PHYSICS REQUIREMENTS FOR ZERO-DEGREE ELECTROMAGNETIC AND HADRONIC CALORIMETRY: SPECTATOR TAGGING IN LIGHT SYSTEMS AND IMPACT PARAMETER TAGGING IN HEAVY SYSTEMS

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PHYSICS NEAR ZERO DEGREES

- **Spectator/Fragment tagging in light nuclei.**
- **DVES on heavy nuclei: (≥ C)**
  - **The challenge of true exclusivity**
- Target Fragmentation in DIS
  - Flavor/p_T correlations with current fragmentation region
  - Baryon multiplicity as impact parameter tag
- Fission Fragments in both photo- and electro-production
  - Search for exotic nuclei?

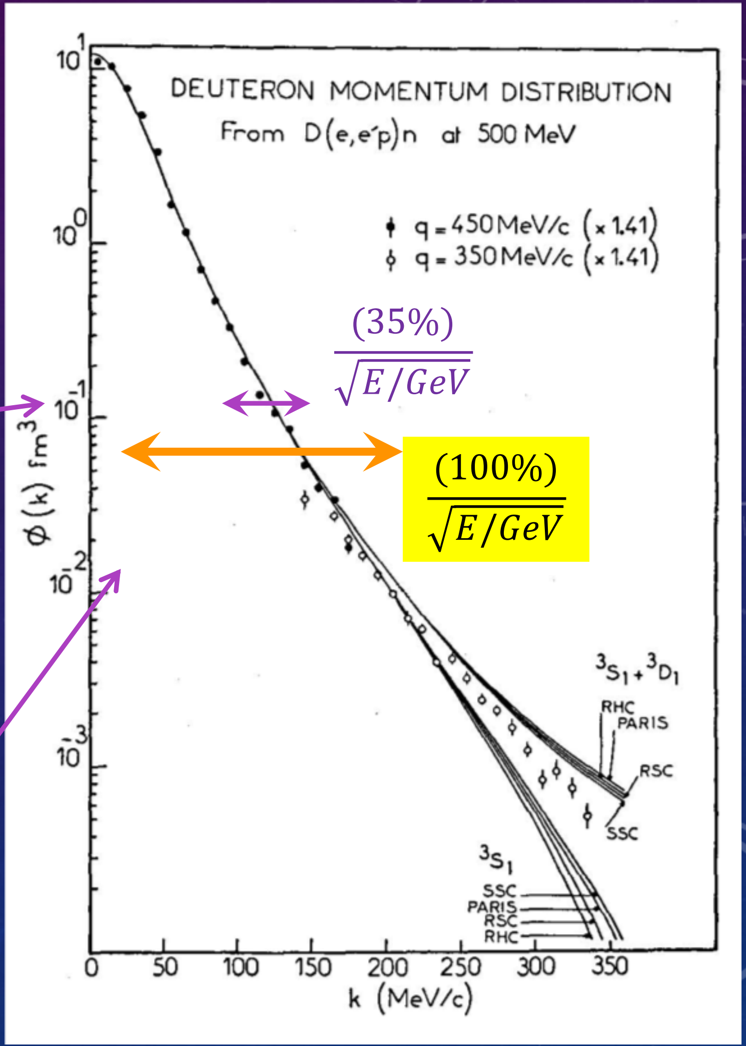
HADRONIC CALORIMETRY: I. LIGHT SYSTEMS

- D(e,e'p_S)X
  - Proton tracking determines p_T, $\alpha = A\frac{p^+}{P_A^+}$
  - Probe neutron structure function for nearly on-shell neutron
  - Probe EMC effect in the deuteron with strongly off-shell neutron
- D(e,e'n_S)X
  - Calibrate "nearly on-shell neutron" with "nearly on-shell proton"

D(e,e'n_S)X ≈ p_{bound}(e,e')X

200 GeV/c D ➔ 100 GeV/c spectator neutron

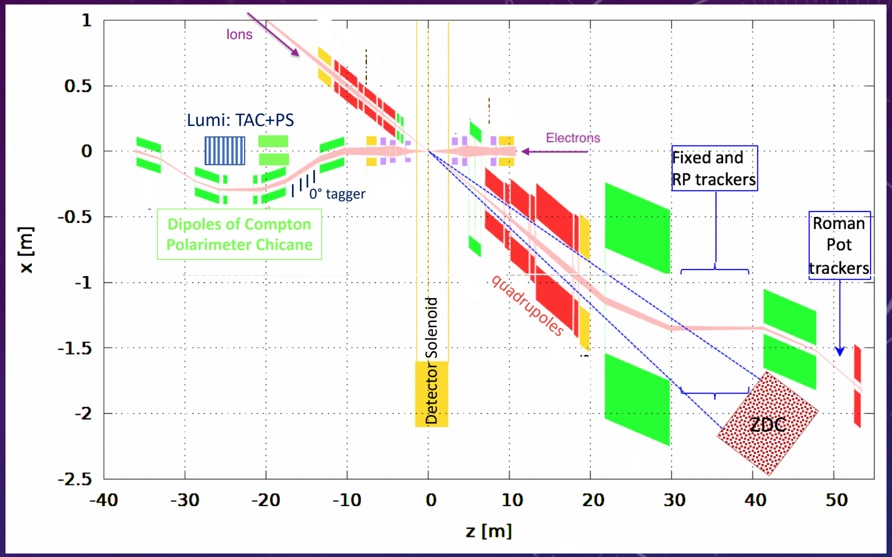
- Hadronic Calorimeter at 45 m (JLEIC)
- Impact point resolution 1.5 cm *rms*:
  - $\frac{\delta p_T}{p} = 0.33$ mrad ➔ $\delta p_T = 33$ MeV
  - Equivalent to *rms* beam spread
- If energy Resolution $\frac{\delta E}{E} = \frac{(35\%)}{\sqrt{E/GeV}}$
  - $\alpha = A\frac{p_n^+}{P_A^+} \approx \left[1+\frac{p_n}{M_N}\right]_{Deuteron\ Rest-Frame}$
  - $\delta\alpha = \frac{\delta E}{E} = 3.5\%$ ➔ $\delta p_n^{D\text{-}rest} \approx 35$ MeV/c
  - If $\frac{(100\%)}{\sqrt{E/GeV}}$ ➔ $\delta p_n^{D\text{-}rest} \approx 100$ MeV/c



HADRONIC CALORIMETRY II: EVAPORATION

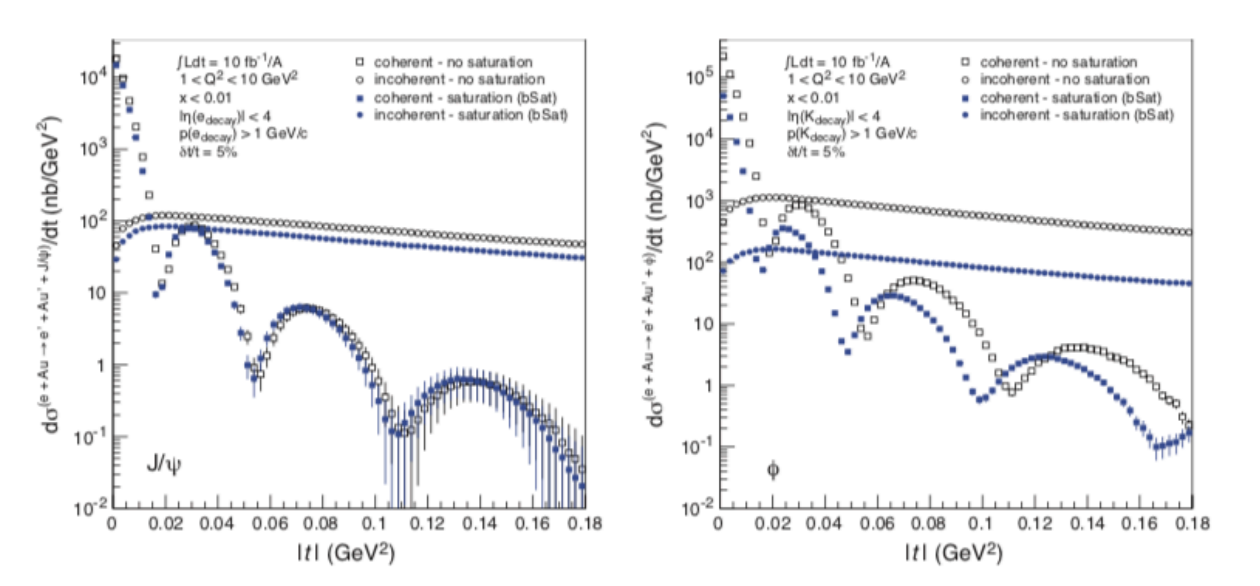
- Evaporation neutrons
    - Thermal Distribution T ~ 10MeV (Nuclear Rest frame)
    - 95% within in angular cone 3mrad
    - HCal must separate shower profiles separated by ~7 cm to count neutrons.
- See also talks by M. Baker, F. Hauenstein

FAR-FORWARD HADRONIC CALORIMETER: TECHNOLOGY



- ZEUS: Depleted Uranium: $\frac{(35\%)}{\sqrt{E/GeV}}$
- High Segmentation e.g. FeSci sampling (longitudinal and transverse)
  - $\frac{(50\%)}{\sqrt{E/GeV}}$
  - < 1 cm transverse spatial resolution
  - Require 50cm lateral size beyond active area.
    - Wrap around Dipole 3? Wedge into space at 50 m between D & Q?
      - Some resolution-loss on beam side may be inevitable

FAR-FORWARD EM CALORIMETRY & GLUON SATURATION

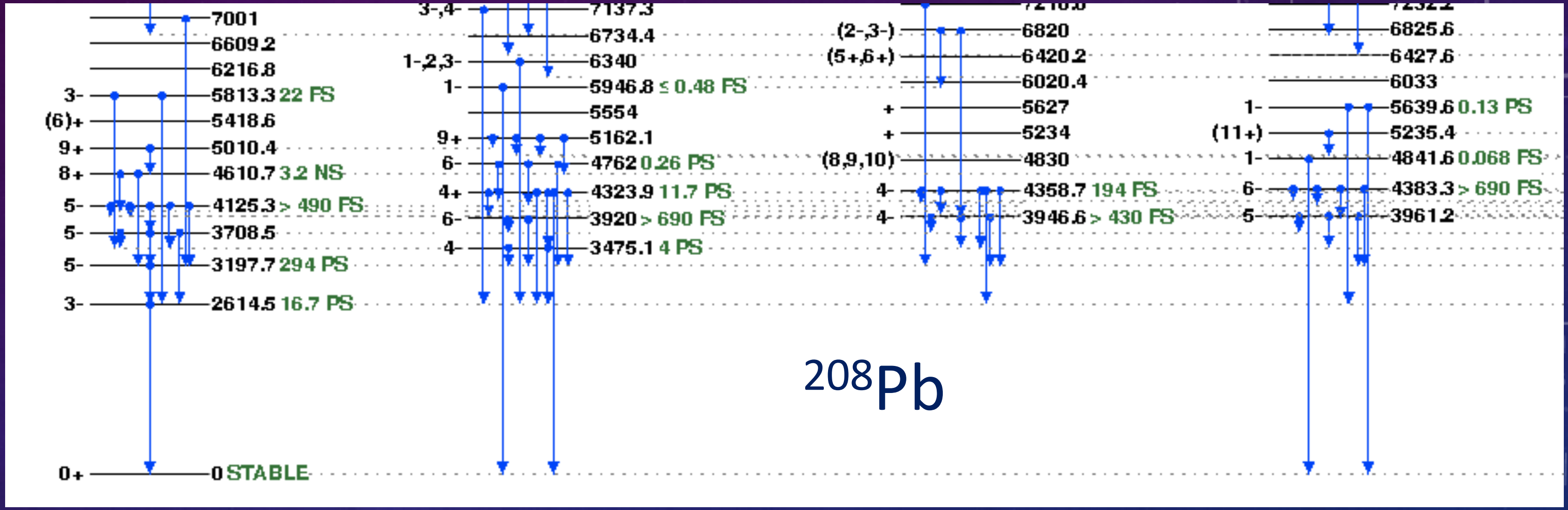


- DVES as a signature for saturation
- Veto Incoherent by nuclear break-up
- What about Nuclear Bound states?
- Based on elastic $^{A}Z(e,e)\,^{A}Z$ and inelastic $^{A}Z(e,e')\,^{A}Z^{*}$ data:
  - Expect even first diffractive minimum to be washed out by excitation diffraction: $^{A}Z(e,e'\,V)\,^{A}Z^{*}_{\text{bound}}$
  - VETO DECAY GAMMAs!

FORWARD EM CALORIMETRY

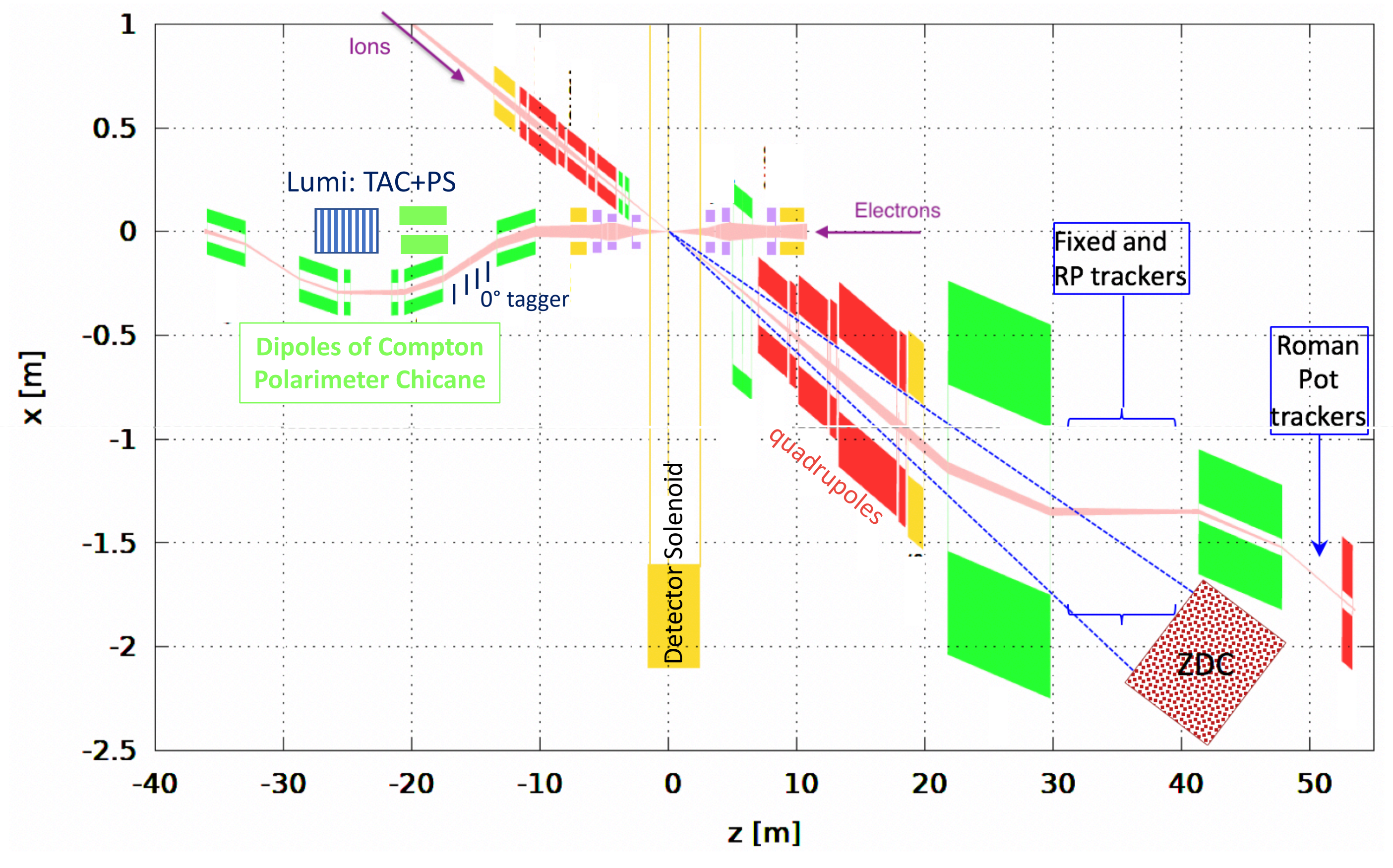
- Proposed signature for gluon saturation:
  - Comparison of low-x deep virtual exclusive J/Psi *vs* phi production.
  - Both are sensitive to gluon density, but with different spatial averaging: ϕ-production sensitive to saturation at larger x_B then J/Psi
- Signature is a shift in the diffractive minima
  - Inelastic production to bound excited states will wash-out the sharp diffractive minima and obscure the saturation signal
- Solution is to detect the gamma-decays to veto bound-state excitation

GAMMA-RAY VETO



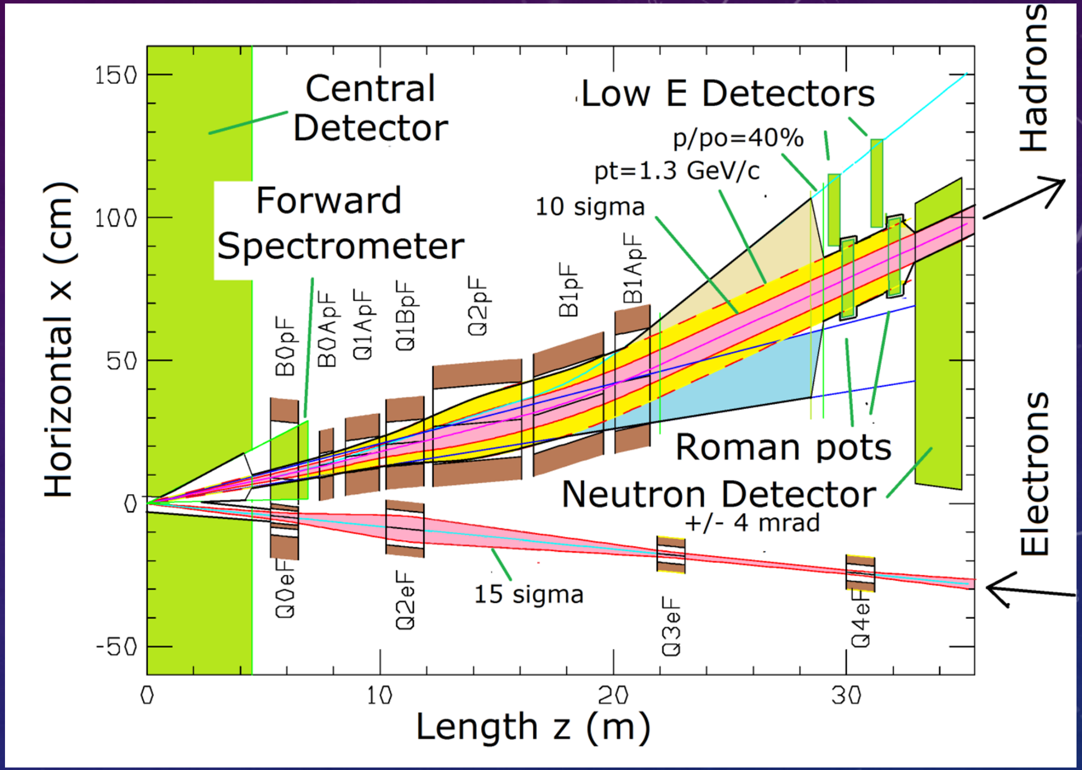
- Requires doubly magic nucleus, *e.g.* ^{208}Pb
  - Every gamma-cascade of ^{208}Pb has least one photon above 2.6 MeV (in nuclear rest-frame).
  - Compare to Au, gamma decay chains with energies < 0.2 MeV

FORWARD γ BOOST/ ACCEPTANCE



- JLEIC: $P_A = Z$ (200 GeV/c),
  - $E_A / M_A \sim 80$
  - 50% of (2.6 MeV) photons are emitted in forward hemisphere of rest frame with detector energy from 220 MeV to 440 MeV
    - 50% of photons are in angular cone ± 1/80 = 12.5 mrad.
    - ±10 mrad aperture would capture 42% of decay photons
    - ±5 mrad aperture would capture only 15% of decay photons

FORWARD BOOST/ACCEPTANCE



- eRHIC: $P_A = Z\,(275\ \mathrm{GeV/c})$,
  - $E_A / M_A \sim 116$
  - 50% of photons are in angular cone ± 8.5 mrad.
    - At least one photon ≥ 300 MeV (if detected)
    - ±4 mrad aperture captures 18% of decay photons

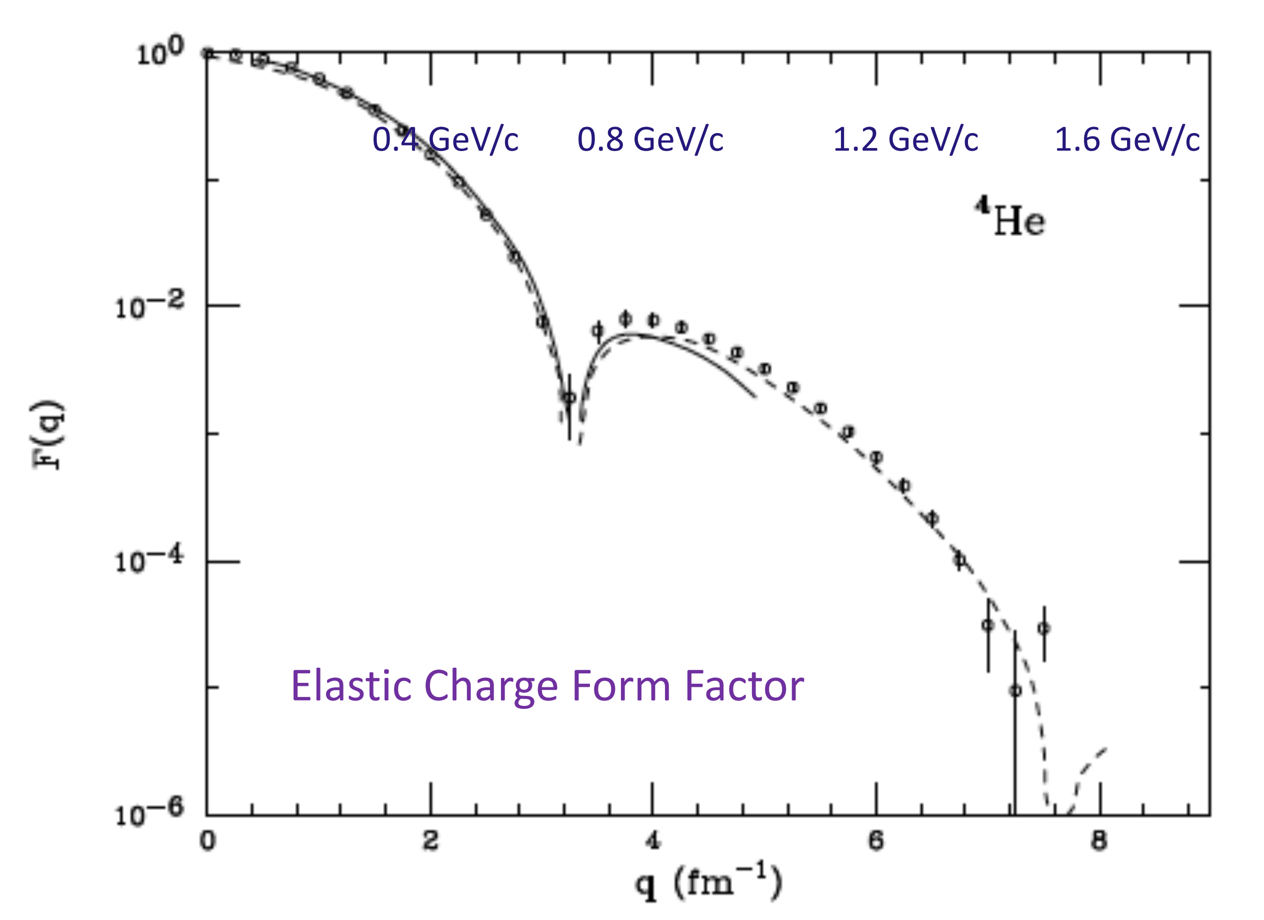
FAR-FORWARD EM CALORIMETRY

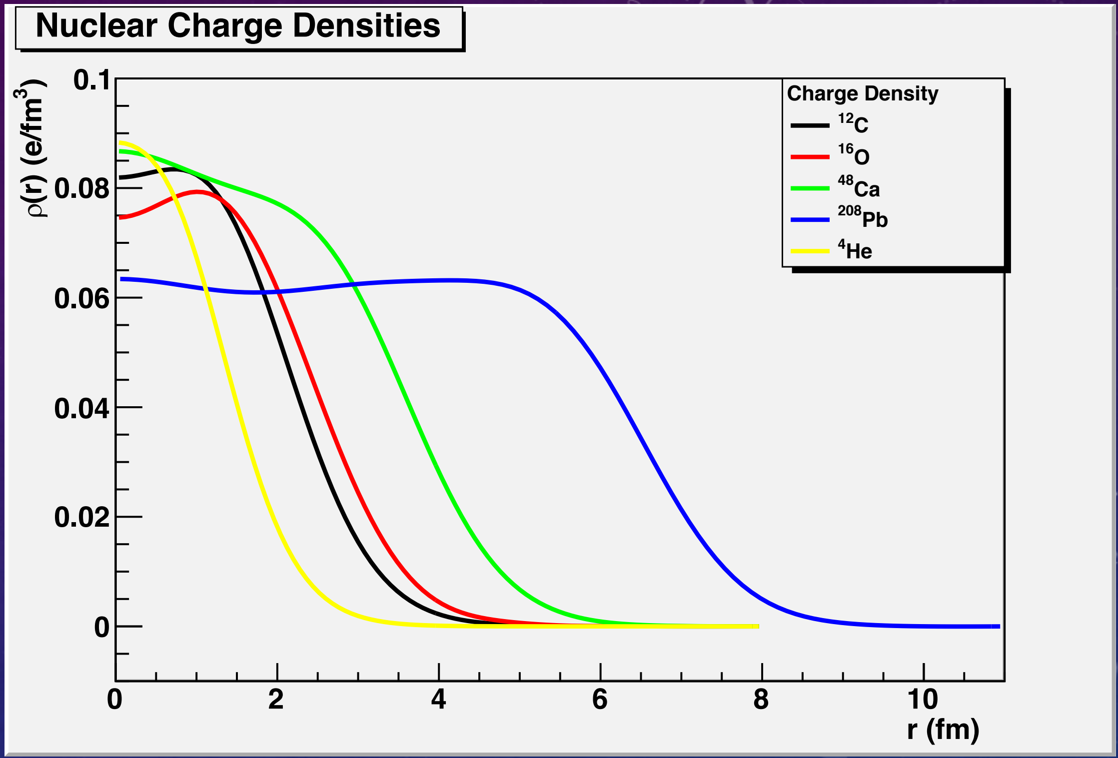
- $PbWO_4$
  - X_0 = 8.9 mm, $r_M = 2.2$ cm, τ=25 nsec
  - 5% resolution at 300 MeV (https://arxiv.org/pdf/hep-ex/9907047.pdf)
- LYSO:
  - X_0 = 11.4 mm, r_M = 2.1 cm, τ=40 nsec
  - SuperB prototype:
    NIM A **718** (2013) 10

$$\frac{\sigma_E}{E} = \frac{(1.1 \pm 0.5)\%}{\sqrt{E(\mathrm{GeV})}} \oplus \frac{(0.37 \pm 0.15)\%}{E(\mathrm{GeV})} \oplus (1.2 \pm 0.7)\%$$

  - 2.6% @ 300 MeV
- Both tolerant to fluence from 100 fb^{-1} at IP $\leq 10^{13}$ neutron/cm^2

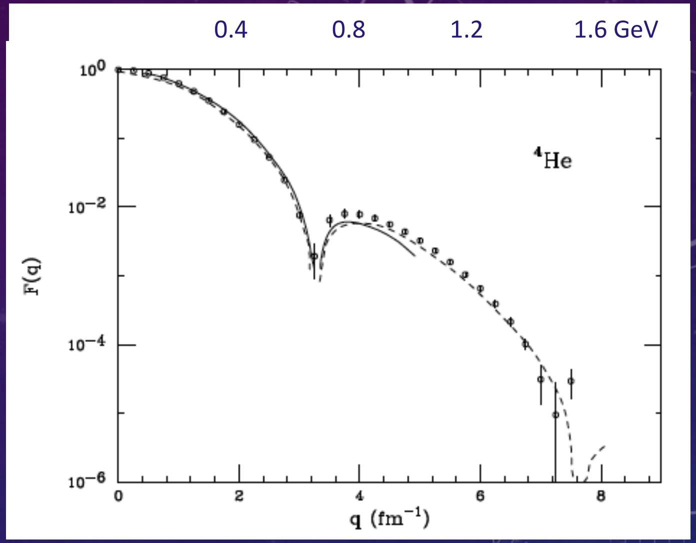
QUARK-GLUON IMAGING OF ^{4}He





- Highest Central Density of any nucleus
  - J=0, I=0
  - $\mathcal{H}_g(\xi, t \mid Q^2), \mathcal{H}_u(\xi, t \mid Q^2) = \mathcal{H}_d(\xi, t \mid Q^2)$

^{4}HE DVES : γ, $\boldsymbol{\rho}^0$, ϕ, ω, J/Ψ



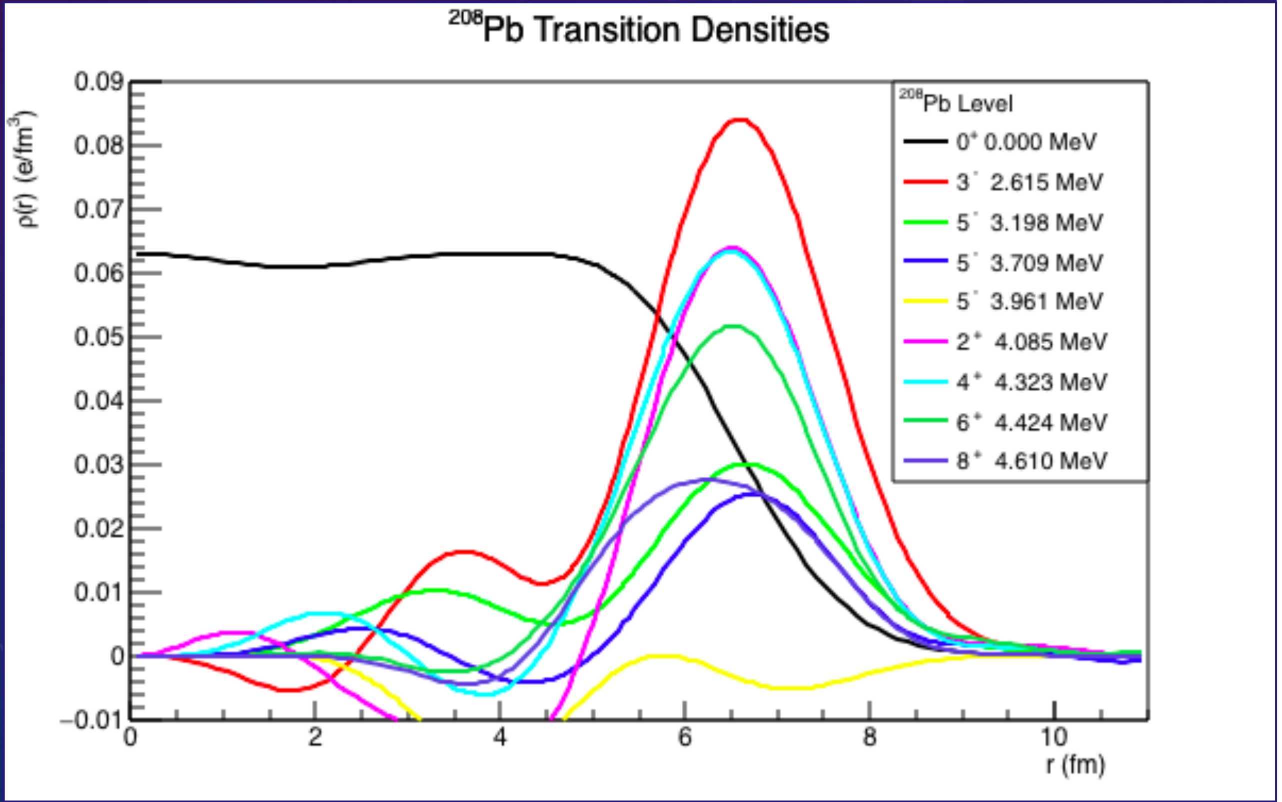
- Diffractive minimum @ *|Δ| ≈ 0.64 GeV/c*
- ^{4}He Beam: 400 GeV/c
  - σ(p) ≈ 0.6·10^{-4} *p* = 240 MeV/c
  - σ(p$_\perp$) ≈ 0.3·10^{-4} *p = 120* MeV/c
  - *0°* recoil nucleus detectable for
    - $x_A = x_{Bj}/A > 0.01$ *(Dispersion = 1m)* → $x_{Bj} > 0.04$,
    - Raw resolution σ ($\Delta_\perp$) ≈ *120 MeV/c* (improvable via over-complete kinematics)

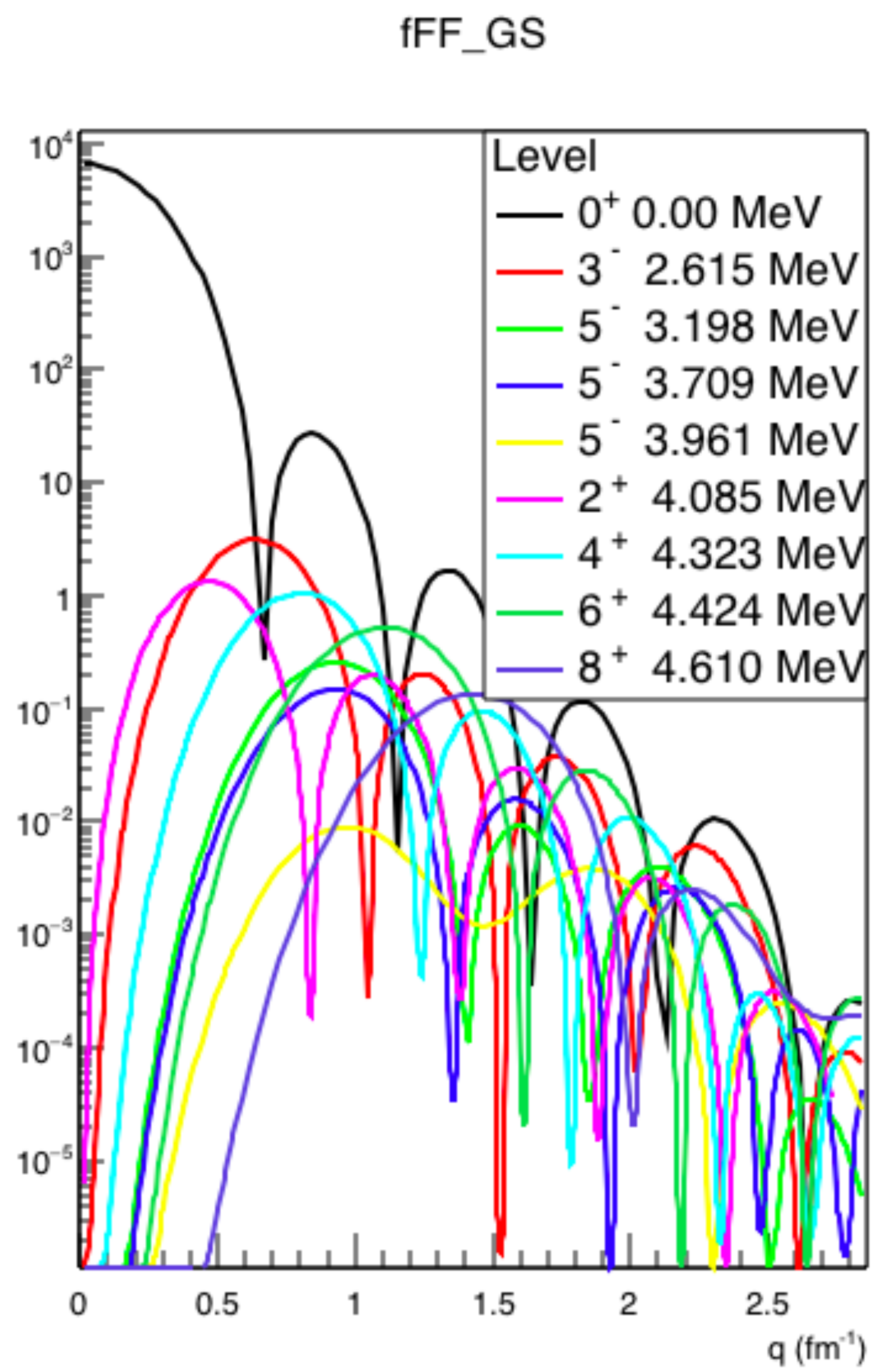
CONCLUSIONS

- There is no separation between the accelerator and the detector
- The Interaction Region and Detector design process is a series of negotiations and re-negotiations.
- We can design and build an accelerator, interaction region and detector that fulfills our science ambitions.

ELASTIC VS INELASTIC SCATTERING

- *Fourier-Bessel expansion of inleastic electron scattering from*
  - *J. Heisenberg et al, Phys Rev C v25 (1982) p.2292*
- Inelastic (e,e') scattering on Pb to bound excited states.
- Deep Virtual excitation will not be identical, but will be similar





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