Probing BFKL dynamics, saturation and diffraction at hadronic colliders

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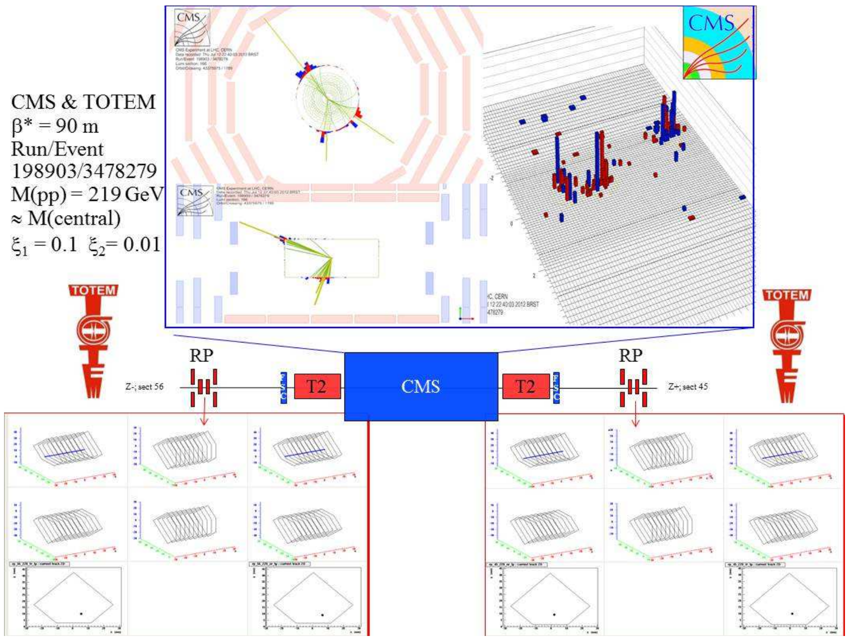
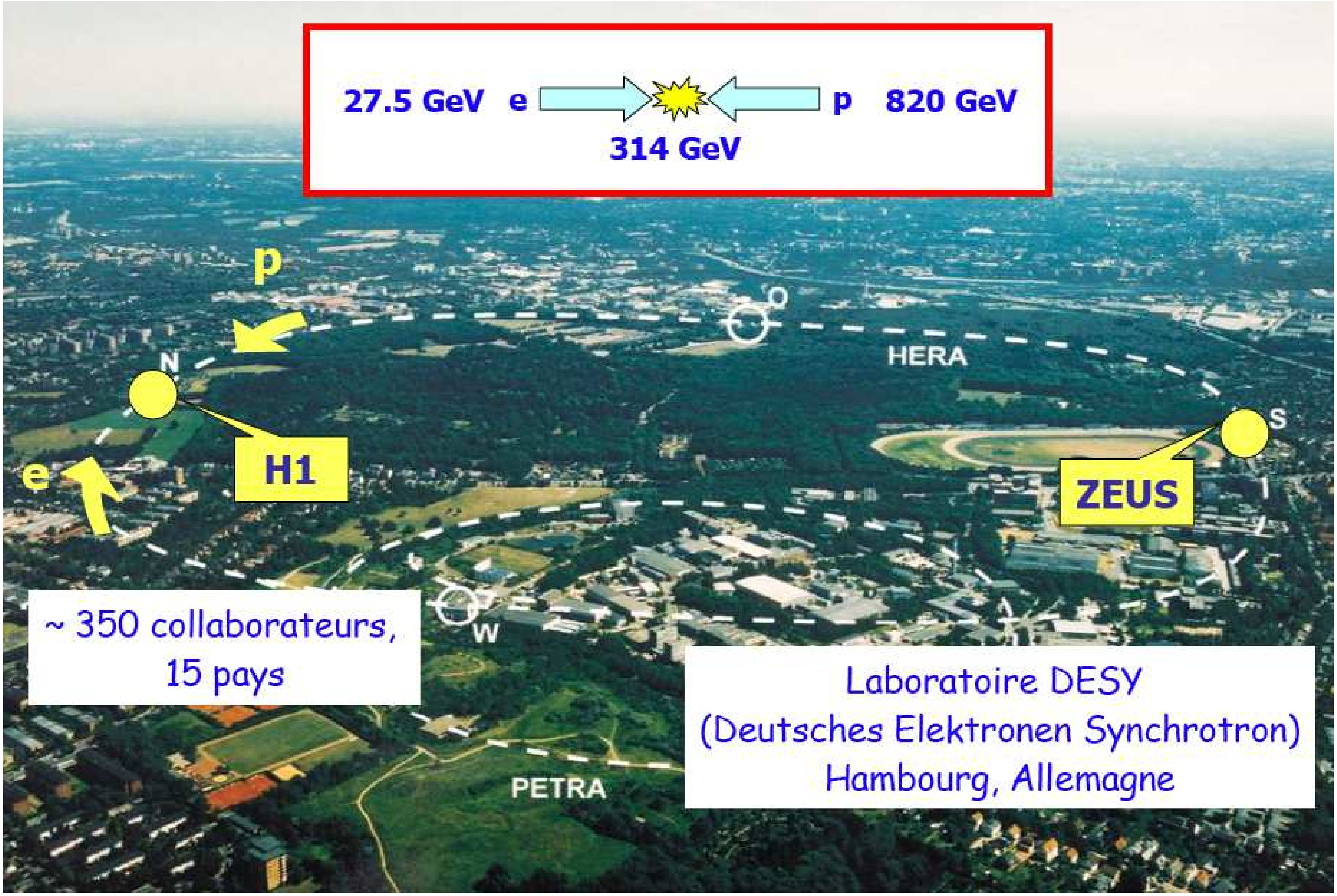
Contents:

- Proton structure (quarks and gluons)
- BFKL dynamics (Forward and Mueller Navelet jets, jet gap jet)
- Jet gap jet in diffraction at the LHC
- Diffractive events: Pomeron structure, jet gap jets
- Photon induced processes



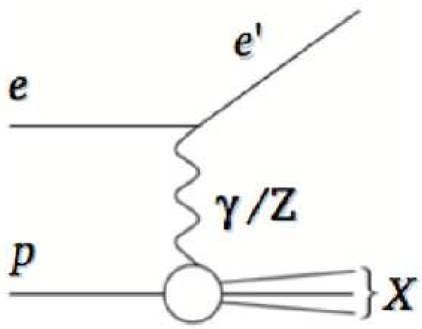
The HERA accelerator at DESY, Hamburg

HERA: ep collider who closed in 2007, about 1 fb^{-1} accumulated

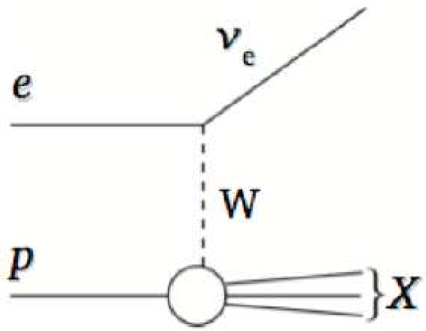


HERA kinematics

NC : $e\,p \rightarrow e'\,X$



CC : $e\,p \rightarrow \nu_e\,X$



Kinematic variables:

- Virtuality exchanged boson

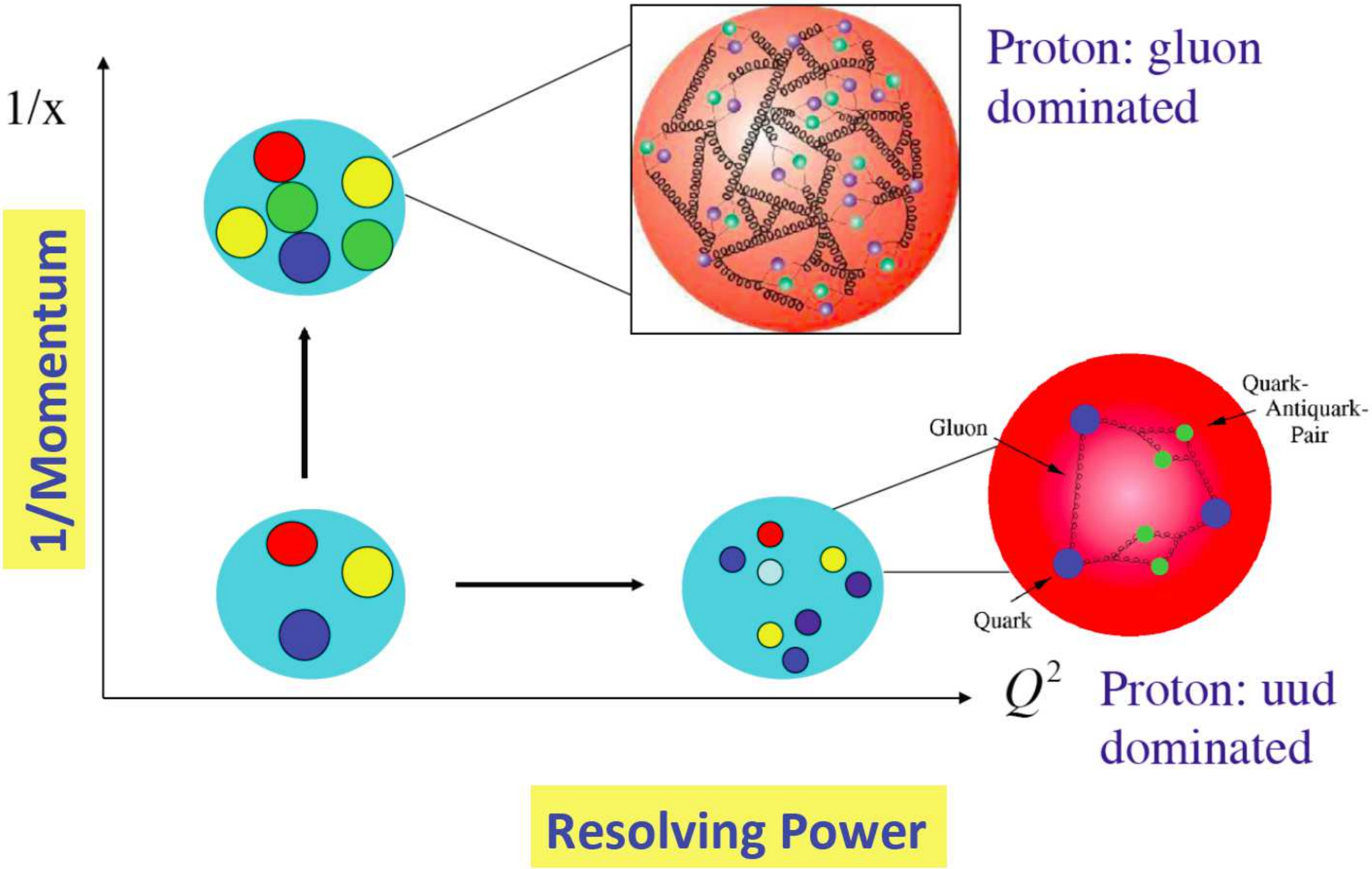
$$Q^2 = -q^2 = -(k - k')^2$$

- Bjorken scaling variable

$$x = \frac{Q^2}{2p \cdot q}$$

- Measurement of the $ep \rightarrow eX$ cross section: as a function of two independent variables x and Q^2
- Many methods available to measure x (momentum fraction of the proton carried by the interacting quark), or Q^2 (transfered energy squared) using scattered electron or hadron information

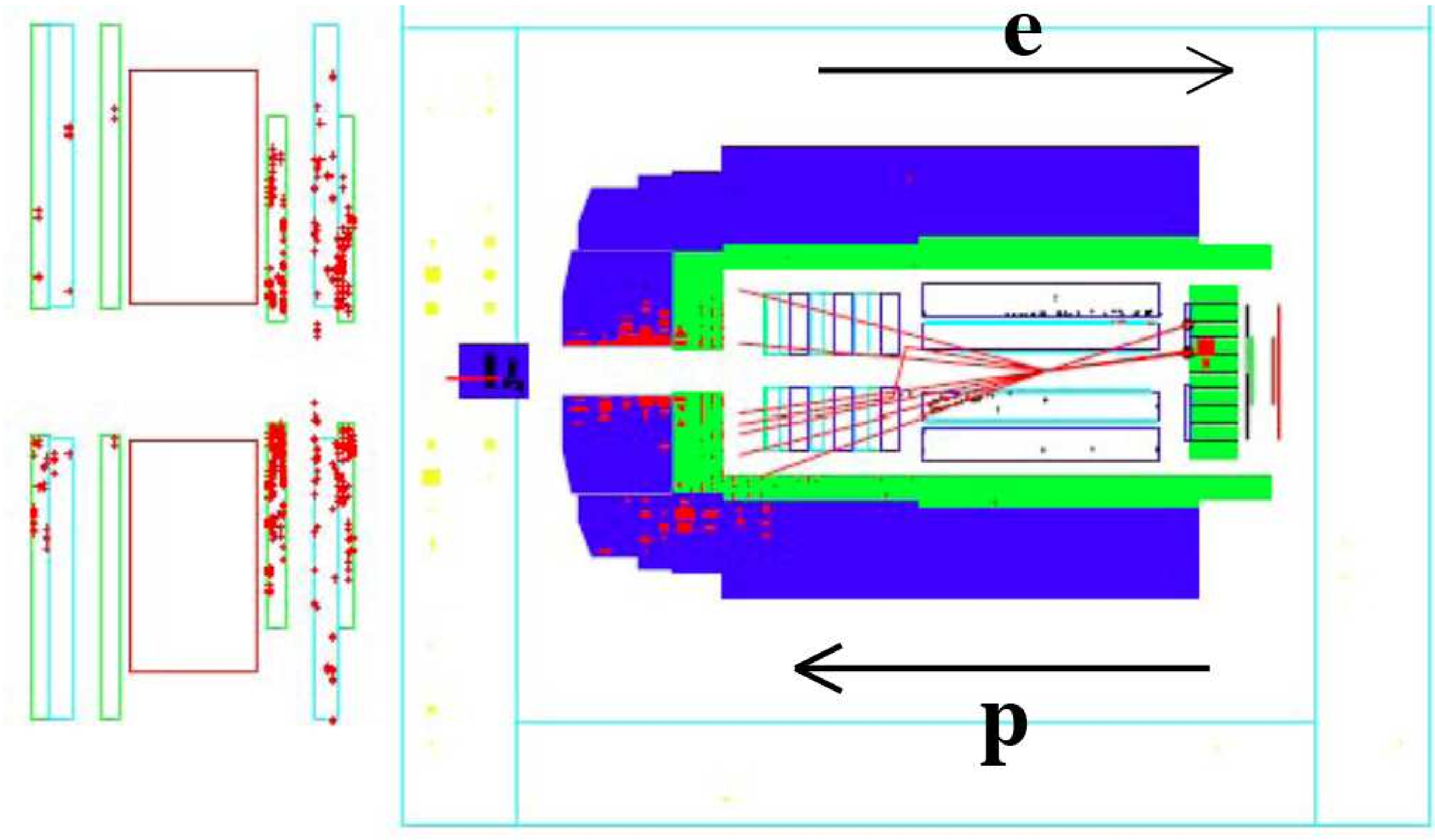
The proton structure



- Study the proton structure as a function of x (Balitski Fadin Kuraev Lipatov evolution equation) or as a function of Q^2 (Dokshitzer Gribov Lipatov Altarelli Parisi)
- Q^2: Resolution power (like a microscope):
- x: momentum fraction of the proton carried away by the quark/gluon how does the gluon density increase at low x?

A picture of one electron-proton interaction

- One electron-proton interaction in the H1 detector: the electron is scattered and the proton is destroyed
- The electron probes the proton structure in terms of quarks and gluons



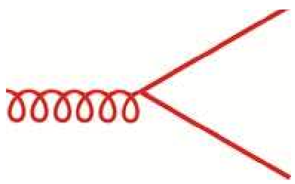
Measurement of the proton structure function F_2

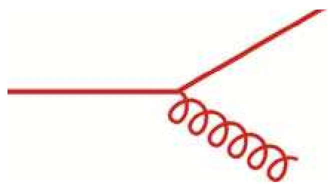
- Measurement of the DIS cross section

$$\frac{d\sigma}{dxdQ^2} = \frac{4\pi\alpha^2}{2xQ^4}\left[(1+(1-y)^2)F_2(x,Q^2) - y^2 F_L(x,Q^2)\right]$$

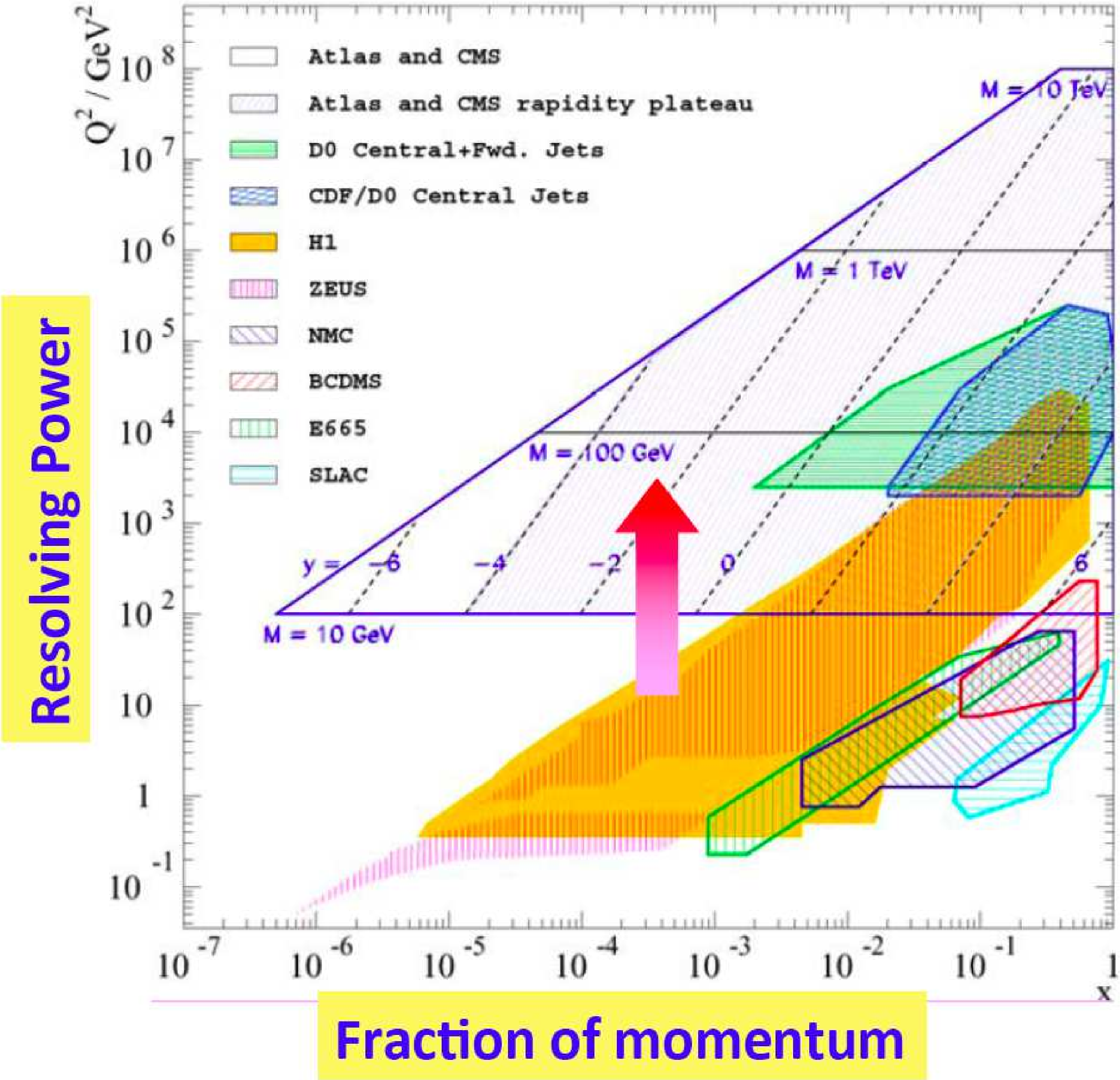
- Use these data to make QCD fits using NLO (or NNLO) Dokshitzer Gribov Lipatov Altarelli Parisi evolution equation and determine the proton structure in quarks and gluons $\rightarrow$ allows to predict cross section at Tevatron/LHC
- At low x: evolution driven by $g \rightarrow q\bar{q}$, at high x, $q \rightarrow qg$ becomes important
- Take all data for $Q^2 >\sim 4$ GeV^2, to be in the perturbative QCD region

$$\frac{dF_2}{d\log Q^2} \sim \frac{\alpha_S}{2\pi}\left[P_{qg}\otimes g + P_{qq}\otimes \Sigma\right]$$



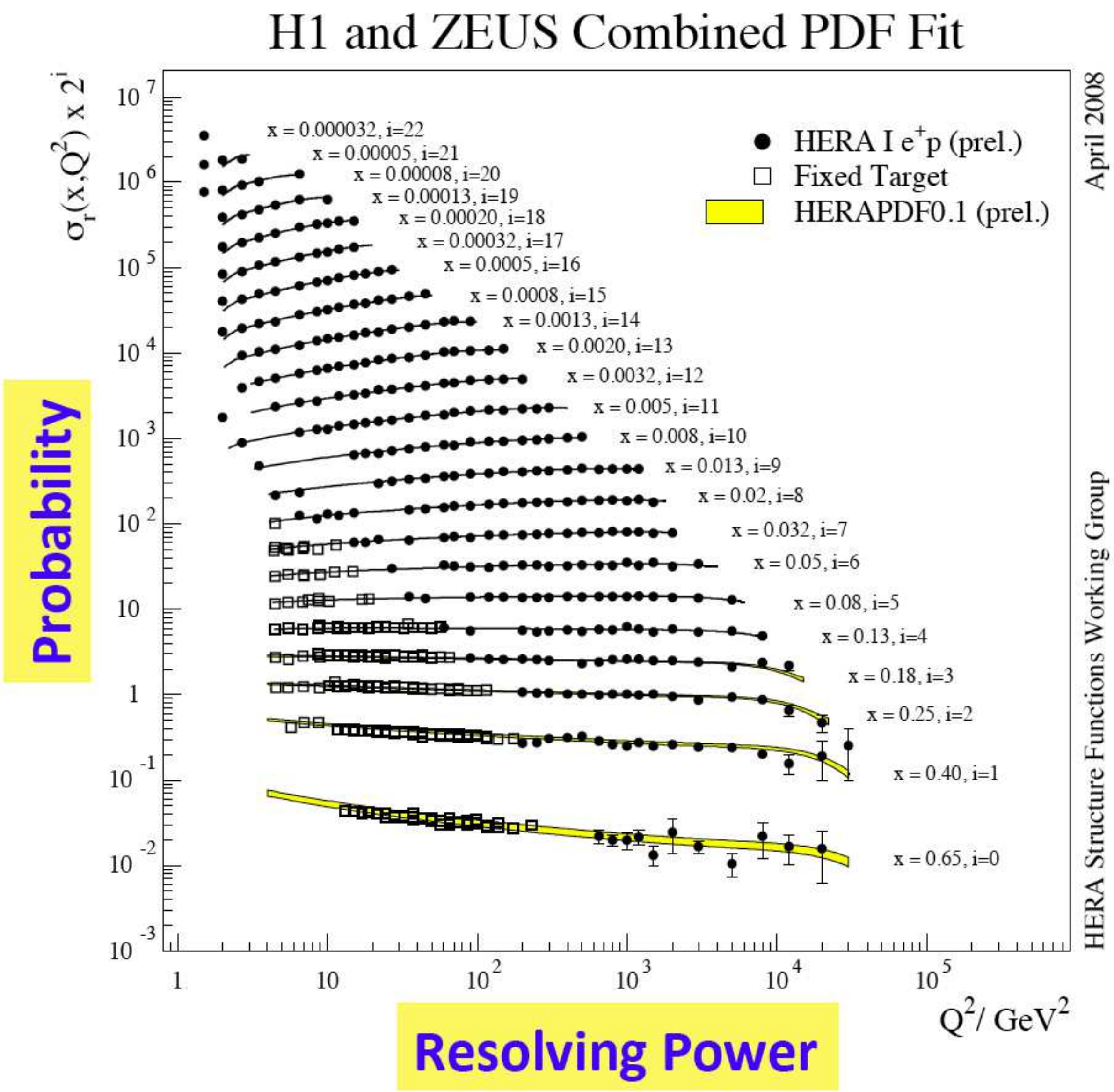


Kinematical domain at HERA



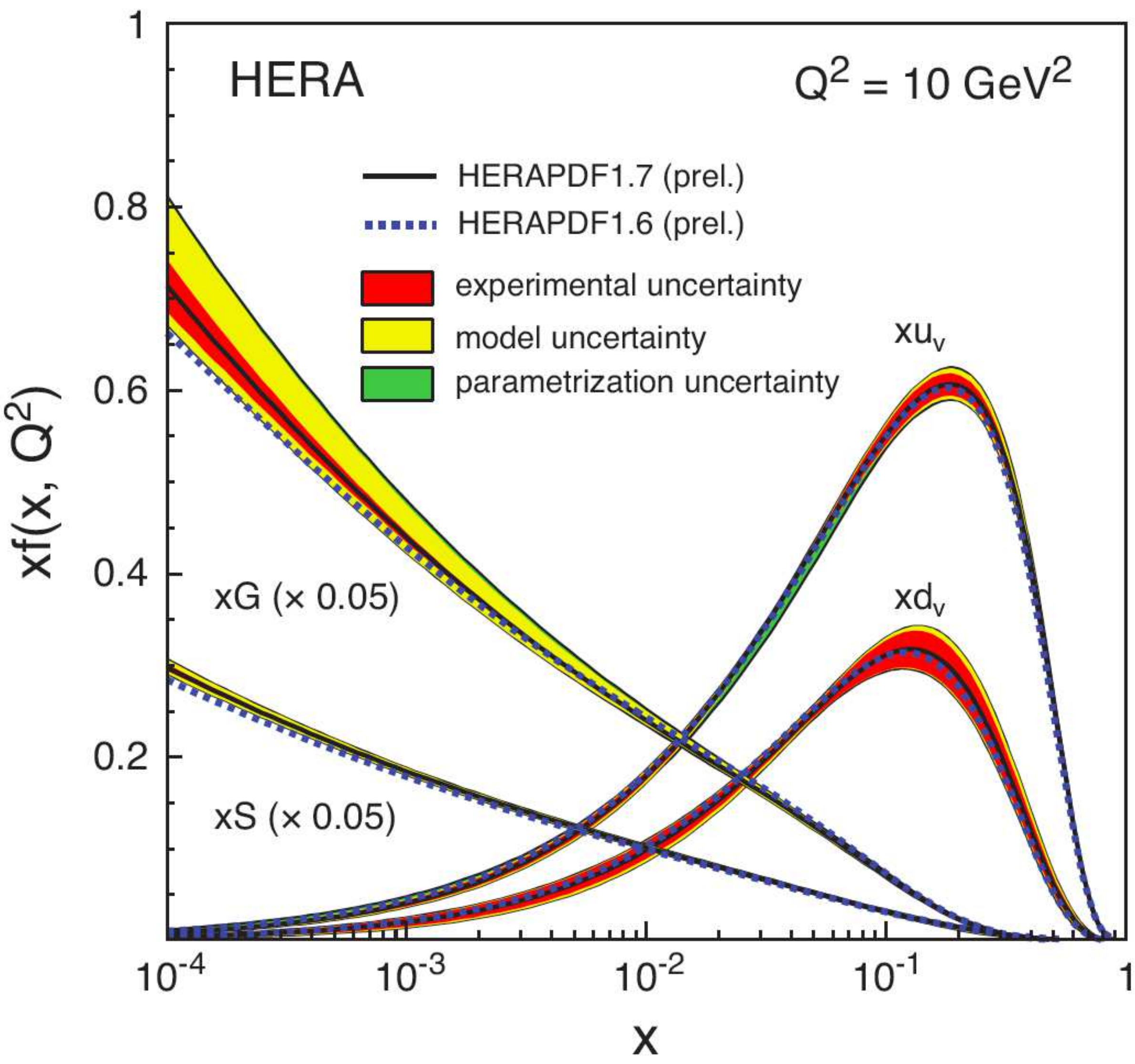
15 years of proton structure measurements at HERA

- Low x and high gluon density: new field, main discovery at HERA
- 15 years of work: proton structure in terms of quarks and gluons: NLO QCD is working well!
- Missing transverse information (TMDs, GPDs...): to be performed at the EIC, also using Deeply Virtual Compton Scattering events



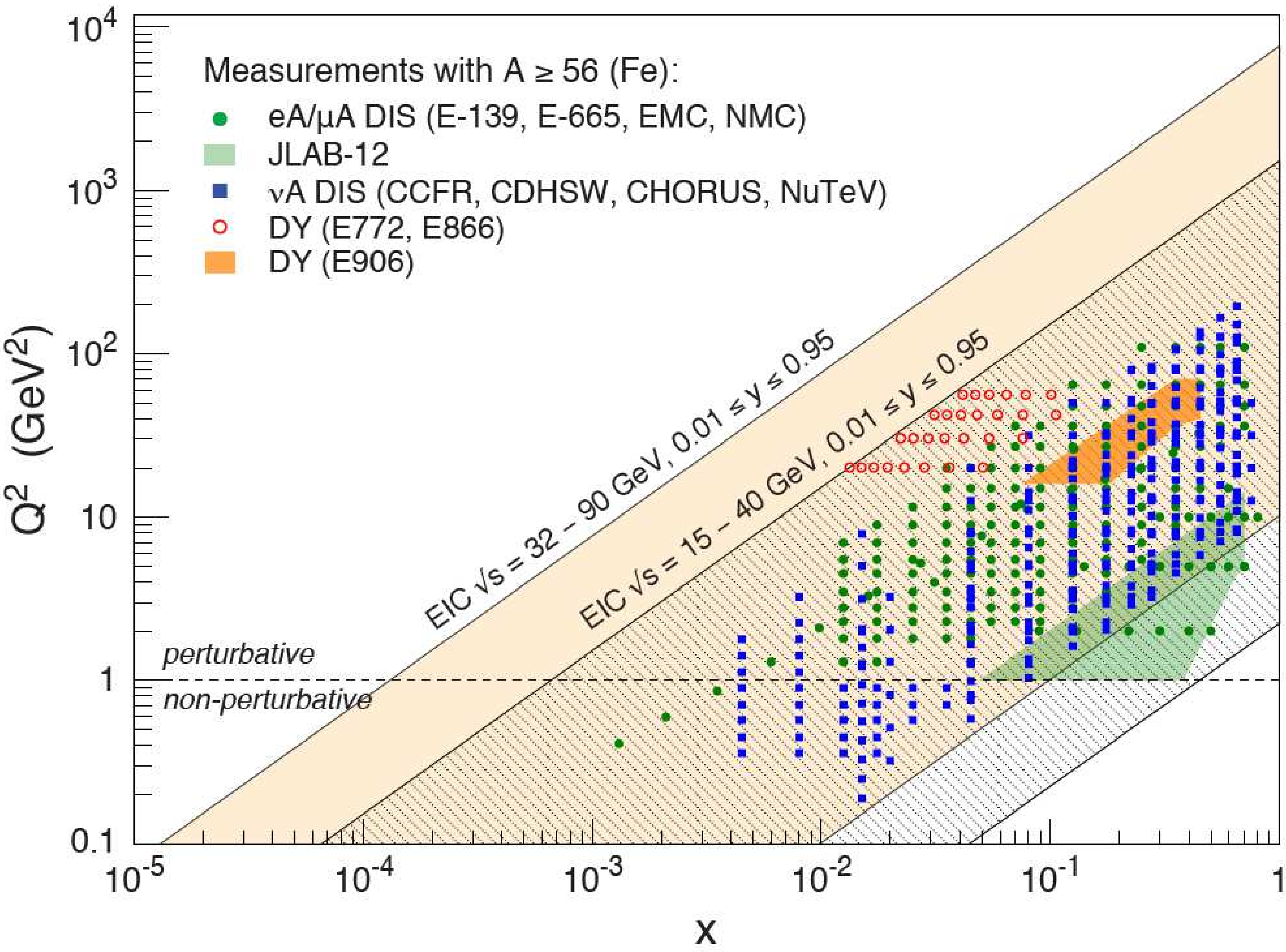
Quark and Gluon extraction

- Using the DGLAP evolution equation, obtain the quark and gluon densities in the proton as a function of x and Q^2
- Method: Assume quark and gluon distributions at $Q_0^2 = 4\ GeV^2$ with some parameters, compute cross section for different Q^2 using DGLAP, and fit the parameters so that they describe the measured values
- Proton is gluon dominated at small x



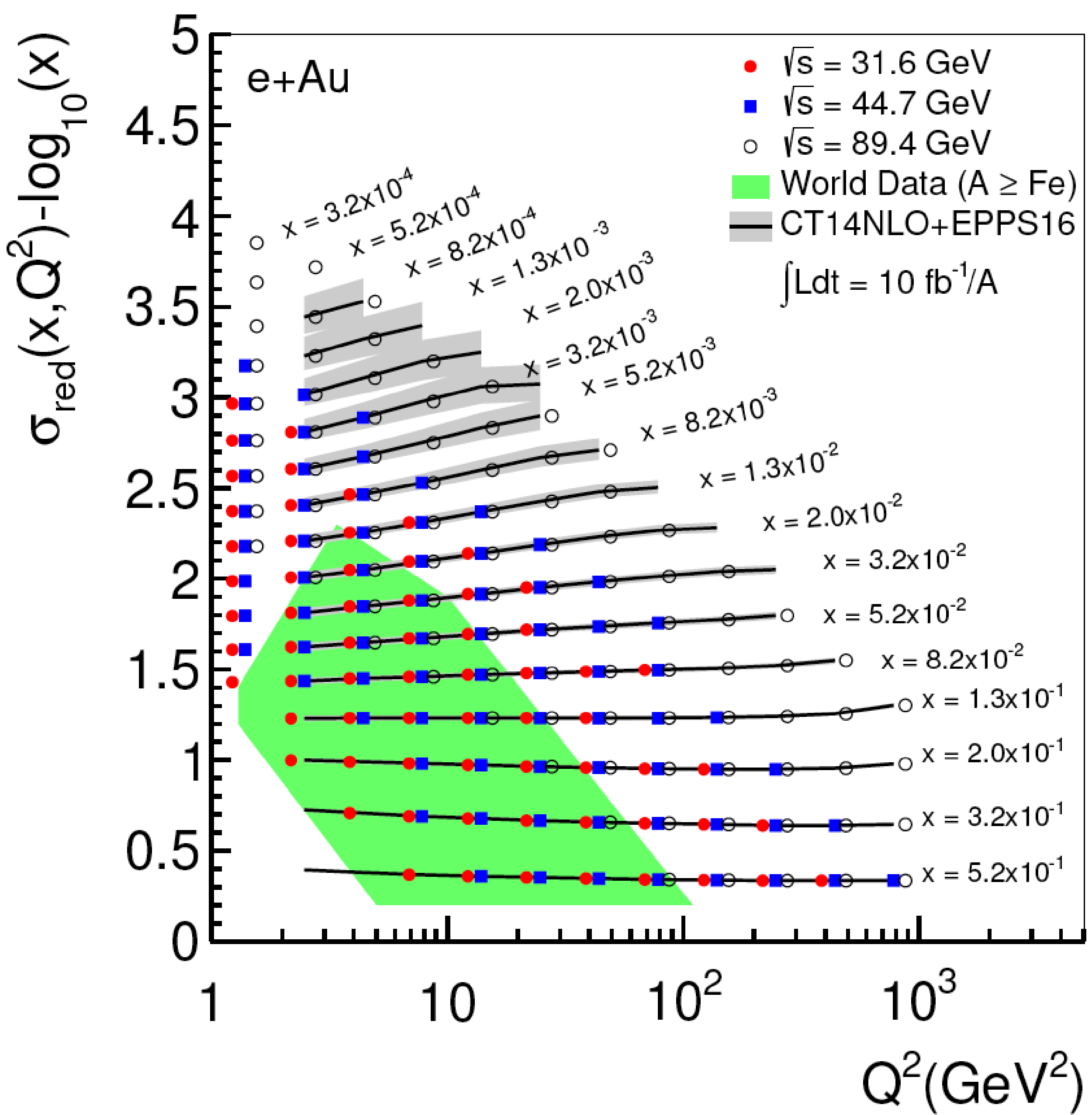
A better understanding of the heavy ion structure

- Kinematical domain at the EIC
- The heavy ion structure is poorly known at low x and also at high Q^2: similar situation as before HERA but for nuclei
- Similar gain in kinematical domain (x and Q^2) for nuclei compared to HERA for the proton
- See E.C. Aschenauer at al., ArXiv:1708.05654



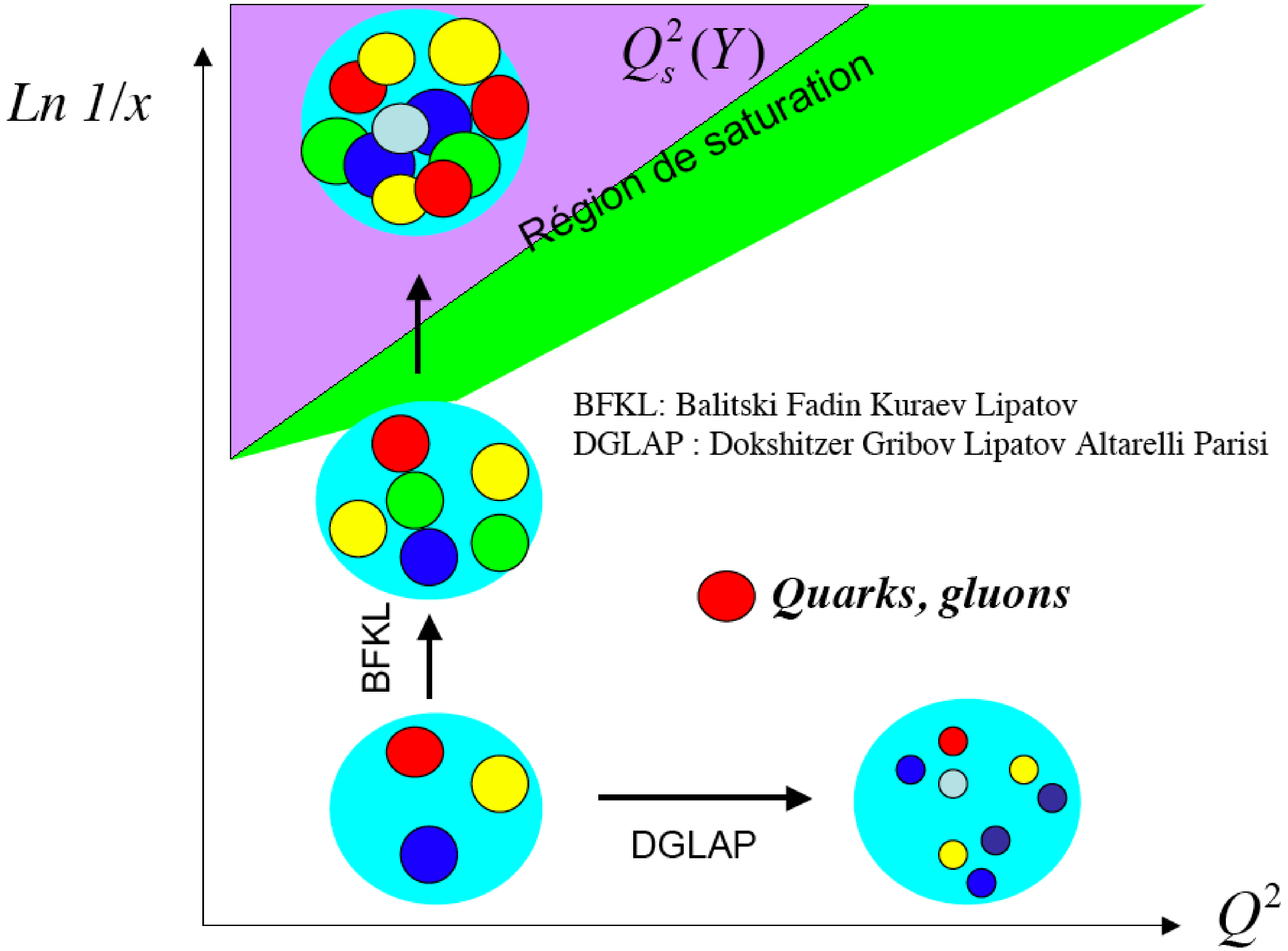
A better understanding of the heavy ion structure

- As an example: measure $eA \to eX$ cross section
- eAu cross section measurement
- Very good precision expected: can we see new effects in QCD such as saturation (higher gluon density in heavy ions)

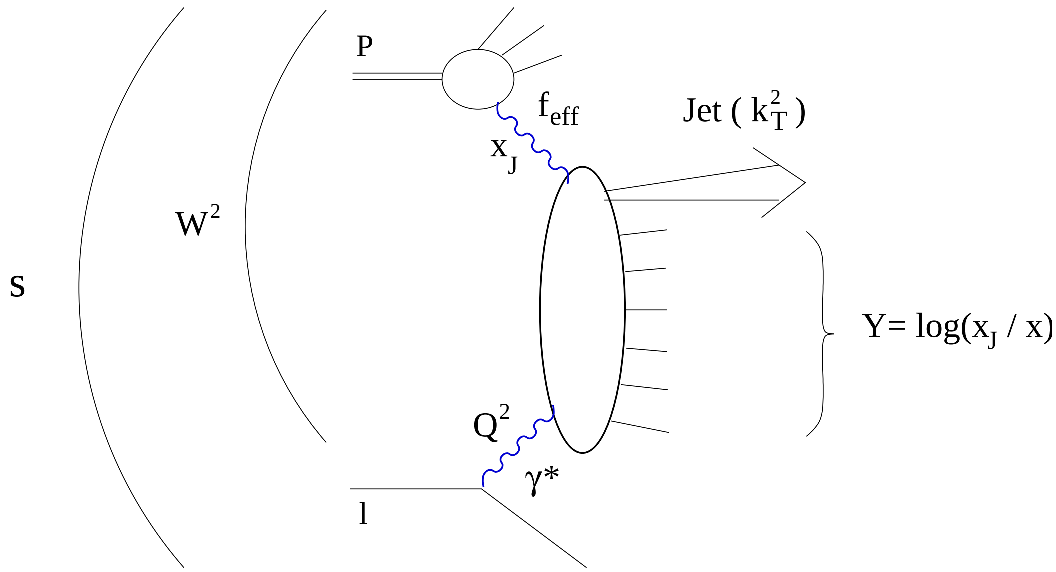


Looking for BFKL/saturation effects

Looking for BFKL effects (x-resummation) at HERA/LHC in dedicated final states



Forward jet measurement at HERA



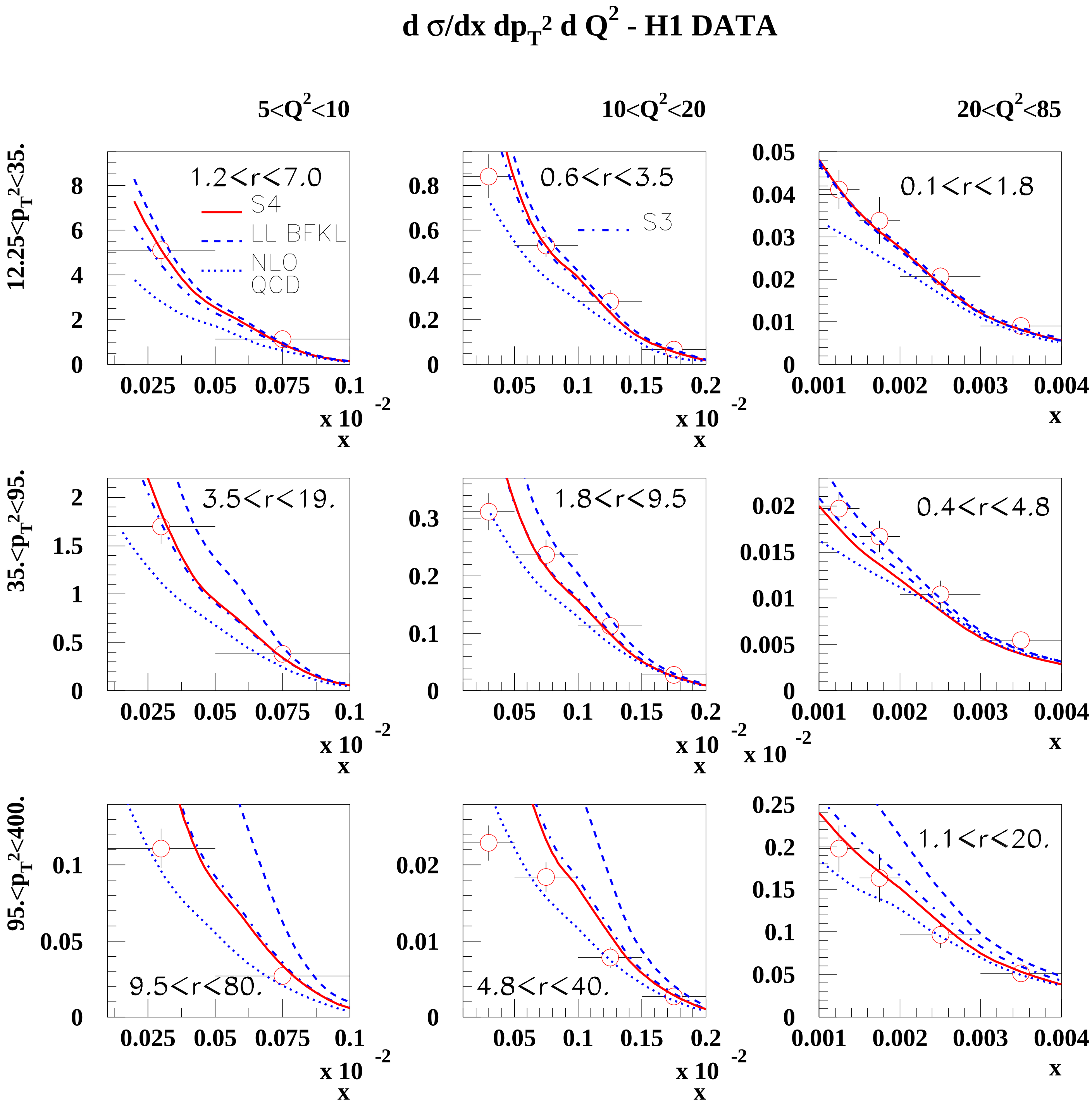
- Full BFKL NLL calculation used for the BFKL kernel, available in S3 and S4 resummation schemes to remove the spurious singularities (modulo the impact factors taken at LL)
- Equation:

$$\frac{d\sigma_{T,L}^{\gamma^* p \rightarrow JX}}{dx_J dk_T^2} = \frac{\alpha_s(k_T^2)\alpha_s(Q^2)}{k_T^2 Q^2} \; f_{eff}(x_J, k_T^2)$$

$$\int \frac{d\gamma}{2i\pi} \left(\frac{Q^2}{k_T^2}\right)^{\gamma} \phi_{T,L}^{\gamma}(\gamma) \; e^{\bar{\alpha}(k_T Q)\chi_{eff}[\gamma,\bar{\alpha}(k_T Q)]Y}$$

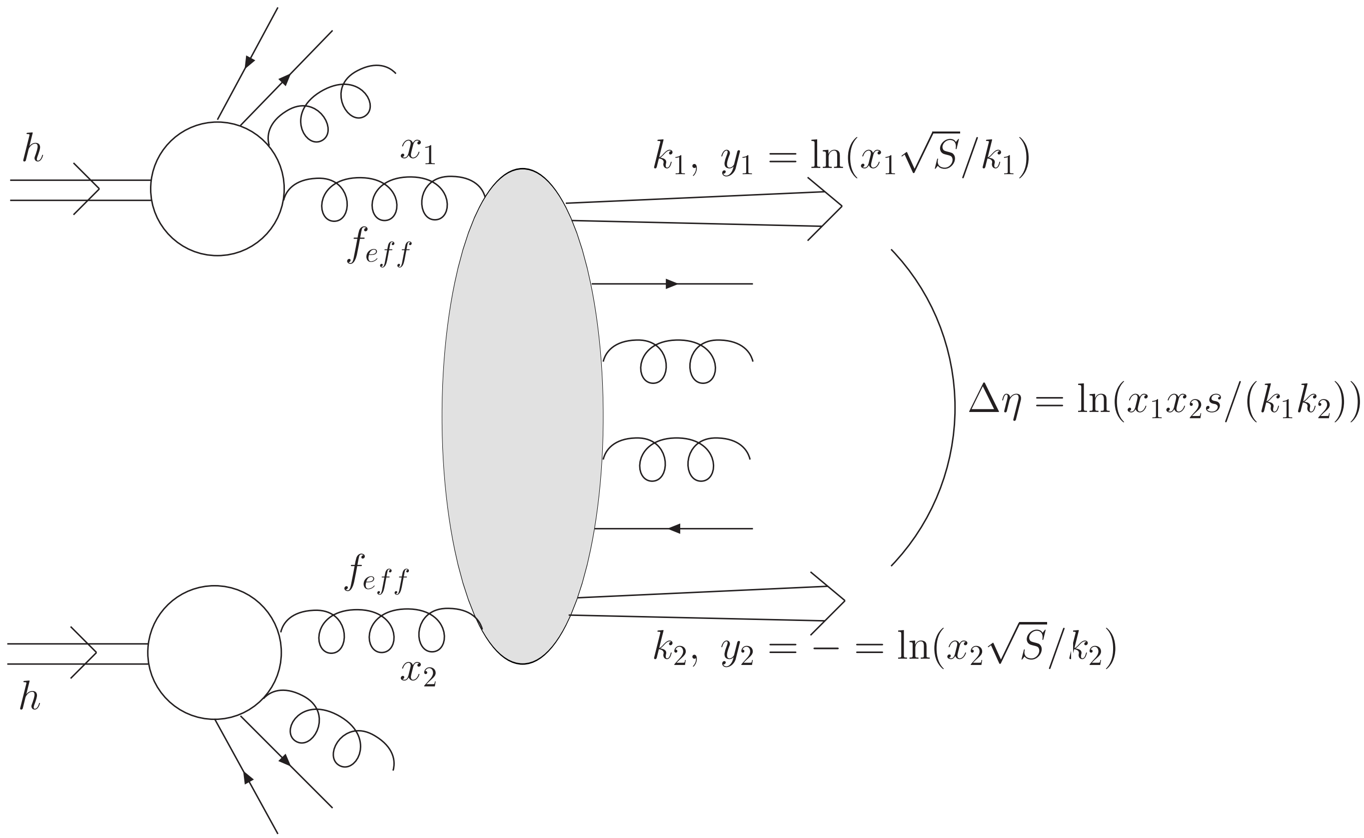
- Implicit equation: $\chi_{eff}(\gamma, \alpha) = \chi_{NLL}(\gamma, \alpha, \chi_{eff}(\gamma, \alpha))$ solved numerically (Nucl. Phys. B 739 (2006) 131; Phys. Lett. B 655 (2007) 236; Eur. Phys. J. C55 (2008) 259)

Comparison with H1 triple differential data



Mueller Navelet jets

Same kind of processes at the Tevatron and the LHC



- Same kind of processes at the Tevatron and the LHC: Mueller Navelet jets
- Study the $\Delta\Phi$ between jets dependence of the cross section:
- See papers by Papa, Murdaca, Wallon, Szymanowski, Ducloue, Sabio-Vera, Chachamis...

Mueller Navelet jets: $\Delta\Phi$ dependence

- Study the $\Delta\Phi$ dependence of the relative cross section
- Relevant variables:

$$\begin{aligned} \Delta\eta &= y_1 - y_2 \\ y &= (y_1 + y_2)/2 \\ Q &= \sqrt{k_1 k_2} \\ R &= k_2/k_1 \end{aligned}$$

- Azimuthal correlation of dijets:

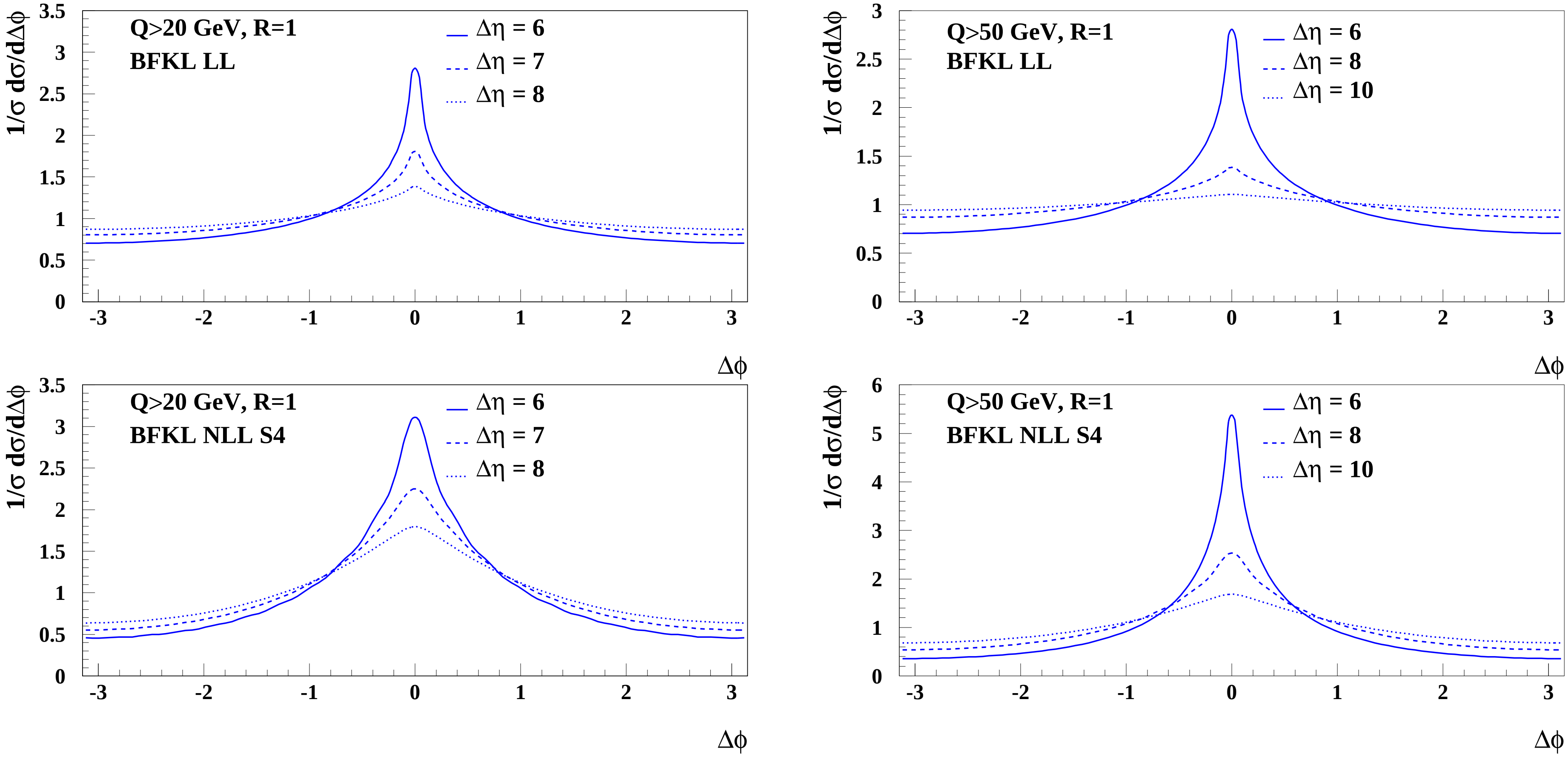
$$2\pi \frac{d\sigma}{d\Delta\eta dR d\Delta\Phi} \Bigg/ \frac{d\sigma}{d\Delta\eta dR} = 1 + \frac{2}{\sigma_0(\Delta\eta, R)} \sum_{p=1}^{\infty} \sigma_p(\Delta\eta, R) \cos(p\Delta\Phi)$$

where

$$\sigma_p = \int_{E_T}^{\infty} \frac{dQ}{Q^3} \alpha_s(Q^2/R) \alpha_s(Q^2 R) \left(\int_{y_<}^{y_>} dy x_1 f_{eff}(x_1, Q^2/R) x_2 f_{eff}(x_2, Q^2 R) \right) \int_{1/2-\infty}^{1/2+\infty} \frac{d\gamma}{2i\pi} R^{-2\gamma} \, e^{\bar{\alpha}(Q^2)\chi_{eff}(p)\Delta\eta}$$

Mueller Navelet jets: $\Delta\Phi$ dependence

- $1/\sigma d\sigma/d\Delta\Phi$ spectrum for BFKL LL and BFKL NLL as a function of $\Delta\Phi$ for different values of $\Delta\eta$, scale dependence: $\sim$20%



- C. Marquet, C.R., Phys. Rev. D79 (2009) 034028
- Mueller Navelet jets at NLL and saturation effects: Study in progress with F. Deganutti, T. Raben, S. Schlichtling

Effect of energy conservation on BFKL equation

- BFKL cross section lacks energy-momentum conservation since these effects are higher order corrections
- Following Del Duca-Schmidt, we substitute $\Delta\eta$ by an effective rapidity interval y_{eff}

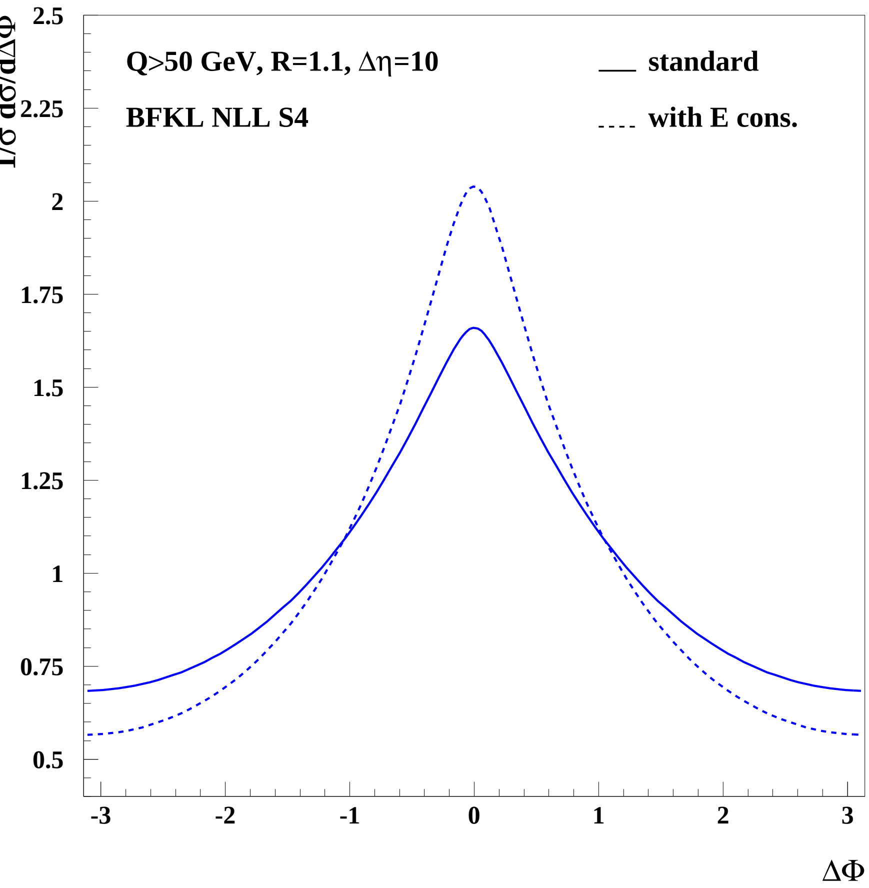
$$y_{eff} = \Delta\eta \left(\int d\phi \cos(p\phi) \frac{d\sigma^{O(\alpha_s^3)}}{d\Delta\eta dy dQ dR d\Delta\Phi} \right) \left(\int d\phi \cos(p\phi) \frac{d\sigma^{LL-BFKL}}{d\Delta\eta dy dQ dR d\Delta\Phi} \right)^{-1}$$

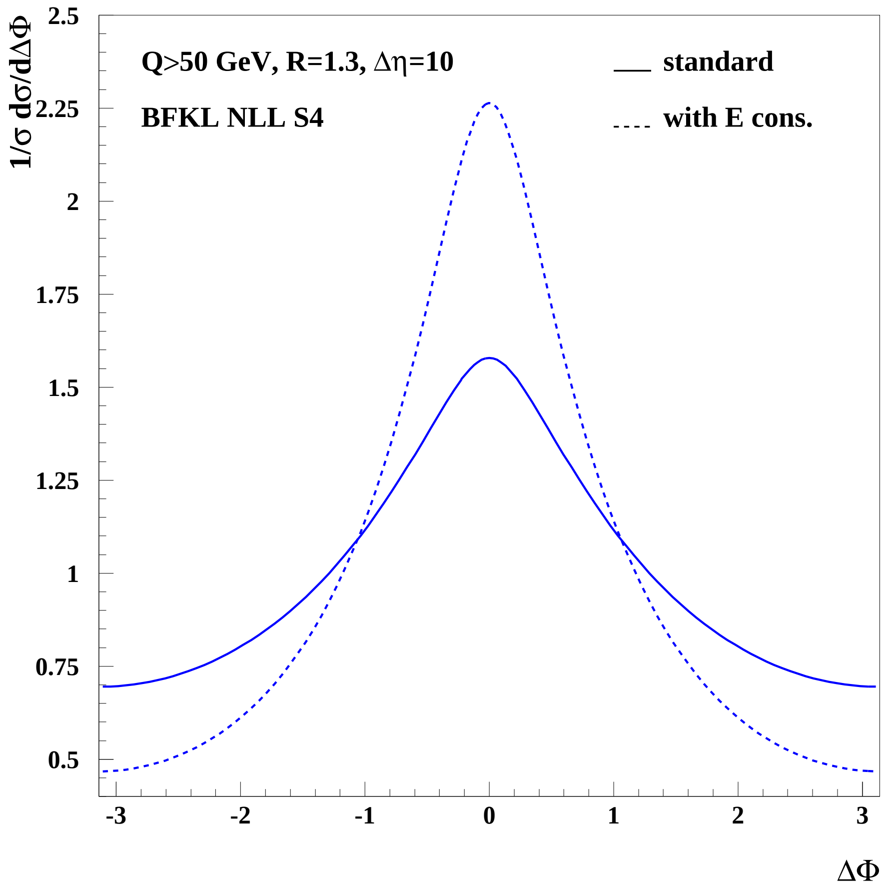
where $d\sigma^{O(\alpha_s^3)}$ is the exact $2 \to 3$ contribution to the $hh \to JXJ$ cross-section at order α_s^3, and $d\sigma^{LL-BFKL}$ is the LL-BFKL result

- To compute $d\sigma^{O(\alpha_s^3)}$, we use the standard jet cone size $R_{cut} = 0.5$ when integrating over the third particle's momentum

Mueller Navelet cross sections: energy conservation effect in BFKL

- Effect of energy conservation on BFKL dynamics
- Large effect if jet p_T ratios not close to 1: goes closer to DGLAP predictions, needs jet p_T ratio $<$ 1.1-1.15



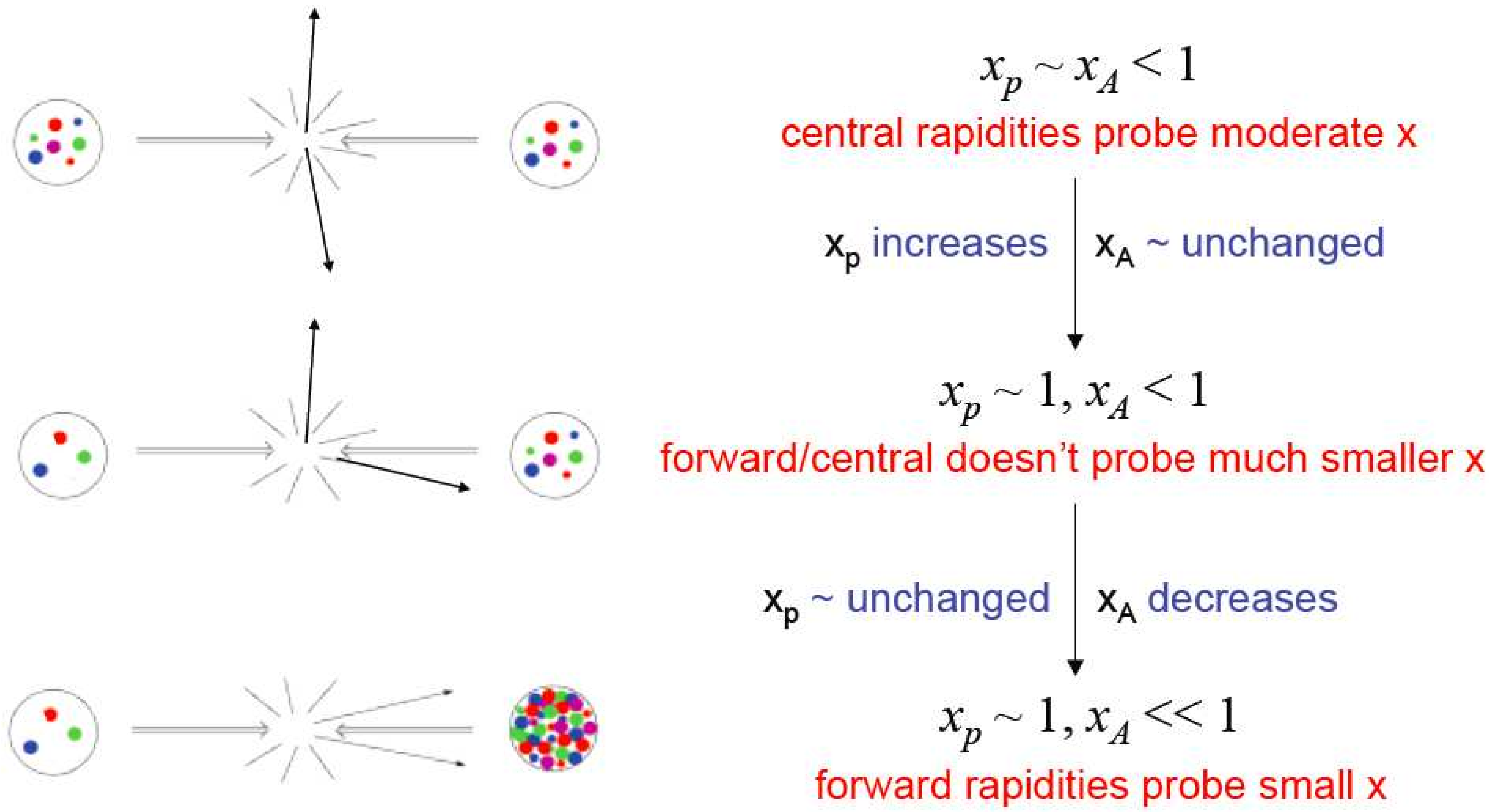


Saturation effects at the LHC: Use pA data

- Saturation effects: need to go to low x, jets as forward as possible on the same side
- Compare pp and pA runs in order to remove many systematics

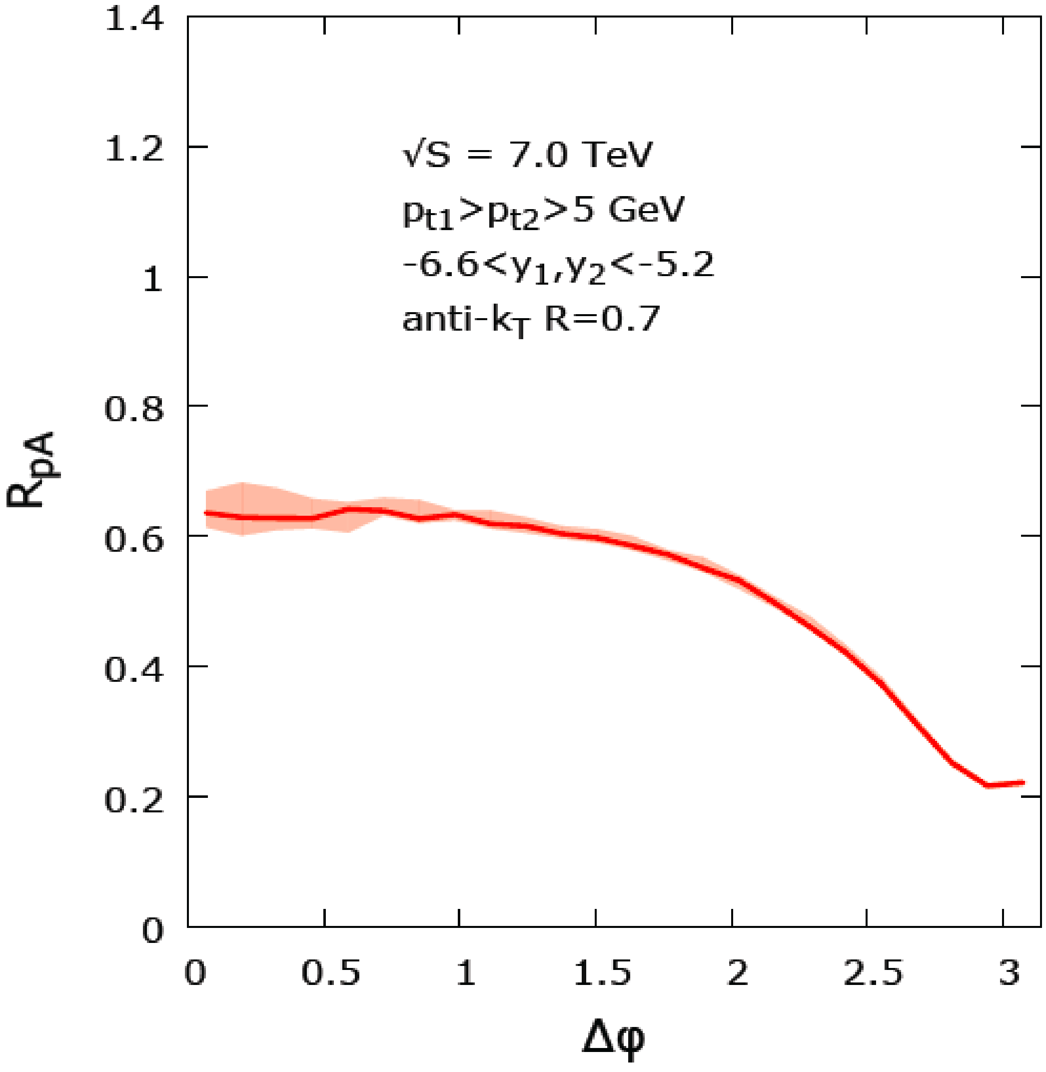
final state : $k_1, y_1 \quad k_2, y_2$ $\qquad x_p = \frac{k_1 e^{y_1} + k_2 e^{y_2}}{\sqrt{s}} \qquad x_A = \frac{k_1 e^{-y_1} + k_2 e^{-y_2}}{\sqrt{s}}$

scanning the wave functions:

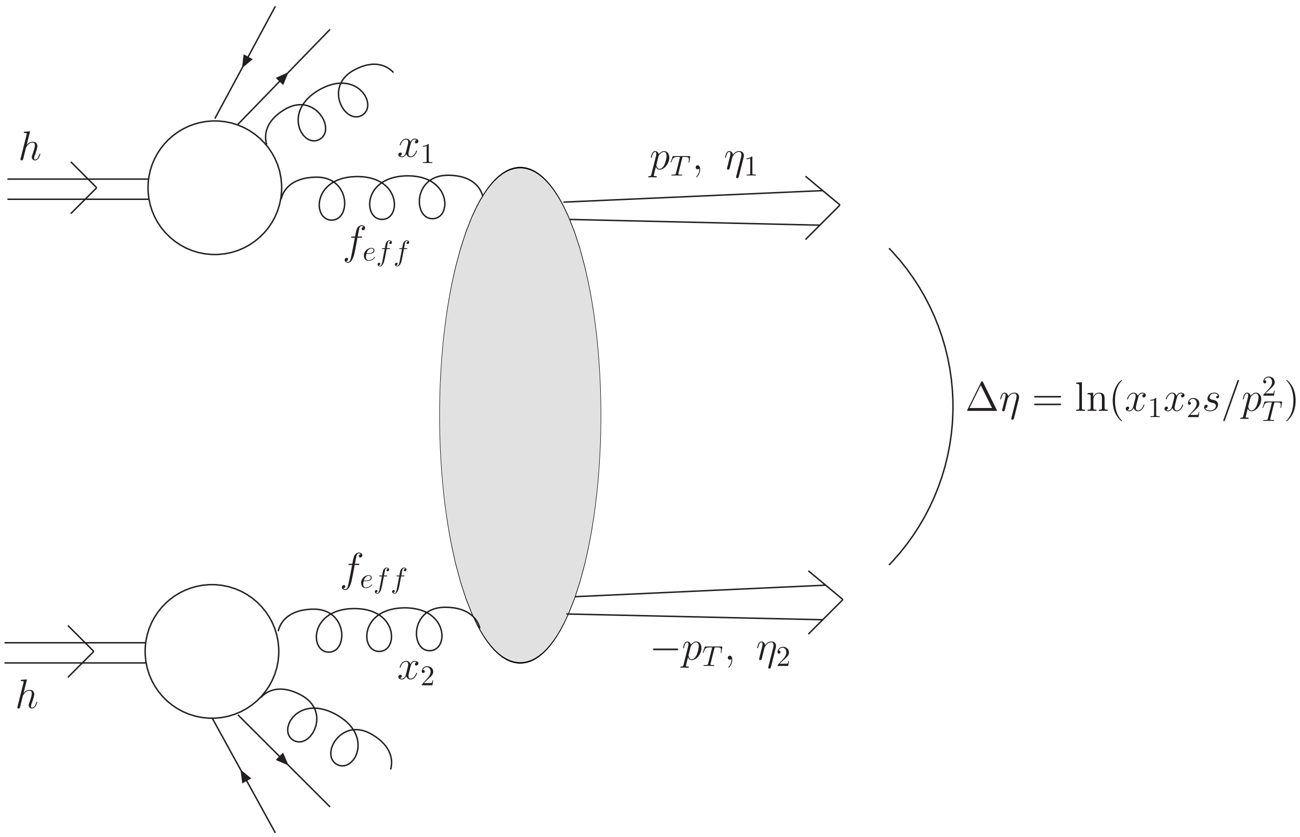


Saturation effects at the LHC

- Suppression factor between pp and pA runs: estimated to be 1/2 in CASTOR acceptance
- Important to get CASTOR in pA and low lumi pp data
- Study performed by Cyrille Marquet et al.; in progress by F. Deganutti, M. Hentschinski, T. Raben, S. Schlichting, CR



Jet gap jet cross sections



- Test of BFKL evolution: jet gap jet events, large $\Delta\eta$, same p_T for both jets in BFKL calculation
- Principle: Implementation of BFKL NLL formalism in HERWIG Monte Carlo (Measurement sensitive to jet structure and size, gap size smaller than $\Delta\eta$ between jets)

BFKL formalism

- BFKL jet gap jet cross section: integration over ξ, p_T performed in Herwig event generation

$$\frac{d\sigma^{pp\to XJJY}}{dx_1 dx_2 dp_T^2} = \mathcal{S}\frac{f_{eff}(x_1,p_T^2)f_{eff}(x_2,p_T^2)}{16\pi}\left|A(\Delta\eta,p_T^2)\right|^2$$

where S is the survival probability (0.1 at Tevatron, 0.03 at LHC)

$$A(\Delta\eta,p_T^2) = \frac{16N_c\pi\alpha_s^2}{C_F p_T^2}\sum_{p=-\infty}^{\infty}\int\frac{d\gamma}{2i\pi}\frac{[p^2-(\gamma-1/2)^2]}{[(\gamma-1/2)^2-(p-1/2)^2]} \frac{\exp\left\{\frac{\alpha_S N_C}{\pi}\chi_{eff}\Delta\eta\right\}}{[(\gamma-1/2)^2-(p+1/2)^2]}$$

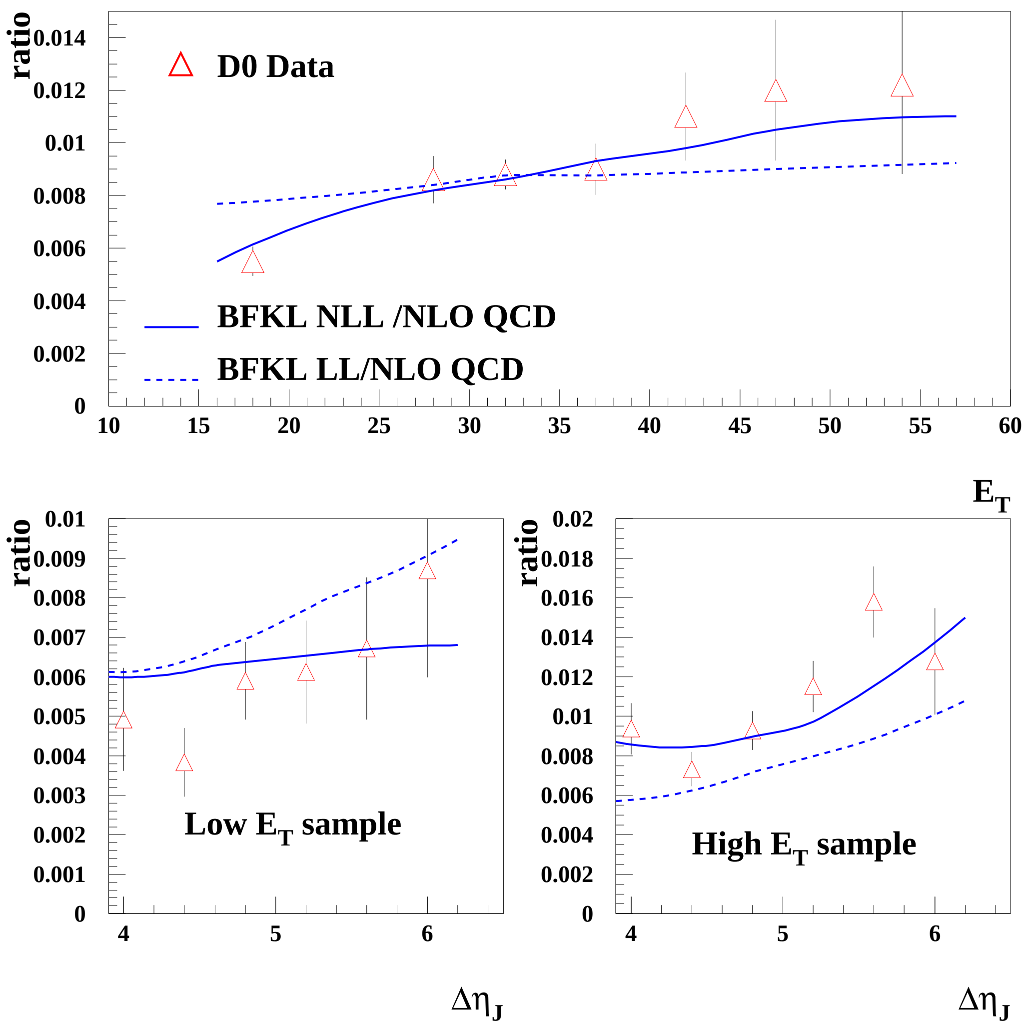
- α_S: 0.17 at LL (constant), running using RGE at NLL
- BFKL effective kernel χ_{eff}: determined numerically, solving the implicit equation: $\chi_{eff} = \chi_{NLL}(\gamma, \bar{\alpha}\ \chi_{eff})$
- S4 resummation scheme used to remove spurious singularities in BFKL NLL kernel
- Implementation in Herwig Monte Carlo: needed to take into account jet size and at parton level the gap size is equal to $\Delta\eta$ between jets
- Herwig MC: Parametrised distribution of $d\sigma/dp_T^2$ fitted to BFKL NLL cross section (2200 points fitted between $10 < p_T < 120$ GeV, $0.1 < \Delta\eta < 10$ with a $\chi^2 \sim 0.1$)

Comparison with D0 data

- D0 measurement: Jet gap jet cross section ratios as a function of second highest E_T jet, or $\Delta\eta$ for the low and high E_T samples, the gap between jets being between -1 and 1 in rapidity
- Comparison with BFKL formalism:

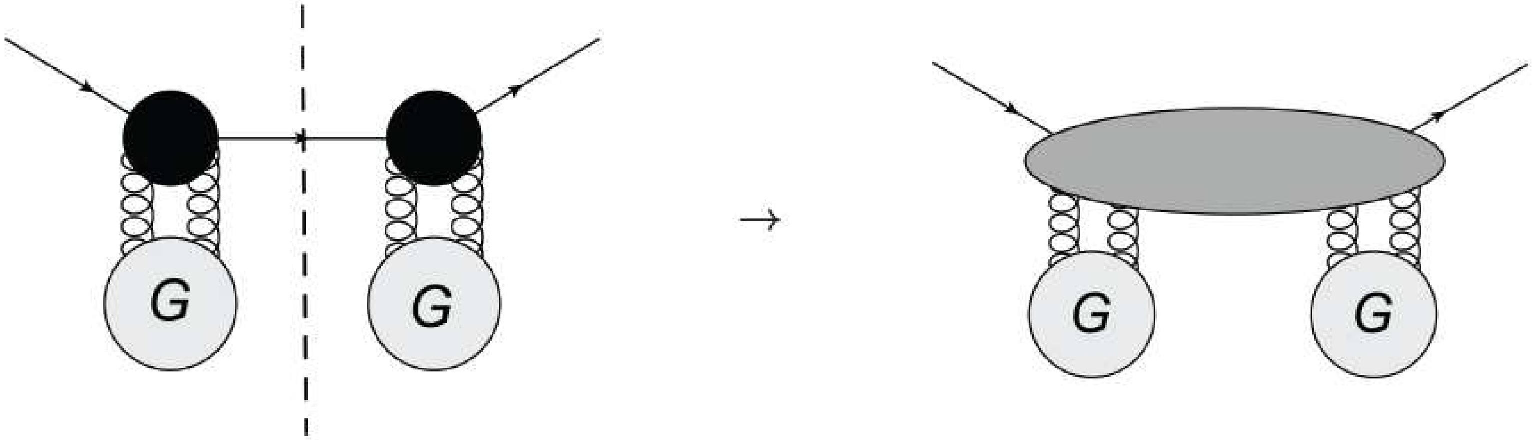
$$Ratio = \frac{BFKL\ NLL\ Herwig}{Dijet\ Herwig} \times \frac{LO\ QCD\ NLOJet++}{NLO\ QCD\ NLOJet++}$$

- Reasonable description using BFKL NLL formalism



Full NLL calculation (in progress)

- Combine NLL kernel with NLO impact factors (Hentschinski, Madrigal, Murdaca, Sabio Vera 2014)
- At NLO, impact factors are much more complicated!



- NLL impact factors

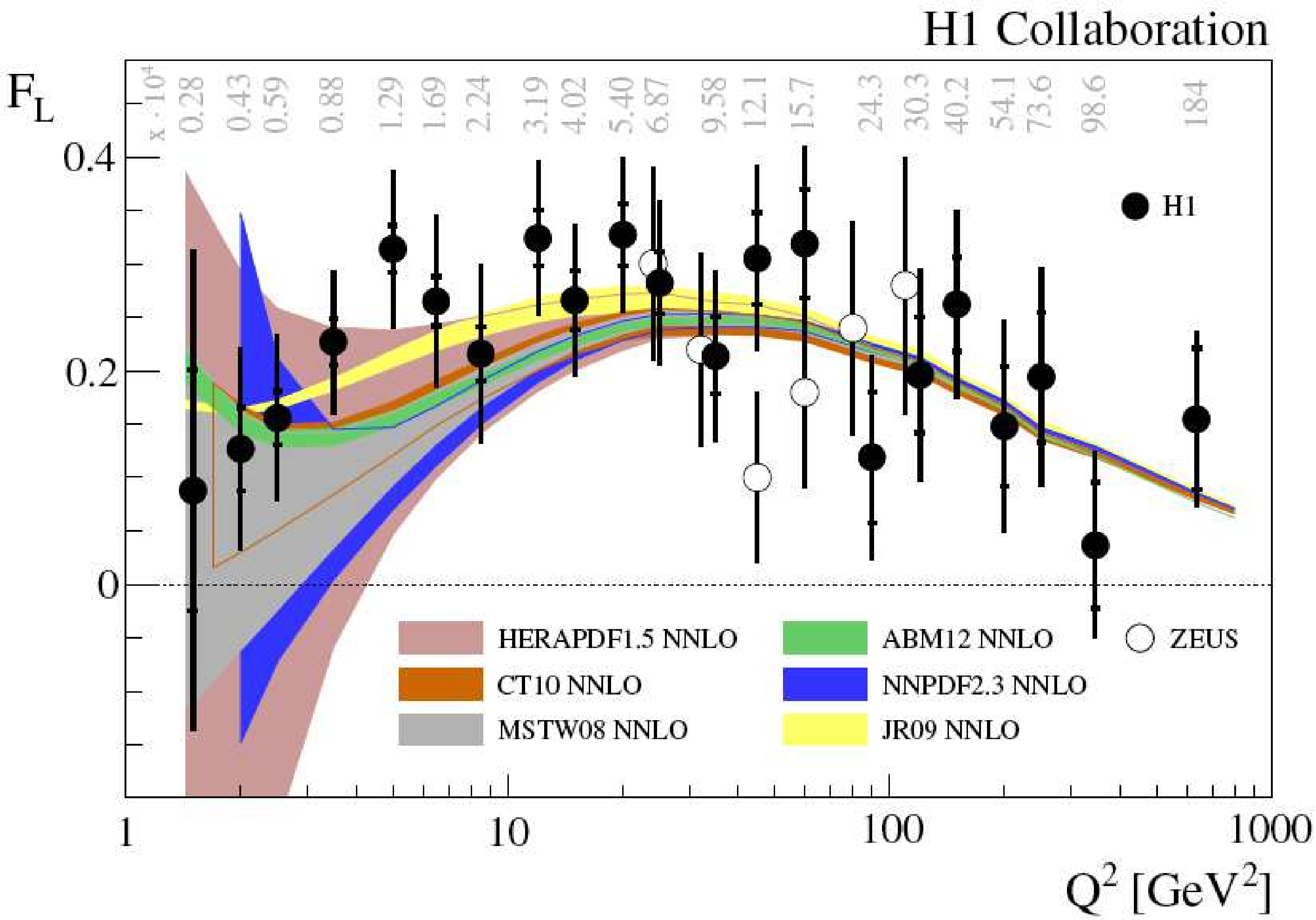
  – Mix loop momenta (not factorized)
  – Involve jet distributions with two final states
  – Contain complicated non-analytic progress
  – Work in progress by D. Colferai, F. Daganutti, T. Raben

- Will lead to an improved parametrisation to be omplemented in HERWIG

Understanding saturation? F_L measurement at HERA

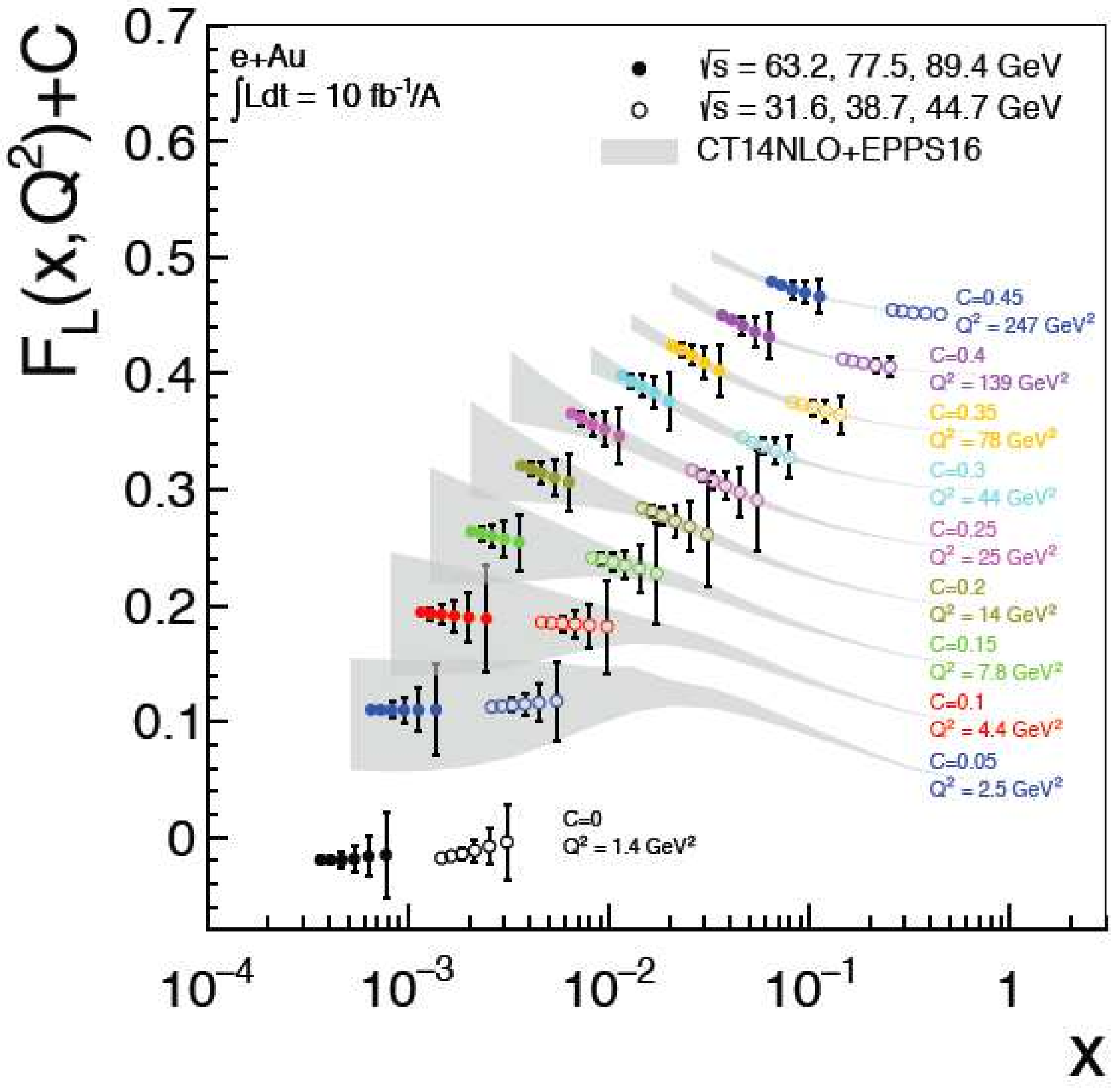
- Different impacts of saturation on longitudinal and transverse cross sections
- Important to measure F_2 and F_L independently at HERA: unfortunately, the error bars were large

$$\frac{d\sigma}{dxdQ^2} = \frac{4\pi\alpha^2}{2xQ^4}\left[(1+(1-y)^2)F_2(x,Q^2) - y^2 F_L(x,Q^2)\right]$$

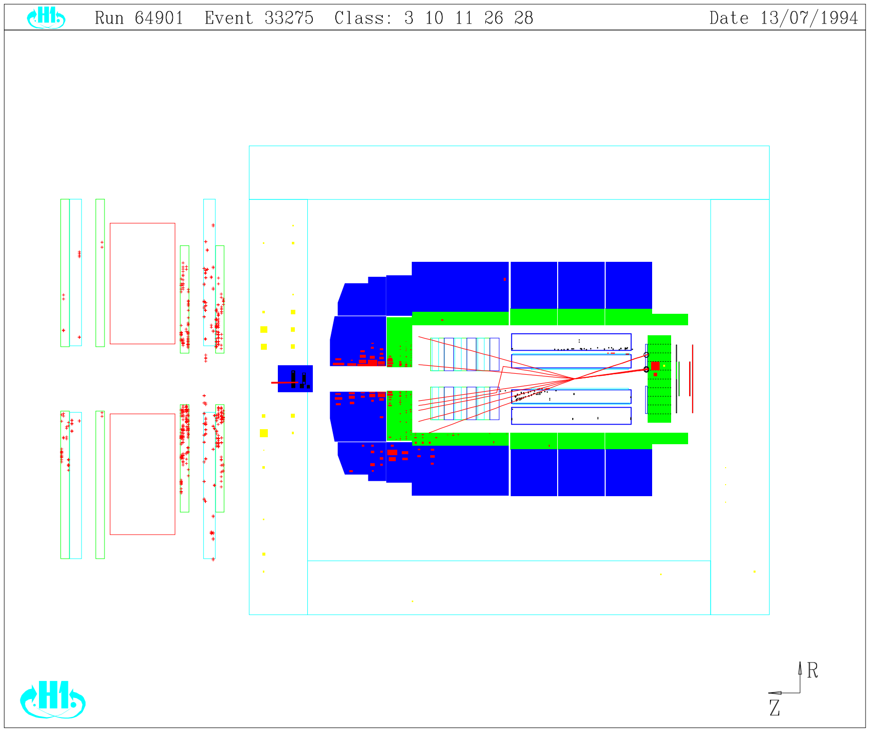


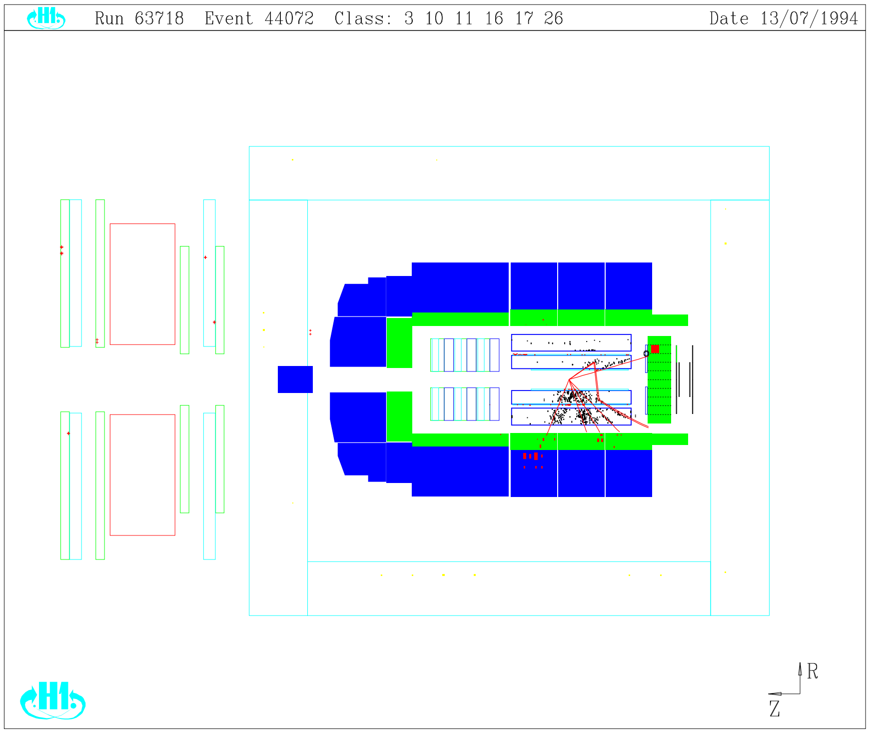
F_L measurement at the EIC

- F_L measurement in eA collisions
- High precision expected: important to probe saturation effects, and see different evolutions between F_2 and F_L
- This could be a clear indication of saturation!



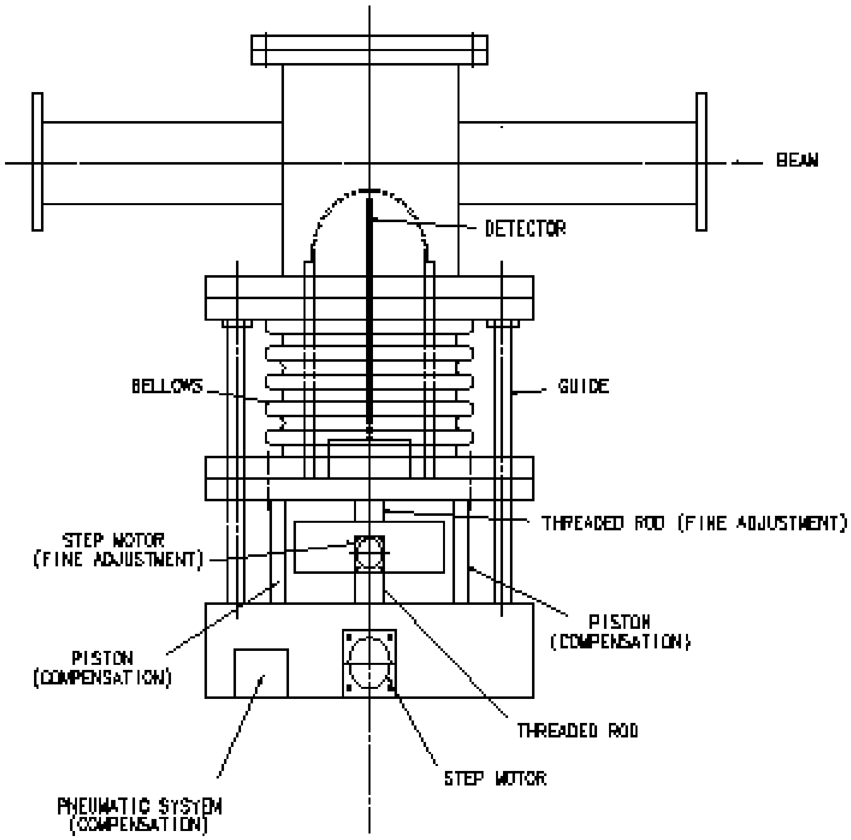
Diffraction: DIS and Diffractive event at HERA



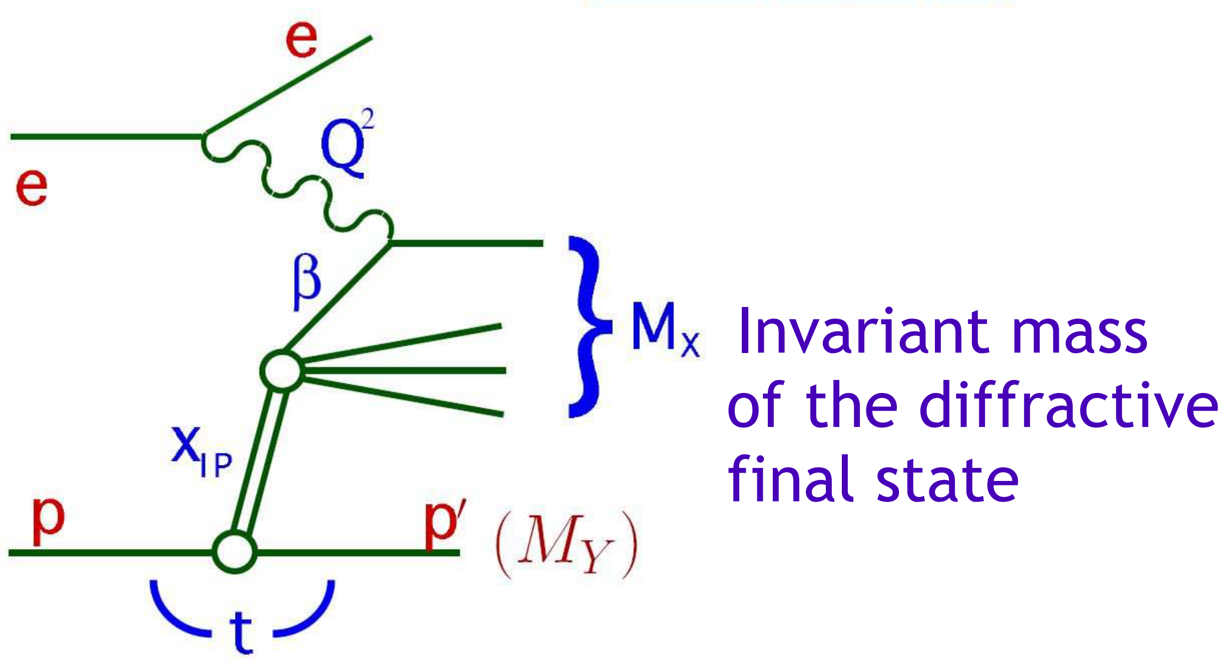


Definition of diffraction: example of HERA

- Typical DIS event: part of proton remnants seen in detectors in forward region (calorimeter, forward muon...)
- HERA observation: in some events, no energy in forward region, or in other words no colour exchange between proton and jets produced in the hard interaction
- Leads to the first experimental method to detect diffractive events: rapidity gap in calorimeter: difficult to be used at the LHC because of pile up events
- Second method to find diffractive events: Tag the proton in the final state, method to be used at the LHC (example of AFP project)



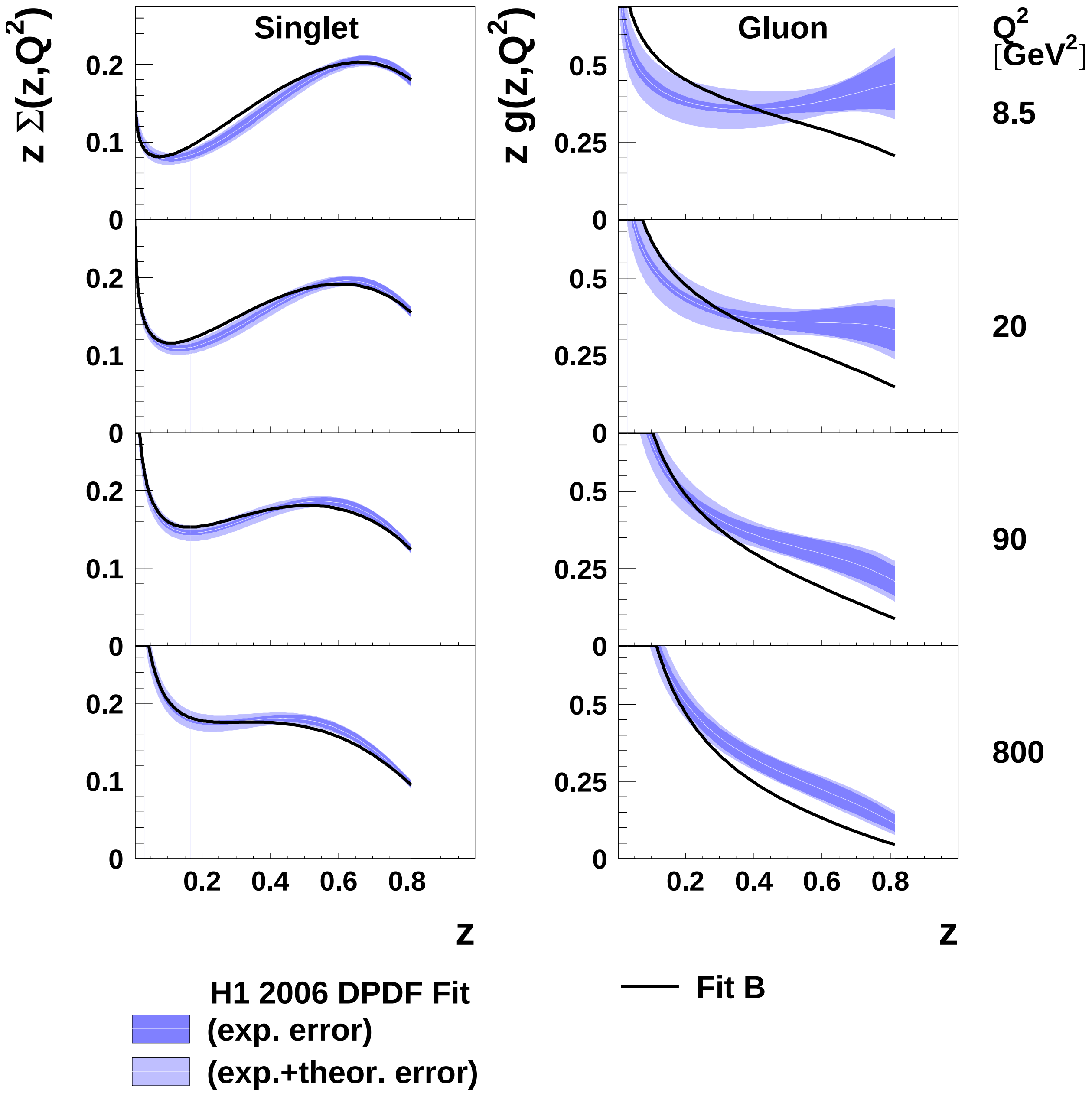
Diffractive kinematical variables



- Momentum fraction of the proton carried by the colourless object (pomeron): $x_p = \xi = \frac{Q^2+M_X^2}{Q^2+W^2}$
- Momentum fraction of the pomeron carried by the interacting parton if we assume the colourless object to be made of quarks and gluons: $\beta = \frac{Q^2}{Q^2+M_X^2} = \frac{x_{Bj}}{x_P}$
- 4-momentum squared transferred: $t = (p - p')^2$

Parton densities in the pomeron (H1)

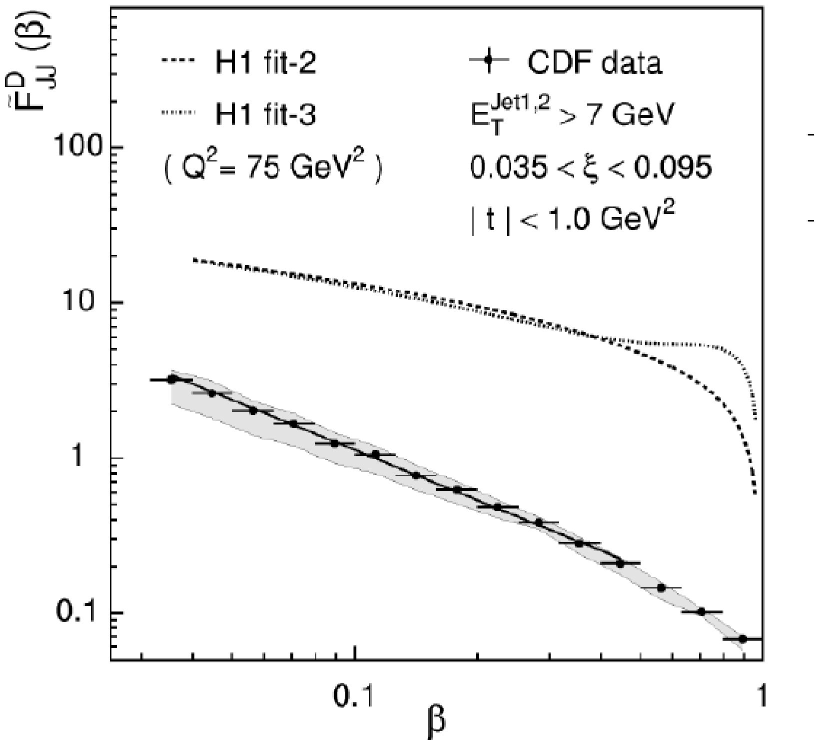
- Extraction of gluon and quark densities in pomeron: gluon dominated
- Gluon density poorly constrained at high β

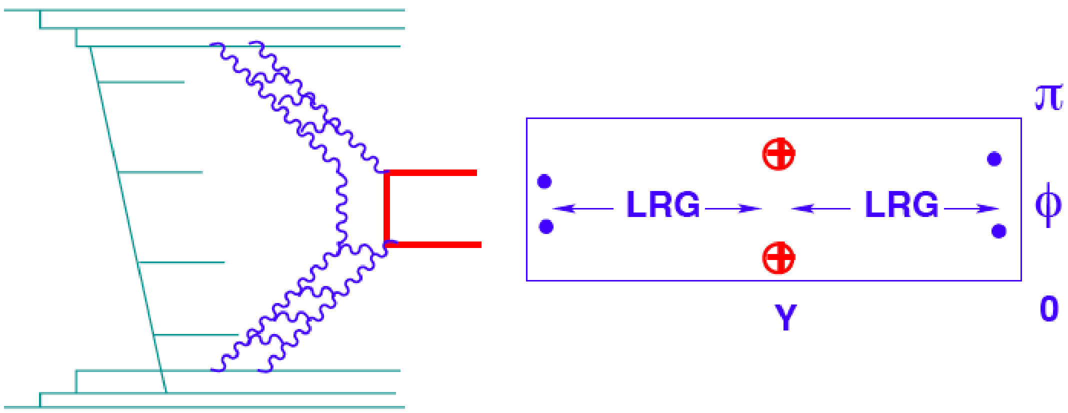


Factorization breaking between ep and pp

- Comparison between Tevatron CDF data and extrapolations from HERA
- Discrepancy due to survival probability

Phys. Rev. Lett. 84 5043 (2000)

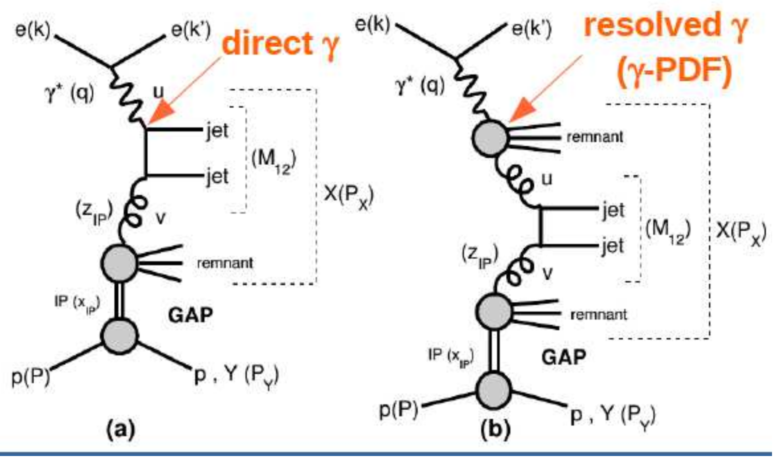


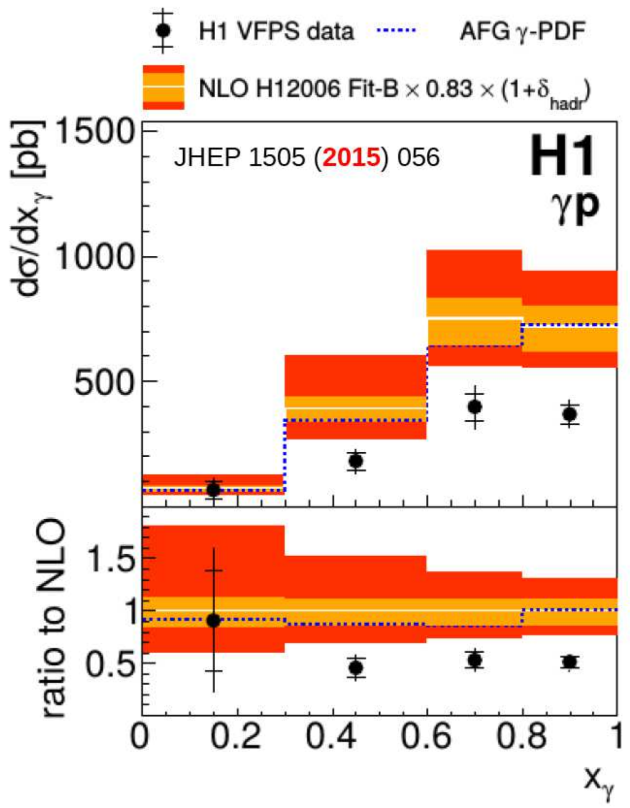


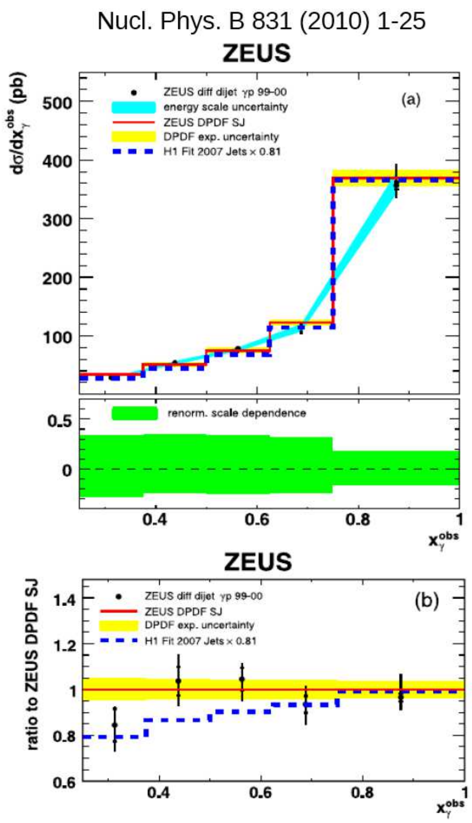
a) b)

Factorization studies at HERA in Photoproduction

- Factorization is not expected to hold for resolved γ
- Observed by H1 but not by ZEUS; measurement to be done at the EIC?

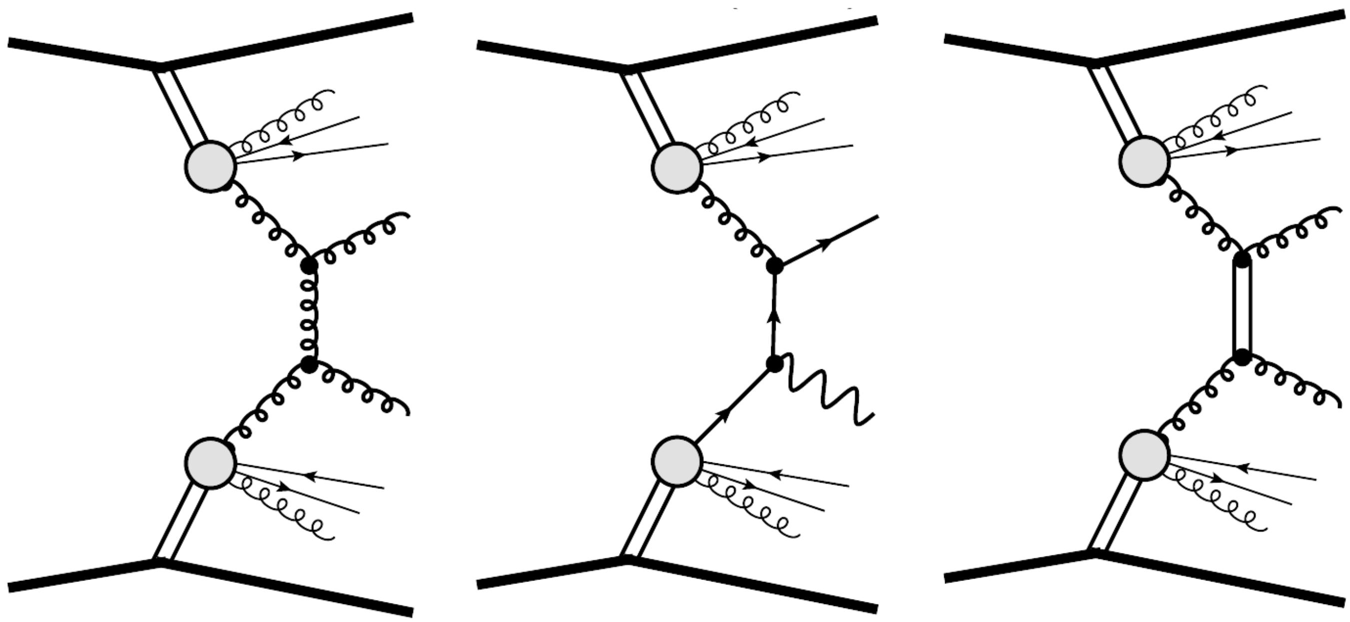






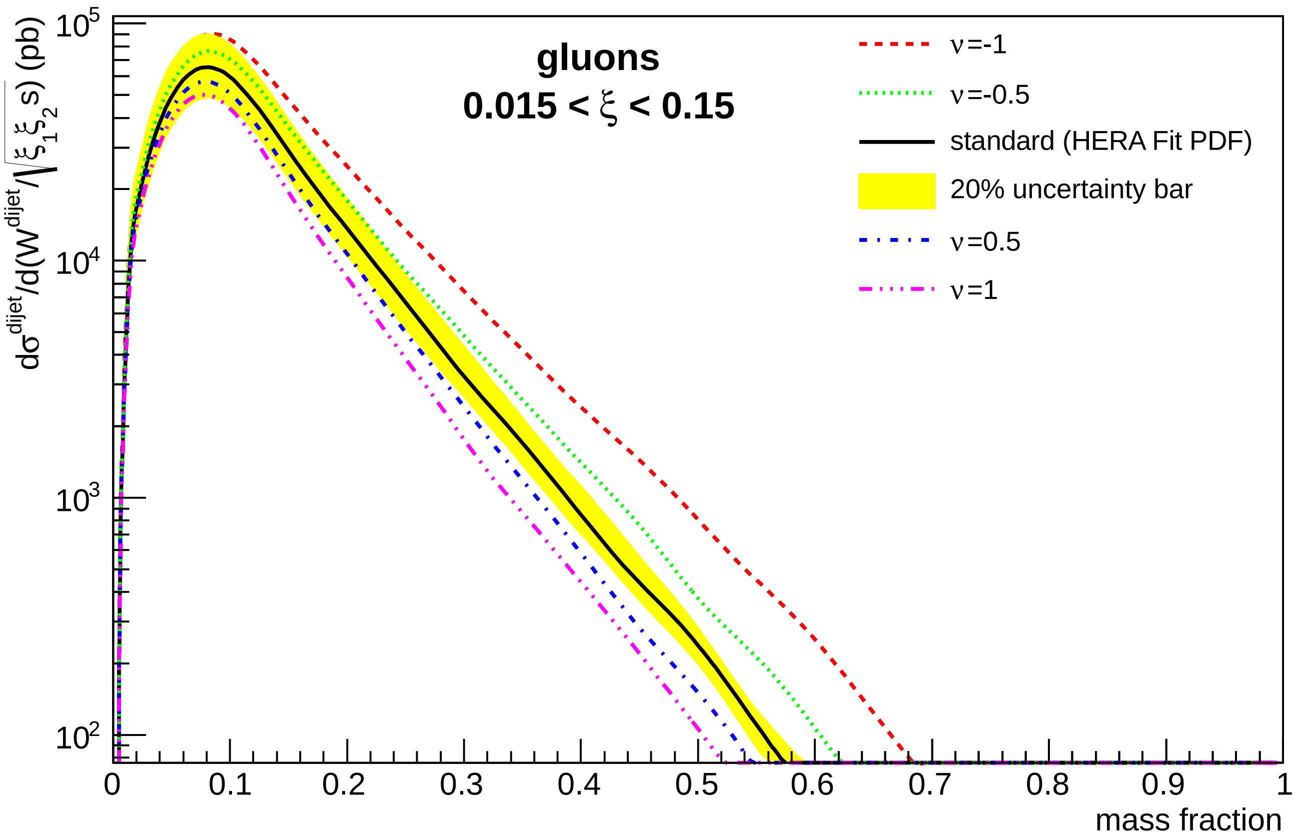
Hard diffraction at the LHC

- Dijet production: dominated by gg exchanges; γ+jet production: dominated by qg exchanges
- Jet gap jet in diffraction: Probe BFKL
- Three aims
  - Is it the same object which explains diffraction in pp and ep?
  - Further constraints on the structure of the Pomeron as was determined at HERA
  - Survival probability: difficult to compute theoretically, needs to be measured, inclusive diffraction is optimal place for measurement



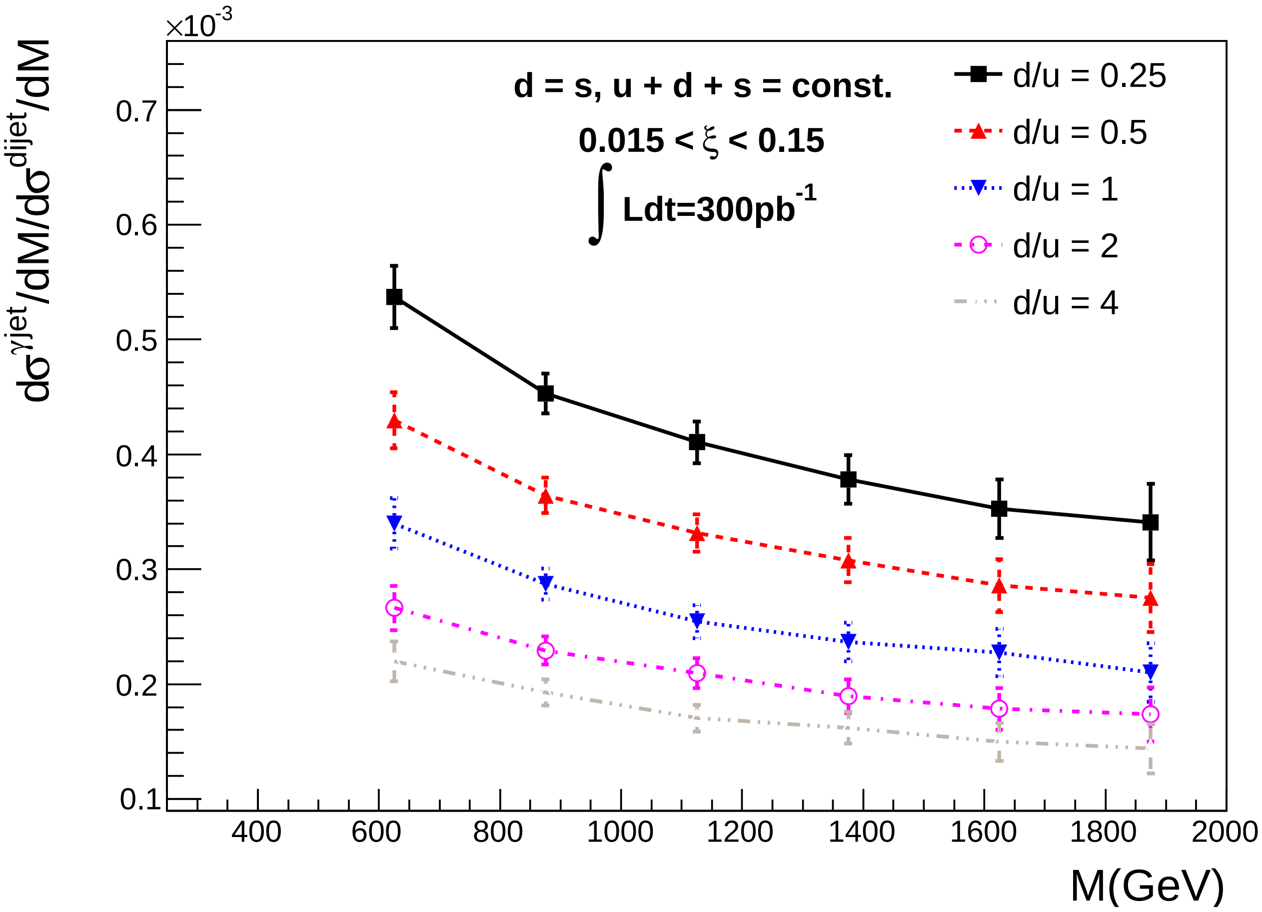
Inclusive diffraction at the LHC: sensitivity to gluon density

- Predict DPE dijet cross section at the LHC in AFP acceptance, jets with p_T >20 GeV, reconstructed at particle level using anti-k$_T$ algorithm
- Sensitivity to gluon density in Pomeron especially the gluon density on Pomeron at high β: multiply the gluon density by $(1-\beta)^\nu$ with $\nu = -1, ..., 1$
- Measurement possible with 10 pb^{-1}, allows to test if gluon density is similar between HERA and LHC (universality of Pomeron model)
- Dijet mass fraction: dijet mass divided by total diffractive mass ($\sqrt{\xi_1 \xi_2 S}$)



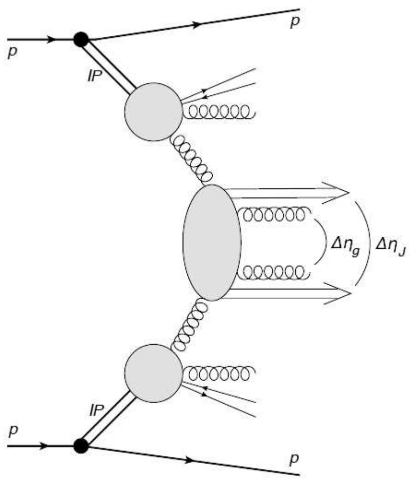
Inclusive diffraction at the LHC: sensitivity to quark densities

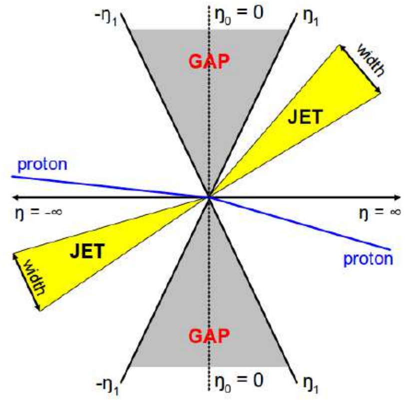
- Predict DPE γ+jet divided by dijet cross section at the LHC
- Sensitivity to universality of Pomeron model
- Sensitivity to quark density in Pomeron, and of assumption: $u = d = s = \bar{u} = \bar{d} = \bar{s}$ used in QCD fits at HERA
- Measurement of W asymmetry also sensitive to quark densities
- Perform the diffractive/ultra-peripheral studies at the EIC

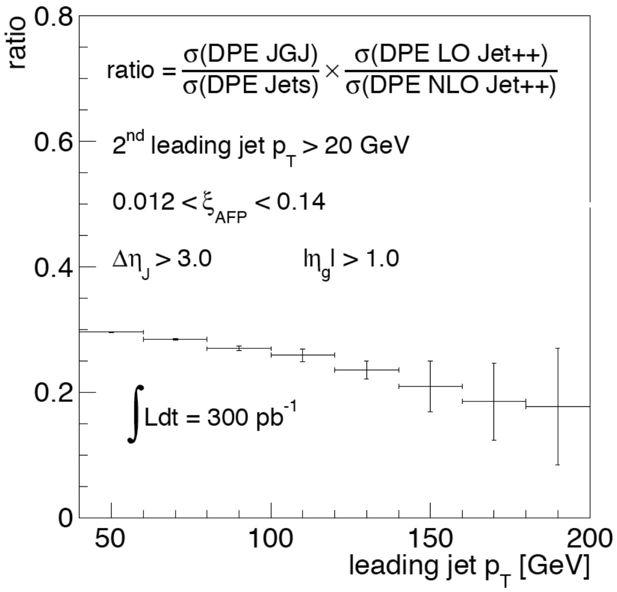


Jet gap jet events in diffraction

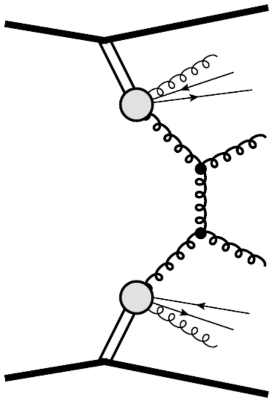
- Jet gap jet events in DPE processes: clean process, allows to go to larger $\Delta\eta$ between jets
- See: Gaps between jets in double-Pomeron-exchange processes at the LHC, C. Marquet, C. Royon, M. Trzebinski, R. Zlebcik, Phys. Rev. D 87 (2013) 034010
- Can be studied at EIC: gaps between jets

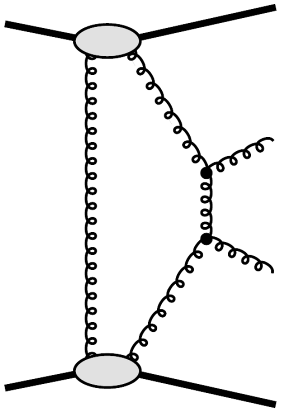


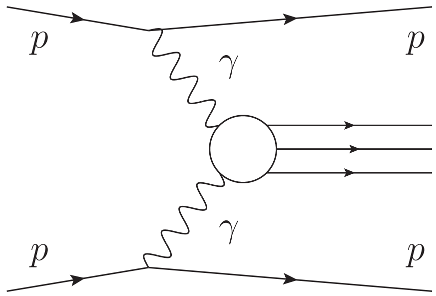


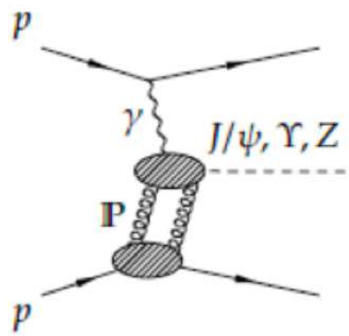


Exclusive diffraction at the LHC (and the EIC)



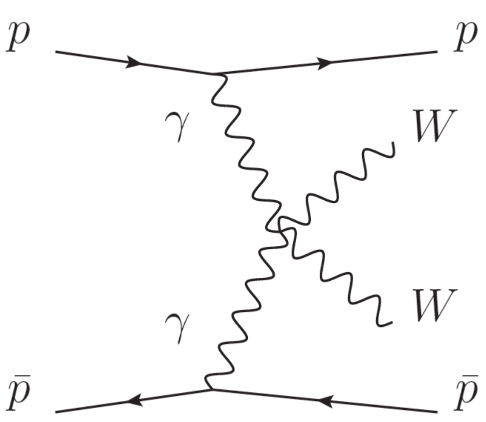


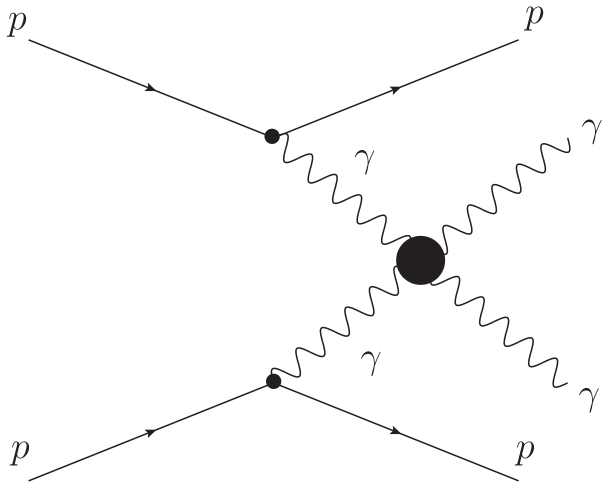




- Many exclusive channels can be studied at medium and high luminosity: jets, χ_C, charmonium, J/Ψ....
- Possibility to reconstruct the properties of the object produced exclusively (via photon and gluon exchanges) from the tagged proton: system completely constrained
- Central exclusive production is a potential channel for BSM physics: sensitivity to high masses up to 1.8 TeV (masses above 400 GeV, depending how close one can go to the beam)
- Very interesting channel at high mass sensitive to $\gamma\gamma\gamma\gamma$ anomalous couplings (via loops or resonane) (see S. Fichet, G. von Gersdorff, C. Royon, Phys. Rev.. D93 (2016) no.7, 075031; Phys. Rev. Lett. 116 (2016) no.23, 231801
- Exclusive production can be studied both in ep and eA at the EIC

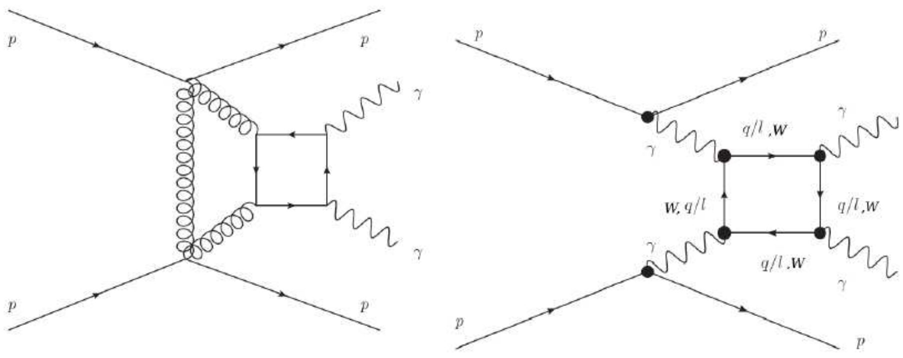
Search for $\gamma\gamma WW$, $\gamma\gamma\gamma\gamma$ quartic anomalous coupling at the LHC

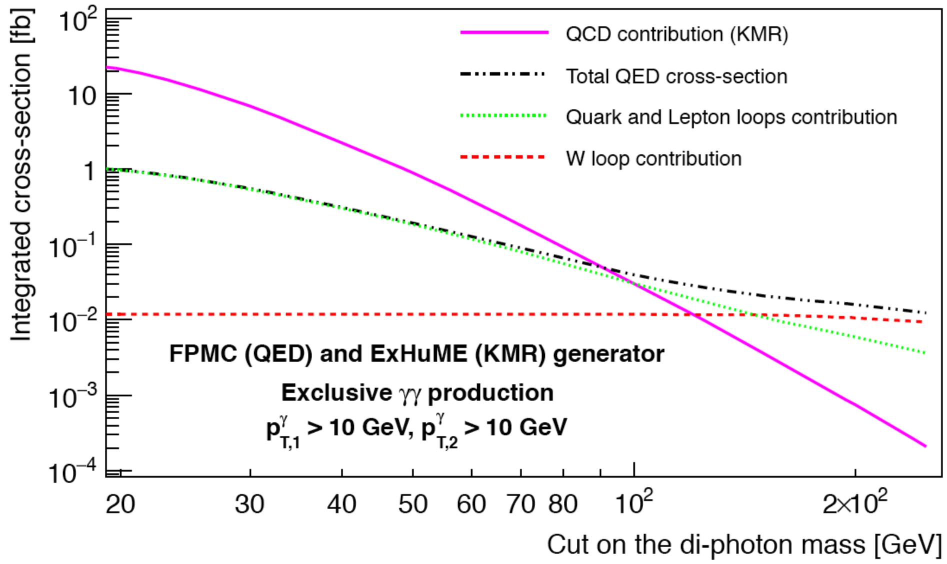




- Study of the process: $pp \to ppWW$, $pp \to ppZZ$, $pp \to pp\gamma\gamma$
- Standard Model: $\sigma_{WW} = 95.6$ fb, $\sigma_{WW}(W = M_X > 1TeV) = 5.9$ fb
- Process sensitive to anomalous couplings: $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$; motivated by studying in detail the mechanism of electroweak symmetry breaking, predicted by extradim. models
- Rich $\gamma\gamma$ physics at LHC: see papers by C. Baldenegro, E. Chapon, S. Fichet, G. von Gersdorff, O. Kepka, B. Lenzi, C. Royon, M. Saimpert: Phys. Rev. D78 (2008) 073005; Phys. Rev. D81 (2010) 074003; Phys.Rev. D89 (2014) 114004 ; JHEP 1502 (2015) 165; Phys. Rev. Lett. 116 (2016) no 23, 231801; Phys. Rev. D93 (2016) no 7, 075031; JHEP 1706 (2017) 142

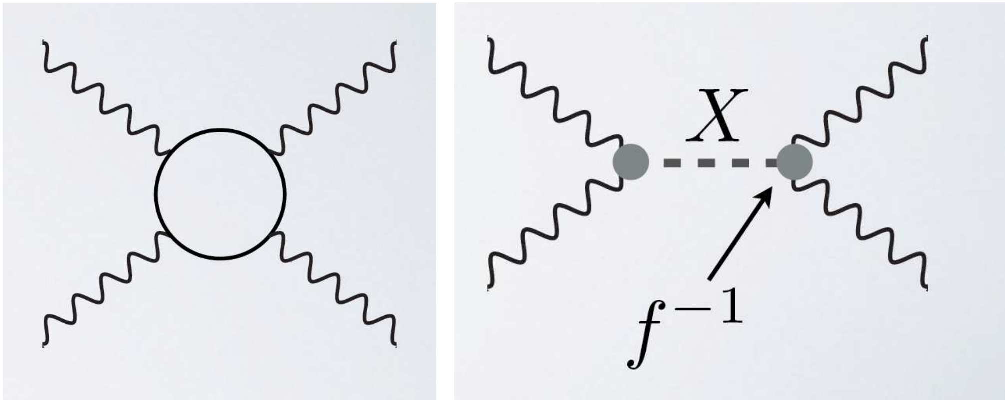
$\gamma\gamma$ exclusive production: SM contribution





- QCD production dominates at low $m_{\gamma\gamma}$, QED at high $m_{\gamma\gamma}$
- Important to consider W loops at high $m_{\gamma\gamma}$
- At high masses (> 200 GeV), the photon induced processes are dominant
- **Conclusion: Two photons and two tagged protons means photon-induced process**

Motivations to look for quartic $\gamma\gamma$ anomalous couplings



- Two effective operators at low energies

$$\mathcal{L}_{4\gamma} = \zeta_1^{\gamma} F_{\mu\nu} F^{\mu\nu} F_{\rho\sigma} F^{\rho\sigma} + \zeta_2^{\gamma} F_{\mu\nu} F^{\nu\rho} F_{\rho\lambda} F^{\lambda\mu}$$

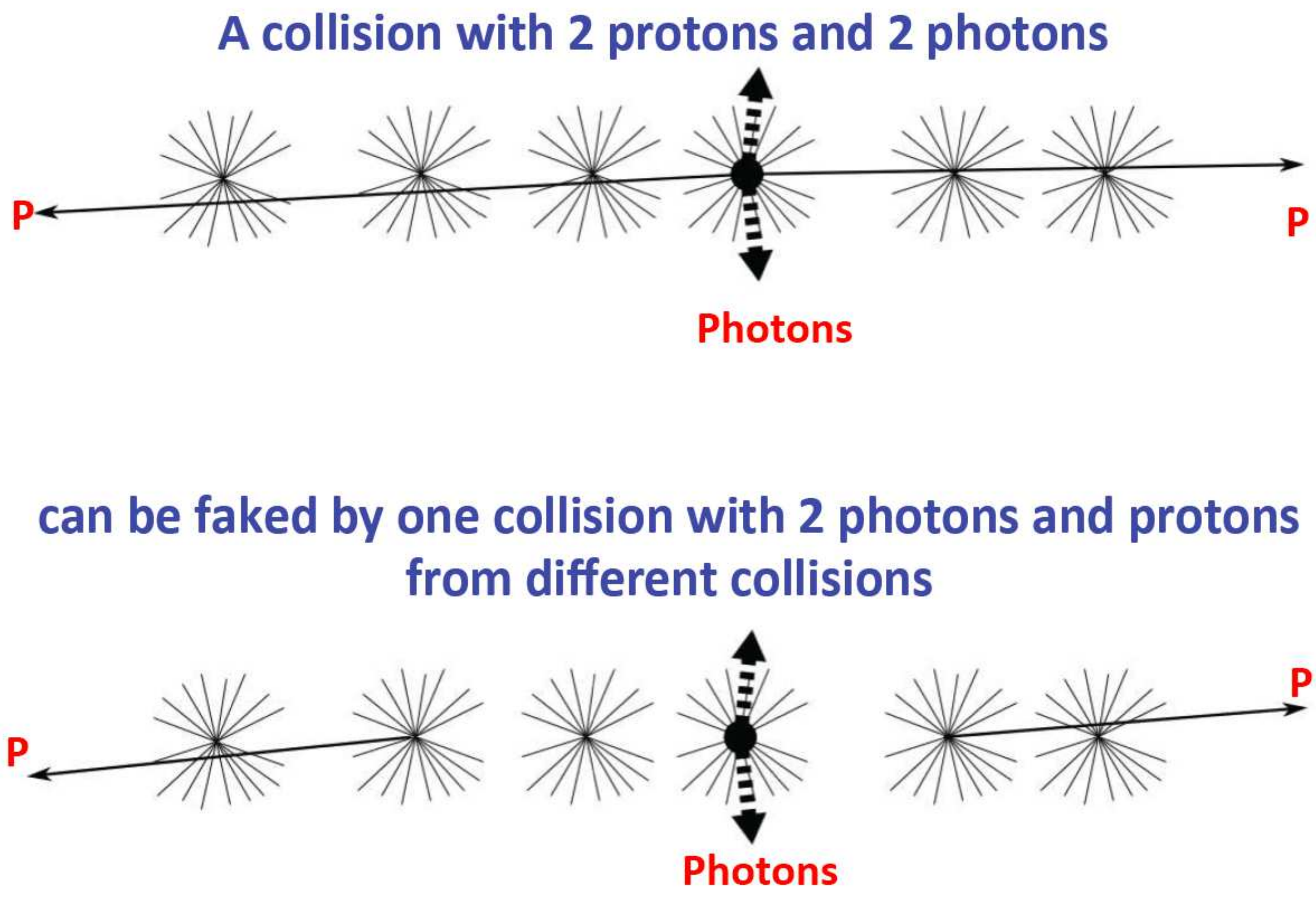
- $\gamma\gamma\gamma\gamma$ couplings can be modified in a model independent way by loops of heavy charge particles

$$\zeta_1 = \alpha_{em}^2 Q^4 m^{-4} N c_{1,s}$$

  where the coupling depends only on $Q^4 m^{-4}$ (charge and mass of the charged particle) and on spin, $c_{1,s}$ depends on the spin of the particle
  This leads to ζ_1 of the order of 10^{-14}-10^{-13}

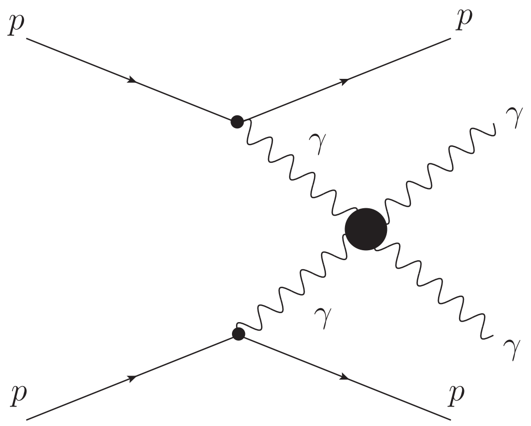
- ζ_1 can also be modified by neutral particles at tree level (extensions of the SM including scalar, pseudo-scalar, and spin-2 resonances that couple to the photon) $\zeta_1 = (f_s m)^{-2} d_{1,s}$ where f_s is the $\gamma\gamma X$ coupling of the new particle to the photon, and $d_{1,s}$ depends on the spin of the particle; for instance, 2 TeV dilatons lead to $\zeta_1 \sim 10^{-13}$

One aside: what is pile up at LHC?

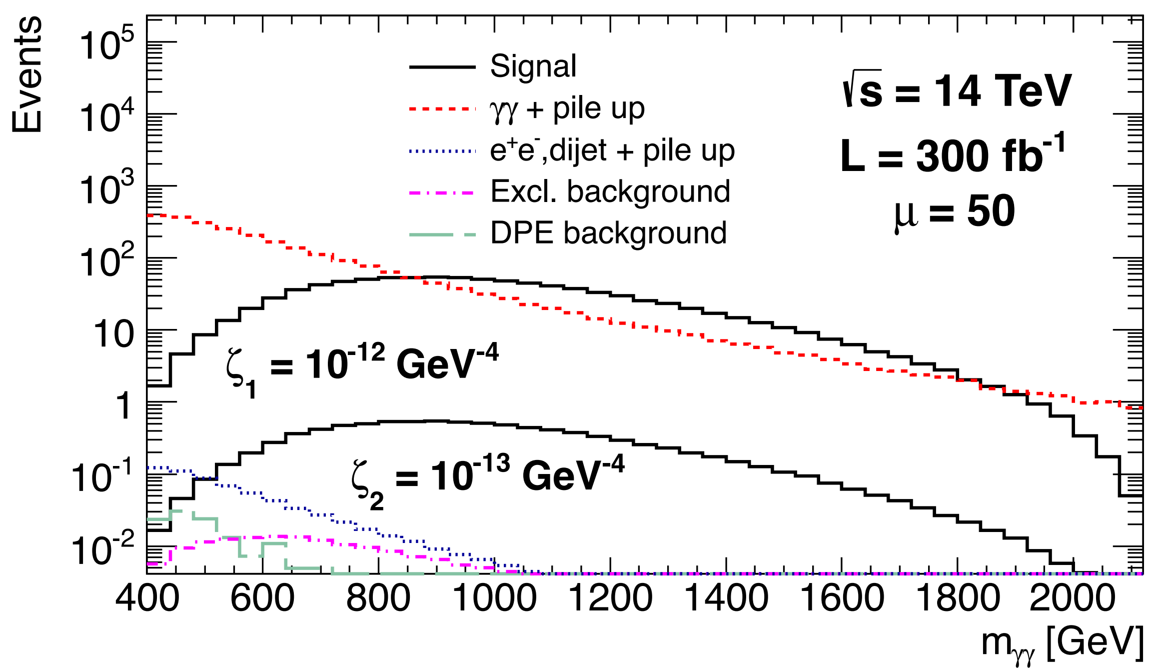


- The LHC machine collides packets of protons
- Due to high number of protons in one packet, there can be more than one interaction between two protons when the two packets collide
- Typically up to 50 pile up events

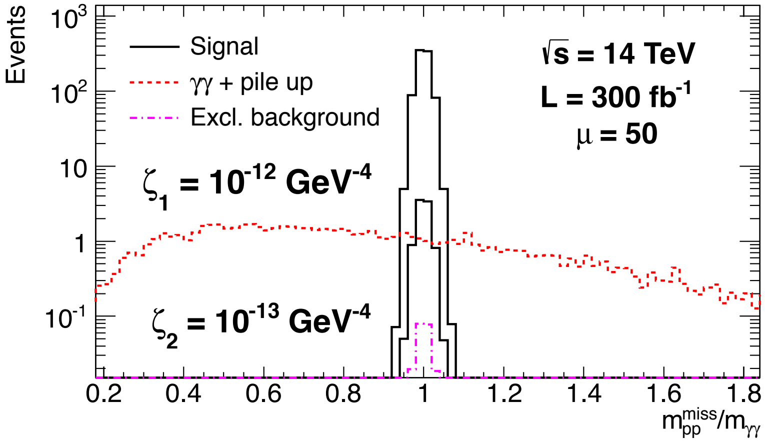
Search for quartic $\gamma\gamma$ anomalous couplings

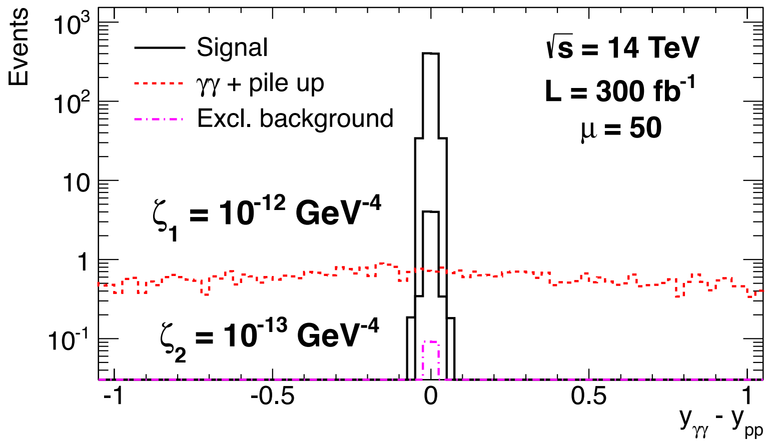


- Search for $\gamma\gamma\gamma\gamma$ quartic anomalous couplings
- Couplings predicted by extra-dim, composite Higgs models
- Analysis performed at hadron level including detector efficiencies, resolution effects, pile-up...



Search for quartic $\gamma\gamma$ anomalous couplings

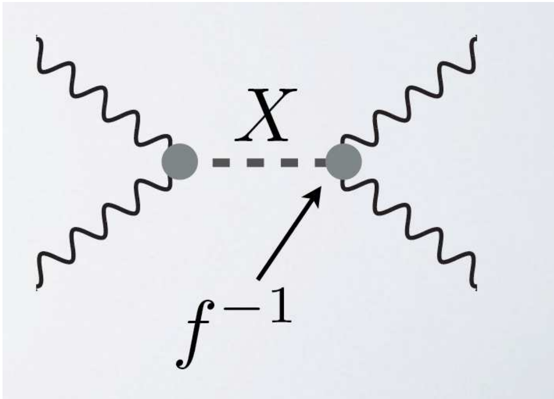


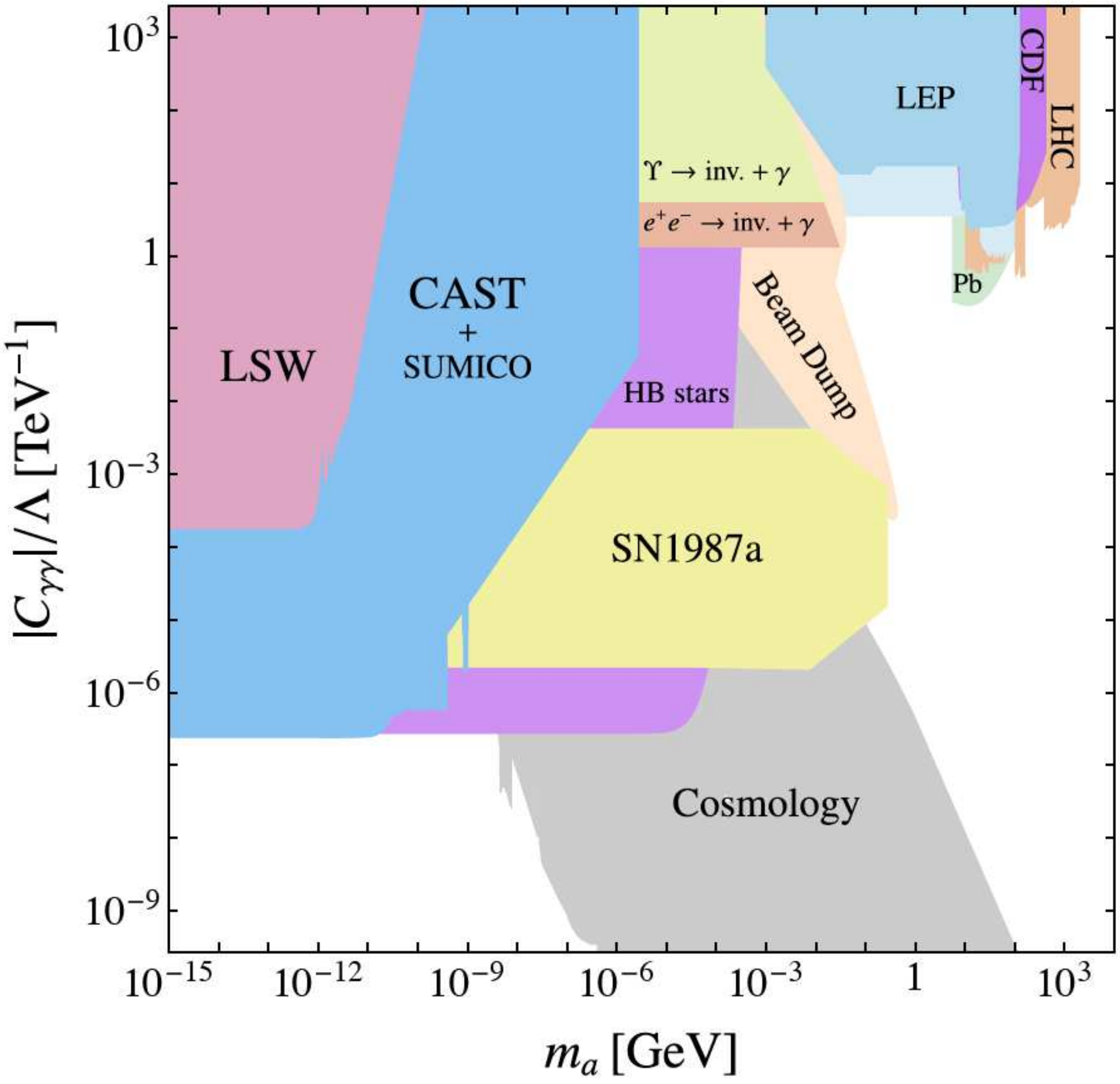


Cut / Process	Signal (full)	Signal with (without) f.f (EFT)	Excl.	DPE	DY, di-jet + pile up	$\gamma\gamma$ + pile up
$[0.015 < \xi_{1,2} < 0.15$, $p_{T1,(2)} > 200, (100)$ GeV]	130.8	36.9 (373.9)	0.25	0.2	1.6	2968
$m_{\gamma\gamma} > 600$ GeV	128.3	34.9 (371.6)	0.20	0	0.2	1023
$[p_{T2}/p_{T1} > 0.95$, $\lvert\Delta\phi\rvert > \pi - 0.01]$	128.3	34.9 (371.4)	0.19	0	0	80.2
$\sqrt{\xi_1 \xi_2 s} = m_{\gamma\gamma} \pm 3\%$	122.0	32.9 (350.2)	0.18	0	0	2.8
$\lvert y_{\gamma\gamma} - y_{pp}\rvert < 0.03$	119.1	31.8 (338.5)	0.18	0	0	0

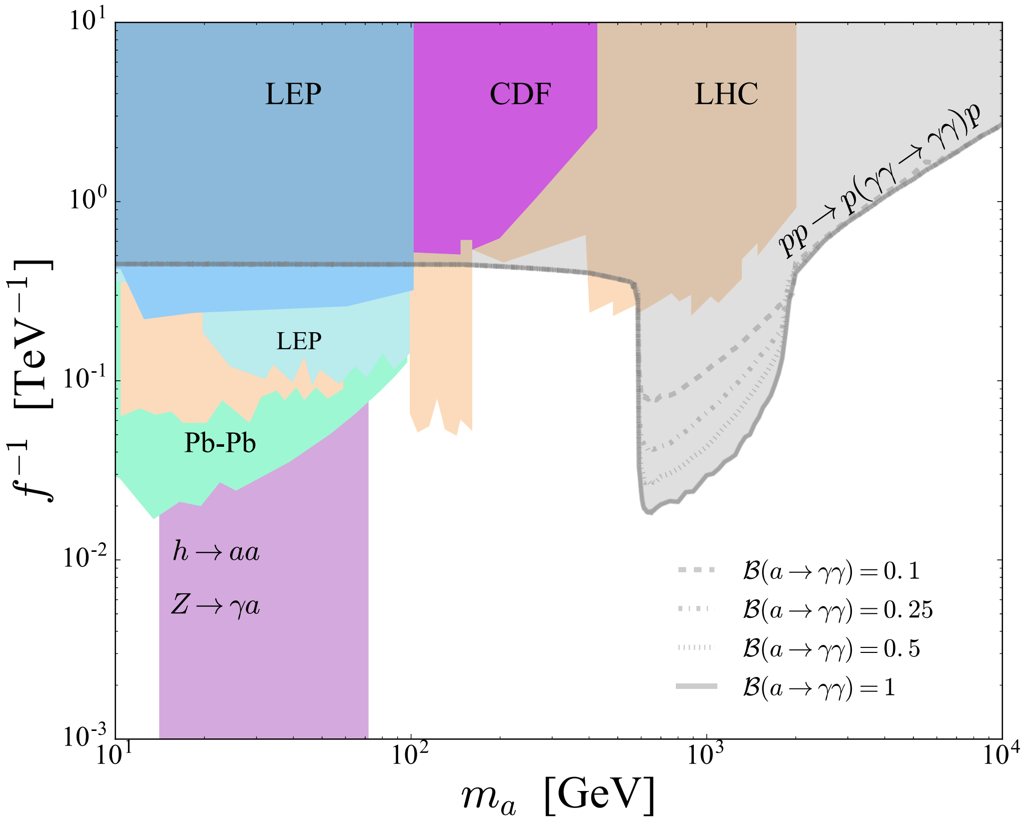
- No background after cuts for 300 fb^{-1}: sensitivity up to a few 10^{-15}, better by 2 orders of magnitude with respect to "standard" methods
- Exclusivity cuts using proton tagging needed to suppress backgrounds
- For $Z\gamma$ production: gain of 3 orders of magnitude compared to usual LHC searches (looking for Z decaying leptonically and hadronically)

Generalization - Looking for axion lile particles



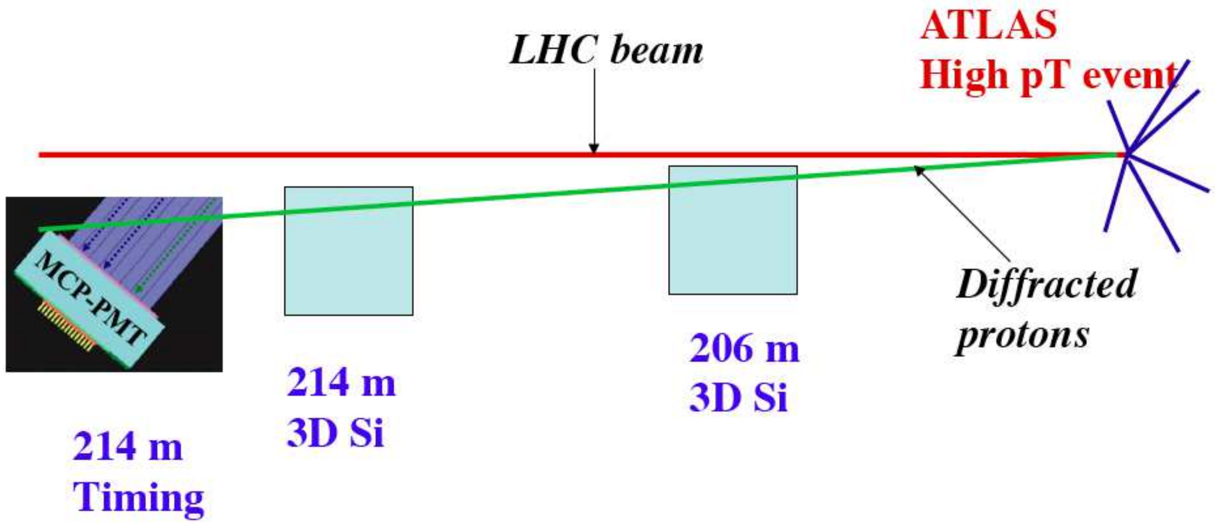


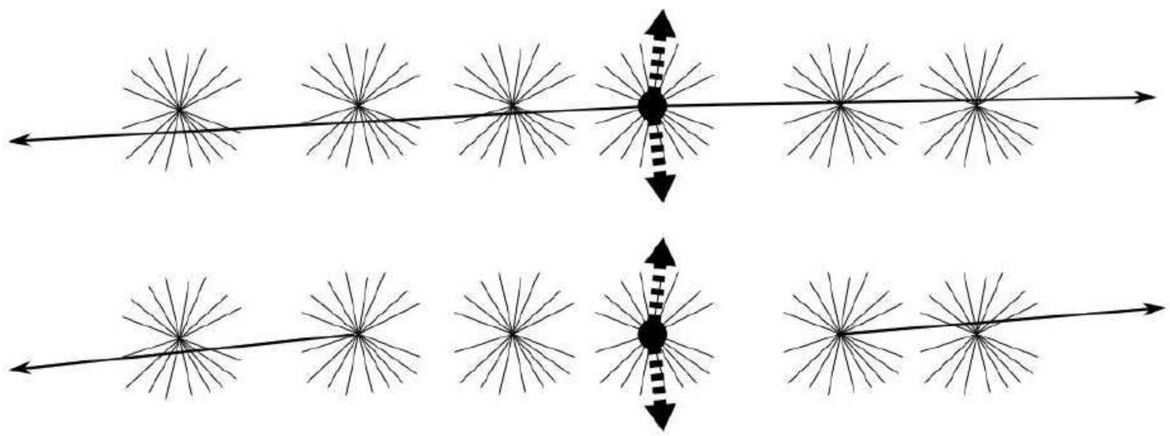
Search for axion like particles



- Production of axions via photon exchanges and tagging the intact protons in the final state complementary to the usual search at the LHC (Z decays into 3 photons): sensitivity at high axion mass (spin 0 even resonance, width 45 GeV)- C. Baldenegro, S. Fichet, G. von Gersdorff, C. Royon, ArXiv 1803.10835
- Complementarity with Pb Pb running: sensitivity to low mass diphoton, low luminosity but cross section increased by Z^4

Removing pile up: measuring proton time-of-flight





- Measure the proton time-of-flight in order to determine if they originate from the same interaction as our photon
- Typical precision: 10 ps means 2.1 mm

Conclusion

- Inclusive structure function measurement: well described by perturbative QCD, too inclusive to look for saturation/BFKL resummation effects
- EIC: ideal to understand better the ion structure
- Use dedicated observables for BFKL/saturation effects: very forward jets (HERA/EIC) and dijets (CASTOR in CMS for instance), Mueller Navelet jets (LHC), Jet gap jets (EIC/LHC)
- Full implementation of BFKL NLL kernel including impact factors (in progress) for many jet proceeses at HERA, Tevatron, LHC and then EIC: to be implemented in MC
- Diffractive studies: Pomeron structure in terms of quarks and gluons (LHC/EIC)
- Photon exchange processes: Exploratory physics at the LHC