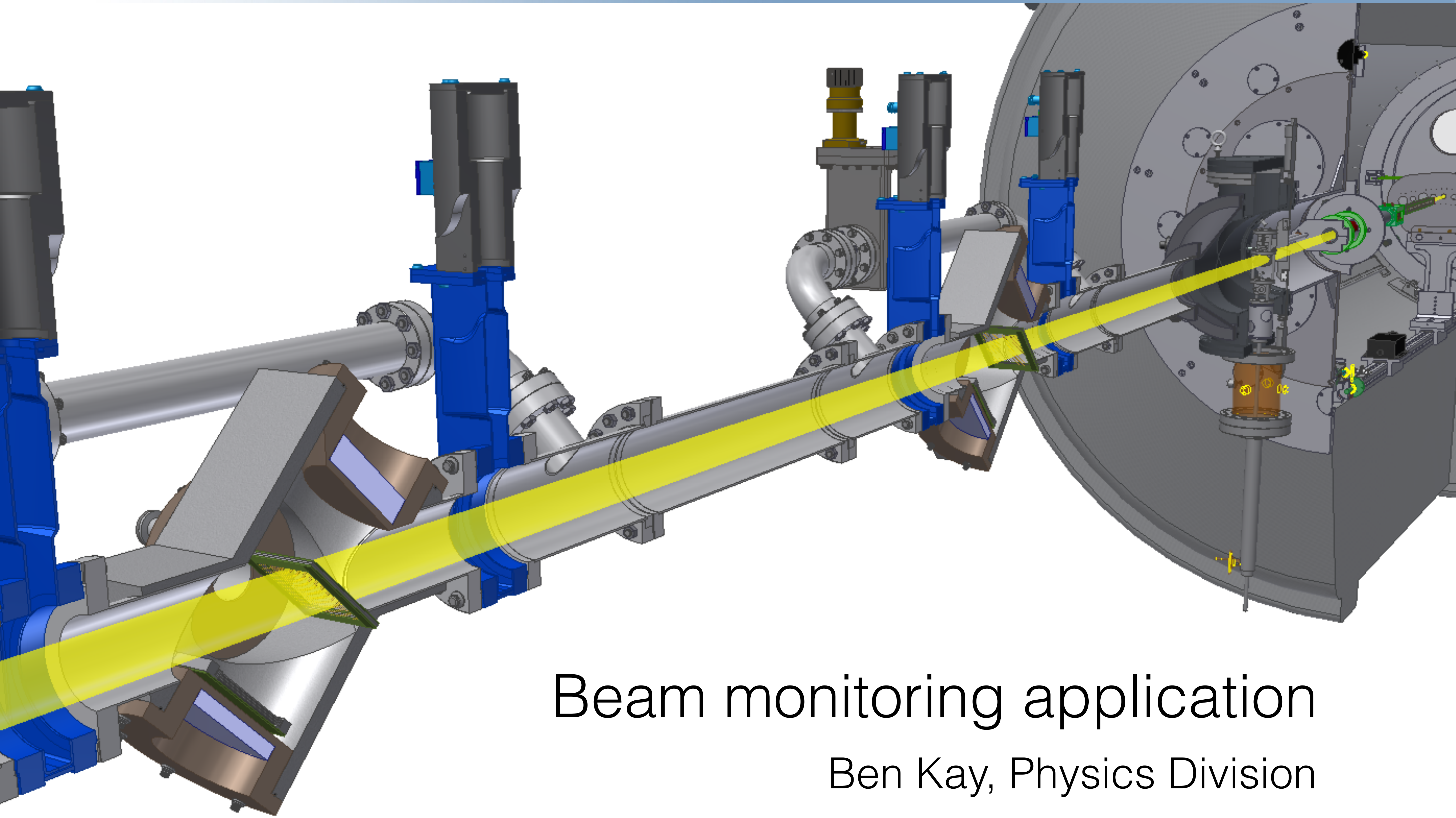

Beam monitoring application

Ben Kay, Physics Division

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(Argonne PHY, HEP, and ES Divisions)

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Overview

Brief overview of the ATLAS (not that one) facility at Argonne

- *Stable beams*
- *Radioactive ion beams, planned upgrades, beam quality*

The HELIOS spectrometer (among other instruments)

- *Outstanding Q-value resolution, limited by beam properties*

Key metrics for a beam tracking system

- *Correcting for physical beam size, longitudinal and transverse emittance, etc.*

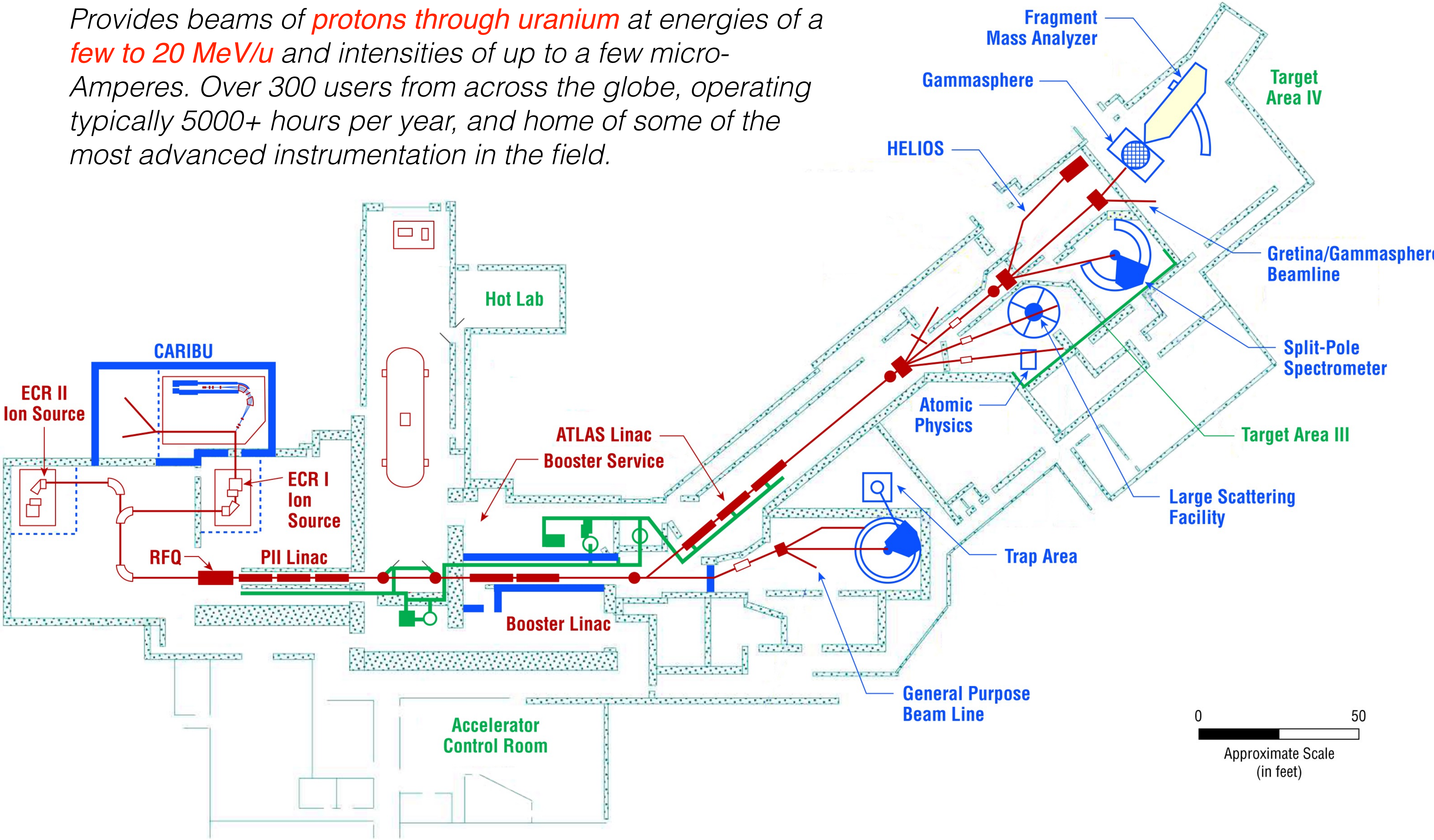
Possible application of MCP technology

- *Technique*
- *Preliminary designs and the way forward*

The ATLAS (not that one) facility

The nation's premier stable-beam facility …

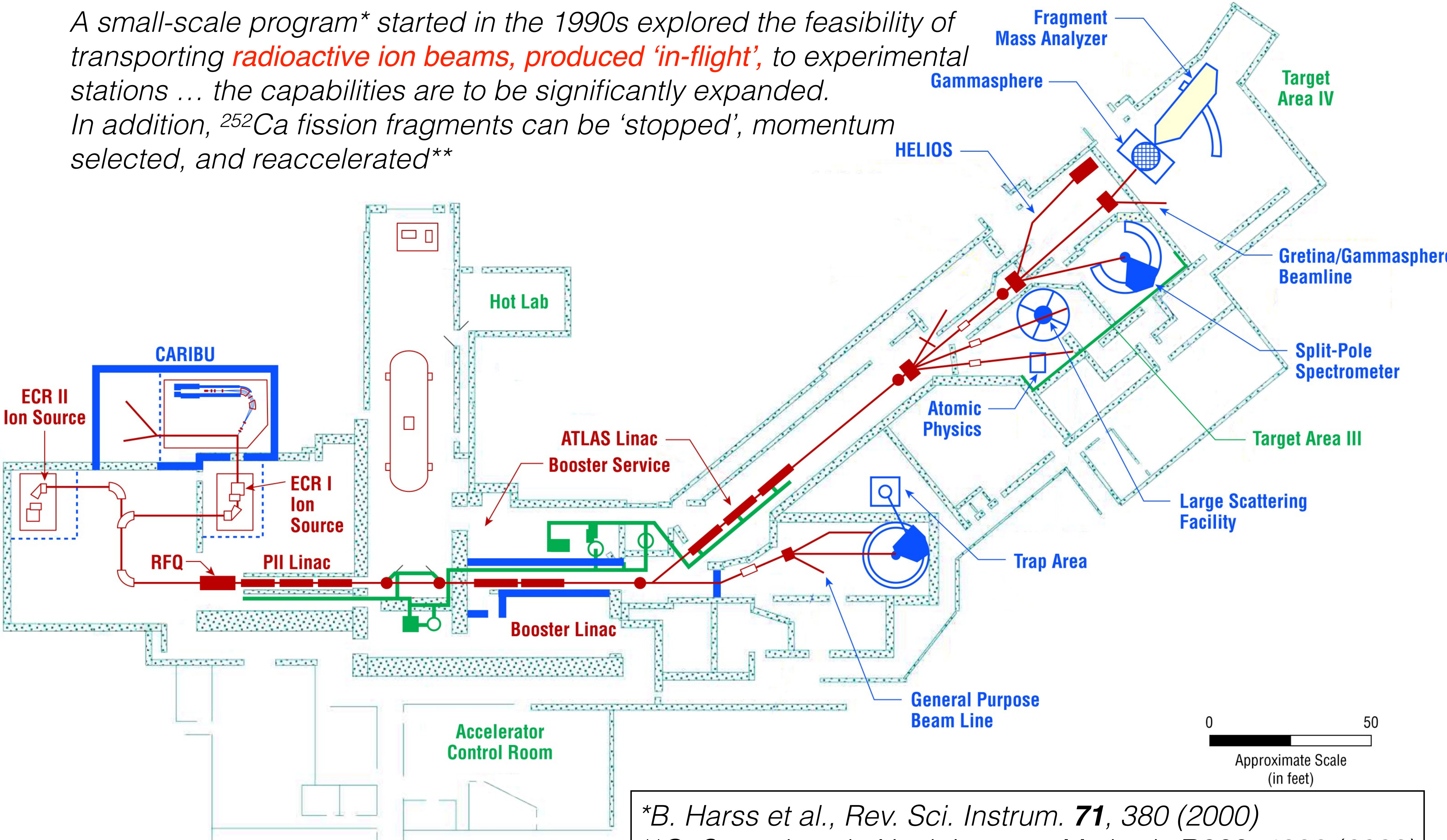
Provides beams of protons through uranium at energies of a few to 20 MeV/u and intensities of up to a few micro-Amperes. Over 300 users from across the globe, operating typically 5000+ hours per year, and home of some of the most advanced instrumentation in the field.



The ATLAS facility

… also radioactive ion beams

A small-scale program started in the 1990s explored the feasibility of transporting* *radioactive ion beams, produced 'in-flight',* *to experimental stations … the capabilities are to be significantly expanded.*
*In addition, ^{252}Ca fission fragments can be 'stopped', momentum selected, and reaccelerated***



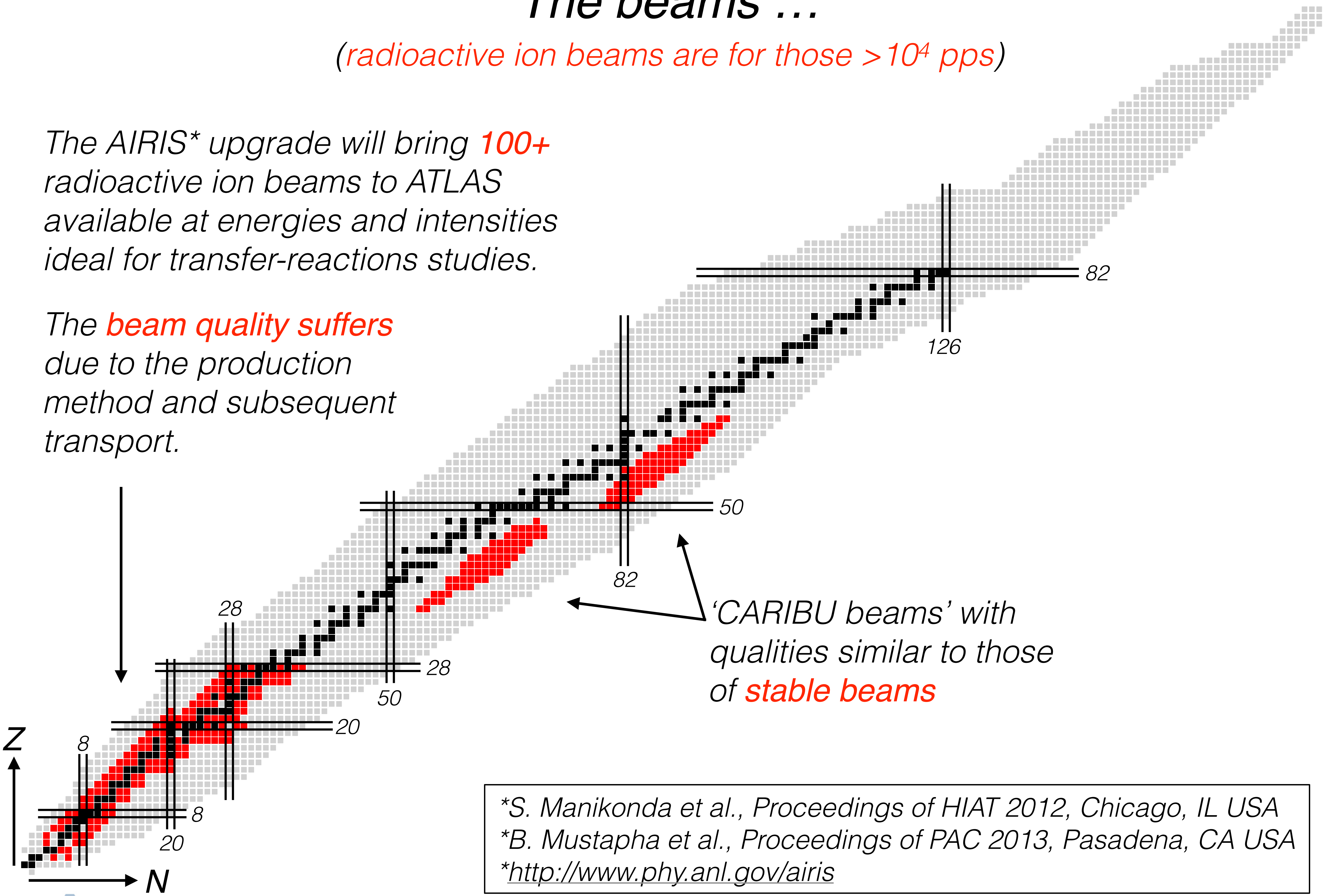
*B. Harss et al., Rev. Sci. Instrum. **71**, 380 (2000)
G. Savard et al., Nucl. Instrum. Methods **B266, 4086 (2008)

The beams …

(radioactive ion beams are for those >10^4 pps)

The AIRIS upgrade will bring* ***100+*** *radioactive ion beams to ATLAS available at energies and intensities ideal for transfer-reactions studies.*

The ***beam quality suffers*** *due to the production method and subsequent transport.*

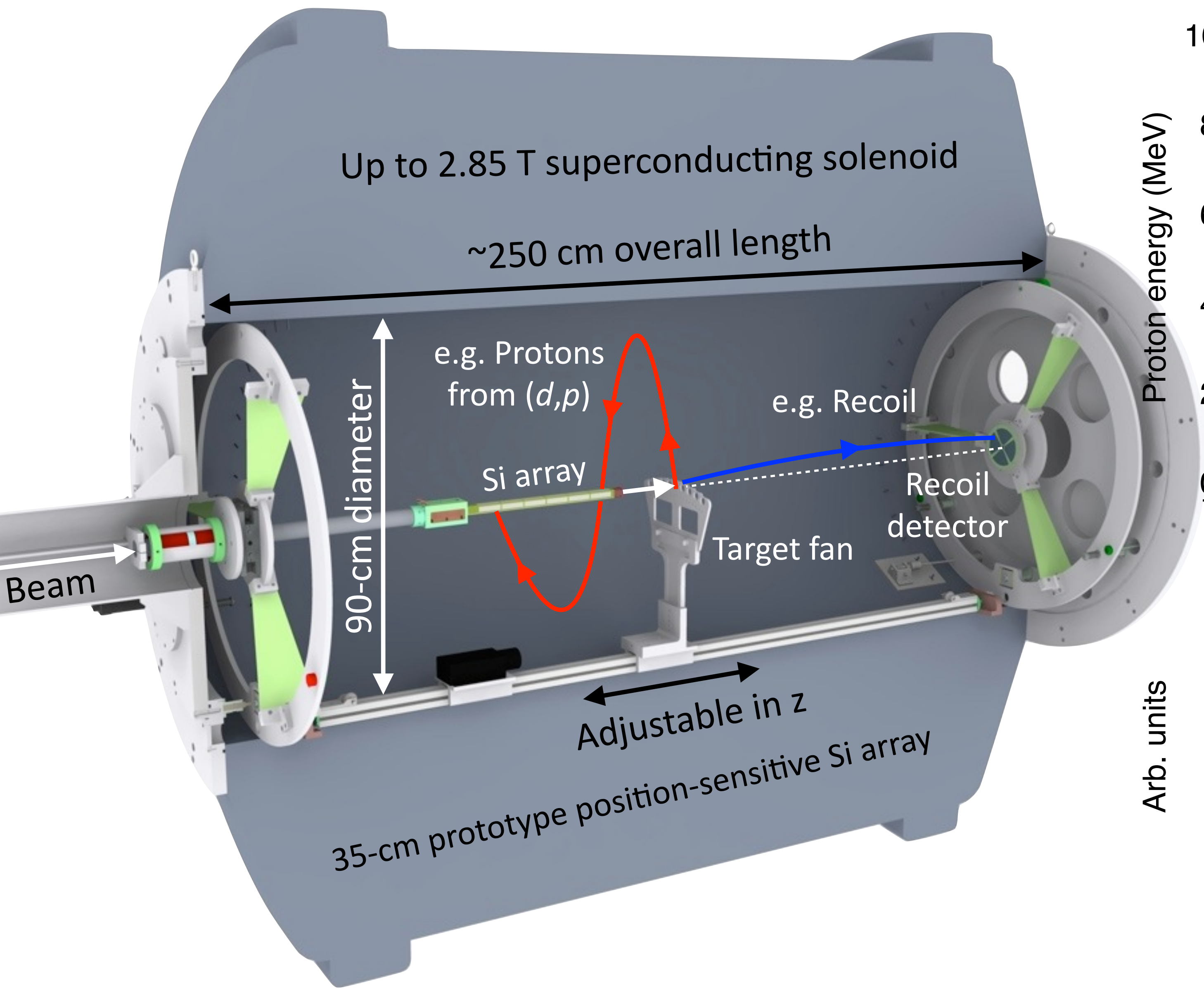


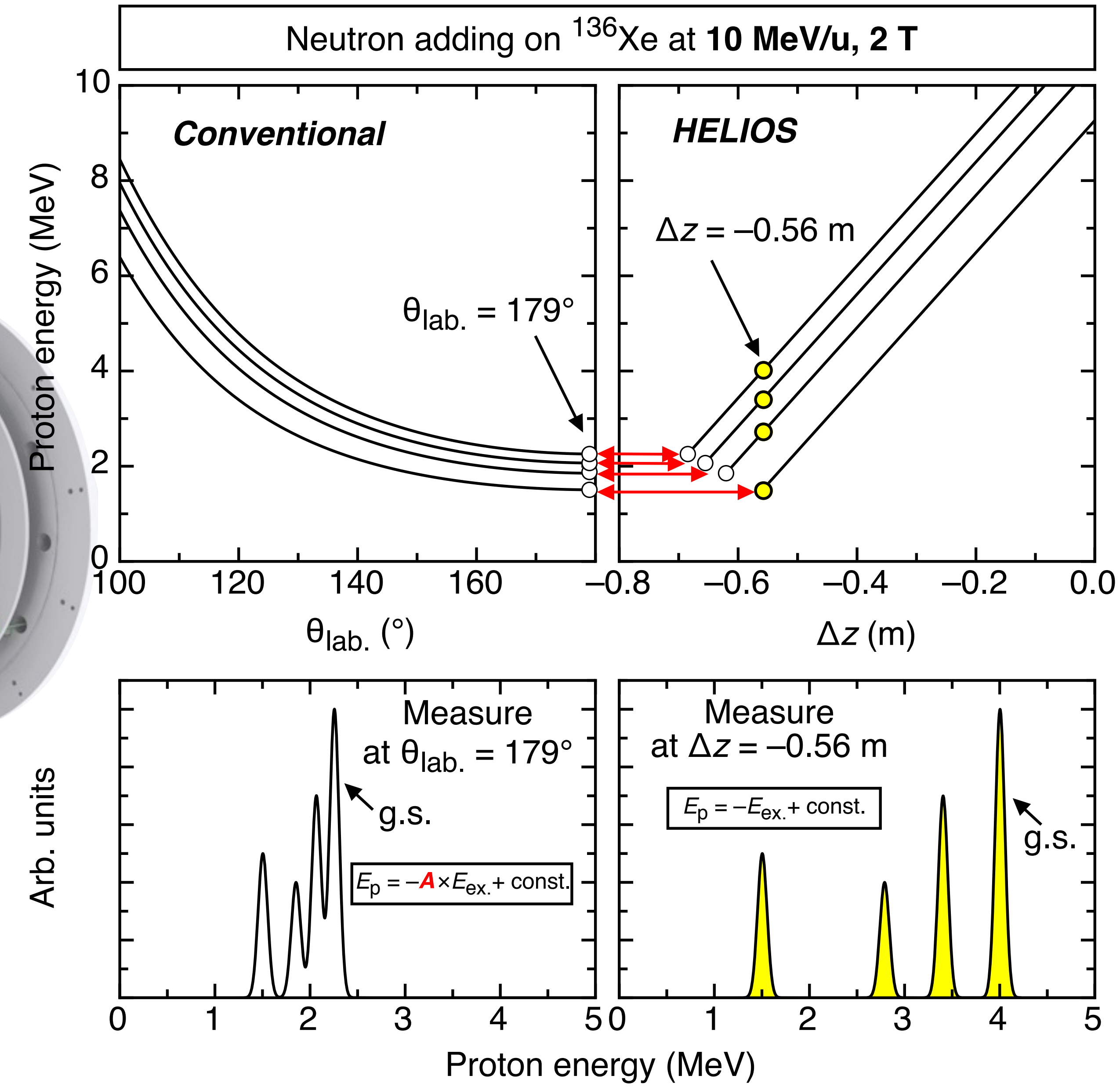
'CARIBU beams' with qualities similar to those of ***stable beams***

*S. Manikonda et al., Proceedings of HIAT 2012, Chicago, IL USA
*B. Mustapha et al., Proceedings of PAC 2013, Pasadena, CA USA
*http://www.phy.anl.gov/airis

Solenoidal spectrometers

So far a class of one … HELIOS … a novel charged-particle spectrometer*





*J. C. Lighthall et al., Nucl. Instrum. Methods A622, **97** (2010)*
***B. B. Back et al., Phys. Rev. Lett. **71**, 132501 (2010)*

*Can achieve a Q-value resolution of <100-keV** — limited by the beam …*

Characteristics of in-flight beams

Central to the HELIOS program …

Typical stable beam characteristics:

- Energy spread of **<<1%**
- Emittance of **<1 pi mm mrad**, far better than limit set by the HELIOS array (10 pi mm mrad)
- Physical size: **<3 mm**

Typical 'in-flight' beam characteristics (expected from AIRIS):

- Energy spread of **>1%** (often a few percent)
- Emittance of **~10 pi mm mrad**, comparable to HELIOS acceptance, but can improve on this (…next slide)
- Physical size: **? (much larger)**

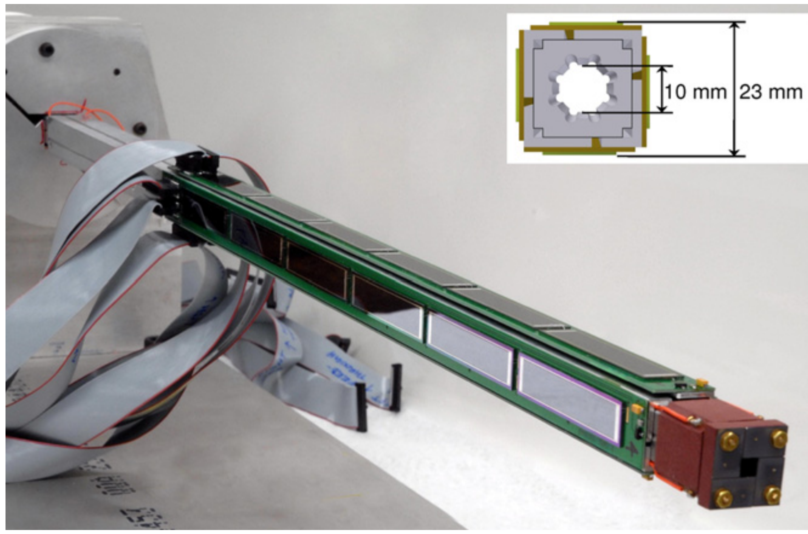
Just collimate the beam?

- No … these beams are *too weak* to 'throw away' intensity

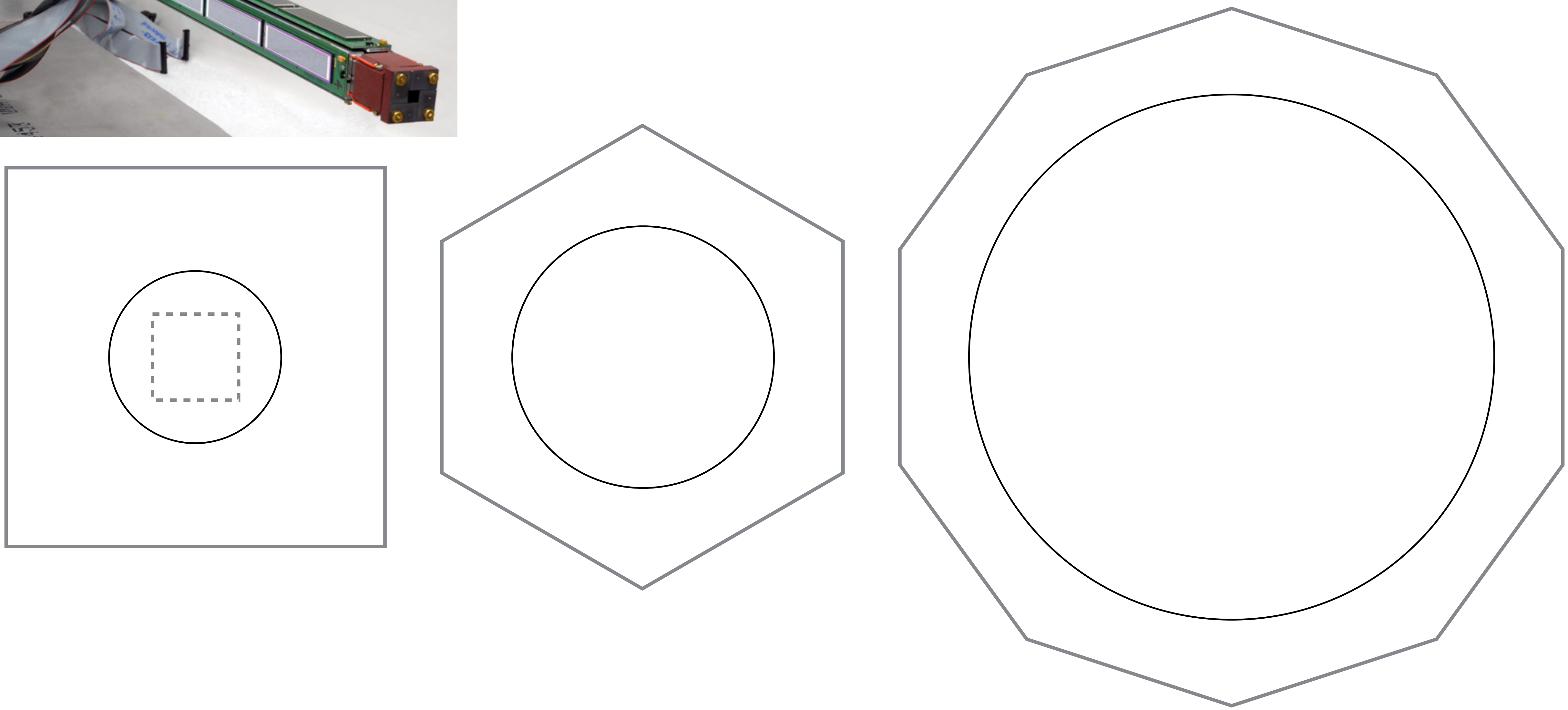
We would like (in many cases need) better than 100 keV Q-value resolution

The HELIOS Si array

How far off axis can we be?



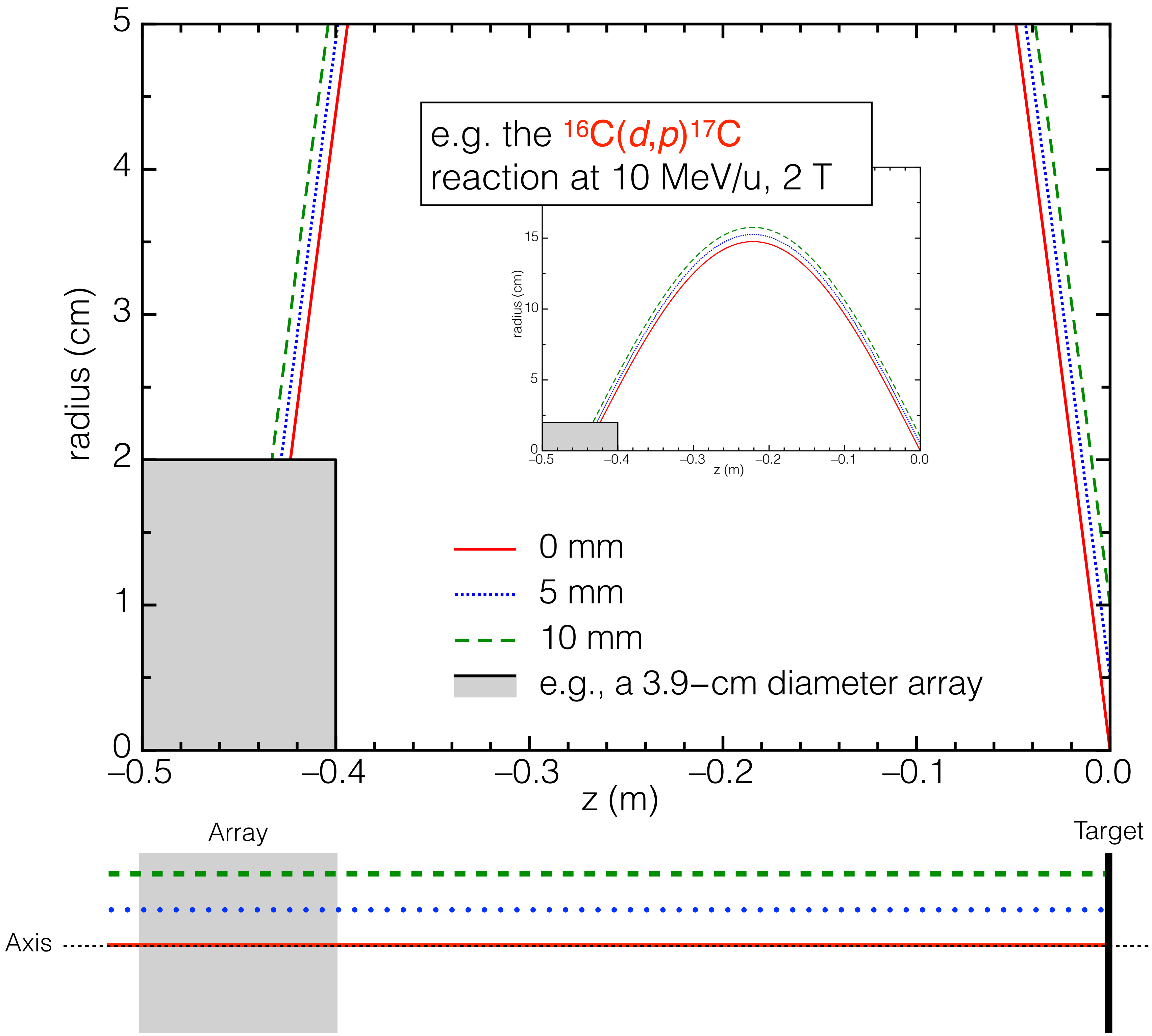
Next generation of arrays designed to accept 'lower quality' beams



10.00 mm ID 23 mm OD	15.24 mm ID (0.6") 23.31 mm OD (0.918")	30.48 mm ID (1.2") 38.56 mm OD (1.518")

Beam intercepts the target off axis

The physical size of the beam

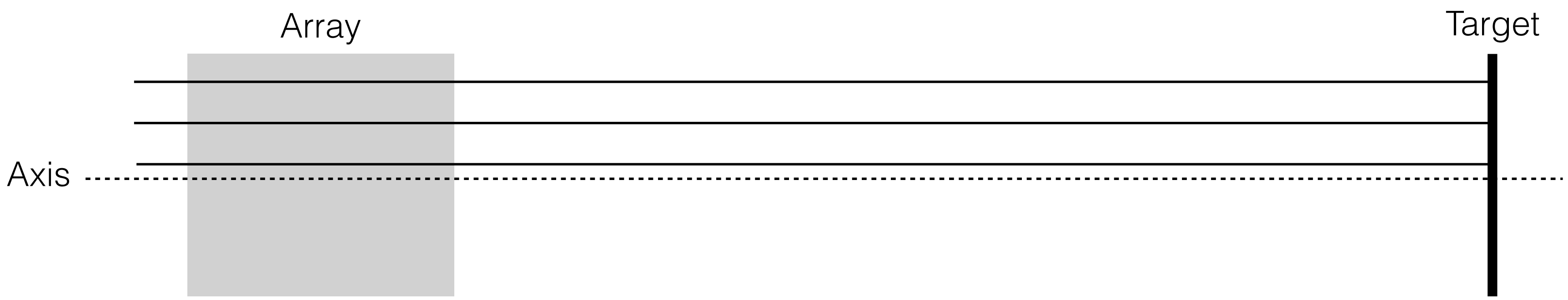


Beam intercepts the target off axis

The physical size of the beam

Beam offset (mm)	ΔE (keV), 5° c.m.	ΔE (keV), 15° c.m.	ΔE (keV), 30° c.m.
0	0	0	0
1	42	13	4
2	**85**	25	8
3	**127**	38	12
4	**169**	**51**	16
5	**212**	**64**	20
10	**424**	**127**	39

Calculations for $^{16}C(d,p)^{17}C$ reaction to the ground state at 10 MeV/u and a field of 2 T. It is worst at forward angles.

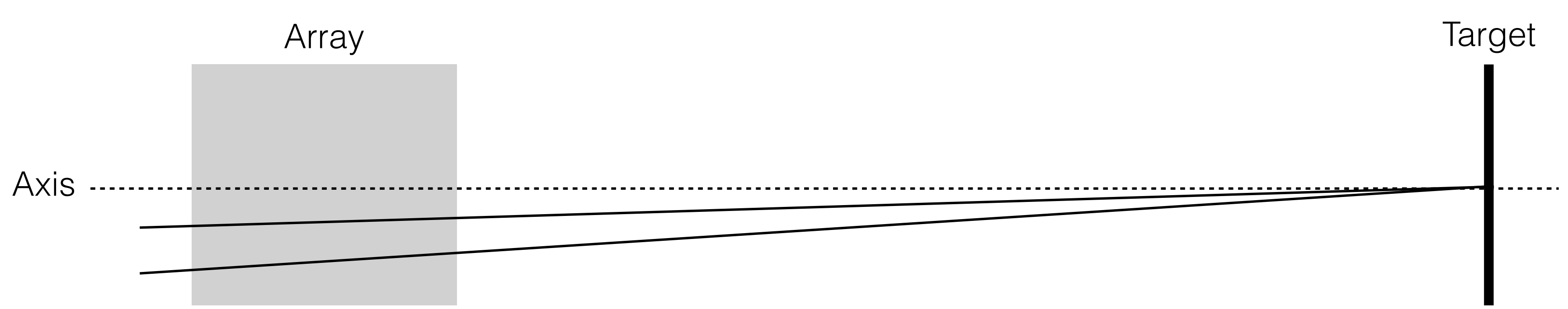


Beam intercepts the target at an angle

Dealing with the transverse emittance of the beam

Angle (mrad, deg)	ΔE (keV), 5° c.m.	ΔE (keV), 15° c.m.	ΔE (keV), 30° c.m.
0, 0	(1.318 MeV)	(1.993 MeV)	(4.219 MeV)
1, 0.06	0.6	2.4	8.2
3, 0.17	1.7	7.2	24
5, 0.29	2.9	12	40
10, 0.57	5.7	24	**79**
15, 0.86	8.5	**36**	**118**
20, 1.15	11	**47**	**156**
25, 1.43	14	**58**	**194**

Calculations for $^{16}C(d,p)^{17}C$ reaction to the ground state at 10 MeV/u and a field of 2 T. It is worst at more backwards angles.



Beams intercepts the target at different energies

Dealing with the poor energy resolution of the beam, longitudinal emittance

$\Delta E/E_{beam}$ (%, MeV)	ΔE (keV), 5° c.m.	ΔE (keV), 15° c.m.	ΔE (keV), 30° c.m.
0 (160 MeV)	–	–	–
1, 1.6	17	24	48
2, 3.2	34	48	**95**
3, 4.8	**51**	**73**	**143**
4, 6.4	**68**	**97**	**191**
5, 8	**85**	**121**	**238**
10, 16	**171**	**242**	**475**
20, 34	**340**	**480**	**950**

Calculations for $^{16}C(d,p)^{17}C$ reaction to the ground state at 10 MeV/u and a field of 2 T. It is worst at more backwards angles.

While this can be determined with beam line diagnostics, it only provides an average spread and cannot be corrected for.

Track the beam to correct for these contributions?

Better than 100-keV resolution … 5 key requirements

Define position to ≤1 mm

- *Less than 50 keV* contribution at the most forwards angles (negligible at others).

Define angle to ≤5 mrad (0.29°)

- *Less than 50 keV* contribution at all angles (negligible at most). Can be accomplished by *≤1-mm position resolution defined at **two** positions* in the beam line.

Measure energy to < 1%

- *Less than 50 keV* at all angles. Can be accomplished by time-of-flight measurement of better than ~250 ps over 3 m.

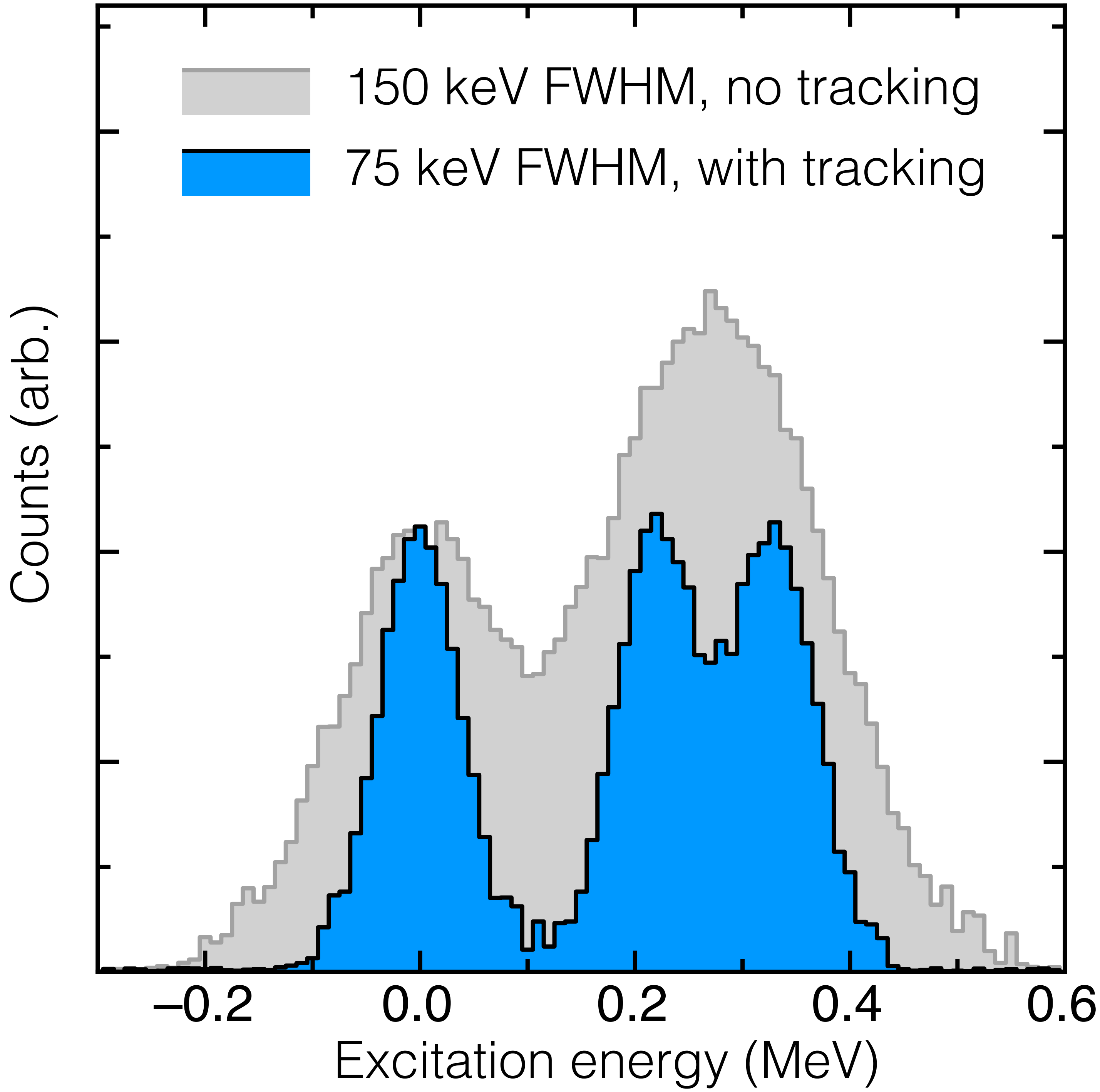
Operate at up to 10^6 beam particles per second

- To be functional with the most intense in-flight beams and/or those with significant contamination.

Operate at less than 10% loss (nondestructive)

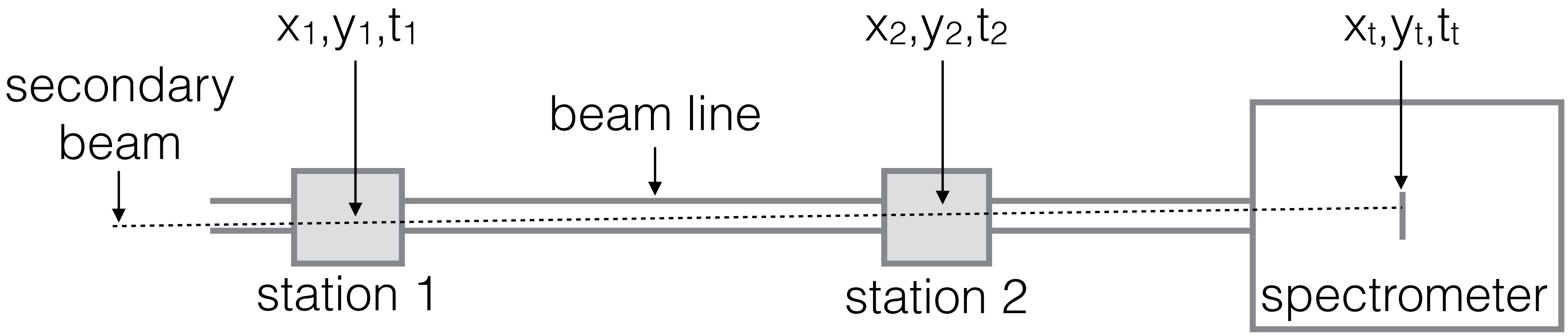
For the $^{16}C(d,p)$ example, what can we expect?

(from a simplistic simulation … a factor of two improvement …)



How to implement this?

Tracking of the beam through the beam line



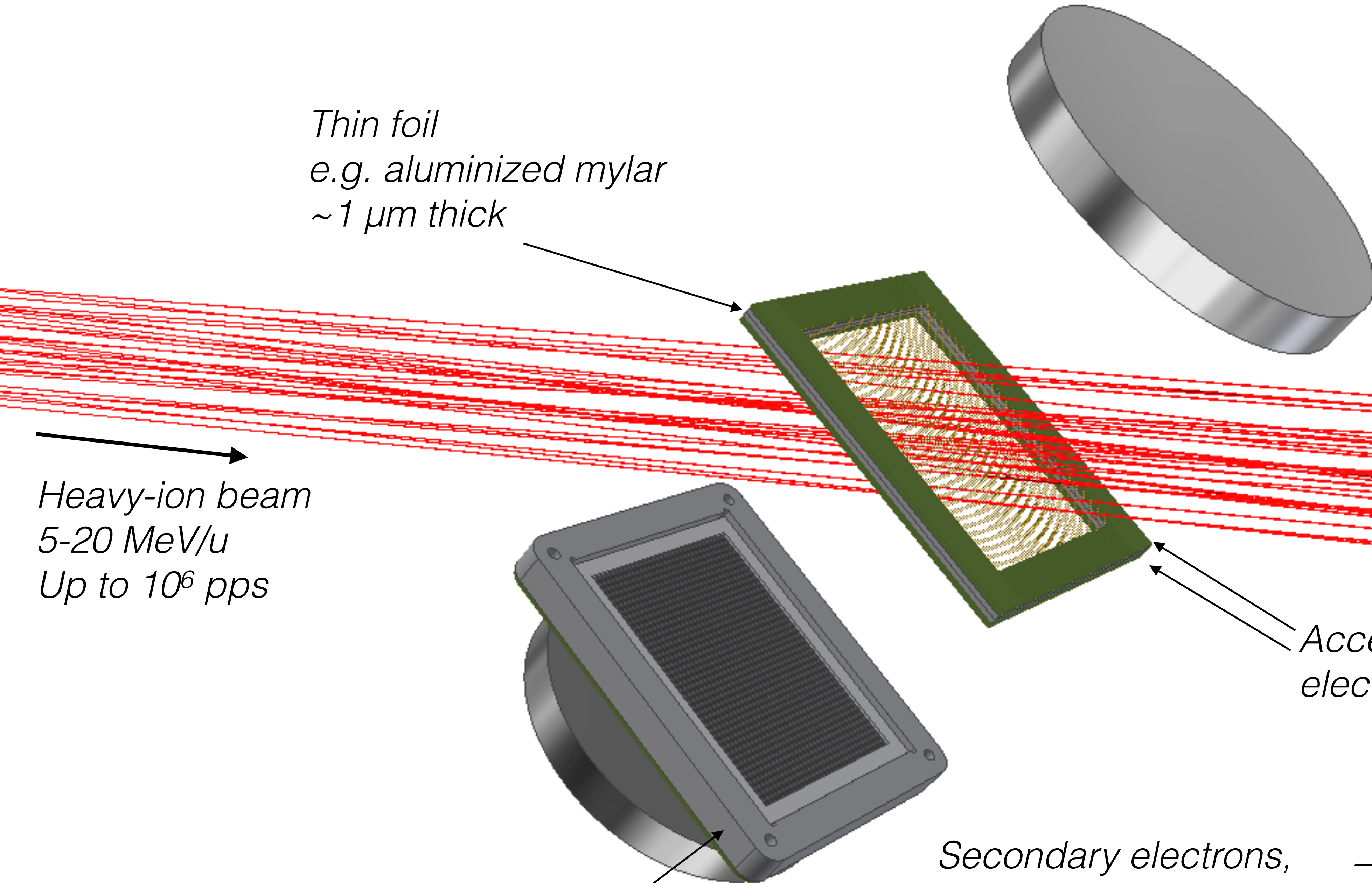
This is not a new problem

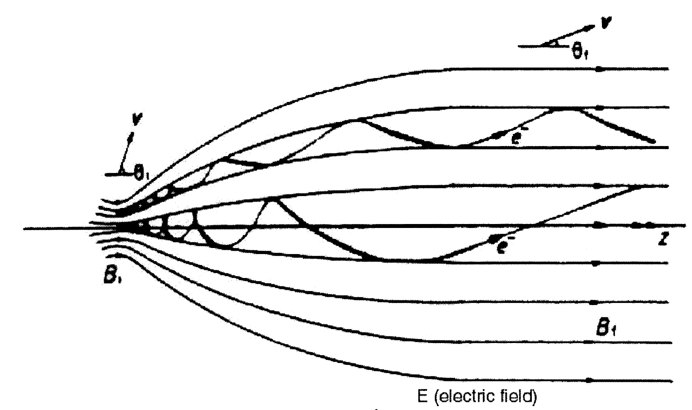
- Somewhat *commonplace for 'fragmentation' or 'intermediate-energy' facilities*, where beam energies are ~100 MeV/u and technologies such as multi-wire proportional counters, etc., are an option*.
- But … true tracking has *not been implemented for 'low-energy beams'* before (often only time of flight).
- Having the beam impinge a thin foil, *detecting the secondary electrons using an MCP*, has been explored before**, and is successful at higher energies.

S. Ottini-Hustache et al., Nucl. Instrum. Methods **A431, 476 (1999).*
***e.g. D. Shapira et al., Nucl. Instrum. Methods **A454**, 409 (2000).*

Schematic of the device

*Components of a single 'station' based on similar previous works**

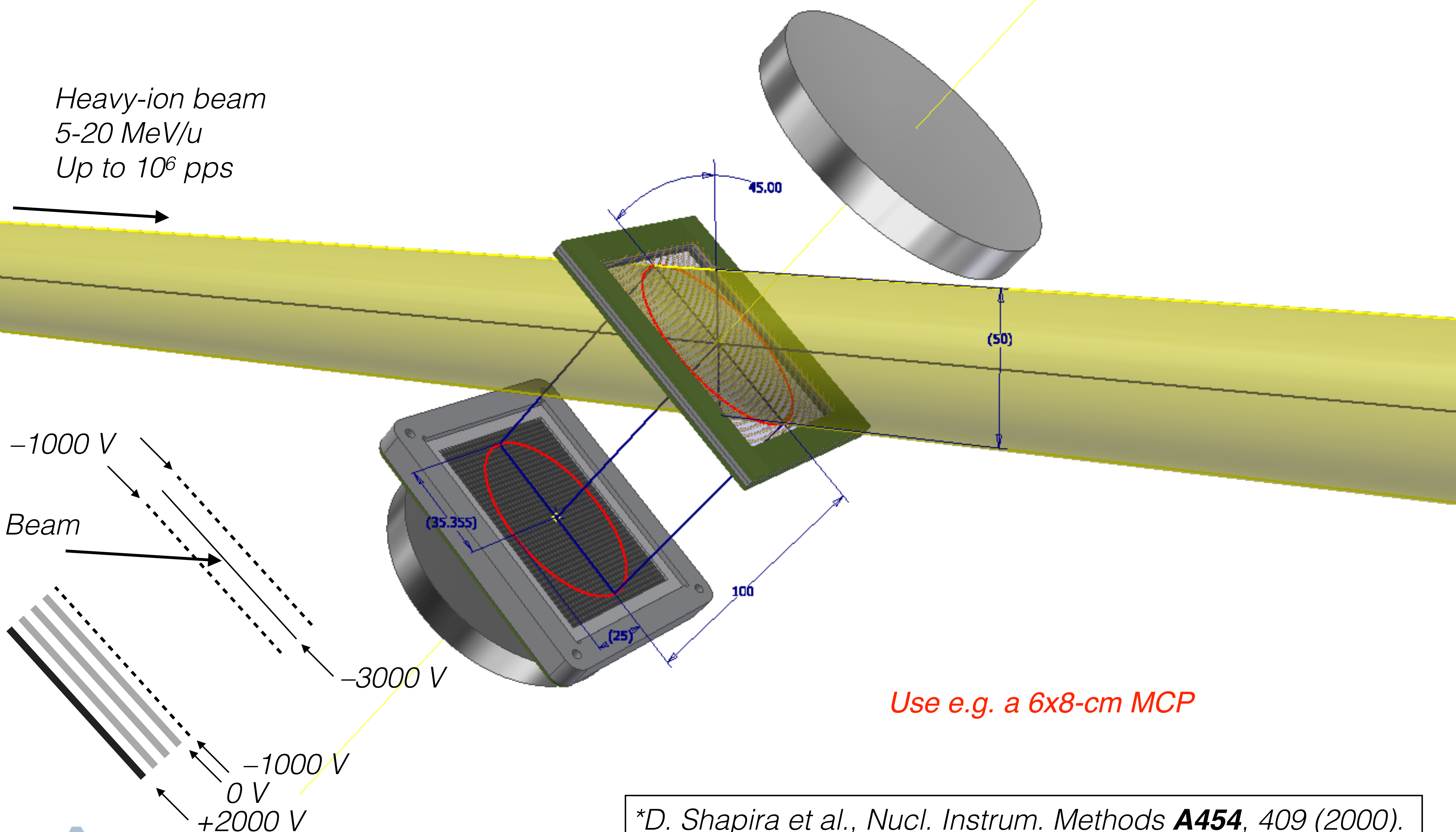




*D. Shapira et al., Nucl. Instrum. Methods **A454**, 409 (2000).

Schematic of the device

*Components of a single 'station' based on similar previous works**

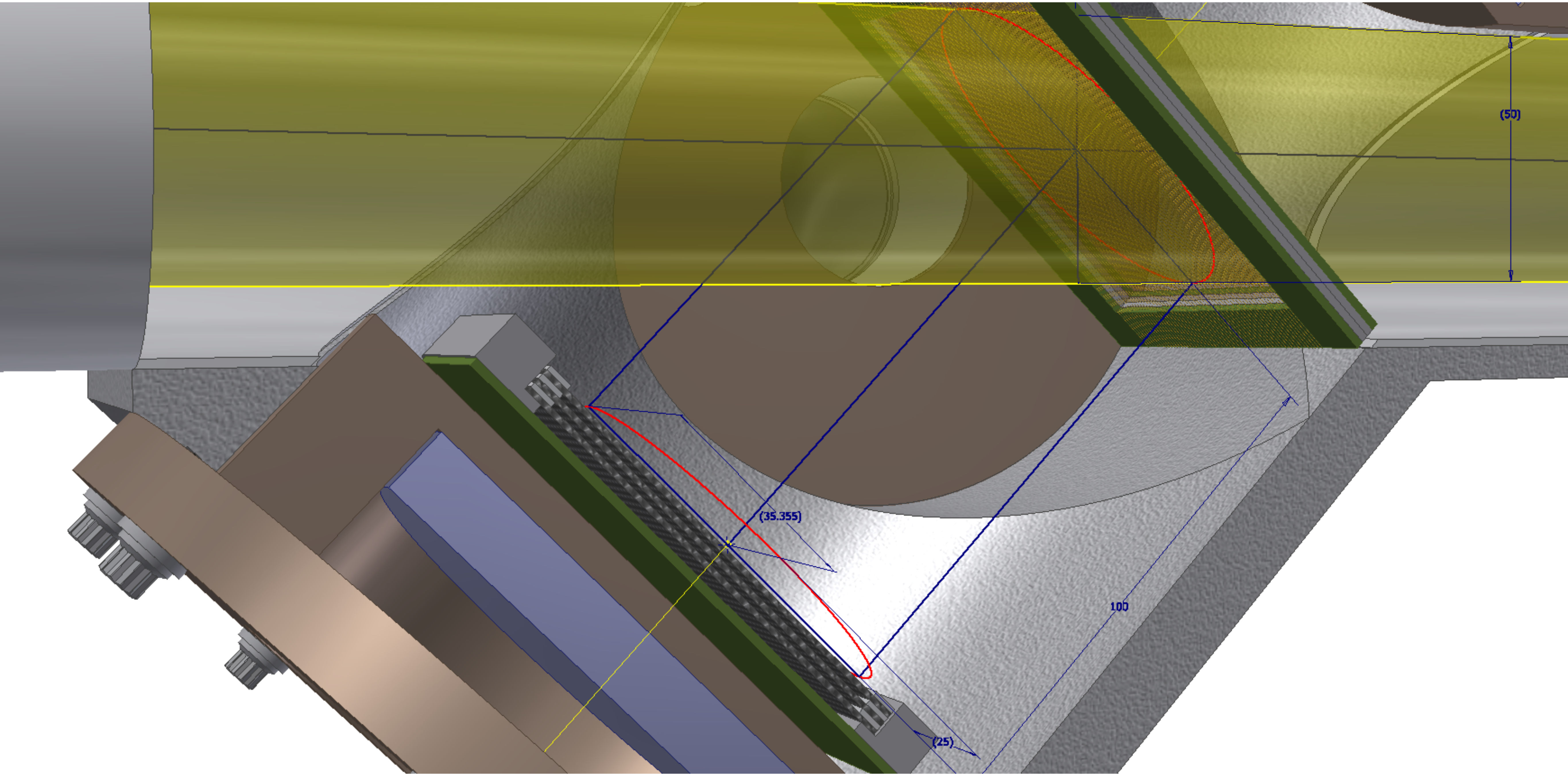


Use e.g. a 6x8-cm MCP

D. Shapira et al., Nucl. Instrum. Methods* ***A454**, 409 (2000).*

Schematic of the device

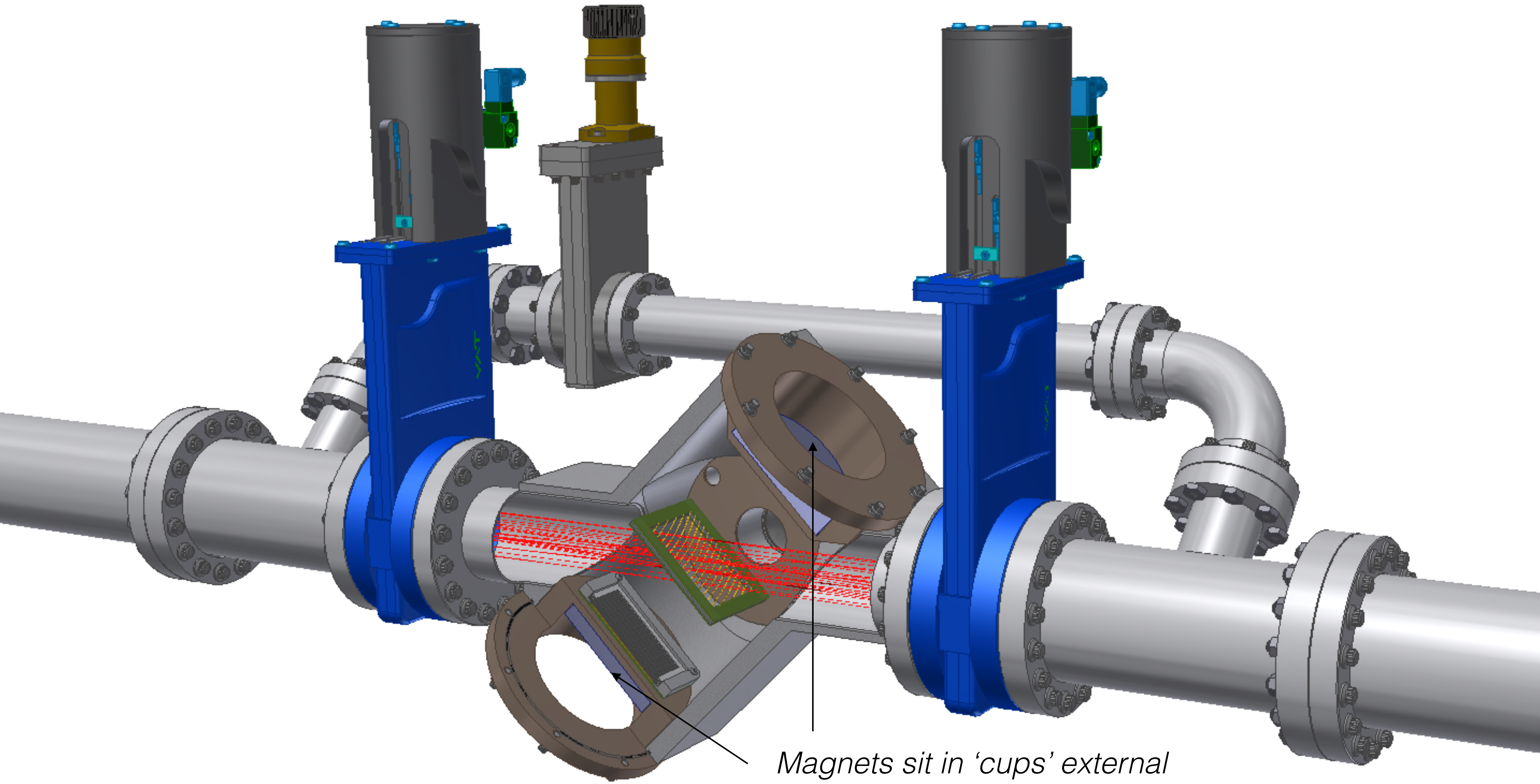
Zoom in of the MCP stack and anode structure



No decision has been made as to the anode structure and readout.
For a demonstration (low rate) use simple delay line readout?

Schematic of the device

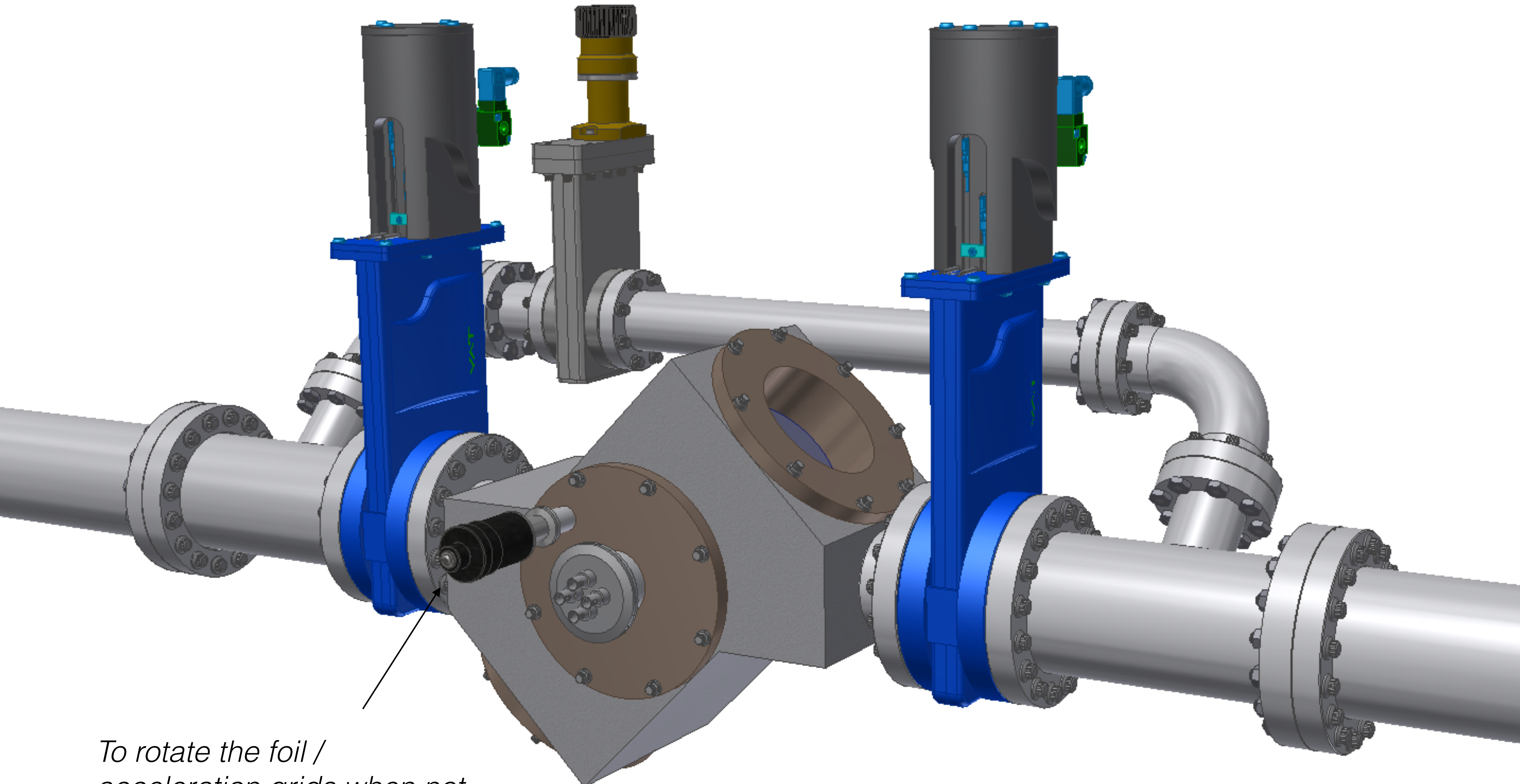
Possible assembly in the beam line



Magnets sit in 'cups' external to the vacuum, for removal when e.g., running stable beams

Schematic of the device

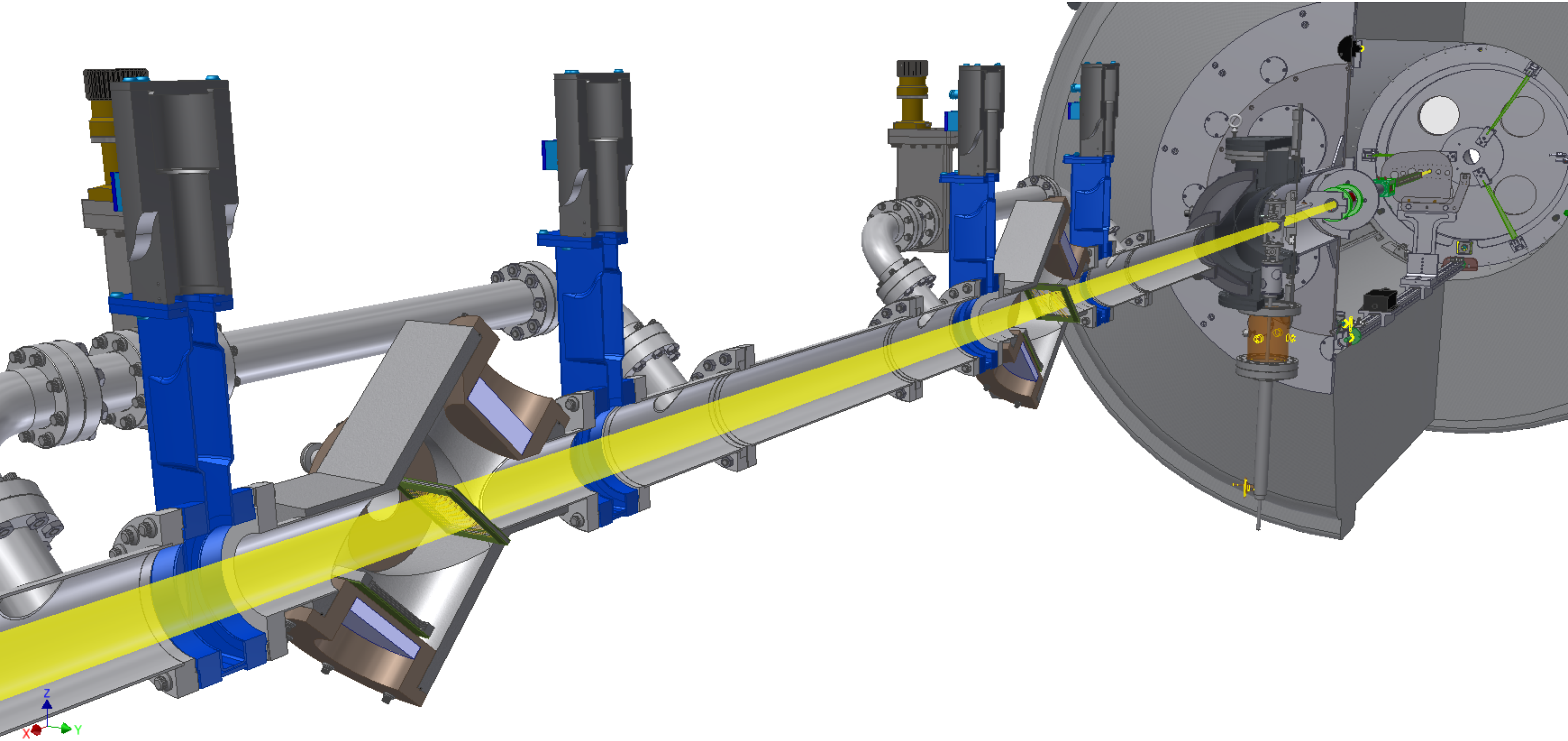
Possible assembly in the beam line



To rotate the foil / acceleration grids when not needed

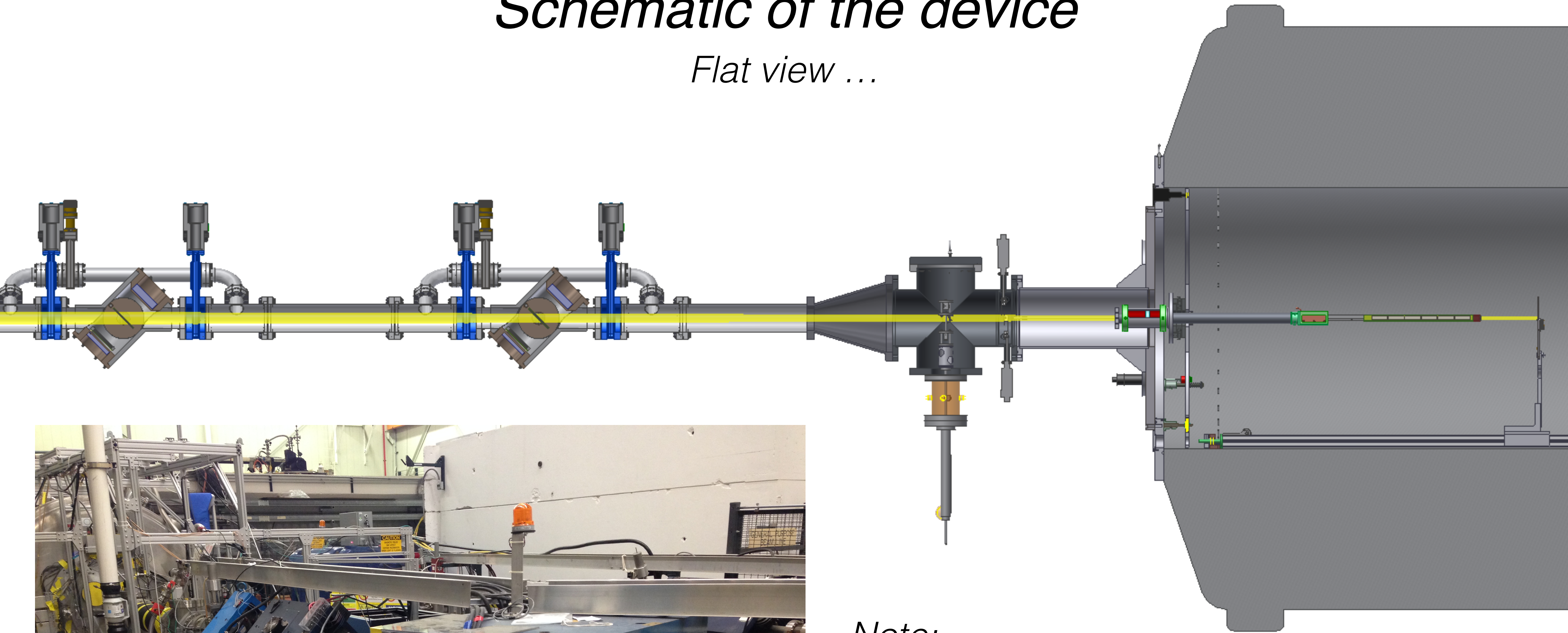
Schematic of the device

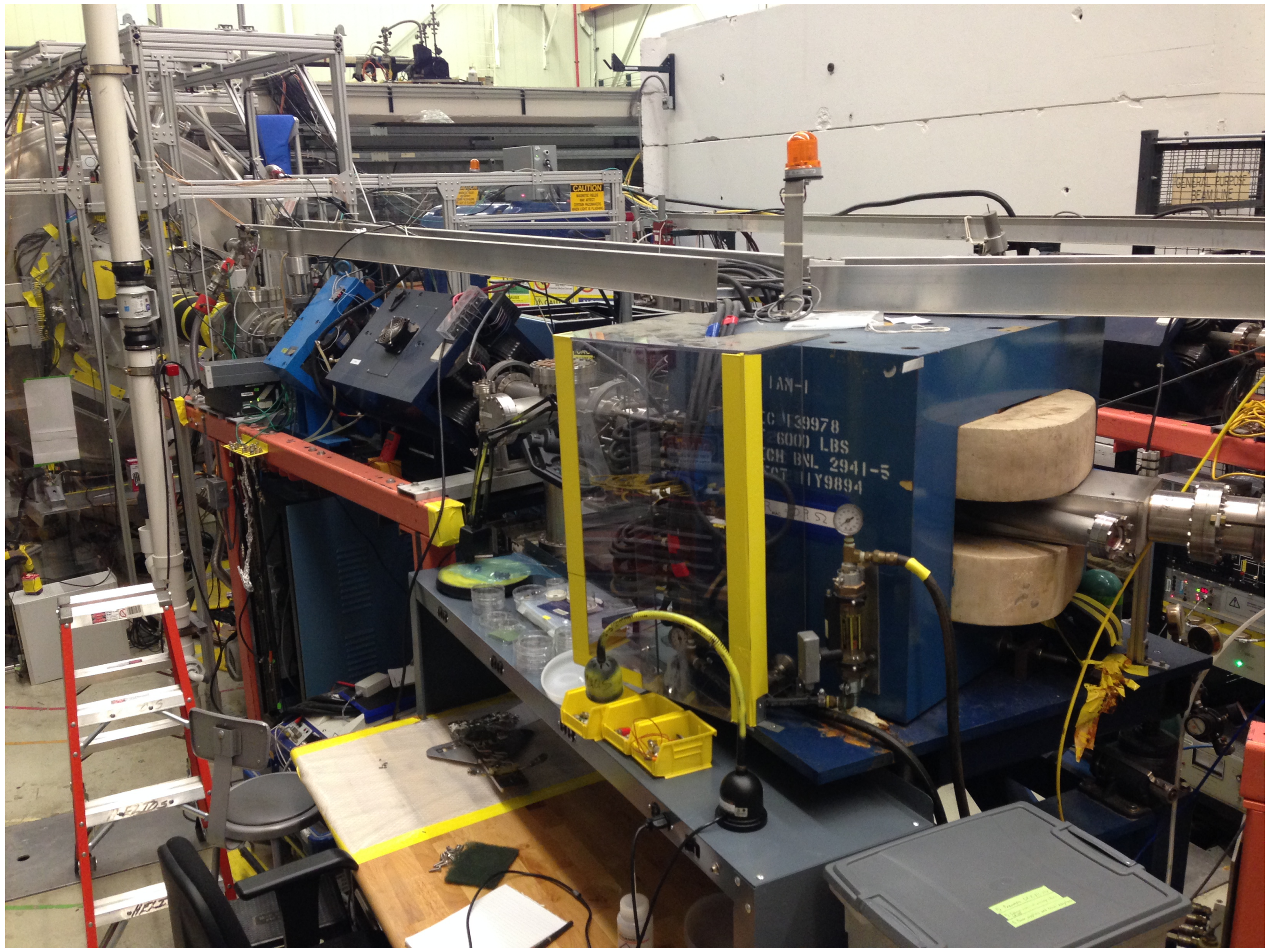
A shortened version of the two stations coupled to HELIOS



Schematic of the device

Flat view …





Note:
*The intention is to have '**station—3 m—station—3 m—target**' structure. In reality this may be complicated by beam line components (pumps, valves, etc).*
Also, the last quadrupole in the beam line and the solenoid fringe field needs to be accounted for.

Comments / conclusions

Significant efforts to deal with poor quality beams in nuclear-structure studies via transfer reactions

- E.g. at CERN plans are afoot to use a storage ring, i.e. cooled beams, coupled to a solenoidal spectrometer*
- *Somewhat commonplace at 'fragmentation' facilities*

This is a small-scale research project to explore the feasibility with 'low-energy' beams

- Initial work done at ORNL in 2000s
- Actual tracking, through two or more stations, never done, and design never optimized

Plan to build a single prototype station to assess using ATLAS beams

- Test with diffuse (poor) stable beams at various rates
- Use masks
- Develop the readout scheme

Potential to use on all beam lines, and at other facilities …

- …e.g., the reaccelerated beams at FRIB

*M. Grieser et al., Eur. Phys. J **207**, 1 (2012).*