Low-intensity exotic beam studies using an active-target time-projection chamber

Alan Howard

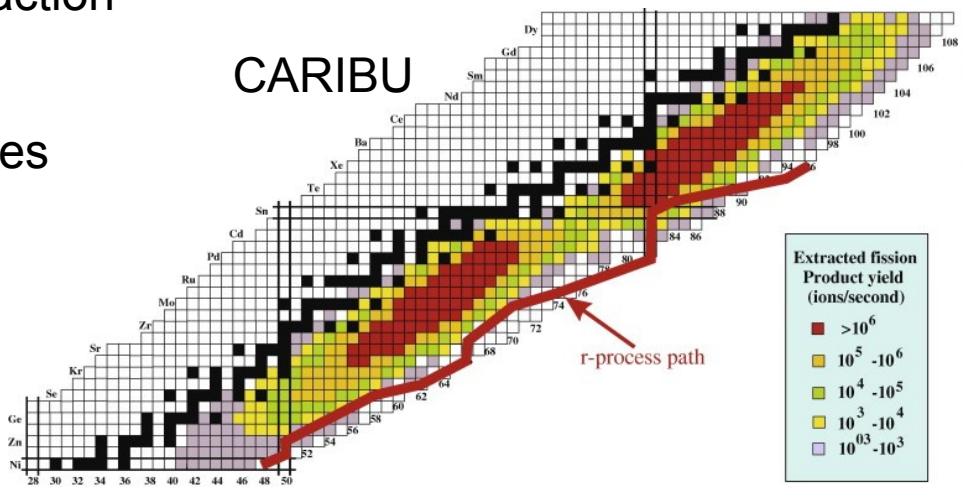
Exotic beam opportunities

New and next generation RIB facilities should provide new insight into the structure and reaction dynamics of exotic nuclei

However, many of the most interesting species produced with very low intensities

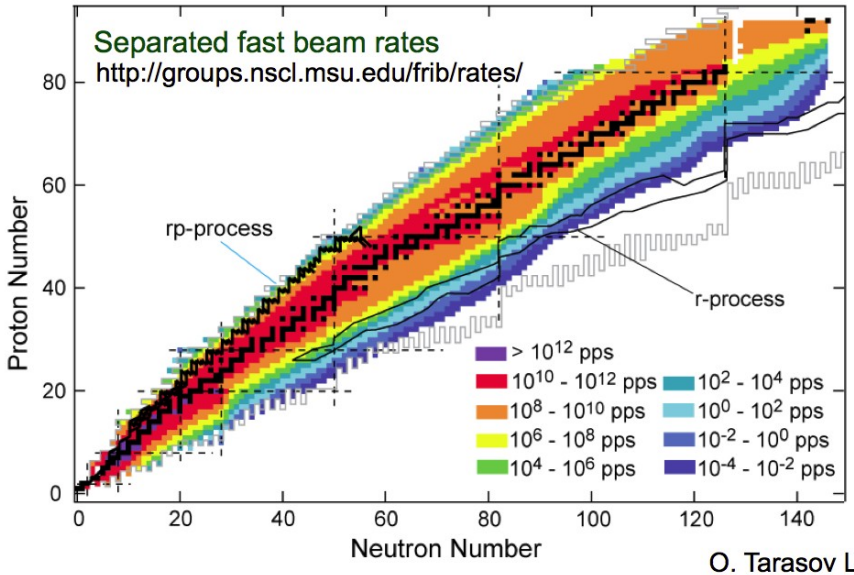
To fully exploit physics opportunities need to make full use of beams provided

CARIBU



G. Savard et al., Nucl. Inst. and Meth. B, **266** (2008) 4086-4091

FRIB



O. Tarasov LISE++

Typical stable beam studies use beams of order 10^9 – 10^{13} particles per second

This is a major challenge facing experimentalists

Active target approach

Target material also acts as detecting medium

Electric field drifts charge towards an anode plane

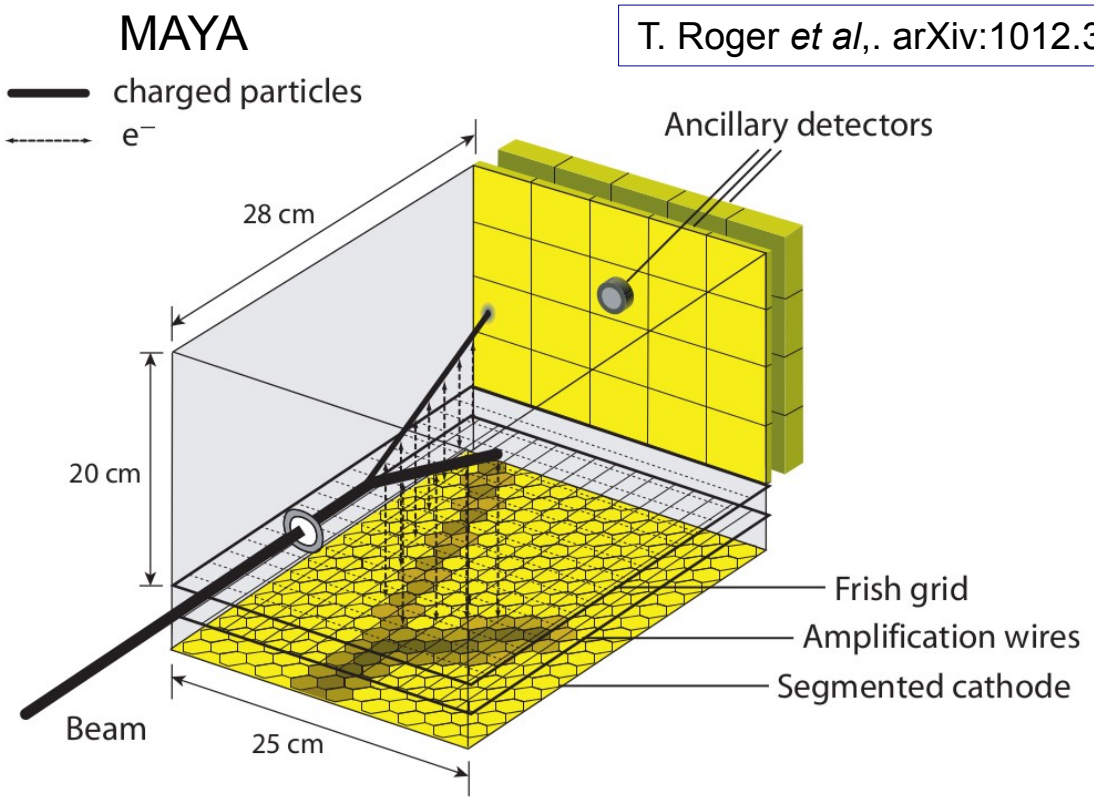
A position sensitive anode and sampling permit track images to be produced

Reaction vertices can be localised - no loss of resolution with increased target thickness

Full geometric coverage for outgoing ions - simultaneous study of break-up, transfer, incomplete fusion etc.

C.E. Demonchy *et al*., Nucl. Inst. and Meth. A, **583** (2007) 341–349

T. Roger *et al*,. arXiv:1012.3560



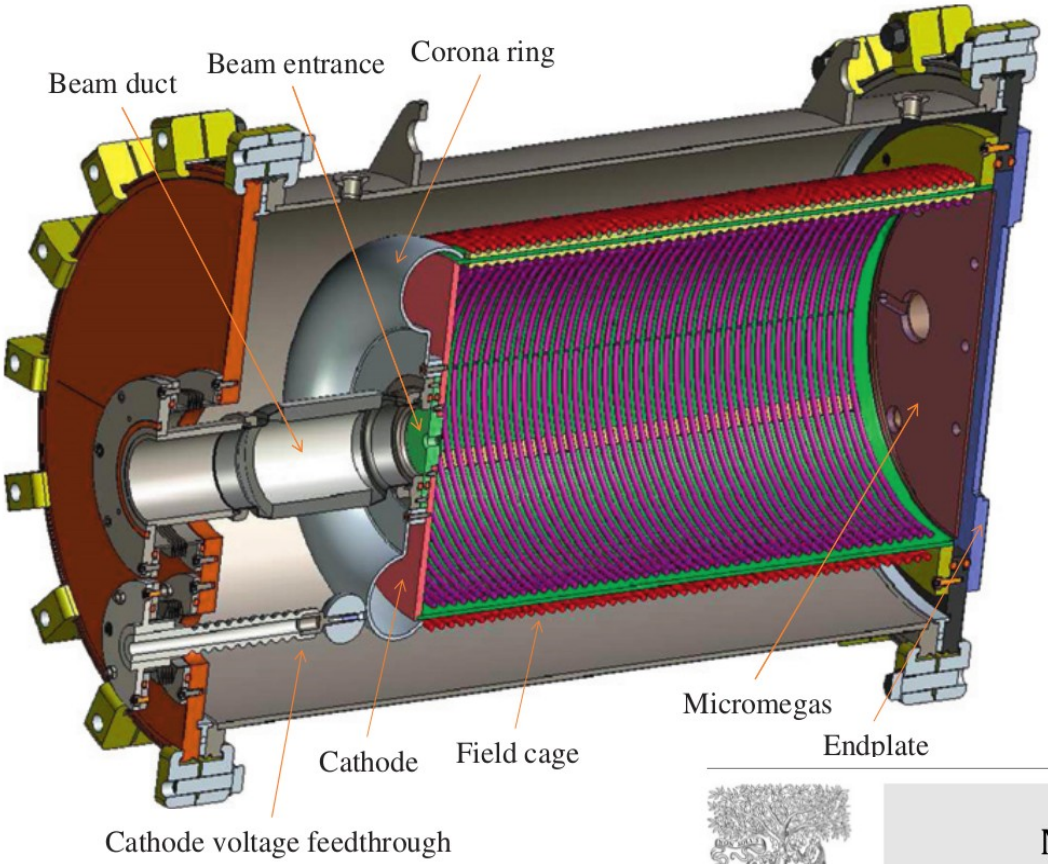
Dynamic range can also be a limitation, ways to reduce this however

Choice of targets limited by requirements of detection gas

Physics case

Measurement	Physics	Beam Examples	Beam Energy (A MeV)	Min Beam (pps)	Scientific Leader
Transfer & Resonant Reactions	Nuclear Structure	^{32}Mg(d,p)^{33}Mg ^{26}Ne(p,p)^{26}Ne	3	100	Kanungo
Astrophysical Reactions	Nucleosynthesis	^{25}Al(^{3}He,d)^{26}Si	3	100	Famiano, Montes
Fusion and Breakup	Nuclear Structure	^{8}B+^{40}Ar	3	1000	Kolata
Transfer	Pairing	^{56}Ni+^{3}He	5-19	1000	Macchiavelli
Resonances	Quasimelecular structures	^{8}He+^{4}He	0-3	1000	Suzuki
Fission Barriers	Nuclear Structure	^{199}Tl, ^{192}Pt	20 - 60	10,000	Phair
Giant Resonances	Nuclear EOS, Nuclear Astro.	^{54}Ni-^{70}Ni, ^{106}Sn-^{127}Sn	50 - 200	50,000	Garg
Heavy Ion Reactions	Nuclear EOS	^{106}Sn - ^{126}Sn, ^{37}Ca - ^{49}Ca	50 - 200	50,000	Lynch

Prototype AT-TPC



Half-scale prototype for testing and development of critical components

For example, Micromegas electron amplification and GET (general electronics for TPCs)

Provides essential feedback for development of the full-scale device

Nuclear Instruments and Methods in Physics Research A, **691** (2012), 39-54

Also a great opportunity to investigate the physics capabilities of the device

Contents lists available at SciVerse ScienceDirect

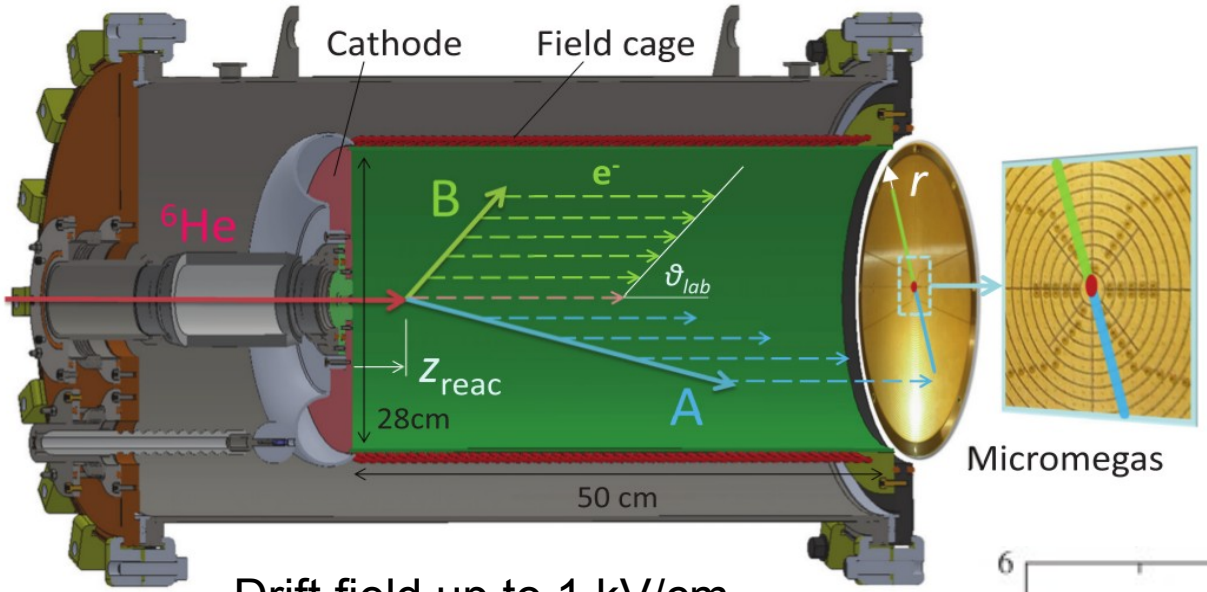
Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Prototype AT-TPC: Toward a new generation active target time projection chamber for radioactive beam experiments

D. Suzuki [a,*], M. Ford [b,1], D. Bazin [a], W. Mittig [a,b], W.G. Lynch [a,b], T. Ahn [a], S. Aune [c], E. Galyaev [a], A. Fritsch [a,b], J. Gilbert [b,2], F. Montes [a], A. Shore [a,b], J. Yurkon [a], J.J. Kolata [d], J. Browne [d,a,b], A. Howard [d], A.L. Roberts [d], X.D. Tang [d]

Prototype AT-TPC



Drift field up to 1 kV/cm

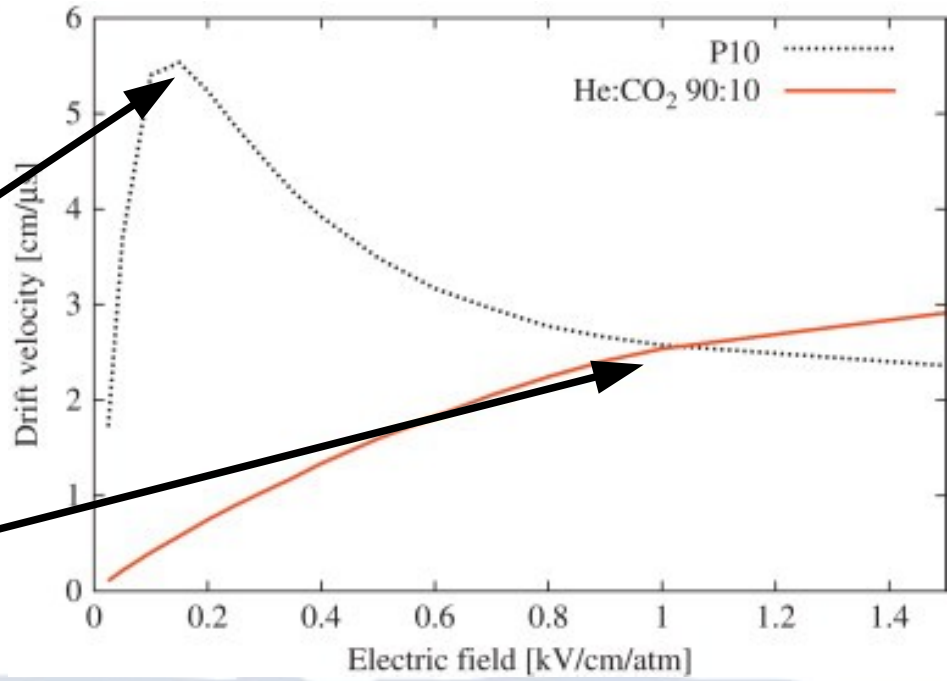
Daisuke Suzuki *et al.*, Phys. Rev. C **87**, 054301 (2013)

Ions create ionisation trails effectively instantaneously

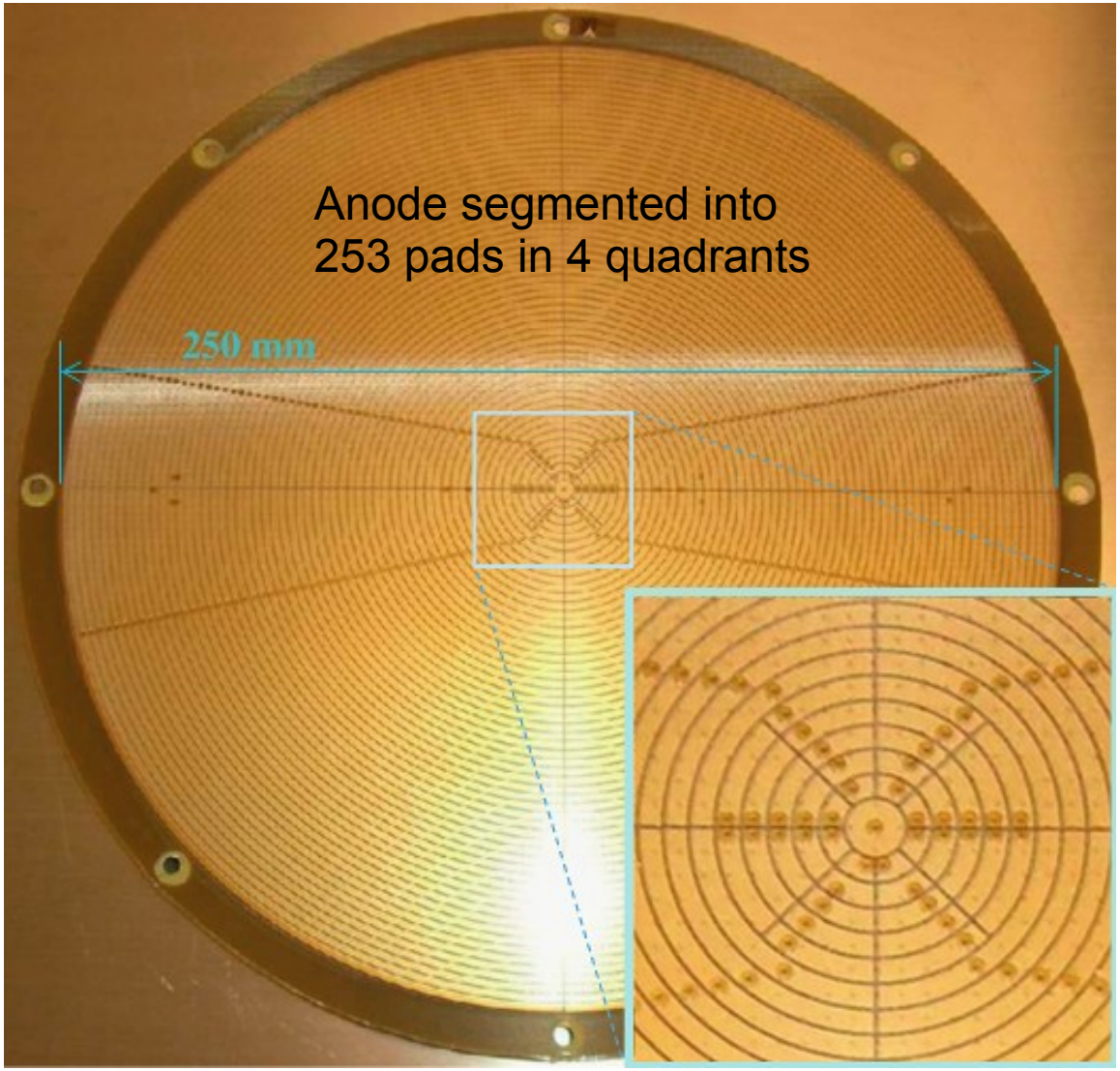
Ionisation trail drifts to the anode- projection onto the anode plane is sampled as a function of time

For P10 drift field of ~0.15 kV/cm/atm is optimal

For $HeCO_2$ maximum obtainable drift field is desired



Micromegas



Covered by a micromesh, held at a distance of 128 μm by resistive pillars

Uniform amplification properties, very stable with respect to time and position

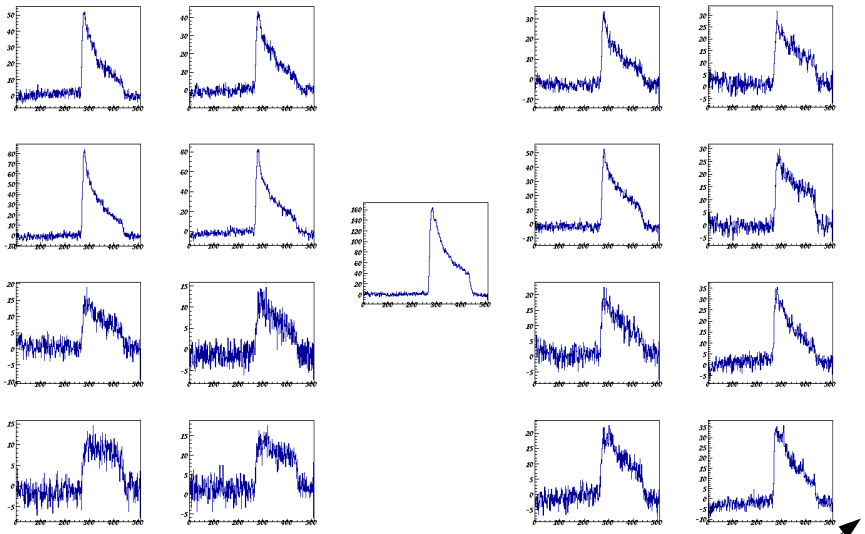
Rapid collection of +ve ions permits high rate operation

Adjusting individual pad potentials permits varying gain – expansion of dynamic range

However, micromesh is **very** sensitive – any deformation is catastrophic

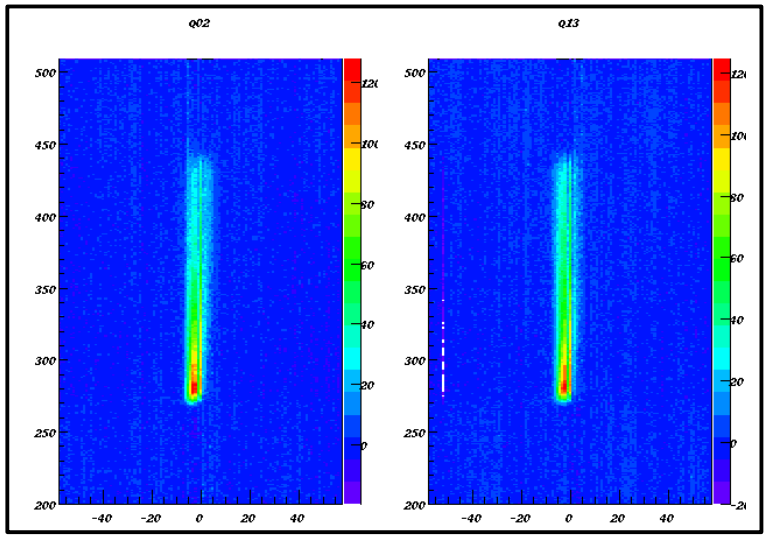
Data stream

Each pad is sampled at up to 25 MHz, waveforms are recorded

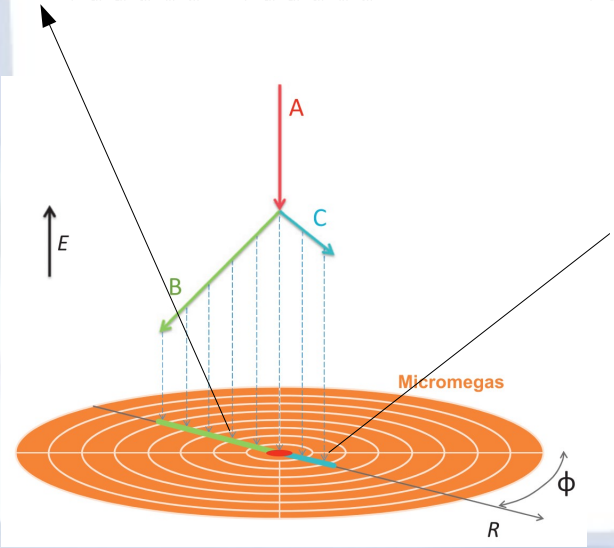


Typical 'beam' event

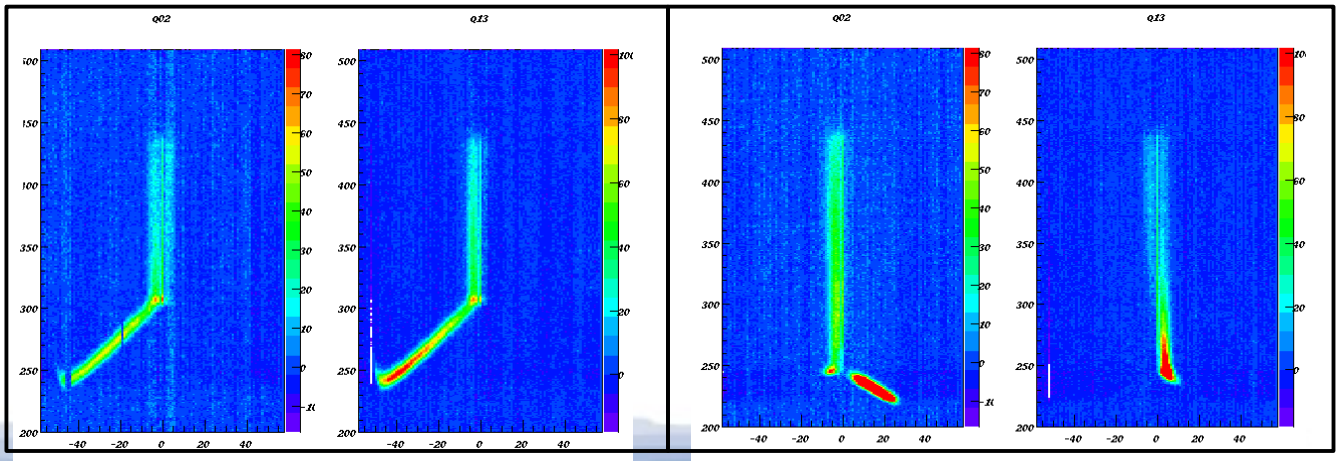
Time (depth)



Radius (back-to-back quadrants)



Scatter events



Use case – ^{10}Be + ^{40}Ar Fusion

Many open questions remain

Role of positive Q-value transfer channels

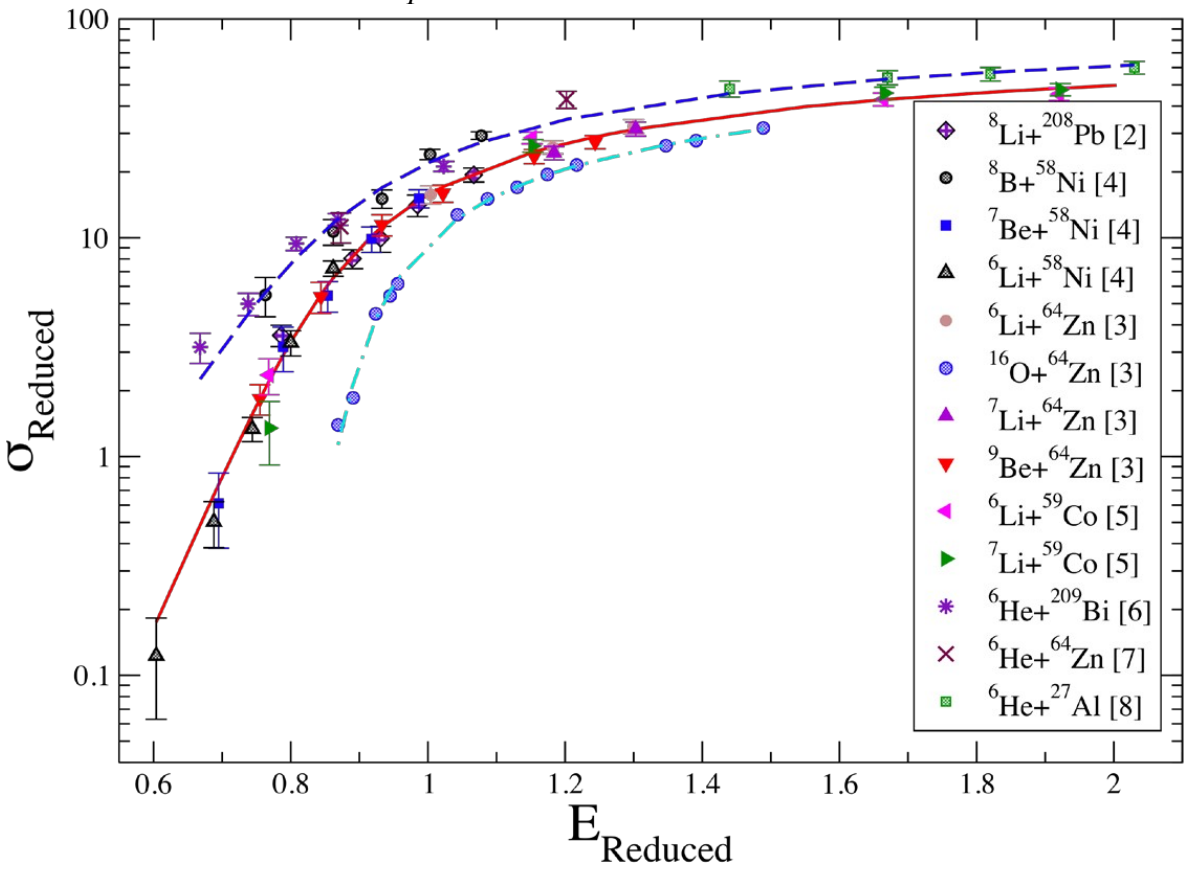
Effect of skin and halo structures

Influence of other channels, e.g. scattering, break up and transfer

Competition between complete and incomplete fusion

$$R = R_0\left(A_p^{1/3} + A_T^{1/3}\right)$$

$$E_{\text{reduced}} = \frac{E_{cm}}{\left(Z_p Z_T\right)} R \qquad \sigma_{\text{reduced}} = \frac{\sigma_{\text{exp}}}{R}$$



J.J. Kolata and E.F. Aguilera, Phys. Rev. C **79** (2009) 027603

Experimental aims and considerations

Move the prototype AT-TPC to Notre Dame and look at ^{10}Be fusion with ^{40}Ar

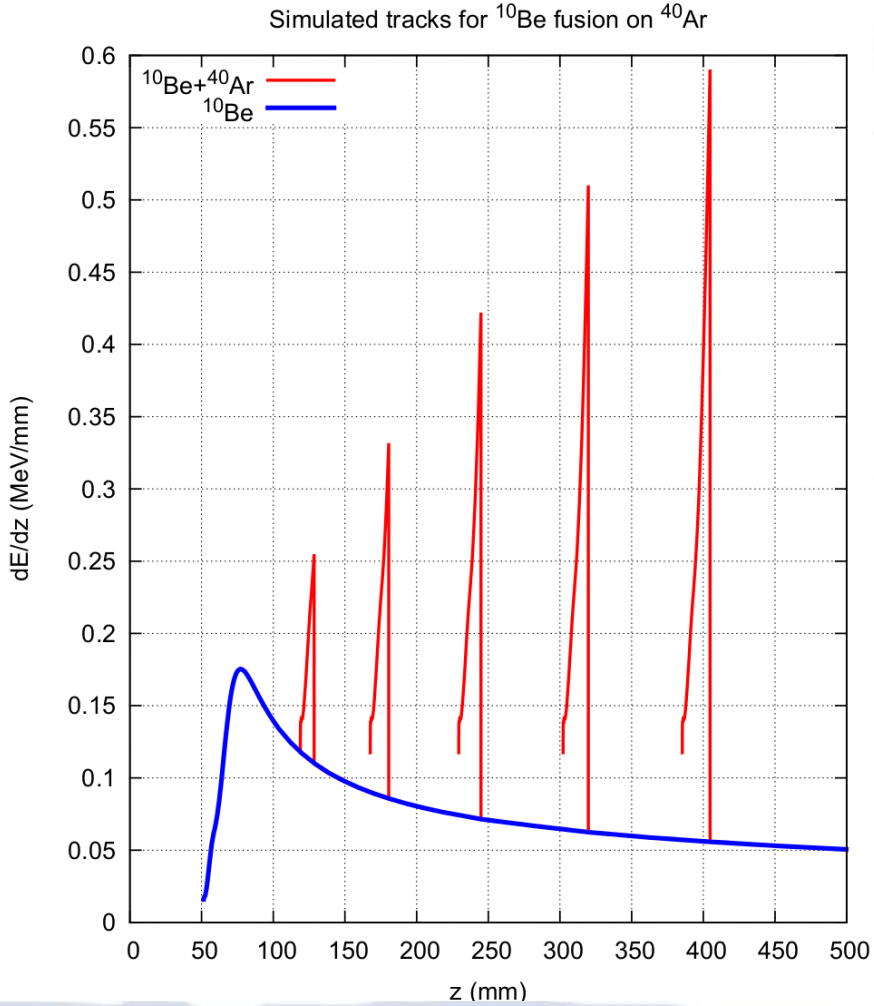
Opportunity to develop knowledge and technique for future use

^{10}Be fusion measured on ^{209}Bi previously - extend data to lower Z

C. Signorini *et al*., Nuc Phys A, **735** (2004), 329-344

Coulomb barrier is at ~15 MeV, beam energy of 35 MeV permits measurement above and below barrier

SRIM calculation for ^{10}Be into 235 torr P-10 at 35 MeV

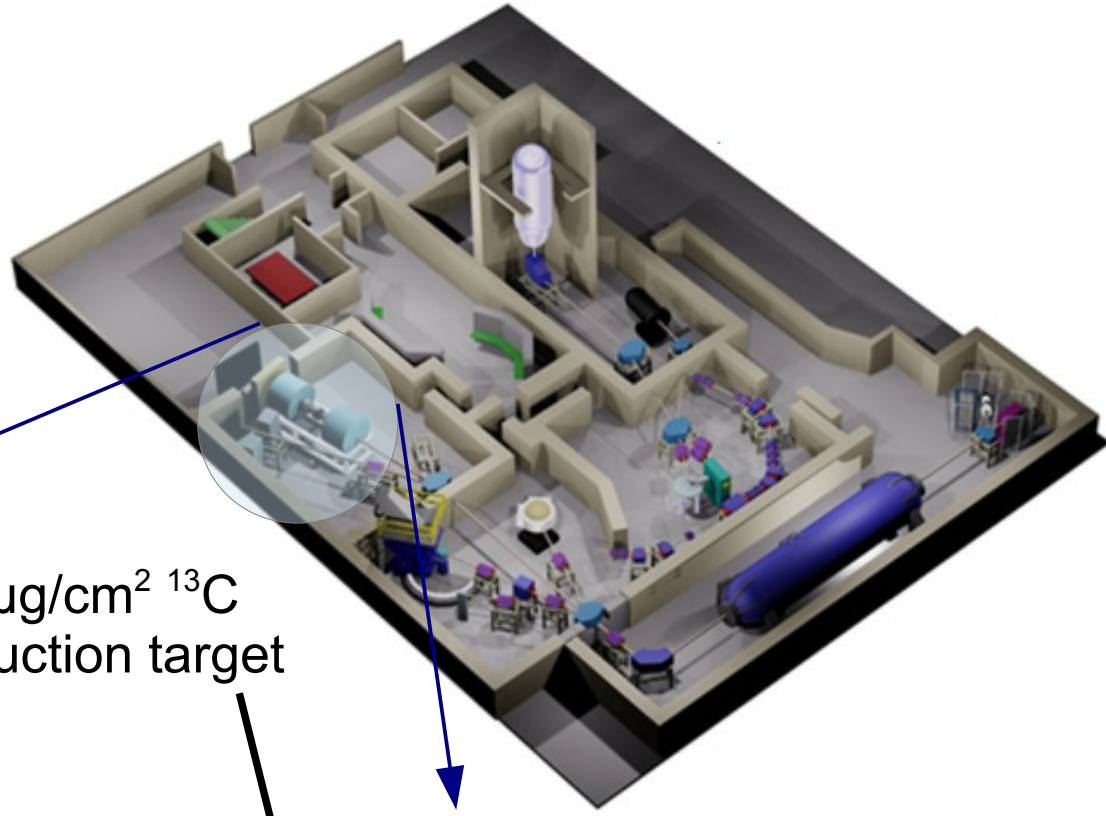


RNB production at Notre Dame

RNB programme since 1987

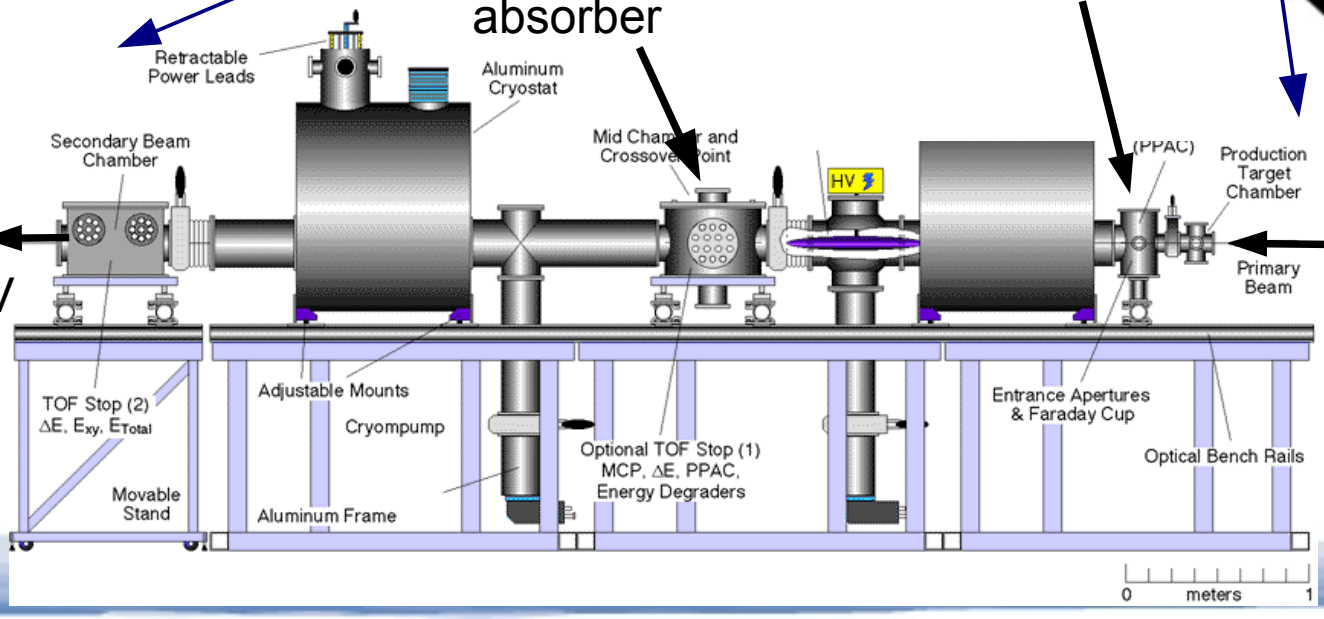
TwinSol upgrade completed in 1997

Two 6T superconducting solenoids



400 μg/cm^2 ^{13}C production target

Mid-plane absorber



TPC

35 MeV ^{10}Be

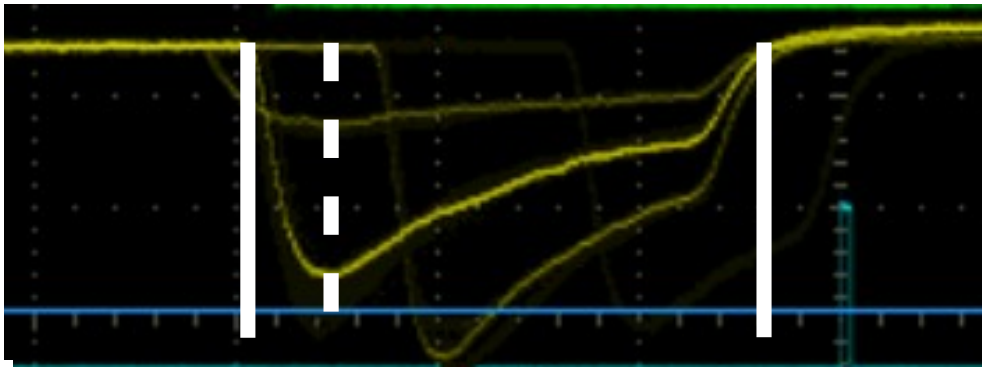
Bunched ^{11}B beam @ 45 MeV

1 bunch per 100 ns

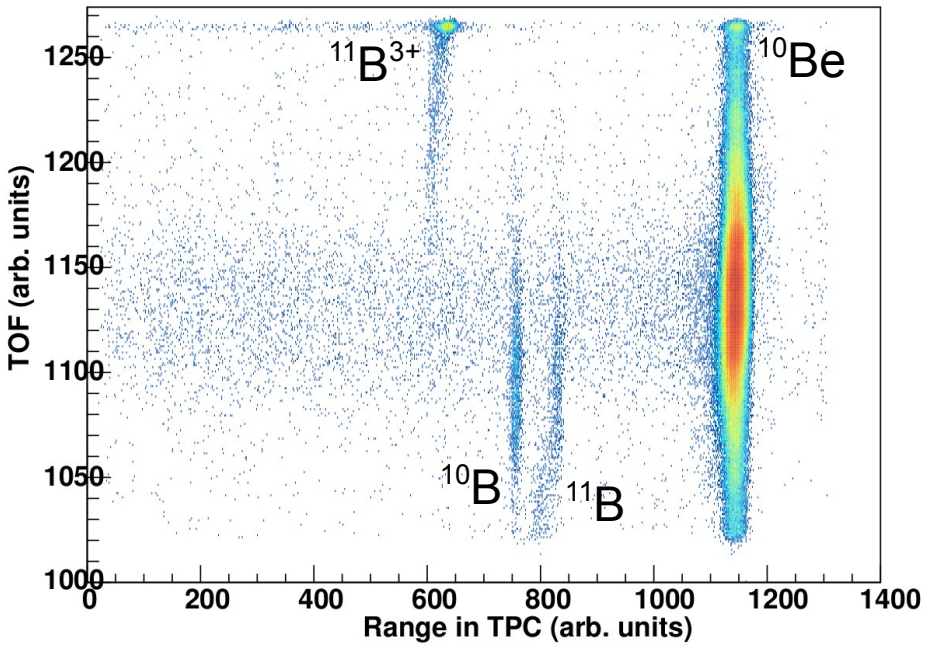
Trigger conditions

Trigger rate limited to 10-20 Hz
(new electronics > 100Hz)

Including hardware cut on
TOF reduces rate to <200 Hz



Pulse length = ion range

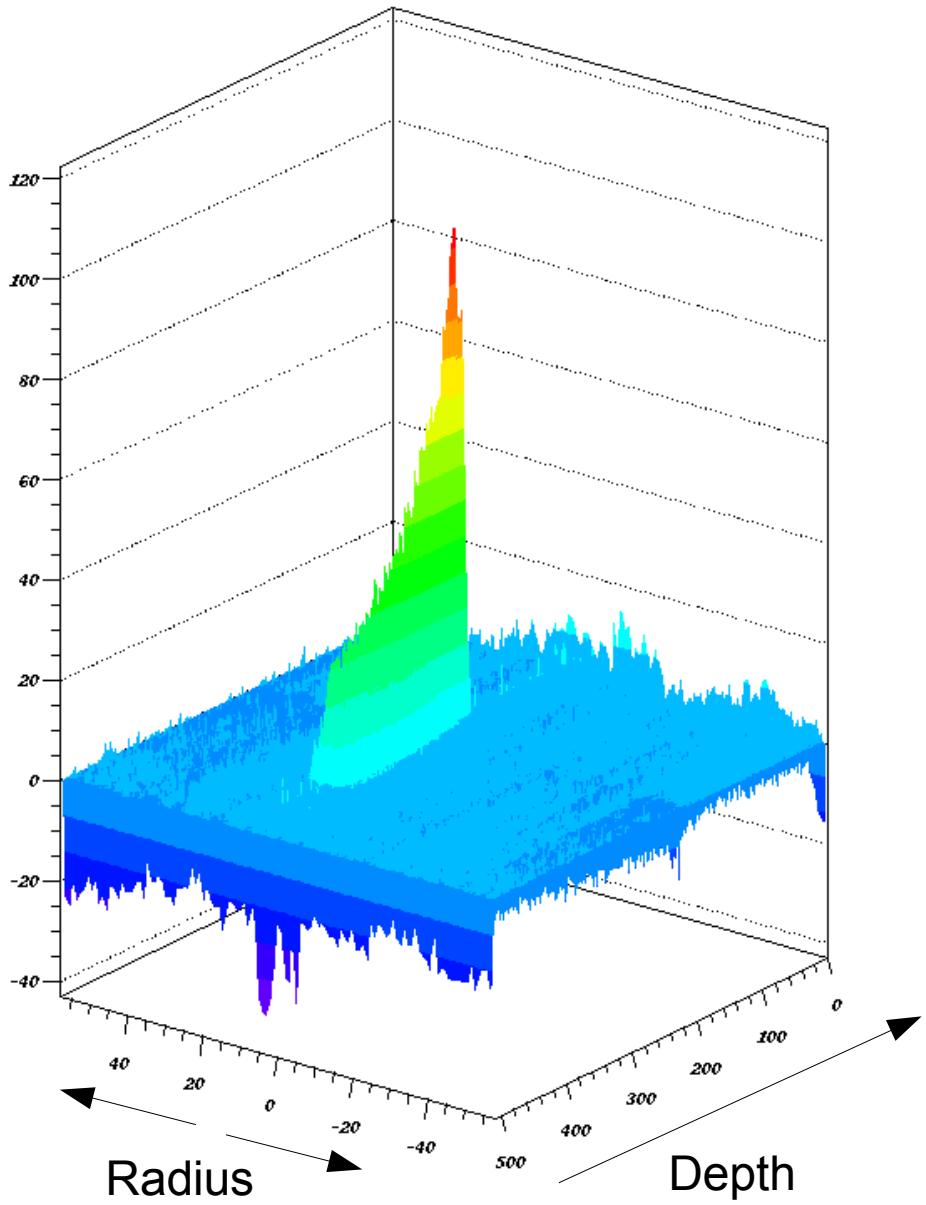


Further hardware gate on ion range
in AT-TPC reduces rate to <20Hz

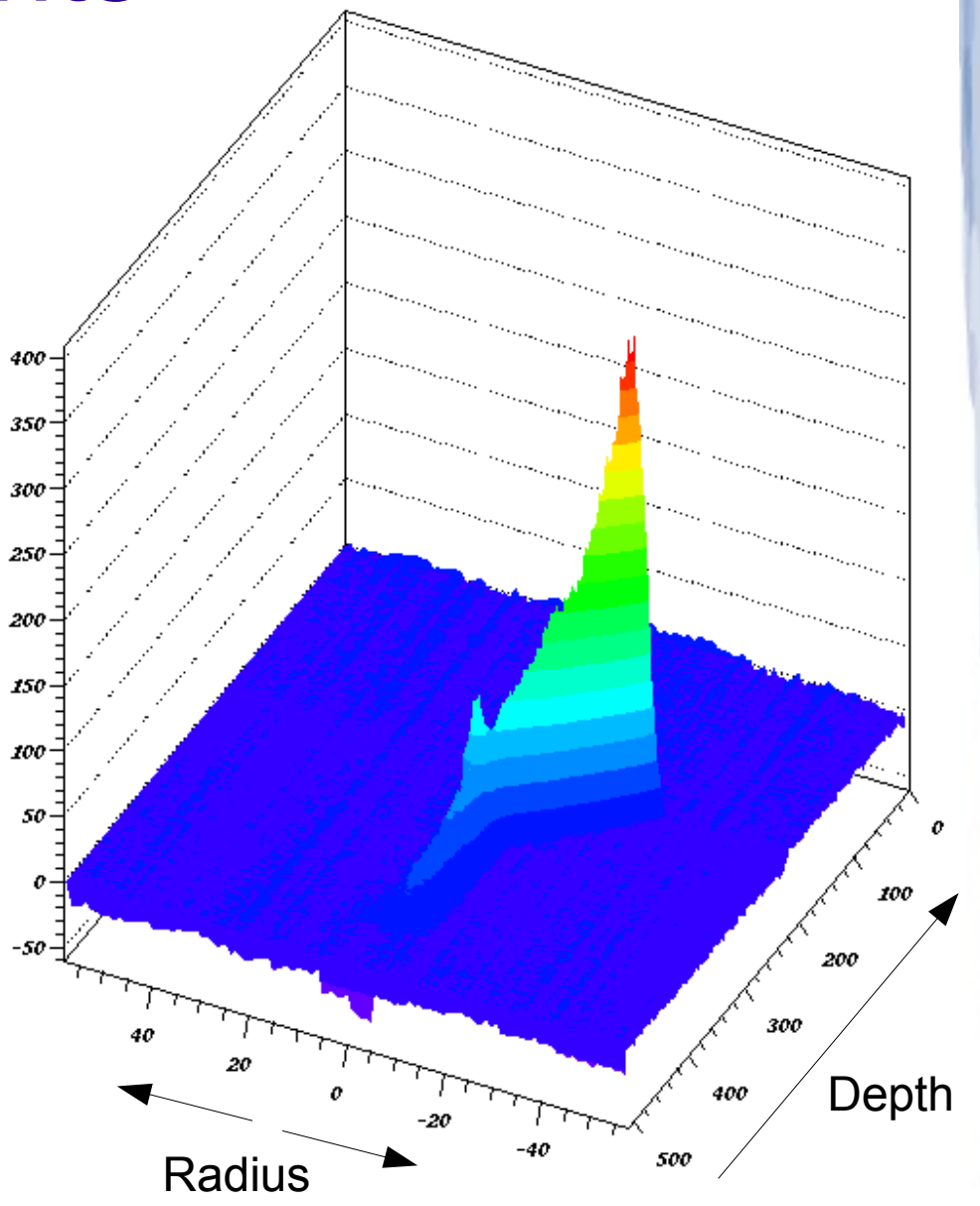
Option exists to trigger also on
radius or back-to-back quadrants

Events

Low-energy ^{10}Be

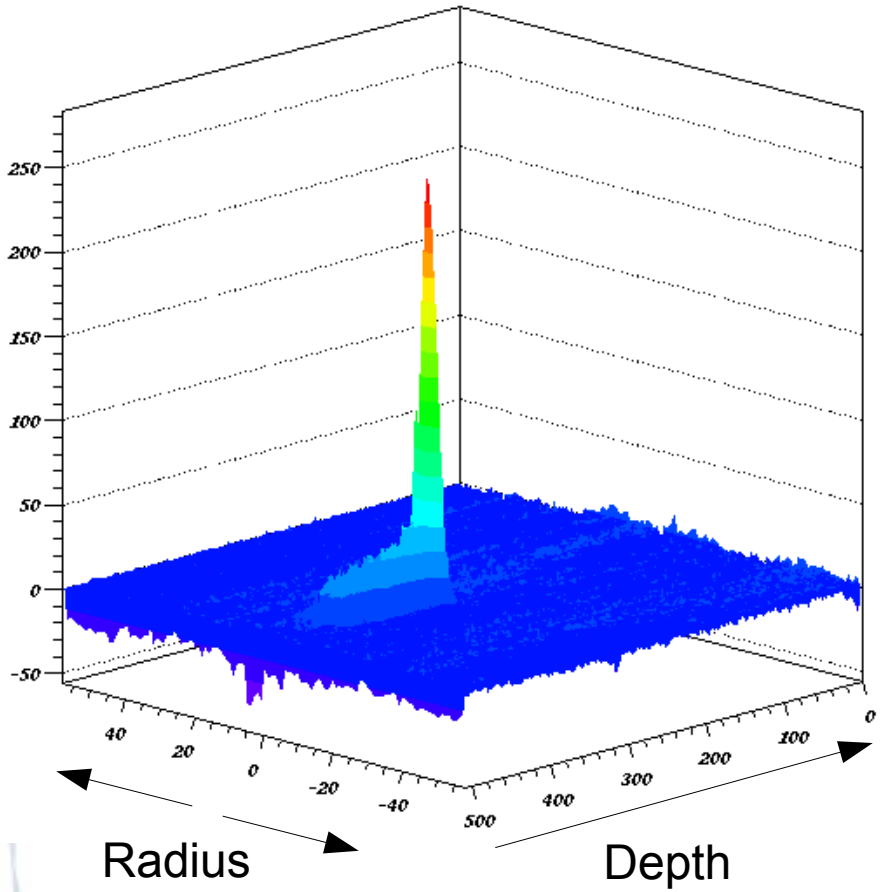


Scattered ^{10}Be



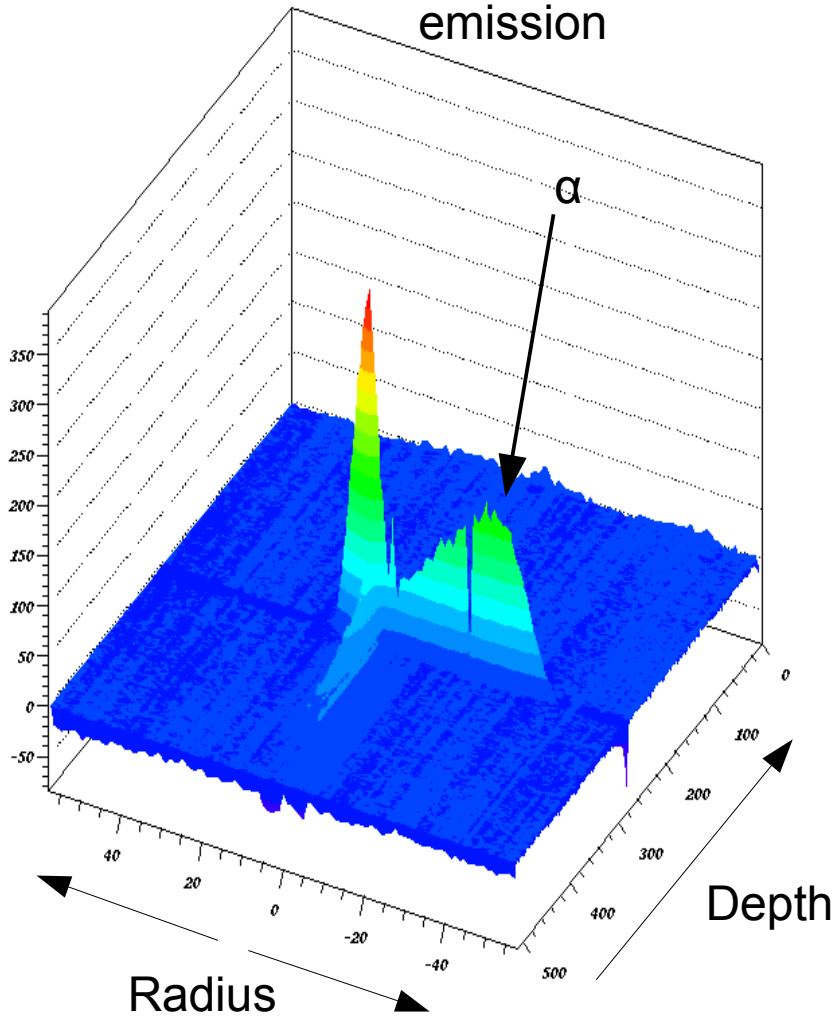
Events

~7000 fusion events
collected over 3 days



Fusion – no charged
particle emission

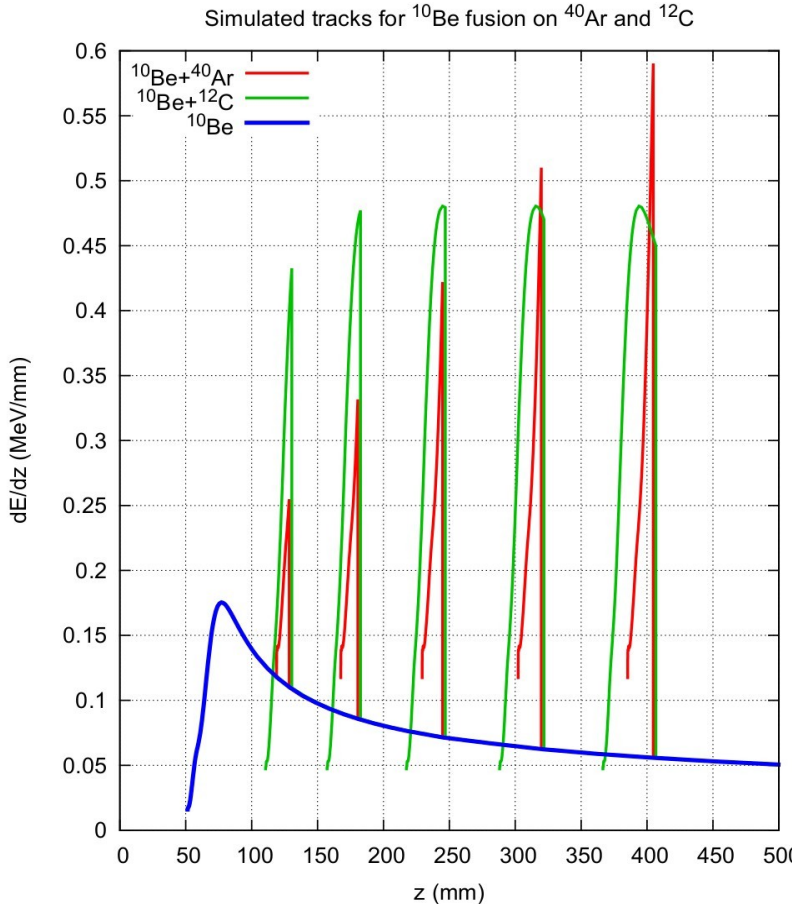
Fusion – α-particle
emission

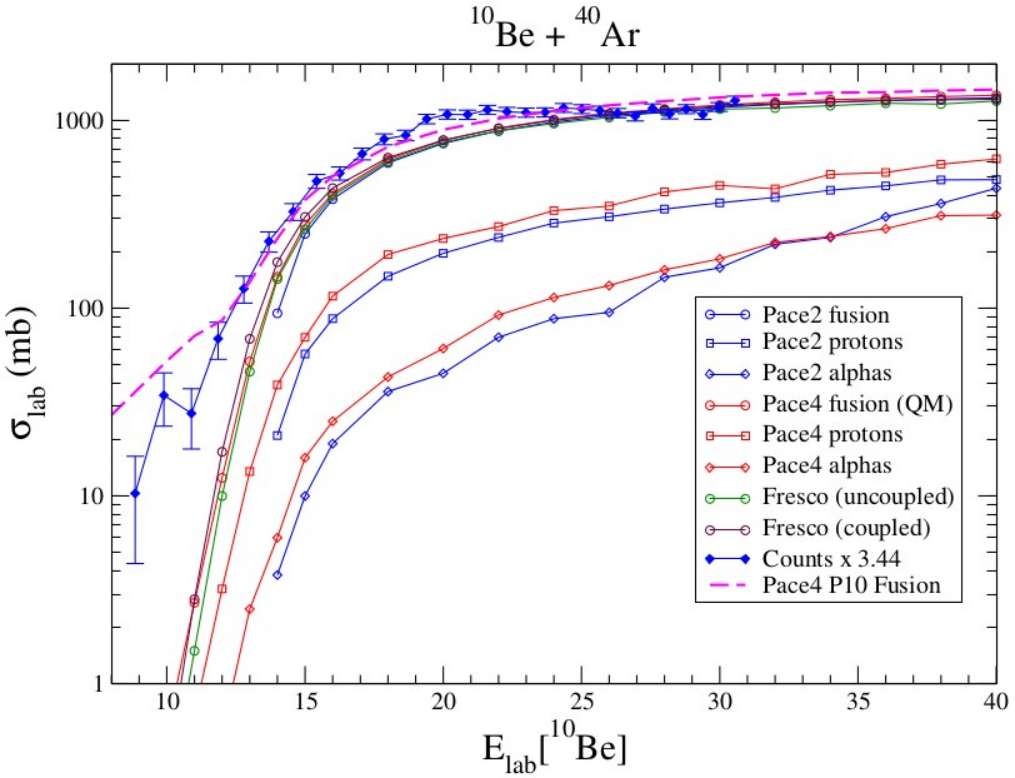


Outcomes

We can certainly quantitatively measure fusion

Fusion on ^{12}C not entirely separable from ^{40}Ar





Also – gas properties are very important, e.g. purity, temperature/pressure

Other work

PHYSICAL REVIEW C **87**, 054301 (2013)

UNIVERSITY OF NOTRE DAME

Resonant α scattering of ^{6}He: Limits of clustering in ^{10}Be

D. Suzuki,[1,2,*] A. Shore,[1,3] W. Mittig,[1,3] J. J. Kolata,[4] D. Bazin,[1] M. Ford,[1,†] T. Ahn,[1] F. D. Becchetti,[5] S. Beceiro Novo,[1] D. Ben Ali,[6] B. Bucher,[4] J. Browne,[1,3,4] X. Fang,[4] M. Febbraro,[5] A. Fritsch,[1,3] E. Galyaev,[1] A. M. Howard,[4] N. Keeley,[7] W. G. Lynch,[1,3] M. Ojaruega,[5] A. L. Roberts,[4] and X. D. Tang[4]

Cluster structures in ^{14}C via α scattering of ^{10}Be

Adam Fritsch, MSU

UNIVERSITY OF NOTRE DAME

Argonne NATIONAL LABORATORY

Tan Ahn, MSU

Resonant proton scattering of ^{124}Sn

Exploratory run for planned ^{132}Sn run

Implantation of ^{12}B and triple alpha decay of ^{12}C

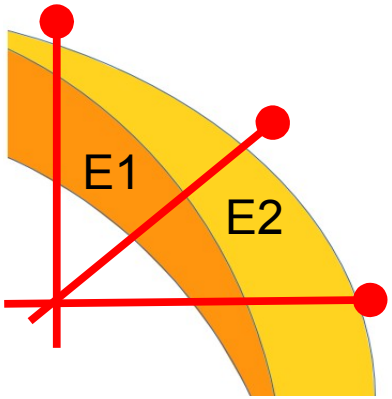
Cathleen Fry, MSU

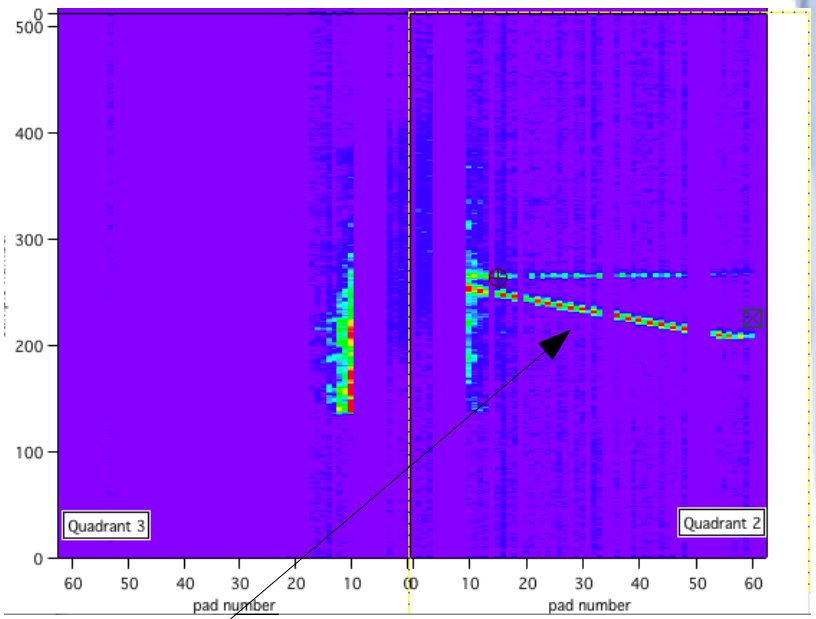
UNIVERSITY OF NOTRE DAME

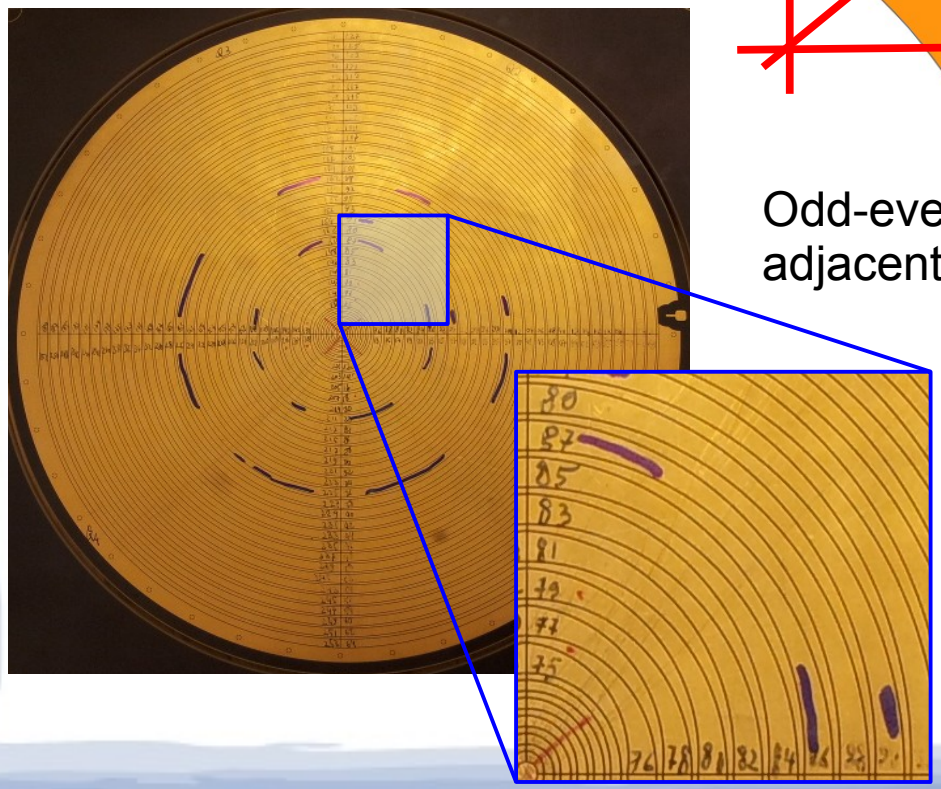
Backgammon Micromegas

'Backgammon' Micromegas designed and developed to provide φ sensitivity

Downside - some loss of radial sensitivity

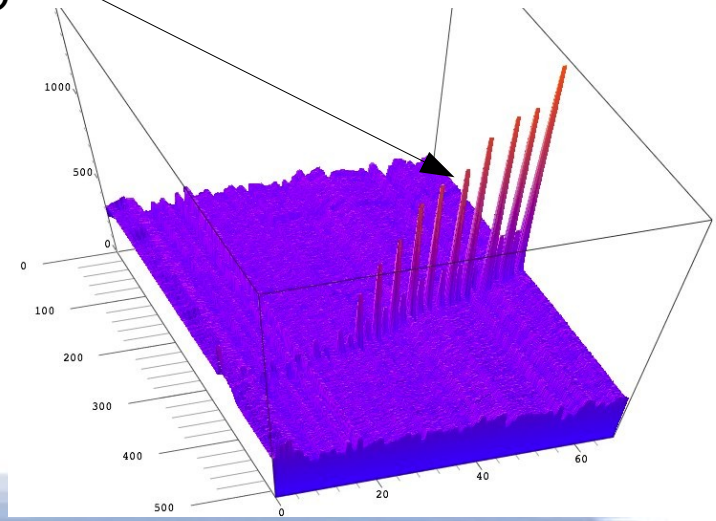






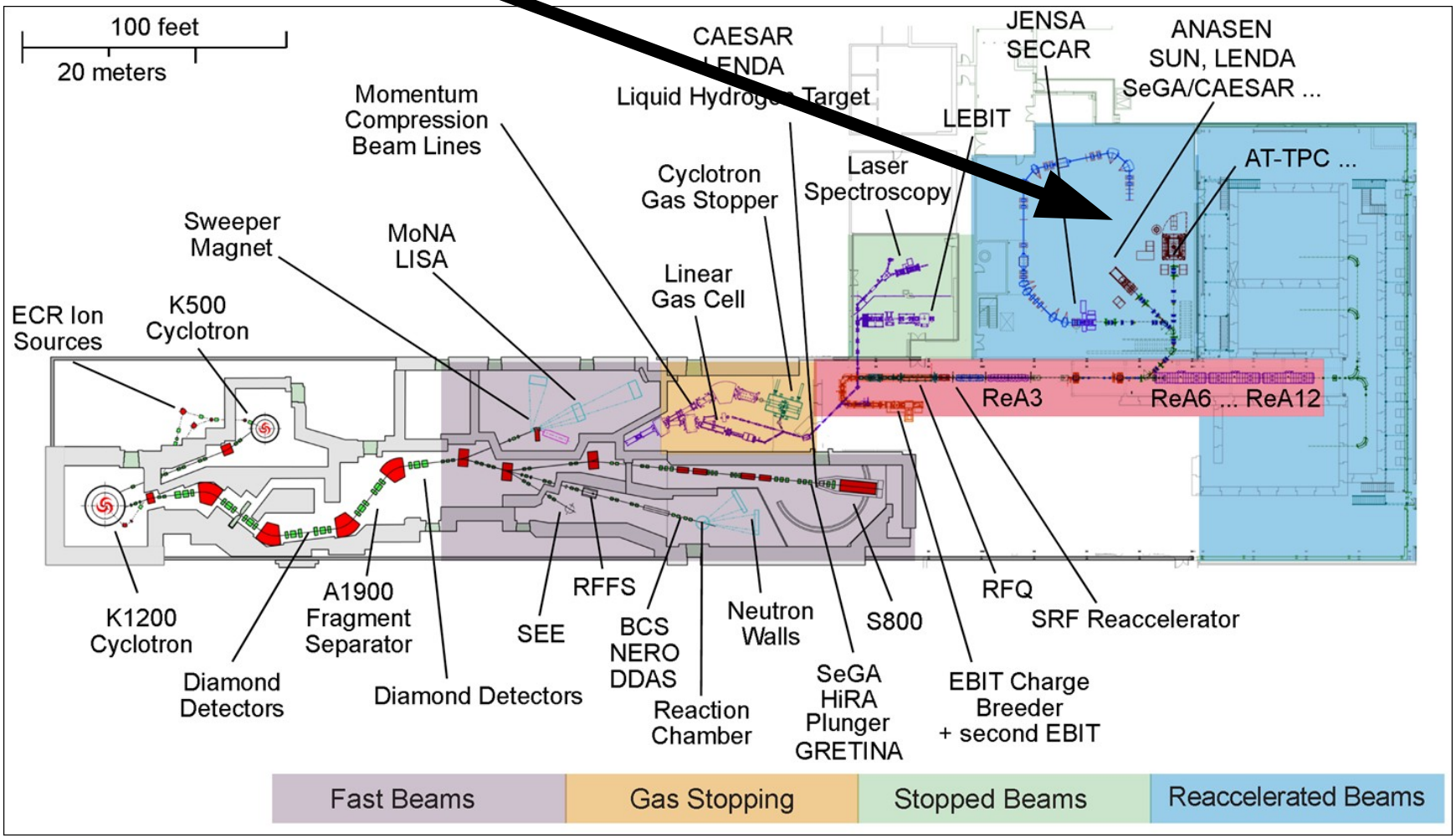
Odd-even staggering of adjacent pads gives φ

Tan Ahn, MSU



Full-scale AT-TPC

Now under construction at the NSCL in the ReA3 hall



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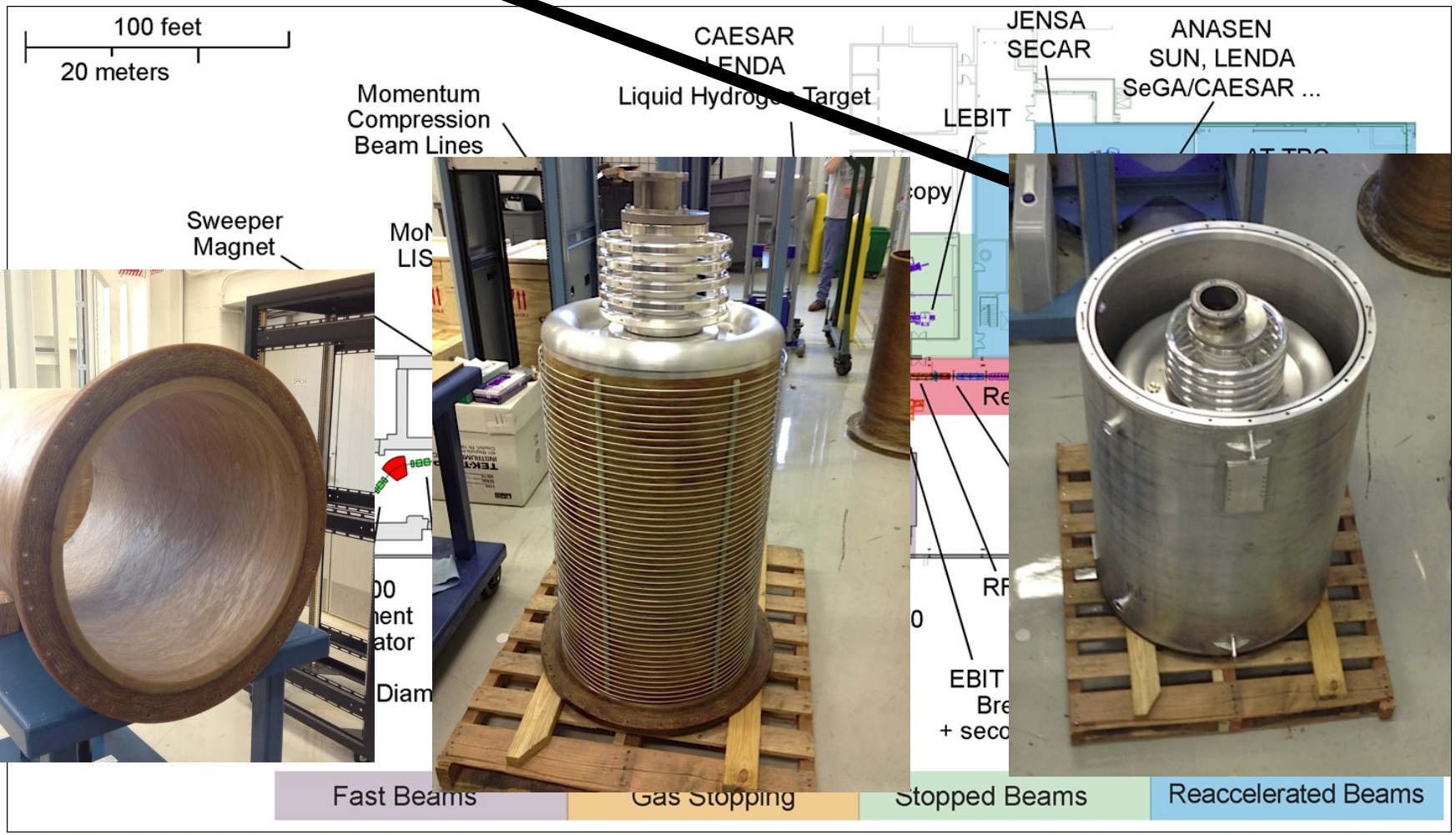
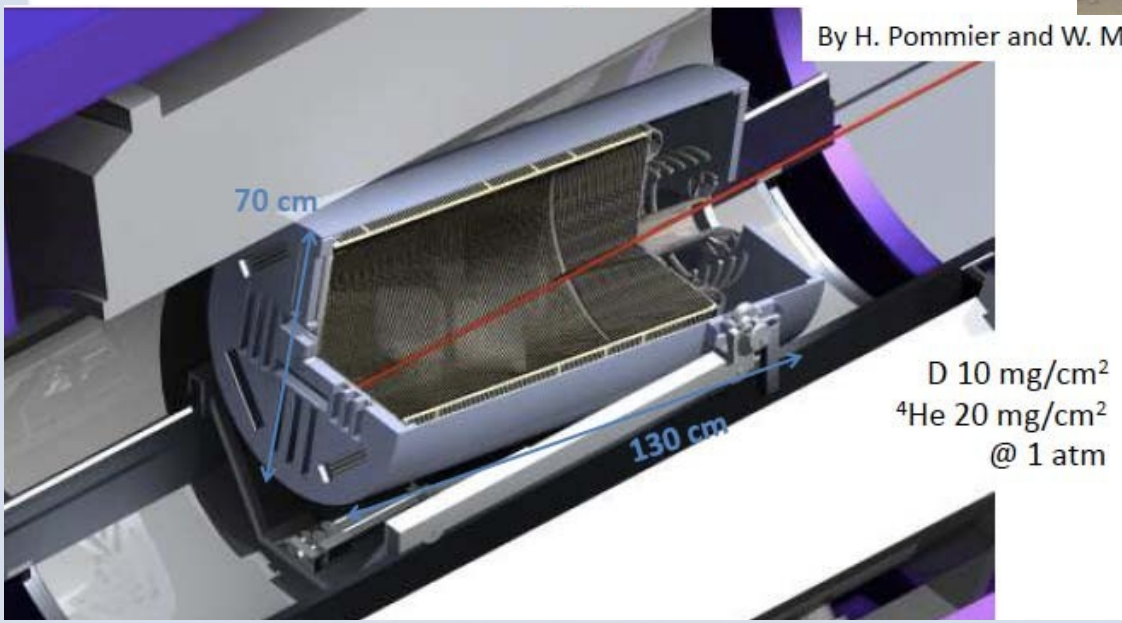


Full-scale AT-TPC

Twice the size of prototype – 1 m long by 0.5 m in diameter

Anode plane will have > 10,000 triangular pads and will provide much improved radial and φ sensitivity



By H. Pommier and W. Mittig

Chamber to be housed in solenoidal field, providing both containment and identification of ejectile ions

Will have full particle tracking included in analysis code

Acknowledgements

A.M. Howard, J.J. Kolata, A. Roberts
Department of Physics, The University of Notre Dame, USA

W. Mittig, T. Ahn , D. Bazin , S. Beceiro-Novo , Z. Chajecki , A. Fritsch , W.G. Lynch , A. Shore
National Superconducting Cyclotron Laboratory, Michigan State University, USA

F.D. Becchetti , M. Febbraro , R.O. Torres-Isea
Department of Physics, University of Michigan, USA