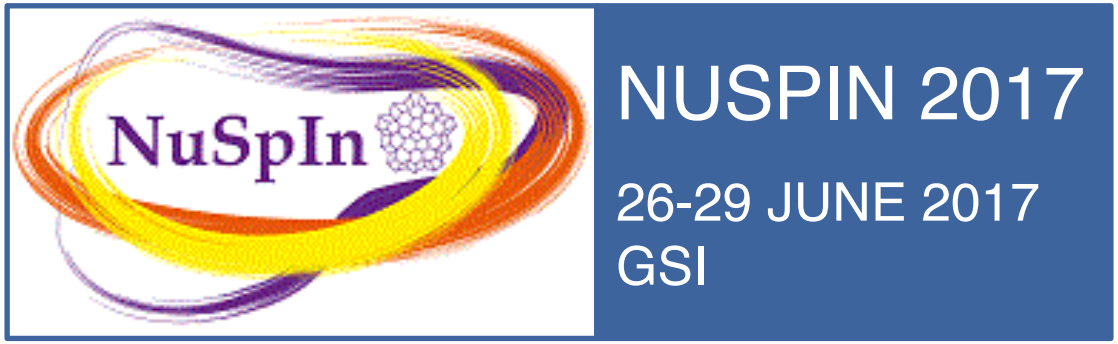
Novel experimental approaches to transfer reactions with RIBs

Riccardo Raabe

KU Leuven, Instituut voor Kern- en Stralingsfysica



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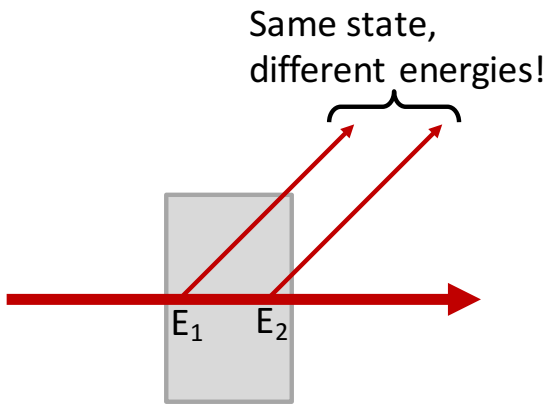
Reactions studies with RIBs: challenges

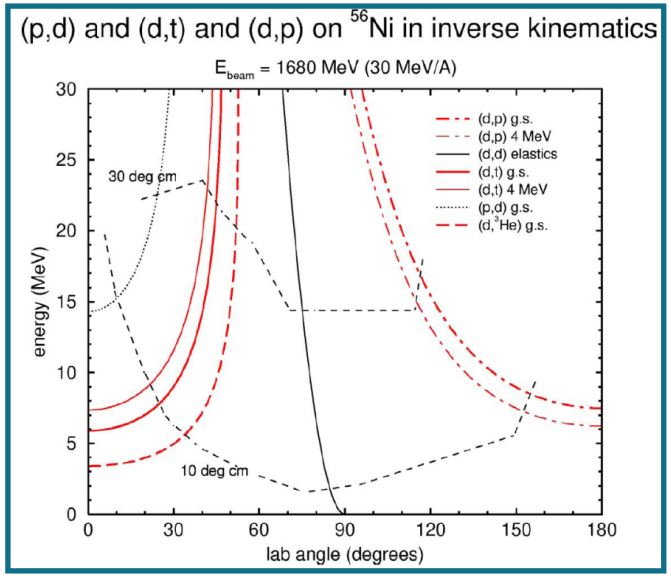
- The luminosity dilemma
  Low beam intensities → use larger target thickness

  → **worse energy resolution**
  → no access to low momentum-transfer reactions



- Inverse kinematics
  → Energy changes fast with lab angle
  → Kinematic compression
  very small differences in energy
  of the light particle for different *E**

  → **worse energy resolution**



Typical values 200-300 keV resolution in *E

Particle-gamma coincidence

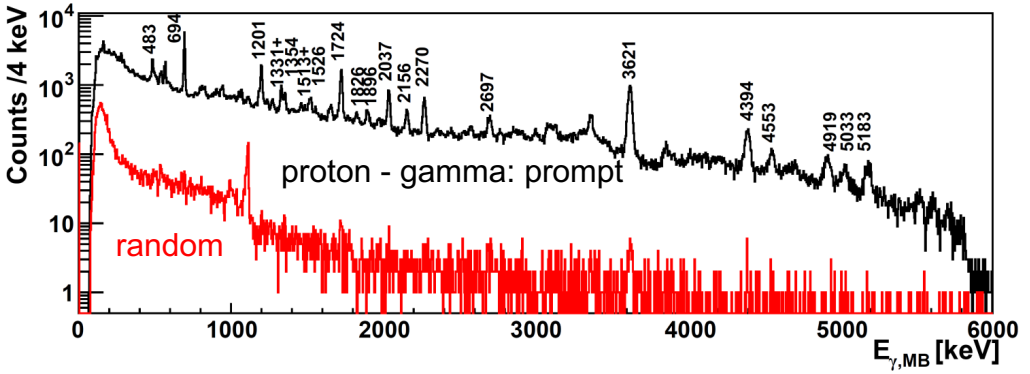
^{66}Ni(d,p)^{67}Ni at REX-ISOLDE

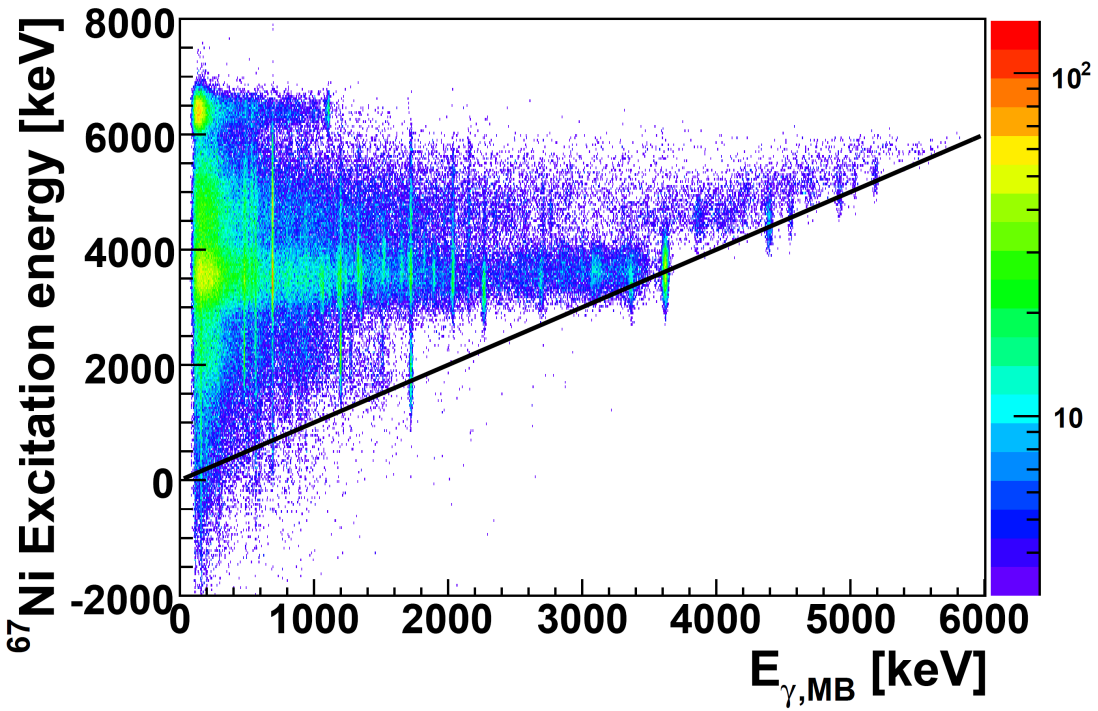
J. Diriken et al, PLB 736 (2014) 533

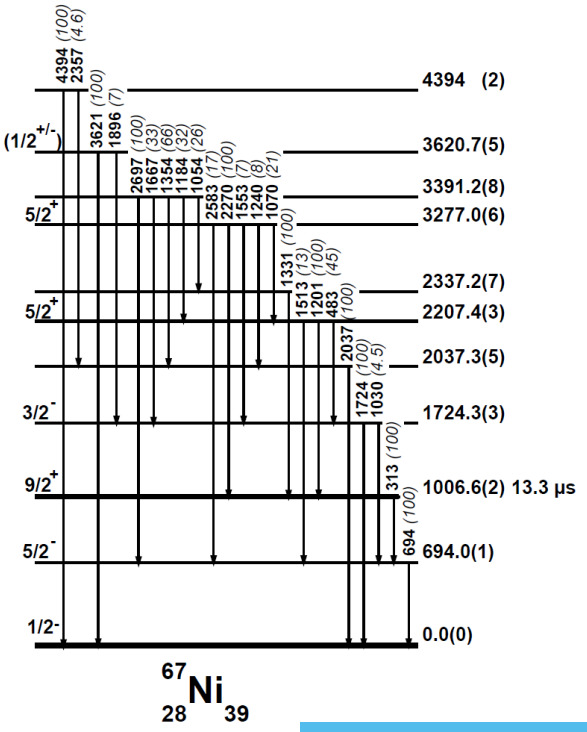
Relatively high intensities

Not all states decay gamma

→ still a compromise







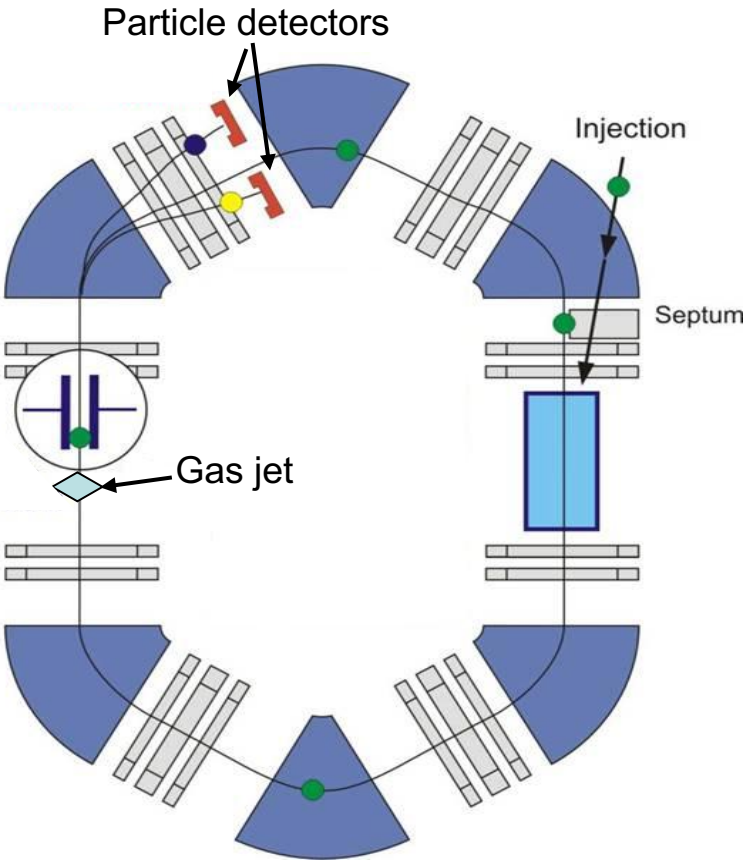
Transfer reactions in rings

Advantages

- Recirculating beam
  → increased intensity
  (but beam lifetime?)
- Cooled beams
  and **very thin** targets
  → excellent resolution,
  low detection thresholds

Problems to overcome

- High-density gas-jet target
- Detectors in ultra-high vacuum

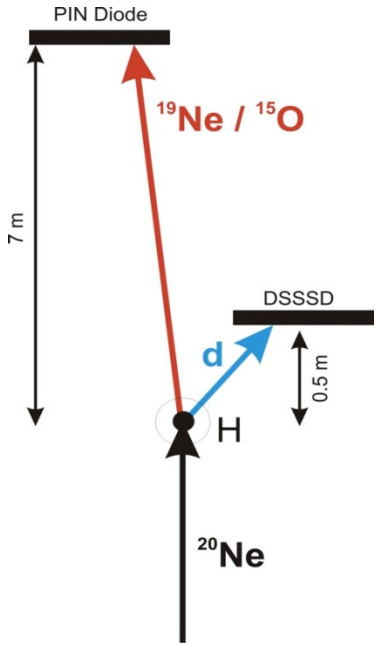


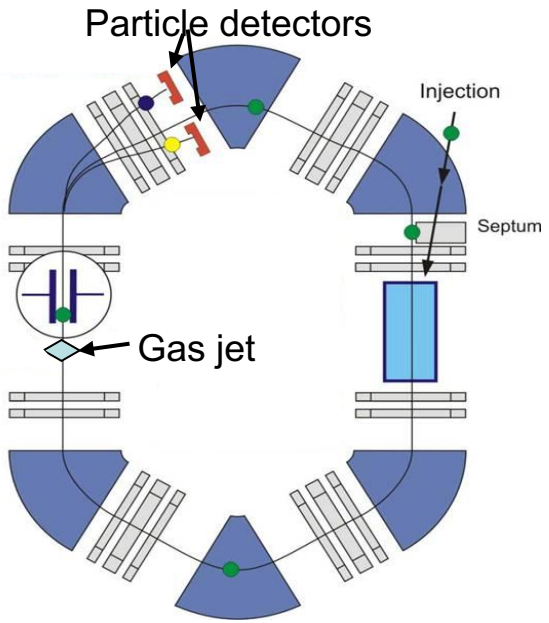
Q. Zhong, Journal of Physics:
Conference Series 202 (2010) 012011

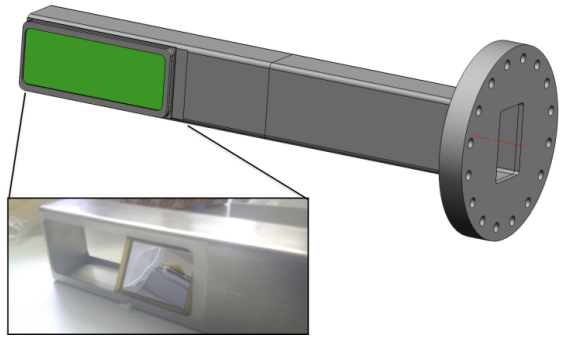
Transfer reactions in rings

Measurements at ESR

- (p,γ), (α,γ) and (p,d) in inverse kinematics
- ^{96}Ru(p,γ)^{97}Rh B Mei et al, PRC 92 (2015) 035803
  ^{20}Ne(p,d)^{19}Ne D T Doherty et al, Phys Scr 2015 014007
- Windowless gas target (10^{13} H_2/cm^2)
  Decelerated beam
  Luminosity 10^{25} cm^{-2} s^{-1}
- Detectors in pockets separated from UHV



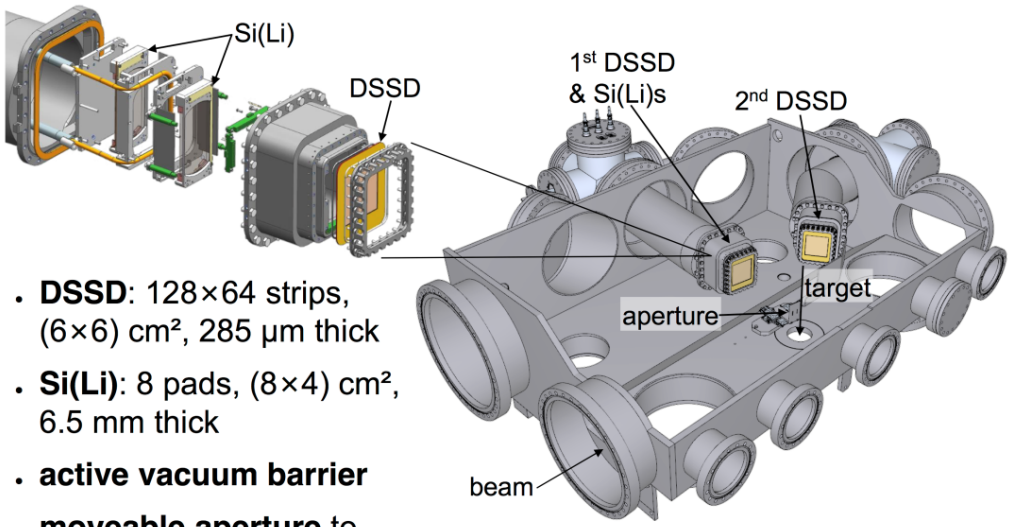




Low momentum-transfer reactions

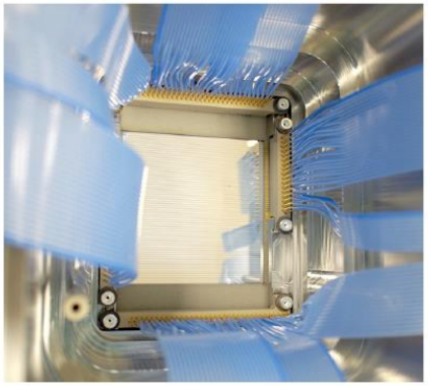
Low energy recoils: detectors as vacuum interfaces

P. Egelhof (GSI), **EXL** Collaboration
H. Moeini et al., NIMA 634 (2011) 77

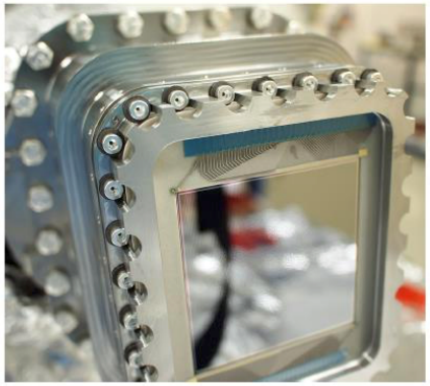


- **DSSD**: 128×64 strips, (6×6) cm², 285 µm thick
- **Si(Li)**: 8 pads, (8×4) cm², 6.5 mm thick
- **active vacuum barrier**
- **moveable aperture** to improve angular resolution

► Auxilliary vacuum side



► Ultra-high vacuum side



Low momentum-transfer reactions

Physics Letters B 763 (2016) 16–19

Contents lists available at ScienceDirect

Physics Letters B

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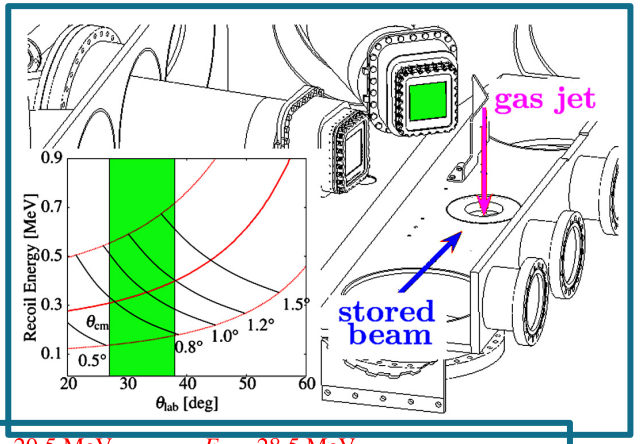
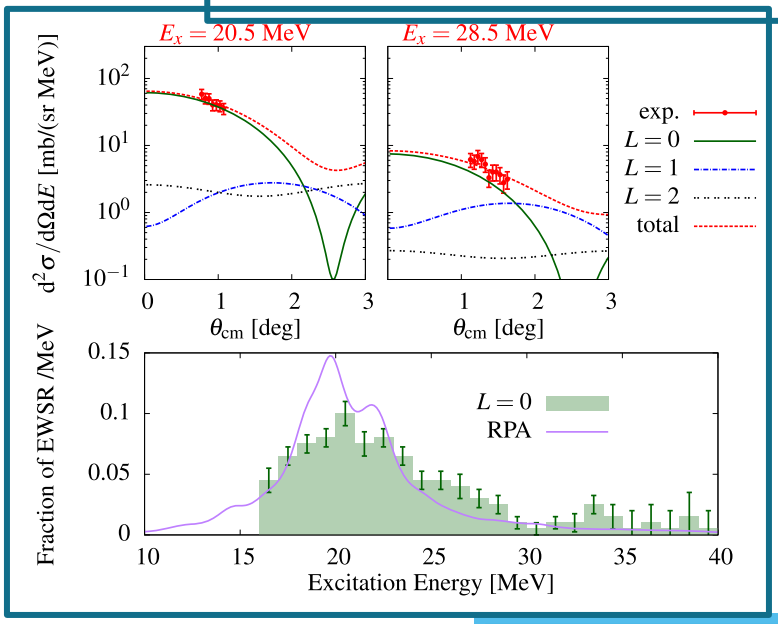
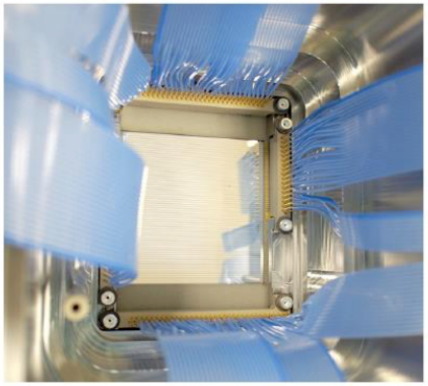
First measurement of isoscalar giant resonances in a stored-beam experiment

J.C. Zamora [a,*], T. Aumann [a,b], S. Bagchi [c,b], S. Bönig [a], M. Csatlós [d], I. Dillmann [b], C. Dimopoulou [b], P. Egelhof [b], V. Eremin [e], T. Furuno [f], H. Geissel [b], R. Gernhäuser [g], M.N. Harakeh [c], A.-L. Hartig [a], S. Ilieva [a], N. Kalantar-Nayestanaki [c], O. Kiselev [b], H. Kollmus [b], C. Kozhuharov [b], A. Krasznahorkay [d], Th. Kröll [a], M. Kuilman [c], S. Litvinov [b], Yu.A. Litvinov [b], M. Mahjour-Shafiei [h,c], M. Mutterer [b], D. Nagae [i], M.A. Najafi [c], C. Nociforo [b], F. Nolden [b], U. Popp [b], C. Rigollet [c], S. Roy [c], C. Scheidenberger [b], M. von Schmid [a], M. Steck [b], B. Streicher [b], L. Stuhl [d], M. Thürauf [a], T. Uesaka [j], H. Weick [b], J.S. Winfield [b], D. Winters [b], P.J. Woods [k], T. Yamaguchi [l], K. Yue [a,b,m], J. Zenihiro [j]

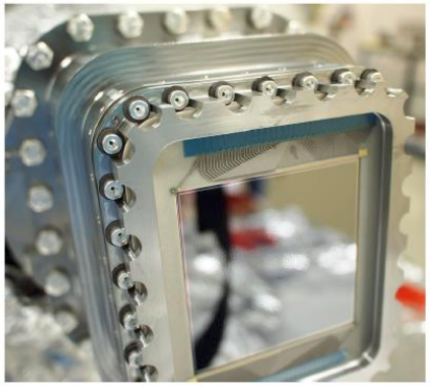




► Auxilliary vacuum side



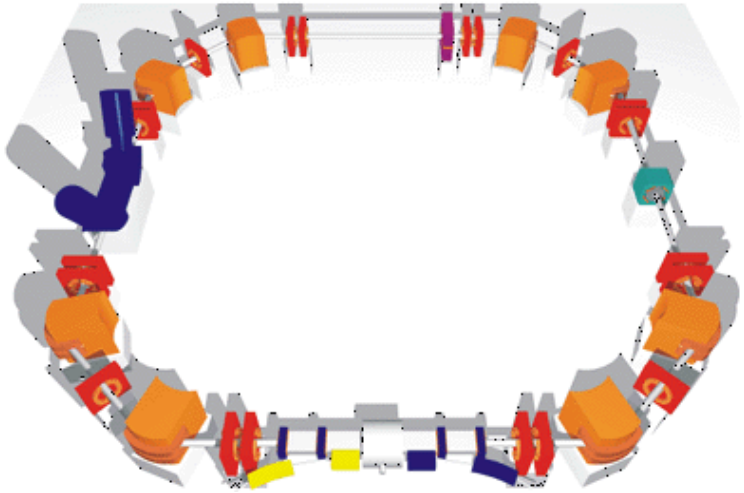
► Ultra-high vacuum side

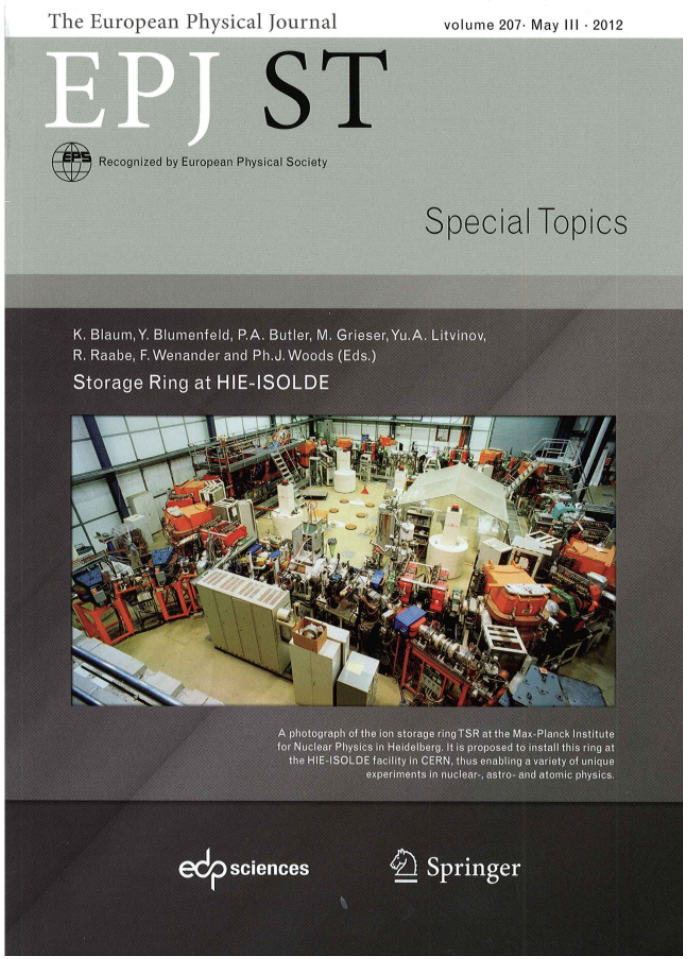


Storage ring at ISOLDE

K. Blaum (MPI-K Heidelberg and GSI), Y. Blumenfeld (CERN), P.A. Butler (Univ. Liverpool), M. Grieser (MPI-K Heidelberg), Yu.A. Litvinov (Univ. Heidelberg and GSI), R. Raabe (KU Leuven), F. Wenander (CERN), Ph.J. Woods (Univ. Edinburgh) (eds.)

TSR@ISOLDE





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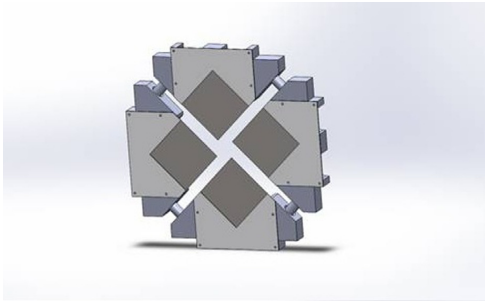
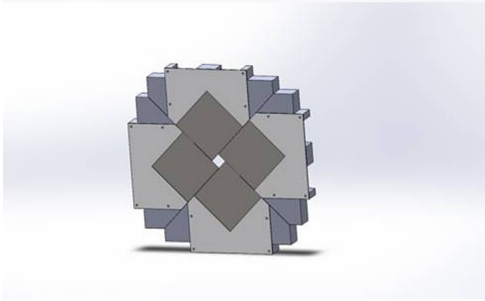
Storage ring at ISOLDE

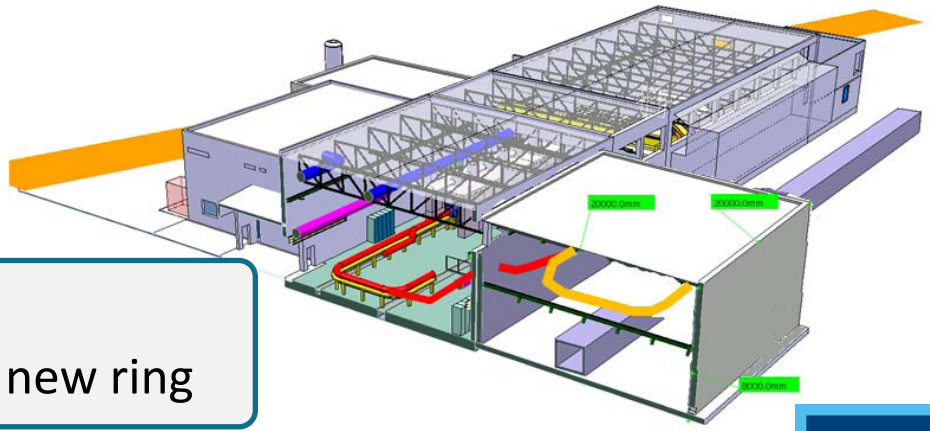
Physics programme

- Astrophysics
  Capture, transfer reactions
  ^{7}Be half life
- Atomic physics
  Effects on half lives
  Di-electronic recombination
- Nuclear physics
  Reaction studies (with limitations → improve source)
  Isomeric states
  Decay of halo states
  Laser spectroscopy
- Neutrino physics

Reactions: UK STFC grant







No TSR
Ideas started for a different, new ring

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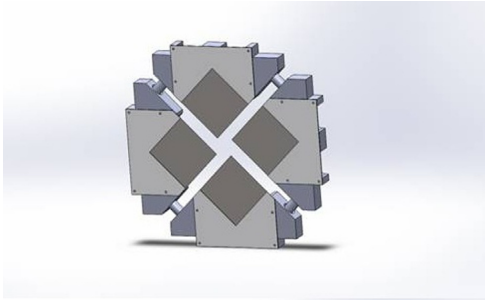
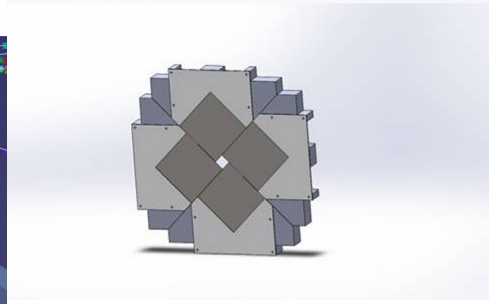
CRYRING

Research with CRYRING@ESR

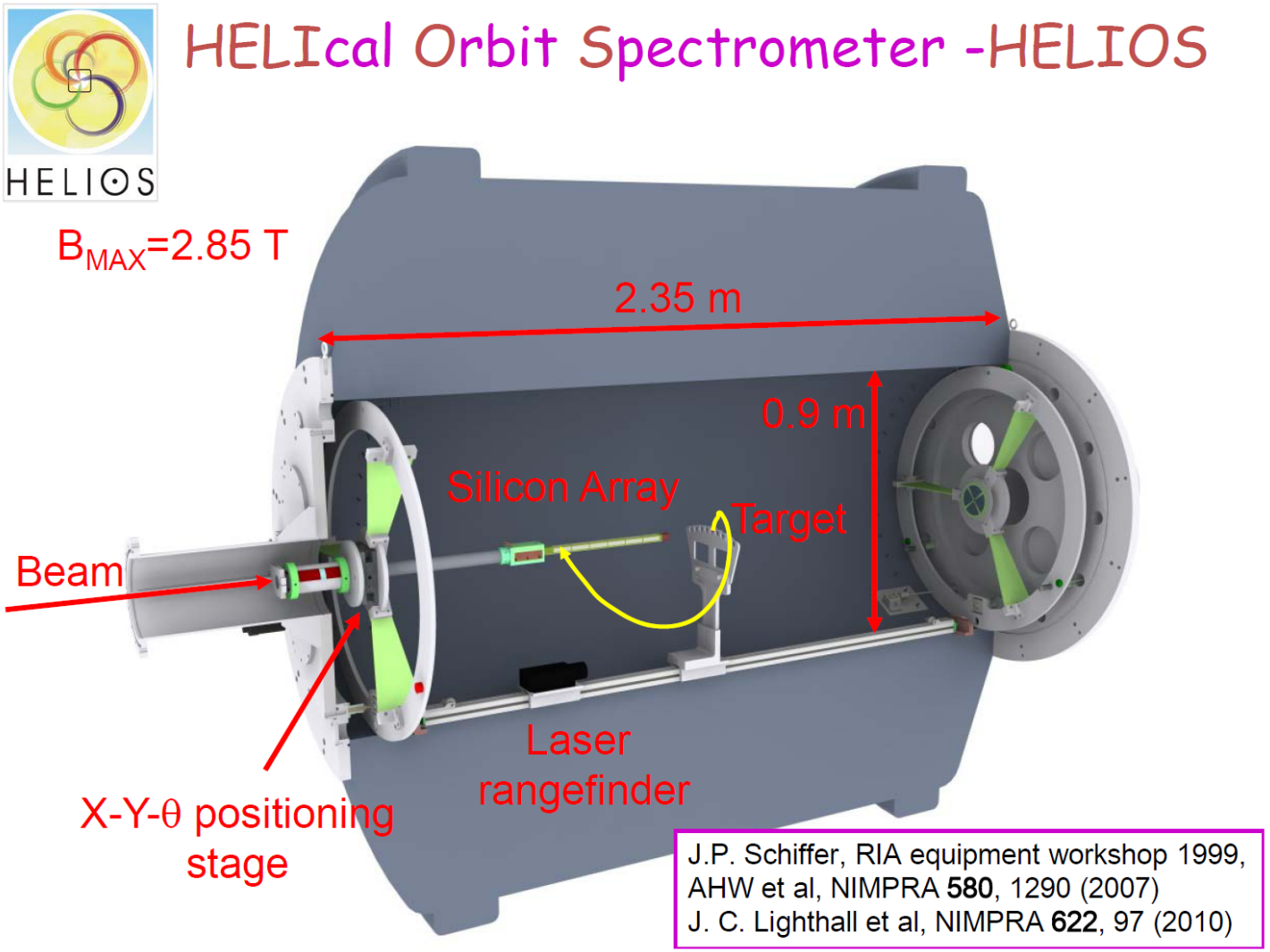
- Workshop 24-25 April 2017
- Physics book Eur. Phys. J. Spec. Top. (2016) 225
- TDR 2016

- Astrophysics (reactions)
- Atomic physics
- Nuclear physics
  (with atomic methods)





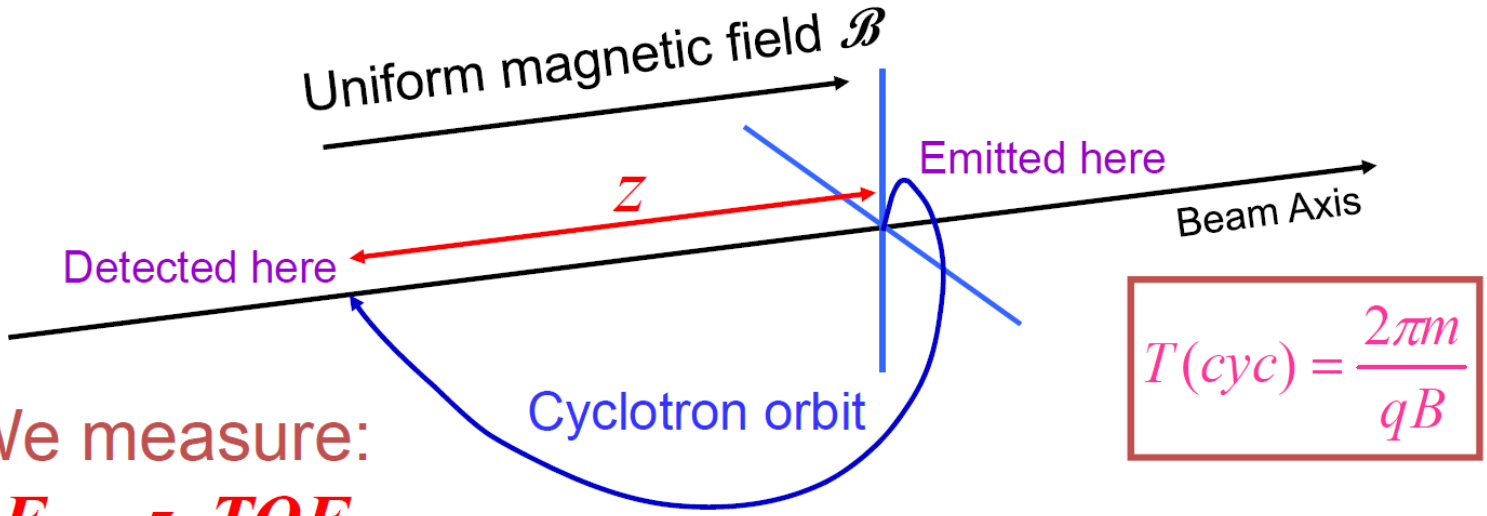
A different approach: the HELIOS solenoidal spectrometer



J.P. Schiffer, RIA equipment workshop 1999,
AHW et al, NIMPRA **580**, 1290 (2007)
J. C. Lighthall et al, NIMPRA **622**, 97 (2010)

A different approach: the HELIOS solenoidal spectrometer

Eliminates kinematic compression



$$T(cyc) = \frac{2\pi m}{qB}$$

We measure:

E_{lab}, z, TOF

We deduce:

E_{CM}, θ_{CM}

$$z \propto \cos\theta_{CM}$$

$$E_{lab} = E_{CM} - A + Bz$$

For a given state

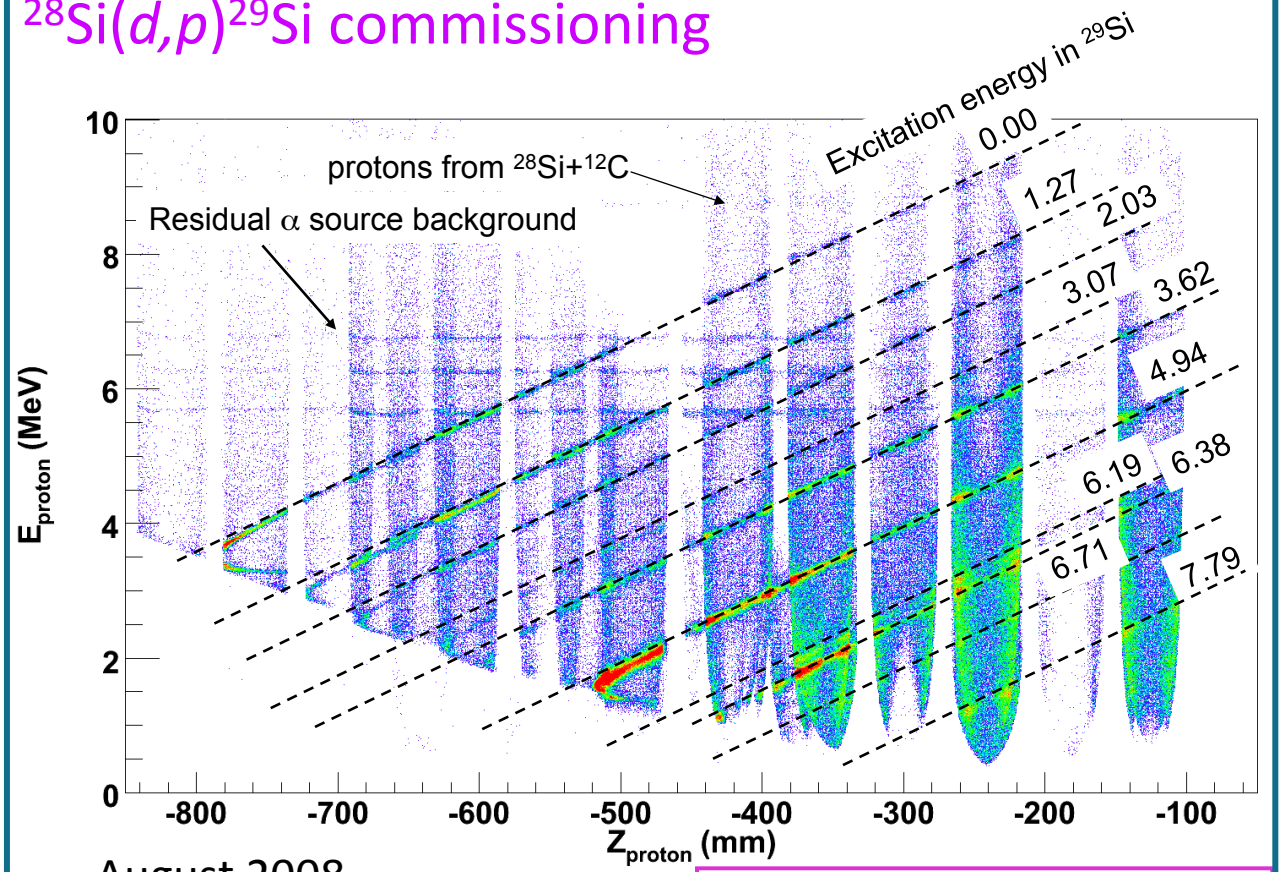
$$\Delta E_{lab} = \Delta E_{CM}$$

For two states at fixed z

Some HELIOS results

Figures and info: A. Wuosmaa, Workshop Solenoid at ReA, ARGONNE 2017

$^{28}Si(d,p)^{29}Si$ commissioning



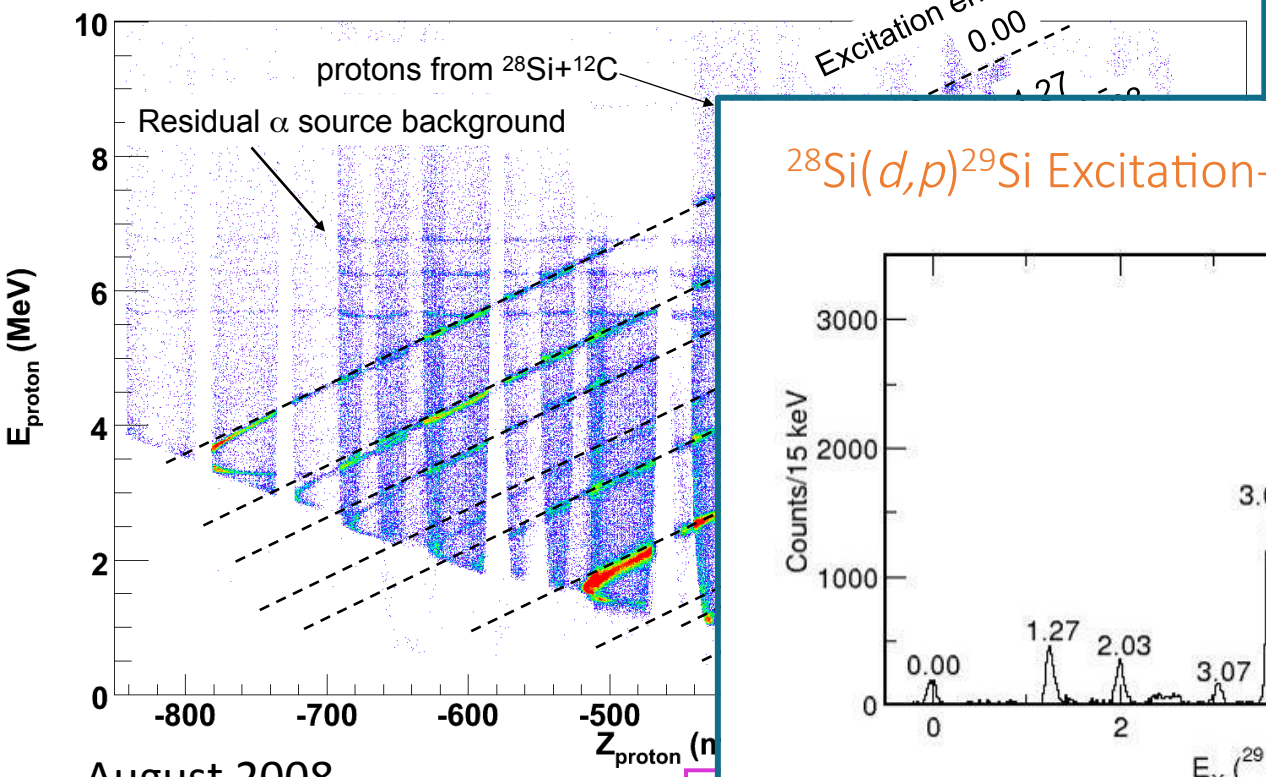
August 2008

J. C. Lighthall et al, NIMPRA **622**, 97 (2010)

Some HELIOS results

Figures and info: A. Wuosmaa, Workshop Solenoid at ReA, ARGONNE 2017

$^{28}Si(d,p)^{29}Si$ commissioning



$^{28}Si(d,p)^{29}Si$ Excitation-energy spectrum

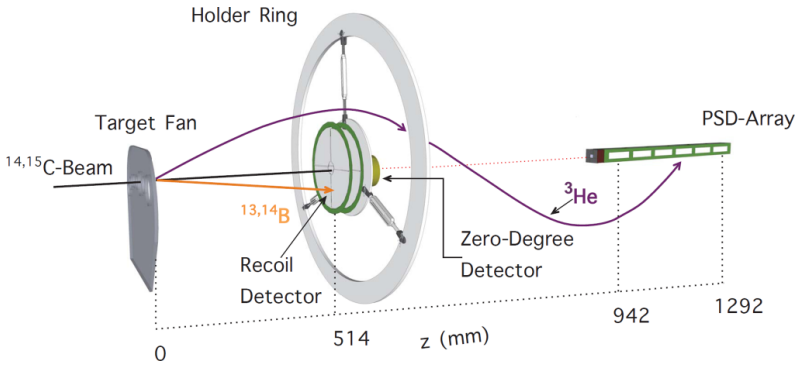
Typical resolution ~ 120 keV FWHM
Best resolution ~ 80 keV FWHM

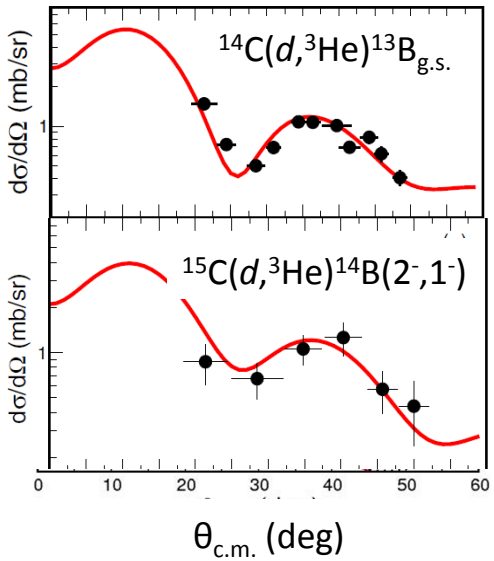
J. C. Lighthall et al, NIMPRA **622**, 97 (2010)

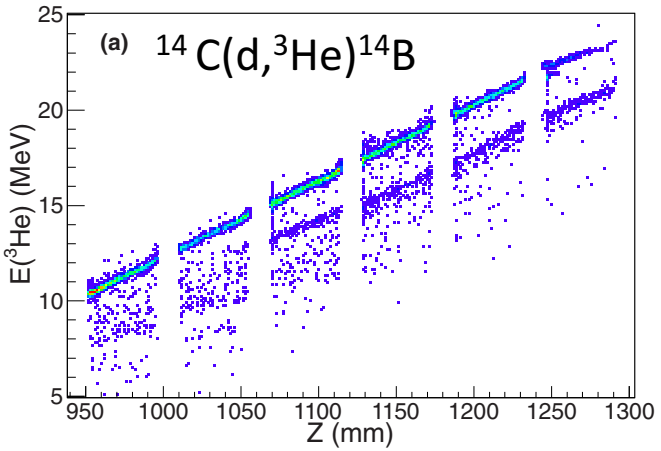
Some HELIOS results

Figures and info: A. Wuosmaa, Workshop Solenoid at ReA, ARGONNE 2017

- (d,p) on heavy stable beams ^{86}Kr, ^{136}Xe
- Reactions with light RIBs
  (d,p)
  ^{10}B(p,p')^{10}B*
  ^{14,15}C(d,^{3}He)^{13,14}B
  ^{27}Al(d,t)^{26}Al
  ^{14,15}C(d,α)^{12,13}B
  (α,p)
  (^{3}He,d)
  (^{6}Li,d)
- 13 publications to date



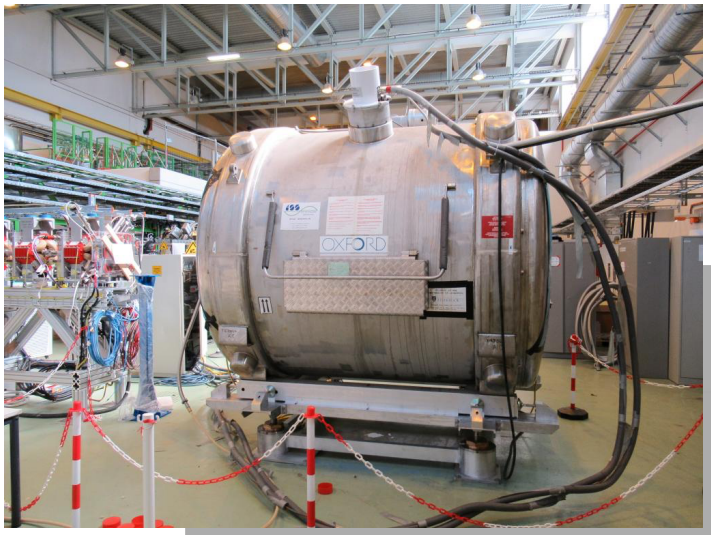




S. Bedoor PRC 93, 044323

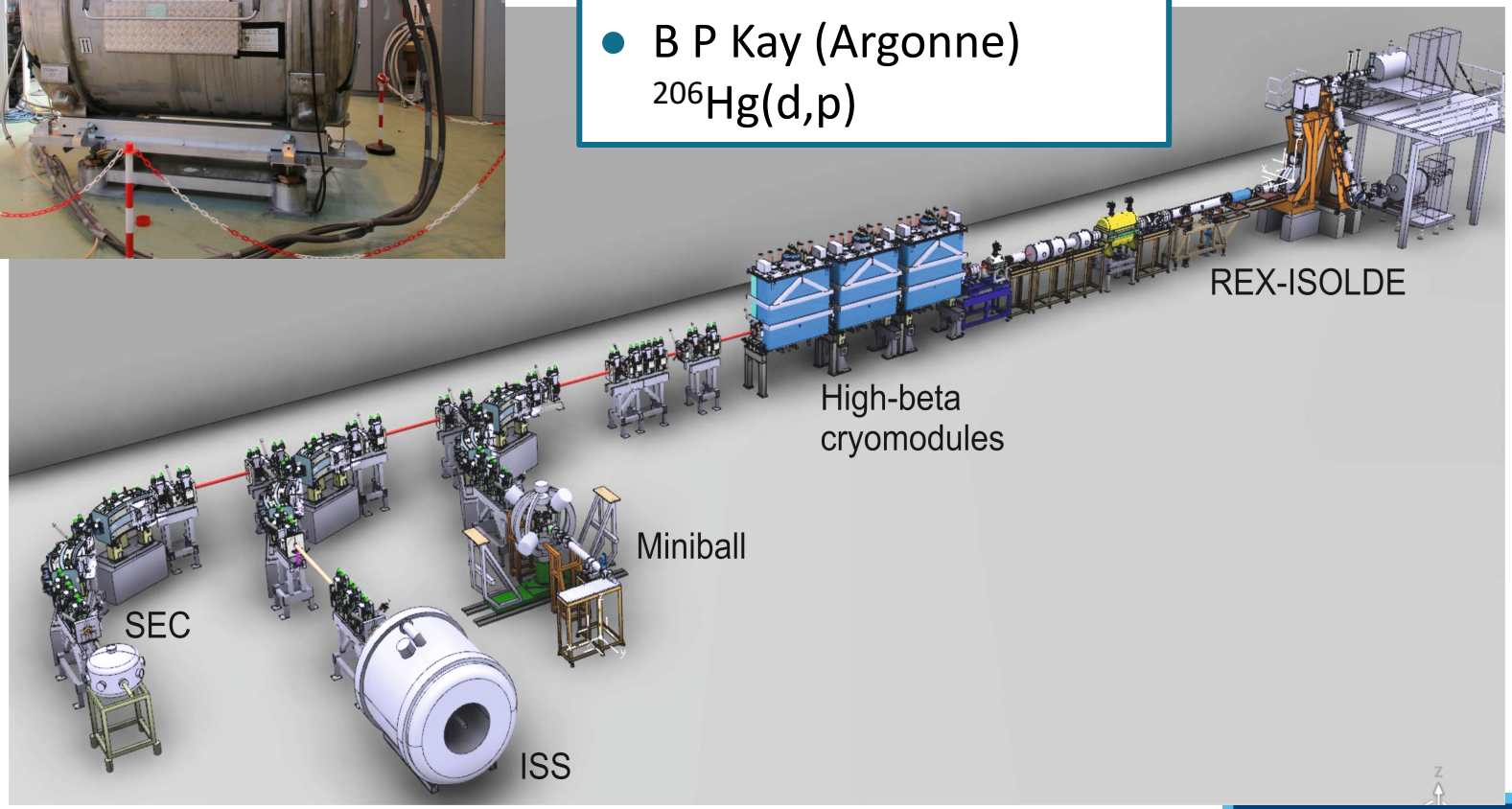
ISOL Solenoidal Spectrometer at ISOLDE

P Butler, S Freeman, R Page
Liverpool, Manchester, Daresbury



Approved proposals

- D K Sharp (Manchester)
  ^{28,29}Mg(d,p)
- B P Kay (Argonne)
  ^{206}Hg(d,p)

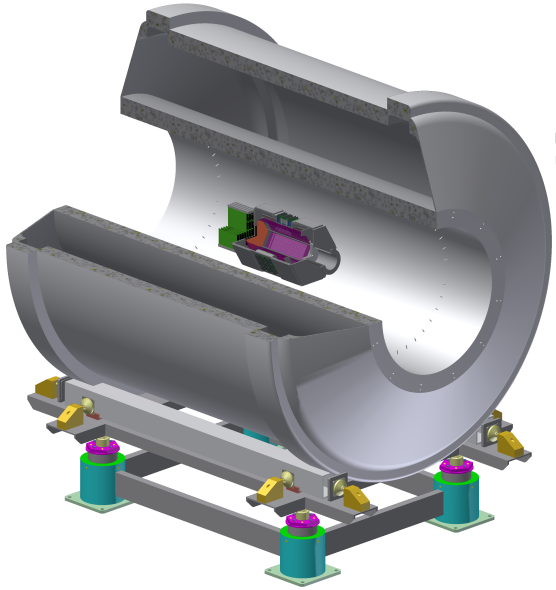


ISS at ISOLDE: SpecMAT

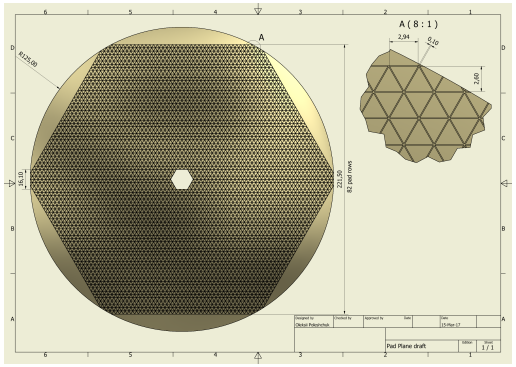
IKS, KU Leuven

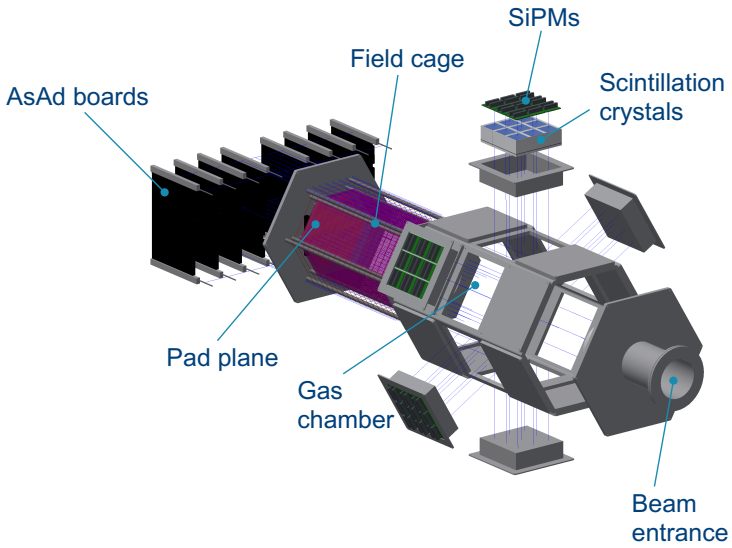
SpecMAT
Active target + γ-ray detection

- High luminosity, preserving resolution
- Transfer reactions
- Low momentum-transfer reactions



erc
European Research Council
Established by the European Commission





Summary

- Transfer reactions:
  - Solenoids now routinely used
  - Rings at present limited to few cases (astrophysics), for more general use still issues to be assessed
- Low momentum-transfer reactions
  - Rings (ESR) first measurements
  - Active targets may prove competitive
- Scope of rings is very broad – extremely exciting machines!