Opportunities for cross sections measurements at GSI/FAIR

Laurent Audouin

IJC Lab, Université Paris-Saclay

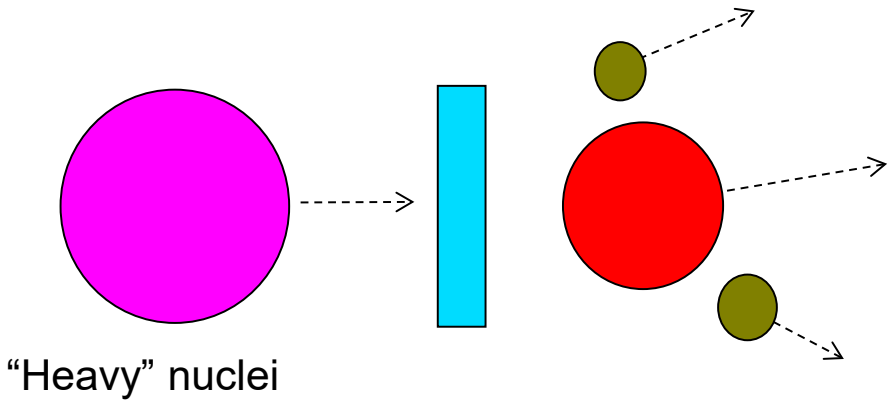
Food for thought: the nuclear energy approach

- No code can produce nuclear quantities at 3% out of the box
- Few percent precision is requested also in energy, therapy, nucleosynthesis…
  - Therapy uses a very narrow energy range : can afford code tuning

- Measurement compilation and reviewing (EXFOR database)
- Semi-empirical data modelling
- Production of evaluated libraries (JEFF, ENDF, JENDL…)
- Software to produce reduced, usable data

Inverse kinematics

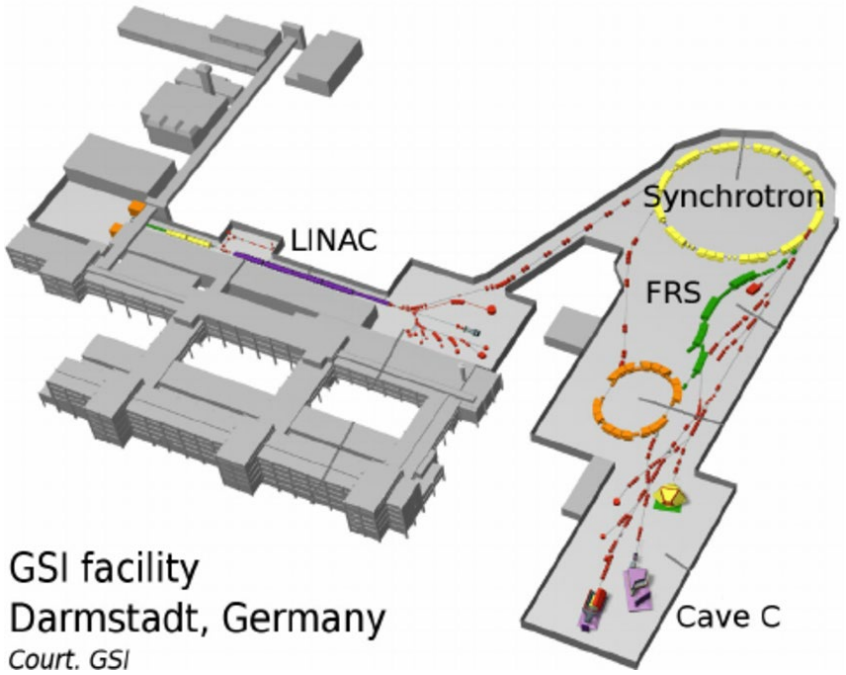
- ✓ Possibility to use radioactive beams
  - Not the first priority for CR, but…?
- ✓ Forward-focused reaction
  - Reduced solid angles
- ✓ Nuclei can be identified before decay
- ✗ Fixed energy (no excitation function)



- ✓ Recoil spectrometer : high resolution in A and Z
  - Charge-states become an issue in the 10-100s MeV/u energy range
  - Light fragments might be measured as well

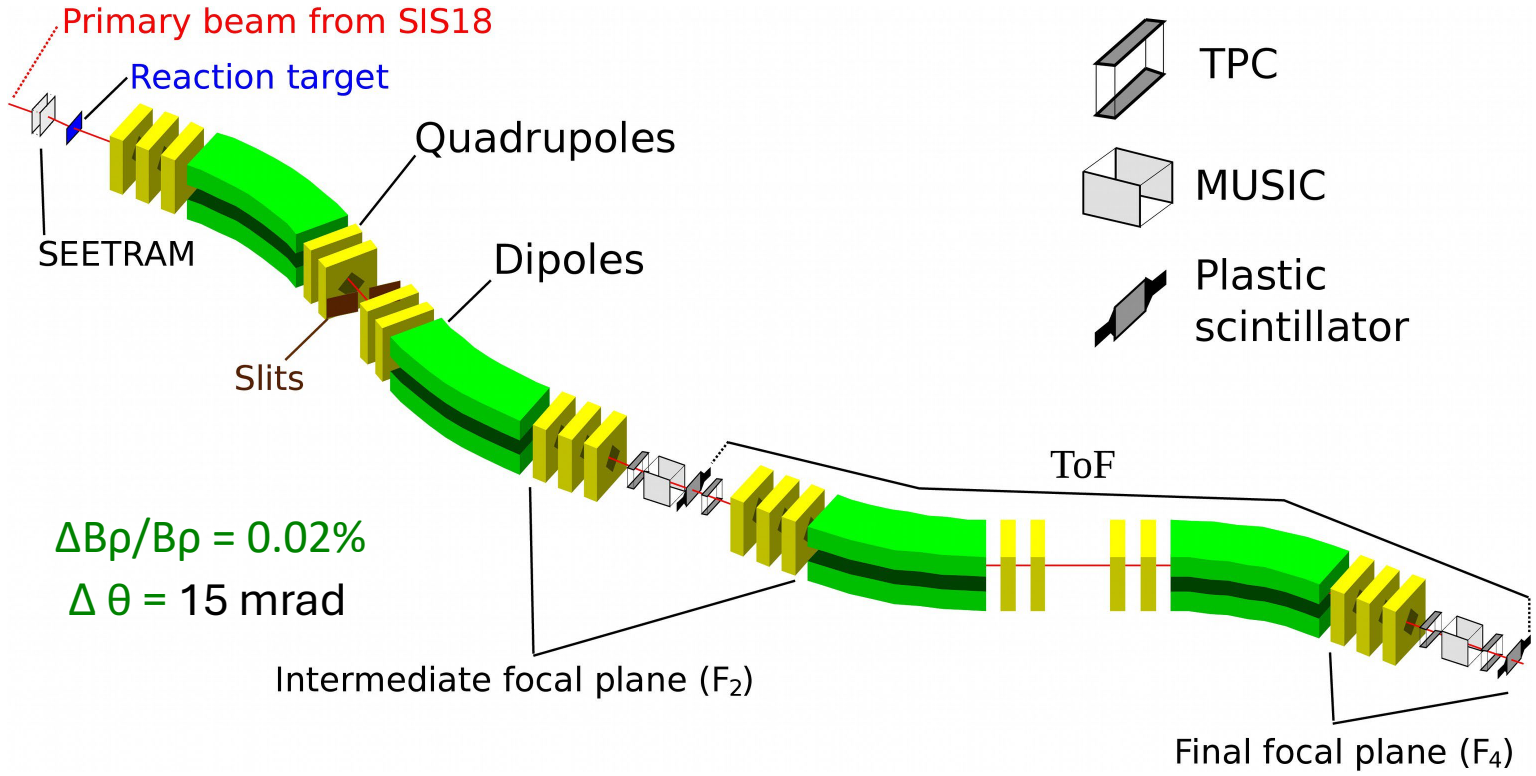
- ✗ Relativistic heavy ions beams world-wide: RHIC, GSI, CERN

Historical tool for spallation at GSI : the FRS



GSI facility
Darmstadt, Germany
Court. GSI

H. Geissel et al., NIMB 70, 286 (1992)

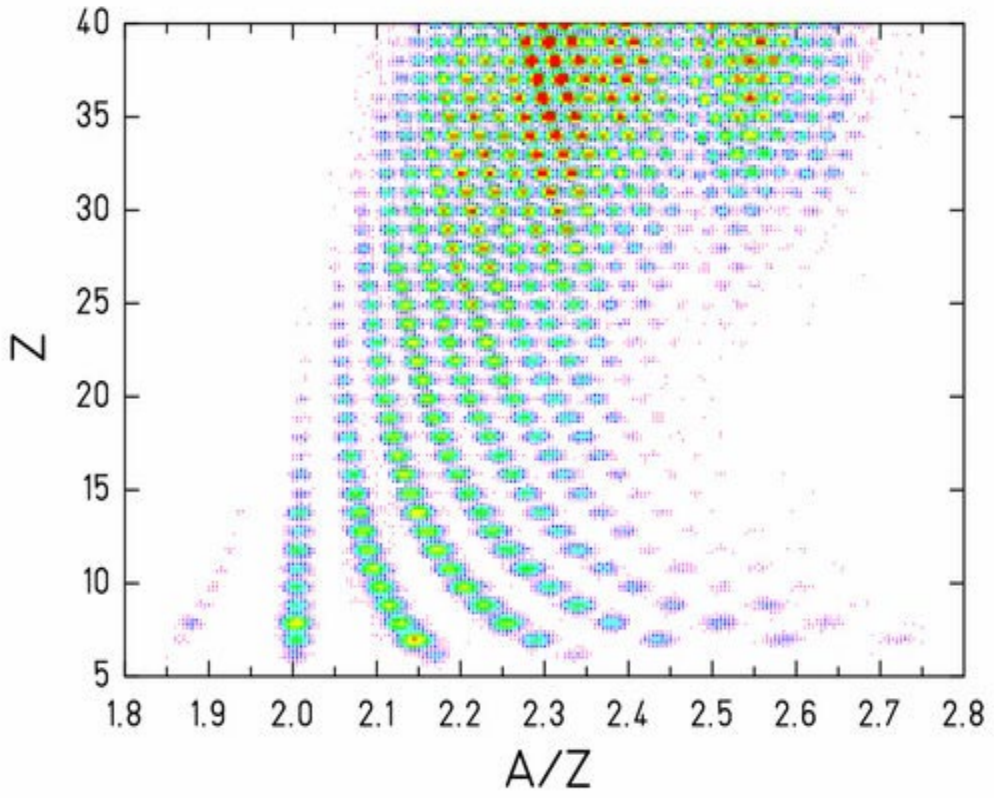


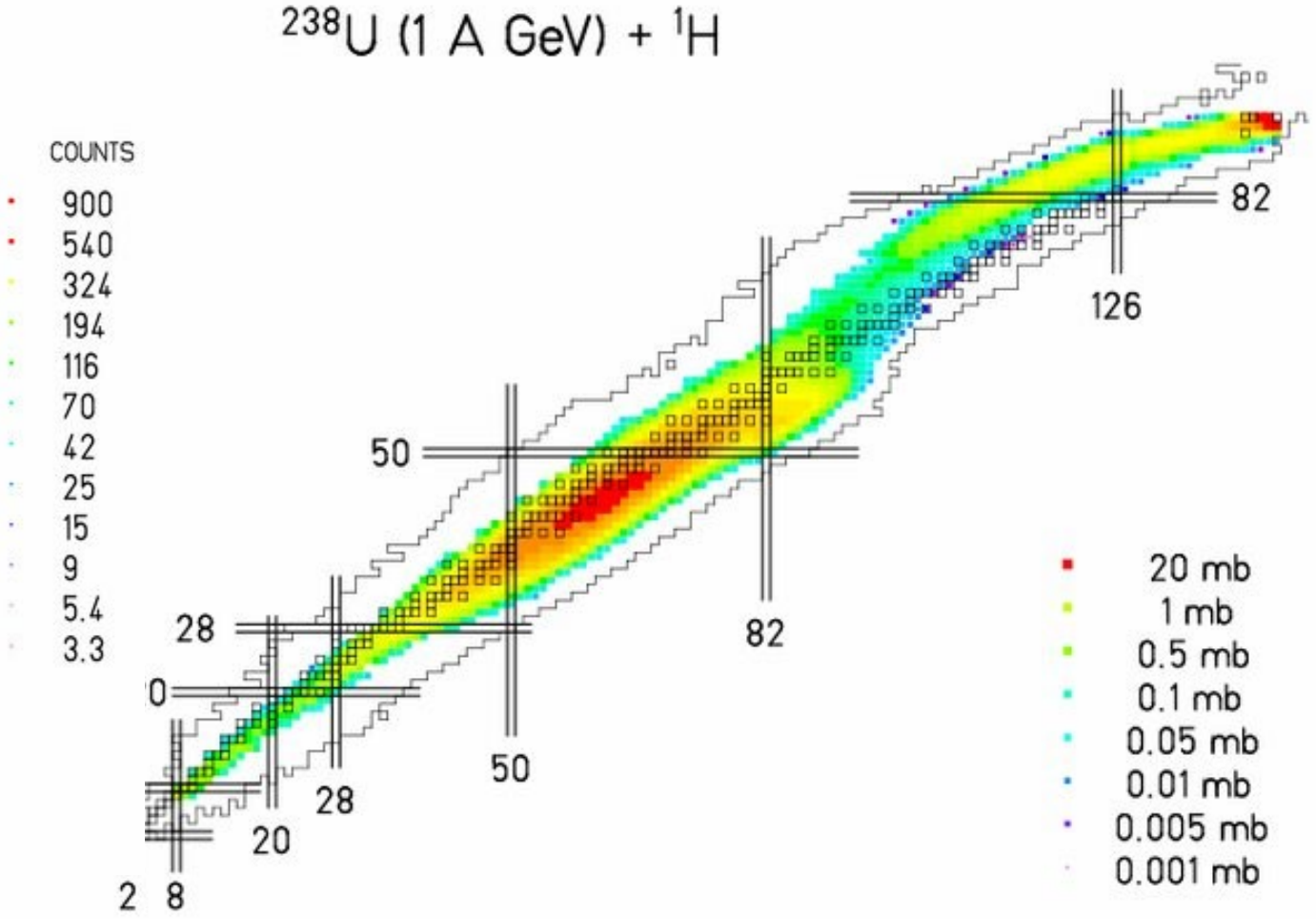
ΔBρ/Bρ = 0.02%
Δ θ = 15 mrad

$$\frac{A}{Z} = \frac{e}{u}\frac{B\rho}{\gamma\beta c}$$

$Z \sim \sqrt{\Delta E}$ from ionization chambers
$B\rho$ from tracking detectors
β from ToF measurements

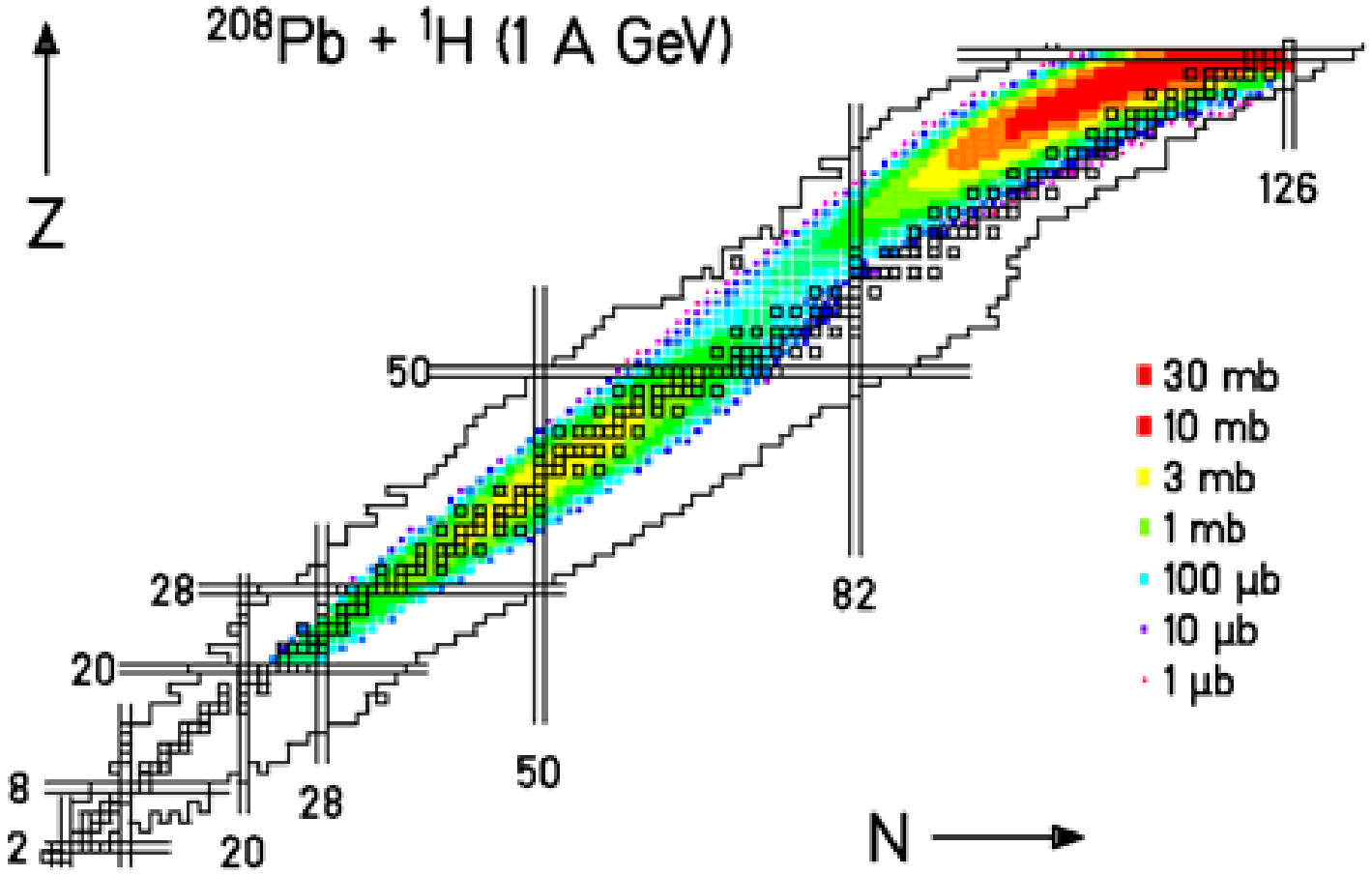
Spallation of Uranium @ FRS (H_2 target)





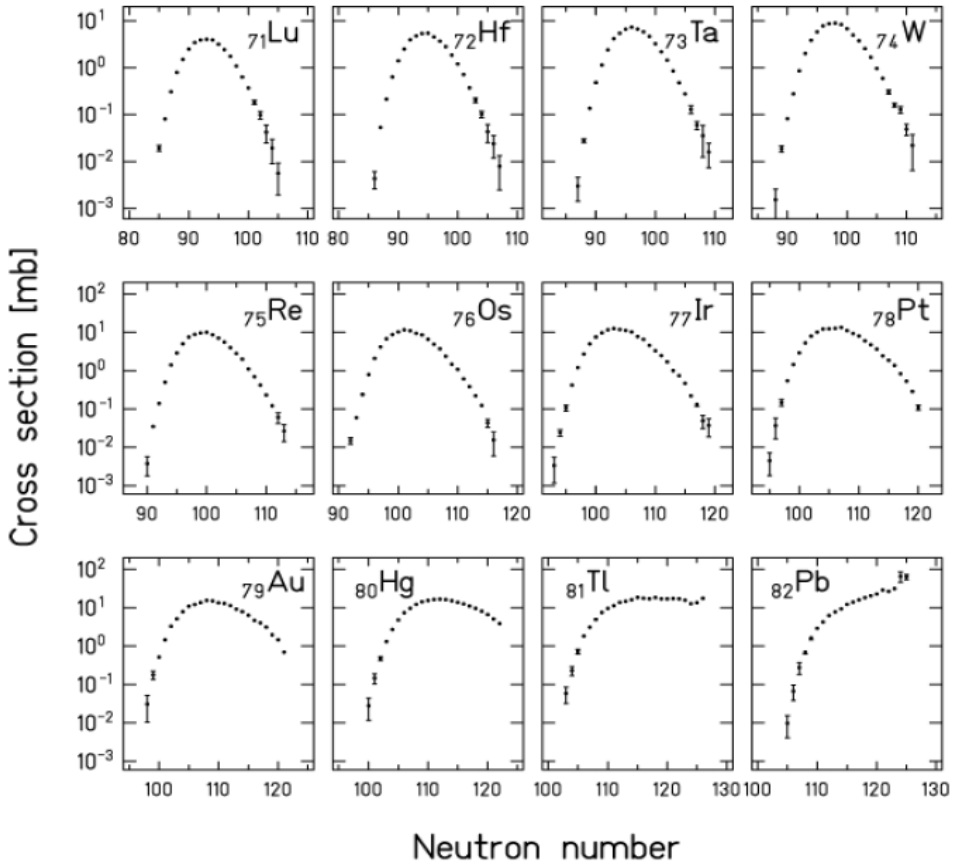
Aleksandra Kelić et al. AIP Conf. Proc. 912, 332–341 (2007)

Spallation of Lead @ FRS (H_2 target)



T. Enqvist et al., Nucl. Phys. A 686, 481 (2001)

- 870 cross sections
- Accuracy around 4%



Spallation of Xenon @ FRS (H_2 target)

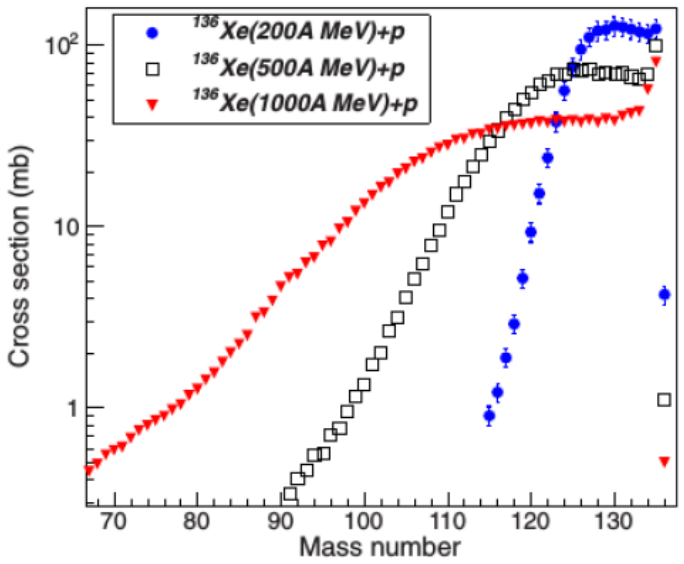
^{136}Xe + p at different kinetic energies

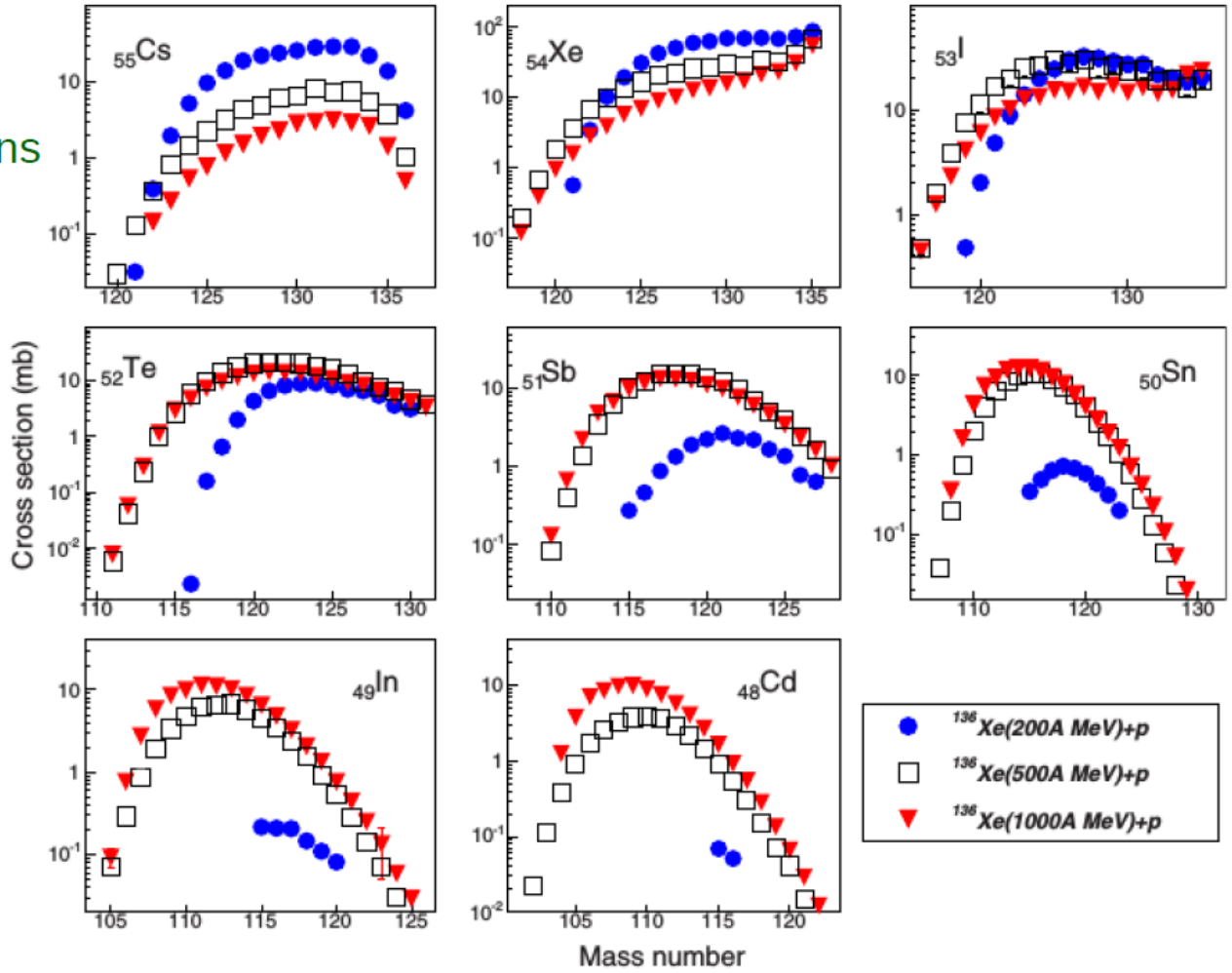
P. Napolitani et al., PRC 76, 064609 (2007)
C. Paradela et al., PRC 95, 044606 (2017)

- More than 1000 cross sections
- Accuracy 3%

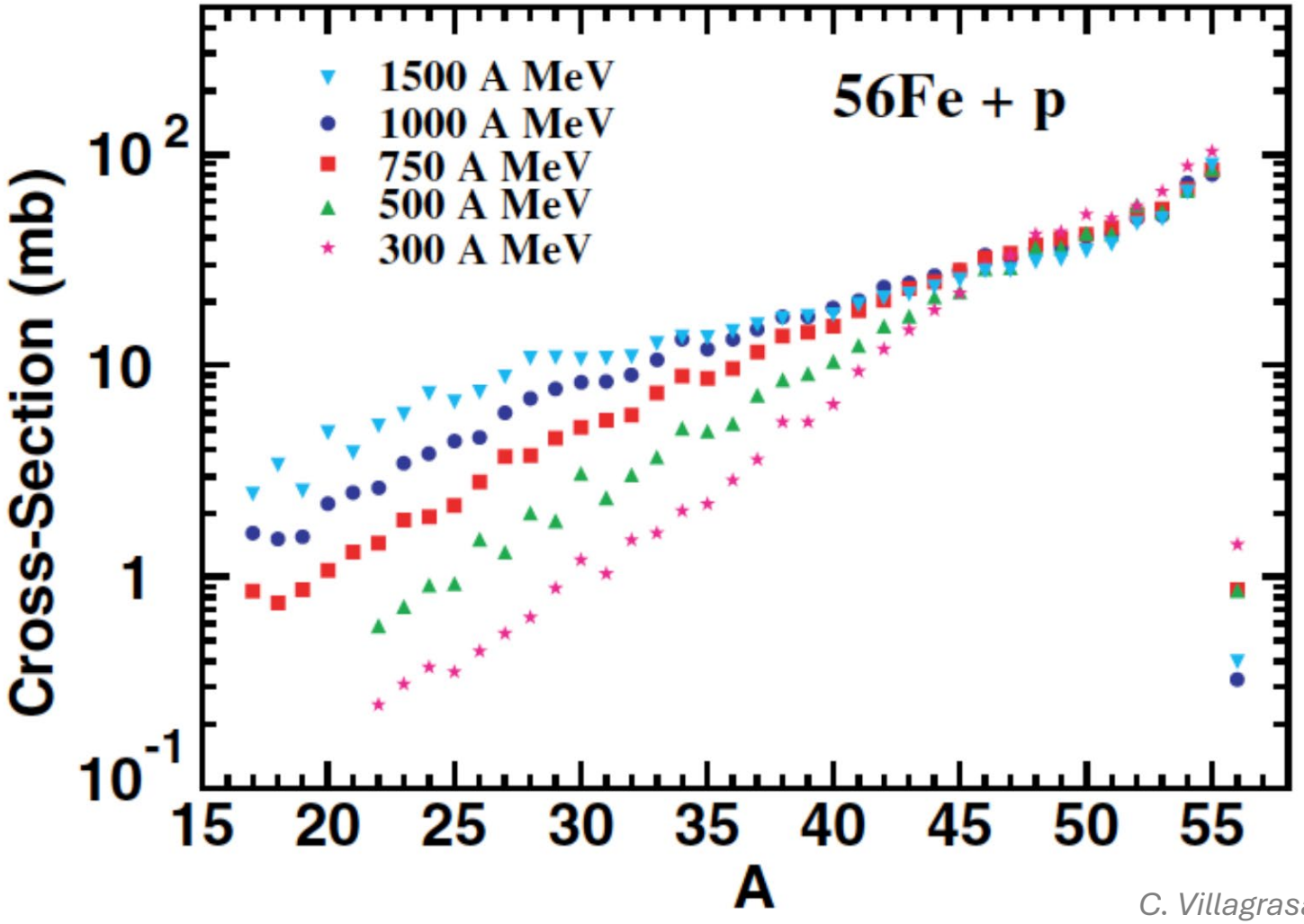
Evolution of isotopic cross sections with the energy

Improvement of empiral models SPACS, EPAX, ...





Spallation of Iron @ FRS (H_2 target)



C. Villagrasa et al., PRC 75, 044603 (2007)

Spectrometer acceptance: a bottleneck?

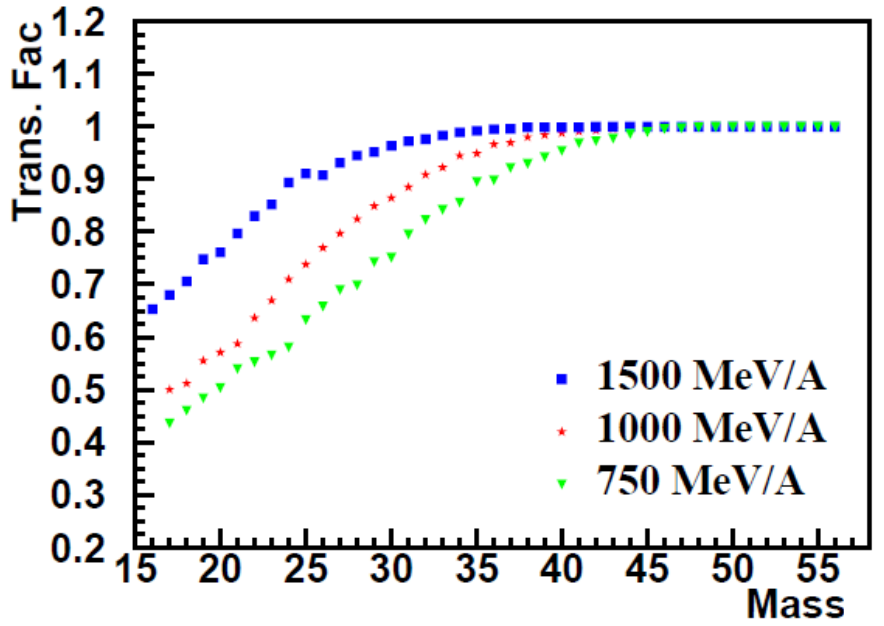
- Limited acceptance of FRS : 2% in transverse impulsion
  - Horizontal component: different magnetic settings
  - Vertical component: has to be simulated/measured… precision??

- Dispersion increases with « distance » from projectile

$$\sigma_{p_\perp}^2 = \sigma_o^2 \frac{F(A-F)}{A-1} + \sigma_1^2 \frac{F(F-1)}{A(A-1)}$$

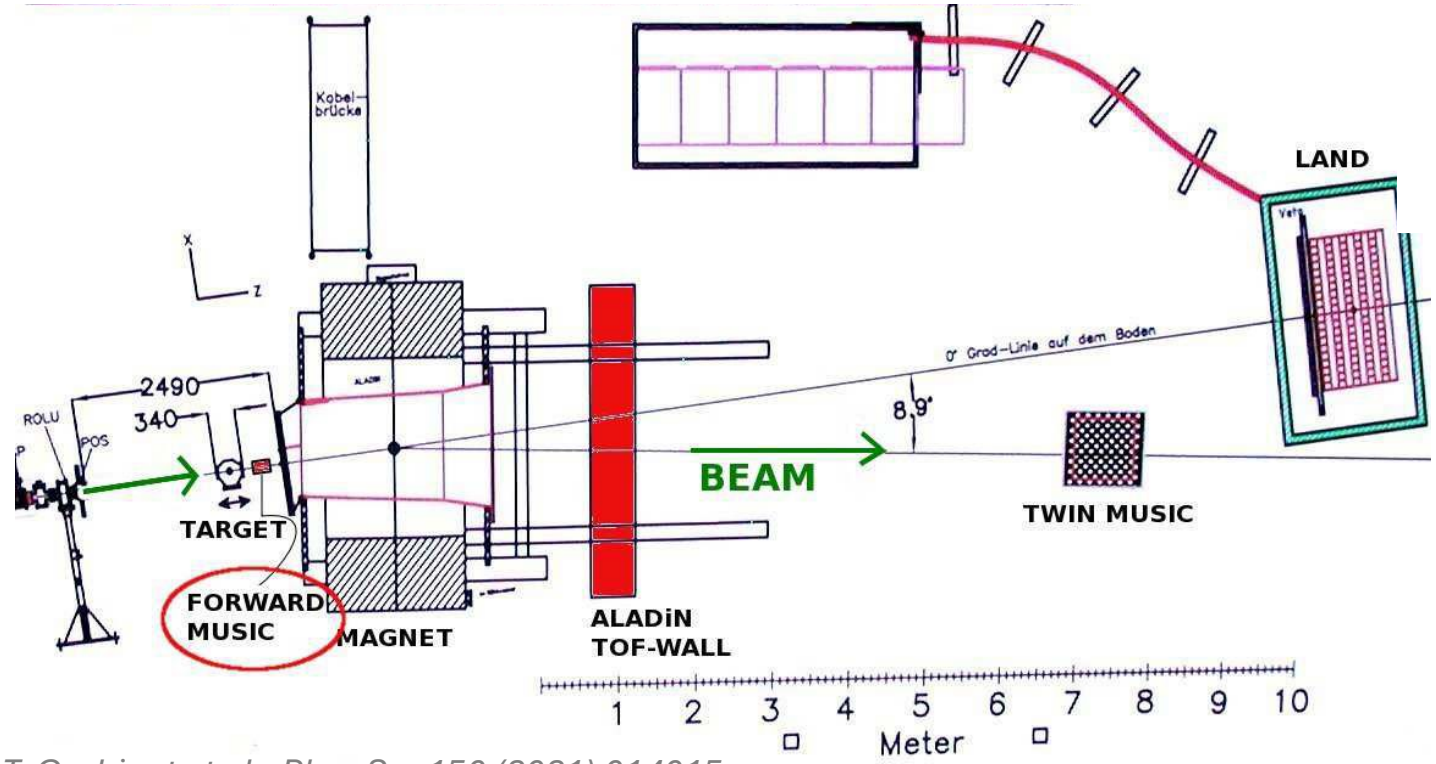
K. Van Bibber et al., Phys. Rev. Lett., 43:840–844 (1979)

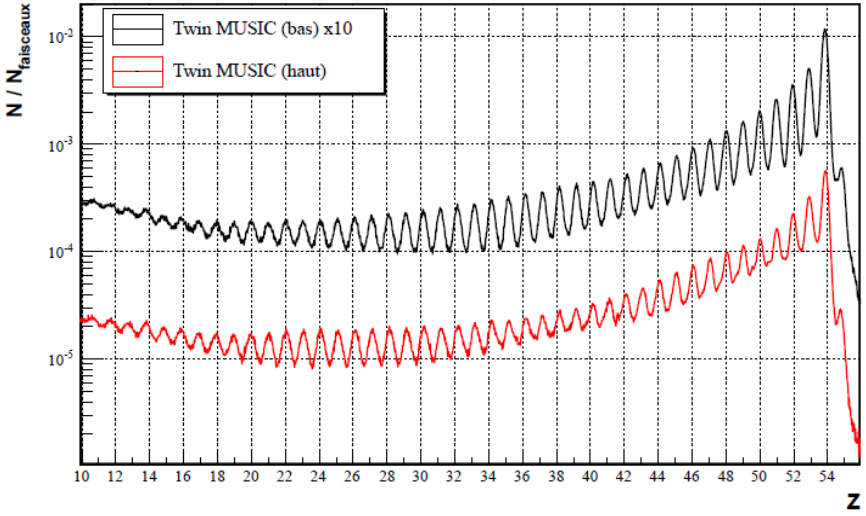
- Significant impact on Xe+p
- … even stronger in Fe+p

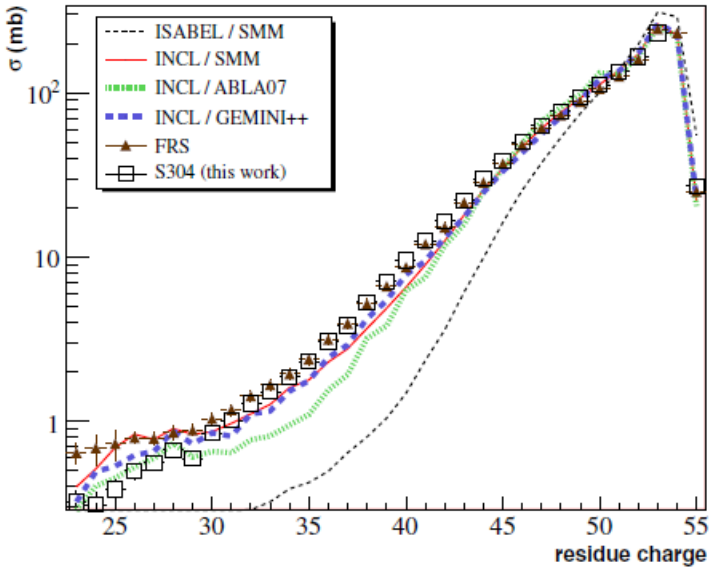


Large-acceptance measurement: SPALADIN

- Exclusive experiment
- Large dipole magnet, neutron wall, LCP wall
- Mass not measured, huge parasitic reactions



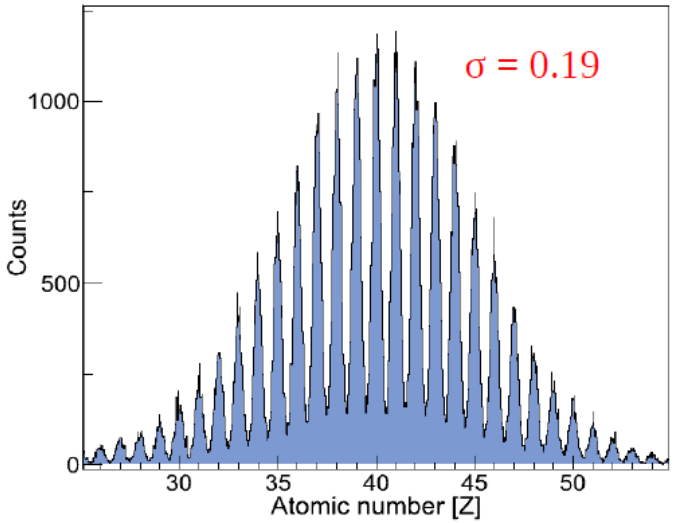


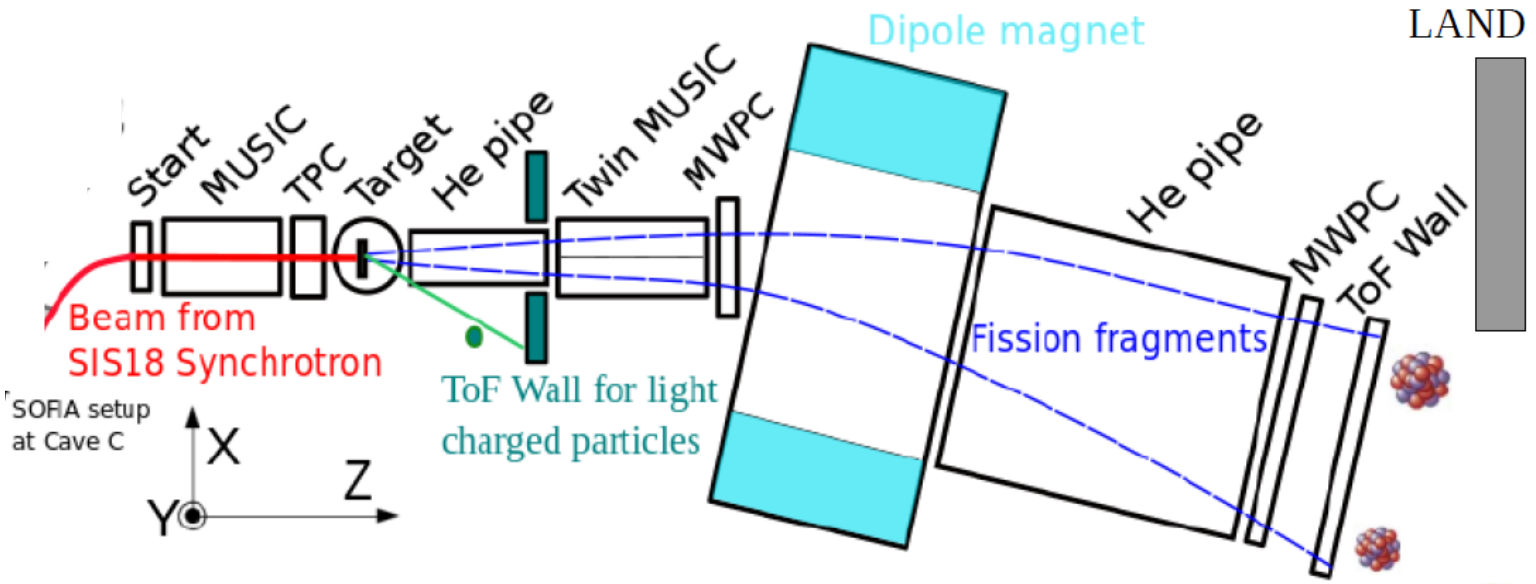


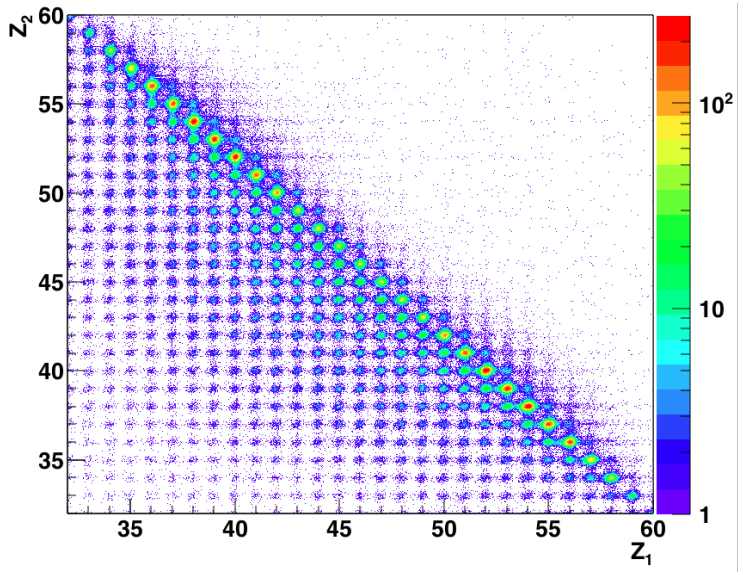
T. Gorbinet et al., Phys Scr 150 (2021) 014015

Large-acceptance measurement: SOFIA

- Fission yields experiments
- Identification of both fragments in A and Z
- Radioactive beams from FRS (100 systems in a few days)
- Very large acceptance spectrometer (fission recoil)

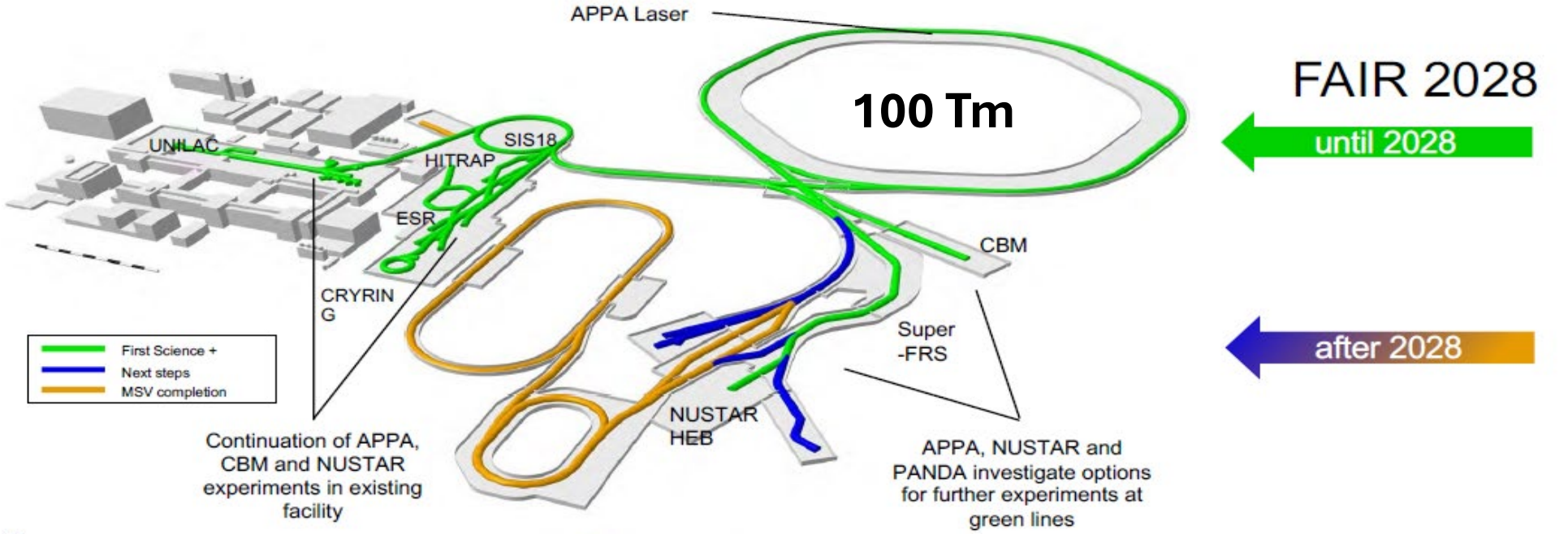


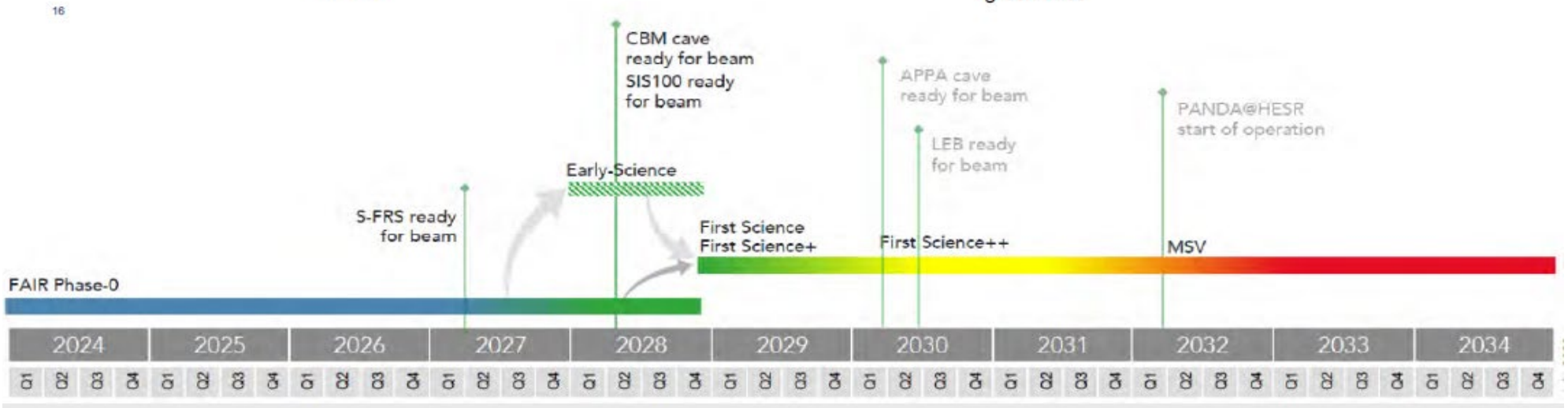




E. Pellereau et al., Phys Rev C 95 (2017) 054603

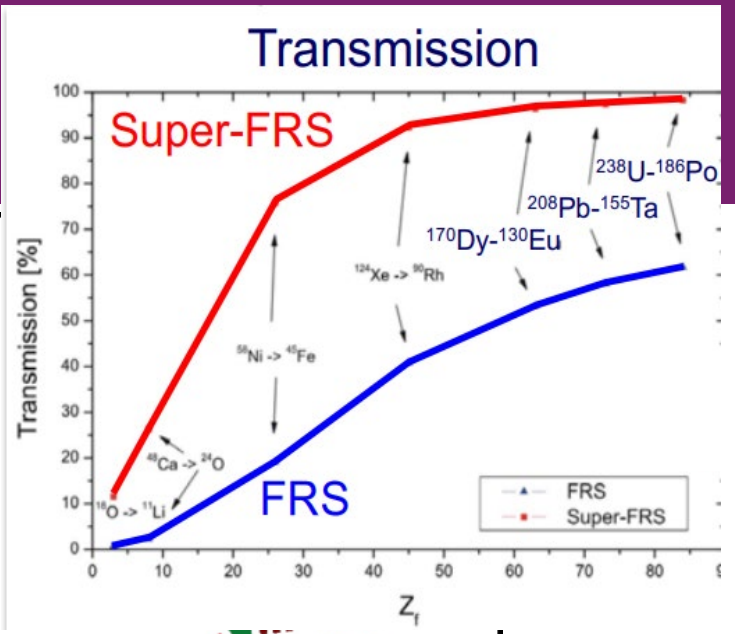
The FAIR facility





The FAIR facility as of June 2024

New tool: the Super-FRS



Important beam parameters:
- all elements from H through U
- intensity up to ~ 10^{12} ions/sec.
- beam energies up to 1.5 GeV/u
- fast and slow (DC-type) extraction

Super-FRS characteristics:

$\varepsilon_x = \varepsilon_y = 40\ \pi$ mm mr

$\varphi_x = \pm 40$ mr,

$\varphi_y = \pm 20$ mr

$\frac{\Delta p}{p} = \pm 2.5\ \%$

$B\rho_{max} = 20$ Tm

$R_{ion} = 1500$

Pre-Separator

Main Separator

Focusing System

Low-Energy Branch

High-Energy Branch

Storage-Ring Branch

Four experimental areas:
- superconducting fragment separator
- high-energy branch with reaction setup
- storage-ring complex
- low-energy branch with energy focusing and dispersion-matched high-resolution spectrometer

50m

Could we measure Cosmic Rays XS at FAIR?

- SFRS measurement
  - Soon-to-be existing system
  - Can measure sub-mb cross-sections (10^7 Hz beam)
  - Precision on cross-section depends on the knowledge of the transmission
  - CH_2 target
  - Energy up to 2 GeV/u
- Large acceptance set-up
  - To be designed and built.
  - Not for very small cross sections (10^5 Hz beam)
  - H_2 target, He possible
  - Energy up to 2 GeV/u

- CBM cave : up to 10 GeV/u… but can CBM identify heavy residues? Be modified?