Total Reaction Cross-Section Measurements in the S444 Commissioning Experiment

Lukas Ponnath

R3B Week - Budapest
May 2023

Overview: Setup & Total Reaction Cross-Section

Sensitivity of Carbon Identification

Influence of Position Dependent Efficiency

Supported by BMBF 05P21WOFN1 and 05P19WOFN1.

The results presented here are based on the experiment s444/s473, which was performed at the beam line/infrastructure Cave C at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt (Germany) in the frame of FAIR Phase-0.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC 2094 – 390783311.

ORIGINS Excellence Cluster

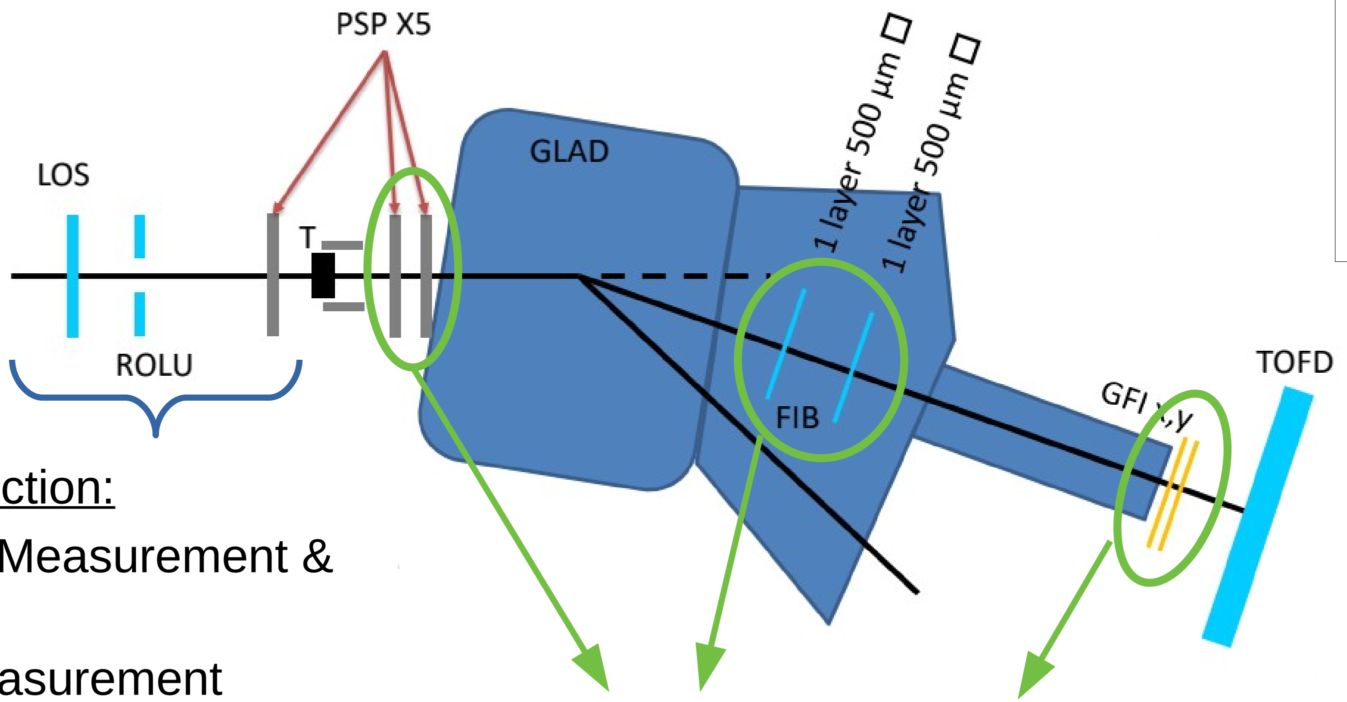
GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

GSI

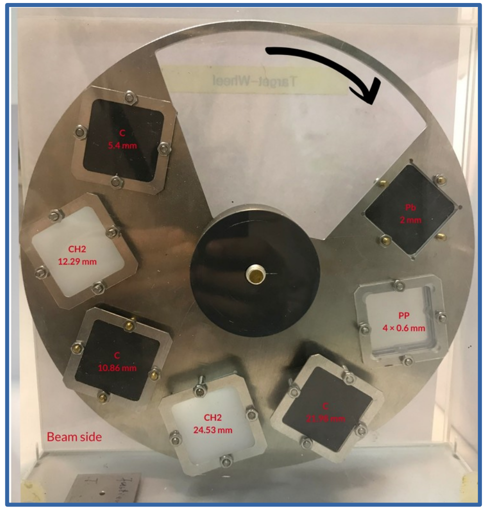
FAIR Phase 0 Research Program

S444 Commissioning Experiment

First common operation of GLAD and R^3B detectors



- Beam: 400 – 1000 AMeV ^{12}C
- Targets: C, CH_2 (different thickness)



Event-Selection:

- Position Measurement & Veto
- Time Measurement
- Charge Identification

Silicon- & Fiber-Tracking:

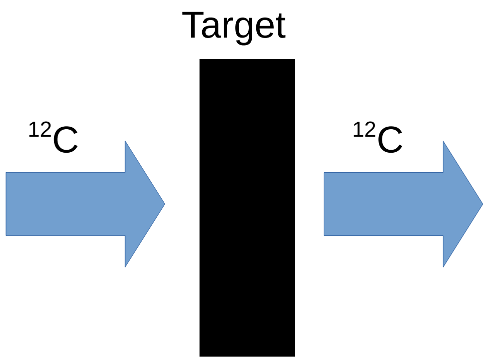
- Position Measurement
- Charge Identification after the target

Total Reaction Cross-Section

Precision Measurement:

Energy dependence of the total reaction cross-section of $^{12}C \rightarrow {}^{12}C$

(Tom Aumann)



Total reaction cross-section: $\sigma_R = \sigma_I + \sigma_{inel}$

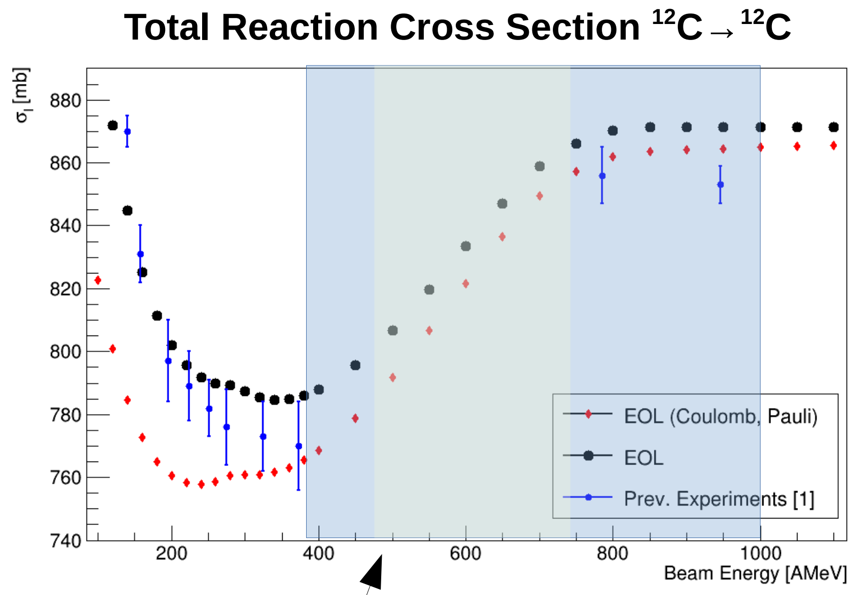
Total interaction cross-section σ_I:

The projectile changes its identity.

At least one nucleon is removed.

Total inelastic cross-section σ_{inel}:

The projectile is excited to a bound state. No nucleon is removed.



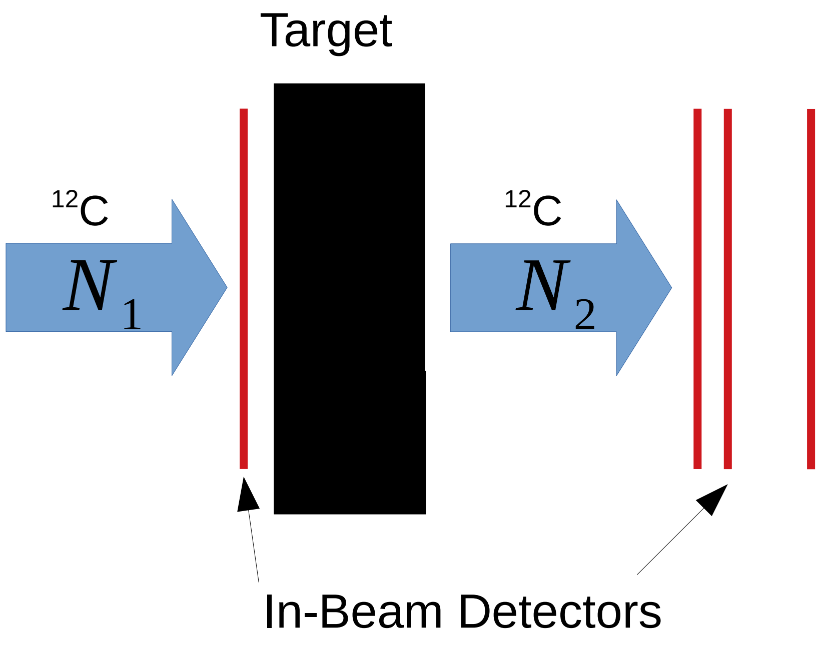
[1] I.Tanihata et al. (Radioactive Nuclear Beams 1990), M. Takechi et al. (PRC – 79 2009) , A. Ozawa et al. (Nuc. Phy. A – 691 2001)

EOL data: E.A. Teixeira, T. Aumann, C.A. Bertulani, B.V. Carlson (Eur. Phys. J.A – 58:205 2022)

^{12}C Beam Energies in S444 Experiment:

400, 550, 650, 800 & 1000 AMeV

Measurement Concept



Surviving-Probability: $$P_{surv.} = \frac{N_2}{N_1} = e^{-N_t \cdot \sigma_R}$$

Exclude reactions in Setup: $$\frac{\overbrace{N_2^i / N_1^i}^{\text{Target-In}}}{\underbrace{N_2^o / N_1^o}_{\text{Target-Out}}} = e^{-N_t \cdot \sigma_R}$$

<u>Transmission method:</u>

$$\sigma_R = -\frac{1}{N_t} \ln\left(\frac{N_2^i / N_1^i}{N_2^o / N_1^o}\right)$$

Measurement Concept

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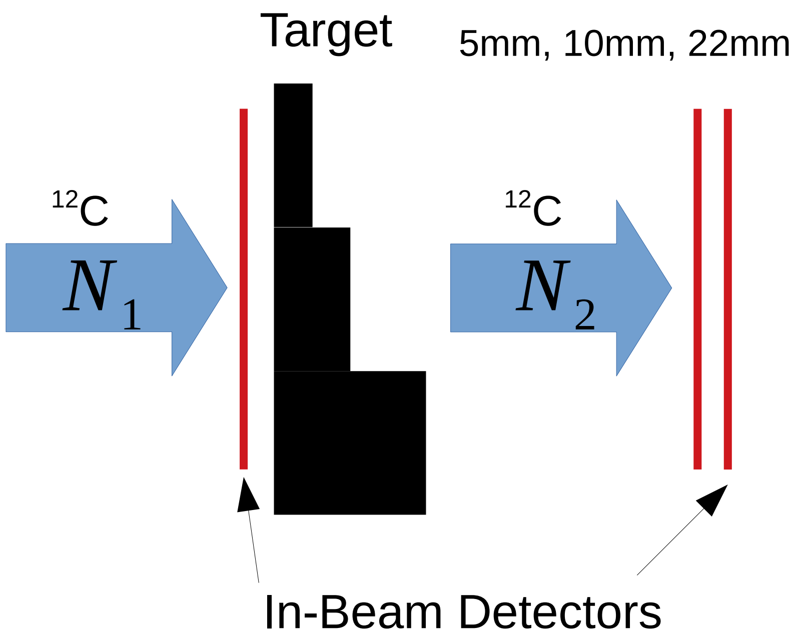

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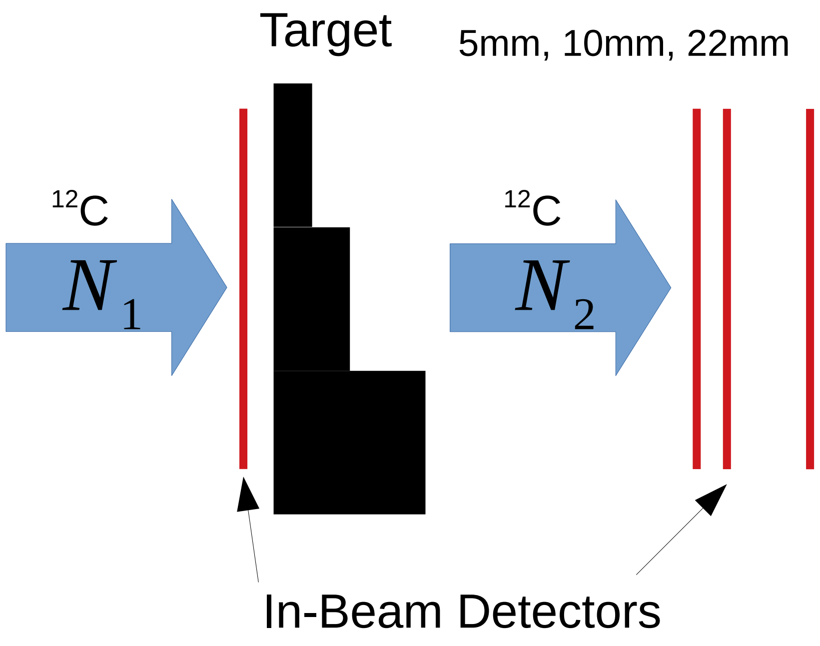
- ➔ N_t is a target specific constant (density, Thickness)
- ➔ N_1, number of incident ^{12}C nuclei (stable beam, Event-Selection)

Measurement Concept



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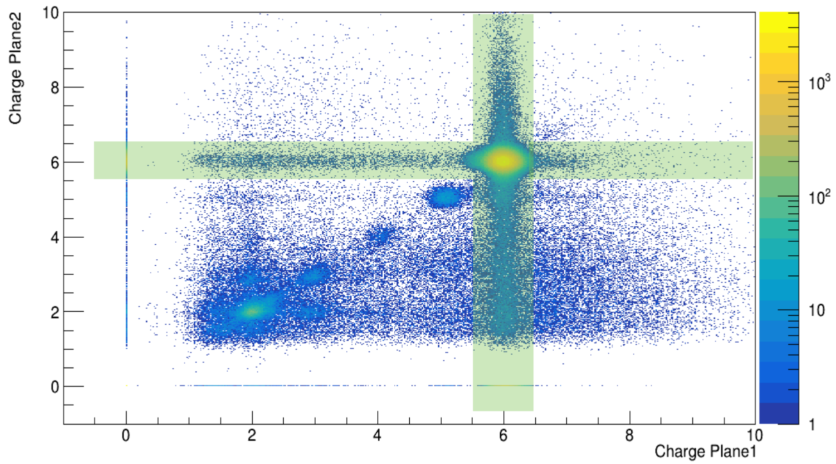
Challenge: Time- & Rate-depended Efficiency & geometrical Acceptance of Detectors

- → N_t is a target specific constant (density, Thickness)
- → N_1, number of incident ^{12}C nuclei (stable beam, Event-Selection)
- → N_2, number of non-reacting ^{12}C nuclei, identified after the target (that’s our big challenge)

Number of non-reacting Nuclei

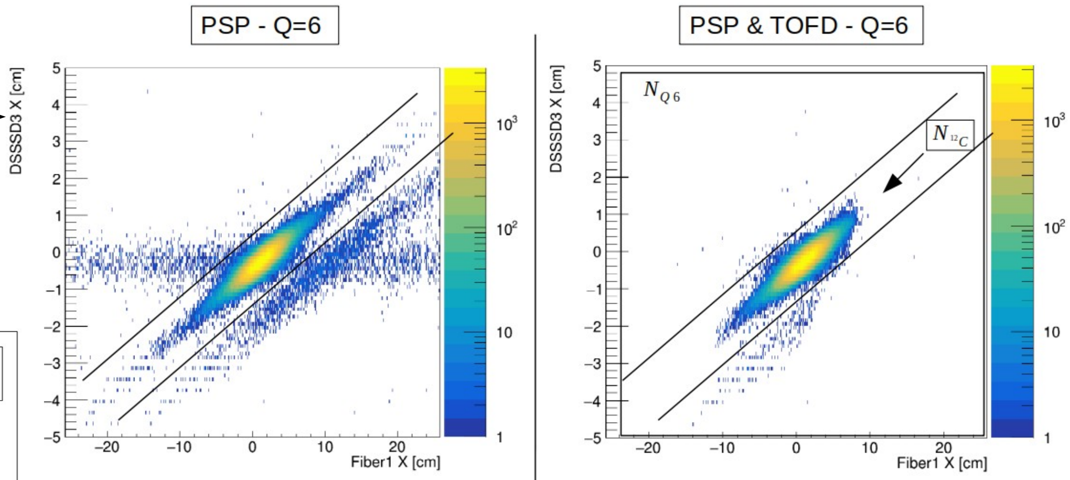
Strategy: minimize systematic uncertainties → minimize Number of detectors

1. Count the number of all Carbon (Q=6) isotopes with TOFD $N_{Q=6}$

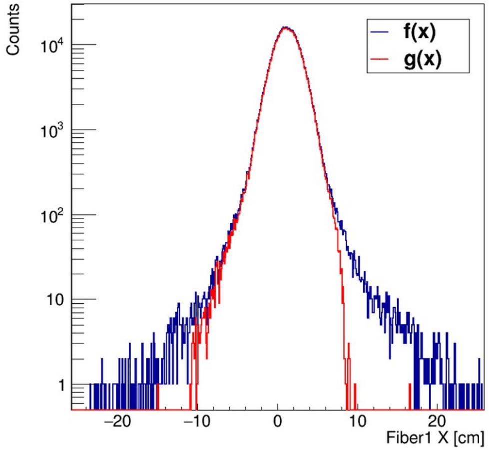


2. Define Correction factors:

2a. Ratio of ^{12}C to all identified Carbon isotopes $R(^{12}C)$



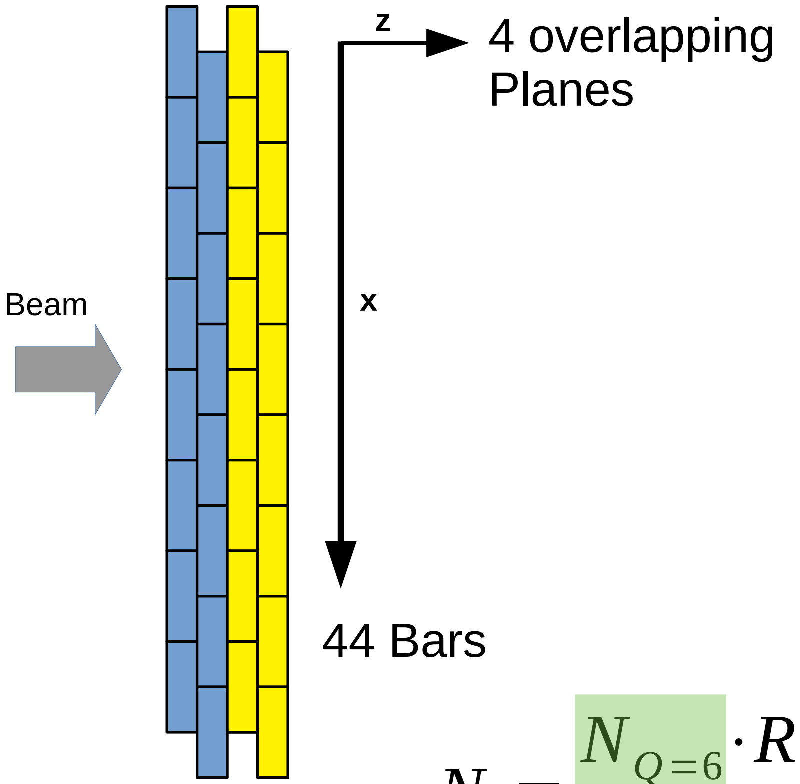
2b. Correction of variable geometrical acceptance A



Non-reacting ^{12}C nuclei:

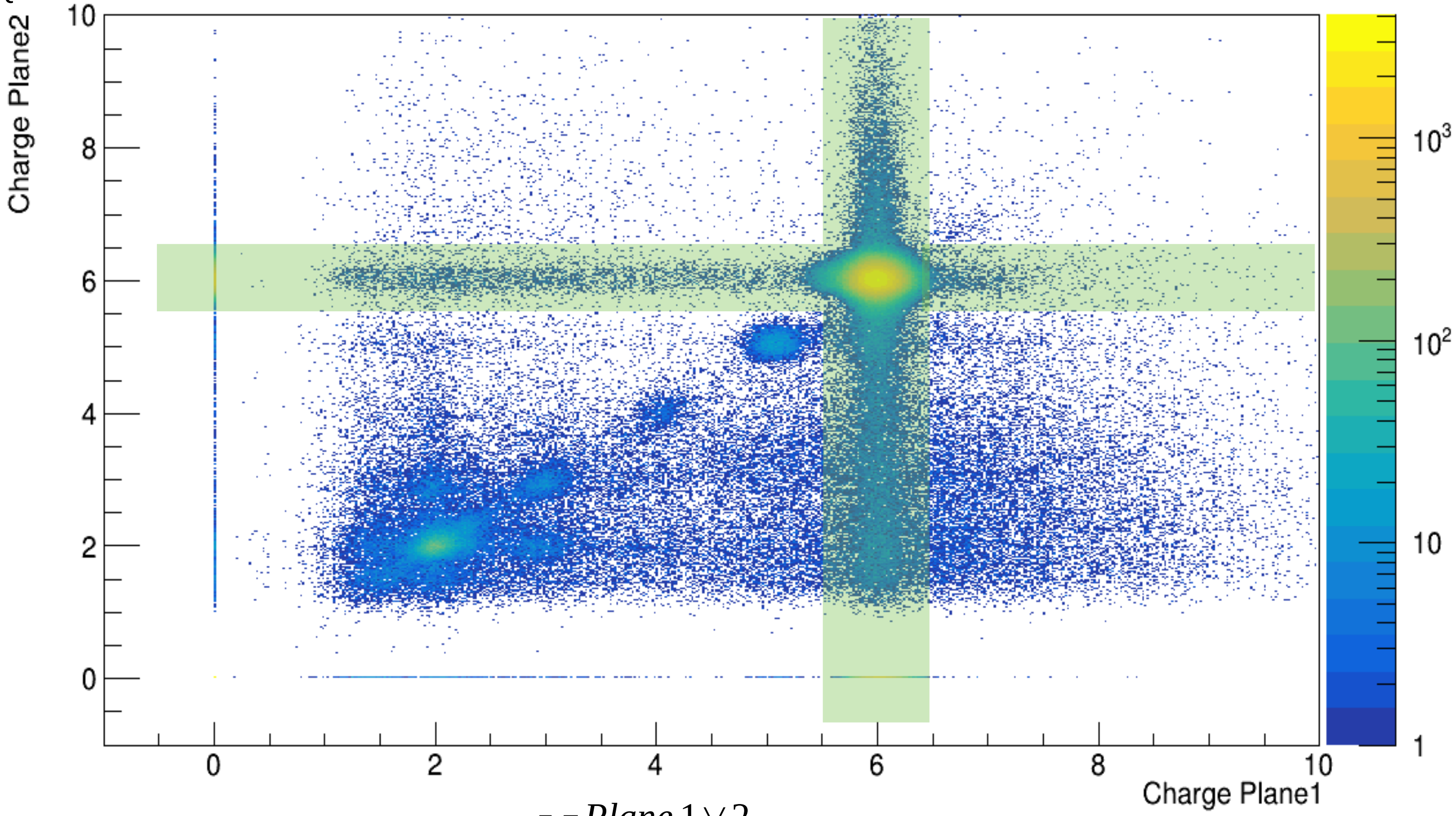
$$N_2^{i/o} = \frac{N_{Q=6}^{i/o} \cdot R^{i/o}(^{12}C)}{\varepsilon^{i/o} \cdot \mathrm{A}^{i/o}}$$

Carbon Identification



$$N_2 = \frac{N_{Q=6} \cdot R(^{12}C)}{\varepsilon \cdot A}$$

$N_{Q=6}$ = Plane1 <u>or</u> Plane2 saw a particle with Q = 6. +/- 0.5 (>99.9993 %)



Check efficiency of Carbon identification: $\varepsilon = \frac{N_{Q=6}^{Plane\,1 \vee 2}}{N_{Q=6}^{Plane\,3 \wedge 4}} = 0.999916(17)\,\%$

Carbon Identification

Is σ_I sensitive to the cut-width?

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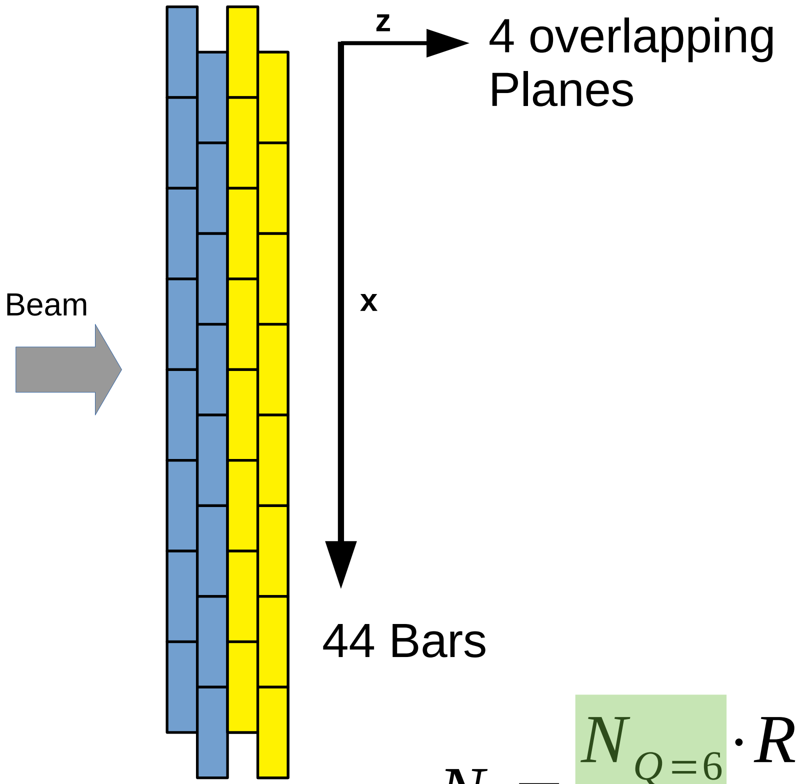

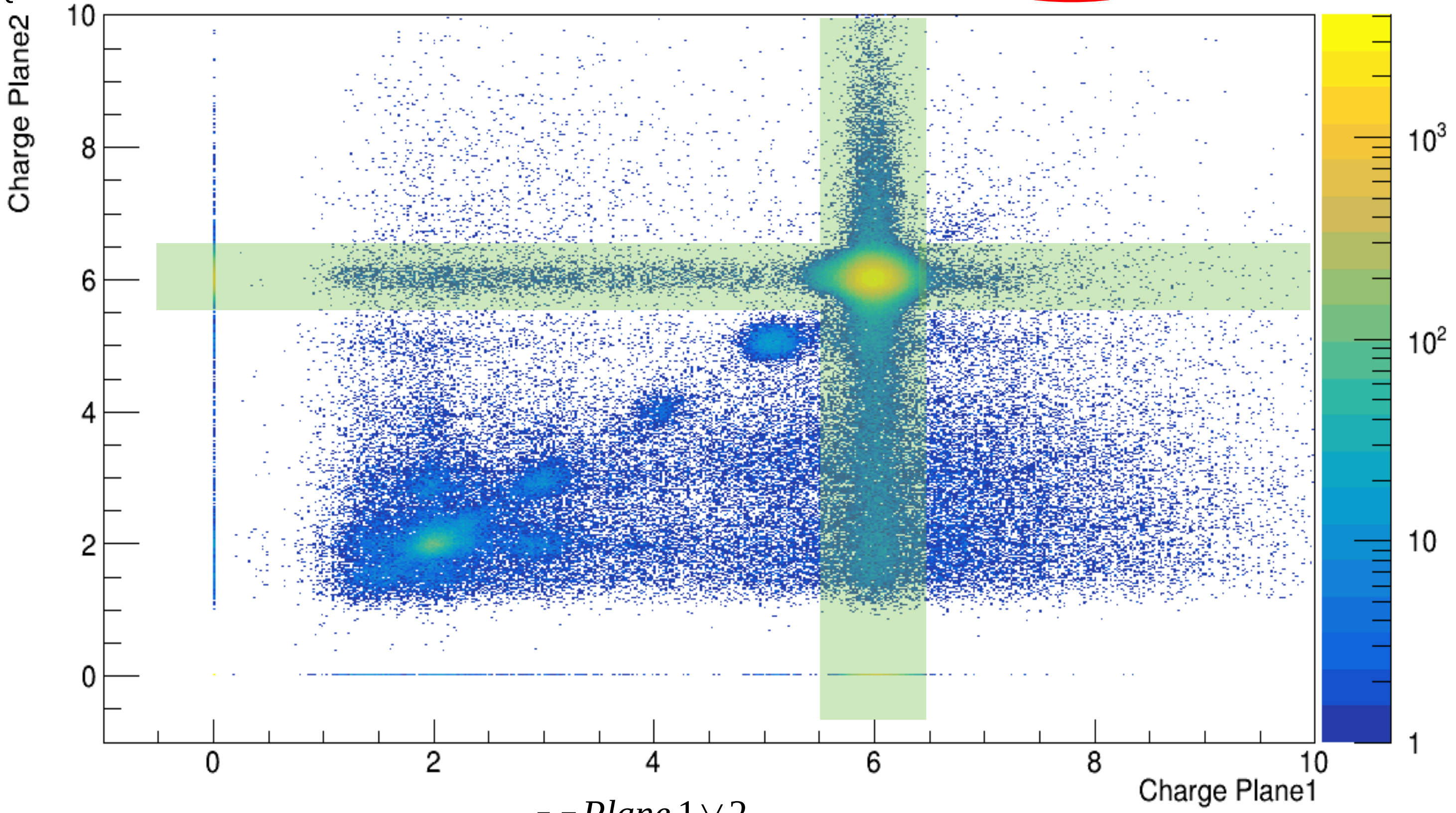

$$N_2 = \frac{N_{Q=6} \cdot R(^{12}C)}{\varepsilon \cdot A}$$

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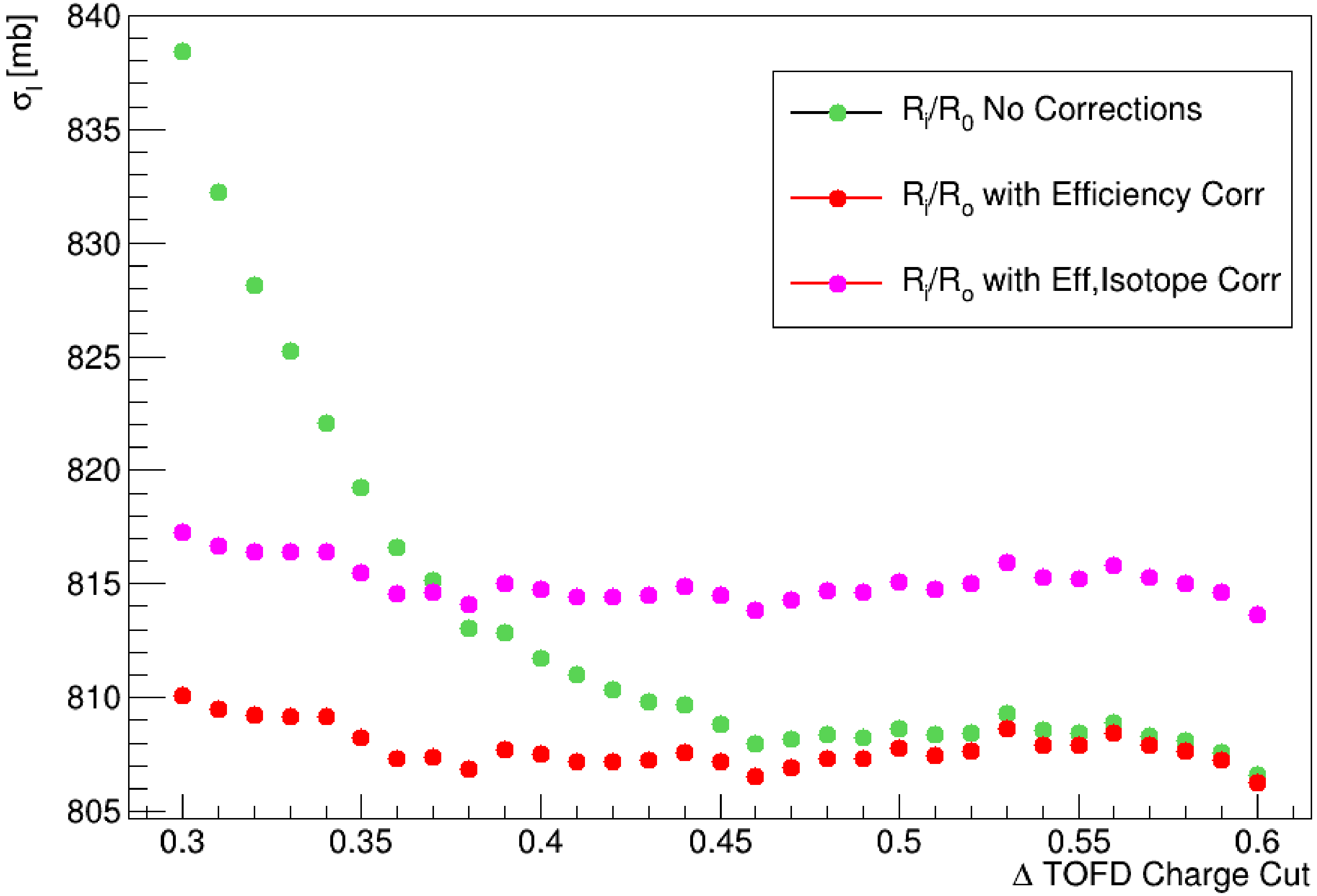
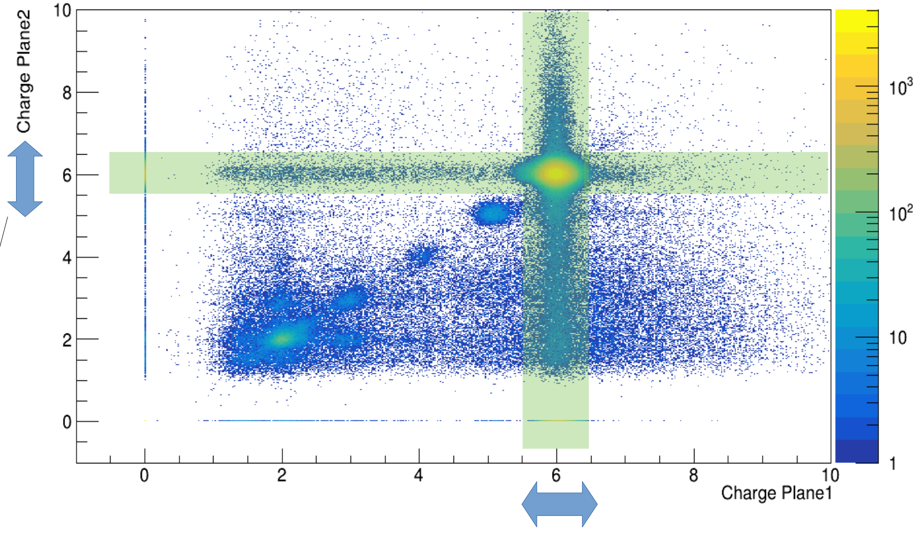
Dependance on Cut Width – Missing Particles

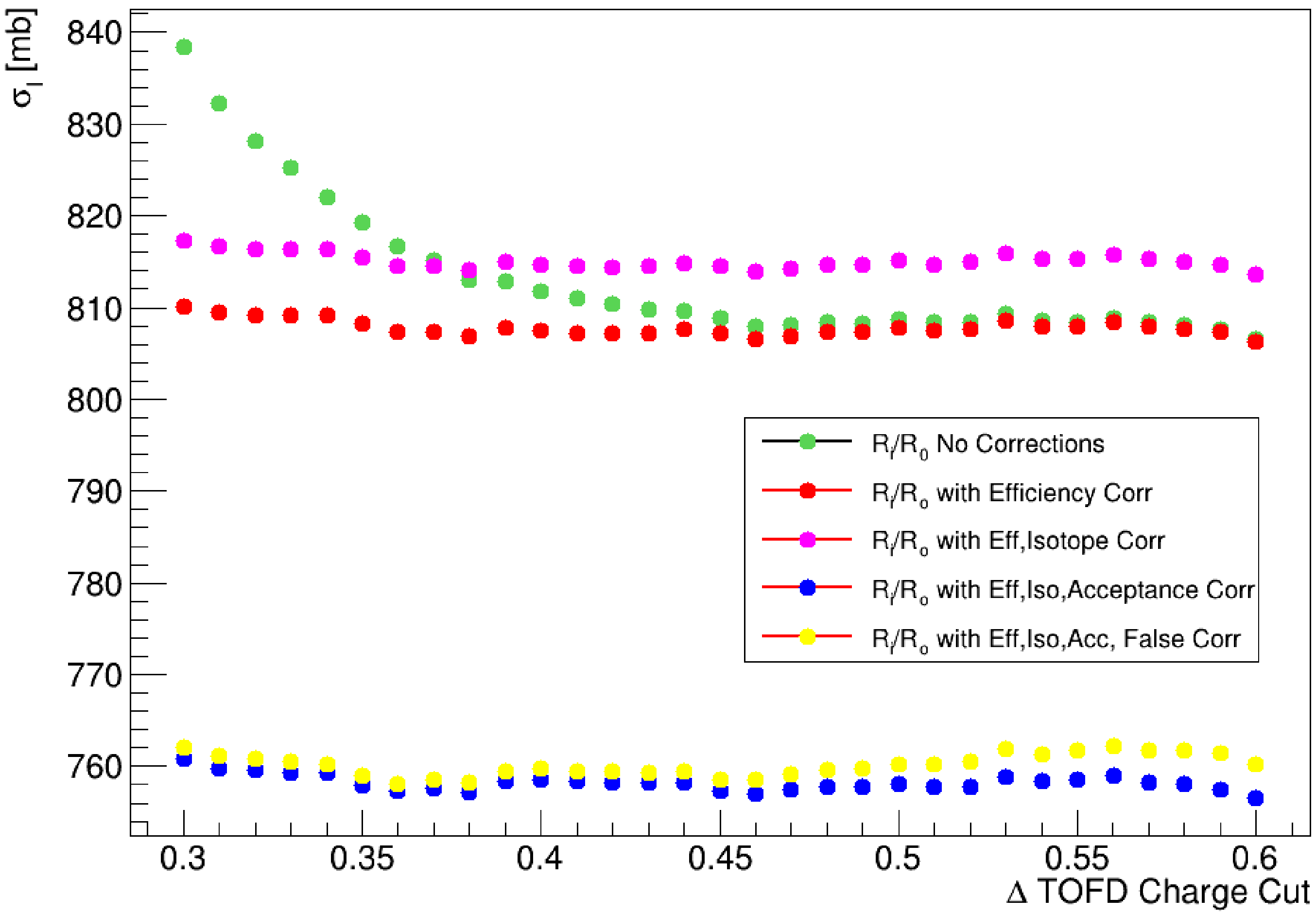


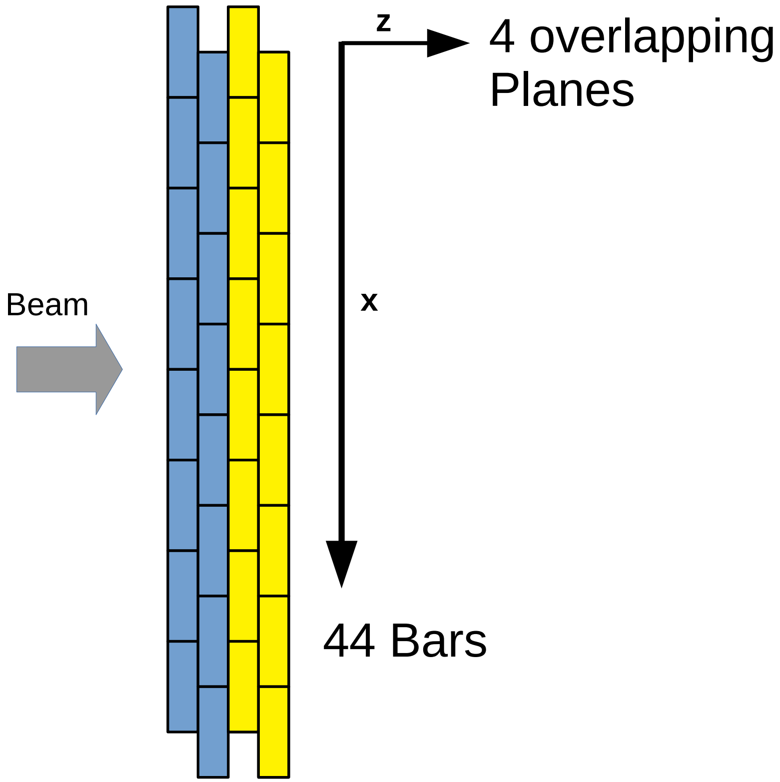


$$\sigma_R = -\frac{1}{N_t} \ln\left(\frac{N_2^i / N_1^i}{N_2^o / N_1^o}\right)$$

$$N_2^{i/o} = \frac{N_{Q=6}^{i/o} \cdot R^{i/o}\left({}^{12}C\right)}{\varepsilon^{i/o} \cdot A^{i/o}}$$

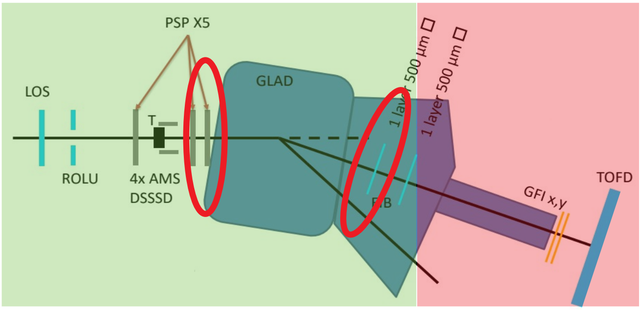
Dependance on Cut Width – False Particles





$$False = \frac{N_{Q\neq 6}^{Plane\,1\vee 2}}{N_{Q=6}^{Plane\,3\vee 4}}$$

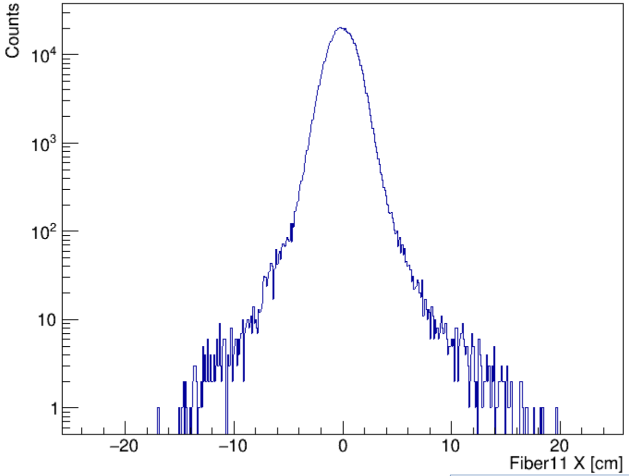
Acceptance-Correction



$$A = \frac{\int_{-25.8\,cm}^{25.8\,cm} g(x)}{\int_{-25.8\,cm}^{25.8\,cm} S \cdot f(x)}$$

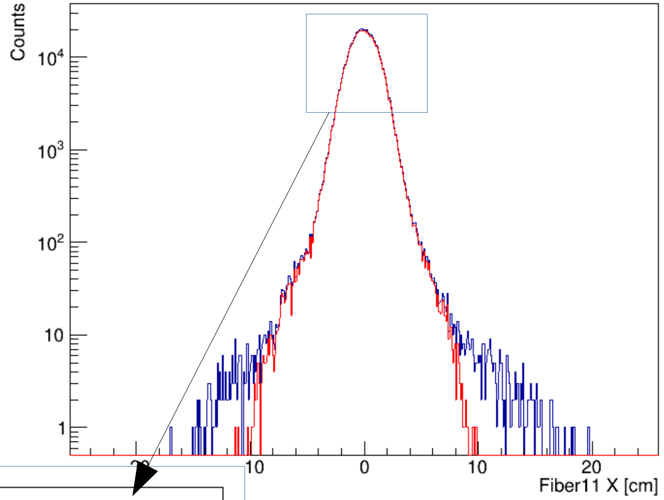
Scaling-Factor

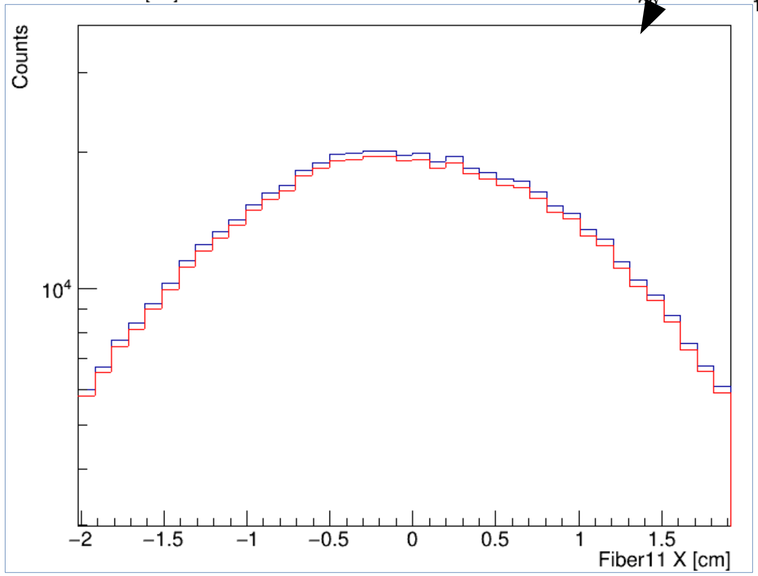
Position-Distribution of ^{12}C f(x)



TOFD Q=6

Position-Distribution of ^{12}C with TOFD g(x)





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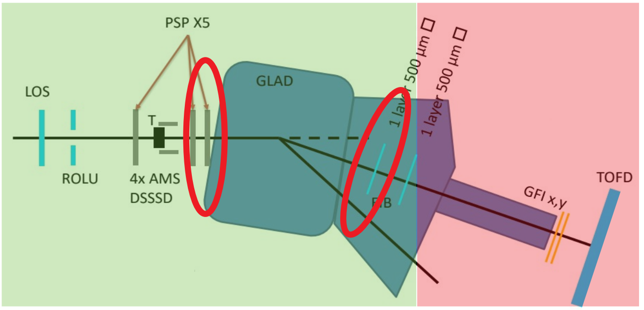

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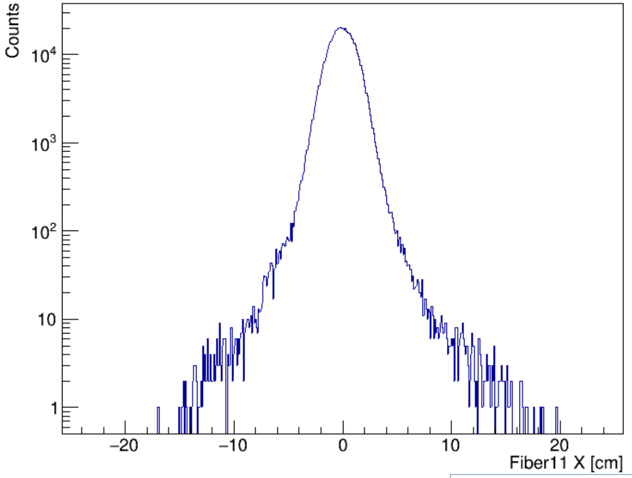

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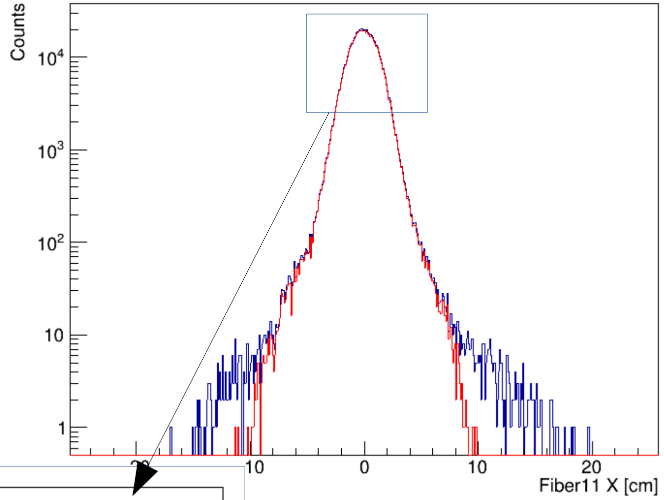
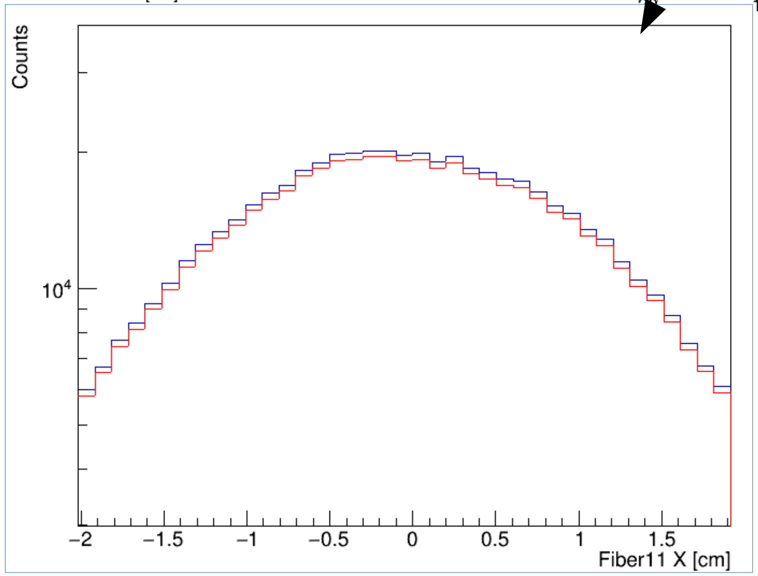
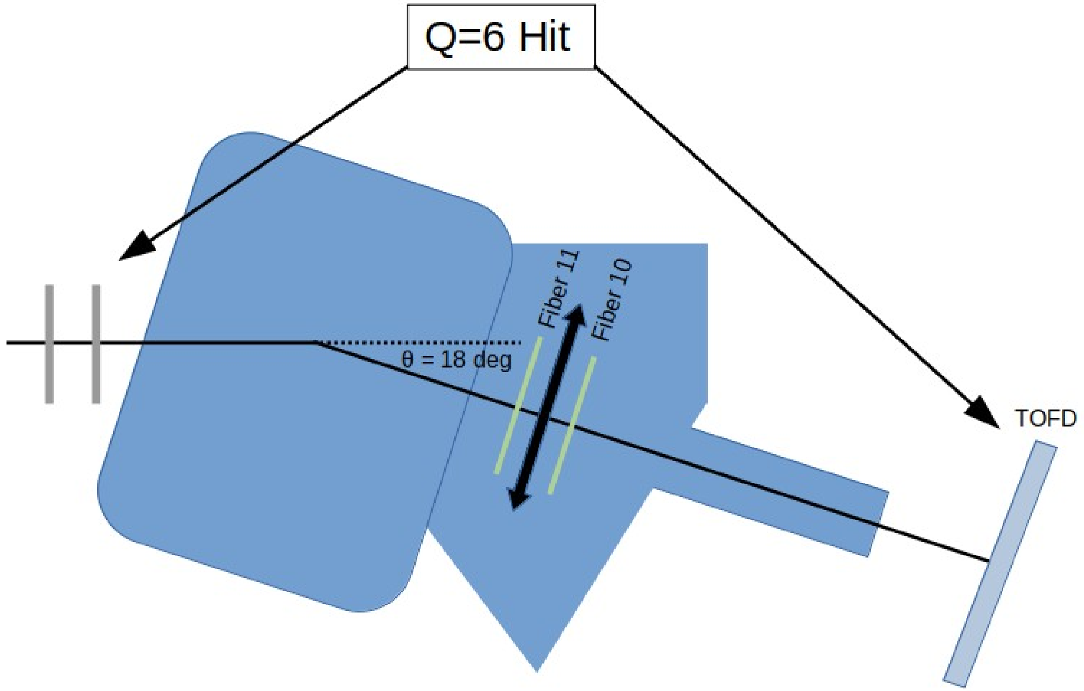


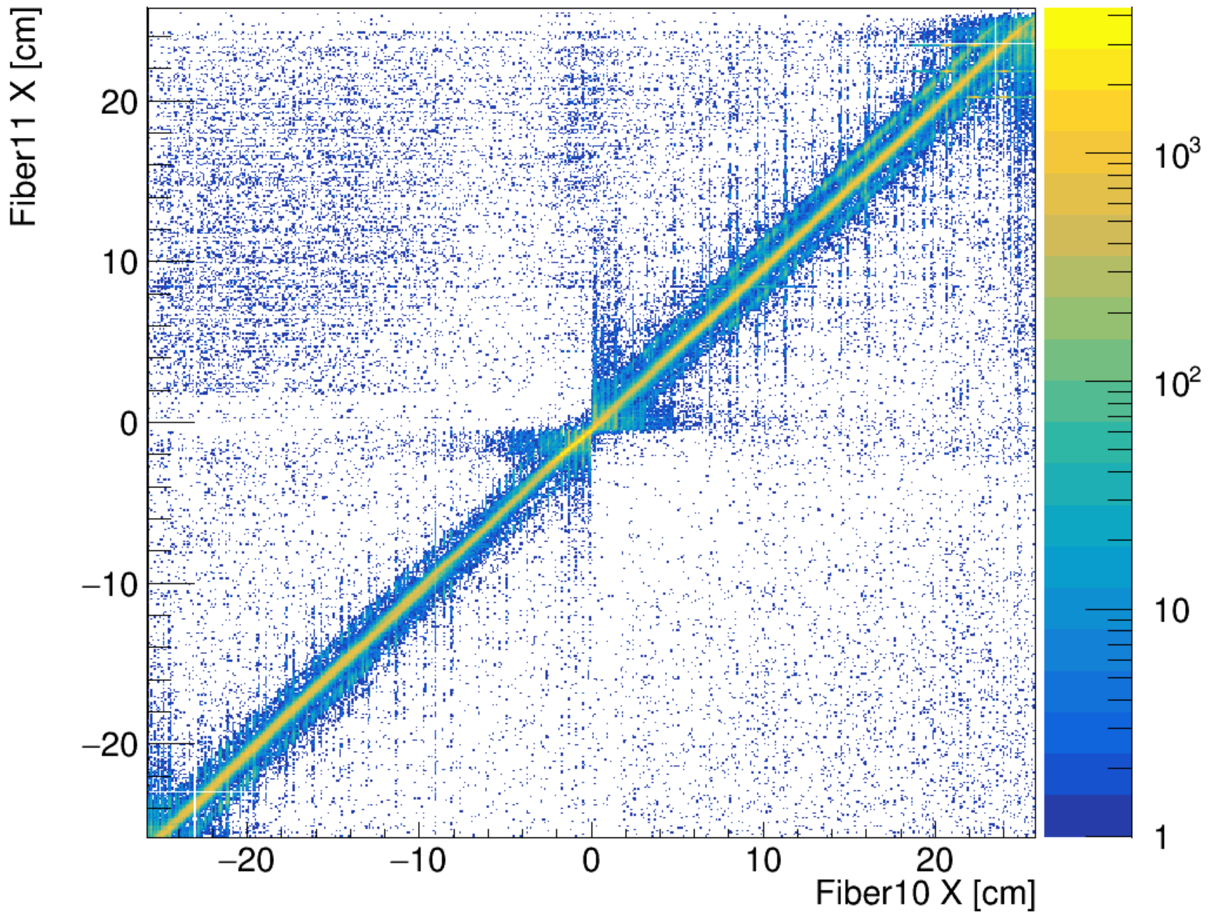


Is σ_I sensitive to a position dependent efficiency?

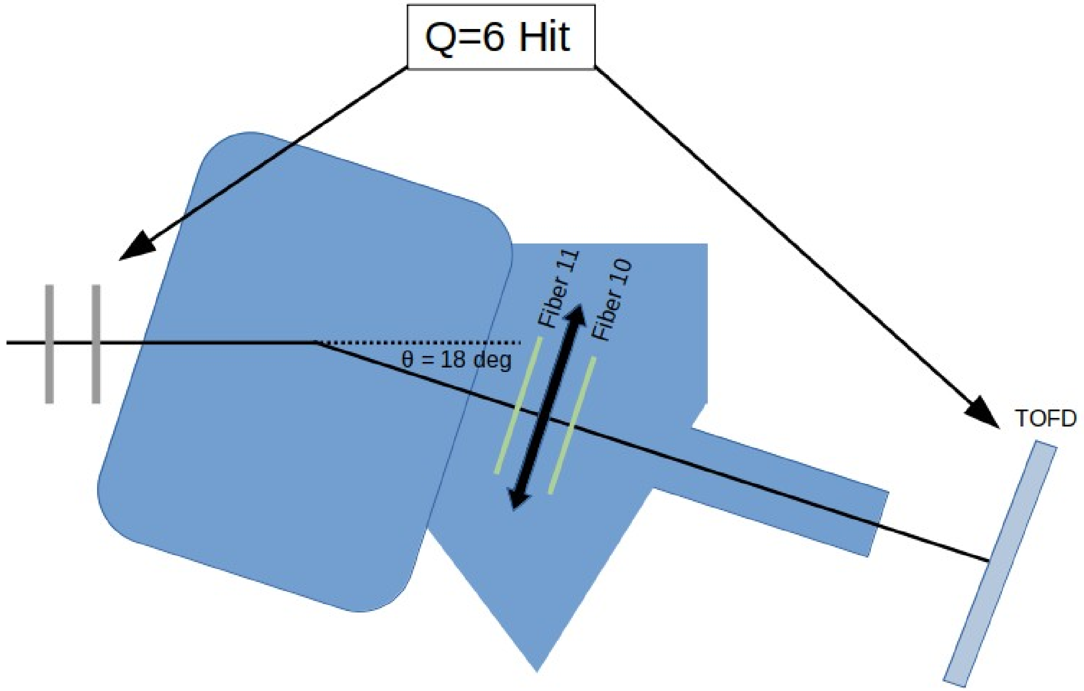
Position Dependent Efficiency

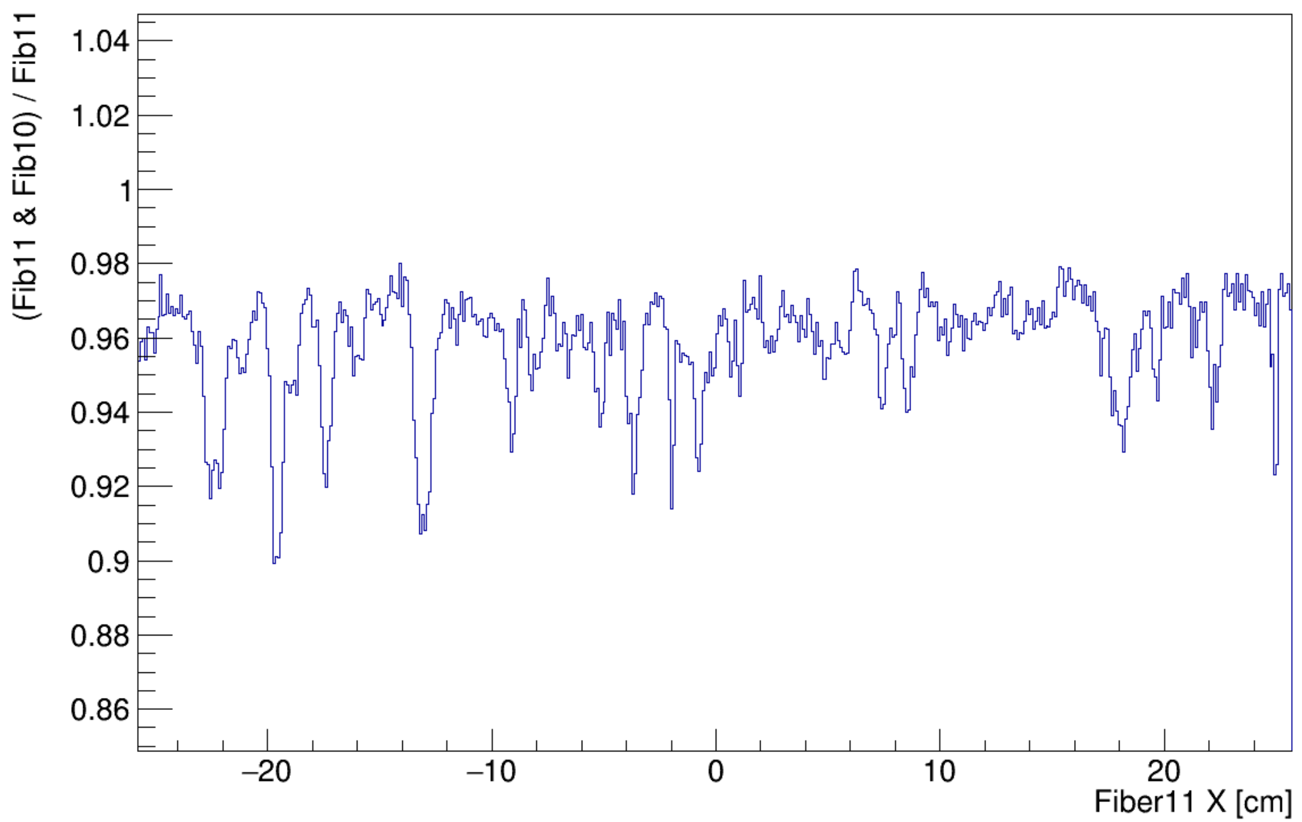


Fiber Sweep-Run



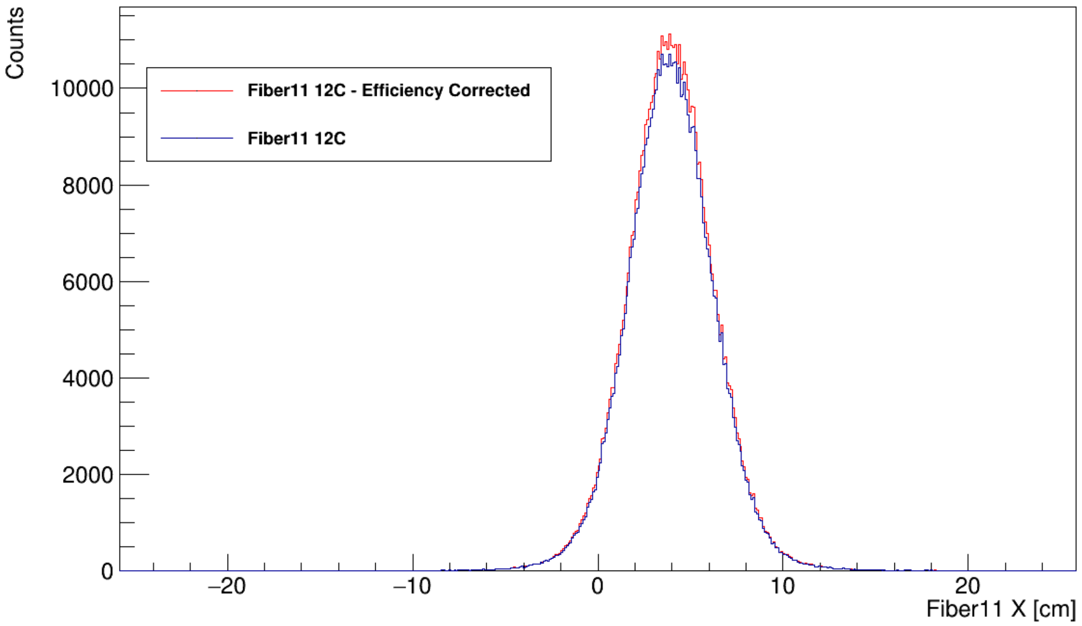
Position Dependent Efficiency

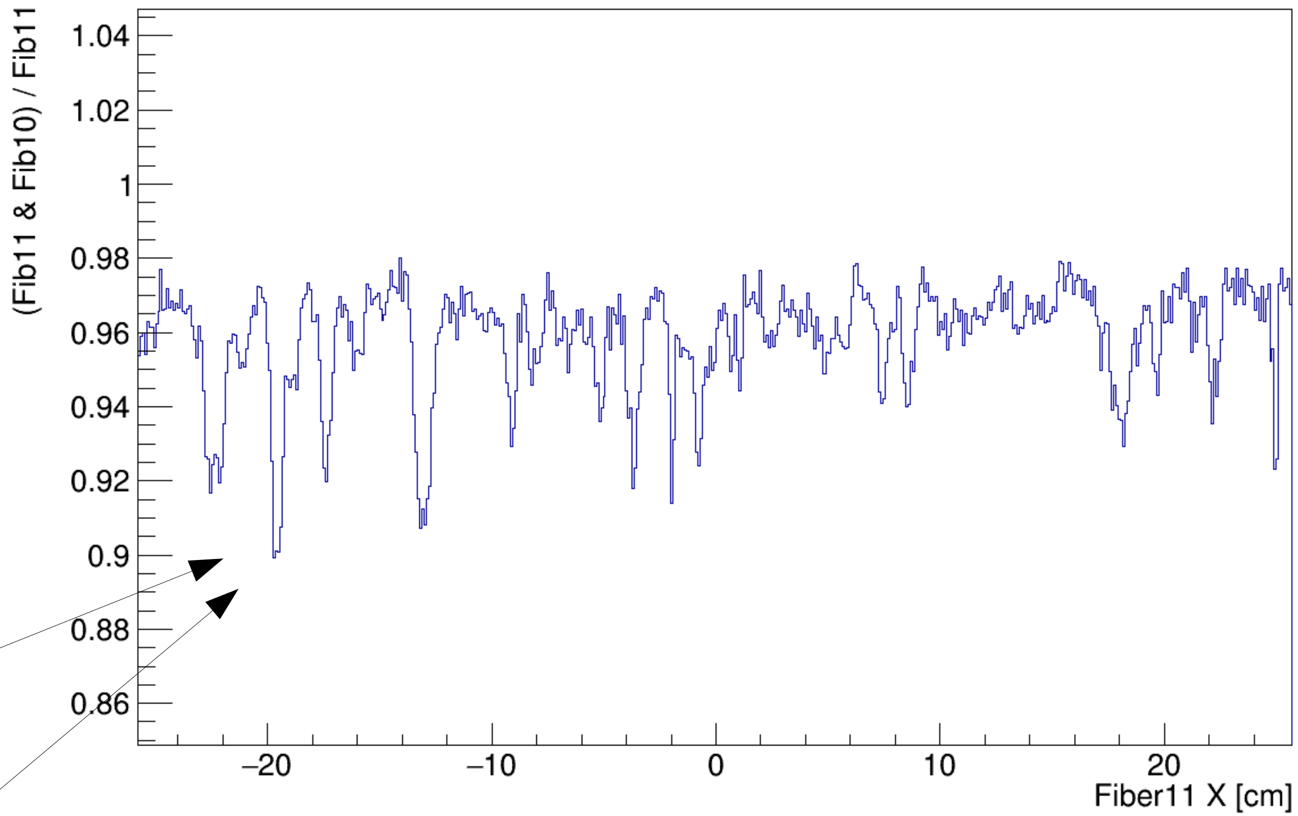




$$\varepsilon_{fib}(X) = \frac{Fib\,11 \wedge Fiber\,10}{Fib\,11}$$

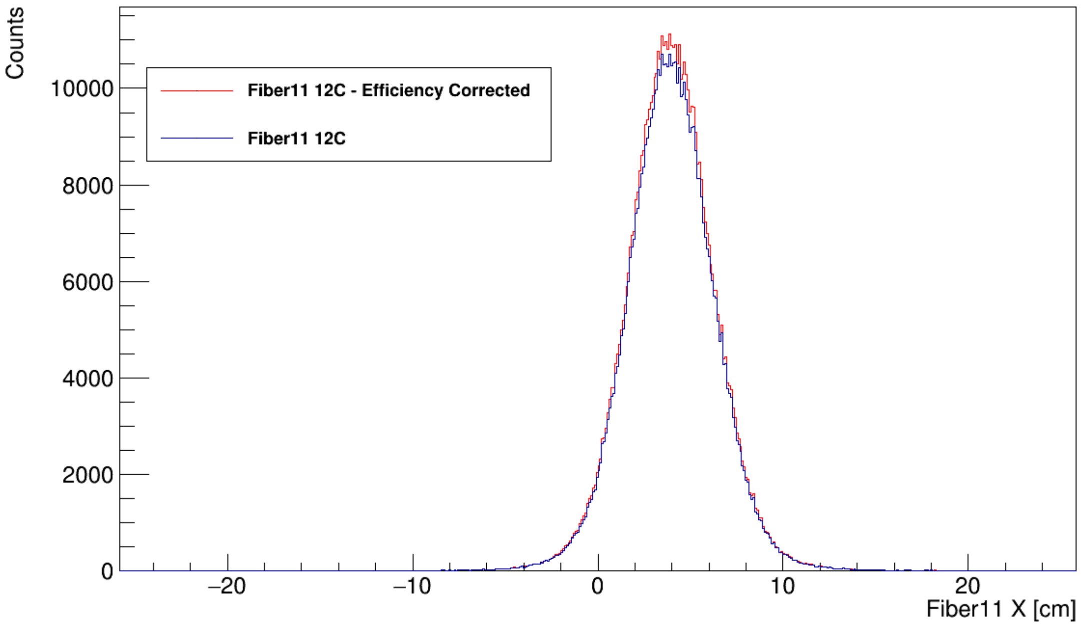
Position Dependent Efficiency





$$A_{Eff.Corr} = \frac{\int_{-25.8\,cm}^{25.8\,cm} g(x) \cdot \varepsilon_{fib}(x)}{\int_{-25.8\,cm}^{25.8\,cm} S \cdot f(x) \cdot \varepsilon_{fib}(x)}$$

Position Dependent Efficiency



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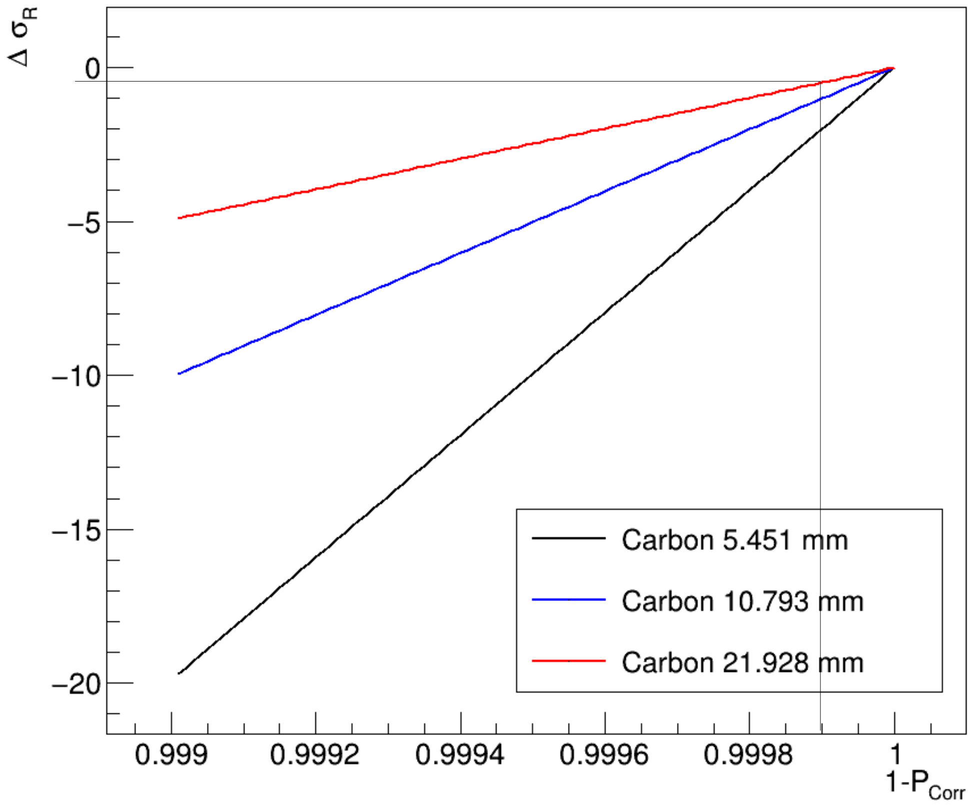
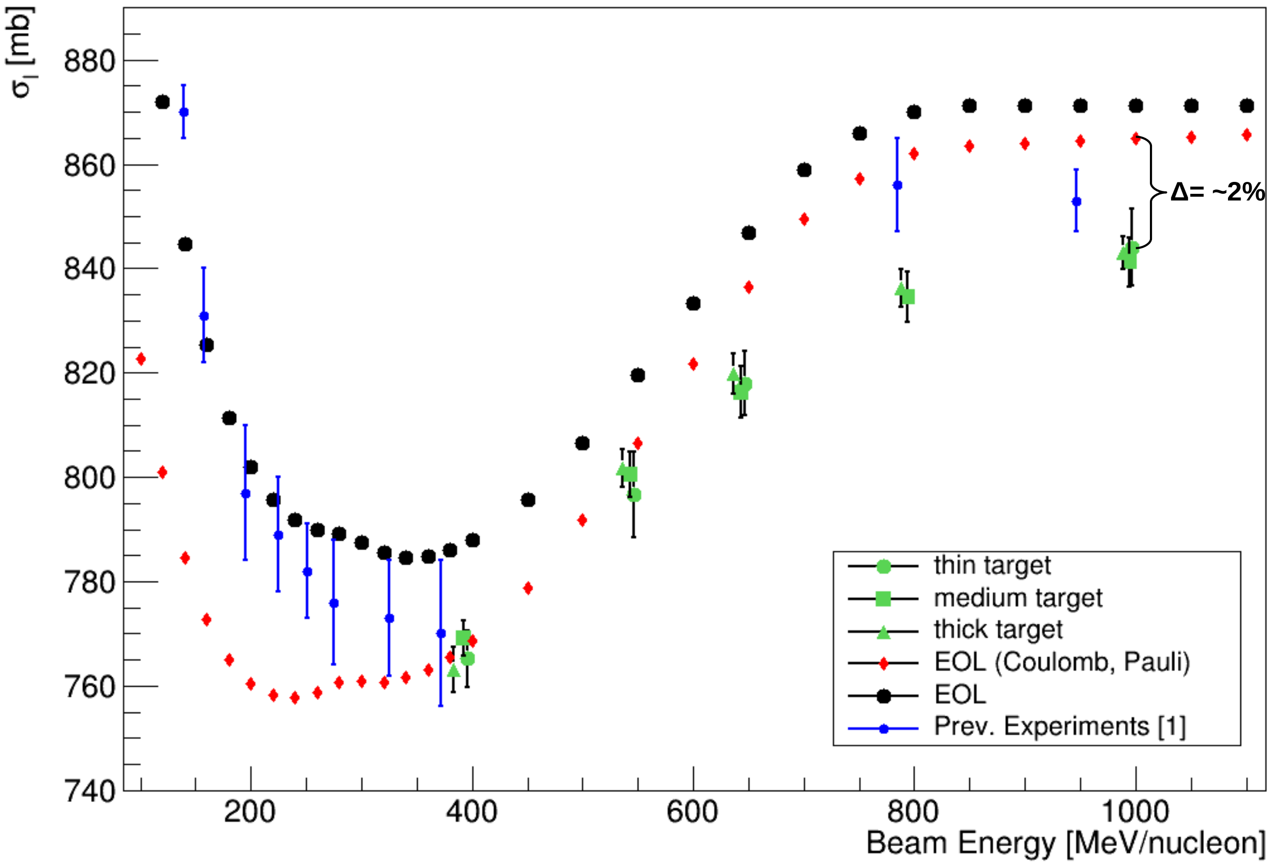


$$A_{Eff.Corr} - A \approx 0.008\%$$

Deviation will be included in systematic uncertainty

Total Reaction Cross-Section



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EOL data: E.A. Teixeira, T. Aumann, C.A. Bertulani, B.V. Carlson (Eur. Phys. J.A – 58:205 2022)

Status:

- Experimental results are in agreement with previous experiments at low energies
- Theory overestimates exp. results at high energies
- No evidence for underestimation in analysis
  - Possible explanation in model?
    - Clustering in ^{12}C
    - Neutron Density
    - QCD effect?

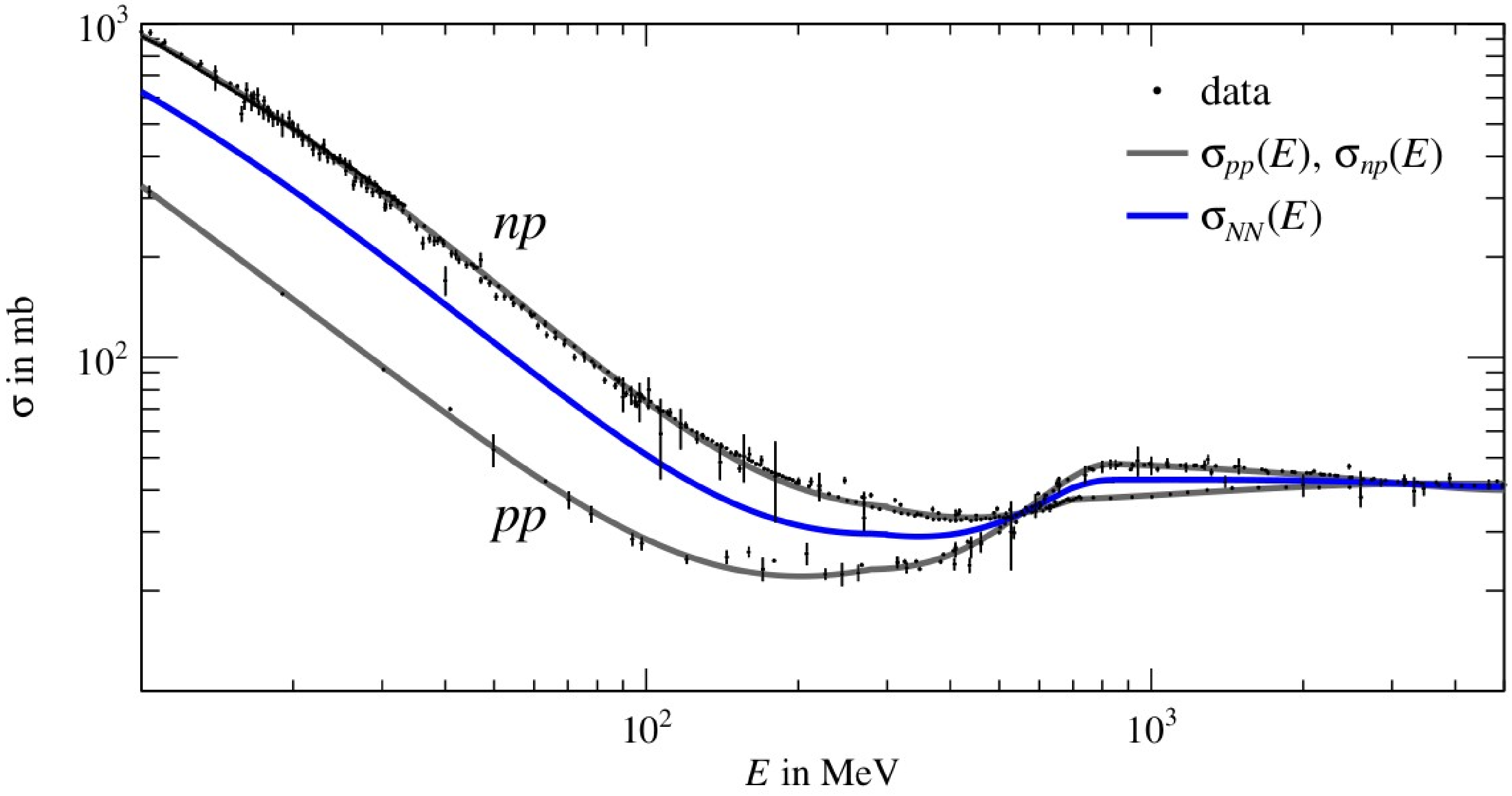
Thank you!

Paper Draft is (almost) ready

CALIFA @ Technical University of Munich (TUM)

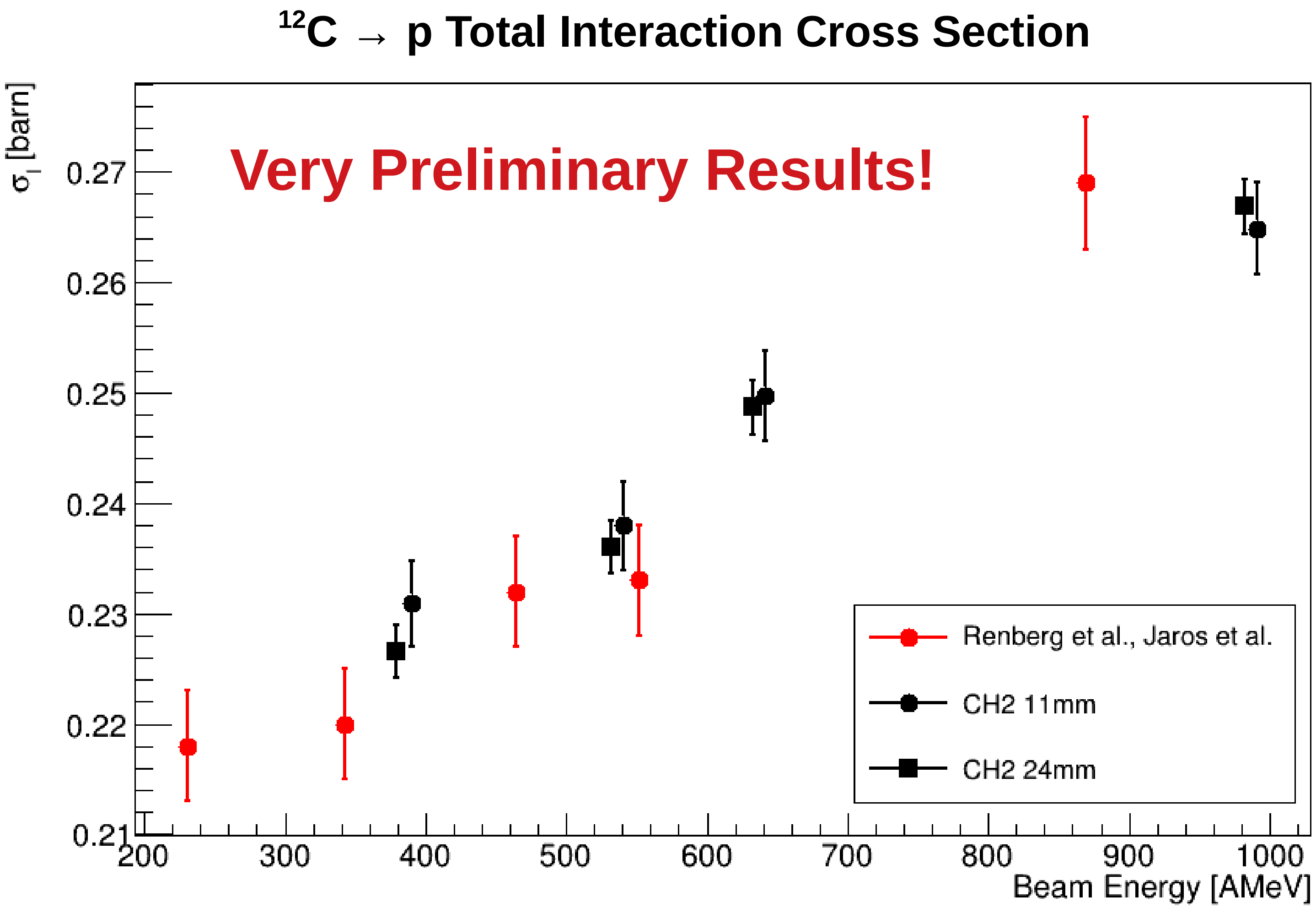
Roman Gernhäuser, Philipp Klenze, Lukas Ponnath, Tobias Jenegger

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung



$$V_{OL}(\vec{b}) \propto \sigma_{NN} \cdot \int \rho_P(\vec{r})\, \rho_T(\vec{r} - \vec{b})$$

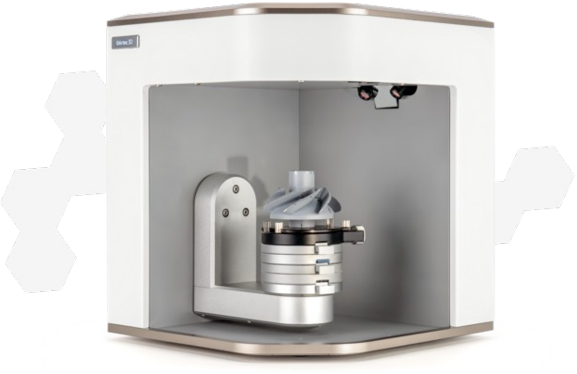
Total Reaction Cross Section

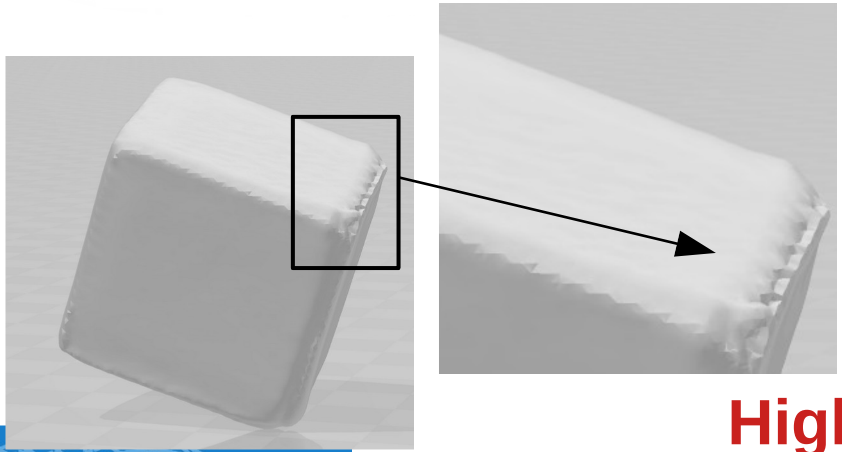


P. Renberg et al. Nuclear Physics A 183 (1972) 81-104

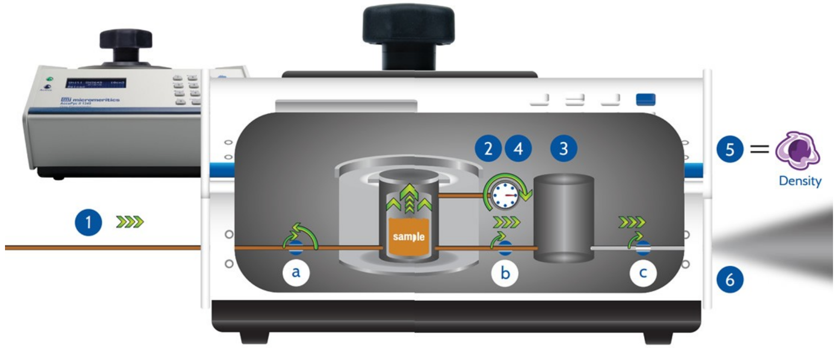
Target Density Measurement

1. Photometry

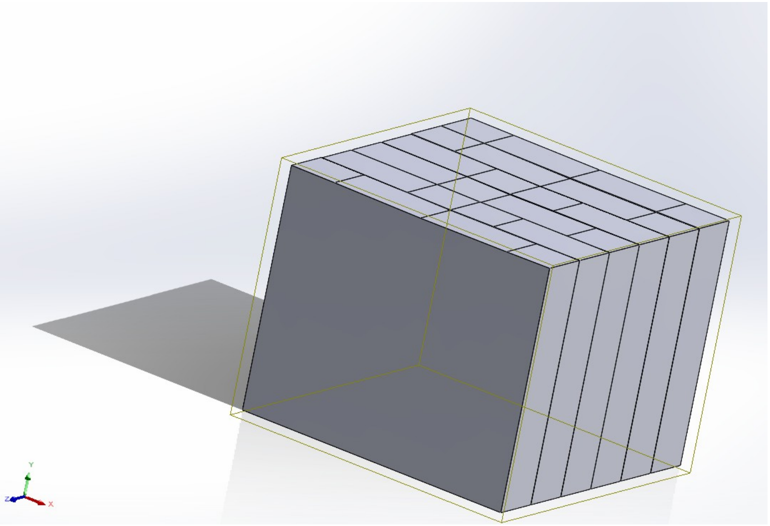




2. Gaspycnometer



3. By Hand / CAD



High uncertainties in all measurements!

But: A density < 1.84 g/cm³ could be excluded

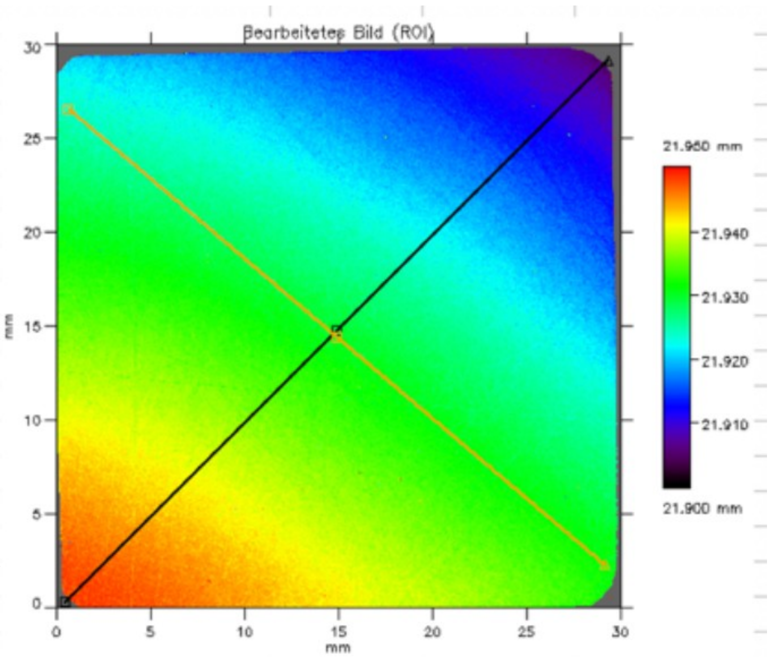
Total Reaction Cross-Section

<u>Number of target scattering centers:</u>

$$N_t = \frac{\rho_t \cdot d_t \cdot N_A}{A_t}$$

where

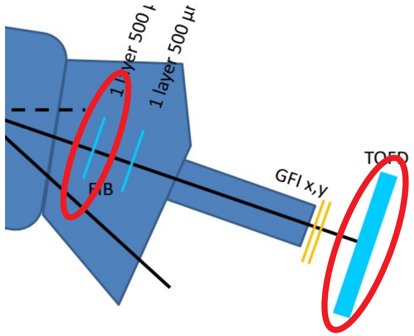
- ρ_t is the volume density of the target (1.84 g/cm^3)
- d_t is the target thickness
- N_A is Avogadro's constant (6.02214*10^{23} mol^{-1})
- A_t is the molar mass of the target (12.0107 u)



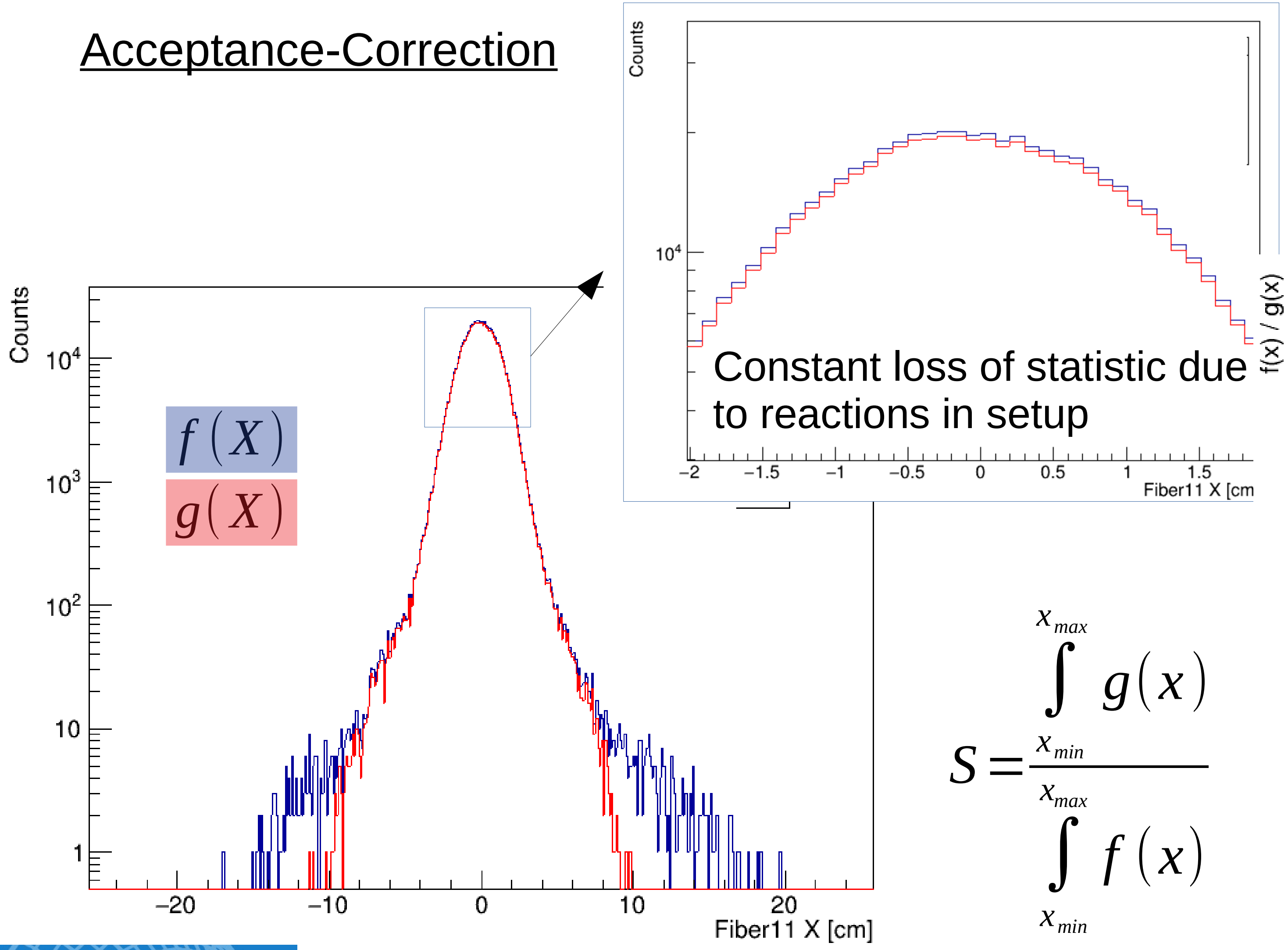
Dt [cm]	Nt
0.5451	5.50334*10^{23}
1.0793	1.09904*10^{24}
2.1928	2.120248*10^{25}

$$\sigma_R = -\frac{1}{N_t} \ln\left(\frac{N_2^i / N_1^i}{N_2^o / N_1^o}\right)$$

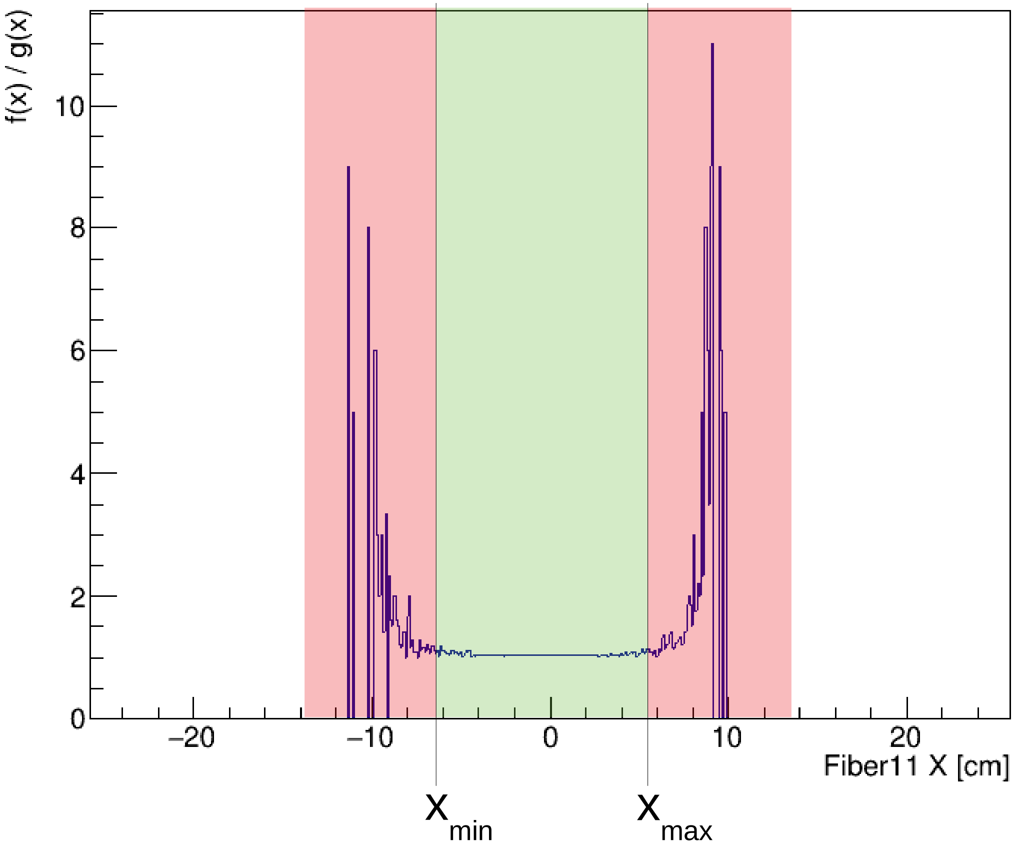
Total Reaction Cross-Section



Acceptance-Correction



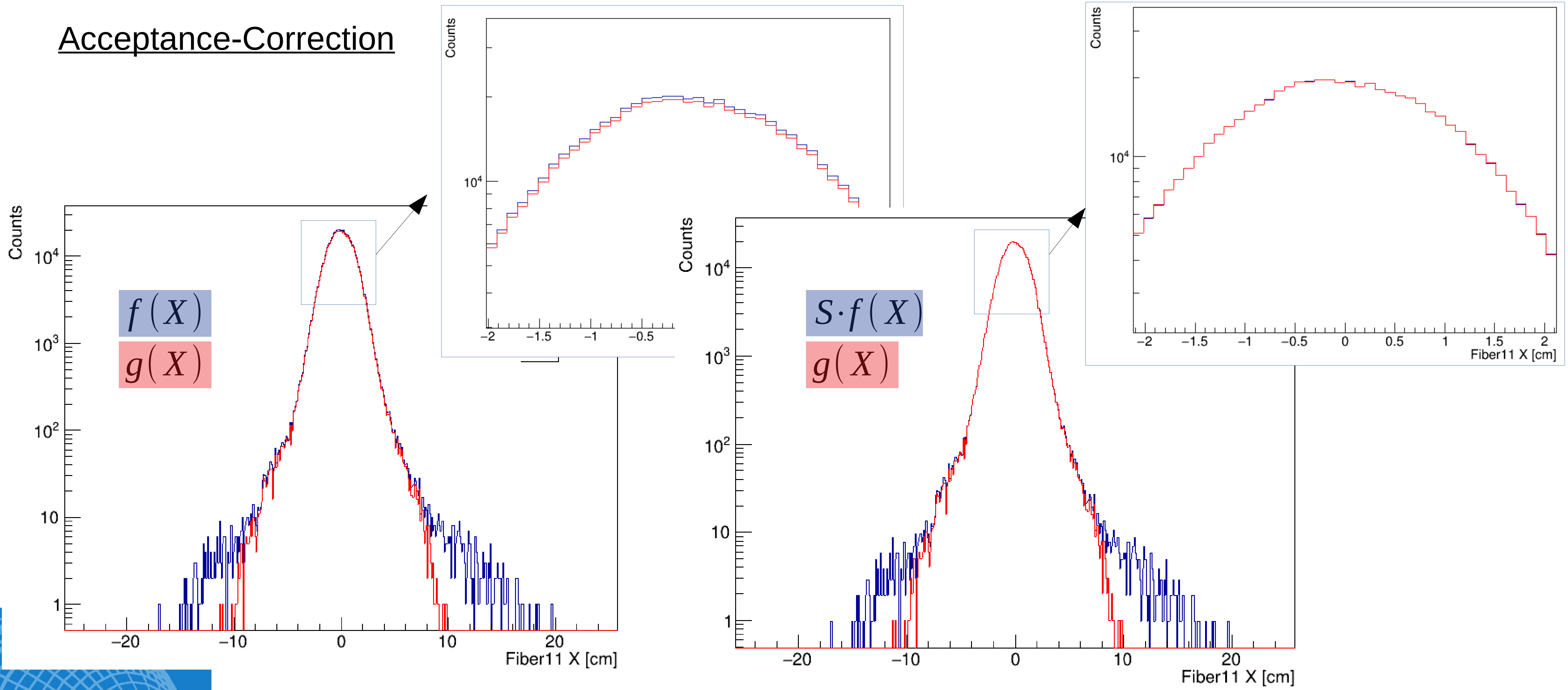
Dividing both distribution



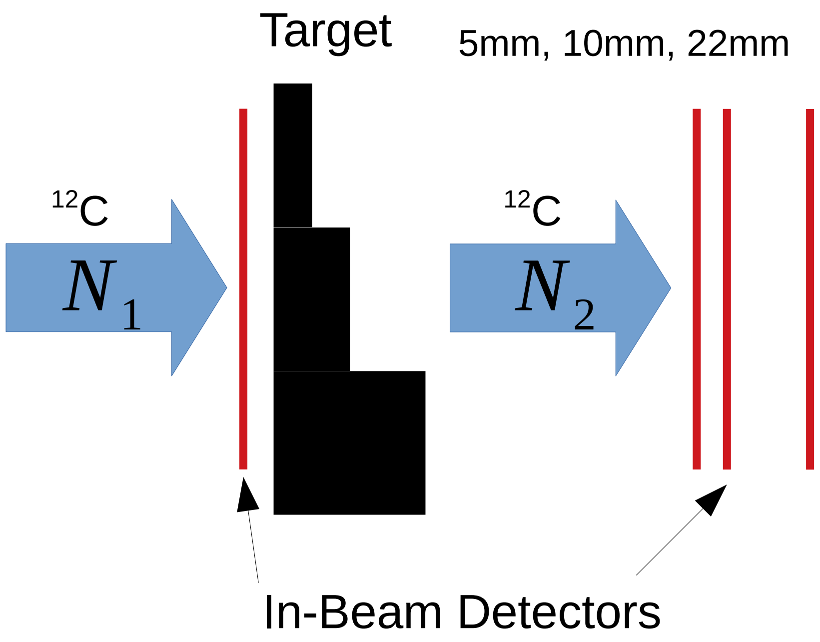
$$S = \frac{\int_{x_{min}}^{x_{max}} g(x)}{\int_{x_{min}}^{x_{max}} f(x)}$$

Total Reaction Cross-Section

Acceptance-Correction



Measurement Concept



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Transmission method:

$$\sigma_R = -\frac{1}{N_t} \ln\left(\frac{N_2^i / N_1^i}{N_2^o / N_1^o}\right)$$

Challenge: Time- & Rate-depended Efficiency & geometrical Acceptance of Detectors

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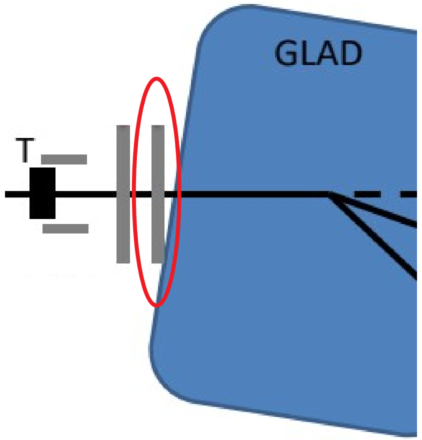
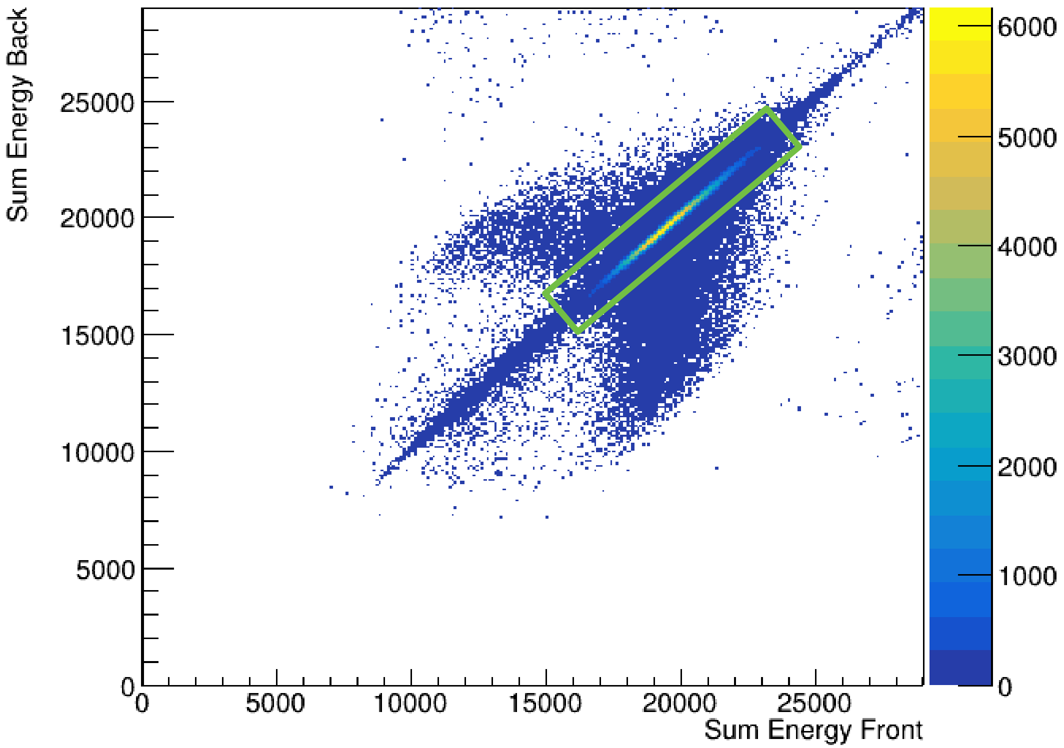
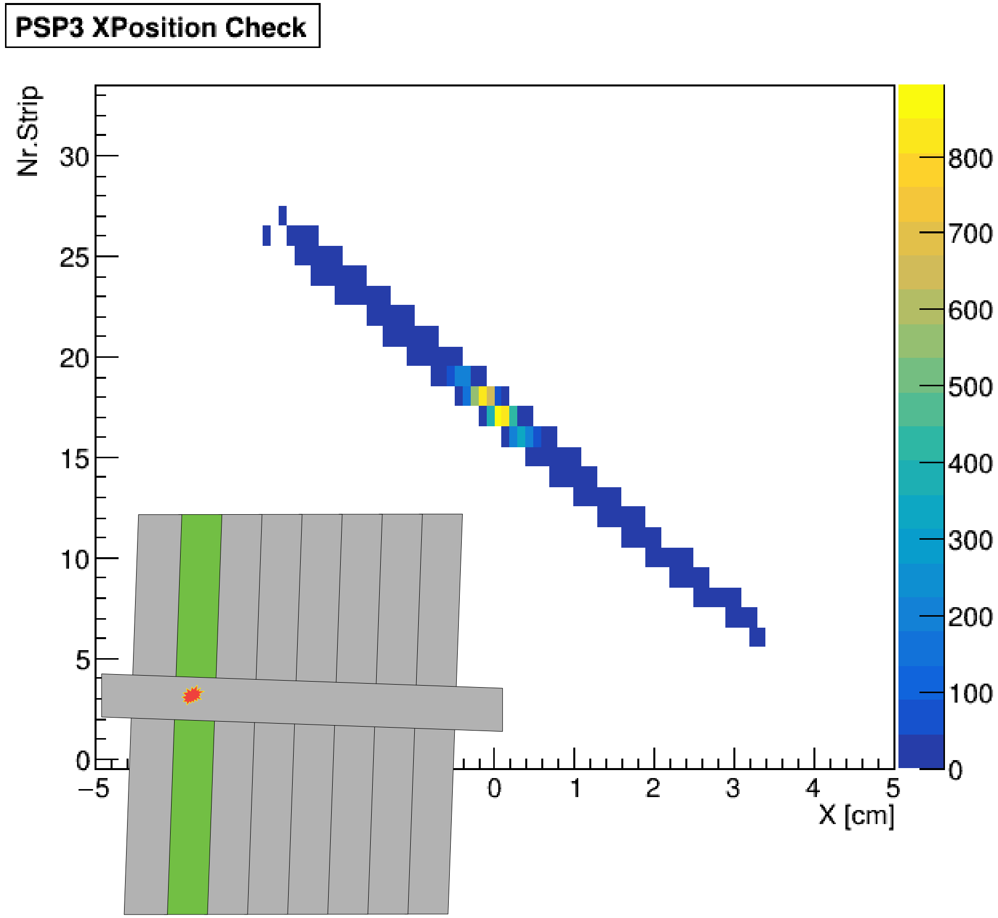
Total Reaction Cross-Section

PSP Detector - X-Position





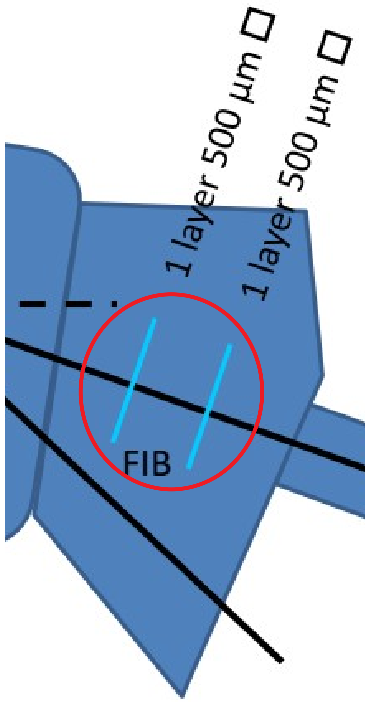
- Multplicity=1 on Front- & Back-Layer
- Same Energy (Q=6) Deposition in both Layers

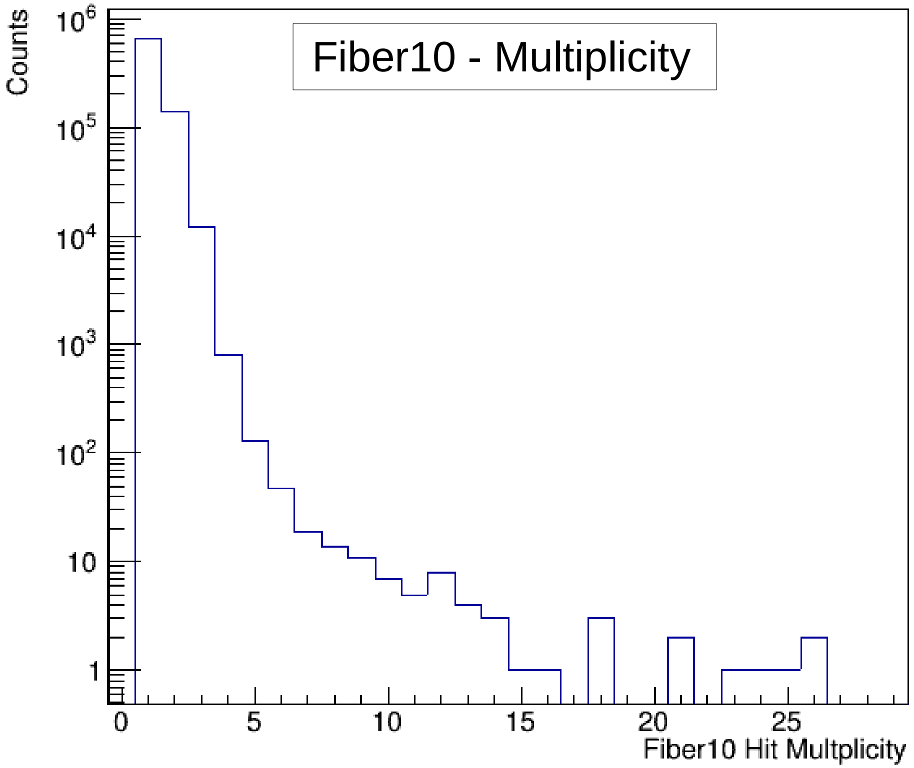


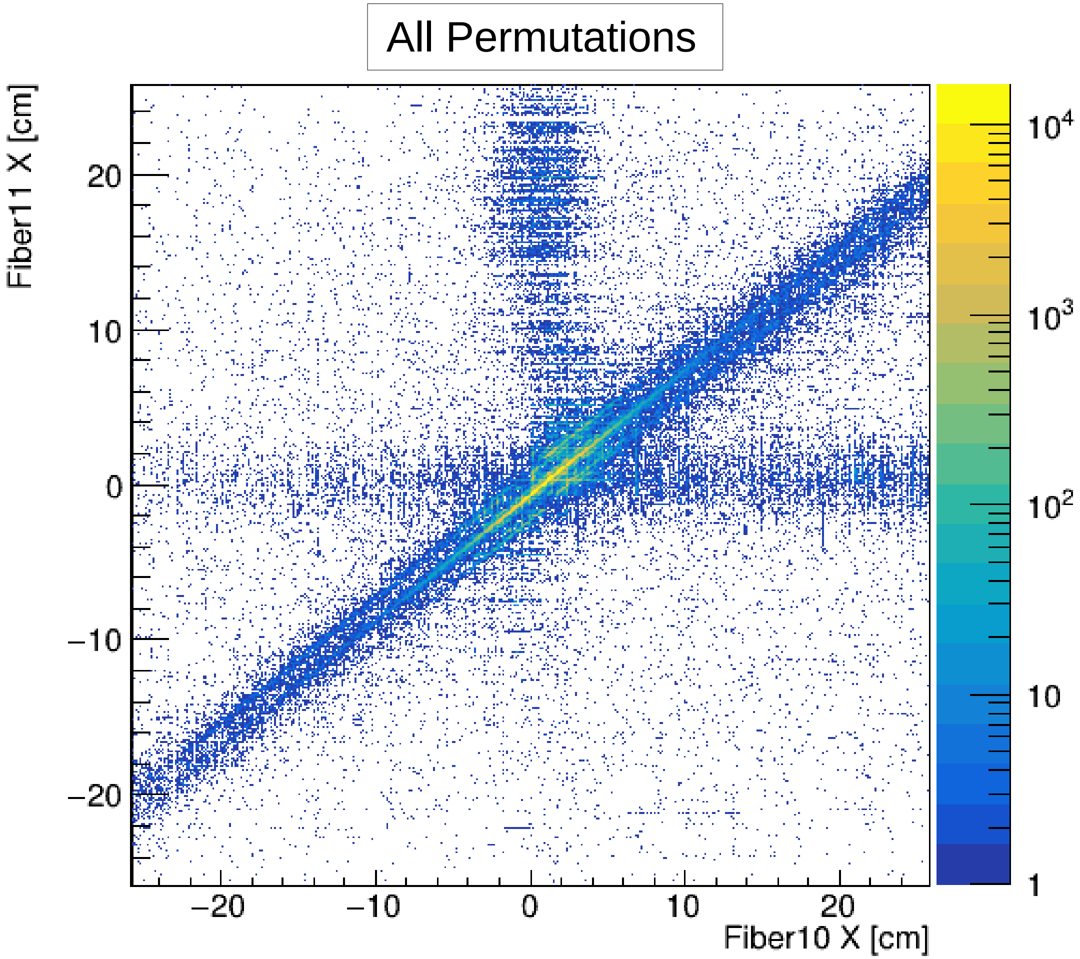
We can cross-check the x-position with the Strip-Nr. of the Front-Layer

Total Reaction Cross-Section

Fiber Detector - X-Position





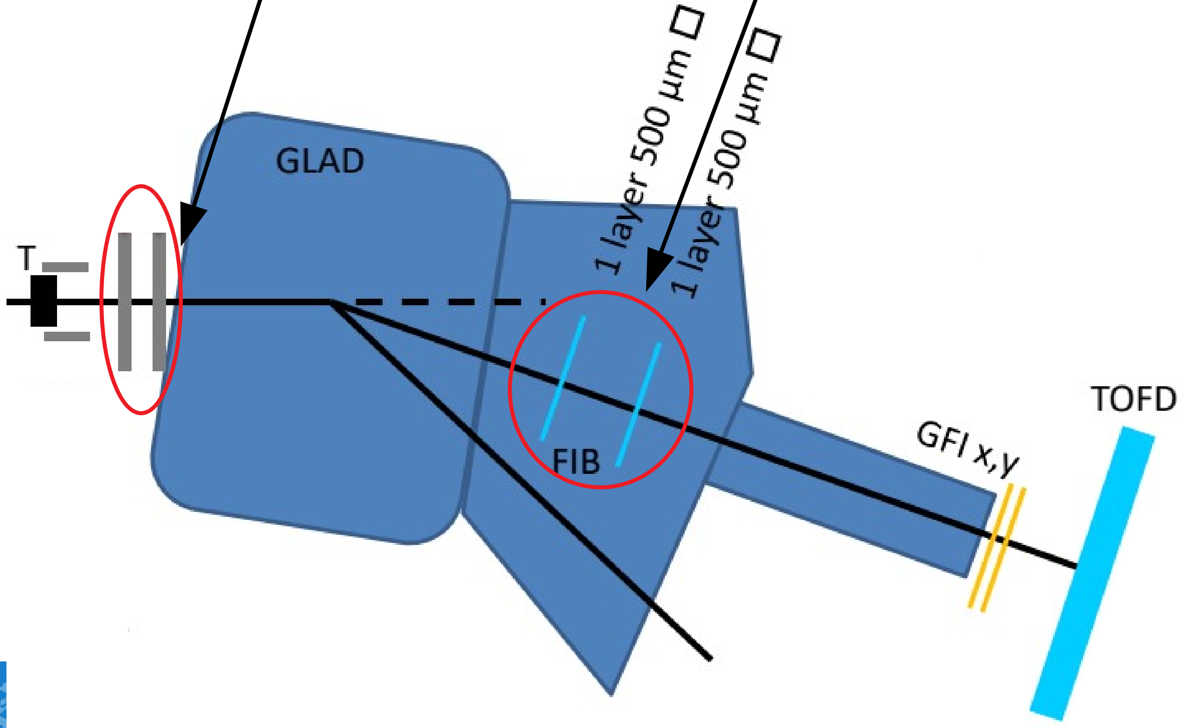


Problem: High Multiplicity due to light cross-talk
How can we find the correct Hit / the correct X-Position?

Isotope-Correction

Isotope-Correction

We need a X-Position in front of Glad (PSP3) and after GLAD (Fiber11)



Isotopes with different mass (A) have a different bending-radius (ρ) in a const. Magentic field (B) .

$$B\rho = \frac{A}{q} \cdot c \cdot \gamma \cdot \beta$$