The EXL Project – Recent Experiments at the ESR and Future Perspectives

Peter Egelhof
GSI Darmstadt, Germany
for the EXL Collaboration

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The EXL Project – Recent Experiments at the ESR and Future Perspectives

I. Introduction

II. The EXL* Project – an Overview

III. First Experiments with Radioactive Beam at the ESR

IV. Future Perspectives

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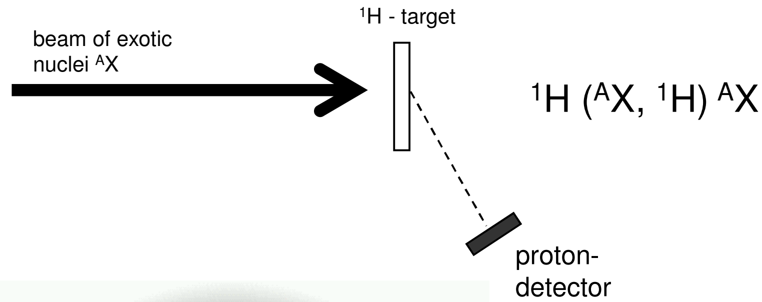
* **EXL**: **Ex**otic Nuclei Studied in **L**ight-Ion Induced Reactions at the NESR Storage Ring

I. Introduction

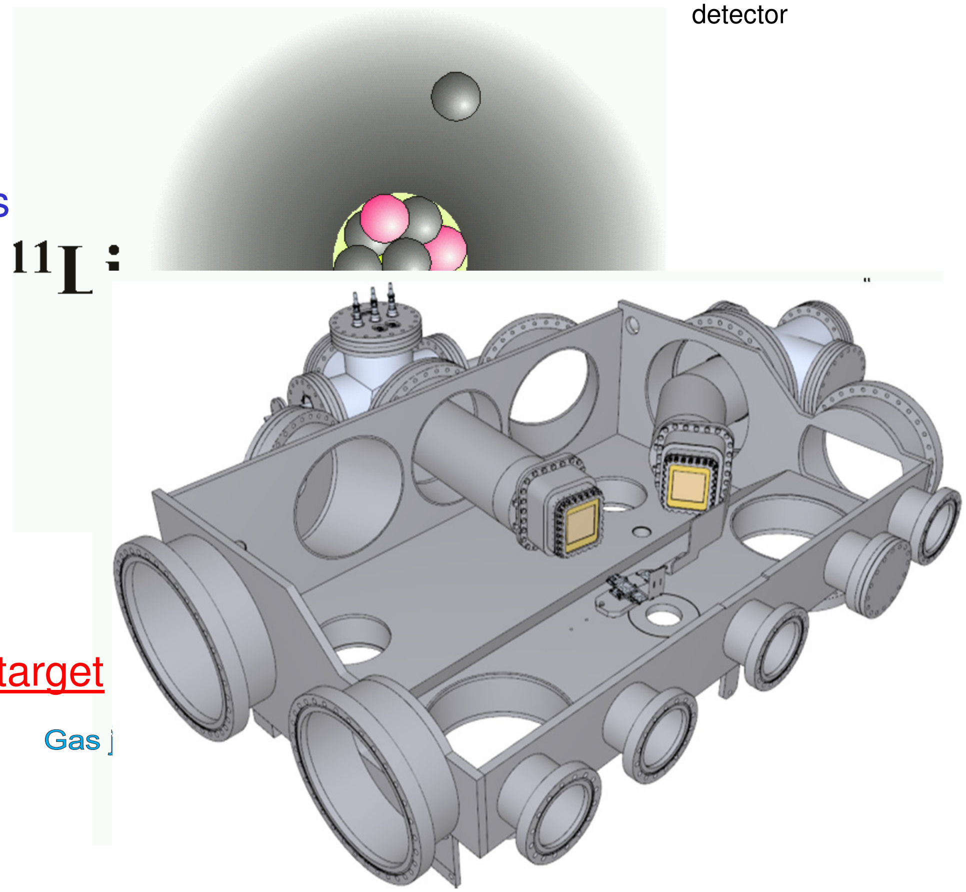


classical method of nuclear spectroscopy:

⇒ light ion induced direct reactions: (p,p), (p,p'), (d,p), ...
⇒ to investigate exotic nuclei: inverse kinematics

past and present experiments:

⇒ light neutron-rich nuclei: skin, halo structures
⇒ only at external targets



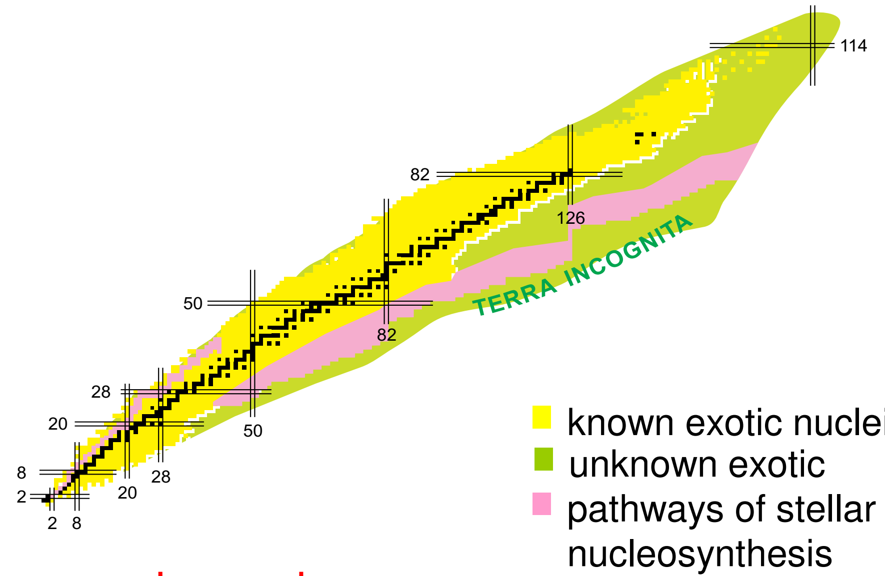
future perspectives at FAIR:

⇒ profit from intensity upgrade (up to 10^4 !!)
⇒ explore new regions of the chart of nuclides
and new phenomena
⇒ use new and powerful methods:

EXL: direct reactions at internal storage ring target
⇒ high luminosity even for very low
momentum transfer measurements

First Experiments at the ESR

The EXL Project – an Overview



regions of interest:

⇒ towards the driplines for 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 asymetric and low-density matter
- astrophysical r and rp processes, understanding of supernovae

Light-Ion Induced Direct Reactions

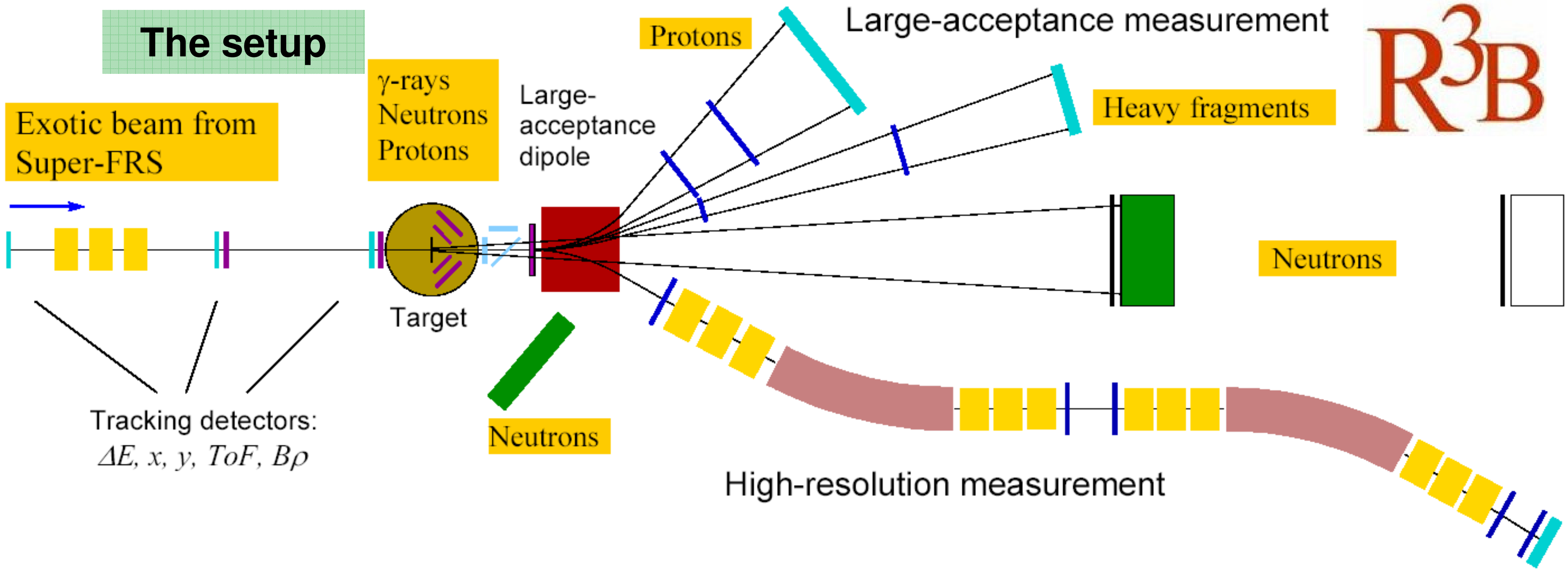
- elastic scattering (p,p), (α,α), …
  nuclear matter distribution ρ(r), skins, halo structures
- inelastic scattering (p,p’), (α,α’), …
  deformation parameters, B(E2) values, transition densities, giant resonances
- charge exchange reactions (p,n), (^{3}He,t), (d, ^{2}He), …
  Gamow-Teller strength
- 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 distributions, cluster correlations

Reactions with Relativistic Radioactive Beams at FAIR

- R^3B: Reactions with Relativistic Radioactive Beams
  ⇒ High Energy Branch
- EXL: EXotic Nuclei Studied in Light-Ion Induced Reactions at the NESR Storage Ring
  ⇒ Ring Branch

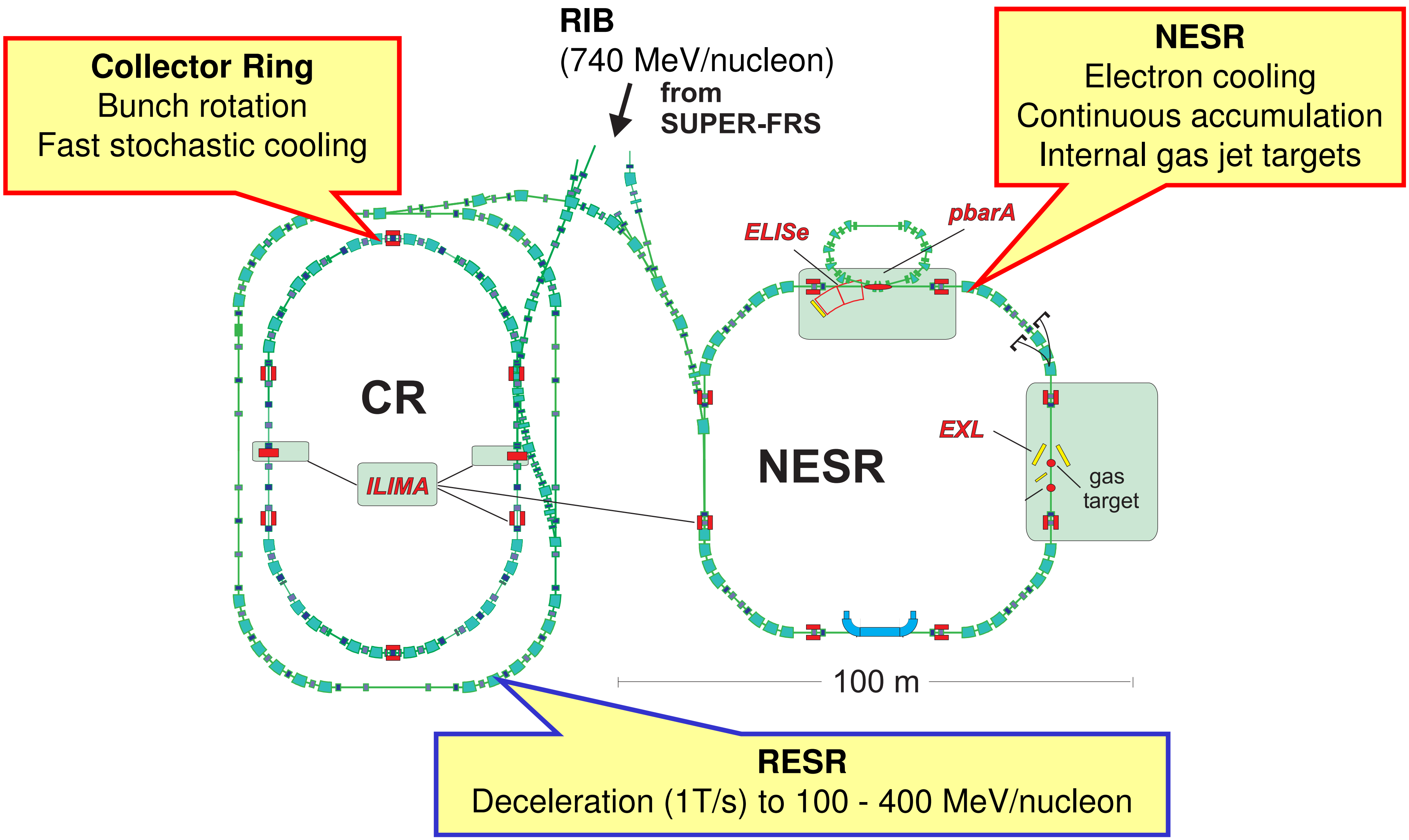
R3B: Reactions with Relativistic Radioactive Beams

The setup

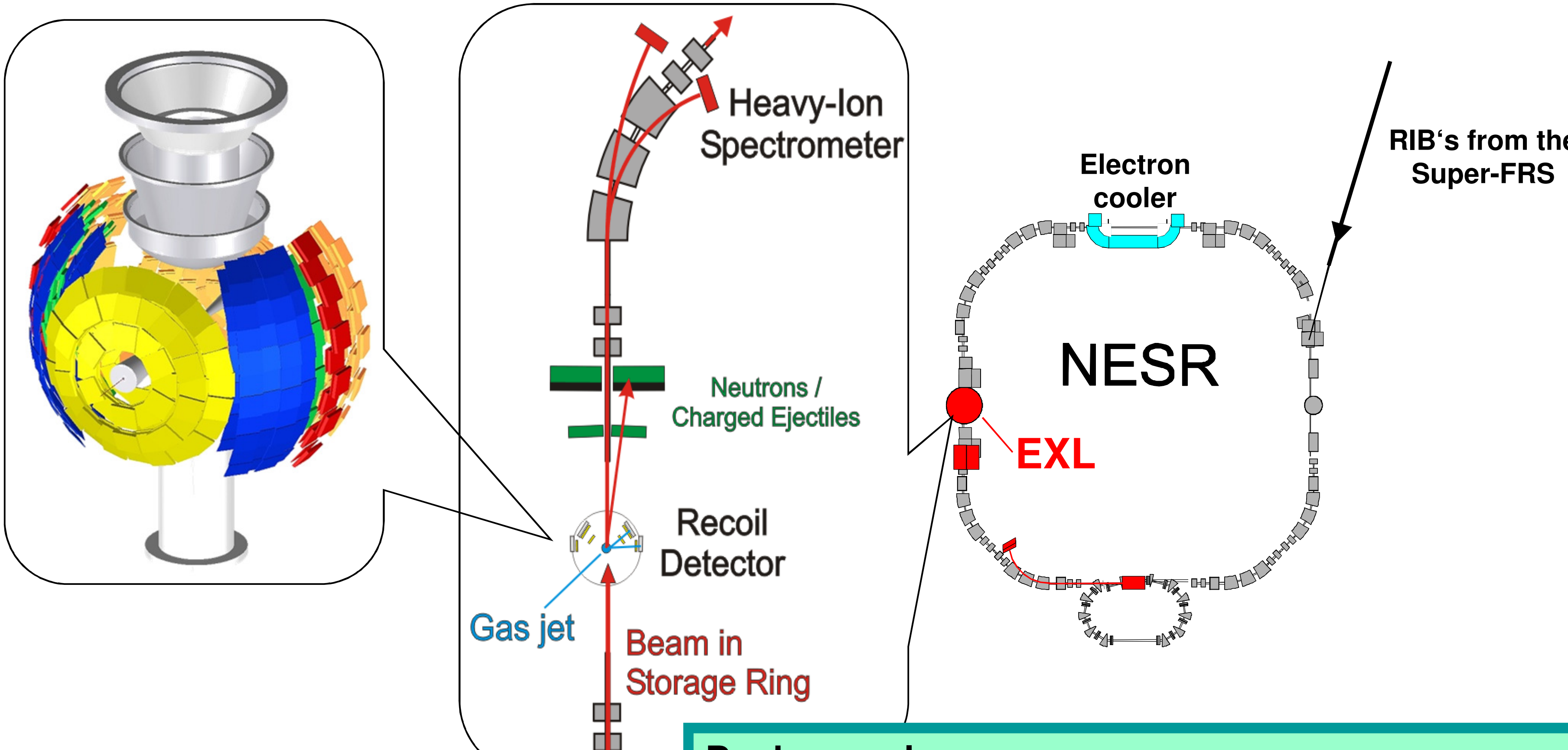


The R³B experiment: a universal setup for kinematical complete measurements

Experiments with Stored Exotic Nuclei



EXL: EXotic Nuclei Studied in Light-Ion Induced Reactions at the NESR Storage Ring



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
- High energy resolution and high angular resolution
- Large solid angle acceptance
- Specially dedicated for low q measurements with high luminosity (> 10^{29} cm^{-2} s^{-1})

Light-Ion Induced Direct Reactions at Low Momentum Transfer

- elastic scattering (p,p), (α,α), …
  nuclear matter distribution ρ (r), skins, halo structures
- inelastic scattering (p,p'), (α,α'), …
  deformation parameters, B(E2) values, transition densities, giant resonances
- 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
- charge exchange reactions (p,n), (^{3}He,t), (d, ^{2}He), …
  Gamow-Teller strength
- [knock-out reactions (p,2p), (p,pn), (p,p ^{4}He)…
  ground state configurations, nucleon momentum distributions]

for almost all cases:

region of low momentum transfer contains most important information

Speciality of EXL:

measurements at very low momentum transfer

⇒ complementary to R^{3}B !!!

Experiments to be Performed at Very Low Momentum Transfer – Some Selected Examples

- Investigation of Nuclear Matter Distributions:

  ⇒ halo, skin structure

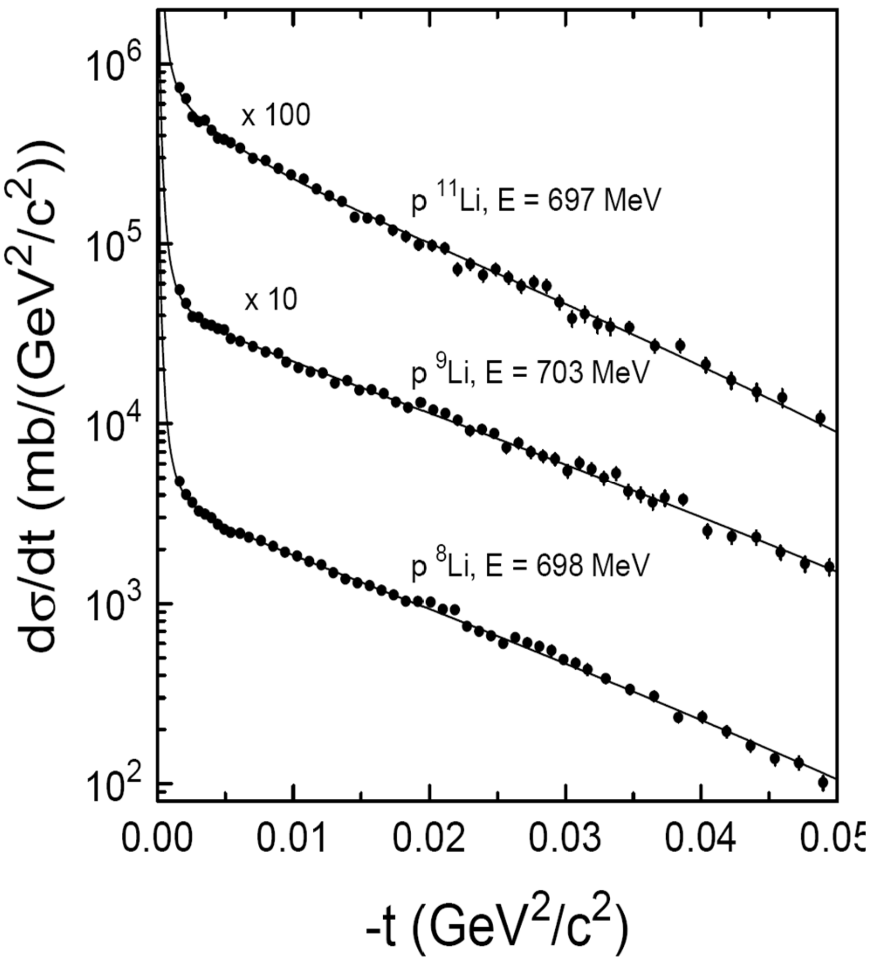
  ⇒ probe in-medium interactions at extreme isospin (almost pure neutron matter)

  ⇒ in combination with electron scattering (ELISe project @ FAIR):
  separate neutron/proton content of nuclear matter (deduce neutron skins)

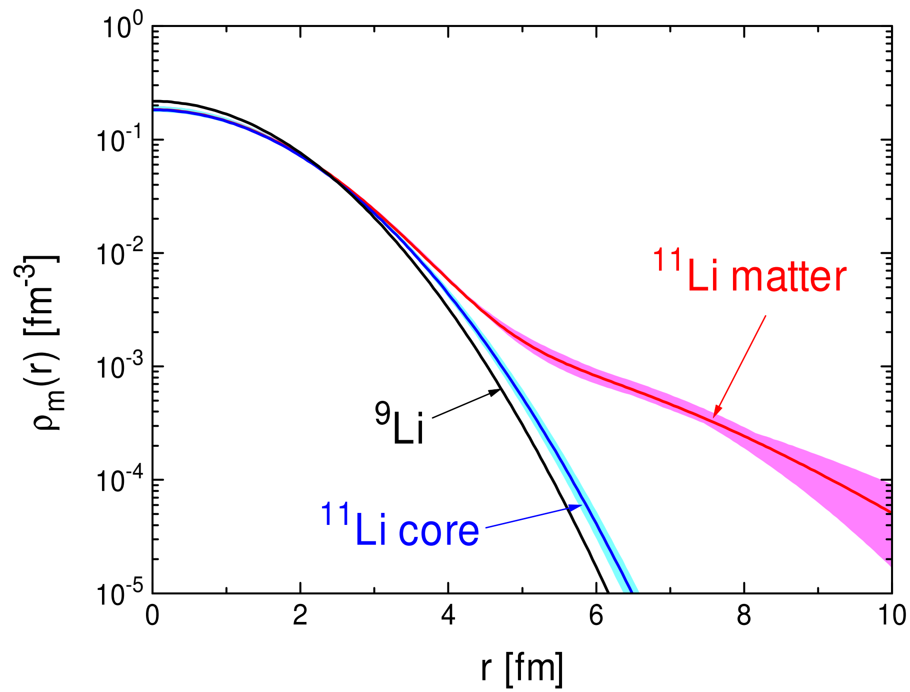
method: elastic proton scattering ⇒ at low q: high sensitivity to nuclear periphery

Investigation of Nuclear Matter Density Distributions of Halo Nuclei by Elastic Proton Scattering at Low Momentum Transfer

small angle proton scattering:



deduced nuclear matter distributions:



P. Egelhof et al., Eur. Phys. J. A 15 (2002) 27

A. Dobrovolsky et al., Nucl. Phys. A766 (2006) 1

Experiments to be Performed at Very Low Momentum Transfer – Some Selected Examples

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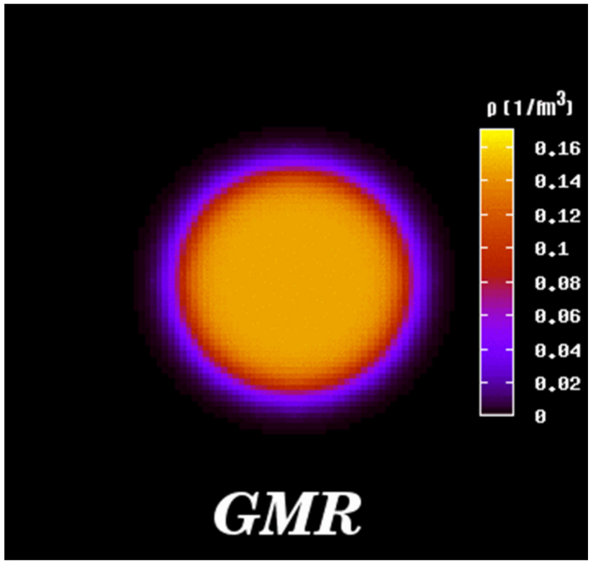
  - ⇒ halo, skin structure
  - ⇒ probe in-medium interactions at extreme isospin (almost pure neutron matter)
  - ⇒ in combination with electron scattering (ELISe project @ FAIR):
    separate neutron/proton content of nuclear matter (deduce neutron skins)

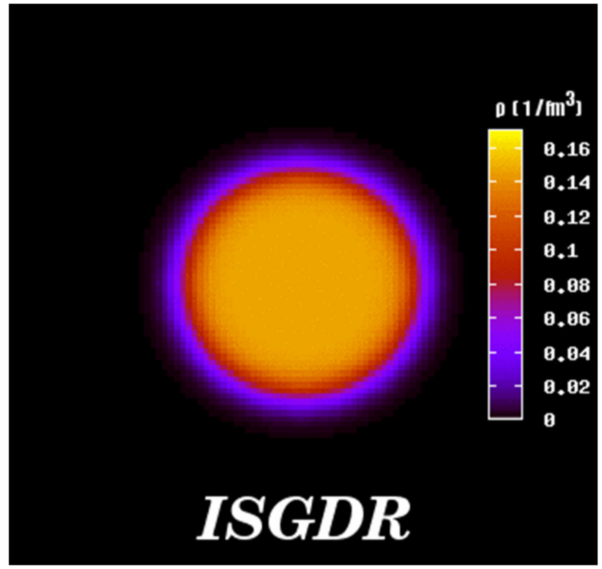
method: elastic proton scattering ⇒ at low q: high sensitivity to nuclear periphery

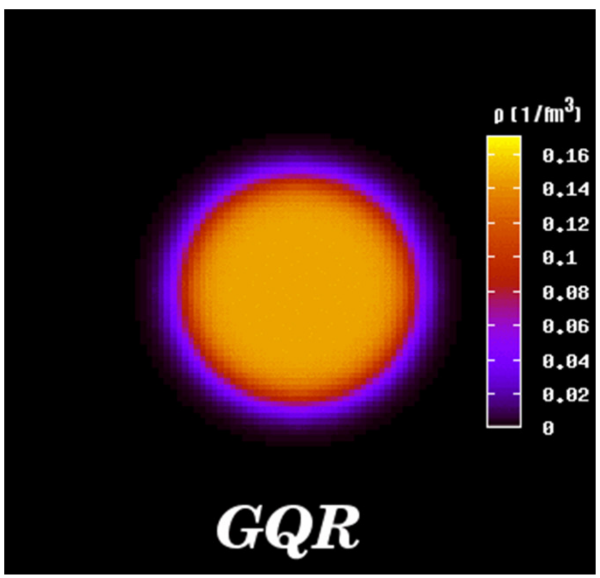
- Investigation of the Giant Monopole Resonance:
  - ⇒ gives access to nuclear compressibility ⇒ key parameters of the EOS
  - ⇒ new collective modes (breathing mode of neutron skin)

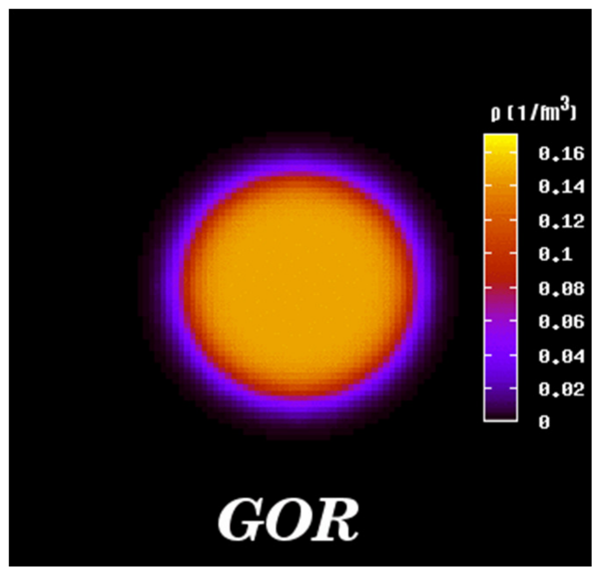
method: inelastic α scattering at low q

The Collective Response of the Nucleus: Giant Resonances









M. Itoh

Investigation of the Giant Monopole Resonance in Doubly Magic Nuclei by Inelastic α-Scattering

- GMR gives access to nuclear compressibility K_{nm} (Z,N) ~ $\rho_0^2 \, d^2(E/A) / d\rho^2 \,|_{\rho 0}$
  ⇨ key parameter of EOS
- investigation of isotopic chains arround ^{132}Sn, ^{56}Ni, … with high $\delta = (N-Z)/A$
  ⇨ disentangle different contributions to
  $K_A = K_{vol} + K_{surf} A^{-1/3} + K_{sym} ((N-Z)/A)^2 + ...$

Experiments to be Performed at Very Low Momentum Transfer – Some Selected Examples

- Investigation of Nuclear Matter Distributions:

  ⇒ 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 the Giant Monopole Resonance:

  ⇒ 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

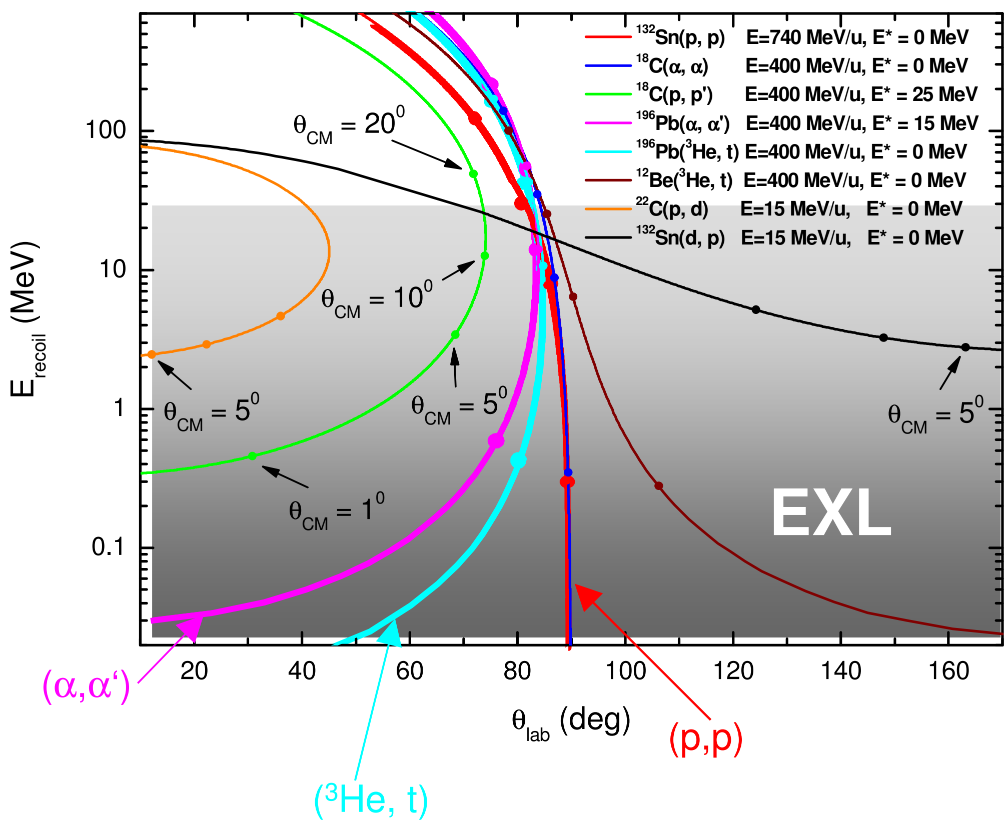
- Investigation of Gamow-Teller Transitions:

  ⇒ weak interaction rates for N = Z waiting point nuclei in the rp-process

  ⇒ electron capture rates in the presupernova evolution (core collaps)

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

Kinematical Conditions for Light-Ion Induced Direct Reactions in Inverse Kinematics



- required beam energies:
  $E \approx 200 \ldots 740$ MeV/u
  (except for transfer reactions)
- required targets: ^{1,2}H, ^{3,4}He
- most important information in region of low momentum transfer
  ⇒ low recoil energies of recoil particles
  ⇒ need thin targets for sufficient angular and energy resolution

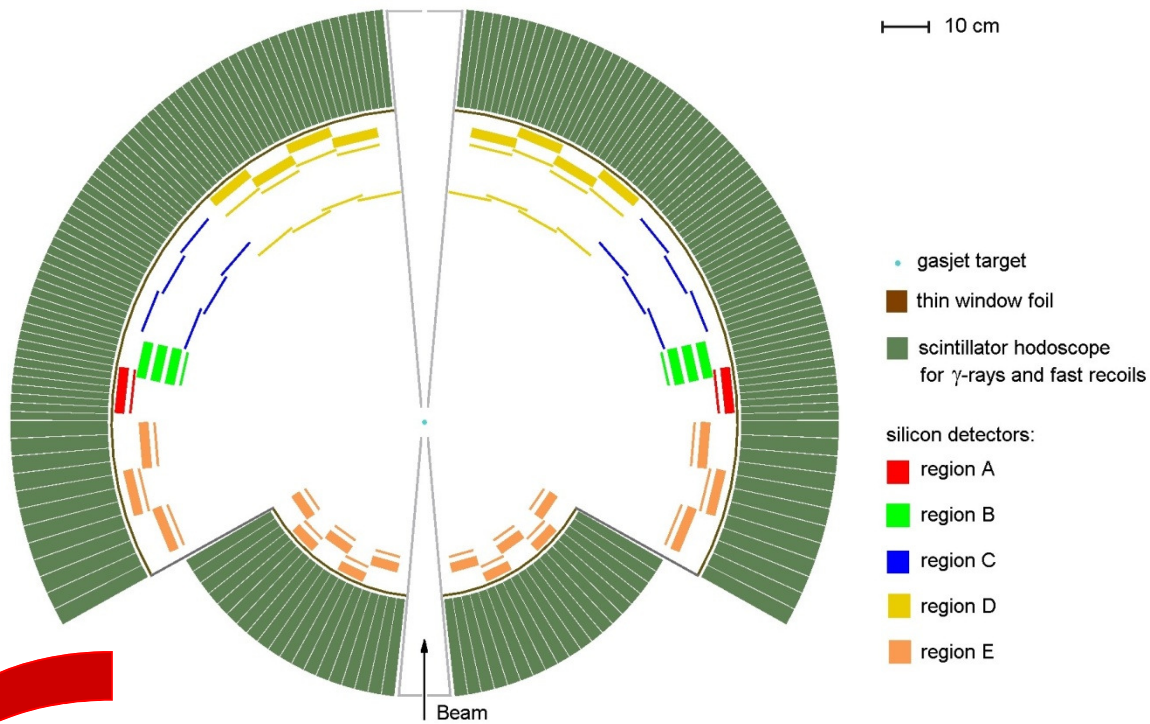
Advantage of Storage Rings for Direct Reactions in Inverse Kinematics

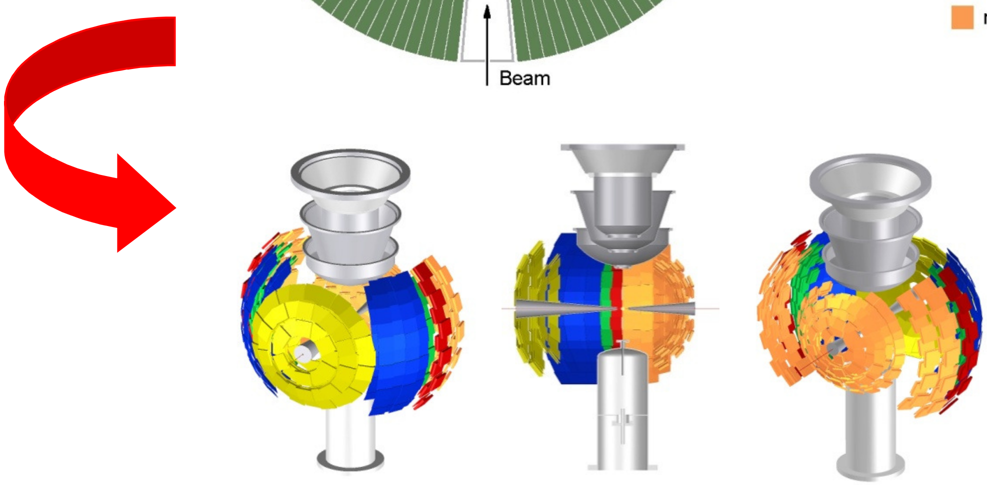
- low threshold and high resolution due to: beam cooling, thin target (10^{14}-10^{15} cm^{-2})
- gain of luminosity due to: continuous beam accumulation and recirculation
- low background due to: pure, windowless $^{1,2}H_2$, $^{3,4}He$, etc. targets
- experiments with isomeric beams

Experiments at very low momentum transfer can only be done at EXL (except with active targets, but with substantial lower luminosity)

Only the world-wide unique combination of the Super-FRS and a Storage Ring provides high resolution experiments with high luminosity

The EXL Recoil and Gamma Array





Si DSSD ⇨ **ΔE, x, y**
300 μm thick, spatial resolution better than 500 μm in x and y,
ΔE = 30 keV (FWHM)

Thin Si DSSD ⇨ **tracking**
<100 μm thick, spatial resolution better than 100 μm in x and y,
ΔE = 30 keV (FWHM)

Si(Li) ⇨ **E**
9 mm thick, large area
100 x 100 mm^2,
ΔE = 50 keV (FWHM)

CsI crystals ⇨ **E, γ**
High efficiency, high resolution, 20 cm thick

III. First Experiments with Radioactive Beams at the ESR

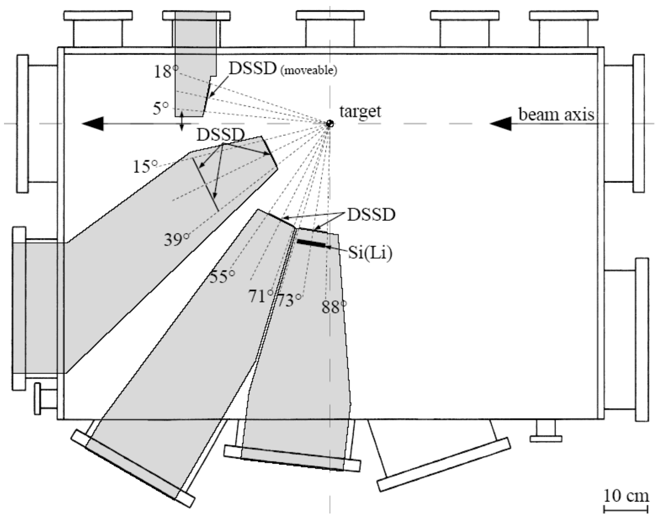
Proposal E105:
Start up of part of the EXL physics program with ^{56}Ni

Spokespersons: N. Kalantar (KVI), P. Egelhof (GSI)
GSI contact: H. Weick (GSI)

for the EXL collaboration

Proposal E105: Feasibility Studies and First Experiments with RIB`s at the ESR

specially designed scattering chamber for the ESR:



reactions with ^{58}Ni:

proof of principles and feasibility studies:

- UHV capability of detector setup
- background conditions in ESR environment at the internal target
- low energy threshold
- beam and target performance

reactions with ^{56}Ni:

^{56}Ni: doubly magic nucleus!!

- (p,p) reactions: nuclear matter distribution
- (α,α`) reactions: giant resonances (GMR) EOS parameters (nucl. compressibility)
- (^{3}He,t) reactions: Gamow-Teller matrix elements, important for astrophys.

First Experiments with Radioactive Beams at the ESR

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Spokespersons: N. Kalantar (KVI), P. Egelhof (GSI)
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for the EXL collaboration

<u>PAC Recommendation:</u>

out of a total of 147 shifts:

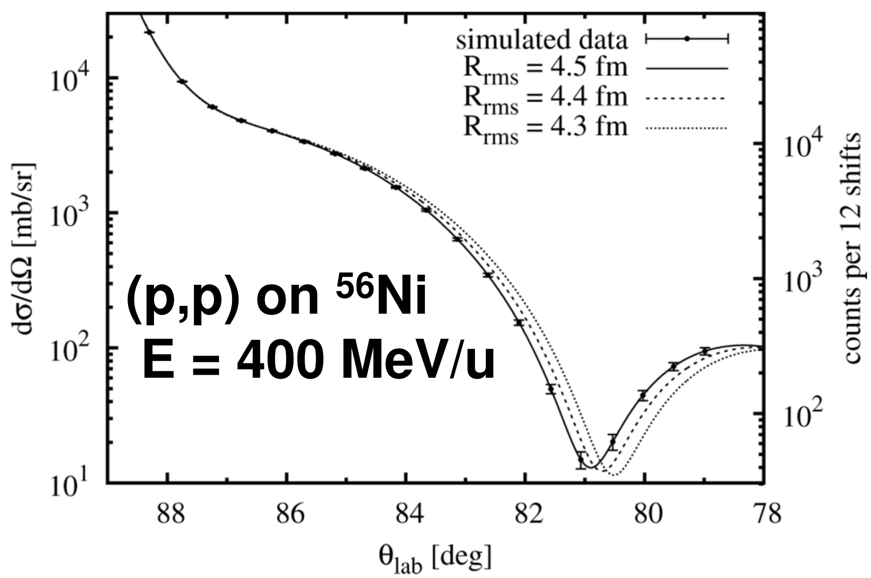
21 Shifts for Feasibility Studies with ^{58}Ni

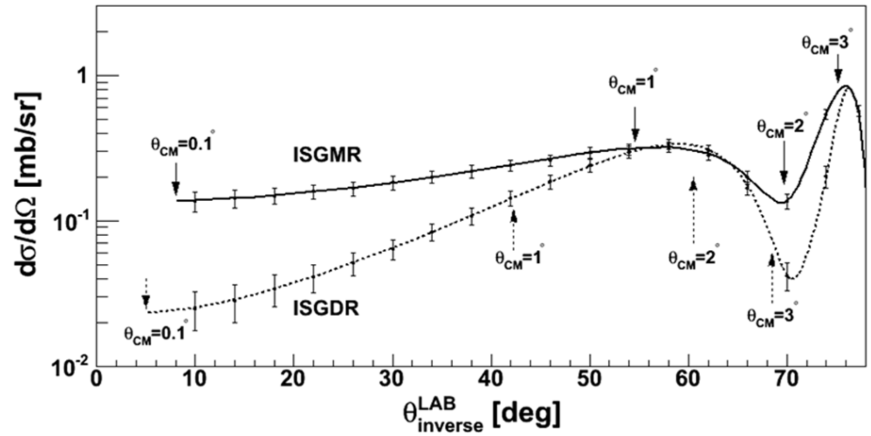
21 Shifts for First Experiments with ^{56}Ni

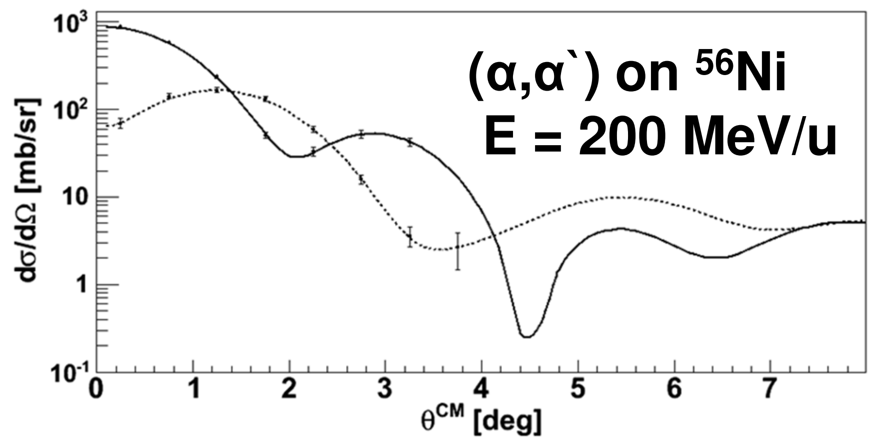
<u>Combination with Exp. E087 (P.J. Woods / Y. Litvinov)</u>

^{20}Ne(p,d)^{19}Ne* reaction in inverse kinematics (21 Shifts)

Theorectical Predictions





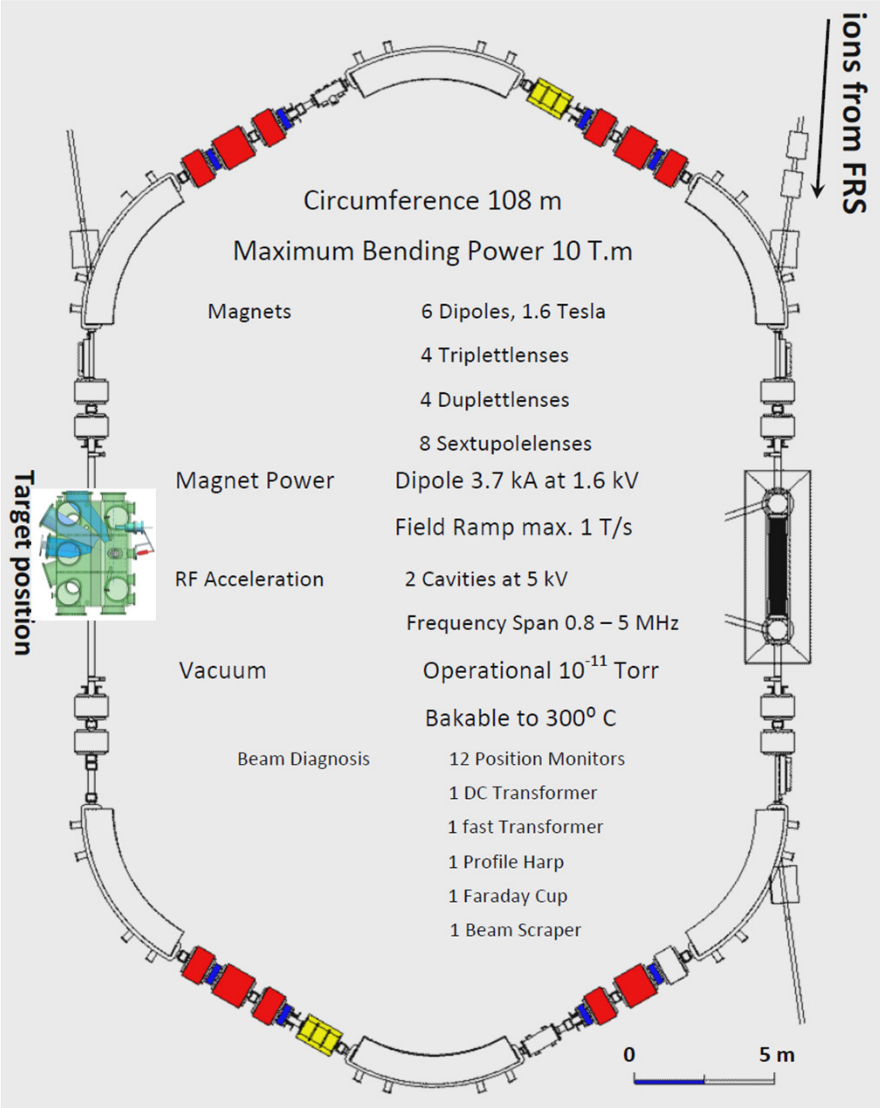


4 days with L = 10^{25} cm^{-2} sec^{-1}
recoil energies: 1 – 45 MeV

14 days with L = 10^{25} cm^{-2} sec^{-1}
recoil energies: 200 – 700 keV

needed: large solid angle detectors with low threshold and large dynamic range

Setup at the ESR Storage Ring



R&D on the EXL Recoil Detector

Aim: determine spectroscopic properties: ΔE, Δ(dE), efficiency, PSD
resolution of total energy reconstruction, energy threshold
UHV capability

Detectors: DSSD`s from PTI St. Petersburg (V. Eremin)
Si(Li)`s from KFZ Jülich, now SEMICON (D. Protic, T. Krings)

Tests:

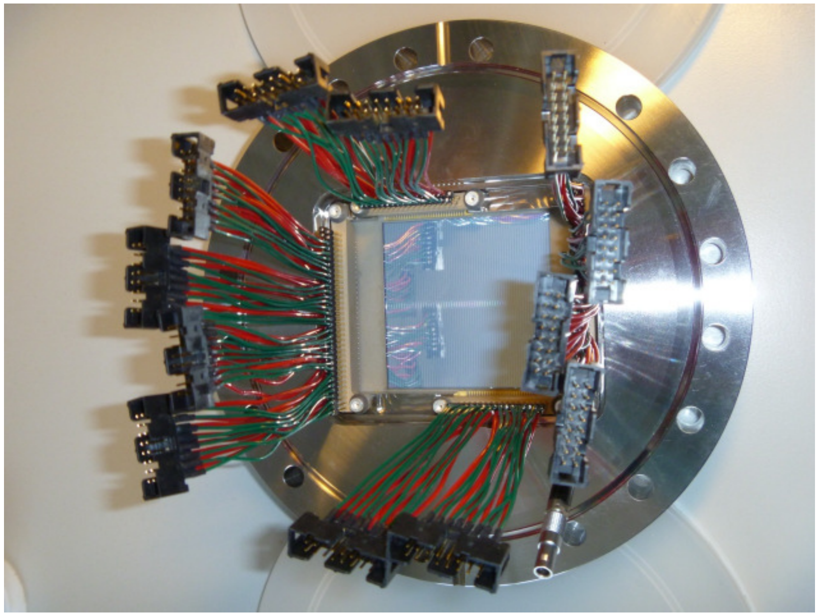
2008/2009: GSI:	α sources
2008: Edinburgh:	α sources
April 2009: KVI Groningen:	protons of 50 MeV
July 2009: TU München:	α particles E < 30 MeV
September 2009: GSI:	protons of 100 and 150 MeV
April 2010: KVI Groningen:	protons of 135 MeV
January 2011: TU Tübingen:	protons of 1.5 MeV down to 70 keV

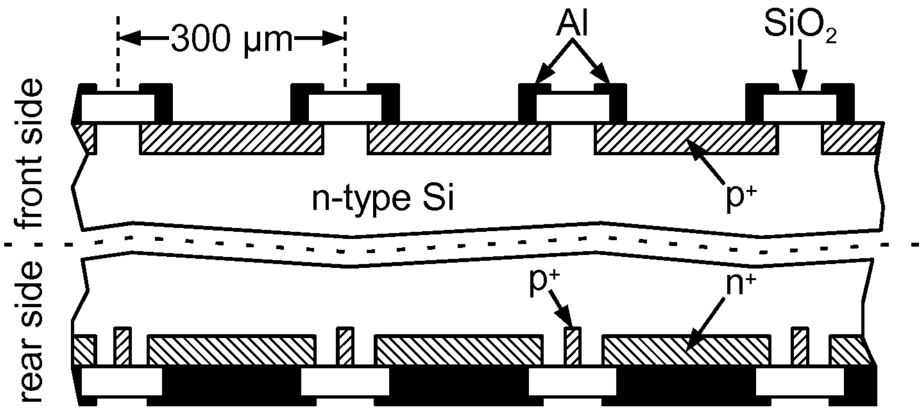
Double Sided Silicon Strip Detectors (DSSD`s) for EXL

Design and Production of Sensors: PTI St. Petersburg (V. Eremin et al.)
Maxwell

Geometry:
active area: 64 x 64 mm^2
thickness: 300 µm
strips: 128 x 64
pitch: 500 µm

Optimized for:
thin entrance window: ≤ 50 nm
high efficiency: 10 µm interstrip gap
energy resolution: ΔE = 15 – 25 keV





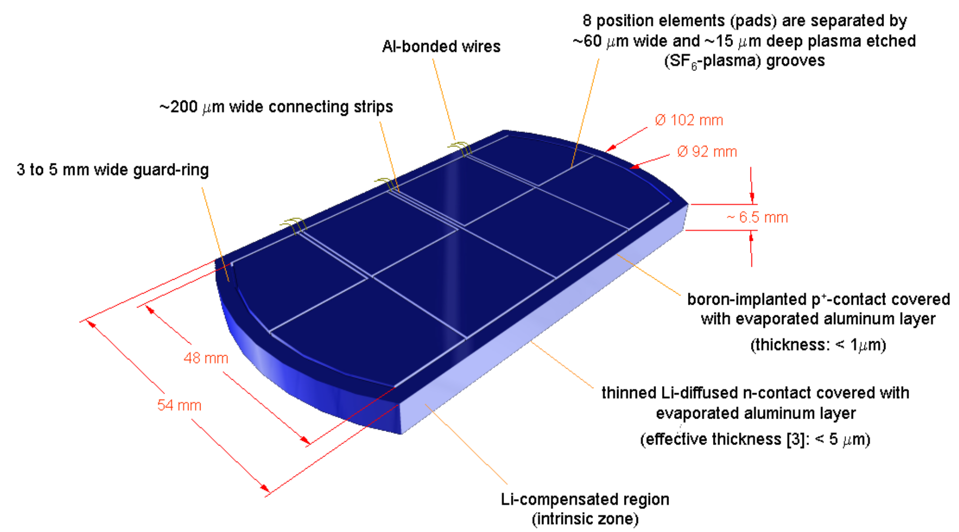
Si(Li) Detectors for EXL

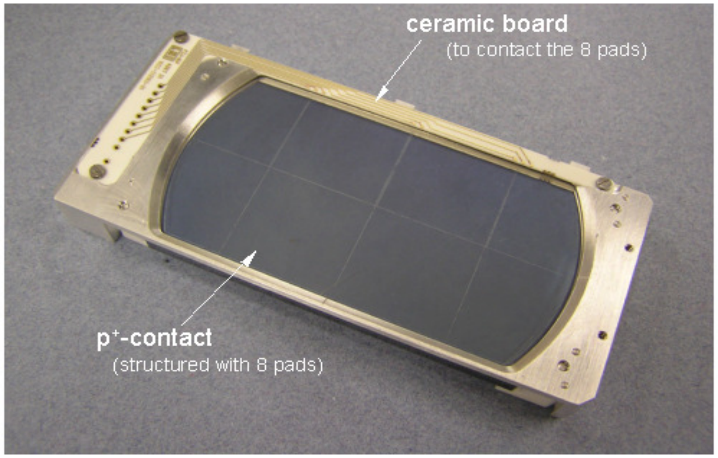
Design and Production: KFZ Jülich (now SEMIKON) (D. Protic, T. Krings)

Geometry: active area: 50 x 80 mm^2 (separated in 8 pads)
thickness: 6.5 mm

Energy Resolution: ΔE = 25 keV for α-source

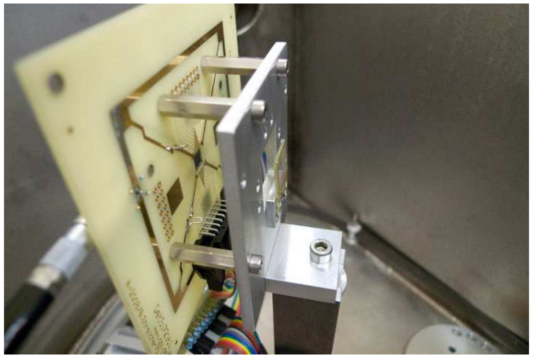
Schematic view of the Si(Li) transmission detector



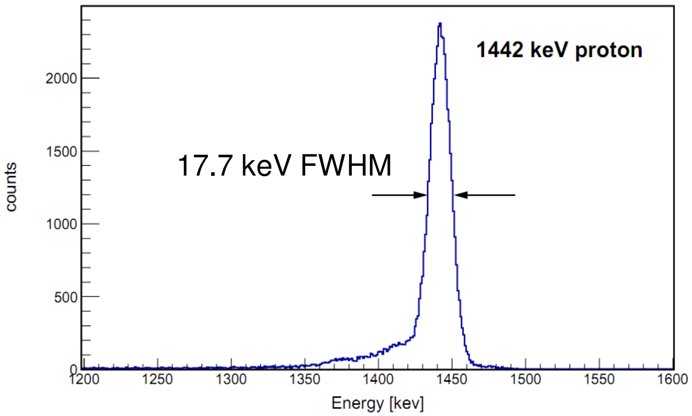


Response to very Low Energy Protons

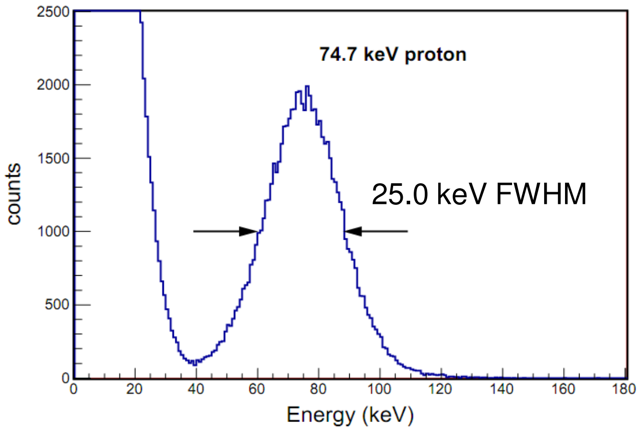
proton beams from the
Tübingen van de Graaf Accelerator



1503 keV protons scattered from C target (37µg/cm²)
⇒ 1442 keV protons



818 keV H_2 scattered from C target, ~3.5 µm Mylar degrader in front of DSSD
⇒ 74.7 keV protons

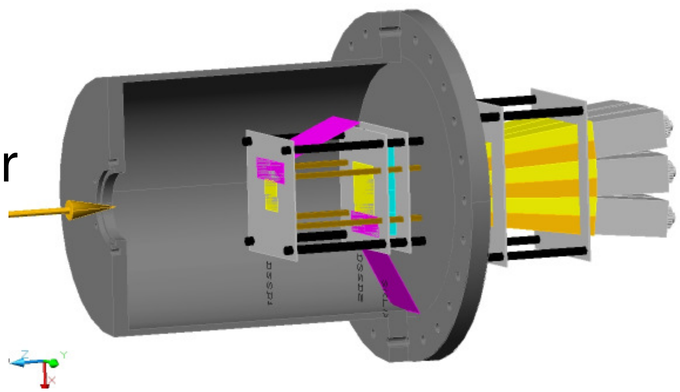


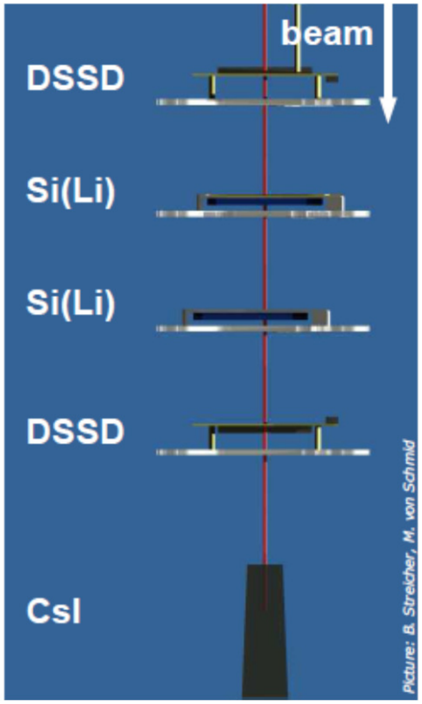
K. Yue et al.,
Proceedings of STORI11
http.//pos.sissa.it

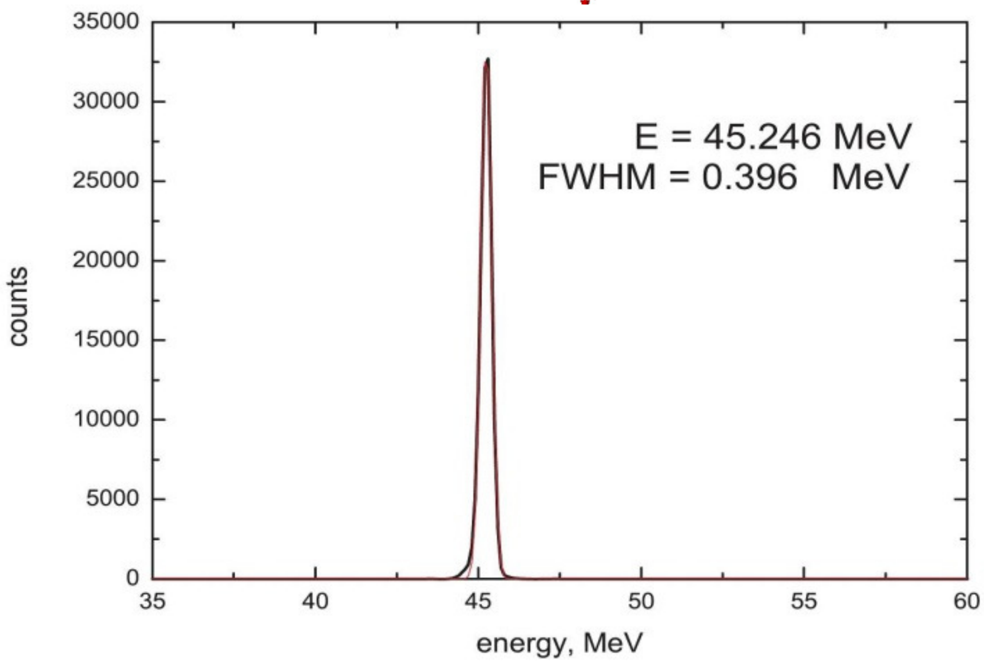
Response to High Energy Protons

50 MeV proton beam from the KVI cyclotron

the EXL Demonstrator





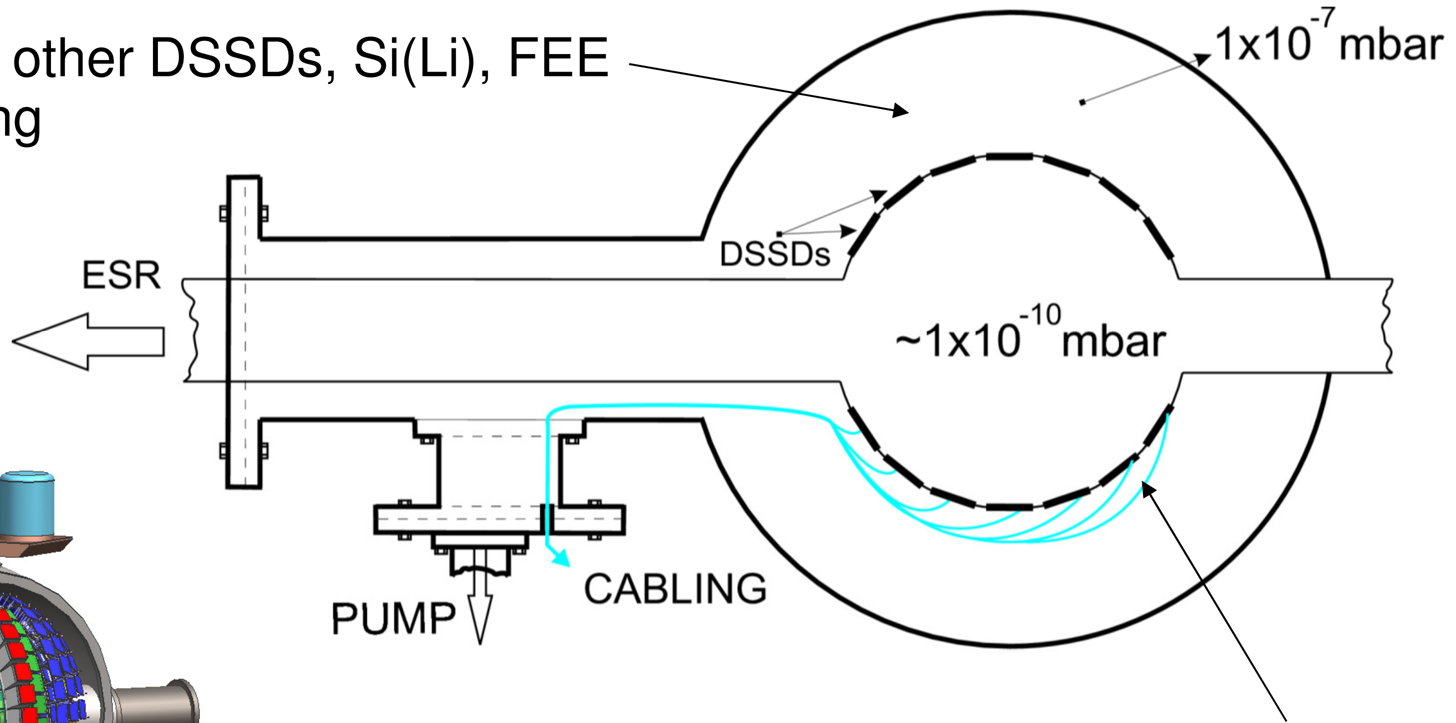


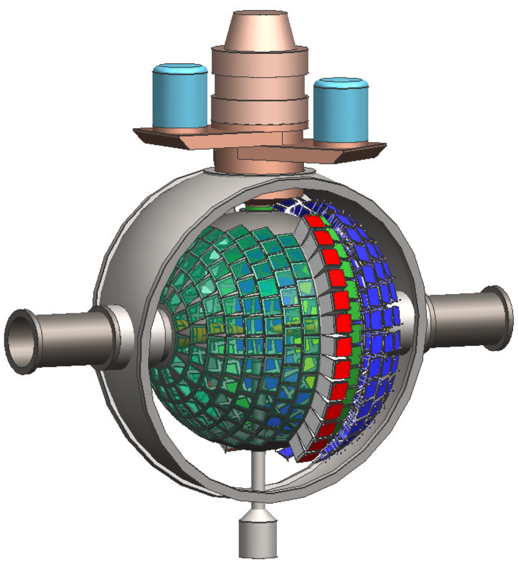
total energy reconstruction

UHV Capability of the EXL Silicon Ball:
Concept: using DSSD`s as high vacuum barrier

- Differential pumping proposed to separate (N)ESR vacuum from EXL instrumentation (cabling, FEE, other detectors)

M. Mutterer

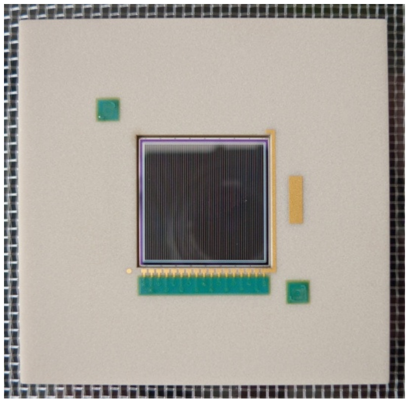




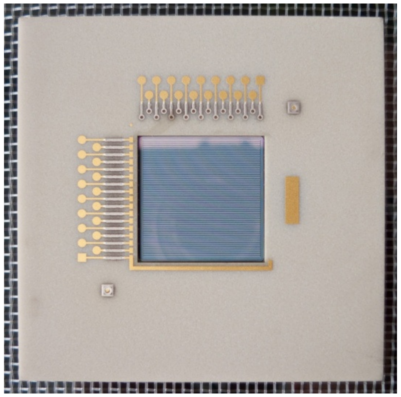
UHV-Barrier DSSD Design

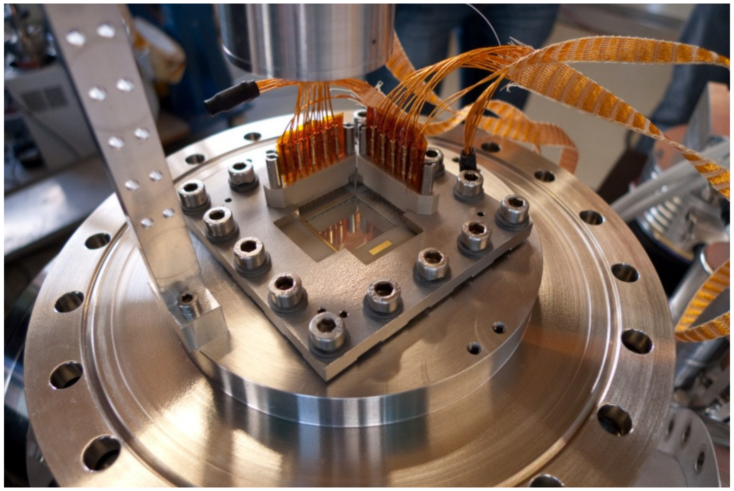
Ceramic Boards:

P-side: in UHV



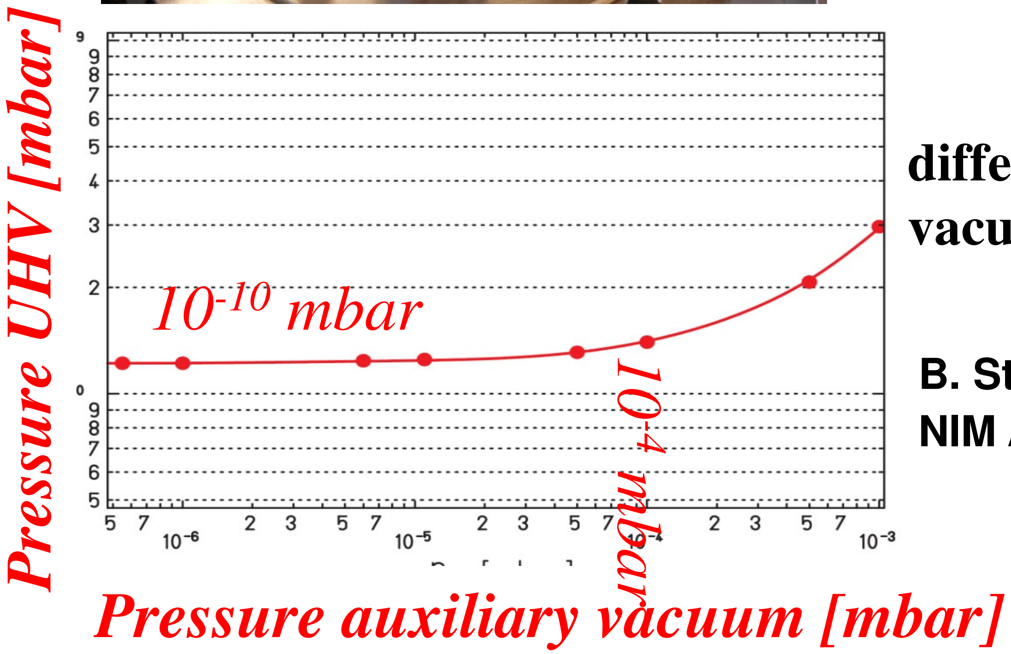
N-side: in low vacuum





low vacuum side:

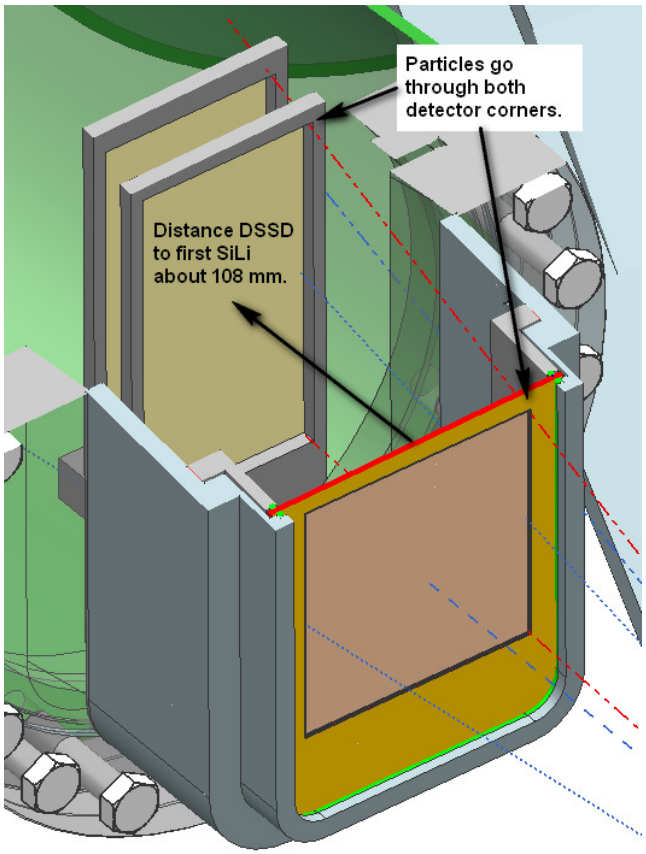
spring pin connectors



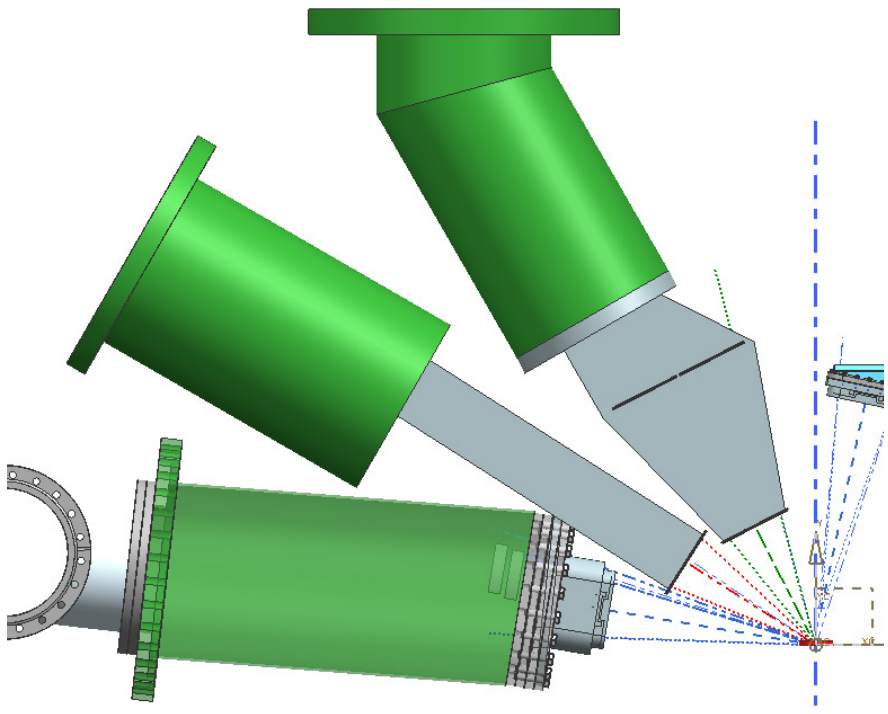
differential vacuum test

B. Streicher et al., NIM A654 (2011)604

Experimental Concept for the E105 Experiment

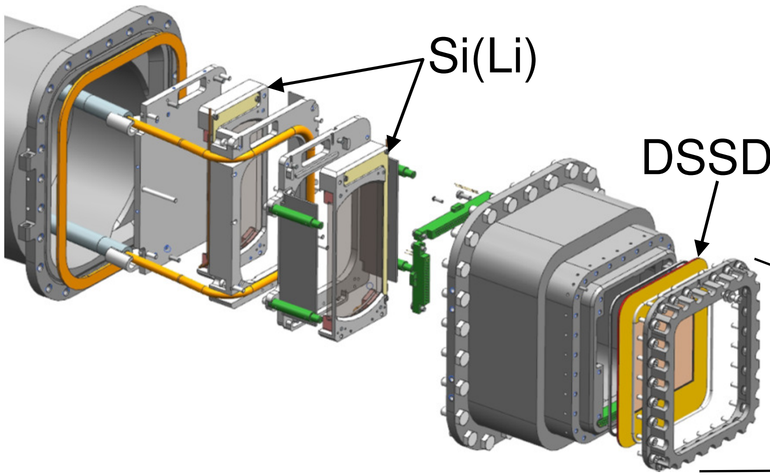


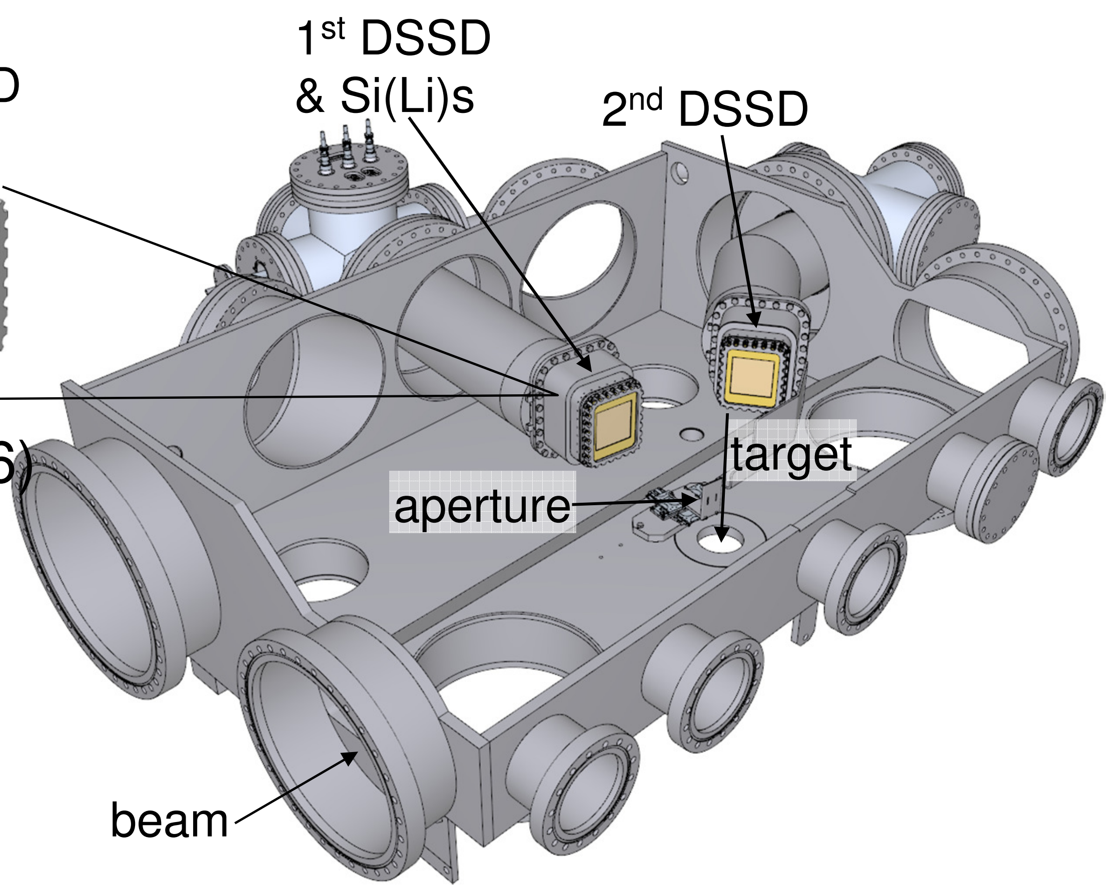
DSSD – SiLi –SiLi telescope



Top view

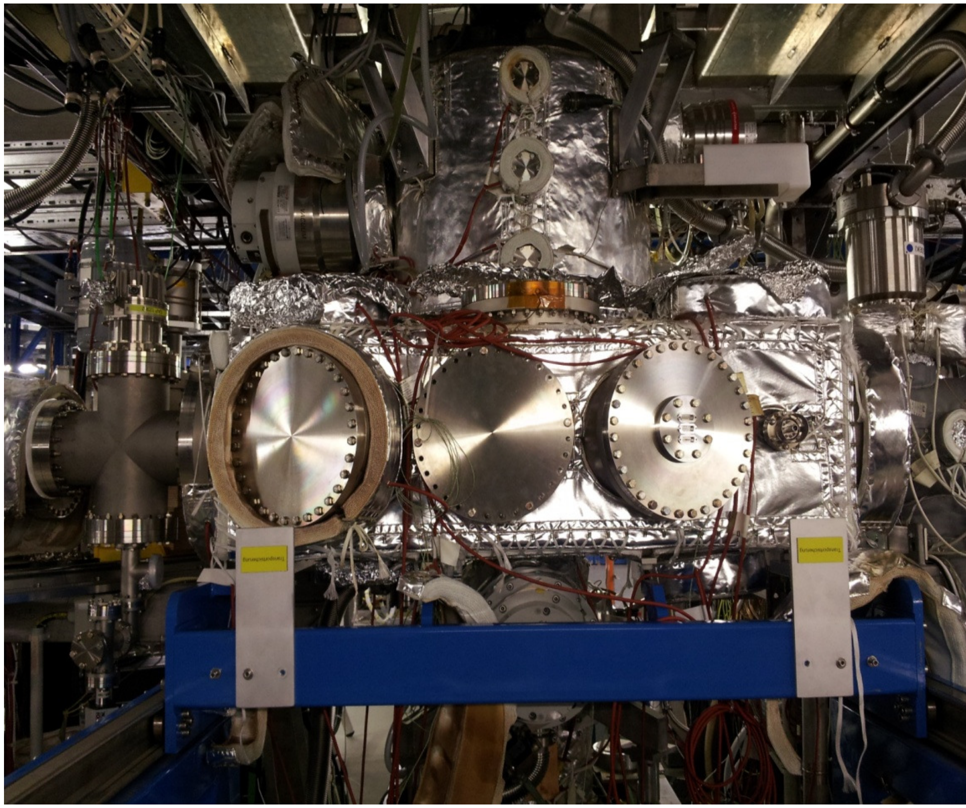
Experimental Concept for the E105 Experiment



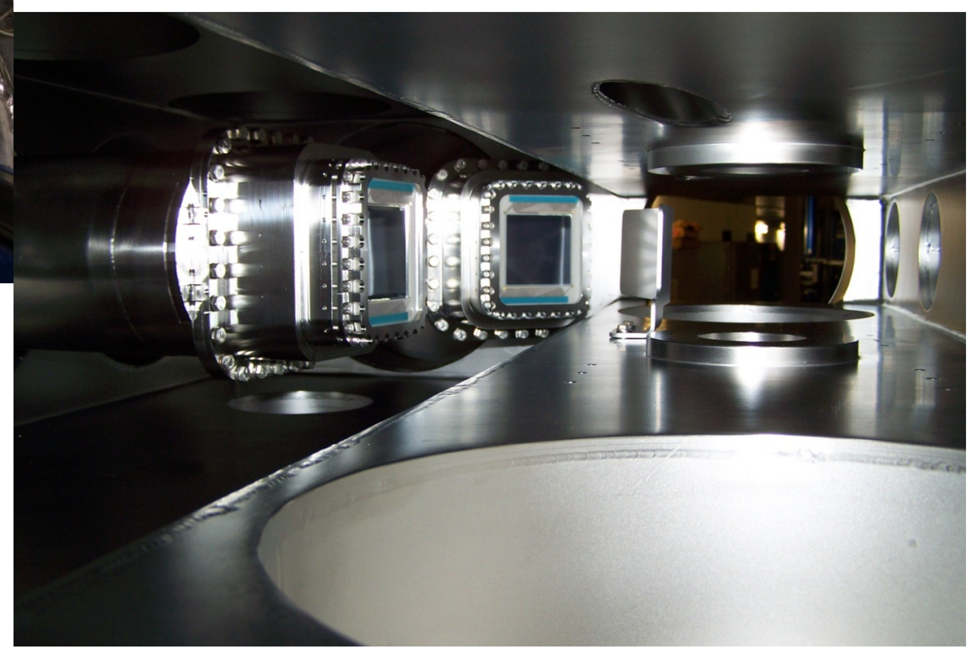


- **DSSD**: 128×64 strips, (6×6) cm², 285 µm thick
- **Si(Li)**: 8 pads, (8×4) cm², 6.5 mm thick
- **active vacuum barrier**
- **moveable aperture** to improve angular resolution

Experimental Setup at the ESR

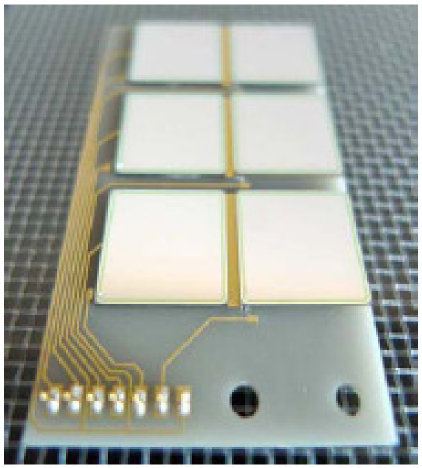


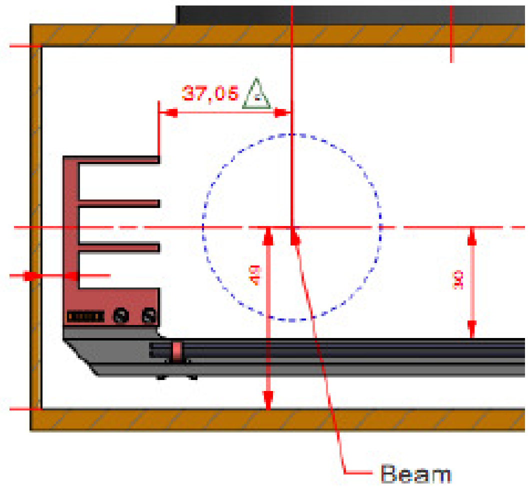
Scattering Chamber mounted at the Internal Target of the ESR

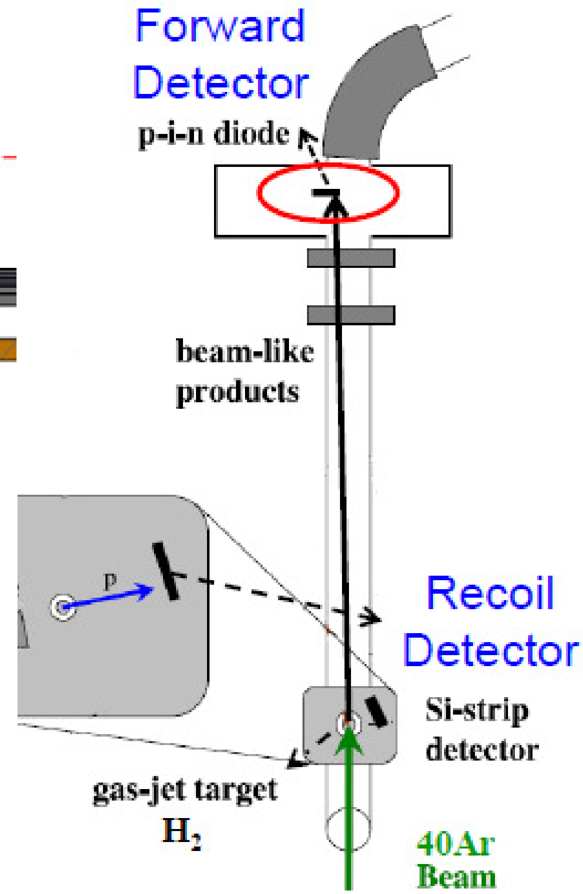


challenge:
UHV capable and bakeable DSSD and Si(Li) detectors

UHV capable Tagging Detector for Beam-Like Reaction Products







- Forward detector before the first dipole, detection of beam like reaction products in coincidence with recoils.
- 6 PIN diodes (1 x 1 cm²) on AlN PCB, directly in the UHV
- Small dead edge, could be very close to the beam
- Baked at 250° C, passed vacuum Test.

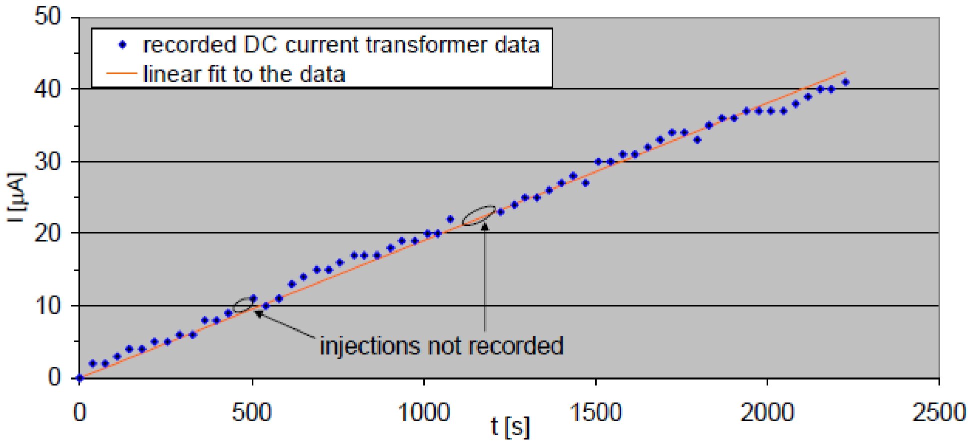
Preparation of the Stored Radioactive ^{56}Ni Beam

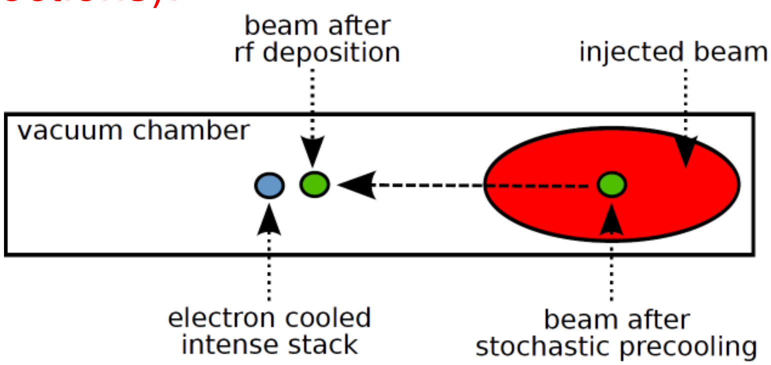
FRS: fragmentation of 600 MeV/u ^{58}Ni beam

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

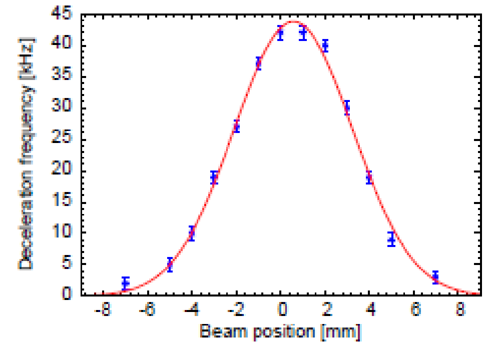
F. Nolden, M. Steck

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





target profile



σ = 3.78 mm x_0 = 0.58 mm

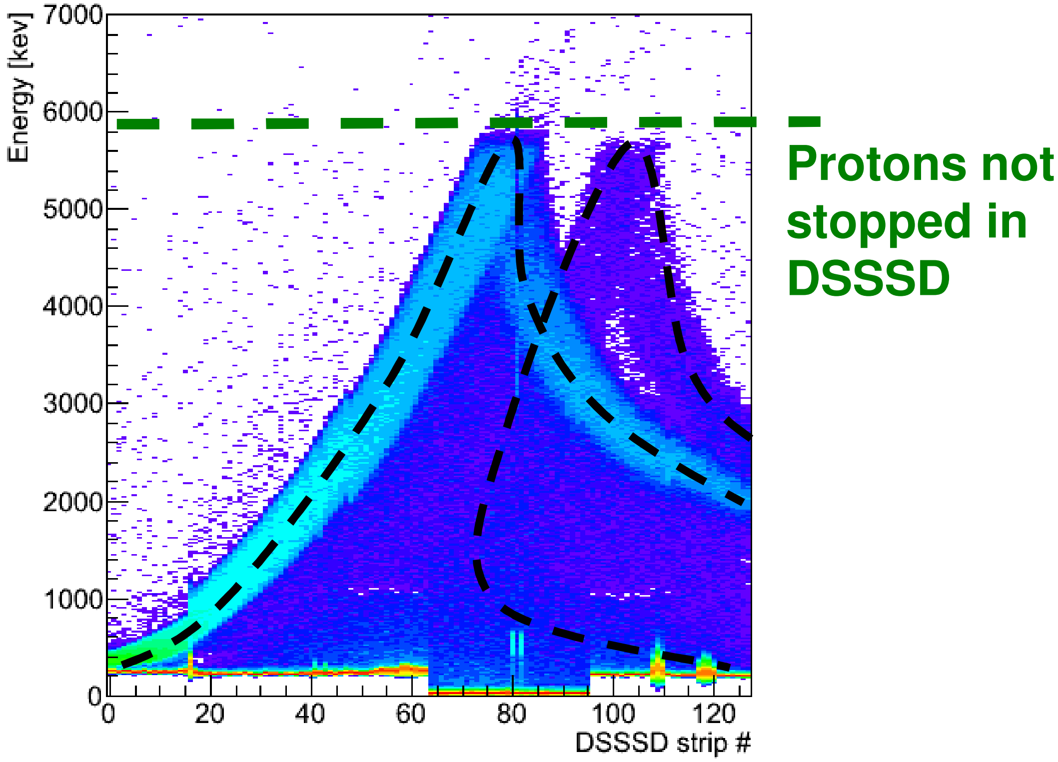
luminosity: H_2 target: 2 x 10^{13} cm^{-2}

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

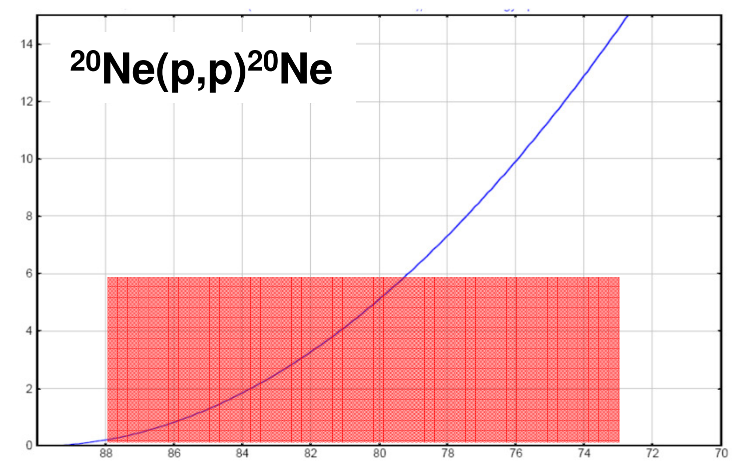
First Results with Stable Beam (preliminary!)

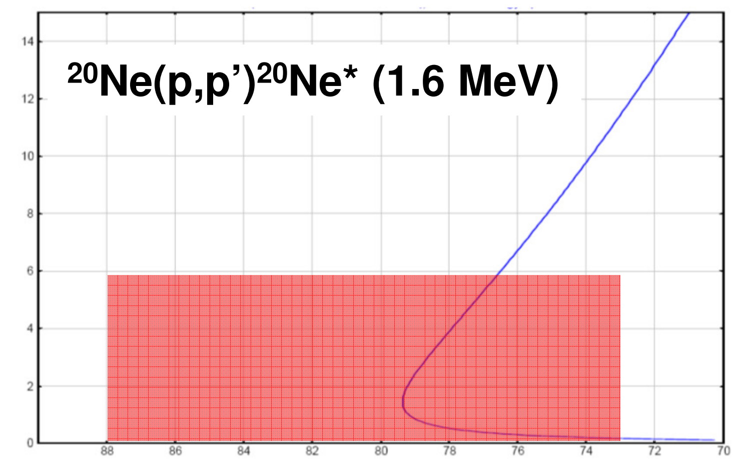
(main exp: E87, P. Woods et al., Univ. of Edinburgh)

^{20}Ne @ 50 MeV/u on H_2 gas jet



Θ_{Lab} = 88° .... 73°





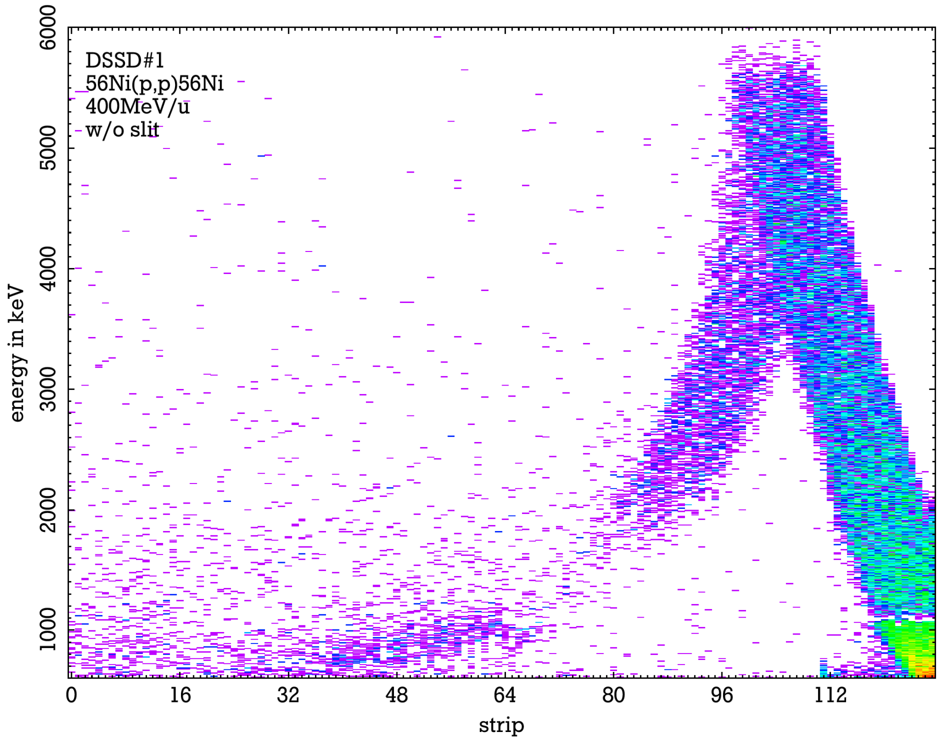
First Results with Stable Beam (preliminary!)

reaction: ^{58}Ni on H_2 target

energy: 400 MeV/u

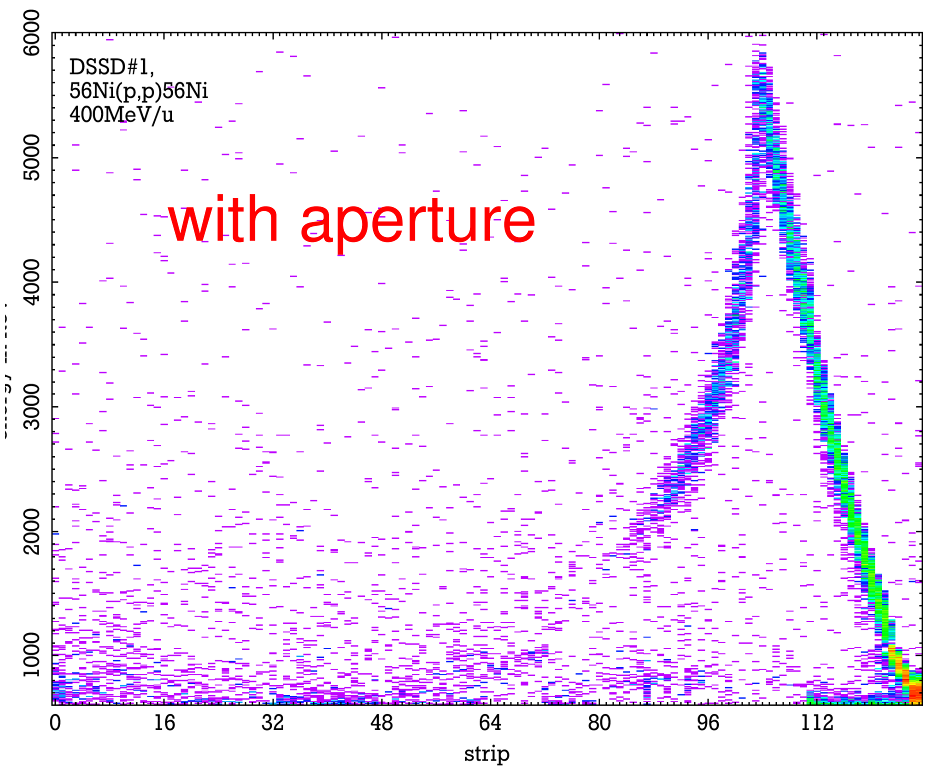
target: 2 X 10^{13} /cm^3

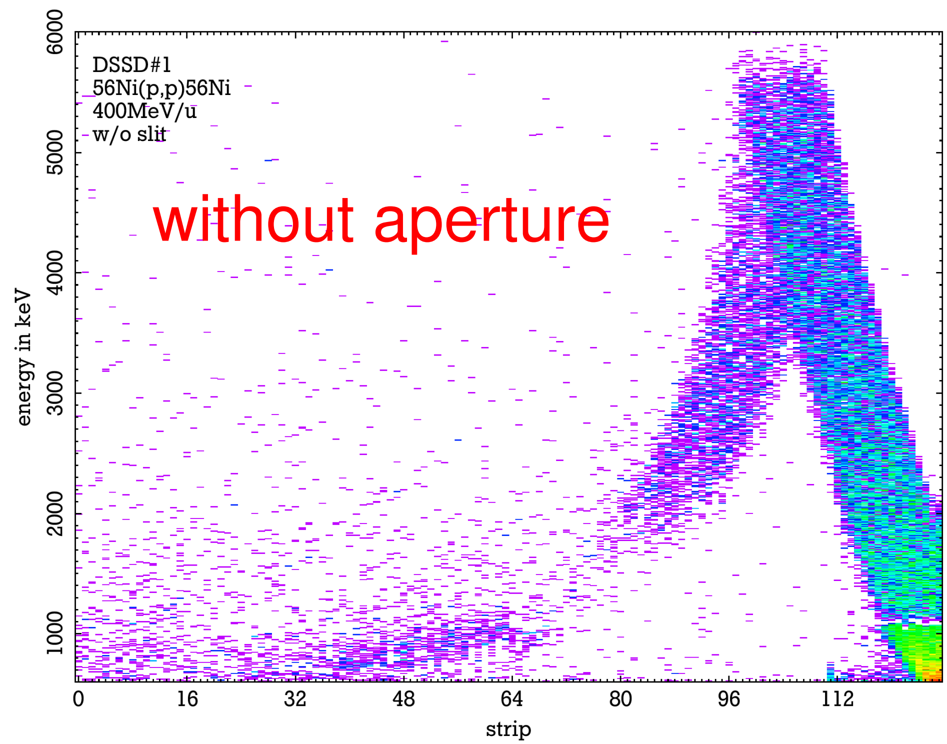
detector: DSSD
$\Theta_{Lab} = 72° - 88°$



Effect of Aperture in Front of Target

^{58}Ni(p,p), E = 400 MeV/u

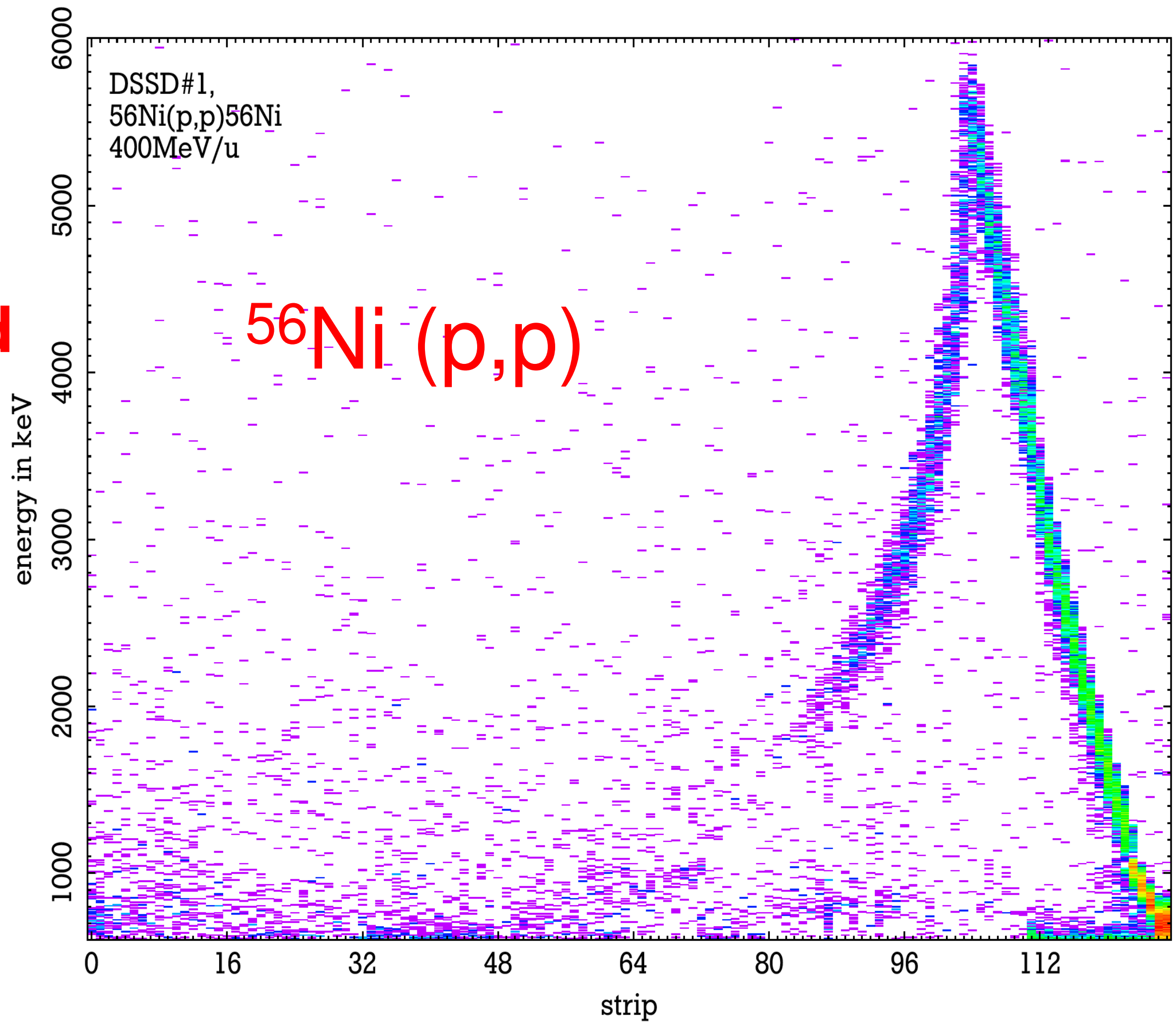




First Results with Radioactive Beam

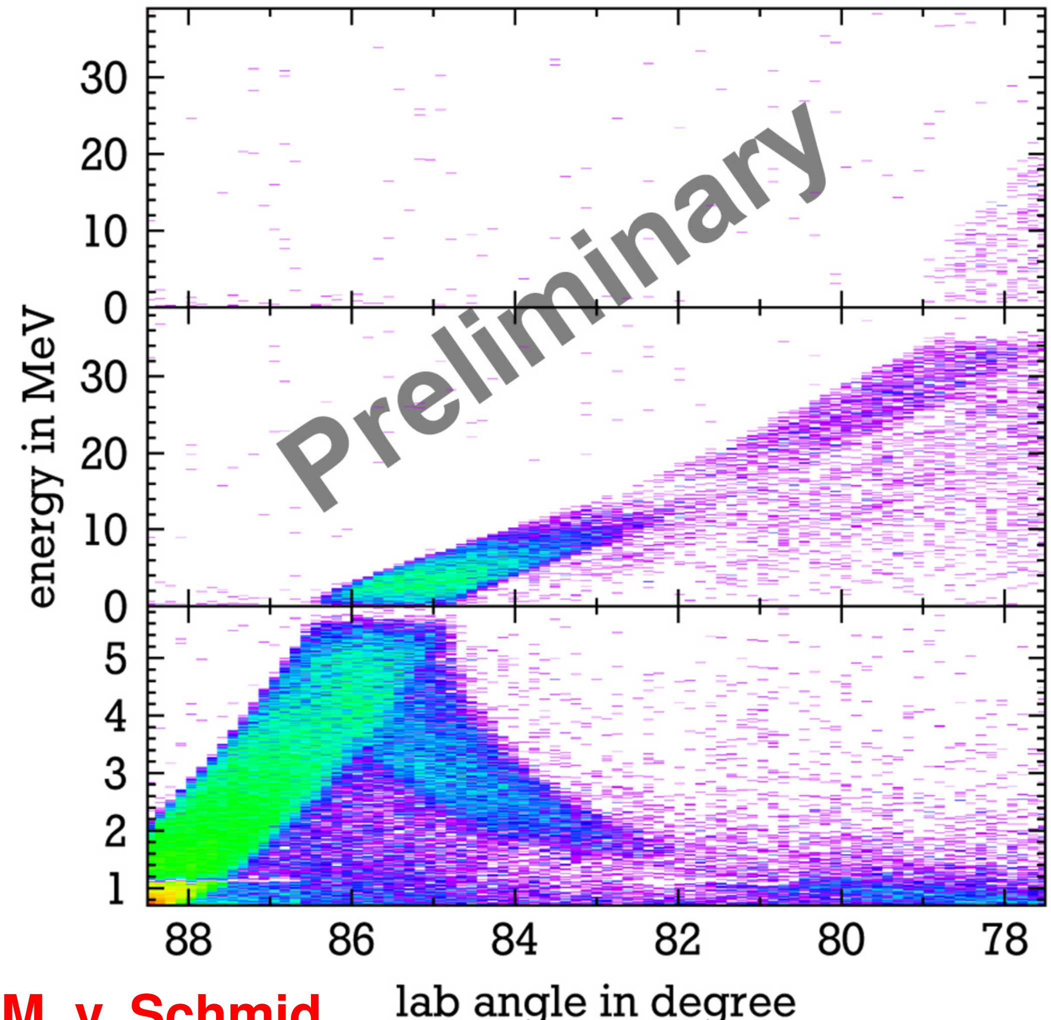
25. 10. 2012:

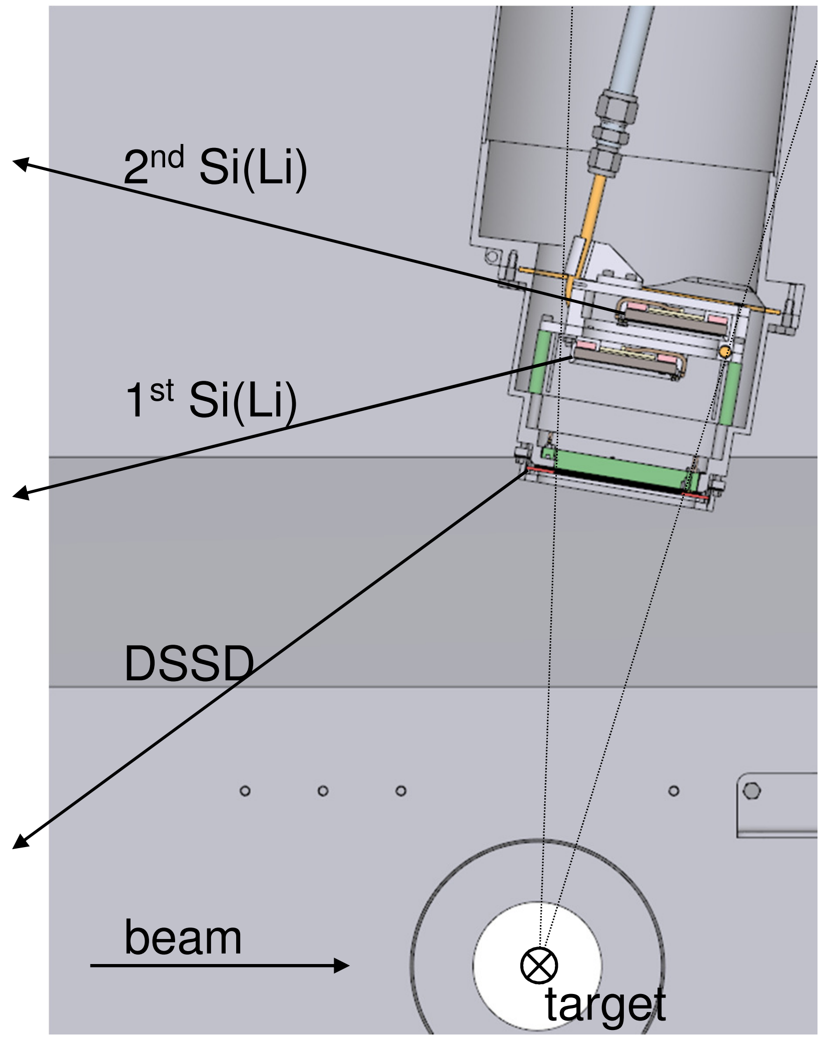
First Nuclear Reaction Experiment with Stored Radioactive Beam!!!!



First Results with Radioactive Beam

^{56}Ni(p,p), E = 400 MeV/u Response of Individual Detectors

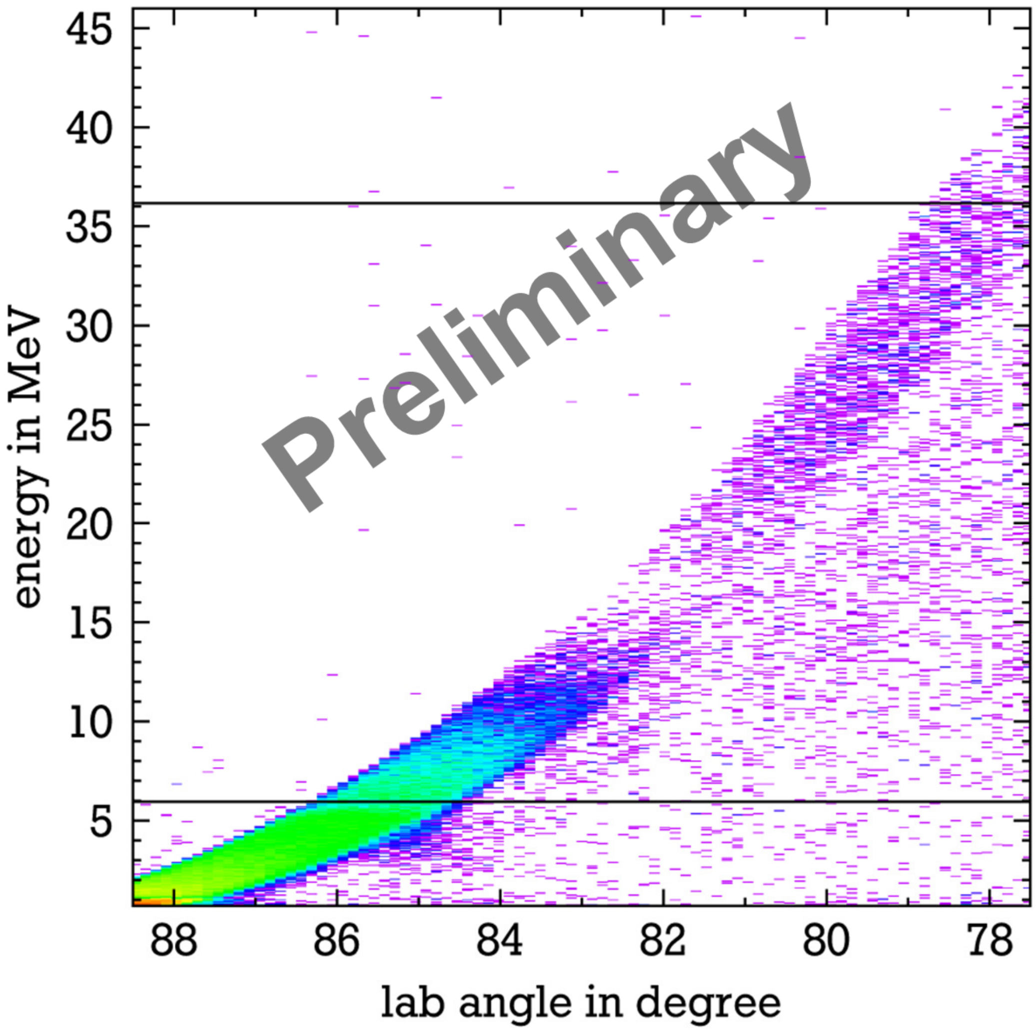


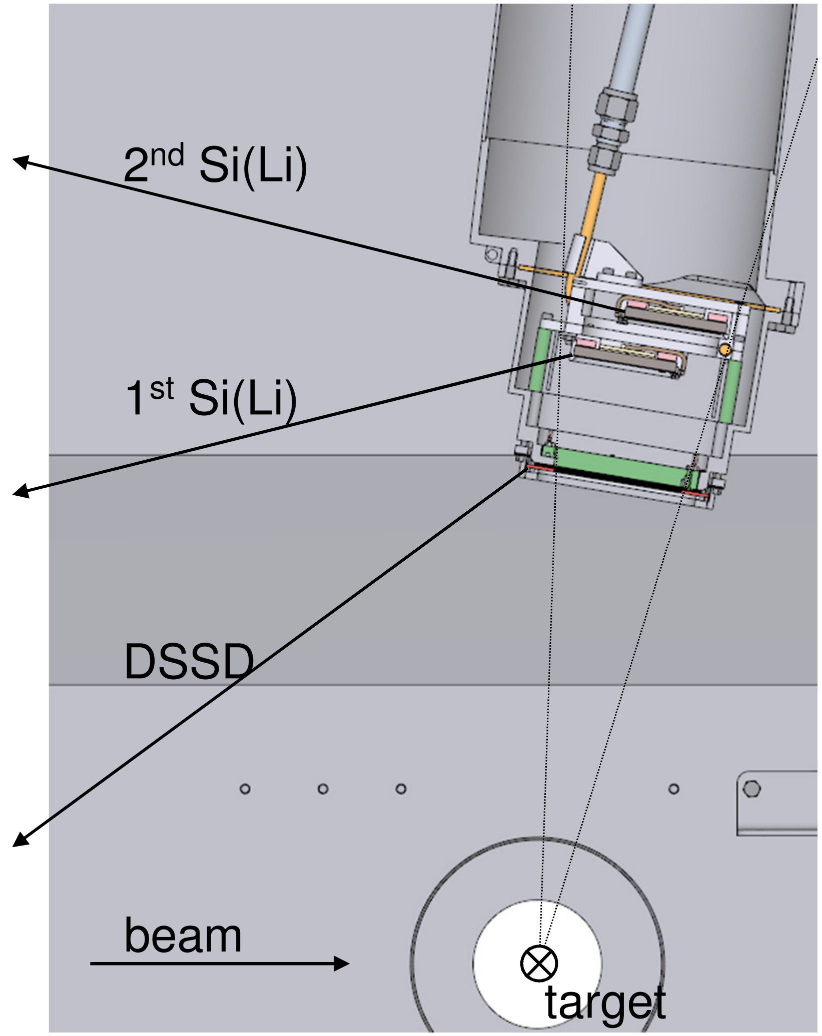


M. v. Schmid

First Results with Radioactive Beam

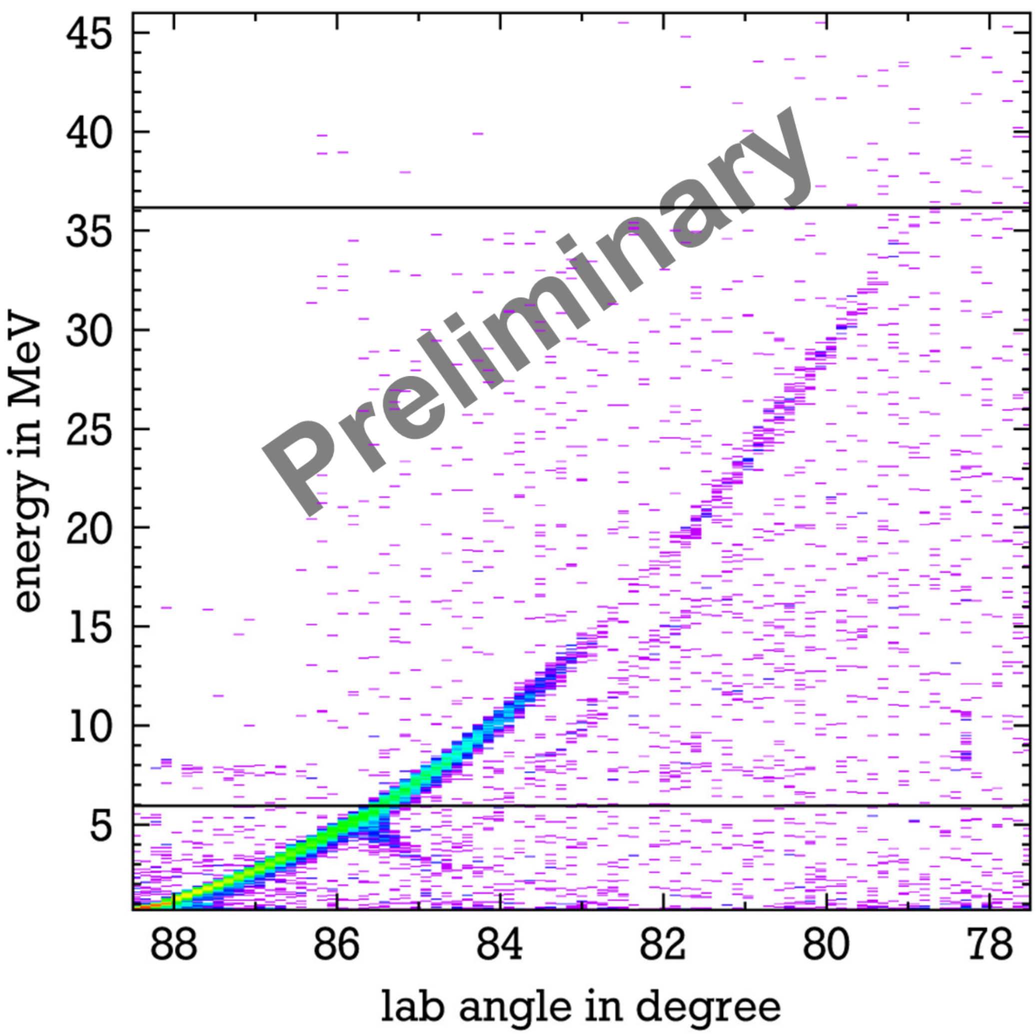
^{56}Ni(p,p), E = 400 MeV/u   Reconstructed Energy

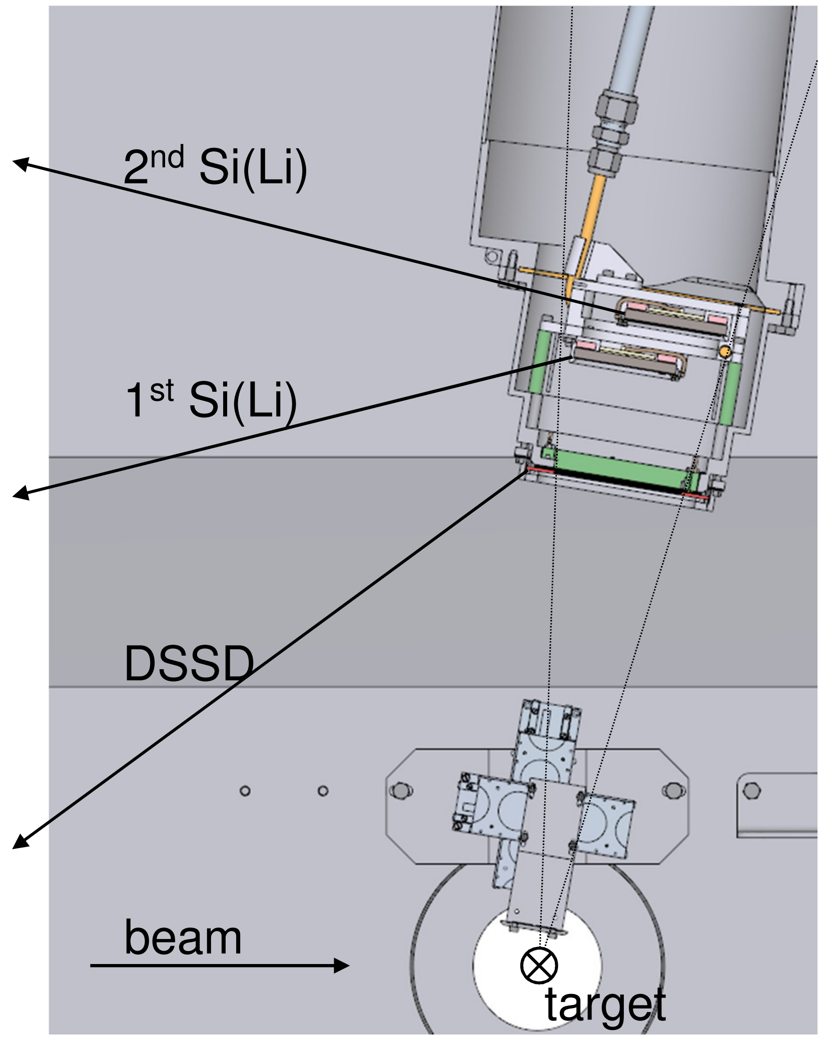




First Results with Radioactive Beam

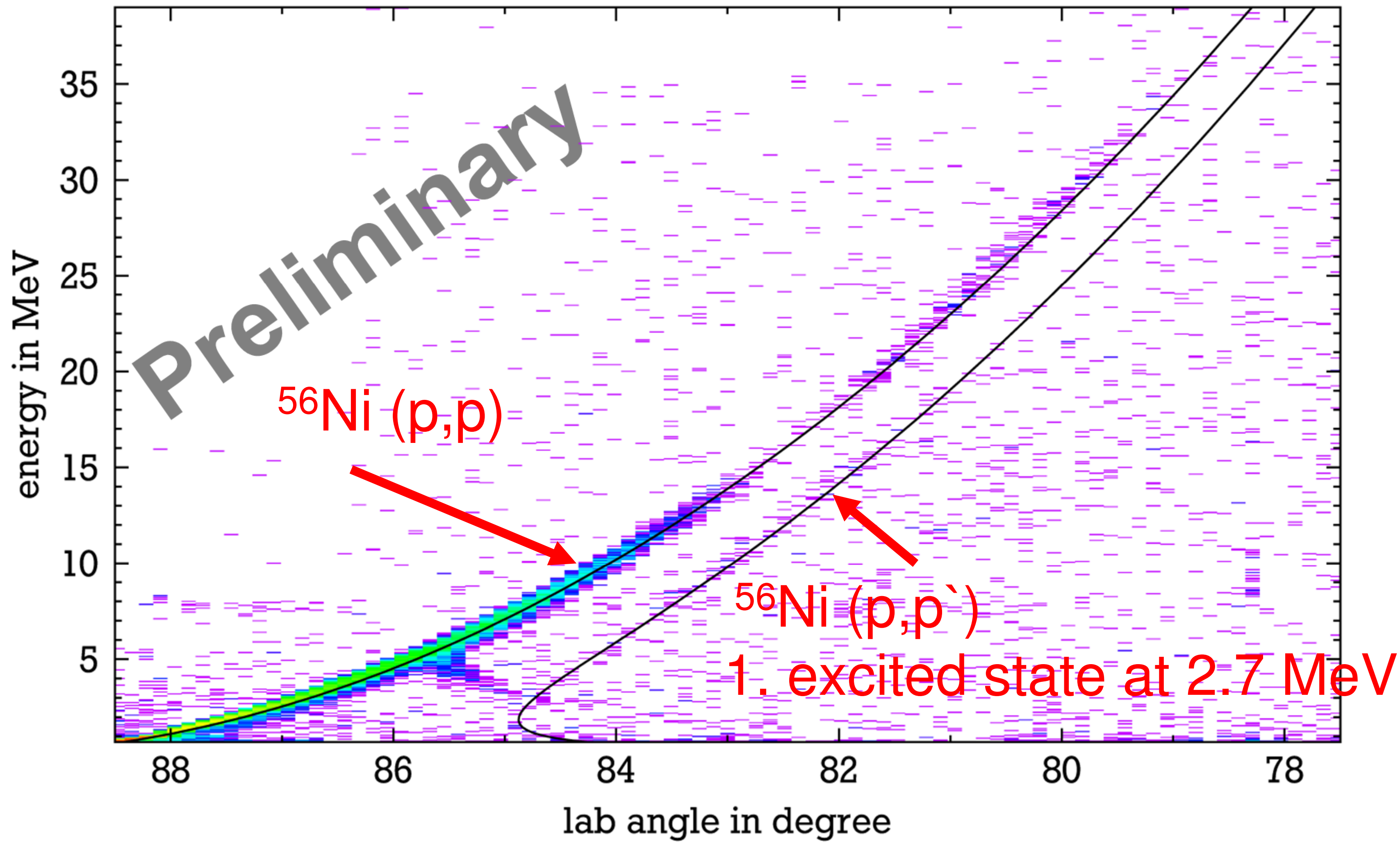
$^{56}Ni(p,p)$, E = 400 MeV/u   Benefit of the 1mm Aperture





First Results with Radioactive Beam

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



Comparison with External Target Experiment

VOLUME 73, NUMBER 13 PHYSICAL REVIEW LETTERS 26 SEPTEMBER 1994

Proton Inelastic Scattering on ^{56}Ni in Inverse Kinematics

G. Kraus, P. Egelhof, C. Fischer, H. Geissel, A. Himmler, F. Nickel, G. Münzenberg, W. Schwab, and A. Weiss
Gesellschaft für Schwerionenforschung, D-64220 Darmstadt, Germany

J. Friese, A. Gillitzer, H. J. Körner, and M. Peter
Technische Universität München, D-85748 Garching, Germany

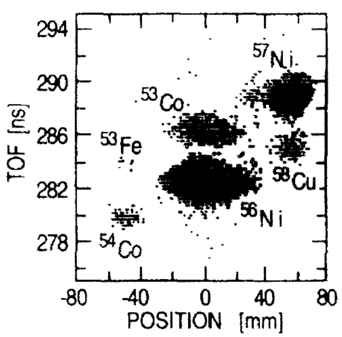
W. F. Henning and J. P. Schiffer
Argonne National Laboratory, Argonne, Illinois 60439

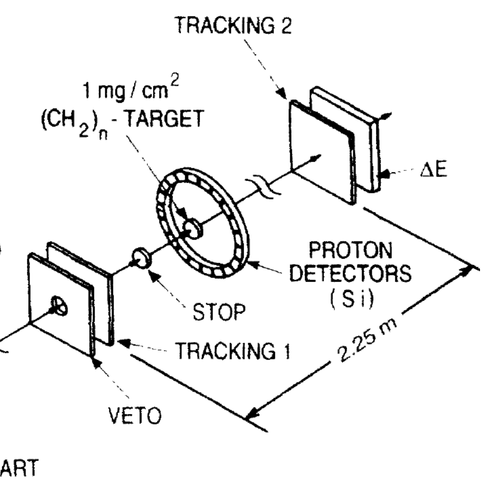
J. V. Kratz
University of Mainz, D-55099 Mainz, Germany

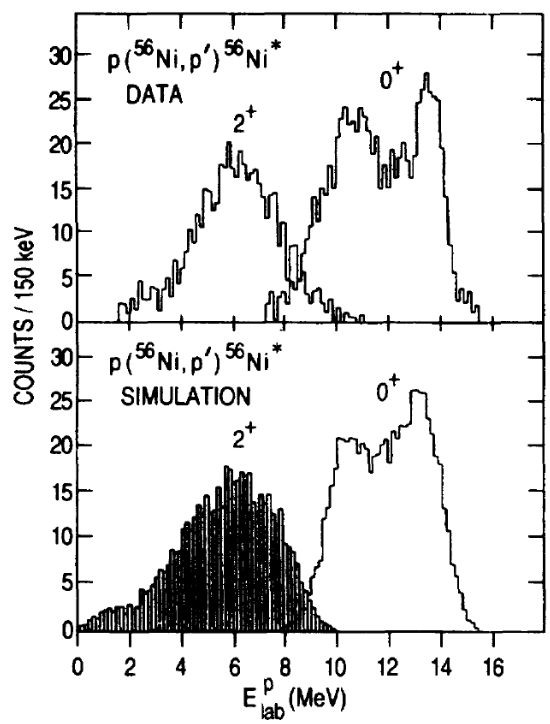
L. Chulkov, M. Golovkov, and A. Ogloblin
I. V. Kurchatov Institute, Moscow, Russia

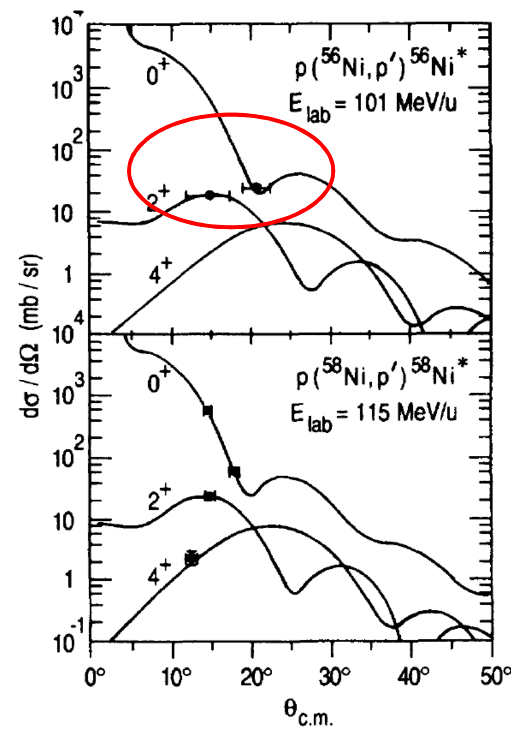
B. A. Brown
Michigan State University, East Lansing, Michigan 4882
(Received 19 May 1994)

same ^{56}Ni intensity
as for ESR experiment









Investigation of the Giant Monopole Resonance in ^{58}Ni

reaction: ^{58}Ni on He target

energy: 100 MeV/u

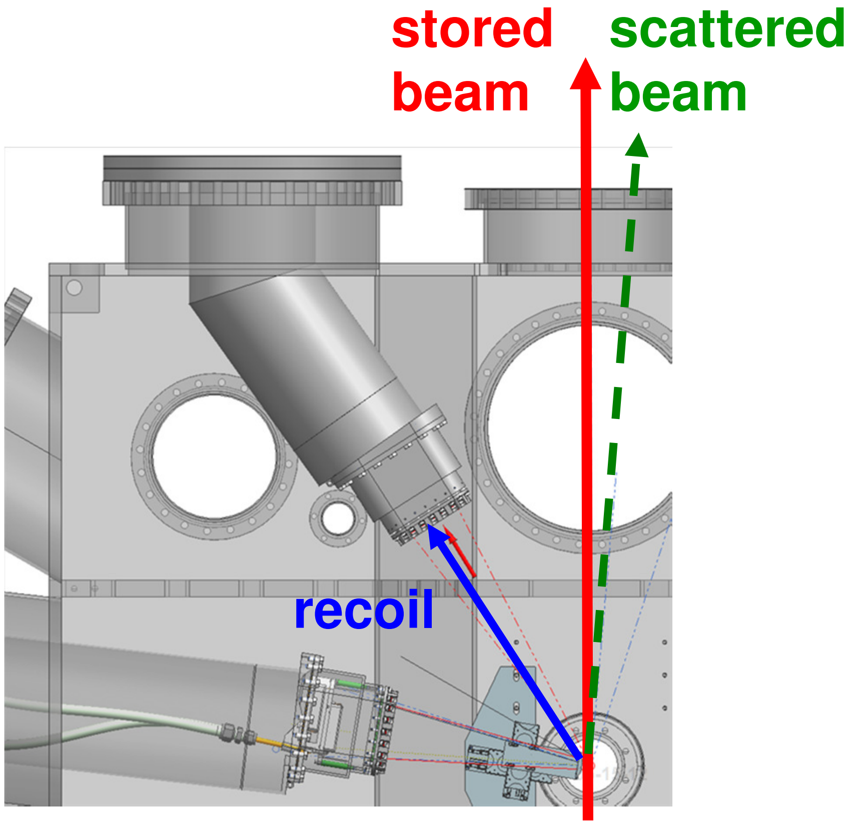
target: 8 X 10^{12} /cm^3

detectors: DSSD

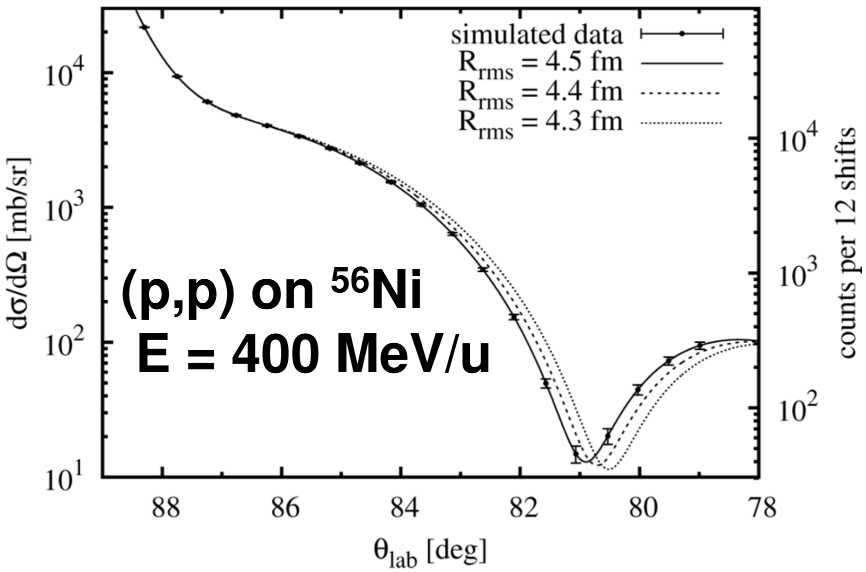
Θ_{Lab} = 27° - 38°

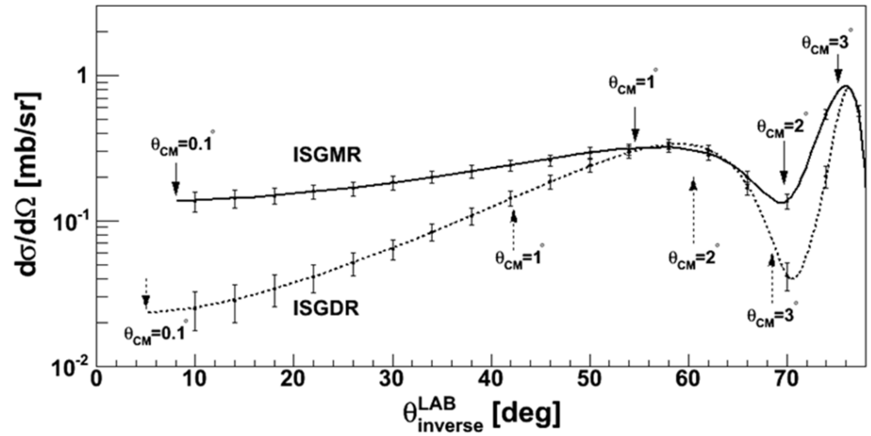
PIN diodes

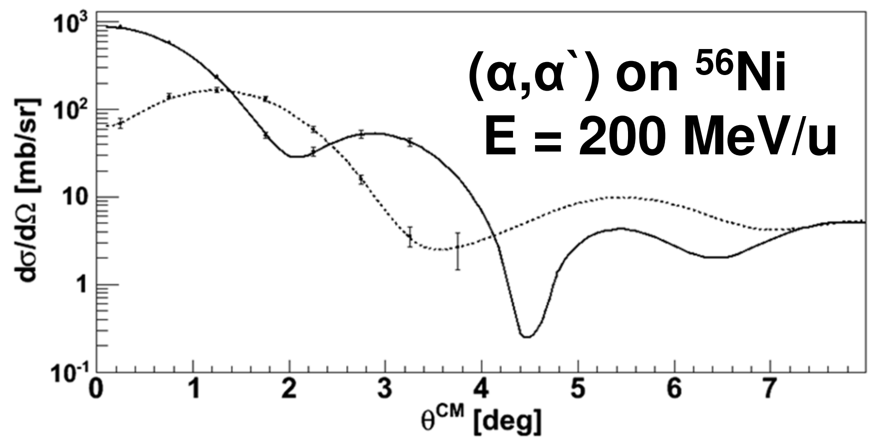
Θ_{Lab} = 0.2° - 1°



Theorectical Predictions







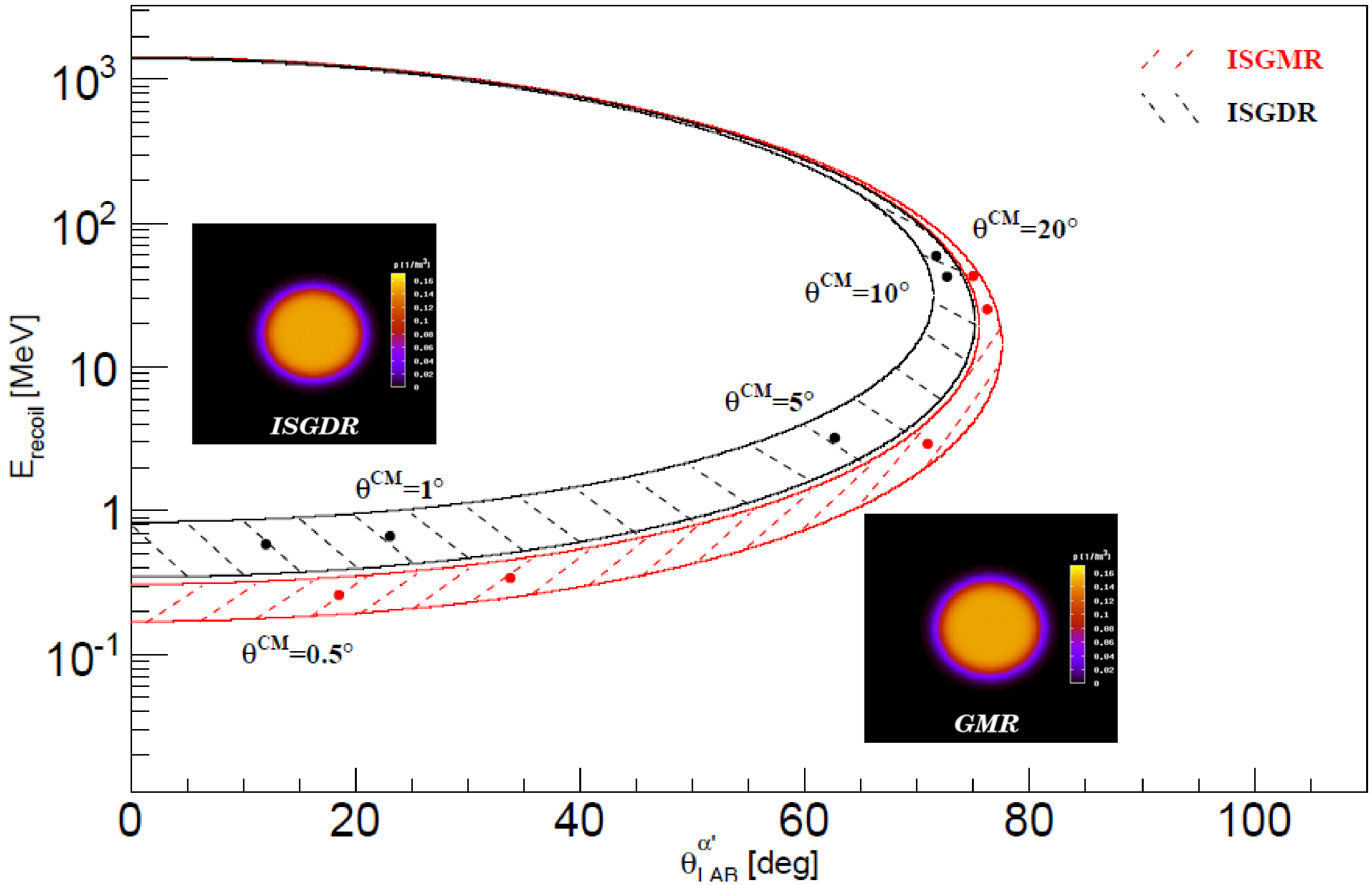
4 days with L = 10^{25} cm^{-2} sec^{-1}
recoil energies: 1 – 45 MeV

14 days with L = 10^{25} cm^{-2} sec^{-1}
recoil energies: 200 – 700 keV

needed: large solid angle detectors with low threshold and large dynamic range

Investigation of the Giant Monopole Resonance in ^{58}Ni

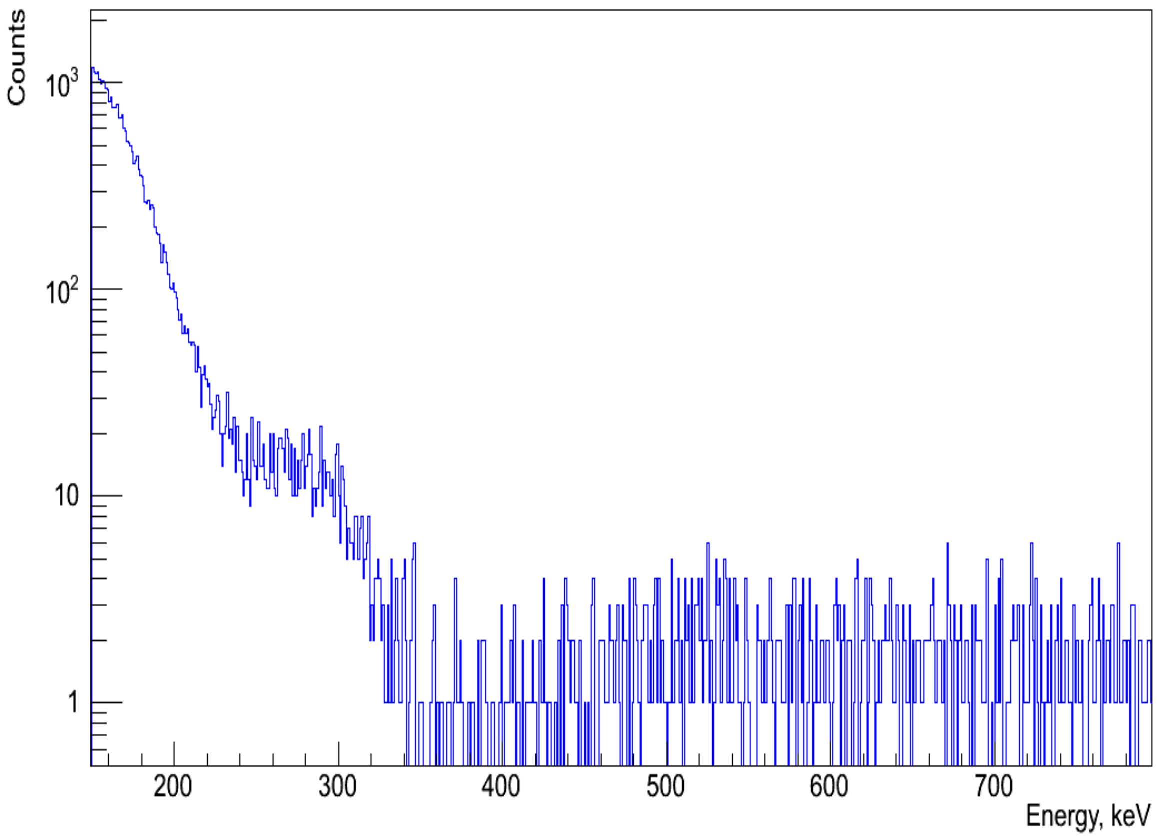
$^{58}Ni(\alpha,\alpha')$, E = 100 MeV/u



challenge: detect and identify very low energy recoils

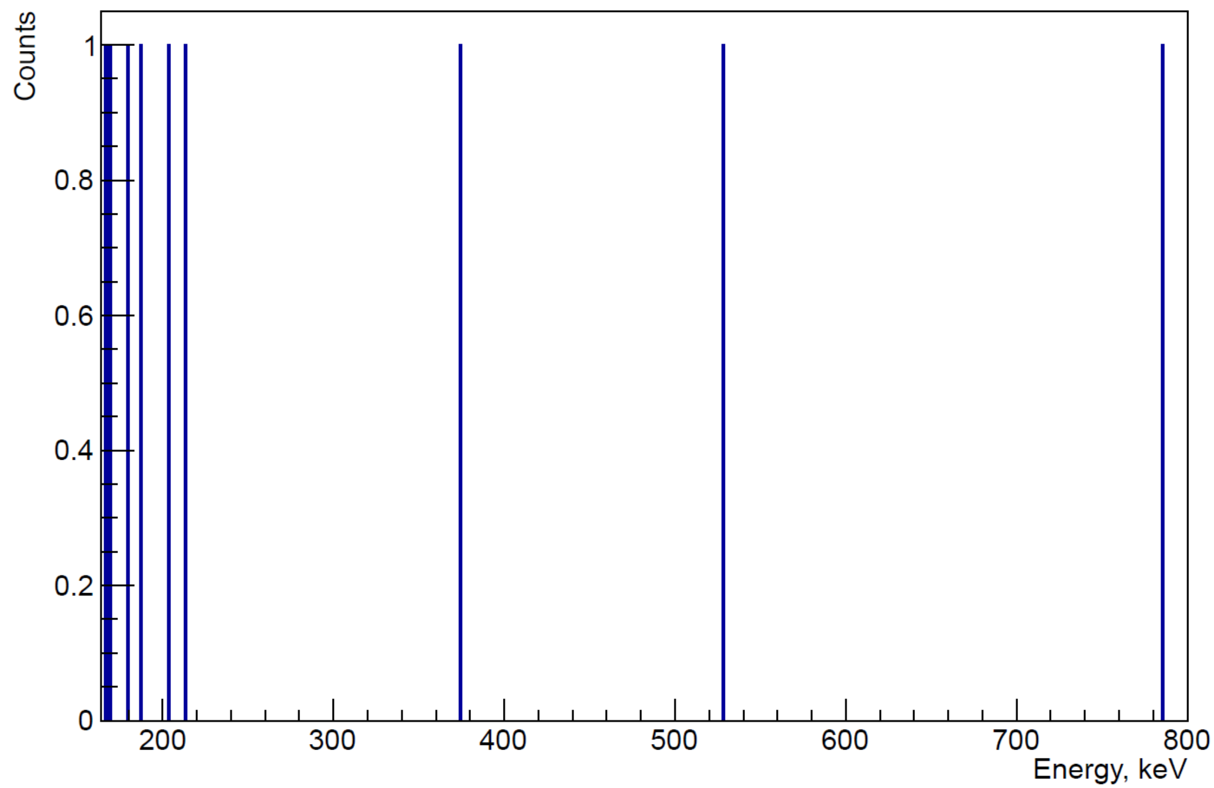
Investigation of the Giant Monopole Resonance in ^{58}Ni

$^{58}Ni(\alpha,\alpha`)$, E = 100 MeV/u, Θ_{lab} = 37 deg



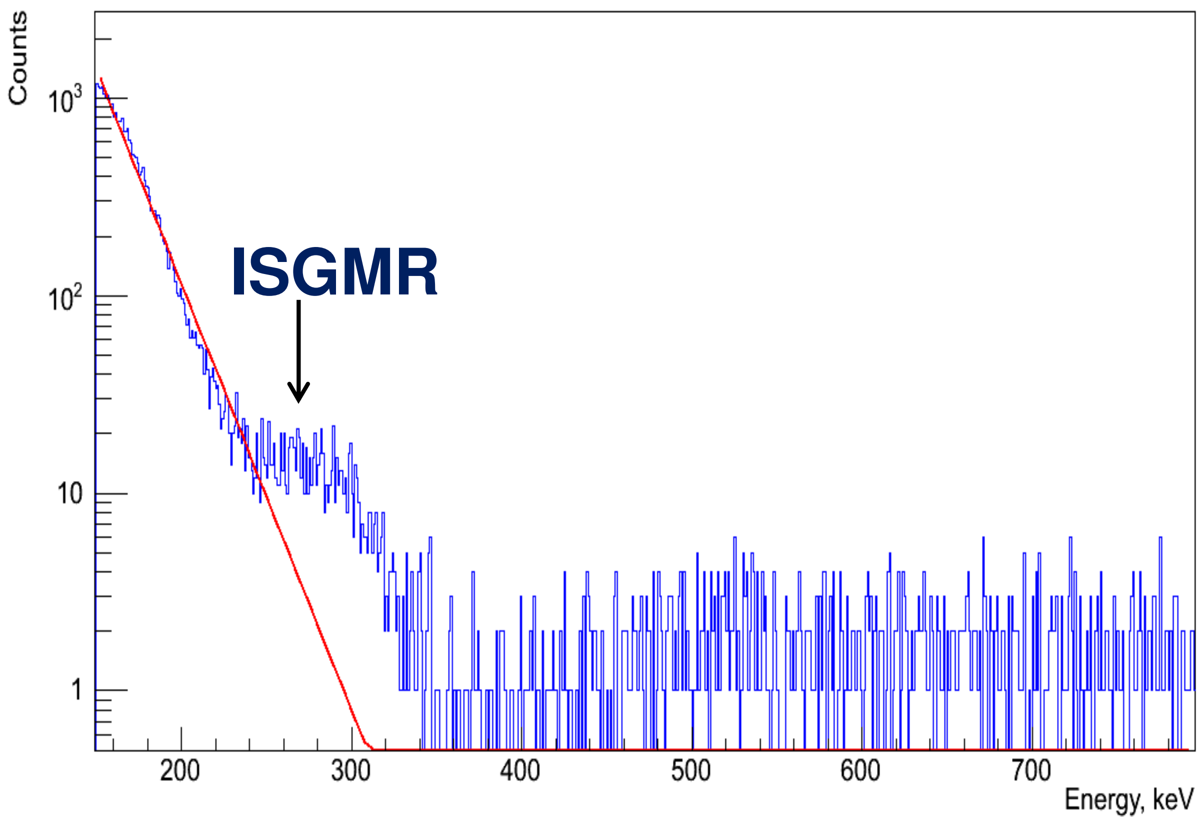
Investigation of the Giant Monopole Resonance in ^{58}Ni

^{58}Ni, empty target, E = 100 MeV/u, Θ_{lab} = 37 deg



Investigation of the Giant Monopole Resonance in ^{58}Ni

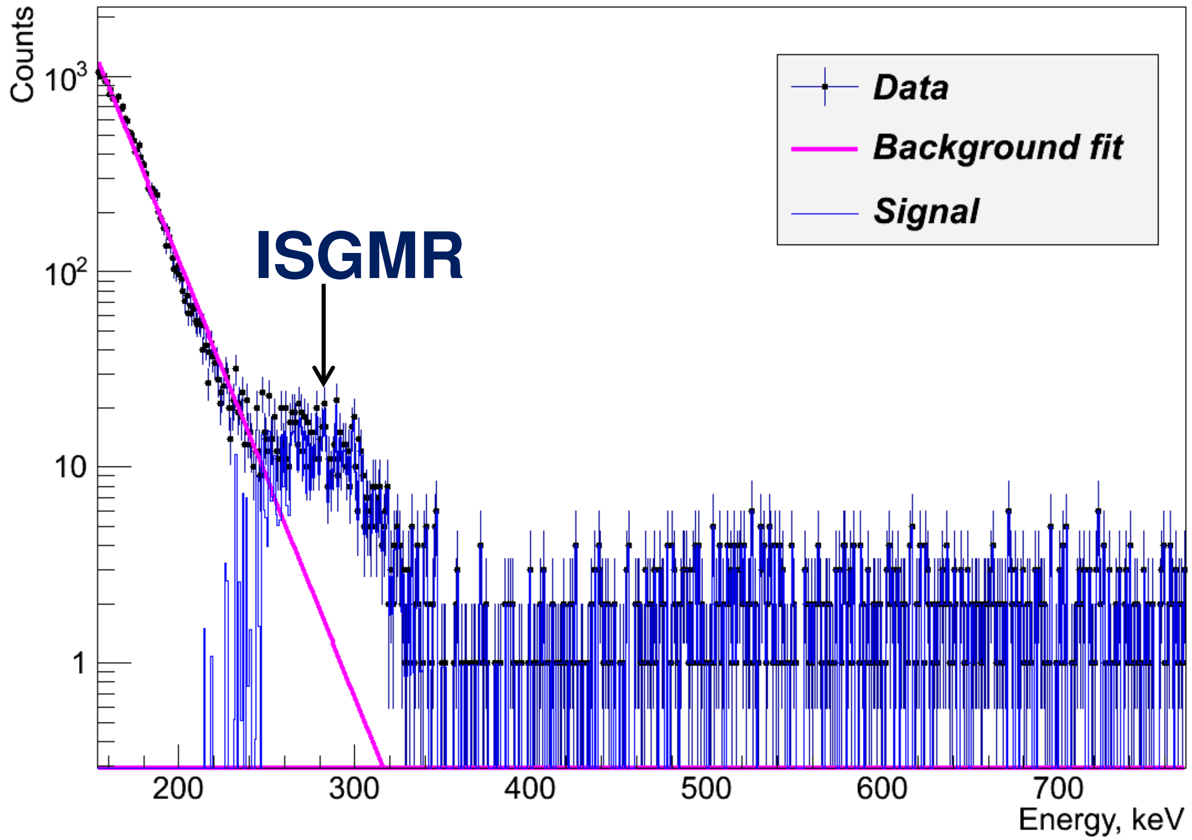
$^{58}Ni(\alpha,\alpha`)$, E = 100 MeV/u, Θ_{lab} = 37 deg



Investigation of the Giant Monopole Resonance in ^{58}Ni

$^{58}Ni(\alpha,\alpha`)$, E = 100 MeV/u, Θ_{lab} = 37 deg

preliminary



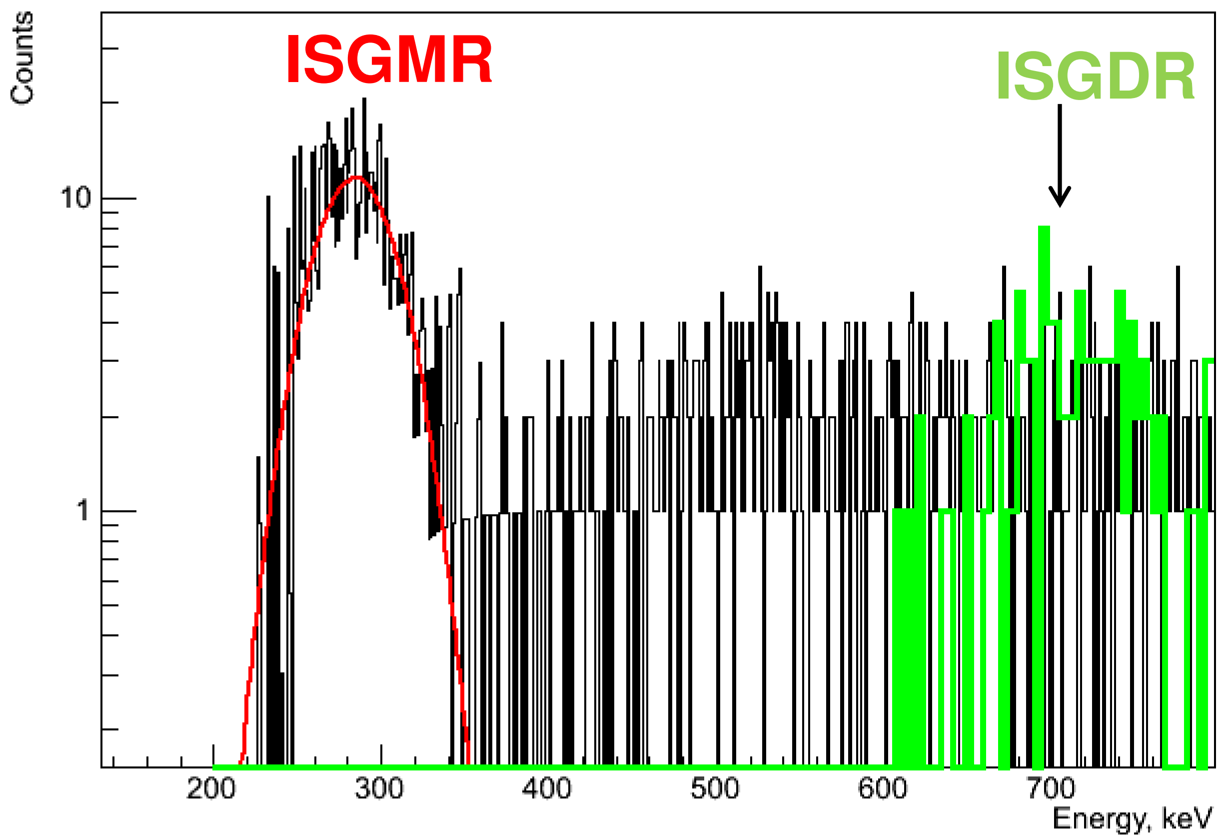
location: E = 284 (30) keV

expected: E = 300 (50) keV (corresponding to Eres (cm) = 19.9 (0.7) MeV)

(from B.K. Nayak et al., PL B637 (2006) 43)

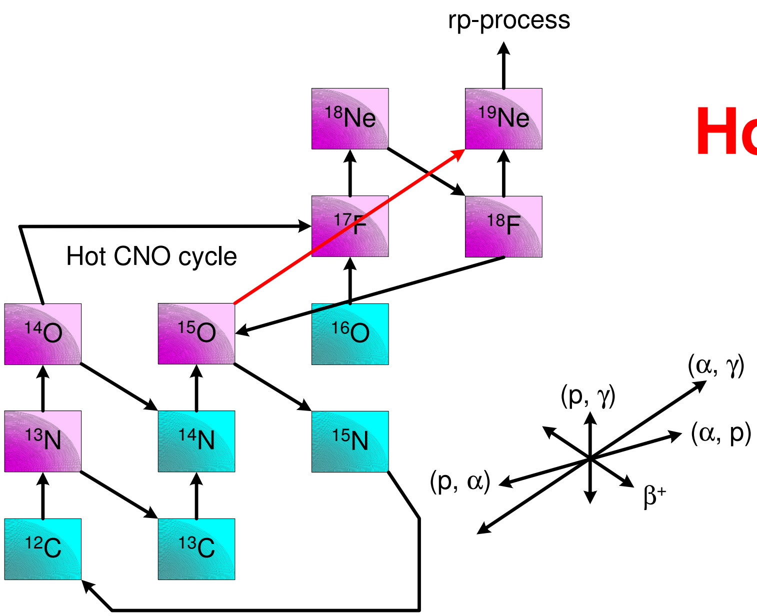
Investigation of the Giant Monopole Resonance in ^{58}Ni

preliminary



simulation for ISGDR assuming predicted cross section ratio for ISGMR and ISGDR

First Results of the E087 Experiment (P. Woods, Y. Litvinov et al.)

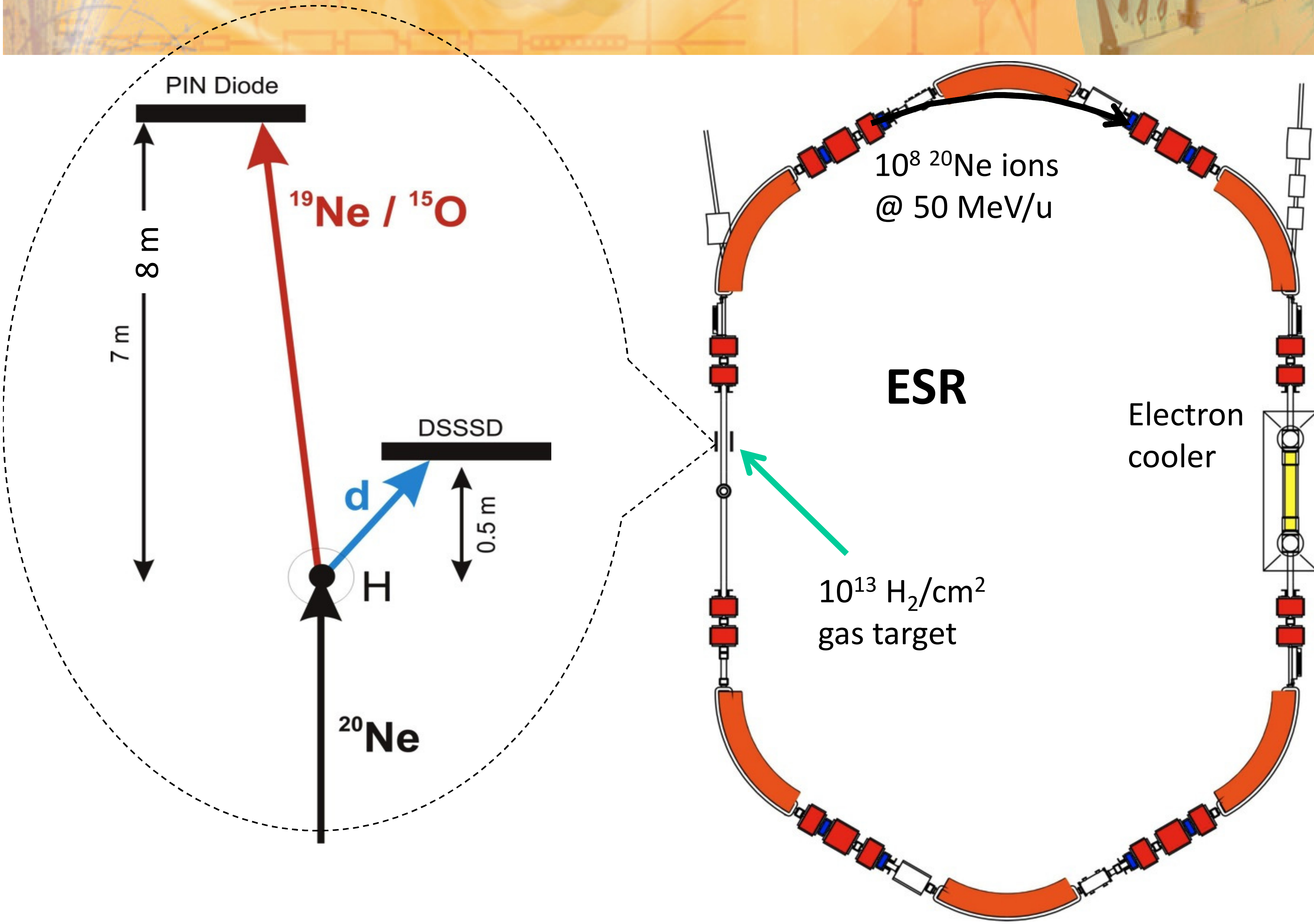


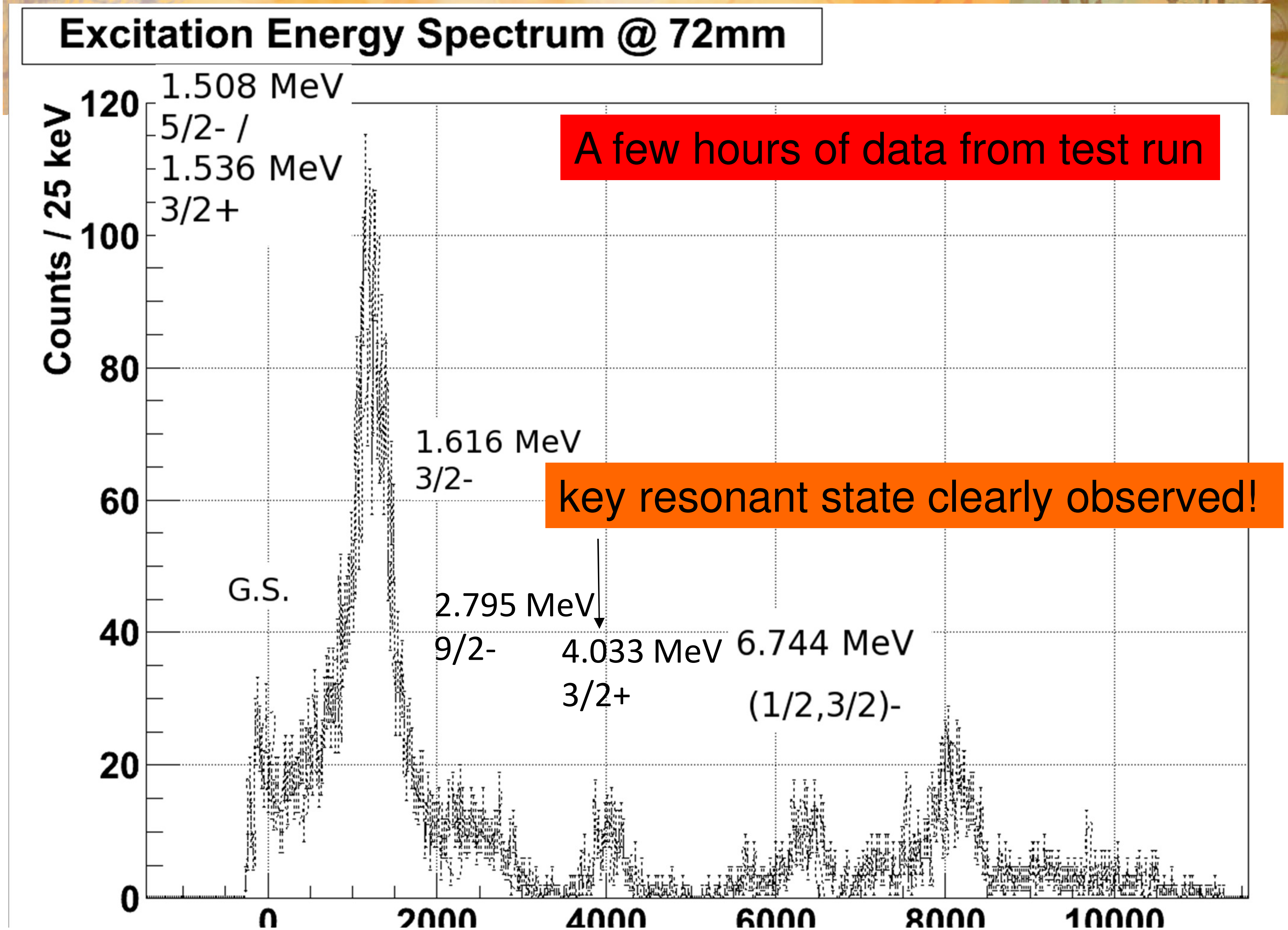
Hot CNO Cycles

^{15}O(α,γ)^{19}Ne reaction rate predicted to be dominated by a single resonance at a CoM energy of 504 keV

Key unknown - α-decay probability from excited state at 4.03 MeV in ^{19}Ne compared to γ-decay, predicted to be ~ 10-4

Study of the $^{20}Ne(p,d)^{19}Ne^*$ Transfer Reaction at the ESR




Excitation Energy Spectrum @ 72mm
Counts / 25 keV
1.508 MeV
5/2- /
1.536 MeV
3/2+
A few hours of data from test run
1.616 MeV
3/2-
key resonant state clearly observed!
G.S.
2.795 MeV
9/2-
4.033 MeV
3/2+
6.744 MeV
(1/2,3/2)-
0
20
40
60
80
100
120
2000
4000
6000
8000
10000

IV. Future Perspectives

short term perspectives:

- (α,α\`) on ^{56}Ni $\Rightarrow$ investigate ISGMR and ISGDR

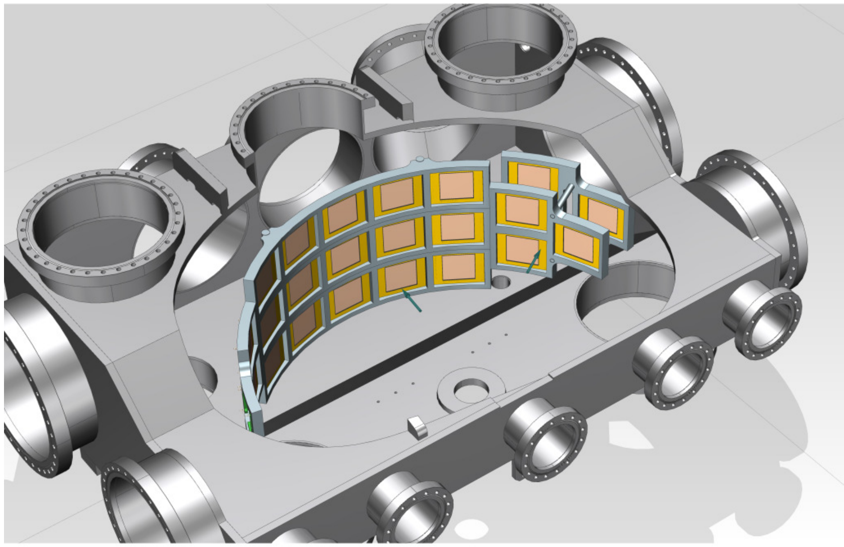
  needs upgrade of detector setup
  and readout (ASICS)

Future Perspectives

short term perspectives:

- (α,α`) on ^{56}Ni $\Rightarrow$ investigate ISGMR and ISGDR

  needs upgrade of detector setup
  and readout (ASICS)



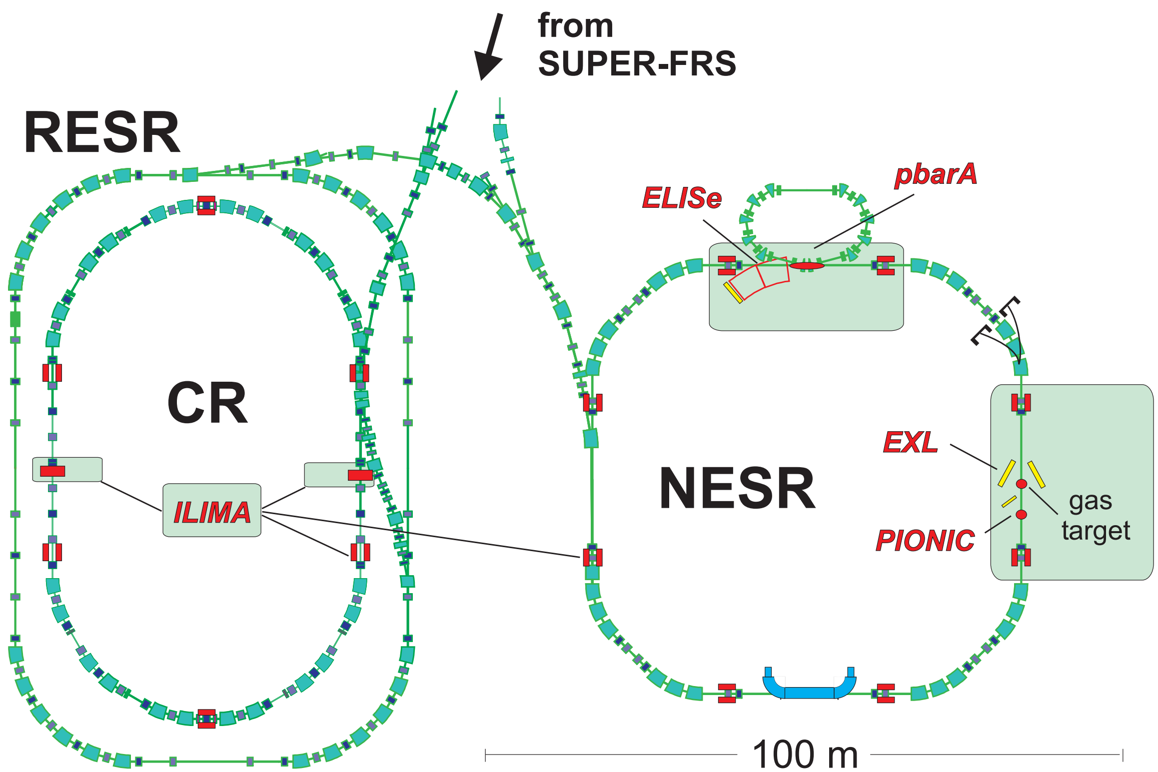
- (^{3}He,t) on ^{56}Ni $\Rightarrow$ investigate Gamow – Teller strength
  needs upgrade of internal target

- (p,p), (p,p`) on heavier Ni and Sn isotopes

Future Perspectives

long term perspectives (EXL @ FAIR):

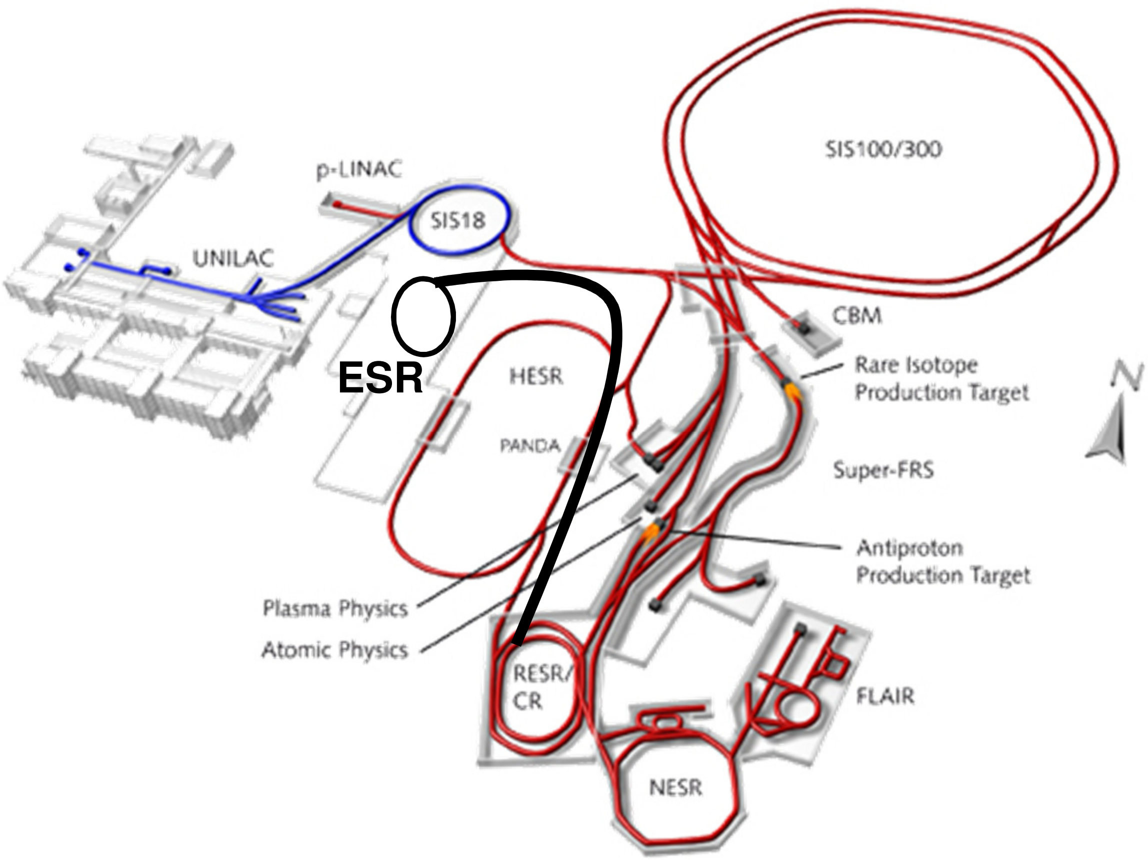
- still first priority:
  EXL at the NESR (full performance of EXL)



Future Perspectives

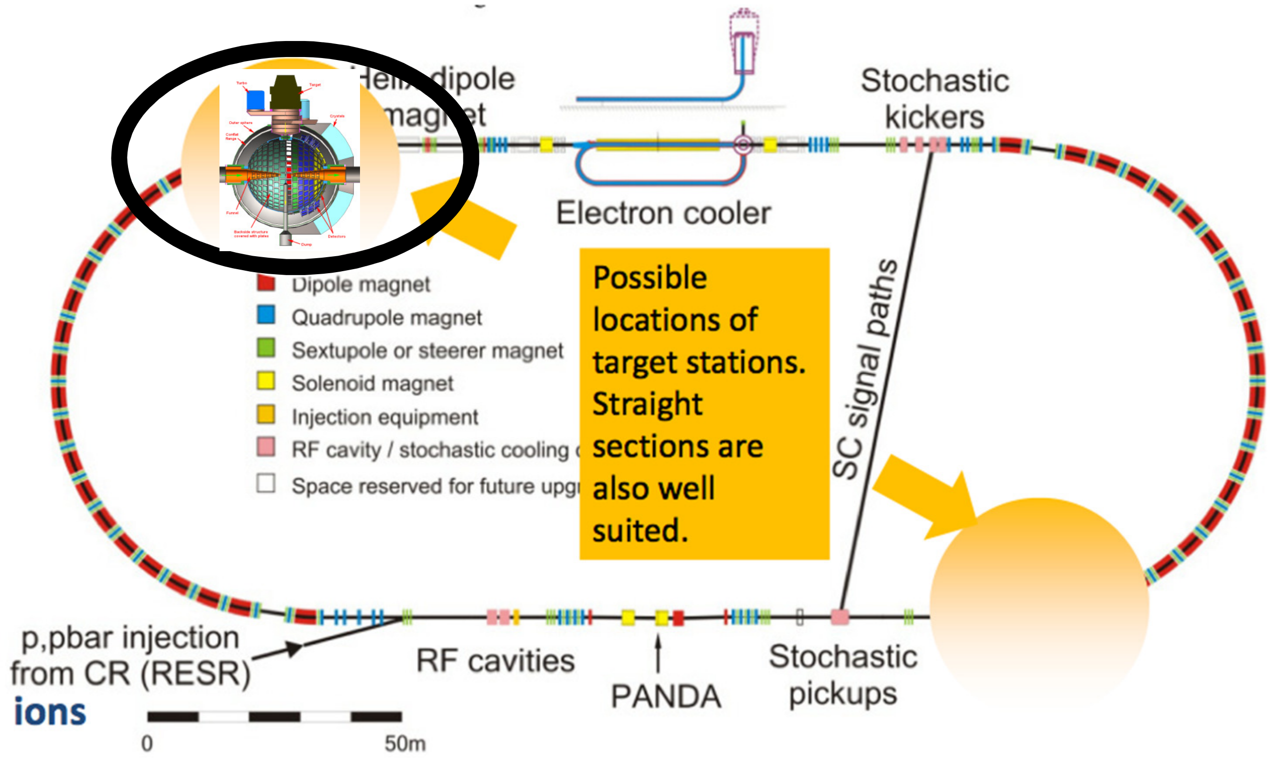
long term perspectives (EXL @ FAIR):

- for first phase of FAIR:
  transfer line from SUPER-FRS / CR to the ESR



long term perspectives (EXL @ FAIR):

- other option:
  place EXL in the HESR



V. Conclusions

- For the First Time (World Wide) a Nuclear Reaction Experiment with Stored Radioactive Beams was successfully performed.
- A “Proof of Principle” of the Experimental Concept with UHV capable Detectors and Infrastructure around the Internal Target was successful.
- A number of Important Physics Questions can be only addressed with the EXL Technique which is up to date World Wide unique.
- EXL@ESR and EXL@FAIR has a large Potential for Nuclear Structure and Nuclear Astrophysics.

The E105 Collaboration

S. Bagachi[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]

[1] KVI, Groningen
[2] Technische Universität Darmstadt
[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

ESR $^{20}Ne(p,d)^{19}Ne^*$ experiment collaboration

University of Edinburgh P. J. Woods*, D. T. Doherty, T. Davinson, A. Estrade, G. Lotay

GSI Y. Litvinov*, C. Brandau, P. Egelhof, A. Gumberidze, M. Heil, O. Kiselev, C. Kozhuharov, F. Nolden, N. Patridis, U. Popp, M. Steck, S. Trotensko, X. L. Yan

KVI, University of Groningen C Rigollet, M. Ali-Najofi, S. Bagchi, N Kalantar, M. Mahjour-Shafei,S. Roy

University of Frankfurt M. Bo, C. Lederer

TUD M. V. Schmid, J.C. Zamora

GSI/ Giessen I. Dillmann, A. Evdokimov

TUM S. Bishop