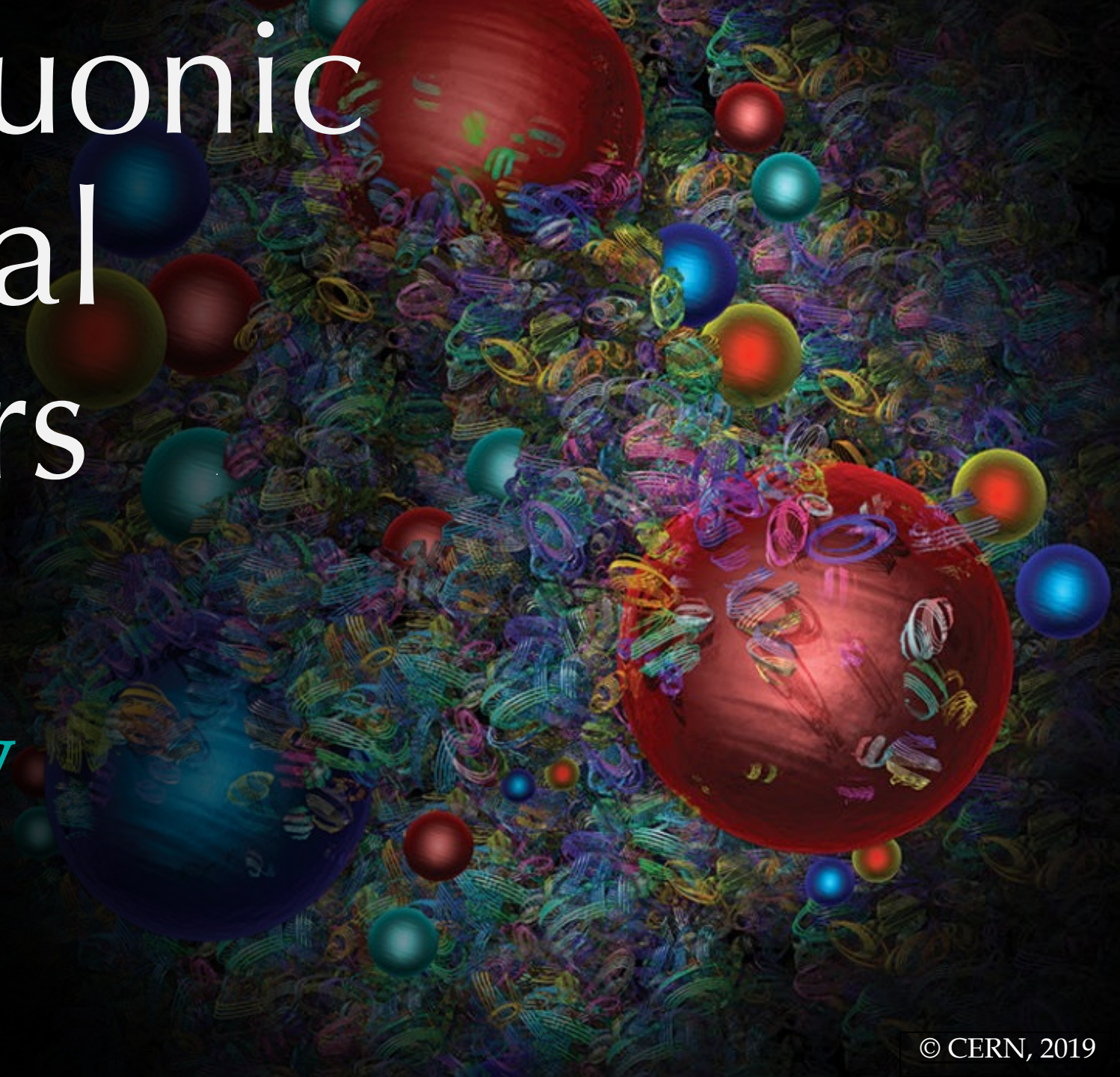
Proton's Gluonic Gravitational Form Factors

Duran *et al.*, Nature **615**, 813–816 (2023)

Suat Baris Tuncay

13.03.2024



Proton has mass. How?

- Mass = Higgs

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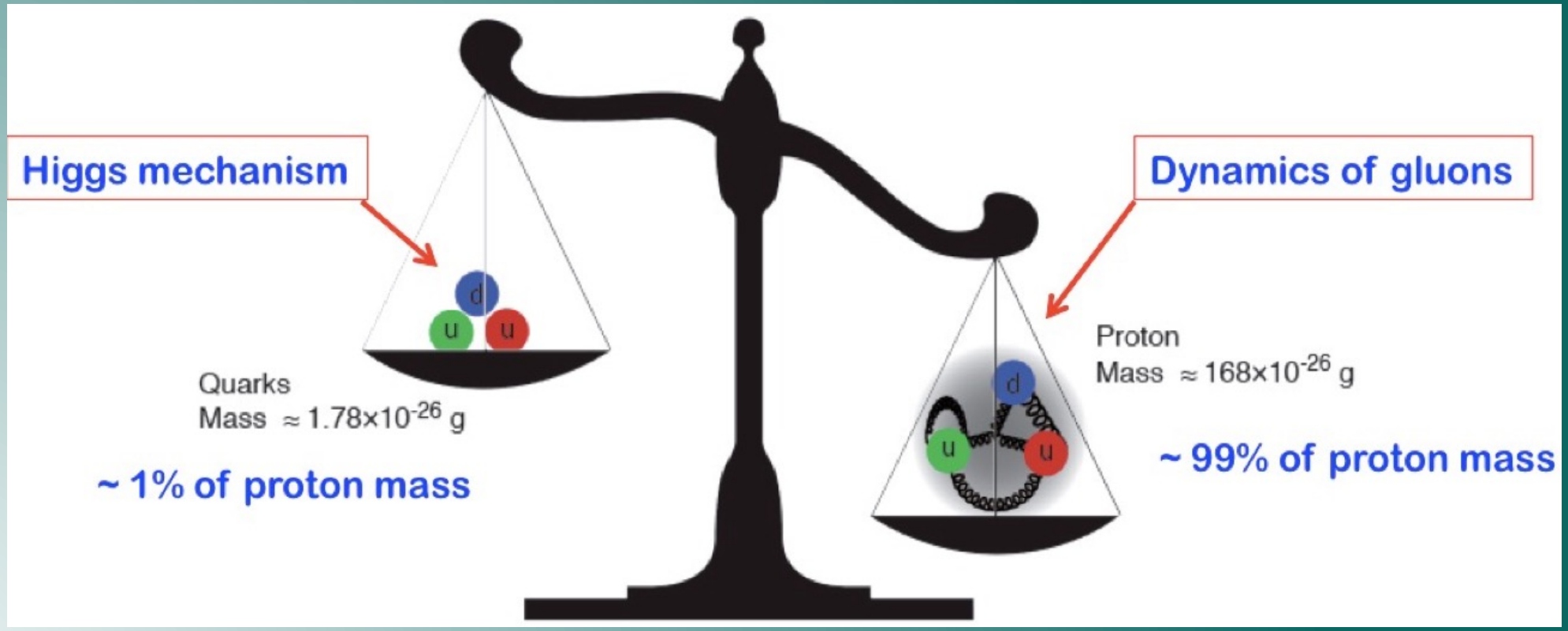
- Mass = Higgs ->Not Entirely



Meziani, 25th International Spin Symposium 2023, "The Proton Gluonic Gravitational Form Factors"

Gravitational Form Factors (GFF)

$$\langle p'|T^{\mu\nu}_{q,g}|p\rangle =$$

Polyakov & Schweitzer, arXiv: 1801.05858v1 [hep-ph]

$$\bar{u}(p')\left(A_{q,g}(t)\frac{\gamma^{\{\mu}P^{\nu\}}}{2}+B_{q,g}(t)\frac{iP^{\{\mu}\sigma^{\nu\}\rho}\Delta_\rho}{4M}+C_{q,g}(t)\frac{\Delta^\mu\Delta^\nu-g^{\mu\nu}\Delta^2}{M}+\bar{C}_{q,g}(t)Mg^{\mu\nu}\right)u(p)$$

$$P=(p+p')/2 \qquad \Delta=p'-p \qquad t=\Delta^2$$

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Kharzeev, Proc. Int. Sch. Phys. Fermi 130 (1996)

$$T^\alpha_\alpha=\underbrace{\frac{\beta(g)}{2g}G^{\alpha\beta a}G^a_{\alpha\beta}}+\sum_{l=u,d,s}m_l(1+\gamma_{m_l})\bar{q}_l q_l+\sum_{h=c,b,t}m_h(1+\gamma_{m_h})\bar{Q}_h Q_h$$

Trace Anomaly of QCD

Gravitational Form Factors (Experimentalist's Version)

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$A_{q,g}(t)$ $B_{q,g}(t)$ $C_{q,g}(t)$ $\bar{C}_{q,g}(t)$

- GFFs are the hadronic (quark/gluon) matrix elements of the QCD energy-momentum tensor and are distributions in terms of momentum transfer
- Connected to global properties

$A_{q,g}(t)$ ~ momentum of partons via $\lim_{t\to 0} A_{q,g}(t) = \langle x \rangle_{q,g}$

$J_{q,g}(t) = (A_{q,g}(t) + B_{q,g}(t))/2$ ~ angular momentum -> $J(0) = 1/2$

$D_{q,g}(t) = 4C_{q,g}(t)$ ~ pressure and shear forces

Why?

- Understanding how the massless gluons constitute 99% of proton mass
- Distribution of this “mass” in the confinement size of the proton

- Gluons are electrically neutral, cannot use elastic electron scattering as before

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Probing Proton’s Inner Mass Density with a Small Colour Dipole: J/ψ

-First determination of gluonic GFFs from data

-Sensitive to gluonic structure of the proton

Article | Published: 29 March 2023

Determining the gluonic gravitational form factors of the proton

B. Duran, Z.-E. Meziani, S. Joosten, M. K. Jones, S. Prasad, C. Peng, W. Armstrong, H. Atac, E. Chudakov, H. Bhatt, D. Bhetuwal, M. Boer, A. Camsonne, J.-P. Chen, M. M. Dalton, N. Deokar, M. Diefenthaler, J. Dunne, L. El Fassi, E. Fuchey, H. Gao, D. Gaskell, O. Hansen, F. Hauenstein, ... Z. Zhao

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Measurement of J/ψ Photoproduction in Threshold Region

- J/ψ-007 experiment performed in Hall C at Jefferson Lab in 2019
- Exclusive J/ψ photoproduction differential cross section (off a nucleon)

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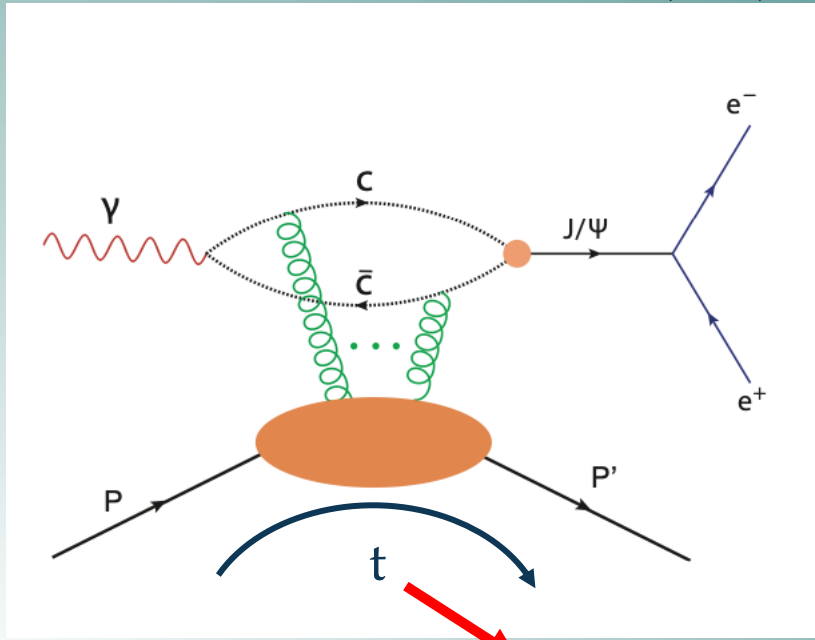

Mandelstam Variable

- Bremsstrahlung photon emitted from 10.6 GeV e-beam -> 8.5% Cu Radiator
- e and γ interact with target

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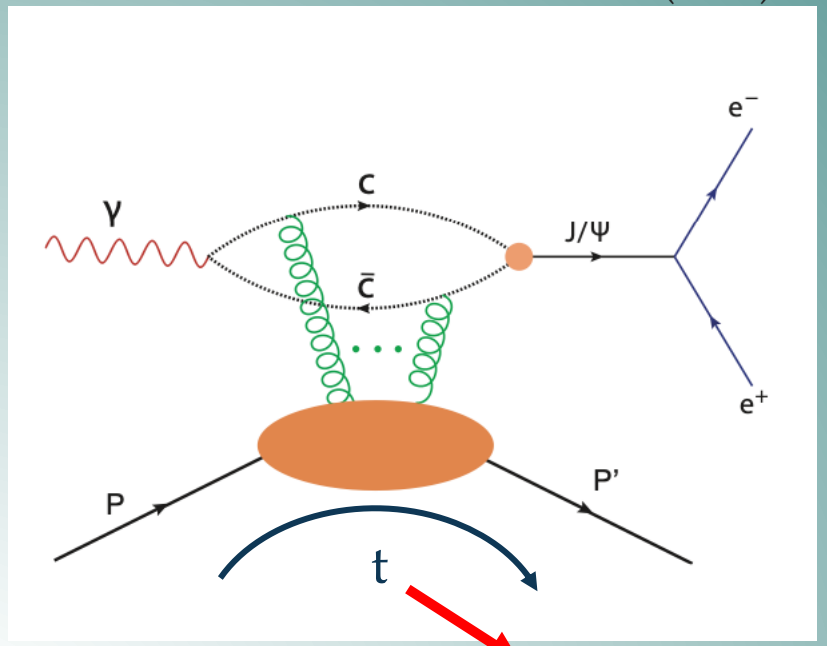

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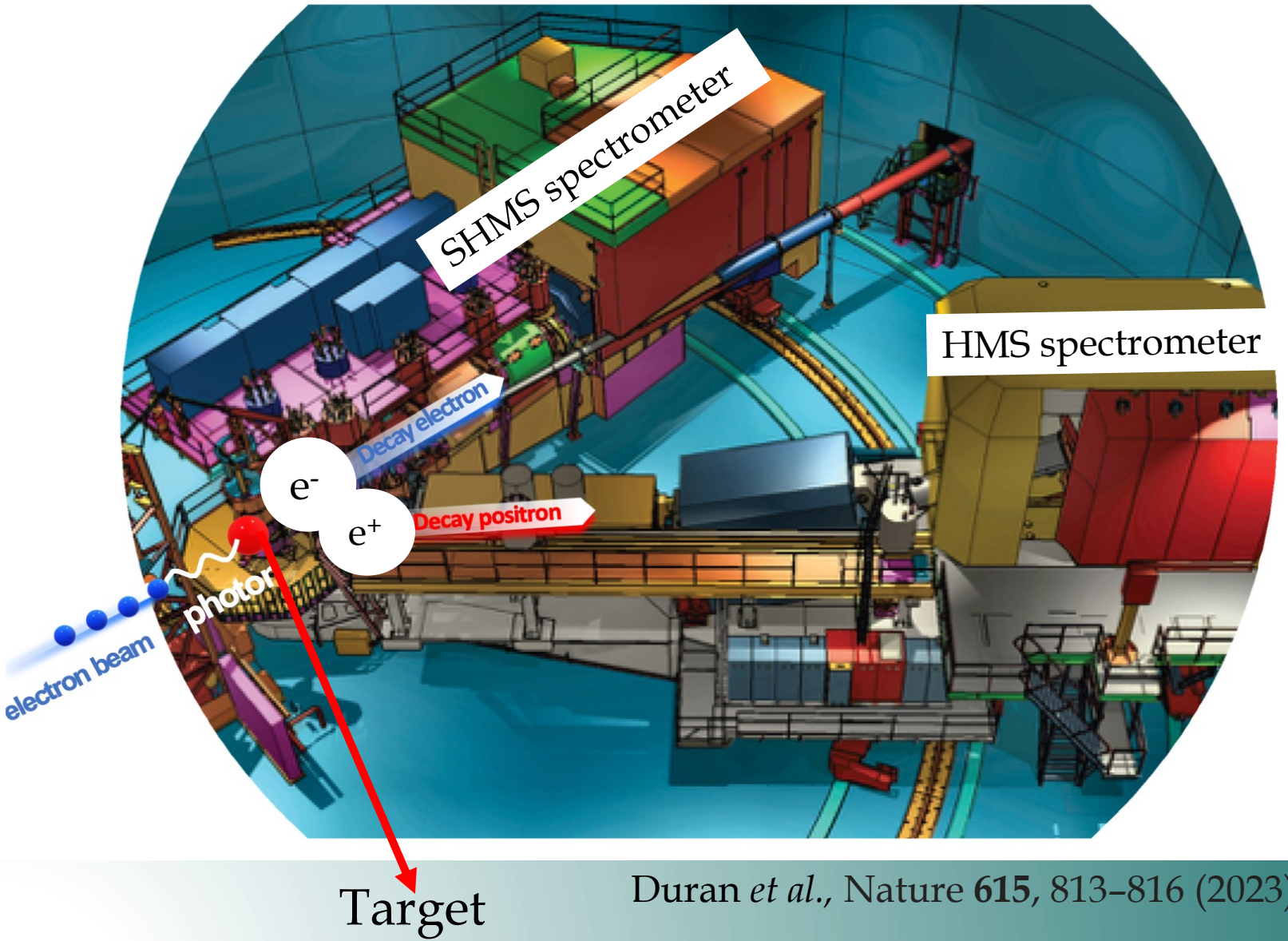
- Target: 10cm cylindric aluminium can with 19K liquid helium inside

Experimental Layout



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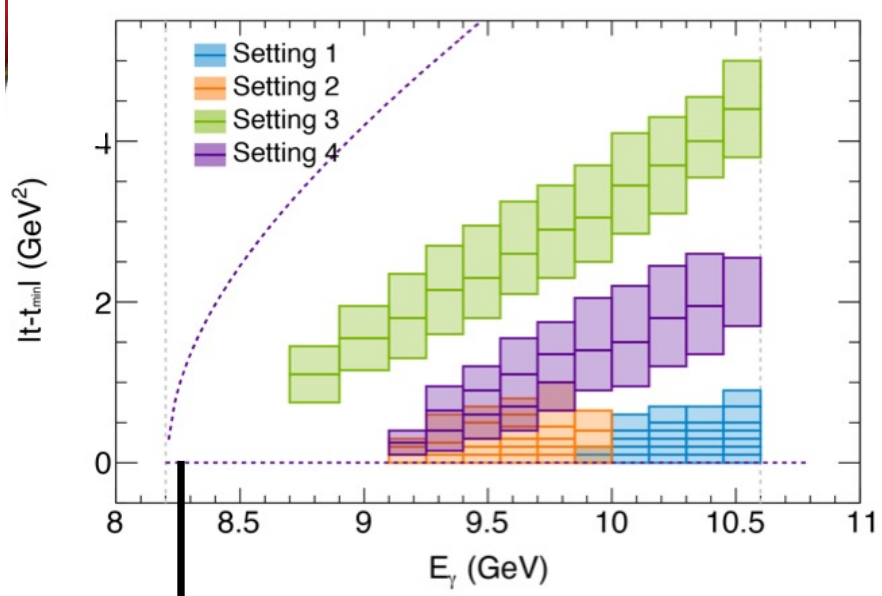
Phase Space $|t - t_{\min}|$ vs E_γ



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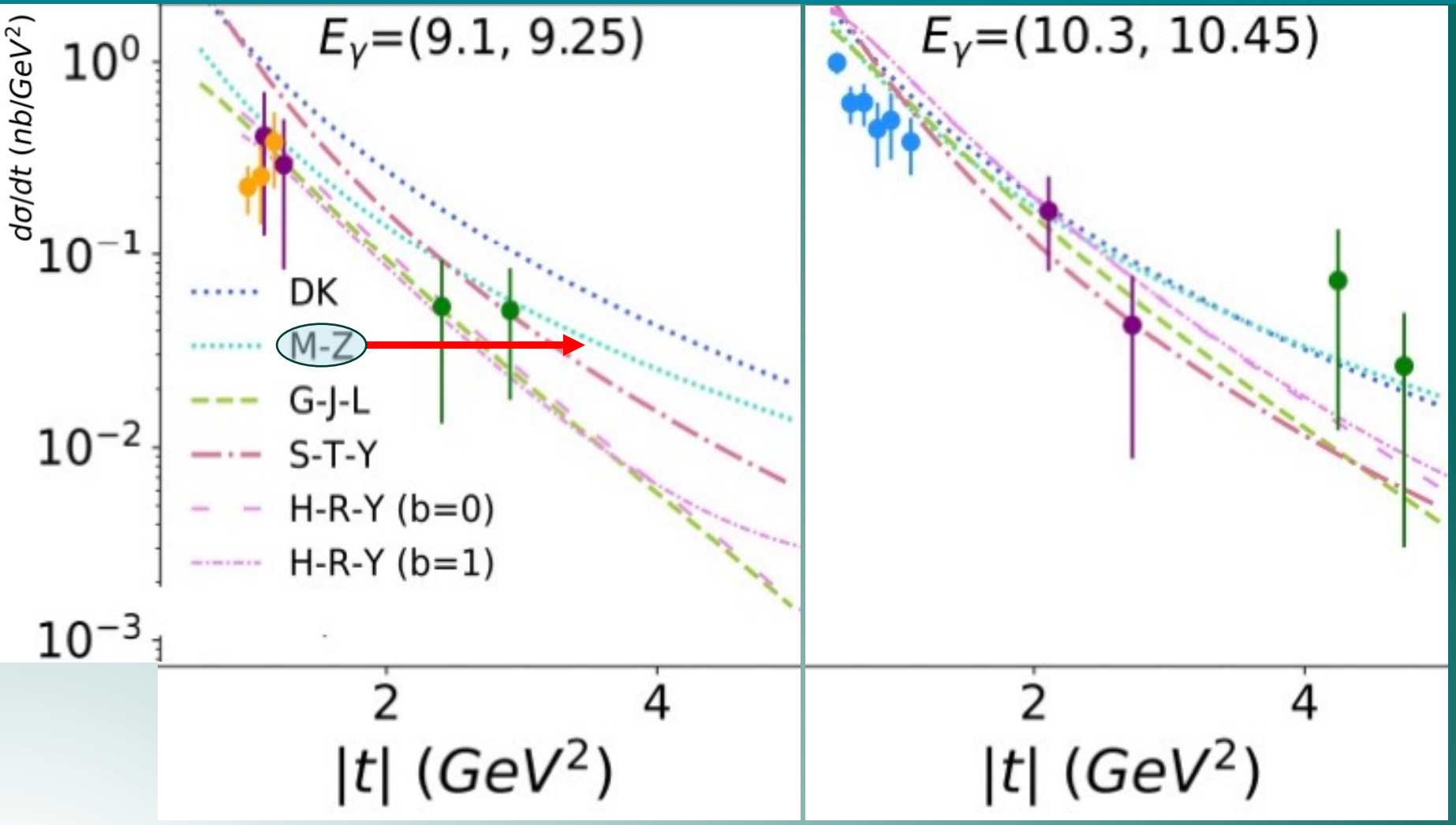
Threshold E_γ

- Lepton pair is detected in coincidence at the spectrometers

Unfolded 2-D Differential Cross Sections



- Different models to calculate cross section, fixed with past photoproduction experiment results
- At higher energies, all models seem to reproduce the data; deviations at lower energies
- M-Z model (light-blue curve) captures the slope change well

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M-Z: Mamo and Zahed, PRD **106,** 086004 (2022)

GFF Extractions

- In the M-Z model, assuming the contribution of $B_g(t)$ to be small in the differential cross section: (LQCD)

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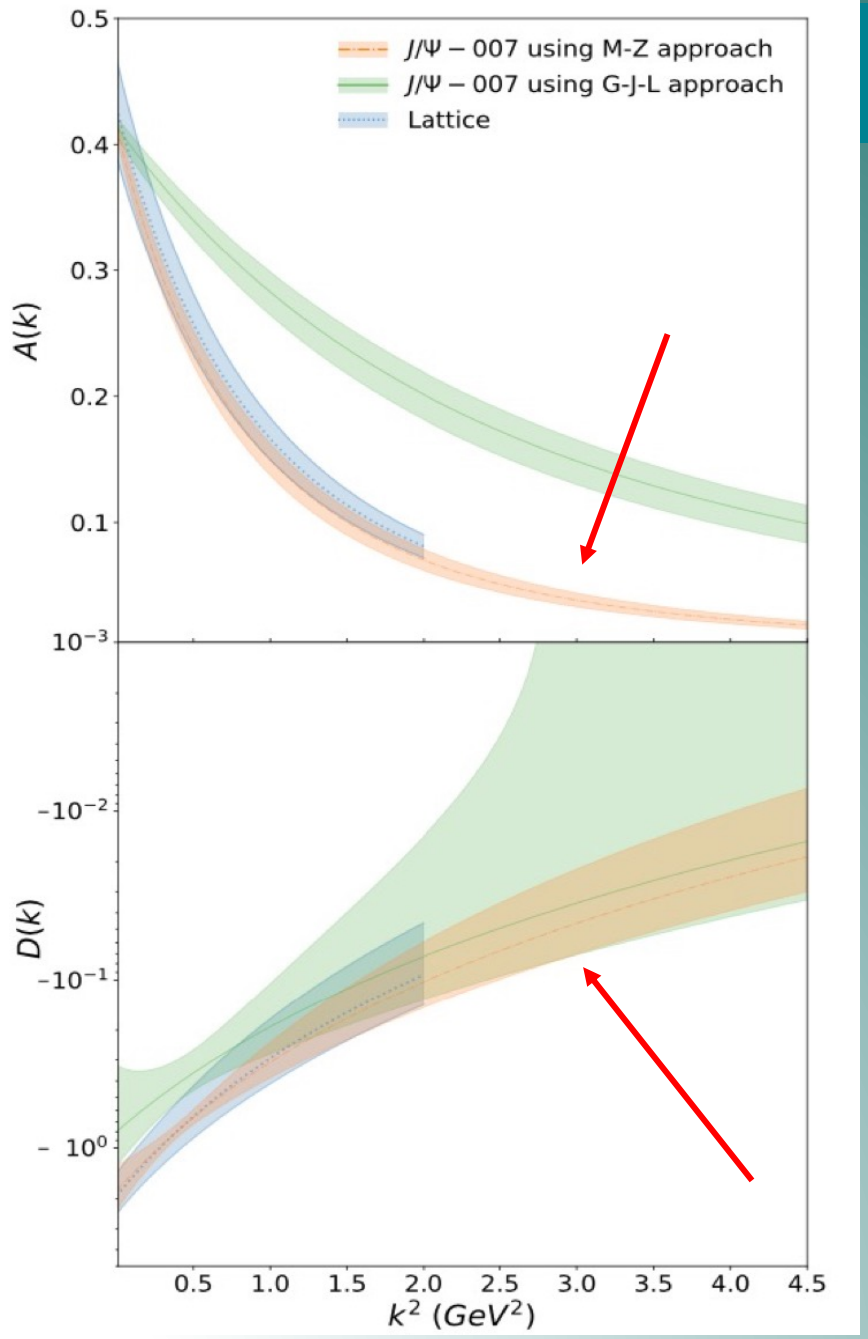
- Parametrise GFFs and perform a 2D fit to measured differential cross sections:
  - $C_g(0)$ and $A_g(0) = \langle x \rangle_g$ -> CT18 Global Fit
  - 2D approach allows the unknown parameters to be all constrained

Results



- Gluonic form factors $A_g(t)$ and $D_g(t) = 4C_g(t)$
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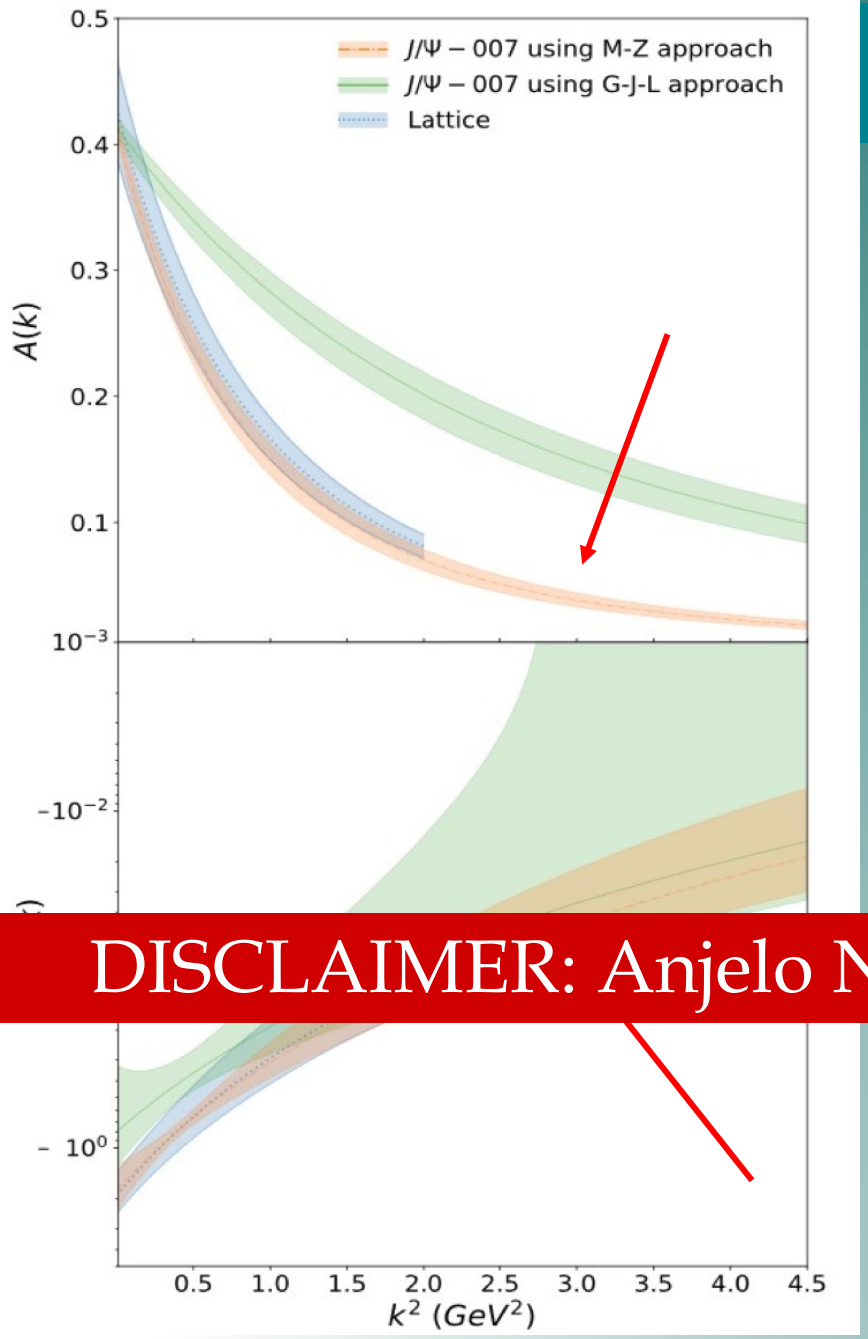

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DISCLAIMER: Anjelo Narendran has given me his consent for that joke.

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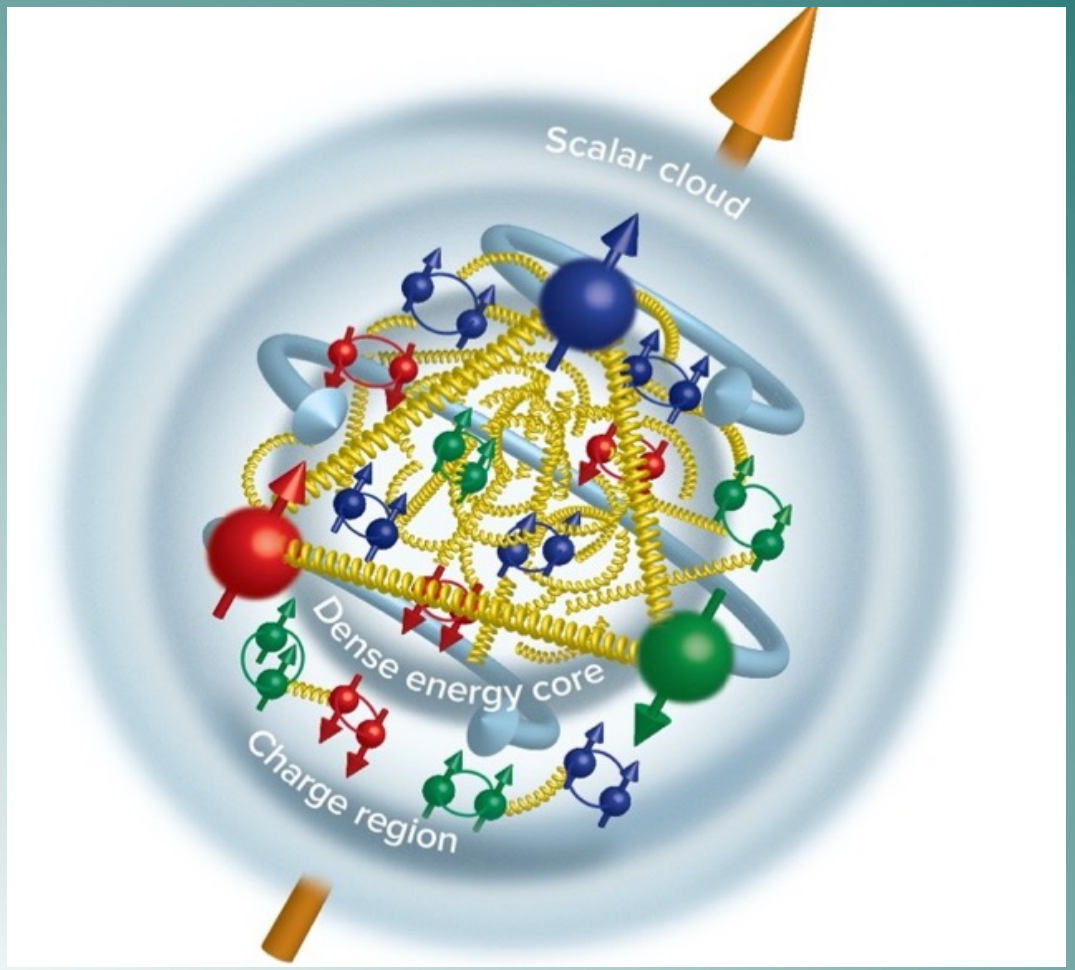
Mass Radius of the Proton



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- M-Z model yields:

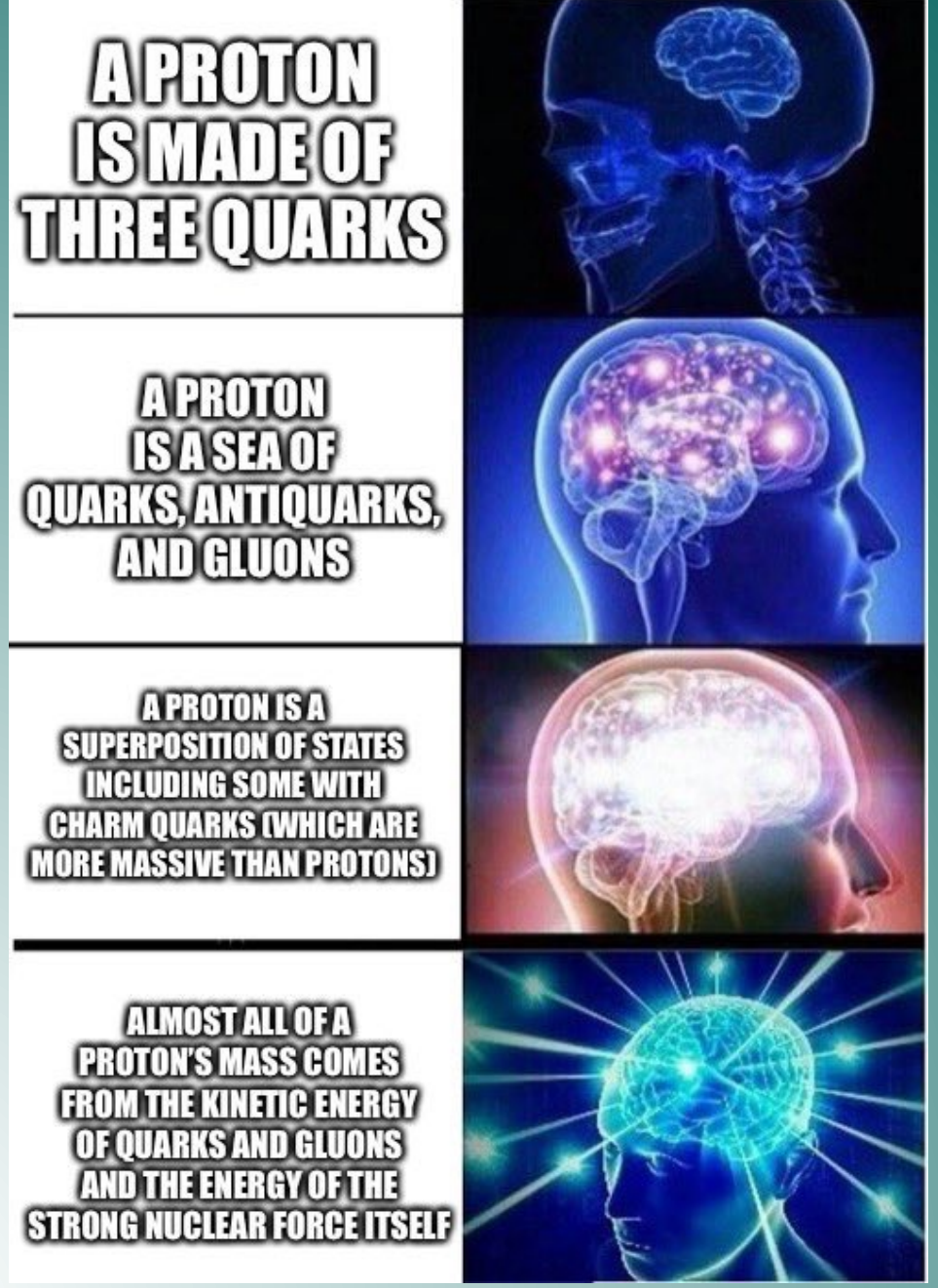
$$\text{Mass Radius} = 0.755 \pm 0.035\,\text{fm}$$

$$\text{Scalar Radius} = 1.069 \pm 0.056\,\text{fm}$$

Future Holds

- Muon channel: doubling the statistics
- Pressure and shear distributions of gluons

- Plans for future SoLID (Solenoid Large Intensity Device) experiment: near-threshold J/ψ production
  - Ultra-high luminosity
  - Hopefully will complement EIC



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Thank You!