中国科学院高能物理研究所
Institute of High Energy Physics
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Simulation studies of the WXPT-TPC

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On behalf of WXPT-TPC group

21th 核电子学与核探测技术学术年会

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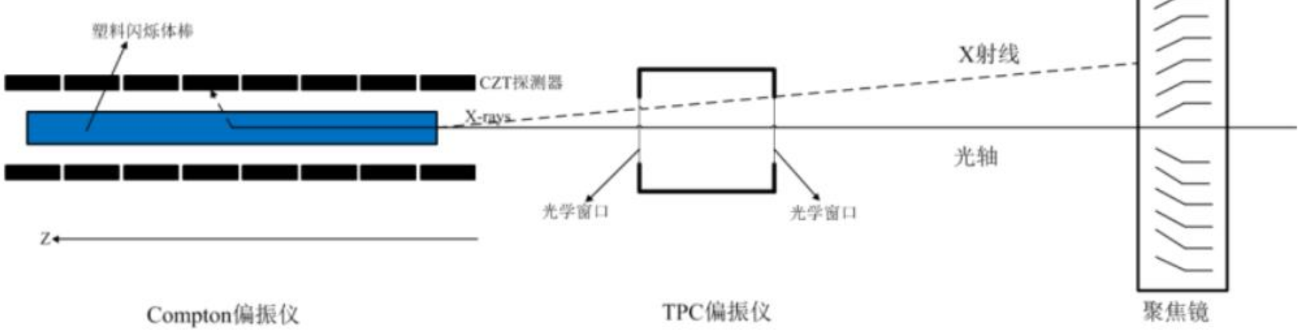
2023年08月10日

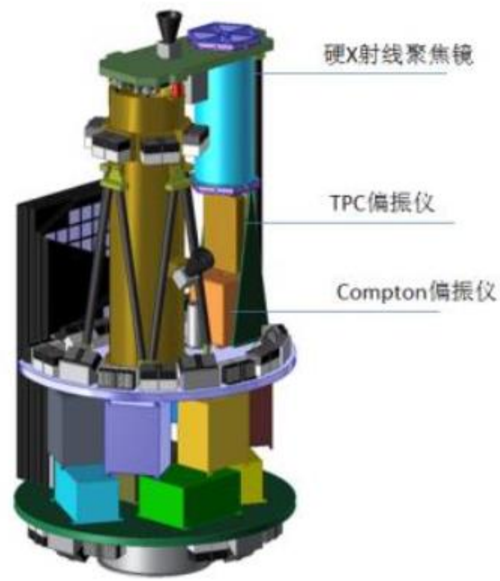
Outline

- Background introduction
- Dimensions design of WXPT-TPC
- Working gas choices of WXPT-TPC
- Summary and plan

Background

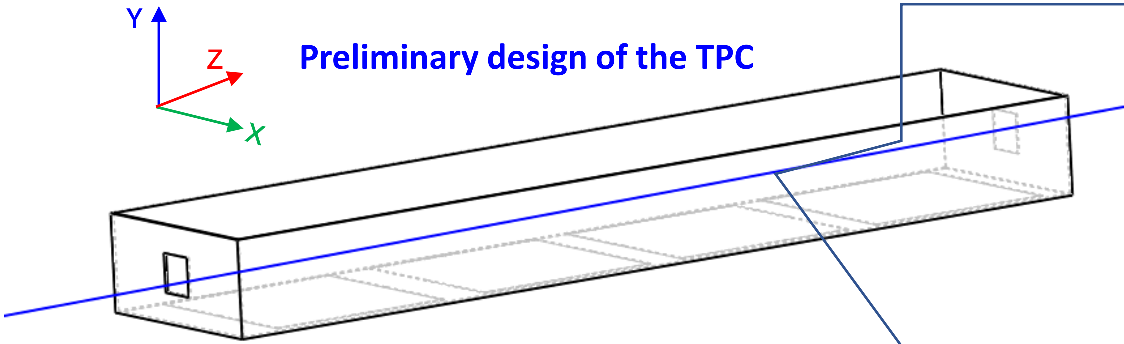
- The Wide band X-ray Polarization Telescope (WXPT)
- Spectral-polarimetry studies of the extreme Universe in the 3-500 keV band
  - silicon multilayer mirrors with f~10 m (3-60 keV)[TBC]
  - A time projection chamber (TPC) polarimeter (3-10 keV)
  - A Compton polarimeter (10-60 keV)
  - Extend to 500 keV (soft γ-ray)



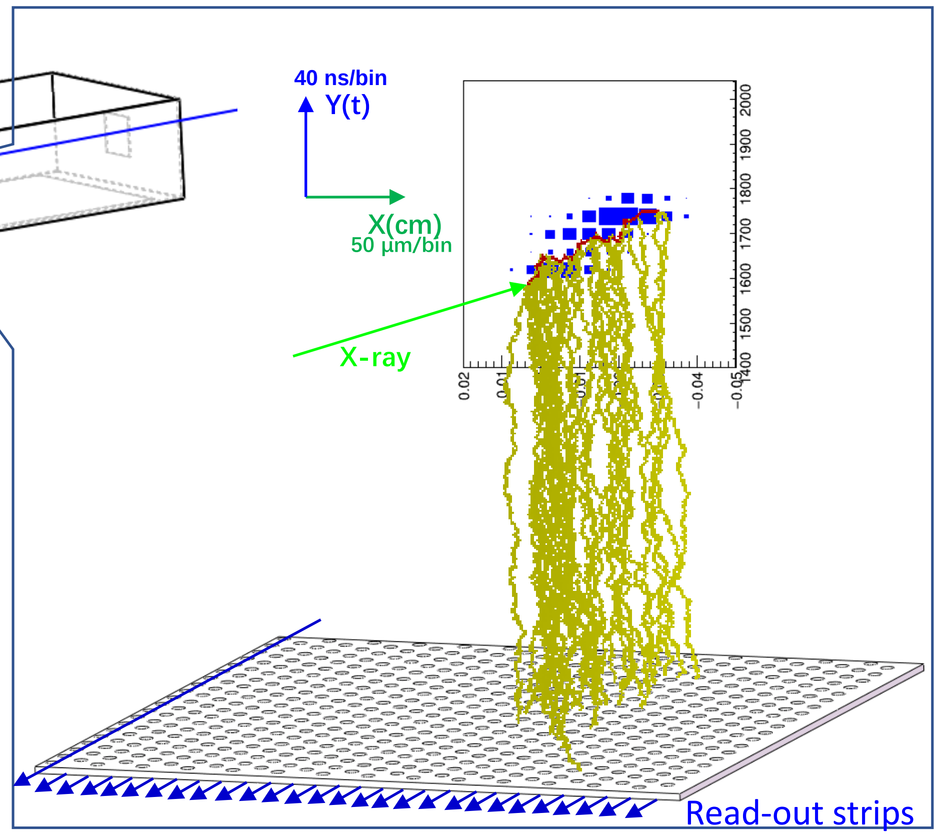


Background

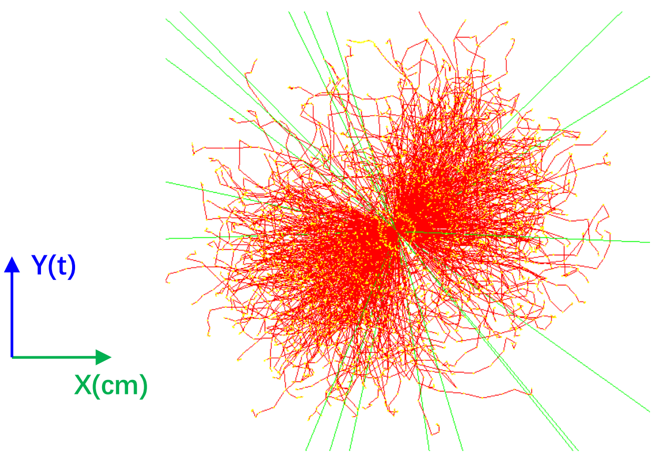
X-ray polarization detection



Projection on X-Y(t) plane



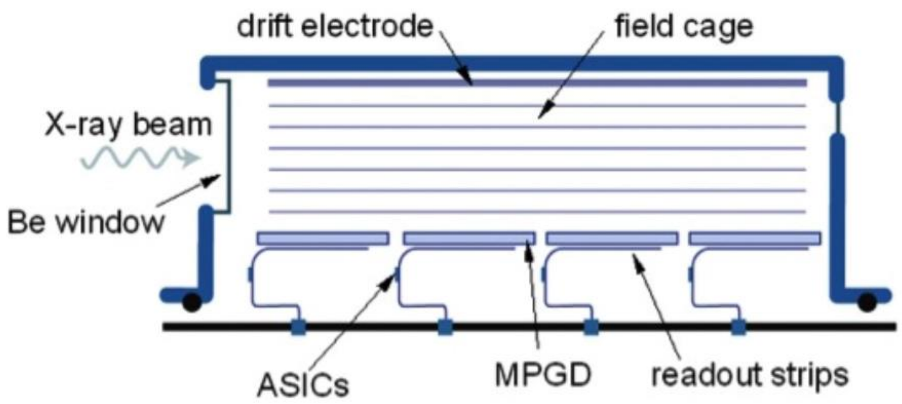
$cos^2(\phi)$ distribution on X-Y plane



Background

Requirements[TBC]

- Energy range 3 ~ 10 keV
- Emit focal spot < 1 cm
- Angle resolution <1′
- Transparency >90%(@ 10 keV)
- Be window 20 mm × 20 mm
- MF >0.4 @6 keV
- Position resolution <140 μm
- Spatial resolution <200 μm



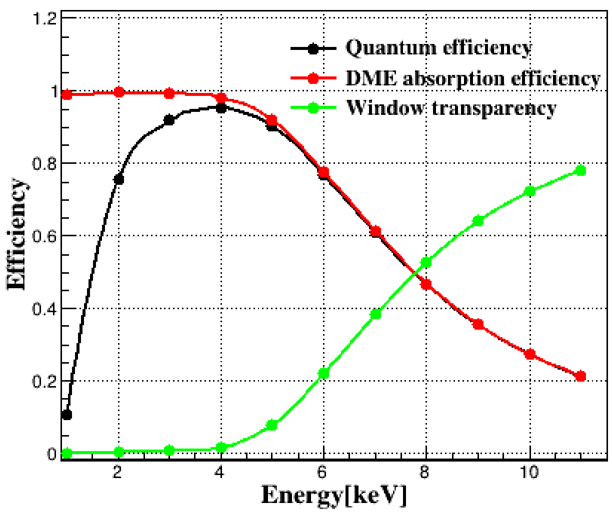
- Depth, height, relative position of the GEM and drift electrode within a TPC (limitation)
- distribution of Electric field and X-ray transparency
- Gas choice and working condition (optimization)
- Quality factor (MF× $\sqrt{\mathrm{PDE}}$)

Detection efficiency

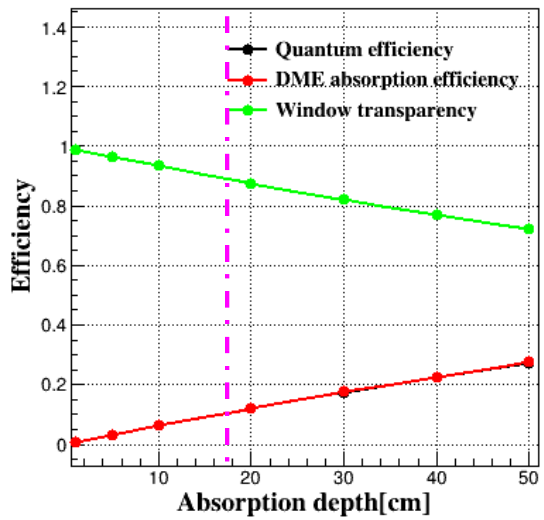
<u>Different depth and pressure</u>

0.5DME+0.5Ne

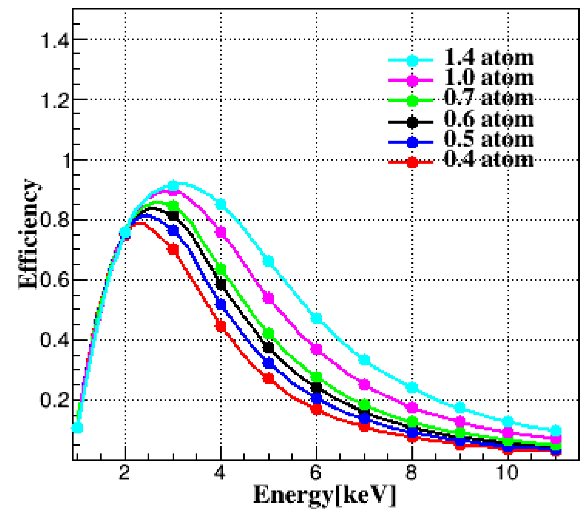
Absorption depth 50 cm



X-ray 10 keV



depth of 10 cm

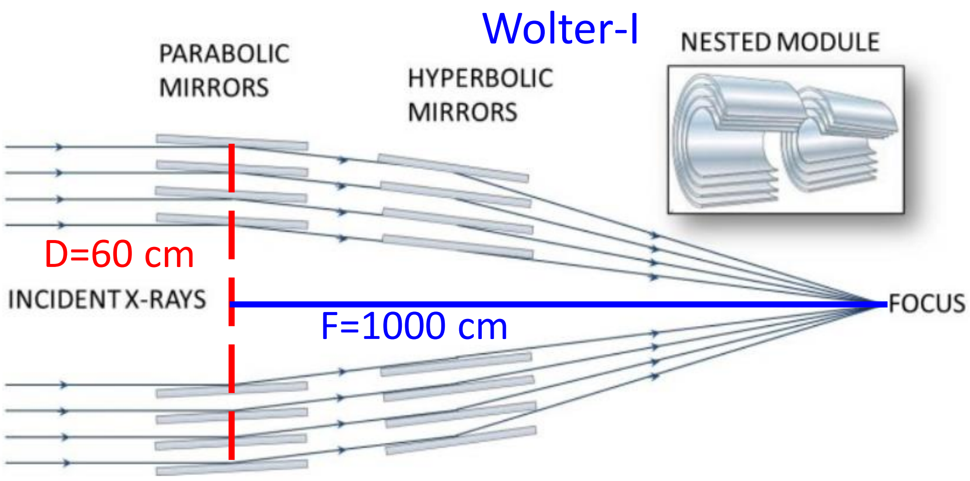


- Detection efficiency versus energy (>10 keV) follows a exponential function
- For 0.5DME+0.5Ne, 0.6 atom, transparency > 90%@10 keV as depth <18 cm
- For 0.5DME+0.5Ne, depth of 10 cm, transparency > 90%@10 keV as pressure <1 atom

Dimension

TPC requirement

① Defocus spot limit is width of the scatter bar with 1 cm
② Angle resolution <1′
③ X-ray transparency >90%(@ 10 keV)

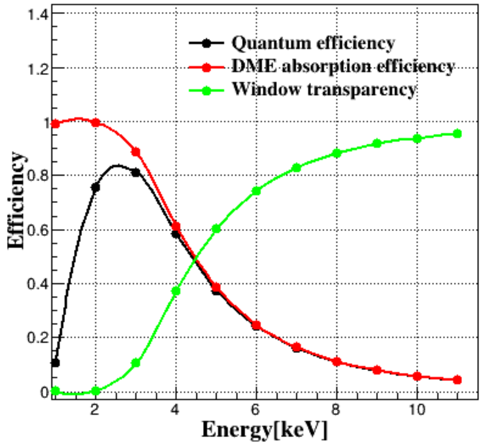


TPC depth

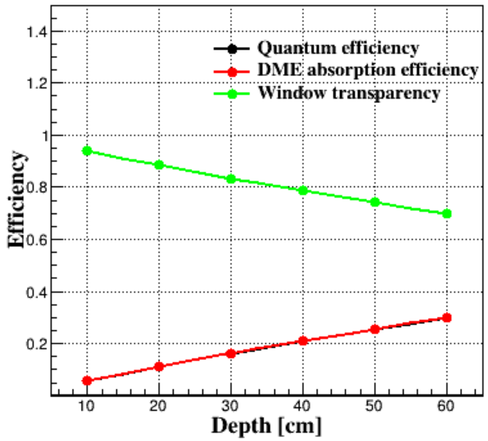
① Depth of the TPC < 66 cm
② Depth of the TPC <10 cm (f=10 m)
③ Depth of the TPC <18 cm

- Transparency ~93%(@10 keV)

Absorption depth 10 cm



X-ray 10 keV



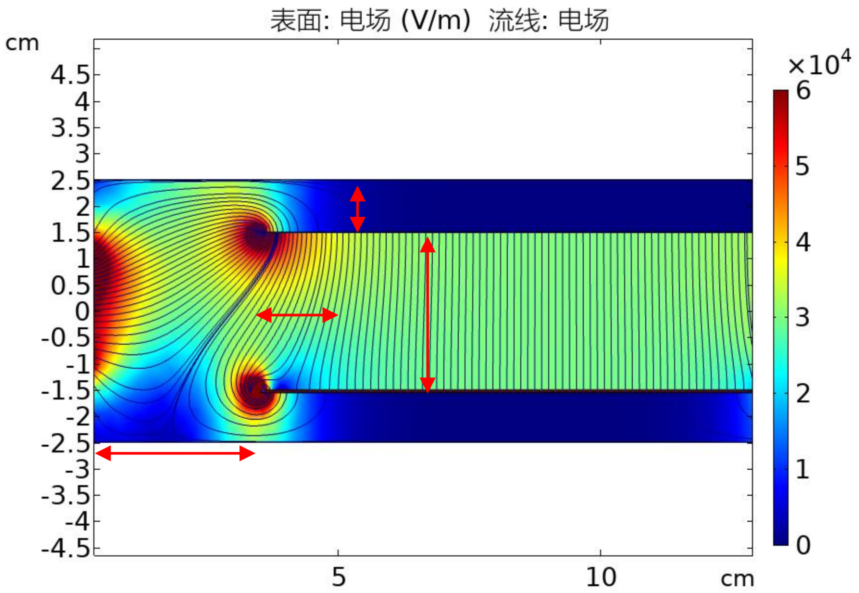
0.5DME+0.5Ne 0.6 atom

Dimension

GEM and drift electrode

- Distance between beryllium window and end point of the drift plane
- Absorption depth and position
- Electric field of drift region
- Limited of the distortion of the electric field (EF)

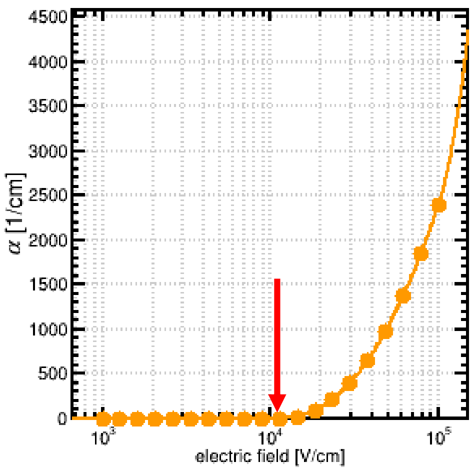
- Electrons amplification (safe distance)
- deviation of position (EF distortion)



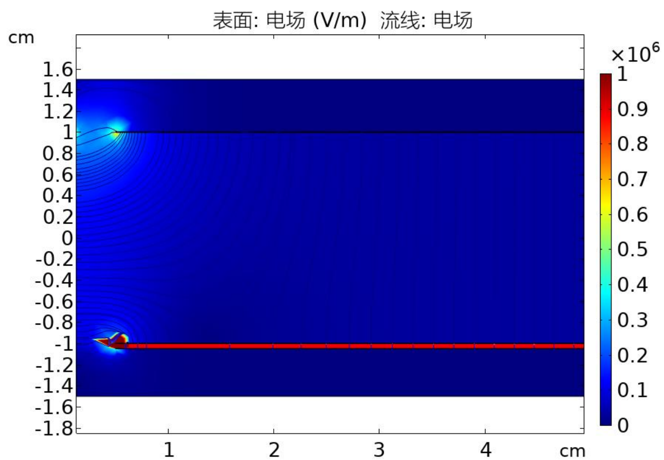
Dimension

Optimization of the drift region

Townsend coefficient

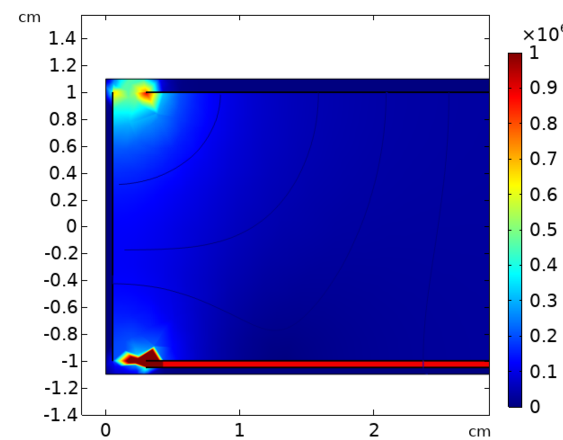


Electric field <10^4V/cm



0.5 cm 0.5 cm

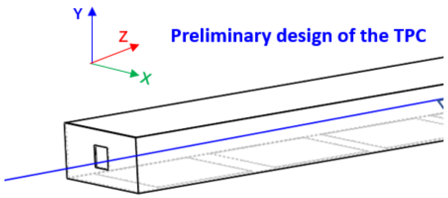
Electric field distribution



0.3 cm 0.1 cm

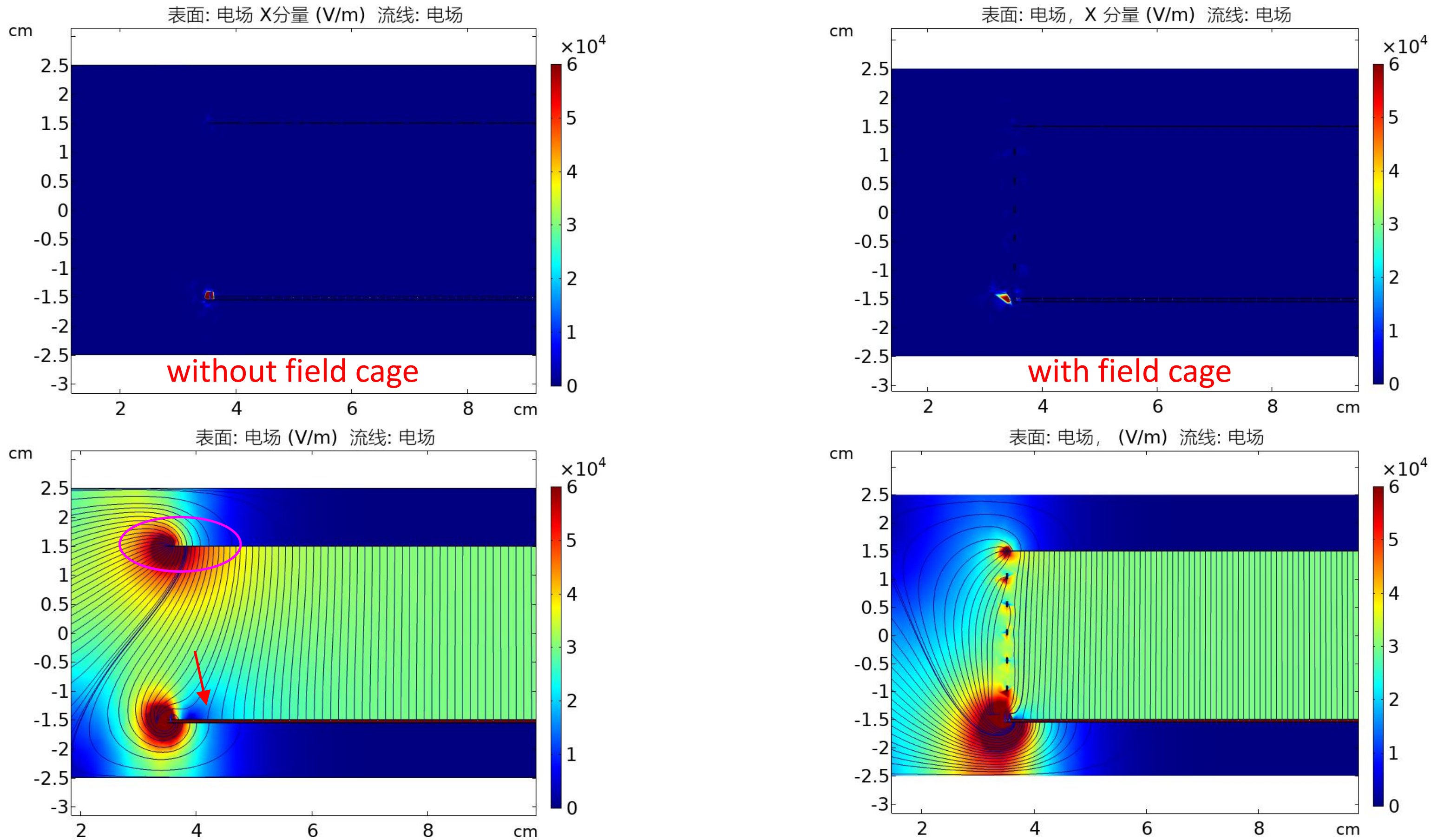
- Distance between beryllium window and end point of the drift plane 0.3 cm
- Drift depth is 2 cm (limited on size of Be)
- Height of the TPC > 2.2 cm

Dimension



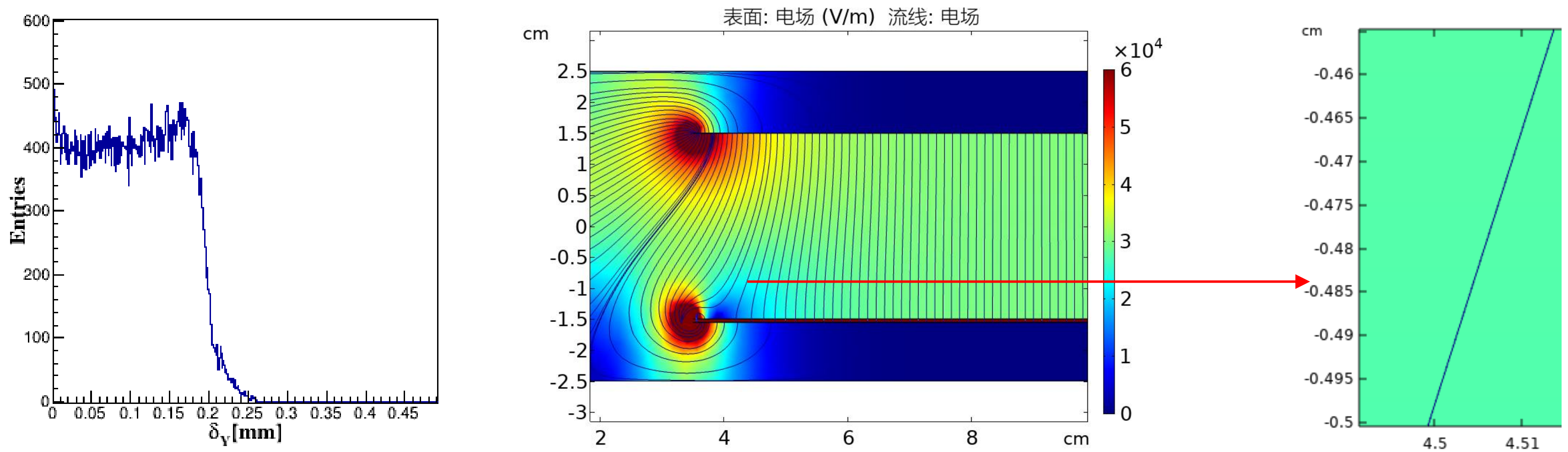
Optimization of electric field

Position and timing ← X and Y direction



Dimension

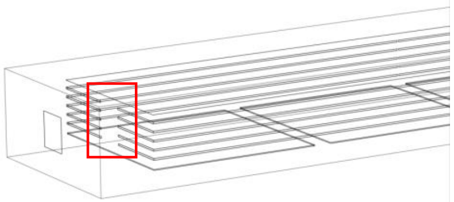
Timing distortion



- Distance between two adjacent ionization electrons < 0.25 mm (Mean free path)
- Timing distortion characterized as distance <0.1 mm (smaller than diffusion[0.15 mm])
- The drift region is accepted if ionization electrons can drift through the GEM plane

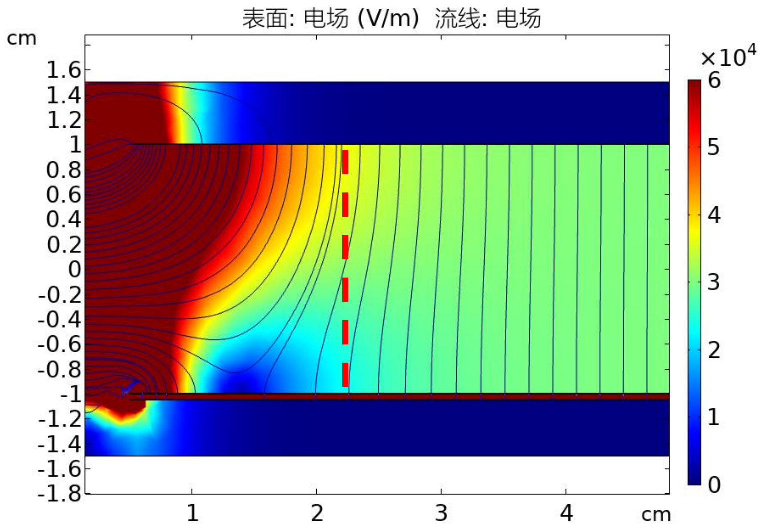
Dimension

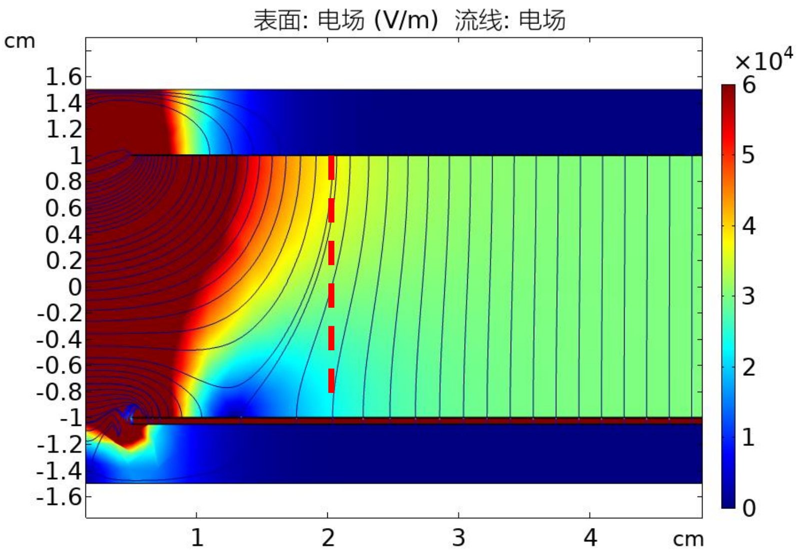
Timing influence



Get the time distribution in this region

Cut the shield region of the field cage



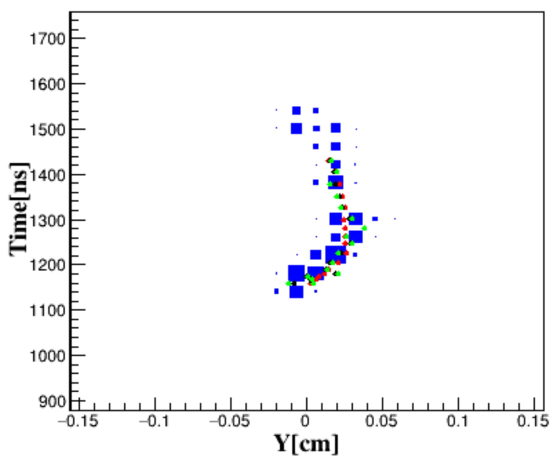


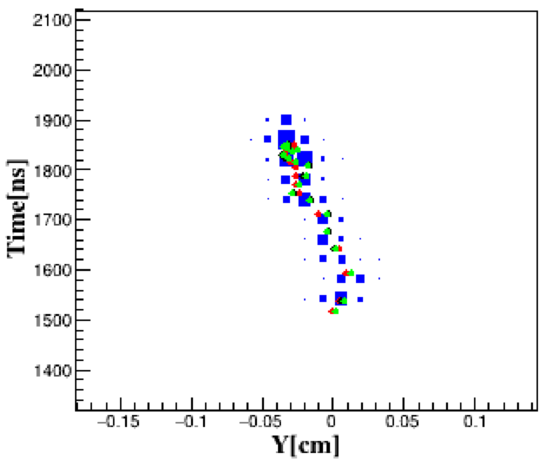
- Increase 1% effective events with field cage
- The affection is not obvious with field cage

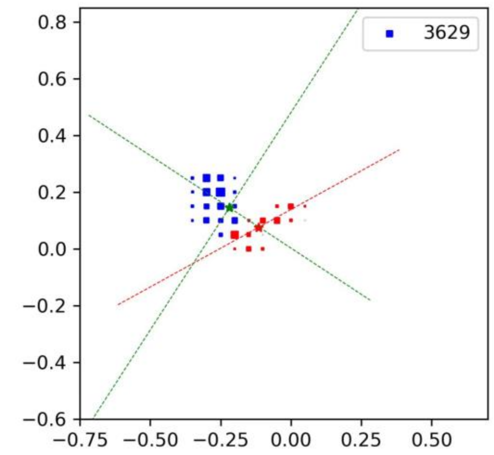
Sample generation

Image generation

- Fast simulation framework
- trip distance (130 um) and drift time (40 ns)
- Effective gain 3000 with Polya function (PDF sampling)



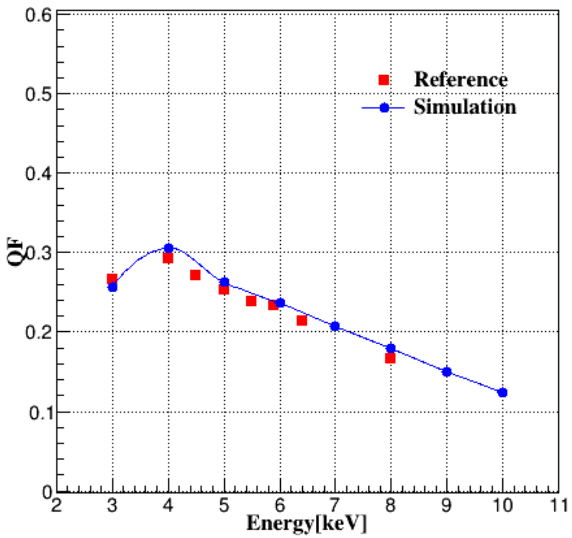




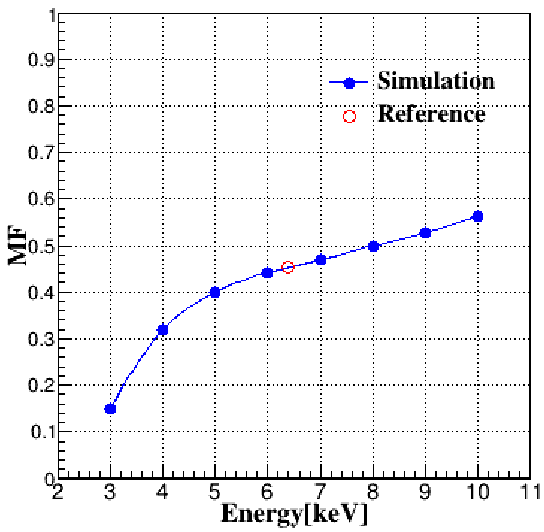
Validation

Comparison

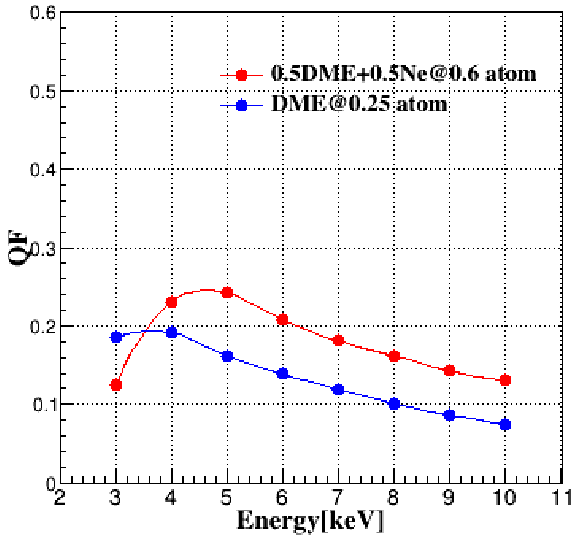
DME,0.25atom, 32 cm



0.5DME+0.5Ne,0.6 atom,
94% Efficiency



Depth of 10 cm



Gas

Candidate

6.4 keV, 0.6 atom, 0.33 cm/us

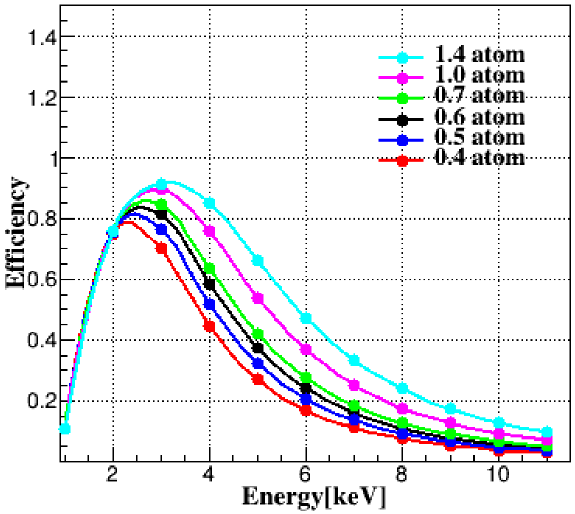
Gas	L [%]	RDE[%]	D[um$\sqrt{cm}$]	EF[V/cm]	L/D	L/D× $\sqrt{E}$
DME	0.69	0.63	**0.72**	600	**0.958333**	0.760654
NE	**1.91**	0.96	16.33	41	0.116963	0.114599
CO2	0.85	0.89	1.04	270	0.817308	0.771047
He	**10.5**	0.001	5.75	60	1.826087	0.057746
Ar	0.39	4.03	14.39	250	0.027102	0.054407
CH4	**1.87**	0.12	4.31	15	0.433875	0.150299
DME+CO2	0.76	0.76	1.02	280	0.745098	0.649561
DME+Ne	1	1	1	307	**1**	**1**
DME+Ar	0.30	3.23	**0.99**	300	0.30303	0.544612
DME+CH4	0.96	0.34	**0.98**	315	**0.979592**	0.571195

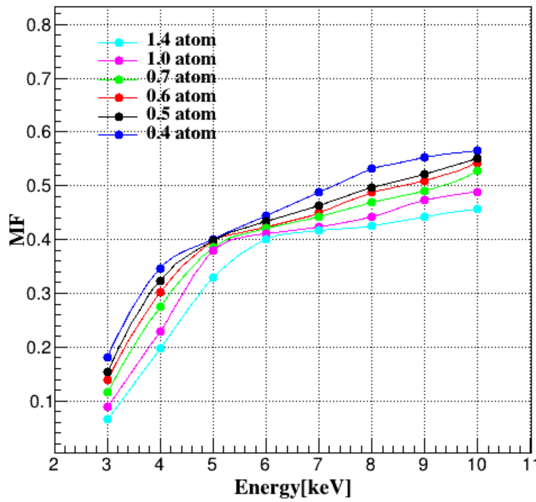
L=Length **RDE**=Relative Detection Efficiency **D**=Diffusion **EF**= Electric Field

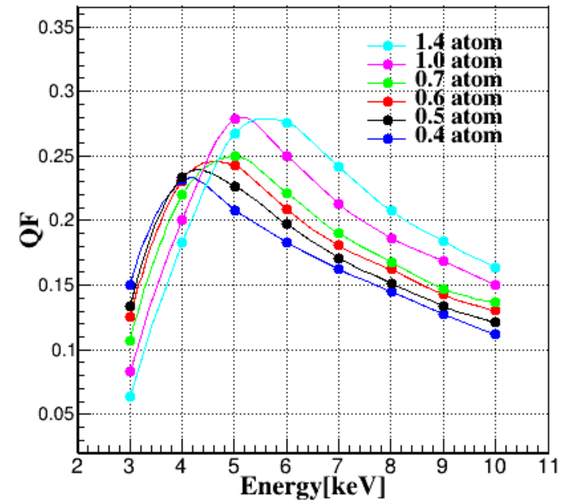
Optimization

Pressure scan

0.5DME+0.5Ne, 10 cm





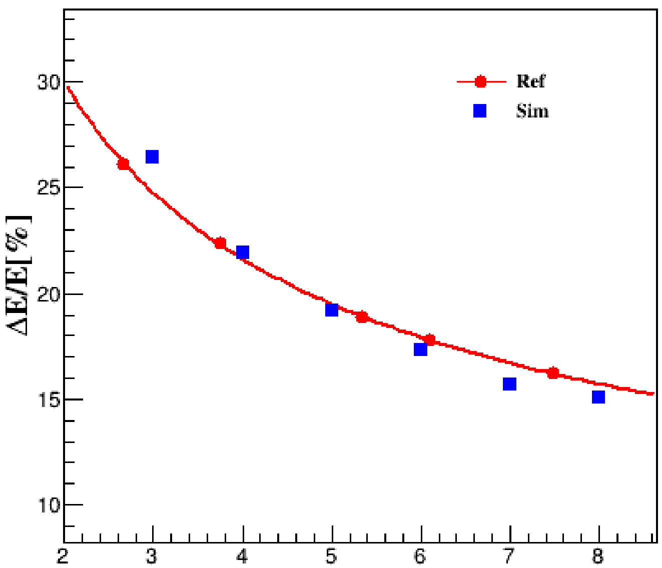


- MF > 0.4 @ 6keV as pressure <1 atom

Energy resolution

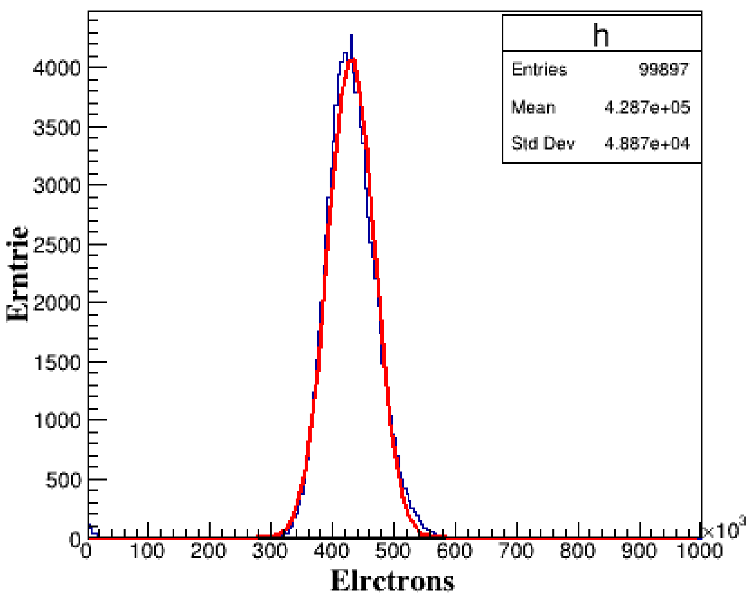
spectrum

DME 0.8 atom



6 keV, 0.5DME+0.5Ne

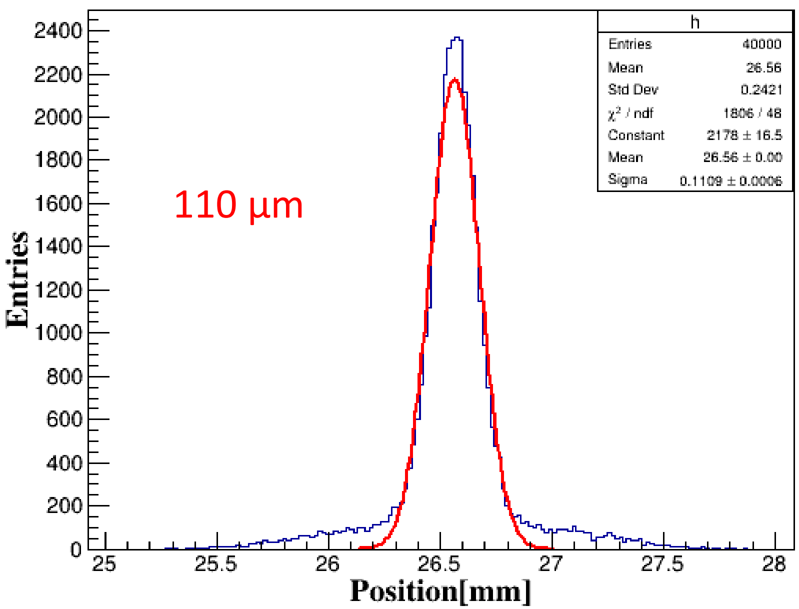
Sim 20.7%
Ref 20%

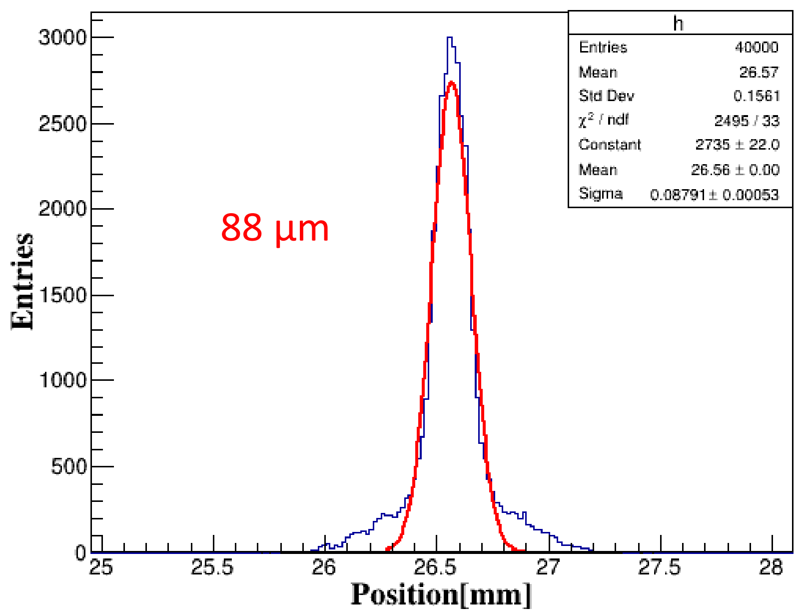


- Energy resolution < 30% @6keV for both of them

Position resolution

5 keV





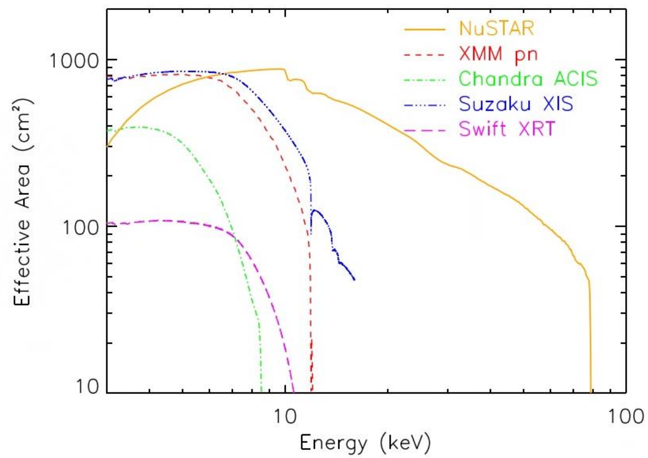
- Position resolution < 140 μm for both of them without rotation

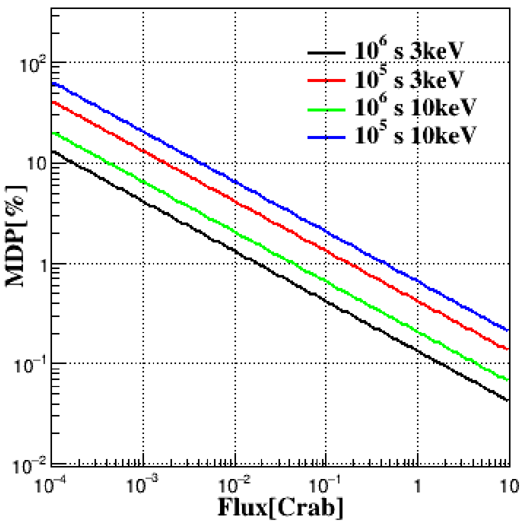
MDP

$$\mathrm{MDP} = \frac{4.29}{\mu\sqrt{F_s A_{\mathrm{eff}} \epsilon T}}$$

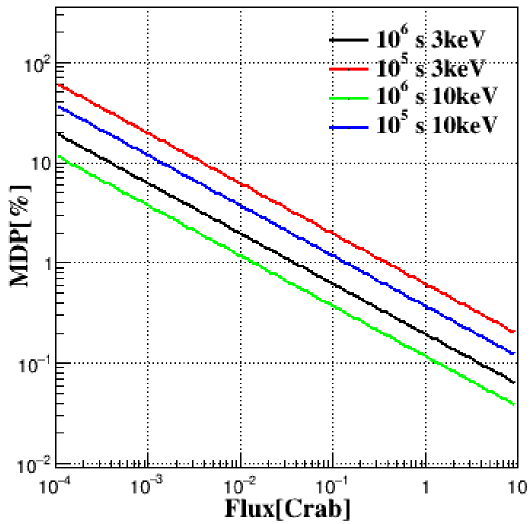
Refer NuSTAR focus mirror

- 305 cm^2@3 keV, 780 cm^2@10 keV
- QF 0.185 @3 keV, DME,0.25atom
- QF 0.074 @10 keV, DME,0.25atom
- QF 0.125 @3 keV, DME+Ne,0.6atom
- QF 0.130 @10 keV, DME+Ne,0.6atom

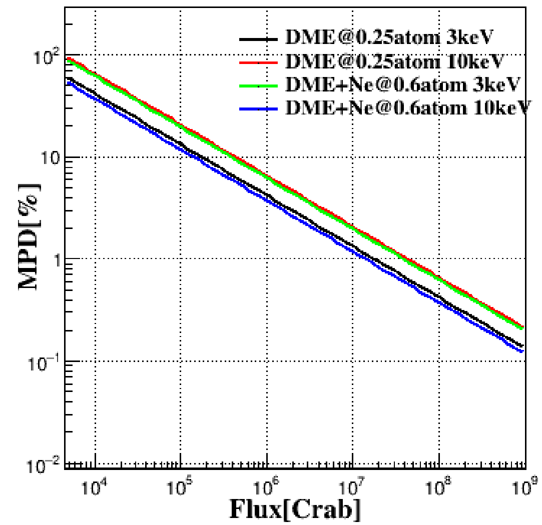




DME,0.25atom



DME+Ne,0.6atom



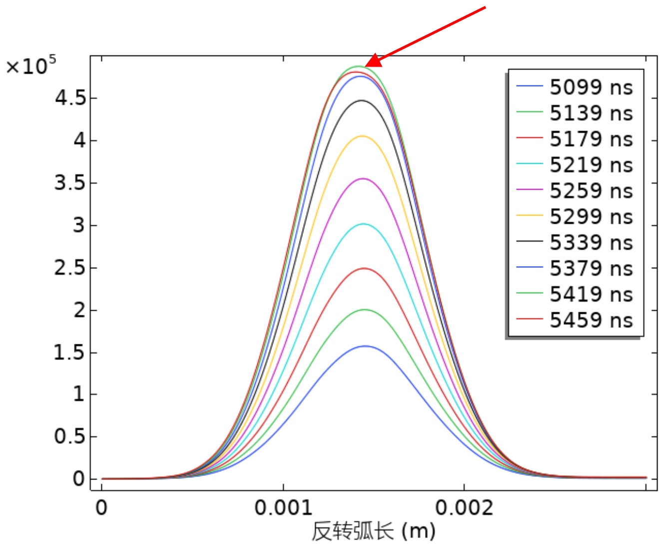
1 mCrab

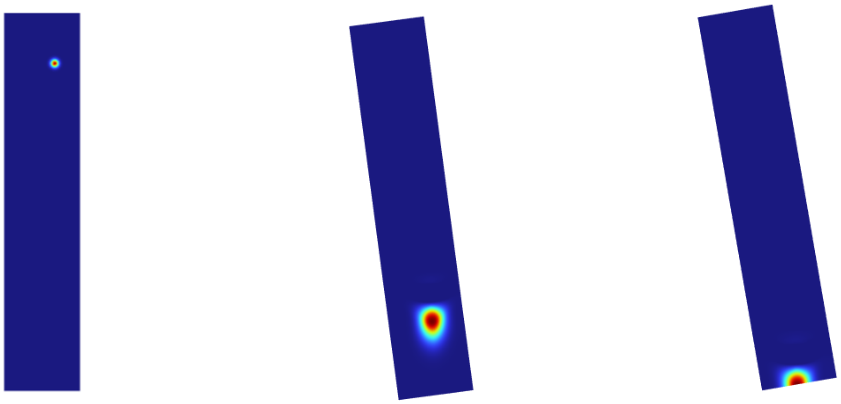
Rotate mode

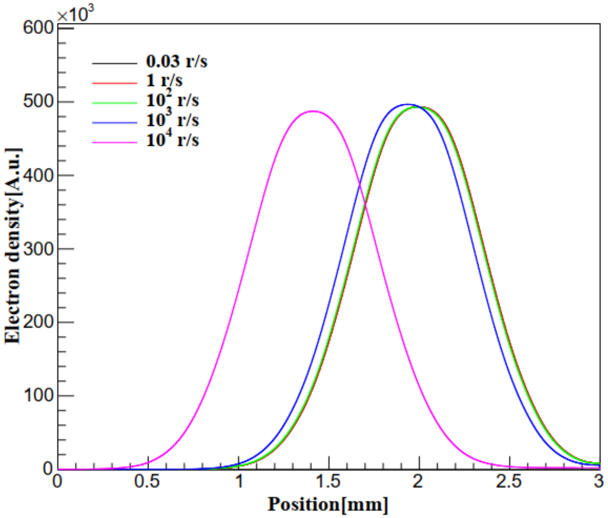
Dependence of angular velocity and optimization

- Hard to evaluate distortion for each electron
- average behavior
- Initial position at point (2 mm, 13 mm)
- DME@0.25atom, 196V/cm

r.p.s	10000	1000	100	1	0
Position [μm]	586.10	59.74	7.06	1.25	1.19
Timing [ns]	12	6	1	<1	<1







Summary

- Distance between beryllium window and GEM >0.3 cm
- Drift depth is 2 cm (limited on size of Be)
- Height of the TPC > 2.2 cm
- Depth of the TPC is 10 cm (f=10 m)

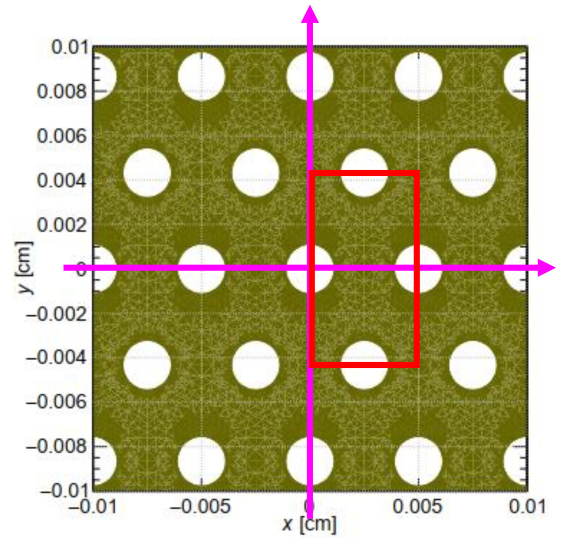
- DME or 0.5MDE+0.5Ne is good choice, both of them can satisfy MF>0.4@6 keV
- Position resolution <140 um without rotating mode
- Pure DME is better for X-ray observation at low energy (< 4 keV)
- 0.5MDE+0.5Ne is better for X-ray observation at high energy (4 ~10 keV)
- Little impact on photoelectric imaging with rotating mode

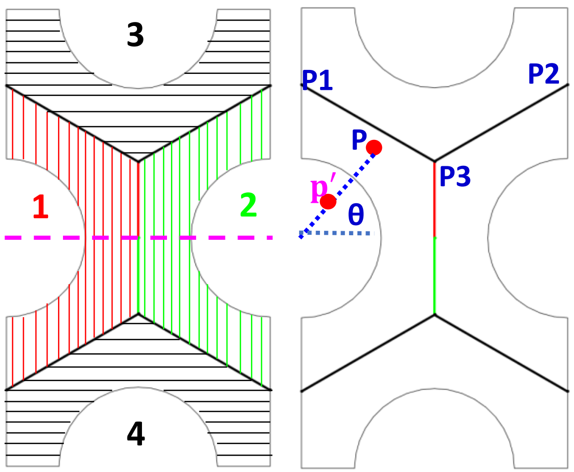
Back up

Sample generation

Fast simulation

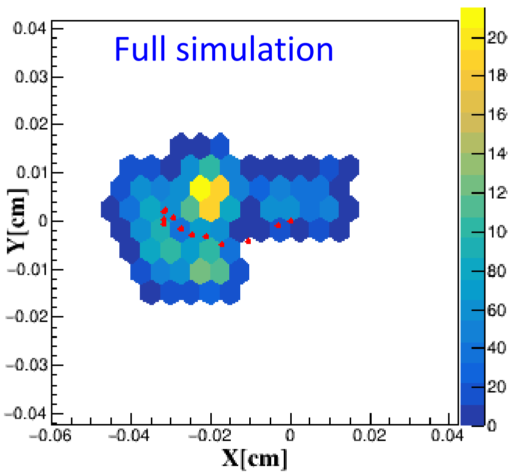
- Sampling point P(x,y)
- Find the related minimal period region (MPR)
- Judge the upper/lower part of the MPR
- Find the boundary point P1,P2,P3
- Give the boundary linear
- Compare the value of the point (x,y) with the boundary linear
- Obtain the nearest GEM hole coordinate P0
- Calculate the ratio R of distance [P,P0] over distance [P1,P2]
- Calculate the angle θ and the radius r, r=R×Ra(the radius of GEM hole)
- Obtain the initial multiplier point p'

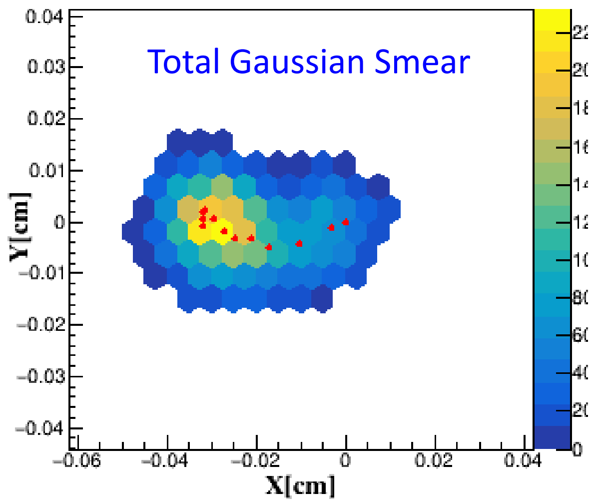


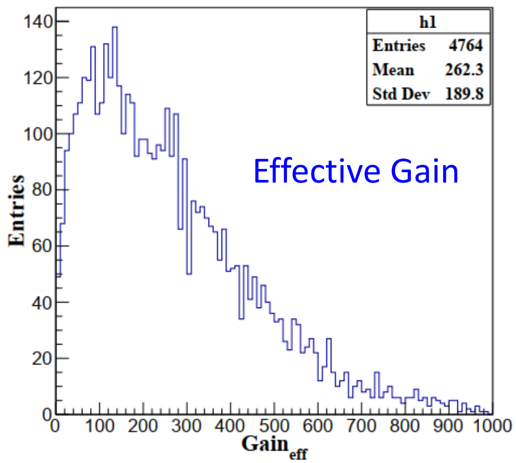


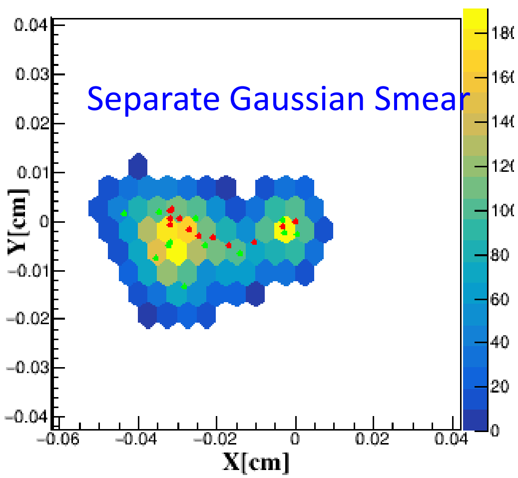
Sample generation

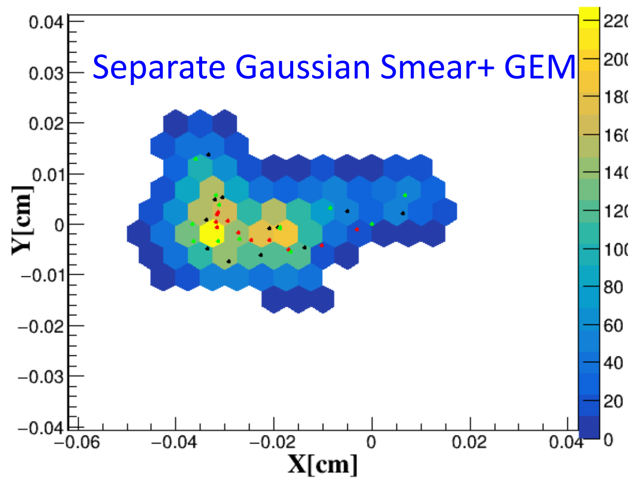
Imagine Generation

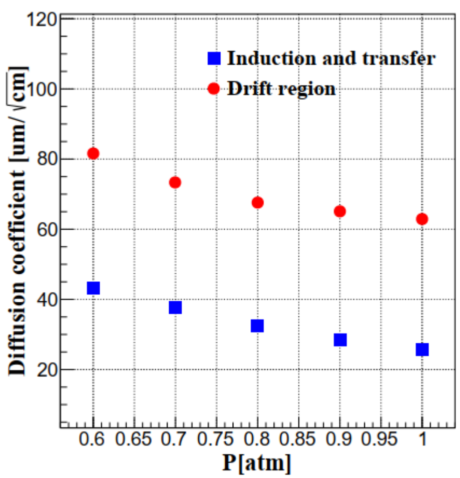








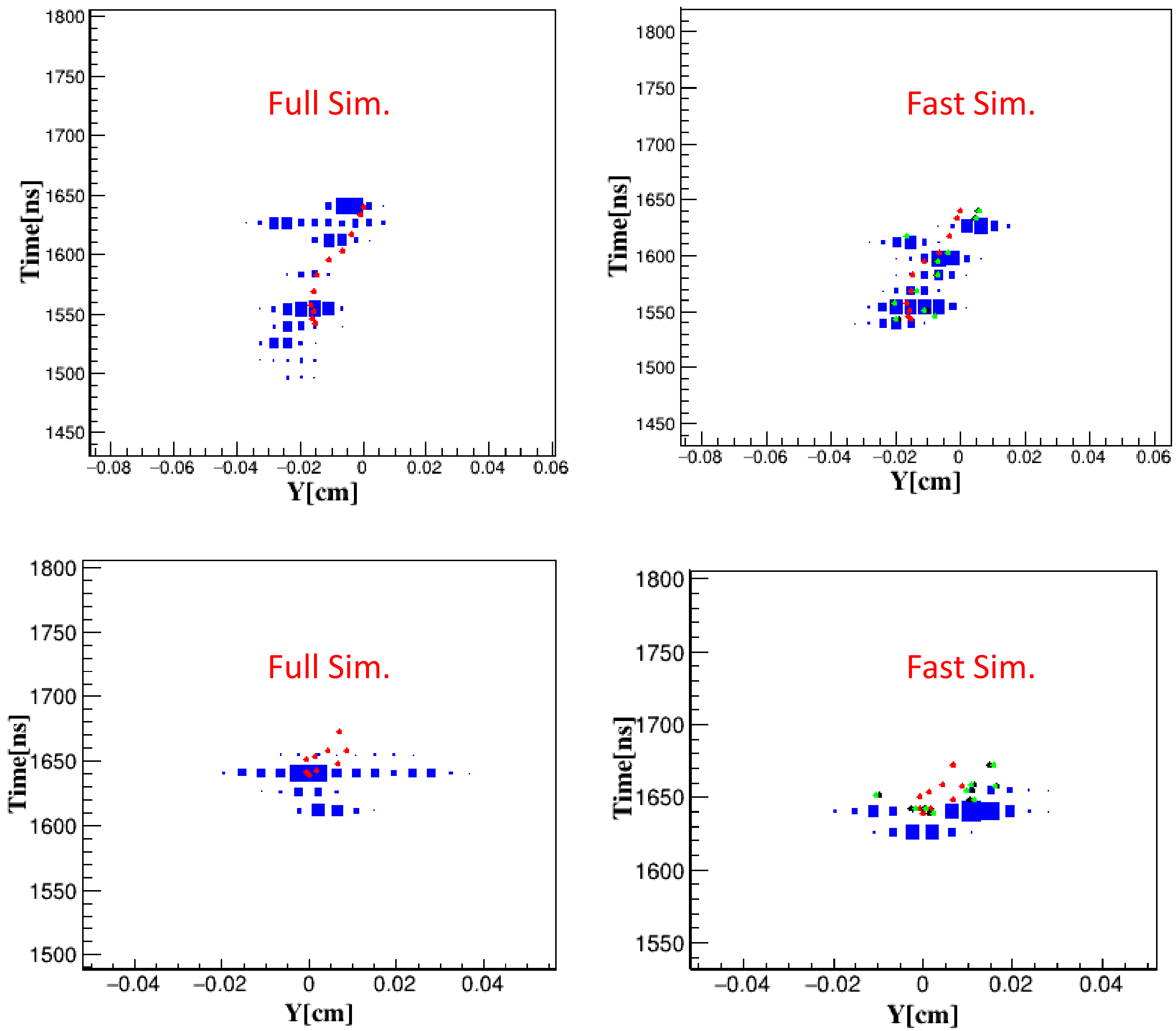




Sample generation

Fast simulation

- Input parameters
  - GEM pitch D
  - GEM hole R
  - GEM plane H
  - Read-out plane h
  - Effective gain G
  - Standard deviation σ_G
  - Diffusion coefficient σ_D
  - Drift velocity v_D
  - Induction region σ_I
  - Induction region v_I

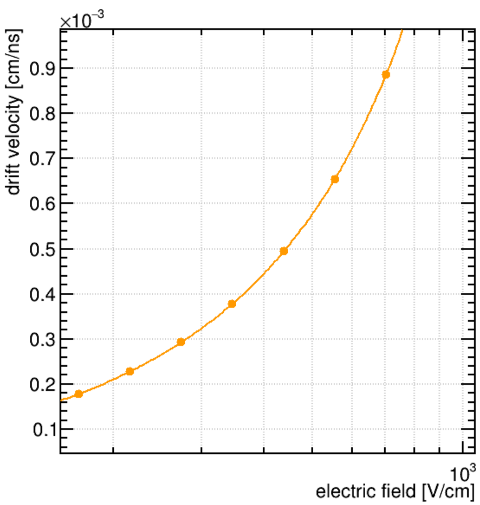


Sample generation

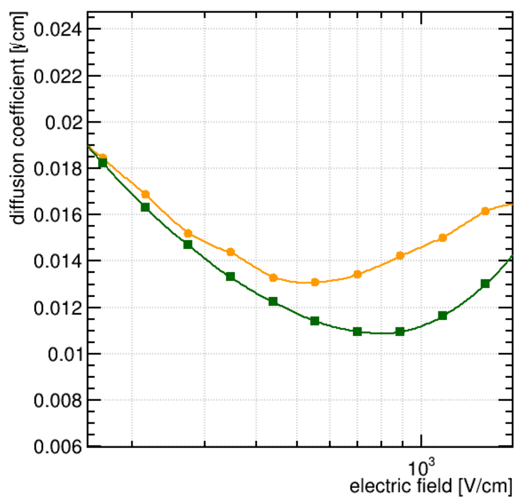
Input parameters

0.5DME+0.5Ne,0.6 atom,

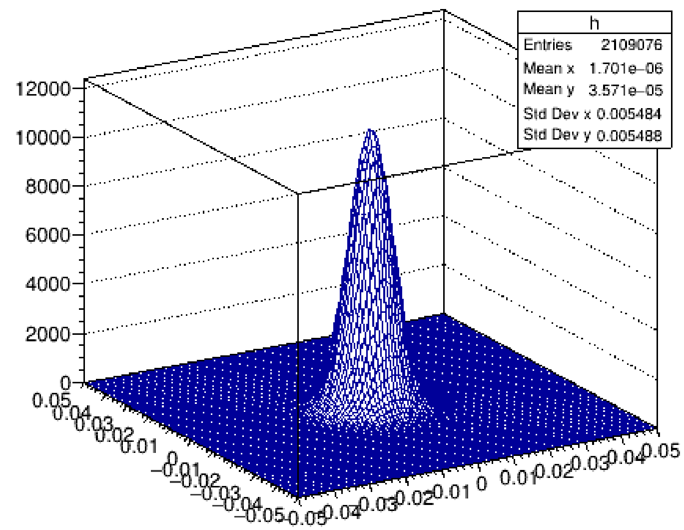
Drift velocity 3.3mm/us



Diffusion $0.0140\sqrt{cm}$



Diffusion 0.005 cm



Pressure

<u>Parameters scan</u>

4 keV, 0.5DME+0.5Ne, 0.33 cm/us,10 cm

Gas	L [%]	RDE[%]	D[um$\sqrt{cm}$]	EF[V/cm]	L/D	L/D× $\sqrt{E}$
0.3	0.411	0.36	200	150	1.431343	0.858806
0.4	0.308	0.44	173	200	1.240043	0.822551
0.5	0.241	0.52	153	250	1.097129	0.791151
0.6	0.201	0.58	140	300	1	0.761577
0.7	0.171	0.64	127	356	0.937831	0.750264
0.8	0.148	0.68	121	408	0.851939	0.702527
0.9	0.131	0.72	114	464	0.800384	0.679148
1	0.115	0.75	107	510	0.748593	0.648301
1.1	0.106	0.78	101	563	0.730998	0.6456
1.2	0.096	0.81	98	612	0.682303	0.614072
1.3	0.088	0.83	95	658	0.645195	0.587801
1.4	0.081	0.85	90	710	0.626866	0.577942

Charge behavior model

- Combination of charges and electric field

$$\frac{\partial \rho}{\partial t} = -\vec{\nabla} \cdot (\rho \vec{v} - D \vec{\nabla} \rho) + R$$

ρ is the unknown

$$\rho_v = \frac{Q_e}{\epsilon_0}(n_i - n_e)$$

For what concerns the boundary conditions, some examples

$$\vec{n} \cdot \vec{J}^{tot} = 0$$ No flux

$$-\vec{n} \cdot \vec{J}^{tot} = \Phi(\vec{x}, t)$$ Input flux

$$\vec{n} \cdot \vec{J}^{diff} = 0$$ Output

$$\rho = \Psi(\vec{x}, t)$$ Concentration

$$\vec{\nabla} \cdot \vec{D} = \rho$$

$$\vec{D} = \epsilon \vec{E}$$

$$\vec{E} = -\vec{\nabla} V$$

$$\vec{\nabla} \cdot \epsilon \vec{\nabla} V = -\rho$$

$$R = n_e u(\alpha - C_a - X)$$