Current status of MPGD simulation in negative ion gas for direction-sensitive dark matter search

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NEWAGE

- **Direction-sensitive** dark matter search at Kamioka Observatory, Japan
- uses gaseous TPC “$\mu$-TPC” with $\mu$ –PIC and low pressure gas
- expects “WIMP-wind” - directional recoil angle distribution

![Diagram showing the direction-sensitive search and the夏能观测站](image)

We are moving toward CYGNUS constellation: expects “WIMP-wind”

- $\text{CF}_4$, 0.1 atm
- $41\text{ cm}$

![Images of $\mu$-PIC and GEM modules](images)

2D readout $+\Delta T_{\text{sig}}$ $+\nu_d$ $=3D$ position

we aim to detect nuclear recoil with Dark Matter

please see
Kentaro Miuchi
Sep 2017
RD51 Collaboration Meeting
Negative Ion TPC for Dark matter search

• Problem: background
  • α-ray backgrounds from U/Th in glass fiber of µ-PIC (radioactive contamination)

Solution:
• production of low-alpha µ-PIC (Low contamination of U/Th)

• full-fiducial analysis with Negative Ion TPC with Negative Ion gas (CS2, SF6,...)
(Related to this talk)

Takashi Hashimoto LRT2017 arXiv:1707.09744
Negative Ion TPC principle

Several ion species are created and drift at different velocity.

Using time difference to determine absolute z position → full-fiducial analysis
MPGD in negative ion gas

Goal: Background reduction with Negative Ion \(\mu\)TPC

- Understanding of MPGD characteristics in NI gas
- Detector Optimization for DM search

\[ SF_6 + e^- \rightarrow SF_6^- \]

need to consider...
- avalanche
- attachment
- detachment

process

Experiment & Simulation & other research

-> Understanding of MPGD characteristics in NI gas

There are 50\(\mu\)m & 400\(\mu\)m thickness GEM results (done by other groups) + 100\(\mu\)m results

-> better understanding of MPGD in NI gas

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RD51 Collaboration Meeting
GEM Gain measurement in SF$_6$

- Double/Triple-GEM (Scienergy LCP 100μmGEM)
- SF$_6$ 100%
- parameters: pressure, electric field

Amp : CREMAT CR-110, Gain : 1.4V/pC, time constant:140μs
Readout : 400μm pitch strip readout 24strip(9.6mm)
HV: Drift, GEMx3's Top&Bottom, Readout
### GEM Gain measurement Result in SF$_6$

- **Double-GEM**
  - Gain up to $7 \times 10^3$ @100Torr
  - $\Delta V_{\text{GEM}} = 550$V
  - FWHM: ~60%

- **Triple-GEM**
  - Gain up to $7 \times 10^3$ @100Torr
  - $\Delta V_{\text{GEM}}$ and Gas Gain (SF$_6$ 60~120torr)
  - FWHM: ~80%

Note: Triple-GEM Gain FWHM: 20~30% @ Ar + C$_2$H$_6$ 90:10 1atm
GEM Gain measurement Result in SF$_6$

From 100Torr Triple/Double-GEM result, plot GEM gain per single GEM $\sqrt[3]{G_{\text{triple}}} \cdot \sqrt[2]{G_{\text{double}}}$ as $\Delta V_{GEM}$ function → On the same gain curve

charge loss between GEMs : negligible? Triple and Double comparison @100Torr

Next Step: Can we reproduce this curve with simulation?
MPGD simulation in $\text{SF}_6$ (Negative Ion gas)

Can we describe and reproduce

- MPGD measurement results in $\text{SF}_6$
  - Gas gain, energy resolution etc.

by simulation?

We want to do that with
Garfield++ or/and Magboltz

- Simulations: help us to understand MPGD characteristics in $\text{SF}_6$ and do optimization for DM search.

- As first step, We tried to reproduce GEM gain results with Magboltz
Garfield++/ Magboltz

About Garfield++ and Magboltz

• Garfield++
  • Gas and semi-conductor detector simulation tool kit with Medium characteristics (Gas, Semi-conductor), geometry, electric field calculation, calculate charge transport

• Magboltz
  • From electron/molecules cross-section, solve Boltzmann equation or Monte Carlo simulation and calculate drift velocity, diffusion, Townsend / Attachment coefficients.
Magboltz - $\text{SF}_6$ data

- $e^-/\text{SF}_6$ cross section data in Magboltz


- Magboltz 10.6 (picked up some reaction, right bottom) (Biagi (Magboltz 10.6 data), ) has 50 $e^-/\text{SF}_6$ cross section data

Does this difference make significant difference?

Biagi (Magboltz 10.6 data)
Result difference between Magboltz Ver.

- In the case of Townsend coefficient calculation at low Electric field, calculation result difference at low Electric field
Is it because of cross section difference or algorithm change?

-> need to be investigated

And Garfield++ can’t call Magboltz Ver. 10.x later because of interface change
- It is need to use newer Magboltz? (with Garfield++)
- How to call from Garfield++?

Now we use Magboltz 11.4 solely for our calculation
Townsend/Attachment coefficient calculation

• Townsend($\alpha$) /Attachment($\eta$) calculation with Magboltz 11.4

Townsend($\alpha$): $[cm^{-1}]$
number of multiplied electrons per length

Attachment($\eta$): $[cm^{-1}]$
number of attached electrons per length

Gain M is
\[ M = \exp((\alpha - \eta) \times \text{gap}) \]

• We started Townsend/Attachment calculation with Magboltz and tried to reproduce experimental results.

\[ \alpha, \eta \]
\begin{align*}
\alpha: \text{Townsend coefficient (blue)} \\
\eta: \text{Attachment coefficient (purple)}
\end{align*}

\[ SF_6 100\text{Torr (Magboltz 11.4)} \]
\[ \alpha - \eta: \text{(yellow)} \]
Comparison between measurement and simulation

We assumed:

\[ M = \exp((\alpha - \eta) \times \text{gap}) \]  

1. Electric field: \( E = \frac{V_{\text{GEM}}}{100 \ \mu m} \) (rough estimation)
2. \( \alpha-\eta \) : from Magboltz 11.4 at above \( E \)
3. Gap length: \( \text{gap} = 27 \mu m \) from \( \Delta V_{\text{GEM}} = 500V \) calculation result

Can we reproduce gain curve?

Result:
Pink dots in the right graph
-> not good agreement with exp. results

Reason?
- detachment effect @ Low E field
- uniform electric field assumption

\[ \text{gap} = \frac{\ln M}{\alpha - \eta} \]
Hypothesis

- Effective Townsend coefficient is suppressed at low electric field because of small detachment and few seed electrons?

- Low electric field suppresses electron detachment and there are fewer seed electrons → also suppress avalanche?
  → steep Townsend coefficient slope

Plan:
introduce this effect parameter and try to reproduce gain curve and confirm this.
Too rough GEM electric field assumption?

- Electric field Map by Gmsh(mesh)+ Elmer (electric field)
- Not uniform
- Lower E than we assumed → if we did overestimate E field, Townsend coefficient slope: eepst

Future plan:
More detailed GEM electron field for Gain calculation
Toward Negative ion gas MPGD simulation...

We want to include MPGD geometry in simulation but...

- How is the detachment process?
- Detachment position fluctuation → avalanche gap variance? → gain fluctuation?

- Current Garfield++: Not detachment implementation need negative ion / electron treatment class

- Future plan implement these class and establish simulation method?

SF₆

avalanche vs GEM hole electric field
Future plan

- Try to do MPGD simulation with geometry using Garfied++
- compare Garfield++/Magboltz simulation with experiment result and establish negative ion model inside MPGD and confirm

Conclusion

- In SF$_6$ we measured Triple/Double-GEM Gas Gain with several parameters
- electron attachment to SF$_6$ could effect energy resolution
- Tried to reproduce GEM gain curve with Magboltz
- We started Garfield++/Magboltz simulation activity in SF$_6$