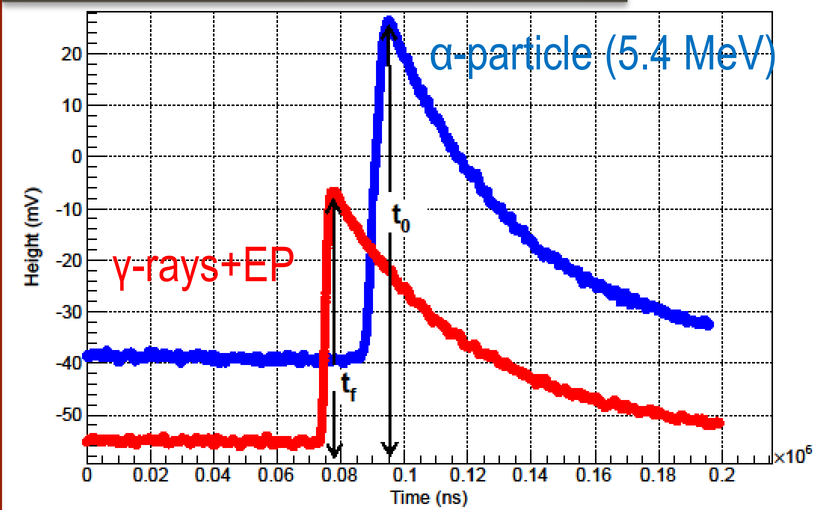
Rate <2 Hz



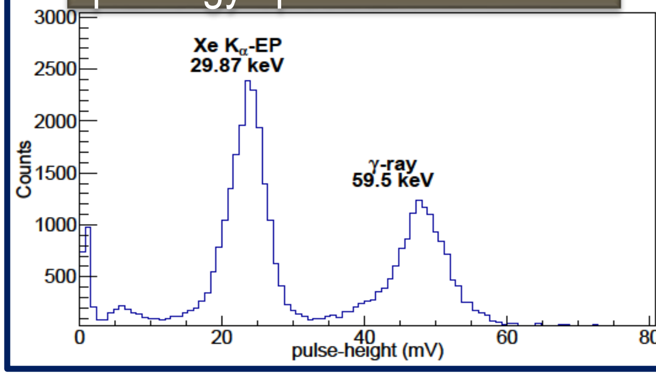
Outline

Results: Electron life time

Coincidence acquisition



γ-Energy spectrum

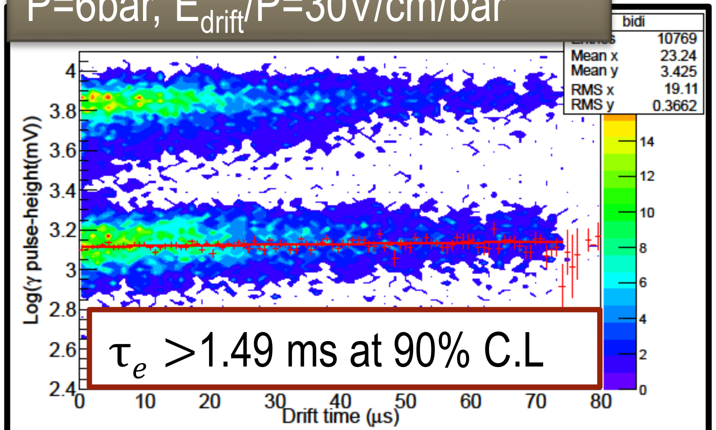


In absence of attachment the pulse-height of the signal should be independent of the drift time, otherwise it would have an exponential behaviour with the drift time

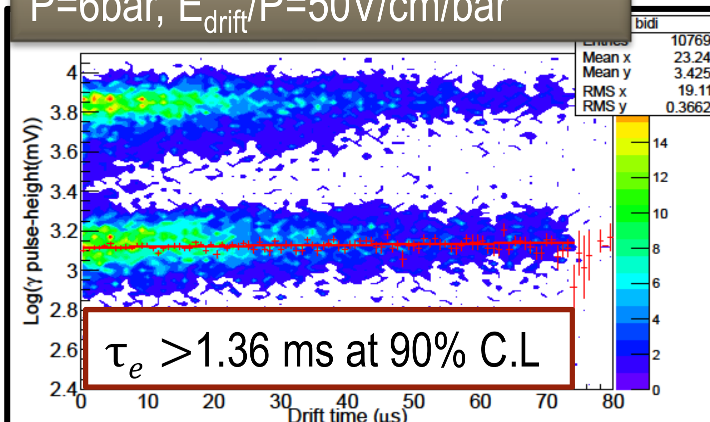
Pulse-height →H

$$Log(H) = Log(H_0) - \frac{1}{\tau_e}\Delta t$$

P=6bar, E_{drift}/P=30V/cm/bar



P=6bar, E_{drift}/P=50V/cm/bar



Not attachment

Outline

Results: Recombination

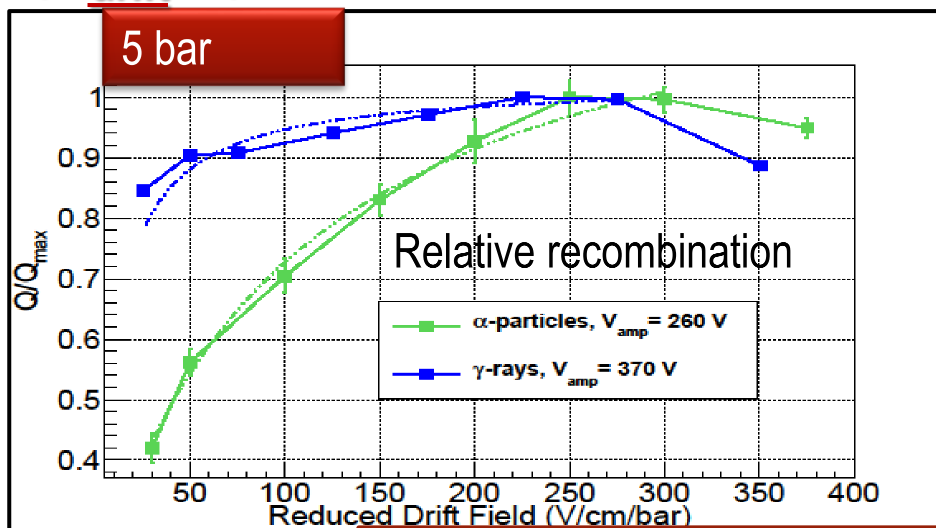
Charge vs reduced electric field (E_{drift}/P)

The pulse-height spectra of charge produced by α- particles and γ-rays were measured as function of E_{drift} at different pressures.

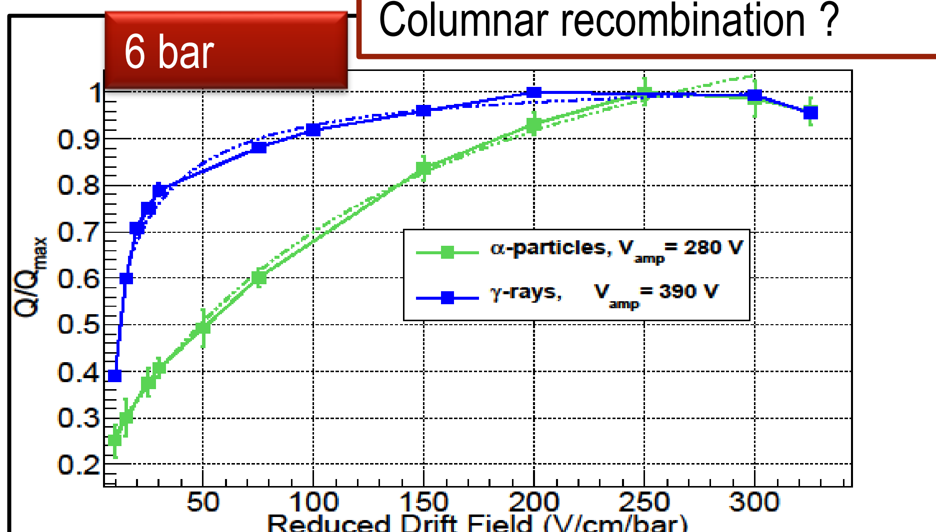
The peak position was determined:

- ❑ γ-rays→peak at 29 keV (Xe K_α escape peak from 59 keV γ-rays)
- ❑ α- particles at 5.4 MeV

γ-rays presents lower recombination than α- particles



Columnar recombination ?



Outline

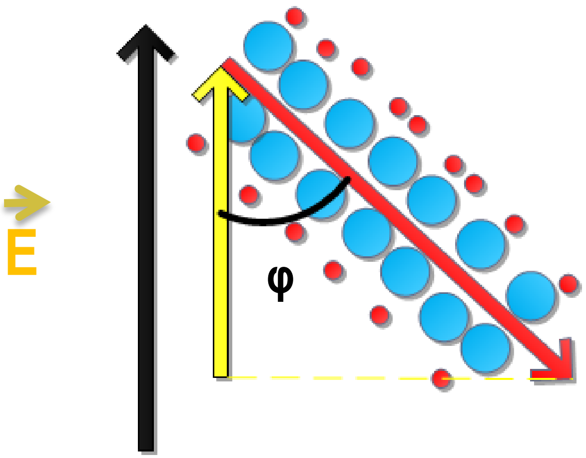
Charge vs φ angle for α-particles

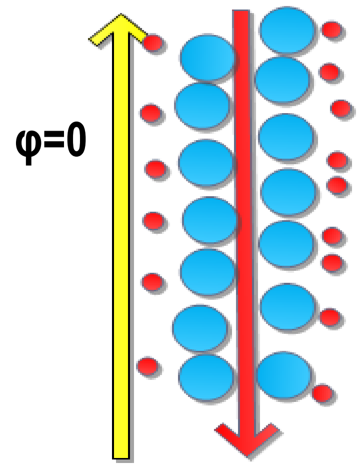
Pulse shape analysis:

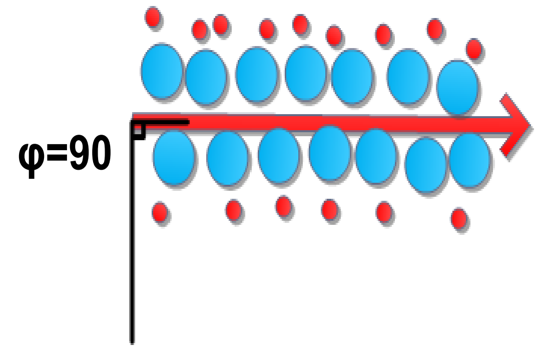
✓ pulse-height⟶ Charge

✓ Rise-time ⟶ φ angle respec to E_{drift}

Rise-time is the temporal projection of the track over the E_{drift} direction







$Rise_{max}$⟶ parallel tracks

$Rise_{min}$ ⟶ perpendicular tracks related with the diffusion

Temporal length of the track

$$t_{track} = \sqrt{rise^2{}_{max} - rise^2{}_{min}}$$

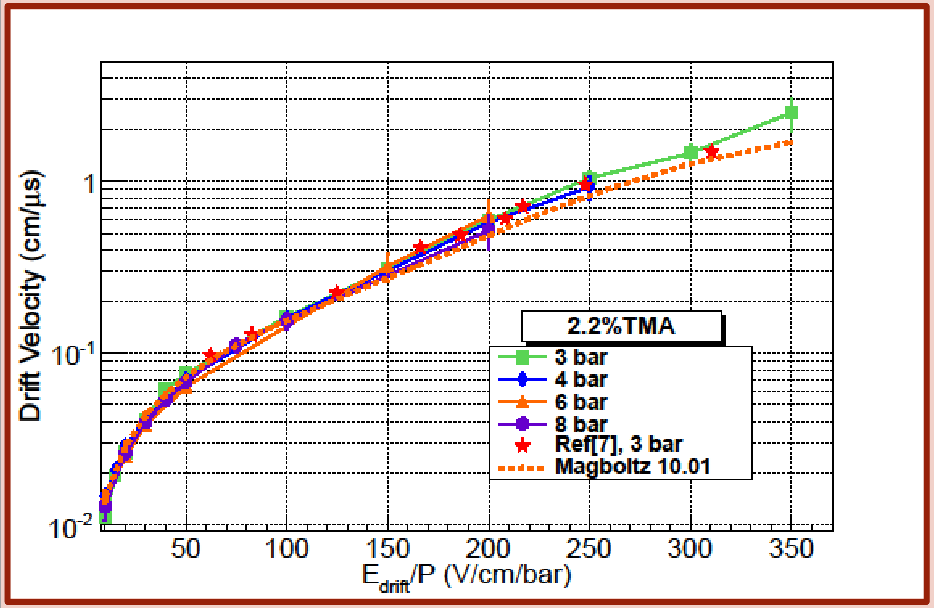
Transformation between rise-time and φ

$$\cos\varphi = \frac{\sqrt{rise^2 - rise^2{}_{min}}}{\sqrt{rise^2{}_{max} - rise^2{}_{min}}}$$

Electronic properties

Drift Velocity

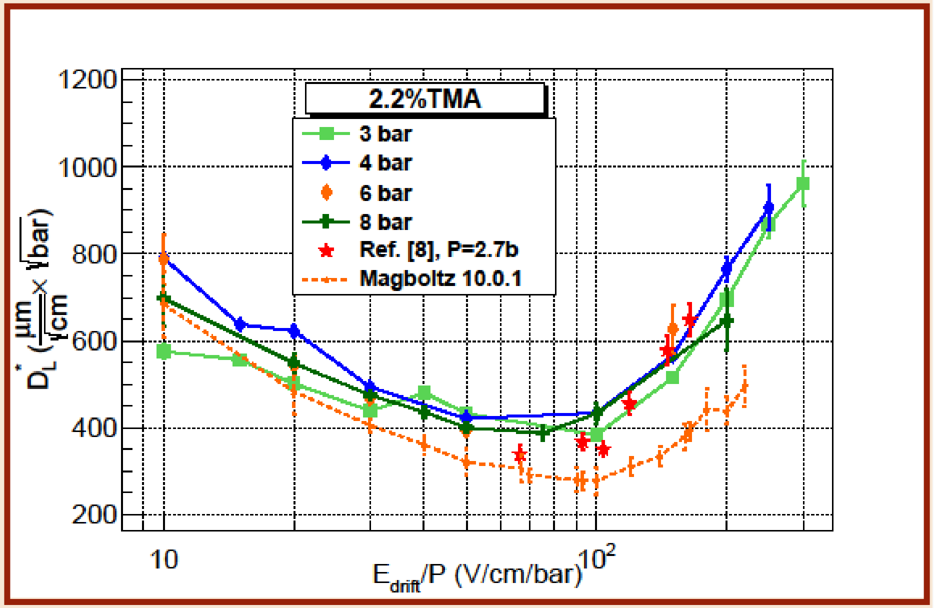
$$v_{drift} = k_1 \frac{d}{t_{track}},\ k_1=0.8$$



[7] D.C. Herrera , J. Phys. Conf. Ser. **460** (2013) 012012

Longitudinal diffusion coefficient

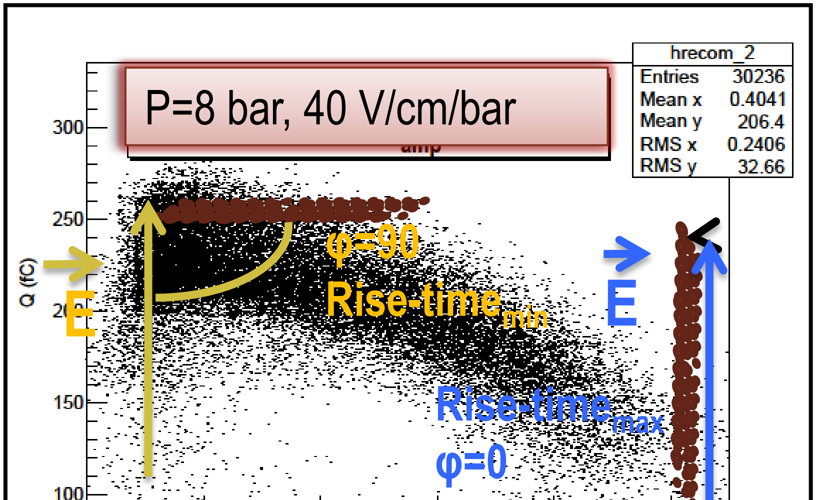
$$D^*_L = k_2 \frac{\sqrt{P}}{\sqrt{d}} rise_{min} v_{drift}, K_2 = 0.36$$



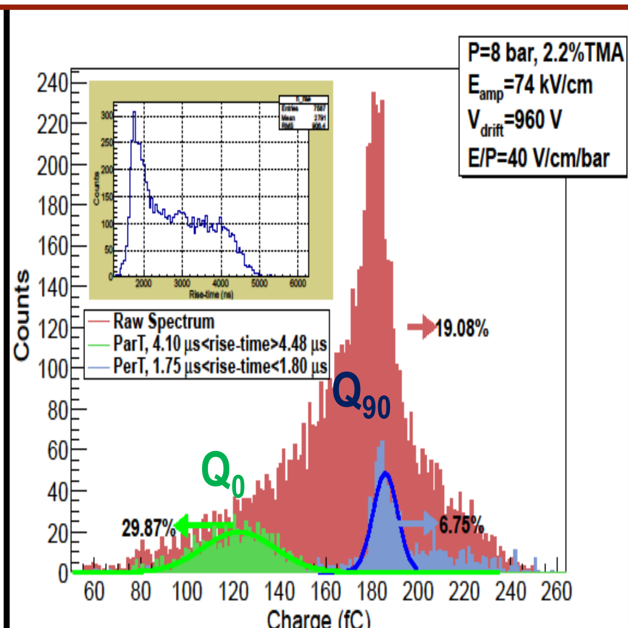
*[8] V Álvarez et al, JINST **9** C04015 (2014)*

- ✓ The electronic properties are in agreement with experimental results published in Xe+TMA
- ✓ The PSA as well as the transformation between rise-time and φ are appropriated

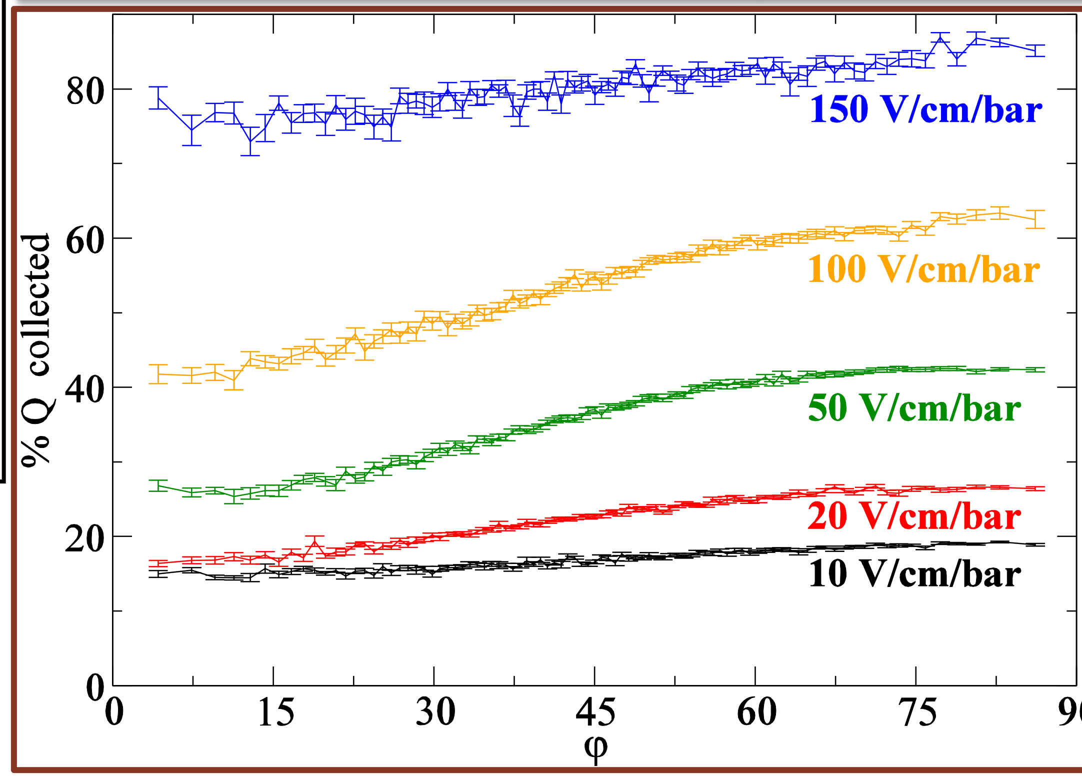
Charge vs φ angle for α-particles



Compatible with Columnar recombination



At 8 bar, Charge vs φ angle at different E_{drift}/P



Cut applied on rise-time
Selecting tracks:

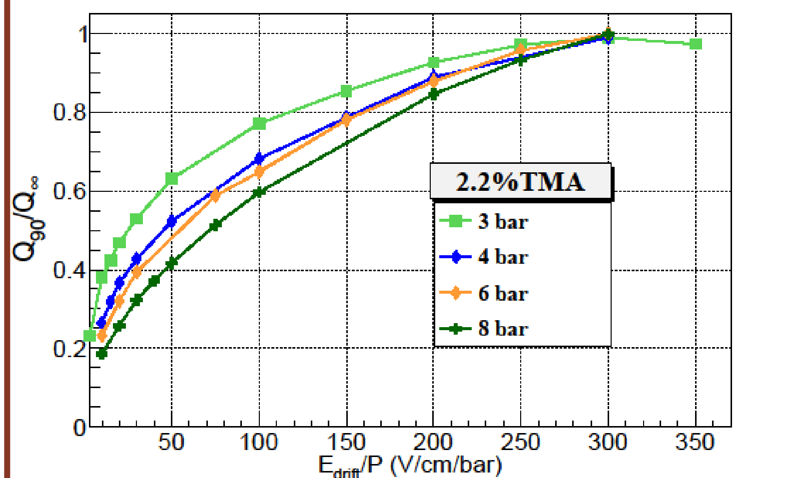
- **Q_0** → cosφ : [0.9,1]
  0-25º
- **Q_{90}** →cosφ :[0,0.1]
  85-90º

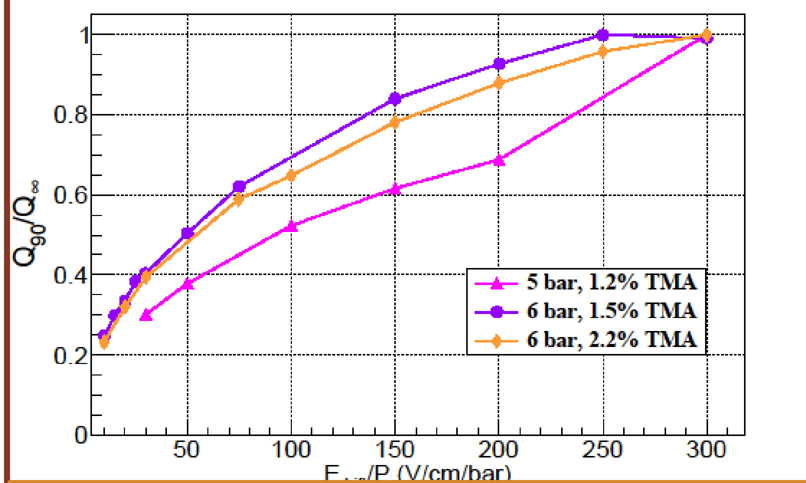
Definition of a figure of merit to quantify the CR

$$r = \frac{Q_0}{Q_{90}}$$

Charge vs φ angle for α-particles

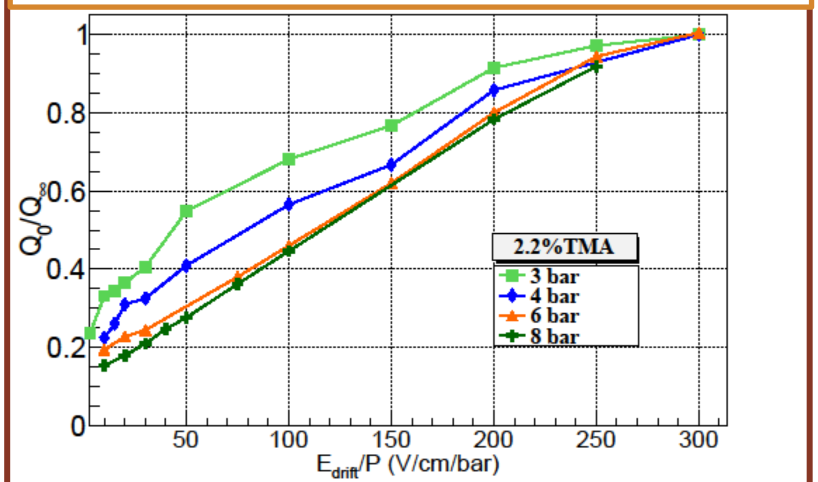
Q_0 and Q_{90}

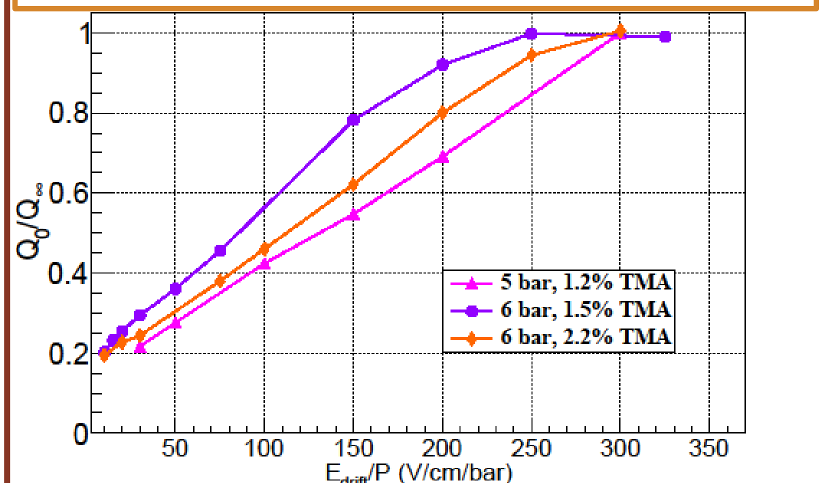




- Systematic behavior with pressure

- Dependency with the %TMA





Charge vs φ angle for α-particles

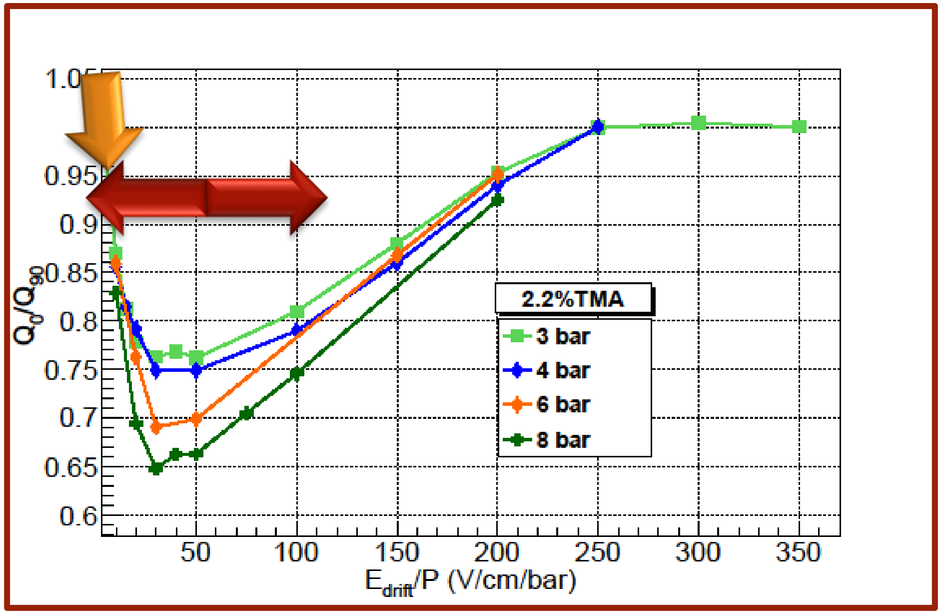
Columnar Recombination $Q_0/Q9_0$ ratio

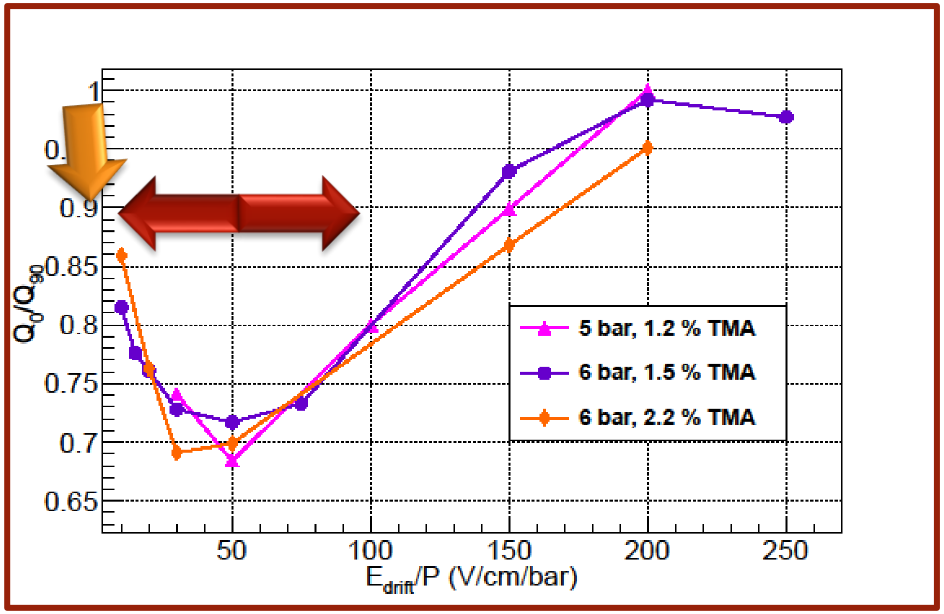
Q_0/Q_{90} ratio follows the same tendency from 3 to 8 bar.

Region 3 - 50 V/cm/bar - columnar recombination increases

Is the geminal recombination the most important effect at the lowest values of REdrift?

Region 50- 250 V/cm/bar - columnar recombination decreases





✓ CR depends on the pressure

CR increases with pressure

✓ CR depends on the TMA concentration

Outline

Conclusions and Outlook

Conclusions

1. The new drift configuration allows to study the recombination of α-particles and γ-rays as well as to measure the electronic properties and control the level of purity during the measurement.
2. The columnar effect on the loss of charge by recombination is observed, showing a substantial dependency with the track angle, pressure and TMA concentration
3. This is a first step towards understanding the effect in Xe+TMA mixtures

Outlook

- Model columnar recombination within Jaffé theory
- In parallel, experimental and simulation efforts continue, in order to test the idea of measuring directionality in Xe+TMA mixtures
  1. Xe+TMA charge and light yields is being measured (for EL, S1, Penning and recombination).
  2. Microphysics simulations of recombination in ideal nuclear recoils
  3. Plan for direct measurement of directionality signal in nuclear recoils with high energy pion beam in Xe+TMA mixtures in FermiLab

THANKS FOR YOUR ATTENTION

Zaragoza group

Igor García Irastorza
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Xavi Gracia
Elisa Ruiz
Diana Carolina Herrera Muñoz

Lawrence Berkeley group

Lawrence Berkeley Lab group

David Nygren
Azriel Goldzmith
Carlos Bastos de Oliveira
Megan Long
Josh Renner

BUCK UP SLIDES

Data analysis for α-particles

Pulse Shape Analysis

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Procedure

1. higher frequencies suppressed via FFT analysis
2. Pulses parameters are calculated to use as input parameters in the Fit
3. Fit of the filtered pulse is calculated

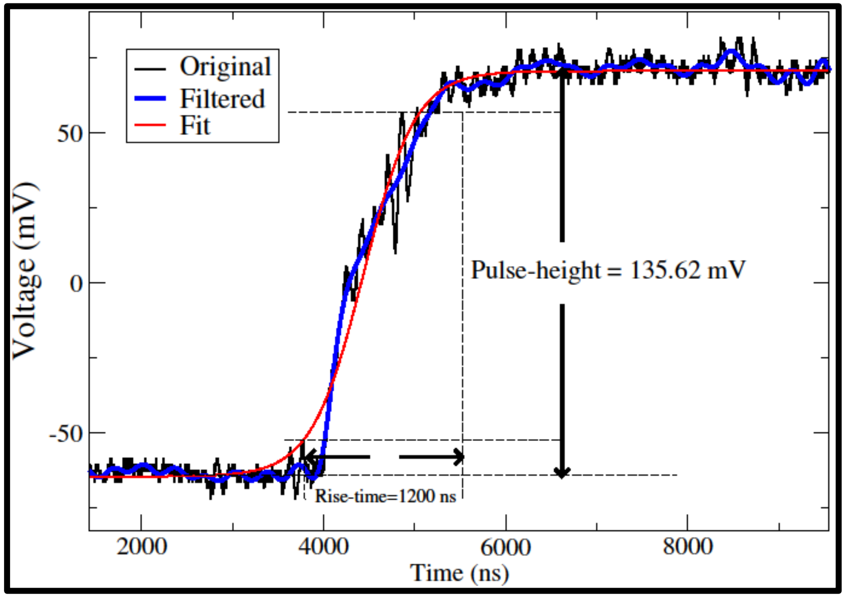
$$H(t) = -\frac{Htot}{1 + exp[(t - t_{half})/s]} + C$$

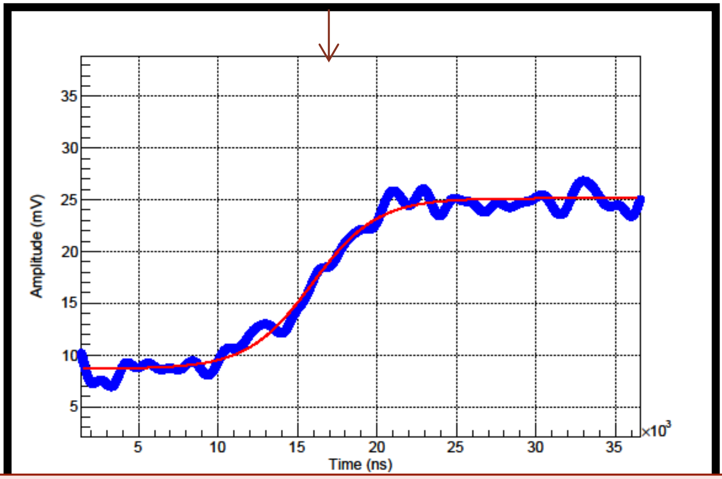
4. Pulse-height and rise-time are obtained from the fit function pulse

Htot= Pulse- height

Rise-time = t_{90}-t_{10}

High frequency noise suppressed



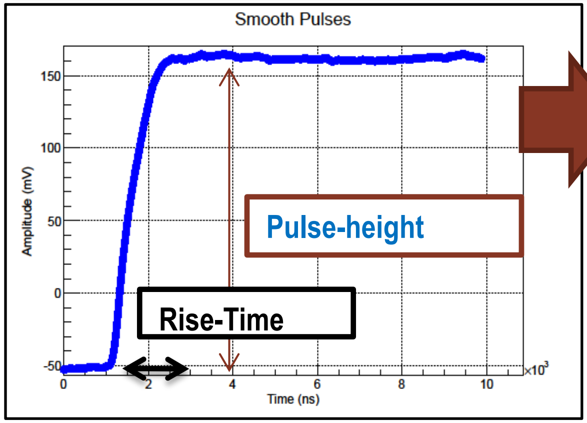


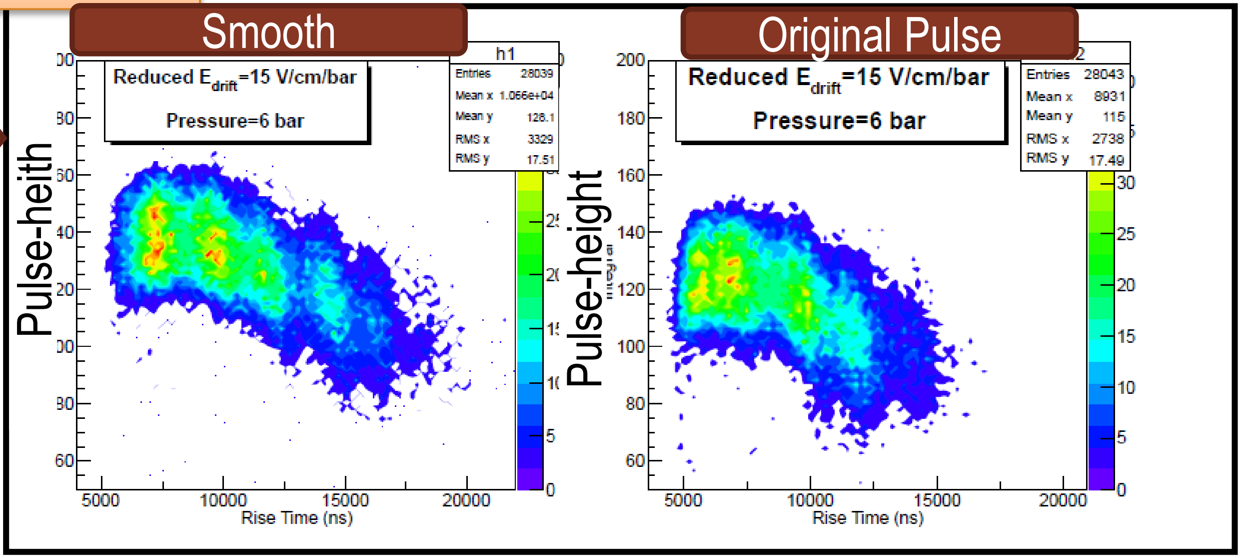
With this procedure:

- Better estimation of rise-time and p-height
- Improve the energy resolution

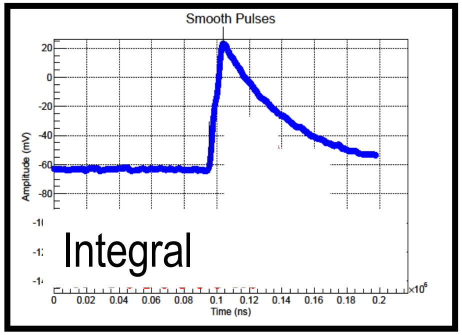
Ballistic effect

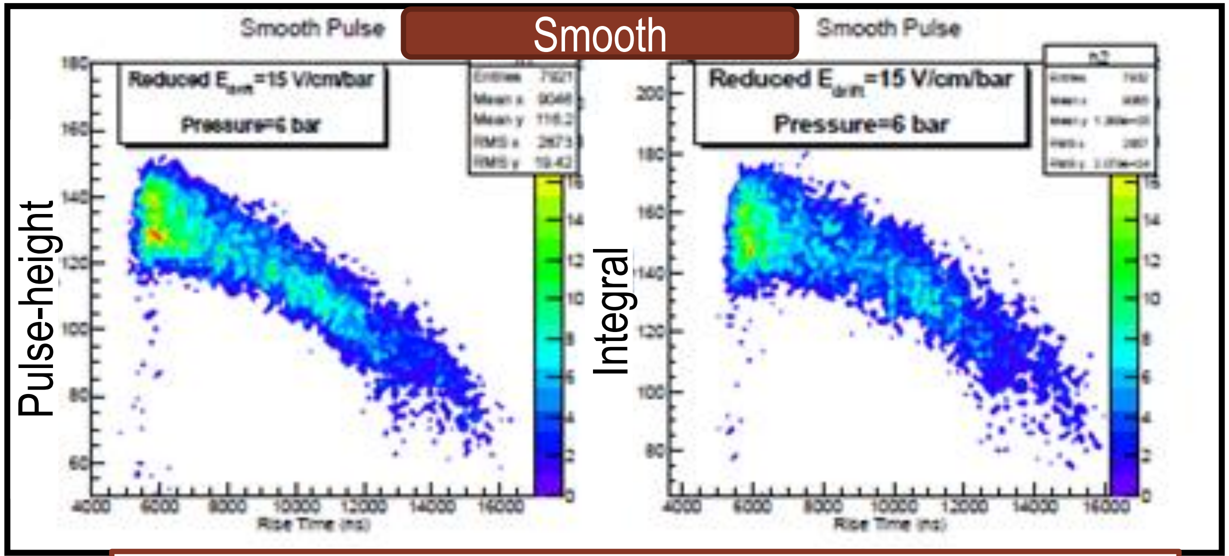
Acquired with Ortec preamplifier





Acquired with Canberra Preamplifier



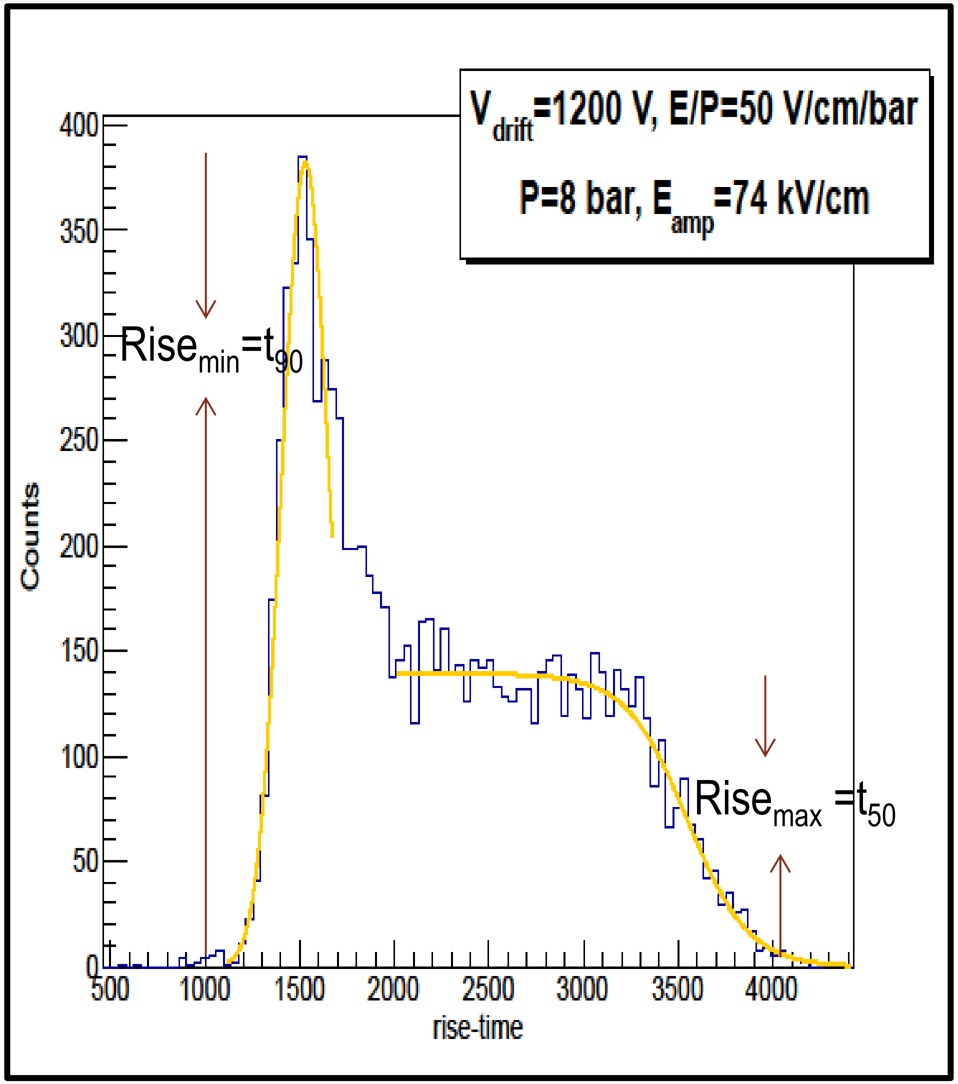


Ballistic effect discarded

Definition $Rise_{max}$ and $Rise_{min}$

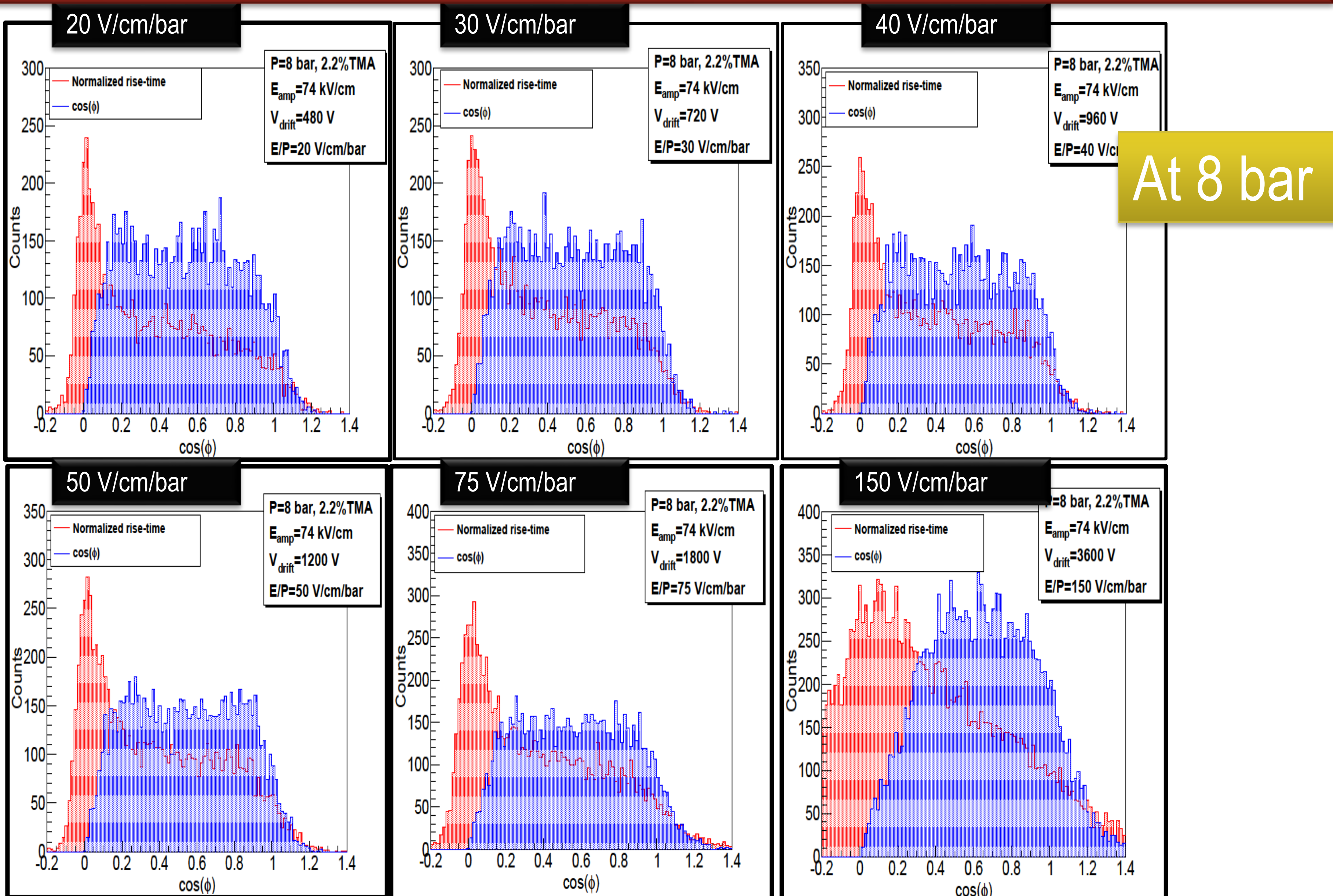
$Rise_{min}$:
Left side is adjusted to a Gaussian function, where the the rise at which the height is the 90 % of the total height is the $Rise_{min}$
Error: σ from Gaussian fit.

$Rise_{max}$:
Right side is fitted to an sigmoid function, t_{50} corresponds to $Rise_{max}$
Error: temporal distance between t_{90} and t_{50}



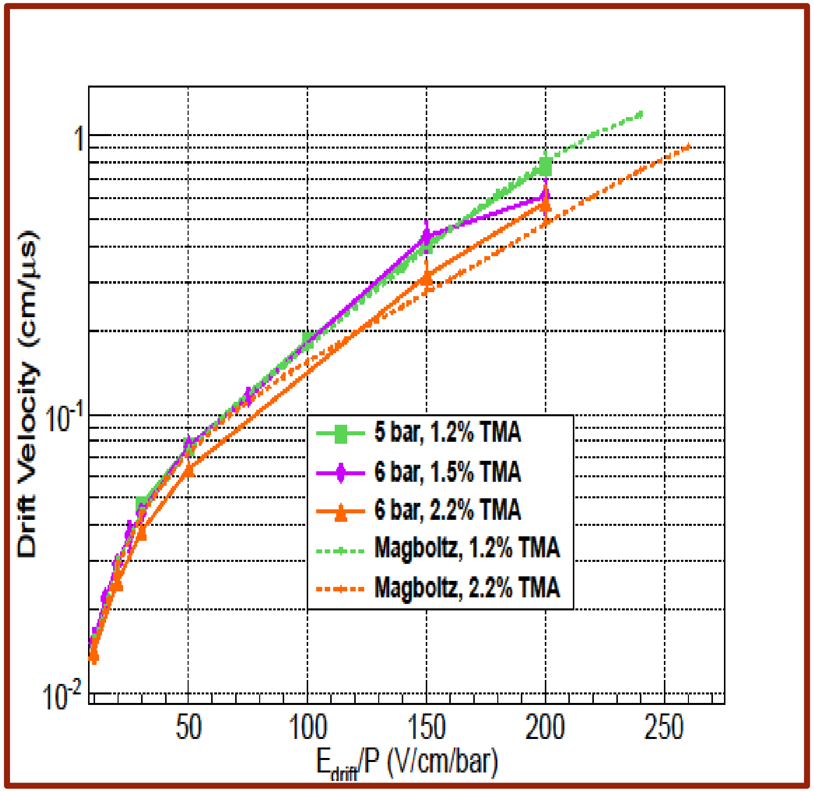
This a typical rise-time distribution at low drift fields

Charge vs φ angle for α-particles



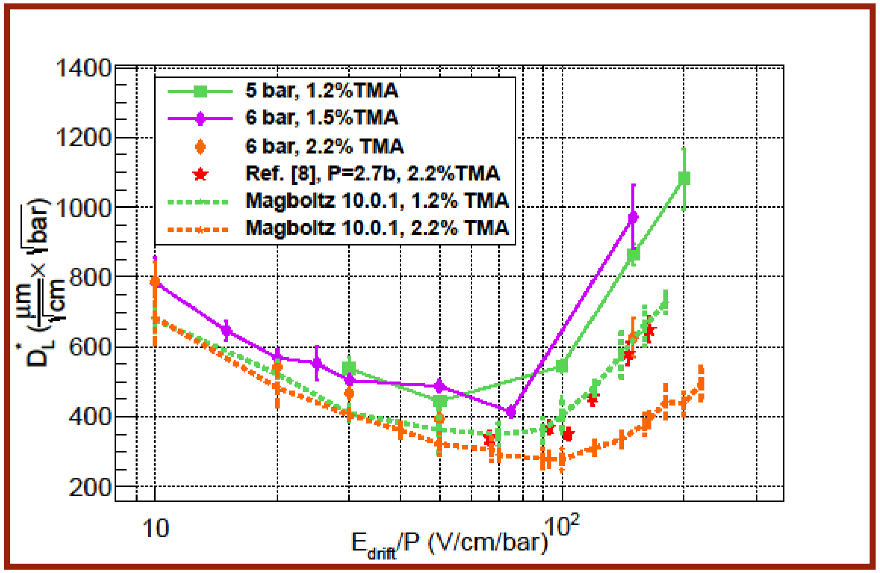
Charge vs φ angle

Drift Velocity



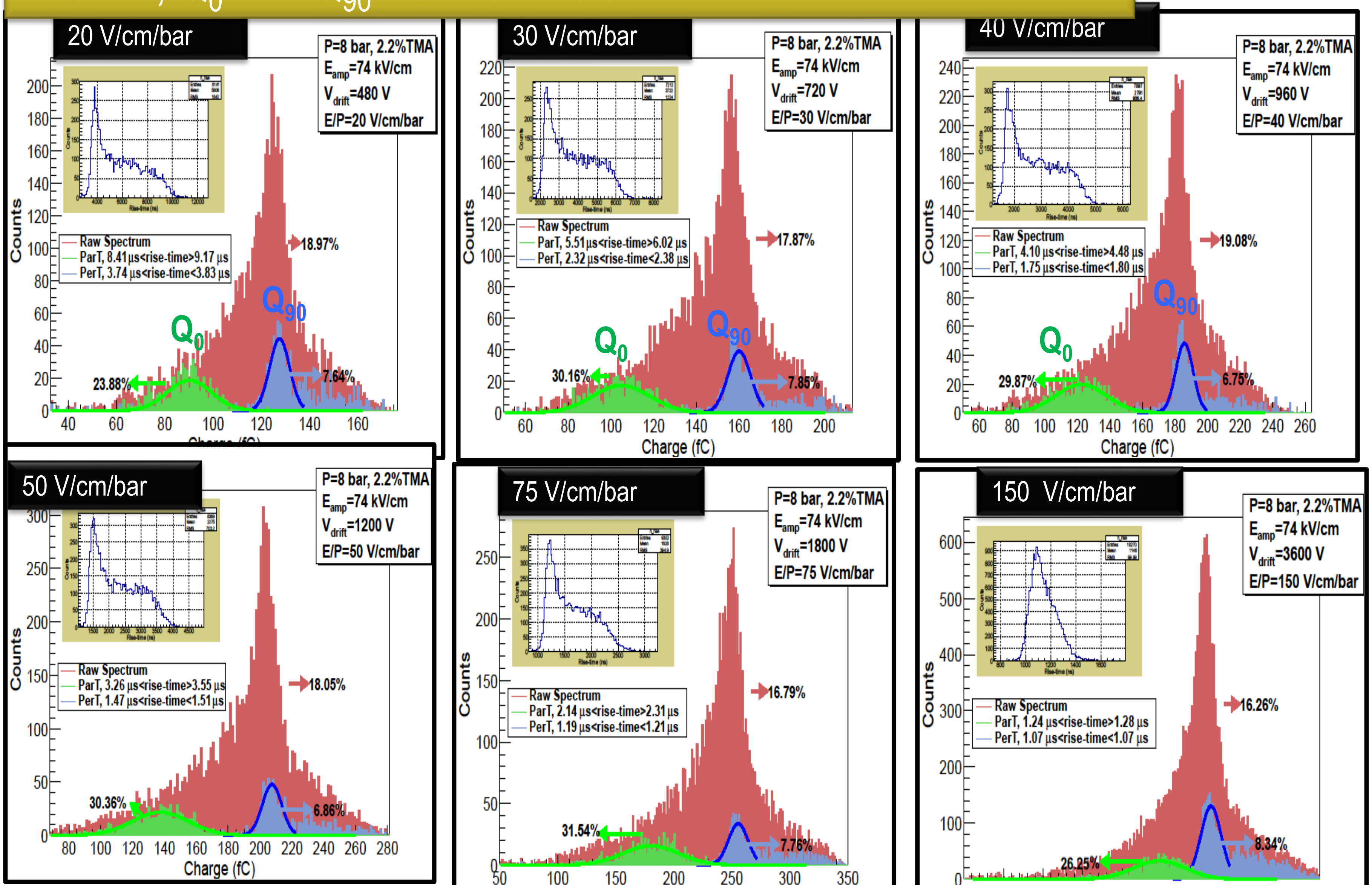
Variation with the percentage of TMA

Longitudinal diffusion coefficient

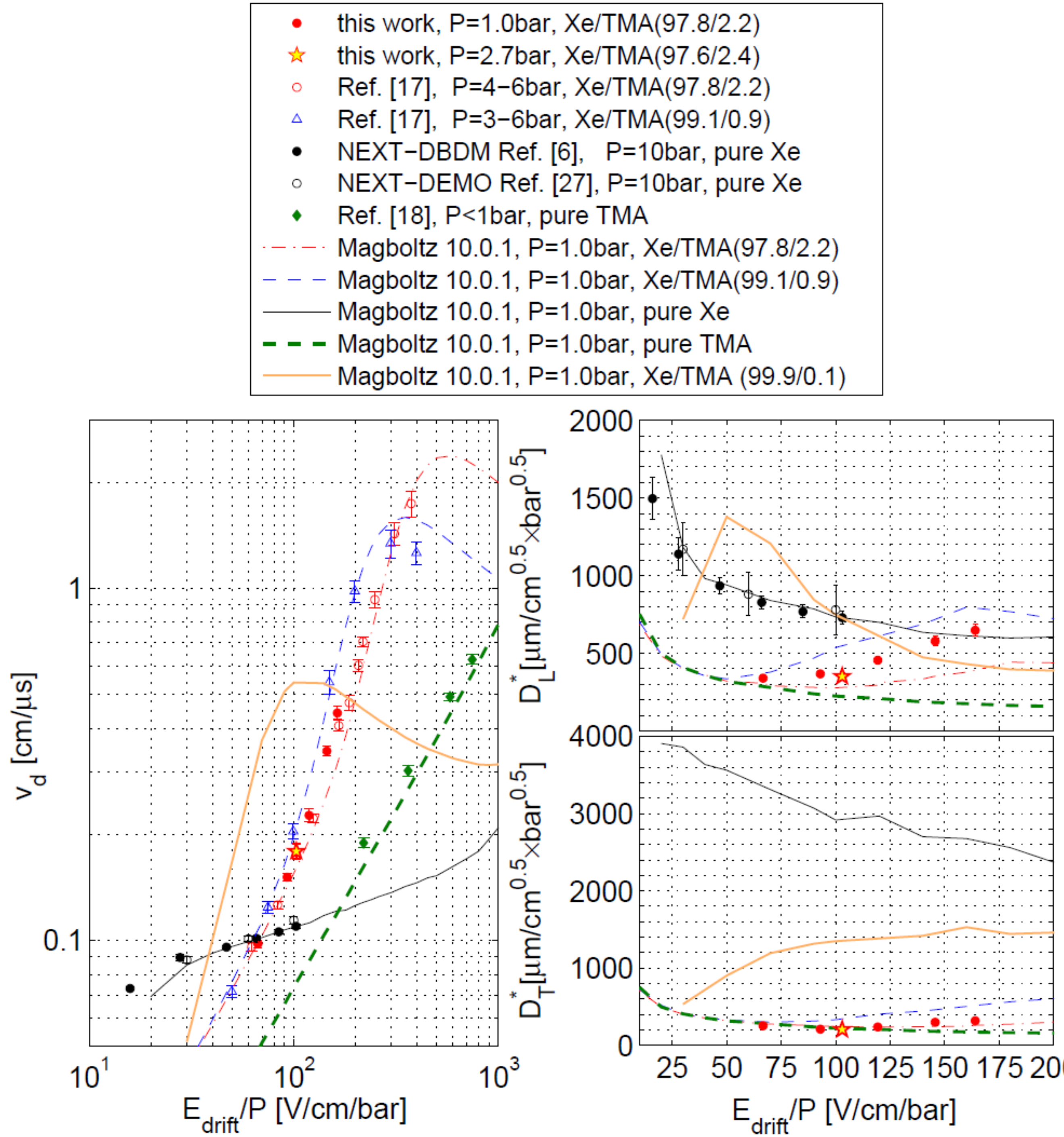


Charge vs φ angle for α-particles

At 8 bar, Q_0 and Q_{90} distributions at different RDF



Xe-TMA properties in a nut-shell



Preliminary comparison with Jaffé theory

Jaffé theory

- In base of the solution of the continuity equation
- As a first approach the Jaffé's solution is integrated

$$N(t, E_0, \theta) = \frac{N_0}{1 + \alpha \int_0^t \frac{\exp\{-[t'^2 sin^2\theta / t_0(t' + t_1)]\}}{t' + t_1} dt'}$$

- α, t_0, t_1 parameters that depend on diffusion (*D*), movility (μ) of e- and ions →We measure this parameters with this setup
- the radio of the electron cloud ***b***
- recombination coefficient ***k***

Free parameters

For tracks at 8 bar (0.27 cm)