Summary of Parallel Sessions: Novel Observables & Building on Lessons Learned

Speakers:

Phiala Shanahan, James Maxwell, Tanja Horn, Cédric Mezrag; Sergei Alekhin, Michael Murray, Christophe Royon, Jan Bernauer

Ian Cloët
Argonne National Laboratory

The Electron Ion Collider User Group Meeting

Argonne, 7–9 July 2016

U.S. DEPARTMENT OF ENERGY | Office of Science

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Massachusetts Institute of Technology

Exotic Glue in the Nucleus?

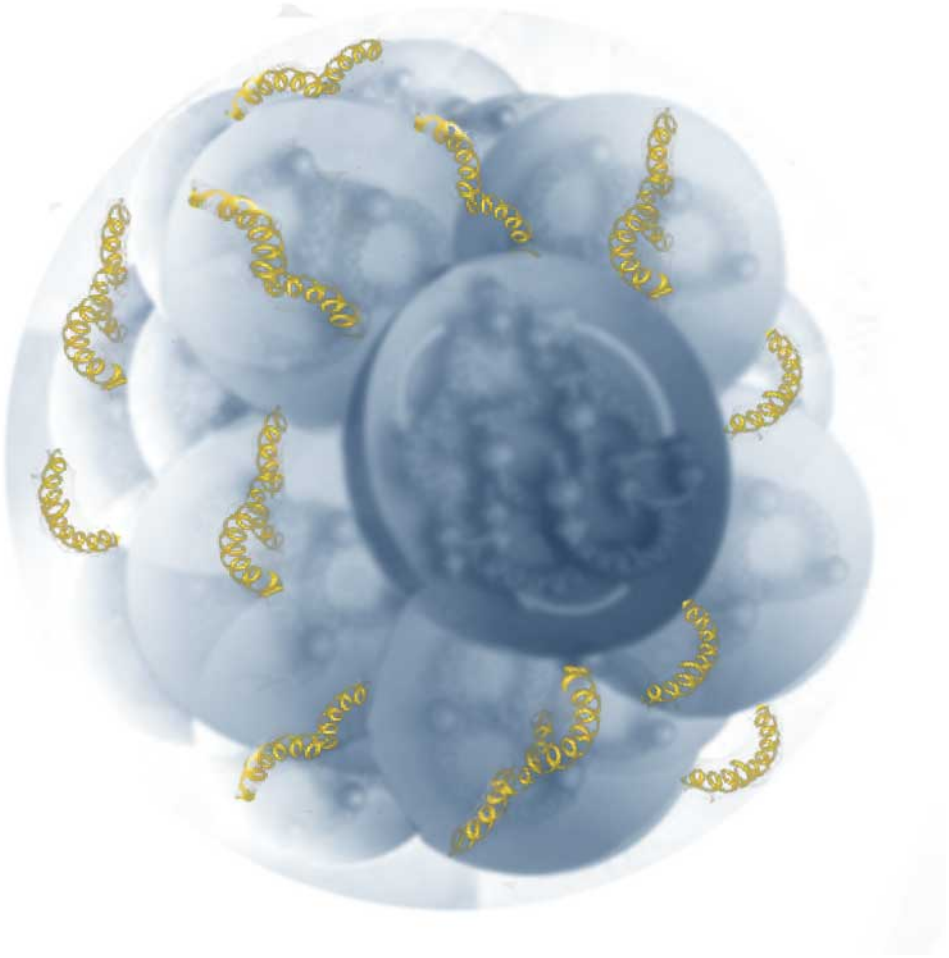
Gluonic Transversity Structure Functions from Lattice QCD

Phiala Shanahan, Will Detmold

Massachusetts Institute of Technology

July 8, 2016

‘Exotic’ Glue in the Nucleus



‘Exotic’ Glue

Contributions to gluon observables that are not from nucleon degrees of freedom.

Exotic glue operator:

operator in nucleon $= 0$

operator in nucleus $\neq 0$

Double Helicity Flip Gluon Structure Function: $\Delta(x, Q^2)$

Jaffe and Manohar (1989)

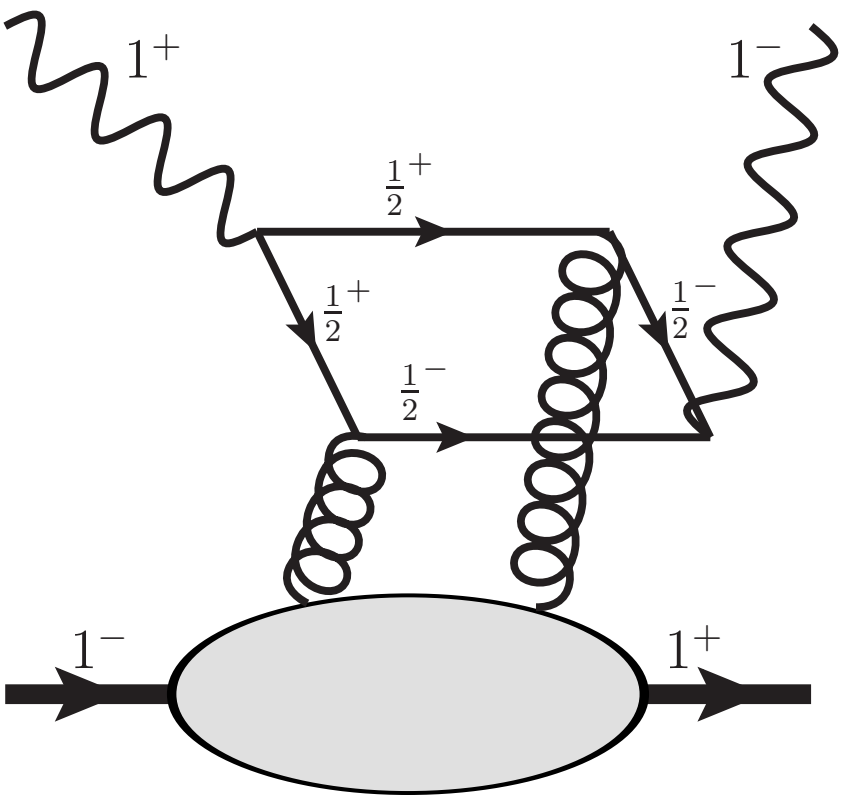
Leading-twist, double-helicity-flipping structure function $\Delta(x, Q^2)$ sensitive to exotic glue in the nucleus

- Clear signature for exotic glue in nuclei with spin ≥ 1:
  NO analogous twist-2 quark PDF $\rightarrow$ unambiguous
- Experimentally measurable (JLab LOI 2016, James Maxwell's talk)
- Moments are calclable on the lattice

First Lattice Study: arXiv:1606.04505

- First moment of $\Delta(x, Q^2)$ in spin-1 ϕ (or ρ) meson

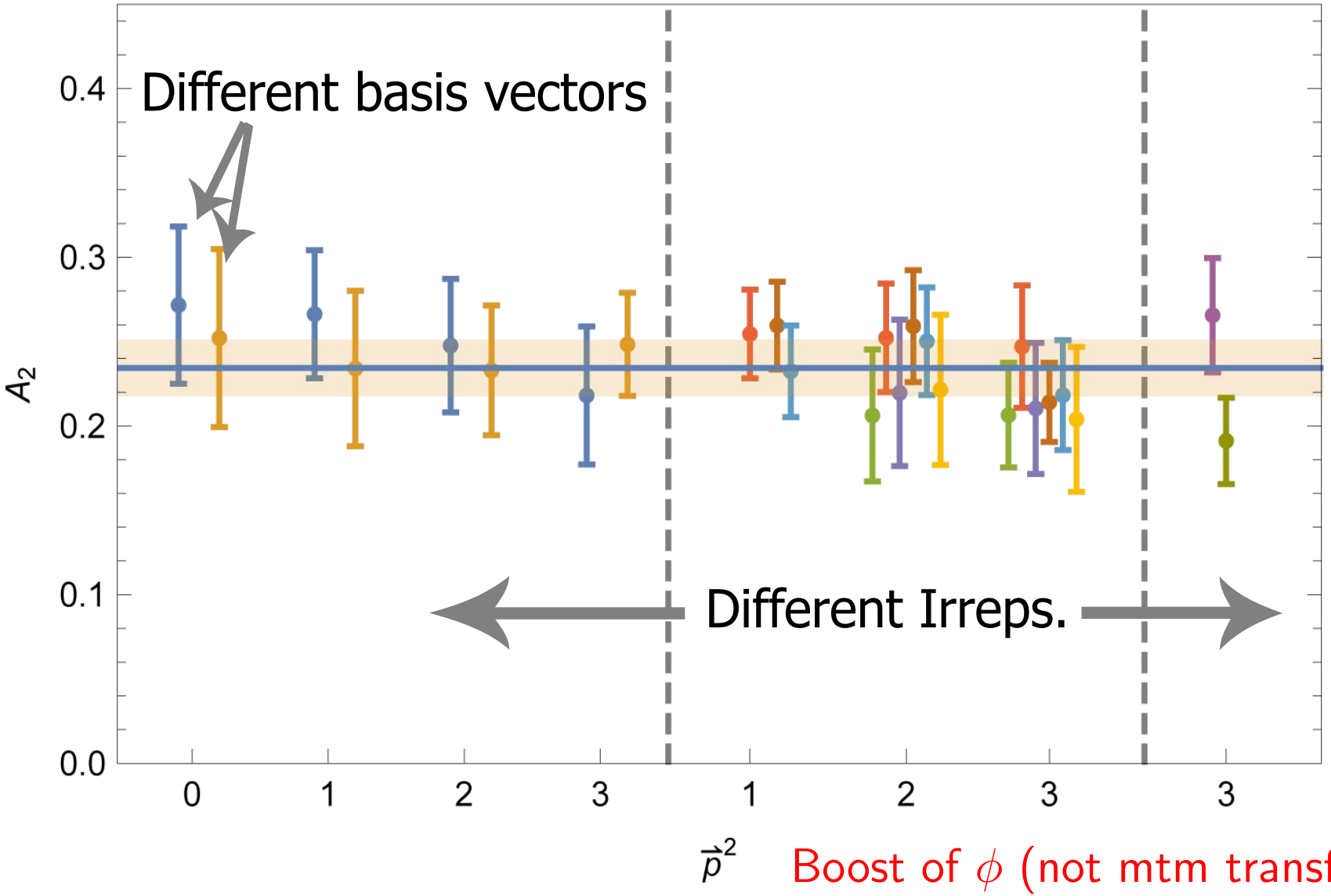
Double Helicity Flip Gluon Structure Function: $\Delta(x, Q^2)$



Double helicity flip amplitude:

$$\Delta(x, Q^2) = A_{+-,-+} = A_{-+,+-}$$

UNRENORMALISED reduced matrix element: ϕ meson



Boost of ϕ (not mtm transfer)

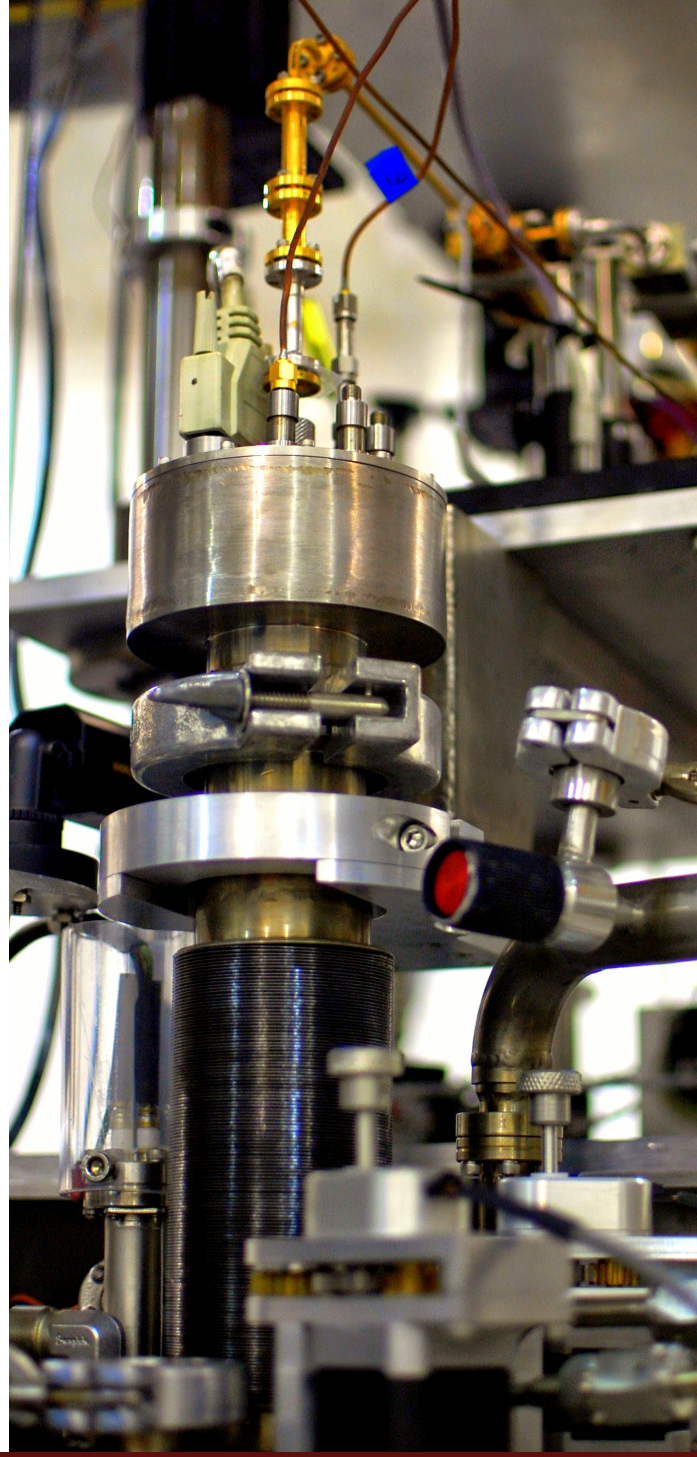
Search for Exotic Gluonic States In the Nucleus

J. Maxwell

with W. Detmold, R. Jaffe, R. Milner, P. Shanahan

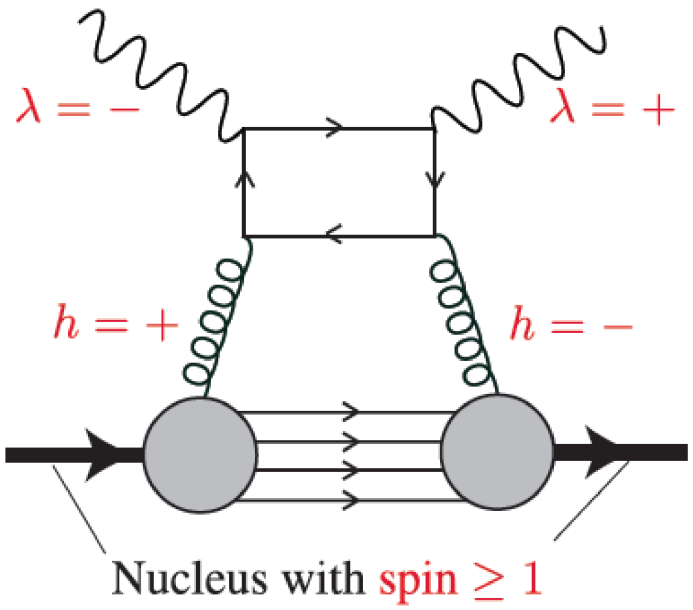
Jefferson Lab

EIC User Group Meeting
July 8th, 2016



Double Helicity Flip Structure Function $\Delta(x, Q^2)$

- $\Delta(x, Q^2)$ corresponds to helicity amplitude $A_{+-,-+}$
- Photon helicity flip of two
- Unavailable to bound nucleons or pions in the nucleus
- Virtual ρ or Δ? Gluons not associated with a nucleon?



- New lattice QCD result for first moment of $\Delta(x, Q^2)$ in a ϕ meson is preliminary, but very promising[1]
- Primary challenge of measurement is polarized target or source

[1] Detmold, Shanahan, arXiv:1606.04505

Measuring $\Delta(x, Q^2)$ via DIS

- Transversely aligned, spin-1 target and unpolarized electron incident from $-z$
- In the Bjorken limit, double helicity component of the hadronic tensor $W^{\Delta=2}_{\mu\nu,\alpha\beta}(E, E')$ becomes (dropping higher twist structure functions)[1]:

$$\lim_{Q^2\to\infty} \frac{d\sigma}{dx\,dy\,d\phi} = \frac{e^4 ME}{4\pi^2 Q^4}\Bigg(xy^2 F_1(x, Q^2) + (1-y)F_2(x, Q^2) - \frac{x(1-y)}{2}\Delta(x, Q^2)\cos 2\phi\Bigg)$$

[1] Jaffe, Manohar, Phys Letters B 223 (2) (1989).

3 ways to measure $\Delta(x, Q^2)$

$$\cancel{(3\cos^2\theta_m - 1)\left(b_1 + \frac{1-y}{xy^2}b_2\right)} - \frac{1-y}{y^2}\sin^2\theta_m \Delta(x, Q^2)\cos(2\phi)$$

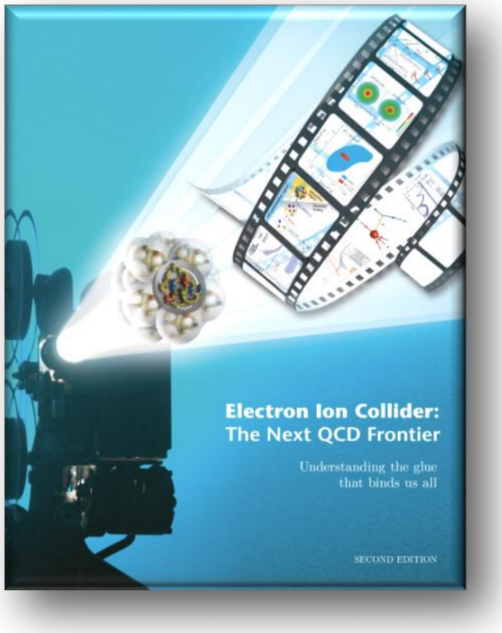
1. Leverage $\cos(2\phi)$ to isolate $\Delta(x, Q^2)$ dependence
   - Need azimuthal detector acceptance
2. Form tensor asymmetry: $\mathcal{A} = \frac{1}{A}\frac{N_+ + N_- - 2N_0}{N_+ + N_- + 2N_0}$
   - $\theta_m = 54.7^\circ$ to cancel b_1, b_2 dependence
   - Change polarization to produce N_+, N_- and N_0 yields
3. Form difference of vector polarized and unpolarized cross sections
   - $\theta_m = 54.7^\circ$ to cancel b_1, b_2 dependence
   - Lose cancellation of acceptances, efficiencies

Electron–Ion Collider Approach

$$\cancel{(3\cos^2\theta_m - 1)\left(b_1 + \frac{1-y}{xy^2}b_2\right)} - \frac{1-y}{y^2}\sin^2\theta_m \Delta(x, Q^2)\cos(2\phi)$$

1. $\cos(2\phi)$ offers $\Delta(x, Q^2)$ sensitivity
   - Vastly increased kinematic space for search
   - Vector polarization observable
2. ~~Form tensor asymmetry:~~ $\cancel{\mathcal{A} = \frac{1}{A}\frac{N_+ + N_- - 2N_0}{N_+ + N_- + 2N_0}}$
   - Set target at $\theta_m = 54.7°$
   - ~~Yields at N_+, N_- and N_0 separated in time: systematic headaches~~
3. ~~Form difference of vector polarized and unpolarized cross sections~~
   - Set target at $\theta_m = 54.7°$
   - ~~Lose advantage of asymmetry, still have systematic headaches~~

Pion and Kaon Structure Functions



Tanja Horn

The Catholic University of America

Jefferson Lab
Thomas Jefferson National Accelerator Facility

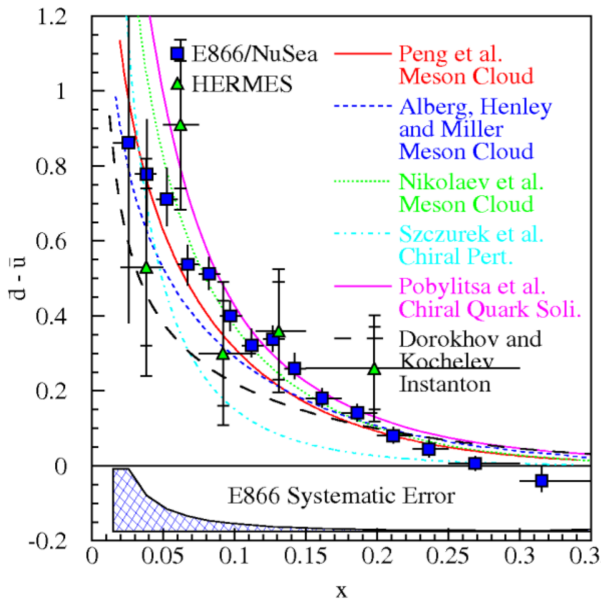
… beyond the science of …

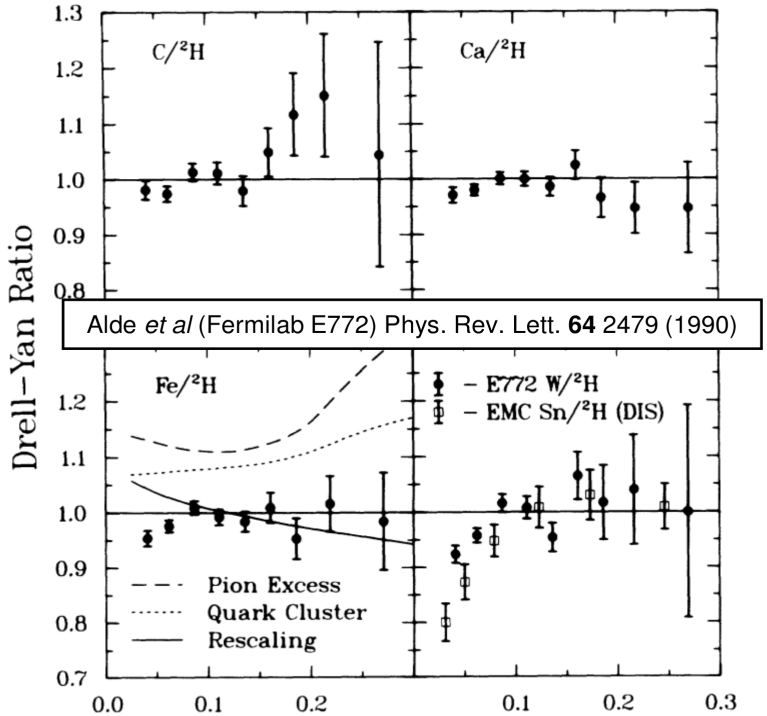
Collaboration with Roy Holt, Paul Reimer, Rolf Ent
Thanks to: Ian Cloet, Craig Roberts, Yulia Furletova and Steve Wood

Why should you be interested in pions and kaons?

Protons, neutrons, pions and kaons are the main building blocks of nuclear matter

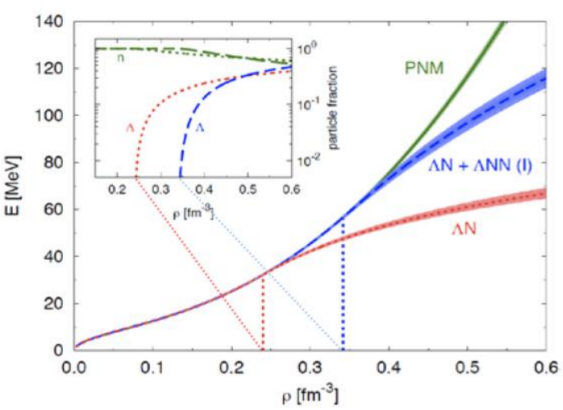
1) The pion, or a meson cloud, explains light-quark asymmetry in the nucleon sea
2) Pions are the Yukawa particles of the nuclear force – but no evidence for excess of nuclear pions or anti-quarks
3) Kaon exchange is similarly related to the ΛN interaction – correlated with the Equation of State and astrophysical observations
4) Mass is enigma – cannibalistic gluons vs massless Goldstone bosons

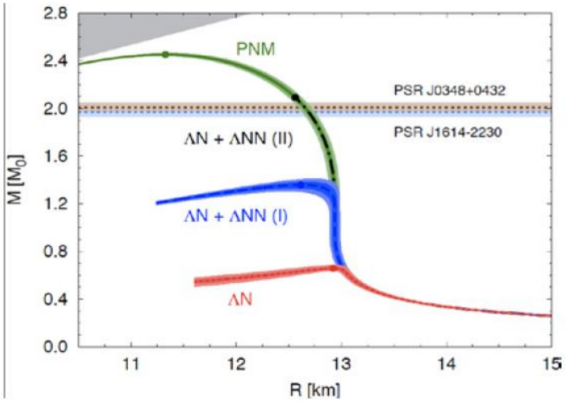




Alde *et al* (Fermilab E772) Phys. Rev. Lett. **64** 2479 (1990)

Equations of state and neutron star mass-radius relations

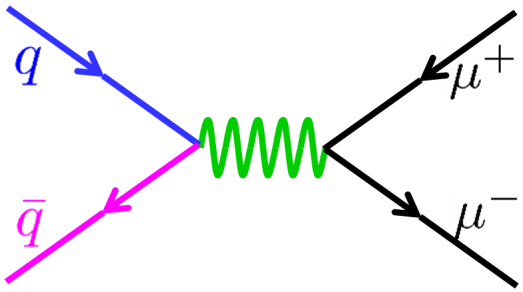




3

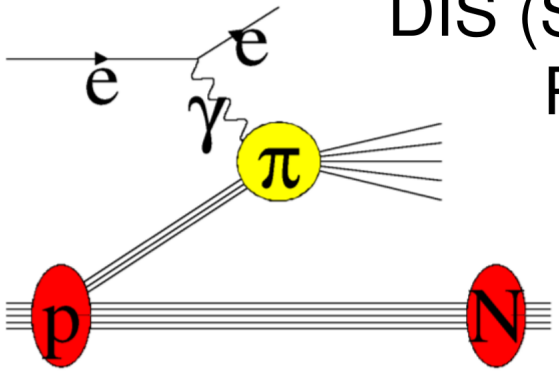
World Data on pion structure function F_2^π

Pion Drell-Yan

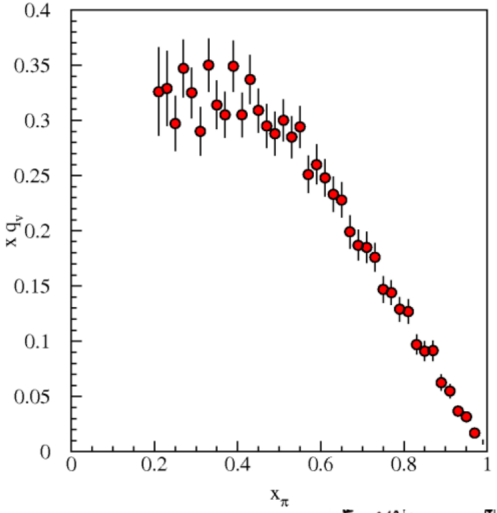


Data much more limited…

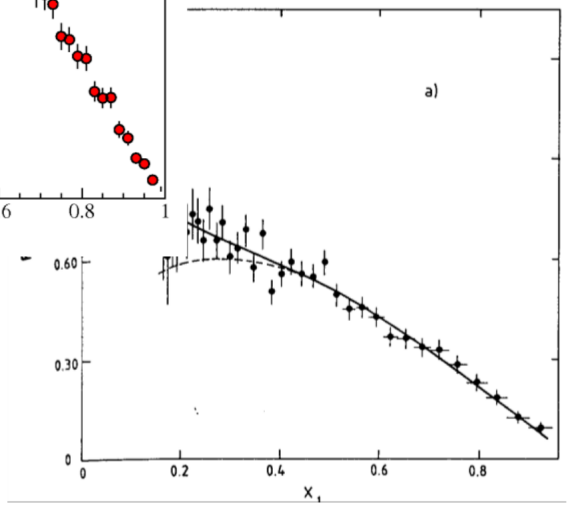
DIS (Sullivan Process)

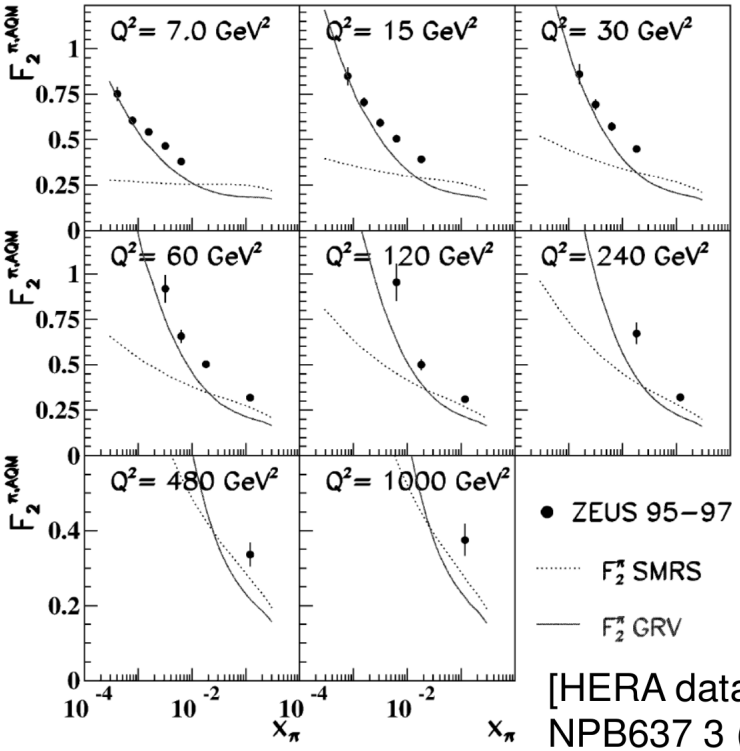


FNAL E615



CERN NA3

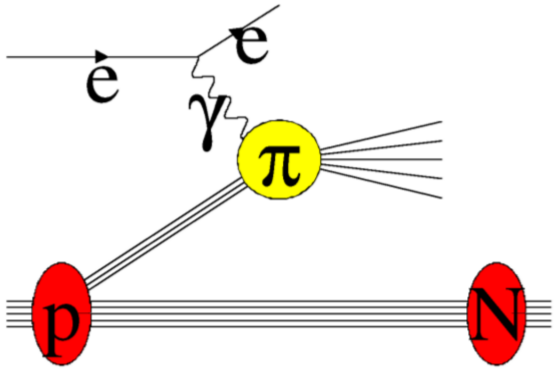




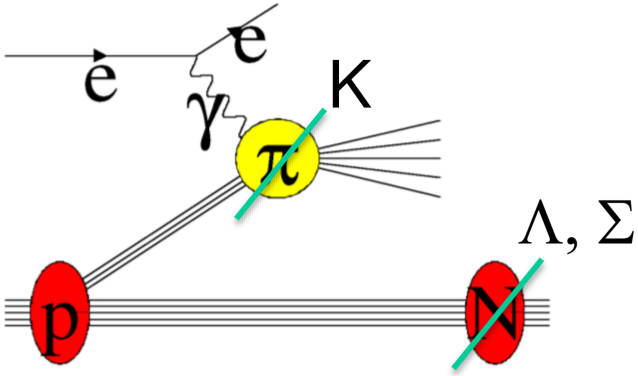
[HERA data [ZEUS, NPB637 3 (2002)]

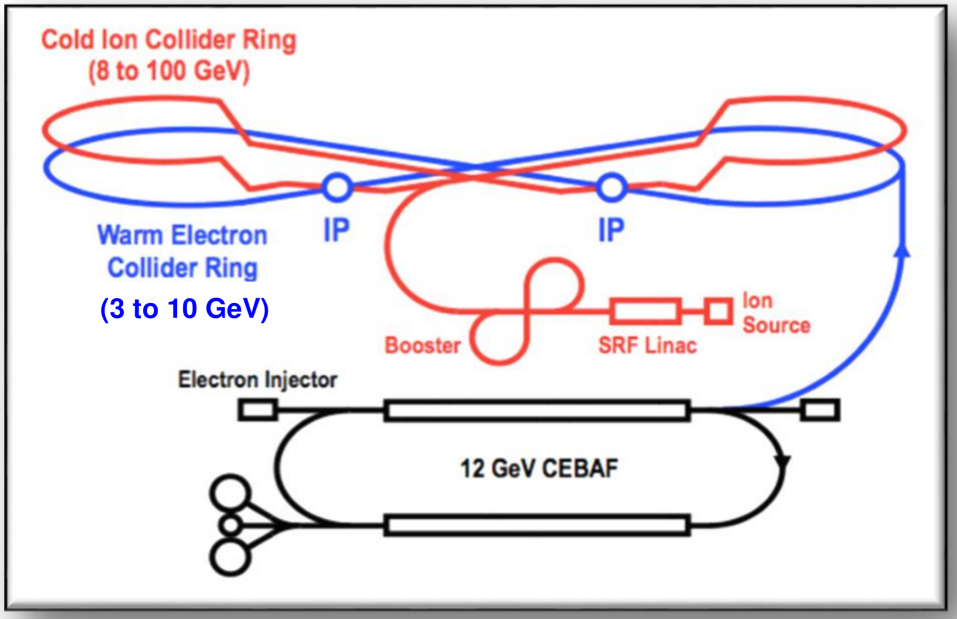
Good Acceptance for n, Λ, Σ detection

Sullivan process for pion SF



And similar process for kaon SF



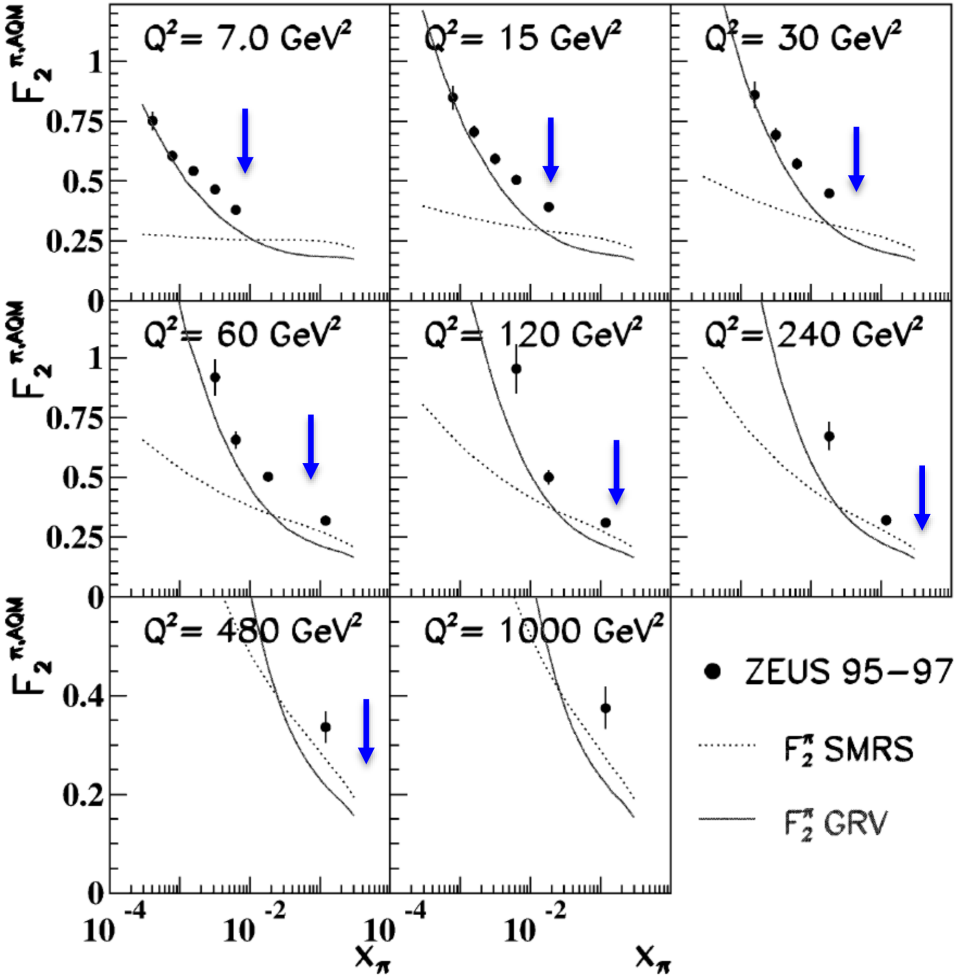


Process	Forward Particle	Geometric Detection Efficiency (at small –t)
$^1H(e,e'\pi^+)n$	N	> 20%
$^1H(e,e'K^+)\Lambda$	Λ	50%
$^1H(e,e'K^+)\Sigma$	Σ	17%

Simulations assume: 5 GeV electrons and 50 GeV protons @ luminosity of 10^{34} $s^{-1}cm^{-2}$

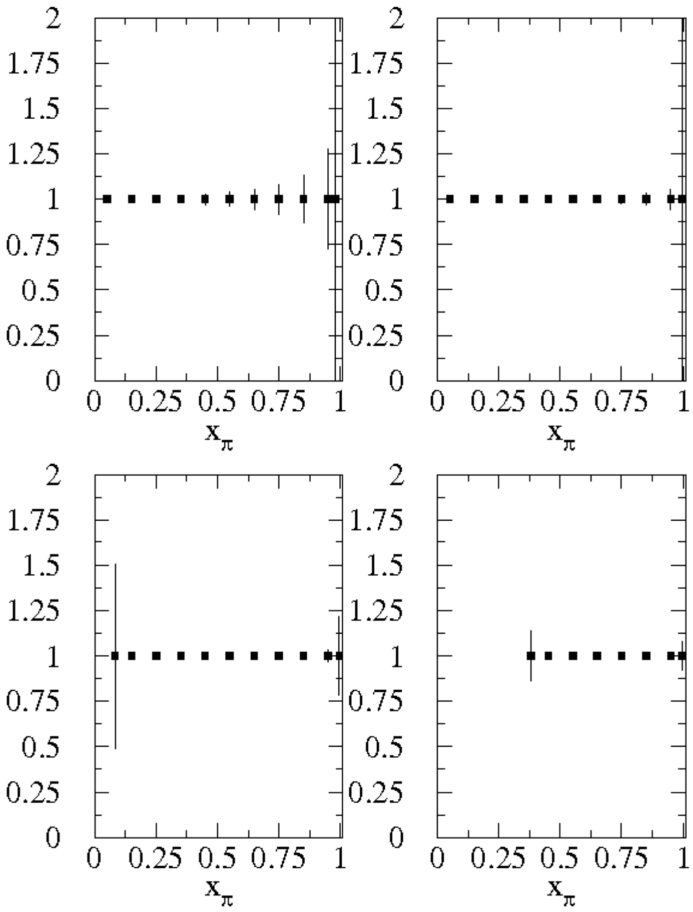
World Data on pion structure function F_2^π

HERA



EIC

roughly x_{min} for EIC projections



Kaon structure functions – gluon pdfs

Based on Lattice QCD calculations and DSE calculations:

- Valence quarks carry 52% of the pion's momentum at the light front, at the scale used for Lattice QCD calculations, or roughly 65% at the perturbative hadronic scale

- At the same scale, valence-quarks carry ⅔ of the kaon's light-front momentum, or roughly 95% at the perturbative hadronic scale

Thus, at a given scale, there is far less glue in the kaon than in the pion:

- heavier quarks radiate less readily than lighter quarks
- heavier quarks radiate softer gluons than do lighter quarks
- Landau-Pomeranchuk effect: softer gluons have longer wavelength and multiple scatterings are suppressed by interference.
- Momentum conservation communicates these effects to the kaon's u-quark.

Nucleon Distribution Amplitudes

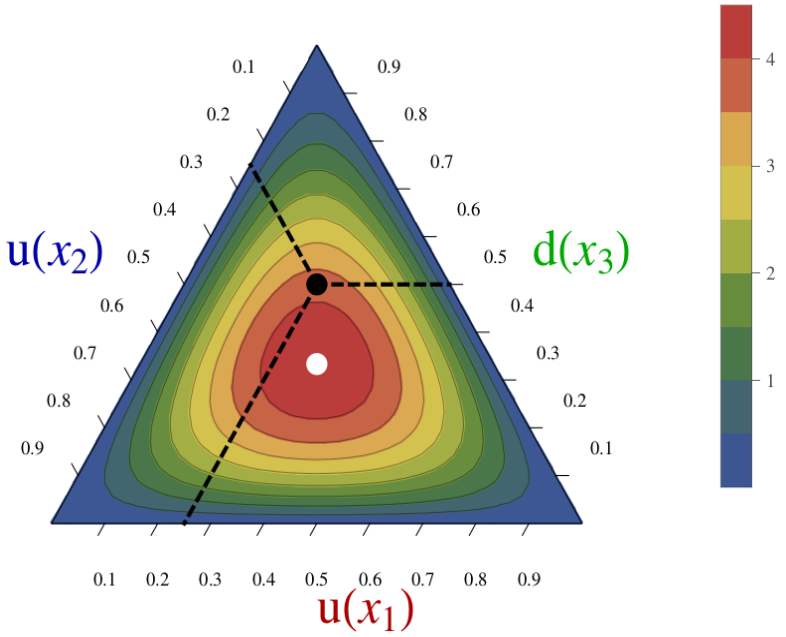
C. Mezrag

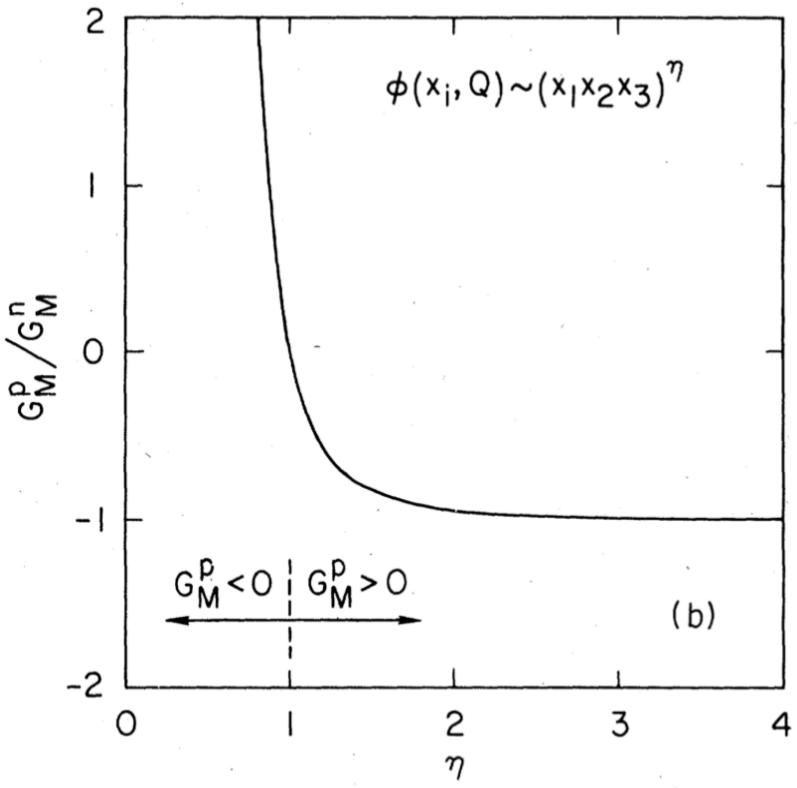
Argonne National Laboratory

May 5th, 2016

In collaboration with:
C.D. Roberts

Proton distribution amplitude



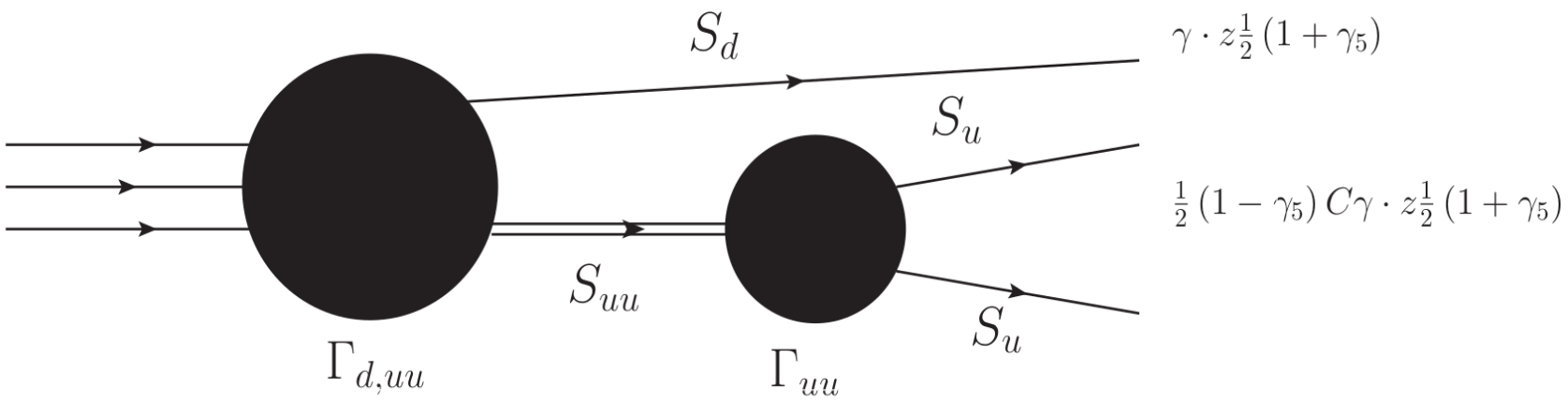


$$\varphi_{As}(x_1, x_2, x_3) = 120 x_1 x_2 x_3$$

Lepage and Brodsky (1980)

What happens when computing the Proton DA within DSEs framework?

Quark-Diquark DA

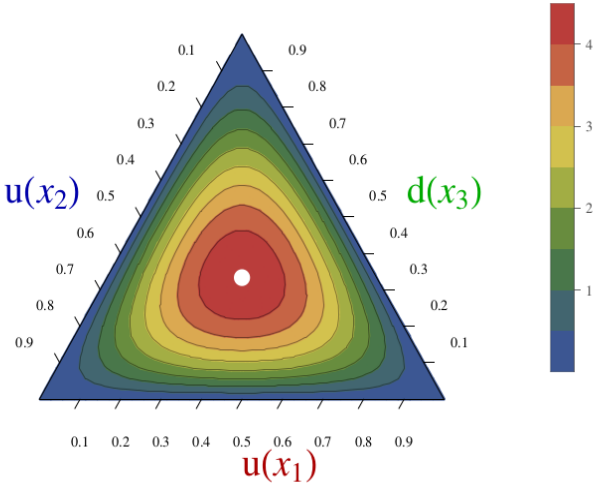


- Need of specific ingredients:
  - quark propagator S_u (S_d),
  - AV diquark propagator S_{uu},
  - diquark Bethe-Salpeter amplitude Γ_{uu},
  - nucleon Bethe-Salpeter amplitude $\Gamma_{d;uu}$.
- Different contributions for the $|u(\uparrow)u(\downarrow)d(\uparrow)\rangle$ state:
  - 1 contribution for the scalar diquark
  - 3 different contributions for the AV diquark

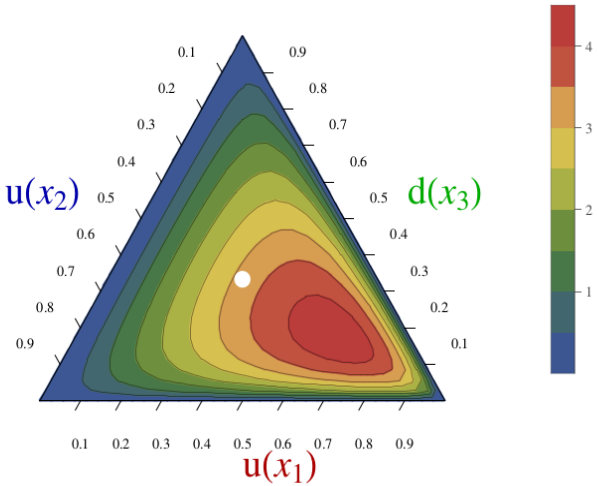
All these objects can be computed non-pertubatively using DSEs-BSEs.

Preliminary results

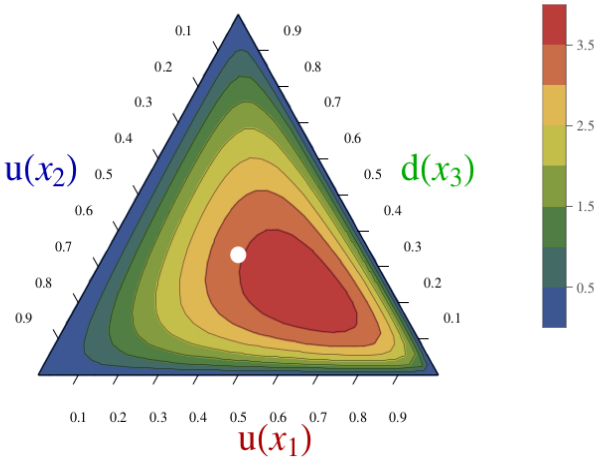
Caveat: transversely polarised diquark is missing



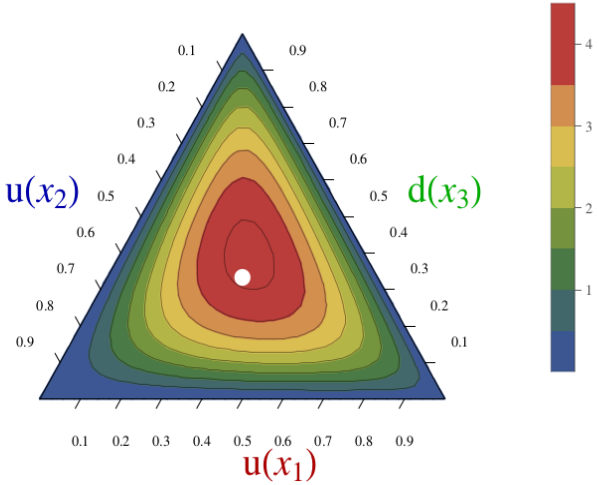
Asymptotic



100% Scalar



70%Scalar 30% AV



100% AV

ABMP16 PDFs

S.Alekhin (*Univ. of Hamburg & IHEP Protvino)*

(in collaboration with J.Blümlein, S.Moch, and R.Plačakytė)

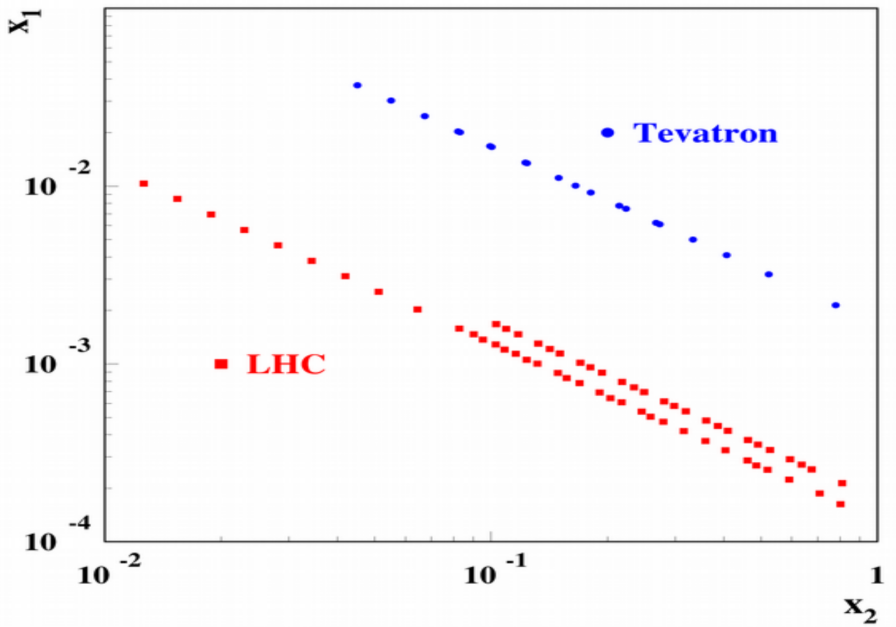
- Drell-Yan data from the LHC and Tevatron: Isospin asymmetry and d/u at large x
- HERA I+II data: $\alpha_s(M_Z)$, m_c, and m_b
- Charm production data from NOMAD and CHORUS: strange sea
- t-quark data: m_t and gluon distribution

sa, Blümlein, Caminada, Lipka, Lohwasser, Moch, Petti, Plačakytė hep-ph/1404.6469

sa, Blümlein, Moch, Plačakytė, hep-ph/1508.07923

EICUG meeting, ANL, 8 *Jul 2016*

Collider W&Z data used in the fit



In the forward region $x_2 >> x_1$

$\sigma(W^+) \sim u(x_2)\ \mathrm{dbar}\ (x_1)$

$\sigma(W^-) \sim d(x_2)\ \mathrm{ubar}(x_1)$

$\sigma(Z) \sim Q_U^2 u(x_2)\ \mathrm{ubar}\ (x_1) + Q_D^2 d(x_2)\ \mathrm{dbar}(x_1)$

$\sigma(\mathrm{DIS}) \sim q_u^2 u(x_2) + q_d^2 d(x_2)$

Forward W&Z production probes small/large x and is complementary to the DIS → constraint on the quark iso-spin asymmetry

Experiment		ATLAS	CMS		D0		LHCb		
$\sqrt{s}$ (TeV)		7	7	8	1.96		7	8	8
Final states		$W^+ \to l^+\nu$ $W^- \to l^-\nu$ $Z \to l^+l^-$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$	$W^+ \to e^+\nu$ $W^- \to e^-\nu$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ $Z \to \mu^+\mu^-$	$Z \to e^+e^-$	$W^+ \to \mu^+\nu$ $W^- \to \mu^-\nu$ $Z \to \mu^+\mu^-$
Cut on the lepton P_T		$P_T^l > 20$ GeV	$P_T^\mu > 25$ GeV	$P_T^\mu > 25$ GeV	$P_T^\mu > 25$ GeV	$P_T^e > 25$ GeV	$P_T^\mu > 20$ GeV	$P_T^e > 20$ GeV	$P_T^e > 20$ GeV
NDP		30	11	22	10	13	31	17	32
χ^2	ABMP16	30.0	22.0	16.8	18.2	19.6	45.4	21.5	45.4
	CJ15	–	–	–	20	29	–	–	–
	CT14	42	–[a]	–	–	34.7	–	–	–
	JR14	–	–	–	–	–	–	–	–
	HERAFitter	–	–	–	13	19	–	–	–
	MMHT14	39	–	–	21	–	–	–	–
	NNPDF3.0	35.4	18.9	–	–	–	–	–	–

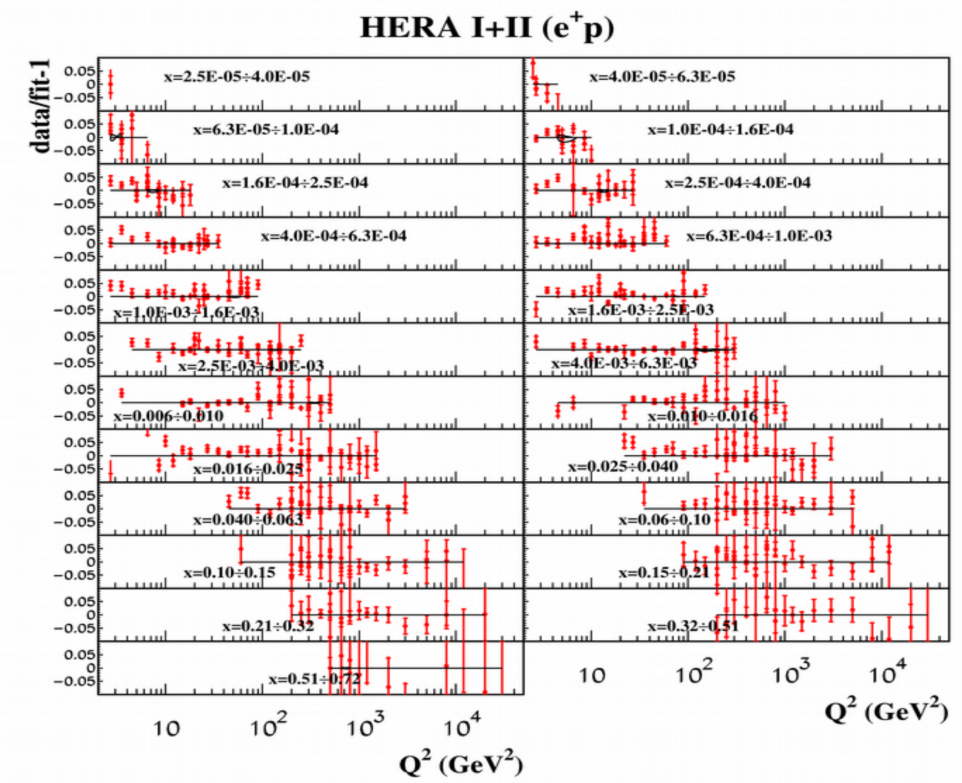
[a]Statistically less significant data with the cut of $P_T^\mu > 35$ GeV are used.

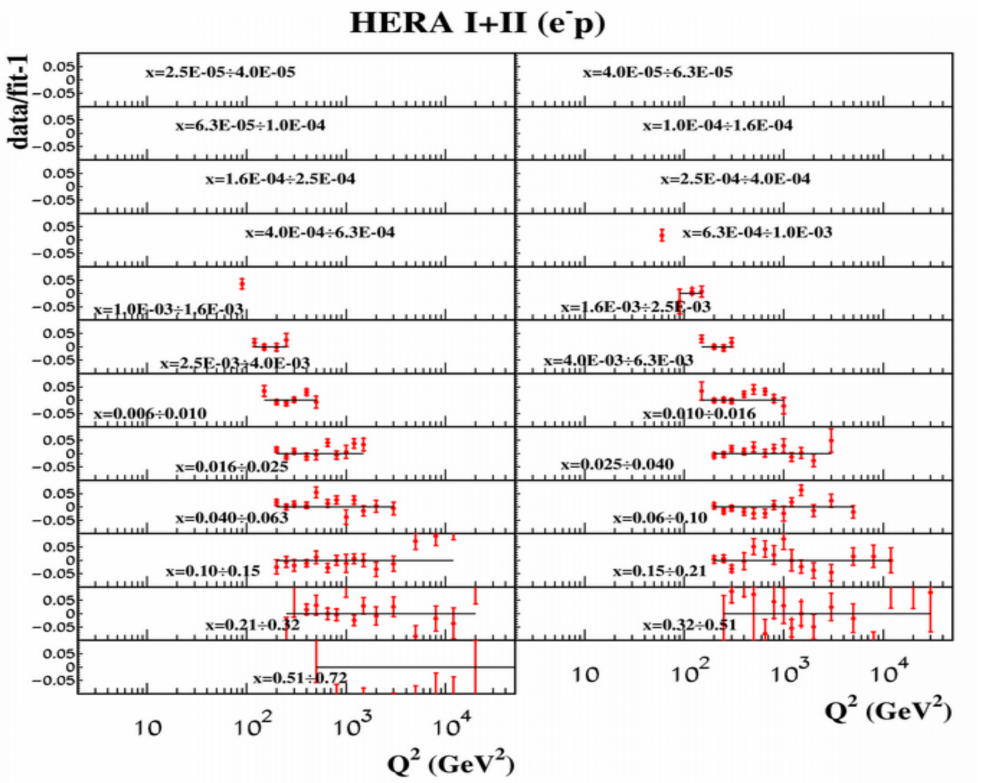
Obsolete/superseded/low-accuracy Tevatron and LHC data are not used

2

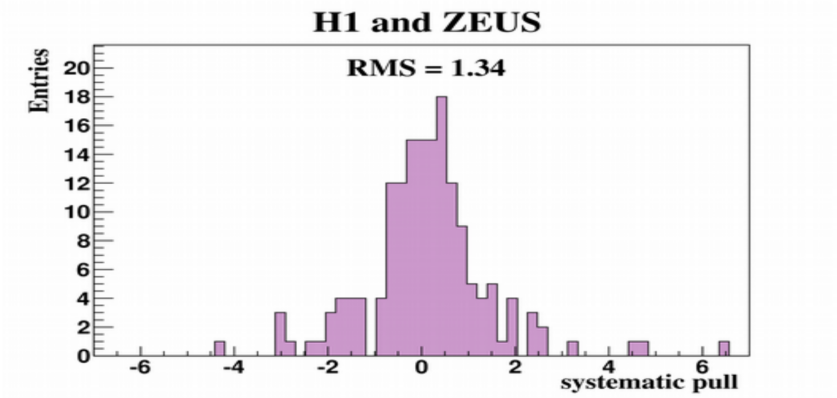
Inclusive HERA I+II data

H1 and ZEUS hep-ex/1506.06042





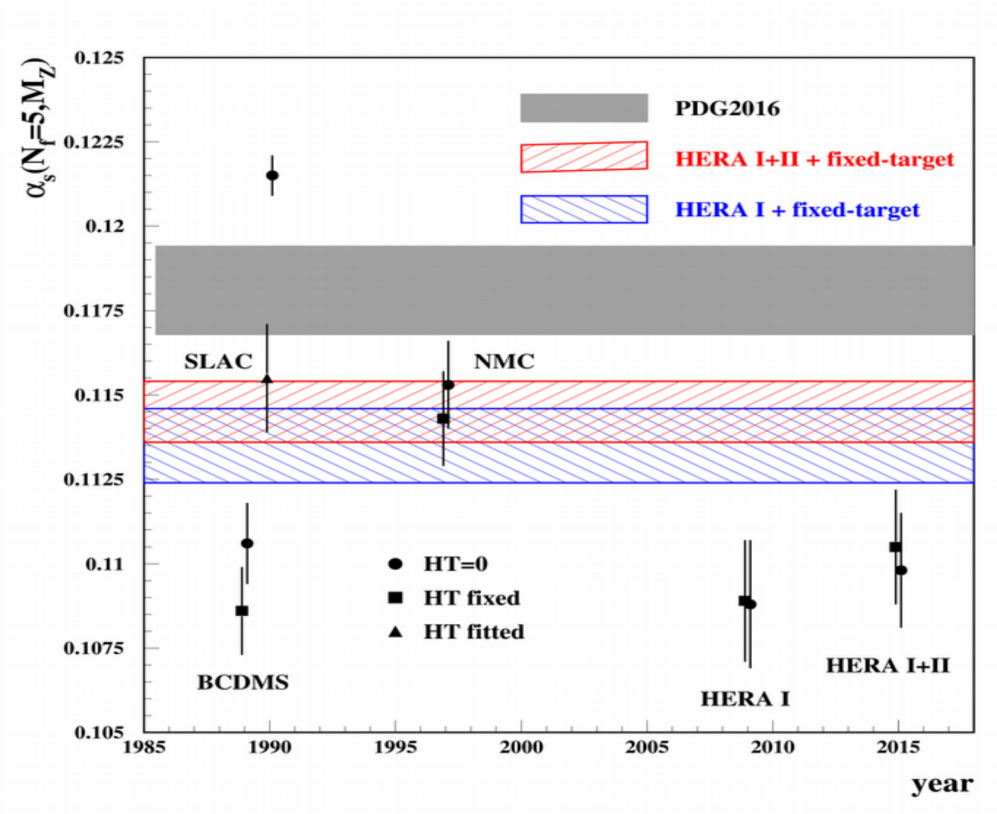
Q^2(HERA)	χ^2/NDP(HERA)
>2.5 GeV²	1505/1168=1.29
>5 GeV²	1350/1092=1.24
>10 GeV²	1225/1007=1.22



The value of χ^2/NDP is bigger than 1, however still comparable to the pull distribution width

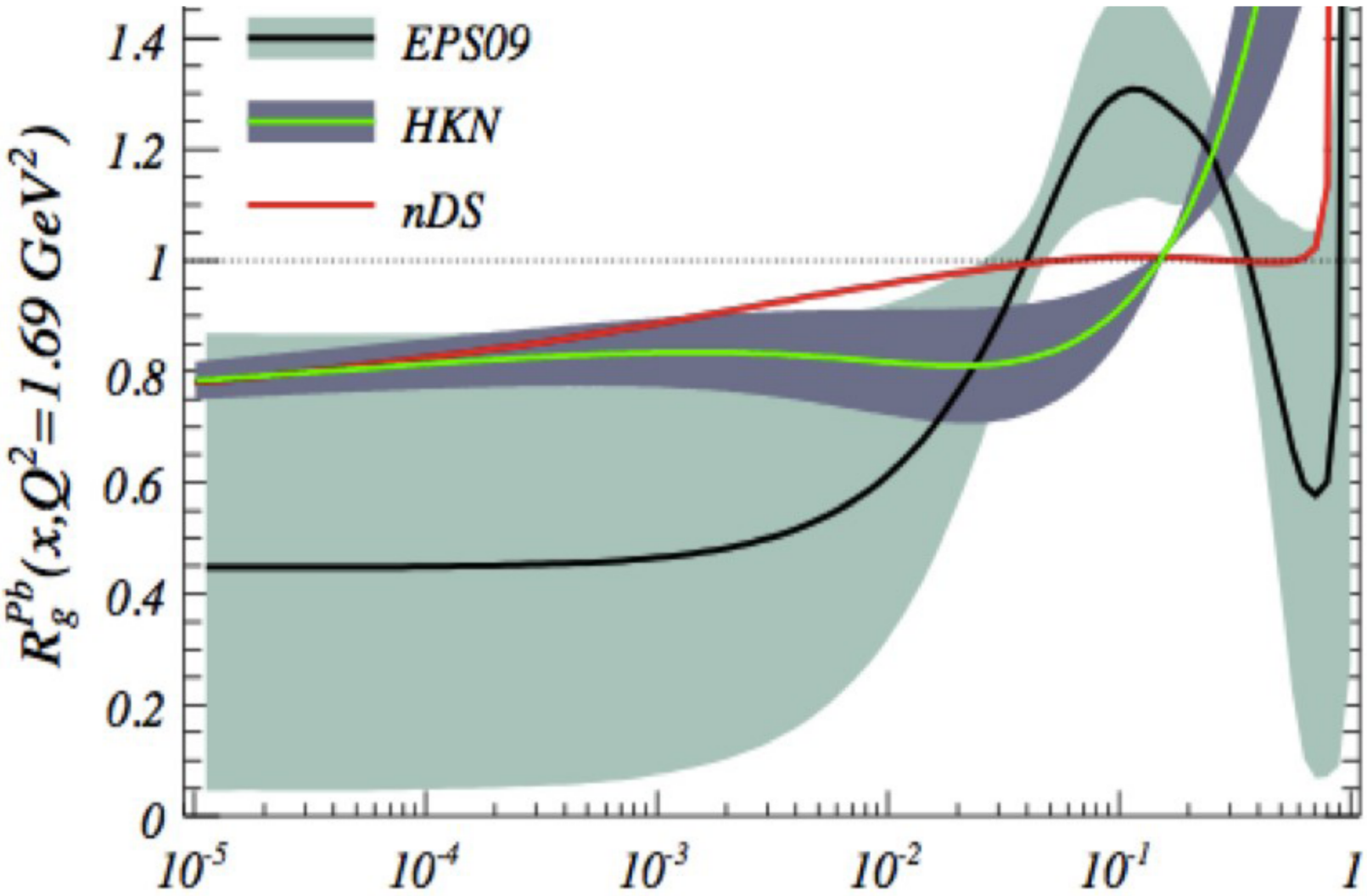
7

α_s updated



- α_s goes up by 1σ with HERA I+II data
- the value of α_s is still lower than the PDG one: pulled up by the SLAC and NMC data; pulled down by the BCDMS and HERA ones
- only SLAC determination overlap with the PDG band provided the high-twist terms are taken into account

Nuclear PDFs at the LHC



1

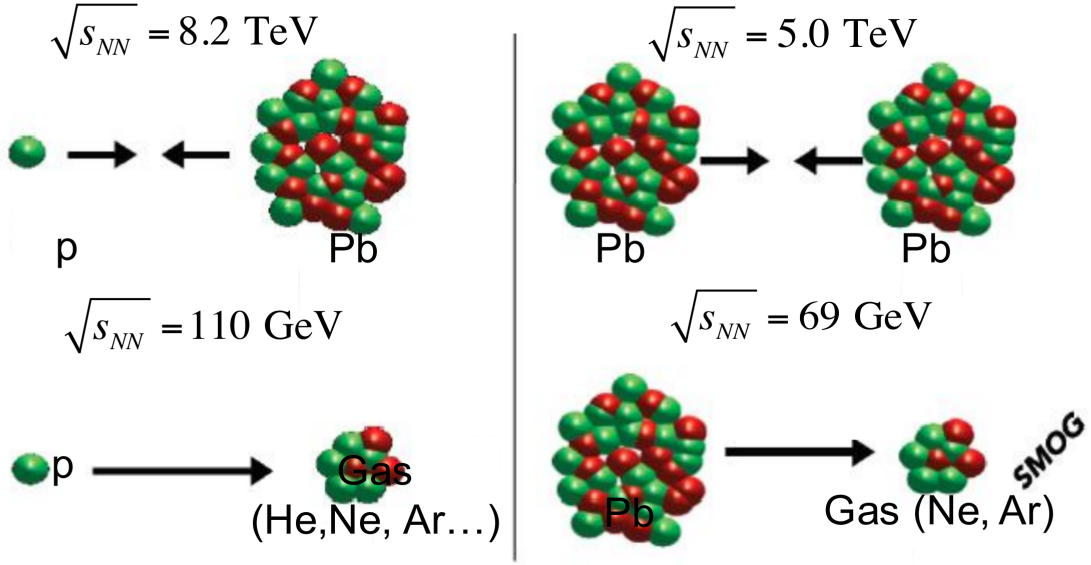
Michael Murray University of Kansas

Running modes

Collider

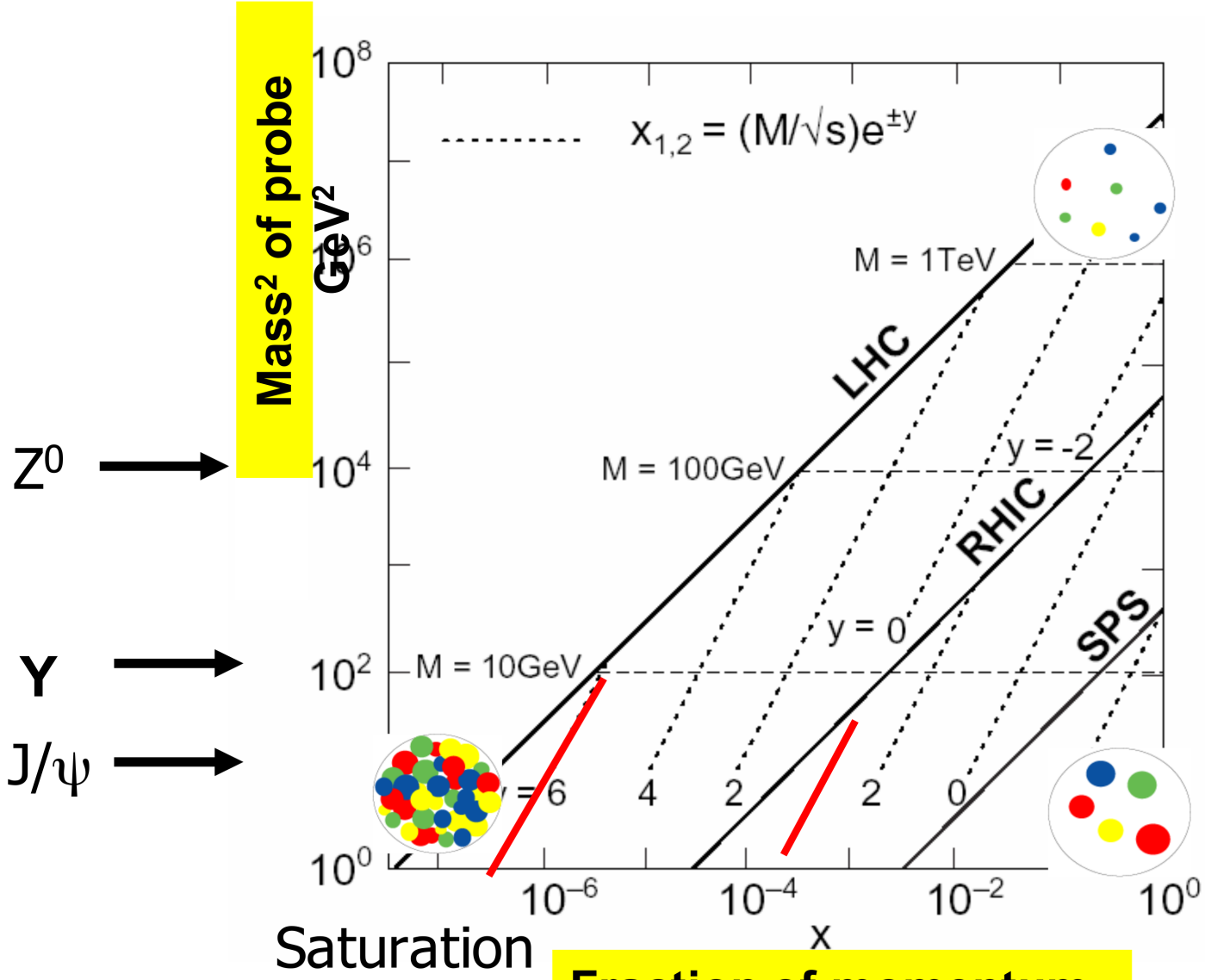
Fixed target

LHCb



In addition ultra-peripheral collisions produce photon – lead collisions with an energy range $W_{\gamma p}$ = 20 – 800 GeV

Kinematic Range of LHC

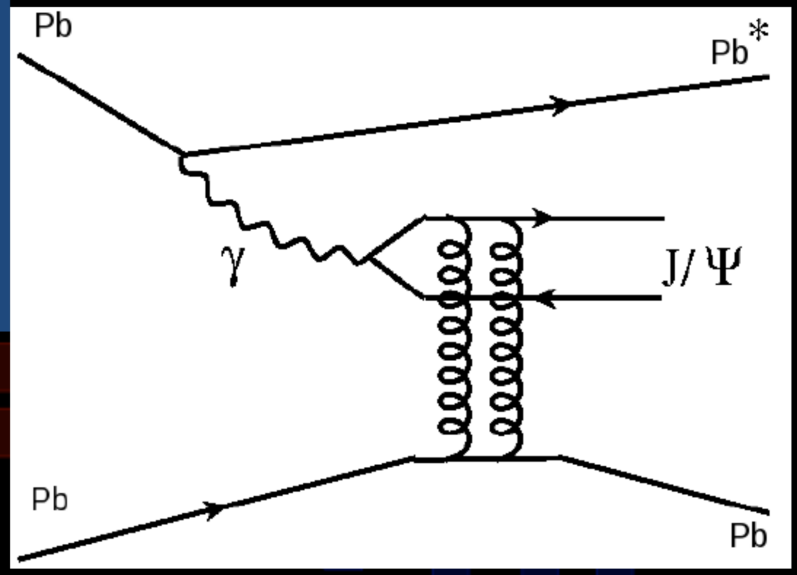


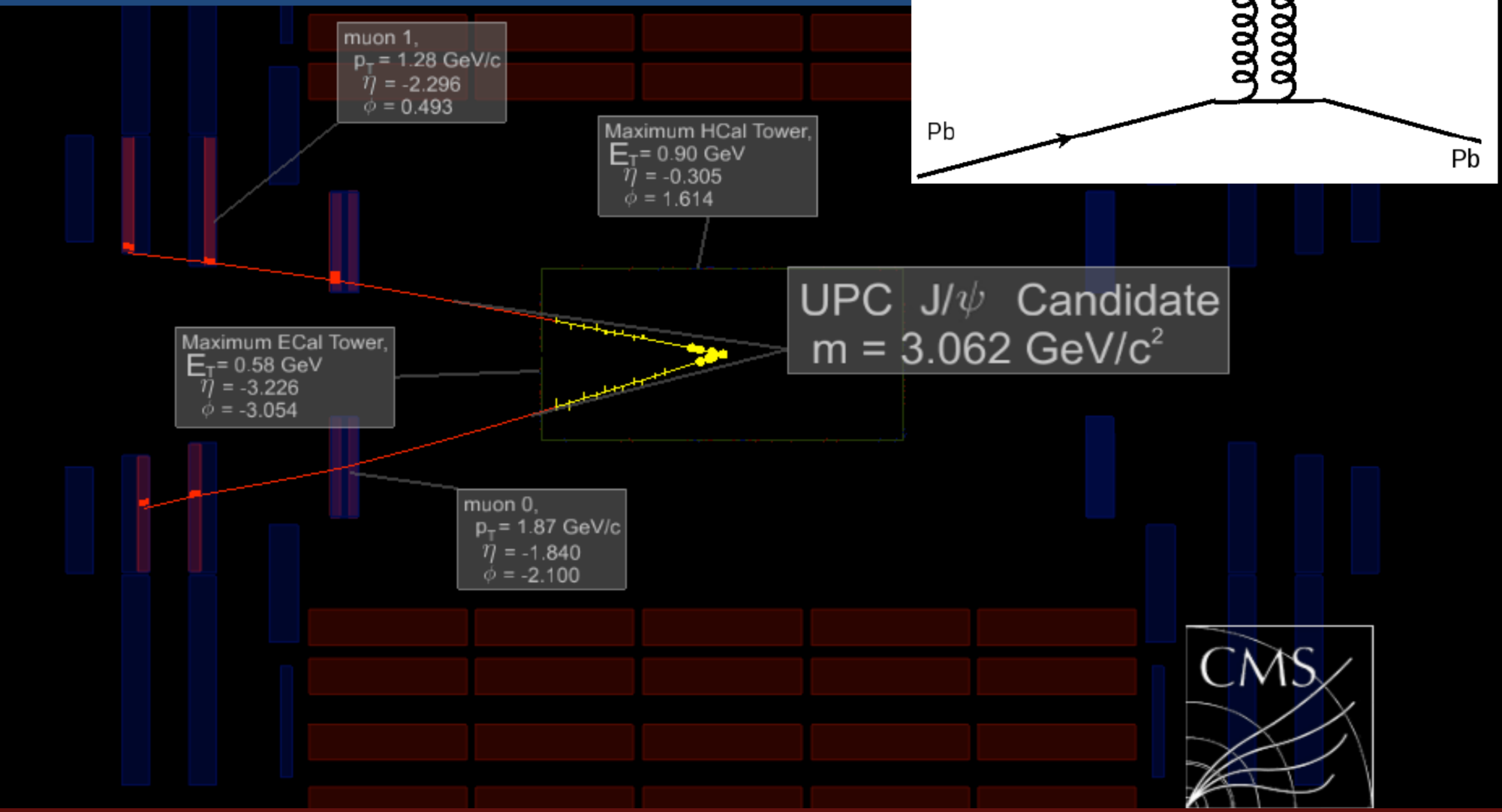
In this talk I will start at high Q^2 and y=0 and move to lower Q^2 and forward rapidity.

Apologies for missing references and CMS centric talk.

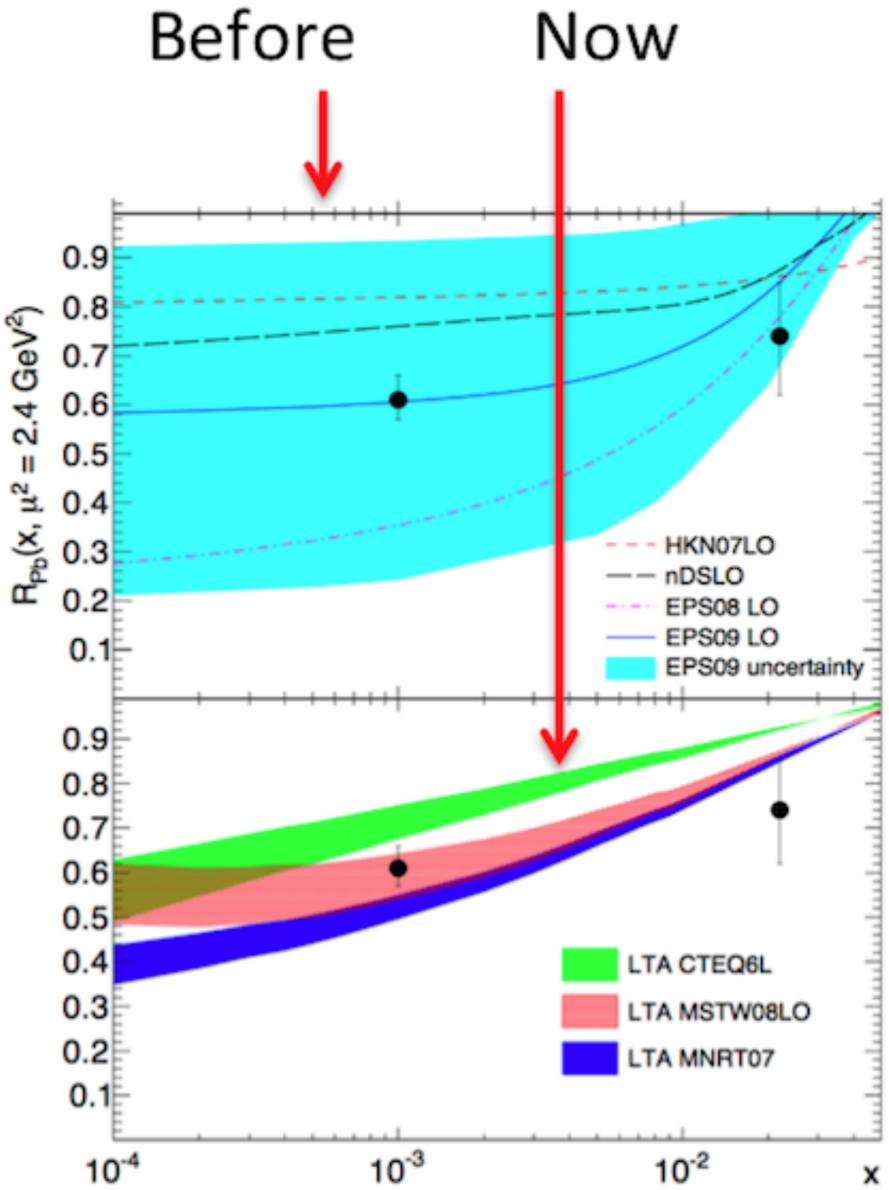
Gluon density has to saturate at low x

Ultra-peripheral PbPb





First attempt to use UPCs in nPDFs



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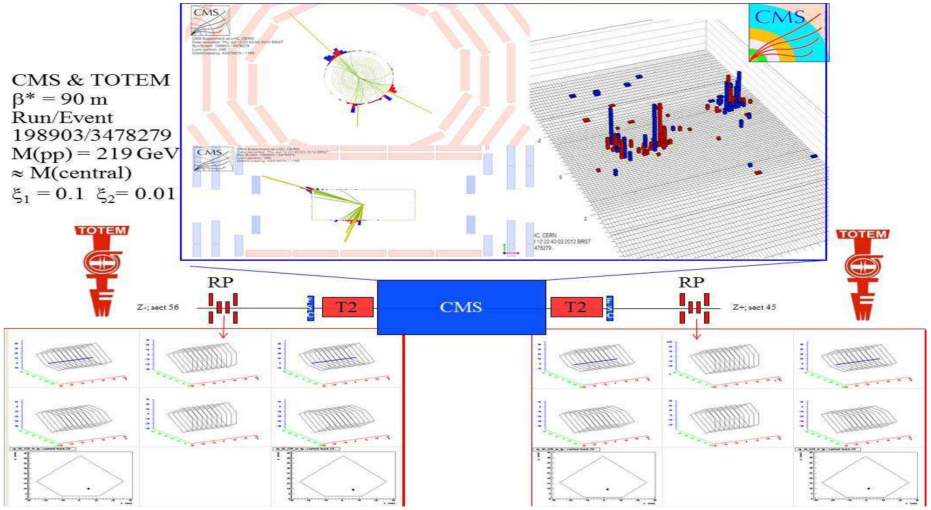
Experience on diffraction at HERA and at the LHC towards the EIC

Christophe Royon
University of Kansas, Lawrence, USA

EIC Users Meeting, Argonne National Lab., July 5-9 2016

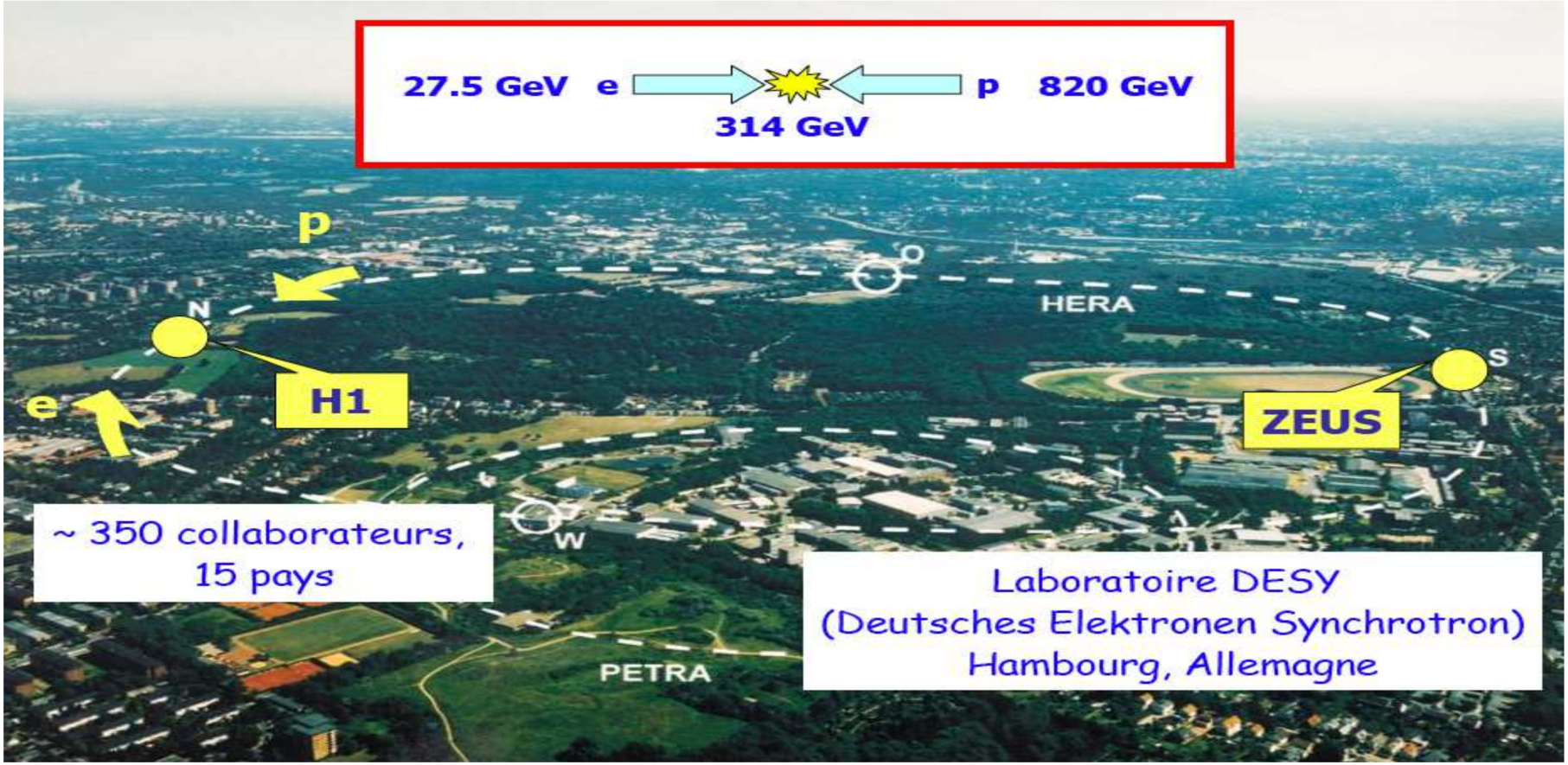


Contents:

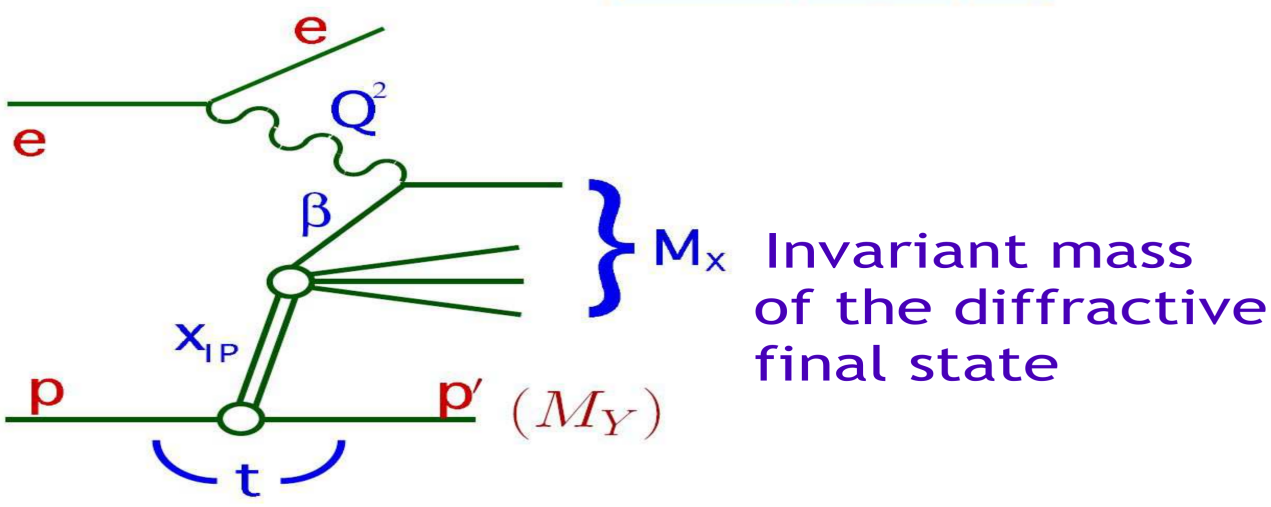
- Diffraction at HERA
- Vector meson production
- PDFs in Pomeron
- Factorization breaking

The HERA accelerator at DESY, Hamburg

HERA: ep collider who closed in 2007, about 1 fb^{-1} accumulated

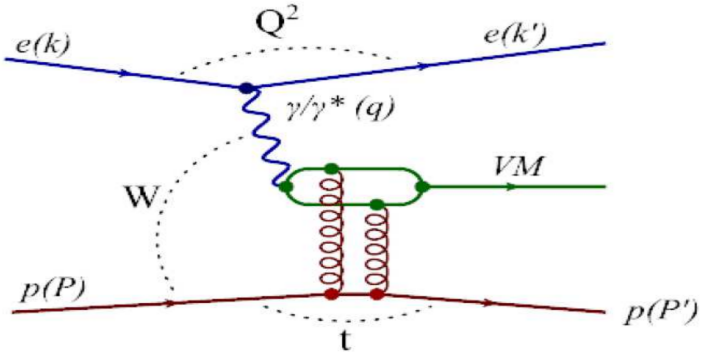


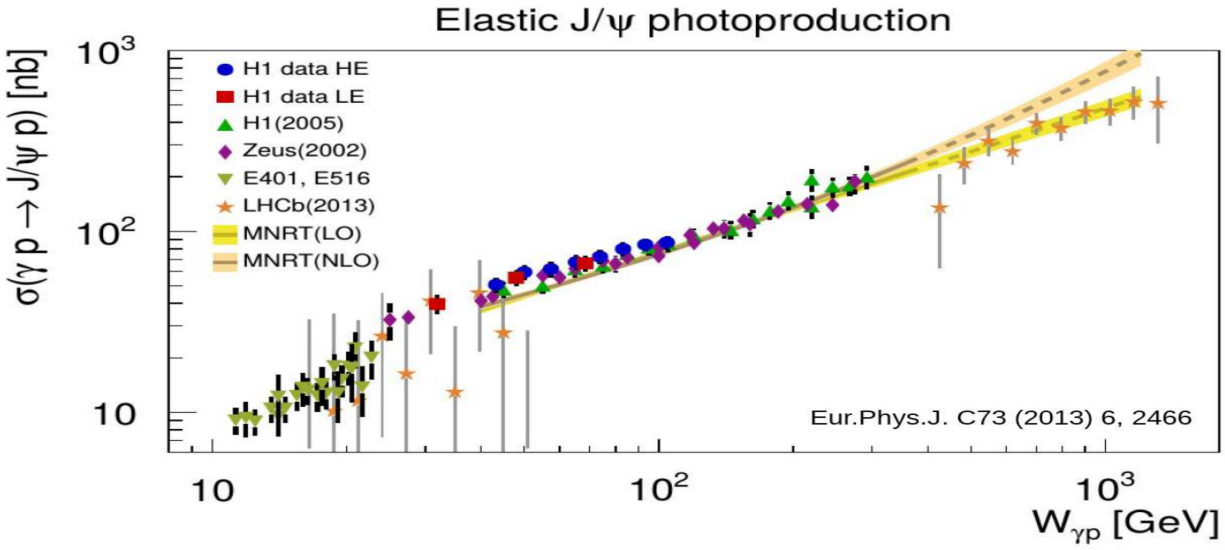
Diffractive kinematical variables



- Momentum fraction of the proton carried by the colourless object (pomeron): $x_p = \xi = \frac{Q^2+M_X^2}{Q^2+W^2}$
- Momentum fraction of the pomeron carried by the interacting parton if we assume the colourless object to be made of quarks and gluons: $\beta = \frac{Q^2}{Q^2+M_X^2} = \frac{x_{Bj}}{x_P}$
- 4-momentum squared transferred: $t = (p - p')^2$

An example: J/Ψ in photoproduction





- Hard scale present due to J/Ψ mass ($Q^2 \sim 0$)
- Description using perturbative QCD and dipole model: Pomeron is modeled by a gluon ladder at lowest order: $\sigma \sim [\alpha_S(\mu^2) x g(x, \mu^2)]^2$

Conclusion

- Many physics topics studied at HERA can be studied with higher precision at the EIC: only a few examples given here
- Vector meson production: study the interface of perturbative/non-perturbative QCD
- Measurement of parton densities in diffractive events: higher precision, use structure function measurements, jets, charm...
- Study survical effects: using γ-p events as an example
- Study BFKL resummation effects and saturation phenomena: important to have a good coverage in the forward directions in order to measure very forward jets, can be also studied in diffractive events
- Exclusive diffraction
- Many topics to be studied at the EIC benefitting from the experience at HERA, Tevatron and LHC

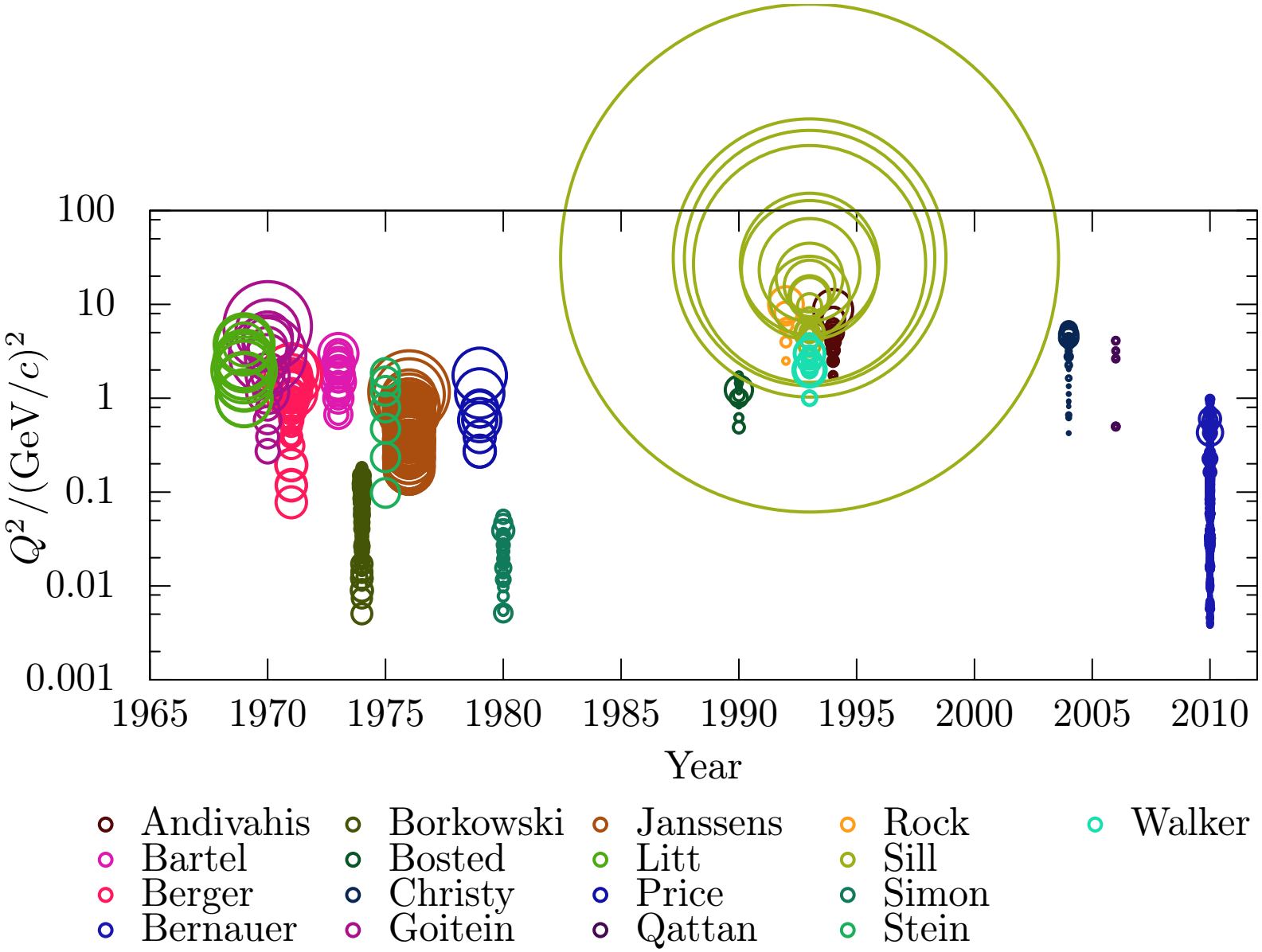
Unique opportunities to measure proton elastic form factors at EIC

Jan C. Bernauer

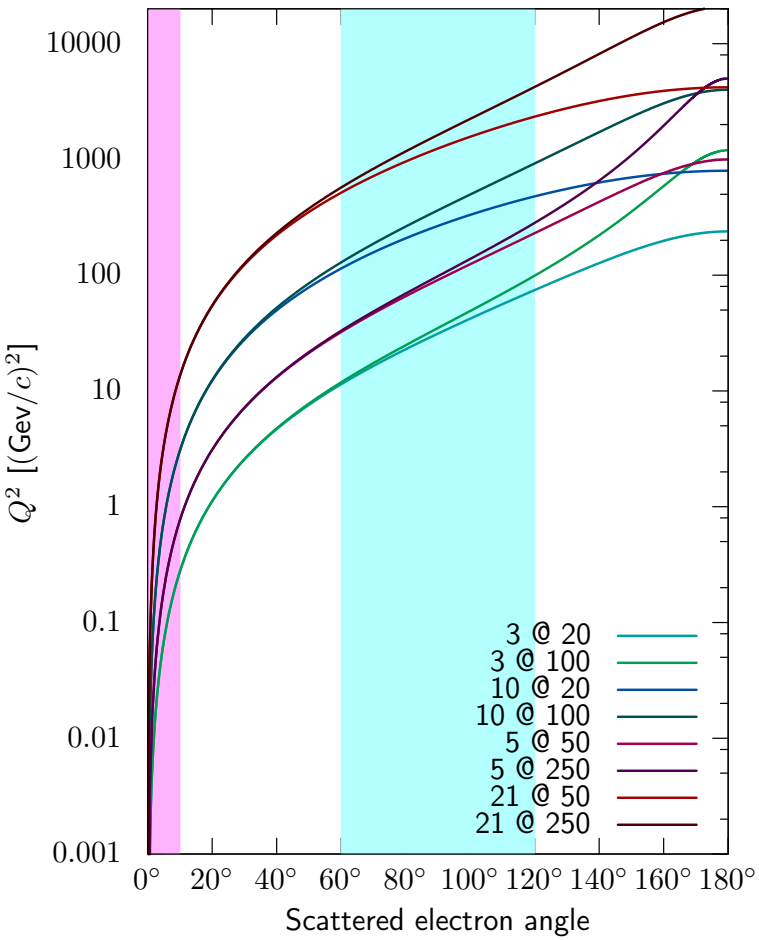
EIC UG Meeting, July 2016

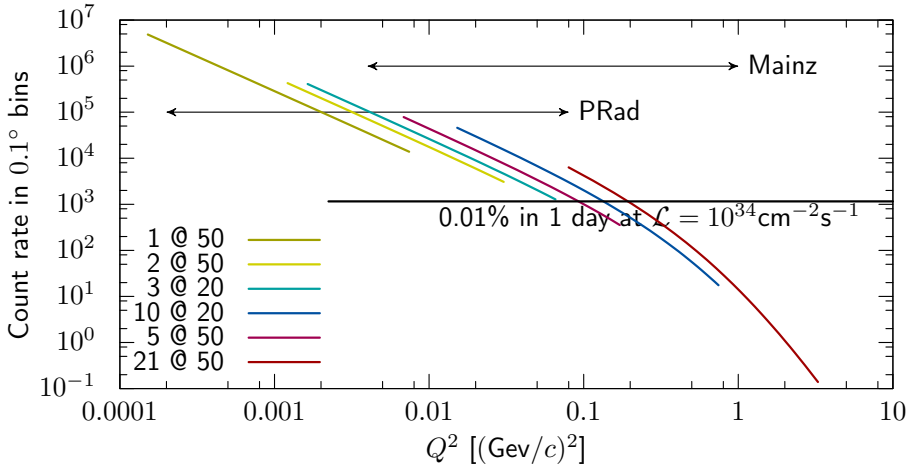
Massachusetts Institute of Technology

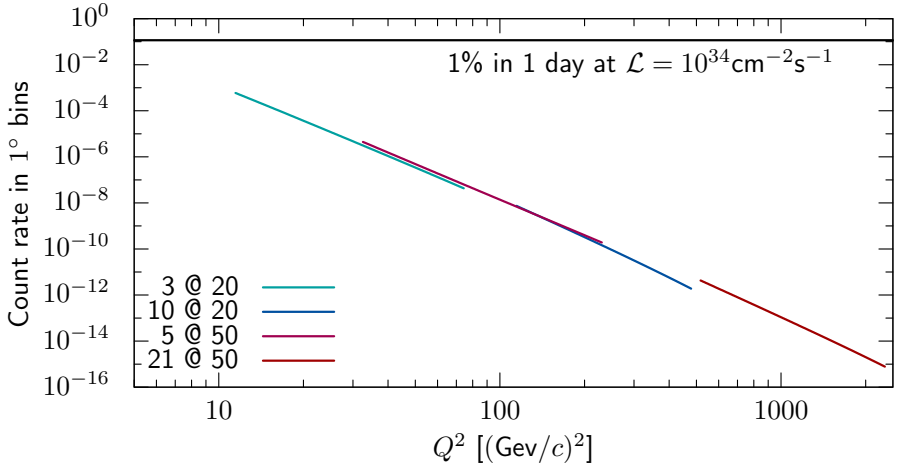
History of unpolarized electron-proton scattering



F.F. summary: Collider kinematics

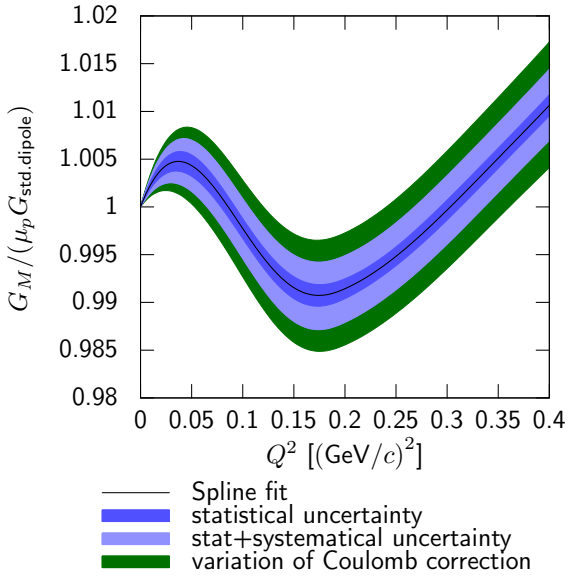


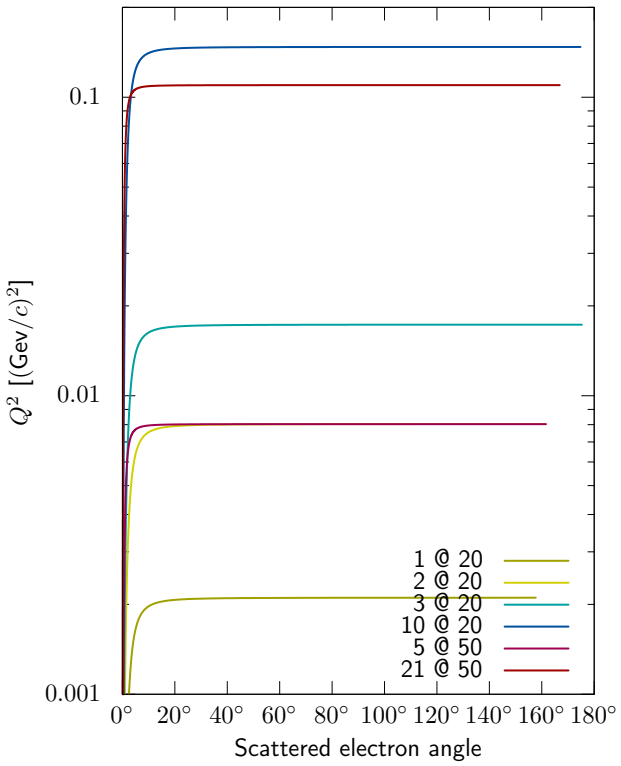


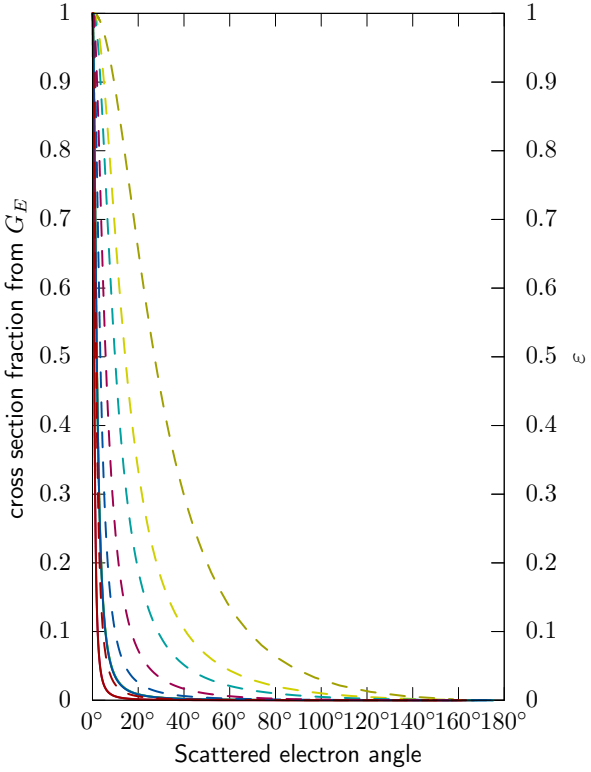


- Can measure proton electric radius without Two-Photon-Exchange effects
- G_M at large Q^2: count rate very small

F.F. summary: "Race" kinematics





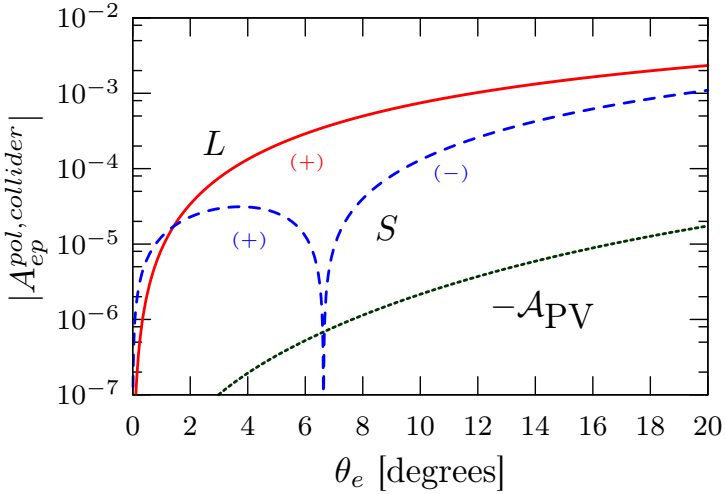


- Unique opportunity to measure low-Q^2 G_M and magnetic radius

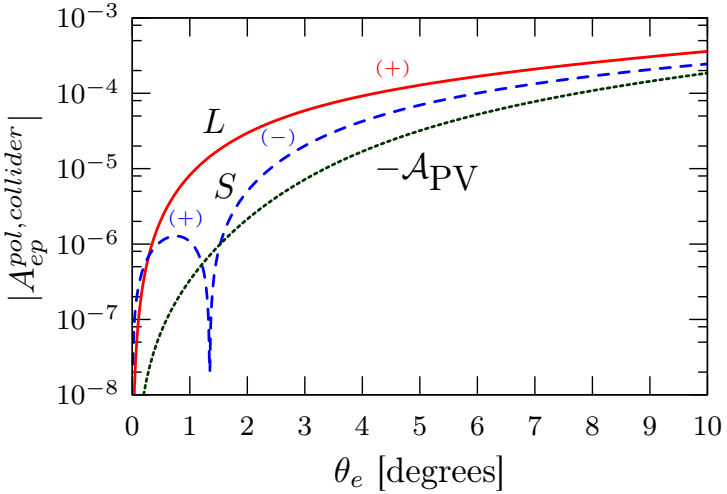
F.F. summary: Polarization variables

Blatantly stolen from C. Sofiatti and T. W. Donnelly,"Polarized e-p Elastic Scattering in the Collider Frame," Phys. Rev. C 84, 014606 (2011)

2 @ 50 GeV



10 @ 250 GeV



- Can study e/m form factor ratios
- Or: Take from fixed target experiments
  $\Longrightarrow$ measurement of beam polarization product
- PV also in reach

Takeaway

Clearly tremendous physics potential for an EIC!

Must build a machine that can truly deliver the physics we are promising