WG2: Summary

Small-x, diffraction and vector mesons

Mario Deile, Lidia Goerlich, Stéphane Munier

Overview of the theory talks

- *Formal developments at small-x*

Next-to-... eikonal	Altinoluk
Next-to-... leading log 1/x	Mulian, Beuf (review) ; Deak
Making contact with large-x	Besse (review)
Strong coupling calculations	Kutak, Djuric

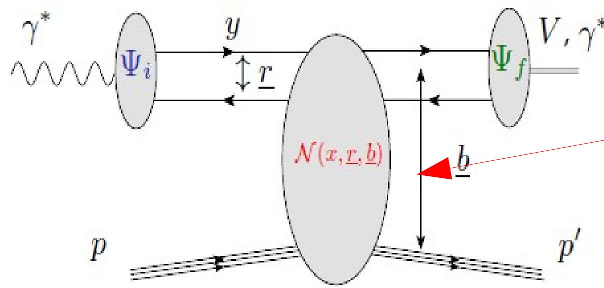
- *Phenomenology from HERA to LHC*

Dipole models	
Inclusive ep	Kowalksi
J/ψ *photo- and hadroproduction*	Rezaien
$pp \to \pi^0 X$ *, ultraperipheral* $AA \to J/\psi$	Mantysaari (x2)
k_T*-factorization*	
Mueller-Navelet jets	Ducloué, Maciula
Forward jets	Kotko
J/ψ *photo- and hadroproduction*	Cisek, Motyka
Higgs production	Szczurek
Exclusive muon pair via photon fusion in pp	Schaefer
Soft diffraction *	Lebiedowicz, Goulianos
Central exclusive production processes *	Khoze (Review)

Formal developments at small x
Standard "leading-order" picture

Example: *electroproduction of vector meson/DIS* (From the review of Besse)

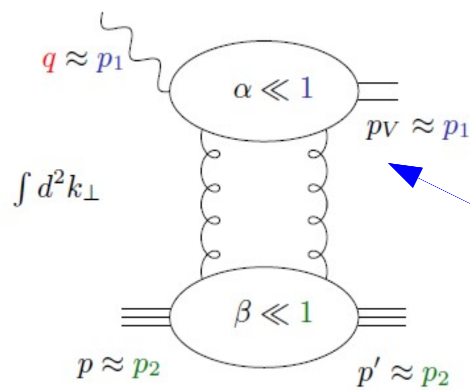
Dipole factorization



Dipole cross section
Model, or compute
LO: 2-gluon exchange which couple eikonally
Interaction instantaneous

$$\mathcal{M}_{\lambda_V\lambda_\gamma}(Q^2,x) = is\int dy \int d\underline{r}\, \Psi^*_{\lambda_V}(y,\underline{r})\, \Psi_{\lambda_\gamma}(y,\underline{r})\, \hat{\sigma}(x,\underline{r})$$

k_T*-factorization*



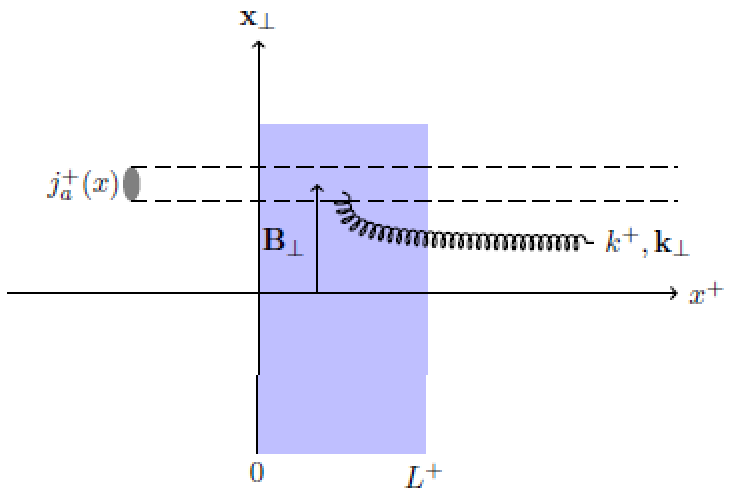
Impact factor

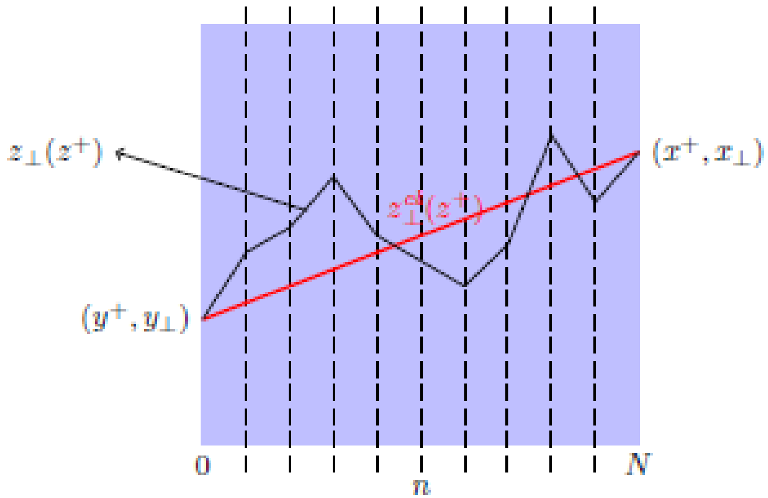
$$\mathcal{M}_{\lambda_V\lambda_\gamma} = is\int \frac{d^2\,\underline{k}}{(2\pi)^2(\underline{k}^2)^2}\,\Phi^{\gamma^*(\lambda_\gamma)\to V(\lambda_V)}(\underline{k})\ \Phi^{P\to P}(-\underline{k})$$

Formal developments at small x
Next to... eikonal

Altinoluk

Finite-width target:





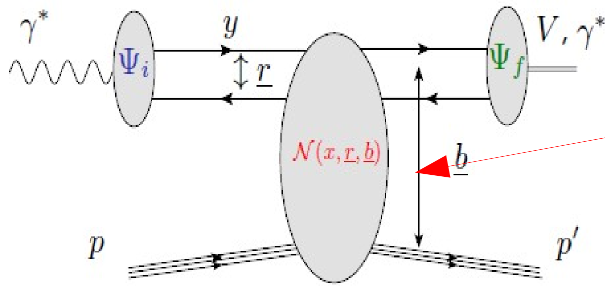
Systematic expansion of the gluon propagator in the background field in powers of the size of the target

The leading correction vanishes in the case of inclusive gluon production!

Formal developments at small x

Standard "leading-order" picture – QCD evolution

Dipole factorization

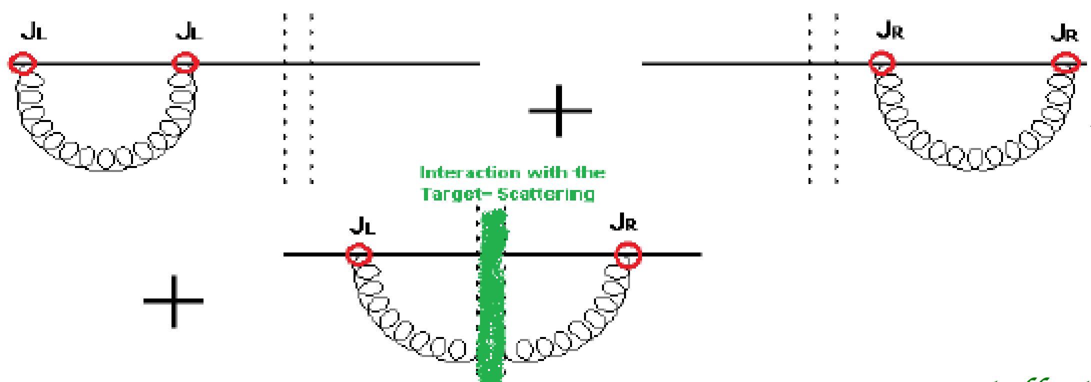


Dipole cross section
Either model, or compute

LO: 2-gluon exchange which couple eikonally

$$\mathcal{M}_{\lambda_V\lambda_\gamma}(Q^2,x) = is\int dy\int d\underline{r}\,\Psi^*_{\lambda_V}(y,\underline{r})\,\Psi_{\lambda_\gamma}(y,\underline{r})\,\hat{\sigma}(x,\underline{r})$$

LO QCD evolution: enough to add 1 gluon to wavefunction of the projectile (in all possible ways)



These graphs give the kernel of the evolution equation for the observable

$$\frac{d}{dY}\mathcal{O} = -H^{JIMWLK}_{\text{LO}}\,\mathcal{O}$$

*Full: BK/JIMWLK (nonlinear/**saturation**)*

Dilute limit: BFKL kernel (linear)

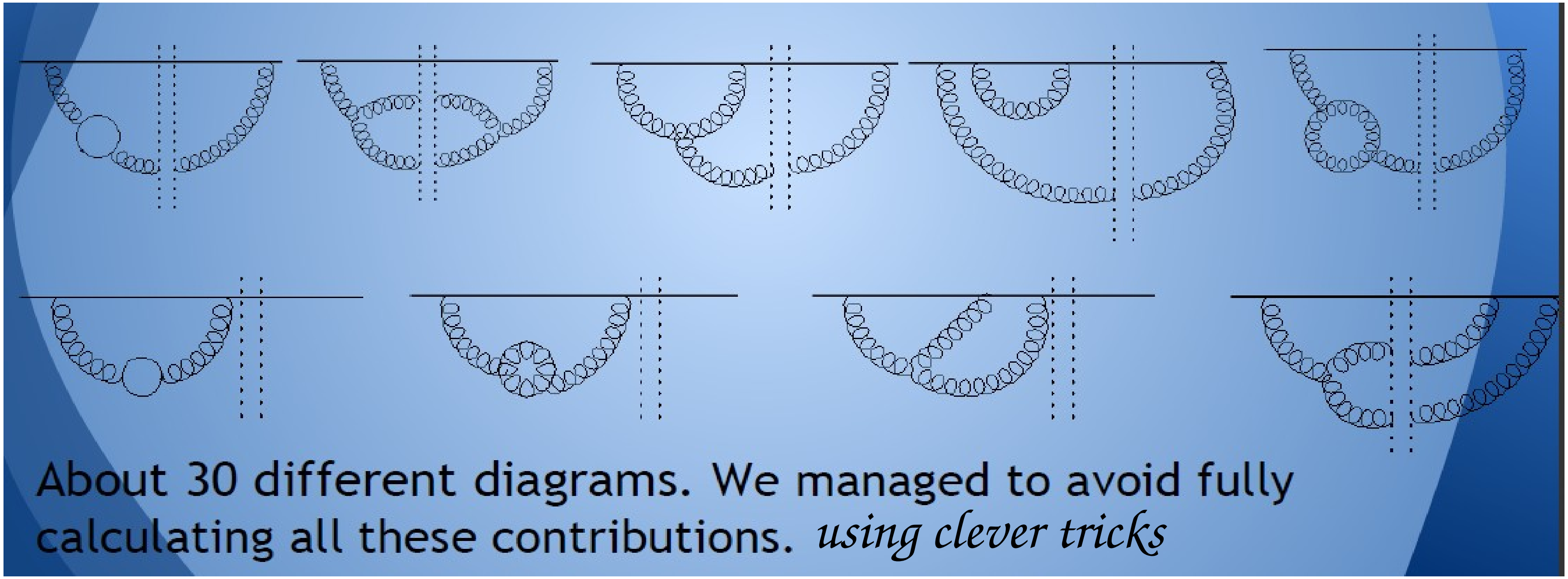
(NB: in the k_T factorization approach, promote the proton impact factor to the unintegrated gluon density)

Formal developments at small x
Next to... leading log 1/x

Mulian

NLO JIMWLK kernel: need more diagrams...

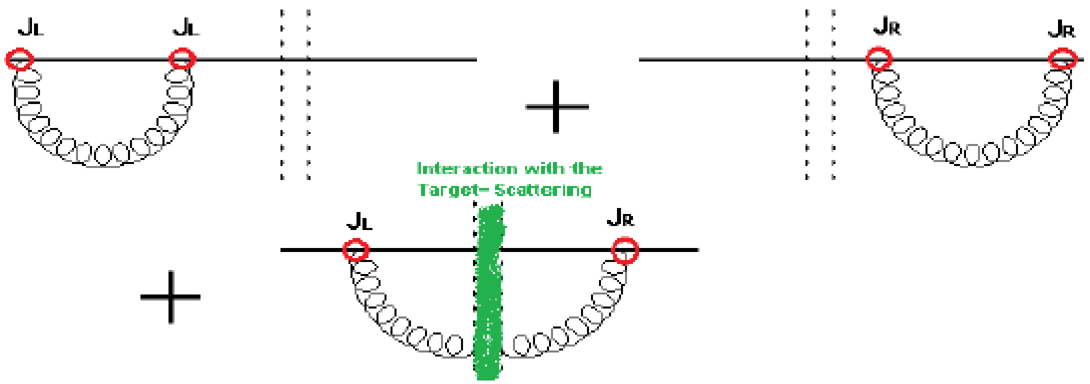
$$\frac{d}{dY}\mathcal{O} = -H^{JIMWLK}_{\text{NLO}}\,\mathcal{O}$$



Fully computed by this group!

Formal developments at small x
Next to... leading log 1/x

LO kernel: kinematics of the emitted gluon are not exact Beuf



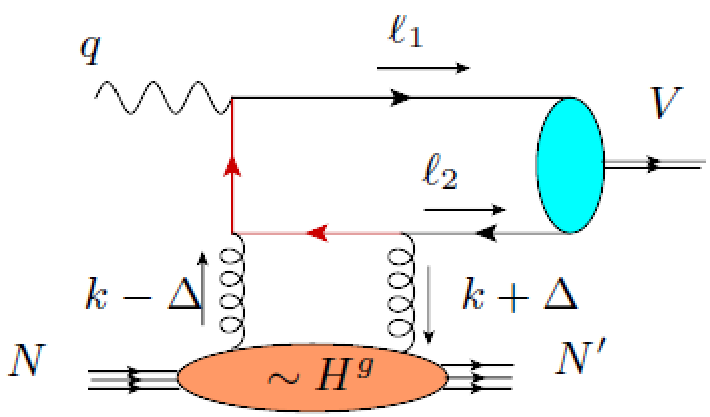
One may restore it by imposing a kinematical constraint on the gluon emission
This was know in momentum space, now it is done **in coordinate space**, *more natural for dipole formulation.*

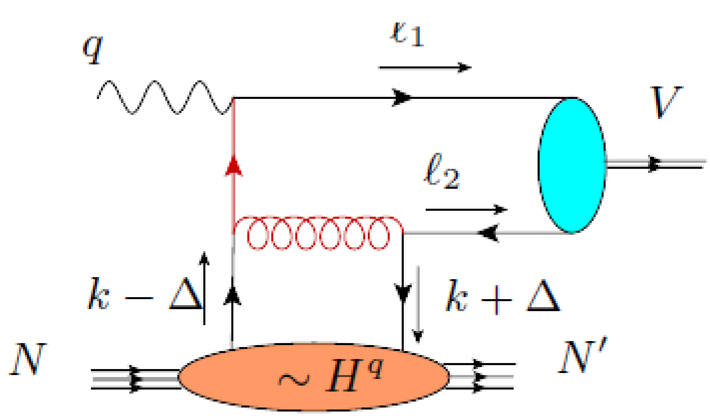
__Also:__ impact factor for heavy-quark production computed at NLO Deak

Formal developments at small x
Making contact with large-x

At large-x, the dipole factorization is a priori not true... Besse

Familiar (?) collinear factorization more appropriate!





Non-dipole graph!

But... it seems that for a particular helicity amplitude (at least), the collinear formulation exhibits the factorization of the overlap of the wavefunctions as in the dipole model picture!

Formal developments at small x
Strong coupling

The DGLAP-improved BFKL equation+kinematical constraint may be extrapolated to large coupling

Extend this procedure to the nonlinear regime:

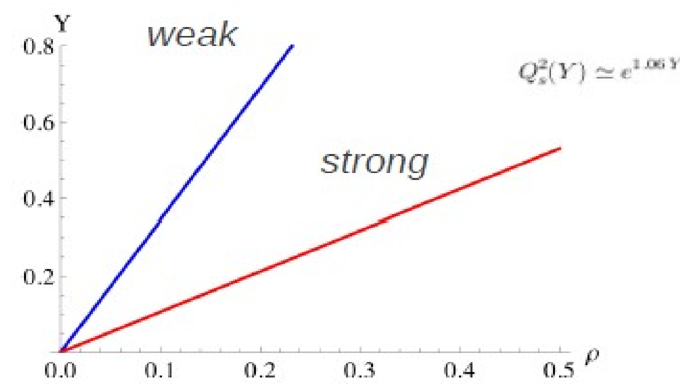
Kutak

$$\partial_Y \Phi(Y,\rho) = \frac{1}{2}\chi'_{st}\partial^2_\rho \Phi(Y,\rho) + \frac{1}{2}\chi'_{st}\partial_\rho \Phi(Y,\rho) + (\lambda_{st} + \chi'_{st}/8)\Phi(Y,\rho) - \frac{\bar{\alpha}_s}{\pi R^2}\Phi^2(Y,\rho)$$

Pomeron intercept:

$$j = 1 + \omega = 2 - \frac{c_0}{\sqrt{\bar{\alpha}_s}},$$

Saturation scale:



Smells like gravity... AdS/CFT correspondence?

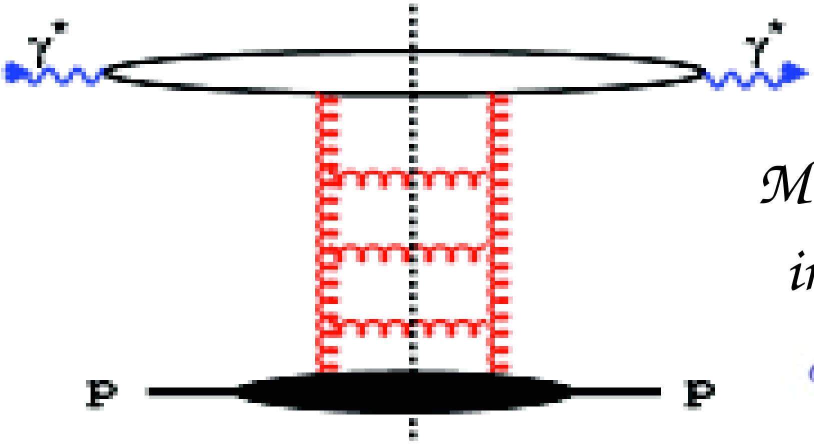
Djuric

Description of DIS observables in a strong coupling expansion using this tool.
In particular, good description of vector meson production data at HERA...
but a lot of parameters need to be fit!

Theory vs experiments
Dipole picture: from HERA...

Update of dipole fits with new HERA data...

Kowalski



Model for dipole cross section:

impact-parameter integrated IP-sat dipole model.

$$\hat{\sigma}(r,x) = \sigma_0 \left\{1 - \exp\left[-\pi^2 r^2 \alpha_s(\mu^2) x g(x,\mu^2)/(3\sigma_0)\right]\right\}$$

The precise HERA data can be very well described by the kT factorized, DGLAP evolved, gluon density evaluated within the (BGK) dipole model

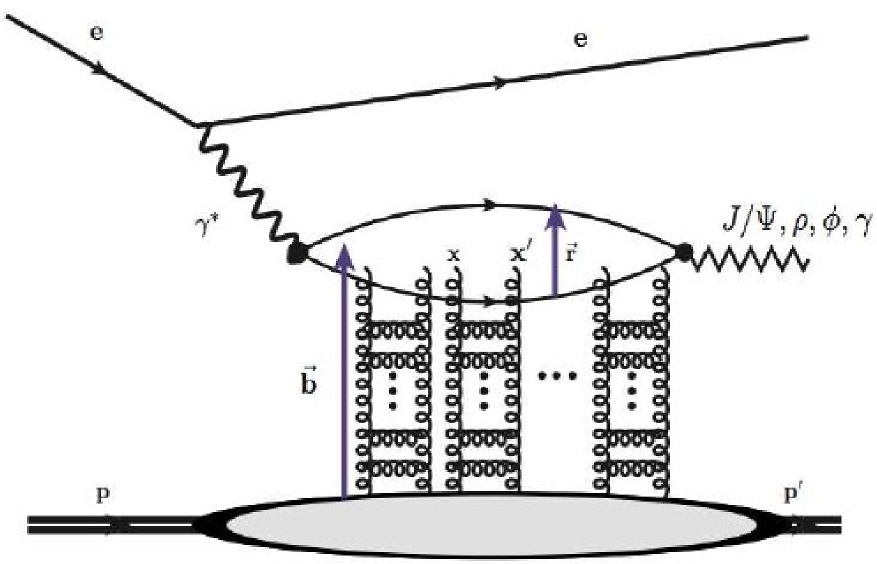
Valence quark contribution added to the dipol model (BGK) improve the fits significantly (χ^2 ↘) in comparison to fits with the pure dipole contribution

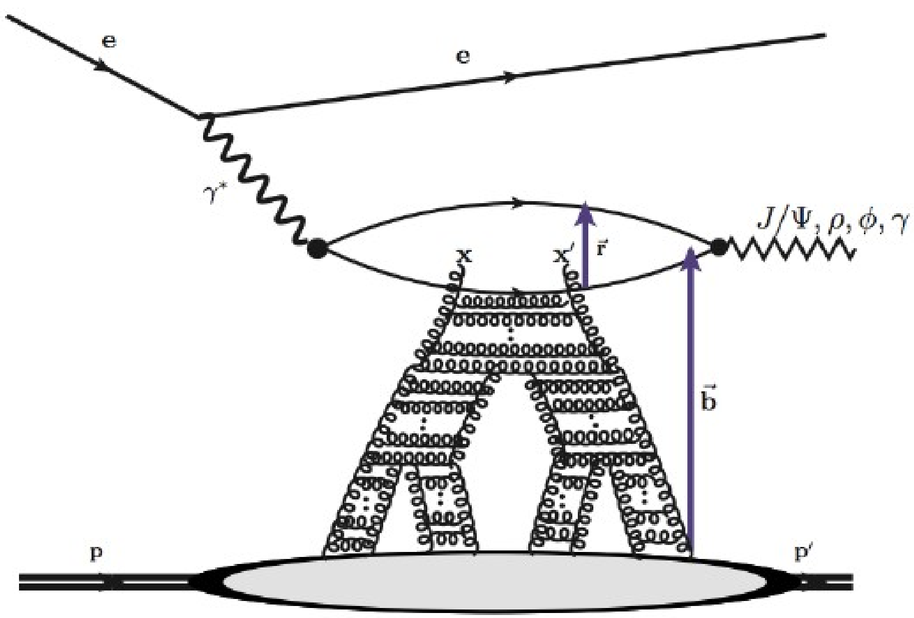
Theory vs experiments
Dipole picture: from HERA...

IP-sat *versus* b-CGC Rezaien

(Based on JIMWLK)

Example: J/ψ *electroproduction*



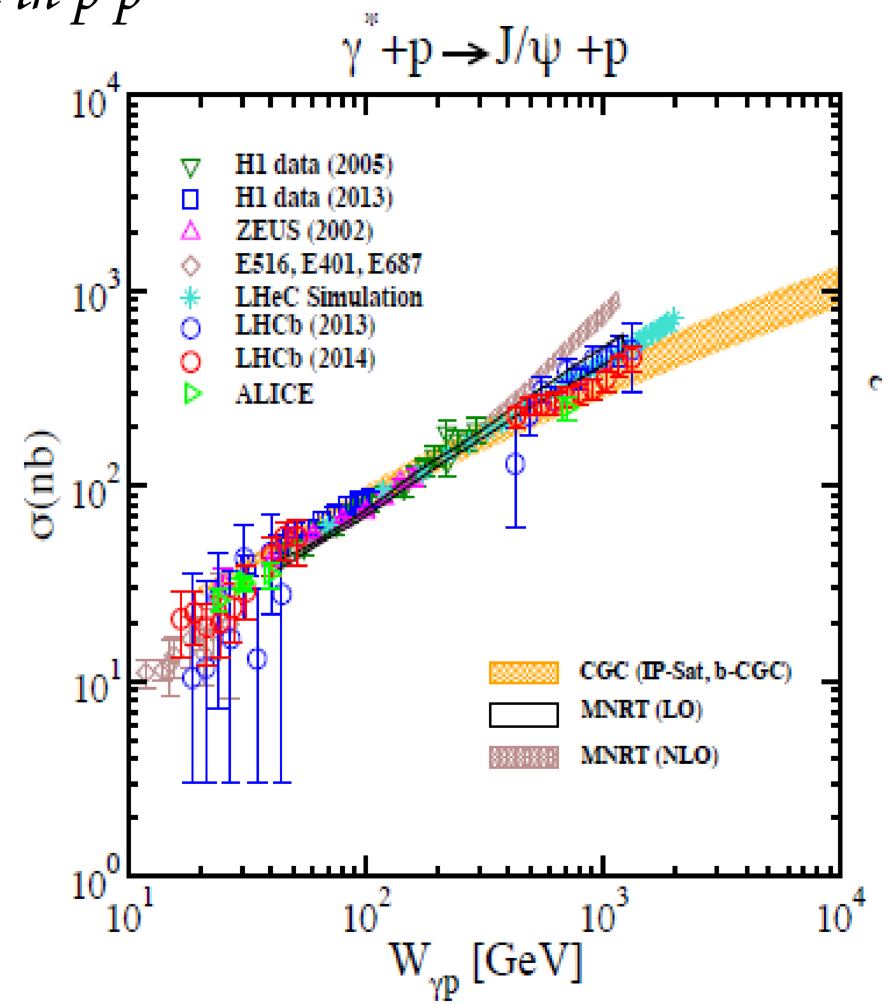


Both the b-CGC and the IP-Sat models give generally good description of all HERA data at $x \leq 0.01$ including combined HERA data:

Differences between the models show up at large t and at very small-x

Theory vs experiments
Dipole picture: ...to LHC

J/ψ *photoproduction in p p* Rezaien

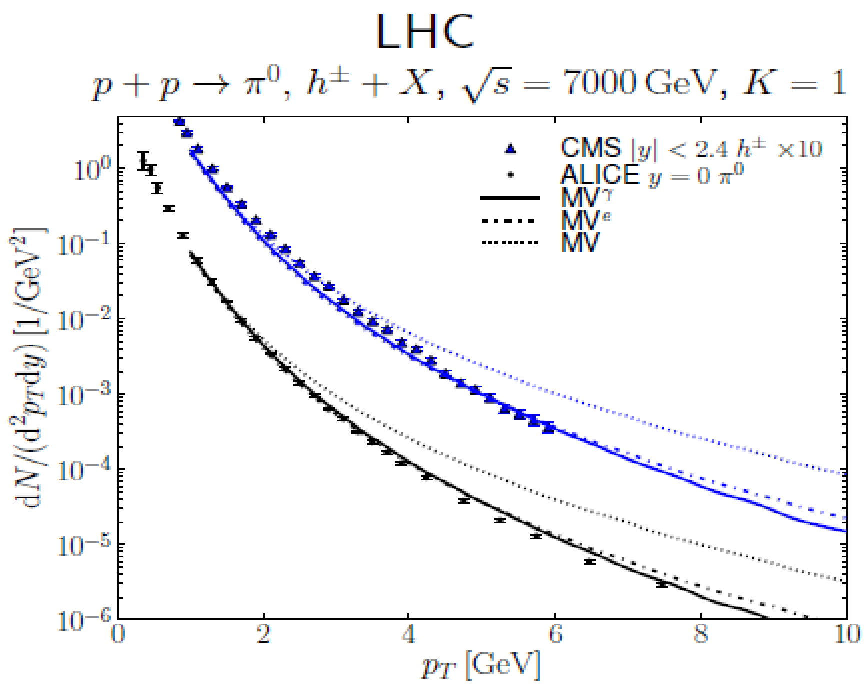


The recent LHCb data (2014) in p+p collisions for exclusive diffractive photoproduction of J/Ψ is favour of CGC/saturation predictions.

Theory vs experiments
Dipole picture: ...to LHC

Dipole model with running coupling BK evolution Mantysaari

Prediction e.g. of single hadron inclusive production



Needed to describe these data

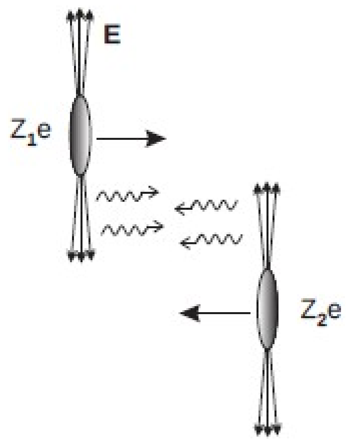
Solve rcBK with modified MV model initial condition

$$N_p(r, y=0) = 1 - \exp\left[\frac{-(r^2 Q_{sp}^2)^{\gamma}}{4} \ln\left(\frac{1}{r\Lambda_{QCD}} + e_c \cdot e\right)\right]$$

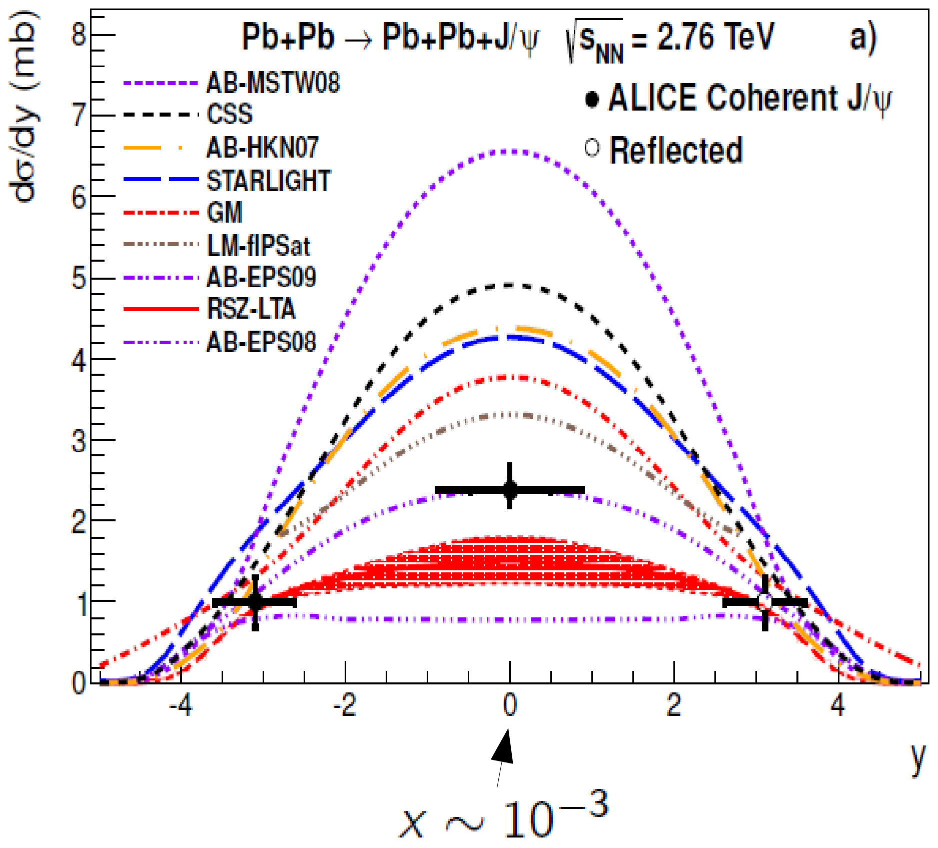
*Fit one **or** the other to HERA data*

Theory vs experiments
Dipole picture: ...to LHC

Diffractive photoproduction of J/ψ *in AA ultraperipheral collisions* Mantysaari



$\gamma A \rightarrow J/\psi A'$

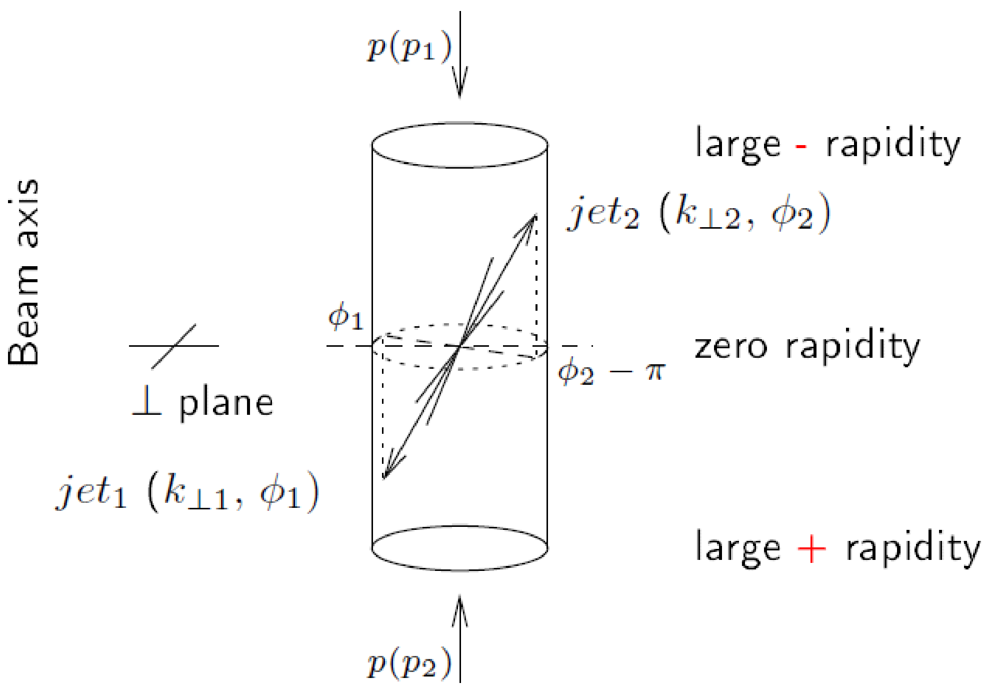


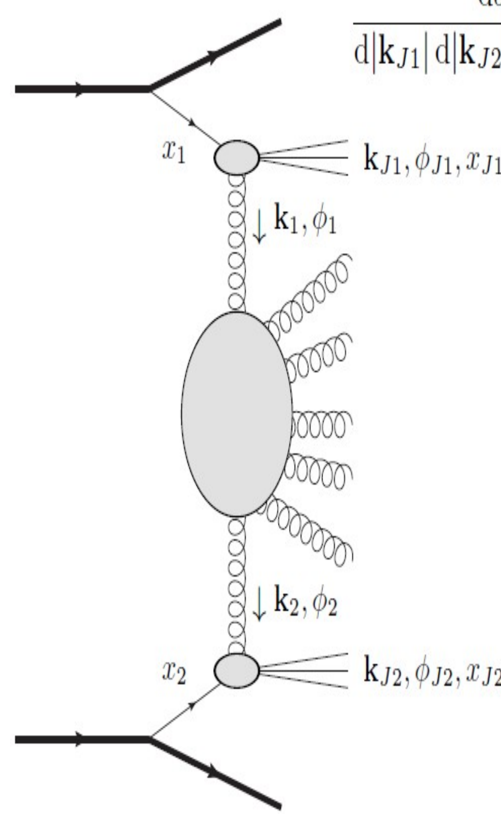
Unshadowed model (AB-MSTW08) clearly fails ⇒ saturation effects seen

Theory vs experiments
k_T*-factorization*

Mueller-Navelet jets

Ducloué





$$\frac{d\sigma}{d|\mathbf{k}_{J1}|\, d|\mathbf{k}_{J2}|\, dy_{J1}\, dy_{J2}} = \int d\phi_{J1}\, d\phi_{J2} \int d^2\mathbf{k}_1\, d^2\mathbf{k}_2$$

$$\times\, \Phi(\mathbf{k}_{J1}, x_{J1}, -\mathbf{k}_1)$$

$$\times\, G(\mathbf{k}_1, \mathbf{k}_2, \hat{s})$$

$$\times\, \Phi(\mathbf{k}_{J2}, x_{J2}, \mathbf{k}_2)$$

Effectively a one-scale process if $k_{T1} \sim k_{T2}$

If large rapidity between jets, should be a clean "probe" of BFKL dynamics

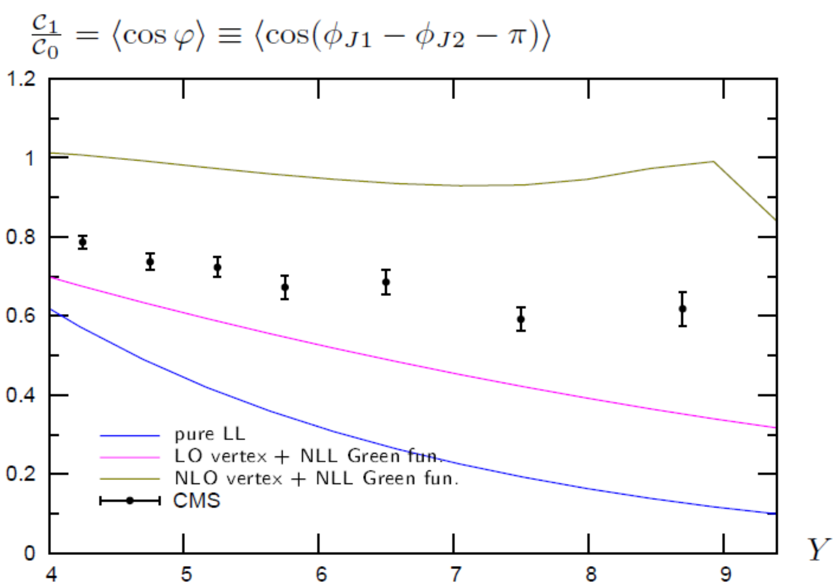
Theory vs experiments
k_T-factorization

Mueller-Navelet jets

Seemlingly confusing situation: Van Mechelen

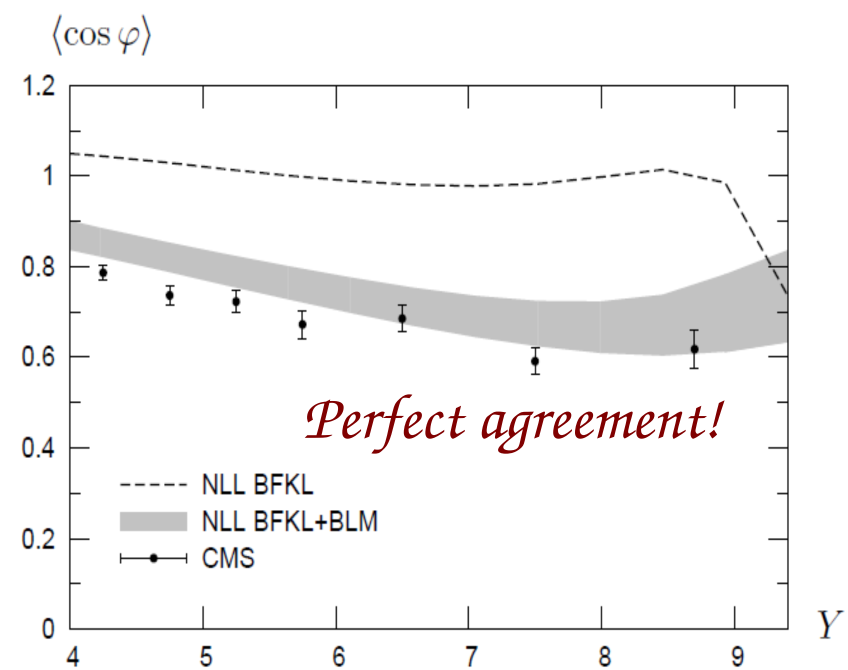
DGLAP (Monte Carlo!) describes the data when it should fail...
NLL BFKL fails miserably (cf DIS 2013) in describing the angular distribution...

At DIS 2013:



Fixed renormalization scale

At DIS 2014: Ducloué



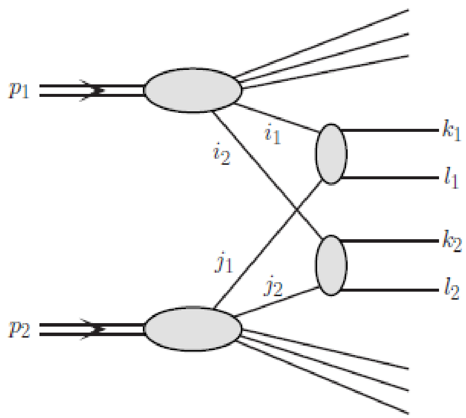
BLM renormalization scale fixing

Theory vs experiments
k_T*-factorization*

Mueller-Navelet jets

Maciula

In a simple probabilistic picture:

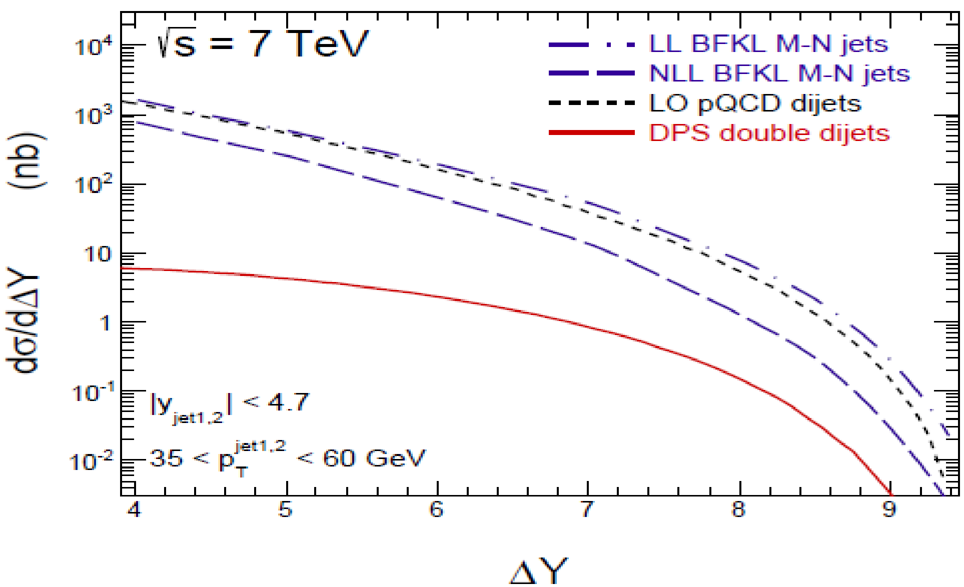


process initiated by two simultaneous hard parton-parton scatterings in one proton-proton interaction ⇒

$$\sigma^{DPS}(pp \to 4\text{jets}X) = \frac{C}{\sigma_{eff}} \cdot \sigma^{SPS}(pp \to \text{dijet}X_1) \cdot \sigma^{SPS}(pp \to \text{dijet}X_2)$$

two subprocesses are not correlated and do not interfere

analogy: frequently considered mechanisms of double gauge boson production and double Drell-Yan anihillation



DPS is significant at large rapidity!

It has a flat angular dependence – may compete with Mueller-Navelet?

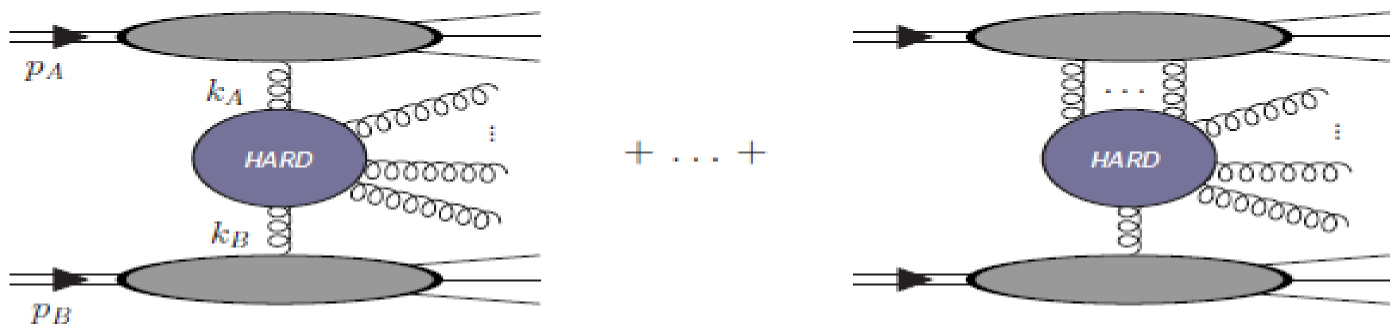
But not exactly the same observable!

Theory vs experiments
k_T-*factorization*

Forward jets

Kotko

"Hybrid" high energy factorization formula relevant for forward jets
[e.g. M. Deak, F. Hautmann, H. Jung, K. Kutak, JHEP 0909 (2009) 121]



$$k_A = x_A p_A + k_{TA},\ k_A^2 = k_{TA}^2, \quad k_B = x_B p_B,\ k_B^2 = 0, \quad x_A \ll x_B$$

$$d\sigma_{AB\to X} = \int \frac{d^2 k_{TA}}{\pi} \int \frac{dx_A}{x_A} \int dx_B\, \mathcal{F}\left(x_A, k_{TA}, \mu\right) f_{b/B}\left(x_B, \mu\right) d\sigma_{g^*b\to X}\left(x_A, x_B, k_{TA}, \mu\right)$$

Investigate saturation effects in

Forward dijets: azimuthal decorrelations, transverse momentum spectrum

Forward trijets...

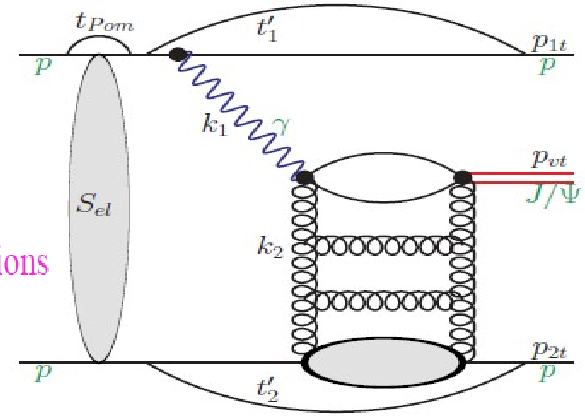
Forward-central dijet decorrelations

Theory vs experiments
k_T*-factorization*

J/ψ *exclusive photoproduction in ep and pp*

Cisek

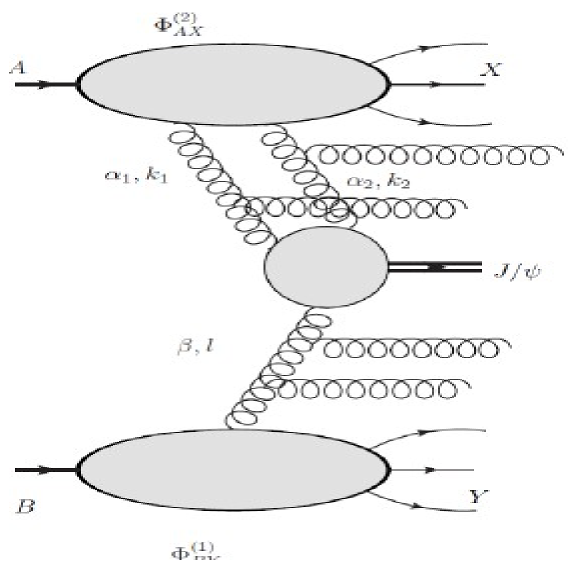
Absorptive corrections



Sensitivity to the quarkonium wave function and testing UGDF.

J/ψ *hadroproduction*

Motyka



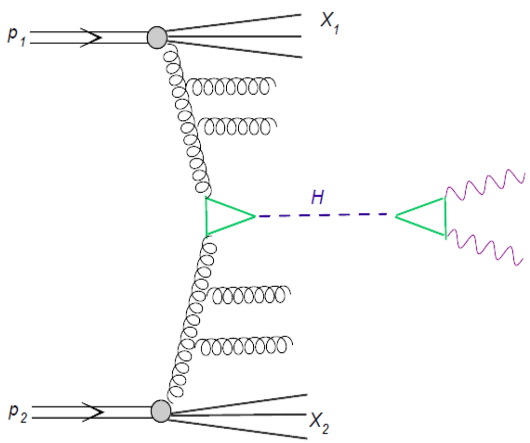
Multiple gluon exchanges

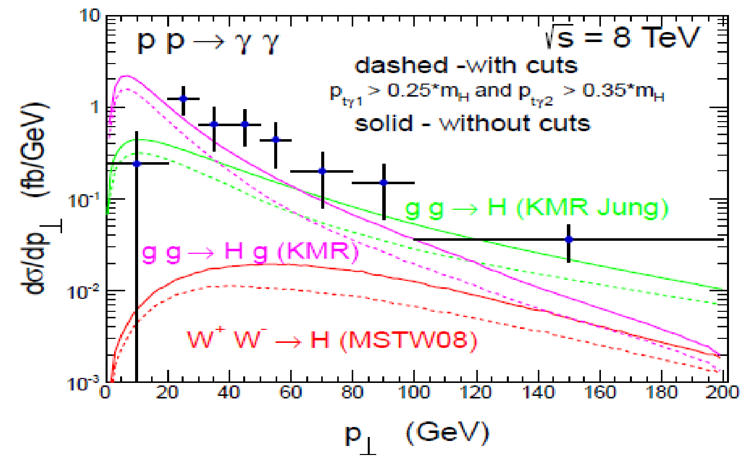
Color singlet rescattering corrections are sizeable: at Tevatron and LHC: larger than standard color singlet contributions and may make up to 25% of direct J/ψ cross section at moderate pT

Theory vs experiments
k_T-*factorization*

Szczurek

Hadroproduction of Higgs

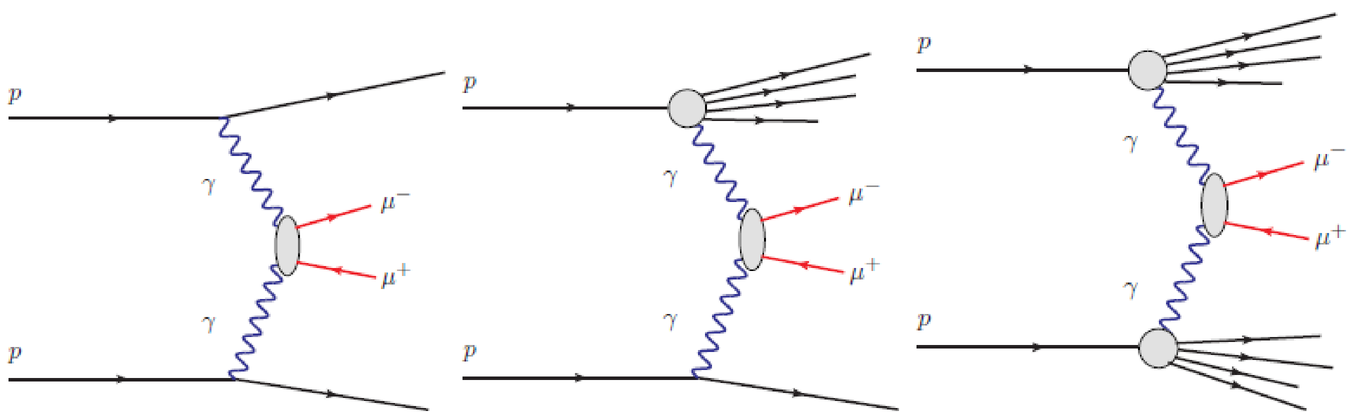




Different UGDFs give quite different results.
NLO corrections have to be taken into account.
Electroweak corrections are large.

Central exclusive production of lepton pairs

Schaefer



production of dilepton pairs with large transverse momenta has a large contribution from proton dissociation events (at the "Born" level).

Diffraction at HERA

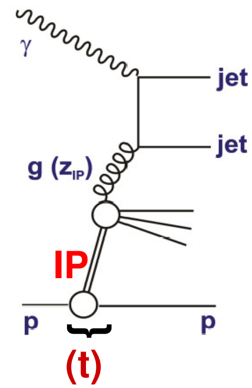
Measurement of proton-tagged diffractive dijets in DIS and photoproduction

Test of QCD collinear factorisation

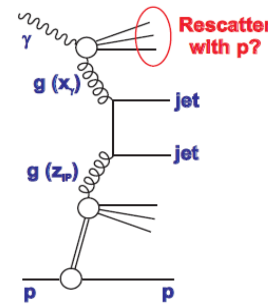
$$d\sigma^{ep\rightarrow eXp} = \Sigma f_i^{D}(x,Q^2,x_{IP},t)\otimes d\sigma^{ei}(x,Q^2)$$

f_i^D = IP flux · IP structure function

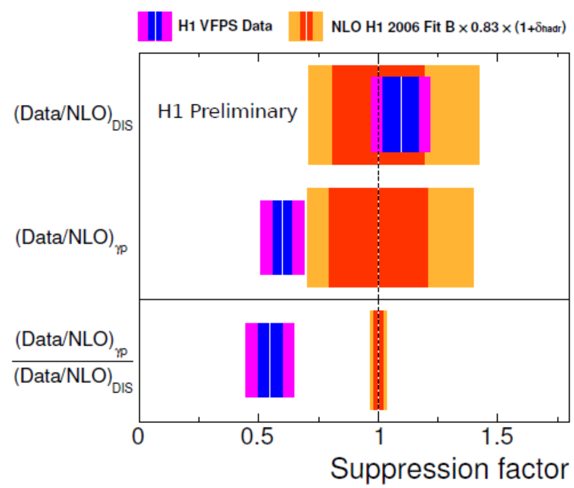
DDIS, direct photoproduction

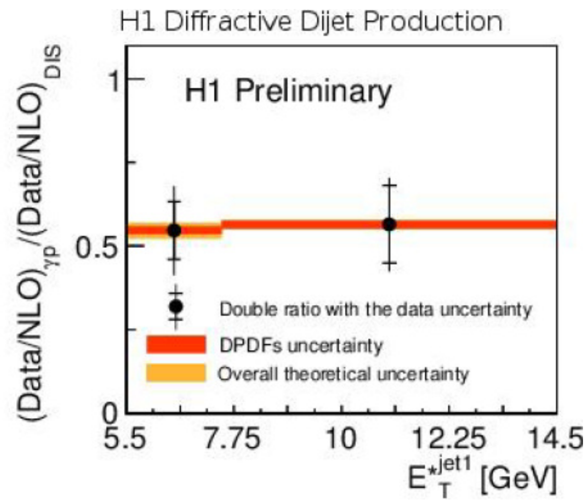


resolved photoproduction



- **Confirmation of the previous H1 measurement based on large rapidity gap method**
- **Suppression factor in photoproduction ~0.55**
- **No dependence of supression factor on E_T of the leading jet**
- **ZEUS data on diffractive dijet photoproduction consistent with no supression**

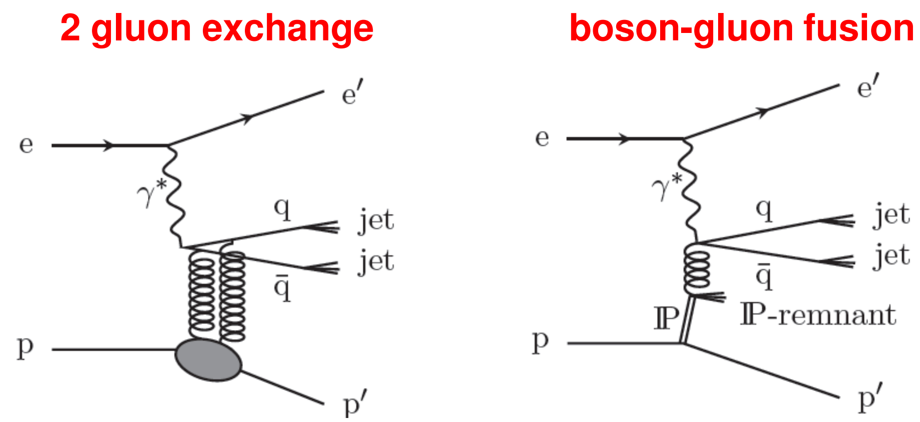




The cross section double ratio of data to NLO prediction for photoproduction and DIS :

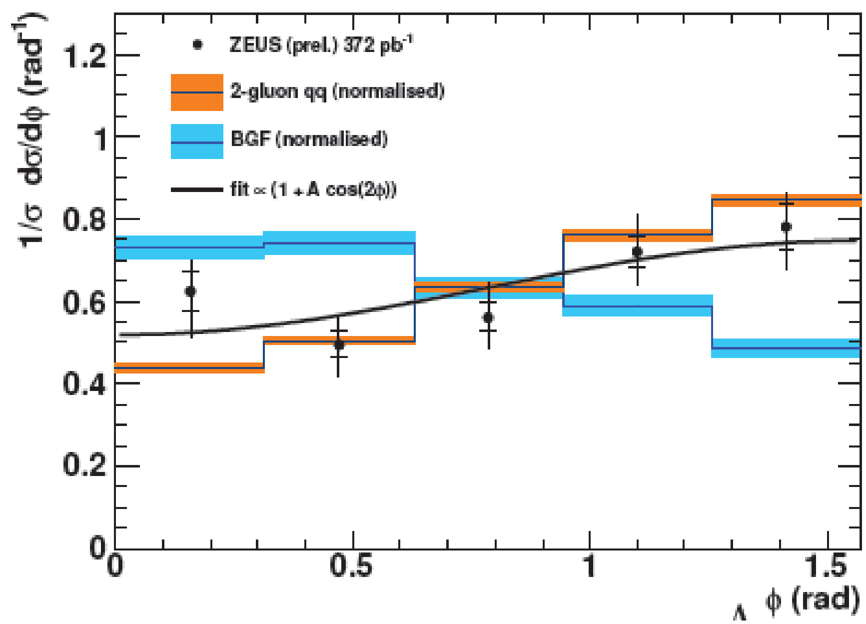
$$\frac{(\mathrm{DATA/NLO})_{\gamma p}}{(\mathrm{DATA/NLO})_{\mathrm{DIS}}} = 0.55 \pm 0.10\,(\mathrm{data}) \pm 0.02\,(\mathrm{theor.})$$

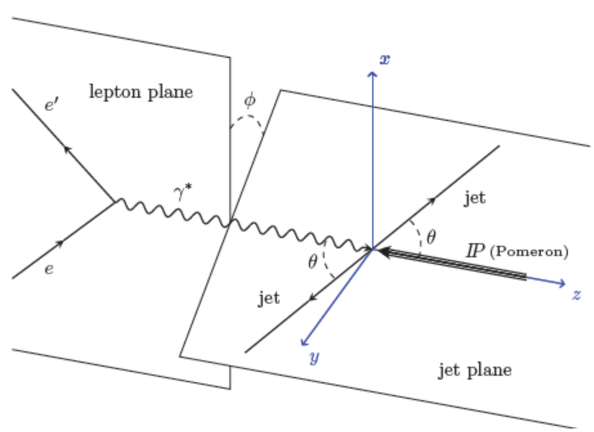
Diffraction at HERA



- Measurement of exlusive diffractive dijets in DIS: e+p → e + p + jet + jet
- **Study of nature of diffractive dijet production**

- **First measurement of the azimuthal angular distribution of exclusive dijets in DDIS**
- **The data favour 2-gluon exchange model of quark anti-quark production over boson-gluon fusion**

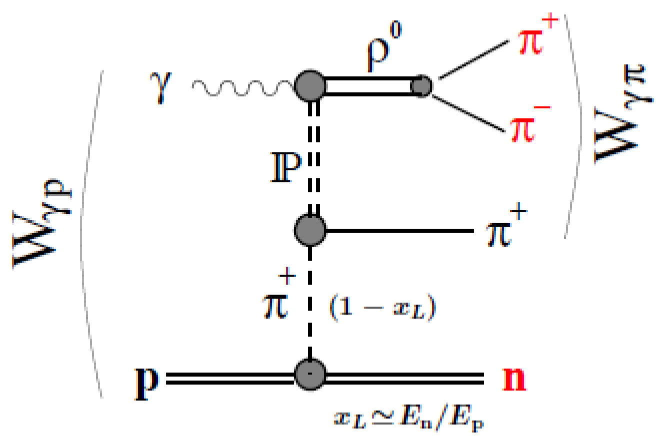




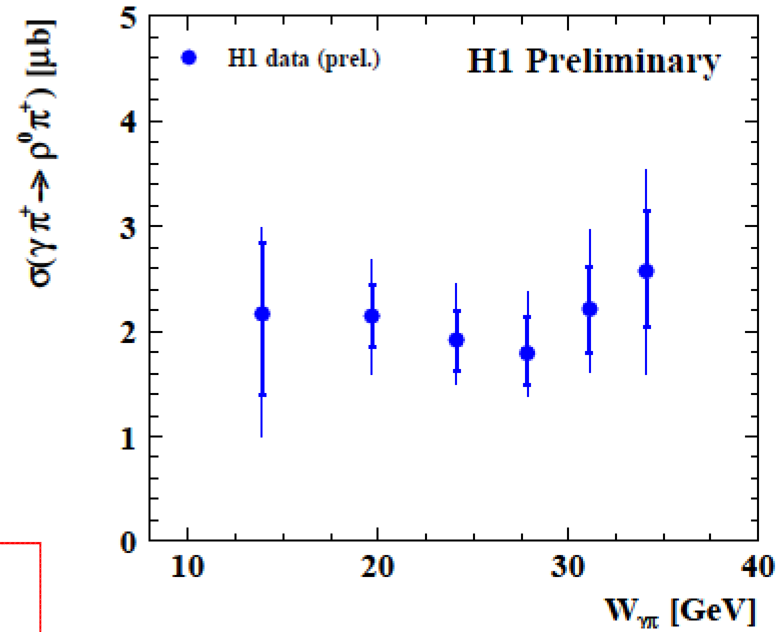
Φ – angle defined between lepton and jet plane in γ*IP CMS

Exclusive photoproduction of ρ meson with leading neutron at HERA

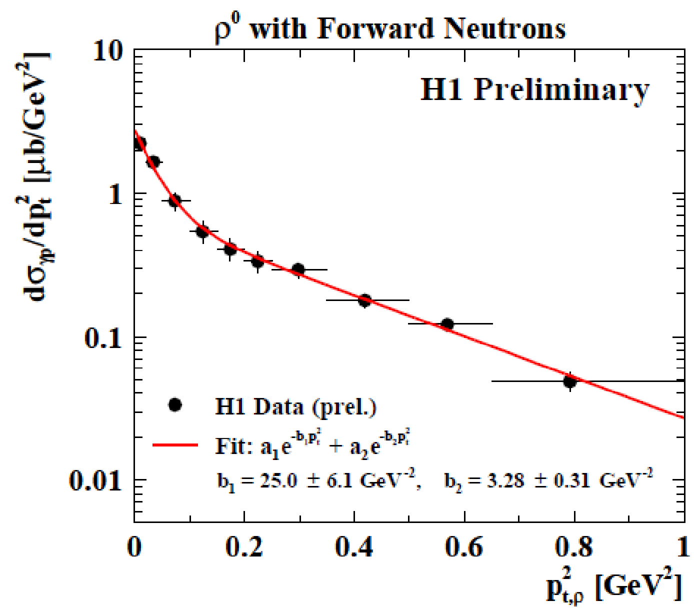
$\gamma^* + p \rightarrow \rho^0 \pi^+ n$

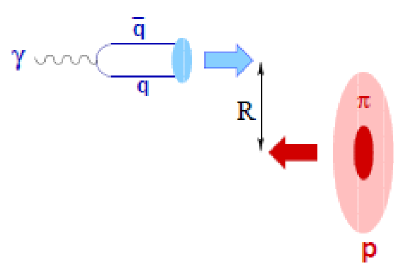


The elastic photon-pion cross section



- First measurement of exclusive photoproduction of ρ^0 meson with leading neutron at HERA
- Differential cross sections for the reaction $\gamma p \rightarrow \rho^0 n \pi^+$ exhibit features typical for exclusive **double peripheral process**





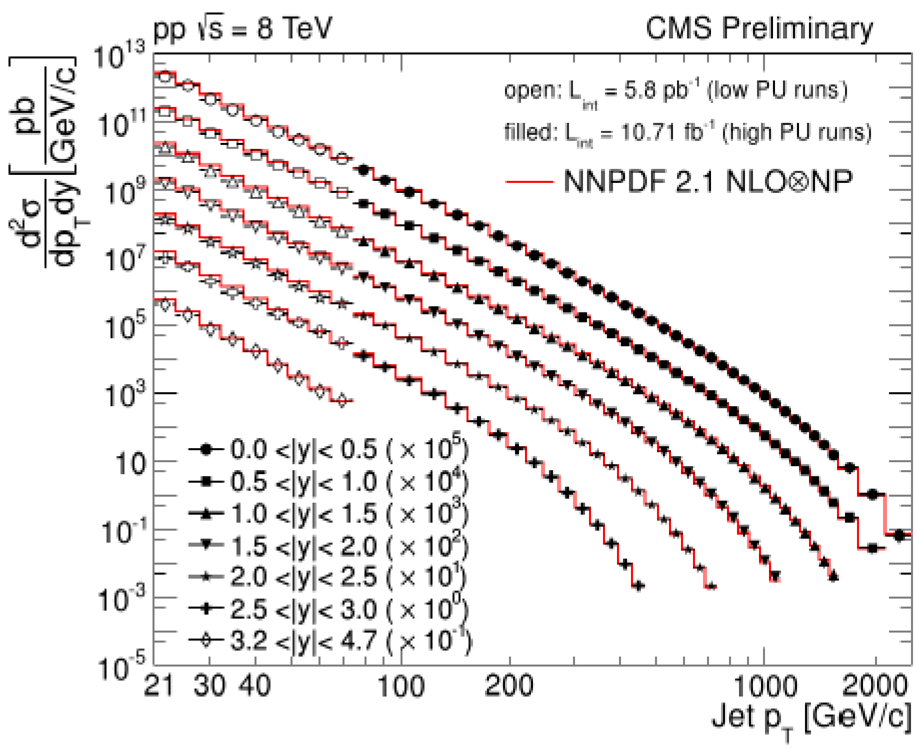
Geometric interpretation:

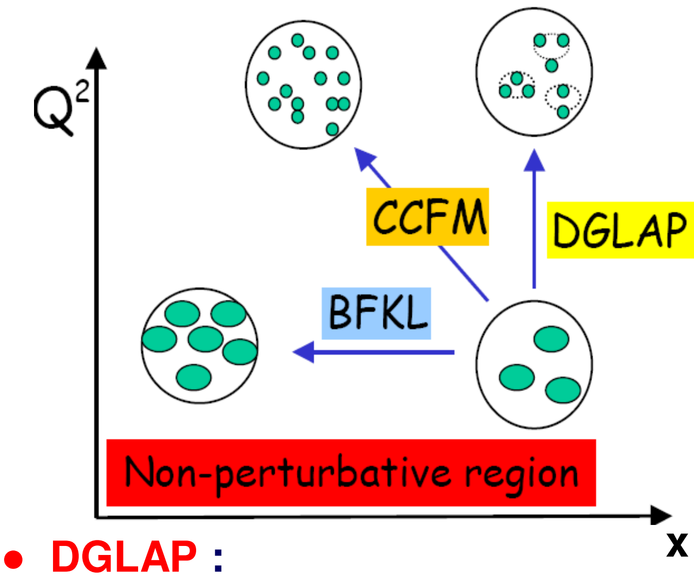
$\langle r^2 \rangle = 2b_1 \cdot (\hbar c)^2 \approx 2\ \mathrm{fm}^2 \rightarrow (1.6\ R_p)^2$

→ ultra-peripheral process

Novel parton dynamics at low-x

- cross section of inclusive forward jet production
- azimuthal decorrelation of Mueller-Navelet jets
- inclusive and exclusive dijet production ratios
- forward-central jet correlations





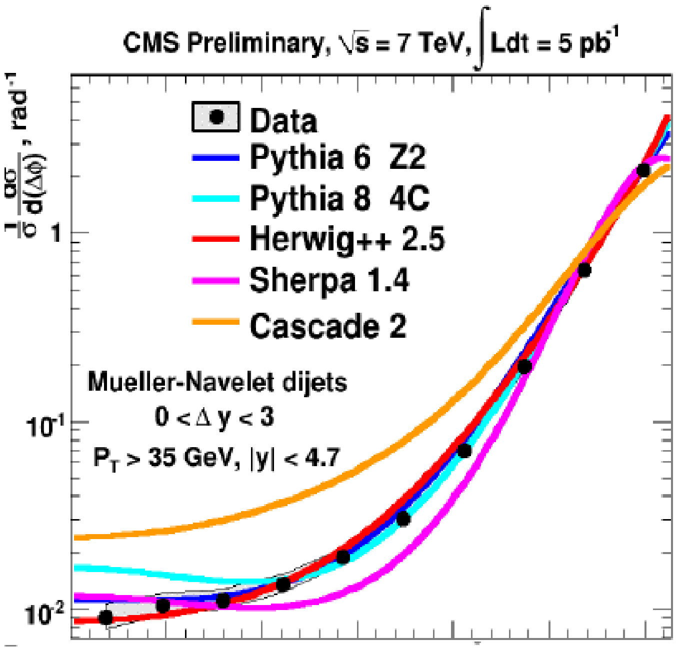
- **DGLAP :** parton cascades strongly ordered in k_T
- **BFKL :** no ordering in k_T
  Transition from DGLAP to BFKL scheme expected at low x
- **CCFM :** reproduces DGLAP at large x and BFKL at x → 0

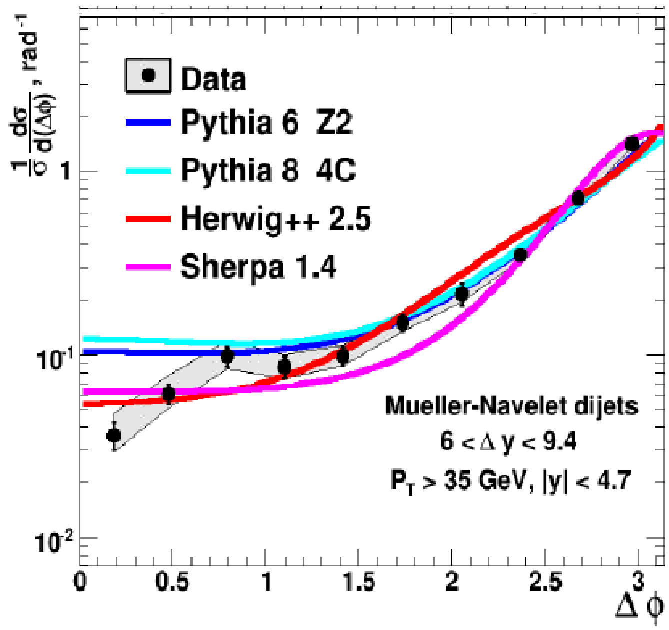
Inclusive forward jet cross section well described in wide range of p_T and rapidity by NLO·NP predictions

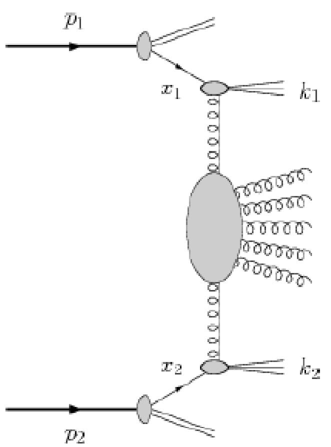
Novel parton dynamics at low-x

Azimuthal decorrelation of Mueller-Navelet jets measured up to Δy = 9.4

dijets widely separated in rapidity







$p_{T,\,jet}$ > 35 GeV

- **Jets are more decorrelated with increasing rapidity separation**
- **DGLAP-based HERWIG++ gives the best description of data**
- **CCFM (Cascade) predicts too strong decorrelation**

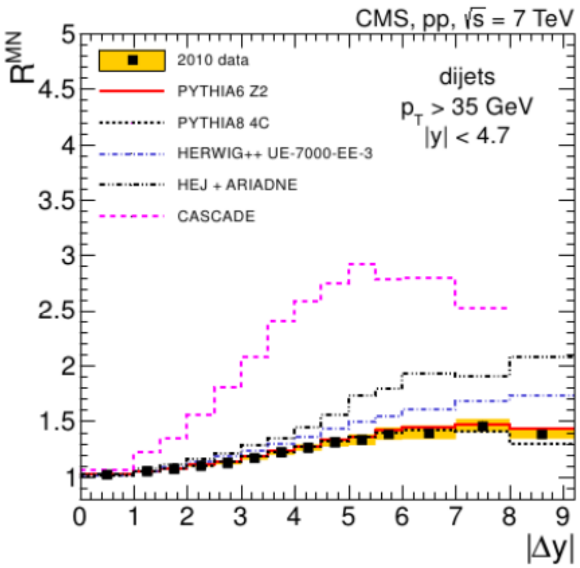
- **ratios of cosines of Fourier coefficients consistent with NLL BFKL predictions (B. Ducloue, L. Szymanowski, S. Wallon)**

Novel parton dynamics at low-x

Measurement of dijet production ratios as a function of rapidity separation

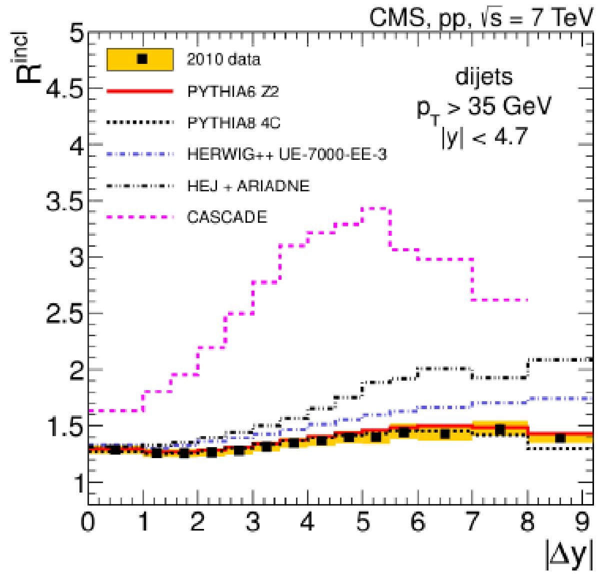
Mueller-Navelet

$$R^{\mathrm{MN}} = \sigma^{\mathrm{MN}} / \sigma^{\mathrm{excl}}$$



inclusive

$$R^{\mathrm{incl}} = \sigma^{\mathrm{incl}} / \sigma^{\mathrm{excl}}$$



σ^{excl} veto on additional jets

σ^{MN} only MN pair taken

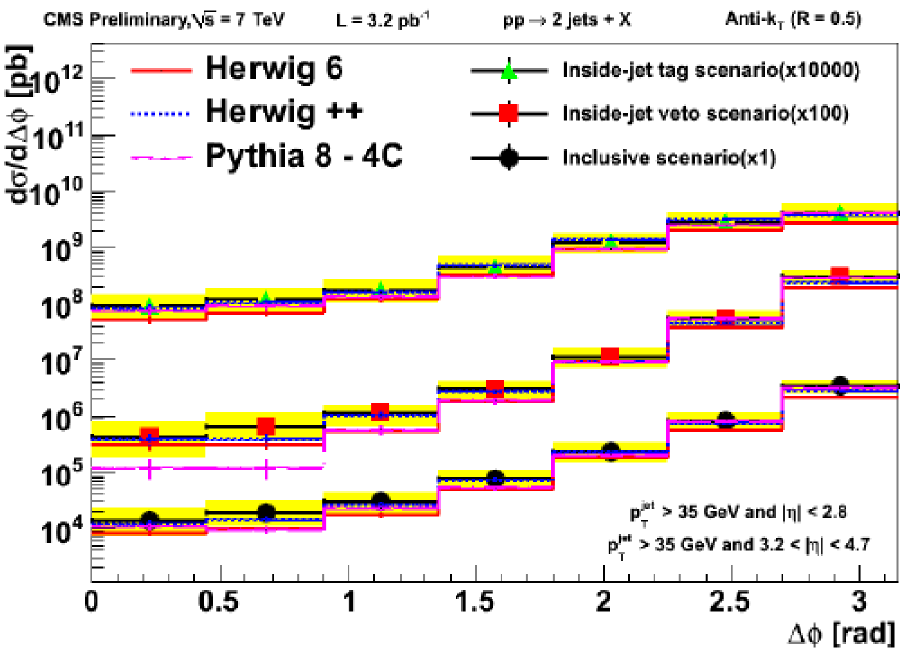
σ^{incl} no veto, all pairwise combinations

BFKL evolution predicts strong increase of the ratios with increasing rapidity separation between jets (increased phase space for parton radiation)

- R^{MN} and R^{incl} ratios are well desribed by DGLAP-based parton shower models
- BFKL inspired models, CASCADE and HEJ, overestimate the data

Novel parton dynamics at low-x

Measurement of azimuthal correlations $\Delta\phi$ between forward and central jets



$\Delta\sigma/d\Delta\phi$ vs. $\Delta\phi$ for different forward, central and "extra jet " topologies

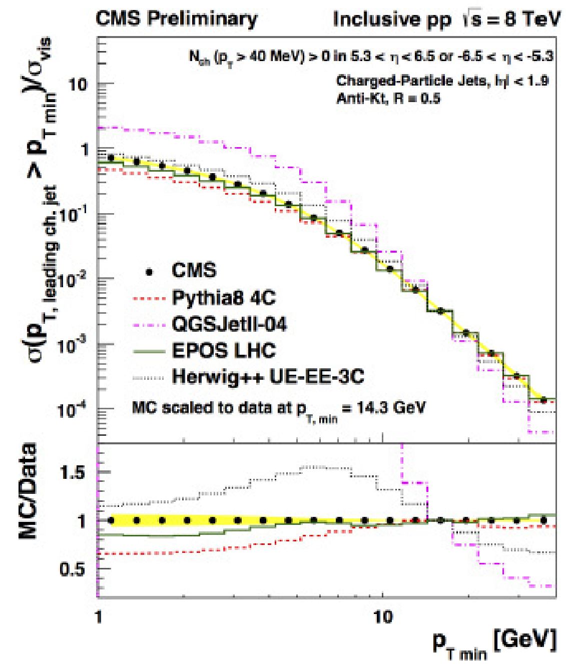
DGLAP-based MC generators describe the observables very well

CMS measurements of forward jets, Mueller-Navelet jets, forward jets associated with central jets are well described by DGLAP-based predictions.

No clear evidence of BFKL dynamics.

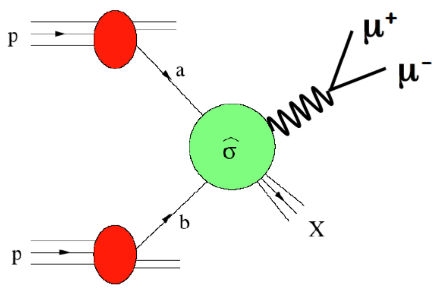
Leading tracks and leading jet cross sections at small transverse momenta

Normalised integrated cross-sections for events with a leading charged particle jet with $p_T > p_{T,min}$ as function of p_T



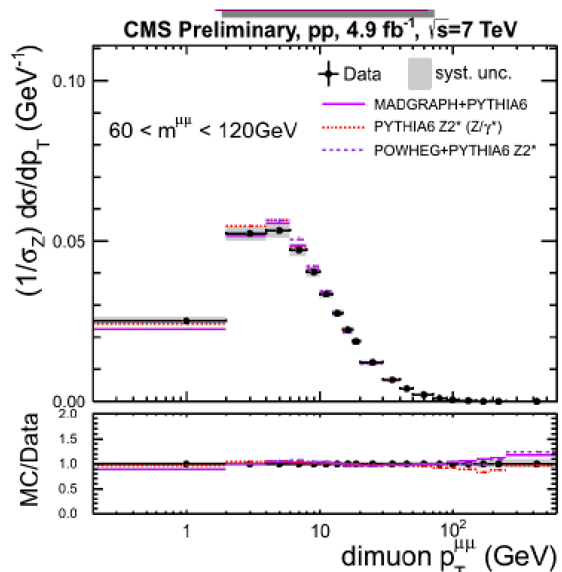
- the measurements are not well described by models
- the integrated distributions probe the transition from the the perturbative to the non-perurbative regions

Measurement of Drell-Yan and associated jet cross section at low and high invariant masses

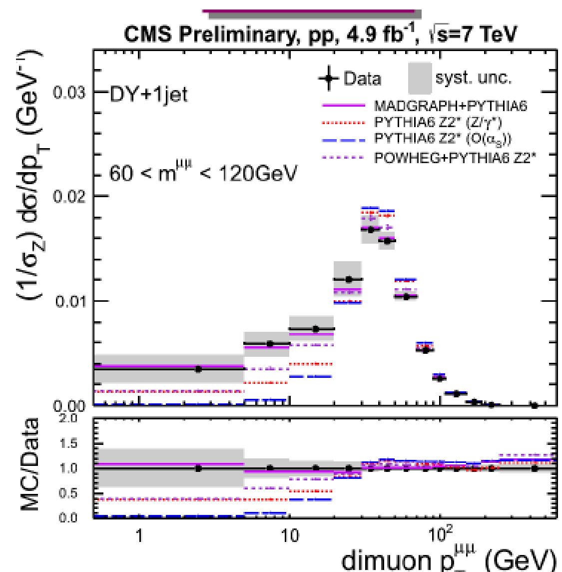


Double differential cross section in mass and transverse momentum of the μμ pair

- increased sensitivity to soft gluon resummation by using DY + jets
- soft gluon resummation well described by PS algorithm



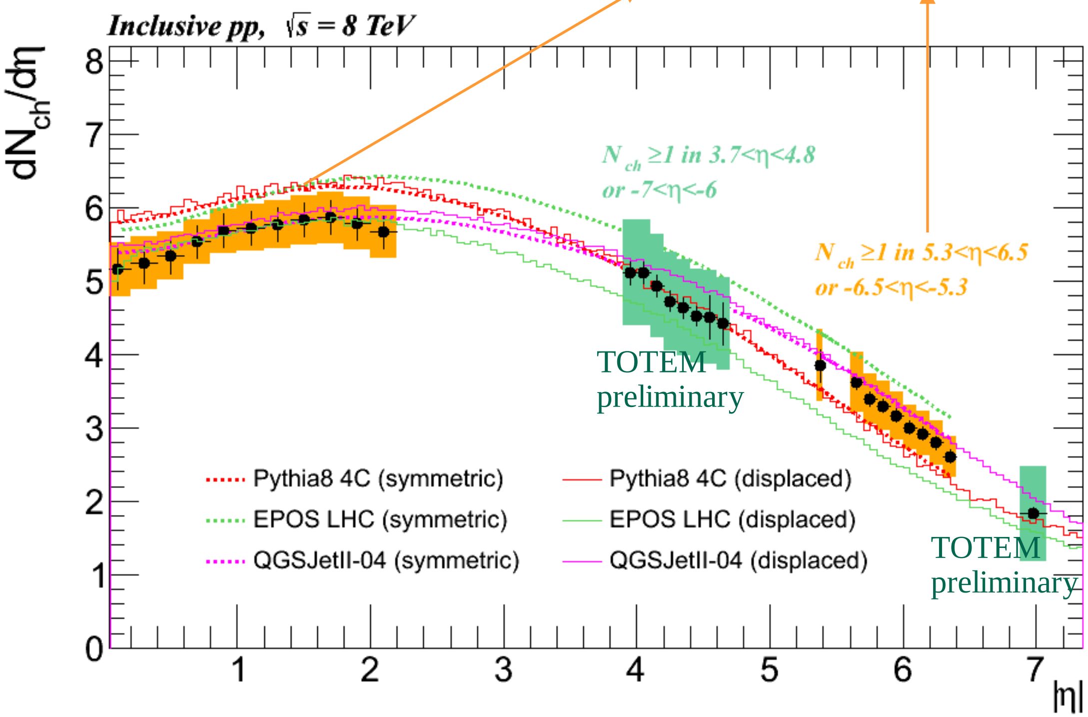
inclusive

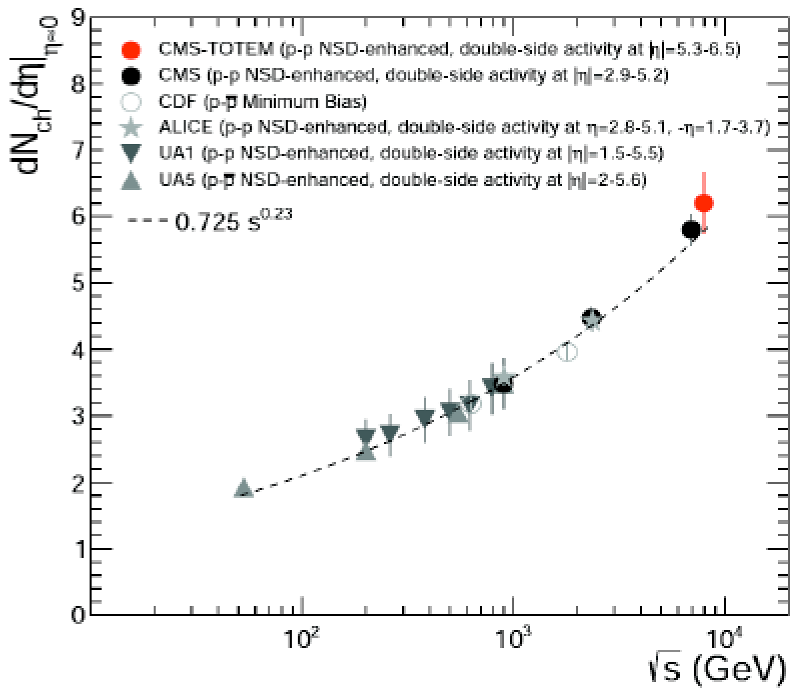


DY + 1 jet

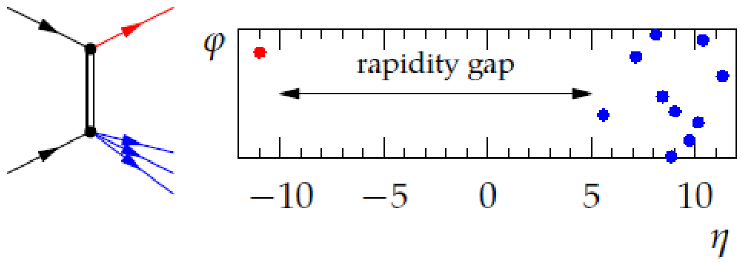
Pseudorapidity Distribution of Charged Particles at 8 TeV

first common CMS+TOTEM publication [CMS FSQ-12-026, TOTEM-2014-2]

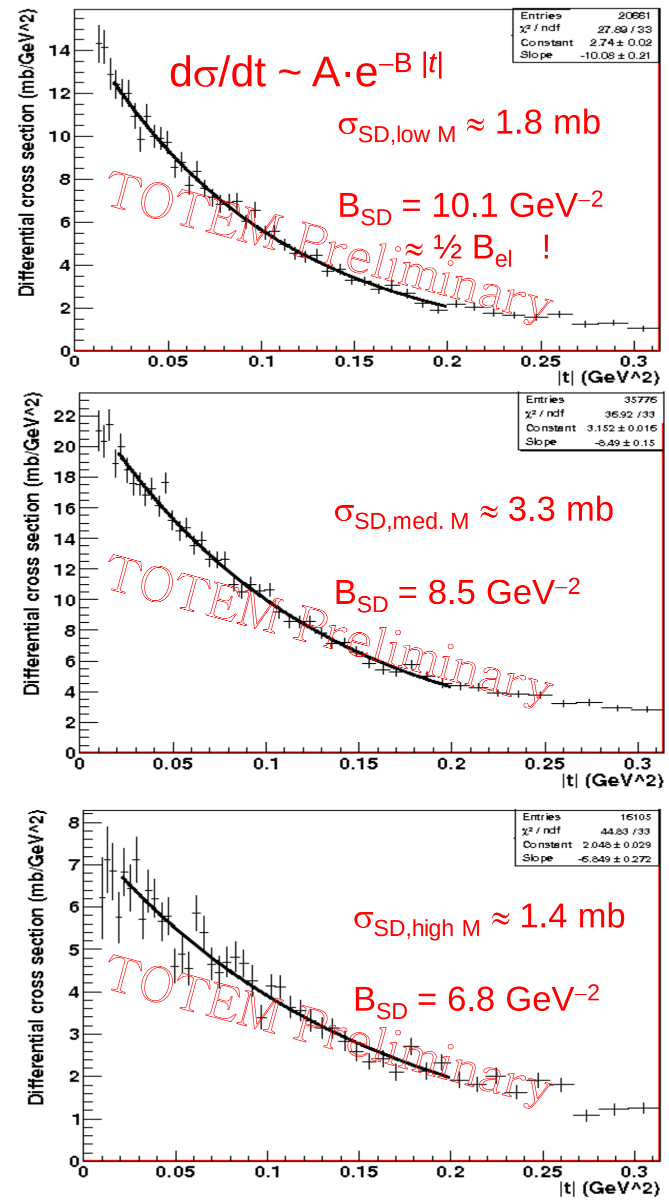




Soft Single Diffraction at LHC

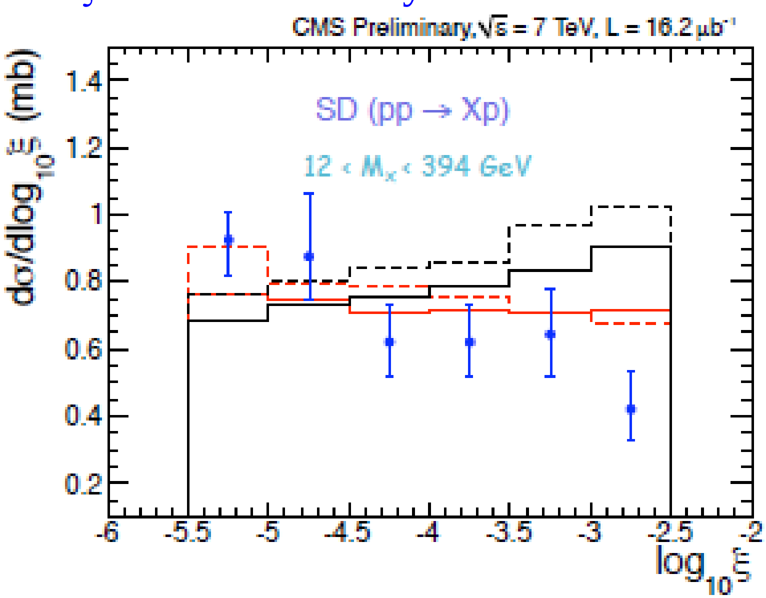


SD events tagged by proton, ξ from rapidity gap



SD events tagged by rapidity gap,
ξ from diffractive system:

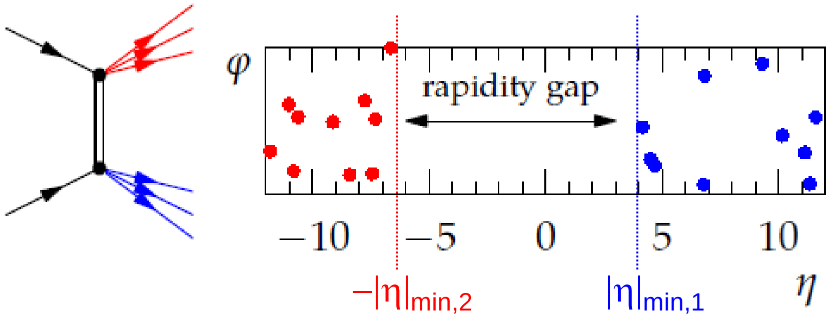
$$\xi = \frac{M_X^2}{s} = \frac{\sum\left(E^i + p_Z^i\right)}{\sqrt{s}}$$

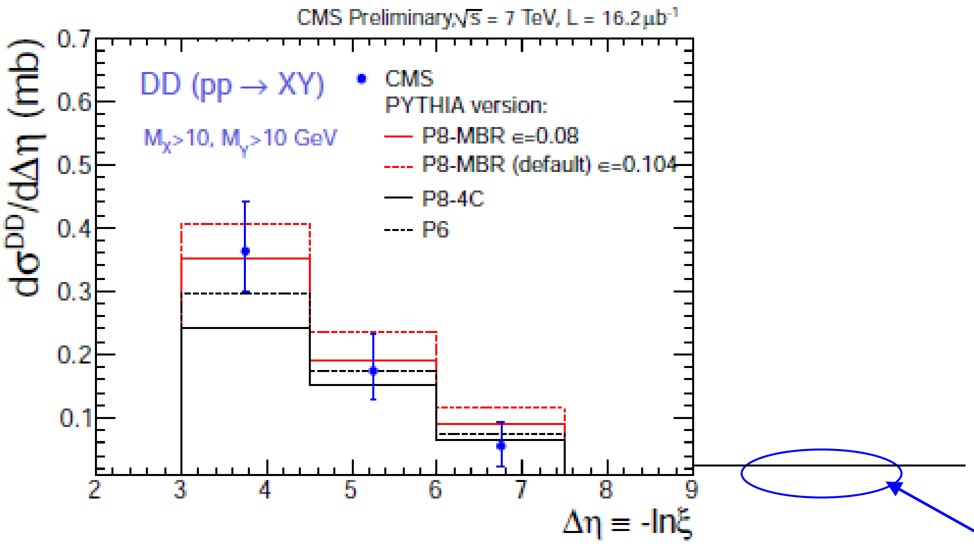


→ Single diffractive cross section integrated over -5.5 < log ξ < -2.5:

$\sigma_{vis}^{SD} = 4.27 \pm 0.04(stat.) + 0.65/-0.58(syst.)$ mb for 1.1 < log(M_X/GeV) < 2.6

Soft Double Diffraction at LHC





→ Double diffractive cross section integrated over Δη>3, M_X > 10 GeV, M_Y > 10 GeV:

$$\sigma^{DD}_{vis} = 0.93 \pm 0.01(stat.) + 0.26/-0.22(syst.) \quad \text{mb}$$

Partial 2-dim. cross-section in 2 x 2 bins:

	$-4.7>\eta_{min2}>-5.9$	$-5.9>\eta_{min2}>-6.5$
$4.7<\eta_{min1}<5.9$	65±20 μb	26±5 μb
$5.9<\eta_{min1}<6.5$	27±5 μb	12±5 μb

Sum:

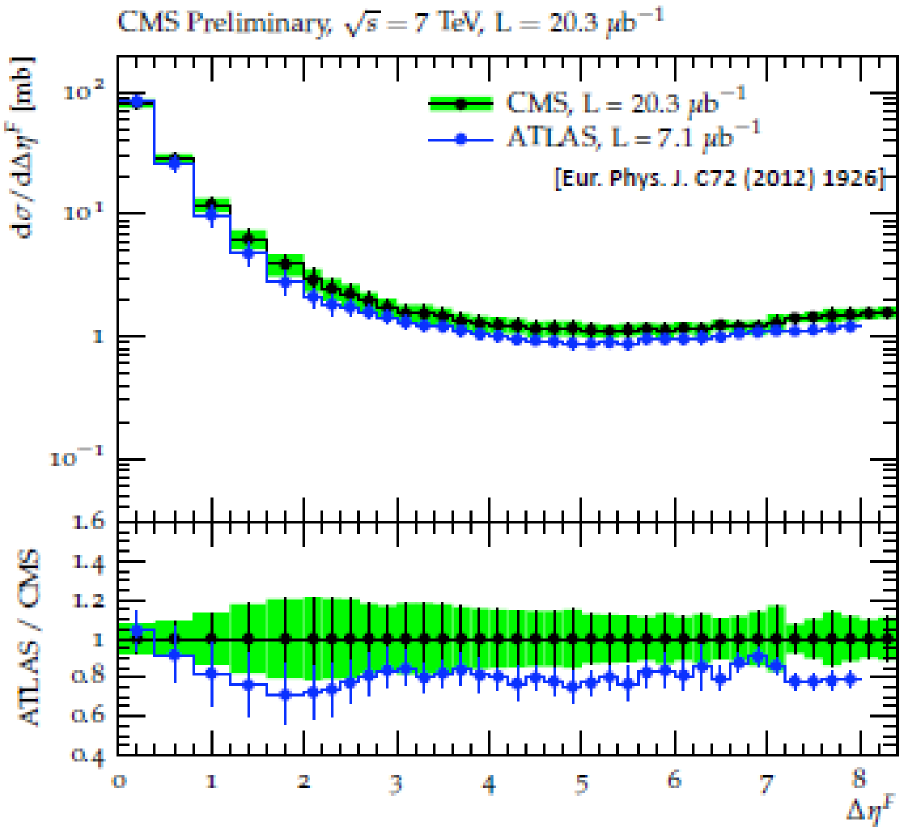
$$\sigma_{DD(4.7<|\eta_{min}|<6.5)} = 116 \pm 25 \ \mu b$$

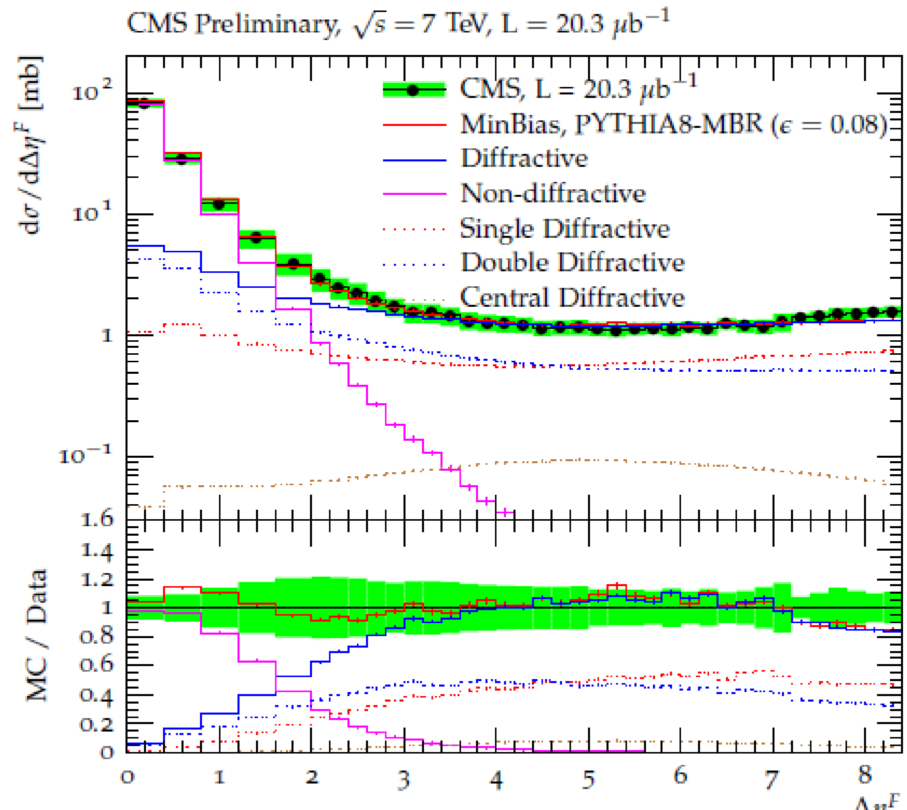
[PRL 111 (2013) 262001]

Forward Rapidity Gap Cross-Section

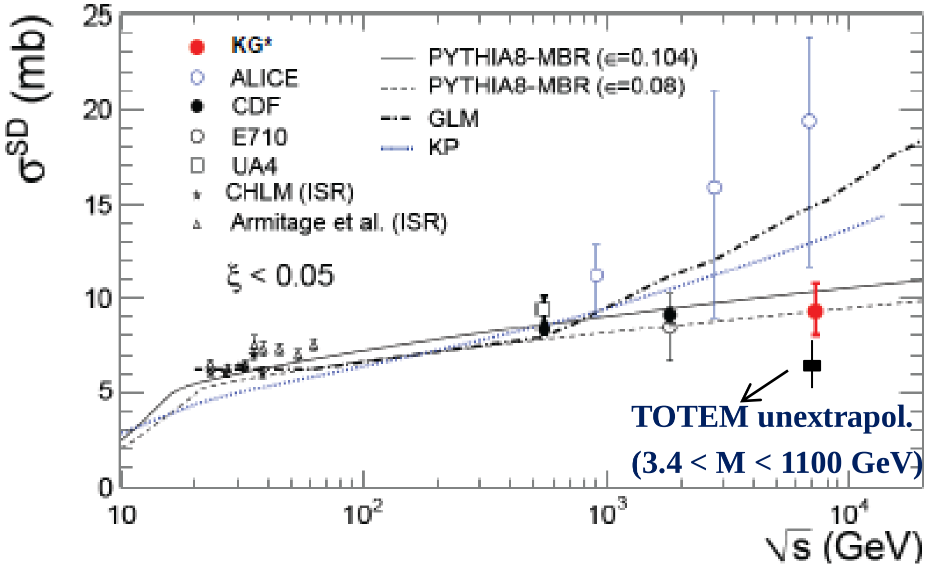
Forward rapidity gap $\Delta\eta^F$ extending from the edge of the detector acceptance ($\eta = \pm 4.7$) to the nearest particle candidate: $\Delta\eta^F = Max(4.7 - \eta_{max}, 4.7 + \eta_{min})$

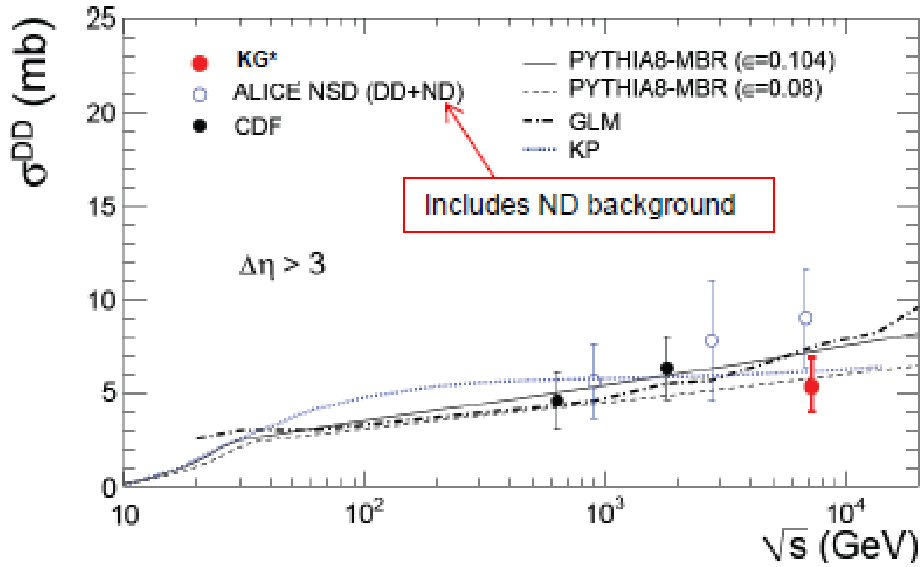
Inclusive measurement (no separation of ND, SD, DD)





Energy Evolution of SD and DD Cross-Section





K. Goulianos:

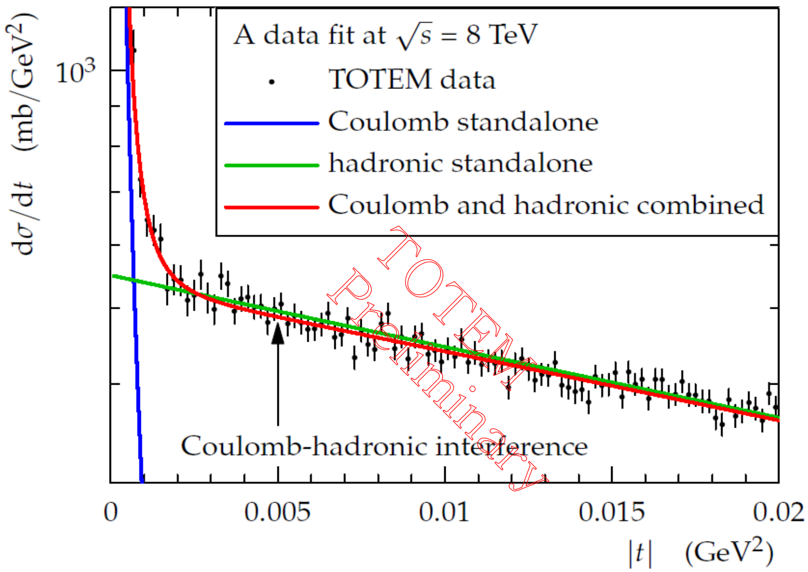
❑ KG*: after extrapolation into low ξ from the measured CMS data using MBR model

= Minimum Bias Rockefeller

TOTEM : p + rap gap + diffractive system: σ_{SD}= 6.5 ± 1.3 mb (3.4 < M_{diff} < 1100 GeV)

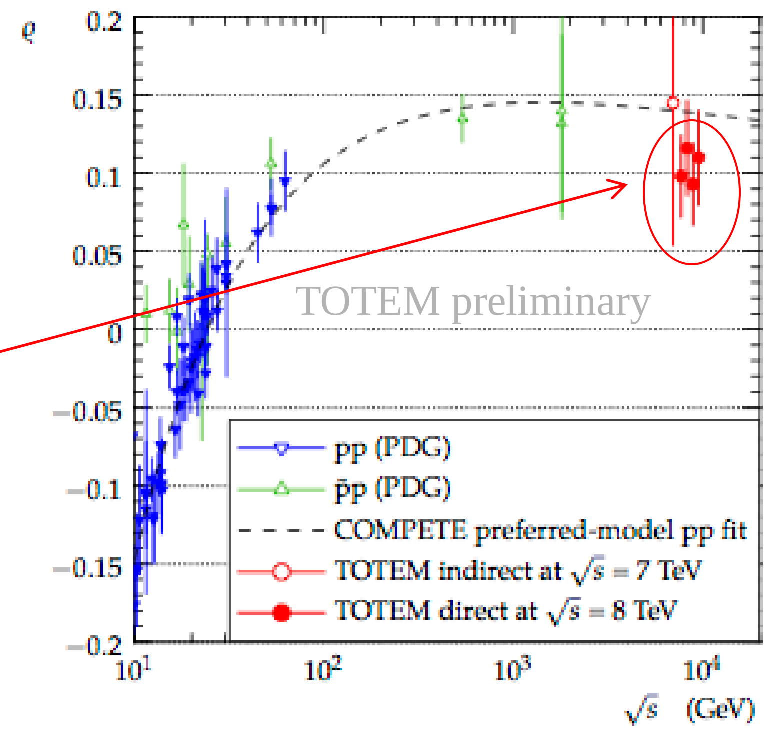
ALICE & CMS: rap gap + diffractive system

Coulomb-Nuclear Interference in Elastic pp Scattering at LHC



$$F^{C+H} = F^{C} + F^{H} e^{i\alpha\Psi}$$

$$\rho = \frac{\Re F^{H}(t=0)}{\Im F^{H}(t=0)}$$

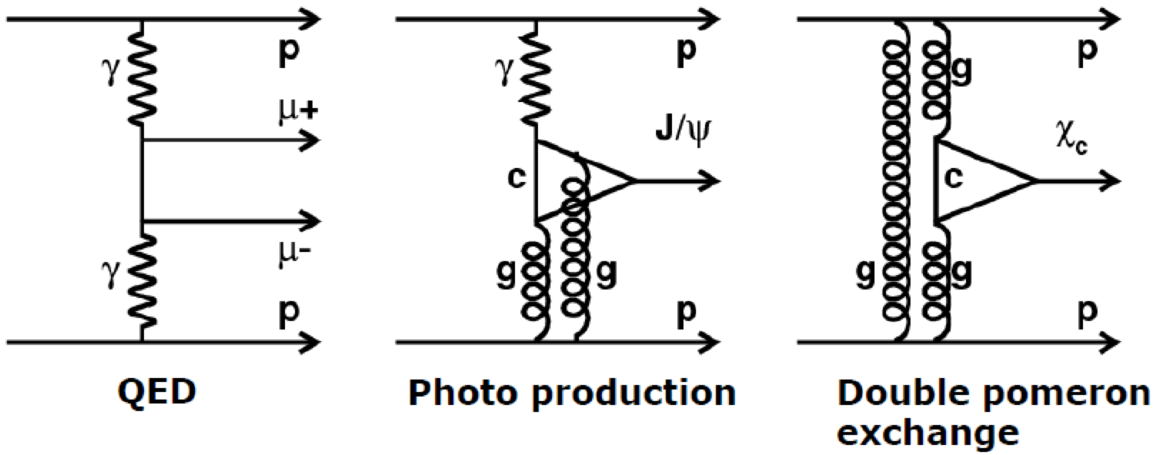


4 alternative ρ results
for different parameterisations
of the hadronic amplitude

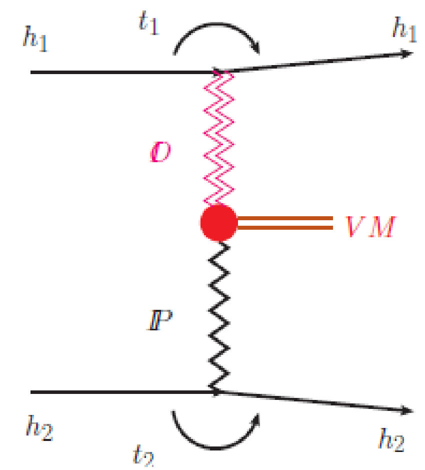
Experimental constraint on
interference description:
traditional Simplified West-Yennie
formula ruled out.

Exclusive Central Production

Related phenomena where the colourless object creates a particle



+ Odderon contributions?



clean signature, selection rules (→ process is spin-parity analyser), kinematically over-constrained if protons are tagged.

→ search for new states (e.g. glue balls):

known states serve as standard candles (V. Khoze): e.g. Durham pred. vs. LHCb in $\chi_{c0,1,2}$

Pomeron spin? Tensor and vector pomeron describe available data, theory prefers tensor (P. Lebiedowicz)

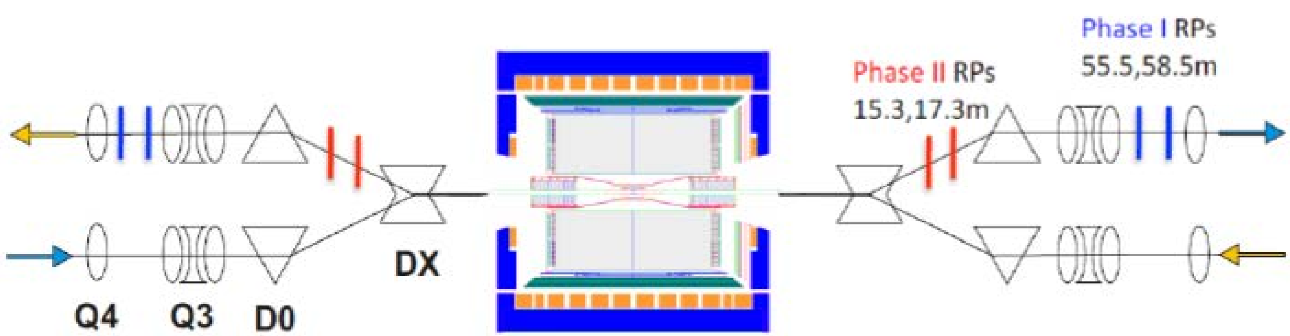
→ want more data

Activities in many experiments!

Not represented here:

- CDF (recent ππ resonance studies)
- ALICE (ππ resonances)
- CMS+TOTEM with tagged protons (in progress)
- COMPASS (search for glue-balls, partial wave analysis)

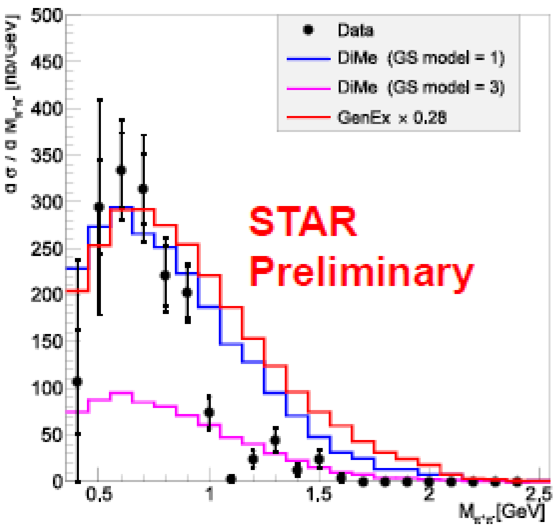
Two-Pion Resonances in CEP: STAR (RHIC)



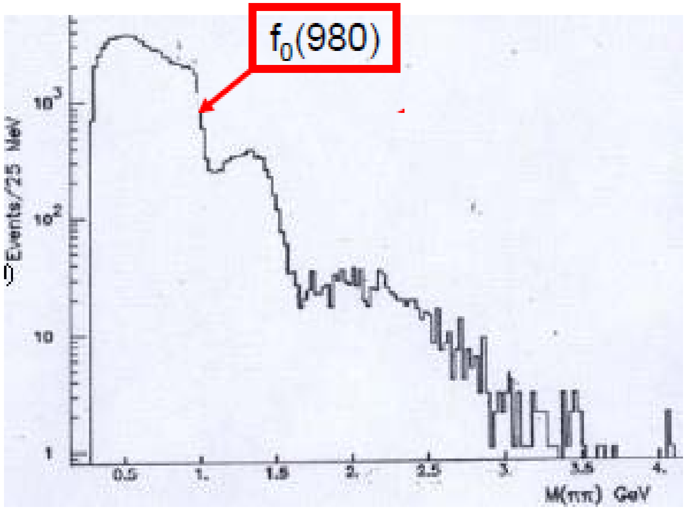
- transverse momentum balance

$$p_T^{miss} = |(\vec{p}_E + \vec{p}_W + \vec{\pi^+} + \vec{\pi^-})_T|$$

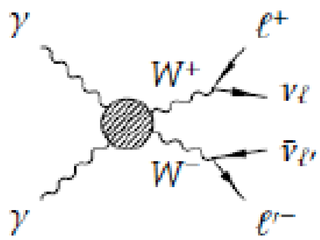
- requirement of $p_T^{miss} < 0.02$ GeV

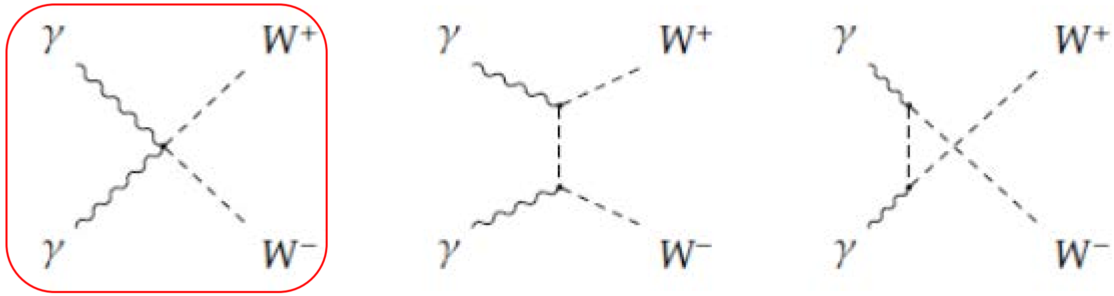


Axial Field Spectrometer at ISR : NP B264(1987)154



Two-Photon Production of WW Pairs: CMS





$$\mathcal{L}^{WW\gamma\gamma} = -e^2 \left(W_\mu^+ W^{-\mu} A_\nu A^\nu - W_\mu^+ W_\nu^- A^\mu A^\nu\right)$$

+ aQGC
(anomalous couplings):

$$\mathcal{L}_6^0 = \frac{e^2}{8}\frac{a_0^W}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W_\alpha^- - \frac{e^2}{16\cos^2\Theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

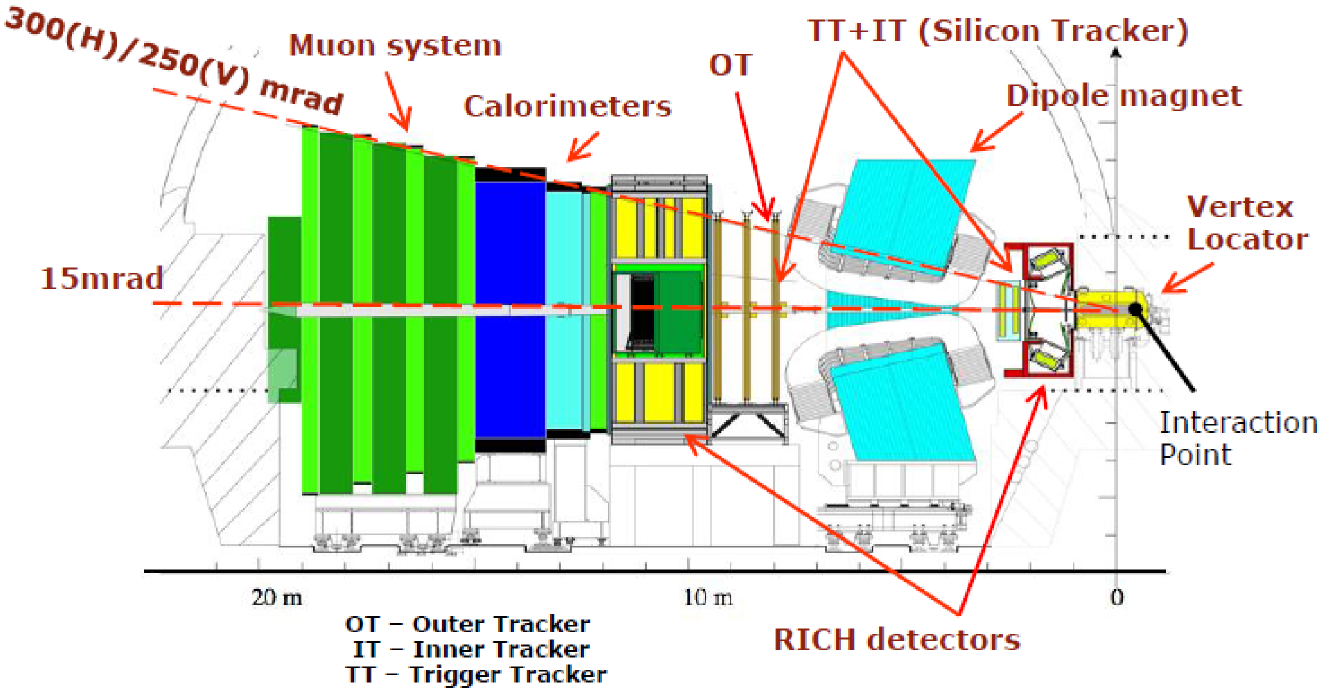
$$\mathcal{L}_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2} F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W_\beta^- + W^{-\alpha}W_\beta^+) - \frac{e^2}{16\cos^2\Theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

?

$$\sigma\left(pp \to p^{(*)}(\gamma\gamma \to W^+W^-)p^{(*)}\right) \times BR(W^\pm \to \mu^\pm\nu,\ e^\pm\nu) = 2.2^{+3.3}_{-2.0}\ \text{fb}$$ (SM prediction 4.0 ± 0.7 fb)

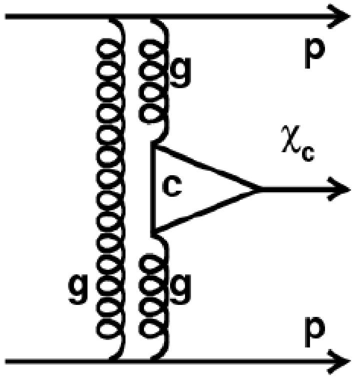
		OPAL (2004)	DØ (2013)	CMS (2013)
a_0^W/Λ^2	no form factor	$\pm 2 \times 10^{-2}$	$\pm 4.3 \times 10^{-4}$	$\pm 4.0 \times 10^{-6}$
	Λ_{cutoff} = 500 GeV		$\pm 2.5 \times 10^{-3}$	$\pm 1.5 \times 10^{-4}$
a_c^W/Λ^2	no form factor	${}^{+3.7}_{-5.2} \times 10^{-2}$	$\pm 1.5 \times 10^{-3}$	$\pm 1.5 \times 10^{-5}$
	Λ_{cutoff} = 500 GeV		$\pm 9.2 \times 10^{-3}$	$\pm 5.0 \times 10^{-4}$

LHCb: Central Exclusive Production with Dimuon Final States



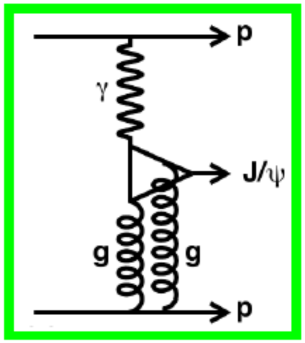
- Single arm spectrometer geometry
- Fully instrumented in pseudorapidity range $2 < \eta < 5$
- Capable of reconstructing backward tracks ($-4 < \eta < -1.5$)

Earlier result: $\chi_{c0,1,2}$ production (not presented here)

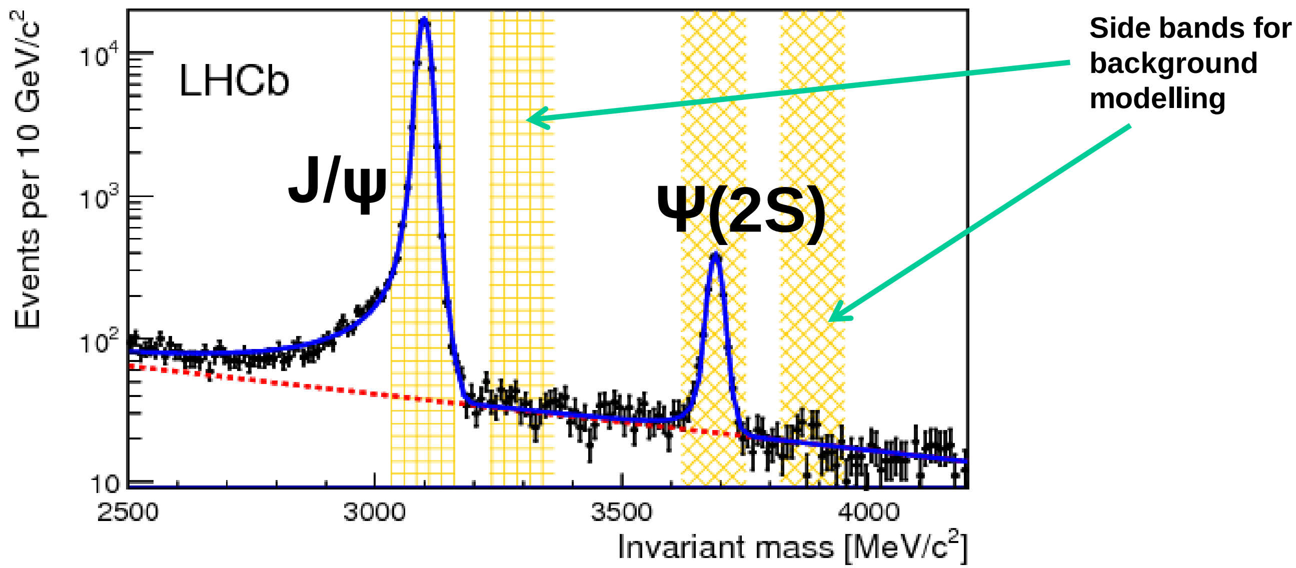


Double pomeron exchange

LHCb: Exclusive J/Ψ and Ψ(2S) Production



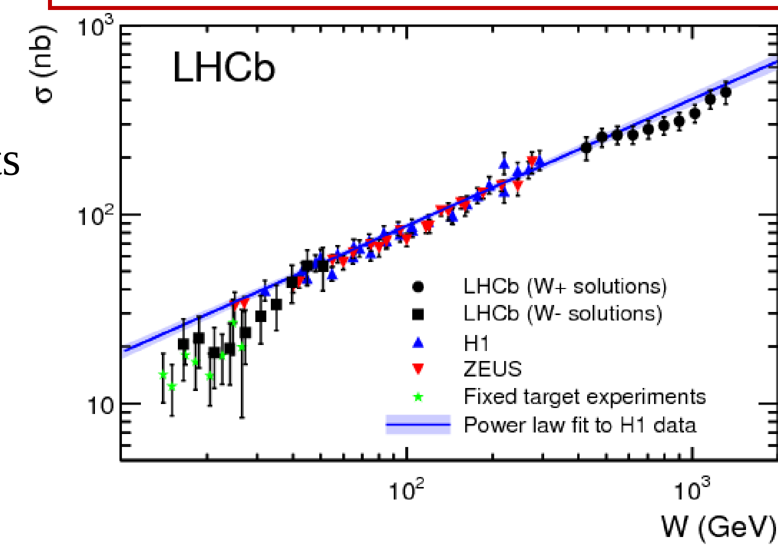
Photoproduction



$$\sigma_{J/\psi\to\mu^+\mu^-}\left(2 < \eta_{\mu^+}\eta_{\mu^-} < 4.5\right) = 291 \pm 7(stat.) \pm 19(sys.)pb$$

$$\sigma_{\psi(2S)\to\mu^+\mu^-}\left(2 < \eta_{\mu^+}\eta_{\mu^-} < 4.5\right) = 6.7 \pm 0.9(stat.) \pm 0.4(sys.)pb$$

Result can be related to HERA measurements of σ(γp → J/Ψ p)



... and is found compatible

See later: ALICE in p-Pb

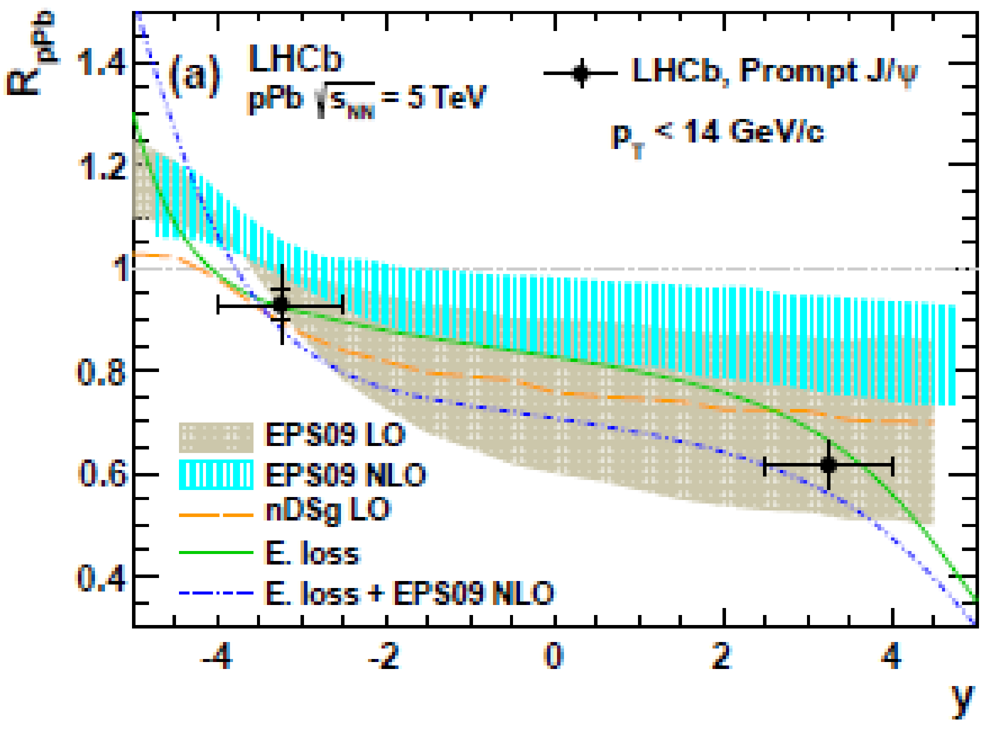
LHCb: J/Ψ Production in p-Pb

Double differential cross-section $\frac{d\sigma}{dp_T\,dy}$ for

- prompt production
- J/Ψ from b

Nuclear Modification Factor $R_{pA}(y, \sqrt{s_{NN}}) = \frac{1}{N_{coll}} \frac{d\sigma_{pA}(y, \sqrt{s_{NN}})/dy}{d\sigma_{pp}(y, \sqrt{s_{NN}})/dy}$

Production of heavy quarkonia suppressed at large rapidity in pA collisions.



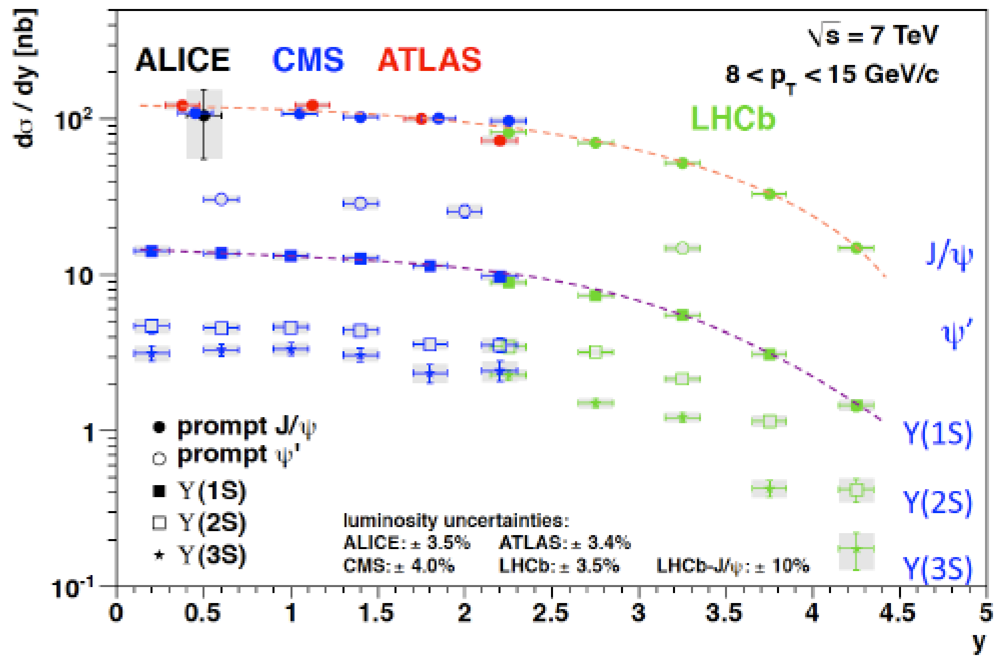
Non-CEP Quarkonium Production

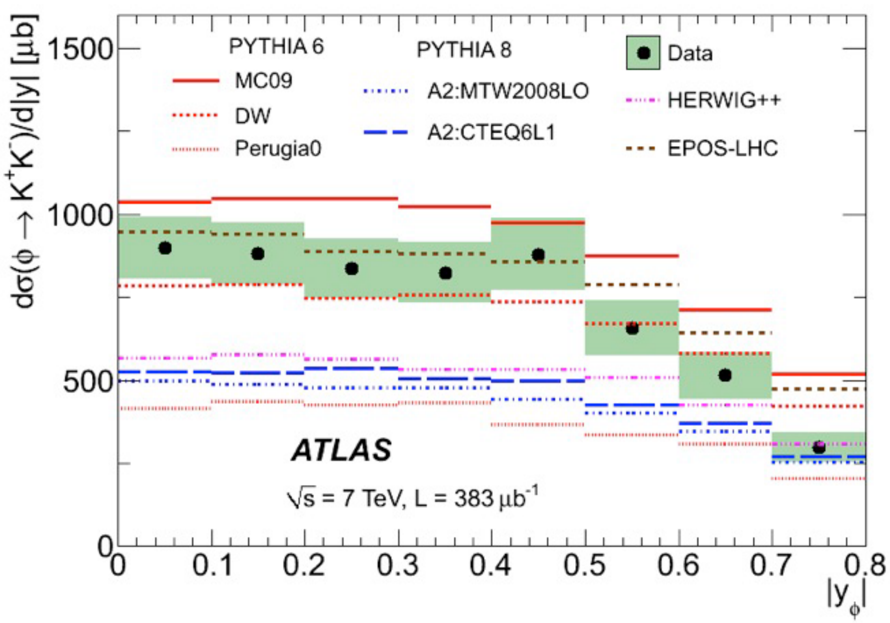
LHCb:

wealth of $c\bar{c}$ and $b\bar{b}$

(production cross-sections, polarisation)

Example:

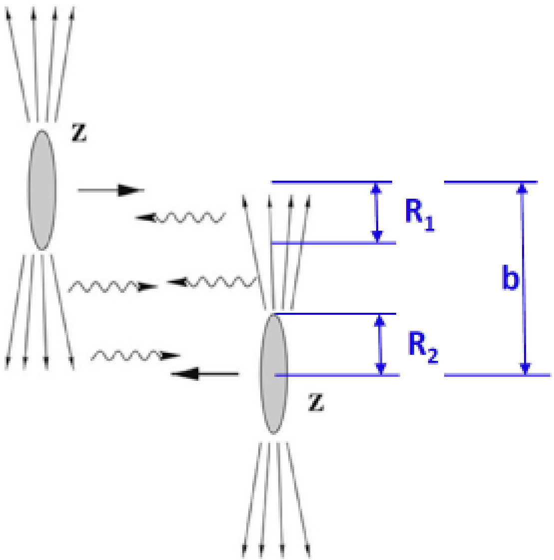




ATLAS:

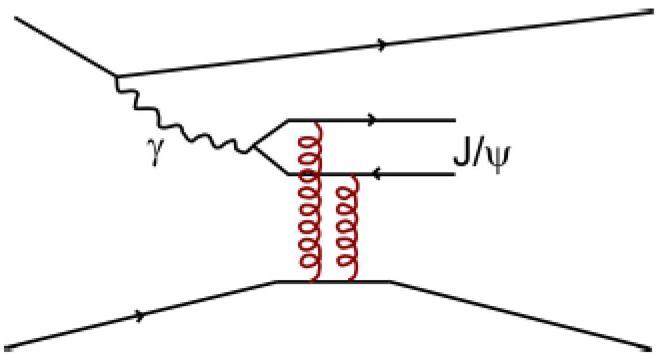
Φ (sbar s): 1019.455 ± 0.020 MeV

CEP in Ultraperipheral Collisions (p-Pb, Pb-Pb)



When $b > (R_1 + R_2)$, hadronic interactions are very much suppressed, and photon processes become important.

Photon flux $\propto Z^2$



$$\frac{d\sigma_{\gamma^* p/Pb}(t=0)}{dt} = \frac{16\Gamma_{ee}\pi^3}{3\alpha_{em} M_{J/\psi}^5}\left\{\alpha_s\left(Q^2\right) G_{p/Pb}\left(x, Q^2\right)\right\}^2$$

$$R_g^A(x, Q^2) = \frac{G_A(x, Q^2)}{G_p\left(x, Q^2\right)}$$

J/ψ photoproduction in Pb-Pb UPC gives information on gluon shadowing in nuclei at low x.

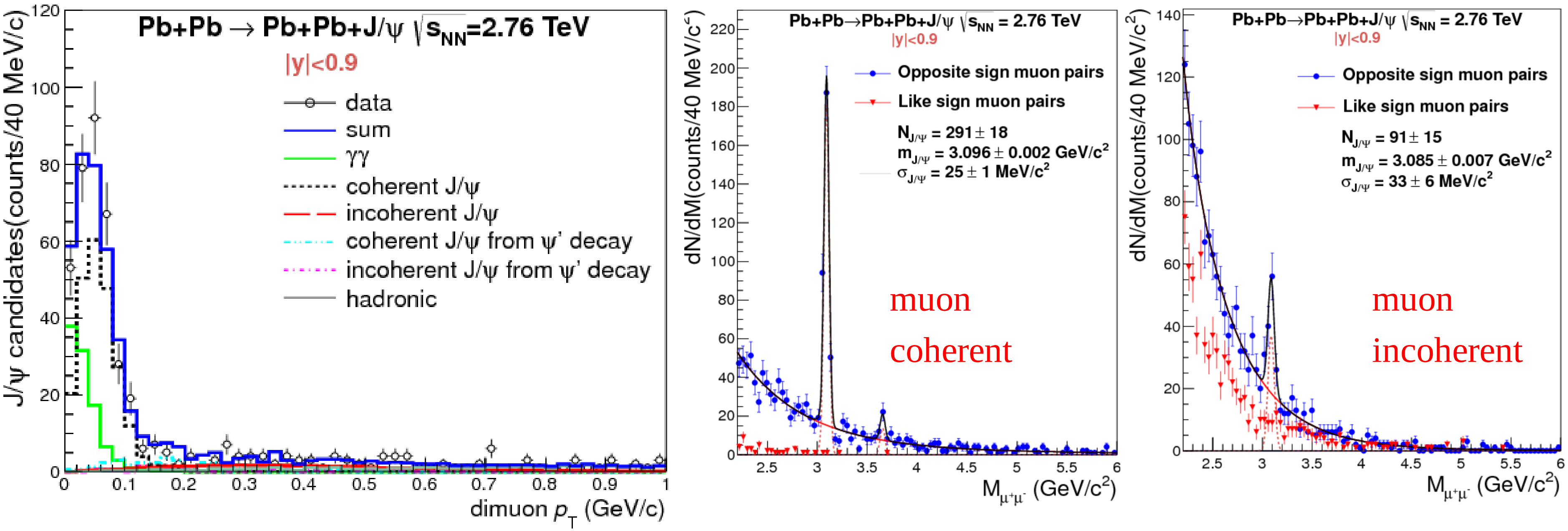
$$Q^2 \sim \frac{M_{J/\psi}{}^2}{4} \sim 2.5\ \text{GeV}^2$$

$x_{Bj} \sim 10^{-2} - 10^{-5}$

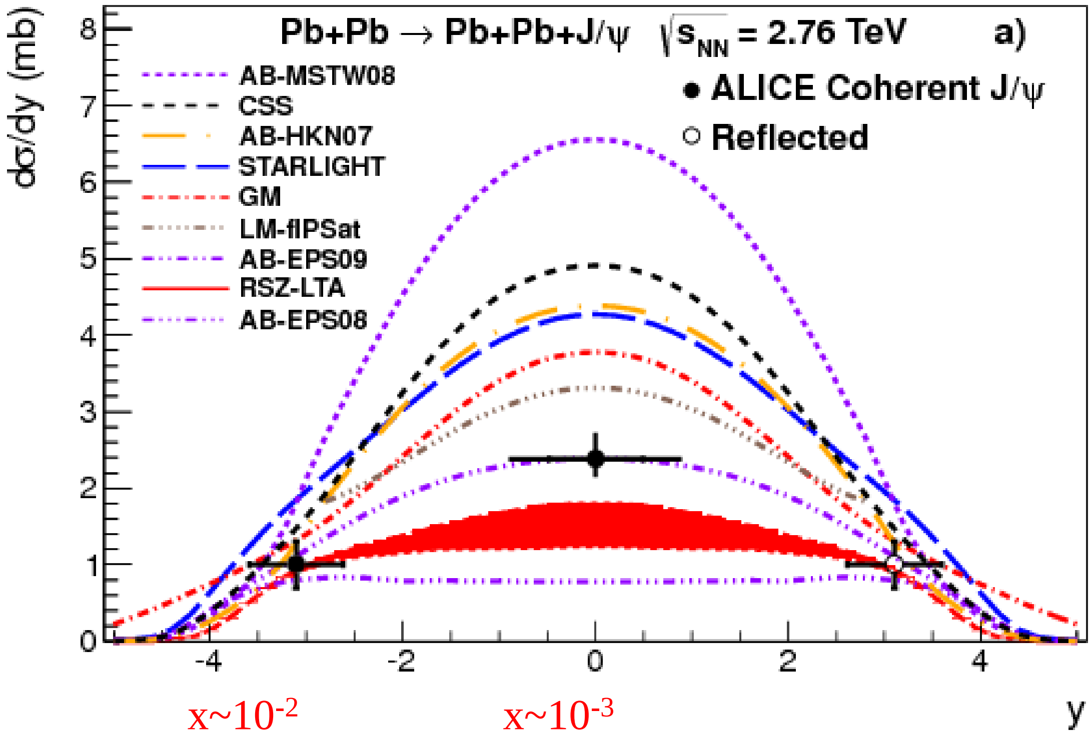
J/Ψ Production in Pb-Pb

- Measurement of J/Ψ production at forward and central rapidities
- use dimuon p_T to separate coherent (γ couples to all nucleons) from incoherent production

Example: central rapidities



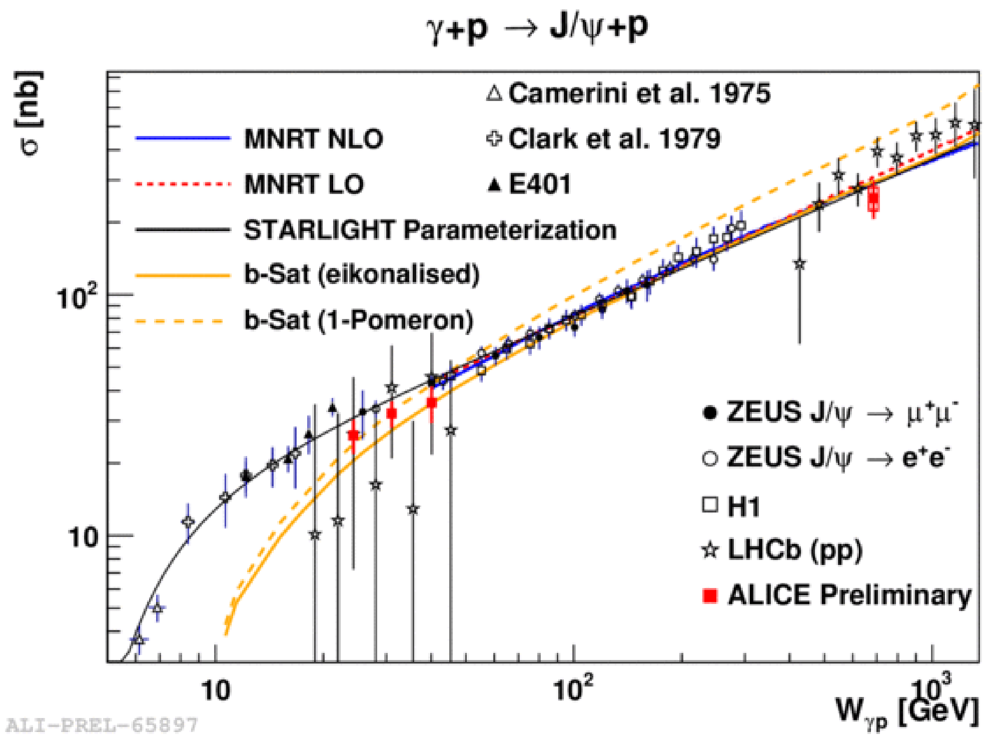
J/Ψ Production in Pb-Pb



$x \sim 10^{-2}$ $x \sim 10^{-3}$

Agreement is best for models incorporating nuclear gluon shadowing.

J/Ψ Production in p-Pb



LHCb points not updated in this plot

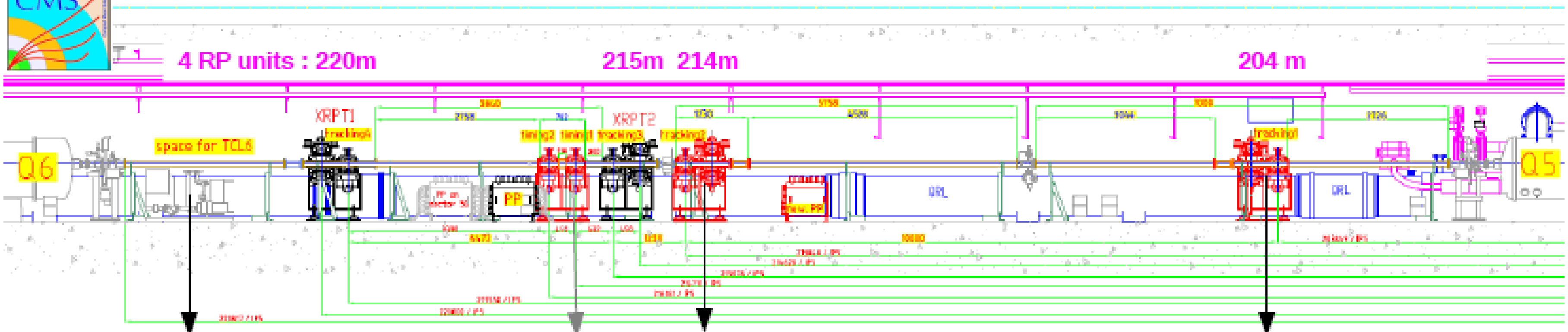
$$\frac{d\sigma}{dy}\left(p+Pb \rightarrow p+Pb+J/\psi\right) = k\frac{dn}{dk}\sigma\left(W_{\gamma p}\right)$$

$\sigma(W) \sim W^{\delta}$ gives $\delta = 0.67 \pm 0.06$.

HERA Measurements:

H1	$\delta = 0.67 \pm 0.03$
ZEUS	$\delta = 0.69 \pm 0.02$

Future Forward Physics Projects at LHC



Installation of a collimator to protect Q6

2 new horizontal cylindrical pots

RP147 (fully equipped) relocated at 203-213m
1 unit rotated by 8 degrees
Horizontal pots equipped with RF shielding

AFP – Forward Protons Detectors for ATLAS

R. Staszewski

The AFP Detectors

The Physics Programme

AFP status

- 4 RPs: stations at 206 and 214 m from IP, on both outgoing beams
- Two stations on each side – trajectory position and direction
- Tracking detectors: IBL sensors + FEI4
- Timing detectors in stations at 214 m: precise (ps) timing for reconstructing longitudinal vertex position