First characterization of Short-Range Correlations (SRC) in an exotic nucleus at R^3B

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Outline

Introduction

- Short Range Correlations (SRC);
- Motivation and goals of the experiment.

Experimental Set-up

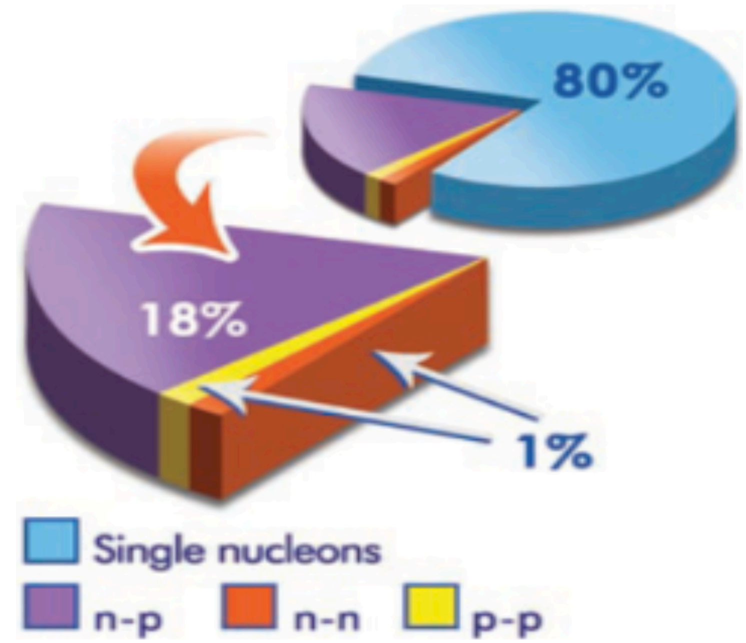
- R^3B Set-up and (p,2p) kinematics.

Data analysis

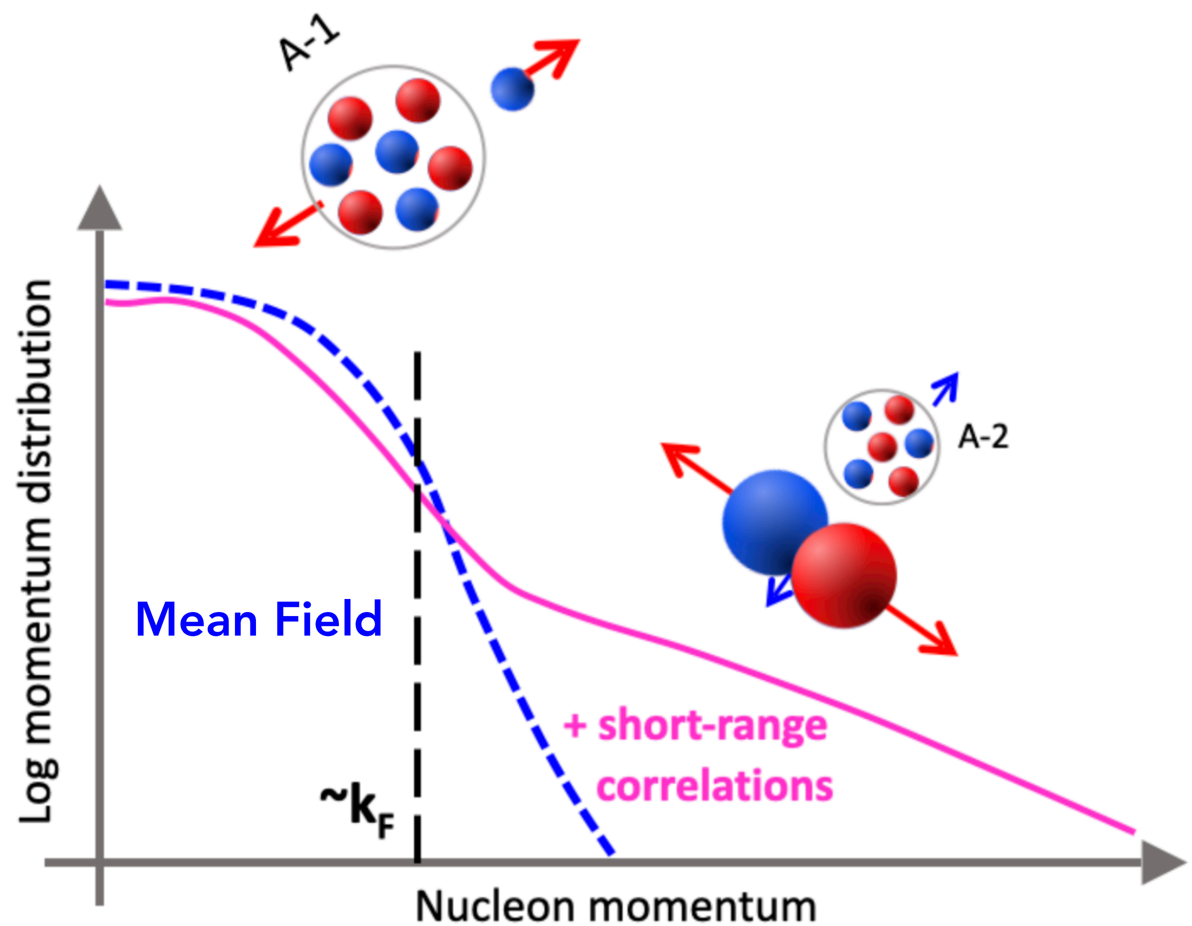
- Fragments identification with Multi-Dimensional Fit functions;
- (p,2p) analysis.

Perspectives

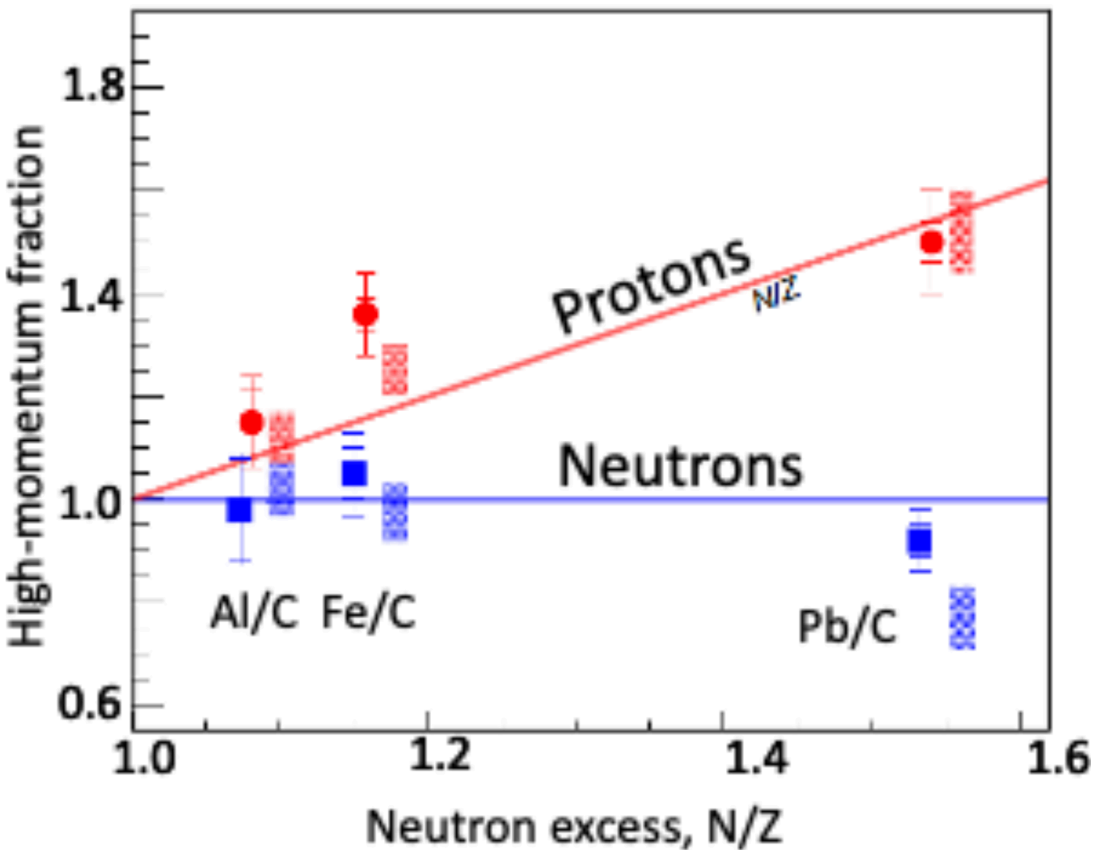
- **High relative momentum and low centre of mass (c.m.) momentum pairs**;
- mainly proton-neutron (pn) pairs;
- pp/pn ratio does not change with A;
- The fraction of high momentum protons increases with N/Z.



R.Saubedi,Science,Vol 320, (2008)



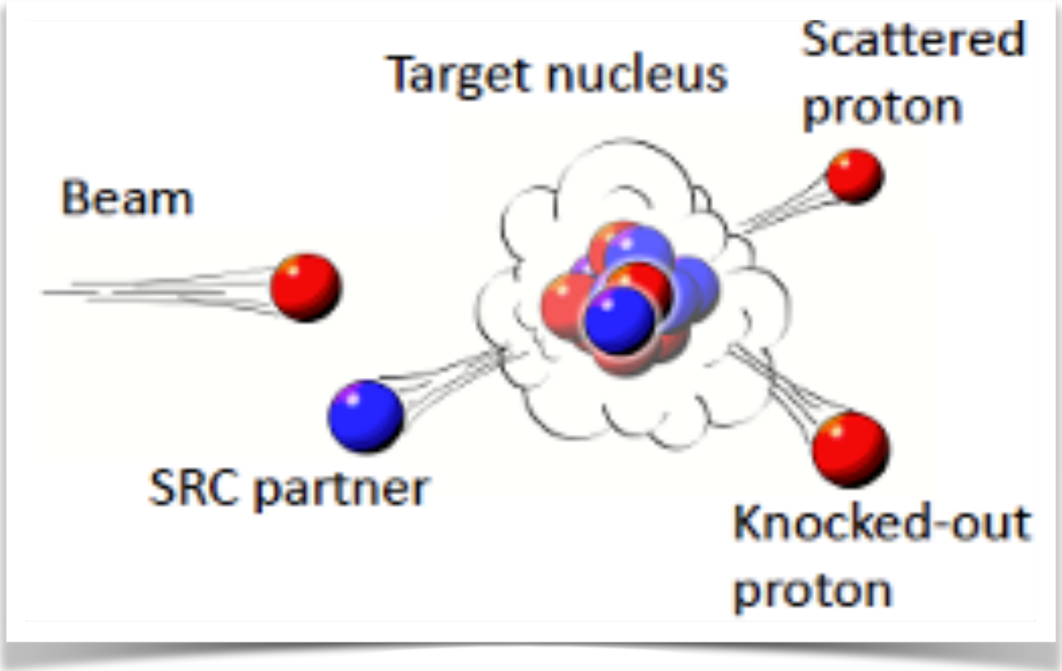
O. Hen et al. (CLAS Collaboration), Science, 346 (6209):614, 2014.



Adapted from M. Duer et al. (CLAS Collaboration), Nature, 560:617, 2018.

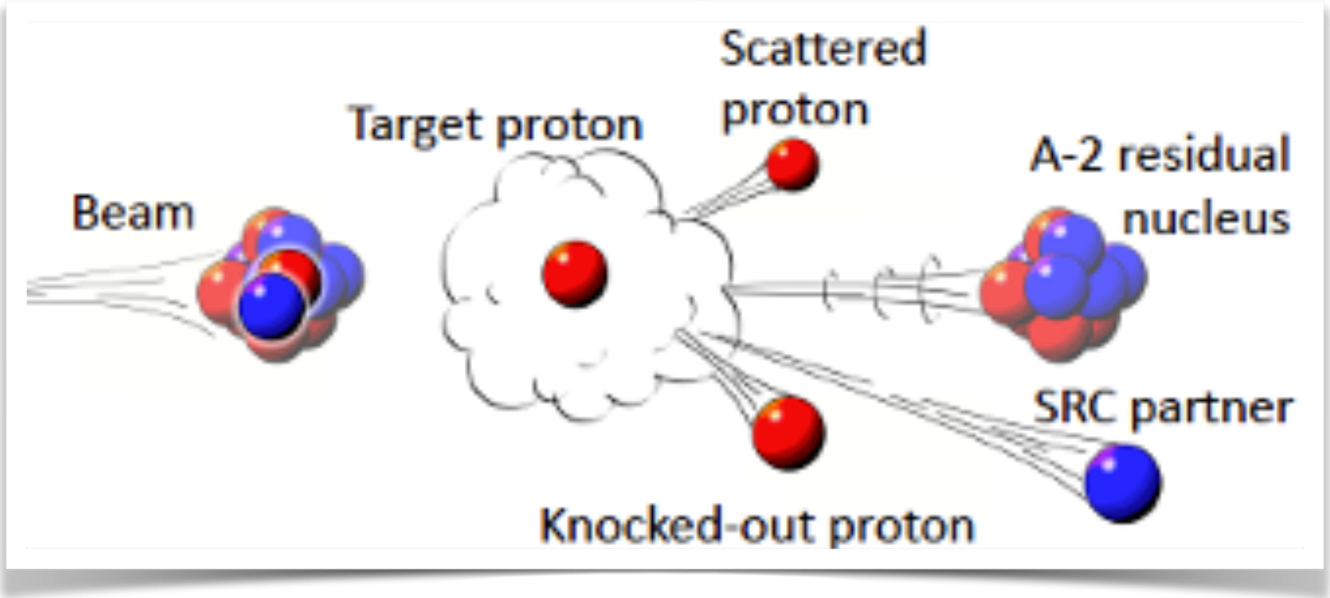
Direct kinematics

- ☑ P_{miss}, E_{miss}, P_{recoil};
- ☑ P_{cm} (indirectly);
- ✗ Fragment ID.



Inverse kinematics

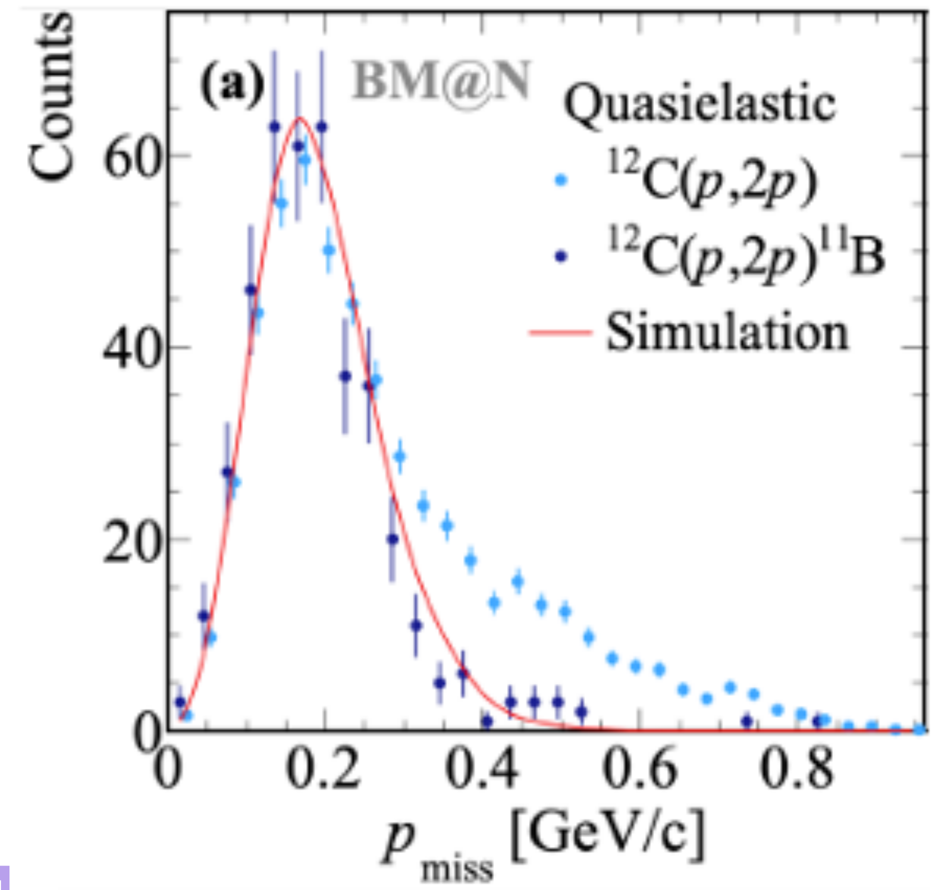
- ☑ P_{miss}, E_{miss}, P_{recoil};
- ☑ p_{cm} (directly);
- ☑ Fragment ID;
- ☑ Exotic nuclei;
- ☑ Higher cross-section for protons;
- ISI/FSI challenges data interpretation.



Proton scattering experiments

- BM@N (JINR) pilot experiment (2018);
- R^3B **(GSI) Experiment (May 2022)**;
  - Probe SRC in an exotic nucleus for the first time.

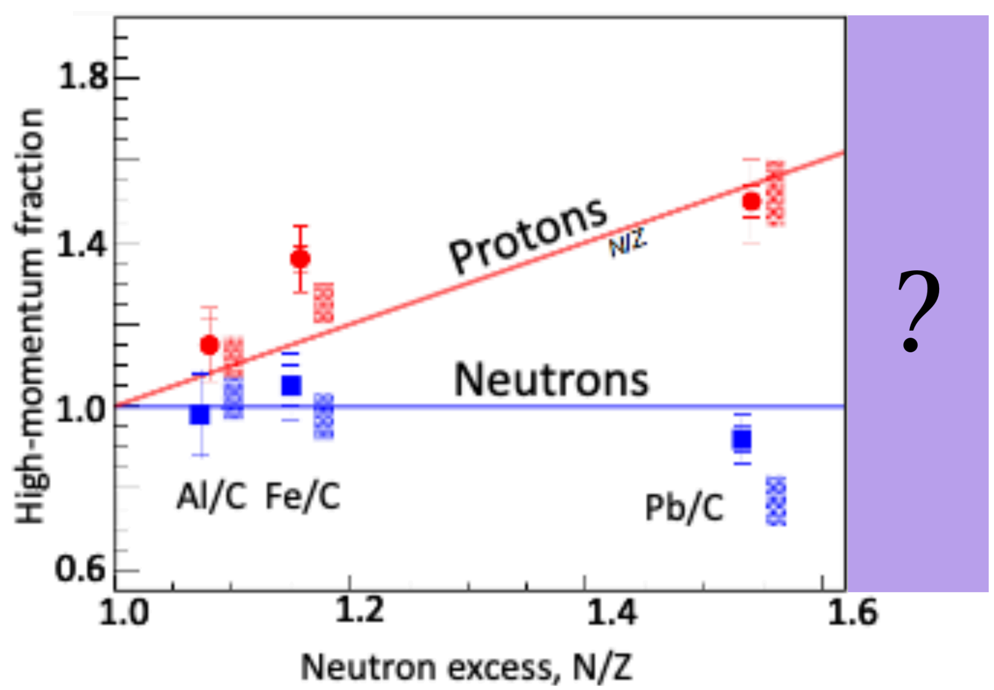
M.Patsyuk,Nature Physics, volume 17, pages 693–699 (2021)



Motivations

- Existing trend based on a few points;
- behaviour can depend on shell structure (open/closed shell effects);
- mass and N/Z excess cannot be disentangled with stable nuclei.

- **New measurement at N/Z = 1.67 (^{16}C), above the largest available N/Z and at a much smaller mass.**



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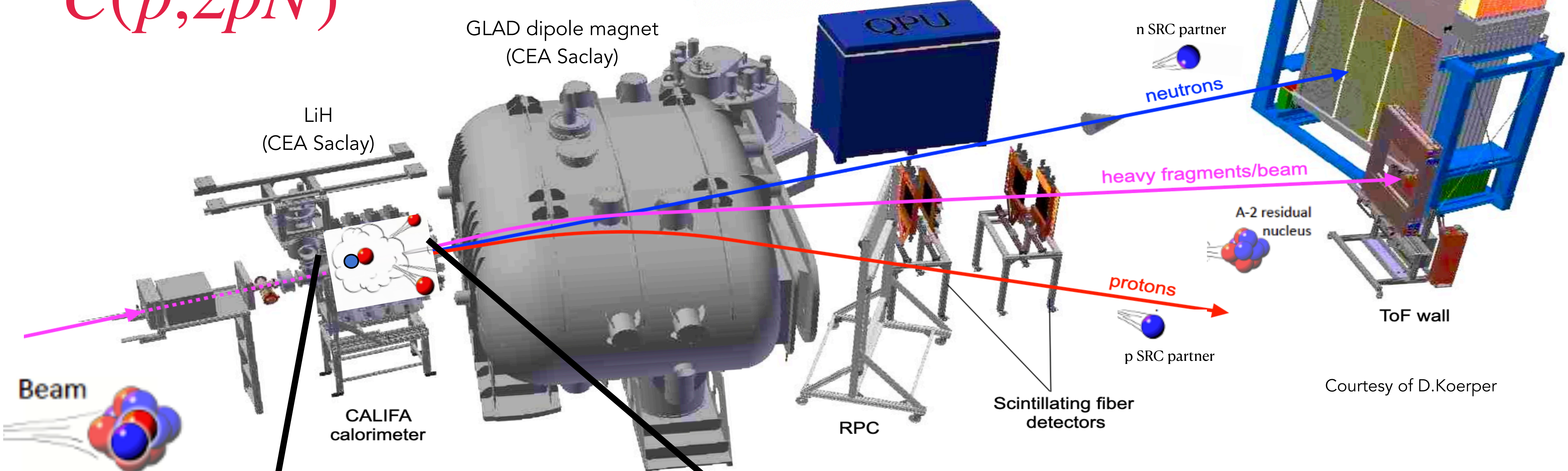
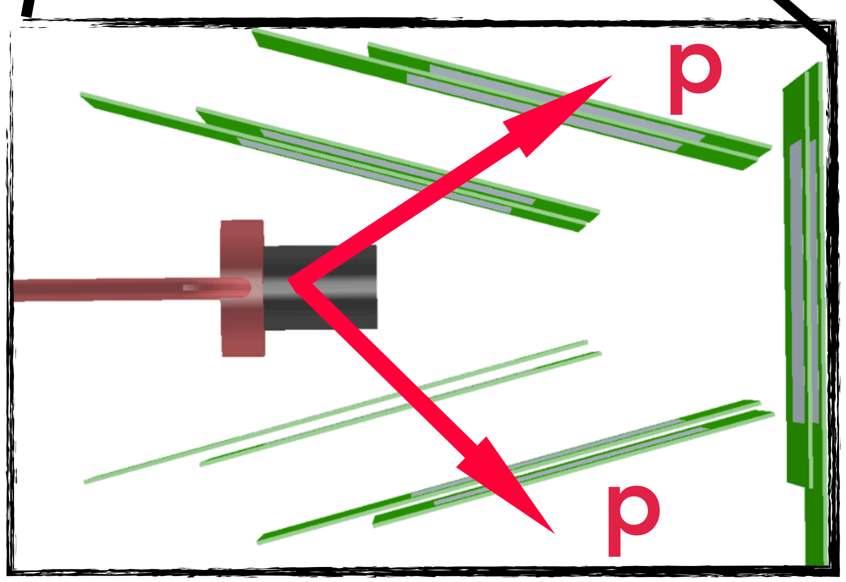
R^3B Experimental Set-up

$^{12}C(p,2pN)$

$^{16}C(p,2pN)$

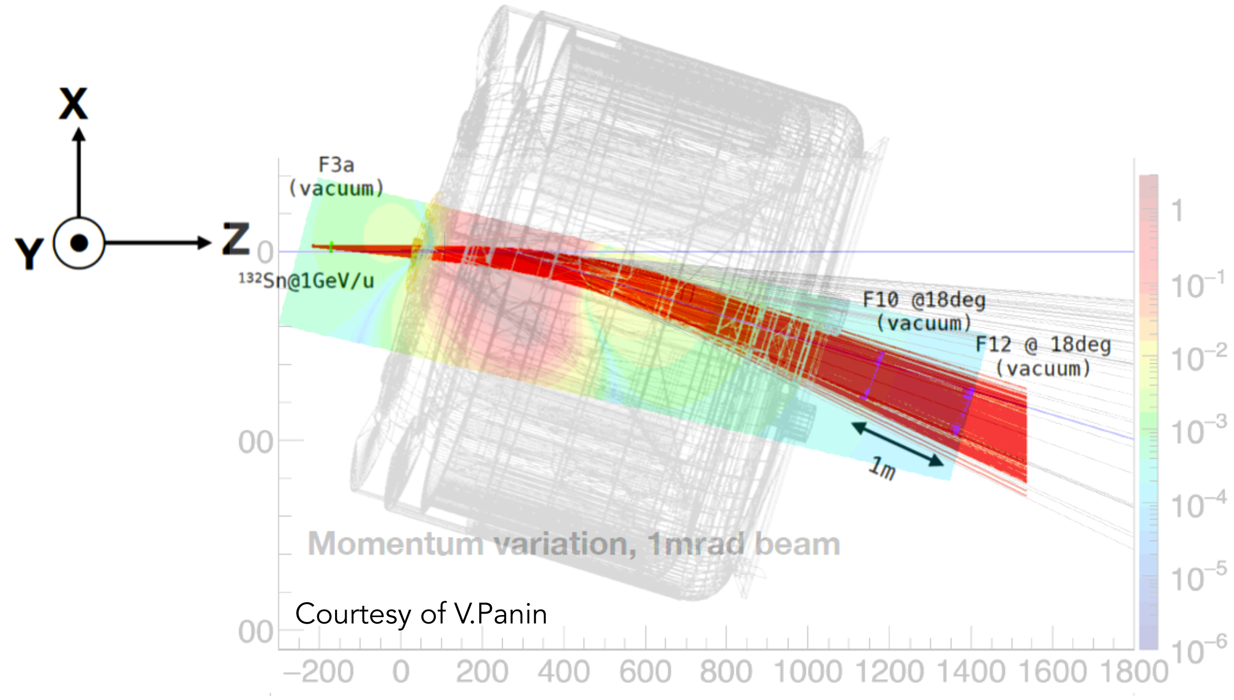
1.25 GeV/u
10^5 pps Intensity





- tracking and momentum of the **two scattered protons** under large laboratory angles;
- **pair-recoil nucleon** (n or p) momentum;
- **A-2 fragment momentum.**

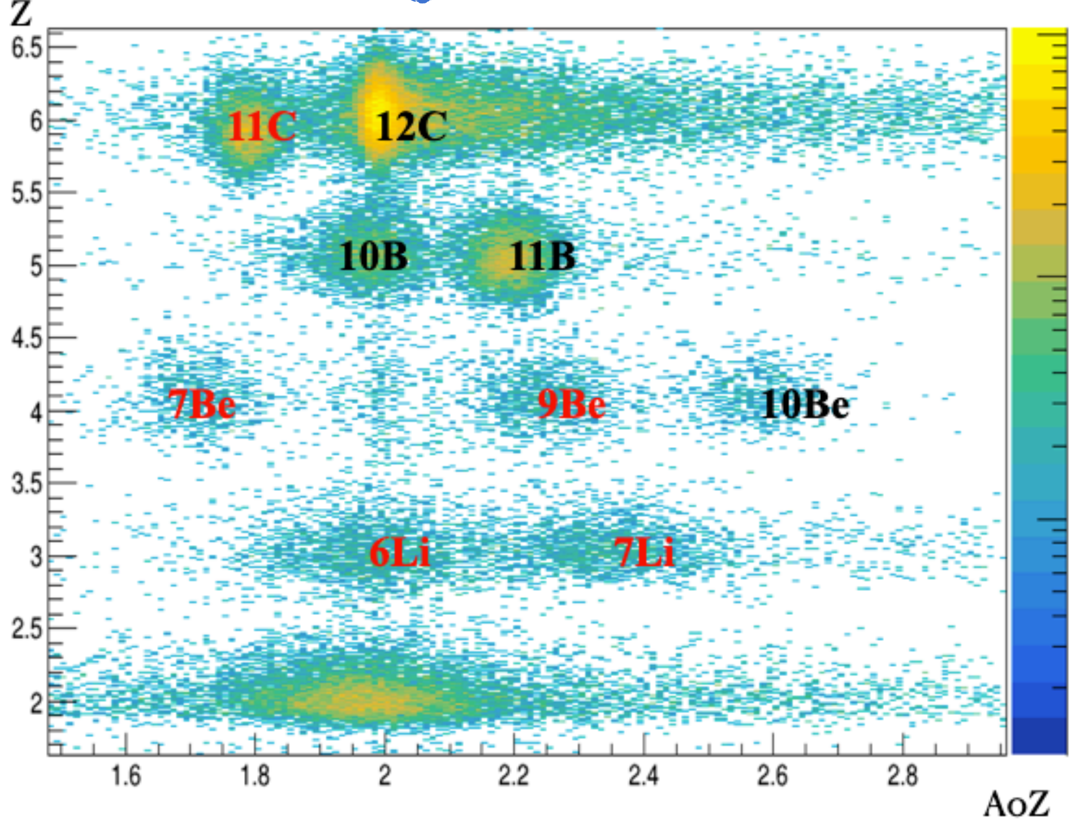
Fragment analysis: MDF Tracking



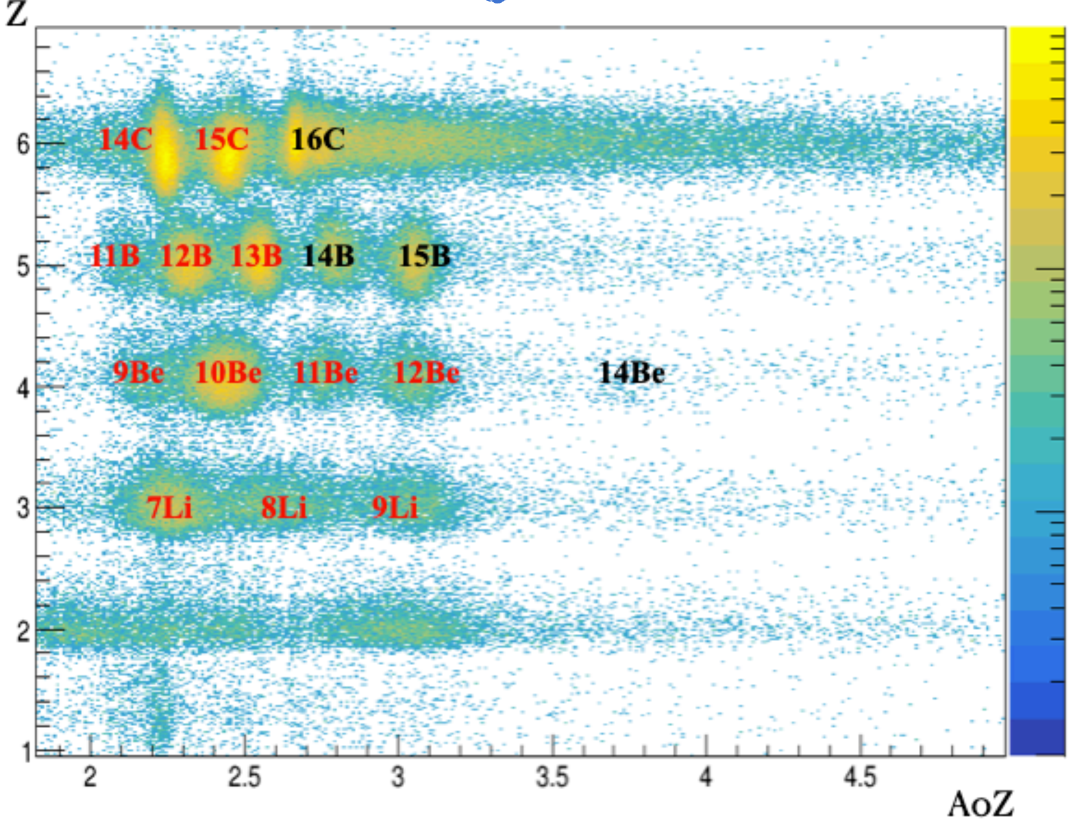
Multi-Dimensional Fit (MDF)

- Find an expression to correlate the independent observables (positions) with dependent quantity (momentum) via a **least squares fitting procedure;**
- The function can then be used to compute the quantity of interest (**mass, momentum and angles**).

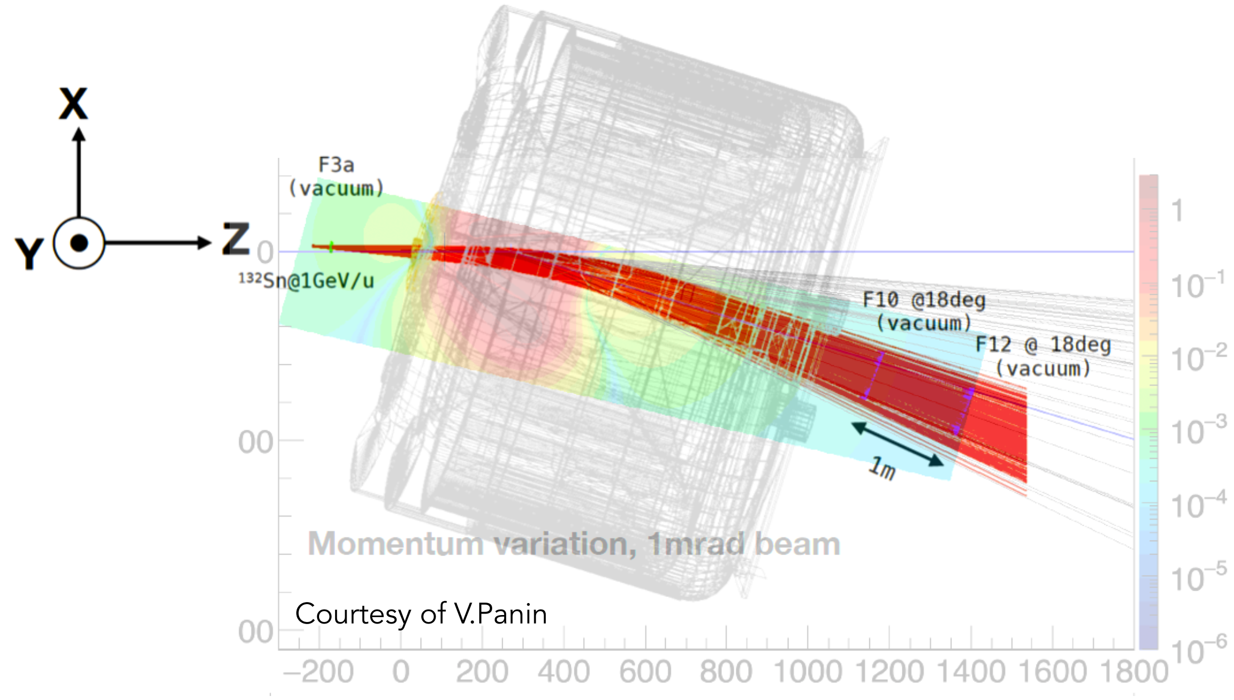
12C Fragments PID



16C Fragments PID



Fragment analysis: MDF Tracking



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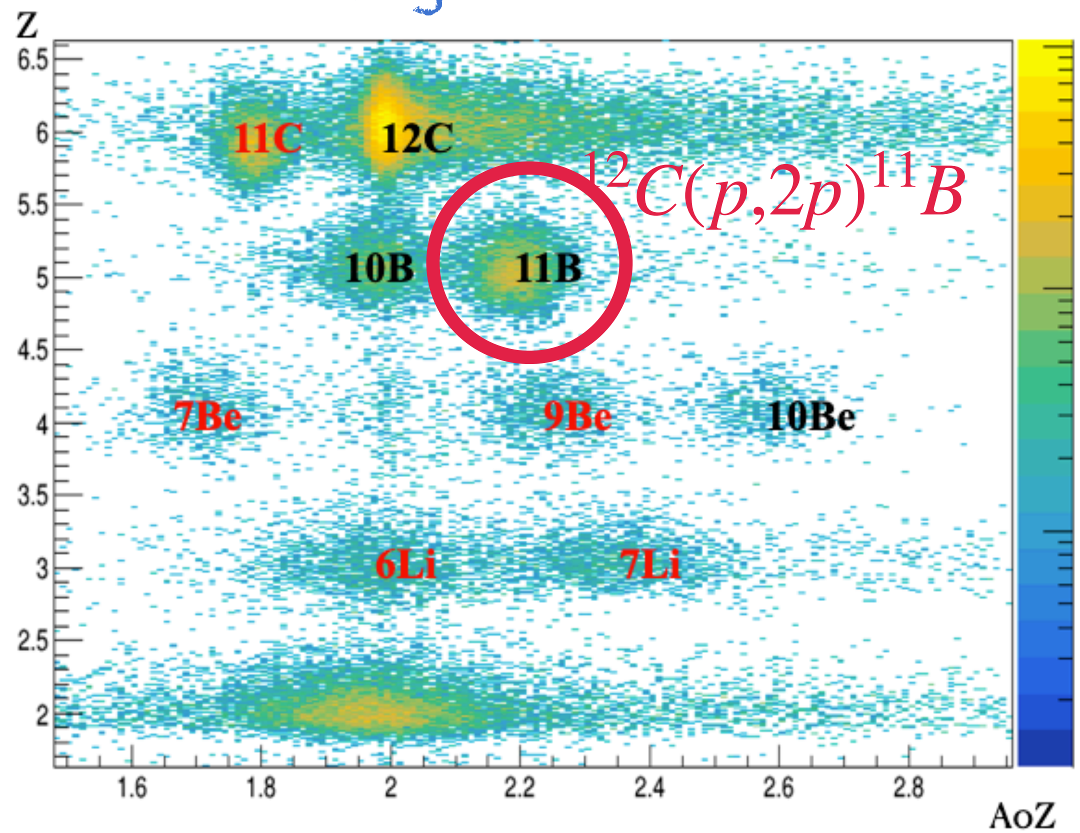

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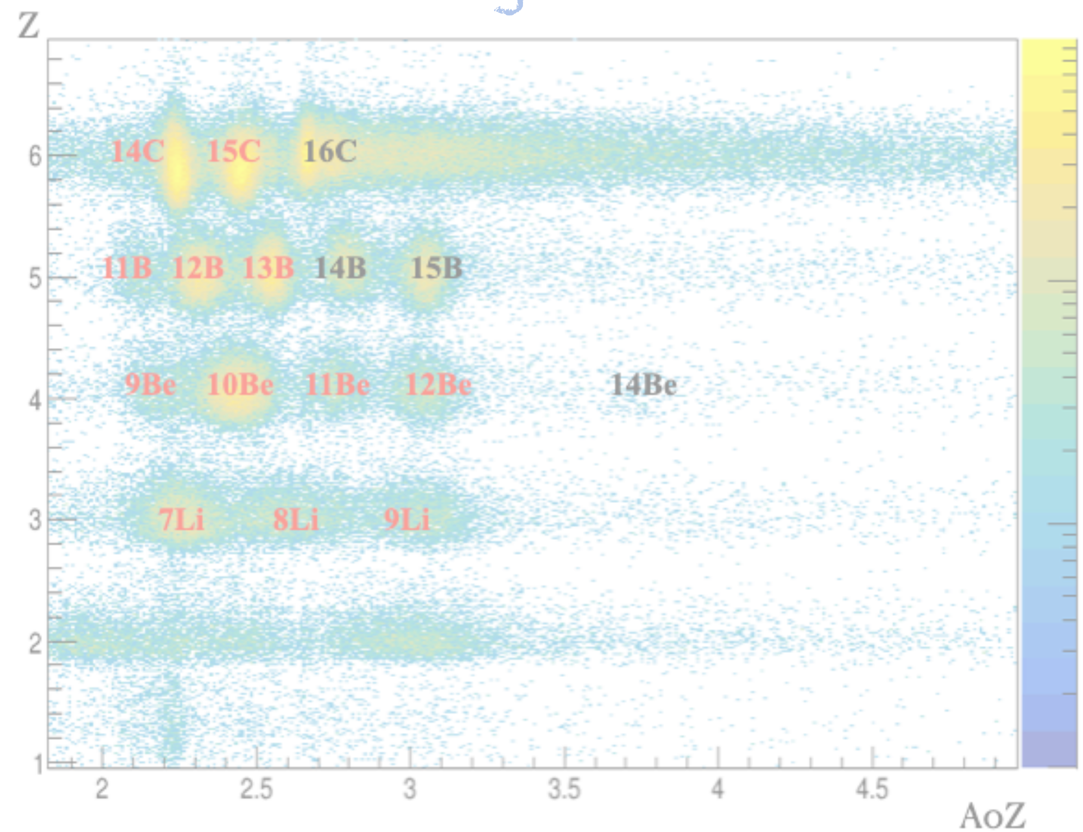
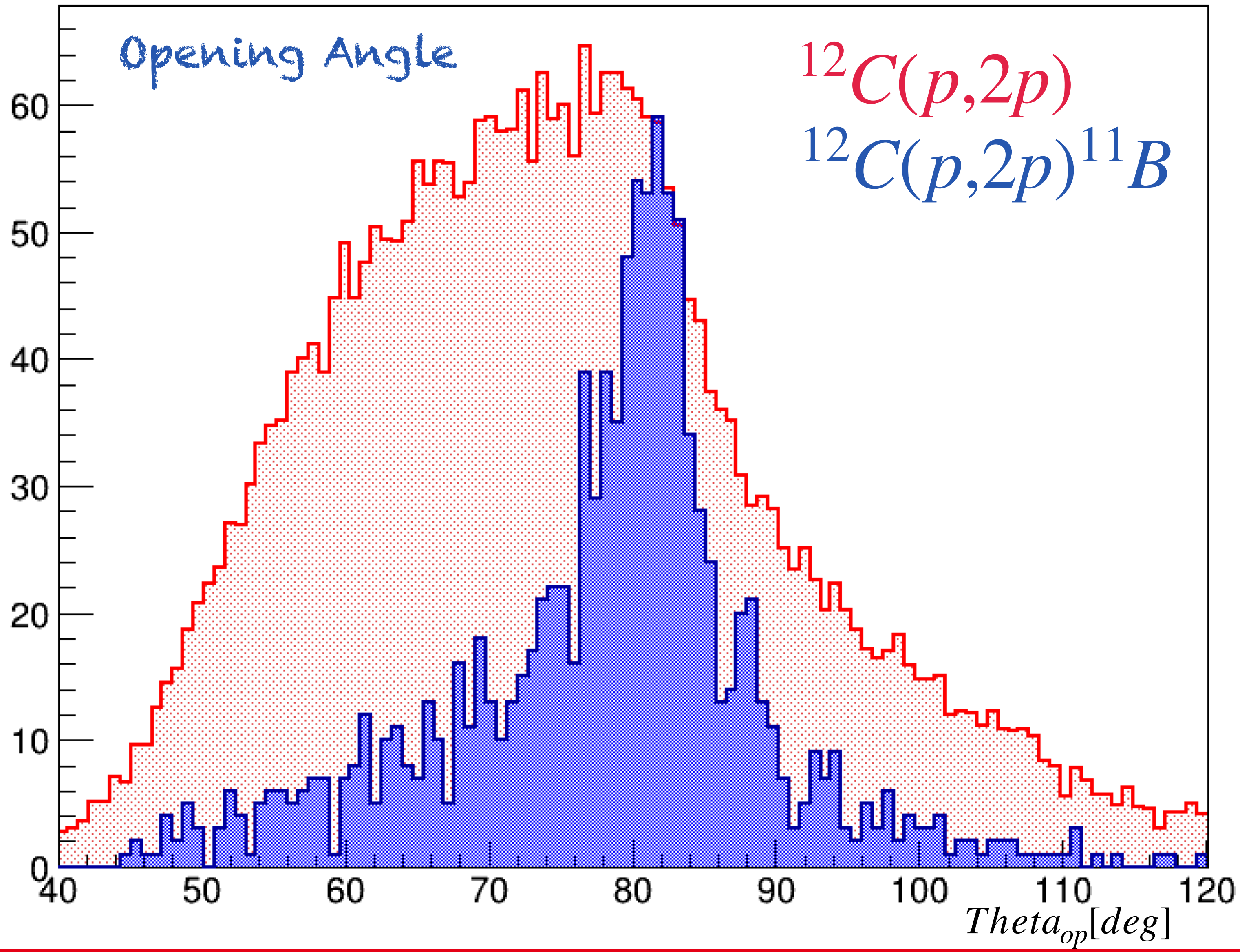
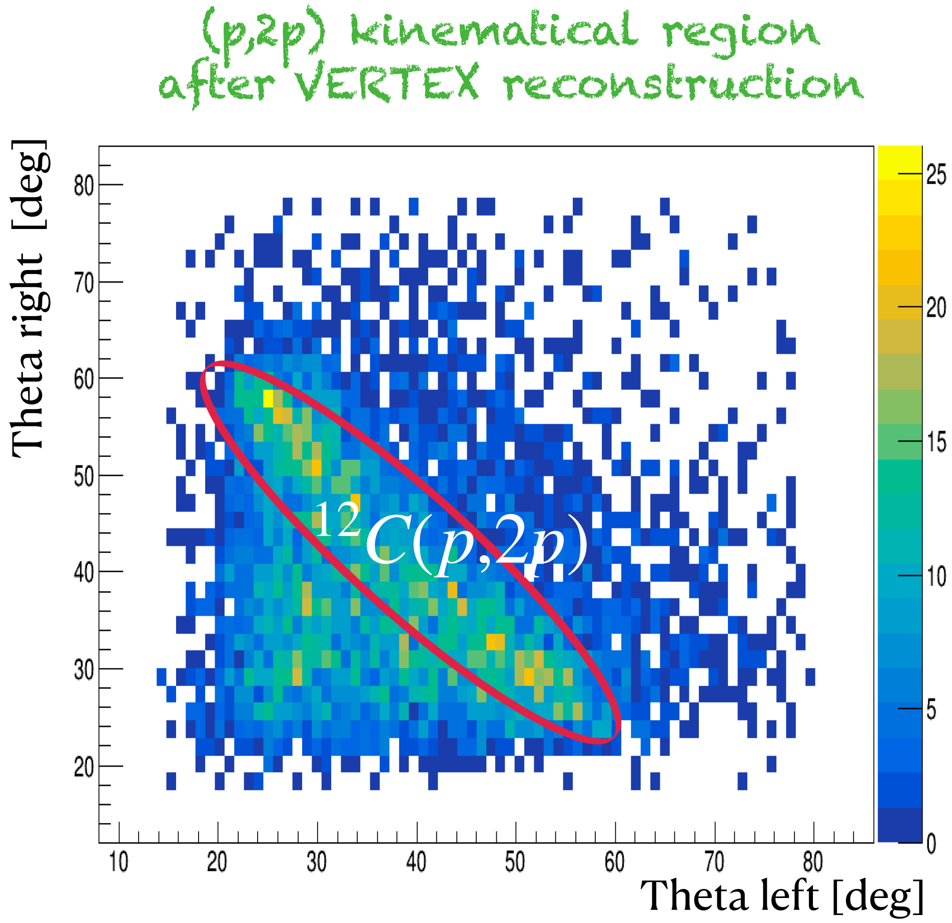
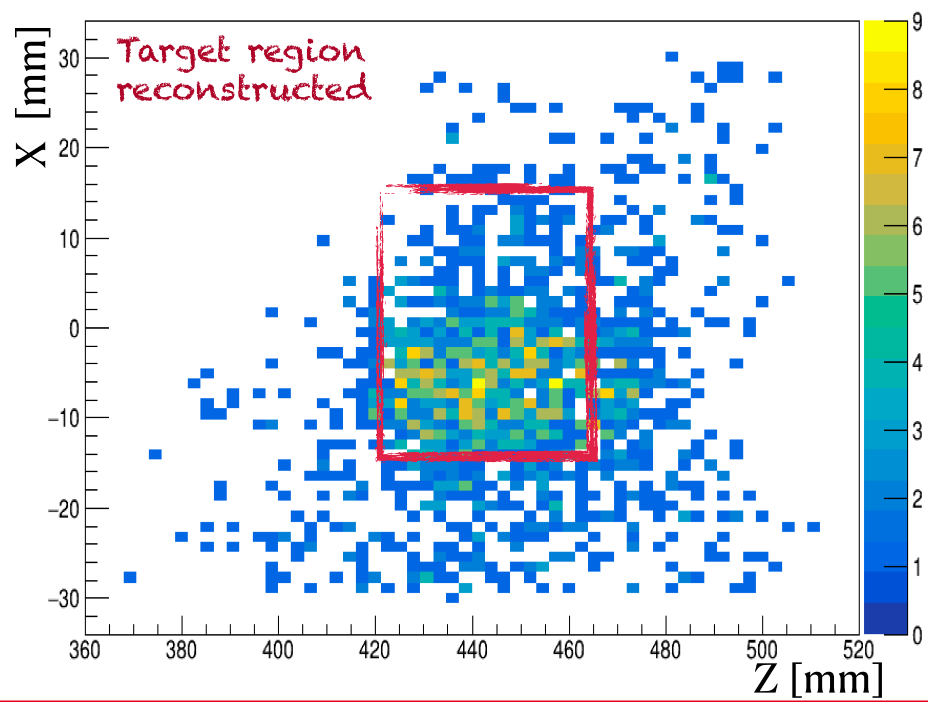


(p,2p) analysis for ^{12}C

- Vertex obtained using FOOT silicon trackers and CALIFA calorimeter;
- **Minimum distance** and matching with **CALIFA angles;**
- **(p,2p)** kinematics investigation with selection on ^{11}B;
- Very strong effect for **ISI/FSI events rejection**.







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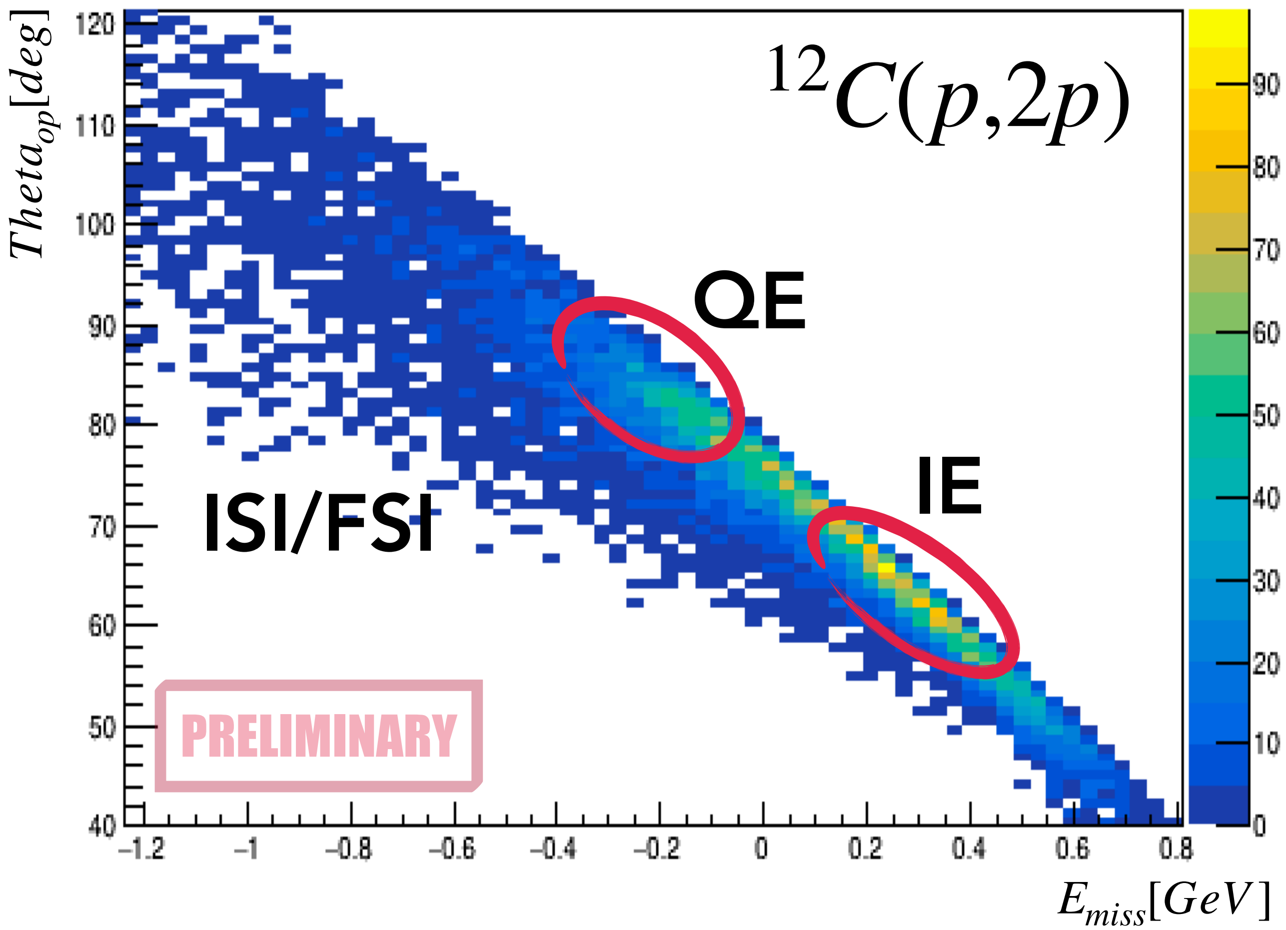

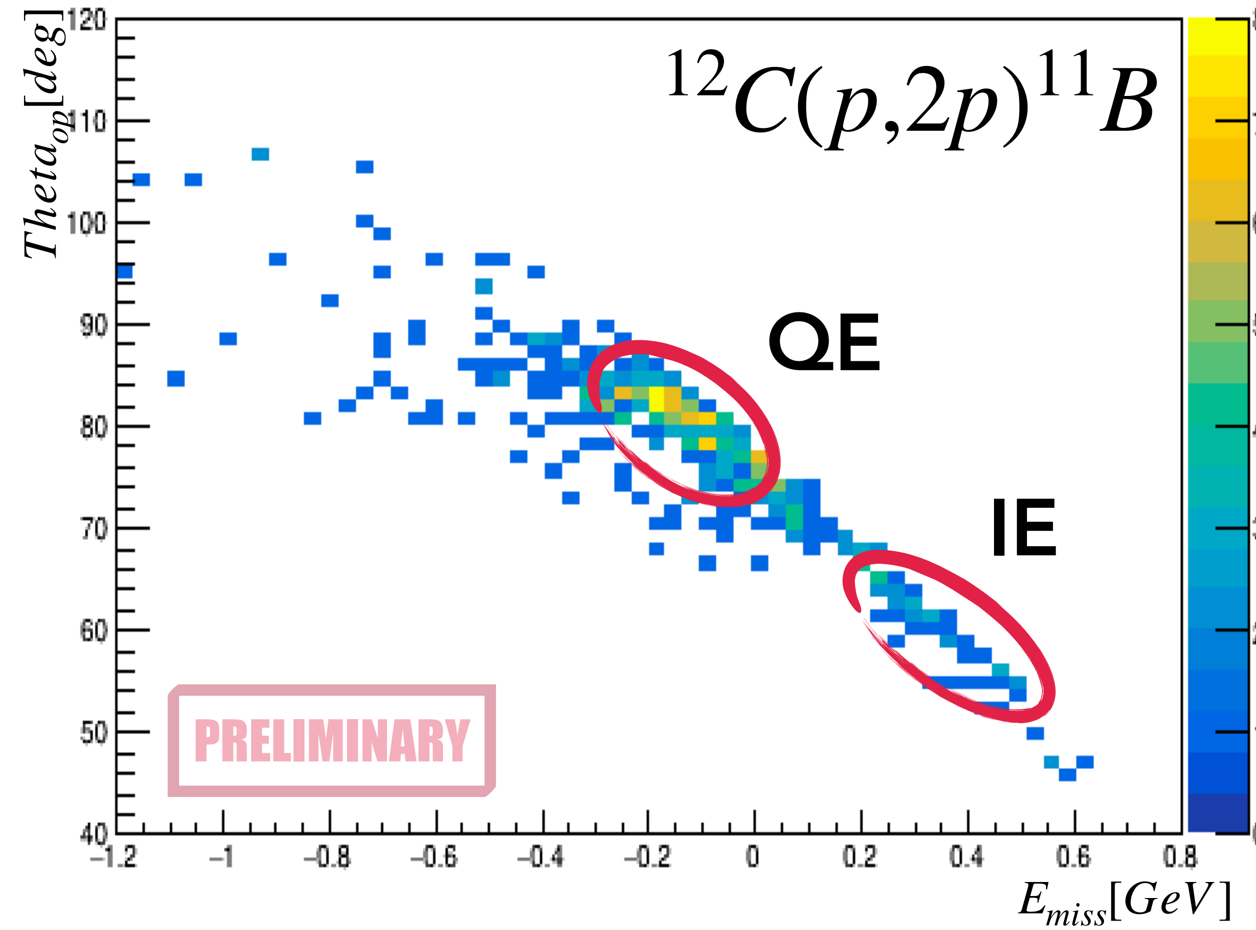

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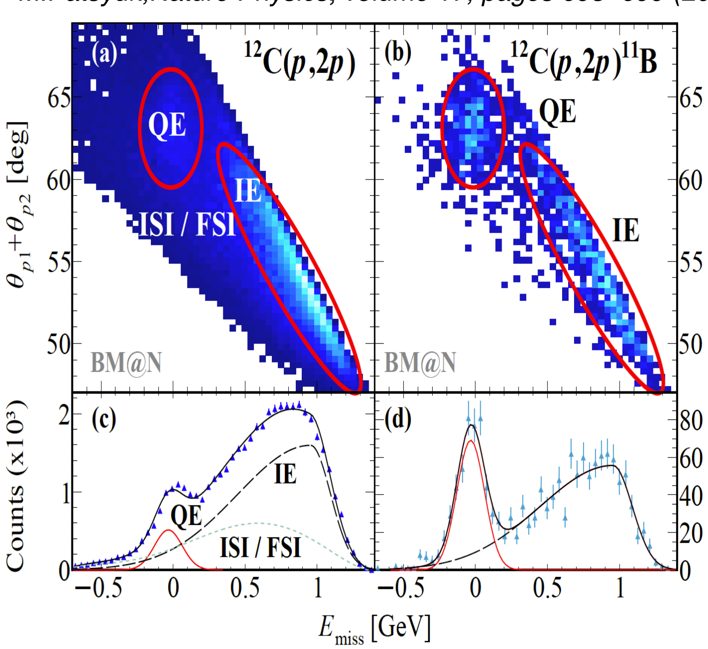
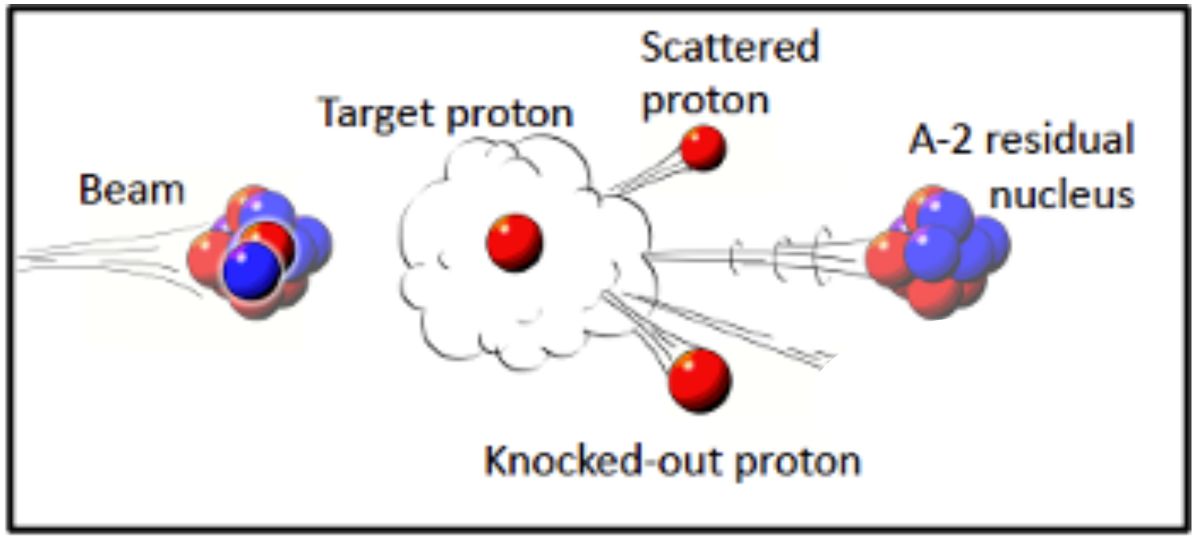
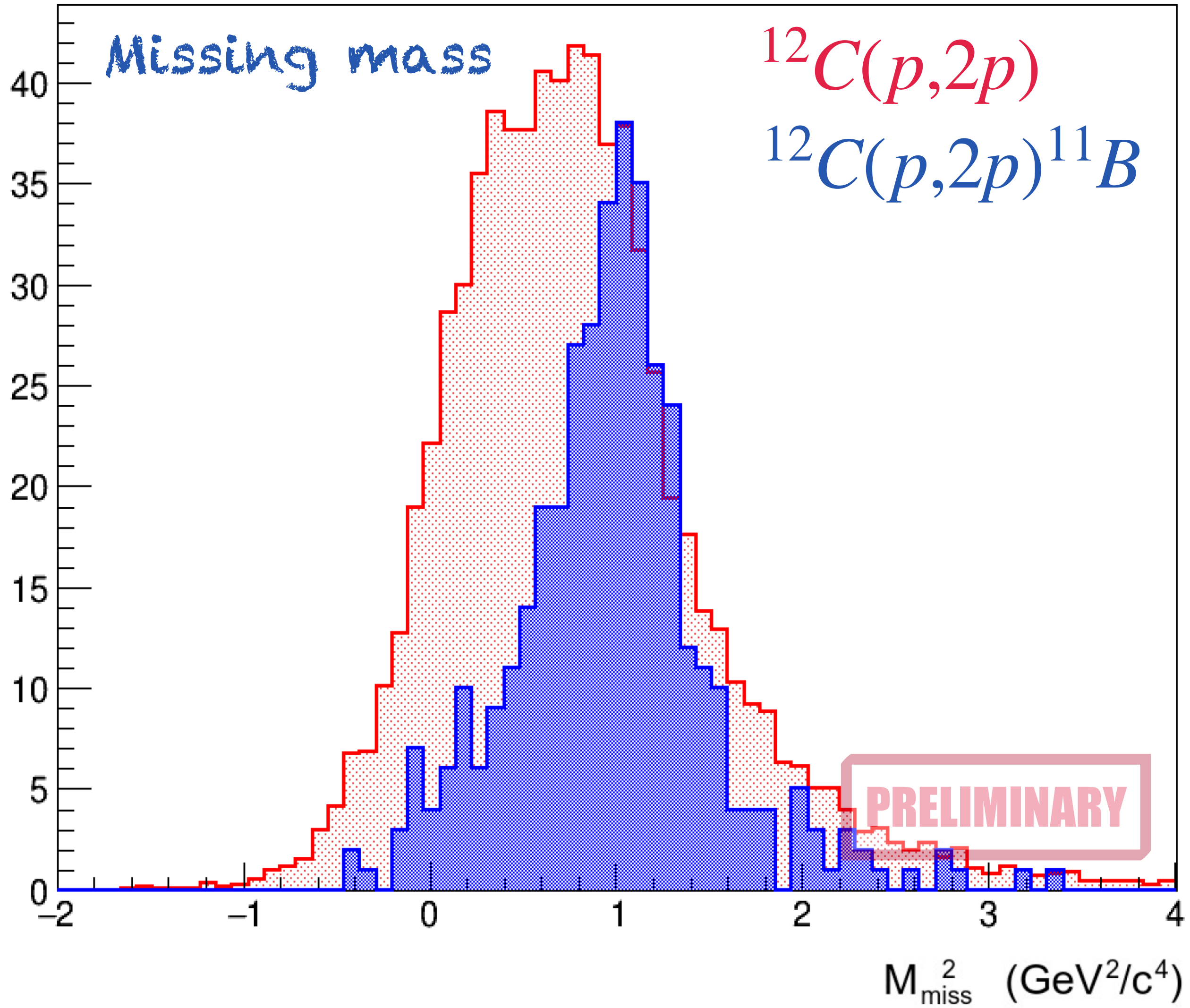


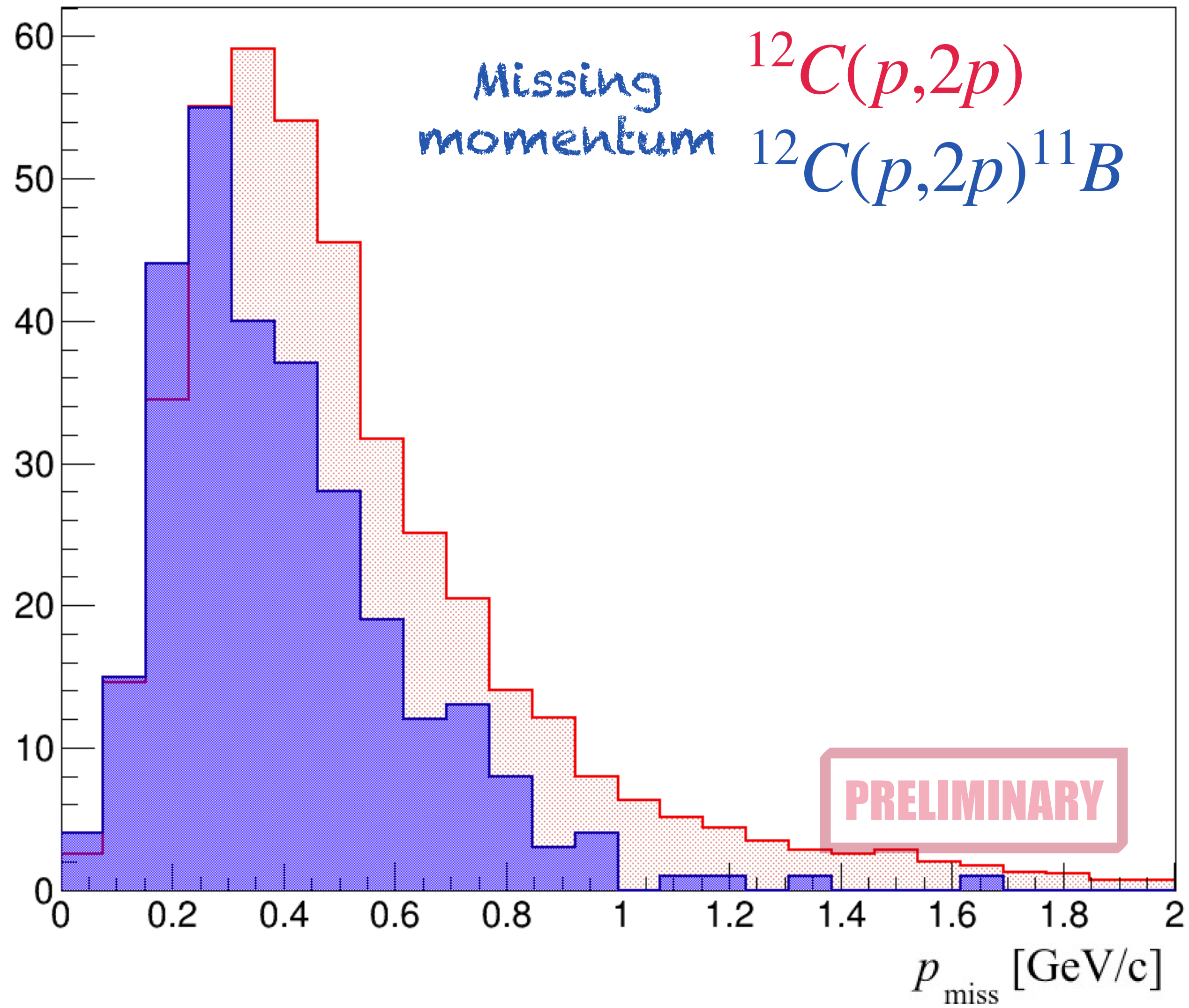
- The ^{11}B detection is shown to select the **QE part of the reaction**;
- Similar to BM@N (JINR) experiment.

(p,2p) analysis for ^{12}C

- Selectivity of the QF mechanism: **proton missing mass M_{miss} and missing momentum P_{miss};**
- Missing momentum important to constrain SRC kinematical region.





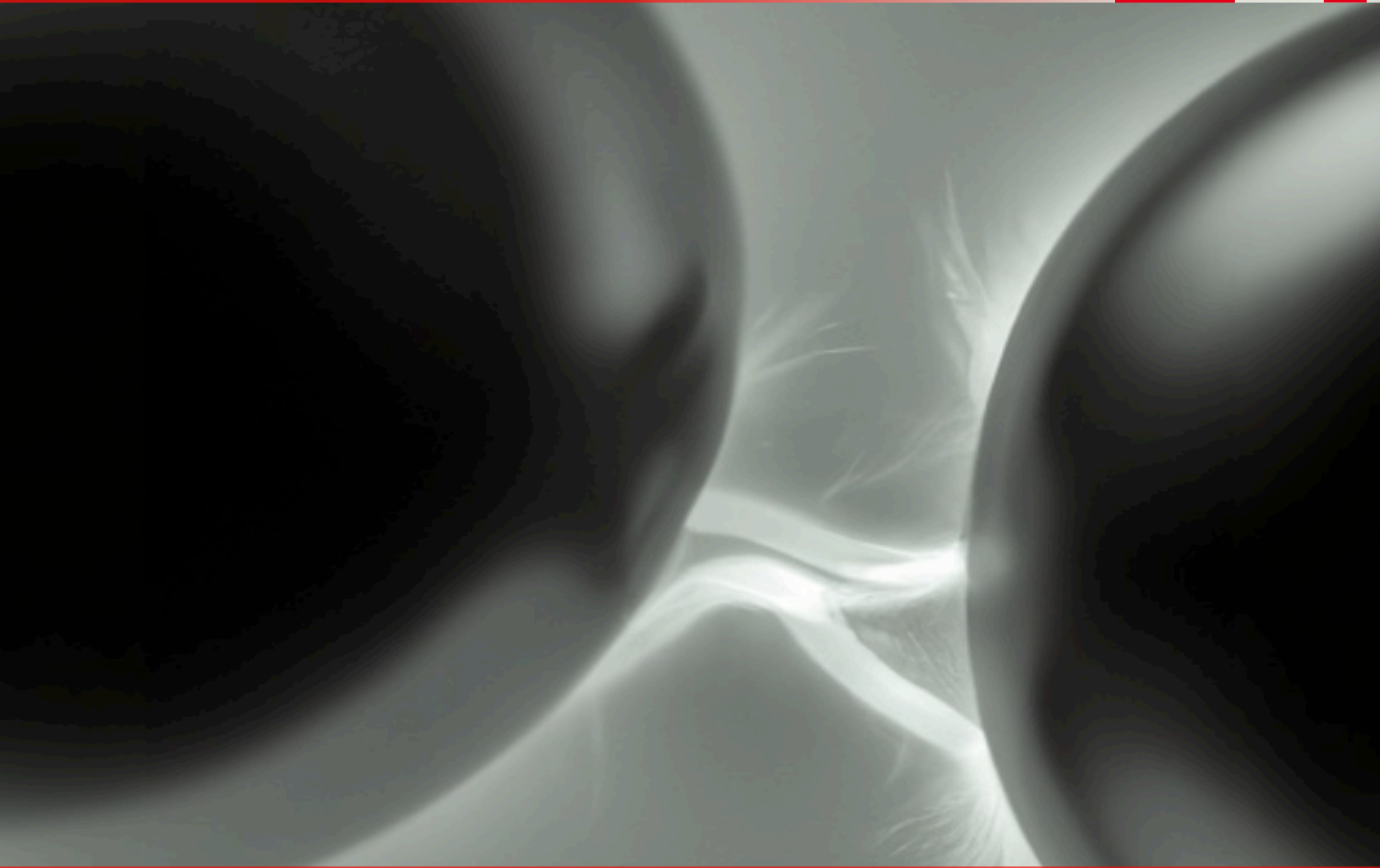


Perspectives

- **Identification of SRC** using P_{miss} and A-2 fragment selection;
- **(p,2pN) ratio** $^{16}C/^{12}C$ and pp/pn ratio estimation;
- **Bound final states**: investigation in A-2 fragments;
- **Unbound final states**: fragment break-up investigation after SRC removal;
- **Quenching of (p,2p) cross section** at high momentum transfer.

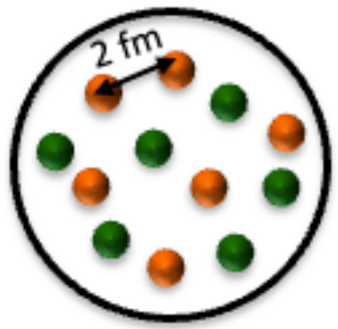
Thanks for your attention!

Backup slides



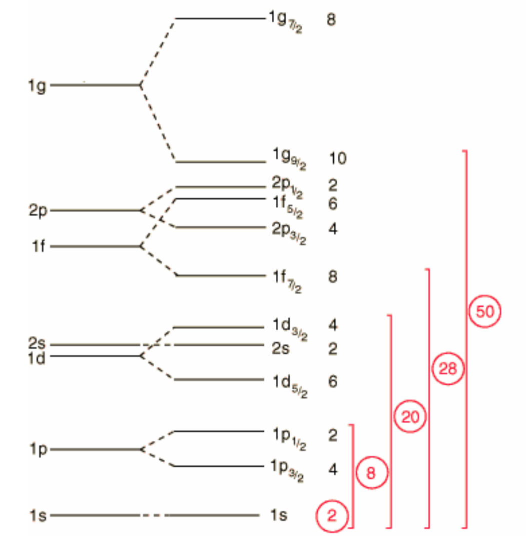
INTRODUCTION

INDEPENDENT PARTICLES



ρ_0=0.16 nucleons.fm^{-3}

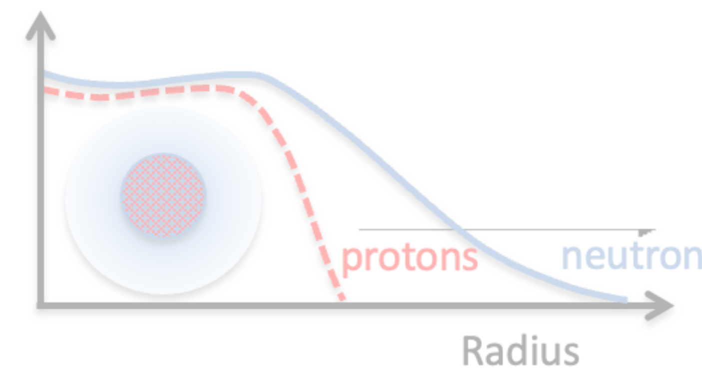
- Neutrons and protons move independently in well-defined quantum orbits;



CLUSTERING

$\rho << \rho_0$

- Alpha clustering, Hoyle state;
- Di-neutron correlation;



SHORT RANGE CORRELATIONS

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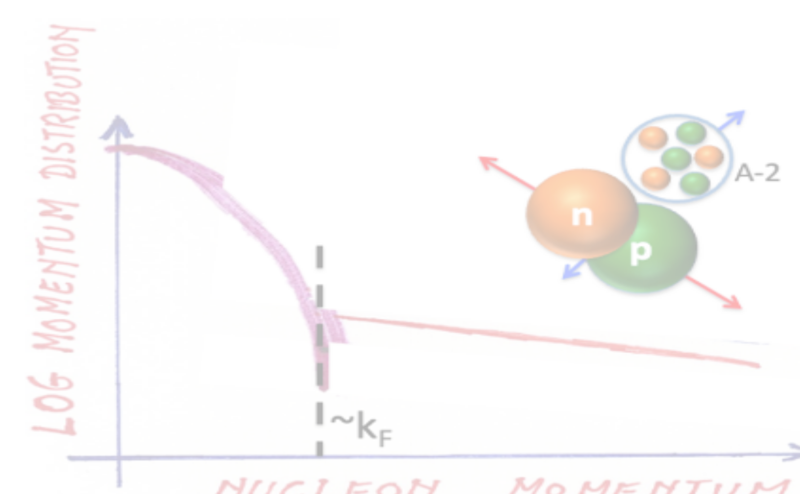
- **High relative momentum and low centre of mass (c.m.) momentum pairs**;



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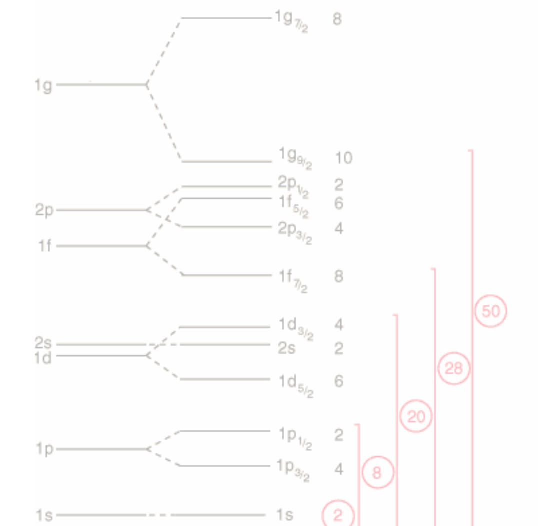

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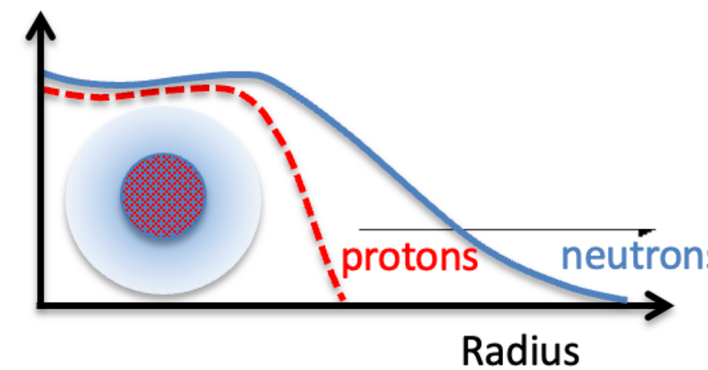

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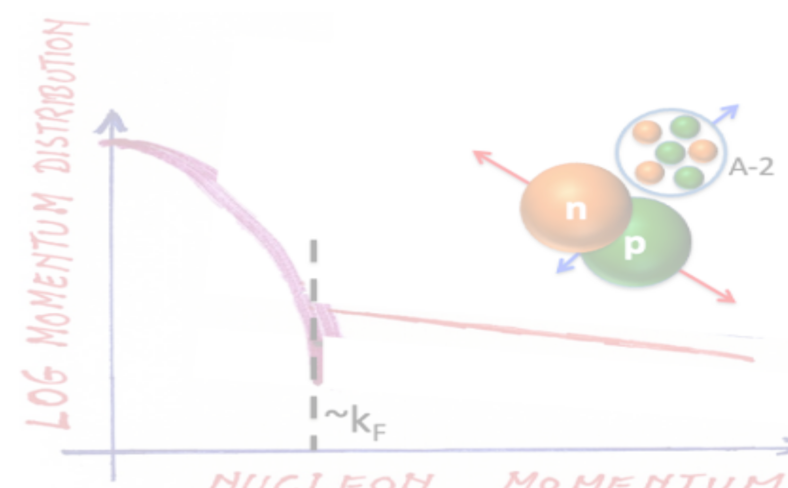

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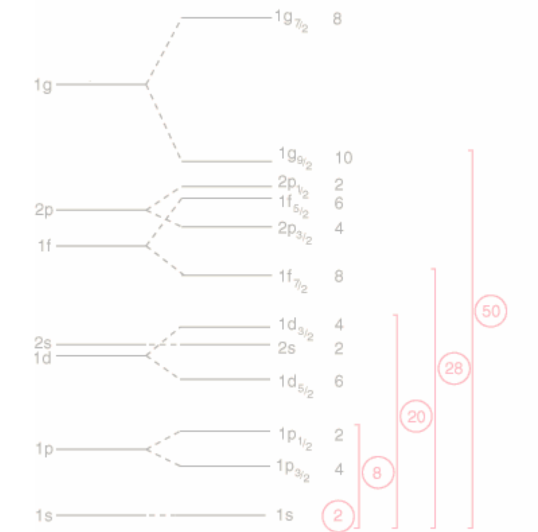

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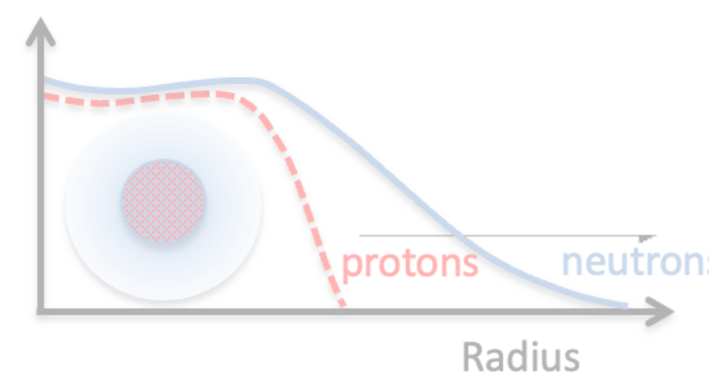

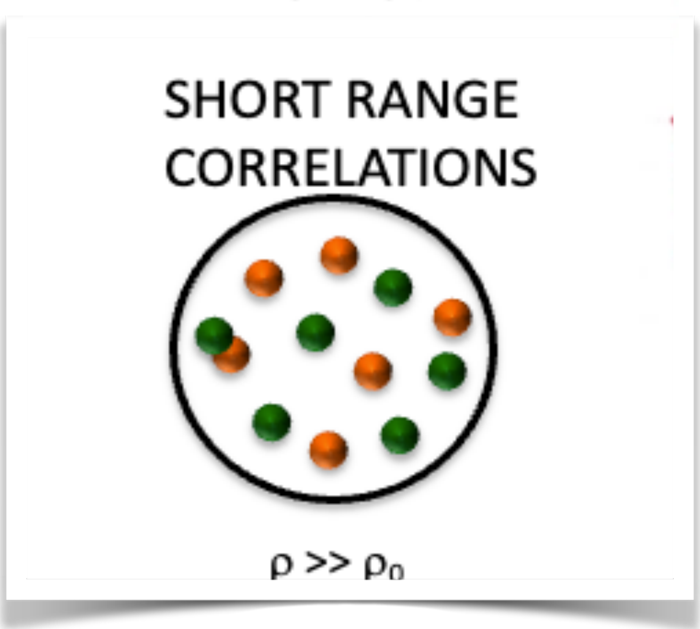

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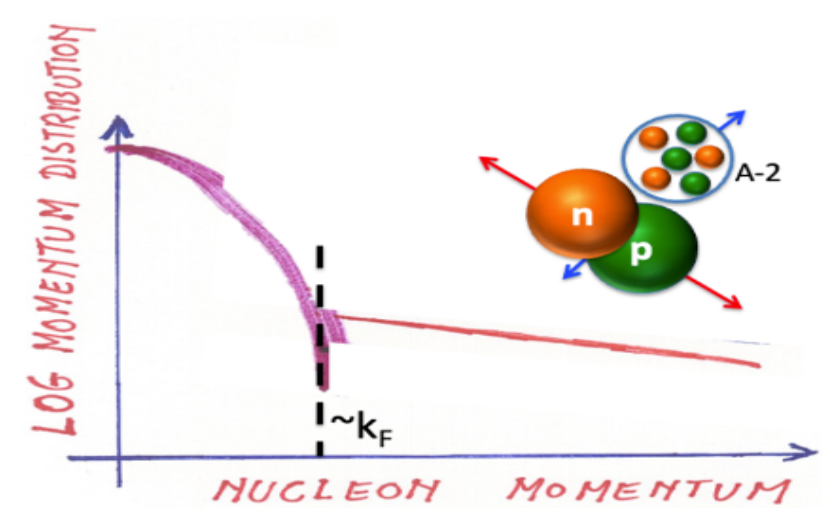
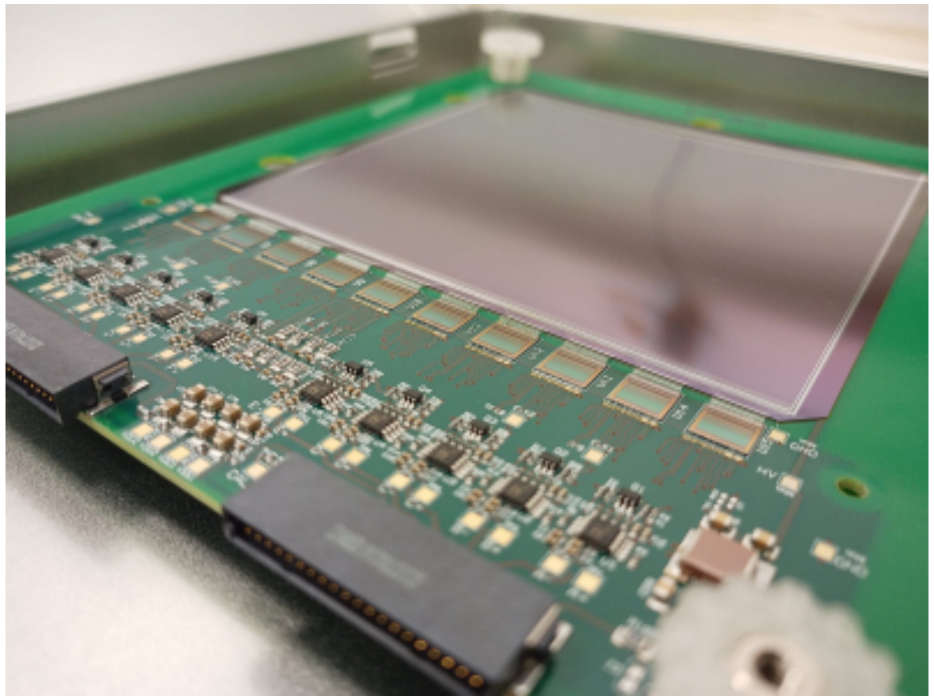


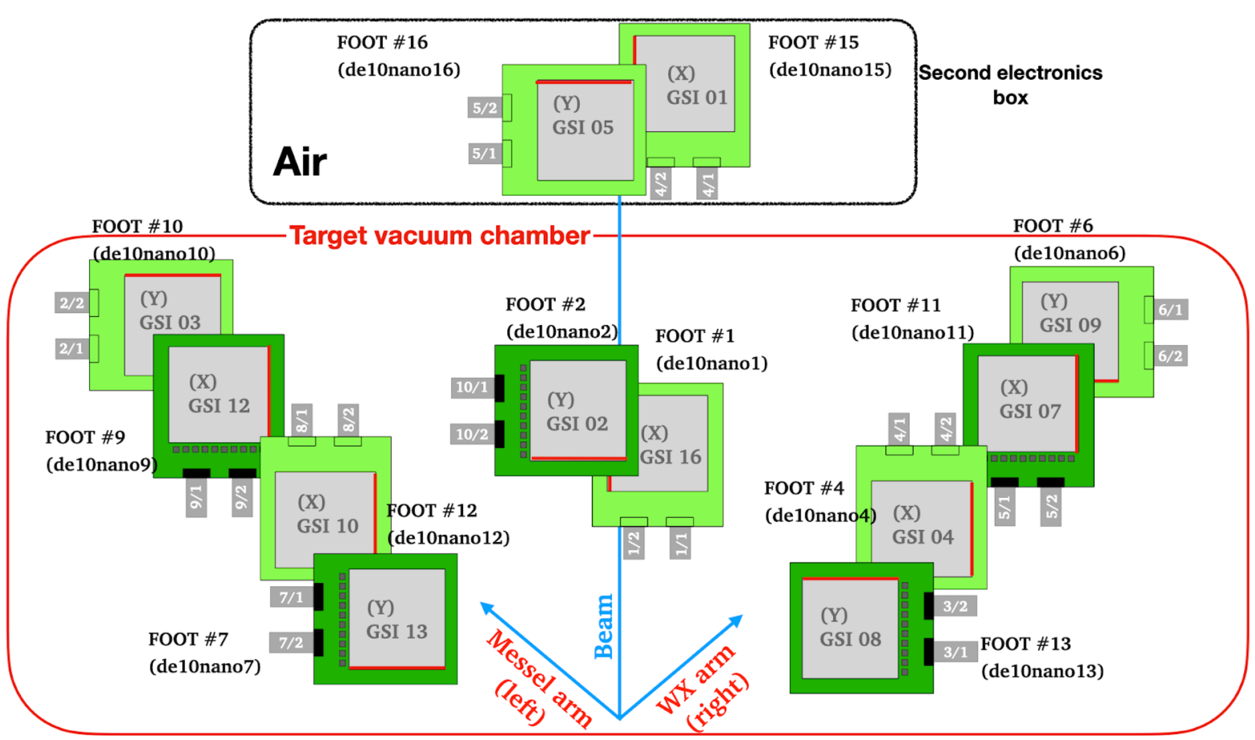
FOOT

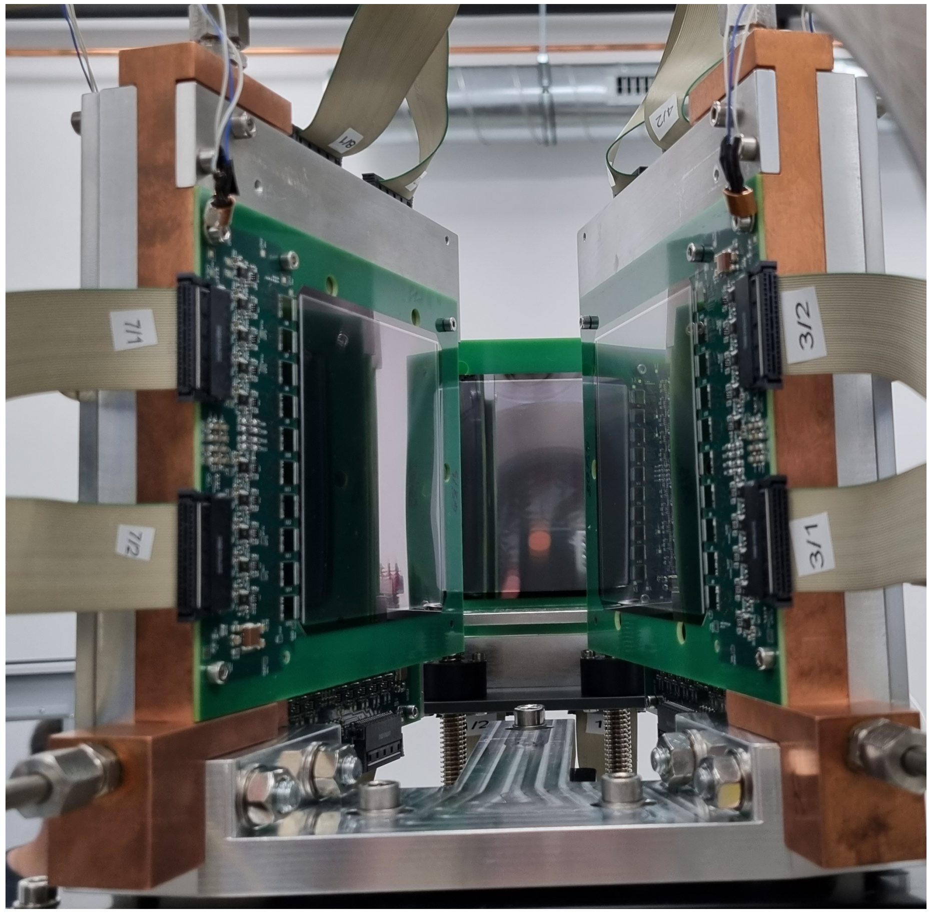
FOOT DETECTORS:

- New single-sided silicon tracking system used for the first time in R^3B for proton tracking, fragments ID and vertex reconstruction ;
- 640 strips, 10x10 cm^2 active area;
- 150 um thick;



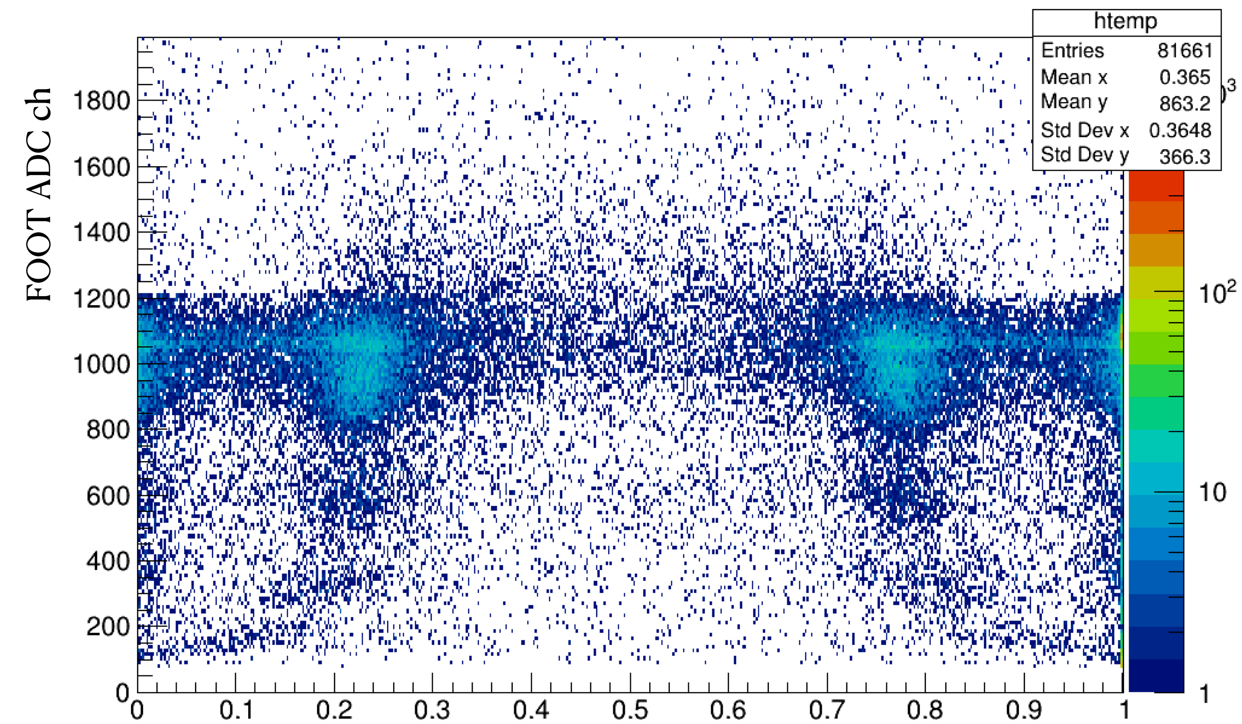
FOOT Mapping s509/s522

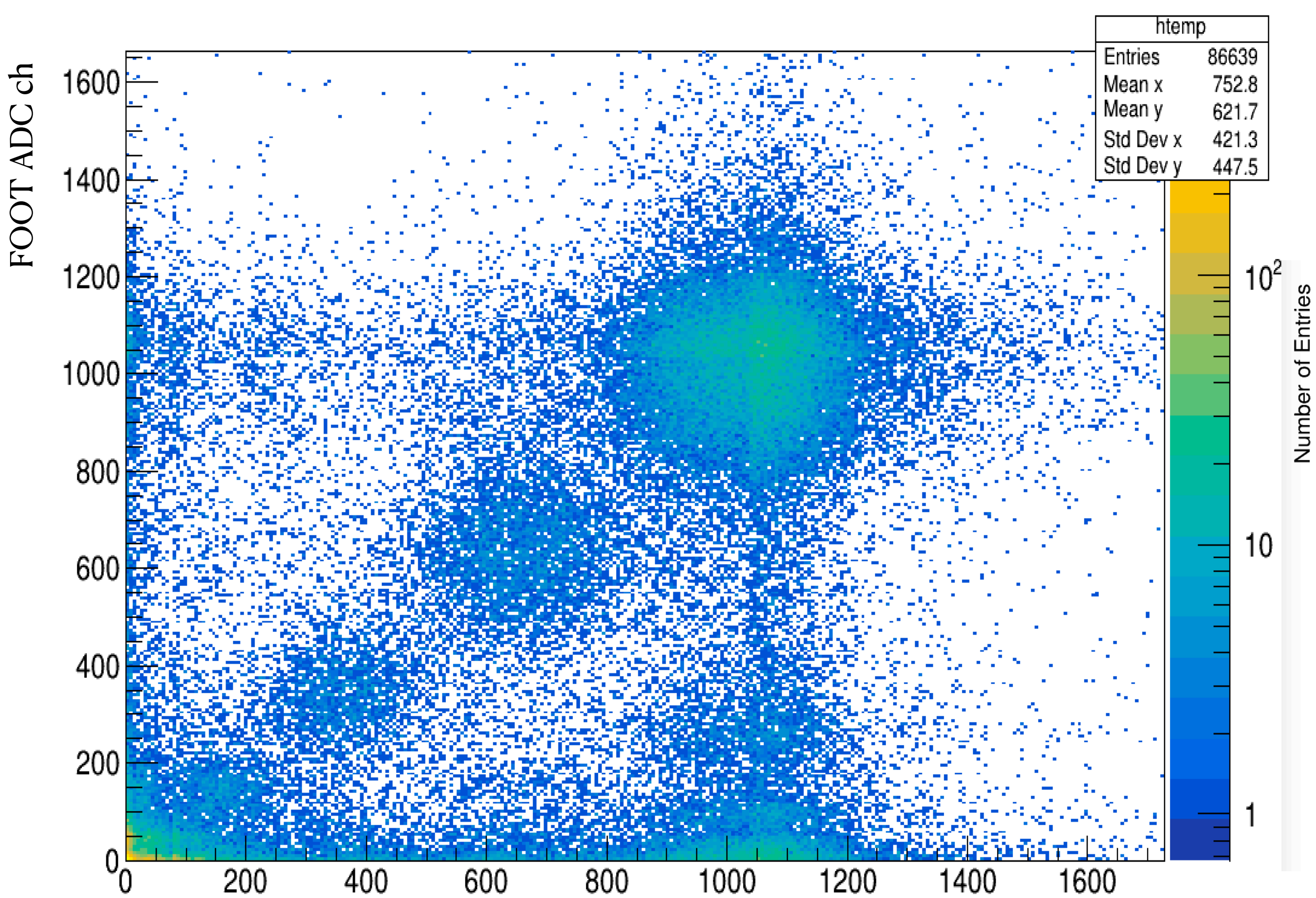


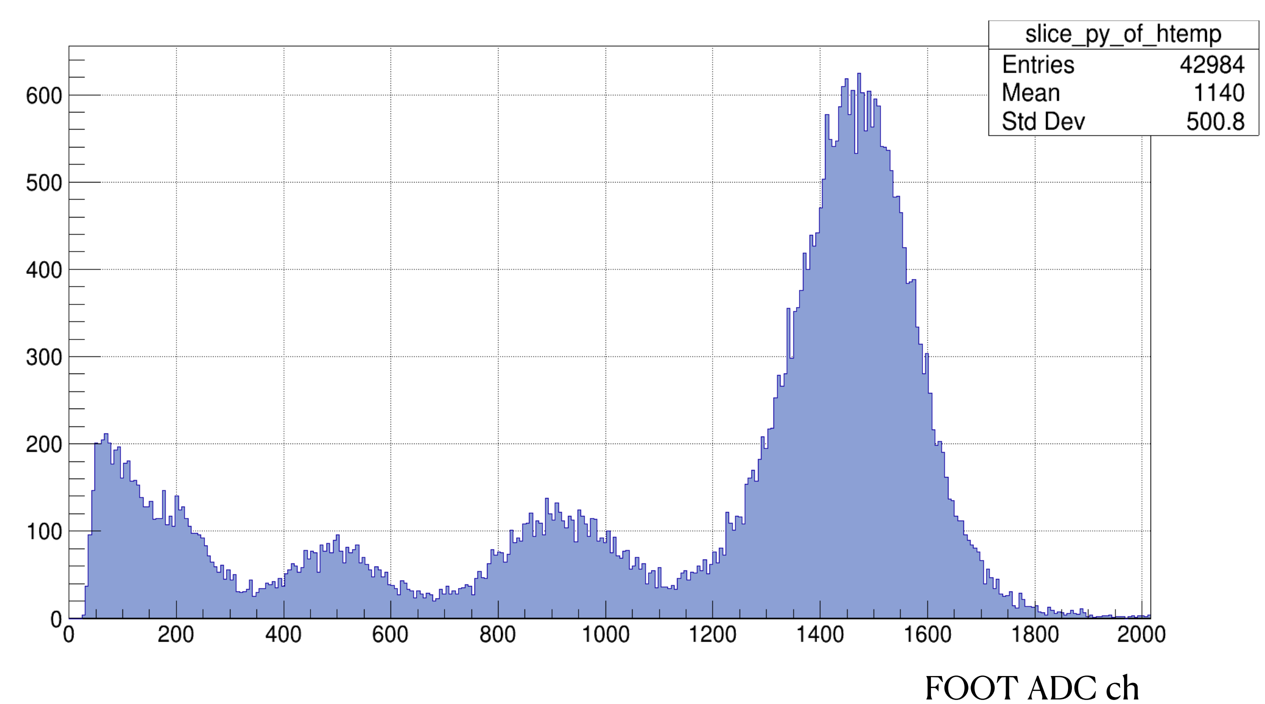


FOOT

- In order to decrease the multiplicity we decided to use FOOT energy correlations;
- New s522/s509 calibration for Energy-eta dependence;
- Energy correlation FOOT 0 and FOOT 1 (in beam FOOT);

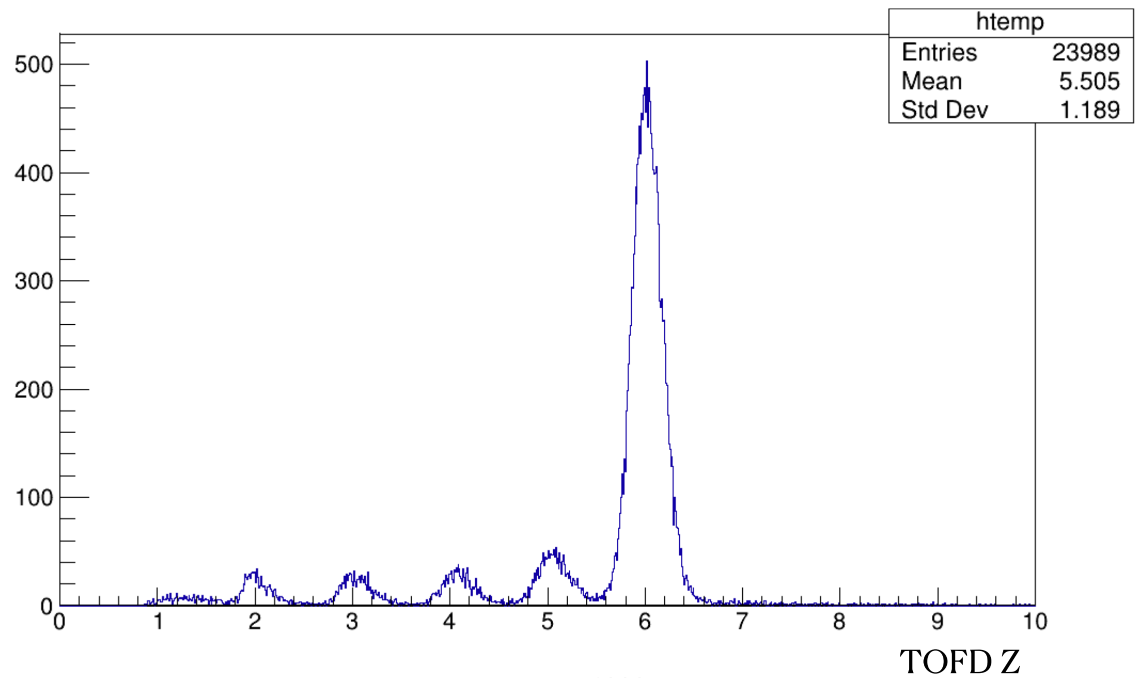


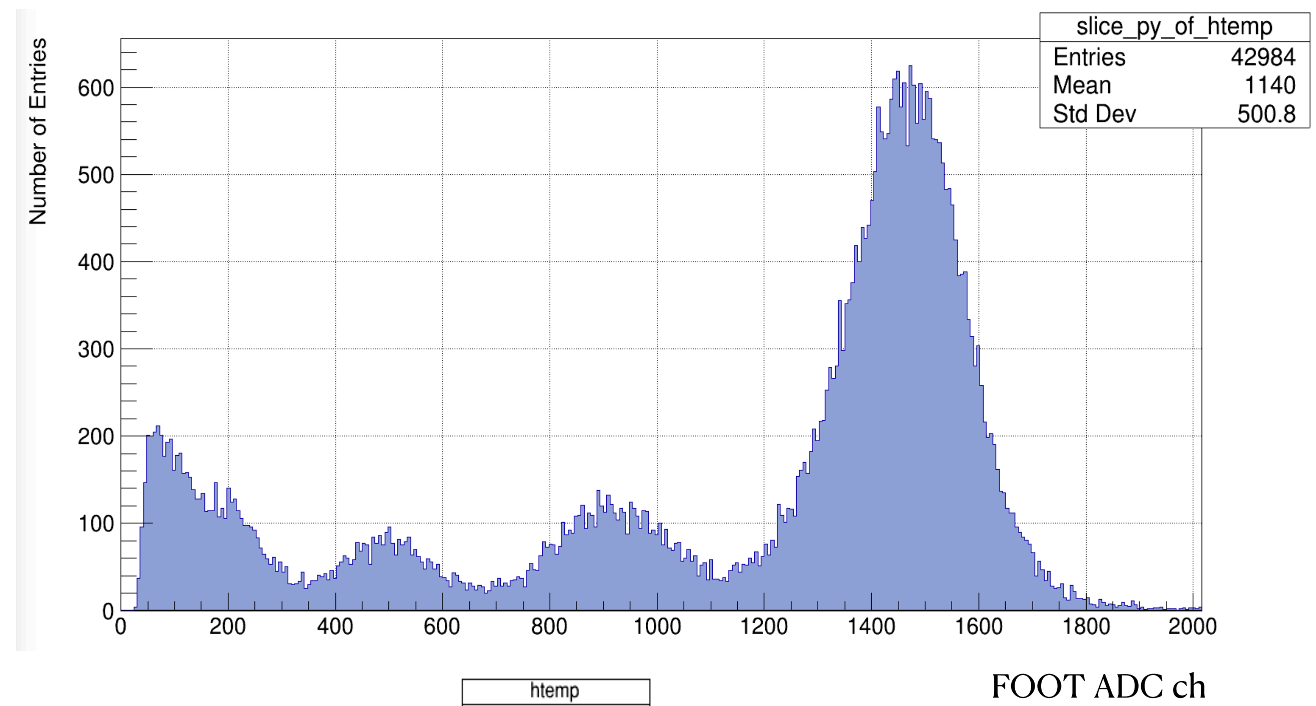


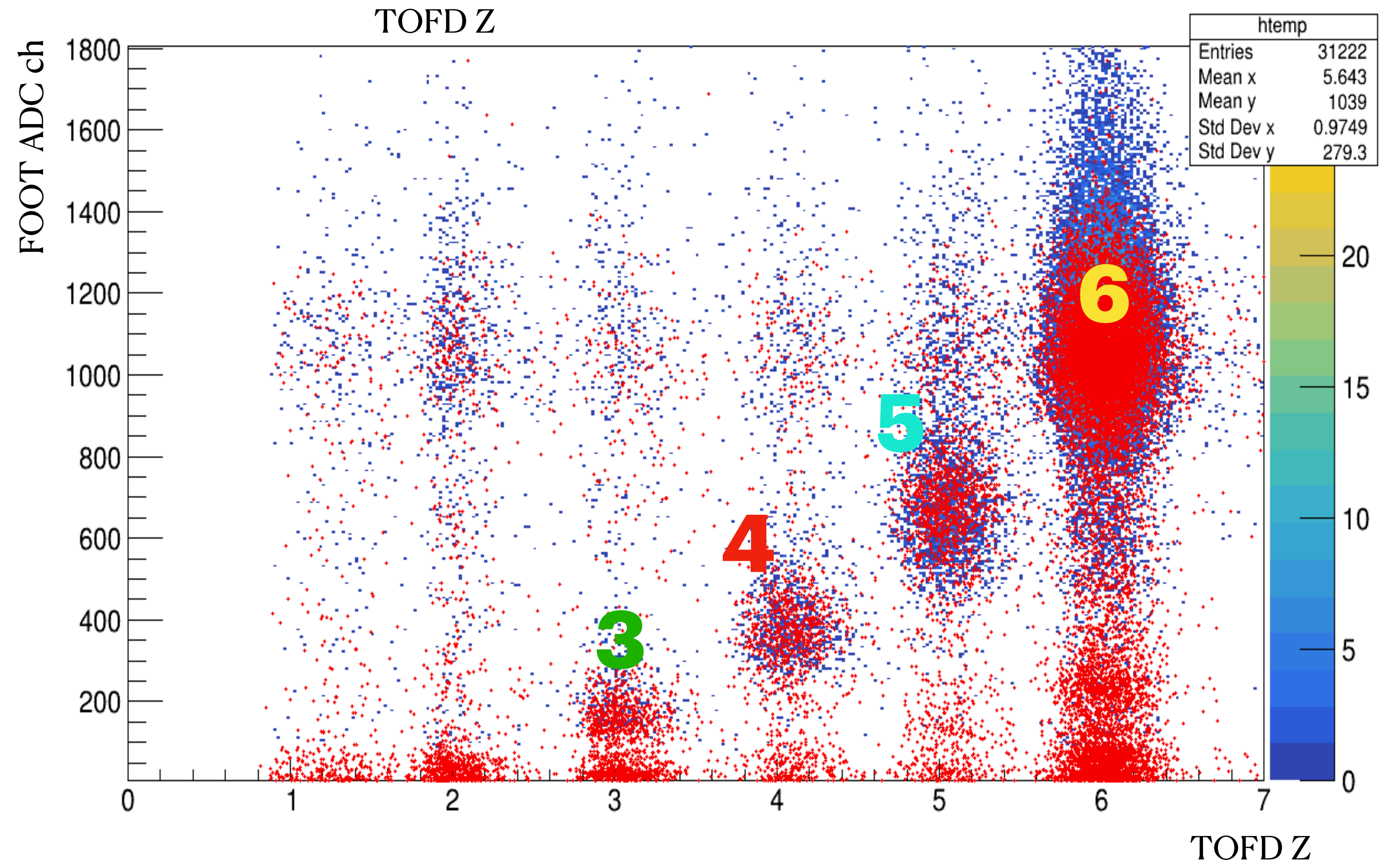


FOOT - TOFD correlation

- FOOT0 multiplicity one;
- TOFD plane 1 and multiplicity one.







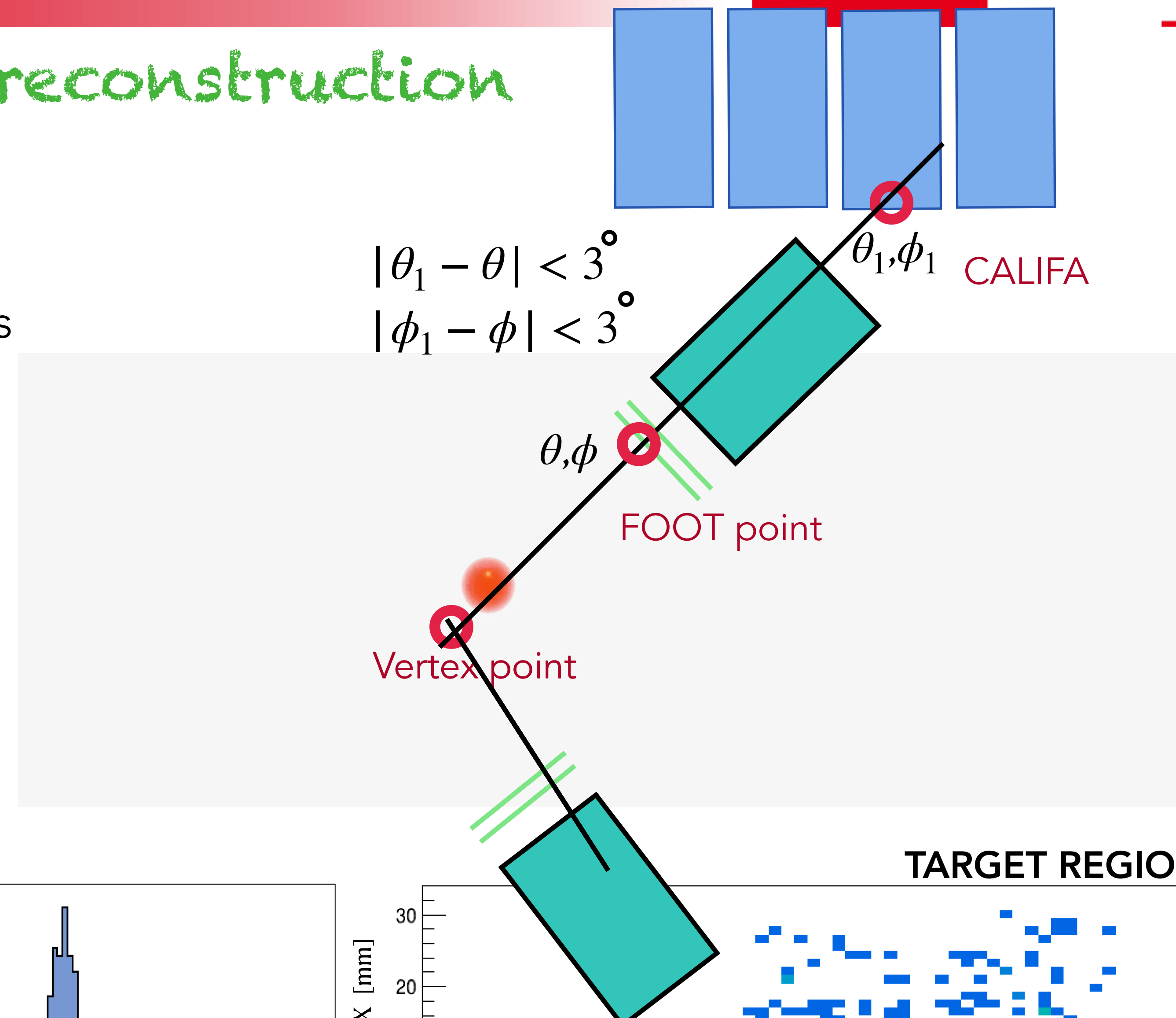
Vertex reconstruction CALIFA

(p,2p) VERTEX reconstruction

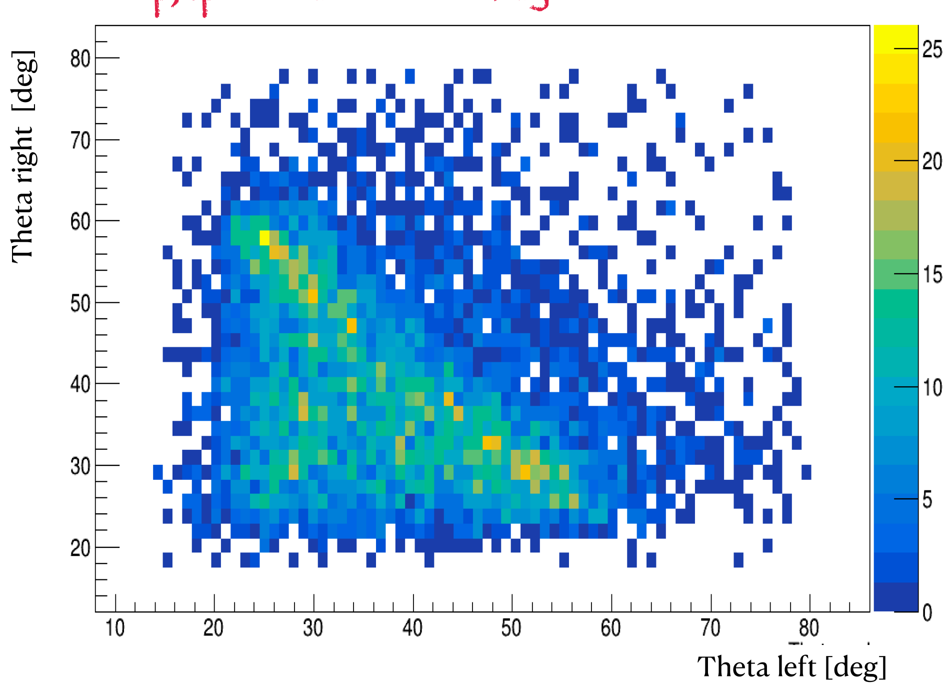
Challenges

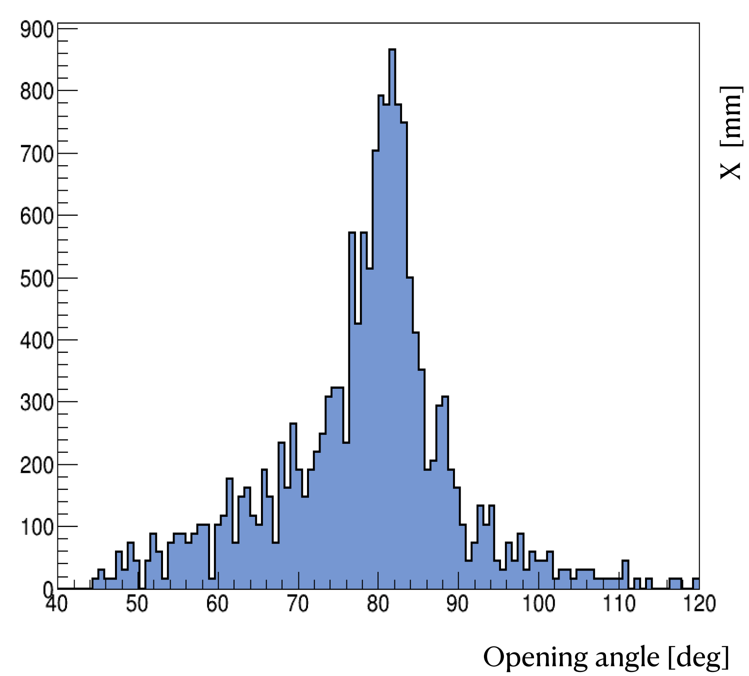
- High beam **energy** and **intensity**;
- High **background** and **noise** level (delta electrons and baseline fluctuations);
- Low proton **energy deposited**.

✓ **Minimum distance** between al possible combinations of FOOT tracks from the left arm and right arm;
✓ Matching with **CALIFA angles**.

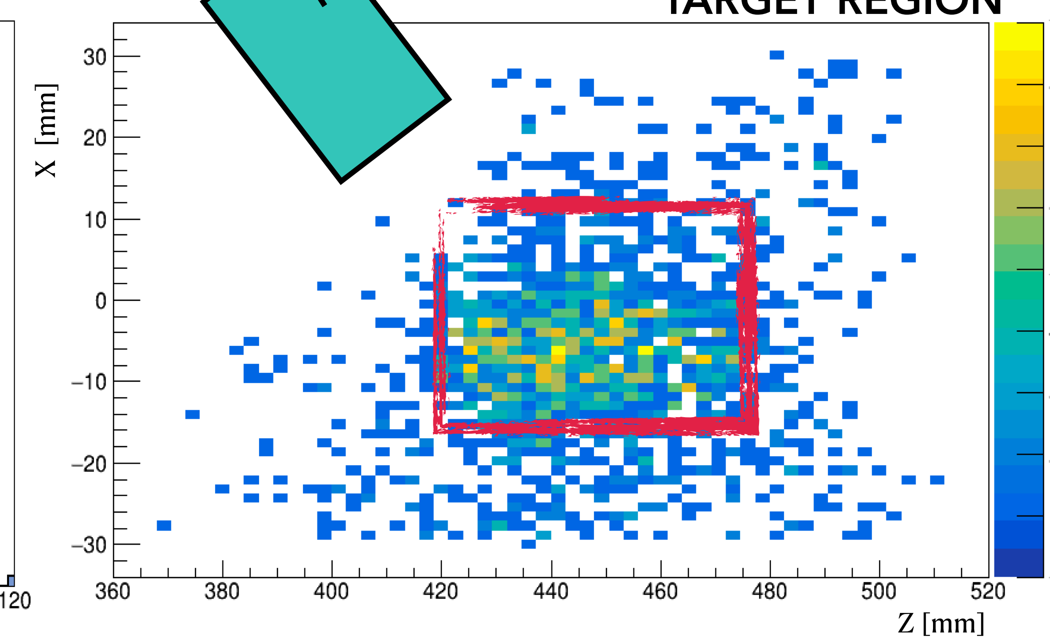


p,2p kinematical region





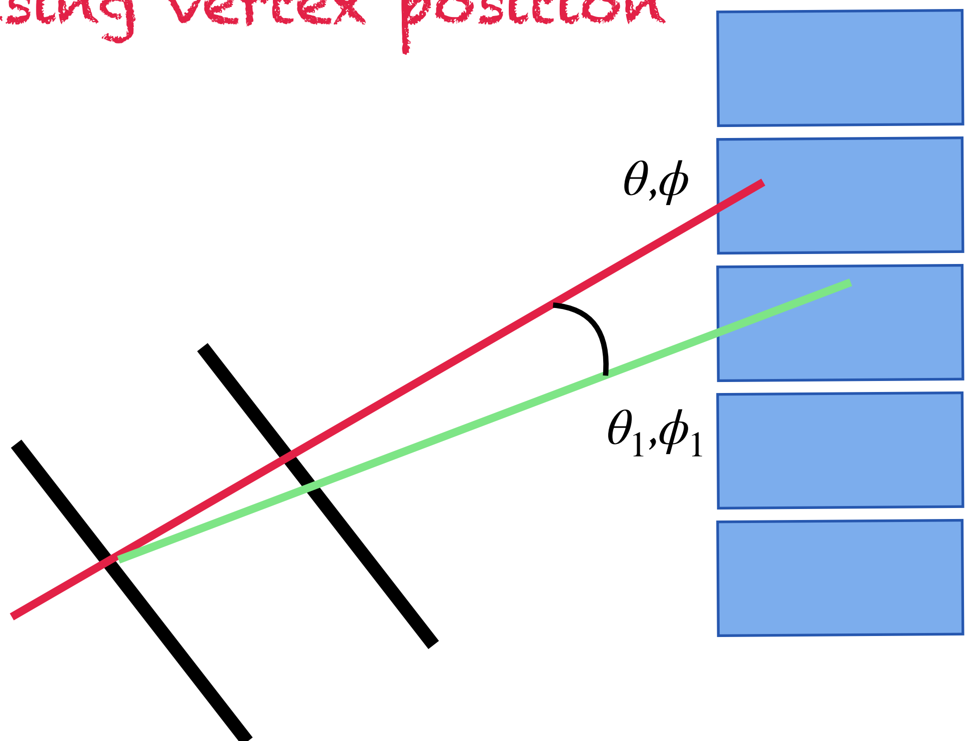
TARGET REGION



Vertex reconstruction CALIFA

- Removed condition on number of strip hit per detector;
- Decrease the threshold in the FootMap2Cal task from 3 to 2 sigma;
- Implemented correlations with CALIFA to select proper track in FOOT.

Not using vertex position

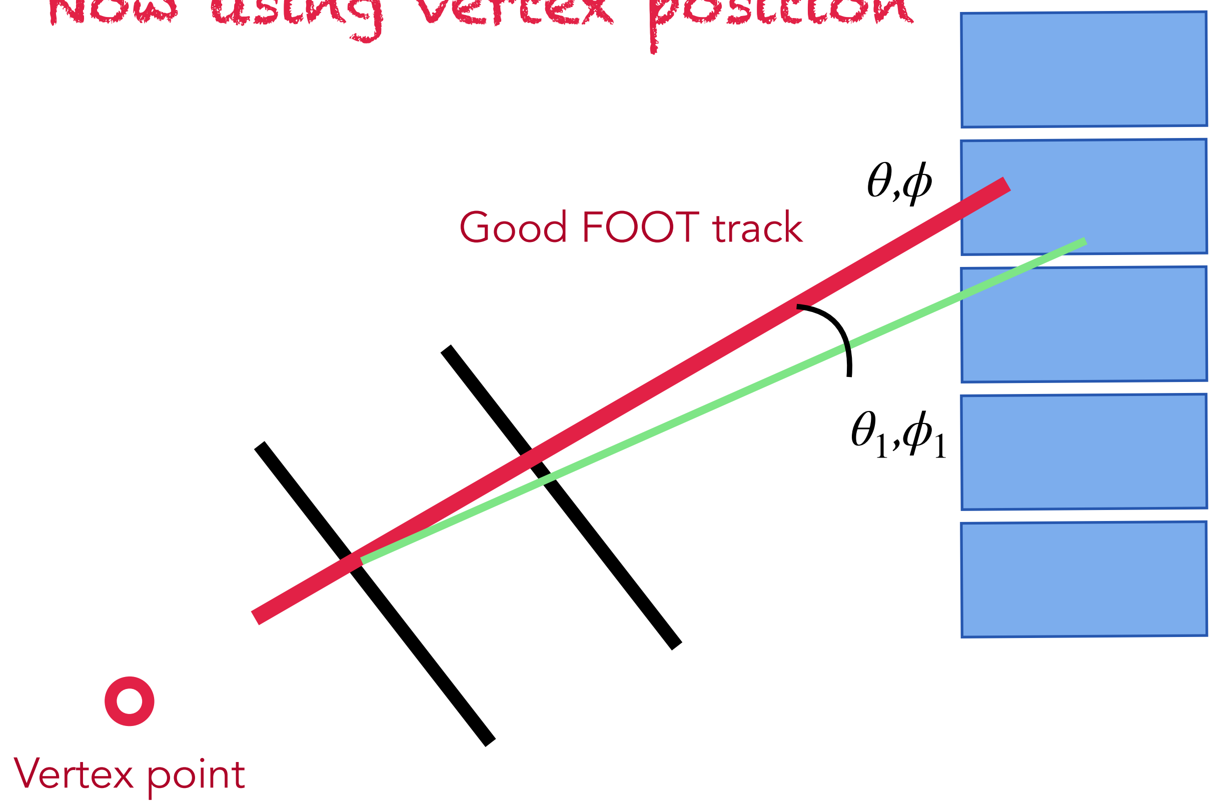


- FOOT θ,ϕ:
  - From tracking;
- CALIFA $\theta 1,\phi 1$:
  - From aligned geometry file ;

$$|\theta_1 - \theta| < 3^{\circ}$$

$$|\phi_1 - \phi| < 3^{\circ}$$

Now using vertex position

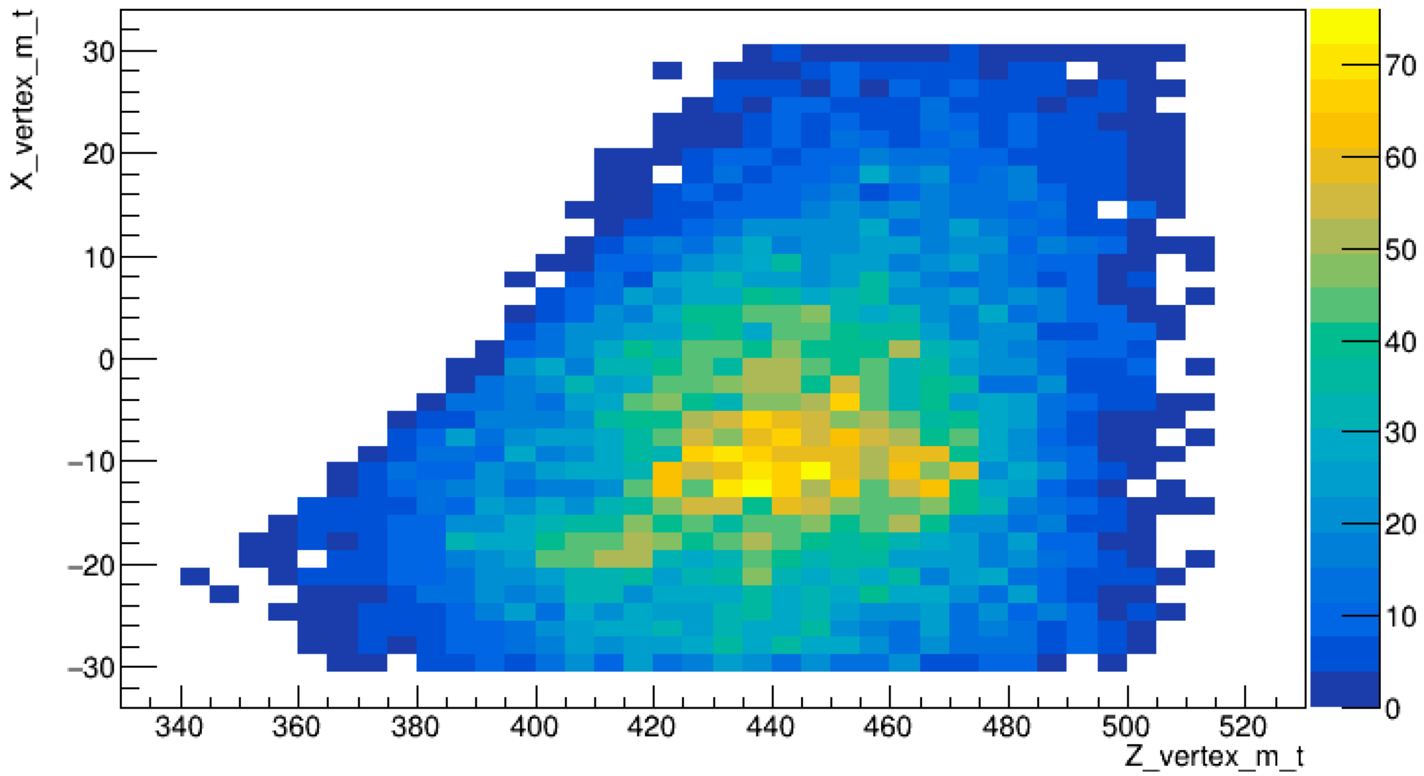


(x,y,z) vertex

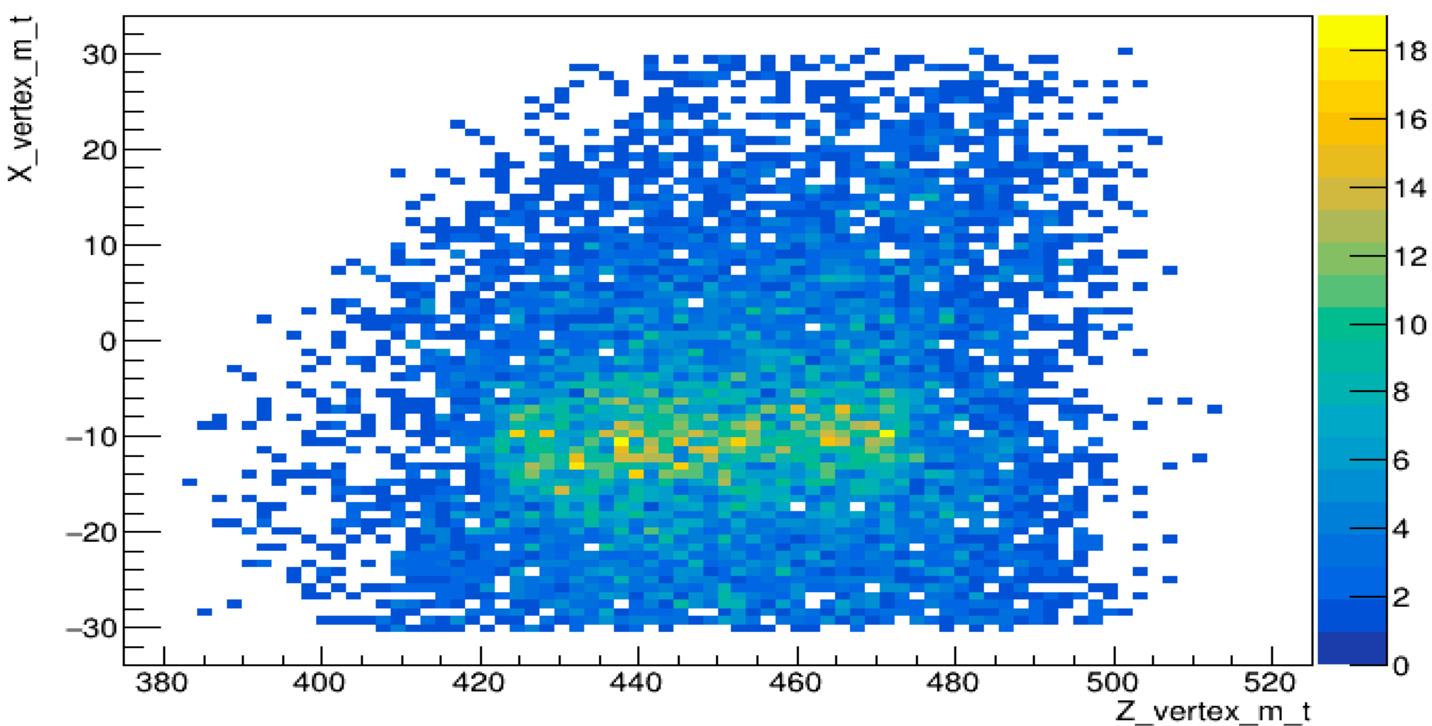
(x,y,z) CALIFA geometry

$\rightarrow$ θ_c,ϕ_c

Vertex ^{16}C

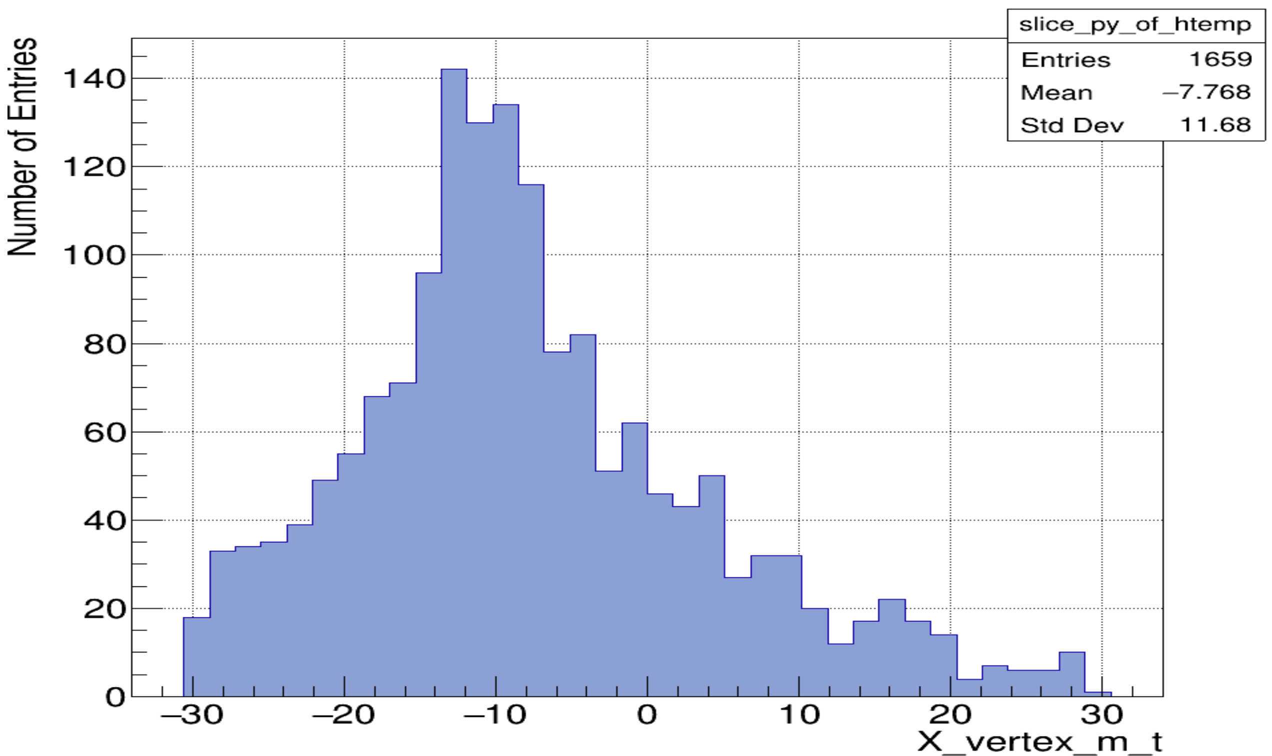


- X-Z correlation;
- No conditions applied;
- Two structure, target region and ring of the target;
- Beam was very close to the ring of the target.

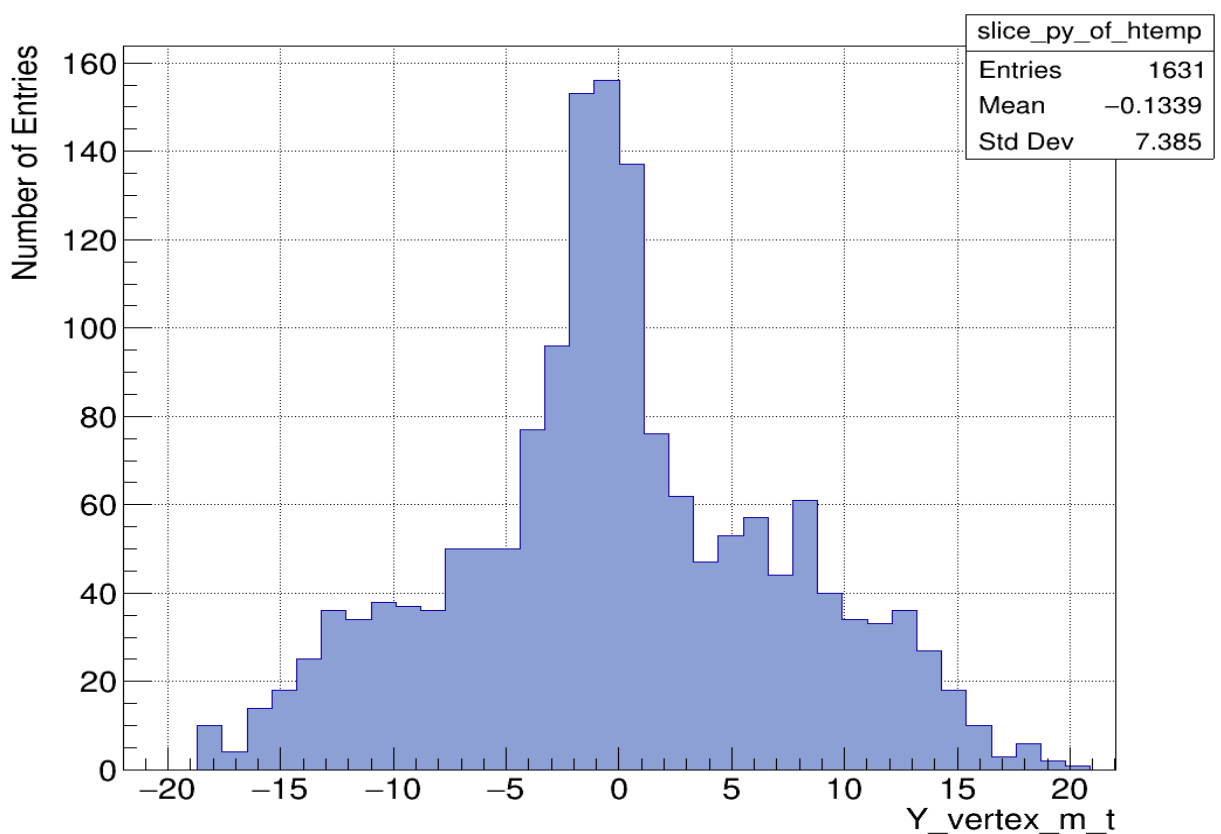


- Condition on TOFD charge 5;
- Condition on minimum distance < 0.5 mm;

Vertex ^{16}C x,y vertex

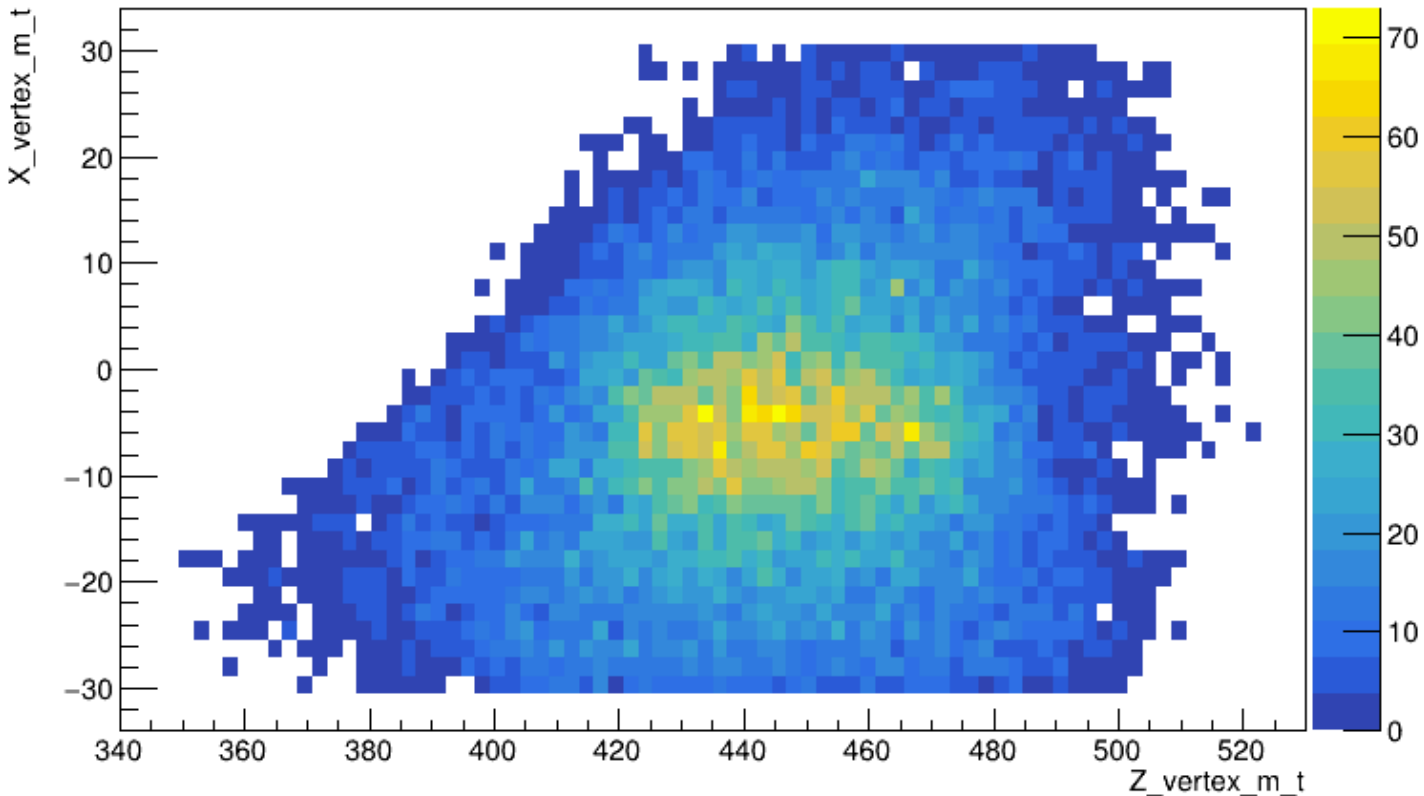


- Condition on TOFD charge 5;
- Condition on minimum distance < 0.5 mm;
- X vertex distribution centered at -10.01 mm;
- Ring of the target starts at -15 mm.

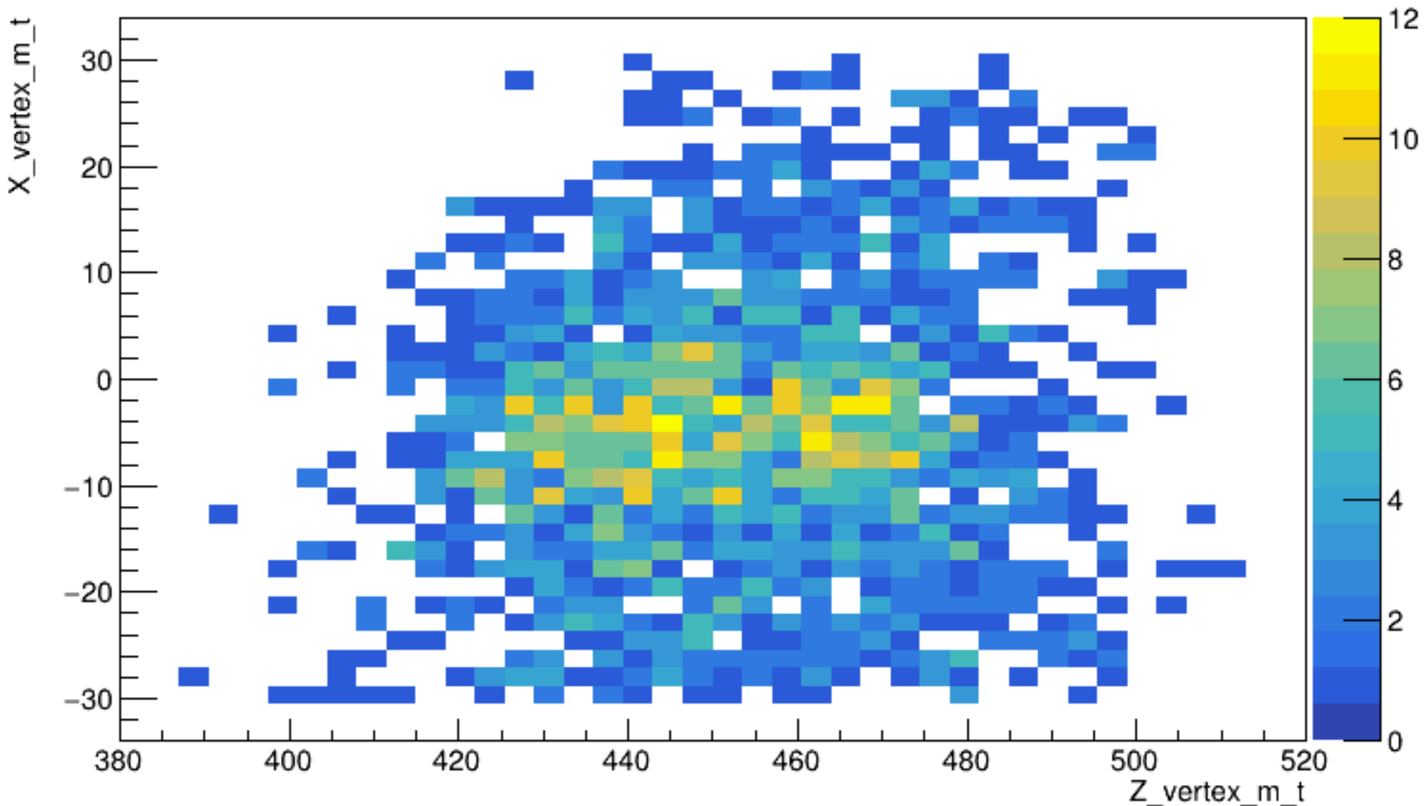


- Condition on TOFD charge 5;
- Condition on minimum distance < 0.5 mm;
- Y vertex distribution centered at -3.09 mm;

Vertex ^{12}C

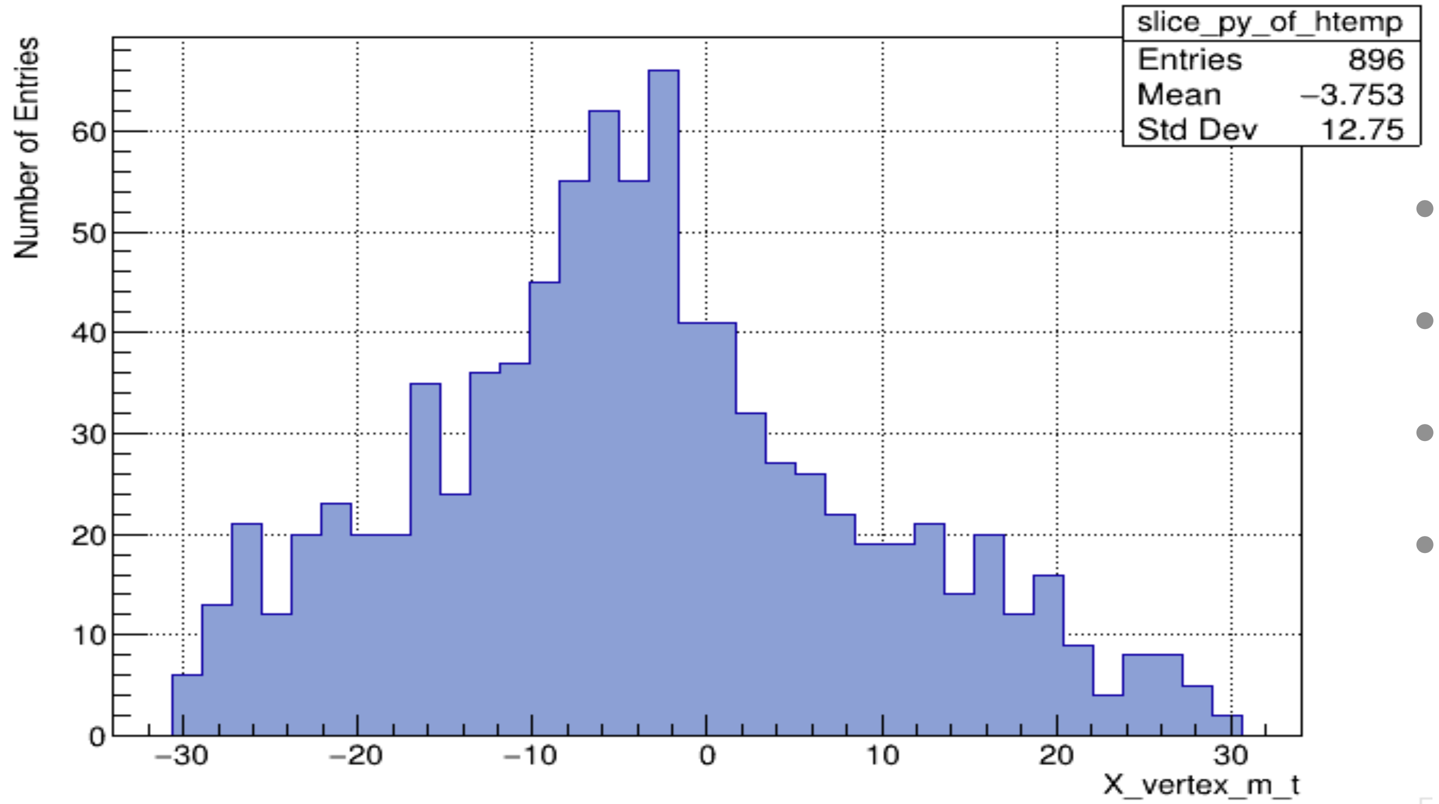


- X-Z correlation;
- No conditions applied;
- One structure associated with the target region;
- Beam was more centred at the centre of the target.

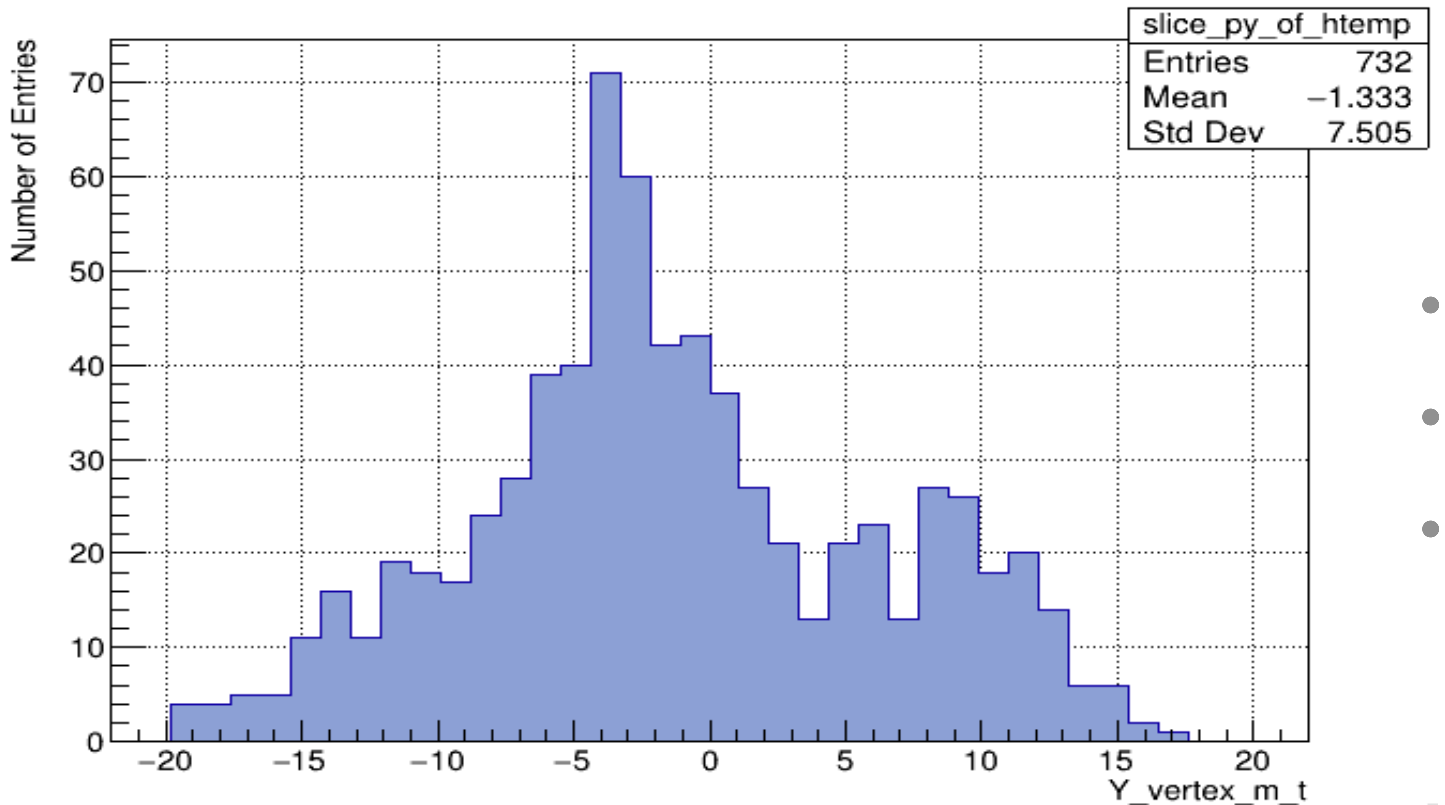


- Condition on TOFD charge 5;
- Condition on minimum distance < 0.5 mm;

Vertex ^{12}C x,y vertex

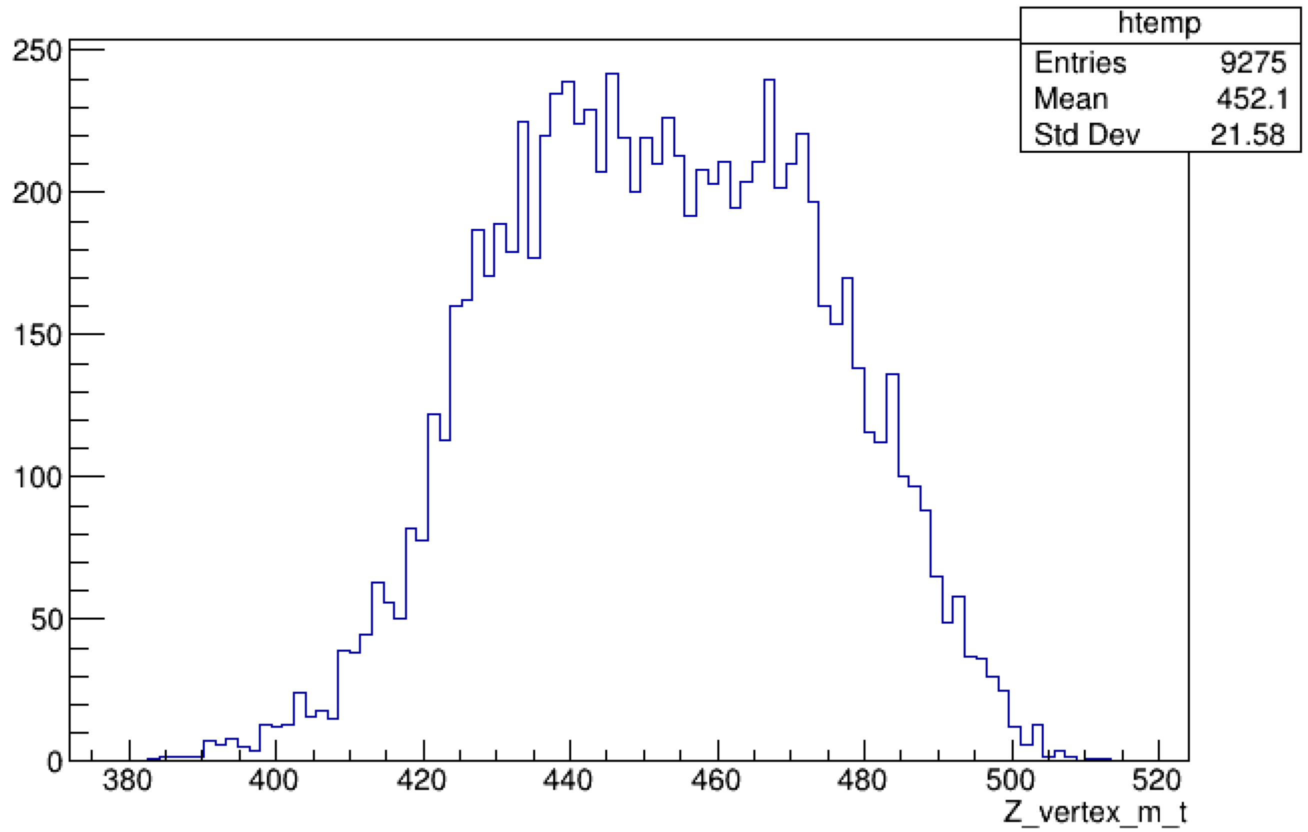


- Condition on TOFD charge 5;
- Condition on minimum distance < 0.5 mm;
- X vertex distribution centered at -3.03 mm;
- Ring of the target starts at -15 mm.



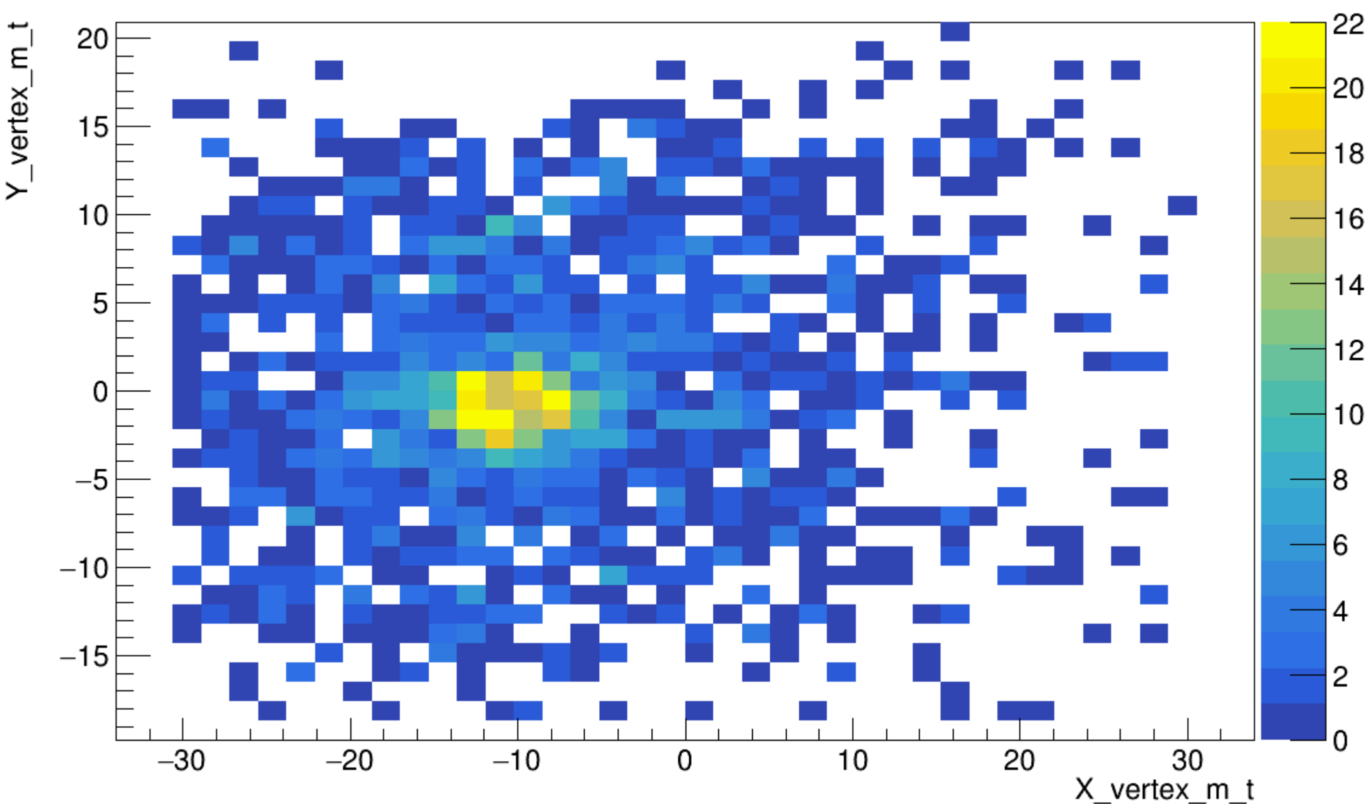
- Condition on TOFD charge 5;
- Condition on minimum distance < 0.5 mm;
- Y vertex distribution centered at -4.03 mm;

Vertex ^{16}C plots



- Condition on TOFD charge 5;
- Condition on minimum distance < 0.5 mm;
- Z vertex distribution;

- Condition on TOFD charge 5;
- Condition on minimum distance < 0.5 mm;
- Target beam spot;

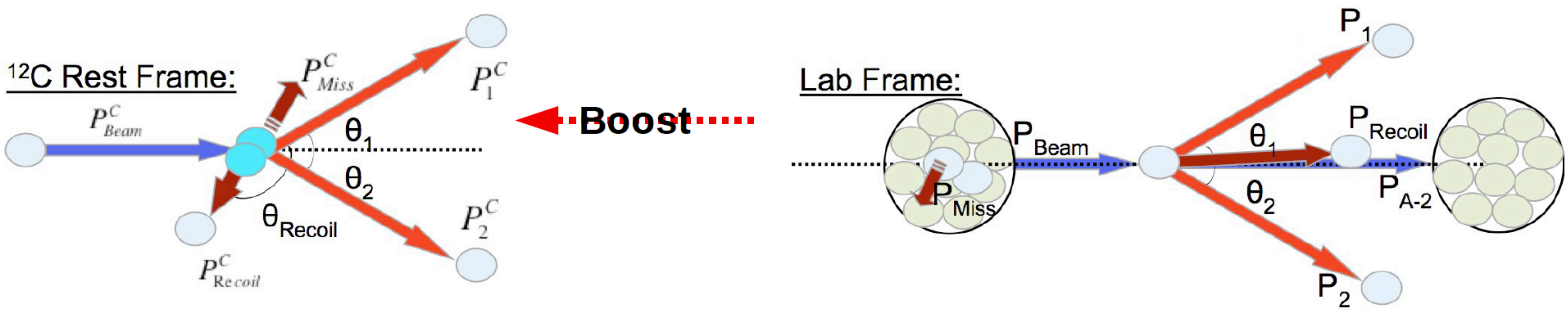


P_{miss} and M_{miss}

$$P^{\mu}_{miss} = P^{\mu}_{1} + P^{\mu}_{2} - P^{\mu}_{target}$$

$$E_{miss} = m_p - P^{0}_{miss}$$

$$M^2_{miss} = E^2_{miss} - \vec{P}^{2}_{miss}$$



S522 Tracker

- Developed Tracker code for S522;
- Initially incoming with FOOT detectors-> High humber of global tracks multiplicity;
- Use vertex-> Not so much statistics but clean selection of the fragments (following slides);
- Put together tracks from Fib31 and Fib33;
- Input a fake vertex for each event to have a view of the fragments detected and have an idea on the number of fragments.