# The HELIOS spectrometer at Argonne

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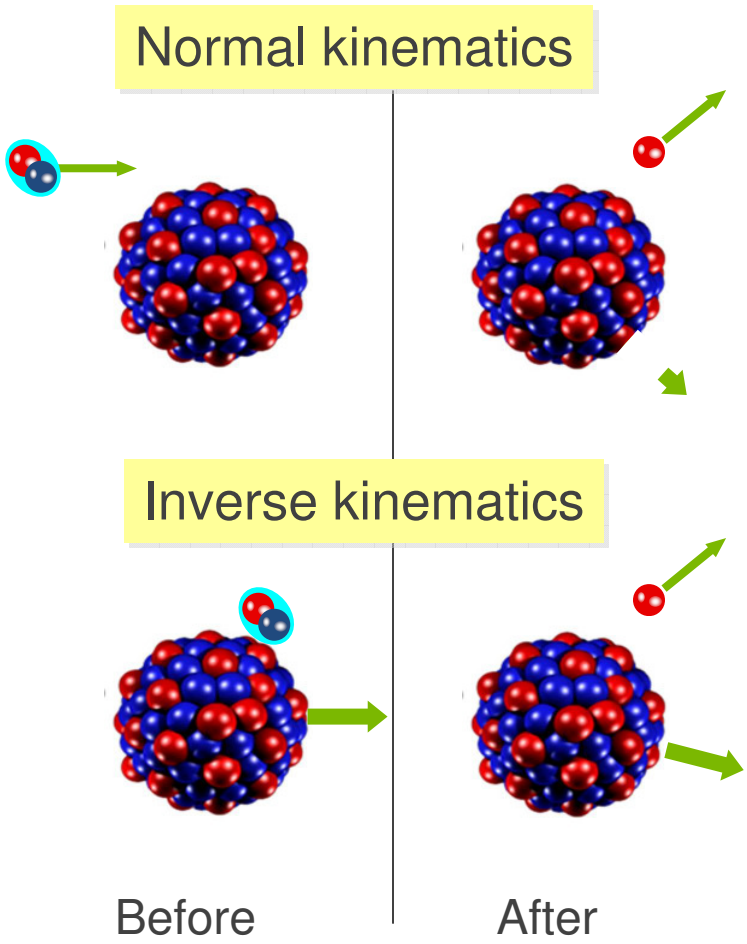
# Outline:

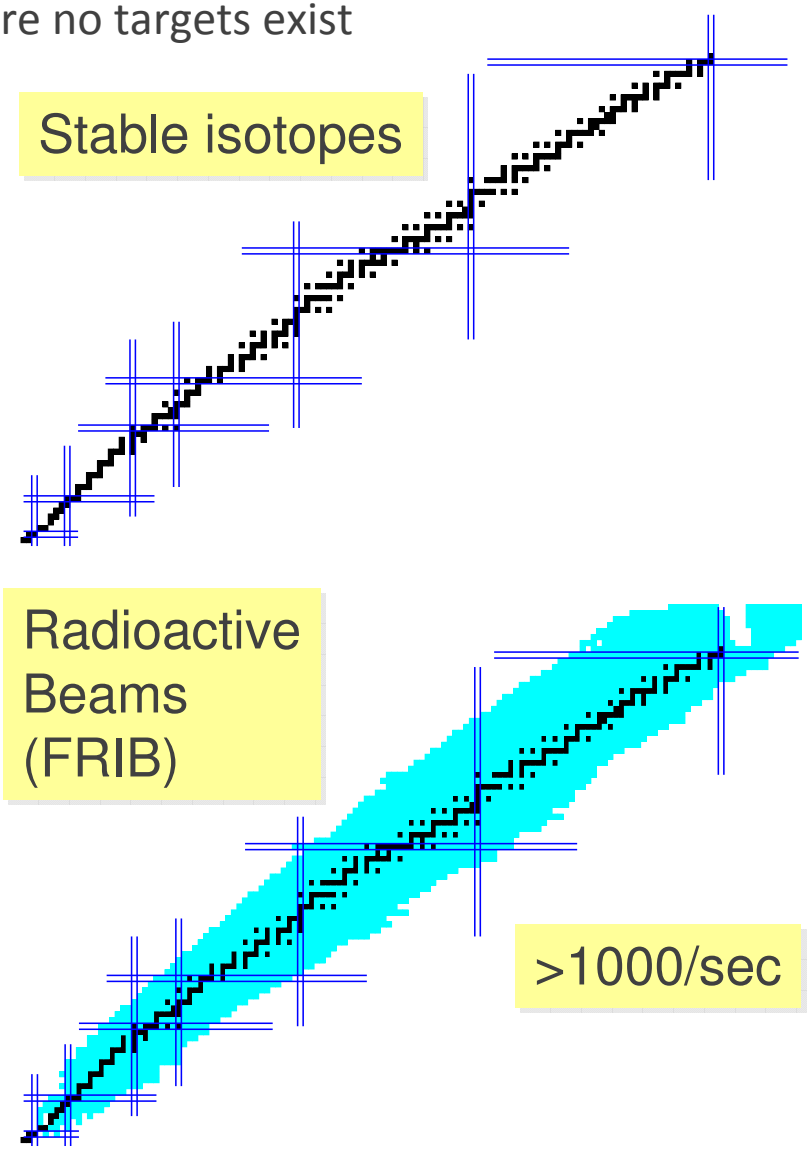
- Motivation for studying light-ion reactions in inverse kinematics
- The concept
- HELIOS at Argonne
- Some performance results
- HELIOS-type spectrometers elsewhere

# Motivation for studying light-ion reactions in inverse kinematics

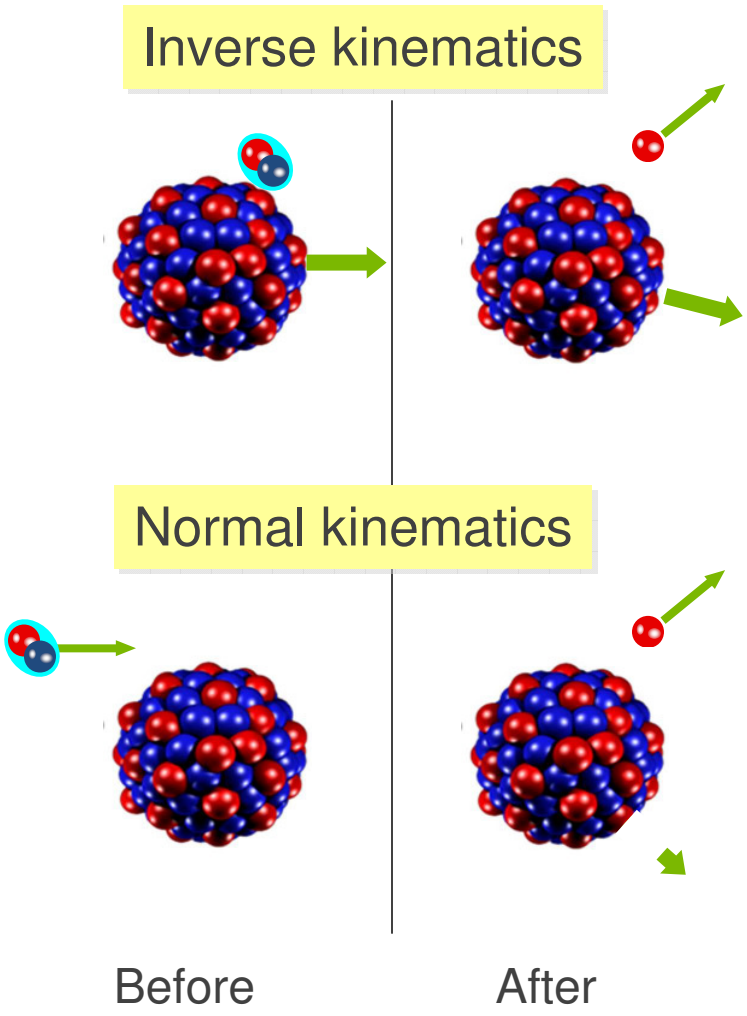
# Inverse kinematics – wide applications

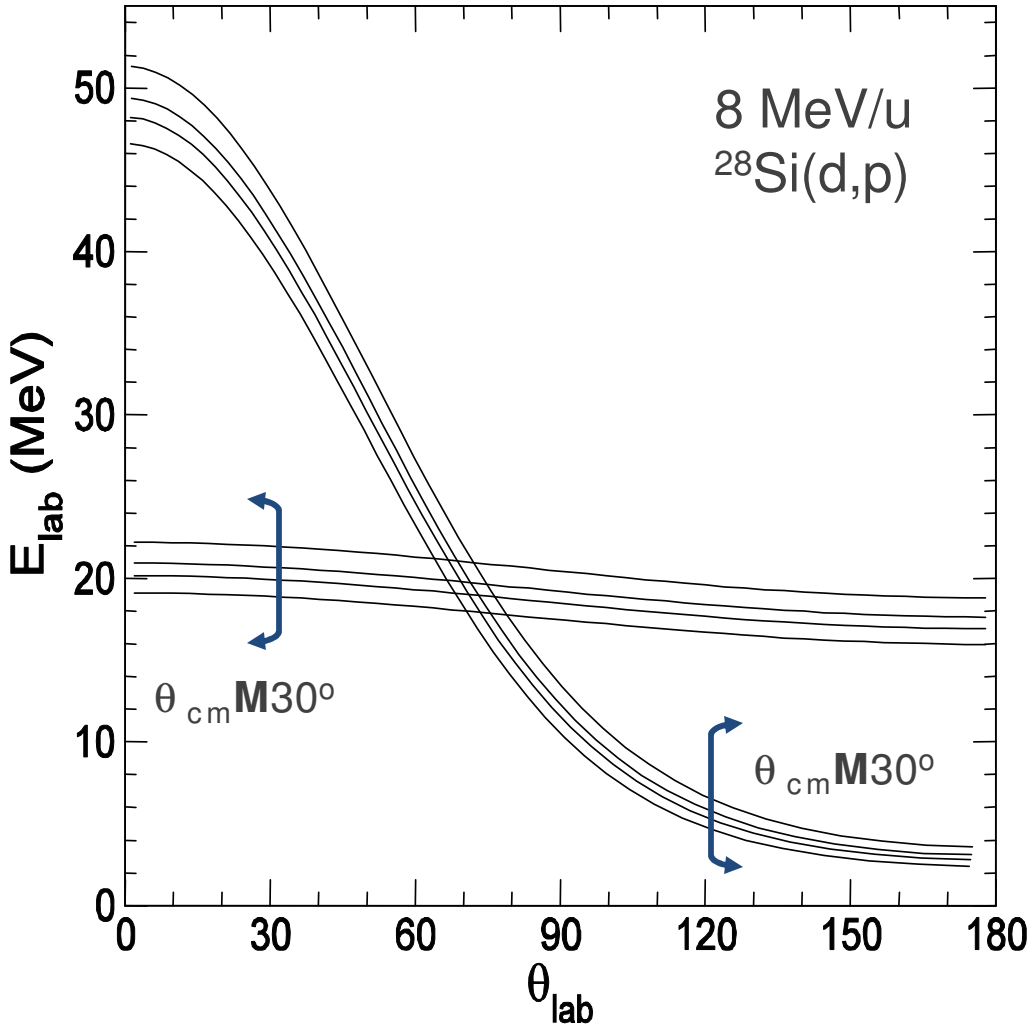
- Precision studies of nuclei in regions where no targets exist



# Inverse kinematics problem



# The HELIOS Spectrometer concept

# Principle of operation

HELIOS

**Measured quantities**

Flight time: $T_{flight}=T_{cyc}$

Position: $z$

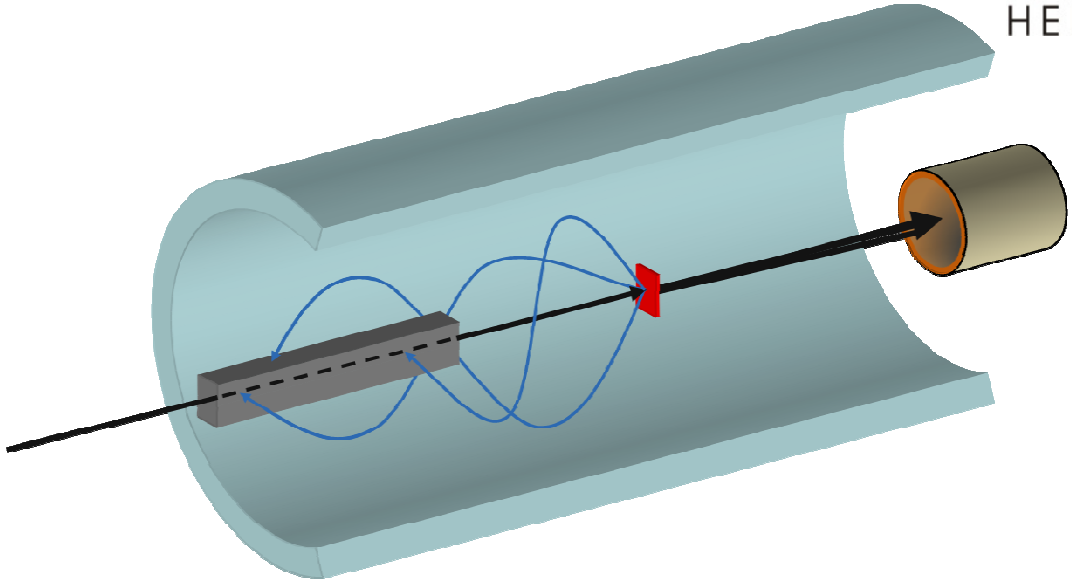
Energy: $E_{lab}$

**Derived quantities**

Part. ID: $m/q$

Energy: $E_{cm}$

Angle: $\theta_{cm}$



$$\frac{m}{q} = \frac{eB}{2\pi} \times T_{flight}$$

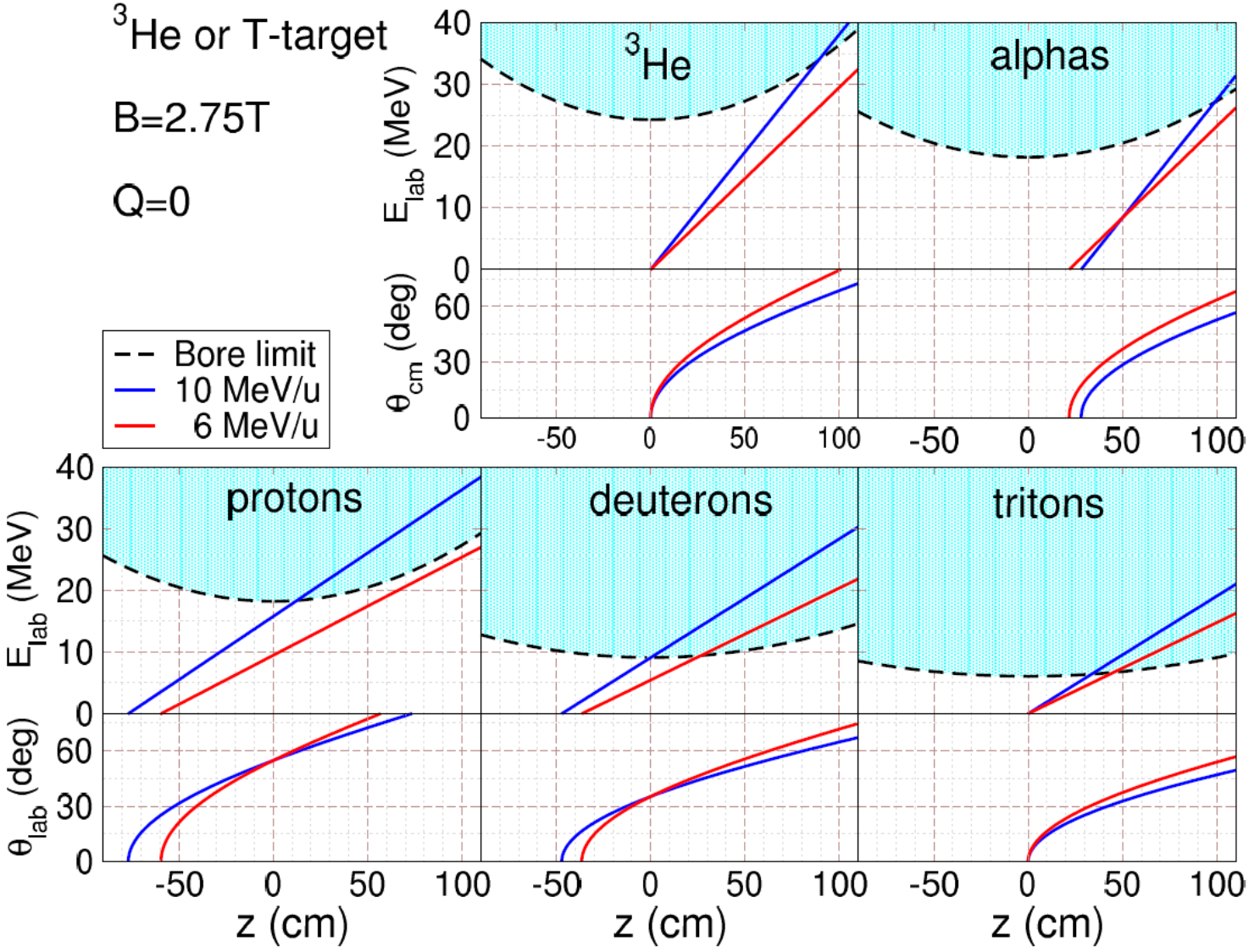
$$E_{cm} = E_{lab} + \tfrac{1}{2} m V_{cm}^2 - \frac{V_{cm} qeB}{2\pi} z$$

$$\theta_{cm} = \arccos\left( \frac{1}{2\pi} \frac{qeBz - 2\pi m V_{cm}}{\sqrt{2mE_{lab} + m^2 V_{cm}^2 - mV_{cm} qeBz/\pi}} \right)$$

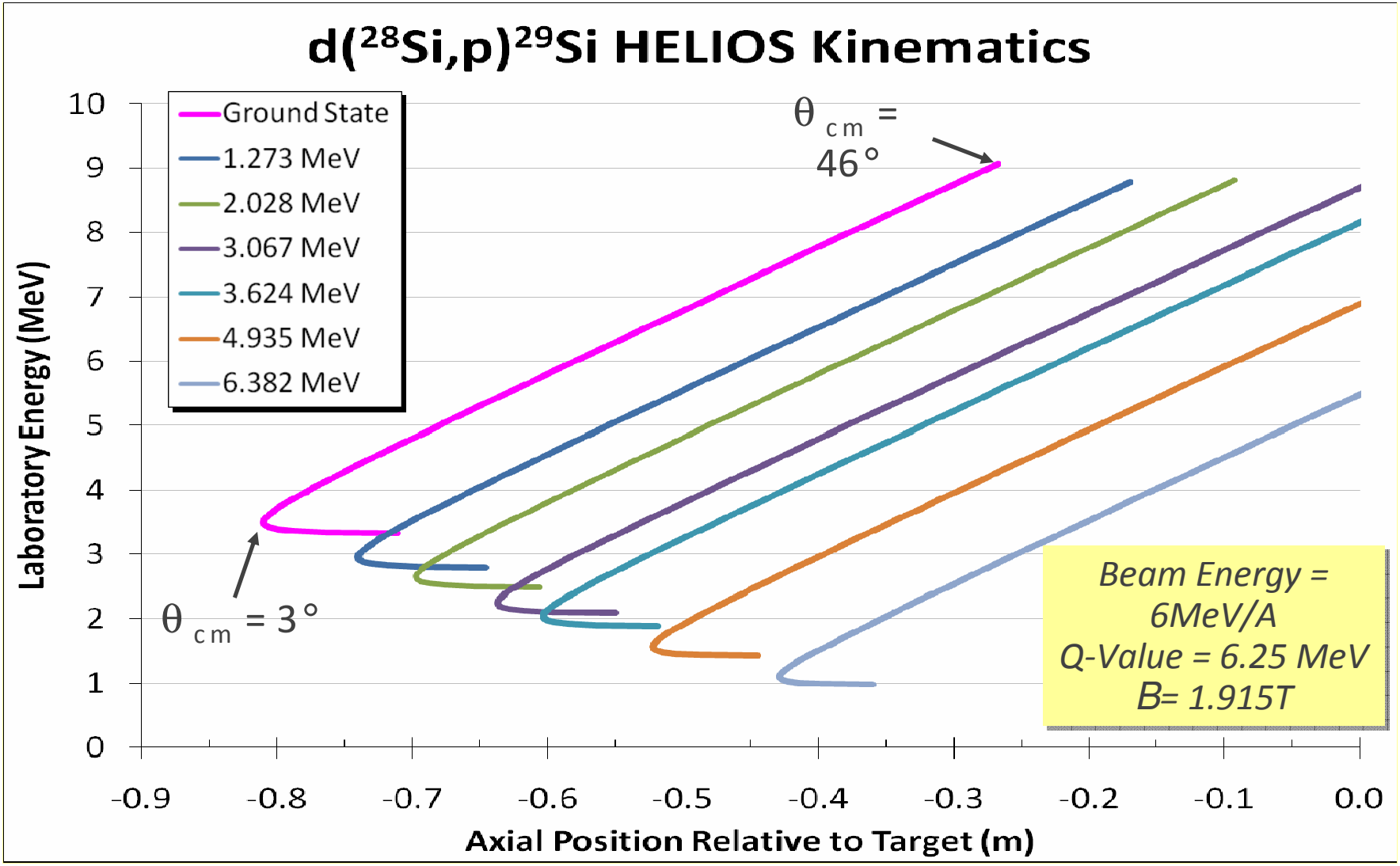
**B=2T**

| Particle | $T_{cyc}$ (ns) |
|---|---|
| p | 34.2 |
| $^3He^{2+}$ | 51.4 |
| d, α | 68.5 |
| t | 102.7 |

# Q=0 transfer reactions on $^3$He or T target



# Kinematics for the reaction d($^{28}$Si,p)$^{29}$Si





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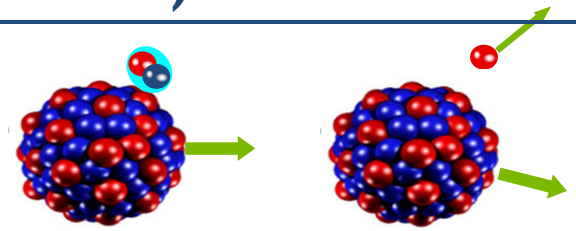
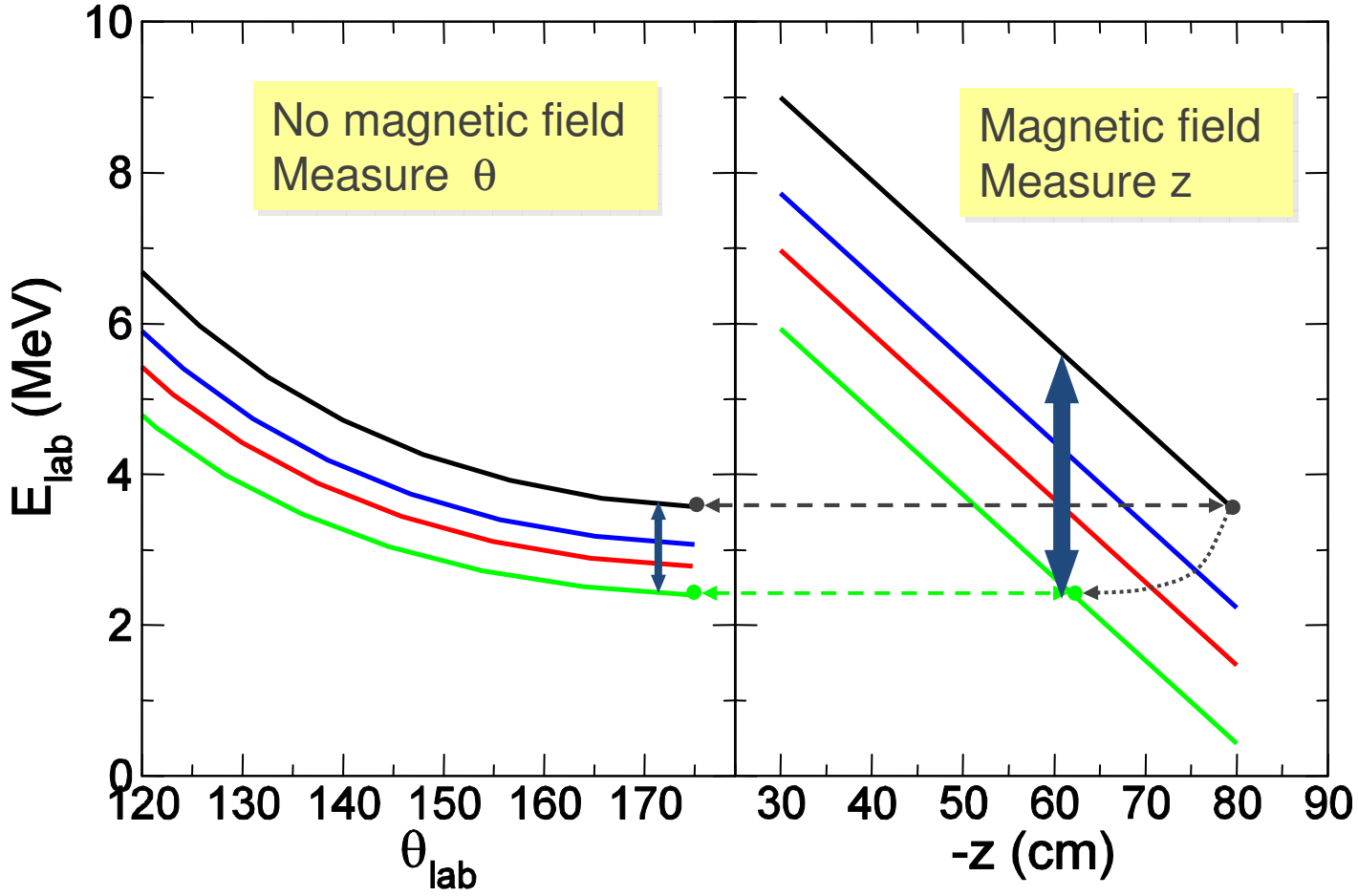
# Measure Θ or z (in magnetic field)?

Inverse kinematics





# The Argonne implementation of HELIOS

# The Siemens Magnet

*MRI Scanner in Tübingen, Monday, Nov 6, 2006*

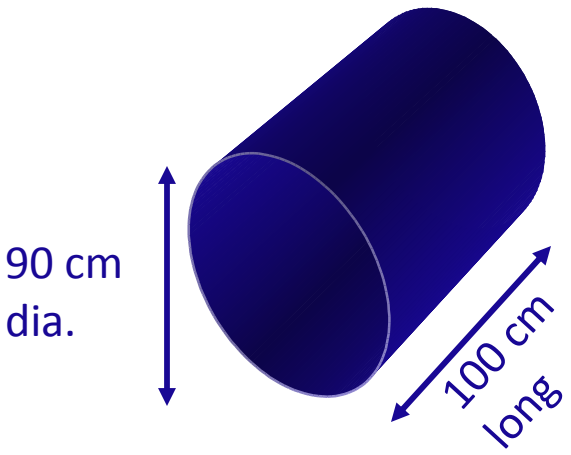

Ernst Rehm

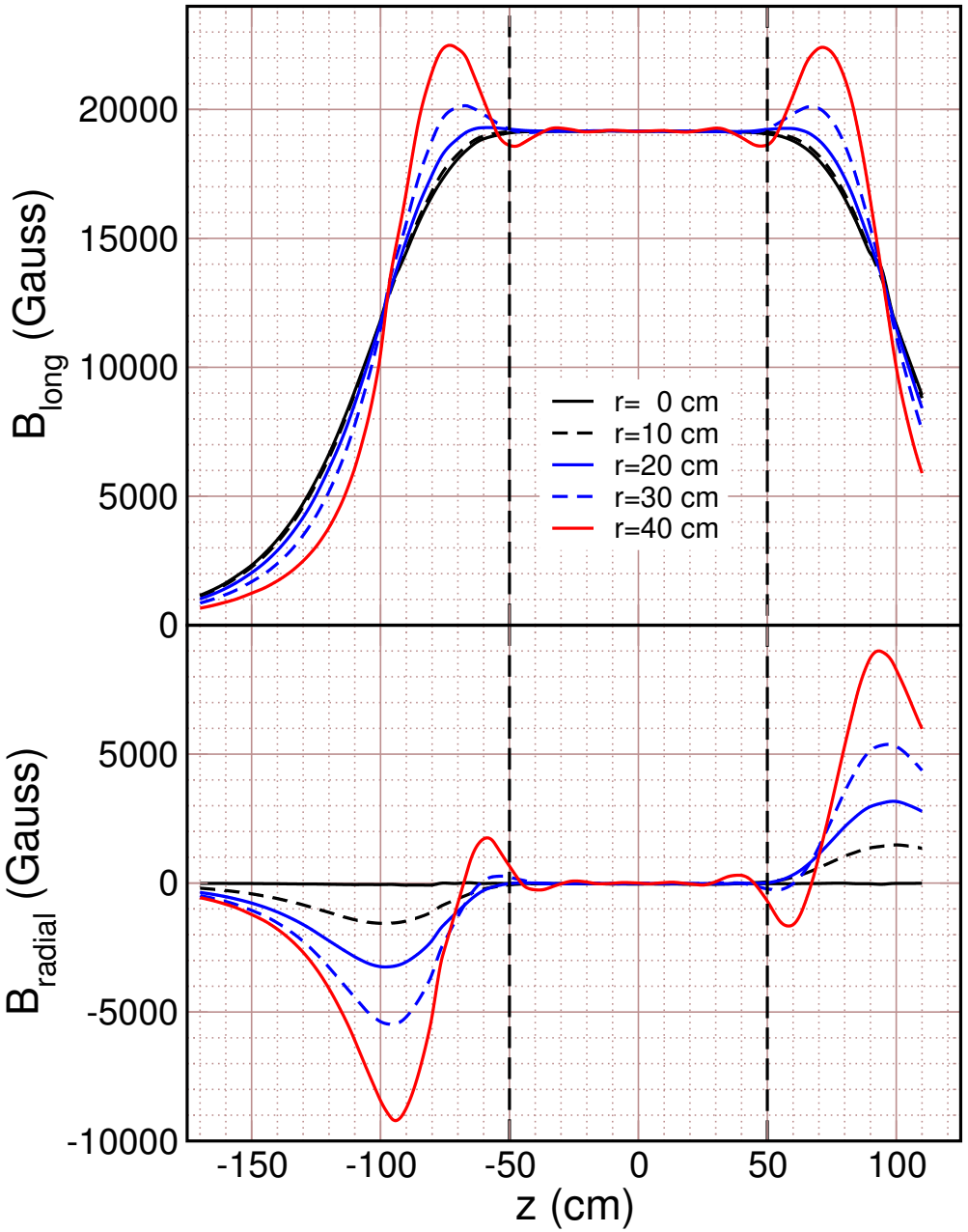
## Two days later

*onto the truck*

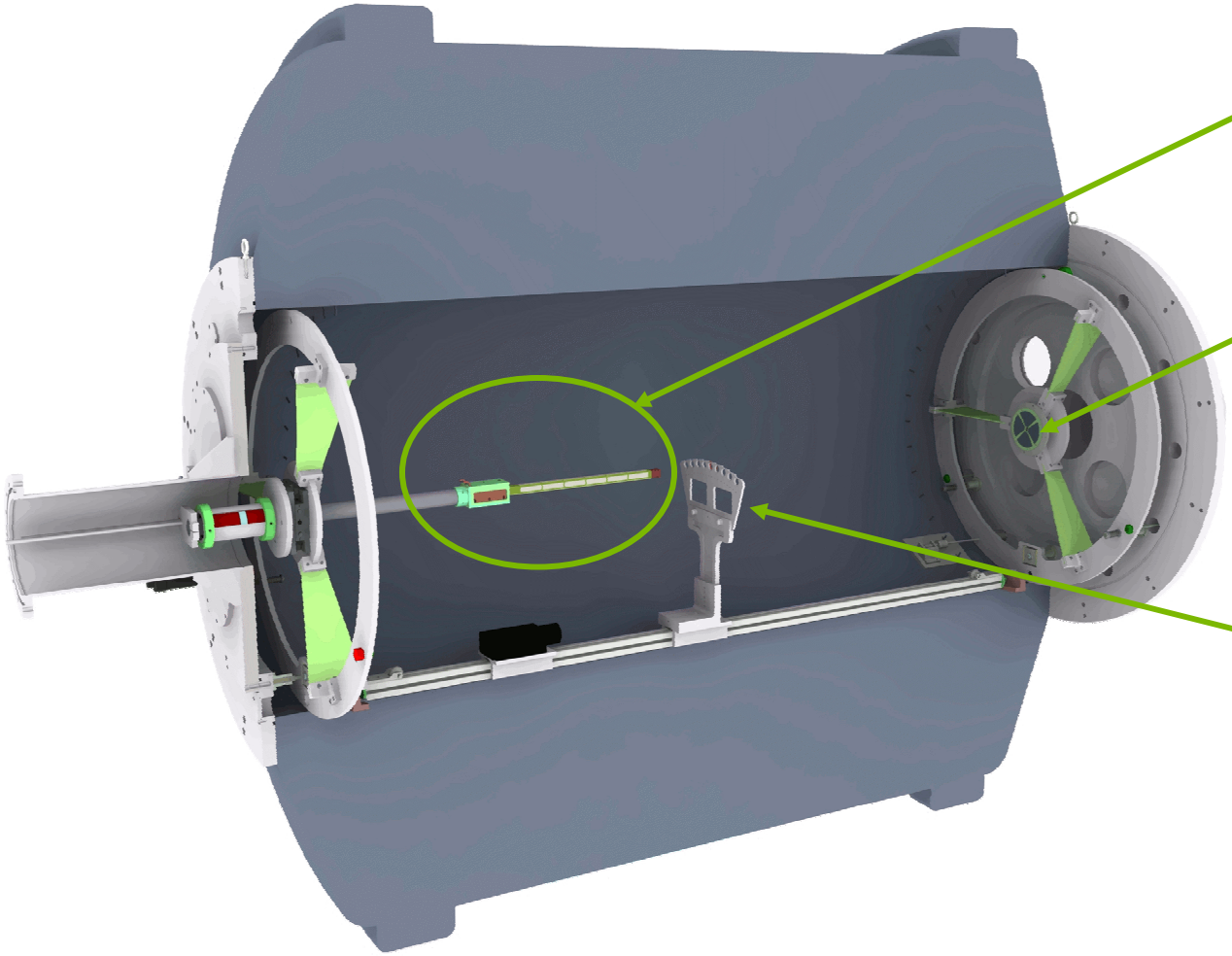
# HELIOS Field map

Homogeneous region

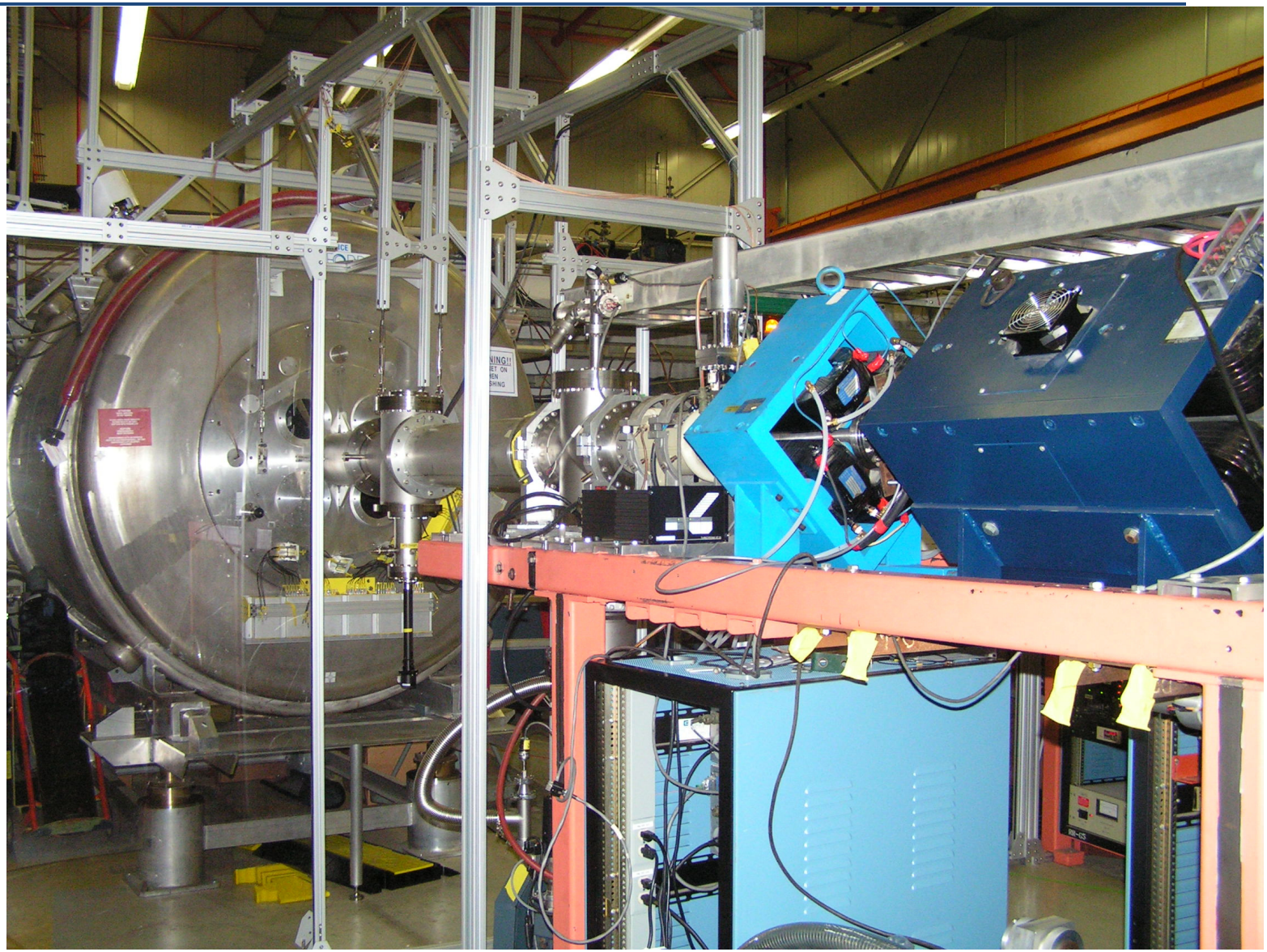


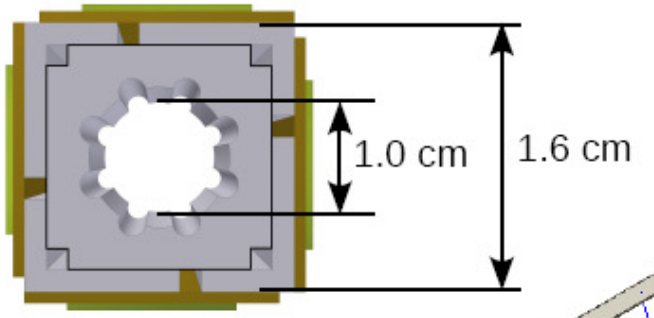
# Solenoid → Spectrometer



# July 2008, Installed - ready to go



# Prototype Si-detector array







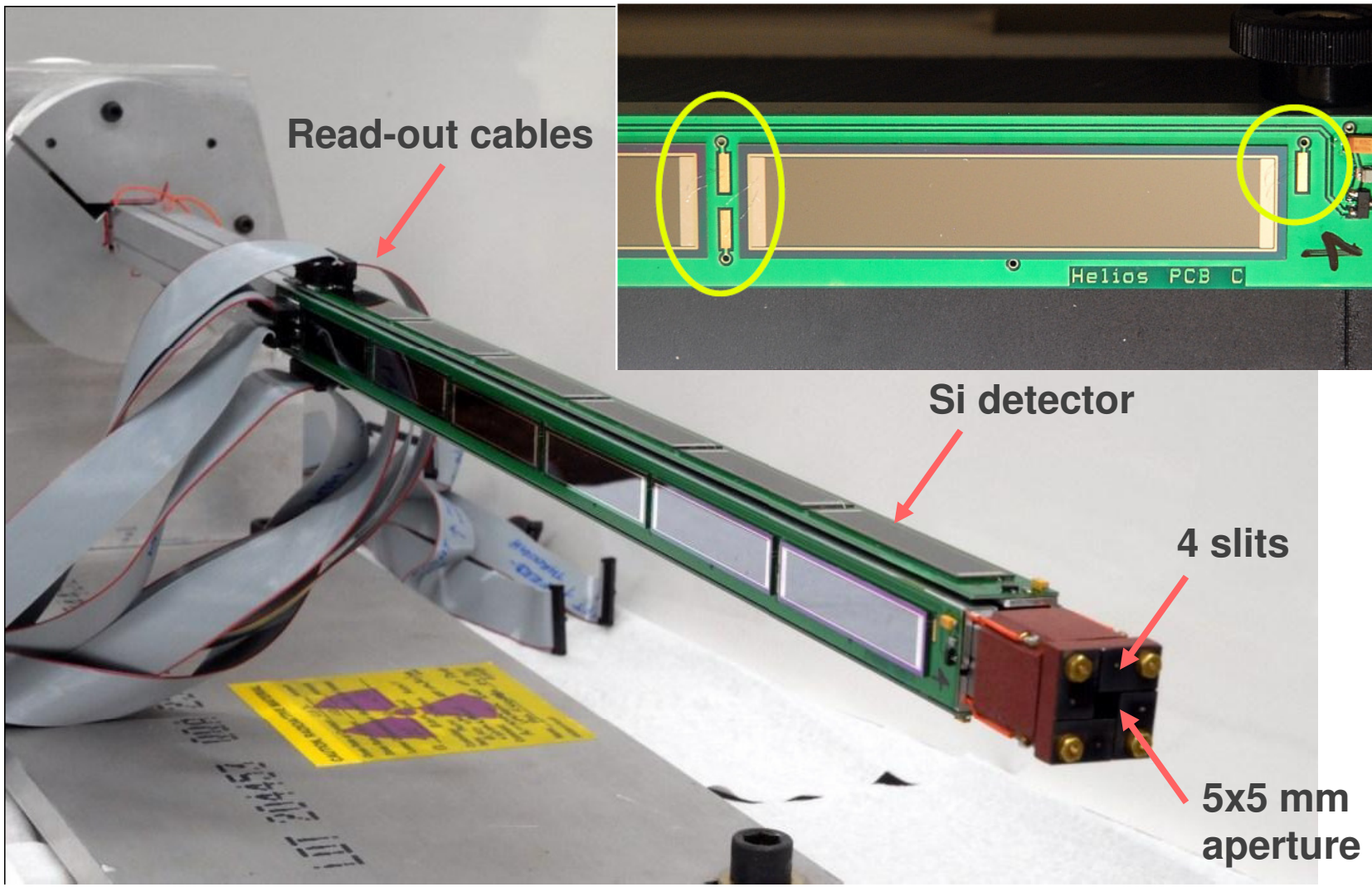



Position ≈ (X1-X2)/E

- Four detector modules in a rectangular configuration around a hollow aluminum rail
- Six 500 μm x 5.6 cm x 1.2 cm detectors per module
- Three channels per detector (72 total)

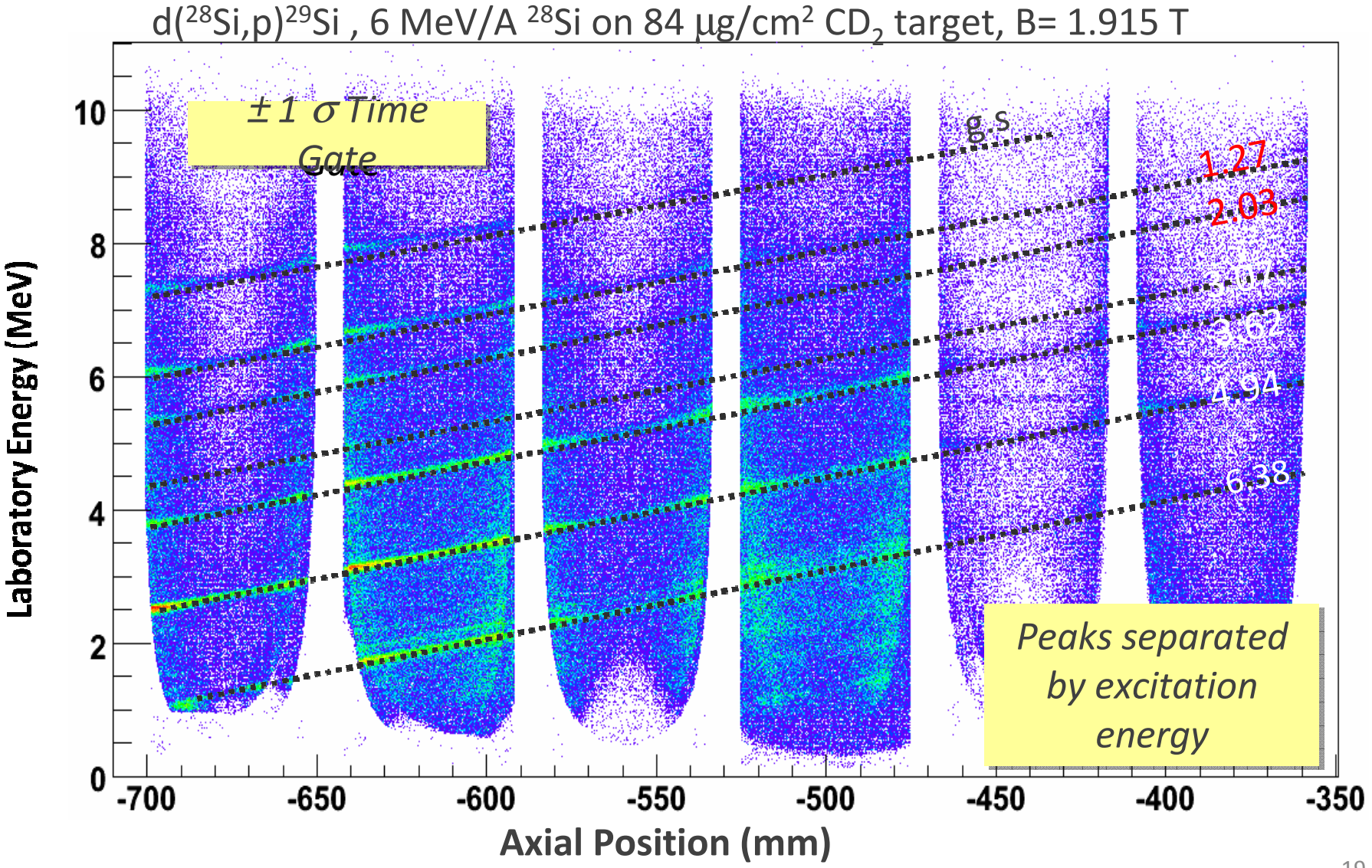
Isolated slits for beam tuning and collimation (5 x 5 $mm^2$)

# Assembled prototype array

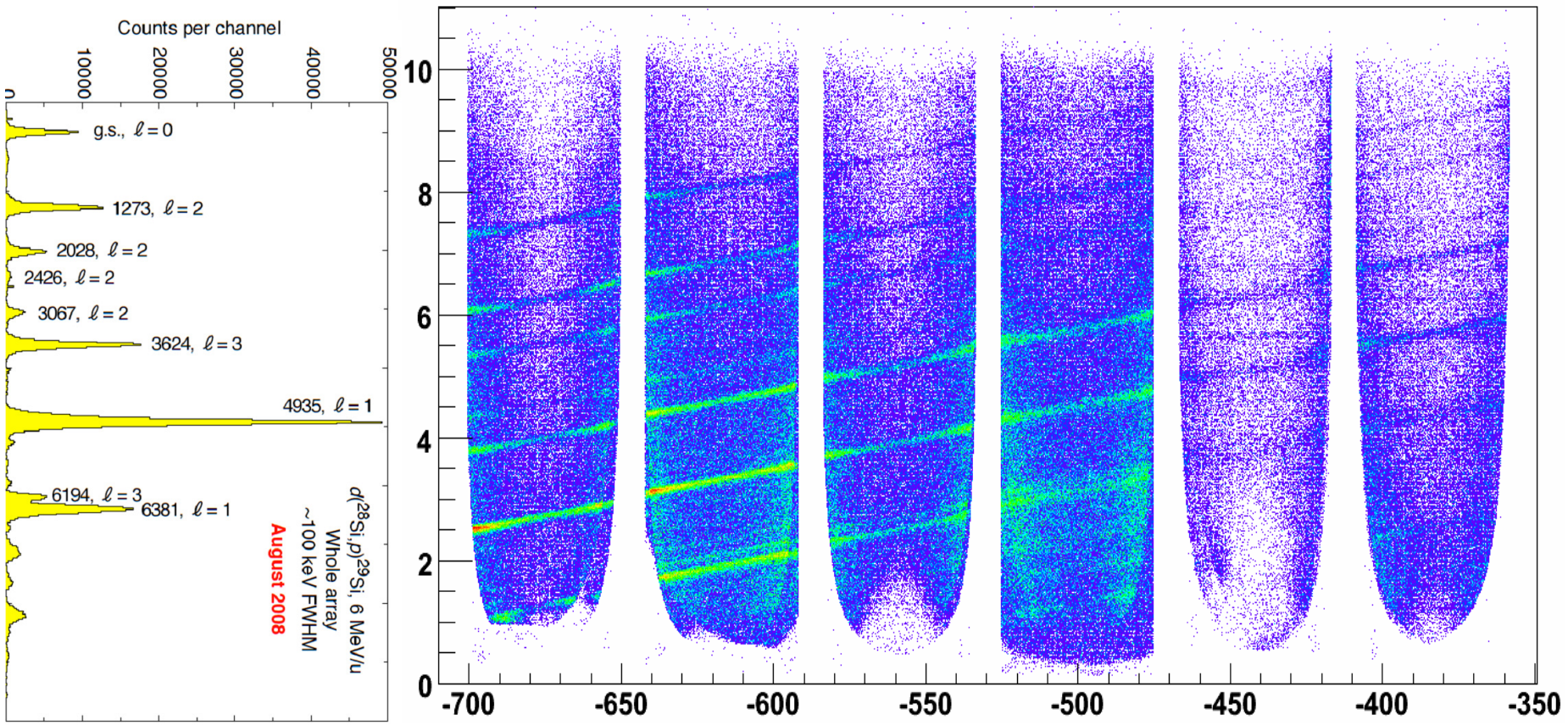


# Some performance results

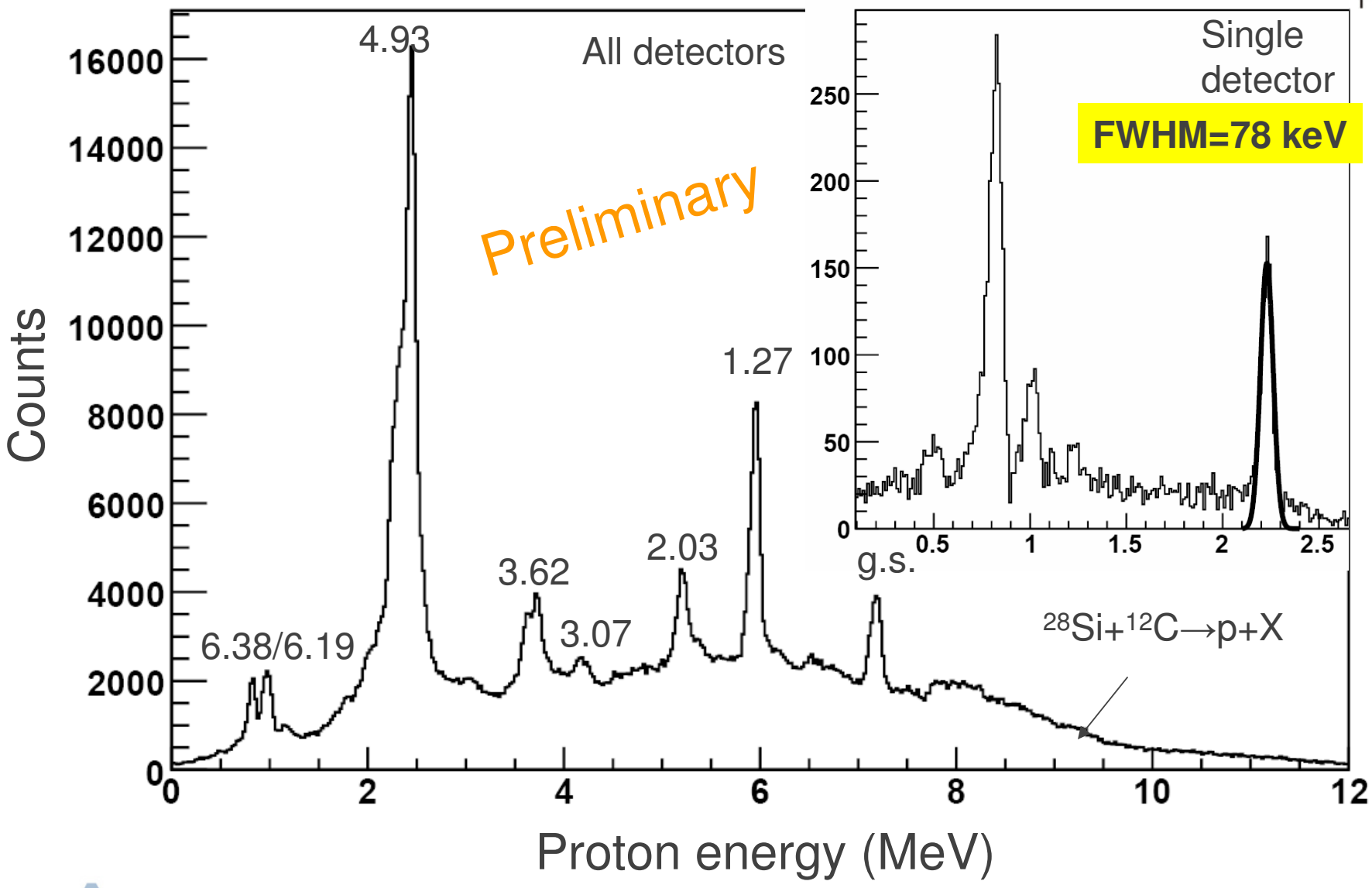
# Comissioning experiment: August 2008



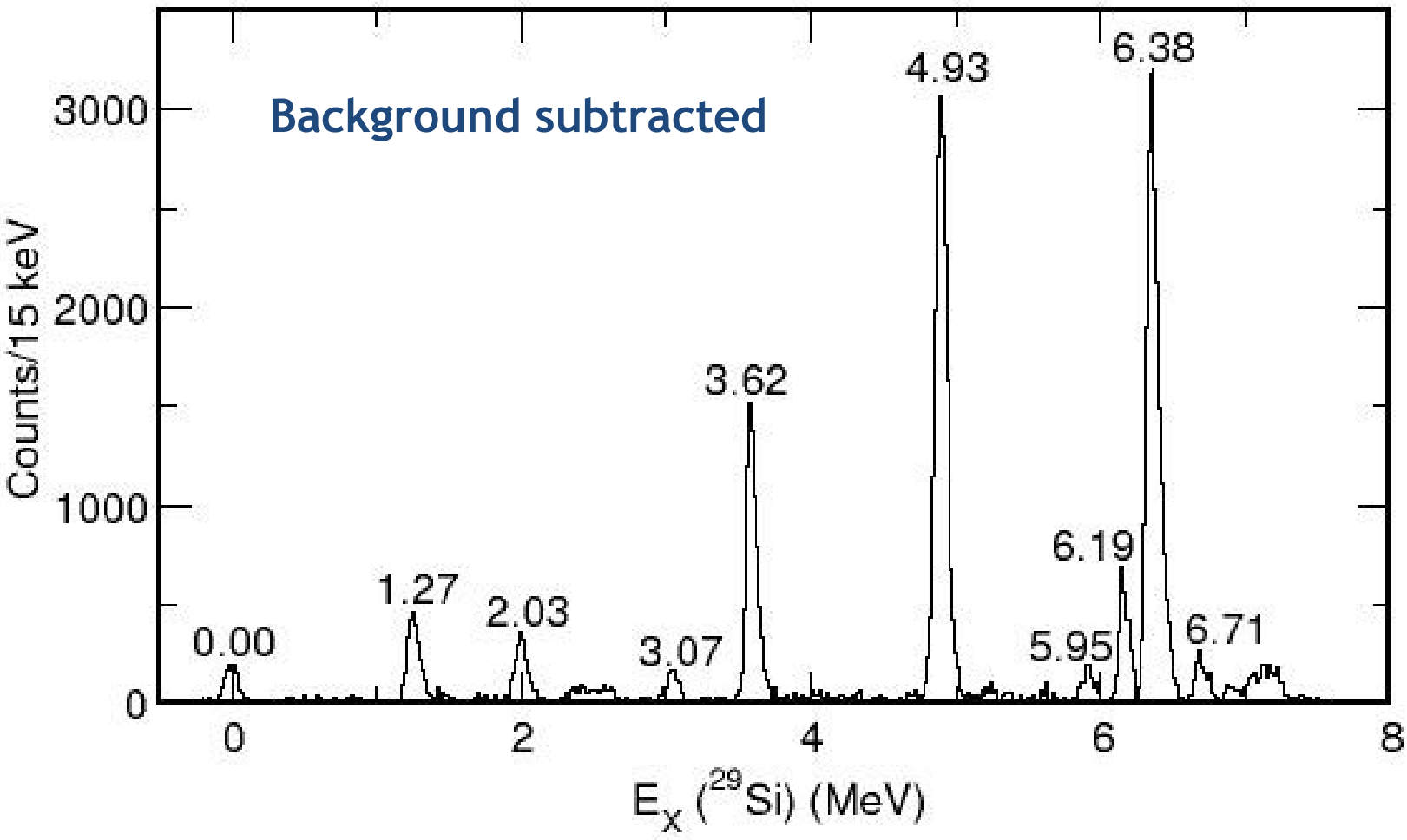
# Lab energy - excitation energy



# First HELIOS spectra



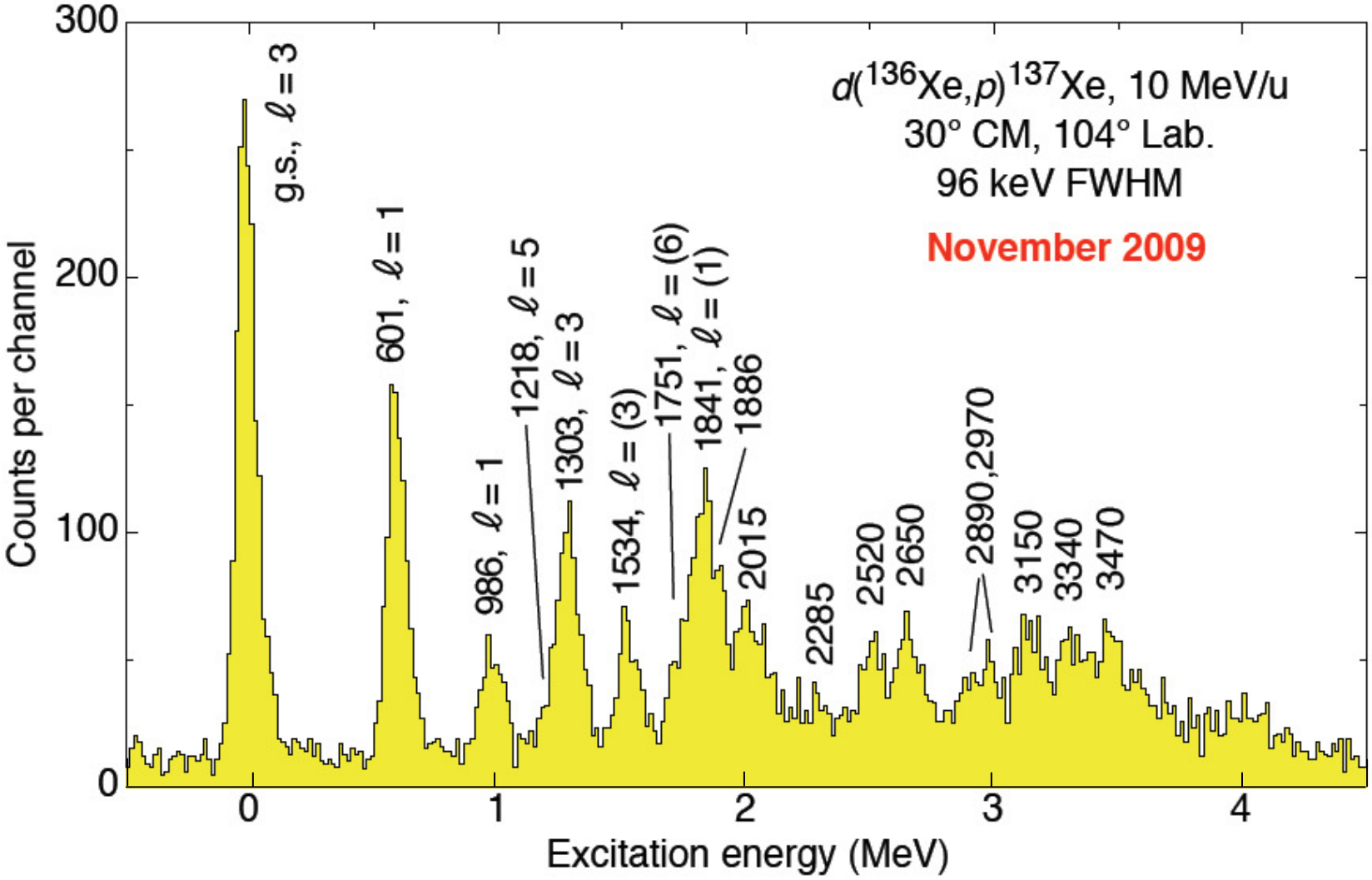
# Excitation energy spectrum for $^{28}Si(d,p)^{29}Si$




Typical resolution ~ 120 keV FWHM

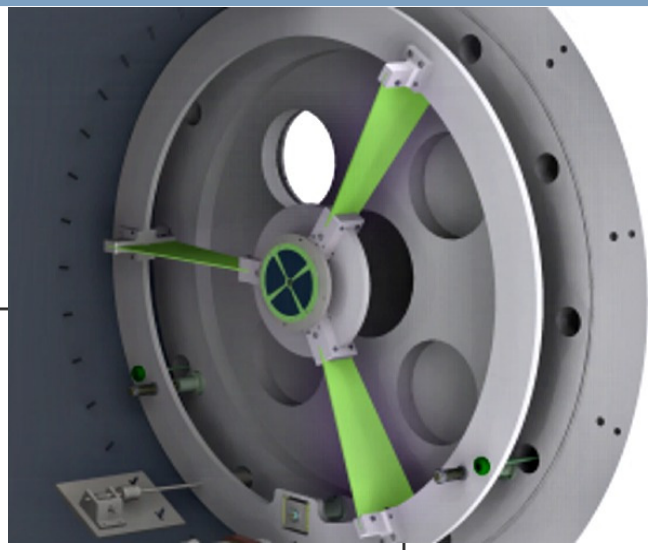
Best resolution ~ 75 keV FWHM

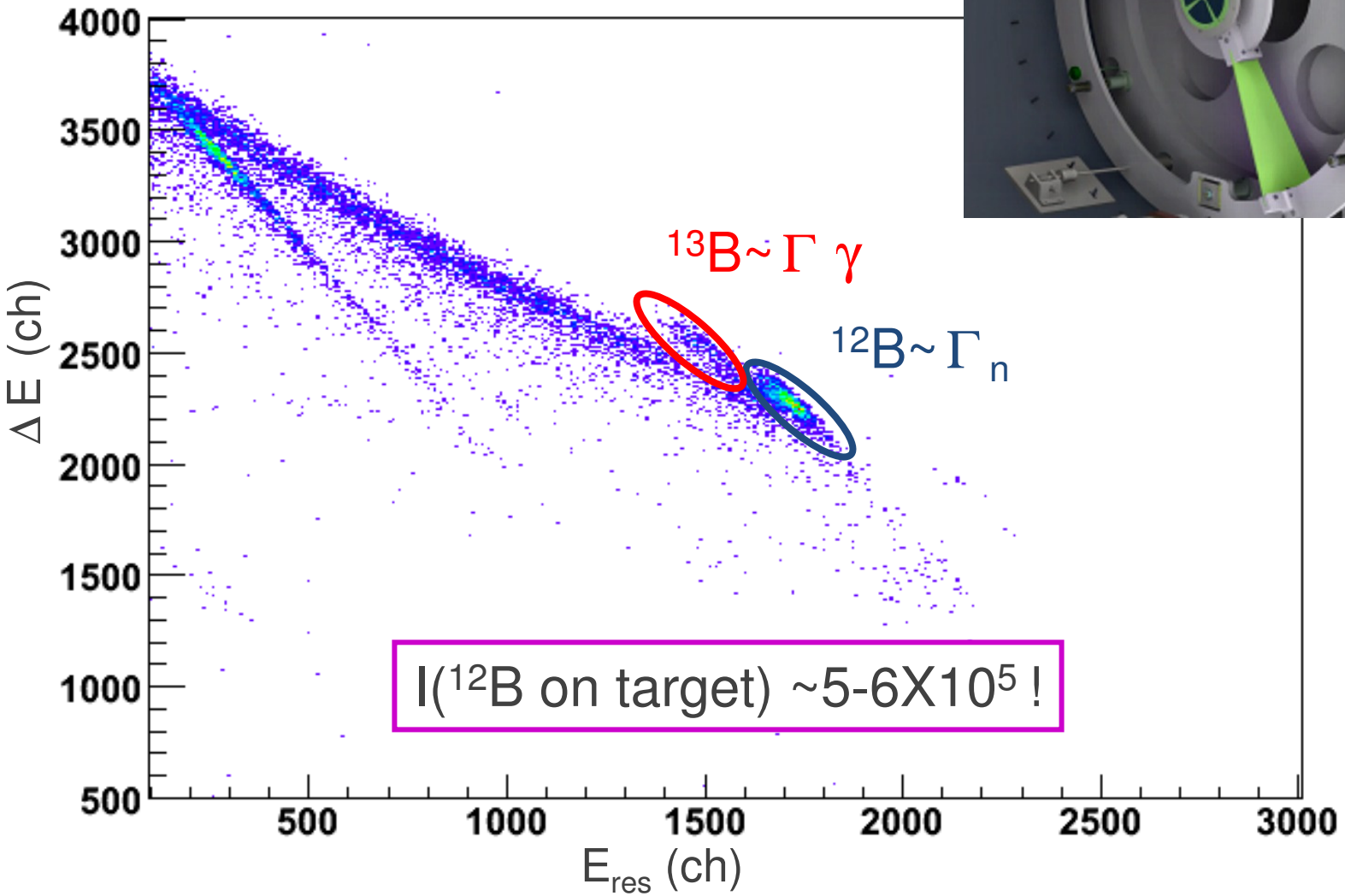
# $^{136}$Xe(d,p) online spectrum – B.Kay, Nov. 2009



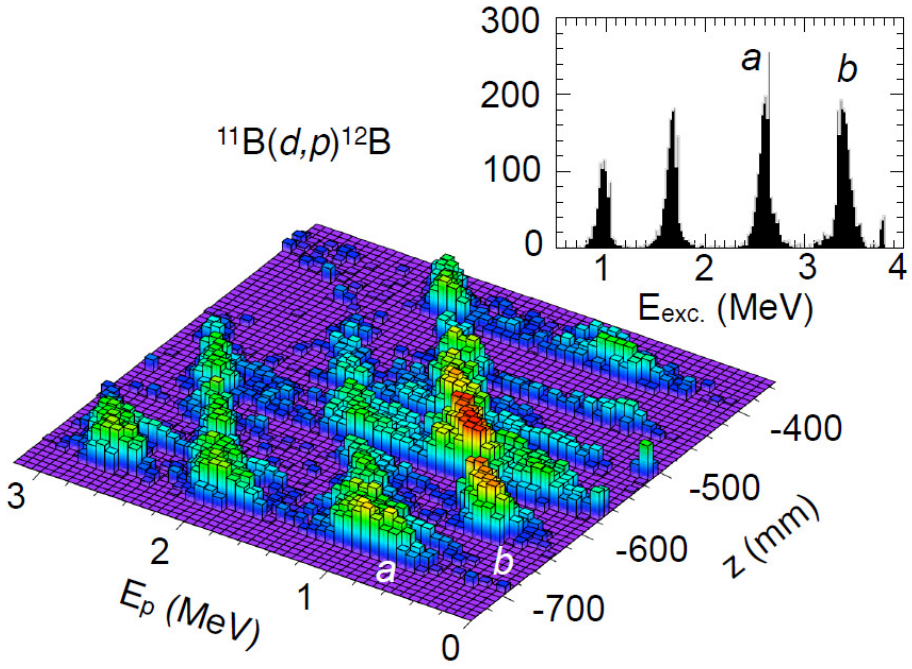
# $^{12}B/^{13}B$ particle ID

Si Telescope
Recoil Detector

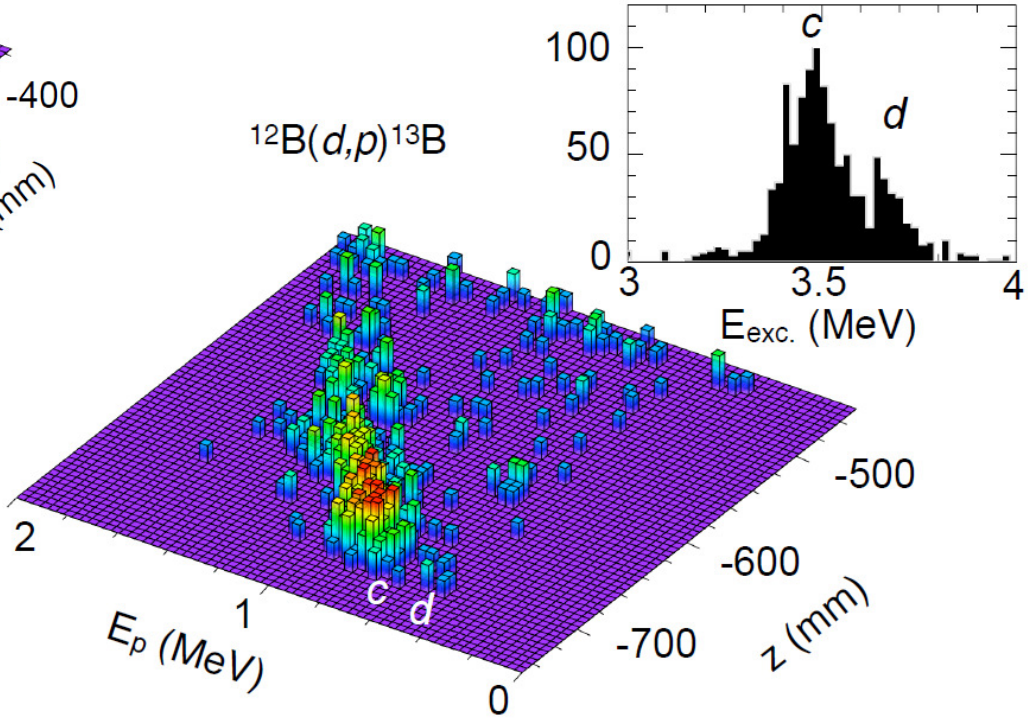




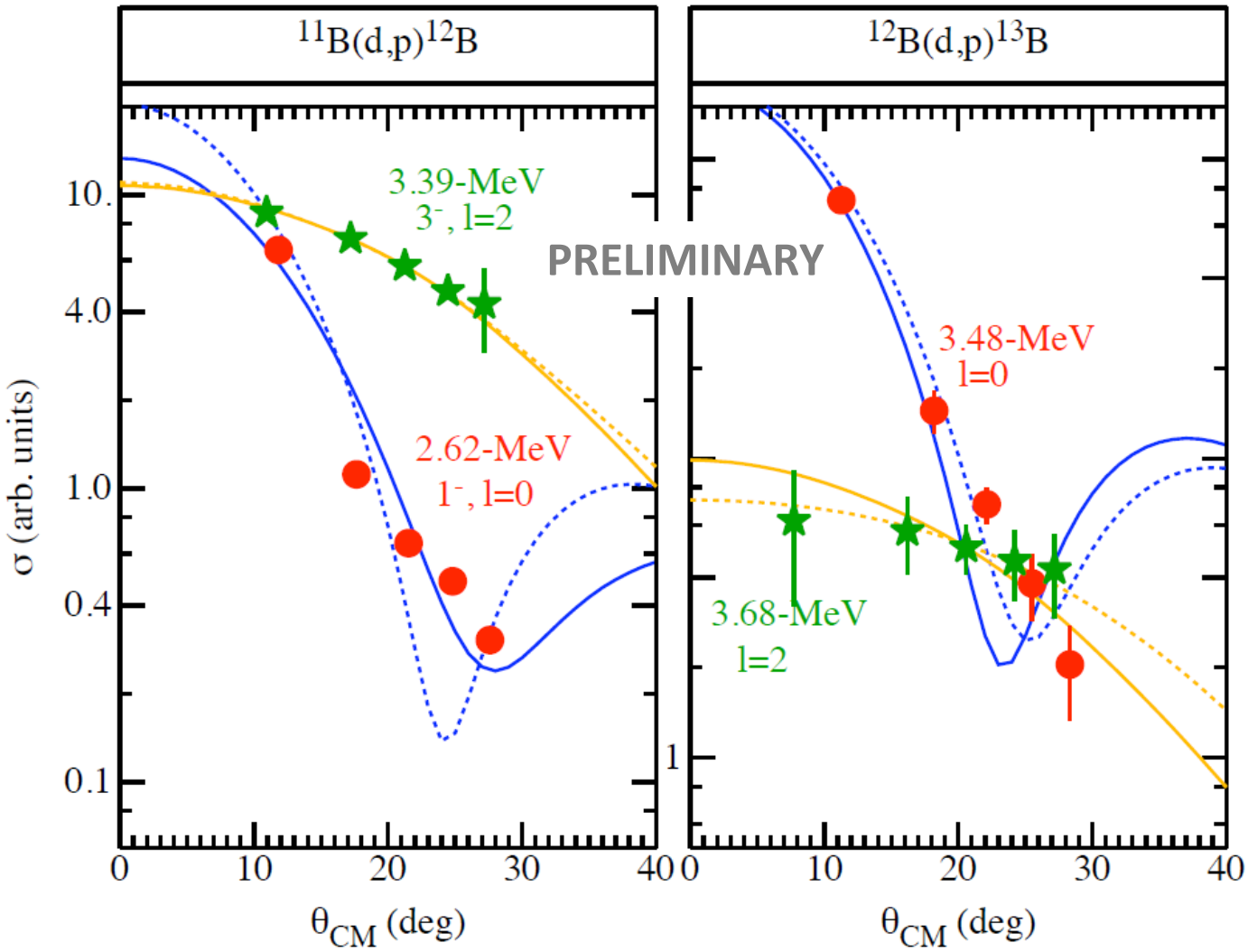
# $^{11}B(d,p)^{12}B$ and $^{12}B(d,p)^{13}B$ data




Separate two positive parity states at 3.48 and 3.68 MeV



# Angular distributions for $^{11,12}$B(d,p)



# HELIOS Experiments to date

- Aug. 2008 — $d(^{28}Si,p)^{29}Si$ — Commissioning experiment- stable beam
- Mar. 2009 — $d(^{12}B,p)^{13}B$ — Commissioning w. radioactive beam
- Aug. 2009 — $d(^{17}O,p)^{18}O$ — $\Gamma_n$ / $\Gamma_\gamma$ ratio of unbound states in $^{18}O$
  - $^{6}Li(^{14}C,d)^{18}O$ — - " –
  - Argonne National Laboratory
  - Western Michigan University
  - Colorado School of Mines
  - Lawrence Berkeley National Laboratory
- Aug. 2009 — $d(^{15}C,p)^{16}C$ — Spec. factors for n-transfer to $0^+$, $2^+$, and $3^+$ states
  - Western Michigan University
  - Argonne National Laboratory
  - University of Manchester, UK
  - Lawrence Berkeley National Laboratory
- Nov. 2009 — $d(^{136}Xe,p)^{137}Xe$ — Systematics of s.p. states outside N=82 shell
  - $d(^{130}Xe,p)^{131}Xe$ — Occupancy of s.p. states – $\beta\beta0\nu$ COURICINO
  - $d(^{124}Xe,p)^{125}Xe$ — Spec. factor of $11/2^-$ state $h_{11/2}$ orbital
  - Argonne National Laboratory
  - Lawrence Berkeley National Laboratory
  - JINA, Michigan State University
  - University of Manchester, UK
  - University of Western Michigan

# Future HELIOS Experiments

## On the books

| | |
|---|---|
| $p(^{12}C,p)^{12}C$ | Pair decay branch in $0^+_2$ state in $^{12}C$ |
| | Michigan State University |
| | Western Michigan University |
| | Argonne National Laboratory |
| $d(^{20}Ne,t)^{19}Ne$ | Study of the breakout reaction $^{15}O(\alpha\ ,\ \gamma\ )^{19}N$ |
| | Argonne National Laboratory |
| | Michigan State University |
| | University of Western Michigan |
| | Colorado School of Mines |
| | Hebrew University, Jerusalem |
| | University of Chicago |

## Coming up

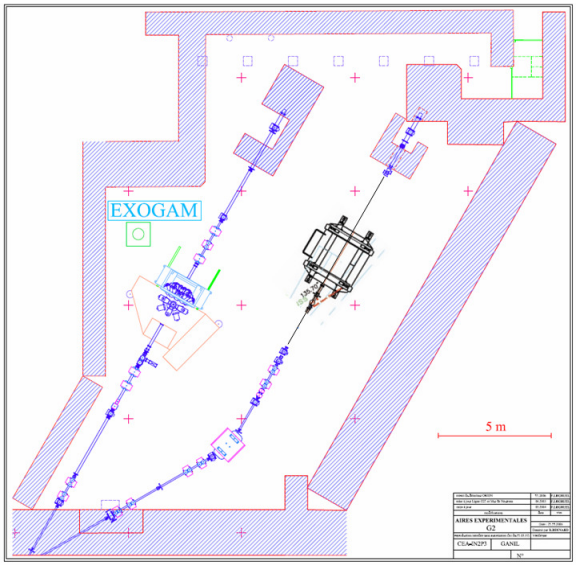
| | |
|---|---|
| $d(^{132}Sn,p)^{133}Sn$ | Studies near Z,N=50, 82 doubly magic shell w. |
| $d(^{134}Te,p)^{135}Te$ | CARIBU beams |

# Conclusion from HELIOS at ATLAS

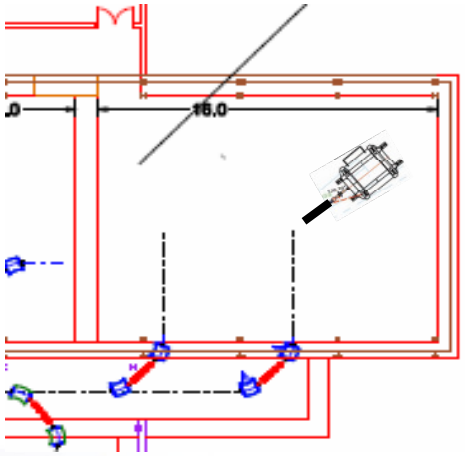
- The HELIOS concept has lived up to its promise
- Opens the study of transfer reactions for radioactive re-accelerated beams

# HELIOS-like spectrometer elsewhere

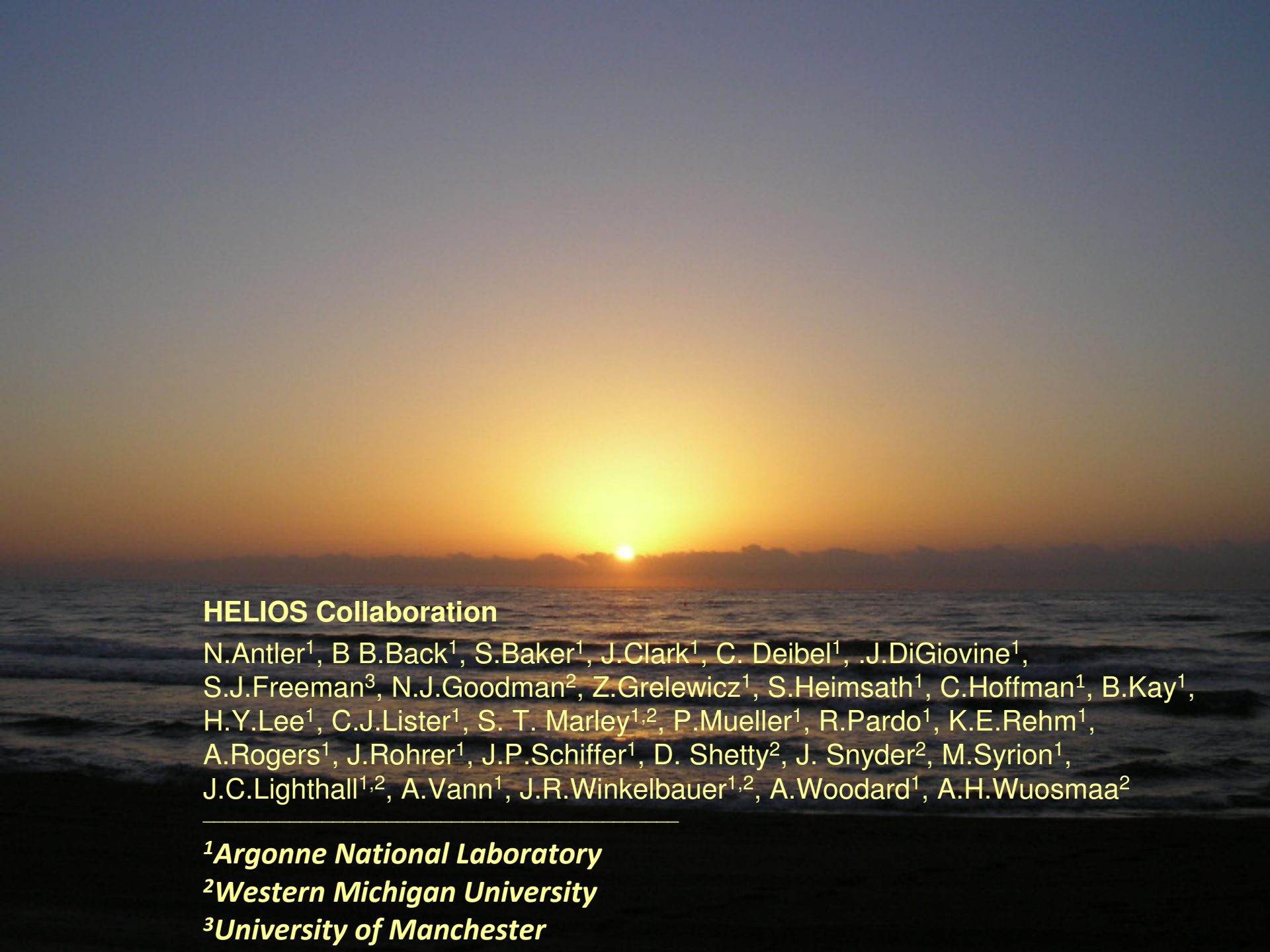
- HELIOS spectrometer at Spiral-2 (2013/14)
  - Proposal presented at Spiral-2 week, January 28, 2010
  - DOE funding proposal accepted




- HELIOS spectrometer at FRIB
  - Proposal presented at FRIB Instrumentation Workshop, February 20, 2010
  - Well received by FRIB Science Advisory Committee
  - No funding yet – collaboration in process of forming.



# Here is a nice big solenoid for you - Katrin through Leopoldshafen



**HELIOS Collaboration**

N.Antler[1], B B.Back[1], S.Baker[1], J.Clark[1], C. Deibel[1], .J.DiGiovine[1], S.J.Freeman[3], N.J.Goodman[2], Z.Grelewicz[1], S.Heimsath[1], C.Hoffman[1], B.Kay[1], H.Y.Lee[1], C.J.Lister[1], S. T. Marley[1,2], P.Mueller[1], R.Pardo[1], K.E.Rehm[1], A.Rogers[1], J.Rohrer[1], J.P.Schiffer[1], D. Shetty[2], J. Snyder[2], M.Syrion[1], J.C.Lighthall[1,2], A.Vann[1], J.R.Winkelbauer[1,2], A.Woodard[1], A.H.Wuosmaa[2]

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# The HELIOS Collaboration, August 2009