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
Relevant Questions

Best Tools
Accel., exp. devices

Precise Answers
FRIB: Facility for Rare Isotope Beams

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

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

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

Nucleosynthesis in the r-process
Joint Institute for Nuclear Astrophysics 2012
Time: 1.7e-03 s
Temperature: 5.46 GK
X-ray bursts

Time: $-3.900 \times 10^3$ s
Temperature: 0.186 GK
Why an Active Target-TPC?

- Nuclear Structure Investigations of Exotic Nuclei with Secondary Beams

1) from normal kinematics to inverse kinematics

- $p,d,^3\text{He}$
- $^{12}\text{C},^{40}\text{Ca}$
- $^{18}\text{C},^{32}\text{Mg}$
- $p,d,^3\text{He}$
Why an Active Target-TPC?

• Nuclear Structure Investigations of Exotic Nuclei with Secondary Beams

1) from normal kinematics to inverse kinematics

\[
p,d,^3\text{He} \\
\text{beam} \\
^12\text{C},^40\text{Ca} \\
\text{target} \\
^18\text{C},^32\text{Mg} \\
p,d,^3\text{He}
\]
Normal kinematics versus inverse kinematics

- Example: $d(^{32}\text{Mg},^{33}\text{Mg})p$ gs, 100keV
Beam Intensity $\sim 10^{-9}$ with respect to stable beams

Thick Targets without resolution loss: tracking of reaction vertex
High detection efficiency: $4\pi$
Measurement of the Two-Halo Neutron Transfer Reaction $^1H(^{11}Li, ^9Li)^3H$ at 3A 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 $^1H(^{11}\text{Li}, ^9\text{Li})^3\text{H}$ 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
$1-2*10^3$ $^{11}\text{Li}$/s

Soft Giant resonance in $^{68}\text{Ni}$ by $(\alpha,\alpha')$

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


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

Low density gas: chemical equilibrium \( n, p, d, \alpha, \ldots \)

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: $ρ \sim ρ_0/10$

Nuclei: $ρ = ρ_0$
Cluster States: from low density gas to nuclear systems

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

....M.Girod,... constrained HFB
$^{14}\text{C}$ (T. Suhara (Kyoto) and Y. Kanada-En’yo (YITP), 2010)

Structures which are expected to appear on the ($\beta, \gamma$) plane

Shell Model (Spherical)

Equilateral-triangular (oblate)

Obtuse-angle triangular (triaxial)

Linear-Chain (prolate)

Excess neutrons deform largely (triaxial)
$^{10}\text{Be} + ^4\text{He} \rightarrow ^{14}\text{C}$
The diagram illustrates the energy levels of a system with different quantum states and corresponding figures showing the density distributions. The energy levels are labeled with subscripts indicating parity and angular momentum. The density distributions are color-coded, with keys indicating the density values in $1/fm^3$. The lower part of the diagram shows a reaction scheme with a transition probability and angular distribution for different angular momenta and parity states.
Principle of detection
proto AT-TPC

Insulator gas volume
- He, H, D ...
- 50 kVDC (1kV/cm)

N_{2} gas \: 30 \text{kV/cm} \times 6 \text{cm} = 180 \text{kV}

Ref.: NIM A 691 (2012) 39
by D. Suzuki, et al.
IAS $^{124,132}\text{Sn}(p,p)$

Tan Ahn et al., ANL-Caribu, March 2013
Example: 2p decay of $^{45}\text{Fe}$

K. Miernik, PRL 99, 192501 (2007), $Q_{2p}$ 1:15 MeV
FIG. 1: (Color Online) A typical image recorded by the CCD camera of three alpha-particles from the reaction $^{12}$C($\gamma,\alpha_0$)$^{8}$Be. 

FIG. 3: (Color online) Angular distribution for $^{12}$C($\gamma,\alpha_0$)$^{8}$Be 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($\gamma,\alpha_0$)$^{8}$Be reaction. (b) The measured E1-E2 relative phase angle ($\phi_{12}$) together with the phase angle calculated from a two-resonance model.
Tentative of direct observation
“democratic” 3 body decay of
$^{12}$C($0^+_{2}$, Hoyle state) in the 3 dim

10Torr isobuthane

sequential decay $^{12}$C-->alpha+8Be
alpha1 in x direction
events in x-y plane dr/r=5% dx=2.35mm[FWHM]

"democratic" decay $^{12}$C--> 3 alpha
alpha1 in x direction
events in x-y plane dr/r=5% dx=2.35mm[FWHM]
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: ~10000 channels

Data flow at 1000 cts/s

$512 \times 10^4 \times 10^3 \times 2$

~$10^{10}$ bytes/s

= 10 Gbytes/s before reduction
TACTIC: York-TRIUMF Collaboration

IKAR-GSI

Mizoi et al

MSTPC

Maya@Ganil

Prototype AT-TPC at MSU

CNS-Riken

OTPC Warsaw-ORNL

O-TPC at TUNL

Anasen

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

Figure 3: Schematics of MAIKo.

Figure 4: Structure of $\mu$-PIC. Electron avalanche simulated by Garfield [6] is also drawn.
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,† F.D. Becchetti,5 D. Ben Ali6 B. Bucher,4 J. Browne,4,1,3
X. Fang,4 M. Febraro,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. Tang4

## Specifications

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<tr>
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<th>Details</th>
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<tr>
<td><strong>Large volume</strong></td>
<td>100 cm x 60 cm  e.g. $\text{D}_2$ 10 mg/cm$^2$ @ 1 atm</td>
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<td><strong>High granularity</strong></td>
<td>10,000 pads, ~5 x 5 mm$^2$</td>
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<td><strong>$B\rho$ analysis</strong></td>
<td>Solenoid 2 T (Triumf)</td>
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**Commissioning:** spring 2014
Prototype Exp. $^{10}\text{Be}+^{4}\text{He}$
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