

Astrophysics Opportunities using the (P)AT-TPC

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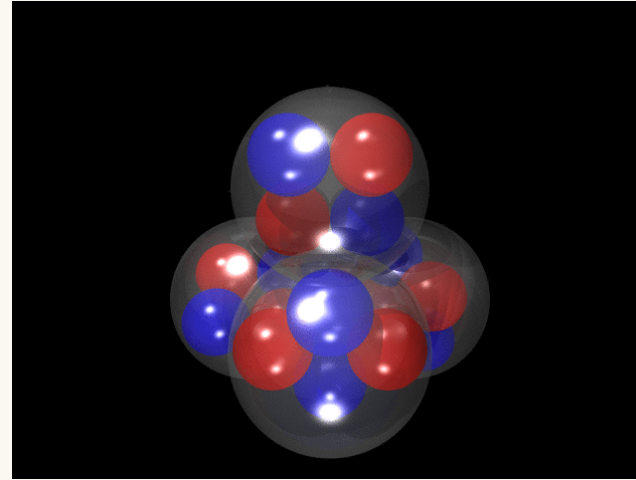
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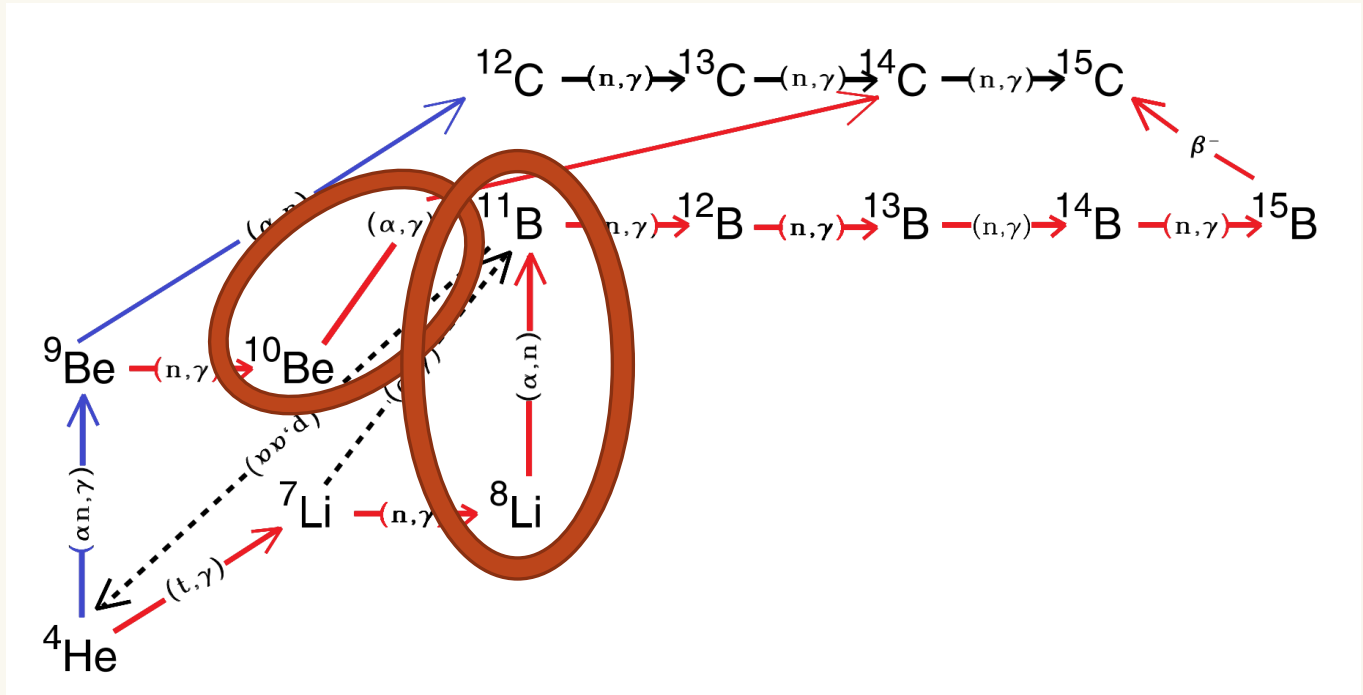
Nuclear Structure: Clusters in Nuclei



http://www.scholarpedia.org/article/Clusters_in_nuclei

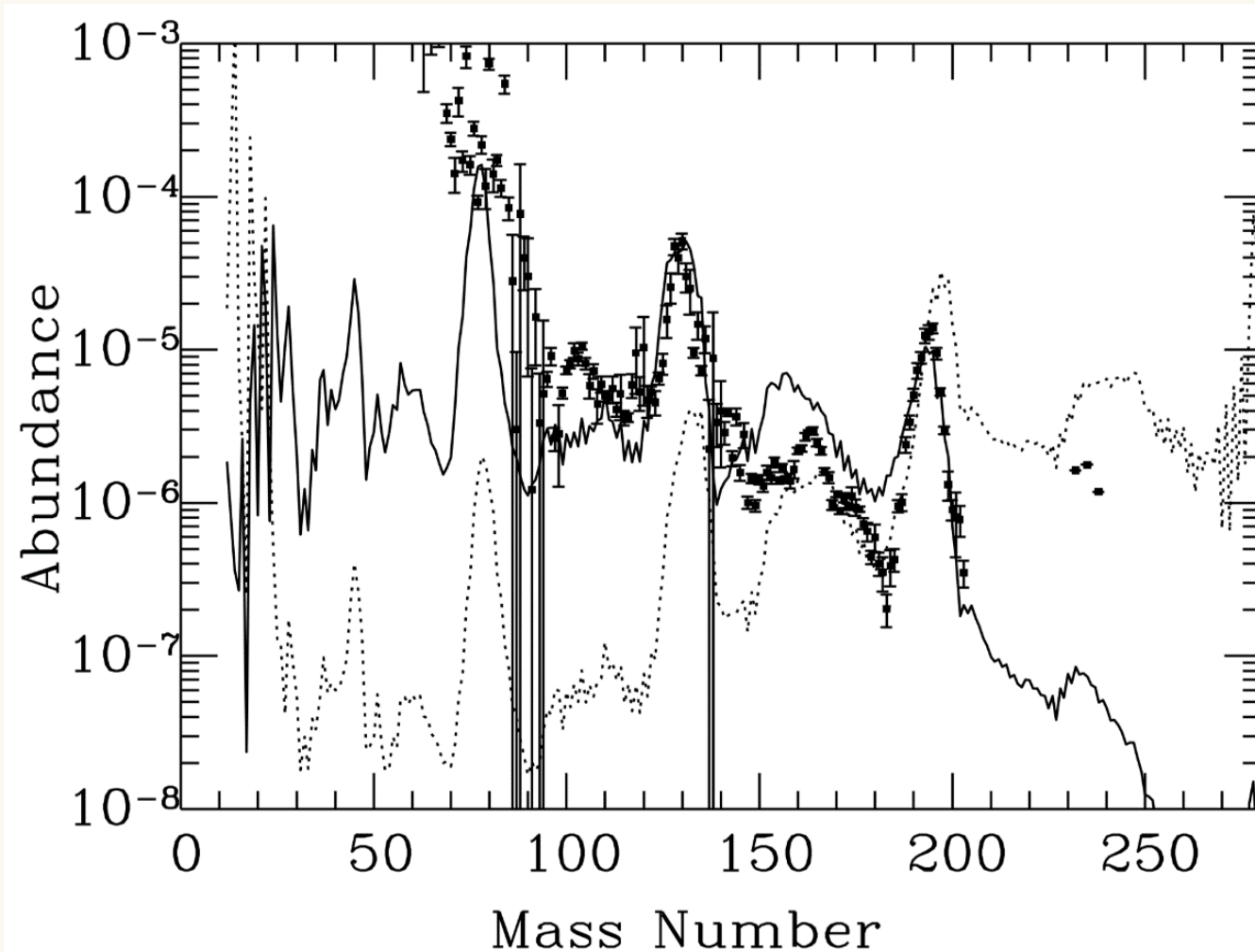
- ◇ alpha-particle (2 protons, 2 neutrons) clusters
- ◇ What causes nuclei to cluster?
- ◇ What role does clustering play in element formation?

Making Seed Nuclei for r-process



- ◇ Terasawa et al. ApJ 562, 470 (2001), Sasaqui et al. ApJ 645, 1345 (2006)
- ◇ Short dynamical time-scale: Core-collapse supernovae, neutron star mergers
- ◇ Can there be an enhancement in these reactions?

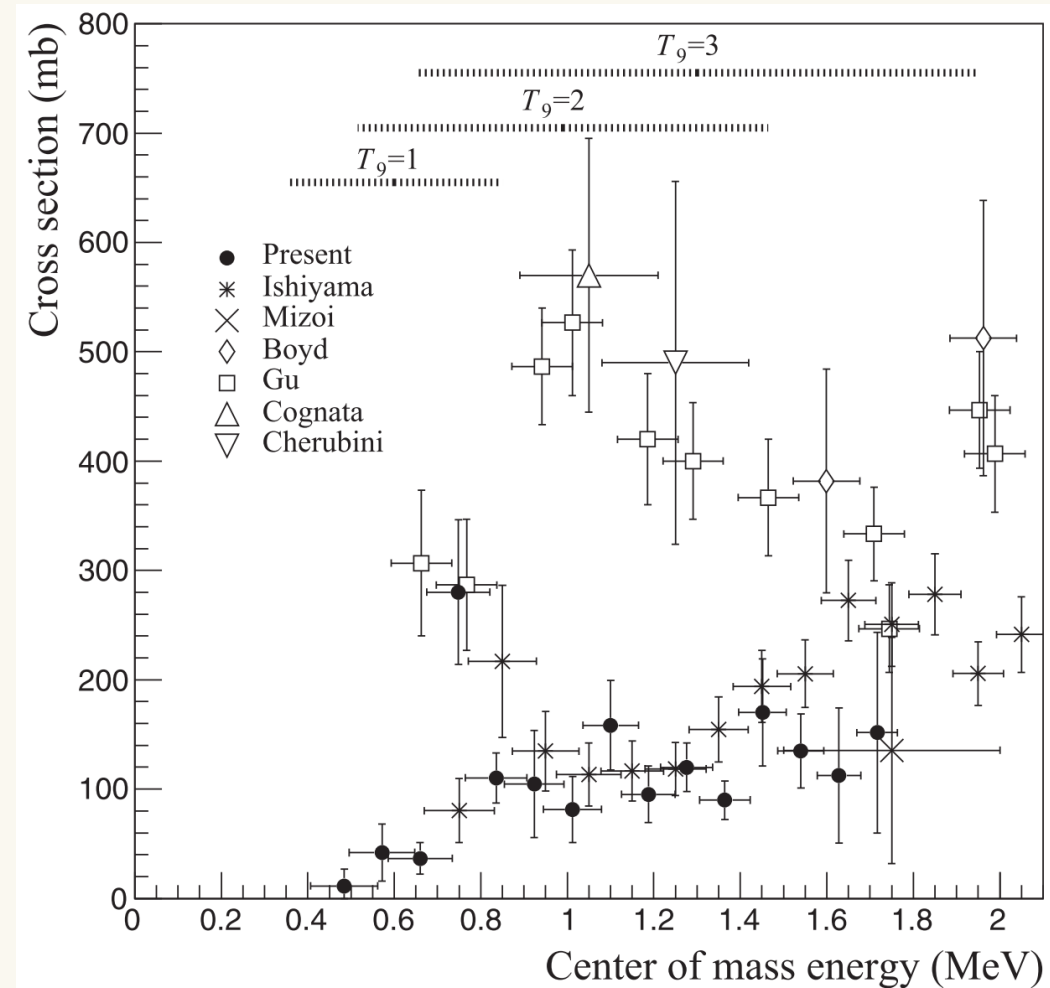
Abundance Yields with Light-Element Network



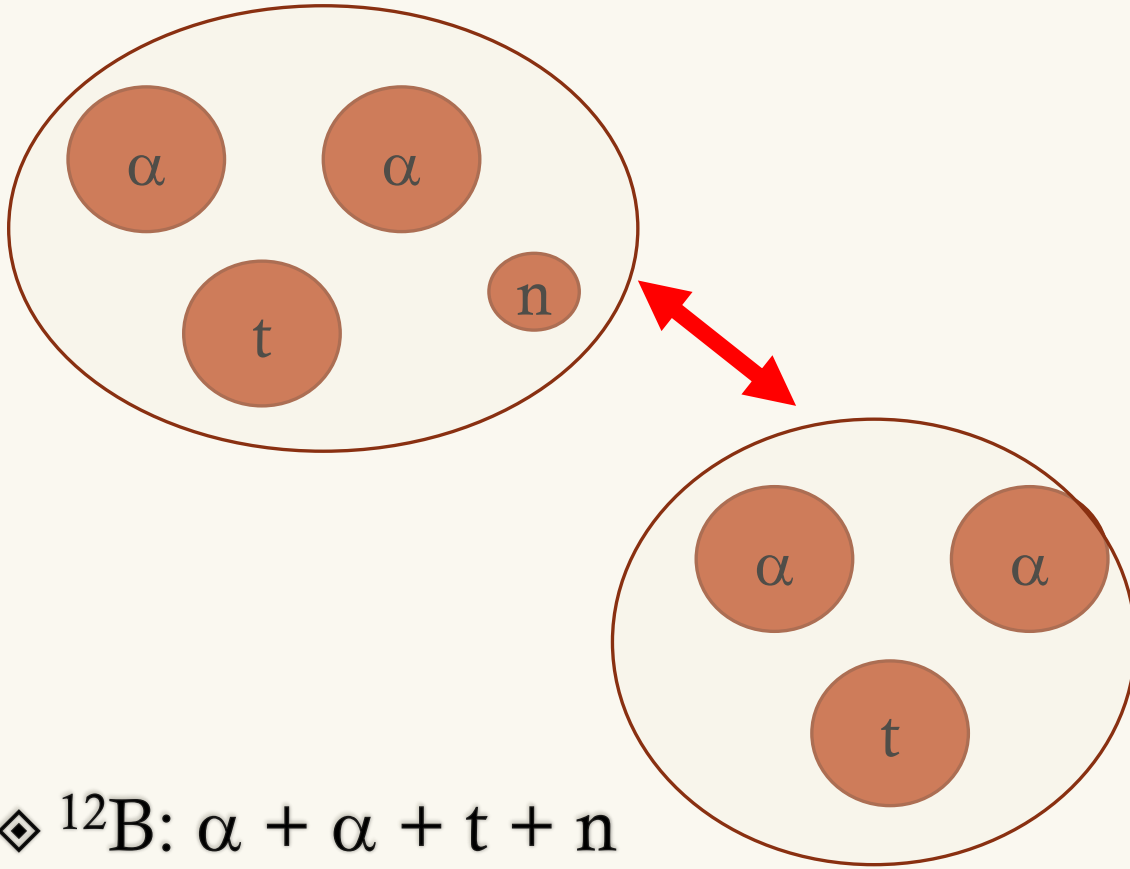
◇ Comparison with and without larger light-element network

$^8\text{Li}(\alpha, n)^{11}\text{B}$ cross section discrepancy

- ◆ Factor 5 difference in cross section
- ◆ Difference was confirmed in latest 2017 measurement
(Das et al. PRC 95 055805)

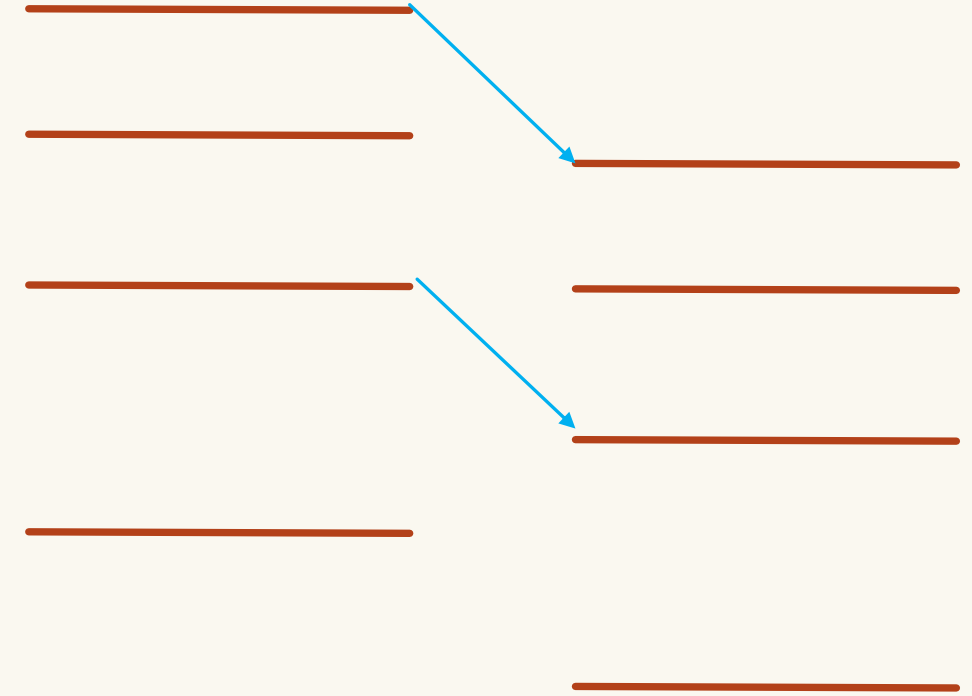


Cluster states in ^{11}B and ^{12}B



◇ ^{12}B : $\alpha + \alpha + t + n$

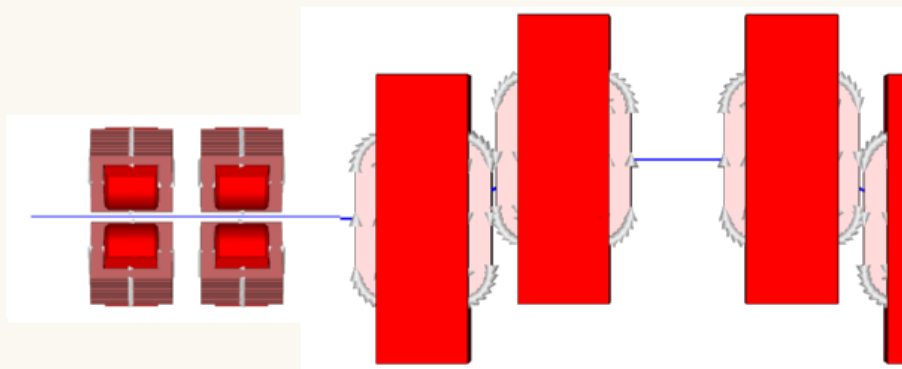
◇ ^{11}B : $\alpha + \alpha + t$



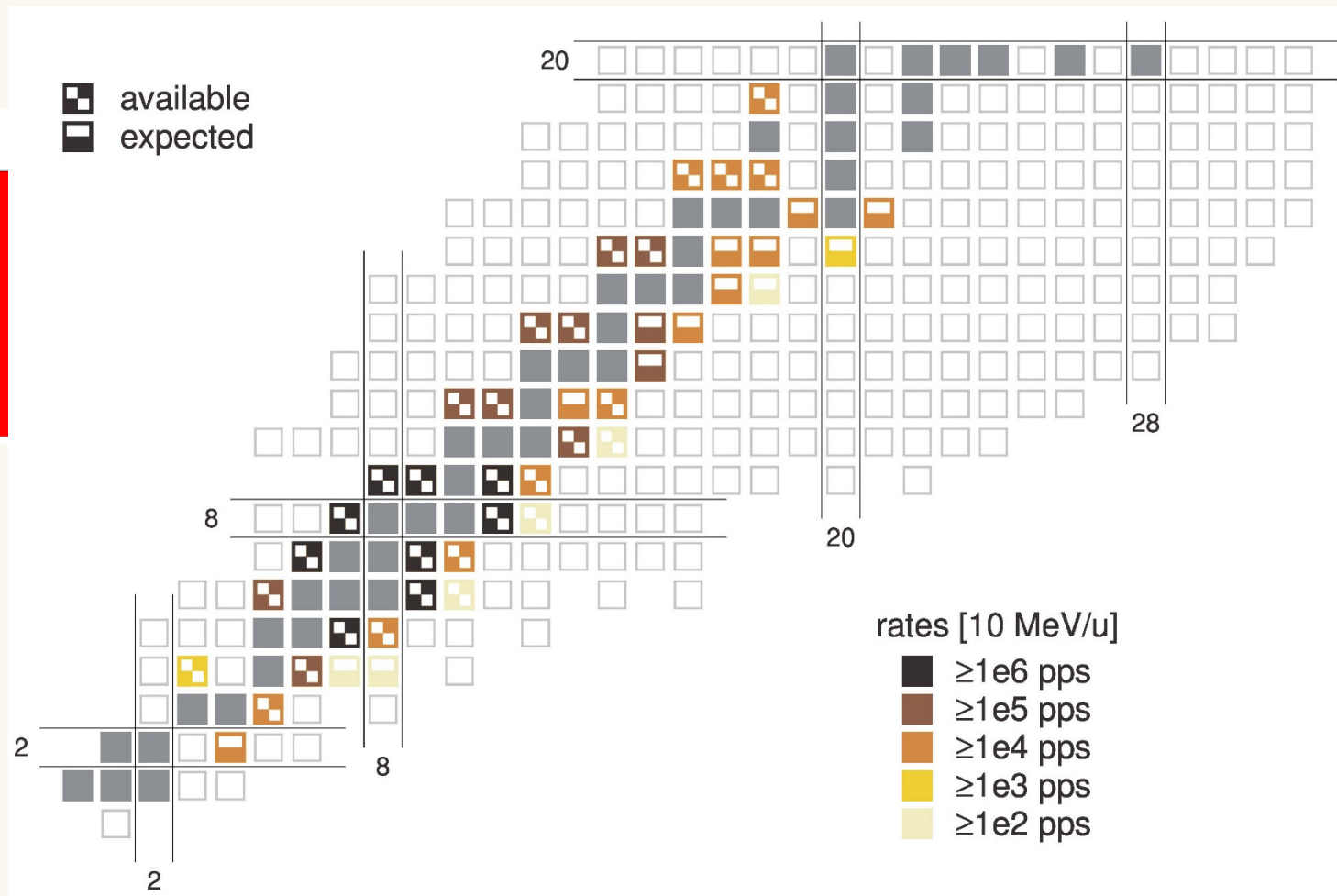
^{12}B

^{11}B

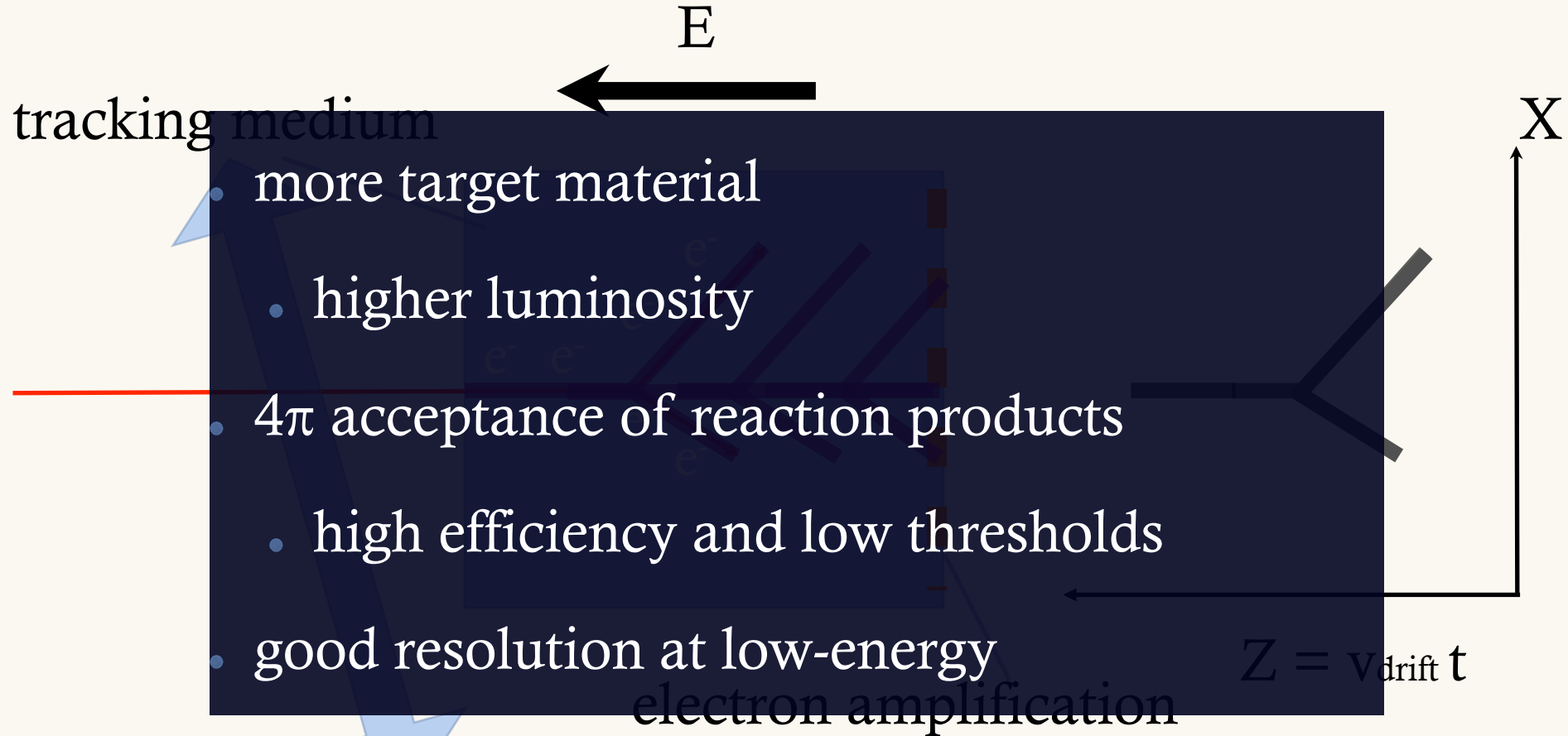
Radioactive beams with RAISOR



- ◇ In-flight beams using reactions
- ◇ Many light radioactive beams
- ◇ Energies ~ 10 MeV/A

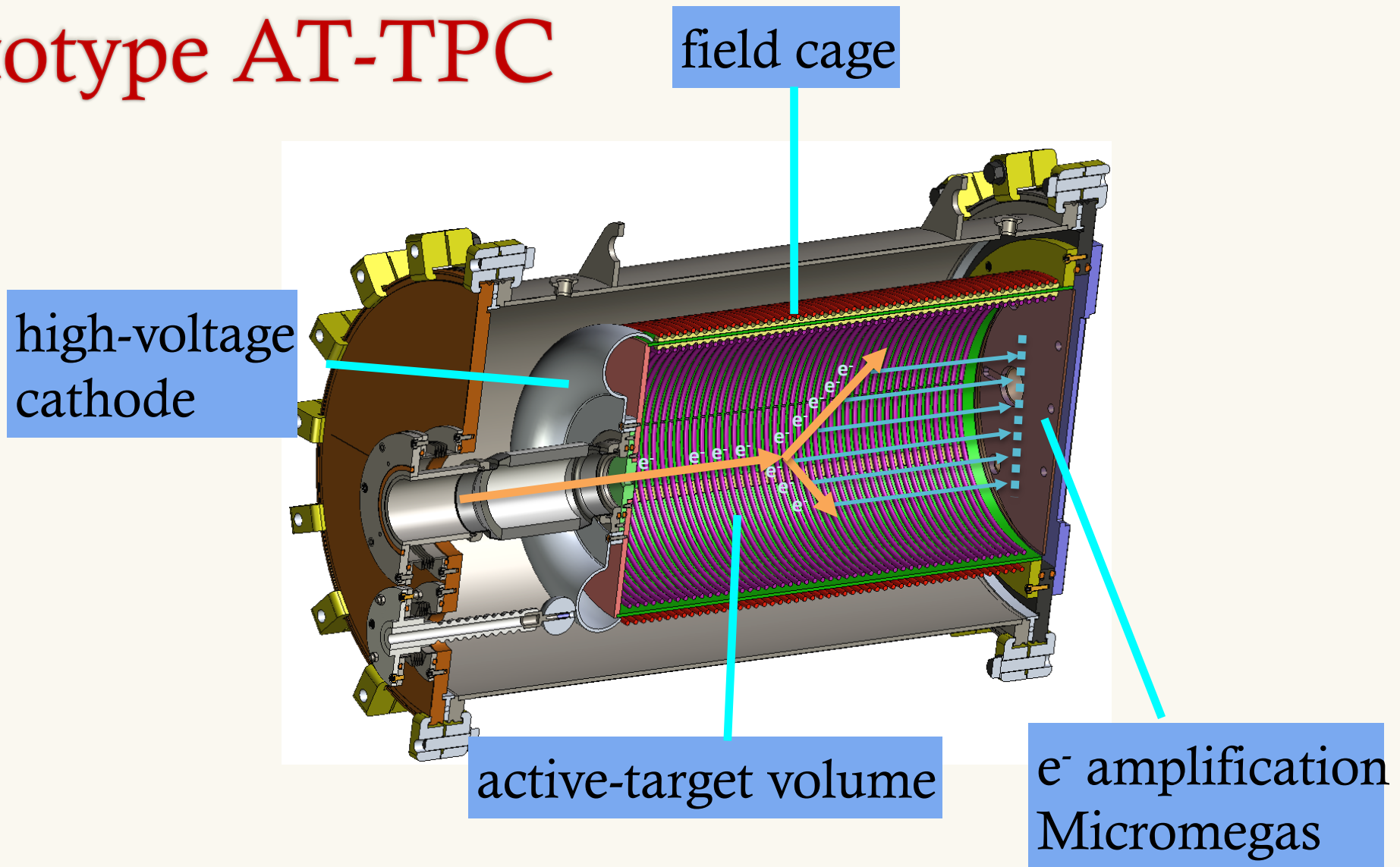


Active-Target Time-Projection-Chamber



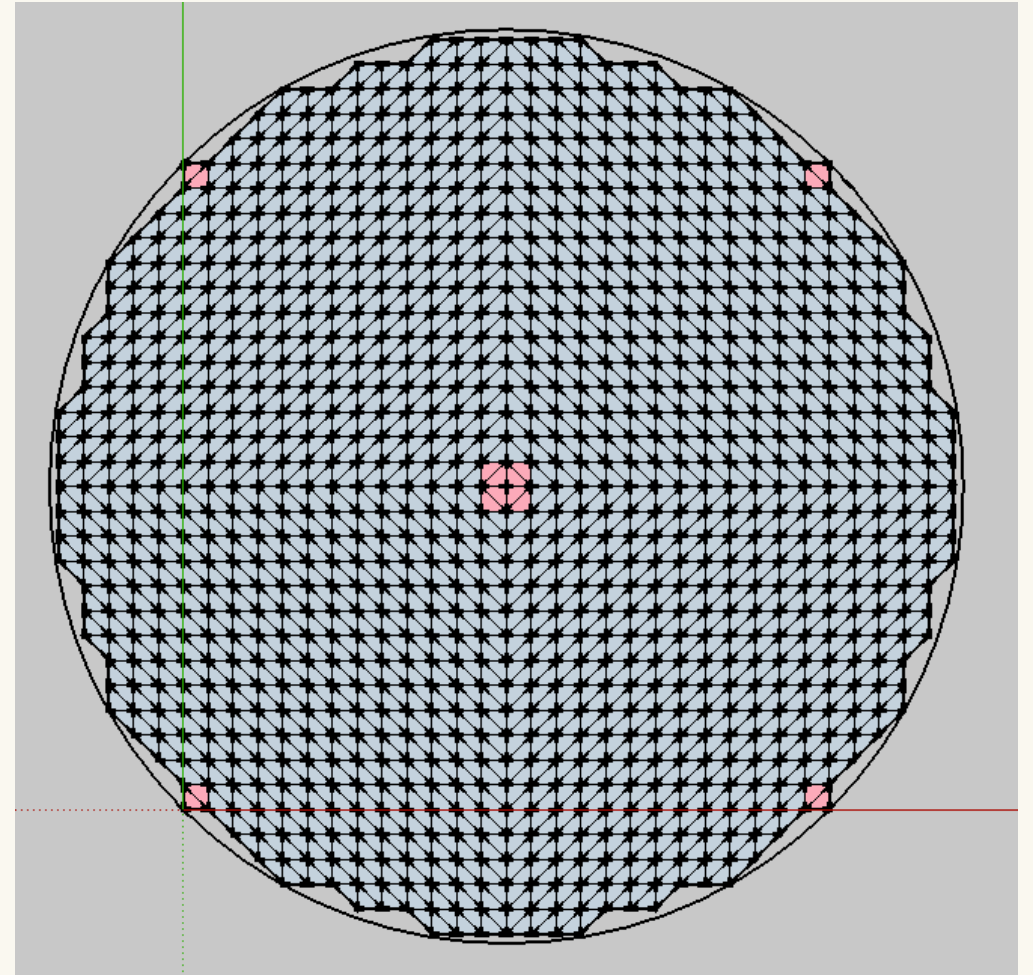
- Active-Target Time-Projection Chamber

Prototype AT-TPC



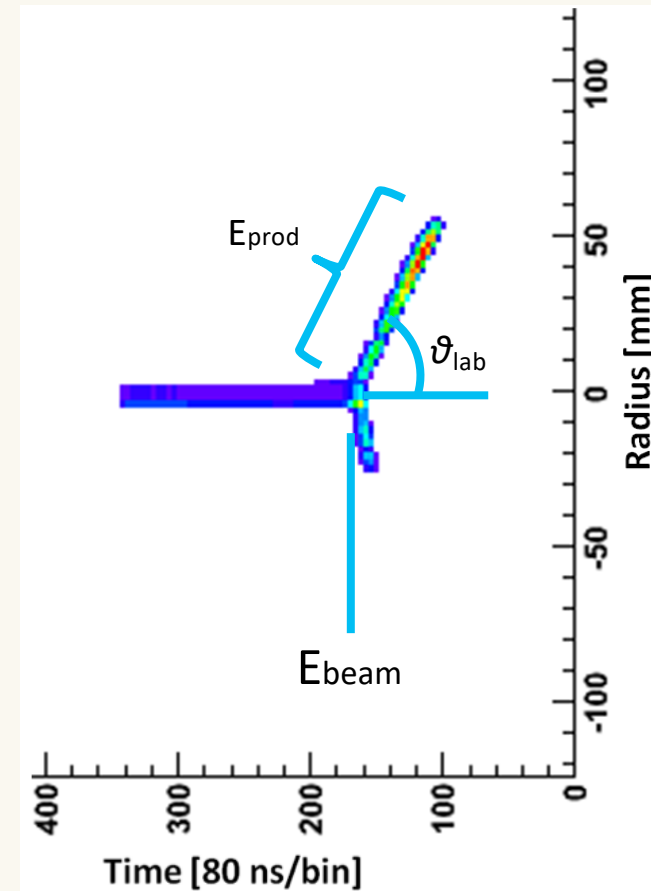
Micromegas upgrade

- ◆ Micromegas, GEMS
 - ◆ Proportional Counting Devices
- ◆ Number of pads increased 253 to 2016
- ◆ Double-thick GEMS hybrid setup
 - ◆ Eliminate quench gas (CO_2)
 - ◆ Use pure He

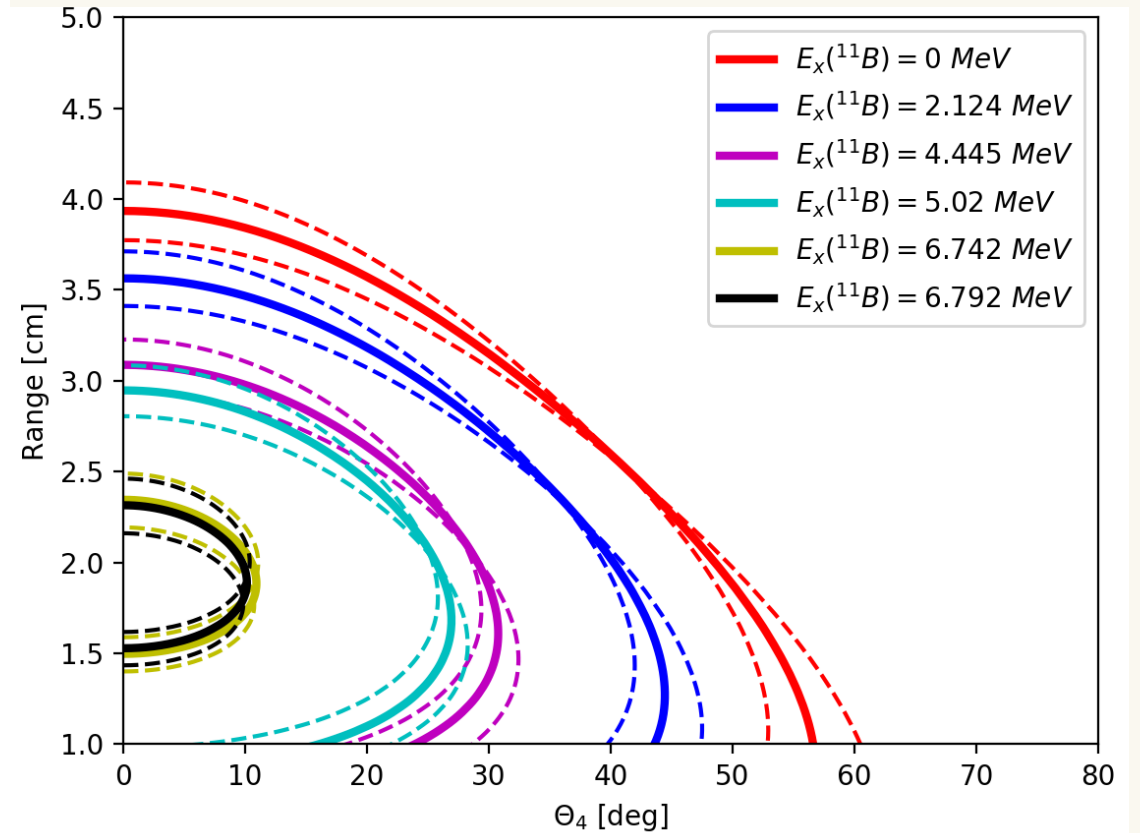
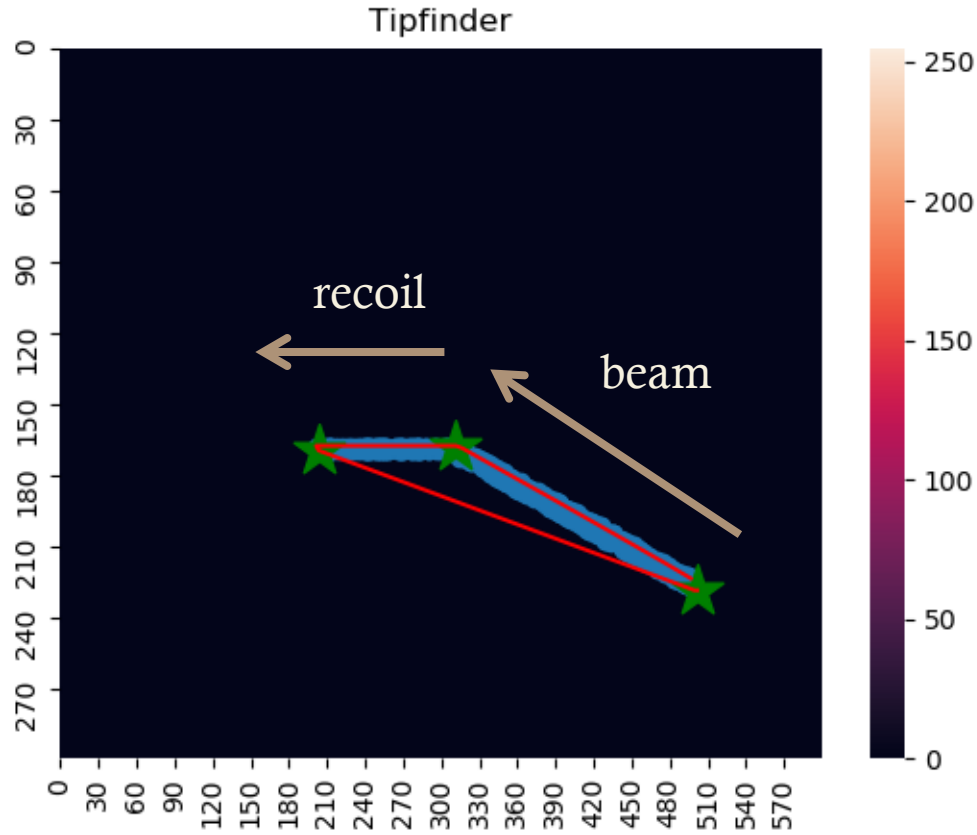


What We Measure

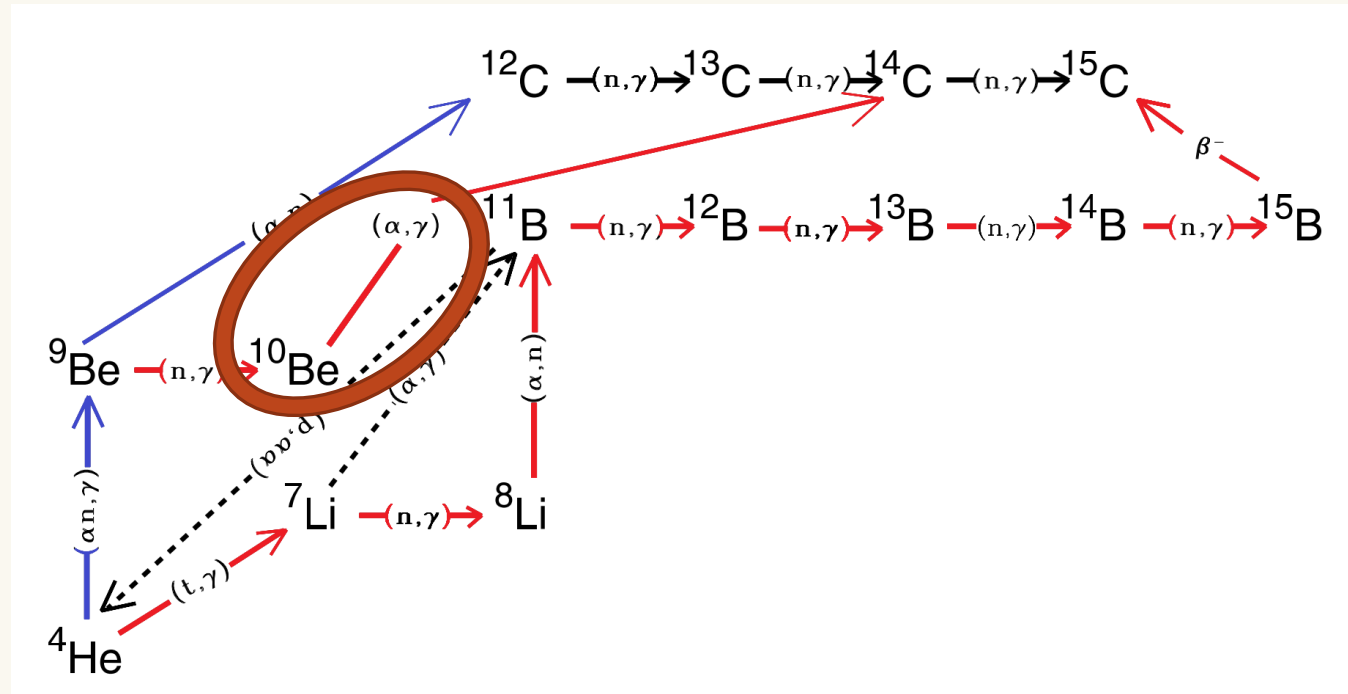
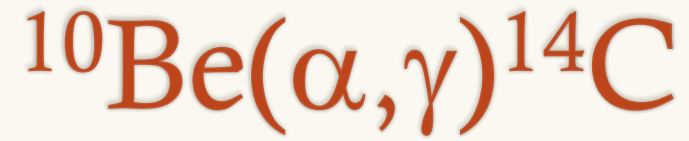
- ◆ Energy of the beam, E_{beam}
 - ◆ Position
- ◆ Angle, θ_{lab}
- ◆ Energy, Momentum, E_{prod}
- ◆ Cross Section, $d\sigma/d\Omega(E, \theta)$



Tracks for (α, n) experiments

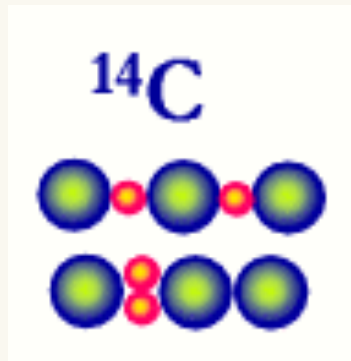


- ◇ Neutron is missing in track
- ◇ Vertex finder still finds the vertex as one of the corners
- ◇ Range and angle of the ^{11}B recoil



- ◇ No data on $^{10}\text{Be} + \alpha$ channel
- ◇ Difficulty of using unstable beam with ^4He target

3-Cluster Shapes in ^{14}C

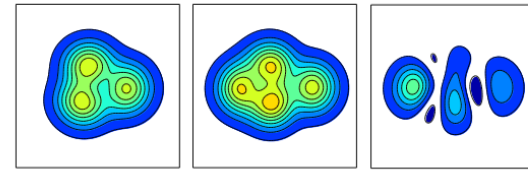


(III) triaxially deformed

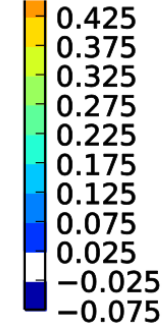
ρ_p

ρ_n

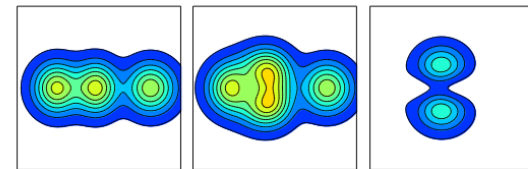
$\rho_p - \rho_n$



[1/fm³]

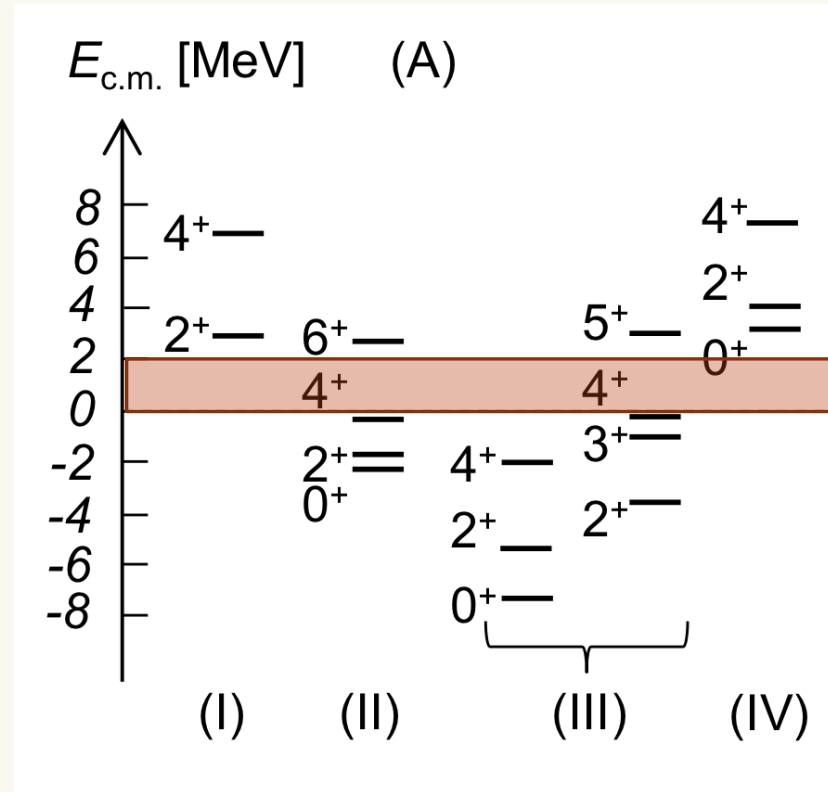


(IV) linear chain



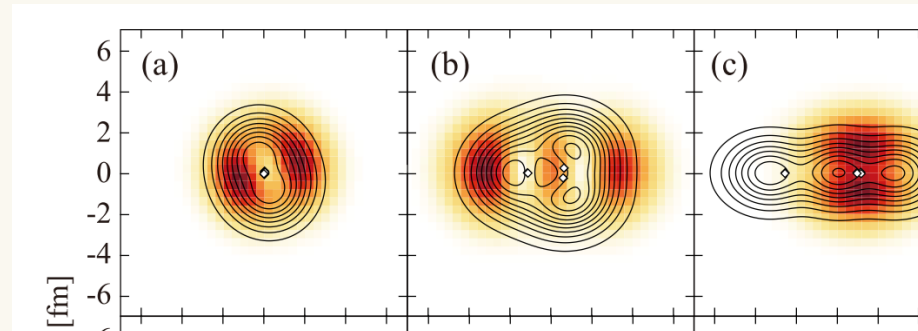
- ◆ Triaxial and Linear-Chain States
- ◆ Anti-symmetrized Molecular Dynamics
- ◆ Suhara and Kanada-Enyo PRC 82, 044301 (2010)

Candidate for Linear-Chain State in ^{14}C

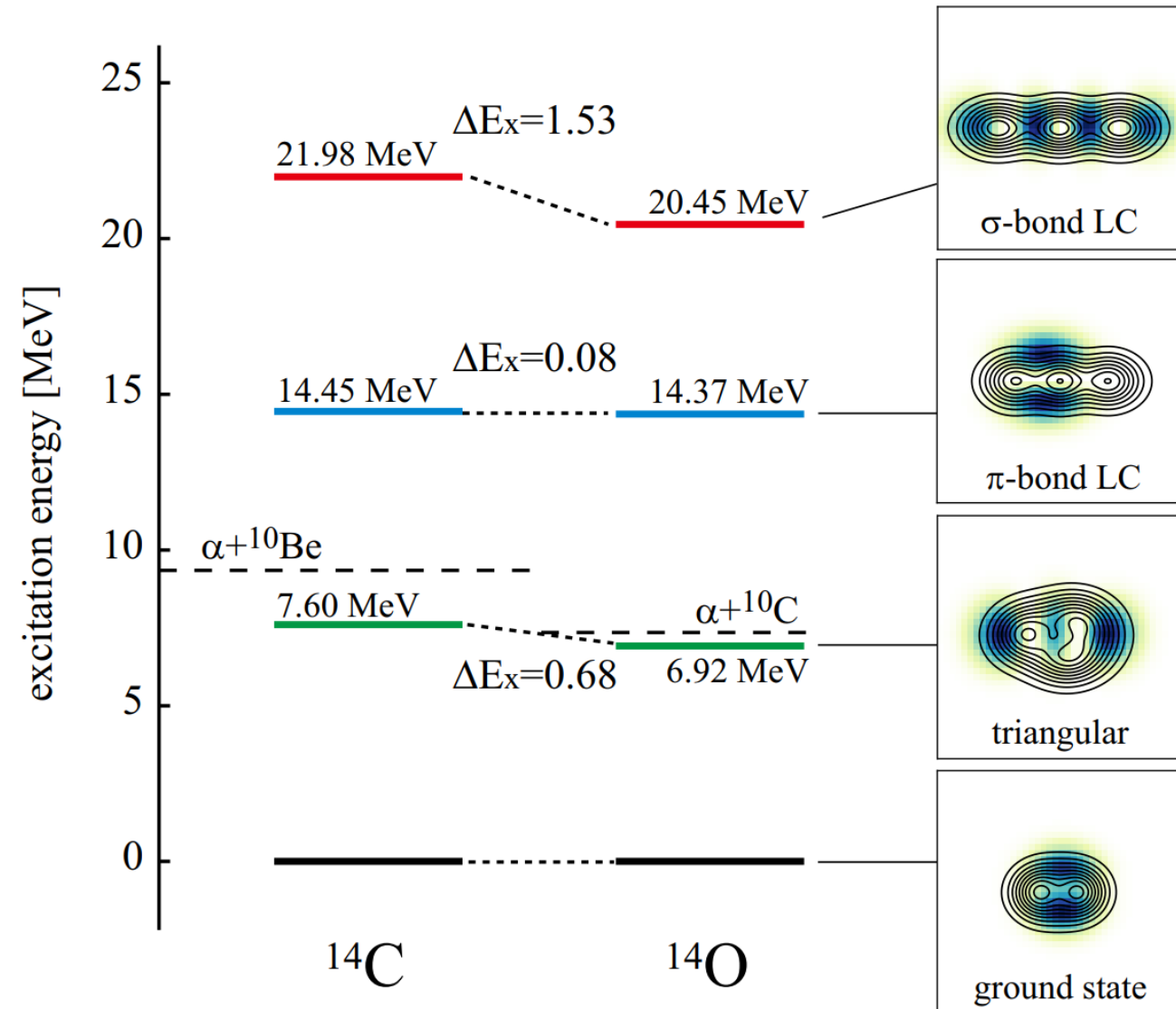


◆ Low-energy resonances not known for low energies

Deformed AMD α -cluster states in ^{14}C



- ◆ Deformed AMD, Baba et al., PRC 94, 044303 (2016)
- ◆ Coulomb shifts, Baba et al., PRC (2019)
- ◆ Use PAT-TPC or similar for (α, α)
 - ◆ Higher energy
- ◆ Use PAT-TPC or MUSIC type for (α, γ)



Summary

- ◆ Alpha-induced reactions important for nucleosynthesis in many astrophysical scenarios
 - ◆ Light-element reactions for fast time scale events: core-collapse supernovae, compact mergers
- ◆ Use of radioactive beams and active-target TPC's
 - ◆ Availability of low-energy radioactive beams
 - ◆ Thick target, good energy resolution, tracking
 - ◆ Low thresholds for detection of low-energy particles
- ◆ Many other reaction possibilities: (α, p) , (d, p) , (p, α) , etc.

Thank you for your attention!