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

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On behalf of the EXL collaboration

NUSTAR week

Milan, Italy

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university of groningen

kvi - center for advanced radiation technology

Why low momentum transfer hadronic scattering?

✓ Investigation of Nuclear Matter Distributions along Isotopic Chains:

⇒ halo, skin structure

⇒ probe in-medium interactions at extreme isospin (almost pure 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

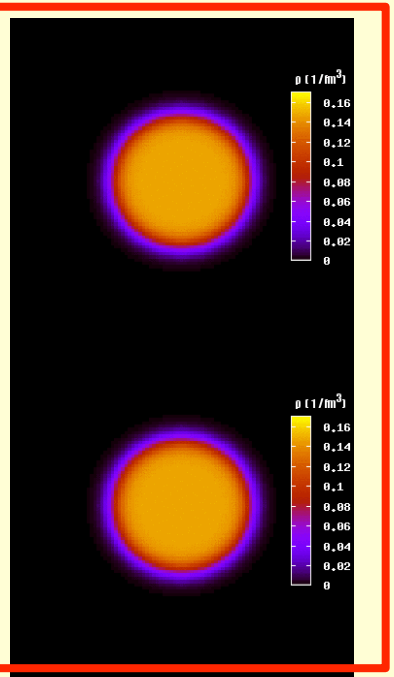
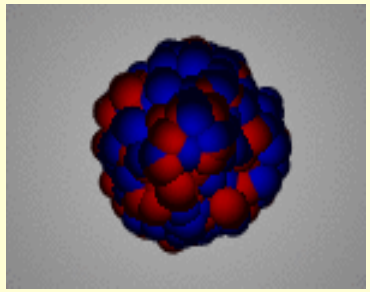
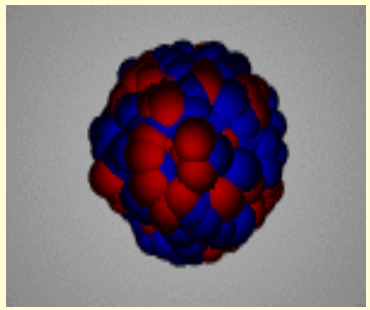
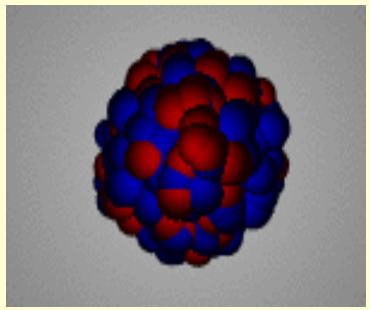
⇒ electron capture rates in the pre-supernova evolution (core collapse)

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

Bulk Properties

Example:
The Collective Response of the Nucleus: Giant Resonances

Compression modes

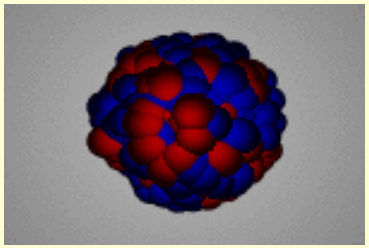
	Isoscalar (In phase) $\Delta T = 0$	*Isovector (Out of phase)* $\Delta T = 1$
Monopole $\Delta L = 0$ *(GMR)*		
Dipole $\Delta L = 1$ *(GDR)*		
Quadrupole $\Delta L = 2$ *(GQR)*		

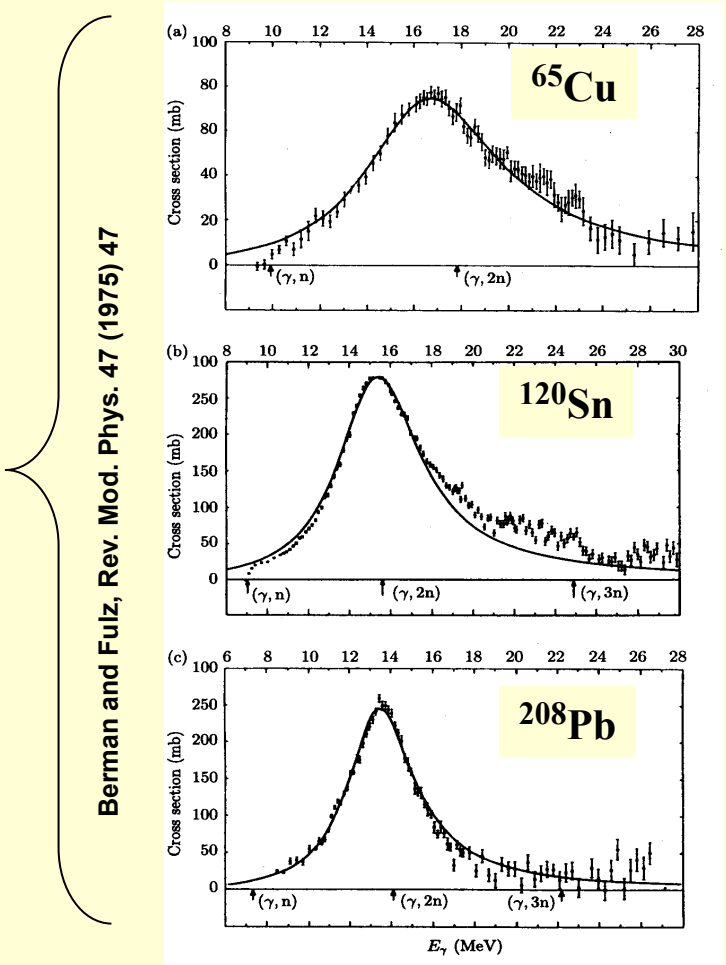
Example:
The Collective Response of the Nucleus: Giant Resonances

Photo-neutron cross sections

Electric giant resonances

Dipole (GDR)





Berman and Fulz, Rev. Mod. Phys. 47 (1975) 47

Example:
The Collective Response of the Nucleus: Giant Resonances

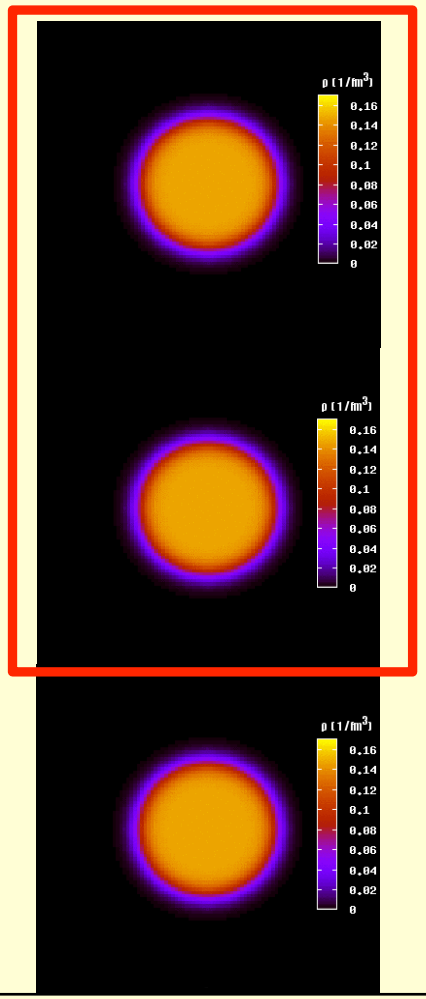
Compression modes

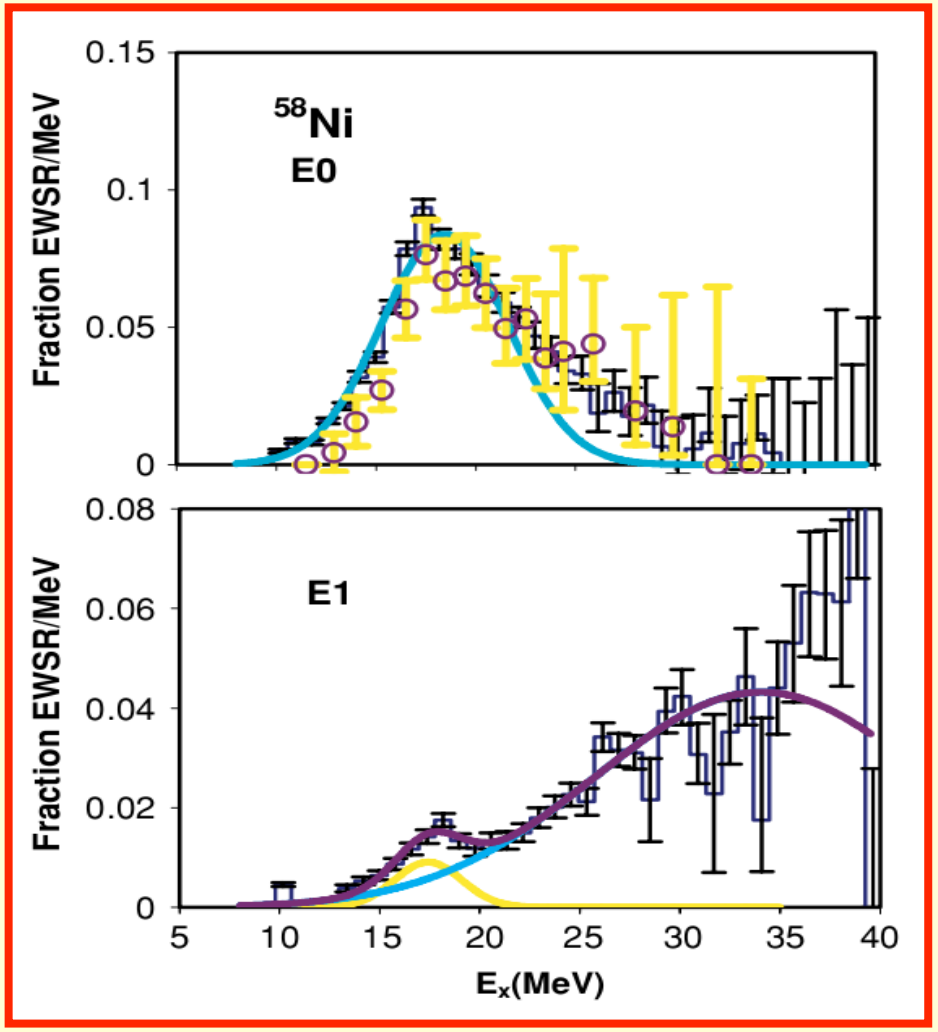
Monopole
ΔL = 0
(GMR)

Dipole
ΔL = 1
(GDR)

Quadrupole
ΔL = 2
(GQR)

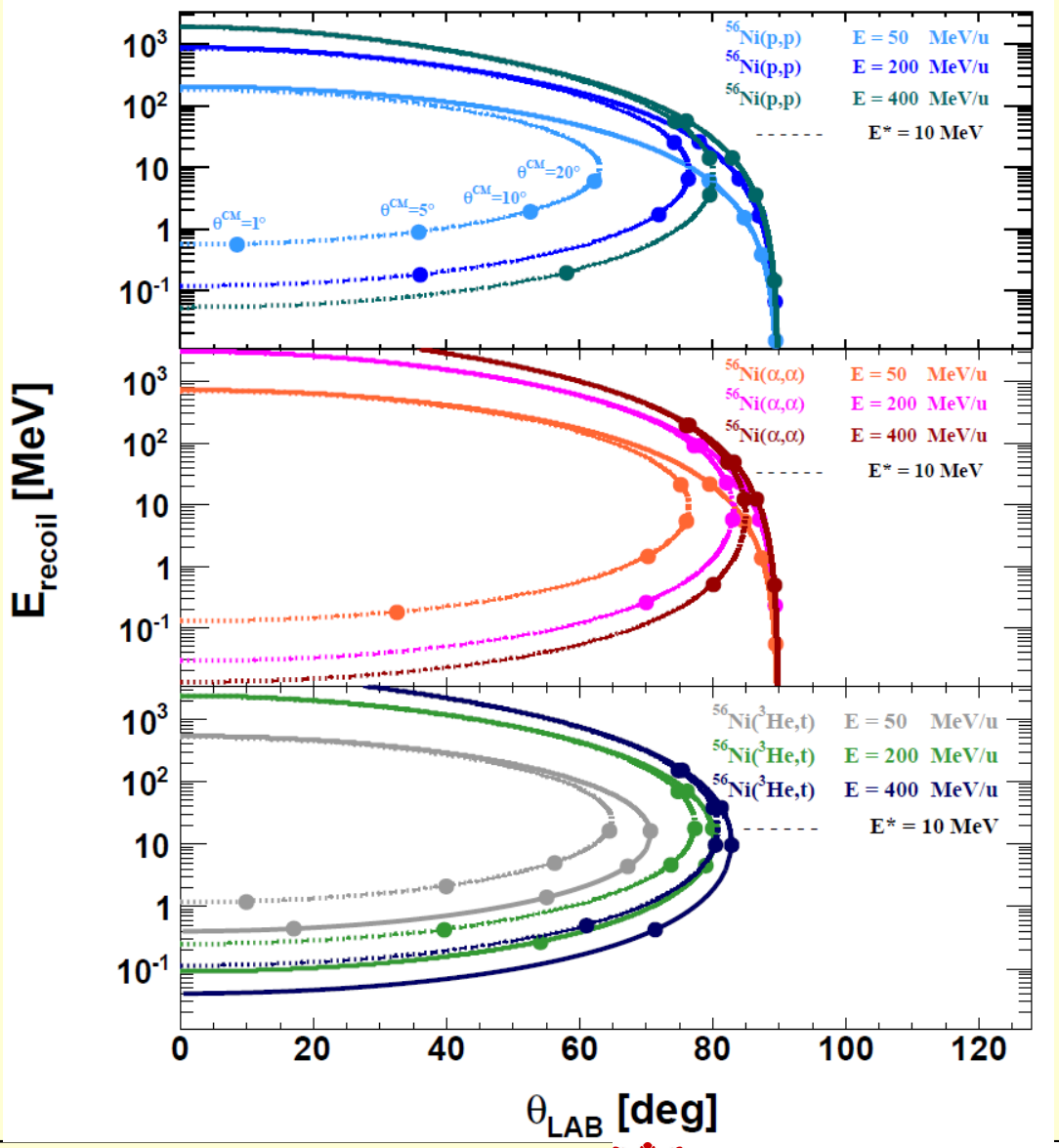
Isoscalar (In phase)
ΔT = 0



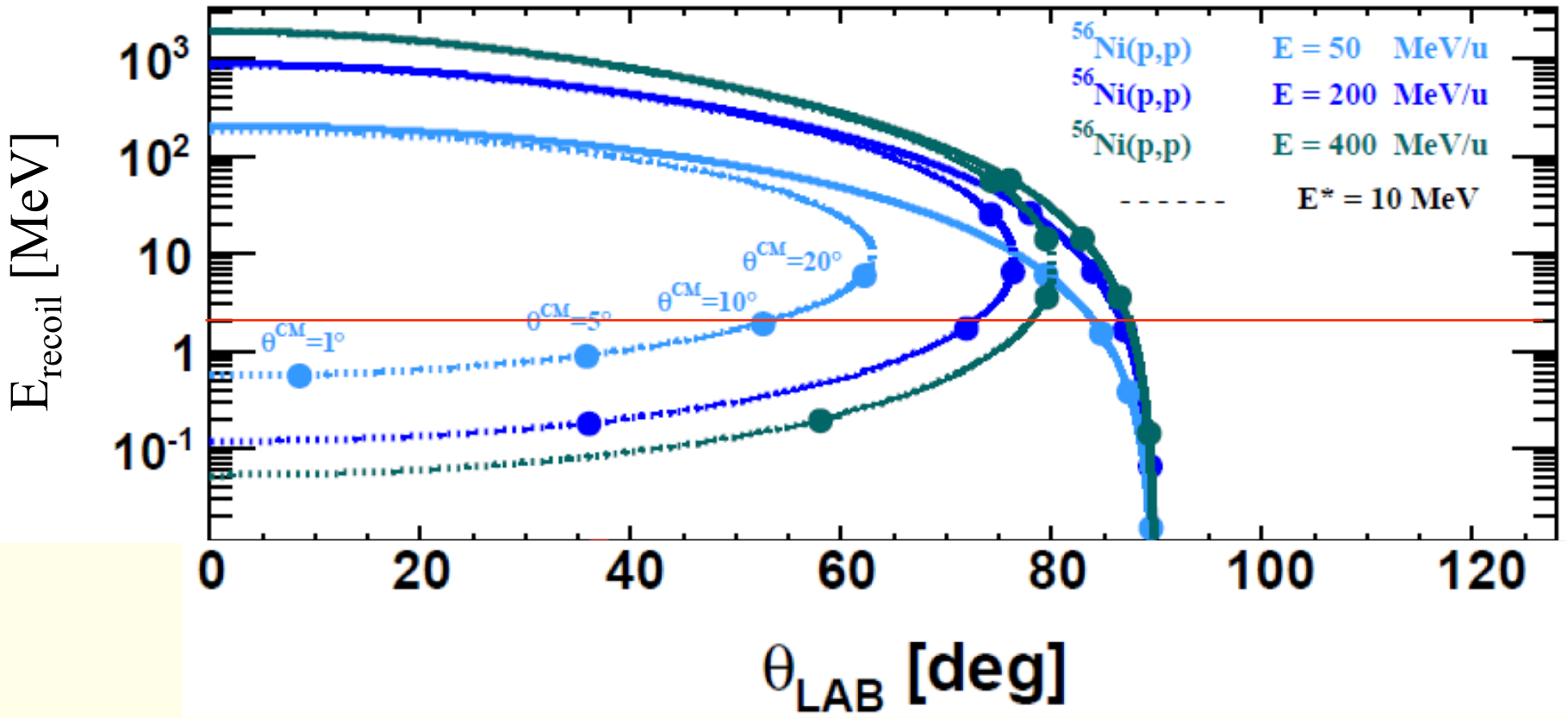


Y.-W. Lui et al., Phys. Rev. C 73 (2006) 014314

Kinematics for inverse reaction for ^{56}Ni

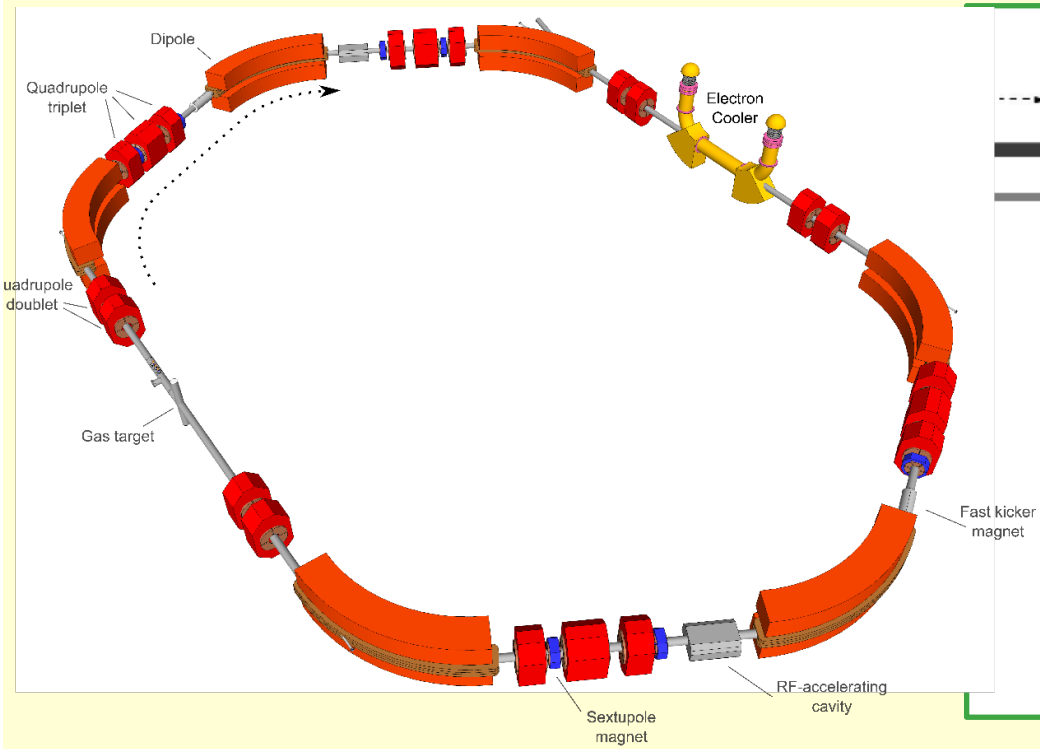


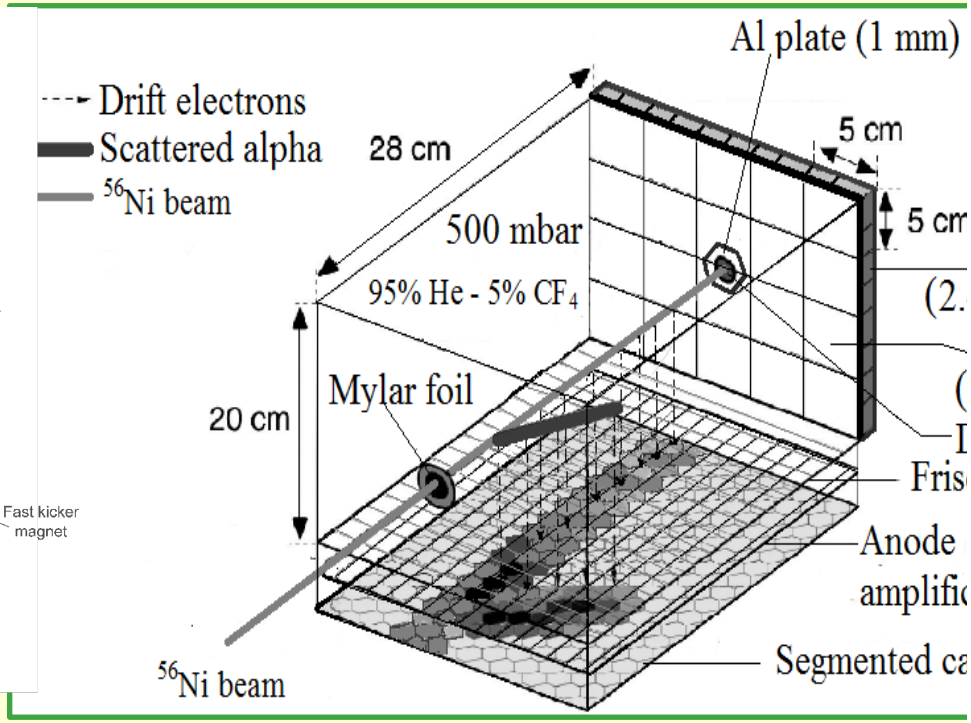
Kinematics for inverse reaction for ^{56}Ni



Storage Ring

Active Target

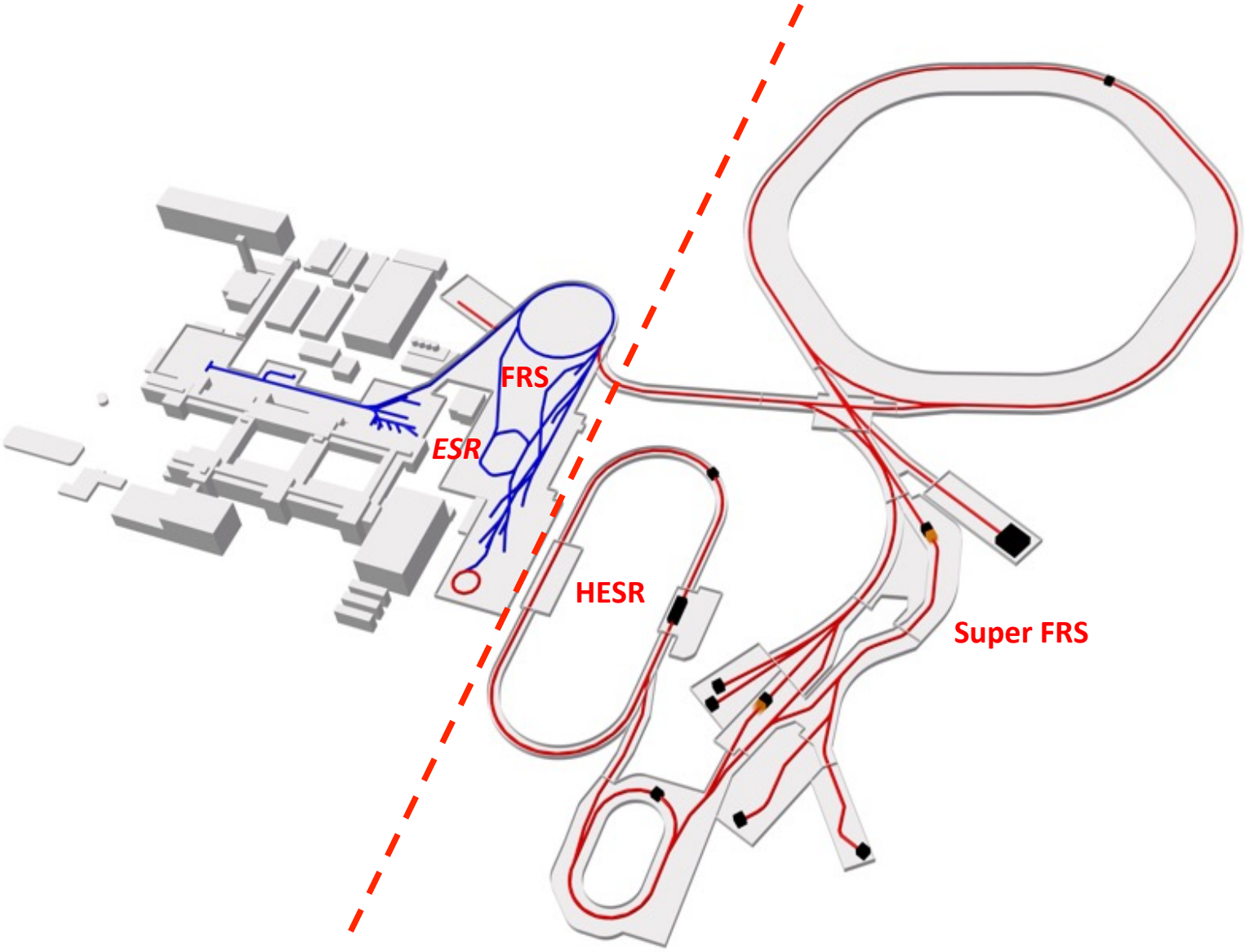




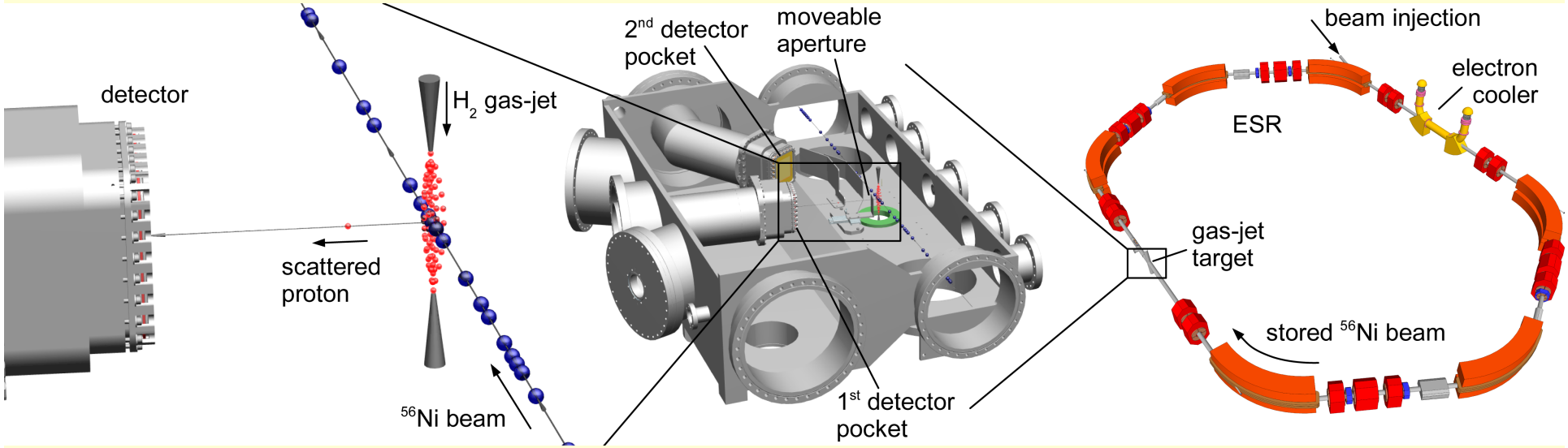
First EXL experiment with the existing storage ring at GSI (ESR)

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

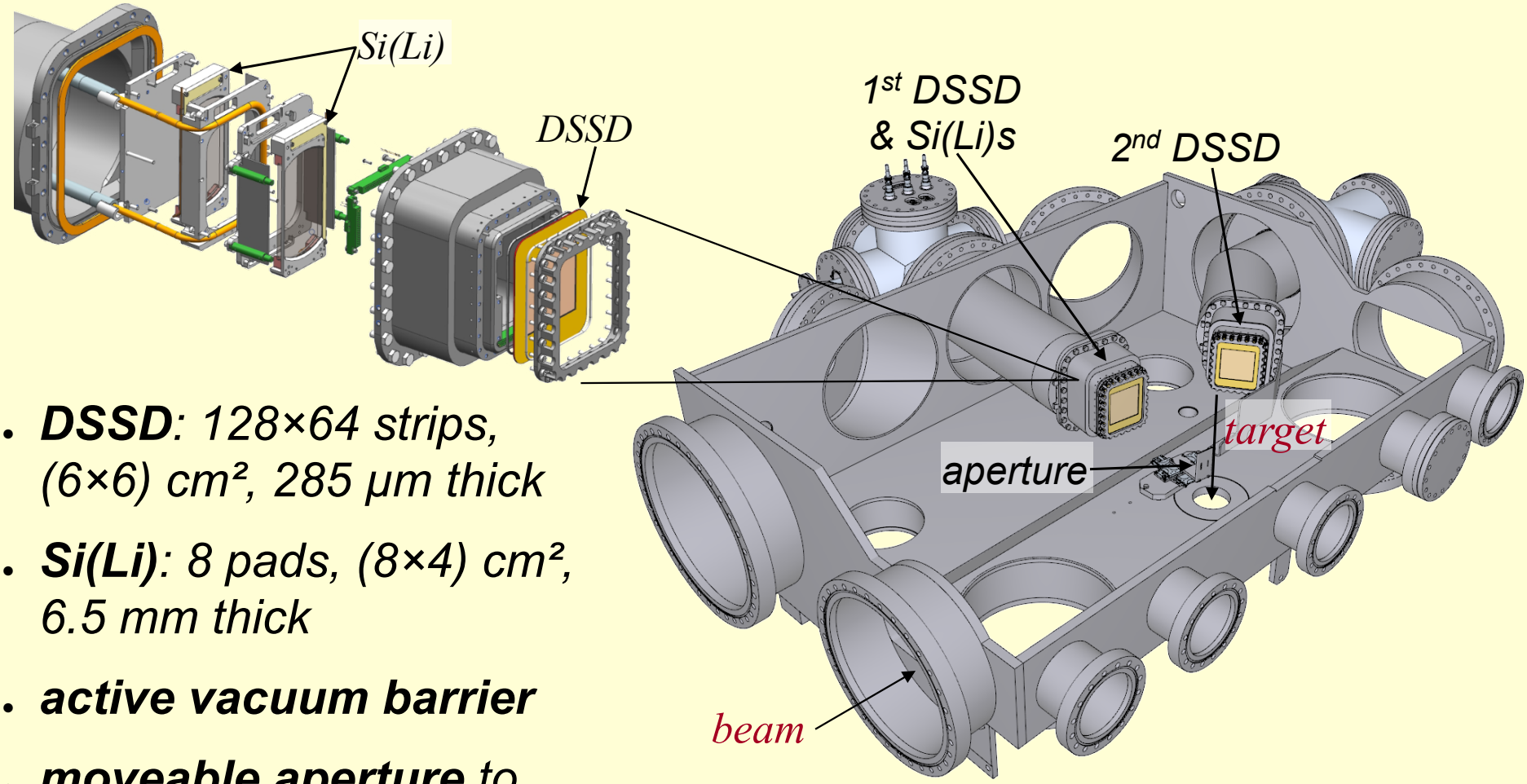
GSI and FAIR



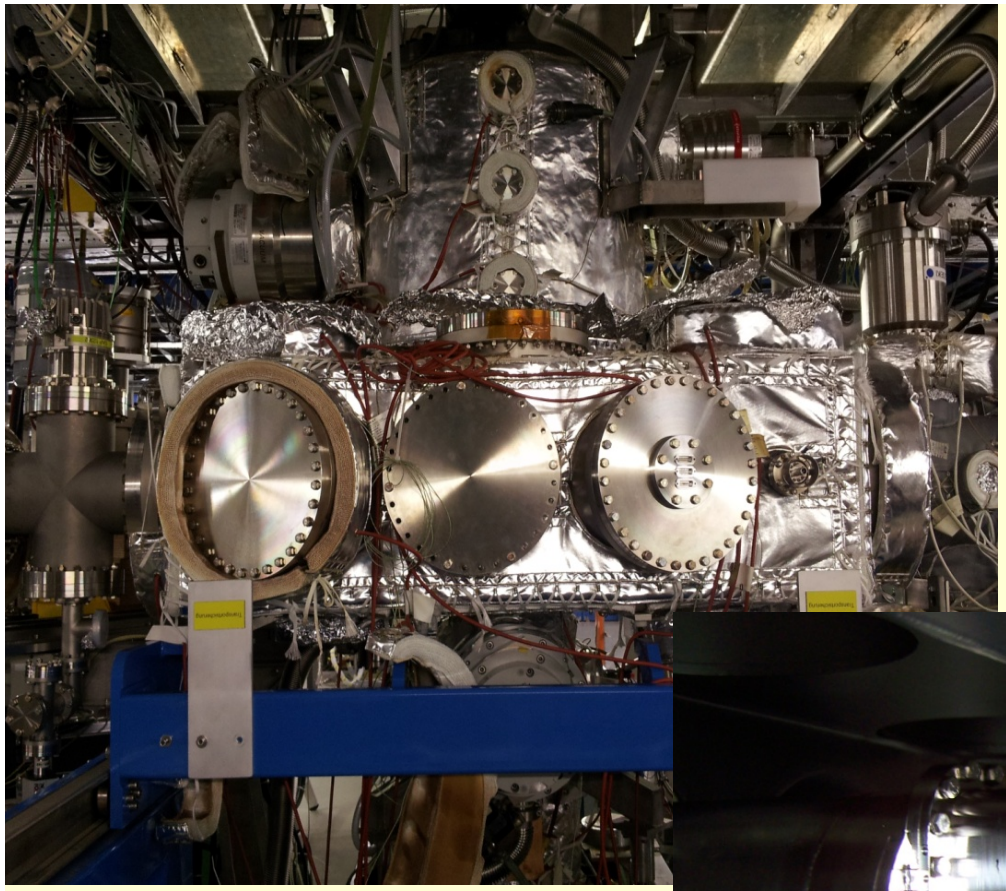
EXL setup @ ESR

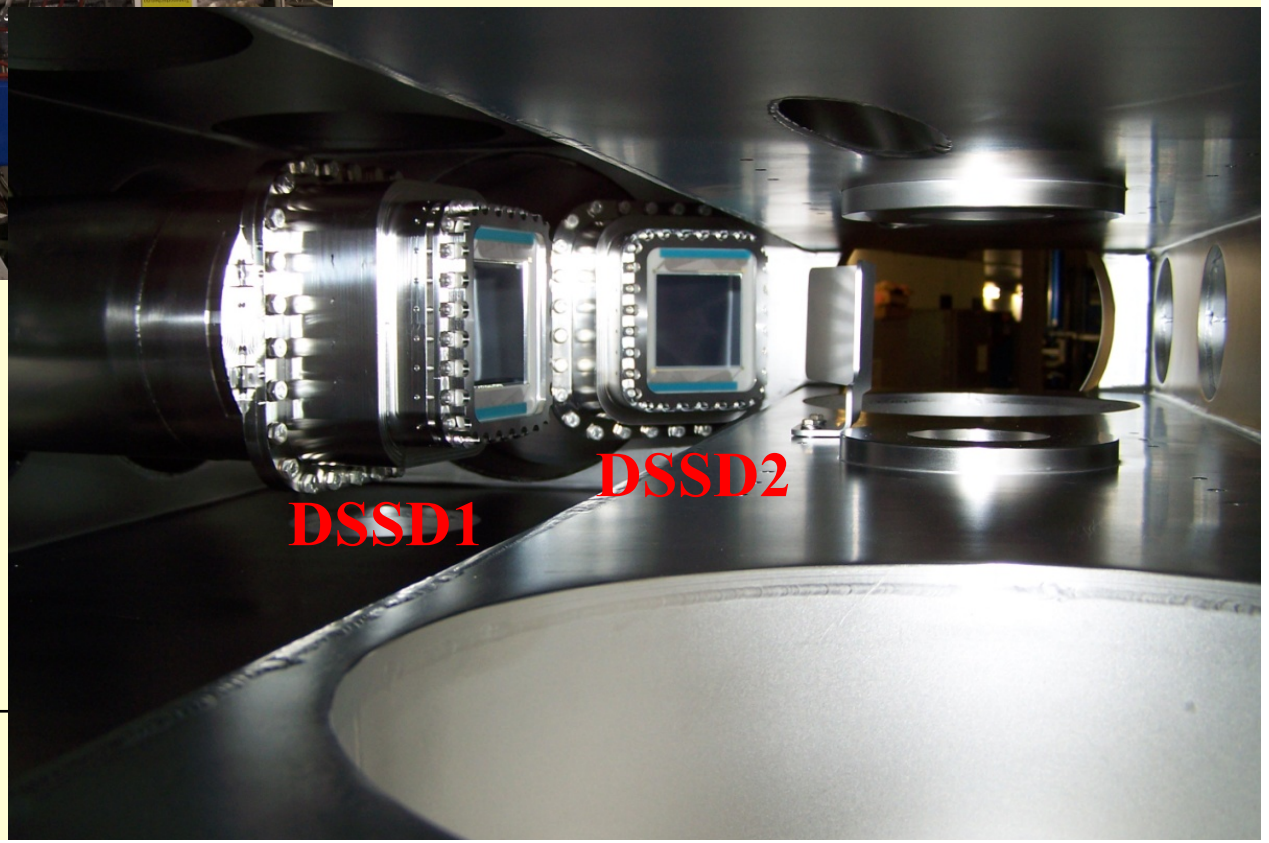


The new ESR Scattering chamber

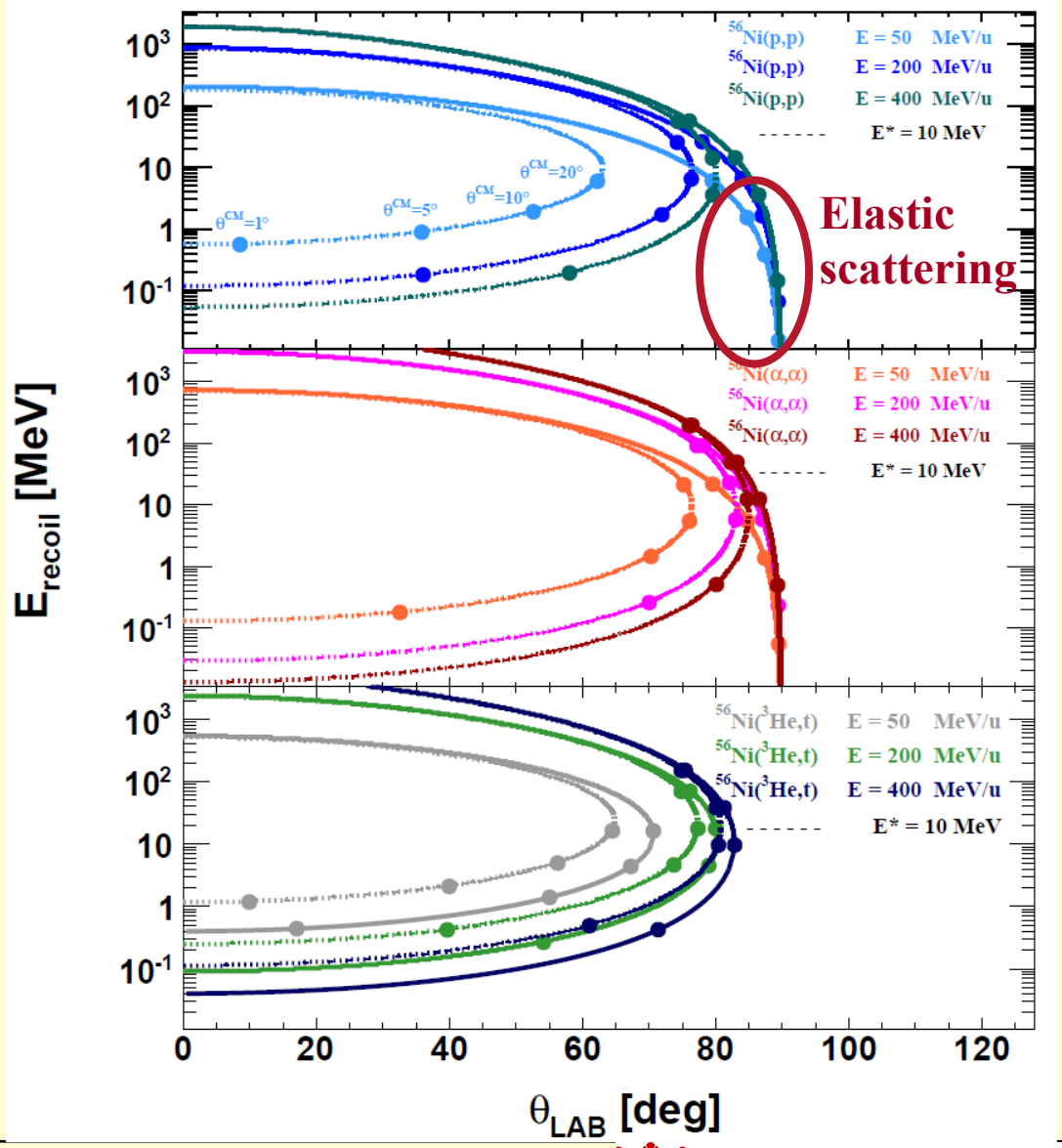


- ***DSSD**: 128×64 strips, (6×6) cm², 285 μm thick*
- ***Si(Li)**: 8 pads, (8×4) cm², 6.5 mm thick*
- ***active vacuum barrier***
- ***moveable aperture** to improve angular resolution*




DSSD2
DSSD1

Kinematics for inverse reaction for ^{56}Ni

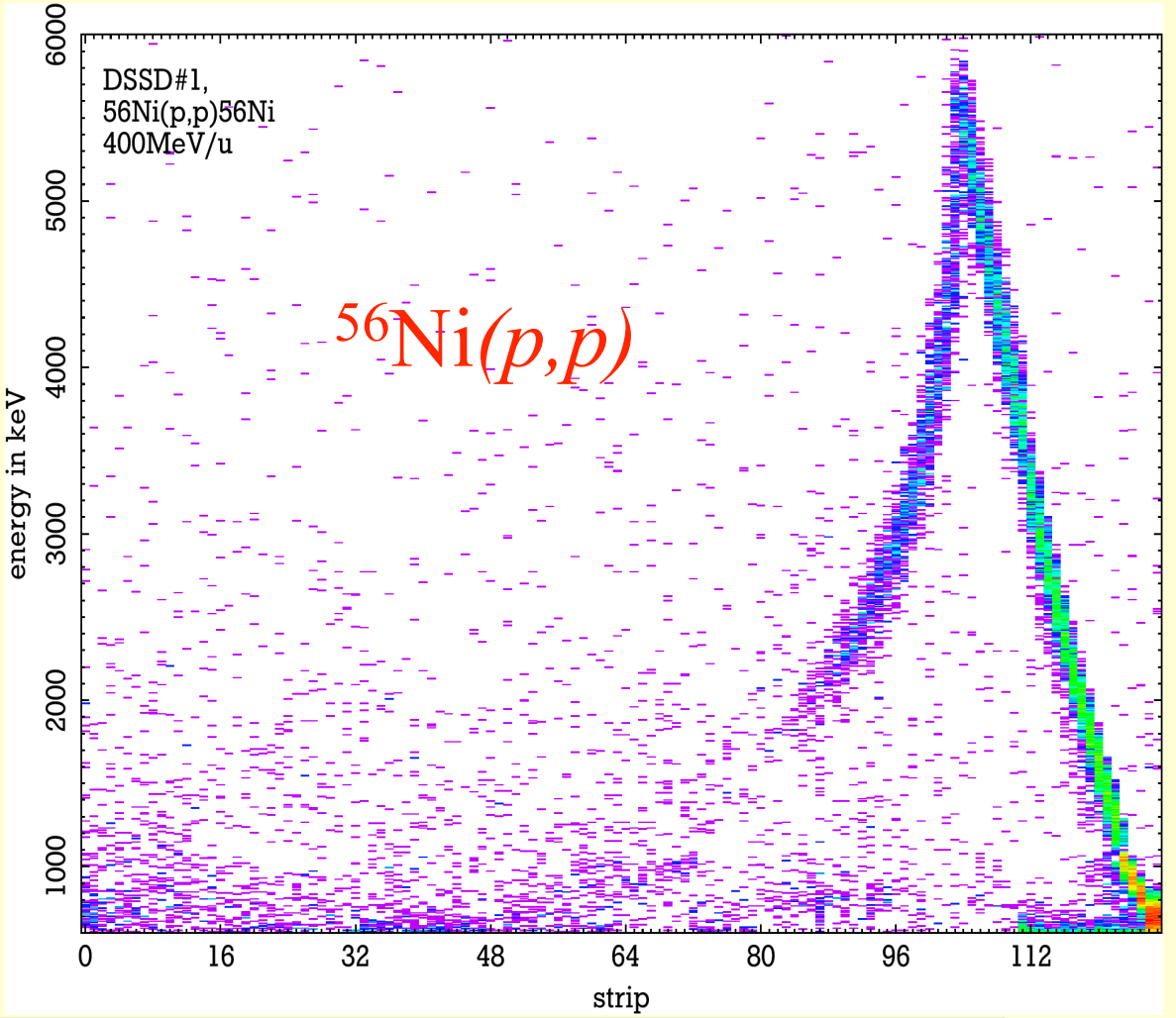


First results with radioactive beam

October 25, 2012:

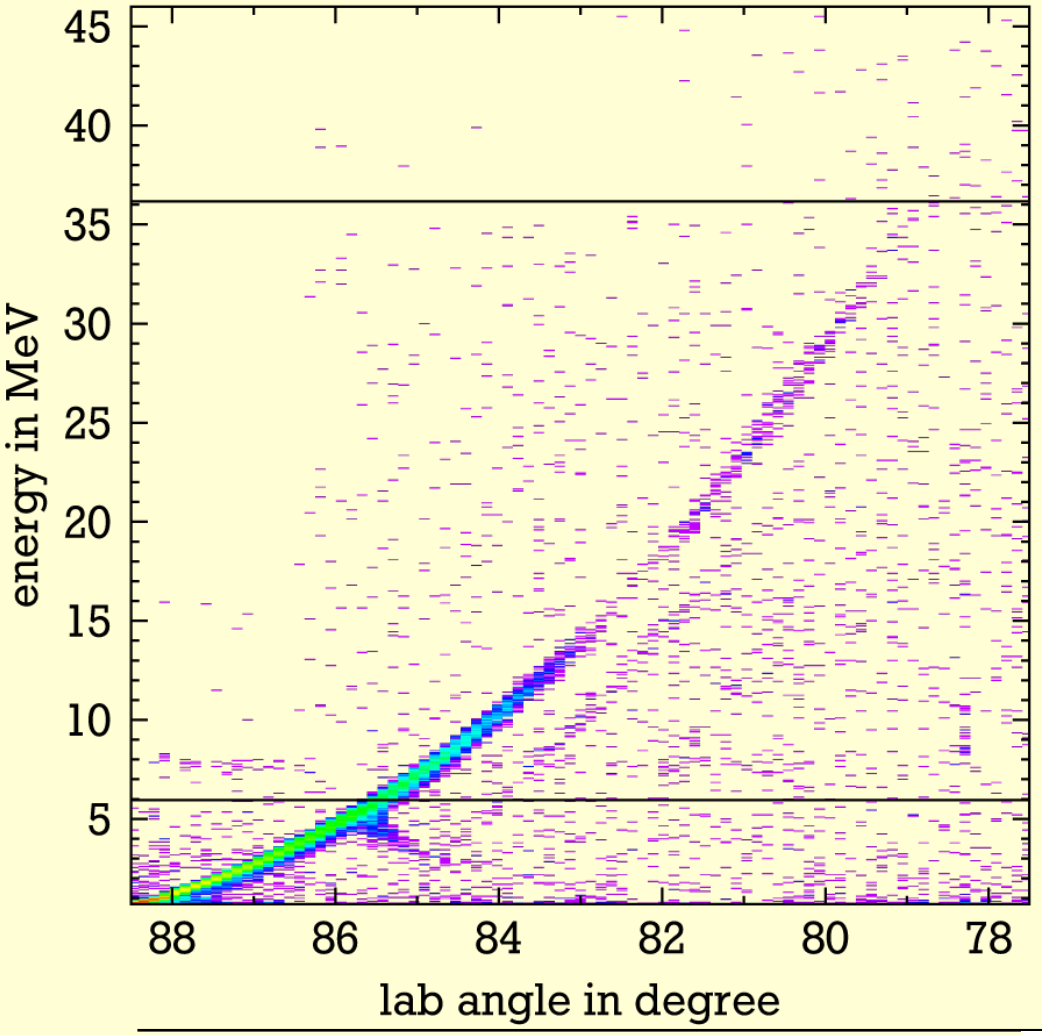
First Nuclear Reaction Experiment with Stored Radioactive Beam!!!!

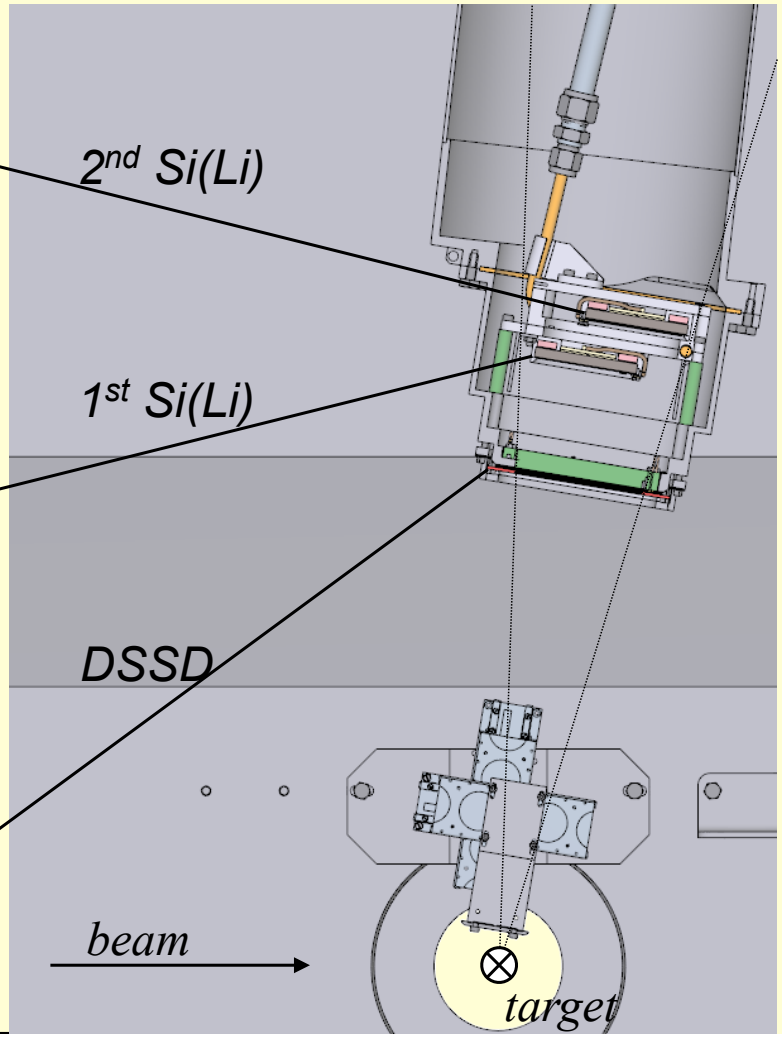
Beam energy 400 MeV/u



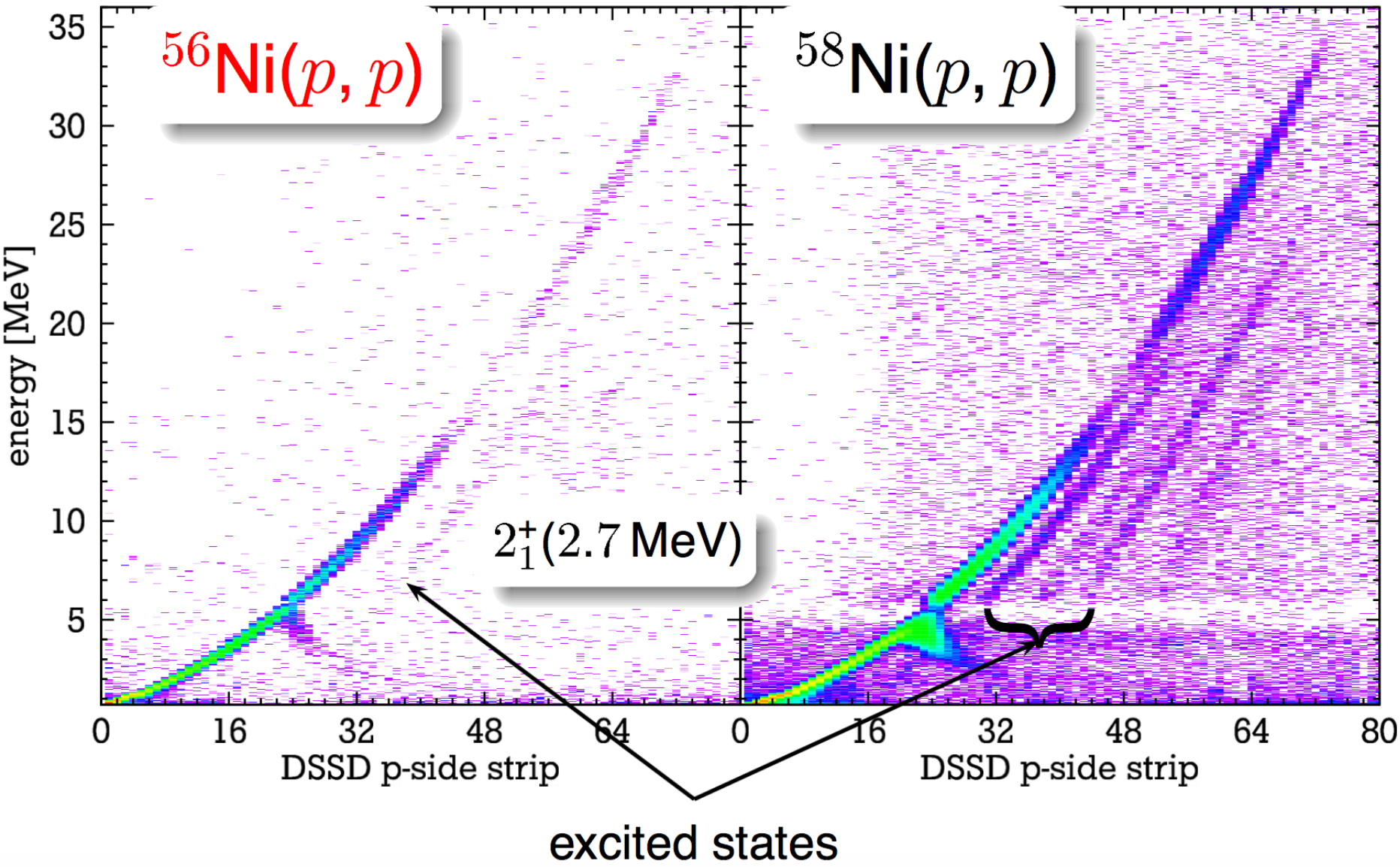
First results with radioactive beam

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



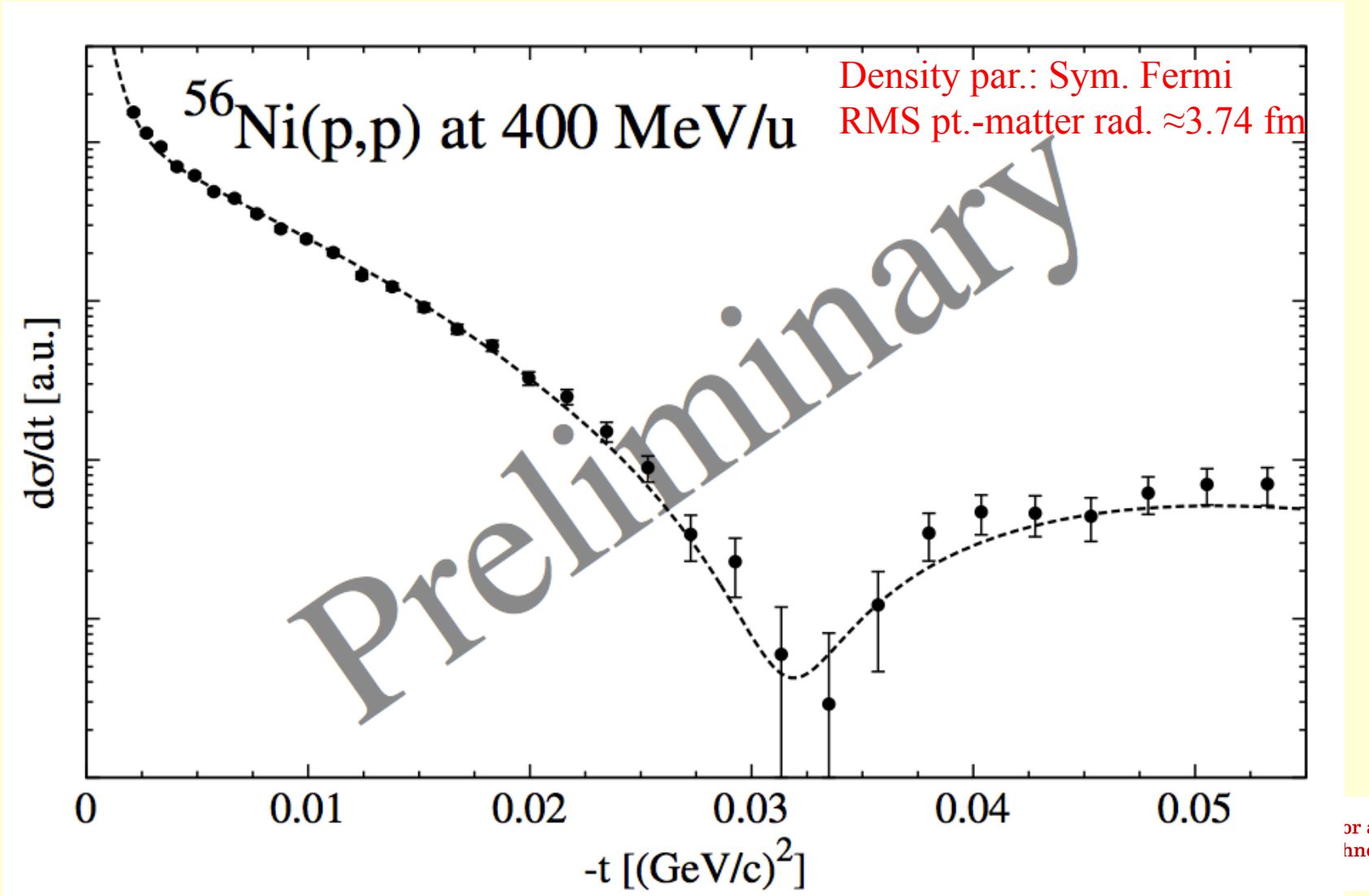


First results with radioactive beam



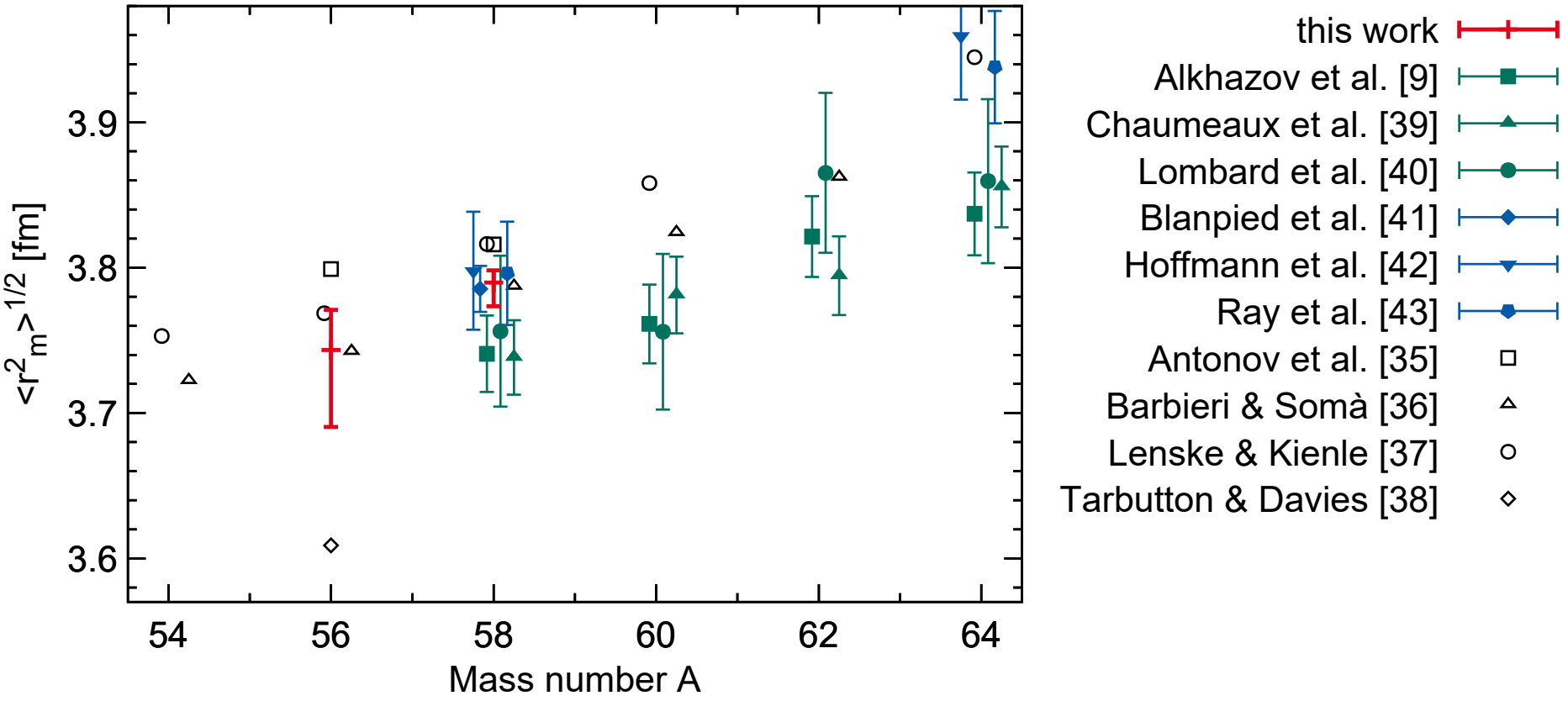
First results with radioactive beam

- Elastic p-scattering off ^{56}Ni (E105), M. von Schmid



or advanced
hnology

First results with radioactive beam and proton target

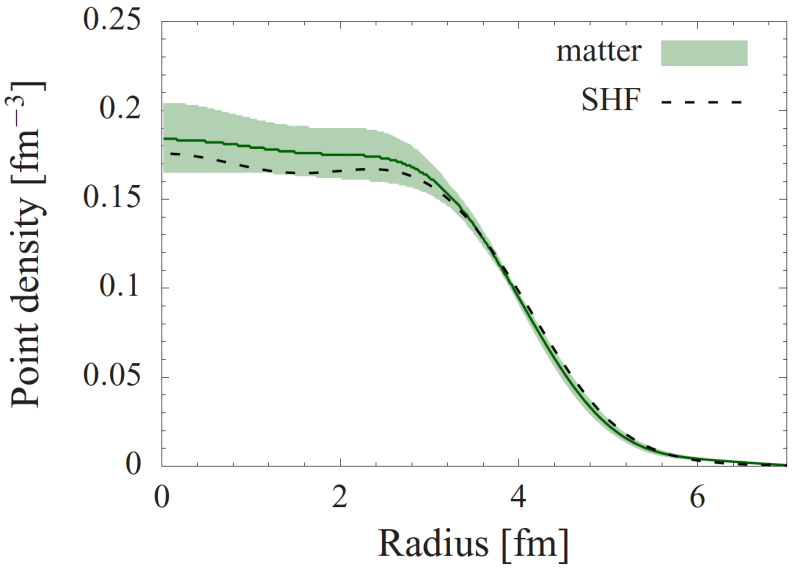


M. von Schmid et al., preliminary results

Elastic alpha scattering off ^{58}Ni at 100 and 150 MeV/nucleon

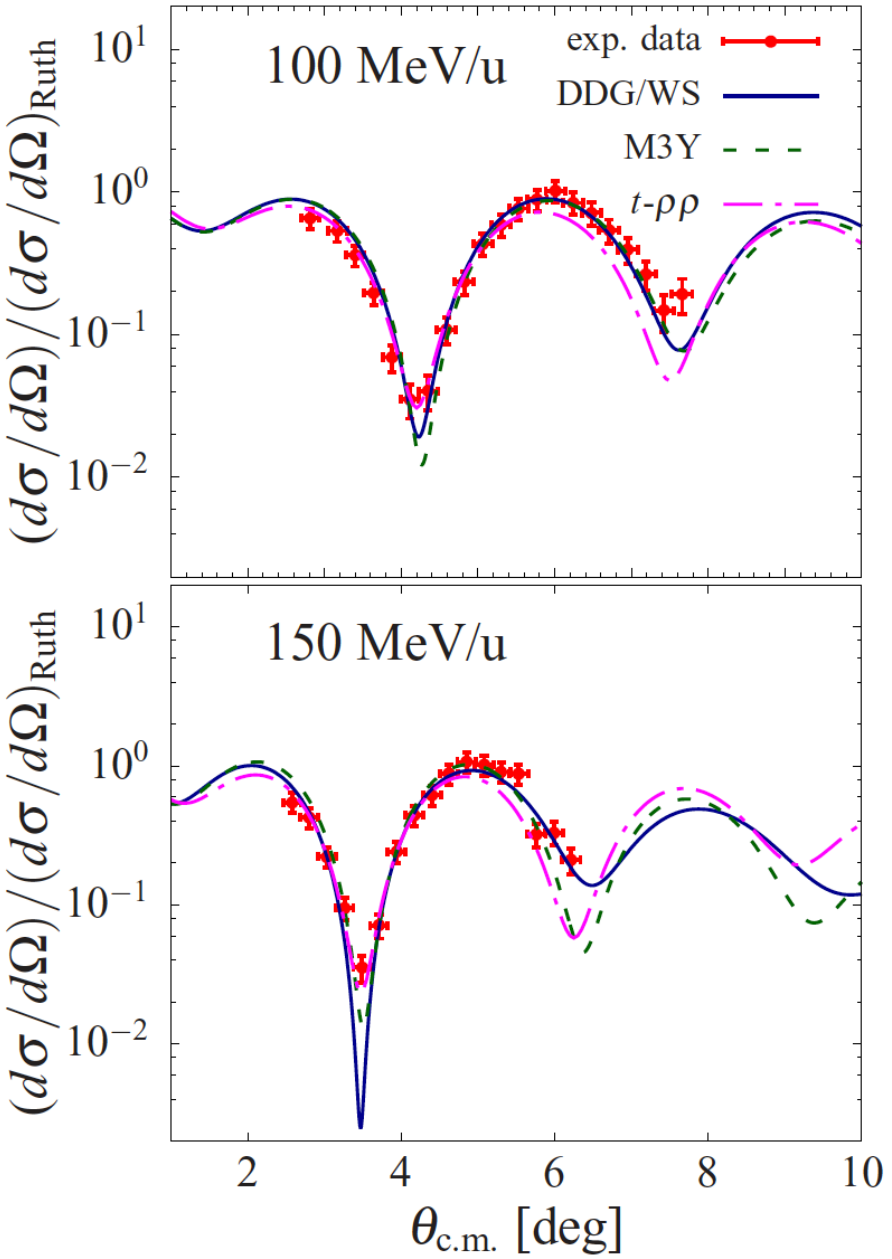
- Ph.D., J.C. Zamora,
- Zamora et al.,

  PRC **96**, 034617 (2017)



Total-r_{RMS} = 3.78(7) fm

Point-r_{RMS} = 3.70(7) fm



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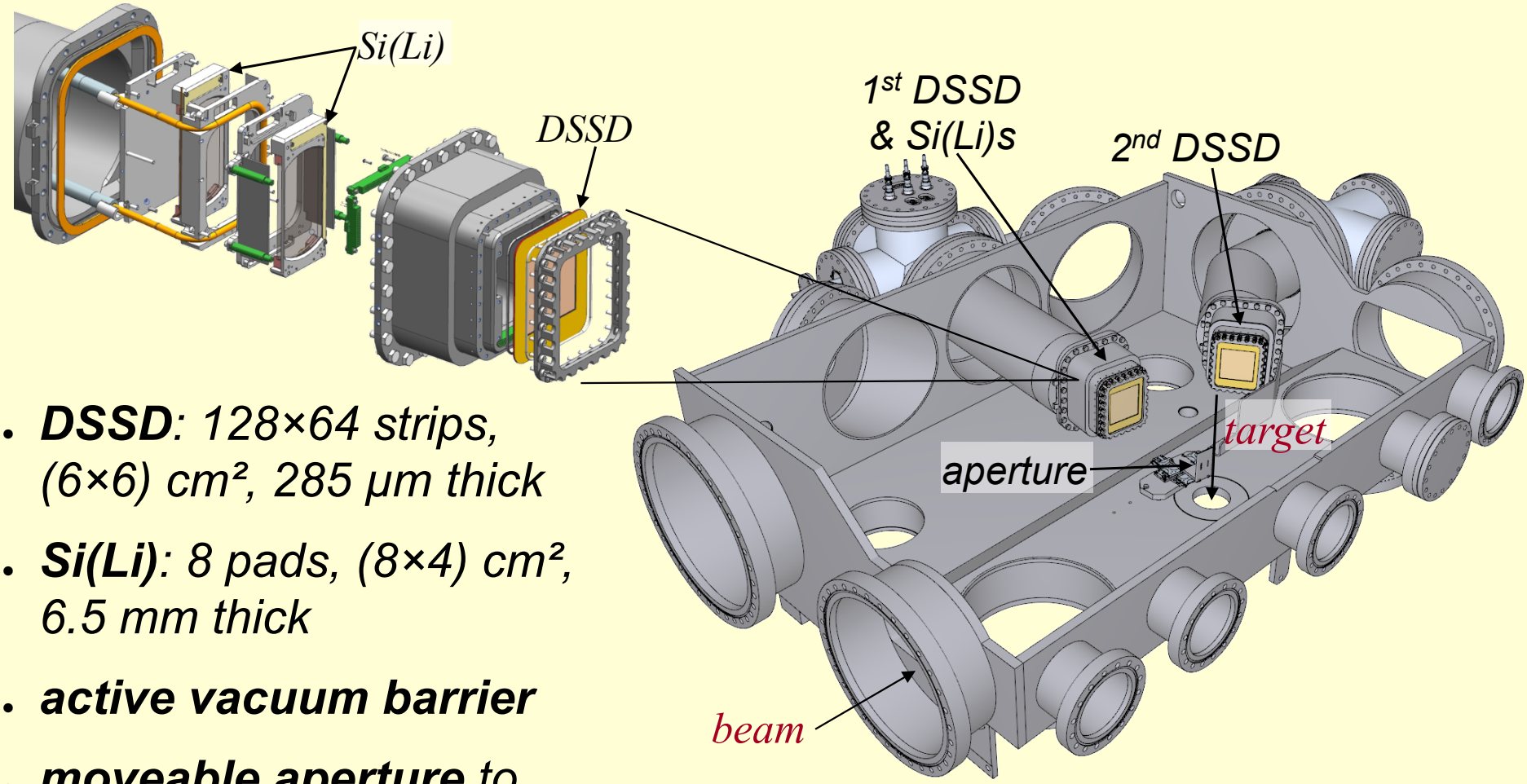

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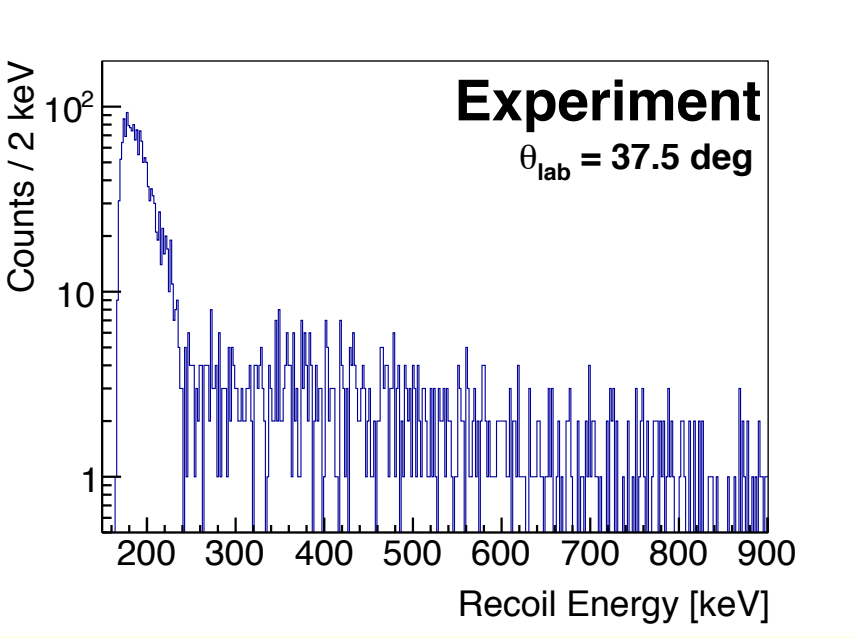
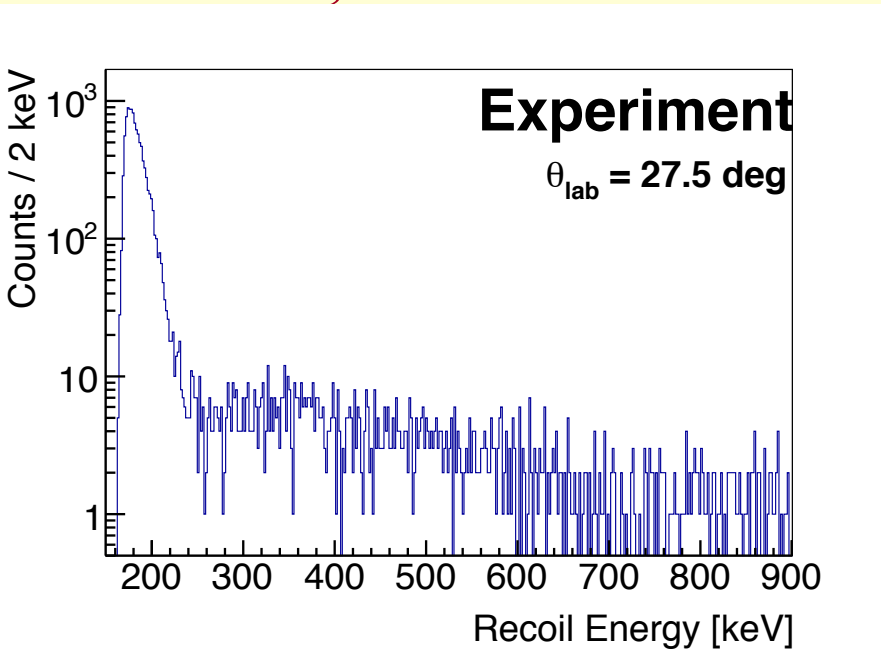
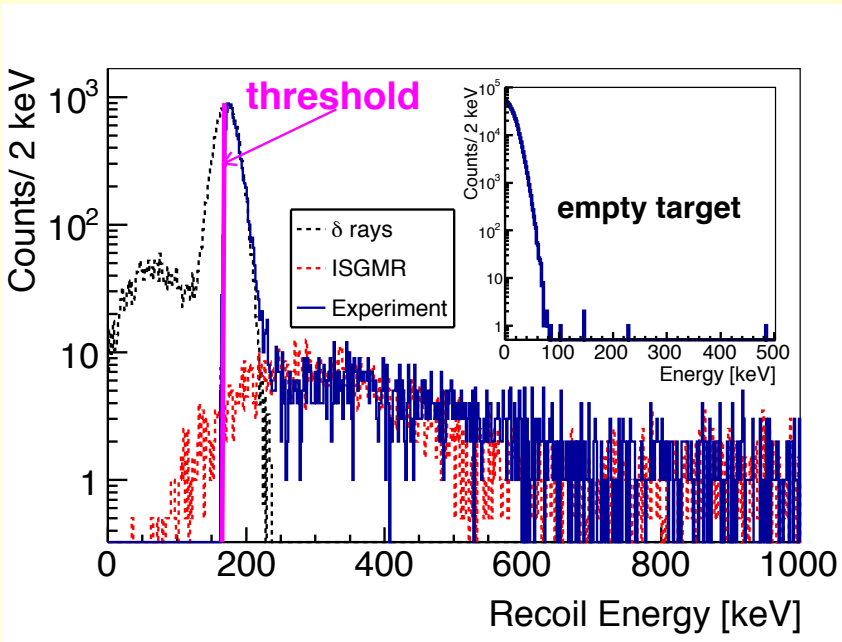
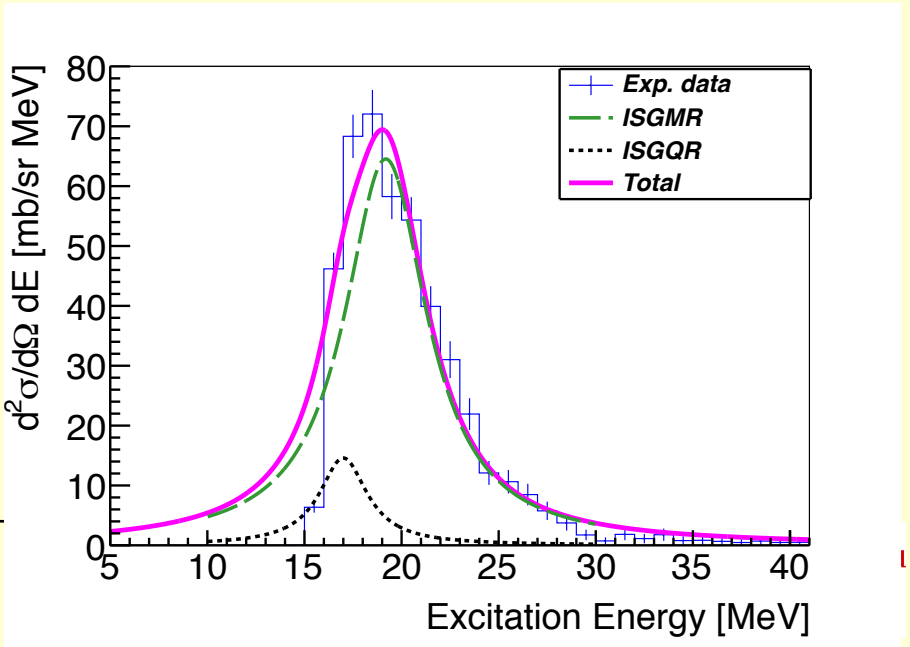
- ***moveable aperture** to improve angular resolution*

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



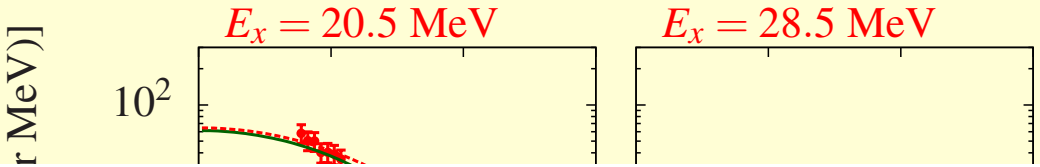




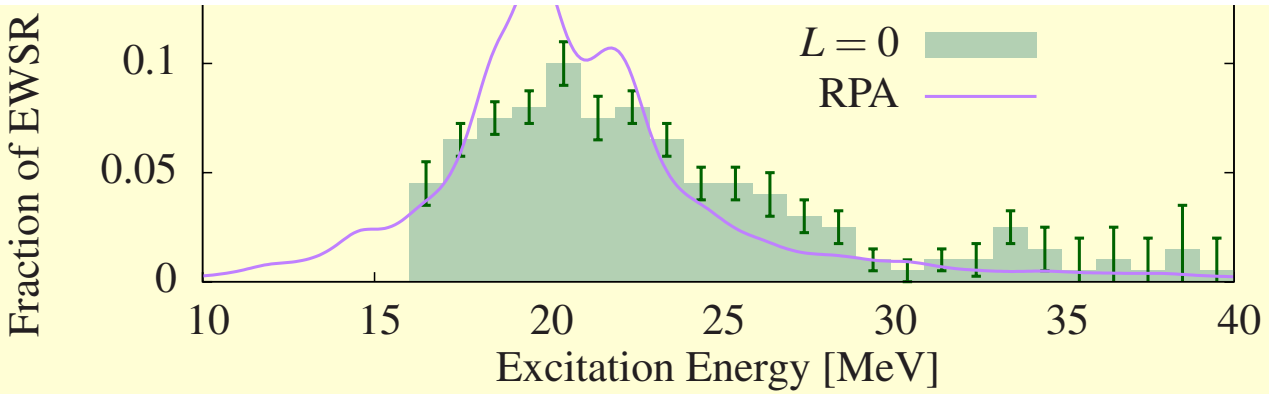


Inelastic alpha scattering (100 MeV/nucleon) from ^{58}Ni

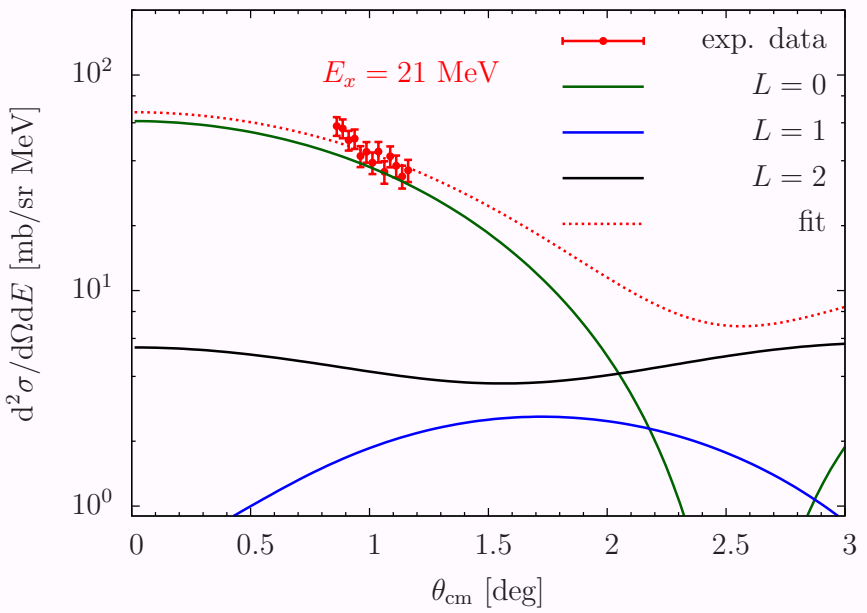
- J.C. Zamora et al., PLB 763, 16 (2016)

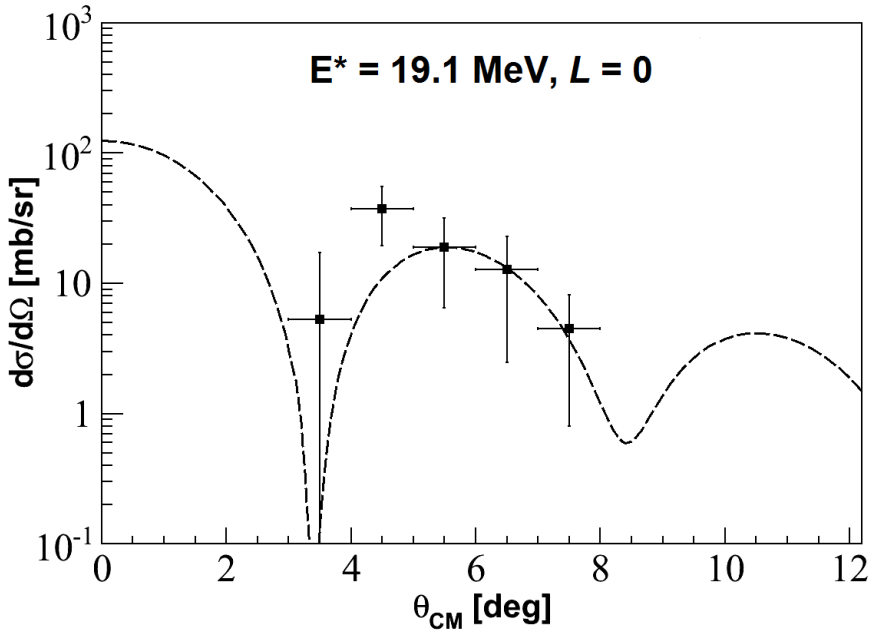


Reference	Centroid [MeV]	$\text{Width}_{\text{RMS}}$ [MeV]	EWSR [%]
this work	20.5(6)	4.6(6)	79^{+12}_{-11}
PRC 73, 014314 (2006)	$19.20^{+0.44}_{-0.19}$	$4.89^{+1.05}_{-0.31}$	85^{+13}_{-10}
PRC 61, 067307 (2000)	$20.30^{+1.69}_{-0.14}$	$4.25^{+0.69}_{-0.23}$	74^{+22}_{-12}
PLB 637, 43 (2006)	$19.9^{+0.7}_{-0.8}$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



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





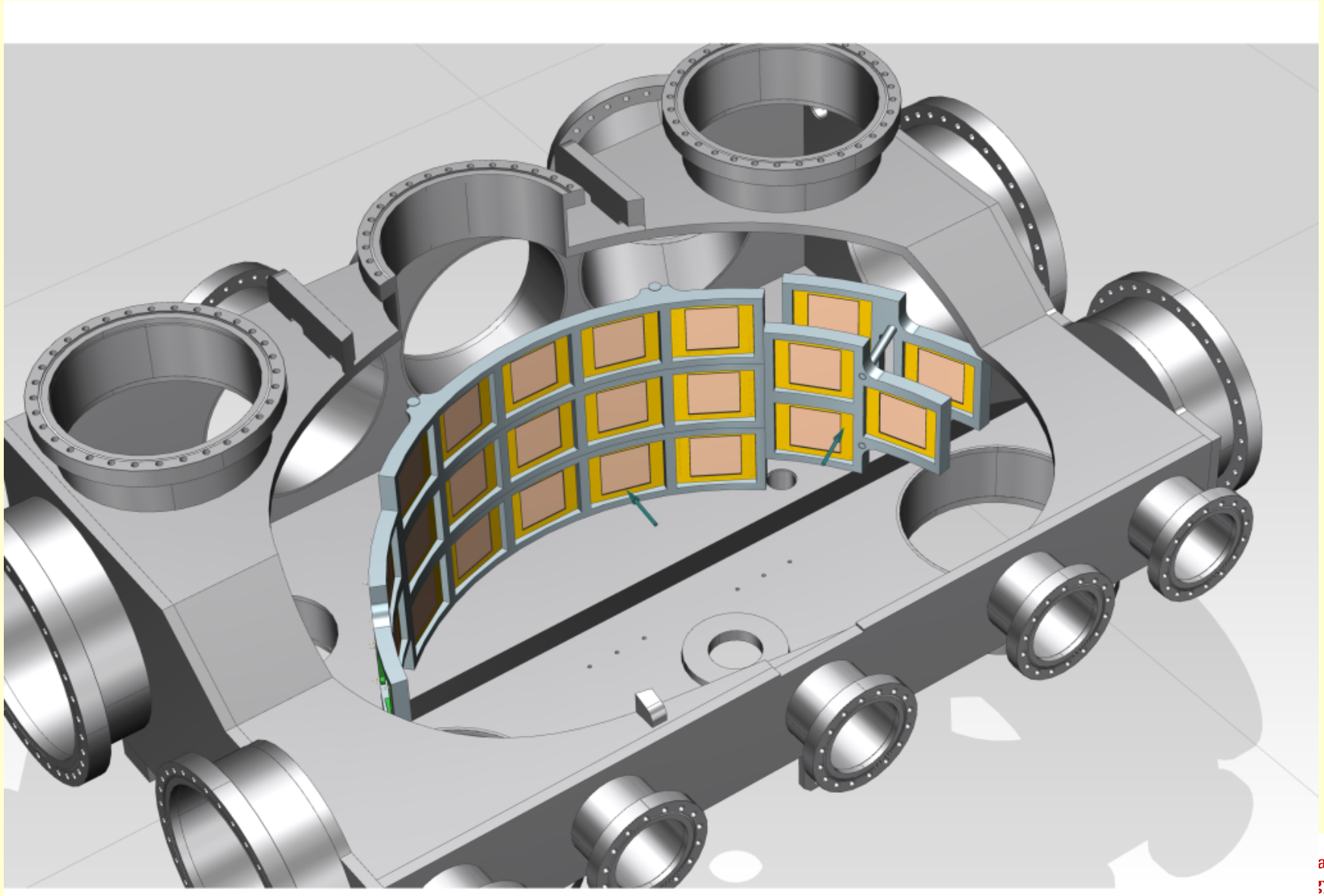
^{58}Ni

^{56}Ni

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 with both systems (ESR, HESR, ACTAR …), but with major improvements and for various reactions.

Upgrade of the first EXL experiment



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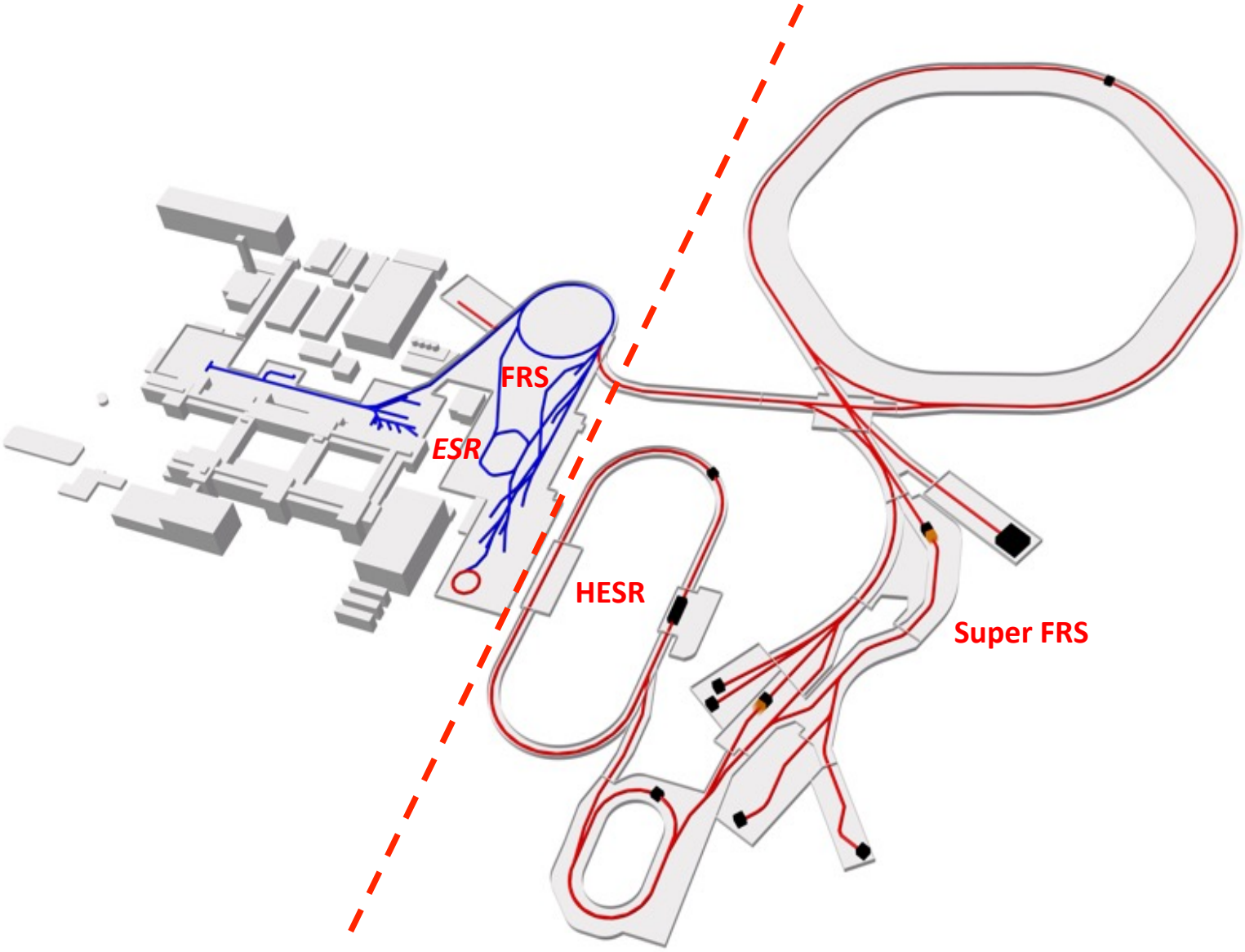
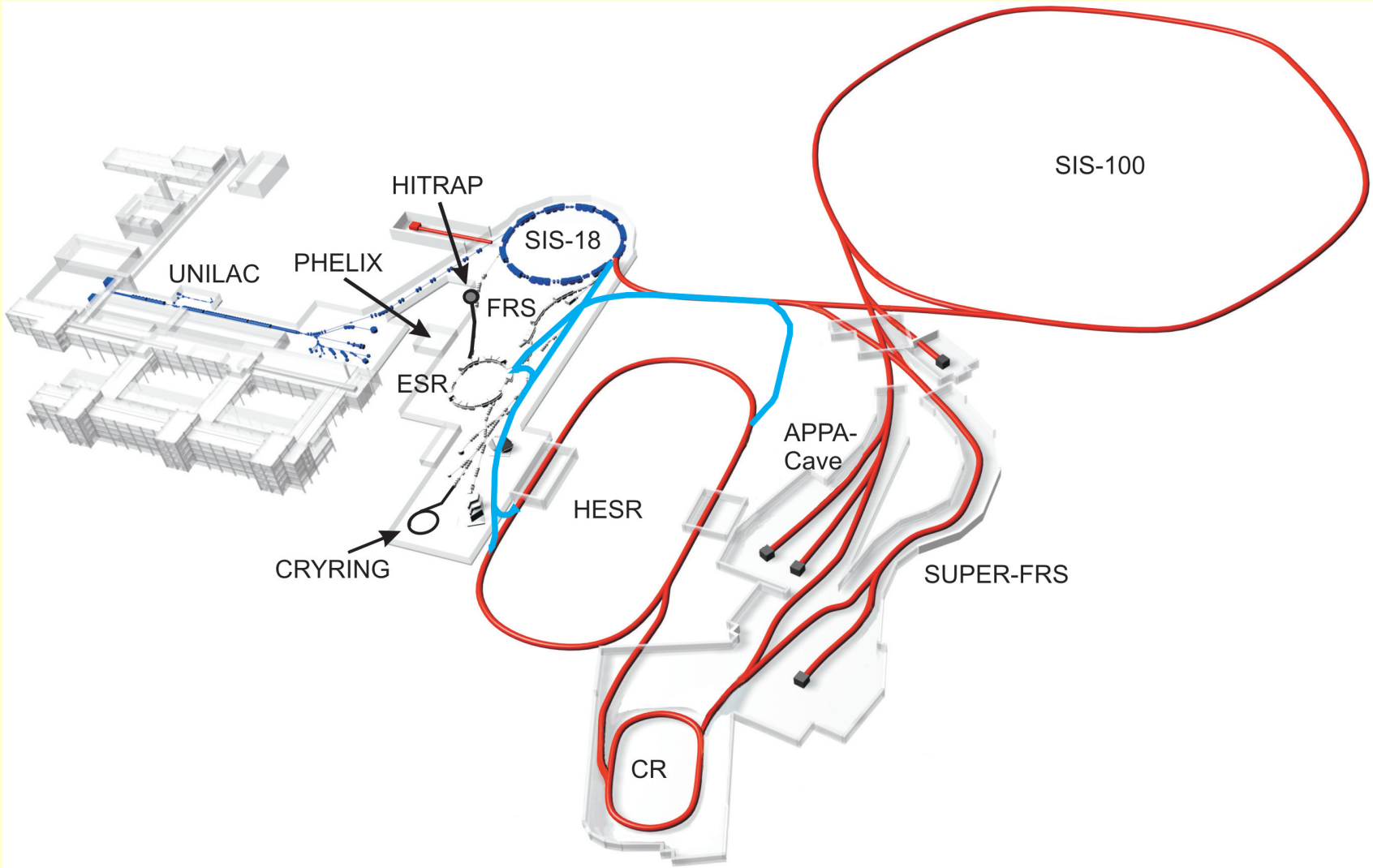
GSI and FAIR



Intermediate-range Plans for rings



Exotic nuclei studied in storage rings

The EXL-E105 Collaboration

S. Bagchi[1], S. Bönig[2], M. Castlós[3], I. Dillmann[4], C. Dimopoulou[4], P. Egelhof[4], V. Eremin[5], H. Geissel[4], R. Gernhäuser[6], M.N. Harakeh[1], A.-L. Hartig[2], S. Ilieva[2], N. Kalantar-Nayestanaki[1], O. Kiselev[4], H. Kollmus[4], C. Kozhuharov[4], A. Krasznahorkay[3], T. Kröll[2], M. Kuilman[1], S. Litvinov[4], Yu.A. Litvinov[4], M. Mahjour-Shafiei[1], M. Mutterer[4], D. Nagae[8], M.A. Najafi[1], C. Nociforo[4], F. Nolden[4], U. Popp[4], C. Rigollet[1], S. Roy[1], C. Scheidenberger[4], M. von Schmid[2], M. Steck[4], B. Streicher[2,4], L. Stuhl[3], M. Takechi[4], M. Thürauf[2], T. Uesaka[9], H. Weick[4], J.S. Winfield[4], D. Winters[4], P.J. Woods[10], T. Yamaguchi[11], K. Yue[4,7], J.C. Zamora[2], J. Zenihiro[9] for EXL coll.

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[3] ATOMKI, Debrecen
[4] GSI, Darmstadt
[5] Ioffe Physico-Technical Institute, St.Petersburg
[6] Technische Universität München
[7] Institute of Modern Physics, Lanzhou
[8] University of Tsukuba
[9] RIKEN Nishina Center
[10] The University of Edinburgh
[11] Saitama University

university of groningen

kvi center for advanced radiation technology

Thank you!