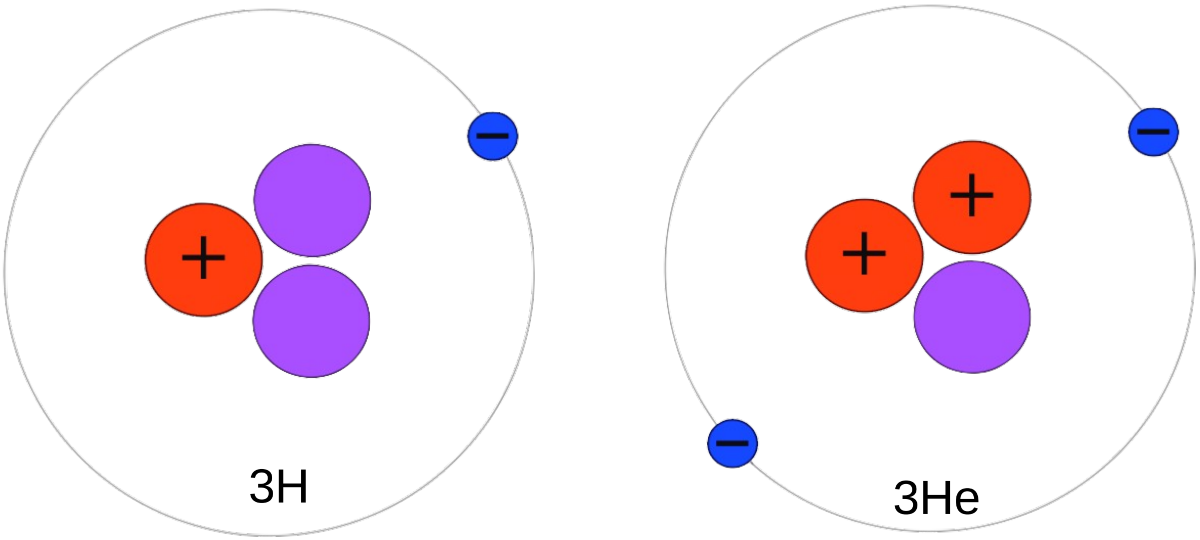
JLab Tritium Target Physics Program Overview

Using A=3 Mirror Nuclei to Probe the Nucleon Structure



Buddhini Waidyawansa
(Argonne National Lab)

22nd International Spin Symposium
September 27th, 2016

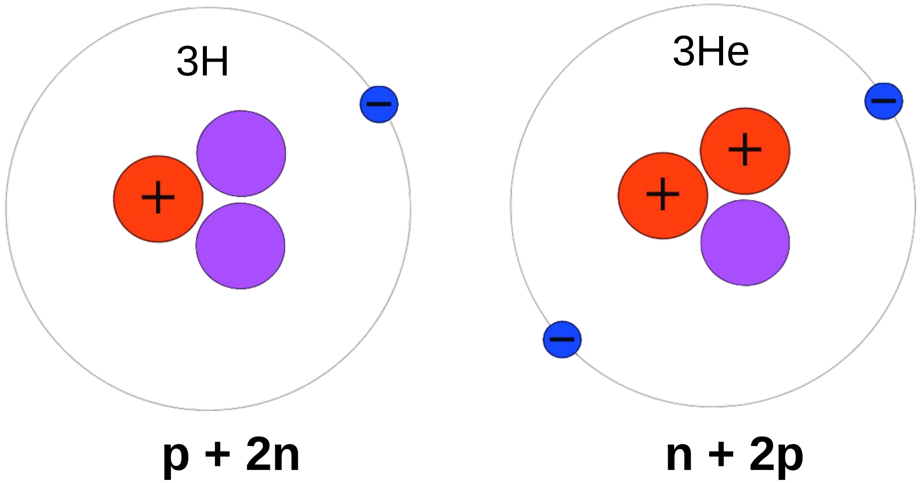
Argonne NATIONAL LABORATORY

Jefferson Lab EXPLORING THE NATURE OF MATTER

Why Mirror Nuclei?

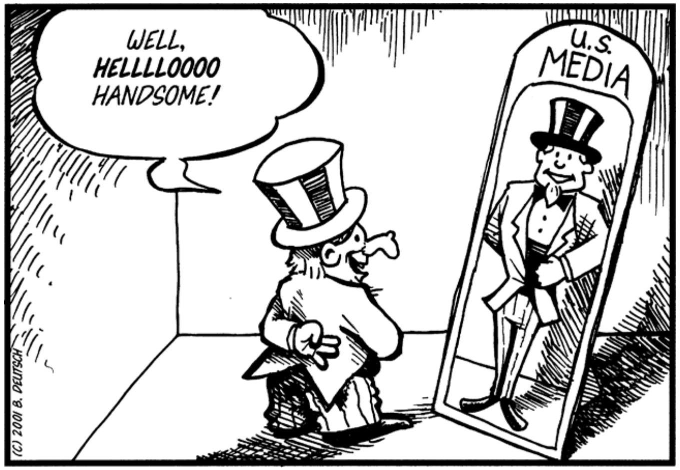
In the absence of Coulomb interactions between the protons, a perfectly charge-symmetric and charge-independent nuclear force would result in the binding energies of all the mirror nuclei being identical

- They are structurally identical.
  - Studying differences in their properties reveals information about protons and neutrons structure



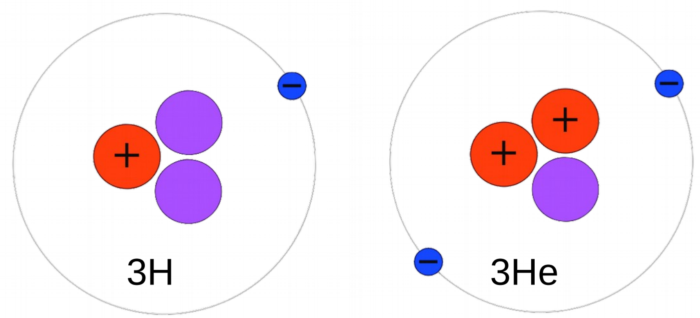
Why A=3 Mirror Nuclei?

- **Lightest and the simplest mirror system**
  - **Proton in 3H = Neutron in 3He**
- **Differences in the nuclear effects are small**
  - Binding energy
  - EMC effect
- **Nuclear effects cancel in the cross-section ratios**
  - FSI contributions
  - Radiative effects
    - **Cleaner measurements**



THE TRICK IS FINDING THE RIGHT MIRROR

What we plan to measure @ JLab



Reaction	Cmpare 3He vs 3H	Measure	Jlab Experiment
DIS e scattering	n+2H vs p+2H	F2n/F2p and d/u EMC effect in A=3	MARATHON
QE e scattering	(p+2n) – (2p+n) vs 2(pn)+(nn) - 2(pn)+(pp)	n(k) of protons and neutrons	(e,e'p)
		Isospin structure of 2N-SRC	SRC @ x>1
Elastic e scattering	r^2_n vs r^2_p	Difference in charge radii Form factors	Elastic

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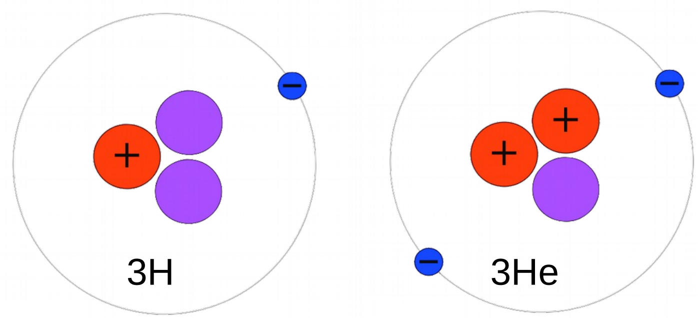

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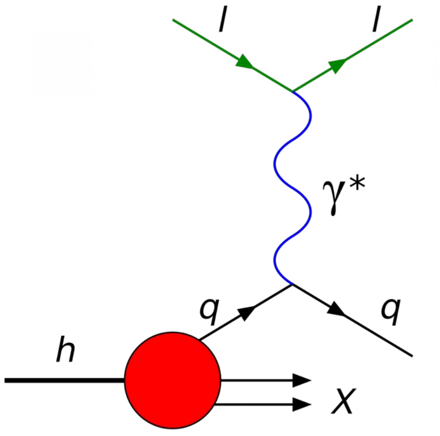
F2n/F2p, d/u Ratios for x→ 1

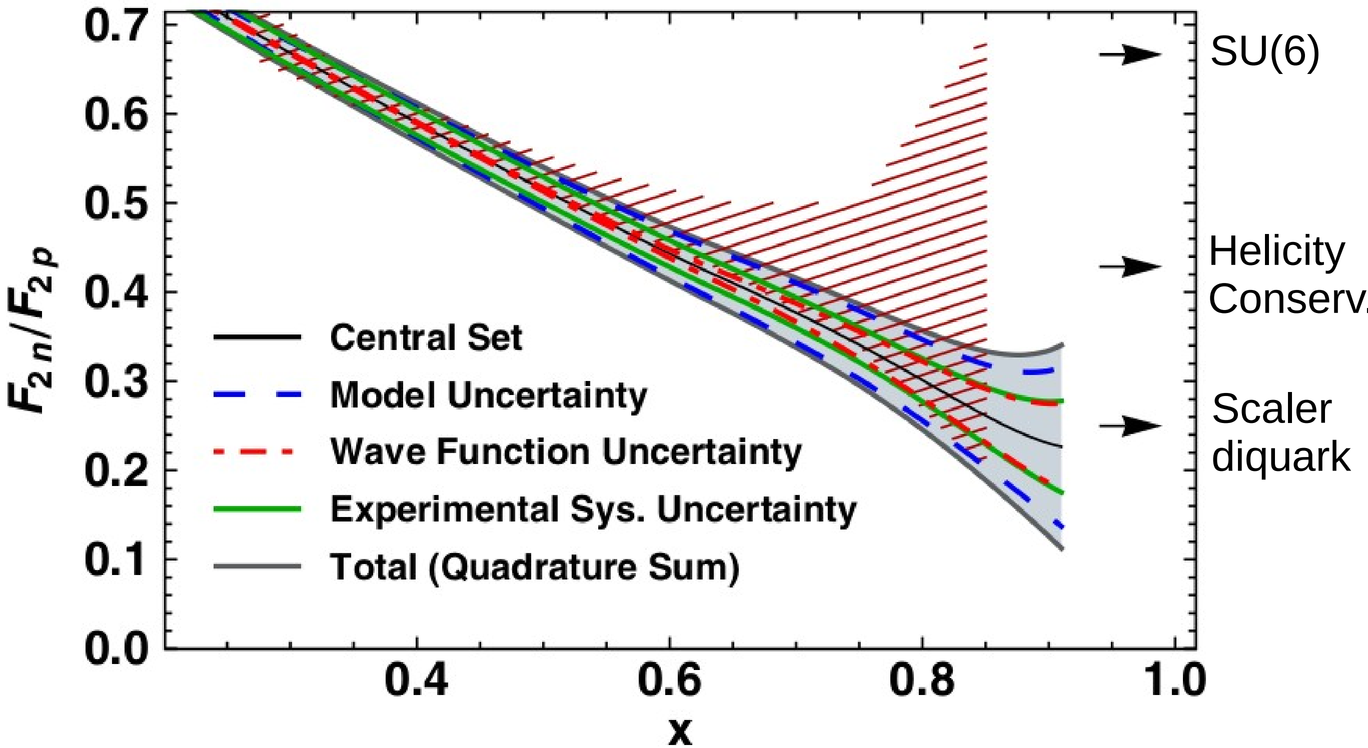
Historically extracted using DIS from proton and deuteron targets

$$\sigma \propto F_2(x, Q^2) \xrightarrow{\text{Parton Model}} F_2(x) = x \sum e_i^2 (q_i(x) + \bar{q}_i(x))$$



$$\frac{F_2^n}{F_2^p} = \frac{1 + 4(d/u)}{4 + (d/u)}$$

Arrington et al. PRL 108, 252001 (2012)



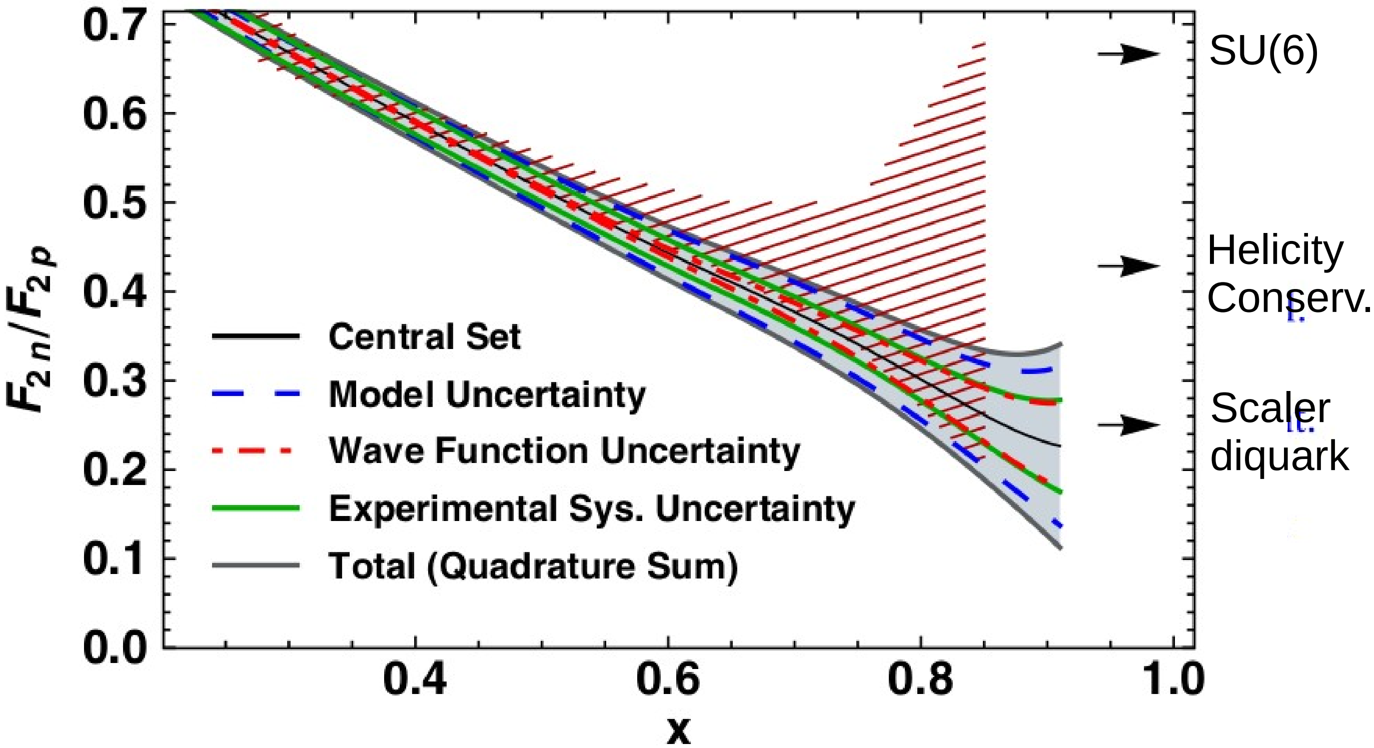
Buddhini Waidayawansa

F2n/F2p, d/u Ratios for x→ 1

Current status

Extraction of F2n / F2p at high x is sensitive to the poorly known high-momentum components of the deuteron wave function

Arrington et al. PRL 108, 252001 (2012)



At Jlab we plan to reduce the error on the ratios as x → 1 using A=3 mirror nuclei

Measurement of deep inelastic ratios from 3H an 3He nuclei (MARATHON)

spokespersons: G. Petratos, R. Holt R. Ransome, J. Gomez

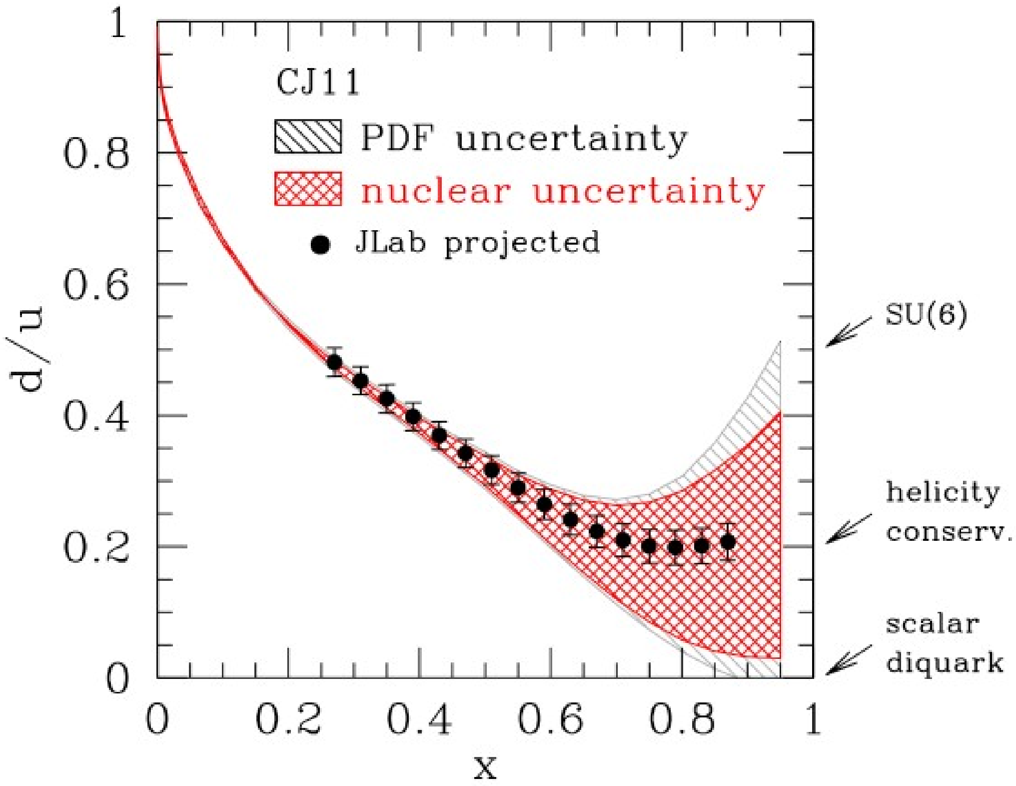
- 11 GeV, DIS from 3H, 3He and 2H
- Construct EMC cross-section ratios

$$R(^3\mathrm{H}) = \frac{F_2^{^3\mathrm{H}}}{F_2^p + 2F_2^n} \quad R(^3\mathrm{He}) = \frac{F_2^{^3\mathrm{He}}}{2F_2^p + F_2^n}$$

- Extract
  - F2n/F2p and d/u ratios
- Mirror symmetry makes ratios independent of nuclear effects

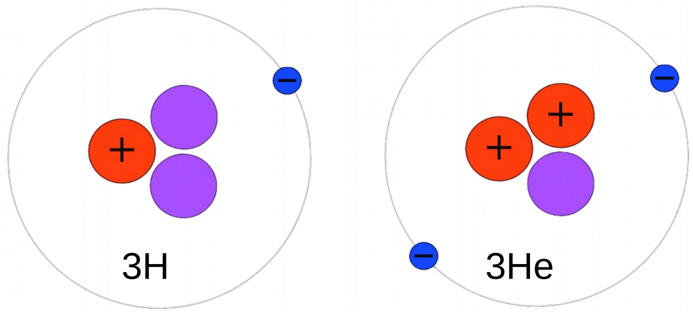
$$\frac{F_2^n}{F_2^p} = \frac{2\mathcal{R} - F_2^{^3He}/F_2^{^3H}}{2F_2^{^3He}/F_2^{^3H} - \mathcal{R}}$$

Projected Results



Precise extraction of F2n/F2p, d/u ratio independent of nuclear effects

What we plan to measure @ JLab



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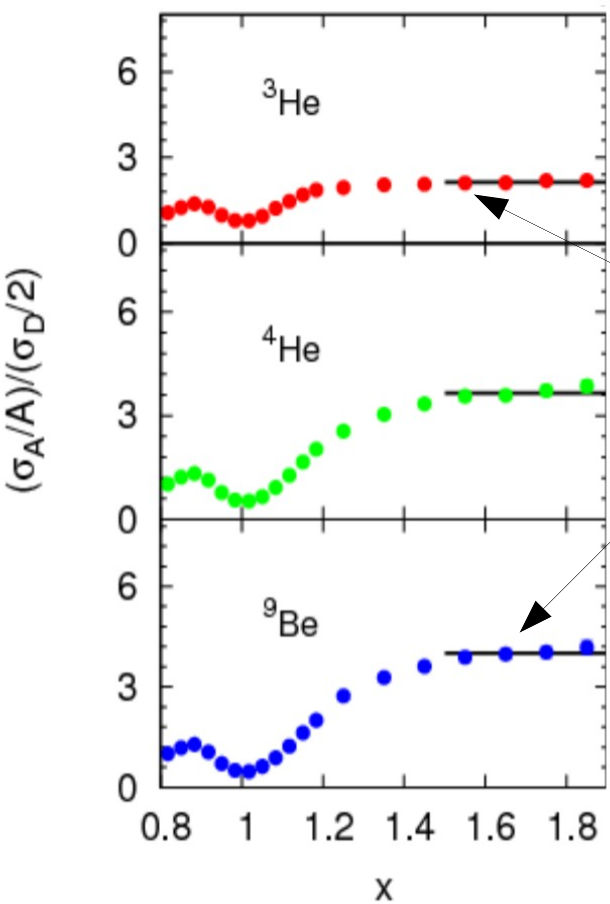
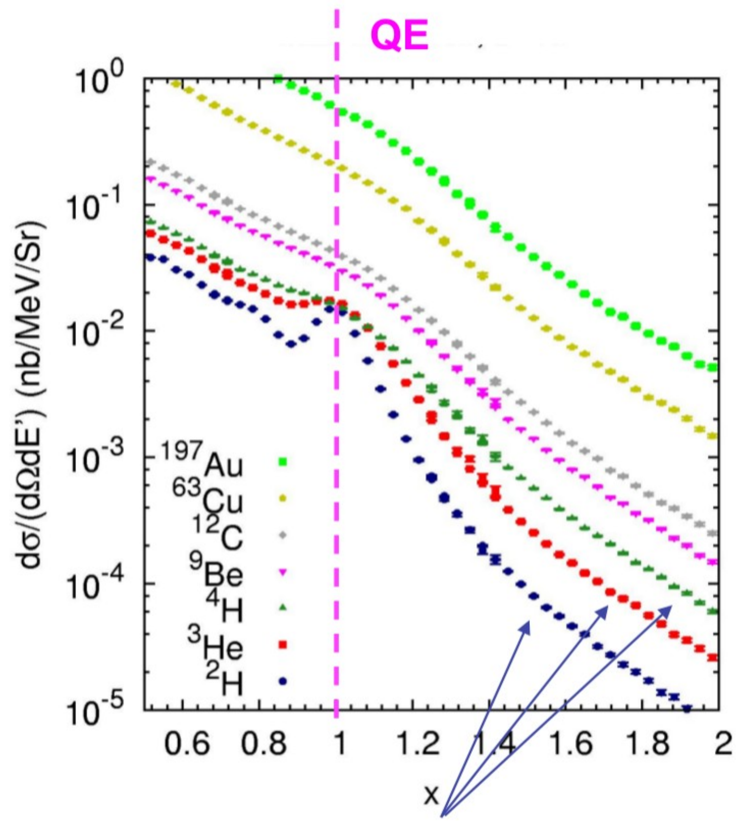
2N-Short Range Correlations

First evidence of 2N-SRC at x>1.5 seen at SLAC (PRC48, 2451 (1993)) and confirmed at JLab



Q2 independent plateau above x ~ 1.4

N. Fomin, et al., PRL 108 (2012) 092052

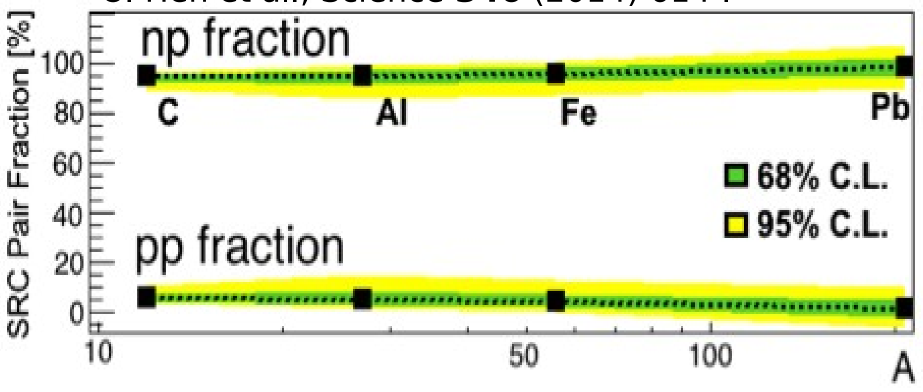


High momentum tails will result in a constant ratio if dominated by SRC

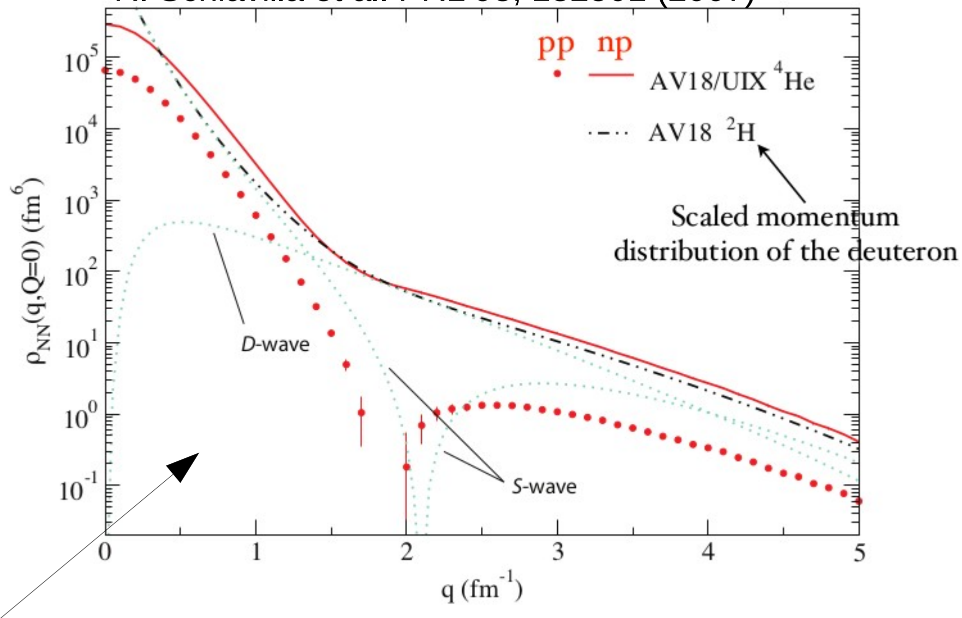
Isospin dependence of 2N-SRC

Simple SRC model assumes isospin independence

O. Hen et al., Science **346** (2014) 614 .



R. Schiavilla et al. PRL 98, 132501 (2007)



Data show large asymmetry between np, pp pairs:

Qualitative agreement with calculations; effect of tensor force. Huge violation of often assumed isospin symmetry

At Jlab we will use A=3 mirror nuclei to extract the isospin structure of 2N-SRC with low contribution of FSI

Isospin dependance of 2N-SRC

spokespersons: P. Solvignon, J. Arrington, D. Day, D. Higinbotham

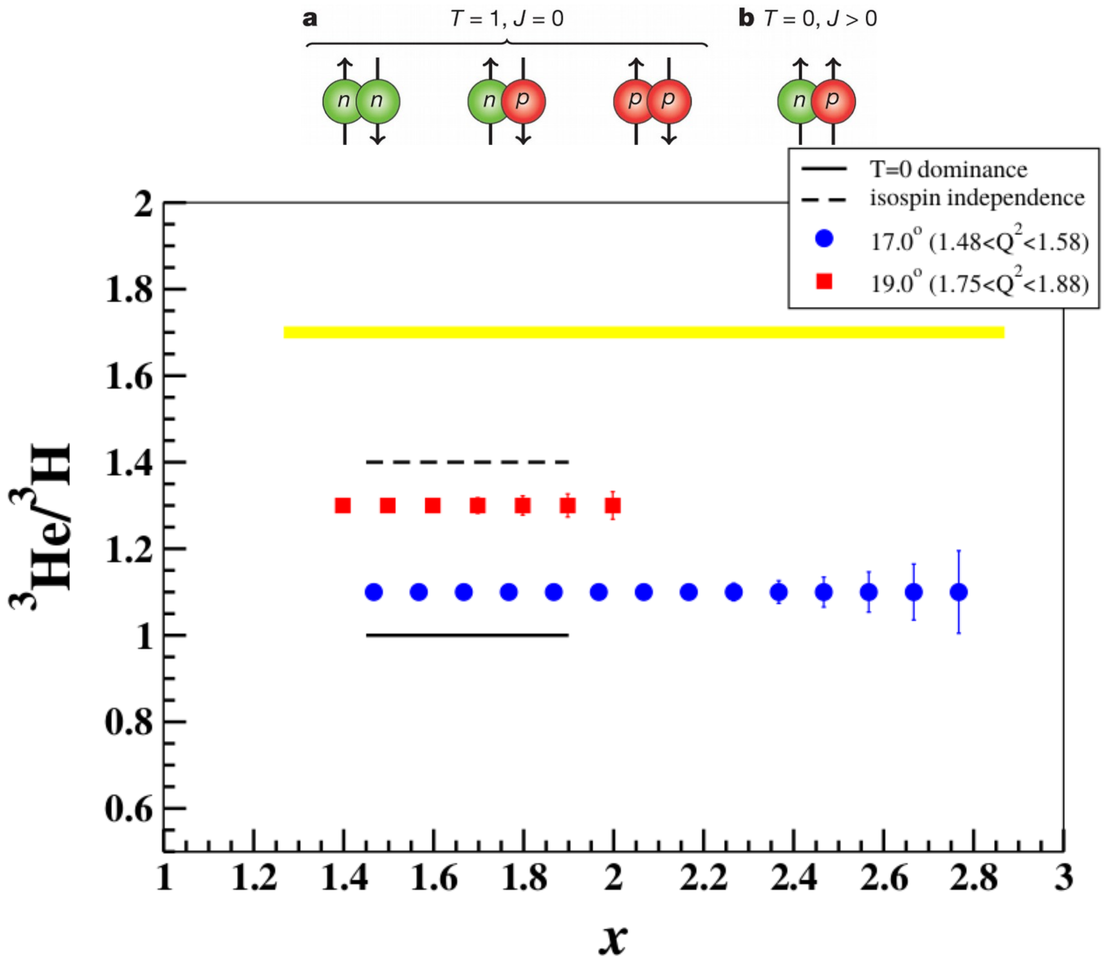
- Measure inclusive QE scattering from 3H and 3He
- Extract 2N-SRC ratios asuming

Isospin independent

$$\frac{\sigma_{^3He}/3}{\sigma_{^3H}/3} = \frac{(2\sigma_p + 1\sigma_n)/3}{(1\sigma_p + 2\sigma_n)/3} \xrightarrow{\sigma_p \approx 3\sigma_n} 1.40$$

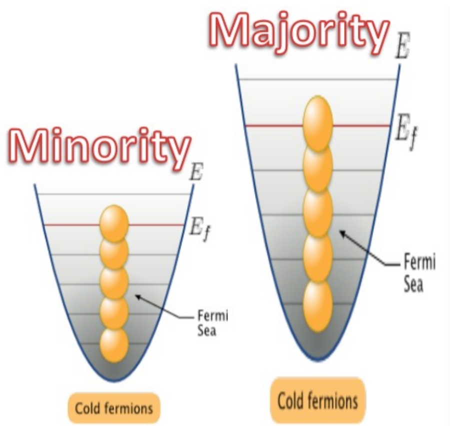
Full n-p dominance (T=0)

$$\frac{\sigma_{^3H}/3}{\sigma_{^3He}/3} = \frac{(2\,pn + \cancel{1\,nn})/3}{(2\,pn + \cancel{1\,pp})/3} = 1.0$$



Precision measurement of the isospin dependance in the 2N-SRC region (x>1)

Kinetic Energy Sharing of n and p in Asymmetric Nuclei



Non-interacting two-component Fermi system:

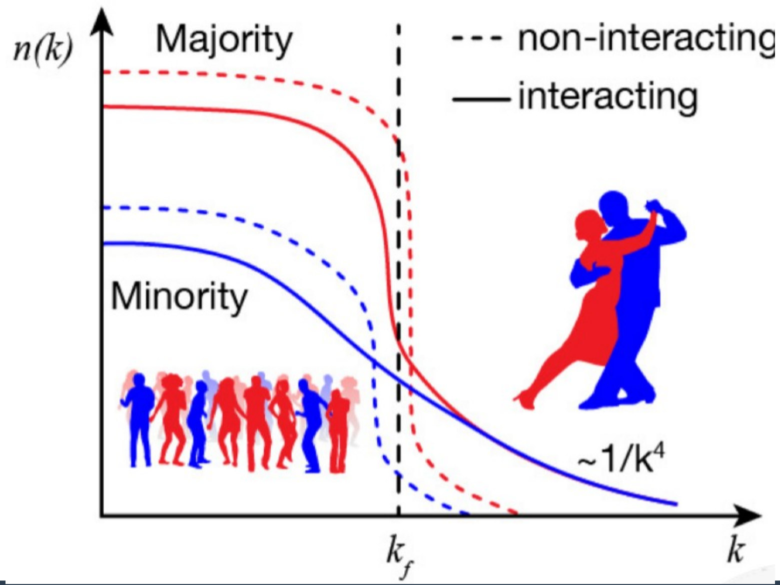
- **Pauli Principle :**
  - MAJORITY fermions move FASTER (higher Fermi momentum)

- **n-p correlations:**
  - MINORITY move FASTER (greater paring probability)

Which process dominates?

We plan to find out @ Jlab

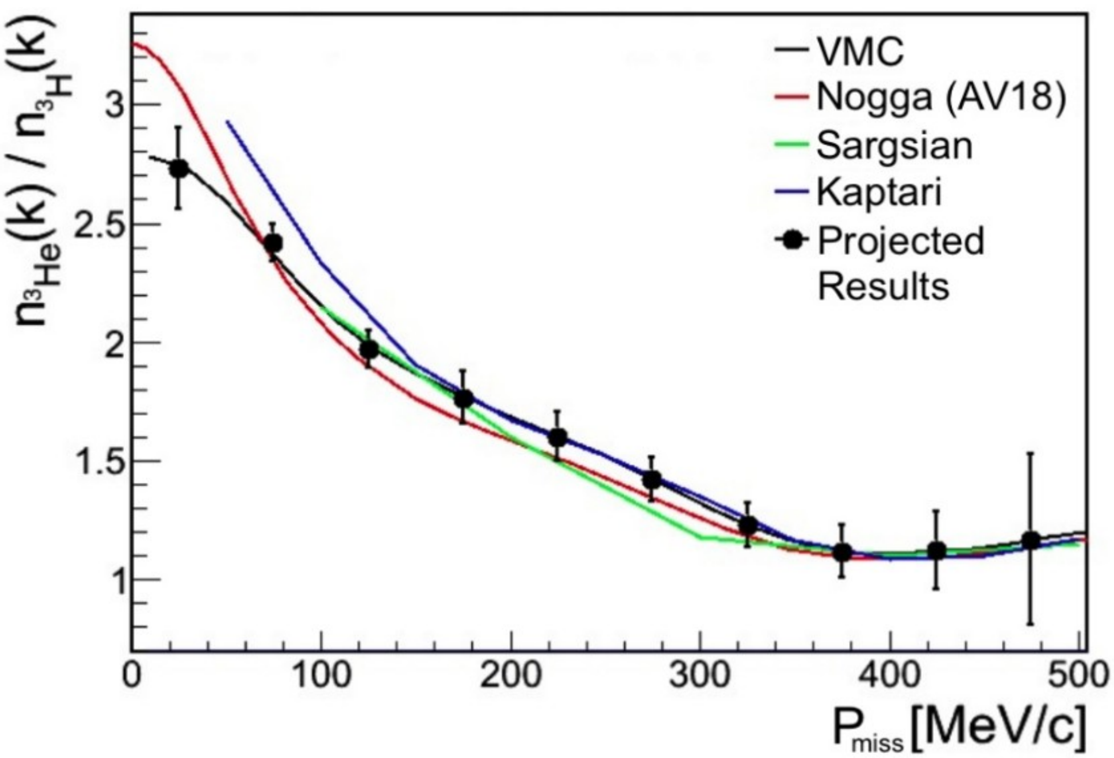
O. Hen et al., Science **346** (2014) 614 .



Proton and Neutron Momentum Distributions in 3H and 3He

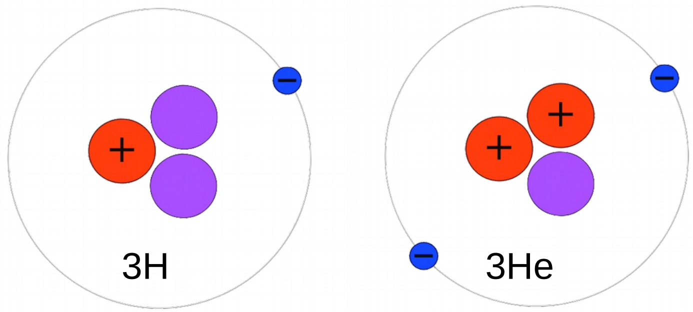
spokespersons: O. Hen, L. Weinstein, S. Gilad, W.Boeglin

- Measure the quasi elastic (e,e'p) reaction on 3H and 3He
  - First measurement of 3H(e,e'p)
  - First measurement of 3He(e,e'p) with minimized effects from FSI
- Measure cross-section sensitive to ground state momentum distributions
- Will show kinetic energy of minority (p in 3H) > kinetic energy of majority (p in 3He)



First high precision model independent extraction of nuclear momentum distribution ratio

What we plan to measure @ JLab



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Charge Radii of 3H and 3He

spokespersons: J. Arringtone, L. Myers, D. Higinbotham

- Measure elastic scattering cross-section ratio of 3H to 3He
  - Extract the relative charge radius
- One time opportunity for 3H at JLab

	$<r^2_{rms}>_{3H}$ (fm)	$<r^2_{rms}>_{3He}$ (fm)	ΔR_{rms} (fm)
GFMC	1.77(1)	1.97(1)	0.20 (1)
χEFT	1.756(6)	1.962(4)	0.21 (7)
SACLAY	1.76(9)	1.96(3)	0.20 (10)
BATES	1.68(3)	1.97(3)	0.30(3)
Atomic	--------	1.959(4)	--------

GFMC, χEFT: Precise (~1%) theoretical calculations

SACLAY, BATES: Large uncertainties and discrepancy in measurements

Improve precision of ΔR_{rms} by factor of 3-5 over SACLAY to check existing theory and experimental results

(Piarulli et al., Phys. Rev. C 87 014046)

Jlab Tritium Target Program

- **E12-06-118** : Measurement of deep inelastic ratios from 3H/3He (MARTHON)
- **E12-11-112** : isospin dependance of short range correlations in x>1 region
- **E12-14-011** : Proton neutron momentum distributions in A=3 nuclei
- **E12-14-009** : 3H – 3He charge radius difference from elastic scattering

Starts data collecting in Spring 2017!

Uses Jlab tritium target and the Hall A High Resolution Spectrometers.

Buddhini Waidayawansa

Tritium Gas Targets @ electron accelerators

Lab	Year	Quantity (kCi)	Thickness (g/cm^2)	Current (µA)	Power loss (mW/mm)
Stanford	1963	25	0.8	0.5	3.2
MIT-Bates	1982	180	0.3	20	47.7
SAL	1985	3	0.02	30	4.8
JLab	**(2016)**	**1**	**0.08**	**20**	**12.7**

- Jlab radioactivity very low
- JLab luminosity ~ **2.0 x 10^{36} tritons/cm^2/s**

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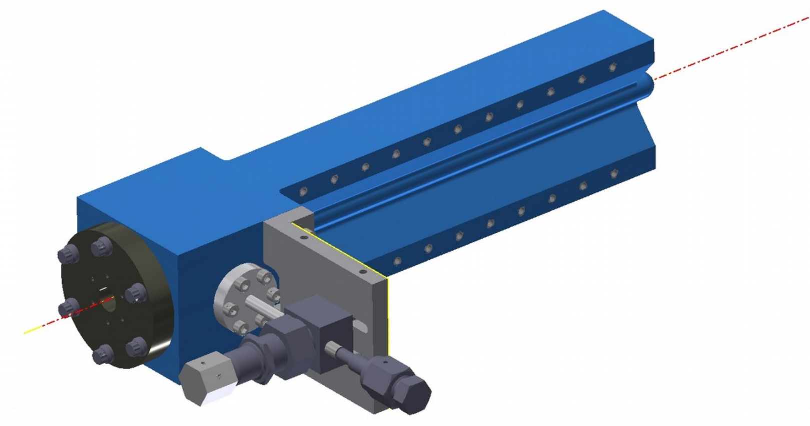
Jlab Tritium Target

First tritium target @ JLab



- **Thin Al windows**
  - Beam entrance: 0.010”
  - Beam exit: 0.011”
  - Side windows: 0.018”
  - 25 cm long cell at ~200 psi T_2 gas

- **Tritium cell filled and sealed at Savannah River National Lab**
  - Purity: 99.9% T_2 gas, main contaminant is D_2
  - 12.32 y half-life: after 1 year ~5% of ^3H decayed to ^3He

- **Administrative current limit: 25 μA**

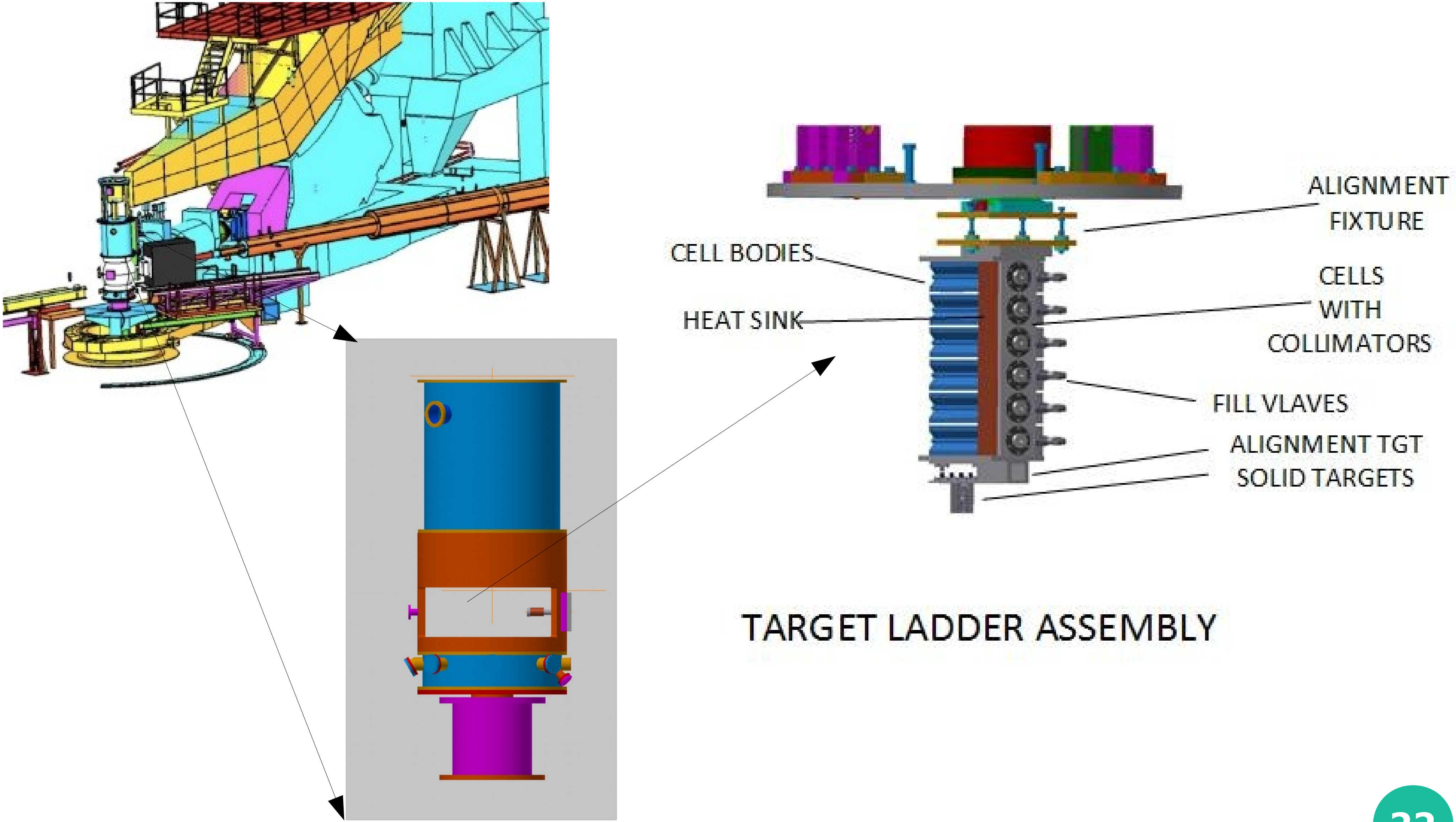
Summery

- Four experiments to study the nucleon structure using 3H and 3He mirror symmetry
  - Elastic to Deep inelastic kinematics
  - Nucleon structure functions, charge radii, momentum distributions and SRC
  - Excellent candidates to test theory calculations

- Experiments are ready to take data starting in Spring 2017!

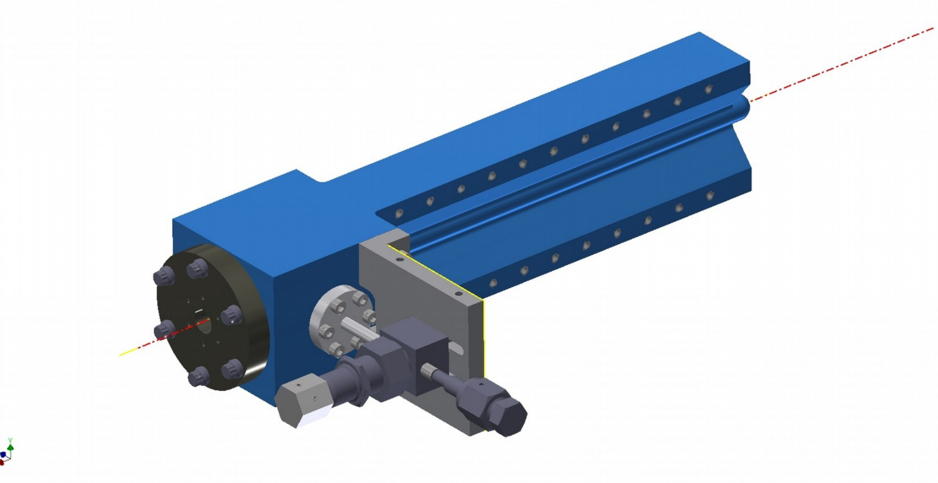
Backup Slides

Tritium Target Ladder



JLab Tritium Target

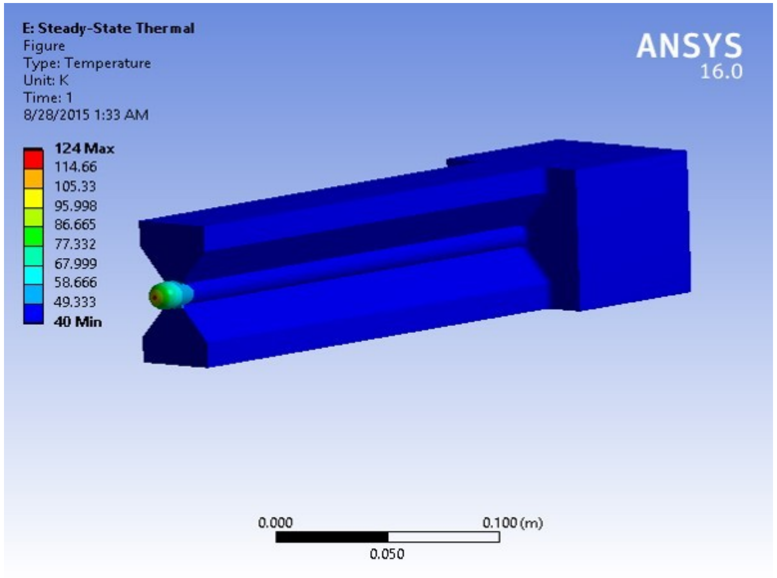
- **Design**



Main Body and Entrance
Window made of ASTM B209
AL 7075-T651

090 Ci of T2 (0.1 g)
~ 200 psi @295 K
L = 25 cm and ID = 12.7 mm
Volume = 34 cc

- **Beam Heating**



$I_{beam} = 20\mu A$ Max beam current
$A_{raster} = 2x2mm^2$ min raster

3W in Entrance
3.3 W in Exit
$T_{max} = 125K$ on exit
$T_{max} = 120K$ on entrance