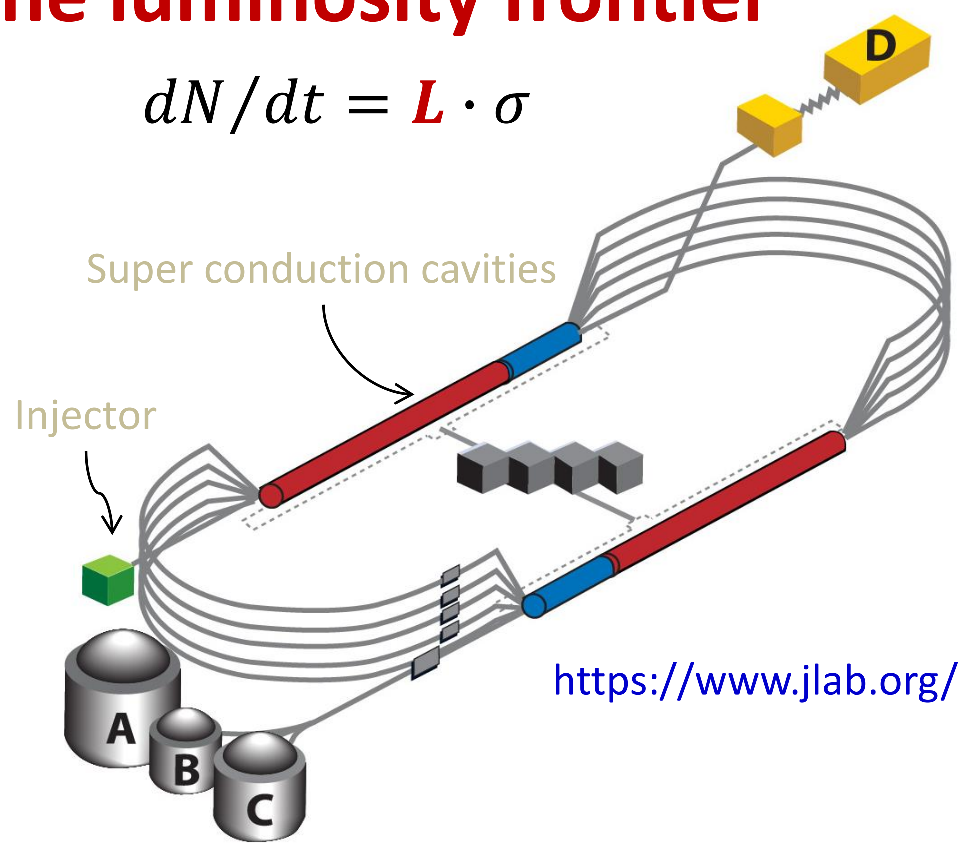
The RM1 collaboration
@ JLab

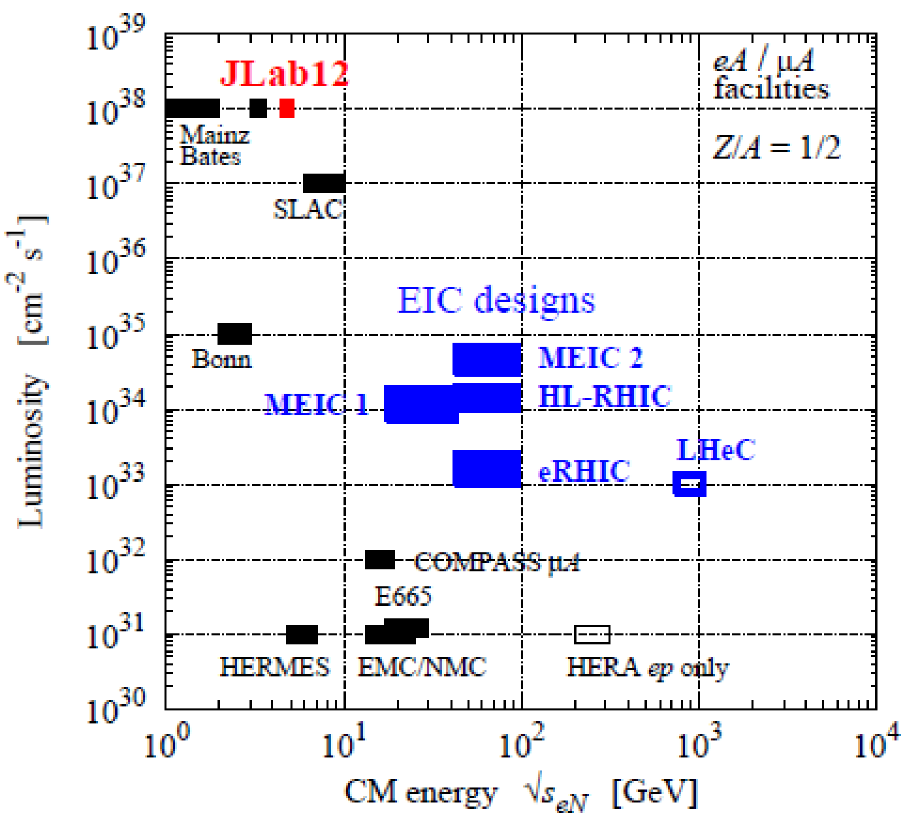
At the luminosity frontier

$$dN/dt = \boldsymbol{L} \cdot \sigma$$

CEBAF Linear electron accelerator
T. Jefferson National Laboratory
(Virginia/USA)



https://www.jlab.org/



Energy up to ***12 GeV*** with $\delta E/E \sim 10^{-4}$

Emittance: ~ few nm-rad

Polarized beam: long. **~ 85%** (1kHz helicity flip)

Current $\leq$ ***100 μA*** 100% duty factor (CW, 499 MHz)

4 experimental Halls

Targets: from H to Pb (also polarized)

Fundamental measurements in nuclear physics (Jlab)

I:

the nucleon structure
and the nature of quark confinement

⇓

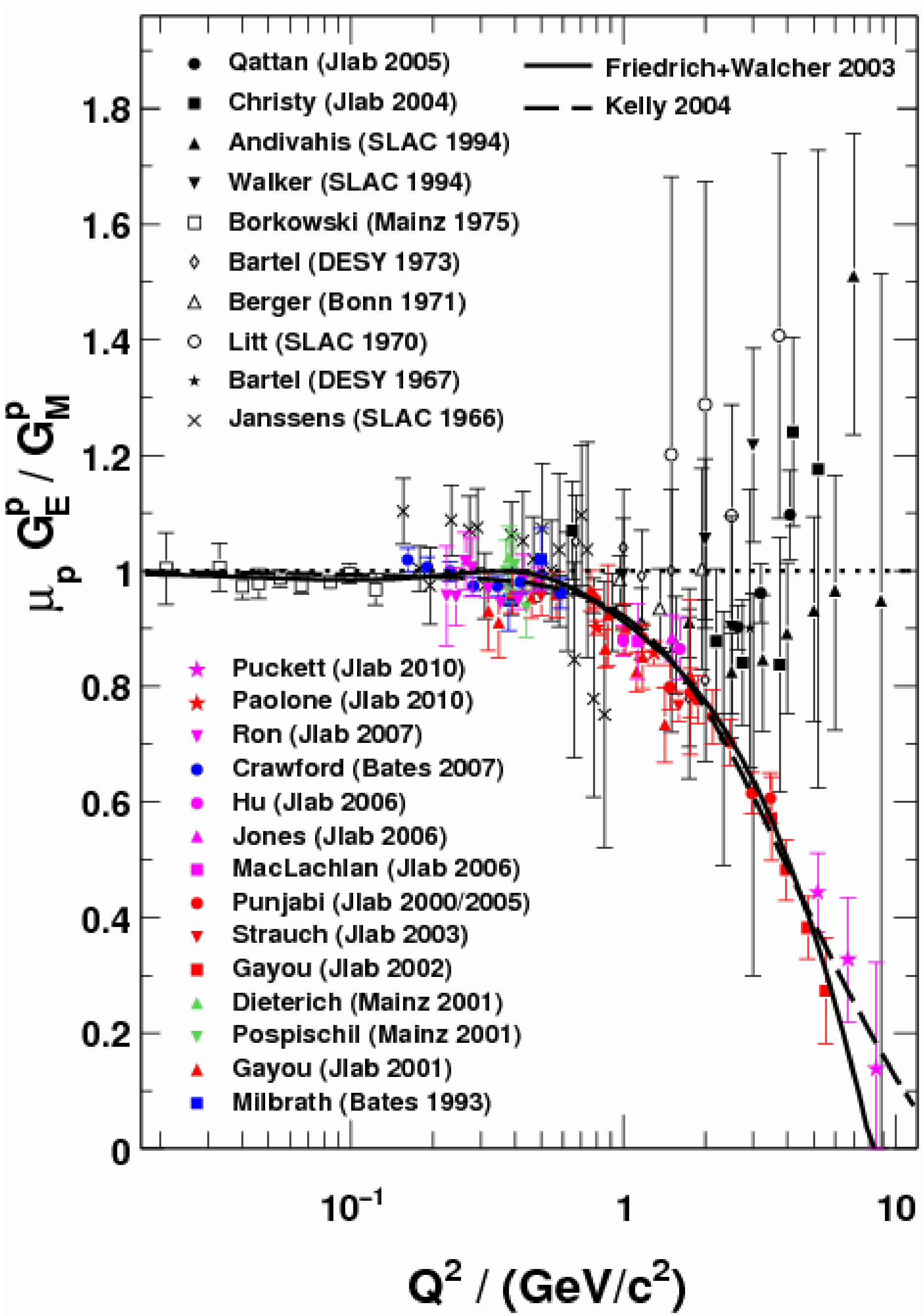
The origin of the hadron mass:

how do quarks of few MeV mass lead to the heavy proton and neutron?
(question connected to the great and more general question of the origin of mass)

The Higgs mechanism cannot be invoked, being 99% of the proton mass due to the kinetic and potential energy of the massless gluons and the "essentially" massless quarks, confined within the proton ➔ strongly related to the dynamics of the inner constituents, gluons and quarks

More details in next talk

Proton Form Factors G_E/G_M – **unexpected discrepancy**



$$\frac{d\sigma}{d\Omega} \propto G_{Ep}^2 + \frac{\tau}{\varepsilon} G_{Mp}^2$$

Rosenbluth Separation: assume single photon approximation

Before 2000: proton G_E/G_M fairly constant with Q^2

$$R_p = \mu_p \frac{G_E(Q^2)}{G_M(Q^2)} \approx 1 - \underbrace{0.13\,(Q^2 - 0.29)}_{\textit{Pol. Transfer Discr.}}$$

$$\mu \frac{G_{Ep}}{G_{Mp}} = -\mu \frac{P_t}{P_l} \frac{(E_{beam} + E_e)}{2M_p} \tan\frac{\vartheta_e}{2}$$

Polarization transfer from the incident electron to the scattered proton

At JLab, new class of experiments show proton G_E/G_M decreasing linearly with Q^2

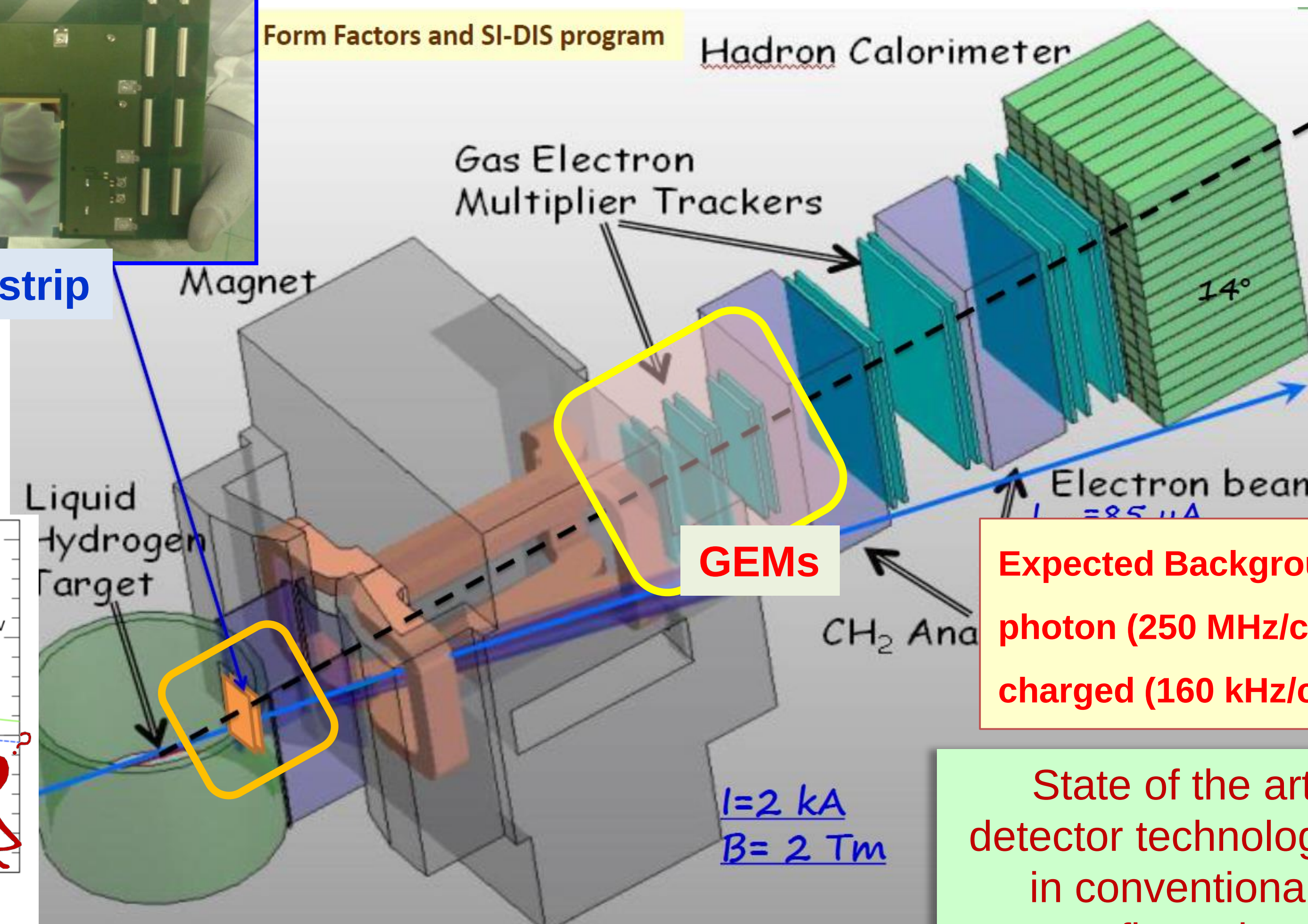
Form Factors are an important probe of the **color CONFINEMENT** at all energy ranges!

SuperBigbite Spectrometer in Hall A/JLab

Physics Cases:
Nucleon Form Factors, Neutron spin and TMD, Pion structure functions
… an experimental tool for hadron structure investigation

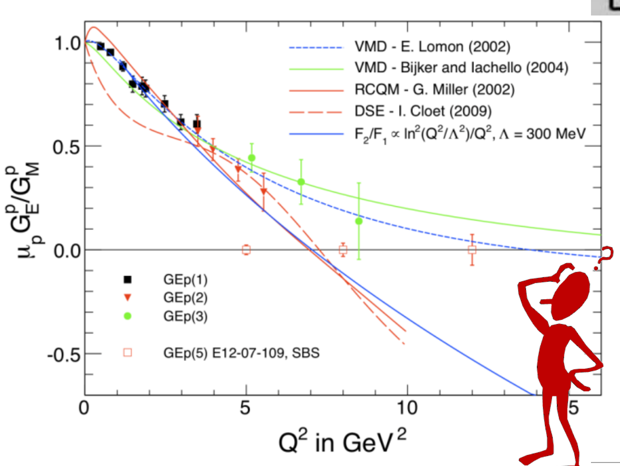
for high luminosity experiments!

Silicon microstrip



GEMs

Expected Background:
photon (250 MHz/cm2)
charged (160 kHz/cm2)

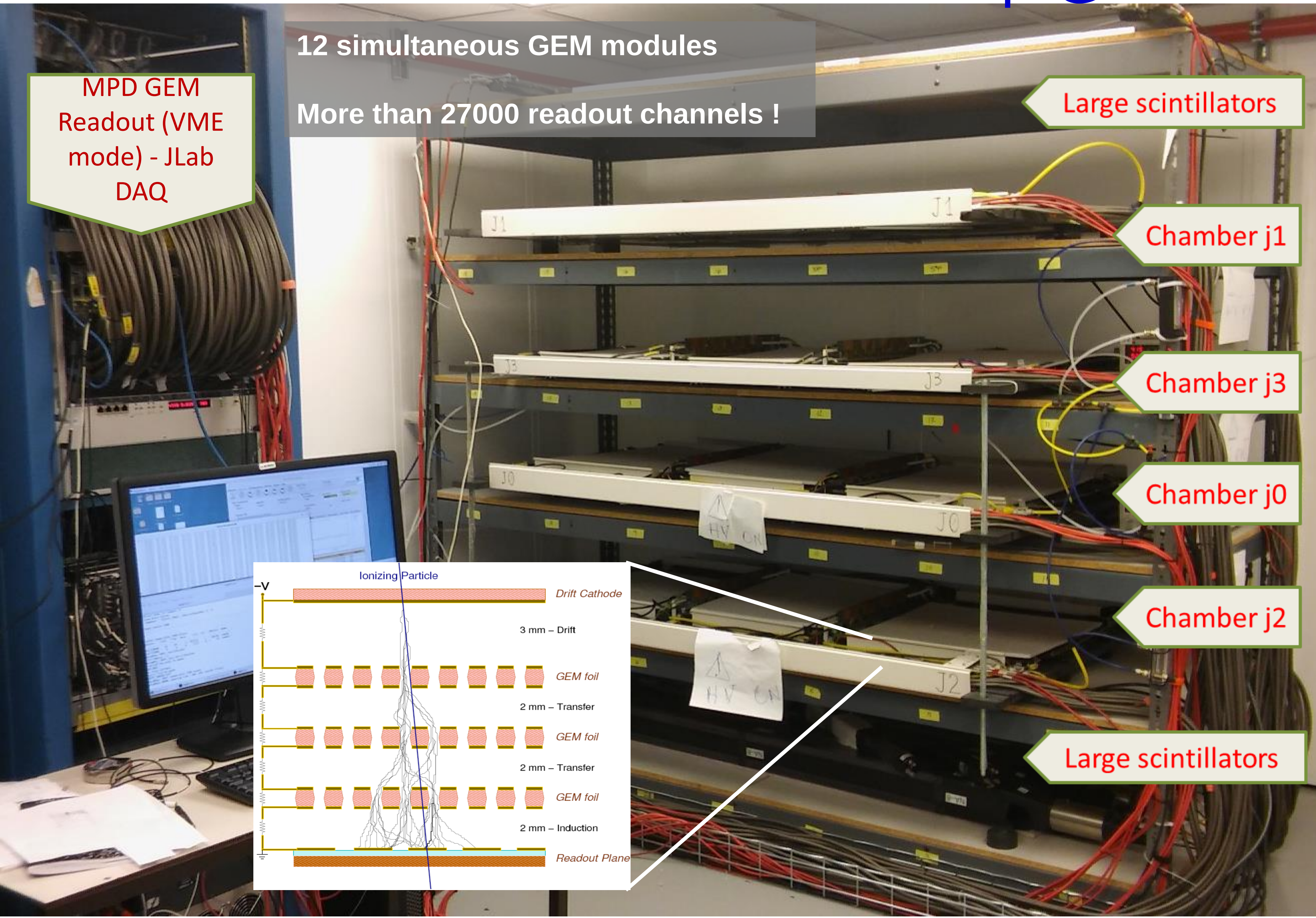


State of the art detector technologies in conventional configuration

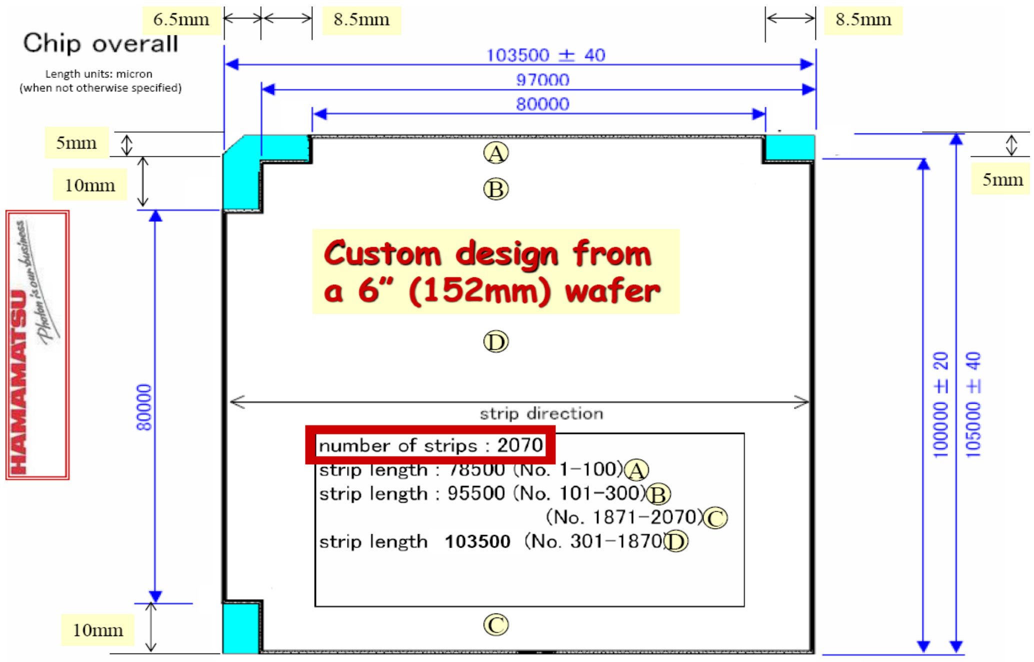
GEM Tracker / Cosmic Setup @ JLab

12 simultaneous GEM modules

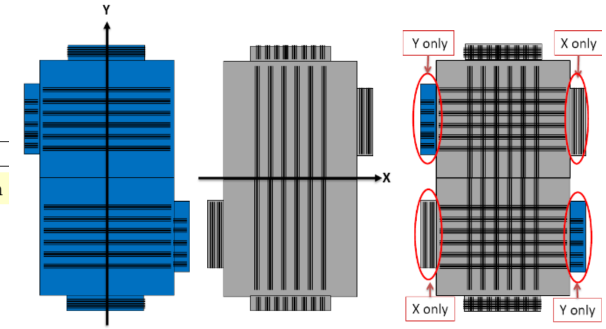
More than 27000 readout channels !



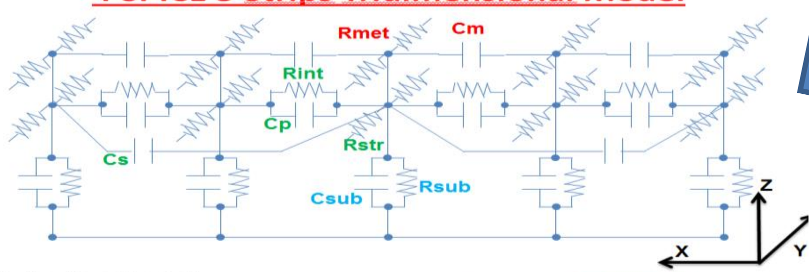
Silicon microstrip detectors



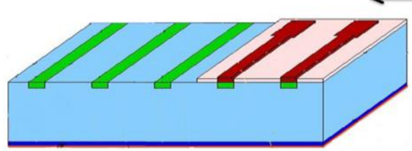
X-Y planes constructed from one single kind of detector



PSPICE 5 Strips Tridimensional Model



- Detector Model
  - ➔ 1 Cell: L_{strip} = 250 μm
  - ➔ 400 Cells: L_{strip} = 10 cm



... final model extended to include 15 strips

Updated !!!

Unexpected too strong dependence of the detector response on MIP impact point. Simulation in progress to fully understand the problem and to possibly lessen it redesigng the PCB

Fundamental measurements in nuclear physics (Jlab)

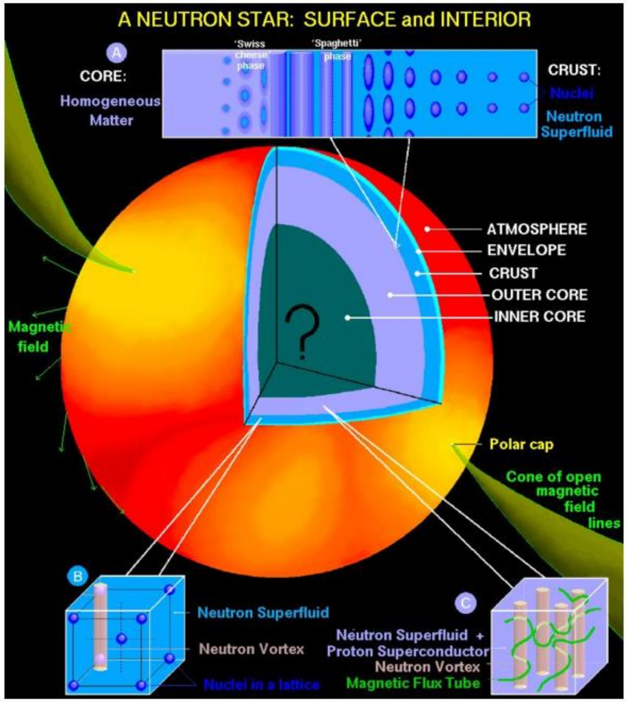
II:

the nucleus structure

neutron star features

(Neutron Star: a «giant nucleus»!)

- The NS core is supposed to be a sort of neutral fluid of neutrons, protons, muons and electrons in equilibrium (respect to weak interaction)
- This fluid is described by the Equation of State (EoS) of strong interacting matter: relate Pressure, Energy density and Temperature
- The derivation of EoS from nuclear interaction is an extremely complex theoretical problem



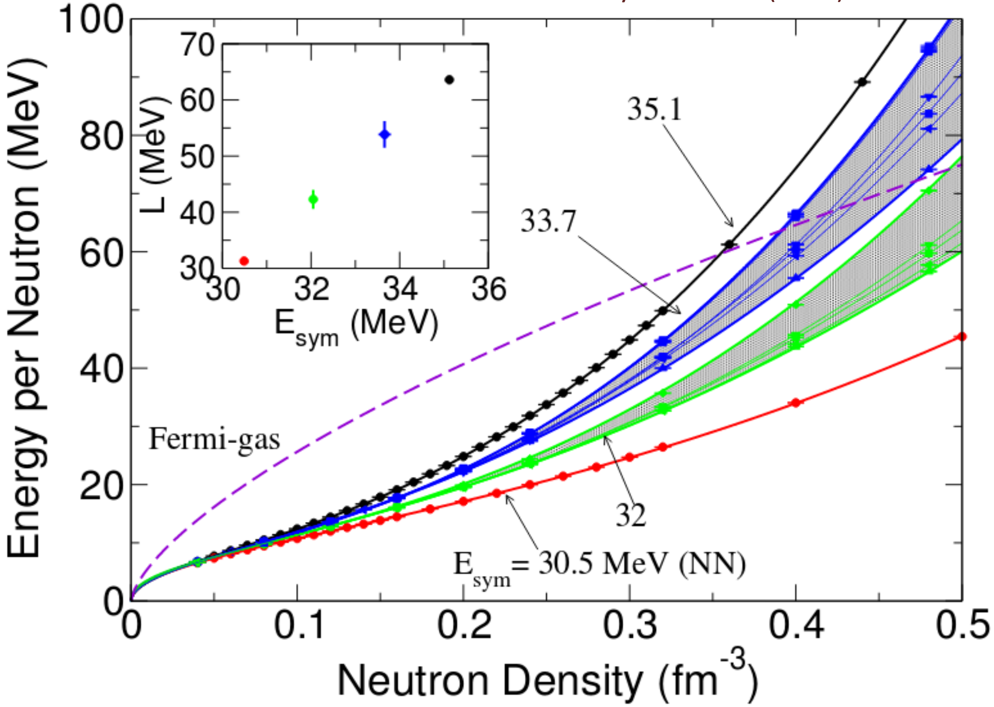
Neutron Star EoS and Symmetry Energy

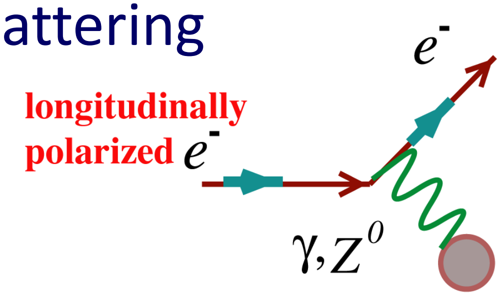
The **EoS** is the derivative of the energy function and strictly related to the asymmetry term (a_a) in nuclear binding energy

$$B = a_v A - a_s A^{2/3} - \frac{a_c Z(Z-1)}{A^{1/3}} - \frac{a_a (N-Z)^2}{A} - a_p A^{-3/4}$$

The **asymmetry term** can be precisely measured from the neutron-proton radius difference in heavy nuclei (PREX* experiments) by **parity violation** in polarized electron elastic scattering

S. Gandolfi et al. Phys. Rev. C 79(2009)054005





$$A_{PV} \sim \frac{G_F Q^2}{4\pi\alpha}\left[\underbrace{1 - 4\sin^2\theta_W}_{\sim 0} + \frac{F_n(Q^2)}{F_p(Q^2)}\right]$$

←Right-Left Asymmetry

***PREX-II** is going to run within days at JLab*

PREX & Neutron Stars

(C.J. Horowitz, J. Piekarweicz)

Crab Pulsar

R_N calibrates EOS of Neutron Rich Matter

→ Crust Thickness
→ Explain Glitches in Pulsar Frequency

Combine PREX R_N with Obs. Neutron Star Radii

→ Phase Transition to "Exotic" Core ?
→ **Strange star ?** **Quark Star ?**

Some Neutron Stars seem too Cold

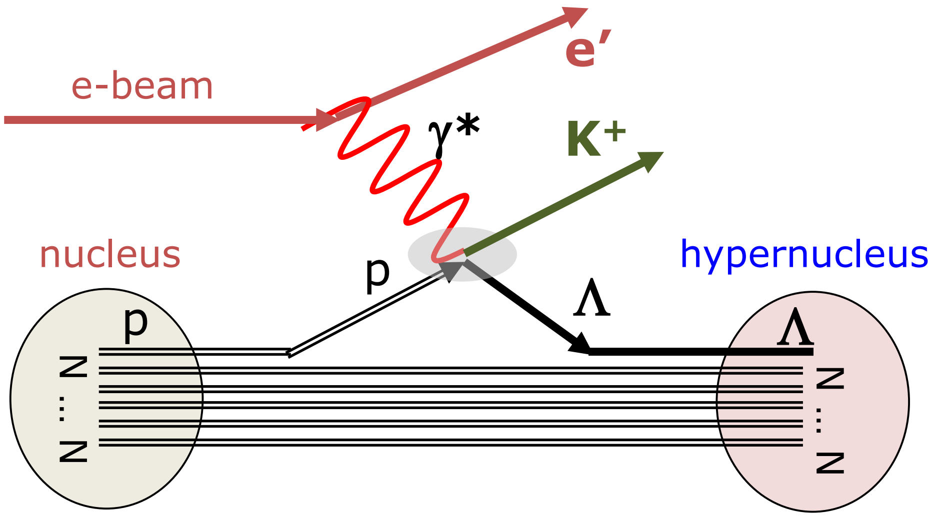
→ Cooling by neutrino emission (URCA)
→ $R_n - R_p > 0.2$ fm → URCA probable, else not

Fundamental measurements in nuclear physics (Jlab)

III:

(hyper)nucleus energy levels

1) neutron star features
2) Charge Symmetry Breaking in hyperon-nucleon interactions



Hypernuclear electroproduction is one of the peculiar physics highlights at JLab.

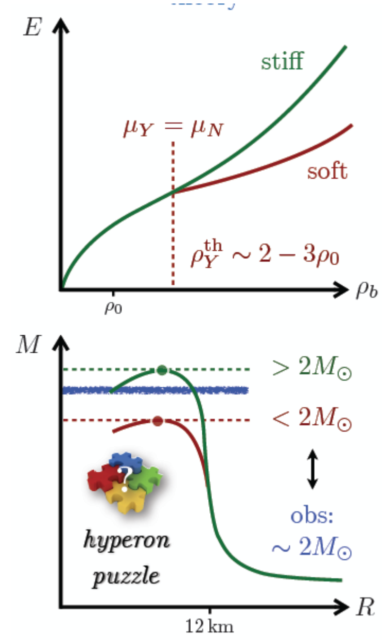
The hyperon puzzle

Neutron stars are remnants of the gravitational collapse of massive stars having masses of (1-2 Mo ~ 2 x 10^{33} Kg)

Hyperons are expected to appear in their core at $\rho \sim (2\text{-}3)\rho_o$ when μ_N is large enough to make conversion of N to Y energetically favorable

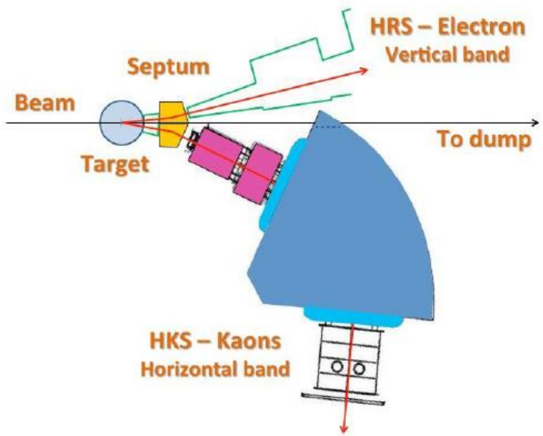
BUT

The relief of the Fermi pressure due to its appearance → EoS softer → reduction of the mass to values incompatible with observation (~ 2 Mo that requires much stiffer EoS)

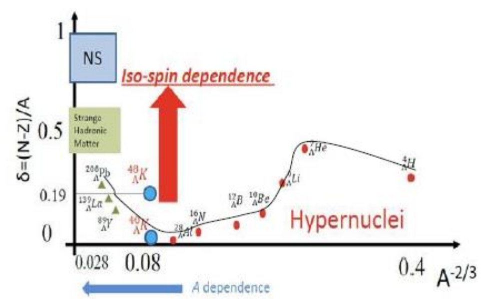


Strong softening of the EoS of dense matter due to the appearance of hyperons which leads to maximum masses of compact stars that are not compatible with the observations

E12-15-008 will measure the binding energies B_Λ of ${}^{48}_{\Lambda}K$ and ${}^{40}_{\Lambda}K$ with a precision of <100 keV providing the first data for isospin dependence of ΛNN force and hence contributing to the solution of the so called "hyperon puzzle" (the existence of neutron stars with masses ≈ 2 solar masses).



E12-15-008 Experimental setup

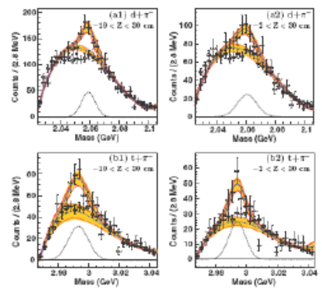


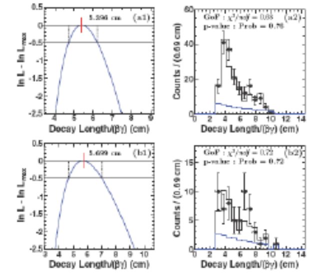
Precise measurements of B_Λ in ${}^{40}Ca(e,e'K^+){}^{40}_{\Lambda}K$ and ${}^{48}Ca(e,e'K^+){}^{48}_{\Lambda}K$ could provide the first data to assess iso-spin dependence of the phenomenological three-body hyperon-nucleon force.

Has a bound neutral $^{3}_{\Lambda}n$ system been seen at GSI?

A recent experiment (HypHI at GSI) studied the data collected from the reaction of ^{6}Li projectiles at 2A GeV on a fixed graphite (^{12}C) target for the invariant mass distributions of $d + \pi^-$ and $t + \pi^-$, considered to be from weak decays of few-body (A = 2 and 3) hypernuclei produced by heavy ion collisions.

The estimated mean values of the invariant mass of $d + \pi^-$ and $t + \pi^-$ systems were reported to be 2059.3 ± 1.3 ± 1.7 MeV/c^2 and 2993.7 ± 1.3 ± 0.6 MeV/c^2, respectively. Their lifetimes were estimated to be 181^{+30}_{-24} ± 25 ps and 190^{+47}_{-35}± 36 ps, respectively, significantly shorter than the lifetime of a free Λ (~260 ps).

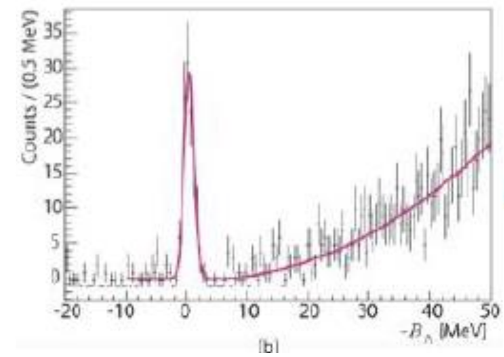




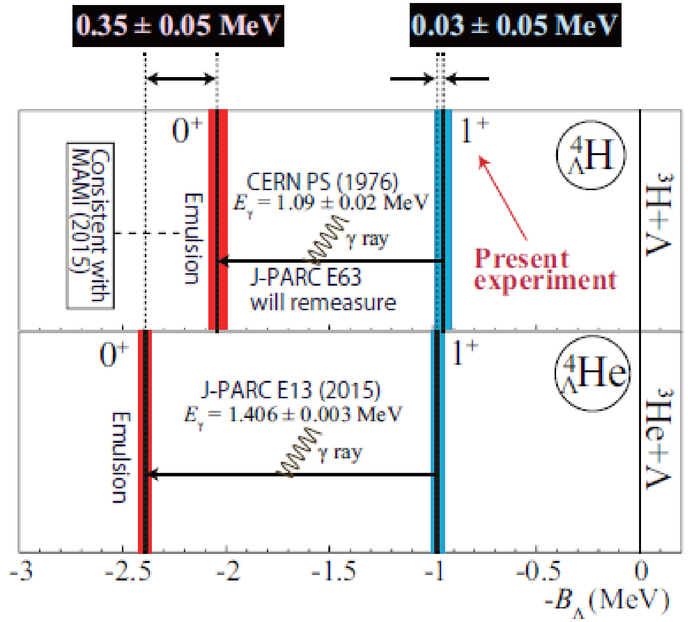
These final states were interpreted as the two-body and three-body decay modes of a bound 3-body hypernucleus, thus suggesting a possible observation of a bound neutral $^{3}_{\Lambda}n$ system.

The method of analysis employed was identical to the one successfully applied for the determination of binding energies of $^{4}_{\Lambda}H$ and $^{4}_{\Lambda}He$

$$^{3}H(e,e'K^{+})nn\Lambda$$



$$^{4}He(e,e'K^{+})^{4}_{\Lambda}H$$



Fundamental measurements in nuclear physics (Jlab)

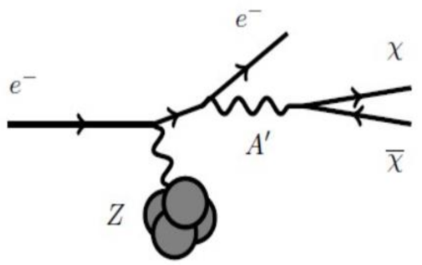
IV:
Dark Matter Search

The BDX experiment

Beam Dump eXperiment: LDM direct detection in a e^- beam, fixed-target setup

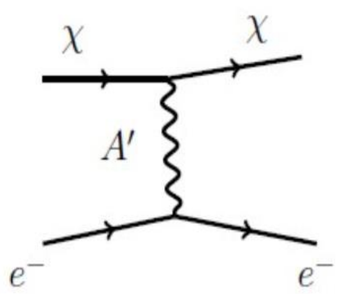
LDM production

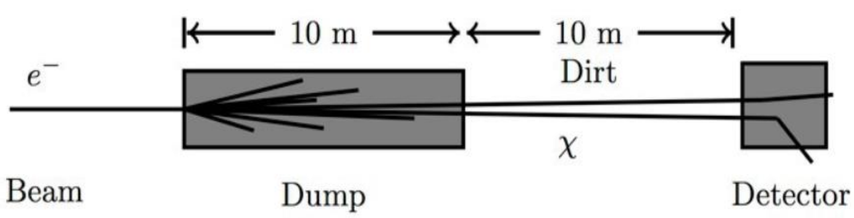
- High-energy, high-intensity e^- beam impinging on the dump
- LDM particles pair-produced radiatively, through A' emission



LDM detection

- Detector placed behind the dump at ~ 20m
- Neutral-current scattering on atomic e^- through A' exchange, recoil releasing visible energy
- Signal: *O*(100 MeV) - EM shower





WaveBoard digitizer for calorimeter readout
Talk F. Ameli

https://arxiv.org/abs/1607.01390

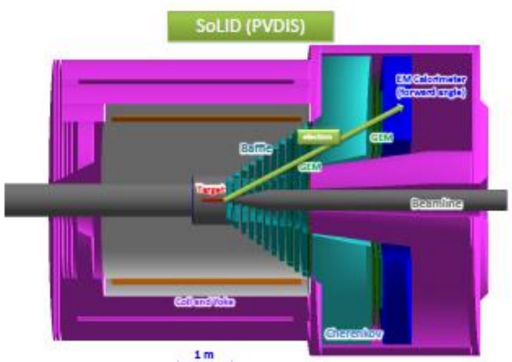
Fundamental measurements in nuclear physics (Jlab)

V:

Standard Model checks/Physics beyond the standard model

SOLID →

Measurement, through APV in DIS, of C1q(C2q), the four-Fermi coupling constants with axial(vector) electron currents and vector(axial) quark currents.

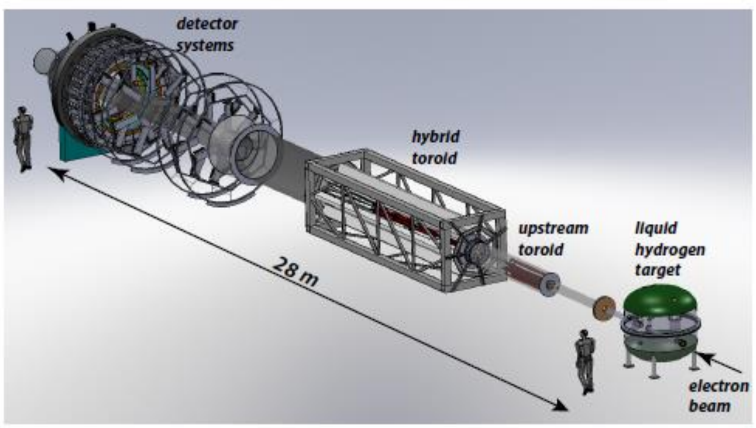


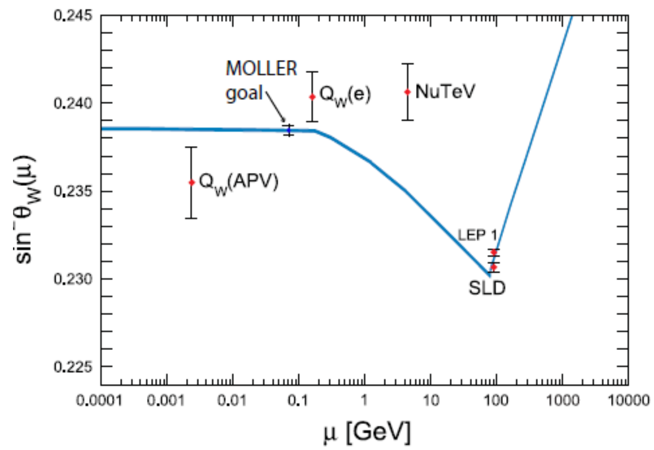
For the Standard Model

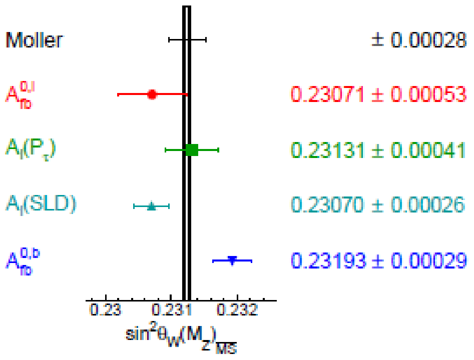
$$
\begin{aligned}
C_{1u} &= g_A^e g_V^u \approx -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W \approx -0.19 \\
C_{1d} &= g_A^e g_V^d \approx \frac{1}{2} - \frac{2}{3}\sin^2\theta_W \approx 0.34 \\
C_{2u} &= g_V^e g_A^u \approx -\frac{1}{2} + 2\sin^2\theta_W \approx -0.030 \\
C_{2d} &= g_V^e g_A^d \approx \frac{1}{2} - 2\sin^2\theta_W \approx 0.025
\end{aligned}
$$

MOLLER →

An Ultra-Precise Measurement of the Weak Mixing Angle measuring APV in Moller Scattering







RM1 Staff at JLab

- 3 senior researches + 1 Assegno di Ricerca
- RM1 people involved in Jlab Hall A experiments ~ 4/400 = 1%
- RM1 Spokespersonships = 7/117 = 6%

Skill and expertises

- Tracking detectors (GEM, Silicon microstrip detectors).
- RICH and Cherenkov detectors.
- Magnet Design.
- PCB design.
- DAQ
- Monte Carlo simulations for apparatus design and experiment previsional studies
- Analysis algorithms

Needs

- Human resources
- (Reasonably moderated) Fundings