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

D. C. Herrera, on behalf of the Zaragoza group

Universidad de Zaragoza, Spain

in collaboration with Lawrence Berkeley Lab, USA

RD51 mini week

June 19 2014

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
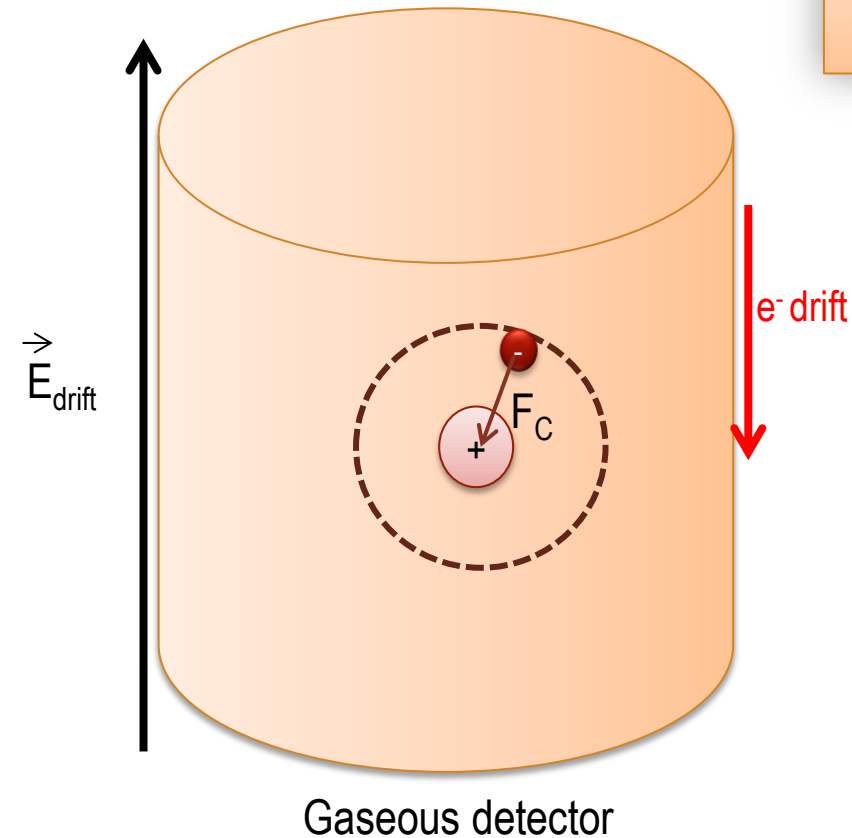
5. Conclusions and Outlook

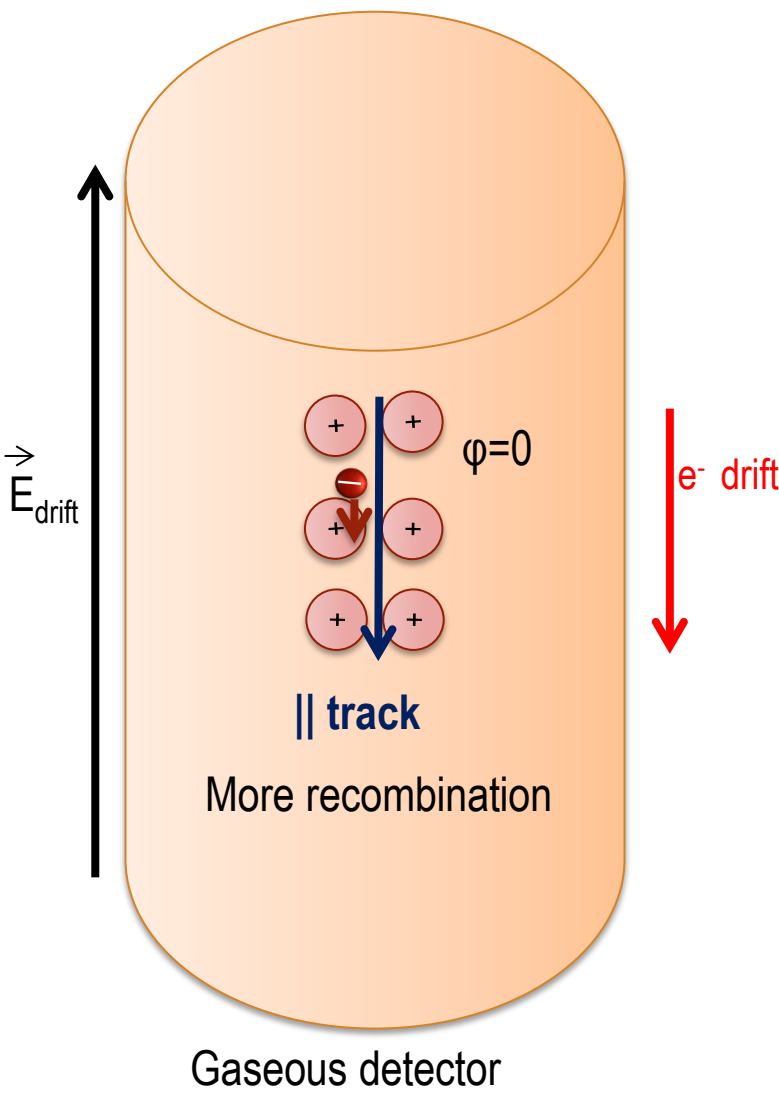# Outline

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*

$\vec{E}_{drift}$

e⁻ drift

F_C

\+

\-

Gaseous detector

Introduction

Geminate or Initial recombination

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- Electron's Brownian motion under the action of an external field. [1] L. Onsager, Phys. Rev. 54 (1938) 554
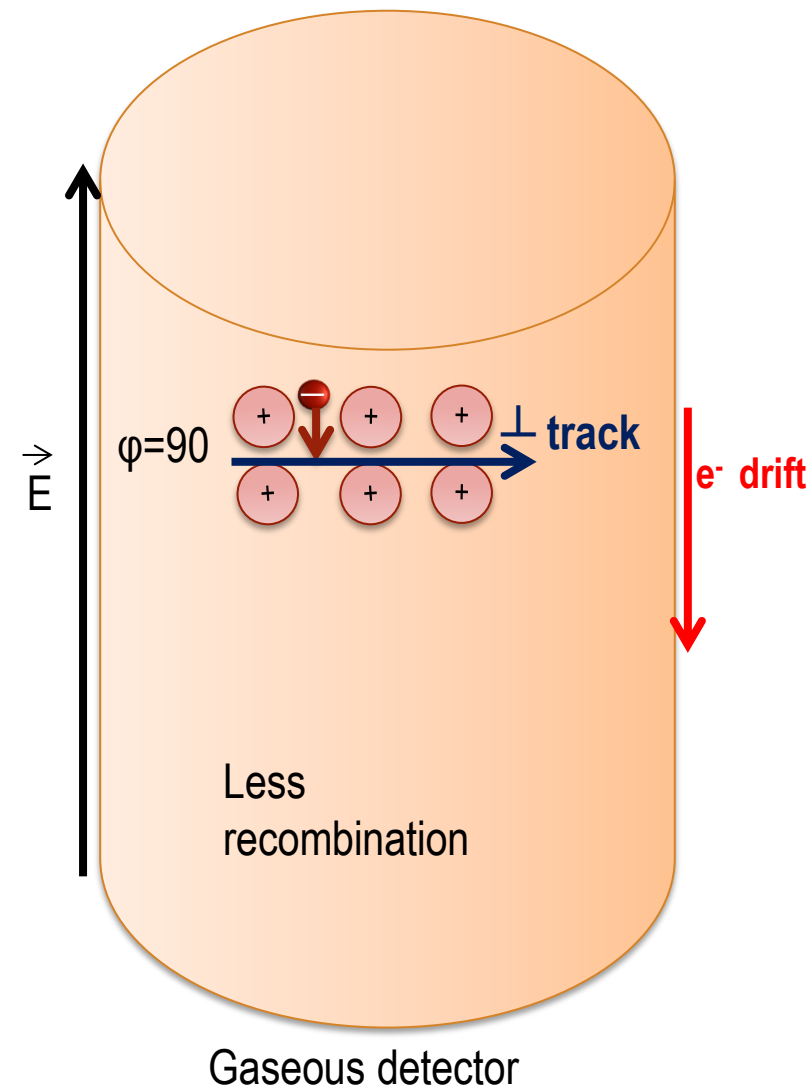
Columnar or volume recombination

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)

$\vec{E}_{drift}$

$\varphi = 0$

e⁻ drift

|| **track**

More recombination

Gaseous detector

Introduction

φ=90   ⊥ **track**

$\vec{E}$

e⁻ drift

Less recombination

Gaseous detector

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*

Columnar or volume recombination

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

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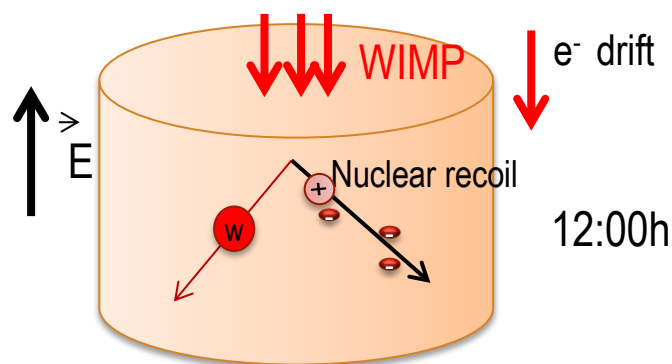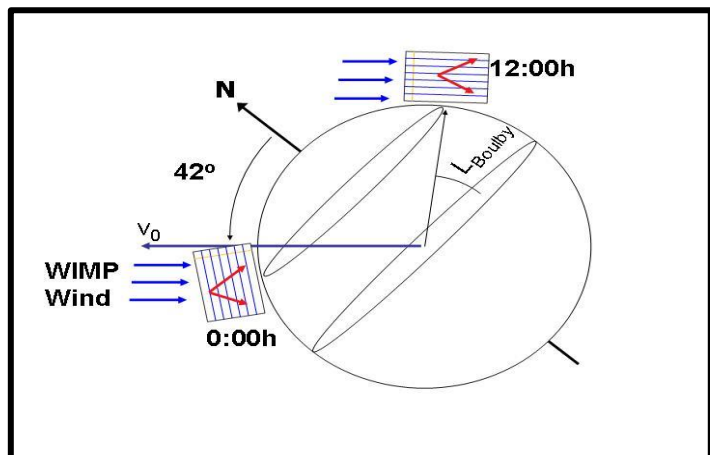
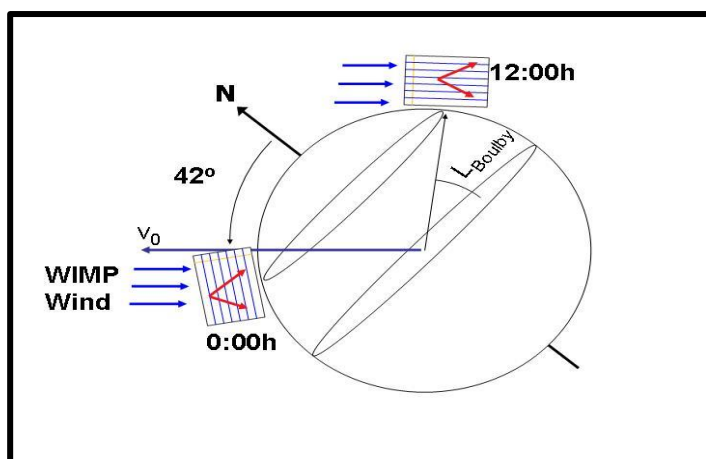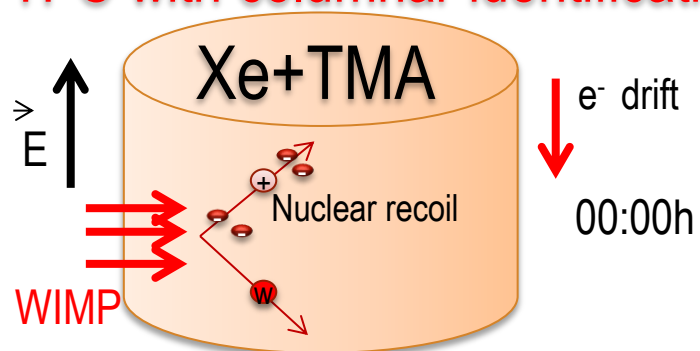*[3]* D. Nygren, J. Phys. Conf. Ser. **309** (2011) 012006.
[4] A. Goldschmidt. Talk Symposium Berkeley, May 2014

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

HP TPC with columnar identification

Xe+TMA

e⁻ drift

Nuclear recoil

00:00h

WIMP

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
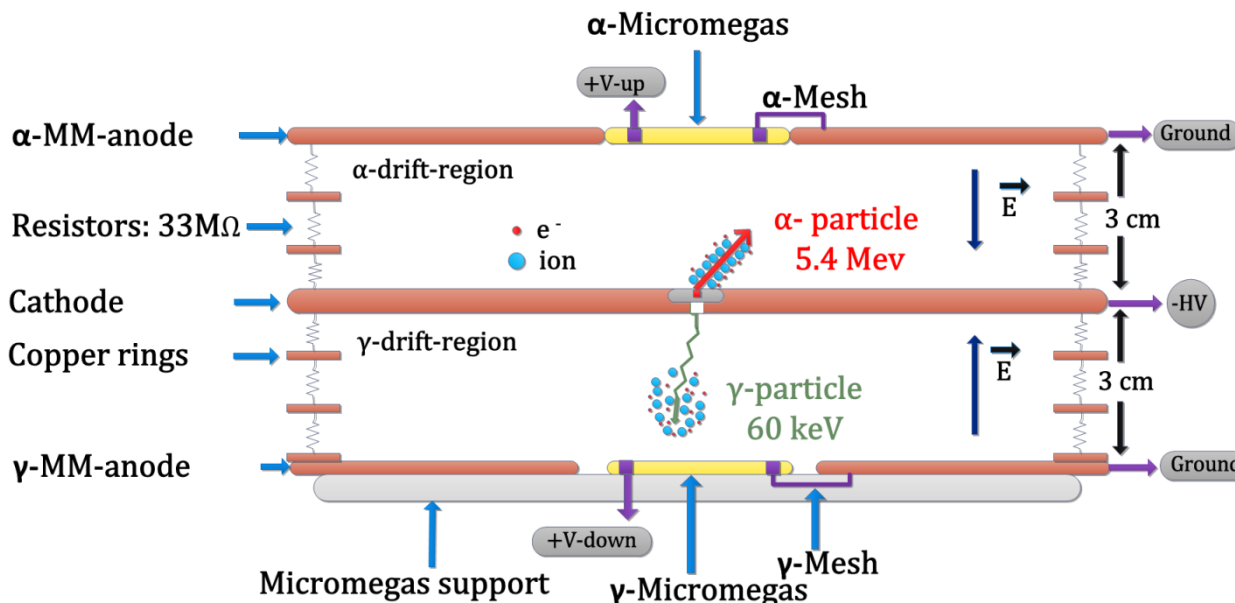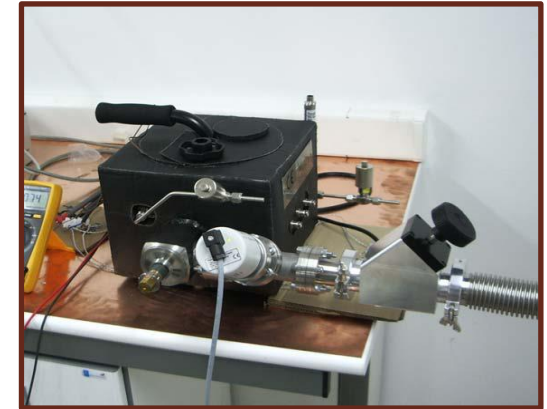
Methodology

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

Outline

- 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

1

Two configurations

Recombination

1. **Q versus E_{drift} for α- particles and γ-rays**
2. **Q versus φ angle for α- particles**
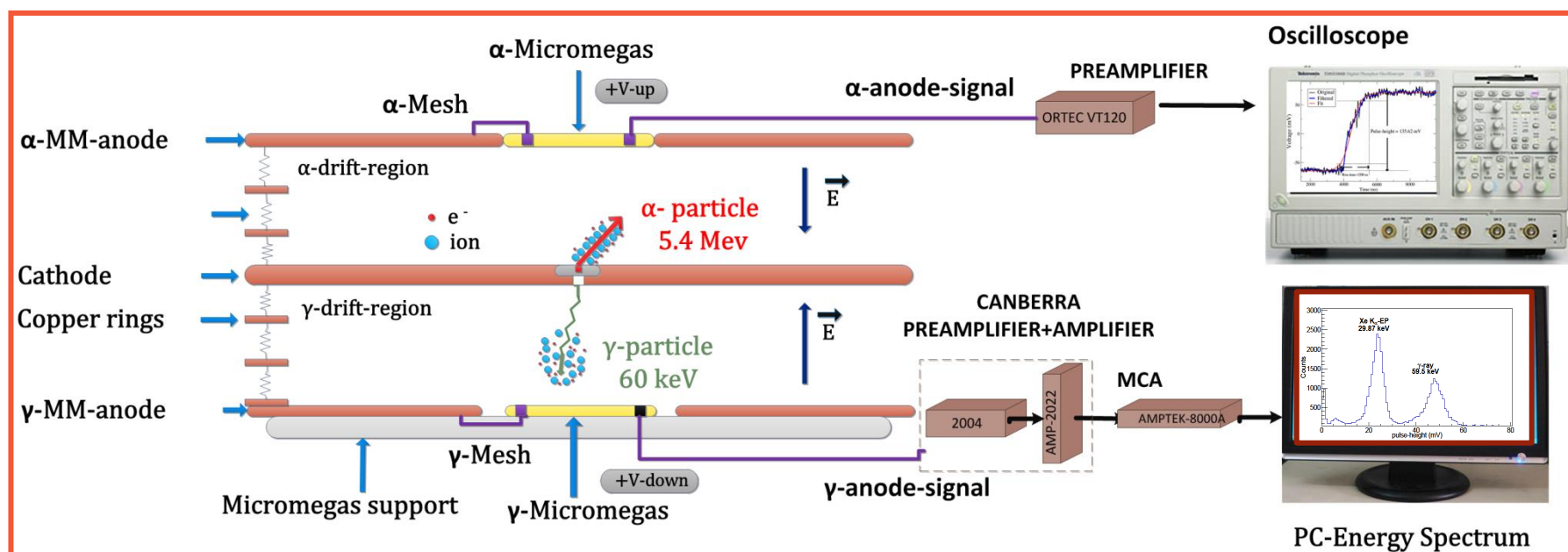
Rate= 130 Hz

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
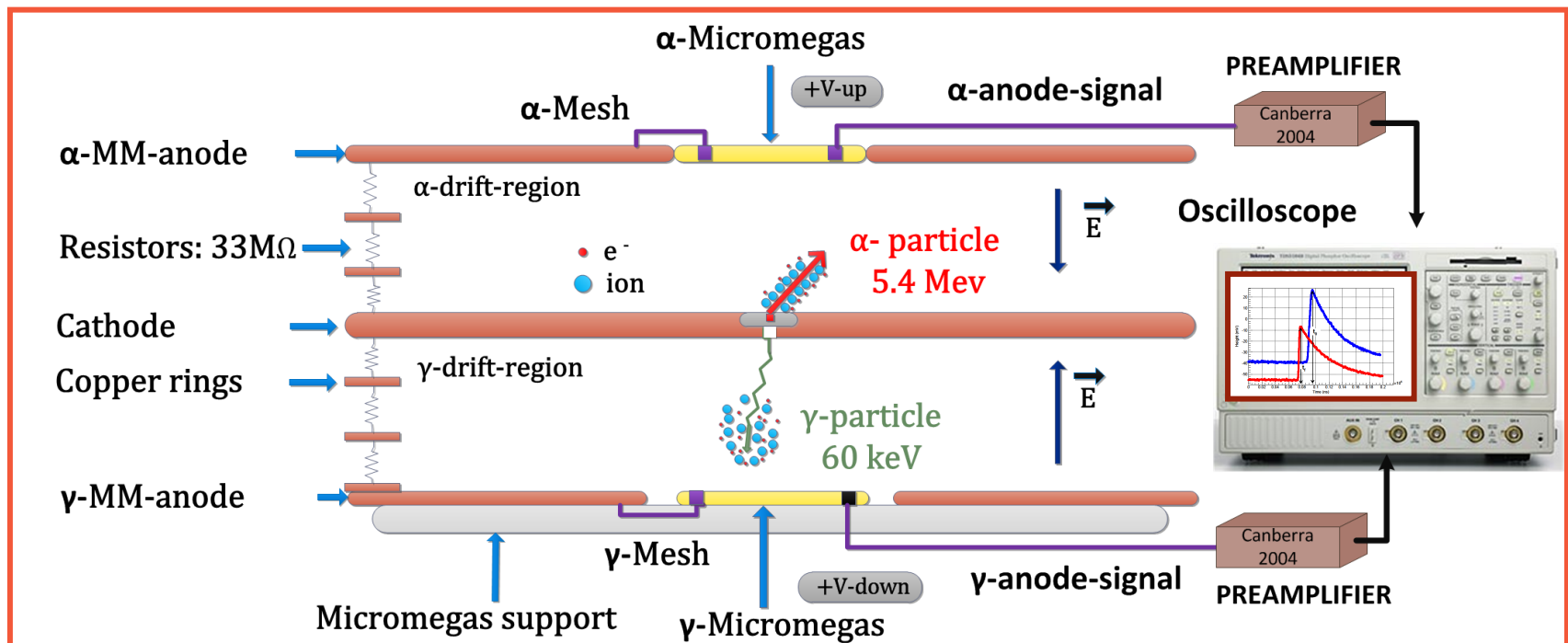
Experimental setup and procedure

Two configurations

Measurements:

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

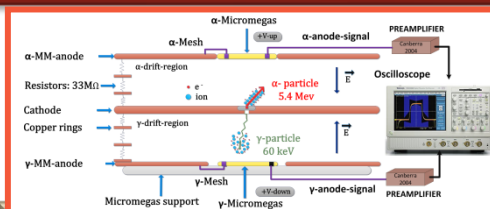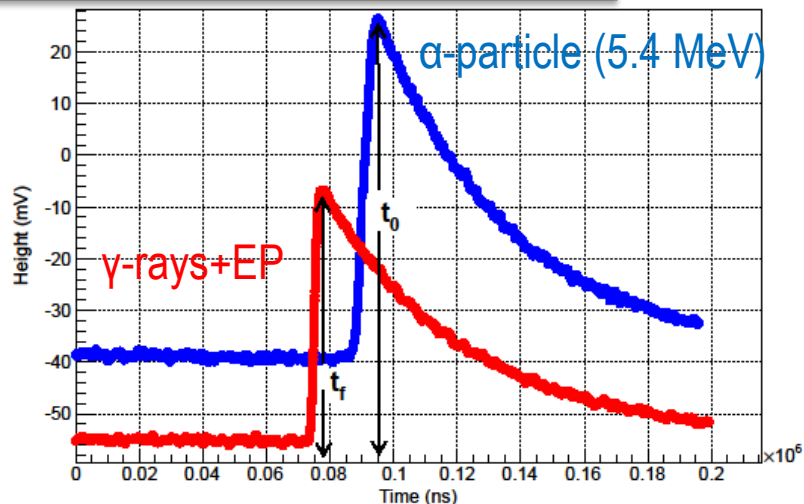Attachment

1. **Electron life time at different E_{drift}**

Rate <2 Hz

Outline

1 Introduction

2 Experimental setup and Experiment

3 Results:Electron life time

4 Results: Recombination setup

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

4.2 Charge vs φ angle for α-particles

6 Conclusions and Outlook

Results: Electron life time

Coincidence acquisition

α-particle (5.4 MeV)

γ-rays+EP

t_0

t_f
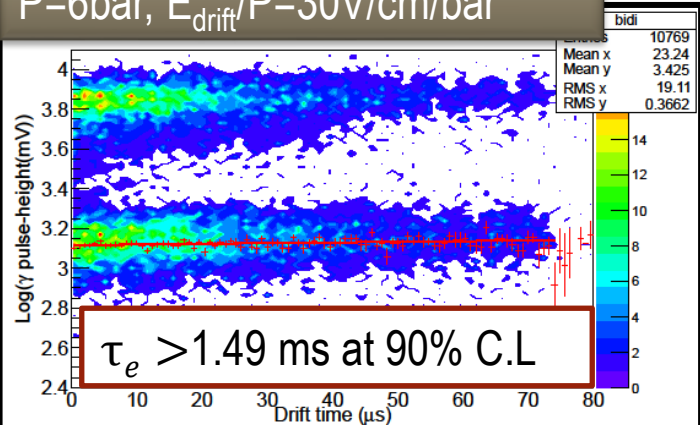

γ-Energy spectrum

Xe K_α-EP
29.87 keV

γ-ray
59.5 keV
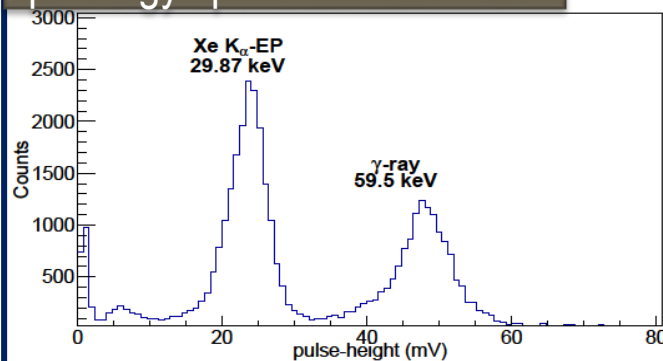
✓ In absence of attachment the pulse-height should be independent of the drift time, otherwise

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

Pulse-height →H

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

τ_e >1.49 ms at 90% C.L

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

τ_e >1.36 ms at 90% C.L

Not attachment

Outline

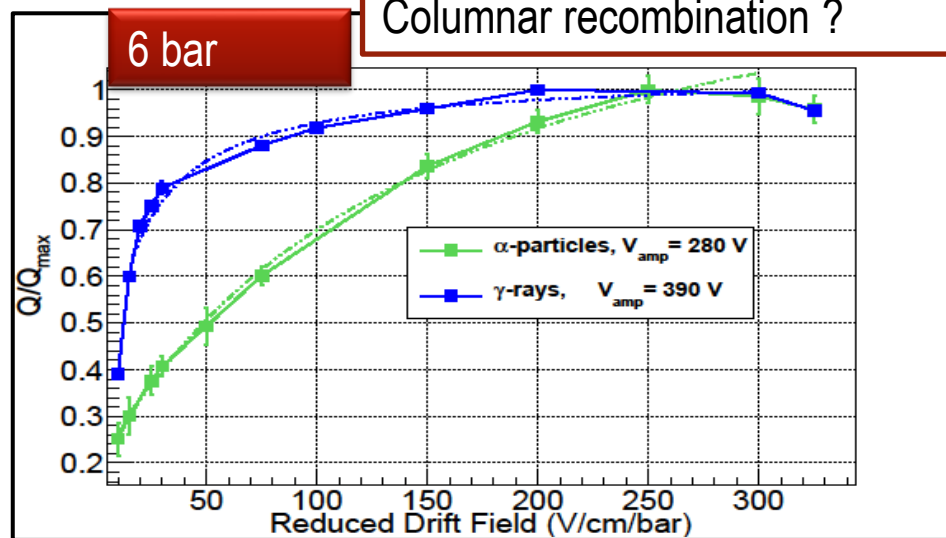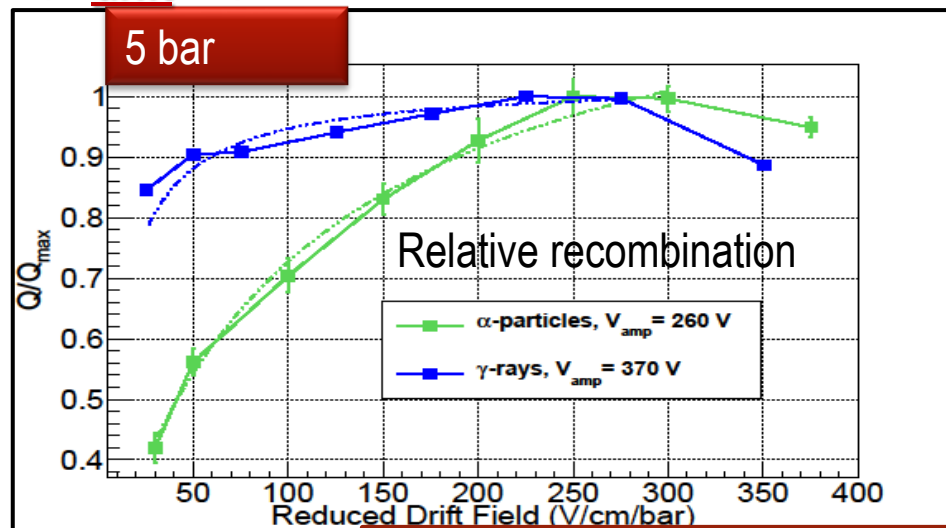Columnar Recombination in Xe+TMA mixtures using MM-TPC

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
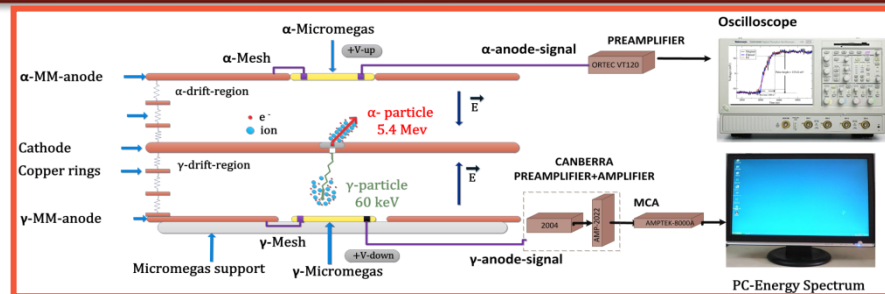
γ-rays presents lower recombination than α- particles

5 bar

Relative recombination

- α-particles, V_{amp} = 260 V
- γ-rays, V_{amp} = 370 V

Columnar recombination ?

6 bar

- α-particles, V_{amp} = 280 V
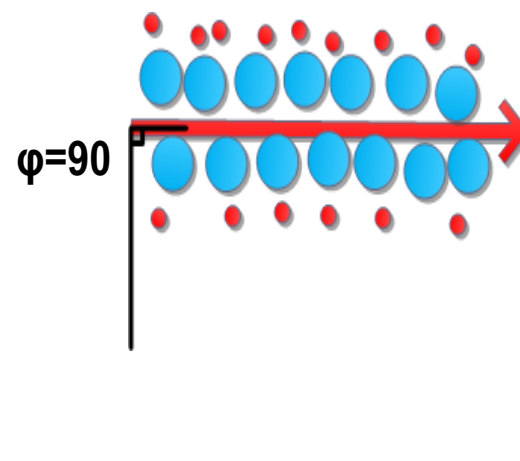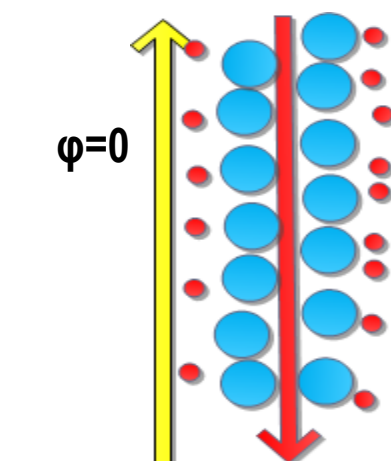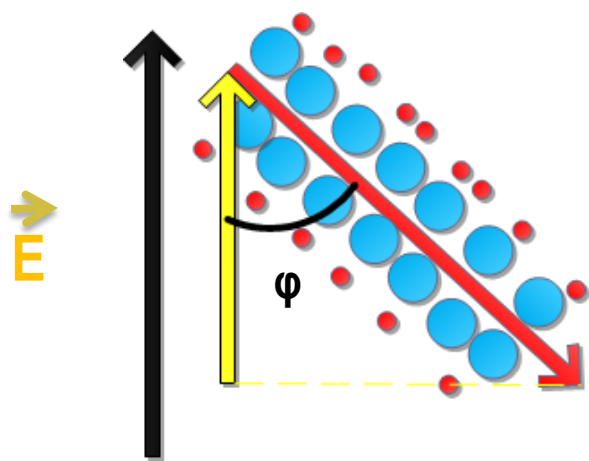- γ-rays, V_{amp} = 390 V

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

E

φ

φ=0

φ=90

$Rise_{max} \rightarrow$ parallel tracks

$Rise_{min} \rightarrow$ perpendicular tracks related with the diffusion

Temporal length of the track

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

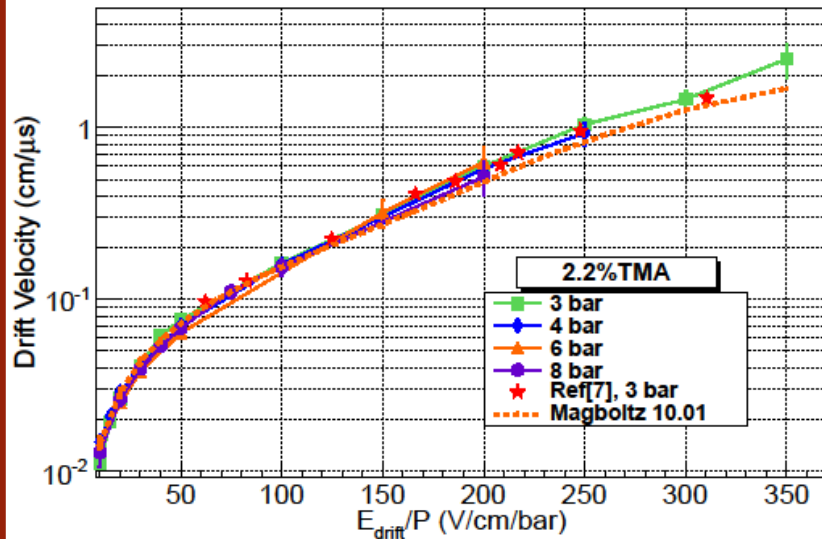Transformation between rise-time and φ

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

Electronic properties
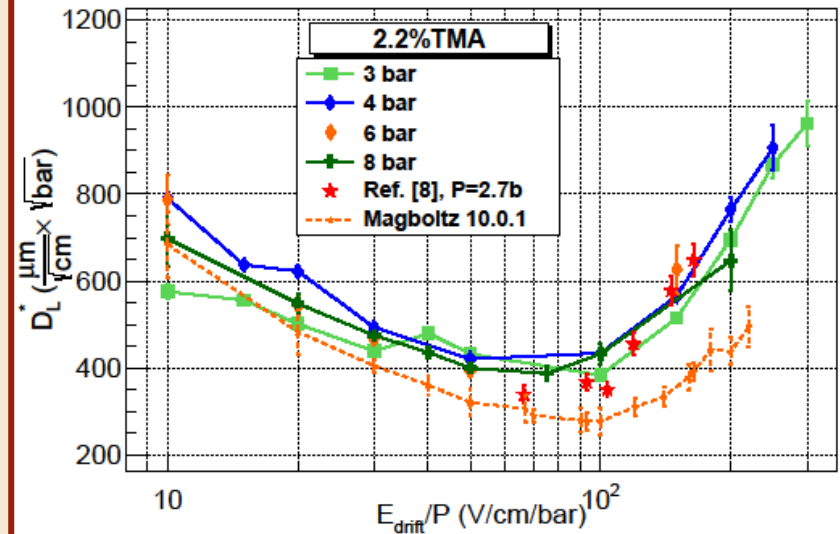
Drift Velocity

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

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

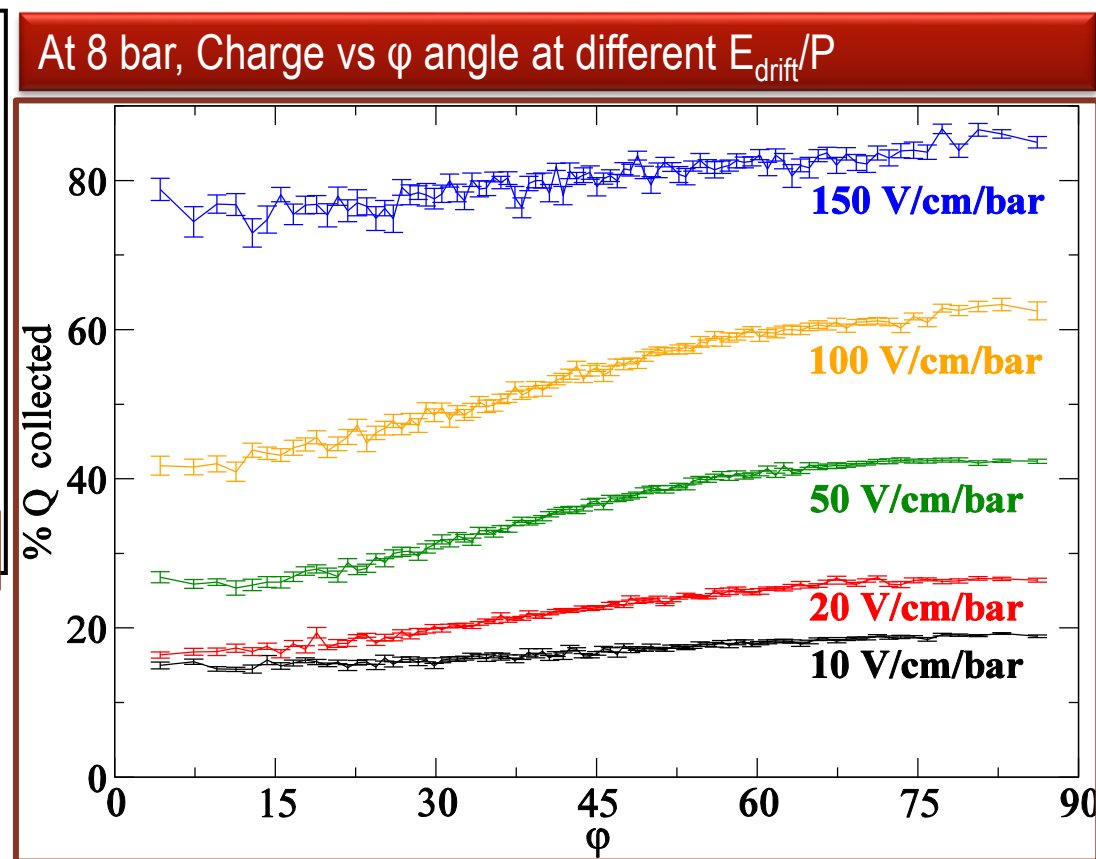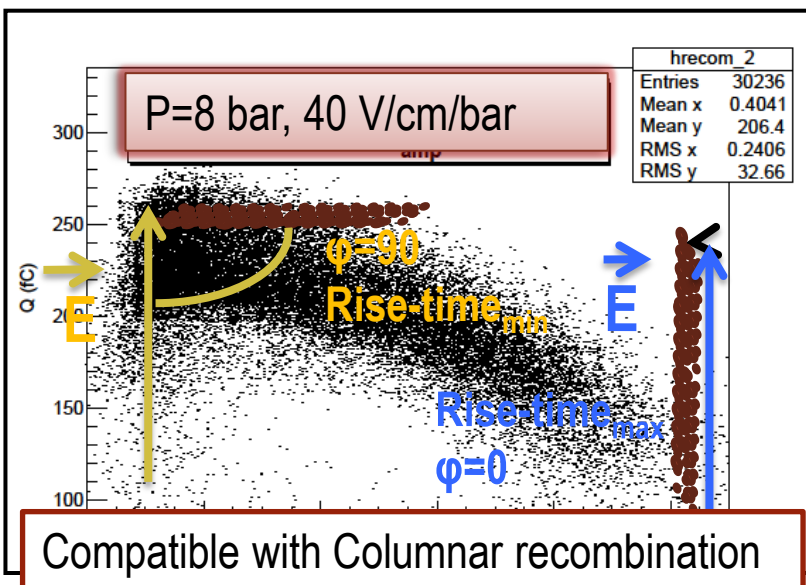### Longitudinal diffusion coefficient

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

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

✓ The PSA as well as the transformation between rise-time and φ are appropriated
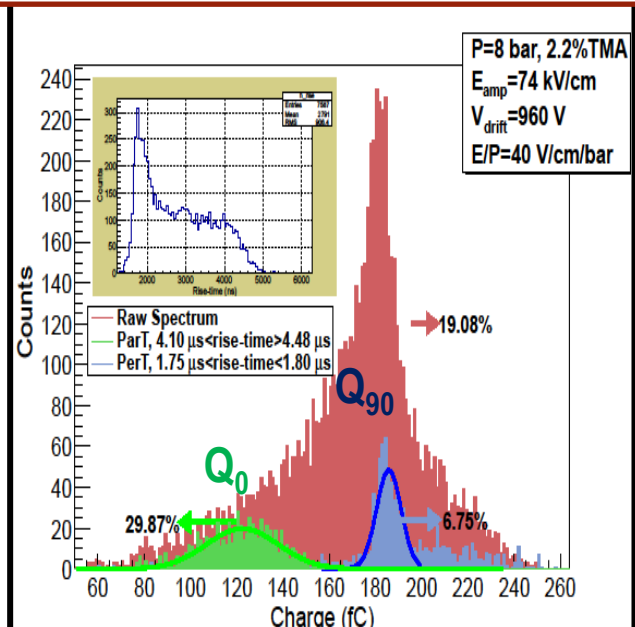
Charge vs φ angle for α-particles

P=8 bar, 40 V/cm/bar

hrecom_2	
Entries	30236
Mean x	0.4041
Mean y	206.4
RMS x	0.2406
RMS y	32.66

φ=90
Rise-time$_{min}$

E

φ=0
Rise-time$_{max}$

E

Compatible with Columnar recombination

P=8 bar, 2.2%TMA
E_{amp}=74 kV/cm
V_{drift}=960 V
E/P=40 V/cm/bar

Raw Spectrum
ParT, 4.10 μs<rise-time>4.48 μs
PerT, 1.75 μs<rise-time<1.80 μs

19.08%

Q_{90}

Q_0

29.87%

6.75%

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

150 V/cm/bar

100 V/cm/bar

50 V/cm/bar

20 V/cm/bar

10 V/cm/bar

% Q collected

φ

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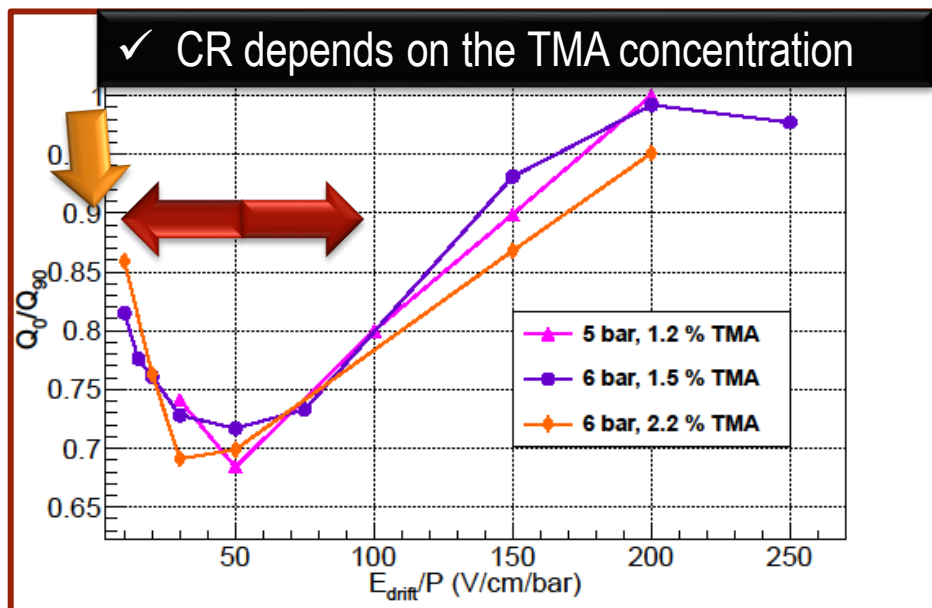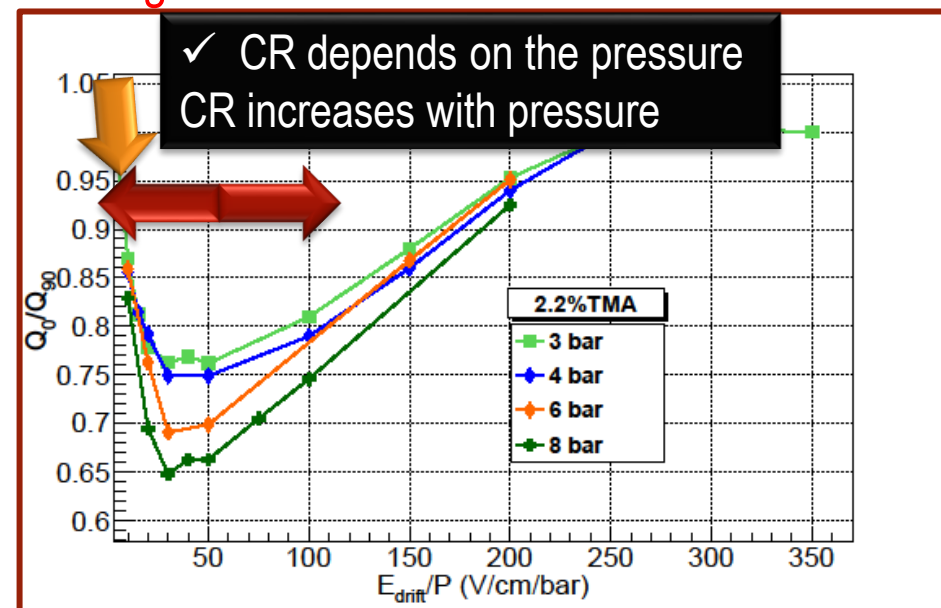
$$r = \frac{Q_0}{Q_{90}}$$

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

2.2%TMA
■ 3 bar
◆ 4 bar
■ 6 bar
■ 8 bar

✓ CR depends on the TMA concentration

▲ 5 bar, 1.2 % TMA
■ 6 bar, 1.5 % TMA
◆ 6 bar, 2.2 % TMA

This effect could be produced **by recombination in the amplification region.**

- Dependency with the track angle, P, and E_{drift}
- Dependency with gain
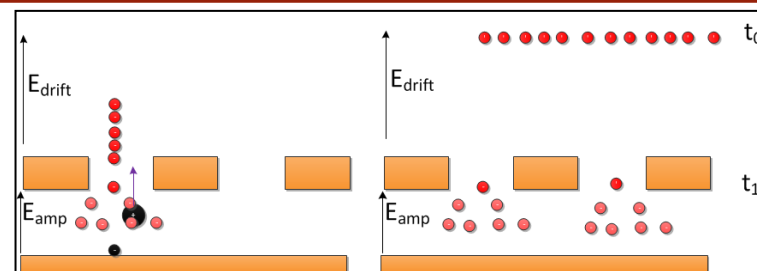
Outline

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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Diana Carolina Herrera Muñoz

Lawrence Berkeley group

Lawrence Berkeley Lab group
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Azriel Goldzmith
Carlos Bastos de Oliveira
Megan Long
Josh Renner

Columnar Recombination in Xe+TMA mixtures using MM-TPC

BUCK UP SLIDES

Data analysis for α-particles

Pulse Shape Analysis

.

Procedure

1. higher frequencies suppressed via FFT analysis
Pulses parameters are calculated to use as input

2. parameters in the Fit
Fit of the filtered pulse is calculated

3.

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

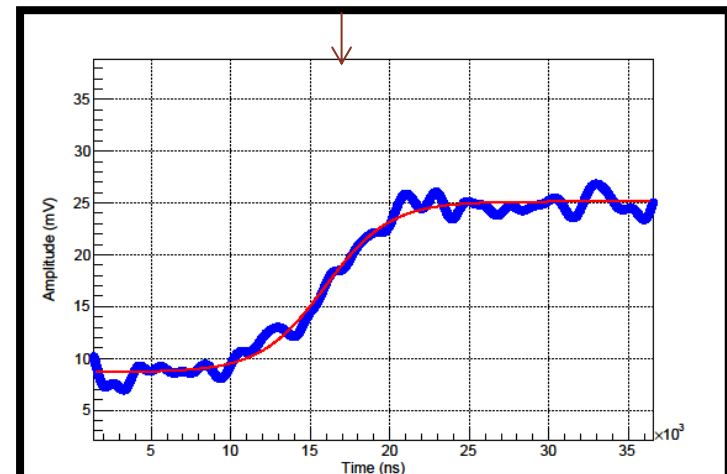Pulse-height and rise-time are obtained

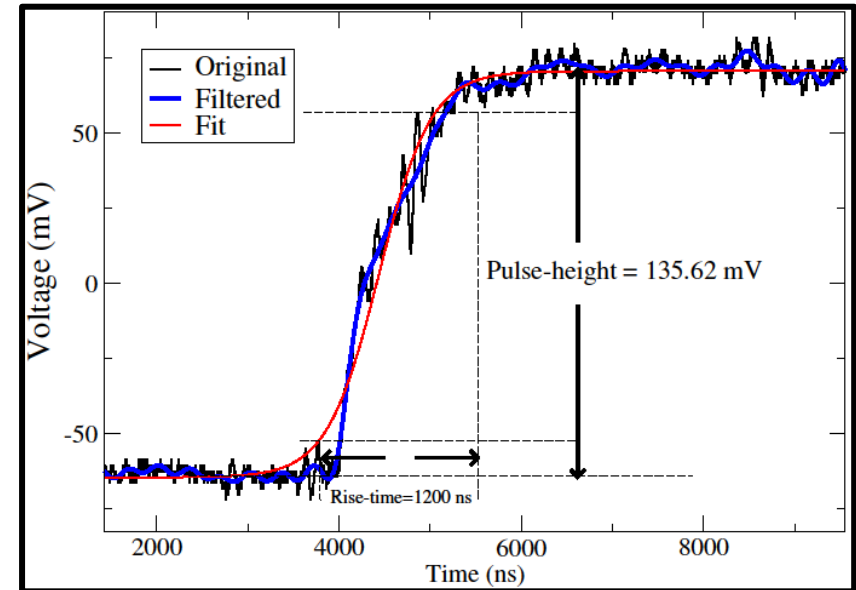4. from the fit function pulse

Htot= Pulse- height
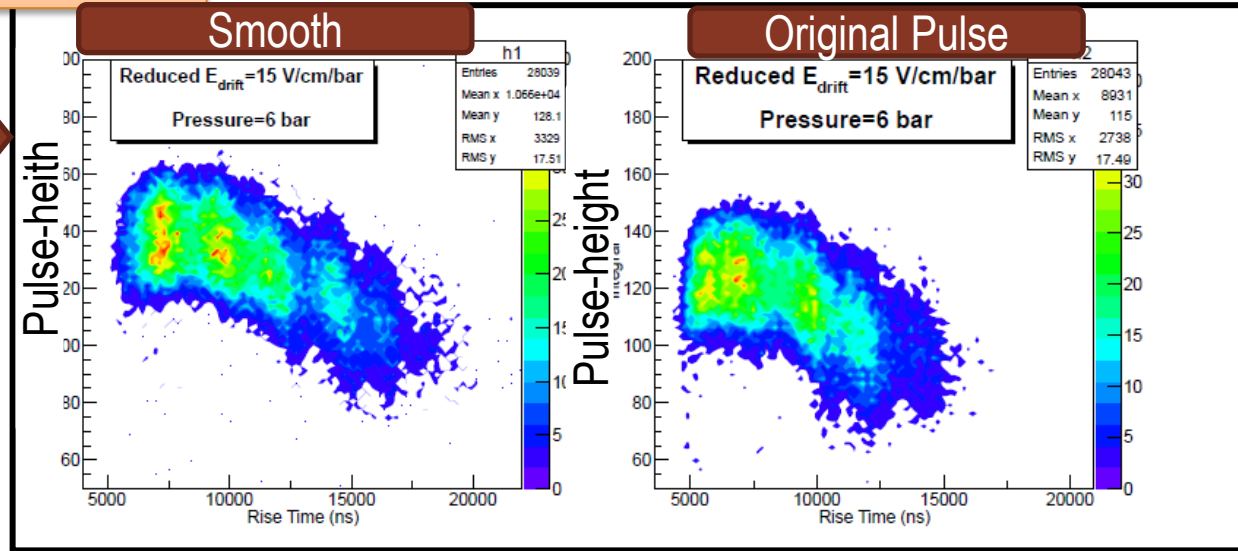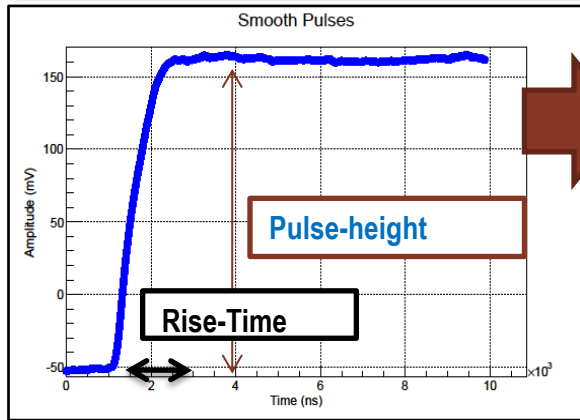**Rise-time** = t_{90}-t_{10}

With this procedure:
- Better estimation of rise-time and p-height
- Improve the energy resolution
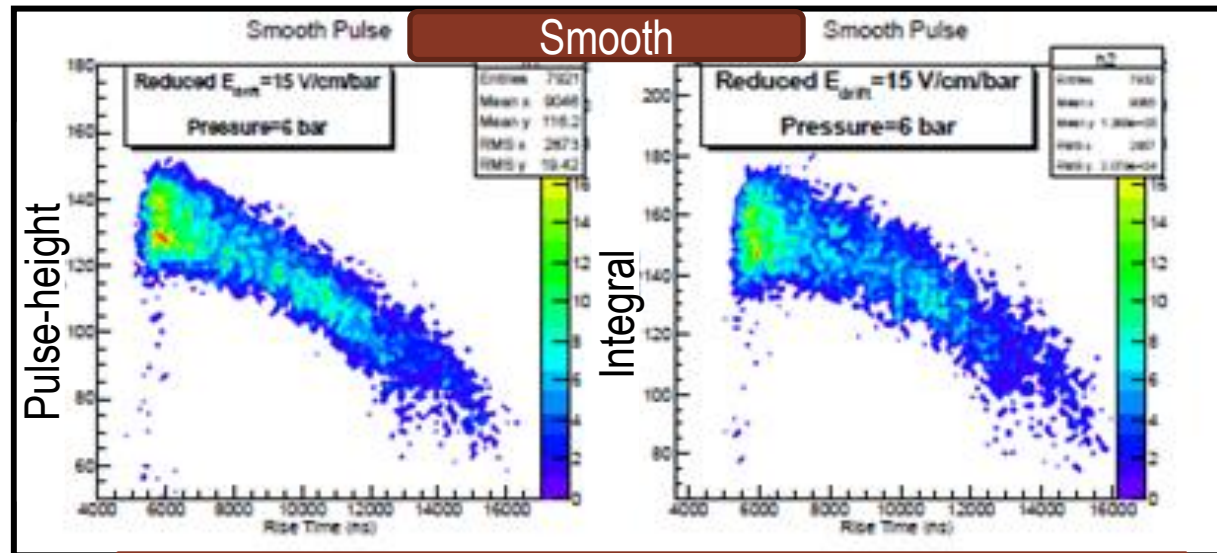
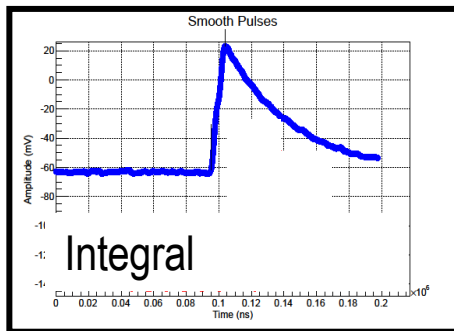High frequency noise suppressed

Columnar Recombination in Xe+TMA mixtures using MM-TPC

Ballistic effect

Acquired with Ortec preamplifier

Acquired with Canberra Preamplifier

Ballistic effect discarded

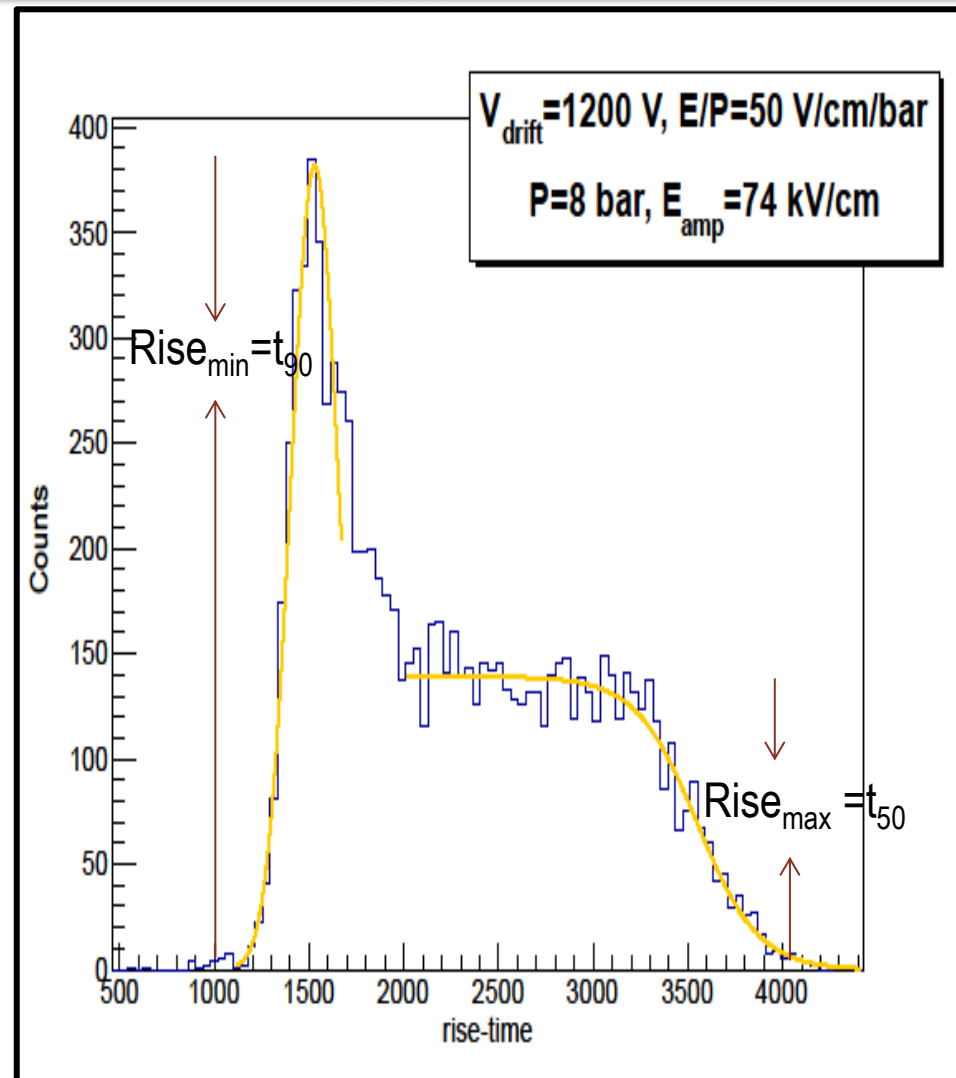Columnar Recombination in Xe+TMA mixtures using MM-TPC

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$_{min}$
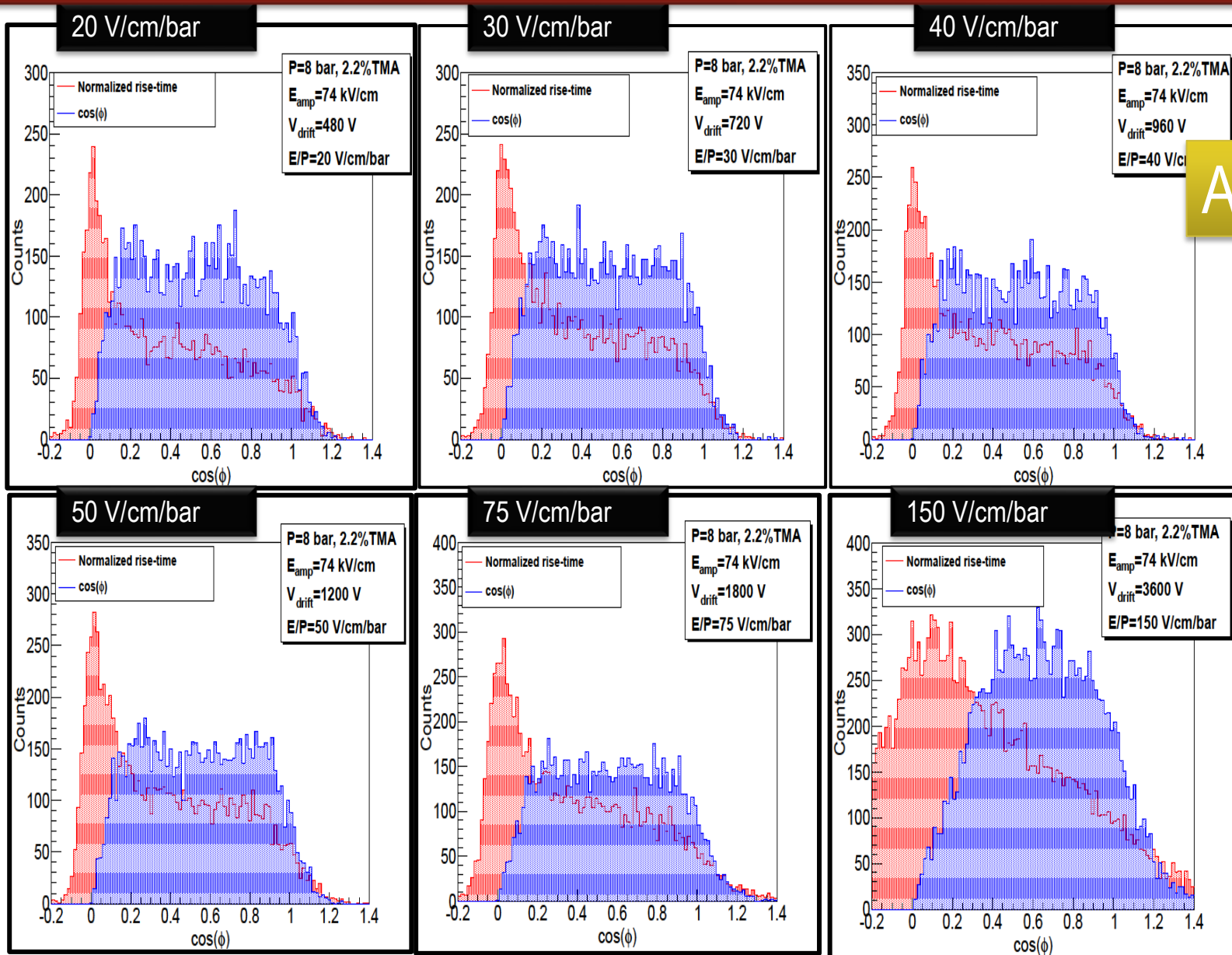Error: σ from Gaussian fit.

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}

V_{drift}=1200 V, E/P=50 V/cm/bar

P=8 bar, E_{amp}=74 kV/cm

Rise$_{min}$=t_{90}

Rise$_{max}$ =t_{50}

This a typical rise-time distribution at low drift fields

Columnar Recombination in Xe+TMA mixtures using MM-TPC

Charge vs φ angle for α-particles

20 V/cm/bar

P=8 bar, 2.2%TMA
E_{amp}=74 kV/cm
V_{drift}=480 V
E/P=20 V/cm/bar

30 V/cm/bar

P=8 bar, 2.2%TMA
E_{amp}=74 kV/cm
V_{drift}=720 V
E/P=30 V/cm/bar

40 V/cm/bar

P=8 bar, 2.2%TMA
E_{amp}=74 kV/cm
V_{drift}=960 V
E/P=40 V/cm/bar

At 8 bar

50 V/cm/bar

P=8 bar, 2.2%TMA
E_{amp}=74 kV/cm
V_{drift}=1200 V
E/P=50 V/cm/bar

75 V/cm/bar

P=8 bar, 2.2%TMA
E_{amp}=74 kV/cm
V_{drift}=1800 V
E/P=75 V/cm/bar

150 V/cm/bar

P=8 bar, 2.2%TMA
E_{amp}=74 kV/cm
V_{drift}=3600 V
E/P=150 V/cm/bar

Normalized rise-time
cos(φ)

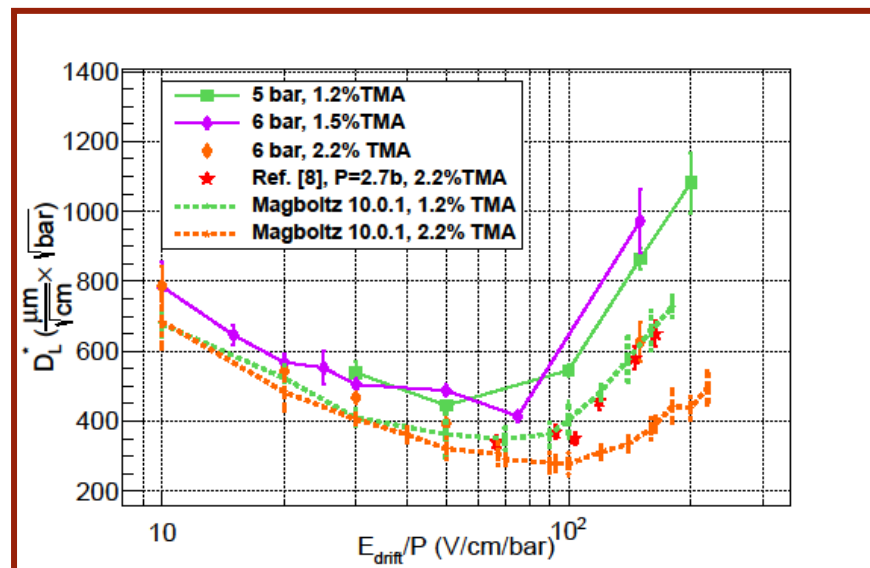Columnar Recombination in Xe+TMA mixtures using MM-TPC

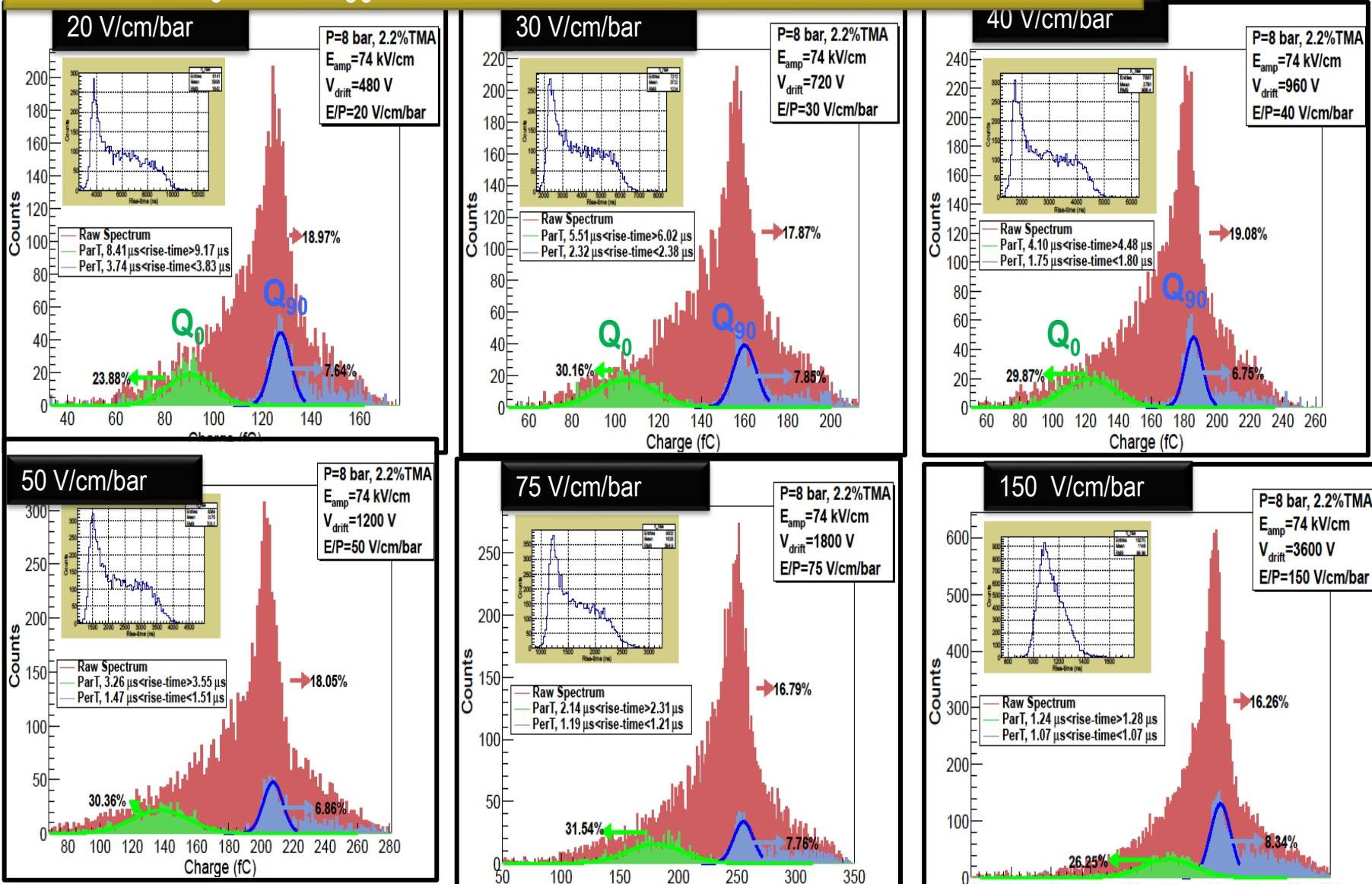# Charge vs φ angle

Drift Velocity

Variation with the percentage of TMA

Longitudinal diffusion coefficient

Charge vs φ angle for α-particles

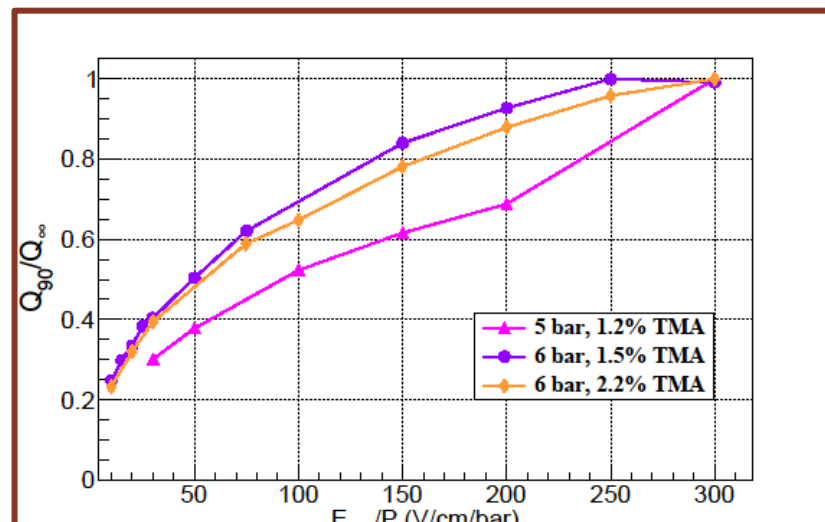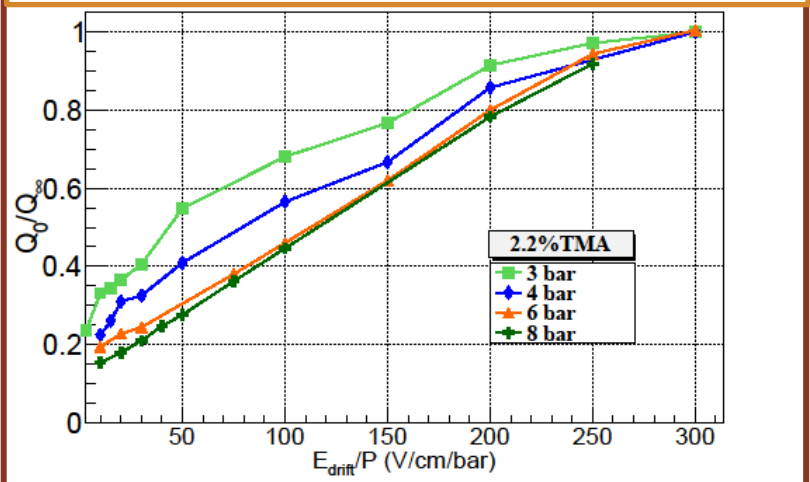## At 8 bar, Q_0 and Q_{90} distributions at different RDF

Columnar Recombination in Xe+TMA mixtures using MM-TPC

Charge vs φ angle for α-particles

Q_0 and Q_{90}
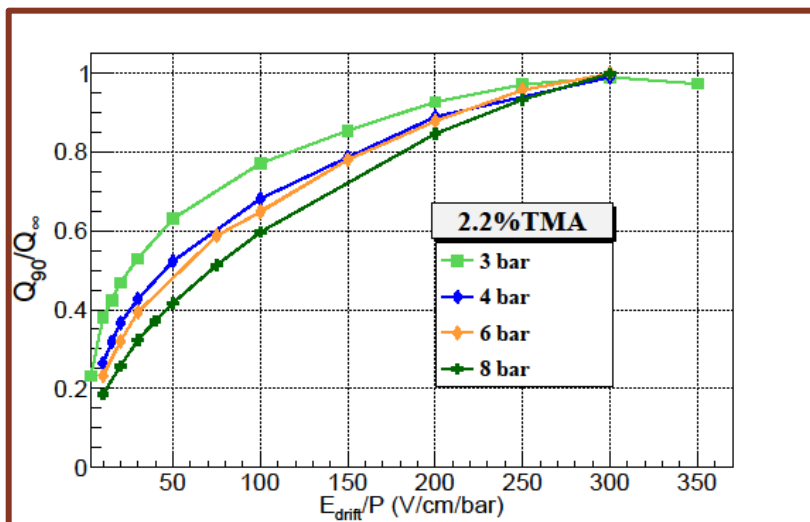
- Systematic behavior with pressure

- Dependency with the %TMA

Columnar Recombination in Xe+TMA mixtures using MM-TPC
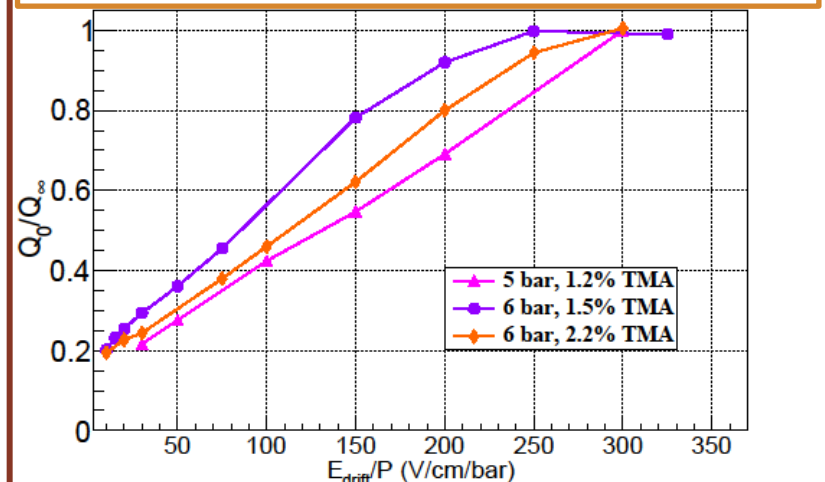
Xe-TMA properties in a nut-shell
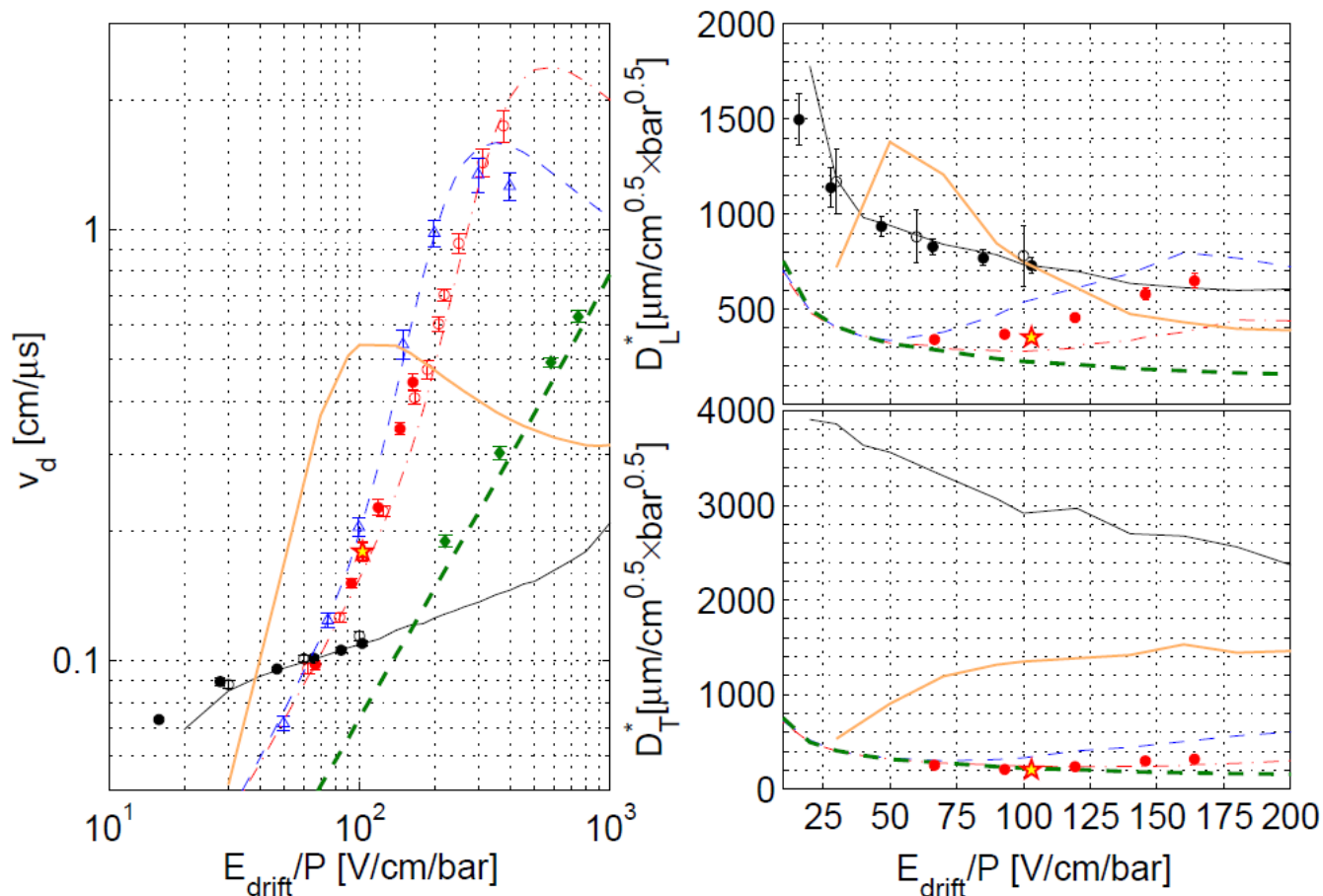
Jaffé theory

- 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)

Legend:
- E/P=20 V/cm/bar, k= 16e-8, L=0.27 cm
- E/P=50 V/cm/bar, k= 16e-8, L=0.27 cm

y-axis: % charge survive
x-axis: φ (degrees)

Preliminary