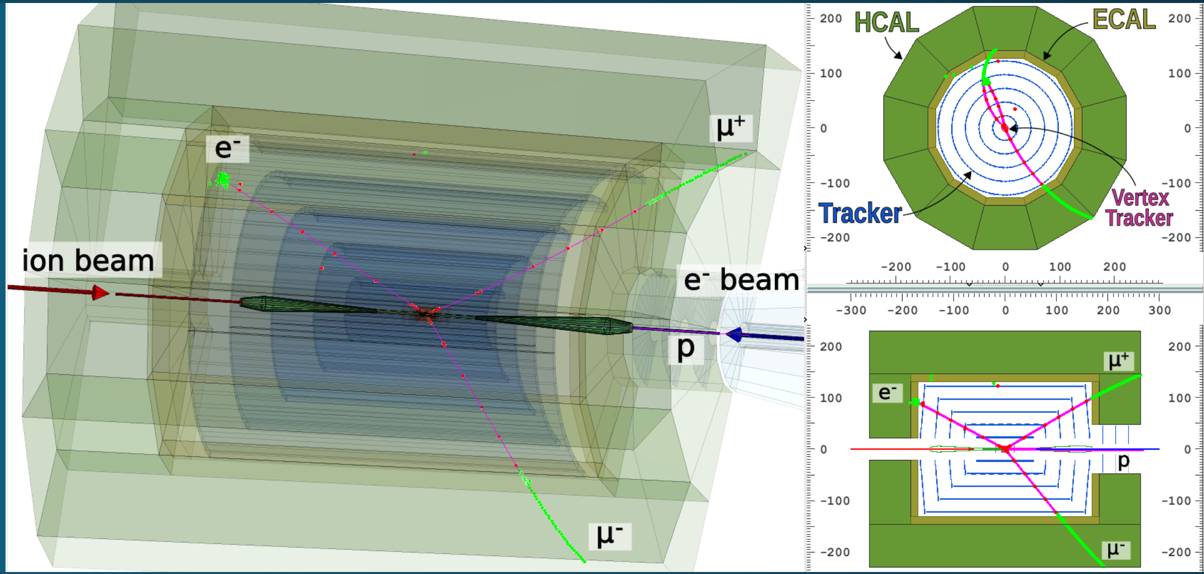
J/psi and Upsilon Electro- and Photo-production at the EIC using ToPSiDE



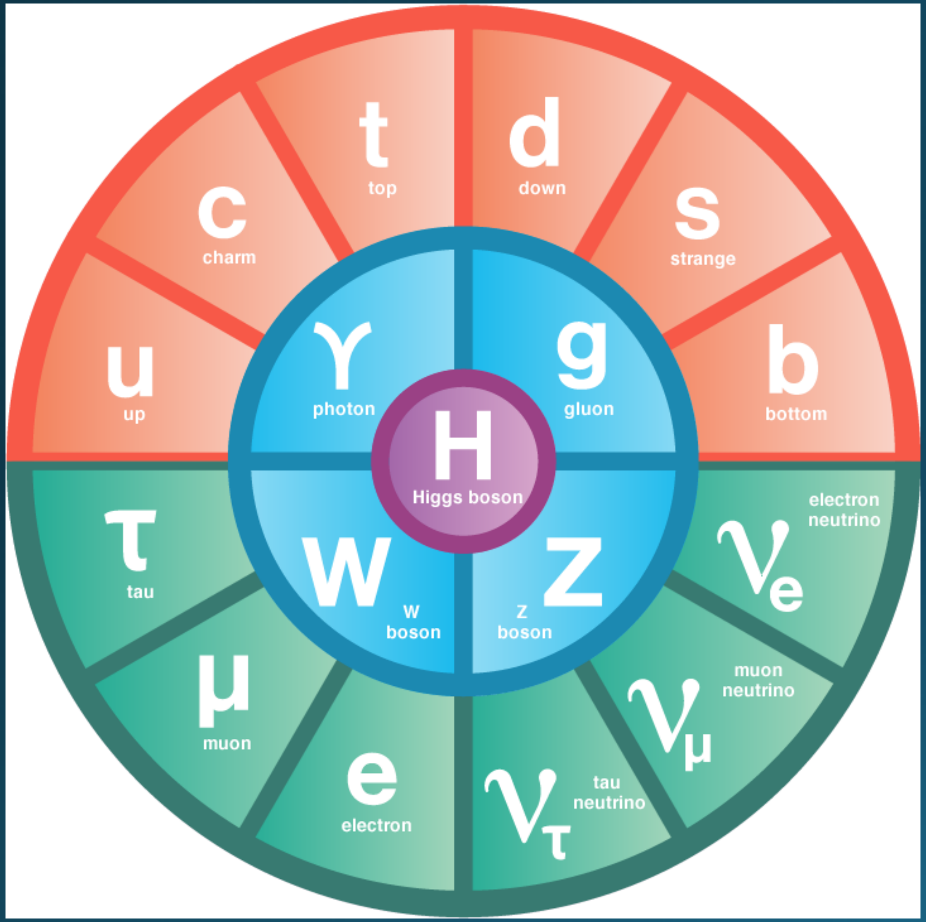
ZEIN-EDDINE MEZIANI

Argonne National Laboratory

Ad-hoc meeting on SOI

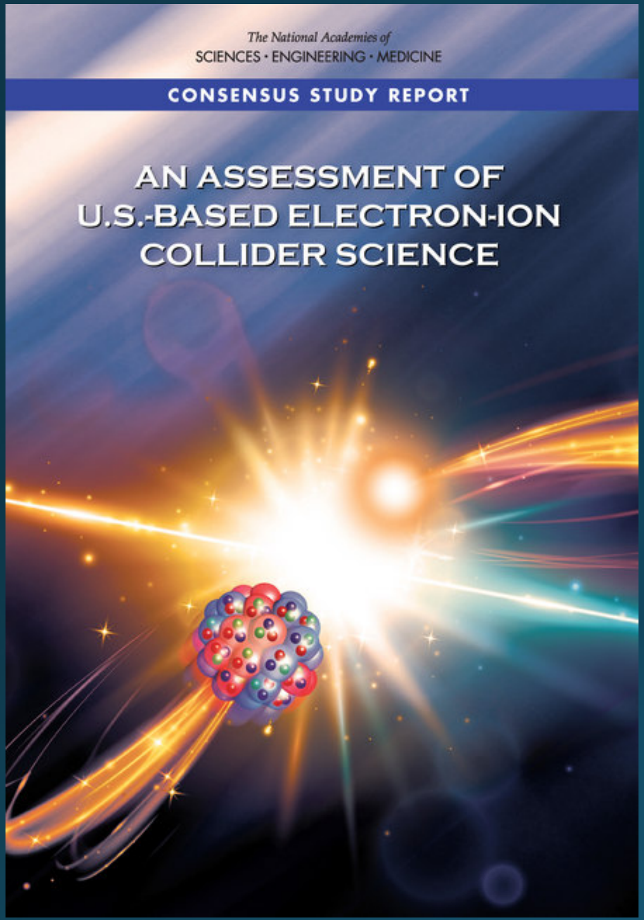
June11, 2020

QCD in the Standard Model of Particle Physics



- The Higgs mechanism is responsible for the mass of elementary particles but not of nucleons and nuclei thus the visible universe.
- Quantum Chromodynamics (QCD) is responsible for most of the visible matter in the universe providing mass to nucleons and nuclei through the "trace anomaly" a consequence of scale invariance
- Gravitational form factors (GFFs) with info, on energy/mass distribution in the nucleon and nuclei can be accessed through the second Mellin moments of leading-twist GPDs.

EIC Science Assessment by NAS



Finding 1:

An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:

- How does the mass of the nucleon arise?
- How does the spin of the nucleon arise?
- What are the emergent properties of dense systems of gluons?

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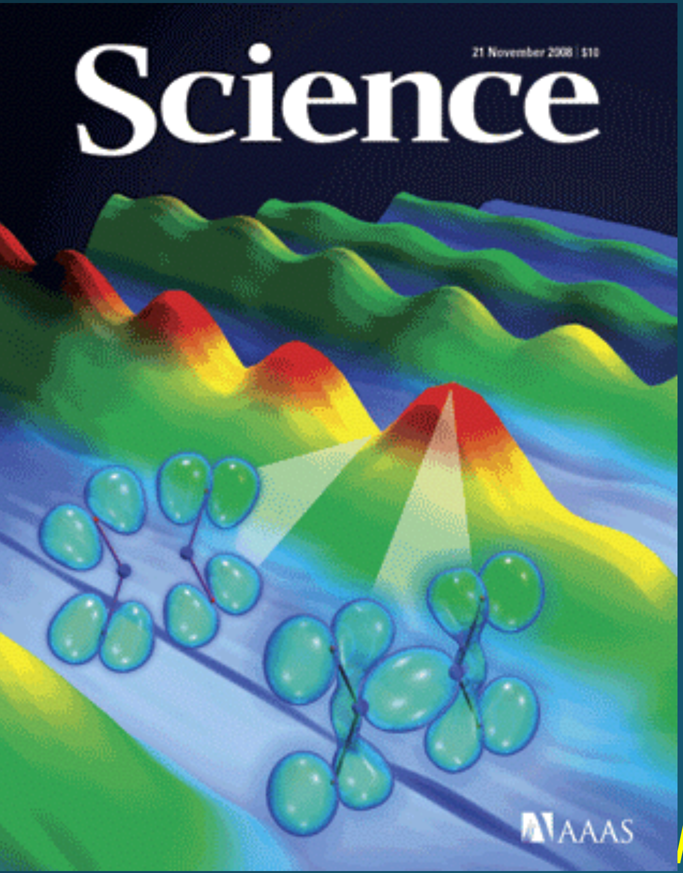
How does QCD generate the nucleon mass?

"… The vast majority of the nucleon's mass is due to quantum fluctuations of quark-antiquark pairs, the gluons, and the energy associated with quarks moving around at close to the speed of light. …" ***The 2015 Long Range Plan for Nuclear Science***

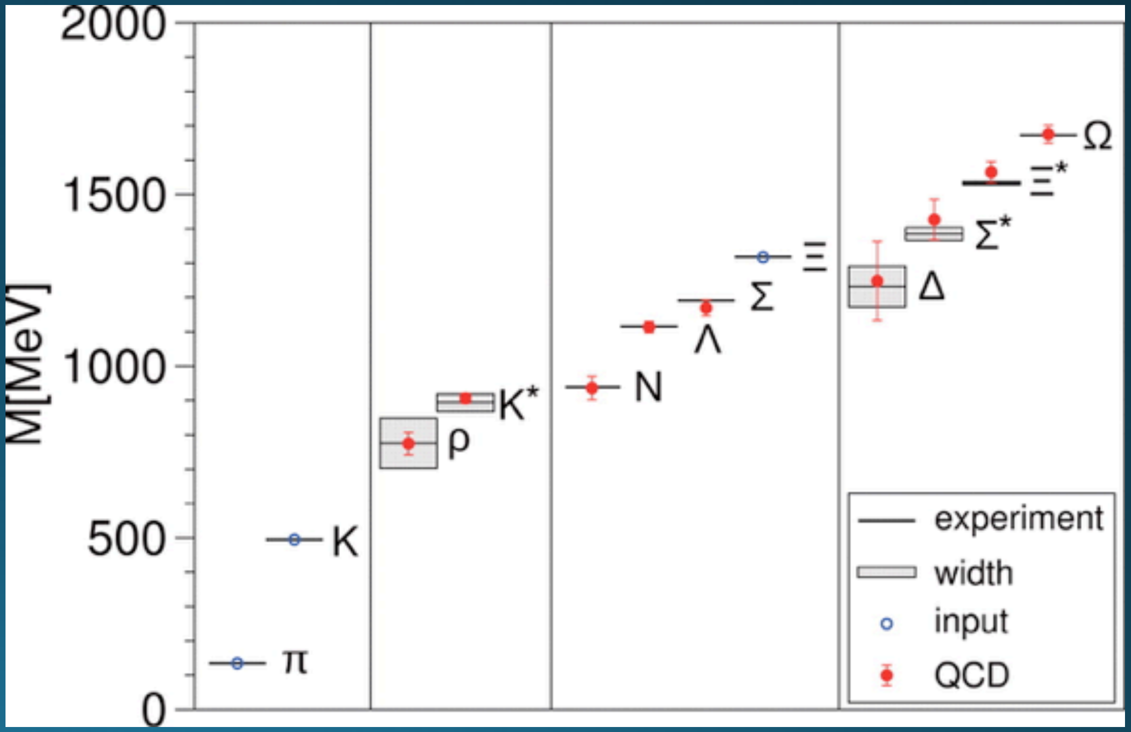
❑ Hadron mass from Lattice QCD calculation:



Ab Initio Determination of Light Hadron Masses
S. Dürr, Z. Fodor, C. Hoelbling, R. Hoffmann, S.D. Katz, S. Krieg, T. Kuth, L. Lellouch, T. Lippert, K.K. Szabo and G. Vulvert

2008
Science 322 (5905), 1224-1227
DOI: 10.1126/science.1163233

568 citations



How does QCD generate this? The role of quarks and of gluons?

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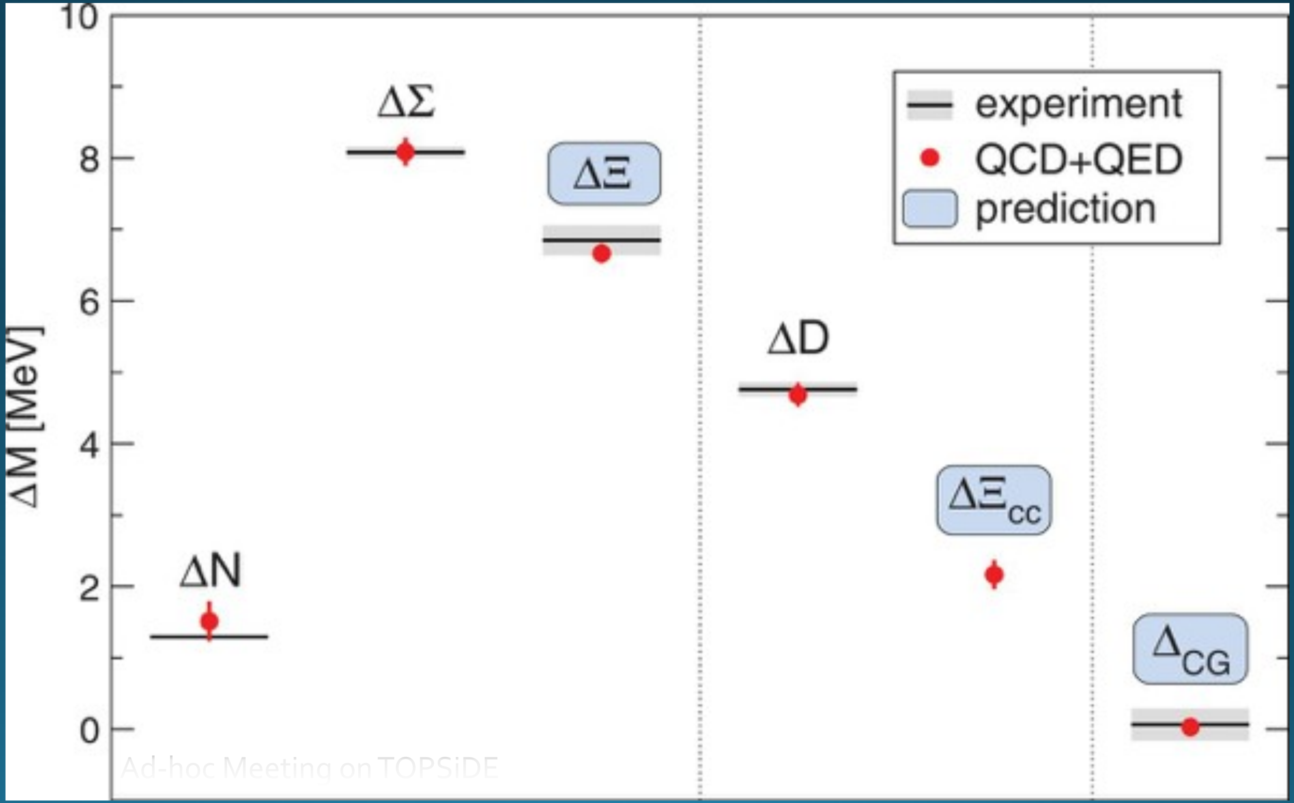
Science

2015

Ab initio calculation of the neutron-proton mass difference

Sz. Borsanyi, S. Durr, Z. Fodor, C. Hoelbling, S. D. Katz, S. Krieg, L. Lellouch, T. Lippert, A. Portelli, K. K. Szabo and B. C. Toth

Science **347** (6229), 1452-1455.
DOI: 10.1126/science.1257050



261 Citations

- What is the origin of hadron masses?
  - A case study: the proton
- What is the size of the interaction between a quarkonium and a proton? Color Van der Waals force?
- Do heavy quarkonia enable pentaquarks to exist?
- Are bound states of quarkonia in nuclei possible?

What are the science questions enabled by J/ψ or Upsilon in TOPSiDE at an EIC?

What is the Origin of the Proton Mass?

- The trace anomaly and the proton mass
  - Sensitivity to the threshold cross section of upsilon or J/psi
  - Q^2 dependence and unraveling the gluon contribution
- Search for possible pentaquark states and measure their properties
  - Examine t distributions carefully
- Understanding the gluonic interaction in the proton; color Van-der Waals forces
  - Possible J/psi-N bound states

Threshold electro-photoproduction of quarkonium can probe the mass distribution inside the proton and nuclei

Proton Mass Decomposition

useful to find the role the constituents but not unique

- Covariant decomposition
  - see, e.g., [M. Shifman et al., Phys. Lett. 78B (1978), D. Kharzeev, Proc. Int. Sch. Phys. Fermi 130 (1996)]

- Rest frame decomposition

- [X.D. Ji, Phys. Rev. Lett. 74, 1071 (1995), X. D. Ji, Phys. Rev. D 52, 271 (1995)]

- Decomposition with Pressure effects
  - [C. Lorce´, Eur. Phys. J. C78 (2018) 2, arXiv:1706.05853]

- Revisiting the Mechanical Properties of the Nucleon
  - [C. Lorcé, H. Moutarde and A. Trawińsk, Eur. Phys. J C79 (2019)

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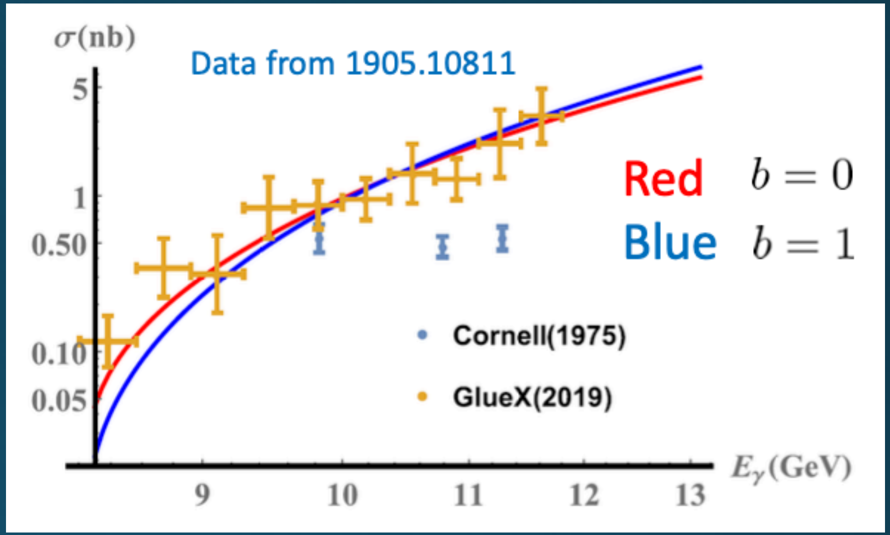
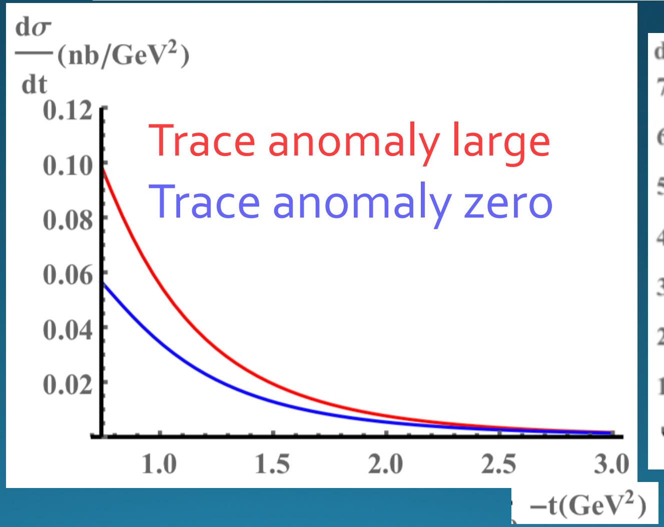
Y. Hatta *et al.*, PRD 98 no. 7, 074003 (2018)
Y. Hatta *et al.*, 1906.00894 (2019)

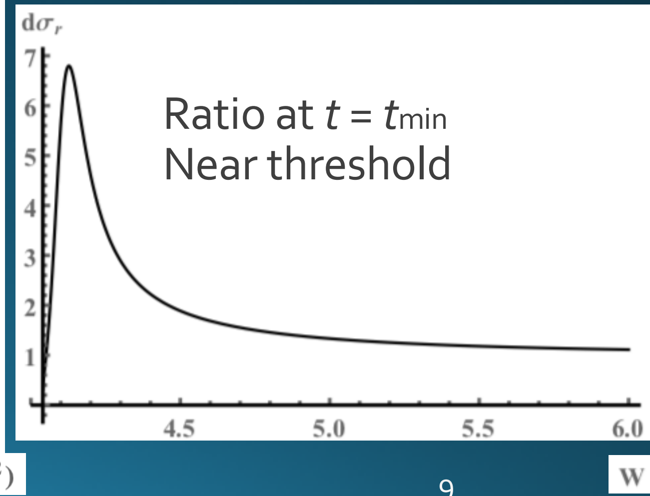
Sensitivity to Trace Anomaly near threshold of J/Psi Production?

Holographic approach (AdS/CFT)

- Perturbative approach difficult
  (no factorization for twist-4 trace anomaly operator)
- Use non-perturbative method instead through AdS/CFT
  (gauge-string duality: dilaton dual to $F^{\mu\nu}F_{\mu\nu}$)
- **No appropriate for high energies** (Amplitude should be imaginary in this approach it is real)
- **At low energies**: Scattering amplitudes are real as they should
- Predicts largest sensitivity to trace anomaly near threshold at low *t*
- New development, numerical predictions carry large model uncertainties





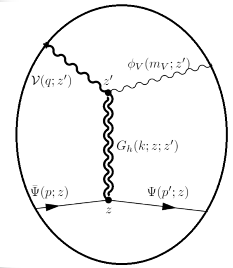


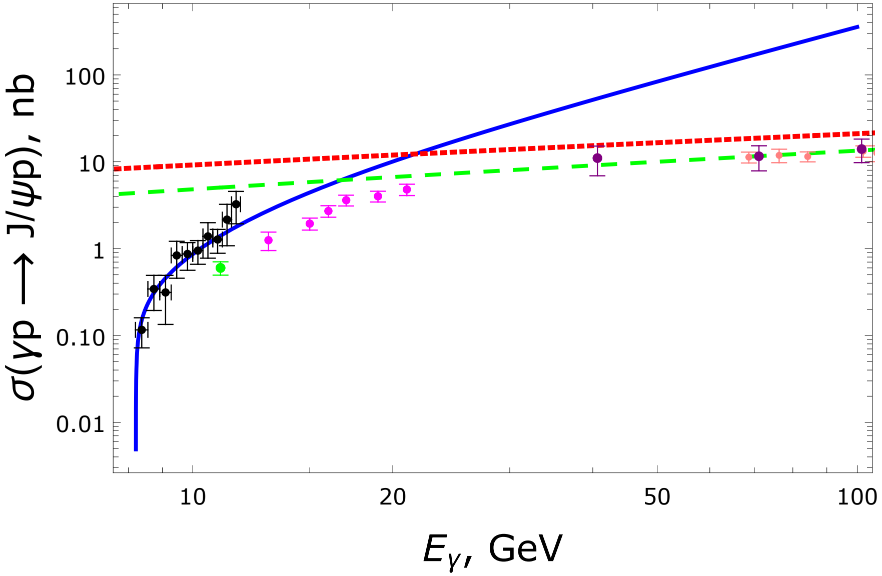
Another Holographic Approach

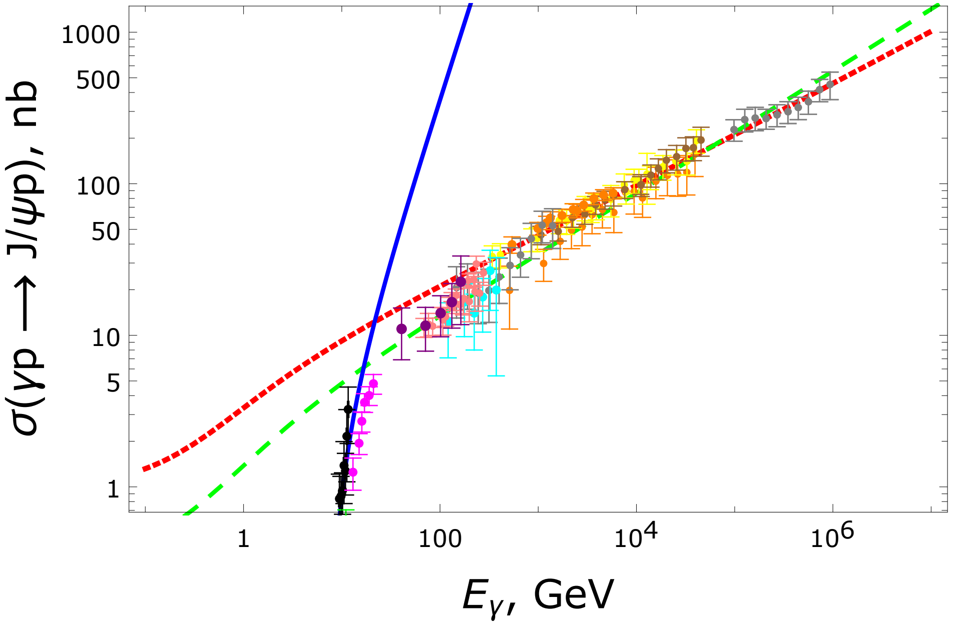
K. Mamo & I. Zahed, “Diffractive photoproduction of J/ψ and Υ using holographic QCD: Gravitational form factors and GPD of gluons in the proton” Phys. Rev. D 101, 086003 (2020)

Conclusion: We have analyzed heavy meson photoproduction for all sqrt(s), using a bottom-up approach holographic construction.

We have used the Witten diagrams in AdS_5 for diffractive photoproduction of J=ψ, shown in Fig. 2, and explicitly computed the differential cross section for the heavy meson production, first near threshold, where it is dominated by the exchange of massive 2^{++} glueballs as spin-2 gravitons in bulk, and second away from threshold, where the exchange involves a tower of spin-j states that transmute to the Pomeron.
Our construction is general, and carries readily to heavier meson production such as Υ. We have presented direct predictions for this production near and away from threshold.

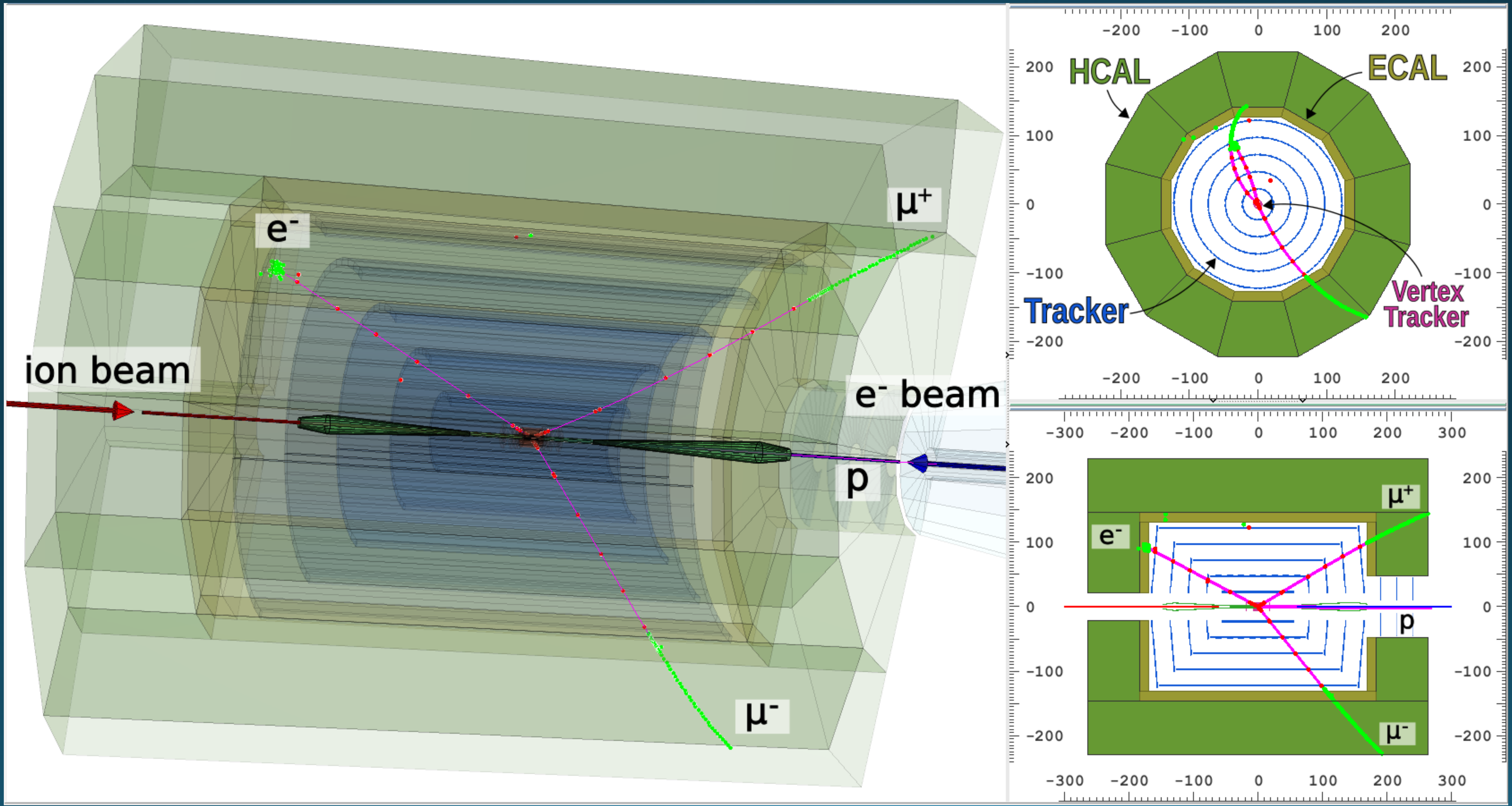






TOPSiDE: Timing Optimized PID Silicon Detector for the EIC

5D Detector Concept → Measure {E,x, y, z, t}



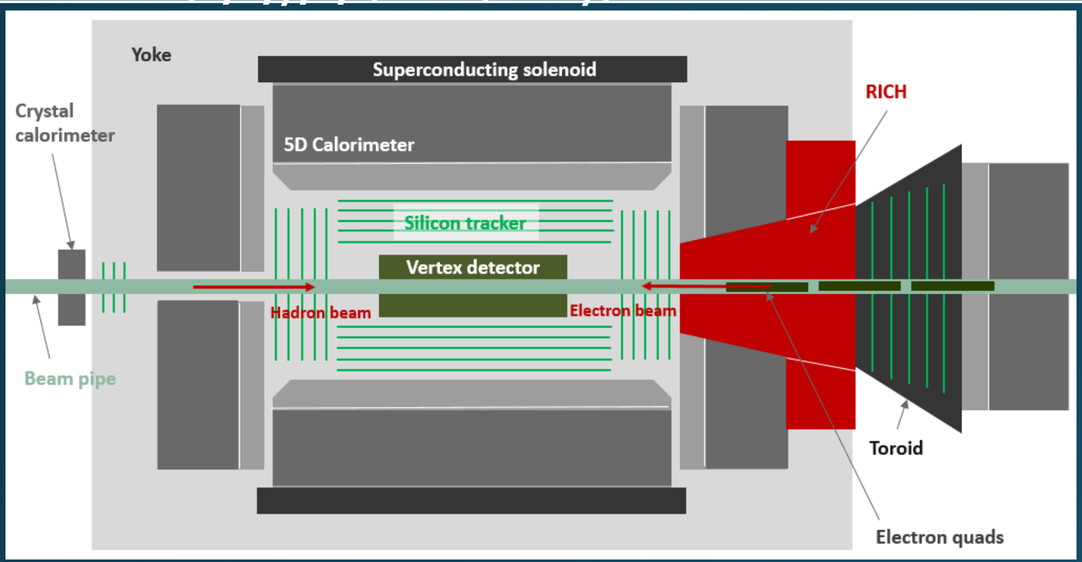
Basic Idea behind TOPSiDE

- Ultra-fast Si trackers (UFSD) and high granular imaging calorimeters
- Full PID over entire central and backward regions ($-5 < \eta < 3$)
- Covers a well defined central region where no extra PID detectors are needed
- Focused efforts for dedicated PID detectors in forward region where it is needed (Gas Ring Imaging Detector)

TOPSiDE: The 5D Concept

The idea

Measure (E,x,y,z,t) for (every) hit in tracker + calorimeter



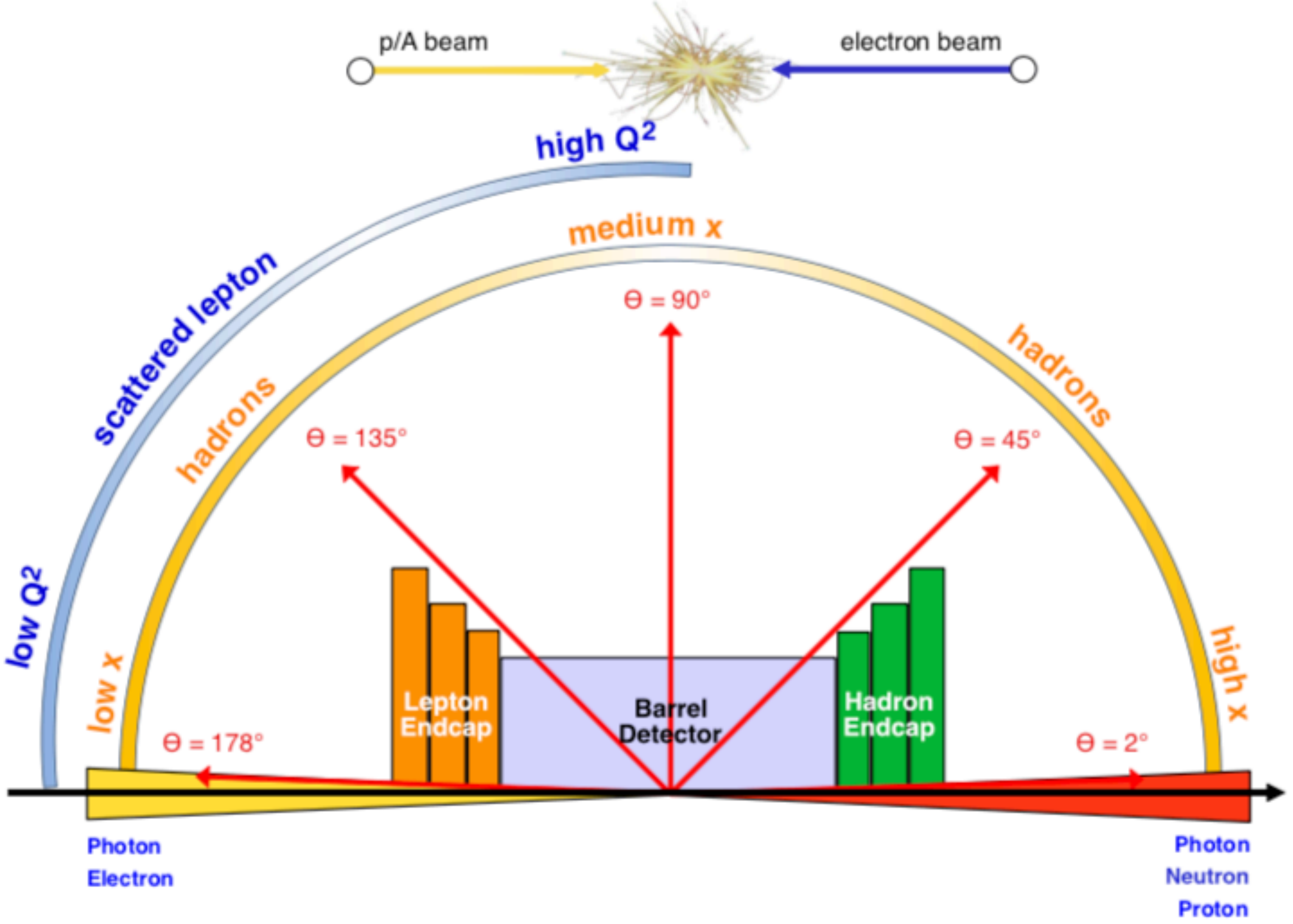
Silicon pixel vertex + strip tracker
Imaging calorimeter
Superconducting solenoid (3T)
Forward gaseous RICH
Forward dipole
Forward silicon disks
Forward calorimetry
Backward silicon disks
Backward crystal calorimeter

Particle identification (π – K – proton separation) ⟵ Important at the EIC

Particle momenta < 10 GeV/c for most of the solid angle: TOF using tracker + calorimeter
Requires **silicon sensors with time resolution of 10 ps or better**
Forward direction (momenta up to 50 GeV/c): **requires RICH with pixelated photosensor**

Eliminates

The need for pre-shower counters, TRDs, TOF or Čerenkov (in front of the calorimeter), muon chambers (in back of calorimeter)


p/A beam
electron beam
high Q2
scattered lepton
low Q2
medium x
hadrons
hadrons
low x
high x
Θ = 90°
Θ = 135°
Θ = 45°
Θ = 178°
Θ = 2°
Lepton Endcap
Barrel Detector
Hadron Endcap
Photon
Electron
Photon
Neutron
Proton

EIC Detector Requirements from the EIC HANDBOOK

published February 25, 2020

Table 2: Physics requirements for an EIC detector

η	Nomenclature			Tracking			Electrons		π/K/p PID		HCAL	Muons
				Resolution	Allowed X/X_0	Si-Vertex	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Resolution σ_E/E	
-6.9 — -5.8	↓ p/A	Auxiliary Detectors	low-Q^2 tagger	$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2								
…												
-4.5 — -4.0			Instrumentation to separate charged particles from photons				2%/√E					
-4.0 — -3.5												
-3.5 — -3.0		Central Detector	Backwards Detectors	$\sigma_p/p \sim 0.1\% \times p + 2.0\%$	~5% or less	TBD		π suppression up to 1:10^4	≤ 7 GeV/c	≥ 3σ	~50%/√E	
-3.0 — -2.5												
-2.5 — -2.0				$\sigma_p/p \sim 0.05\% \times p + 1.0\%$								
-2.0 — -1.5							7%/√E					
-1.5 — -1.0												
-1.0 — -0.5			Barrel	$\sigma_p/p \sim 0.05\% \times p + 0.5\%$		$\sigma_{xyz} \sim 20$ µm, $d_0(z) \sim d_0(r\phi) \sim 20/p_T$ GeV µm + 5 µm	(10-12)%/√E		≤ 5 GeV/c		TBD	TBD
-0.5 — 0.0												
0.0 — 0.5												
0.5 — 1.0												
1.0 — 1.5			Forward Detectors	$\sigma_p/p \sim 0.05\% \times p + 1.0\%$		TBD			≤ 8 GeV/c		~50%/√E	
1.5 — 2.0												
2.0 — 2.5									≤ 20 GeV/c			
2.5 — 3.0				$\sigma_p/p \sim 0.1\% \times p + 2.0\%$								
3.0 — 3.5									≤ 45 GeV/c			
3.5 — 4.0	↑e	Auxiliary Detectors	Instrumentation to separate charged particles from photons									
4.0 — 4.5												
…												
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\lvert t\rvert)/\lvert t\rvert < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c								