

The use of storage rings in the study of reactions at small momentum transfers

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“Paris”, France

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Why low momentum transfer hadronic scattering?

✓ Investigation of Nuclear Matter Distributions along Isotopic Chains:

- ⇒ halo, skin structure
- ⇒ probe in-medium interactions at extreme isospin (towards neutron matter)
- ⇒ in combination with electron scattering (ELISE project @ FAIR):
separate neutron/proton content of nuclear matter (deduce neutron skins)

method: elastic proton scattering at low q : high sensitivity to nuclear periphery

✓ Investigation of Giant Monopole Resonance in Doubly Magic Nuclei:

- ⇒ gives access to nuclear compressibility ⇒ key parameters of the EOS
- ⇒ new collective modes (breathing mode of neutron skin)

method: inelastic α scattering at low q

✓ Investigation of Gamow-Teller Transitions:

- ⇒ weak interaction rates for $N = Z$ waiting point nuclei in the rp-process
- ⇒ electron capture rates in the pre-supernova evolution (core collapse)

method: ($^3\text{He}, t$), ($d, ^2\text{He}$) charge exchange reactions at low q



Example:

The Collective Response of the Nucleus: Giant Resonances

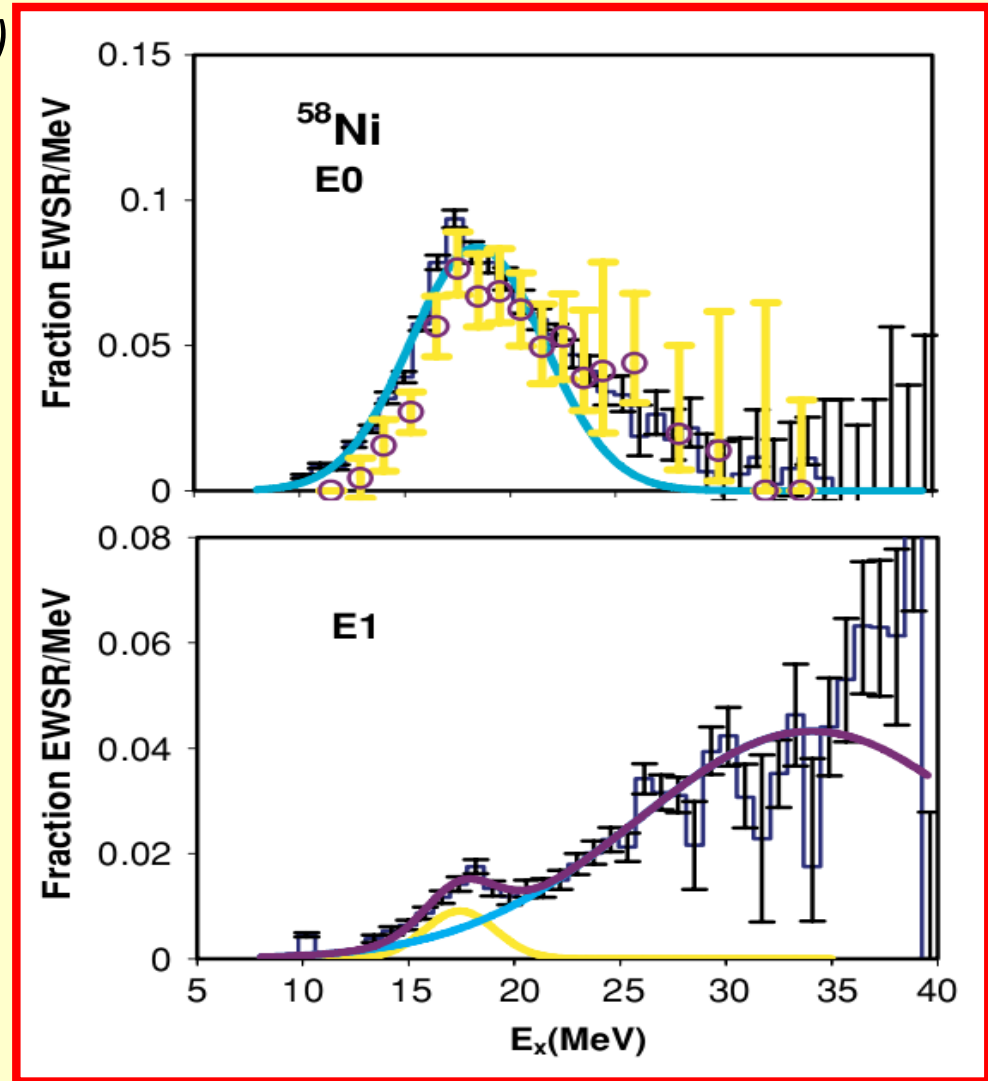
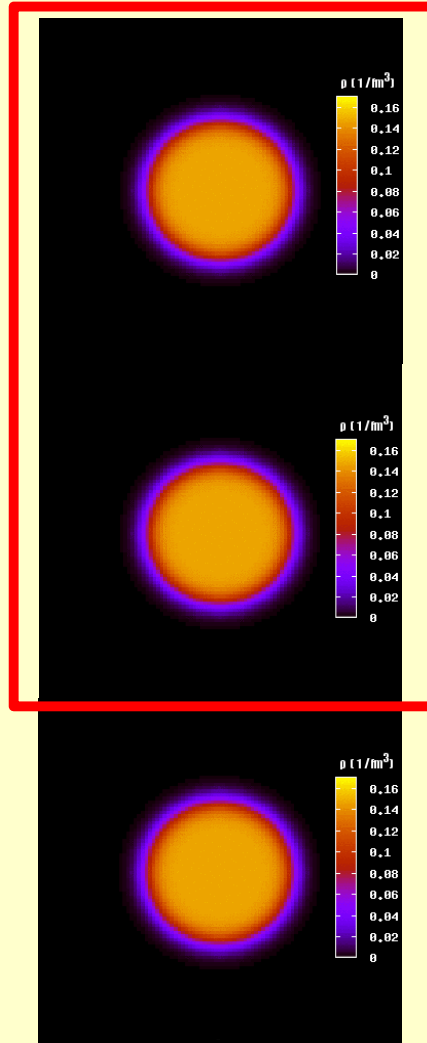
Compression
modes

Isoscalar (In phase)
 $\Delta T = 0$

Monopole
 $\Delta L = 0$
(GMR)

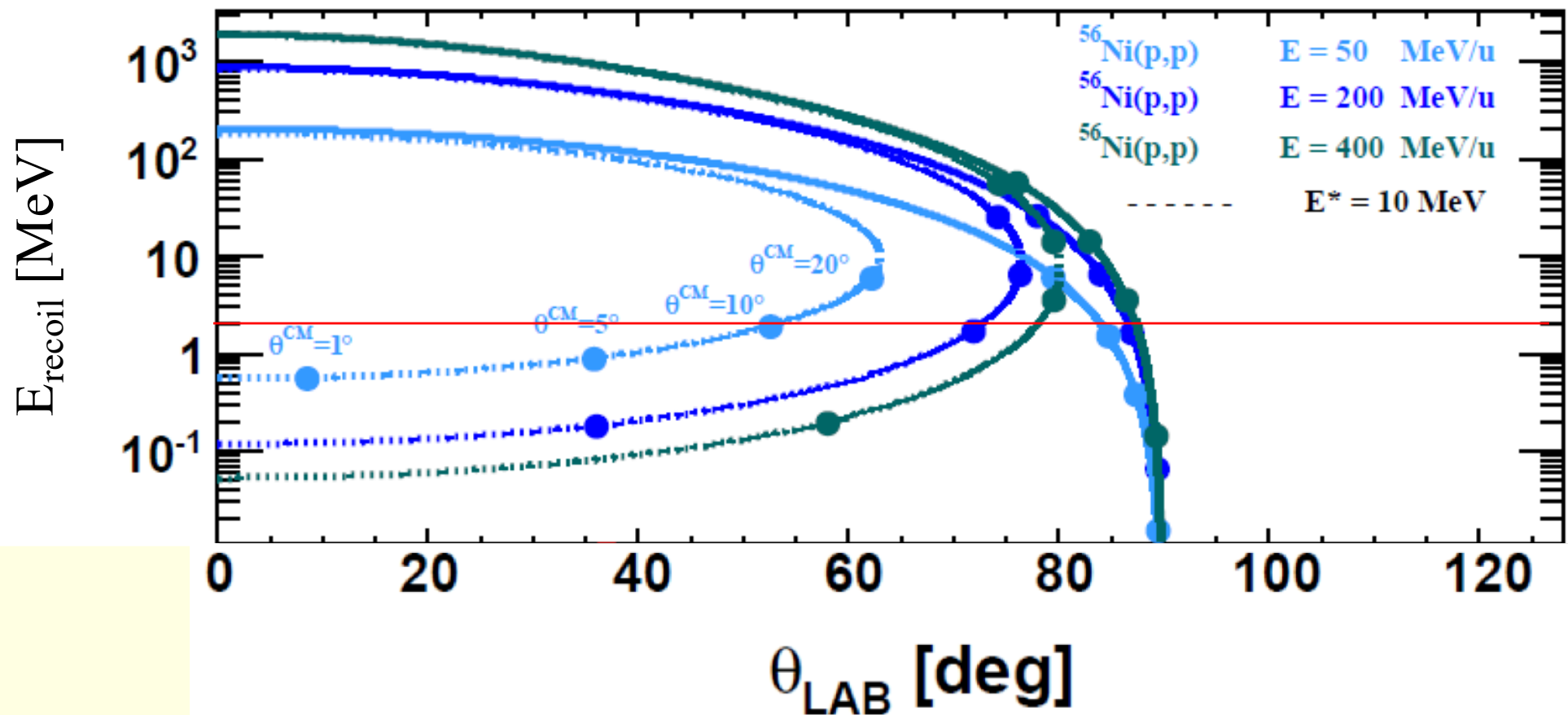
Dipole
 $\Delta L = 1$
(GDR)

Quadrupole
 $\Delta L = 2$
(GQR)



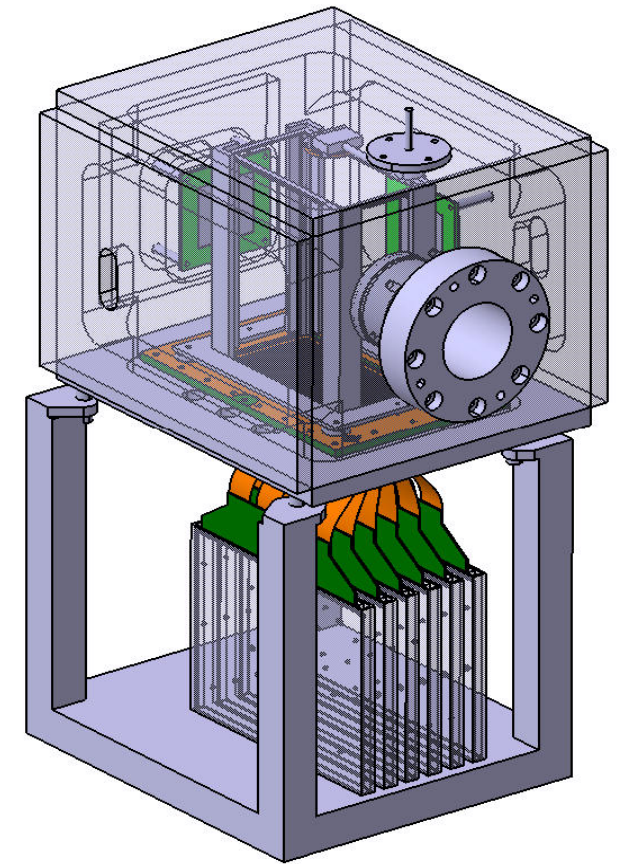
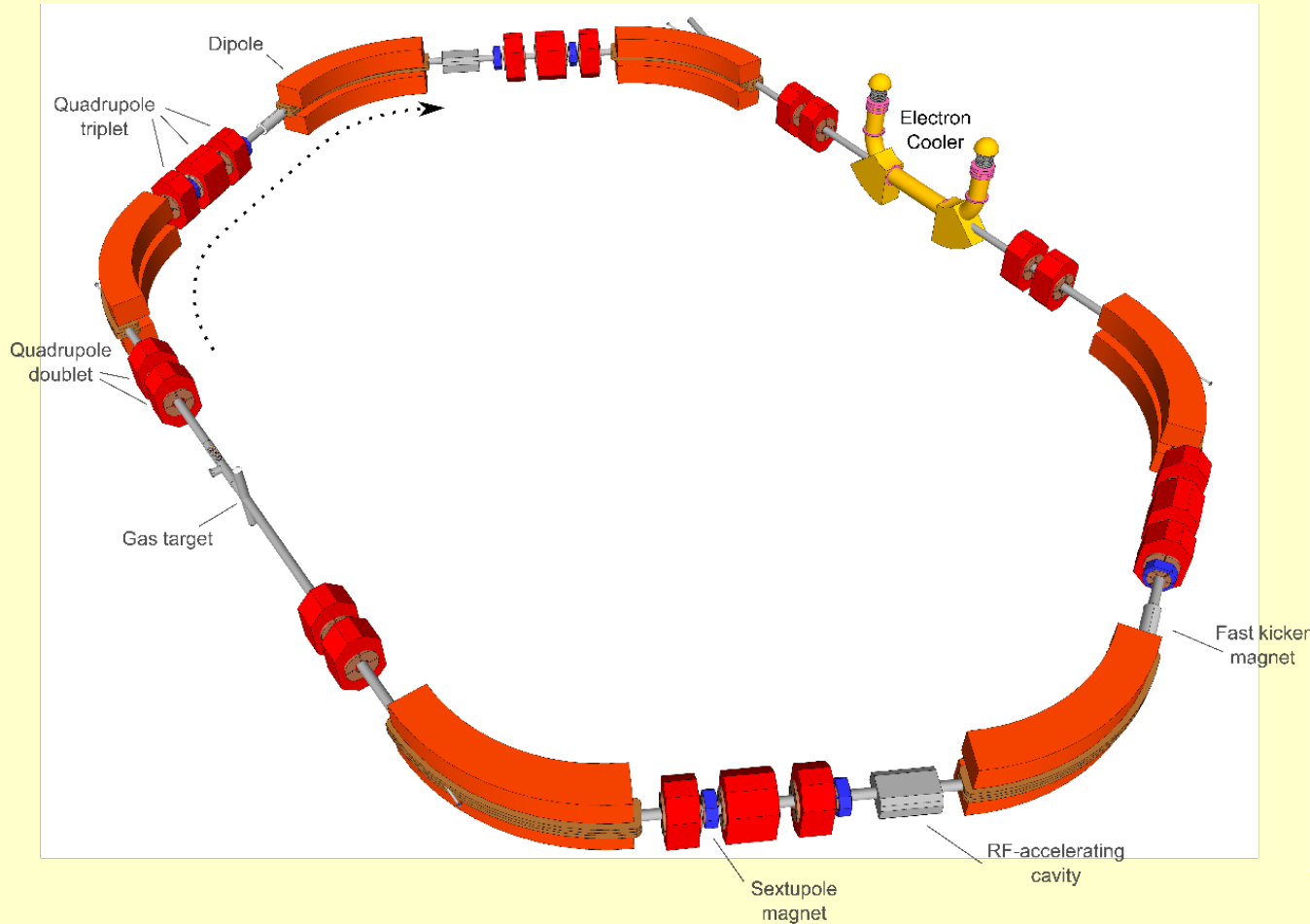
Y.-W. Lui et al., Phys. Rev. C 73 (2006) 014314

Kinematics for inverse reaction for ^{56}Ni



Storage Ring

Active Target



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Advantages and disadvantages of storage-ring experiments

Advantages:

Large intensities in the ring (around 5×10^{12} /s)

Little energy loss in the target

No target window (no background)

High resolution of the beam (cooling)

Forward focusing for high-energy particles

Low energy threshold

Disadvantages:

Ultra high vacuum with an operational target

Very small recoil energies for low q

Thin targets ($3 \times 10^{13}/\text{cm}^2$, for hydrogen target)



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First EXL experiment with the existing storage ring at GSI (ESR)

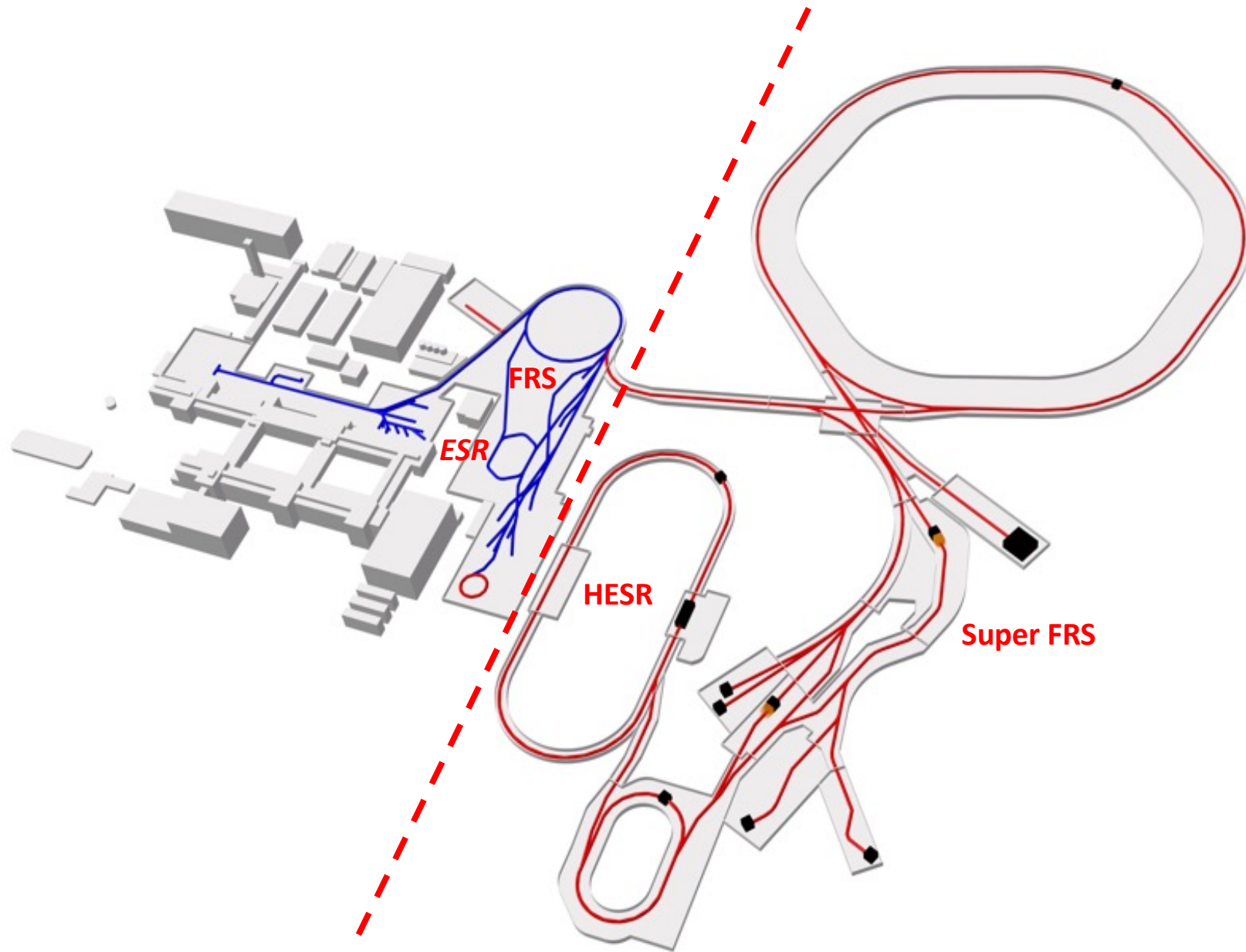
EXL=EXotic nuclei studied with Light-ion induced reactions at storage rings



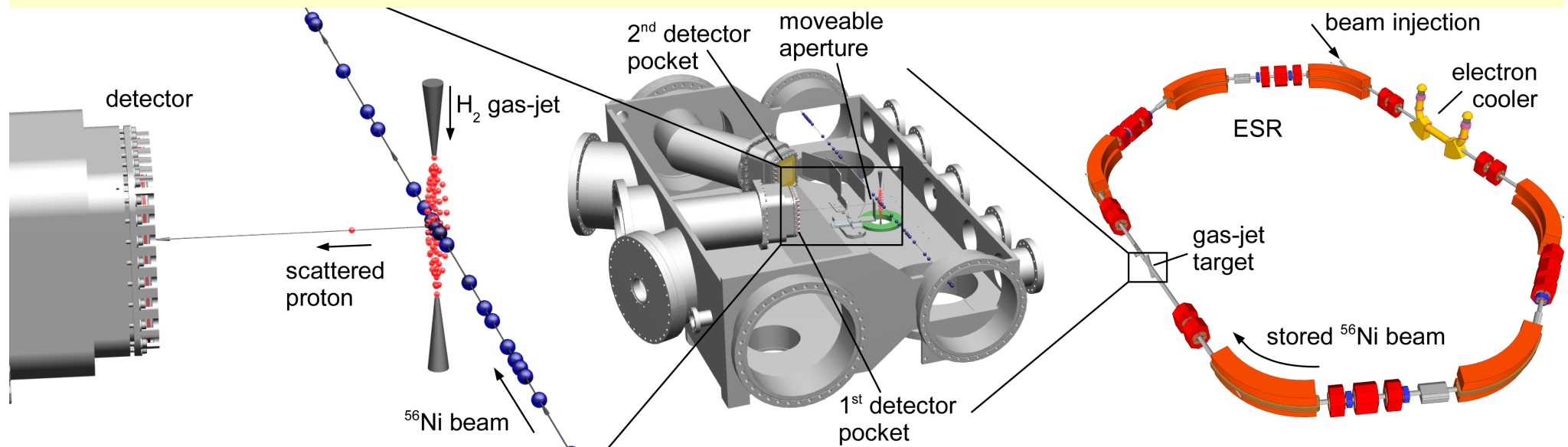
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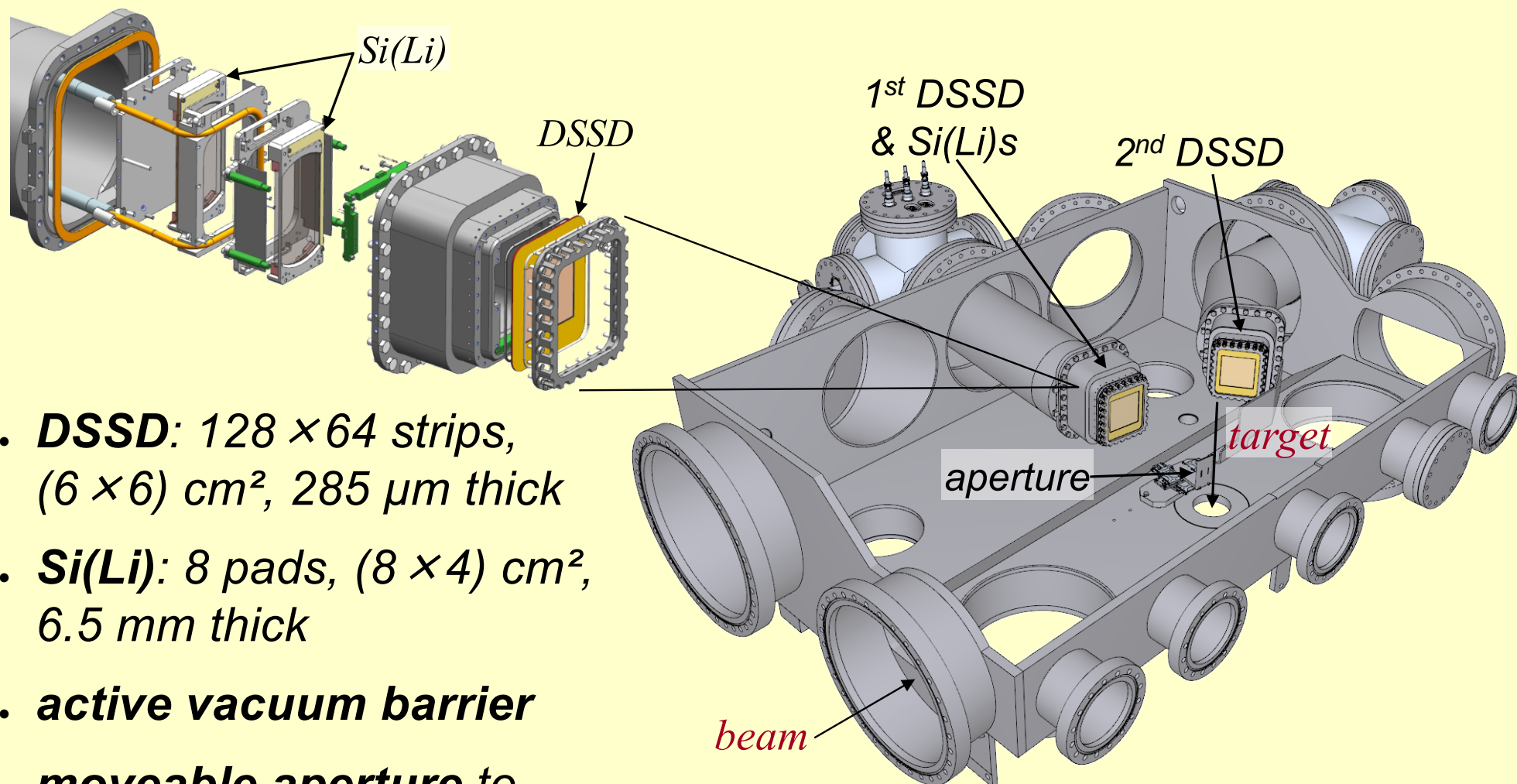
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EXL setup @ ESR

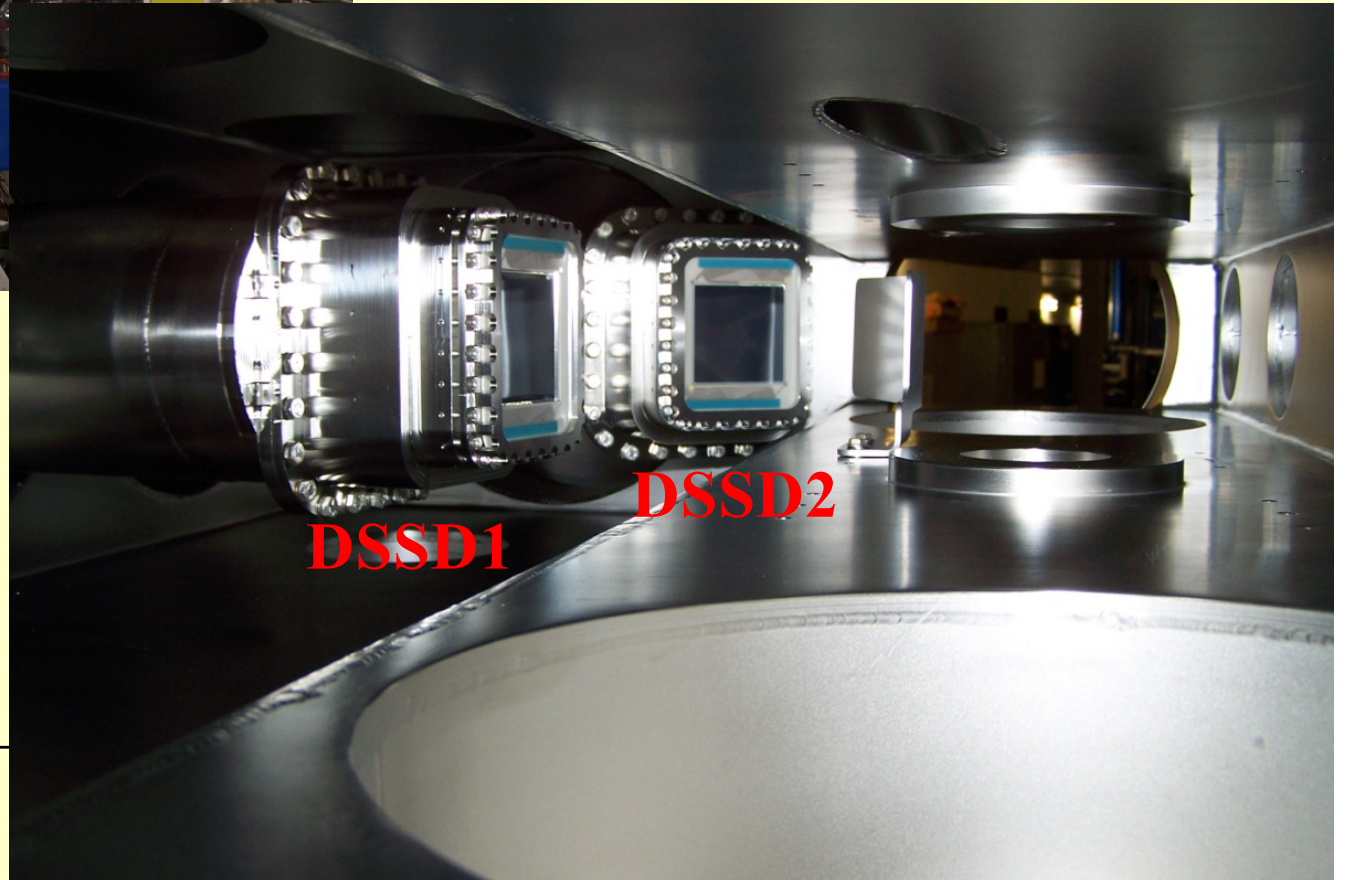
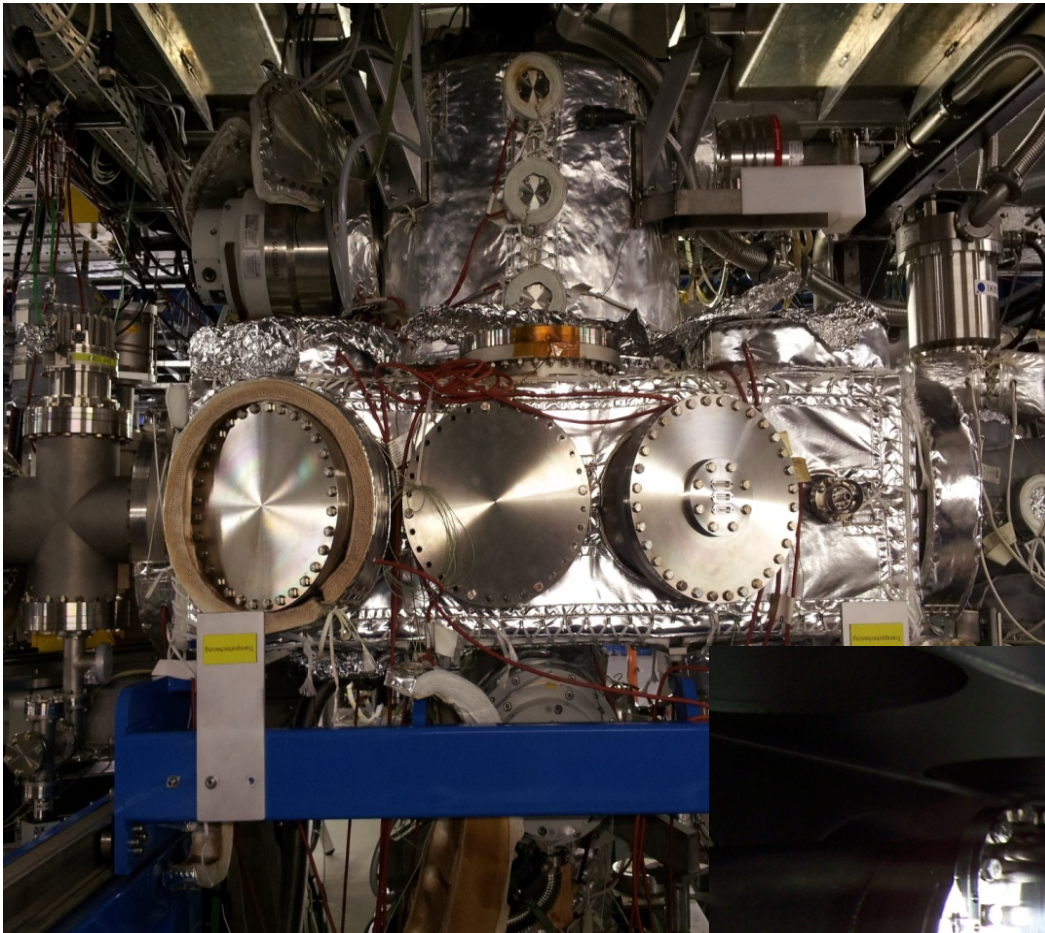


The new ESR Scattering chamber

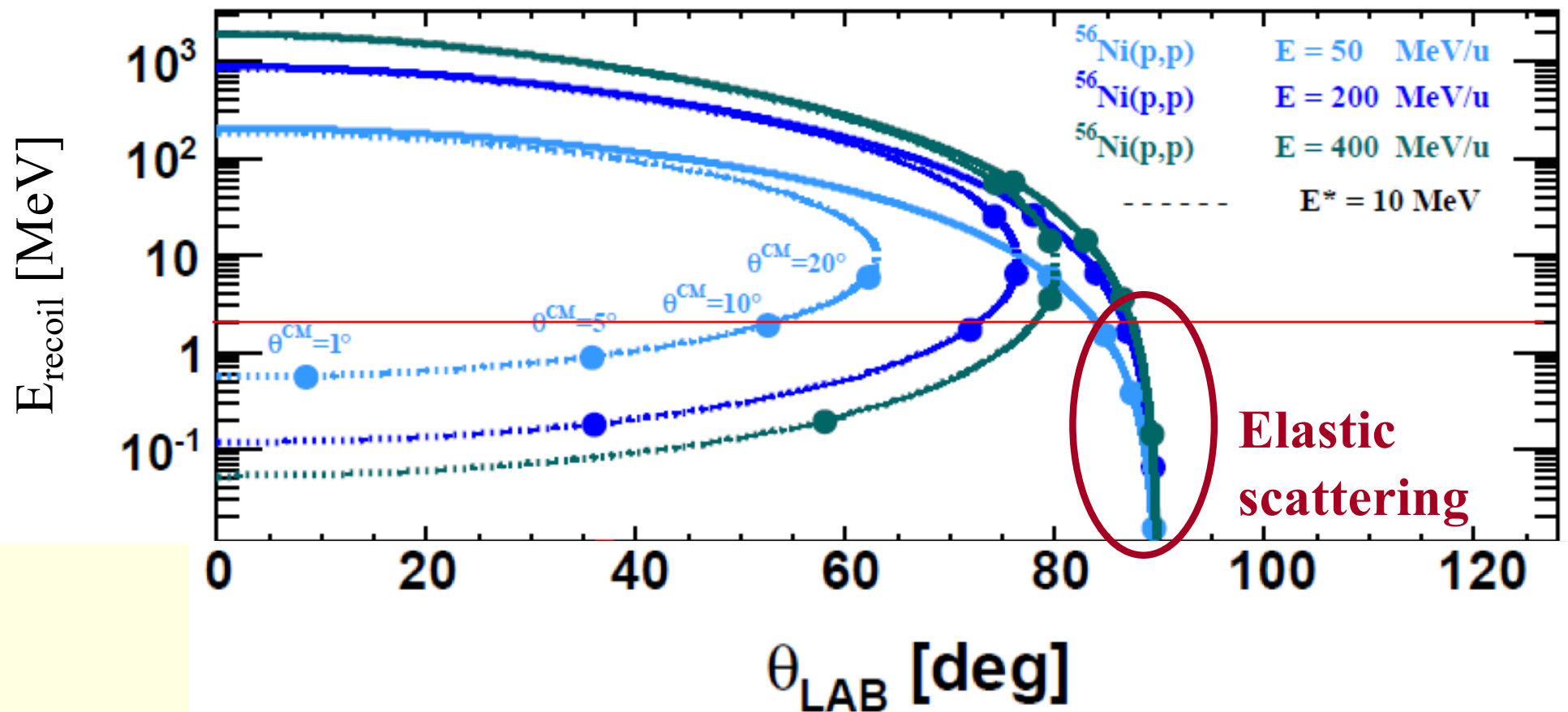


- **DSSD:** 128×64 strips, $(6 \times 6) \text{ cm}^2$, $285 \mu\text{m}$ thick
- **Si(Li):** 8 pads, $(8 \times 4) \text{ cm}^2$, 6.5 mm thick
- **active vacuum barrier**
- **moveable aperture to improve angular resolution**





Kinematics for inverse reaction for ^{56}Ni

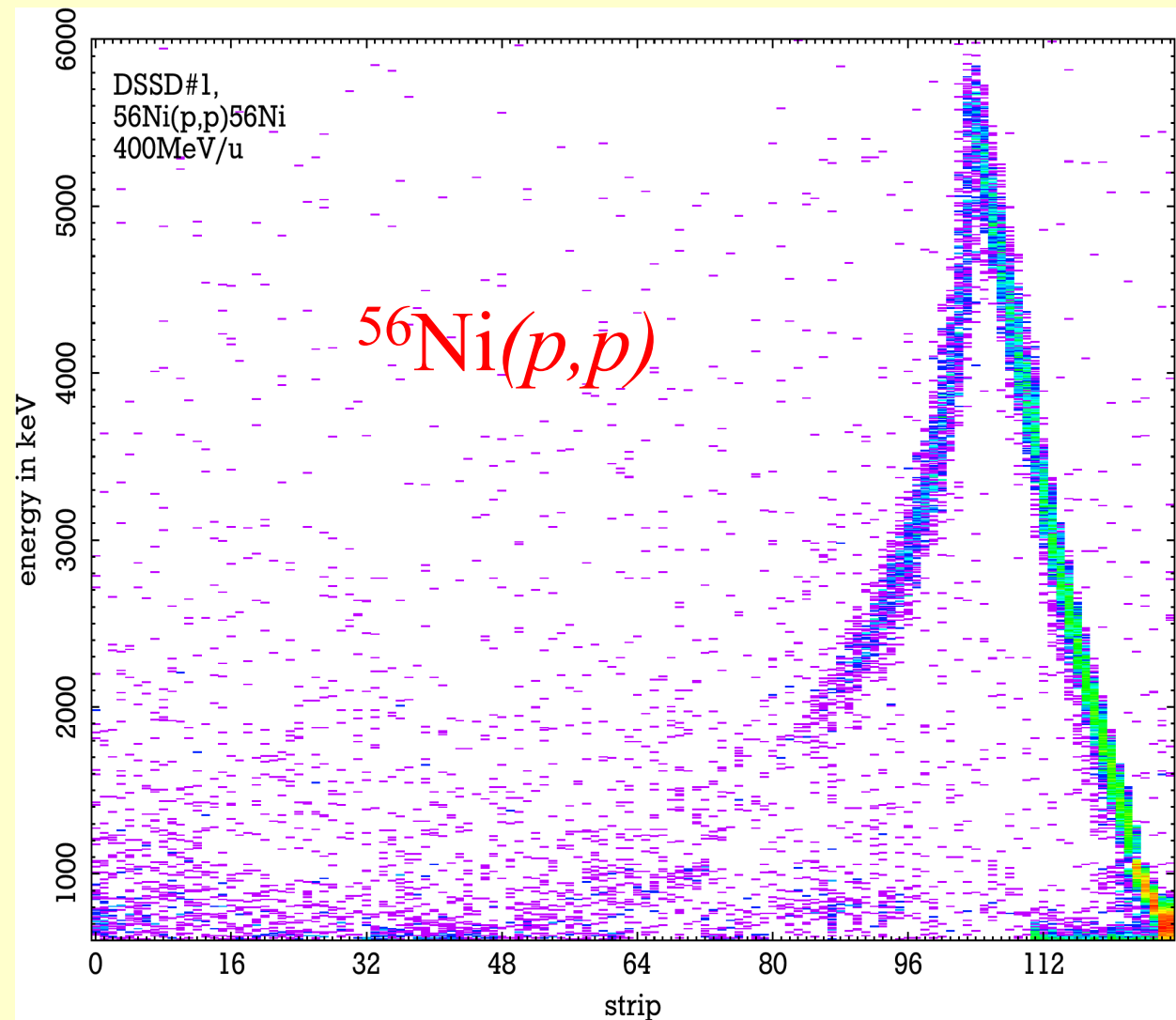


First results with radioactive beam

October 25, 2012:

**First Nuclear Reaction
Experiment with Stored
Radioactive Beam!!!!**

Beam energy 400 MeV/u

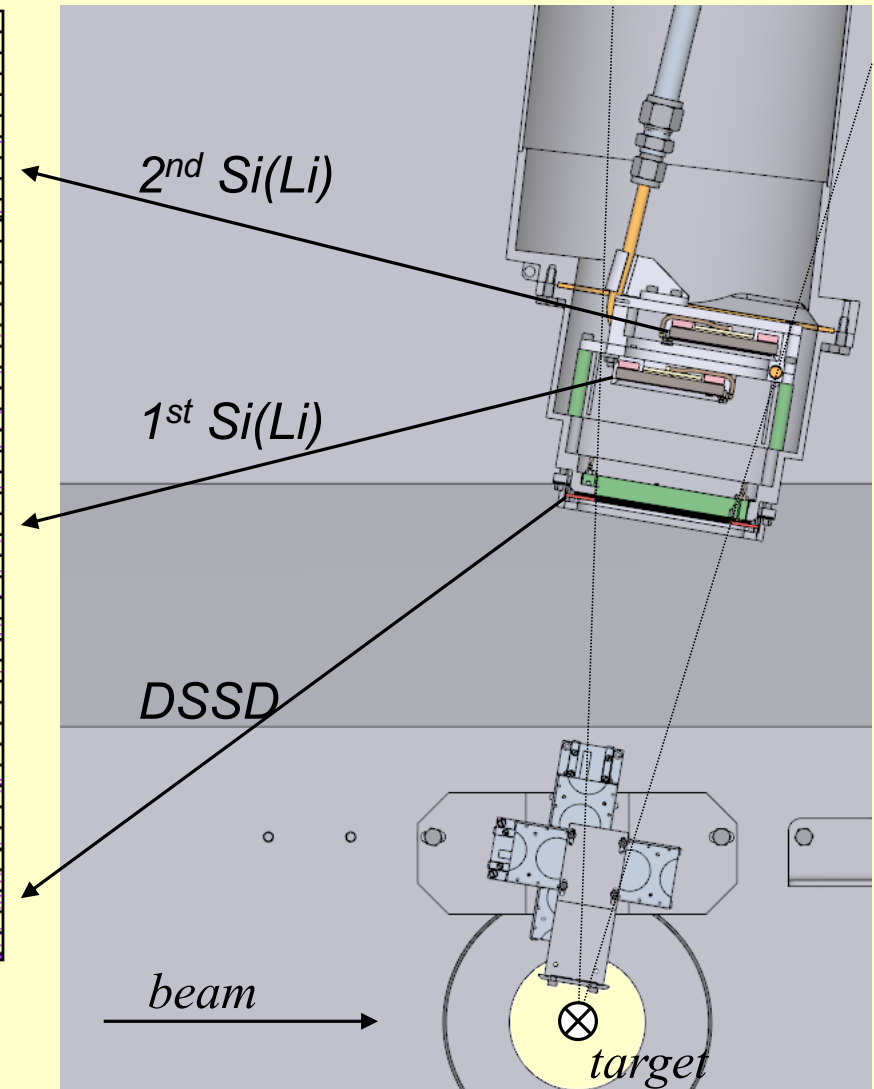
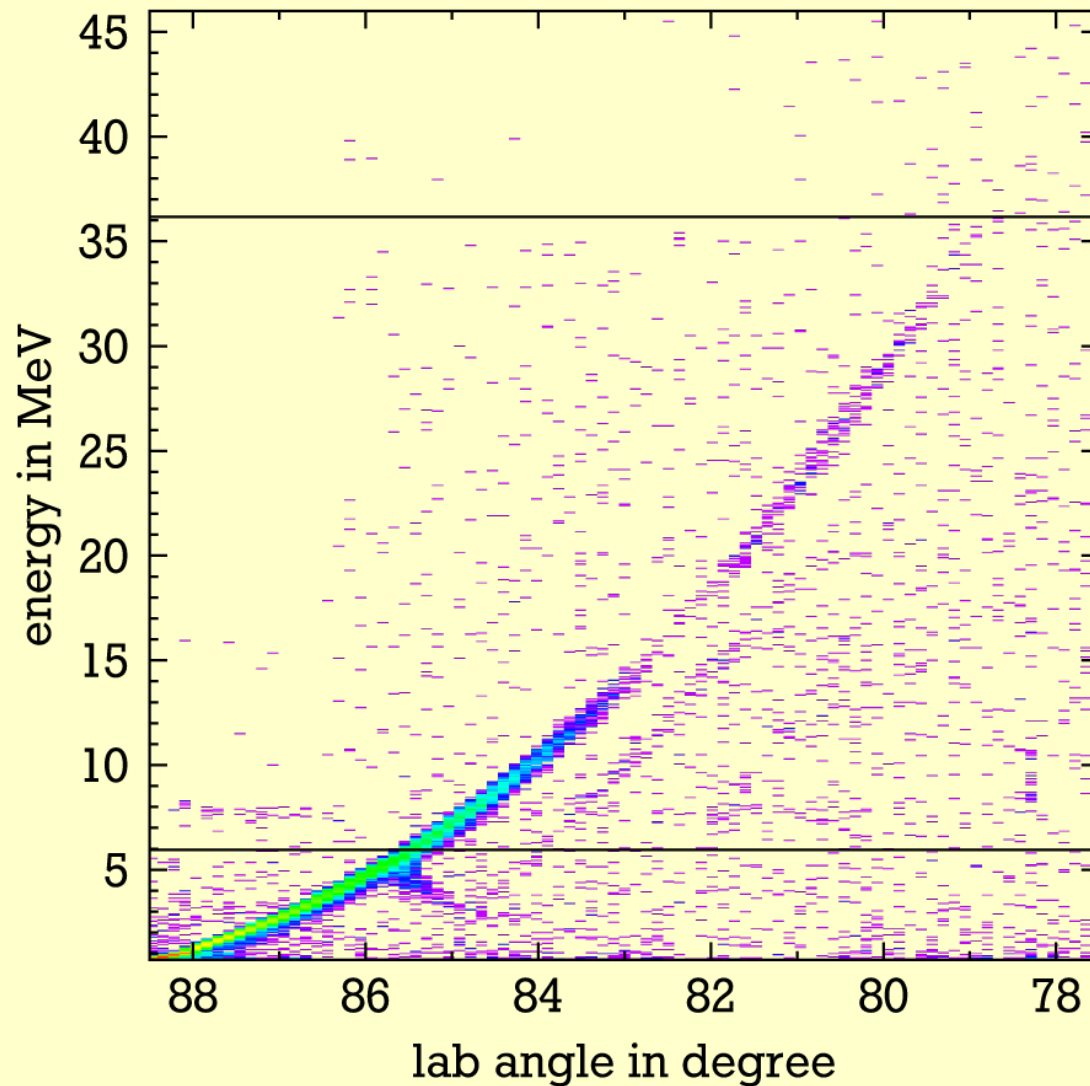


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First results with radioactive beam

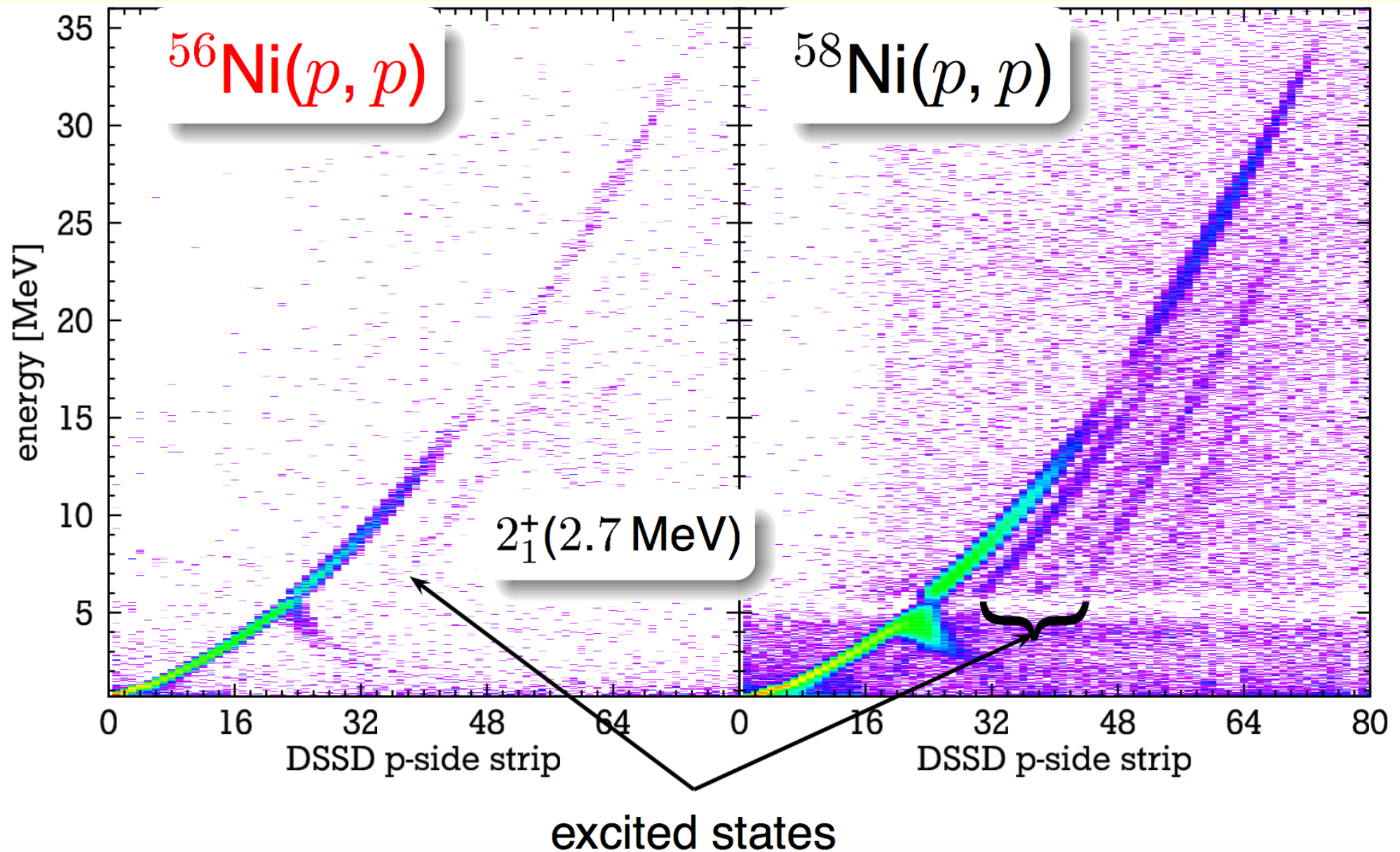
$^{56}\text{Ni}(p,p)$, $E = 400 \text{ MeV/u}$



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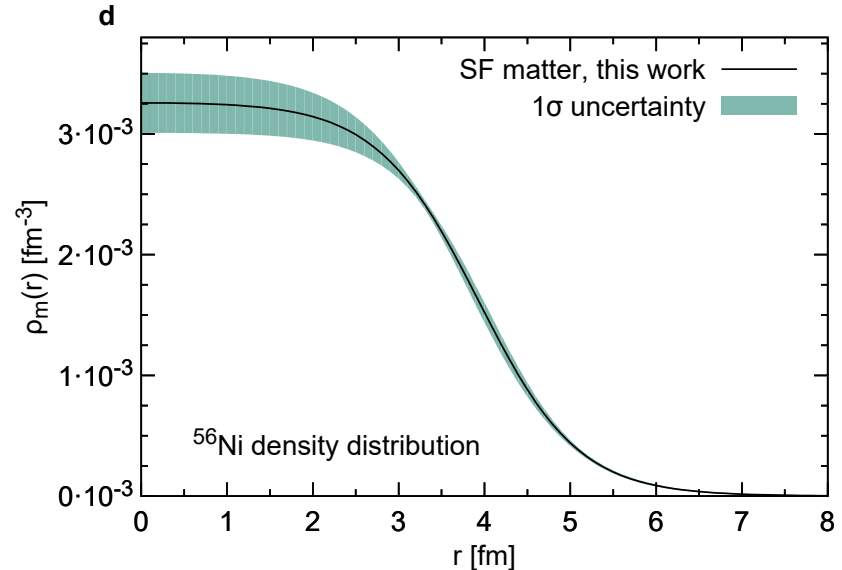
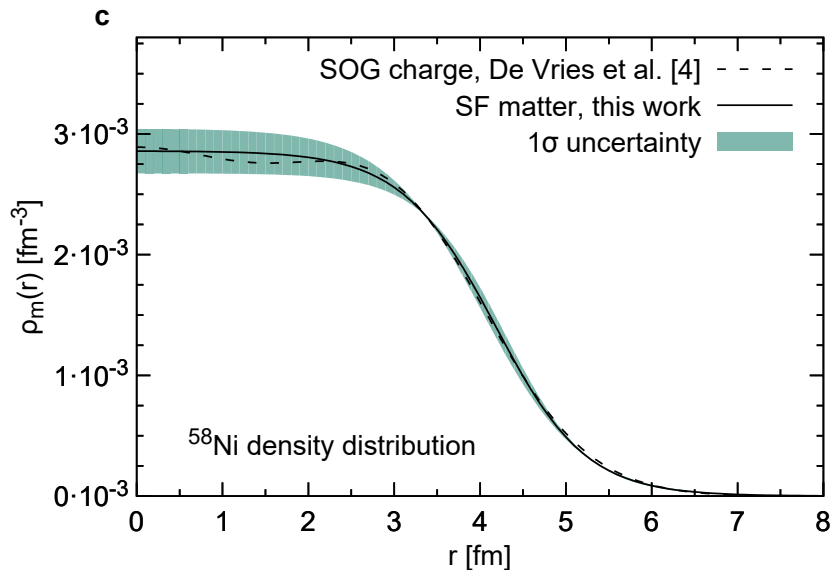
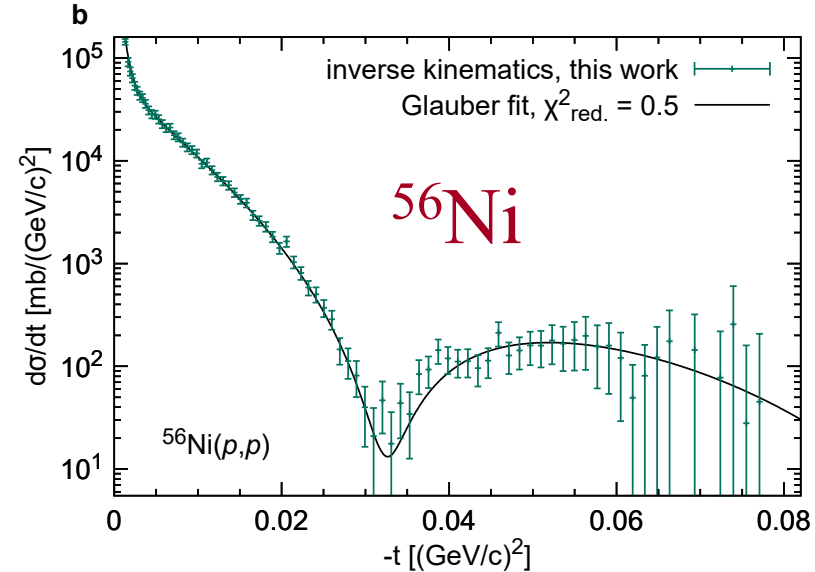
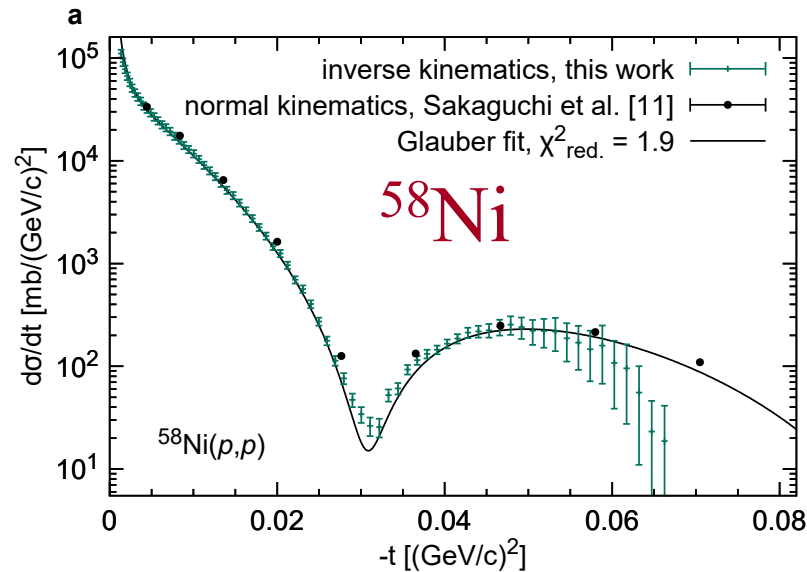
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First results with radioactive beam

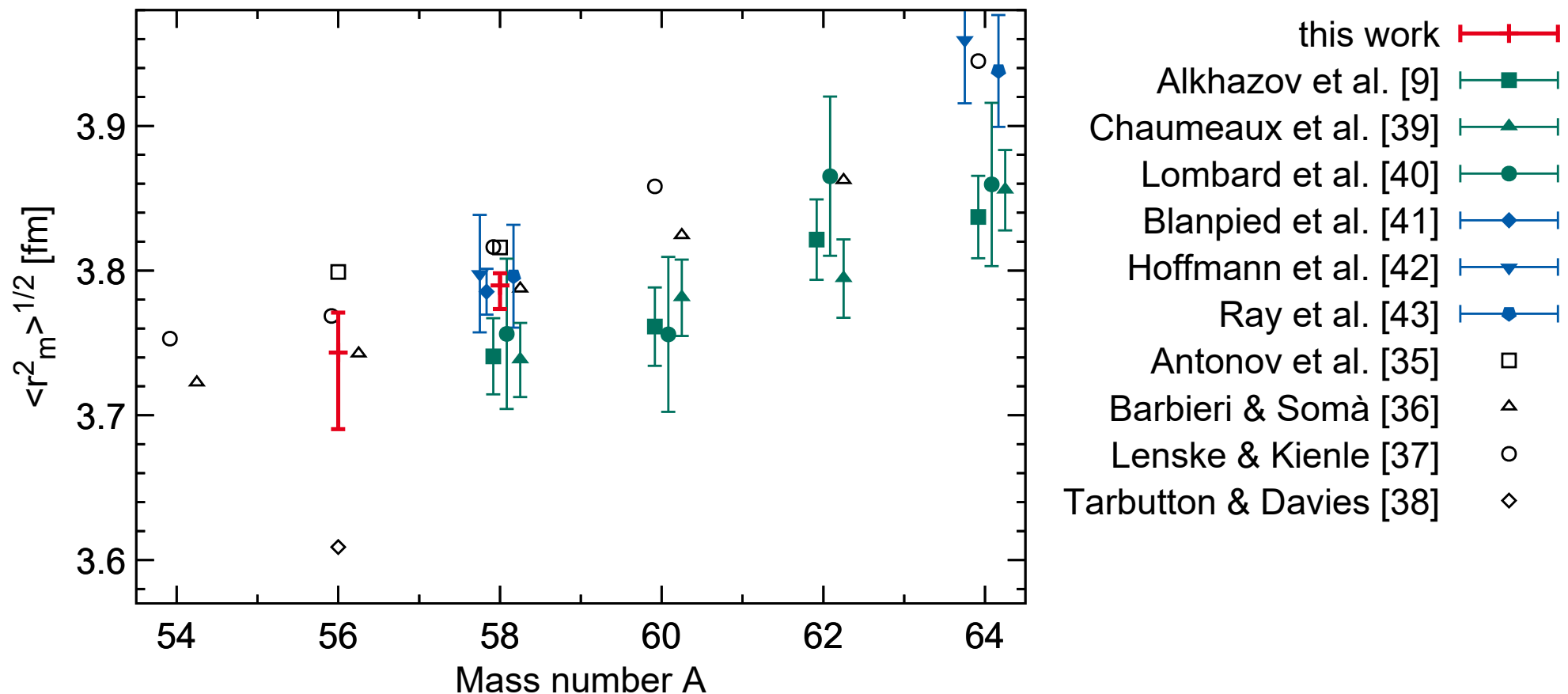


First results with radioactive beam

- Elastic p-scattering off Ni isotopes (E105)



First results with radioactive beam and proton target



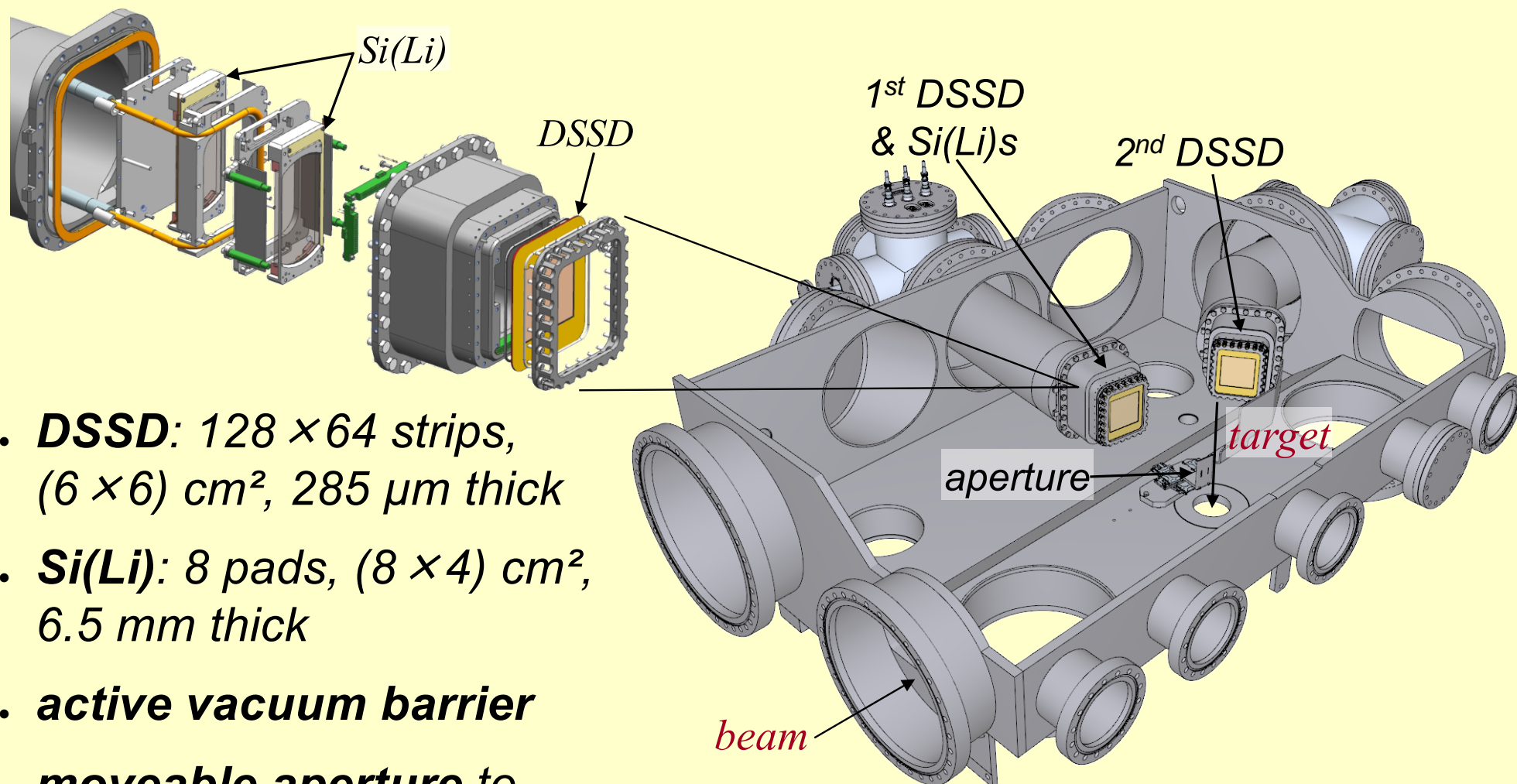
M. von Schmid et al., Submitted to Nature



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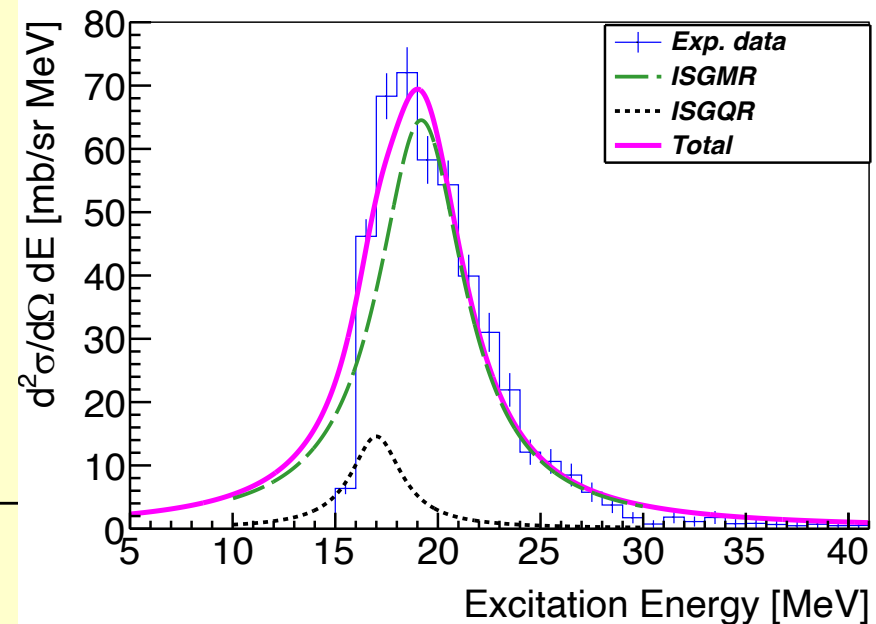
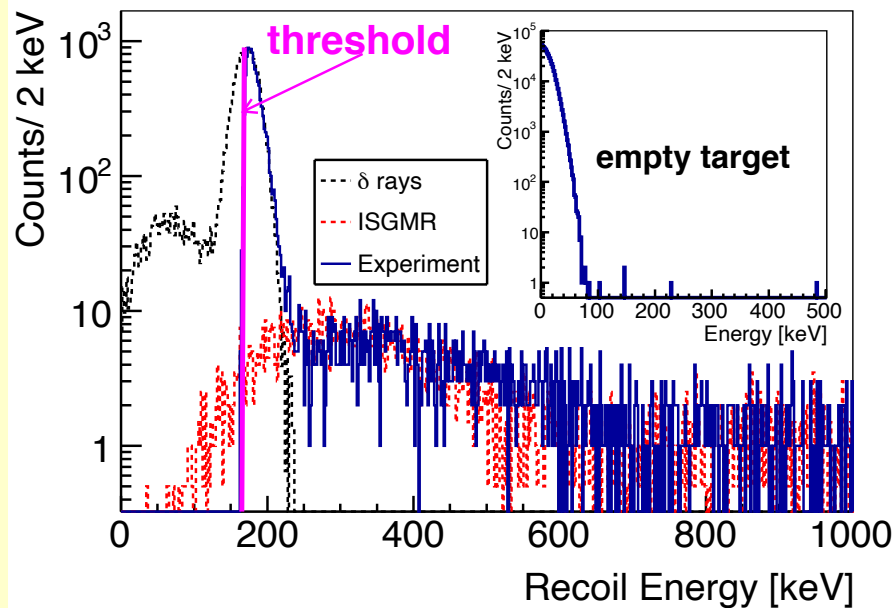
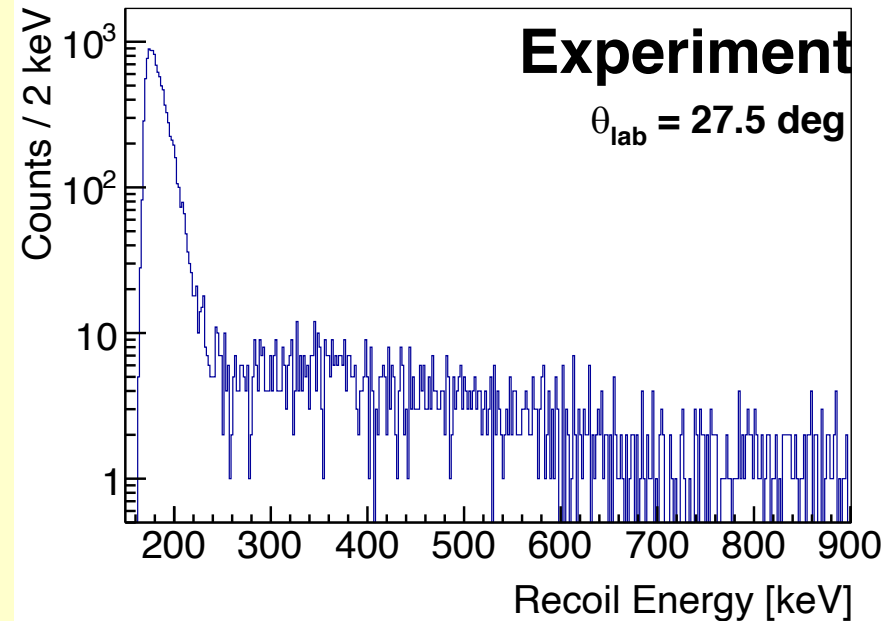
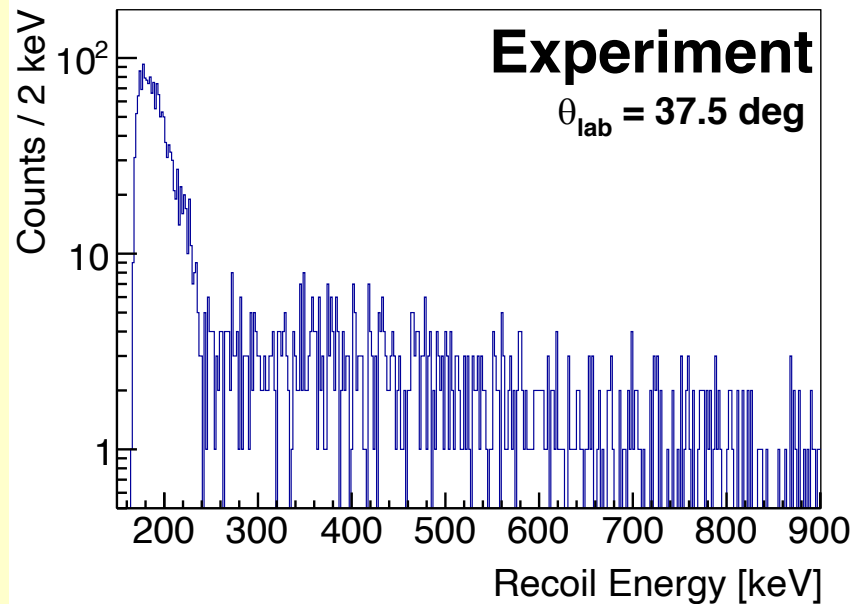
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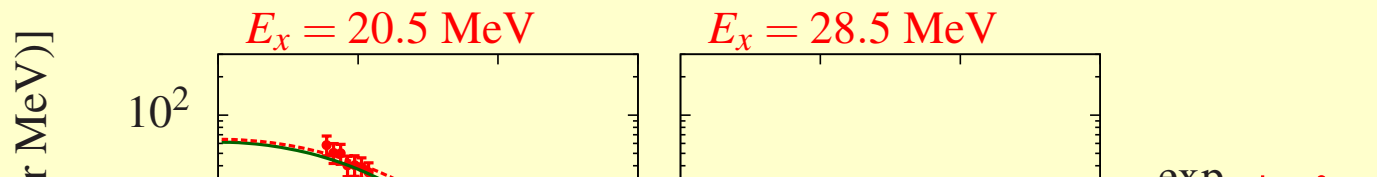


Inelastic alpha scattering (100 MeV/nucleon, PhD J.C. Zamora)

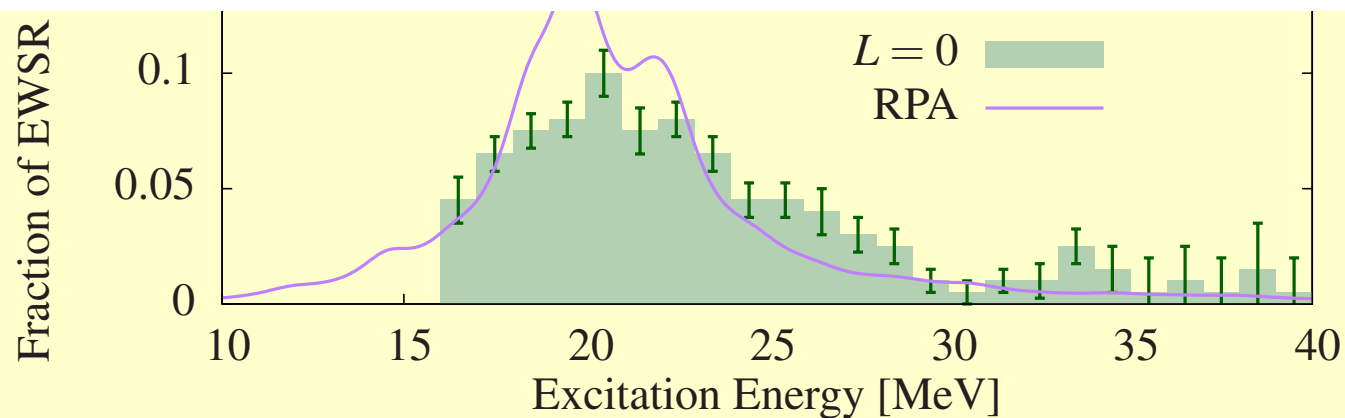


Inelastic alpha scattering (100 MeV/nucleon) from ^{58}Ni

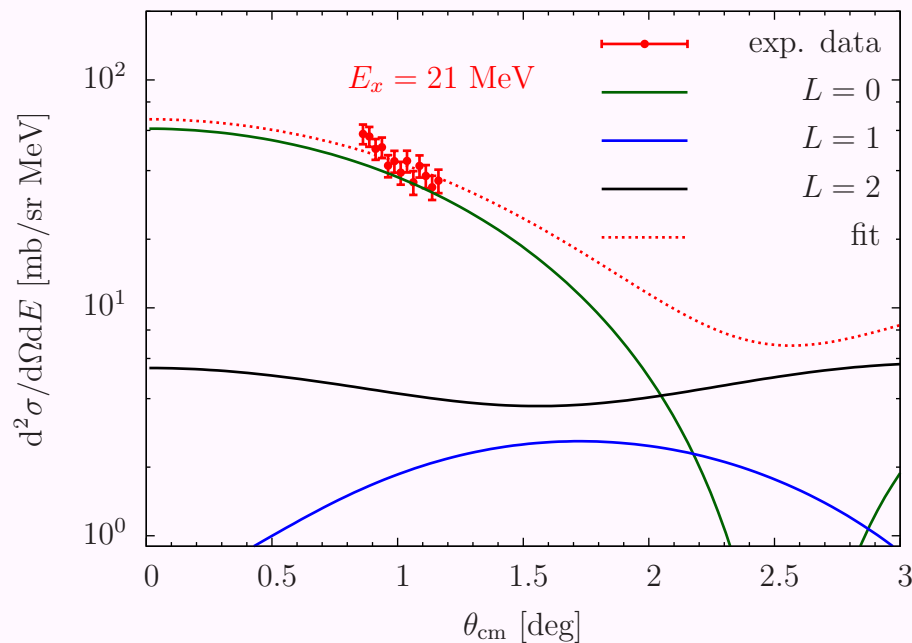
- J.C. Zamora et al., PLB 763, 16 (2016)



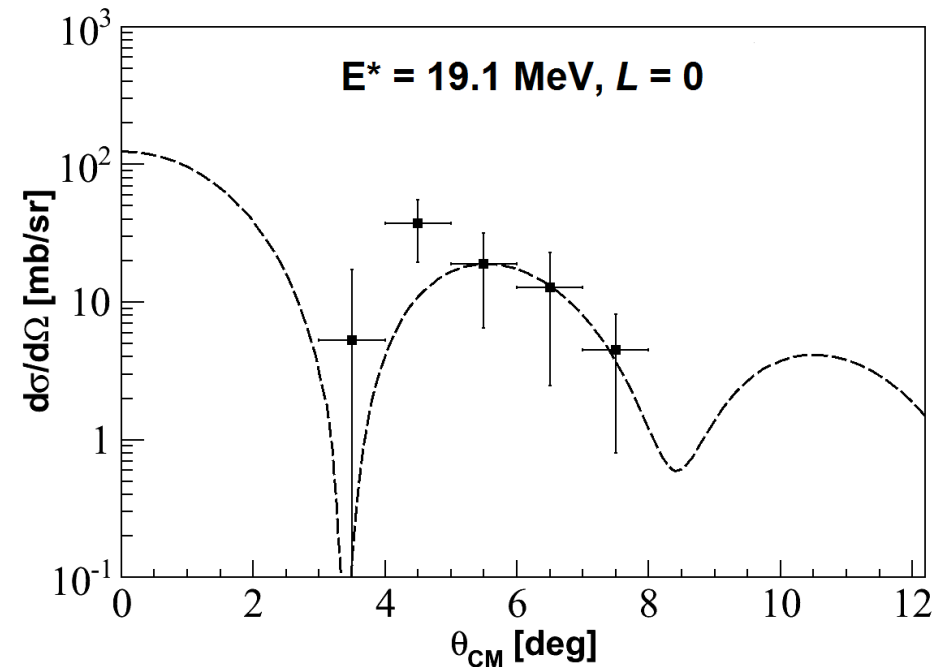
Reference	Centroid [MeV]	Width _{RMS} [MeV]	EWSR [%]
this work	20.5(6)	4.6(6)	79^{+12}_{-11}
PRC 73, 014314 (2006)	$19.20^{+0.44}_{-0.19}$	$4.89^{+1.05}_{-0.31}$	85^{+13}_{-10}
PRC 61, 067307 (2000)	$20.30^{+1.69}_{-0.14}$	$4.25^{+0.69}_{-0.23}$	74^{+22}_{-12}
PLB 637, 43 (2006)	$19.9^{+0.7}_{-0.8}$	–	92^{+4}_{-3}



Monopole mode in ^{58}Ni and ^{56}Ni : Ring vs. active target



^{58}Ni



^{56}Ni



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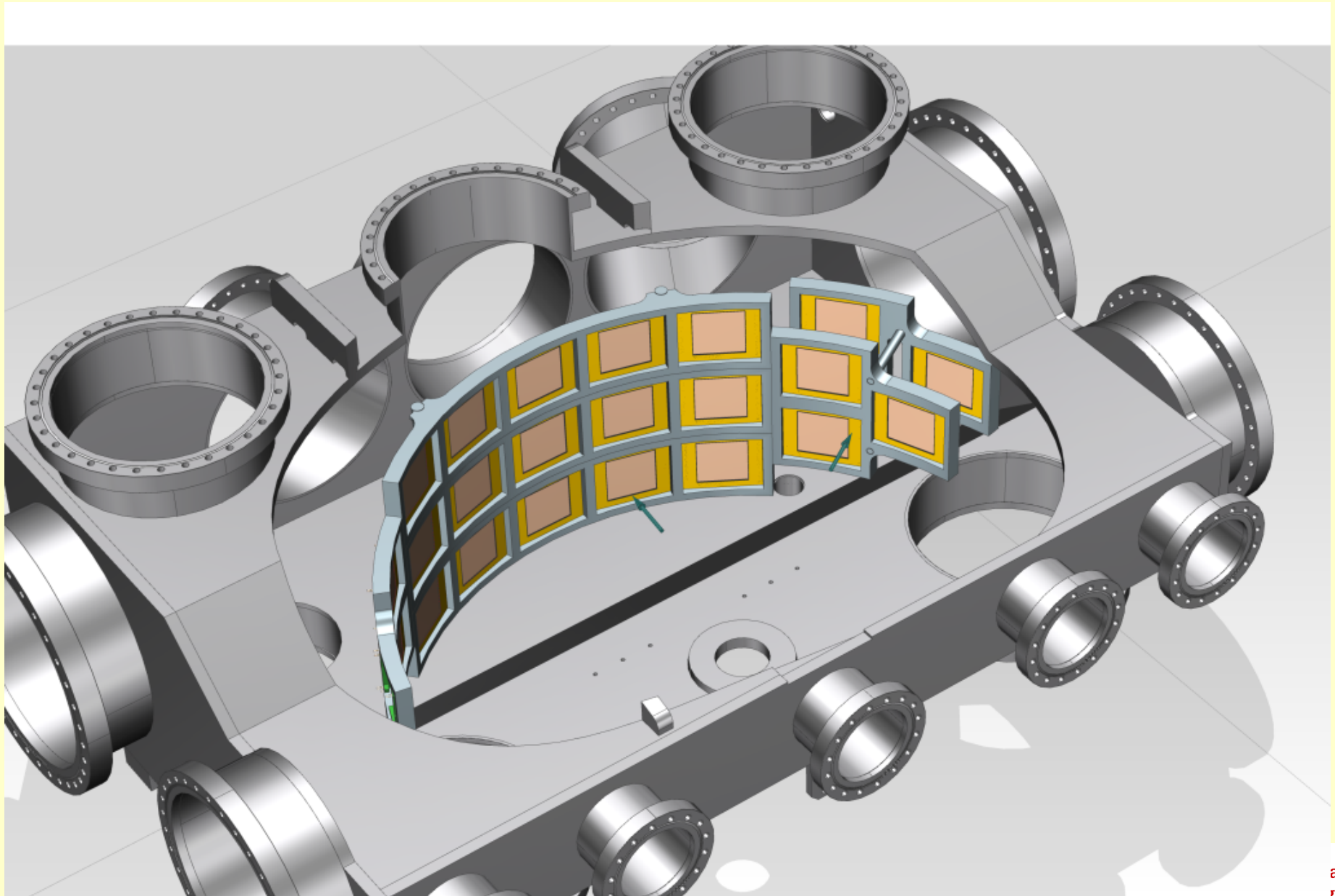
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Conclusions and outlook

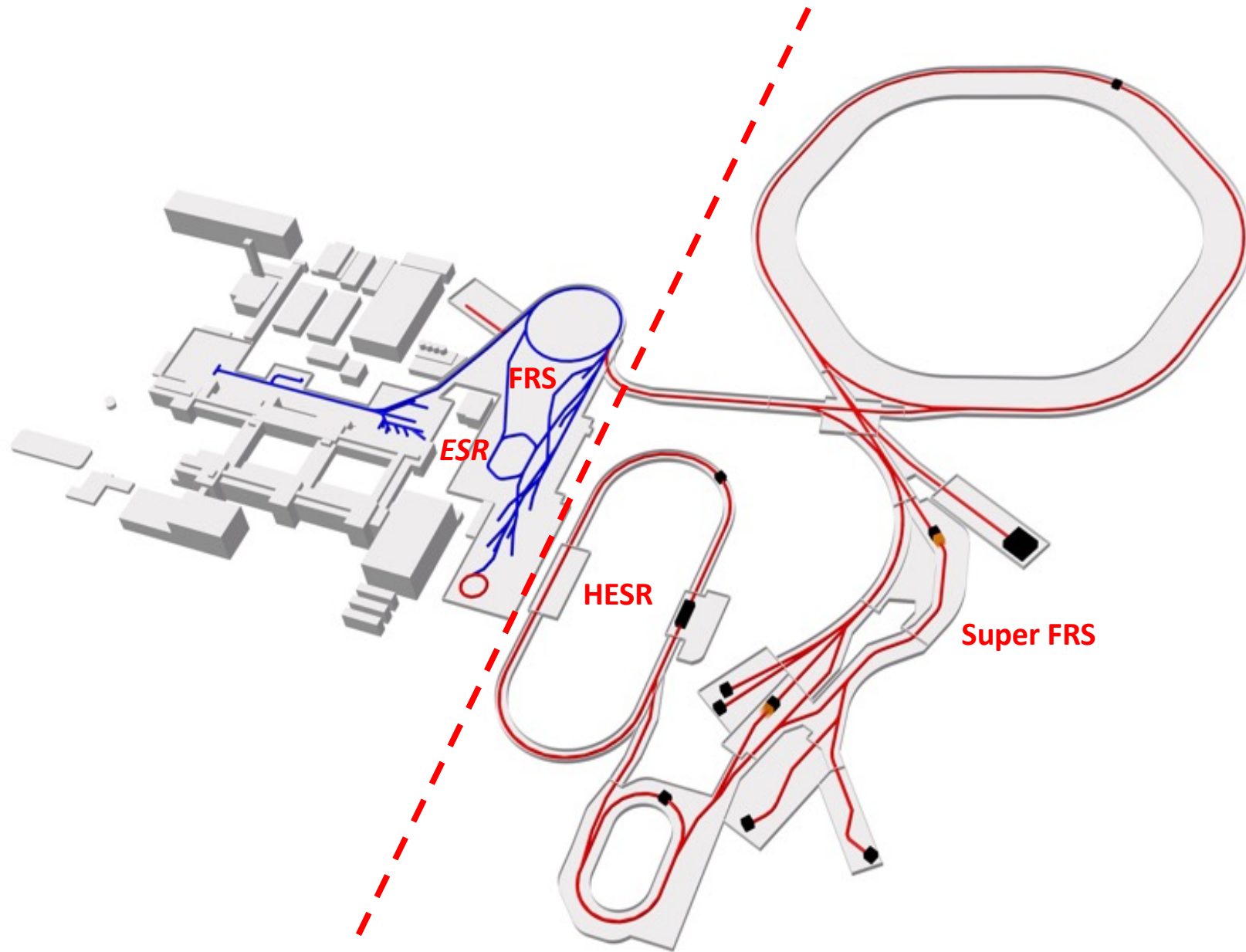
- Large efforts are taking place for both the ring environments as well as for active targets.
- Bulk properties (radius, compressibility etc.) are the main subject of the present low-q measurements.
- The goal is to go towards neutron-rich medium heavy and heavy nuclei (astrophysical processes).
- First measurements are done with Ni isotopes.
- First physics measurements have already produced beautiful results.
- More measurements are planned or being discussed with both systems (ESR, HESR, ACTAR ...), but with major improvements and for various reactions.



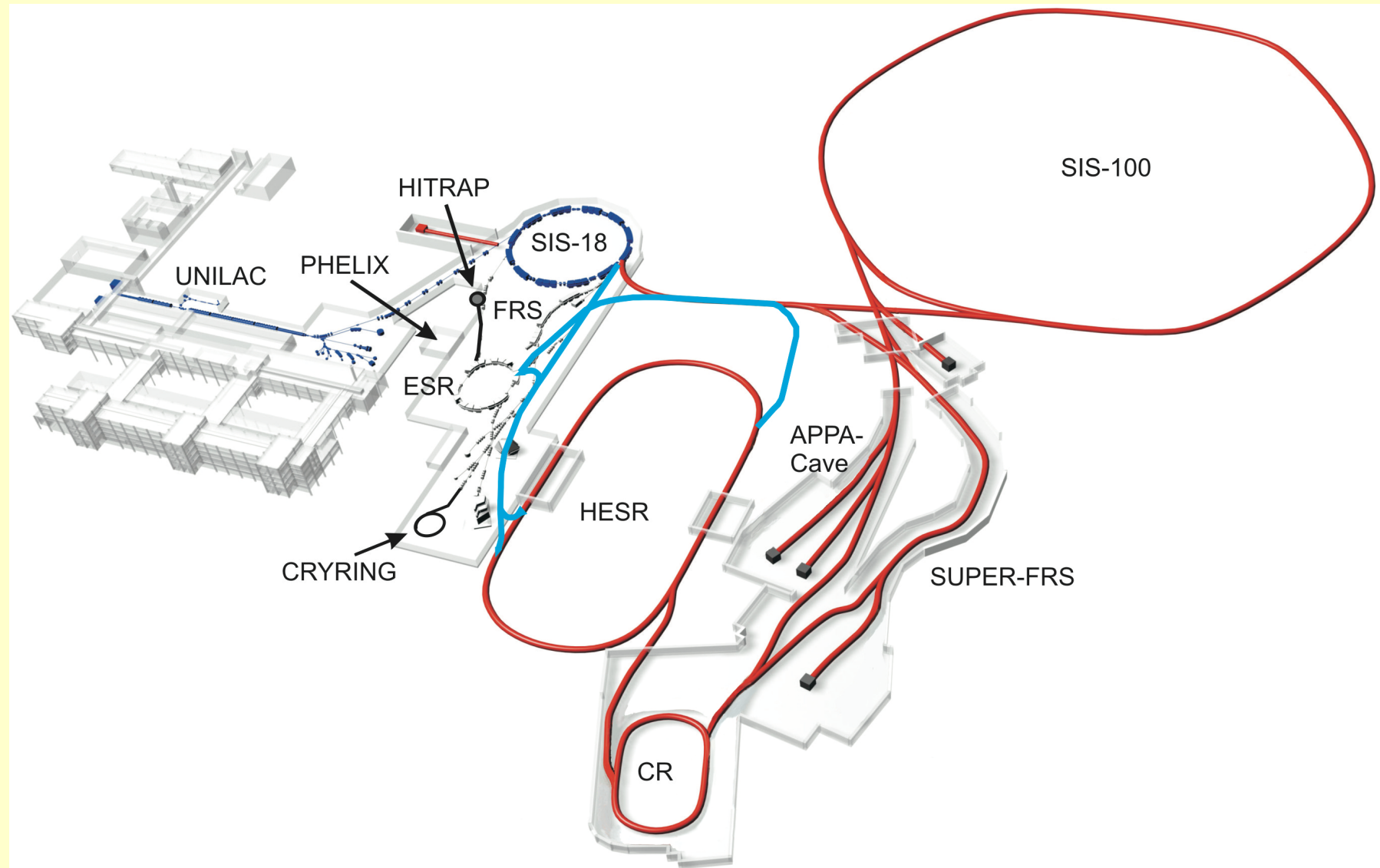
Upgrade of the first EXL experiment



GSI and FAIR



Intermediate-range Plans for rings



Exotic nuclei studied in storage rings

The EXL-E105 Collaboration



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B. Streicher^{2,4}, L. Stuhl³, M. Takechi⁴, M. Thürauf², T. Uesaka⁹, H. Weick⁴, J.S. Winfield⁴,
D. Winters⁴, P.J. Woods¹⁰, T. Yamaguchi¹¹, K. Yue^{4,7}, **J.C. Zamora**², J. Zenihiro⁹ for EXL coll.

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¹⁰ The University of Edinburgh

¹¹ Saitama University



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Thank you!



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