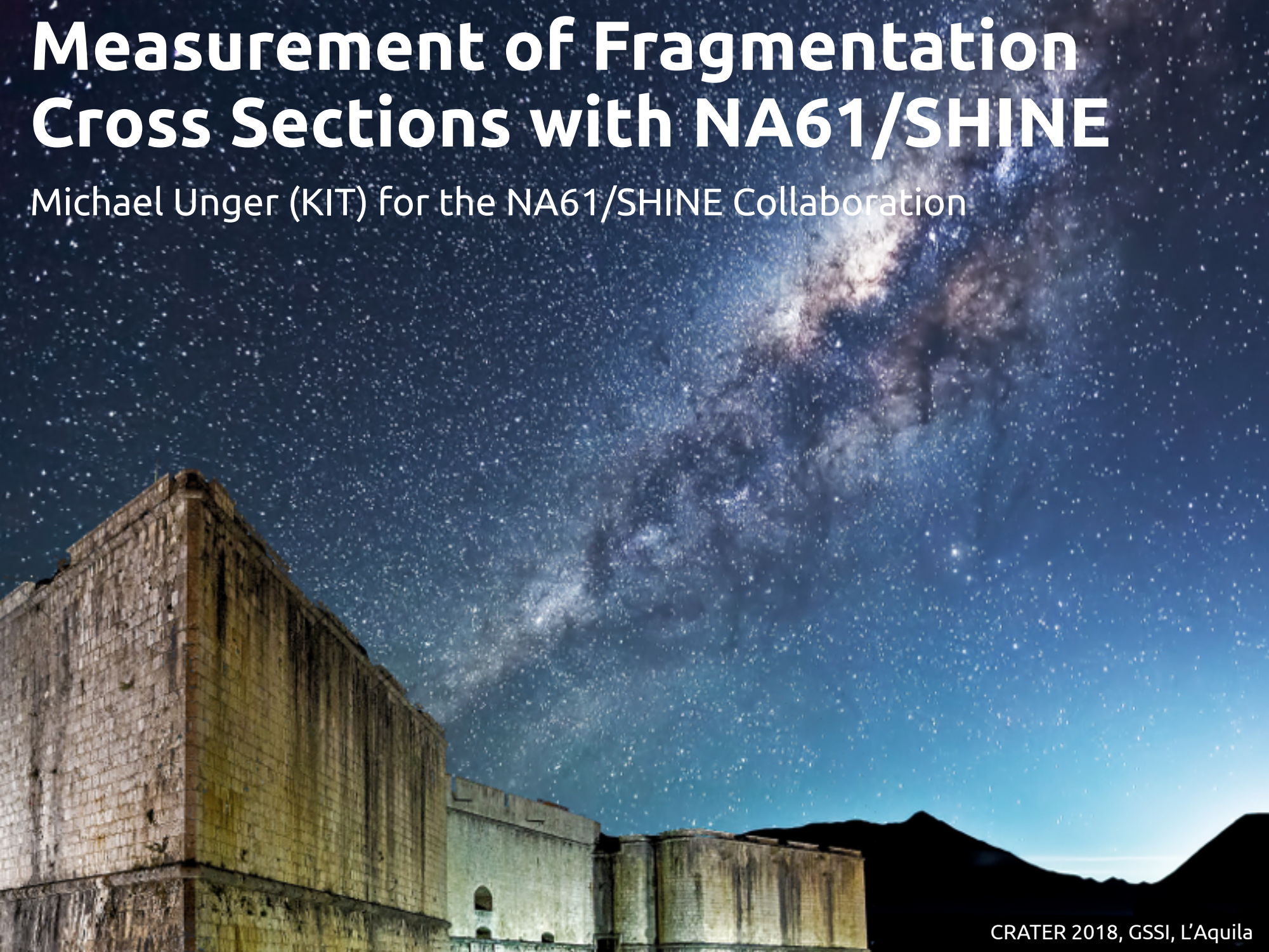
Measurement of Fragmentation Cross Sections with NA61/SHINE

Michael Unger (KIT) for the NA61/SHINE Collaboration



CRATER 2018, GSSI, L'Aquila

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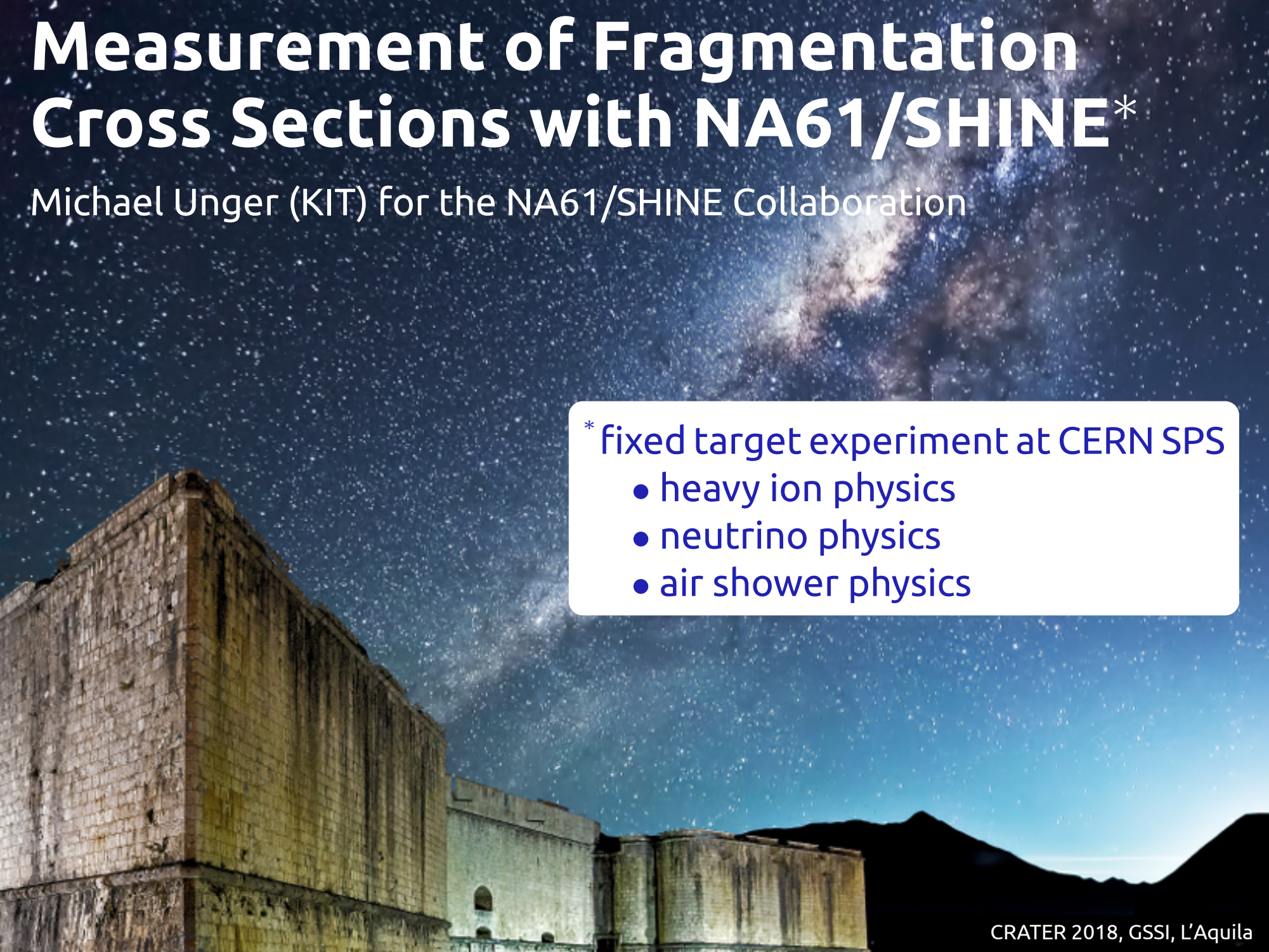


* fixed target experiment at CERN SPS
  - heavy ion physics
  - neutrino physics
  - air shower physics

CRATER 2018, GSSI, L'Aquila

XSCRC2017: Cross sections for Cosmic Rays @ CERN

29 Mar 2017, 14:00 → 31 Mar 2017, 19:00 Europe/Zurich

503-1-001 - Council Chamber (CERN)

Description New space borne experiments are ushering us into the era of precision direct measurements in cosmic ray physics. However, a poor knowledge of several particle physics and nuclear physics inputs - such as antiproton production or spallation cross sections - can seriously limit the relevant astroparticle physics information that can actually be extracted from these data, for instance for Galactic propagation parameters or indirect dark matter searches. The goal of the workshop, bringing together different communities, is to review theoretical motivations for the measurements of key processes, current galactic models and recent advances in cosmic ray observations that crucially depend on some of these inputs. The workshop also strongly aims at presenting current efforts and discussing forthcoming perspectives for particle/nuclear measurement campaigns.

Duration: The workshop will start Wednesday, March 29 in the late morning, and will end Friday, March 31 at about 4pm.

Organizing Committee: Bruna Bertucci (Perugia University), Fiorenza Donato (Torino University, chair), Gian Giudice (CERN), Giovanni Passaleva (INFN, Florence), Pasquale D. Serpico (LAPTH, Annecy, co-chair)

Current status and desired accuracy of the isotopic production cross sections relevant to astrophysics of cosmic rays I. Li, Be, B, C, N

Yoann Génolini
Service de Physique Théorique, Université Libre de Bruxelles, Belgium

David Maurin
LPSC, Université Grenoble-Alpes, CNRS/IN2P3, France

Igor V. Moskalenko
HEPL and KIPAC, Stanford University, USA

Michael Unger
IKP. Karlsruhe Institute of Technology. Germany

submitted to PRC, arXiv:1803.04686

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

CERN-SPSC-2017-035

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

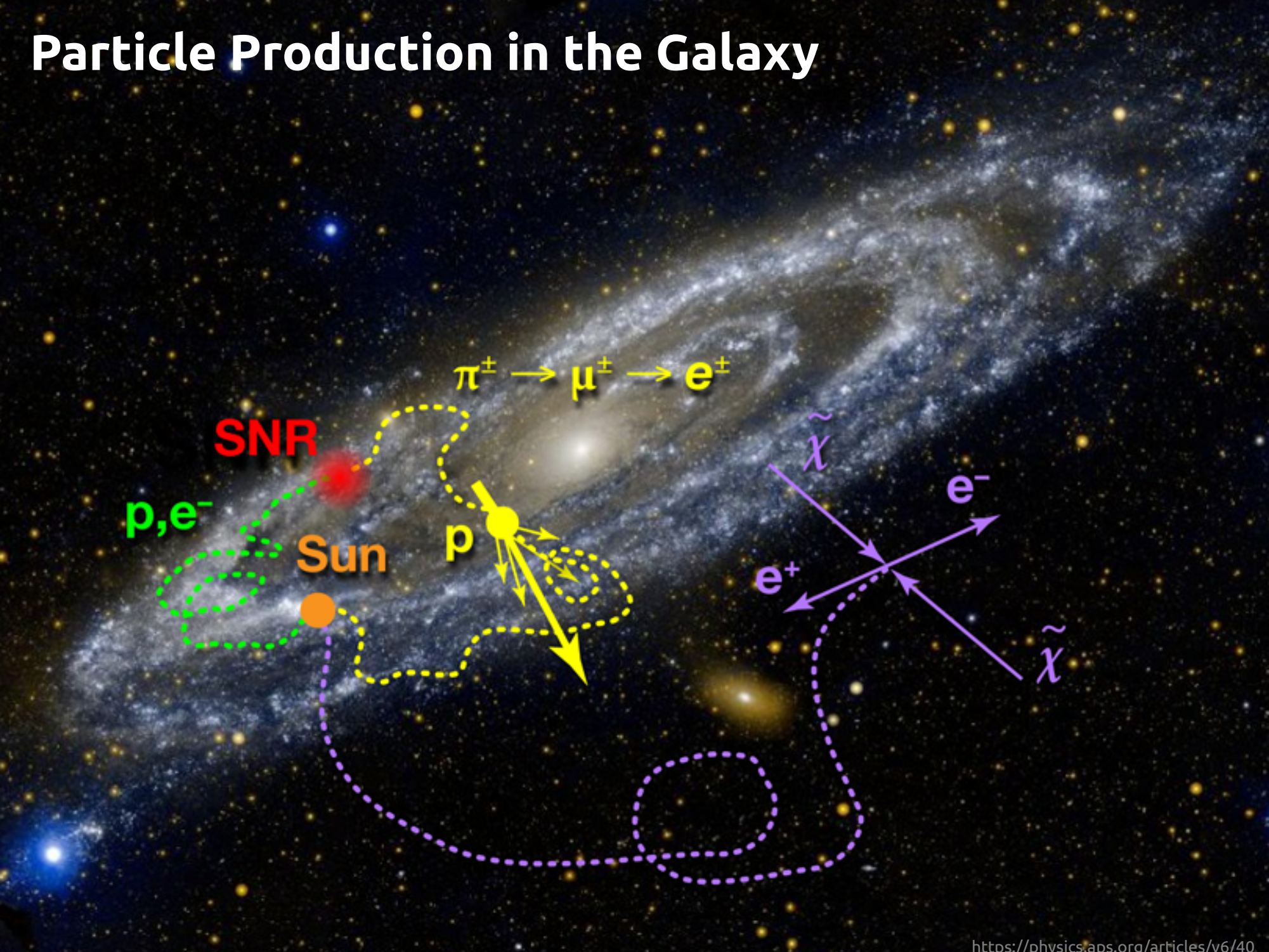
Study of Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS

Early Post-LS2 Measurements and Future Plans

The NA61/SHINE Collaboration and the CERN team

CERN-SPSC-2018-008

Particle Production in the Galaxy



https://physics.aps.org/articles/v6/40

Particle Production in the Galaxy

- CR-grammage X ("target thickness") from secondary nuclei, e.g.

$$(\mathrm{B/C}) \sim \frac{\left(1 - e^{-X/\lambda_{\mathrm{prod}}}\right) e^{-X/\lambda_B}}{e^{-X/\lambda_{\mathrm{prod}}}}.$$

$$\lambda_{\mathrm{prod}} = \frac{m_p}{\sigma_{\mathrm{prod}}} = m_p \left(\frac{\sum \Psi_i \times \sigma(i + p \to B)}{\sum \Psi_i} \right)^{-1}, \qquad i = \mathrm{C, N, O, \ldots}$$

- $X \ll \lambda_{XB}$ and $X \ll \lambda_B$

$$X \sim (\mathrm{B/C}) \frac{m_p}{\sigma_{\mathrm{prod}}}$$

- prediction for e.g. anti-protons ($X \ll \lambda_{p\bar{p}}$):

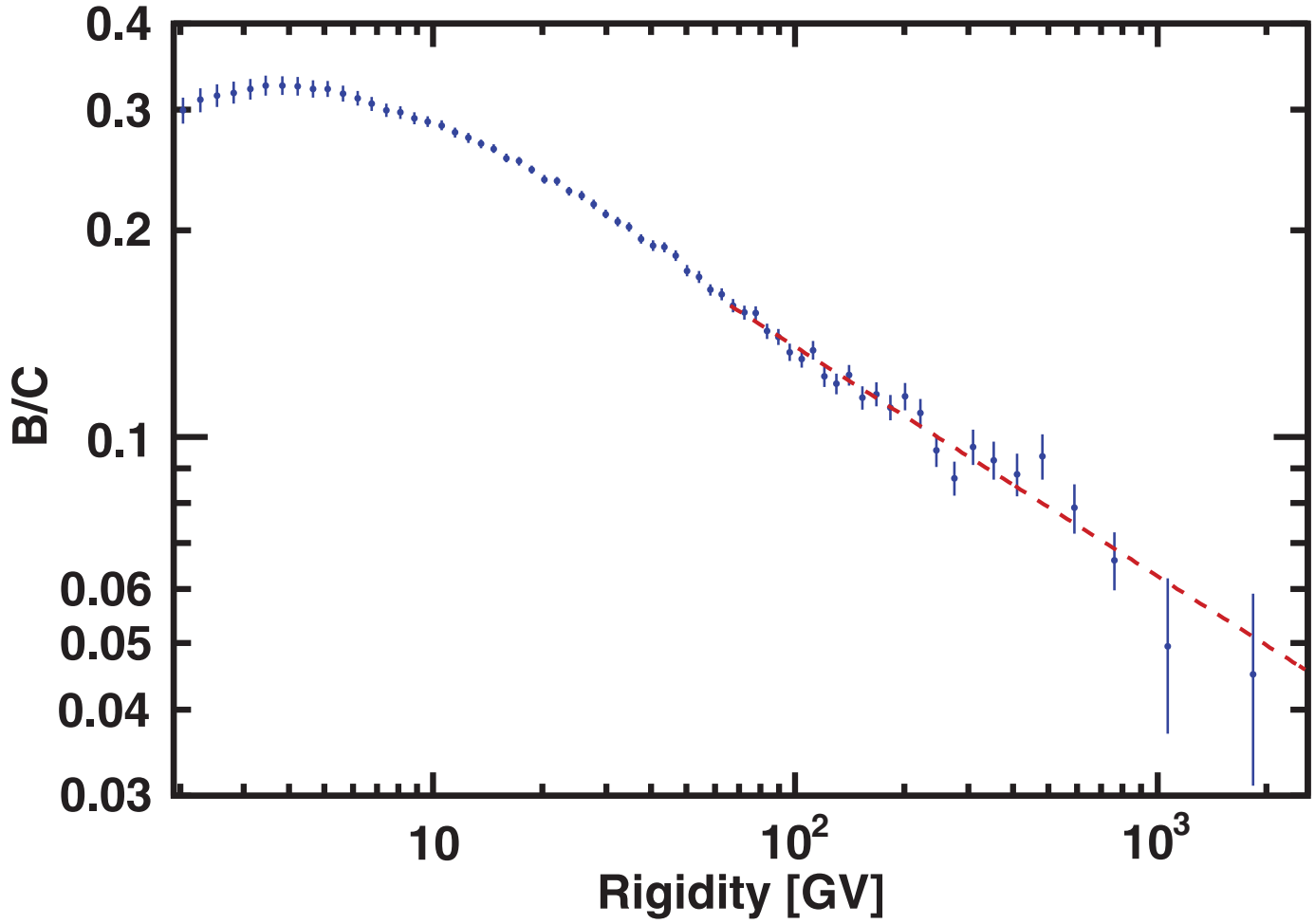
$$(\bar{p}/p) \sim X/\lambda_{p\bar{p}} = (\mathrm{B/C}) \frac{\sigma_{p\bar{p}}}{\sigma_{\mathrm{prod}}}$$

- relative uncertainty $\delta_X = \delta(X)/X$

$$\delta^2_{\bar{p}/p} \sim \delta^2_{(\mathrm{B/C})} + \delta^2_{\sigma_{p\bar{p}}} + \delta^2_{\sigma_{prod}}$$

$(\bar{p}/p)$ Uncertainty

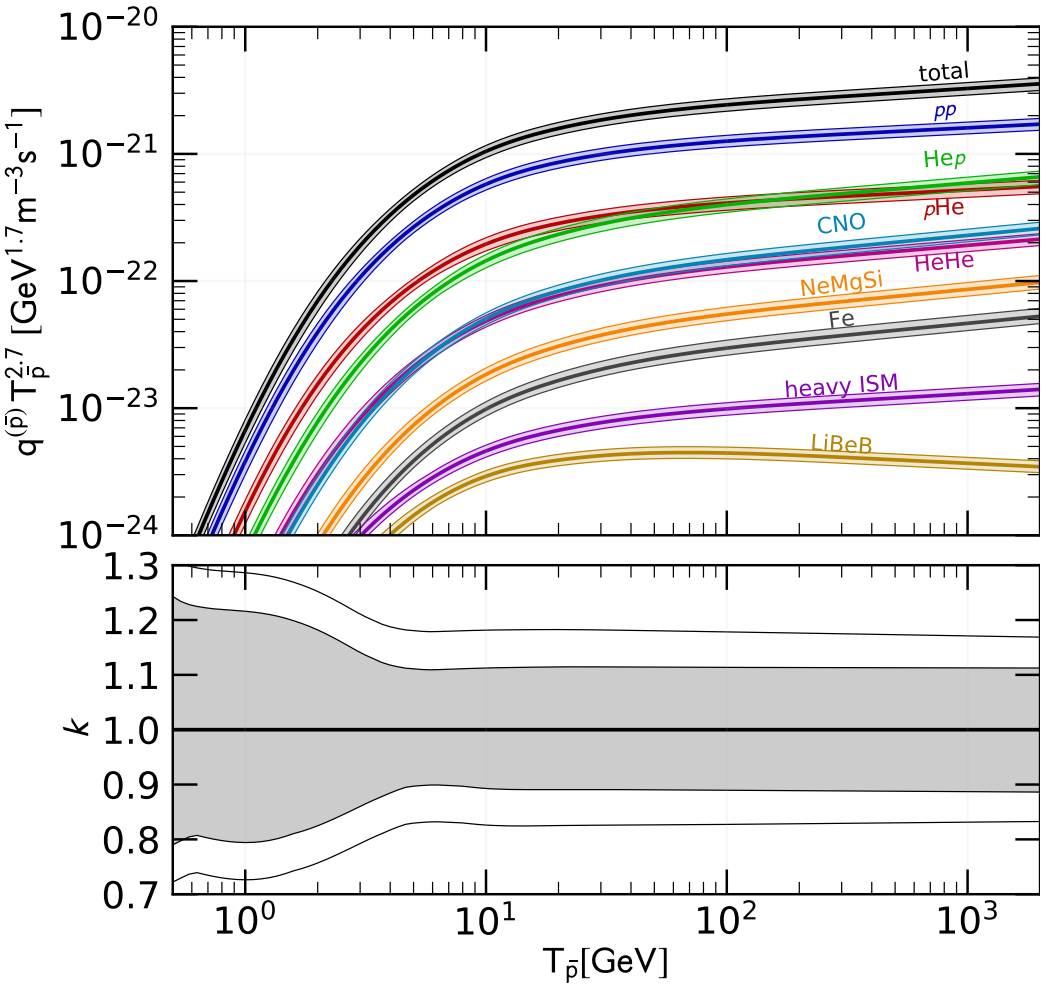
$$\delta^2_{\bar{p}/p} \sim \delta^2_{(B/C)} + \delta^2_{\sigma_{p\bar{p}}} + \delta^2_{\sigma_{prod}}$$
$$\sim 0.03^2$$



AMS, PRL 2016

$(\bar{p}/p)$ Uncertainty

$$\delta^2_{\bar{p}/p} \sim \delta^2_{(B/C)} + \delta^2_{\sigma_{p\bar{p}}} + \delta^2_{\sigma_{prod}}$$
$$\sim 0.03^2 + 0.2^2$$

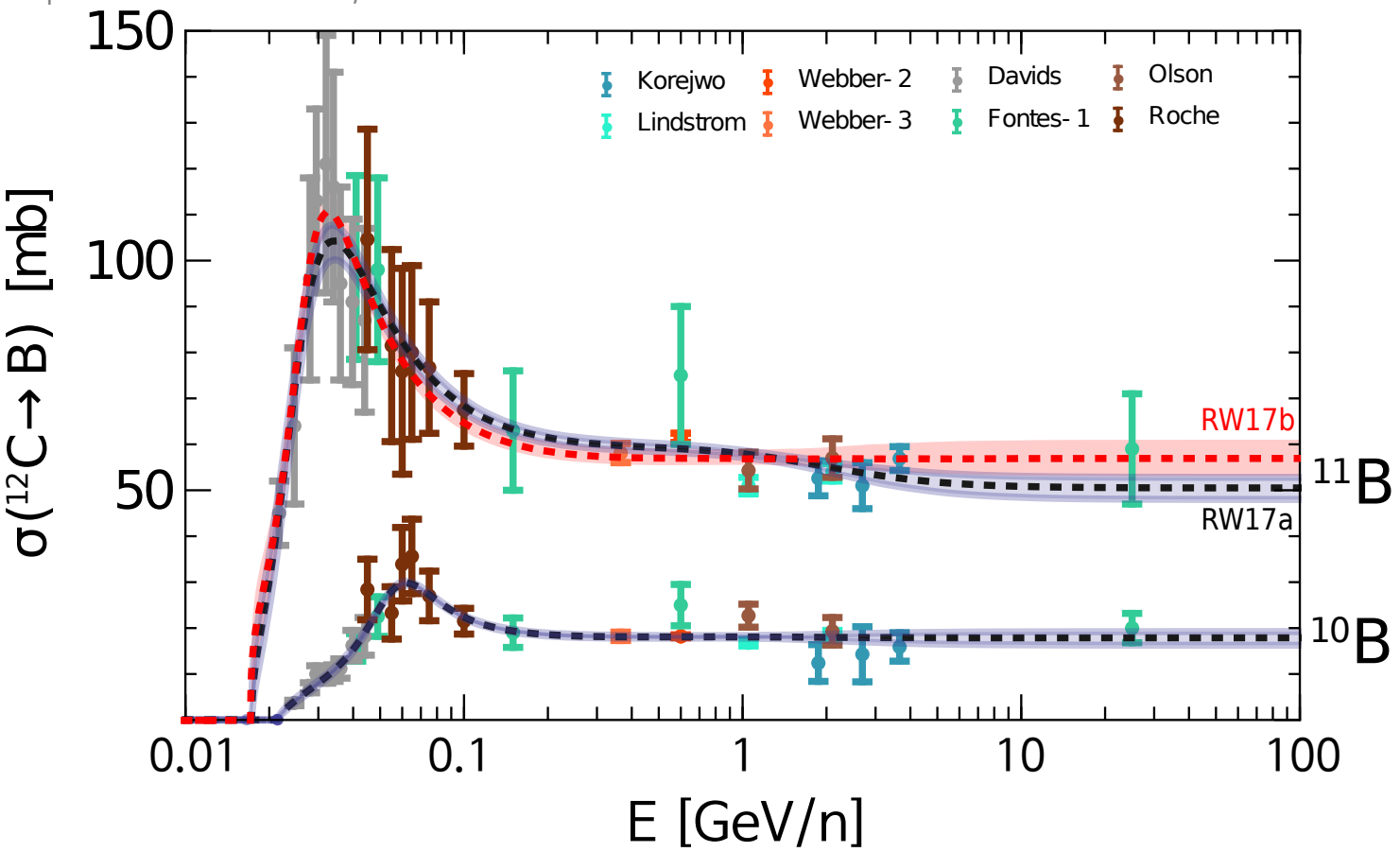


Korsmeier+, arXiv:1802.03030

$(\bar{p}/p)$ Uncertainty

$$\delta^2_{\bar{p}/p} \sim \delta^2_{(B/C)} + \delta^2_{\sigma_{p\bar{p}}} + \delta^2_{\sigma_{prod}}$$
$$\sim 0.03^2 + 0.2^2 + 0.2^2 = 0.28^2$$

adapted from Reinert&Winkler, arXiv:1712.00002



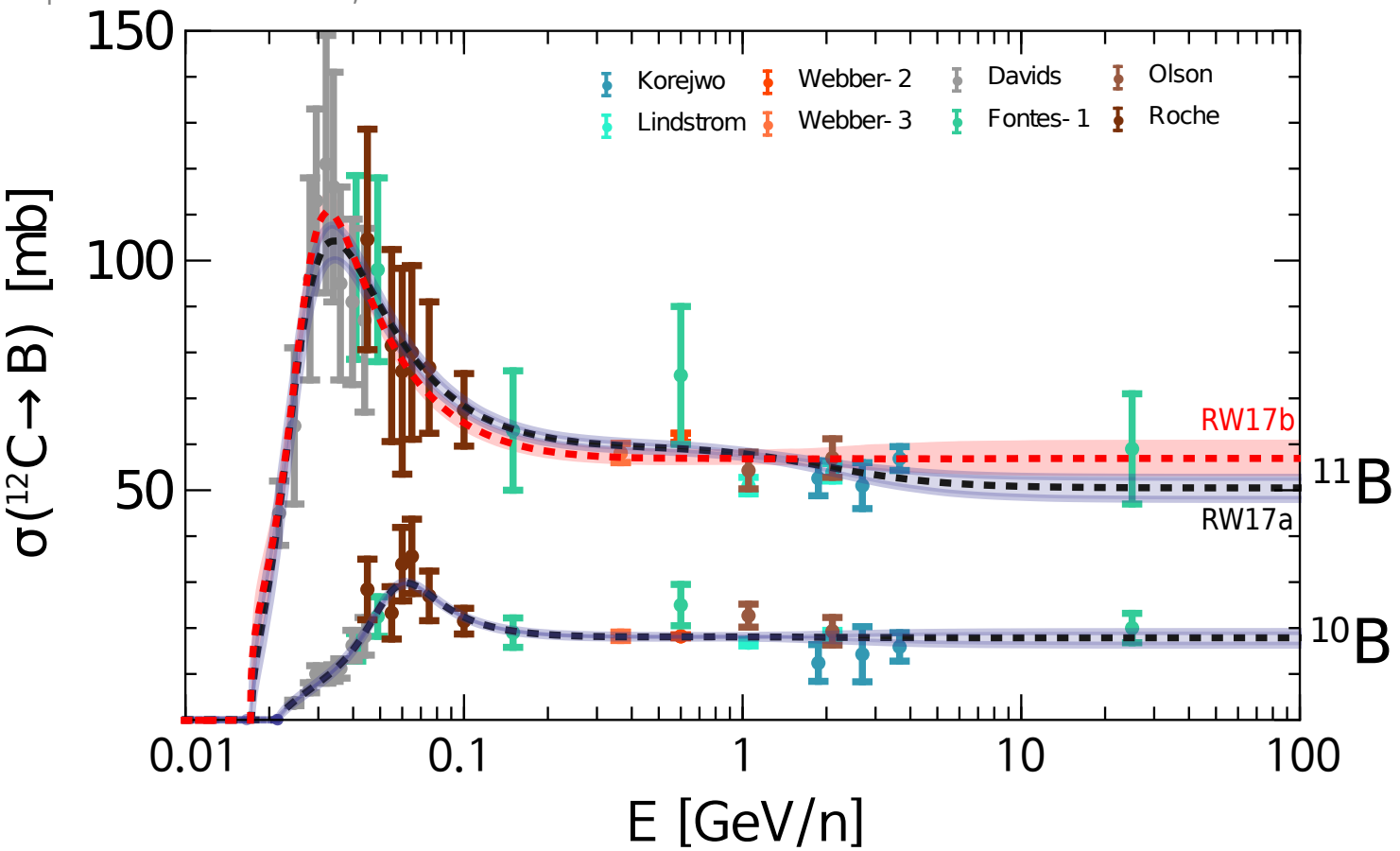
asymptotic ^{12}C→B cross section:

(68.6 ± 2.6) mb (RW17a), (75.8 ± 4.2) mb (RW17b), 61.0 mb (WSKR03)

$(\bar{p}/p)$ Uncertainty → dominated by cross section uncertainties!

$$\delta^2_{\bar{p}/p} \sim \delta^2_{(B/C)} + \delta^2_{\sigma_{p\bar{p}}} + \delta^2_{\sigma_{prod}}$$
$$\sim 0.03^2 + 0.2^2 + 0.2^2 = 0.28^2$$

adapted from Reinert&Winkler, arXiv:1712.00002

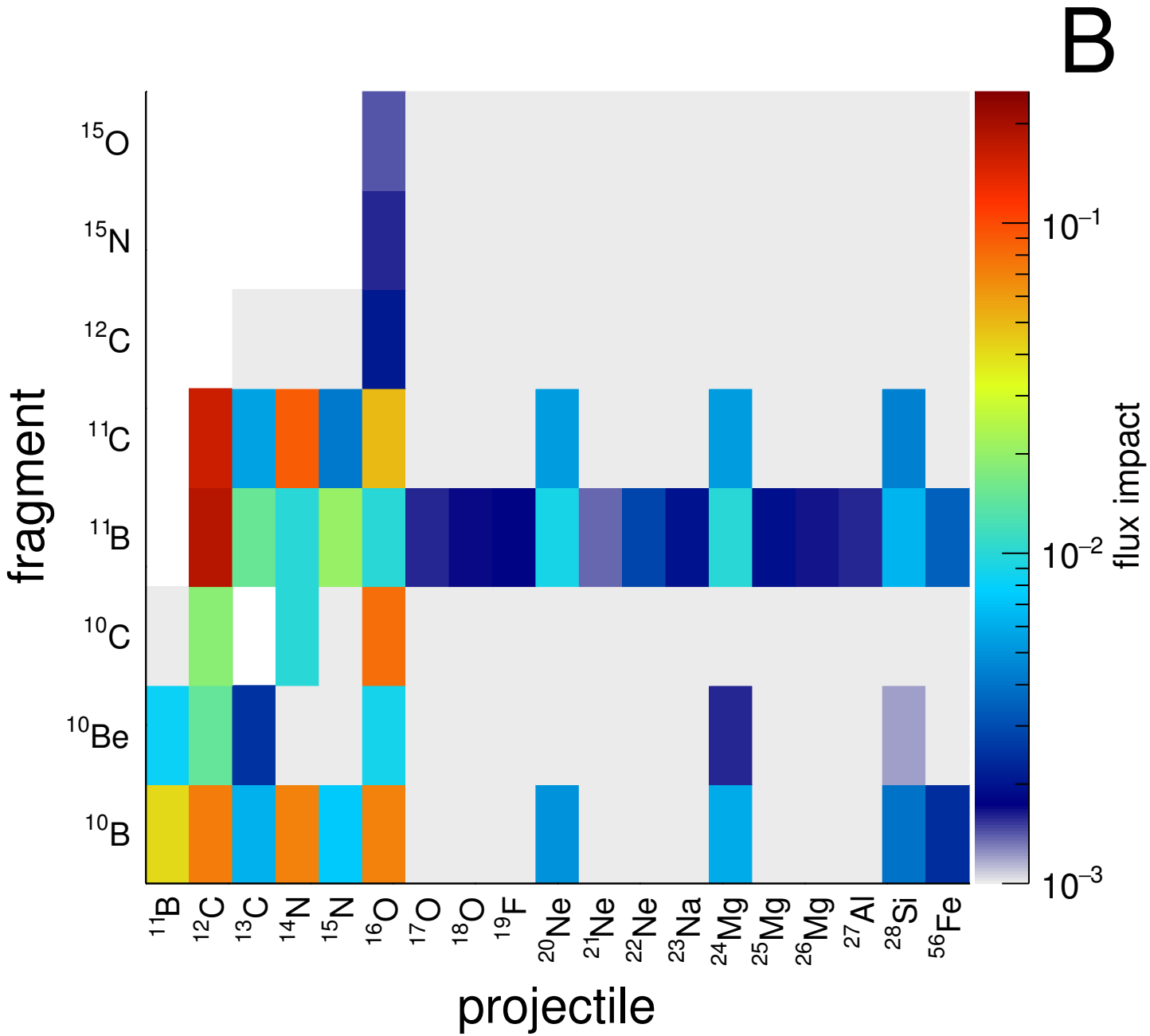


asymptotic ^{12}C→B cross section:

(68.6 ± 2.6) mb (RW17a), (75.8 ± 4.2) mb (RW17b), 61.0 mb (WSKR03)

Flux Impact

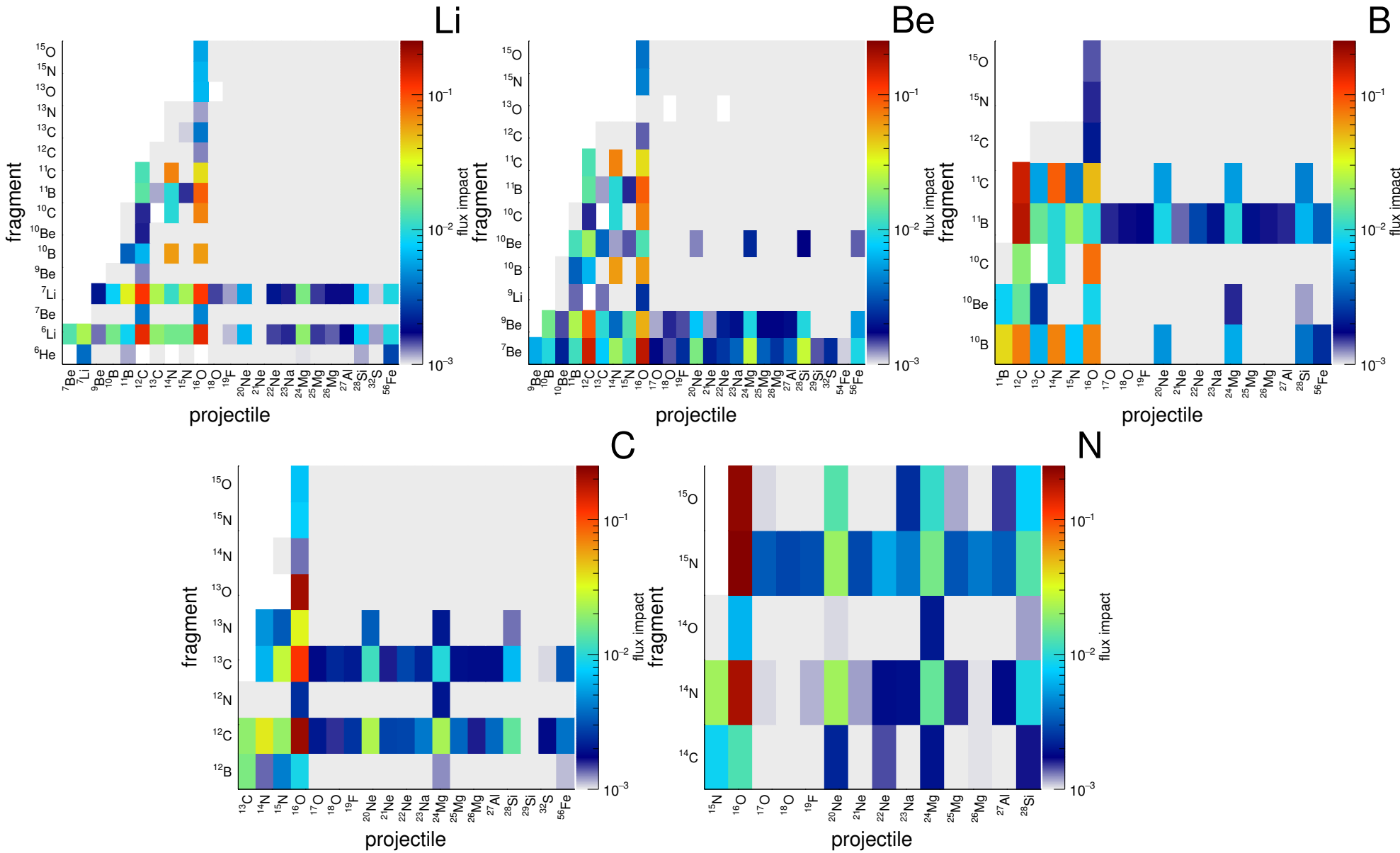
$$f_{abc} = 1 - \frac{\psi^{\text{sec}}(\sigma^{a+b\to c}=0)}{\psi^{\text{sec}}(\text{ref})}$$



Y. Génolini, D. Maurin, I. Moskalenko and MU, submitted to PRC, arXiv:1803.04686

Flux Impact

$$f_{abc} = 1 - \frac{\psi^{\text{sec}}(\sigma^{a+b\to c}=0)}{\psi^{\text{sec}}(\text{ref})}$$



Y. Génolini, D. Maurin, I. Moskalenko and MU, submitted to PRC, arXiv:1803.04686

Uncertainty of Secondary Fluxes

- fully correlated uncertainties:

$$\left(\frac{\Delta\psi^{\text{tot}}}{\psi^{\text{tot}}}\right)^{\text{corr}} \approx \sum_{a,b,c} f_{abc}\frac{\Delta\sigma^{abc}}{\sigma^{abc}}$$

- uncorrelated uncertainties:

$$\left(\frac{\Delta\psi^{\text{tot}}}{\psi^{\text{tot}}}\right)^{\text{uncorr}} \approx \sqrt{\sum_{a,b,c}\left(f_{abc}\frac{\Delta\sigma^{abc}}{\sigma^{abc}}\right)^2}$$

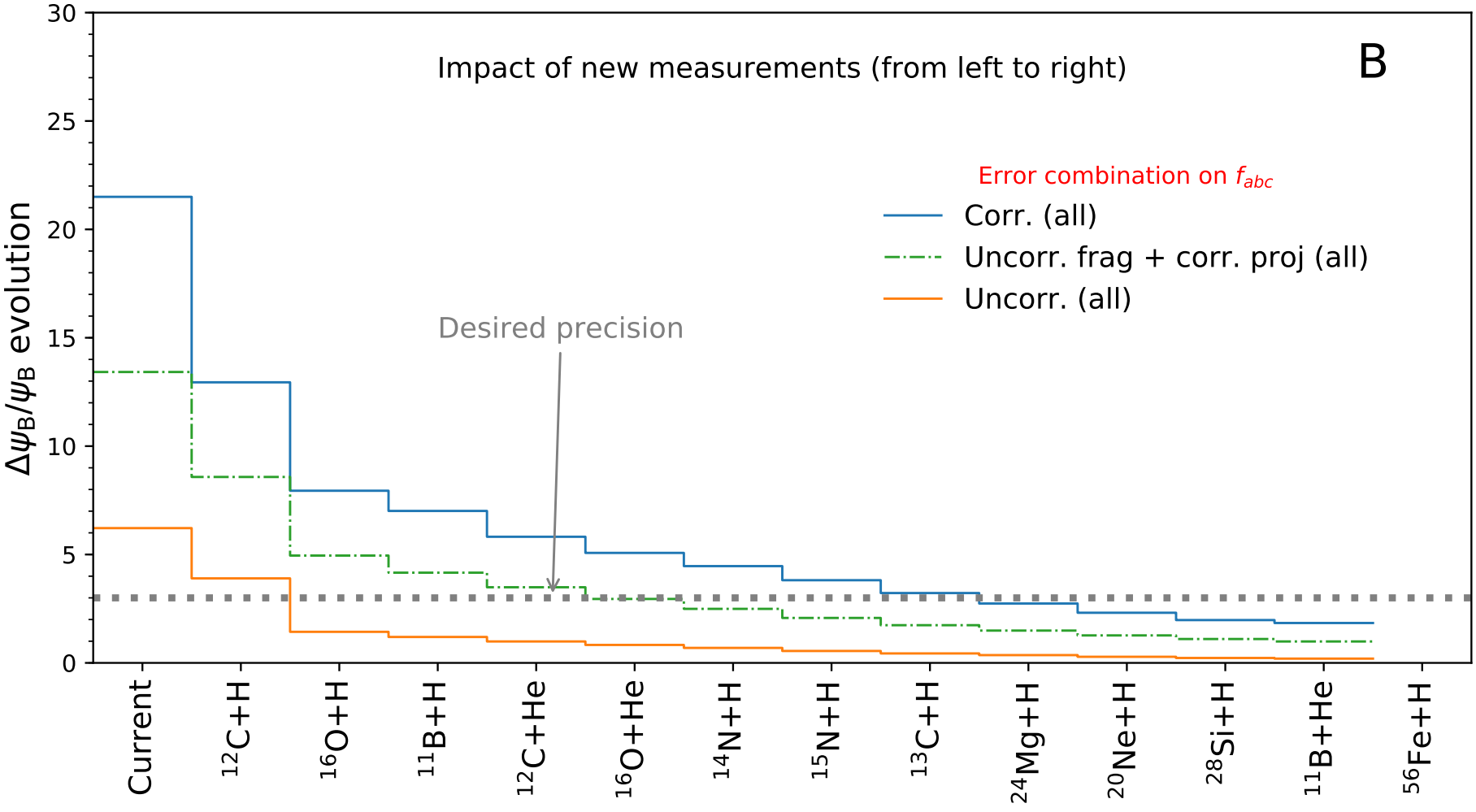
- uncorrelated uncertainties for fragments of the same projectile, but correlated for different projectiles:

$$\left(\frac{\Delta\psi^{\text{tot}}}{\psi^{\text{tot}}}\right)^{\text{mix}} \approx \sum_{a}\sqrt{\sum_{b,c}\left(f_{abc}\frac{\Delta\sigma^{abc}}{\sigma^{abc}}\right)^2}$$

- relative cross section uncertainty $\frac{\Delta\sigma^{abc}}{\sigma^{abc}}$

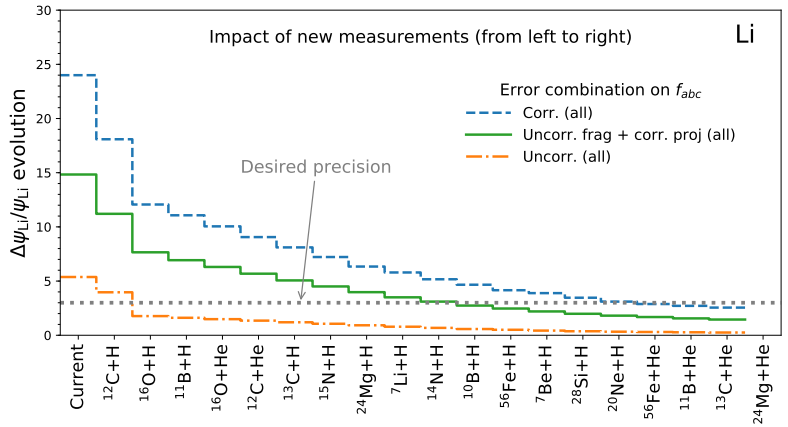
Uncertainty of B Flux

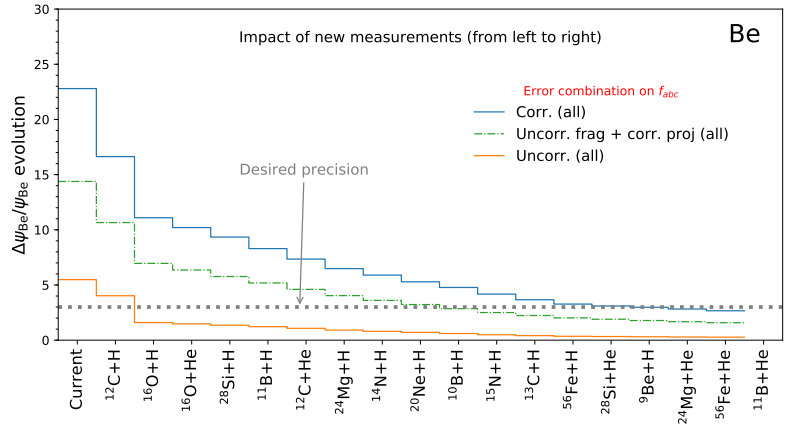
assuming a current relative cross section uncertainty of 20%

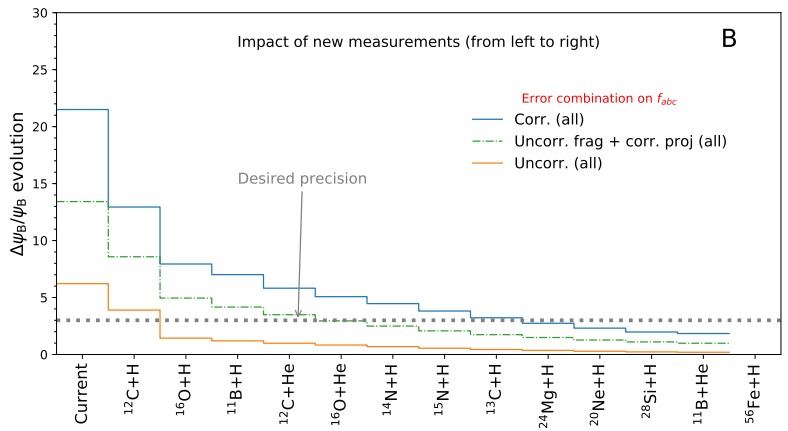


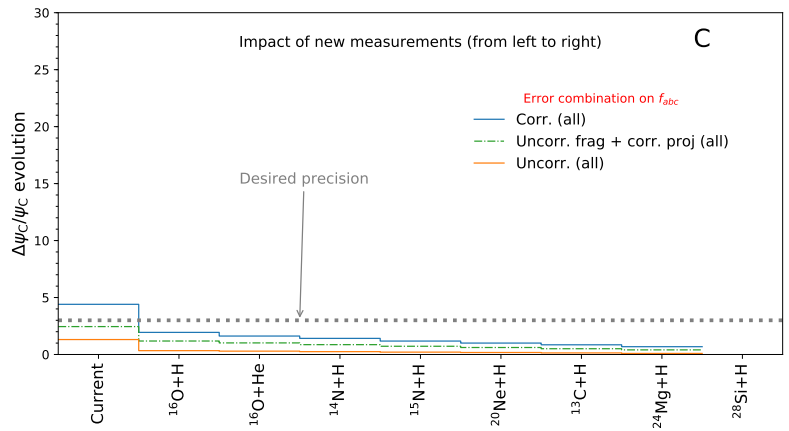
Y. Génolini, D. Maurin, I. Moskalenko and MU, submitted to PRC, arXiv:1803.04686

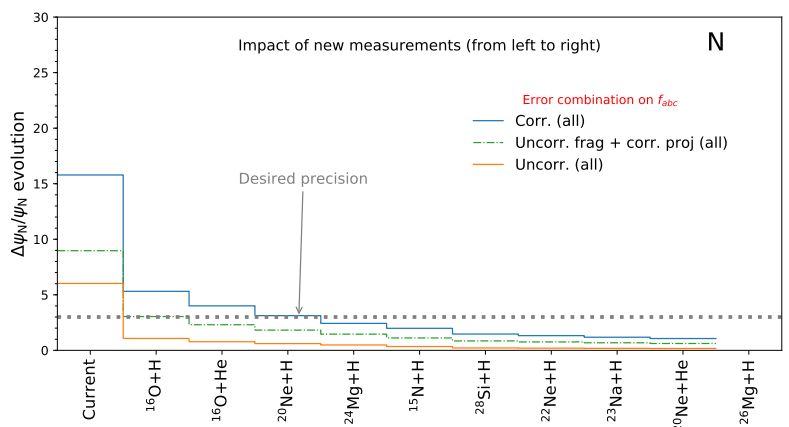
Uncertainty of Li/Be/B/C/N Flux











Proposed Measurements of Fragmentation Cross Sections with NA61/SHINE

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

The NA61/SHINE Collaboration

CERN-SPSC-2017-035

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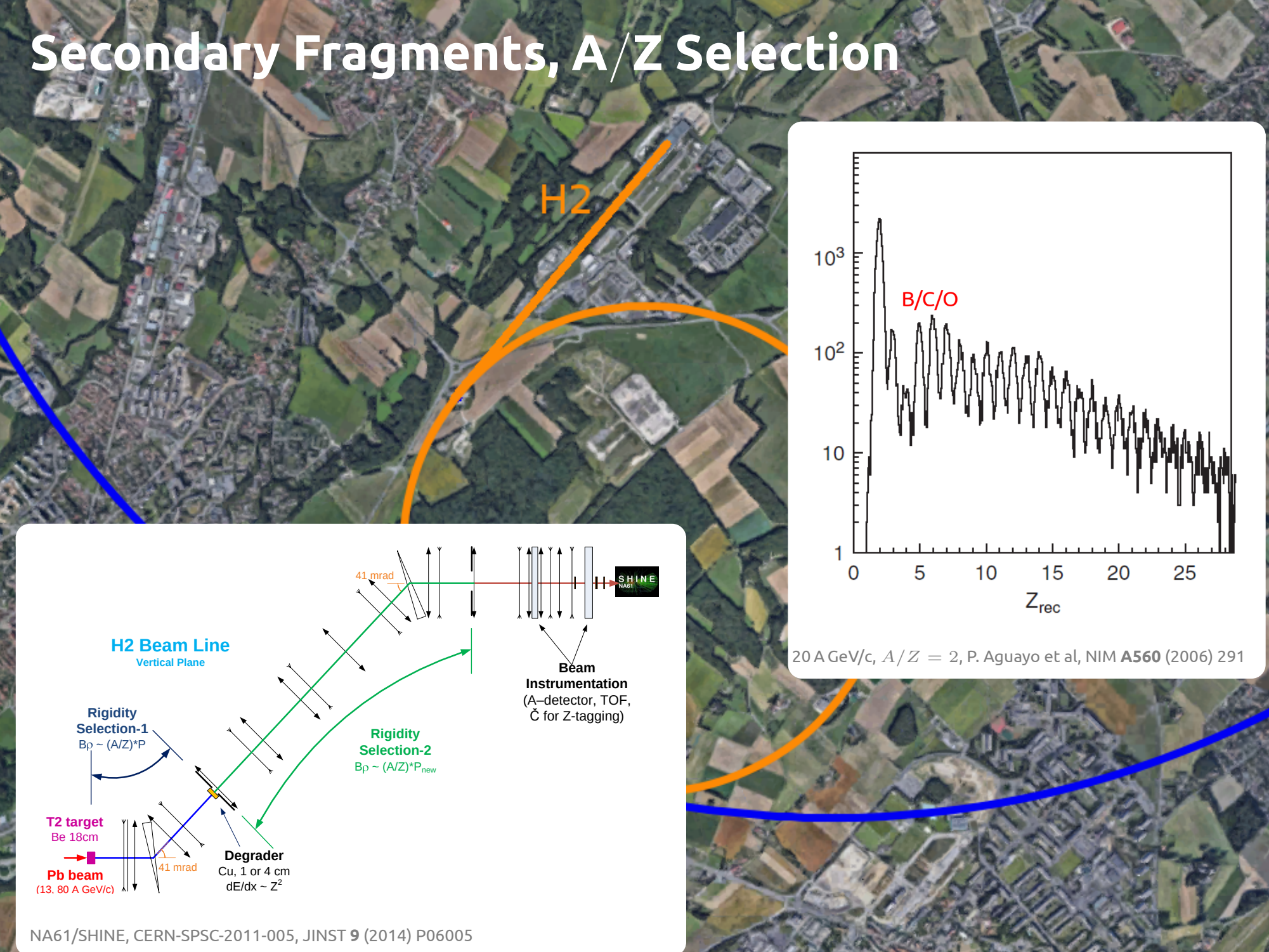
CERN-SPSC-2018-008

Pb/Ar 13...150 A GeV/c from SPS on Primary Target

LHC

SPS

Secondary Fragments, A/Z Selection

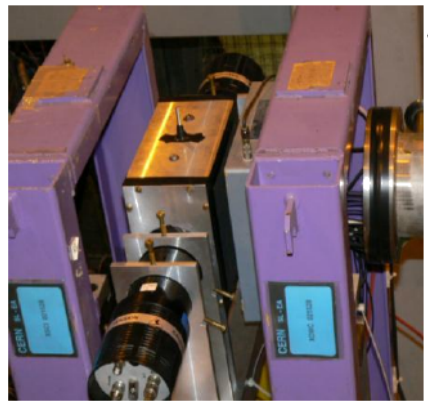


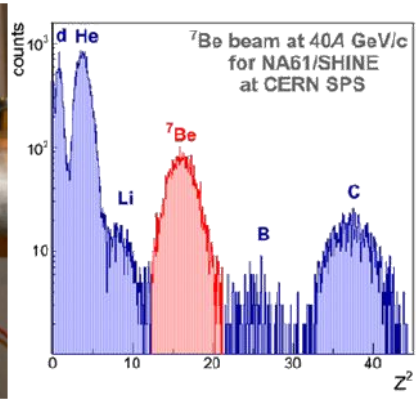
20 A GeV/c, $A/Z = 2$, P. Aguayo et al, NIM **A560** (2006) 291

NA61/SHINE, CERN-SPSC-2011-005, JINST **9** (2014) P06005

Beam Particle Id (A and Z with ToF, dE/dX, Č)

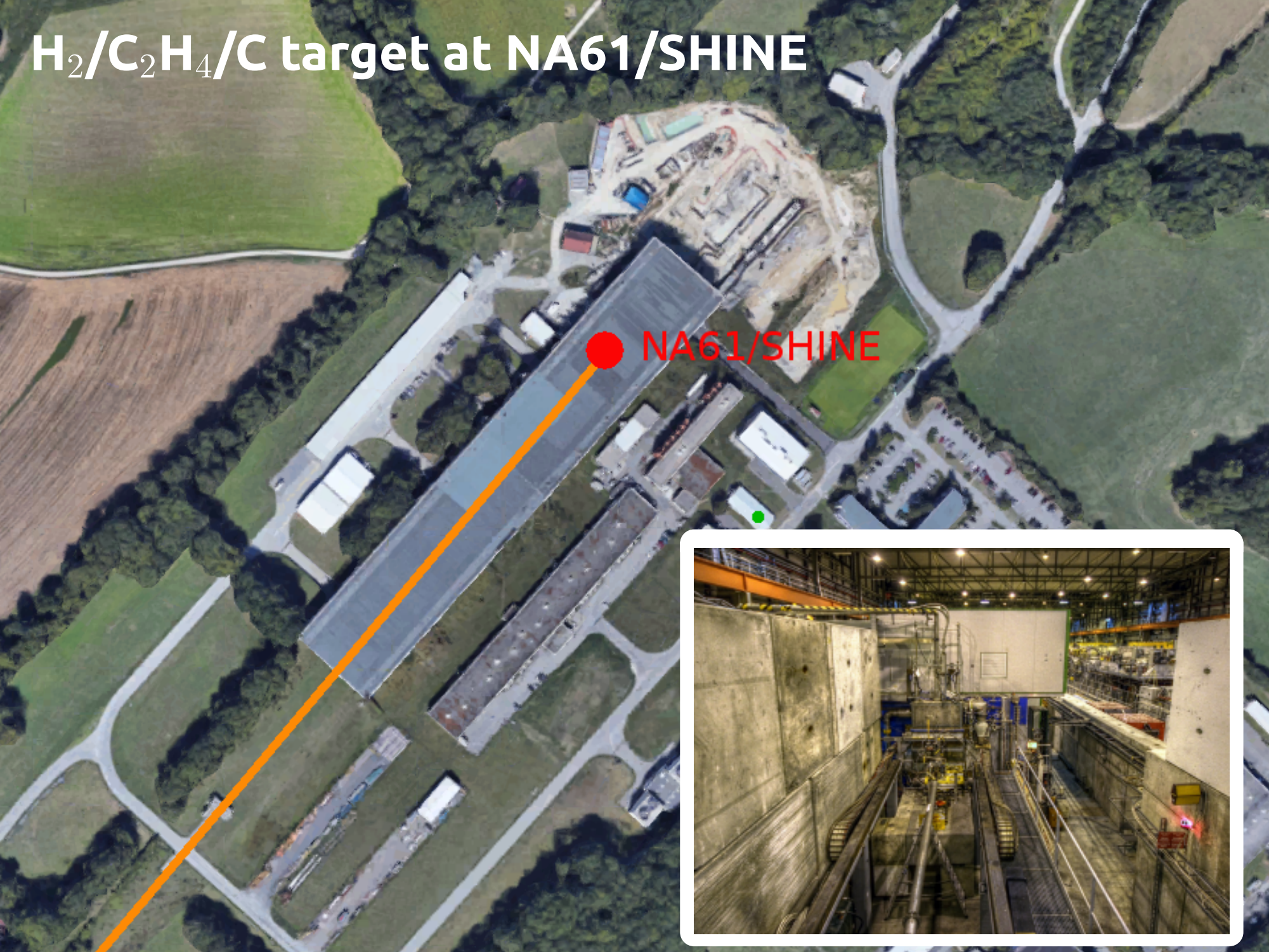
installation of ToF cable along H2 beam line, Feb 2018



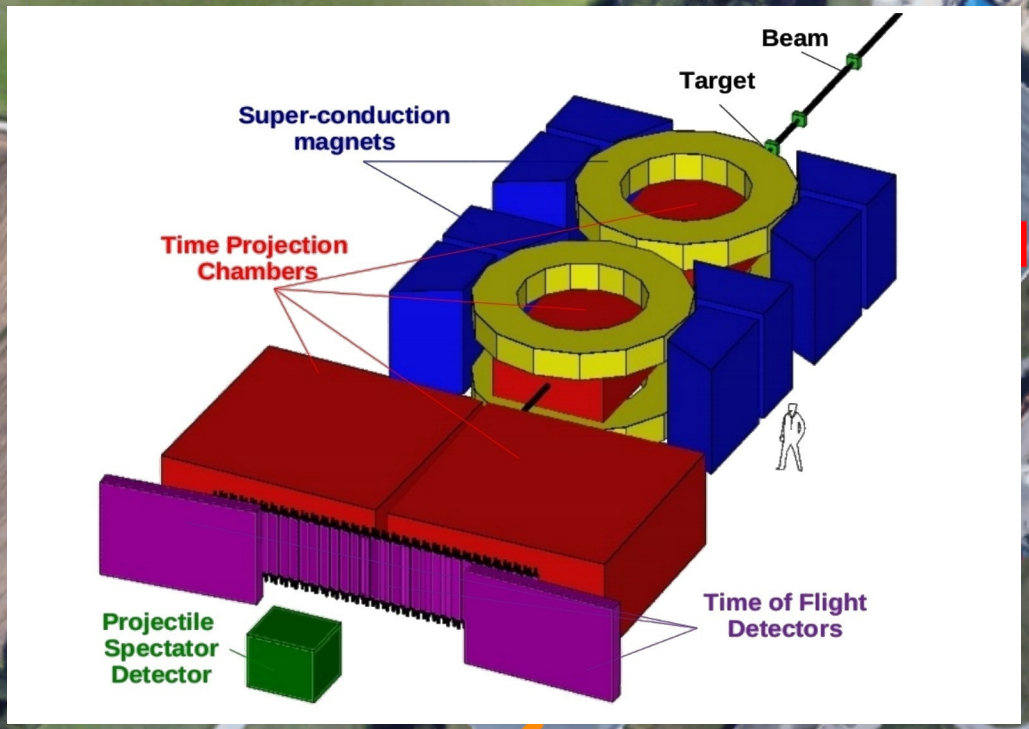


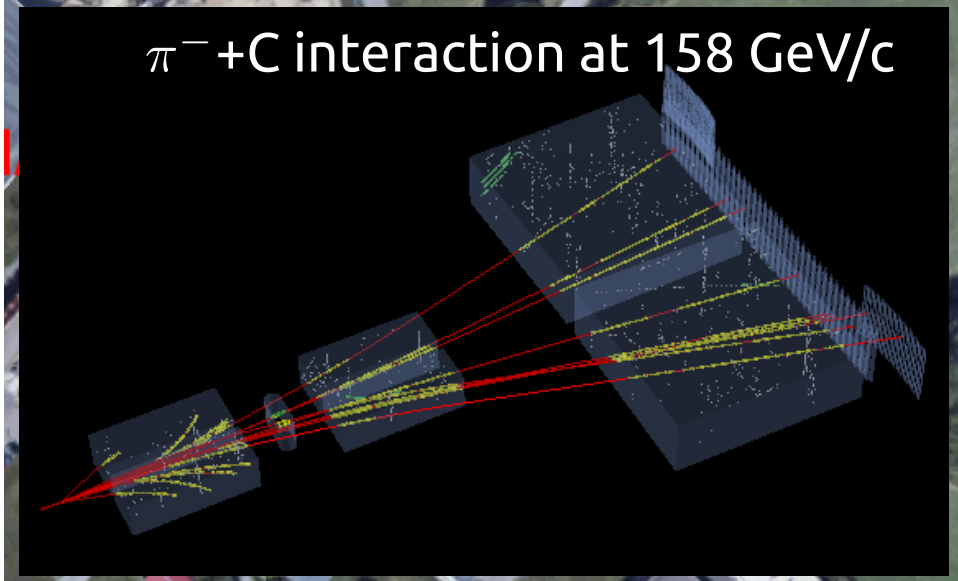
Z^2 detector, Be run (Cherenkov in Quartz)

$H_2/C_2H_4/C$ target at NA61/SHINE



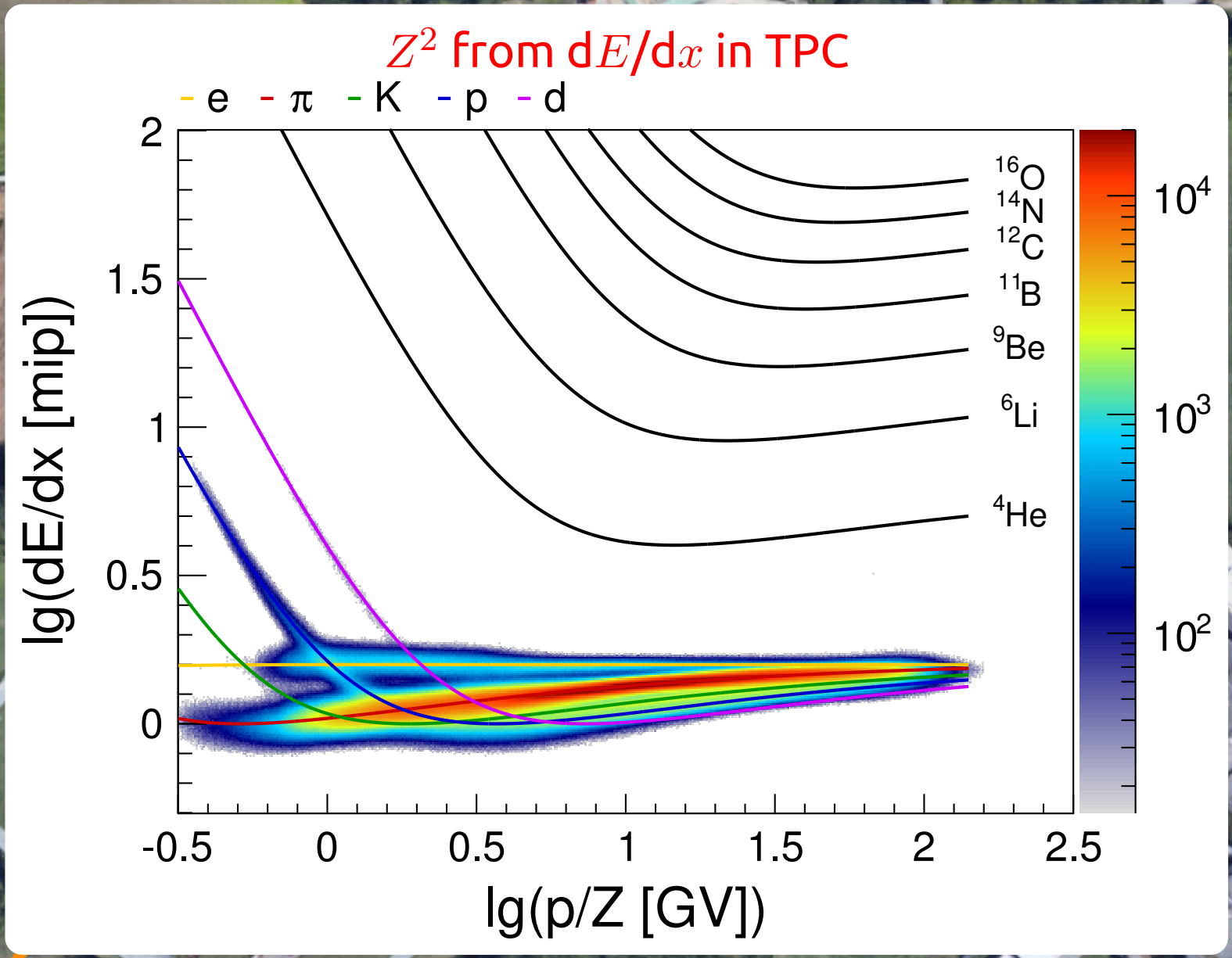
NA61/SHINE Experiment at SPS





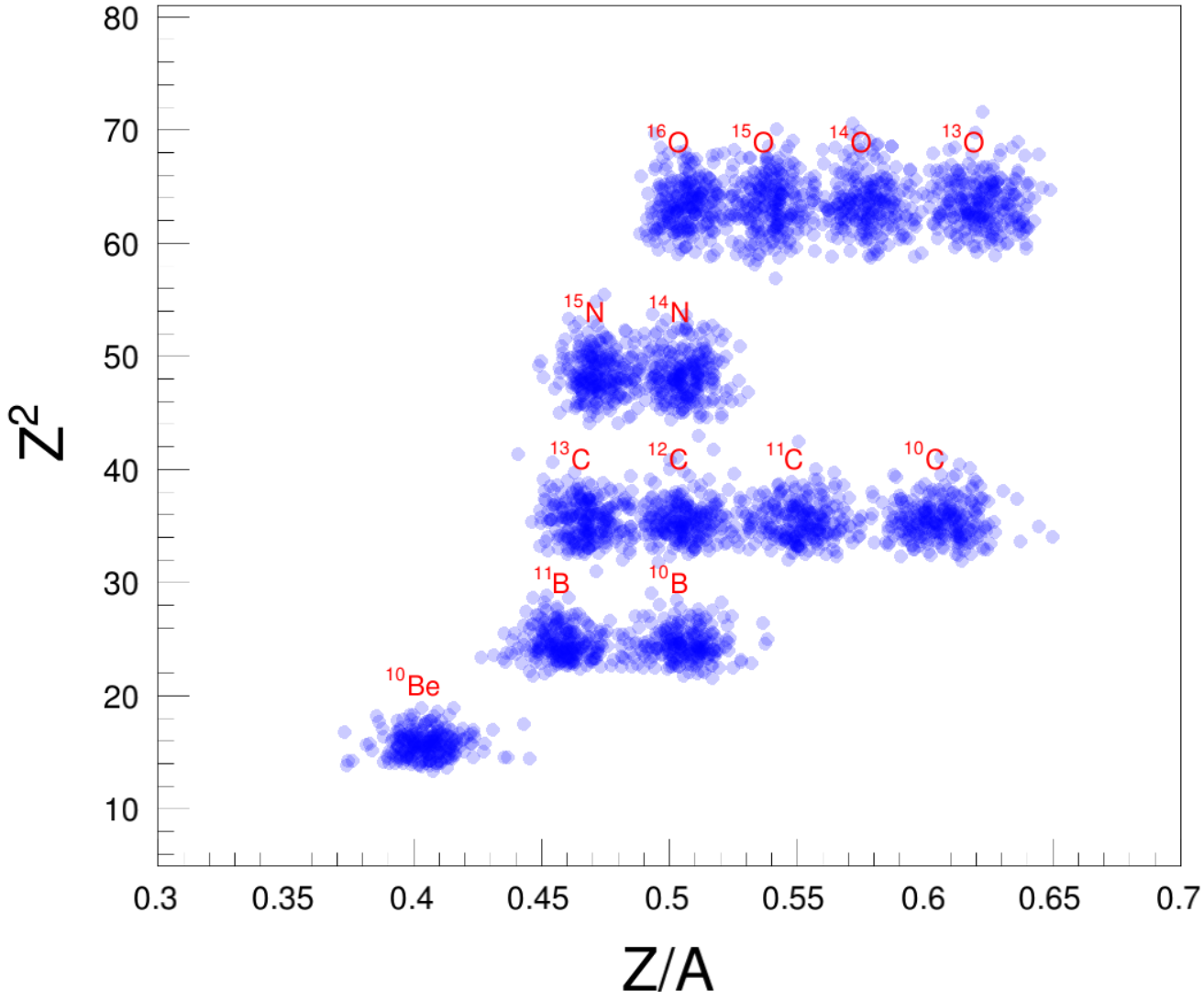
- large acceptance $\approx 50\%$ at $p_T \leq 2.5\,\mathrm{GeV/c}$
- momentum resolution: $\sigma(p)/p^2 \approx 10^{-4}(\mathrm{GeV/c})^{-1}$
- tracking efficiency: $> 95\%$

Fragment Identification (A and Z)

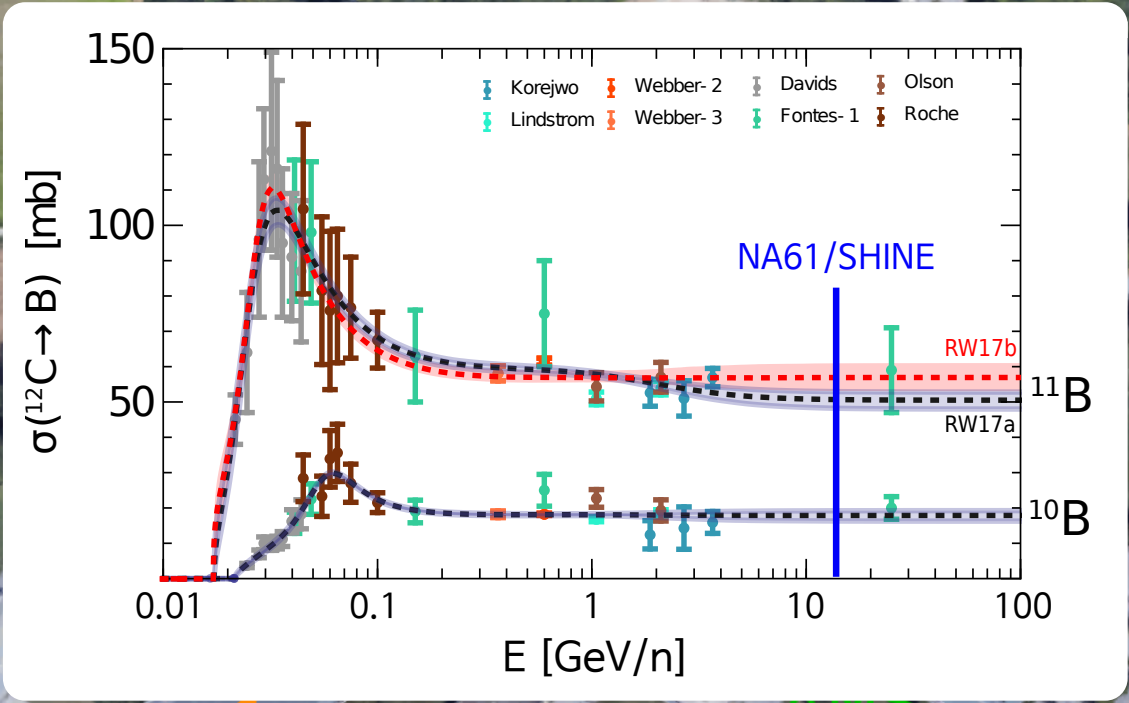


Fragment Identification (A and Z)

Z^2 vs. Z/A (from deflection at full B)



Data Taking Plans



- 1 week pilot run scheduled in December 2018!
  → trigger on ^{12}C and ^{16}O beam.
- 3 weeks dedicated CR running after LS2 (2022?)
  → upgraded DAQ
  → measure all σ relevant for Li, Be, B, C and N (trigger on Li ... Si)
  → mainly X+p, what about He target?
  → secondary flux uncertainty from $\sigma < 1\%$

NA61 p+p Measurements relevant for GCRs

Eur. Phys. J. C (2017) 77:671
DOI 10.1140/epjc/s10052-017-5260-4

THE EUROPEAN PHYSICAL JOURNAL C

CrossMark

Regular Article - Experimental Physics

Measurements of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ spectra in proton-proton interactions at 20, 31, 40, 80 and 158 GeV/*c* with the NA61/SHINE spectrometer at the CERN SPS

NA61/SHINE Collaboration

Eur. Phys. J. C (2016) 76:198
DOI 10.1140/epjc/s10052-016-4003-2

THE EUROPEAN PHYSICAL JOURNAL C

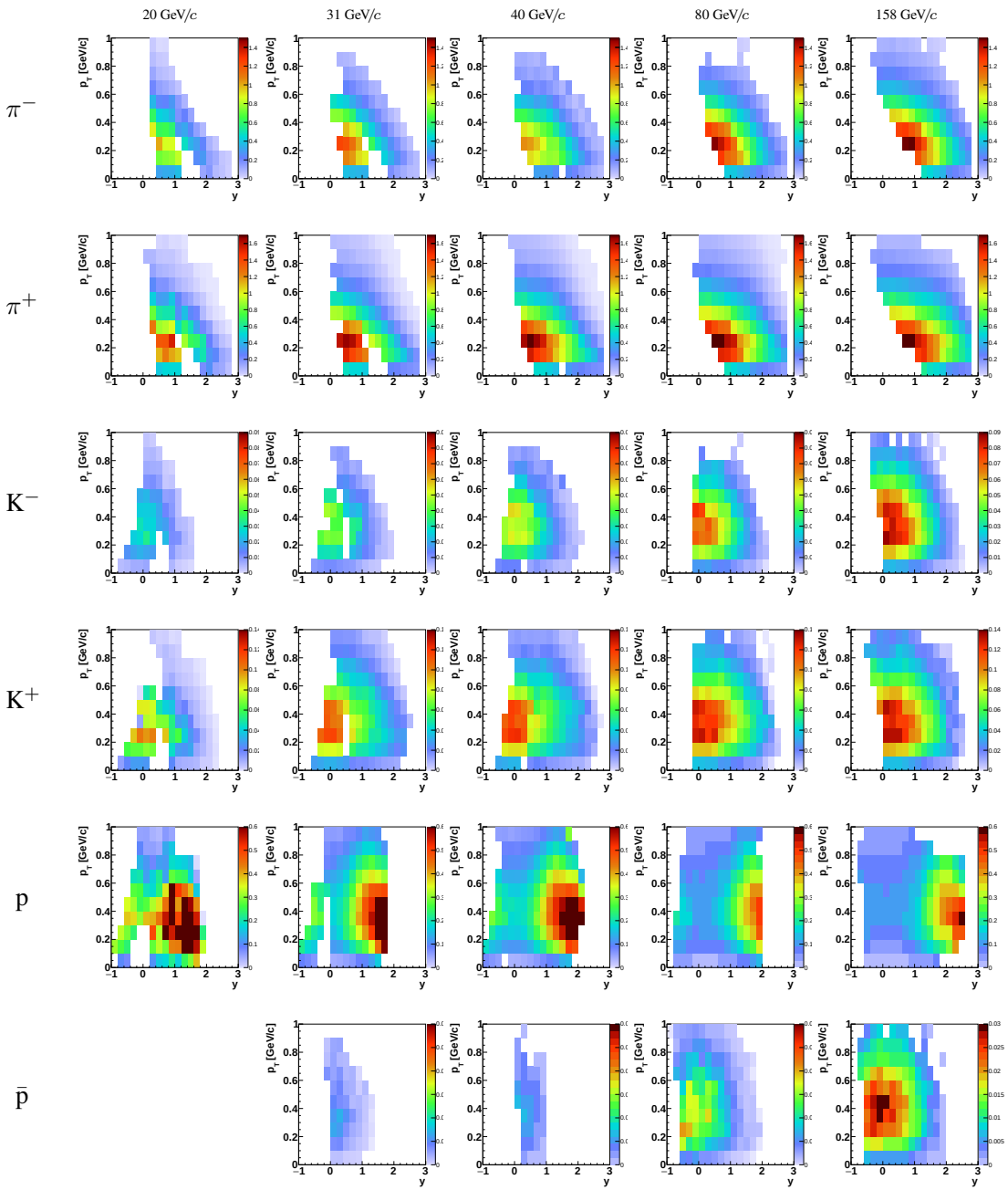
CrossMark

Regular Article - Experimental Physics

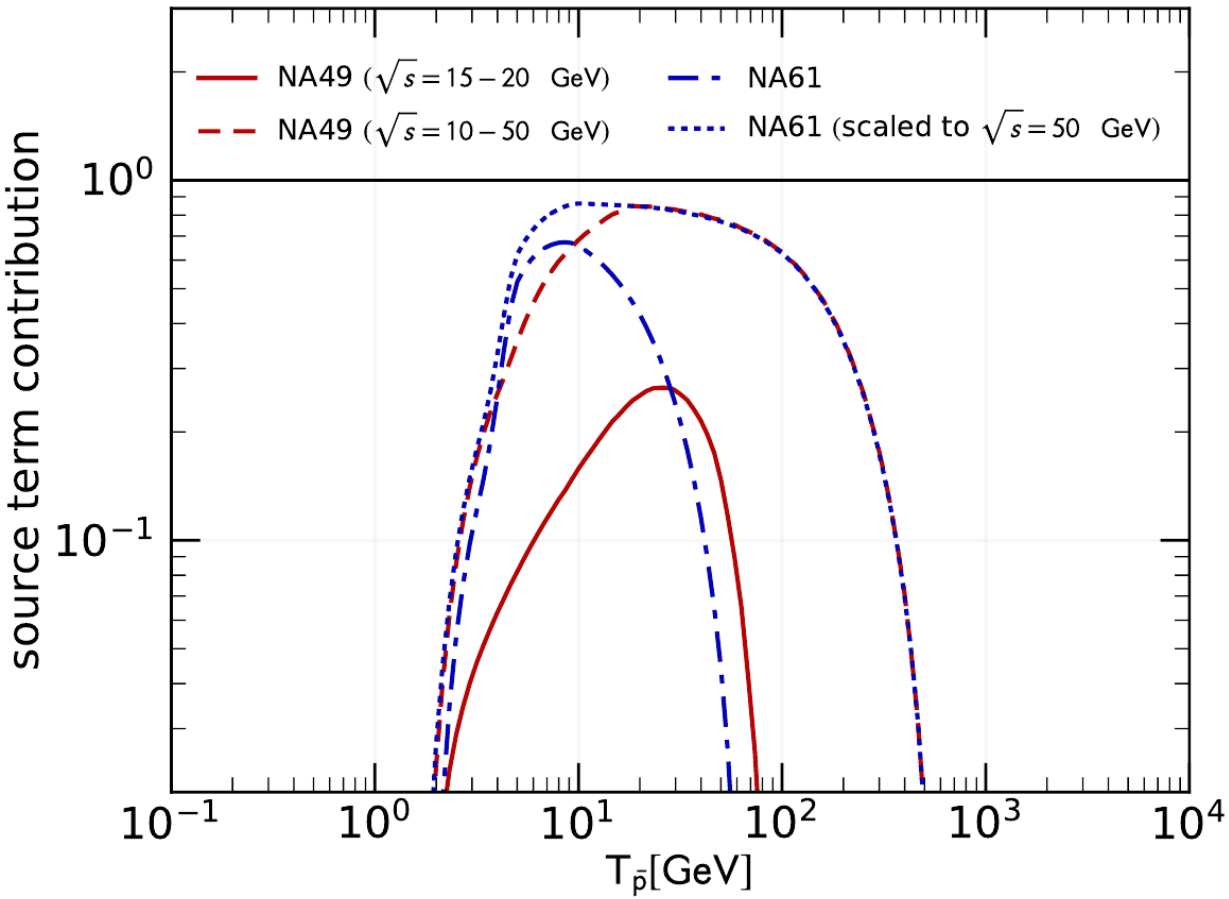
Production of Λ-hyperons in inelastic p+p interactions at 158 GeV/*c*

NA61/SHINE Collaboration

NA61 p+p Measurements relevant for GCRs

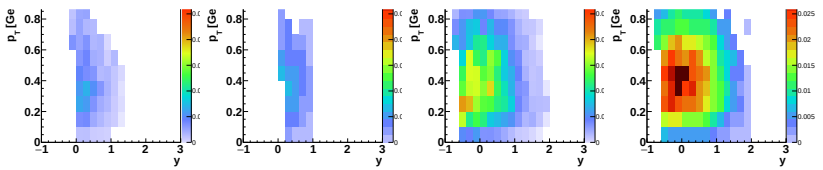


NA61 p+p Measurements relevant for GCRs

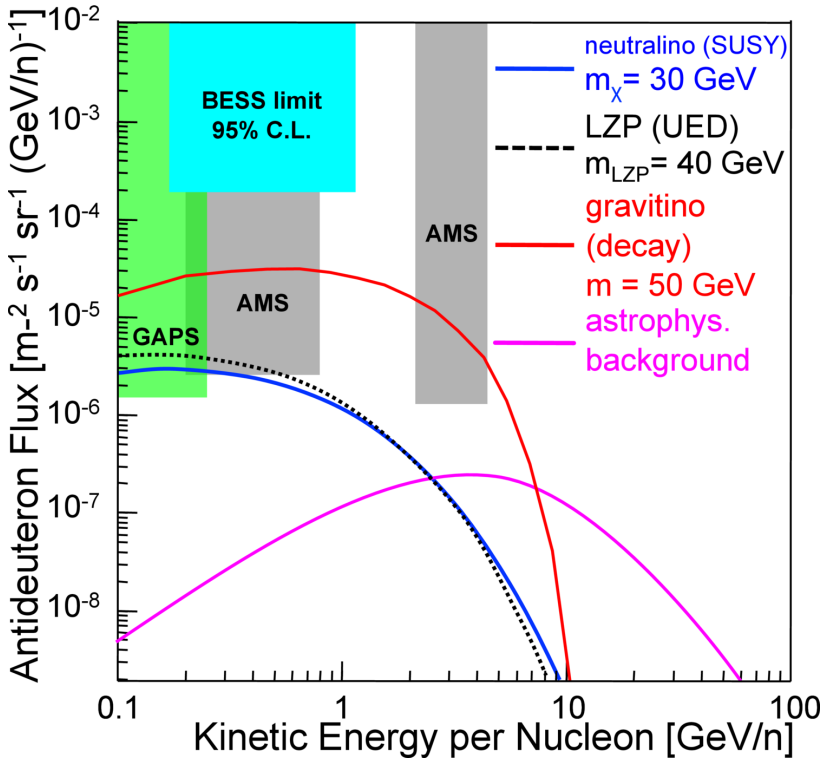


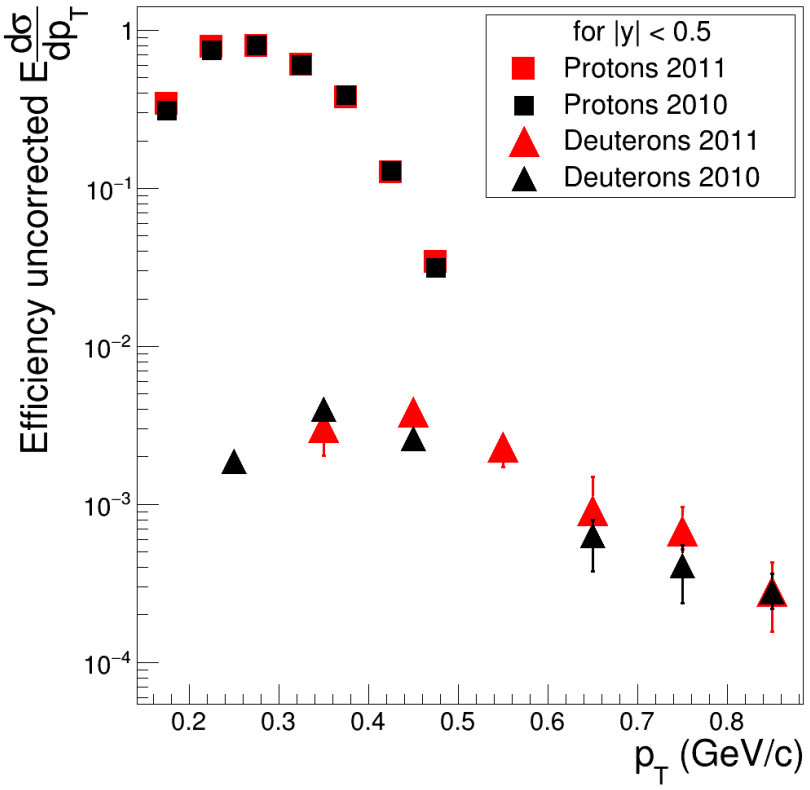
Korsmeier+, arXiv:1802.03030

$\bar{p}$



Work in Progress: (Anti-)deuteron Production





Thanks!

NA61 Collaboration meeting, St. Petersburg, May 2018