Low x, diffraction and vector mesons: DIS 2016 – WG5 summary

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Session composition

- 9 sessions + joint session with Heavy Flavor WG
- 35 talks + 5 talks in the joint session
- 19 theory / phenomenology talks + 21 experimental talks

This summary: profile and subject driven selection: 18 talks

- General observation: the weight is moving towards hadronic and nuclear processes and observables (mostly at LHC and RHIC), still some interesting new analyses of HERA data, which are also used as a reference for studies of hadronic diffractive and exclusive processes

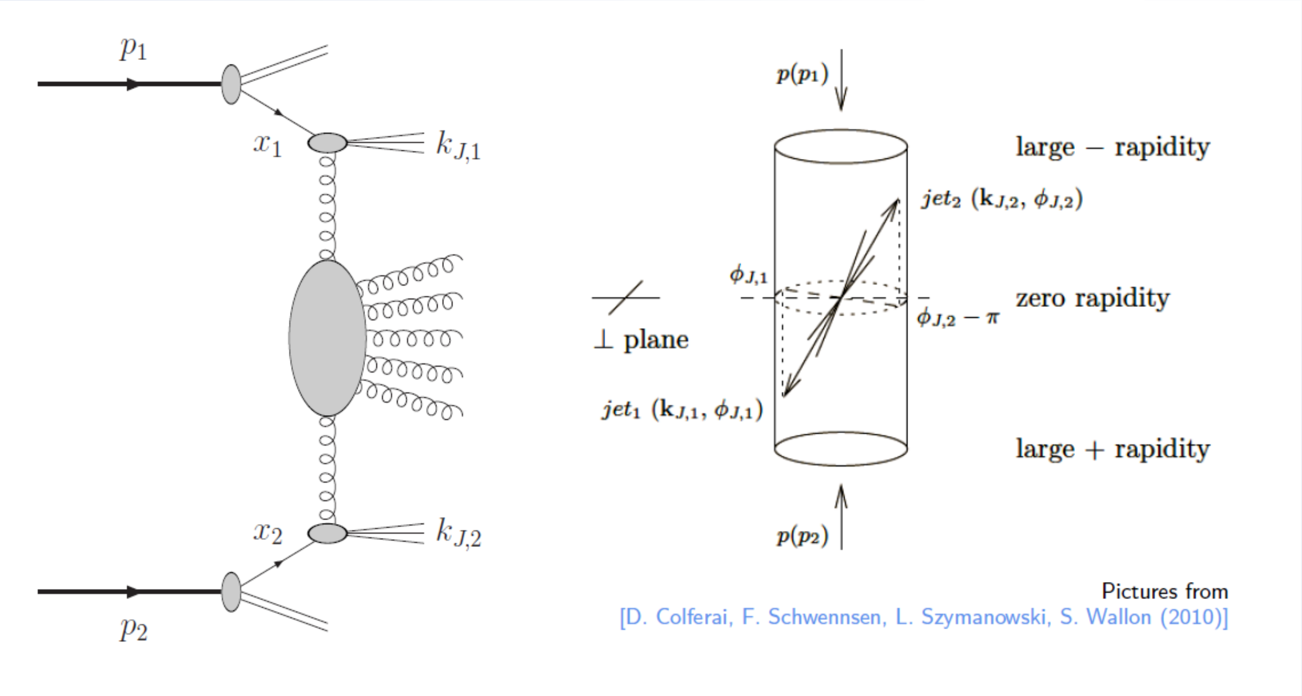
- Lots of vivid discussions, interesting and successful session

Theory summary: topics

- Small x resummation theory (8 talks):
  - – small x effects in NLL BFKL evolution: multi-jet final states
  - – NLO impact factors
  - – non-linear effects of Baltisky-Kovchegov evolution equation beyond the LL: NLL and improved NLL
- Color glass condensate and color dipole model phenomenology (5 talks):
  - – diffractive and diffractive exclusive scattering at HERA
  - – scattering off nuclei
  - – diffractive scattering with leading neutron
- KT factorization approach to high energy observables (3 talks)
  - – forward Drell-Yan process
  - – exclusive vector meson hadroproduction
  - – diffractive vector meson hadroproduction
- New concepts and fits of inclusive and inclusive diffractive HERA data (2 talks)

Small-x effects in Mueller-Navelet and multi-jet observables

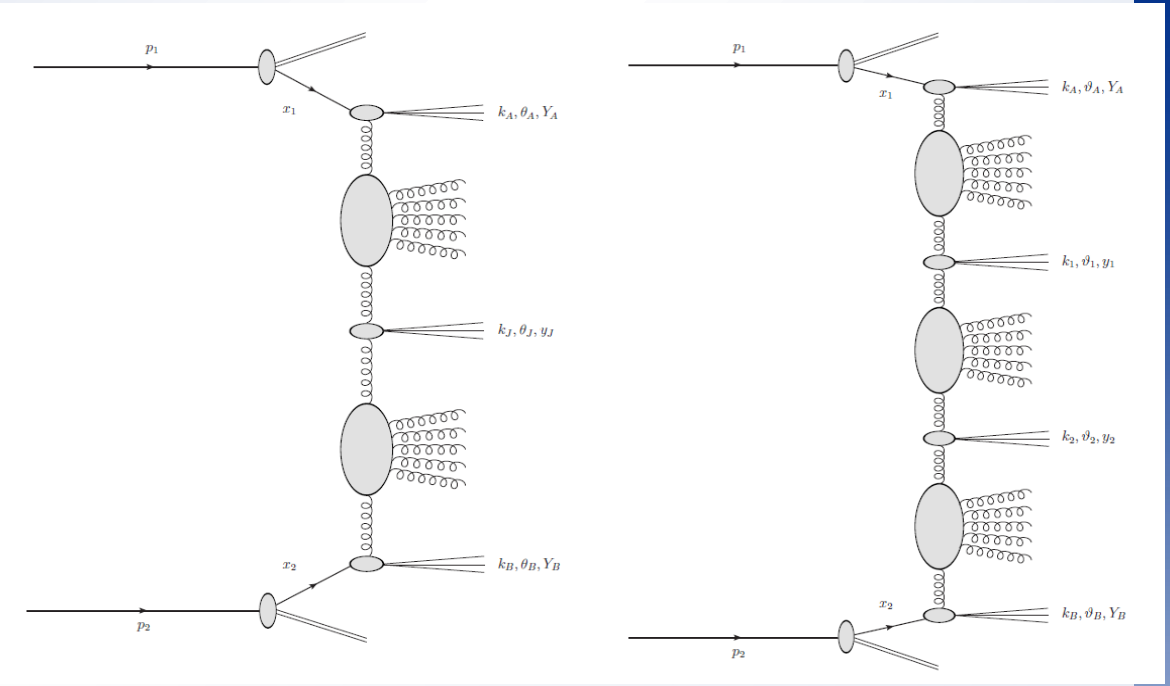
- F. Celiberto and G. Chachamis: exploration and generalisation of Mueller-Navelet jets using NLL BFKL approach



- F. Celiberto (1): application of NLL BFKL Green's function and NLO jet impact factors + BLM scale fixing scheme to study properties of azimuthal distributions of Mueller-Navelet jets

Continued – higher number of jets:

- Proposal to study angular distributions of 3 jets (G. Chachamis) and 4 jets (F. Celiberto) [work in progress]



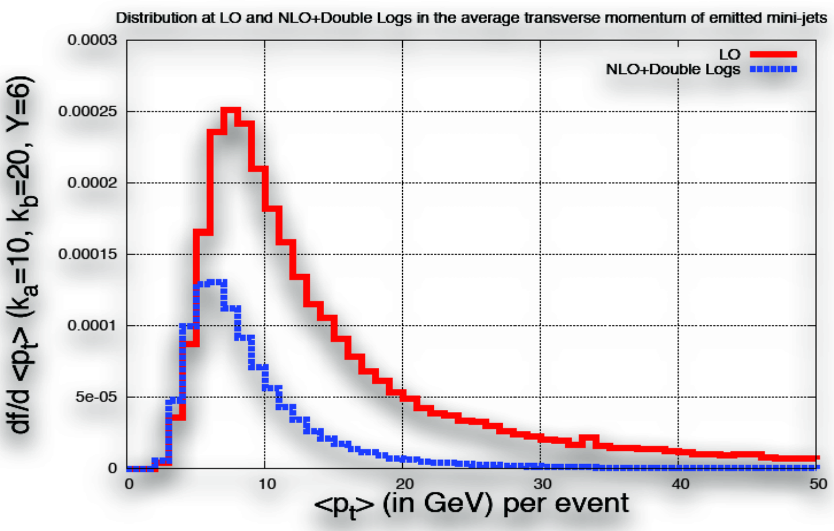
$$\mathcal{R}^{M,N}_{P,Q} = \frac{\langle \cos\left(M\left(\theta_A - \theta_J - \pi\right)\right)\cos\left(N\left(\theta_J - \theta_B - \pi\right)\right)\rangle}{\langle \cos\left(P\left(\theta_A - \theta_J - \pi\right)\right)\cos\left(Q\left(\theta_J - \theta_B - \pi\right)\right)\rangle}$$

BFKL radiation – final state analysis

- G. Chachamis: introducing event characteristics in multi-jet final state
  - average p_t $\quad \langle p_t \rangle = \frac{1}{N} \sum_{i=1}^{N} |k_i|$
  - average azimuthal angle $\quad \langle \phi \rangle = \frac{1}{N} \sum_{i=1}^{N} \phi_i$
  - rapidity ratio between subsequent jets $\quad \langle \mathcal{R}_y \rangle = \frac{1}{N+1} \sum_{i=1}^{N+1} \frac{y_i}{y_{i-1}}$

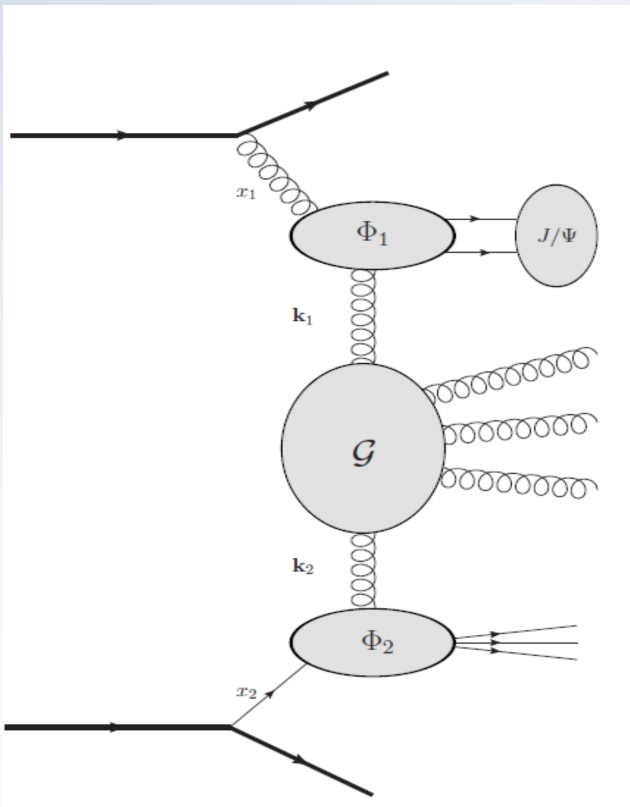
    $y_0 = y_a,\ y_{N+1} = y_b = 0$ and $y_{i-1} > y_i$

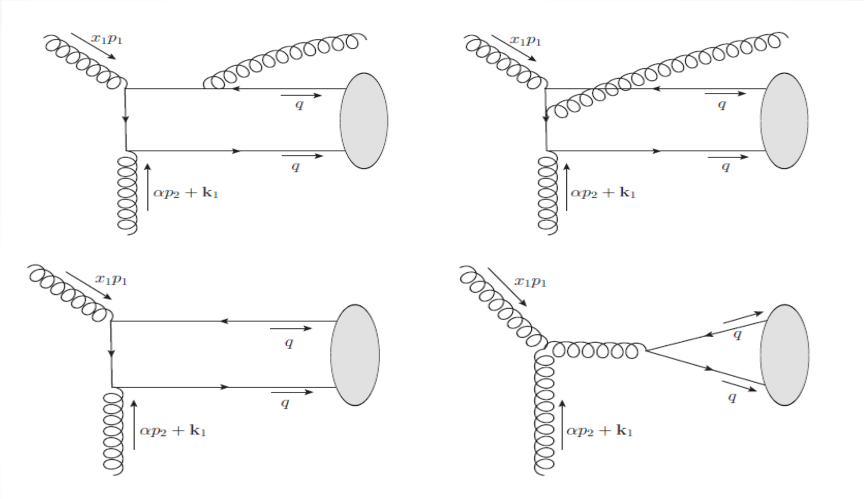
- Shown to discriminate between LL and NLL BFKL



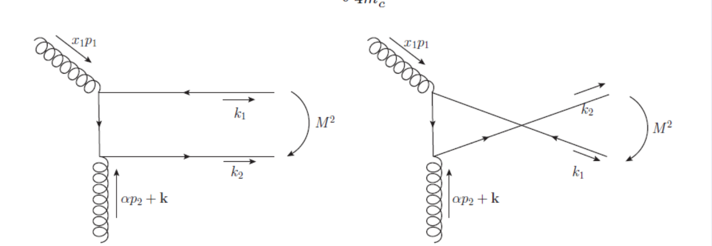
Interesting new observable a la Mueller-Navelet jets: forward J /ψ + backward jet in pp collisions

- Boussarie: BFKL formalism combined with two mechanisms of meson hadroproduction: Color-Singlet / Octet Model and Color Evaporation Model





$$\sigma_{J/\psi} = F_{J/\psi} \int_{4m_c^2}^{4m_D^2} dM^2 \frac{d\sigma_{c\bar{c}}}{dM^2}$$



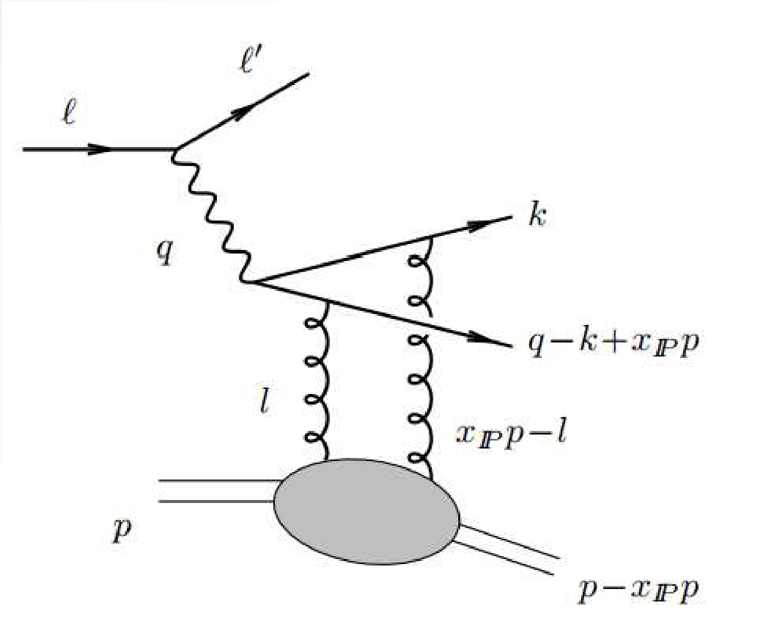
- Interesting observable to measure

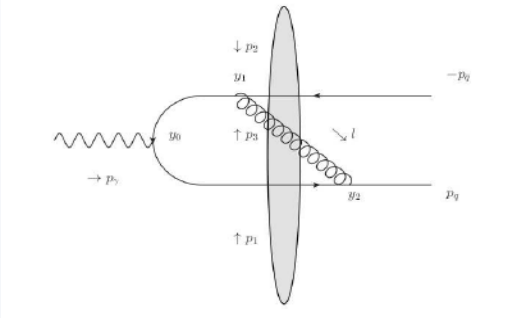
NLO impact factors of BFKL: Diffractive dijet production

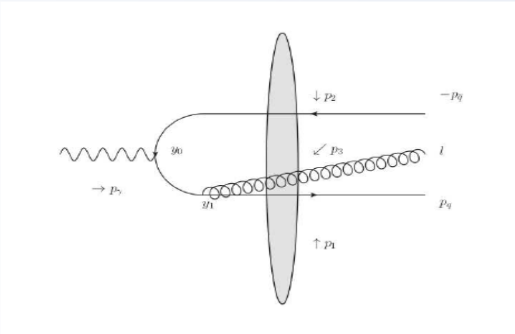
R. Boussarie:

– Computation of the NLO impact factor in Balitsky's shock-wave approach [work in progress]

- – Inclusion of real and virtual corrections
- – Cancellation of UV, collinear, soft and rapidity divergencies
- – Lot's of possible applications





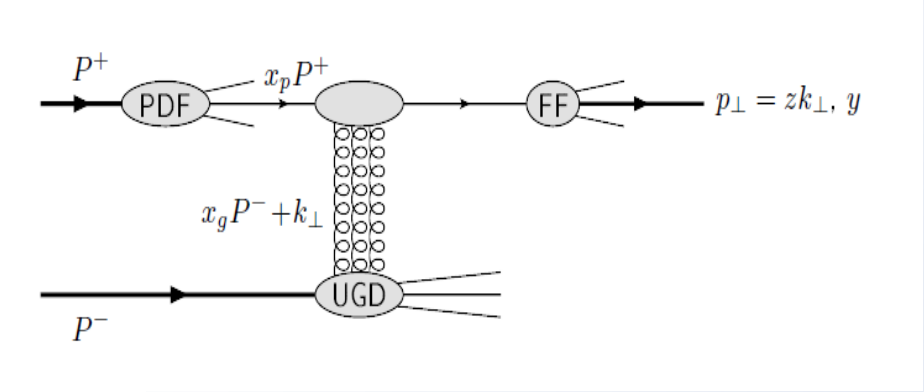


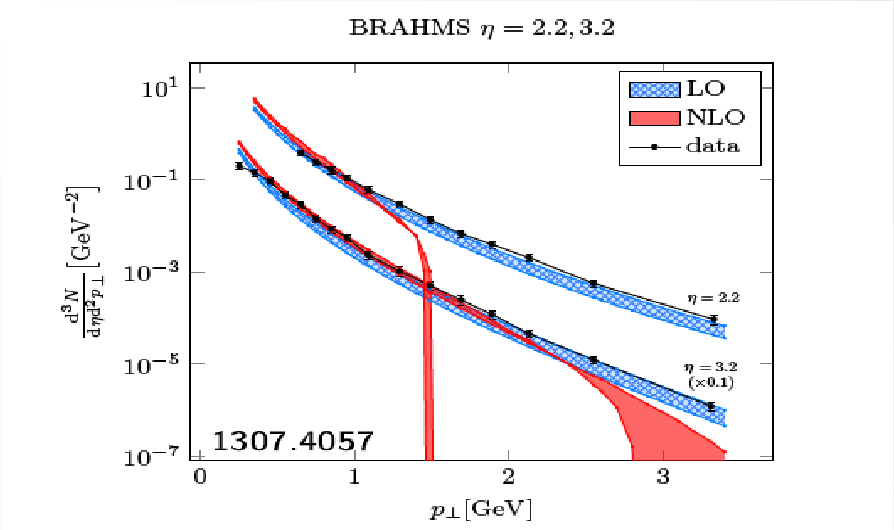
NLO impact factor: Single inclusive forward hadron distribution

- Sensitive probe of scattering amplitudes at very small x, where non-linear (saturation) effects play important role

- Problem at NLO: negative cross-sections at large pT

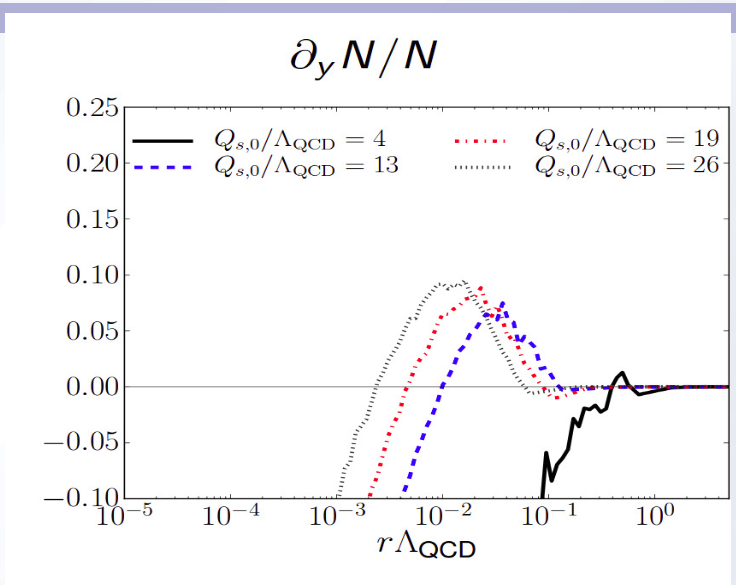
- Ducloue: proposal to handle this problem via more physical procedure of rapidity divergence subtraction [work in progress]



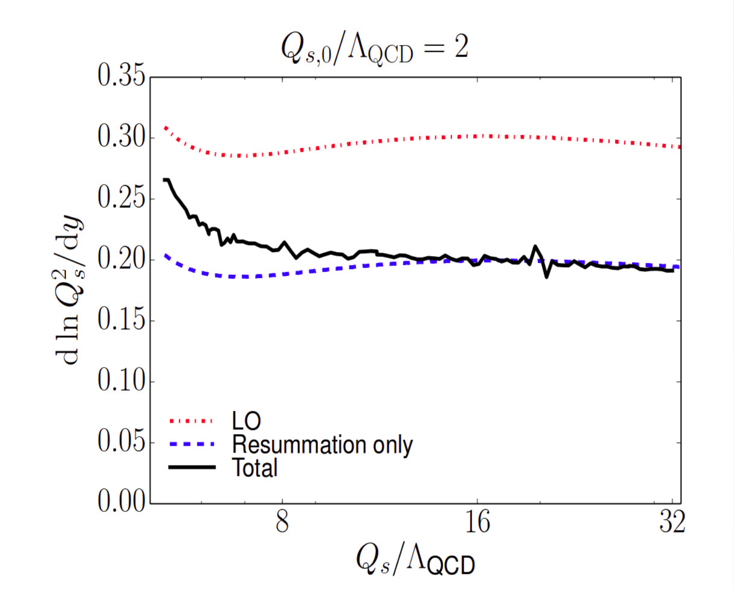


Non-linear BFKL: Balitsky-Kovchegov equation at NLL and beyond

- Problem of BK equation at NLL – correction enhanced by single and double logarithmic contributions leads to pathologies:

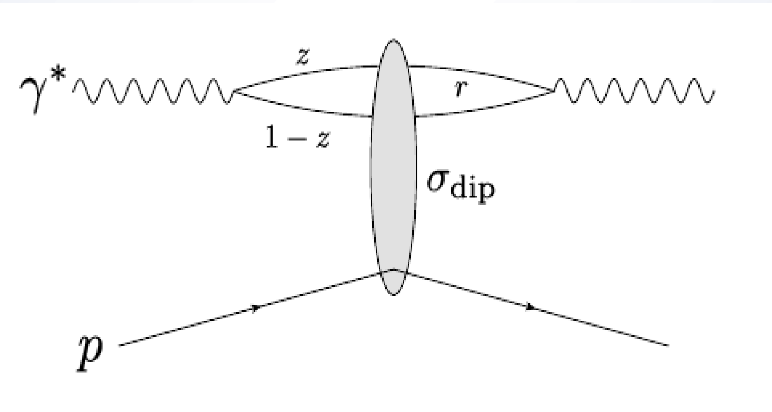


- Mantysaari: curing the problem by double and single logarithmic resummation

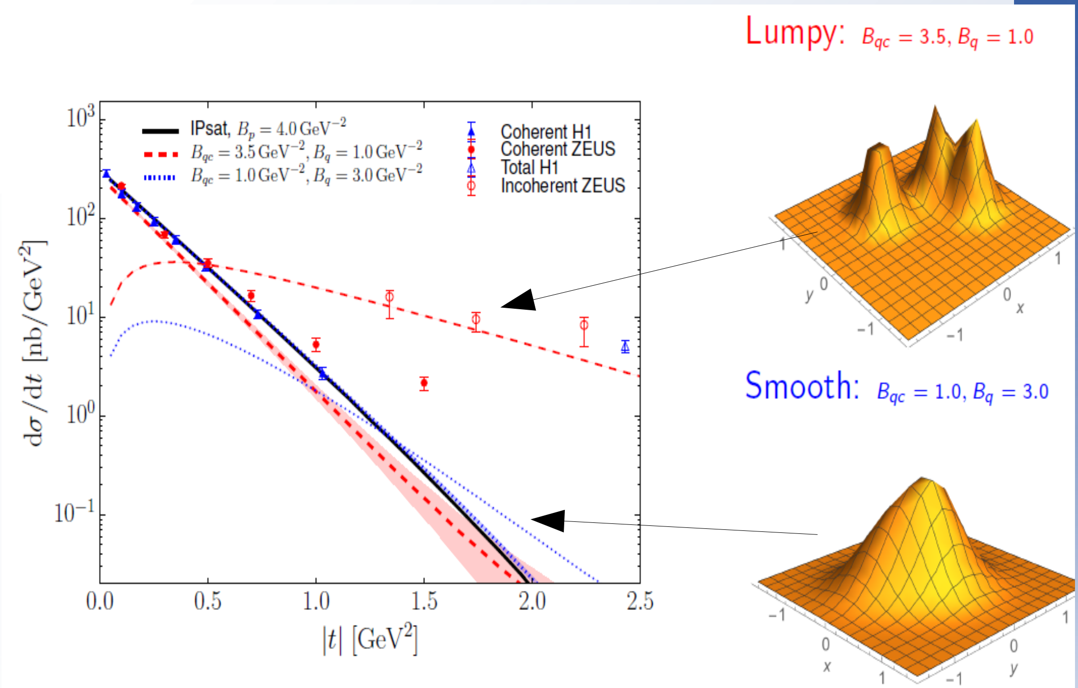


Color glass condensate / dipole model phenomenology – matter distribution in proton from diffractive VM prod.

- High energy scattering off dense targets: conveniently described in a hybrid representation of transverse position and longitudinal momentum. Dense target / multiple scattering effects are absorbed into dipole scattering amplitude / Wilson loop operator
- Diffractive meson photoproduction: is `X-raying' proton / nucleus probing matter distribution in the target
- Coherent (exclusive process, no target break-up) / non-coherent (break-up) diffraction



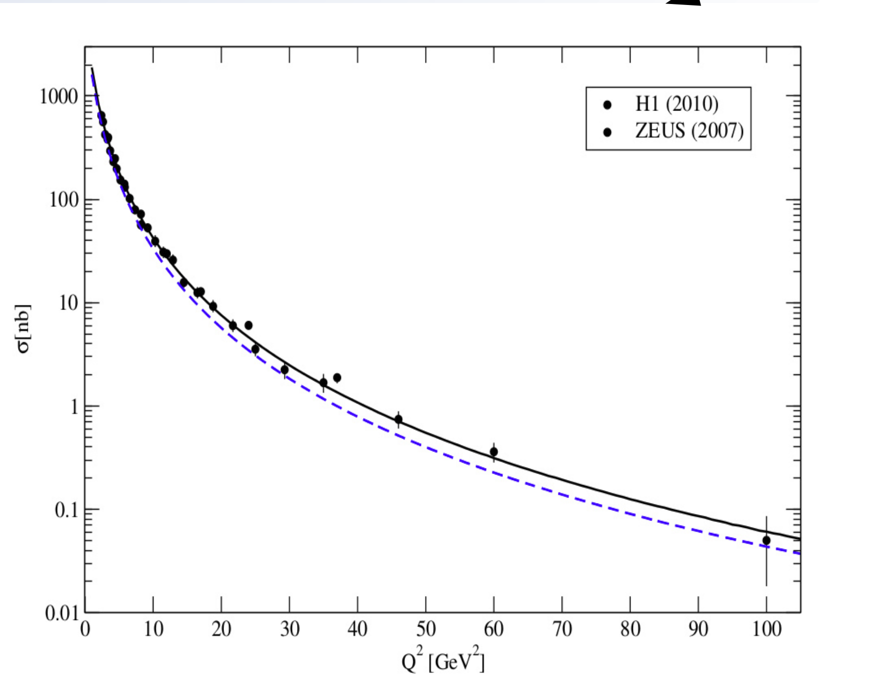
- Mantysaari: non-coherent diffraction data require nontrivial matter distribution / fluctuations in transverse section of proton

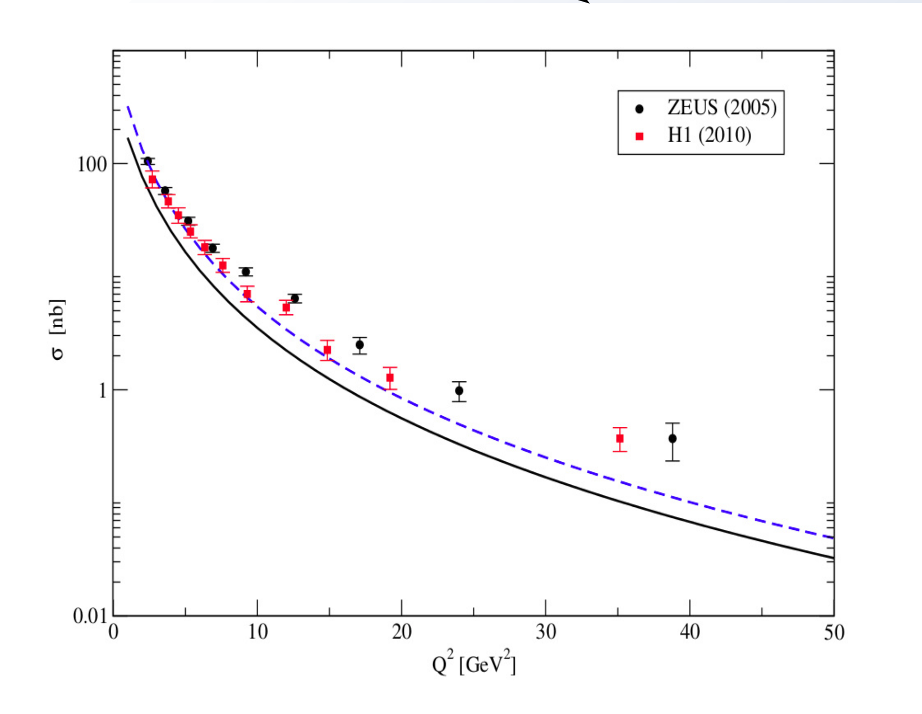


H.M., B. Schenke, arXiv:1603.04349

Color dipole phenomenology + AdS / CFT phenomenology in exclusive VM production at HERA

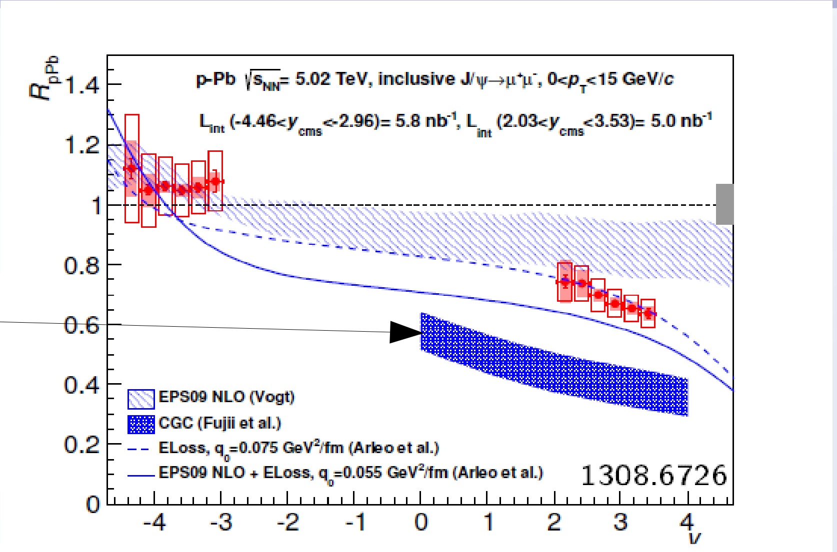
- Ahmady: combination of dipole scattering amplitude with light meson wave functions taken from a modified (to match QCD) AdS-CFT correspondence → leading to already used “boosted Gaussian” wave functions
- Reasonably good description of data for rho and phi



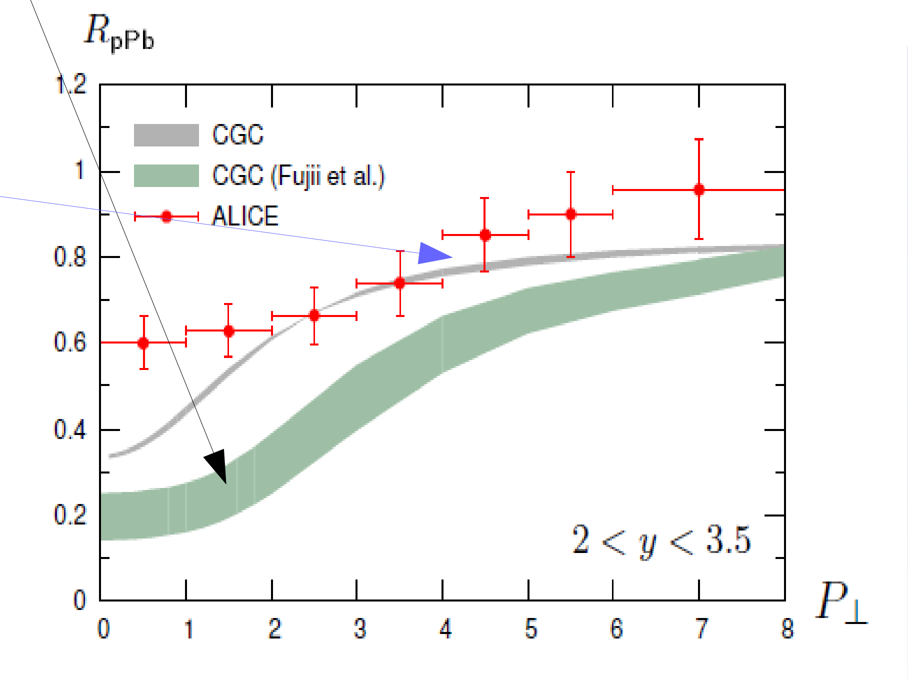


CGC in forward J/ψ production in proton-nucleus conditions

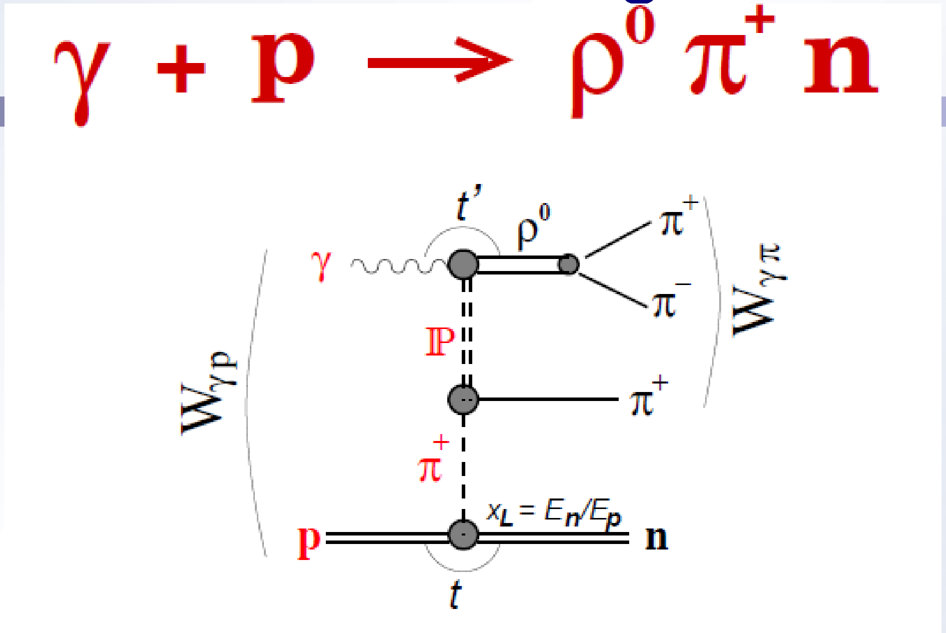
- Meson production rate off large and dense target like nucleus is reduced by nuclear absorption effects
- Reference estimate of Fujii and Watanbe uses hard production mechanism combined with eikonal rescattering amplitude of charm-anticharm pair in nuclear matter



- Ducloue: improvements of the rescattering cross-section (solution of Balitsky-Kovchegov equation) and local density distribution of the nuclear matter

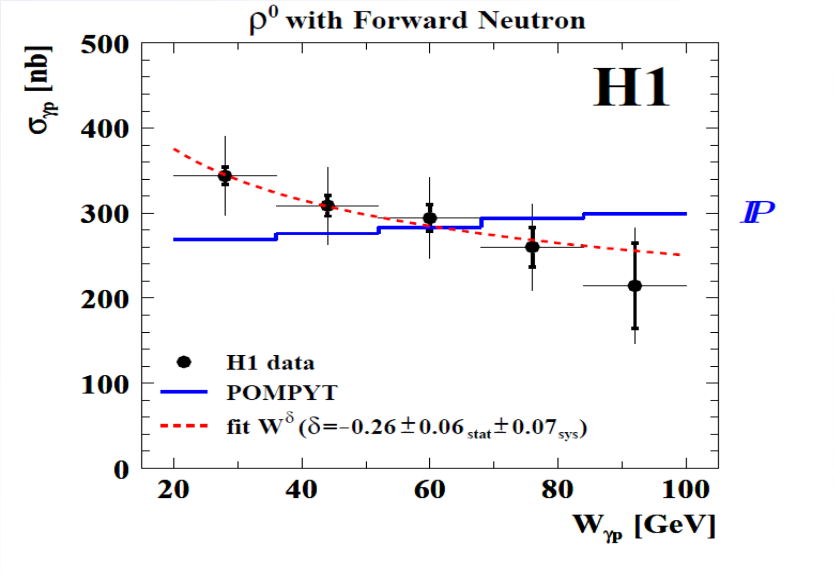


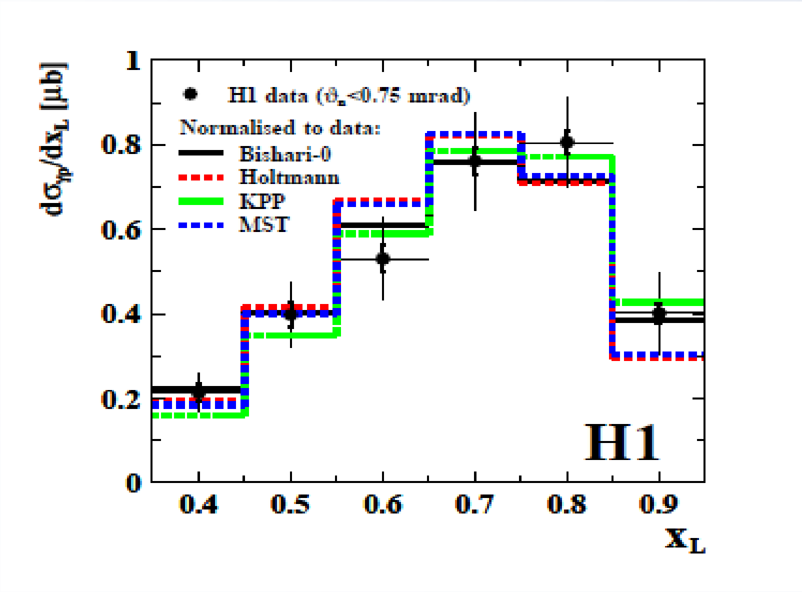
Diffractive vector meson production with leading neutron at HERA



- Levonian: H1 measurement of a `4P' process: proton-photon-pion-pomeron
- Probe of proton-neutron-pion coupling, pion exchange, rescattering effects
- Many interesting observables!

  energy dependence, xL dependence, absorptive factor



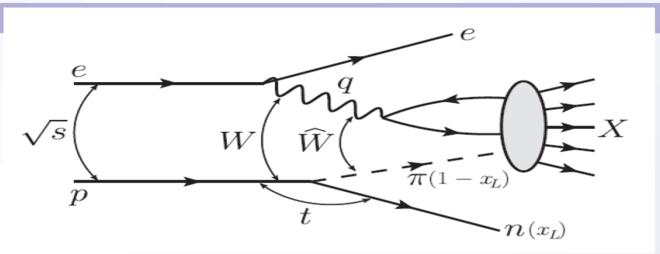


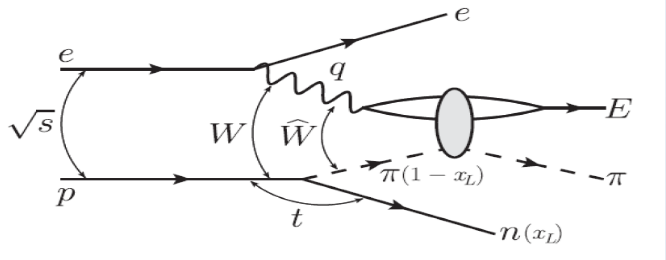
Diffractive vector meson production with leading neutron at HERA: color dipole approach

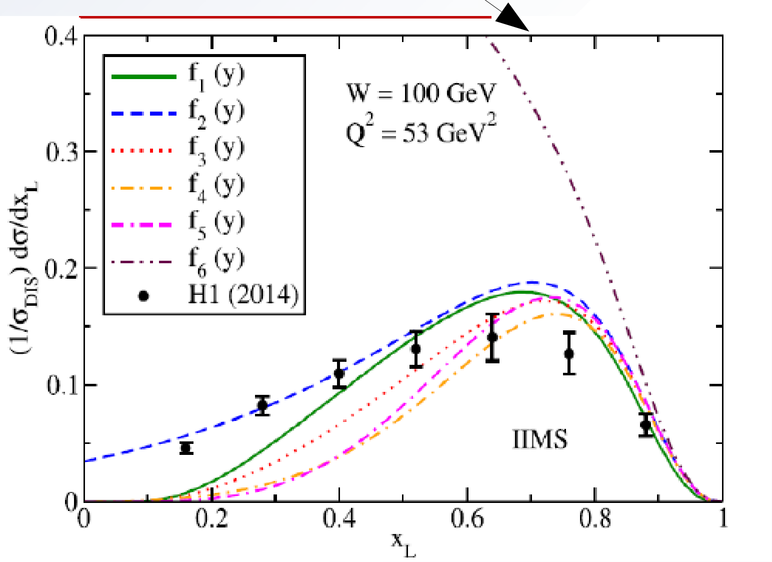
- Goncalves: description of inclusive and exclusive processes with leading neutron in color dipole approach

- Several models of pion exchange

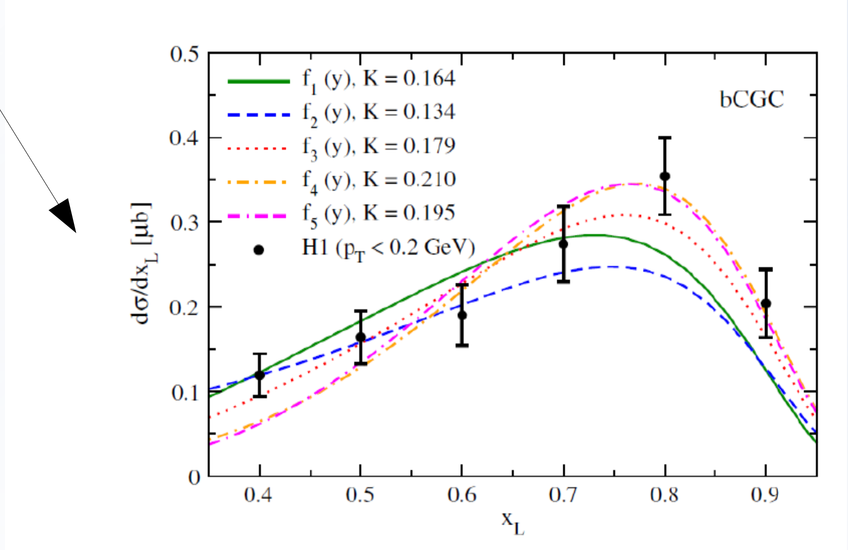
- Free absorption factors
  Good description of inclusive and exclusive data, test of pion flux







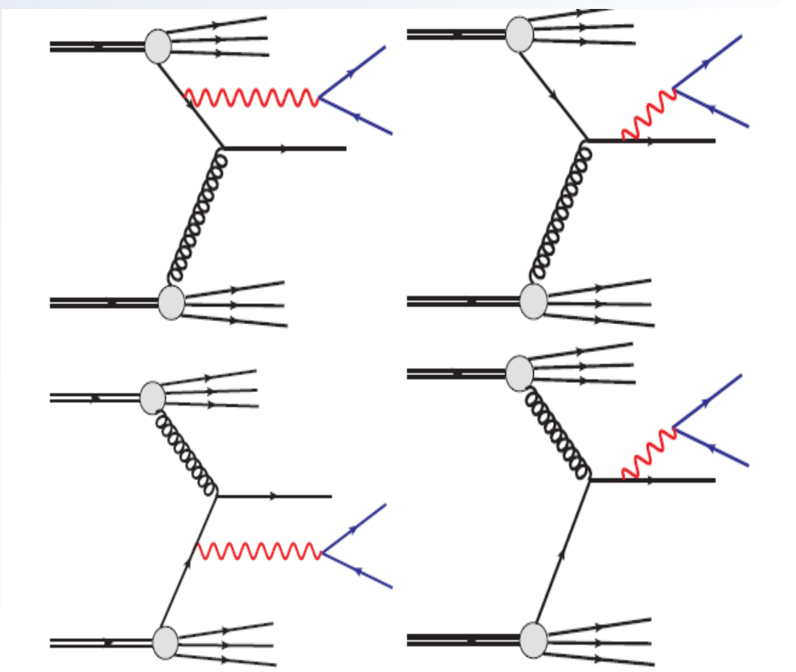
Dependence on the pion flux:

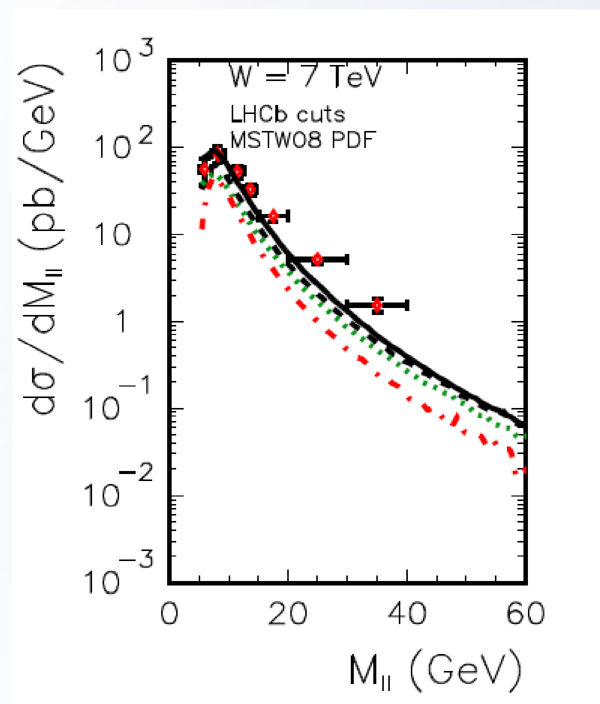


kT-factorization in forward Drell-Yan process

- In kT-factorization scheme parton transverse momenta are taken into account in parton distributions and matrix elements – approach beyond the collinear factorization. Pros: expected better representation of kinematics, cons: more uncertainty than collinear factorisation approach. Most relevant for small-x gluons.
- Szczurek: application of the kT-factorisation framework to forward Drell-Yan (dilepton) production in full momentum space (so far the color dipole model in hybrid representation was used here). Evaluation of all 4 DY structure functions.

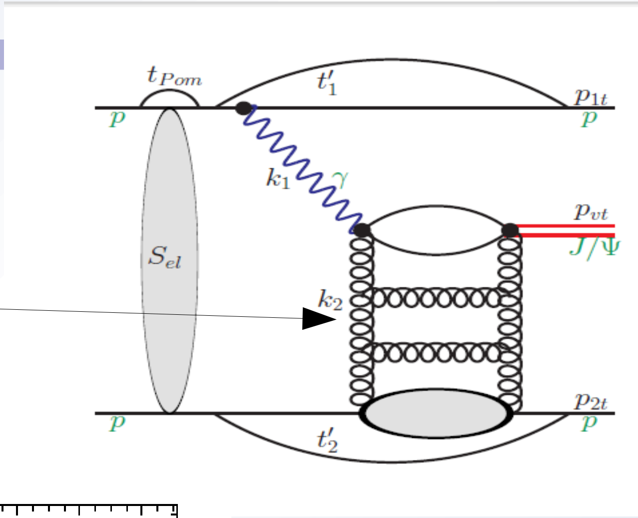
Reasonable agreement with LHCb data

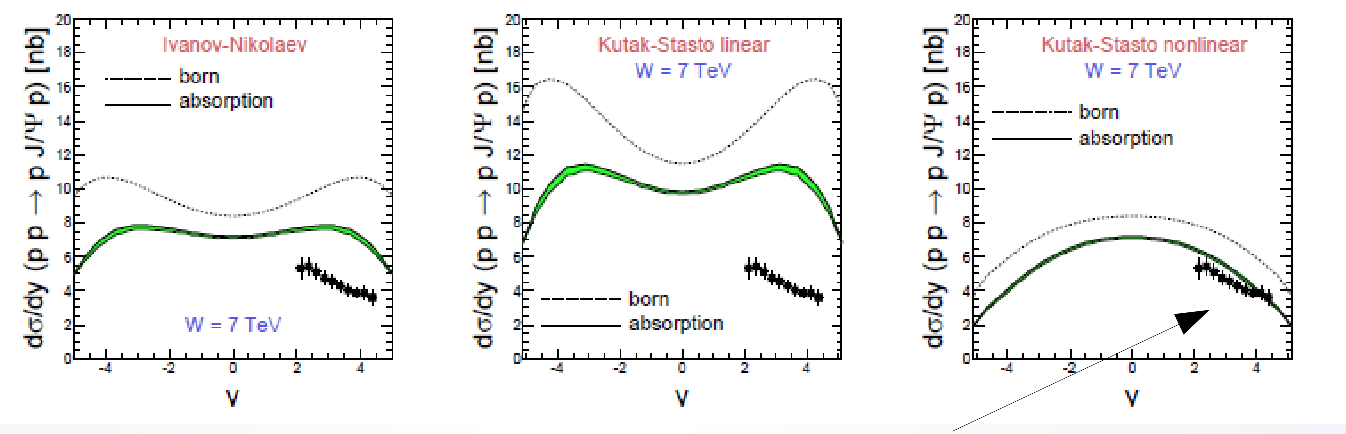




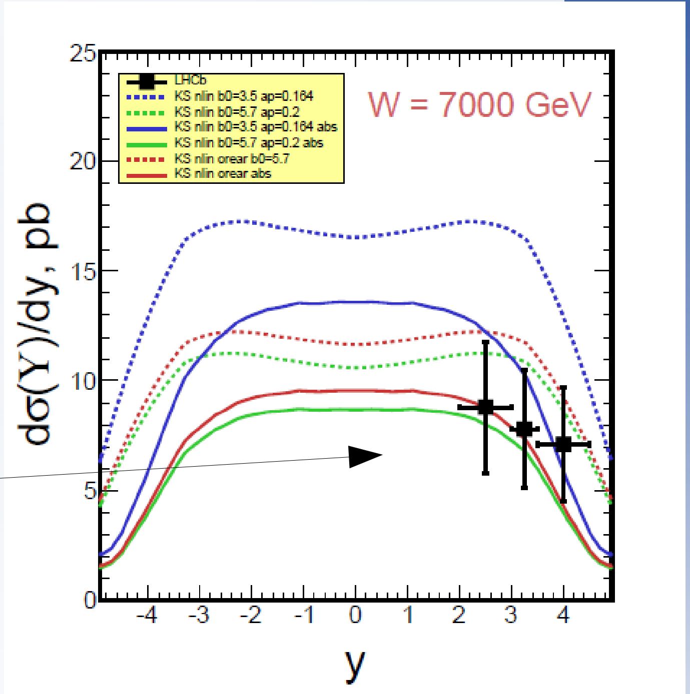
kT-factorisation in exclusive heavy VM hadroproduction

- Schafer: exclusive production of vector mesons in pp collisions as a probe of unintegrated gluon distribution and non-linear effects in gluon evolution
- Inclusion of absorptive correction



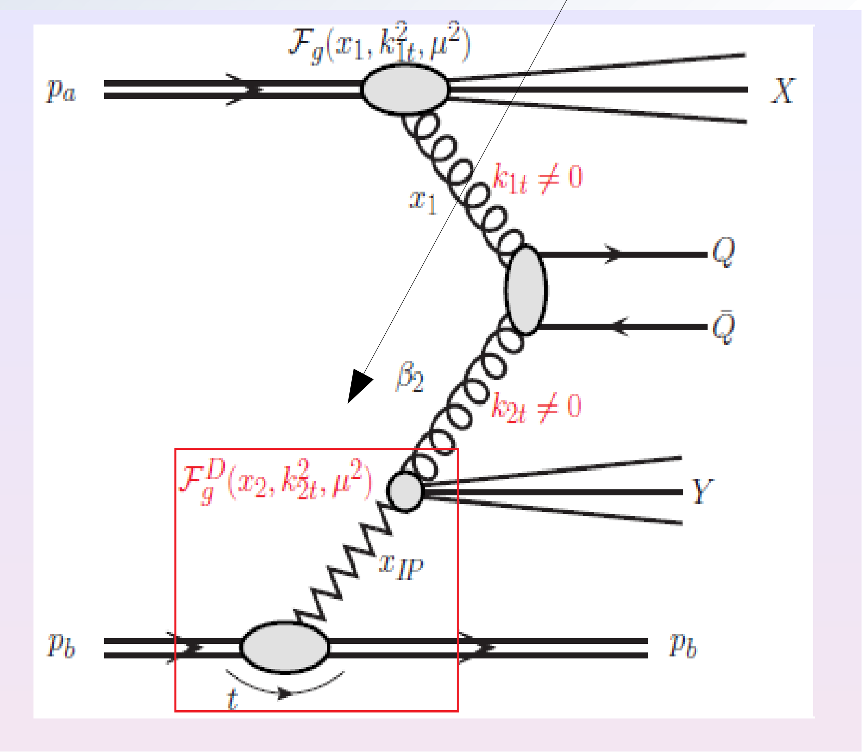


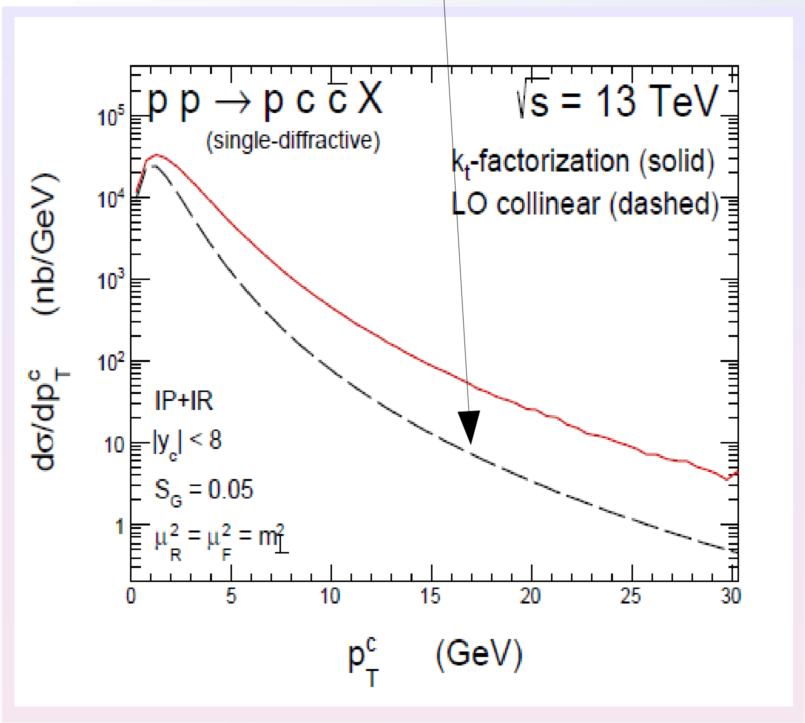
- 7 TeV (pp) J/psi data best described with non-linear Kutak-Staśto unintegrated gluon, the same conclusion for psi' and Upsilon



kT factorisation in diffractive heavy quarks / mesons hadroproduction

- M. Łuszczak: new idea to use Kimber-Martin-Ryskin prescription to derive unintegrated diffractive parton densities from collinear diffractive parton densities
- Application to diffractive charm and bottom production at the LHC
- Predictions of strong enhacement w.r.t. LO collinear results





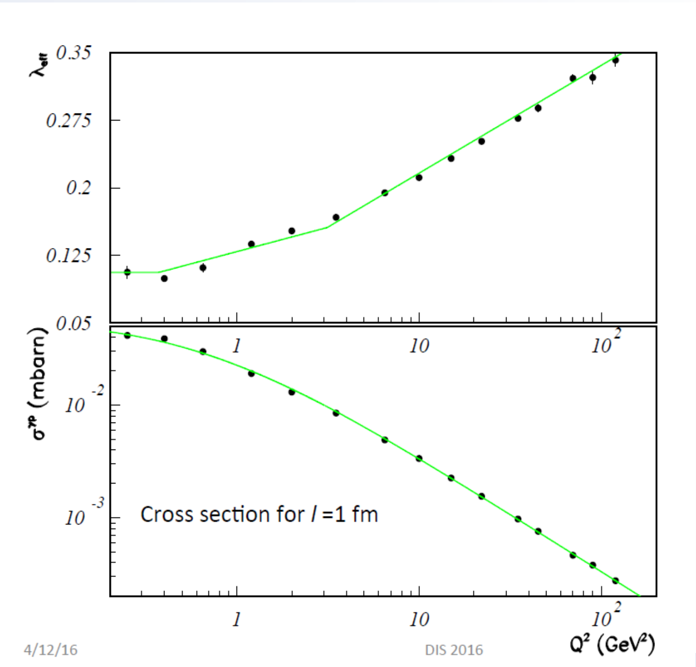
Fresh look on total $\gamma^*(Q^2)p$ cross-section at small x

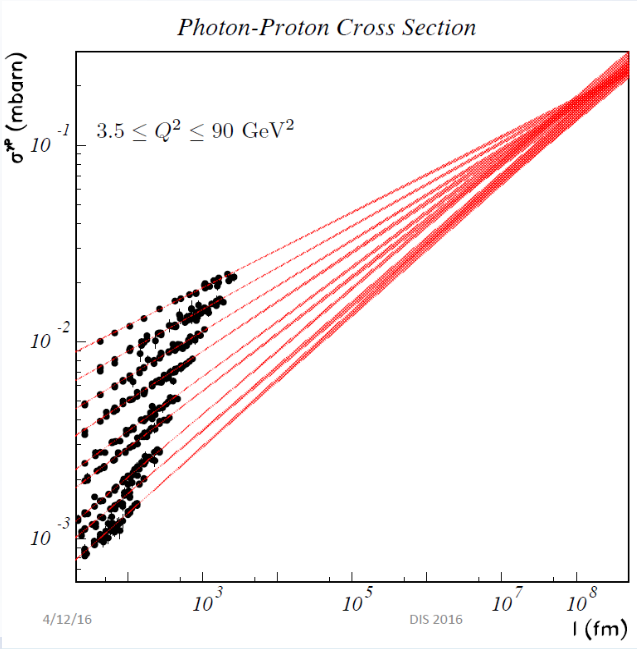
- Caldwell: Fit of small x HERA F_2 data in terms in terms of interaction coherence length L ~ 1/x
- Effective power assumed for given virtuality Q^2 – fixed power at given Q^2
- Good description of data- “effective Pomeron intercept”:

$$\sigma^{\gamma p} = \sigma_0 \frac{M^2}{Q^2 + M^2} \left(\frac{l}{l_0}\right)^{\epsilon_{\rm eff}(\epsilon_0,\epsilon_1,\epsilon',Q_0^2,Q_1^2)}$$

$$\epsilon_{\rm eff} = \epsilon_0 + (\epsilon_1 - \epsilon_0)\frac{\ln(Q^2/Q_0^2)}{\ln(Q_1^2/Q_0^2)}$$

extrapolation towards very low x



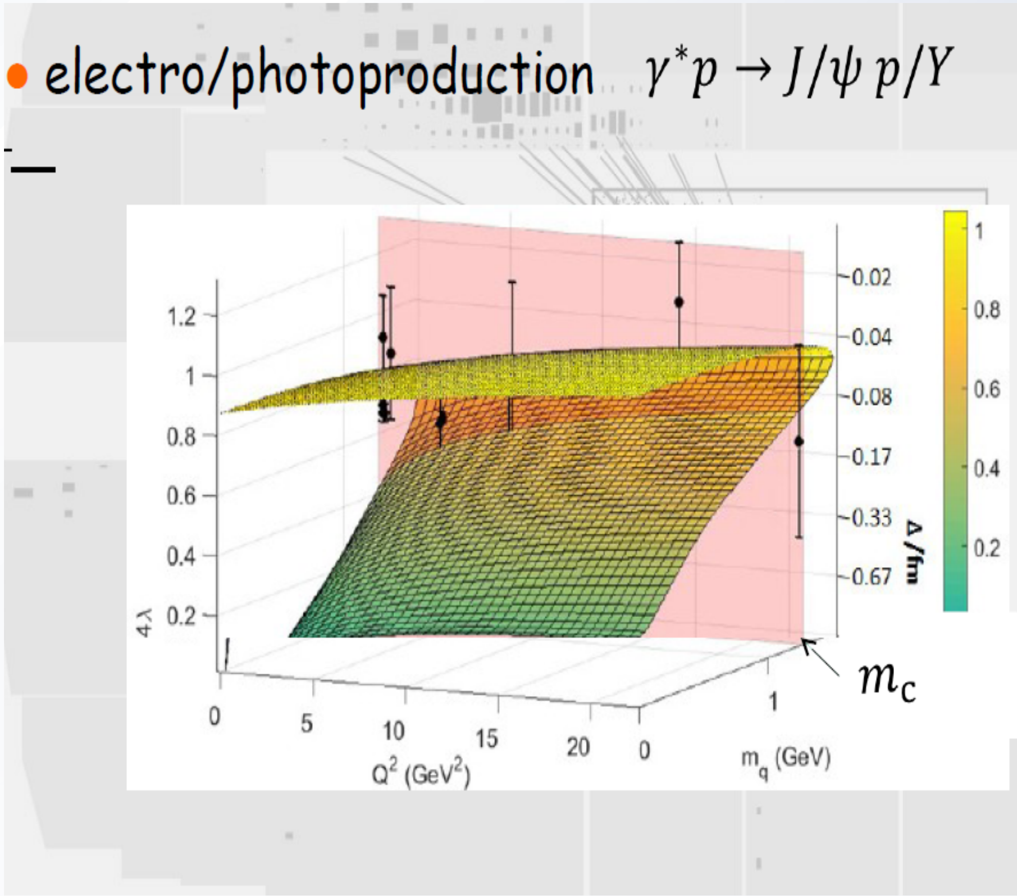


Fresh look on diffractive scattering at HERA

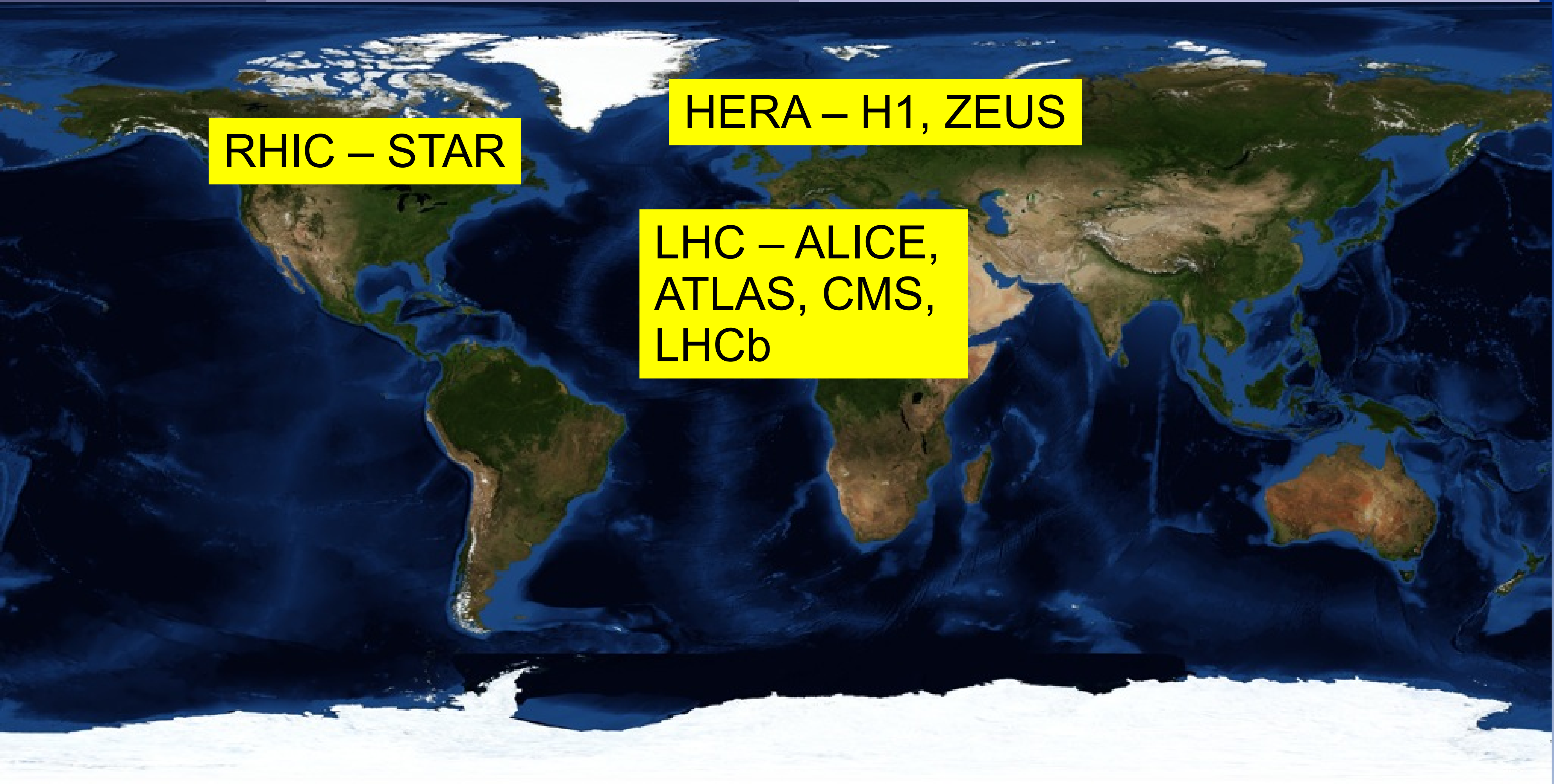
- Dainton: attempt to understand diffractive scattering in terms of elastic quark – proton Rutherford-like scattering within volume allowed by confinement

- Diffractive cross-section x and Q^2-dependence for elastic VM production described in terms of effective quark form-factor represented by Q^2-mass and effective color singlet exchange x-power

- Work in progress



Results from following collaborations:

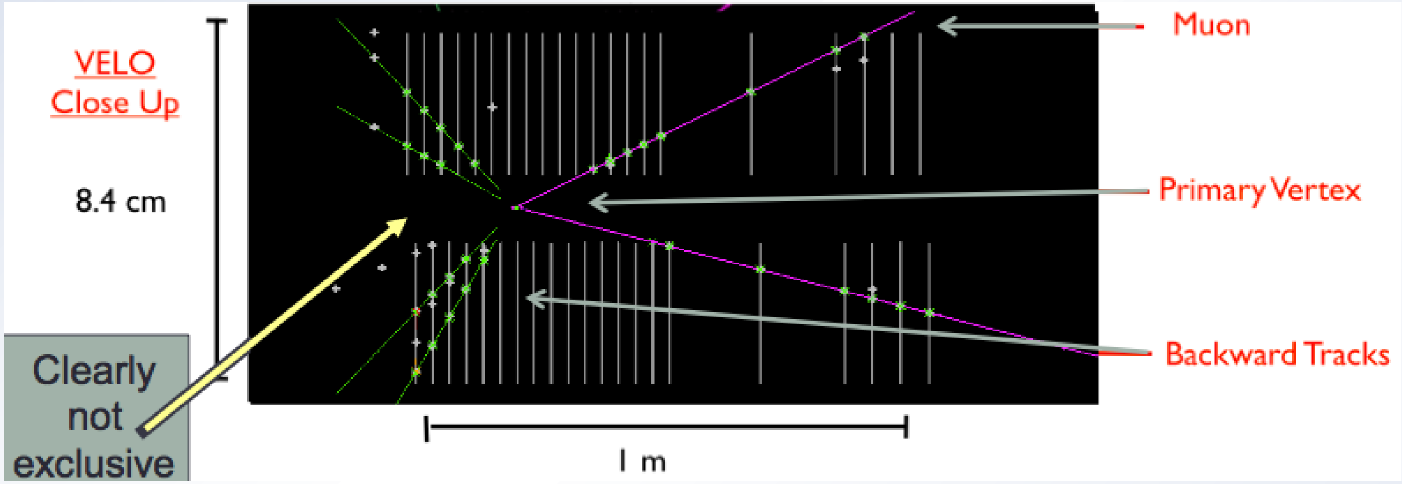


HERA, DESY, Hamburg: ep (3 talks)
LHC, CERN, Geneva: pp, p-Pb, Pb-Pb (15 talks)
RHIC, Brookhaven National Laboratory, New York: p↑ Au-Au (2 talks)

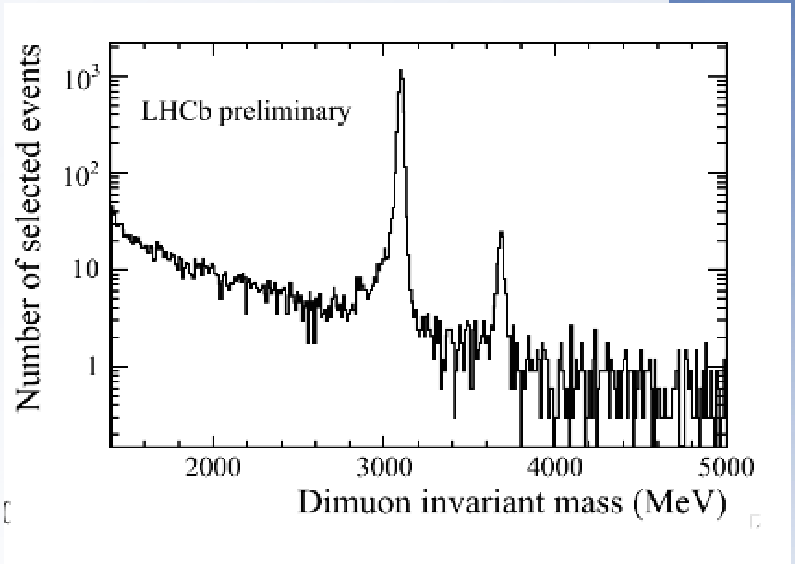
Central exclusive production of J/ψ and ϒ at LHCb

Ronan McNulty

- J/ψ measured by LHCb at very high W (low x) already at Run I



- For Run II new Forward Scintillation Counters installed for background studies and larger rapidity gap from 5 units to 11
- J/ψ at 13 TeV measured, results will be available shortly

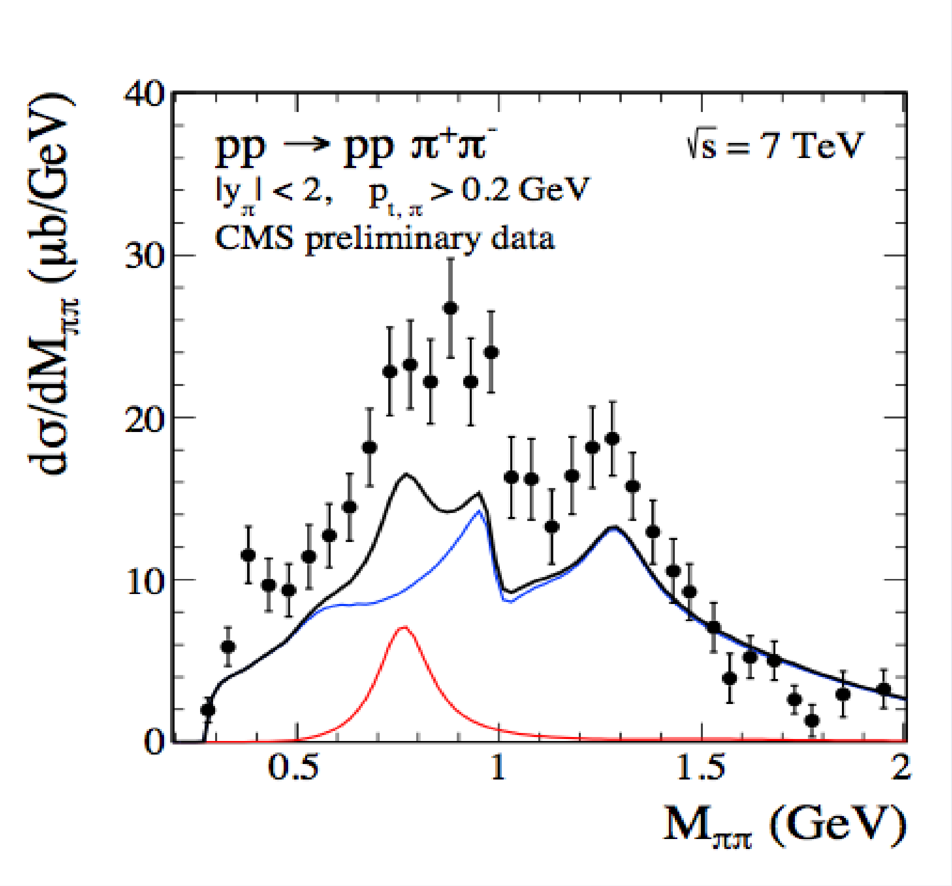


Central exclusive diffractive production at CMS

Mohsen Kahkzad

- pp → pp π+π− at 7 TeV at CMS

- The π+π- cross sections as a function of invariant mass, pT, and y have been compared to model predictions



- σ higher than expected, could be due to a large dissociation contribution

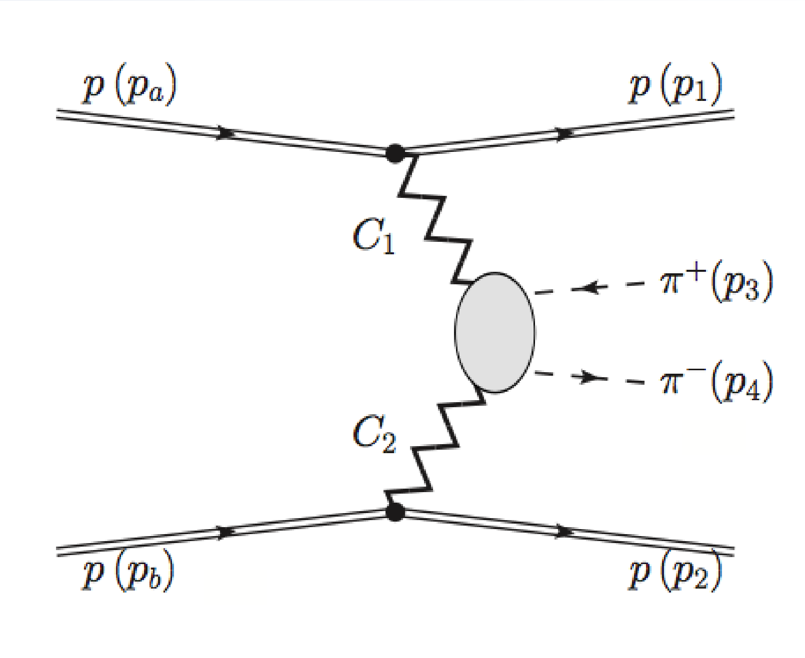
- Invariant mass shows a rich pattern of structure, described by models (Piotr Lebiedowicz talk)

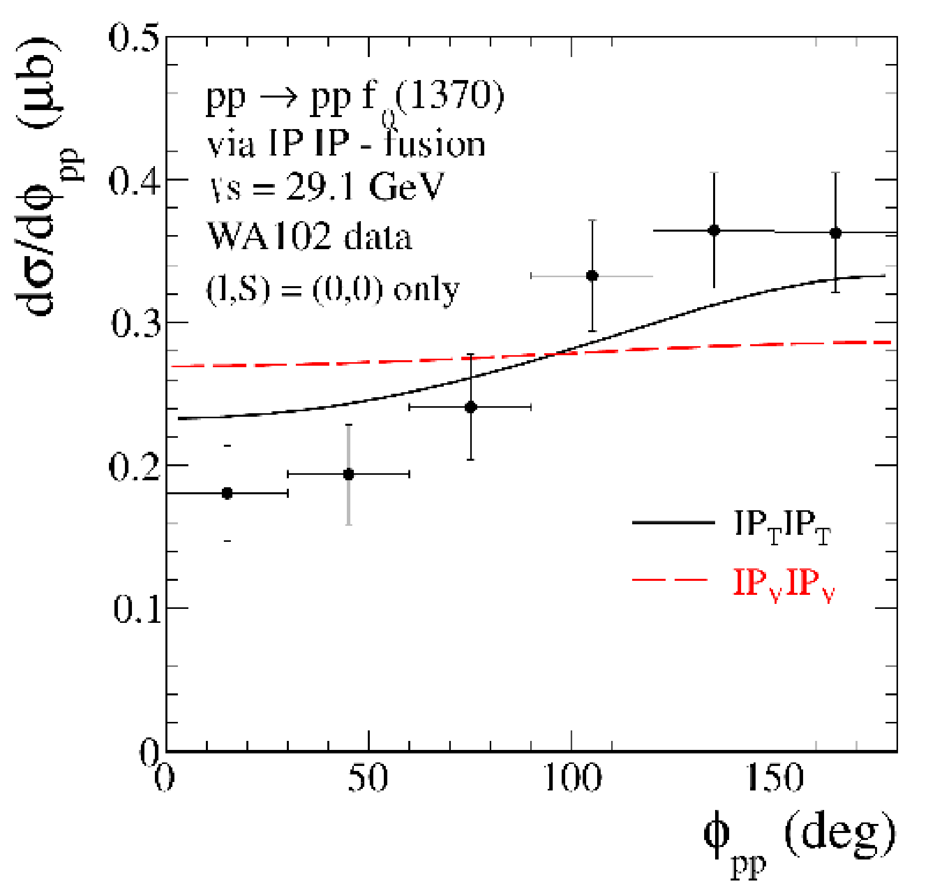
Central exclusive diffractive production

Piotr Lebiedowicz

- pp → ppπ+π−
- model presented for soft high energy (Lebiedowicz) based on a tensor Pomeron model + dipion continuum
- Describes feature of CDF, CMS, STAR data

Arxiv:1601.04537





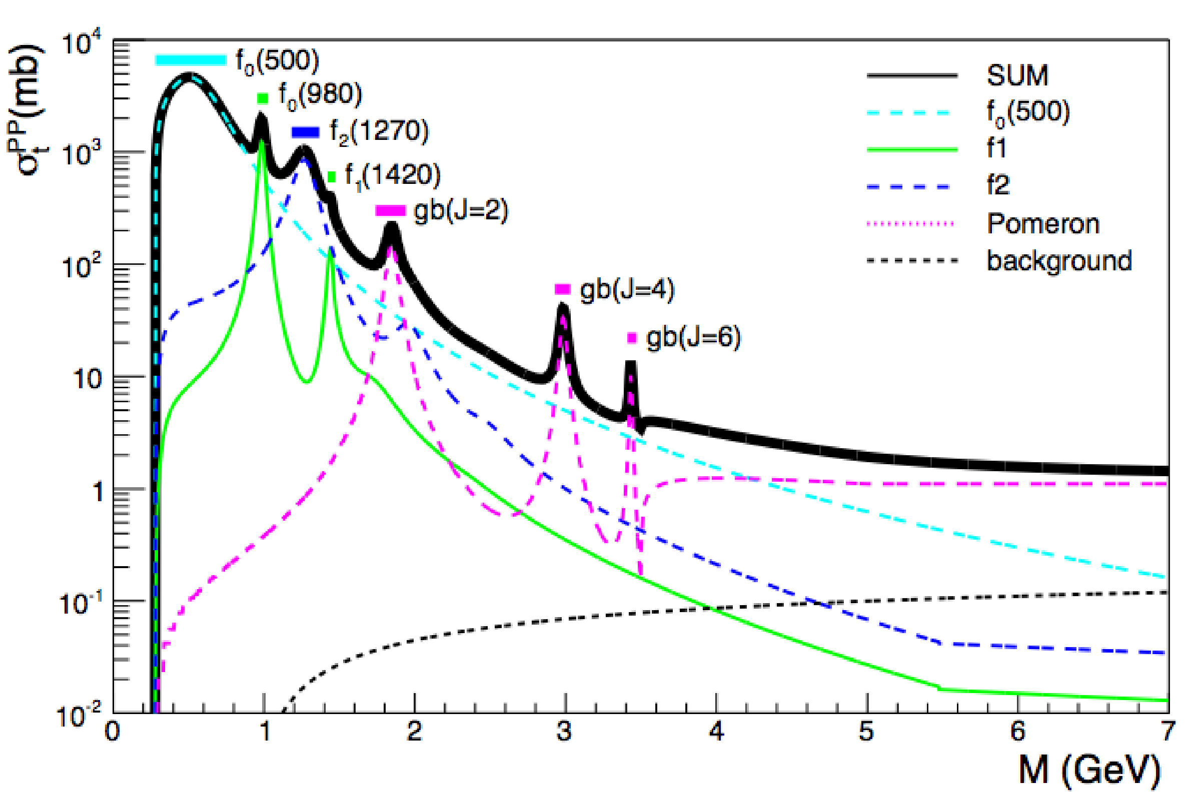
Central exclusive diffractive production – a model

Rainer Schicker

- A Regge pole model for resonance production in Pomeron–Pomeron collisions at the LHC, for M < 5 GeV
- The relative strength of resonances are determined from the analysis of experimental data

- Starting point for a comprehensive study of central exclusive production

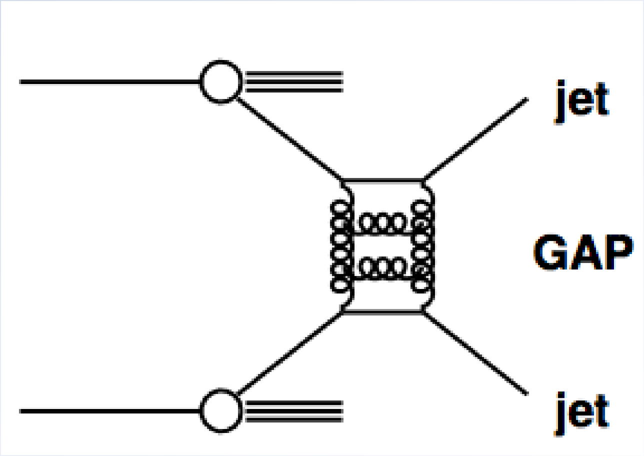
Eur.Phys.J.C76 (2016)

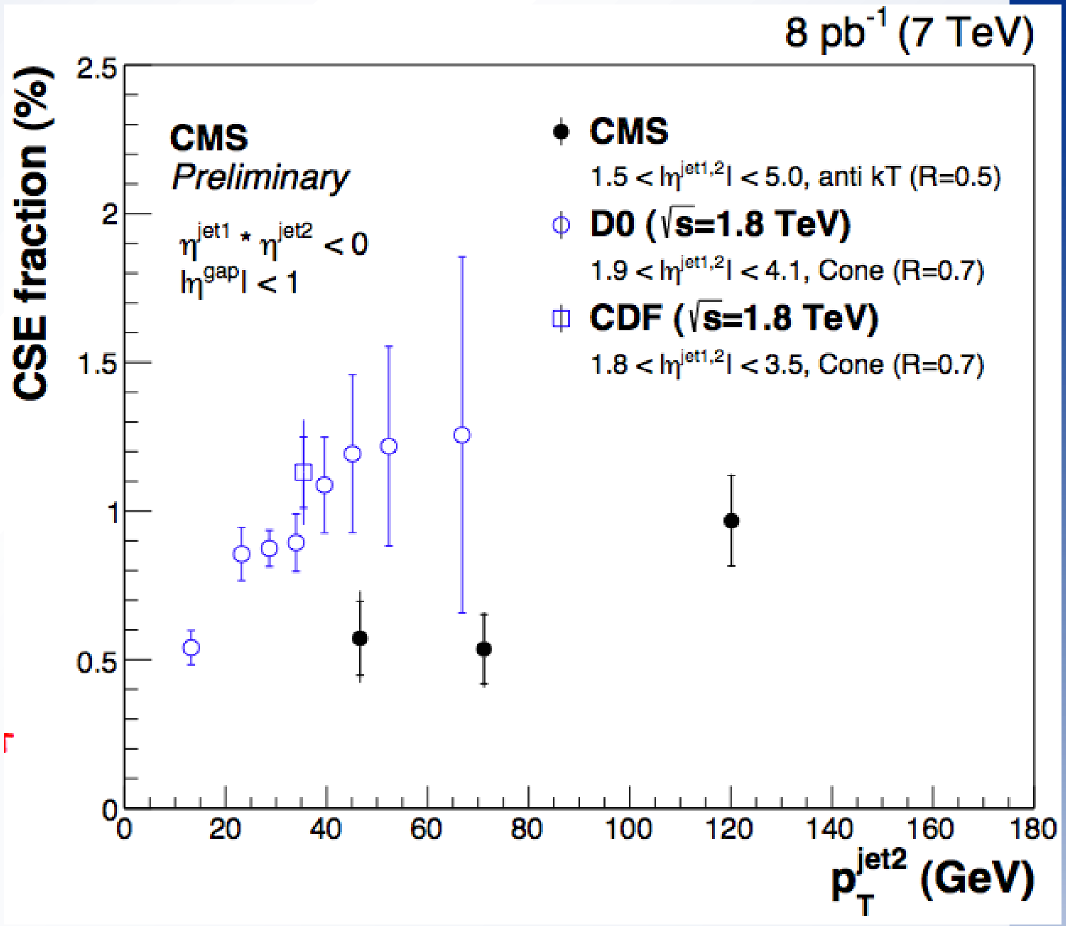


Rapidity gap between jets in CMS

Marta Ruspa

- Measured at CDF, D0, HERA, first observation at LHC !



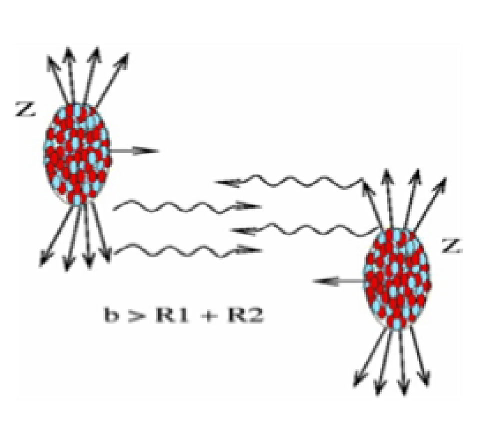


- Colour Singlet Exchange fraction suppressed by a factor of about 2 wrt CDF and D0 results

- in agreement with earlier observation by CDF and D0 gap fraction decreases when √s increases

Ultra-Peripheral Collisions (UPC) in nuclear collisions at LHC and RHIC

- Ultra peripheral collision is a collision at impact parameter greater than the sum of the nuclear radii R1+R2

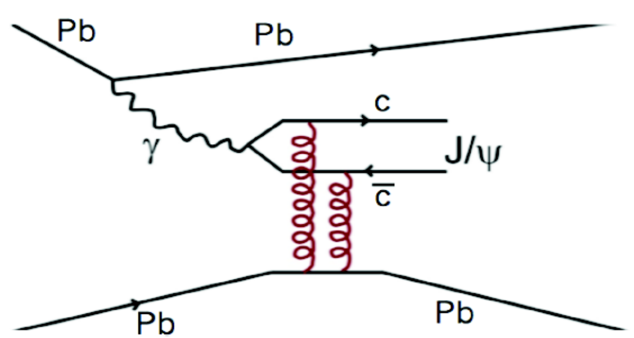


- It is mediated only by EM forces.
- Intensity of the photon beam proportional to Z^2
- The photon is emitted coherently, its virtuality is restricted by the radius of the emitting particle:

  $Q^2 \approx hc/(2\pi R)^2$, for Pb: $Q^2 \approx (30\ \mathrm{MeV})^2$

  The max. energy of the photons in lab system is given by the boost of the emitting particle
- Sensitive to saturation phenomena and nucleon gluon shadowing

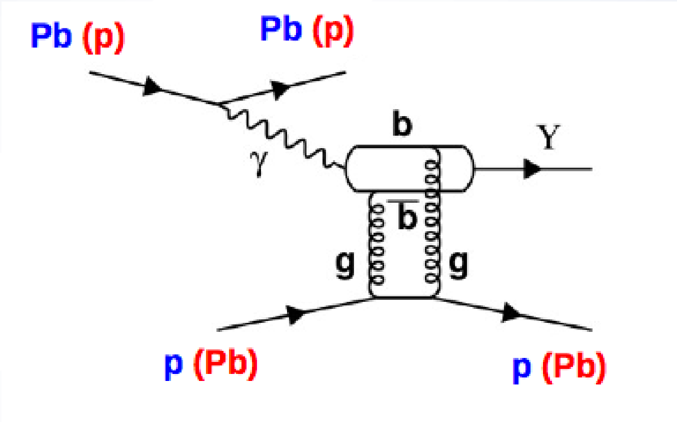
$$\frac{d\sigma_{\gamma^{*}\mathrm{p/Pb}}(t=0)}{dt} = \frac{16\Gamma_{ee}\pi^3}{3\alpha_{\mathrm{em}} M^5_{J/\psi}} \left\{\alpha_s\left(Q^2\right) G_{\mathrm{p/Pb}}\left(x, Q^2\right)\right\}^2$$

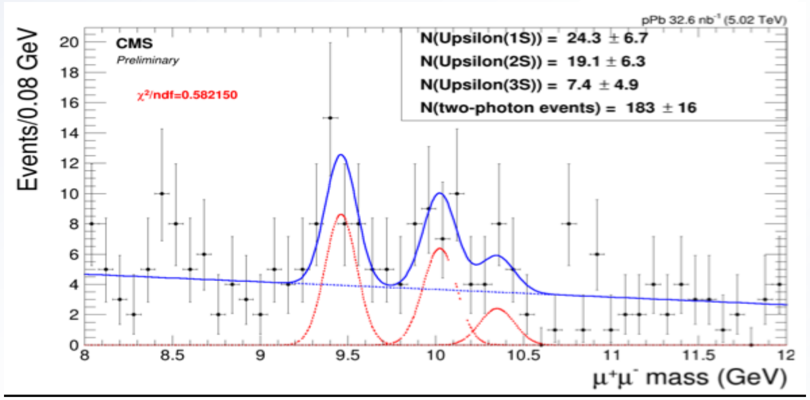


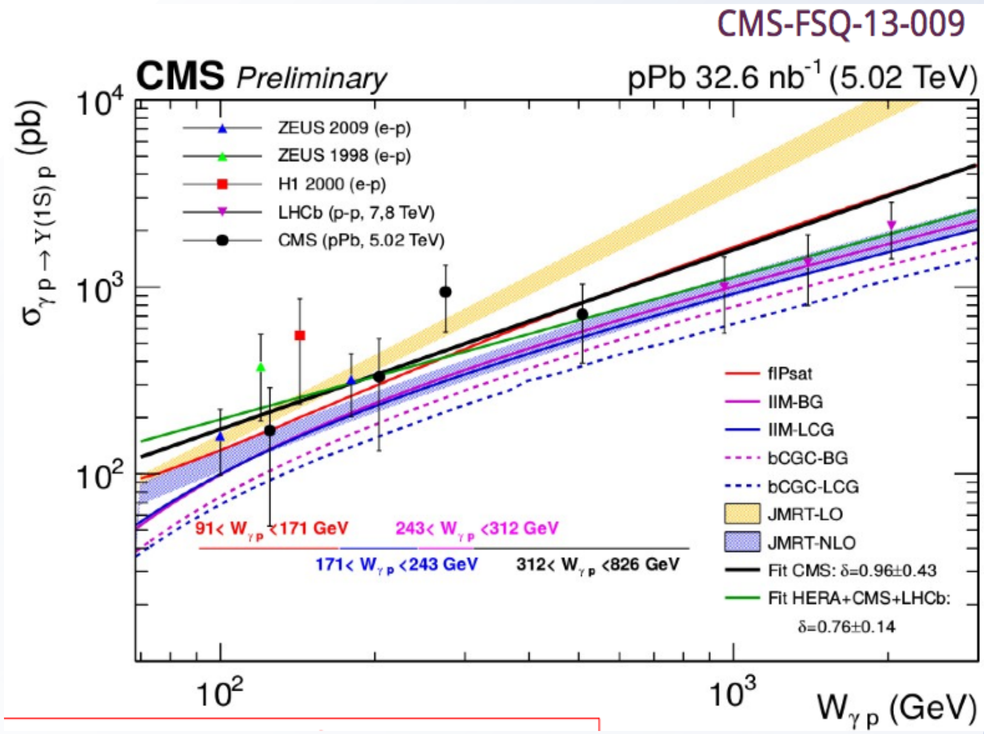
Ultra-Peripheral Collisions – ϒ at CMS Run I

Ruchi Chudasama

- First measurement of ϒ exclusive photoproduction in pPb ultra peripheral collisions at 5.02 TeV
- Compared to LHCb and HERA results

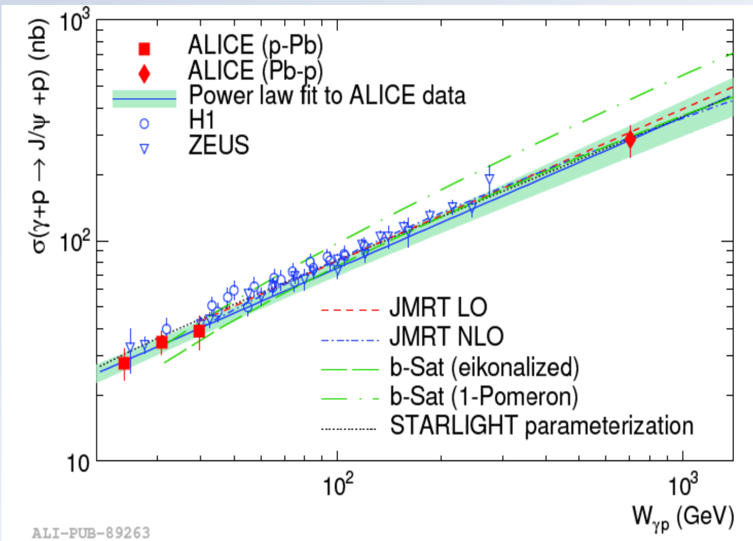






Ultra Peripheral Collisions in pPb and PbPb at ALICE

J. Adam
K. Graham

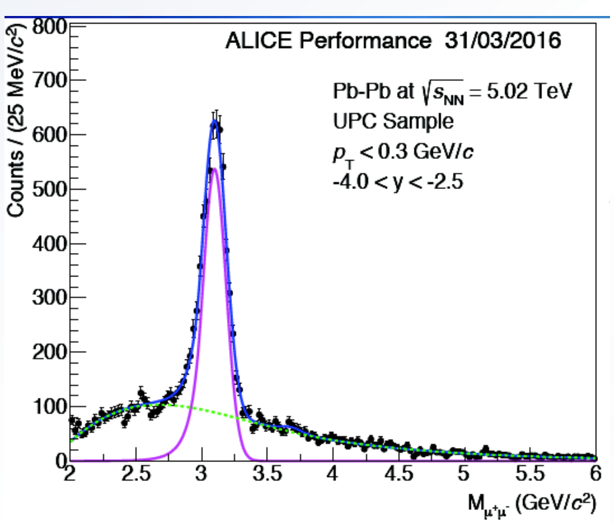


LHC Run I: no significant change in behavior gluon density going from HERA to LHC energy

Kinematics:

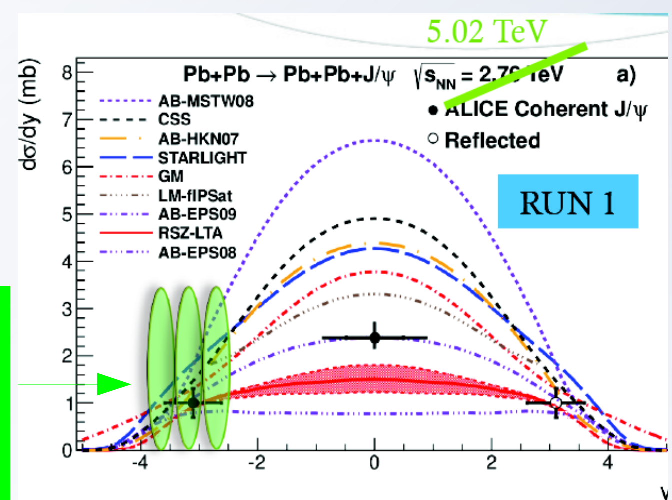
$$W_{\gamma p}^2 = 2E_p M_{J/\psi} \exp(-y)$$

rapidity y of J/Psi measured along proton beam direction (energy E_p)



50 times as many J/ψ in Run II as compared to Run I

Run II data analyzed in 3 bins
at forward rapidities,
allows to
discriminate between
models



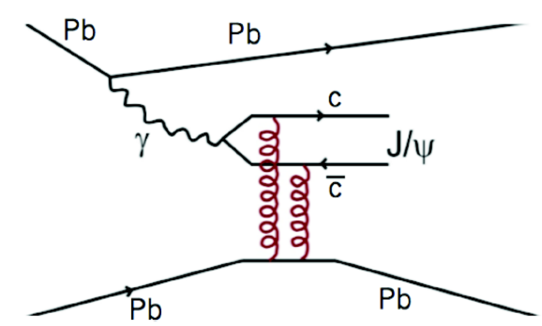
Ultra-Peripheral Collisions – in ALICE Run I

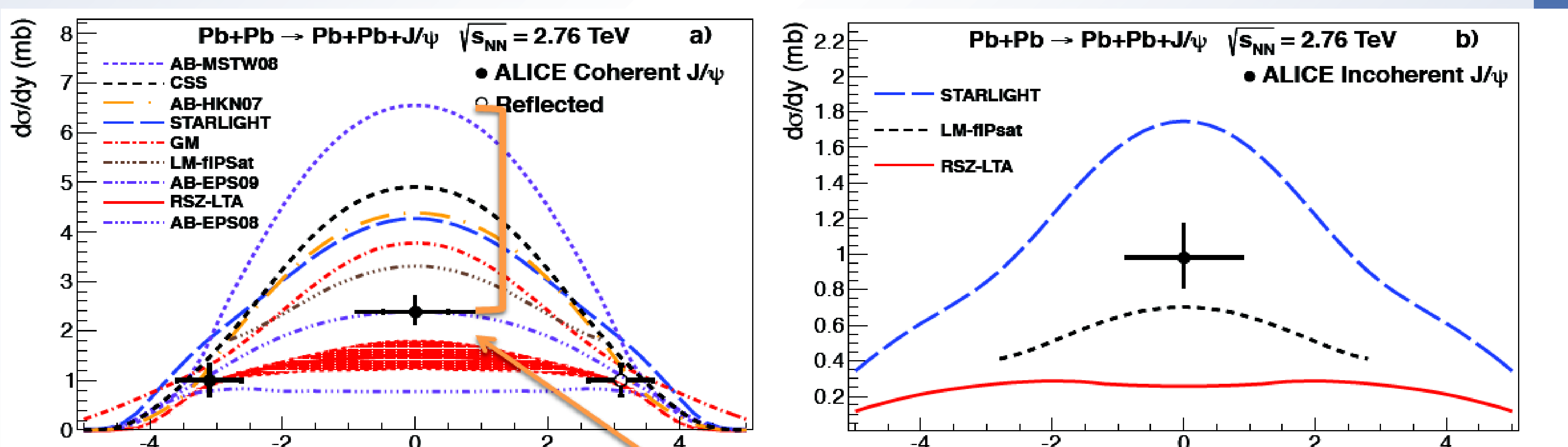
Guillermo Contreras

Coherent photo-nuclear production of vector mesons in PbPb collisions.

Under some assumptions, ALICE measurements can be translated into LO pQCD constraints for small-x gluon shadowing

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





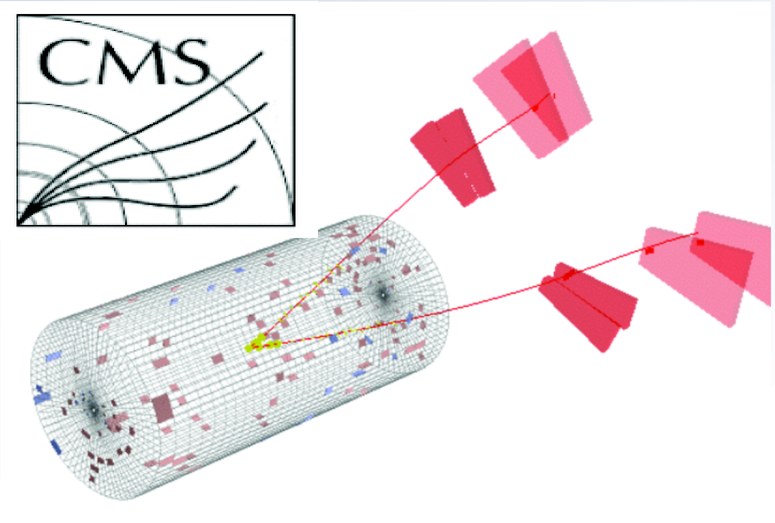
$x\sim10^{-2}$ $x\sim10^{-3}$

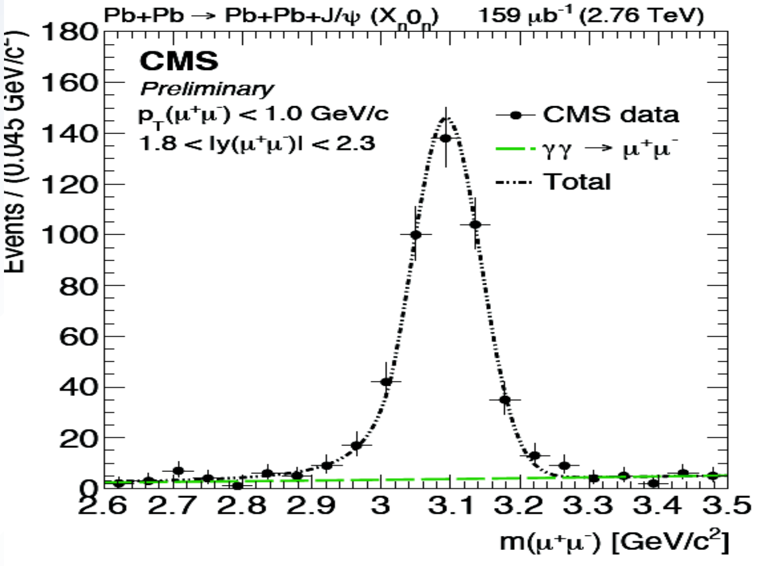
Direct observation of (moderate) gluon shadowing

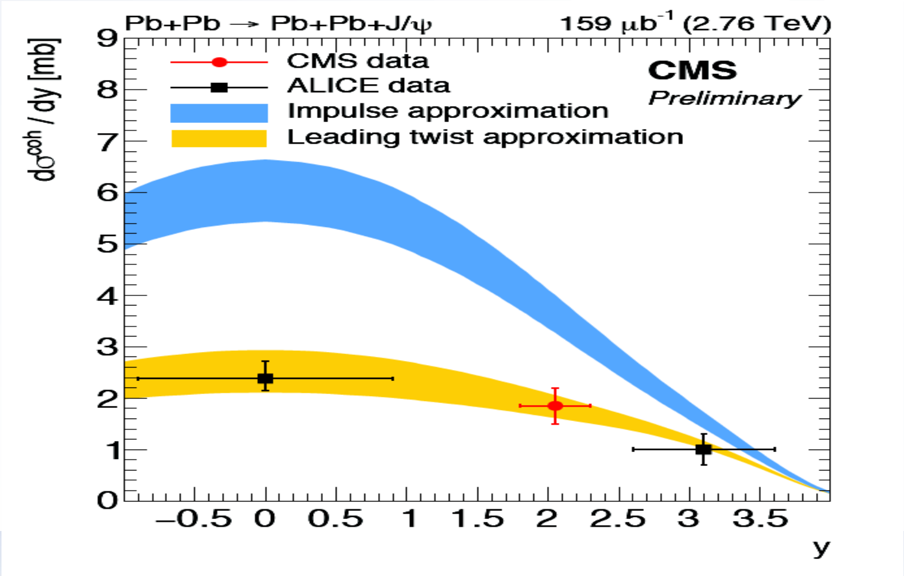
Ultra-Peripheral Collisions – J/ψ at CMS Run I

Daniel Takaki

Coherent J/Psi photoproduction in UPC PbPb at 2.76 TeV





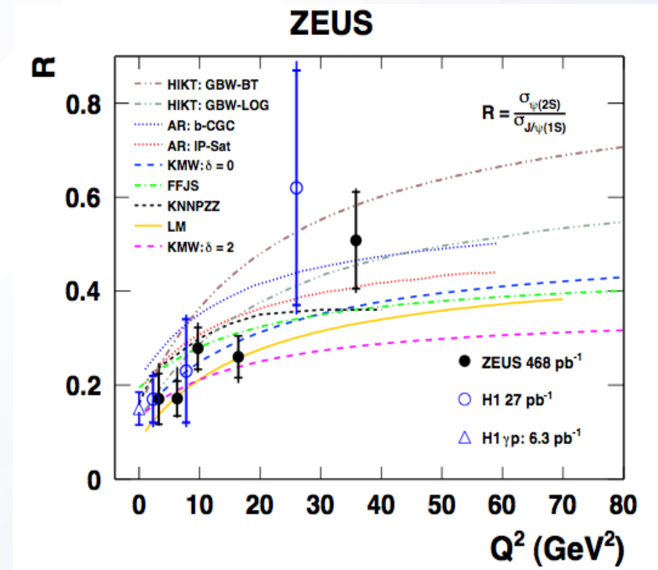


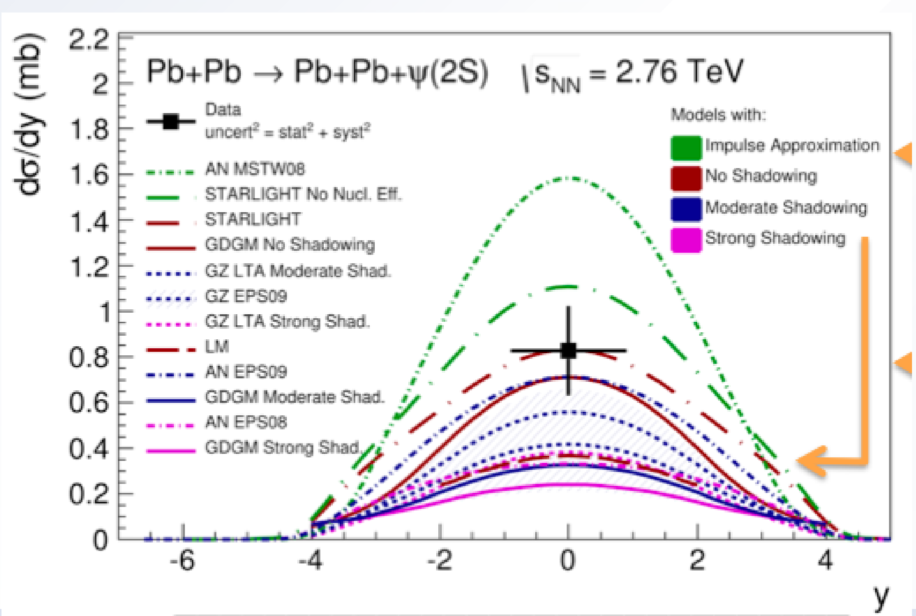
CMS measurement supporting ALICE data
Experimental evidence of nuclear effects in Pb at low Bjorken-x

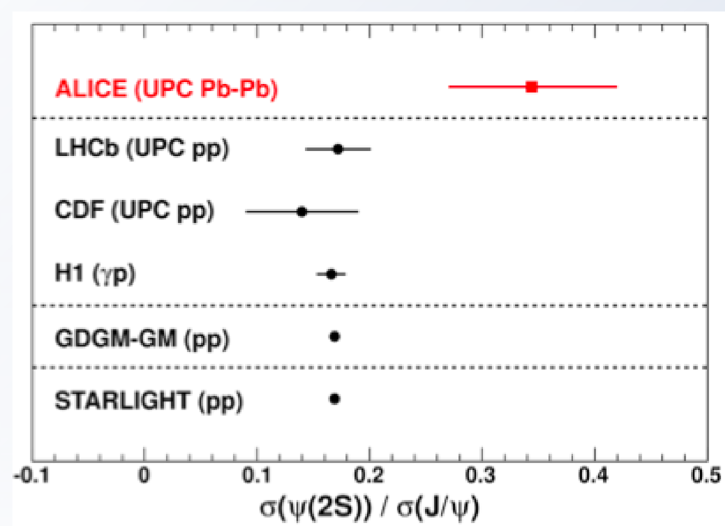
σ(ψ(2S))/σ(J/ψ(1S)) – **in central exclusive production and ultra peripheral collisions**

Natalia Kovalchuk
Guillermo Contreras

- R=σ(ψ(2S))/σ(J/ψ(1S)) measured at ALICE in coherent UPC and at HERA in central exclusive production
- Measurement sensitive to charmonium wave function and QCD dynamics
- Looking for nuclear effect in UPC, better precision needed



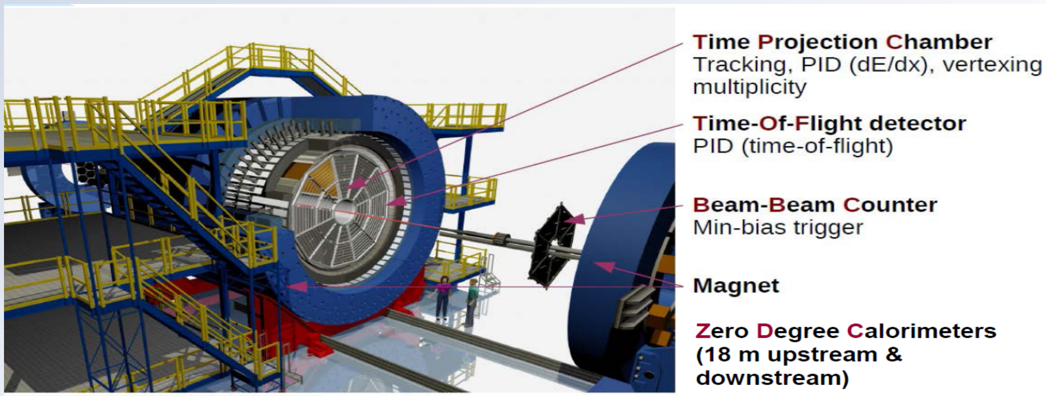


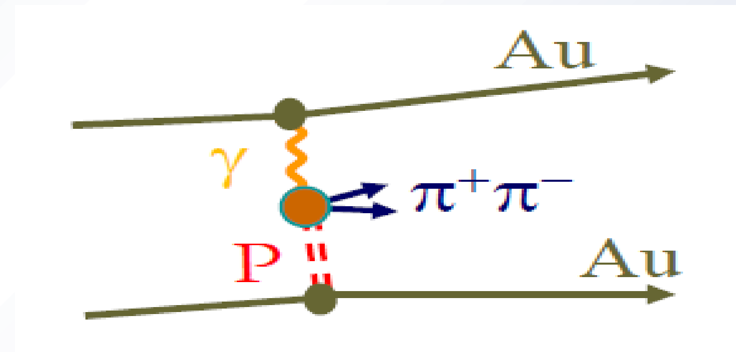


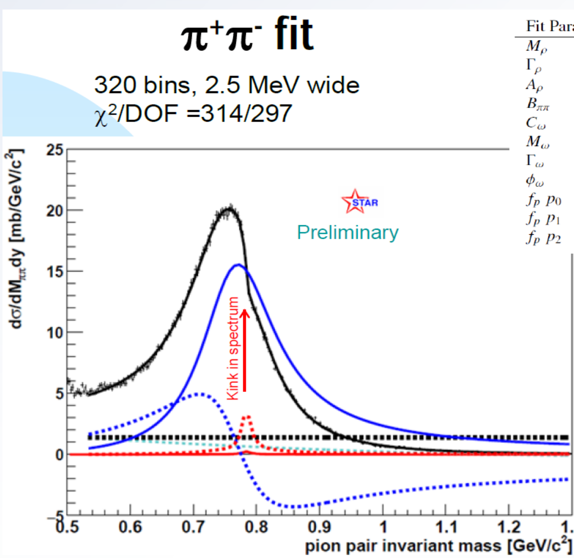
Ultra-Peripheral collisions in Au-Au at RHIC

Spencer Klein

STAR: UPC dipions production







Fit Parameter	value	units
M_ρ	0.7757 ± 0.0006	GeV/c^2
Γ_ρ	0.1475 ± 0.0014	GeV/c^2
A_ρ	1.511 ± 0.005	
$B_{\pi\pi}$	-1.176 ± 0.016	(GeV/c^2)$^{-1/2}$
C_ω	0.0626 ± 0.004	
M_ω	0.7838 ± 0.0009	GeV/c^2
Γ_ω	0.0163 ± 0.0017	GeV/c^2
ϕ_ω	1.73 ± 0.13	radians
$f_p\ p_0$	3.566 ± 0.304	
$f_p\ p_1$	-5.084 ± 0.53	
$f_p\ p_2$	1.743 ± 0.24	

Statistical errors only

Black: data points & fit
Solid blue: – ρ^0
Dotted blue: ρ^0/direct $\pi\pi$ interference
Solid red: ω
Dotted red: ω/ρ interference

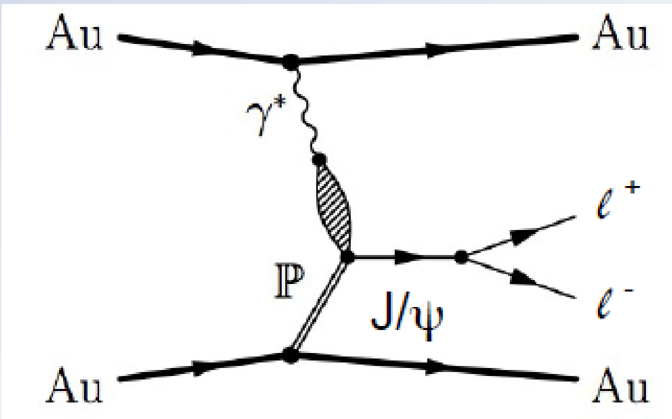
STAR has made a high-statistics study of photoproduced ππ in ultra-peripheral collisions.

Observed ρ, direct ππ and ω photoproduction

An excited state with a mass of 1653 MeV and width of 164 MeV has been observed

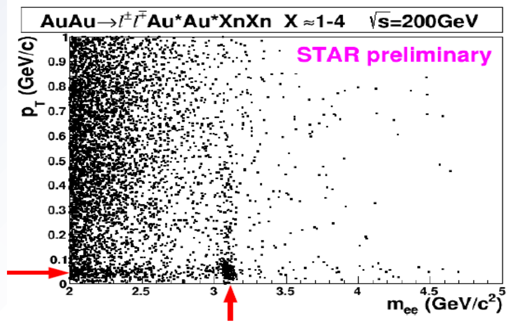
William Schmidke

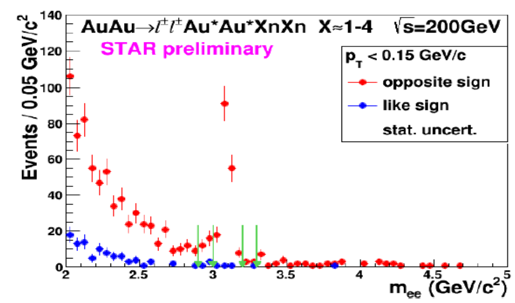
STAR: J/ψ production



Pair mass, p_T distributions

- Selections give sample of $J/\psi \to e^+e^-, \mu^+\mu^-$:

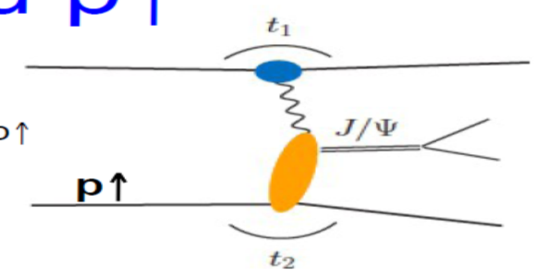




UPC with polarized p↑

- WW photon from one beam particle
- Target particle polarized proton p↑:
  - $d\sigma/d\varphi \propto (1 + A_{UT} \cdot \cos\varphi)$, φ = J/ψ azimuthal angle w.r.t. p↑
  - measure J/ψ transverse asymmetry A_{UT}

  (Unpolarized beam γ, Transverse polarized target p↑)



- A_{UT} calculable with GPDs:

$$A_{UT}(t,t) \sim \frac{\sqrt{t_0 - t}}{m_p} \frac{\mathrm{Im}(E^* H)}{|H|} \qquad t = \frac{M^2_{J/Y}}{s}$$

$A_{UT} \propto E_g \Rightarrow$ sensitive to gluon orbital angular momentum L_g

J/ψ in p↑p↑ UPC

- Planned: $\sqrt{s}$=500 GeV p↑p↑ Run17 L~400 pb^{-1}

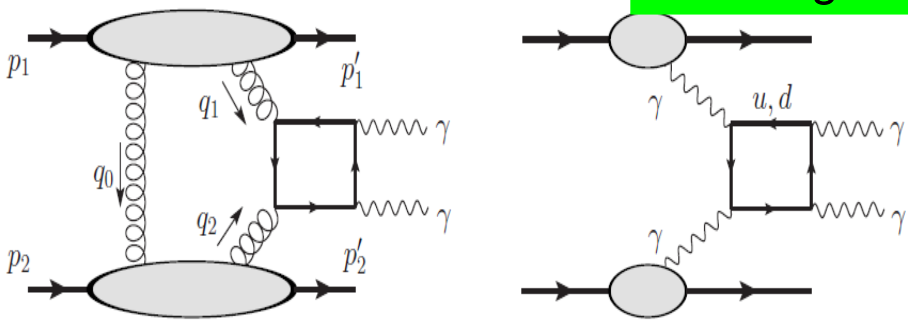
RHIC plans:
Spin arXiv:1501.01220
Cold QCD arXiv:1602.03992

Light-by-light scattering in UPC at the LHC

M. Klusek-Gawenda
presented by A. Szczurek

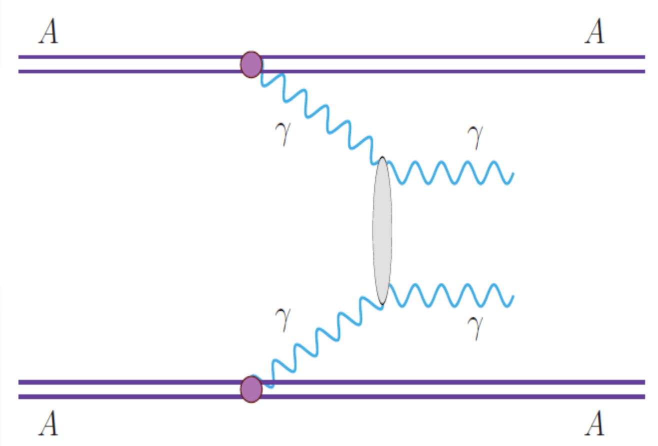
Two mechanisms of the exclusive production:

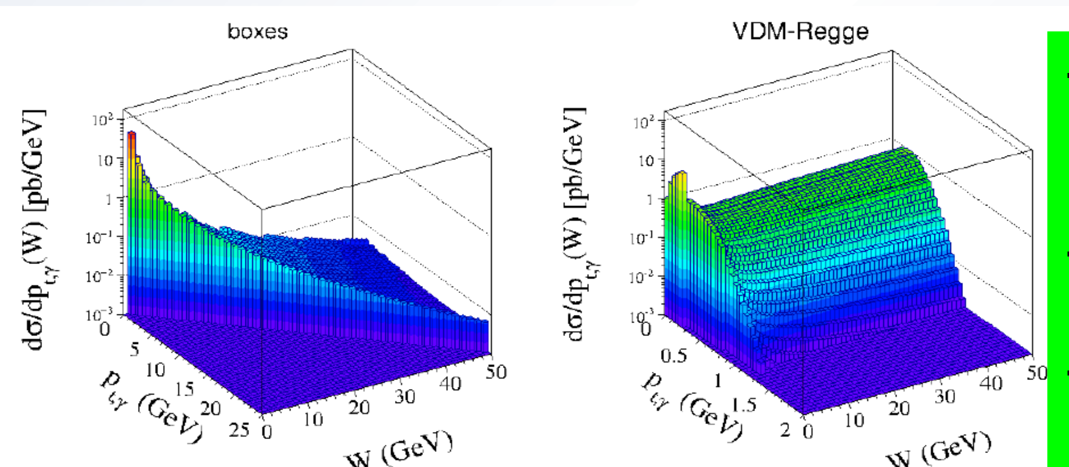
Box-diagrams



The QCD mechanism disturbs to see the QED mechanism

New: soft VDM Regge contribution





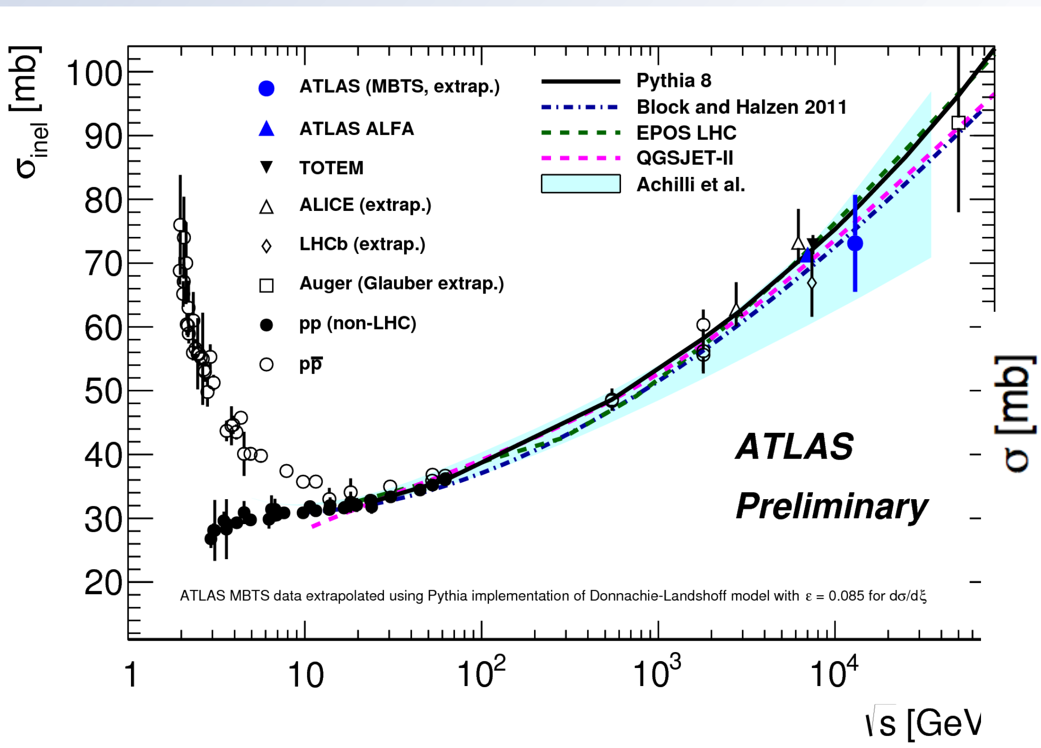
cross sections

- Calculations done in the impact parameter Equivalent Photon Approximation
- Study in kinematical variables of the two photons
- The two subprocesses almost separate in phase space
- Experimental possibilities not completely clear

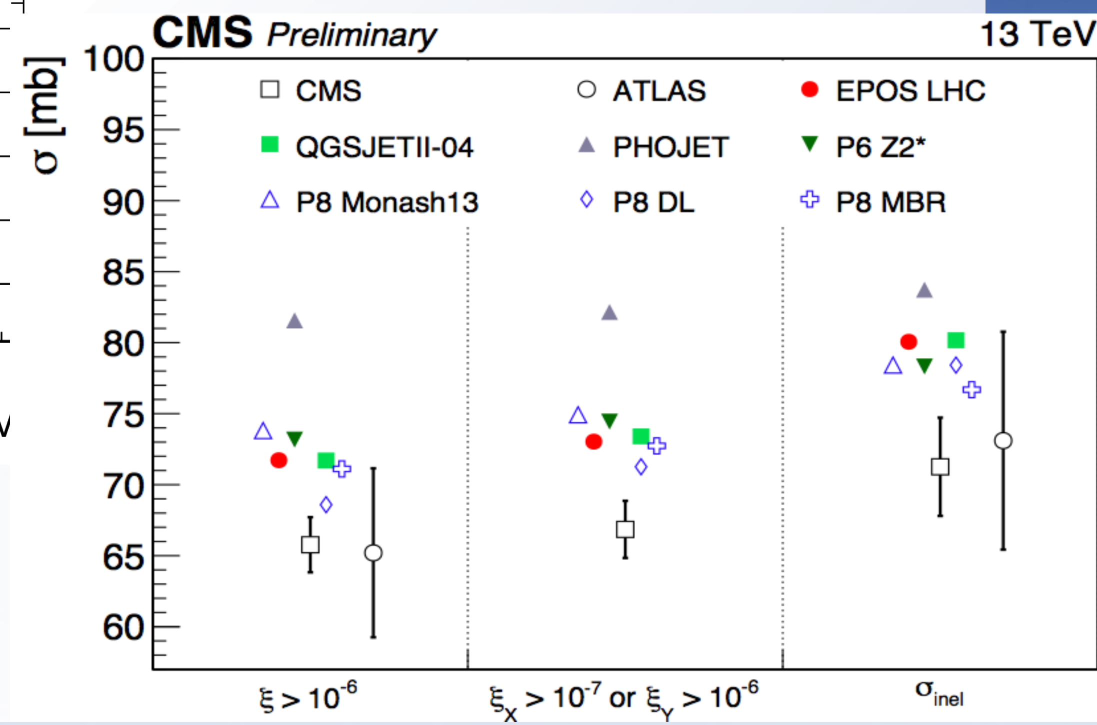
Total inelastic pp x section at $\sqrt{s}$ = 13 TeV

Maciej Trzebinsk
Hans Van Haevermaeti

- ATLAS: σ^{inel} = 73.1 ± 0.9 (exp.) ± 6.6 (lum.) ± 3.8 (extr.) mb
- CMS: σ^{inel} = 71.3 ± 0.5 (exp.) ± 2.1 (lum.) ± 2.7 (ext.) mb



Extrapolation factor reduced
In CMS using forward
calorimeters

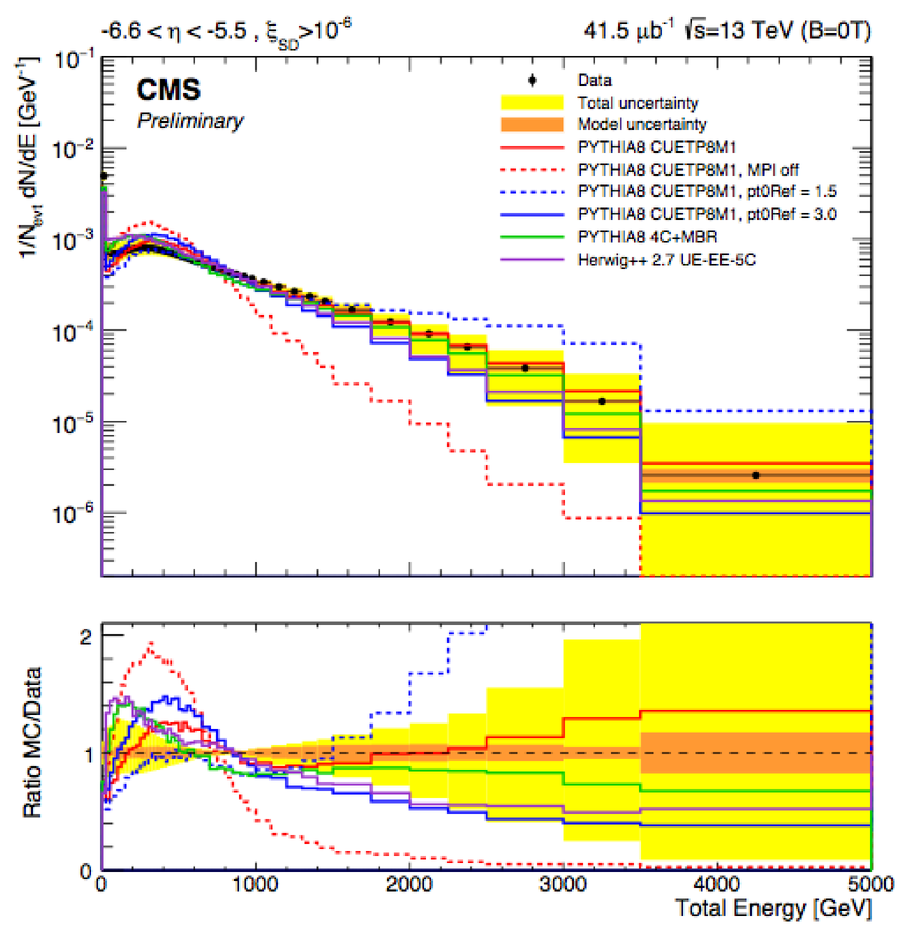


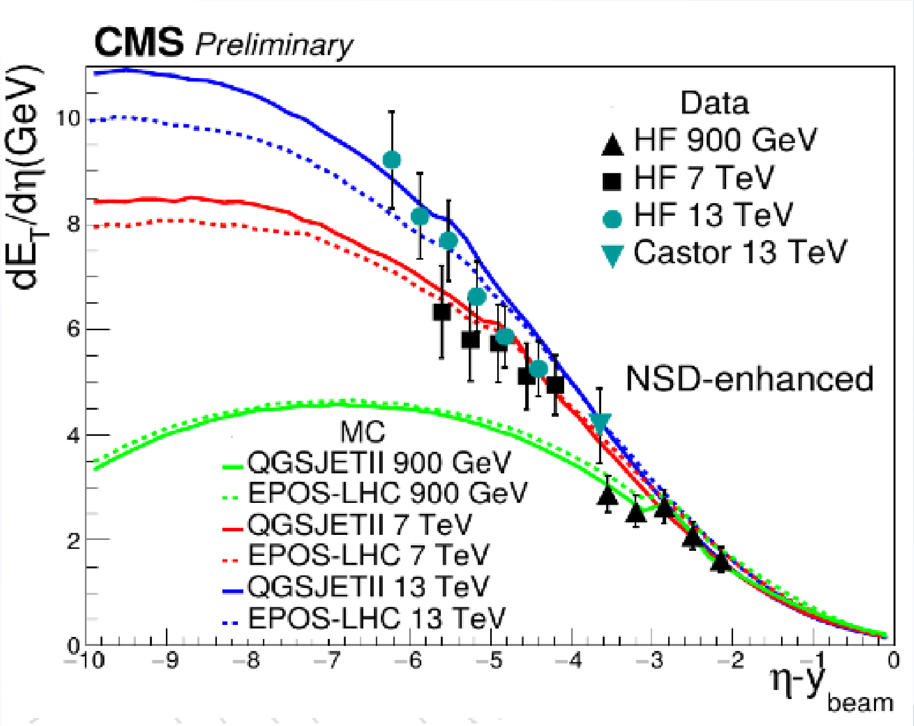
•ATLAS-CONF-2015-038, CMS-PAS-FSQ-15-005

Very Forward energy distribution

Alex Van Spilbeeck
Igor Katkov

- Very forward energy distributions and jet production observed with CASTOR in CMS at 13 TeV
- Energy flow measured pseudorapidity range 3.15 < |η| < 6.6, in pp-collisions at 13 TeV

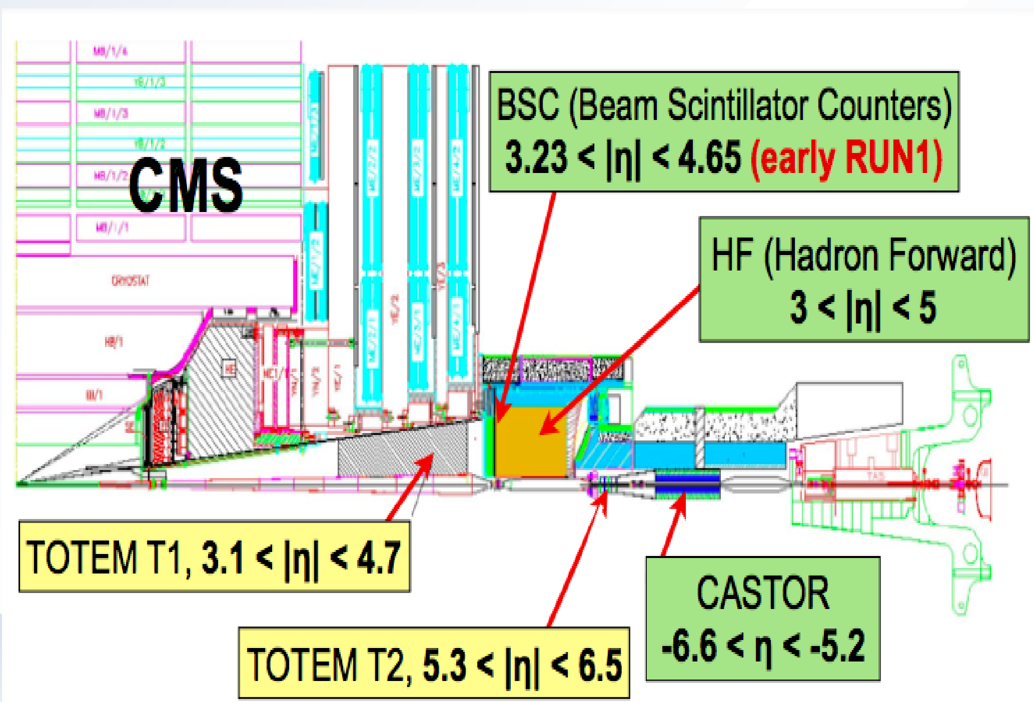


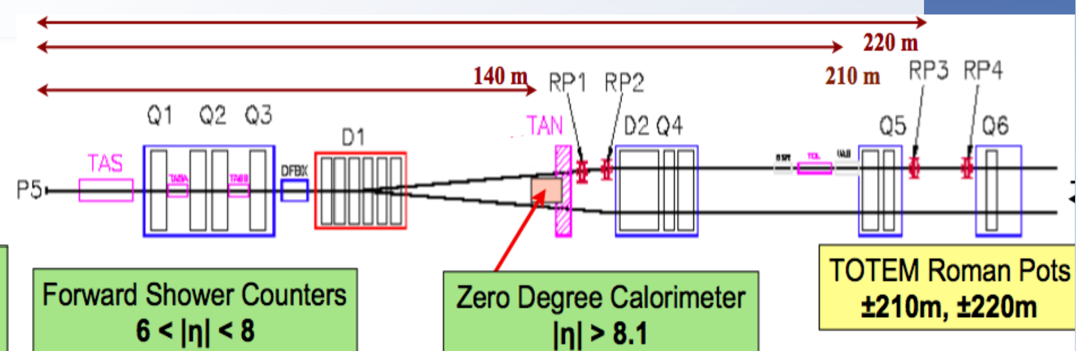


CMS + Totem Collaboration

Sercan Sen

- CMS+Totem span the largest pseudorapidity interval ever measured at the LHC
- Pseudorapidity distributions of charged particles and production of leading charged particles and leading charged-particle jets measured at 8 TeV
- CMS+Totem had joint data taking (0.4 pb-1) in Oct. 2015 at 13 TeV, β^* = 90m (to reach low |t| at any ξ)



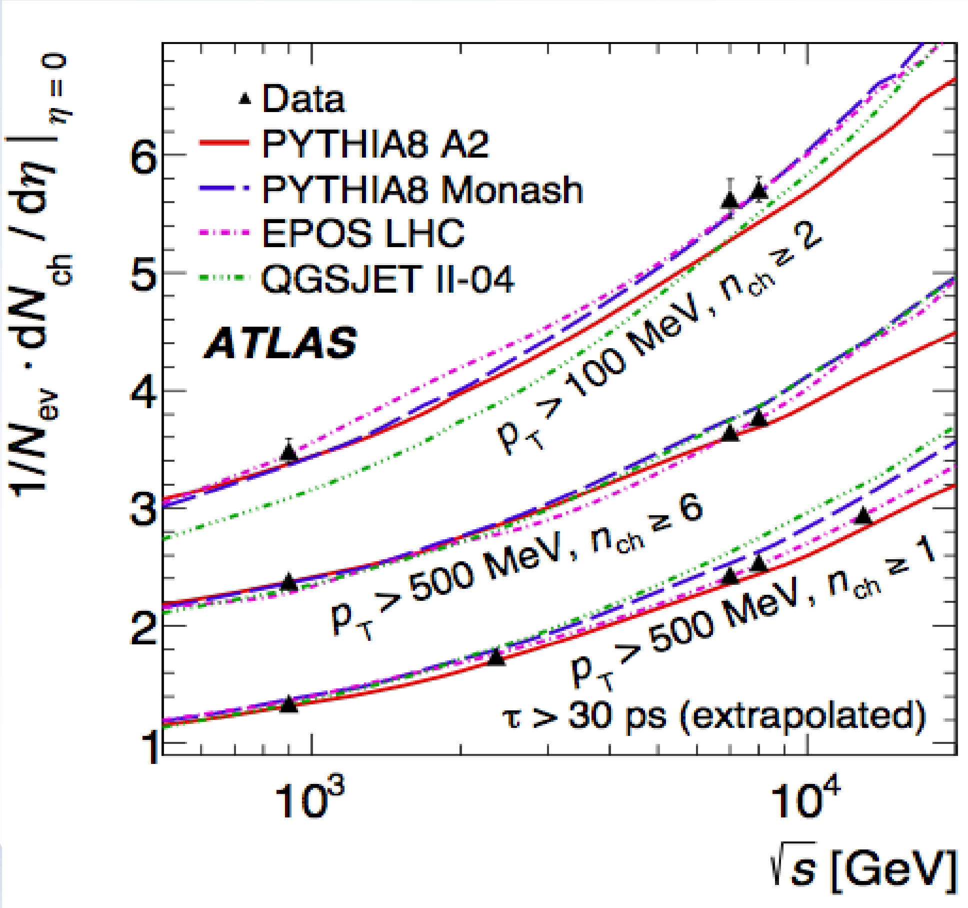


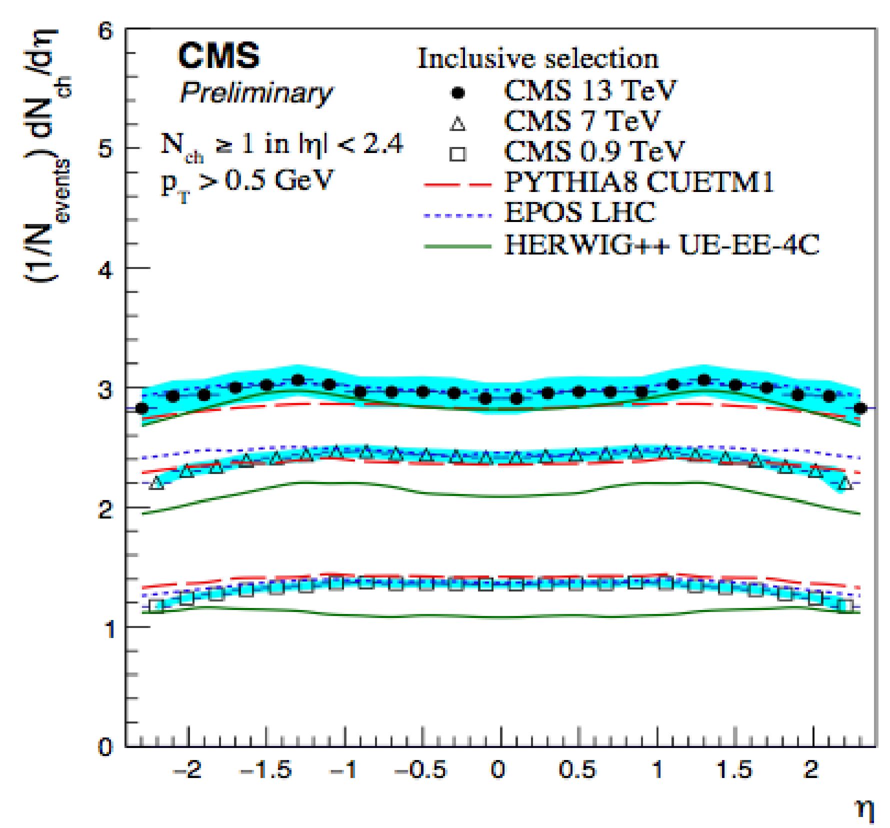
Analyses ongoing

Minimum bias: charged particle distributions

Wolfang Lukas
Juan Manuel Grados Luyando

- charged particle distributions measured at 13 TeV
- models tuned at 7 TeV describe the MPI energy extrapolation well





Thank you to all participating to the session

Thanks to the organisers and to the DIS 2016 team:
Aleksandra, Daniela, Armando, Juan, Ibrahim