Probing QCD in Photon-Nucleus Interactions at RHIC and LHC: the Path to EIC

INT/Seattle, February 13 - 17, 2017

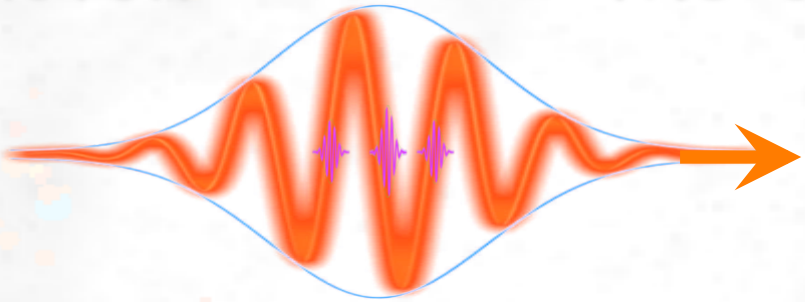
Summary Talk

C.A. Bertulani
Department of Physics and Astronomy
Texas A&M University-Commerce

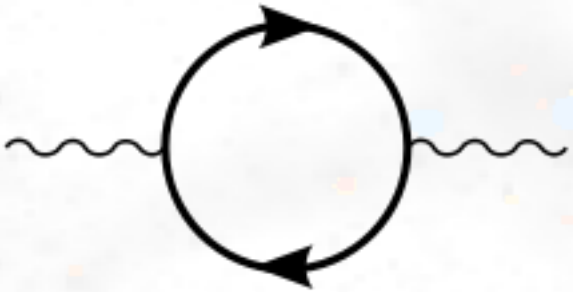
The goal of this workshop was to identify and discuss the theoretical challenges of photon-induced physics, and how to use this knowledge for physics studies at the EIC.

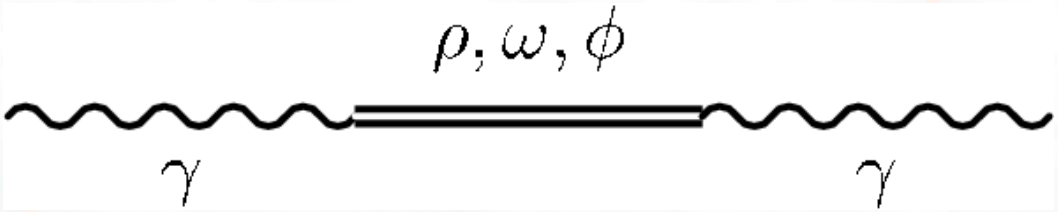
Why Photons?

The clean photon the dirty photon



Can fluctuate into particle-antiparticle pairs, e.g., e+e-, qqbar, etc





$J^P = 1^-$ → fluctuates to ρ, ω, ϕ, J/Ψ

(Vector Meson Dominance model)

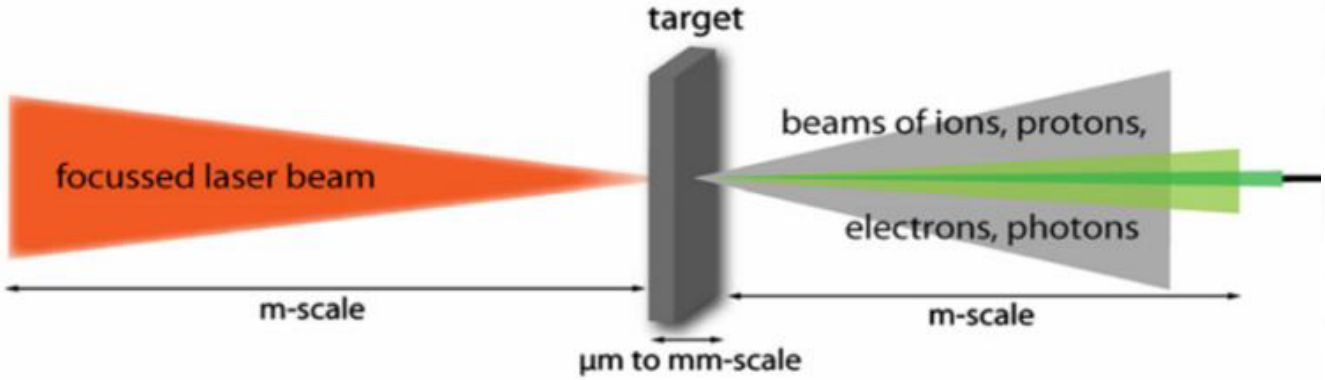
Photon wavefunction:

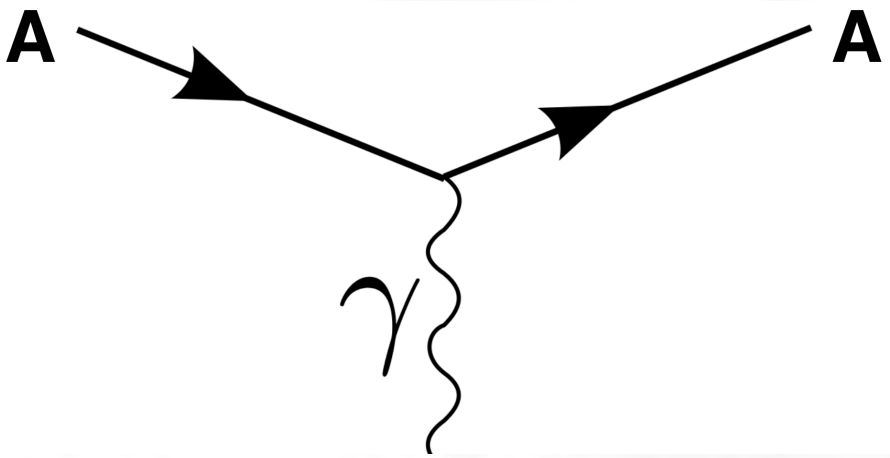
$$|\gamma\rangle = C_{\text{bare}}|\gamma_{\text{bare}}\rangle + C_\rho|\rho\rangle + C_\omega|\omega\rangle + C_\phi|\phi\rangle + \cdots + C_q|q\bar{q}\rangle$$

The photon as a probe

Real photons

ELI (Romania),
XCELS (Russia),
HIPER (Europe), etc





Quasi real photons

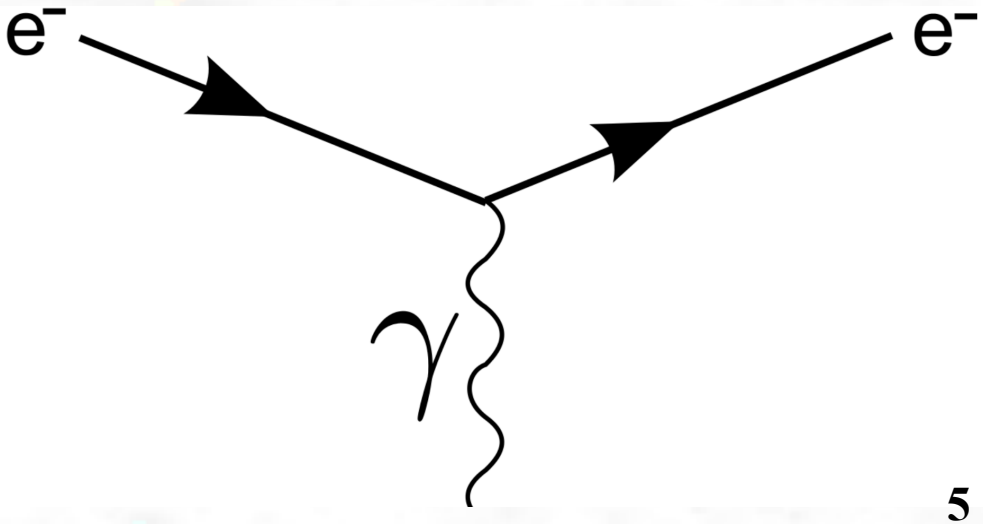
$$\sigma(\Delta E, |\Delta \mathbf{p}| \sim \Delta E)$$

UPCs

Virtual photons

$$\sigma(\Delta E, |\Delta \mathbf{p}| \neq \Delta E)$$

EIC



Proposed UPCs in heavy ion colliders

Electromagnetic processes in relativistic heavy ion collisions
C.A. Bertulani and G. Baur, **Phys. Reports 163 (1988) 299.**

Electromagnetic physics at relativistic heavy ion colliders: for worse and for better
G. Baur and C.A.Bertulani, **Nucl. Phys. A 505 (1989) 835.**

Relativistic heavy ion physics without nuclear contact
C.A. Bertulani and G. Baur, **Physics Today, March 1994, p. 22.**

- **Pair production (RHIC, CERN)**
- **Pair production with capture → anti-Hydrogen (CERN 1996, FERMILAB 1998)**
- **Meson production (RHIC, CERN)**
- **Double Giand Dipole Resonance (GSI 1993)**
- **Nuclear Astrophysics (GSI, RIKEN, MSU, GANIL)**
- **Nucleon Resonances (CERN)**
- **$\gamma+\gamma \rightarrow \gamma+\gamma$ (Delbruck scattering)**

- **Peripheral heavy ion collisions as a probe of the nuclear gluon distribution**
  V.P. Goncalves and C.A. Bertulani, **Phys. Rev. C 65, 054905 (2002) (RHIC,CERN)**

The New York Times

WORLD | U.S. | N.Y. / REGION

Physicists Manage to Create The First Antimatter Atoms

By MALCOLM W. BROWNE
Published: January 5, 1996

PRINT
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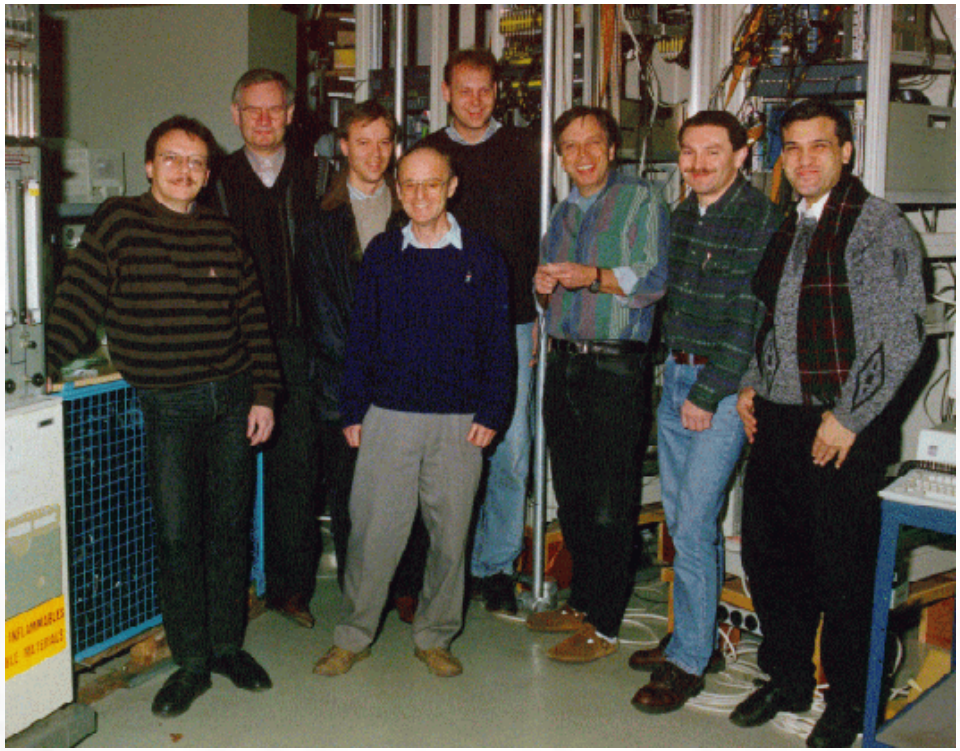
SHARE

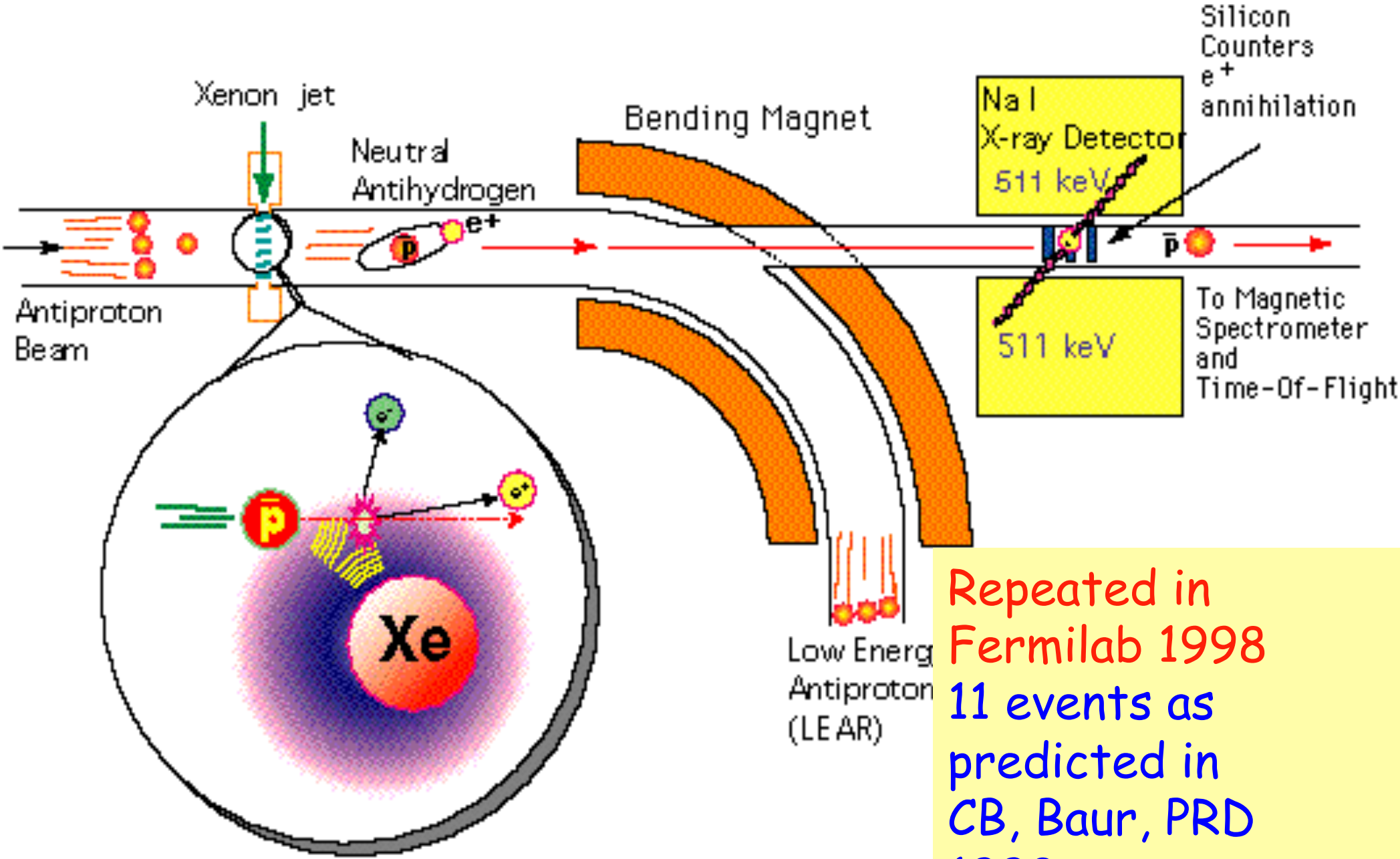
But the neutrality of antihydrogen, like that of ordinary hydrogen, renders it impossible to contain or manipulate using magnetic fields. Moreover, an antiatom cannot be contained in an ordinary vessel, since the slightest contact with the container's wall causes it to annihilate. Consequently, other groups are developing enormously sophisticated methods, including interacting lasers, to manipulate and secure antiparticles inside vacuum chambers.



1996

Two virtual photons are very useful!

First Production of AntiHydrogen
Baur et al, 1996



Repeated in Fermilab 1998
11 events as predicted in CB, Baur, PRD 1998 !

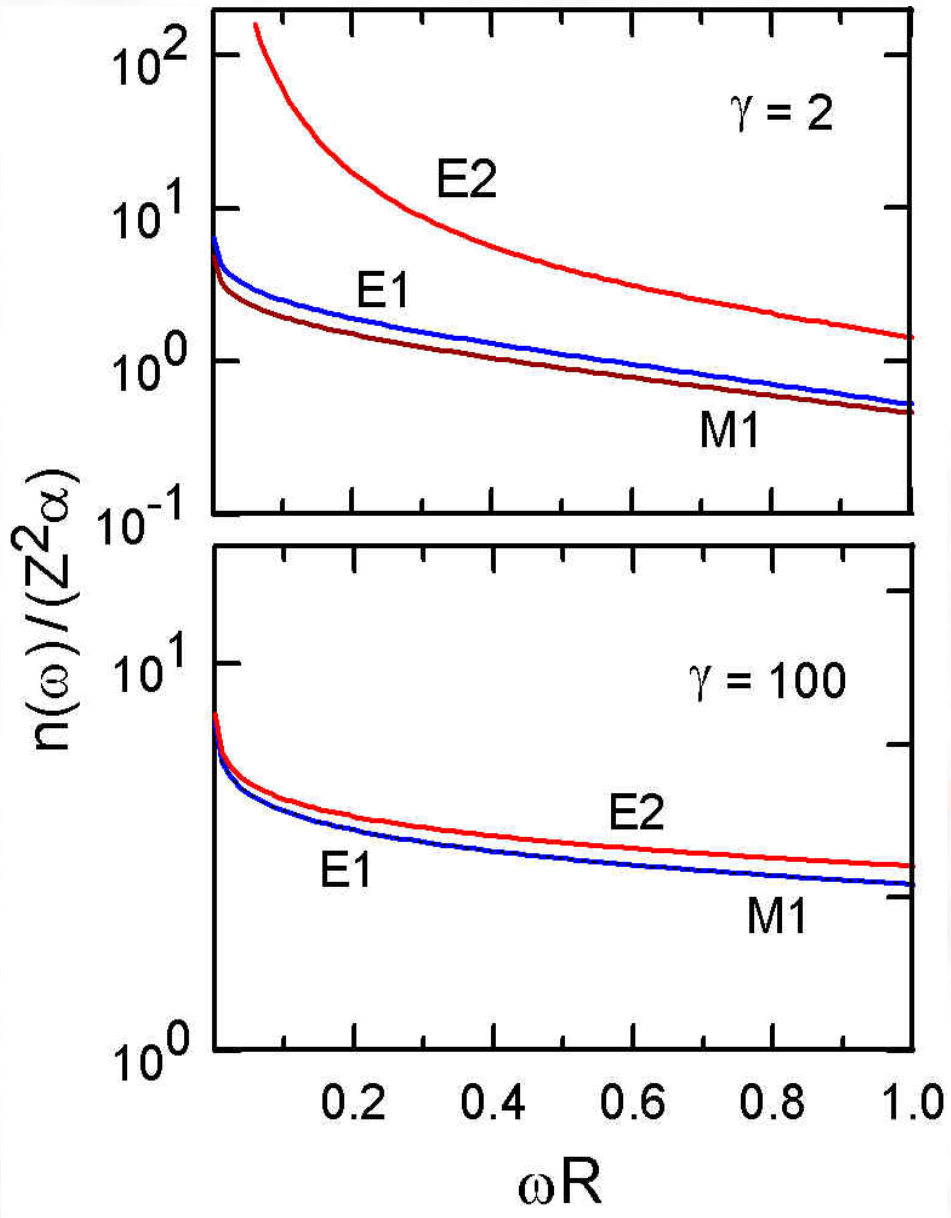
Theoretical

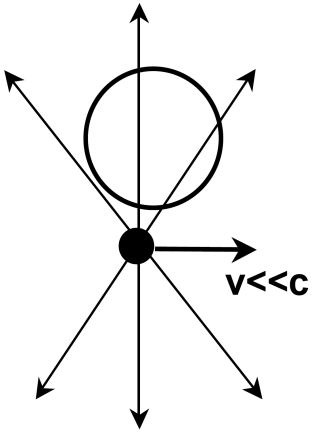
Motivation

and

Challenges

Virtual photon numbers in UPCs

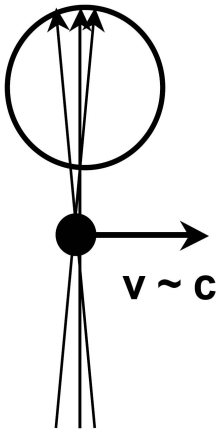




low-energy (tidal)

$$n_{E2} >> n_{E1} >> n_{M1} = \frac{v^2}{c^2} n_{E1}$$

Low-energies:
multipolarity content
Good for low energy pysics



high-energy (contraction)

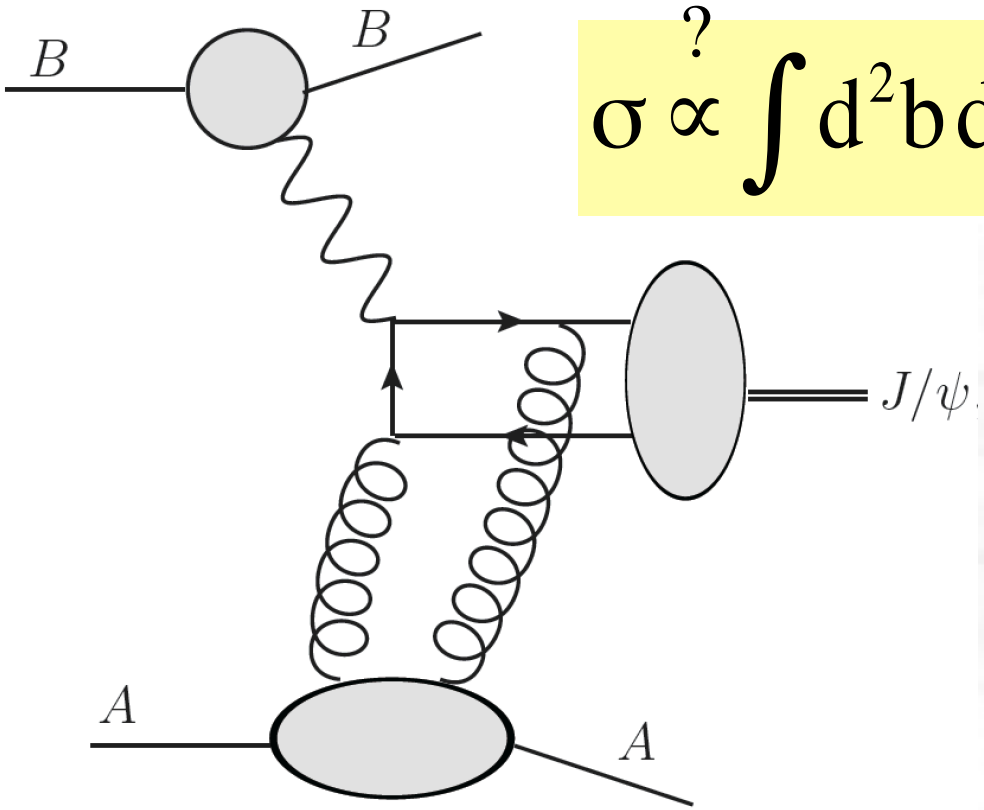
$$n_{E2} \sim n_{E1} \sim n_{M1}$$

No multipolarity content
Good for high energy physics

$$n(\omega, b) = \frac{2Z^2\alpha\omega^2}{\pi\gamma^2}\left[K_1^2\left(\frac{\omega b}{\gamma}\right) + \frac{1}{\gamma^2}K_0^2\left(\frac{\omega b}{\gamma}\right)\right] S_{\text{absorption}}(b)$$

PDFs – ideal scenario

1- Vector meson production as a clean (?) probe of PDFs



$$\sigma \overset{?}{\propto} \int d^2b\, d\omega\, n_A(\omega) n_B(\omega) \left[x G_A(x) \right]^2$$

2- What we want to learn about PDFs?

PDFs

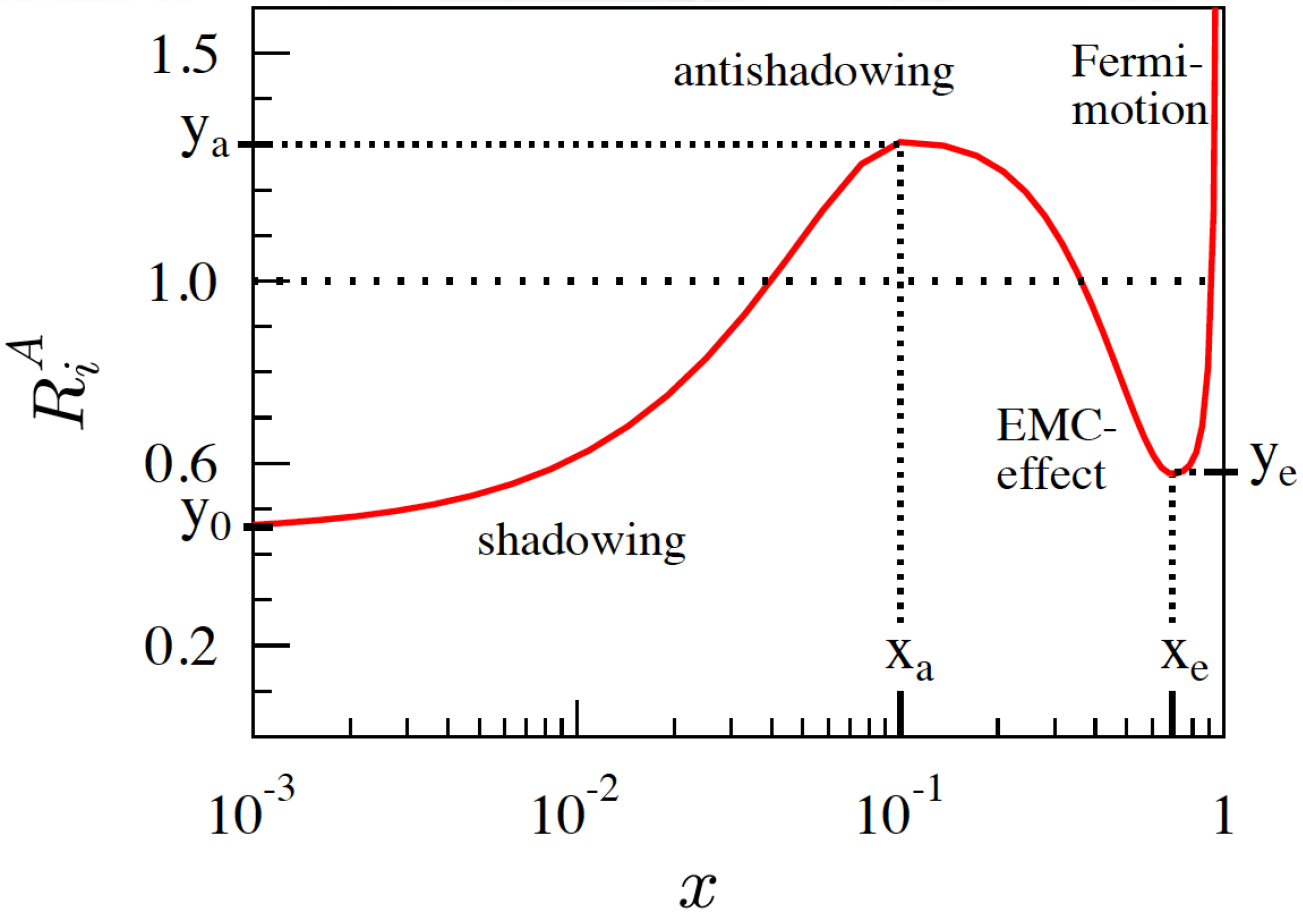
Ramona Vogt (LLNL)
Fred Olness (SMU)
Shunzo Kumano (KEK)

Medium corrections: nPDFs

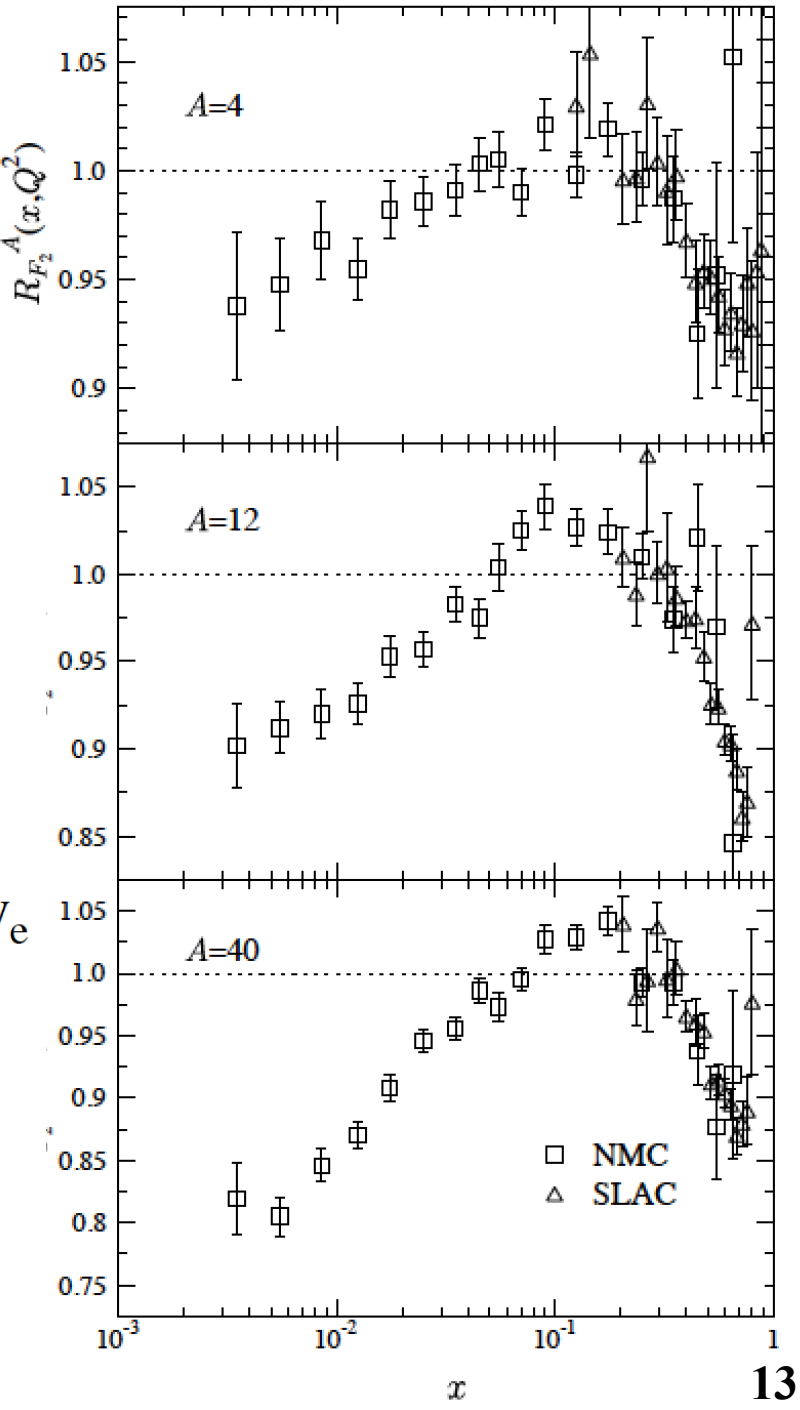
Challenge or opportunity?

$$G_A(x) = R_i^A\left(x,Q^2\right) g_p\left(x,Q^2\right)$$

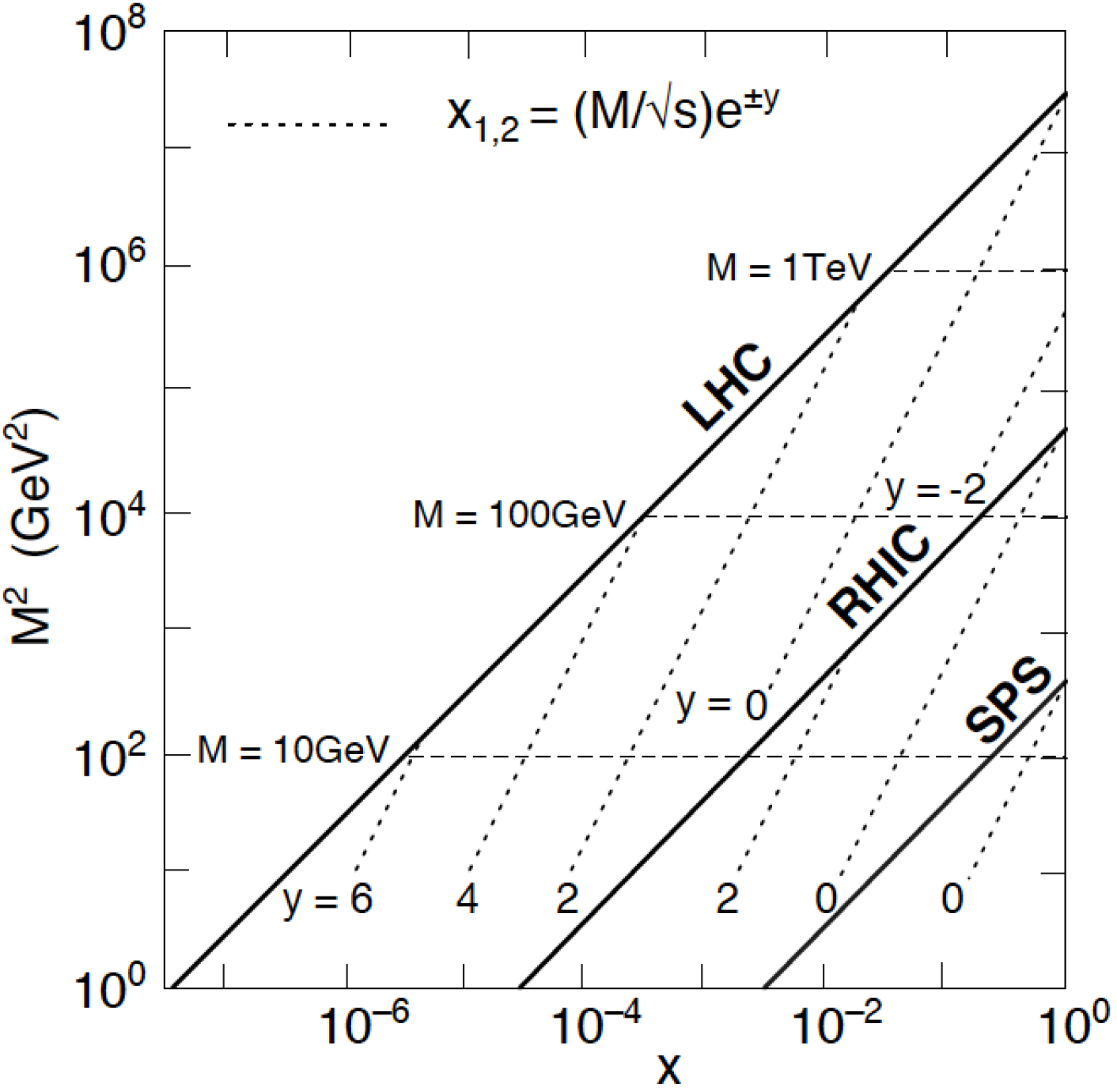
From Ramona Vogt's talk



$Q^2 > 1$ GeV^2

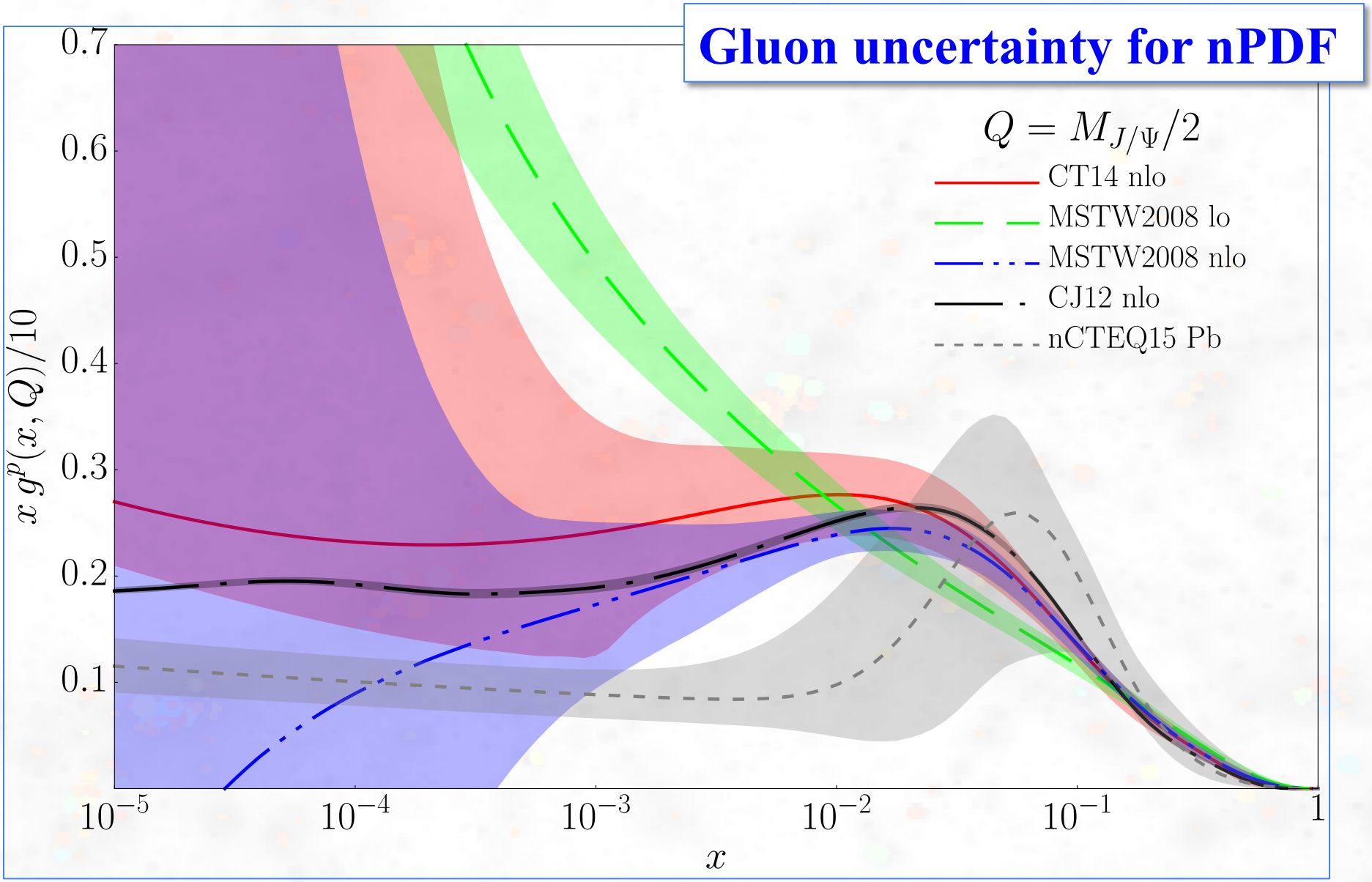


x and Q^2 reach of Heavy Ion Colliders



Charge & Neutrino, DIS, W/Z and QED data contraints

From Fred Olness' and Shunzo Kumano's talk



Diffraction, Jets, Saturation, and Dipoles

Beatriz Gay Ducati (UFRGS)

Anna Stasto (PSU)

Guangyao Chen (Iowa State)

Piotr Kotko (PSU)

Wolfgang Schaefer (Cracow)

Amir Rezaeian (Valparaiso)

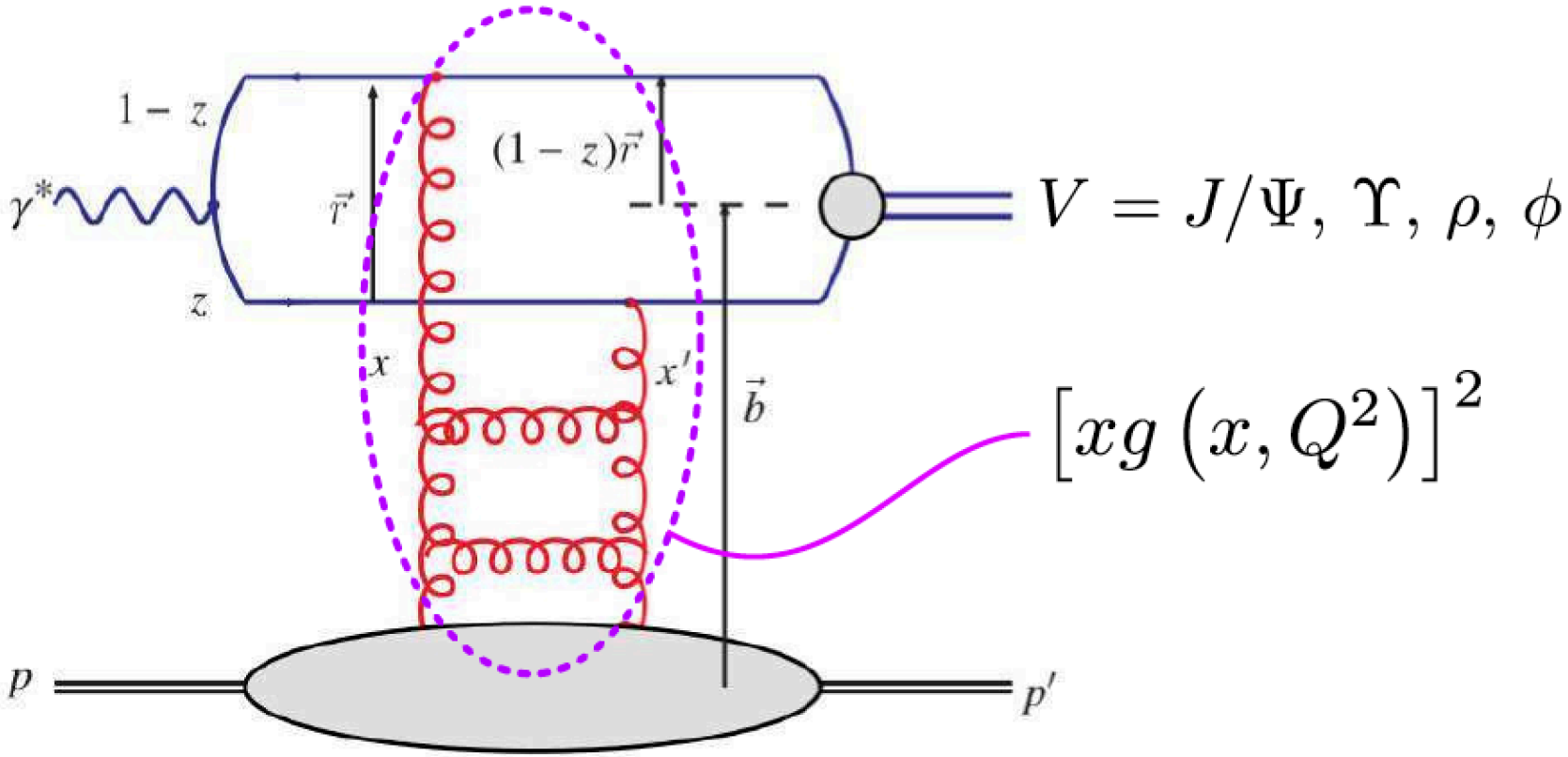
Heikki Mantysaari (BNL)

Misak Sargsian (FIU)

Dipole model

Motivation:

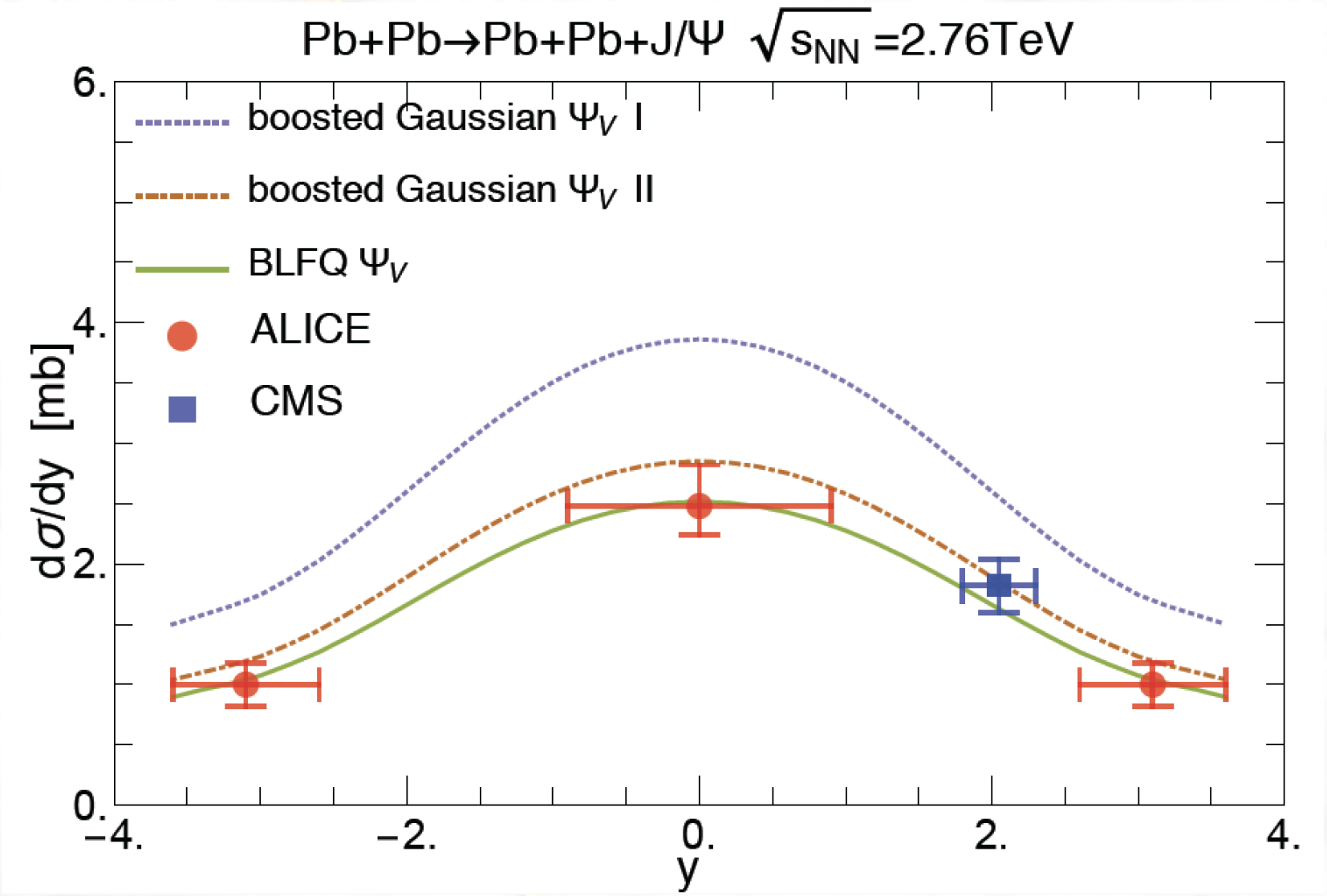
Study Pomeron exchange mechanism



From Beatriz Gay Ducati's talk

Motivation:

Test vector meson wavefunction models

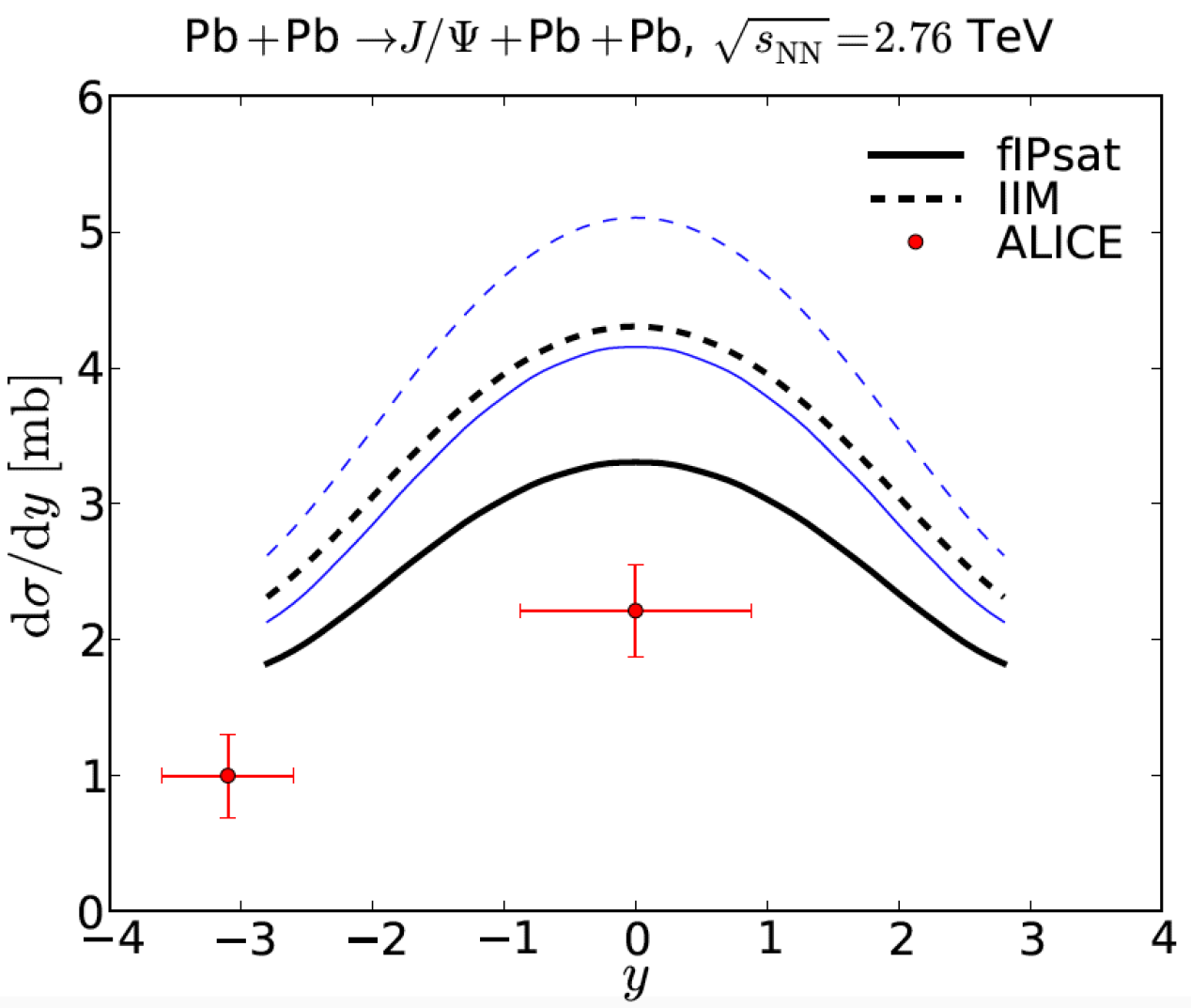


From Guangyao Chen's talk

Motivation:

Test gluon saturation model

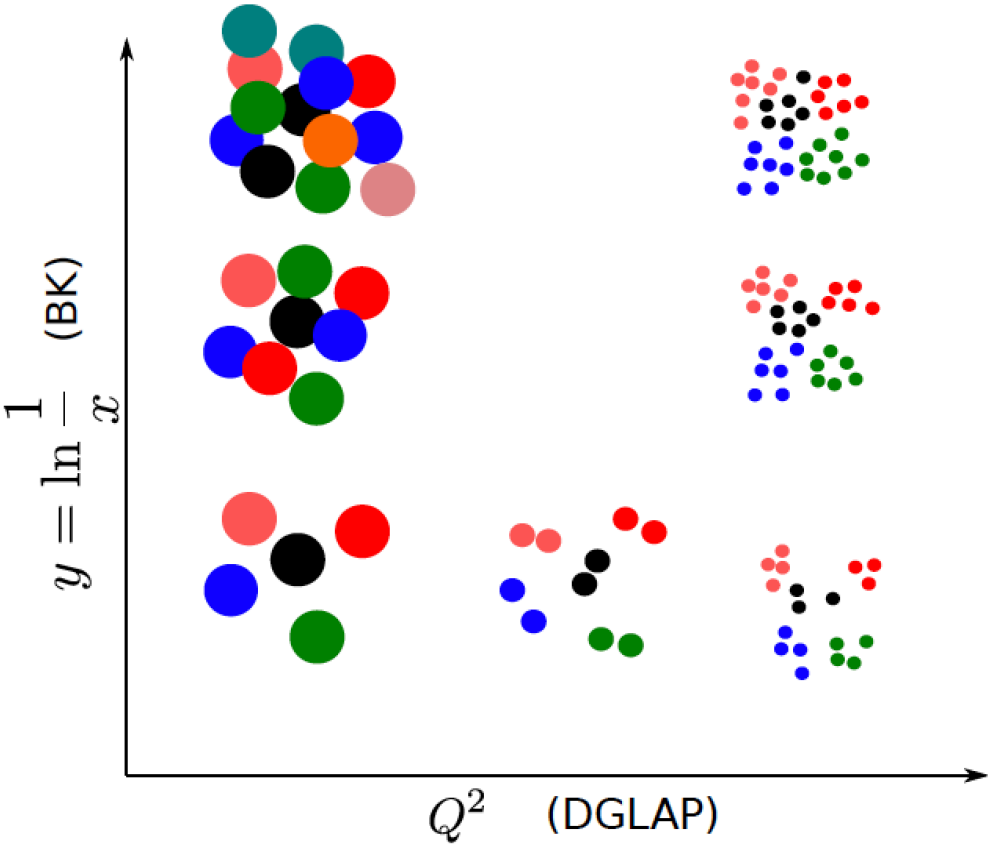
From
Heikki Mantysaari 's
talk



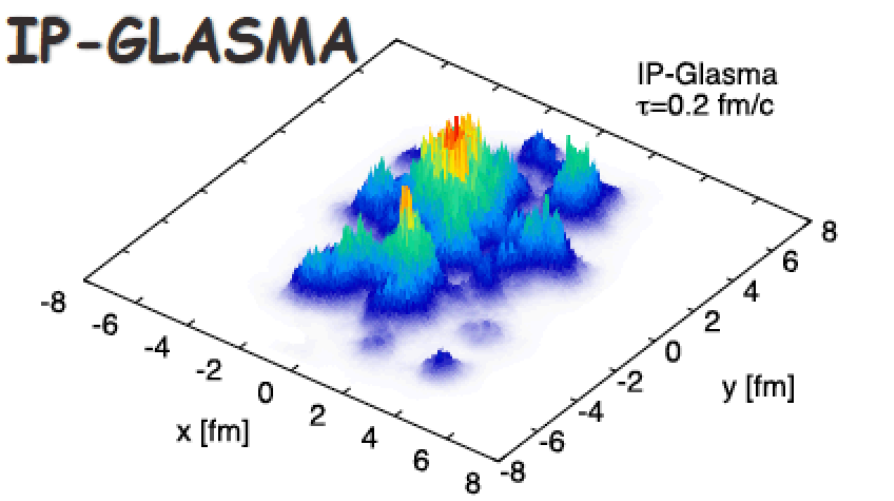
This is becoming precision physics
(linear scale!)

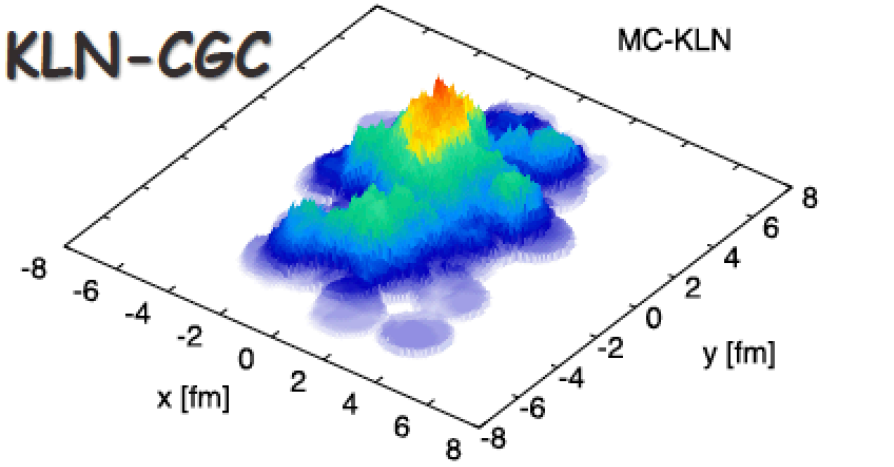
Motivation:

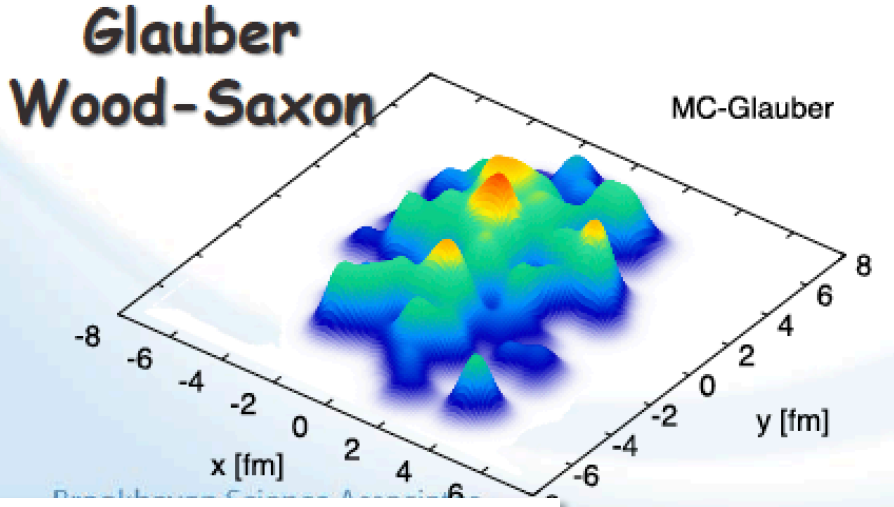
Test gluon saturation model



From
Heikki Mantysaari 's
talk



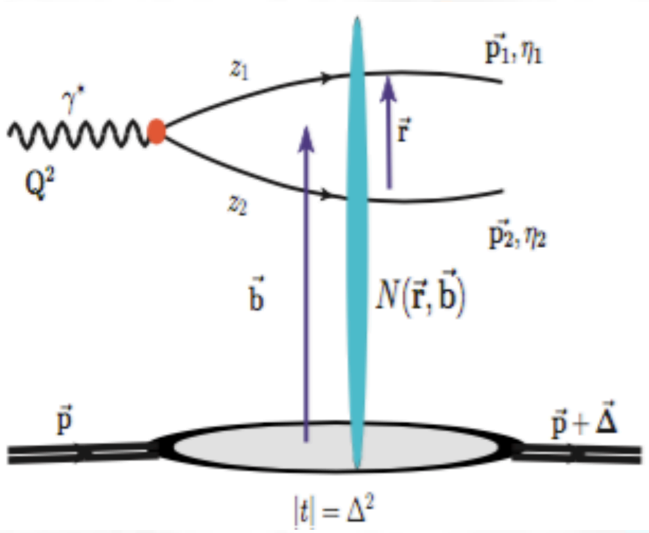




Elke Aschenauer's

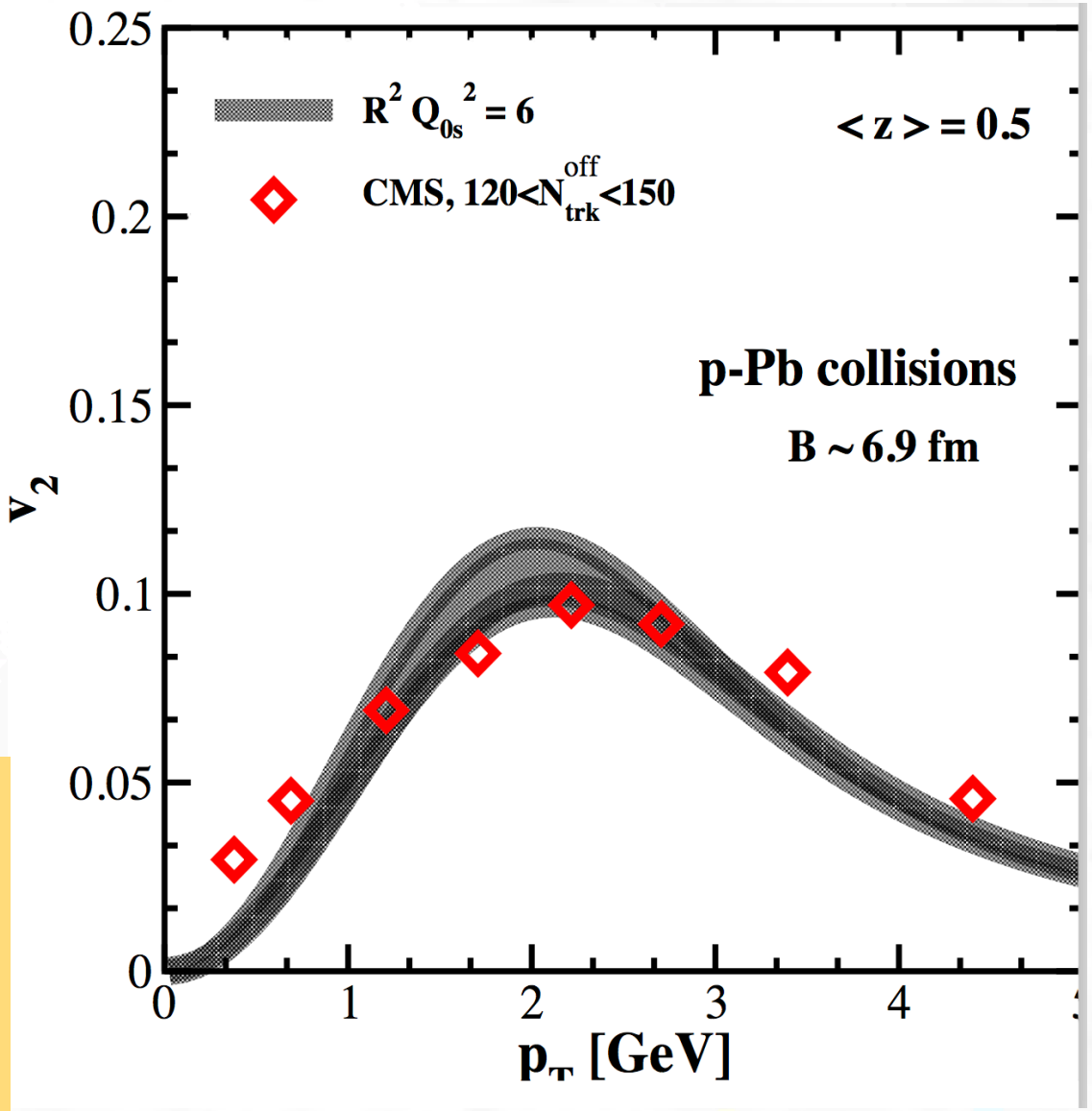
Motivation:

Test gluon saturation model



From Amir Rezaeian's talk

Since jet is color neutral, jet production dominated by q-qbar pairs of smaller transverse size with increasing saturation

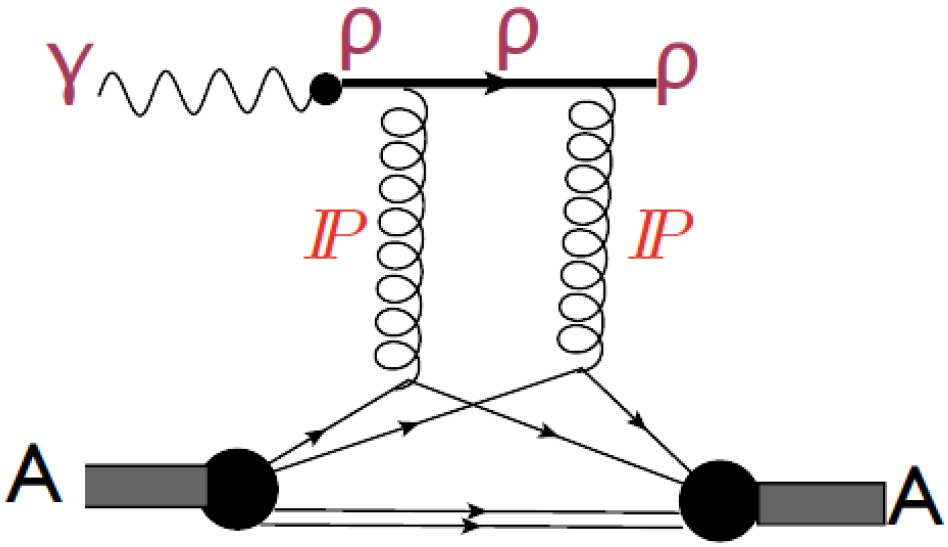


Shadowing

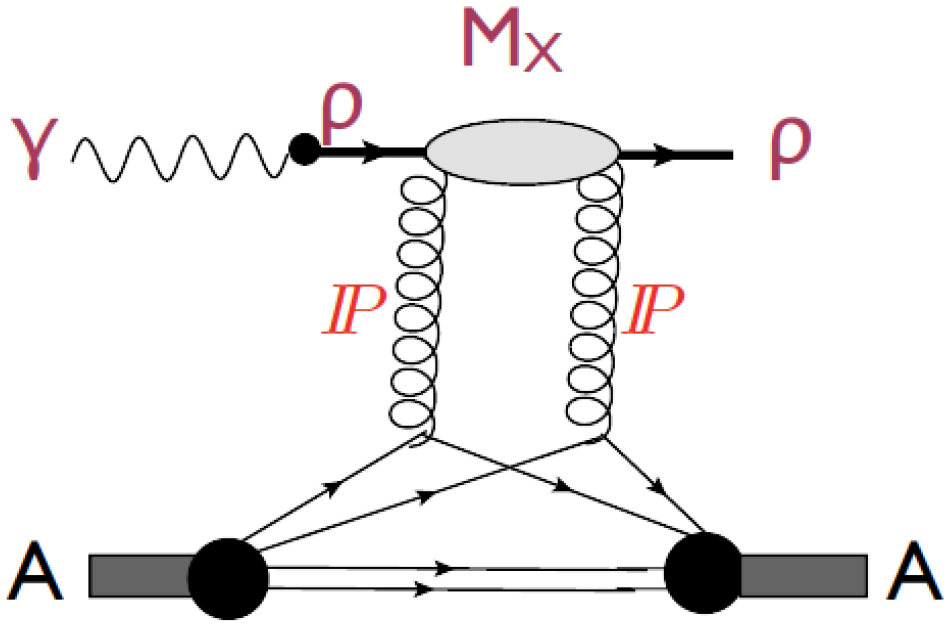
Vadim Guzey (Petersburg)
Leonid Frankfurt (Tel Aviv)
Mark Strikman (PSU)
Boris Blok (Technion)

Shadowing mechanisms

From Leonid Frankfurt's talk



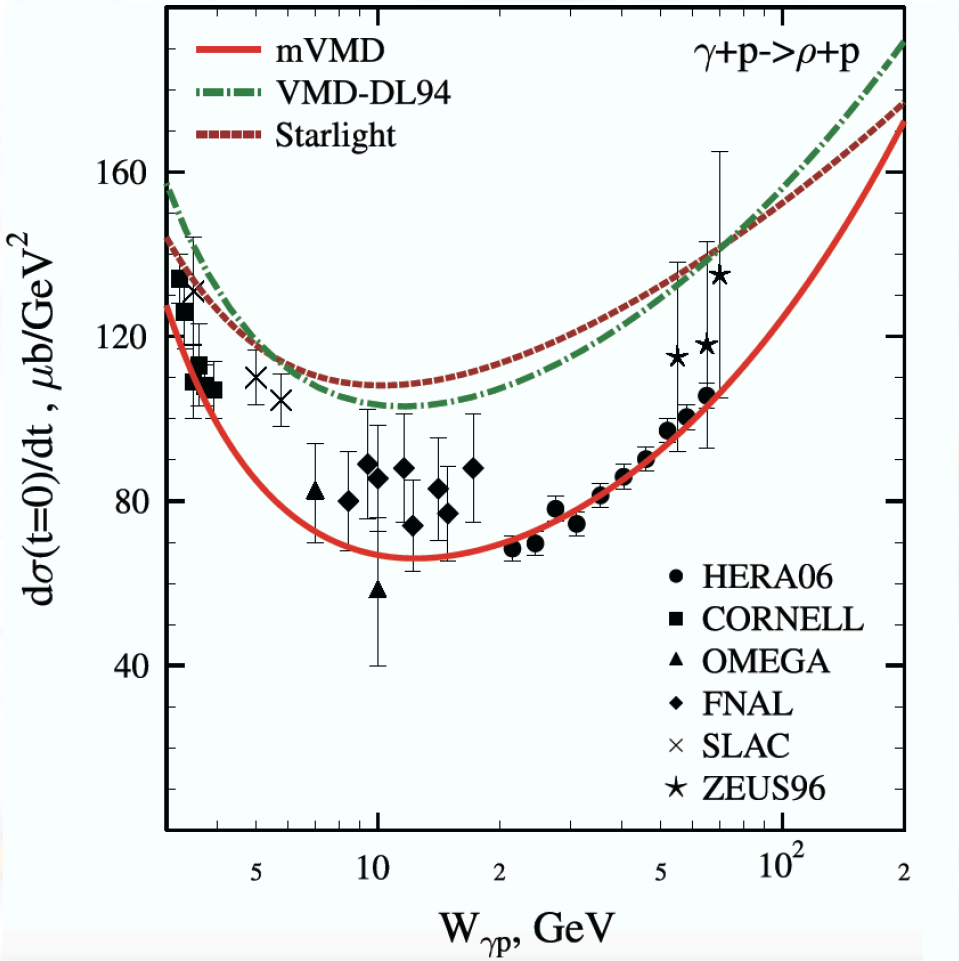
Glauber double scattering

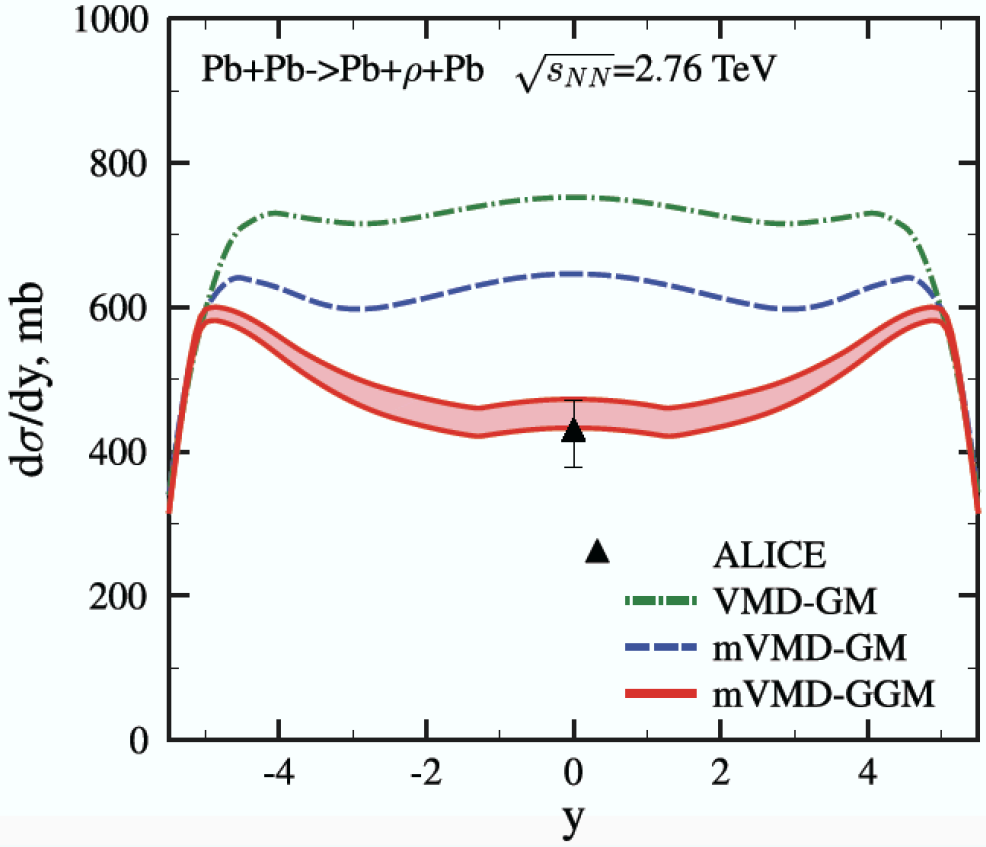


Gribov inelastic shadowing

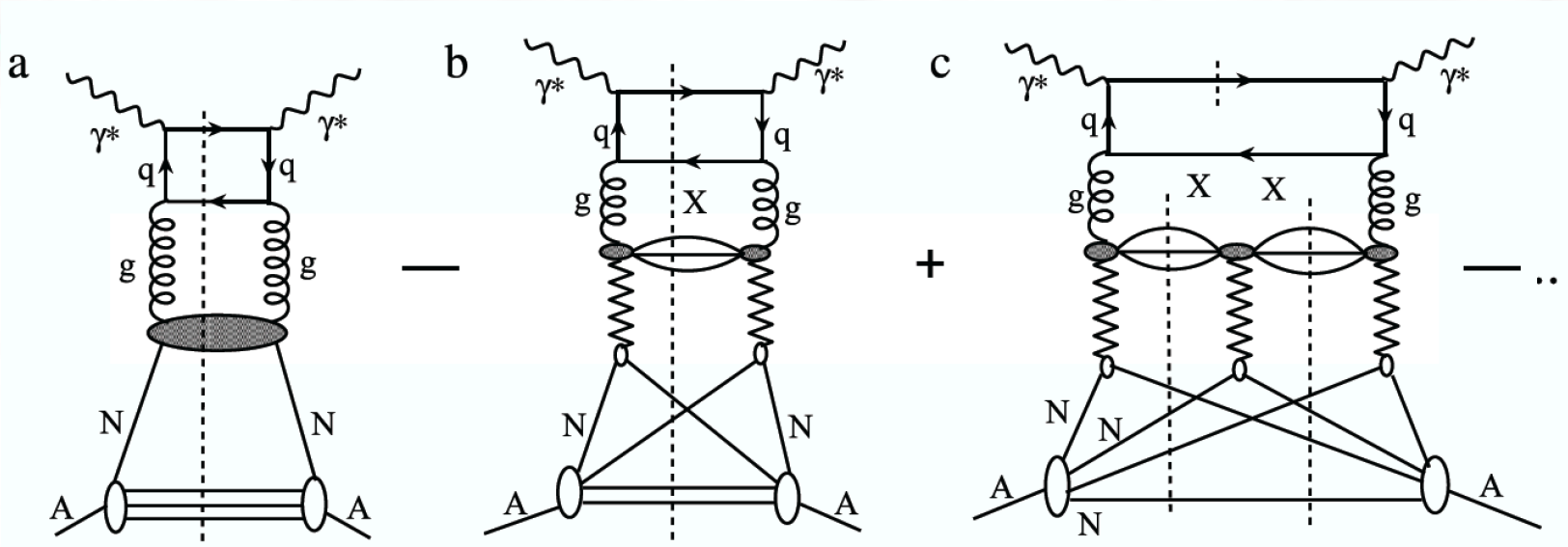
Shadowing with Modified Vector Dominance Mechanism

From Vadim Guzey's talk



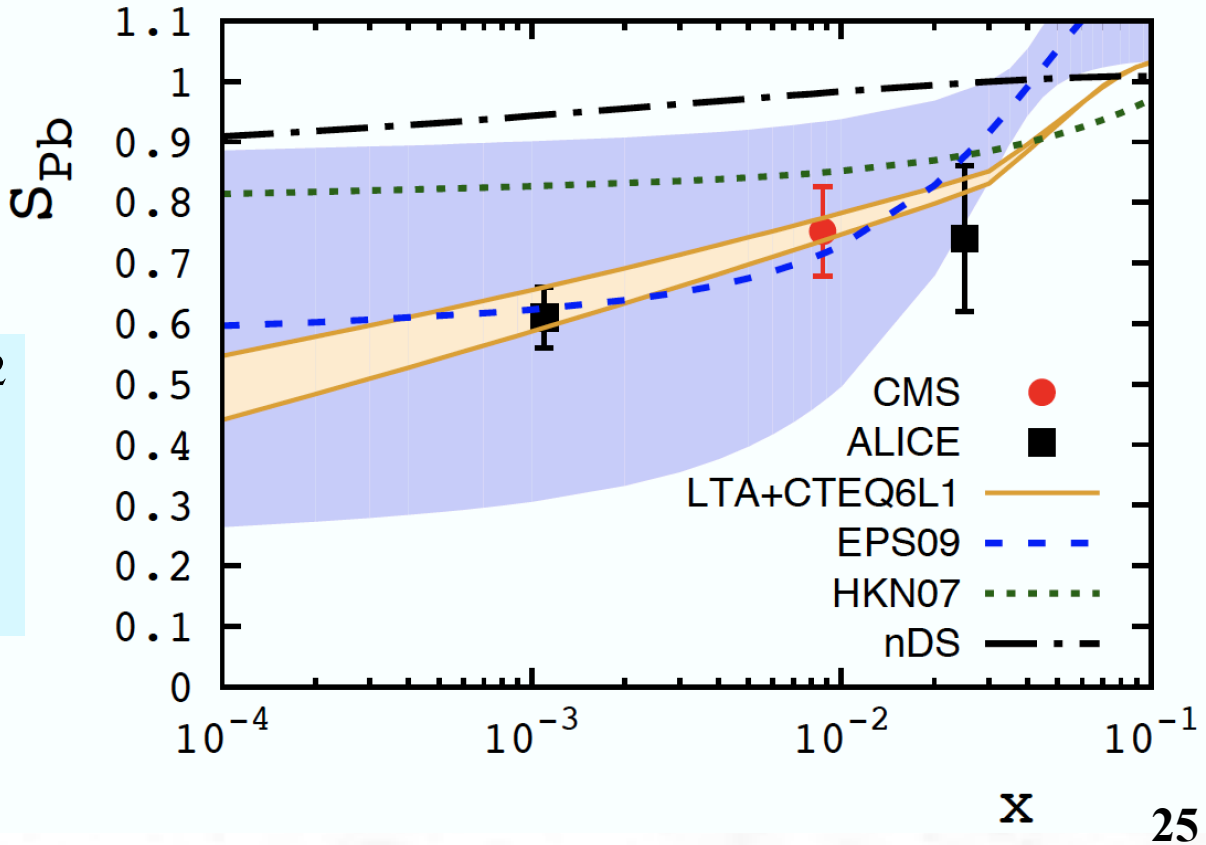


Leading Twist Shadowing Model



From Vadim Guzey's talk

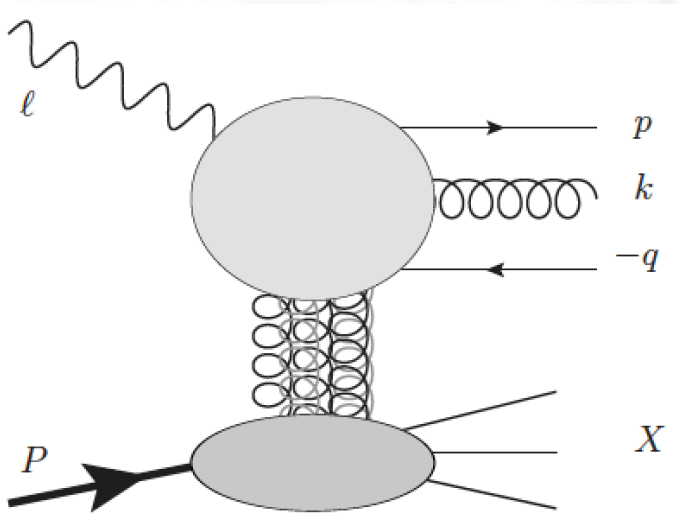
$$S(W_{\gamma p}) = \left[\frac{\sigma_{\gamma Pb \to J/\psi Pb}}{\sigma^{IA}_{\gamma Pb \to J/\psi Pb}} \right]^{`1/2}$$



Polarization in UPCs and EIC

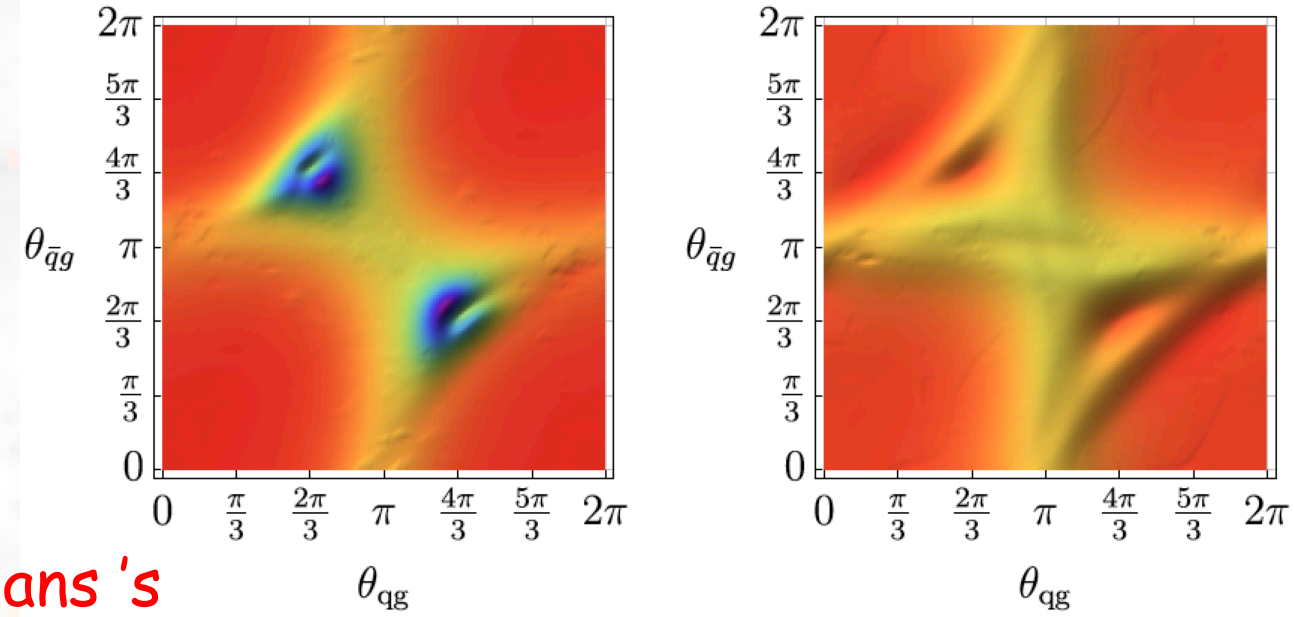
Maria Elena Tejeda-Yeomans
(Sonora)
John Ralston (Kansas)

Polarization in UPCs and EIC



Motivation: use azimuthal angular correlations of 3 partons in inclusive DIS to explore the dynamics of saturated partonic matter

Azimuthal correlations between 3 partons in DIS



From Maria Elena Tejeda-Yeomans 's talk

Experiment

Methods

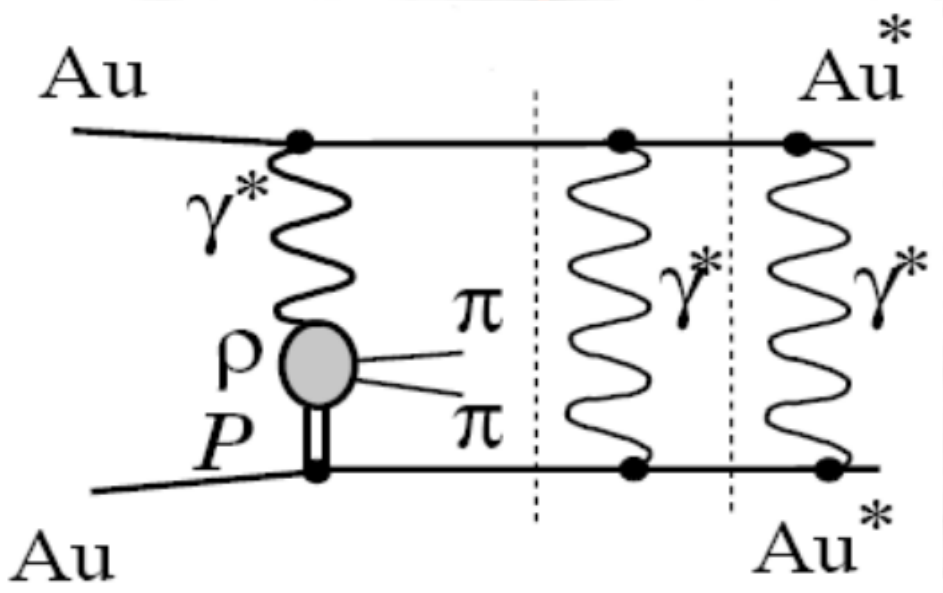
and

Challenges

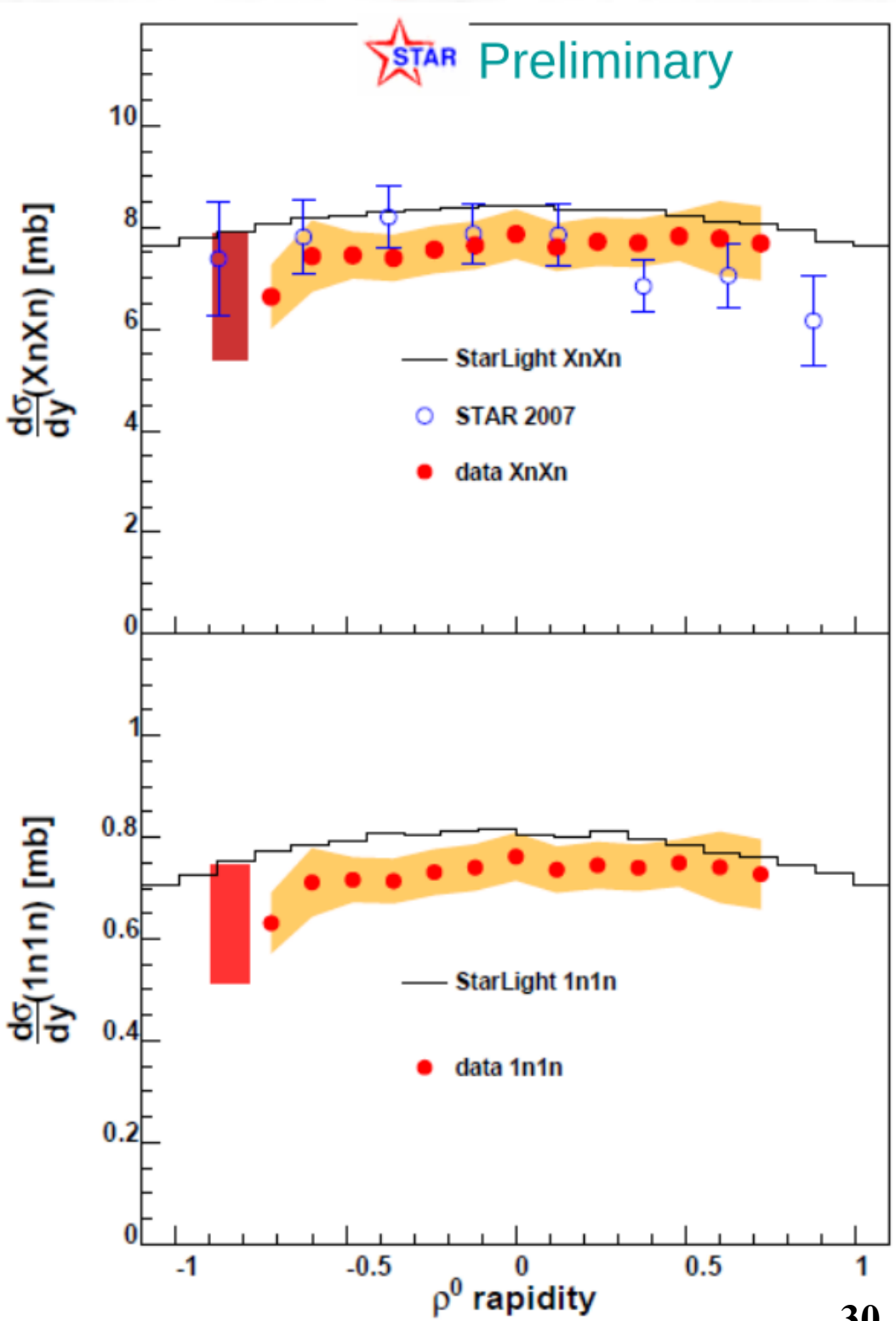
Experiments at RHIC and LHC

Jarda Adam (Creighton)
Aaron Angerami (Columbia)
Evgeny Kryshen (Petersburg)
Michael Murray (Kansas)

Trigger using forward neutrons



From Jarda Adam's talk

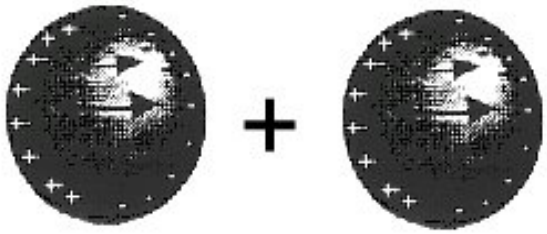


Giant Resonances and Neutron Multiplicities

DGDR accounts for 20% of cross sections in UPCs

Bertulani, BaurPLB 174 (1986) 23 1986

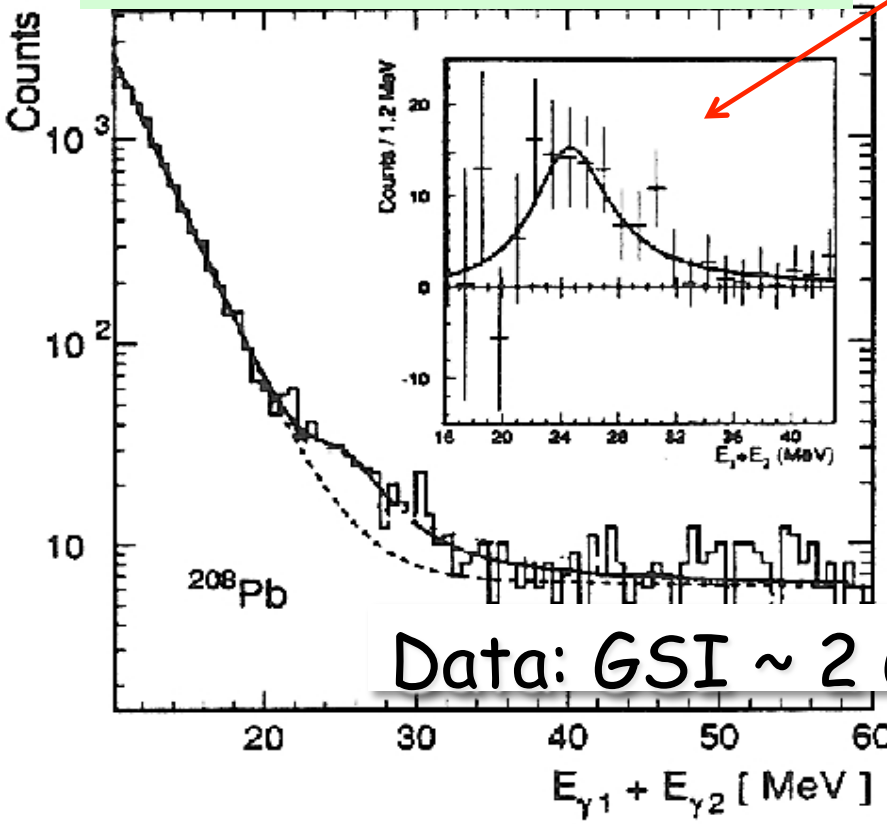
Bertulani, Ponomarev
Phys. Reports 321 (1999) 139



= DGDR

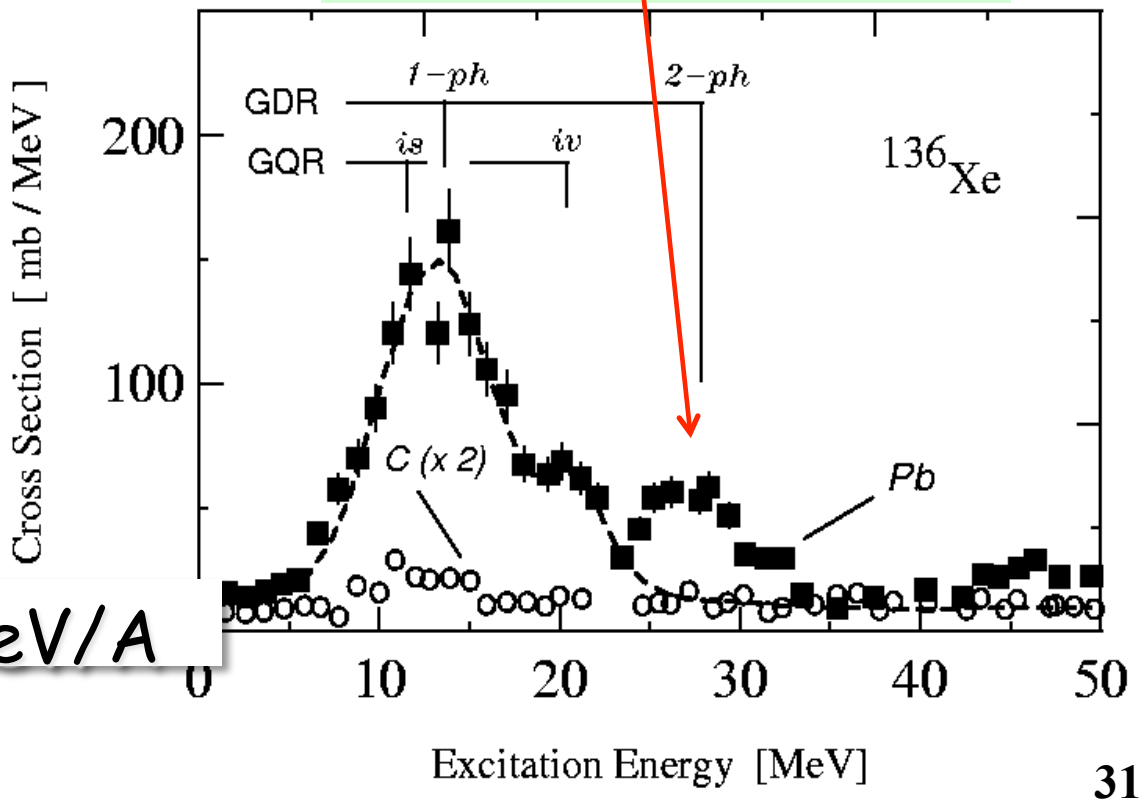
Schmidt et al., PRL 70, 1767 (1993)

Pb + A → Pb + A + γ + γ

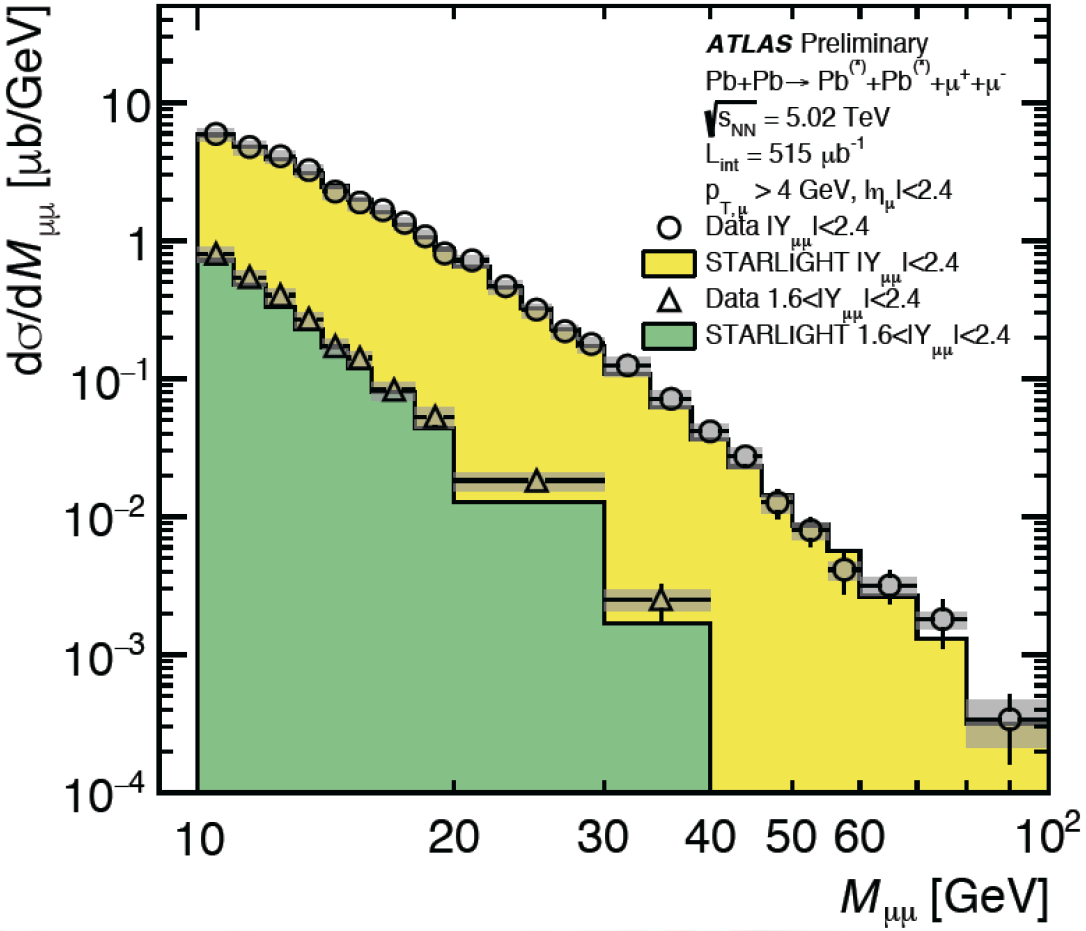


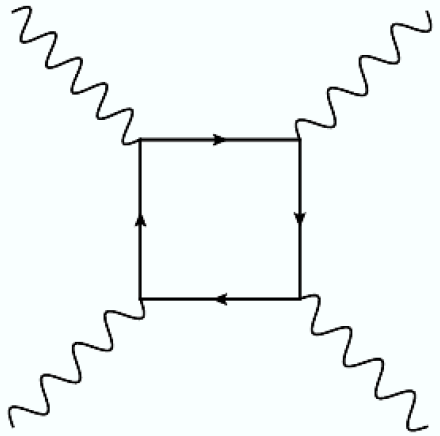
Data: GSI ~ 2 GeV/A

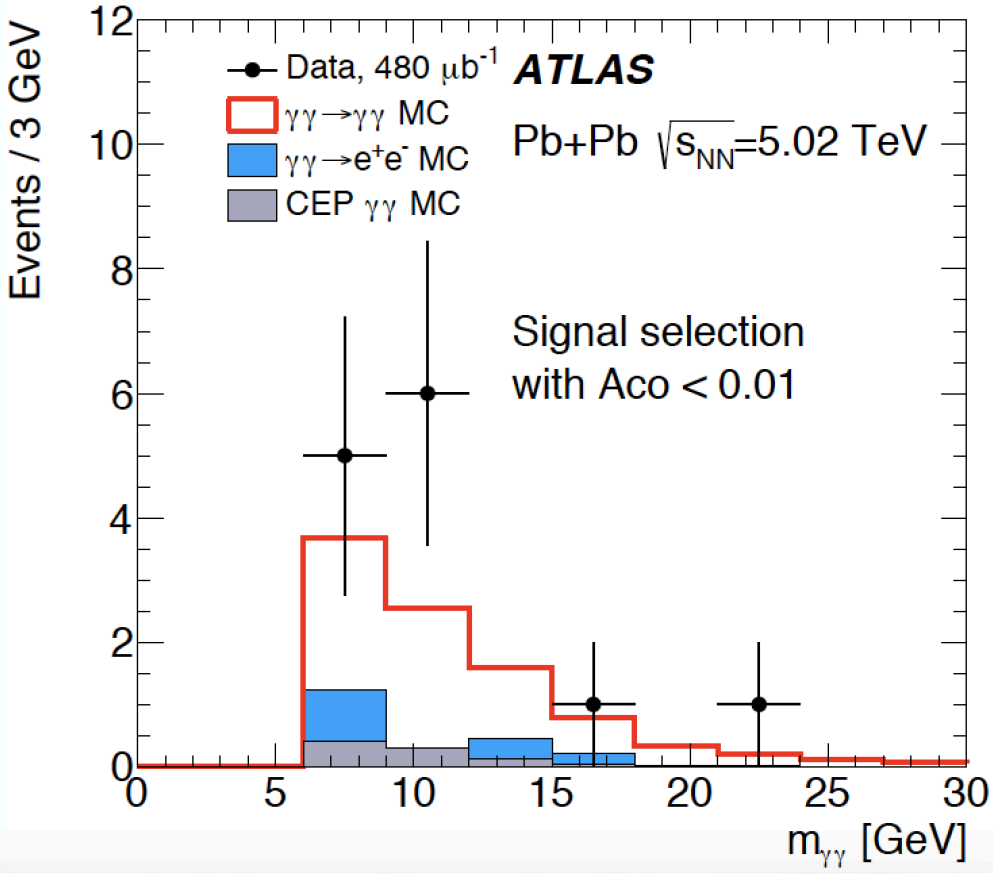
Xe + A → Xe + n + A



Lepton pairs and light-by-light scattering



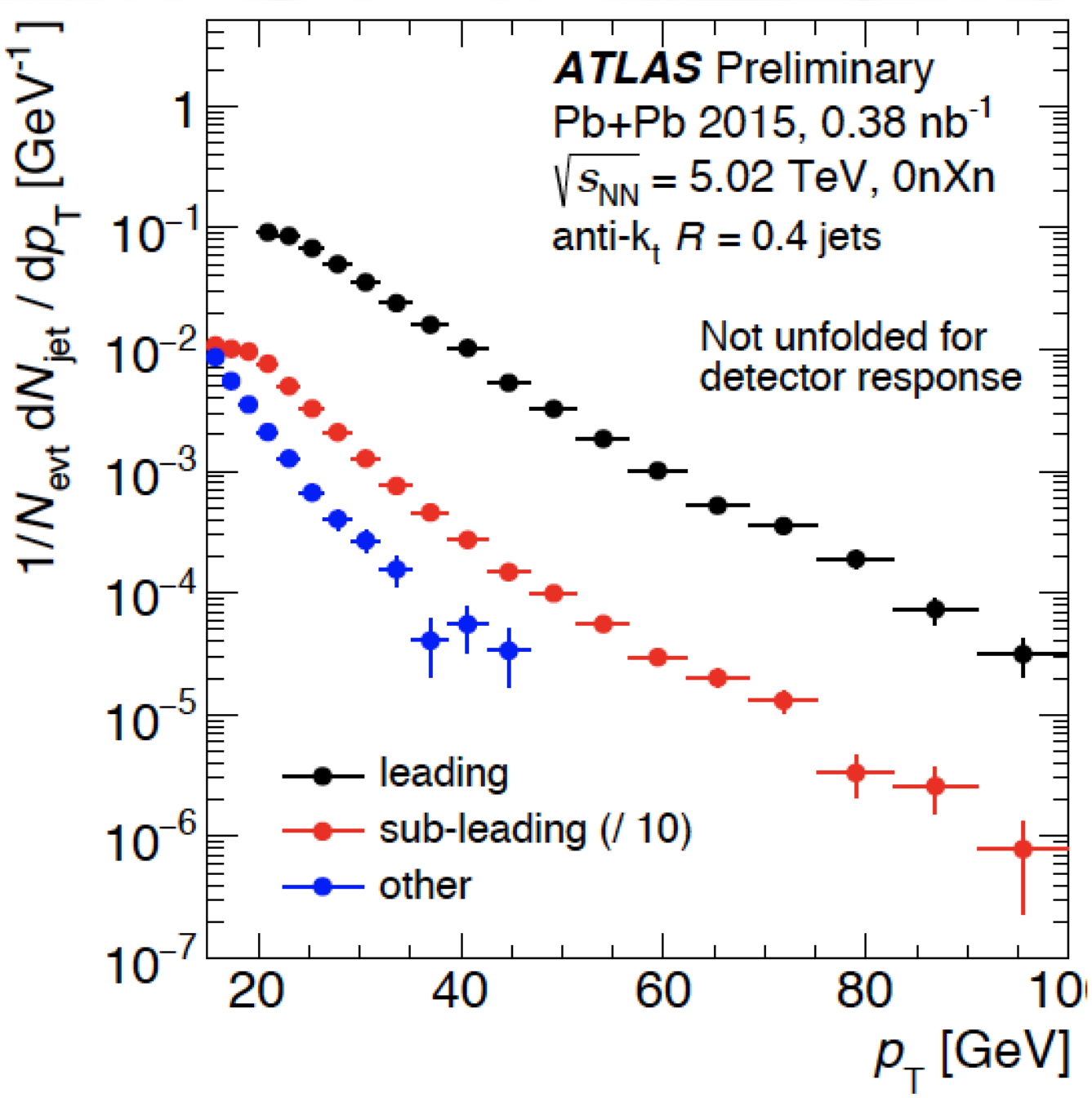




From Aaron Angerami's talk

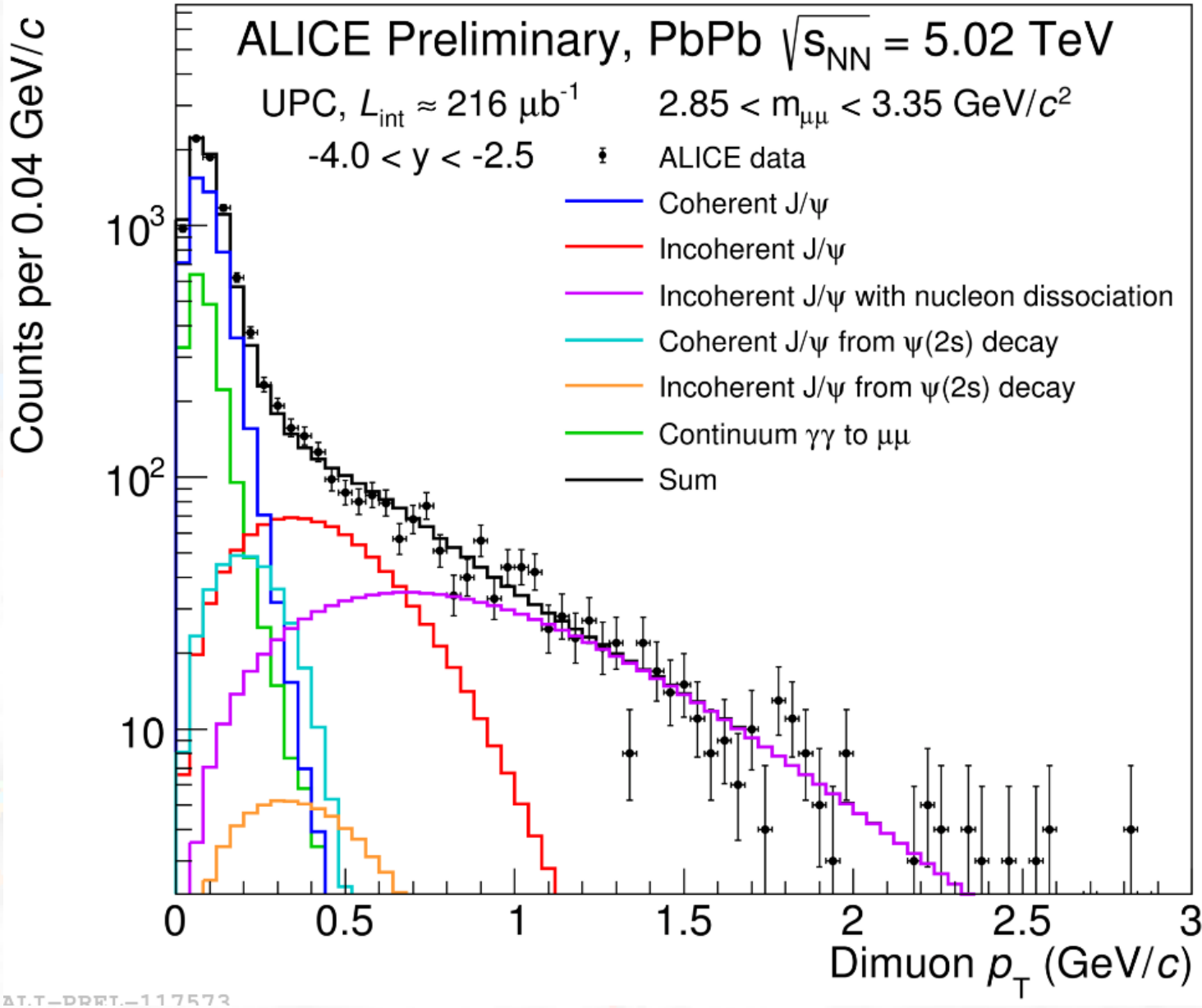
Jets

From
Aaron Angerami's
talk



J/ψ p_T distribution

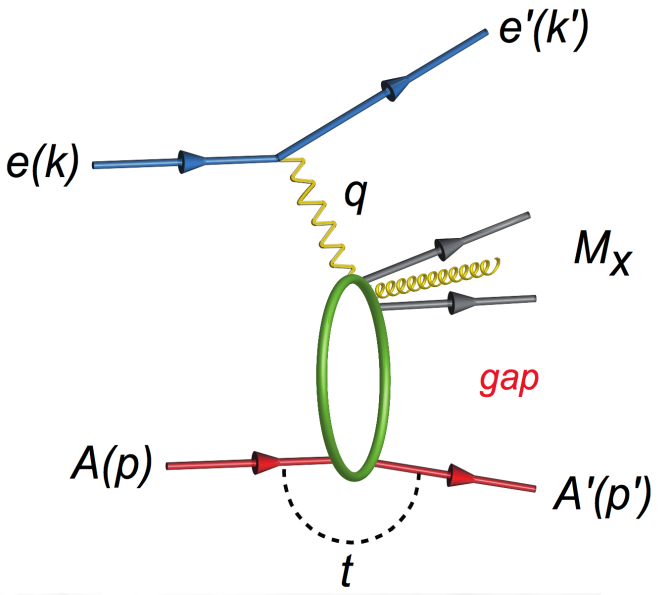
From
Aaron Angerami's
talk



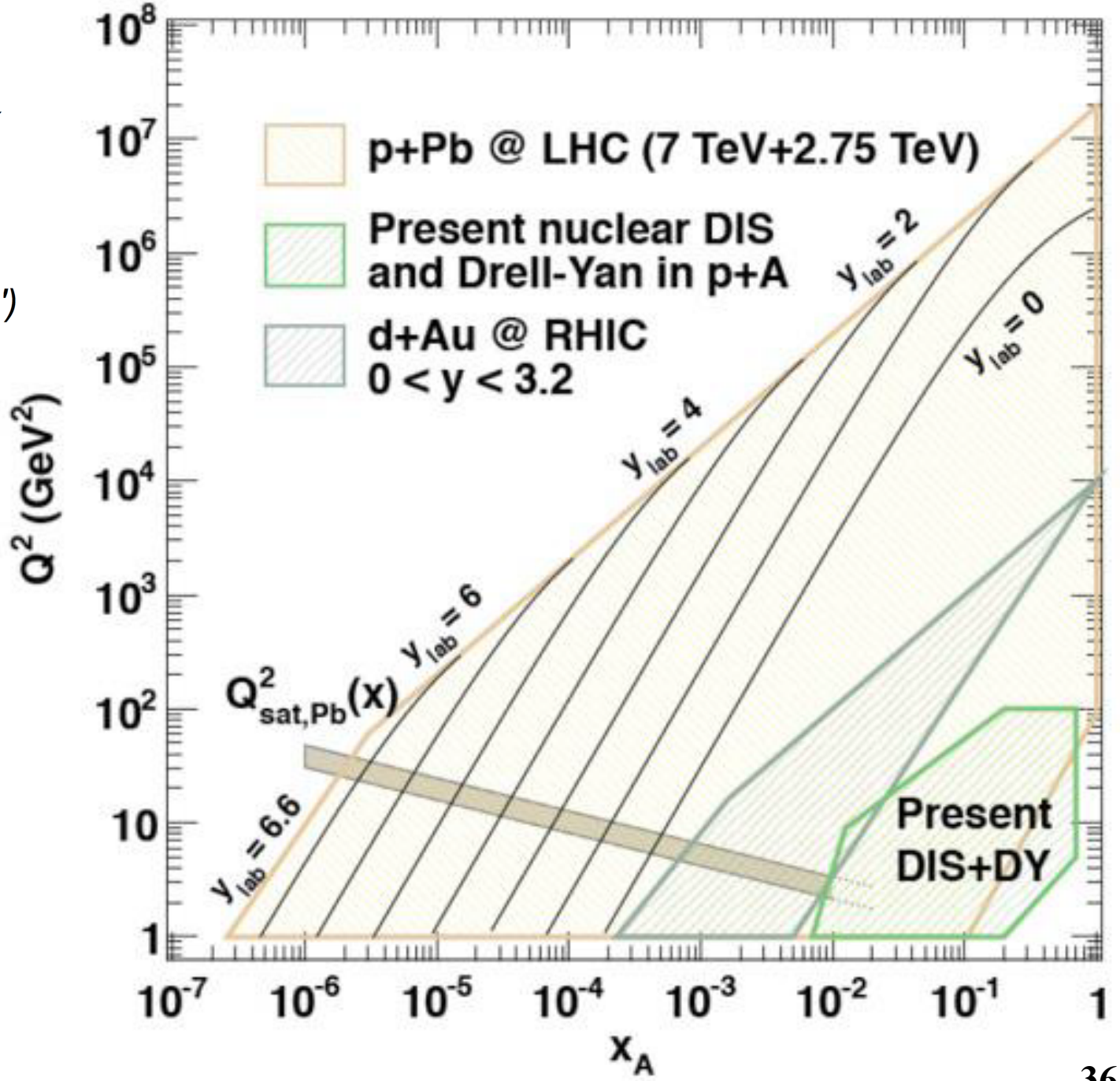
Path to EIC

Elke Aschenauer (BNL)
Christian Weiss (JLab)
Michael Lomnitz (LBNL)

x and Q^2 reach of different facilities

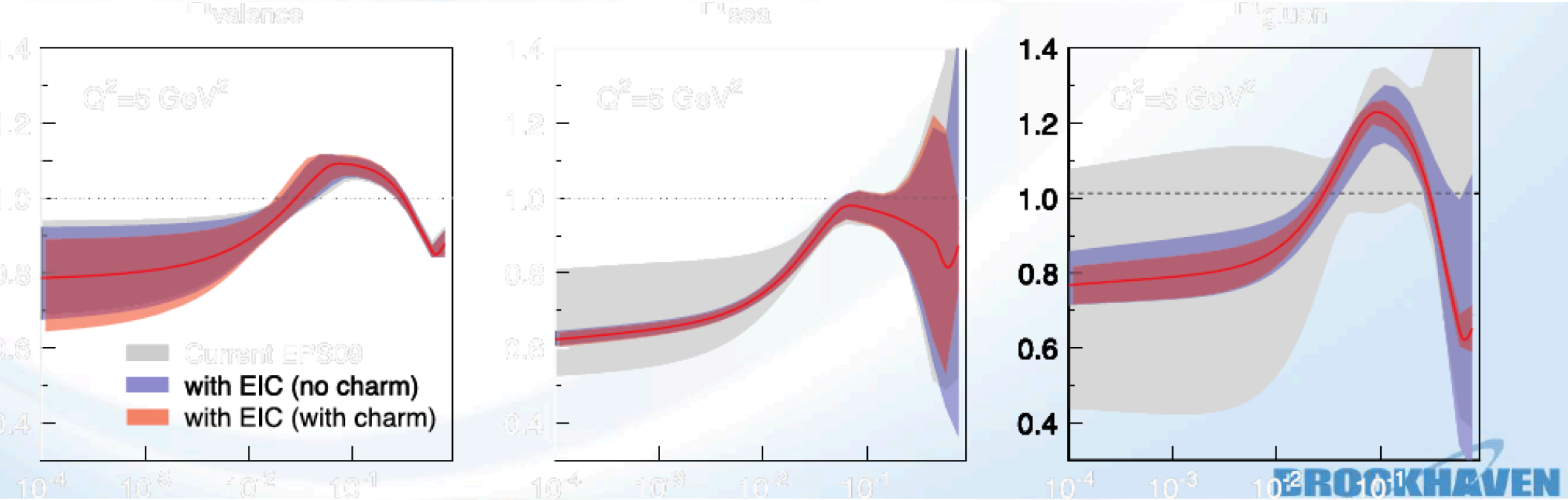


From
Elke Aschenauer's
talk



PDFs before and after EIC

From Elke Aschenauer's talk



UPC in parallel with EIC

- UPCs and EIC complementary

  Highest energy $\leftrightarrow$ control of hard-process kinematics

- Concrete possibilities for "joint" studies

  Mechanism of nuclear shadowing
  Nuclear quarks/gluons at larger x
  Transverse nucleon structure
  Unitarity limit in hard interactions

From Christian Weiss' talk

"Probing QCD in Photon-Nucleus Interactions at RHIC and LHC: the Path to EIC"

INT/Seattle, February 13 - 17, 2017

Excellent talks, challenging theories, great experimental opportunities

The field is very mature