When Three's a Crowd

Konrad Aniol

- Who? Sophia Iqbal's thesis
- What? Structure of ^{4}He nucleus
- Where? Thomas Jefferson National Accelerator Facility
- Why? Creation of the chemical elements
- Cast of characters in this story?
- Fermions
- Bosons

Probing for high momentum protons in ^{4}He via the ^{4}He(e,e′p)^{3}H reaction

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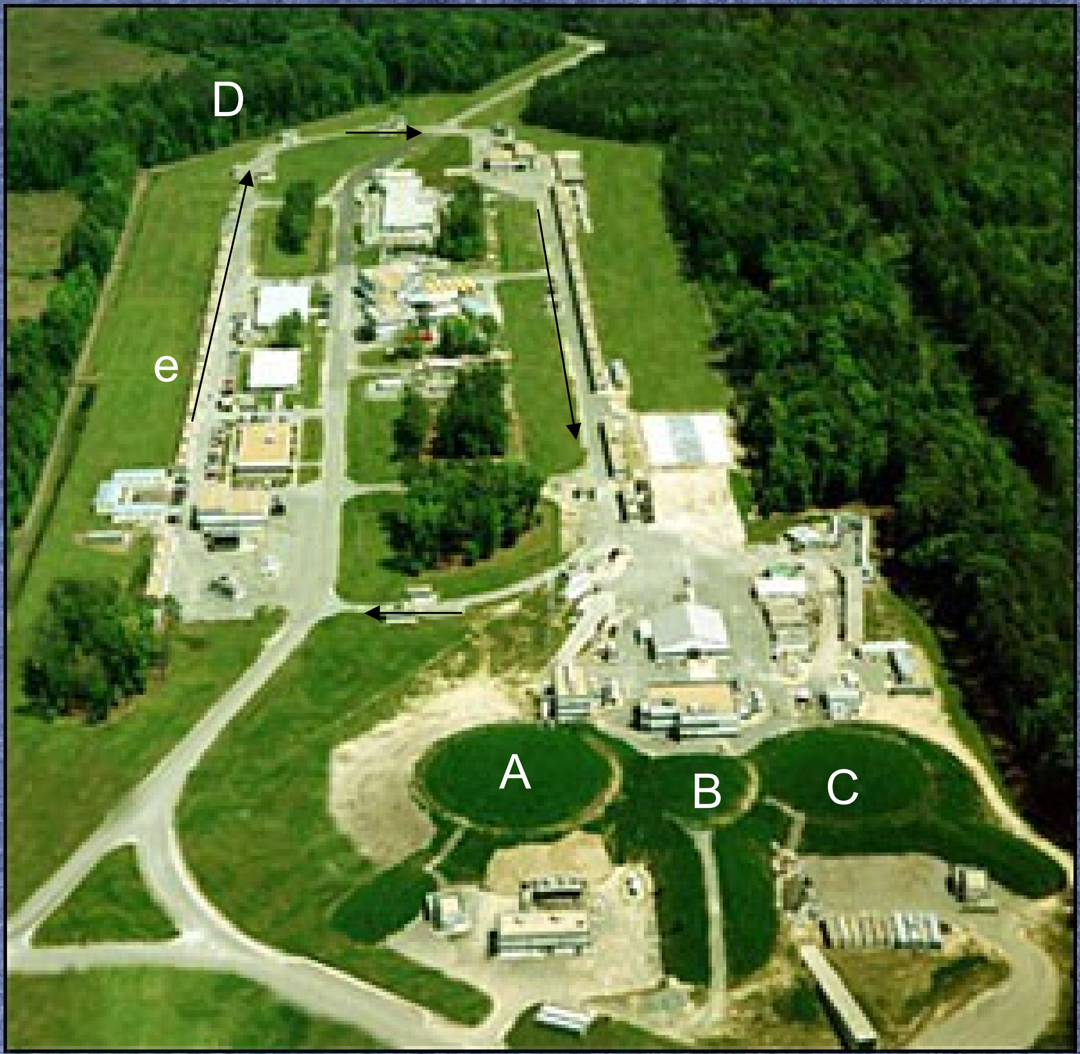
Sophia Iqbal

at Jefferson Lab

Nathaniel See

at Yorktown

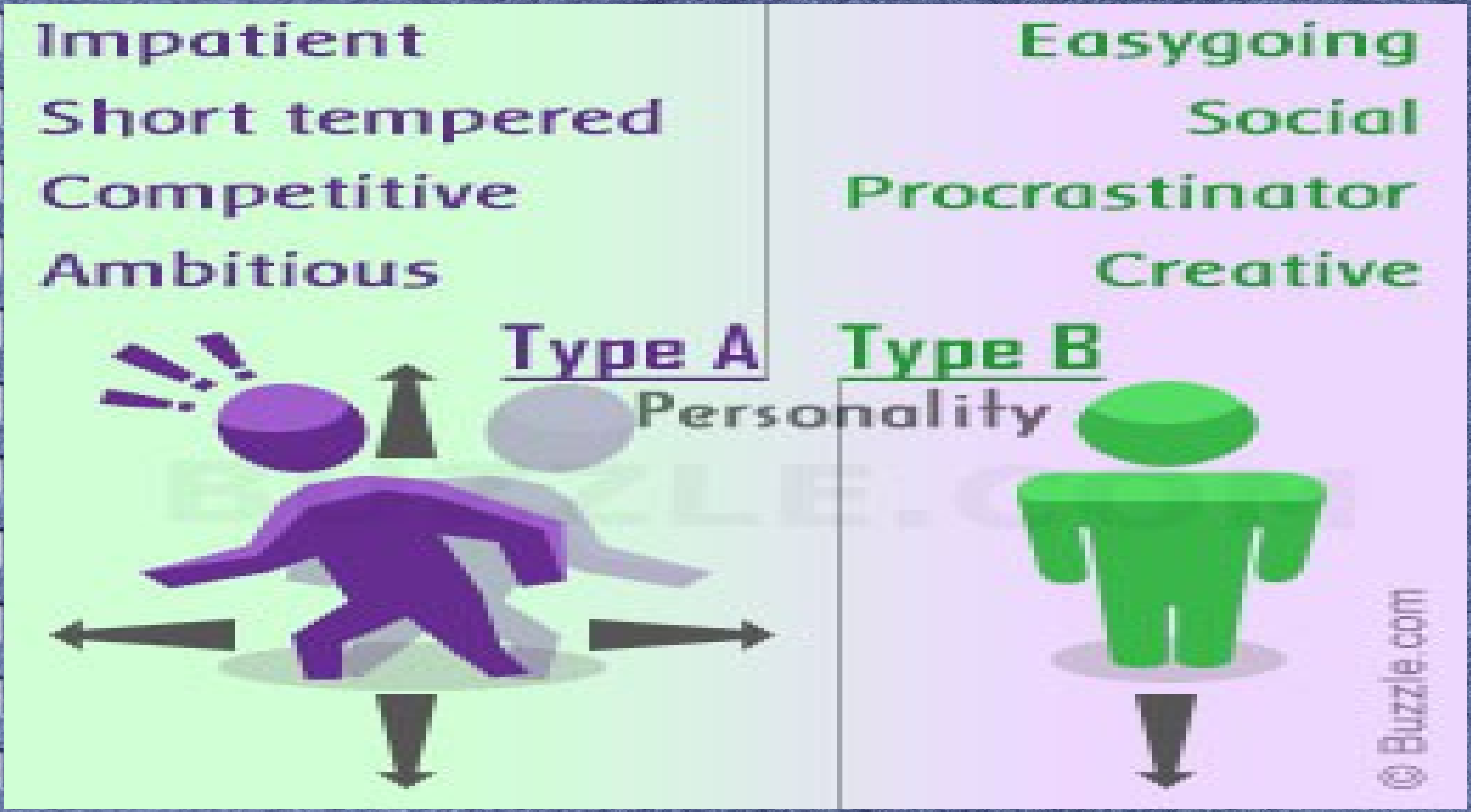
Jefferson Lab, Newport News, VA



Multi billion electron volts accelerator

Quantum Mechanics Sociology

Fermions Bosons



Life with the Fermions
Keep out of my space dude!

Life with the Bosons
Group Hug!

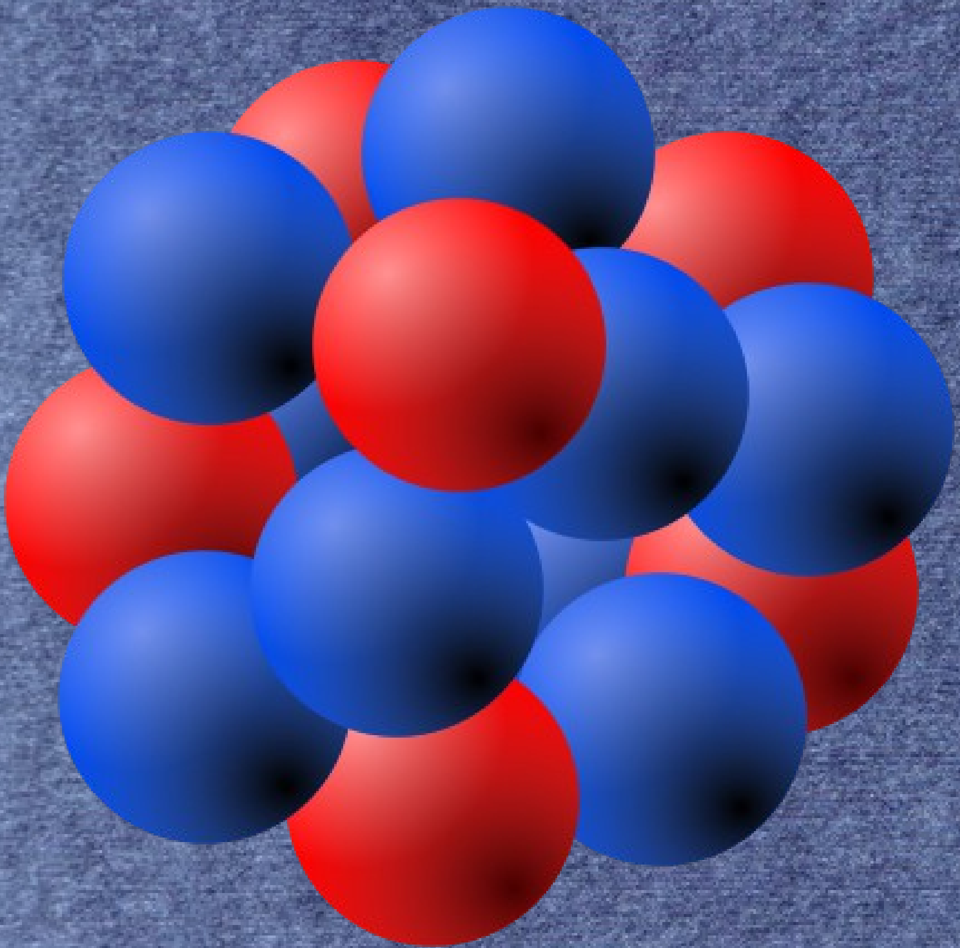
How to Build a Community?
There must be at least a two body interaction

SometimesThree's a Crowd!

Sometimes 3 makes a stronger community

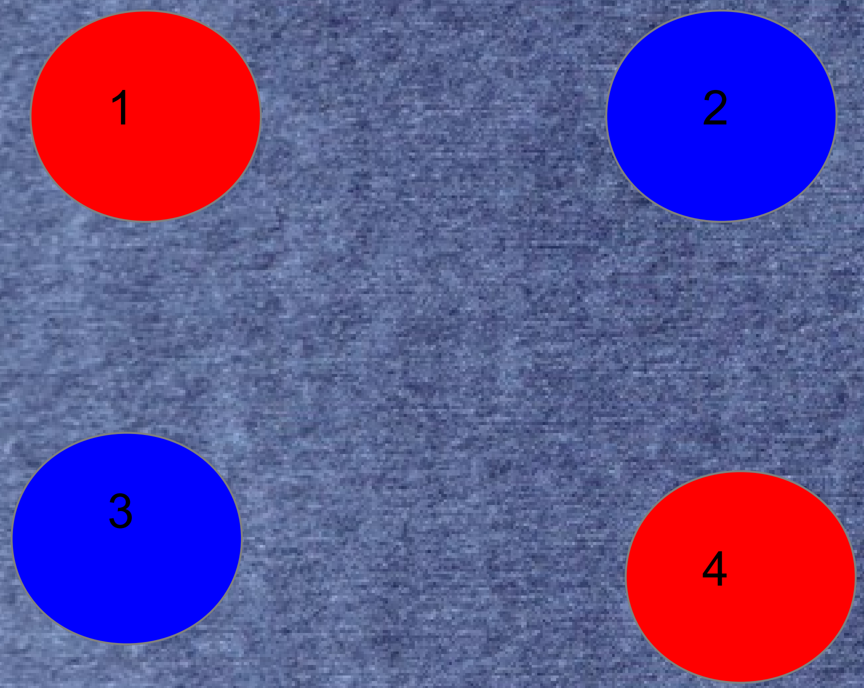
Hand Shaking helps build a community

How can Fermions form a nucleus?

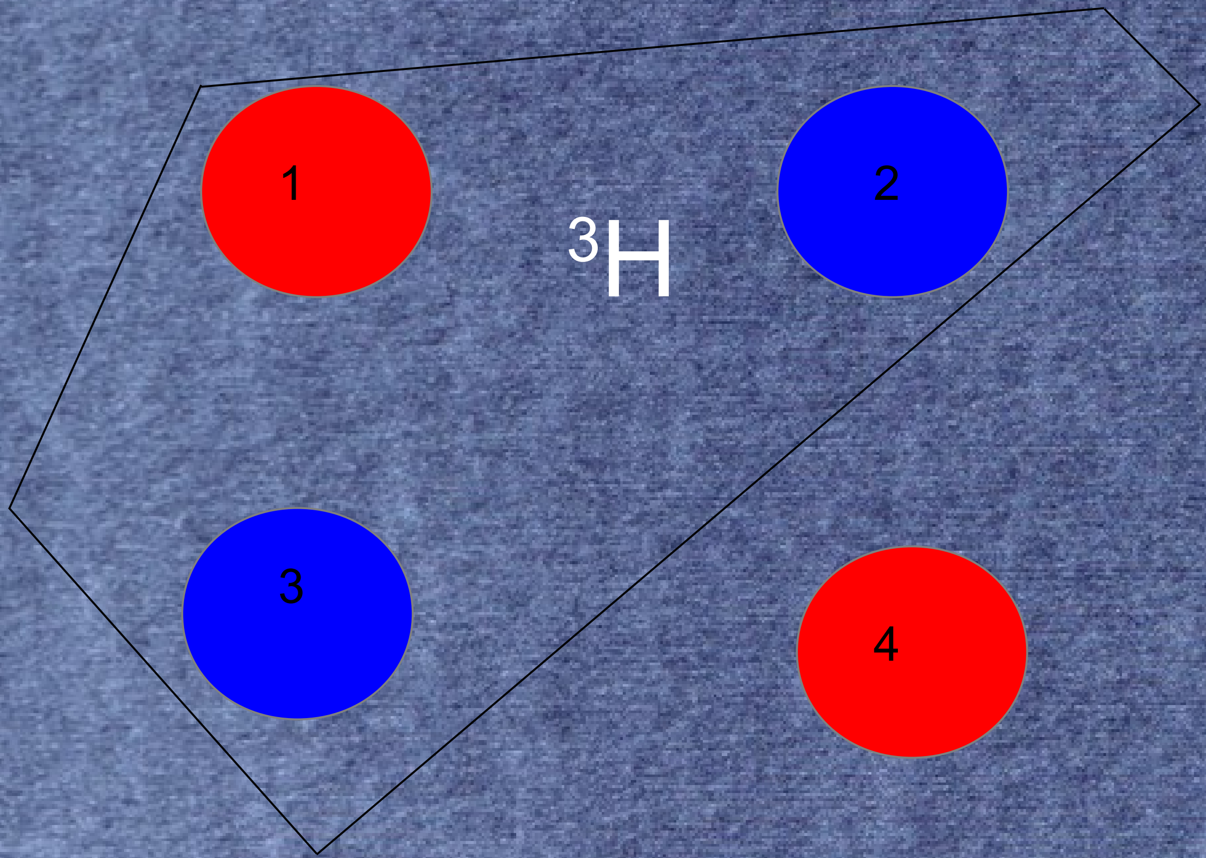


Bosons mediate hand shaking between fermions

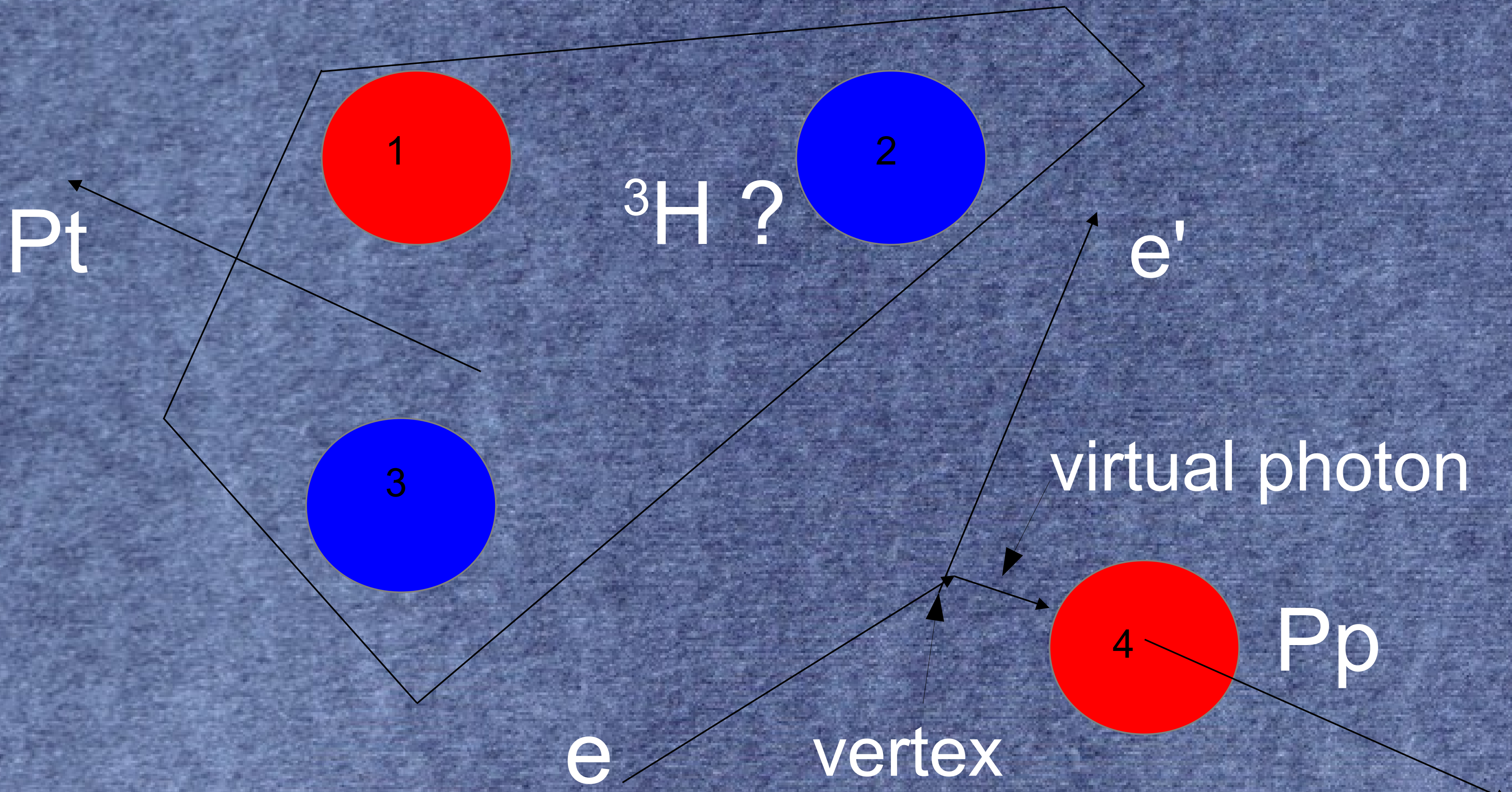
In ^4He there are 2 protons and 2 neutrons



Can ^4He be configured as $^3H + p$?



In Sophia's experiment a high energy electron knocks out a proton



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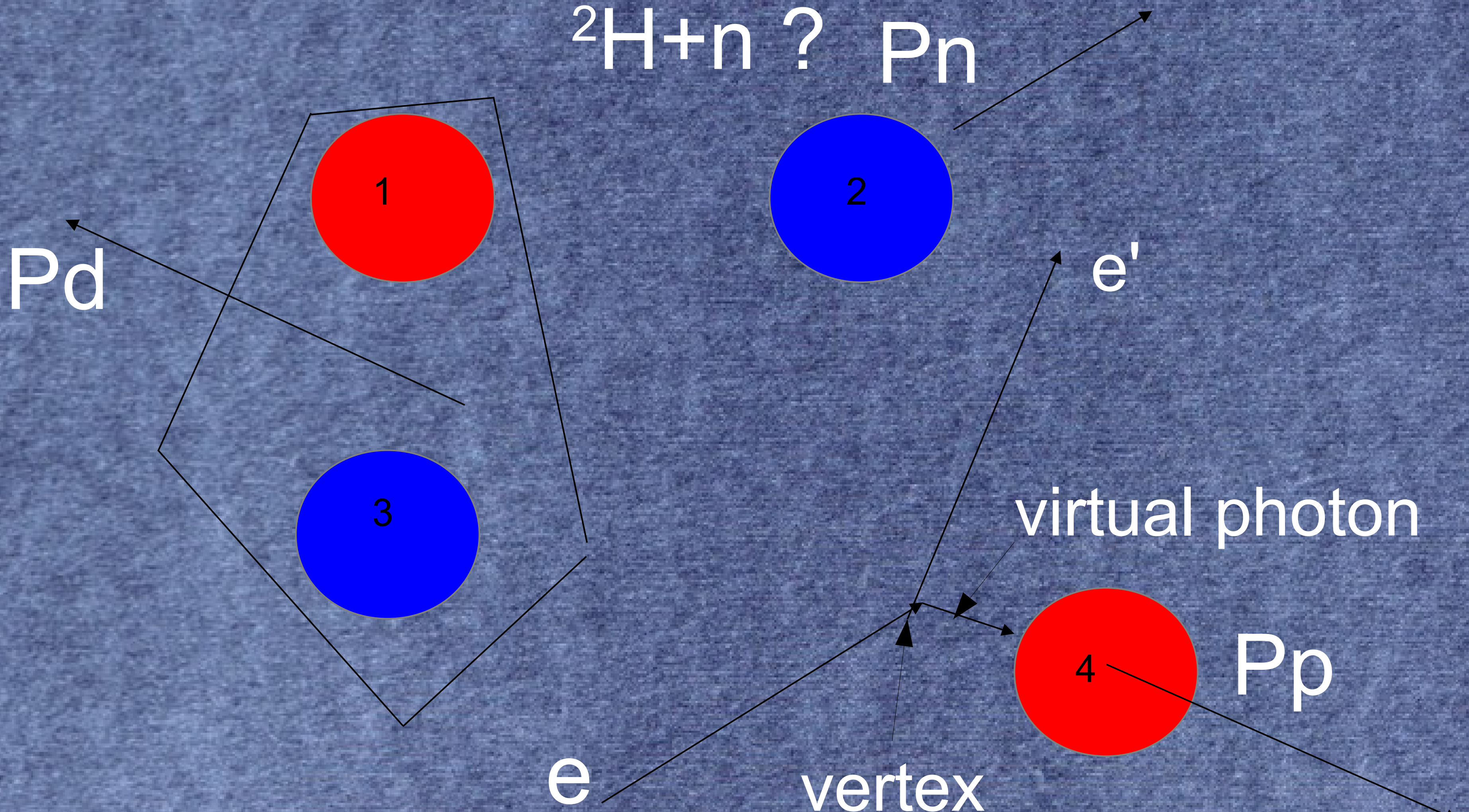

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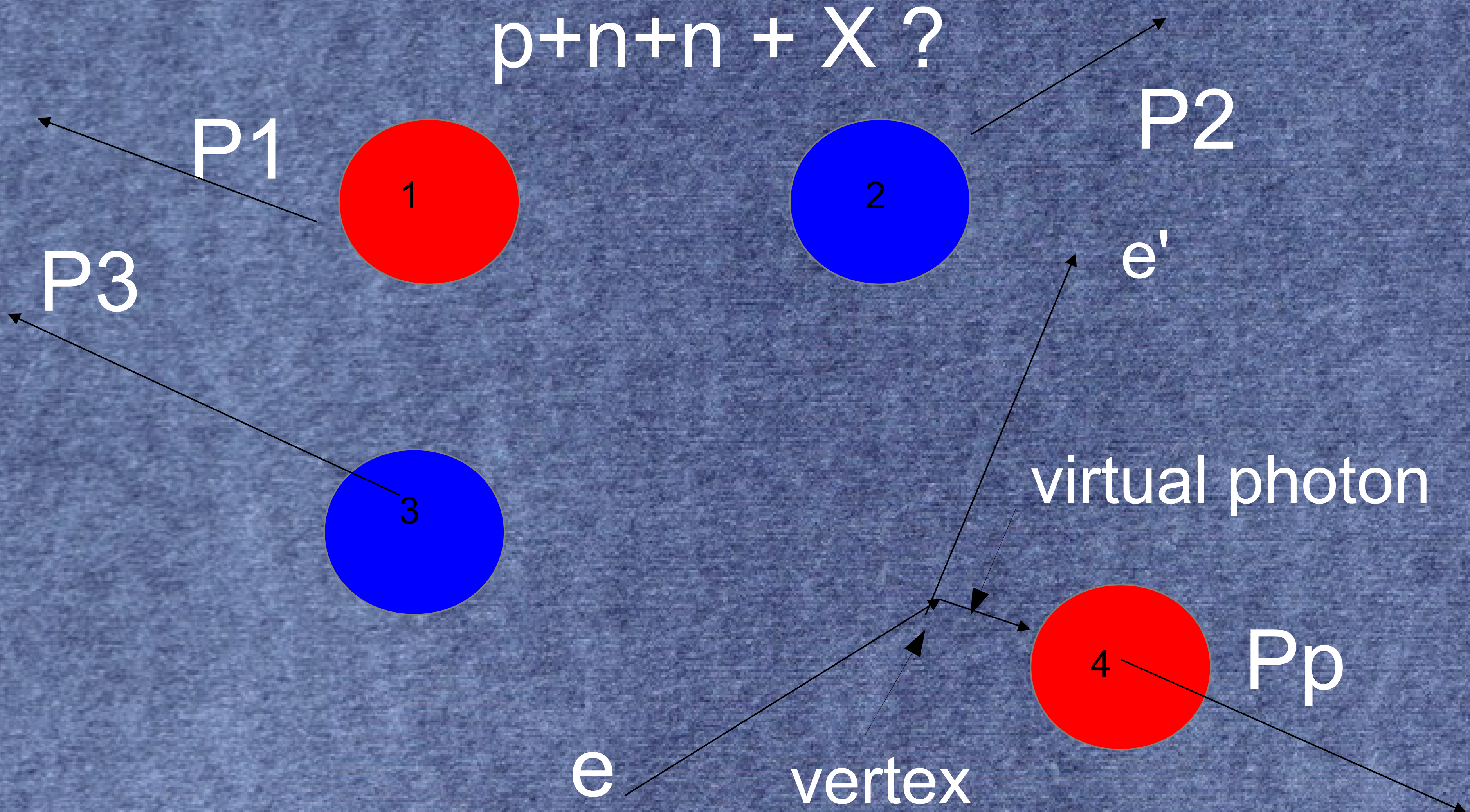
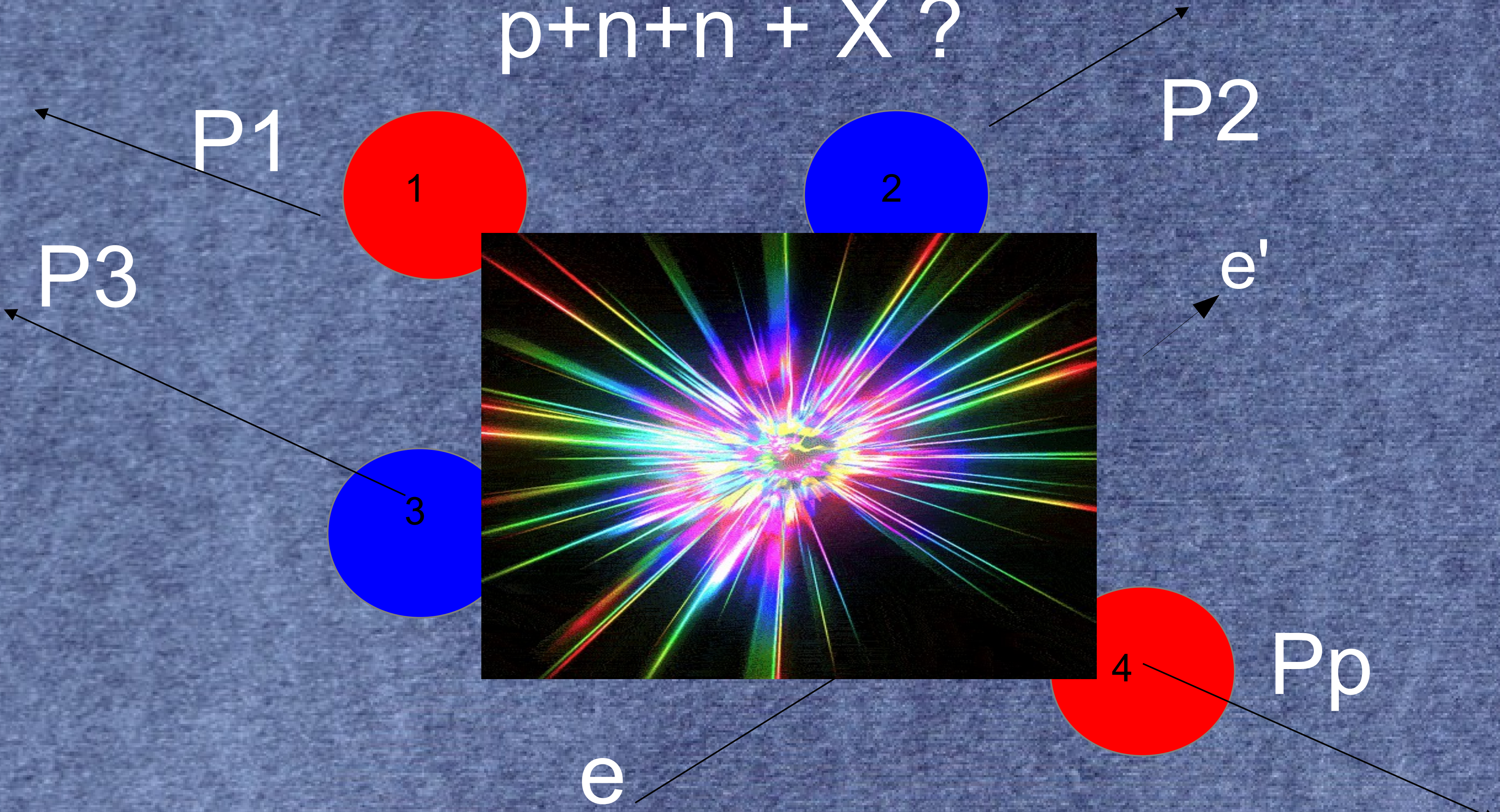


In Sophia's experiment a high energy electron knocks out a proton

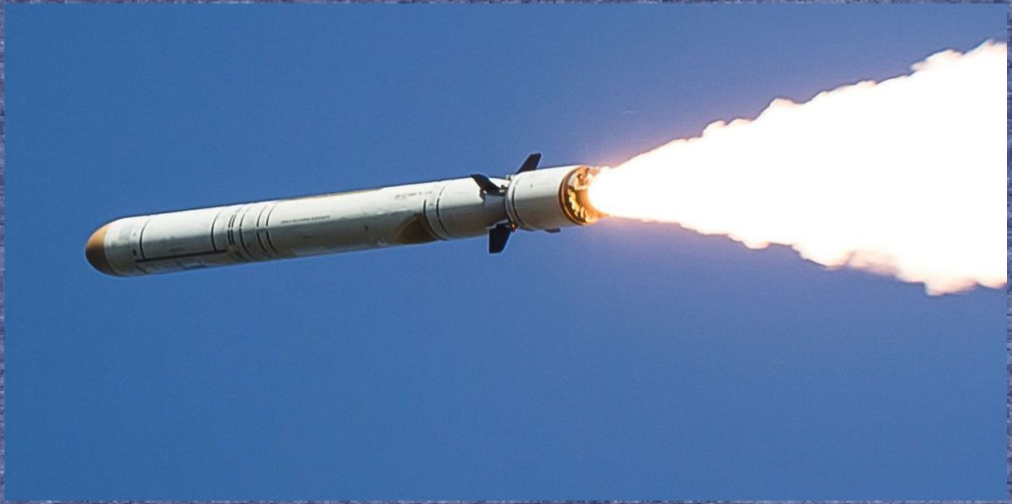
p+n+n + X ?



The virtual photon is more like a cruise missal for the ^{4}He target

How to study automobile structure

+



=

and

and debris X

How much identifiable structure would you expect to find in the debris?

Physics 101
Searching for structure in ^4He

Use conservation of energy and momentum.

Ei = mass of ^4He + energy of electron

Pi = momentum of incoming electron

Measure momentum of scattered electron, Pe'

Measure momentum of knocked out proton, Pp

Measured final state energies $E_{fe} + E_{fp}$

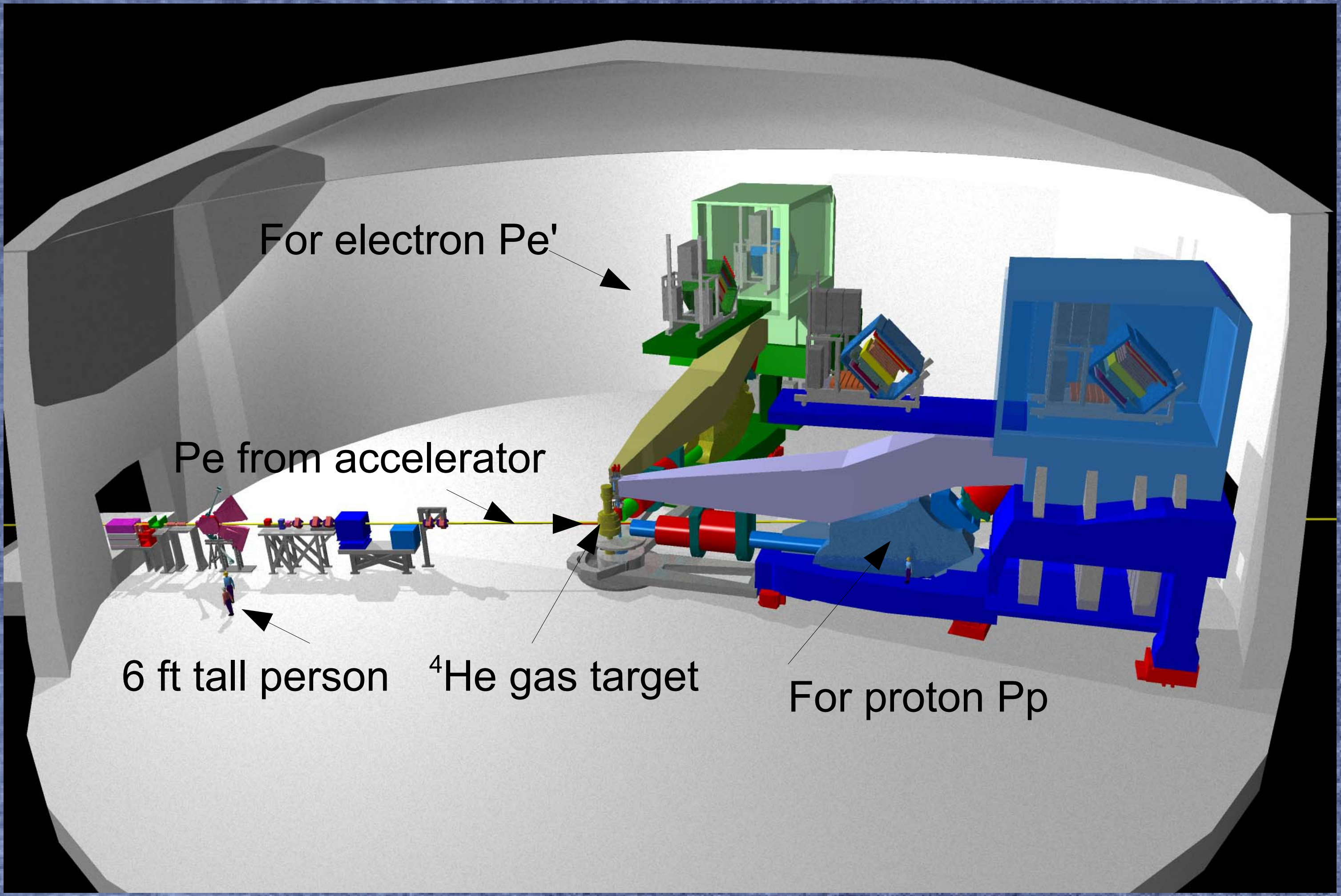
Pf = Pe' + Pp + Px, Px is the missing momentum of the debris

Emiss = Ei – $(E_{fe} + E_{fp})$,

Plot missing energy, Emiss

From the shape of Emiss plot we can identify certain final states

Hall A, High Resolution Spectrometers



Magnetic spectrometers are essential for measuring high momentum particles.

Calculated ^{4}He SRC target properties in electron beam

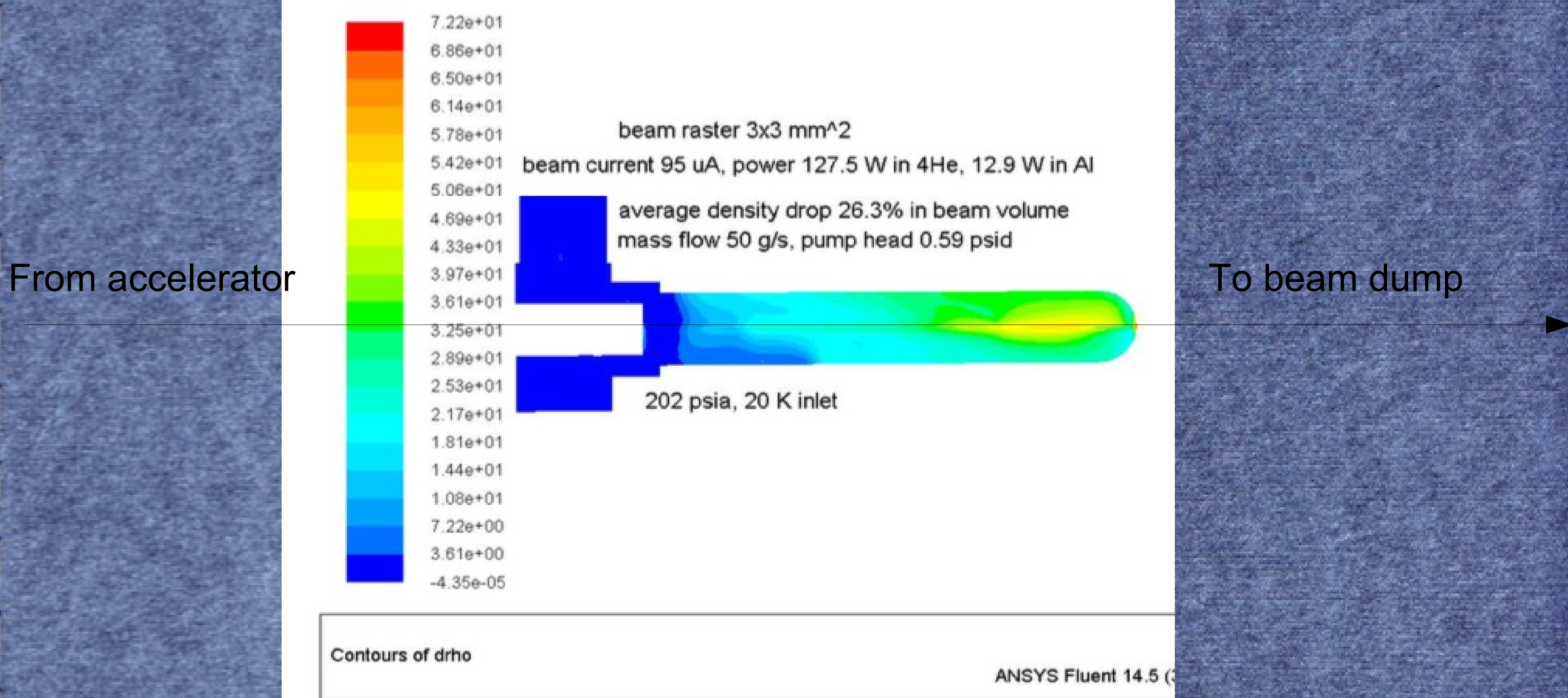


Figure 2: Example of a CFD calculation for the SRC target geometry. The beam enters from the left and the cryofluid enters and exits at the flanges at the left. There is no exit for the cryofluid at the right end of the aluminum can. Calculation and image provided by Silviu Covrig [1].

Computational Fluid Dynamics Calculation

Count rate along the 20cm long SRC target for 3 beam currents

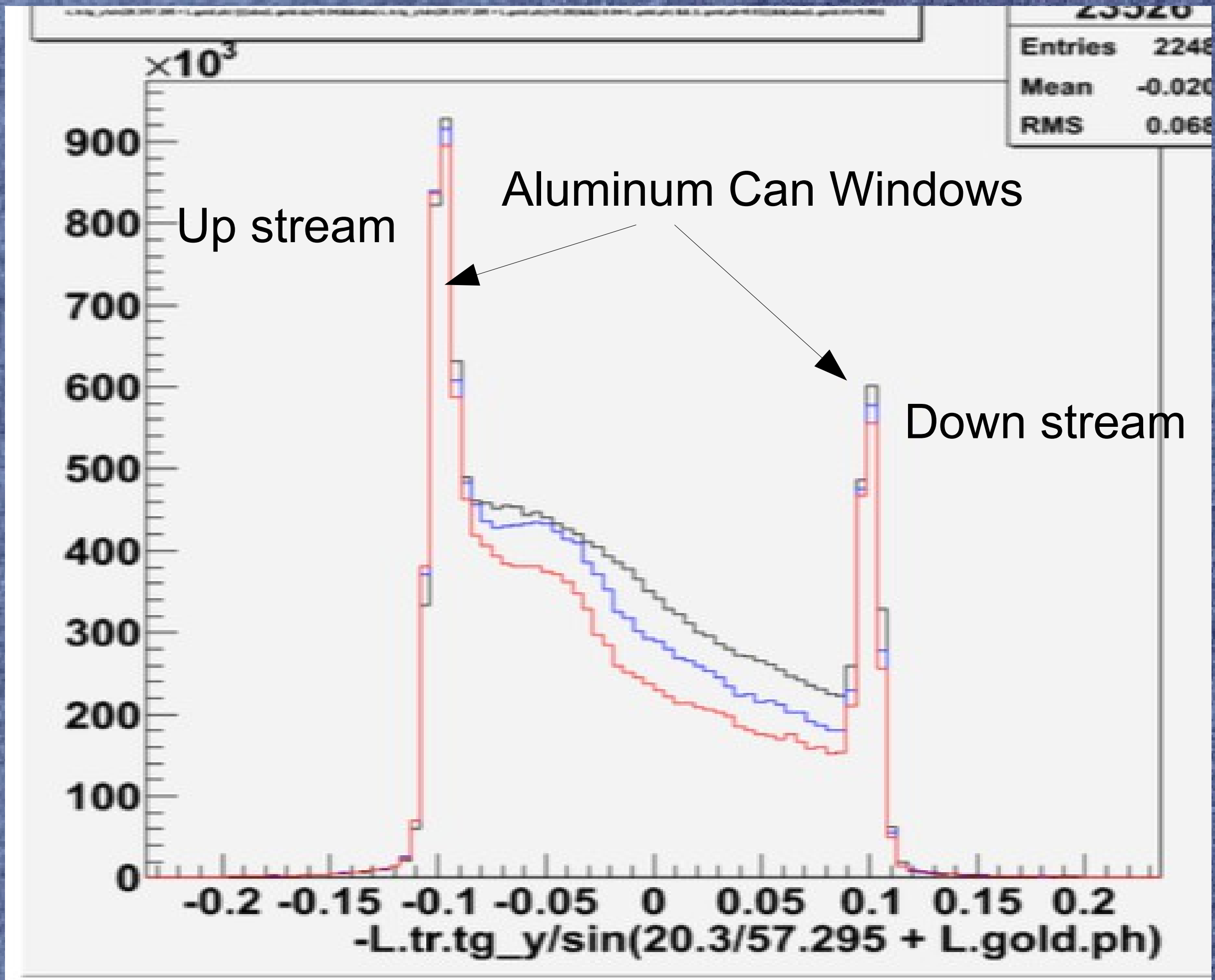


Figure 3: Normalized counts per Coulomb (vertical axis) along the beam's path for 4 different beam currents, 4μA (black), 47μA (blue), 60μA (red). The horizontal axis is along z in meters. The aluminum end caps are seen as sharp spikes at ±0.1 m.

Black curve = 4 uA
Blue curve = 47 uA
Red curve = 60 uA

20K cryogenic Cooling only at beam entrance

The count along the position in the target is affected by the local density and by the cross section which is strongly forward peaked. We need to isolate the cross section effects from the local density effect.

Comparing high current count rates to low current count rates

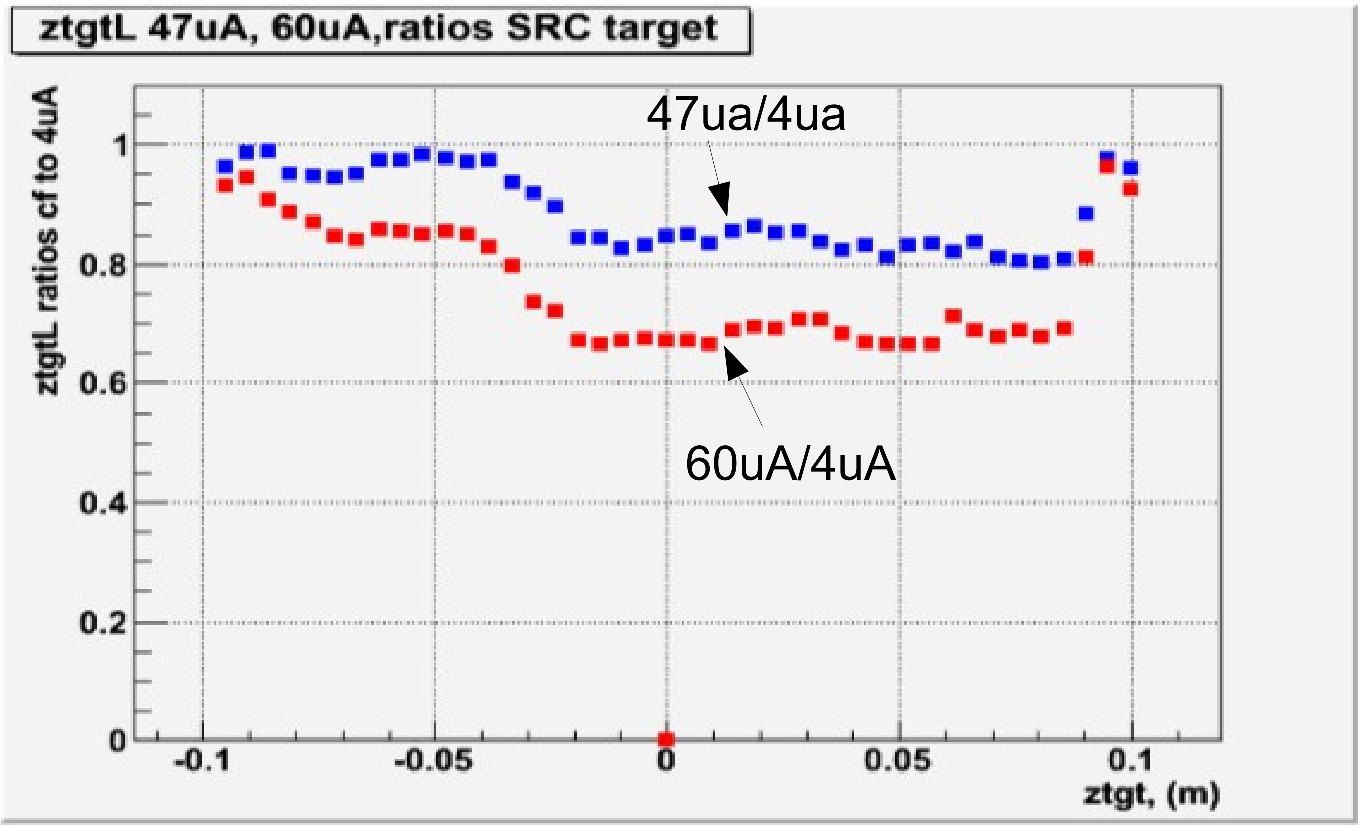


Figure 4: Ratio of normalized counts per Coulomb(vertical axis) along the beam's path for 2 different beam currents, versus z position using equation 2. The blue squares are for the ratio of $47\mu A$ rate compared to $4\mu A$. The red squares are for the ratio of $60\mu A$ rate compared to $4\mu A$.

The ratio of cnts(I)/cnts(4uA) should remove much of the cross section angular dependence.

There may still be local density effects because the hydrodynamics of the fluid may not scale linearly with beam current.

Beam current calculated fluid dynamic effects on gas density

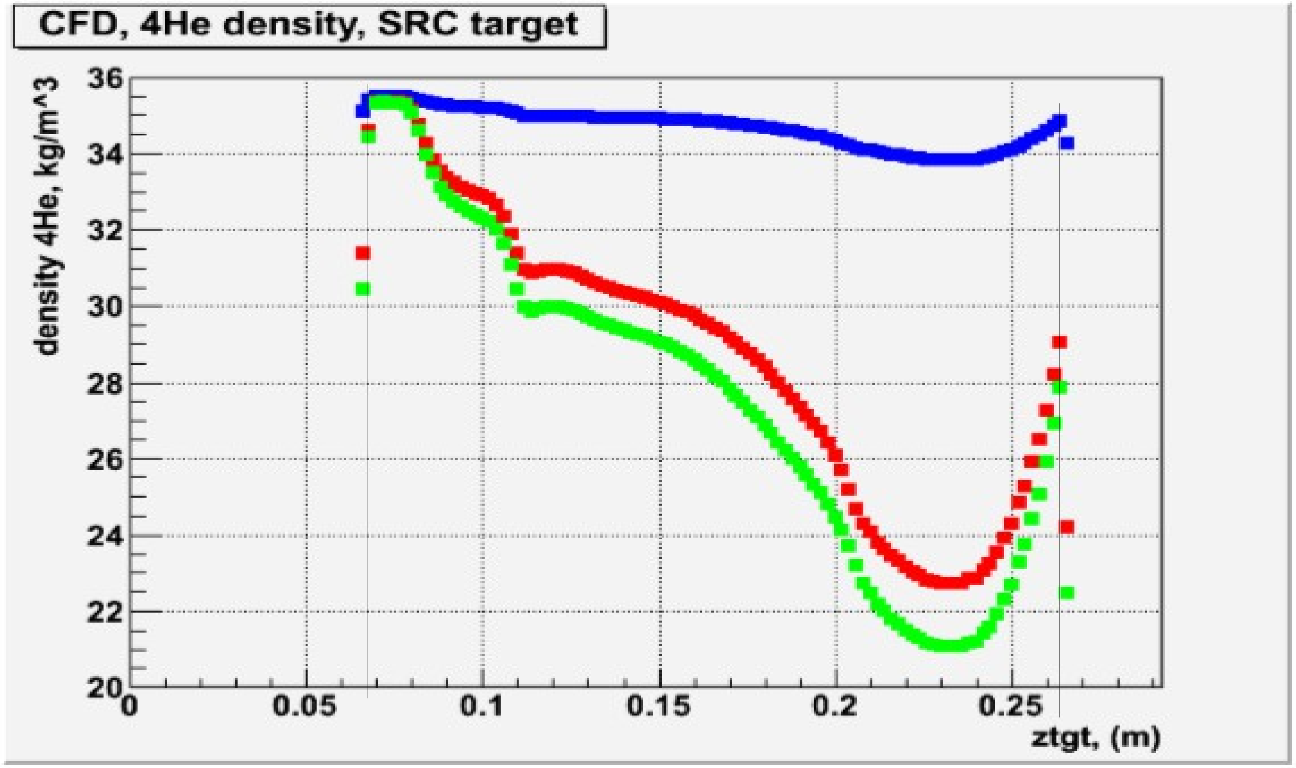
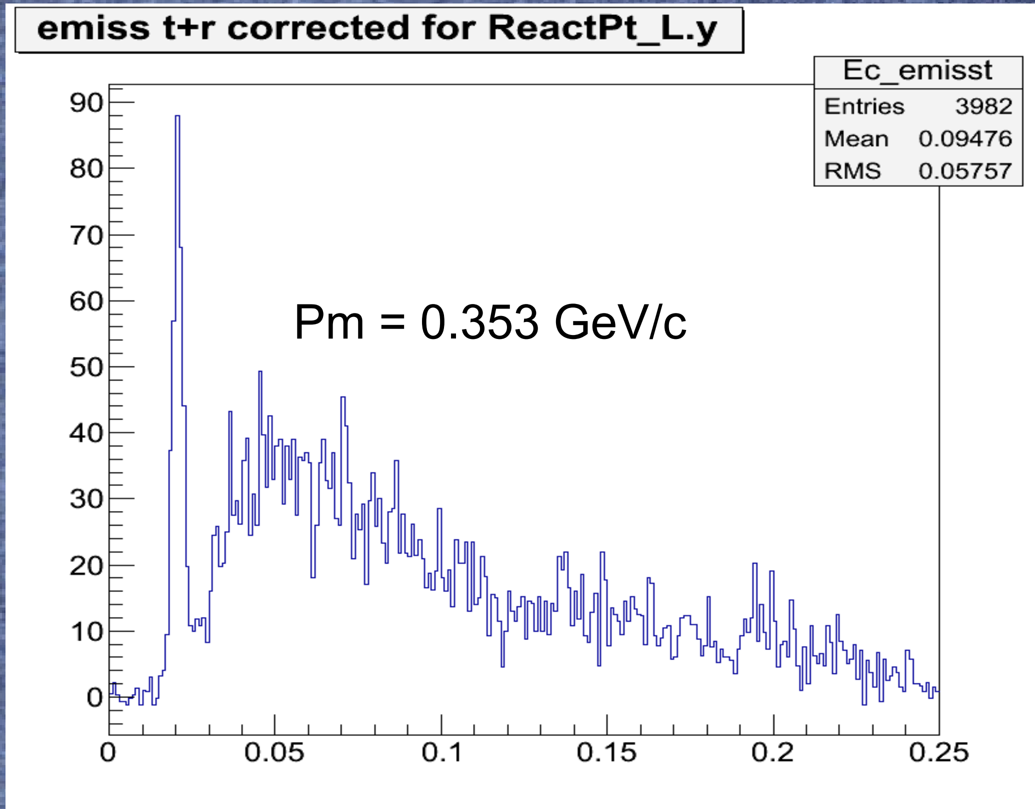
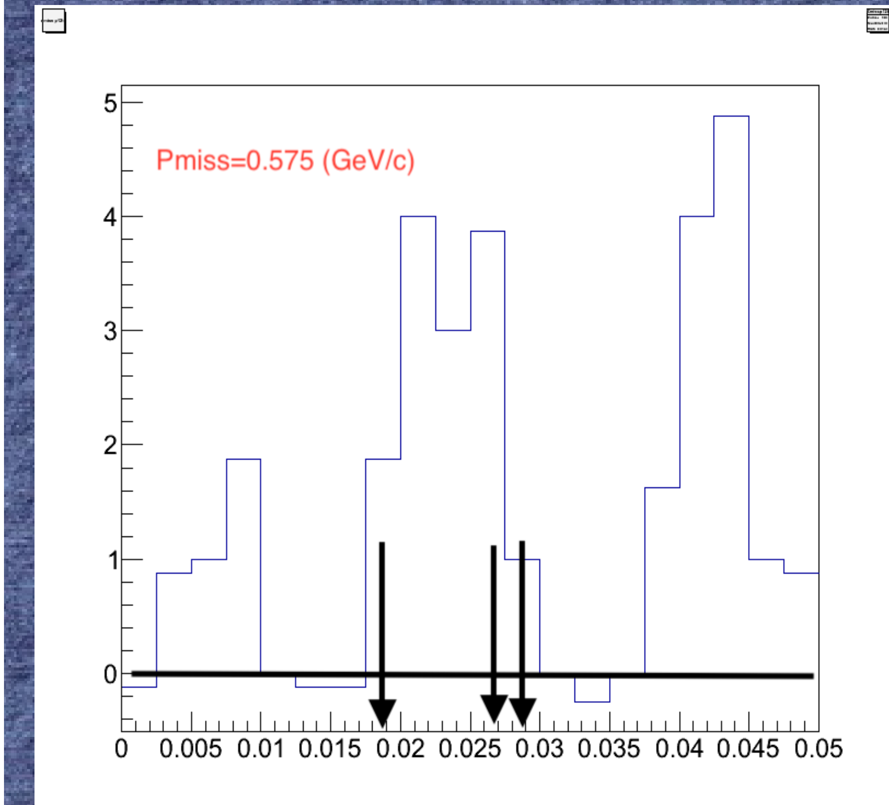


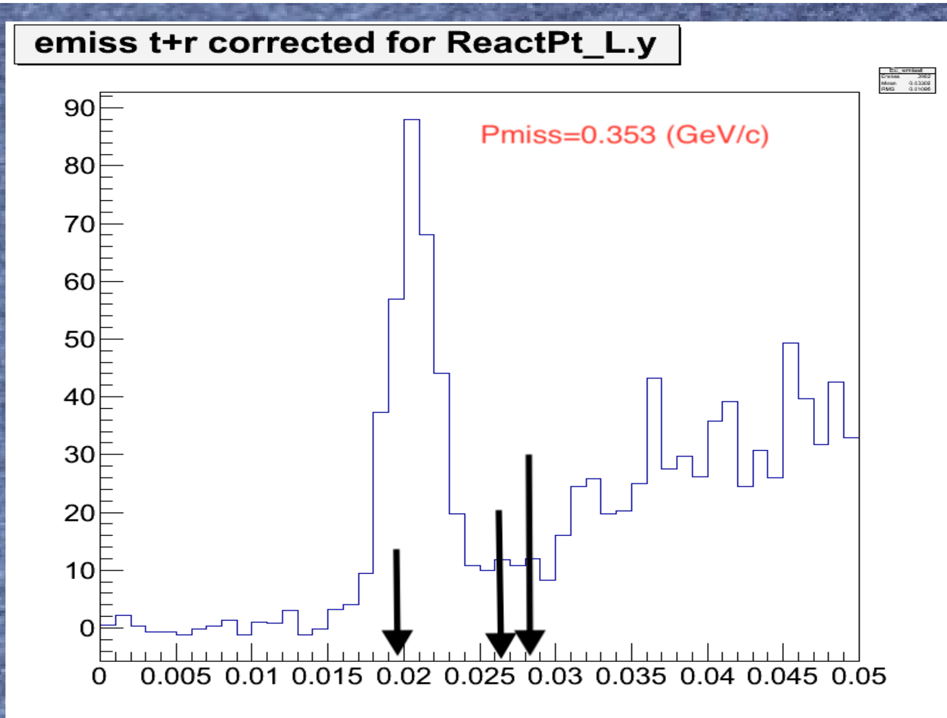
Figure 6: Prediction [1] of the changing target density along the beam path for three beam currents, $4\mu A$(blue), $47\mu A$(red), $60\mu A$(green).

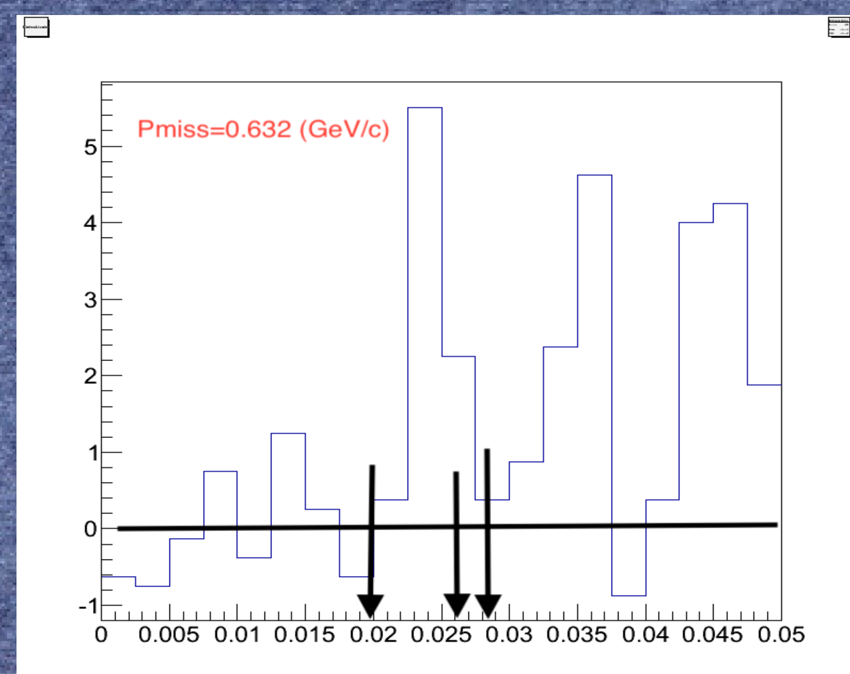
CFD calculations predict complicated density fluctuations for the SRC target.

Predicted density versus target location from Computational Fluid Dynamics

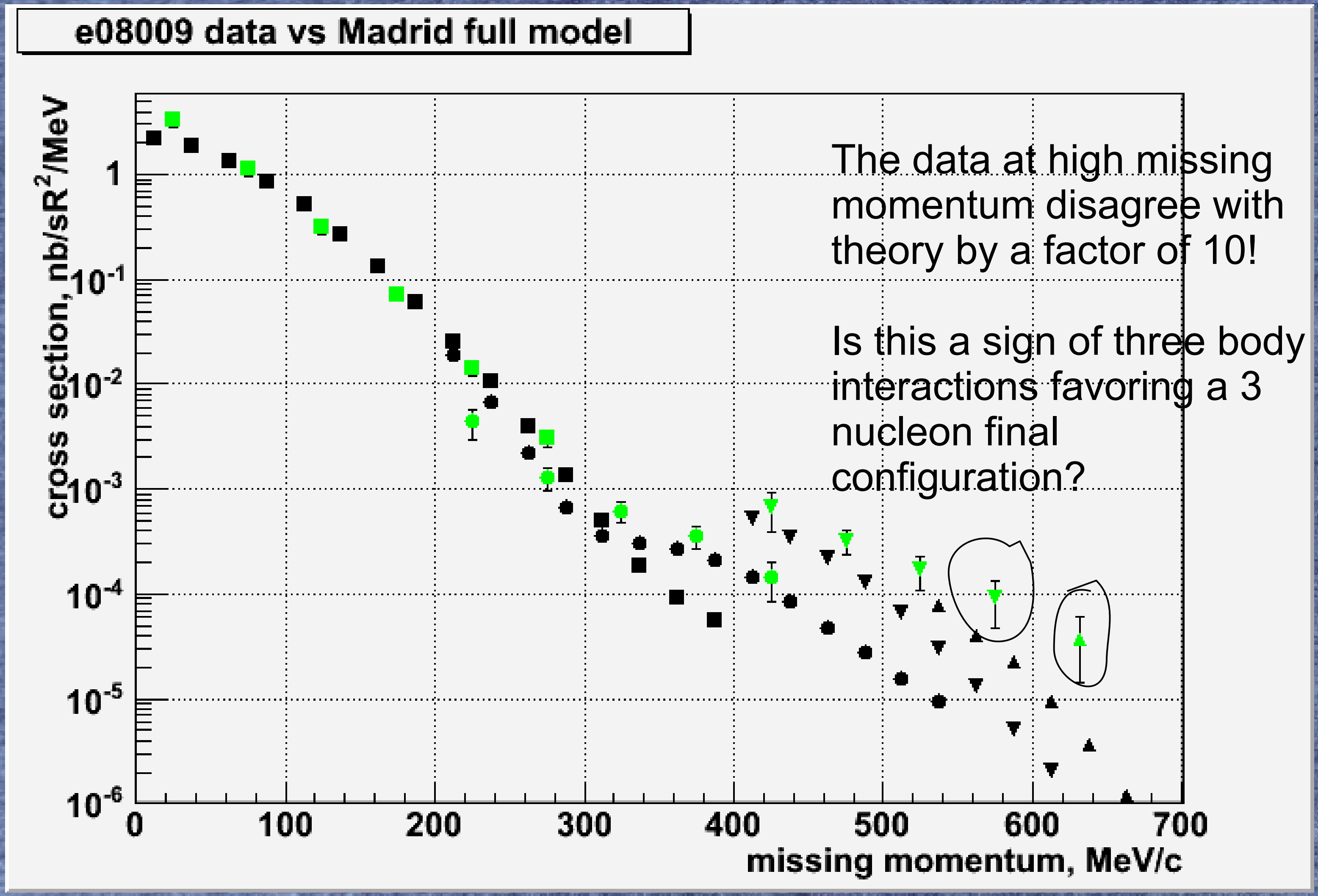

emiss t+r corrected for ReactPt_L.y
Ec_emisst
Entries 3982
Mean 0.09476
RMS 0.05757
Pm = 0.353 GeV/c
0 10 20 30 40 50 60 70 80 90
0 0.05 0.1 0.15 0.2 0.25


Pmiss=0.575 (GeV/c)
0 1 2 3 4 5
0 0.005 0.01 0.015 0.02 0.025 0.03 0.035 0.04 0.045 0.05


emiss t+r corrected for ReactPt_L.y
Pmiss=0.353 (GeV/c)
0 10 20 30 40 50 60 70 80 90
0 0.005 0.01 0.015 0.02 0.025 0.03 0.035 0.04 0.045 0.05


Pmiss=0.632 (GeV/c)
-1 0 1 2 3 4 5
0 0.005 0.01 0.015 0.02 0.025 0.03 0.035 0.04 0.045 0.05

Probability of ^{3}H+p final nuclear state



Three body forces in nuclei provide more binding than two body forces alone

2body forces

Model 3body forces based on pion exchange

PIEPER, PANDHARIPANDE, WIRINGA, AND CARLSON — PHYSICAL REVIEW C 64 014001

TABLE II. Experimental and GFMC energies (in MeV) of particle-stable or narrow-width nuclear states and of neutron drops. Monte Carlo statistical errors in the last digits are shown in parentheses. The final column gives experimental widths in keV.

	AV8′	AV18	UIX	IL1	IL2	IL3	IL4	IL5	Expt.	Γ
$^{3}H(\frac{1}{2}^{+})$	−7.76(1)	−7.61(1)	−8.46(1)	−8.43(1)	−8.43(1)	−8.41(1)	−8.44(1)	−8.41(1)	−8.48	-0.87
$^{3}He(\frac{1}{2}^{+})$	−7.02(1)	−6.87(1)	−7.71(1)	−7.68(1)	−7.67(1)	−7.66(1)	−7.69(1)	−7.66(1)	−7.72	-0.85
$^{4}He(0^{+})$	−25.14(2)	−24.07(4)	−28.33(2)	−28.38(2)	−28.37(3)	−28.24(3)	−28.35(2)	−28.23(2)	−28.30	-4.23
$^{6}He(0^{+})$	−25.20(6)	−23.9(1)	−28.1(1)	−29.4(1)	−29.4(1)	−29.3(2)	−29.3(1)	−29.5(1)	−29.27	-5.37

The need for 3body interactions in ground state and excited nuclear states is well established. A wide range of models can fit these binding energies. The Iqbal experiment suggests another experimental observable is available for 3NN interactions.

We propose that a serious investigation of the shape of the Emiss spectrum in the 3 body region from proton knockout in ^{4}He may constrain the range of possible 3NN interaction models.

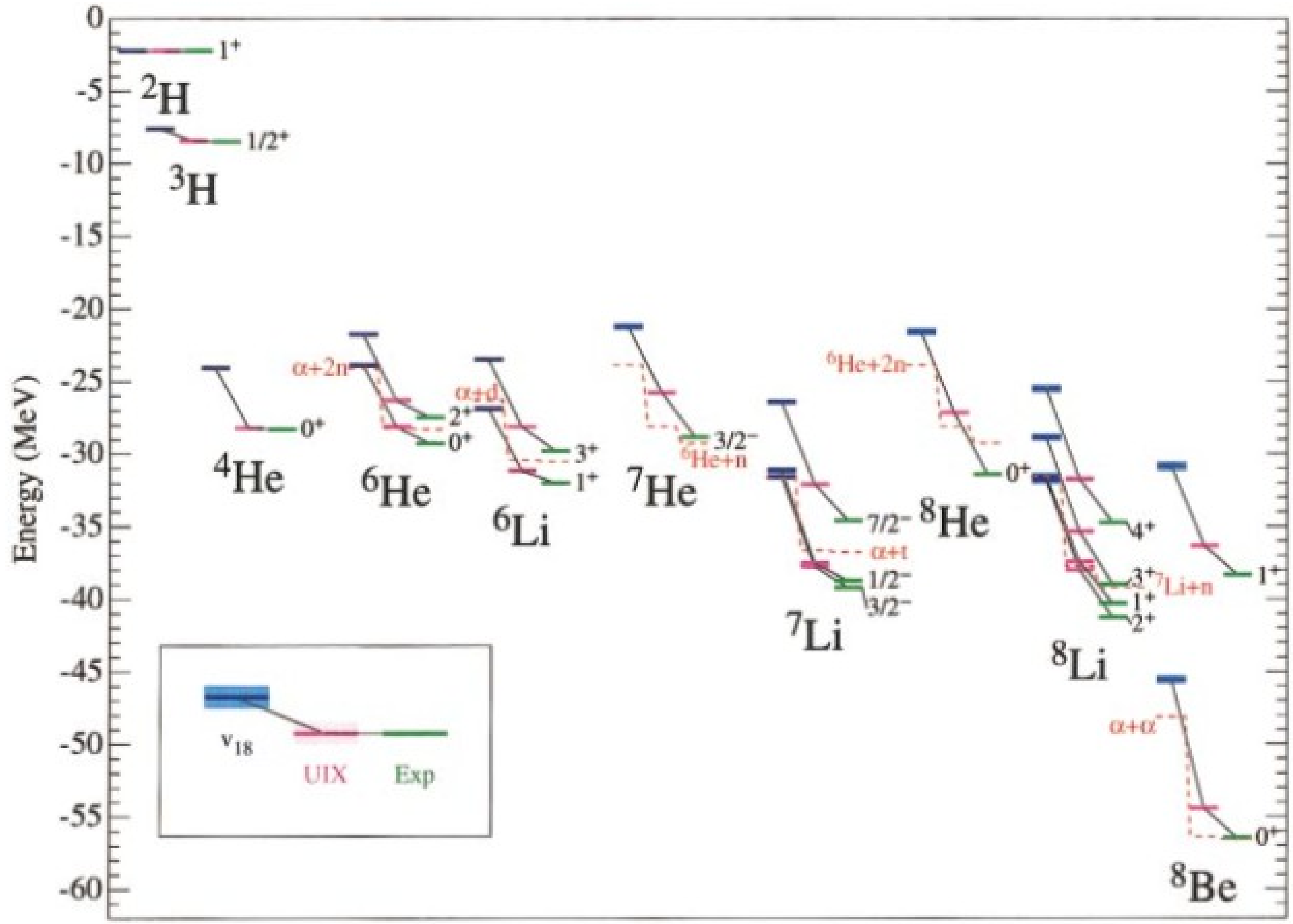
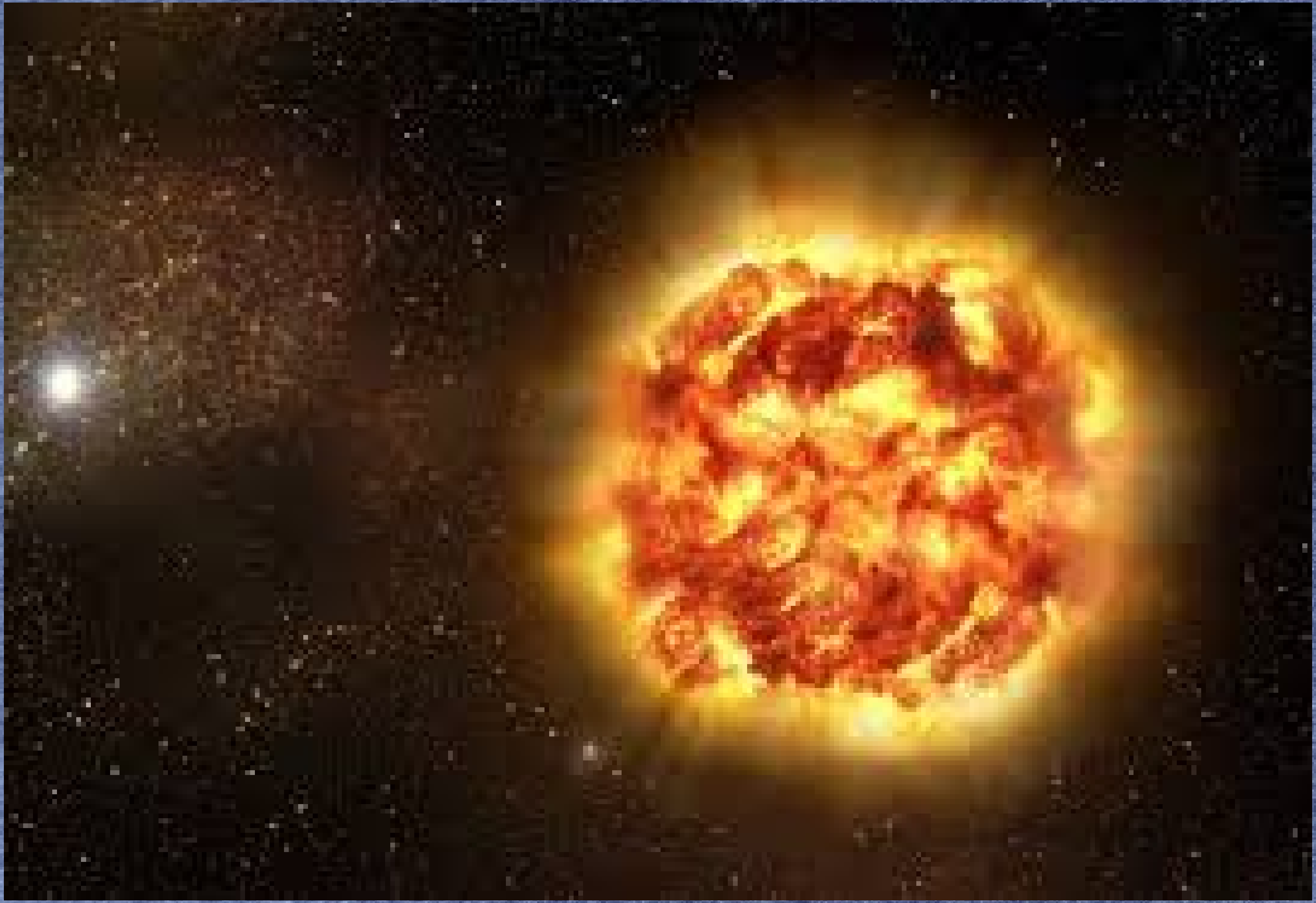


FIG. 1. (Color) Energies of ground or low-lying excited states of light nuclei computed with the AV18 and AV18/UIX interactions, compared to experiment. The light shading shows the Monte Carlo statistical errors. The dashed lines indicate the thresholds against breakup for each model or experiment.

After many decades studying various P+P and N+P reactions it is well established that 2body interactions are insufficient to calculate nuclear structure.

Stars produce the elements

That's why we want to know if three's a crowd.



Nucleosynthesis of the elements depends on how neutrons and protons interact

Unstable nuclei are important ingredients in nucleosynthesis.