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

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On behalf of the EXL collaboration

NuSPRASEN Workshop on Nuclear Reactions (Theory and Experiment)

Warsaw, Poland

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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 (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

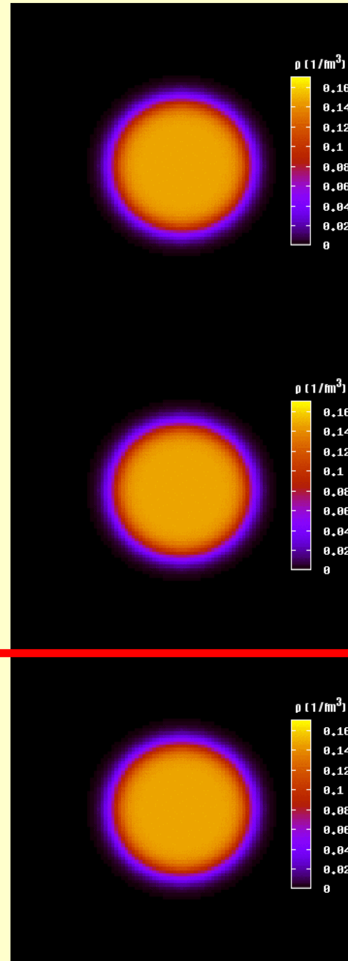
Isoscalar (In phase)
ΔT = 0

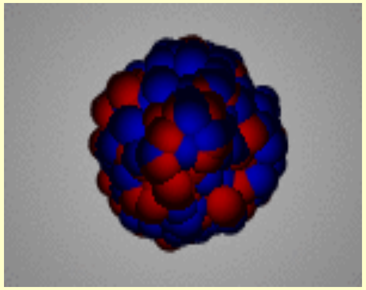
Isovector (Out of phase)
ΔT = 1

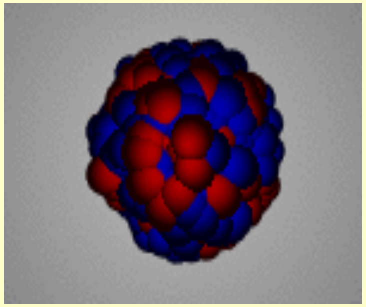
Monopole
ΔL = 0
(GMR)

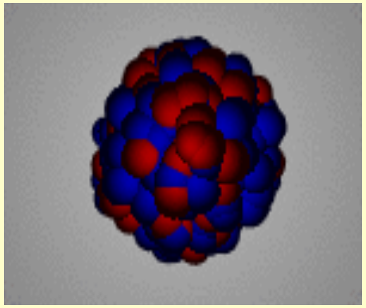
Dipole
ΔL = 1
(GDR)

Quadrupole
ΔL = 2
(GQR)







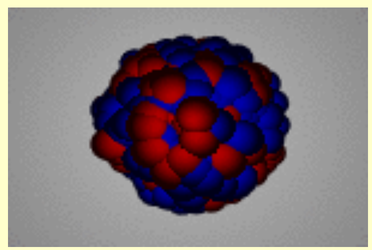


Example:
The Collective Response of the Nucleus: Giant Resonances

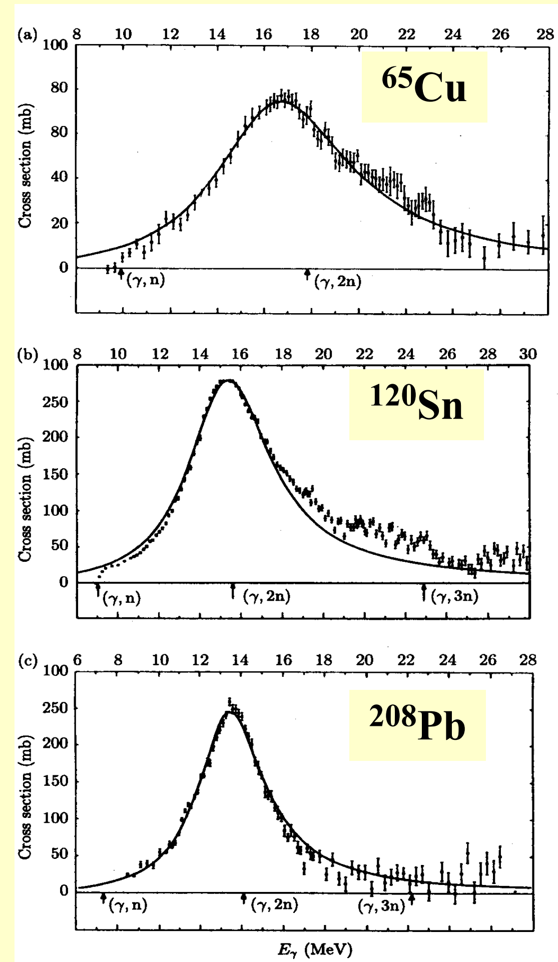
Photo-neutron
cross sections

Electric giant resonances

Dipole
(GDR)



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



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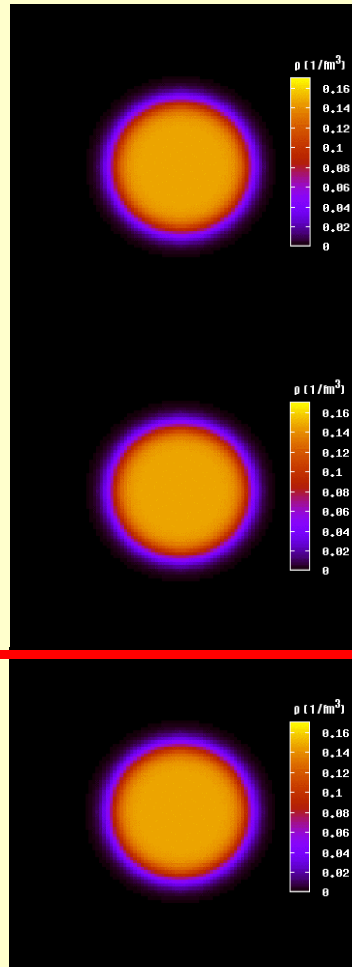
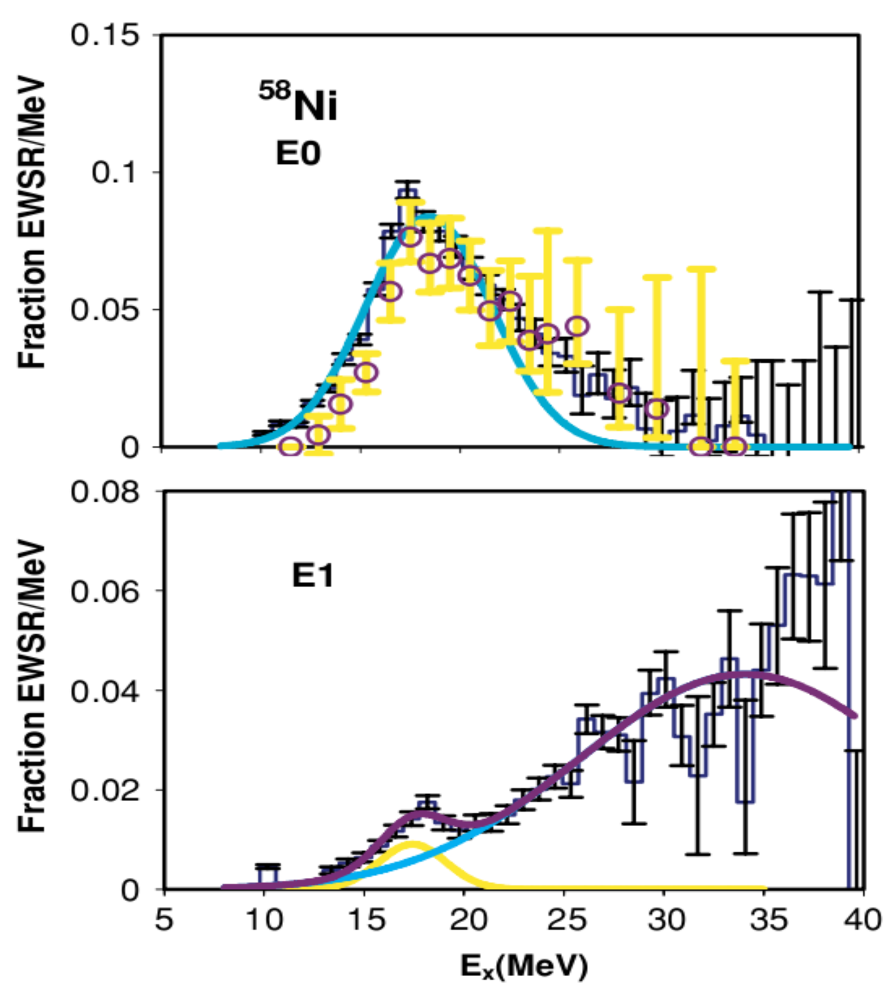
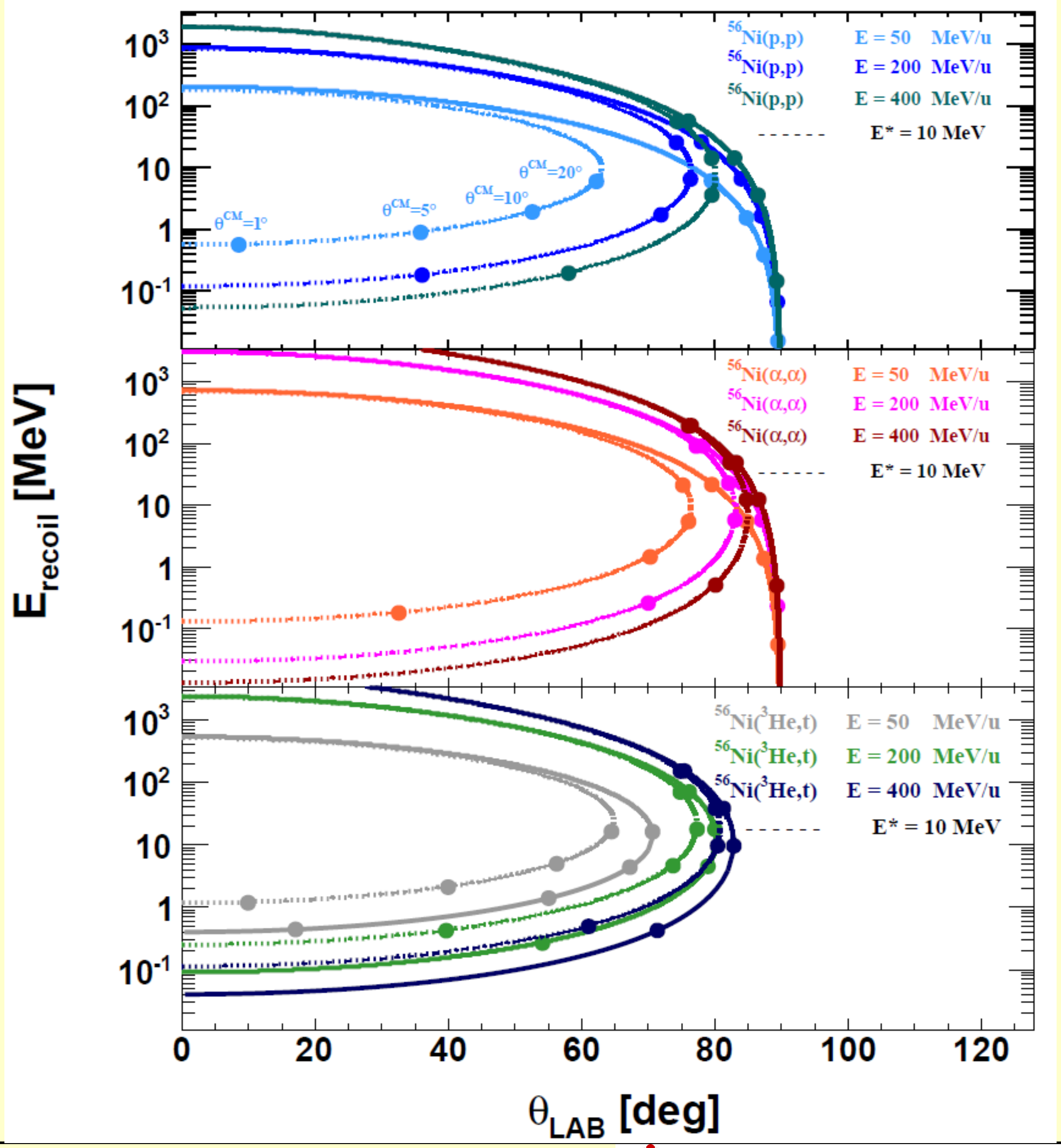




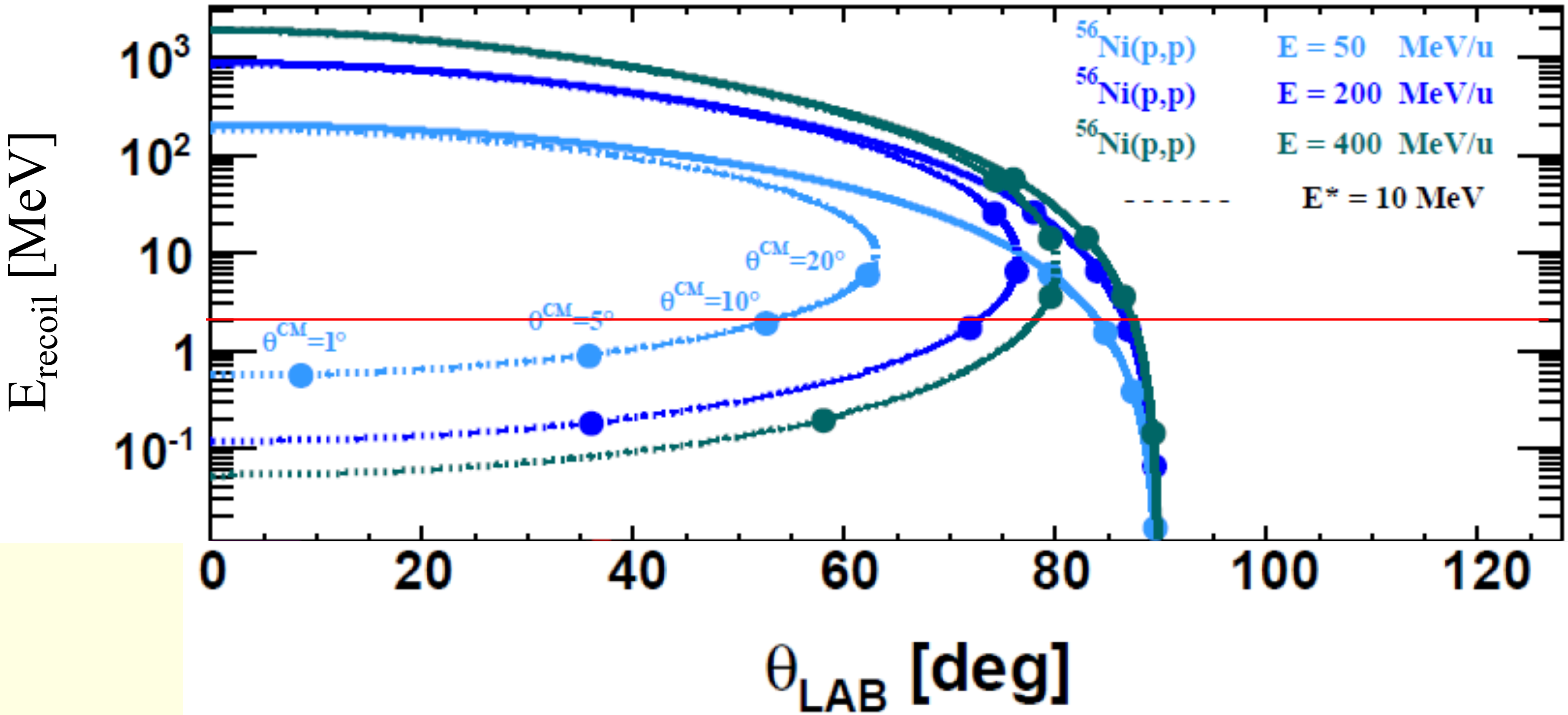
Y.-W. Lui et al., Phys. Rev. C 73 (2006) 014314

M. Itoh

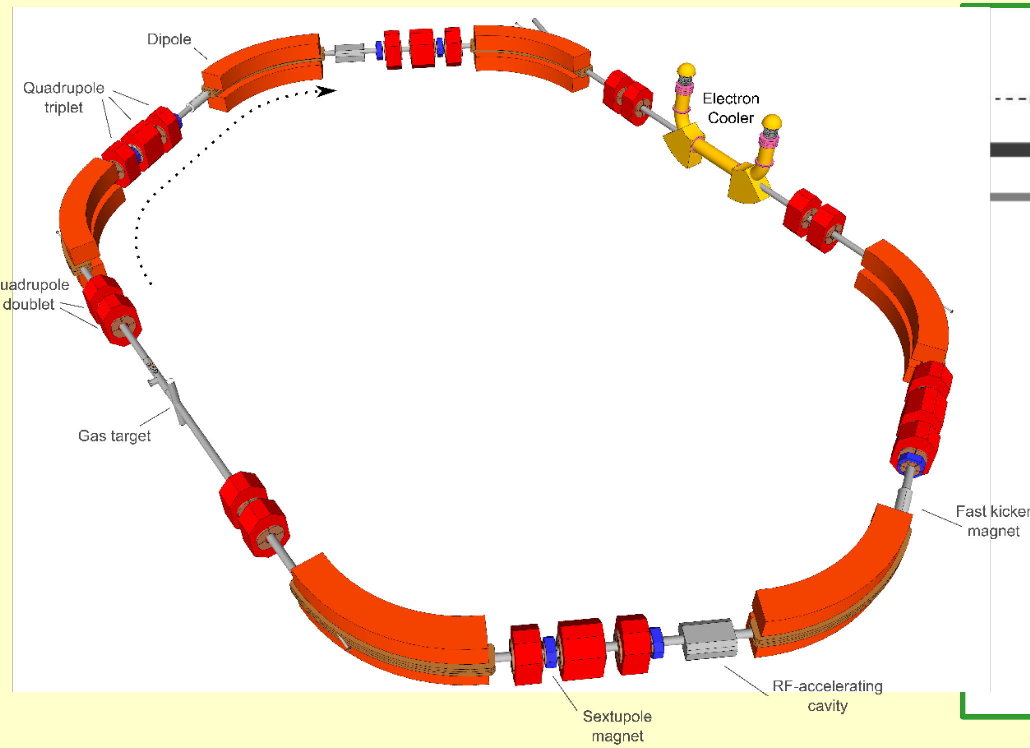
Kinematics for inverse reaction for ^{56}Ni

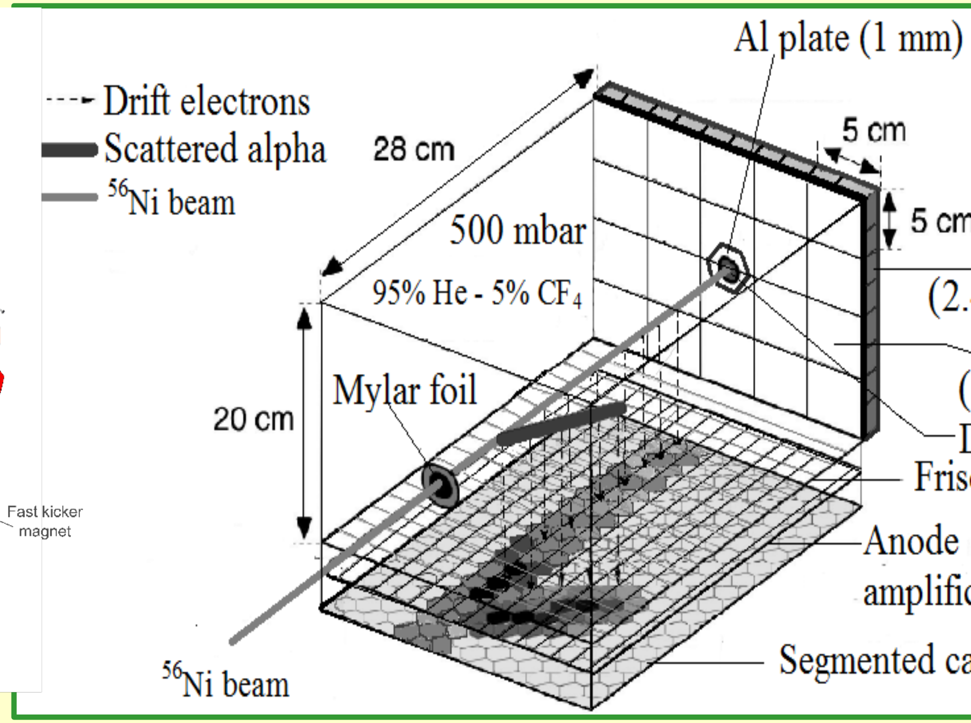


Kinematics for inverse reaction for ^{56}Ni



Storage Ring   Active Target

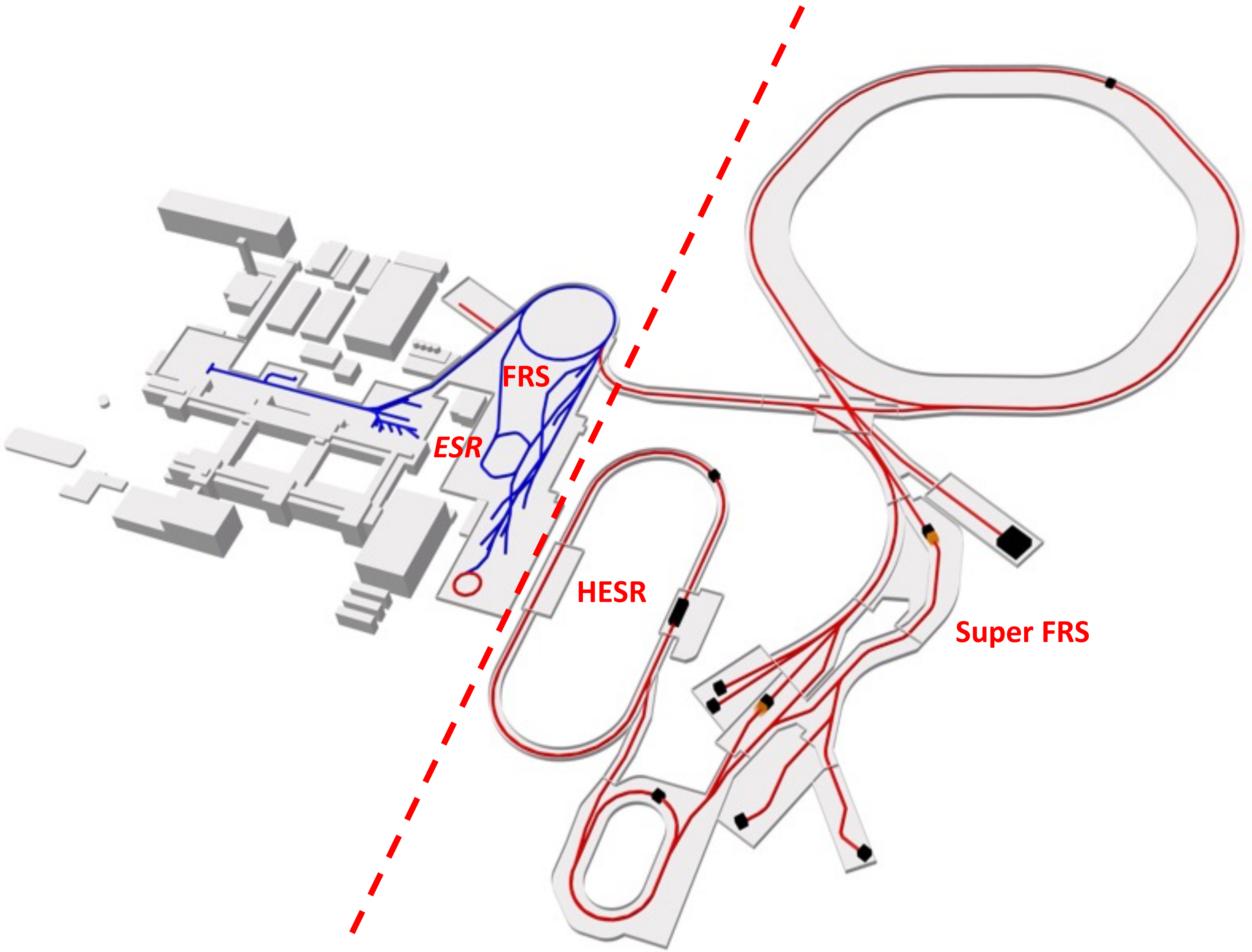




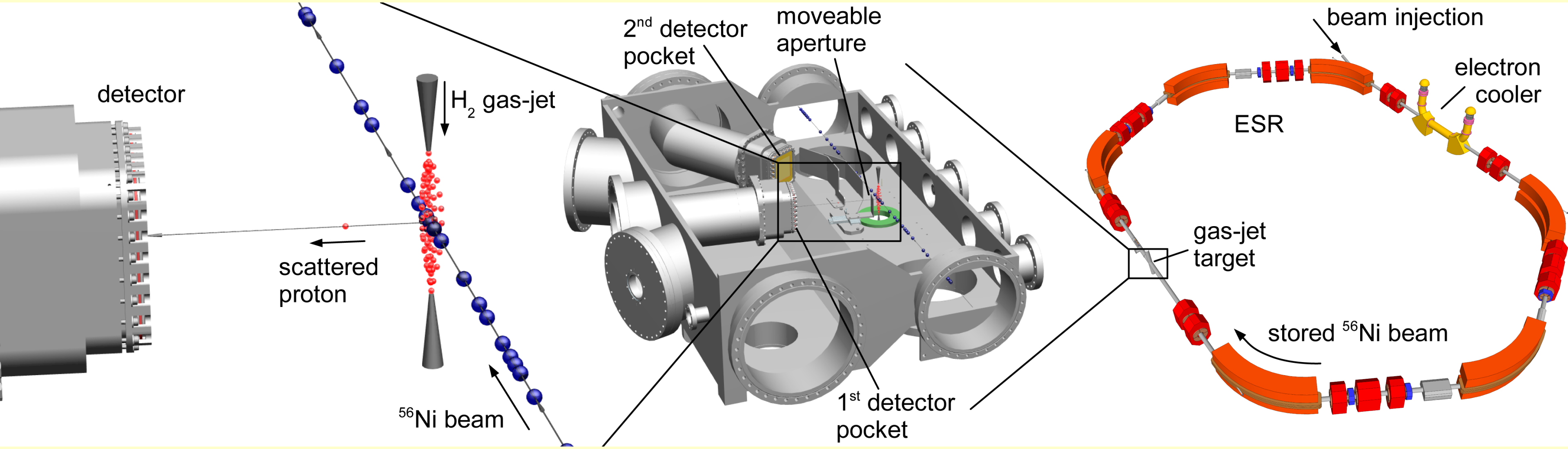
First EXL experiment with the existing storage ring at GSI (ESR)

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

GSI and FAIR



EXL setup @ ESR



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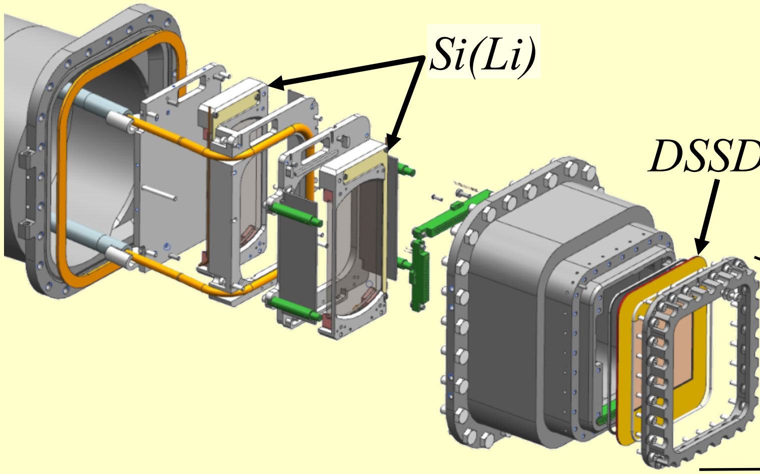
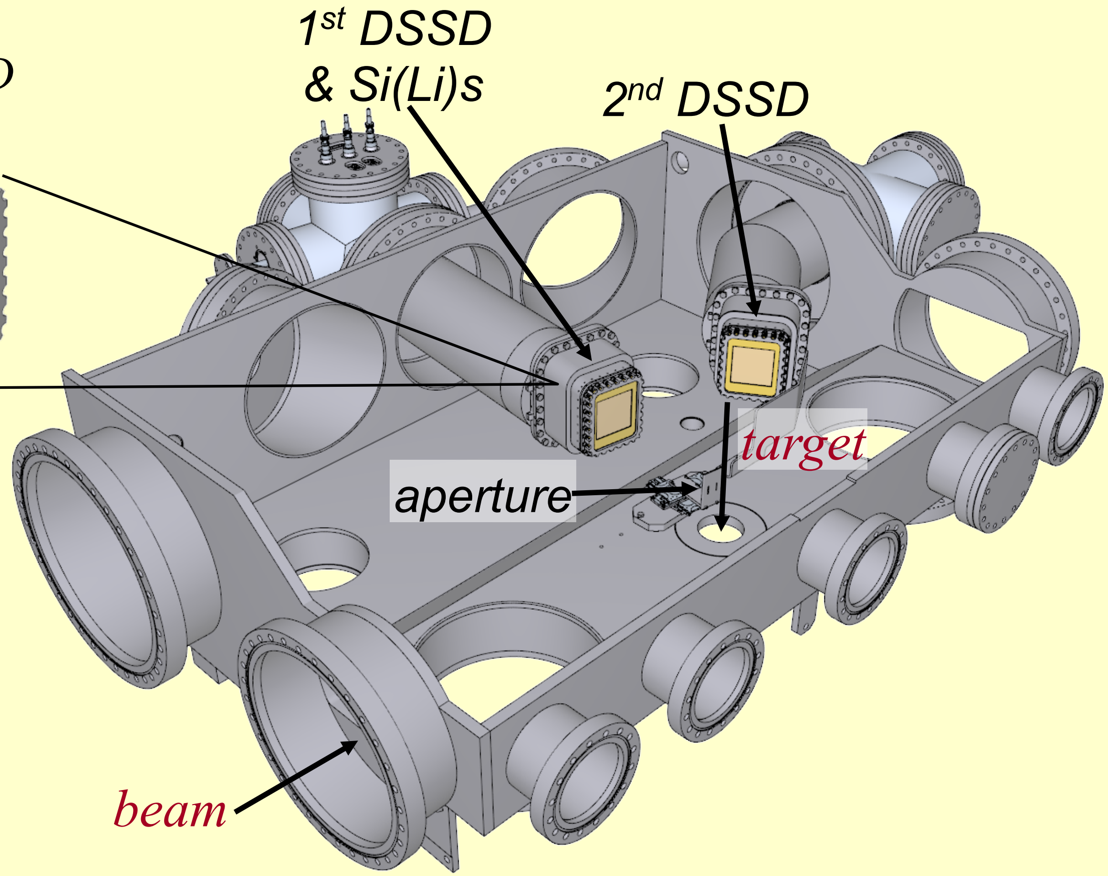
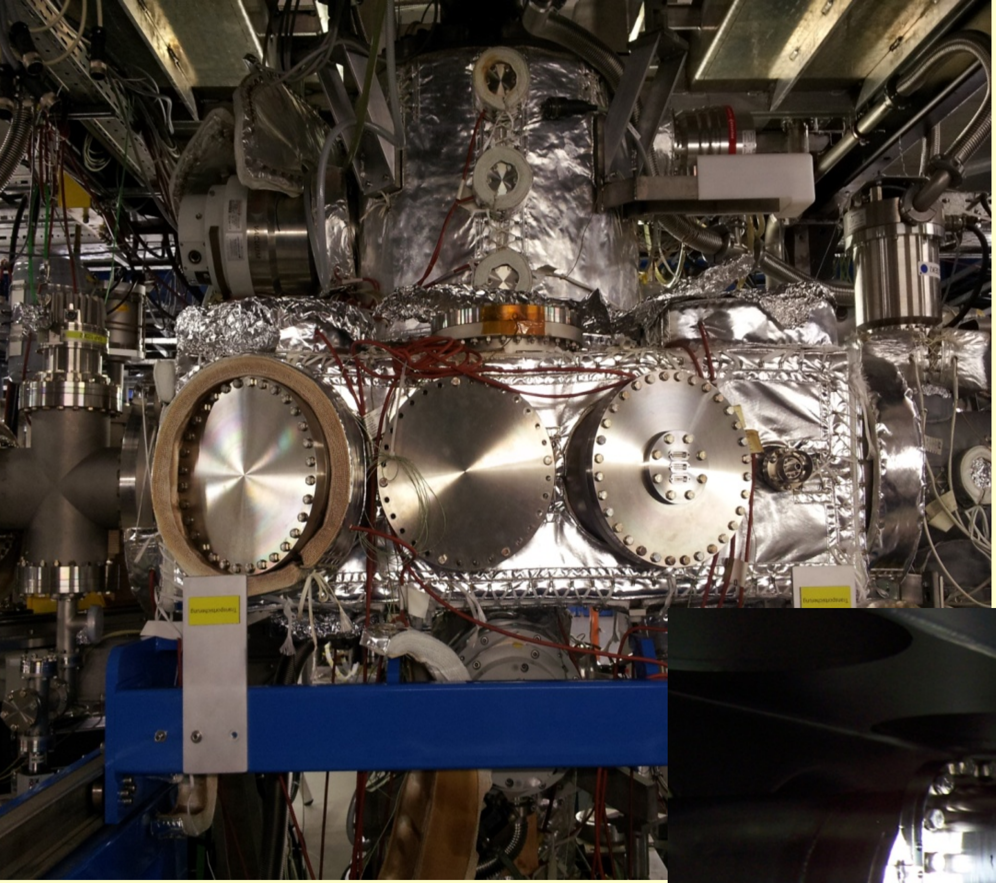
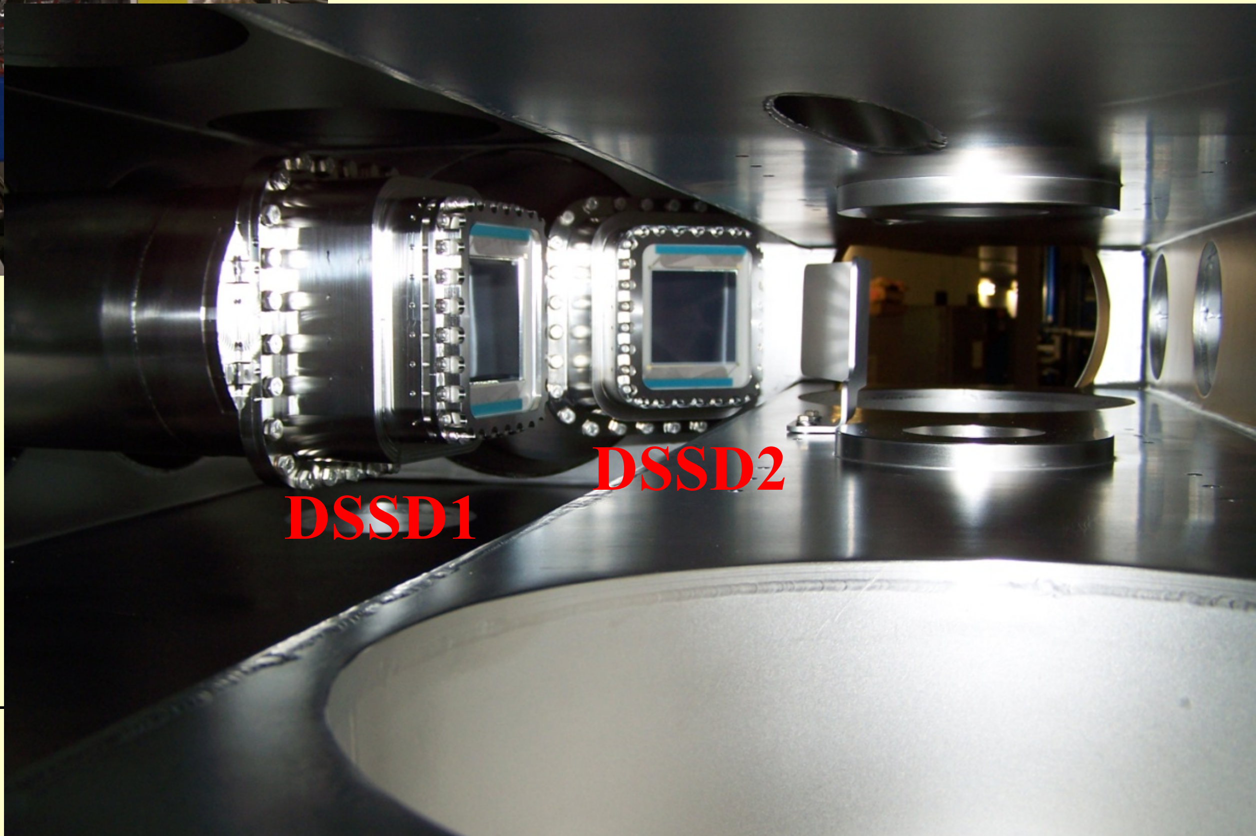
The new ESR Scattering chamber



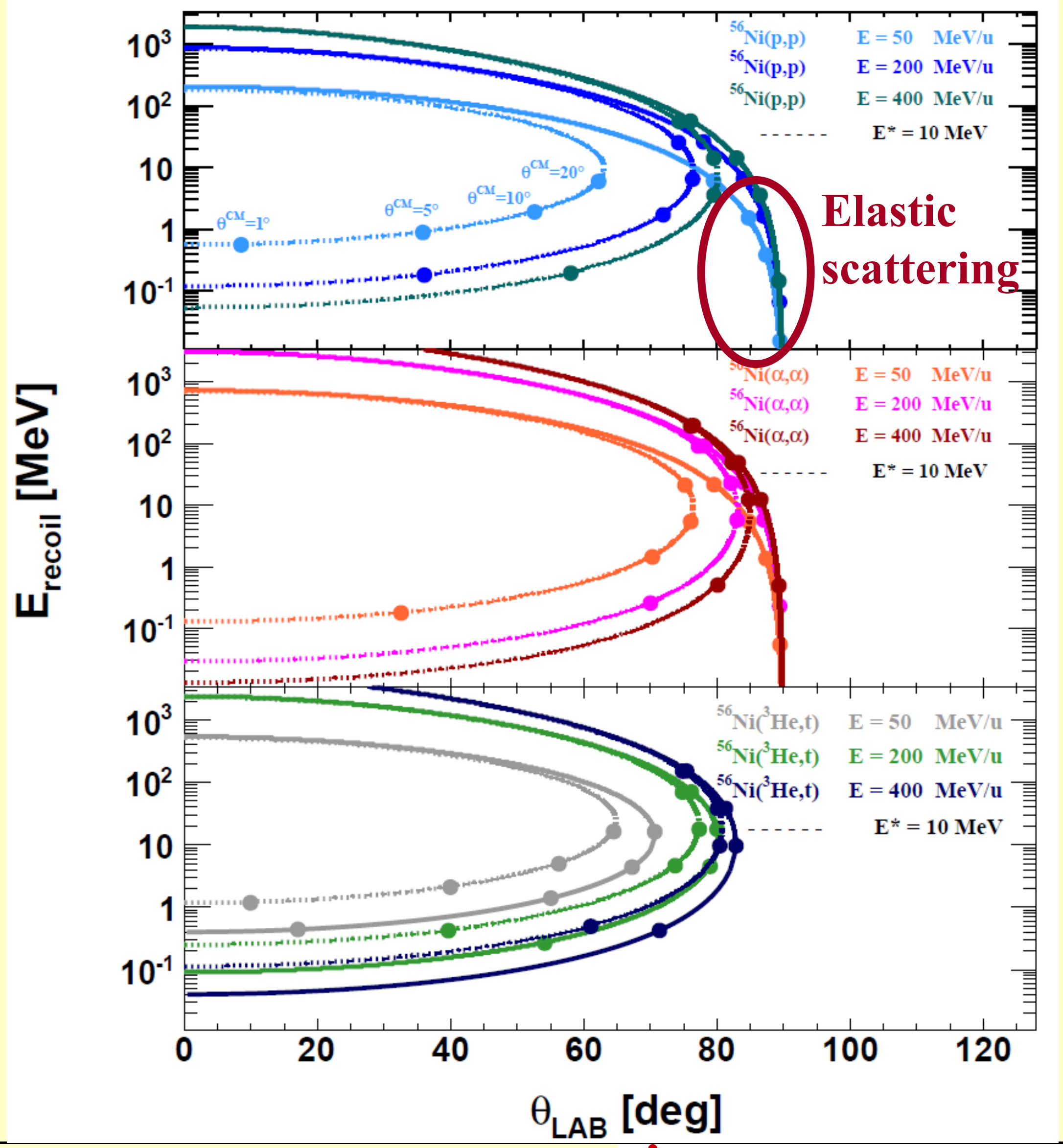


- ***DSSD**: 128 × 64 strips, (6 × 6) cm², 285 µm thick*
- ***Si(Li)**: 8 pads, (8 × 4) cm², 6.5 mm thick*
- ***active vacuum barrier***
- ***moveable aperture** to improve angular resolution*




DSSD1
DSSD2

Kinematics for inverse reaction for ^{56}Ni

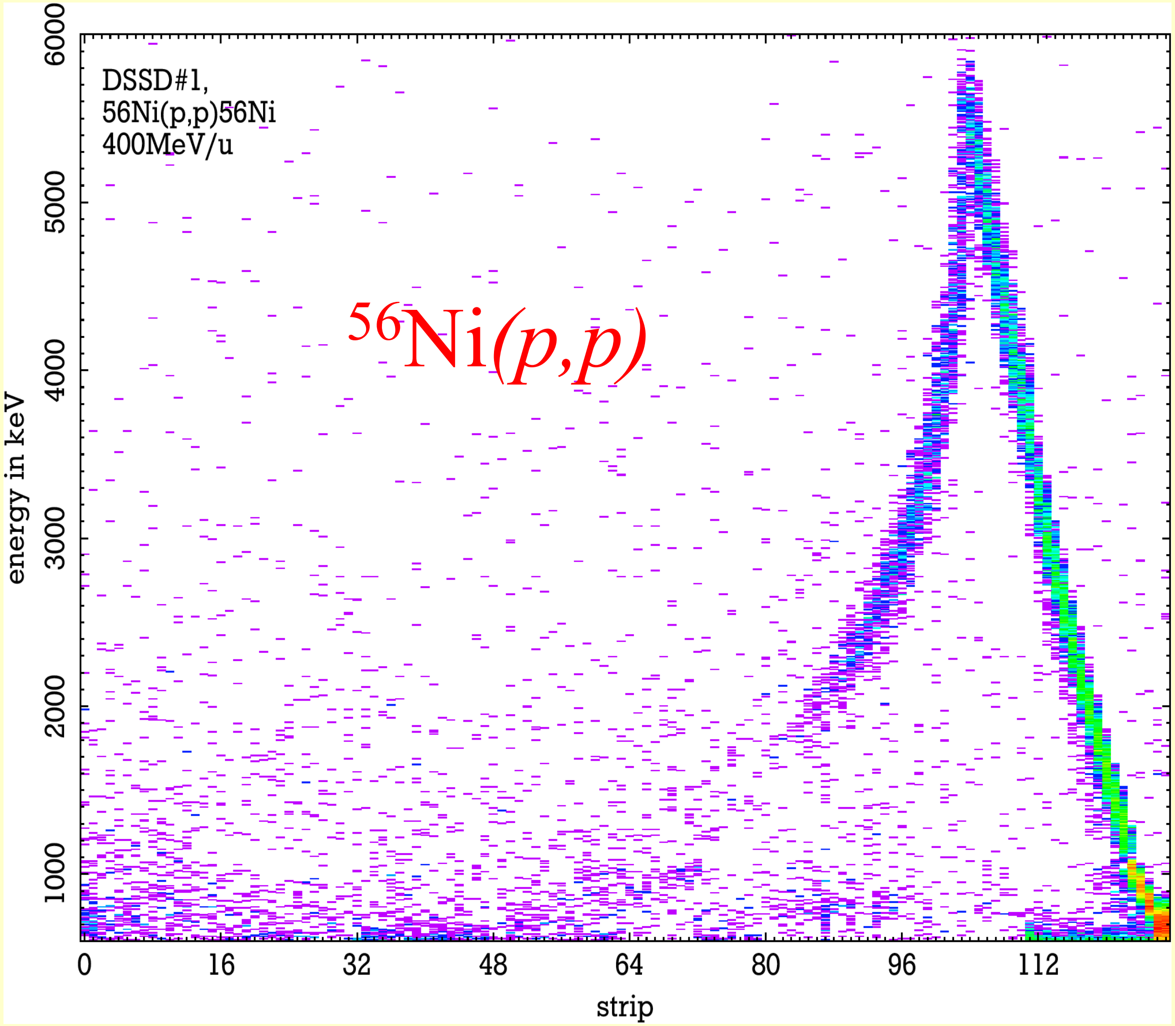


First results with radioactive beam

October 25, 2012:

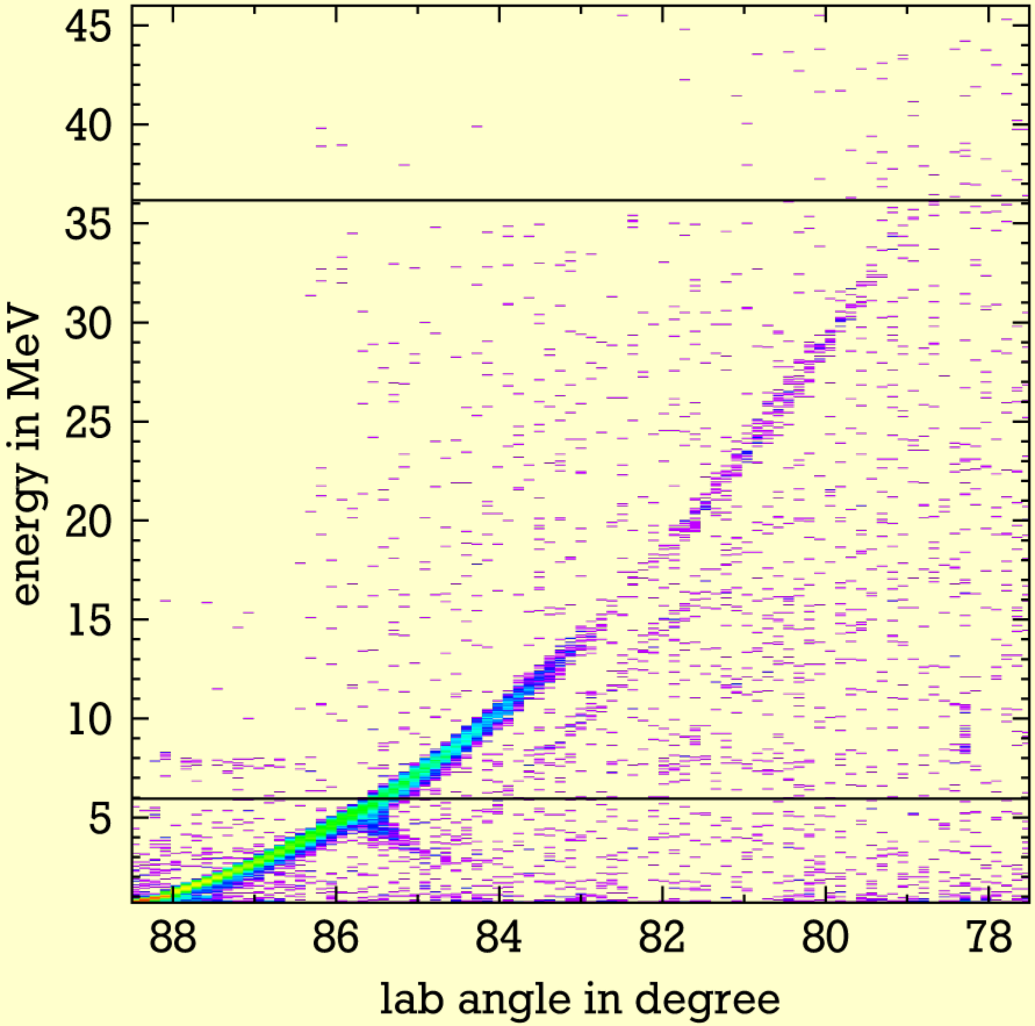
First Nuclear Reaction Experiment with Stored Radioactive Beam!!!!

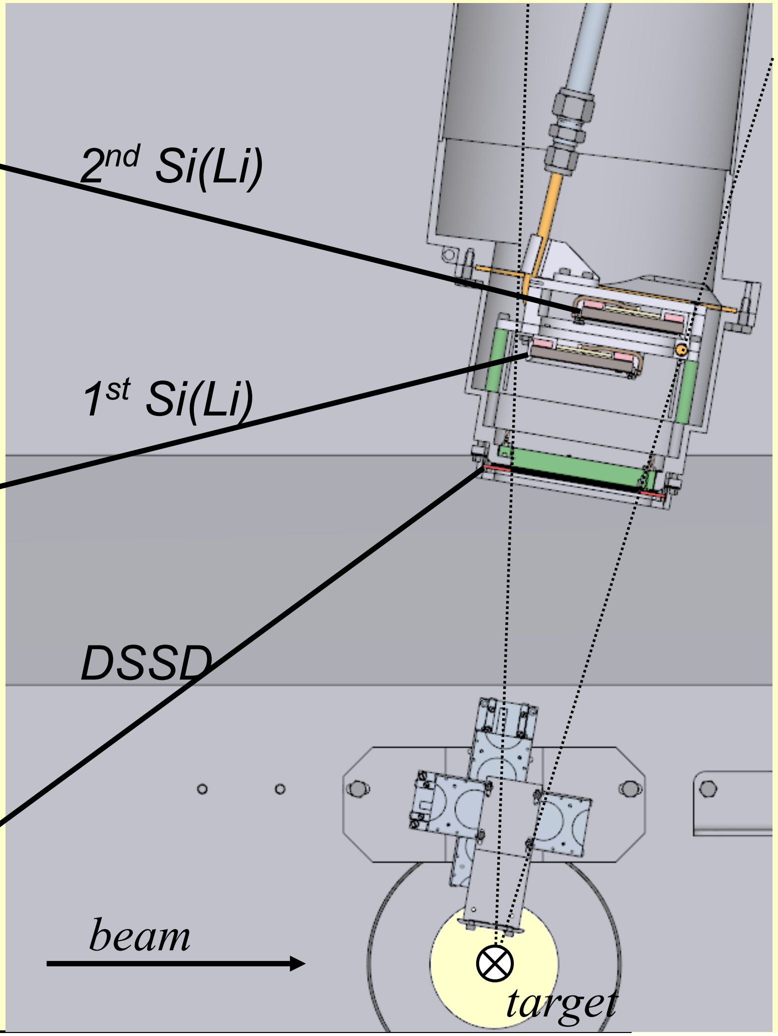
Beam energy 400 MeV/u



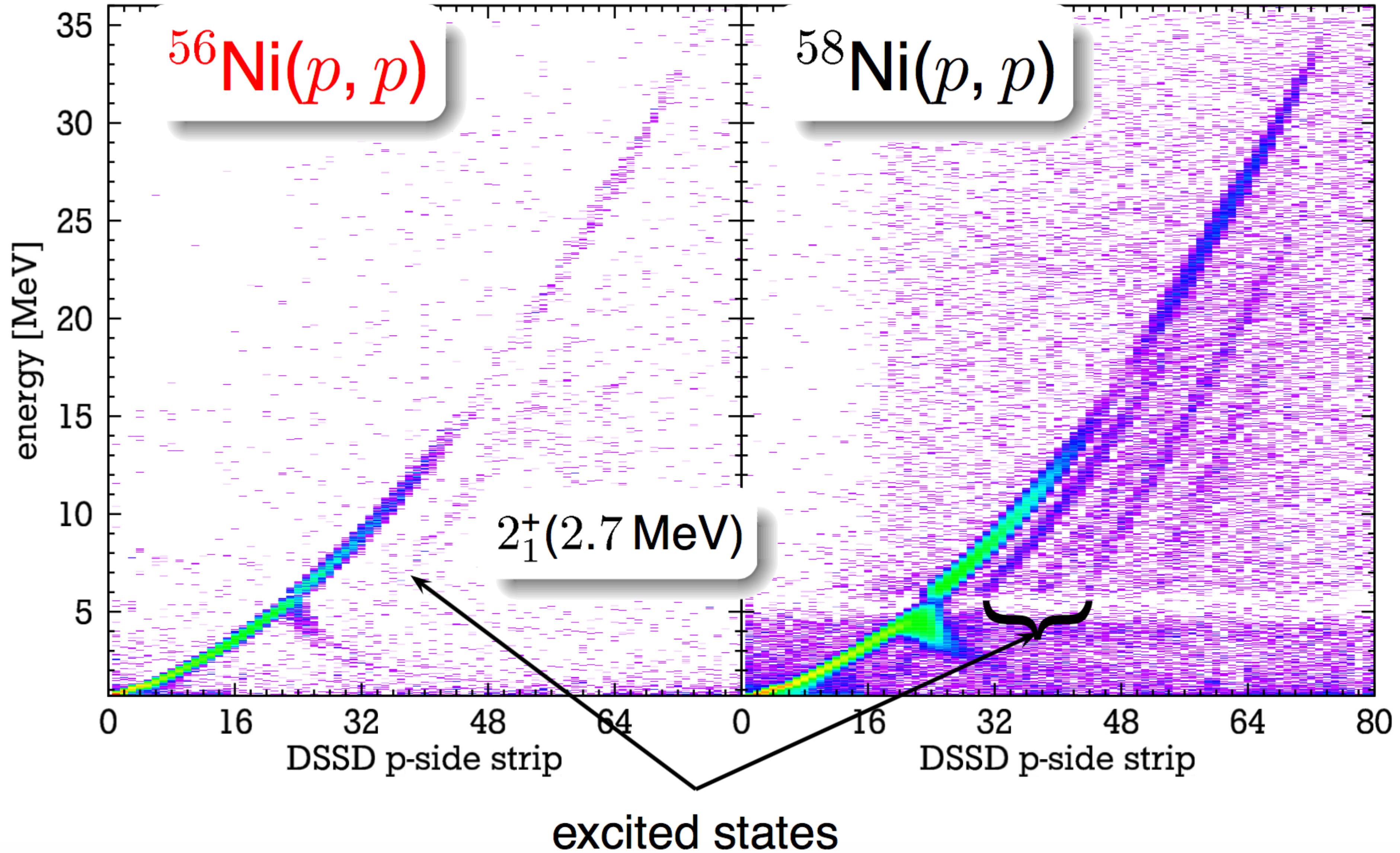
First results with radioactive beam

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



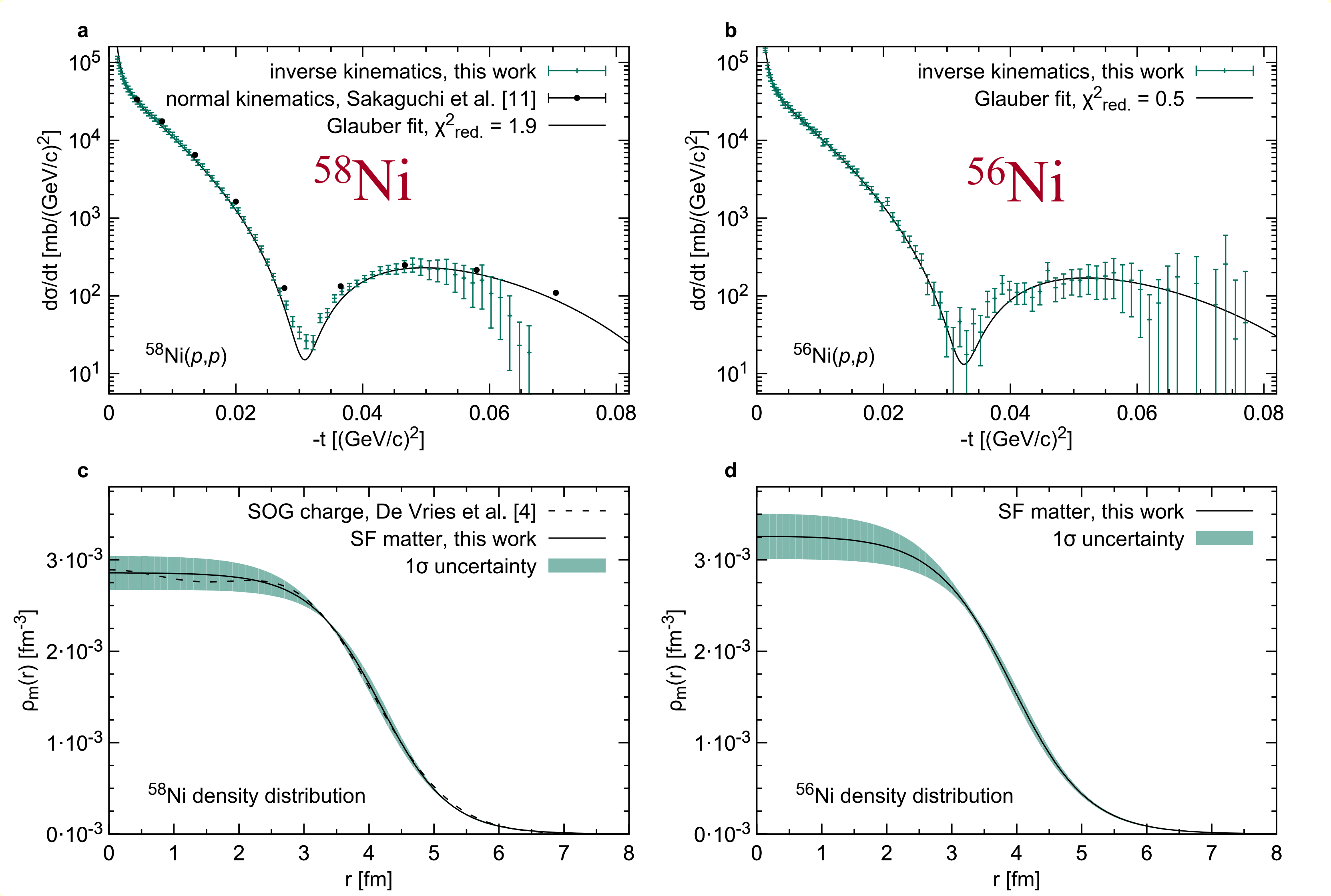


First results with radioactive beam



First results with radioactive beam

- Elastic p-scattering off Ni isotopes (E105)



M. von Schmid et al., Submitted to Nature

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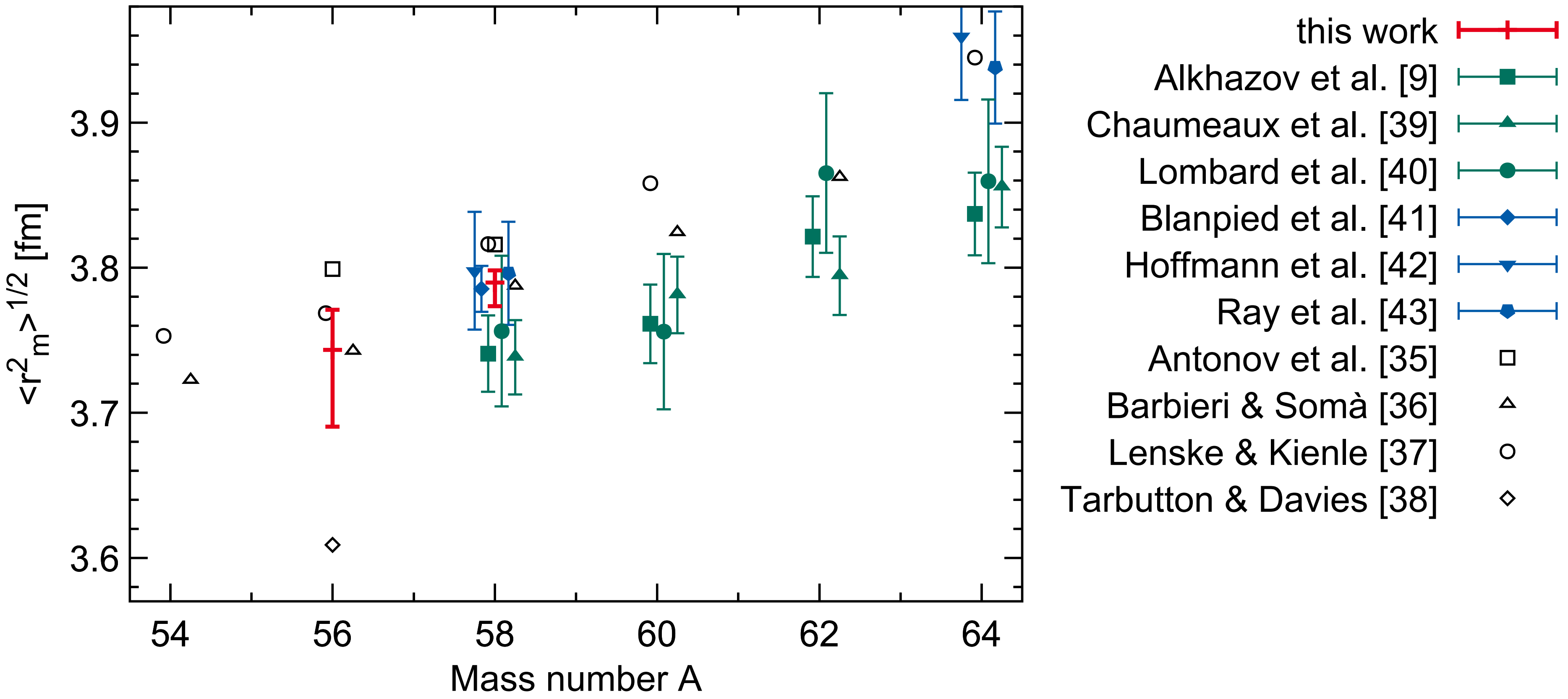
First results with radioactive beam and proton target

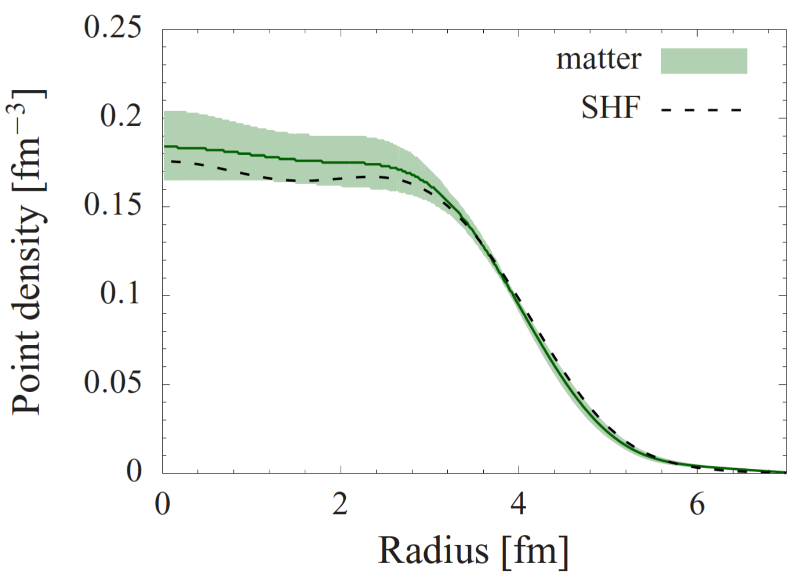


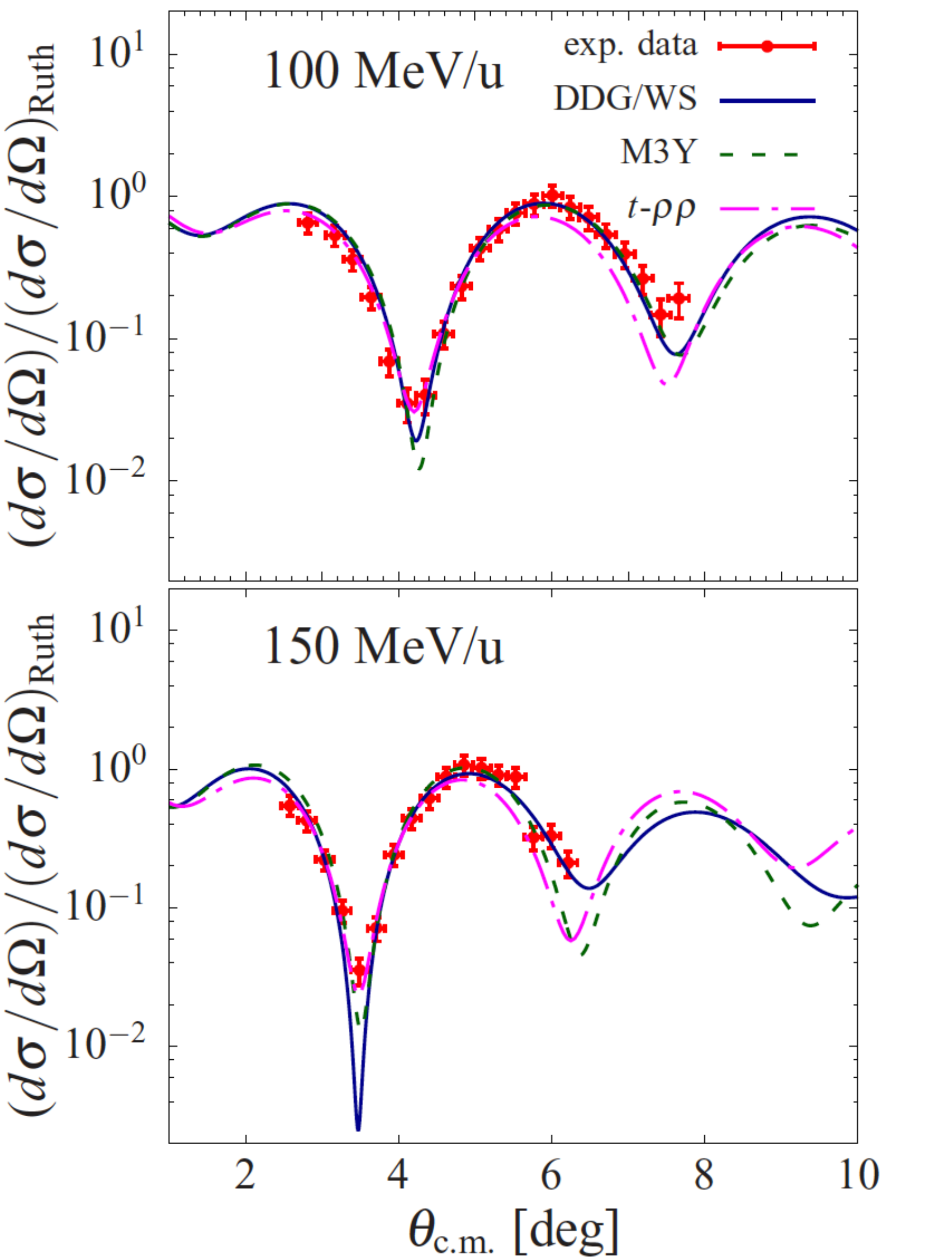
M. von Schmid et al., Submitted to Nature

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

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

  PRC **96**, 034617 (2017)

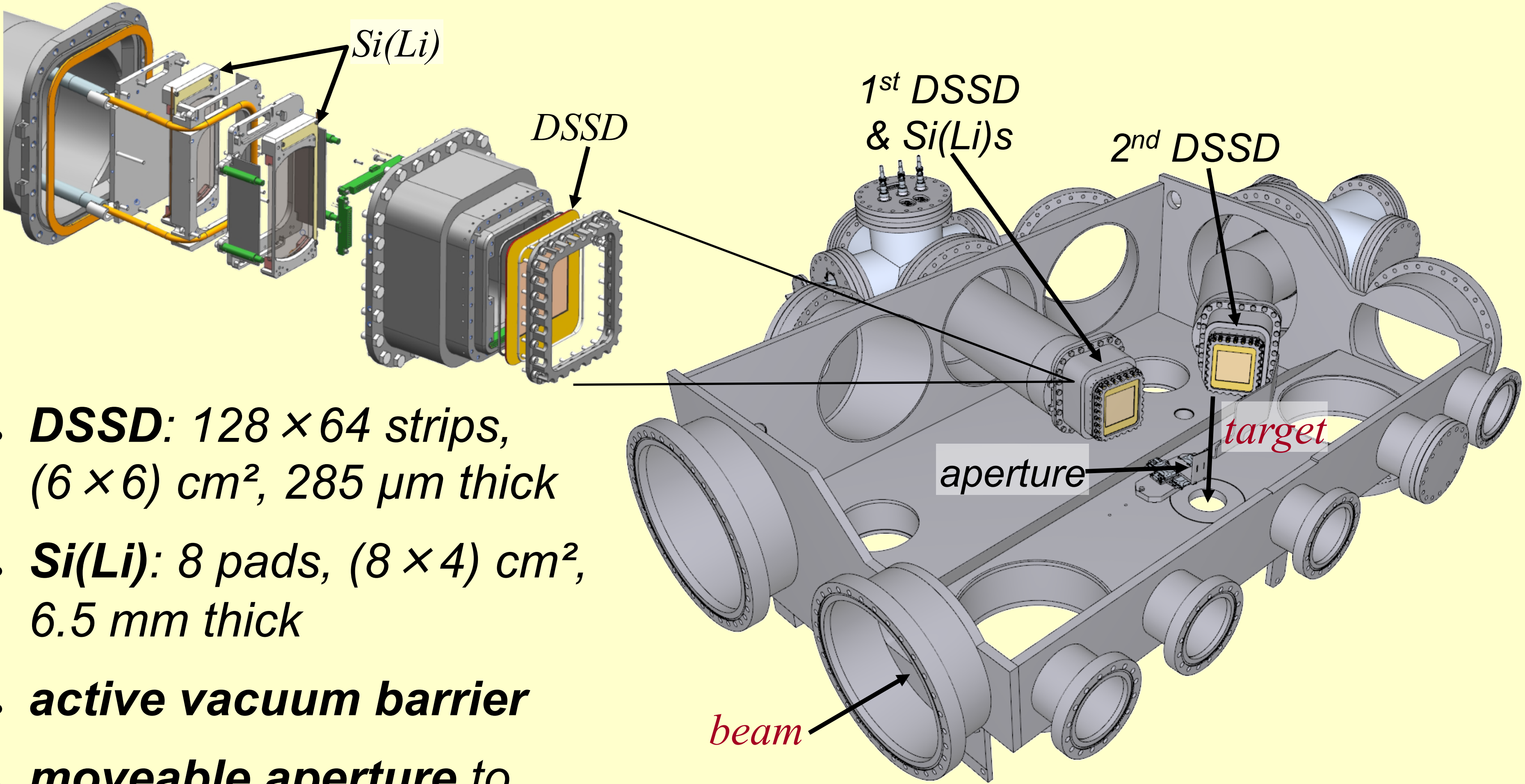




Total-r_{RMS} = 3.78(7) fm

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

The new ESR Scattering chamber



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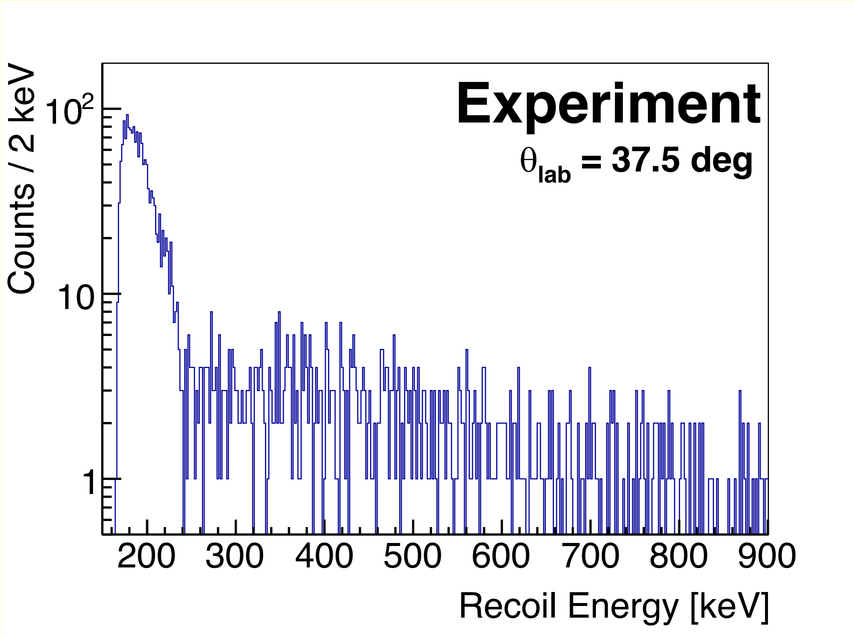
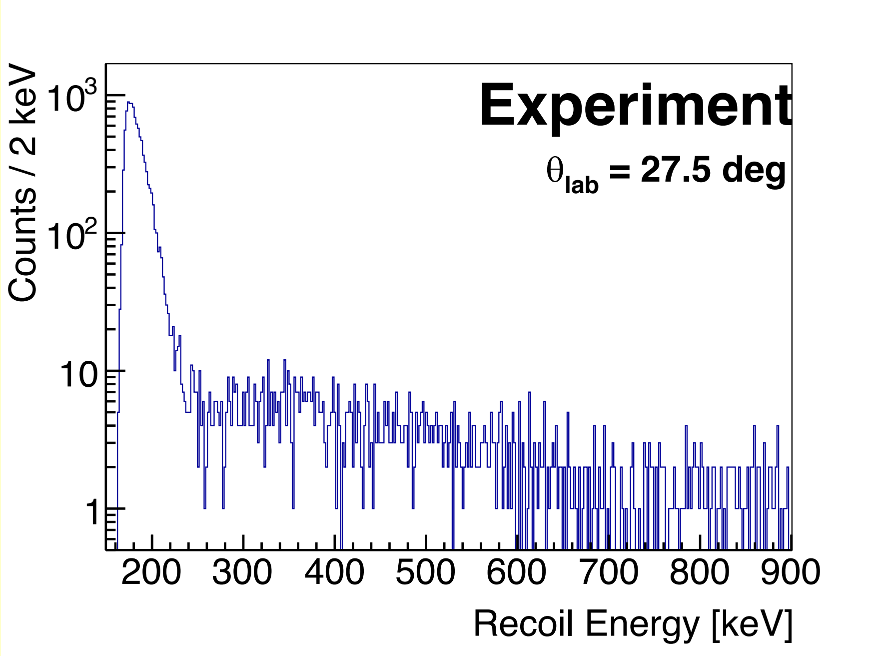
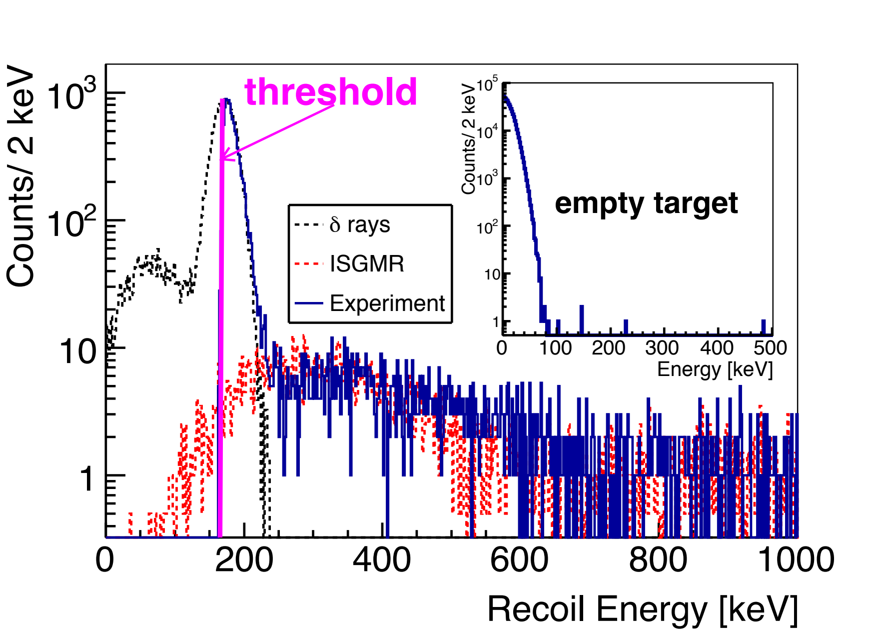
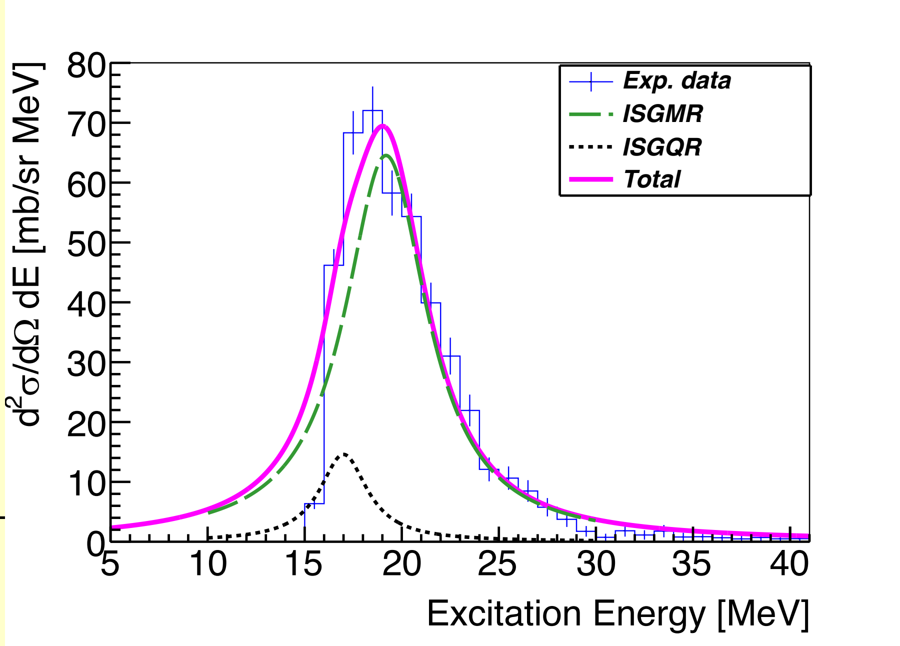
Inelastic alpha scattering (100 MeV/nucleon, PhD J.C. Zamora)



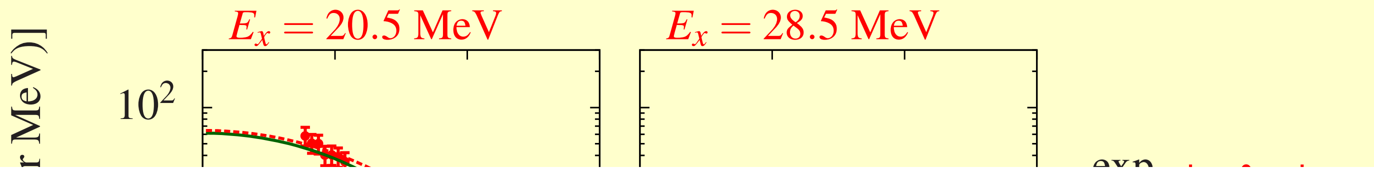




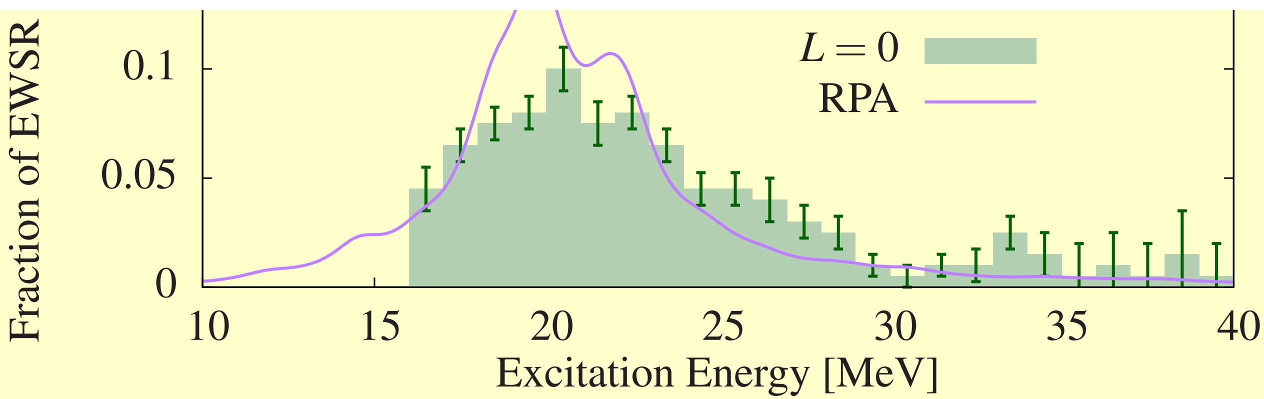


Inelastic alpha scattering (100 MeV/nucleon) from ^{58}Ni

- 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}



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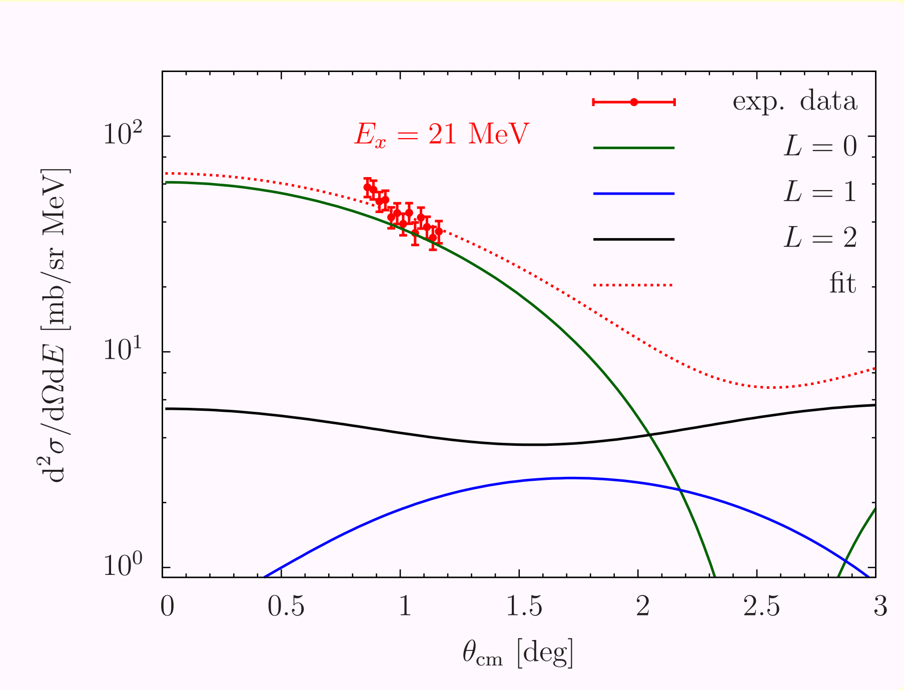
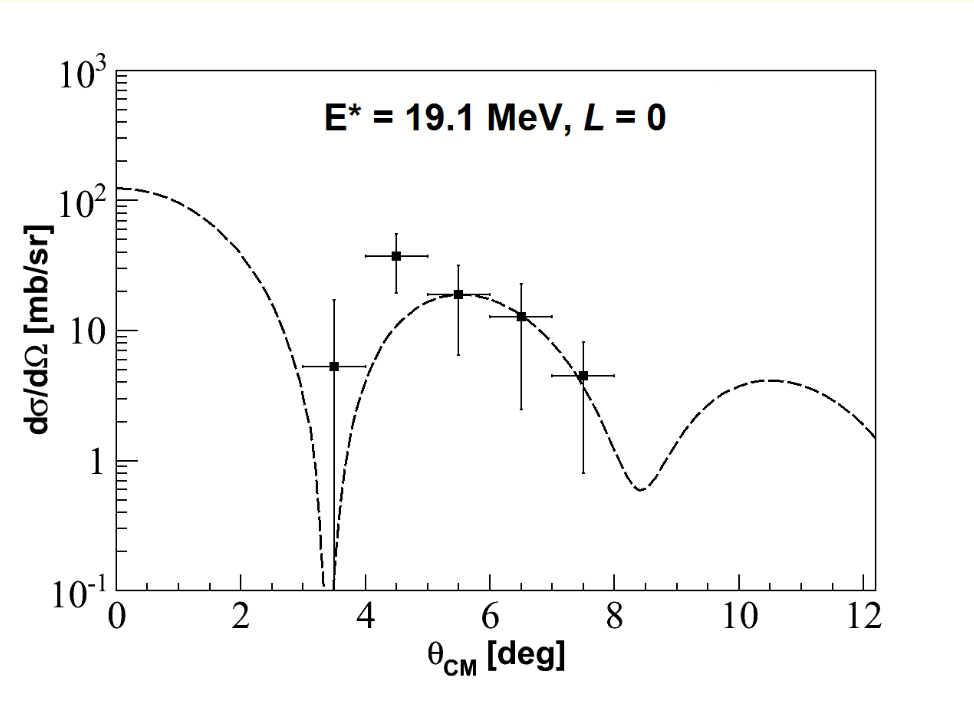
Monopole mode in ^{58}Ni and ^{56}Ni: Ring vs. active target





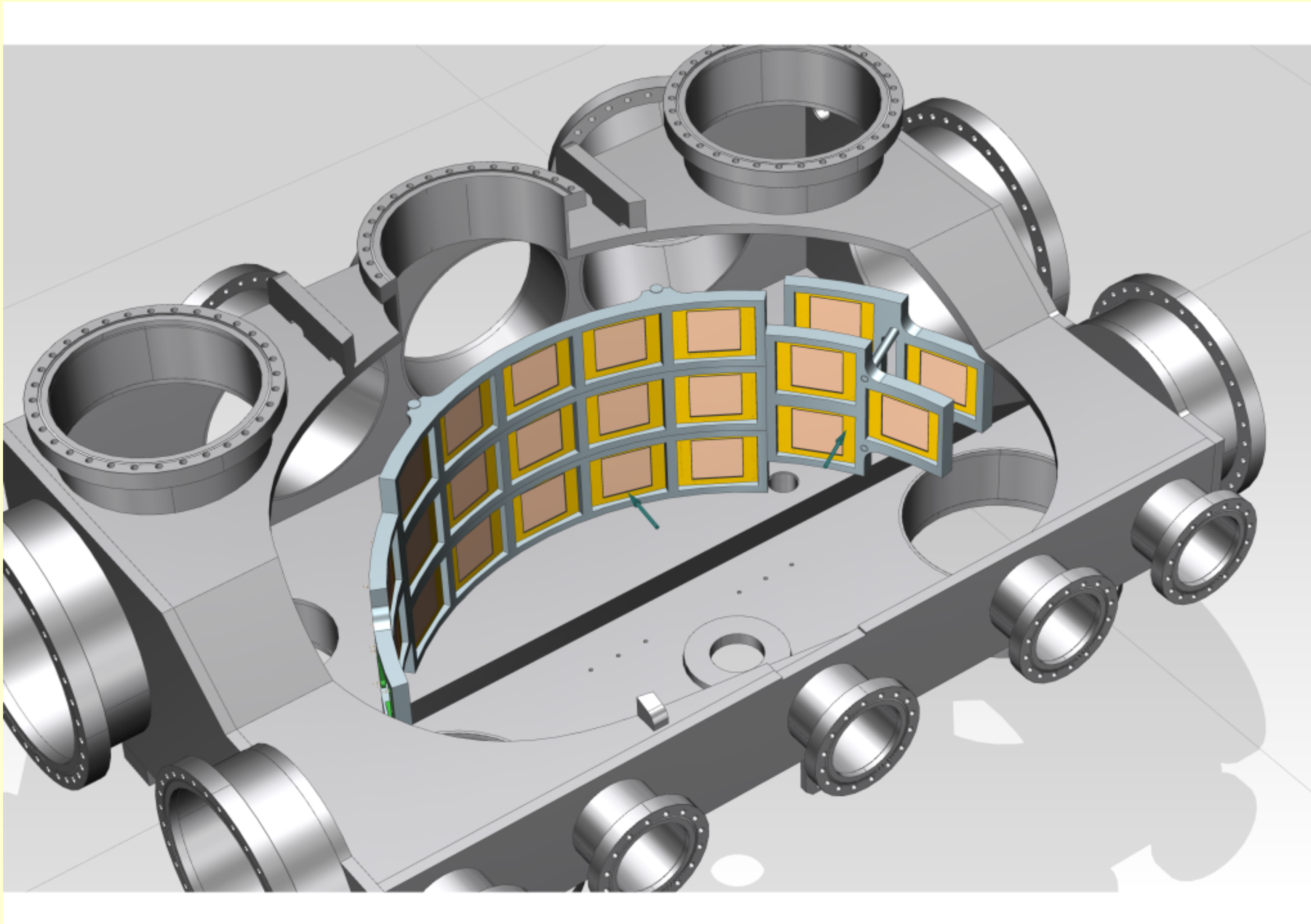
^{58}Ni

^{56}Ni

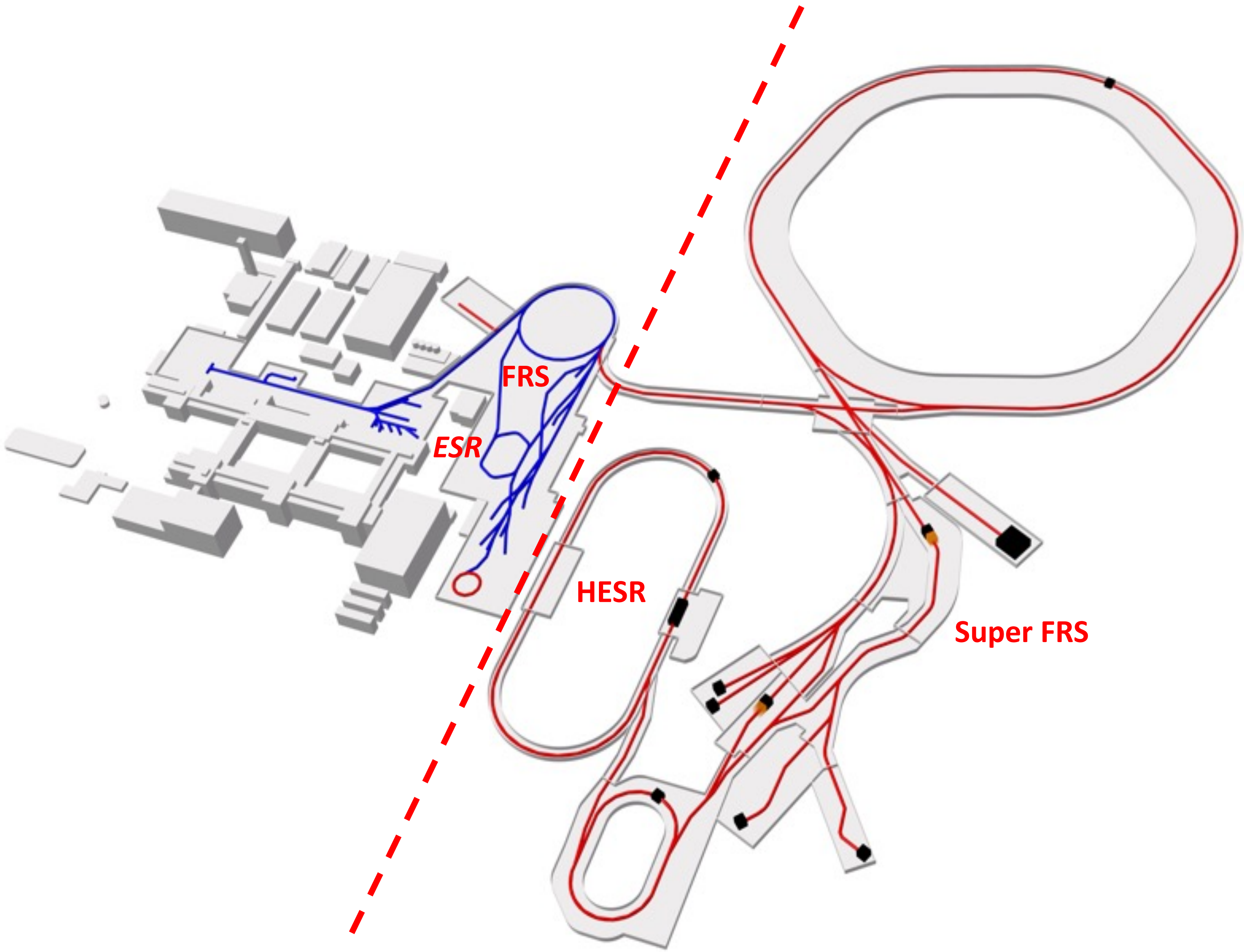
Conclusions and outlook

- 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



GSI and FAIR



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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[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

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Thank you!