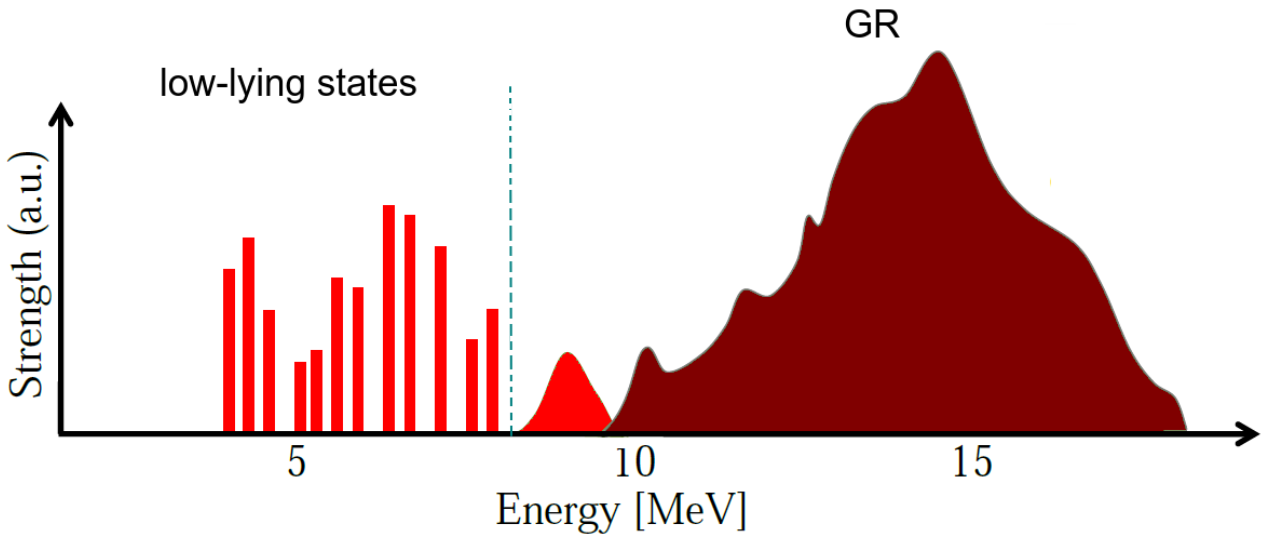
Experimental Techniques for Investigation of Giant Resonances in Inverse Kinematics

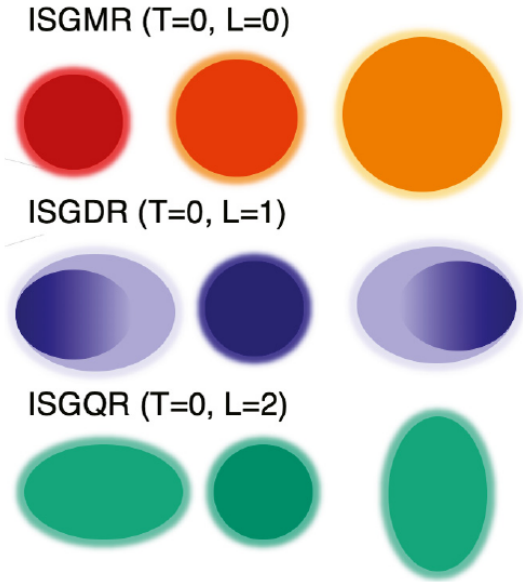
Juan Carlos Zamora

Facility for Rare Isotope Beams

September 24, 2021

Why giant resonaces are important?





	ISOSPIN	SPIN
L=0	IS/IV	flip/non flip
L=1	"	"
.		
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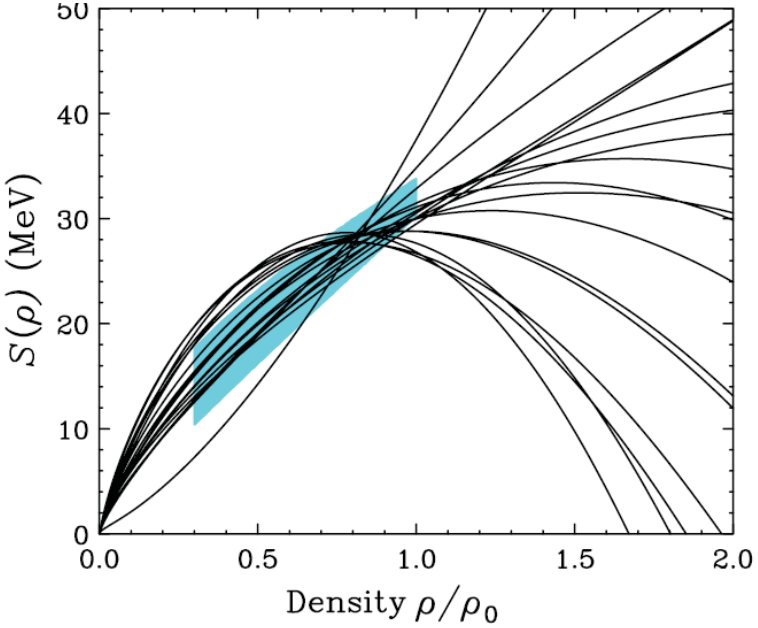
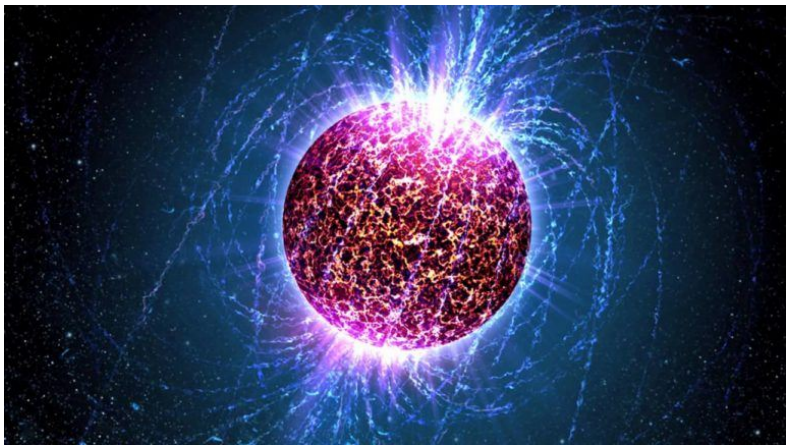
- Collective motion of nucleons
- Located at energies above particle separation
- Exhaust large fraction of EWSR
- Effects of deformation, neutron excess...

Astrophysical implications





- EoS

  A. Carbone et al. PRC 81, 041301(R) (2010)

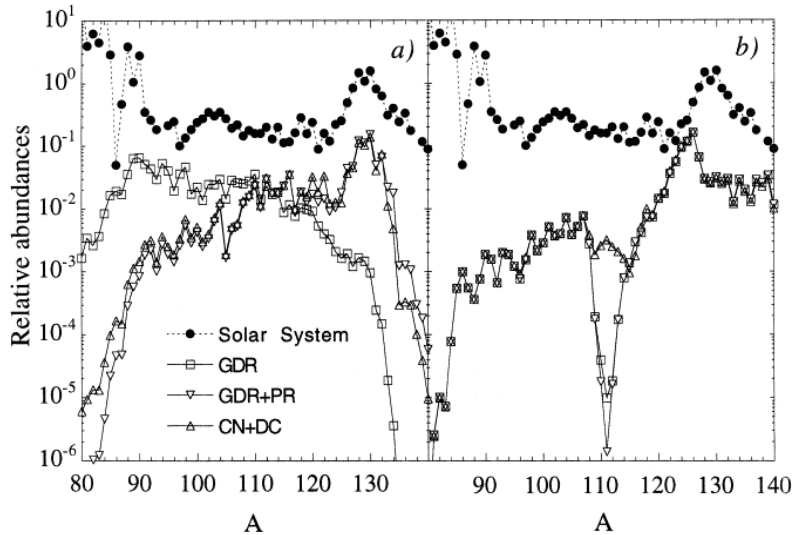
  M. B. Tsang et al. PRC 86, 015803 (2012)

- Neutron stars

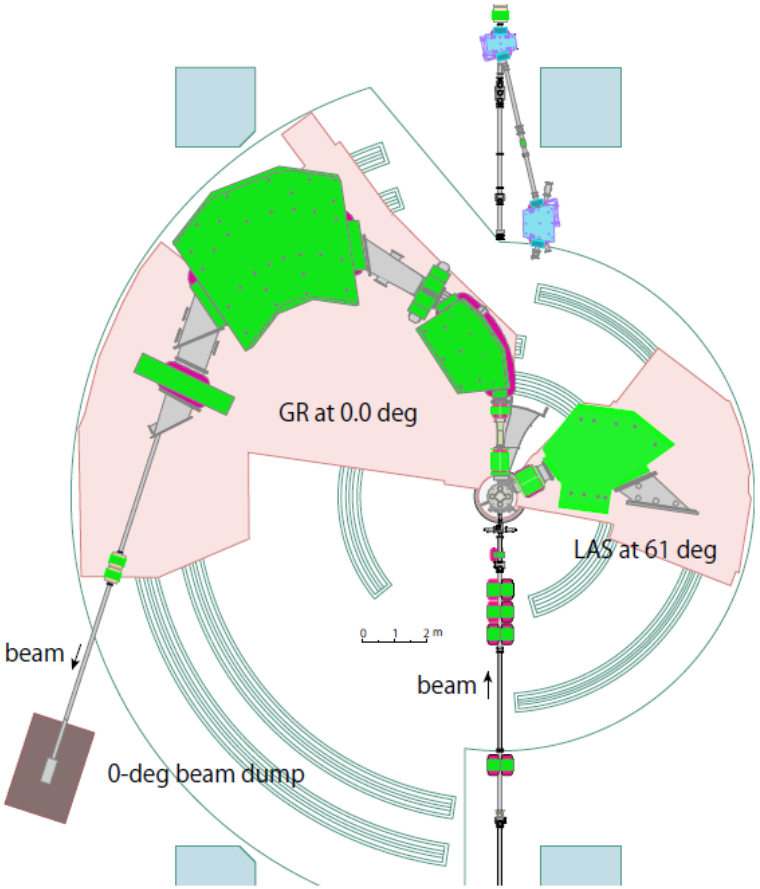
  P.-G. Reinhard PRC 81, 051303(R) (2010)

- Nucleosynthesis

  S.Goriely PLB 436, 10 (1998)



Experimental probes (strong interaction)



A. Tamii, NIM A 605, 326 (2009)

Measurements with spectrometers
KVI, RCNP, TAMU...

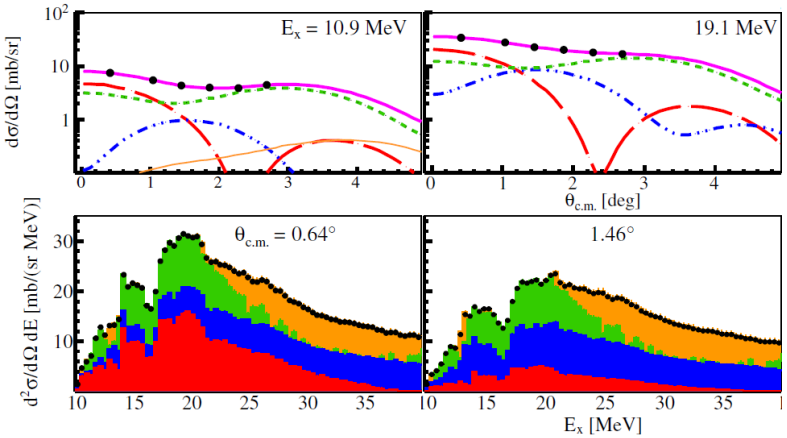
Inelastic scattering
at very forward angles
$E_B \sim 100$ MeV/u

(p, p'): IS/IV

(α, α'): IS

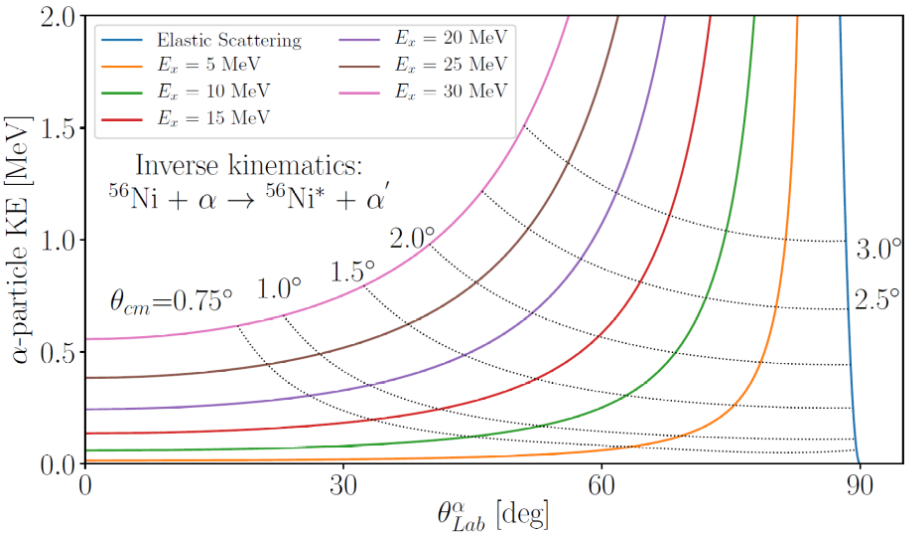
$$\left(\frac{d^2\sigma}{d\Omega dE}\right)^{\text{exp}} = \sum_L a_L(E_x)\left(\frac{d^2\sigma}{d\Omega dE}\right)^{\text{theo}}$$

Zamora et al., PRC 104, 014607 (2021)



Experiments in inverse kinematics

- Suitable for unstable beams
- Reaction channels separated by kinematics
- $\theta_{\text{cm}} \neq \theta_{\text{lab}}$
- Low energy recoils (~ 300 keV)

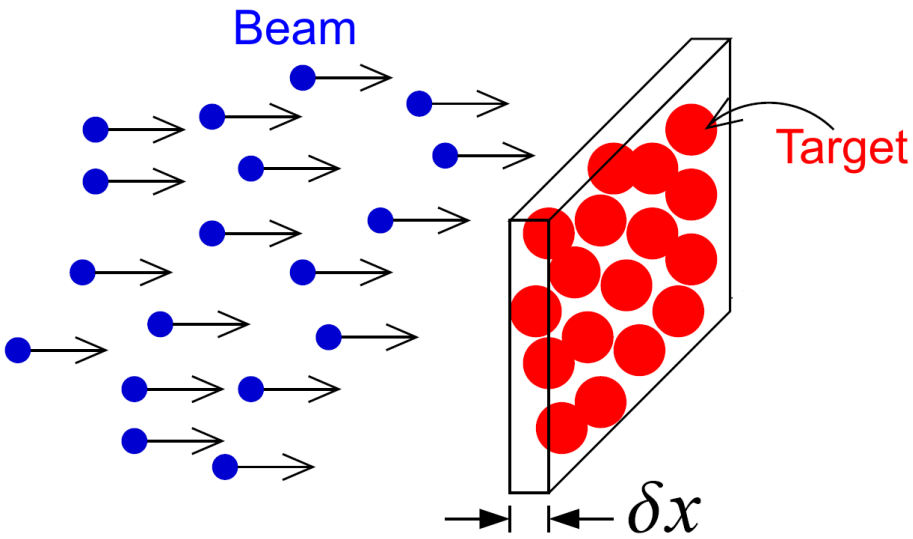


Two possible techniques:

✓ Storage Ring
- Windowless target
- In-ring detection

✓ Active Target
- Windowless target
- Tracking detection

Outline

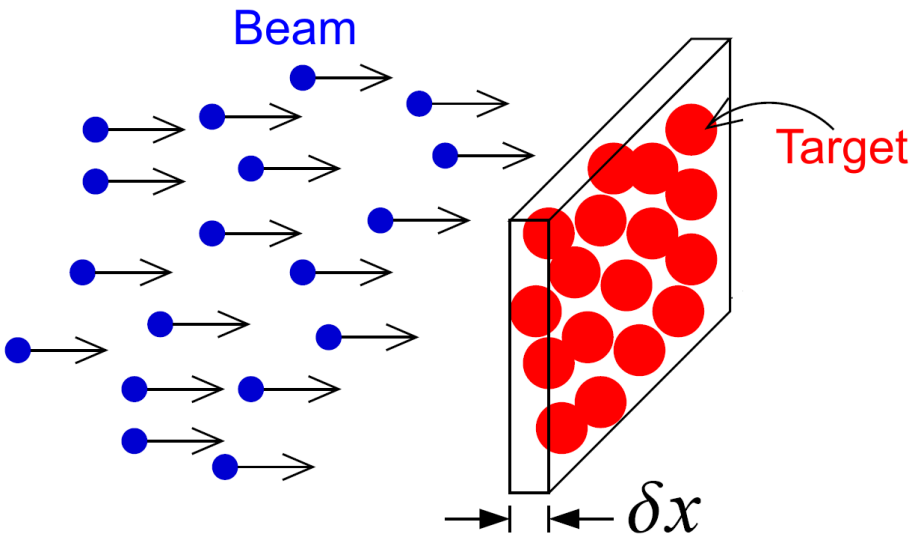


1. Storage Rings ($\uparrow N_B$)
2. Active Targets ($\uparrow \delta x$)

$$\mathcal{L} \propto N_B \cdot \delta x \cdot \rho$$

N_B : # Beam part.
δx : target size
ρ : taget density

Outline



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Storage Ring

It is a is a kind of circular lattice of electromagnets that keeps the beam particles in an orbit

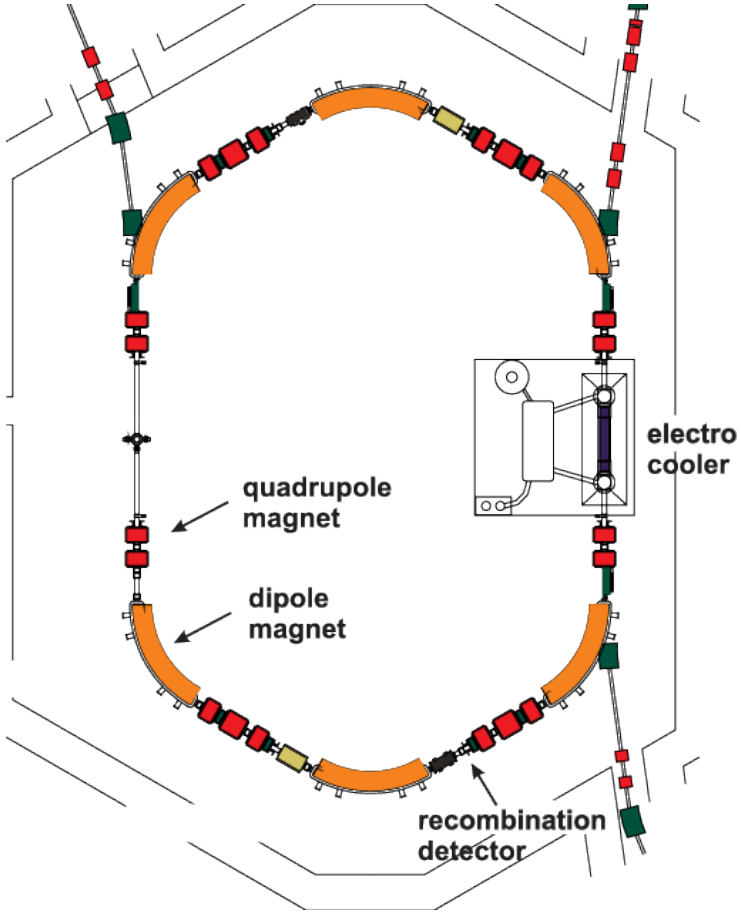
- Colliders
- Electron/Muon
- Heavy ion

ESR/GSI

10^6 rev/s

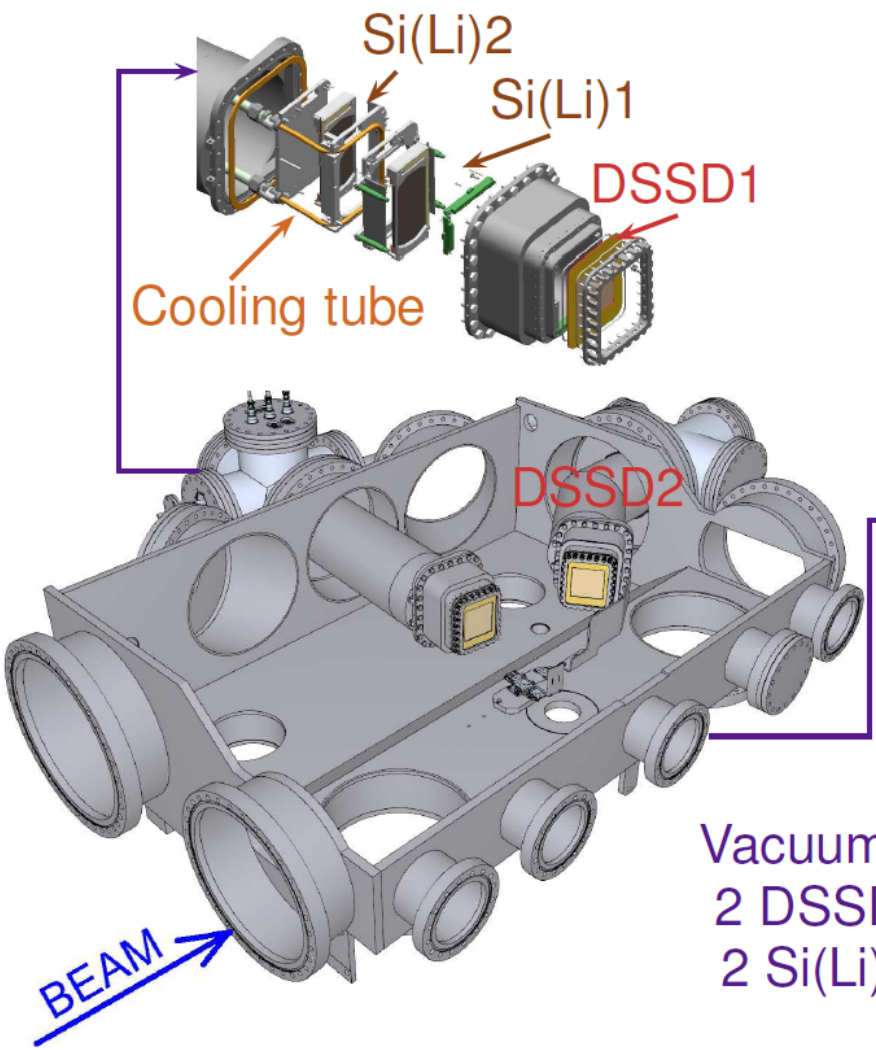
gas-jet target

electron cooler

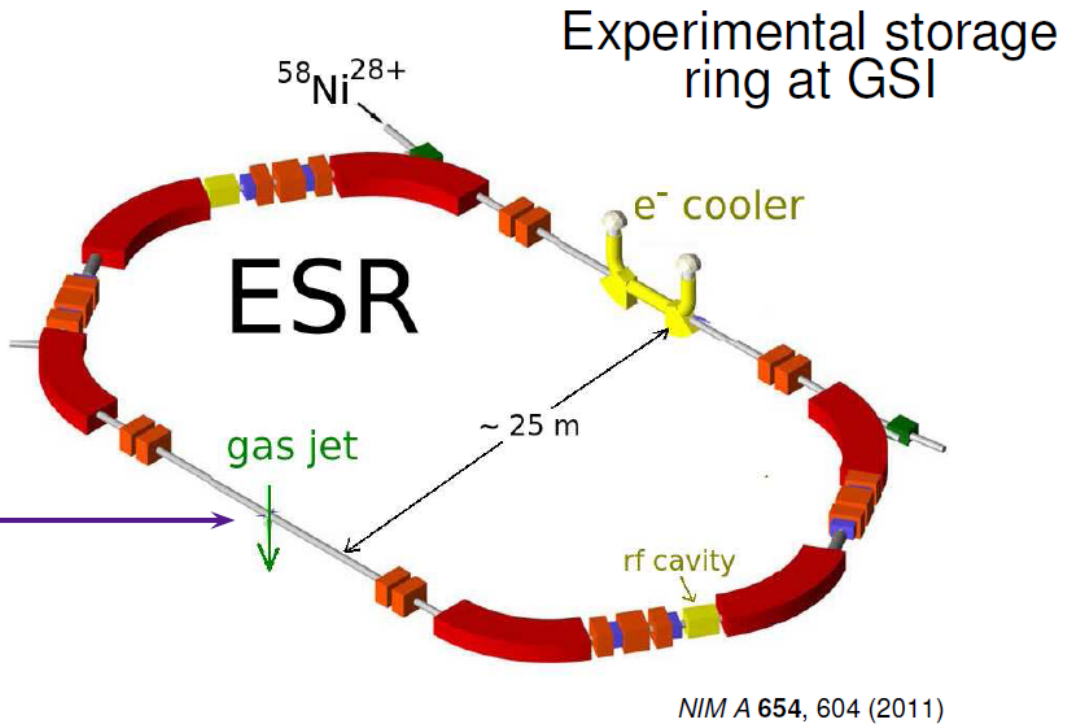


First Experiments at ESR

M. Mutterer, Phys. Scr., 014053 (2015)



Vacuum Chamber
2 DSSDs (64 × 64 mm)
2 Si(Li)s (50 × 100 mm)



NIM A **654**, 604 (2011)

- ✓ UHV compatible elements
- ✓ DSSDs are active windows

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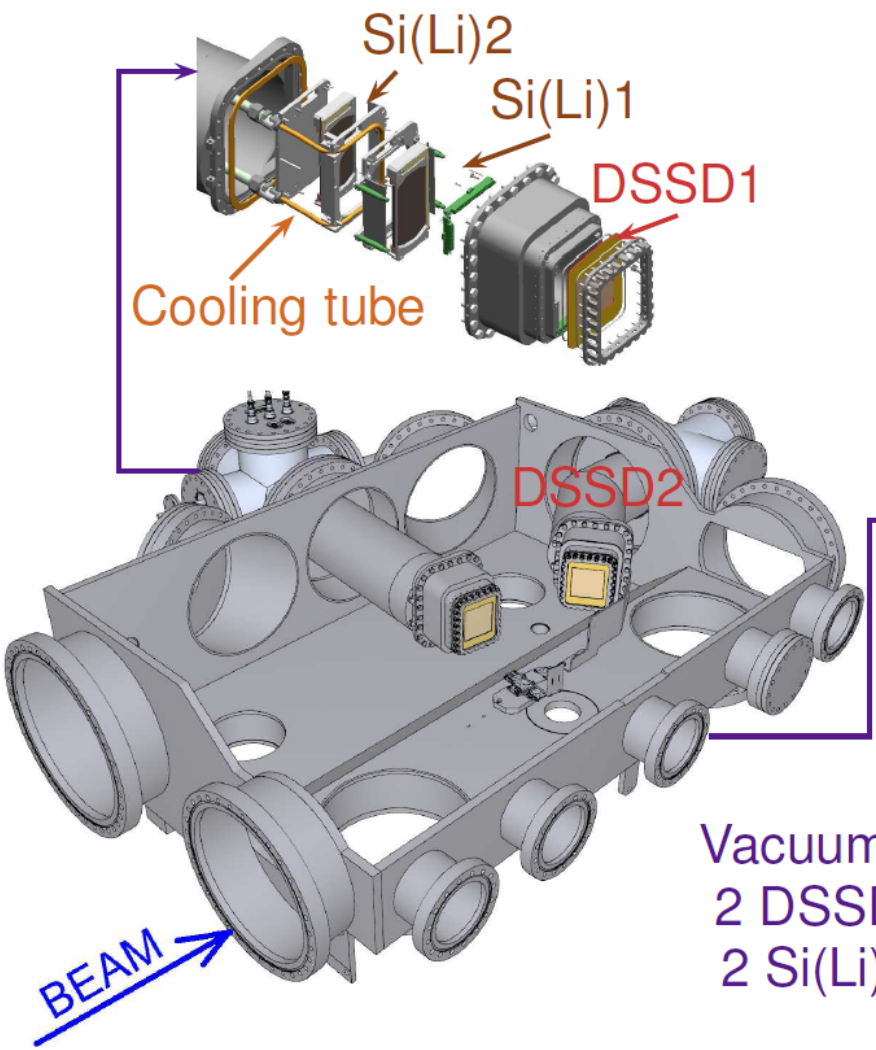
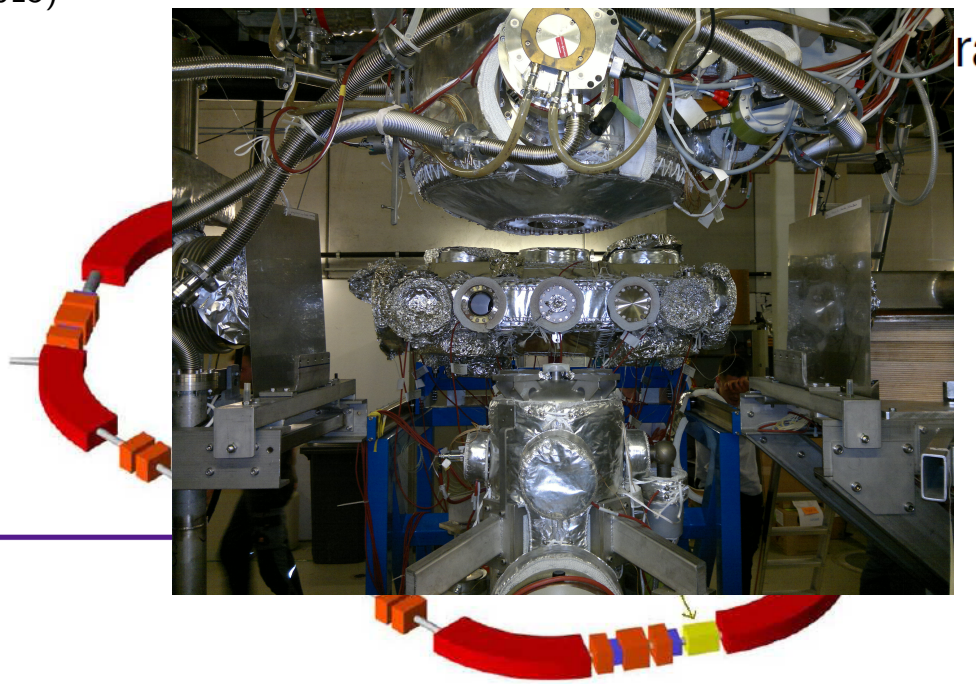


rage



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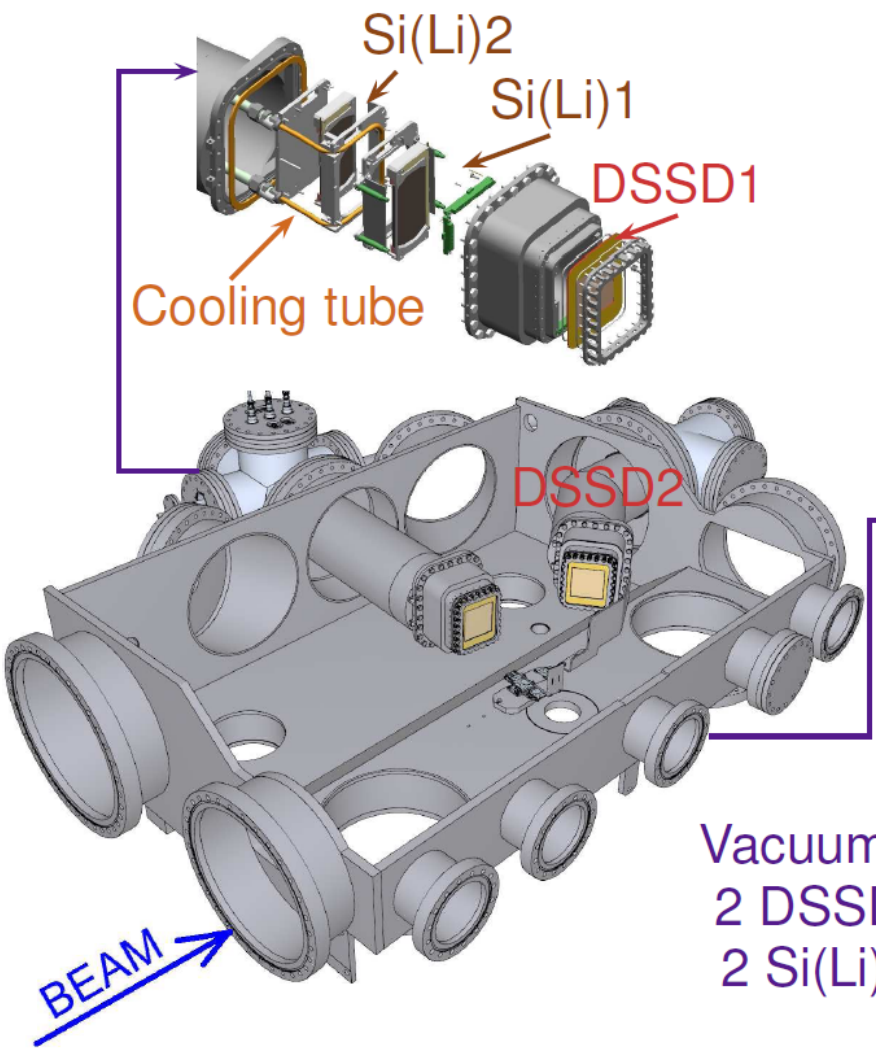

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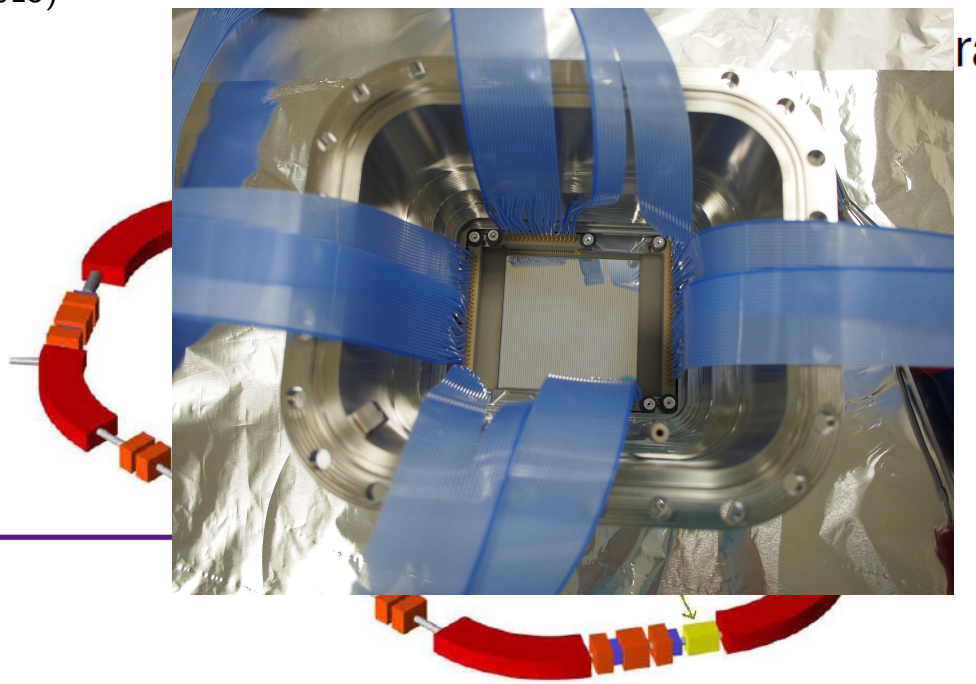

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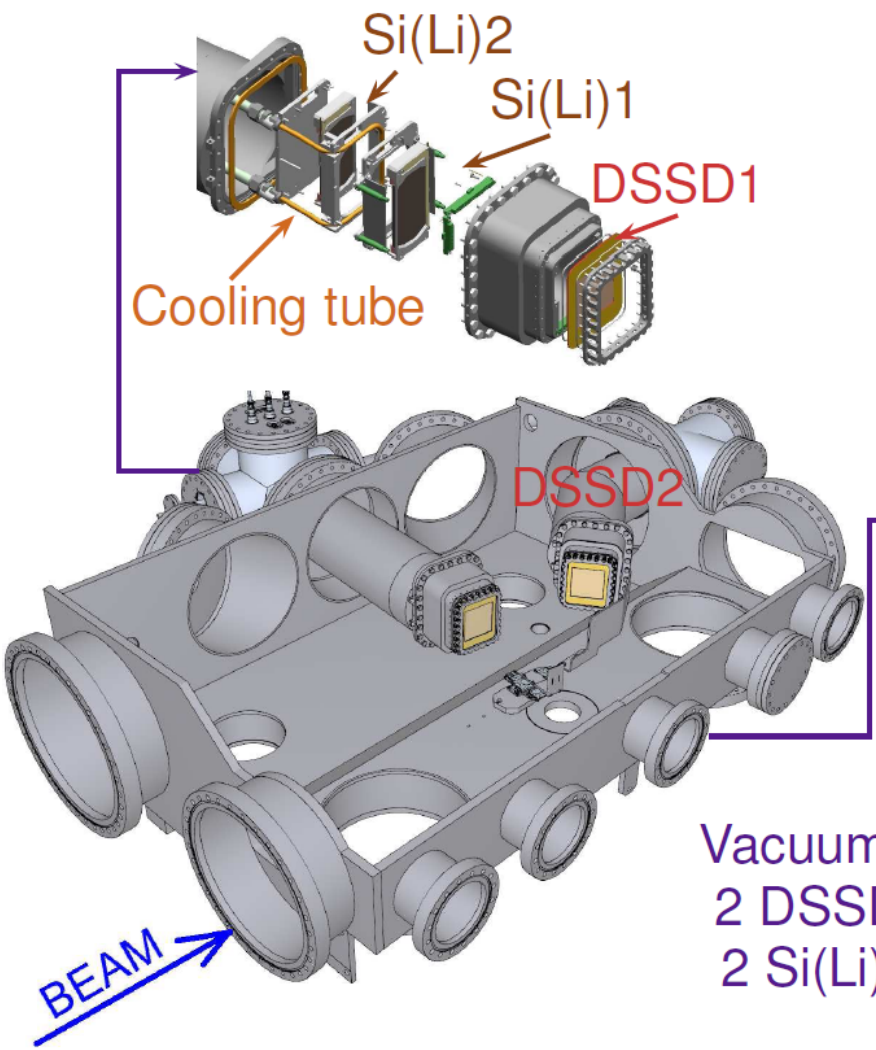

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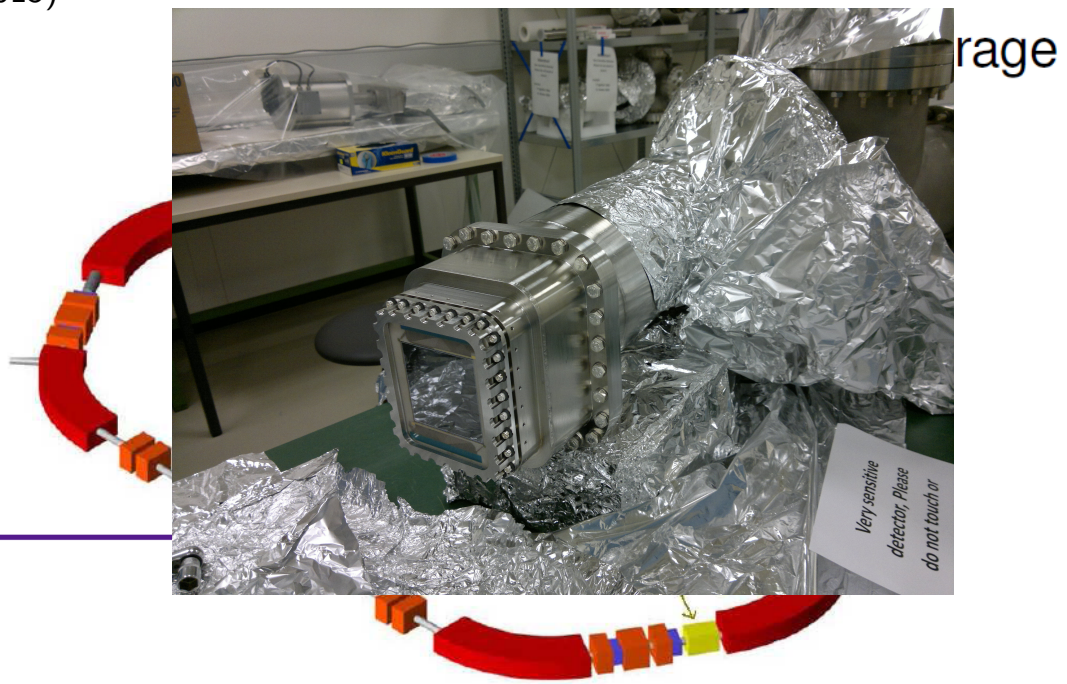

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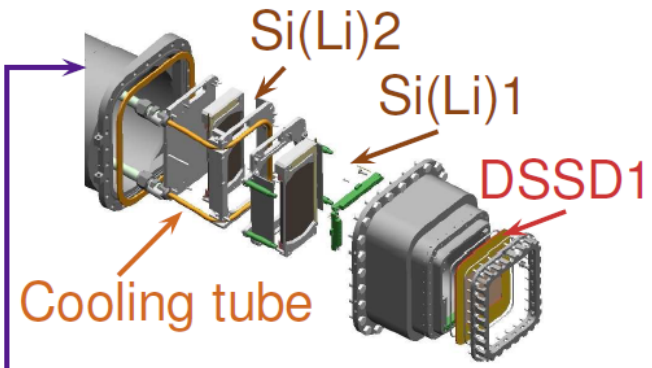

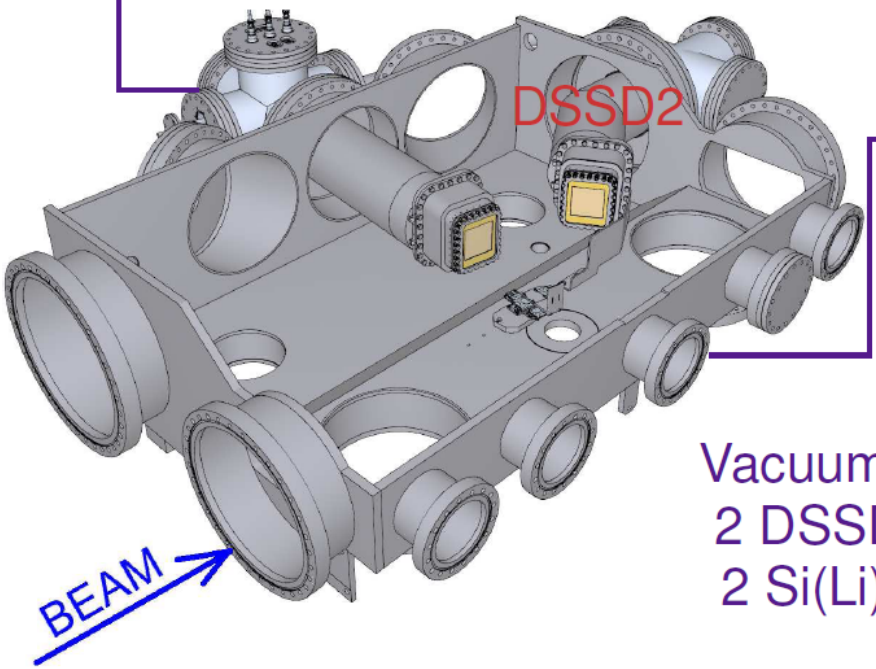

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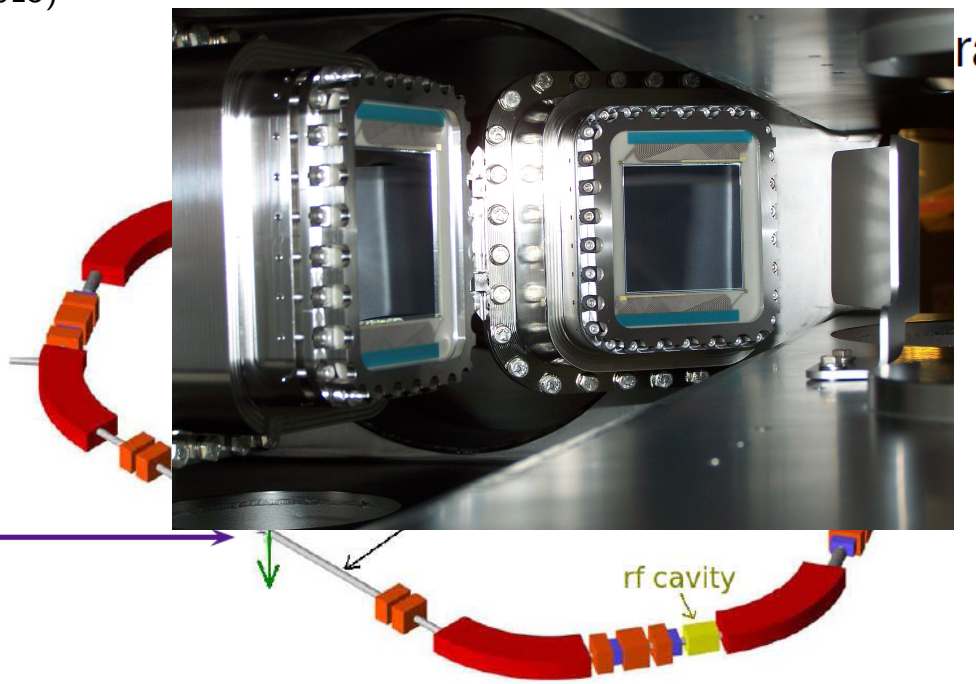

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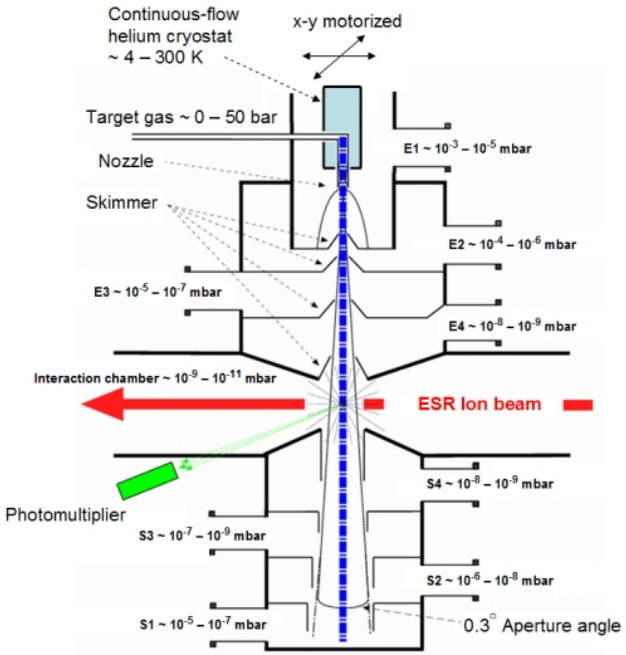
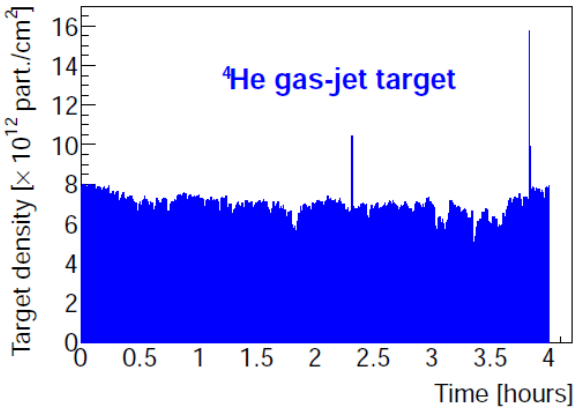
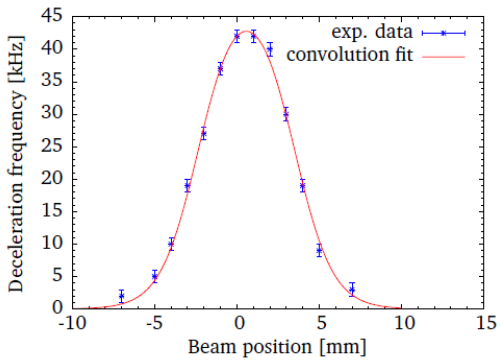
Gas-jet target

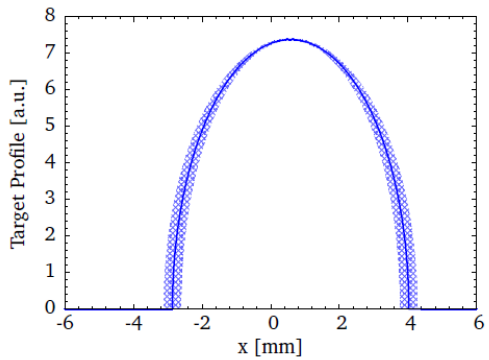




- Windowless
- Temperature ~ 12 K
- Speed ~ 350 m/s
- Density ~ 10^{12} part./cm^2

Target Profile (no halo)

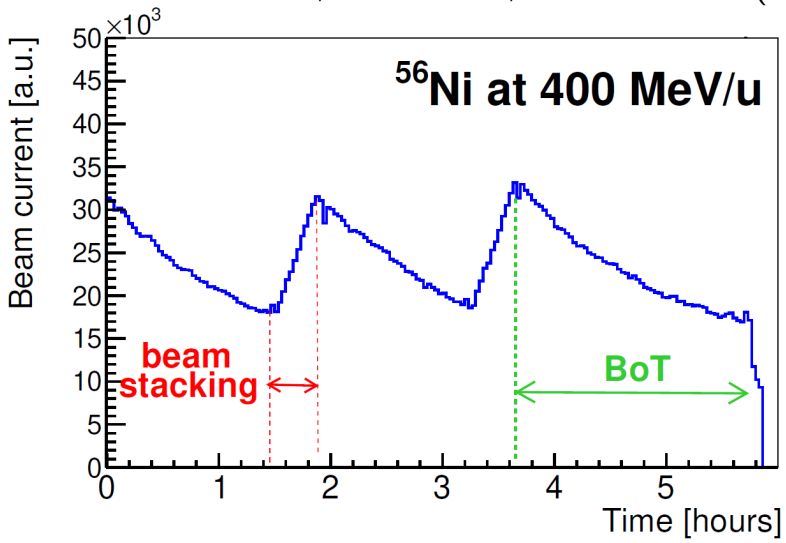


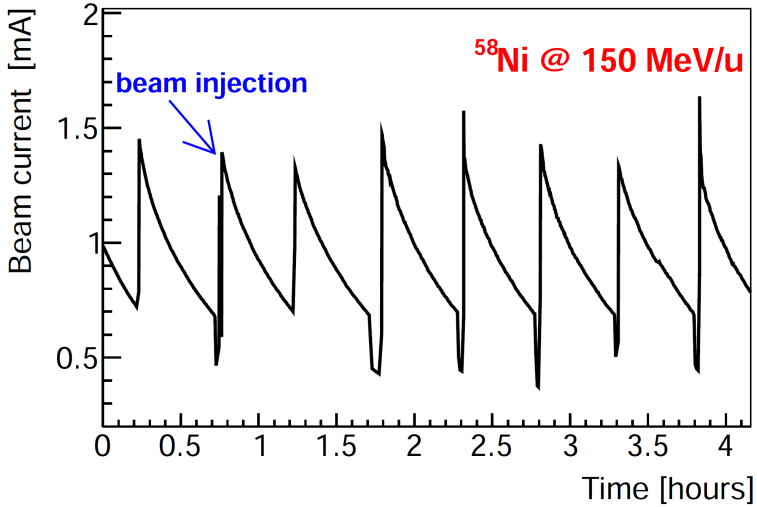


$$d(x) = \int_{-\infty}^{\infty} t(x')b(x-x')dx'$$

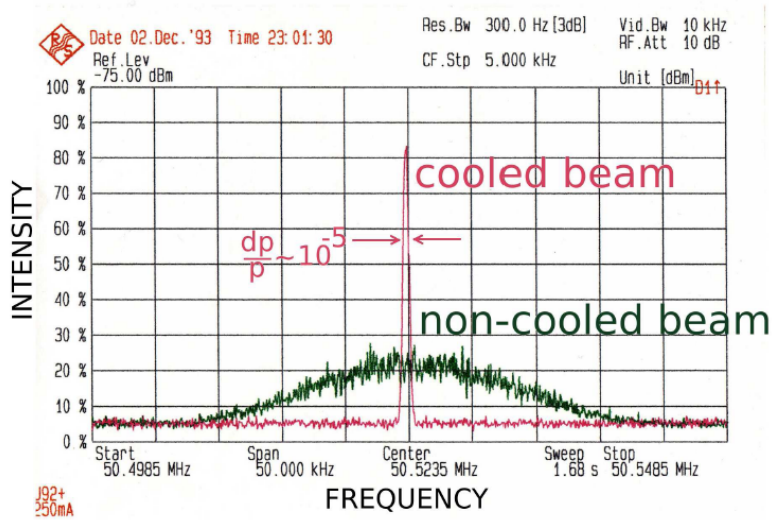
Stored beams

^{56}Ni: M. von Schmid, PhD Thesis, TU Darmstadt (2015)





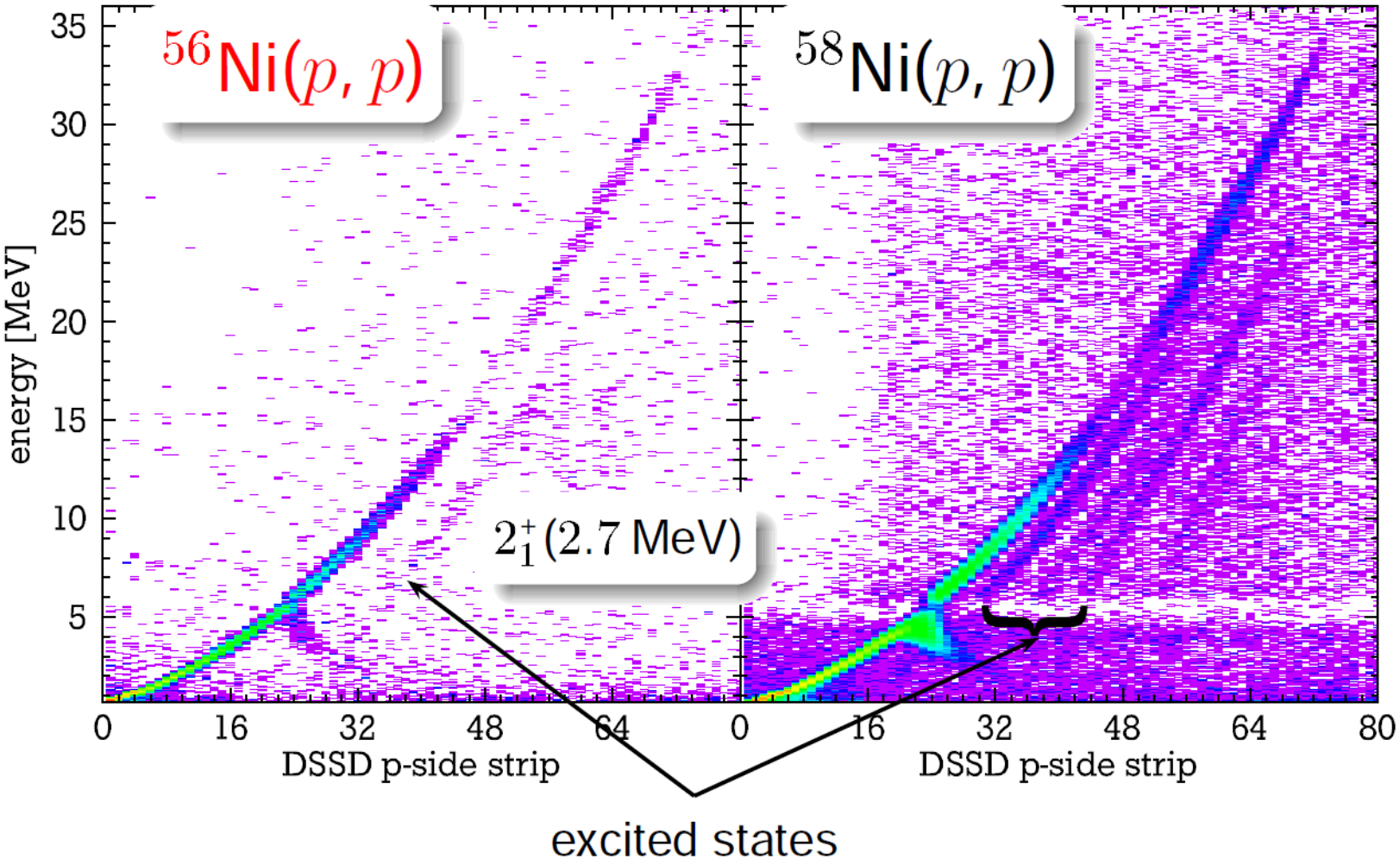
- Electron cooling
- Stored ^{58}Ni beam: 100 and 150 MeV/u
- $\sim 10^8$ part. stored
- Revolution frequency ~ MHz
- $\mathcal{L} \propto (n_B)(f_{\text{rev}})(n_T) \sim 10^{26}\text{cm}^{-2}\text{s}^{-1}$



M. Steck, Storage Rings Lecture (2011)

Proton scattering at 400 MeV/u

(courtesy of M. von Schmid, TU Darmstadt)



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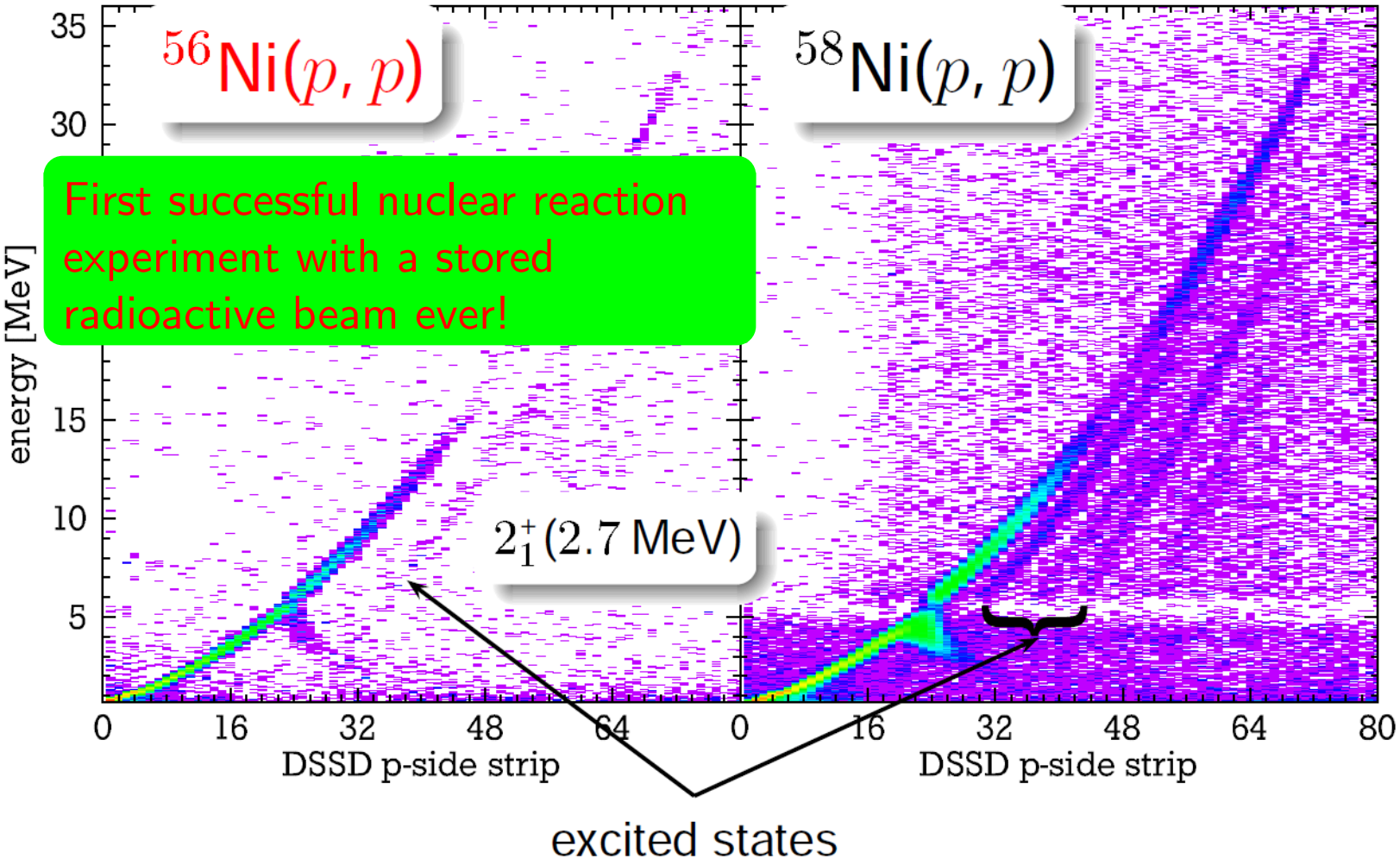
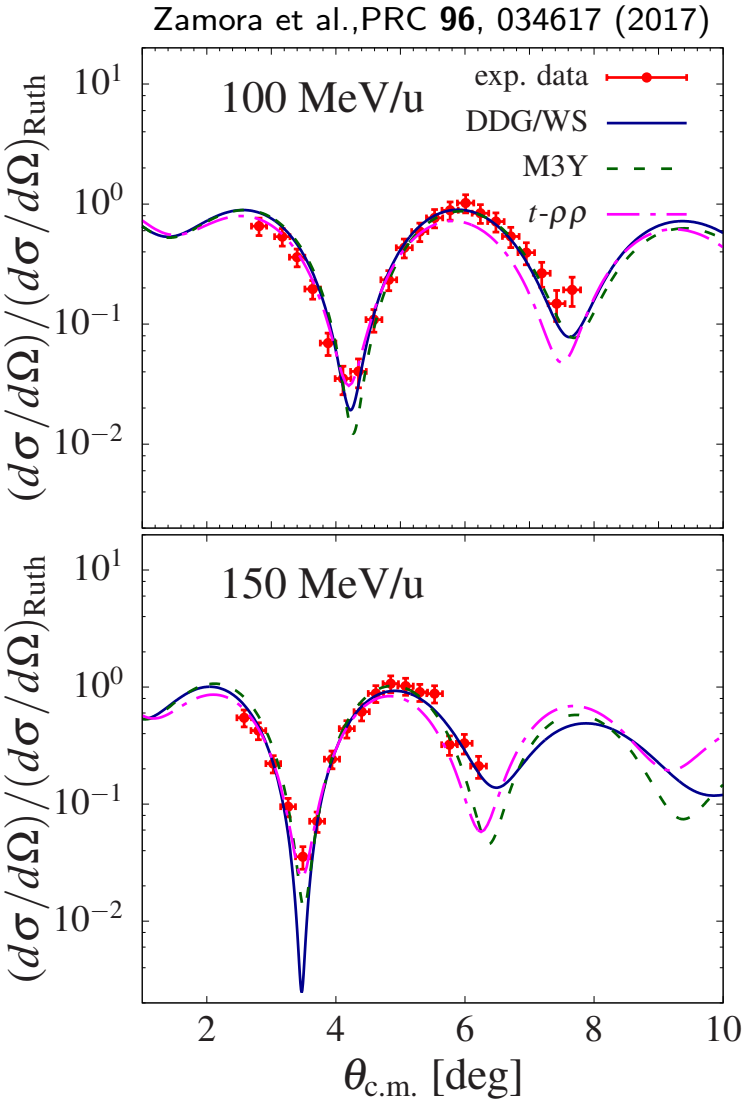


Cross section fitted with Glauber mutiple-scattering theory

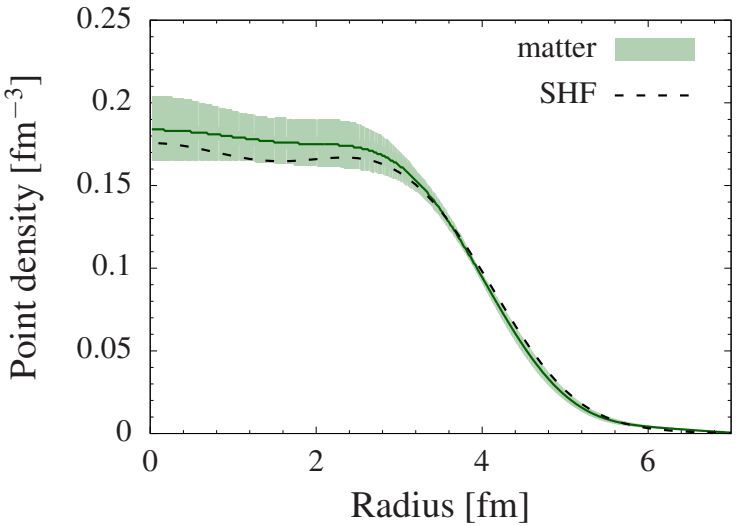
^{56}Ni(p,p)

Elastic scattering (matter radius)
^{58}Ni(α,α)



Optical limit of Glauber Theory

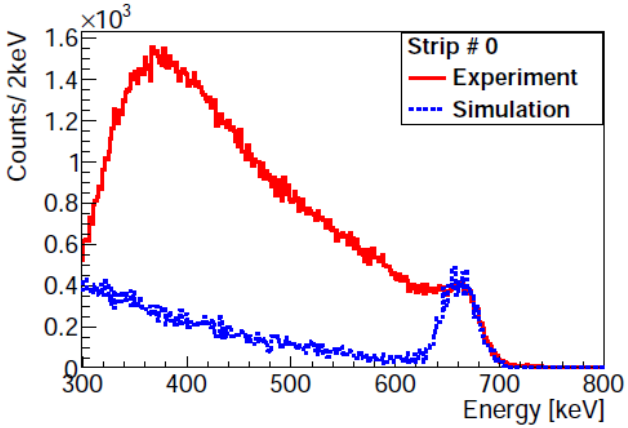
$$f_{NN}(\mathbf{q}=0) = \frac{k_{NN}}{4\pi}\sigma_{NN}(\mathrm{i}+\alpha_{NN})$$



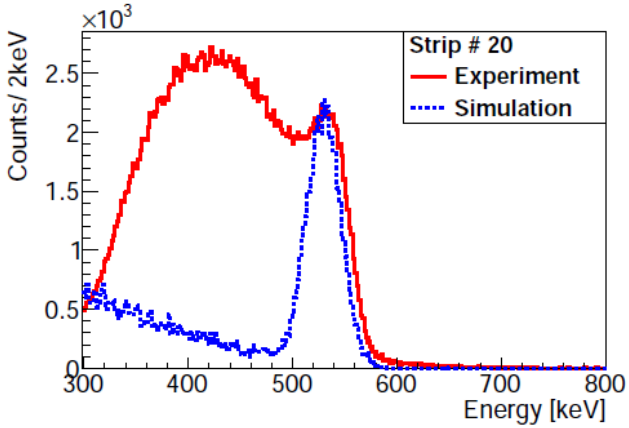
$$\sqrt{\langle r_{\rm m}^2\rangle} = 3.70(7)\ \text{fm}$$

High production of δ rays!!

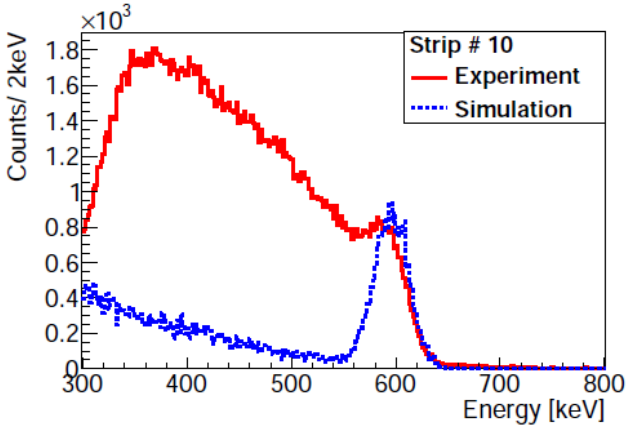
Strip number 0, $\theta_{\text{lab.}} \approx 27.5$



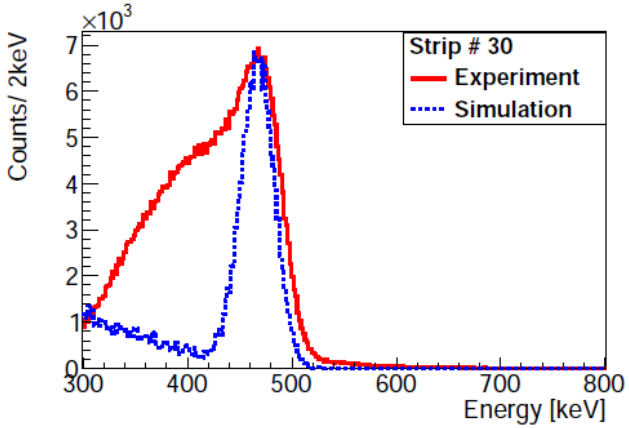
Strip number 20, $\theta_{\text{lab.}} \approx 33.9°$



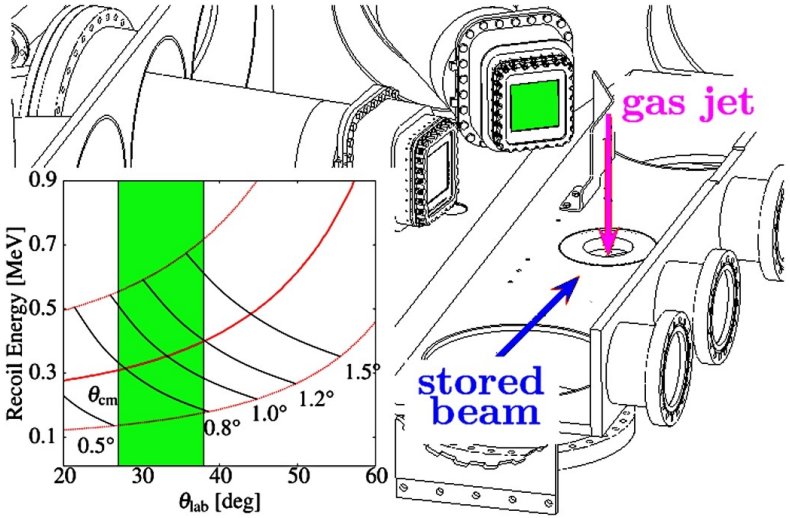
Strip number 10, $\theta_{\text{lab.}} \approx 30.7°$

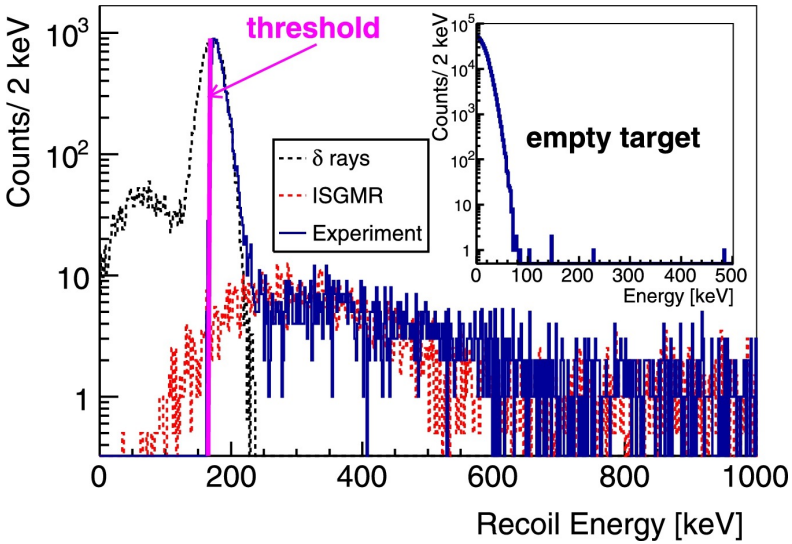


Strip number 30, $\theta_{\text{lab.}} \approx 37.1°$

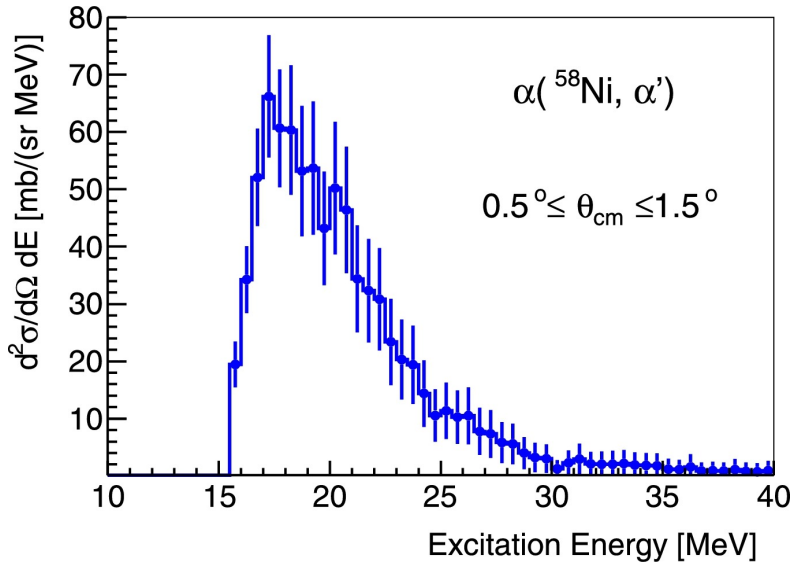


First giant resonances experiment with a stored beam $^{58}\mathrm{Ni}(\alpha,\alpha')$





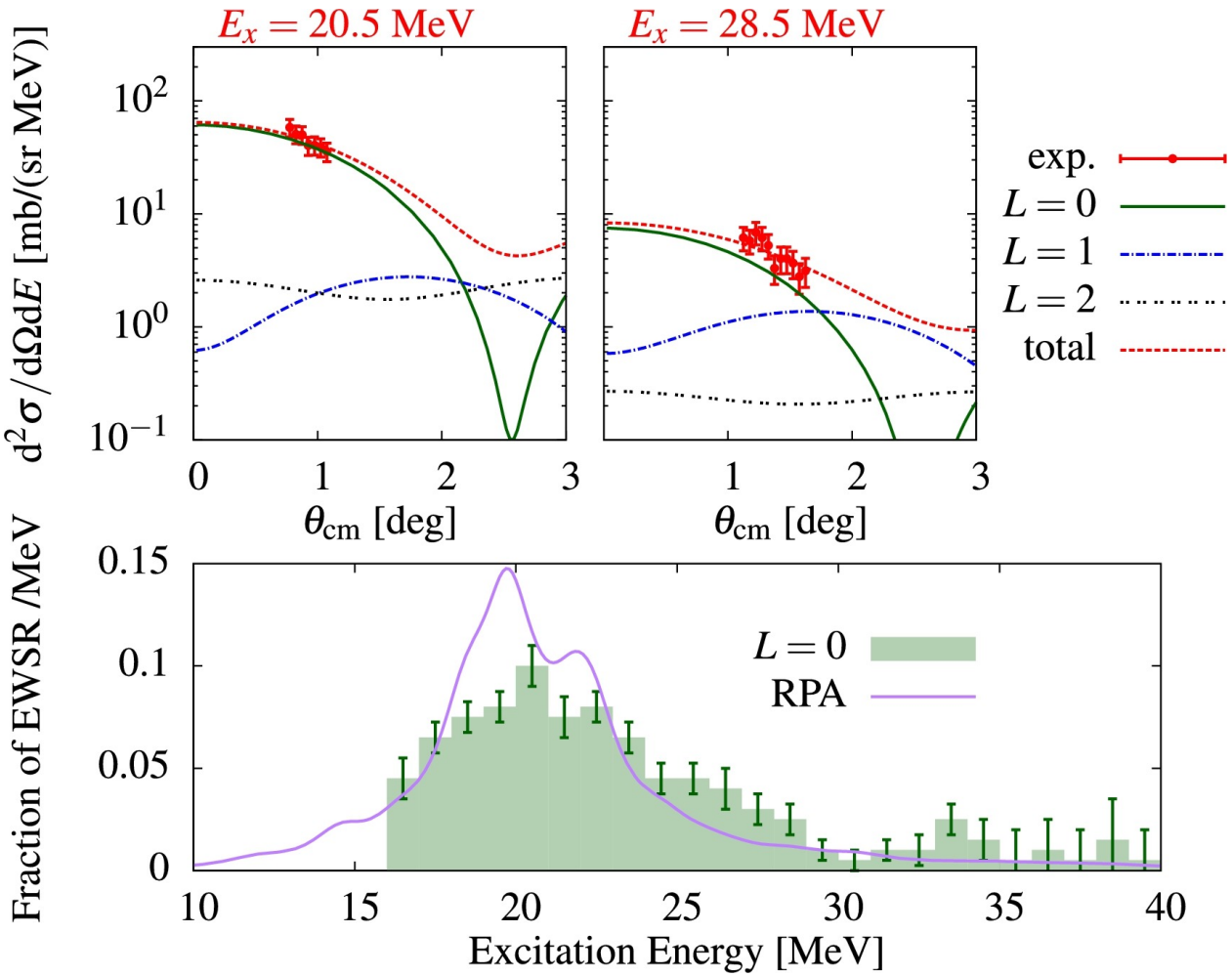
Zamora et al. Phys. Lett. B **763**, 16 (2016)



- α particles at 200-600 keV
- Unexpected high δ-rays production
- Center of mass angles $[0.5°, 1.5°]$
- Simultaneous normalization using elastic scattering

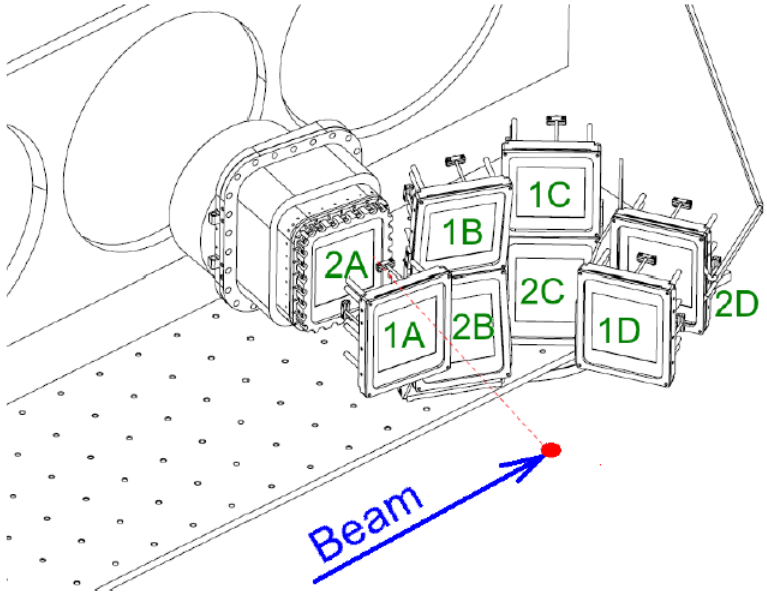
First giant resonances experiment with a stored beam $^{58}\mathrm{Ni}(\alpha,\alpha')$

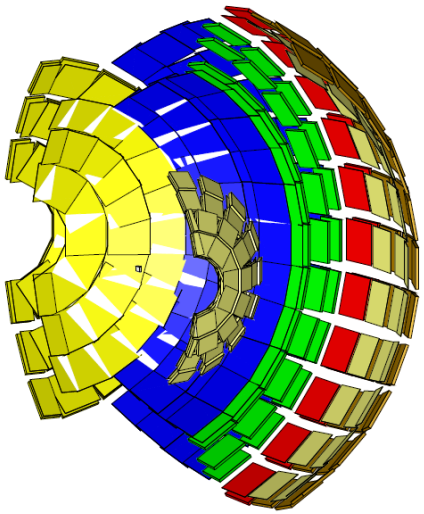
Zamora et al. Phys. Lett. B **763**, 16 (2016)

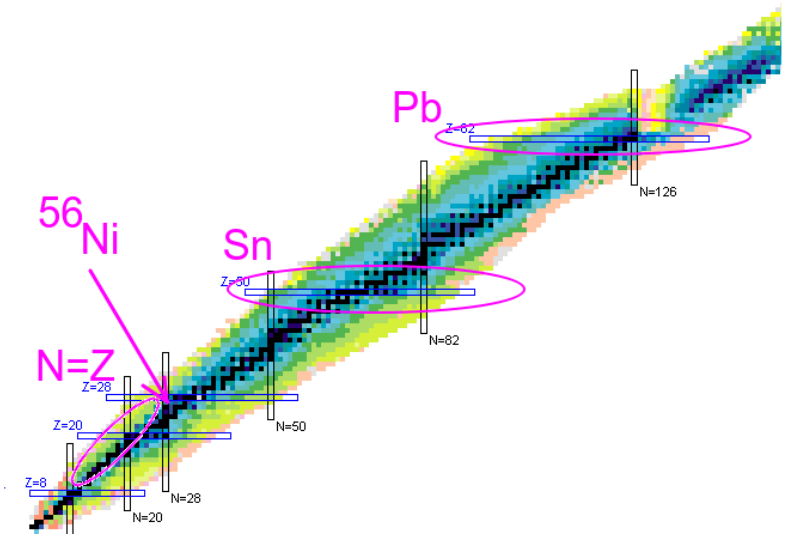


Extension of the technical concept

- ^{56}Ni: new detectors covering $\theta_{cm} > 2$ deg/ tracking
- Sn/Pb isotopes: Asymmetric nuclear matter (EoS)
- $N = Z$ nuclei: α-clustering with astrophysical implications
- Light nuclei: $E1$ response

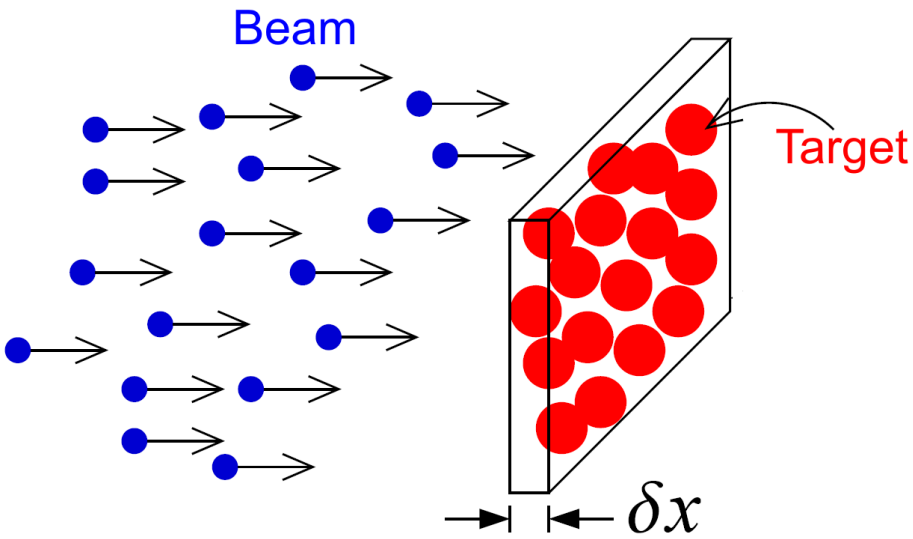






EXL: EXotic nuclei studied in Light ion induced reactions at storage rings

Outline



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δx : target size
ρ : taget density

1. Storage Rings ($\uparrow N_B$)
2. **Active Targets ($\uparrow \delta x$)**

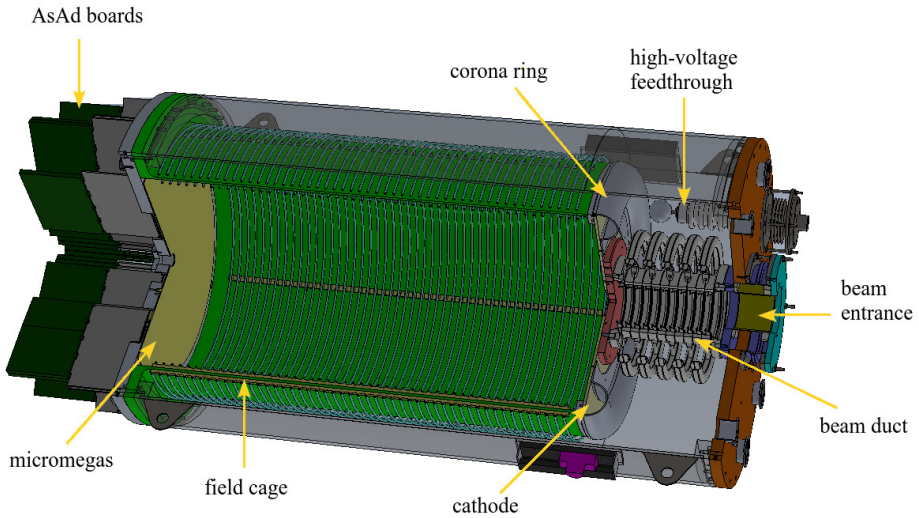
Active Target

- Target/detector same system
- Time Projection Chamber (TPC)
- 4π solid angle
- Particle tracking

Name	Location	Main physics theme
pAT-TPC	NSCL/FRIB	Cluster structure
AT-TPC	NSCL/FRIB	Shell evolution
SPECMAT	Leuven	Shell evolution
MAYA	GANIL	Giant resonances
ACTAR	GANIL	Shell evolution
TexAT	Texas A&M	Shell evolution
MAIKo	RCNP	Cluster structure
TPC	CENBG	Exotic decays
O-TPC	Warsaw	Exotic decays
MUSIC	GSI	Fusion–fission
fissionTPC	LLNL	Fusion–fission
MUSIC	ANL	Astrophysics
GADGET	NSCL/FRIB	Astrophysics
IKAR	GSI	Matter distributions
CAT	CNS	Giant resonances

D. Bazin, et al. Prog. Part. Nucl. Phys. 114 (2020) 103790

AT-TPC (NSCL)

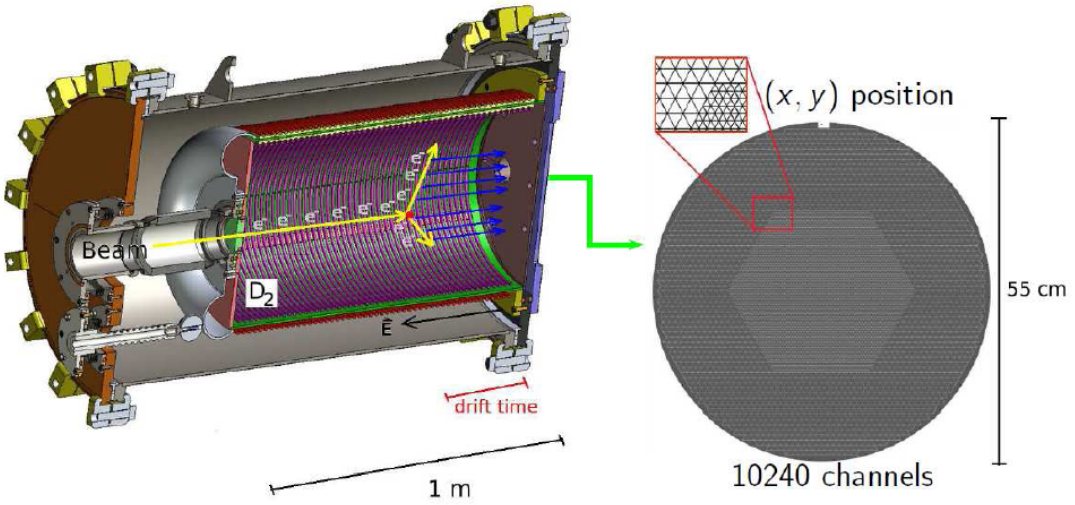


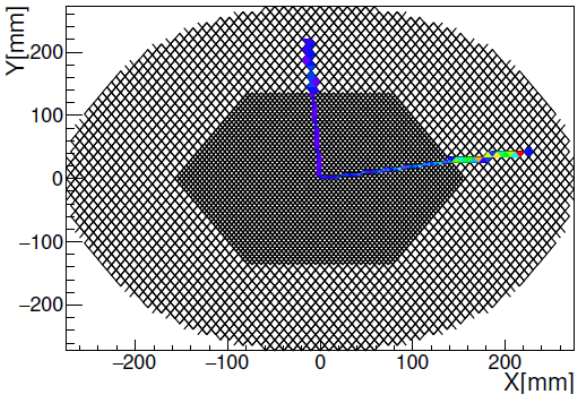
1 m × 50 cm (diameter)

10240 channels

How it works

AT-TPC: Active Target Time Projection Chamber



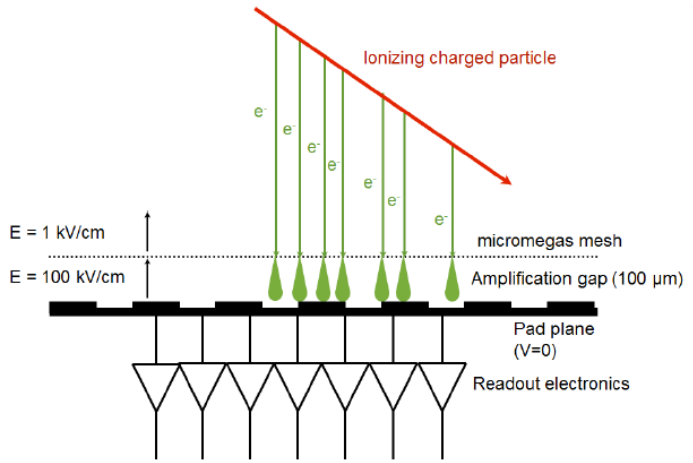


(x, y) : projection

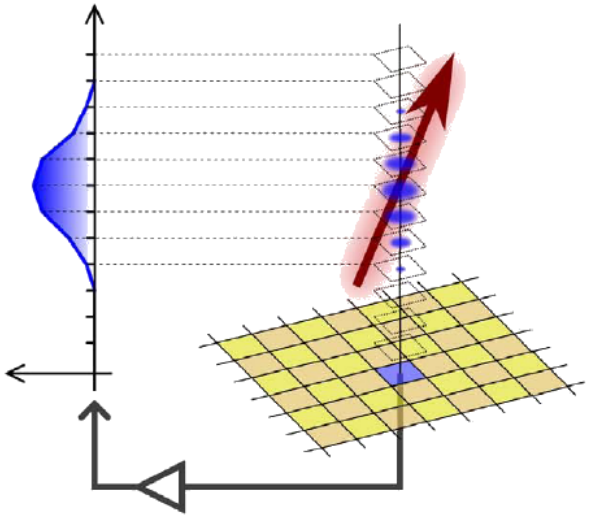
$$z = v_{\text{drift}} \cdot t + z_0$$

D. Suzuki et al., NIM A 691:39, 2012

- Filled with a certain gas, e.g. H_2, ^4He...
- Constant electric field
- Electrons drift with a constant velocity to the pad plane
- Sampling time $\sim$ 40 ns (512 time buckets)

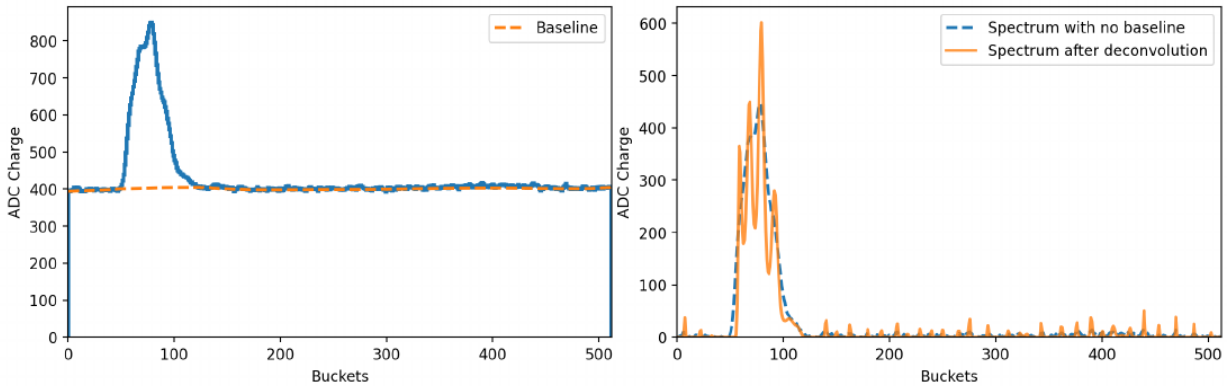


Point cloud reconstruction

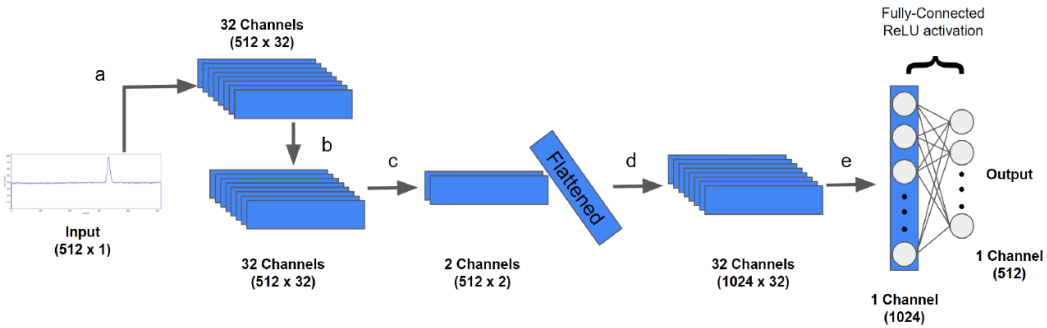


Giovinazzo et al.,NIM A **840**, 15 (2016)

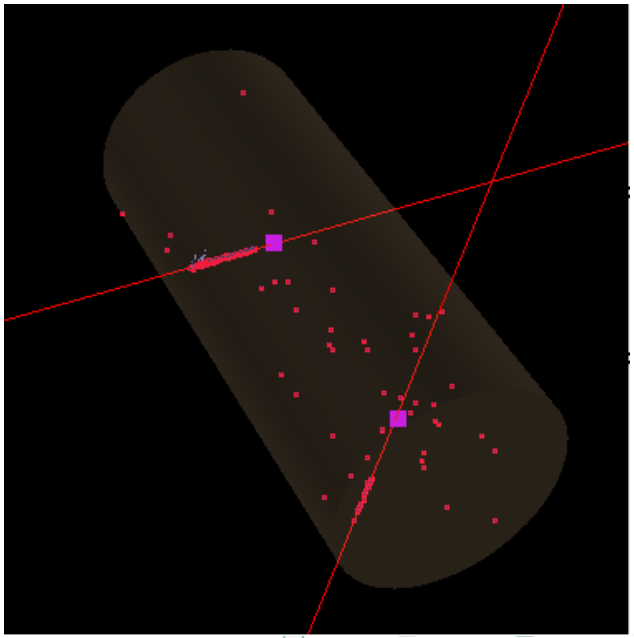
Hundreds of signals/event



Convolutional Neural Networks

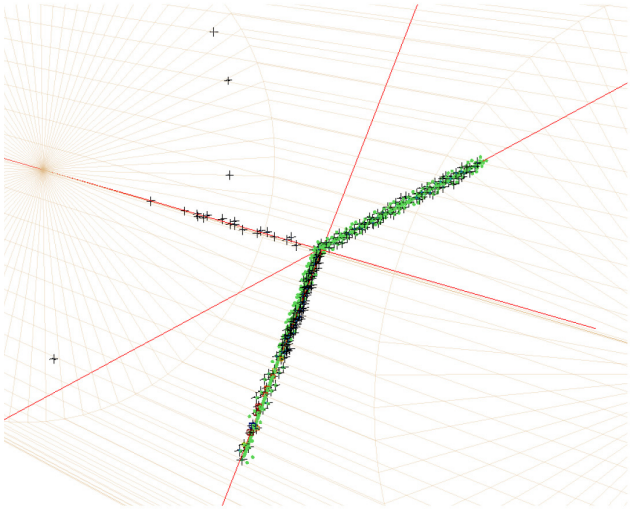


G. Fortino, M.Sc., U. Sao Paulo



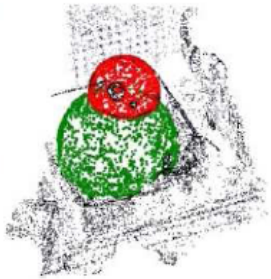
Particle tracking

Ayyad et al. NIM A **880**, 166 (2018)



RANSAC: RANdom SAmple Consensus

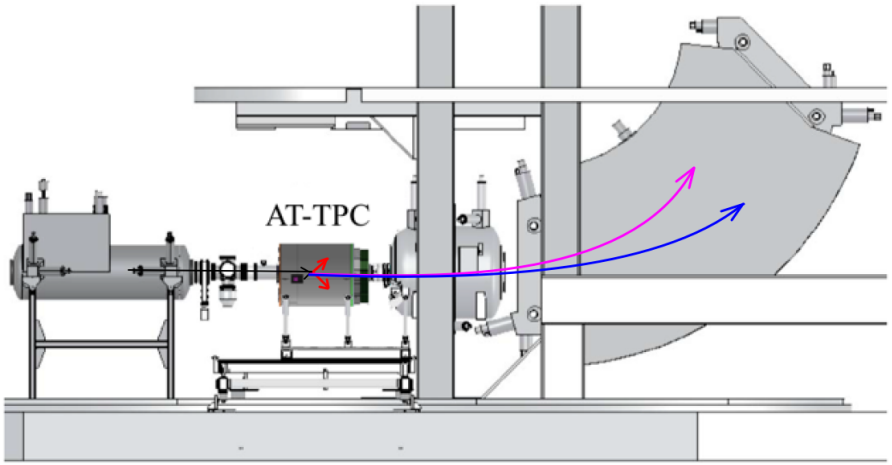
CV algorithms



- Very good outlier rejection
- Reaction vertex reconstruction
- Improved by using probability distributions and modified random sampling

  Zamora and Fortino NIM A **988**, 164899 (2021)
- Coupled with clustering algorithms

AT-TPC + S800 Spectrometer

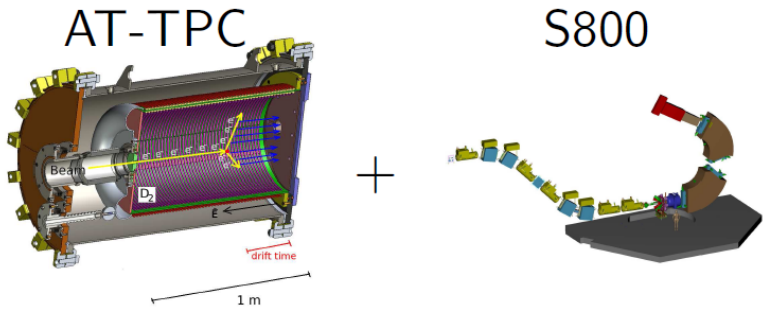


- Trigger: Beam-like particle
- Beam/ejectile windows
- No trivial coupling FP detectors with 10K GET channels
- Corrections for non-uniform electric field
- Dedicated gas-handling system: use of some explosive gases

TPC + Spectrometer: $(d, {}^2\mathrm{He})$ in inverse kinematics

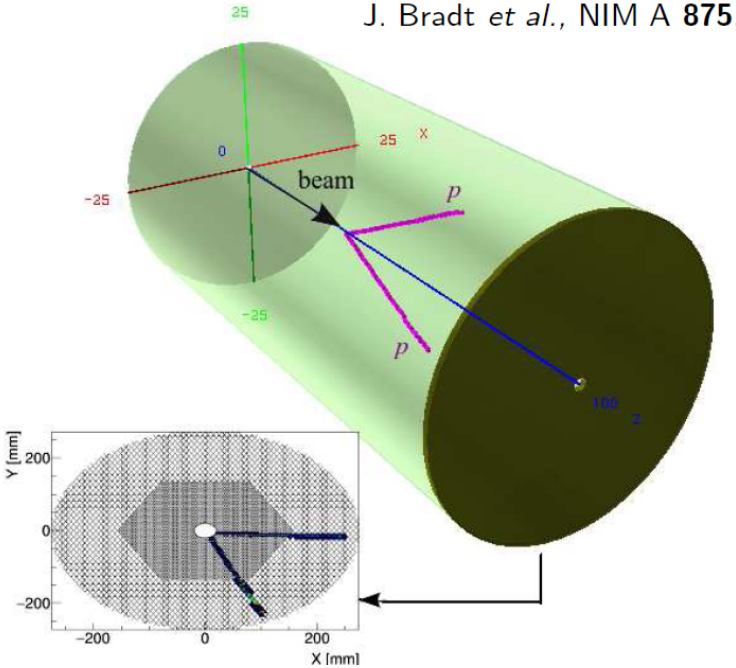
- Well-established probe in forward kinematic experiments
  H. Okamura *et al.*, Phys. Lett. B **345**, 1 (1995)
  H.M. Xu *et al.*, Phys. Rev. C **52**, R1161 (1995)
  S. Rakers *et al.*, Phys. Rev. C **65**, 044323 (2002)

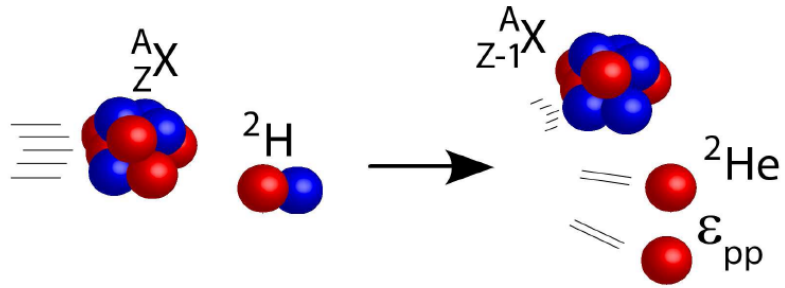
- Feasible technique to achieve (n, p)-type experiments in inverse kinematics

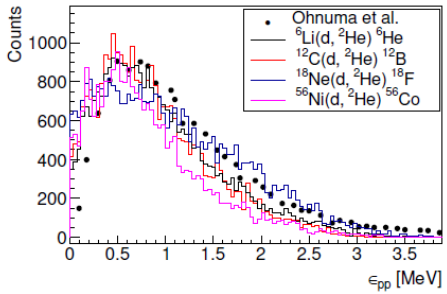


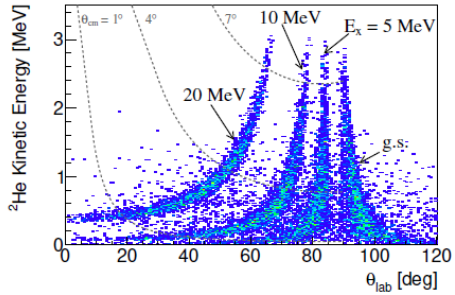
Active Target Time Projection Chamber

J. Bradt *et al.*, NIM A **875**, 65 (2017)

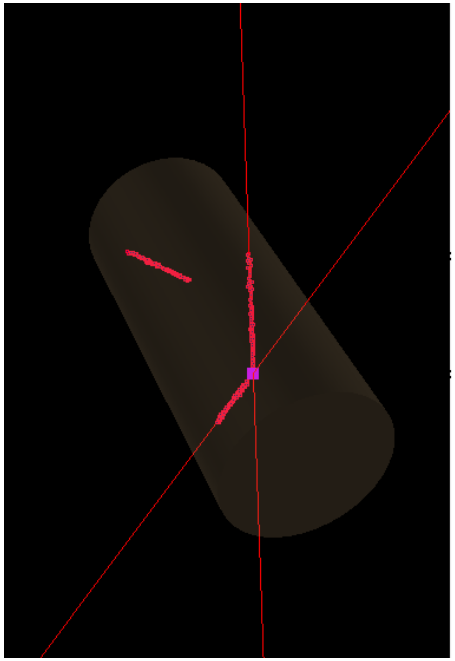


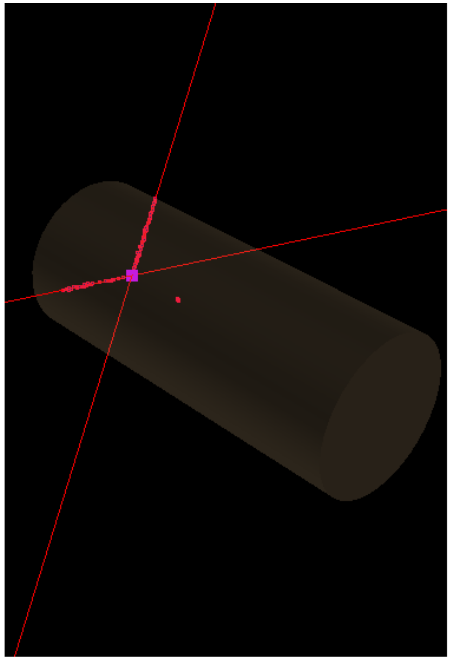






First $(d, {}^2\mathrm{He})$ experiment in inverse kinematics

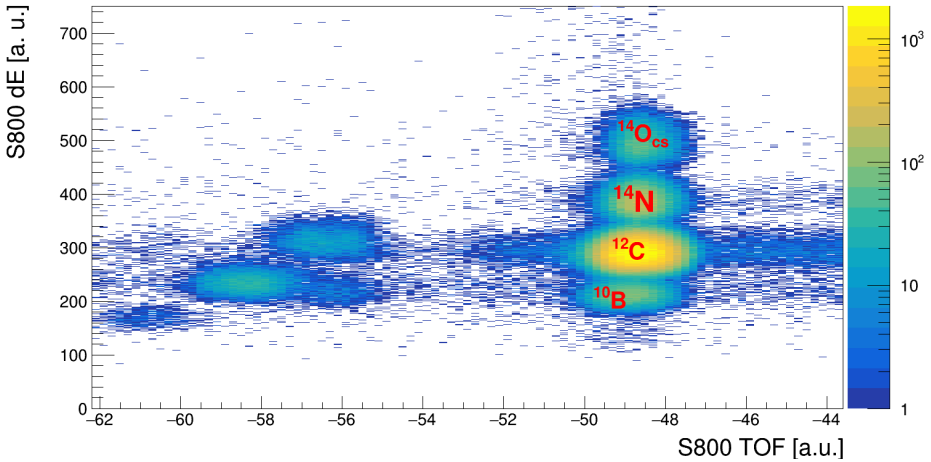




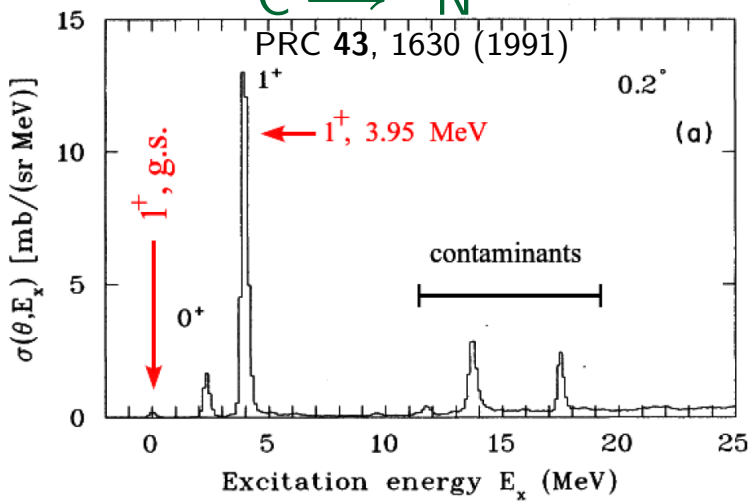
$^{14}\mathrm{O} \longrightarrow {}^{14}\mathrm{N}$

preliminary

courtesy of S. Giraud



$^{14}\mathrm{C} \longrightarrow {}^{14}\mathrm{N}$

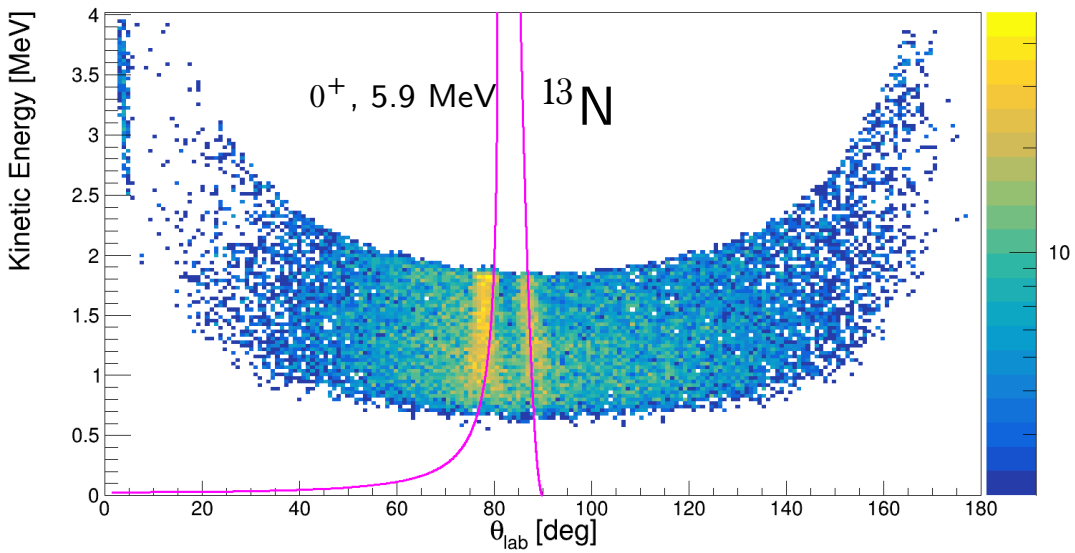


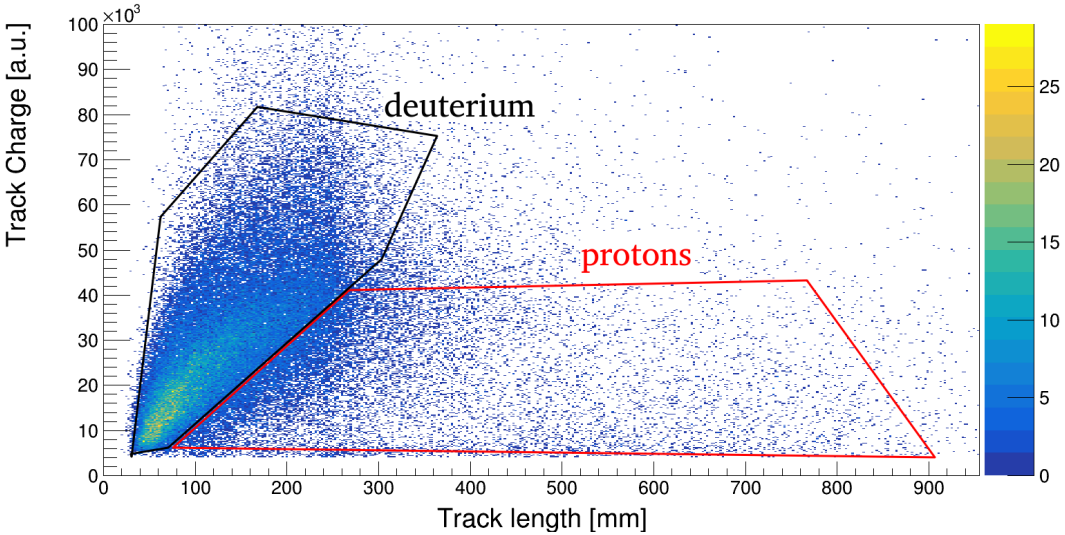
Isoscalar strength of ^{14}O via (d, d') reactions

Focal plane detectors

$$^{14}\mathrm{O}^{*} \longrightarrow {}^{13}\mathrm{N} + p$$
$$S_p = 4.6 \text{ MeV}$$

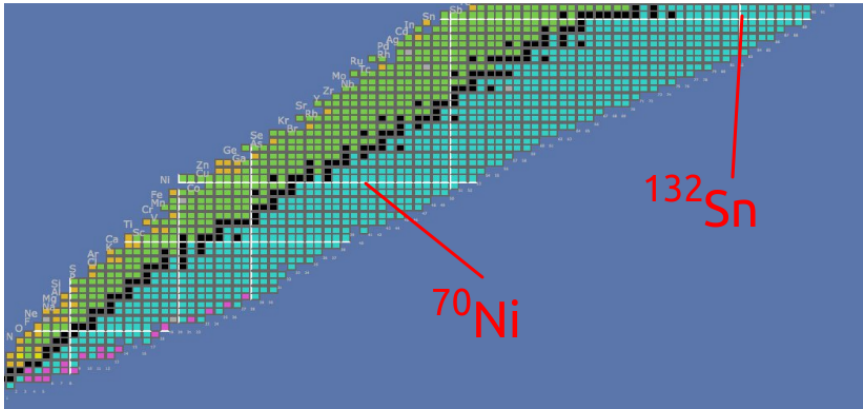
$$^{14}\mathrm{O}^{*} \longrightarrow {}^{12}\mathrm{C} + 2p$$
$$S_{2p} = 6.6 \text{ MeV}$$

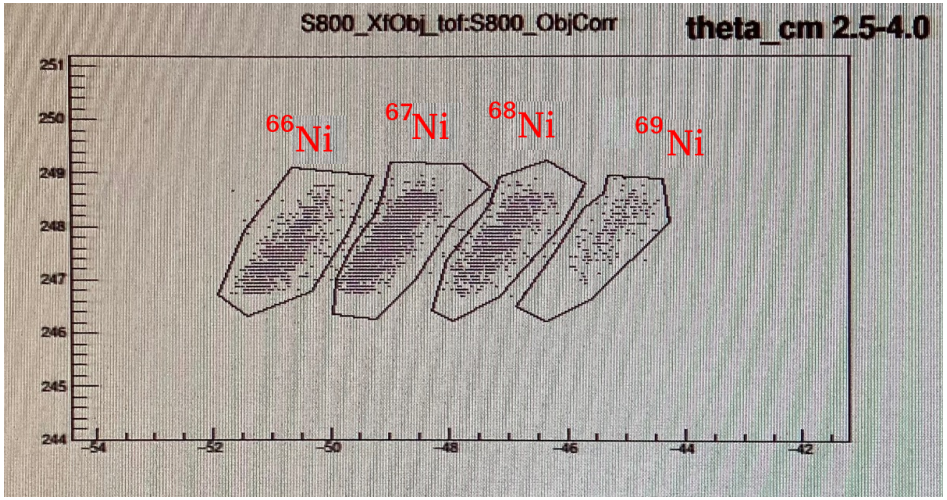


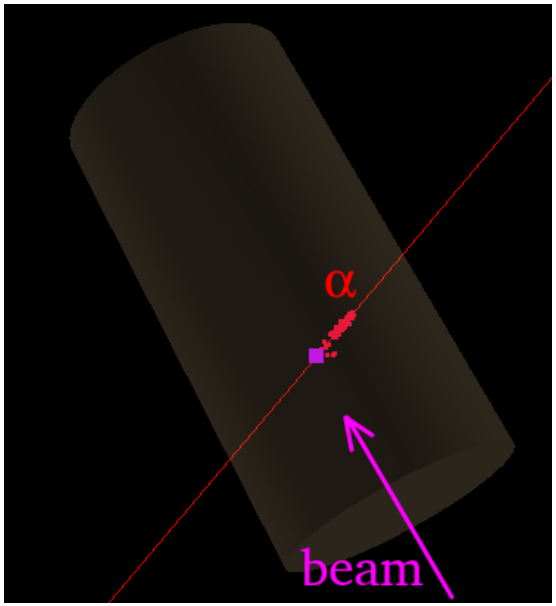


preliminary

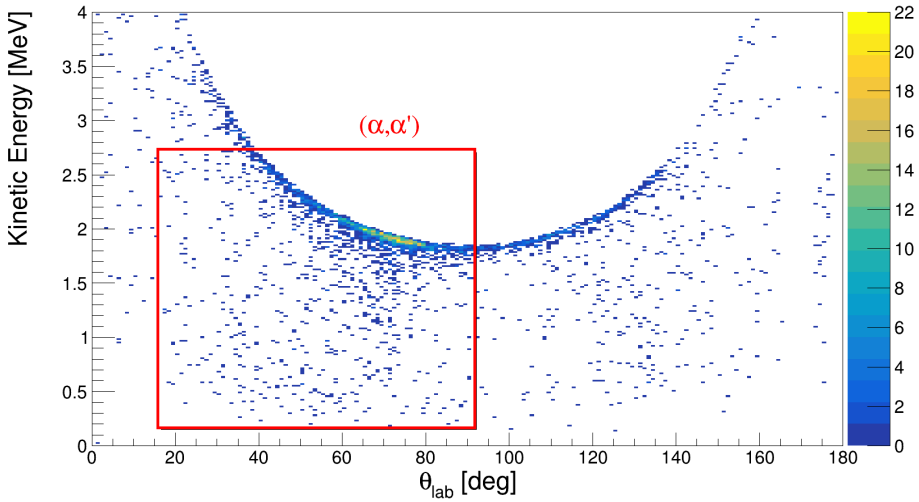
Isoscalar giant resonances from (α, α') experiments







analysis by J. Randhawa



Dipole response using (p, p')

Summary

Storage Rings

- First time GRs are being studied via an experiment with stored beam. The ISGMR in ^{58}Ni was extracted. Proof of principle.
- Technical improvements are needed: beam injection, δ-rays, etc...

Active Targets

- First successful experiments with the AT-TPC + S800 using fast beams.
- Few things need to be studied in detail: space charge effects, drift velocity, beam tracking, etc...

Thank you for your attention!

EXL Collaboration

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