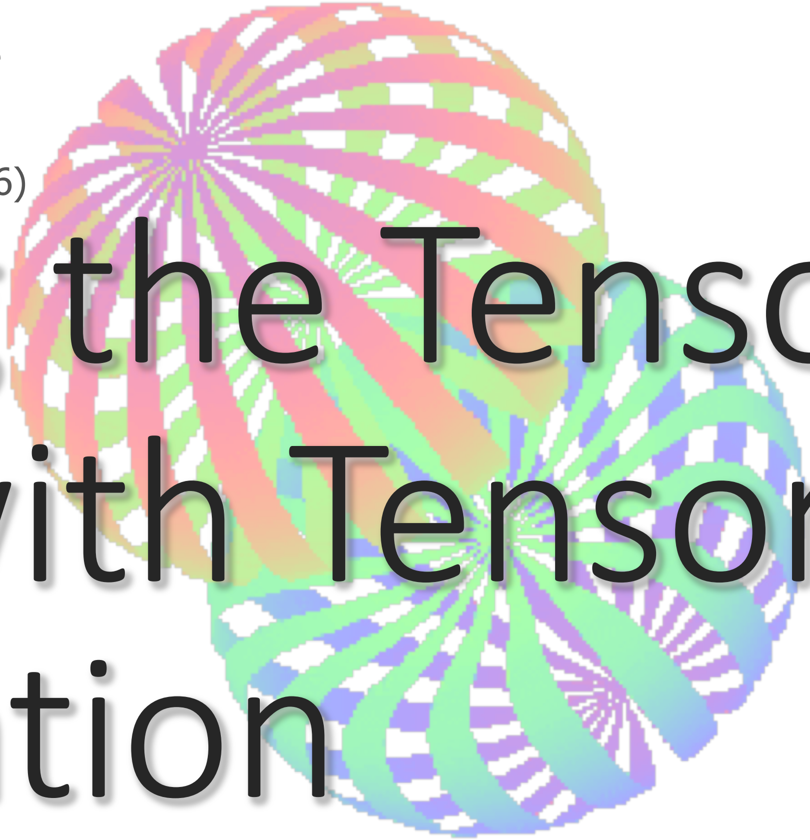
"The proton, **deuteron**, and α particle are most interesting to study because they are among the simplest nuclear structures."

RW McAllister, R Hofstadter, Phys.Rev. **102** 851 (1956)

Probing the Tensor Force with Tensor Polarization



Dr. Elena Long

SRC/EMC Workshop

MIT

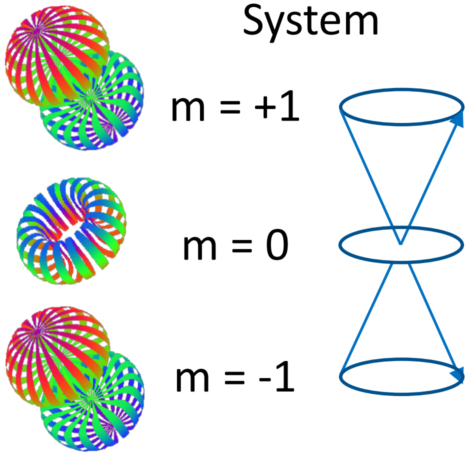
March 22nd, 2019

University of New Hampshire

Long Lab

What is Tensor Polarization?

Spin-1
System



J Forest, *et al*, PRC **54** 646 (1996)

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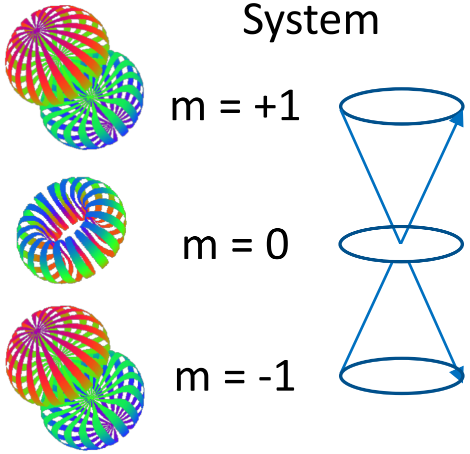

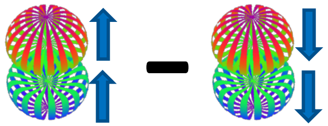

“Normal” Polarization:
Vector $P_z = p_+ - p_-$

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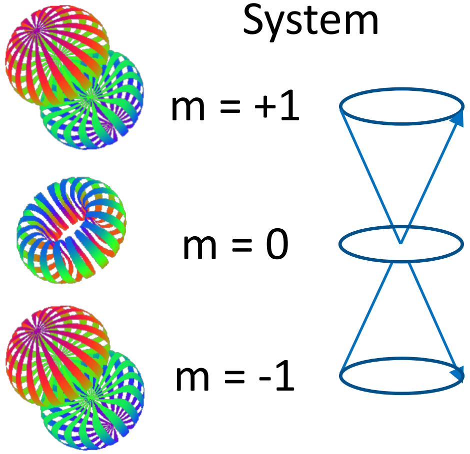

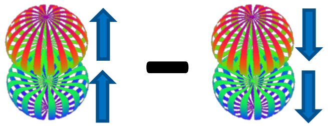

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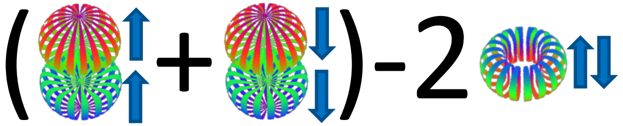

Tensor $P_{zz} = (p_+ + p_-) - 2p_0$

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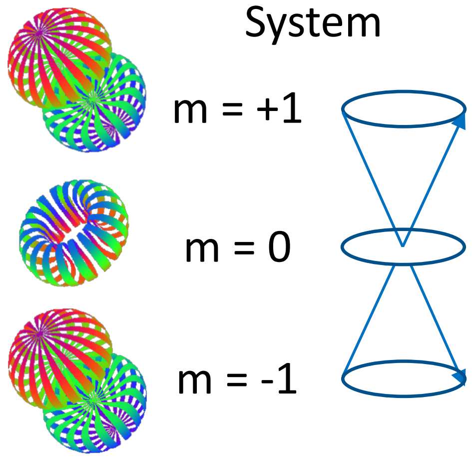

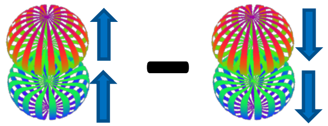

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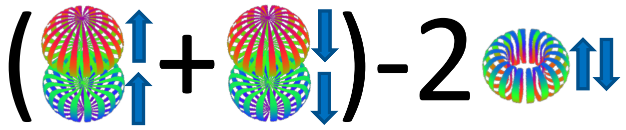

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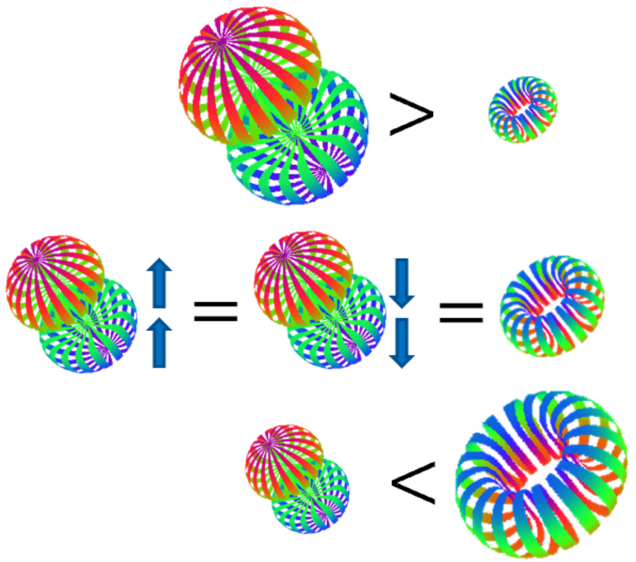

$\rightarrow 0 < P_{zz} \leq 1$

$\rightarrow P_{zz} = 0$

$\rightarrow -2 \leq P_{zz} < 0$

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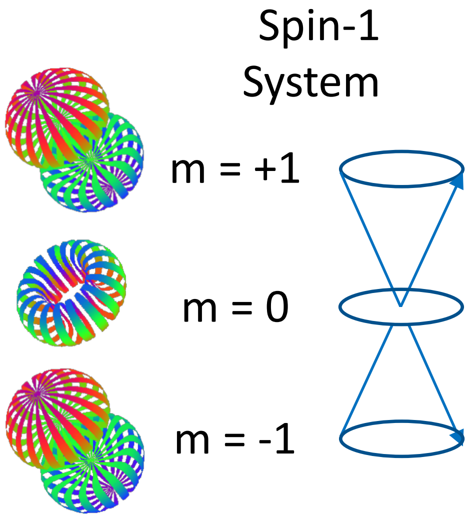
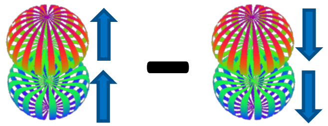
What is Tensor Polarization?

A high-luminosity tensor-polarized target has promise as a **novel probe of nuclear physics**





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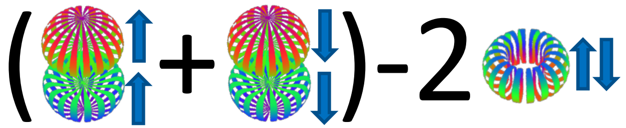

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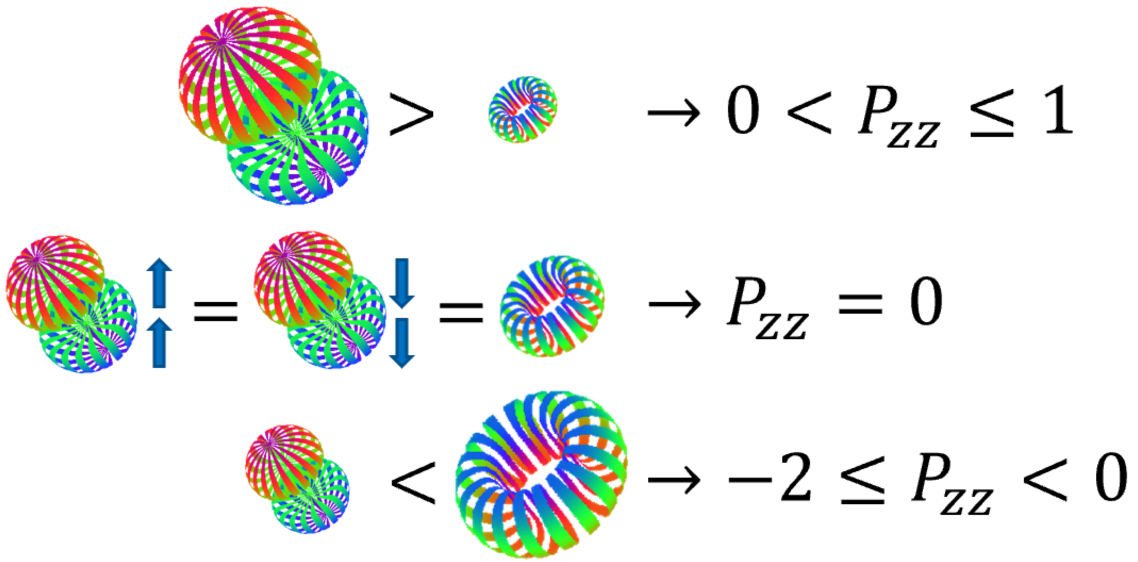

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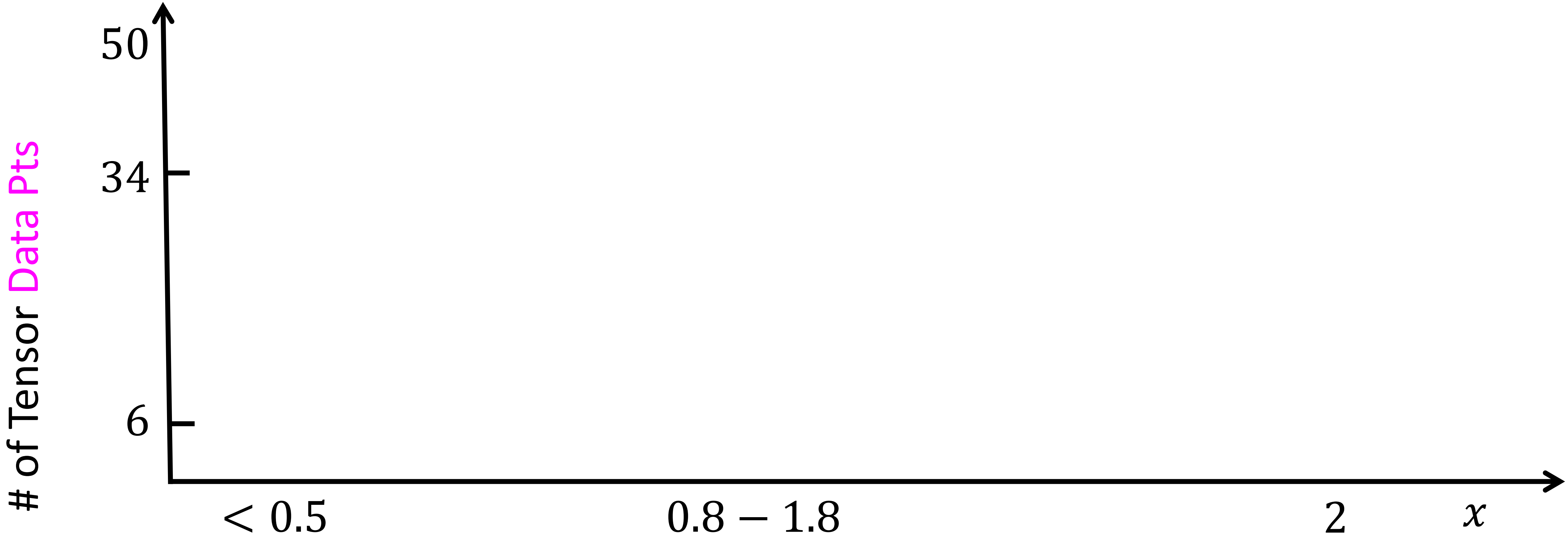
Current Landscape of Tensor Observables



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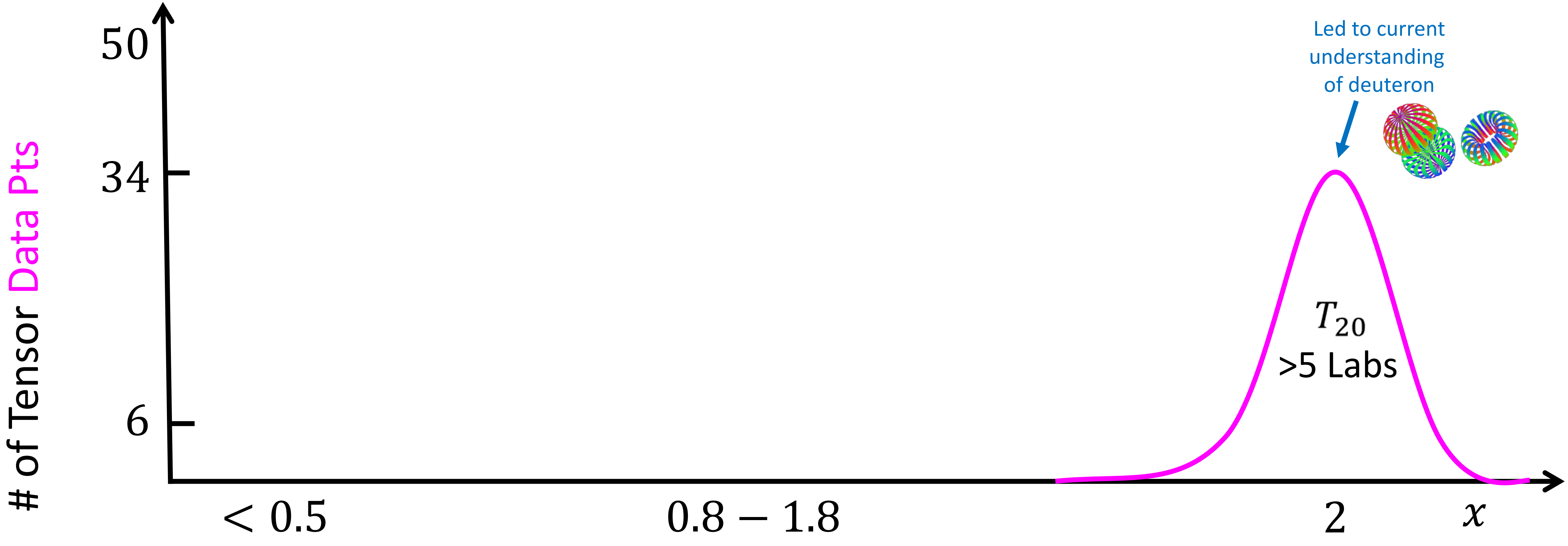

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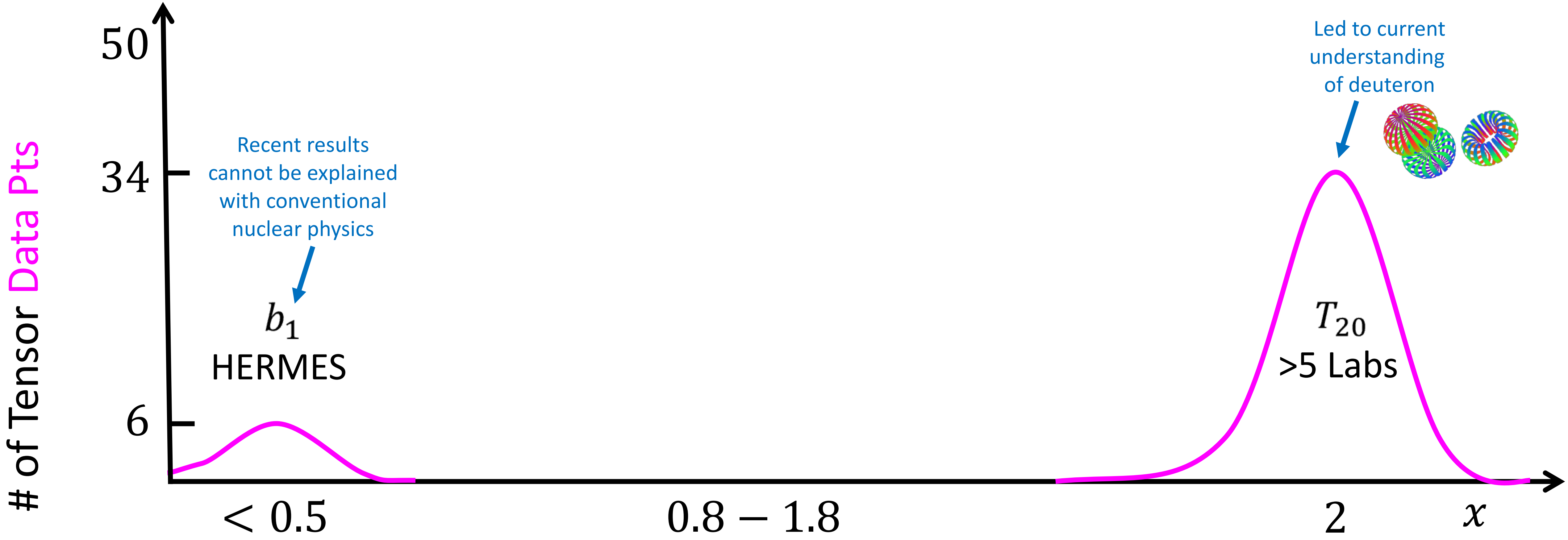

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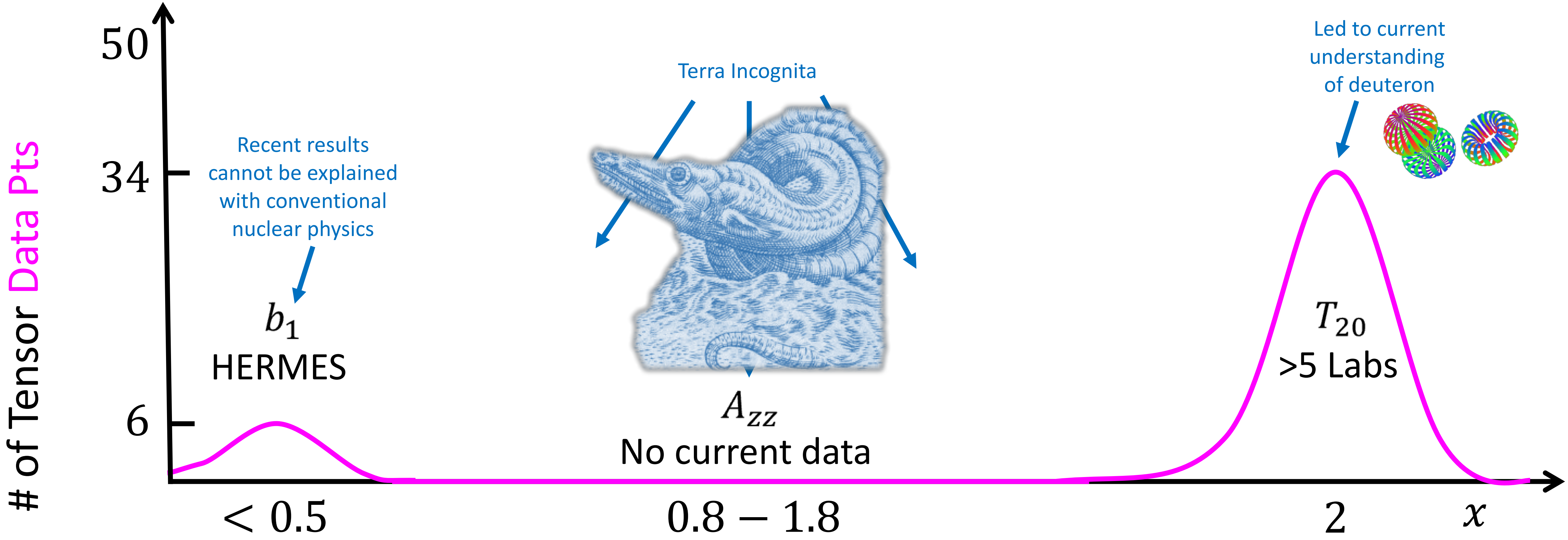

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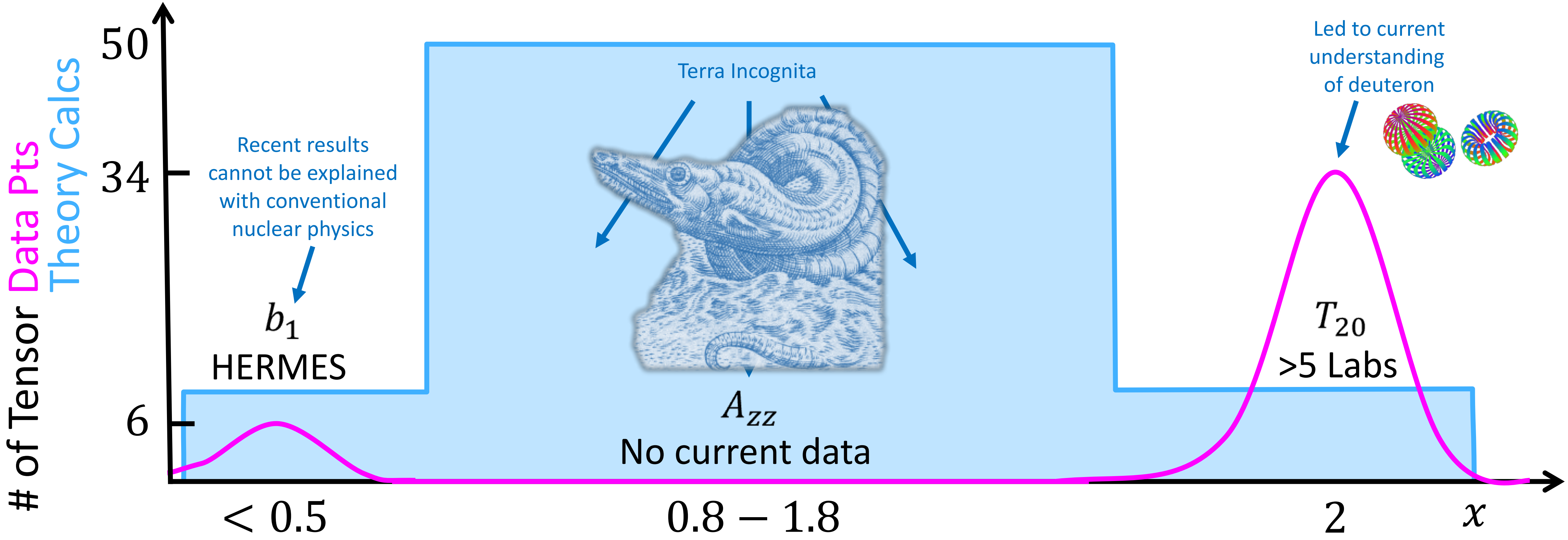
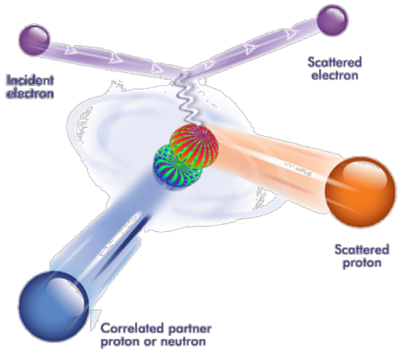


Matter at Small Distances & High Momentum

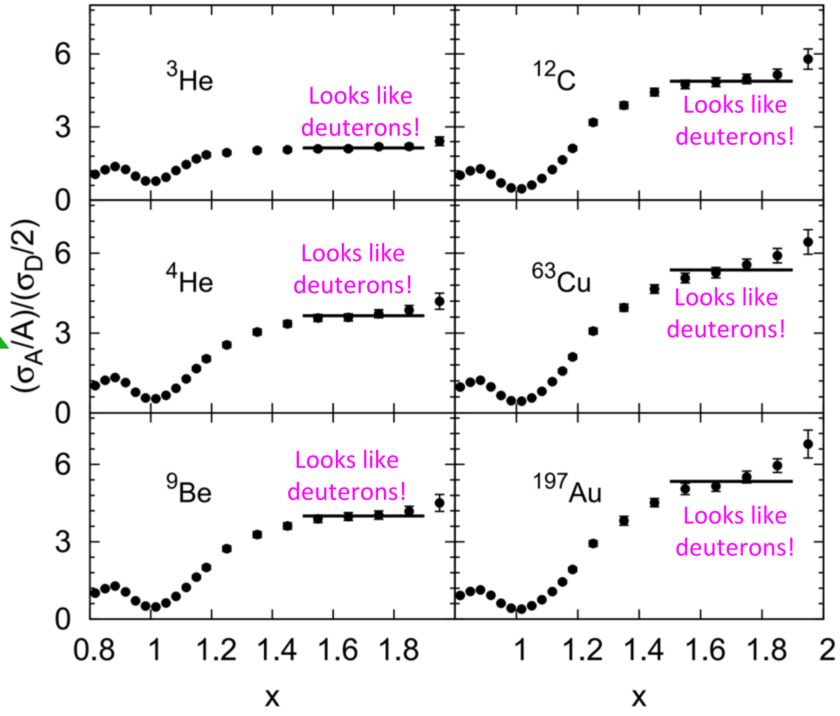


- Short-Range Correlations:

  Everything looks like deuterons!

N Foman, *et al*, PRL **108** 092502 (2012)

$$\frac{\text{Everything}}{\text{Deuteron}}$$



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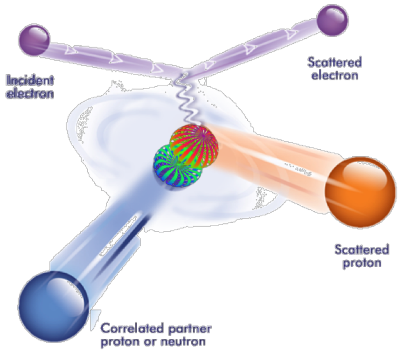

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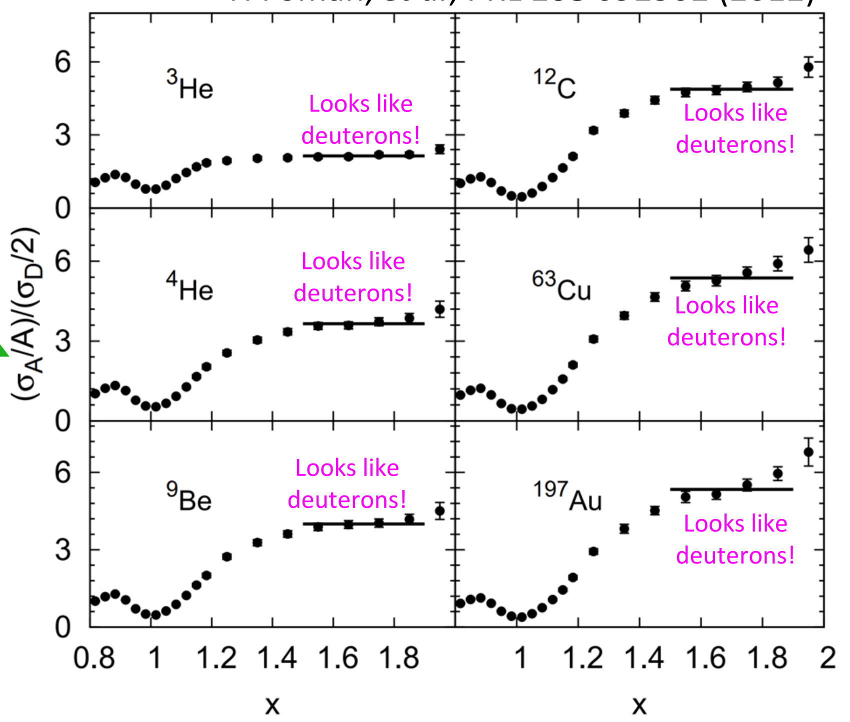
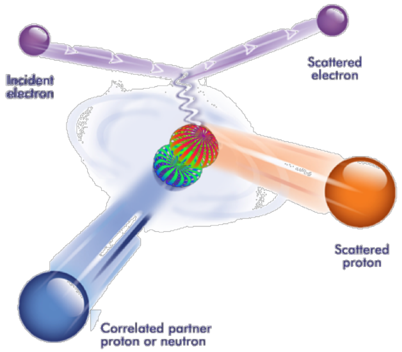


Look @ Deuteron: Simplest composite nuclear system

Matter at Small Distances & High Momentum



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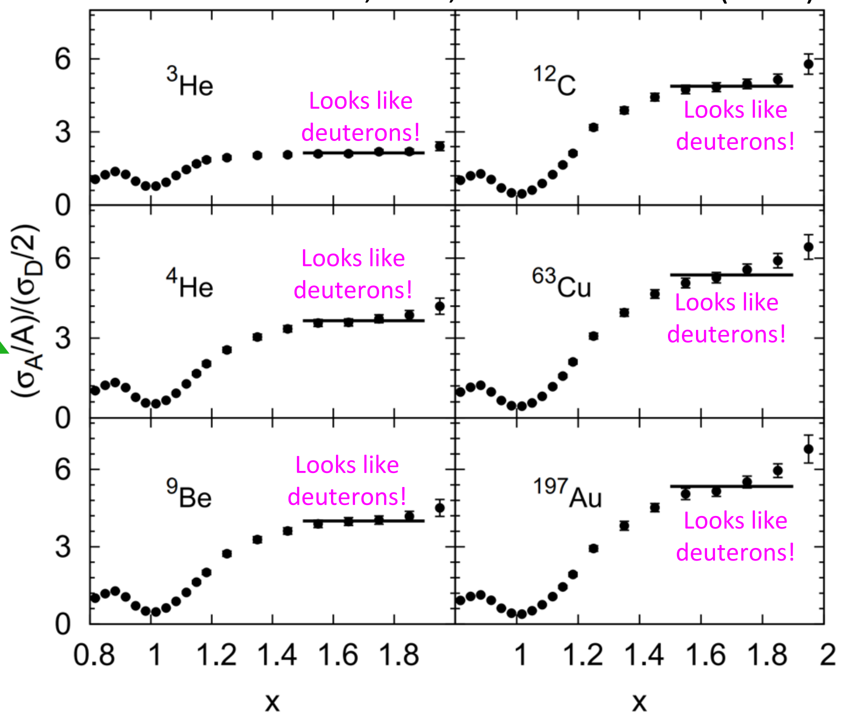

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Short-range, high *p* structure probed with:

- $x > 1$ kinematics
- Enhancing tensor polarization

We combine both techniques

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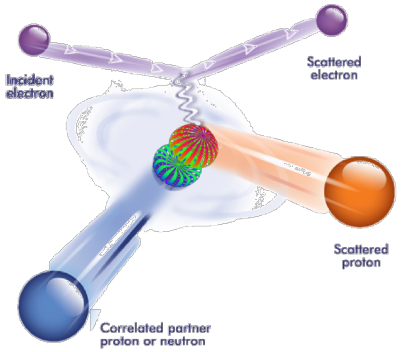

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Probe the tensor force with tensor polarization!

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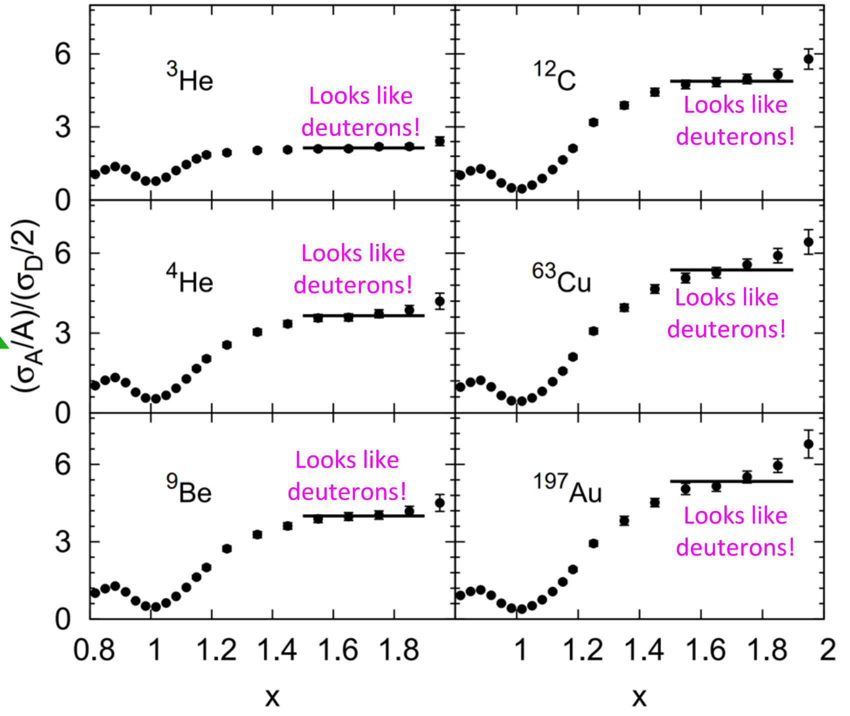

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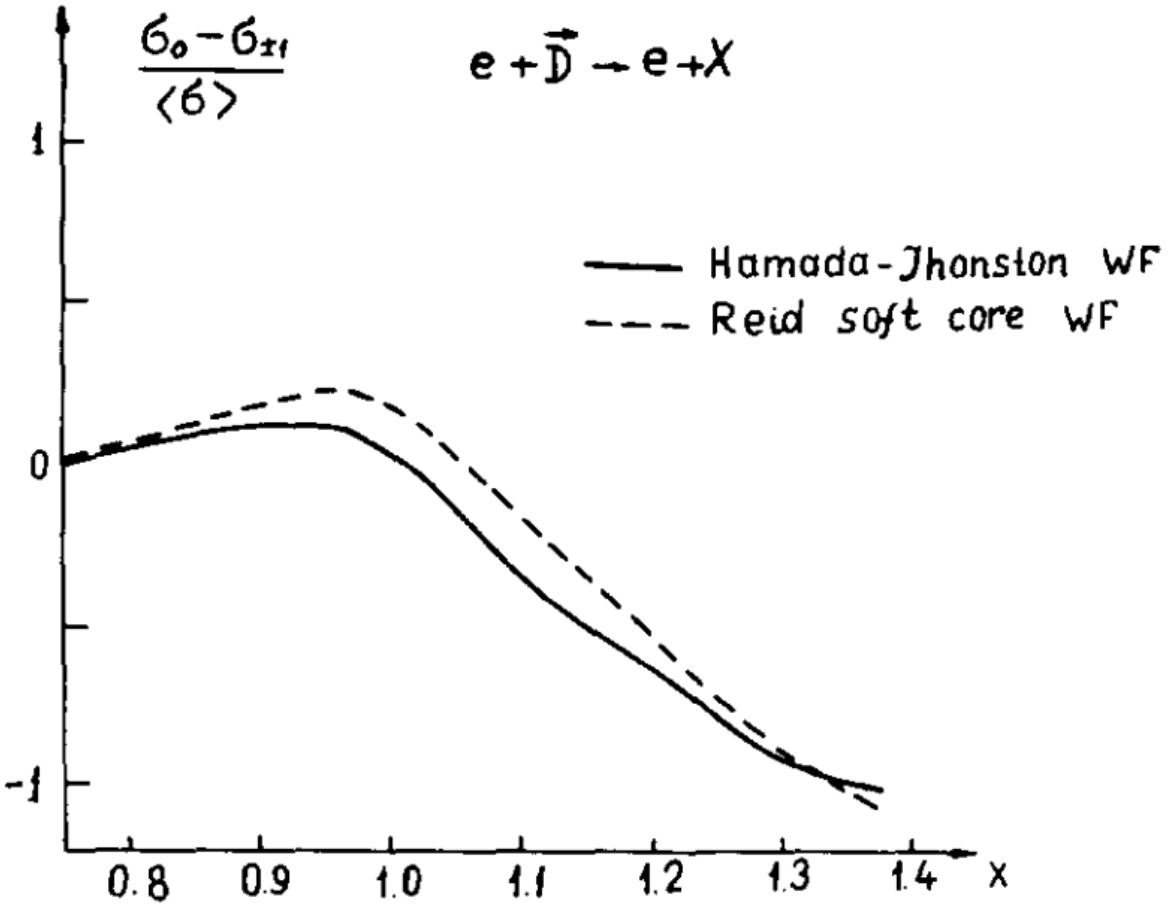
Deuteron Wavefunction

First calculated in the ‘70s, A_{zz} can be used in to discriminate between hard and soft wave functions

$$A_{zz} = \frac{2}{f \cdot P_{zz}}\left(\frac{\sigma_p - \sigma_u}{\sigma_u}\right)$$



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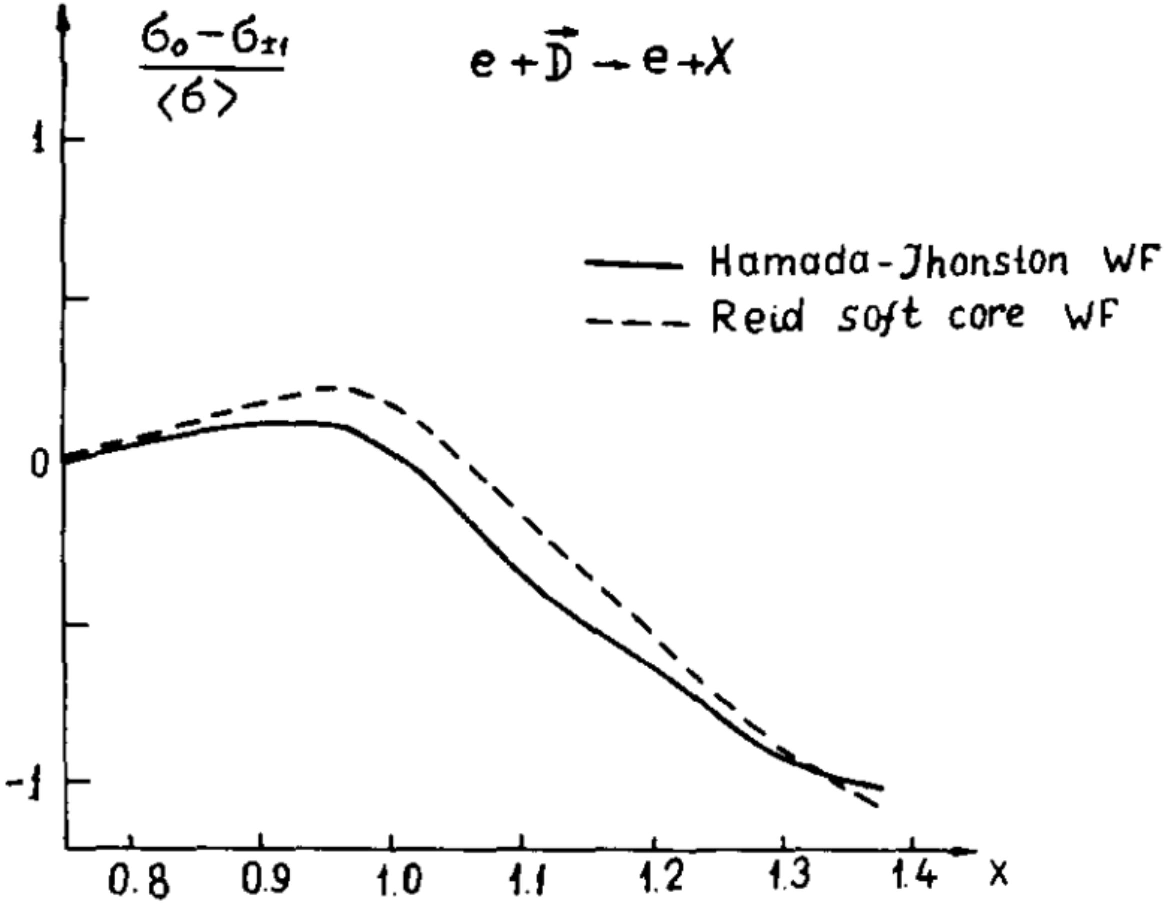
$S \rightarrow u(k)$
$D \rightarrow w(k)$

$$A_{zz} \propto \frac{\frac{1}{2}w^2(k) - u(k)w(k)\sqrt{2}}{u^2(k) + w^2(k)}$$



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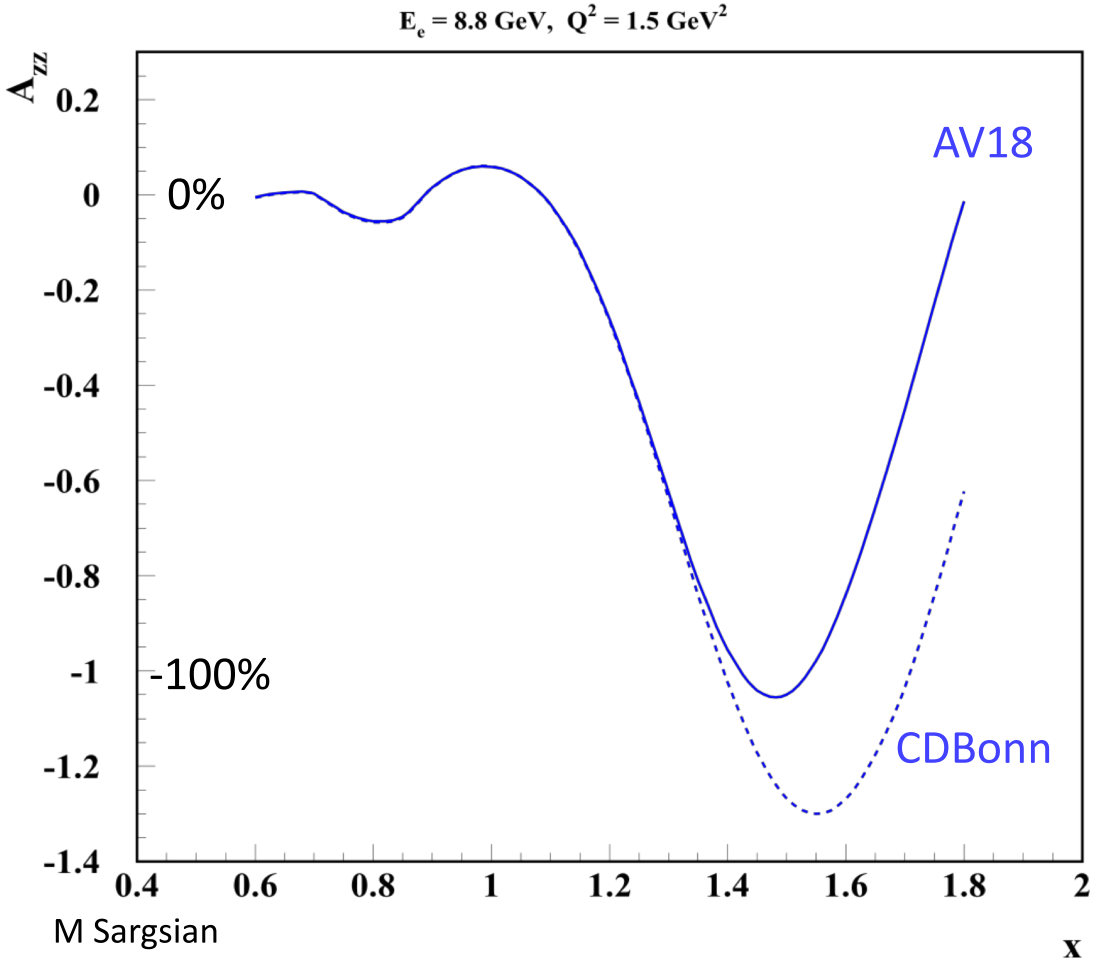

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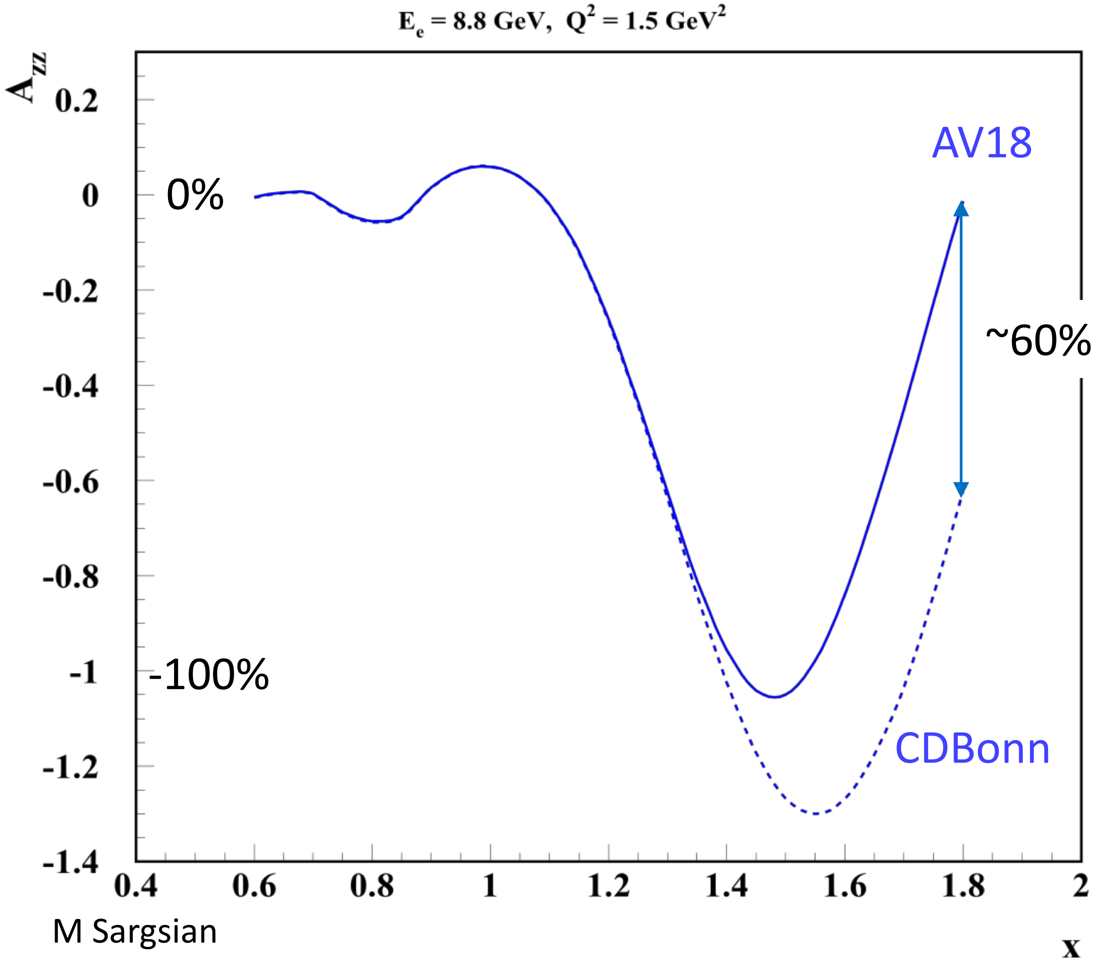

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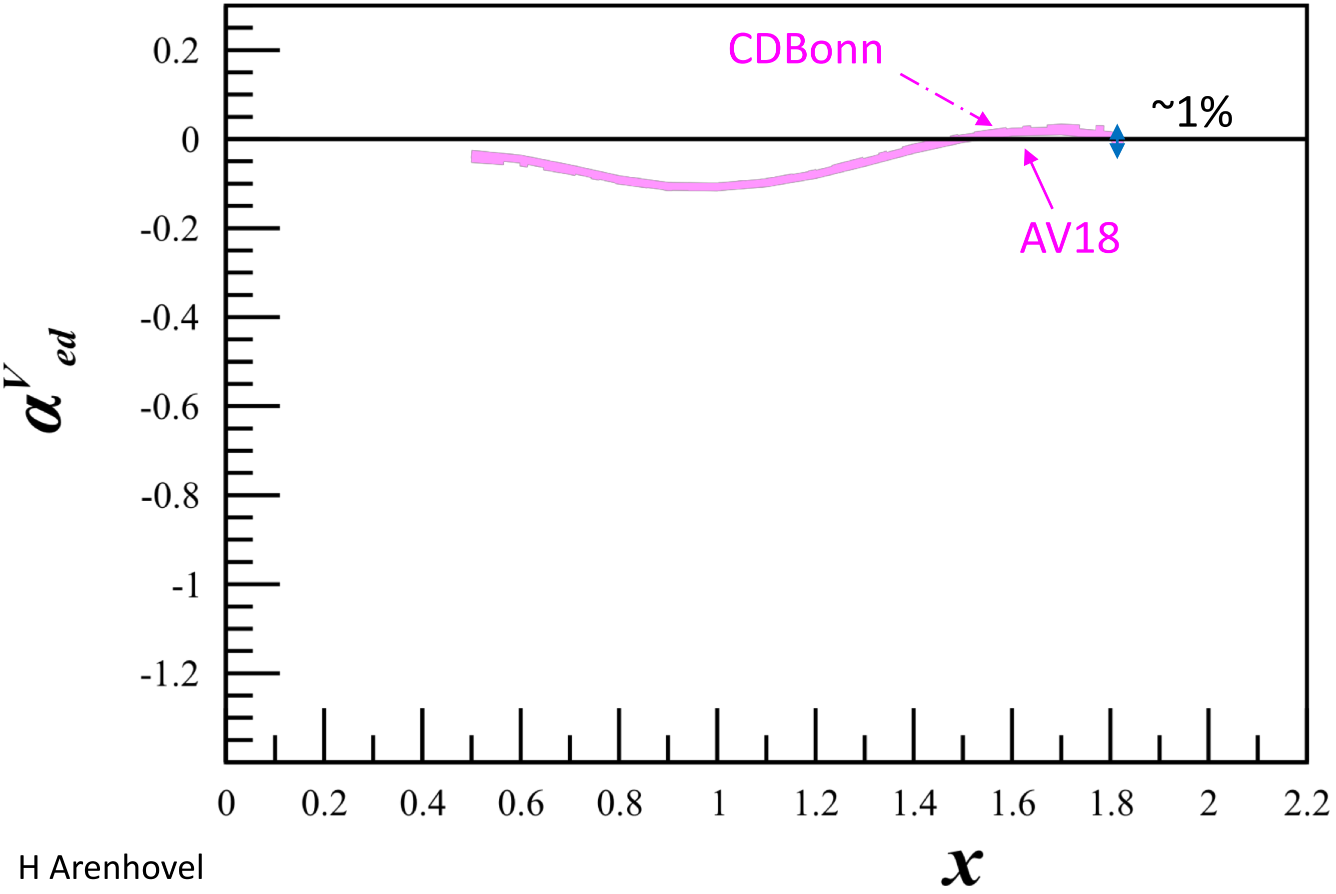
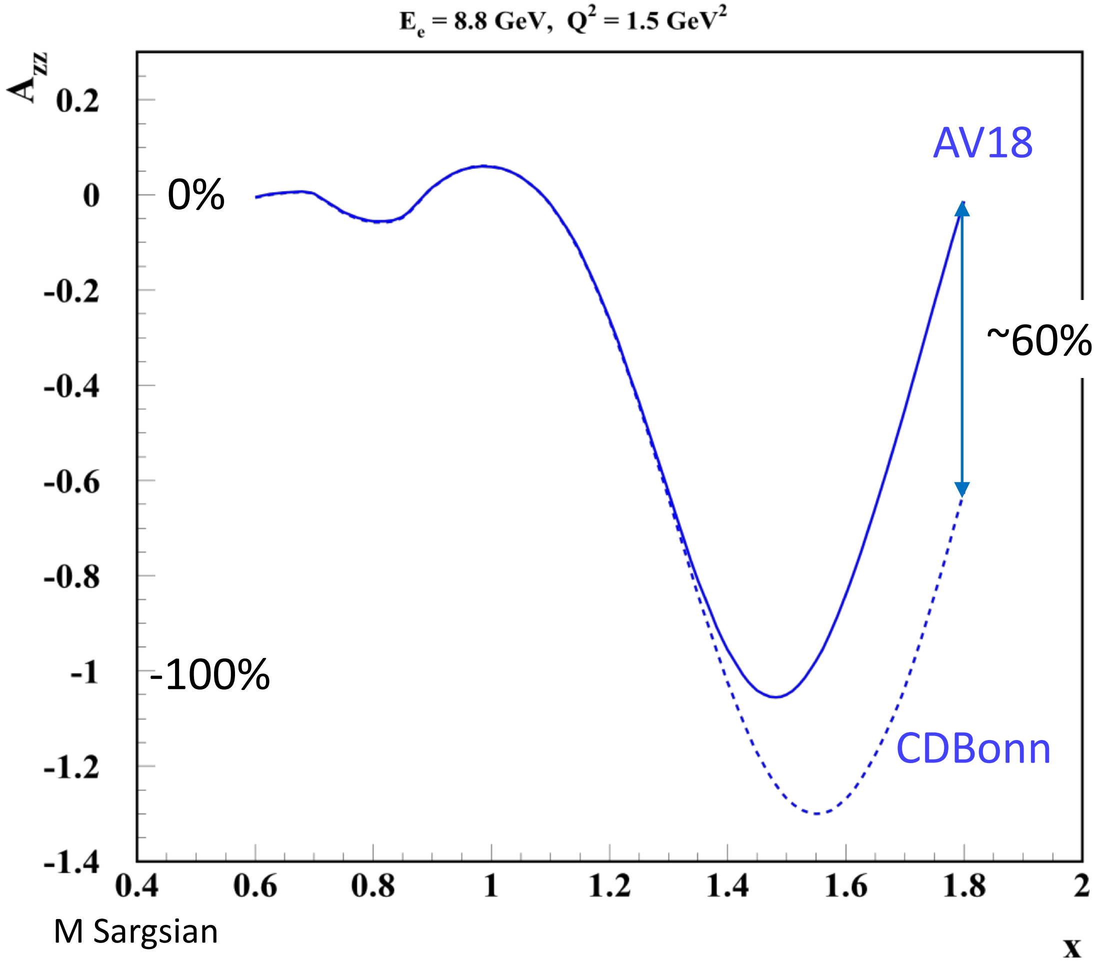
Deuteron Wavefunction

Vector Polarized



H Arenhovel



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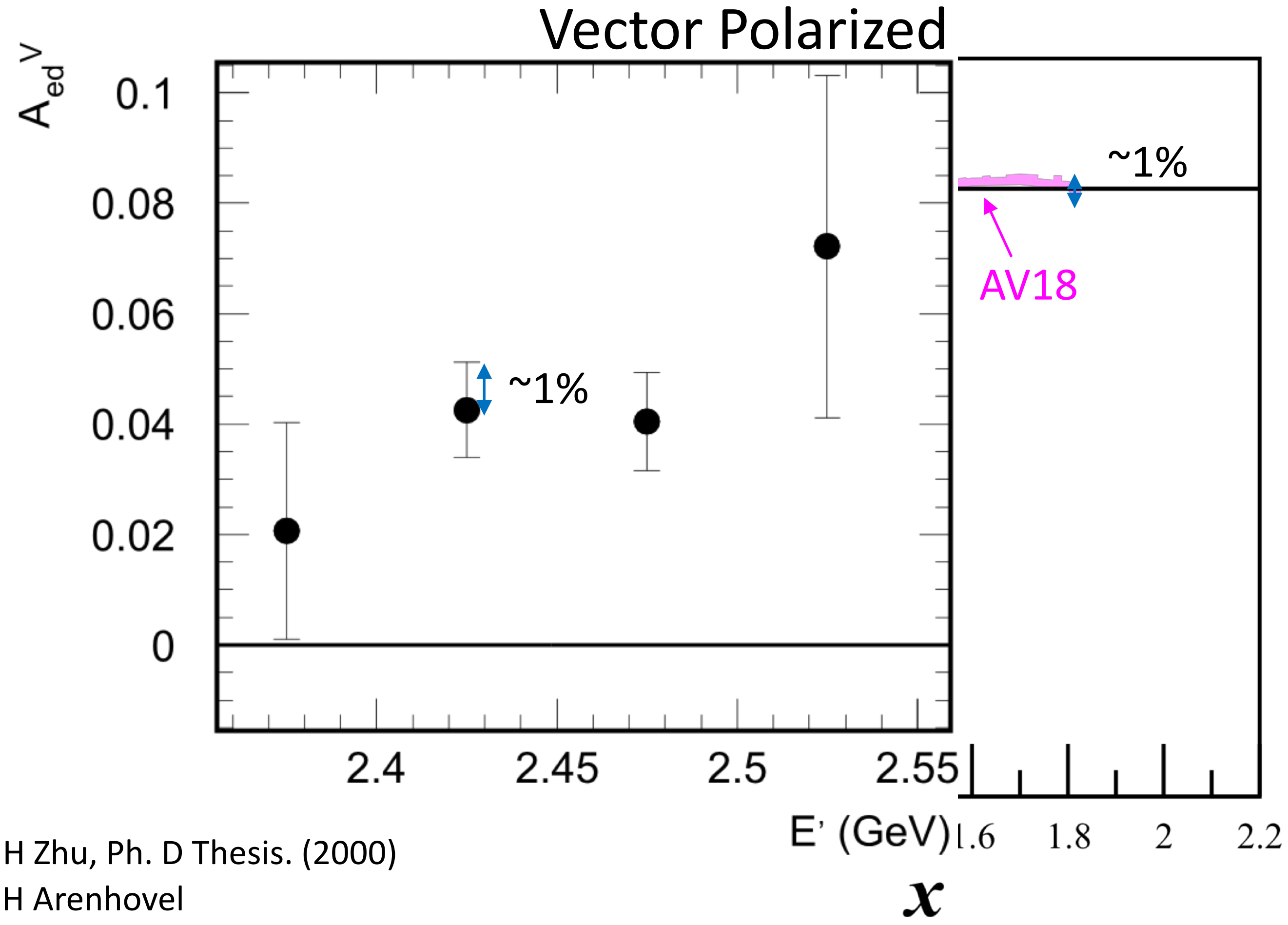
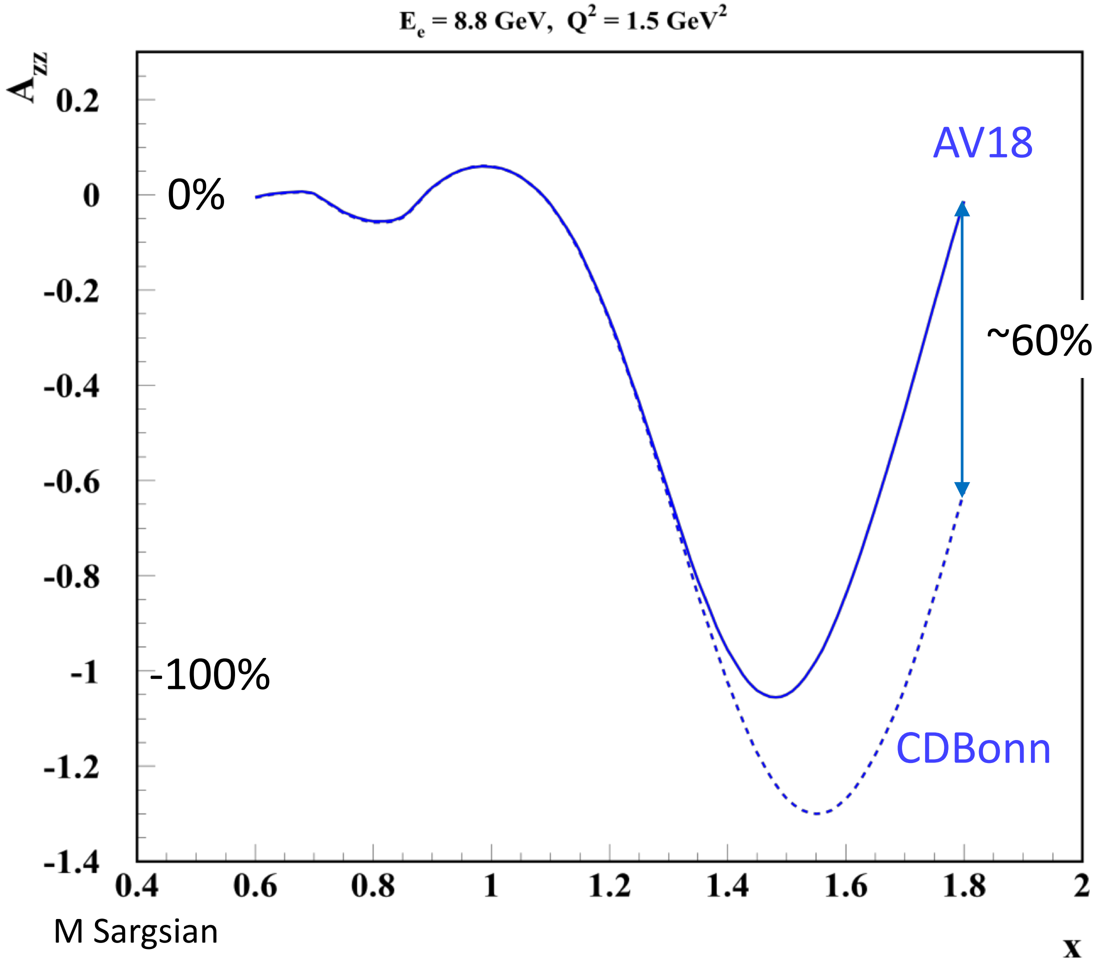


H Zhu, Ph. D Thesis. (2000)
H Arenhovel



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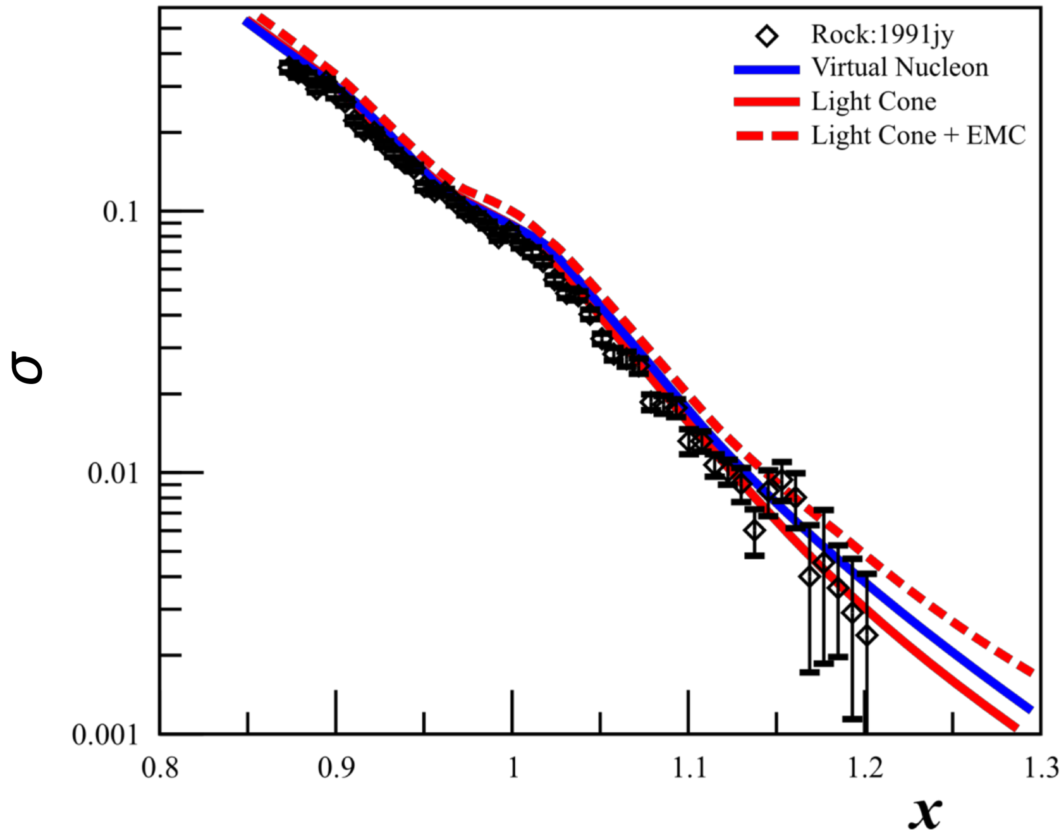
Relativistic *NN* Bound System

Unpolarized



Understanding SRCs requires relativistic calculations at high *p*

Currently two methods:

- Light Cone (LC)
- Virtual Nucleon (VN)

Large $p > 500\ \mathrm{MeV}/c$ needed to discriminate with unpolarized deuterons

- Extremely difficult!

M Sargsian, Tensor Spin Observables Workshop (2014)

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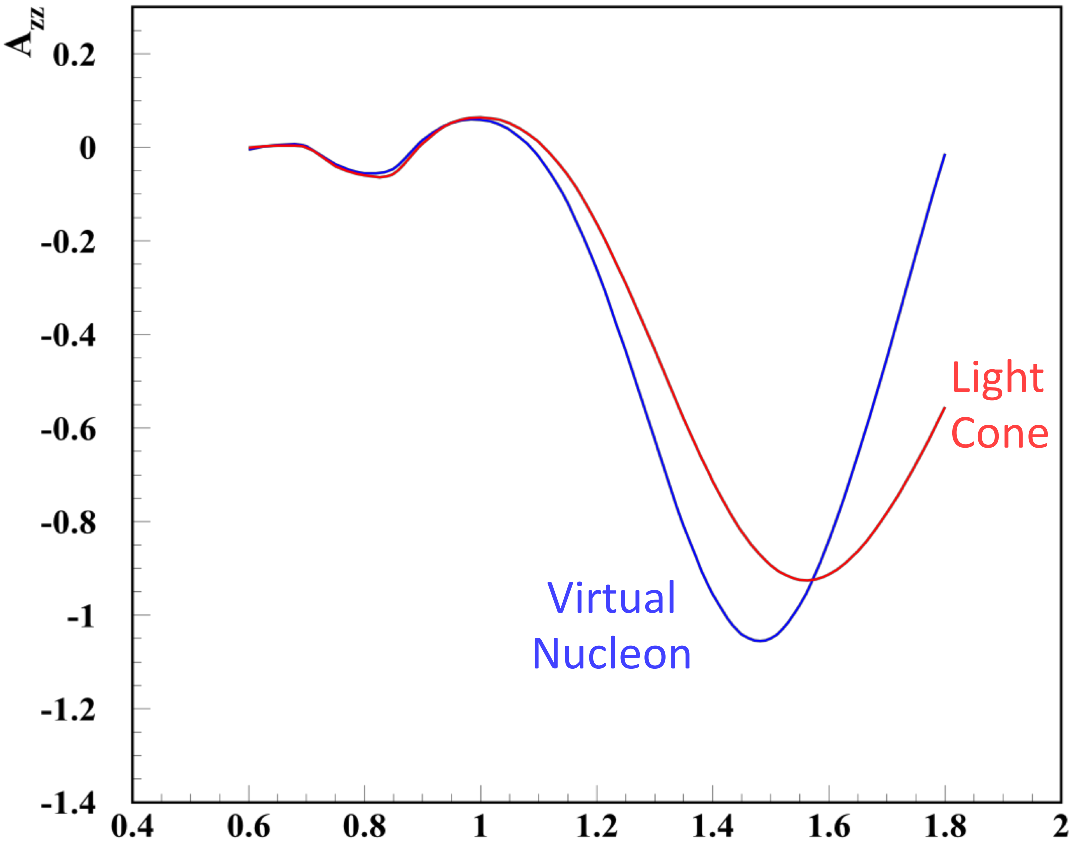
Relativistic *NN* Bound System

Tensor Polarized



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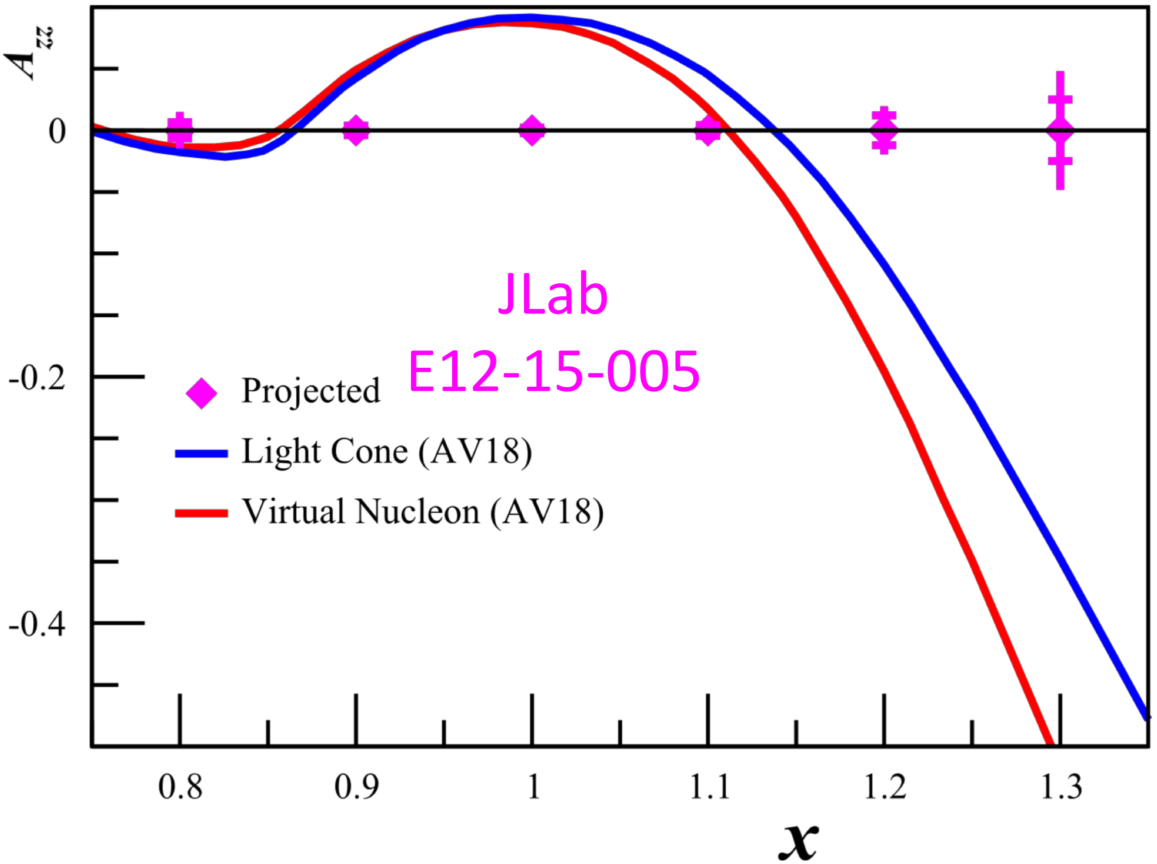

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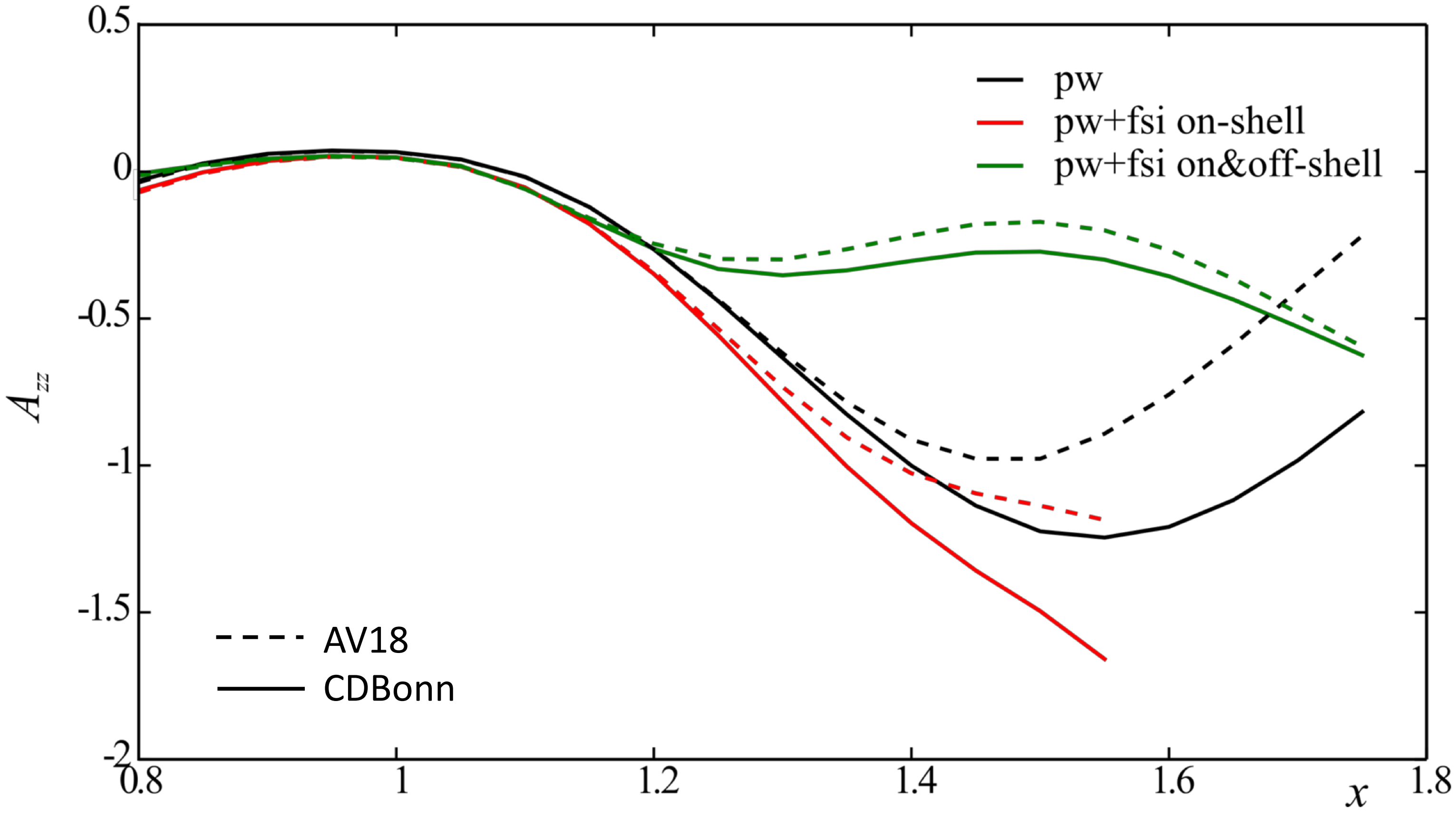
Final State Interactions

FSI must be understood & minimized to get *NN* potential information

Minimum/maximum FSI on A_{zz} calculated by W. Cosyn[1]

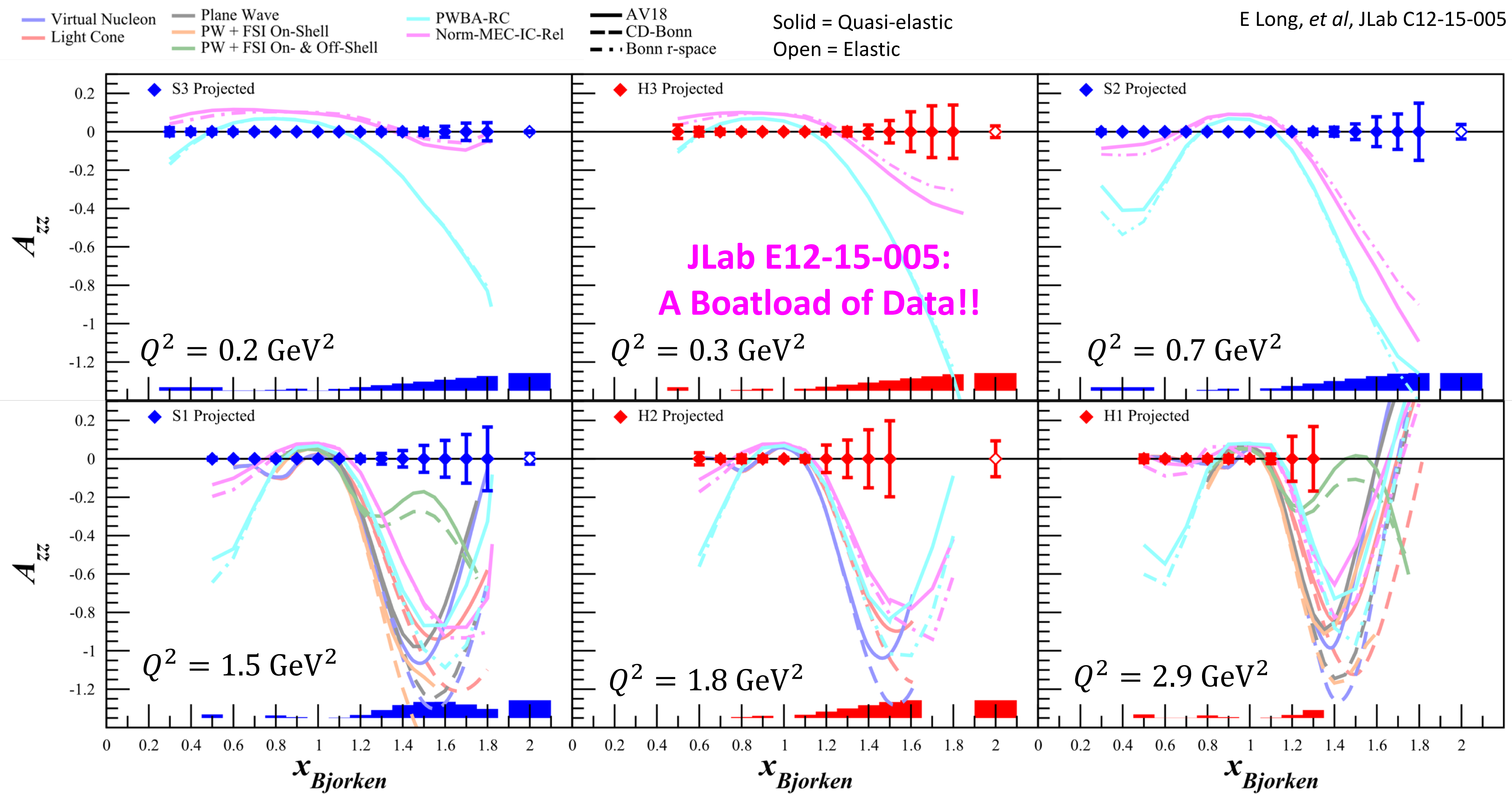
FSIs minimized in kinematic choice (large $x \geq 1.35$ and medium p_m)

- Best suited for attempting to extract information on *D*-wave content[2]



[2] S Jeschonnek, JW Van Orden, arXiv:1606.04072 (2016)

[1] W Cosyn


Virtual Nucleon
Light Cone
Plane Wave
PW + FSI On-Shell
PW + FSI On- & Off-Shell
PWBA-RC
Norm-MEC-IC-Rel
AV18
CD-Bonn
Bonn r-space
Solid = Quasi-elastic
Open = Elastic
S3 Projected
H3 Projected
S2 Projected
S1 Projected
H2 Projected
H1 Projected
JLab E12-15-005:
A Boatload of Data!!
$Q^2 = 0.2$ GeV^2
$Q^2 = 0.3$ GeV^2
$Q^2 = 0.7$ GeV^2
$Q^2 = 1.5$ GeV^2
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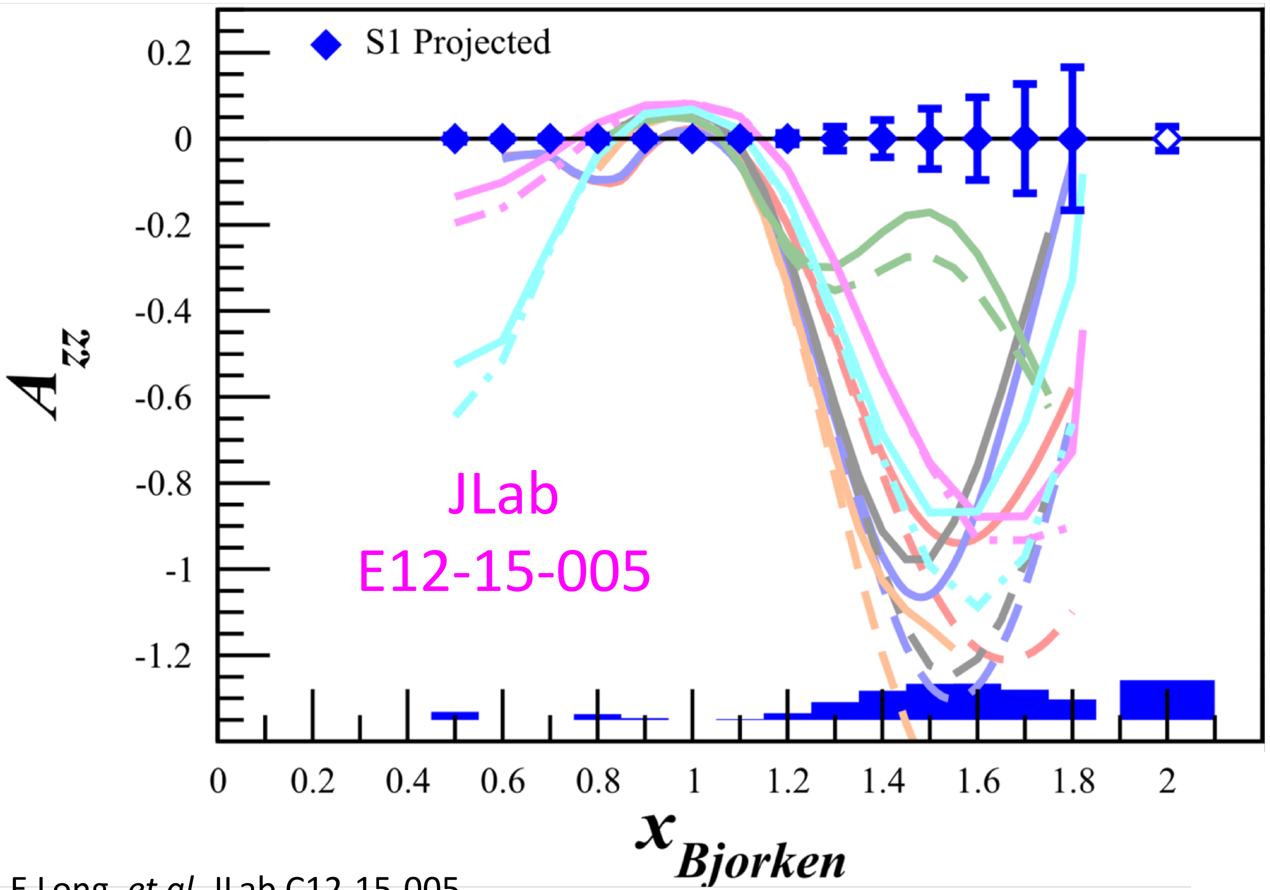
$Q^2 = 2.9$ GeV^2
A_{zz}
$x_{Bjorken}$

First Measurement of Quasi-Elastic A_{zz}



E Long, *et al*, JLab C12-15-005

No current quasi-elastic tensor **measurements**

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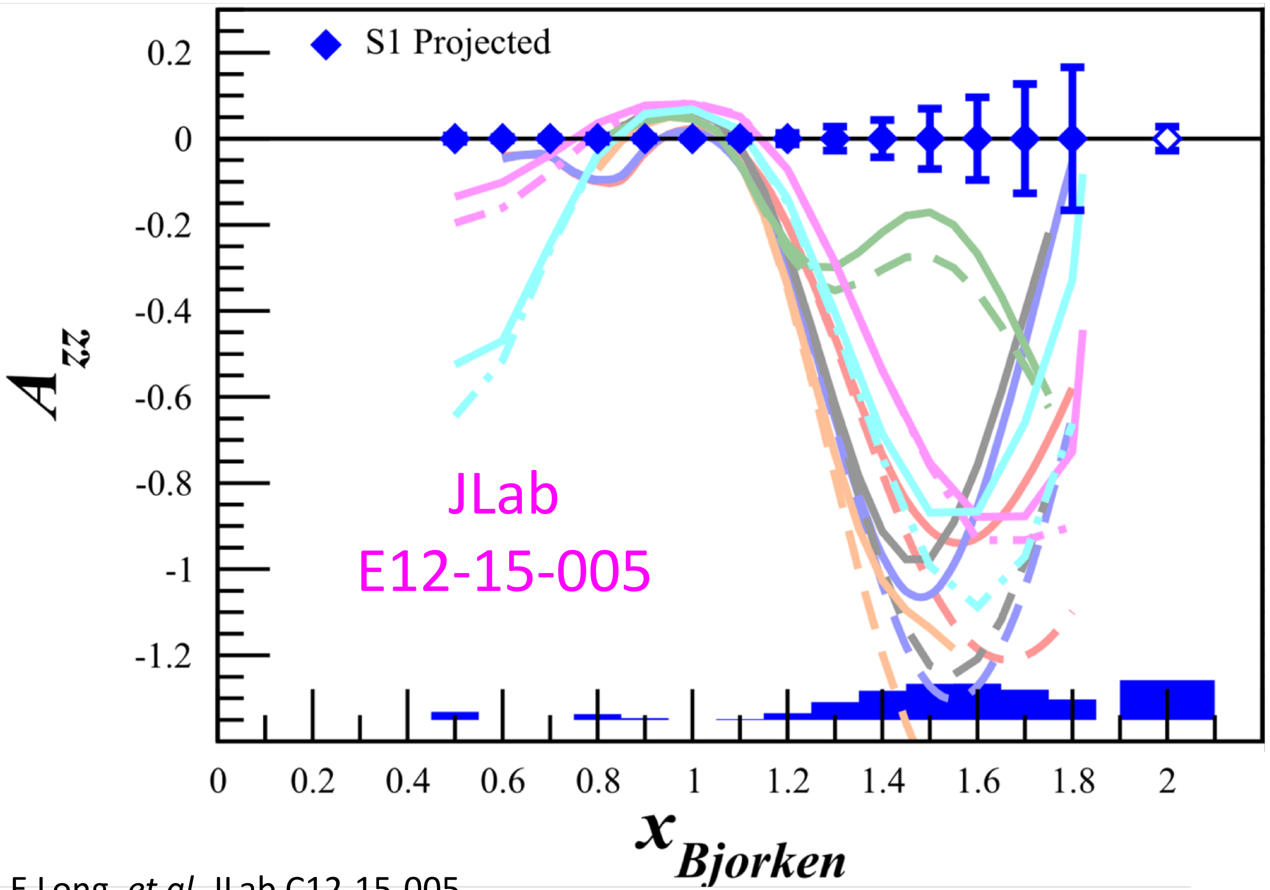

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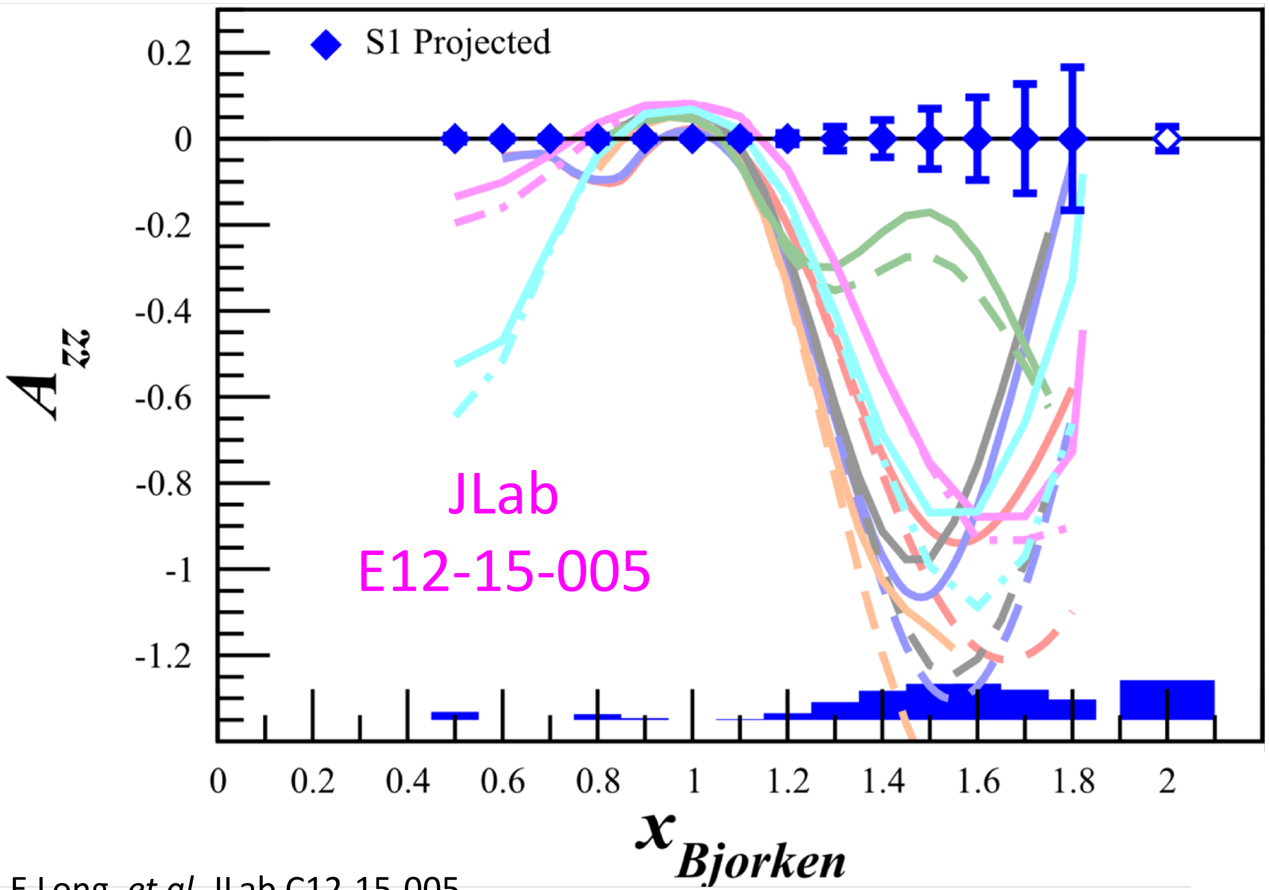

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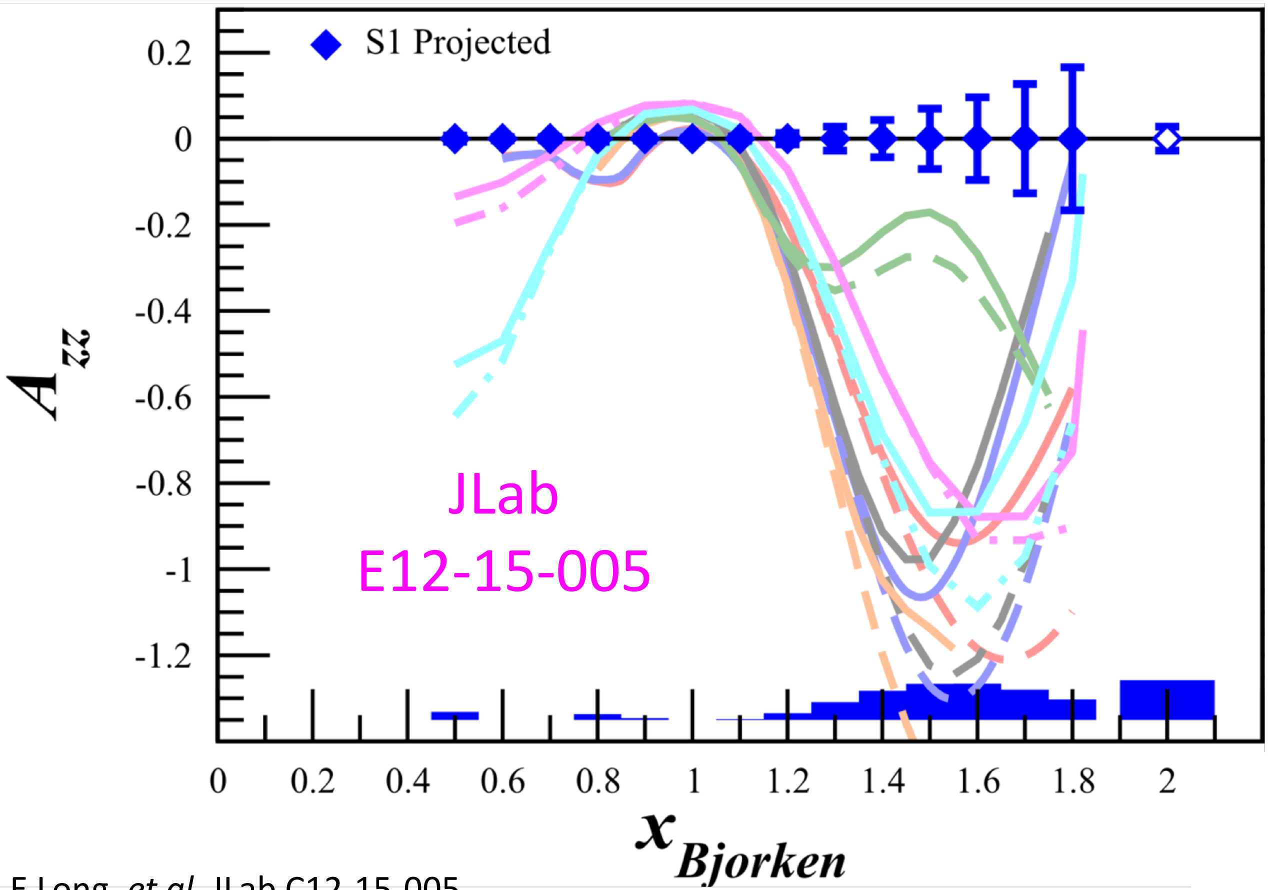

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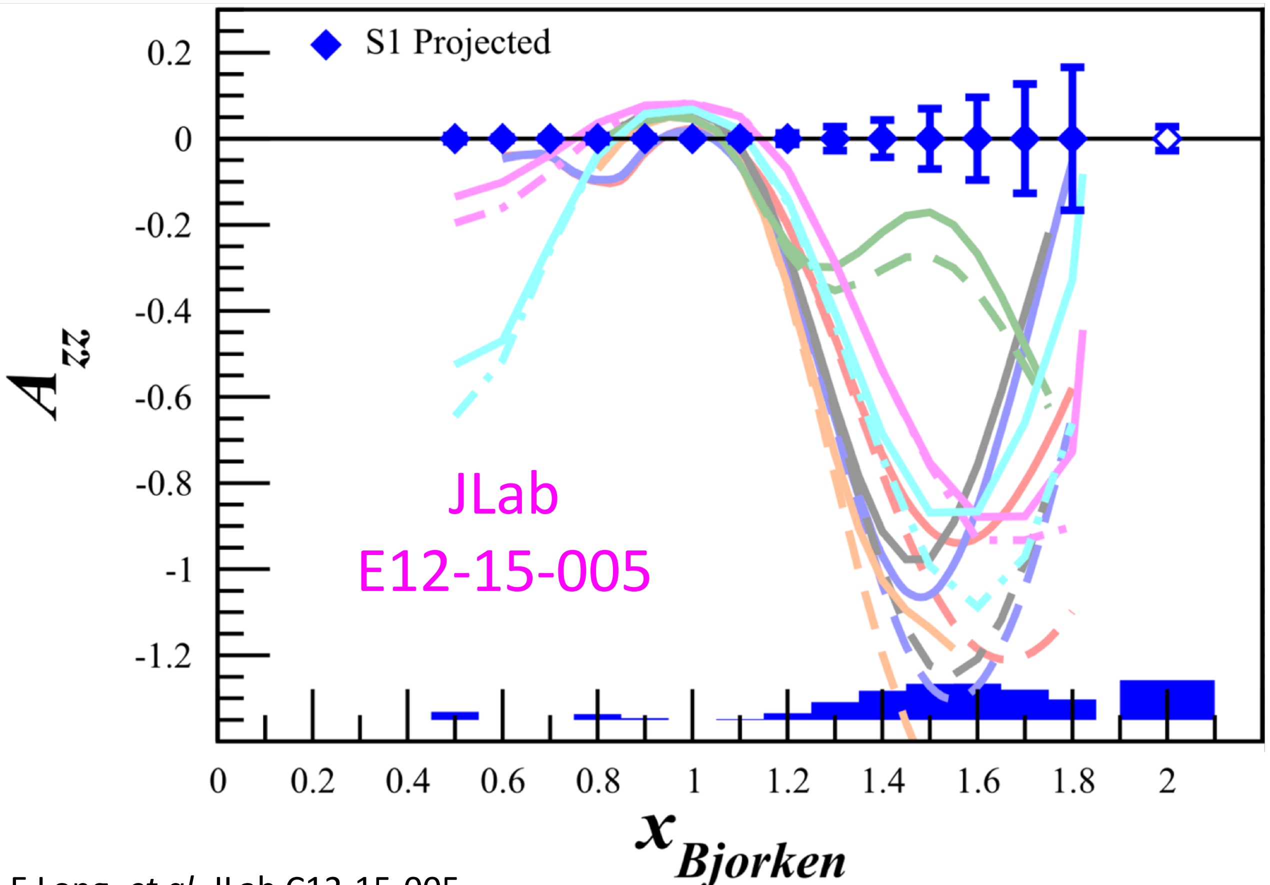

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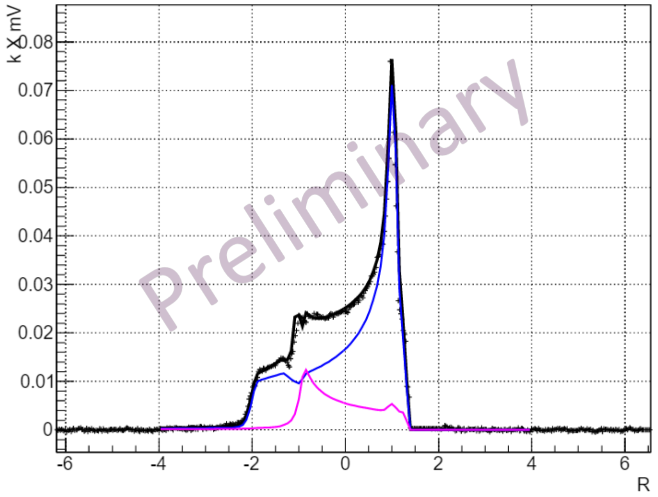
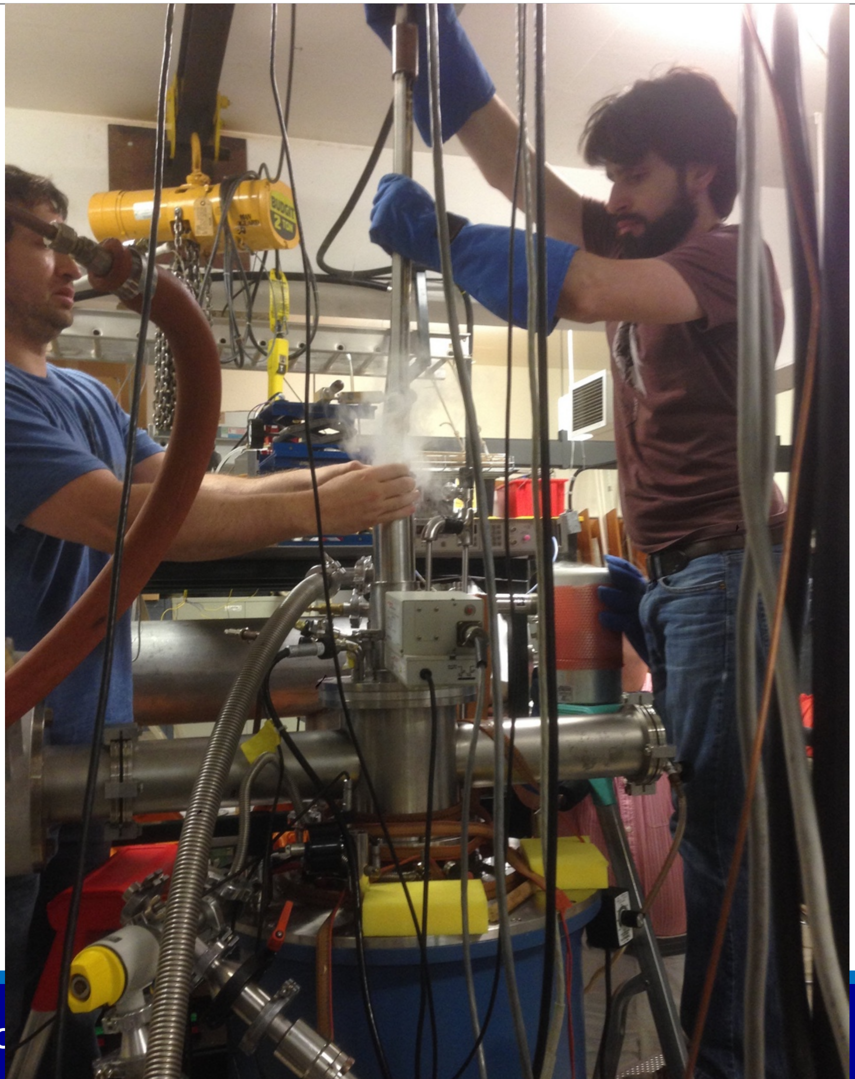
Importance ranges from understanding **short-range correlations** to the **equations of state of neutron stars**

So, How Much Longer?

- Results from UVA are promising, preliminary $P_{zz} > 30\%$ recently achieved on butanol. ND3 in progress.



D Keller, Eur.Phys.J.A., in review (2016)
D Keller, PoS, PSTP2015:014 (2016)
D Keller, J.Phys.Conf.Ser., **543**(1):012015 (2014)
D Keller, Int.J.Mod.Phys.Conf.Ser., **40**(1):1660105 (2016)



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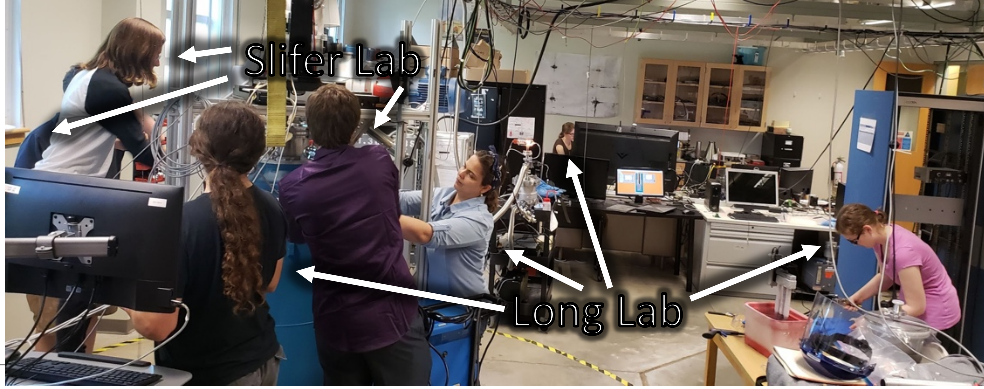
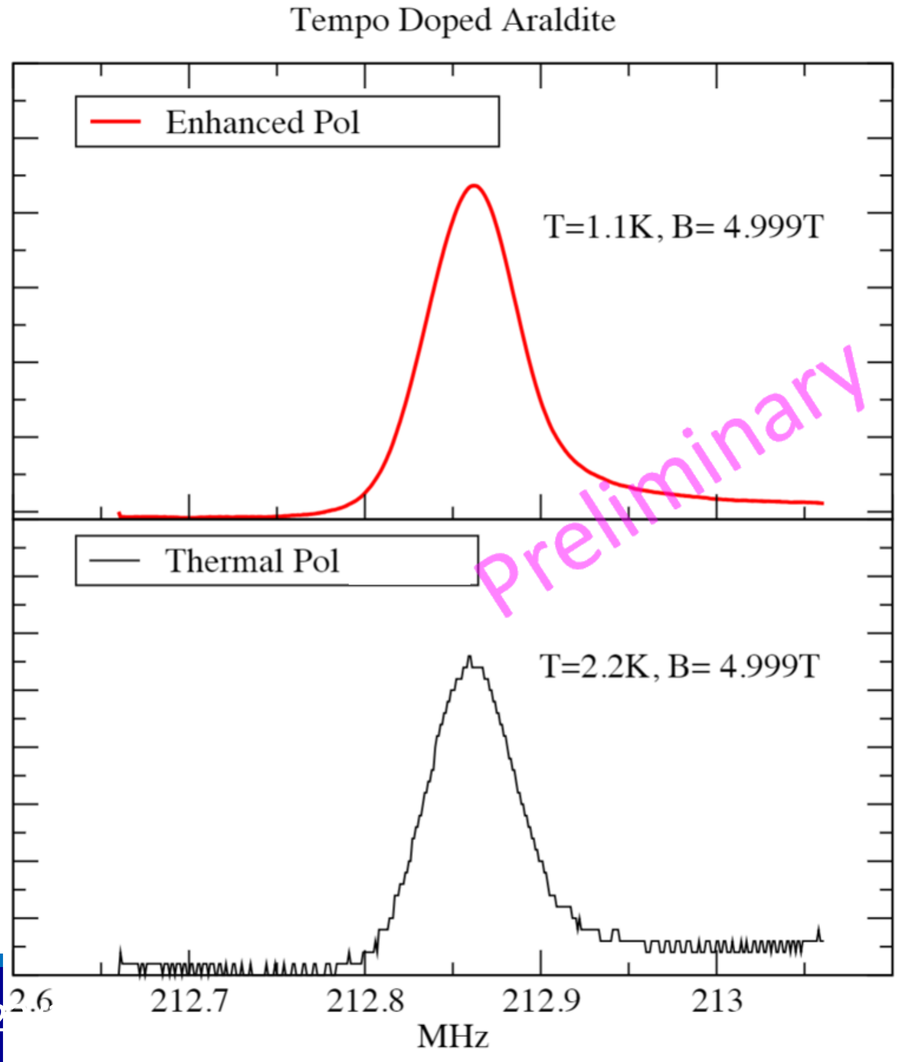
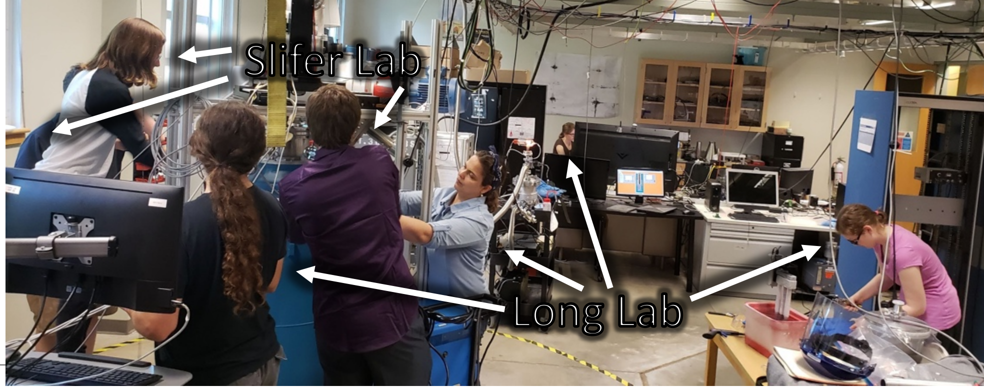
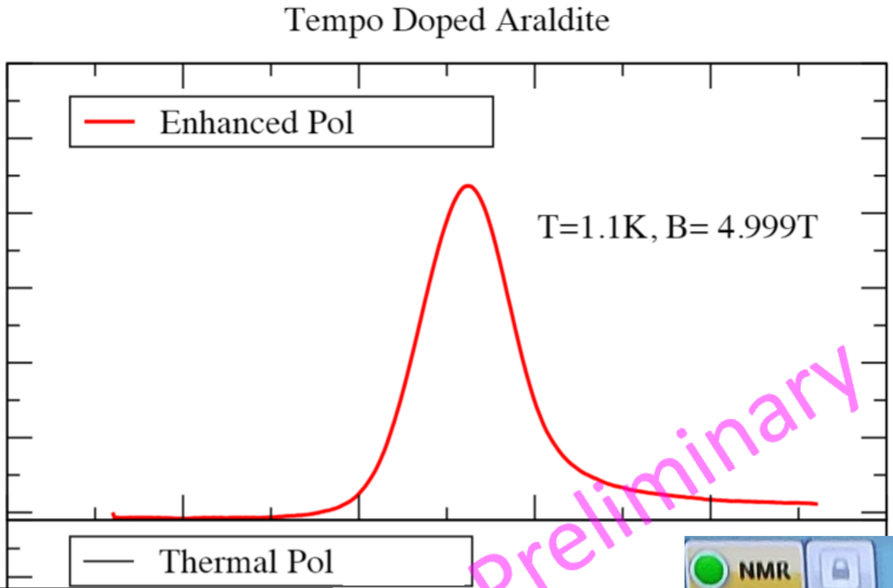




- UNH DNP Lab ***NOW FULLY OPERATIONAL!!***
  - First Proton TE: Nov. 2018 on Araldite
  - First Enhanced Proton: ~30 second later



So, How Much Longer?



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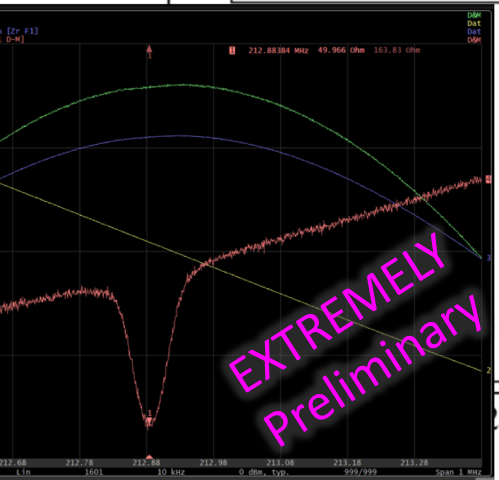
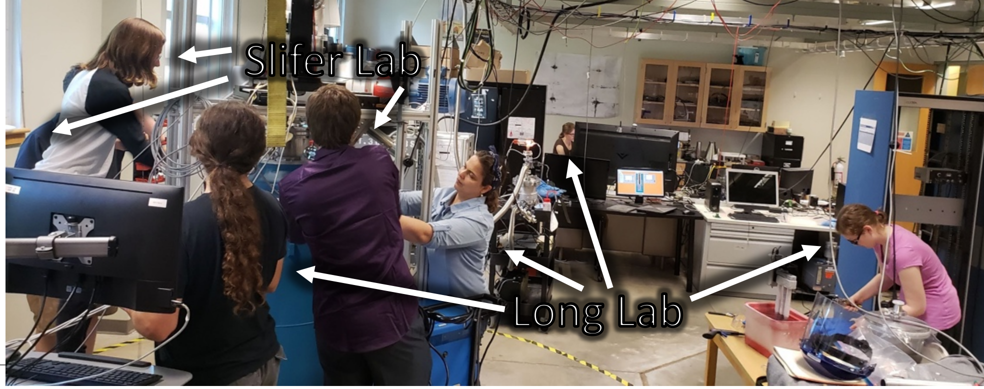
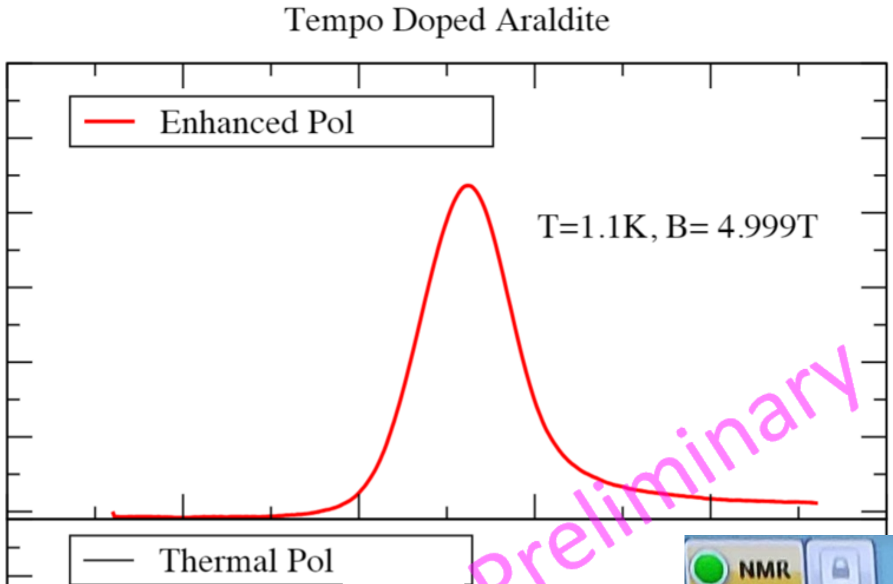


How Much Longer?





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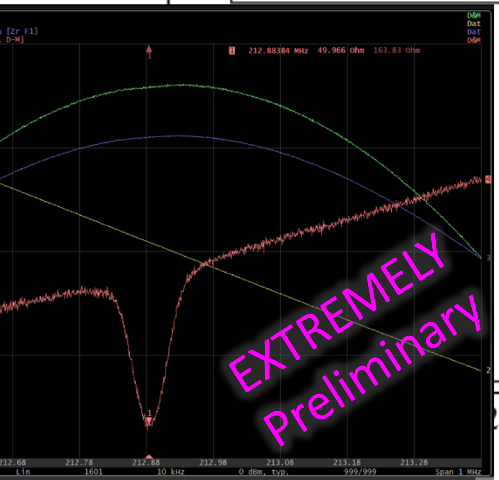

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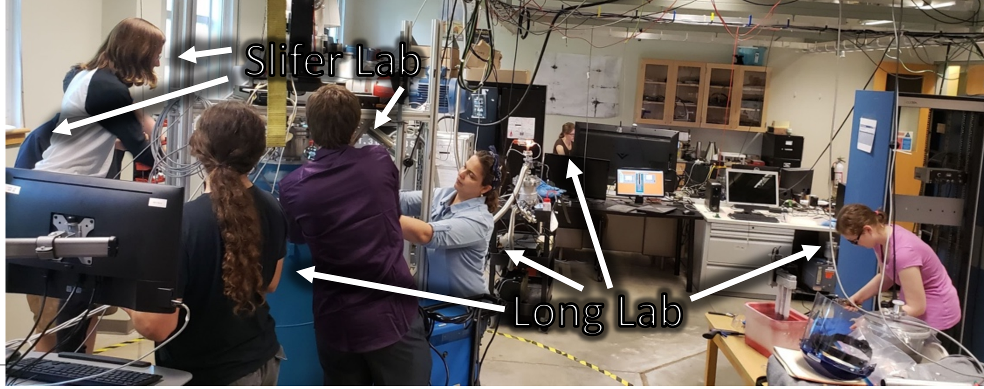

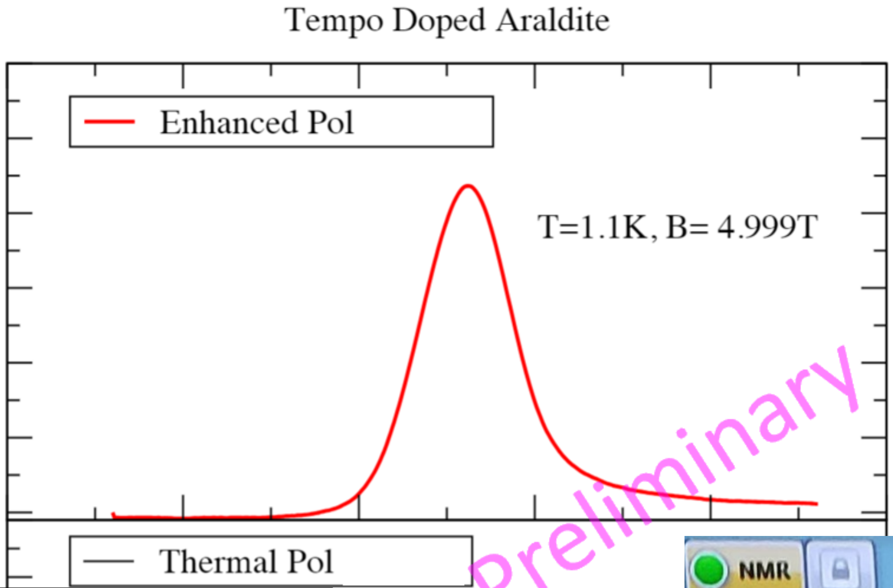

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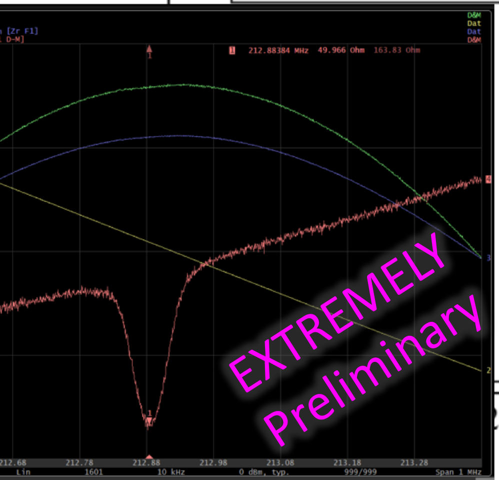
  - First Deuteron Measurements: Coming Summer 2019



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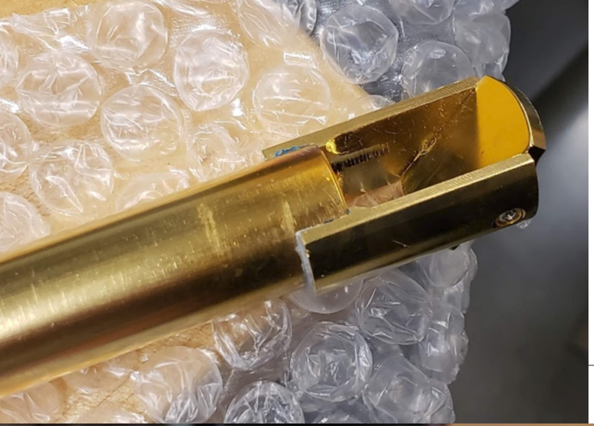
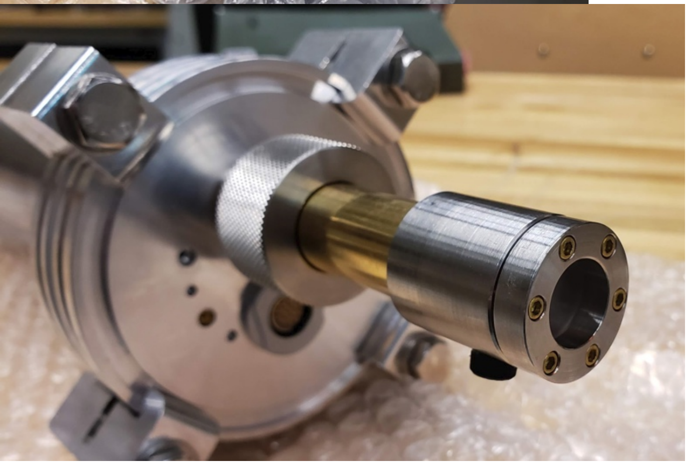
- 1^{st} 3D-printed target stick to survive 1K temperature cycling; no microfractures w/ off-the-shelf SLA resin!





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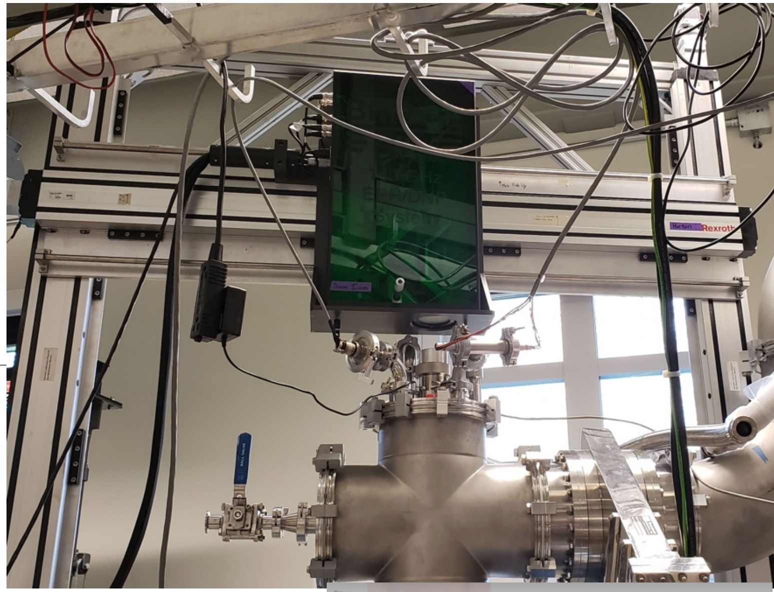
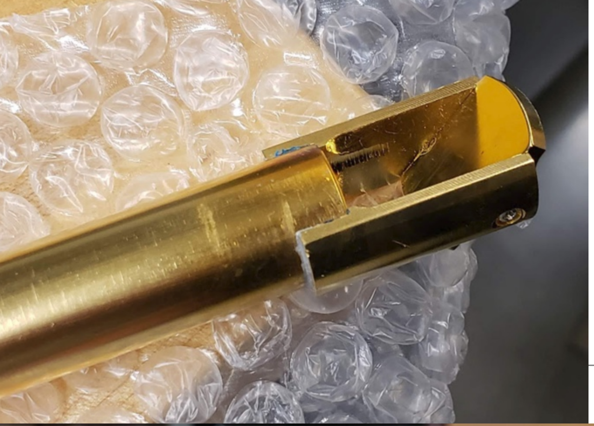
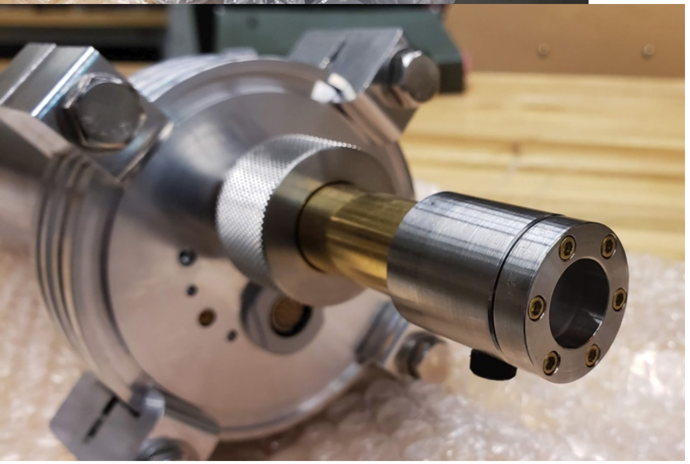


- 1st 3D-printed target stick to survive 1K temperature cycling; no microfractures w/ off-the-shelf SLA resin!
- New solid-state mm-wave system complete, capable of multiple frequencies to attempt $-P_{zz}$





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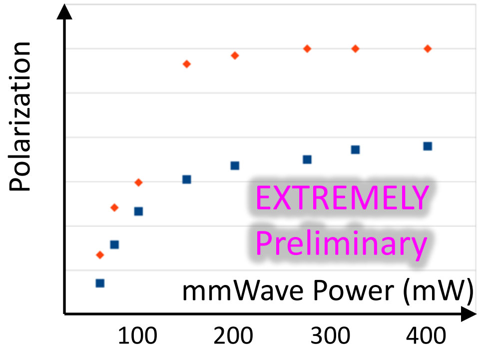

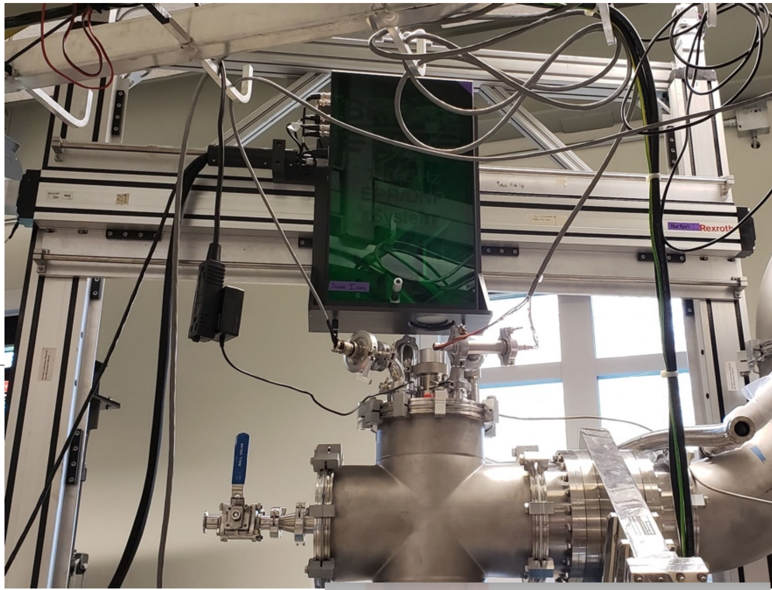

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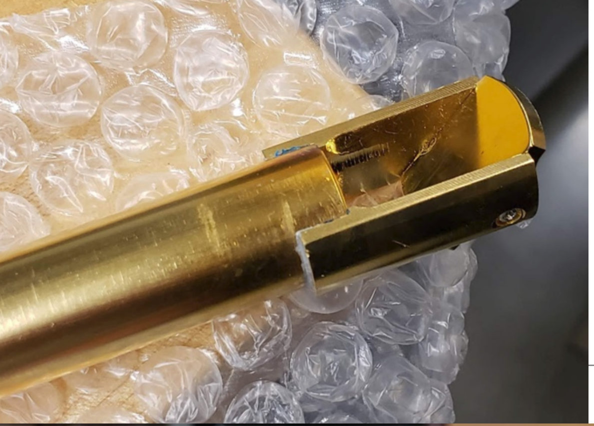

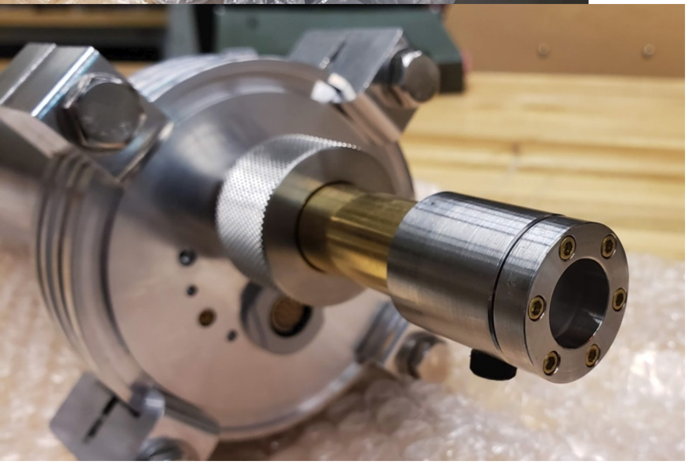

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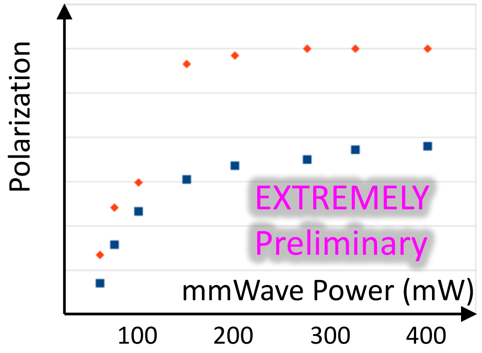

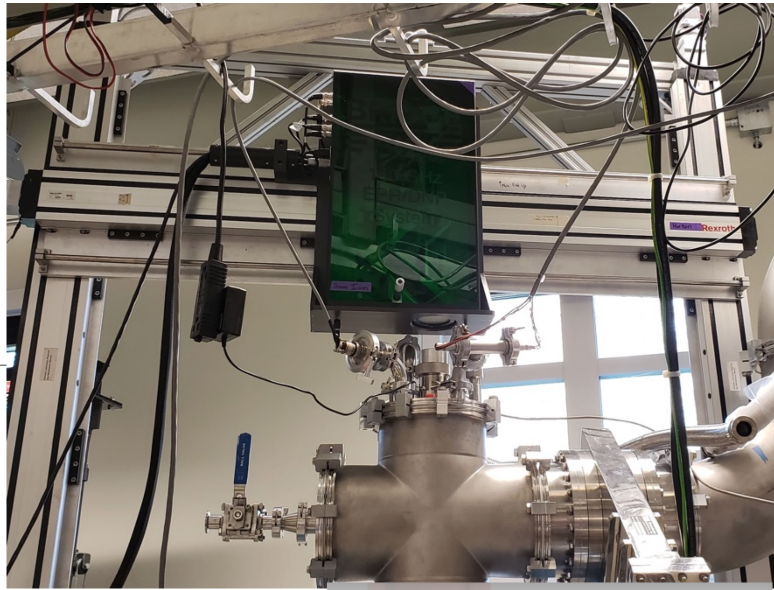

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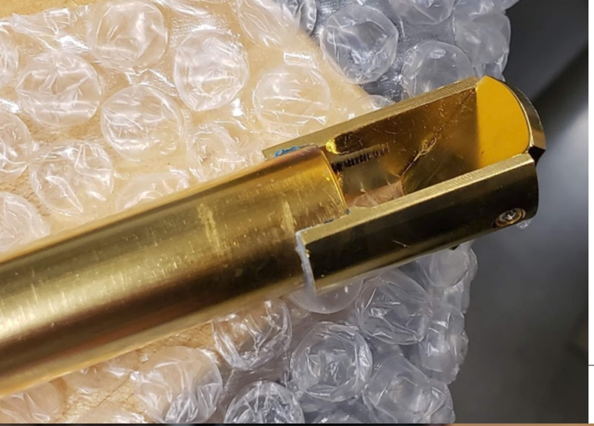

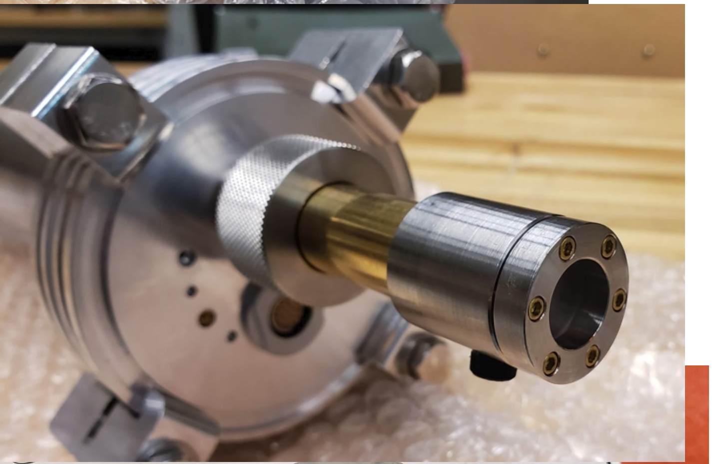

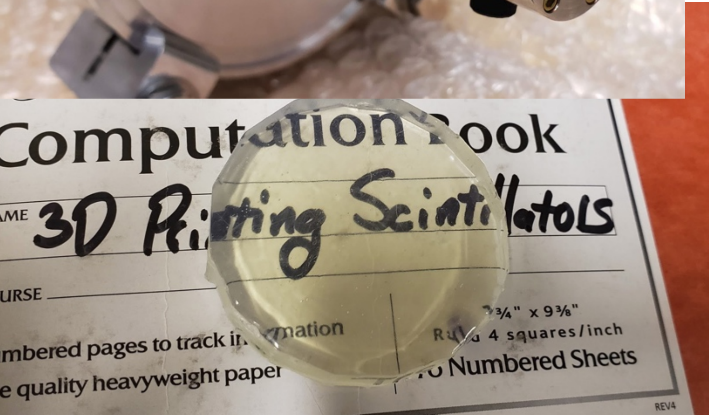

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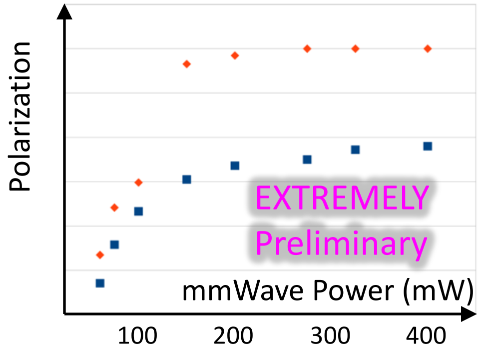

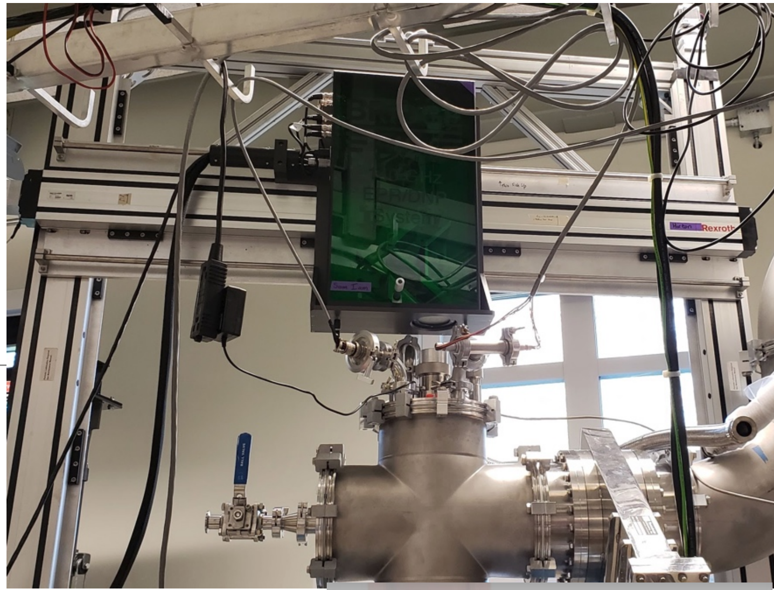

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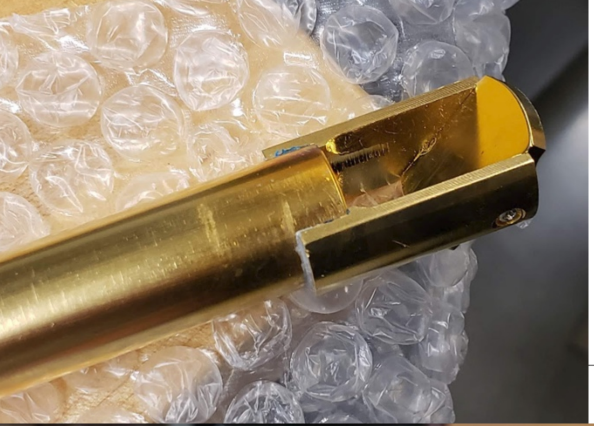
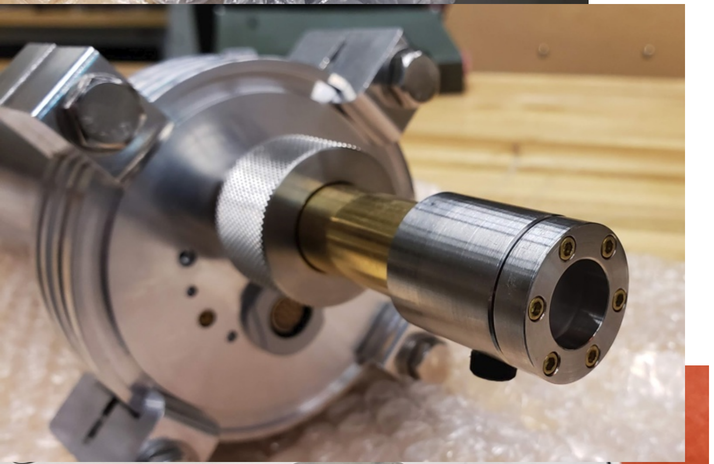
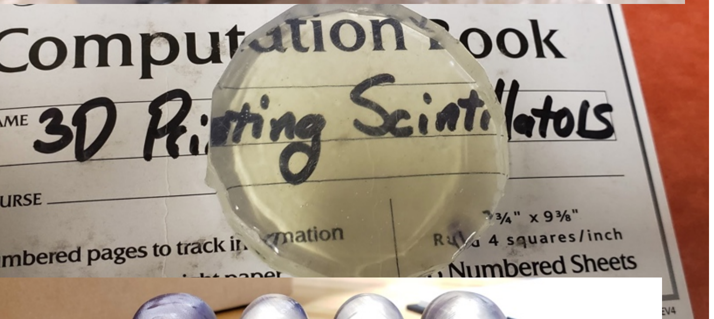
- 3D printing small scintillators for low-energy scattering/proof of P_{zz}







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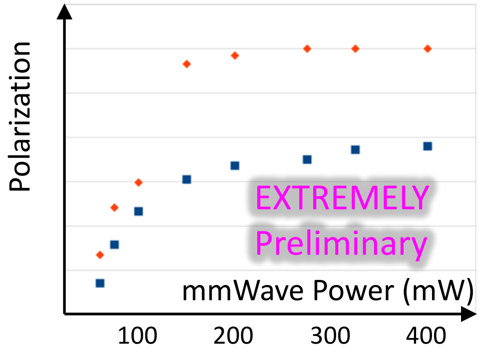

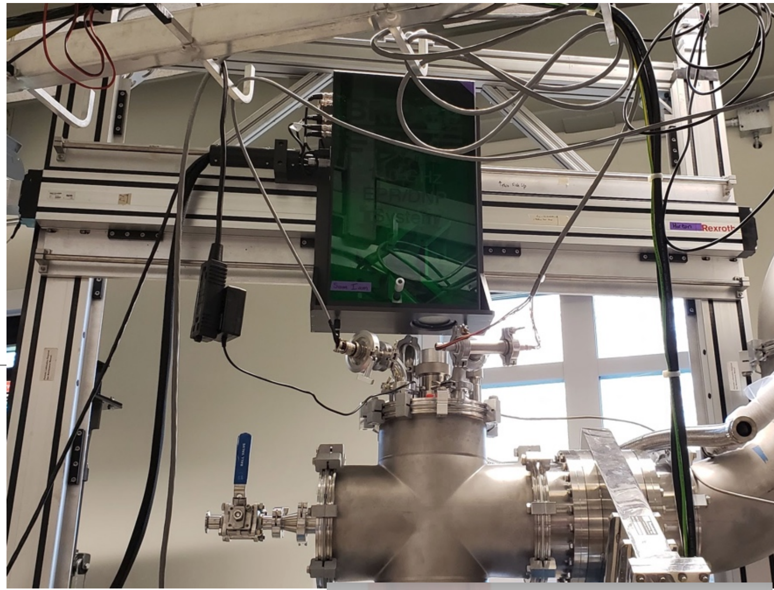

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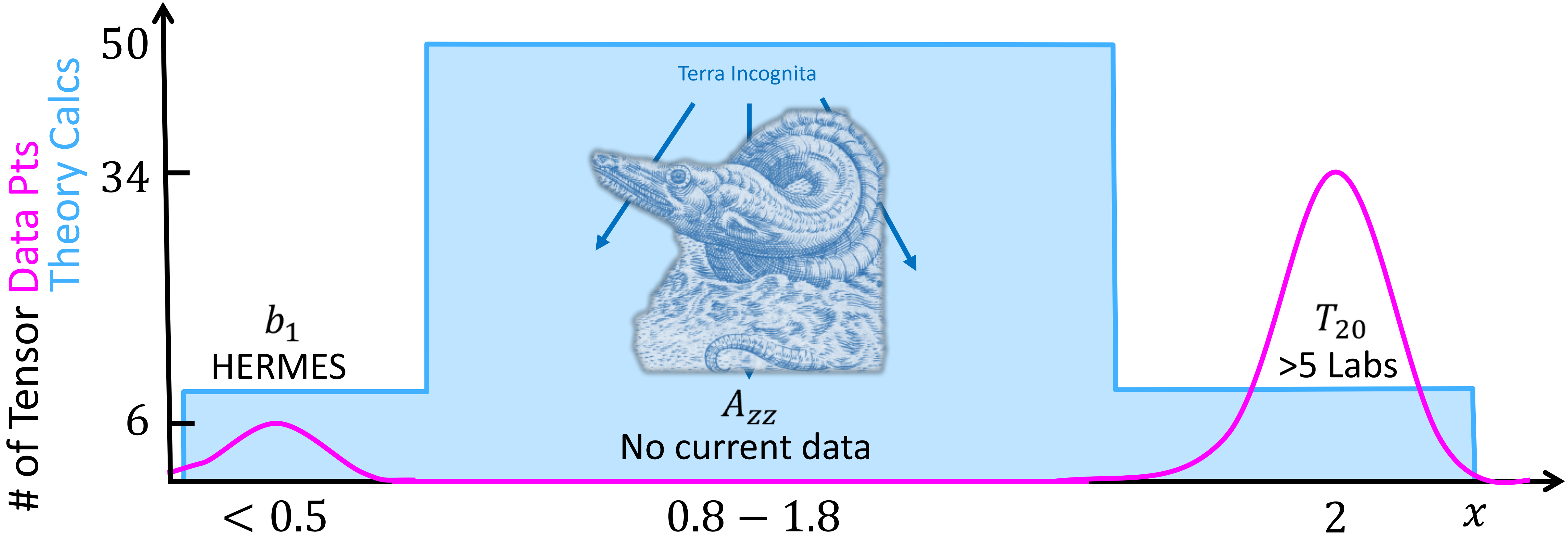
- Attempting to 3D print 10 MeV beamline for target material pre-irradiation with <$4k printer

Where We Are and Where We're Going



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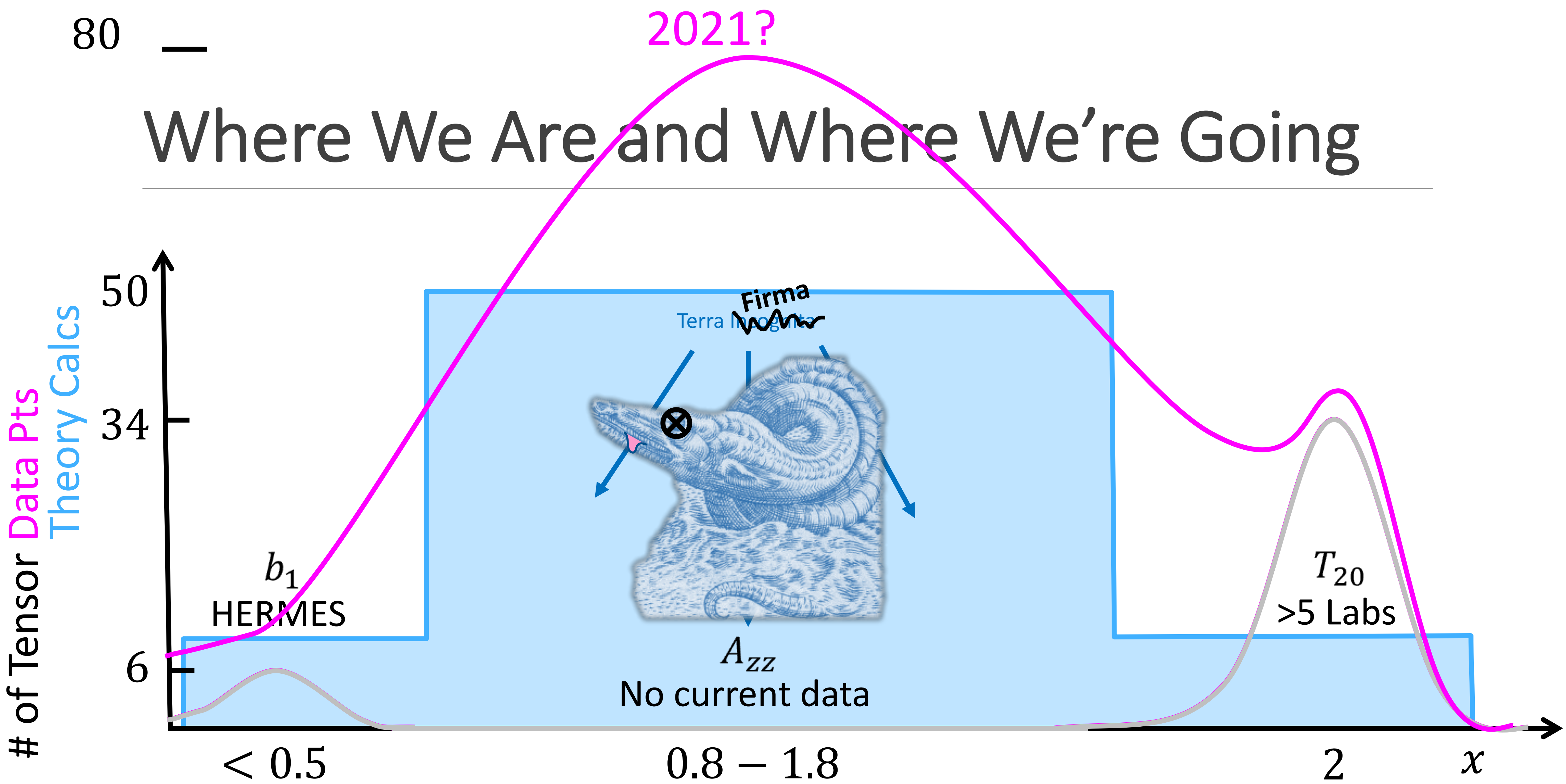
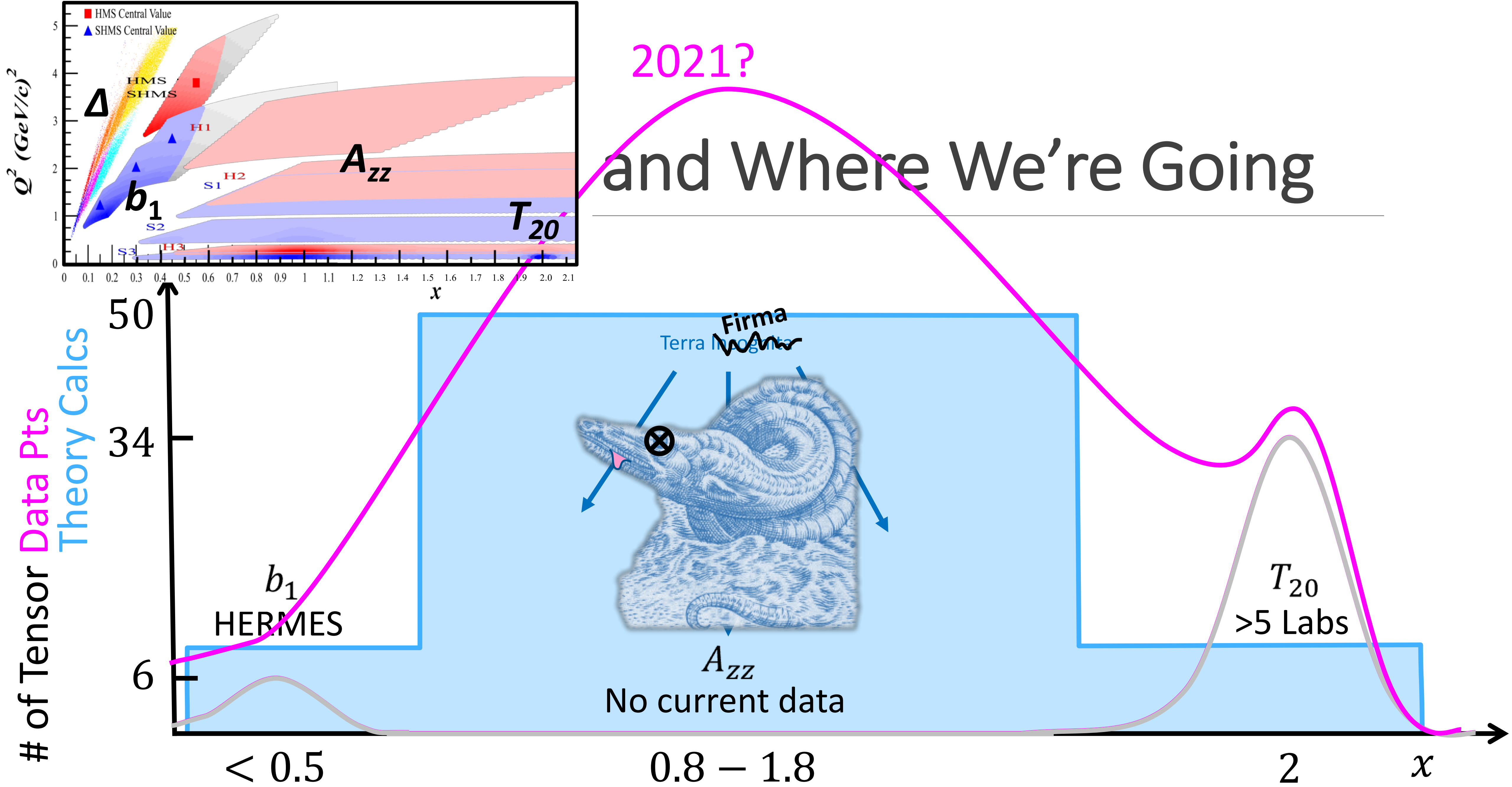


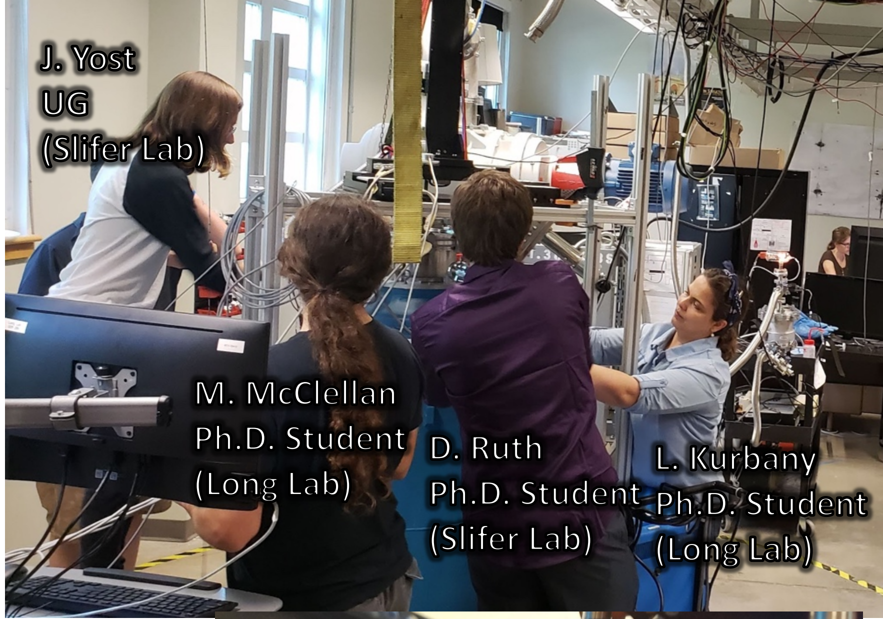
and Where We're Going

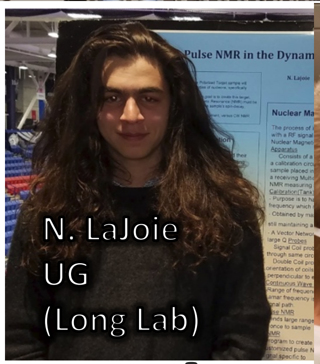


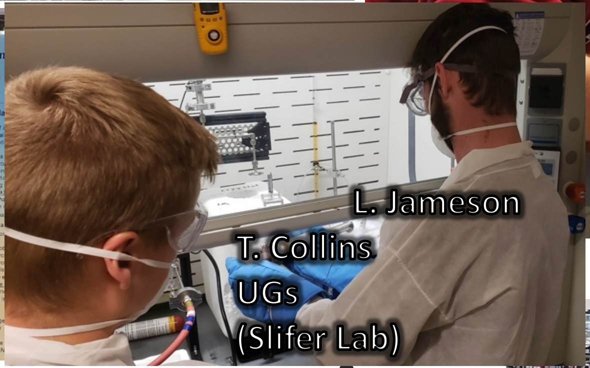

E. Granok
UG
(Long Lab)


K. McGuire
UG
(Long Lab)


R. Williams
UG
(Long Lab)

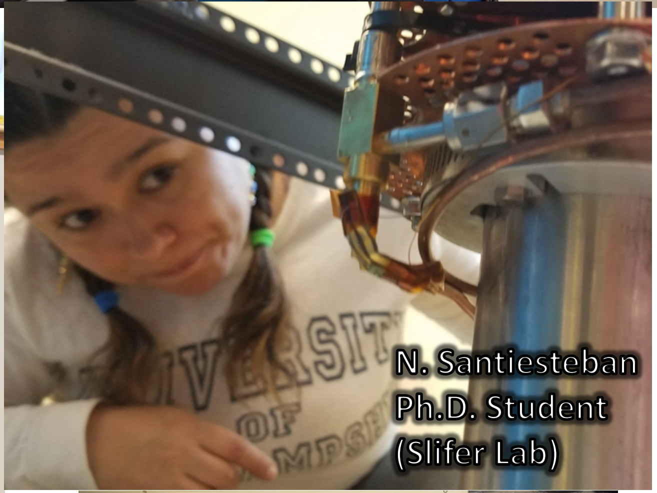

J. Yost
UG
(Slifer Lab)
M. McClellan
Ph.D. Student
(Long Lab)
D. Ruth
Ph.D. Student
(Slifer Lab)
L. Kurbany
Ph.D. Student
(Long Lab)

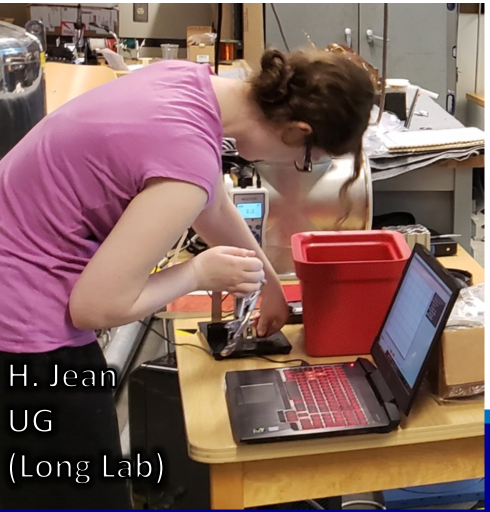

Pulse NMR in the Dynam
N. LaJoie
UG
(Long Lab)

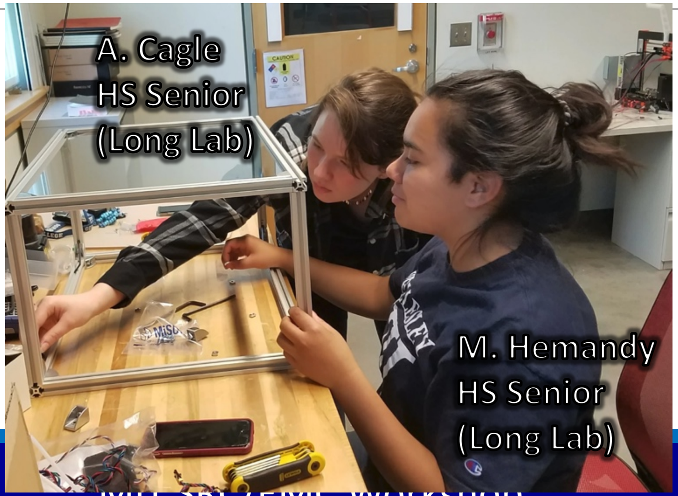

L. Jameson
T. Collins
UGs
(Slifer Lab)

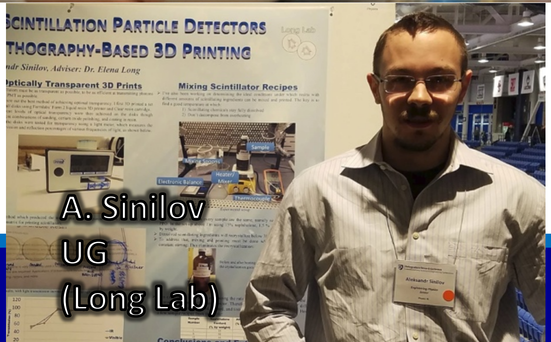
Thank you!


K. Slifer


N. Santiesteban
Ph.D. Student
(Slifer Lab)


H. Jean
UG
(Long Lab)


A. Cagle
HS Senior
(Long Lab)
M. Hemandy
HS Senior
(Long Lab)


SCINTILLATION PARTICLE DETECTORS
THOGRAPHY-BASED 3D PRINTING
A. Sinilov
UG
(Long Lab)