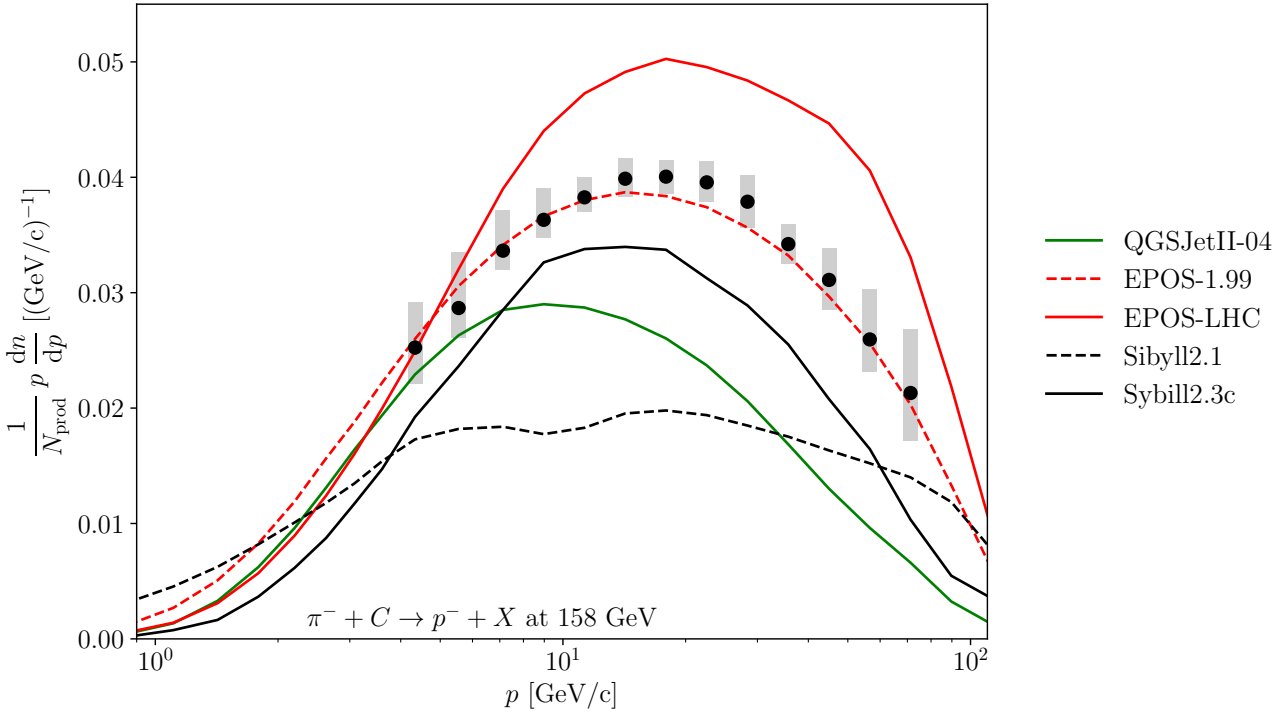
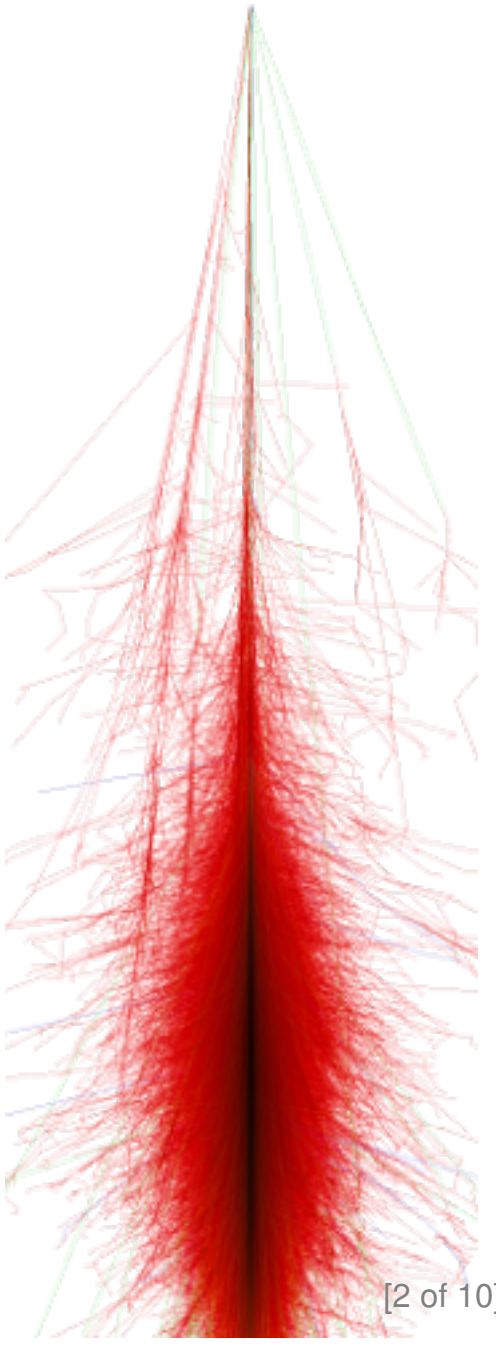
Cosmic-Ray Physics with NA61/SHINE – Status and Plans

M. Unger (KIT) for the NA61/SHINE Collaboration

Previous NA61/SHINE Results for Cosmic-Ray Physics

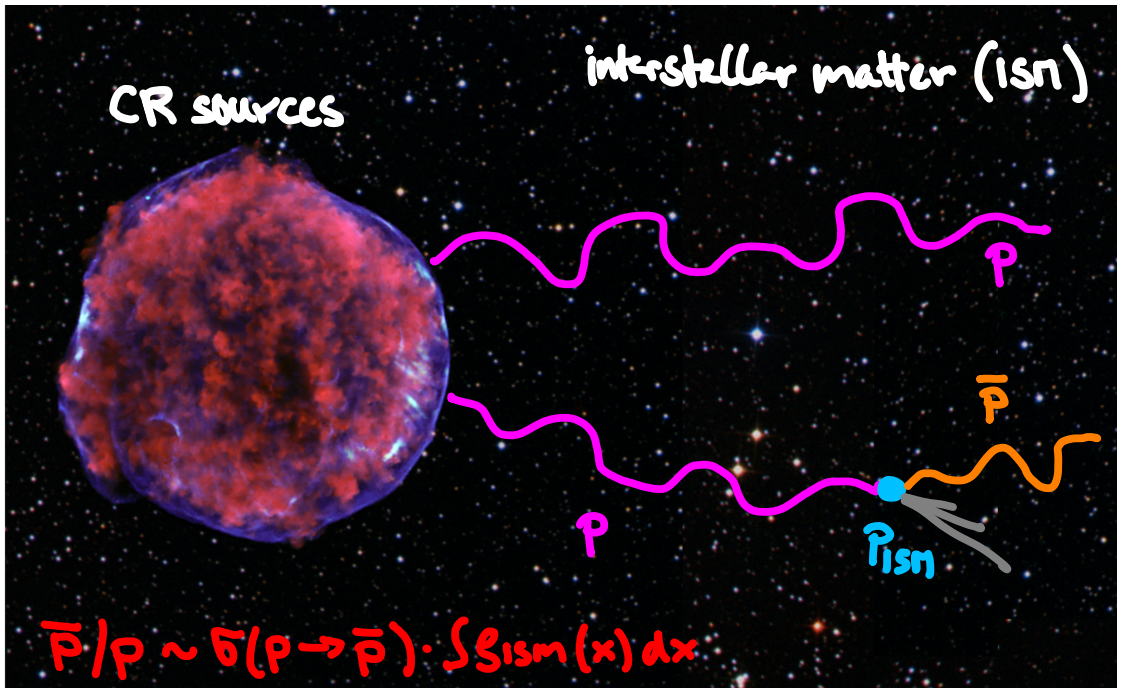
- **propagation in the Galaxy**
  - $\bar{p}$-production in $p + p$ [1]
- **ultrahigh-energy air showers**
  - $\pi^{\pm}$-production in $\pi^- + C$ [2] and $p + C$ [3]
  - ρ^0-production in $\pi^- + C$ [4]
  - $\bar{p}$-production in $\pi^- + C$ [5]

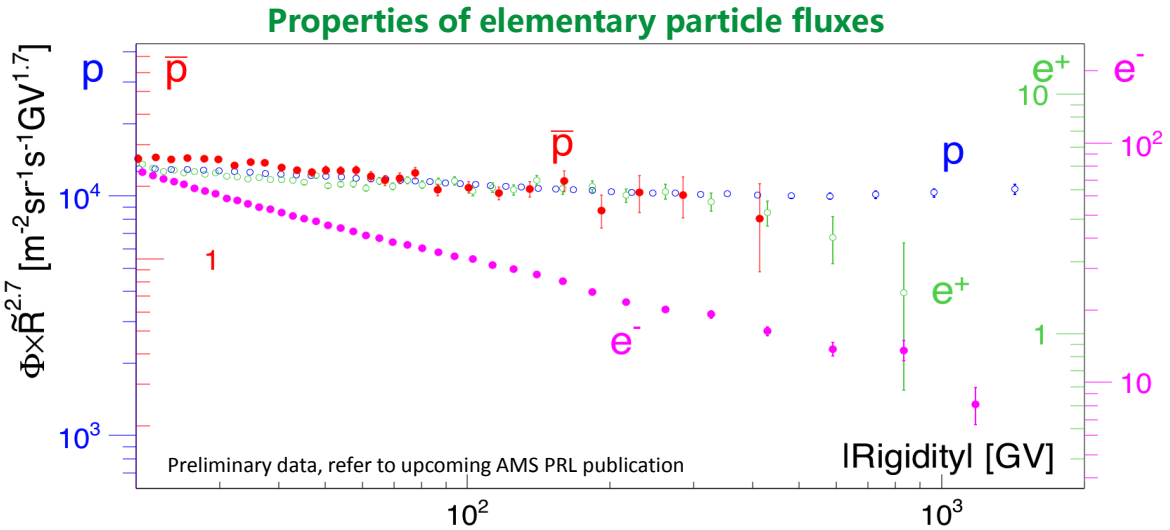




[1] Eur.Phys.J. C77 (2017) no.10, 671; [2] PoS(ICRC2017) 315, arXiv:1909.06294; [3] Phys.Rev. C84 (2011) 034604, Eur.Phys.J. C76 (2016) 84;
[4] Eur.Phys.J. C77 (2017) 626; [5] PoS(ICRC2019) 446

Nuclear Fragmentation and Galactic Cosmic Rays





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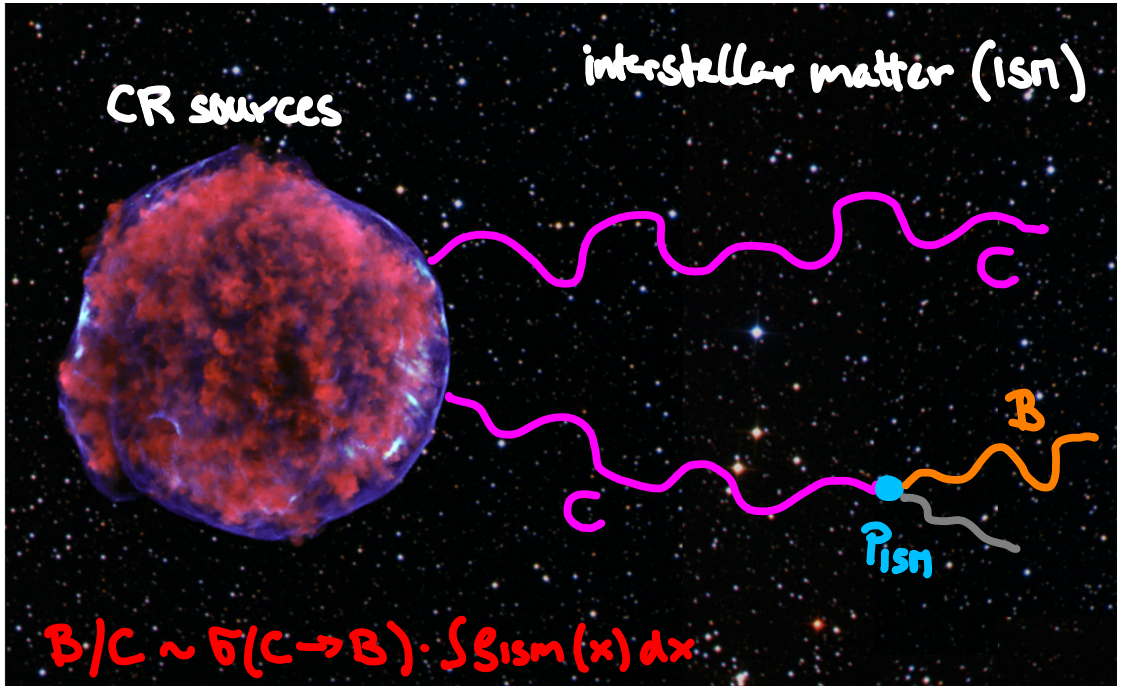

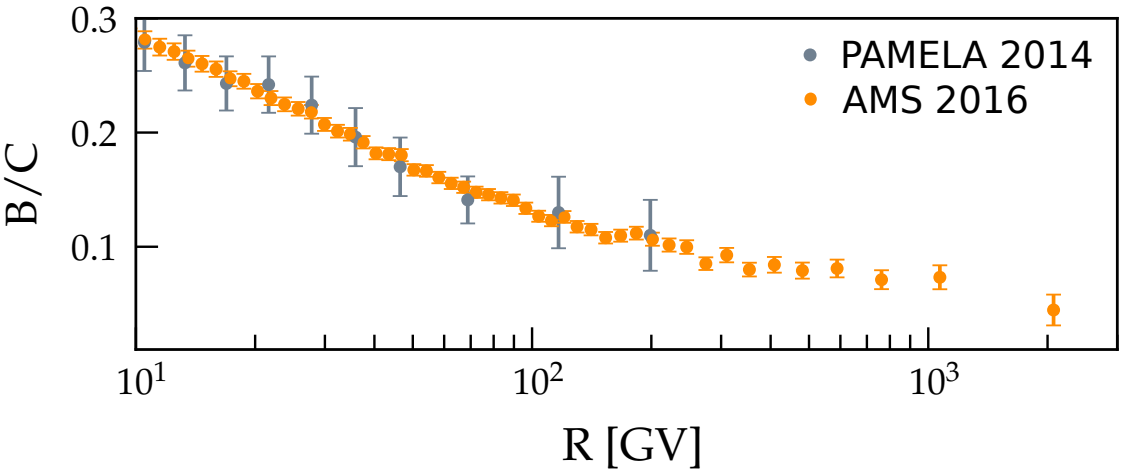

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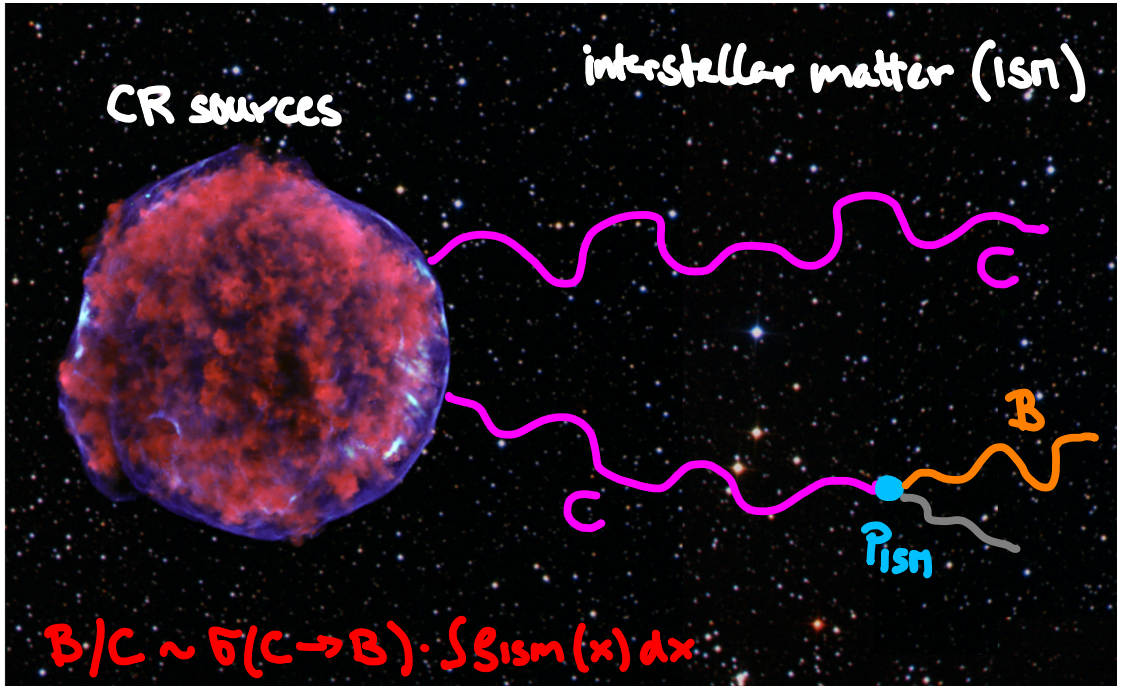

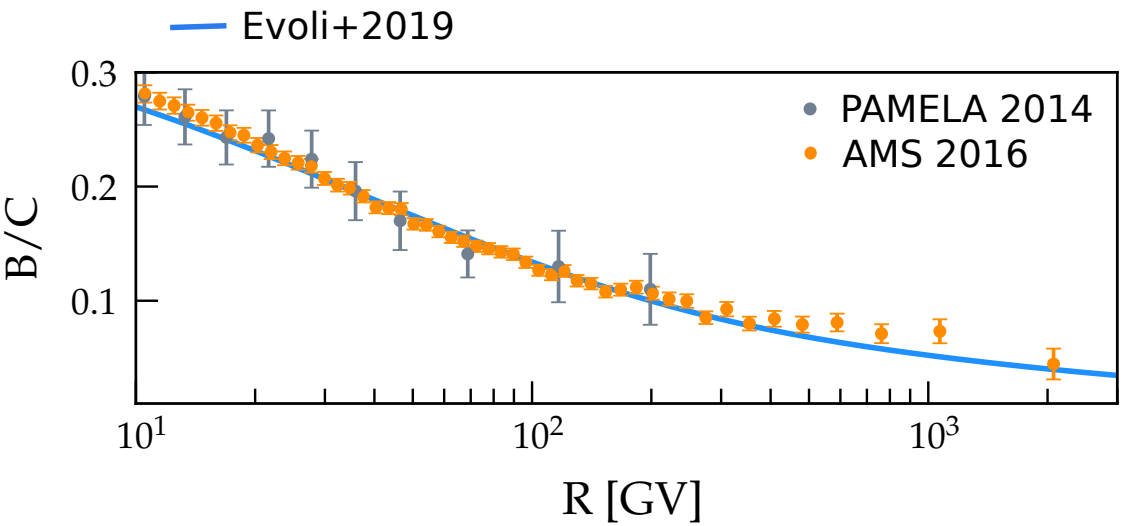

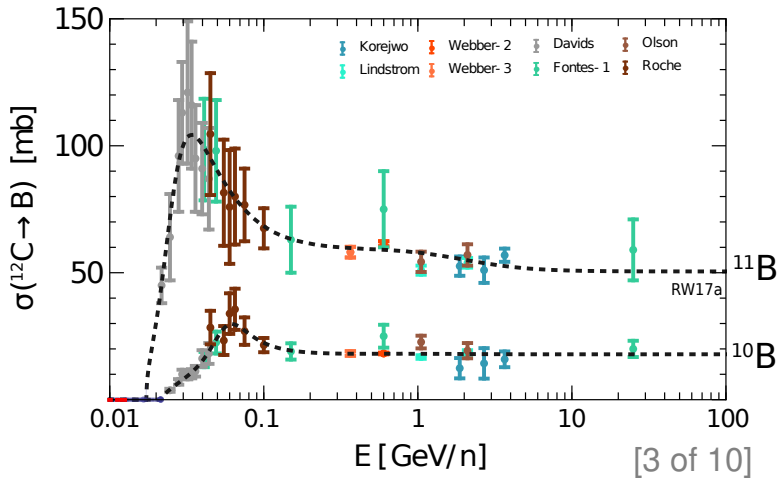

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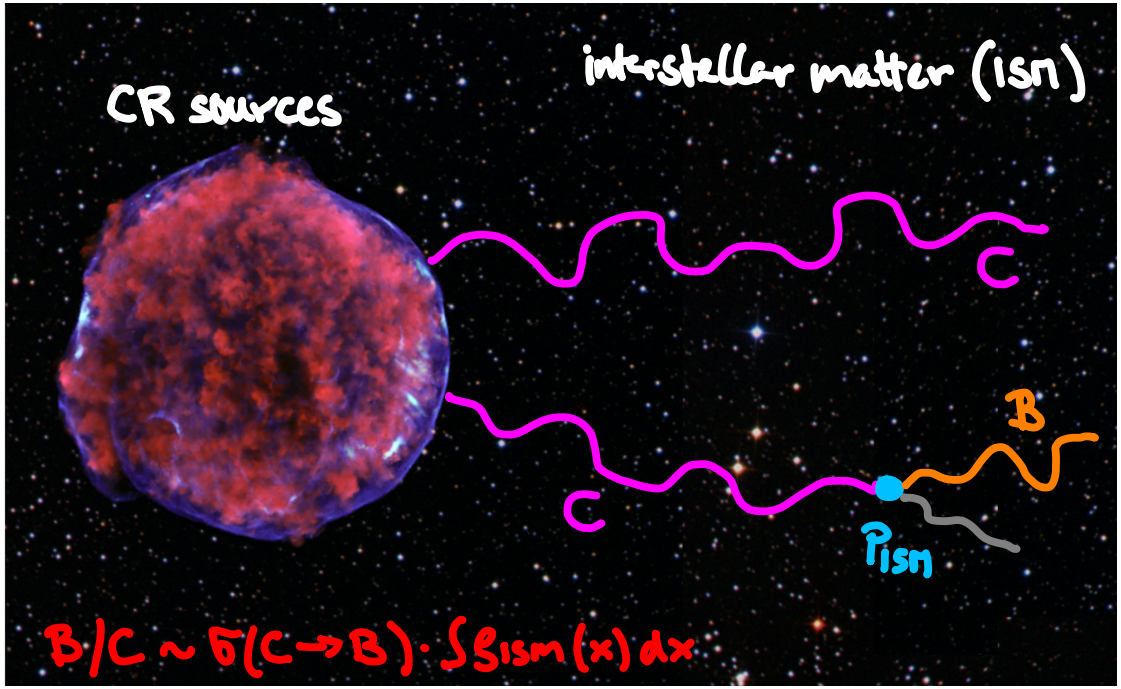

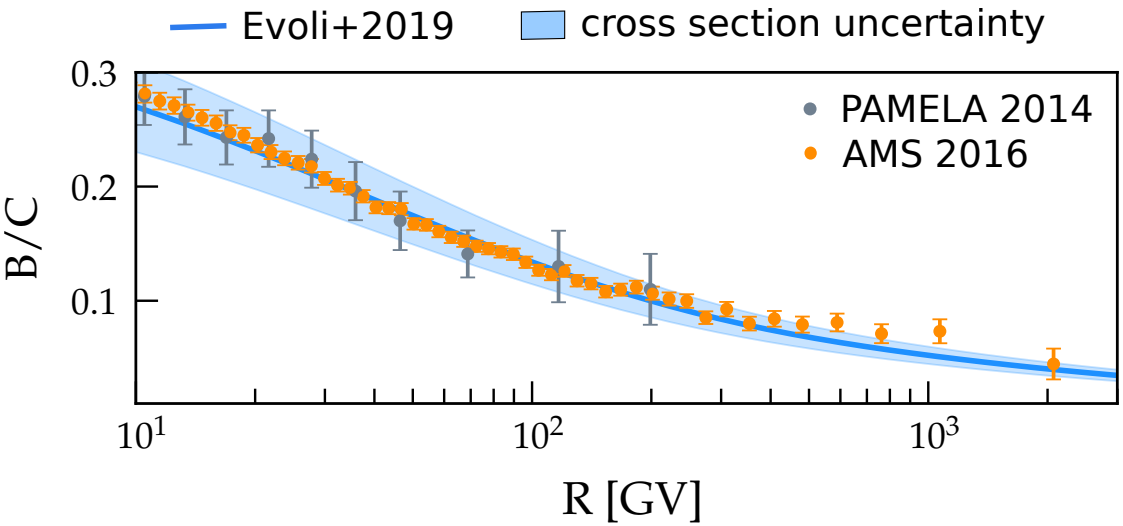

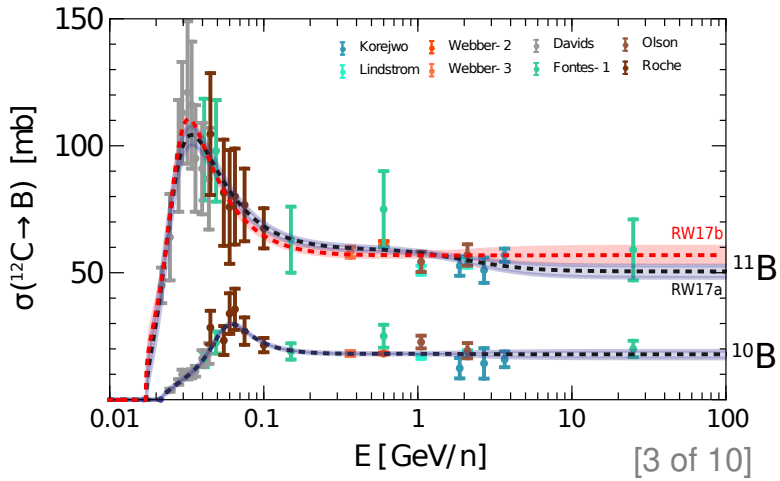

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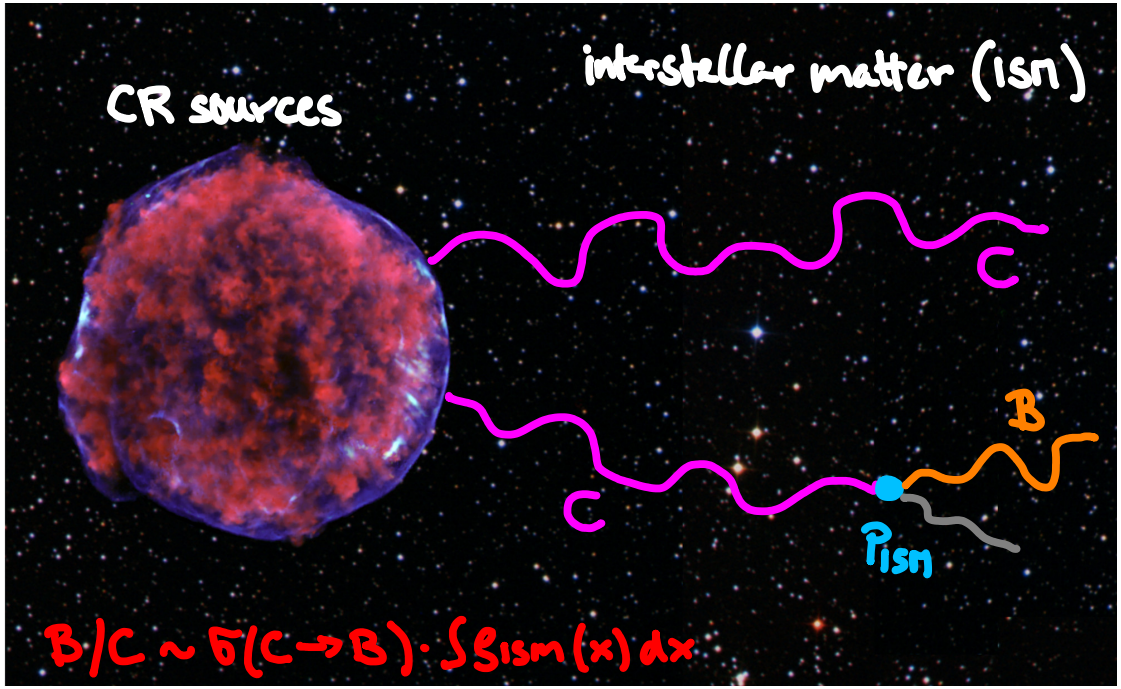
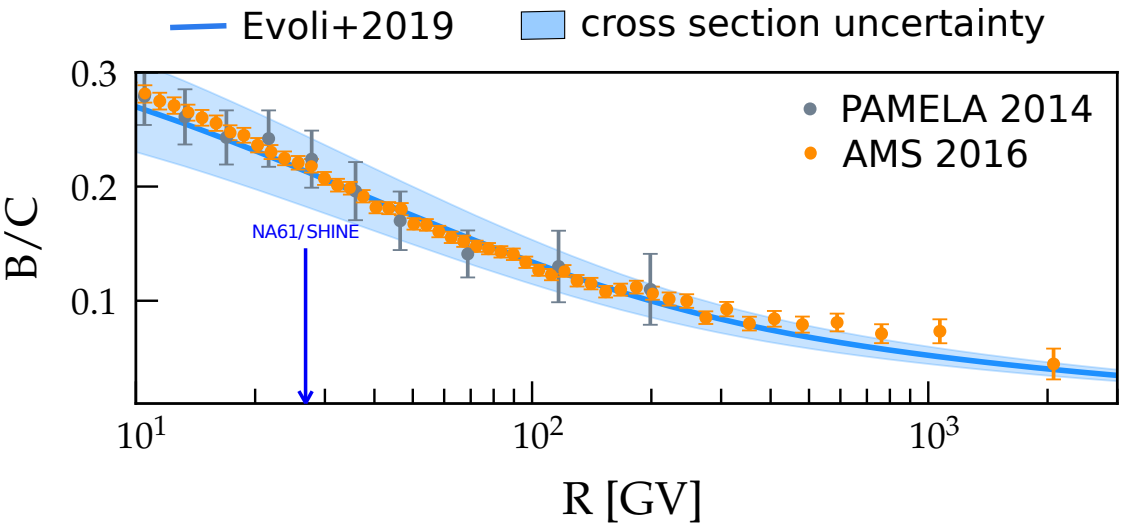
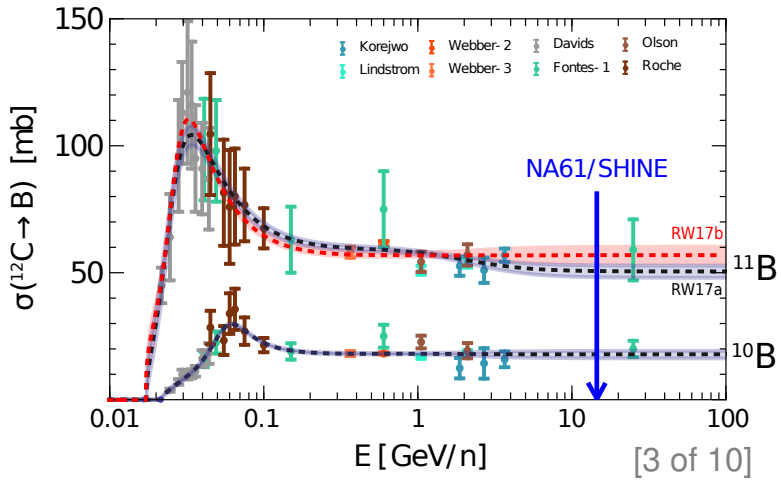
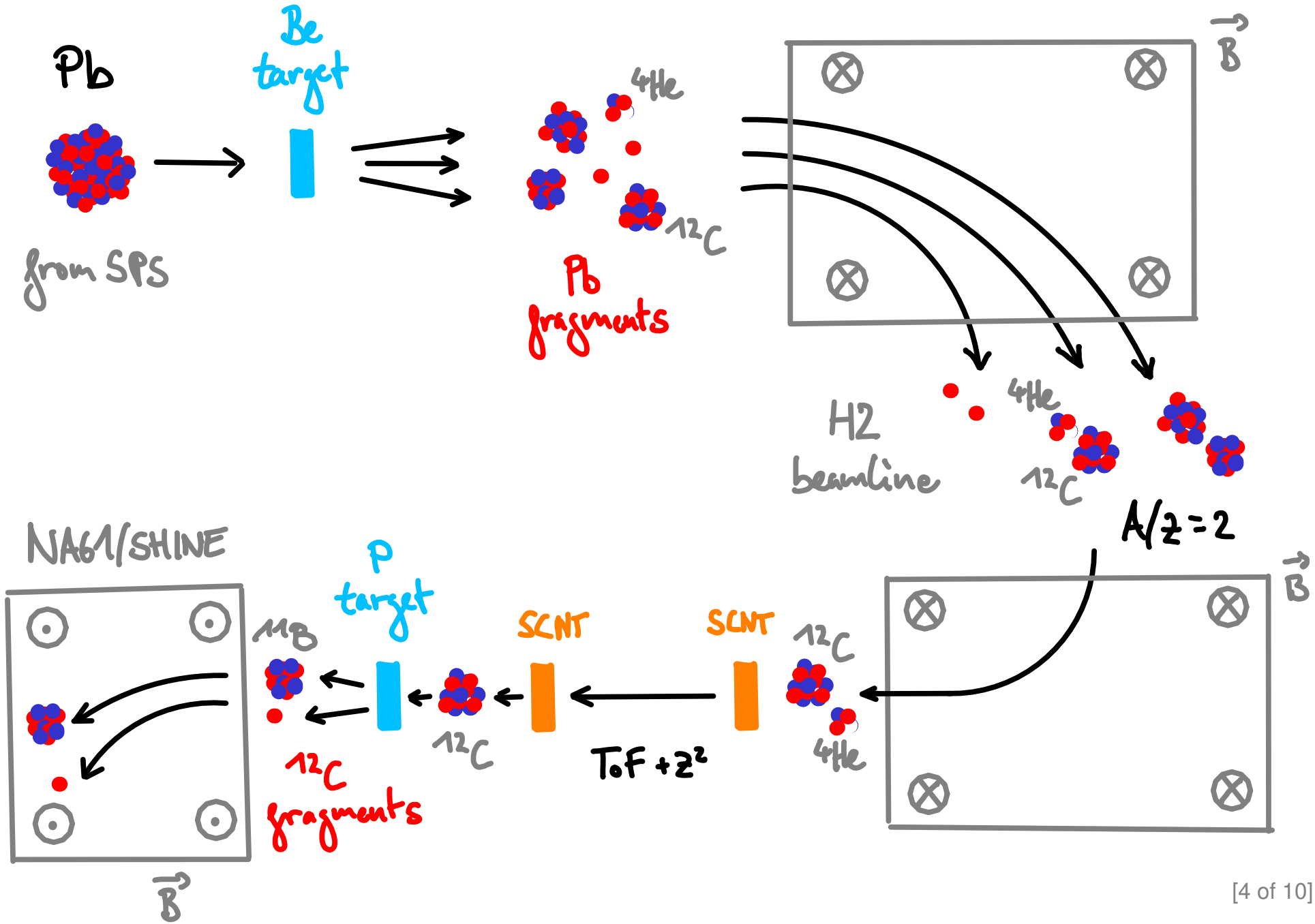




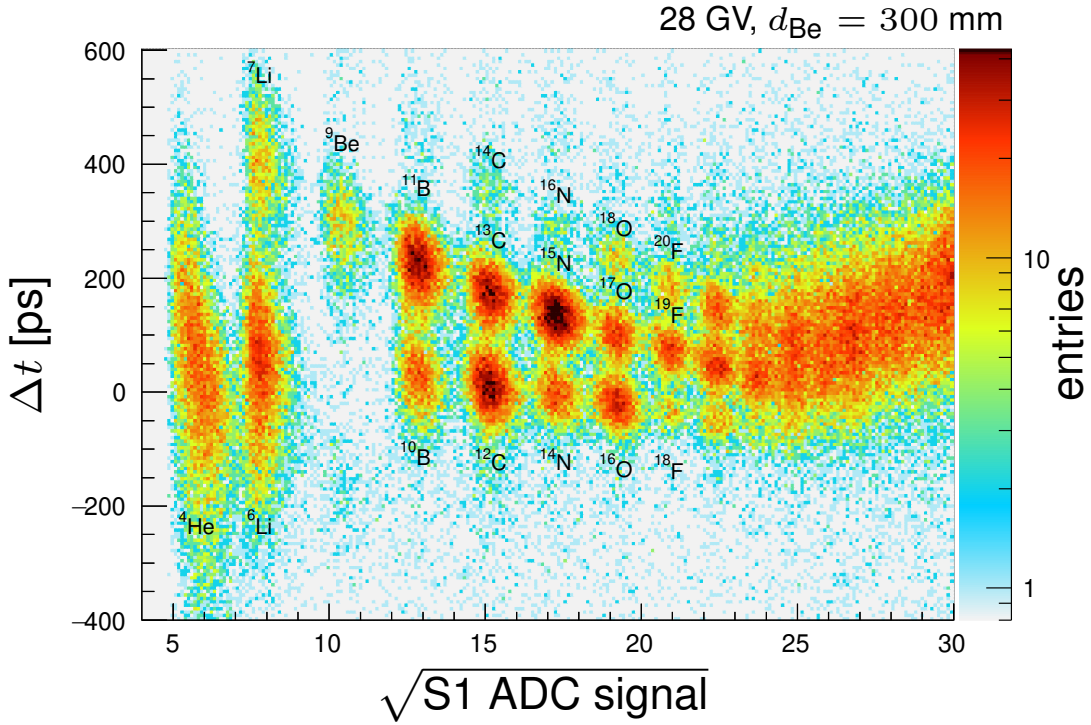


Nuclear Fragmentation with SPS and NA61/SHINE



2018 Pilot Run on Nuclear Fragmentation

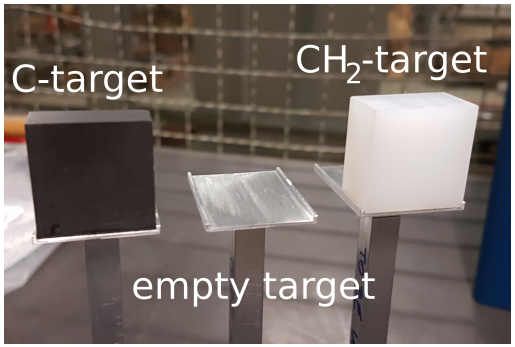
composition of secondary ion beam measured during data taking:



- primary Pb beam on Be target, rigidity selection in H2 beam line
- special H2 beamline optics (simulation and operation by N.Charitonidis)
- three days of data taking at 27 GV
- 1.1 $\times 10^6$ beam trigger on $Z^2 = 36$
- offline selection: 3.6 $\times 10^5$ ^{12}C beam particles
- 20k (^{12}C+CH_2) and 17k (^{12}C+^{12}C) interactions

2018 Pilot Run on Nuclear Fragmentation

"C+p = (C+CH_2) - (C+C) - OUT"

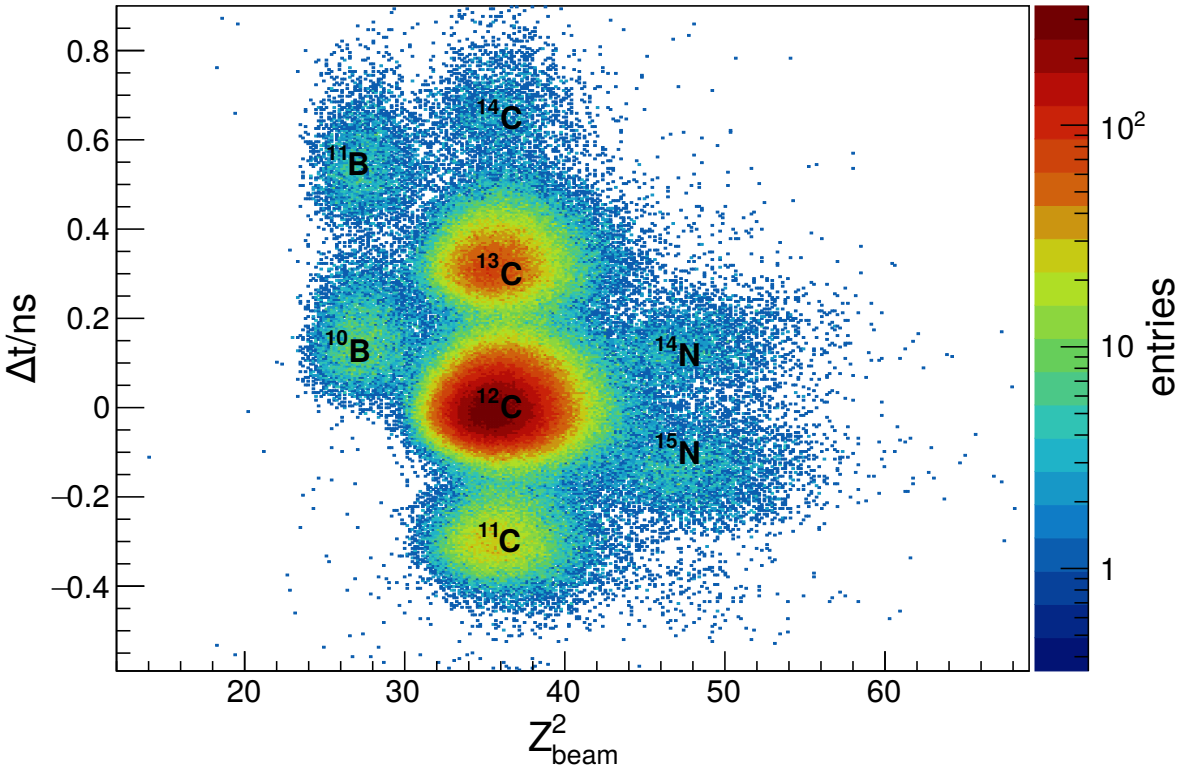


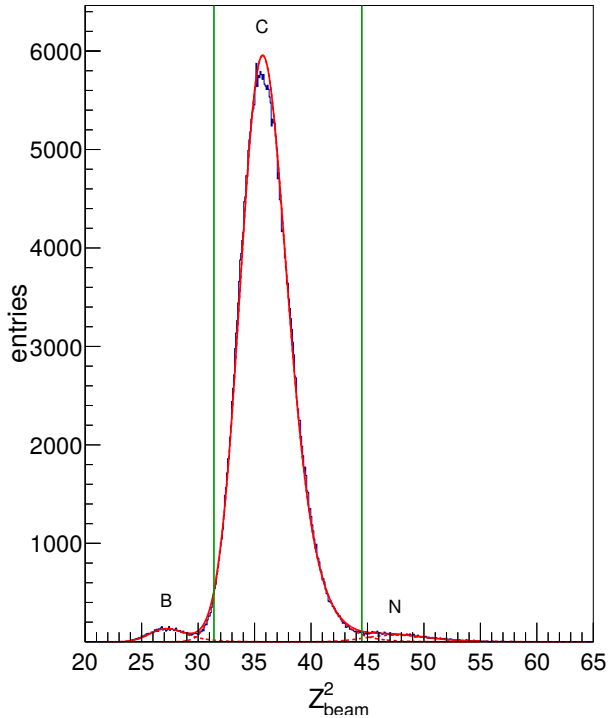
ToF(A to S1) + dE/dx(S1) $\rightarrow$ (A, Z^2)$_{\text{beam}}$

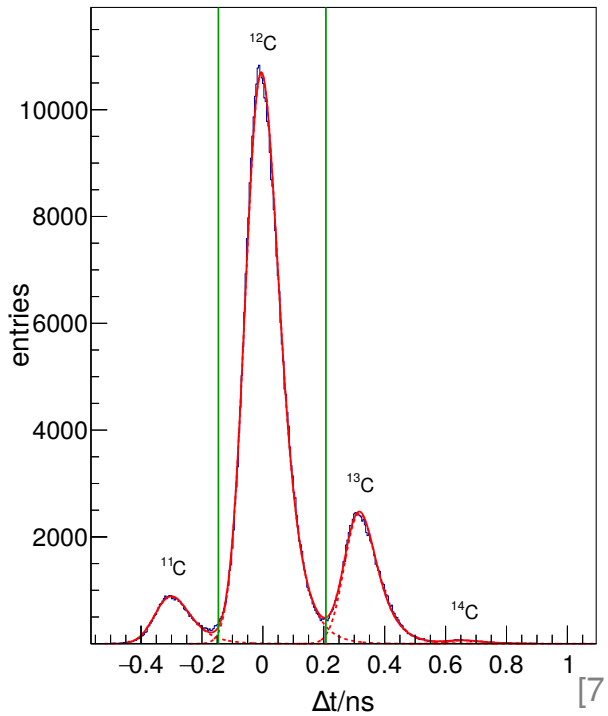
Δ + dE/dx(MTPC) $\rightarrow$ (A, Z^2)$_{\text{fragment}}$

^{12}C Beam Selection

triggered beam composition:



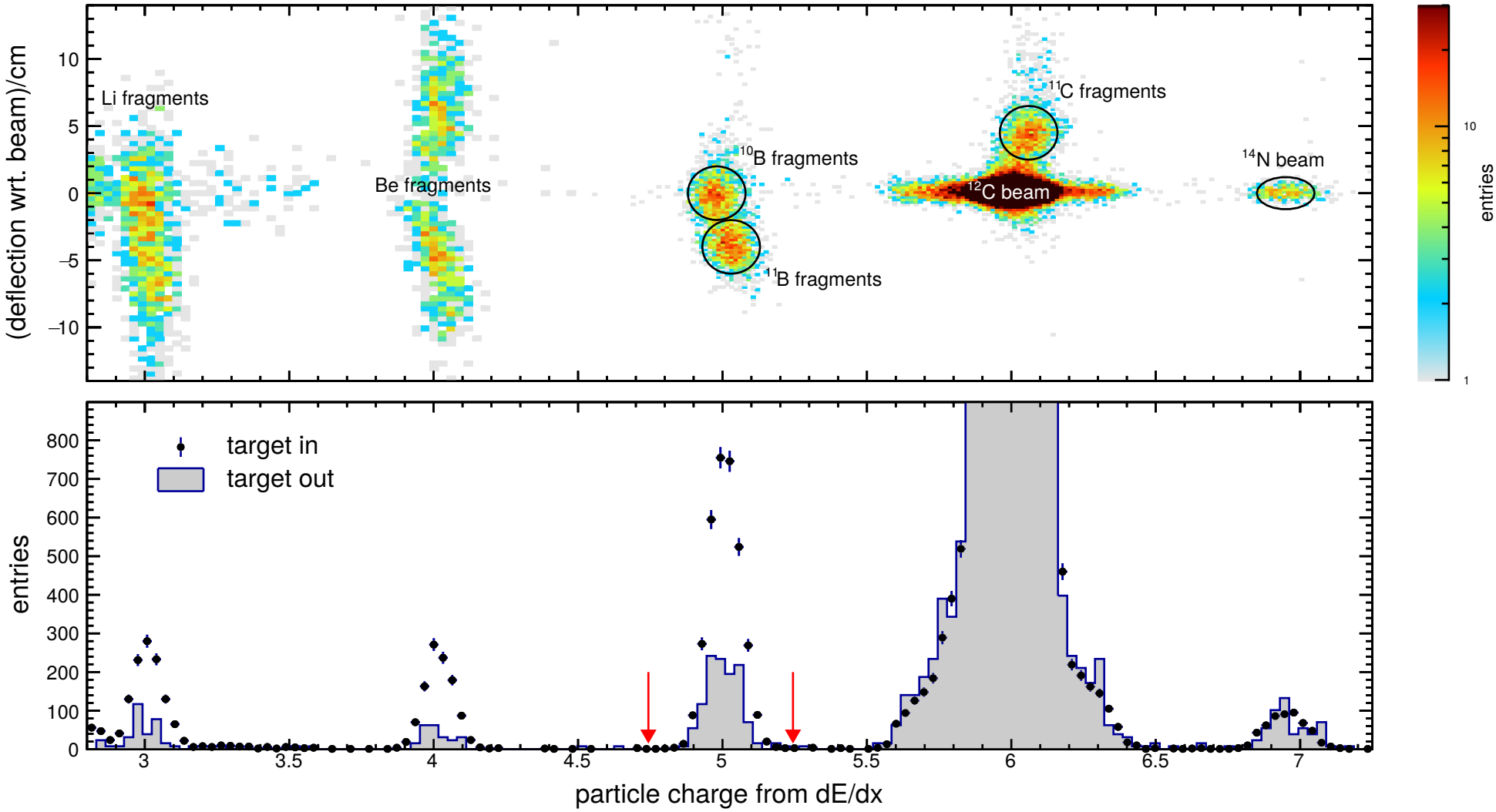




offline beam selection:

- ^{12}C purity: 99.2%
- B contamination: $<$0.1%

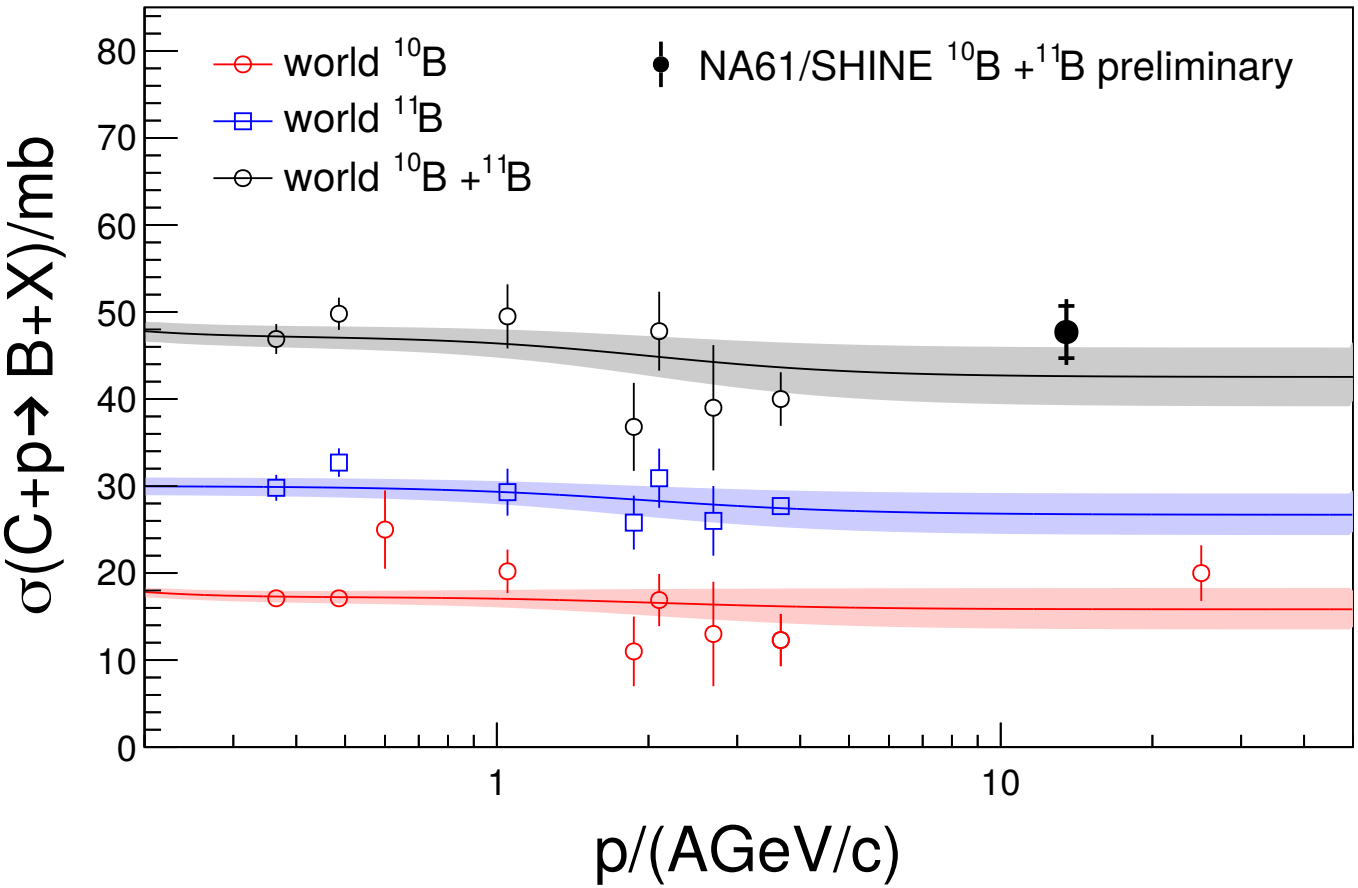
Identification of Isotopes Produced in Target (MTPC)



B-selection indicated by red arrows

Direct ^{10}B + ^{11}B Production (NA61/SHINE preliminary at ICRC19)

$$\sigma(^{12}\mathrm{C} + \mathrm{p} \rightarrow {}^{10}\mathrm{B} + X) + \sigma(^{12}\mathrm{C} + \mathrm{p} \rightarrow {}^{11}\mathrm{B} + \mathrm{X}) =$$
$$47.7 \pm 3.0\ (\mathrm{stat.}) \pm 2.3\ (\mathrm{syst.})\ \mathrm{mb}$$



F. Sutter, Masters Thesis KIT 2019; NA61/SHINE PoS(ICRC2019)446, arXiv:1909.07136

Fit: Evoli+19, Data: Korejwo+02, Korejwo+99, Webber+98, Webber90, Olson+83, Fontes+77

Summary

2018 Pilot Run on Nuclear Fragmentation:

CERN-SPSC-2017-035

Addendum to the NA61/SHINE Proposal SPSC-P-330

Feasibility Study for the Measurement of Nuclear Fragmentation Cross Sections with NA61/SHINE at the CERN SPS

The NA61/SHINE Collaboration

- demonstrated unique capabilities of NA61/SHINE + SPS for nuclear fragmentation measurements
- preliminary results presented at ICRC2019
- test data already useful to constrain asymptotic $\sigma(^{12}\mathrm{C} + \mathrm{p} \rightarrow \mathrm{B} + X)$

Future Plans:

CERN-SPSC-2018-008

Addendum to the NA61/SHINE Proposal SPSC-P-330

Study of Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS
Early Post-LS2 Measurements and Future Plans

The NA61/SHINE Collaboration and the CERN team

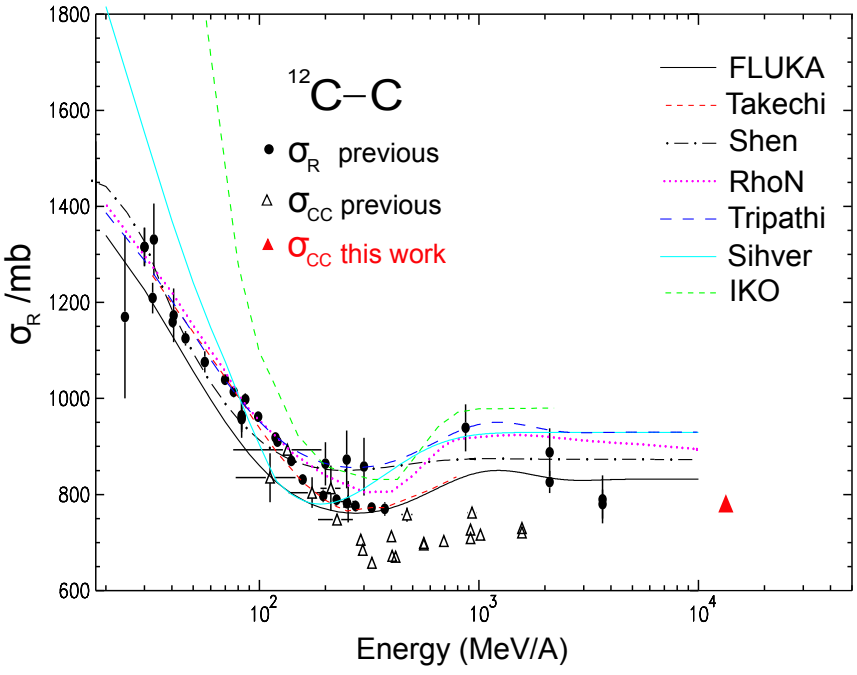
- precise reaction data base for Galactic cosmic-ray studies

Many thanks to the CERN PH, BE and EN Departments for the strong support of NA61/SHINE!

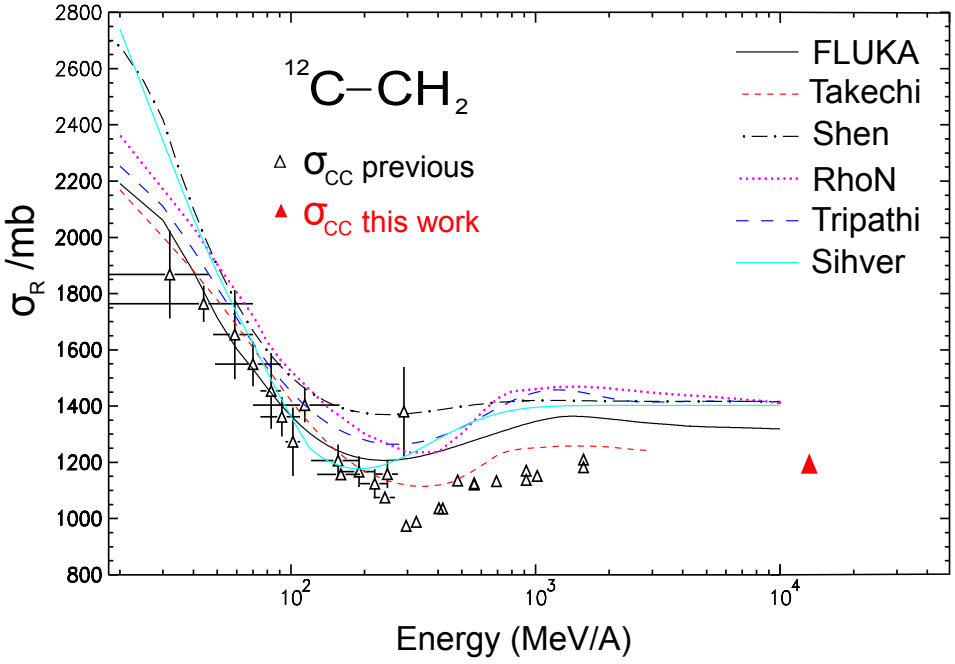
Additional Material

Charge-Changing C+C and C+CH_2 Cross Section

$^{12}C+^{12}C \rightarrow (Z<6) + X$



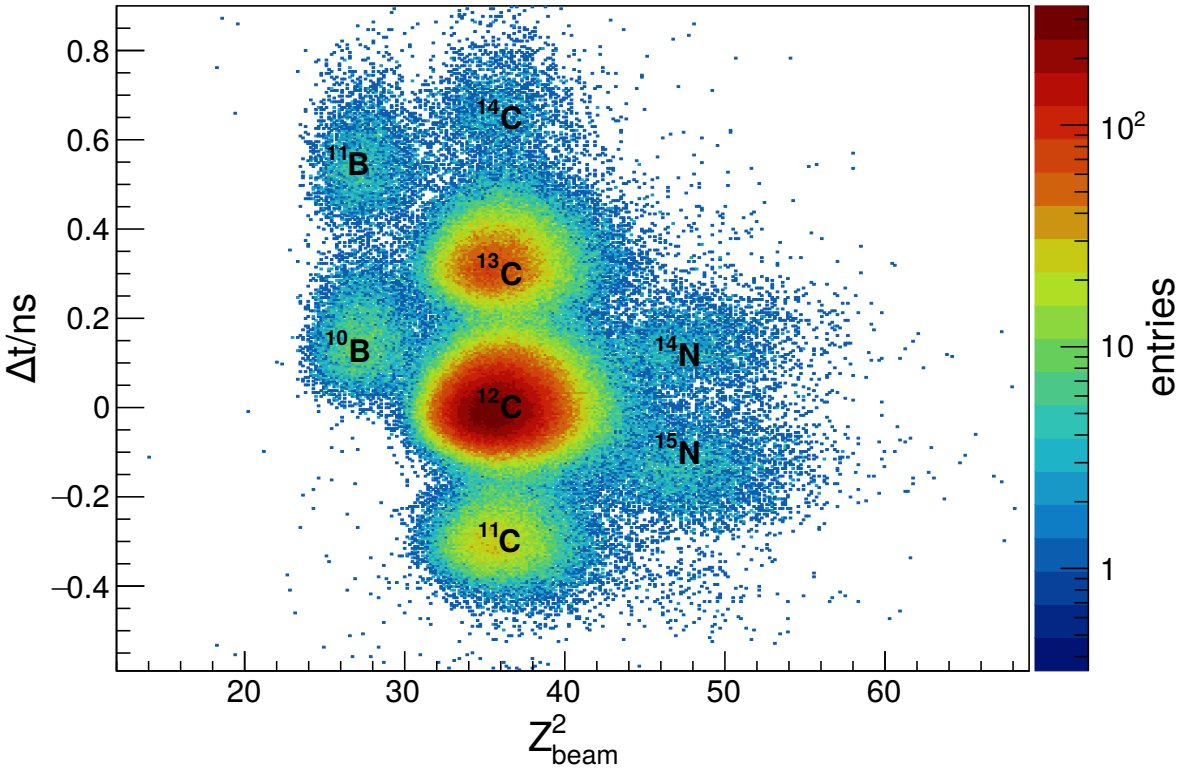
$^{12}C+CH_2 \rightarrow (Z<6) + X$

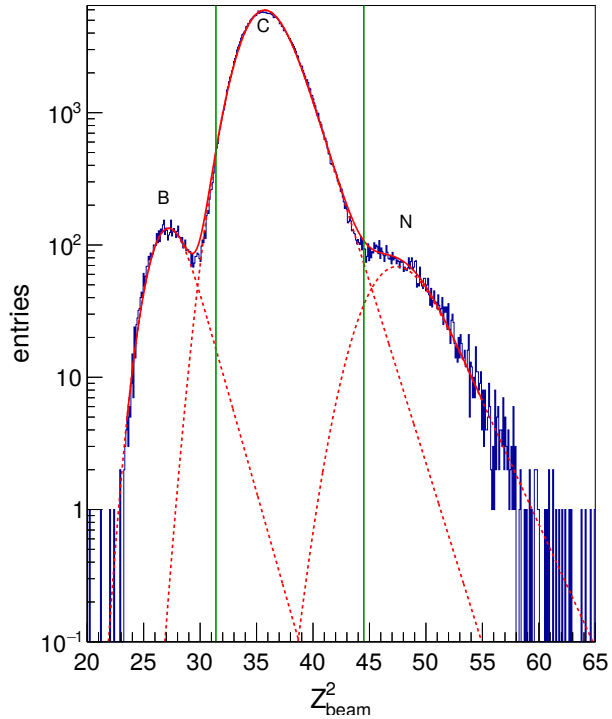


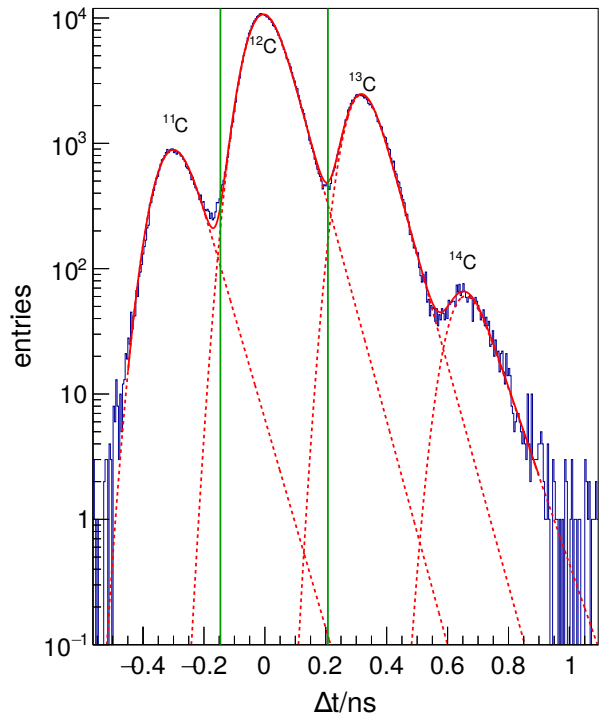
adapted from L. Shiver et al, Adv. Space Research **49** (2012) 812

Reaction	σ [mb]	stat. [mb]	sys. [mb]
$C + CH_2 \rightarrow (Z < 6) + X$	1179	± 24	± 1
$C + C \rightarrow (Z < 6) + X$	755	± 16	± 3
$C + p \rightarrow (Z < 6) + X$	217	± 9	± 2

Upstream ^{12}C Selection (logarithmic sc







fractional impurity $f(i) = N_i/N_{\text{tot}}$ of selected beam:

$f(^{11}\text{C}) = 0.0035$ $\quad$ $f(\text{N}) = 0.0016$

$f(^{13}\text{C}) = 0.0018$ $\quad$ $f(\text{B}) = 0.0007$

$f(^{14}\text{C}) = 0.0000$

$f(\text{tot}) = 0.0076$

Corrections and Systematics

Corrections (B)

• beam impurity	$\leq$ 0.01 mb[1]
• B reinteraction in target	+1.4 mb[1,2]
• B reinteraction in detector	+3.9 mb[1]
• MTPC B cut	+0.08 mb[1]
• ^{12}C interaction in detector	-0.2 mb[1]

[1] from data, [2] model

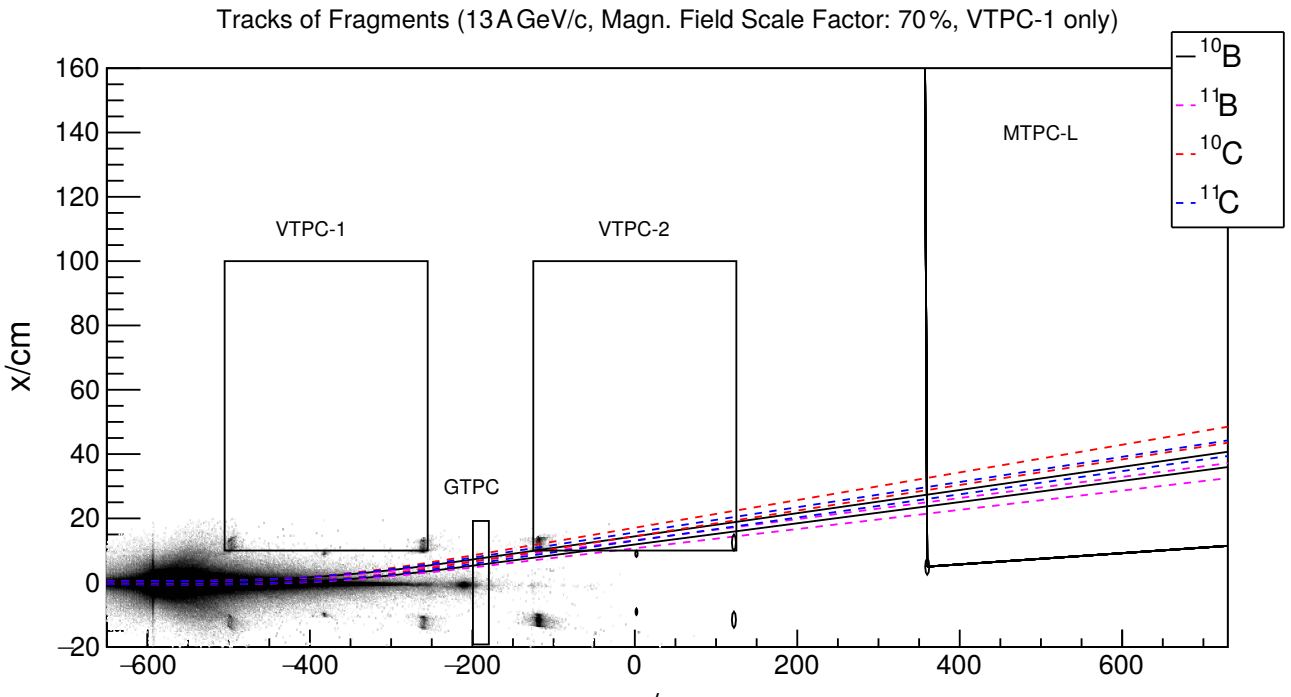
Systematics (B)

• target thickness	0.2 mb
• beam impurity	0.01 mb
• B reinteraction in target	0.3 mb
• B reinteraction in detector	1.4 mb
• MTPC B cut	0.08 mb
• ^{11}B/^{10}B reinter difference	0.03 mb
• underdetermined measurement equation	1.8 mb

Measured Interaction Probabilities

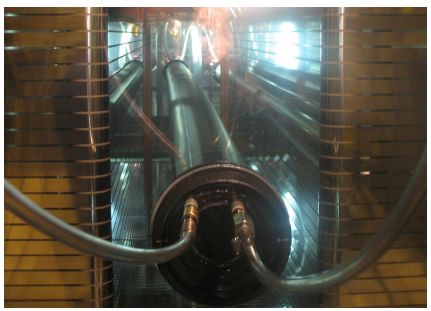
Target	N_{beam}	$N_{^{12}C}$	N_B	$P_{C\to(Z<6)}$	$P_{C\to B}$
CH_2	171399	151871	2259	0.1139 ± 0.0008	0.0132 ± 0.0003
C	147692	131172	1530	0.1119 ± 0.0008	0.0104 ± 0.0003
OUT	37926	36111	174	0.0479 ± 0.0011	0.0046 ± 0.0004

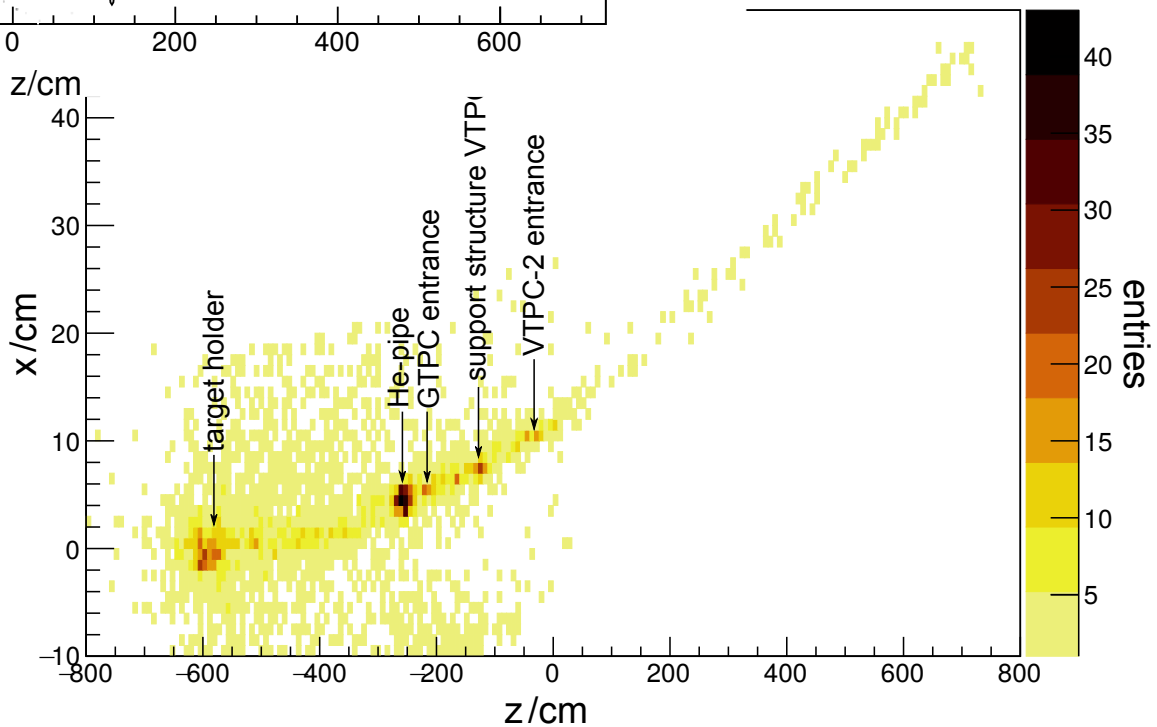
Interactions in Detector Volume



← **Run Settings**

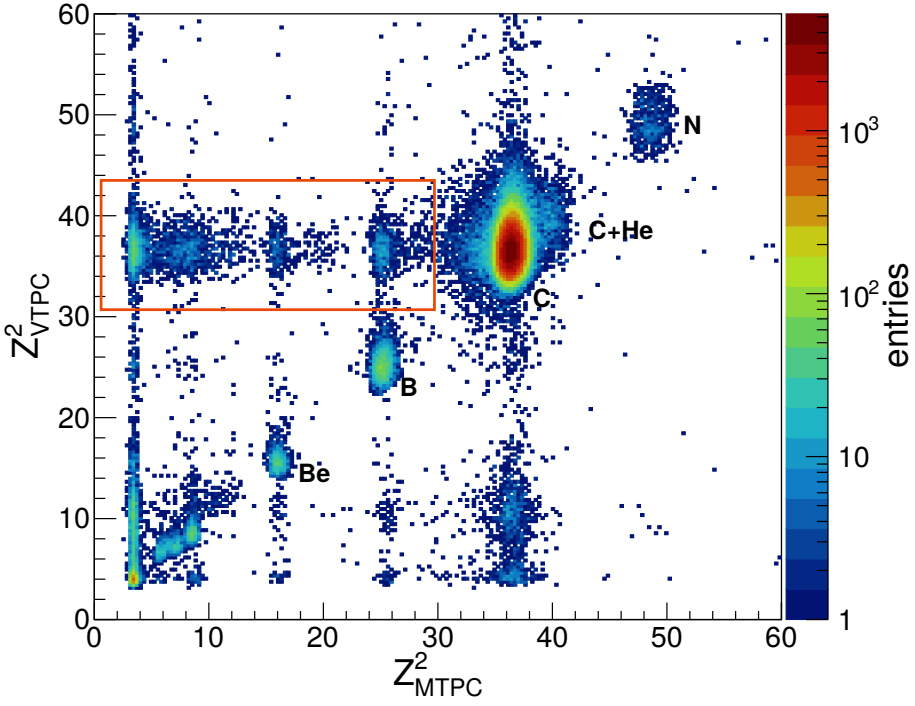
2018 V0 Vertices →

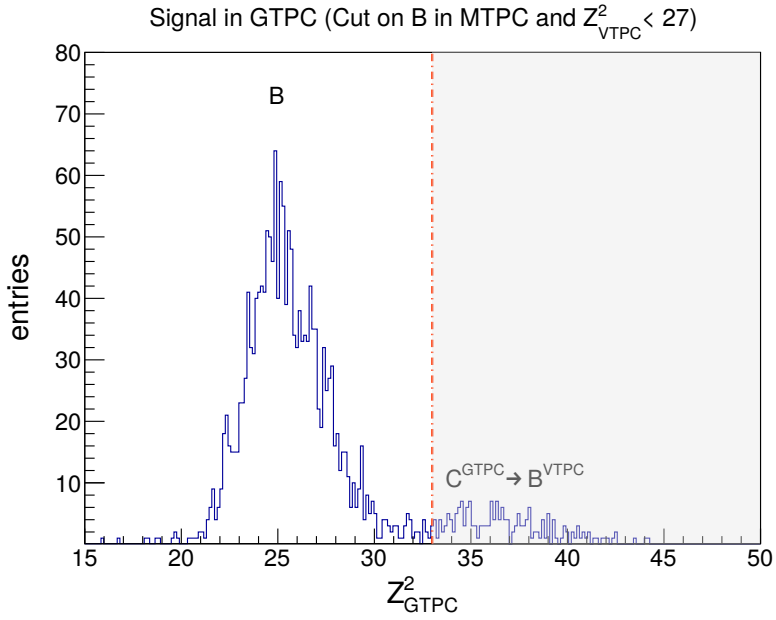


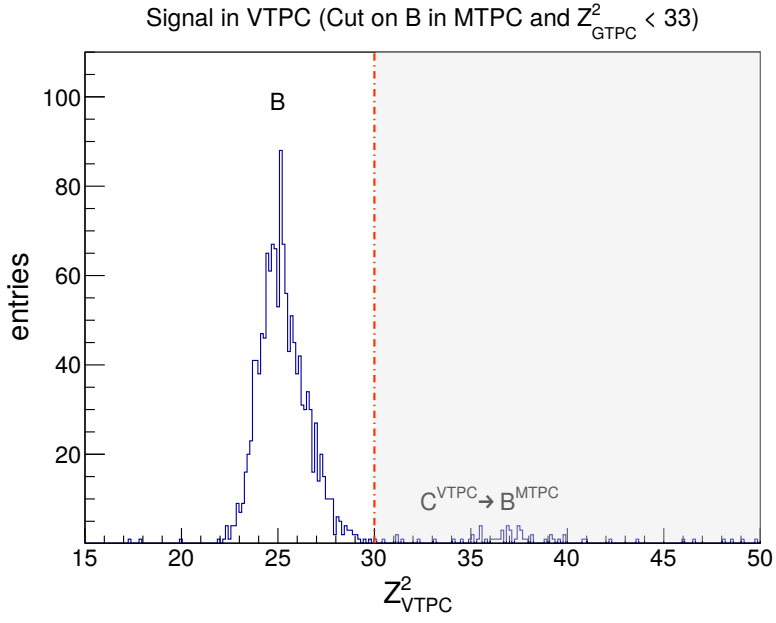


Interactions in Detector Volume

Cut on G/VTPC dE/dx:







$\Rightarrow P_{OUT}(C \rightarrow B) = 0.8\% \rightarrow 0.5\%$