Electron nuclear scattering measurements for neutrino physics

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University of York

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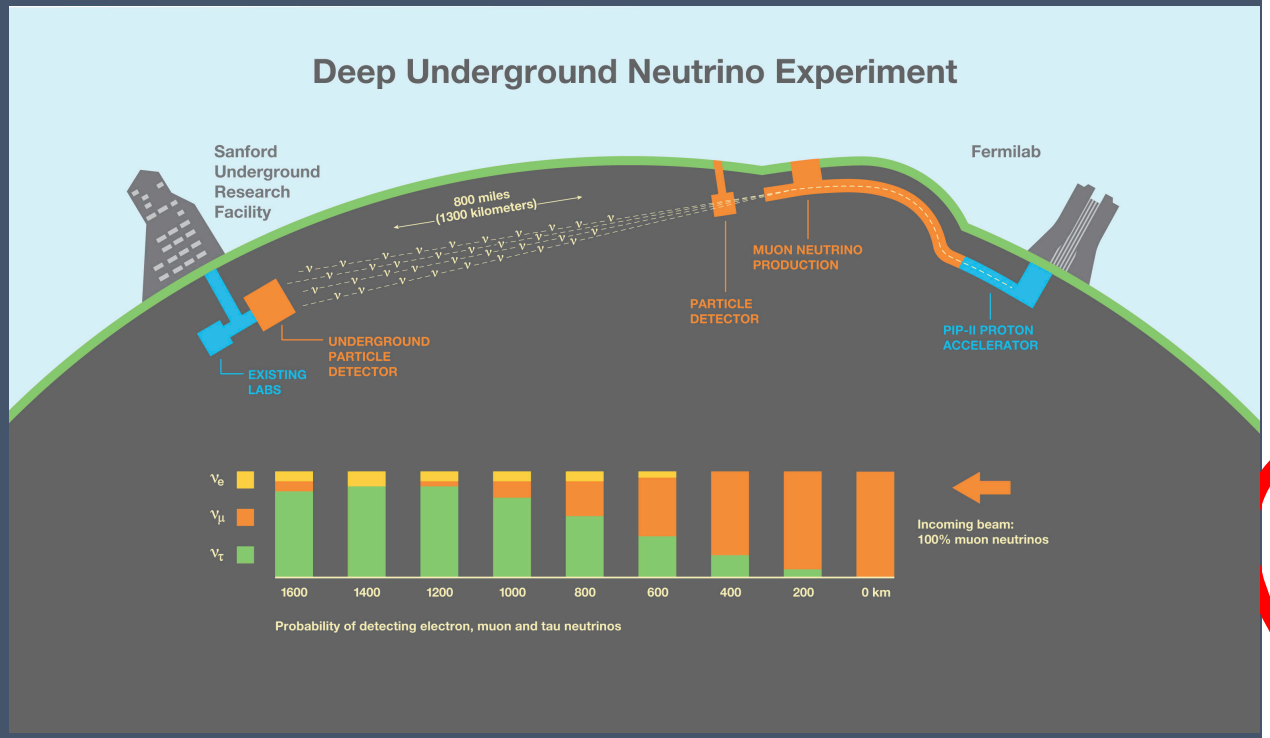
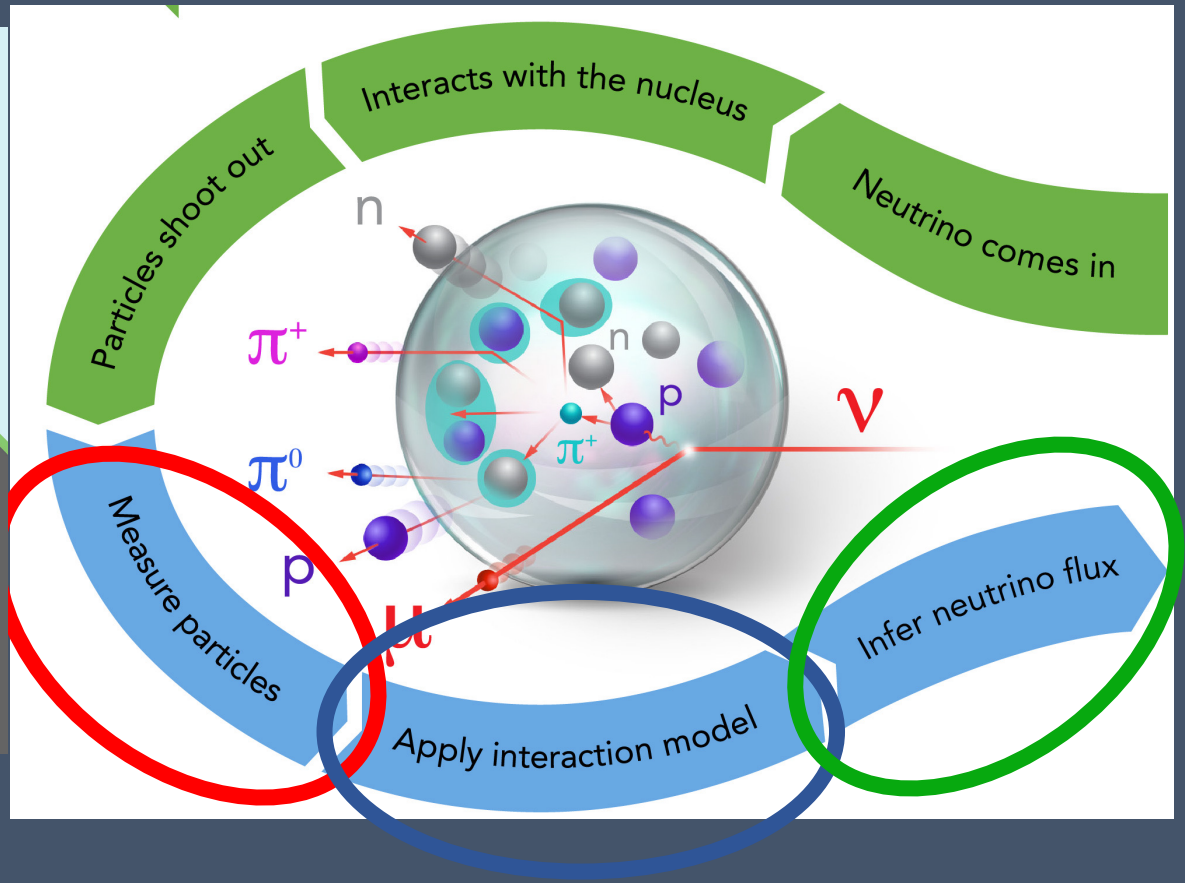
Outline

- Electrons4neutrinos@CLAS(JLAB)
- Weak form factors of heavy nuclei
- Nuclear spin polarized media

Neutrino detection via neutrino-nucleus reactions

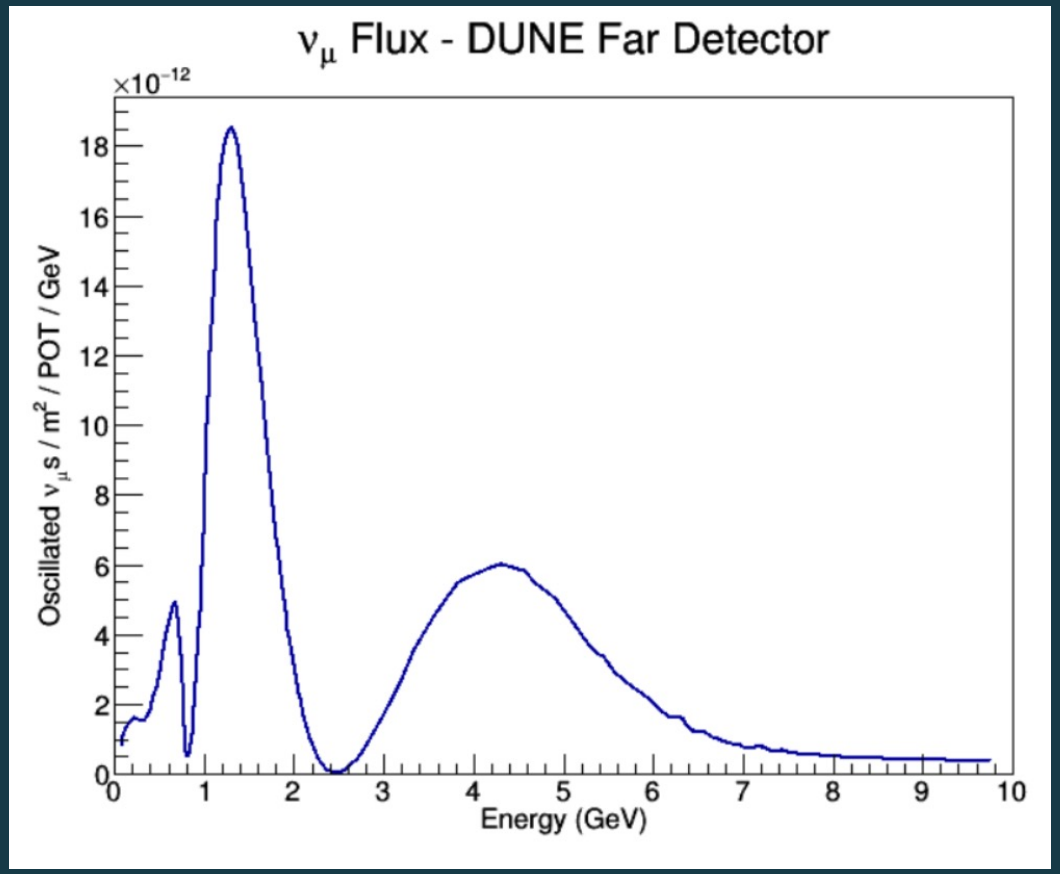


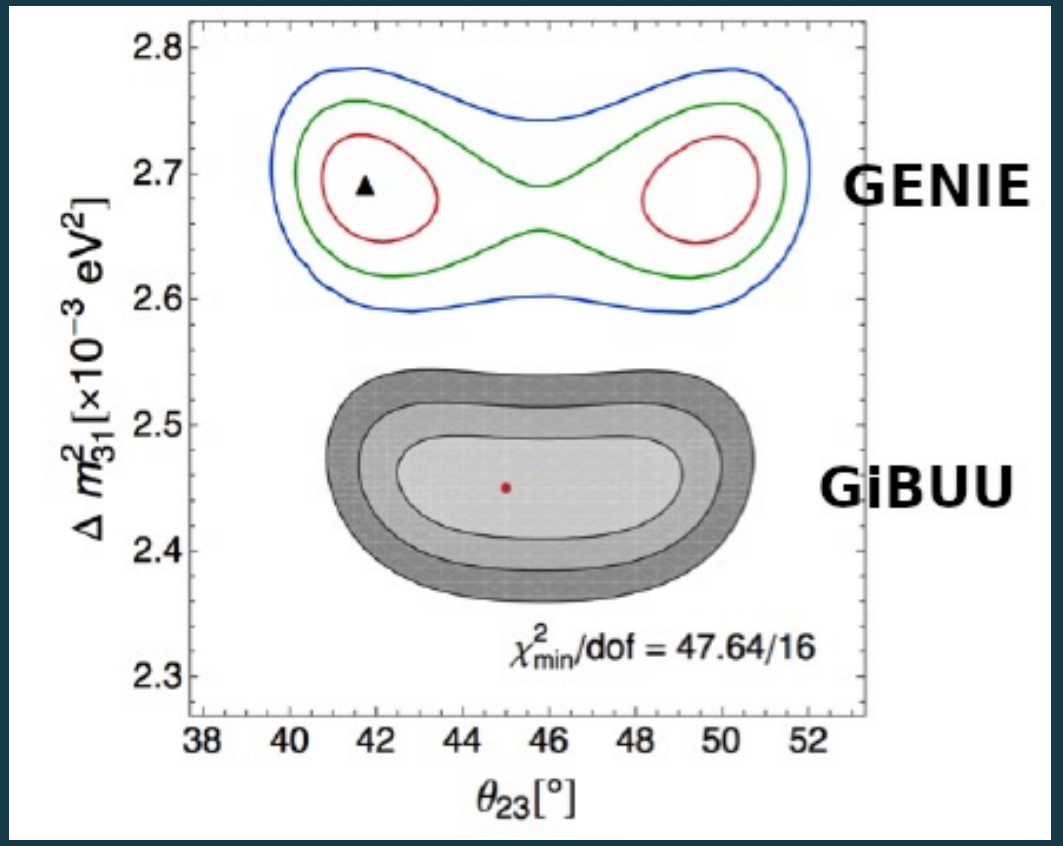


$$N(E_{rec}, L) = \sum_i \int \Phi(E, L) \times \sigma_i(E) f_{\sigma_i}(E, E_{rec}) dE$$

Nuclear physics – a large systematic for DUNE

$$P_{\nu_\alpha \to \nu_\beta}(E_{true}, L) \approx \sin^2(2\theta) \sin^2\left(\frac{\Delta m^2 L}{E_{true}}\right)$$





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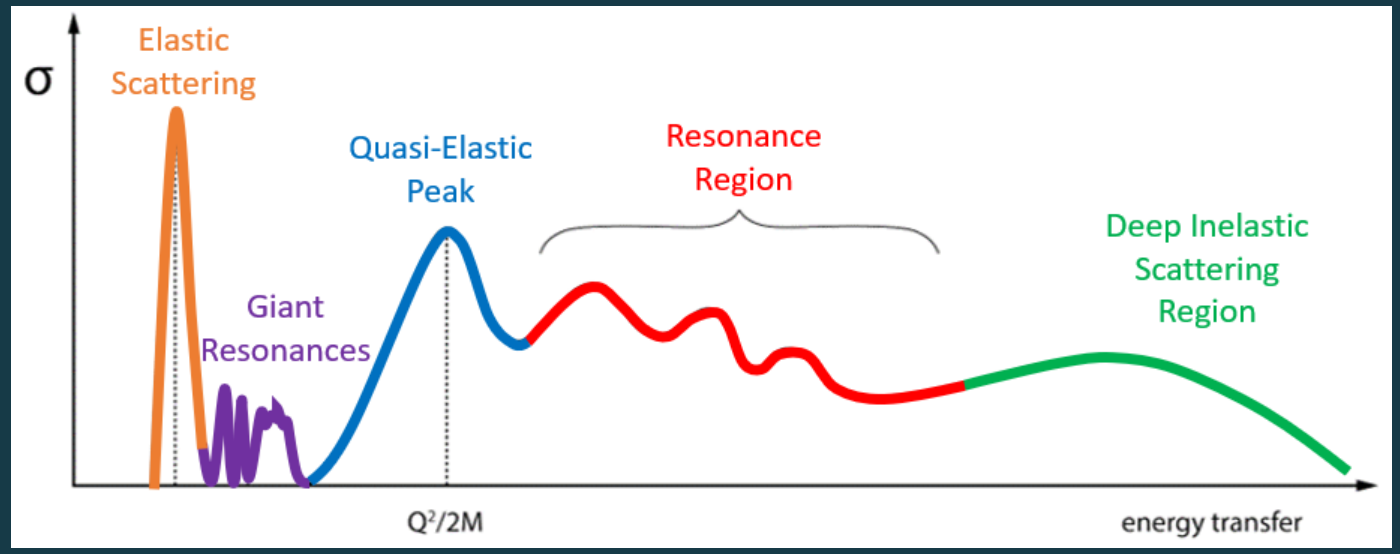
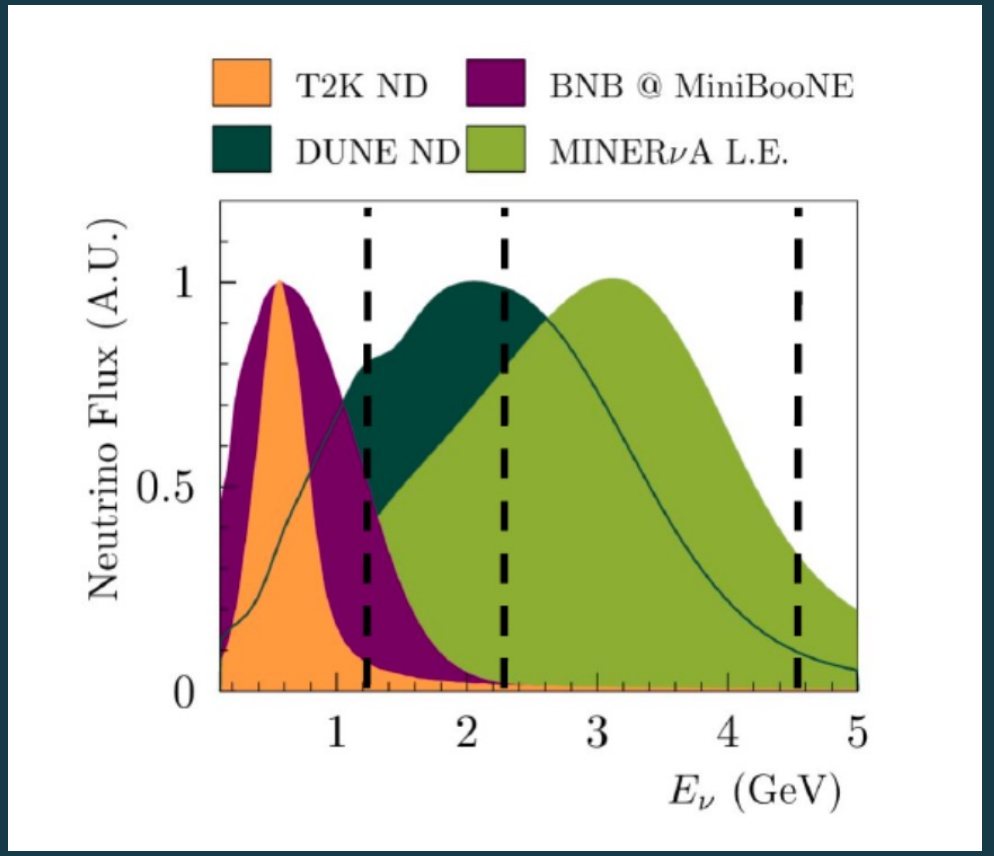
It is getting messy!

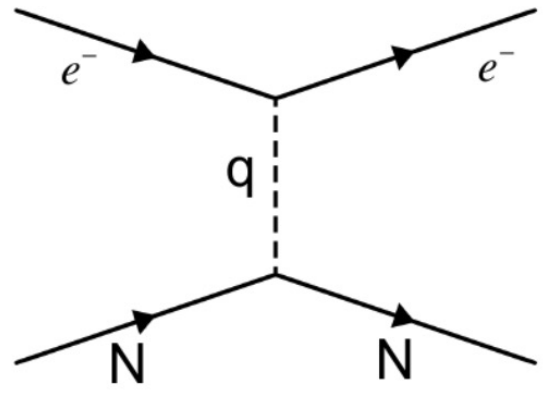




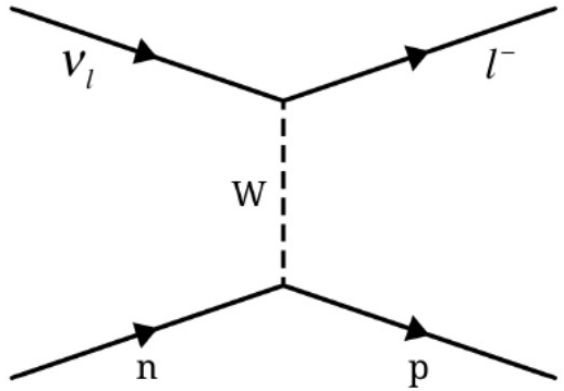
Many resonances
Many decay modes
Medium modifications poorly established (mass, width)
Axial form factors for resonance excitation..
A challenge!

e4nu

- Quasi-Elastic scattering off nuclei similar with both electrons and neutrinos



$$e^- + N \rightarrow e^- + N$$



$$\nu_l + n \rightarrow l^- + p$$

$$\bar{\nu}_l + p \rightarrow l^+ + n$$

Large interdisciplinary team of theorists and experimentalists

ODU, JLAB, FNAL, LBNL, MIT, Tel Aviv, MSU, Rutgers, Oxford, Edinburgh, Pittsburgh, Texas (Arlington), William and Mary , York

Beam energy accurately known

Monoenergetic

High intensity -> many final states

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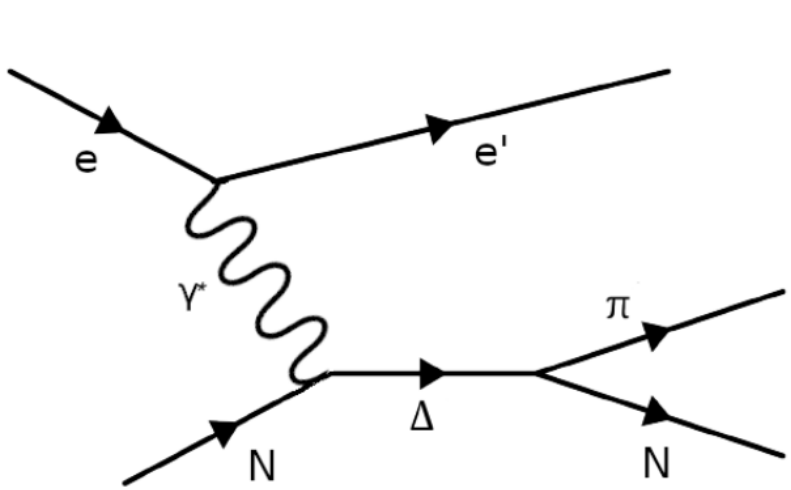
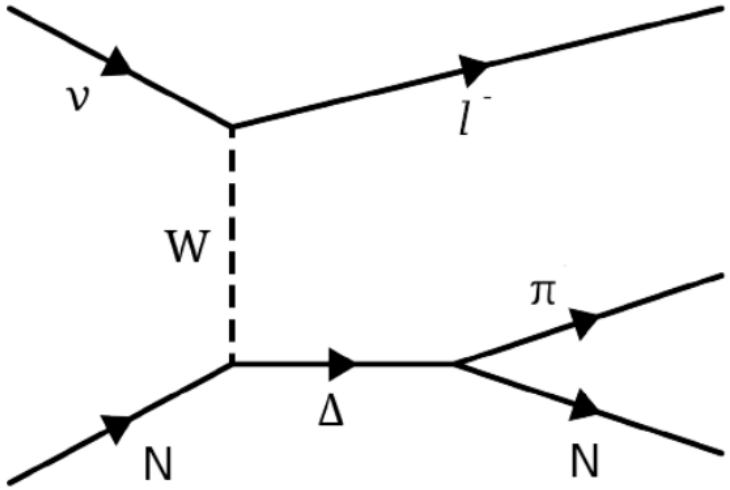
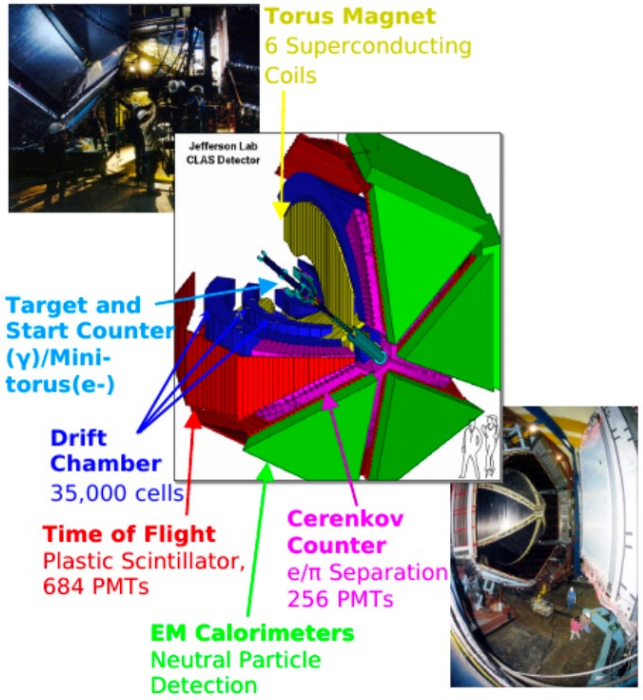
- Resonance production from electrons also similar to that from neutrinos





Jefferson Lab

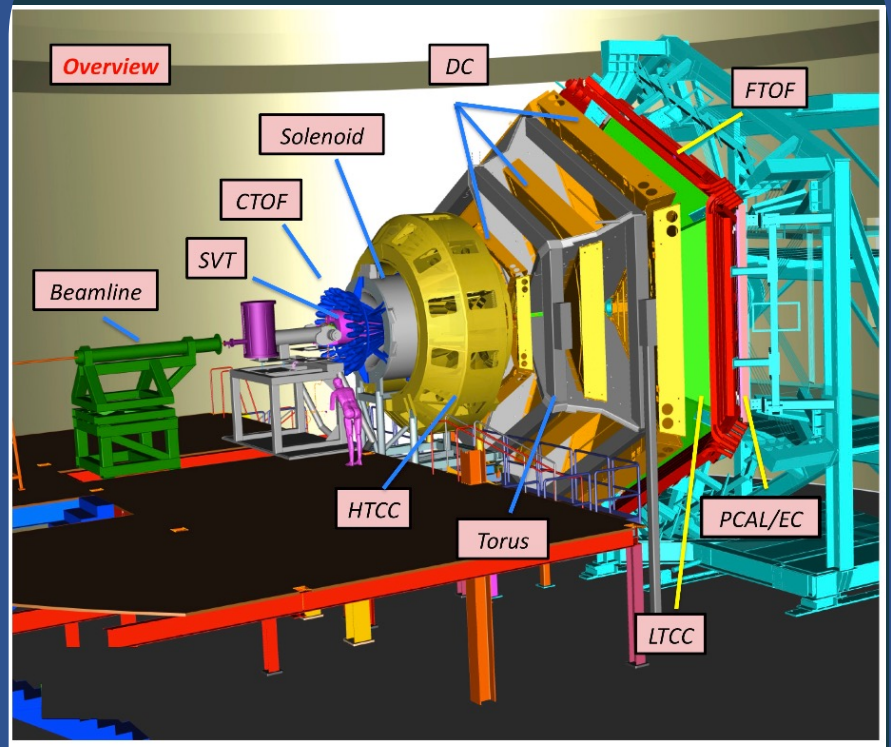
CLAS6



NIM A, 503(3), 2003

	1.1 GeV	2.2 GeV	4.4 GeV
^{3}He	✓	✓	✓
^{4}He	—	✓	✓
^{12}C	✓	✓	✓
^{56}Fe	—	✓	✓

CLAS12

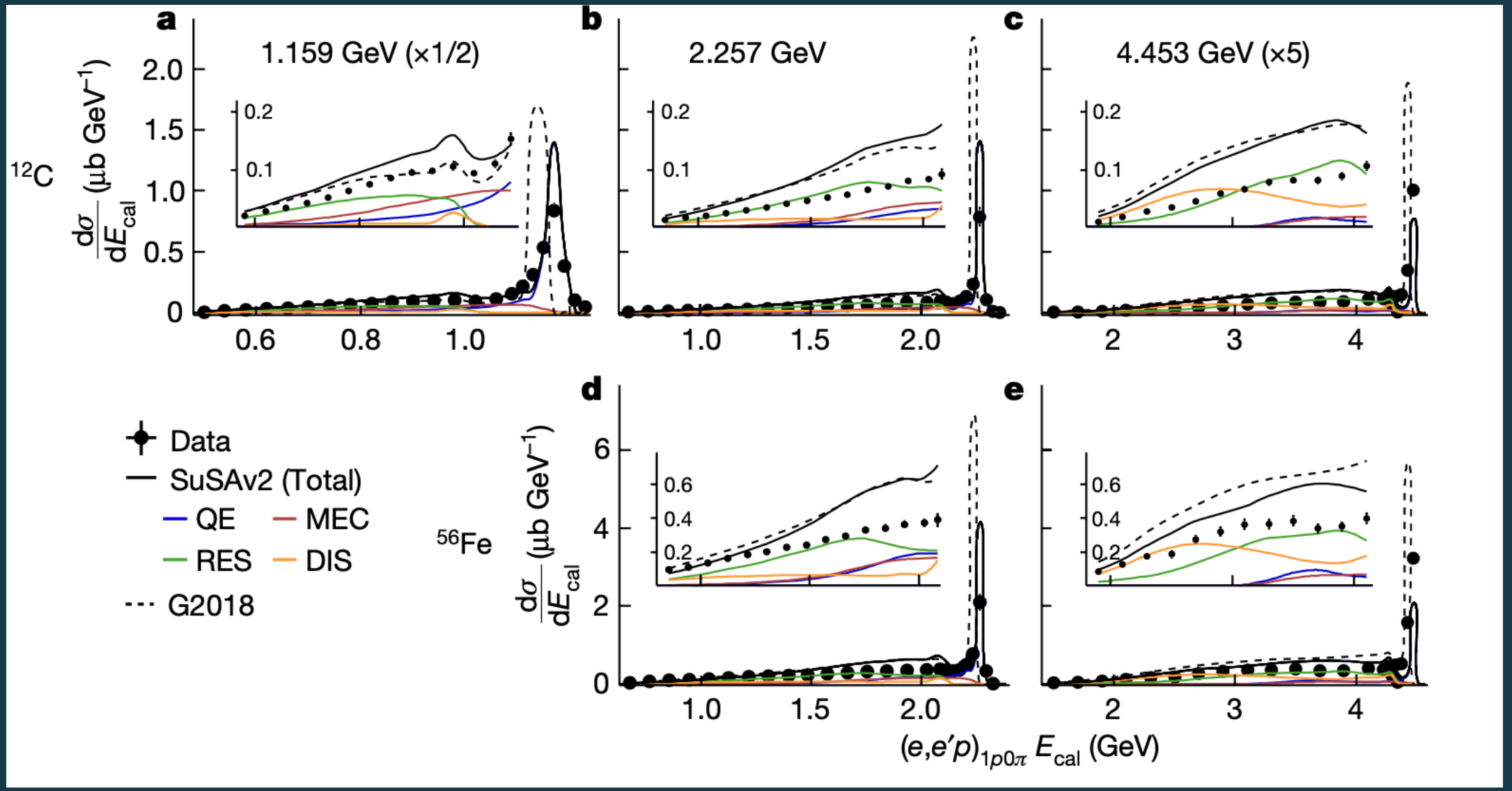


NIM A, 967, 163898 (2020)

More nuclei (D,Ca,Ar,Sn), E_e=1,2,4,6 GeV. Smaller scattering angles, wider range of q

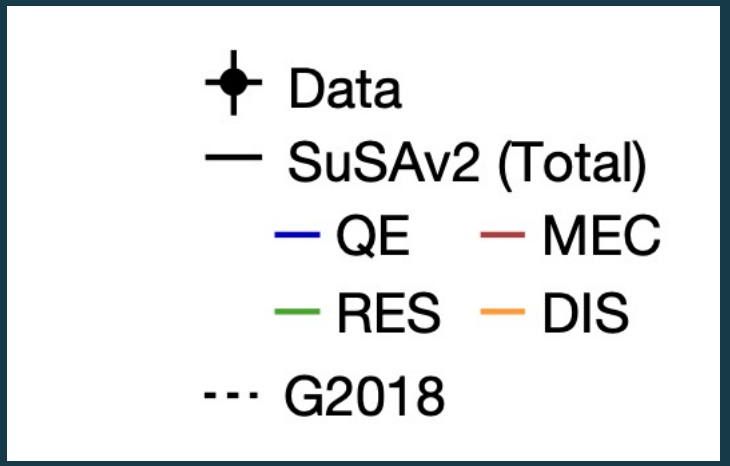
Calibrations *almost* complete

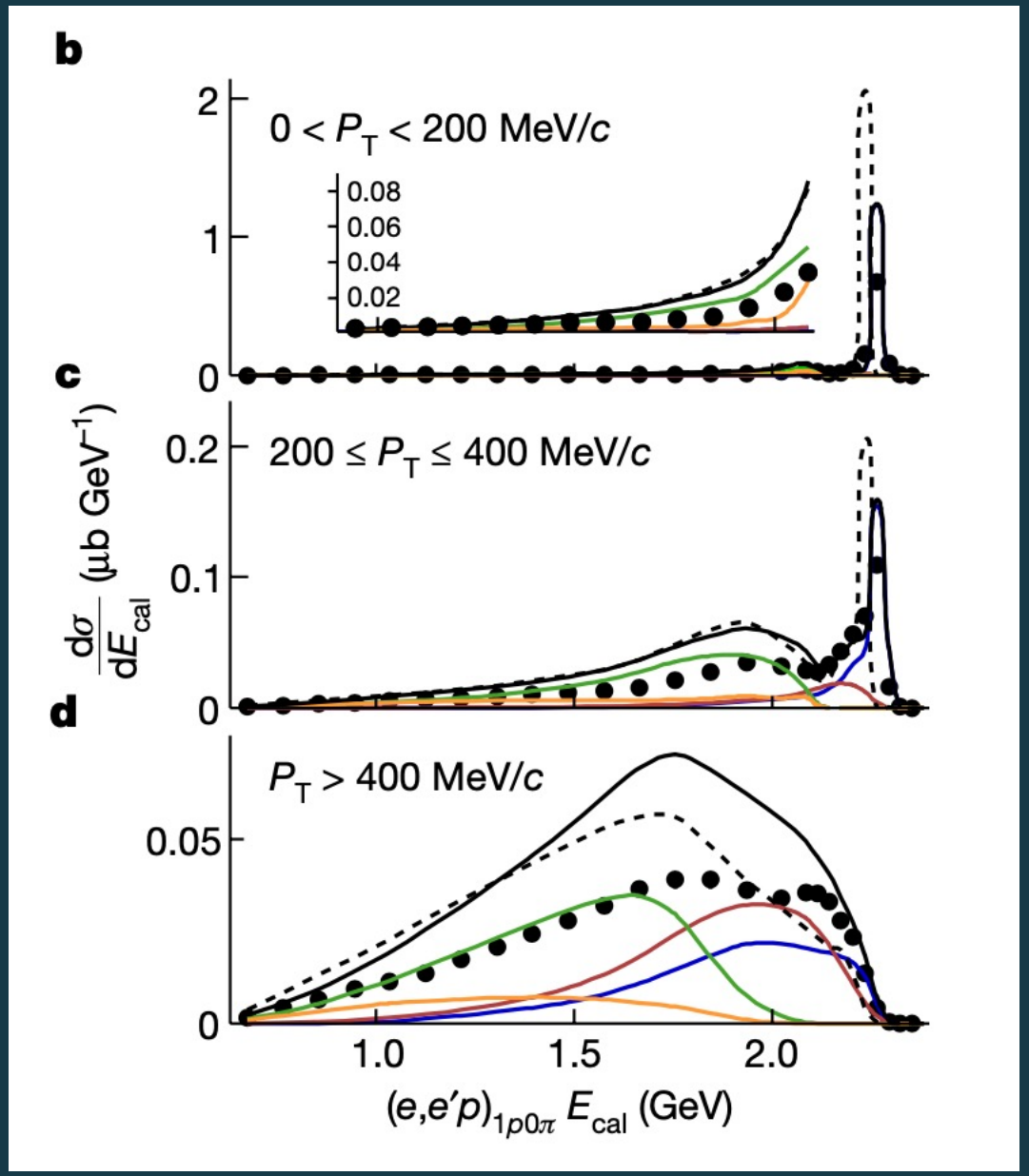
E4nu: CLAS6 1p0π data



Ref: Khachatryan, M., Papadopoulou, A., Ashkenazi, A. *et al. Nature* **599**, 565–570 (2021). https://doi.org/10.1038/s41586-021-04046-5

E4nu: CLAS6 1p0π data





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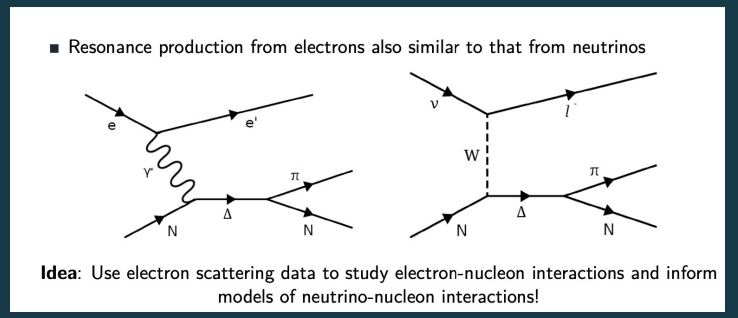
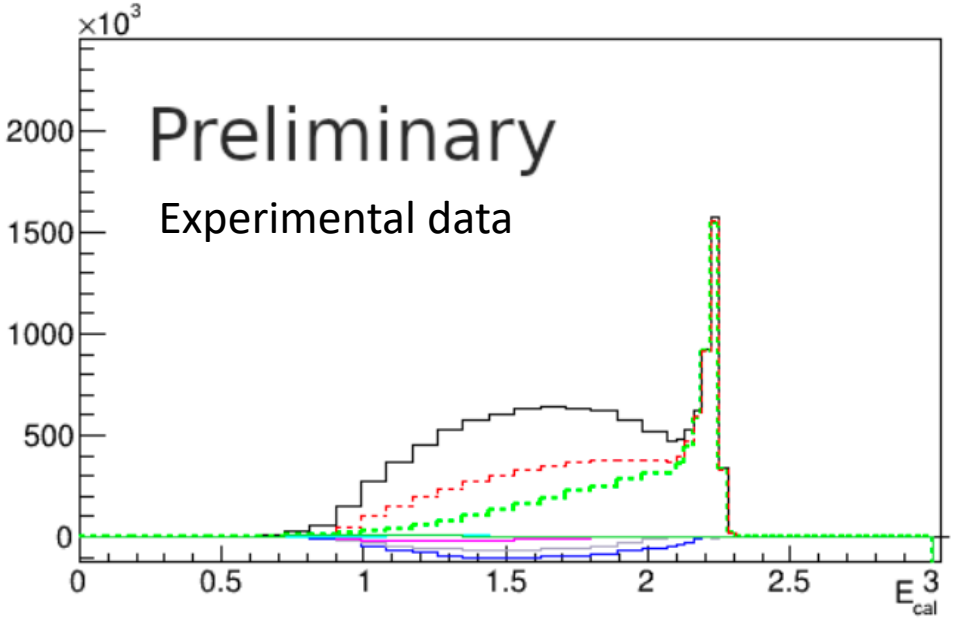
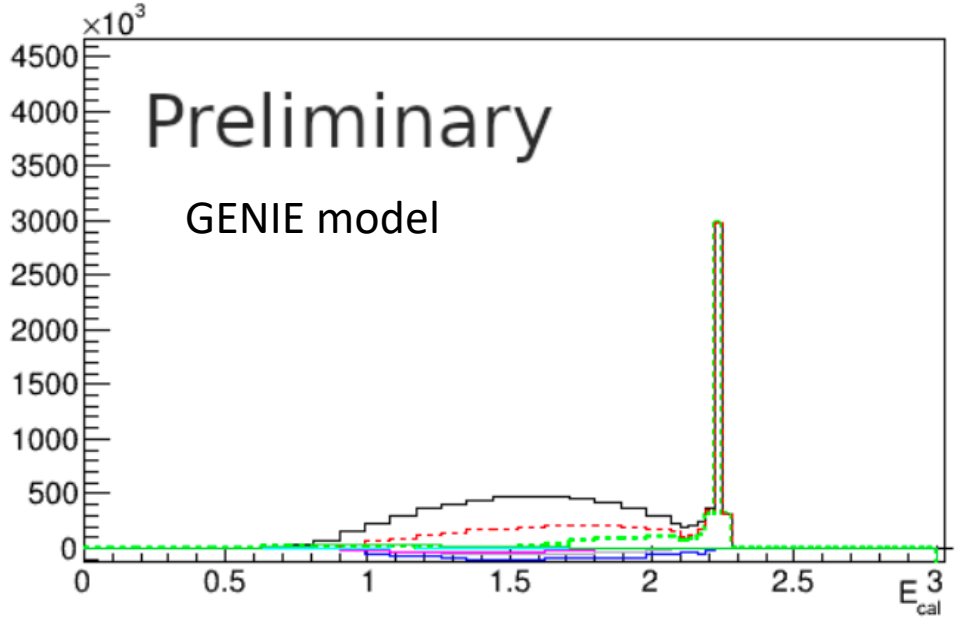
E4nu: CLAS6 1p1π data



Left: Data, Right: GENIE MC

Black: ≥1p≥1π Events, Red: 1p1π Events, Green: Subtracted Spectrum





Fegan (York); Hand, Weinstein (ODU)

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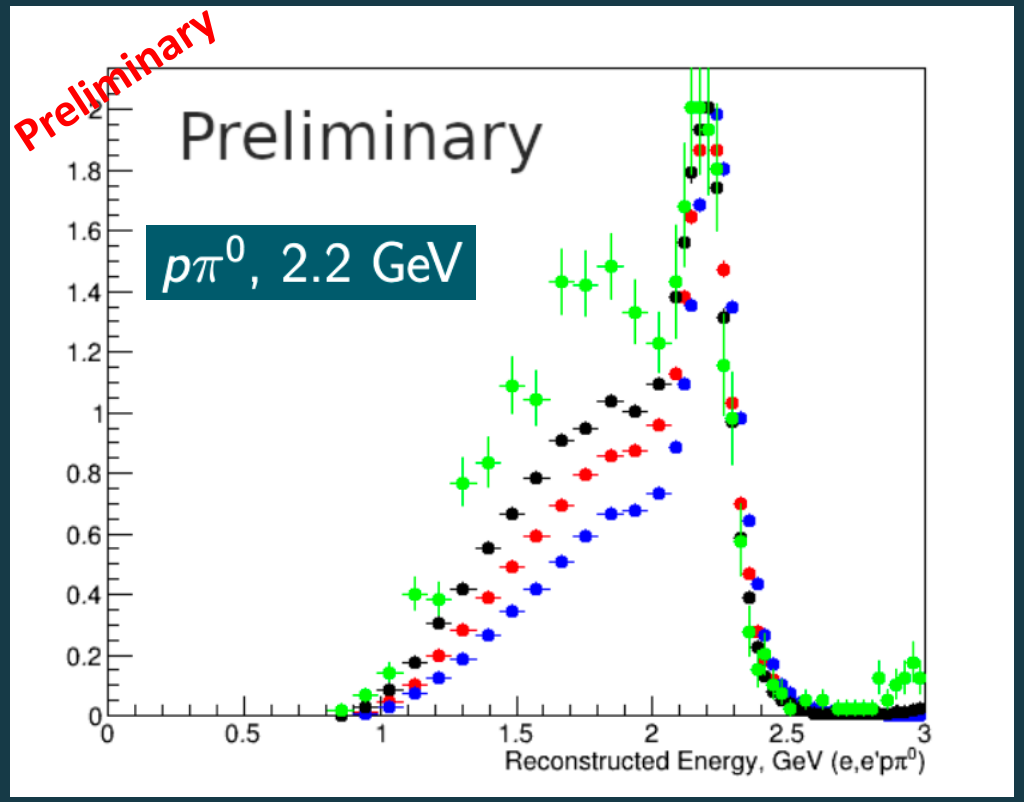
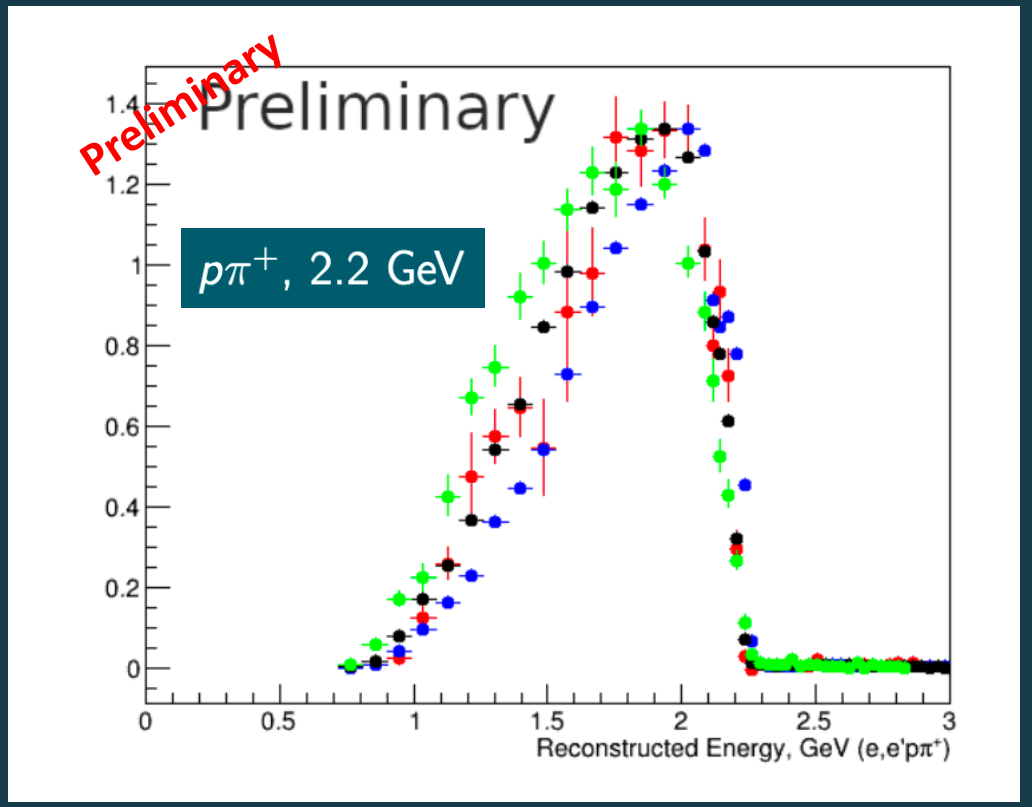
E4nu: CLAS6 1p1π data

^{3}He, ^{4}He, ^{12}C, ^{56}Fe,





Fegan (York); Hand, weinstein (ODU)

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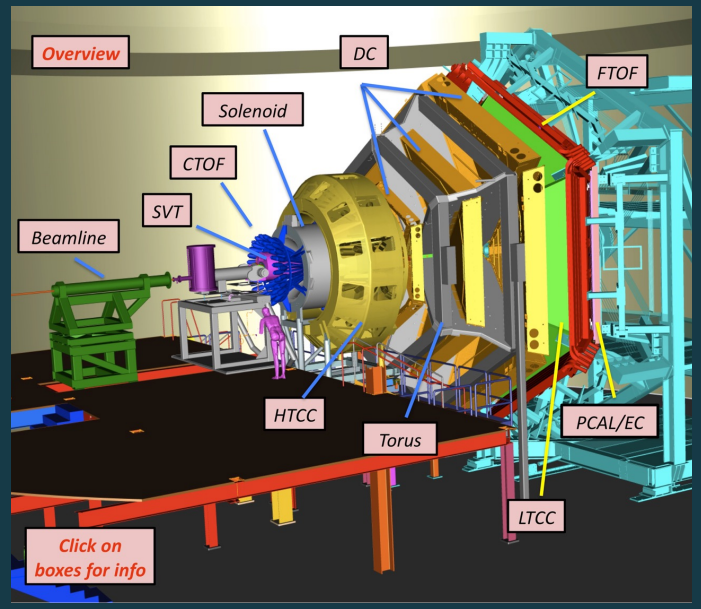
E4nu – Start of the CLAS12 era



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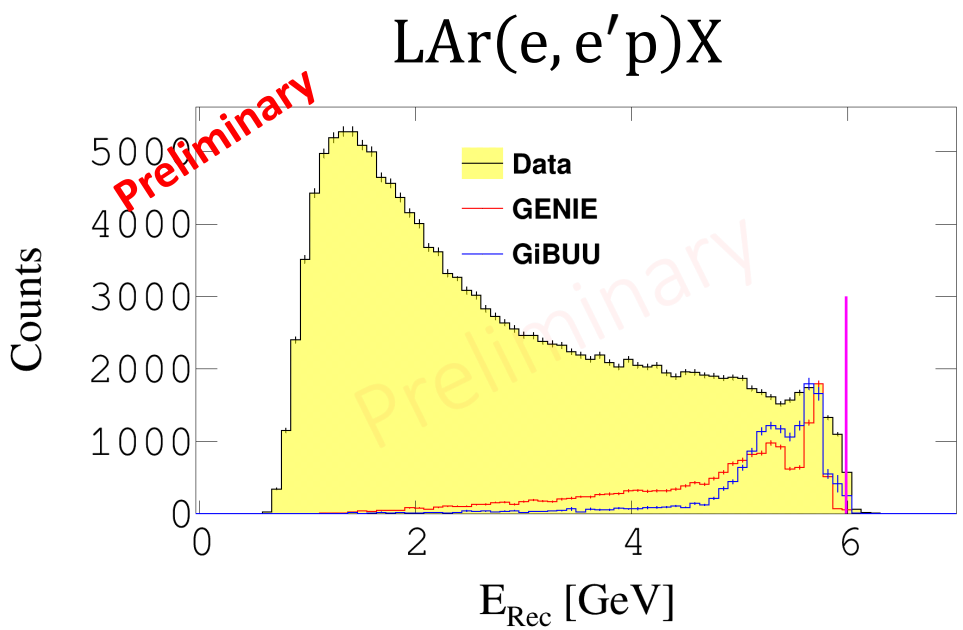
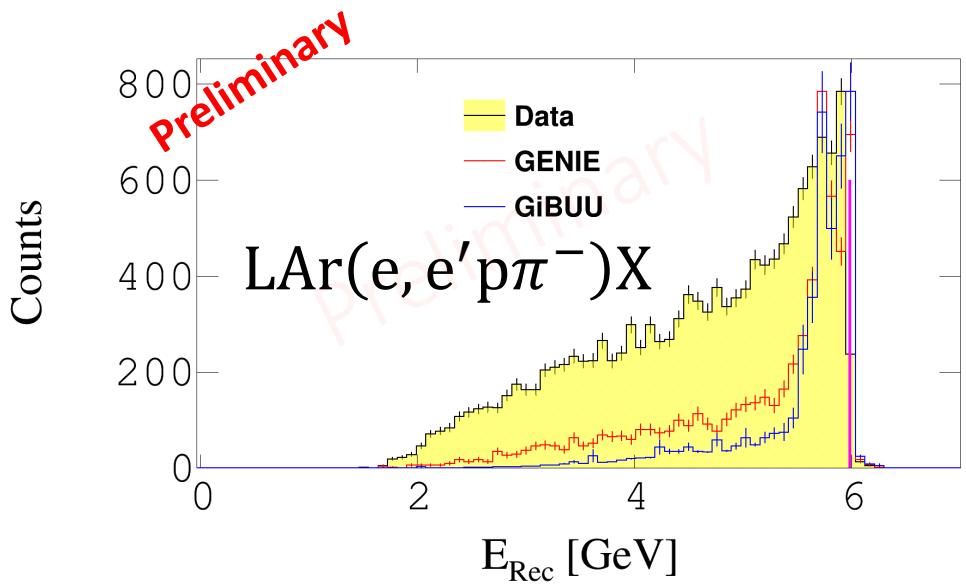
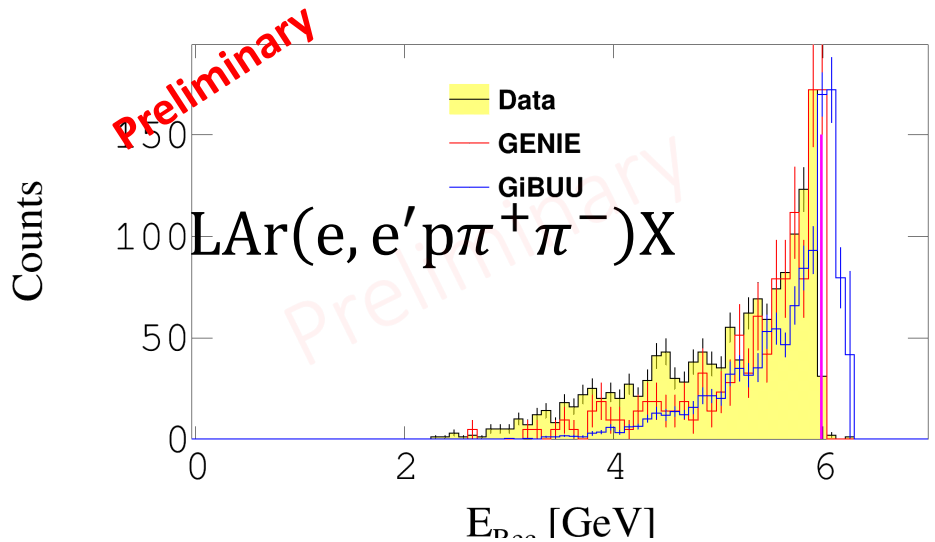
e4nu@CLAS12 – Liquid argon target







PhD Williams (York)
~5% of data

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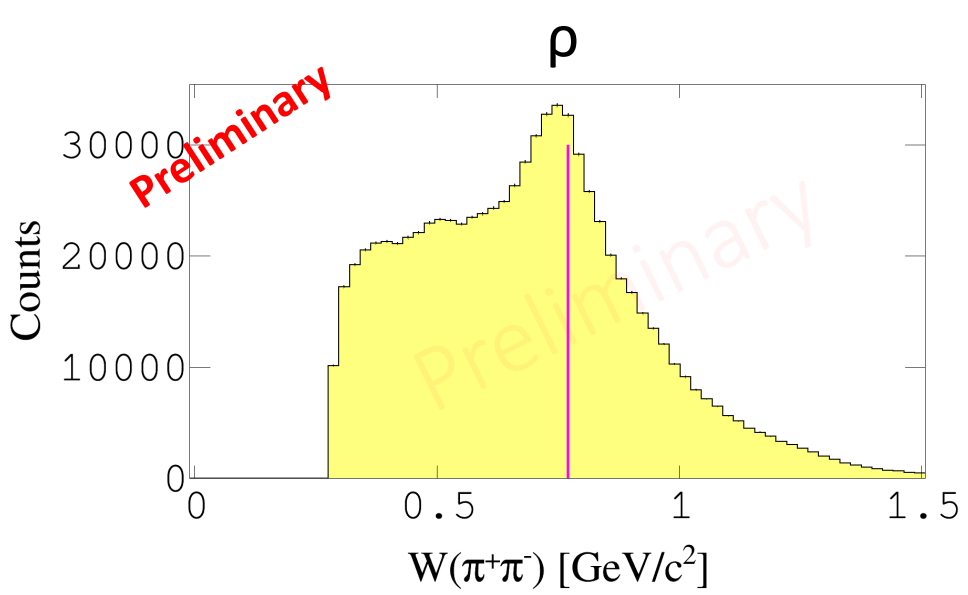
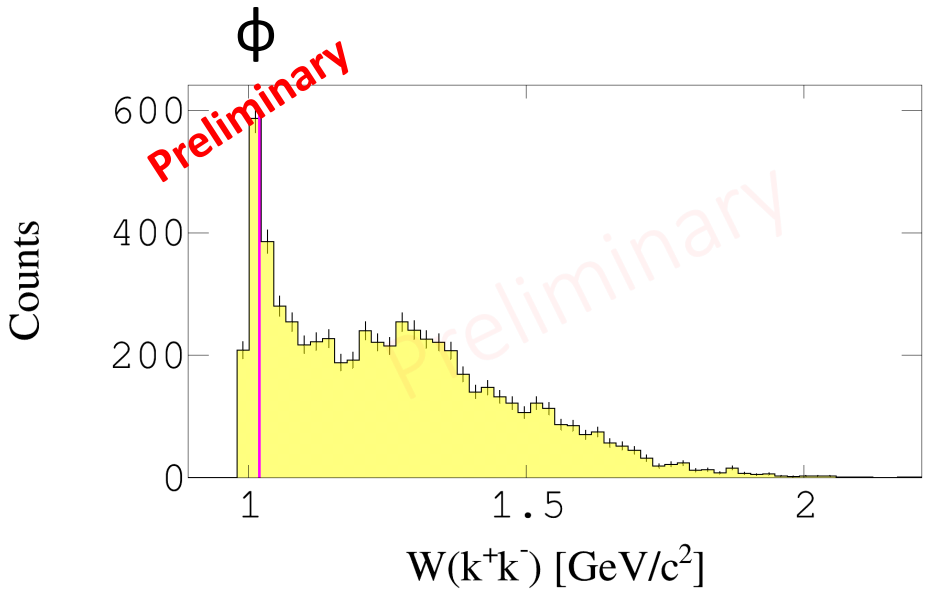
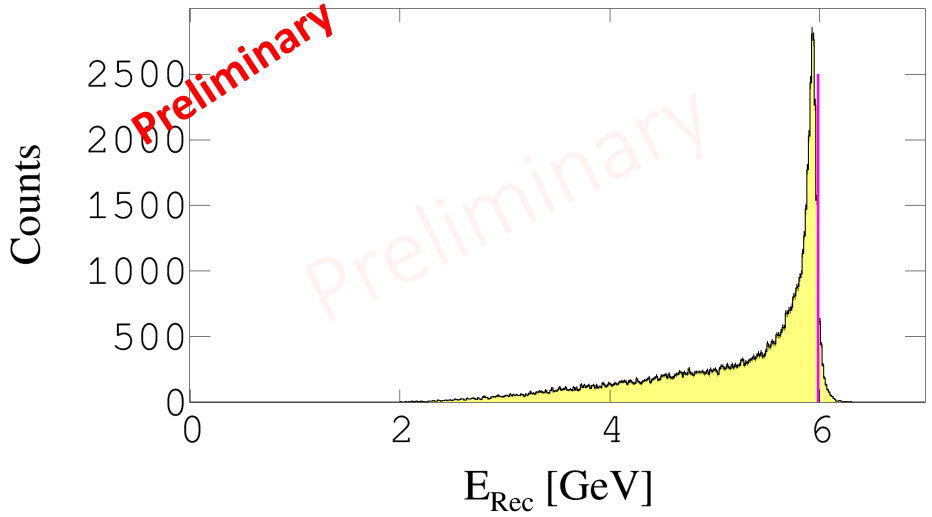
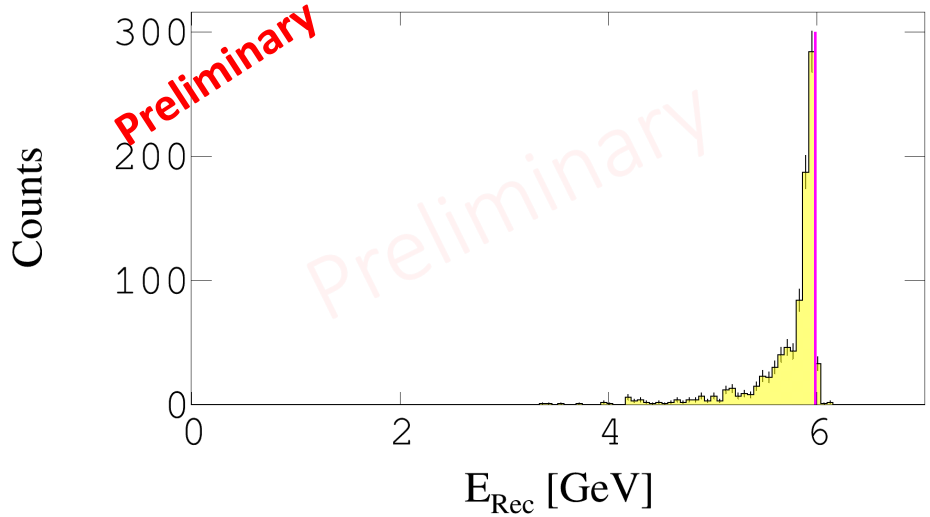
e4nu@CLAS12 – ^{4}He target



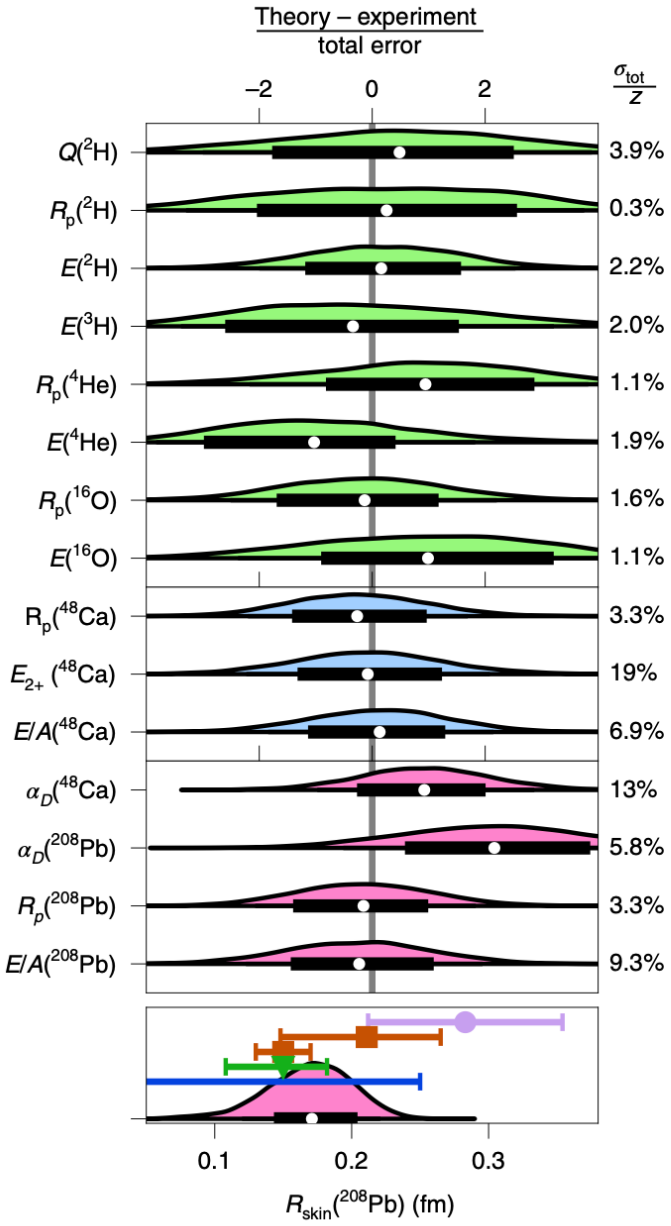


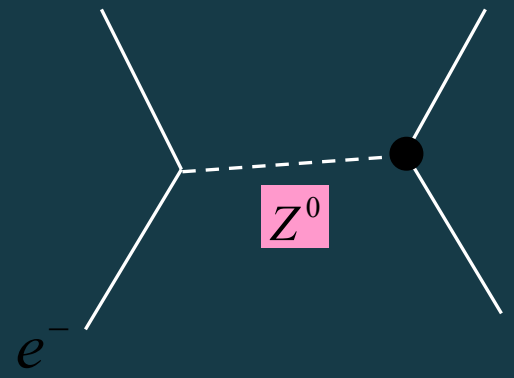




Other topics of potential interest

Neutron skins and Weak nuclear form factor





Parity violating electron scattering (Neutral current)

Coherent scattering from nucleus

-> Weak form factor

“accurate” measurement of neutron distribution

	proton	neutron
Electric charge	1	0
Weak charge	0.08	1

Weak mixing angle 1.2σ smaller than SM? (low energy value not well constrained)
PRC 105 055503 (2022)

ARTICLES
https://doi.org/10.1038/s41567-022-01715-8
nature physics
Check for updates
OPEN

Ab initio predictions link the neutron skin of ^{208}Pb to nuclear forces

Baishan Hu[1,11], Weiguang Jiang[2,11], Takayuki Miyagi[1,3,4,11], Zhonghao Sun[5,6,11], Andreas Ekström[2], Christian Forssén[2]✉, Gaute Hagen[1,5,6], Jason D. Holt[1,7], Thomas Papenbrock[5,6], S. Ragnar Stroberg[8,9] and Ian Vernon[10]

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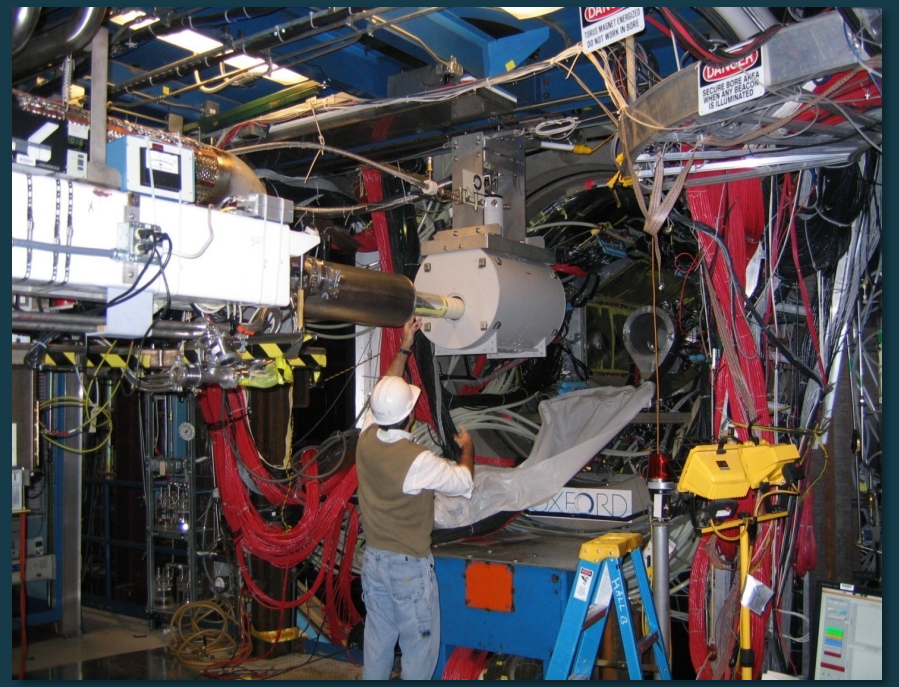
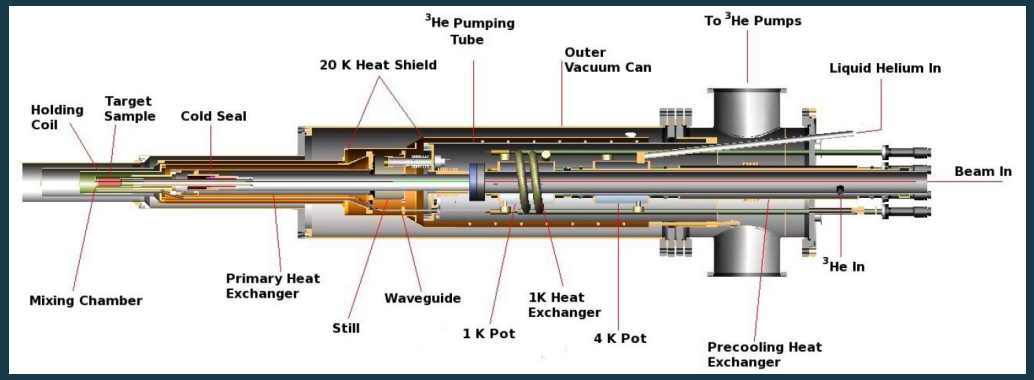
Chemical hyperpolarisation

Traditional polarized nucleon targets

- Dynamic nuclear polarisation - Radicals in target medium (e.g butanol) polarised in strong field (5T), transferred to the nucleons
- Requires cryogenics (mK), holding coils, …
  -> VERY sensitive to temperature changes
  -> Polarisation lost with electron beams at modest intensities
- Can we develop a new technology?
- Active polarised targets?





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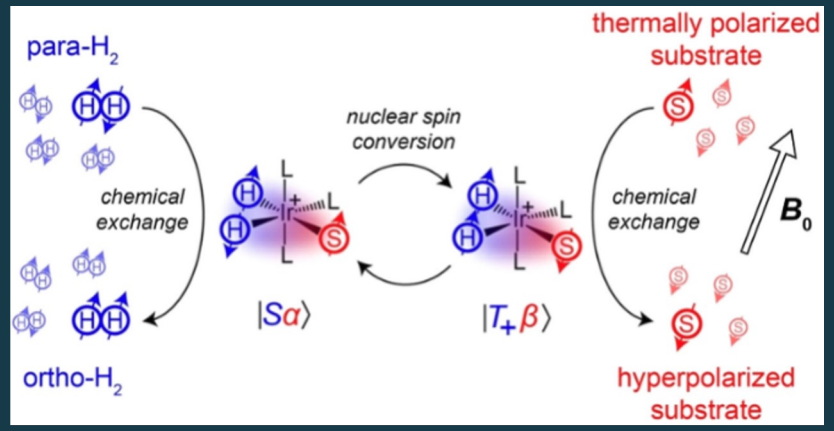
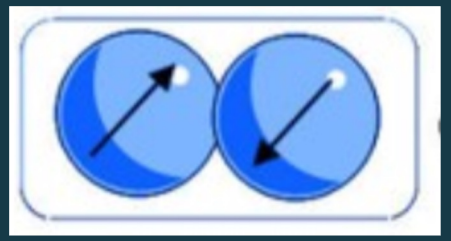
Chemical hyperpolarisation

- Utilises a catalyst to transfer nuclear spin order from parahydrogen (singlet state of H_2) to target nuclei (^1H) by transiently binding the target substrate. Also D, ^{13}C, ^{15}N etc.)
- Room temperature, ~insensitive to <10^o temp changes, fraction polarised nuclei comparable with DNP (Butanol), aligns with weak applied field
- York (Physics/Chemistry) leading new R&D to optimise substrates and catalysts to scale the technology from sub mm^3 used in medical research -> cm^3 needed for viable target
- cm^3 seems feasible with off the shelf para-H2 generator
- Cerenkov & scintillation light from cosmics observed from various substrates – active target possible



SABRE spin transfer



pH_2 spin configuration

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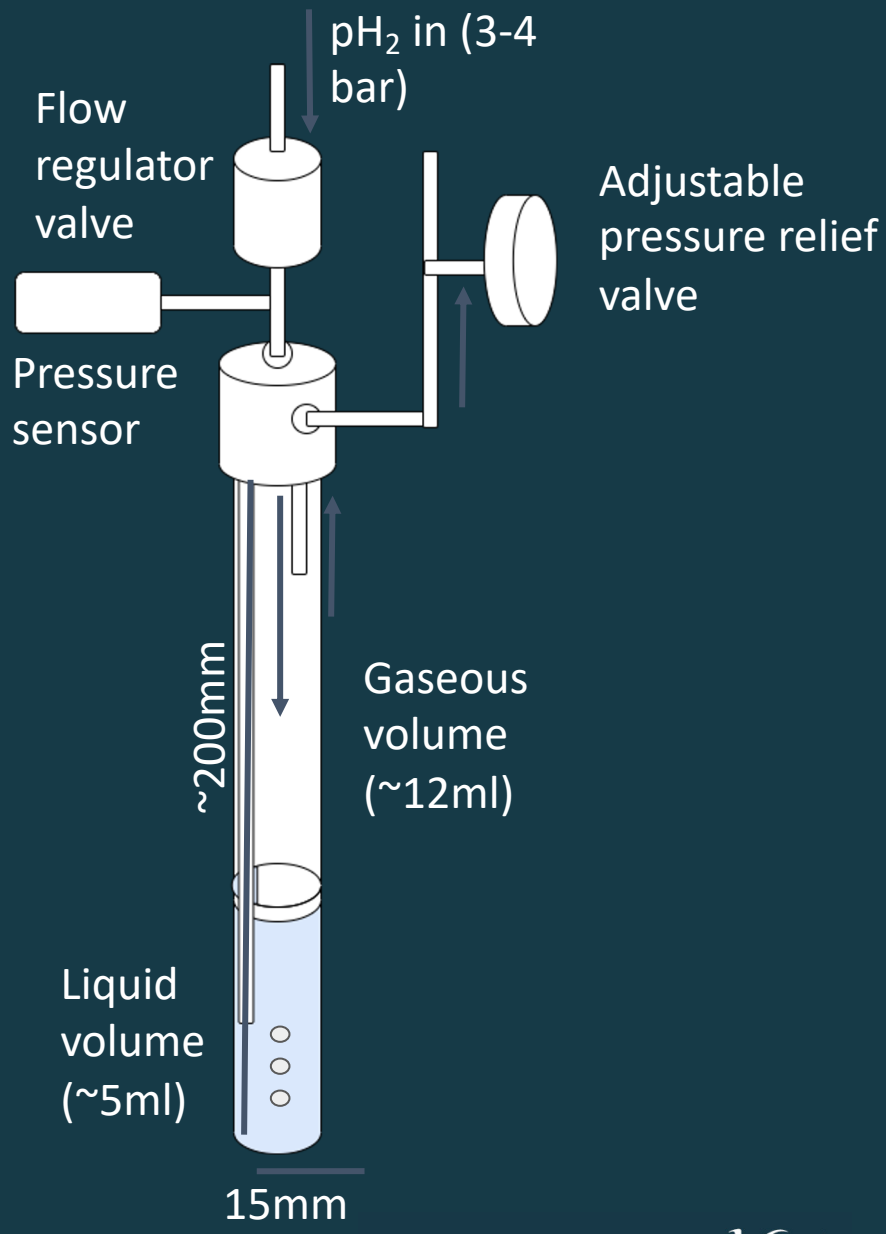
Tests in beam of hyperpolarised cell

- First in beam tests planned later this year (Mainz)
- Test resilience of polarisation to radiation dose and heat deposition
- >cm^3 ? to be explored in R&D programme



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Thanks for listening !

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