27th Workshop on Deep-Inelastic Scattering and Related Subjects - DIS2019
Torino, April 12th 2019

Summary of WG2: Low-x and Diffraction

Néstor Armesto
IGFAE, Universidade de Santiago de Compostela
Robert Ciesielski
The Rockefeller University
Paul R. Newman
University of Birmingham

Talks

Tue 9/4

TH **EXP**

08:00

09:00

10:00

Mass renormalization in light-front perturbation theory — *Guillaume Beuf*
Cavallerizza Reale - Aula Multifunzione 08:30 - 08:50

DIS structure functions at low x in the dipole factorization: including massive quarks at NLO — *Risto Sakari Paatelainen*

Impact of the Double-Logarithmic contribution to Pomeron on the small-x behaviour of the DIS Structure Function F_1 — *Boris Ermolaev*

Non-linear evolution in QCD at low-x beyond leading order — *Dr Dionysios Triantafyllopoulos*
Cavallerizza Reale - Aula Multifunzione 09:30 - 09:50

Gradient corrections to the classical McLerran-Venugopalan model — *Douglas Wertepny*
Cavallerizza Reale - Aula Multifunzione 09:50 - 10:10

11:00

12:00

Diffractive PDF determination from HERA inclusive and jet data at NNLO QCD — *Radek Zlebcik*
Cavallerizza Reale - Aula Multifunzione 10:45 - 11:05

Measurements of single diffraction using the ALFA forward spectrometer at ATLAS — *Marek Tasevsky*
Cavallerizza Reale - Aula Multifunzione 11:05 - 11:25

Recent CMS and CMS-TOTEM results on diffraction — *Katerina Kuznetsova*
Cavallerizza Reale - Aula Multifunzione 11:25 - 11:45

Elastic and Total Cross-Section Measurements by TOTEM — *Frigyes Janos Nemes*
Cavallerizza Reale - Aula Multifunzione 11:45 - 12:05

Searching for odderon in exclusive reactions: $pp \to pp p {\bar p}$, $pp \to pp \phi \phi$ and $pp \to pp \phi$ — *Antoni Szczurek et al.*

14:00

15:00

On correlators of Reggeon fields in high energy QCD — *Dr Sergey Bondarenko*
Cavallerizza Reale - Aula Multifunzione 14:00 - 14:20

One-loop corrections to multiscale effective vertices in the EFT for Multi-Regge processes in QCD — *Dr Maxim Nefedov*

Differential and total cross sections of high energy proton-proton scattering in holographic QCD — *Akira Watanabe*

Hard diffraction and fluctuations in small-x evolution — *Stéphane Munier*
Cavallerizza Reale - Aula Multifunzione 15:00 - 15:20

Diffractive Dijet Production and Wigner Distributions from the Color Glass Condensate — *Dr Heikki Mäntysaari*

16:00

17:00

Forward Drell-Yan and backward jet production as a probe of the BFKL dynamics — *Golec-Biernat Krzysztof et al.*

Inclusive production of two rapidity-separated heavy quarks as a probe of BFKL dynamics — *Alessandro Papa*

Unequal rapidity correlators in the dilute limit of JIMWLK — *Andrecia Ramnath*
Cavallerizza Reale - Aula Multifunzione 16:55 - 17:15

BFKL Pomeron loops in photoproduction and hadroproduction of J/psi at large transverse momenta — *Leszek Motyka*

Production of J/ψ quarkonia in color evaporation model based on k_{T}-factorization — *Rafal Maciula et al.*

Talks

Wed 10/4

TH **EXP**

08:00

09:00

Exclusive $\rho(770)$ photoproduction at HERA — *Arthur Bolz*
Cavallerizza Reale - Aula Multifunzione 08:50 - 09:10

Measurement of the Psi(2S) to J/Psi cross section ratio in photoproduction with the ZEUS detector at HERA — *Alessia Bruni*

Transverse Spin Asymmetries in the $p^{\uparrow}p \to p\pi^{0} X$ Process at STAR — *Christopher Dilks*

10:00

Coherent J/ψ photoproduction in ultra-peripheral collisions at STAR — *Jaroslav Adam*
Cavallerizza Reale - Aula Multifunzione 09:50 - 10:10

11:00

Recent ALICE results on coherent J/psi photoproduction in ultra-peripheral Pb-Pb collisions — *Evgeny Kryshen*

Soft QCD and Central Exclusive Production at LHCb — *Marcin Kucharczyk*
Cavallerizza Reale - Aula Multifunzione 11:05 - 11:25

Recent CMS results on exclusive processes — *Aleksandr Bylinkin*
Cavallerizza Reale - Aula Multifunzione 11:25 - 11:45

12:00

Small-x physics in ultraperipheral collisions at the LHC — *Prof. Mark Strikman*
Cavallerizza Reale - Aula Multifunzione 11:45 - 12:15

14:00

Towards a determination of the low x gluon via exclusive HVM production — *Chris Flett*
Cavallerizza Reale - Aula Multifunzione 14:00 - 14:20

Results and prospects with the CMS-TOTEM Precision Proton Spectrometer — *Antonio Vilela Pereira*
Cavallerizza Reale - Aula Multifunzione 14:20 - 14:40

Photon-photon fusion measurements at ATLAS — *Samira Hassani*
Cavallerizza Reale - Aula Multifunzione 14:40 - 15:00

15:00

Searches for Dark Matter at the LHC in forward proton mode — *Marek Tasevsky*
Cavallerizza Reale - Aula Multifunzione 15:00 - 15:20

16:00

Probing transversity GPDs in diffractive electroproduction on the proton and deuteron at an electron-ion collider — *Wim Cosyn*

Determination of diffractive parton densities at the LHeC and the FCC-eh — *Anna Stasto*
Cavallerizza Reale - Aula Magna 16:35 - 16:55

17:00

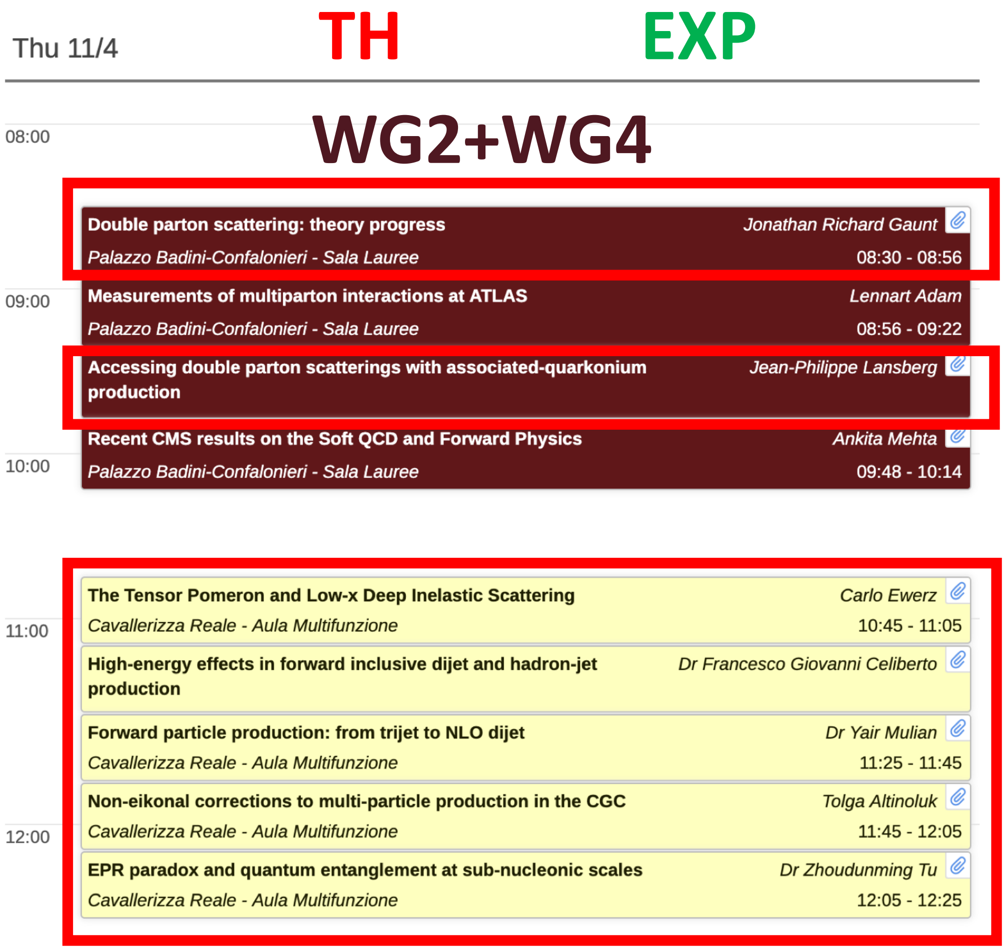
Measuring the Weizsäcker-Williams distribution of linearly polarized gluons at an electron-ion collider through dijet azimuthal asymmetries — *Vladimir Skokov*

Sub-eikonal spin corrections and g1 structure function at low-x — *Giovanni Antonio Chirilli*
Cavallerizza Reale - Aula Magna 17:15 - 17:35

Collinearly improved impact-parameter dependent Balitsky-Kovchegov evolution — *Marek Matas*
Cavallerizza Reale - Aula Magna 17:35 - 17:55

WG2+WG7

Talks



- 37 talks in WG2: 24 TH + 13 EXP
- 5 talks in WG2+WG7: 5 TH (here 4 covered)
- 4 talks in WG2+WG4: 2 TH + 2 EXP (here 2 covered)

Inclusive Xsections: NLO with massive quarks

Quark mass counterterms on the light-front

Earlier results on mass renormalization on the light-front

UV divergent one-loop corrections in QED and QCD on the light-front first calculated long ago
Mustaki, Pinsky, Shigemitsu and Wilson, PRD43 (1991)
Harindranath and Zhang, PRD48 (1993)

→ Puzzling results:

- Same result for the quark vertex mass correction as in covariant PT
- But different result for the quark kinetic mass correction
  ⇒ Do vertex mass and kinetic mass become different objects on the light front, with different counter-terms and different anomalous dimensions?
- Non-zero correction to the gluon mass
  ⇒ Can the bare and the renormalized gluon masses vanish simultaneously in light-front quantization?

Guillaume Beuf (University of Jyväskylä) Mass renormalization in light-front perturbation theory DIS 2019, Torino, 8 - 12 April 2019 5 / 17

$$\int \frac{d^{D-2}\mathbf{k}}{(2\pi)^{D-2}} \int_0^{+\infty} \frac{dk^+}{k^+} \mapsto \frac{2}{(D-2)} \int \frac{d^{D-2}\mathbf{k}}{(2\pi)^{D-2}} \left[1 - \frac{m_i^2}{\mathbf{k}^2 + m_i^2}\right]$$

G. Beuf

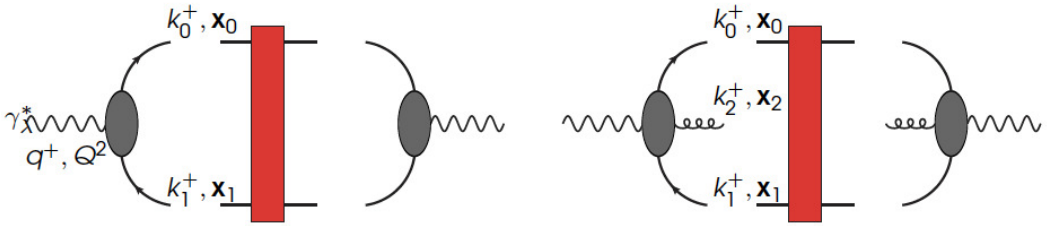
- With this substitution

→ Expected results finally obtained:

- The gluon mass stays zero without needing a counter-term
- The quark mass stays the same in the energy denominators and in the vertices
- The quark mass renormalization constant is the same as in covariant PT, including the finite terms in the on-shell scheme

Reformulation of LFPT with Lorentz-invariant UV regularization

$$\sigma_\lambda^{\gamma^*} = 2N_c \int \widetilde{PS}_{q\bar{q}} |\widetilde{\psi}^{\gamma_\lambda^* \to q\bar{q}}|^2 \Re e[1 - \mathcal{S}_{01}] + 2N_c C_F \int \widetilde{PS}_{q\bar{q}g} |\widetilde{\psi}^{\gamma_\lambda^* \to q\bar{q}g}|^2 \Re e[1 - \mathcal{S}_{012}]$$



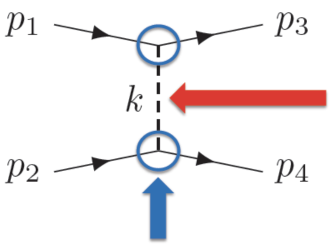
- Full result for the cross section for longitudinally polarised photons with massive quarks!

R. Paatelainen

Inclusive Xsections: soft modelling

A. Watanabe

Model setup



Domokos-Harvey-Mann (2009)

Reggeized spin-2 particle propagator

- 3 adjustable parameters are determined with data

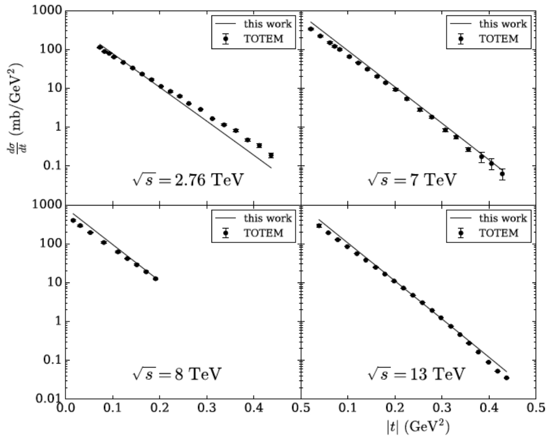
Gravitational form factor

- Calculable with a bottom-up AdS/QCD model
- Model parameters are fixed by hadron properties

Applicable for other hadron-hadron scattering processes by replacing the form factors

$$\frac{d\sigma}{dt} = \frac{\lambda^4 A^4(t)\Gamma^2[-\chi]\Gamma^2\left[1-\frac{\alpha_c(t)}{2}\right]}{16\pi\Gamma^2\left[\frac{\alpha_c(t)}{2}-1-\chi\right]}\left(\frac{\alpha'_c s}{2}\right)^{2\alpha_c(t)-2}$$

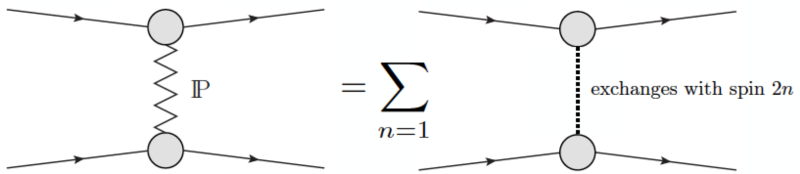
$$\sigma_{tot} = \frac{\pi\lambda^2\Gamma[-\chi]}{\Gamma\left[\frac{\alpha_c(0)}{2}\right]\Gamma\left[\frac{\alpha_c(0)}{2}-1-\chi\right]}\left(\frac{\alpha'_c s}{2}\right)^{\alpha_c(0)-1}$$



- 3 fitting parameters to describe both observables.

Akira Watanabe (IHEP) DIS2019 @ Torino (April 9, 2019) 7

C. Ewerz



$$6\,\text{GeV} \leq \sqrt{s} \leq 318\,\text{GeV}$$

$$0 < Q^2 < 50\,\text{GeV}^2 \quad \text{and} \quad x < 0.01$$

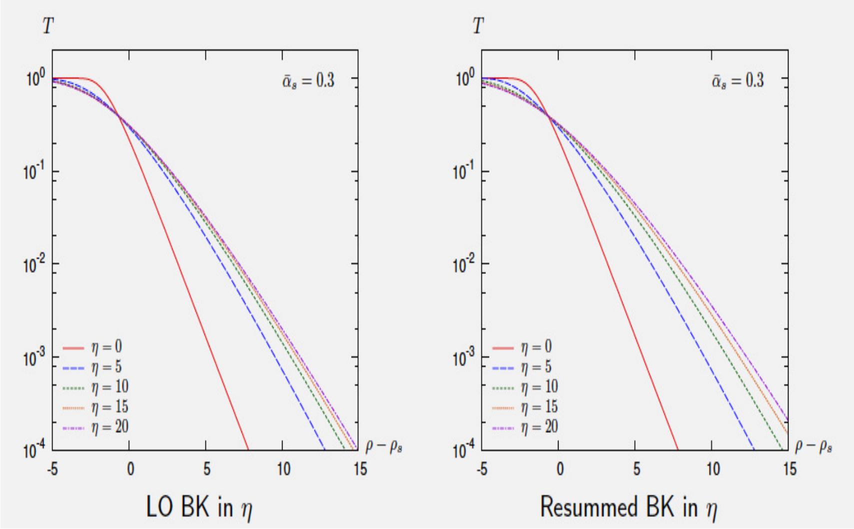
- We have developed a 2-tensor-pomeron model and have made a fit to photoproduction and low-x DIS data from HERA.
- We obtain a very satisfactory fit and determine in particular the intercepts of the two pomerons and the f_2 reggeon.
- For DIS, the soft contribution is still clearly visible up to about $Q^2 = 20$ GeV. The transition from low to high Q^2 is nicely described.

- Regge model: hard+soft tensor pomerons + a Reggeon, to describe DIS σ^{red}: 25 parameters.

Evolution equations: collinear improvements

D. Triantafyllopoulos

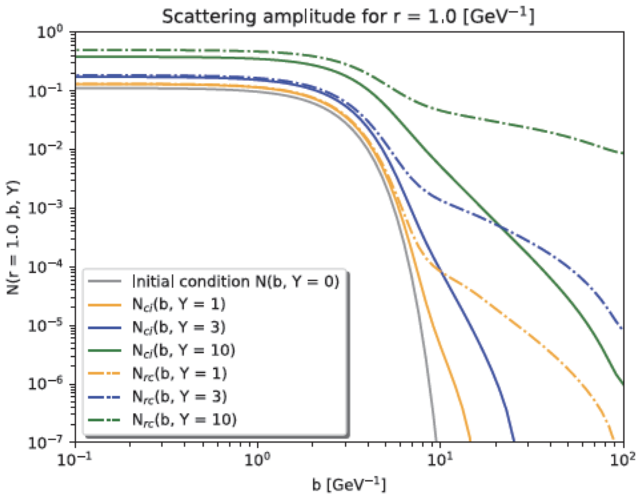
- Instability of NLO BK (large $\ln^2$) motivated resummation: evolution from projectile to target then corrected for lifetime ordering, requires fine tuning.



- Inverted evolution, corrected for k^+-ordering, gives stable and phenomenologically acceptable results.
- Step towards solving the problem of the 'right' evolution variable unifying BK/BFKL with DGLAP.

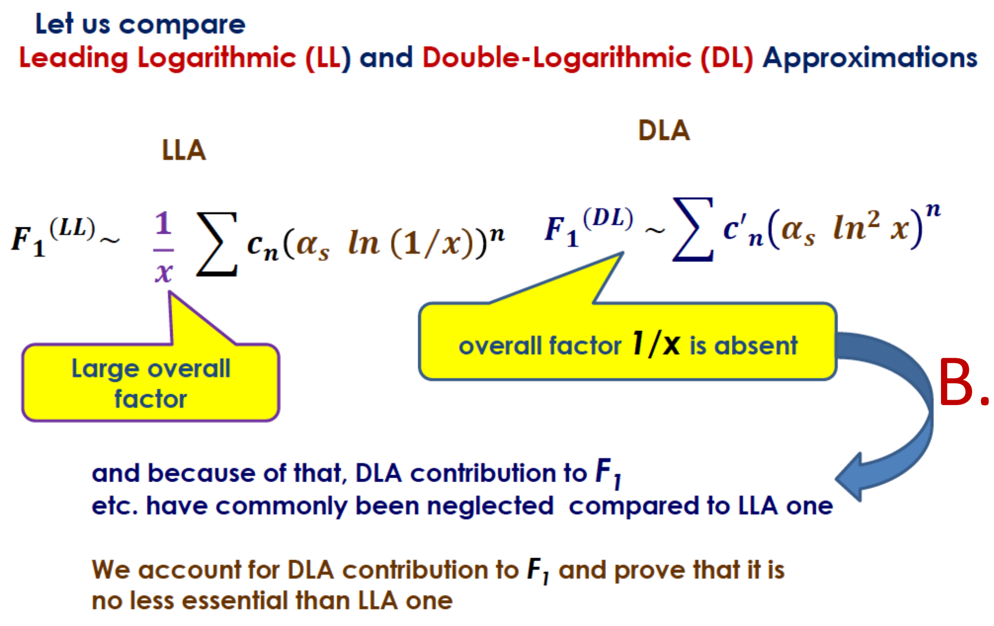
M. Matas

- Problem in BK evolution for large impact parameters: ill-behaved, Coulomb tails to be tamed by confinement.



- Collinear resummations imply a regulation of the BK kernel that seems to cure the problem (without any additional parameter!?): description of inclusive, charm and EVM HERA data.

Evolution equations: DLA


Let us compare
Leading Logarithmic (LL) and Double-Logarithmic (DL) Approximations

LLA

DLA

$$F_1^{(LL)} \sim \frac{1}{x} \sum c_n (\alpha_s \ ln\ (1/x))^n \qquad F_1^{(DL)} \sim \sum c'_n (\alpha_s \ ln^2\ x)^n$$

Large overall factor

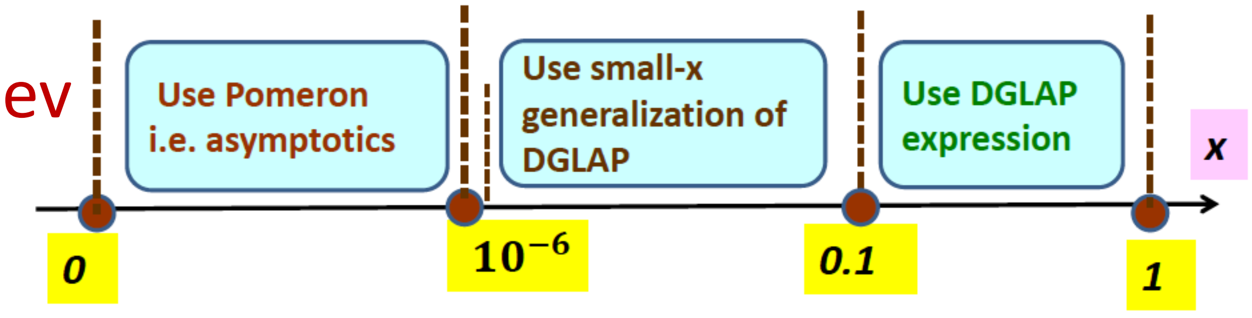
overall factor $1/x$ is absent

and because of that, DLA contribution to F_1 etc. have commonly been neglected compared to LLA one

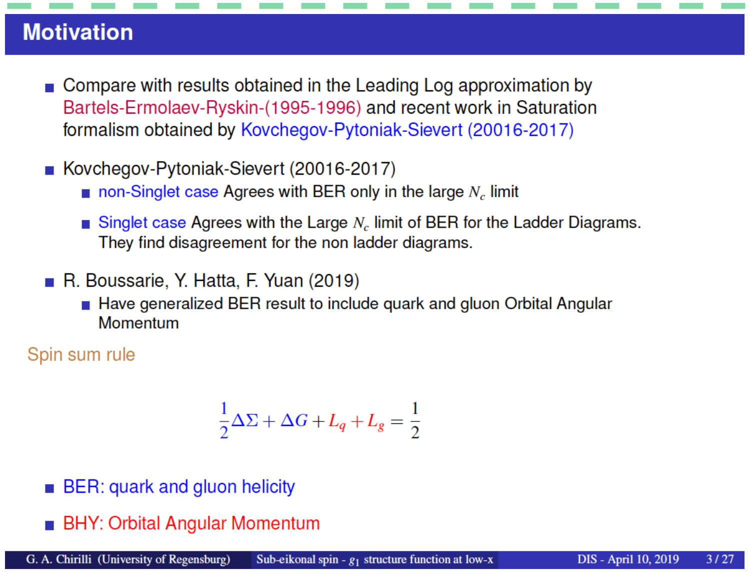
We account for DLA contribution to F_1 and prove that it is no less essential than LLA one

- DLA previously used for g_1, applied here for F_1.
- Leads to asymptotic scaling in Q^2/x^2, and a Pomeron-like behaviour with intercept smaller than BFKL.

B. Ermolaev



G. Chirilli


Motivation

- Compare with results obtained in the Leading Log approximation by Bartels-Ermolaev-Ryskin-(1995-1996) and recent work in Saturation formalism obtained by Kovchegov-Pytoniak-Sievert (20016-2017)
- Kovchegov-Pytoniak-Sievert (20016-2017)
  - non-Singlet case Agrees with BER only in the large N_c limit
  - Singlet case Agrees with the Large N_c limit of BER for the Ladder Diagrams. They find disagreement for the non ladder diagrams.
- R. Boussarie, Y. Hatta, F. Yuan (2019)
  - Have generalized BER result to include quark and gluon Orbital Angular Momentum

Spin sum rule

$$\frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g = \frac{1}{2}$$

- BER: quark and gluon helicity
- BHY: Orbital Angular Momentum

G. A. Chirilli (University of Regensburg) Sub-eikonal spin - g_1 structure function at low-x DIS - April 10, 2019 3 / 27

- Non-eikonal corrections considered in Balitsky's HE OPE, fundamental for spin physics.
- Evolution equations for flavour non-singlet and flavour singlet polarised structure functions presented, coinciding with Bartels-Ermolaev-Ryskin: DLA.

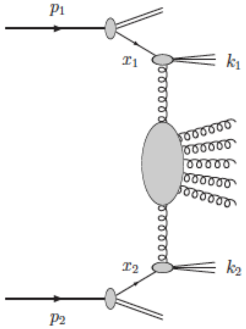
Particle production: BFKL dynamics

- Mueller-Navelet jet production

- NLO jet vertex
[J. Bartels, D. Colferai, G.P. Vacca (2003)]
[F. Caporale, D.Yu. Ivanov, B. Murdaca, A.P., A. Perri (2011)]
[D.Yu. Ivanov, A.P. (2012)] (small-cone approximation)
[D. Colferai, A. Niccoli (2015)]

- azimuthal correlations (full NLA) and other
[B. Ducloué, L. Szymanowski, S. Wallon (2013,2014)]
[F. Caporale, D.Yu. Ivanov, B. Murdaca, A.P. (2014)]
[F.G. Celiberto, D.Yu. Ivanov, B. Murdaca, A.P. (2015)]

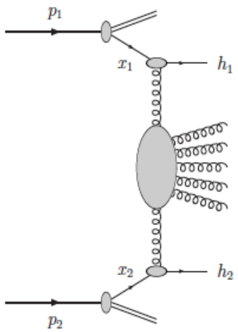
- compatible with CMS (7 TeV)



- hadron-hadron production

- NLO hadron vertex [D.Yu. Ivanov, A.P. (2012)]

- azimuthal correlations (full NLA) and other
[F.G. Celiberto, D.Yu. Ivanov, B. Murdaca, A.P. (2016,2017)]



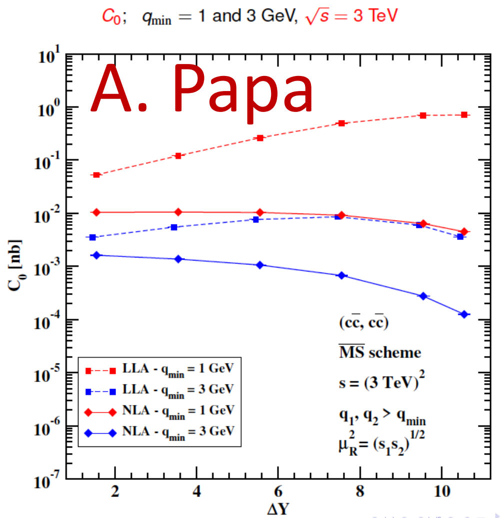
- hadron-jet production (full NLA)
[A.D. Bolognino, F.G. Celiberto, D.Yu. Ivanov, M.M.A. Mohammed, A.P. (2018)]

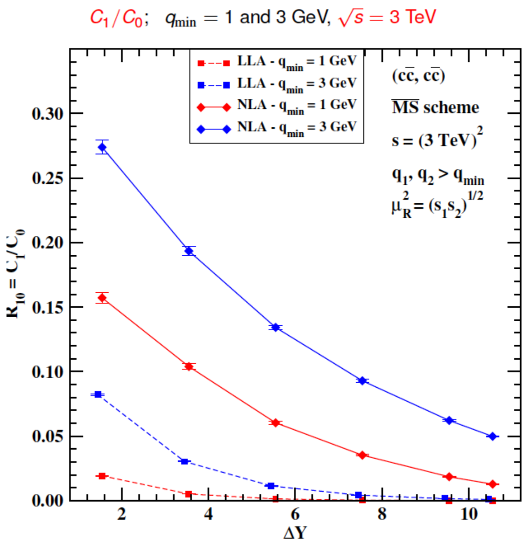
- three / four jet production (partial NLA)
[F. Caporale, G. Chachamis, B. Murdaca, A. Sabio Vera (2016)]
[F. Caporale, F.G. Celiberto, G. Chachamis, A. Sabio Vera (2016)]
[F. Caporale, F.G. Celiberto, G. Chachamis, D.G. Gomez, A. Sabio Vera (2016,2017)]

- J/Ψ - jet production (partial NLA)
[R. Boussarie, B. Ducloué, L. Szymanowski, S. Wallon (2018)]

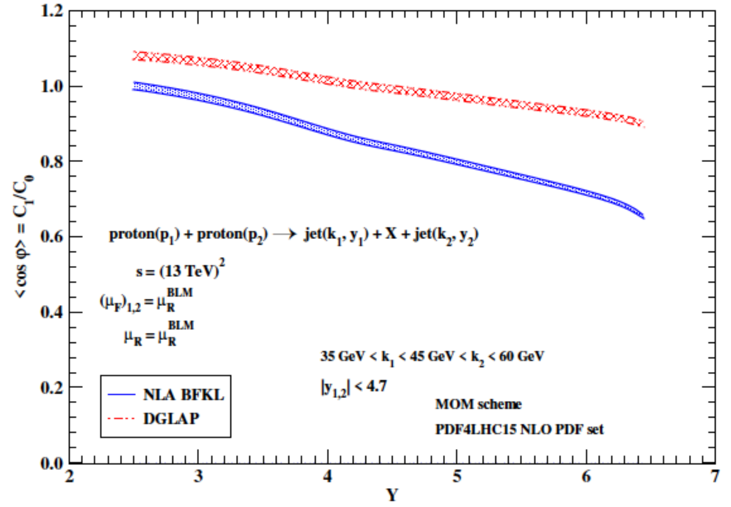
- Drell-Yan pair - jet (partial NLA) [K. Golec-Biernat, L. Motyka, T. Stebel (2018)]

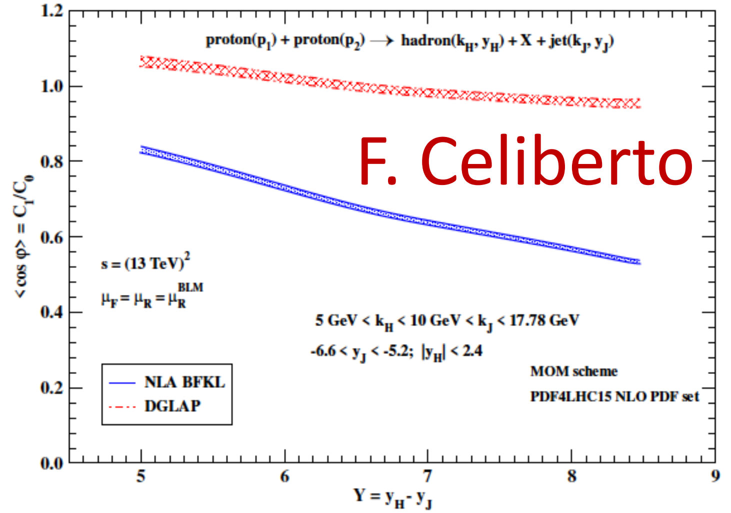
- Rapidity separated QQ in γγ collisions:





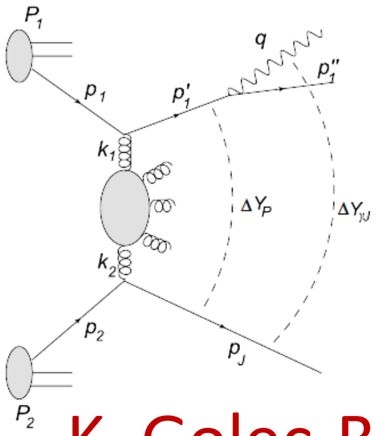
- Rapidity separated h-jet in pp collisions:





Particle production: BFKL dynamics

- Replace one of the jets by forward/backward DY lepton pair

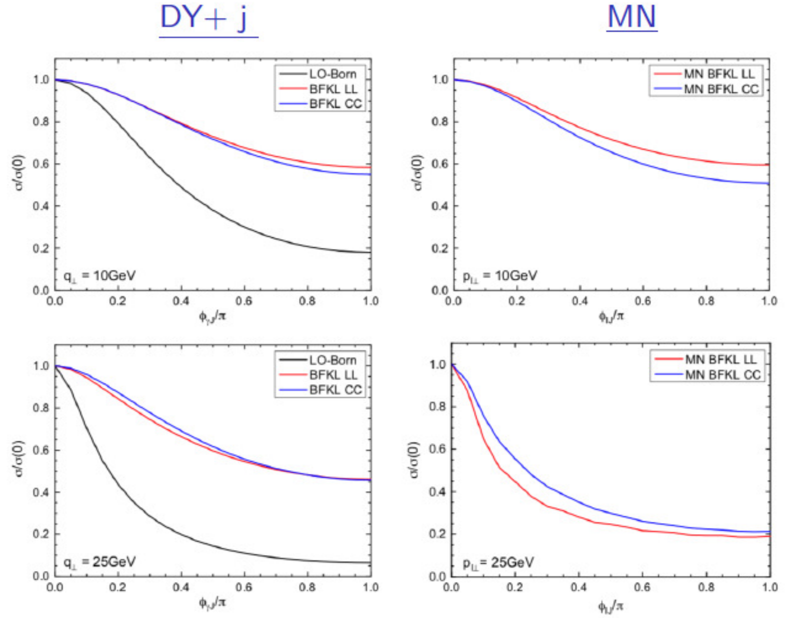


K. Golec-Biernat

- DY pair is more versatile probe than jet itself.

$$\sigma(\phi_{\gamma J}) \equiv \frac{dW_T}{d(\Delta Y_{\gamma j})dp_J^2} + \frac{1}{2}\frac{dW_L}{d(\Delta Y_{\gamma j})dp_J^2}$$

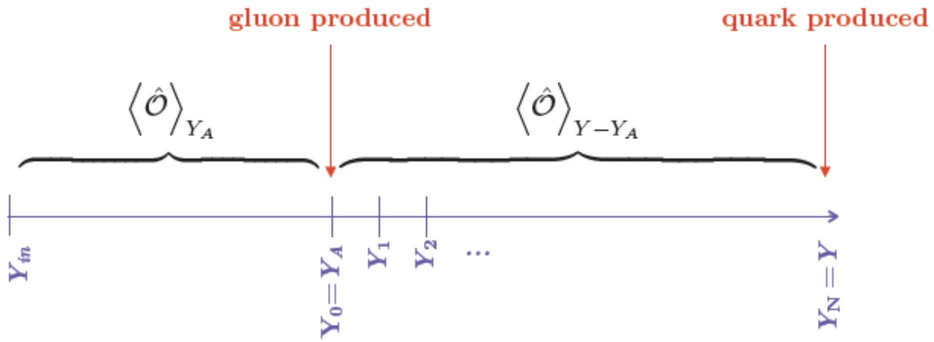
- Helicity structure of the lepton pair angular dependence in DY+jet: stronger decorrelation than in MN.



A. Ramnath

$$\left\langle \hat{\mathcal{O}} \right\rangle_{Y-Y_A} \equiv \int [DU D\bar{U}] W_{Y-Y_A}[U,\bar{U}|U_A,\bar{U}_A]\hat{\mathcal{O}}$$

$$\frac{\partial}{\partial Y} W_{Y-Y_A}[U,\bar{U}|U_A,\bar{U}_A] = H_{\text{evol}} W_{Y-Y_A}[U,\bar{U}|U_A,\bar{U}_A]$$



- Small-x evolution of a qg system separated in rapidity, valid in pA (JIMWLK) sent to the dilute limit: BFKL in pp, first step towards generalising Mueller-Navelet-like observables to dense systems.

Particle production: entanglement

K. Tu

Parton model

- Based on "quasi-free" partons that are frozen in the Infinite momentum frame.

Color confinement

- Partons are not just correlated, they cannot exist as free particles in nature

One conceptual question arises:

- One set of incoherent partons corresponds to a non-zero von Neumann entropy $S \neq 0$

How to understand?

- Proton is a pure quantum mechanical state, its entropy is zero $S = 0$

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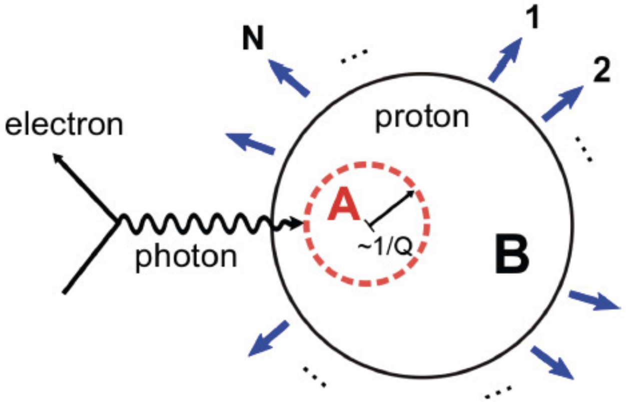
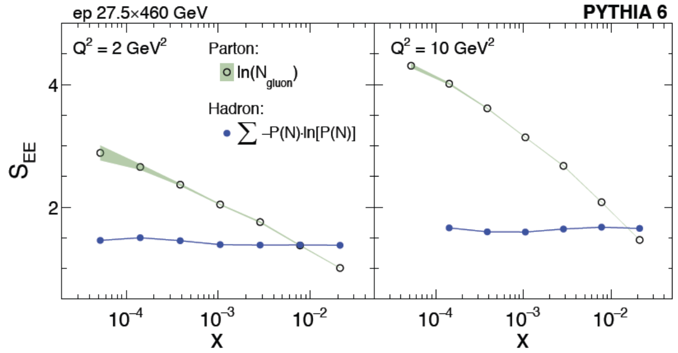


ep



- At similar kinematics in x and Q^2 (region A), the S_{EE} can be checked from the entropy of finite-state hadron around region A

prediction

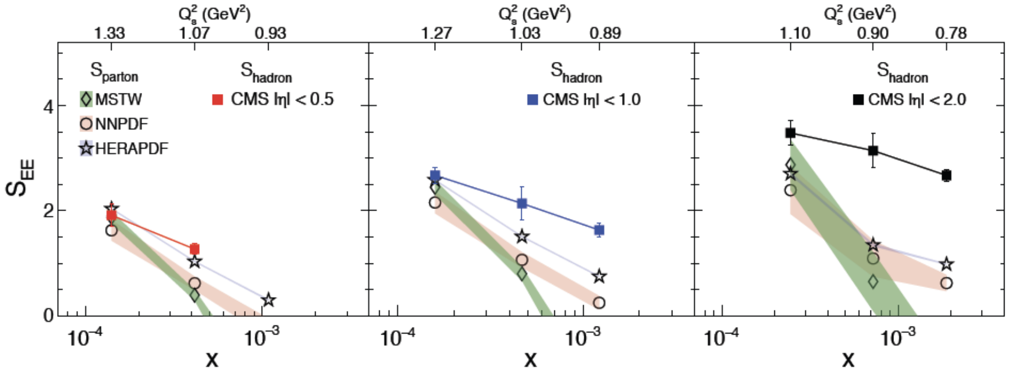
$$S_{EE} = \ln[xG]$$

experiment

$$S_{hadron} = -\sum P(N) \ln[P(N)]$$

Assuming entropy doesn't grow much

pp



- The event kinematics define the region of interest, using relation between x and rapidity,

$$\ln\left(\frac{1}{x}\right) \approx y_{beam} - y_{hadron}$$ *(arXiv:hep-ph/9903536)*

For example,

fixed Q^2, and x, e.g., $\mathbf{x \in (x_1,x_2)}$ → Final-state hadrons $\mathbf{y \in (y_1,y_2)}$

prediction

experiment

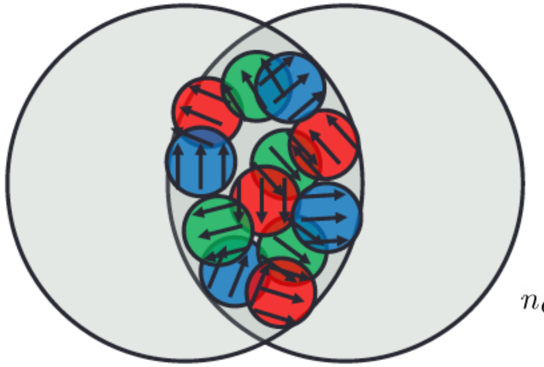
$$S_{EE}^{(x_1<x<x_2)} = \ln[xG] \stackrel{?}{=} S_{hadron}^{(y_1<y<y_2)} = -\sum P(N) \ln[P(N)]$$

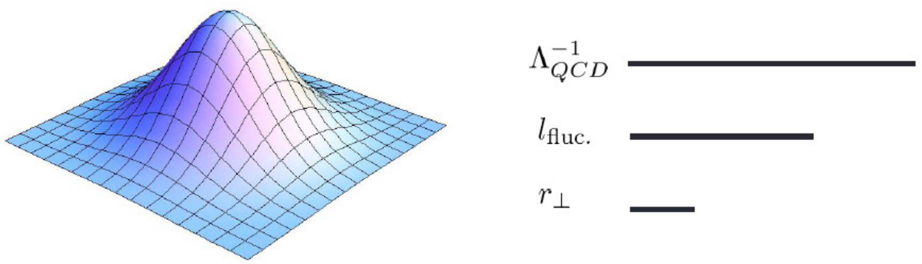
Particle production: correlations

- Azimuthal asymmetries may have final or initial state origin.
- Initial state: microscopic picture based on classical calculations, may the hadron have a non-trivial structure?
- This depends on a hierarchy of scales.

D. Wertepny

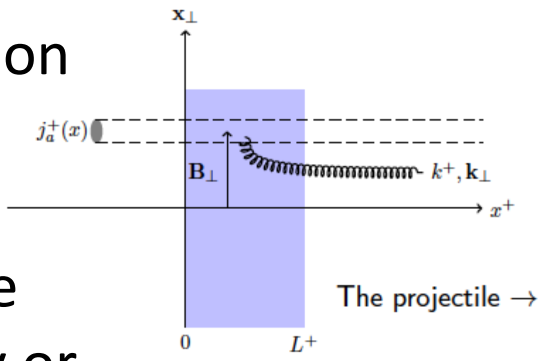
Small Systems





$$n_G(\vec{r},\vec{b}) = \int \frac{d^2p}{(2\pi)^2} e^{i\vec{p}\cdot\vec{b}} \frac{1}{4}\tilde{Q}_s^2(\vec{p})\vec{r}_i\vec{r}_j \left(\delta_{ij}\left(\ln\frac{2}{p_\perp r_\perp} - \gamma_E + 1\right) - \left(\frac{\vec{p}_i\vec{p}_j}{p_\perp^2} - \frac{1}{2}\delta_{ij}\right)\right)$$

- Basic failure for the description of small systems: absence of odd harmonics.
- Several ideas: domains in the hadron, higher order density or non-eikonal corrections? Effects on single and double inclusive.

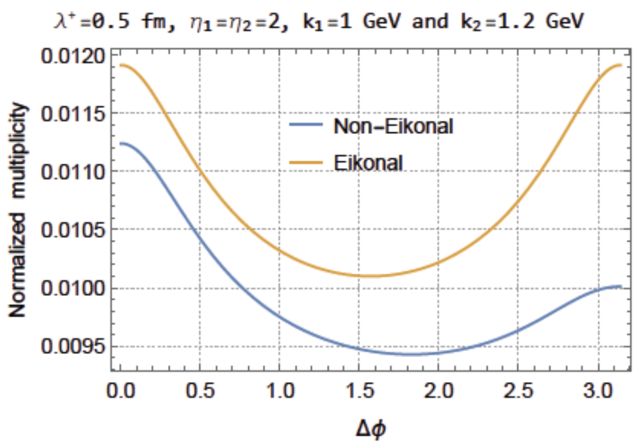


The target $\rightarrow \mathcal{A}^\mu(x) \equiv \delta^{\mu -} \mathcal{A}_a^-(x^+, \mathbf{x})$

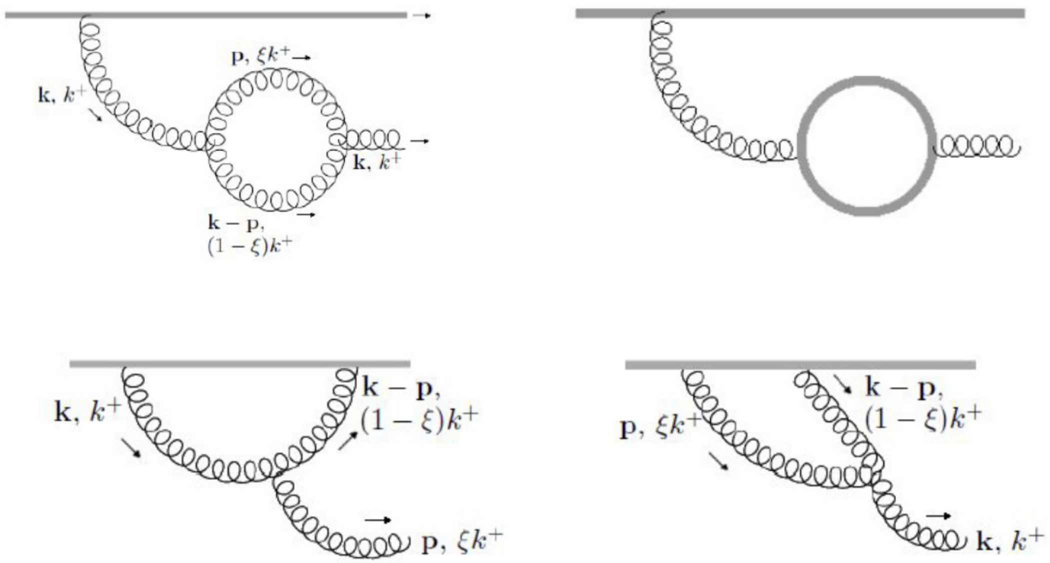
The projectile $\rightarrow j_a^\mu(x) \propto \delta^{\mu +}\delta(x^-)\,\rho^b(\mathbf{x}-\mathbf{B})$

$$L^i_{\rm NE}(k,q) = \left[\frac{(k-q)^i}{(k-q)^2} - \frac{k^i}{k^2}\right] e^{ik^- x^+}$$

T. Altinoluk



Particle production: theory improvements

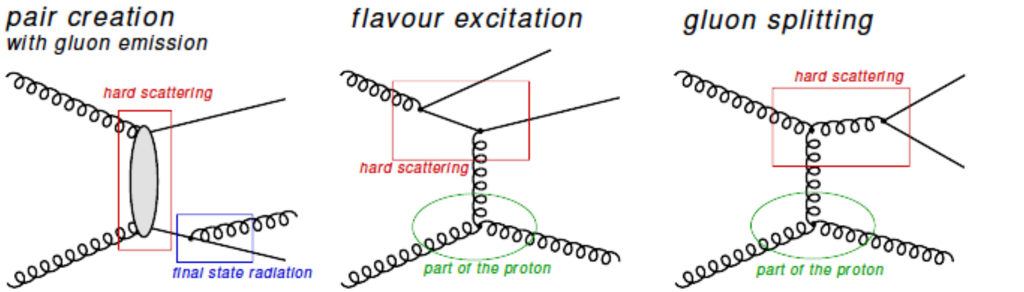


- Calculation in LCPT ongoing of dijet production in the forward direction at NLO: essential for comparison to data and to verify the relation with TMD factorisation at small x beyond LO.

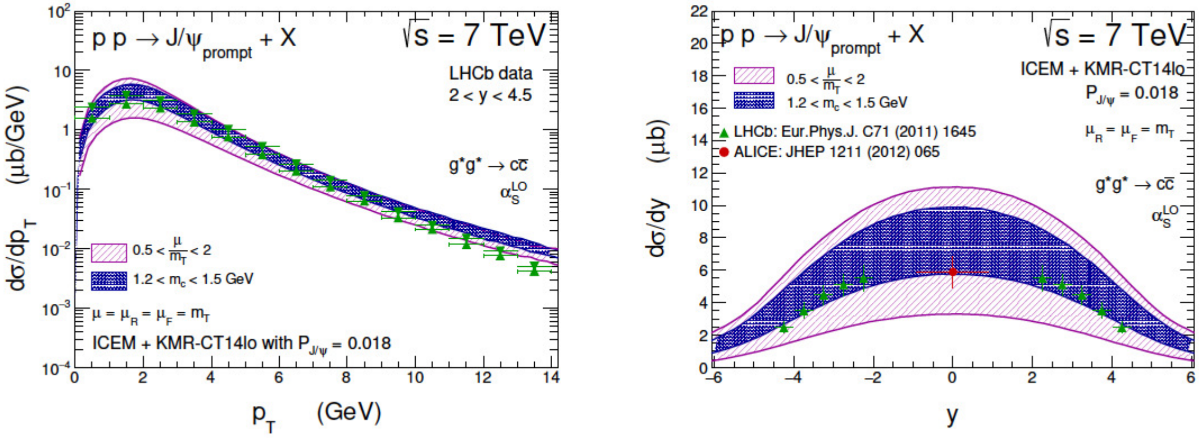
Y. Mulian

- J/ψ production in the improved CEM in k_T-factorisation.

R. Maciula



- Good description of data using several uPDFs.

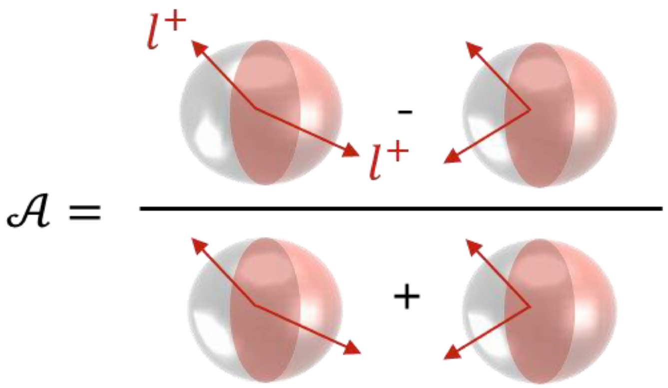


Particle production: DPS

Summary

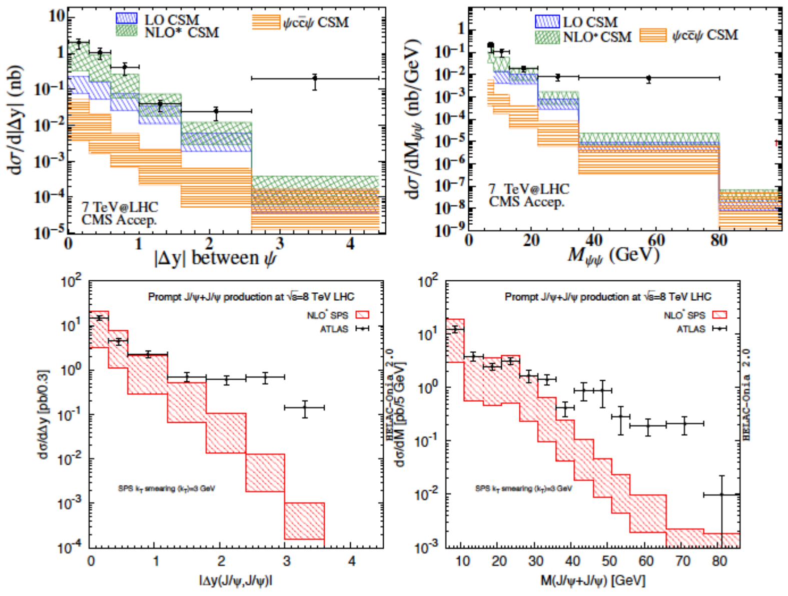
J. Gaunt

- DGS framework: cut-off in DPS cross section + subtraction to avoid double counting. Various advantages (retains individual DPDs per proton…)
- DPS luminosities:
  - generically very large 1v1 with large uncertainty – have to compute SPS and subtraction up to two-loop.
  - some scenarios where DPS more 'prominent' – processes at small x, processes with systems separated in rapidity, same sign WW.
- Theory framework has also been extended to the case of measured transverse momentum. Significant simplifications for perturbative $\boldsymbol{q}_i$.
- Interference & correlated parton contributions in spin, colour, flavour, parton type. Typically washed away quickly by evolution. Possible chance to detect spin correlations in WW?
- Some guide on NP shape of DPDs from models. First info from lattice computations emerging.
- Shower implementation of DGS framework in development.
- pA DPS has two contributions, probe DPDs in different way. Potential prospects to separate the two pieces using centrality dependence.



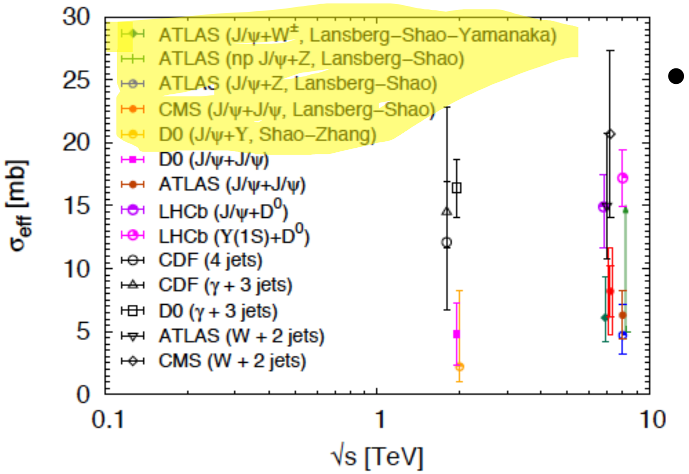
J.-P. Lansberg

Particle production: DPS

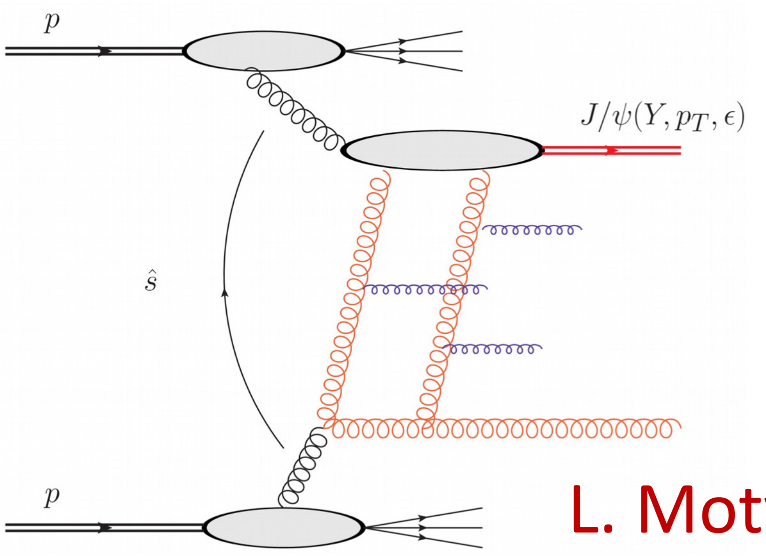


- Under DPS dominance (e.g. large Δy), $\sigma_{ab}^{\rm DPS} = \frac{m}{2}\frac{\sigma_a \sigma_b}{\sigma_{\rm eff}}$ (m: symmetry factor)

$$F_{\psi\psi}^{\chi_c} = F_{\psi}^{\chi_c} \times \left(F_{\psi}^{\chi_c} + 2F_{\psi}^{\rm direct} + 2F_{\psi}^{\psi'}\right), F_{\psi\psi}^{\psi'} = F_{\psi}^{\psi'} \times \left(F_{\psi}^{\psi'} + 2F_{\psi}^{\rm direct} + 2F_{\psi}^{\chi_c}\right), F_{\psi\psi}^{\rm direct} = \left(F_{\psi}^{\rm direct}\right)^2$$

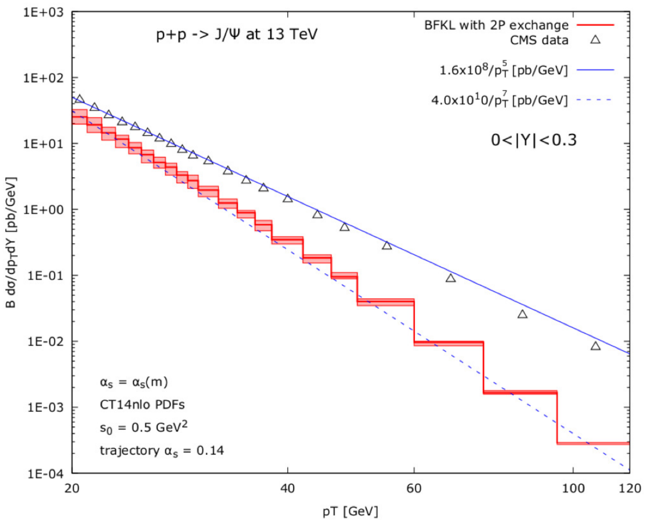


- Quarkonium-based extractions of $\sigma_{\rm eff}$ give a lower value: flavour or rapidity dependence?



L. Motyka

- Quarkonium production in the CSM considering double Pomeron (DPS) contribution: loops, BKP states.
- Seems to have a small effect.



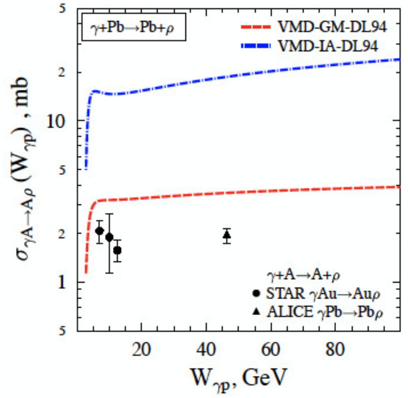
M. Strikman

Particle production: diffraction

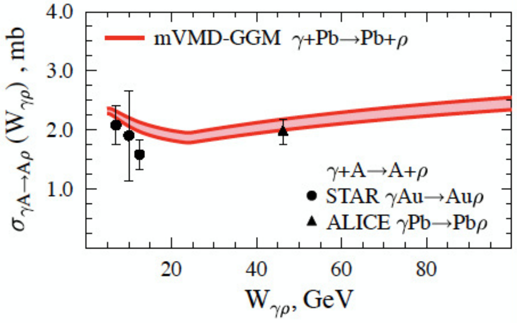
Summary

- LT DGLAP framework for calculation of nuclear pdfs; etc passed the J/psi coherent production test. Possible onset of black regime pushed to much smaller x.
- Gross violation of the Glauber approximation for photoproduction of vector mesons due to CFs. CF are much stronger in photons than in nucleons. and can be regulated using different triggers (charm, jets,…). EIC will allow to study CF in photons at different Q,W - novel tests of interplay of soft and hard physics in γ^* interactions. *UPC = forerunner at the LHC.*
- Rapidity gap processes for fixed produced mass Y - clean probe of high energy hard Pomeron

Glauber model predicts large shadowing, still grossly overestimates the cross section (at LHC factor ~2)

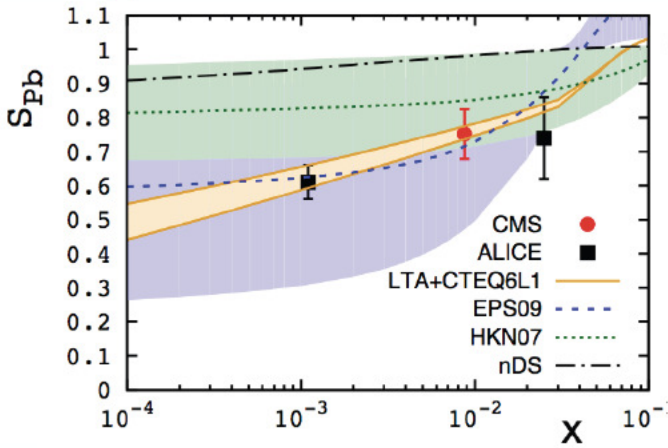


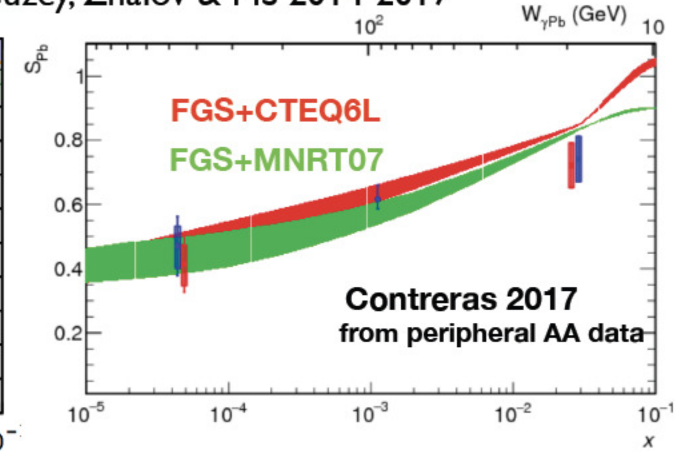
Gribov - Glauber model with cross section fluctuations

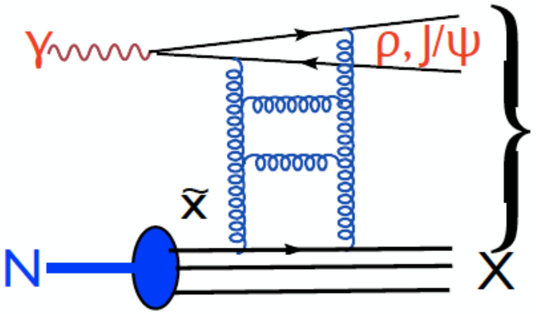


$$S_{Pb} = \left[\frac{\sigma(\gamma A \to J/\psi + A)}{\sigma_{imp.approx.}(\gamma A \to J/\psi + A)}\right]^{1/2} = \frac{g_A(x,Q^2)}{g_N(x,Q^2)}$$

$S_{Pb}(x)$ is extracted from the data by Guzey, Zhalov & MS 2014-2017



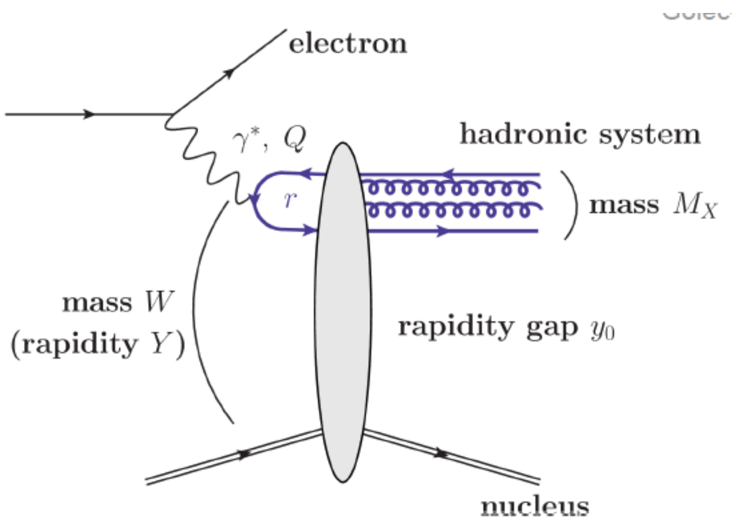




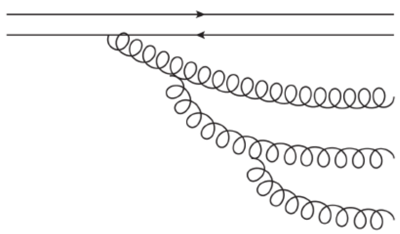
- Definite predictions on nuclear targets: A_{eff} decreases with W and increases with t.

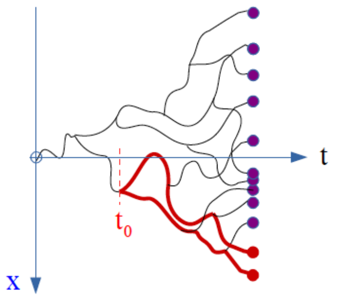
S. Munier

Particle production: diffraction



- From analysing the BK equation for diffraction, predictions and equation for the distribution of the gap.
- Analogy with time distribution of splittings in random walks.





Distribution of rapidity gaps:

$$\frac{1}{\sigma_{tot}}\frac{d\sigma_{diff}}{dy_0} = \text{const} \times \left[\frac{\bar{\alpha}Y}{\bar{\alpha}y_0(\bar{\alpha}Y - \bar{\alpha}y_0)}\right]^{3/2}$$

$\simeq$

$\bar{\alpha}Y \Leftrightarrow t$

$\bar{\alpha}y_0 \Leftrightarrow t_0$

Distribution of decay time of most recent common ancestor?

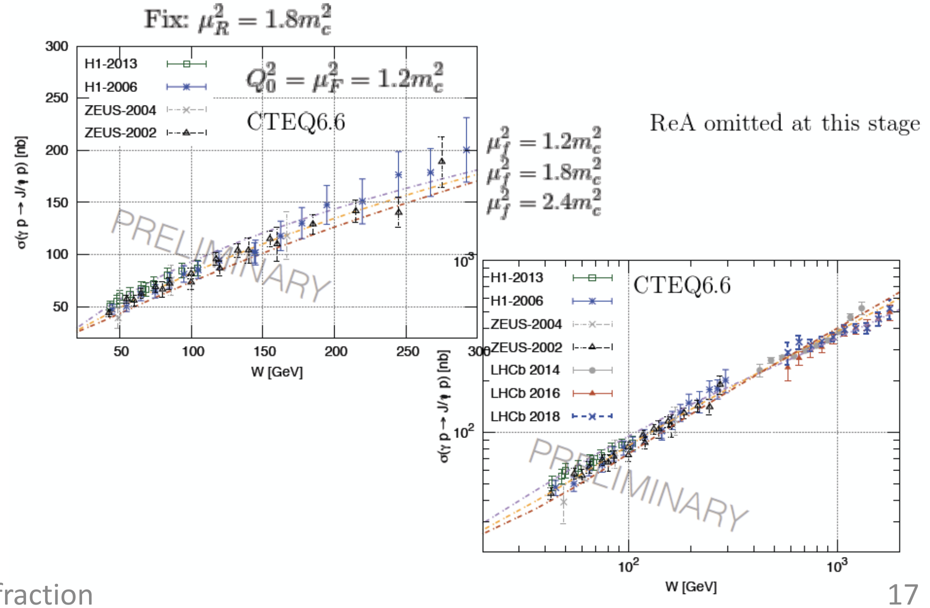
$$\frac{dp}{dt_0} = \frac{1}{\sqrt{4\pi}} \times \left[\frac{t}{t_0(t-t_0)}\right]^{3/2}$$

[Derrida, Mottishaw 2016]

(for branching Brownian motion with diffusion constant 2 and splitting rate 1)

$A(\mu_f) = C^{LO} \times GPD(\mu_F) + C^{NLO}(\mu_F) \times GPD(\mu_f)$

- Work ongoing to reduce the large uncertainty due to the scale dependence, in calculations of exclusive J/ψ electroproduction, to use for constraining PDFs.

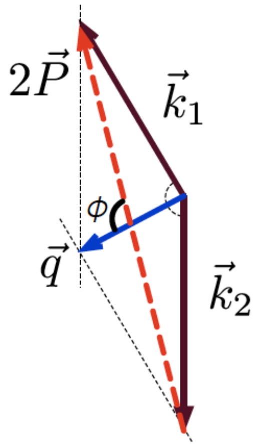


C. Flett

Particle production: diffractive dijets

V. Skokov

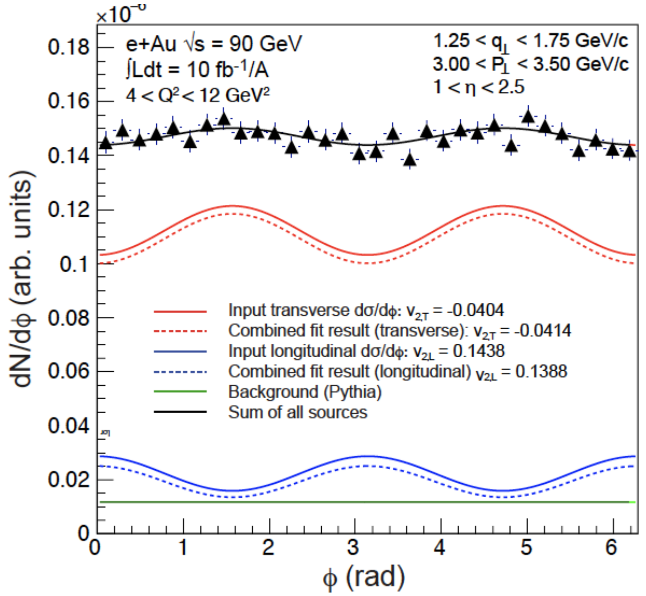
$$E_1E_2\frac{d\sigma^{\gamma_L^* A\to q\bar{q}X}}{d^3k_1\,d^3k_2\,d^2b} = \alpha_{em}e_q^2\alpha_s\delta\left(x_{\gamma^*}-1\right)z^2(1-z)^2\frac{8{\epsilon_f}^2P_\perp^2}{(P_\perp^2+{\epsilon_f}^2)^4}\times\left[\underbrace{xG^{(1)}(x,q_\perp)}_{\text{func of } q_\perp}+\underline{\cos(2\phi)}\;xh_\perp^{(1)}(x,q_\perp)\right]$$



$$2\vec{P} = \vec{k}_1 - \vec{k}_2$$
$$\vec{q} = \vec{k}_1 + \vec{k}_2$$

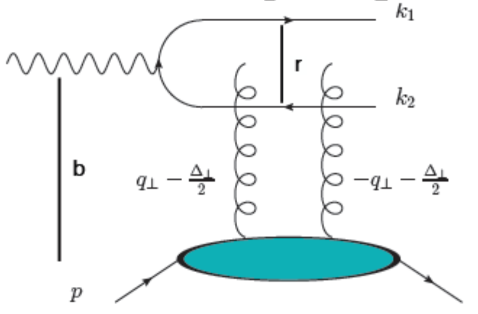
$\mathbf{k}_{1,2} = \mathbf{P} \pm \frac{1}{2}\mathbf{q}$

- Monte Carlo code to compute dijet production in the correlation limit, including JIMWLK evolution and hadronization.
- Acceptance effects important in background subtraction.

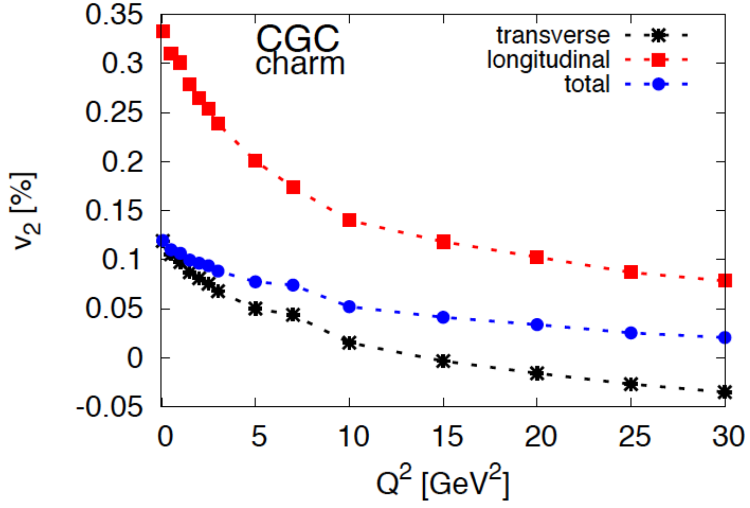


H. Mantysaari

$\gamma^* + p \rightarrow \text{jet}_1 + \text{jet}_2 + p$



- Charm dijet azimuthal harmonics studied, including the effect of JIMWLK evolution.
- Relation with the Wigner distribution: possibility of extracting it.



$W = 100\text{GeV}$

S. Bondarenko

Formalism:

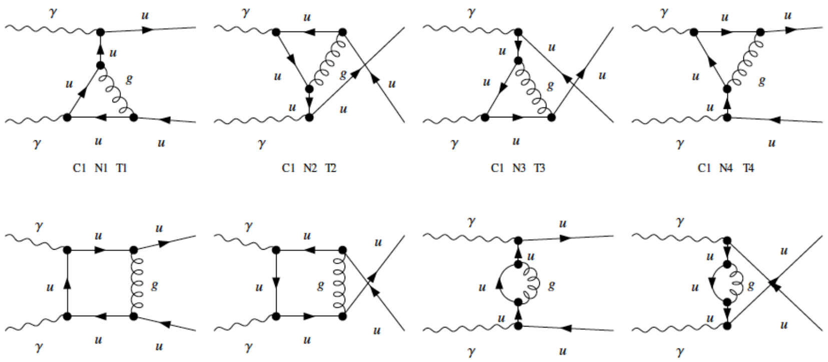
$$S_{eff} = -\int d^4x \left(\frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a + tr\left[\left(\mathcal{T}_+(v_+) - A_+ \right) j^+_{reg} + \left(\mathcal{T}_-(v_-) - A_- \right) j^-_{reg} \right] \right)$$

$$\mathcal{T}_\pm(v_\pm) = \frac{1}{g} \partial_\pm O(x^\pm, v_\pm) = v_\pm O(x^\pm, v_\pm),$$

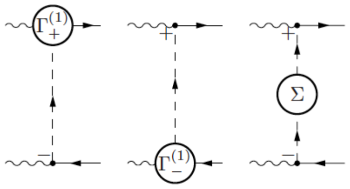
$$j^\pm_{reg\, a} = \frac{1}{C(R)} \partial_i^2 A^\pm_a, \quad \partial_- A_+ = \partial_+ A_- = 0,$$

$$O_x = P e^{g \int_{-\infty}^{x^+} dx'^+ v_+(x'^+)}, \quad O^T_x = P e^{g \int_{x^+}^{\infty} dx'^+ v_+(x'^+)}$$

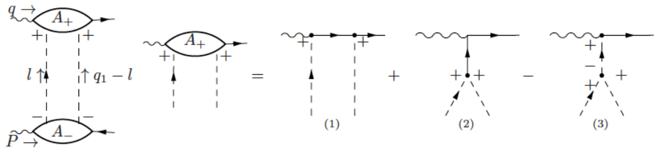
- Lipatov effective action formulated as a Reggeon Field theory: connection with other formalisms like CGC/Balitsky.
- Vertices of the effective action get QCD corrections.
- Besides, there are RFT corrections.
- Both corrections compete, one loop corrections to reggeized gluon propagator computed.



One-Reggeon contribution (*positive signature*, Re+Im parts @ 1 loop):



Two-Reggeon contribution (*negative signature*, Im part @ 1 loop):



- One loop effective vertives in the RFT coming from Lipatov effective action computed: check with QCD in γ*γ→X using the effective γ*Rq vertex.

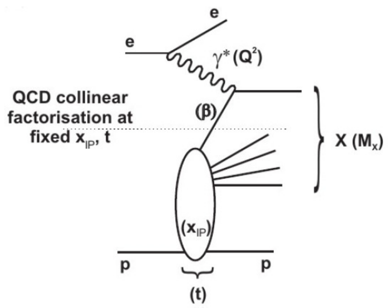
M. Nefedov

Experimental Part

First diffractive PDFs at NNLO from HERA (H1)

Radek Zlebcik

- Last diffractive (NLO) fit with HERA-I data from 2006/2007. Since then:
- NNLO calculations available for inclusive and jet diffractive production
- 400 times higher luminosity in the new incusive data, 6 times higher in jet data



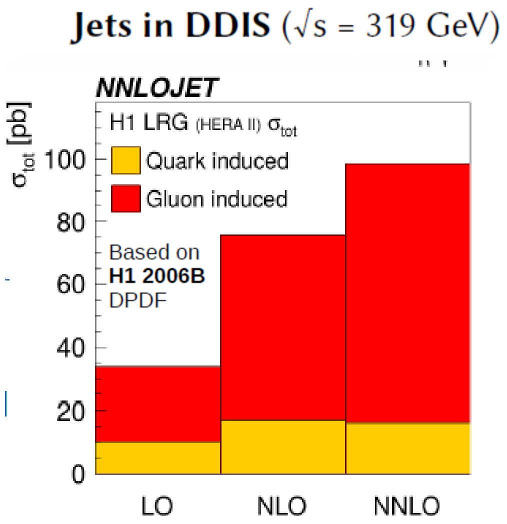
DIS variables:

$Q^2 = -(k-k')^2 \qquad y = \frac{p \cdot q}{p \cdot k}$

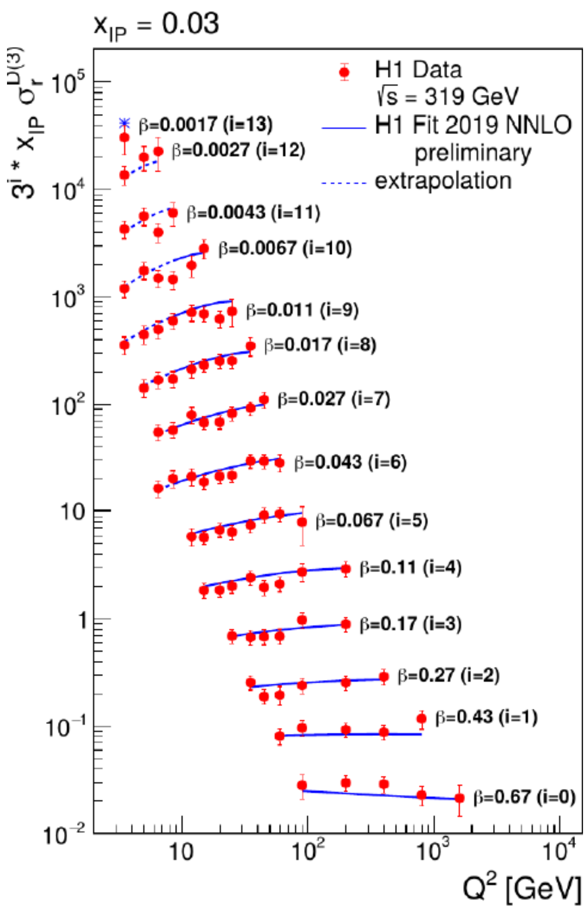
Diffractive variables:

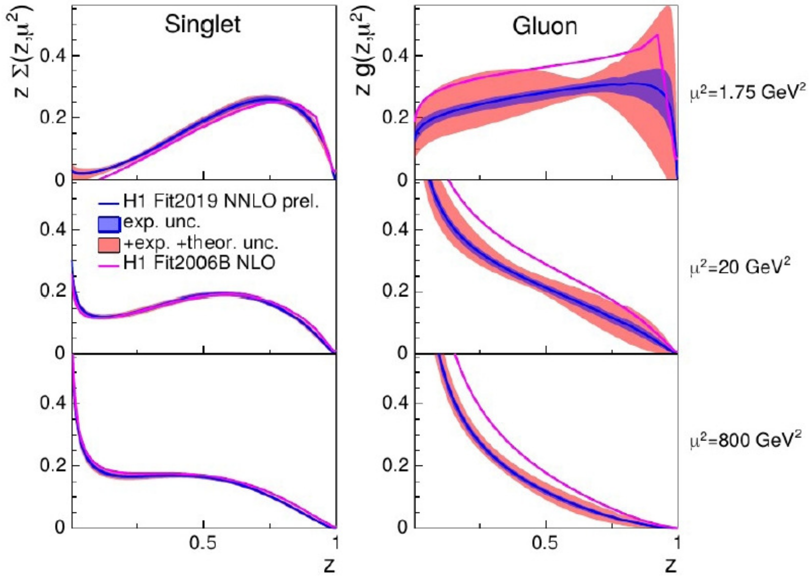
$x_{\mathbb{P}} = 1 - \frac{E'_p}{E_p} \qquad t = (p-p')^2$

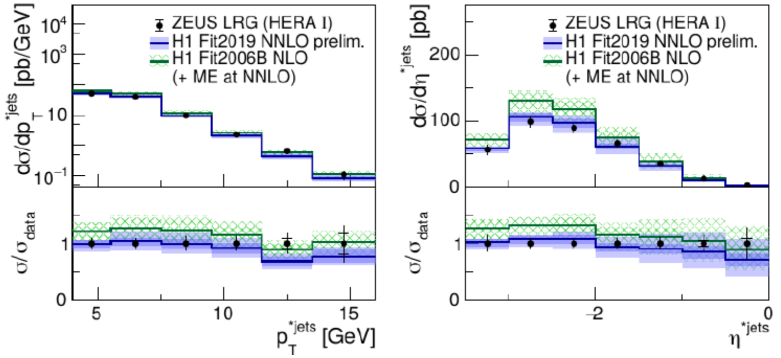
$$\beta = \frac{x_{Bj}}{x_{\mathbb{P}}} = \frac{Q^2}{syx_{\mathbb{P}}}$$



- The gluon-DPDF induced cross section rises gradually with order
- The quark-Induced cross section stagnates at NLO
- At NNLO 84% of the cross section is from gluon DPDF



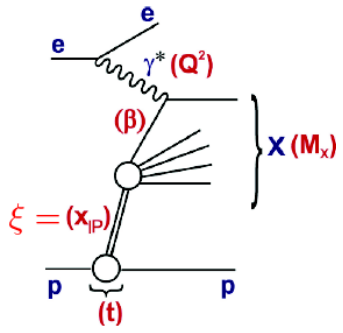




- The jet data compatible with new inclusive data (at both NNLO and NLO)
  → *Factorization in diffractive DDIS up to NNLO established*

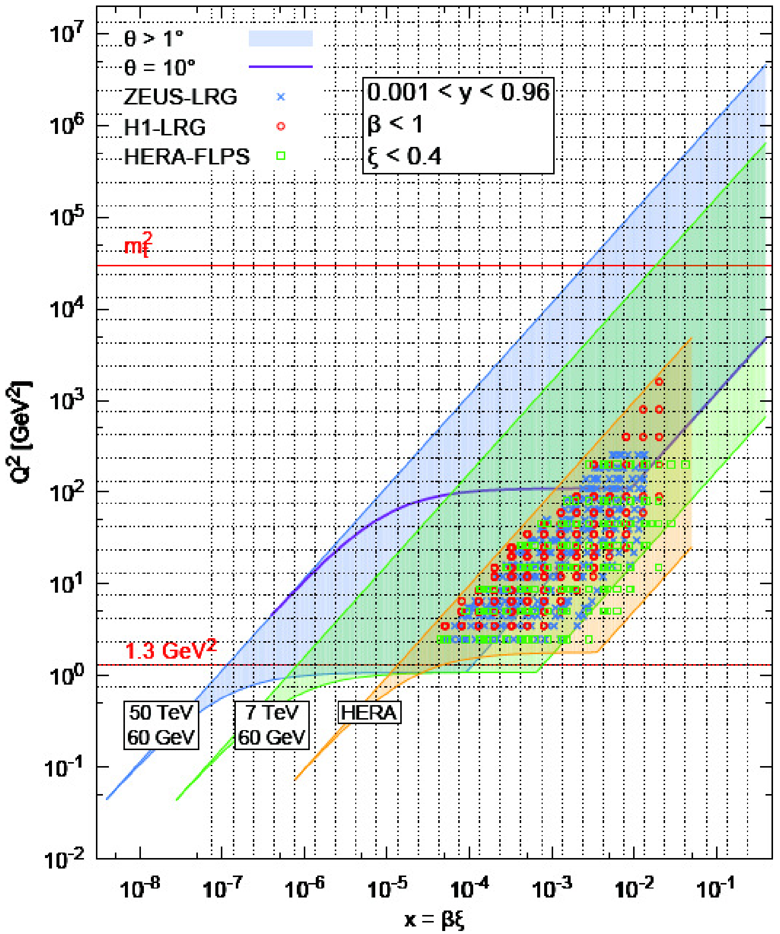
Diffractive (NLO) PDFs at the future LHeC and FCC-eh

Anna Stasto (@joint WG2+WG7 session)

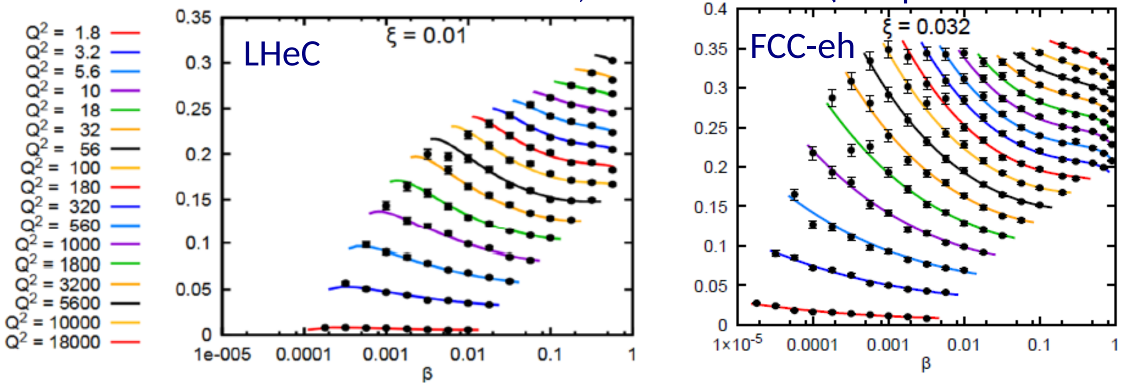


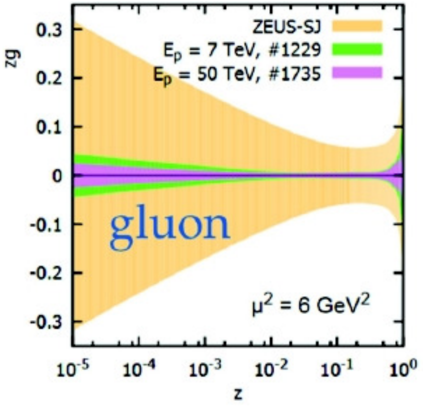
$E_e = 60\ GeV$

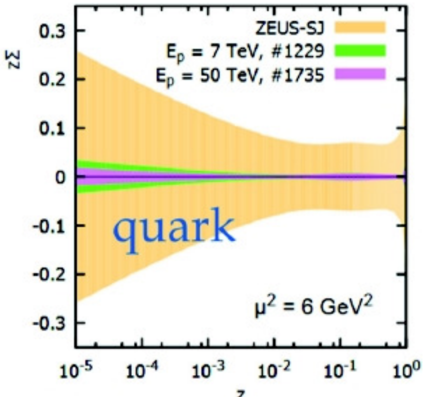
- $E_p = 7$ TeV vs. HERA
  - x_{min} down by factor ~20
  - Q^2_{max} up by factor ~100
- $E_p = 50$ TeV vs. 7 TeV
  - x_{min} down by factor ~10
  - Q^2_{max} up by factor ~10



Reduced cross secitons, simulated data (extapolated HERA DPFs)







Accuracy of extracted DPDFs

$Q^2_{min} \approx 5\ \mathrm{GeV}^2$

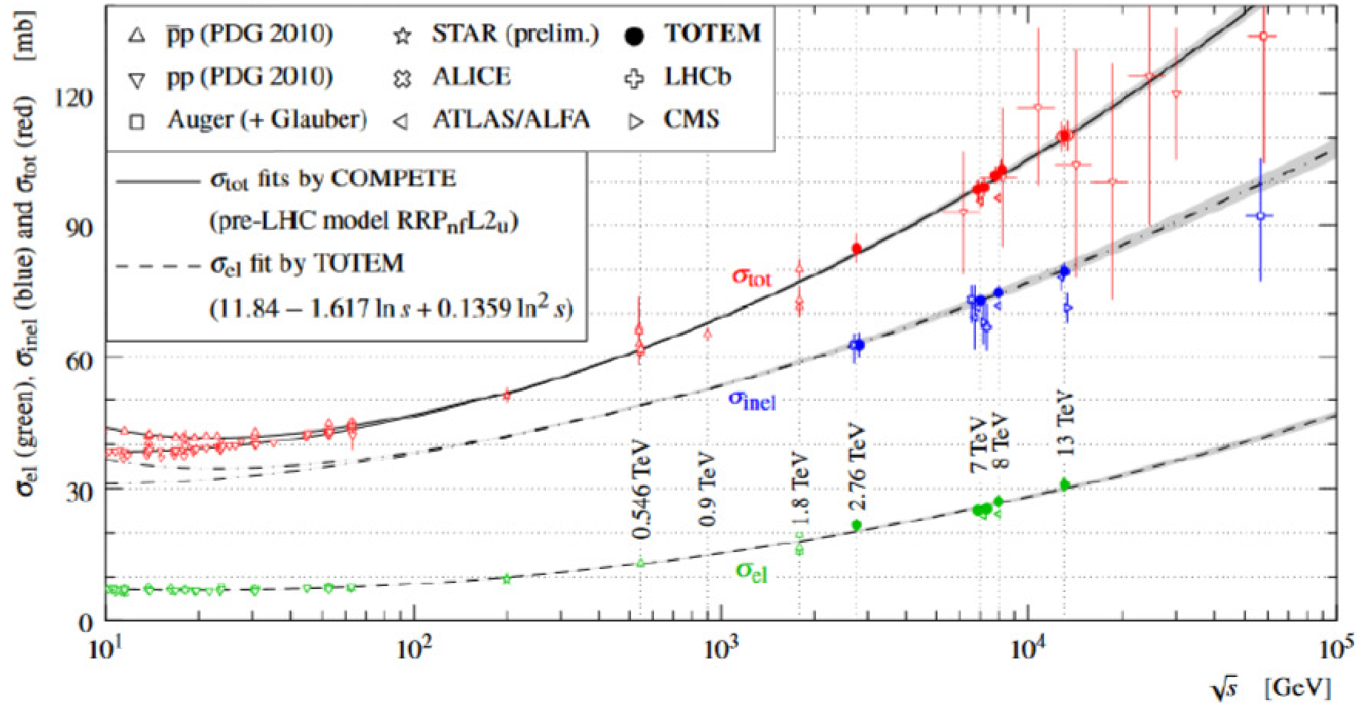
Accuracy increased by
- ✓ factor ~10 for LHeC
- ✓ factor ~20 for FCC-he

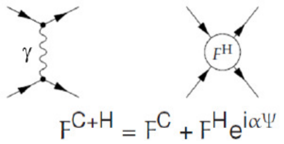
- Lowering initial Q2 increases accuracy, (region to higher twists, saturation etc)
- Possibility of producing dirfractive top quark!
- Analysis of diffraction in ePb ongoing

Elastic and total pp xsecs from TOTEM

$$\sigma^2_{tot} = \frac{1}{L}\frac{16\pi}{1+\rho^2}\frac{dN_{el}}{dt}\Big|_{t\to 0}$$

Frigyes Nemes



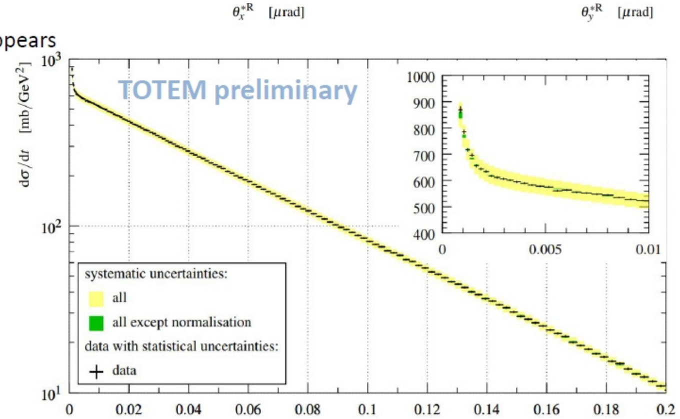


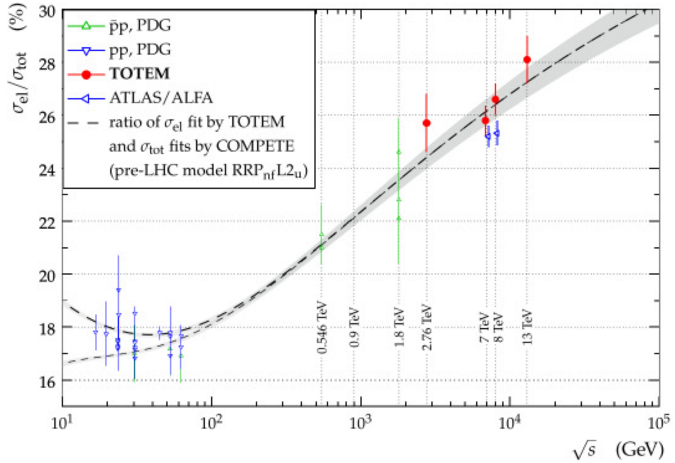
- Interference: the **phase** of hadronic amplitude appears

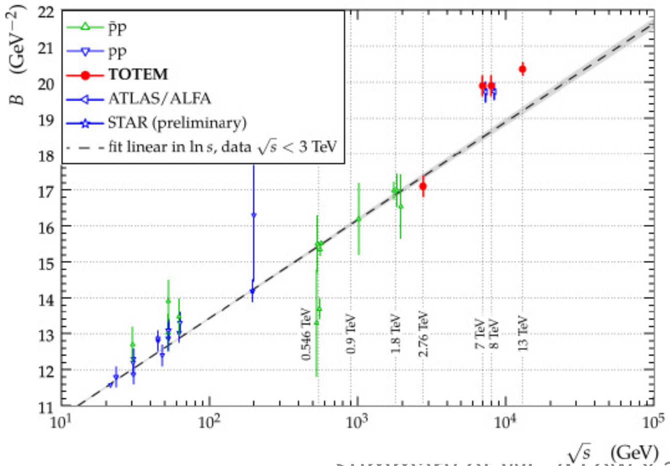
$$\frac{d\sigma}{dt} \propto |A_{C+H}|^2$$

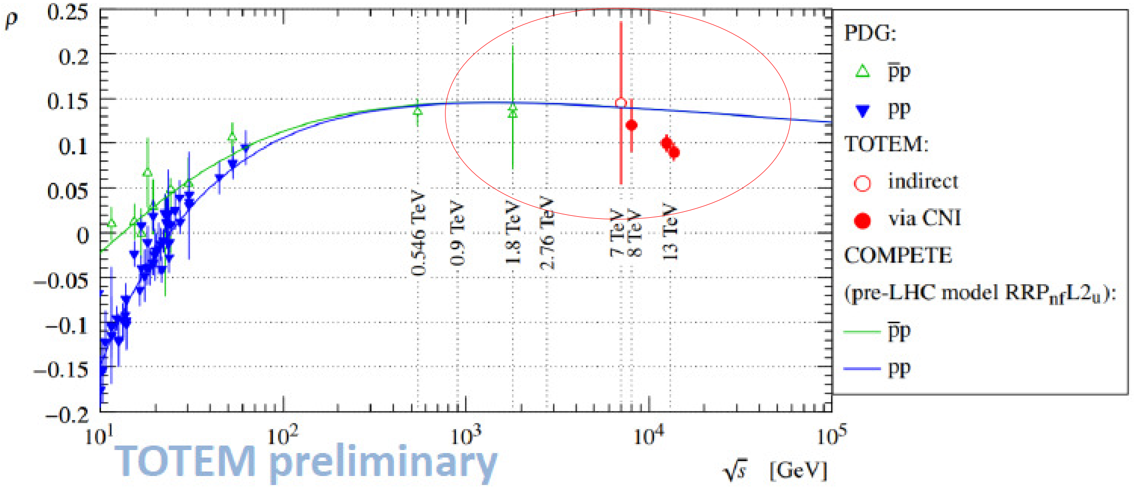
- **The ρ parameter:**

$$\rho = \frac{\mathrm{Re}\,A^H}{\mathrm{Im}\,A^H}\Big|_{t=0}$$

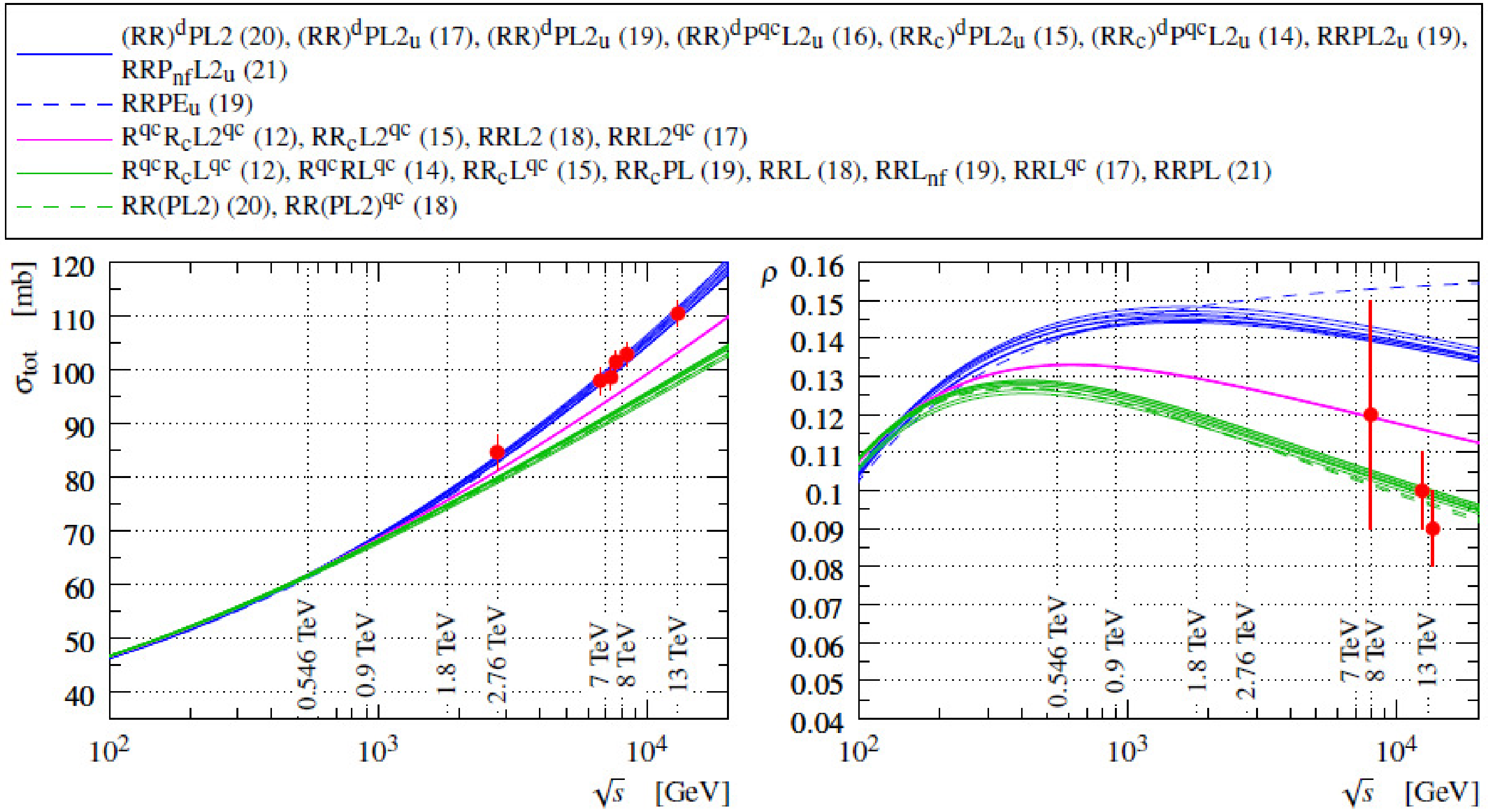








Elastic and total pp xsecs from TOTEM



TOTEM data compared to variations of COMPETE model.

None of the models is able to simultaneously describe the total cross section and the ρ parameter → indication of the existence of a colorless three-gluon bound state (Odderon at t=0)?

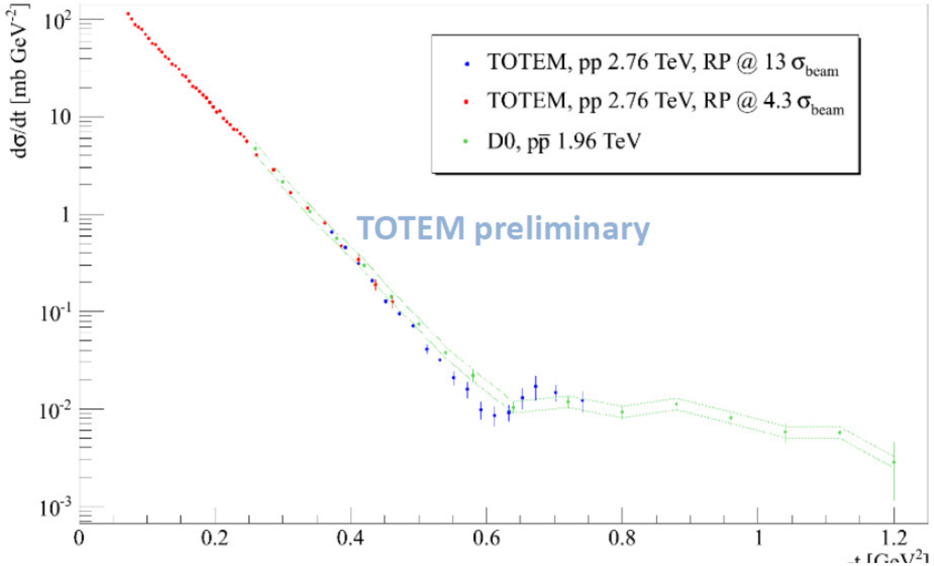
The Odderon is a C=-1 partner of the Pomeron (C=1).

Odderon confirmation in other measurements

Frigyes Nemes

A. Szczurek

Ongoing joint TOTEM + D0 analysis:
pp → pp at 2.76 TeV vs ppbar → ppbar at 1.96 TeV



Note:

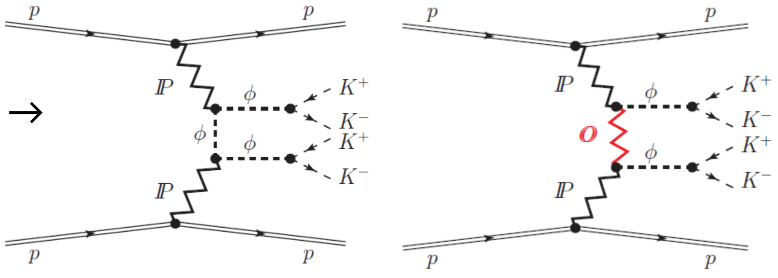
- "Neglecting the small energy difference in √s between the measurements of the TOTEM and D0 collaborations, the results provide evidence for a colourless 3-gluon bound state exchange in the t-channel of proton-proton elastic scattering"

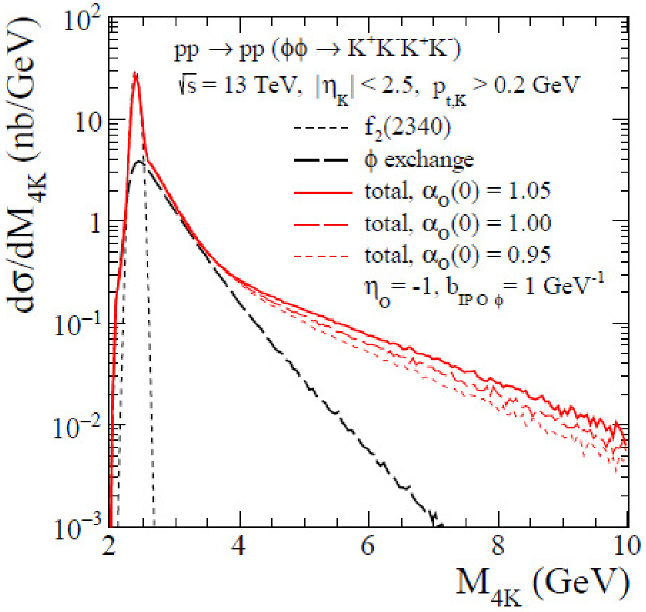
- Hadronic elastic @ TeV sqrt(s) dominated by t-channel exchange of colourless gluon states
- 2 (or even) gluon exchange (PC = ++): "Pomeron" (~ mostly imaginary) ⟹ pp vs ppbar invariance
- 3 (or odd) gluon exchange (PC = - -): "Odderon" (expected ~ real) ⟹ no pp vs ppbar invariance

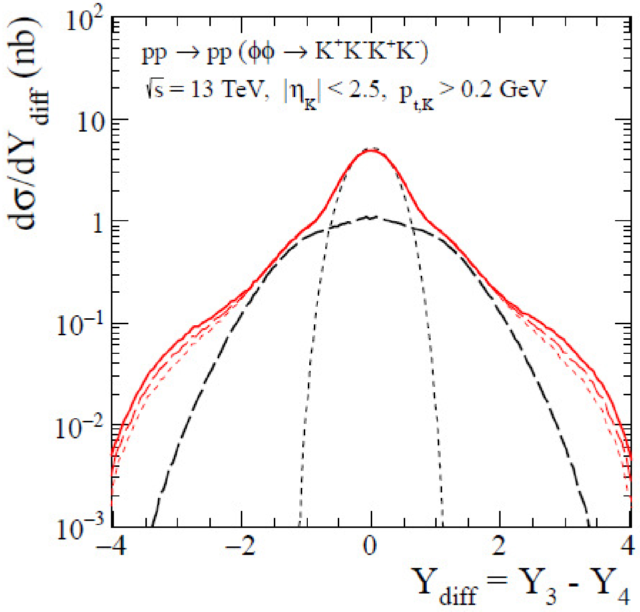
Proposed search for odderon in central exclusive production at the LHC:

pp → ppM   M = φφ, φ, ppbar

Most pronounced in φφ production →



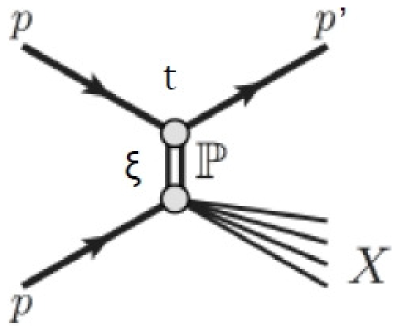




Odderon could be visible for M(φφ) > 6 GeV or $|Y_{diff}|$>3

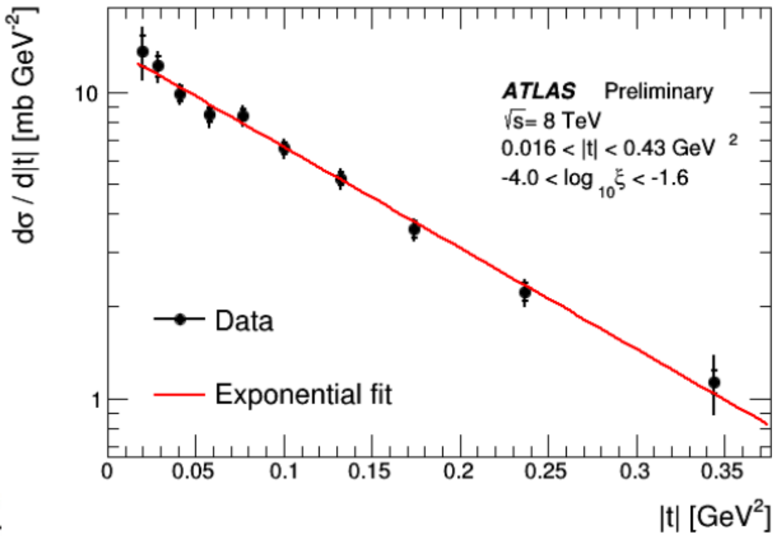
Inclusive SD with proton tag from ATLAS

Marek Tasevsky



$t = (p\text{-}p')$ $\xi = M_X^2/s$

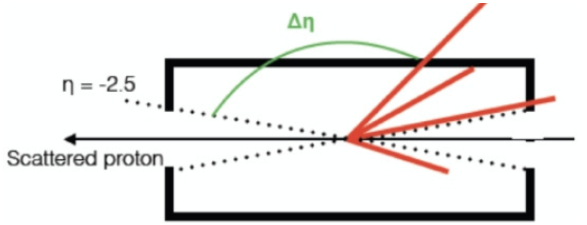
$\Delta\eta \approx -\ln\xi$

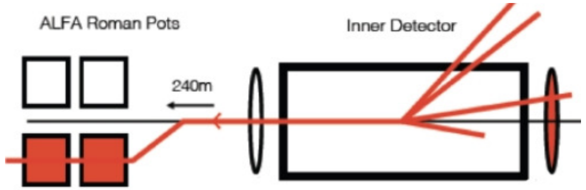


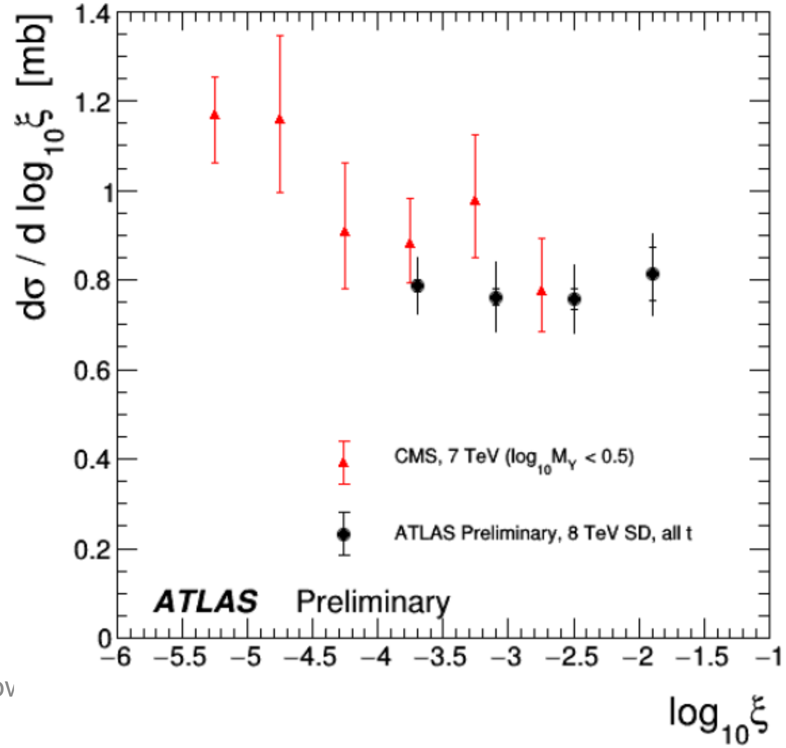
$$\frac{d\sigma}{dt} = Ae^{Bt}$$

- Exponential fit:

B = 7.60 ± 0.23(stat) ± 0.22(syst) GeV^{-2}







- Interpreted in triple Pomeron model:

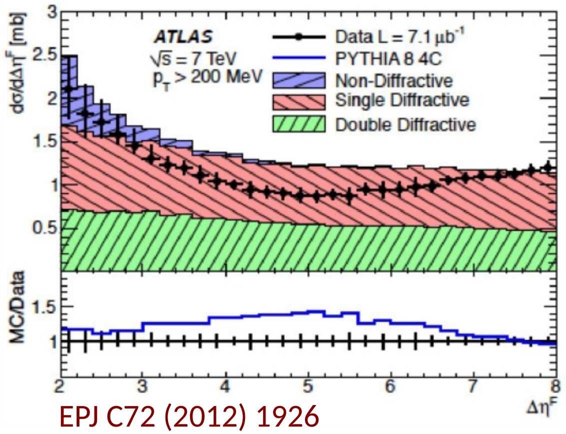
$$\frac{d\sigma_{SD}}{d\log_{10}(\xi)} \propto \left(\frac{1}{\xi}\right)^{\alpha(0)-1} \frac{1}{B}\left(e^{Bt_{\text{high}}} - e^{Bt_{\text{low}}}\right)$$

where $B = B_0 - 2\alpha'\ln(\xi)$; $\alpha(t) = \alpha(0) + \alpha' t$

$\alpha(0)$ = Pomeron intercept t_{high} = -0.016, t_{low} = -0.43

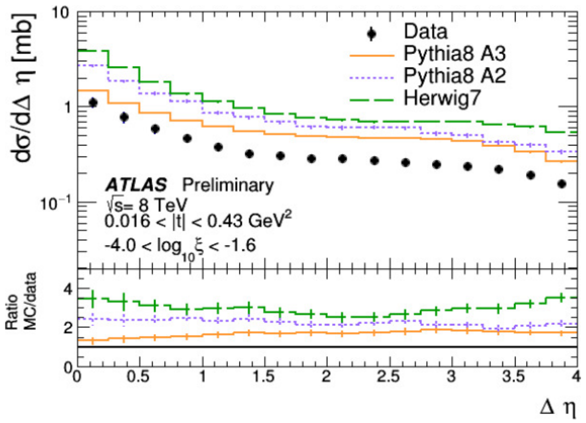
Fit yields:

$\alpha(0) = 1.07 \pm 0.02(\text{stat}) \pm 0.06(\text{syst}) \pm 0.06(\alpha')$



EPJ C72 (2012) 1926

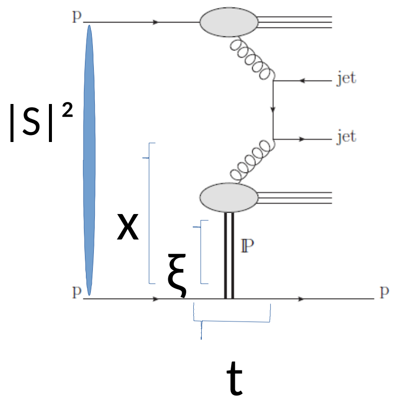
Rapidity gap selection:
SD + DD

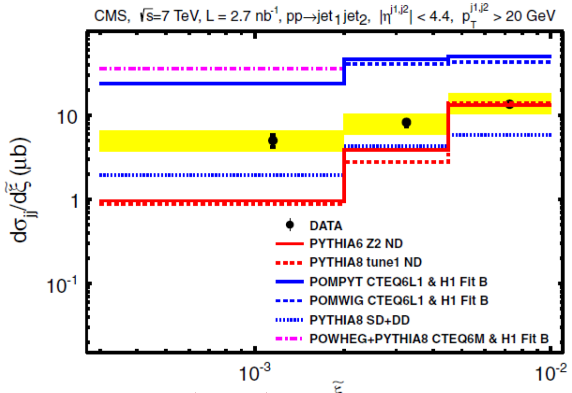


Proton tagging:
SD only

SD dijets with proton tag from CMS-TOTEM

Ekaterina Kusnetsova

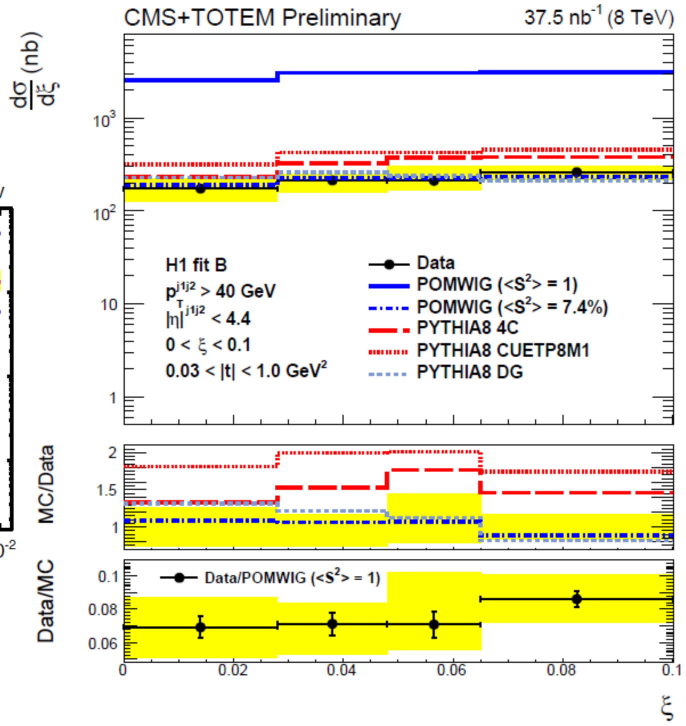




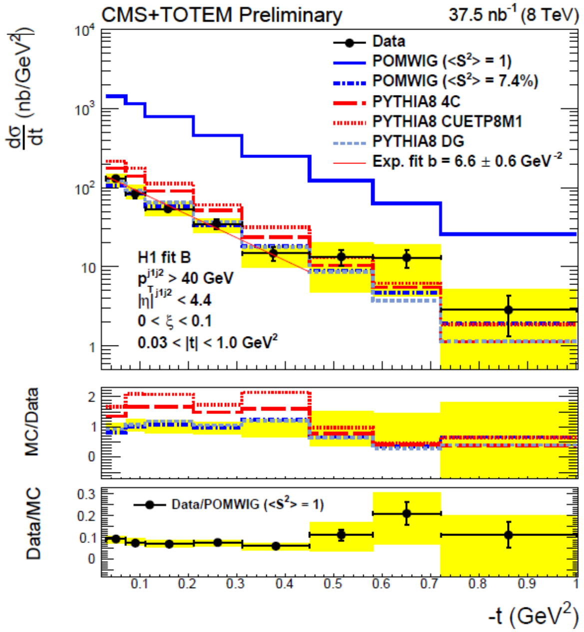
PRD 87 (2013) 012006

Inclusive selection

SD + DD + ND



Proton tagging: SD only



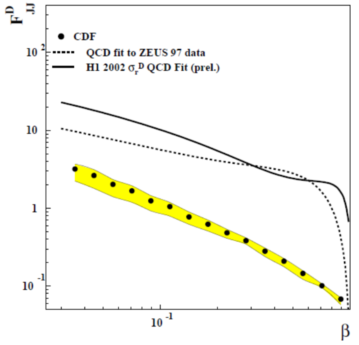
Cross section as a function of t:

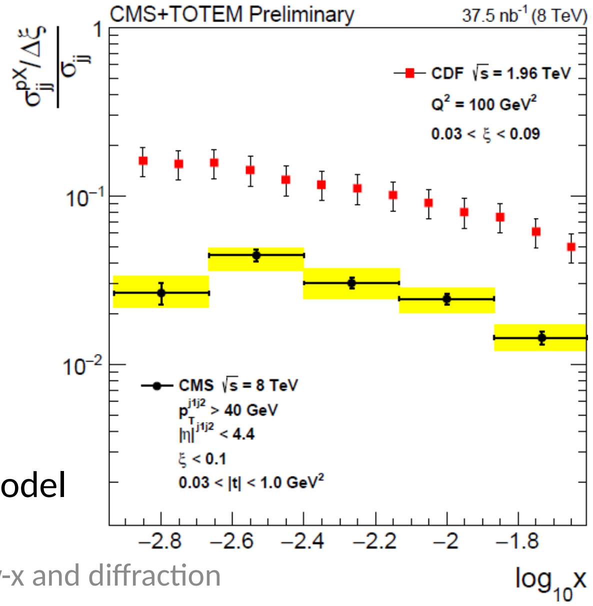
Exponential fit:

$$d\sigma/dt \propto \exp^{-b|t|}$$

$$b = 6.6 \pm 0.6\,(\mathrm{stat})\,^{+1.0}_{-0.8}\,(\mathrm{syst})\,\mathrm{GeV}^{-2}$$

CDF: 5-6 GeV^{-2}





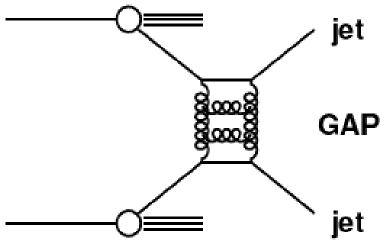
$$R = \left(\sigma_{jj}^{pX}/\Delta\xi\right)/\sigma_{jj} = 0.025 \pm 0.001\,(\mathrm{stat}) \pm 0.003\,(\mathrm{syst})$$

Comparison to Tevatron data @2 TeV:

A factor of ~3 suppression. Larger contribution from rescattering processes

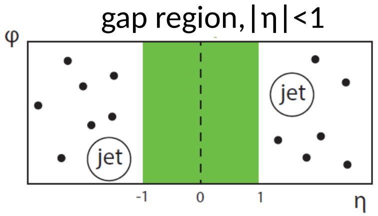
Comparison to theory:

- Ratio of data to POMWIG (H1 DPDFs): 9 ± 2 % a measure of gap survival probability
- PYTHIA8 DG – gap survival with *Dynamic Gap* model based on MPI, good agreement with the data

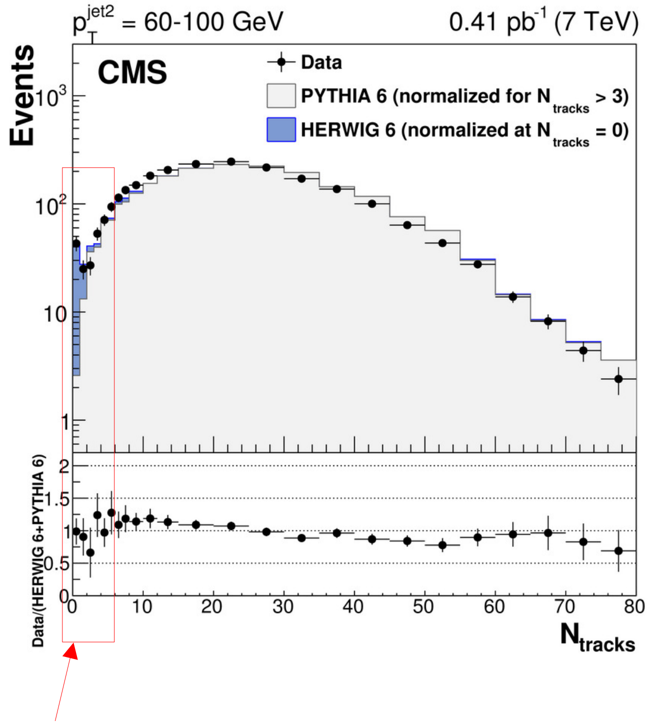


Jet-gap-jet events from CMS

Ekaterina Kusnetsova

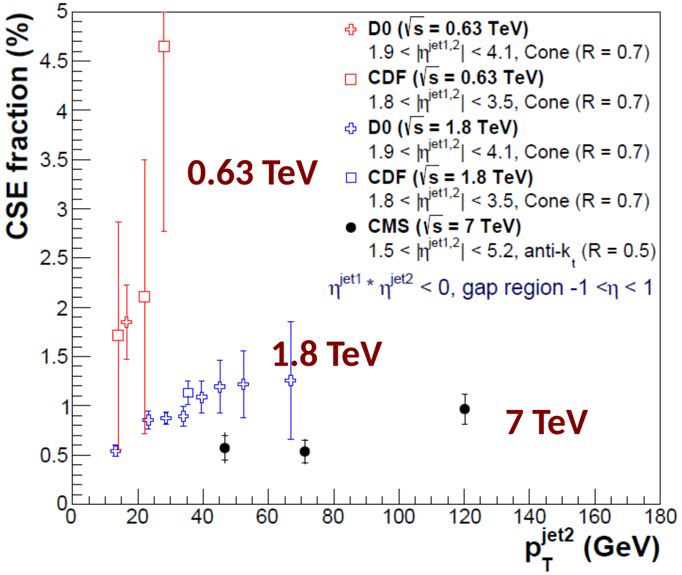


Jets separated by a large rapidity gap (color singlet exchange, CSE)
Sensitive to BFKL dynamics, soft rescattering processes

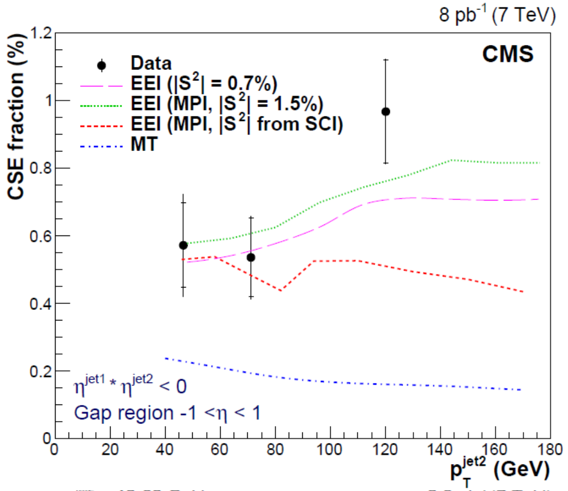


Charged multiplicity in the gap region |η|<1:

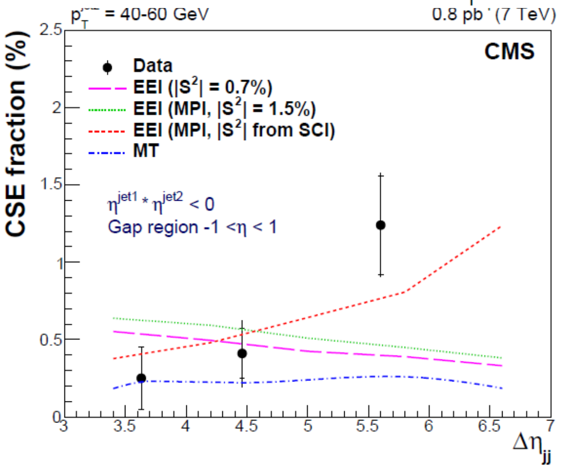
CSE fraction := ratio of dijets with a rapidity gap to all dijets



Comparison to Tevatron data:
A factor of ~2 suppression w.r.t. to 1.8 TeV data, larger contribution from rescattering processes



jet pT



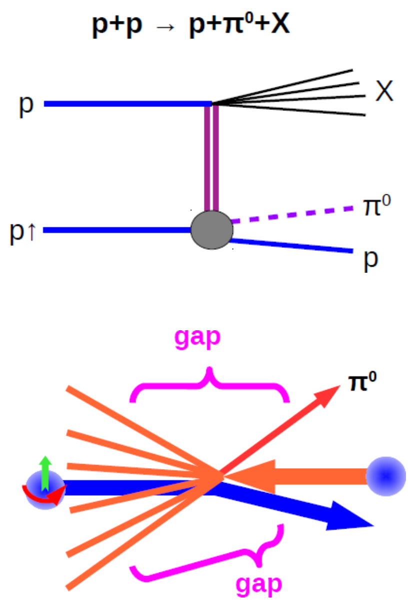
rapidity separation between the jets

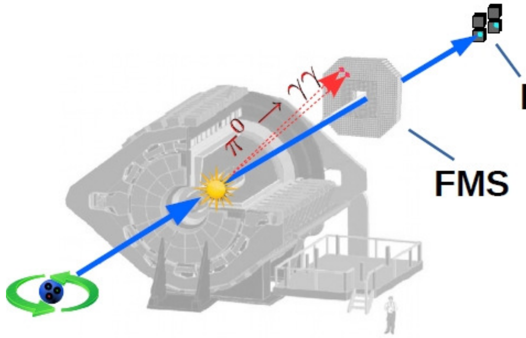
- Excess of gap events over PYTHIA6 prediction (LO DGLAP)
- Described by HERWIG (LL-BFKL, Mueller-Tang model)
- Experimental indication of BFKL dynamics at the LHC.

Comparison to theory:
NLL BFKL by Ekstedt, Enberg and Ingelman, with 3 approaches for gap survival probability (S).
Further improvements in modeling of S needed.

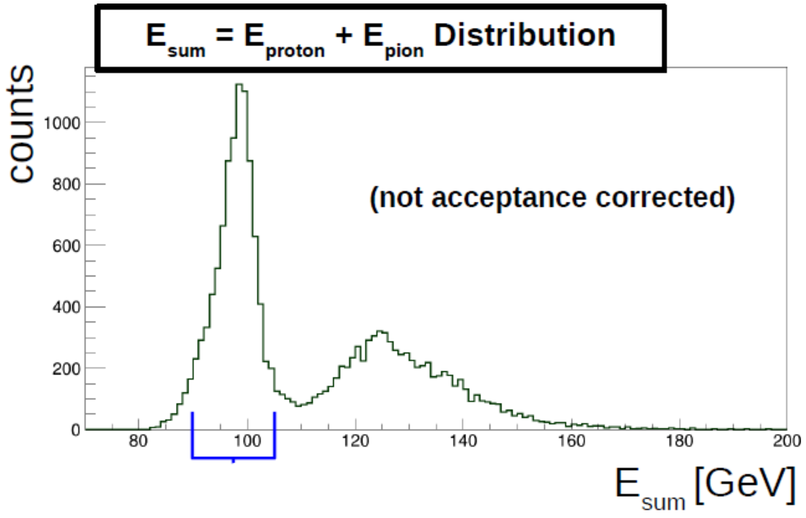
Transverse spin asymmetries in SD $p^{\uparrow}p \rightarrow p\pi^0X$ from STAR

Christopher Dilks

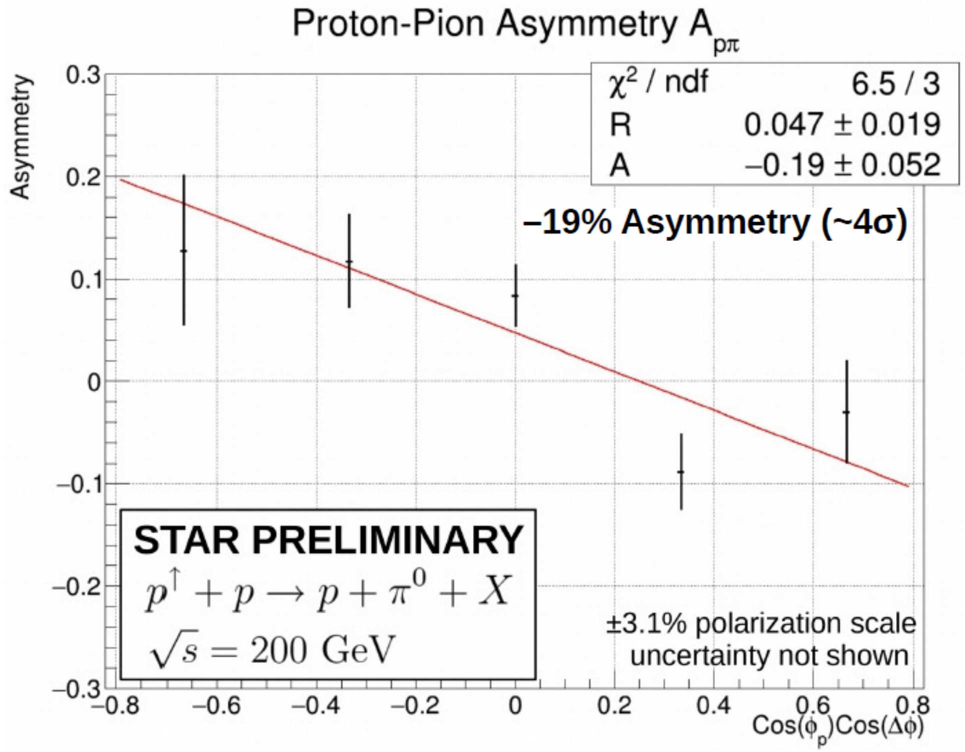




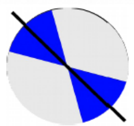
Rate: ~1% of tagged proton events



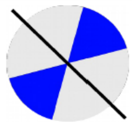
E(scatttered p) + E(pion) = E(initial proton) = 100 GeV



Fit Function: $$\frac{1}{\langle P\rangle}\frac{N^{\uparrow}-N^{\downarrow}}{N^{\uparrow}+N^{\downarrow}} = R + A\cos\phi_p\cos\Delta\phi$$



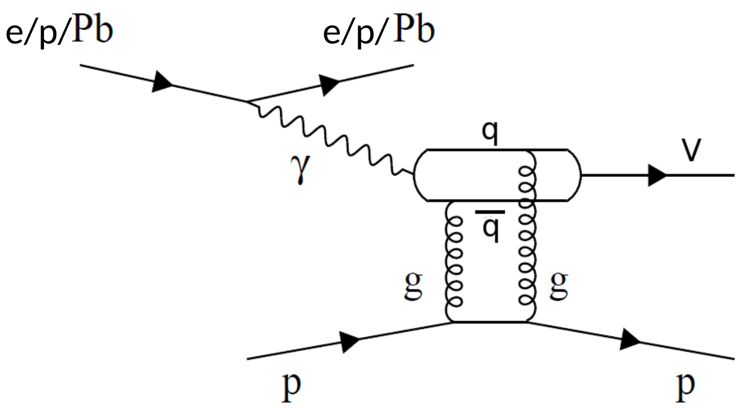
–20% (4σ) pion single-spin asymmetry for in-plane pions



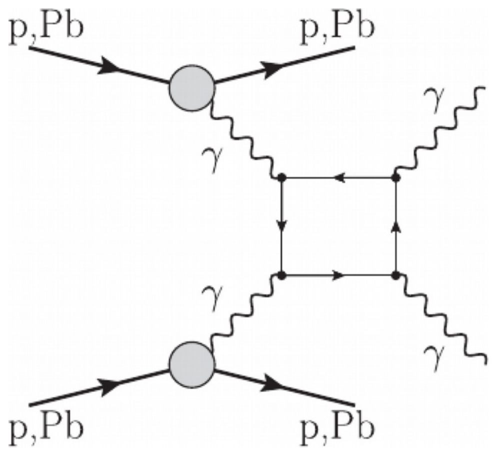
Out-of-plane pion asymmetry consistent with zero

- **The mechanism remains open to interpretation**

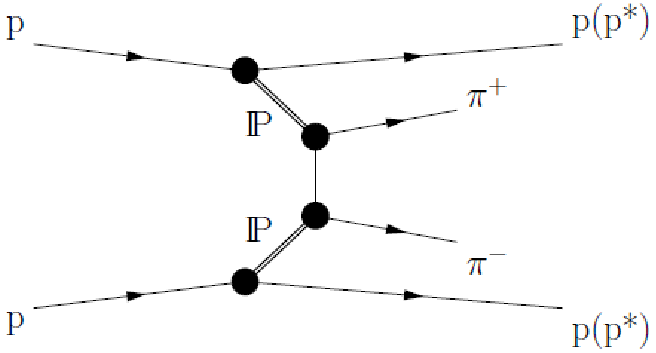
Exclusive processes



Photoproduction



QED



Double Pomeron Exchange (DPE)

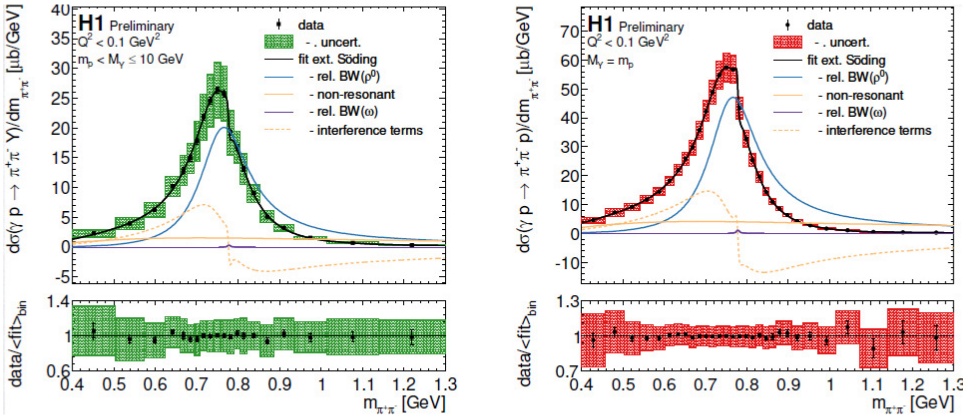
ep at HERA
pp + ultra-peripheral collisions (UPC) in pA, AA at STAR, LHC

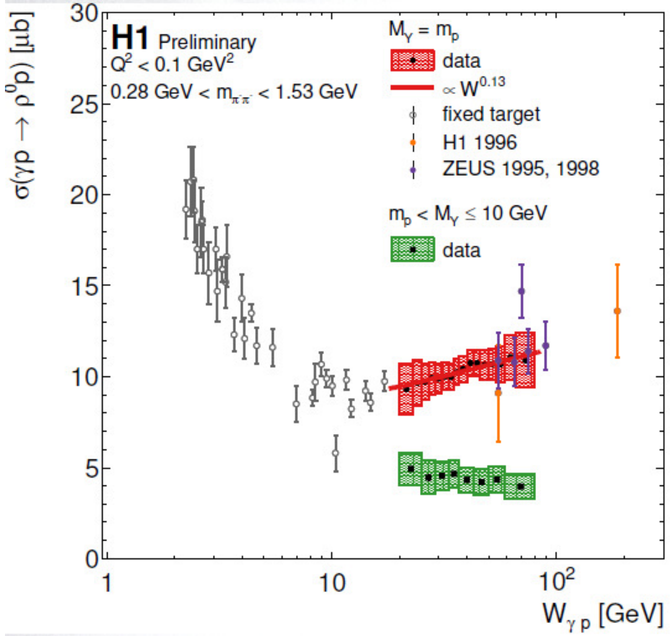
A=Au/Pb rich source of photons (γ flux~Z^2)

Exclusive processes in ep from HERA

$\rho^0 \to \pi^+\pi^-$ Arthur Bolz

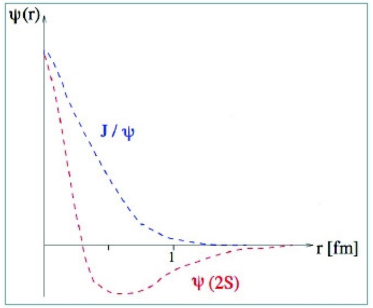
- elastic vs proton-dissociation: tag using forward detectors





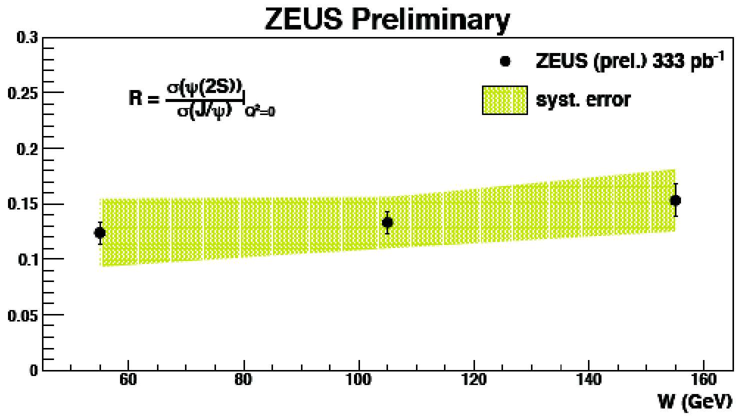
- measure ρ^0 $W_{\gamma p}$ dependence in range $20 < W_{\gamma p} < 80$ GeV
- fills "gap" between fixed target and HERA measurements
- elastic cross-section rises w/ $\sim W_{\gamma p}^{0.13}$
- p-dissociative consistent with constant in fiducial PS
- high statistical precision
- but very large systematic uncertainties
- $W_{\gamma p}$ shape uncertainty dominated by trigger

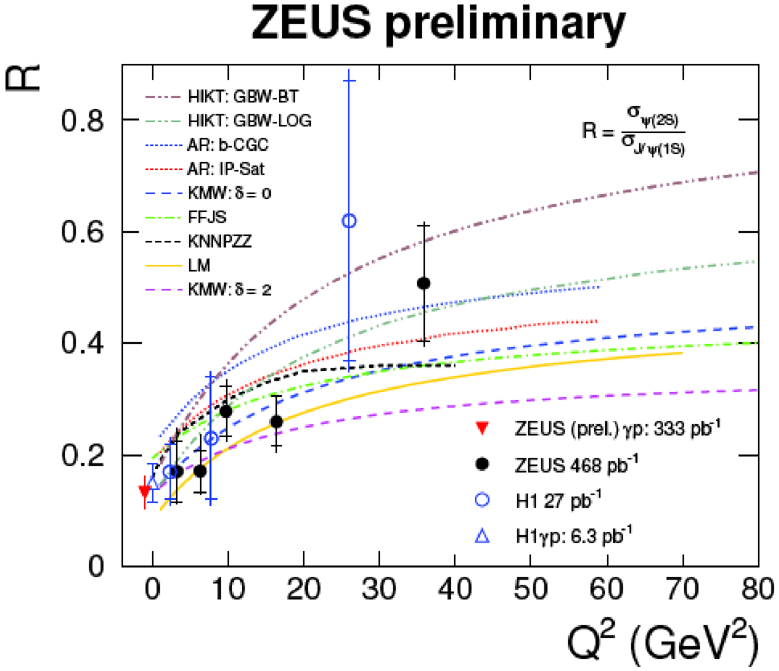
Alessia Bruni



$J/\psi \to \mu+\mu$
$\psi(2S) \to \mu+\mu$ 2-prong

$\psi(2S) \to J/\psi\pi+\pi$
$\to J/\psi \to \mu+\mu-$ 4-prong

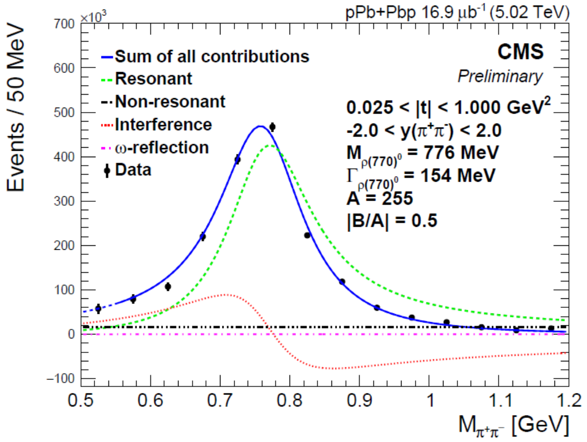


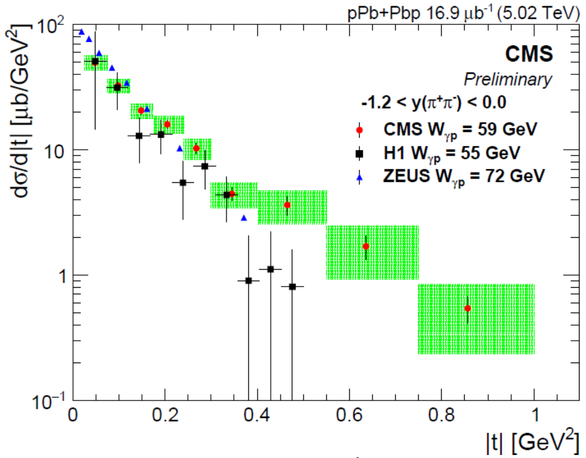


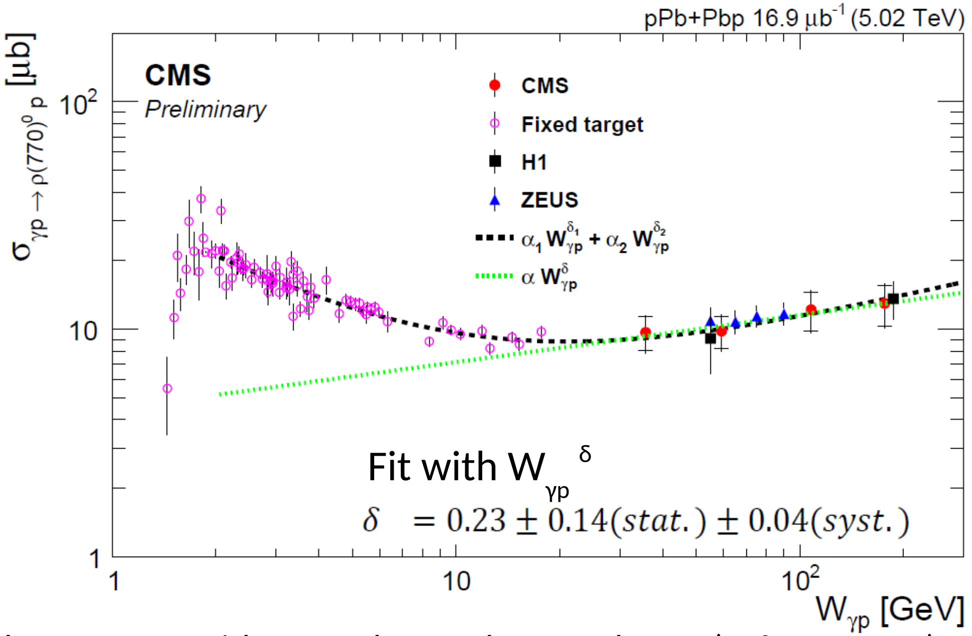
Exclusive processes in pPb from CMS

Alexander Bylinkin

$\gamma p \to \rho^0 p$

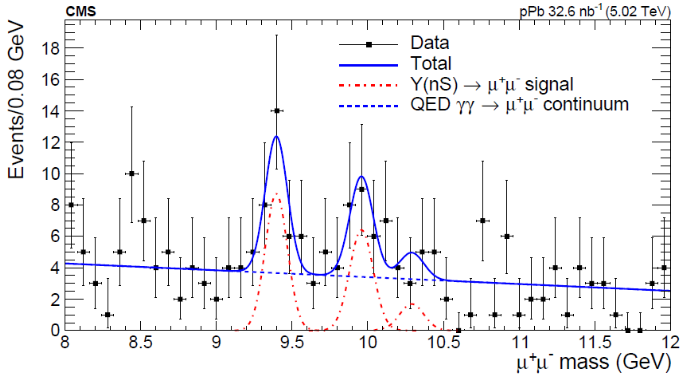


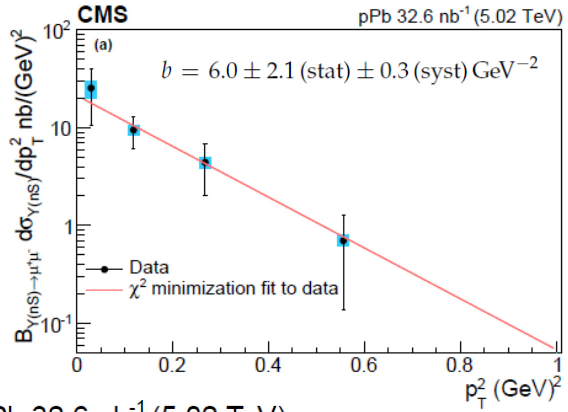


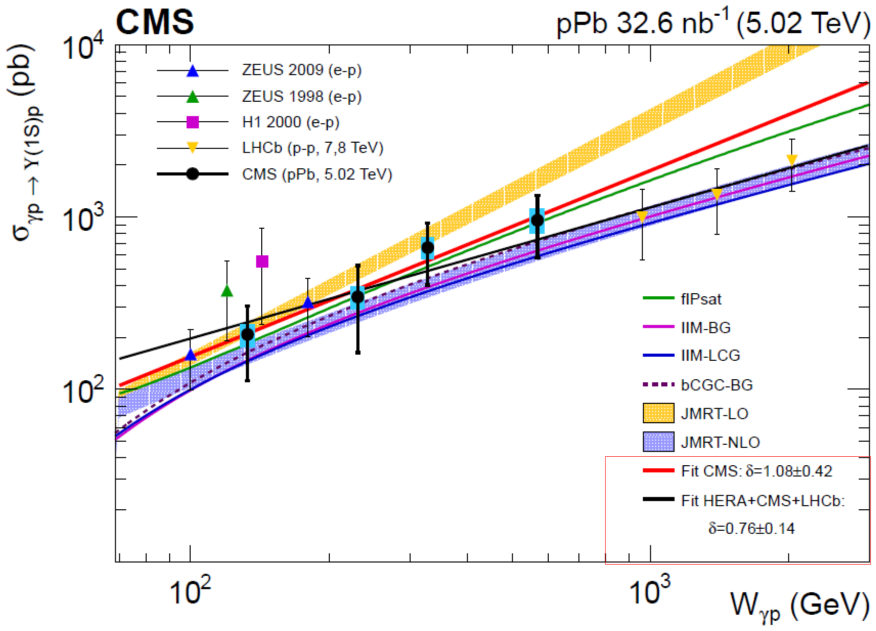


Good agreement with HERA data and Regge theory (soft Pomeron)

$\gamma p \to \Upsilon p$



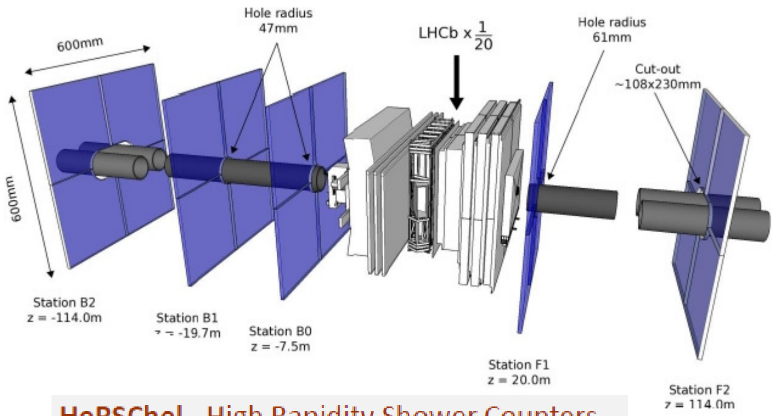




- LHC data extend HERA energy range towards high W (very low x)
- CMS data fill the gap between the HERA and LHCb measurements
- Data has potential to constrain theorerical models

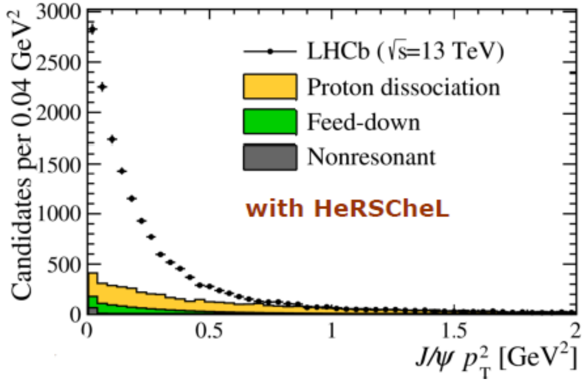
Exclusive (forward) J/ψ and ψ(2S) in pp from LHCb

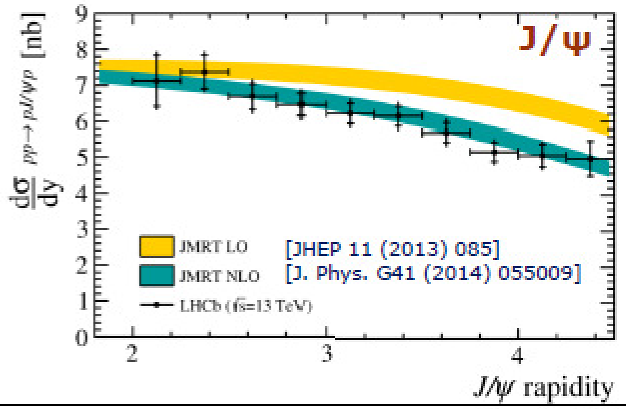
Marcin Kucharczyk

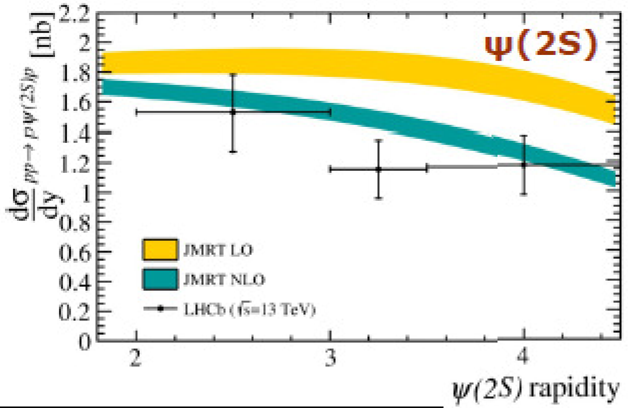


HeRSChel - High Rapidity Shower Counters

- installed at the end of 2014
  → *increase η coverage (5 < |η| < 10)*
- read-out synchronic LHCb
  → *5 stations with 4 scintillators with PMT*
- able to detect forward particle showers and veto events

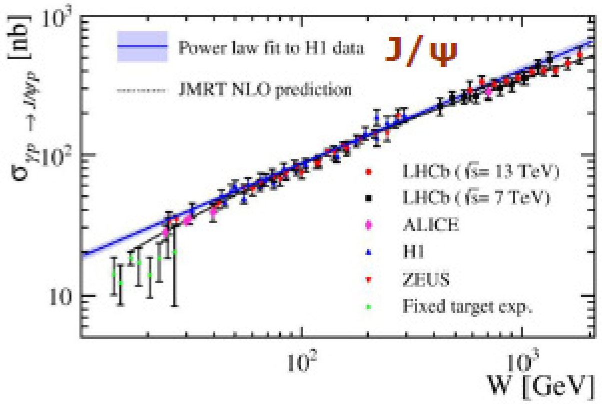


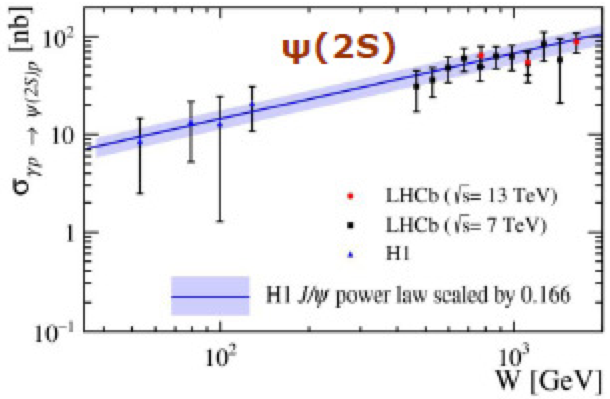




$$\sigma_{pp\to p\psi p} = r(W_+)k_+\frac{dn}{dk_+}\sigma_{\gamma p\to\psi p}(W_+) + r(W_-)k_-\frac{dn}{dk_-}\sigma_{\gamma p\to\psi p}(W_-).$$

r - gap survival factor, $k_\pm$ - photon energy, $dn/dk_\pm$ - photon flux, $W_\pm$ - inv. mass of photon-proton system



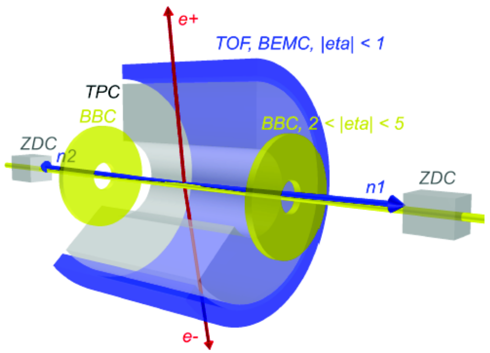


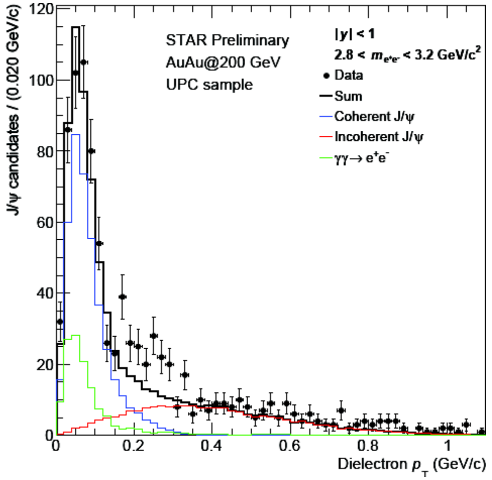
- measured cross sections for *J/ψ* and *ψ(2S)* in better agreement with JMRT NLO
- derived cross section for *J/ψ* photoproduction differs from power-law extrapolation of H1 data

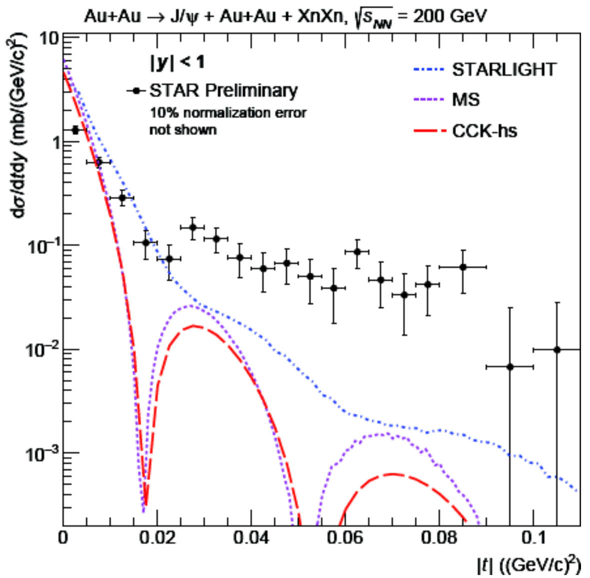
Coherent J/ψ production in AuAu from STAR and PbPb from ALICE

Jaroslav Adam

UPC events selected by requiring neutrons in Zero Degree Calorimeters (ZDC)





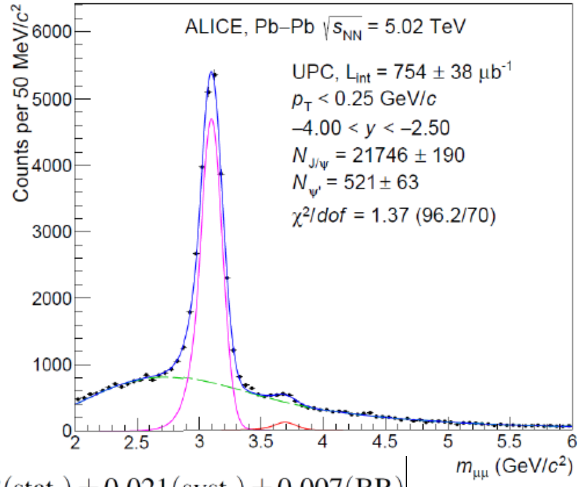


- **STARLIGHT:** Klein, Nystrand, CPC 212 (2017) 258-268
  - Vector meson dominance and Glauber approach
  - Includes effects of photon p_T
- **MS:** Mäntysaari, Schenke, Phys.Lett. B772 (2017) 832-838
  - Dipole approach with IPsat amplitude
  - Scaled to XnXn using STARLIGHT
- **CCK:** Cepila, Contreras, Krelina, Phys.Rev. C97 (2018) no.2, 024901
  - Hot spot model for nucleons, dipole approach
  - Scaled to XnXn using STARLIGHT

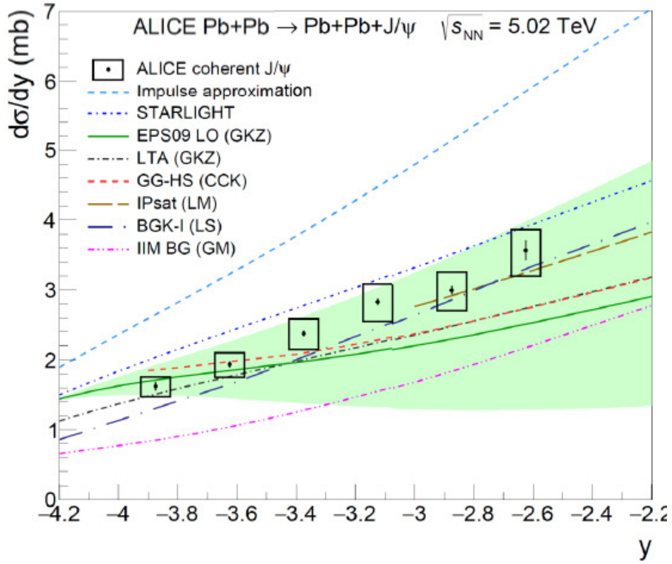
- Diffractive dip around $|t| = 0.02$ GeV² is correctly predicted by MS and CCK models
- Slope below first diffractive minimum is consistent with STARLIGHT

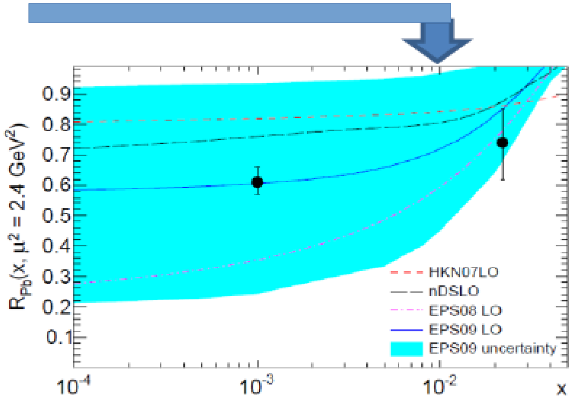
Evgeny Kryshen

Continuous coverage:
-3.7 < η < 5.1
New in Run2
+ ADA: 4.9 < η < 6.3
+ ADC: −7.0 < η < −4.8
+ ZDC at very forward rapidities



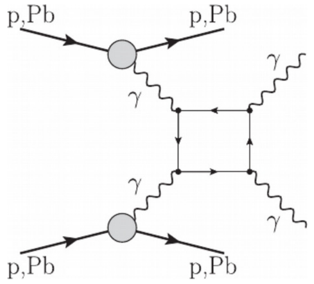
$$R = \frac{\sigma(\psi')}{\sigma(J/\psi)} = 0.150 \pm 0.018(\mathrm{stat.}) \pm 0.021(\mathrm{syst.}) \pm 0.007(\mathrm{BR})$$





Coherent J/ψ cross section in agreement with moderate nuclear gluon shadowing

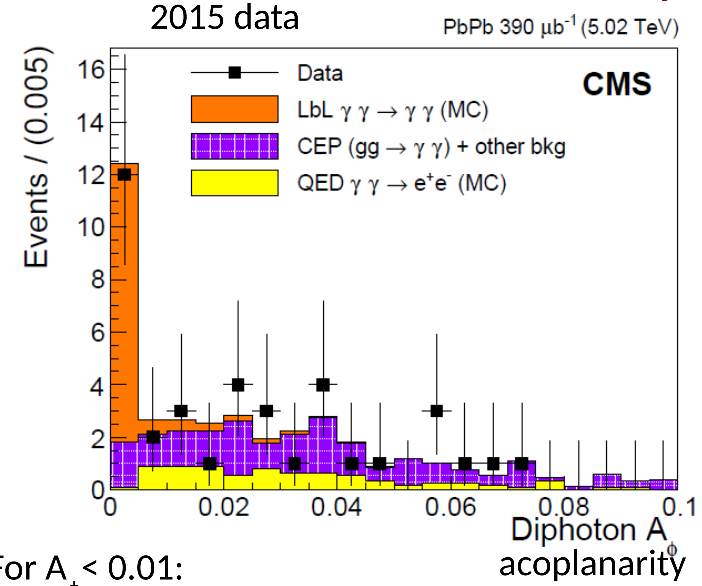
Light-by-light scattering in PbPb UPC from CMS and ATLAS



Elastc γγ→ γγ scatering
- fundamental QED/QCD process
- difficult to observe due to very small $O(\alpha^4)$ cross section
- sensitive to BSM physics, (loop contributions, axions,...)

Alexander Bylinkin

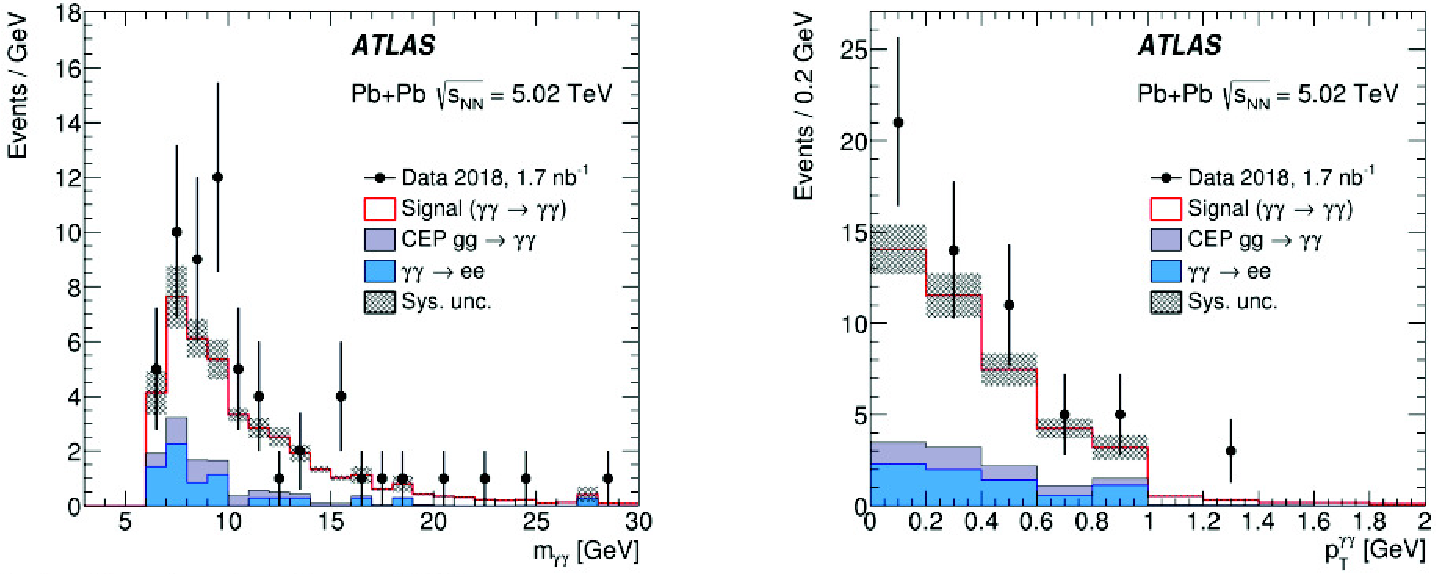
2015 data



For $A_\phi < 0.01$:
Observed: 14 events
Expected: 11.1 ± 1.1 (th) signal
4.0 ± 1.2 (stat) background events,
Significance: 4.1 σ (expected 4.4 σ)

Competitive limits on BSM physics,
Axion-like particles (talk by Ruchi Chudasama in WG3)

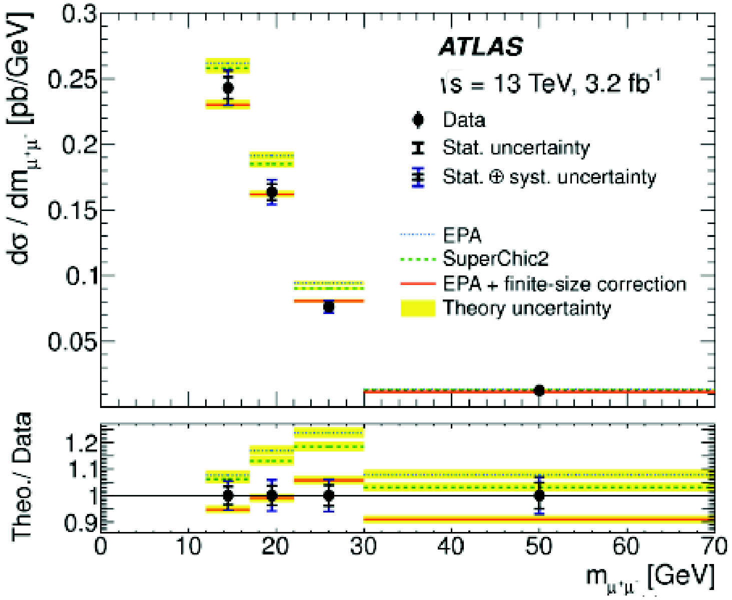
Samira Hassani



- In the Signal region (Aco < 0.01)
  - 59 events observed (12 ±3 background events expected)
- **Significance** is extracted in the region (Aco < 0.005)
  - 42 events observed (6 ±2 background events expected)
  - **8.2 σ (6.2 σ) observed (expected)**
- **Fiducial cross-section: σ = 78 ±13 (stat) ±8 (sys) nb,** Standard Model predictions: σ = 49 ±5 nb
  (Fiducial region definition: $E^{\gamma}_T > 3$ GeV, $|\eta| < 2.4$, $m_{\gamma\gamma} > 6$ GeV, $p^T_{\gamma\gamma} < 1$ GeV, aco < 0.01)

Exclusive γγ → l+l- from ATLAS and CT-PPS

Samira Hassani

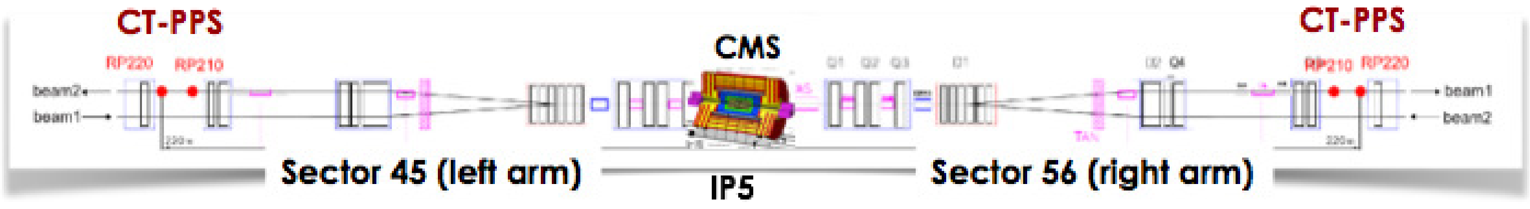


- Cross sections measured in the fiducial region in agreement with the predicted values corrected for proton absorptive effects (corrections ~20%)

  $\sigma(\gamma\gamma \rightarrow \mu^+\mu^-) = 3.12 \pm 0.07(\text{stat.}) \pm 0.14$ (syst.) pb

Antonio Vilela Pereira

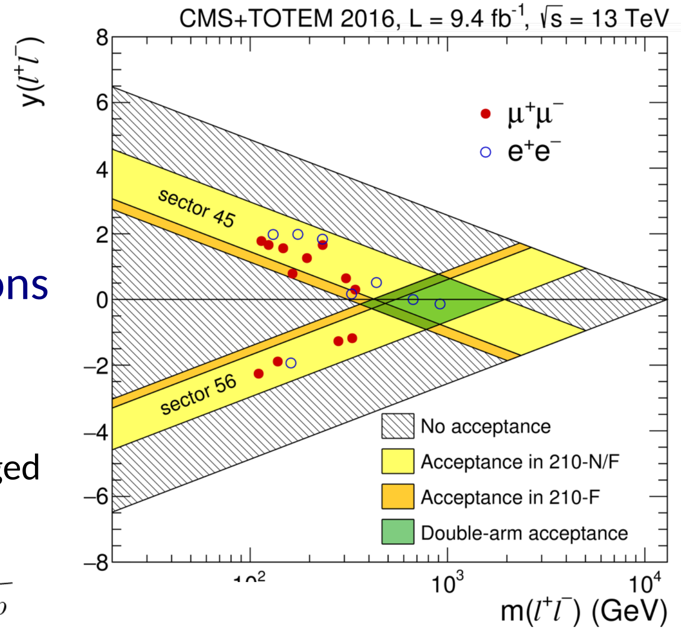
First CT-PPS measurement with tagged protons from high-lumi data.



Observed: 12 μ+μ- and 8 e+e- events with matching kinematics (20 in total)

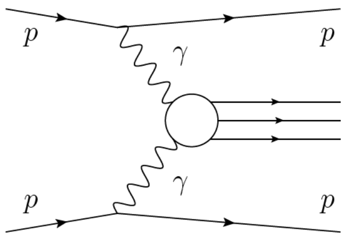
Background estimate:
1.49 ± 0.07 (stat.) ± 0.53 (syst.) μ+μ- events
2.36 ± 0.09 (stat.) ± 0.47 (syst.) e+e- events

Combined significance: 5.1σ



Proton-tagged γγ collisions at the EW scale!

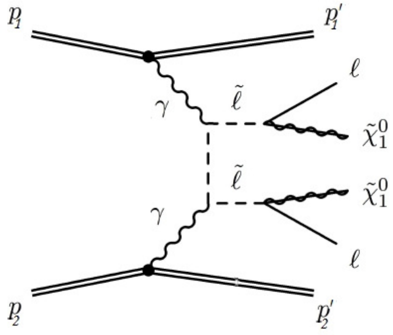
About ~100/fb data with tagged protons collected so far.
Future analyses:



X = W+W-, γγ, γZ, ZZ, tt, jets, BSM etc.

Marek Tasevsky

Feasibility studies of searches for Dark Matter with ATLAS Forward Proton (AFP) and CT-PPS detectors



- S=B~2 per 300fb-1 with current techniques and resolutions
- Suitable for HL-LHC: larger significances expected but additional timing information from Central detector needed

Summary of the summaries

- Many new theory developements
- Many new experimental results
- We thank all the speakers for their contributions!
- The WG2 audience for stimulating discussions!
- And the organizers for this very interesting conference and their hospitality!