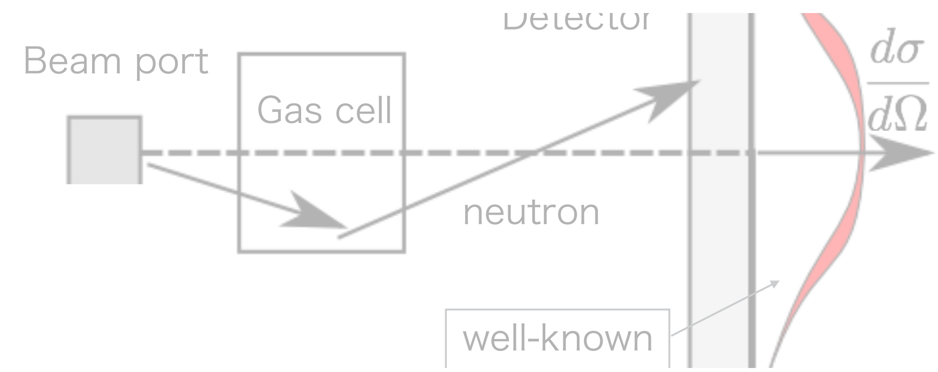
Measurement of neutron scattering with noble gas to search for an unknown force at J-PARC

Noriko OI

Nagoya University



Collaborators

Hirohiko M. Shimizu(Nagoya), Katsuya Hirota(Nagoya), Masaaki Kitaguchi(Nagoya), Christpher Craig Haddock(Indiana),William Michael Snow(Indiana), Kenji Mishima(KEK), Tamaki Yoshioka(Kyushu), Takashi Ino(KEK), Satoru Matsumoto(Kyushu) and Tatsushi Shima(Osaka)

Outline

Introduction

- Motivation
- Experimental principle

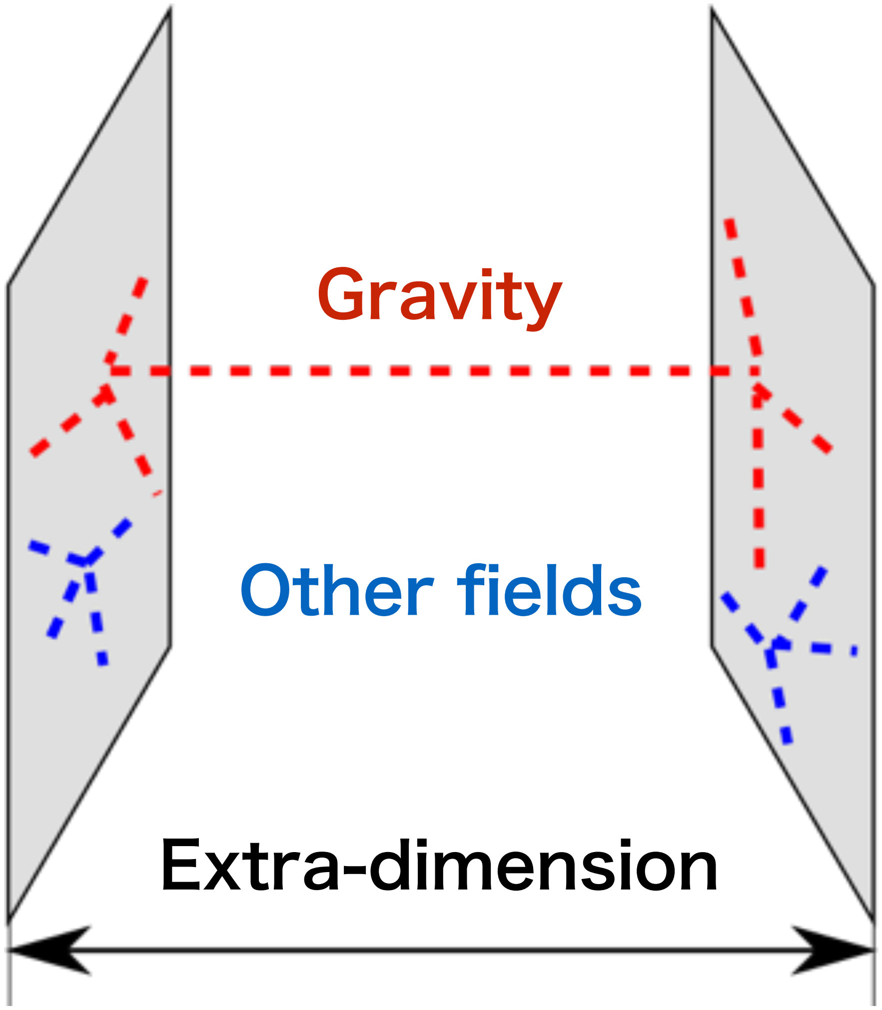
Facilities and Devices

Data analysis

- Method
- Experimental data

Summary

Introduction(Motivation)



If extra-dimension exists, Gravitational potential is different from Newtonian potential at short range.

Nima Arkani-Hamed, Savas Dimopoulos and Gia Dvali
Physics Letters B 429.3 (1998): 263-272.

$$V(r) = G\frac{m_1 m_2}{r}\left(1 + \alpha \exp\left(-\frac{r}{\lambda}\right)\right)$$

Newtonian potential — Yukawa potential

We search for **an unknown interaction**
by the difference from the well-known potential.

Introduction(Motivation)

$$V(r) = G\frac{m_1 m_2}{r}\left(1 + \alpha \exp\left(-\frac{r}{\lambda}\right)\right)$$

Born approximation for Yukawa potential term

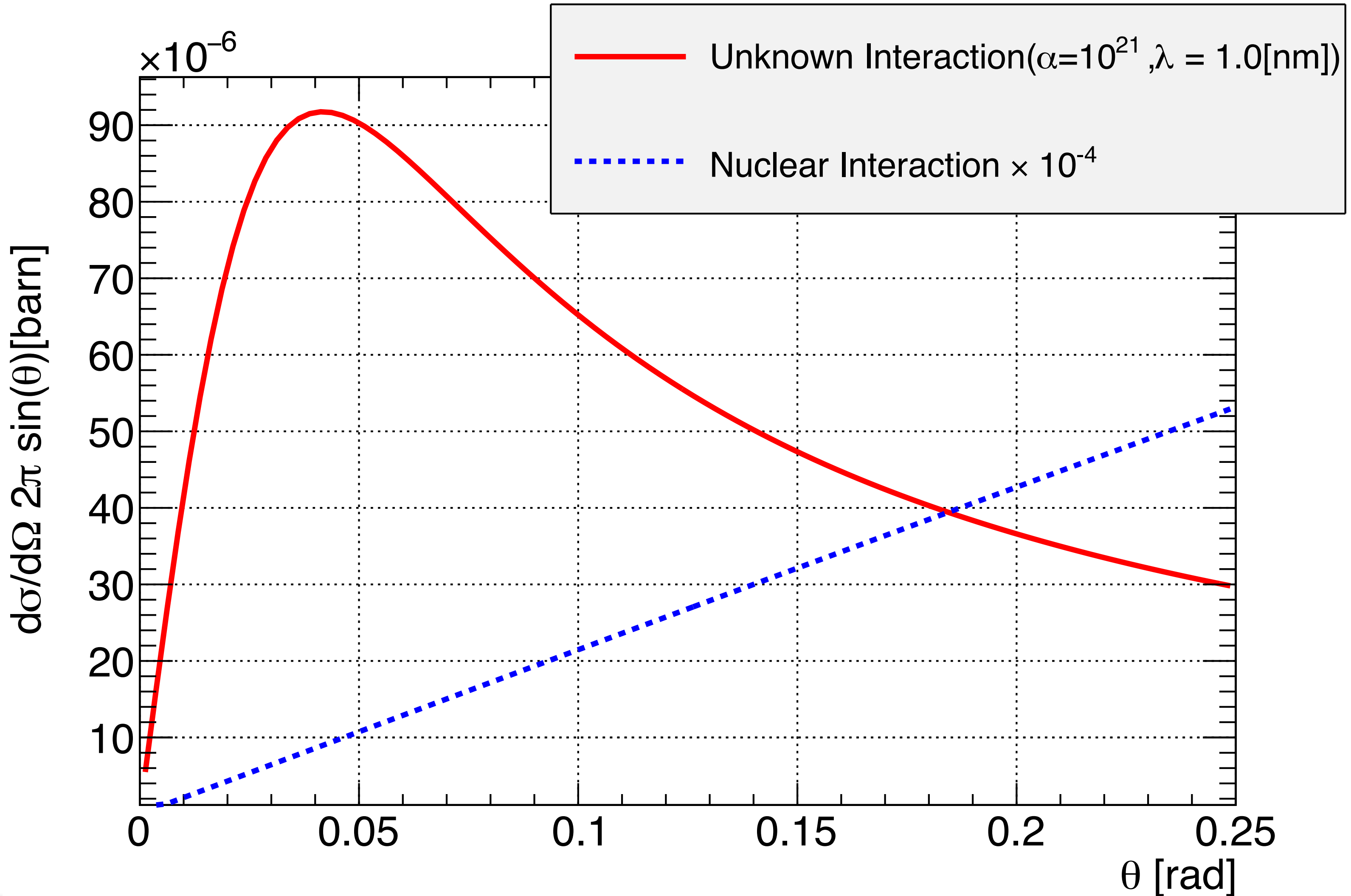
$$\frac{d\sigma}{d\Omega}(\theta)_Y \propto \sqrt{\sigma_{Nuclear}}\alpha m_{Xe}\lambda \left(\frac{1}{1 + C\sin^2\left(\frac{\theta}{2}\right)}\right)$$

Nuclear Scattering

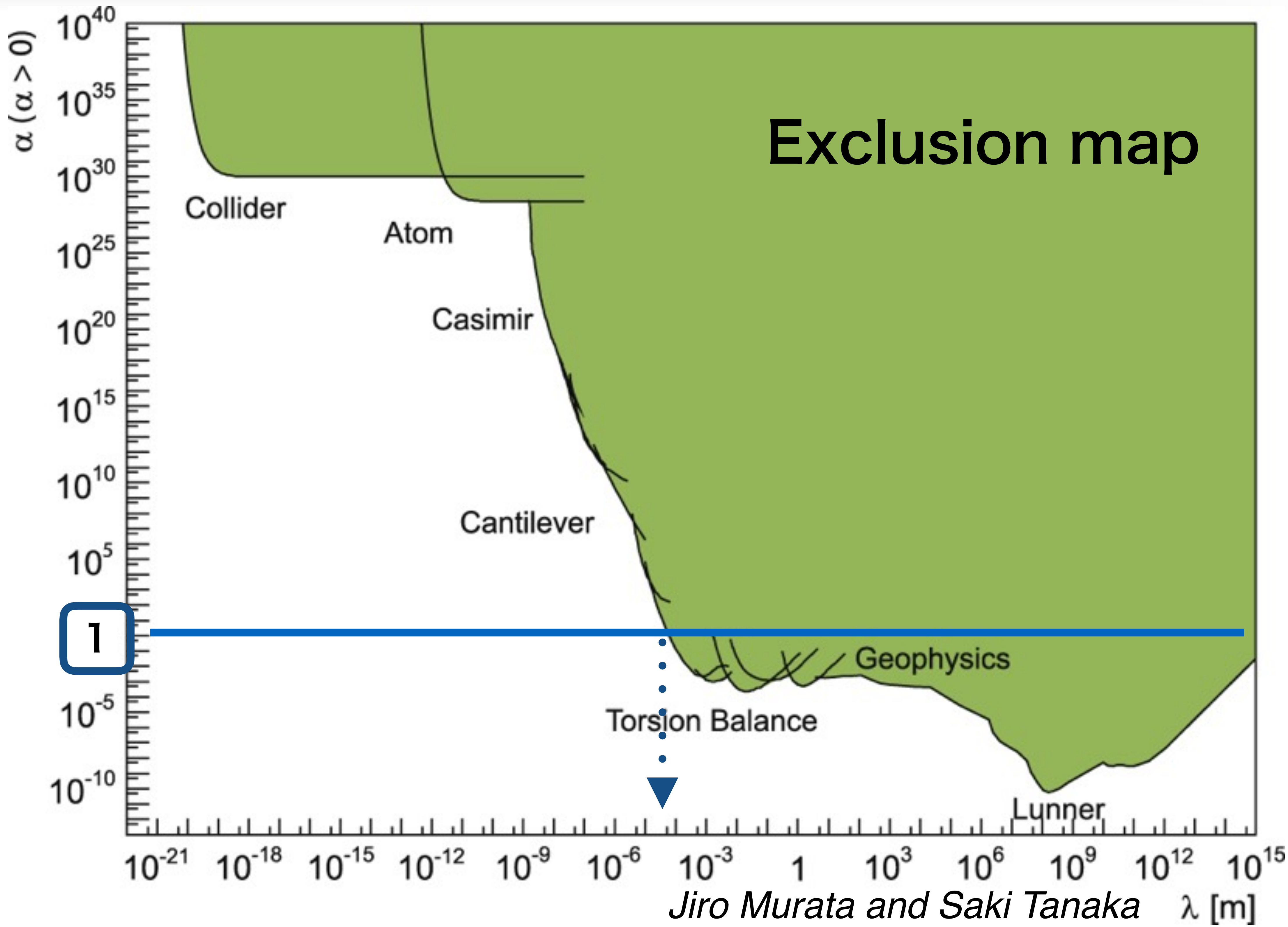
→ **Isotropic**

Yukawa Interaction

→ **Forward Scattering**



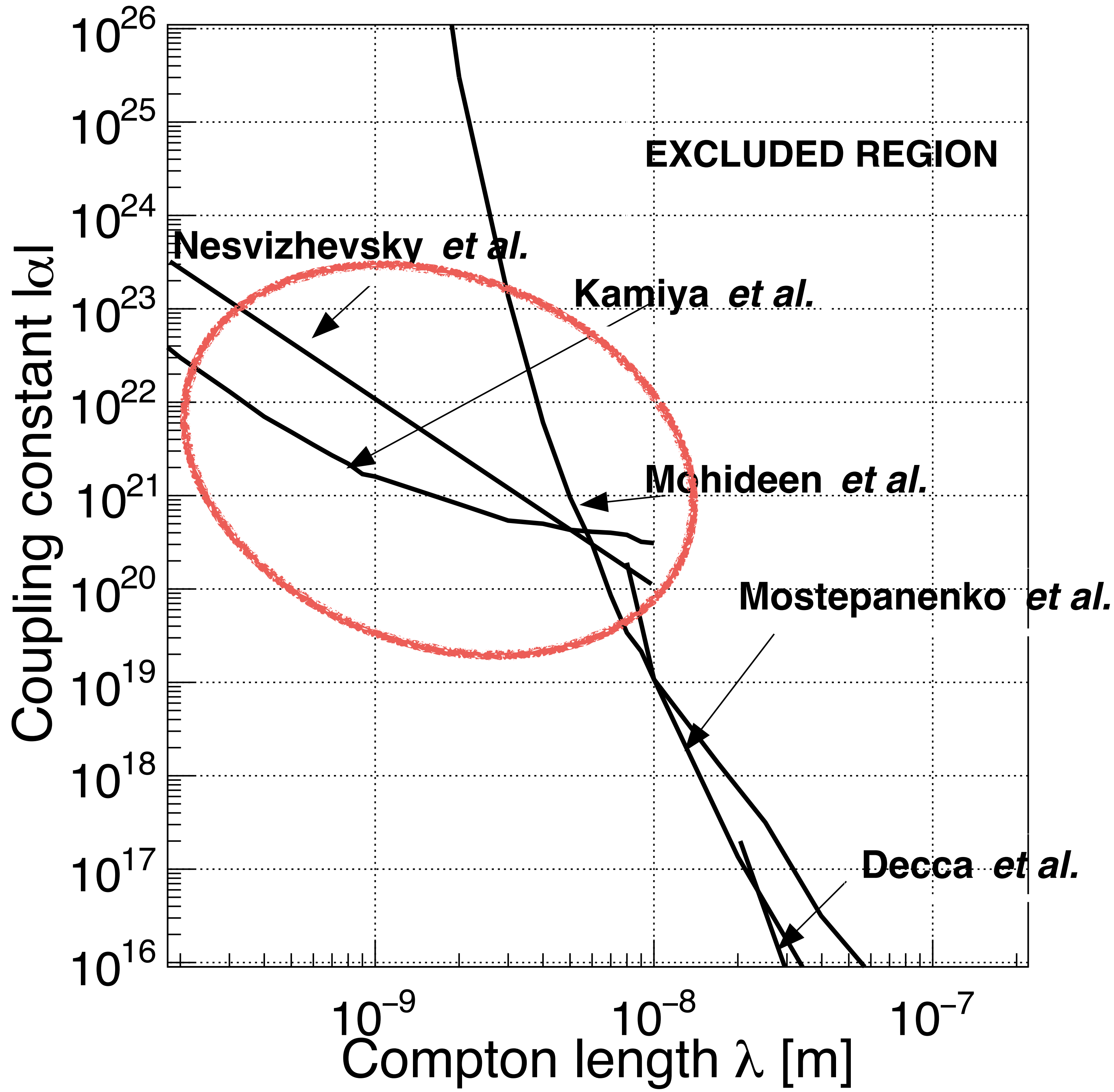
Introduction(Inverse square law)

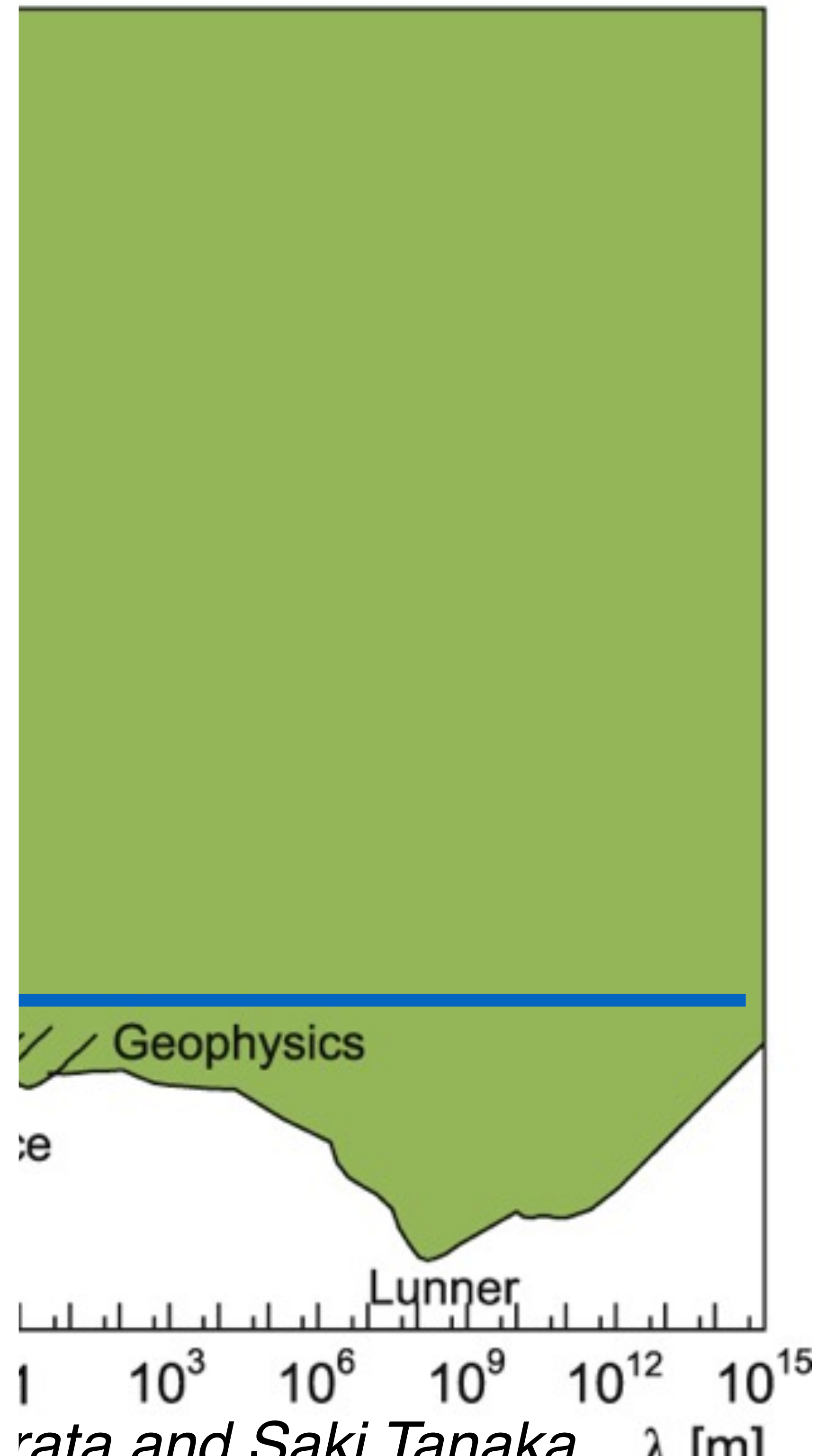


Jiro Murata and Saki Tanaka

Classical and Quantum Gravity 32.3 (2015): 033001.

Introduction(Inverse square law)



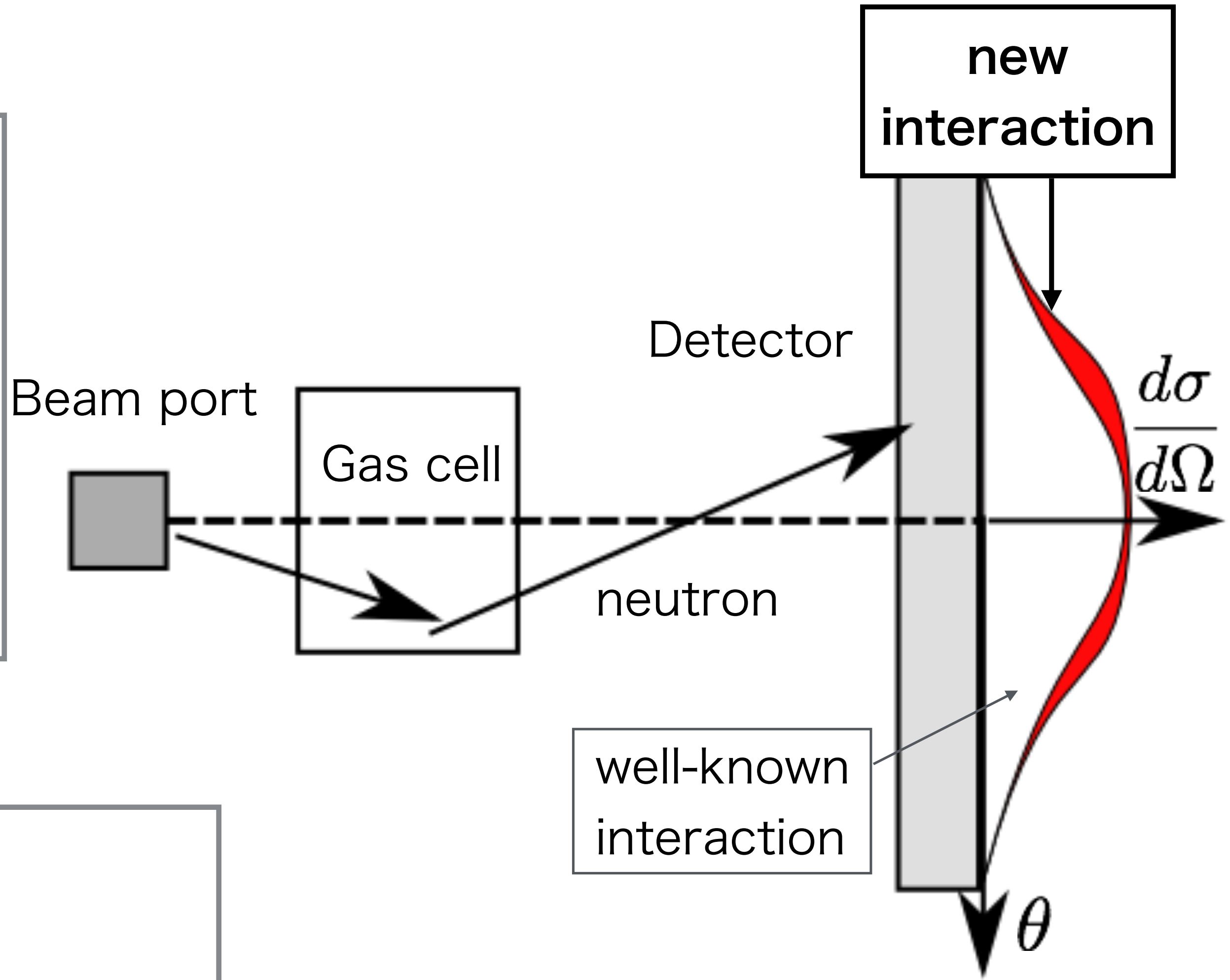


rata and Saki Tanaka
32.3 (2015): 033001.

Introduction (Principle)

Neutron is…

1. Electroneutral
   - ➜ Suppress electromagnetic interaction
     Suppress Van der Waals force
2. Massive
   - ➜ Interact by gravity



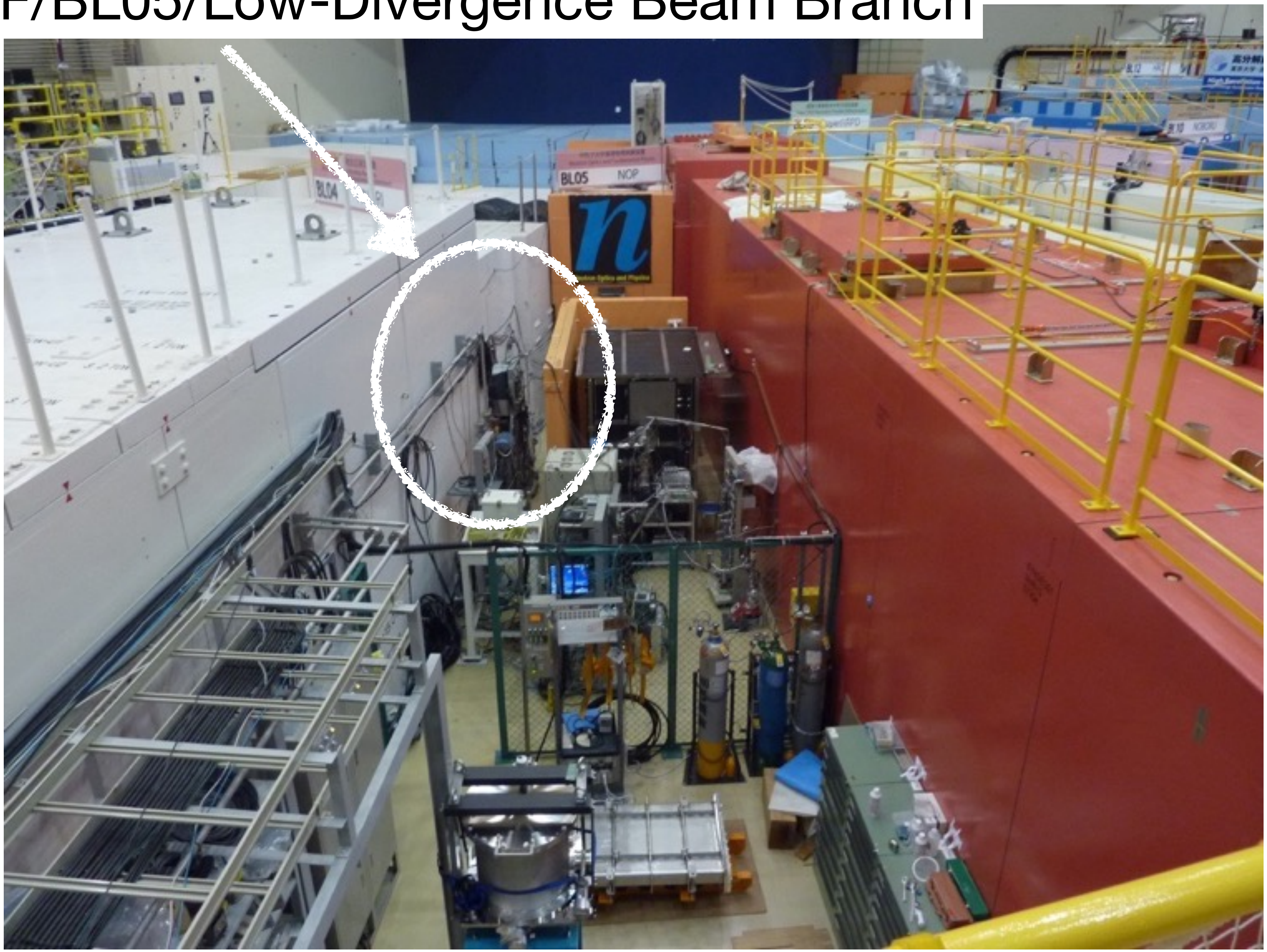
Noble gas has …

1. No molecular/crystal structure
2. Atomic spin 0
   - ➜ Do not need consider the effect of multipole.
3. Chemical stability

To search for an unknown force,
We measure **neutron scattering from noble gases**.

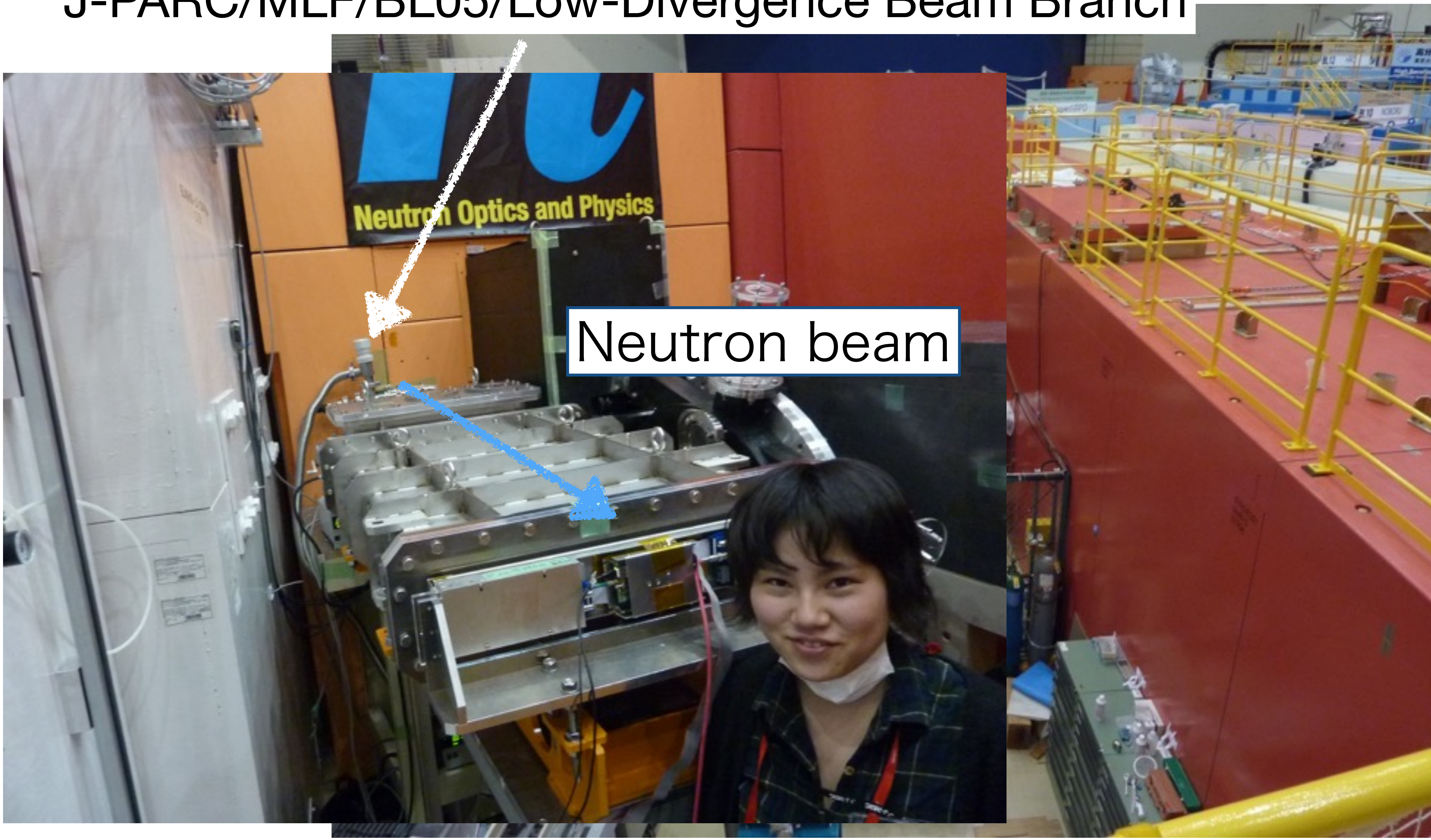
J-PARC/MLF/BL05(NOP)

J-PARC/MLF/BL05/Low-Divergence Beam Branch



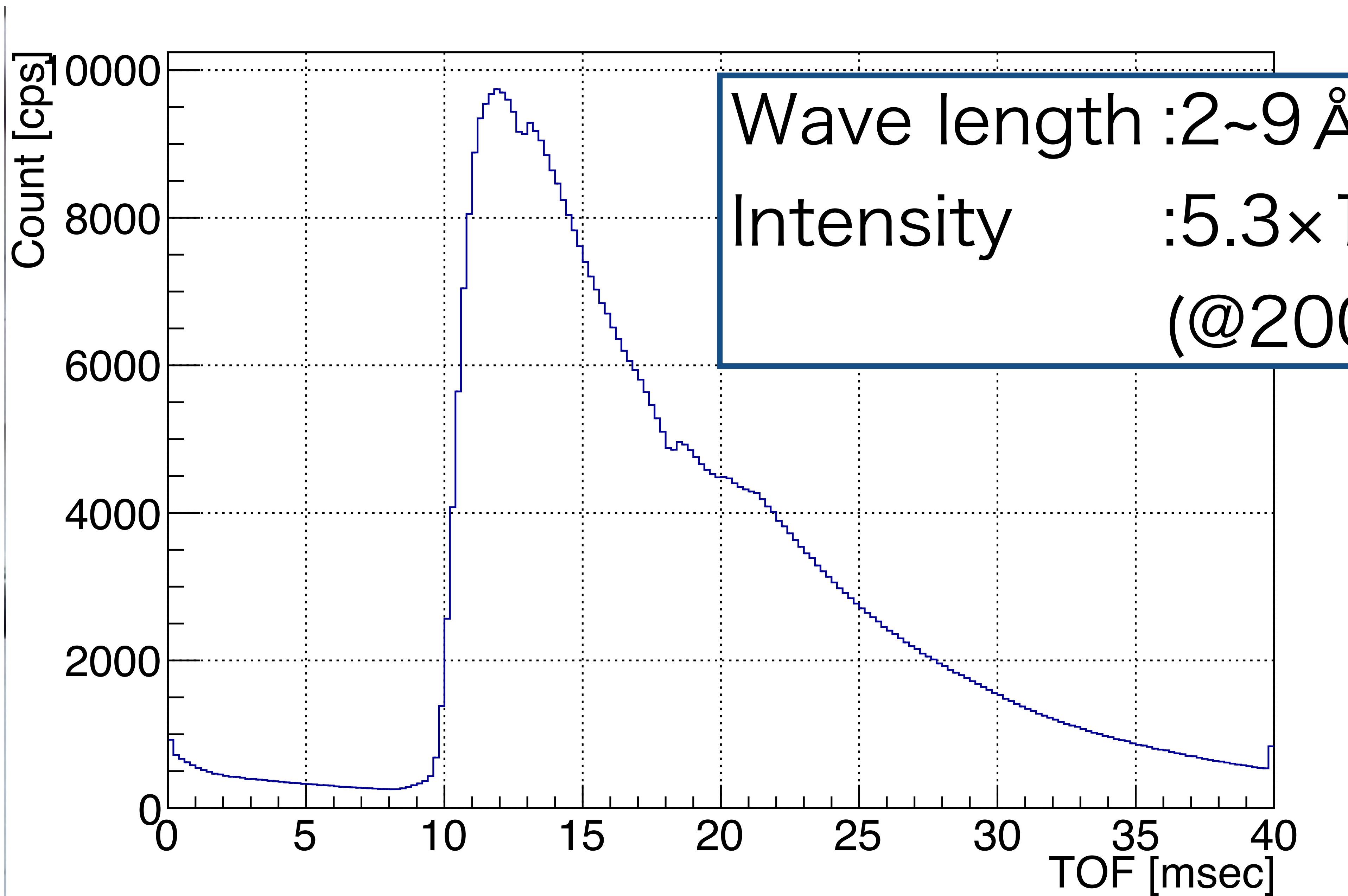
J-PARC/MLF/BL05(NOP)

J-PARC/MLF/BL05/Low-Divergence Beam Branch



J-PARC/MLF/BL05(NOP)

J-PARC/MLF/BL05/Low-Divergence Beam Branch



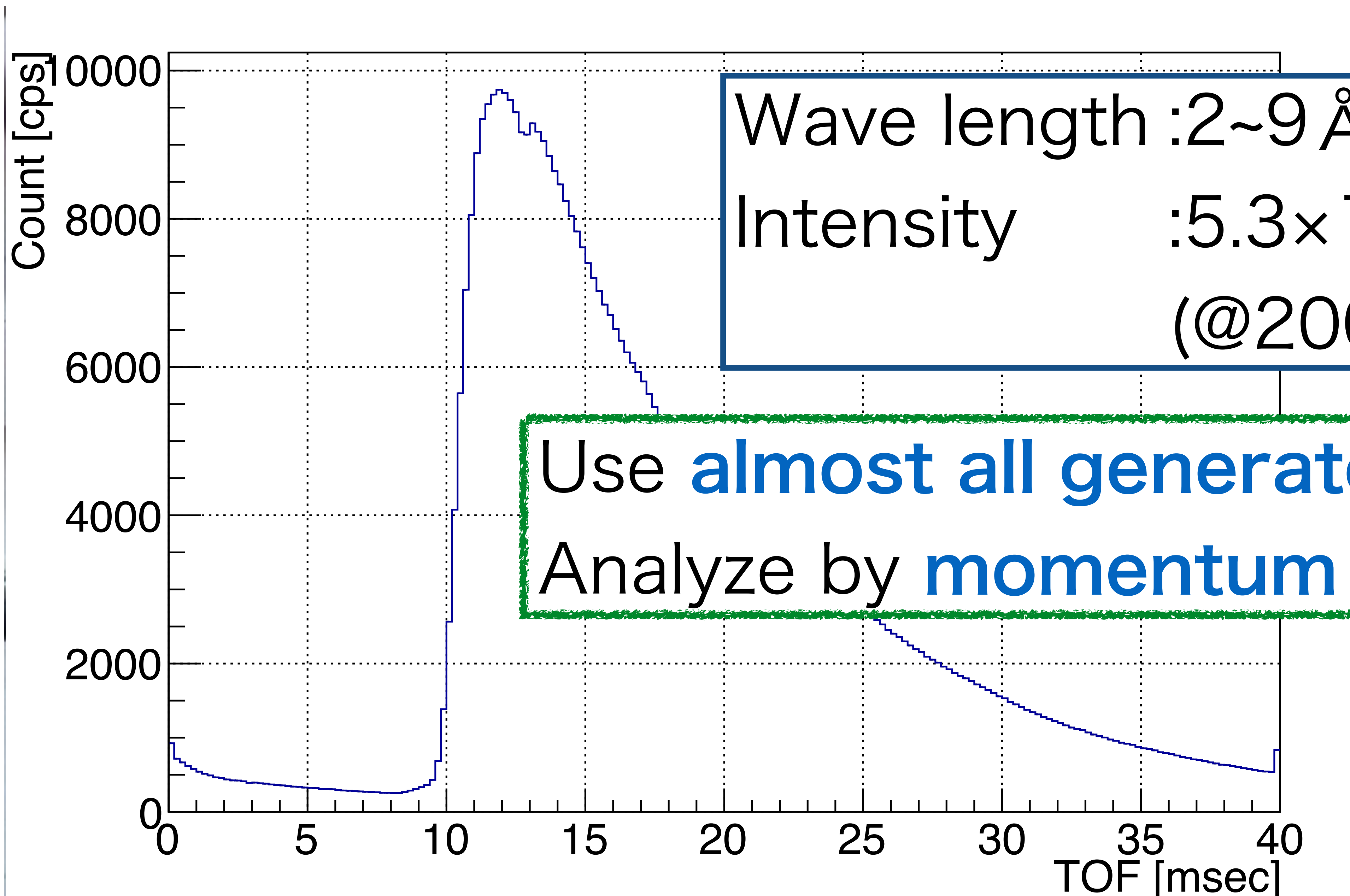
Wave length :2~9 Å

Intensity :5.3×10^{5}cps

(@200kW & ϕ10)

J-PARC/MLF/BL05(NOP)

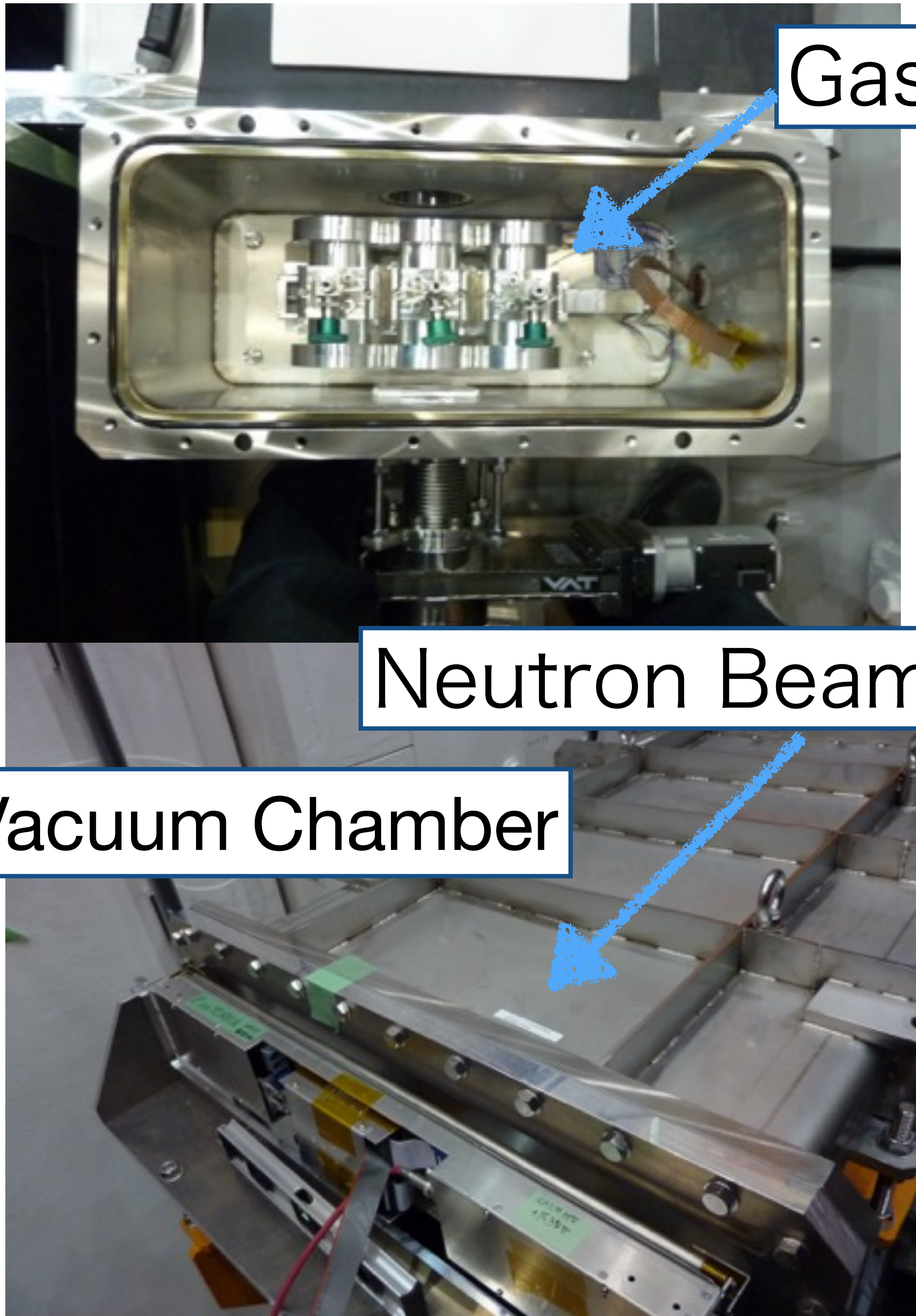
J-PARC/MLF/BL05/Low-Divergence Beam Branch

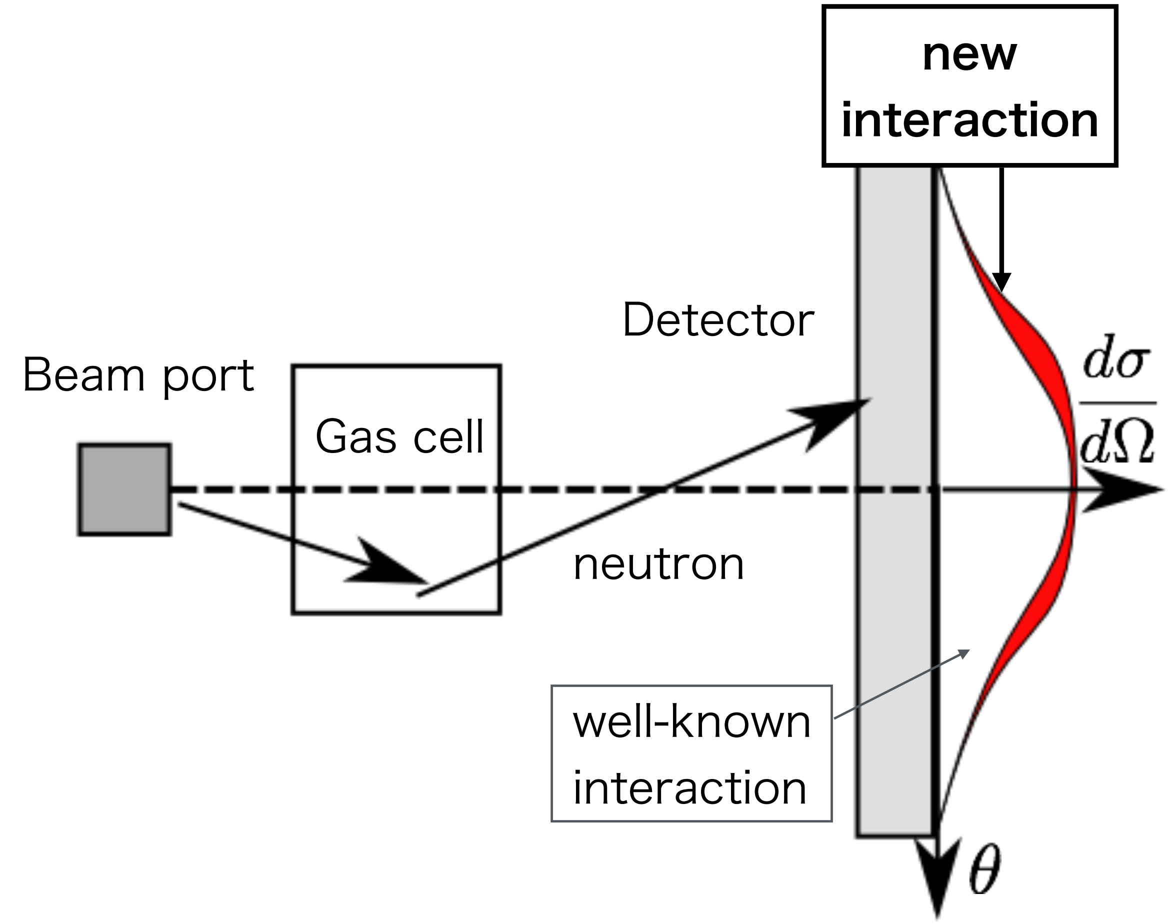


Wave length :2~9 Å
Intensity :5.3×10^{5}cps
(@200kW & ϕ10)

Use **almost all generated neutron**
Analyze by **momentum transfer**

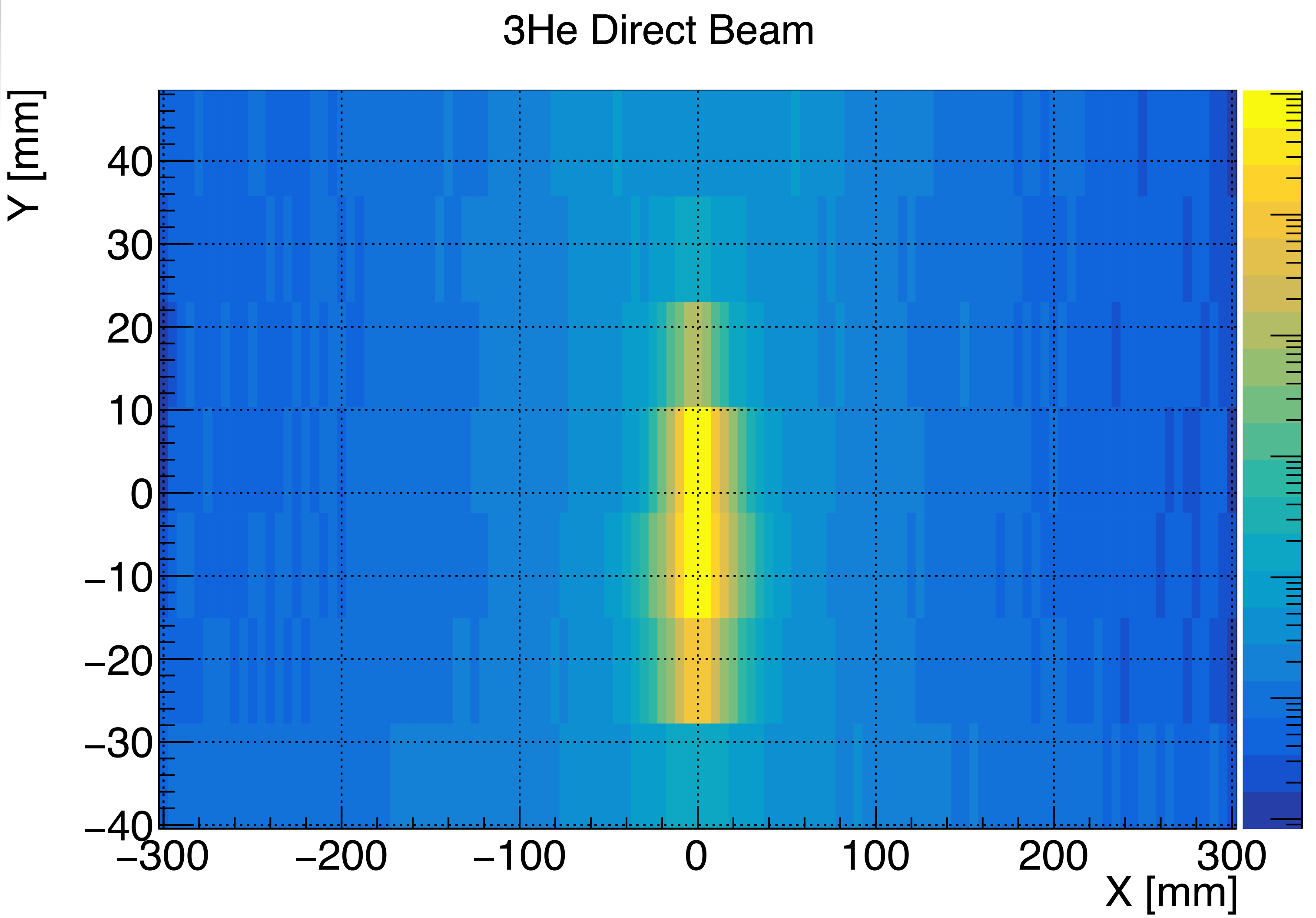
Devices





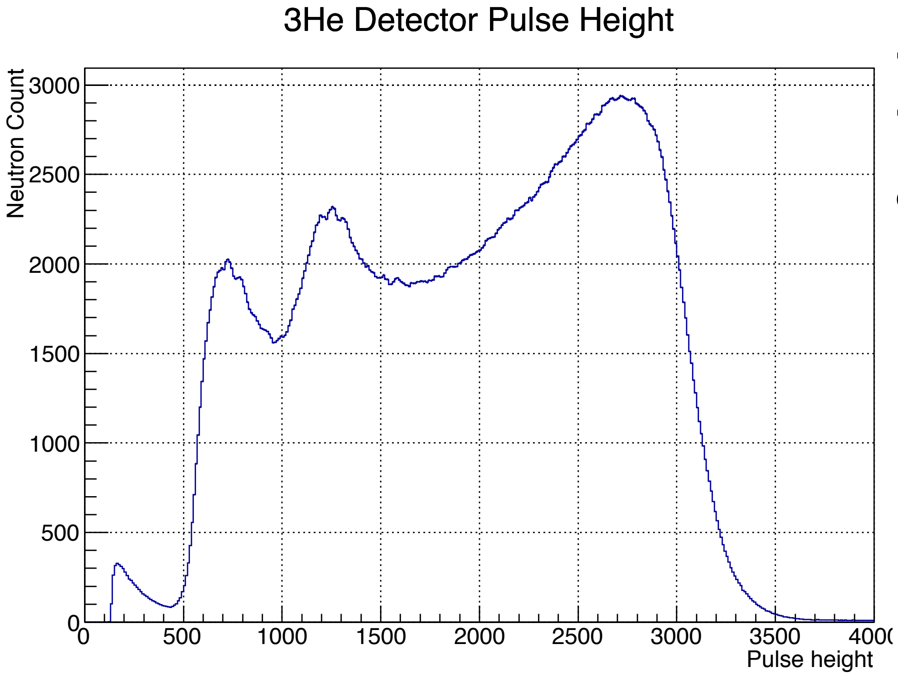
Gas	Xe(1atm.) He(1atm.) Vacuum
Gas Cell Size	ϕ50mm L145mm
Detector Size	600mm×90mm

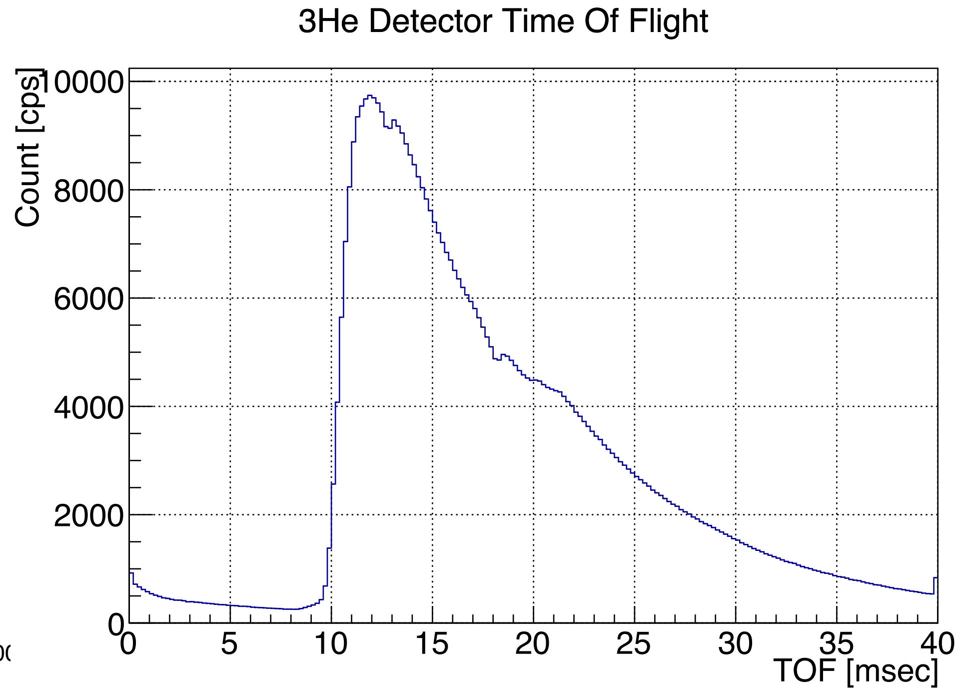
3He PSD



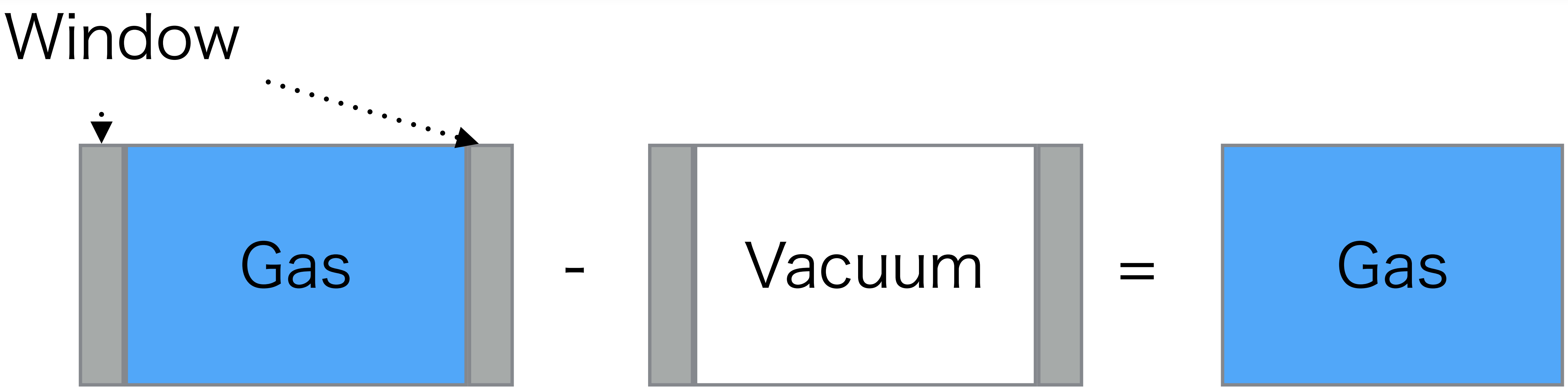
1/2 inch. 7tubes 10atm.

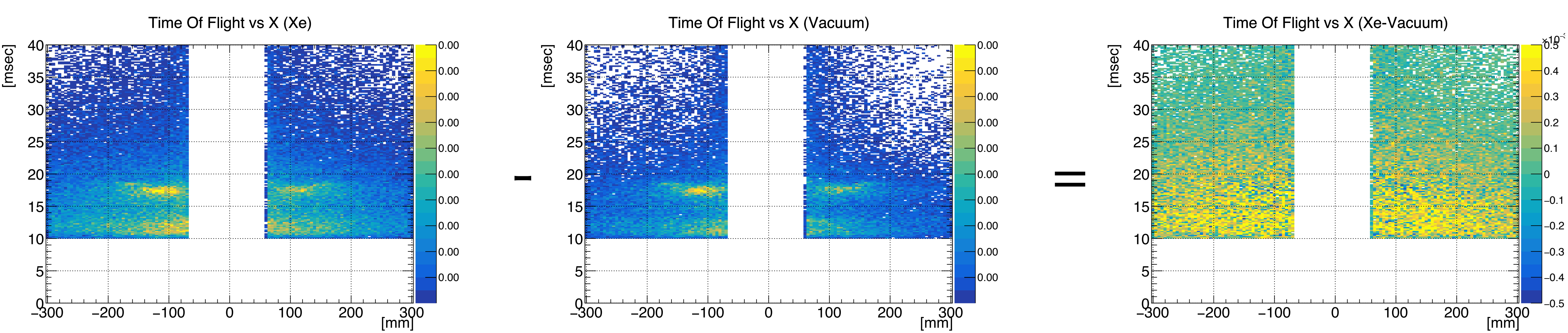
Voltage	:1530V
Efficiency	:100%
X resolution	:~5mm
Linearity	:99.7%



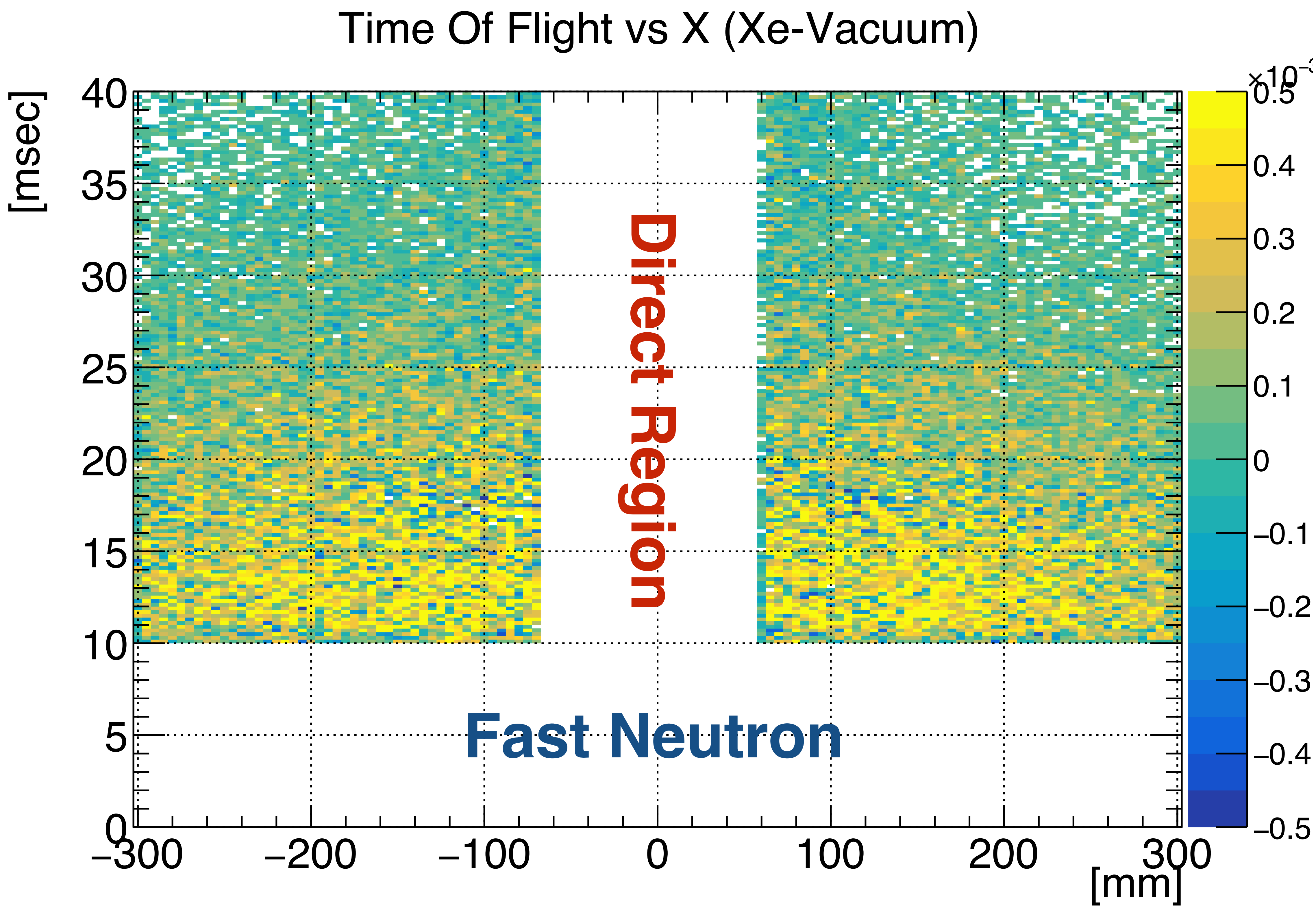


Method


Window
Gas
-
Vacuum
=
Gas


Time Of Flight vs X (Xe)
Time Of Flight vs X (Vacuum)
Time Of Flight vs X (Xe-Vacuum)
[msec]
[mm]
-
=

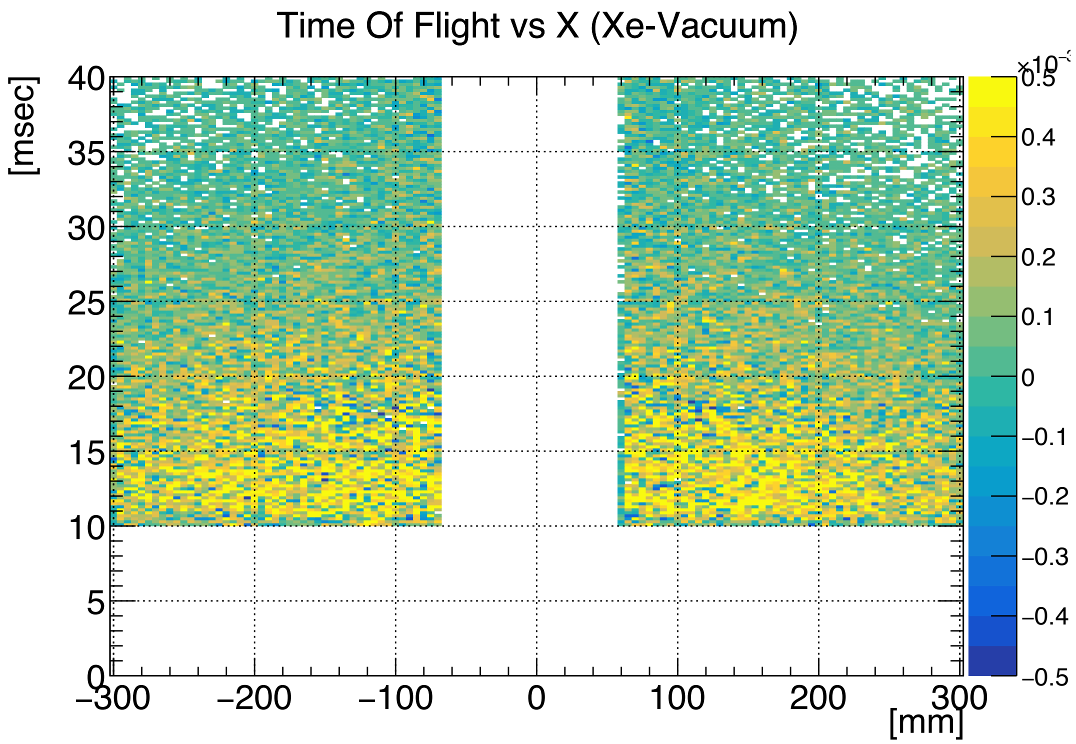
Experimental Data(TOF vs X)



Method

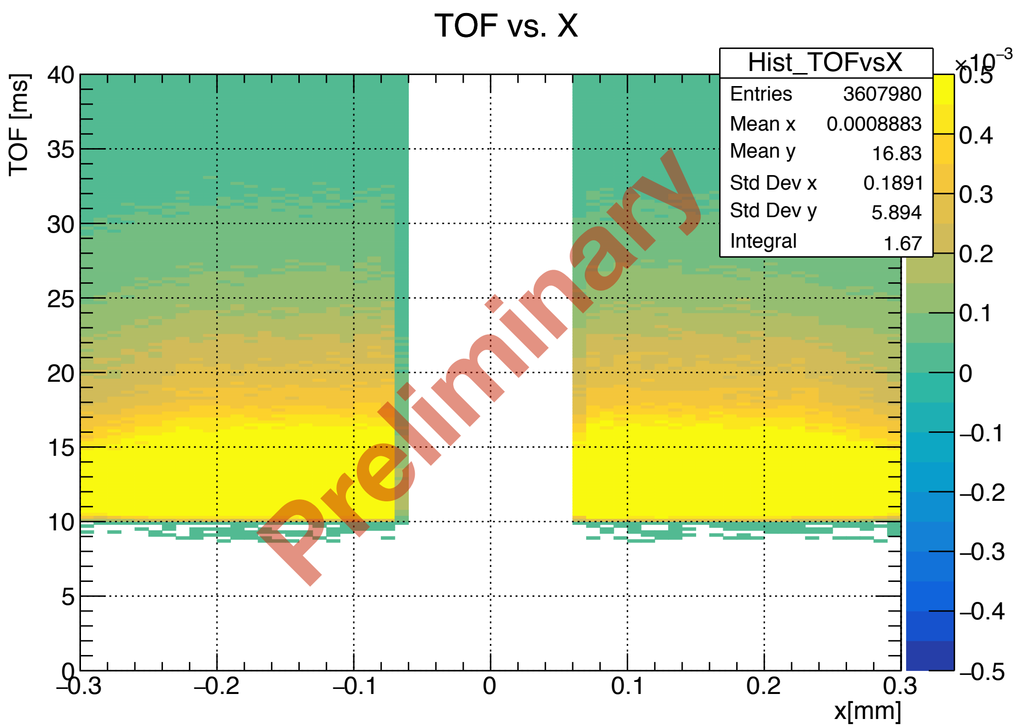
Compare between…

Experimental data

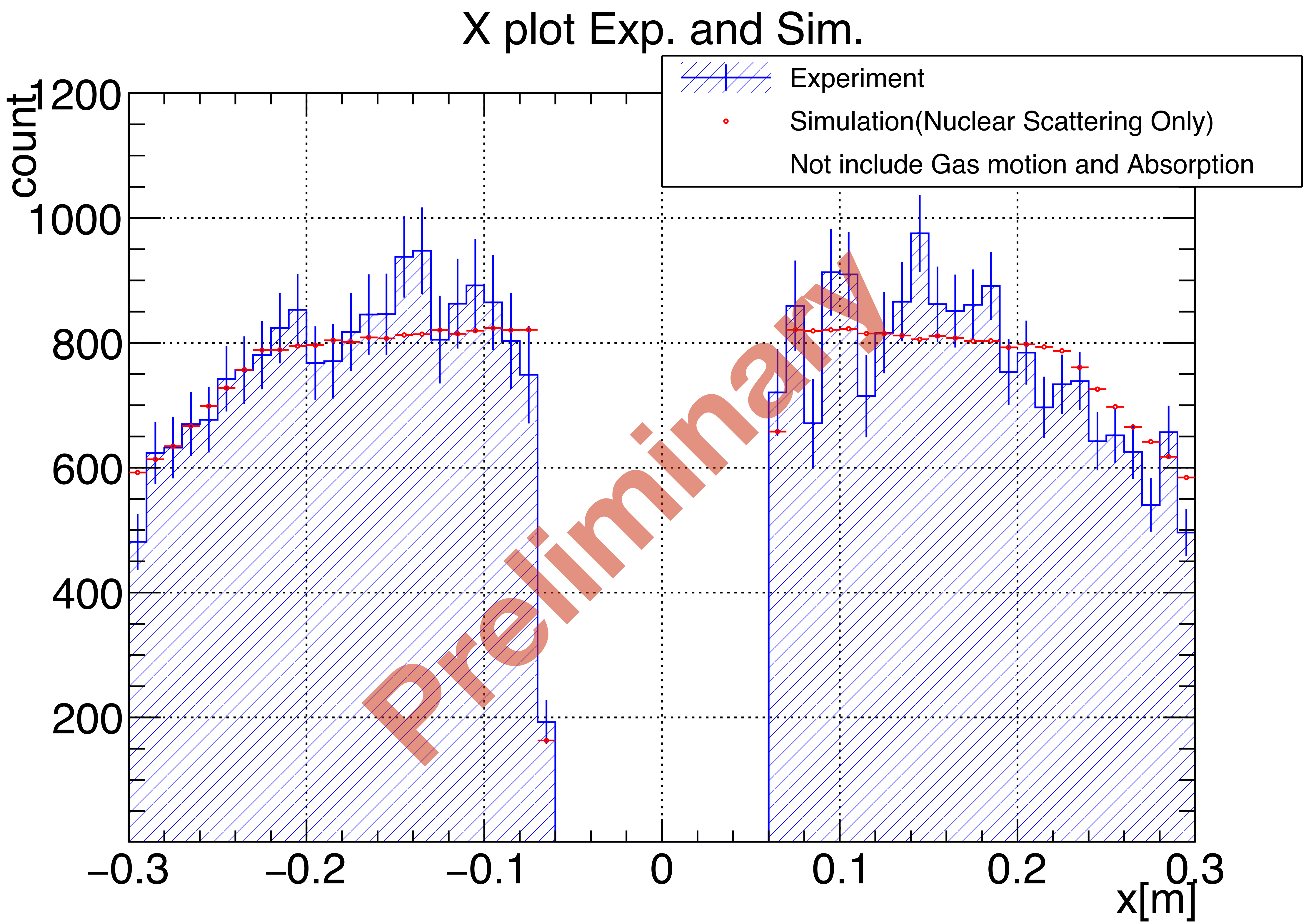


vs

Simulation result

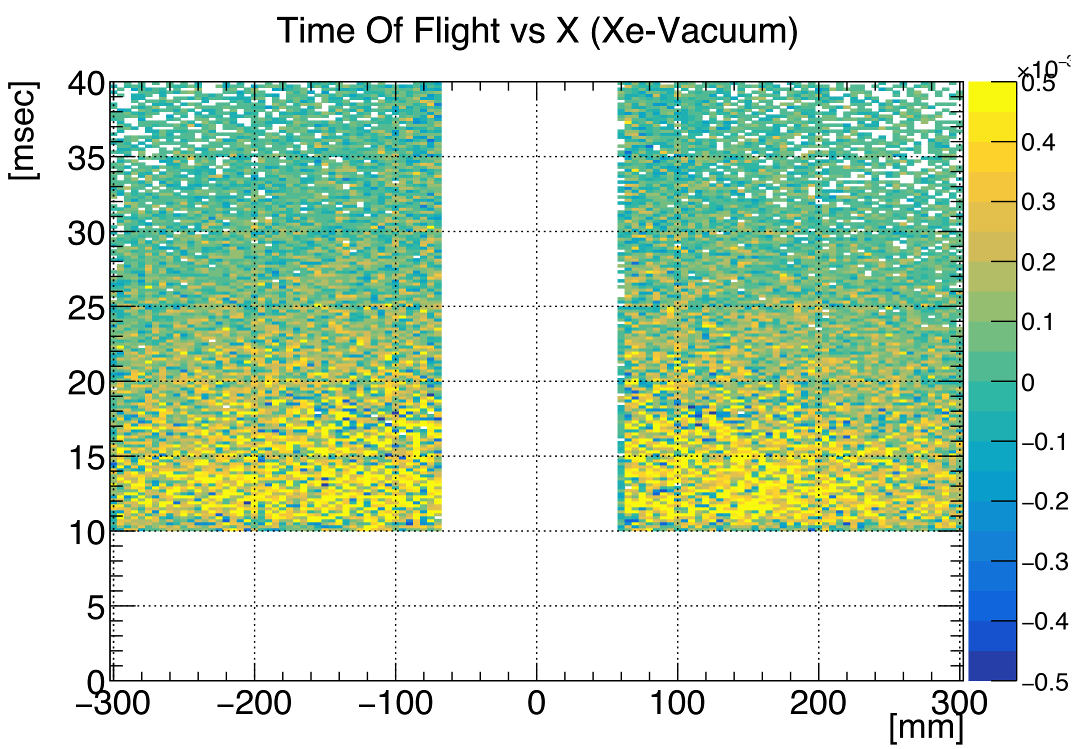


Experimental Data(X Plot)



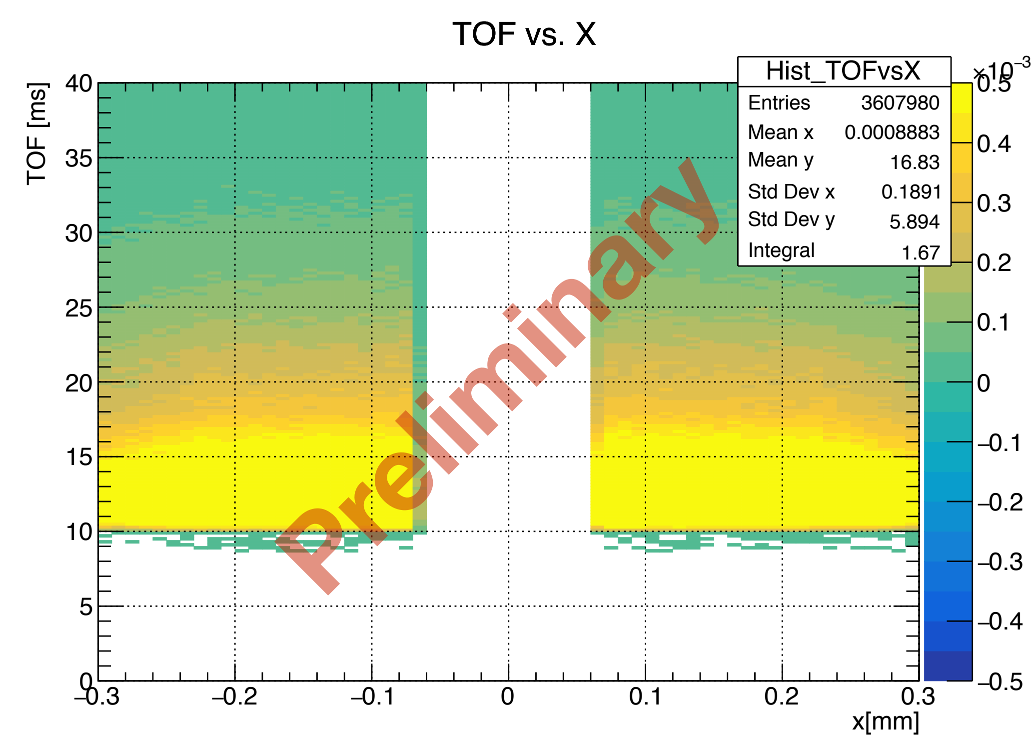
Method

Experimental data



vs

Simulation result

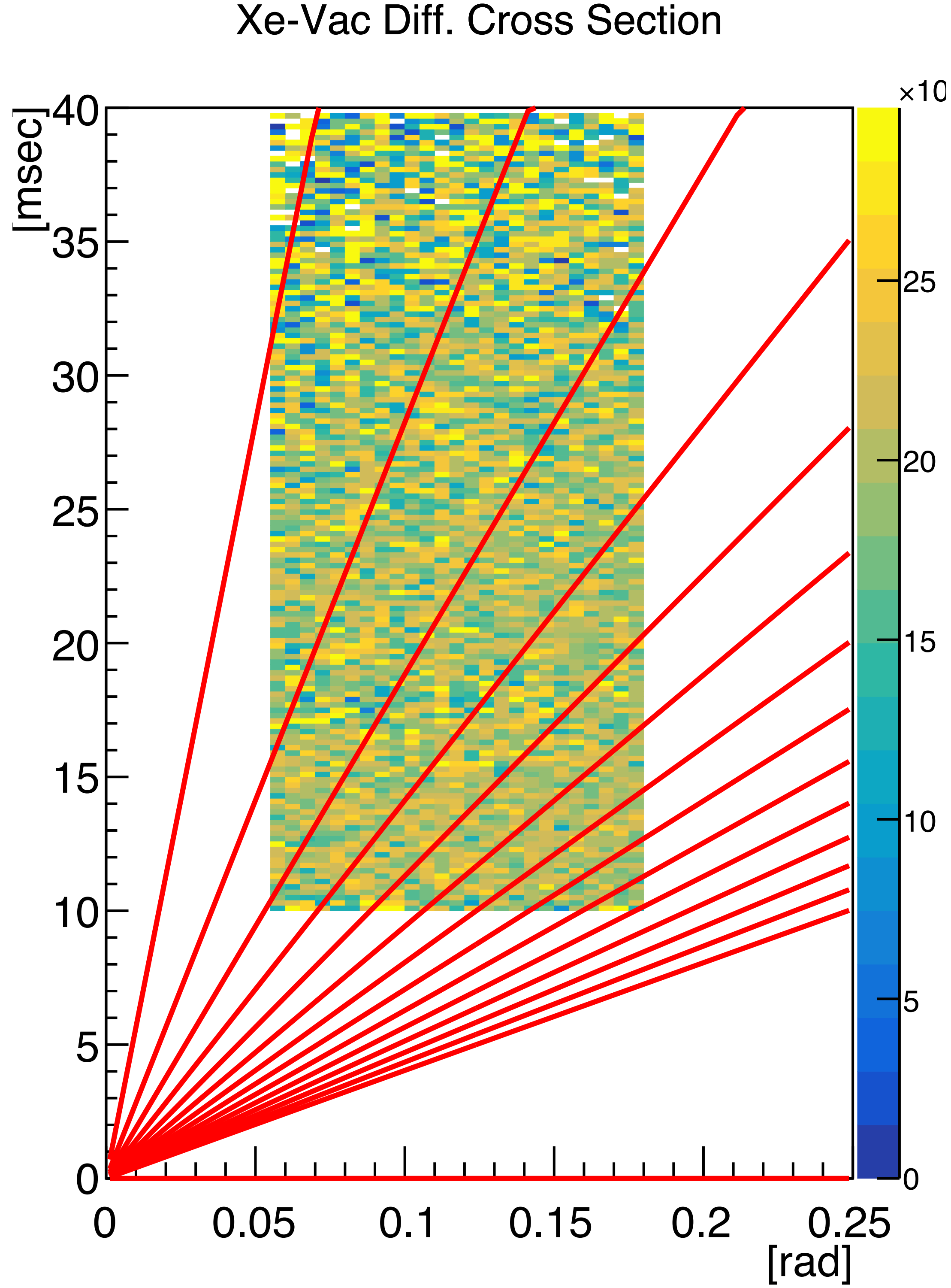


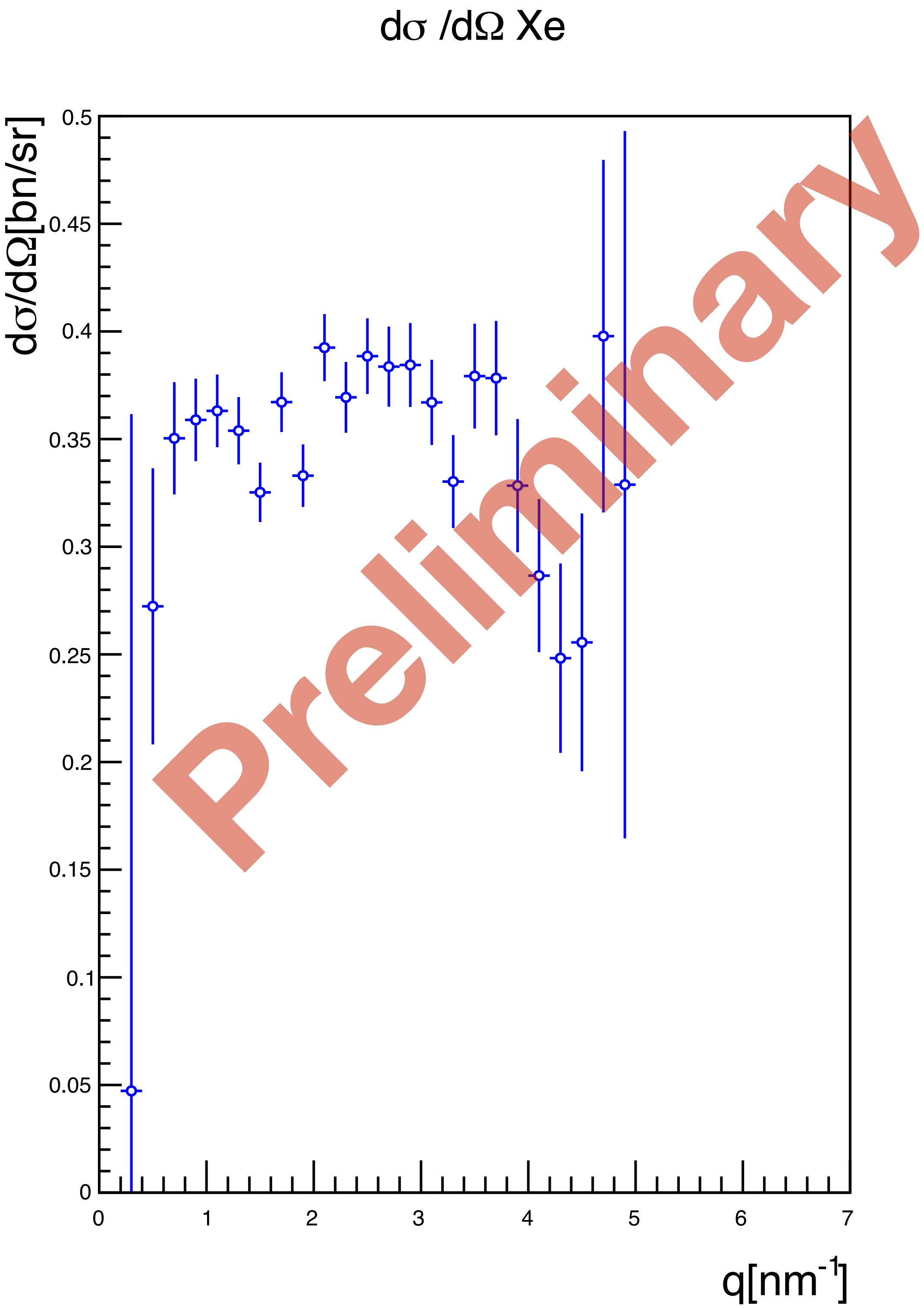
→ Make plots of **differential cross section** as the function of **momentum transfer**

→ Estimate the **sensitivity** of this experiment

dσ/dΩ(q) (Preliminary)

Red line q=0.0~7.0[nm^{-1}]





Summary & Outlook

It's significant to measure gravity at a short range.

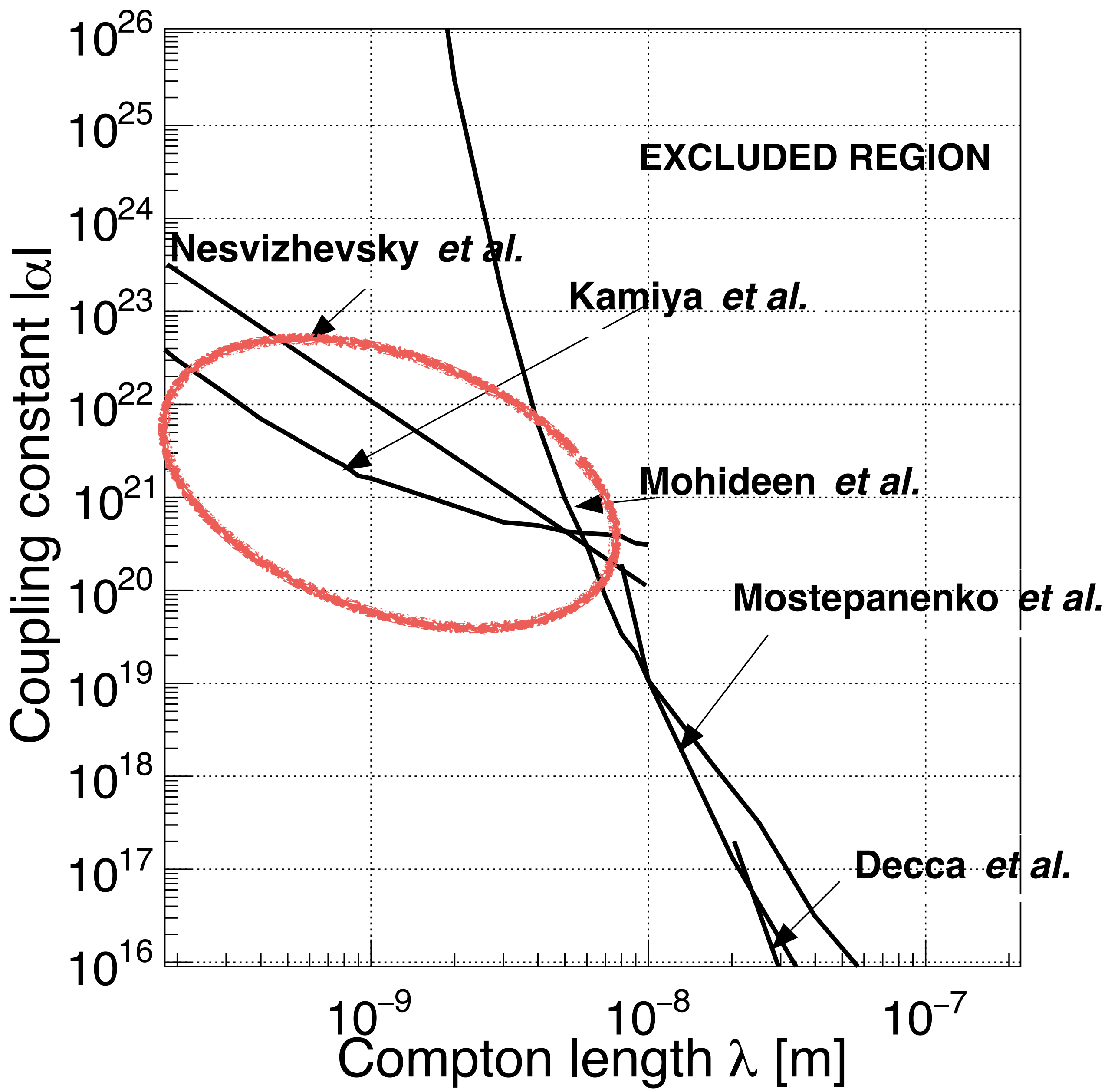
We are analyzing the experiment data very carefully now.

Next experiment plan

1. Increase gas pressure
   (100kPa -> 300kPa)
2. Make larger beam size
   (ϕ10mm -> X10mm x Y30mm)
3. Increase measurement time
   (1day -> 10day)

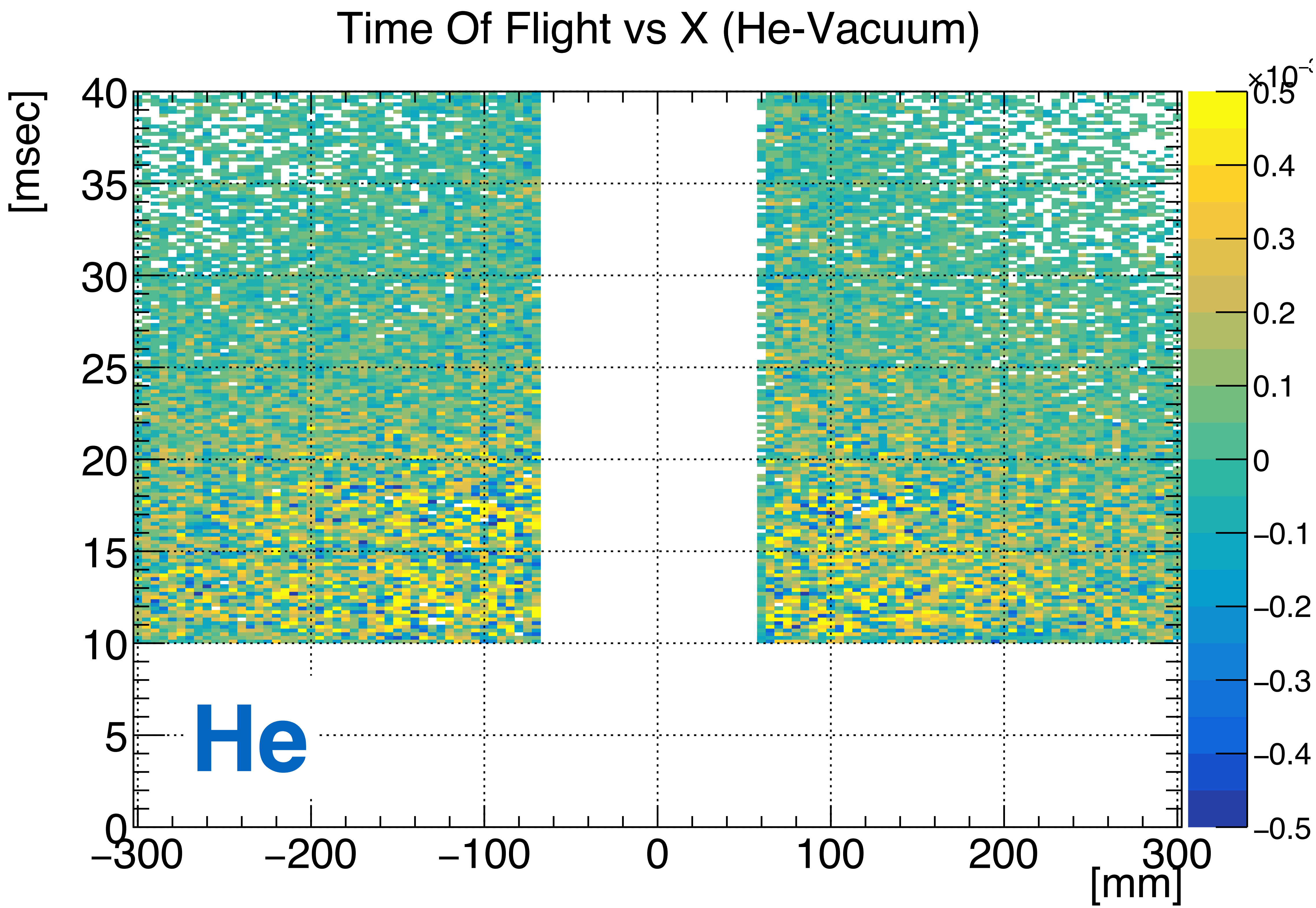
Simulation Upgrade

1. Absorption
2. Gas motion

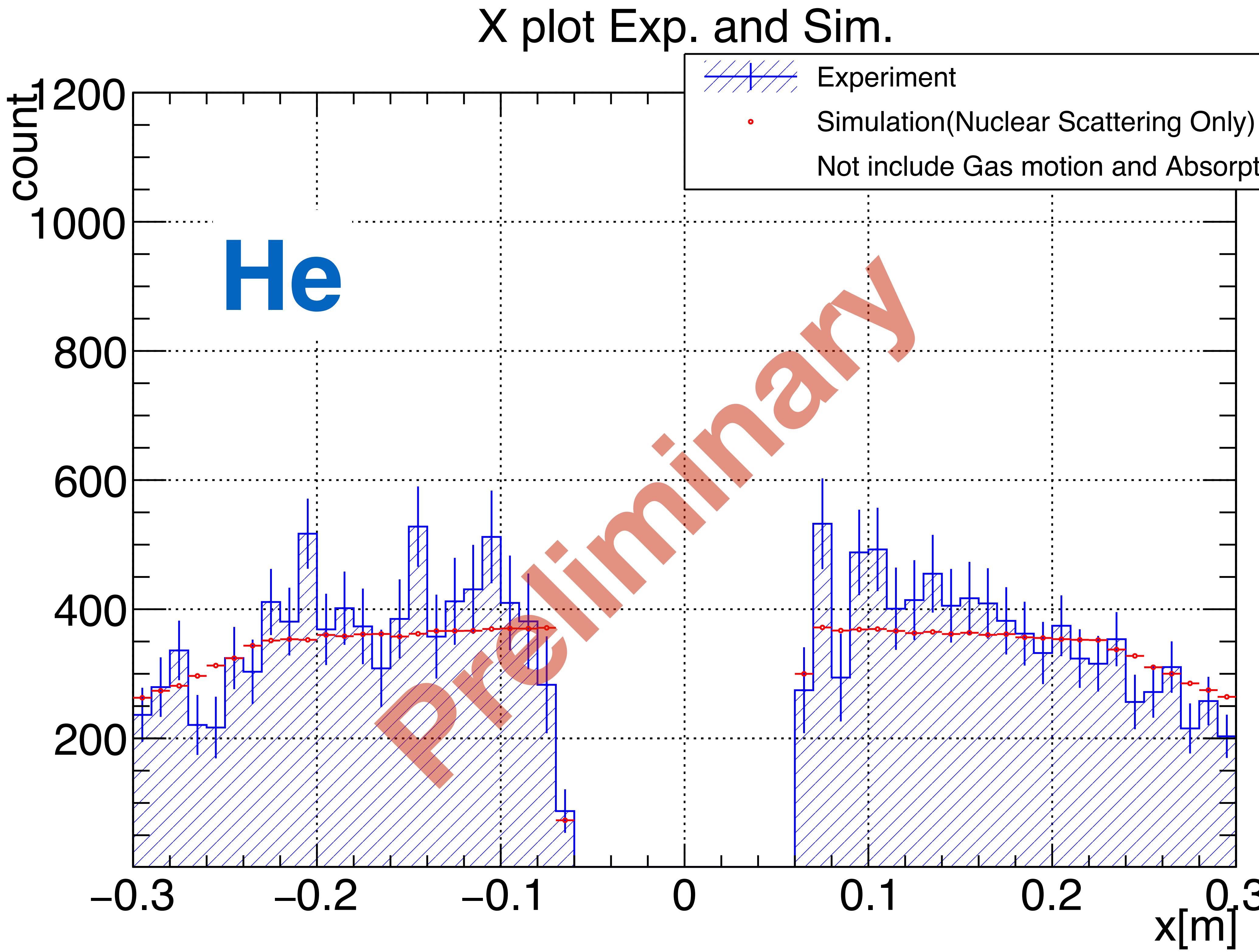


Back Up

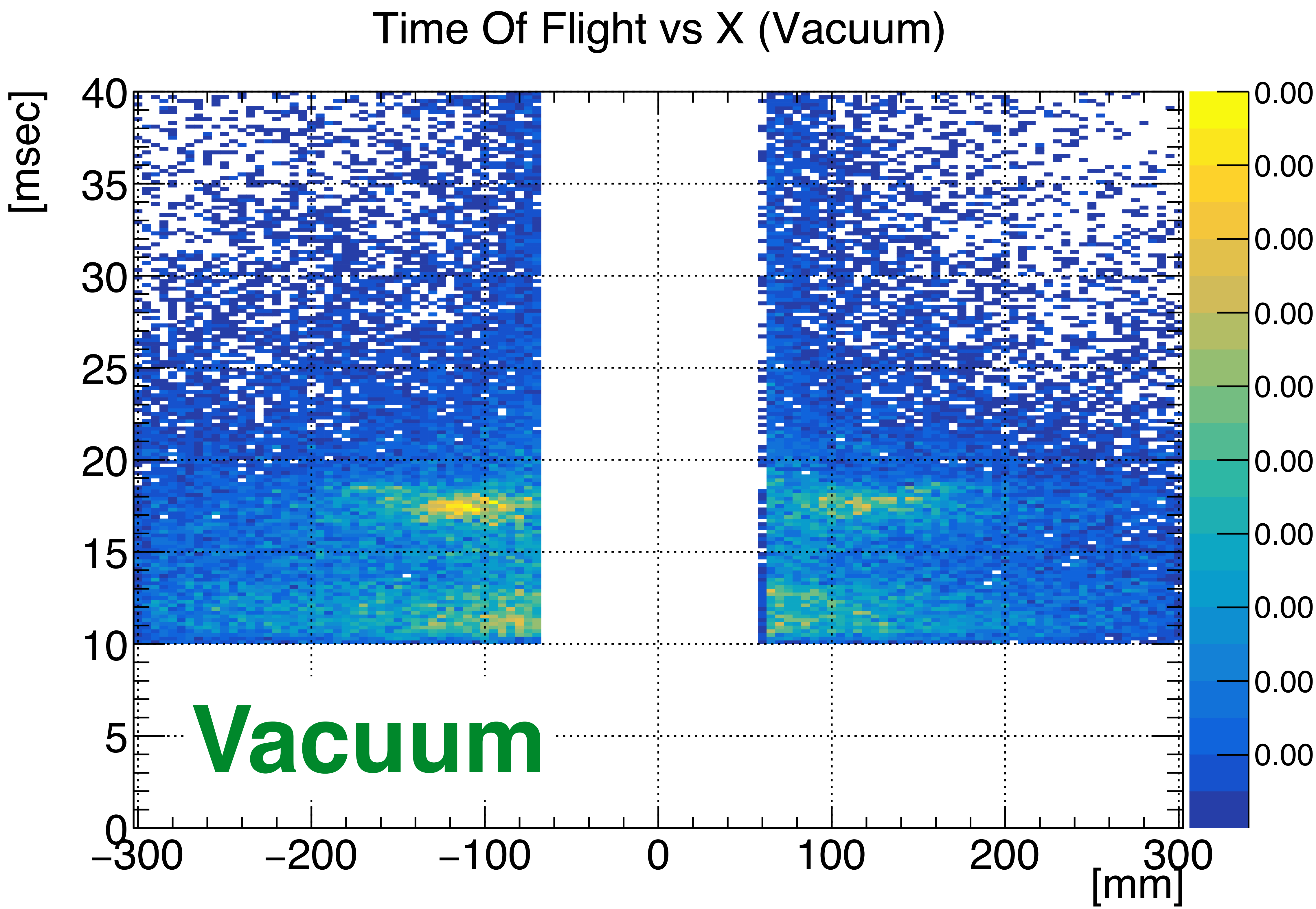
Experimental Data(TOF vs X:He)



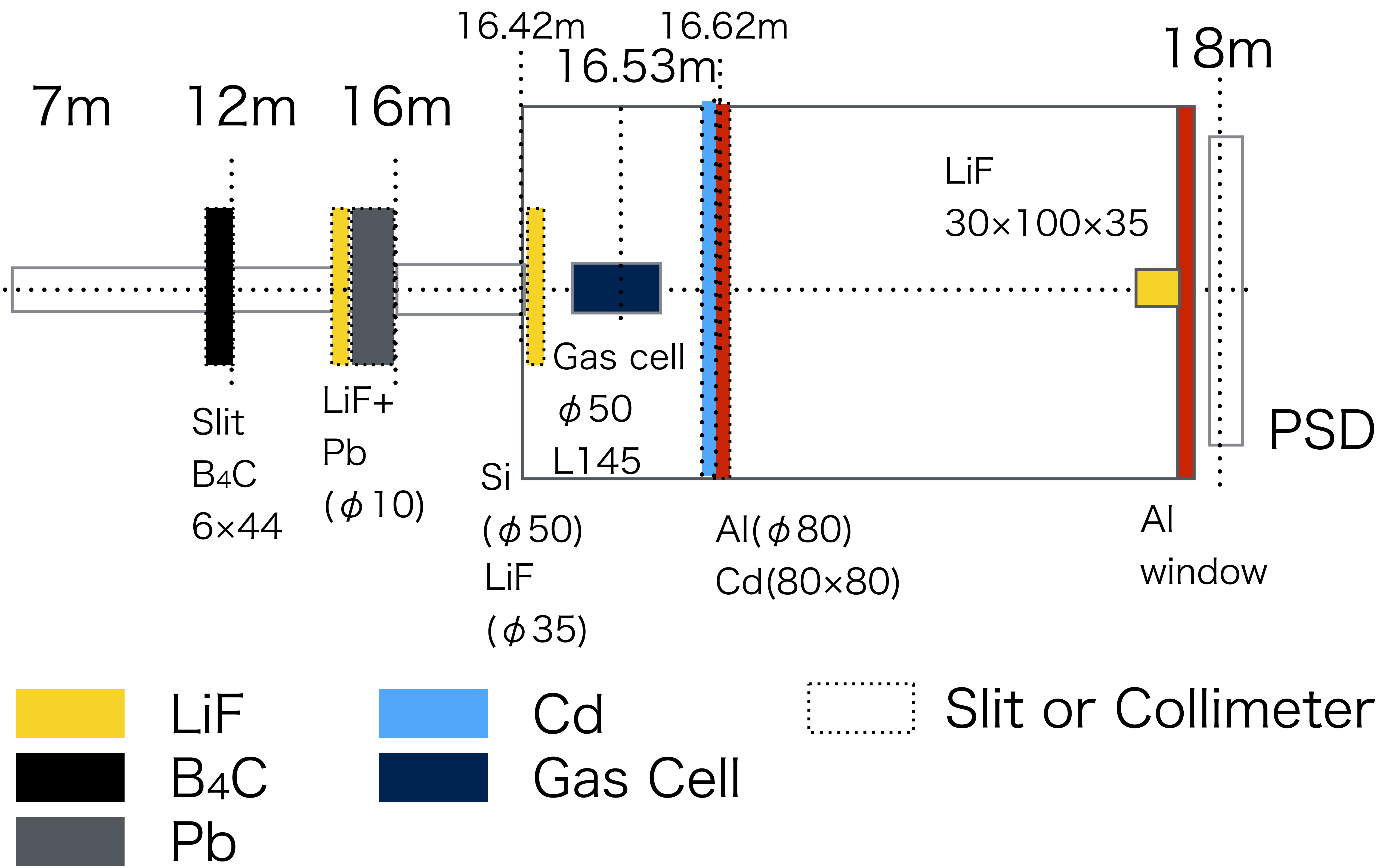
Experimental Data(X Plot:He)



Experimental Data(TOF vs X:He)

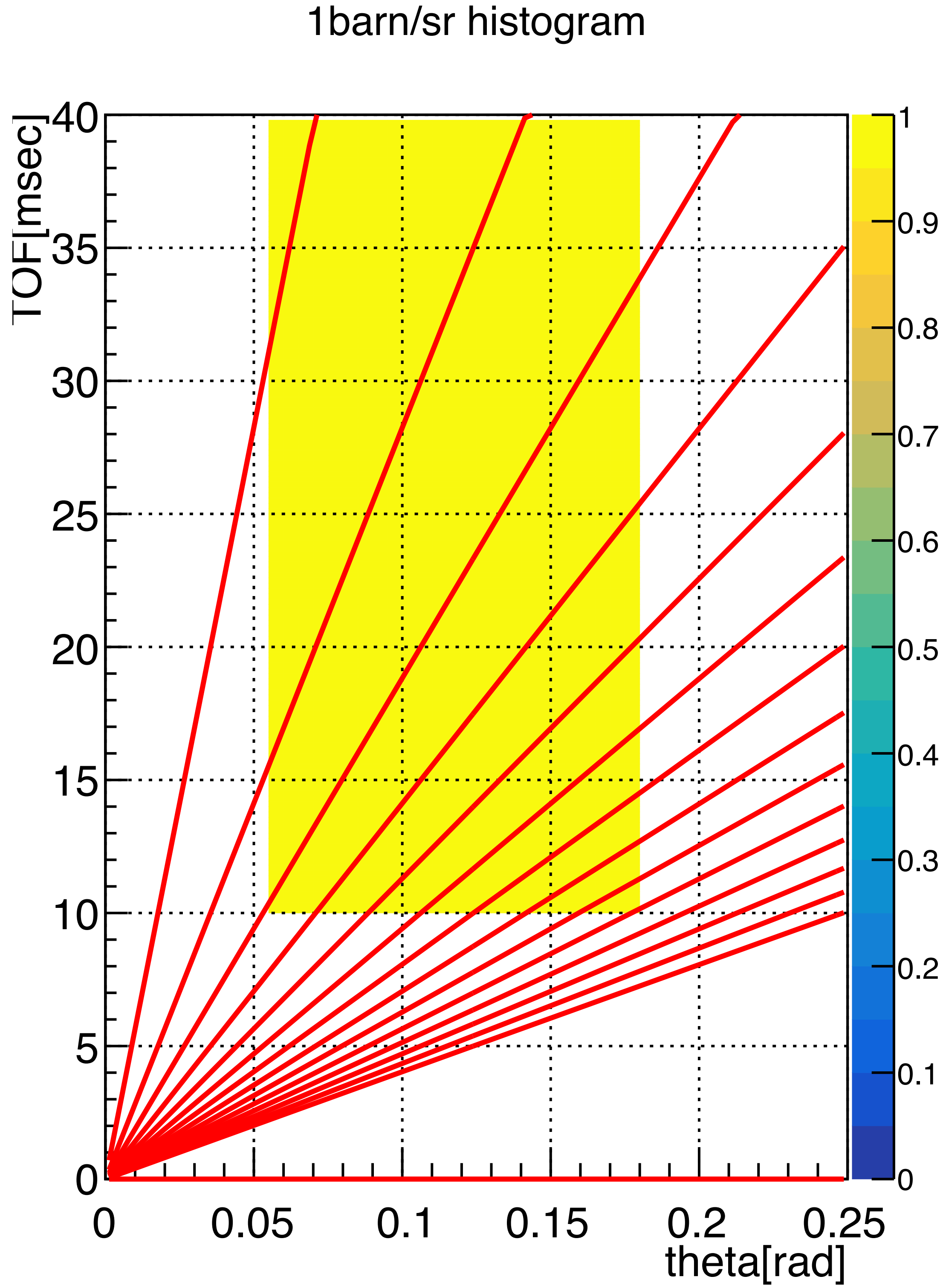


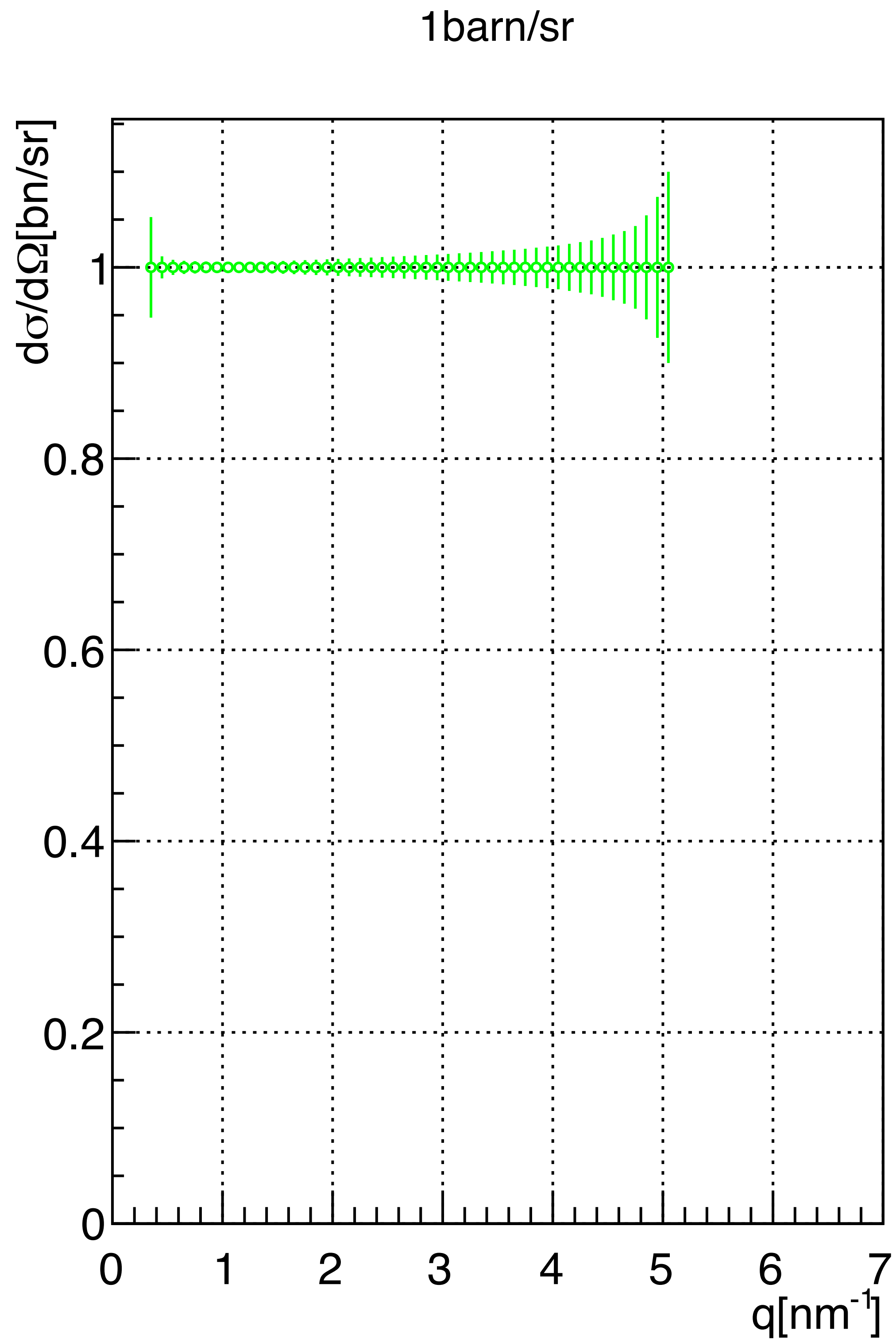
Setup Sketch



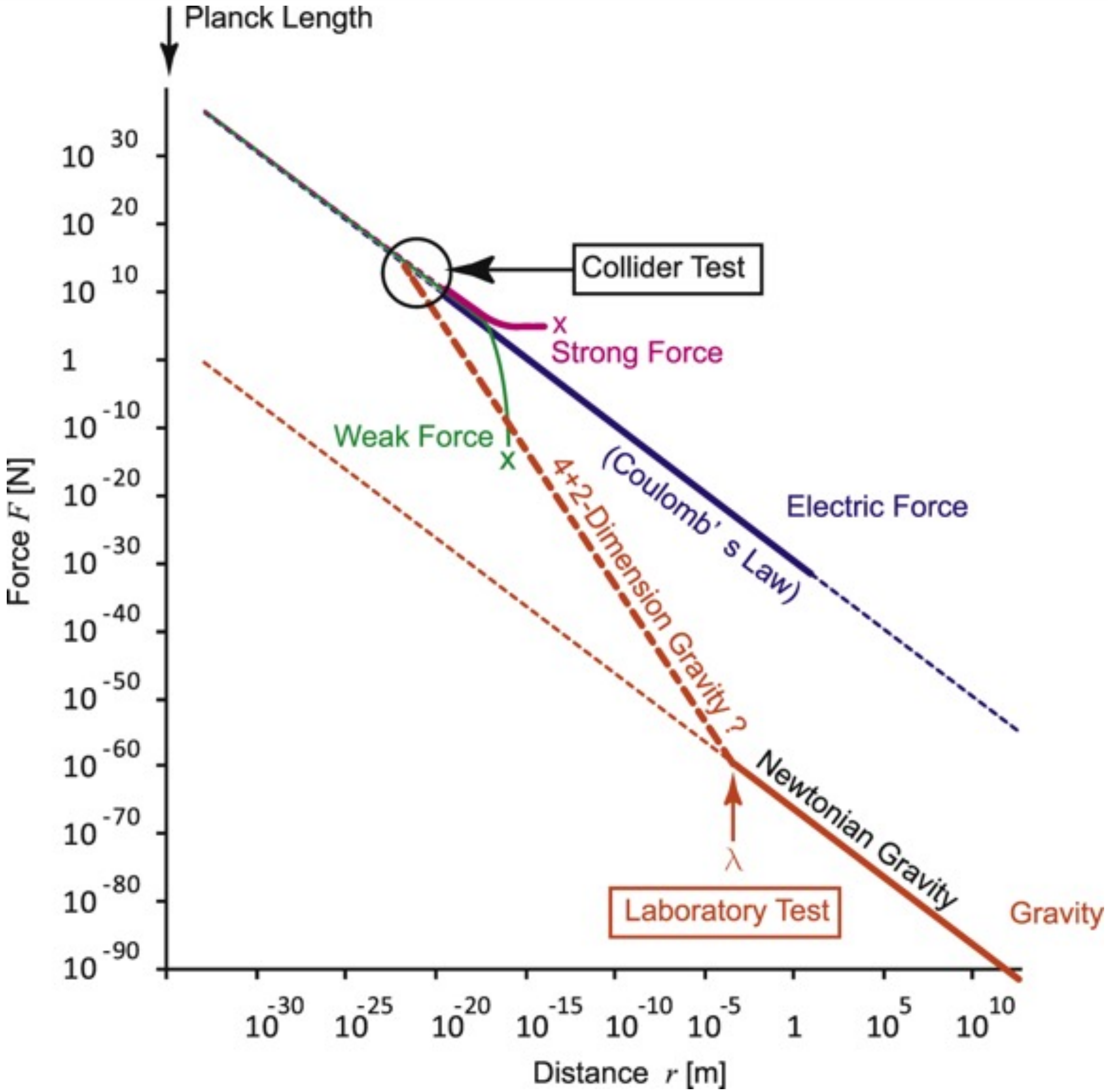
Test dσ/dΩ(q)

Red line q=0.0~7.0[nm^{-1}]





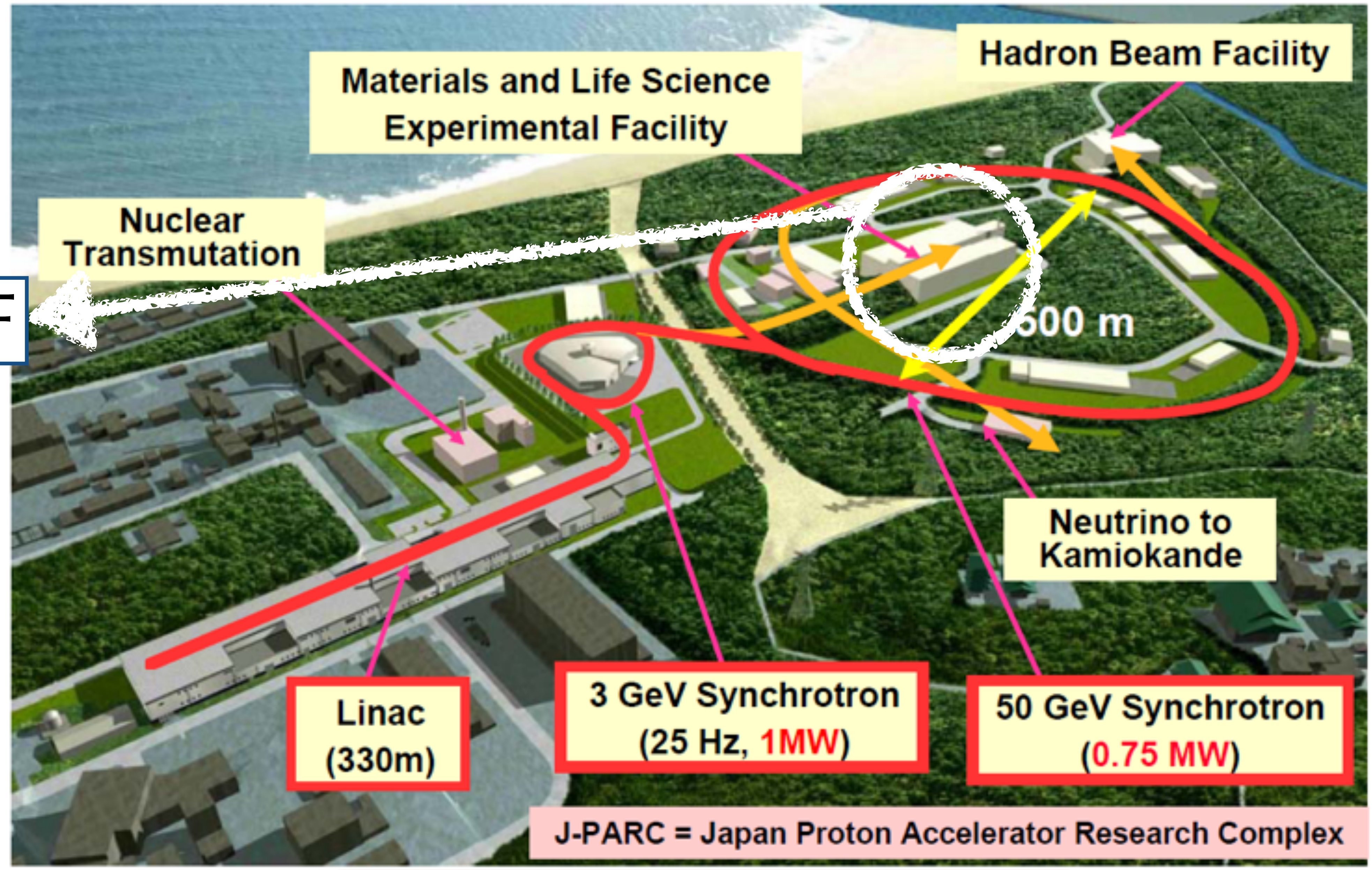
Collider Test and Laboratory Test



Jiro Murata and Saki Tanaka
Classical and Quantum Gravity 32.3 (2015): 033001.

J-PARC（Tokai, Ibaraki, Japan)

MLF



Joint Project between KEK and JAEA

Detector

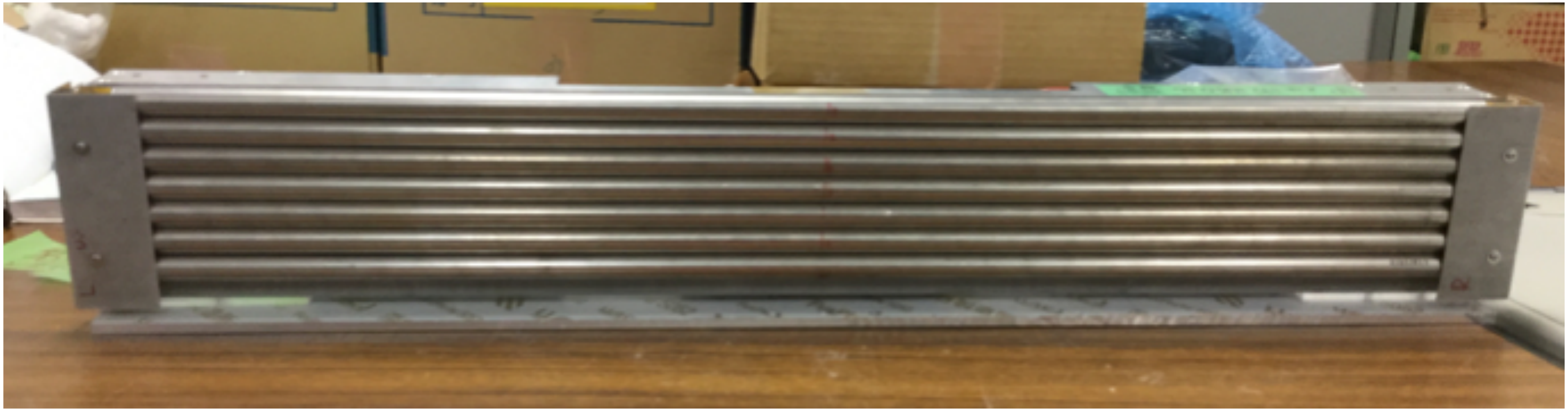
3He Position Sensitive Detector

1/2 inch. 7tubes 10atm.

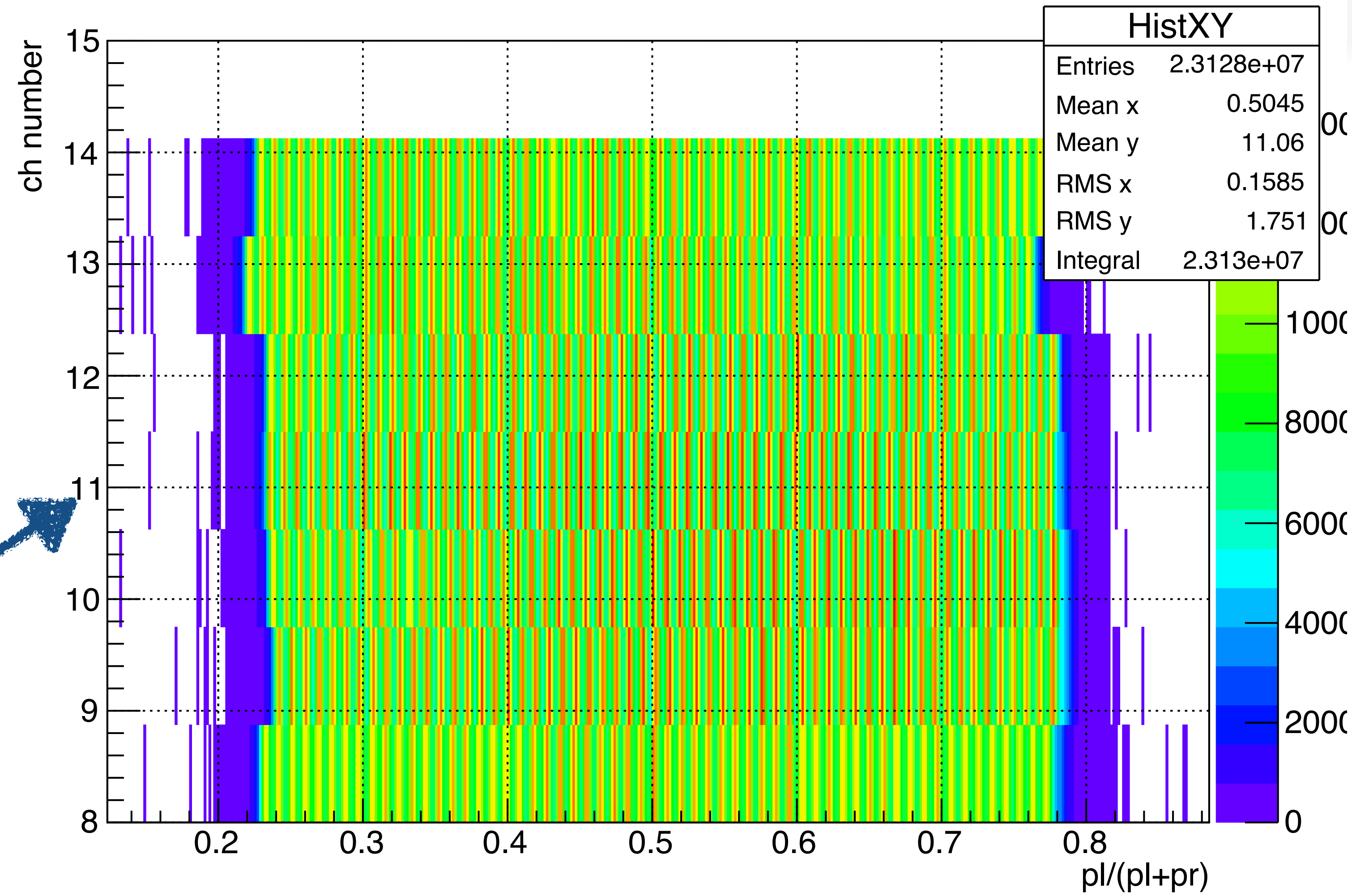
Voltage :1530V

Efficiency :100%

X resolution :~5mm



Detector

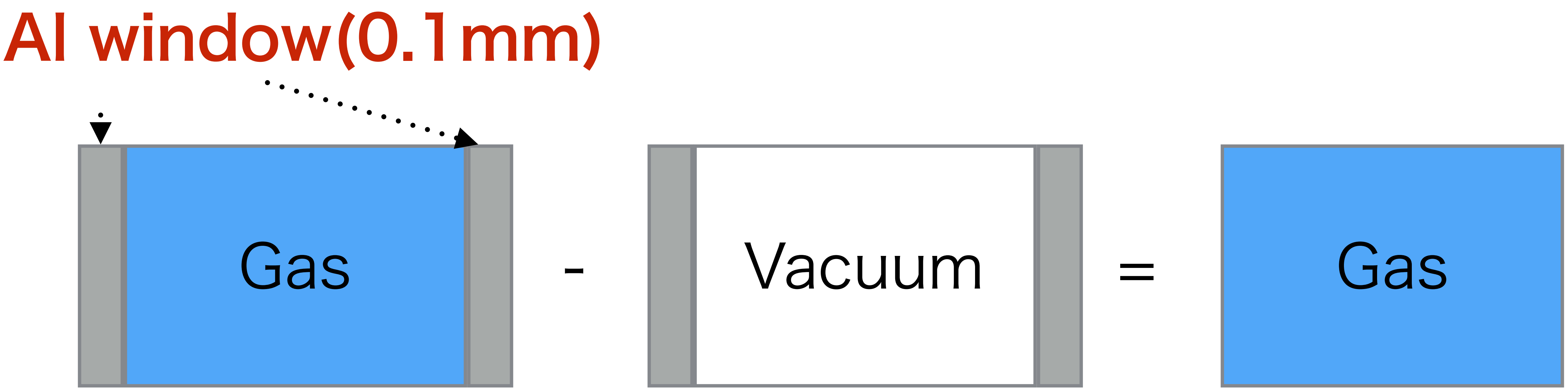


Channel	p0[mm]	p1[mm]
8	$(8.40\pm0.02)\times10^2$	$-(1.075\pm0.003)\times10^3$
9	$(8.54\pm0.01)\times10^2$	$-(1.084\pm0.003)\times10^3$
10	$(8.48\pm0.01)\times10^2$	$-(1.074\pm0.003)\times10^3$
11	$(8.45\pm0.01)\times10^2$	$-(1.076\pm0.002)\times10^3$
12	$(8.44\pm0.01)\times10^2$	$-(1.073\pm0.003)\times10^3$
13	$(8.25\pm0.01)\times10^2$	$-(1.076\pm0.003)\times10^3$
14	$(8.36\pm0.02)\times10^2$	$-(1.078\pm0.003)\times10^3$

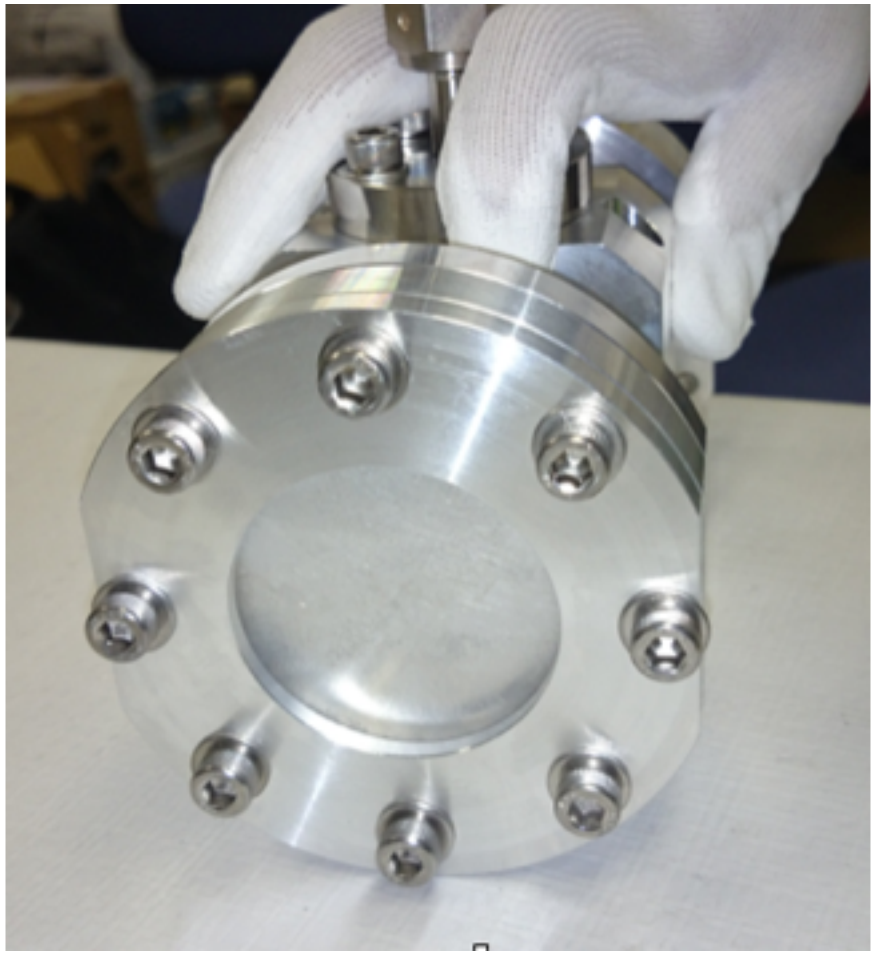
Linearity **99.7%**

$$p0 + p1 \times \left(\frac{\mathrm{pl}}{\mathrm{pl} + \mathrm{pr}}\right)$$

Cell Window



The background can be small because Al window can be thin.



Van der Waals force

- $\lambda \lesssim 10\mu m$: Van der Waals force is the main background.

$$U = -\frac{3\hbar c}{8\pi}\frac{\alpha_0}{r^4}$$

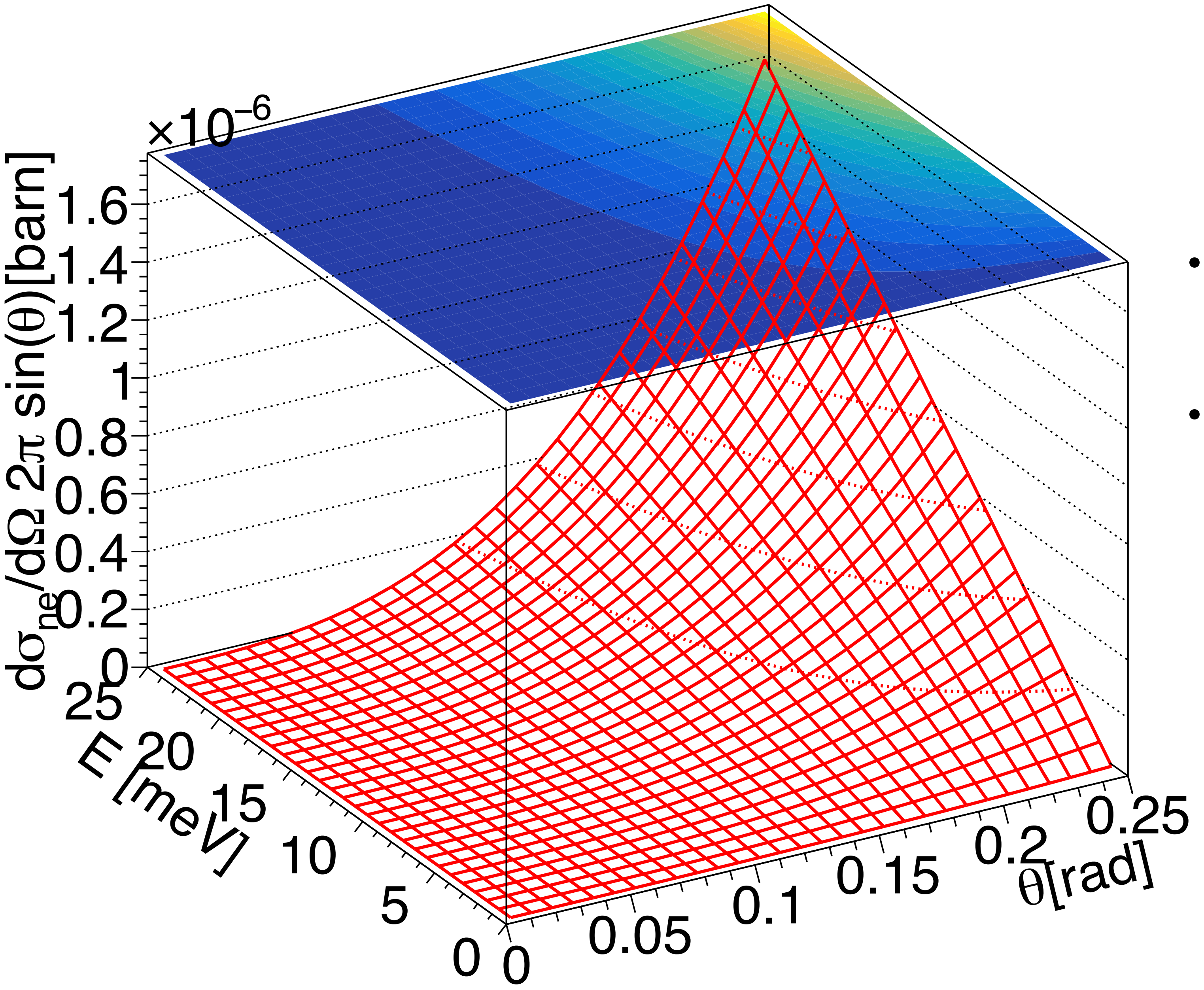
α_0 :Atom electric polarizability

Atoms.(H, He, etc.) $\sim 10^{-30}\mathrm{m}^3$

Neutron $\sim 10^{-48}\mathrm{m}^3$

n-e scattering

n-e differential cross section as a function of Energy and Angle



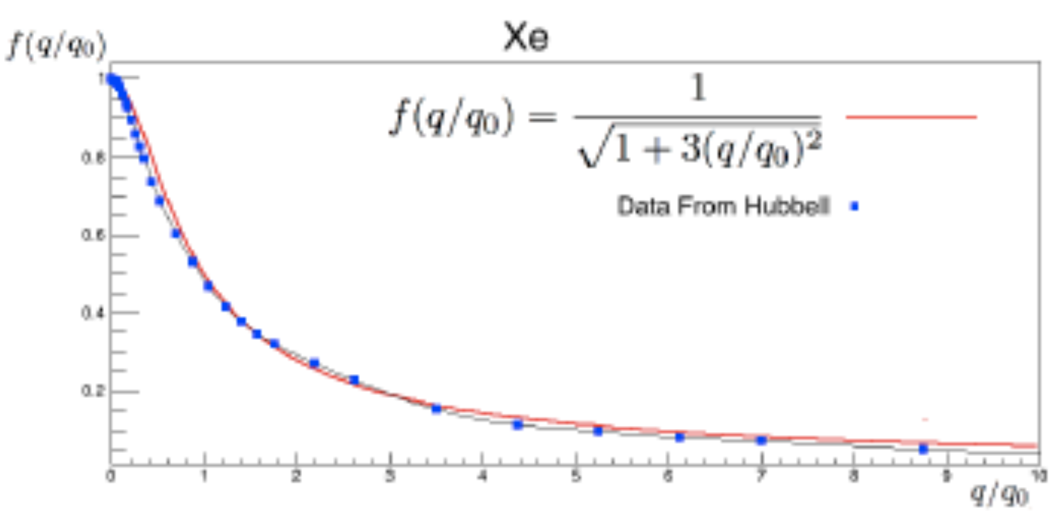
- Backscattering is dominant.
- n-e scattering too small to detect in MC simulation for our detector region

n-e散乱

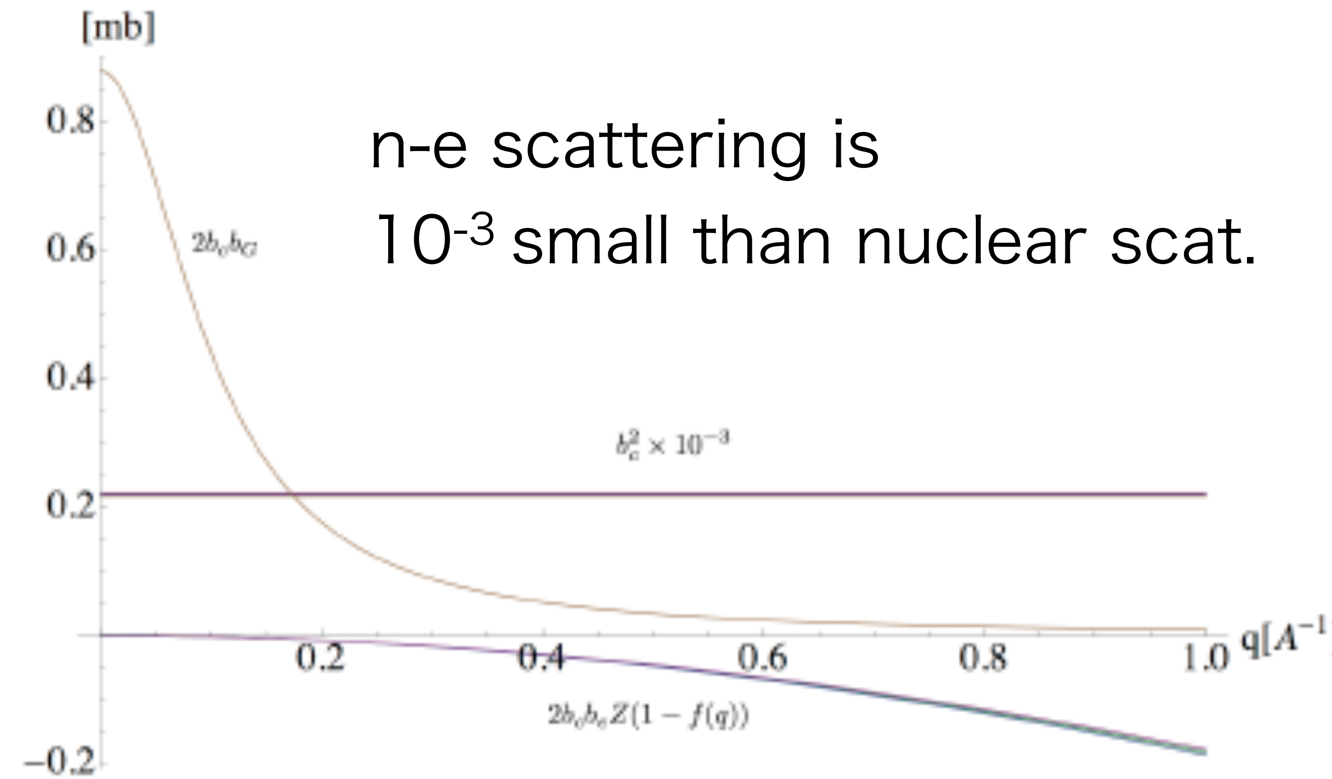
$$\frac{d\sigma}{d\Omega dE'} = \frac{d\sigma}{d\Omega dE'}_{coh} + \frac{d\sigma}{d\Omega dE'}_{inc}$$

$$= \frac{k'}{k}[b_c^2(q) S_c(q,\omega) + b_i^2 S_i(q,\omega)]$$

$$b_c(q) = (b_c - b_e Z(1 - f(q)) + b_G(q)$$



Method used to deduce atomic form factor $f(q)$



n-e scattering is 10^{-3} small than nuclear scat.

Xe-Xe Ineraction

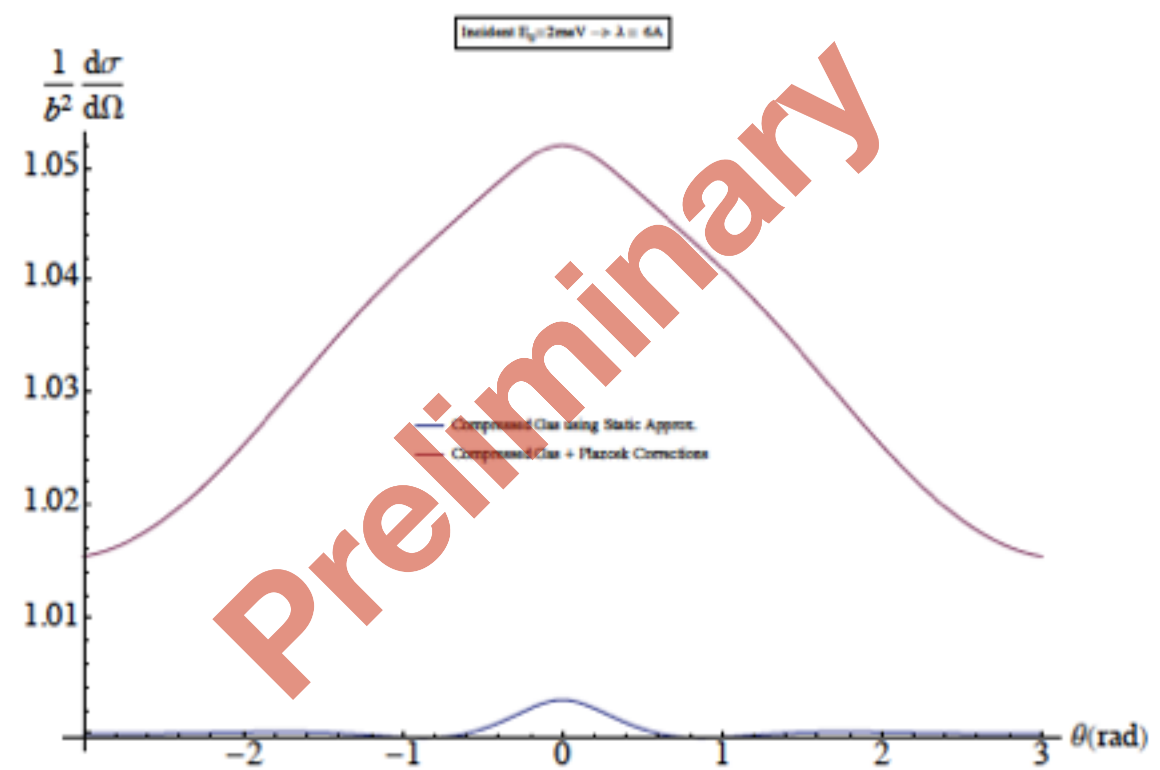
$$\frac{d\sigma}{d\Omega dE'} = \frac{d\sigma}{d\Omega dE'}_{coh} + \frac{d\sigma}{d\Omega dE'}_{inc}$$

$$= \frac{k'}{k}[b_c^2(q)S_c(q,\omega) + b_i^2 S_i(q,\omega)]$$

$$\frac{k'}{k}S_c(q,\omega) = [S_c(q) + \Delta S_c^{Pl}(q)]\delta(\omega)$$

- Static approximation
- Placzek correction
- Lennard Jones interaction between Xe

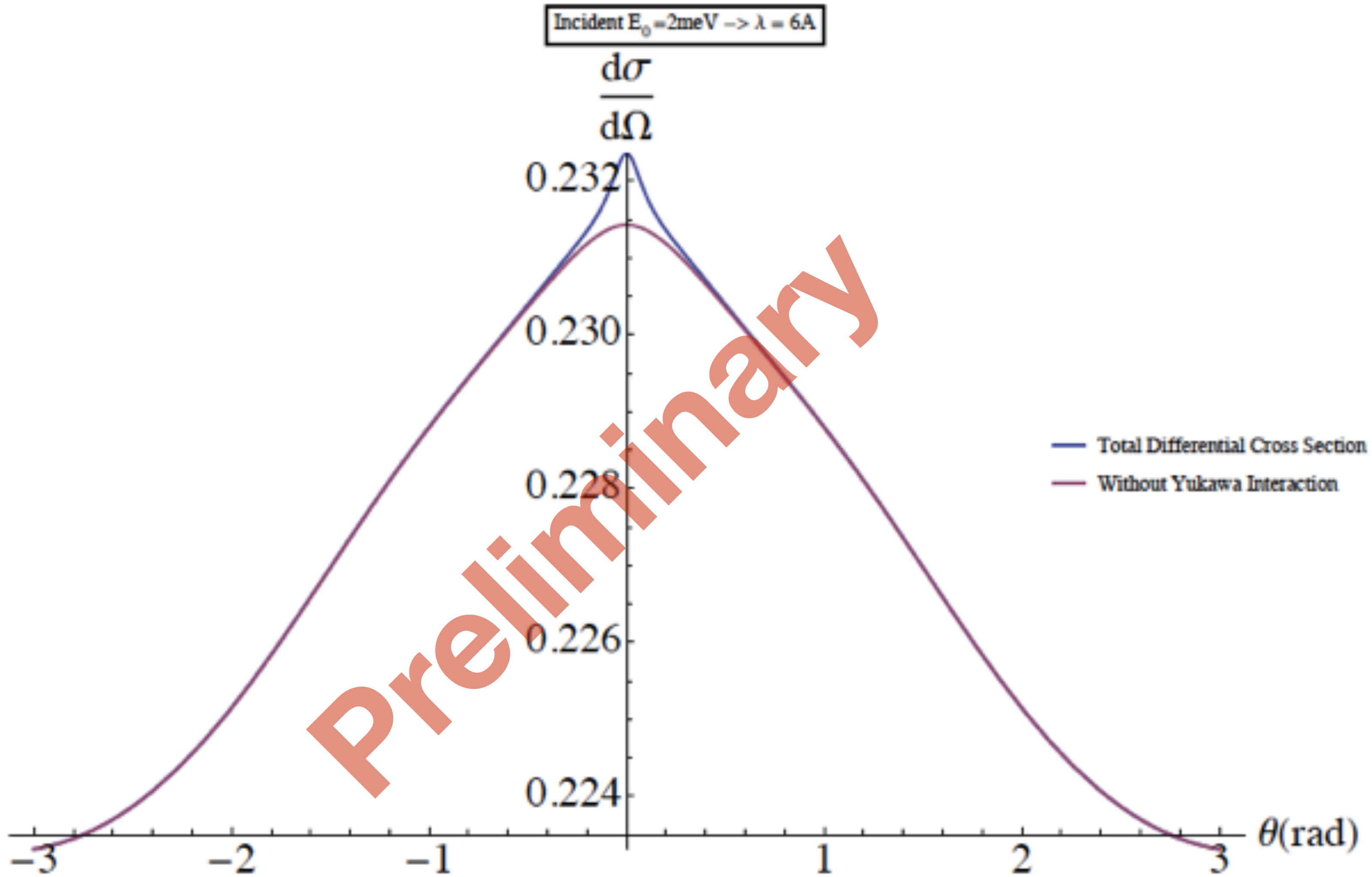
$$u(r) = -\epsilon\left[\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6}\right]$$



Differential Cross Section

$$\frac{d\sigma}{d\Omega dE'} = \frac{d\sigma}{d\Omega dE'}_{coh} + \frac{d\sigma}{d\Omega dE'}_{inc}$$

$$= \frac{k'}{k}[b_c^2(q)S_c(q,\omega) + b_i^2 S_i(q,\omega)]$$



Structure factor

$$S(q,\omega) = S(q)\delta(\omega)$$

$$S(q) = 1 + \frac{2n}{q}\int_0^\infty \{e^{-\frac{E}{k_B T}} - 1\}\, r\sin(qr)\, dr$$

$$\approx 1 + \frac{2n}{q}\int_0^R \{e^{-\frac{\epsilon}{k_B T}} - 1\}\, r\sin(qr)$$

Data acquisition time

Time

100kPa Xe

2.16×10^4sec

100kPa He

2.16×10^4sec

Vacuum

1.80×10^4sec

No cell

1.44×10^4sec