Status of field maps
and
space-charge effect simulation & evaluation method

WA105 Collaboration Meeting

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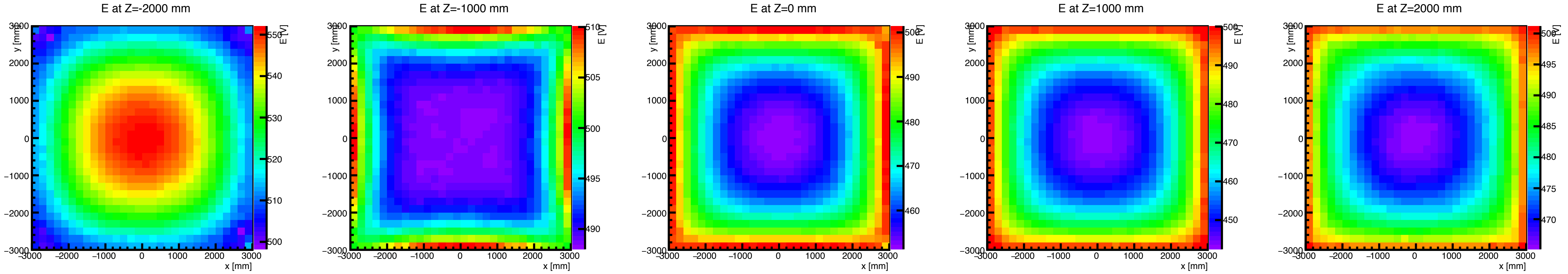
Electric field in the TPC

In order to properly reconstruct the charge, the electric field in the fiducial volume has to be known precisely.
In theory, a uniform electric field [from 0.5 to 1 kV/cm] is applied.
In reality, the electric field is not constant inside the volume due to border effects.

Also, the so-called space-charge effect can locally distort the electric field :
  The Ar^+ cloud produced together with the electrons will slowly drift to the cathode and locally screen the applied electric field.
  In a dual phase configuration, a second Ar^+ produced in the amplification region increases the effect.
    ↳ It is assumed that not all ions will back flow to the liquid (current assumptions is 0 or 10%)



Electric field norm, 500 V/cm, no IBF, at different z positions

COMSOL simulations

Detailed COMSOL simulations of the 3x1x1 and 6x6x6 detectors has been performed with different configurations:

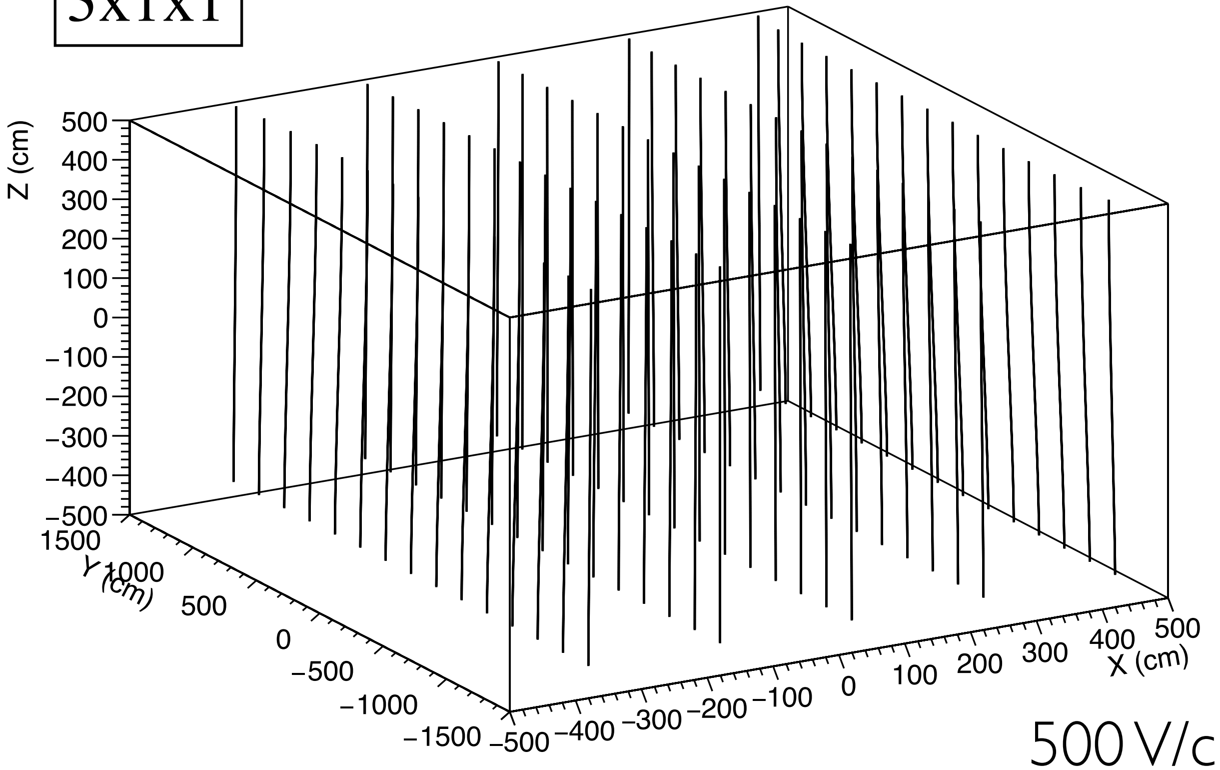
- Applied electric field of 0.5 and 1 kV/cm
- no ion back flow and 10% ion back flow assumed

For each simulation, the electric field components (Ex, Ey, Ez) is stored in voxels of

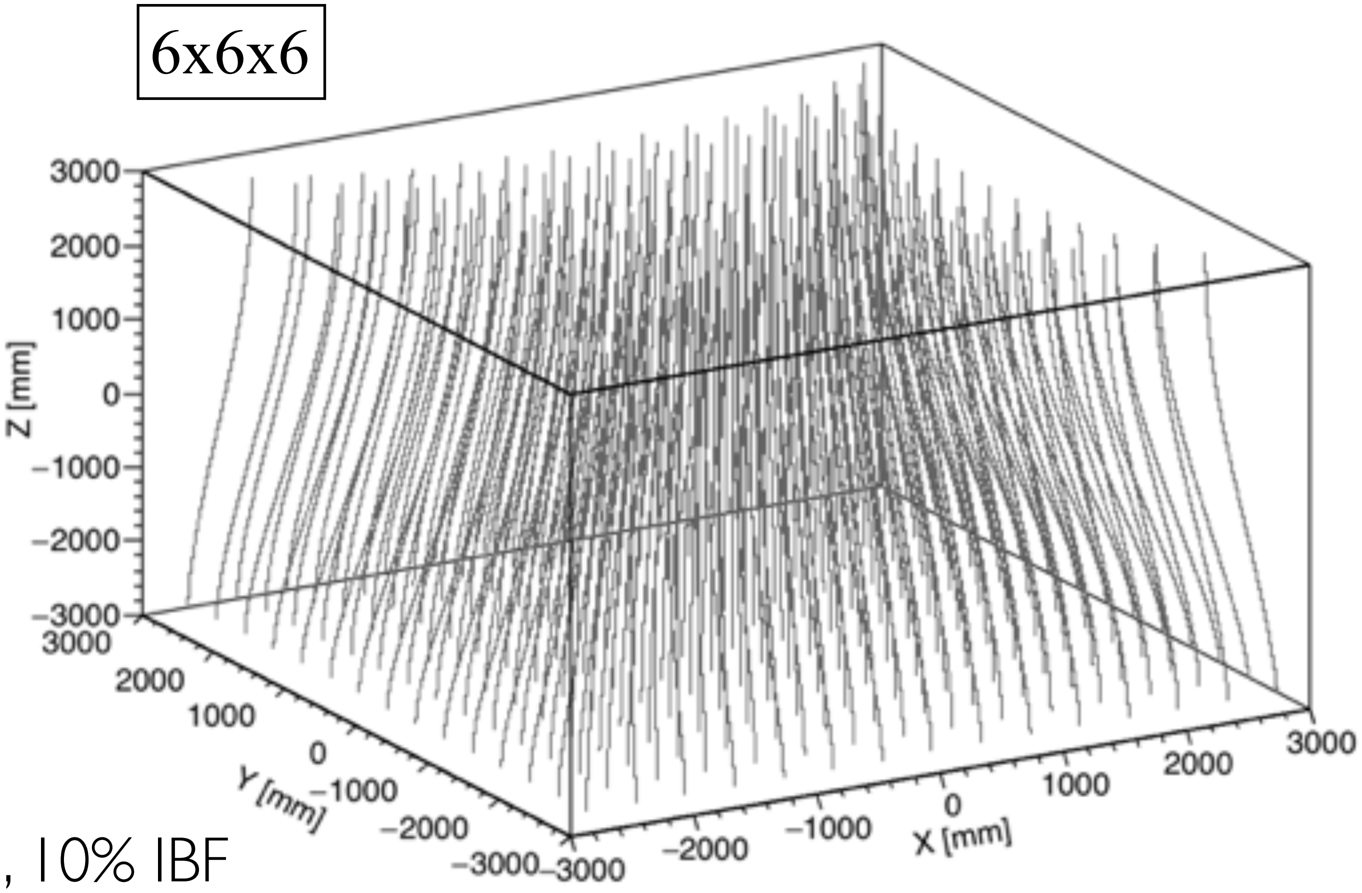
- 10x10x10 cm^3 for the 3x1x1 detector
- 20x20x20 cm^3 for the 6x6x6 detector

Trajectories of electrons produced near the cathode to the anode from COMSOL electric field simulation

3x1x1



6x6x6

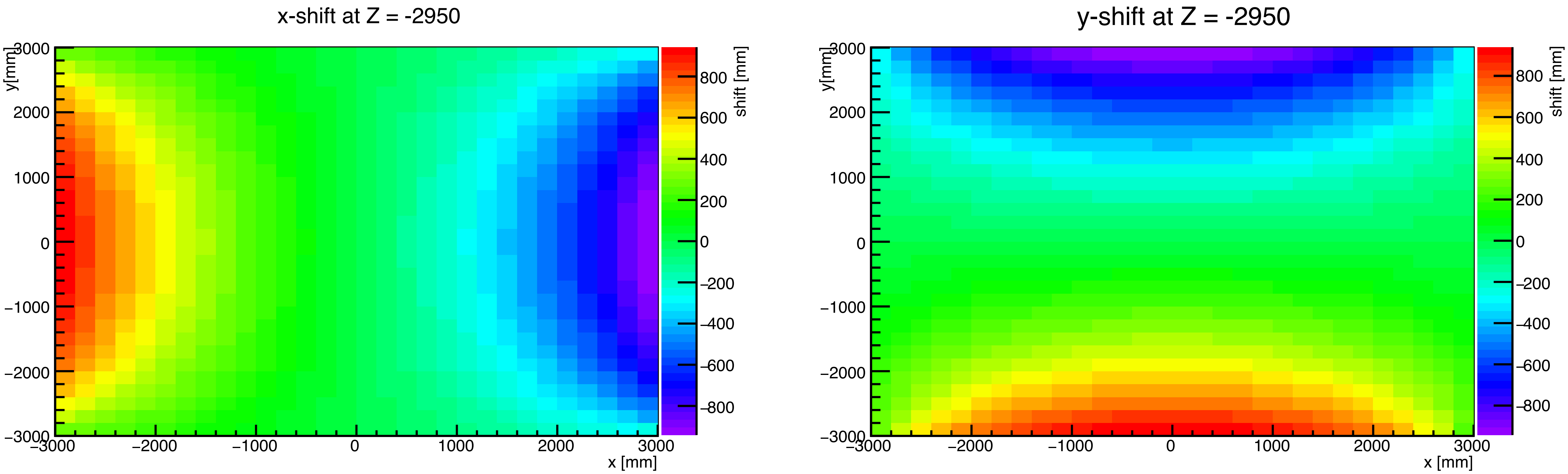


500 V/cm, 10% IBF

Field Map generation & usage

From the COMSOL output, "drift" electrons from each voxel to the anode by steps of 1mm.
The direction of the electrons depends on the field component at each steps.
The field is assumed to vary smoothly and linearly, therefore 3D interpolation is used (weighted mean) and a special care is needed for voxels at the edges (where no 3D interpolation is possible)

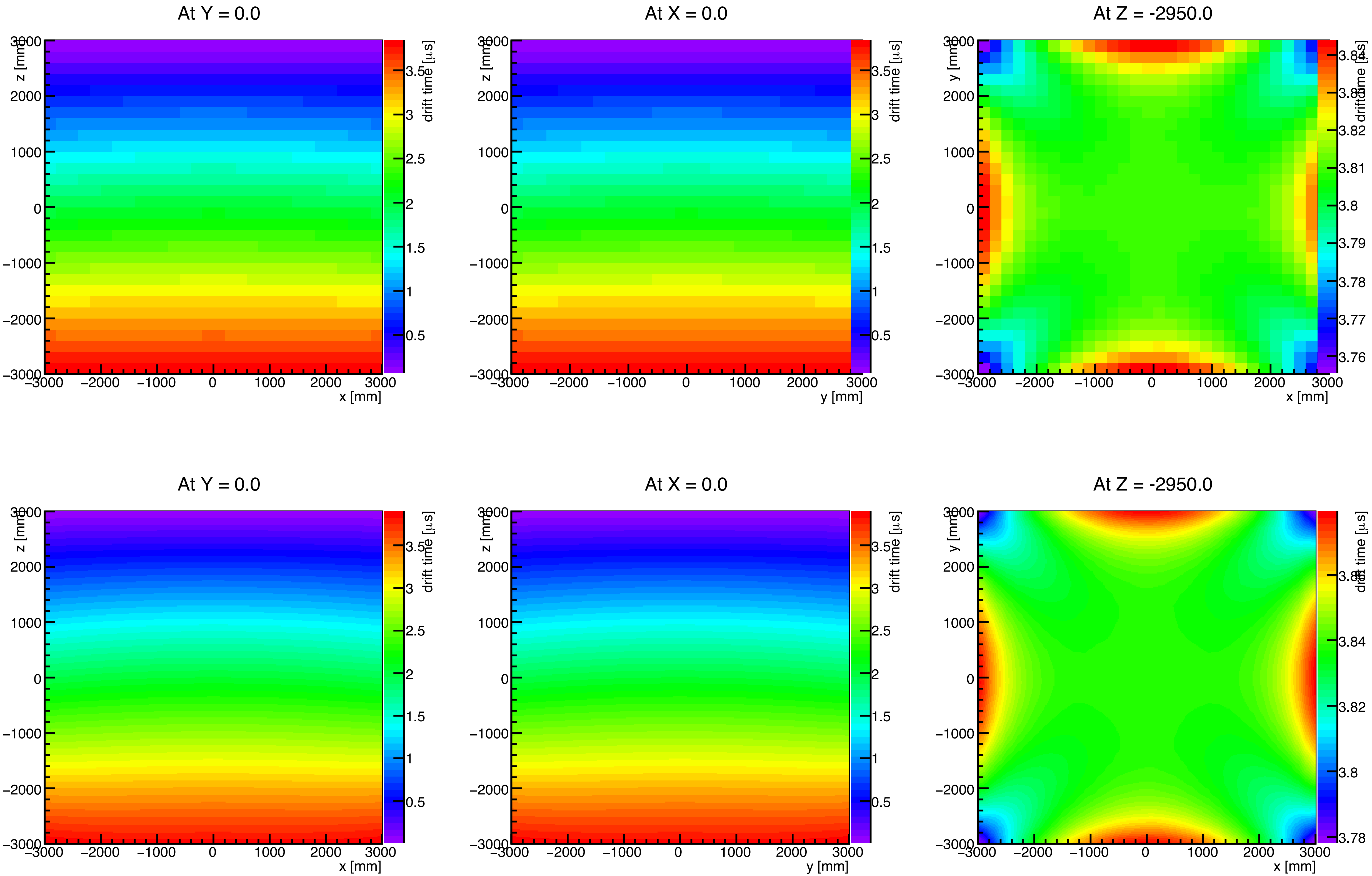
The maps provide, for each voxels :
Ex, Ey, Ez, Drift Time, Drift Length, CRP x-, y-, z- coordinates
in a root file (3D histograms) ➞ Can be read by any LArTPC simulation soft (QScan, LArSoft, …)



500 V/cm, 10% IBF

Field Map inter(extra)polation - drift time

500 V/cm, 10% IBF


At Y = 0.0

At X = 0.0

At Z = -2950.0

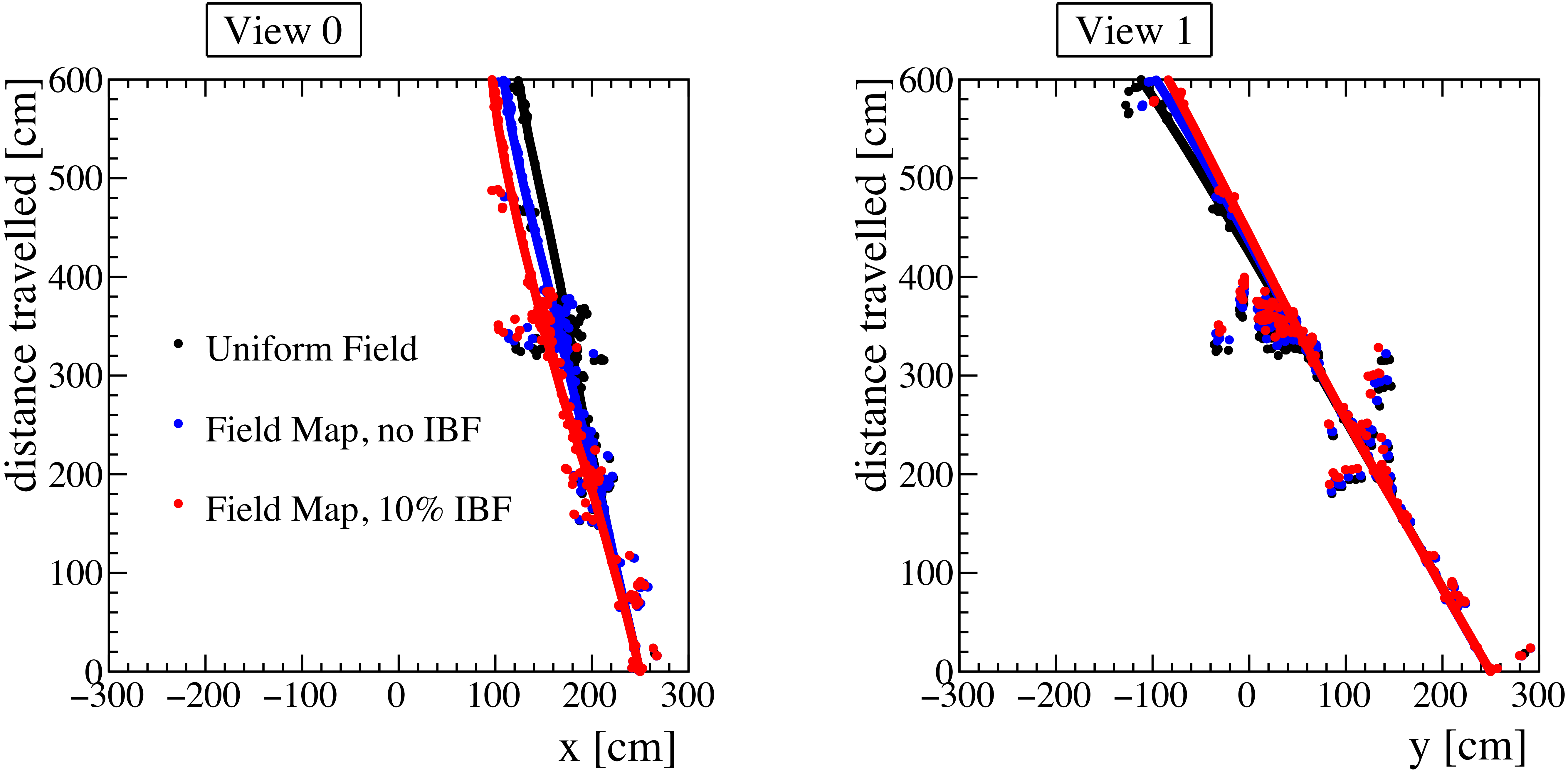
At Y = 0.0

At X = 0.0

At Z = -2950.0

Effect on crossing muon measured track

3 GeV muon crossing the 6x6x6 detector, field at 500 V/cm



Field Map update with diffusion

→Introduce the transverse and longitudinal diffusion to the maps

$$n(\rho, z) = A\exp(-\frac{\rho^2}{2\sigma_T^2})\exp(-\frac{z^2}{2\sigma_L^2})$$

$$\rho = \sqrt{x^2 + y^2}$$

$$\sigma_{L,T}^2 = 2D_{L,T}t$$

$$v_d = \mu \times E$$

$$D_{L,T} = \varepsilon_{L,T} \times \mu(E)$$

$$\frac{D_L}{D_T} = 1 + \frac{E}{\mu}\frac{\partial\mu}{\partial E}$$

$D_{L,T}$ are diffusion coefficient depending of E.

μ is the mobility of the drifting electrons
ε is the electron energy

The key is to find a good parametrization of the diffusion coefficient as a function of E.
Many references available from theoreticians / phenomenologists but very few data available.

Atrazhev et al, Vol 5 No 3 June 1998
Skullerud, J. Phys. B2 696 (1969)
Lowke and J.H. Parker, Jr, Phys. Rev. 181 302 (1969)
Li et al, NIM A 816 (2016) 160–170
…

A simplistic parametrization of $D_{L,T}$ was implemented following NEST prescription
M Szydagis et al 2013 JINST 8 C10003

Parametrization of $D_{L,T}$ as a function of E

Following the results of this recent paper :
Measurement of Longitudinal Electron Diffusion in Liquid Argon
NIM A 816 (2016) 160–170 [1508.07059]

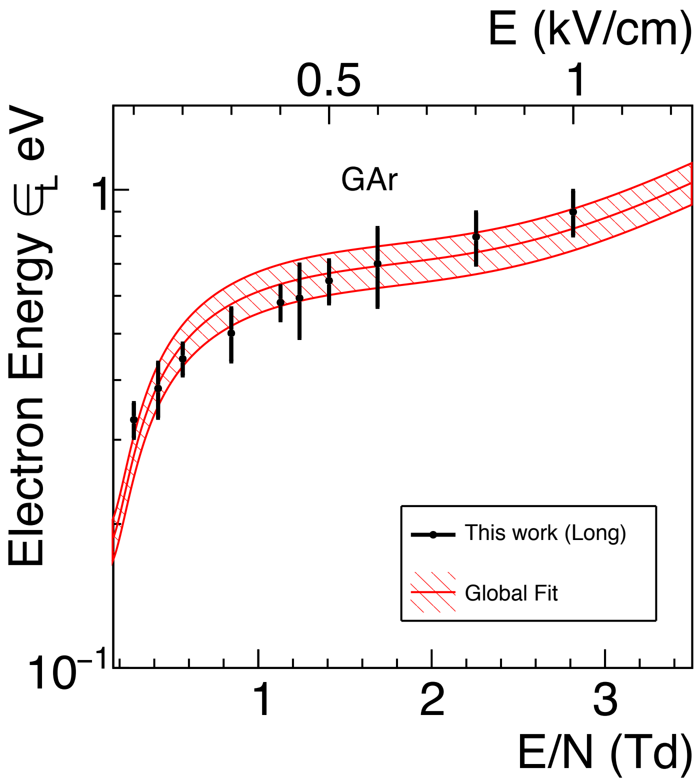
$$D_{L,T}(E \to 0) \simeq 3.88\ \mathrm{cm^2/s}$$

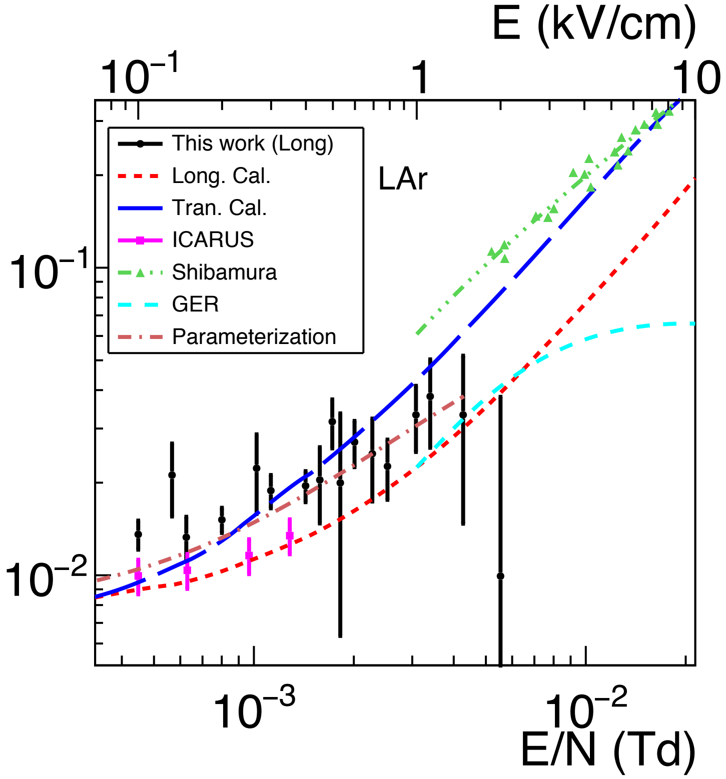
$$\begin{aligned} D_{L,T} &= \varepsilon_{L,T} \times \mu \\ &= \varepsilon_{L,T} \times v_d/E \end{aligned}$$

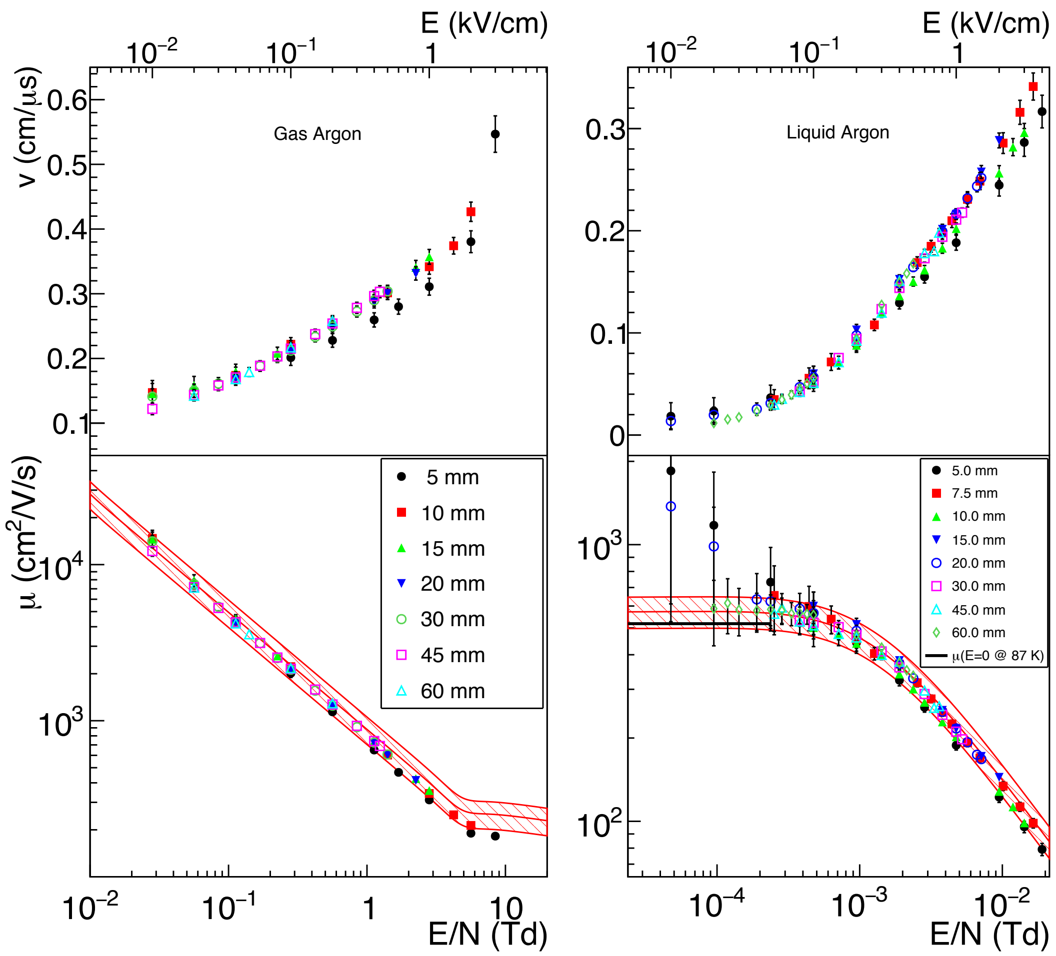
$$\frac{D_L}{D_T} = 1 + \frac{E}{\mu}\frac{\partial \mu}{\partial E}$$

The electron longitudinal energy and the electron mobility has been
- measured in GAr and LAr at different electric fields [0.1 to 4 kV/cm]
- parametrized with polynomial functions

Using this parametrization and the formulas, we can have a description of transverse & longitudinal diffusion coefficients as a function of E.

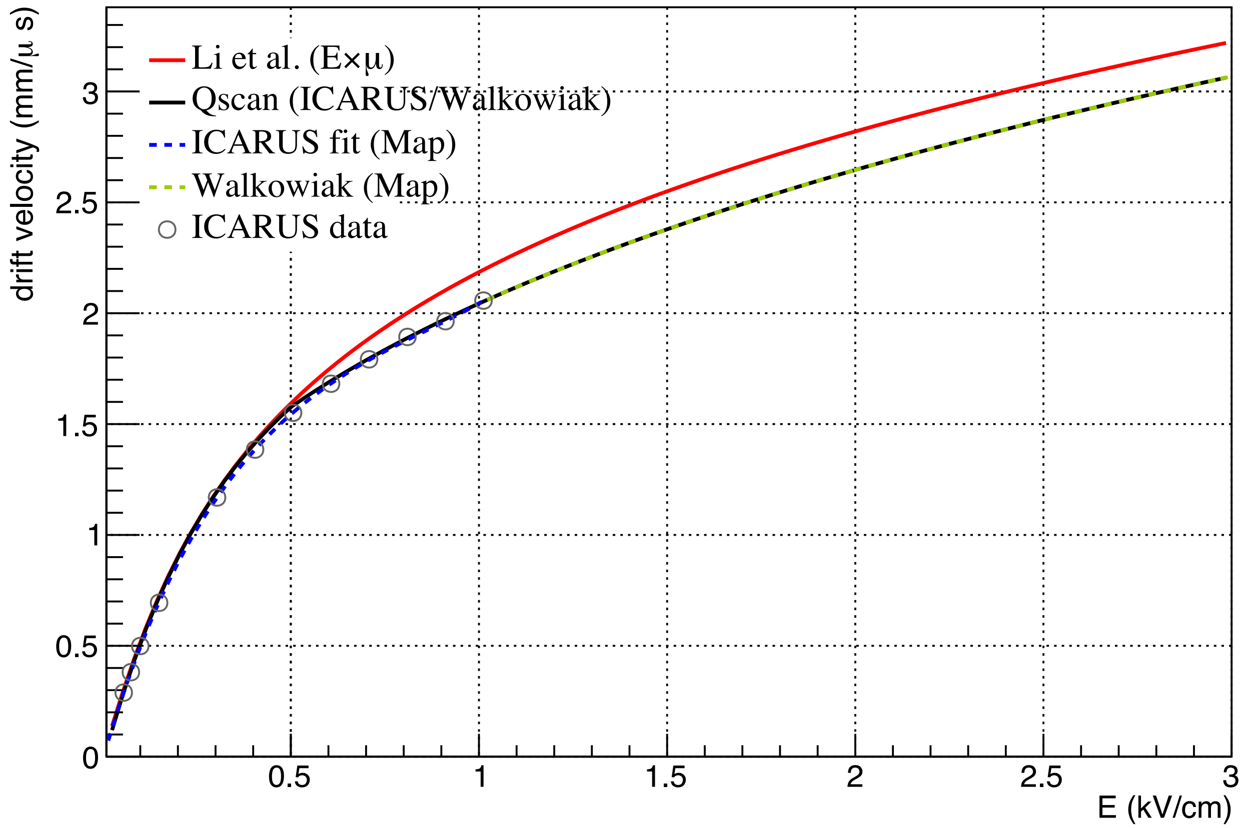






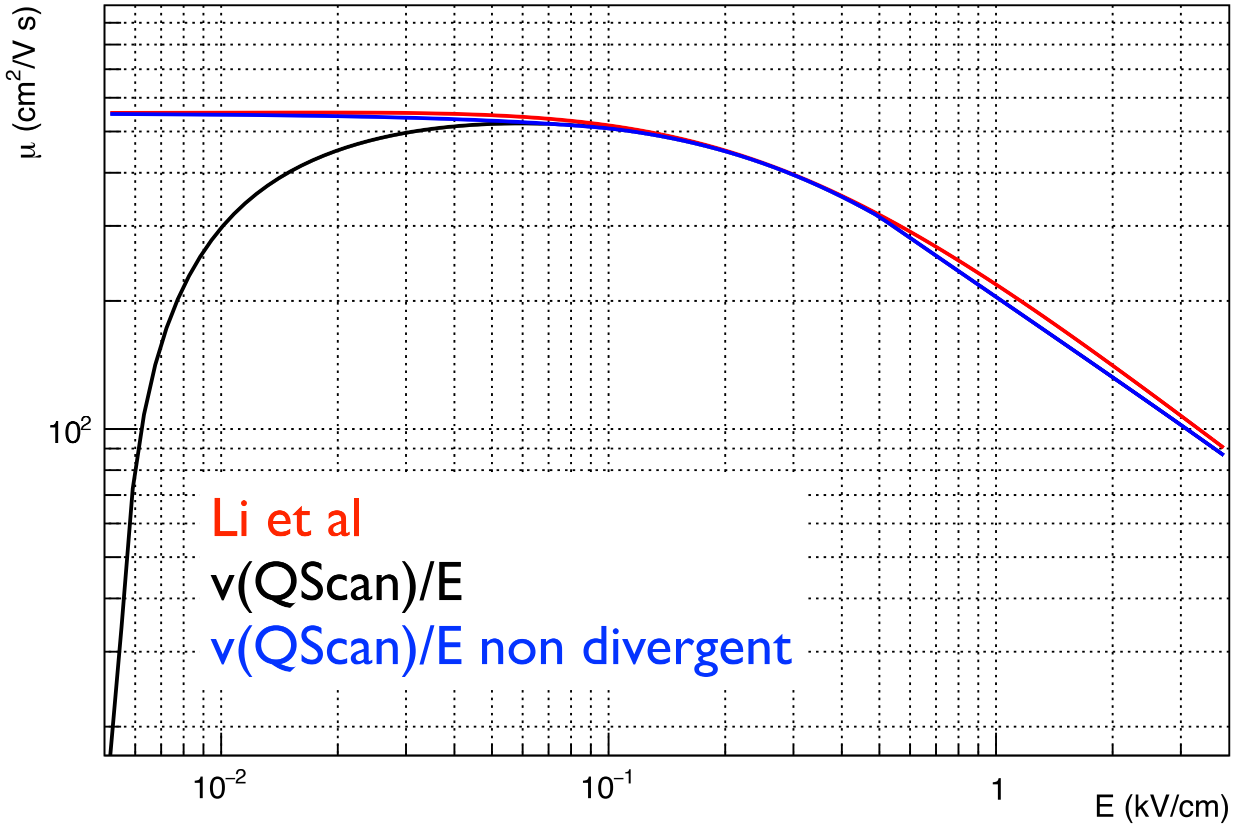
NB = E/N is the reduced electric field by the density, (1 Td = 10^{-17} Vcm^{-2})

Electron drift velocity/mobility parametrization (v=Eμ)



In QScan the drift velocity is parametrized with
- ICARUS for E < 0.5 kV/cm
- Walkowiak for higher field

→ Not in agreement with Li measurements for fields > 0.5 kV/cm

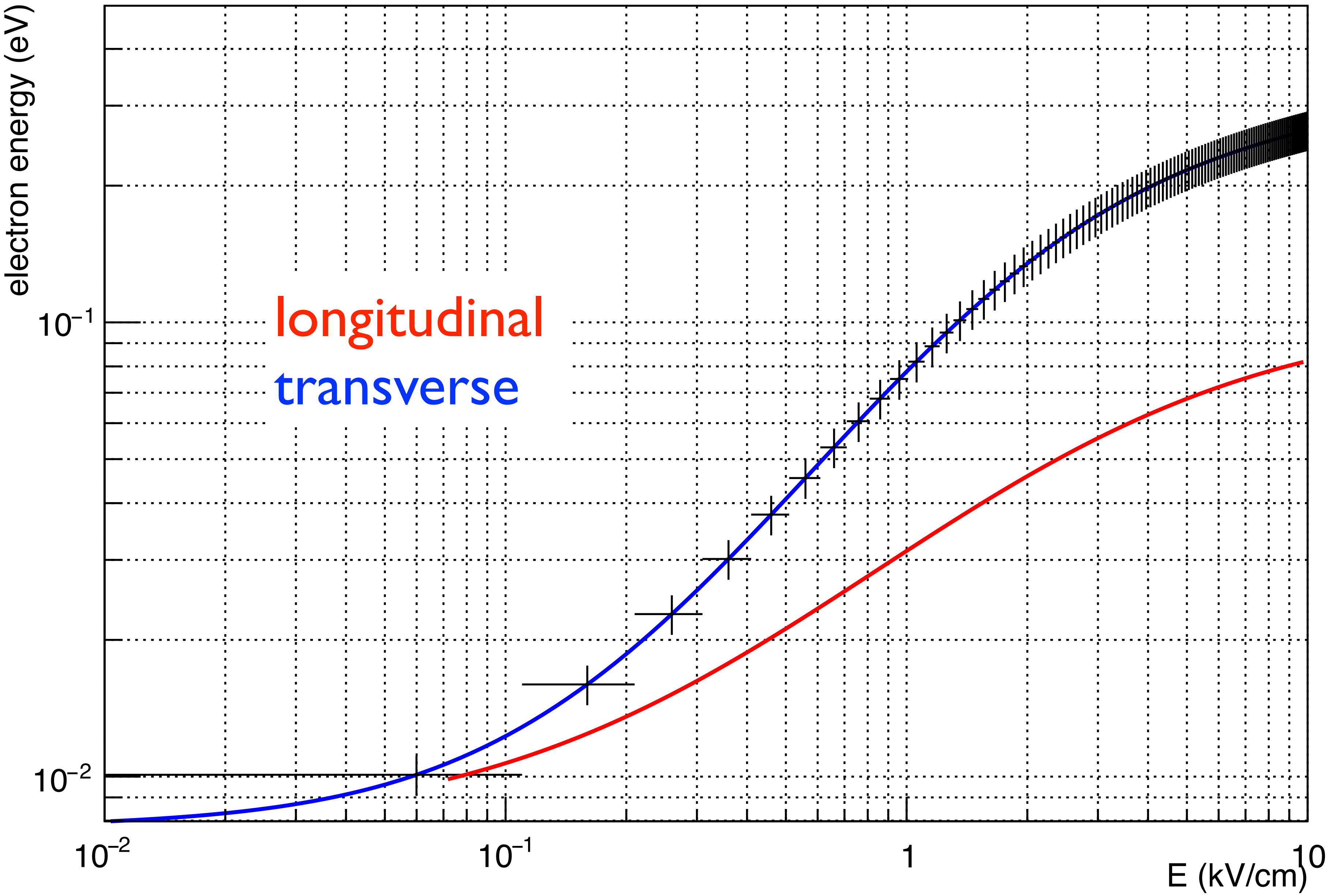


For Diffusion coefficients computation in QScan, use our drift velocity definition for the mobility, making sure that the mobility do not diverge at low field

From litterature μ(E=0) ≃ 518 $cm^2/(Vs)$

Electron energy

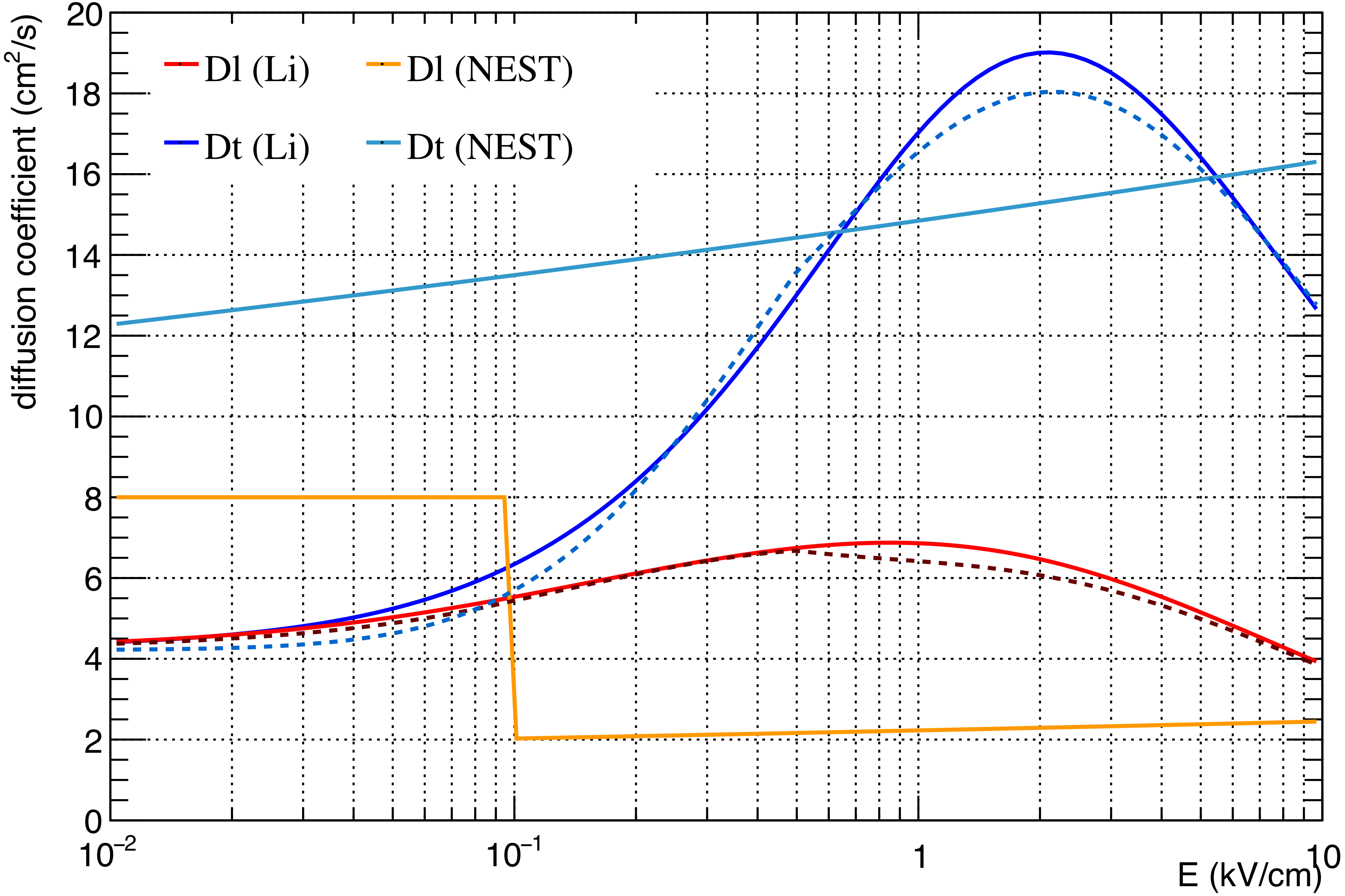
Playing with the formulas, transverse electron energy can be retrieve and parametrized with polynomials, as for the longitudinal electron energy.



Assume 10% error on 'data' points for the fit as in the paper

Diffusion coefficient parametrization

Dotted line : this parametrization

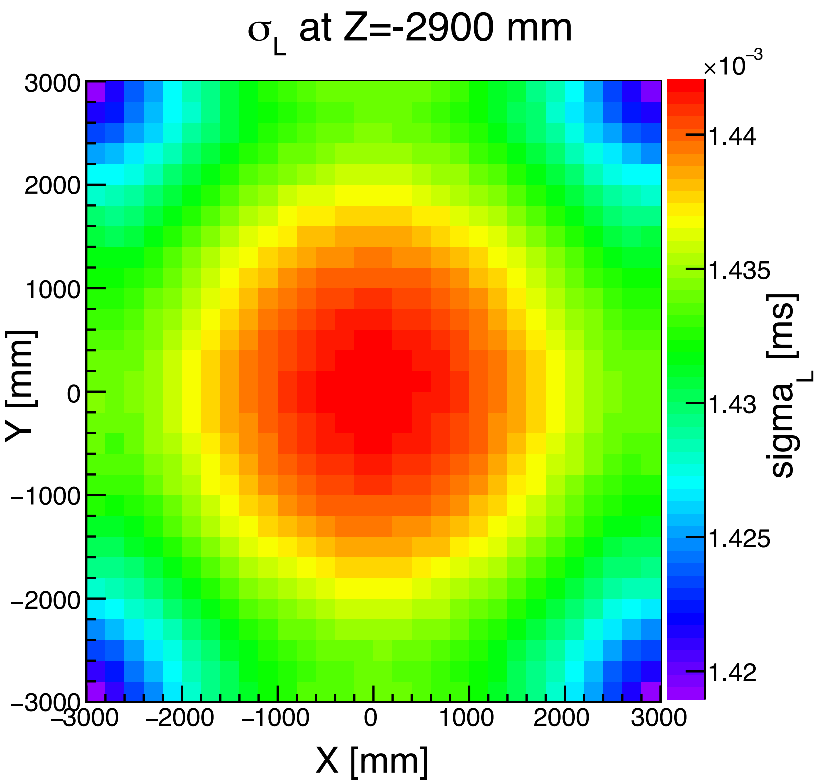


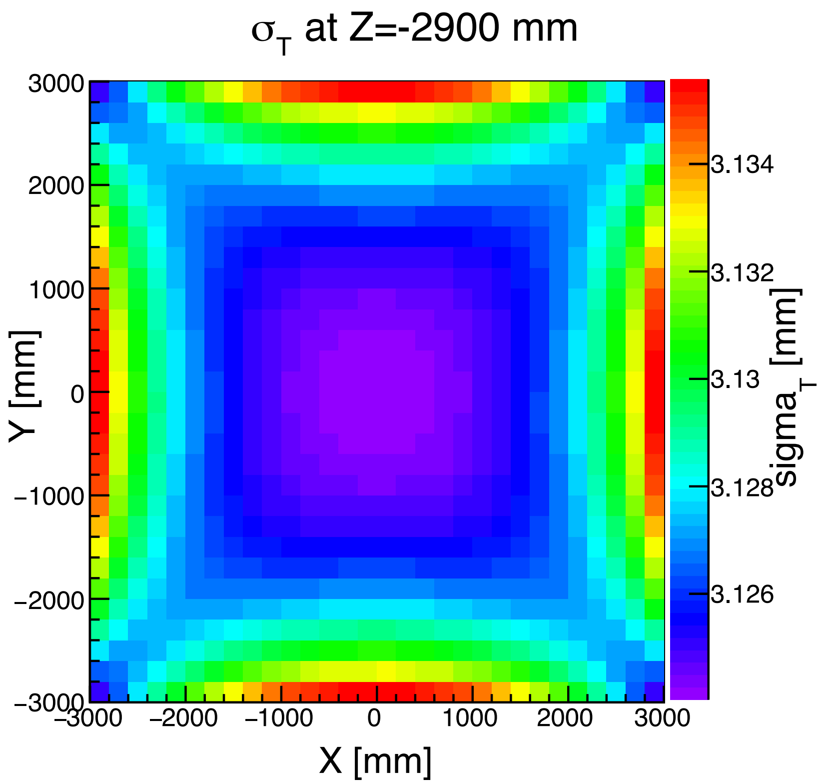
- Breaking point at 100 V/cm for Dl with NEST
- Difference between Li and this parametrization is due to a different drift velocity parametrization
- Dl and Dt converges at low field

[500 V/cm]	This work	(TDR value)	Diffusion for 1 m drift	Diffusion for 6 m drift
Longitudinal	$D_L = 6.7\ \mathrm{cm}^2/\mathrm{s}$	$4\ \mathrm{cm}^2/\mathrm{s}$	$\sigma_L = 0.57\ \mu\mathrm{s}$	$\sigma_L = 1.40\ \mu\mathrm{s}$
Transverse	$D_T = 13.6\ \mathrm{cm}^2/\mathrm{s}$	$13\ \mathrm{cm}^2/\mathrm{s}$	$\sigma_T = 1.3\ \mathrm{mm}$	$\sigma_T = 3.2\ \mathrm{mm}$

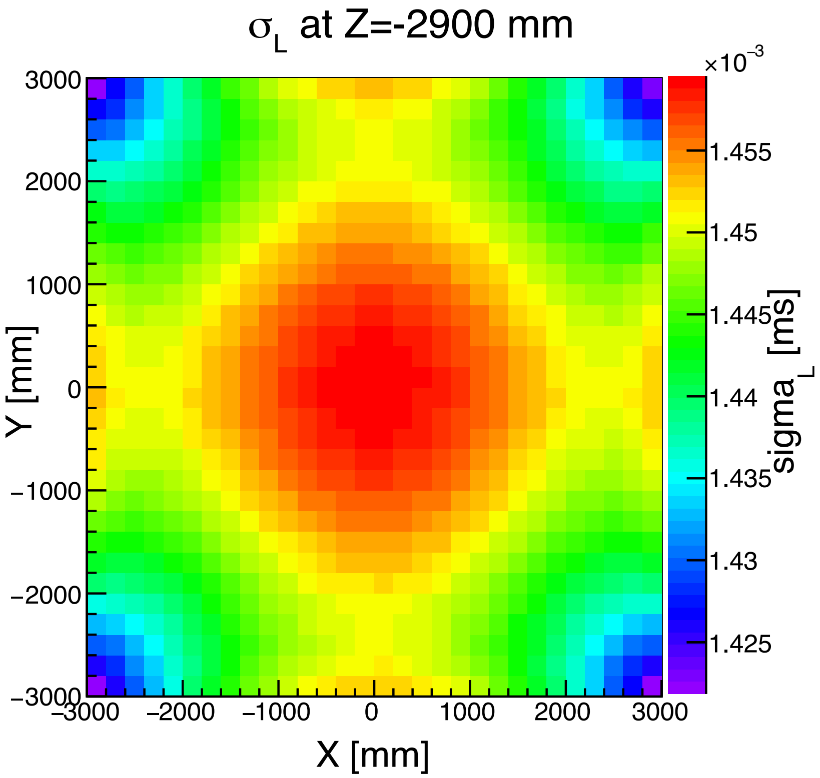
Diffusions added in the field maps

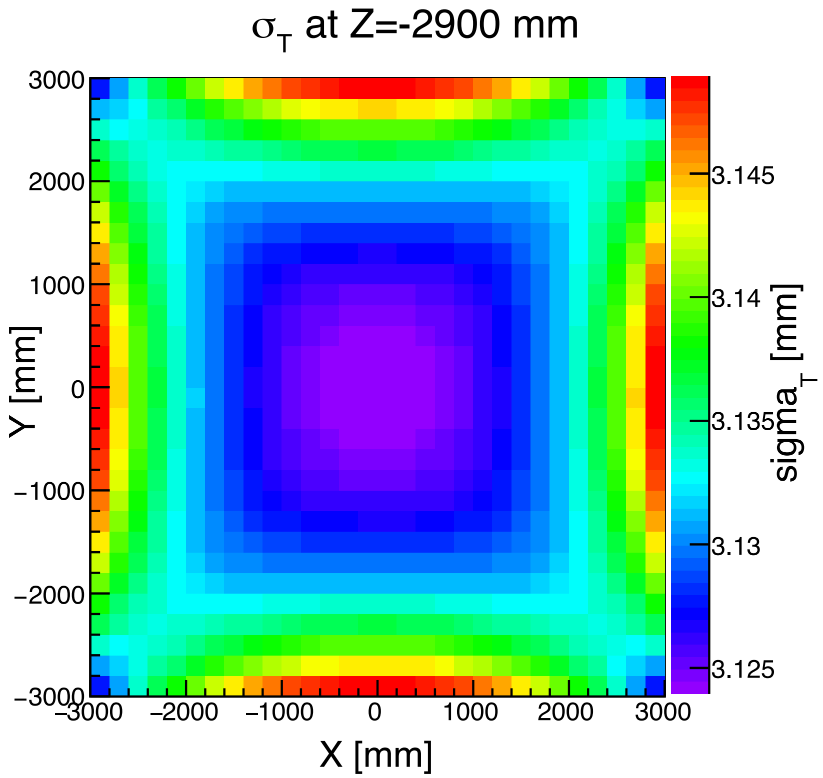
6x6x6 maps, 500 V/cm, no IBF:


σ_L at Z=-2900 mm


σ_T at Z=-2900 mm

6x6x6 maps, 500 V/cm, 10% IBF:


σ_L at Z=-2900 mm

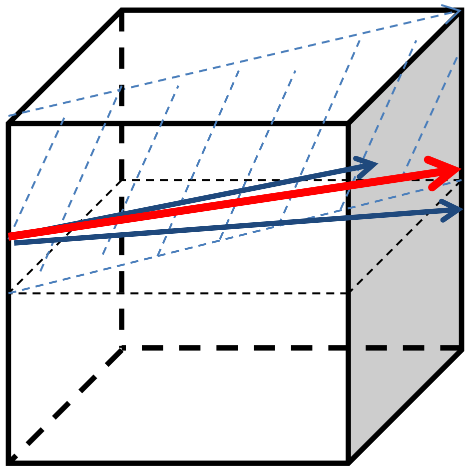

σ_T at Z=-2900 mm

Evaluation of space charge effect in the 6x6x6

Use beam events assuming that the beam entering position and direction is well known

Compare z-displacement between ideal beam track to the reconstructed track

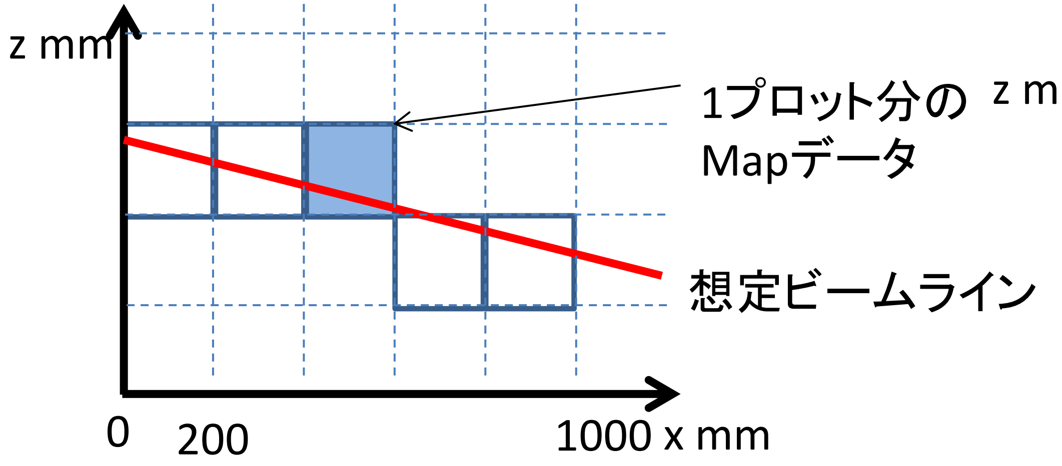
→ Simple analysis at the moment as x-y displacements are not yet taken into account

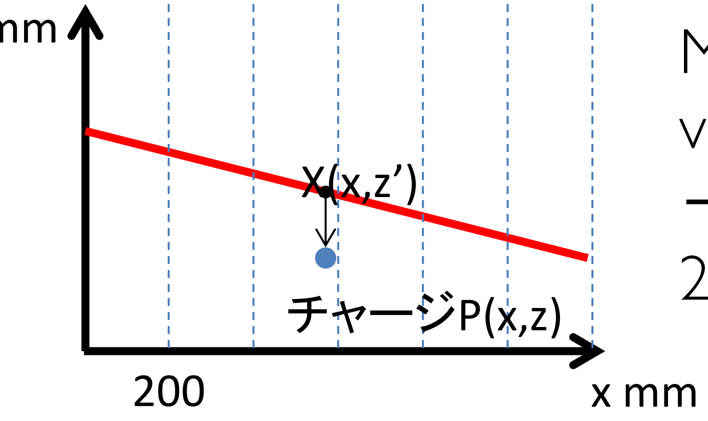


Beam entering position →
(-300, -300, 108.063)

← Beam direction
go through (0, 0, 50.7)

Simulation with :
500 V/cm
4 GeV/c μ^+
10 000 events





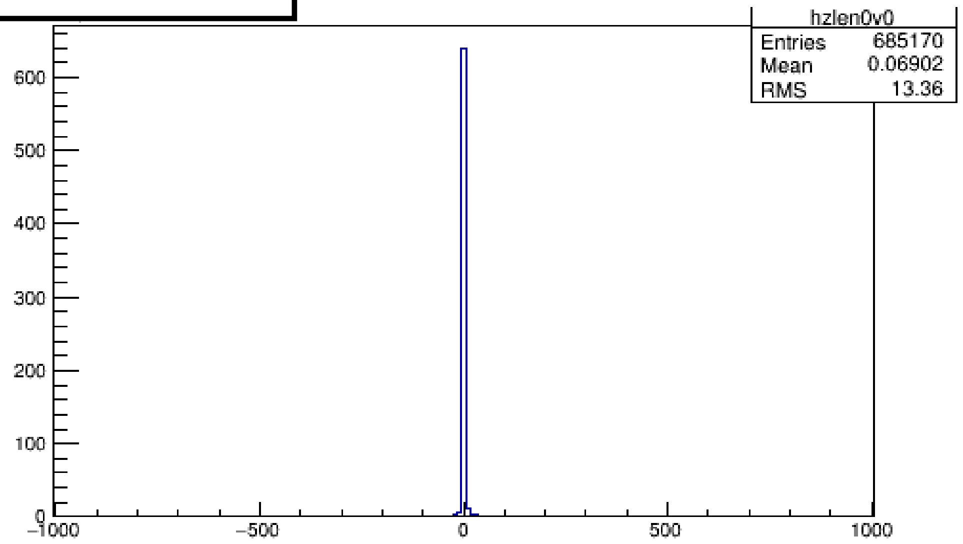
Maps are binned with 200 mm^3 voxels

→Produce Δz distributions for each 200 mm along the X(y) axis

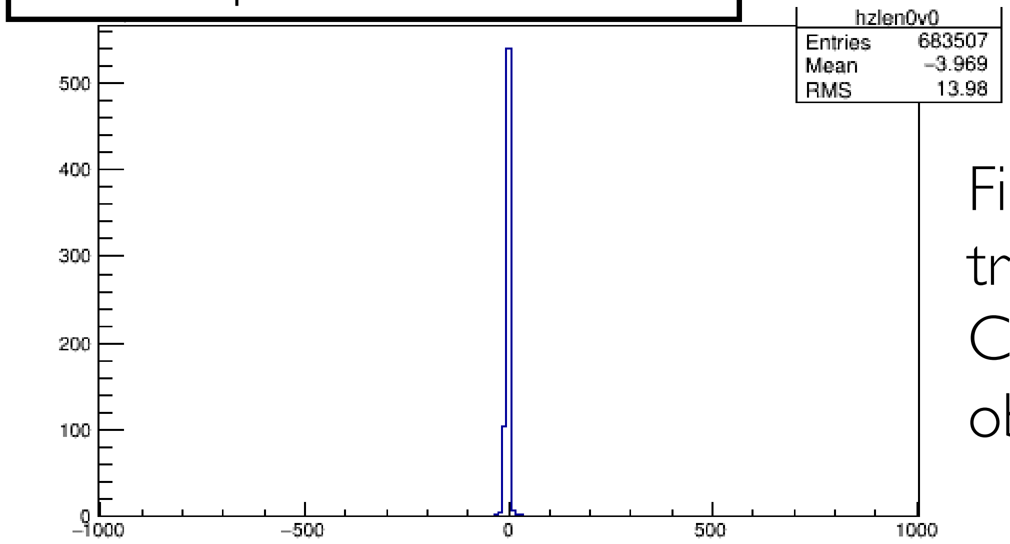
H. Konari

Evaluation of space charge effect in the 6x6x6

Uniform Field



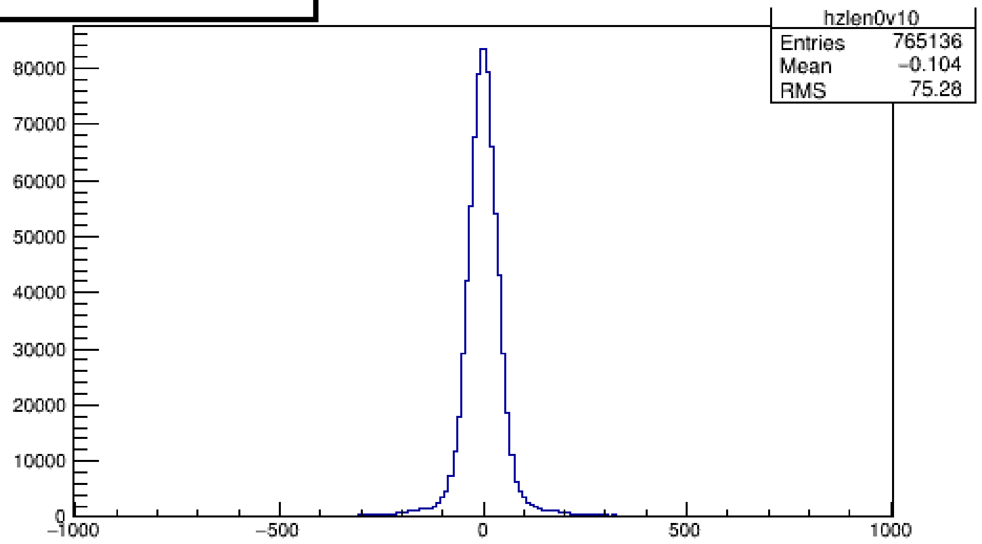
Field Map, 10% of back flow



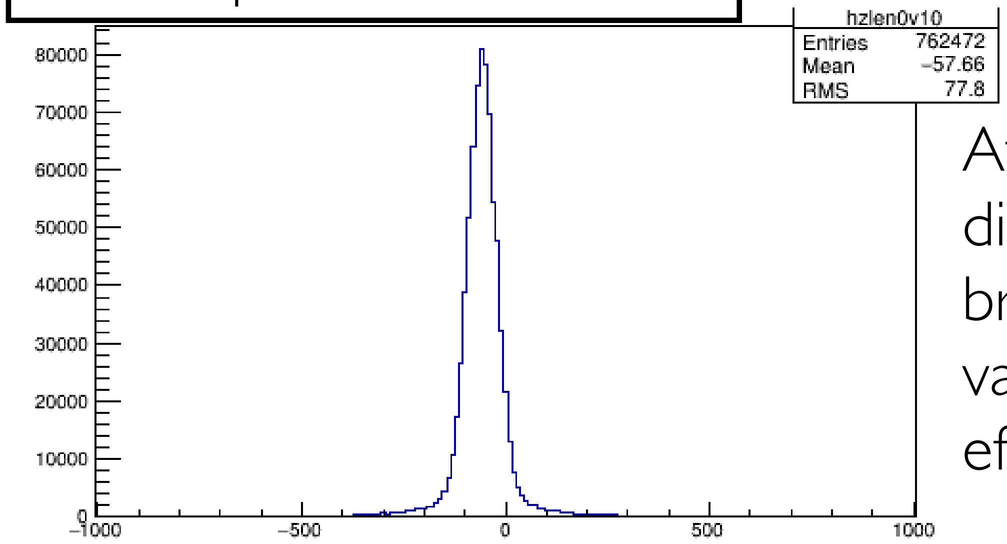
First 20 cm of the track,
Can already observe a **Δ**z shift

$$0mm \leq x < 200mm$$

Uniform Field



Field Map, 10% of back flow



After 2m, distributions are broader, central values indicates SC effect

$$2000mm \leq x < 2200mm$$

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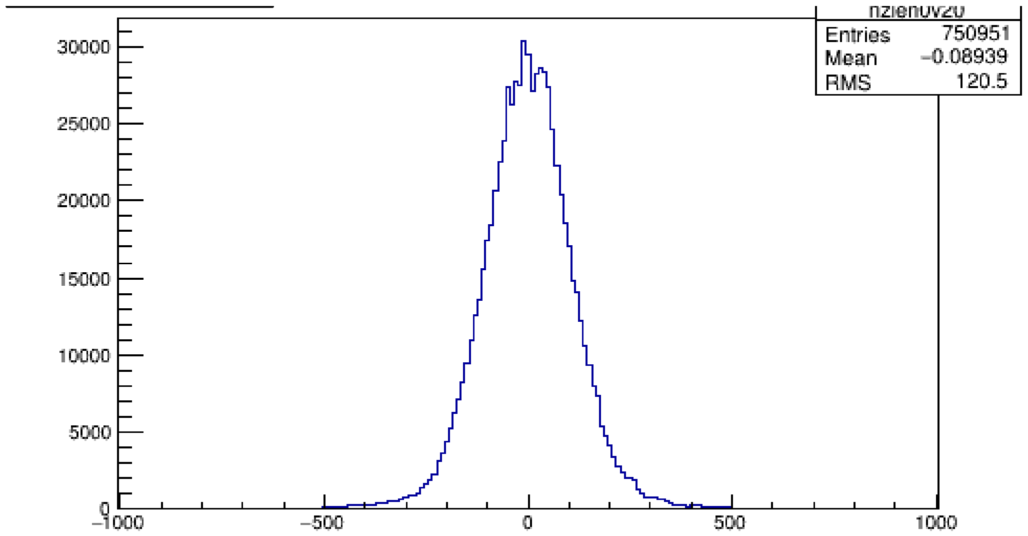
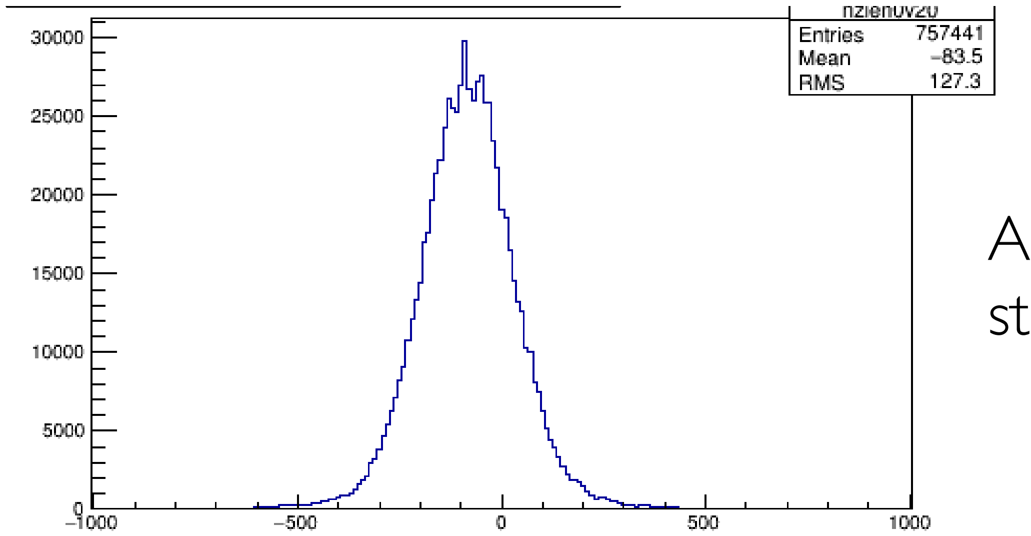
Evaluation of space charge effect in the 6x6x6

Uniform Field



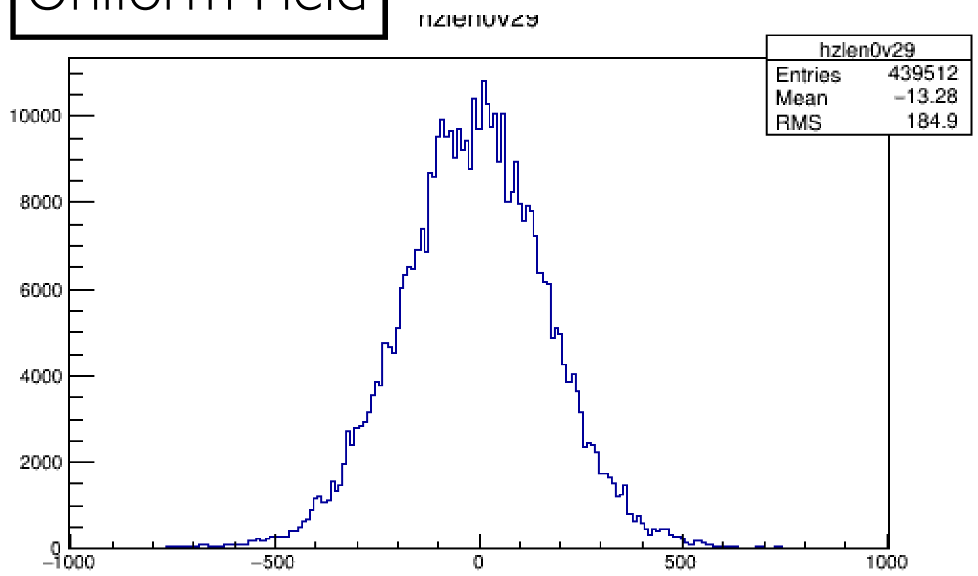
Field Map, 10% of back flow



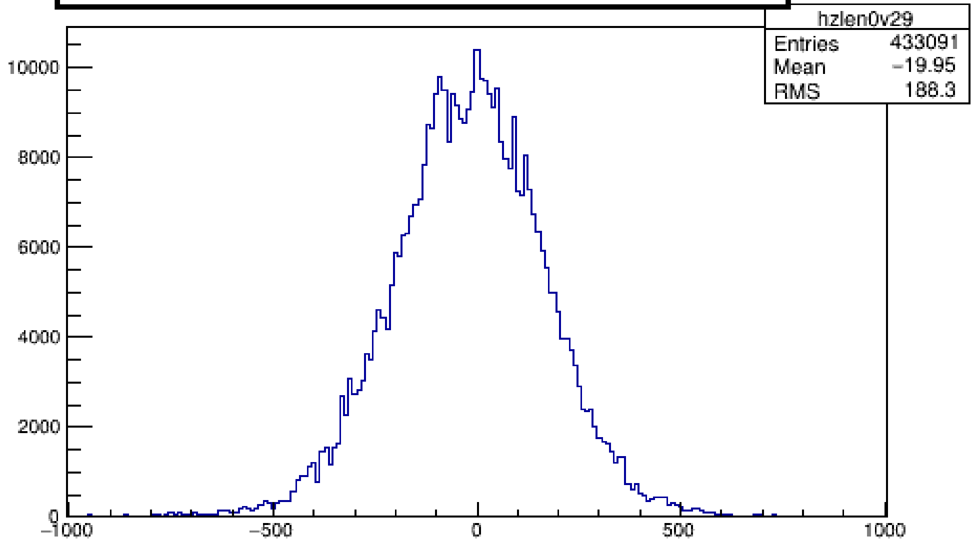
After 4m, effect still seen

$$4000mm \leq x < 4200mm$$

Uniform Field



Field Map, 10% of back flow



At the end of the track (6m) distributions are too broad to conclude

$$5800mm \leq x < 6000mm$$

More details in Konari's presentation at SB [02/22] and in the future

Perspectives

Although no strong field distortions is expected in the 3x1x1, the data will be a great opportunity to understand and map the field inside the tank.
Some analysis as Konari-san started should be also possible in the 3x1x1 :

- ideal track retrieved with the CRT information.
- through going muons ideal track predicted by extrapolating the entering direction (close to the anode where the effects are expected to be small)
- … ?

For the 6x6x6, where the effects are expected to be bigger and measurable :

- Using Konari-san's method, the existence of space charge effects can be assessed (to the extent of beam spread and divergence)
- Should developed other methods with the CR tracks