STUDIES OF SIGNAL FORMATION IN T2K ERAMS

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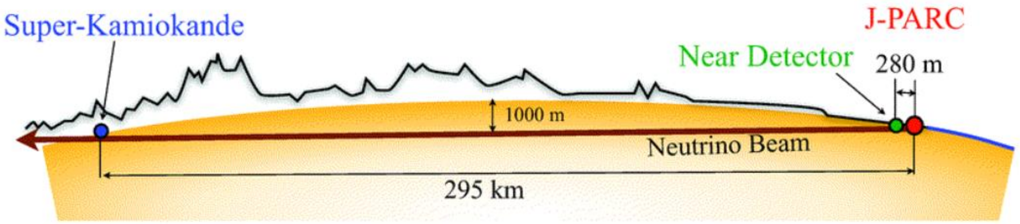
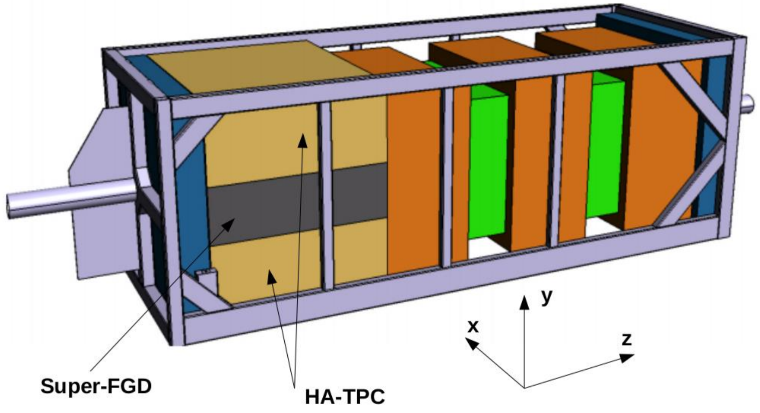
14/10/2024

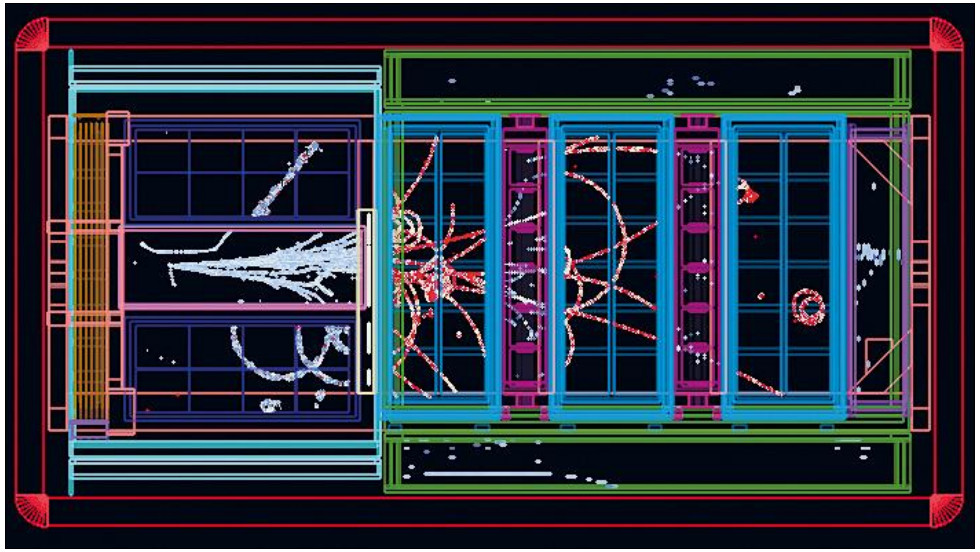
T2K EXPERIMENT



T2K is a long baseline experiments that studies neutrino oscillation parameters via:
> ν_μ disappearance
> ν_e appearance



For T2K phase II, both the beamline and the near detector underwent a major upgrade.

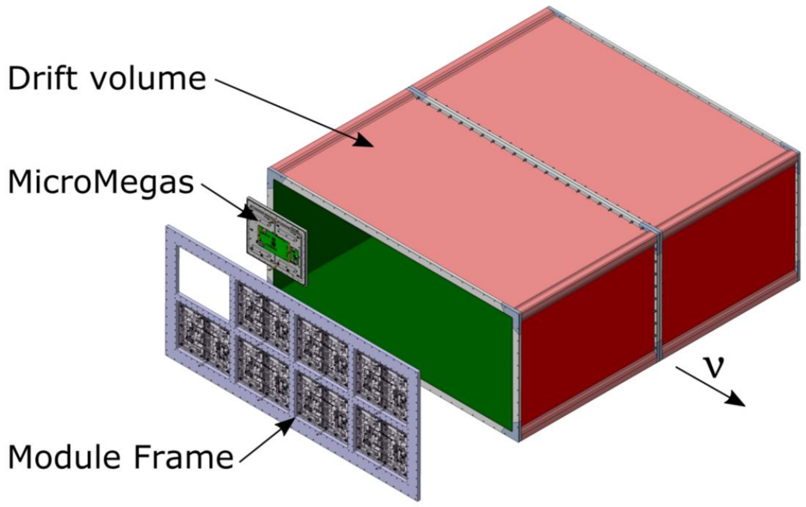


The detector upgrade, completed in May 2024 consists in
> Super Fine Grain Detector(SFGD) - active target
> Two High Angle TPCs (HATPC)
> Time of Flight scintillators (TOF)

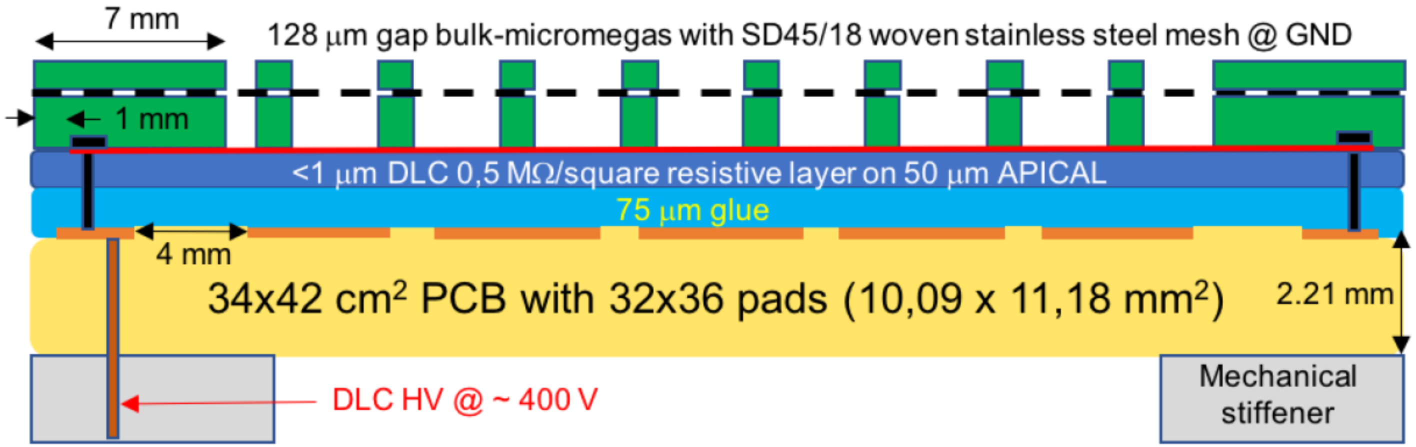
See S. Levorato's talk on Thursday

Encapsulated Resistive Anode Micromegas

The HATPC are equipped with 16 Encapsulated Resistive Anode Micromegas (ERAMS)
The resistive layer allows to achieve good spatial resolution ($\sim 500\ \mu m$) with a large pad size ($\sim 1 \times 1\ cm^2$)
The resistive layer protects against discharges

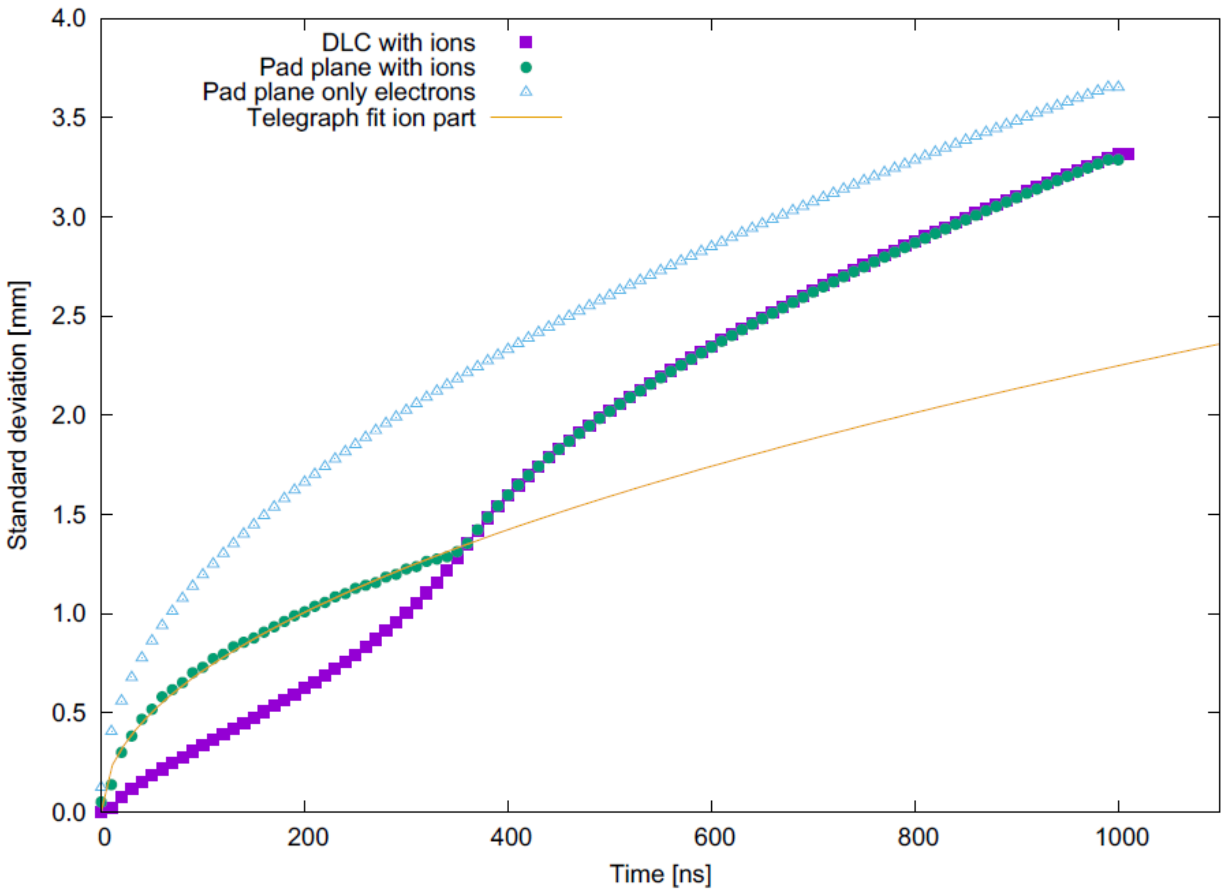


DLC nominal resistivity 400 $k\Omega/square$
stainless steel woven mesh
Wire diameter 18 μm
Mesh pitch 45 μm
Gap size (nominal) 128 μm



ERAMS are operated with a gas mixture of
95 % Ar
3 % CF_4
2 % iC_4H_{10}

THE SHEPHERD DOG EFFECT



The presence of ions in the amplification gap impacts on the charge spread on the resistive layer

A numerical simulation to model the charge spread in the DLC was done.

The evolution of the standard deviation of the charge distribution is followed over time.

Ion effect on the readout pad (green dots) is modeled adding a charge distribution of positive charges that drifts in the amplification gap.

Master thesis of L. Scomparin, University of Padova

ION DRIFT VELOCITY MEASUREMENTS

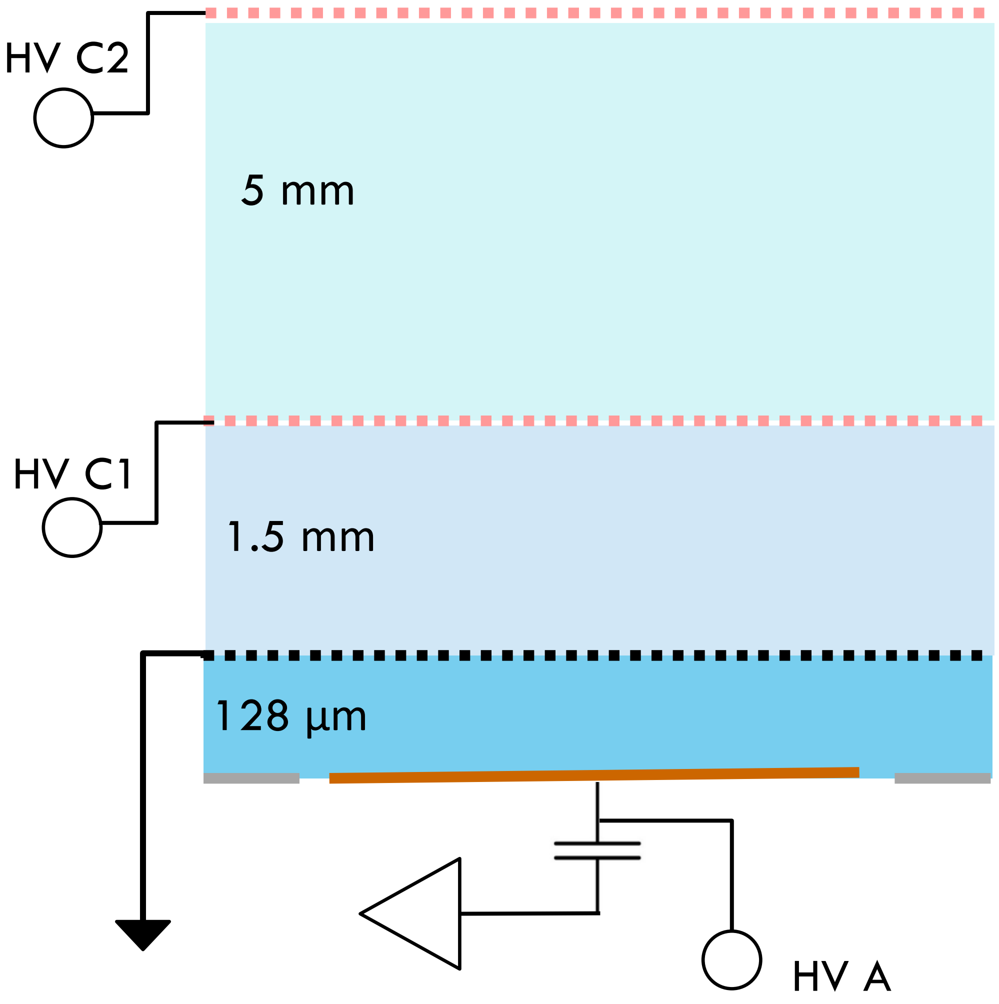
A crucial input to the simulation is the ion drift velocity.

Direct measurements were done using a single pad Micromegas (thanks to GDD lab)

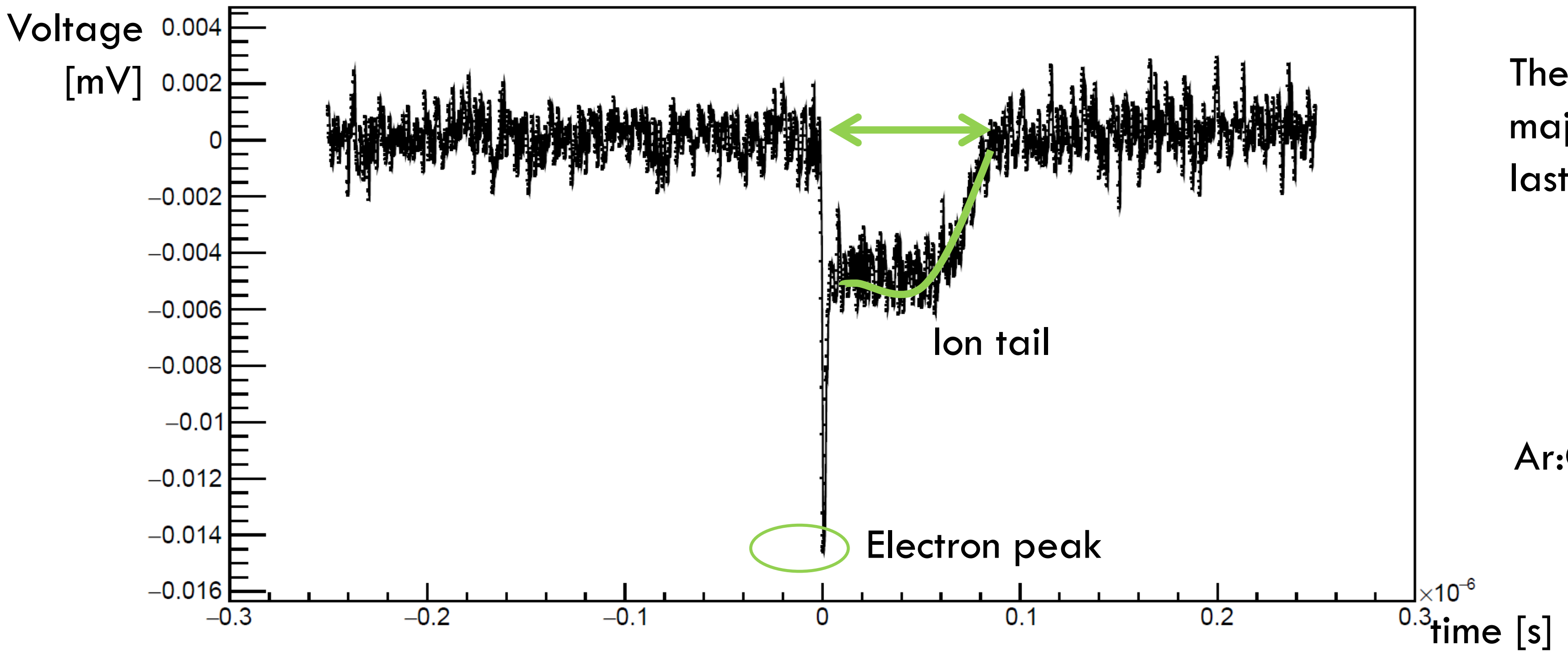
Single, non resistive, pad
stainless steel woven mesh
Wire diameter 18 μm
Mesh pitch 45 μm
Gap size (nominal) 128 μm

Fast front end electronics used to distinguish the different signal components (electrons + ions)
> Cividec Broadband Diamond Amplifier (datasheet here)
> Picosec fast current amplifier (custom design)

Source: 55Fe



ION DRIFT VELOCITY MEASUREMENTS



The measurement assumes that the majority of the ions are produced in the last mean free path.

Ar:CO2 93:7

The time of the ion production, then, is the arrival time of the electron signal, the time of the ion collection at the mesh is the end point of the signal.
The ion drift time is the difference between the two.

Measurements were done with T2K gas mixture and with Ar:CO2 93:7 to compare with existing measurement (D. Janssens, presented at RD51 CM June 2023)

ION DRIFT VELOCITY MEASUREMENTS

Signals of T2K gas are quite different in shapes from the control mixtures (Ar:CO2 93:7 and picosec mixture)

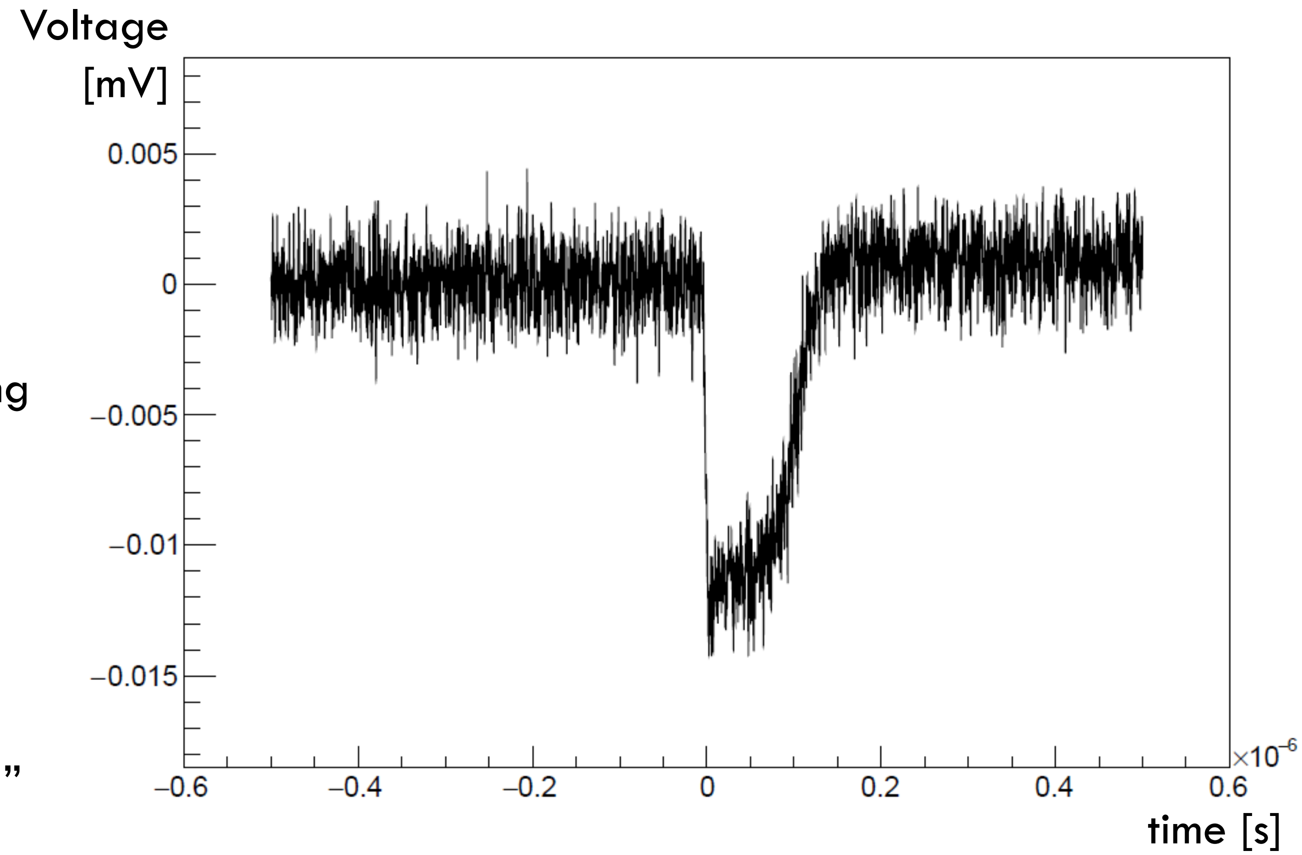
Absence (almost) of electron peak → under investigation

Signals were fitted with a smeared step both for the falling edge and for the rising edge:

$$f_{fall}(t) = A \cdot \frac{1}{1+e^{-\lambda(t-t_0)}}$$

$$f_{rise}(t) = A \cdot [1 - \frac{1}{1+e^{-\lambda(t-t_0)}}]$$

The start time is the time for which the 95% of the “falling” amplitude is reached.
The end time is the time for which the 95% of the “rising” amplitude is reached

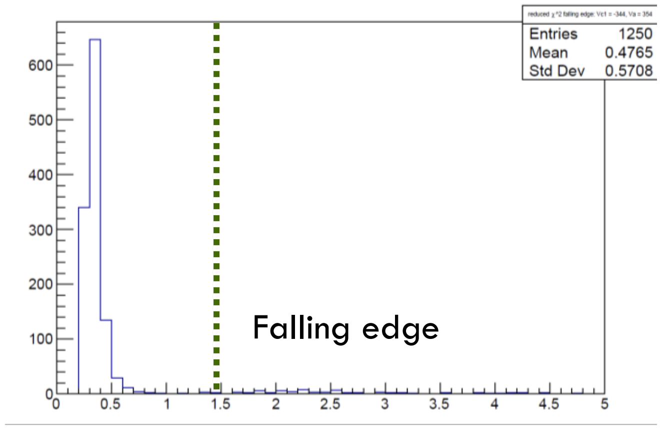


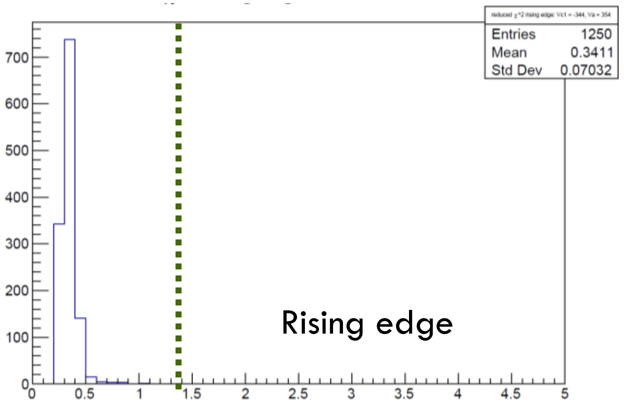
ION DRIFT VELOCITY MEASUREMENTS

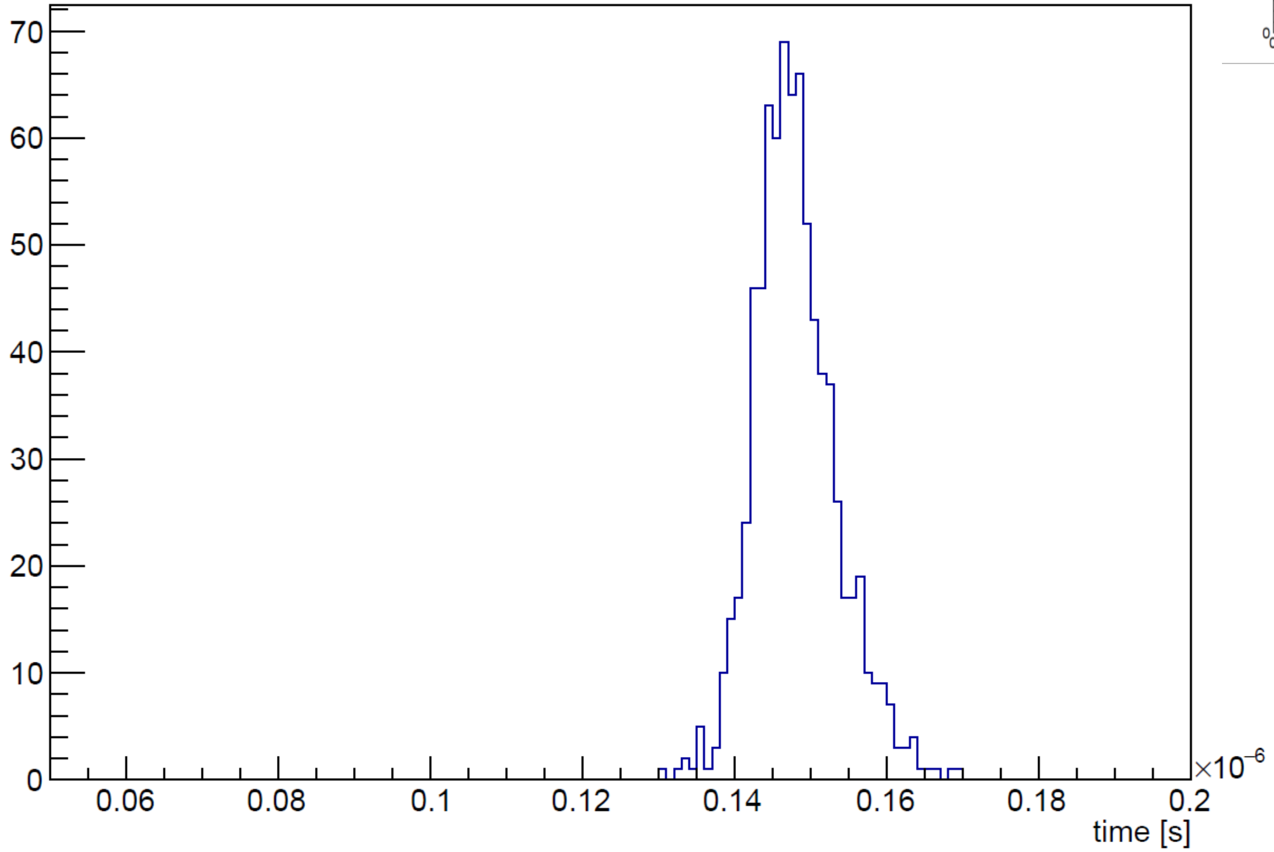
Few basic cuts are done on the fitted waveforms:

> $\frac{\chi^2}{NDF} < 1.5$ for falling edge and rising edge fits

> Negative amplitude A







Distribution of the measured ion drift times at:
$Va = 350\,V$

The distribution is fitted with a Gaussian curve,
Resulting mean Ion Drift Time

$t = 147.8 \pm 0.2\, ns$
$\sigma = 4.7 \pm 0.2\, ns$

ION MOBILITY

From the computed ion drift time we can estimate the ion mobility as

$$\mu = \frac{w^+}{E}$$

under this assumption:

> The amplification gap is 0.0128 cm (nominal value, to be measured)

>

In T2K gas mixture, for $E_a = 27.3\ kV/cm$

$$\mu = 2.7 \pm 0.1 \frac{cm^2}{V \cdot s}$$

A comparison with existing data is not straightforward, as we cannot say which ions are moving in the gas mixture.
A rough estimate can be done by considering Ar^+ ions moving in the gas mixture

$$\frac{1}{\mu_{Ar^+}} = \frac{f_{Ar}}{\mu_{Ar^+;Ar}} + \frac{f_{CF_4}}{\mu_{Ar^+;CF_4}} + \frac{f_{iC_4H_{10}}}{\mu_{Ar^+;iC_4H_{10}}}$$

$$\mu_{Ar^+;T2Kgas} \simeq 1.3 \frac{cm^2}{V \cdot s}$$

Ion mobilities are quoted from:
F. Sauli, *Gaseous Radiation Detectors, Fundamentals and Applications*, Cambridge University Press
Z. Nikitovic et al, *Rate Coefficients of* Ar^+ *Ions in* Ar/CF_4 *Mixtures*, Acta Physica Polonica A, 134 (2018)

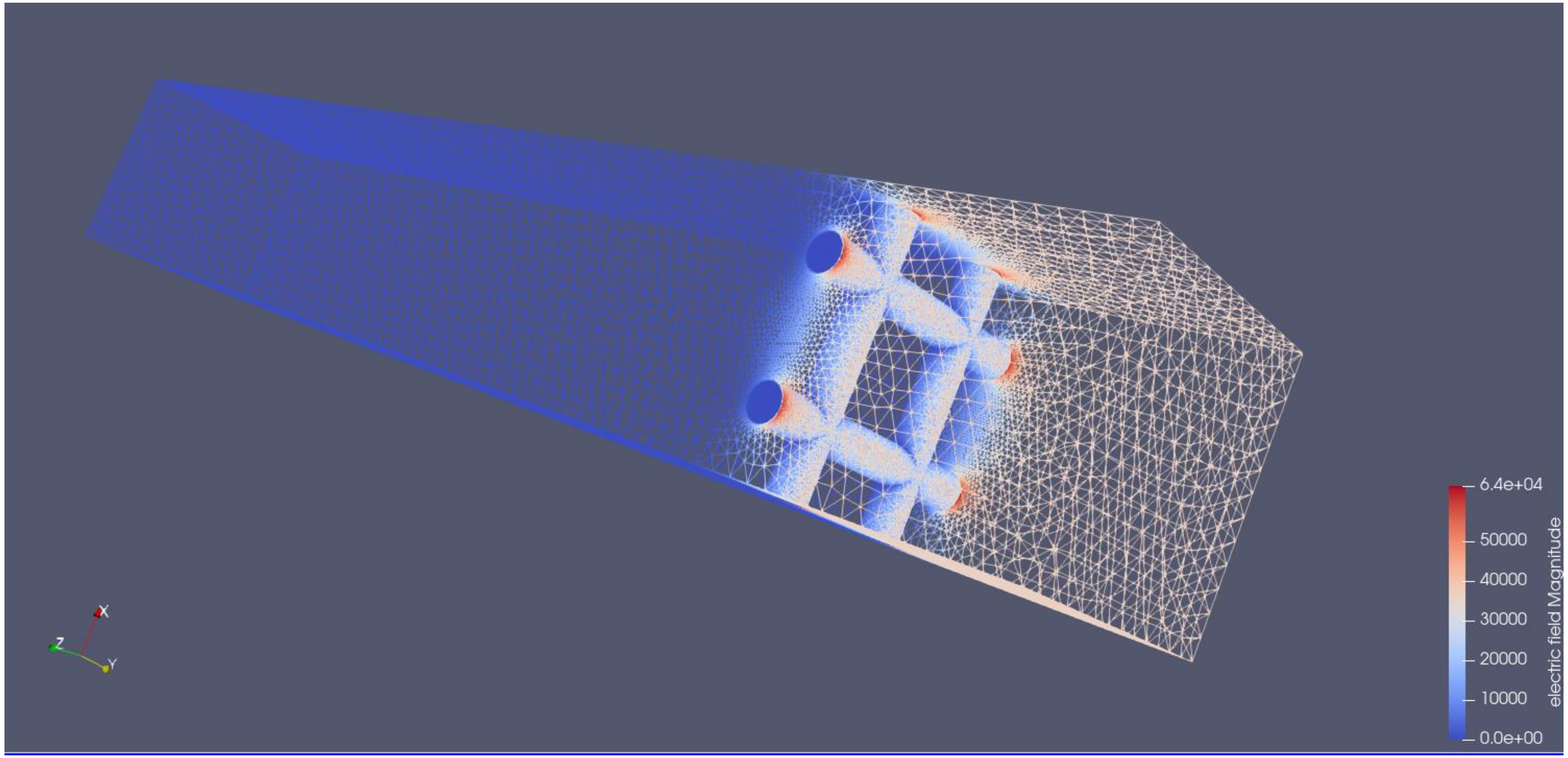
MONTE CARLO SIMULATION

The ion mobility is also an important parameter for Monte Carlo Simulation of the ERAMs.

A MC framework is installed on local cluster

Open-source software (gmsh, ElmerSolver, Garfield++)

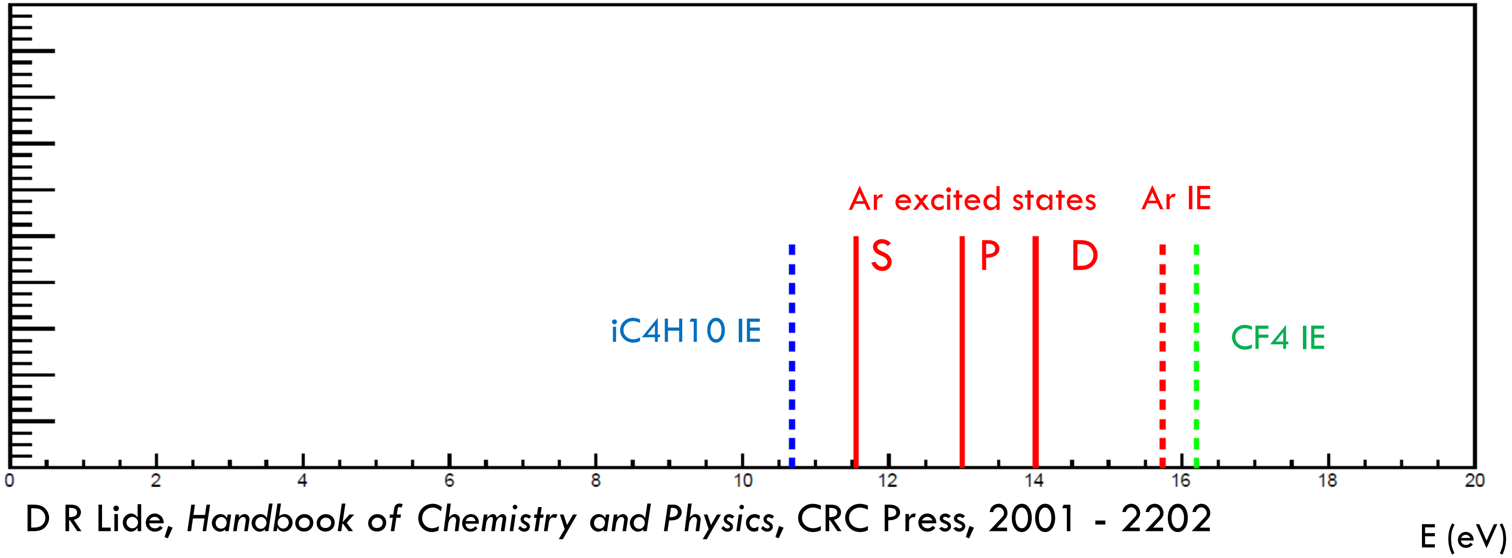
PRELIMINARY STUDIES:
The mesh is made of intersecting cylinders (not woven)



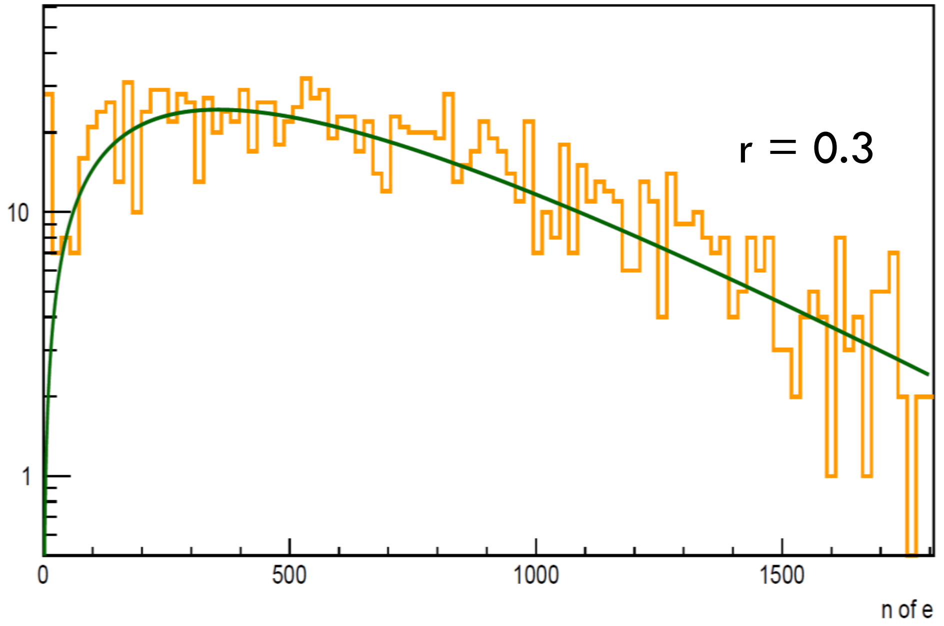
PENNING TRANSFER IN T2K GAS

The Penning transfer probability, crucial parameter for an accurate description of the avalanches, is not known for T2K gas.

$$Ar^* \rightarrow \ Ar + iC_4H_{10}^+ \ + \ e^-$$



D R Lide, *Handbook of Chemistry and Physics*, CRC Press, 2001 - 2202



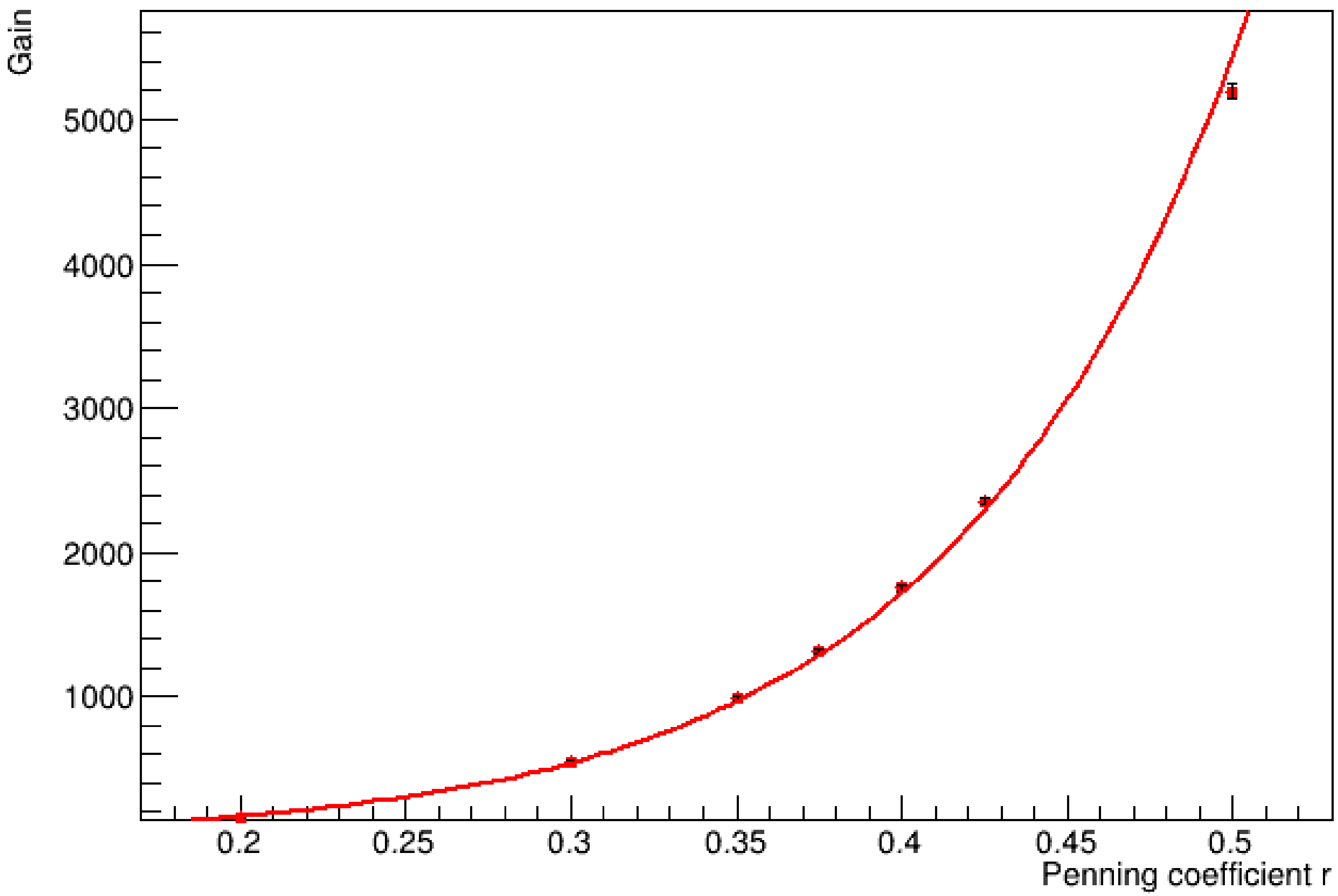
Empirical determination of the Penning r:
Comparison between measurements of gain and MC simulations with fixed Penning r

The number of electrons in the avalanche is fitted with a Polya distribution:

$$P(N_e) = \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{N_e}{\overline{N_e}}\right) \exp\left[-(1+\theta)\frac{N_e}{\overline{N_e}}\right]$$

to obtain the mean number of electrons in an avalanche

PENNING TRANSFER IN T2K GAS - simulation



The mean number of electrons in the avalanche VS the Penning r is fitted with an exponential curve

MC simulations were run at the specific lab conditions:

P = 1012 mbar

T = 21 C

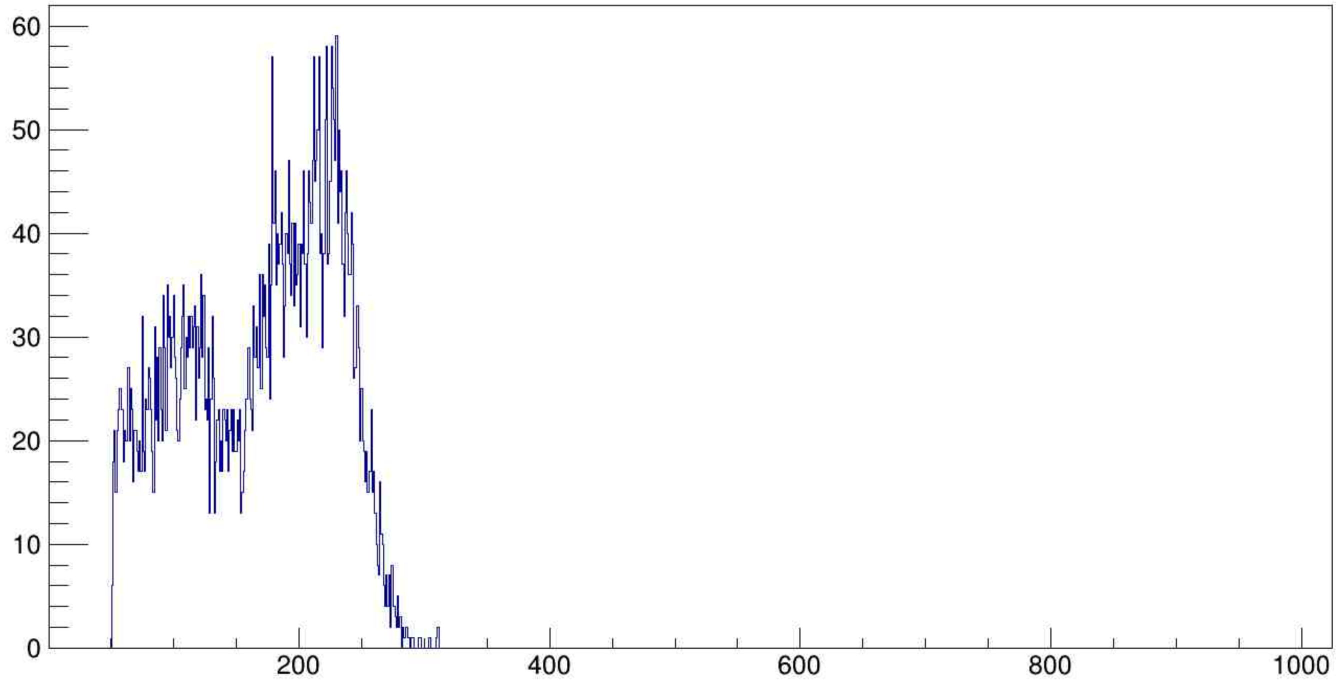
Va = 350 V

Ed = 500 V/cm

GAIN MEASUREMENTS – measurements (preliminary)

Gain was measured using a single pad Micromegas (thanks to GDD lab)

Single, non resistive, pad
stainless steel woven mesh
Wire diameter 18 μm
Mesh pitch 45 μm
Gap (nominal) 128 μm

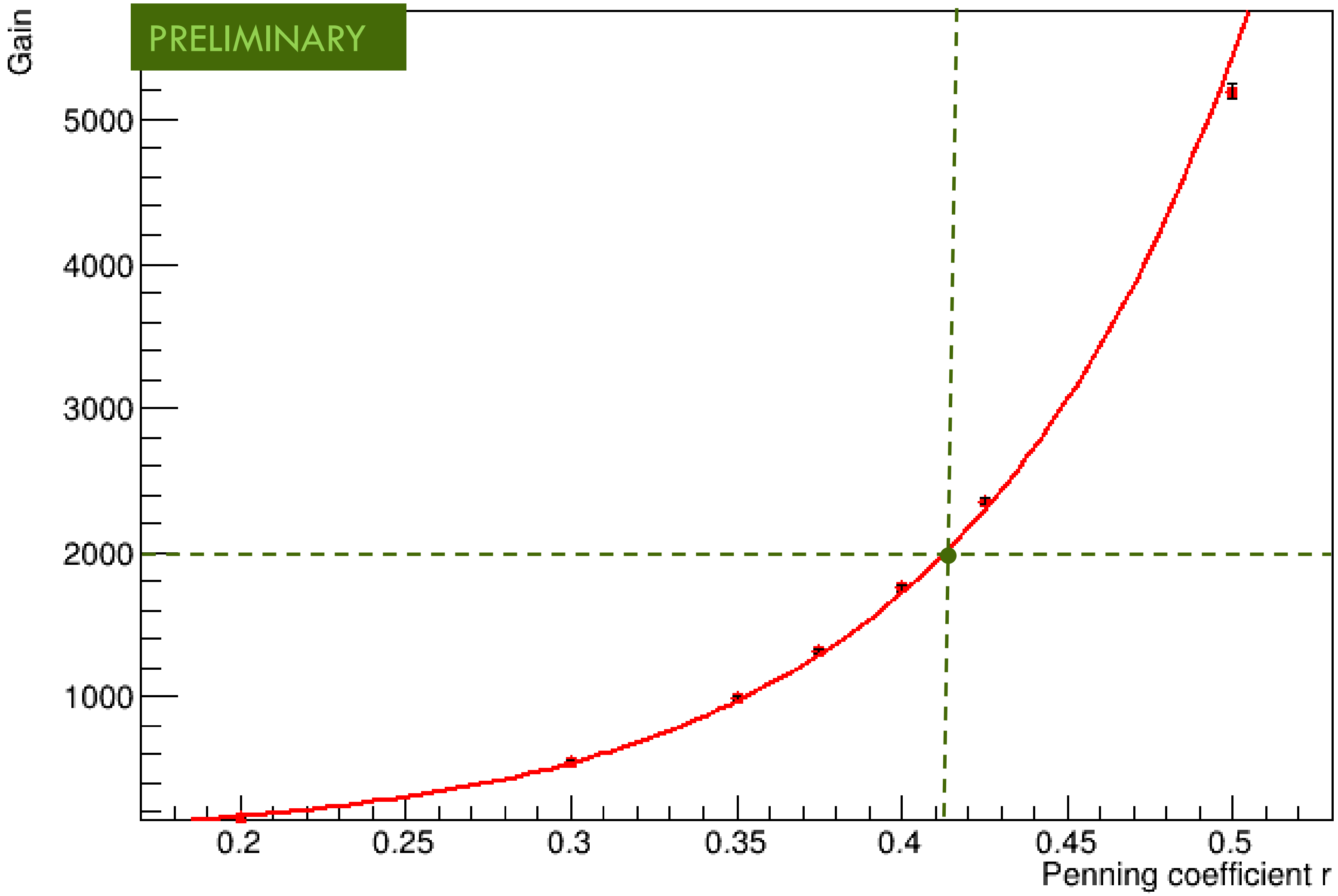


Source: 55Fe
Signals are recorded with a CSA + MCA

The electronic chain is calibrated with a known input charge
The spectrum is fitted to obtain the mean charge at the peak, which corresponds to the 5.9 keV line of 55Fe
Number of primary electrons from the main peak: 232 (estimated for T2K gas)

A more precise method consists in measuring currents but data are not analysed yet.

PENNING TRANSFER IN T2K GAS – data MC comparison



r = 0.41
[more precise results will come]

MC simulations were run at the specific lab conditions:
P = 1012 mbar
T = 21 C
Va = 350 V
Ed = 500 V/cm

The presented result needs to be reproduced for different gas densities and different electric field configurations.

ION DRIFT VELOCITY – FUTURE PERSPECTIVES

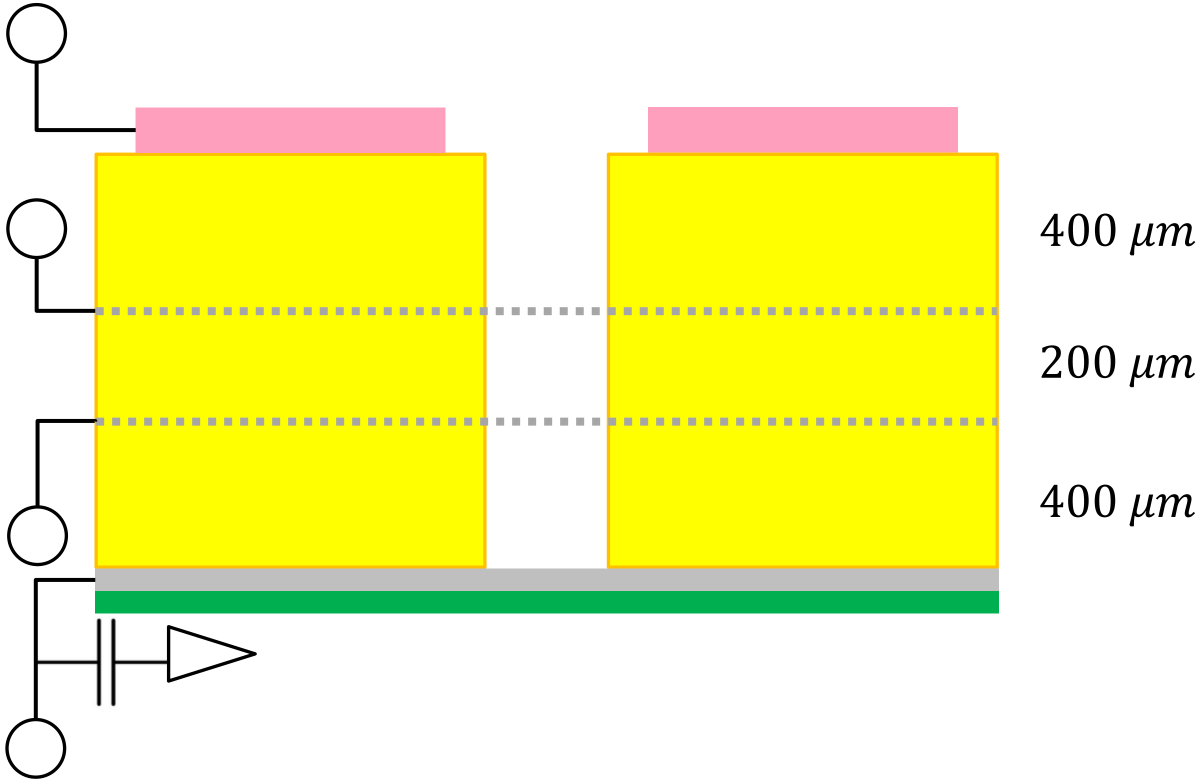
A new detector for the signal generation in T2K gas has been produced and mounted – but not tested yet.

It features a THGEM structure with different hole patterns; embedded in the THGEM, 2 meshes can be independently powered

Read out plane is currently non resistive, the THGEM can be mounted on a DLC sheet as well.

Planned measurement:
> Having an avalanche multiplication between the two meshes, the ions are funneled through the lower one. The expected signal contains only ion contribution

CHALLENGE: transparency is low, we are running Garfield simulations to determine the best voltage configuration



SUMMARY

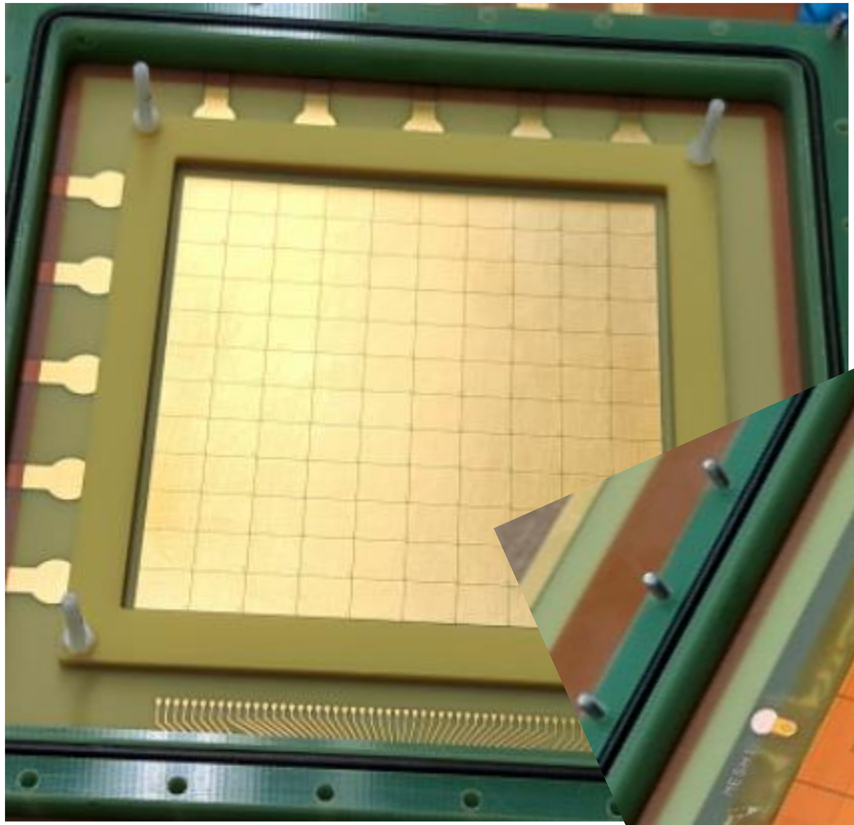
Some important steps have been done in understanding the signal formation in T2K ERAMs

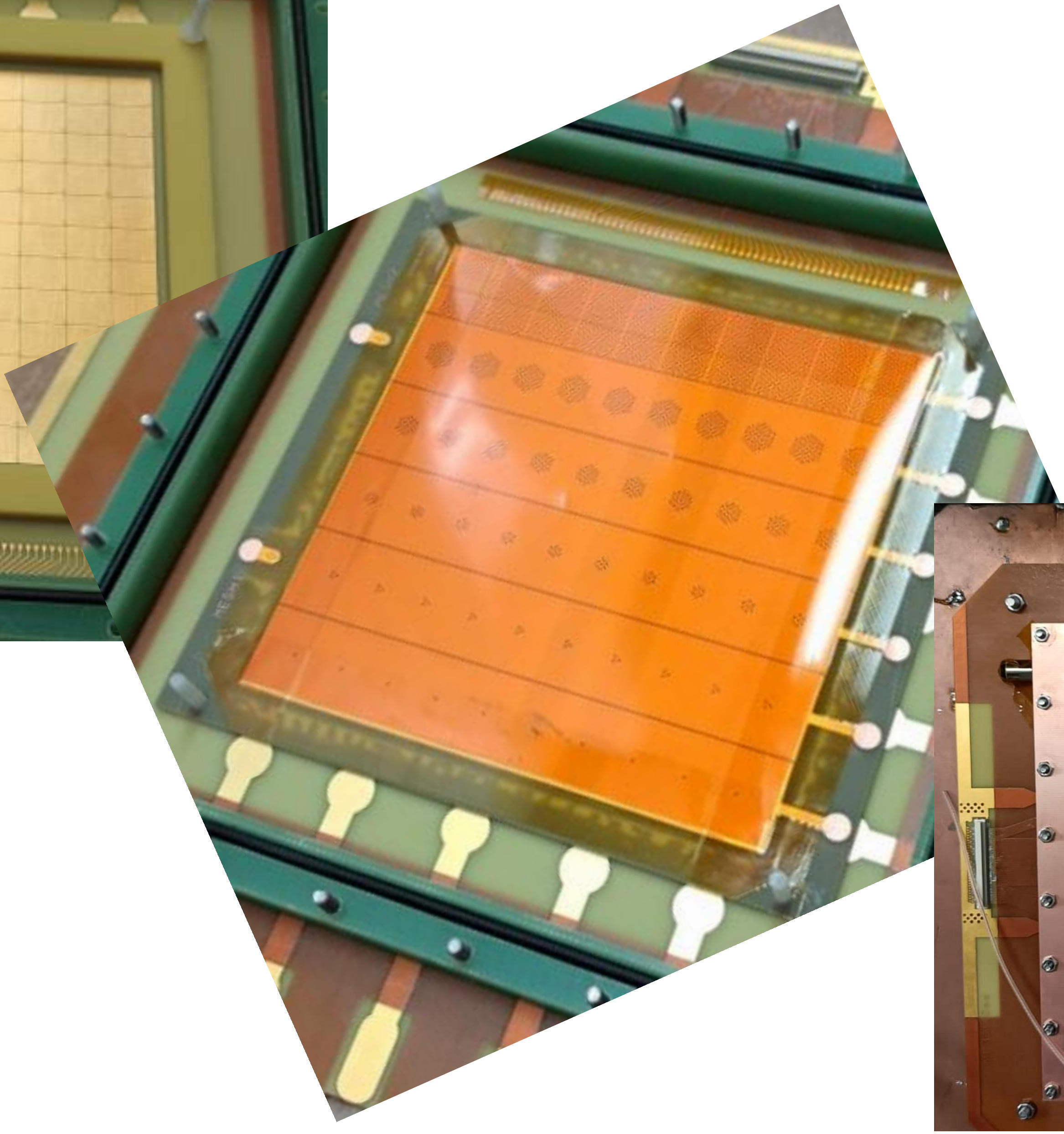
> Ion mobility is measured $\mu = 2.7 \pm 0.1 \frac{cm^2}{V \cdot s}$

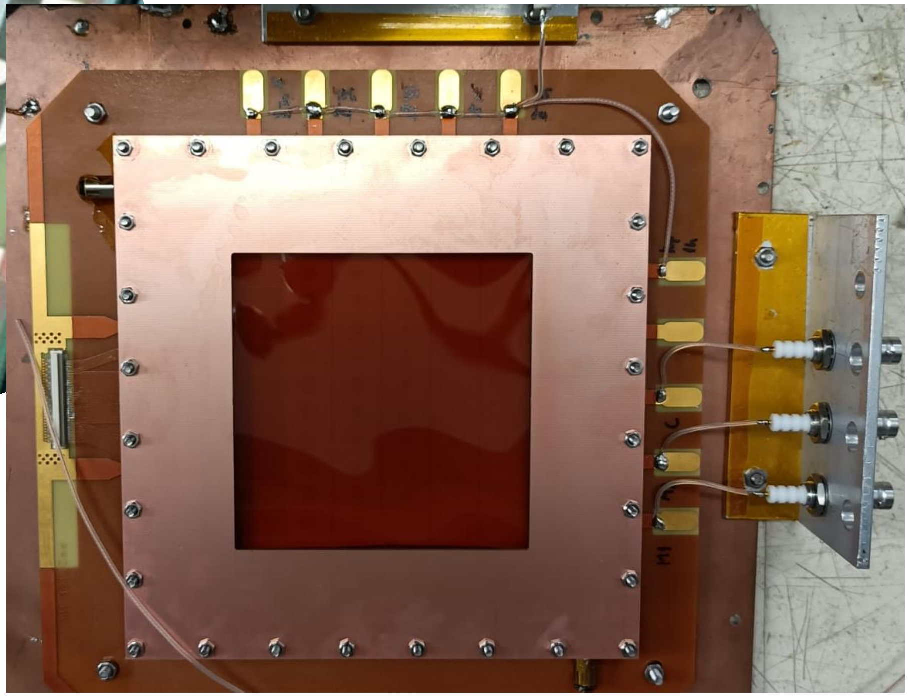
> Penning transfer probability is estimated $r = 0.41$

These results are preliminary but important to provide inputs to numerical computations

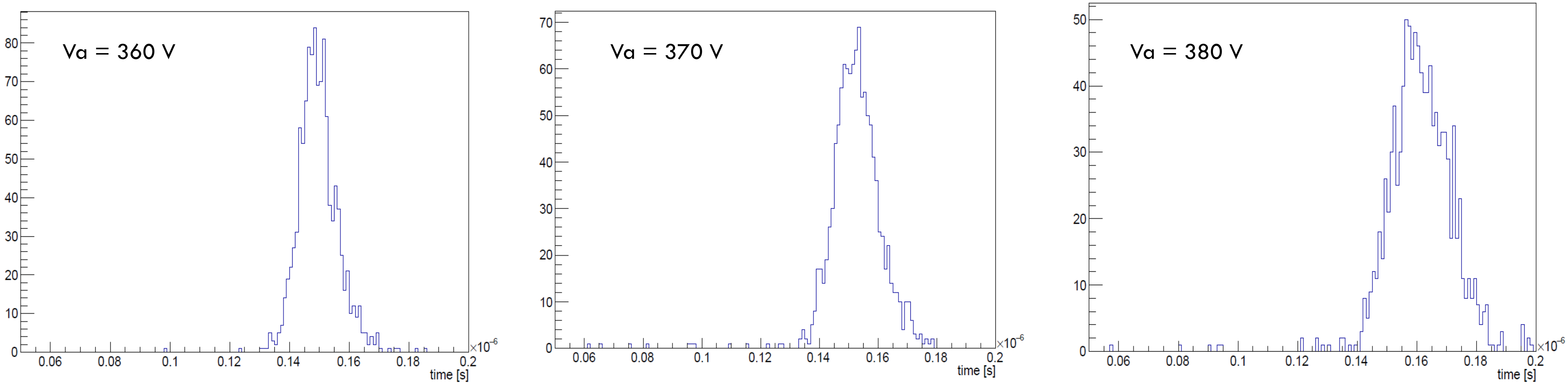
More results are yet to come…







BACKUP – ION MOBILITY AT DIFFERENT Ea



$V_a\ (V)$	$\mu\ (\frac{cm^2}{V \cdot s})$
360	2.6 ± 0.1
370	2.5 ± 0.1
380	2.3 ± 0.1

The ion drift velocity is measured for different amplification fields
Ion mobility is computed for each anodic voltage