Testing Gluon Density and Saturation with J/psi reactions

1. Short review of HERA physics
   - Partons vs Dipoles
   - VM Meson production at HERA
   - t or IP-dependence
2. Nuclear effects

main goal: Understand the properties of gluonic fields

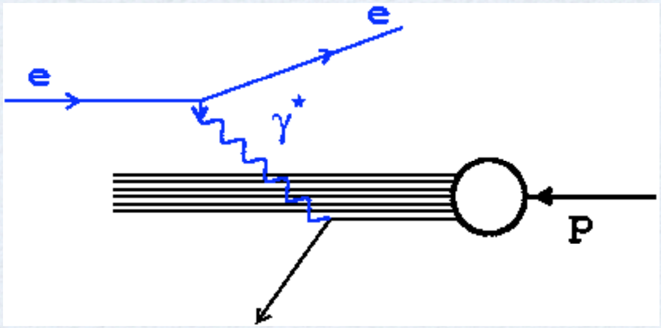
why? Gluons are the most important components of high energy collisions involving nucleons or nuclei

Gluons keep everything together

H. Kowalski, 3rd LHeC Workshop
Geneva, 12 of November 2010

Partons vs Dipoles

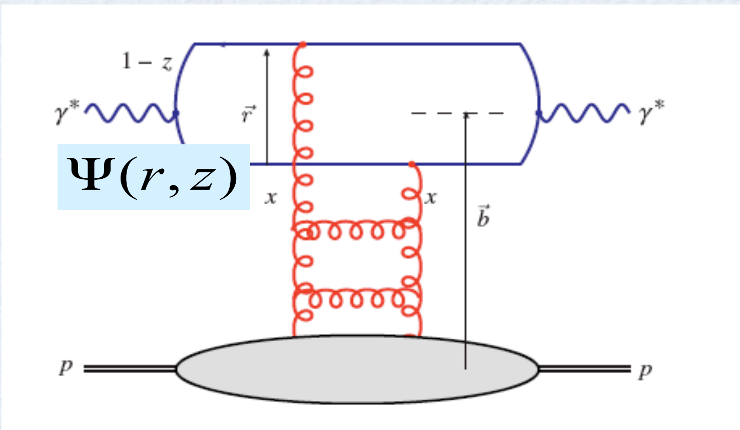
Infinite momentum frame: Partons



F$_2$ measures parton density at a scale Q^2

$$F_2 = \Sigma_f \; e_f^2 \; xq(x, Q^2)$$

Proton rest frame: Dipoles - long living quark pair interacts with the gluons of the proton *dipole life time ≈ 1/(m$_p$ x) = 10 - 1000 fm at x = 10^{-2} - 10^{-4}*

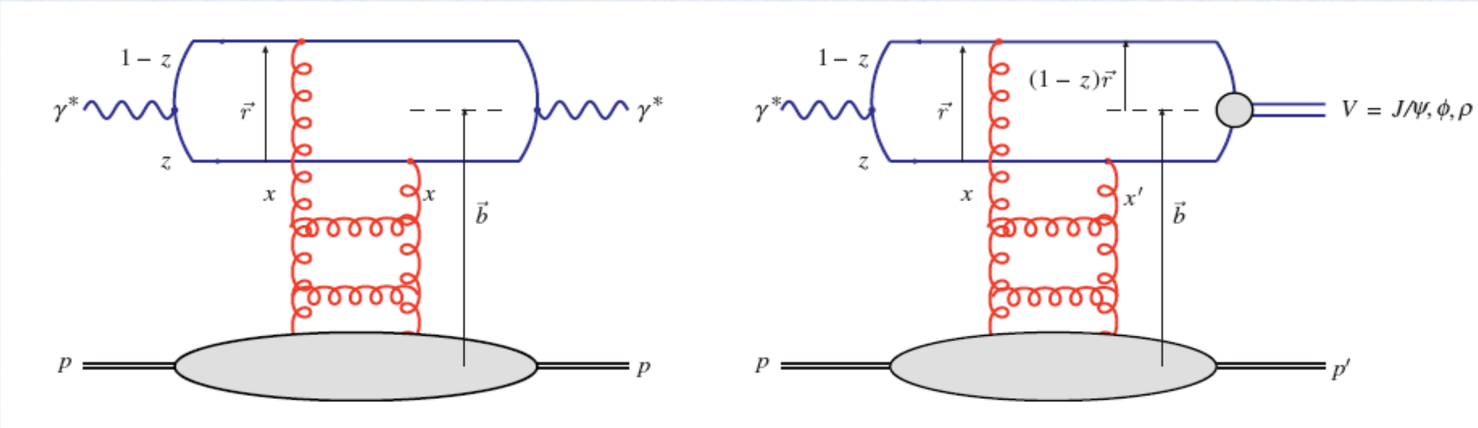


$$\sigma_{tot}^{\gamma^* p} = \int \Psi^* \sigma_{qq} \Psi \; ; \qquad F_2 = \frac{Q^2}{4\pi^2 \alpha_{em}} \sigma_{tot}^{\gamma^* p}$$

for small dipoles, at low-x, dipole picture is equivalent to the QCD parton picture

Diffraction

Observation of inclusive and exclusive diffractive reaction established the dipole picture of DIS



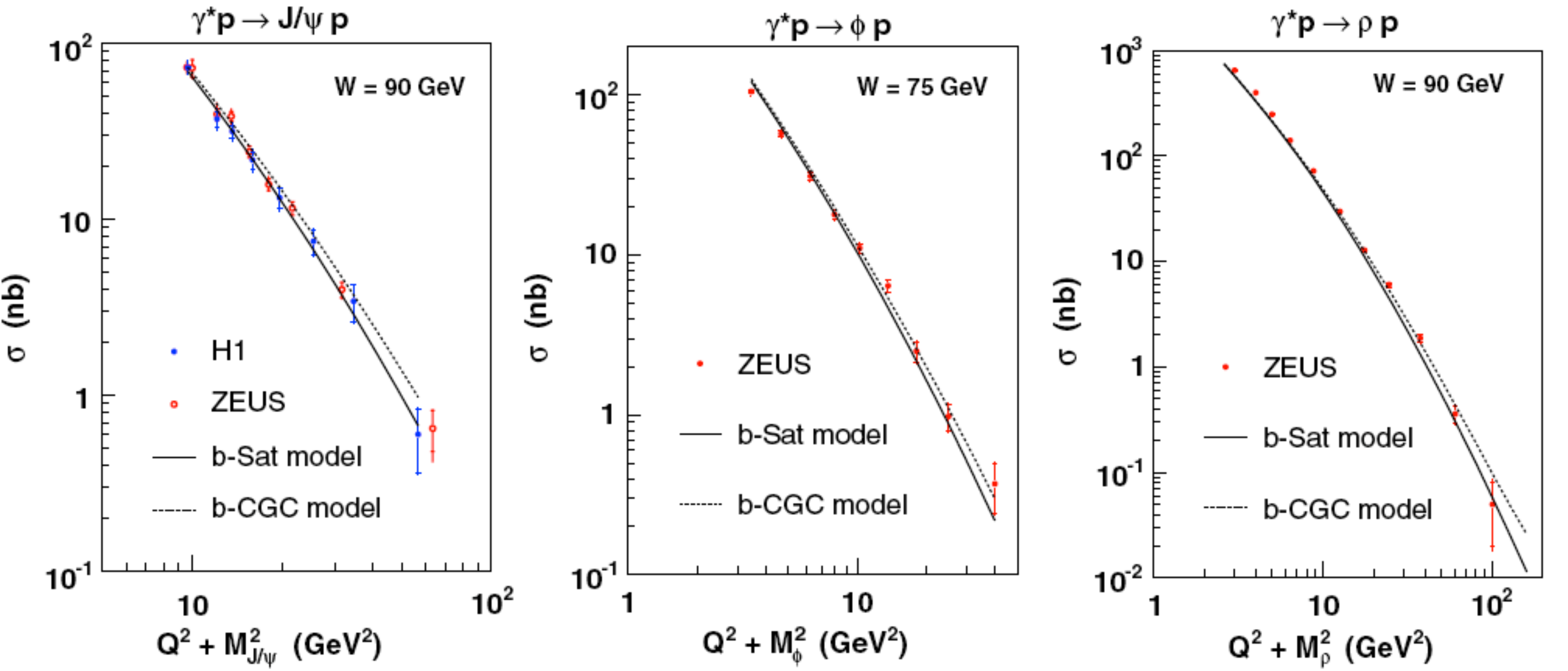
$$\sigma_{tot}^{\gamma^* p} = \int \Psi^* \sigma_{qq} \Psi$$ ← **Optical Theorem** → $$\frac{d\sigma^{\gamma^* p \to Vp}}{dt} \sim \left| \int d^2b \, \Psi_V^* \Psi e^{-i\vec{b}\cdot\vec{\Delta}} \frac{d\sigma_{q\bar{q}}}{d^2b} \right|^2$$

$$\frac{d\sigma_{q\bar{q}}}{d^2b} \sim r^2 \alpha_S x g(x, \mu^2) T(b)$$ **for small gluon density**

The same, universal, gluon density describes the properties of many reactions: F_2, F_L, inclusive diffraction, exclusive J/Psi, Phi and Rho production, DVCS, diffractive jets

Vector Mesons

KMW
PRD 74 074016
PRD 78 014016

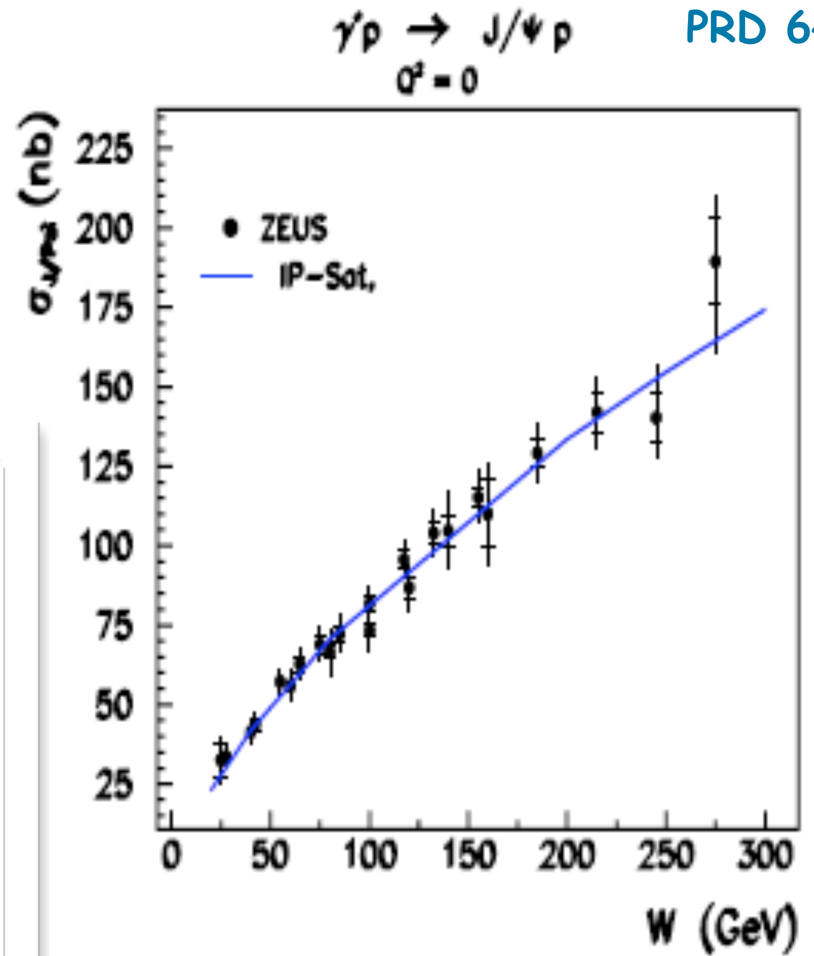


Note: educated guesses for VM wf are working very well

In focus: Exclusive J/psi production

KT
PRD 64 114005

educated guess for VM wf is working very well for J/psi and phi and DVCS

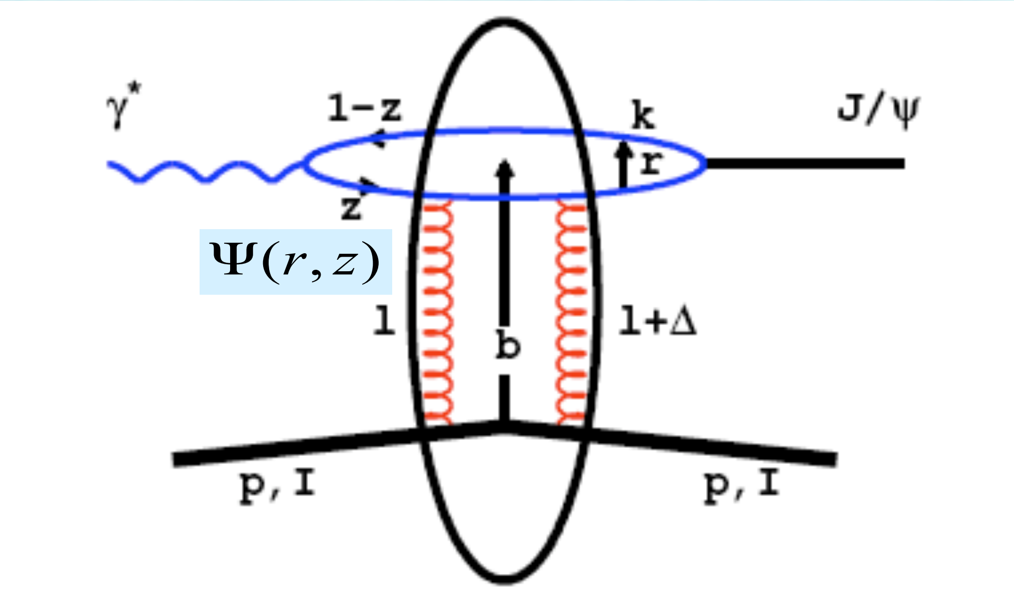


equally good description of Q2 and σ_L/σ_T dependences for J/psi and phi and DVCS

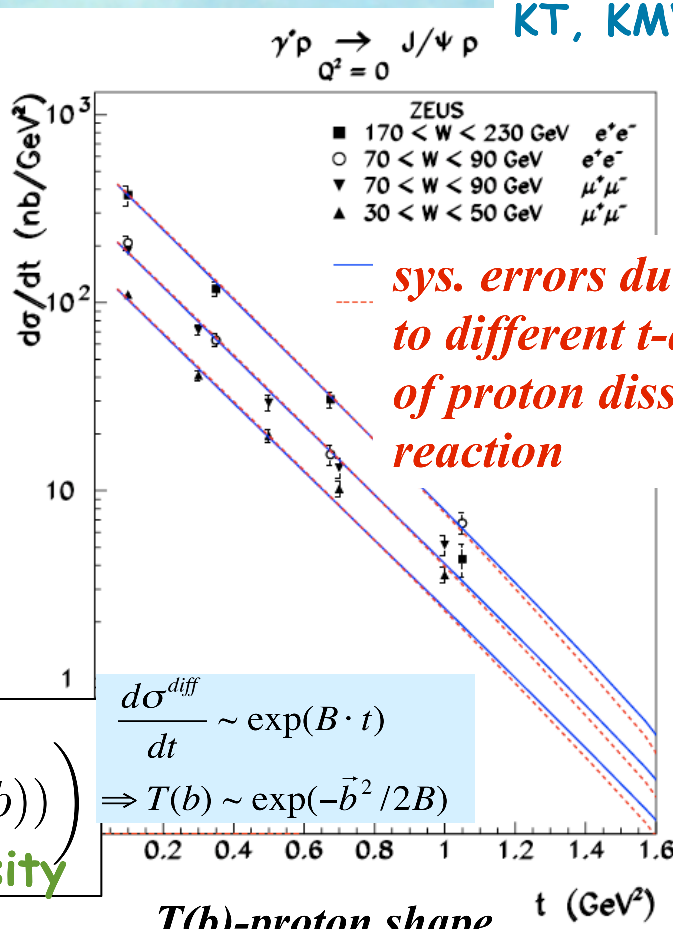
Note:
J/psi x-section grows almost like
$\sigma \propto (x\, g(x,\mu^2))^2$
no valence quarks contribution

➤ **the determination of gluon density with J/psi would be more precise than by F_2 or F_L (MRT) if J/psi would have small systematic errors**

Extracting Proton Shape using dipoles



KT, KMW



sys. errors due to different t-dep. of proton diss. reaction

$$\frac{d\sigma^{diff}}{dt} \sim \exp(B \cdot t)$$

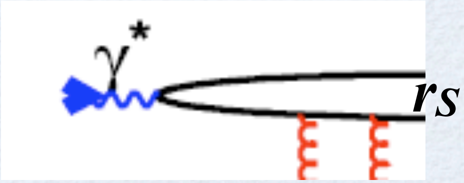
$$\Rightarrow T(b) \sim \exp(-\vec{b}^2/2B)$$

$$\frac{d\sigma_{qq}}{d^2b} = 2\left(1 - \exp(-\frac{\pi^2}{2N_C} r^2\, \alpha_s(\mu^2)\, xg(x,\mu^2)\, T(b))\right)$$

for larger gluon density

T(b)-proton shape

v.g. description of B for all VM and DVCS with the same wf ansatz
➡ determination of the gluonic proton radius, r_{gg} = 0.6 fm is smaller than the quark radius r_p=0.9 fm



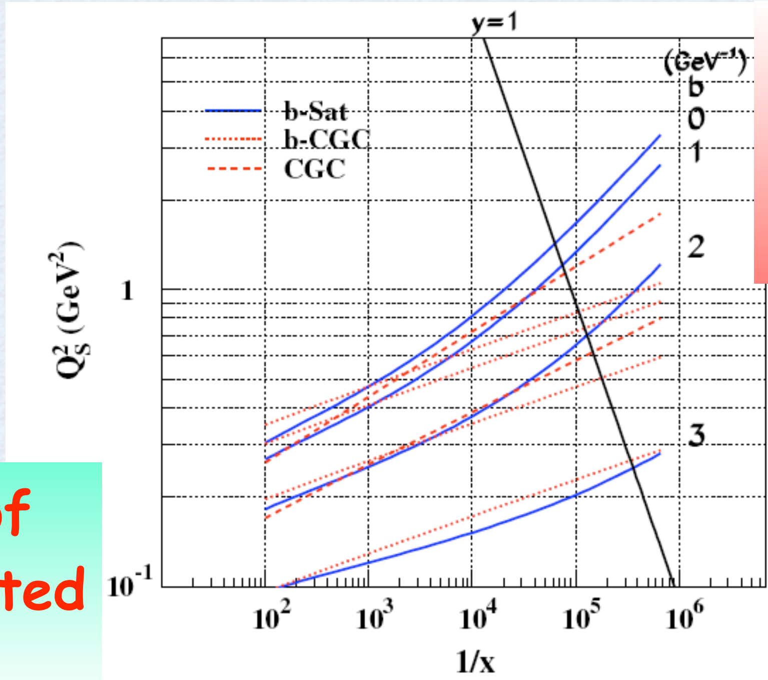
Saturation

Saturation of gluon density is characterized by the size of the dipole, r_S which, at a given x, starts to interact multiple times

$$\frac{d\sigma_{q\bar{q}}}{d^2b} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_C} r^2 \alpha_s \, xg(x,\mu^2) T(b)\right)\right] = 2(1 - \exp(-1/2))$$

Saturated gluons form a new state of matter, CGC?

$$Q_S^2 = 2/r_S^2$$



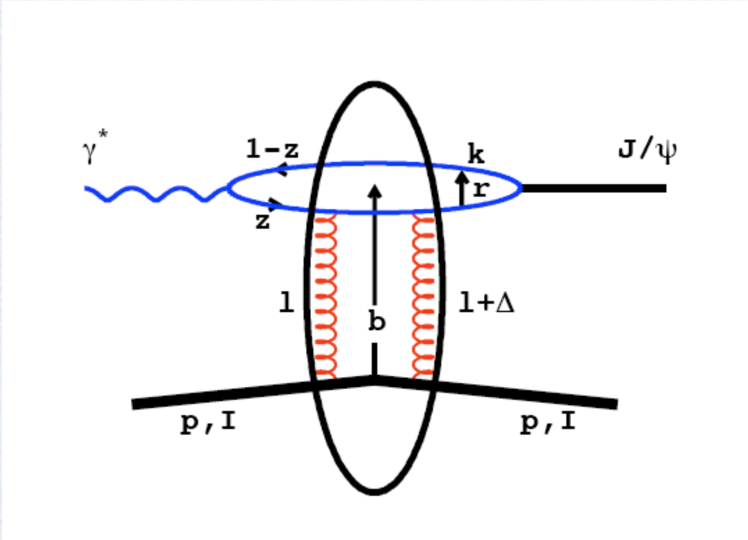
$(Q_S)^2$ =
0.5 GeV^2 at x=10^{-3}
0.8-1.8 GeV^2 at x=10^{-5}
$(Q_{S\text{-}LHC})^2$ = 9/4 $(Q_{S\text{-}HERA})^2$

$A^{1/3}$ increase of saturation expected in nuclei

strong correlations expected between momenta of saturated gluons

CMS correlation?

J/ψ p_T resolution at EIC or LHeC



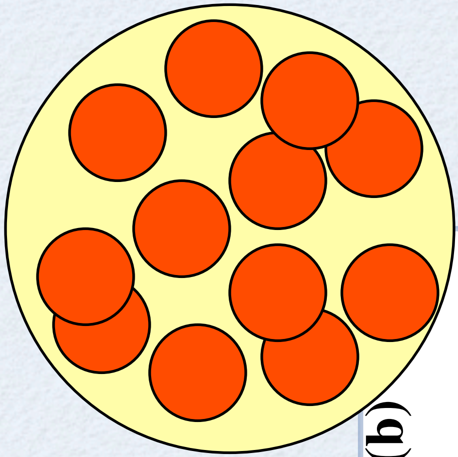
In photoproduction, J/psi p_T is determined from p_T of ee or μμ decay pair

p_T resolution for J/psi - O(1) MeV for a TPC with 2m radius

no measurement of a proton or ion momentum necessary

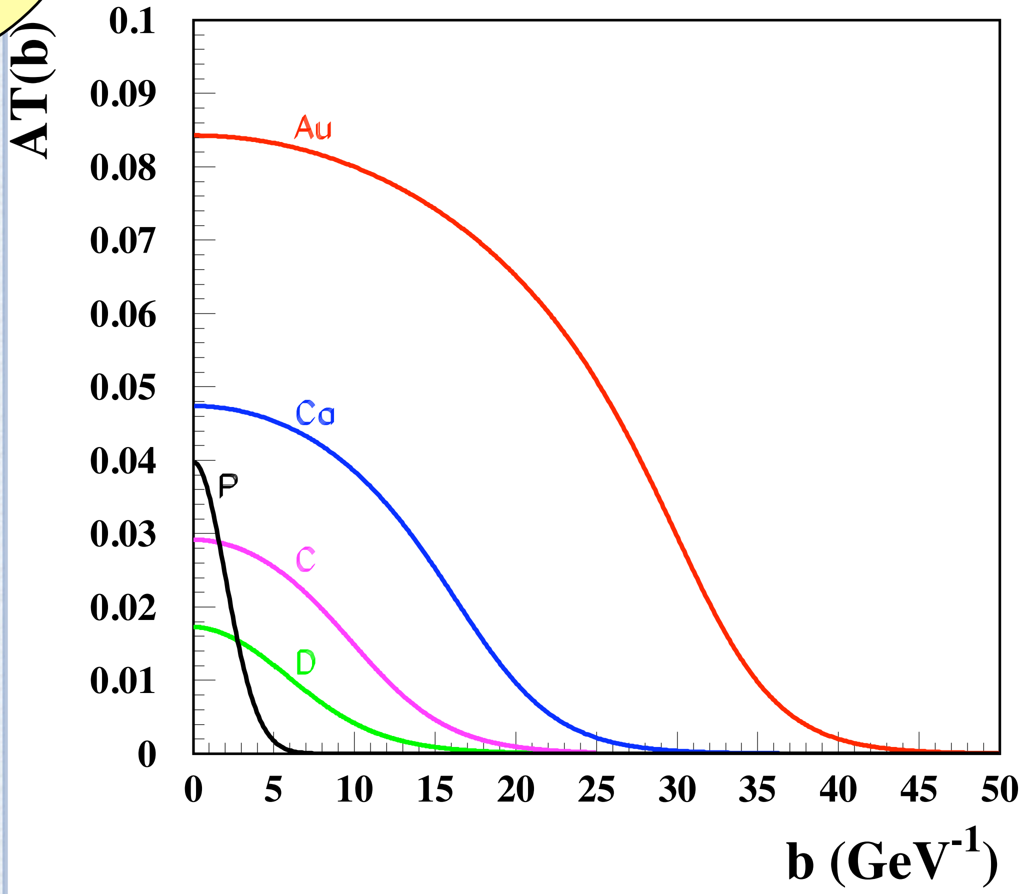
beam electron p_T < 1 MeV (0.2 with cooling MeV) for E_e < 5 GeV

scattered electron can be easily detected in the forward detector



$$\frac{d\sigma_{q\bar{q}}}{d^2b} = 2\left[1-\left(1-\frac{T_A(\mathbf{b})}{2}\sigma^{p}_{q\bar{q}}\right)^{A}\right].$$

Glauber approach

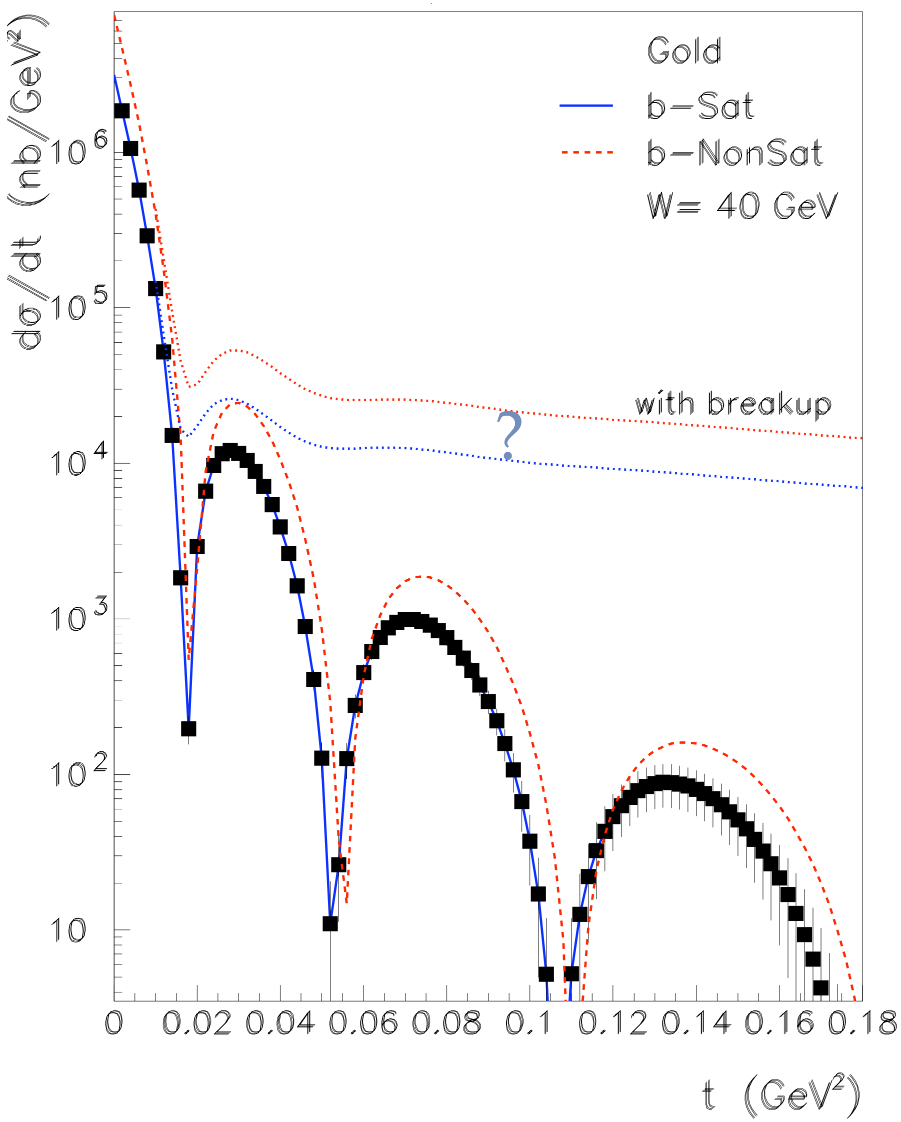


Nuclear gluonic shapes
Coherent and incoherent eA → J/ψA

Dipole projectiles are excellent tools to investigate nuclear matter

measurement precision matches the precision of nuclear physics experiments

AC, HK, PRC 81 025203 (2010)



σ_{diff} and σ_{tot} approach saturation in a different way

sensitivity increase due to

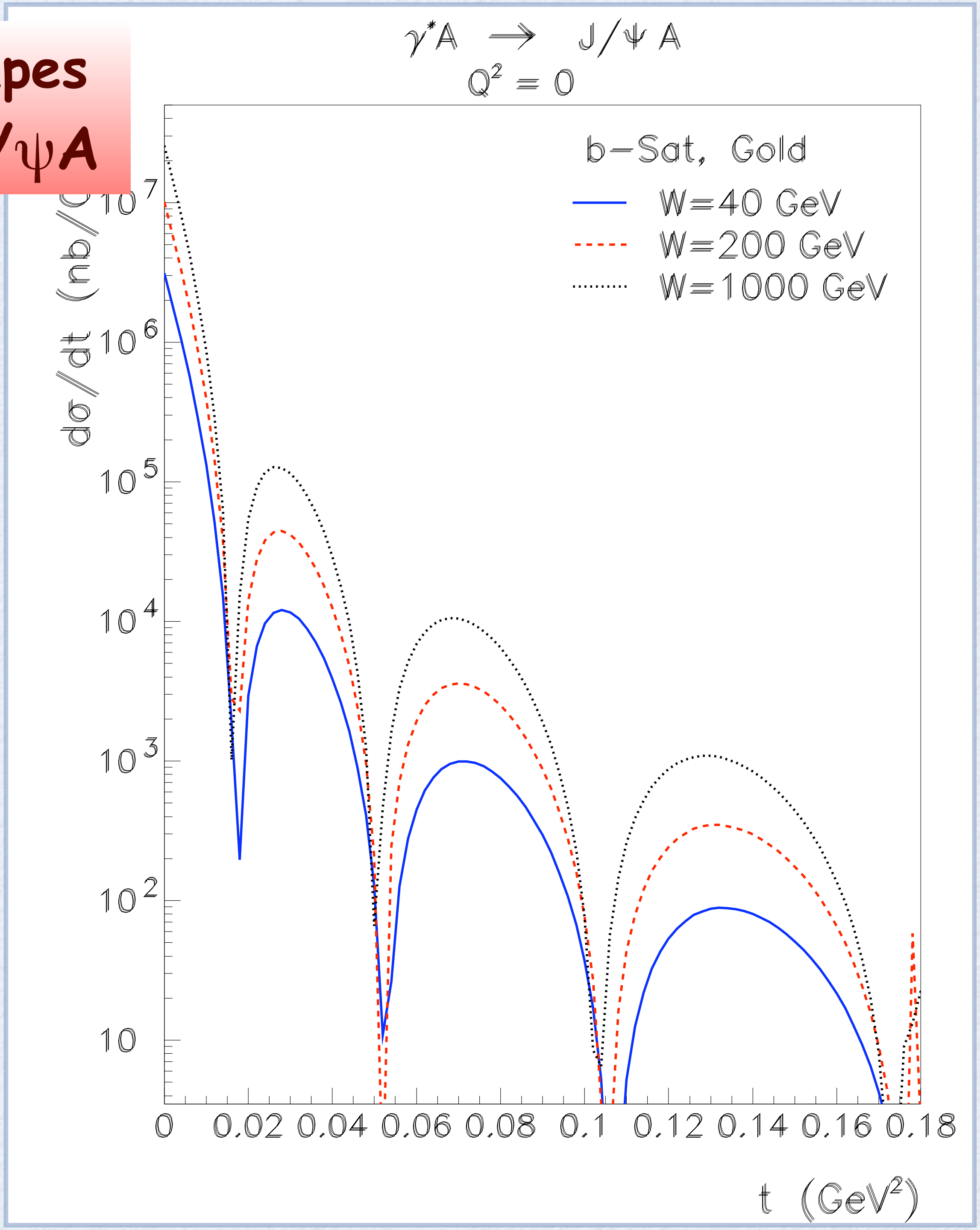
$d\sigma_{diff}/dt \propto (x\, g(x,\mu^2))^2$

and

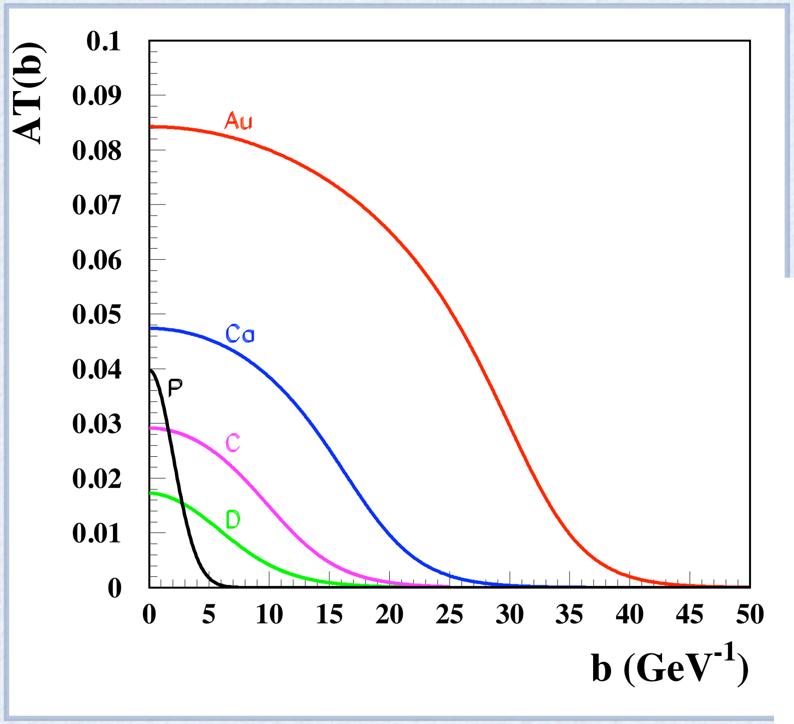
$d\sigma_{diff}/dt|t=0 \sim A^2$

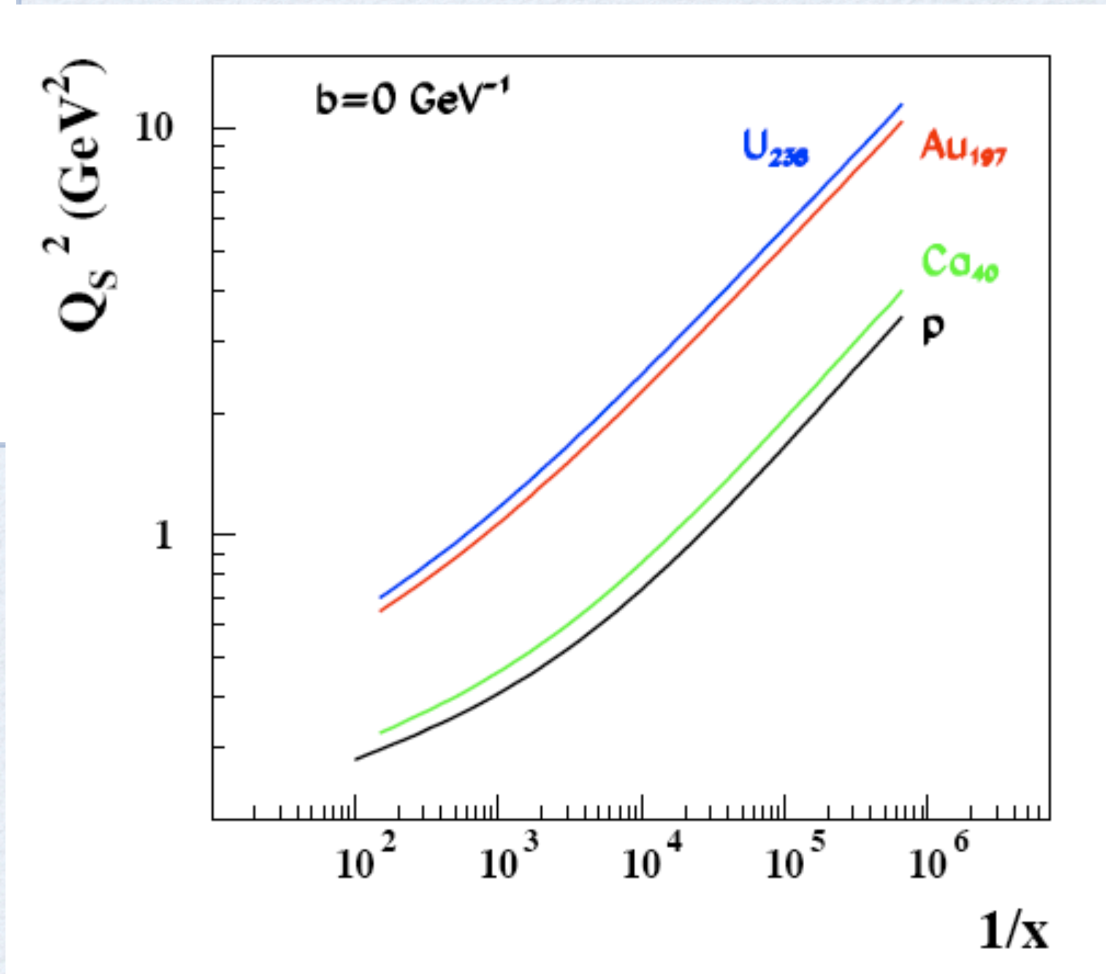
$\sigma_{tot} \sim A$

Nuclear gluonic shapes coherent eA → J/ψA



Saturation scale in nuclei

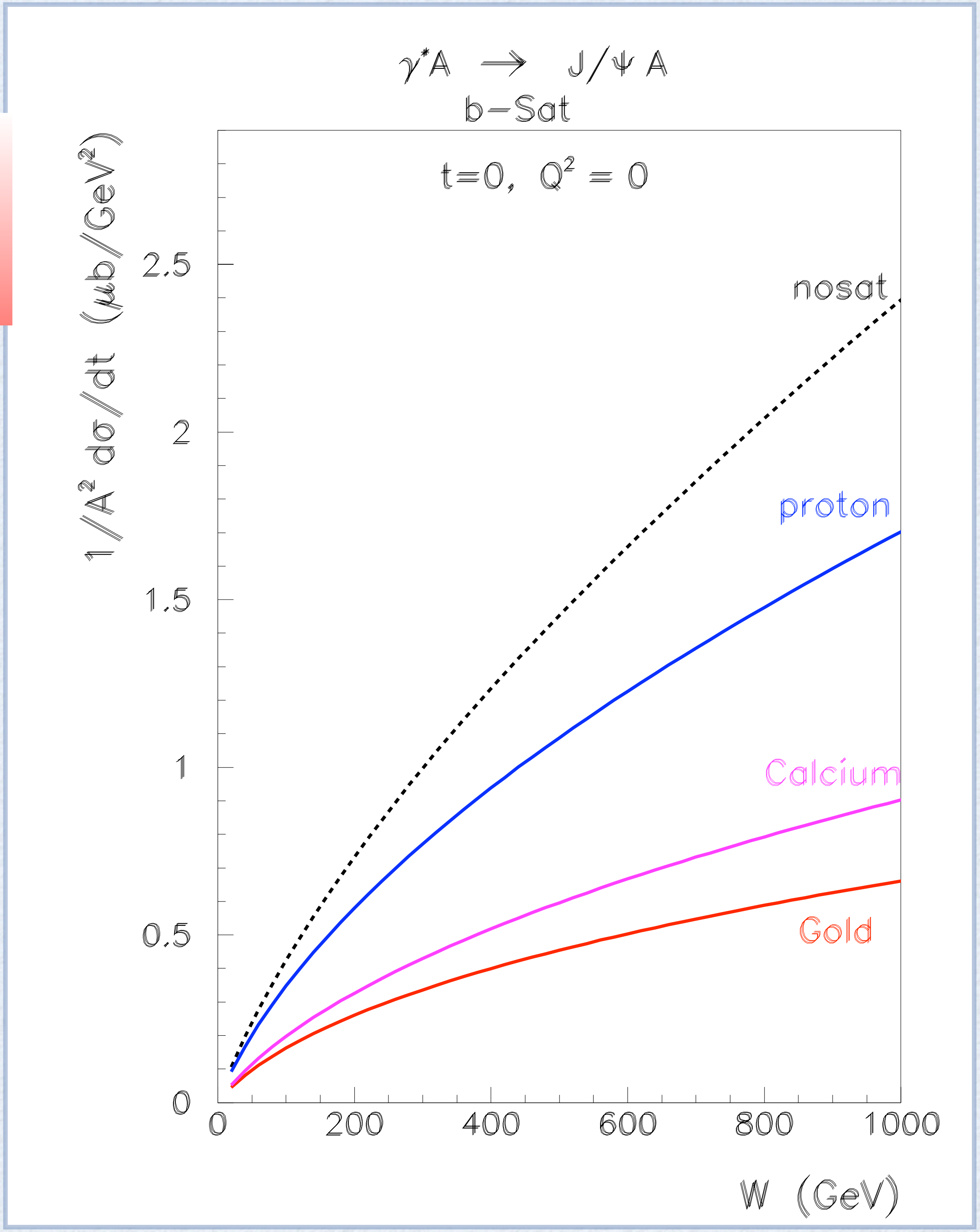




Exclusive, Diffractive J/psi production at t=0

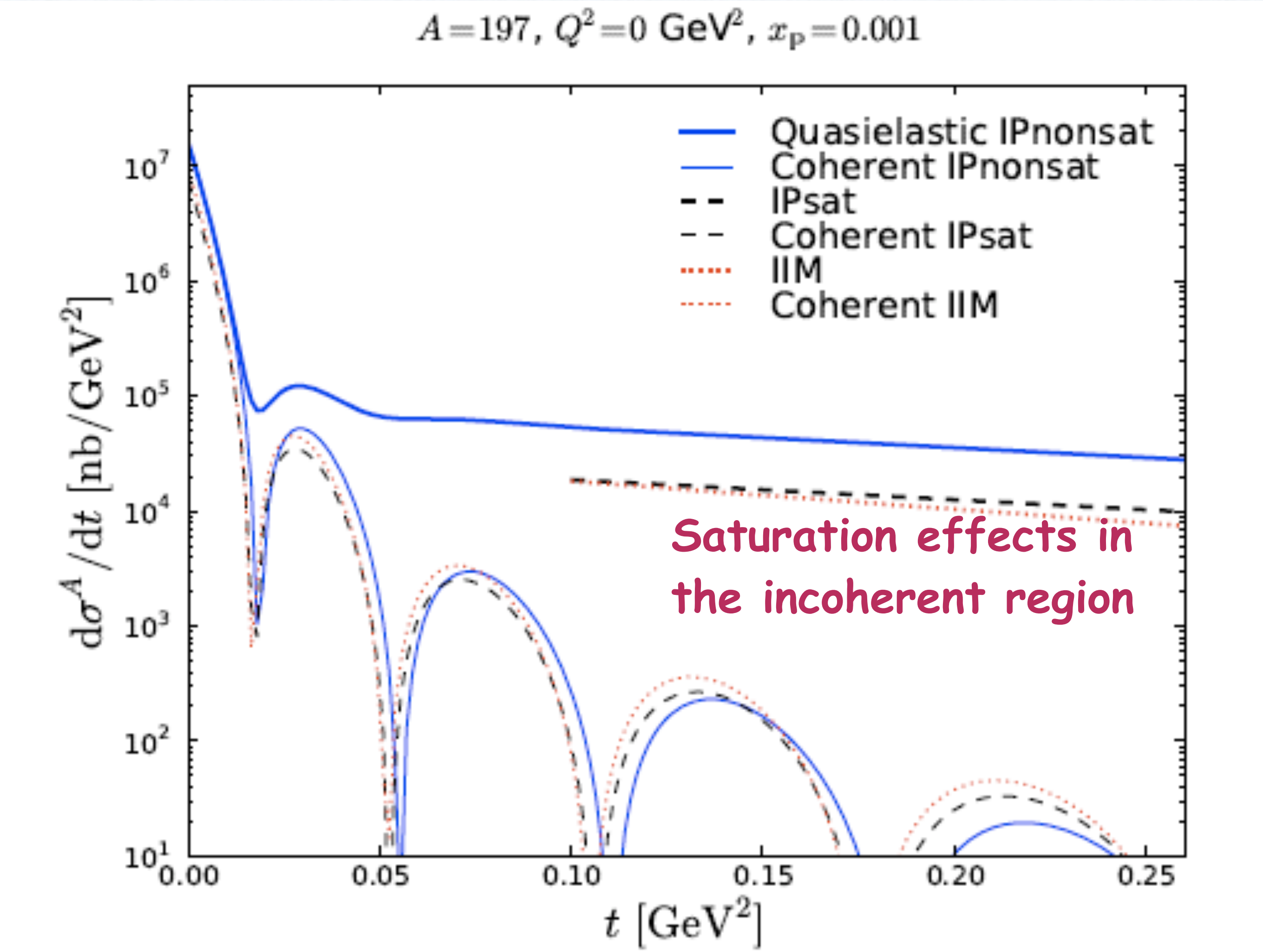
Large saturation or shadowing effects on nuclei

consistent with KLV - PRL 100 022303

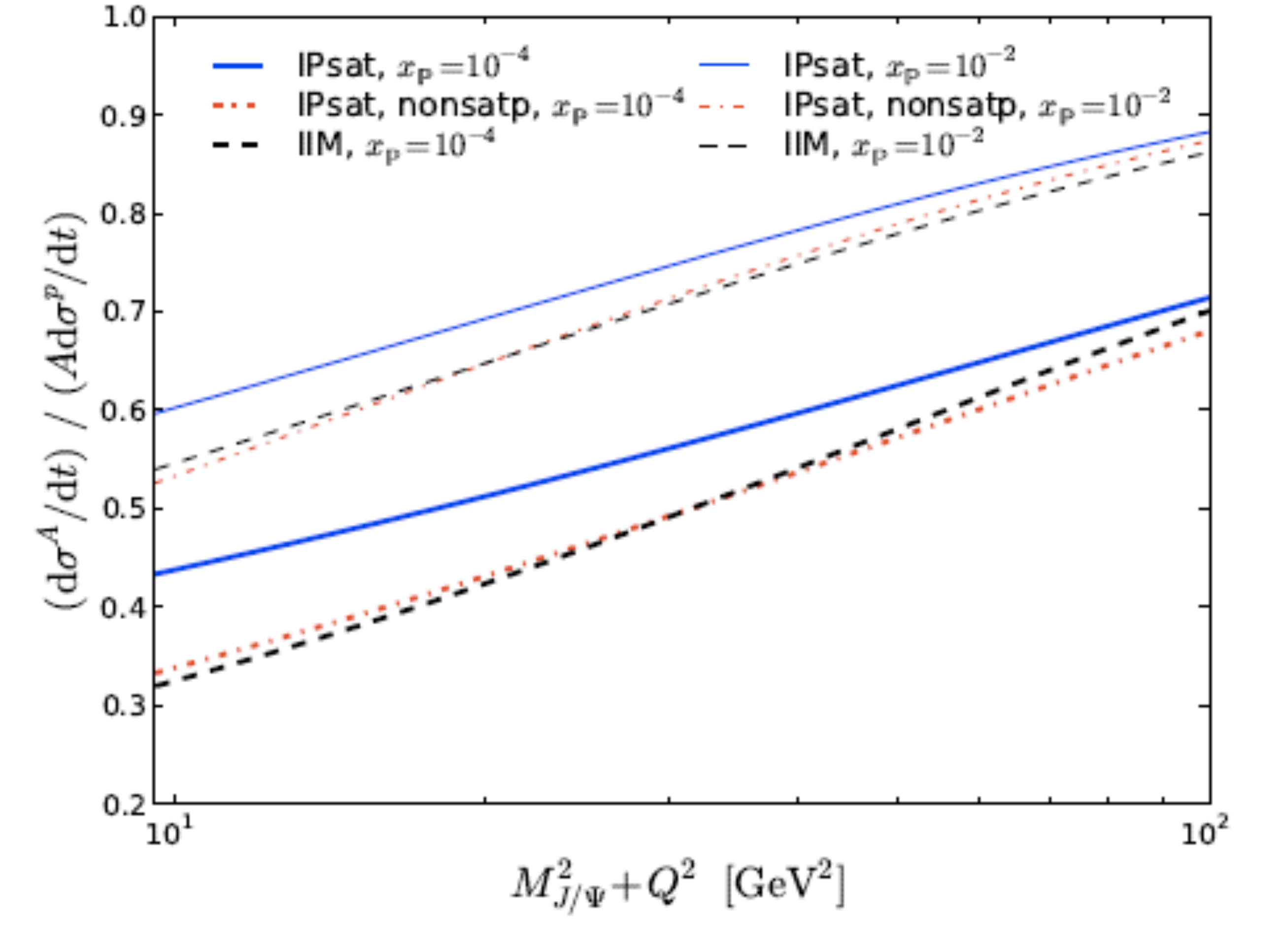


T. Lappi[1,2] and H. Mäntysaari[1]

arXiv 1011.1988

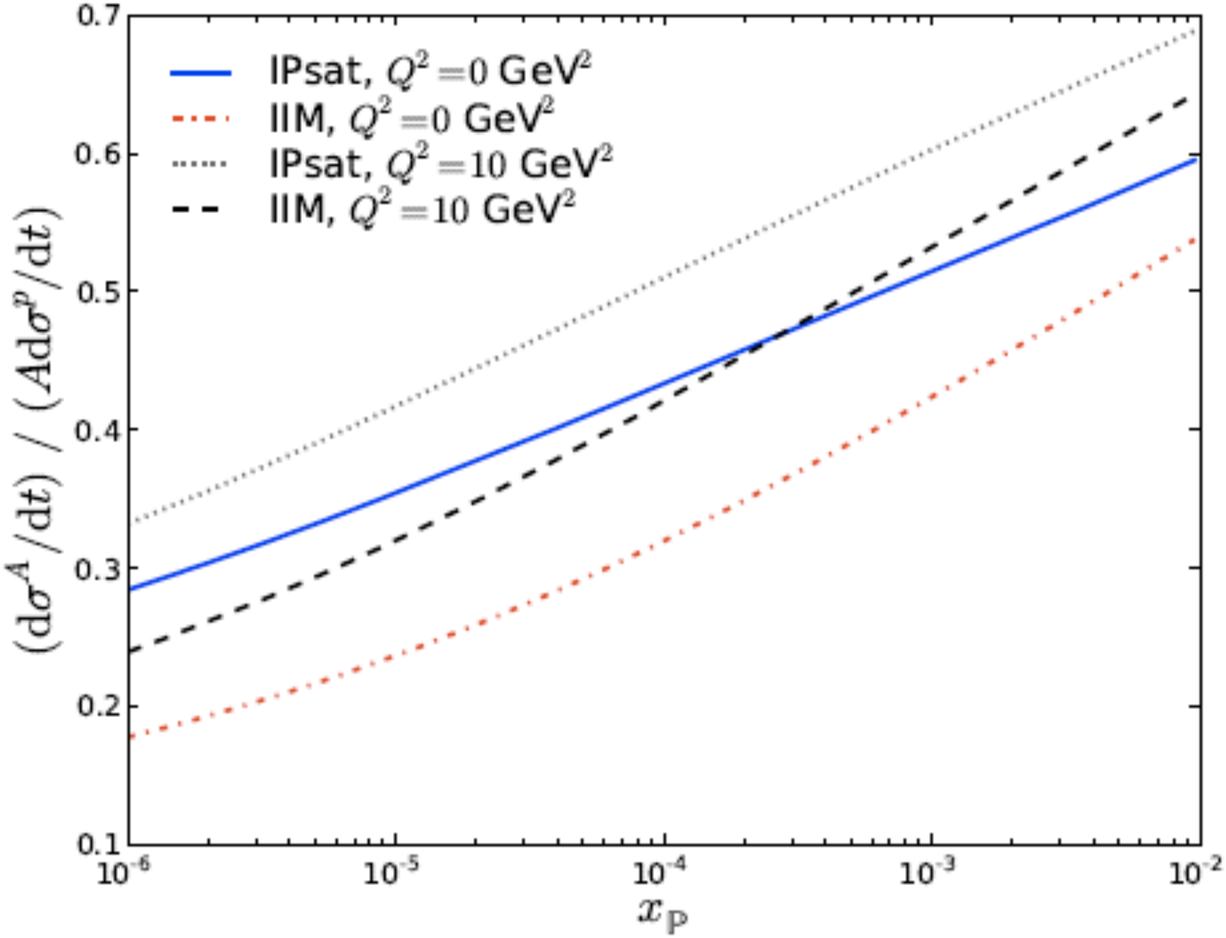


Gold, t=0.5 GeV^2



Large nuclear transparency or saturation effects on nuclei

Gold, t=0.5 GeV^2



Conclusions

Precise determination of the gluon density is necessary to fully exploit the LHC physics potential

As in the case of black body radiation, precise GD will allow to determine what is the space of states of the gluonic field

The nuclear measurements will give access to the substantially enhanced gluon saturation effects. They show up clearly as a function of W, t and A. Clear observation of saturation allows the study of properties of the strong gluonic fields.

Backup

Requirements

main source of information about GD today: F_2, F_2^{charm}
best signatures: F_L , diffractive processes (J/Psi...) and long range correlations

example: exclusive J/psi photoproduction,
x-section for J/psi → ee or μμ is O(1) nb
the statistical errors of ~1% would require L = 1fb^{-1}
→ expected # events O(10^6)

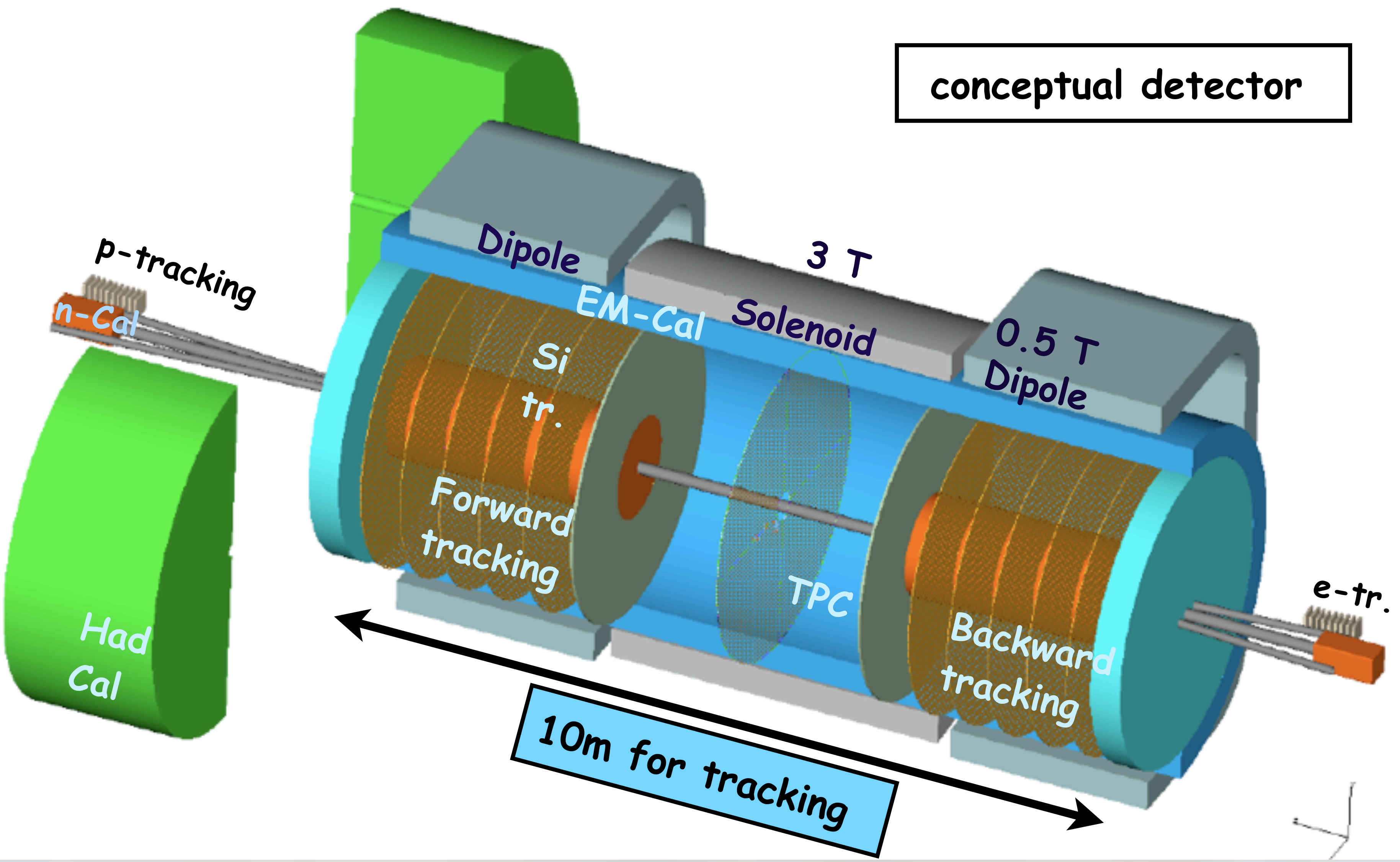
requirement: no systematic errors due to missing proton remnant,
good momentum resolution for J/psi measurements
in O(10) units of rapidity (HERA had ~2)

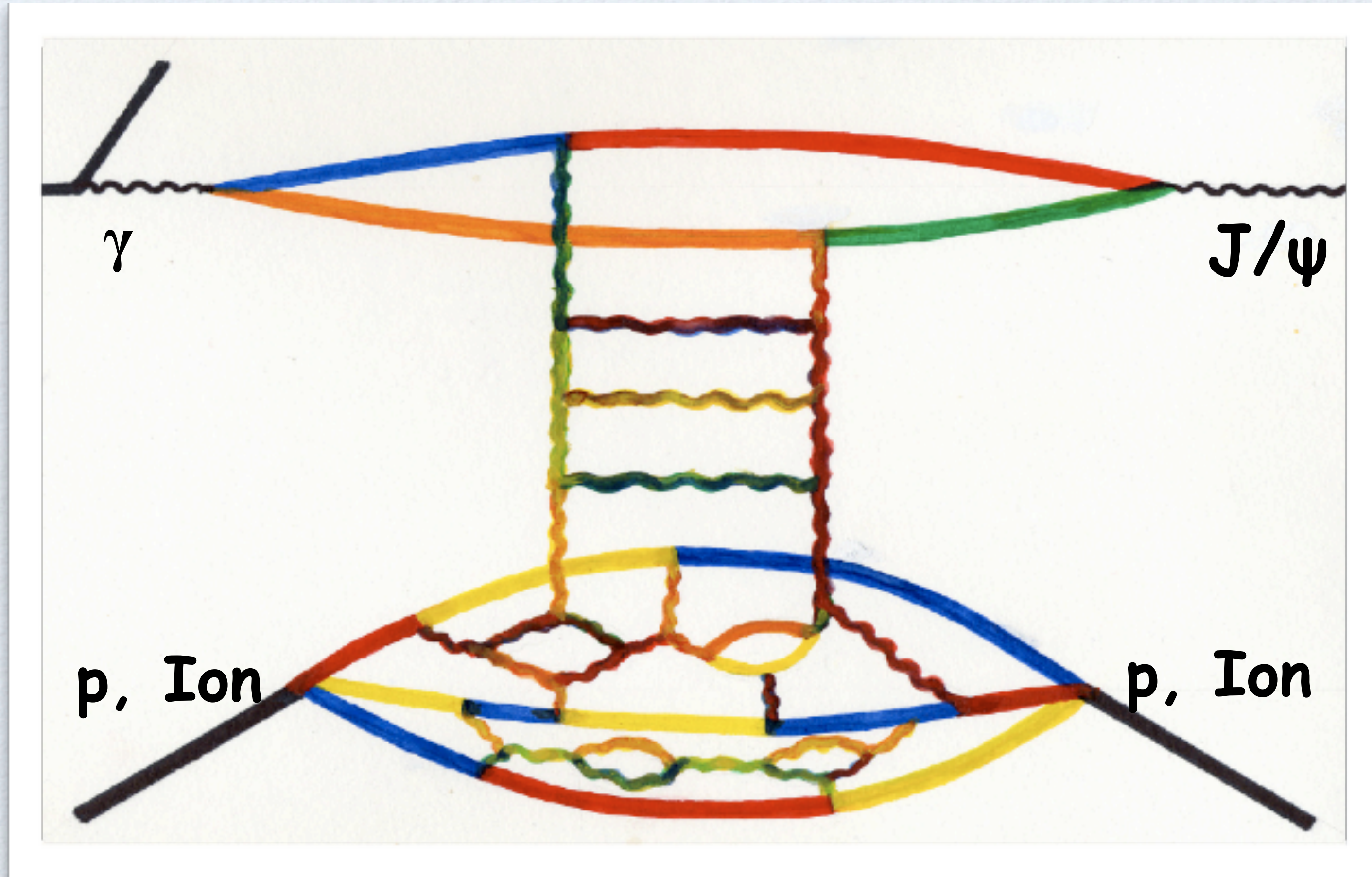
→ detector should cover the full rapidity range with tracking and/or calorimetry

Such a detector can also measure very well F_L, all other diffractive processes and long range correlations
Note: particle identification is of secondary importance → lower cost

BAGHERA

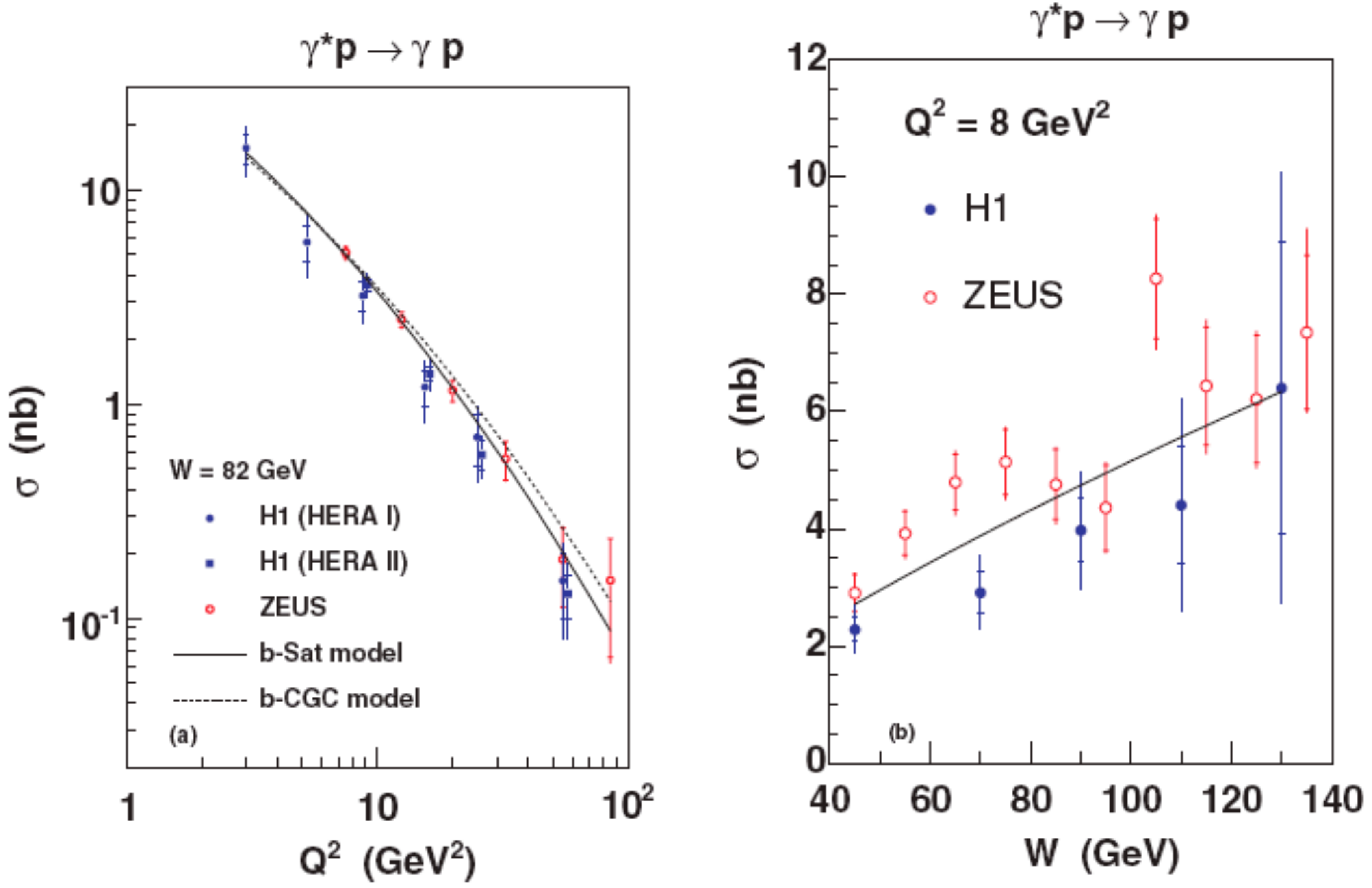
Best Acceptance for Gluons at HERA




γ
J/ψ
p, Ion
p, Ion

DVCS

KMW



γ*p → γ p
σ (nb)
10
1
10^-1
W = 82 GeV
H1 (HERA I)
H1 (HERA II)
ZEUS
b-Sat model
b-CGC model
(a)
1
10
10^2
Q^2 (GeV^2)
γ*p → γ p
Q^2 = 8 GeV^2
H1
ZEUS
(b)
0
2
4
6
8
10
12
40
60
80
100
120
140
W (GeV)

Measurement of momenta of J/ψ decay muons

Expected resolution of drift chambers:

$$(\sigma_{p_t}/p_t)_{meas} = \frac{p_t\,\sigma_{r\phi}}{0.3L^2B}\sqrt{\frac{720}{N+4}}$$

$$(\sigma_{p_t}/p_t)_{MS} = \frac{0.05}{LB\beta}\sqrt{1.43\frac{L}{X_0}}[1+0.038\log(L/X_0)]$$

TPC parameters

1. outer radius R = 2 m
2. solenoidal field B = 3.5 T
3. gas density X_0 = 450 m
4. point resolution σ = 100 μm
5. measurement N = 200 points.

meas *MS*

$$\sigma_{p_t}/p_t = 0.005\cdot p_t \oplus 0.045/\beta\ \%$$

⇓

Δp_T < 1 MeV with p_T =2 GeV