The NSCL Cyclotron Gas Stopper
Under Construction

- Why gas stopping at NSCL
- Linear cells and their limitations
- Cyclotron stopper
    - Simulations
    - Design
    - Construction
- Status

G. Bollen, M. Brodeur,
M. Gehring, N.S. Joshi,
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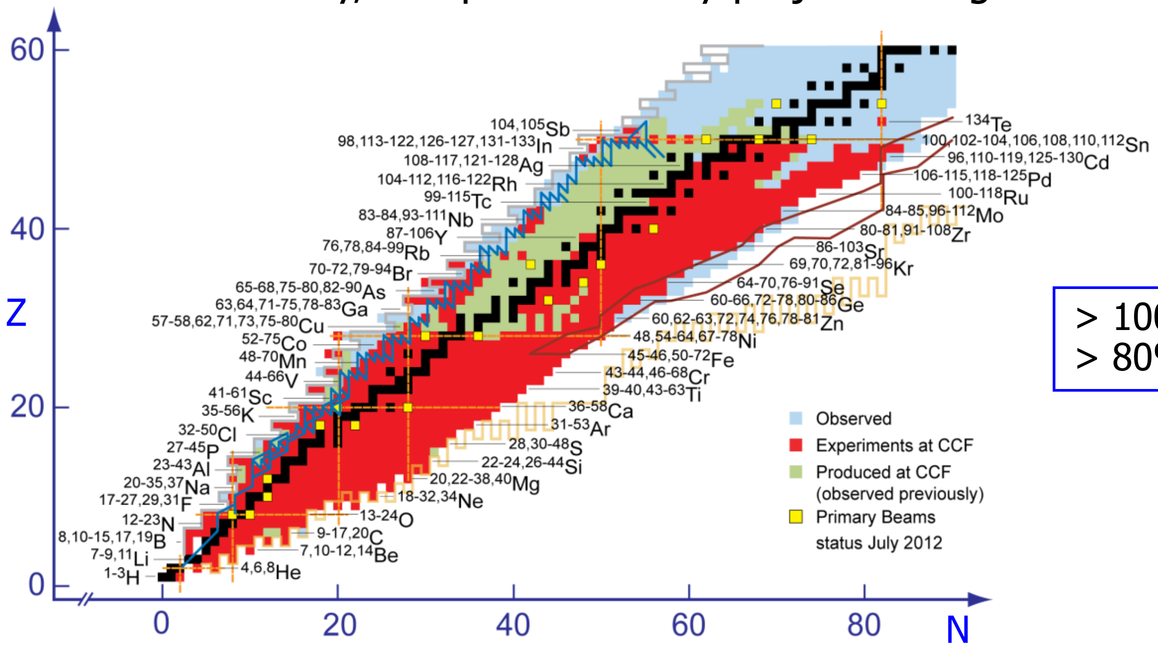
D. J. Morrissey, R. Ringle,
S. Chouhan, J. DeKamp,
J. Ottarson, SCS,
A. Zeller

and many, many more!

Why slow down beams at the NSCL?

NSCL: User facility, RIB production by projectile fragmentation and fission, **fast beams**



> 1000 RIBs made
> 80% RIBs used in experiments

NSCL has successful program with **stopped beams**:

– LEBIT facility for Penning trap mass spectrometry of projectile fragments
– laser spectroscopy coming online

M. Redshaw, Friday

ReA, new science opportunities with rare isotopes from projectile fragmentation

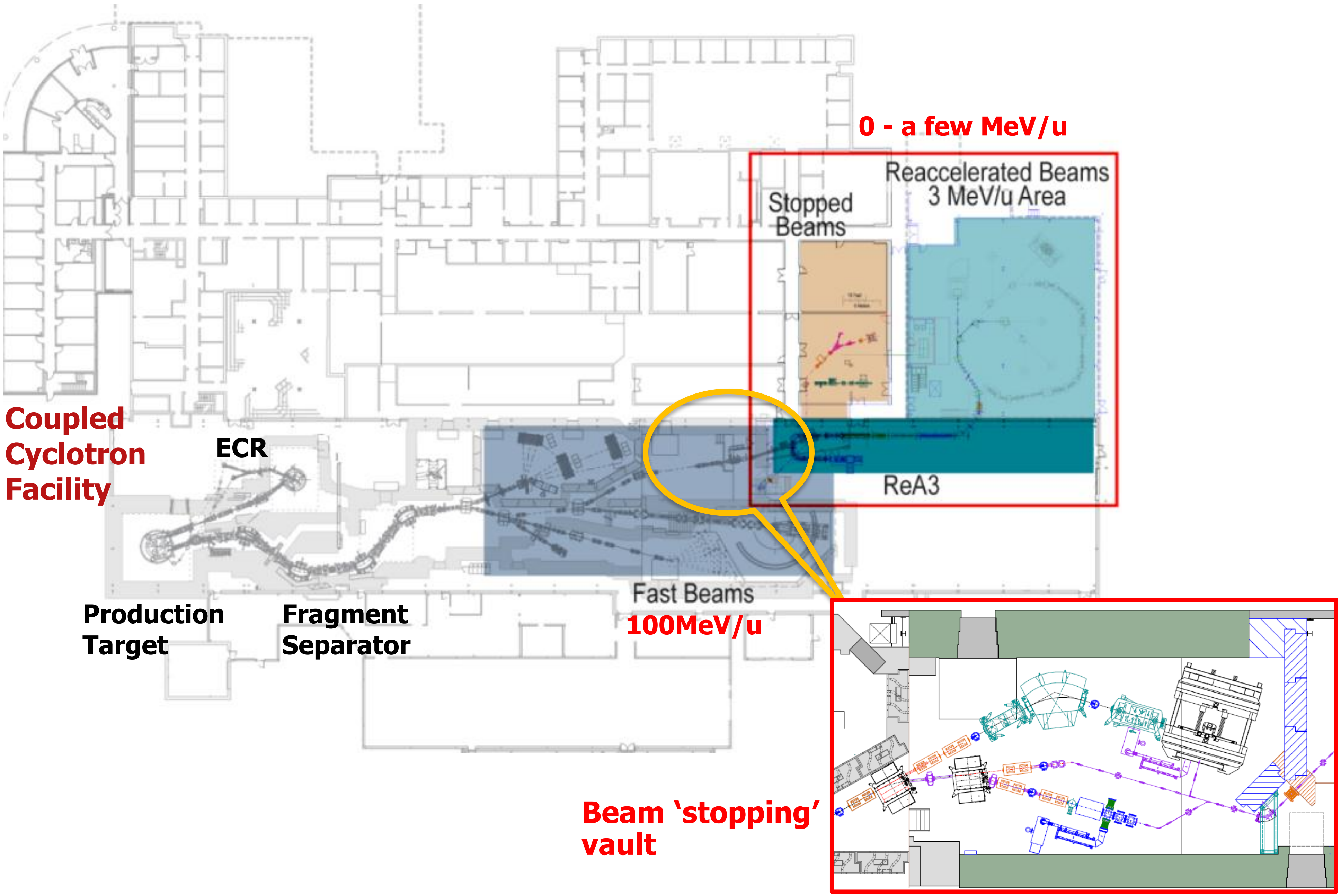
- Nuclear astrophysics: key reactions at near-stellar energies
- Nuclear structure via Coulomb excitation or transfer reactions

D. Leitner, Today

FRIB: fast, **stopped and reaccelerated beams**

G. Bollen Thursday

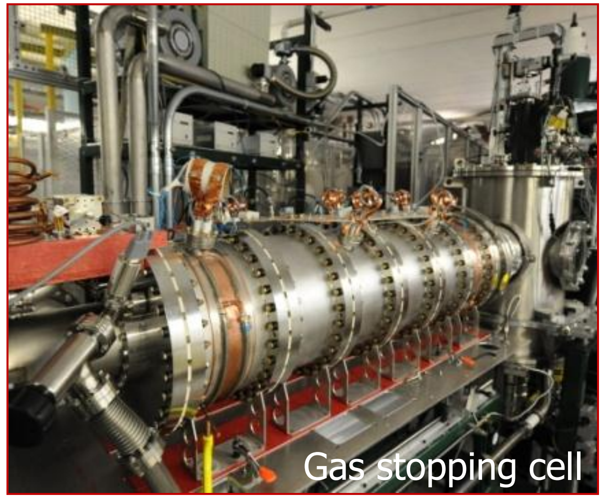
From fast to not-so-fast



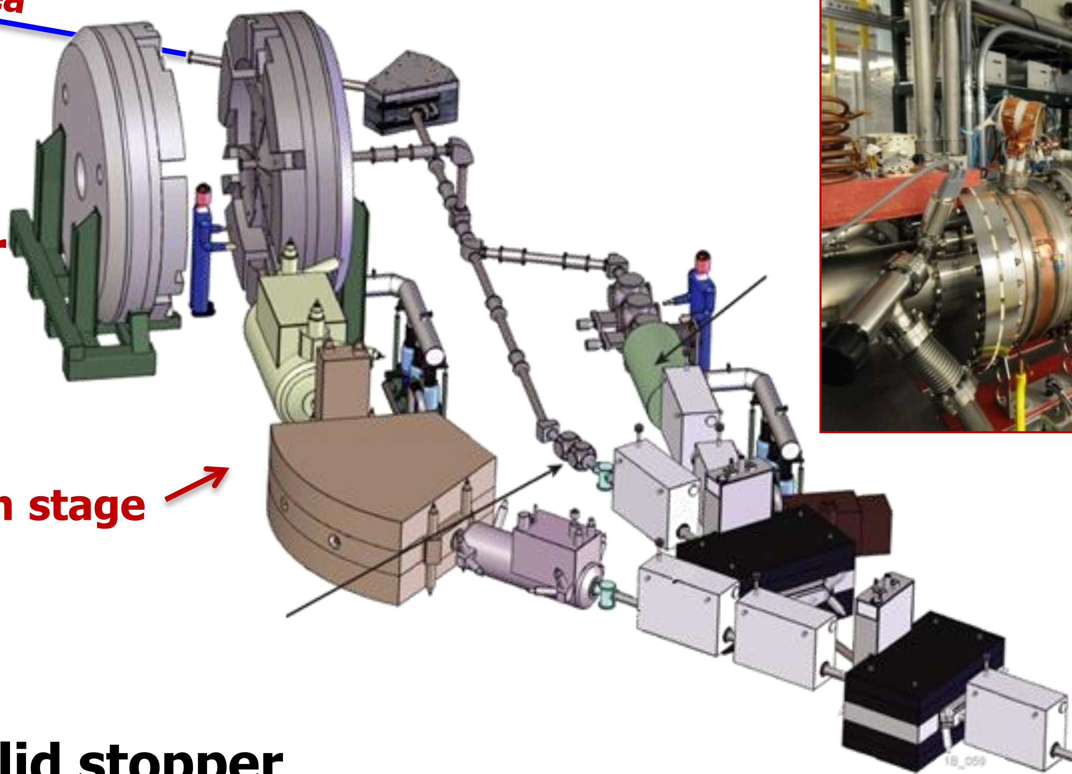
NSCL beam stopping

Complementary
stopper options:

- **Linear gas stopper**
  - Low-pressure with RF carpets
  - Collaboration with ANL (FRIB R&D)



← ReA,
'Stopped' Beam area
60keV



- Future:
  Cyclotron stopper
  Funded by NSF

Momentum compression stage ↗
Used for linear gas cell
+ cyclotron stopper

← CCF, 100 MeV/u

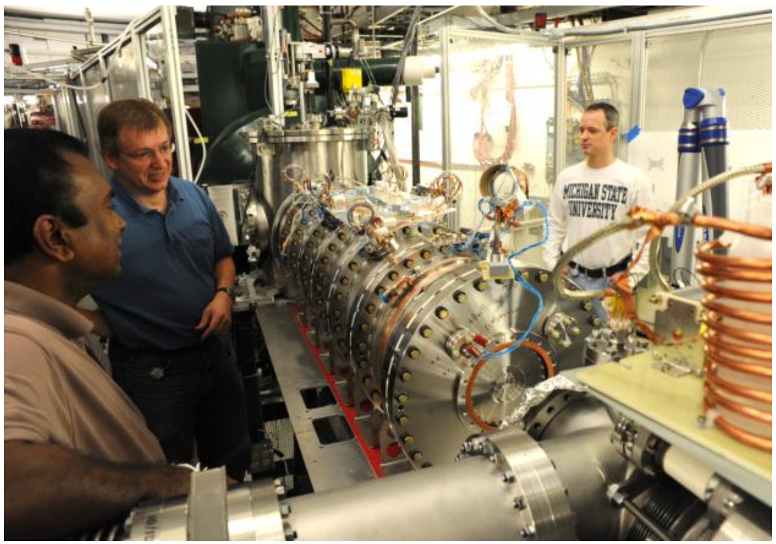
- **Solid stopper**
  Future option for special elements and very high beam rates
  Example: ^{15}O, I >10^{10}/s

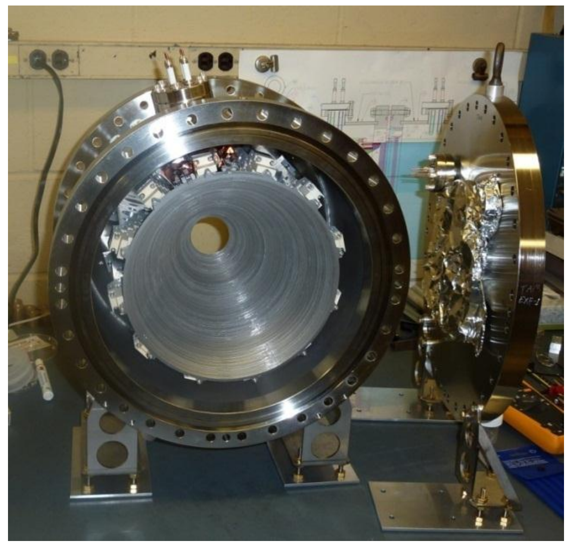
New linear gas cell:

→ Replaces 0.5m long, 1bar-He cell, used successfully for LEBIT in 2005-2009

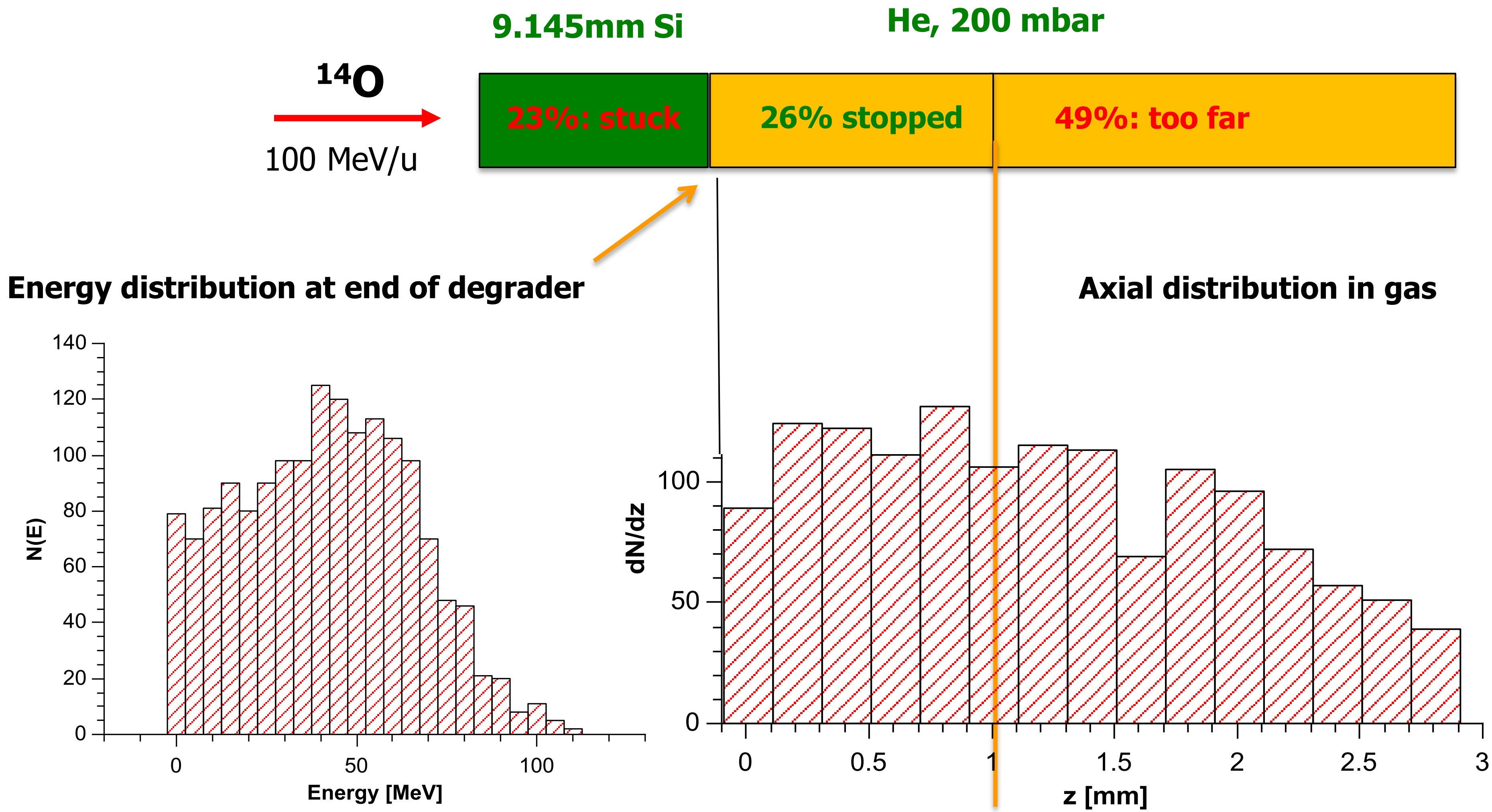
→ **Larger size, lower pressure (L ~ 1 m, p ~ 100 mbar)**
- → Better adapted to large horizontal beam emittance
- → Lower p allows effective RF ion guiding, **RF carpet + funnel**
- → Promises reduced space charge effects, increased rate capability, to be characterized

→ **Commissioning with ^{76}Ga beam in progress**
- → ^{76}Ga, $^{76}Ga(H_2O)$, $^{76}Ga(H_2O)_2$ observed





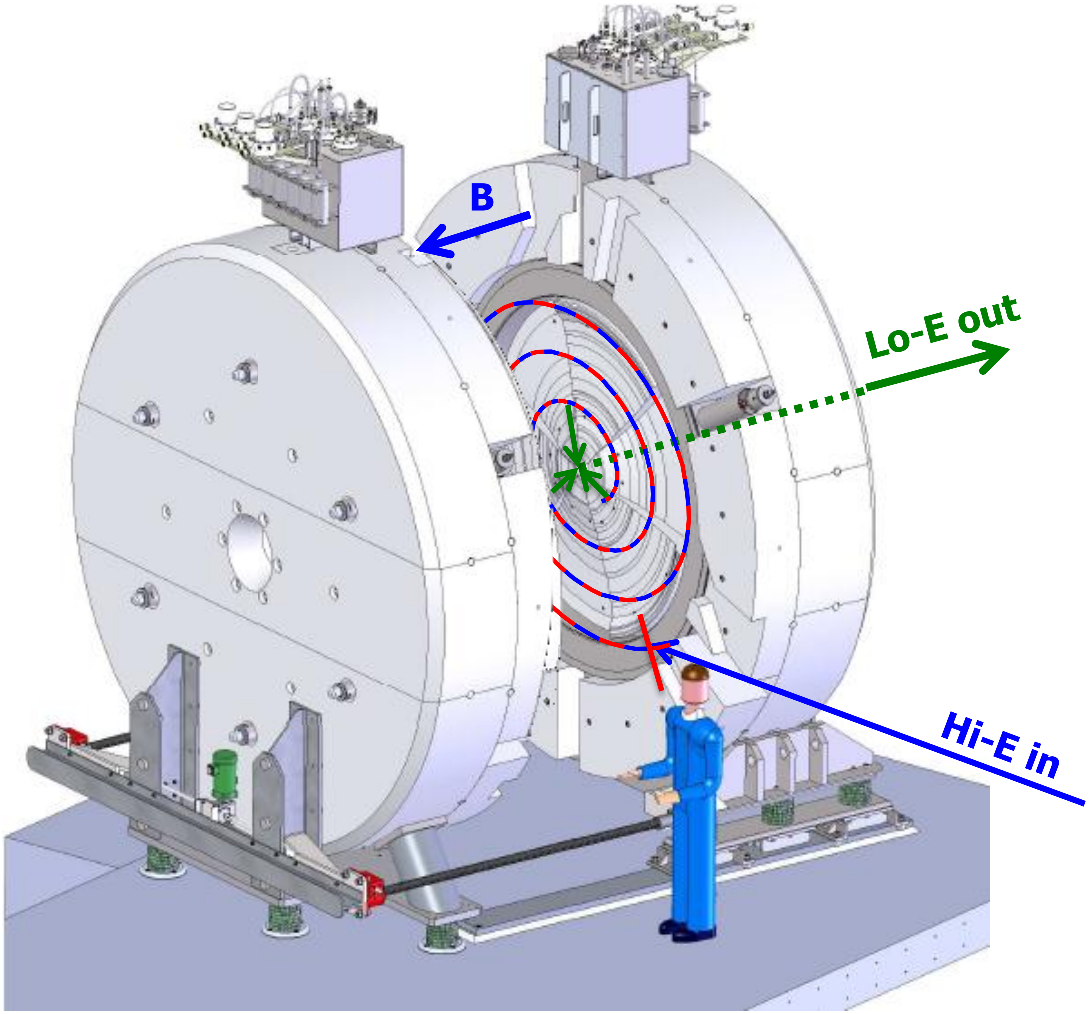
Light ions don't like to stop



... So, let's help them

(TRIM simulation)

Cyclotron stopper – the idea

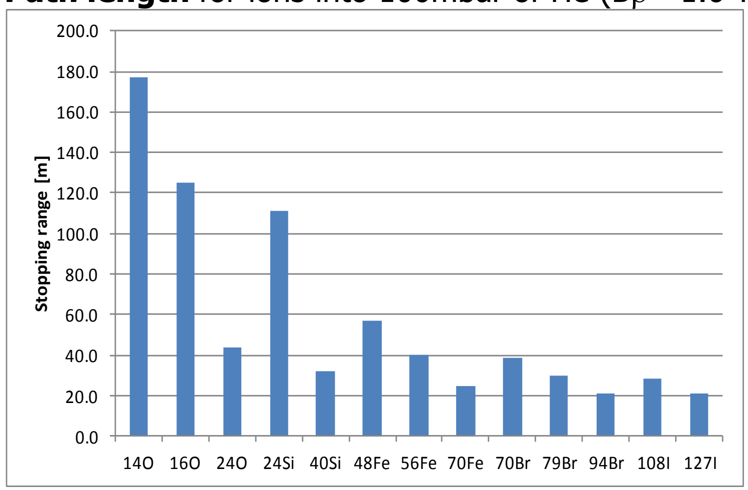


1 Confine:
- **Magnetic field, <2.7 T**
  - 'wind up' trajectory in central chamber
    → confinement in radial direction
  - Cyclotron-type **sector field**:
    → axial focusing

2 Thermalize:
- **Low-pressure gas in cryogenic chamber**
  ions lose energy, spiral towards center

3 Extract:
- Use **HF/RF ion guiding techniques**
  to move thermalized ions to center and out
  within a few 10 ms

Path length for ions into 100mbar of He (Bρ =1.6 Tm)



Origins:
- Decelerate antiprotons: J. Eades and L. M. Simons, NIM A 278 (1989) 368
- Proposal to stop lighter ions: I. Katayama et al., HI 115 (1998) 165

The magnet

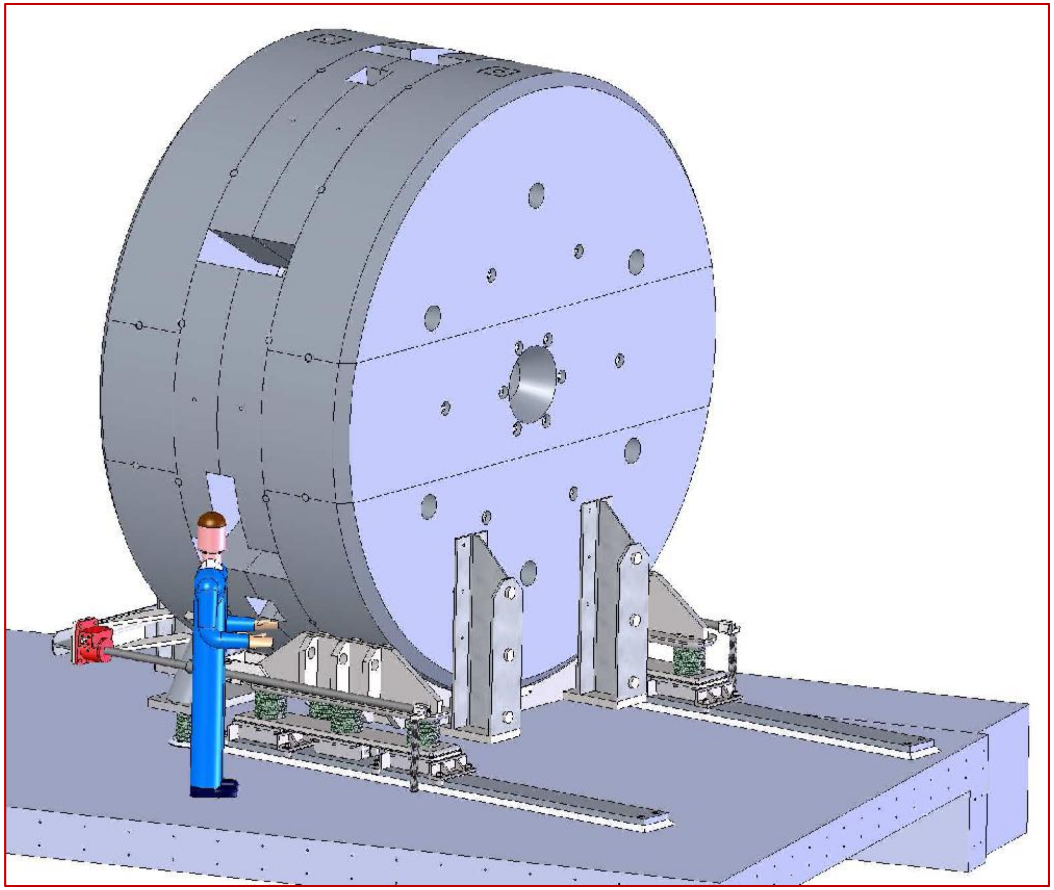
Warm iron superconducting cyclotron dipole

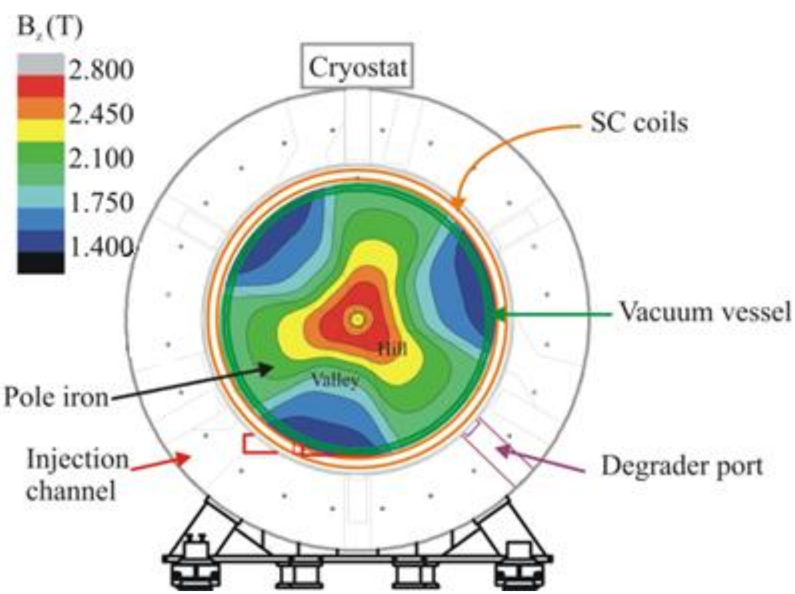
2 superconducting coils, iron dominated	
Magnetic field (max)	2.7 T
Six sectors, 3hills / 3valleys, k =	-0.28
Diameter	3.8 m
Injection radius	0.95 m
Axial gap	180 mm
Beam rigidity	2.6 Tm → 1.6 Tm
Cooling: 2 * 3 1.5W pulse-tube cryo-coolers	
Weight	165 tons

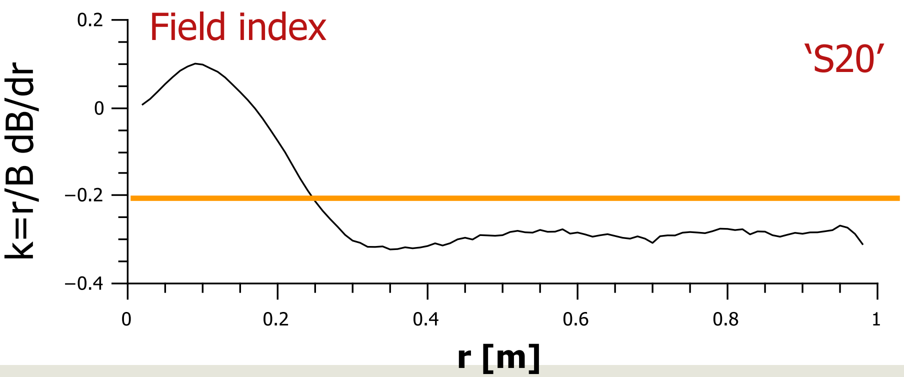
60kV operation

One half moveable

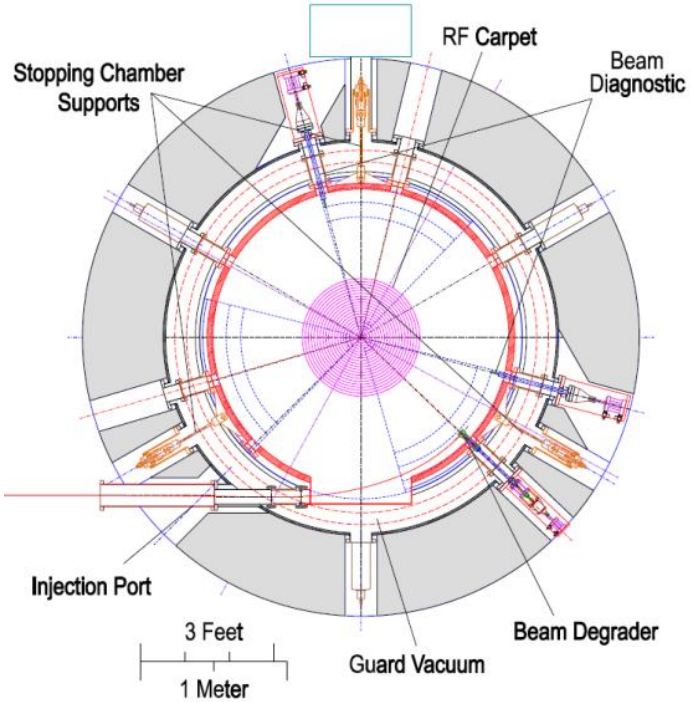
for access to cryogenic stopping chamber







Stopping calculations

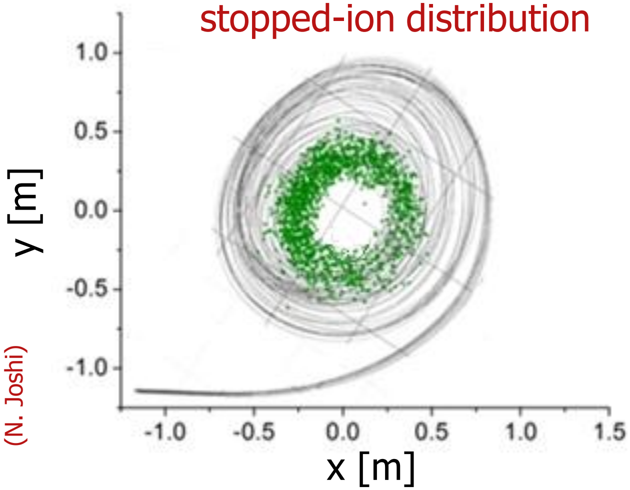


Used:

+ magnetic field (TOSCA 3d)
+ relativistic ion motion
+ Energy loss by collisions with buffer gas: SRIM, stopping and range tables
+ improved charge exchange:
  hi-energy: ETACHA,
  lo-energy: combination of formula
  interpolate between extremes
+ Small-angle-scattering (Amsel's framework)
+ energy loss at degrader: ATIMA

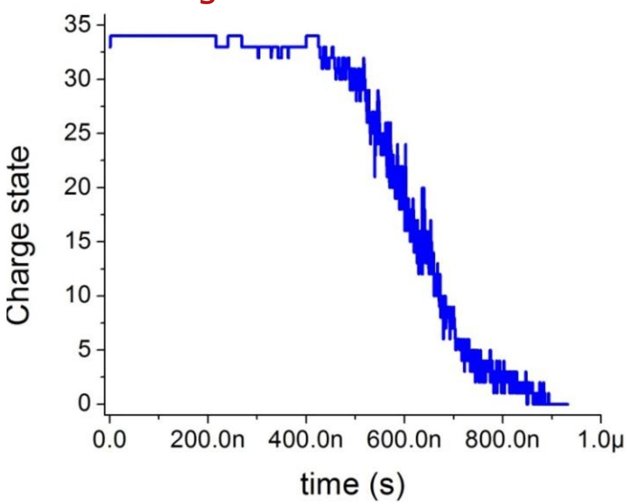
Cases: ^{9}Li, $^{14,\mathbf{24}}$**O**, ^{17,31}F, $^{24,\mathbf{40}}$**Si**, ^{56,70}Fe, $^{70,\mathbf{79}}$**Br**, ^{127}I

^{79}Br trajectory and stopped-ion distribution



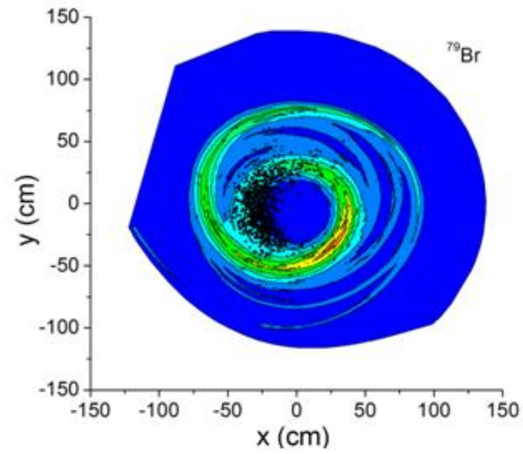
(N. Joshi)

Charge-state evolution

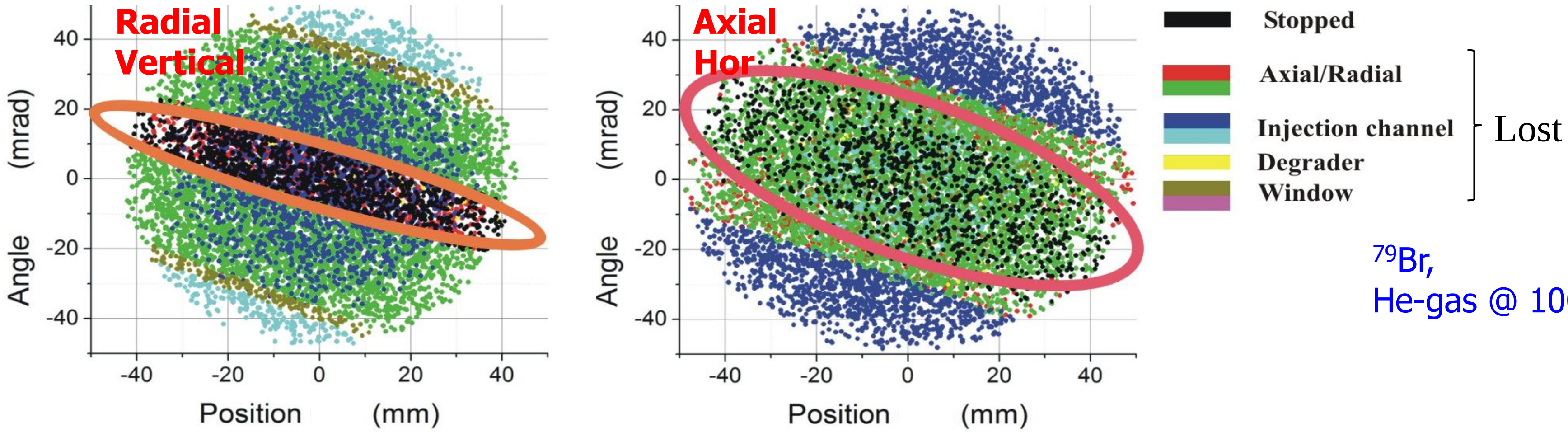


Stopped ion distribution separated from ionization density

→ **Reduced effect from space charge**



Calculated acceptance



^{79}Br,
He-gas @ 100mbar

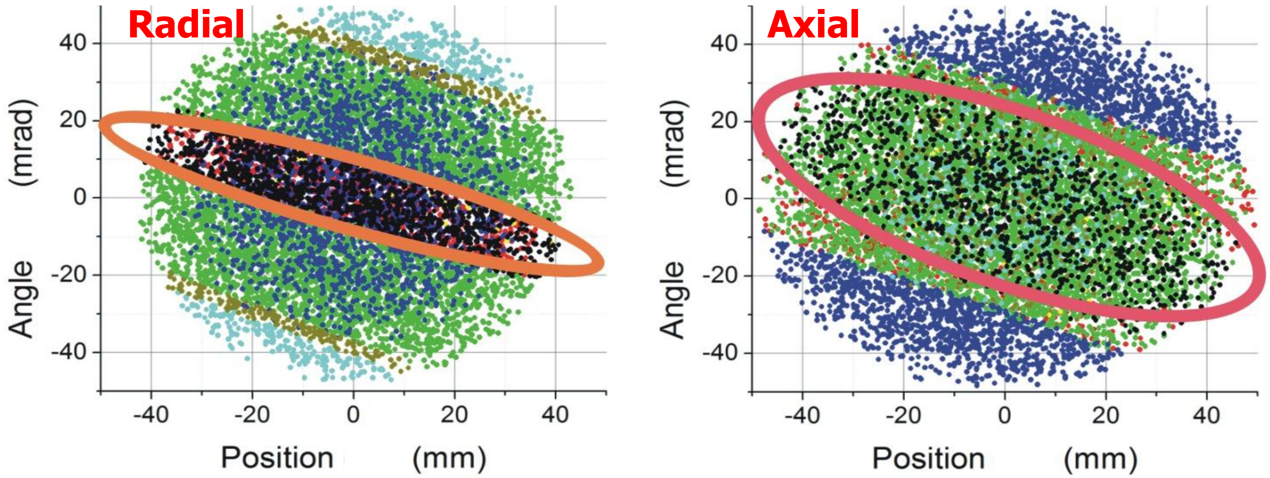
Acceptance of device, calculated from large 4d-input distribution

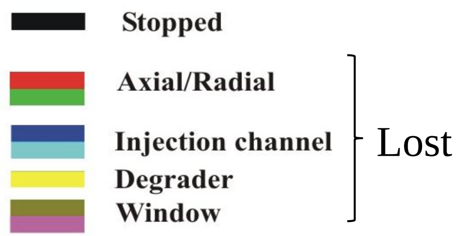
(N. Joshi)

Ion	Radial *Acceptance* CycStop	Axial *Acceptance* CycStop
79Br	897	1190
56Fe	740	1165
40Si	853	1187
24O	707	1179

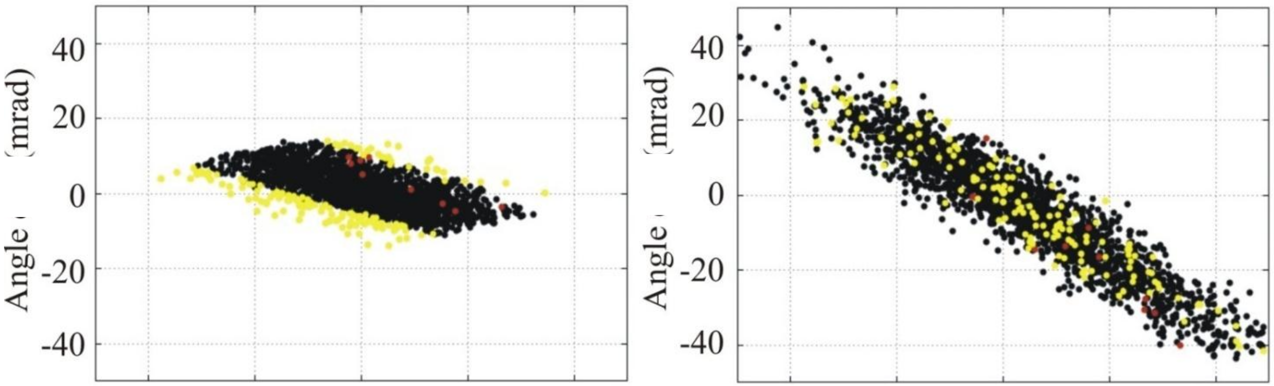
→ High acceptance (**~700-1000 π mm rad**)

Calculated stopping efficiency





^{79}Br,
He-gas @ 100mbar



← LISE++ output phase spaces, transport matched to stopped-ion distributions above

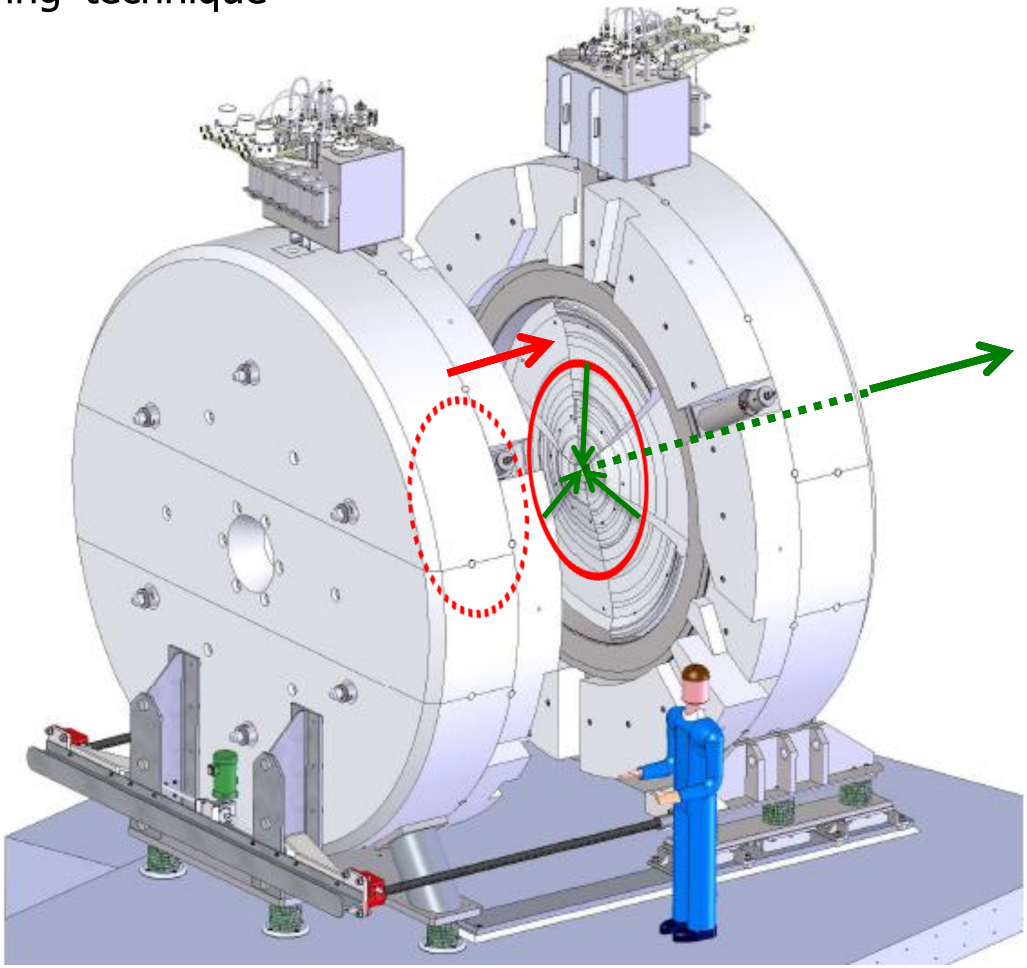
(N. Joshi)

Ion	Radial ***Acceptance*** **CycStop**	Radial ***Emittance*** **LISE++**	Axial ***Acceptance*** **CycStop**	Axial ***Emittance*** **LISE++**	Efficiency
79Br	897	227	1190	424	98.1%
56Fe	740	153	1165	419	96.9%
40Si	853	336	1187	1098	86.5%
24O	707	1550	1179	1038	64.9%

→ High acceptance (**~700-1000 π mm rad**)
→ High stopping efficiency
→ Stopping area r<0.5m

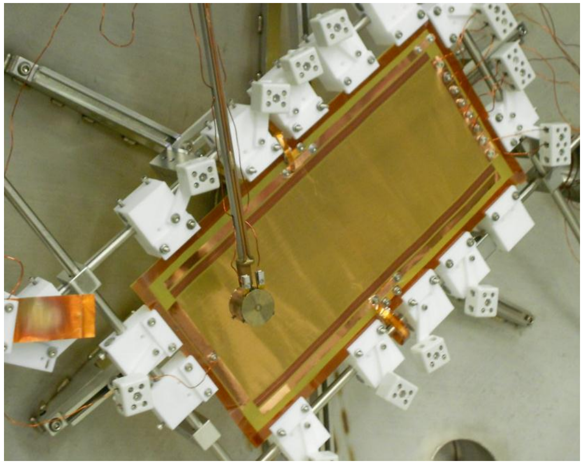
Fast ion extraction

Ion transport to center:
- Large **RF ion carpet**, ~1m diameter
- Likely 6-fold segmented (C, size limitations)
- 'Surfing' technique



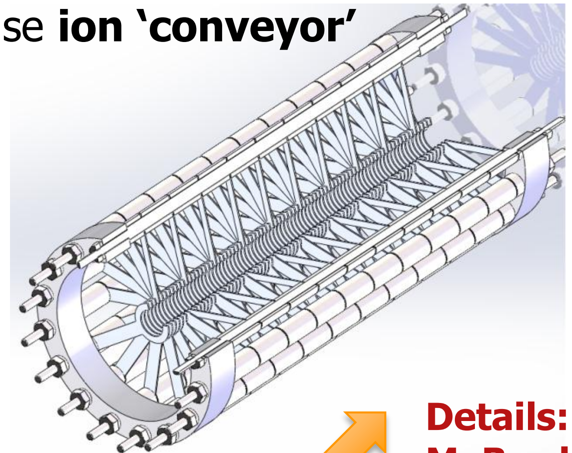
➔ Efficient extraction within ~30ms or less

Surfing carpet in test stand



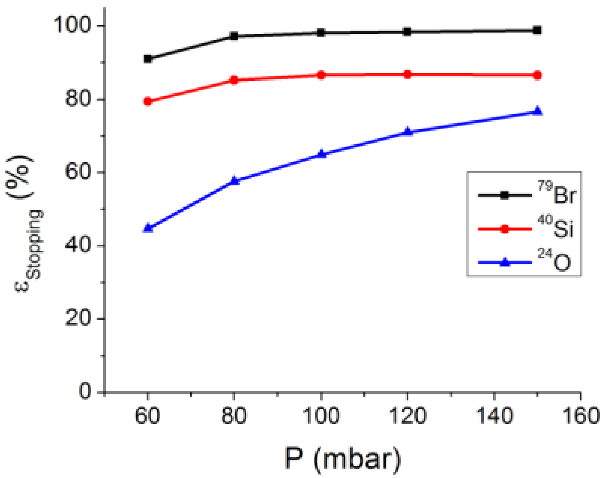
Ion extraction through hole
- RFQ ion guide + B-field = bad idea.
  → Resonance condition, loss

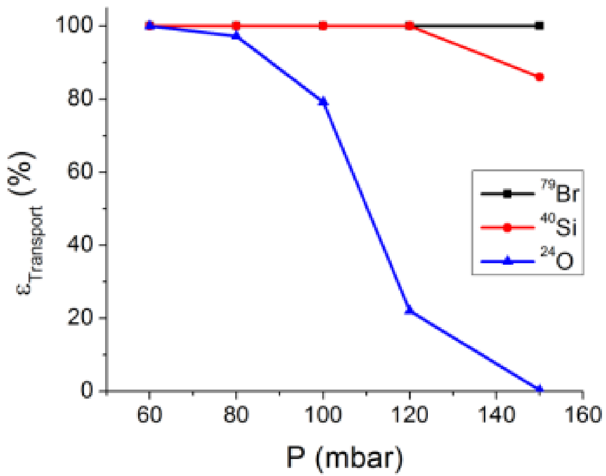
➔ Use **ion 'conveyor'**

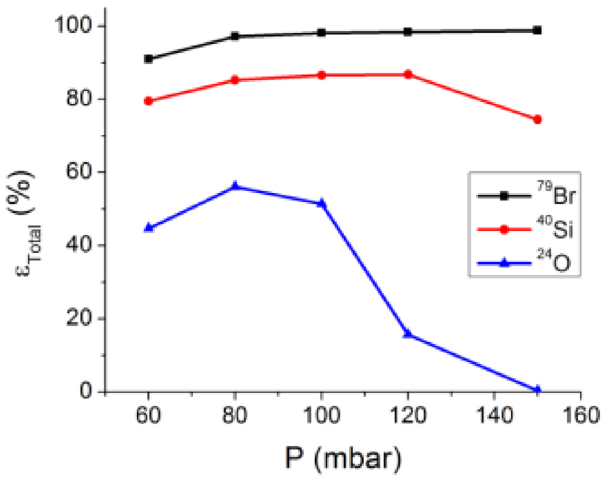


Details:
M. Brodeur

Predicted performance (simulation) :







Stopping * **Carpet transport** = **Total extraction**

Details:
M. Brodeur

Status

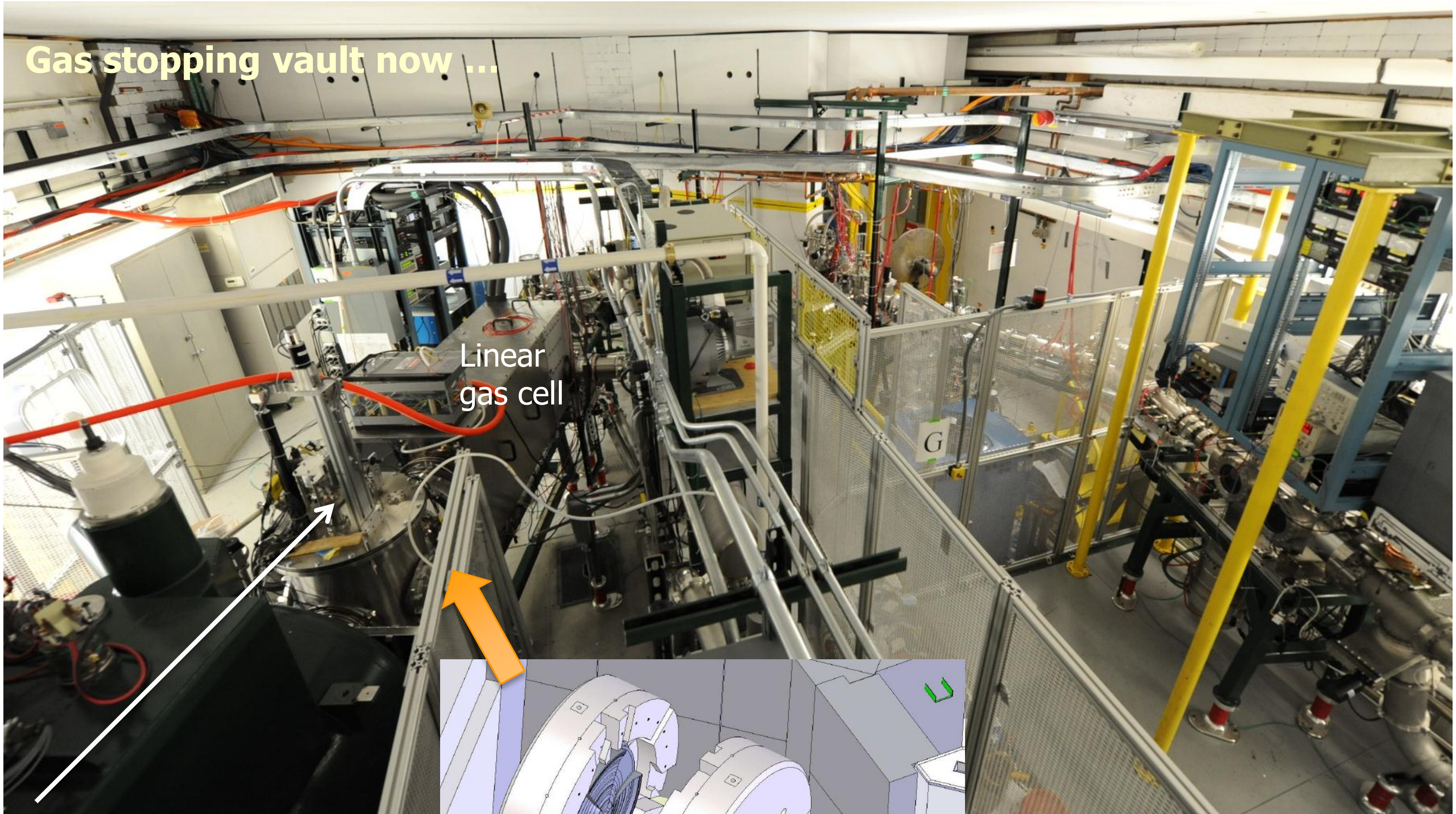
Magnet:
- design complete,
- steel: pole done, ½ yoke delivered
- cryostat: under construction

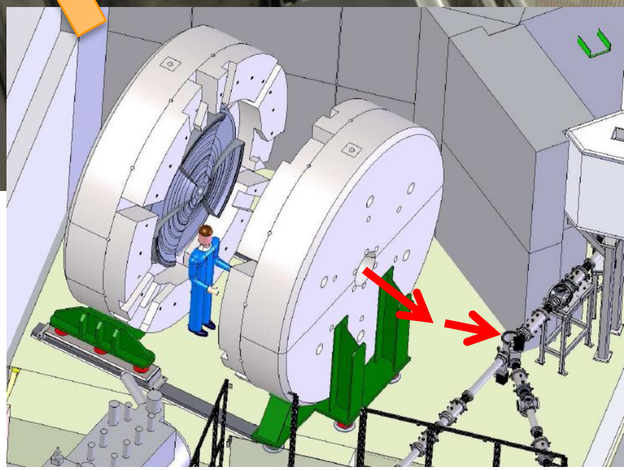
Stopped-ion transport:
- stopping chamber under design
- RF carpets, conveyor in testing

Magnet testing:
- offline 2013

Move to stopping vault: after that

Future





… and once the magnet is tested:

Thanks for listening!

MICHIGAN STATE
UNIVERSITY

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