RARE ISOTOPES, RARE EVENTS and ACTIVE TARGET DETECTORS for STUDIES WITH EXOTIC BEAMS

present and next future

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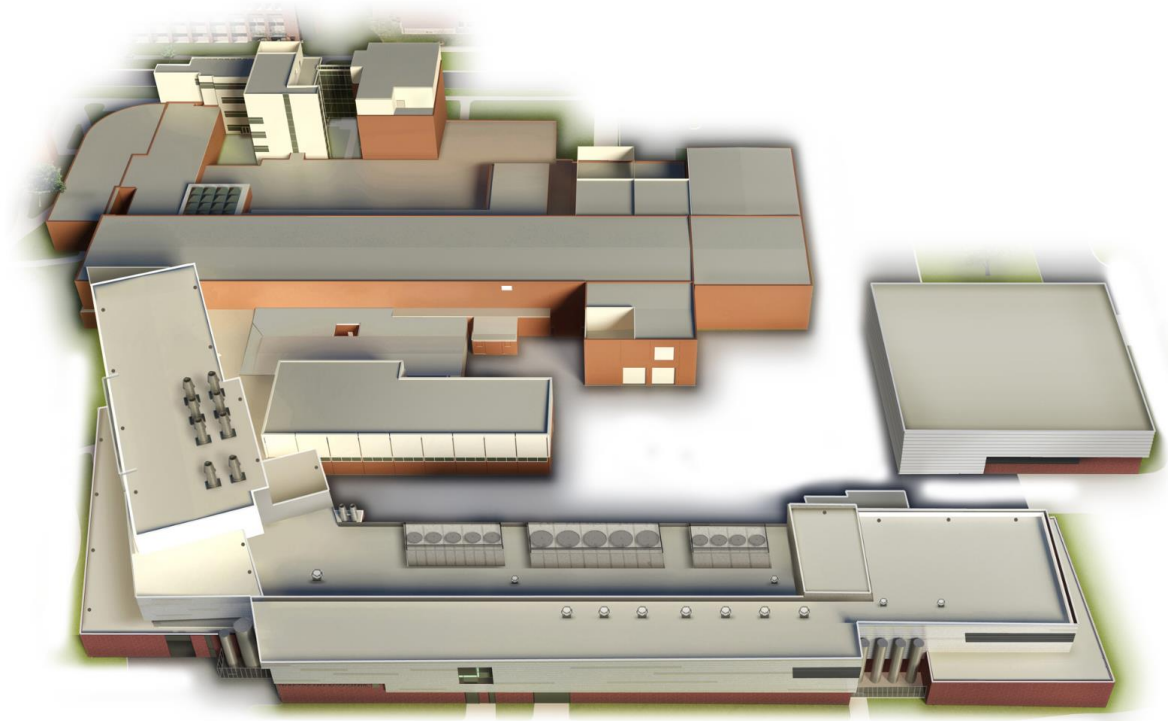
MSU-NSCL

Paris December 15th 2014

U.S. Department of Energy Office of Science
National Science Foundation
Michigan State University

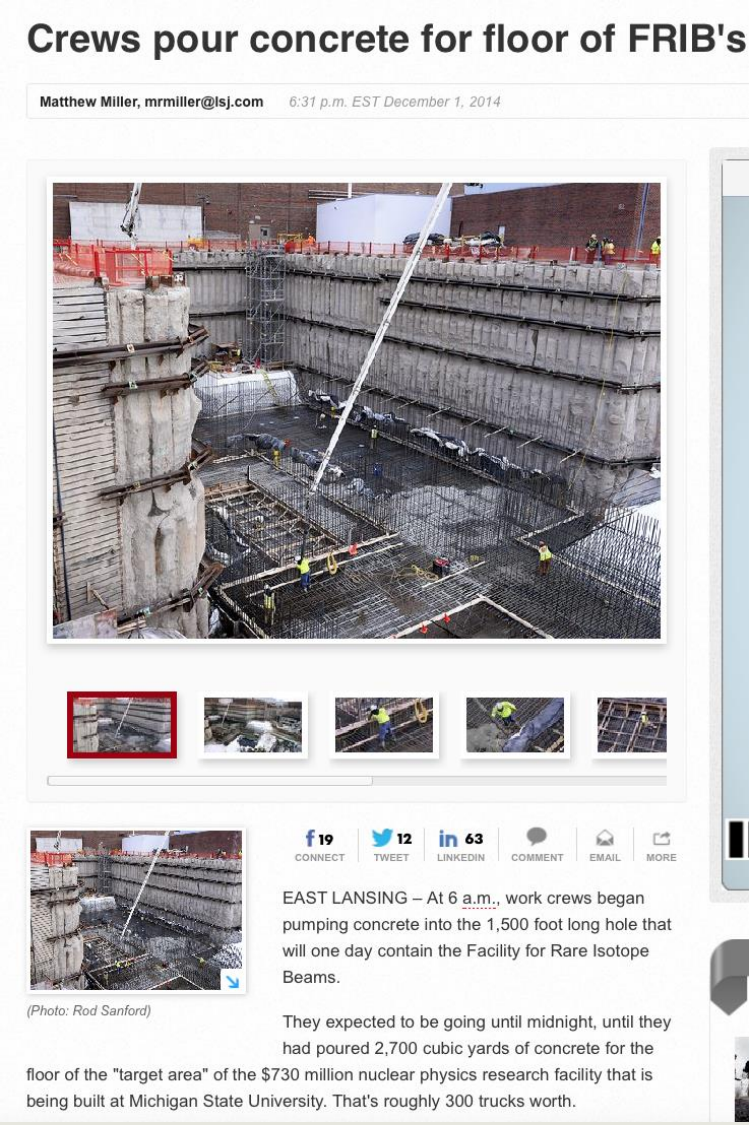

Relevant Questions
Best Tools
Accel., exp. devices
Precise Answers

FRIB: Facility for Rare Isotope Beams



An architectural rendering shows the baselined conventional facilities design of the Facility for Rare Isotope Beams.

High Intensity Heavy Ion Beams:
200MeV/n 400kW O to U



Crews pour concrete for floor of FRIB's

Matthew Miller, mrmiller@lsj.com 6:31 p.m. EST December 1, 2014

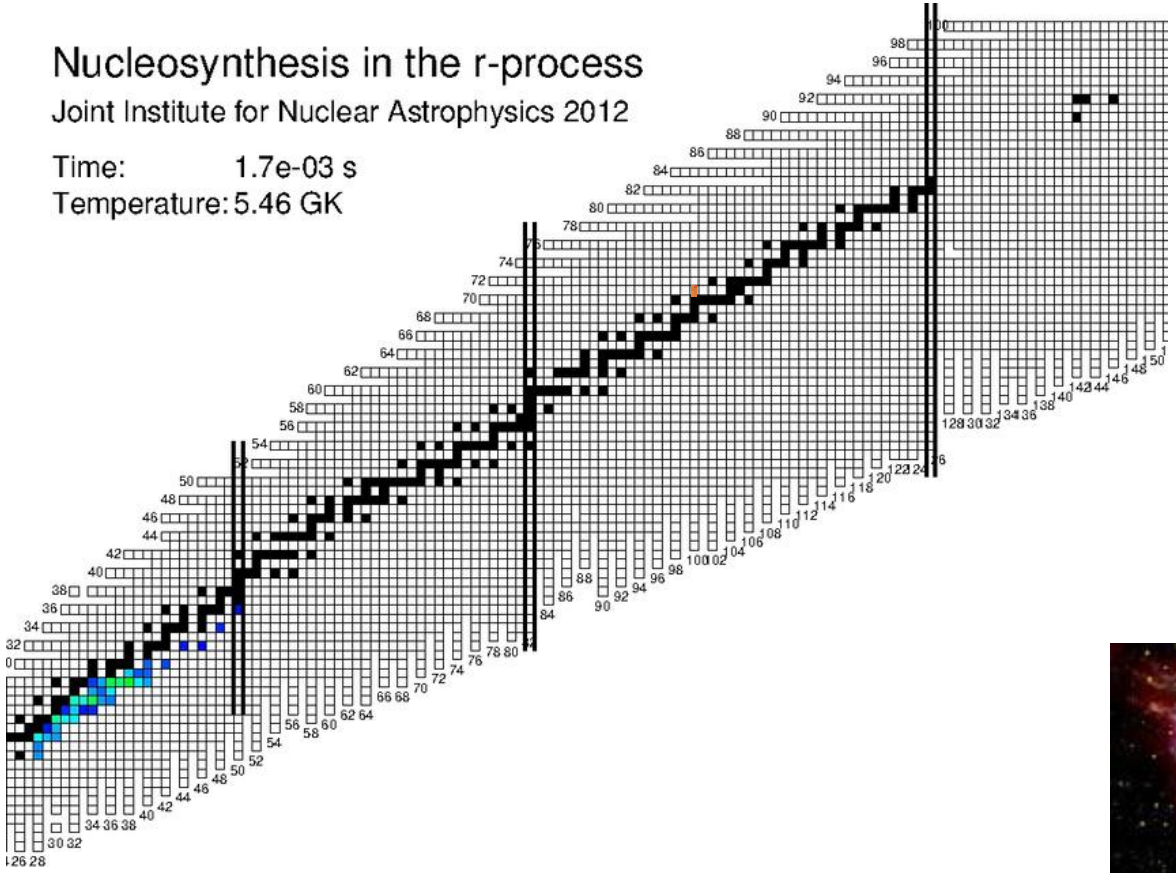
(Photo: Rod Sanford)

19 CONNECT 12 TWEET 63 LINKEDIN COMMENT EMAIL MORE

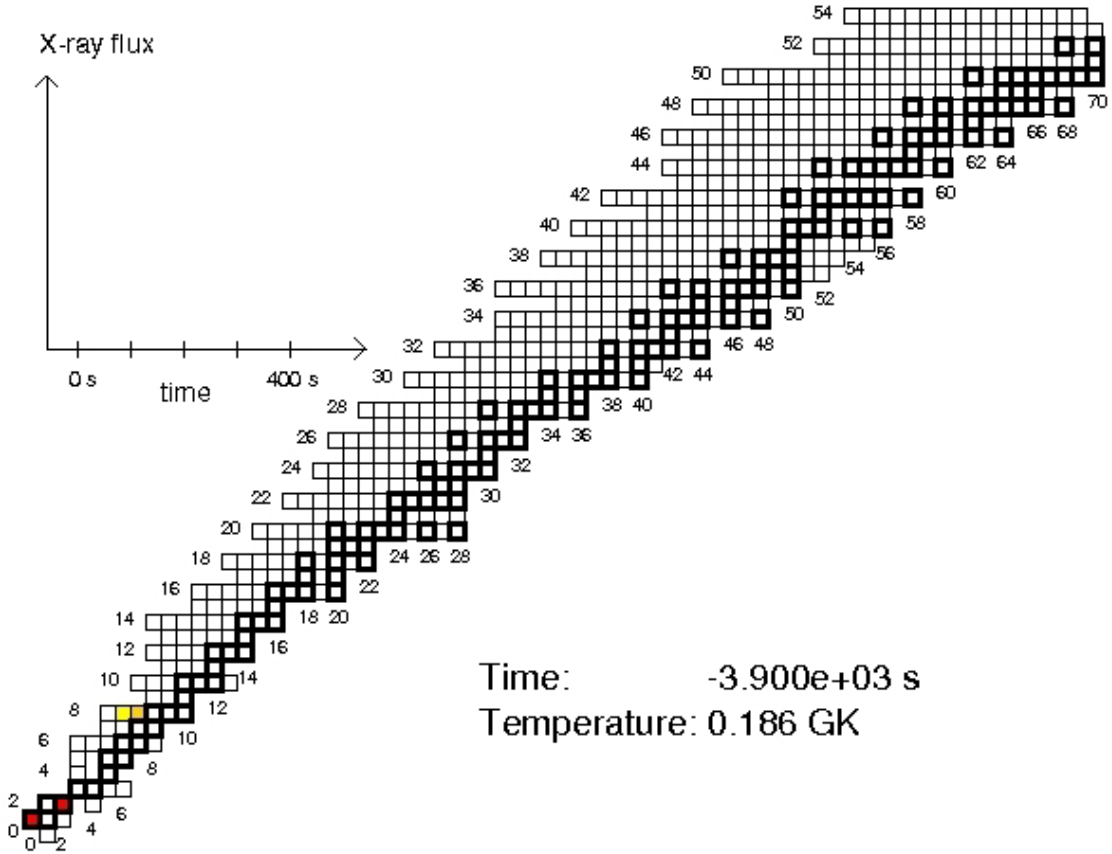
EAST LANSING – At 6 a.m., work crews began pumping concrete into the 1,500 foot long hole that will one day contain the Facility for Rare Isotope Beams.

They expected to be going until midnight, until they had poured 2,700 cubic yards of concrete for the floor of the "target area" of the $730 million nuclear physics research facility that is being built at Michigan State University. That's roughly 300 trucks worth.

Nucleo-synthesis in r-process



X-ray bursts



Why an Active Target-TPC?

- Nuclear Structure Investigations of Exotic Nuclei with Secondary Beams

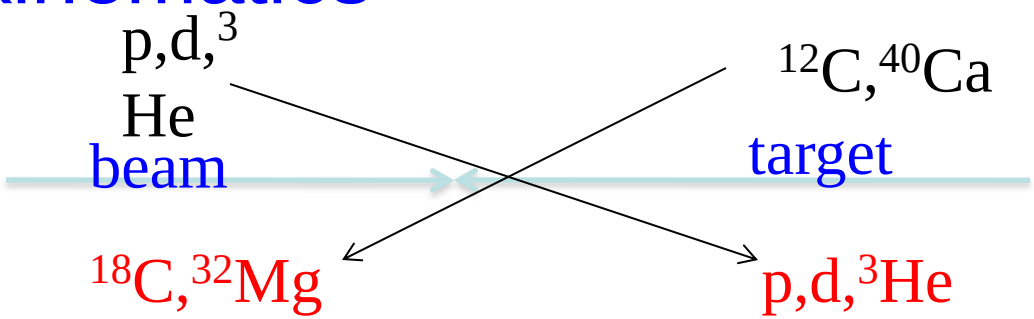
1) from normal kinematics to inverse kinematics

p,d,^{3}He	^{12}C,^{40}Ca
beam →	← target
^{18}C,^{32}Mg	p,d,^{3}He

Why an Active Target-TPC?

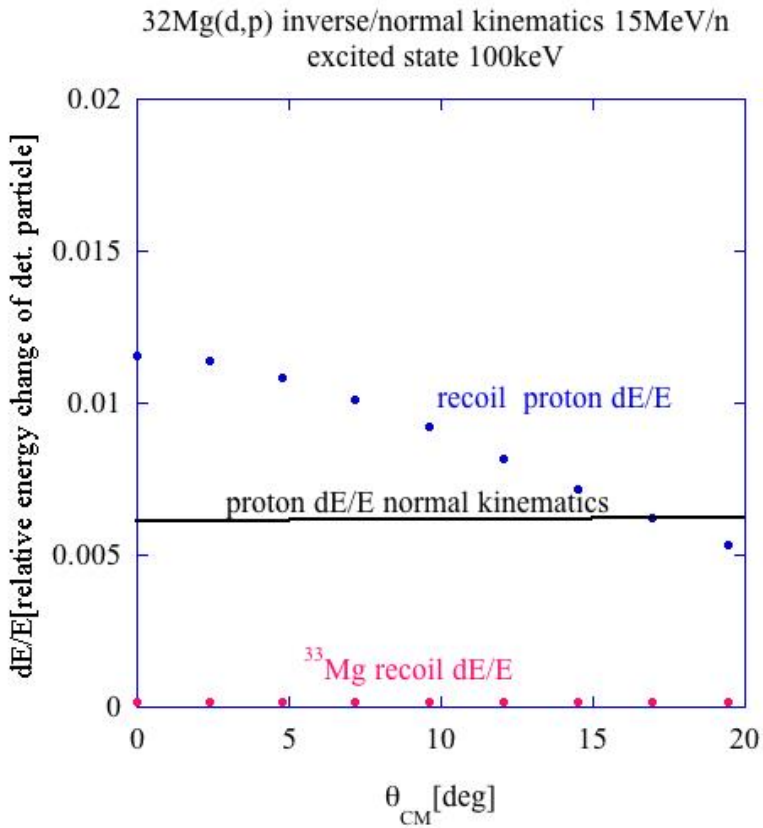
- Nuclear Structure Investigations of Exotic Nuclei with Secondary Beams

1) from normal kinematics to inverse kinematics



Normal kinematics versus inverse kinematics

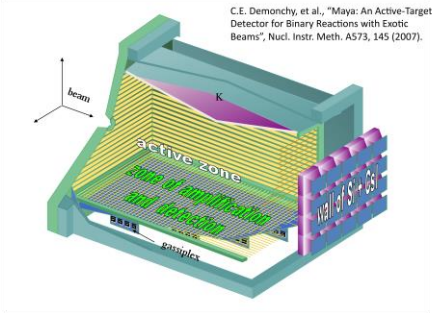
- Example: d(^{32}Mg,^{33}Mg)p gs,100keV



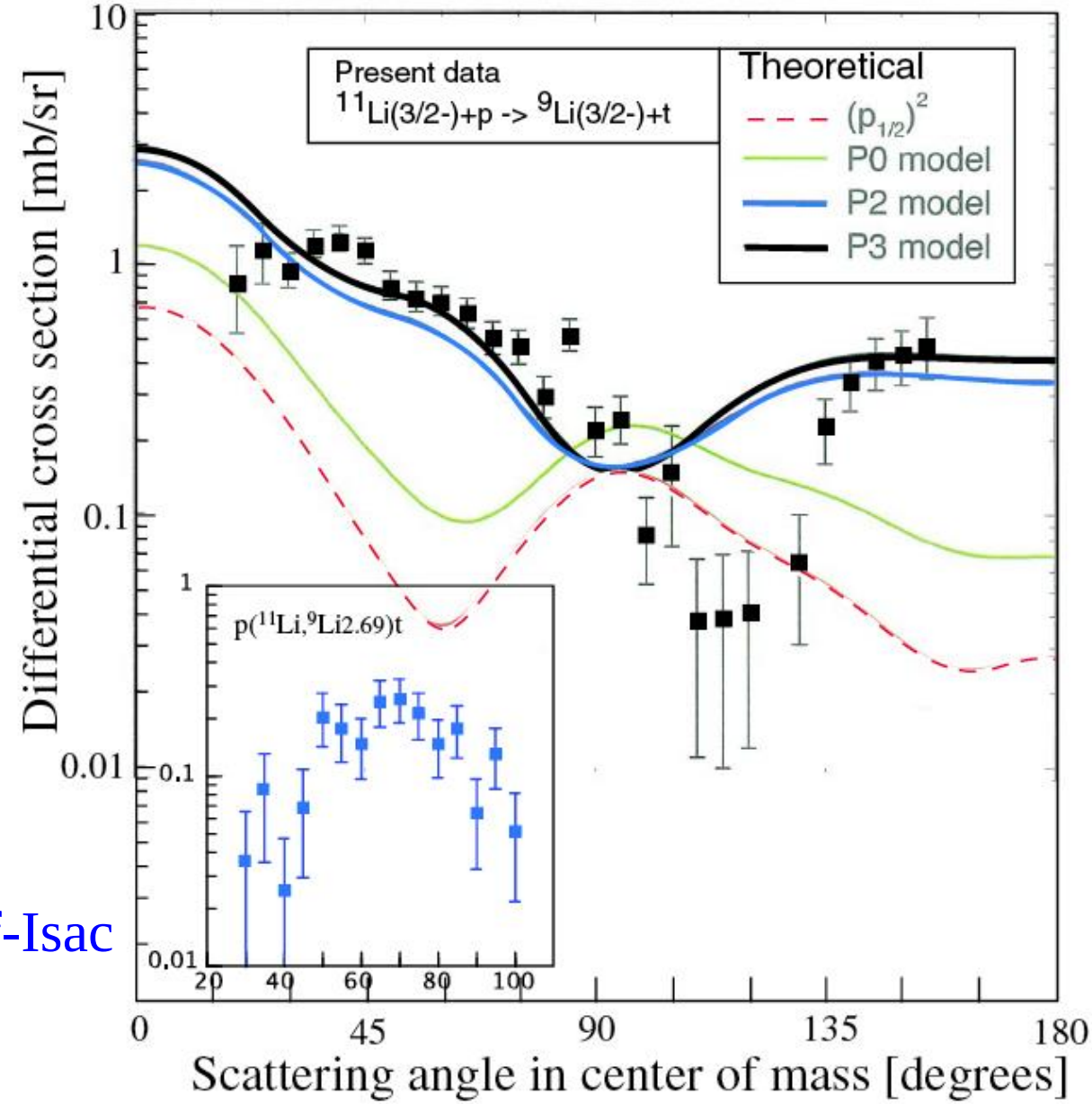
Beam Intensity ~10^{-9} with respect to stable beams

Thick Targets without resolution loss: tracking of reaction vertex

High detection efficiency: 4π

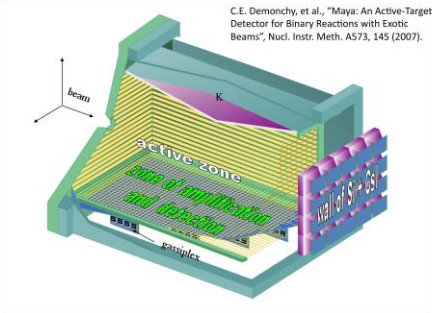


Measurement of the Two-Halo Neutron Transfer Reaction $^{1}H(^{11}Li, ^{9}Li)^{3}H$ at 3*A* MeV

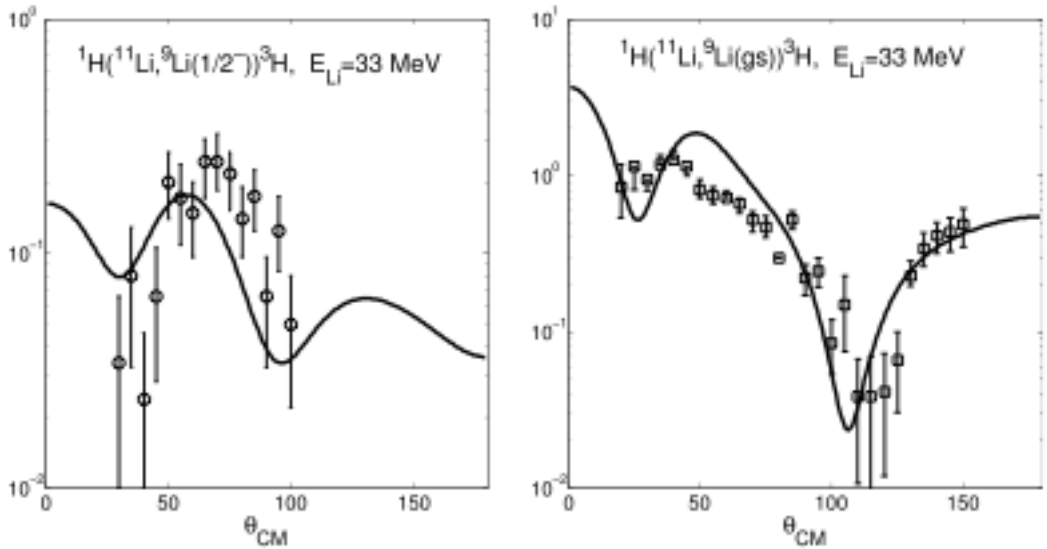


Experiment at Triumf-Isac
1-2*10^3 ^{11}Li/s

I.Tanihata et al., PRL 100, 192502(2008)



Measurement of the Two-Halo Neutron Transfer Reaction $^1H(^{11}Li, ^9Li)^3H$ at 3A MeV

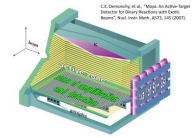


Cooper pair transfer in nuclei

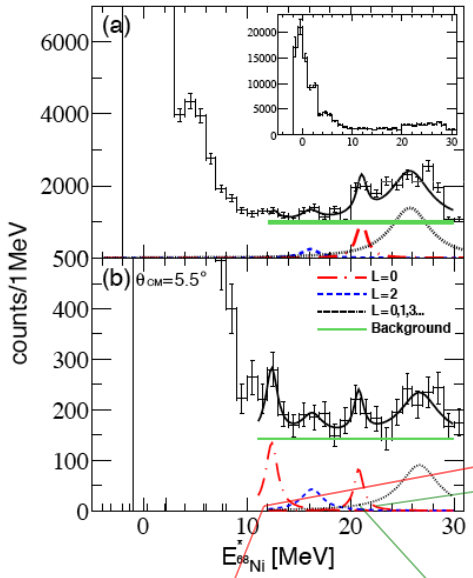
G. Potel[1], A. Idini[2,3,4], F. Barranco[5], E. Vigezzi[4], and R.A. Broglia[3,4,6,7]
(Dated: April 10, 2013)

Experiment at Triumf-Isac
1-2*10^3 ^{11}Li/s

G. Potel et al., Phys. Rev. Lett. 105 (2010)172502



Soft Giant resonance in ^{68}Ni by (α,α')



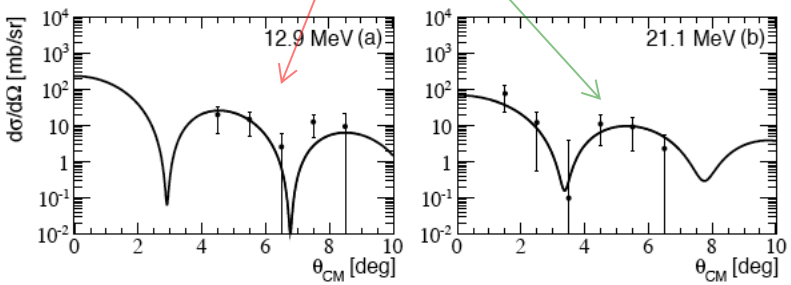
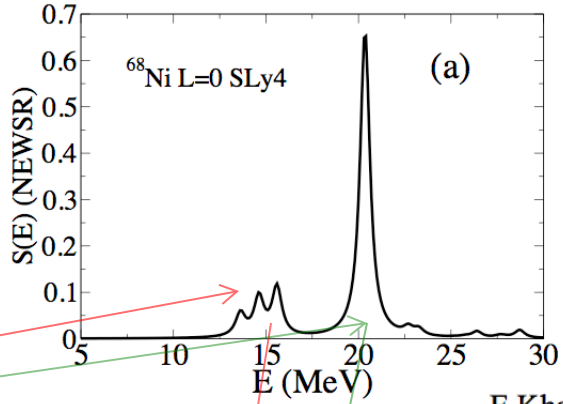
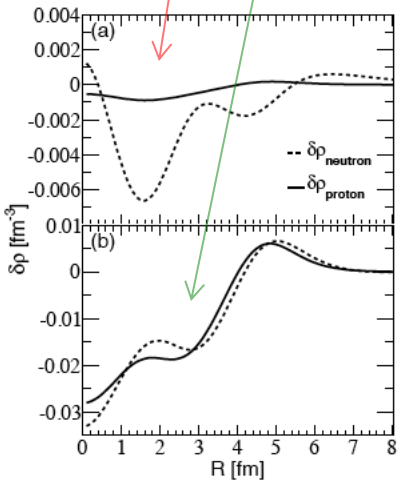


Fig. 6. Angular distributions for the modes at 12.9 MeV (a) and 21.1 MeV (b) fitted by DWB

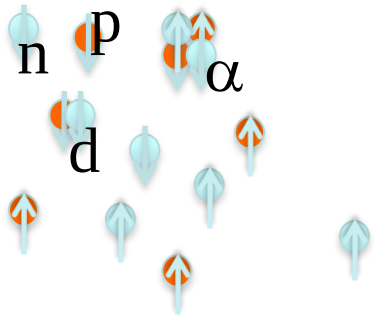


E.Khan et al.
Phys. Rev. C 84, 051301(R) (2011)

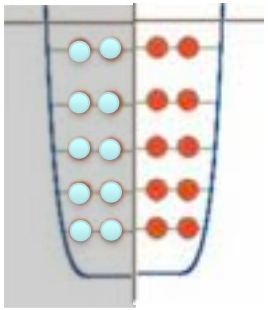


M. Vandebrouck et al., Phys. Rev. Lett. 113, 032504 (2014).

Nuclear Equation of State: Cluster States from low density gas to nuclear systems

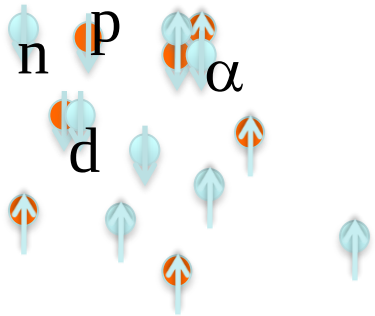


Low density gas:
chemical equilibrium n,p,d,α,…

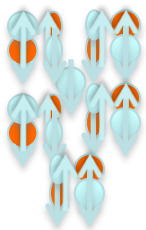


Nuclei: $\rho=\rho_0$

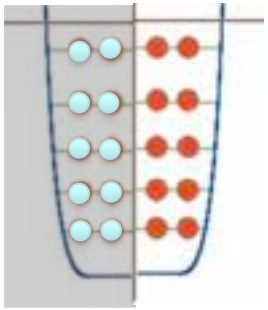
Nuclear Equation of State: Cluster States from low density gas to nuclear systems



Low density gas:
chemical equilibrium n,p,d,α,…

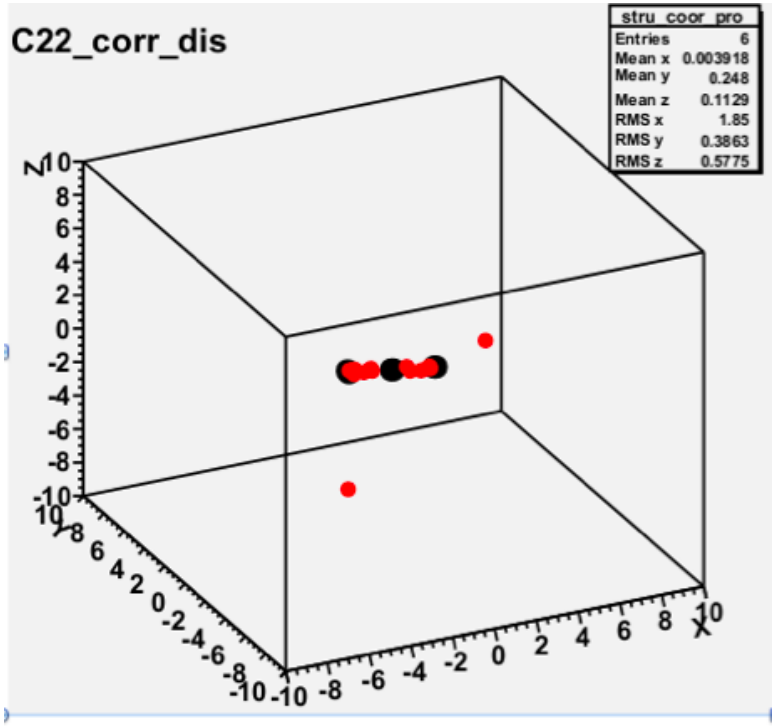


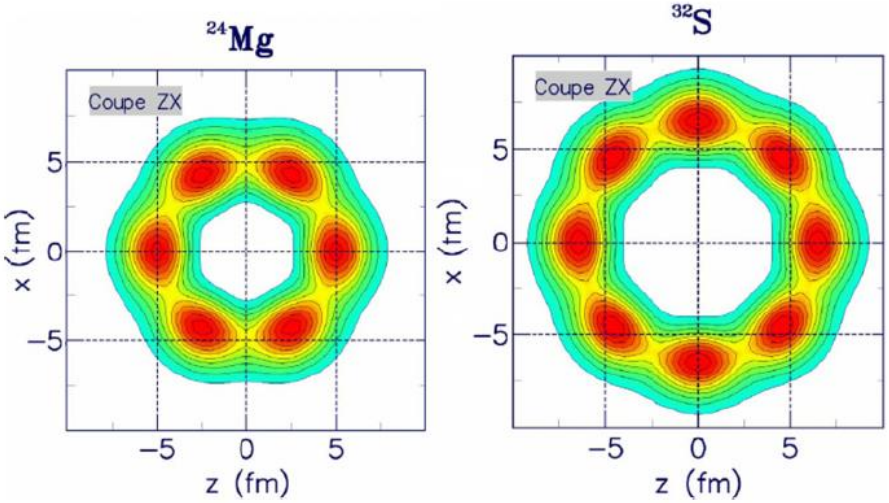
Low density nuclei:
Loosely bound clusters: $\rho \sim \rho_0/10$



Nuclei: $\rho = \rho_0$

Cluster States: from low density gas to nuclear systems





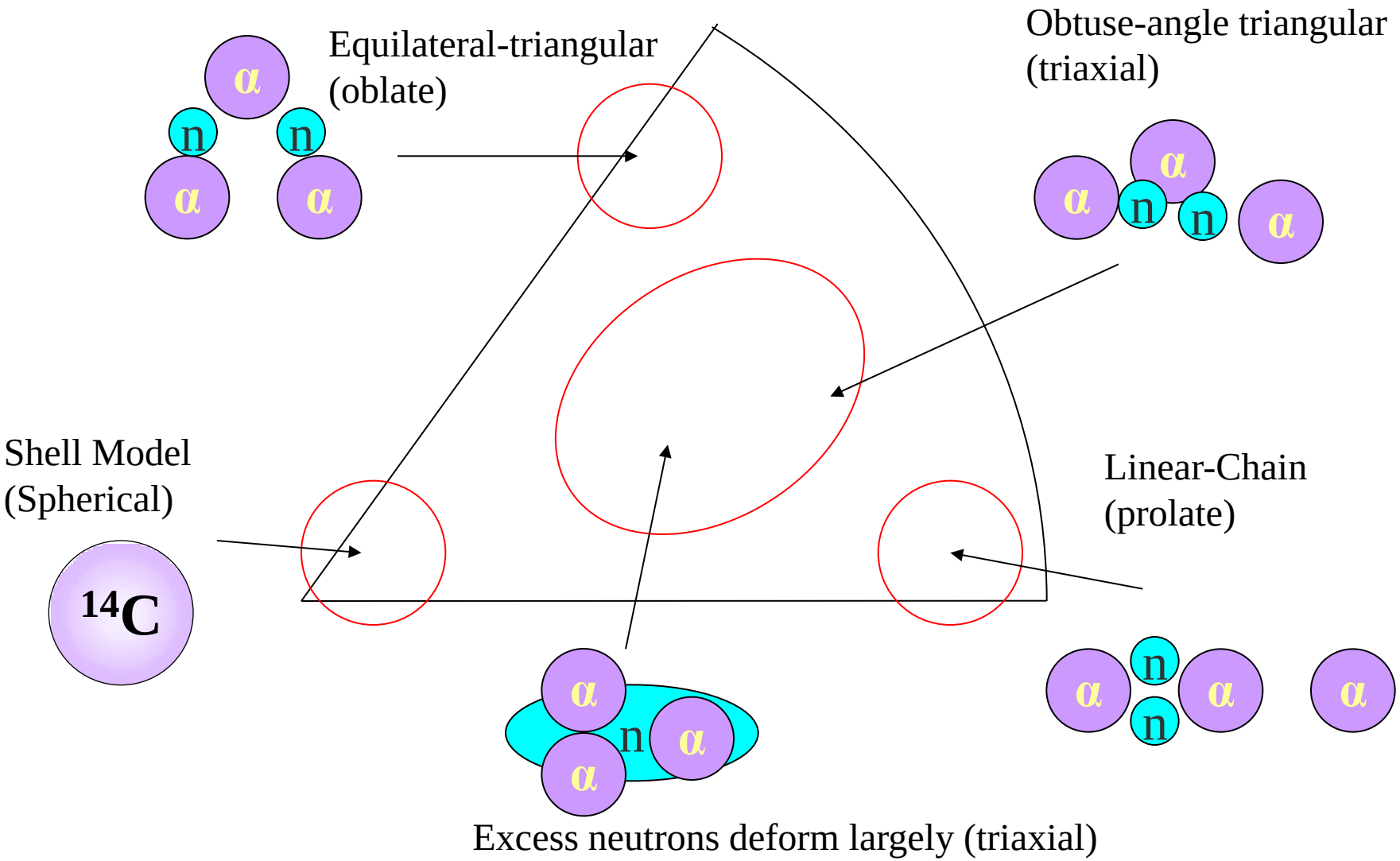
….,M.Girod,… constrained HFB

J. Phys. G: Nucl. Part. Phys. **37** (2010) 064012 (10pp)

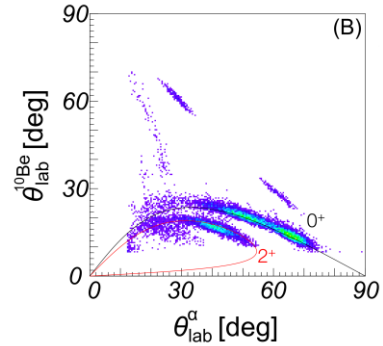
^{22}C AQMD calculation by Xi-Guang Cao et al., private communication, RMS=3.689(→3.0) fm

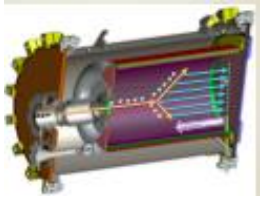
^{14}C (T.Suhara(Kyoto)and Y.Kanada-En'yo(YITP),2010)

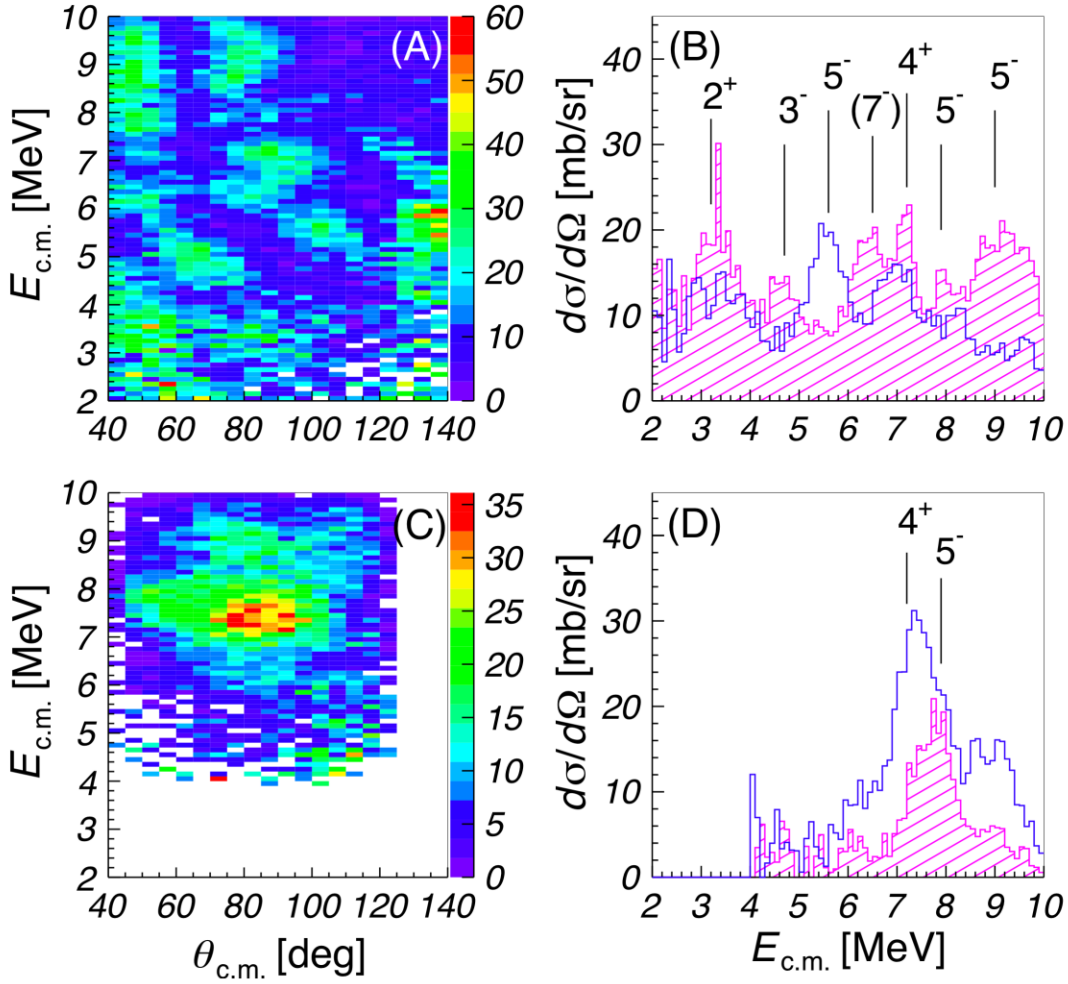
Structures which are expected to appear on the (β、γ) plane

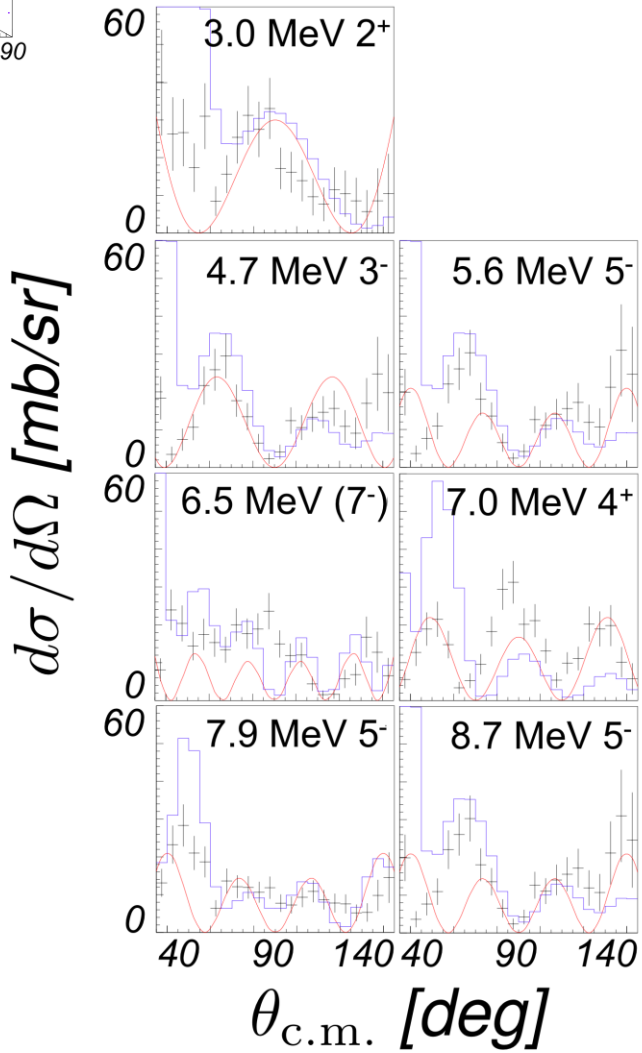


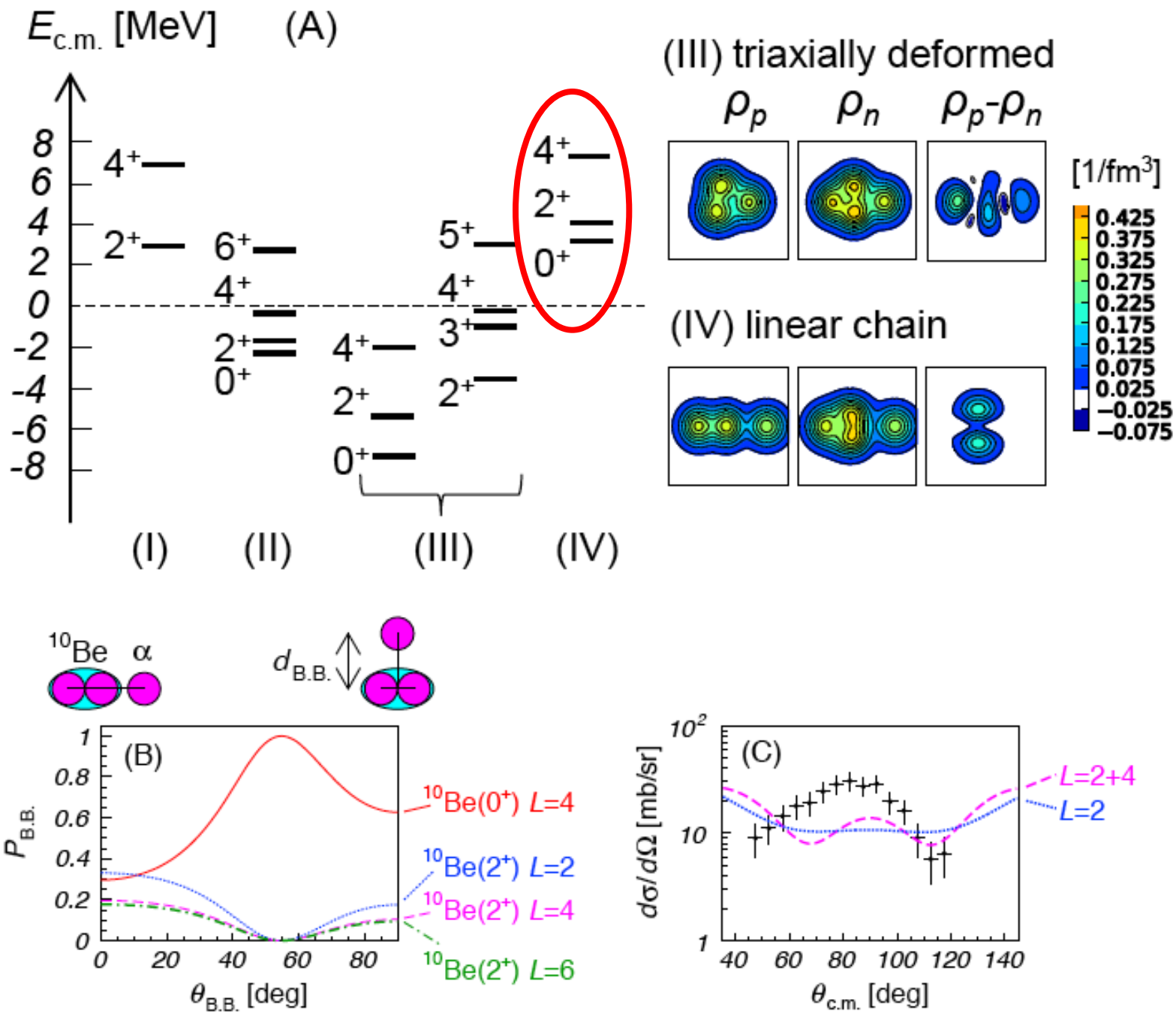
$^{10}Be + ^{4}He \rightarrow ^{14}C$







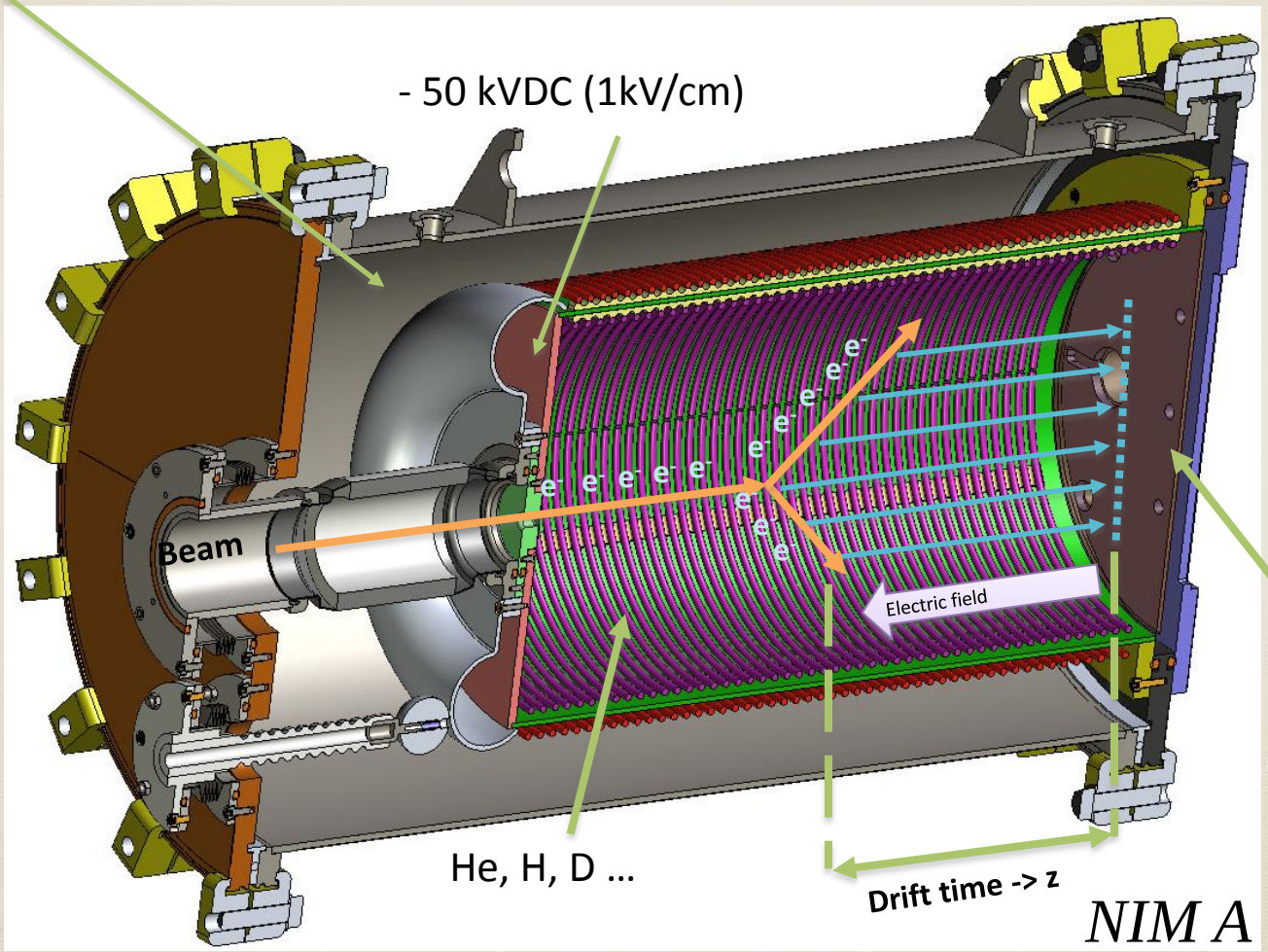



$E_{c.m.}$ [MeV]
(A)
8
6
4
2
0
-2
-4
-6
-8
4+
2+
6+
4+
2+
0+
4+
2+
0+
5+
4+
3+
2+
4+
2+
0+
(I)
(II)
(III)
(IV)
(III) triaxially deformed
ρ_p
ρ_n
ρ_p-ρ_n
[1/fm^3]
0.425
0.375
0.325
0.275
0.225
0.175
0.125
0.075
0.025
−0.025
−0.075
(IV) linear chain
^{10}Be
α
$d_{B.B.}$
(B)
$P_{B.B.}$
$\theta_{B.B.}$ [deg]
^{10}Be(0+) L=4
^{10}Be(2+) L=2
^{10}Be(2+) L=4
^{10}Be(2+) L=6
(C)
$d\sigma/d\Omega$ [mb/sr]
$\theta_{c.m.}$ [deg]
L=2+4
L=2

Principle of detection-proto AT-TPC

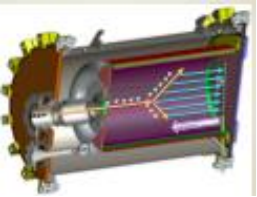
Insulator gas volume

- N_2 gas 30 kV/cm x 6 cm = 180 kV

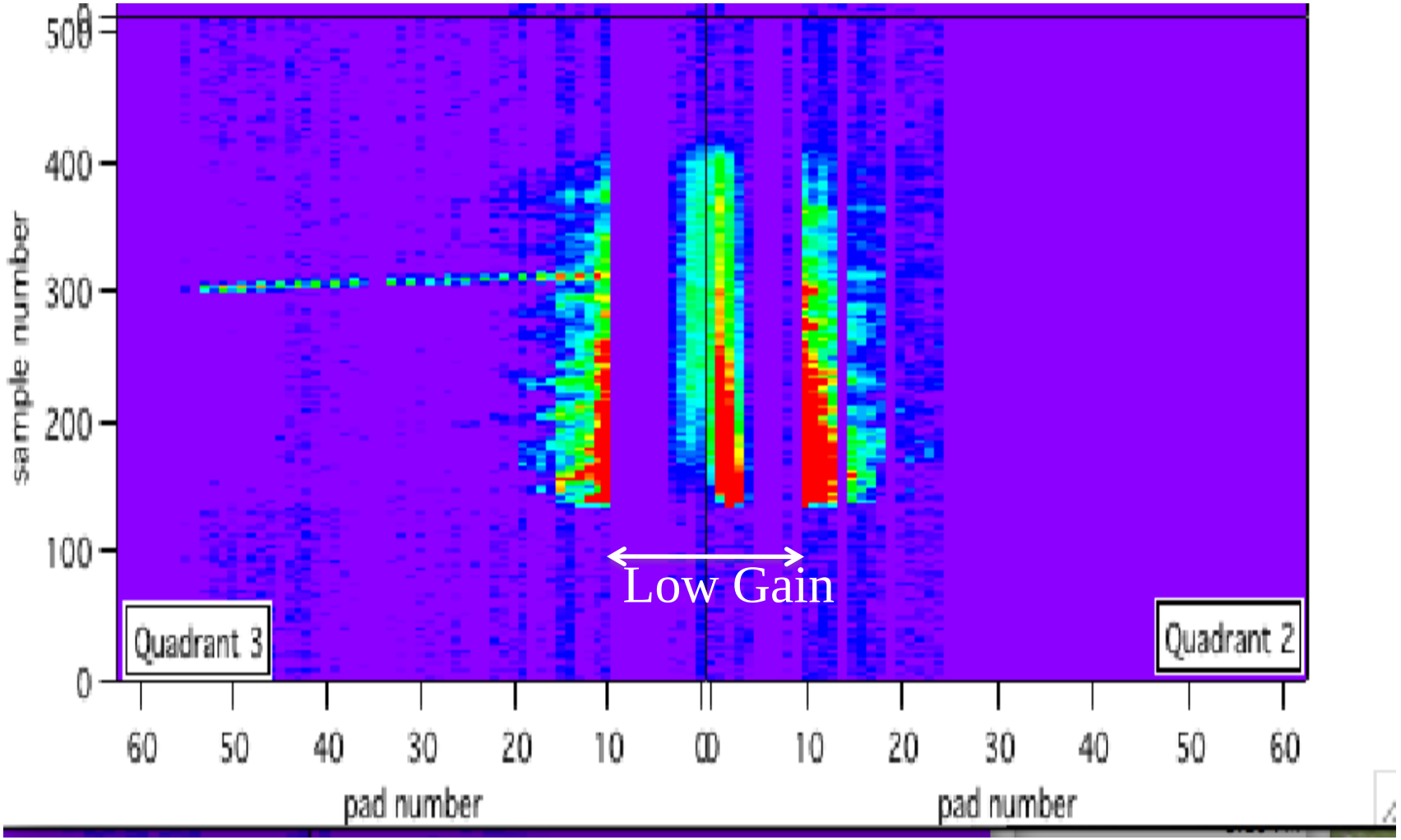


NIM A 691 (2012)39

by D. Suzuki, et al.

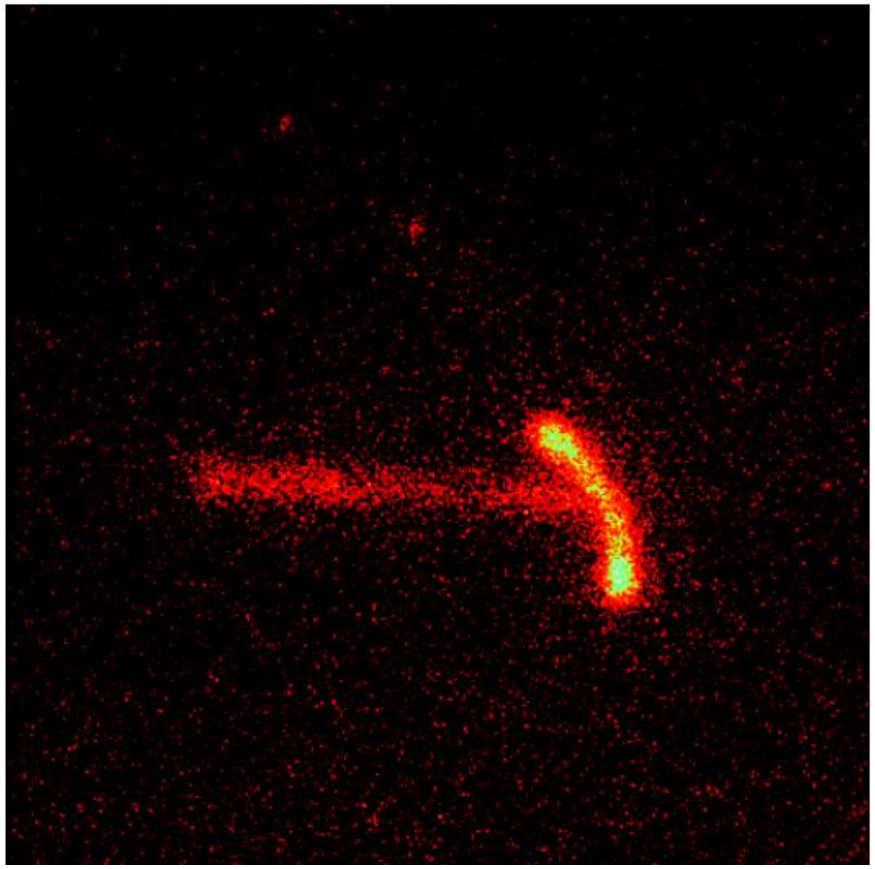


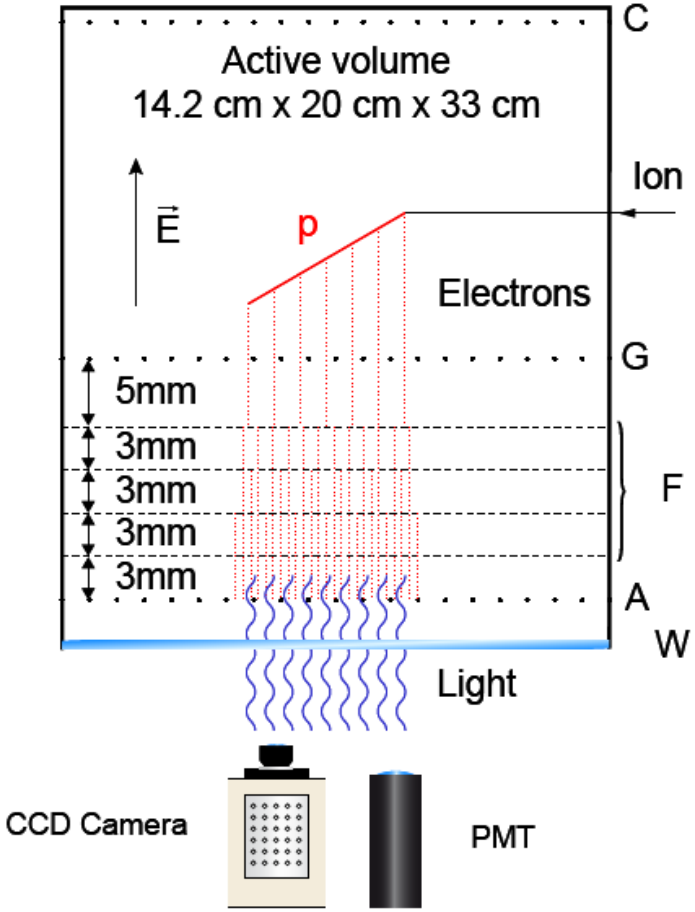
IAS $^{124,132}Sn(p,p)$



Tan Ahn et al., ANL-Caribu, March 2013

Example: 2p decay of ^{45}Fe





K.Miernik, PRL **99, 192501 (2007),** *Q2p 1:15 MeV*

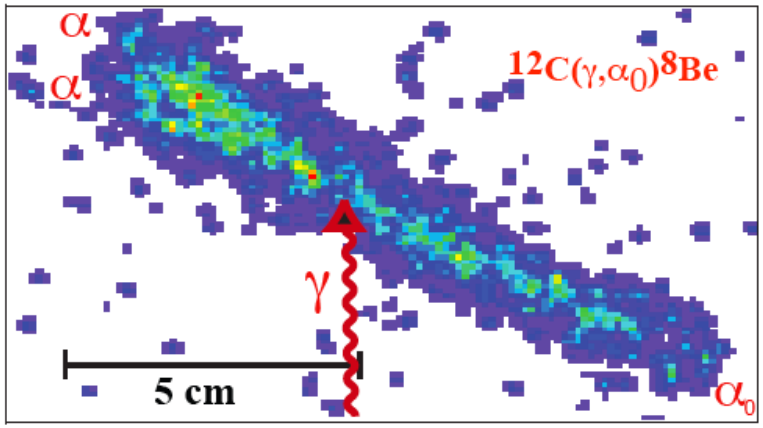


FIG. 1: (Color Online) A typical image recorded by the CCD camera of three alpha-partciles from the reaction $^{12}C(\gamma,\alpha_0)^8Be$

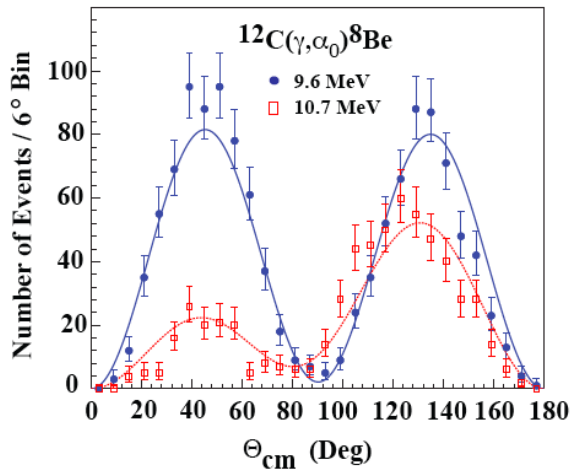


FIG. 3: (Color online) Angular distribution for $^{12}C(\gamma,\alpha_0)^8Be$ events measured at a beam energy of 9.6 and 10.7 MeV. The solid curve is the fit that included E1 and E2 amplitudes as discussed in the text. The error bars are statistical only.

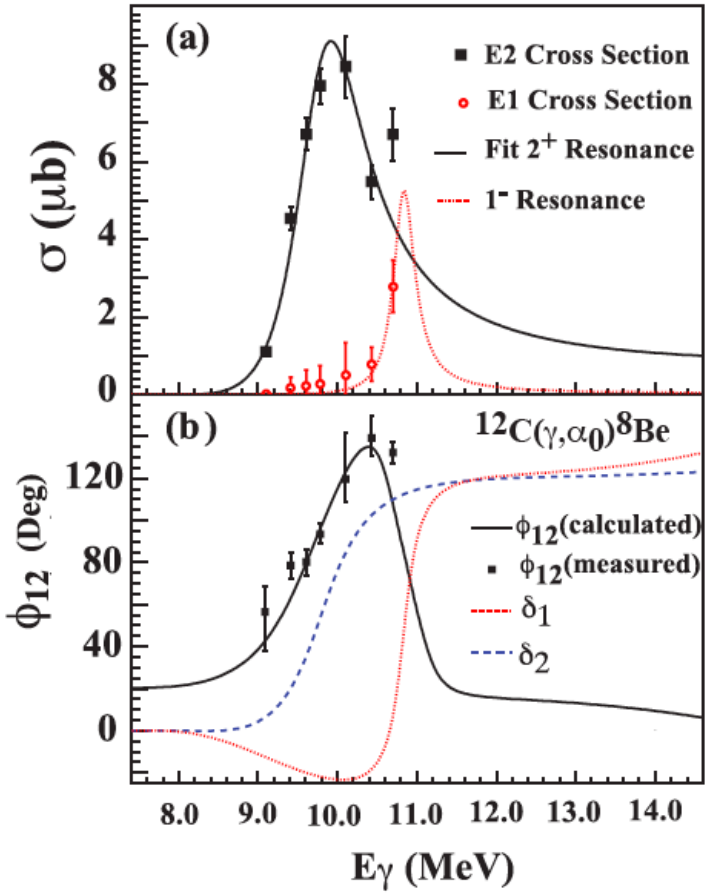


FIG. 4: (Color online) (a) The measured E1 and E2 cross sections of the $^{12}C(\gamma,\alpha_0)^8Be$ reaction. (b) The measured E1-E2 relative phase angle (ϕ_{12}) together with the phase angle calculated from a two-resonance model.

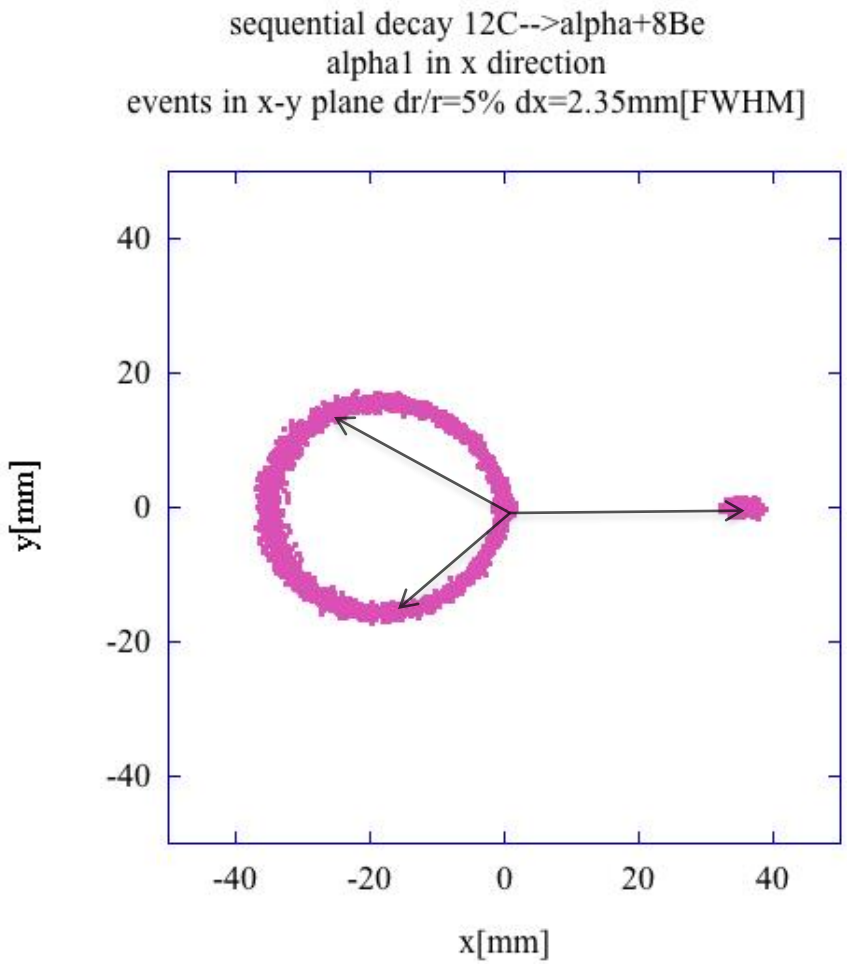
Unambiguous Identification of the Second 2^+ State in ^{12}C and the Structure of the Hoyle State

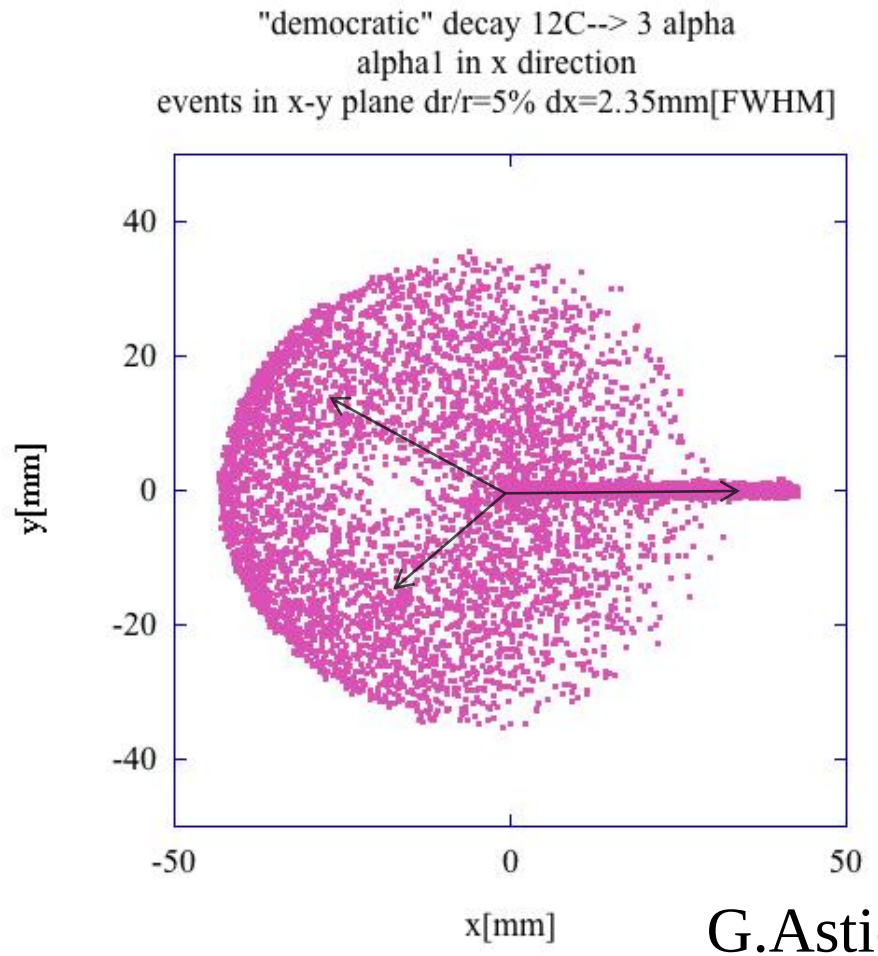
W.R. Zimmerman[1,2], M.W. Ahmed[2,3], B. Bromberger[4], S.C. Stave[2], A. Breskin[5], V. Dangendorf[4], Th. Delbar[6], M. Gai[1,7], S.S. Henshaw[2], J.M. Mueller[2], C. Sun[2], K. Tittelmeier[4], H.R. Weller[1,2] and Y.K. Wu[2]

P

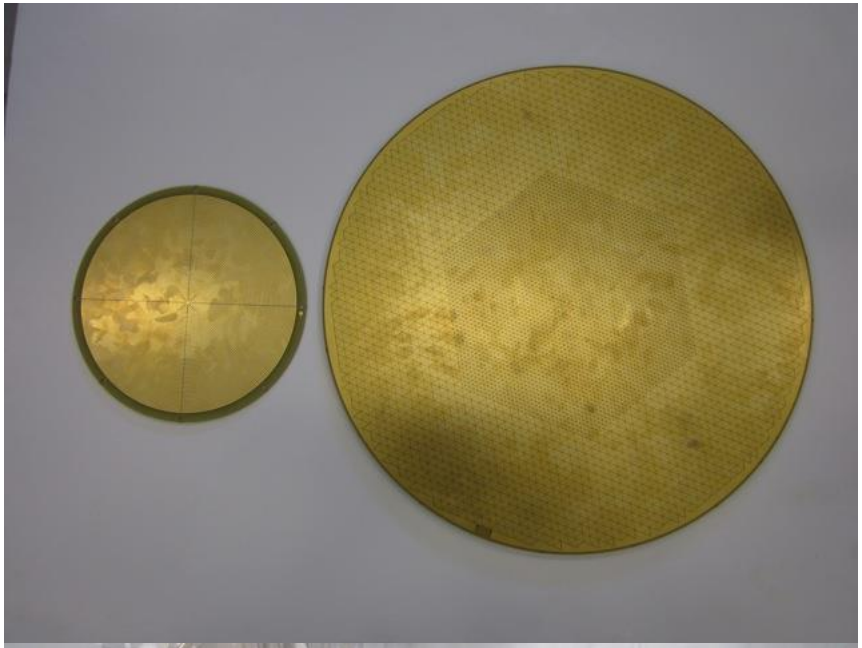
→Tentative of direct observation "democratic" 3 body decay of $^{12}C(0^{+}_{2,}$ Hoyle state) in the 3 dim

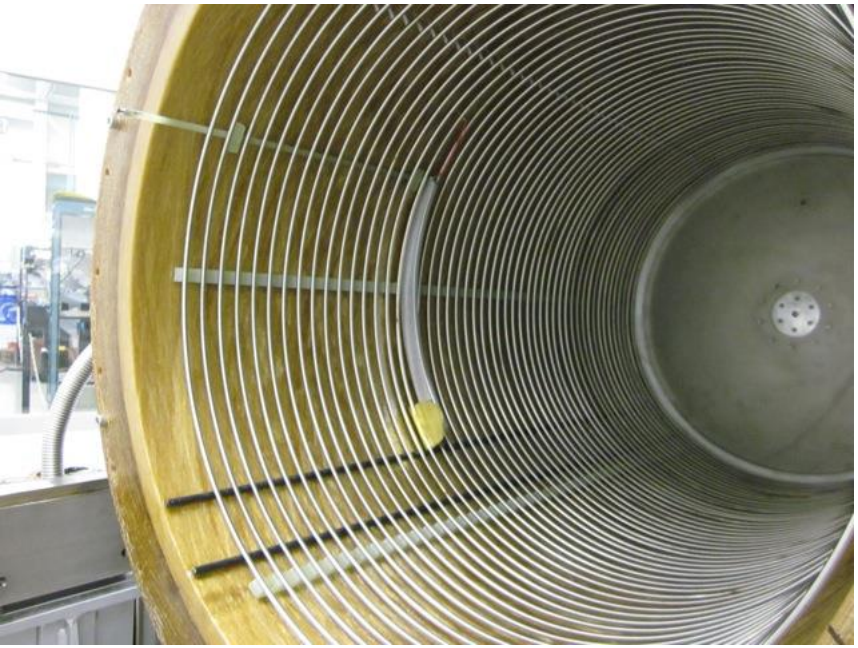
10Torr isobuthane

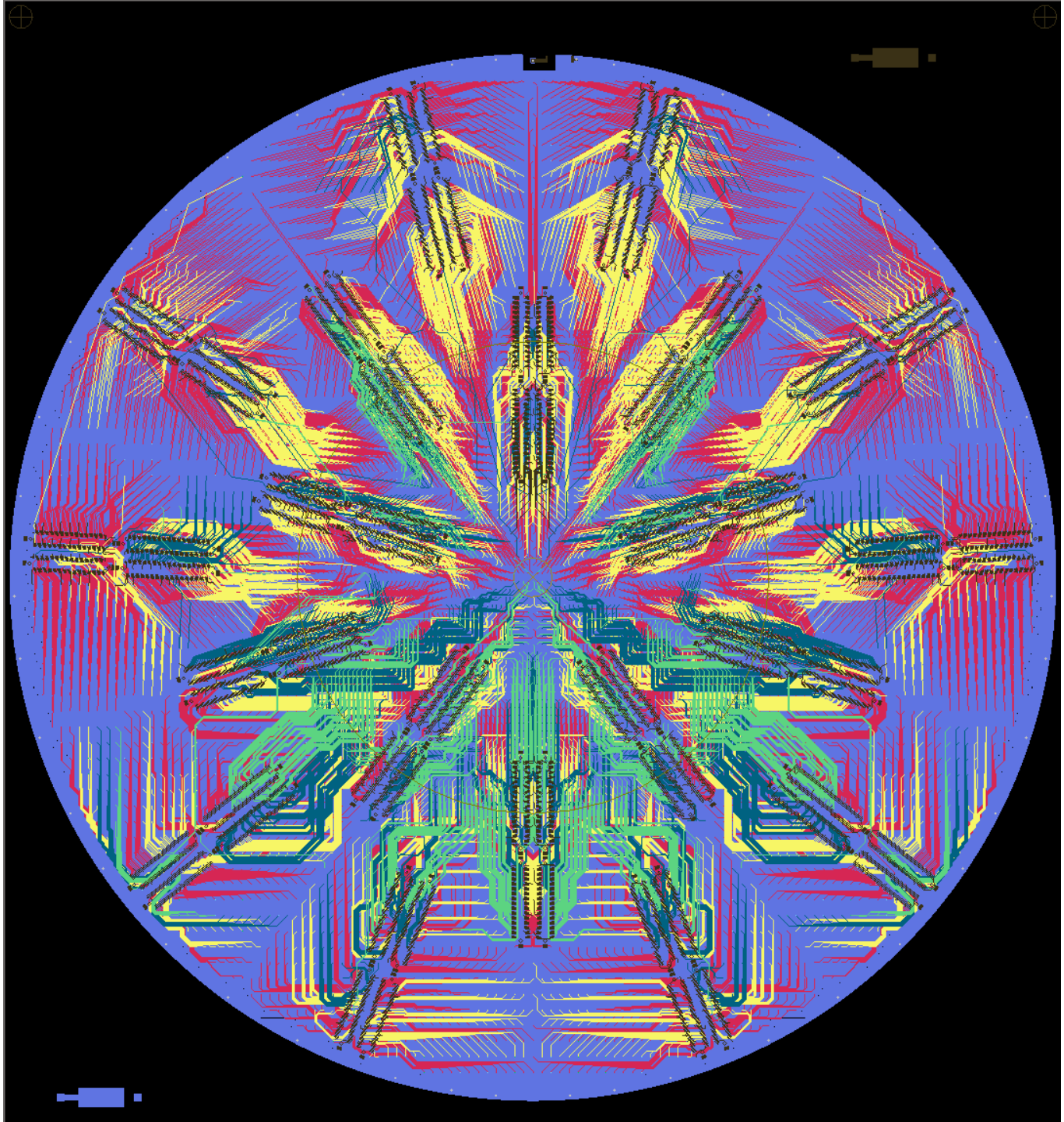




G.Astier







55cm diameter
10000 pads
5000 pads routed
by hand, 8 Layers

PCB: MSU
Bulk: CEA-IRFU

General Electronics for TPCs: GET

IRFU, GANIL, CENBG
MSU

For different detectors

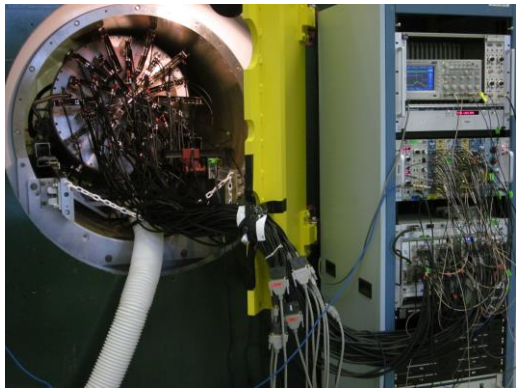
AT-TPC: ~10000channels

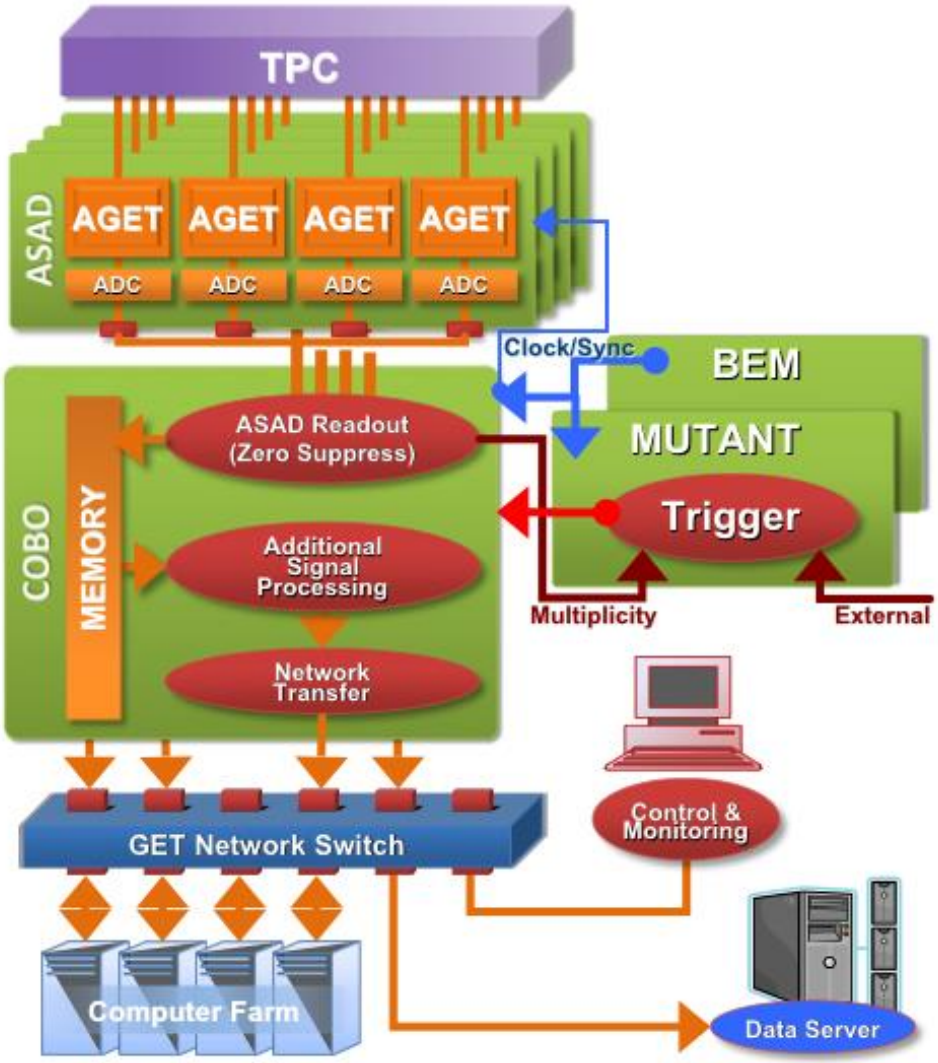
Data flow at 1000cts/s

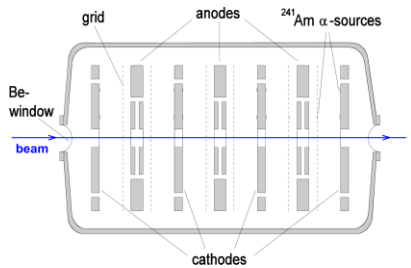
$512*10^4*10^3*2$

$\sim 10^{10}$ bytes/s

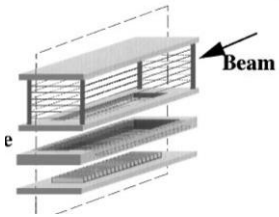
=10Gbytes/s before reduction



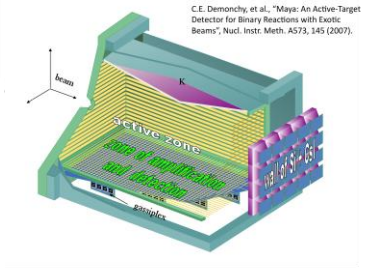




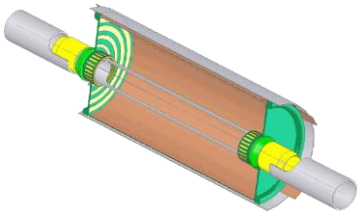
IKAR-GSI



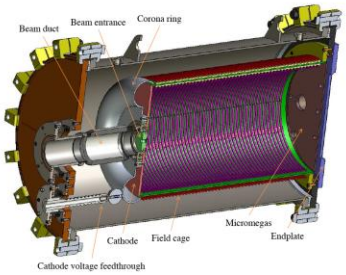
Mizoi et al
MSTPC



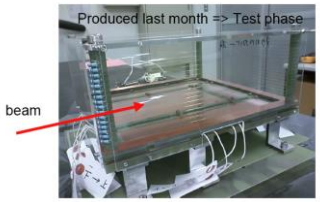
Maya@Ganil



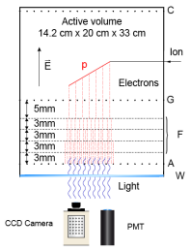
TACTIC: York-TRIUMF Collaboration



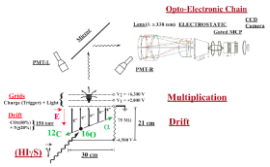
Prototype AT-TPC at MSU



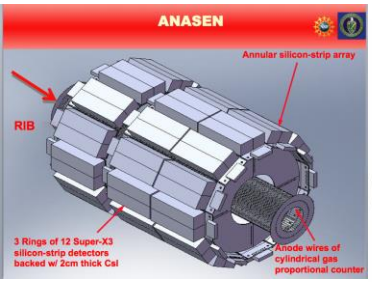
CNS-Riken



OTPC Warsaw-ORNL



O-TPC at TUNL



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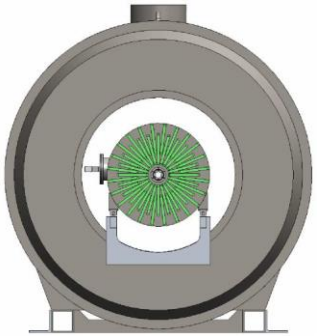
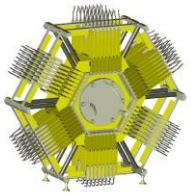
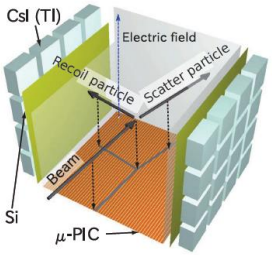


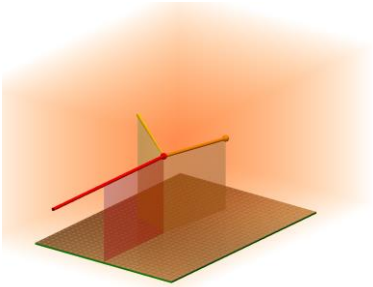
AT-TPC at MSU



Fission TPC LLNL



MaiKo



Actar-Ganil-Saclay-CENBG

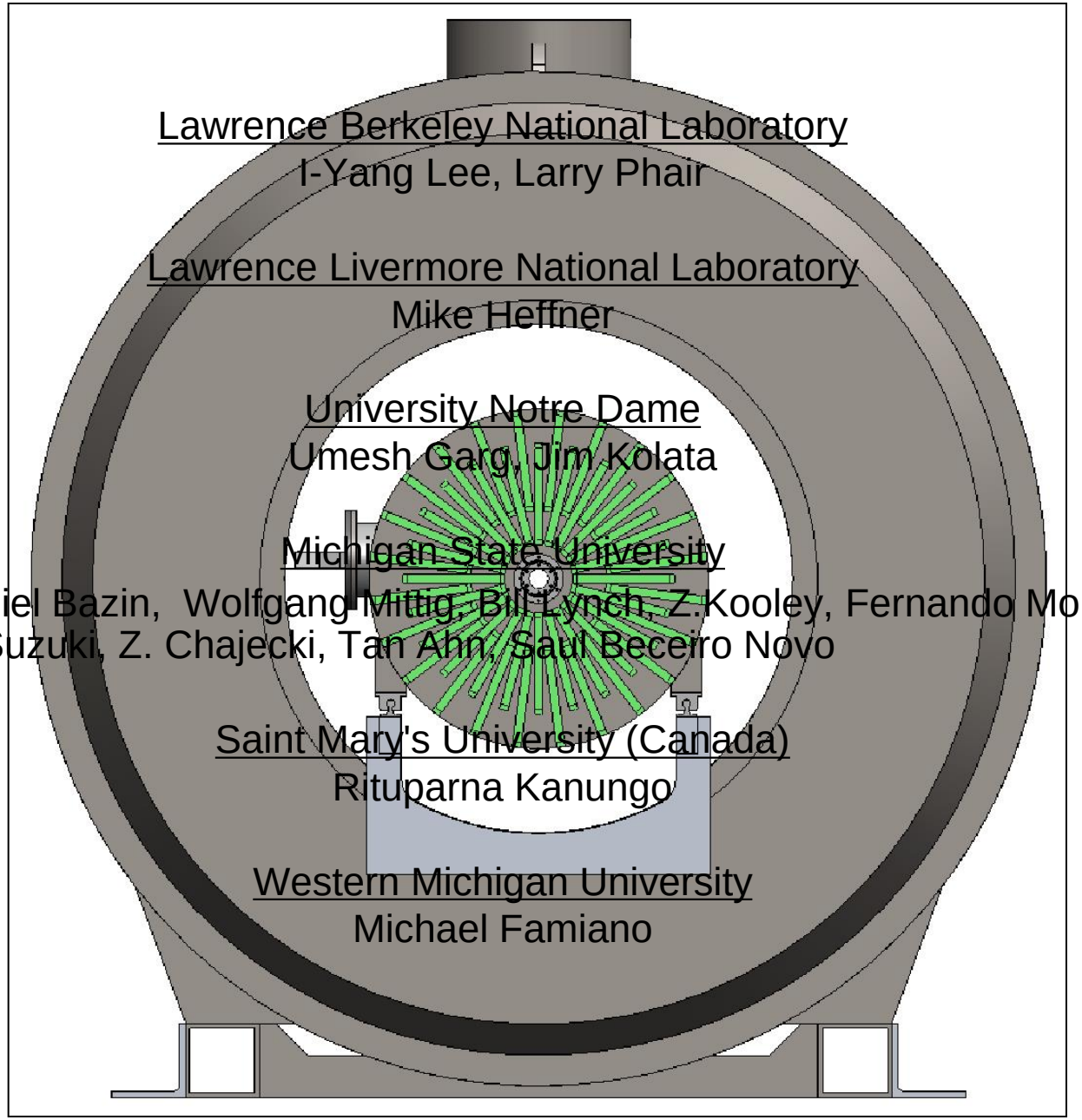
?

R.Raabe

Conclusion

- **Operating Active Targets have largely improved sensitivity for reactions by rare isotope beams; they have already produced many results**
- **The At's need high dynamics, from several hundreds keV to GeV, internal trigger and detector gases that contain the target wanted as pure as possible**
- **Promising subjects that can be particularly well studied with AT-TPCs are: reactions with beams near dripline, low energy recoil reactions (quasi-elastic, giant resonances,…), multi-particle correlations near threshold as signature of cluster emission; rare decays**

AT-TPC Collaboration



Lawrence Berkeley National Laboratory
I-Yang Lee, Larry Phair

Lawrence Livermore National Laboratory
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Daniel Bazin, Wolfgang Mittig, Bill Lynch, Z.Kooley, Fernando Montes, Daisuke Suzuki, Z. Chajecki, Tan Ahn, Saul Beceiro Novo

Saint Mary's University (Canada)
Rituparna Kanungo

Western Michigan University
Michael Famiano

MAIKo RCNP OSAKA (-PIC based active target for inverse kinematics)

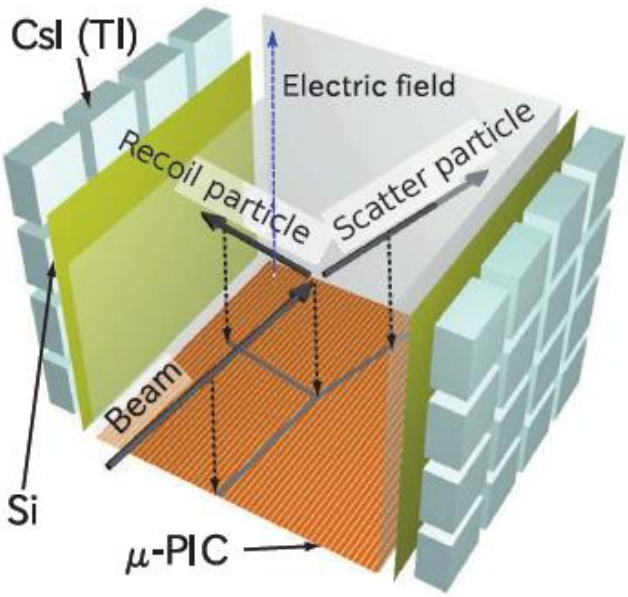


Figure 3: Schematics of MAIKo.

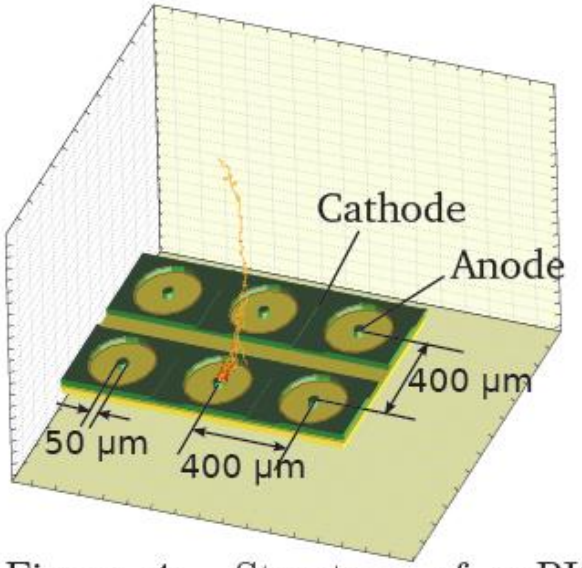
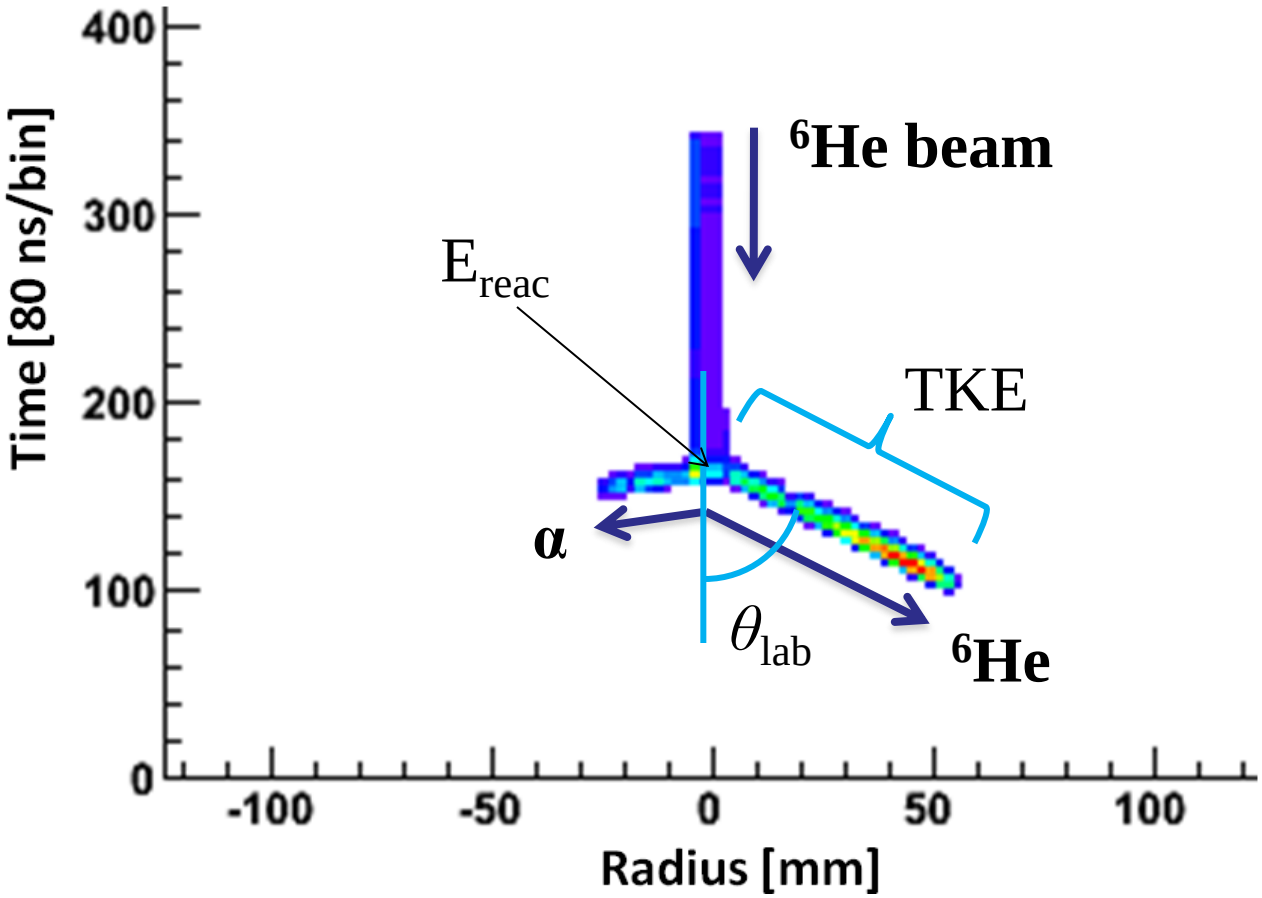
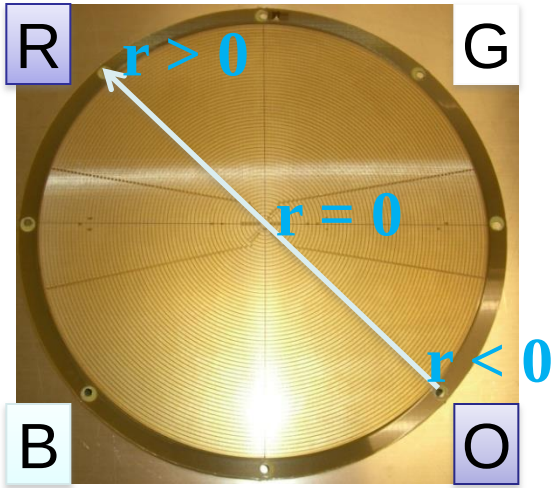
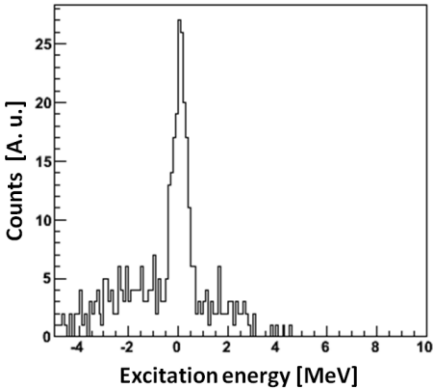


Figure 4: Structure of μ-PIC. Electron avalanche simulated by Garfield [6] is also drawn.

^{6}He + ^{4}He 2.5MeV/n AT-TPC proto at ND





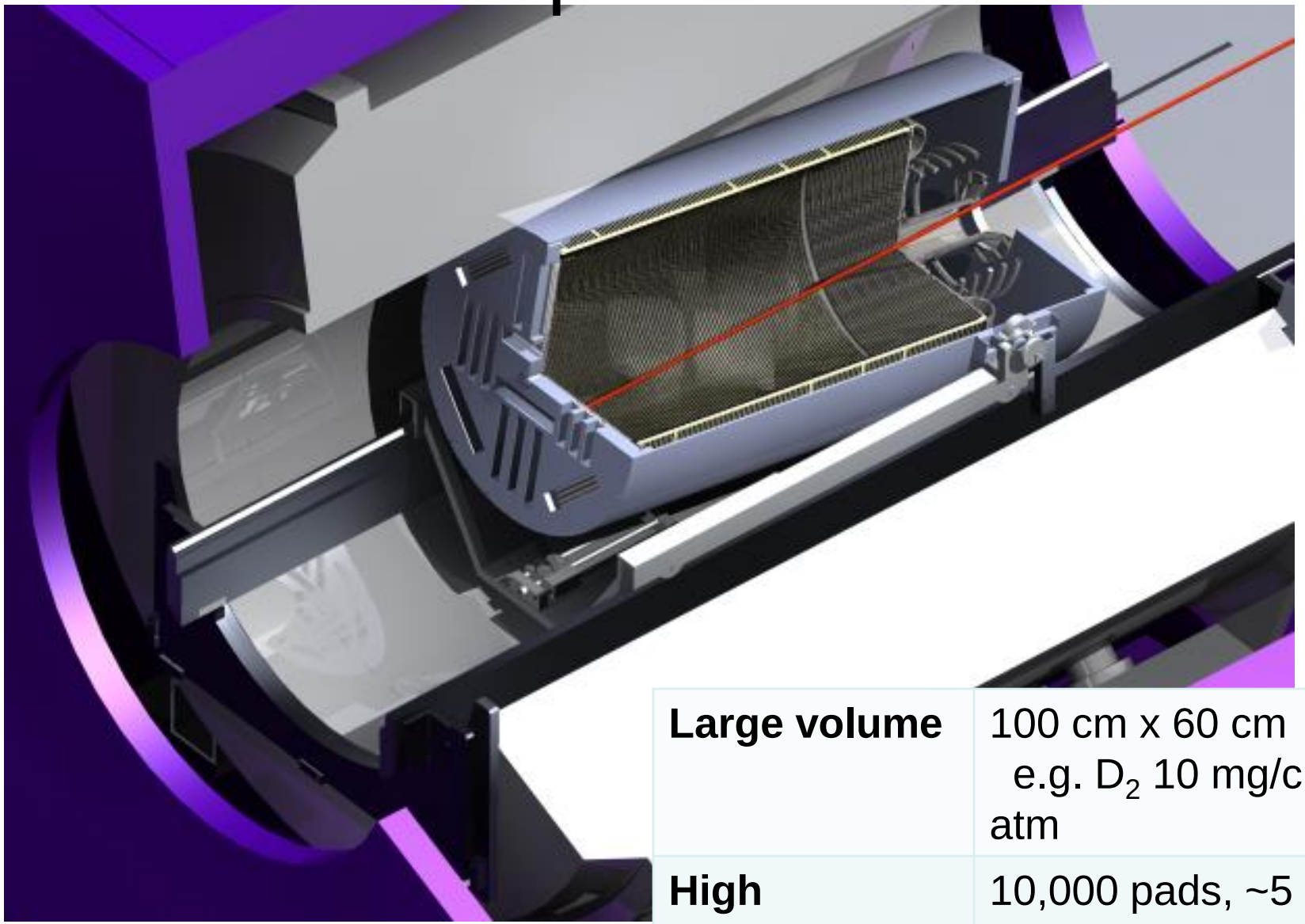


Resonant alpha scattering of ^{6}He: limits of clustering in ^{10}Be

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] D. Ben Ali,[6] B. Bucher,[4] J. Browne,[4,1,3]
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]

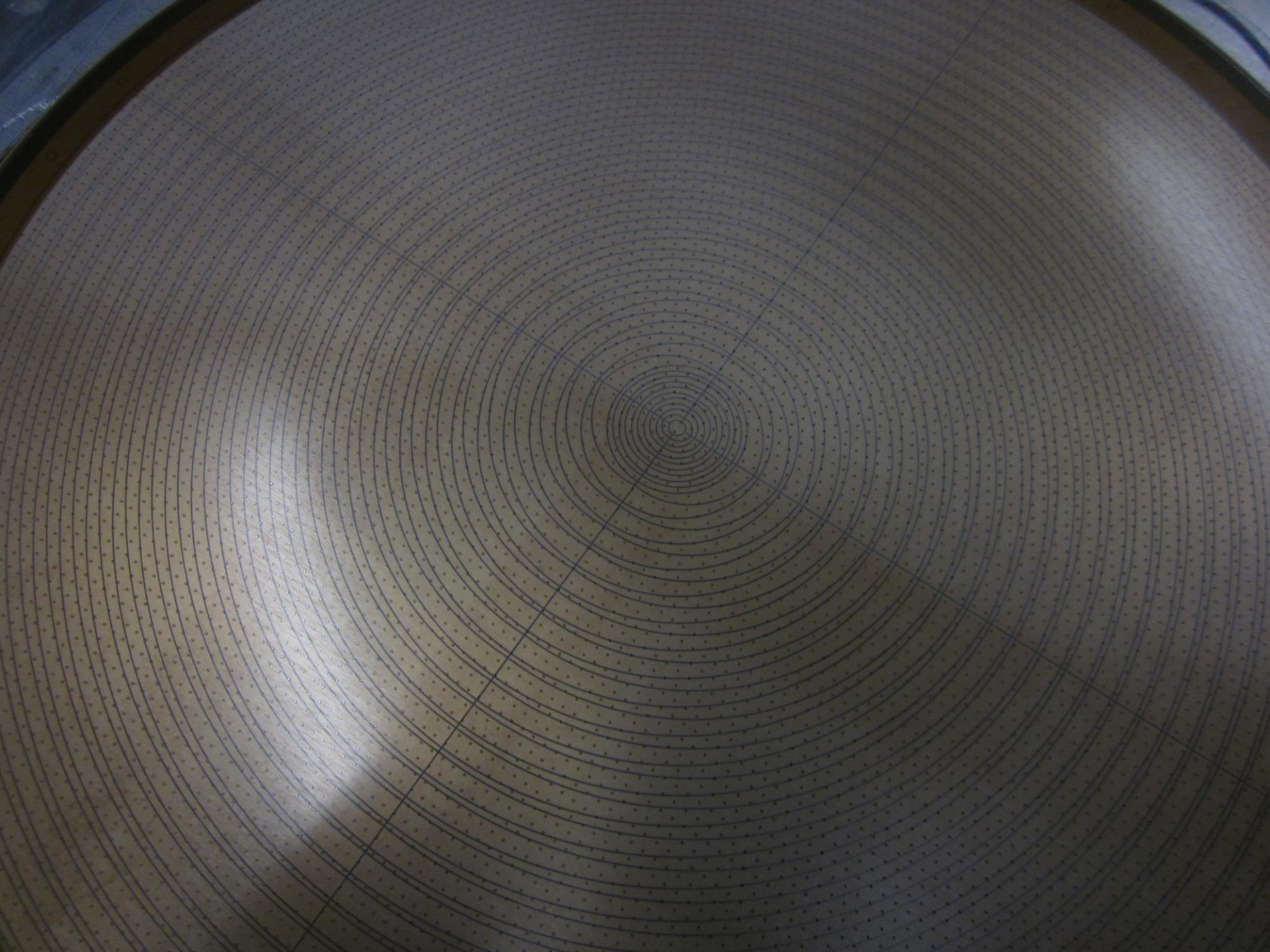
Phys. Rev. C 87, 054301 (2013)

Specifications

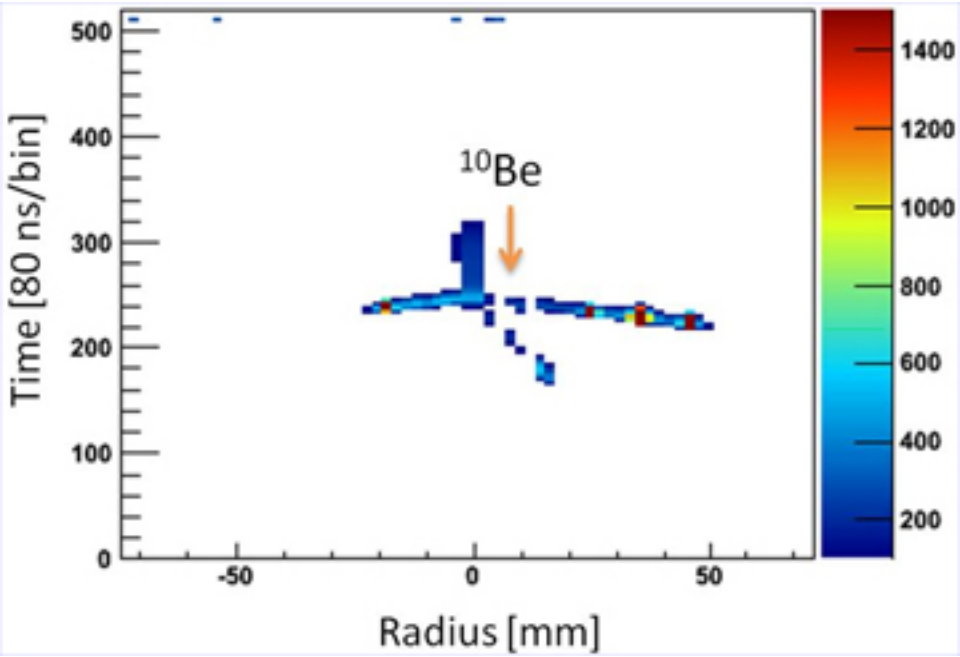


Large volume	100 cm x 60 cm e.g. D_2 10 mg/cm^2 @ 1 atm
High granularity	10,000 pads, ~5 x 5 mm^2
***Bρ* analysis**	Solenoid 2 T (Triumf)

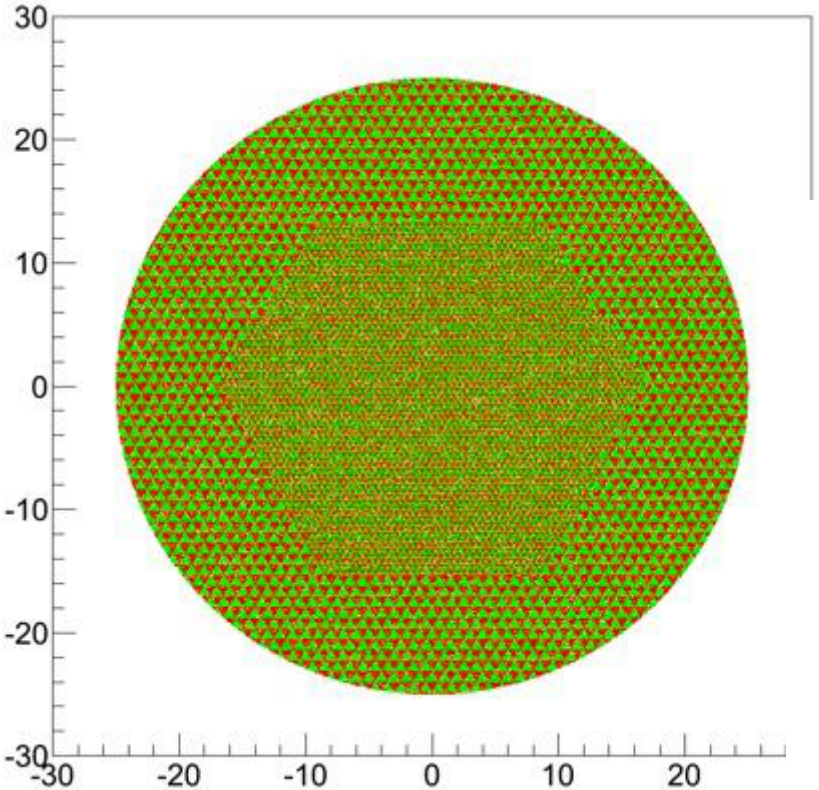
Commissioning: spring2014

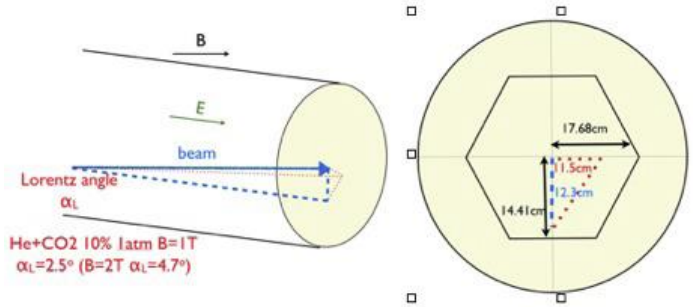


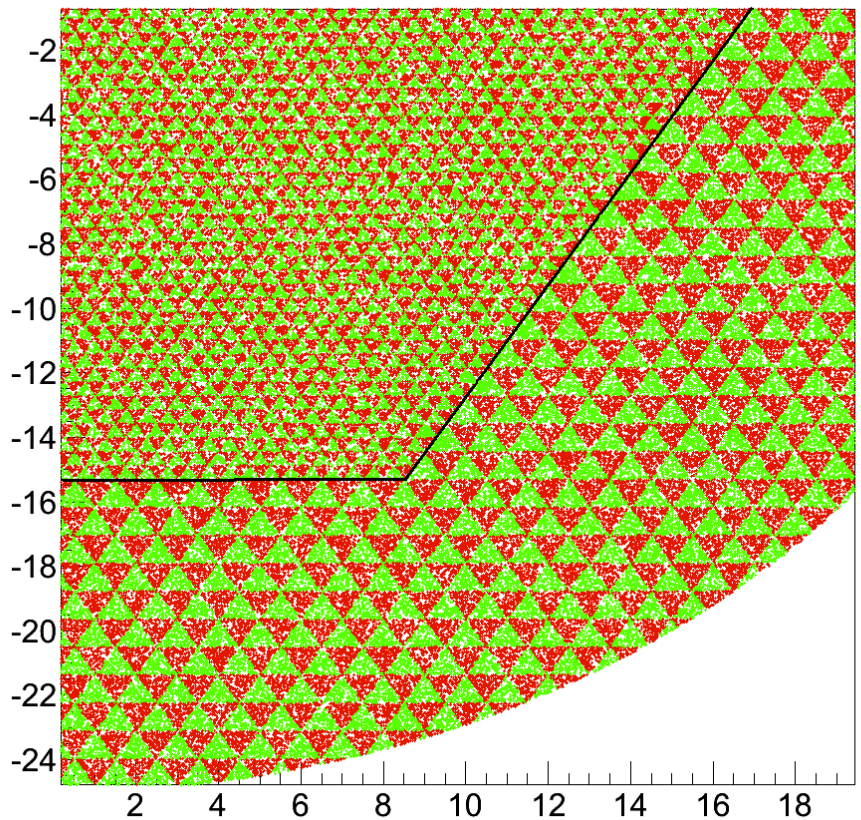
Prototype Exp. $^{10}Be+^{4}He$



A.Fritsch, S.Beceiro No



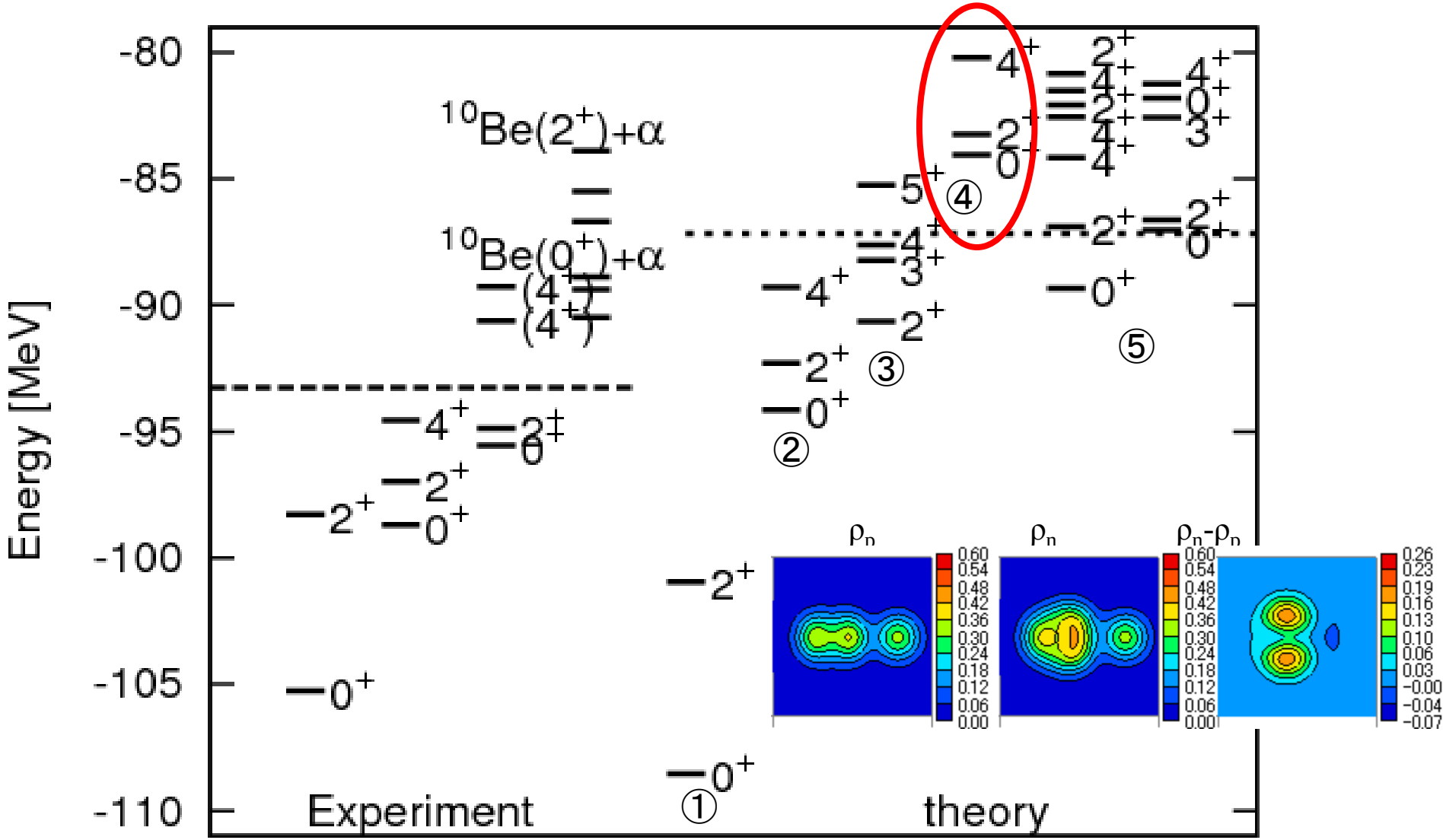




10000 pads
Triangles
Small base 5mm
Big base 10mm

S. Beceiro Novo, F.Abu-Nimeh, D.Bazin,WM

The Energy Levels (+ parity states) (S.+EK.)



①, Shell Model
②, Triaxial (K=0)
③, Triaxial (K=2)
④, Linear-chain
⑤, Other states