Exotic nuclei studied with Light-ion induced reactions in storage rings

Status Report

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KVI, University of Groningen

NUSTAR week 2013
Helsinki, Finland
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The EXL Collaboration

Univ. São Paulo

TRIUMF Vancouver

IMP Lanzhou

VTT Helsinki

IPN Orsay, CEA Saclay

GSI Darmstadt, TU Darmstadt, Univ. Frankfurt, FZ Jülich, Univ. Giessen, Univ. Mainz, Univ. Munich

INR Debrecen

SINP Kolkata, BARC Mumbai

KVI Groningen

INFN/Univ. Milano

Univ. Teheran

Univ. Osaka

JINR Dubna, PNPI Gatchina, KRI St. Petersburg, Ioffe Inst. St. Petersburg, Kurchatov Inst. Moscow

CSIC Madrid, Univ. Madrid

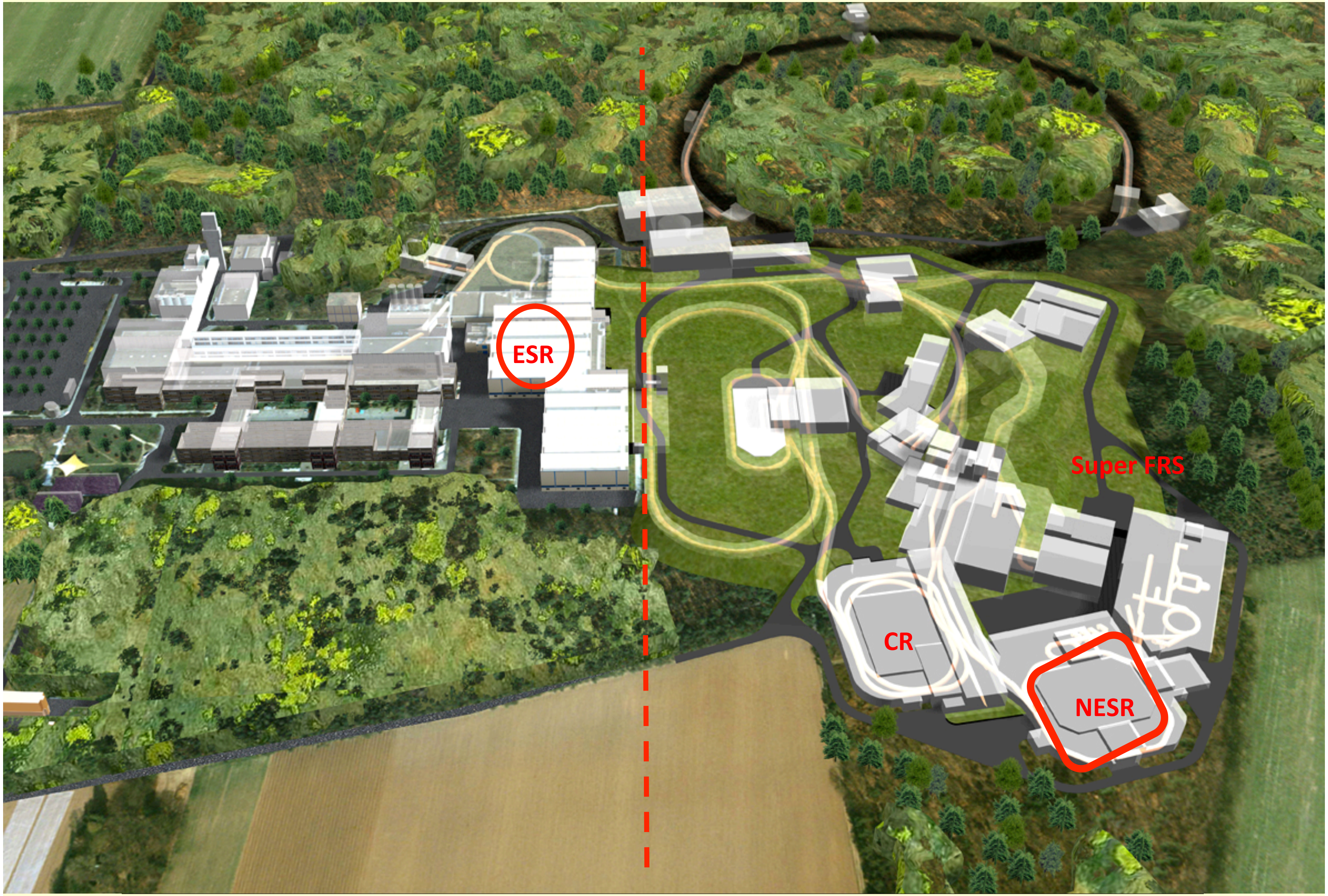
Univ. Lund, Mid Sweden Univ., Univ. Uppsala, Chalmers Inst. Göteborg

Univ. Basel

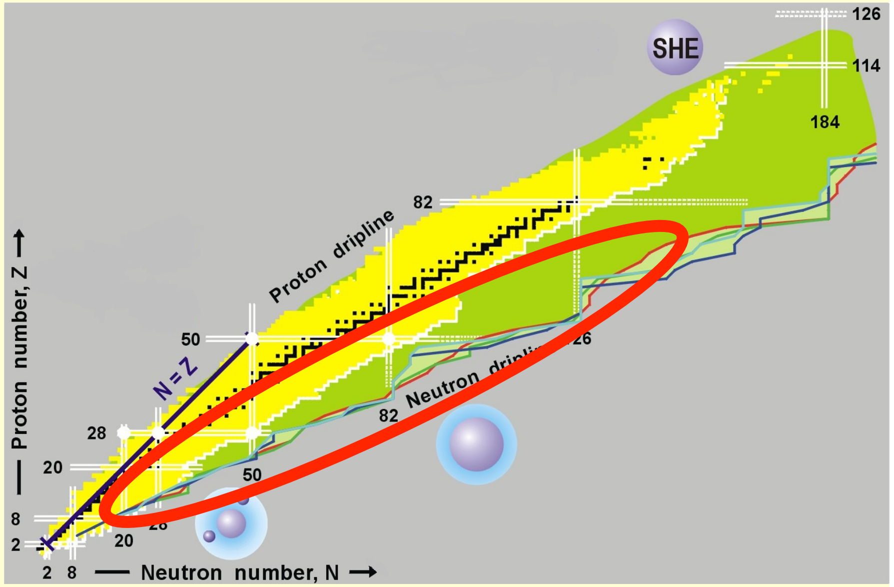
Univ. Birmingham, CLRC Daresbury, Univ. Surrey, Univ. York, Univ. Liverpool, Univ. Edinburgh

Tbilisi State University, Ilia Chavchavadze State University, Tbilisi, Georgia

Spokesperson: N. Kalantar (KVI)
Deputy: P. Egelhof (GSI)
GSI contact: H. Weick (GSI)
18 countries, 34 institutes, ~150 participants


ESR
Super FRS
CR
NESR

Main Physics Goals in Nuclear Structure



regions of interest:

⇒ towards the driplines for
light, medium, medium heavy
and heavy nuclei

physics interest:

- matter distributions (halo, skin…)
- single-particle structure evolution (new magic numbers, new shell gaps, spetroscopic factors)
- NN correlations, pairing and clusterization phenomena
- new collective modes (different deformations for p and n, giant resonance strength)
- parameters of the nuclear equation of state
- in-medium interactions in asymmetric and low-density matter
- astrophysical r and rp processes, understanding of supernovae

Light-ion induced direct reactions

- Elastic scattering (p,p), (α,α), …

  Nuclear matter distribution $\rho_{matter}(r)$, skins, halo structures
- Inelastic scattering (p,p'), (α,α'), …

  Deformation parameters, B(E2) values, transition densities, giant resonances
- Charge exchange reactions (p,n), (^{3}He,t), (d,^{2}He), …

  Gamow-Teller strength
- Transfer reactions (p,d), (p,t), (p, ^{3}He), (d,p), …

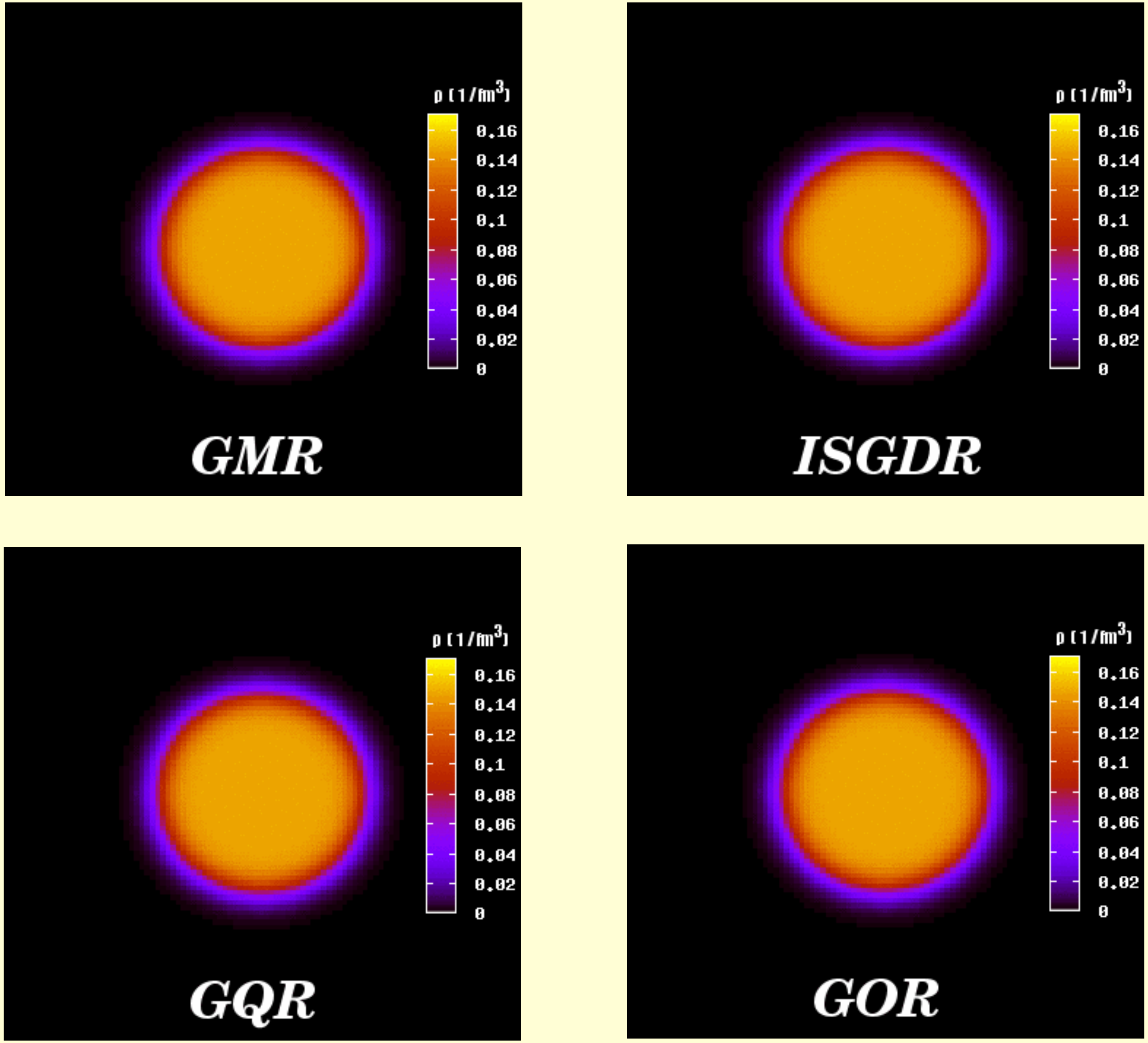
  Single particle structure, spectroscopic factors

  Spectroscopy beyond the driplines

  Neutron pair correlations

  Neutron (proton) capture cross sections
- Knock-out reactions (p,2p), (p,pn), (p,p^{4}He), …

  Ground state configurations, nucleon momentum dist., cluster correlations



M. Itoh

Why low momentum transfers 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

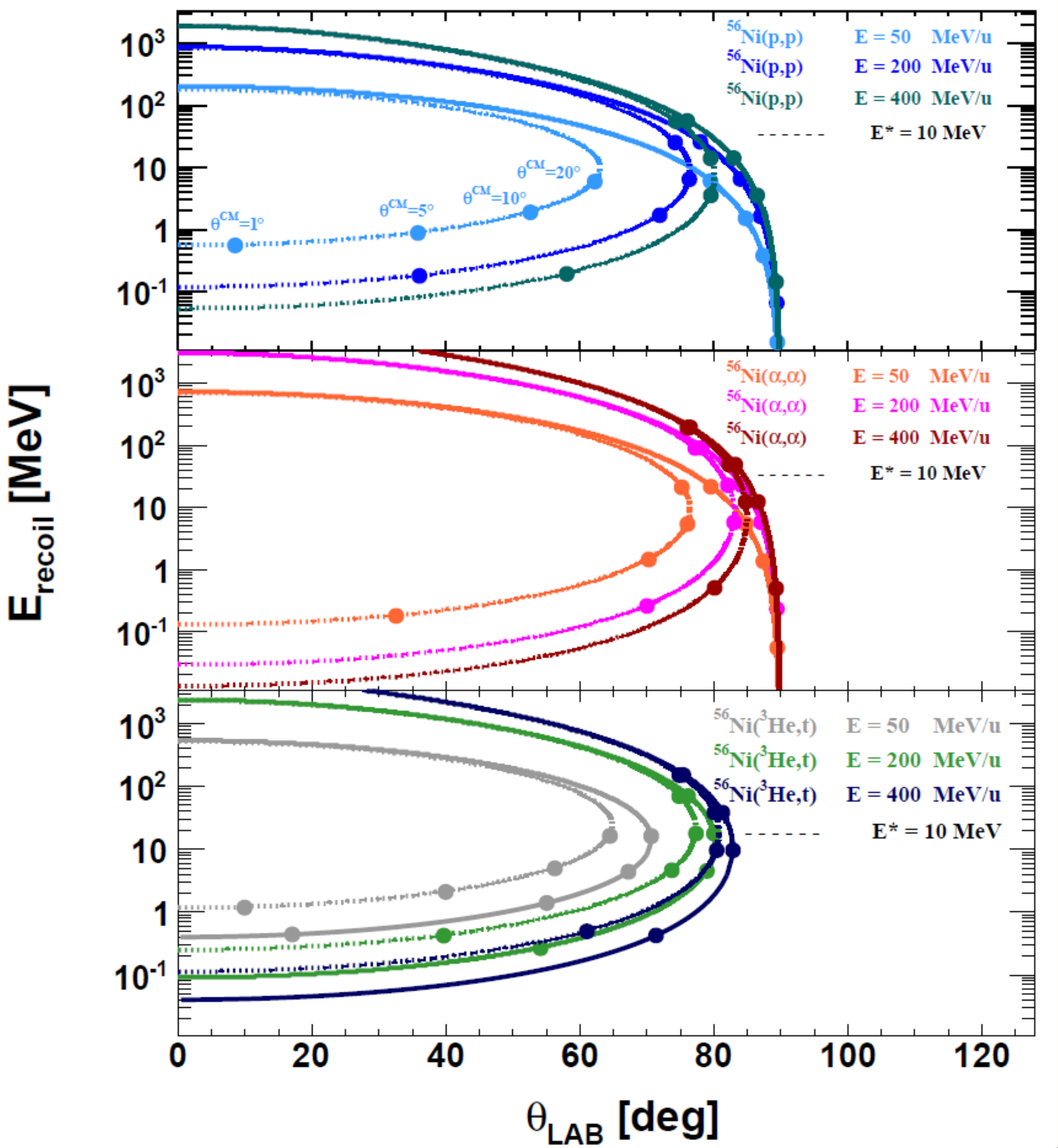
✓ Investigation of Gamow-Teller Transitions:

⇒ 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

Kinematics for inverse reaction for ^{56}Ni



Advantages and disadvantages of storage-ring experiments

Advantages:

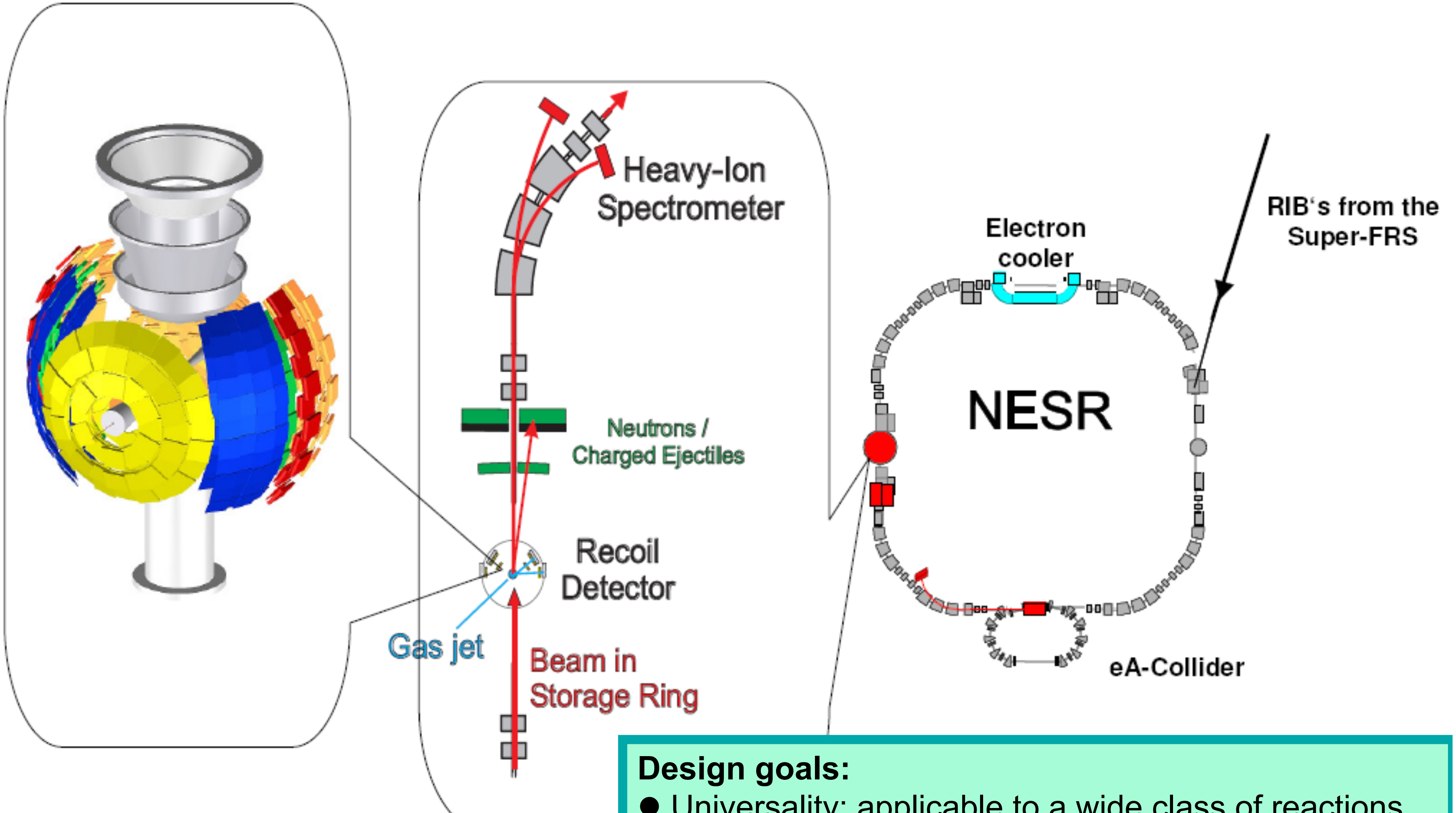
- Large intensities in the ring
- Little energy loss in the target
- No target window (no background)
- High resolution of the beam (cooling)
- Forward focusing for high-energy particles

Disadvantages:

- Ultra high vacuum
- Very small recoil energies for low q
- Thin targets

R^3B (external tar.)	vs.	EXL (ring exp.)
External target (thick)		Internal target (thin)
Low beam current		High beam current
High-energy particles		Low-energy particles
Large momentum transfer		Small momentum transfer
Target contamination		No target window
Quasi-elastic scattering		Giant resonances

Details of the EXL setup

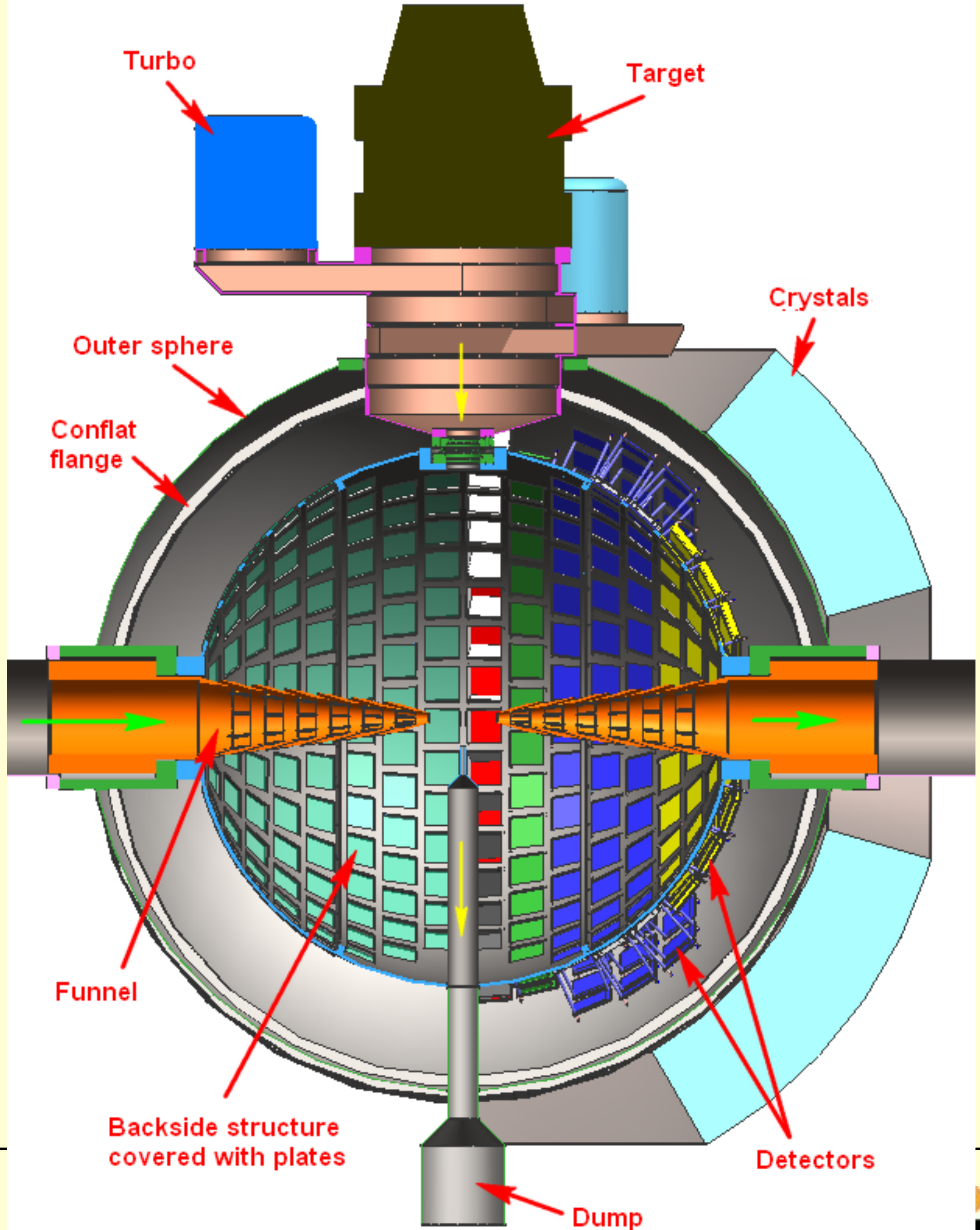


Detection systems for:

- Target recoils and gammas (p,α,n,γ)
- Forward ejectiles (p,n)
- Beam-like heavy ions

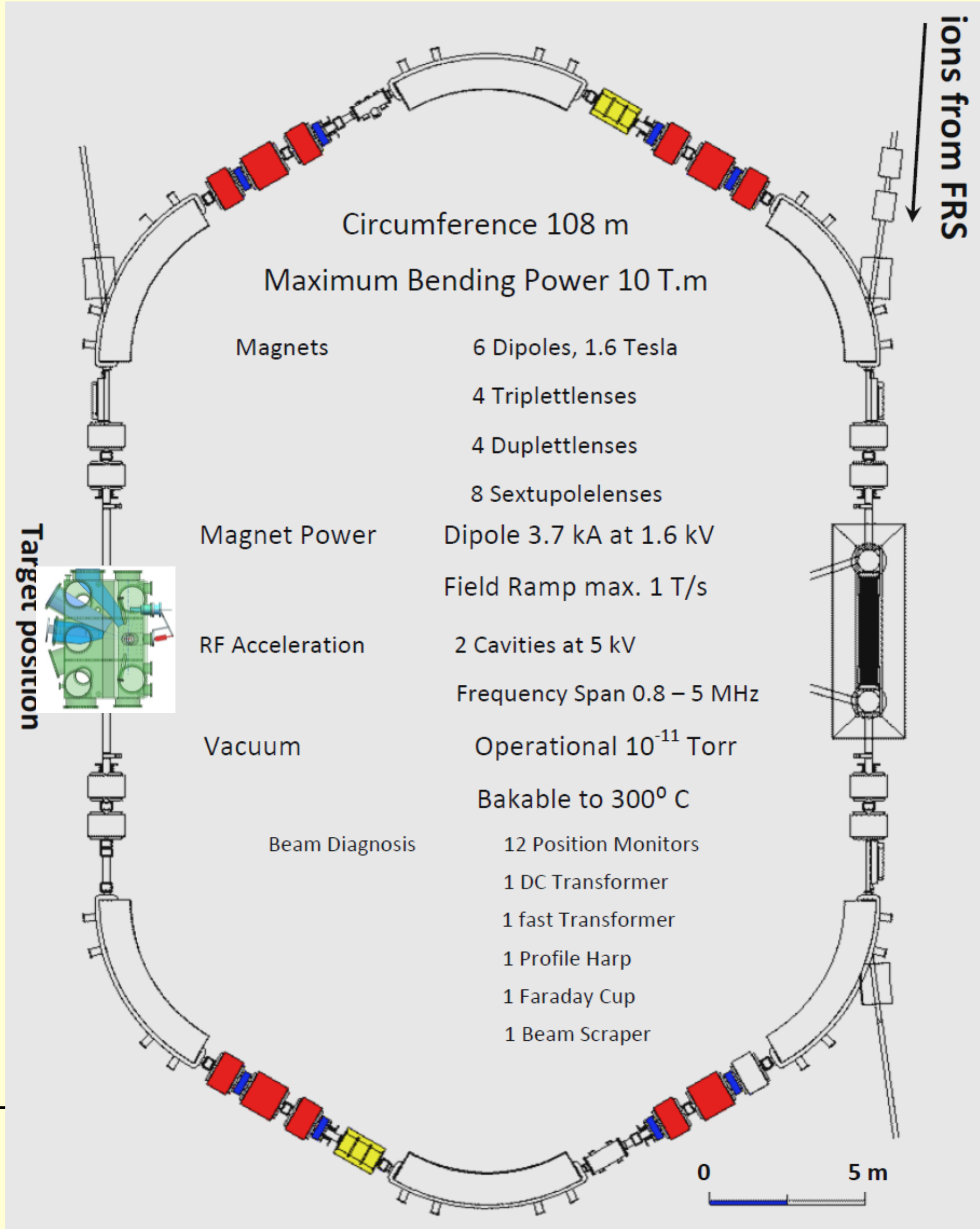
Design goals:

- Universality: applicable to a wide class of reactions
- Good energy and angular resolution
- Large solid angle acceptance
- Specially dedicated for low q measurements with high luminosity (> 10^{28} cm^{-2} s^{-1})


Turbo
Target
Crystals
Outer sphere
Conflat
flange
Funnel
Backside structure
covered with plates
Detectors
Dump

First experiments with the existing ring at GSI (ESR)

Setup @ ESR ring



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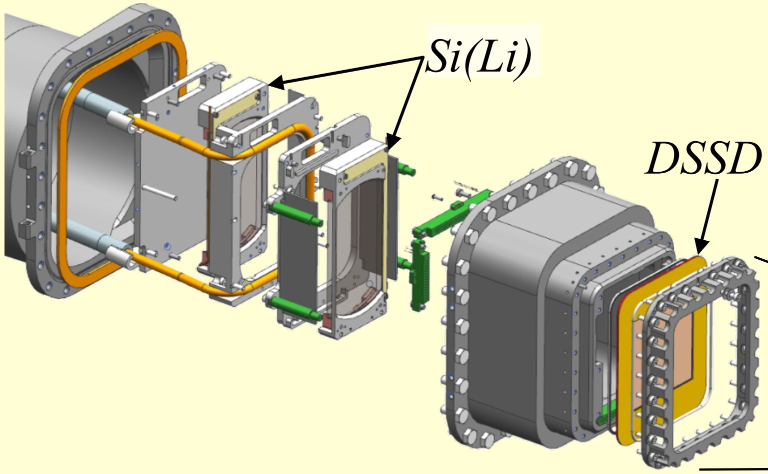
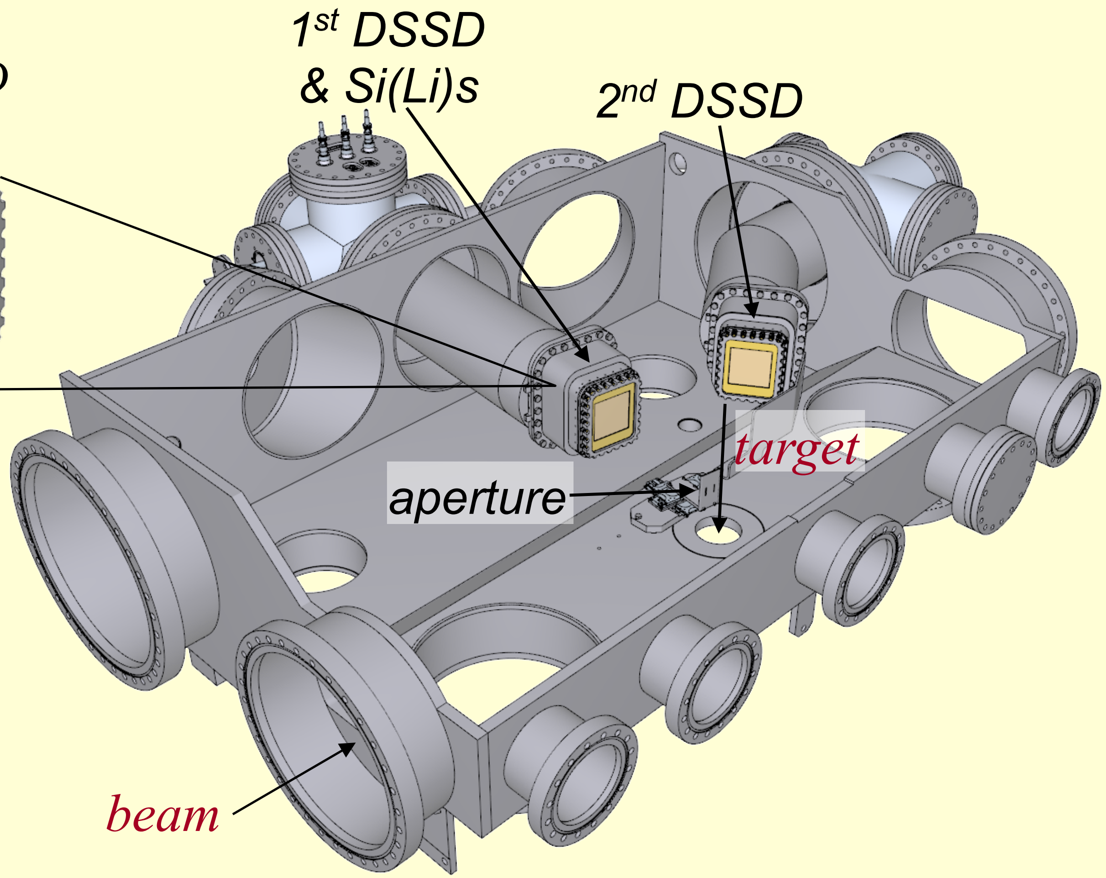
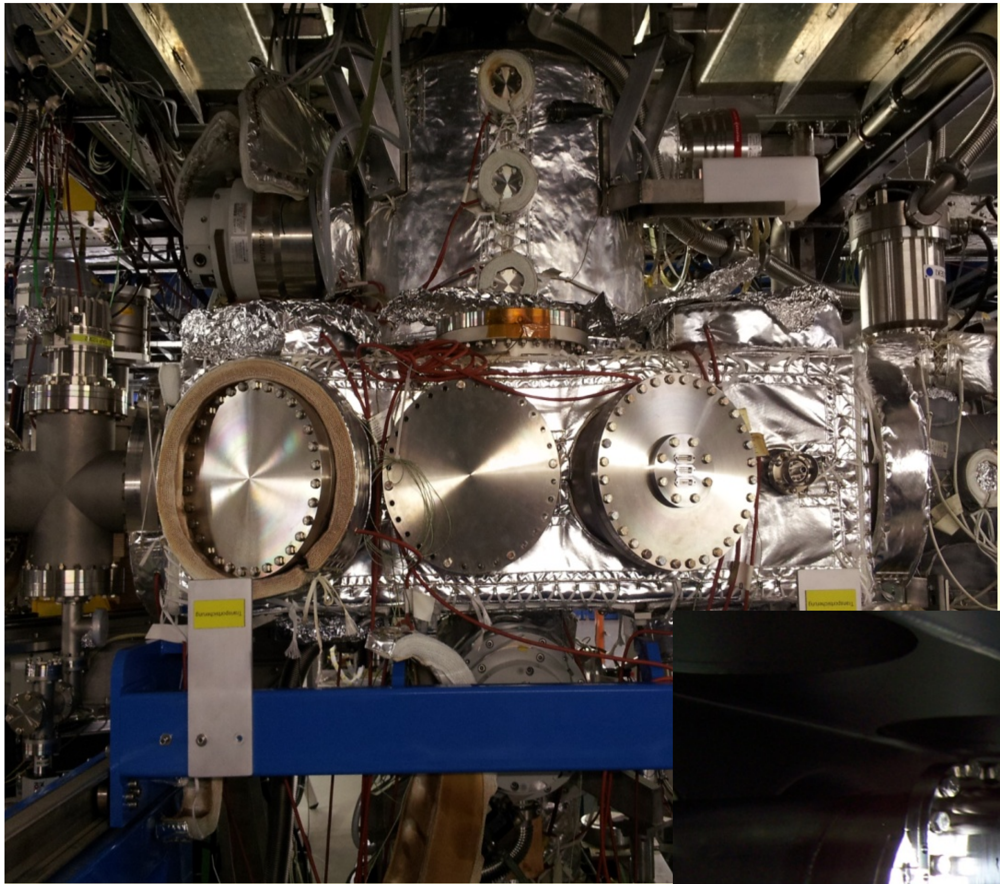
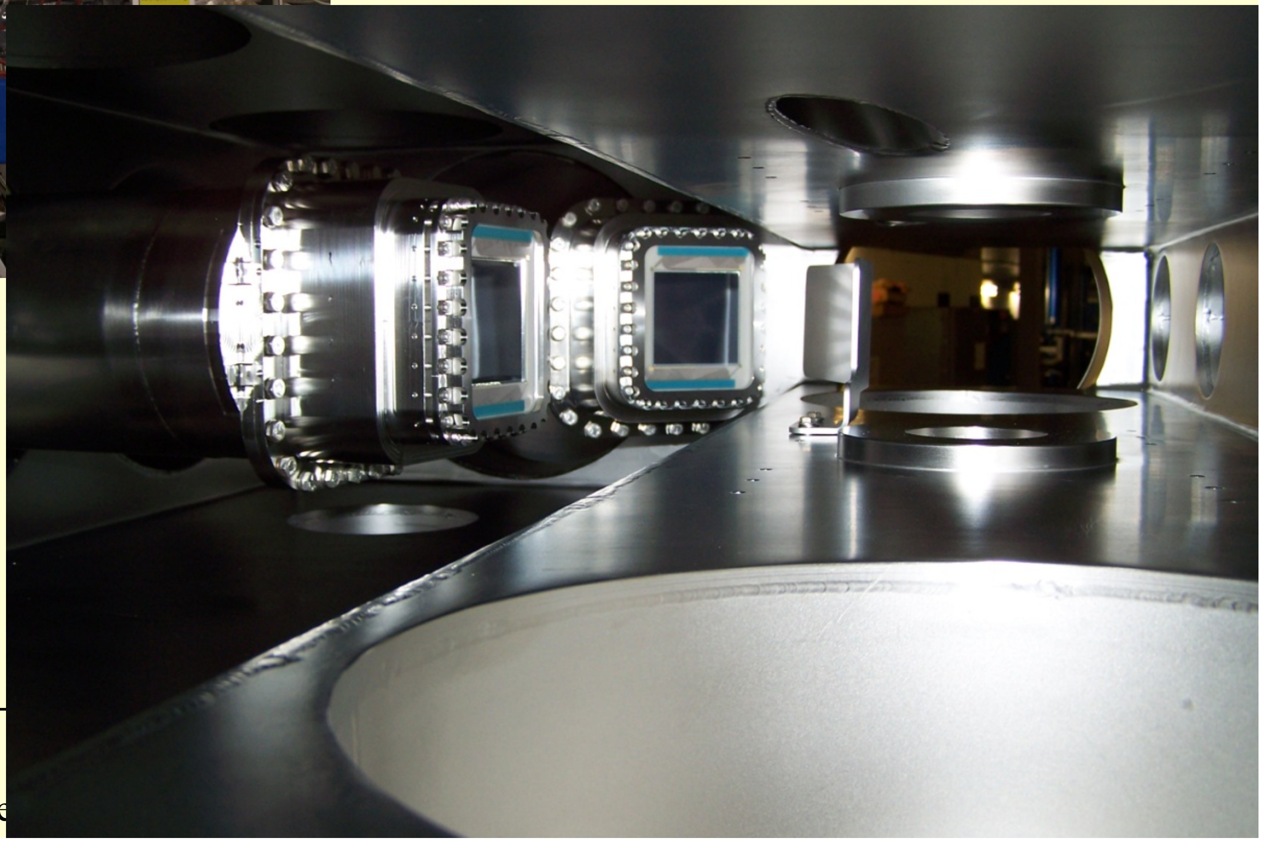
The new ESR Scattering chamber



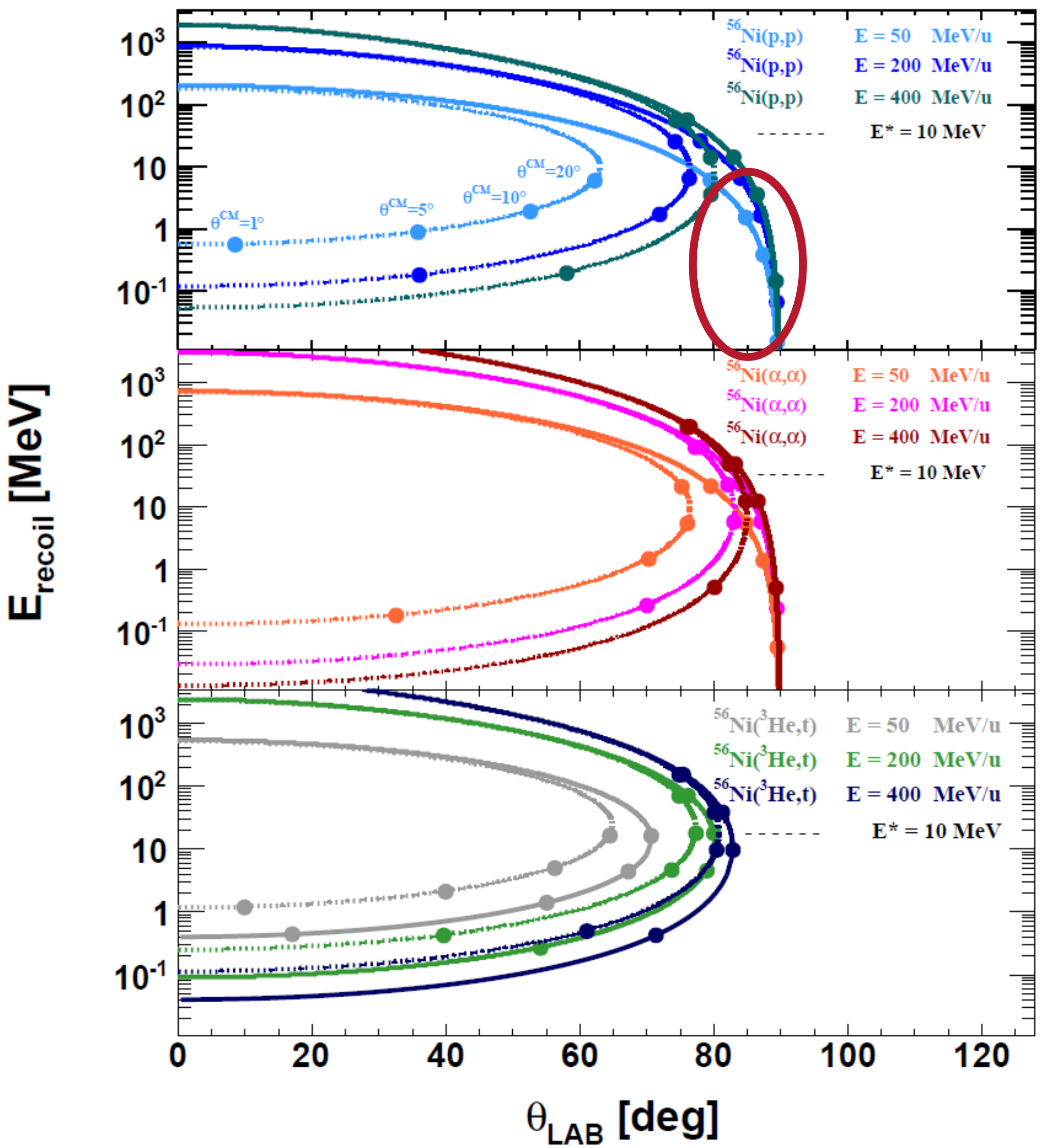


- ***DSSD***: *128×64 strips, (6×6) cm², 285 μm thick*
- ***Si(Li)***: *8 pads, (8×4) cm², 6.5 mm thick*
- ***active vacuum barrier***
- ***moveable aperture** to improve angular resolution*

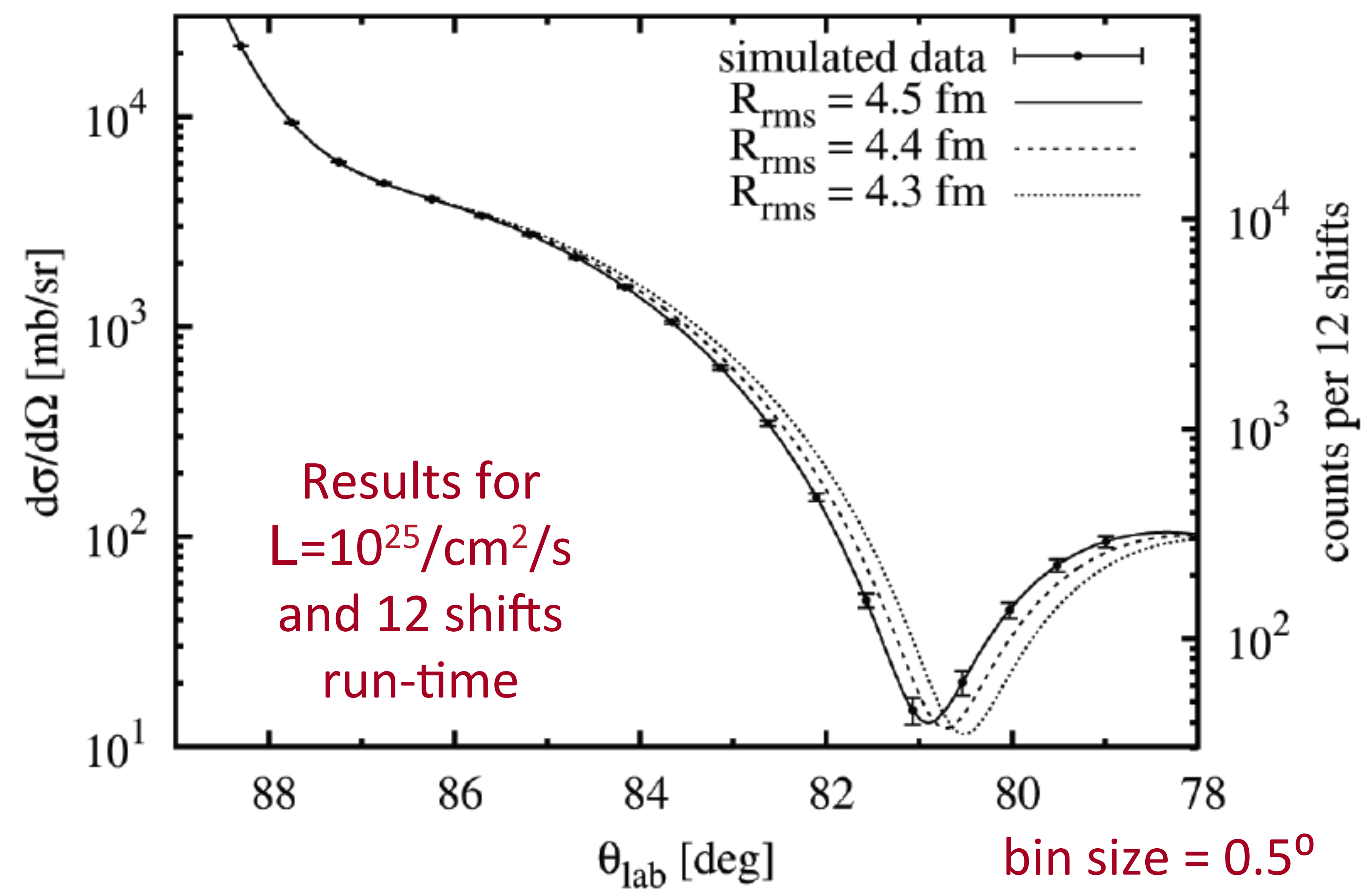




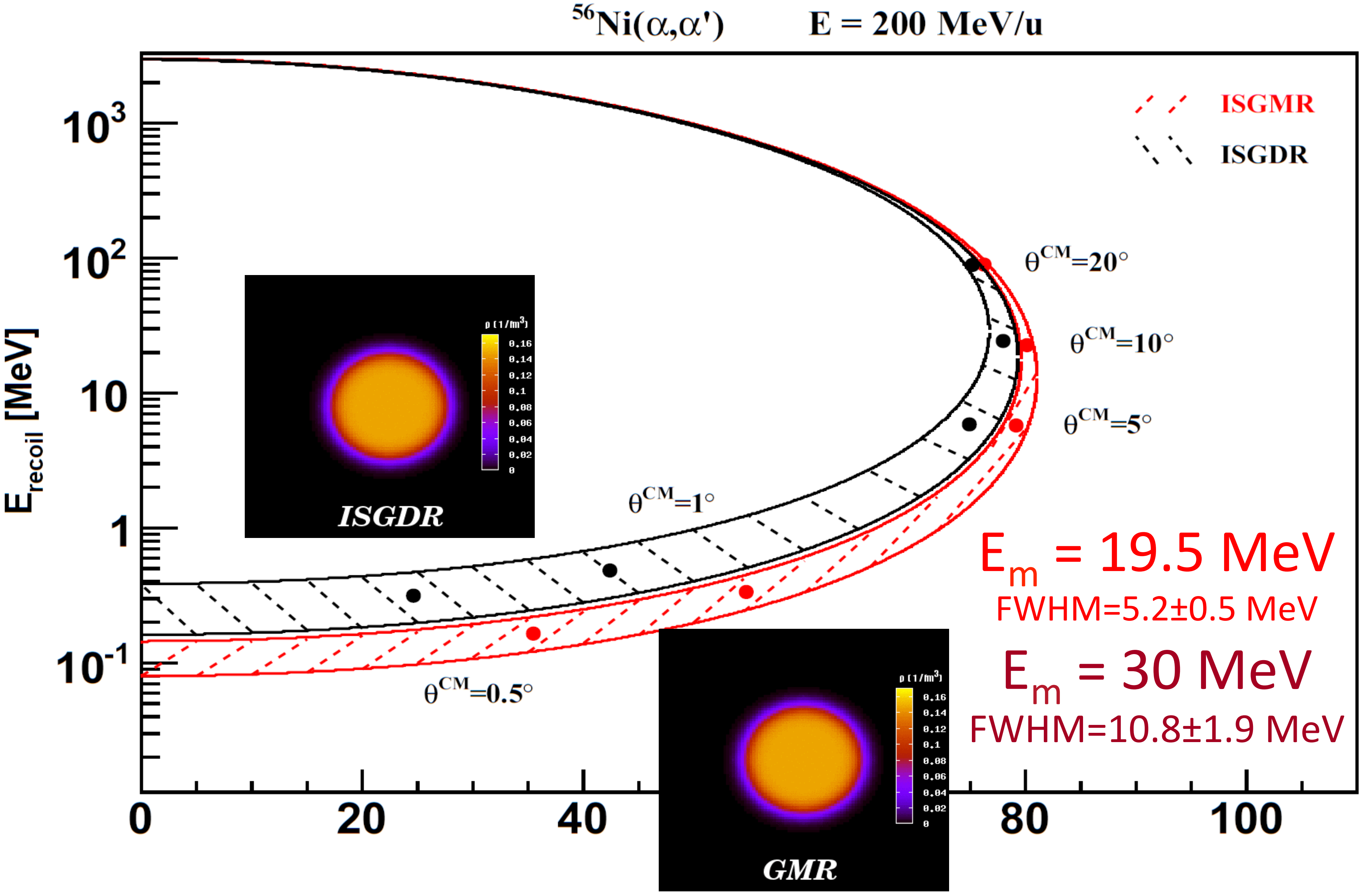
Kinematics for inverse reaction for ^{56}Ni

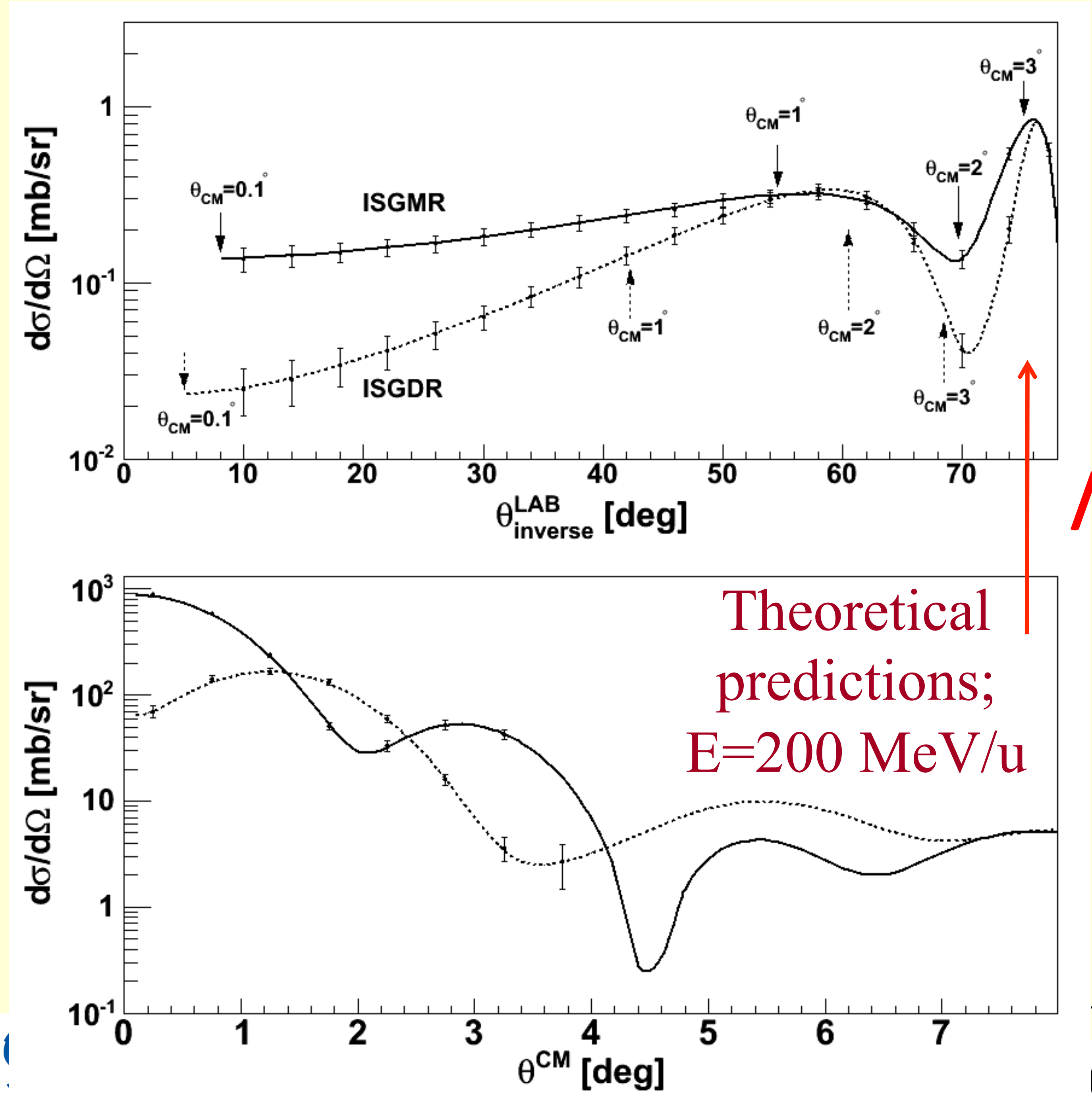


Proton elastic-scattering cross sections at 400 MeV/u



ISGMR/ISGDR channels in ^{56}Ni with (α,α')





Simulation results for $L=10^{25}/cm^2/s$ and 15 days run-time

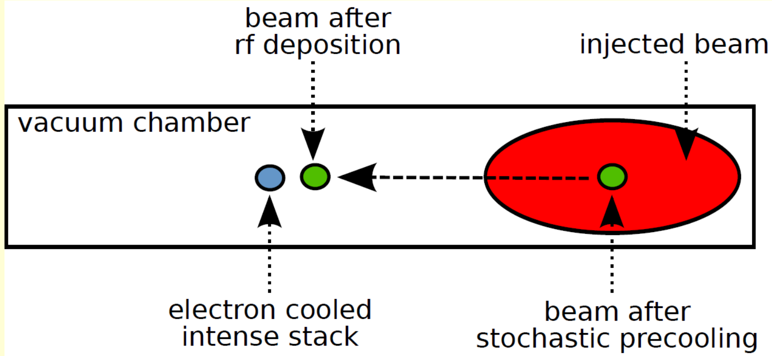
^{56}Ni Beam

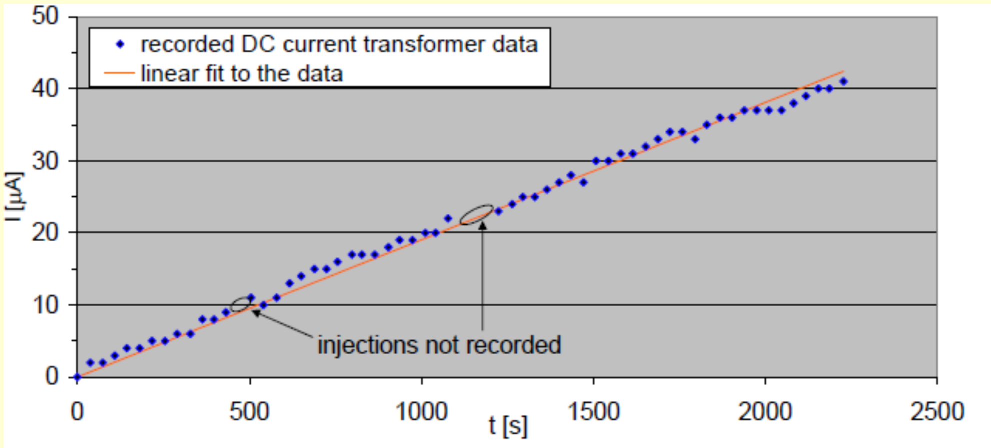
FRS: fragmentation of 600 MeV/u ^{58}Ni beam

injection to ESR: **7 x 10^4** ^{56}Ni per injection

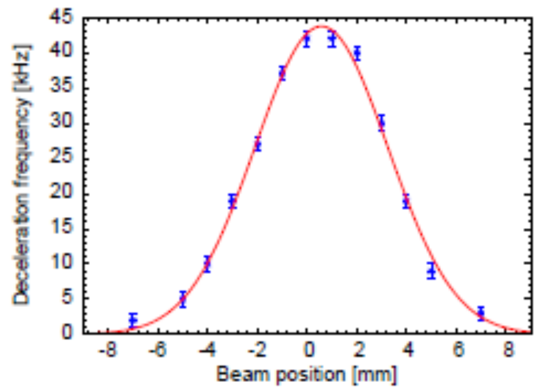
stochastic cooling, bunching and stacking (60 injections):
4.8 x 10^6 ^{56}Ni in the ring

F. Nolden, M. Steck





target profile



σ = 3.78 mm x_0 = 0.58 mm

luminosity: H_2 target: 2 x 10^{13} cm^{-2}

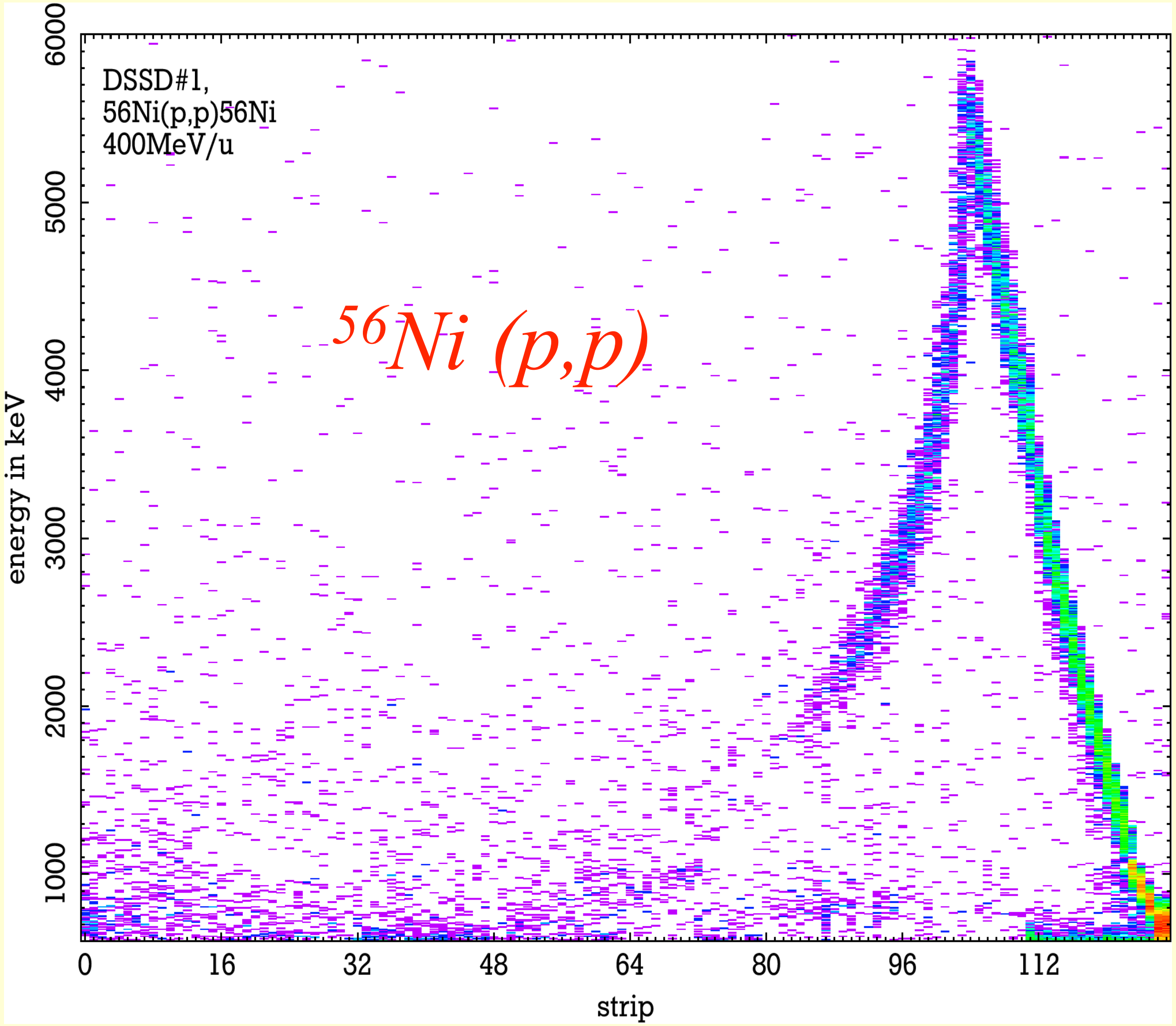
$\Rightarrow$ **L = 2 x 10^{26} cm^{-2} sec^{-1}**
(reduced by aperture)

First results with radioactive beam

October 25, 2012:

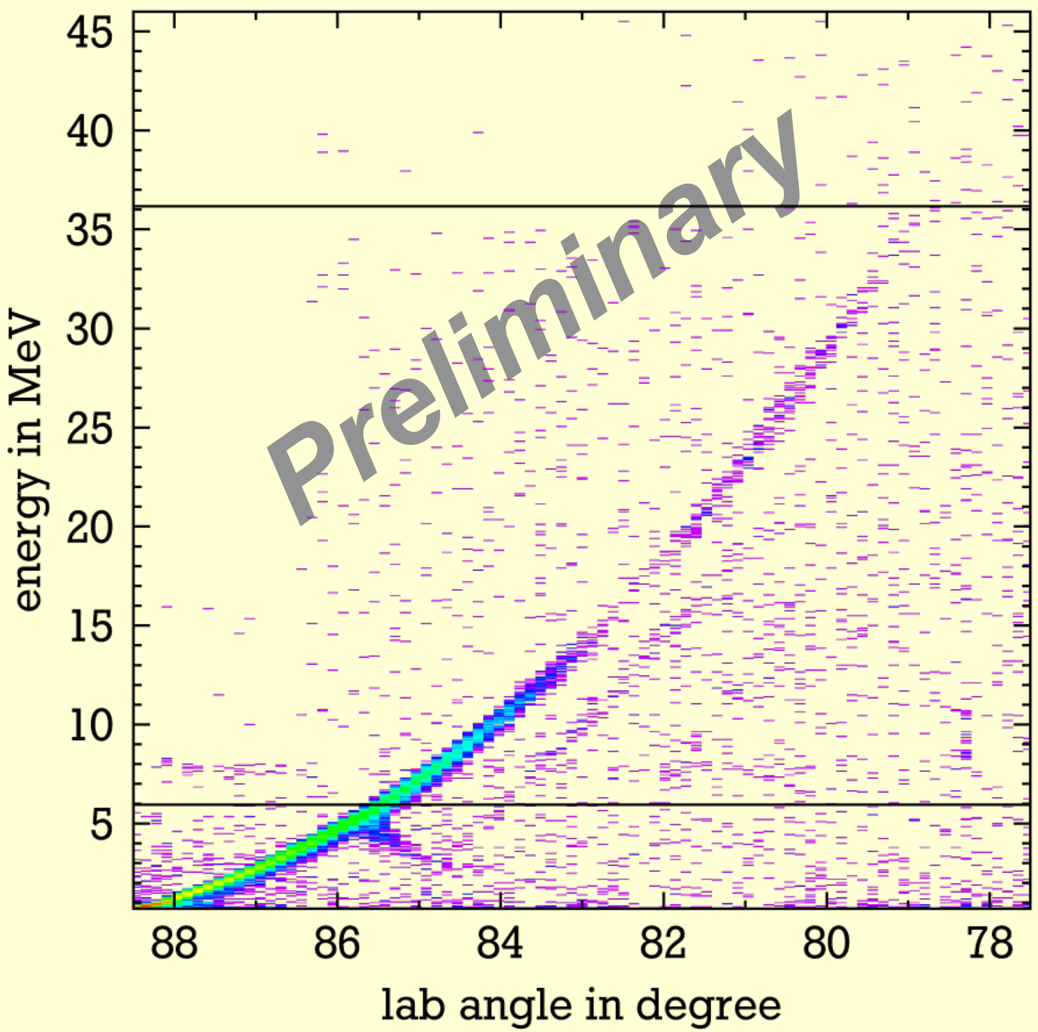
First Nuclear Reaction Experiment with Stored Radioactive Beam!!!!

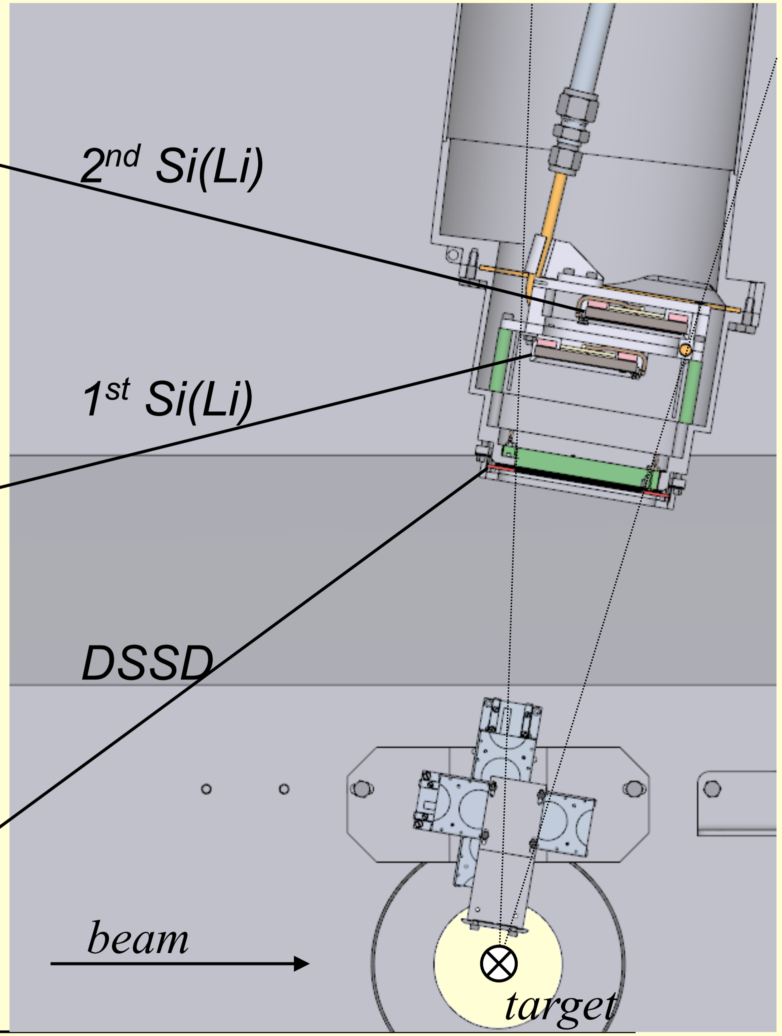
Beam energy 400 MeV/u



First results with radioactive beam

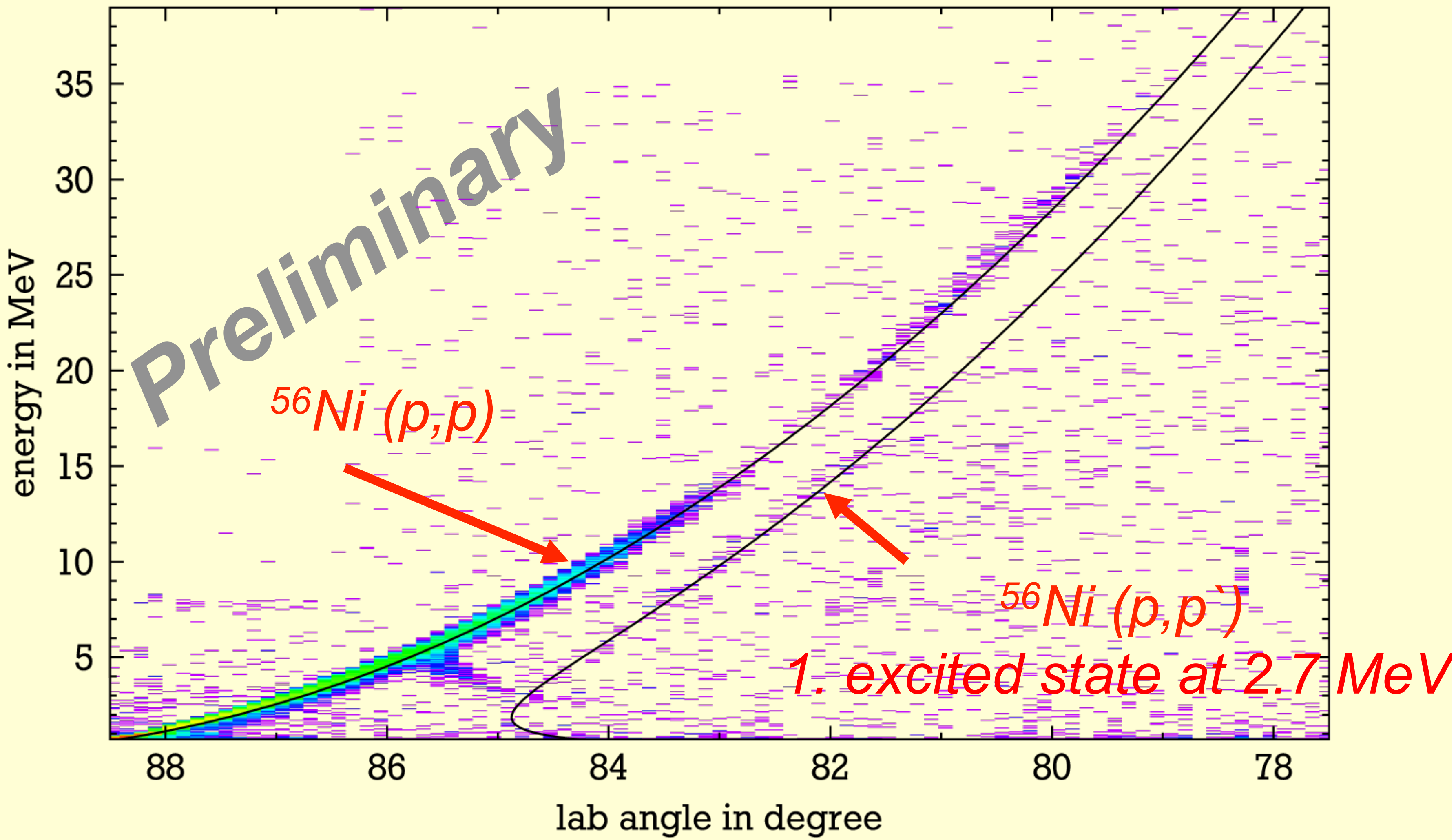
$^{56}Ni(p,p)$, E = 400 MeV/u



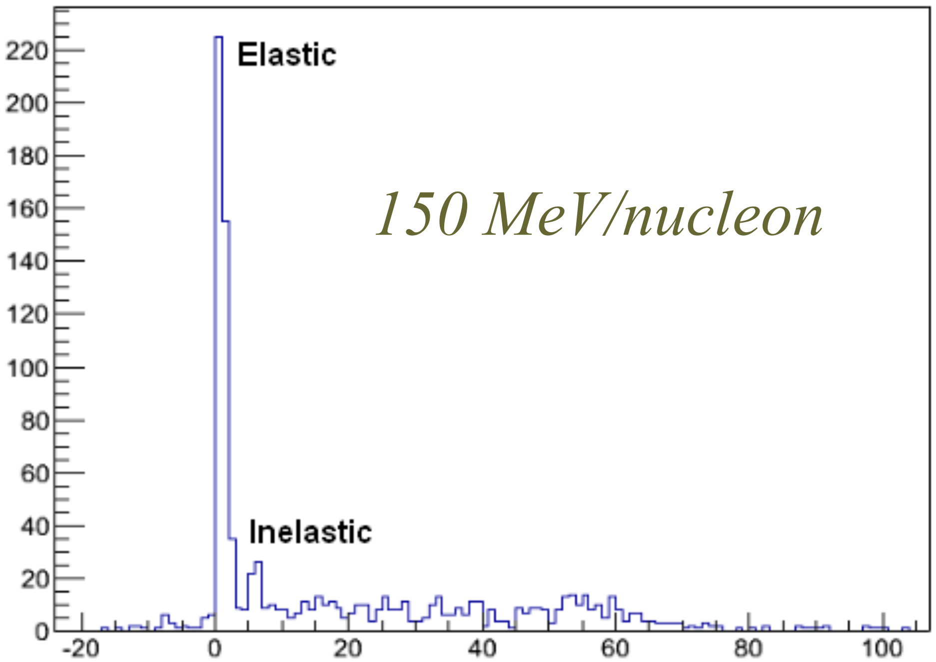


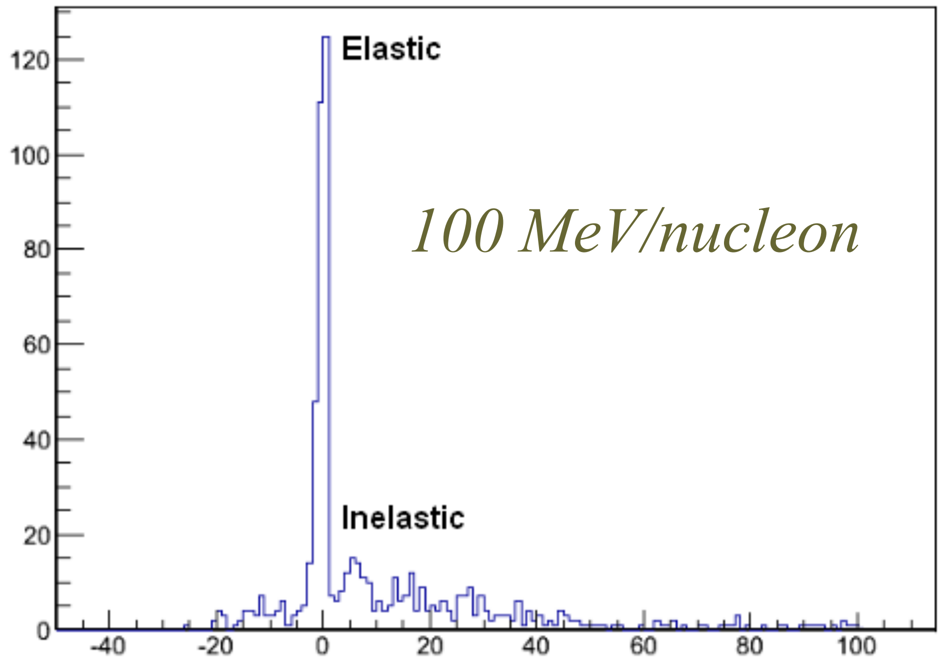
First results with radioactive beam

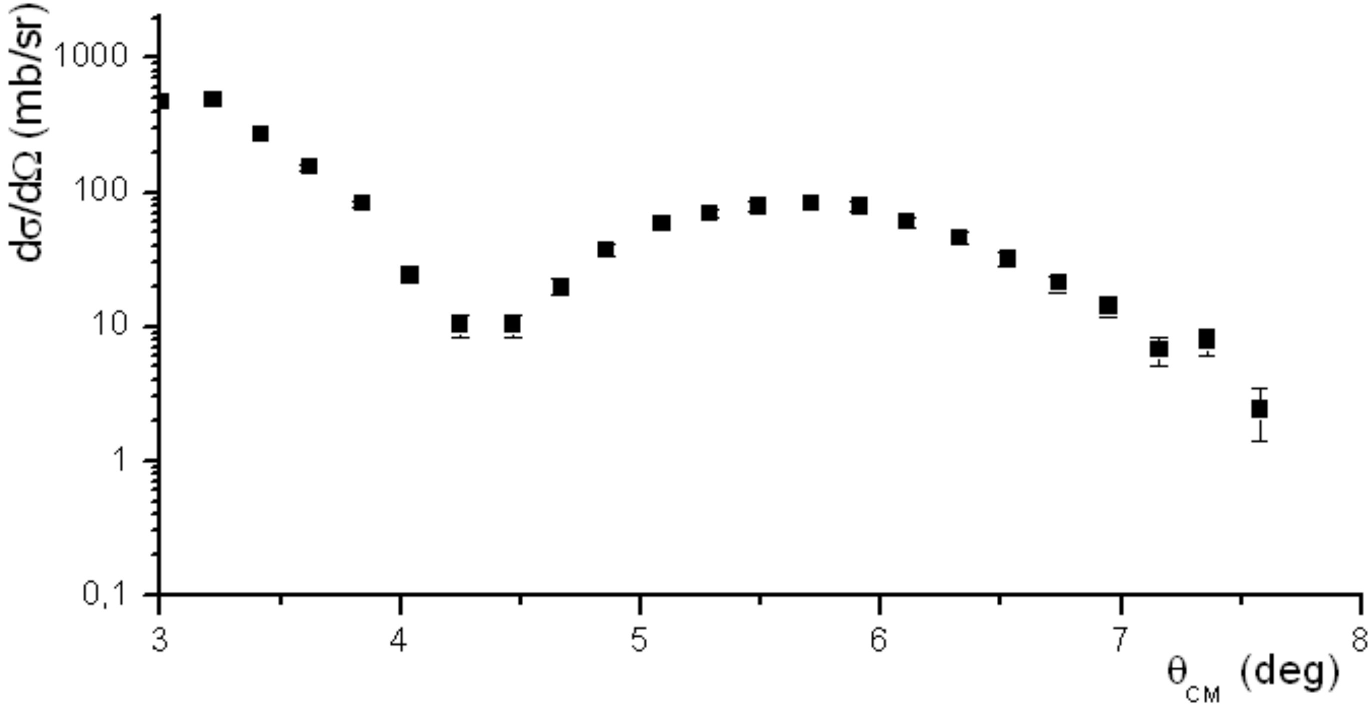
^{56}Ni(p,p`), E = 400 MeV/u   *Identification of Inelastic Scattering*



^{58}Ni with ^{4}He target



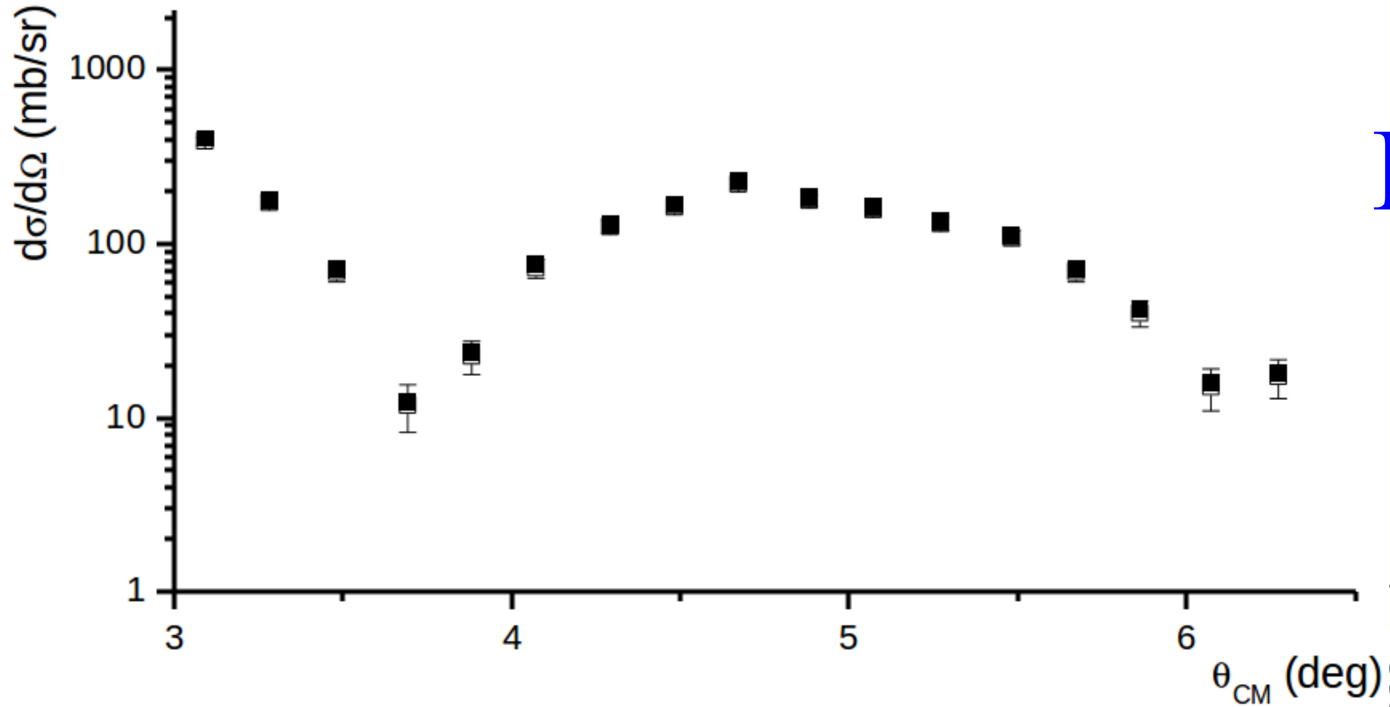




100 MeV/nucleon

^{58}Ni elastic (α,α), Preliminary

150 MeV/nucleon



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Isoscalar Giant Monopole Resonance

reaction: ^{58}Ni on He target

energy: 100 MeV/u

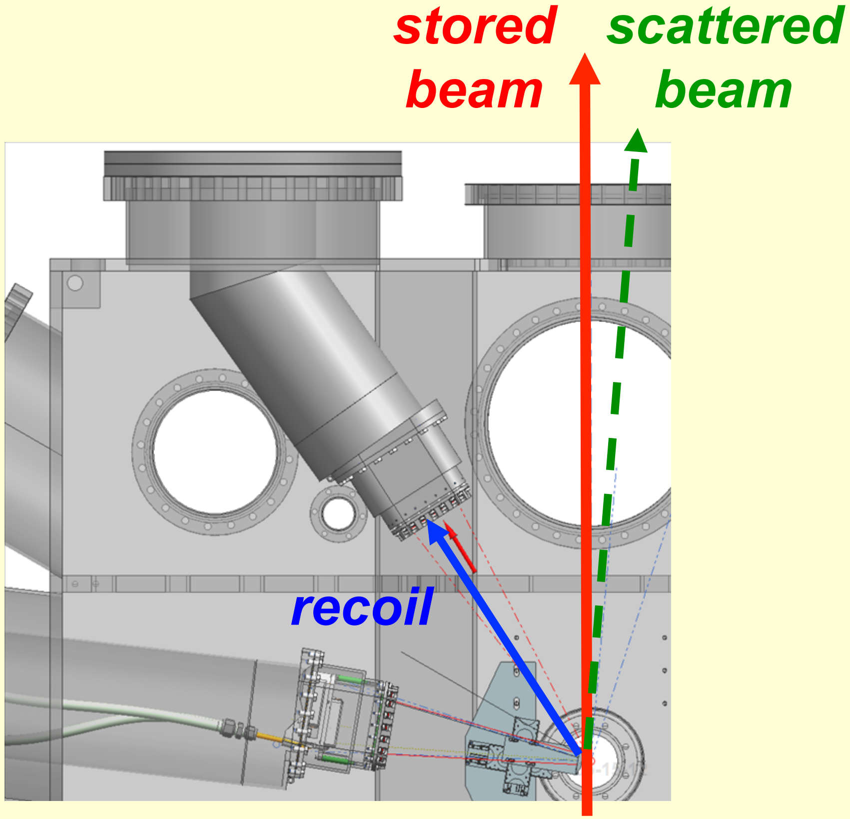
target: 8 X 10^{12} /cm^{3}

detectors: DSSD

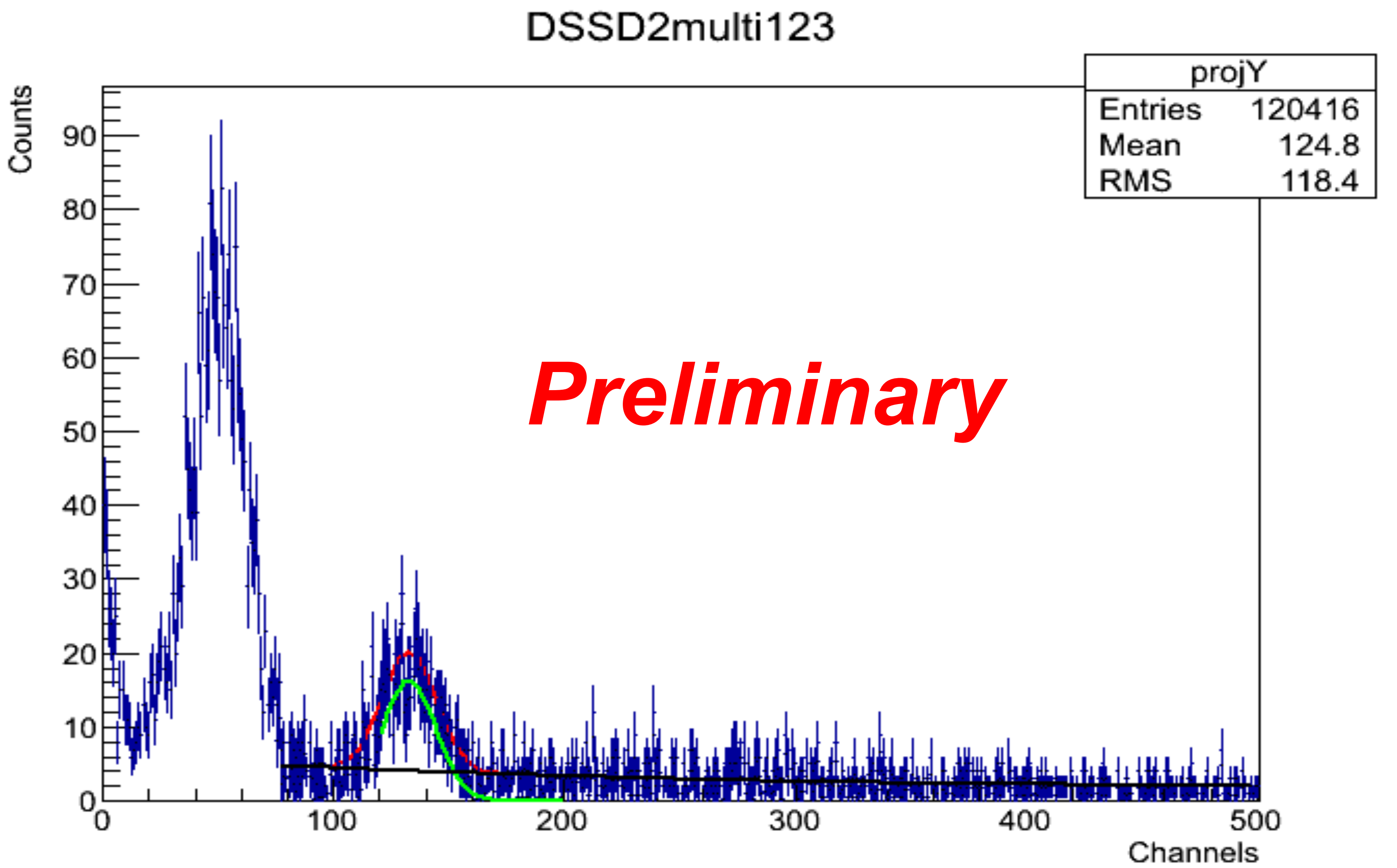
$\Theta_{Lab} = 27° - 38°$

PIN diodes

$\Theta_{Lab} = 0.2° - 1°$

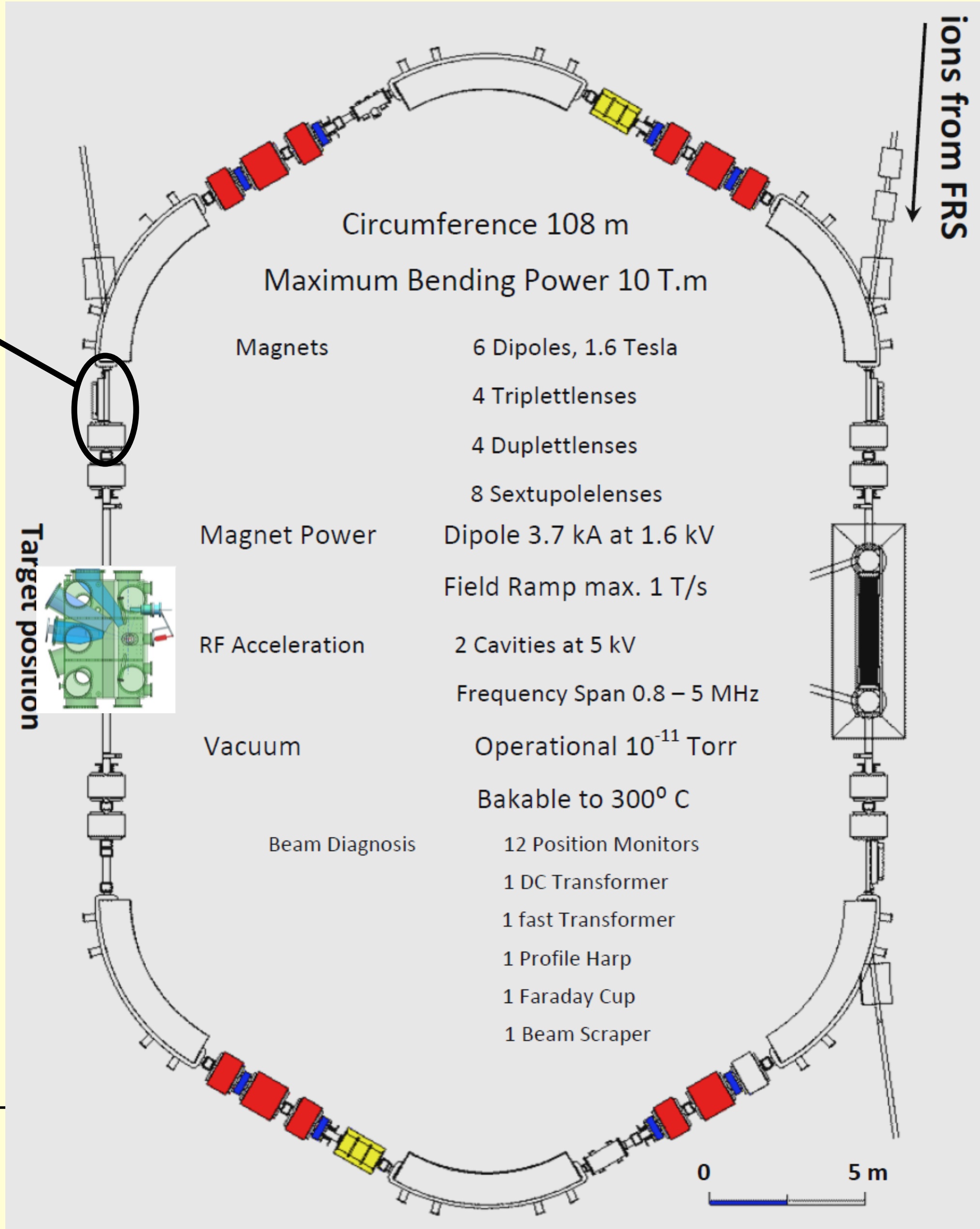


Isoscalar Giant Monopole Resonance

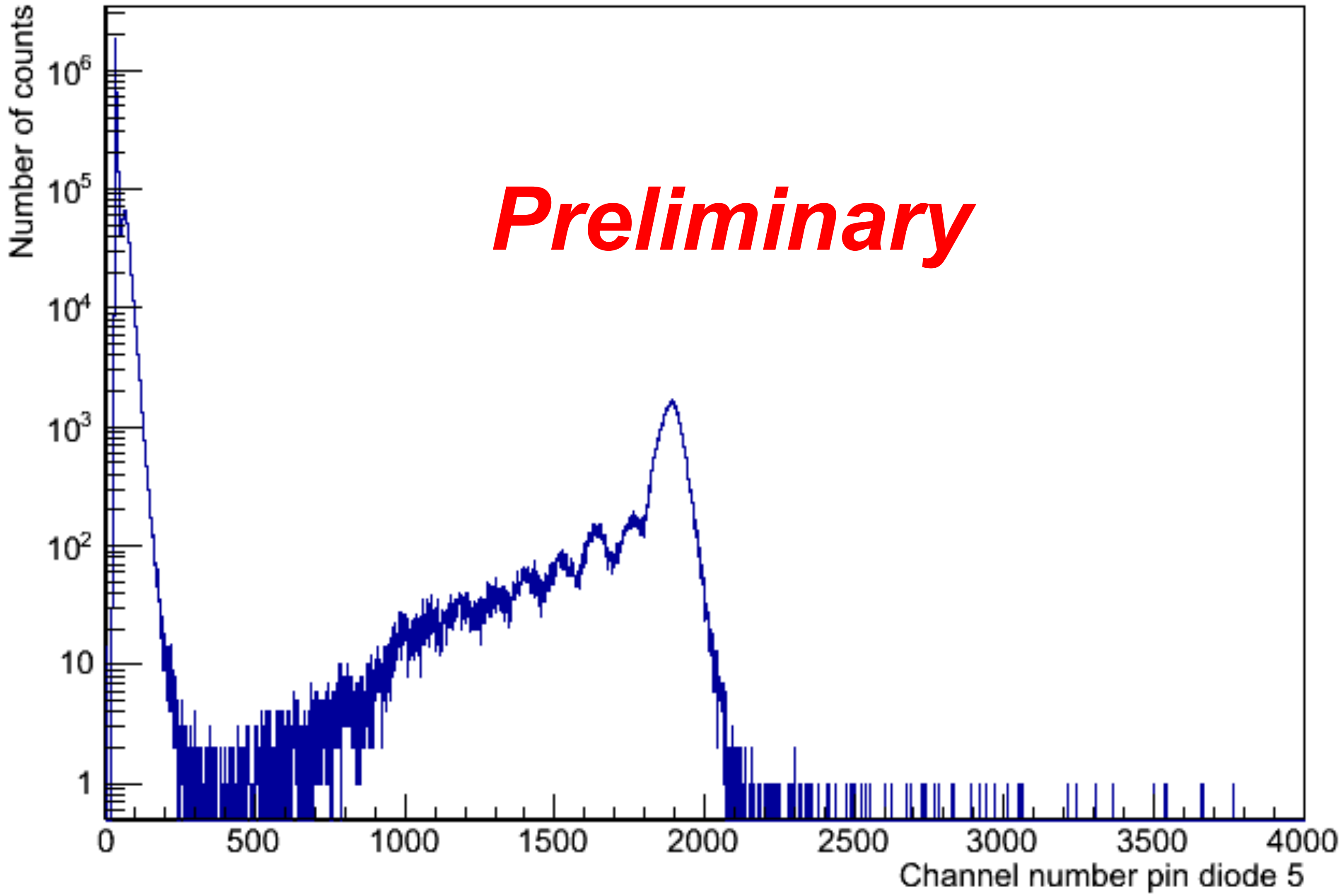


Setup @ ESR ring

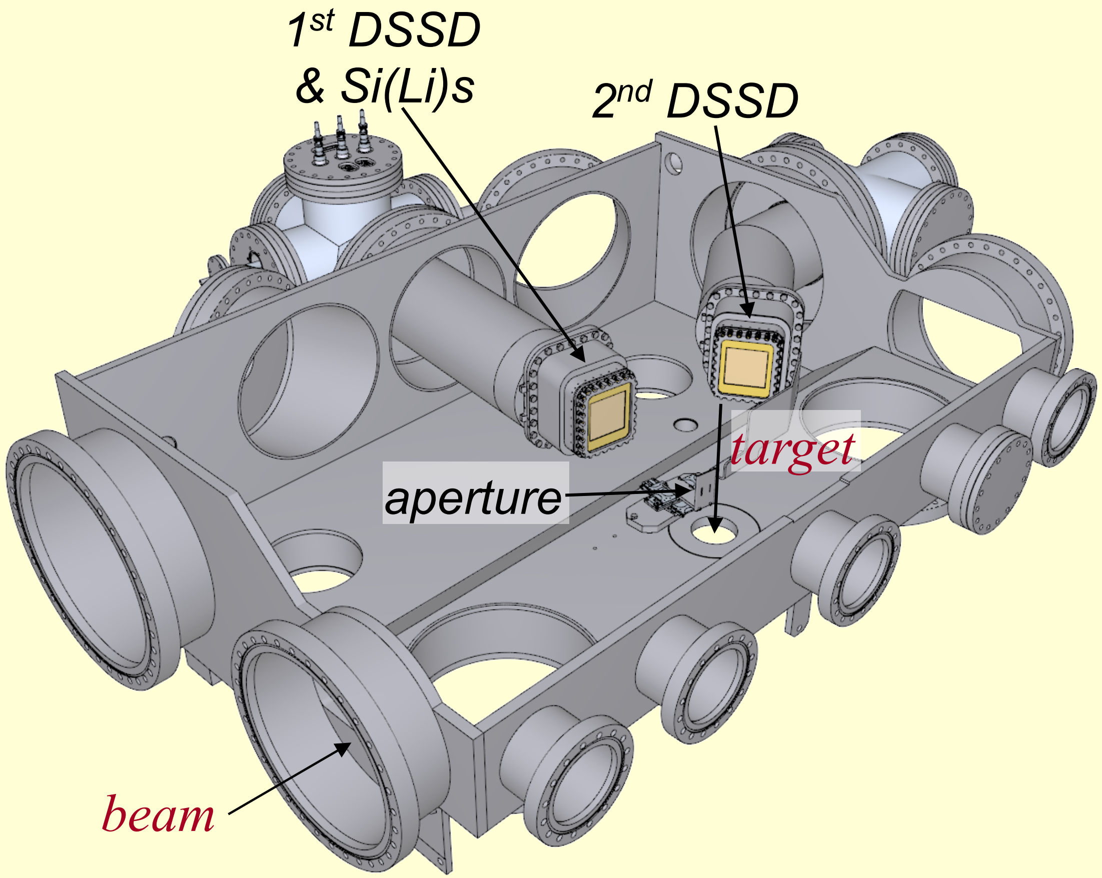
Pin diode



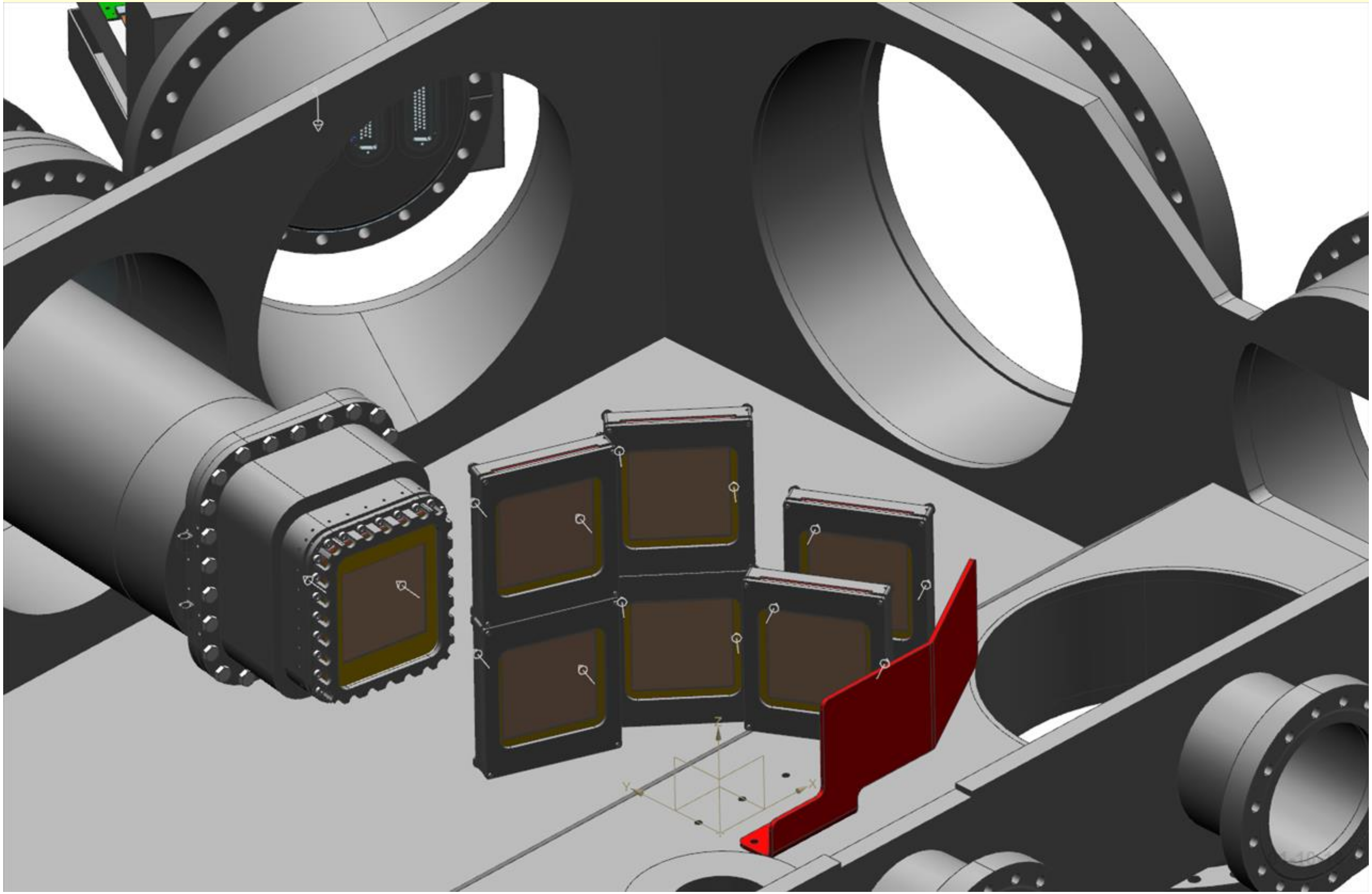
Downstream pin-diode spectrum



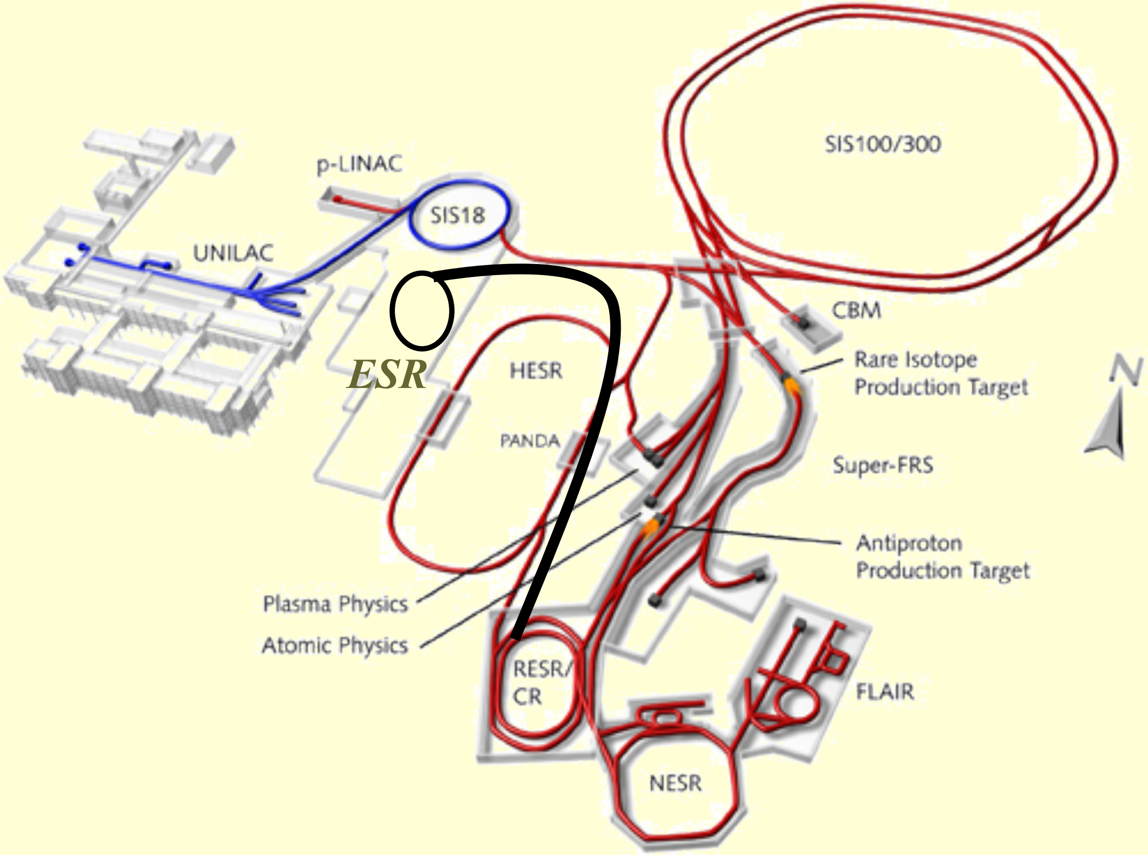
The first EXL experiment



Upgrade of the first EXL experiment



Intermediate-range Plans for rings



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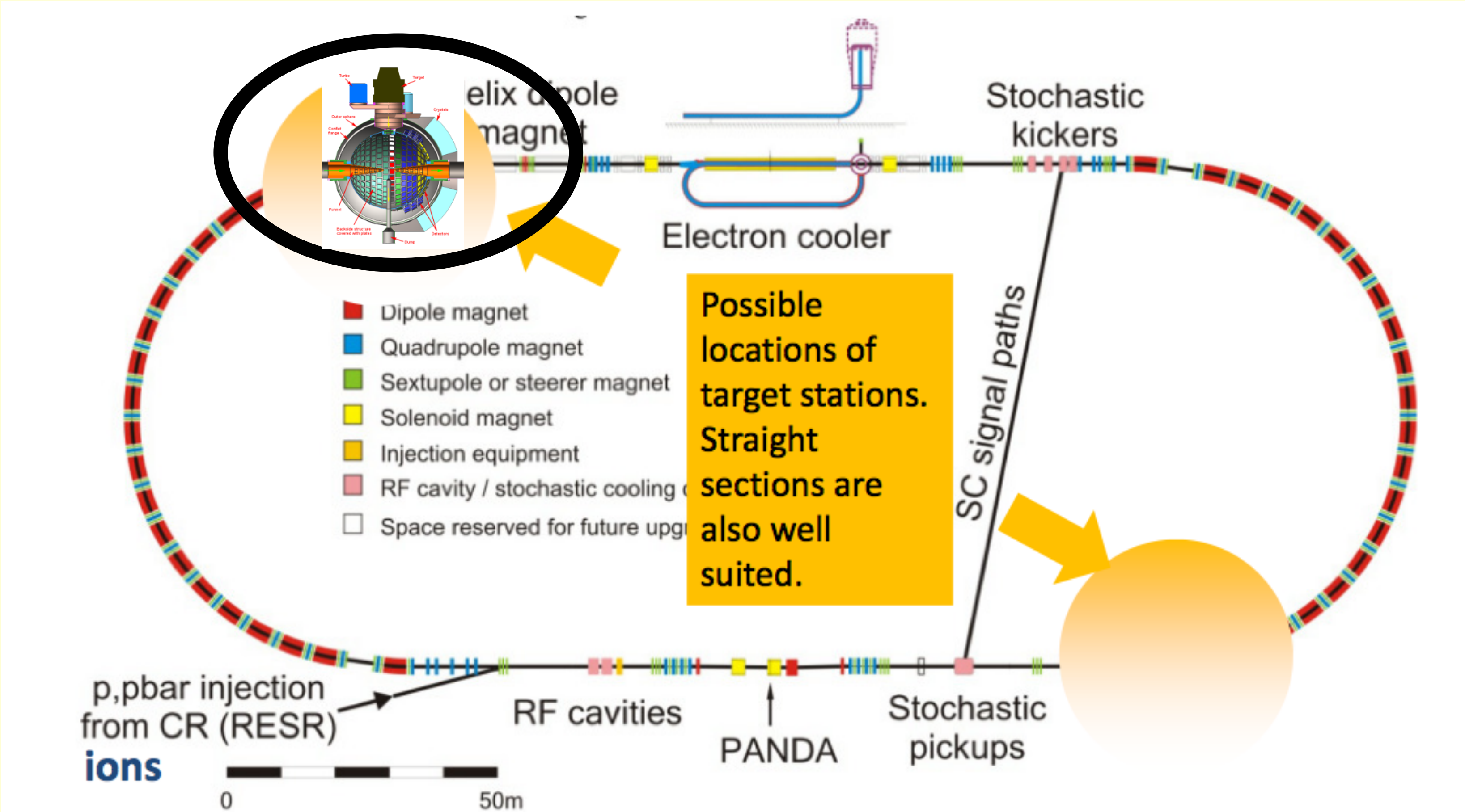
Intermediate-range Plans for rings



Conclusions and outlook

- The EXL physics program covers a large part of nuclear structure and reactions.
- Bulk properties (radius, compressibility etc.), shell structure and correlations will be studied in asymmetric matter.
- The goal is to go towards the medium heavy and heavy nuclei (astrophysical processes).
- R&D is well underway for EXL. TDR expected soon.
- First physics measurements have already been performed and beautiful results are emerging.
- Next measurements proposed for 2014.

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]

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EXL 908

Thank you!