Forward physics at the LHC: QCD, anomalous couplings and Higgs boson

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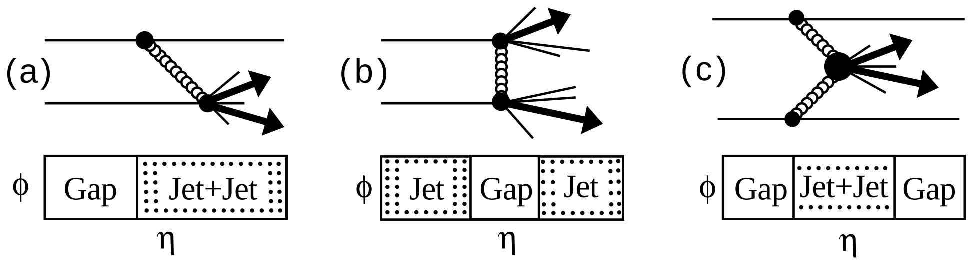
Contents:

- Hard diffraction at the LHC
- Exclusive diffraction at the LHC (Higgs, jets...)
- Anomalous $W\gamma$ couplings at the LHC

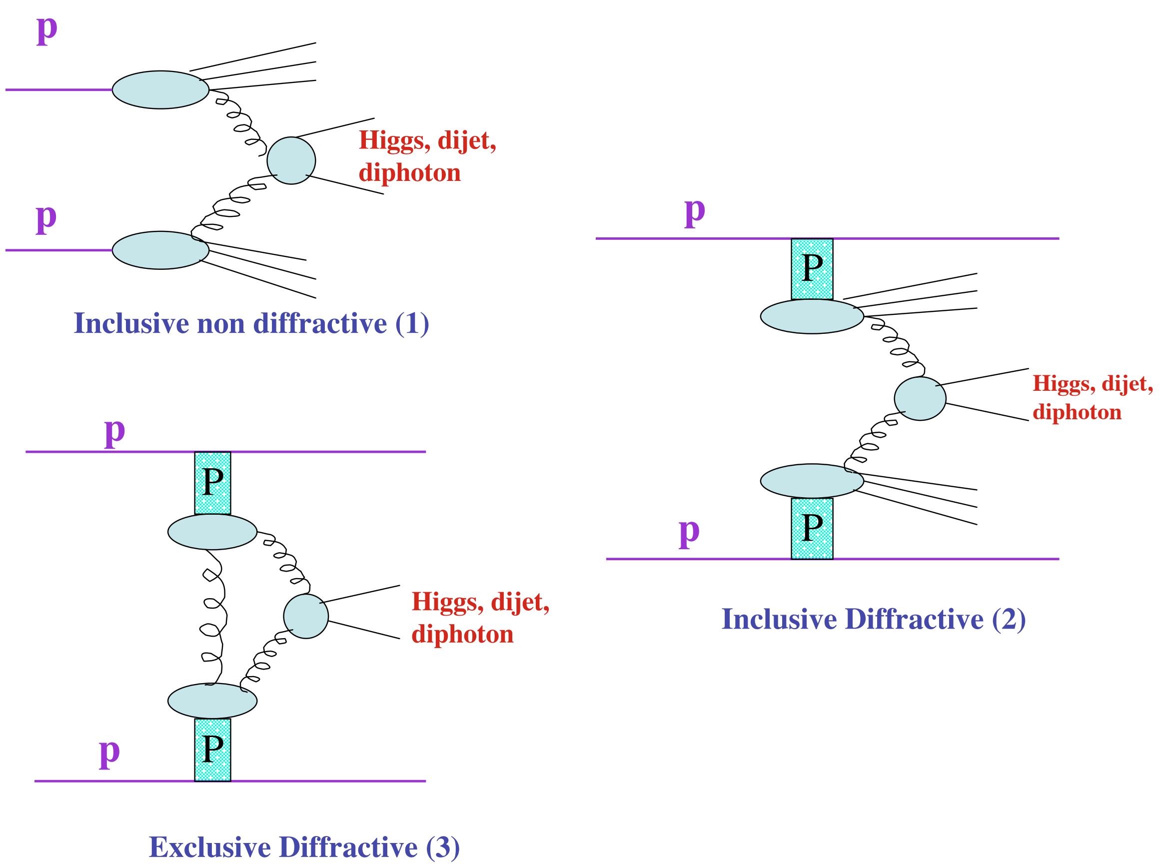
Diffraction at Tevatron/LHC



Kinematic variables

- t: 4-momentum transfer squared
- ξ_1, ξ_2: proton fractional momentum loss (momentum fraction of the proton carried by the pomeron)
- $\beta_{1,2} = x_{Bj,1,2}/\xi_{1,2}$: Bjorken-x of parton inside the pomeron
- $M^2 = s\xi_1\xi_2$: diffractive mass produced
- $\Delta y_{1,2} \sim \Delta\eta \sim \log 1/\xi_{1,2}$: rapidity gap

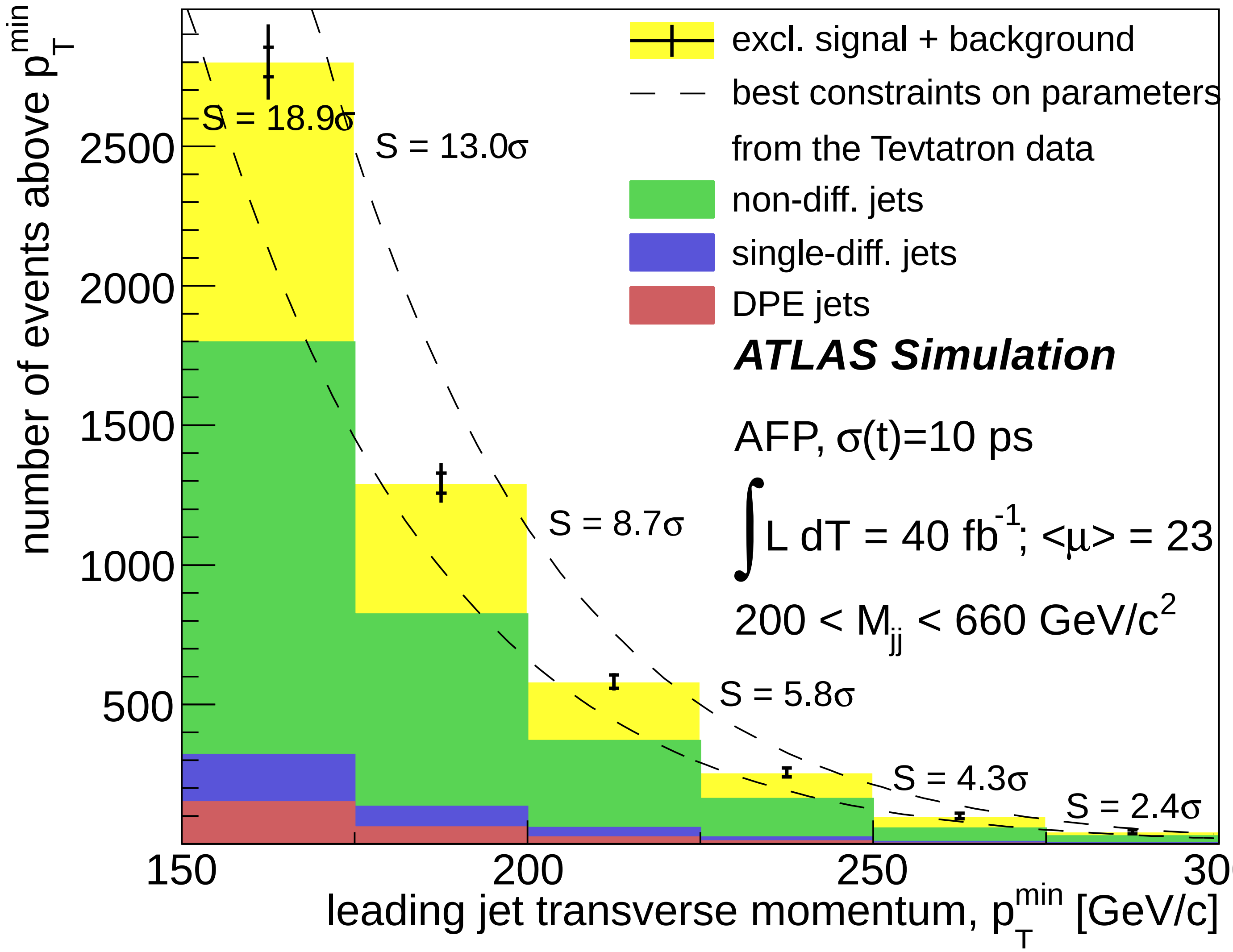
“Exclusive models” in diffraction



- All the energy is used to produce the Higgs (or the dijets), namely $xG \sim \delta$
- Possibility to reconstruct the properties of the object produced exclusively from the tagged proton: system completely constrained
- Possibility of studying any resonant production provided the cross section is high enough
- See papers by Khoze Martin Ryskin - Szczurek at al. - Cudell et al.,...

Exclusive jet production at the LHC

- Jet cross section measurements: up to 18.9 σ for exclusive signal with 40 fb^{-1} ($\mu = 23$): highly significant measurement in high pile up environment, improvement over measurement coming from Tevatron (CDF) studies using $\bar{p}$ forward tagging by about one order of magnitude



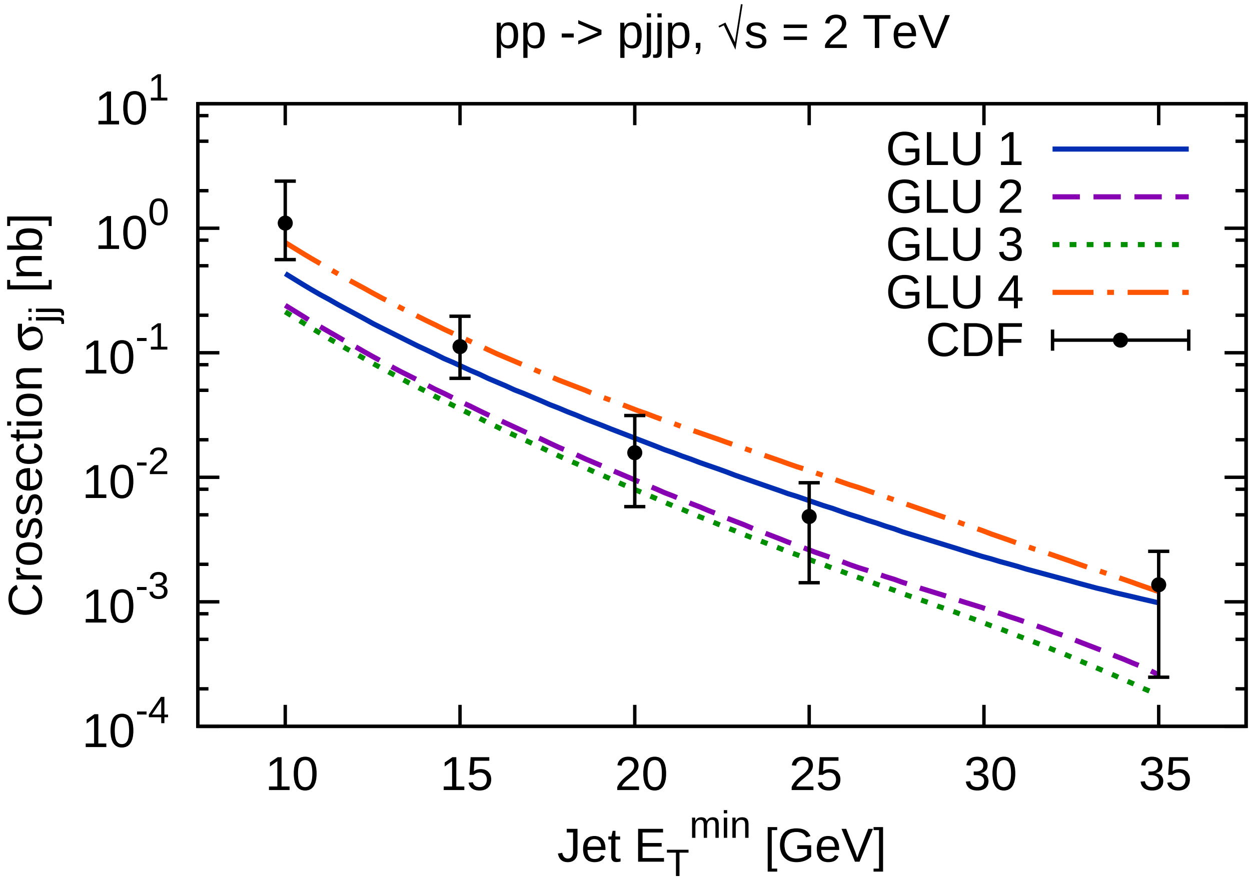
- Important to perform these measurements to constrain exclusive Higgs production: background/signal ratio close to 1 for central values at 120 GeV

Forward Physics Monte Carlo (FPMC)

- FPMC (Forward Physics Monte Carlo): implementation of all diffractive/photon induced processes
- List of processes
  - two-photon exchange
  - single diffraction
  - double pomeron exchange
  - central exclusive production
- Inclusive diffraction: Use of diffractive PDFs measured at HERA, with a survival probability of 0.03 applied for LHC
- Survival probability for photon exchange events: 0.9
- Central exclusive production: Higgs, jets... for Khoze Martin Ryskin and Dechambre Cudell models
- FPMC manual (see M. Boonekamp, A. Dechambre, O. Kepka, V. Juranek, C. Royon, R. Staszewski, M. Rangel, ArXiv:1102.2531)
- Output of FPMC generator interfaced with the fast simulation of the ATLAS detector in the standalone ATLFast++ package

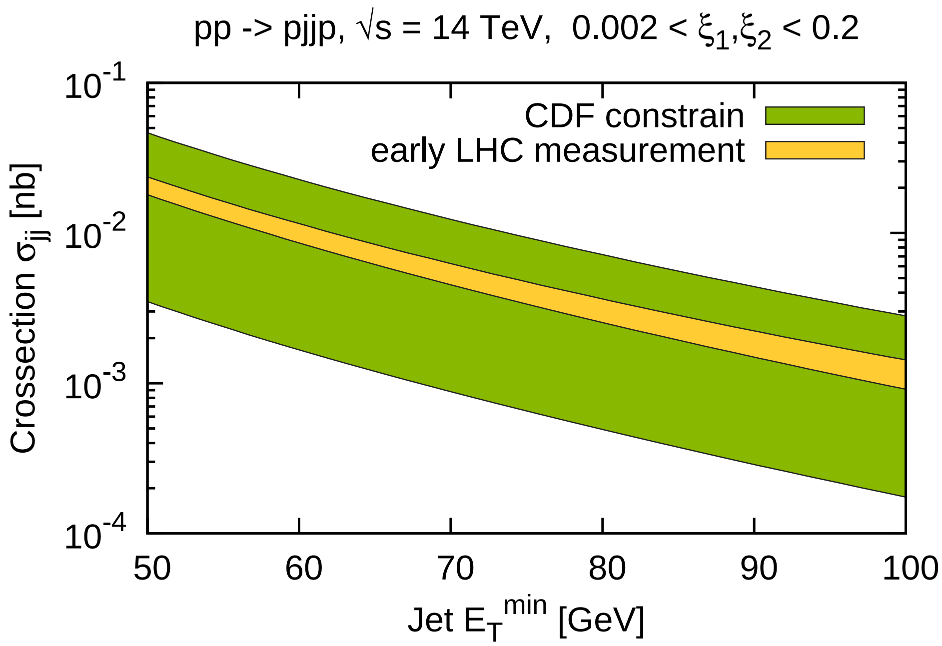
Exclusive model uncertainties - unintegrated gluon

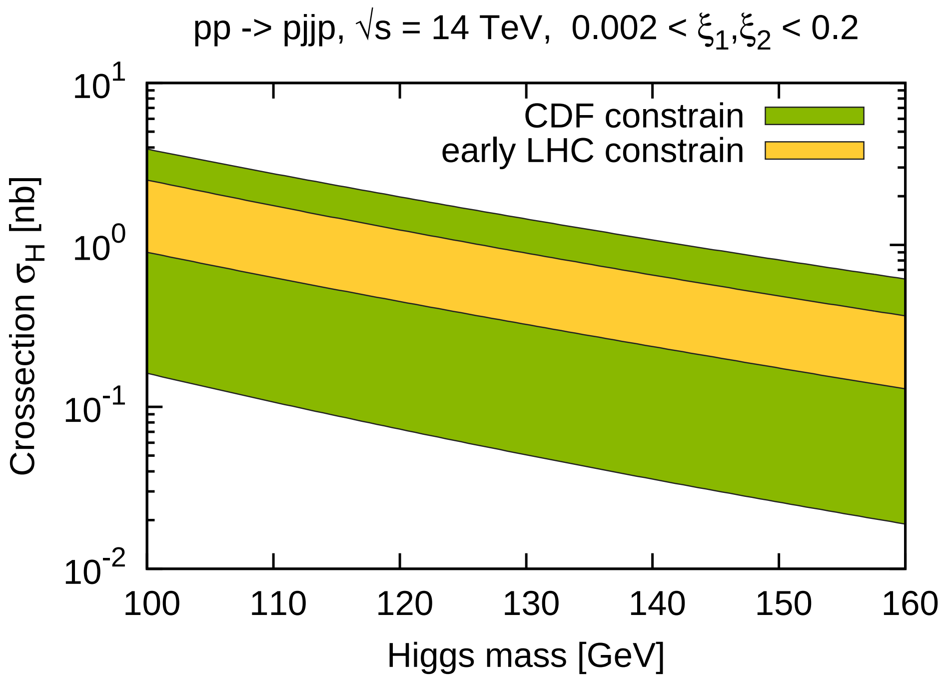
- Study model uncertainties by varying the parameters in CHIDe model
- Survival probability: 0.1 at Tevatron, 0.03 assumed at LHC (multiplication factor to exclusive cross sections, to be measured using diffractive LHC data)
- Uncertainty on unintegrated gluon densities: 4 different gluon densities with same known hard contribution (GRV98) and different assumptions on soft contribution (represent the present uncertainty on soft part)



Impact of future LHC measurements on model uncertainty

- Study model uncertainties on exclusive Higgs production: unintegrated gluon distribution, Sudakov integration lower/upper limits
- Assume new measurement of exclusive jet production at the LHC: 100 pb^{-1}, precision on jet energy scale assumed to be $\sim$3% (conservative for JES, but takes into account other possible systematics)
- Possible constraints on Higgs production: about a factor 2 uncertainty
- Fundamental to perform this measurement as soon as forward detectors are available

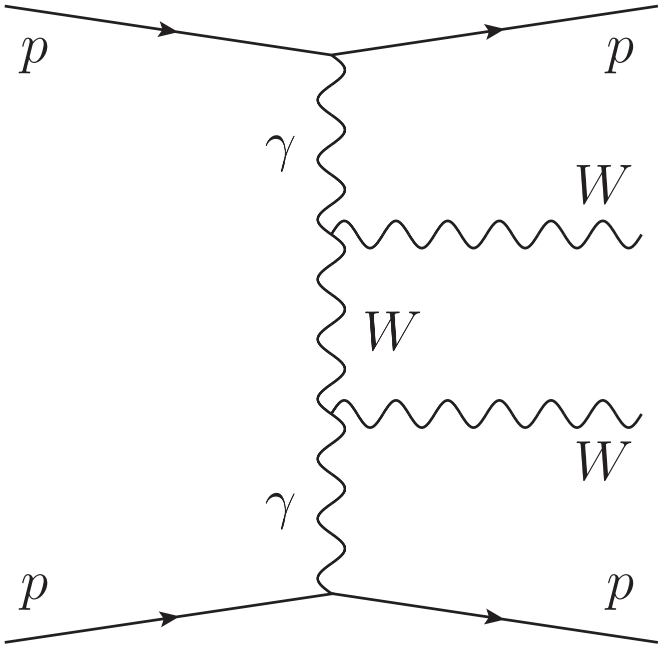




Diffractive Higgs production

- Survival probability: seems to be higher than 0.03 (see CMS measurement at this workshop)
- Thanks to Khoze Martin Ryskin, higher order corrections are now being computed: increase of cross section by a factor 3?
- Needs to recompute S/B with these updates after a full simulation of the ATLAS/CMS detectors
- Needs an extensive study on triggering on those events
- If successful, good motivation to add 420 m proton detectors by 2017-18?

Search for $\gamma\gamma WW$ quartic anomalous coupling



- Study of the process: $pp \rightarrow ppWW$
- 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
- Many additional anomalous couplings to be studied involving Higgs bosons (dimension 8 operators) if Higgs boson is discovered; $\gamma\gamma$ specially interesting (Christophe Grojean)
- Rich $\gamma\gamma$ physics at LHC: see E. Chapon, O. Kepka, C. Royon, Phys. Rev. D78 (2008) 073005; Phys. Rev. D81 (2010) 074003

Quartic anomalous gauge couplings

- Quartic gauge anomalous $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings parametrised by a_0^W, a_0^Z, a_C^W, a_C^Z

$$\mathcal{L}_6^0 \sim \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16\cos^2(\theta_W)}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

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

- Anomalous parameters equal to 0 for SM
- Best limits from LEP, OPAL (Phys. Rev. D 70 (2004) 032005) of the order of 0.02-0.04, for instance $-0.02 < a_0^W < 0.02$ GeV^{-2}
- Dimension 6 operators $\rightarrow$ violation of unitarity at high energies

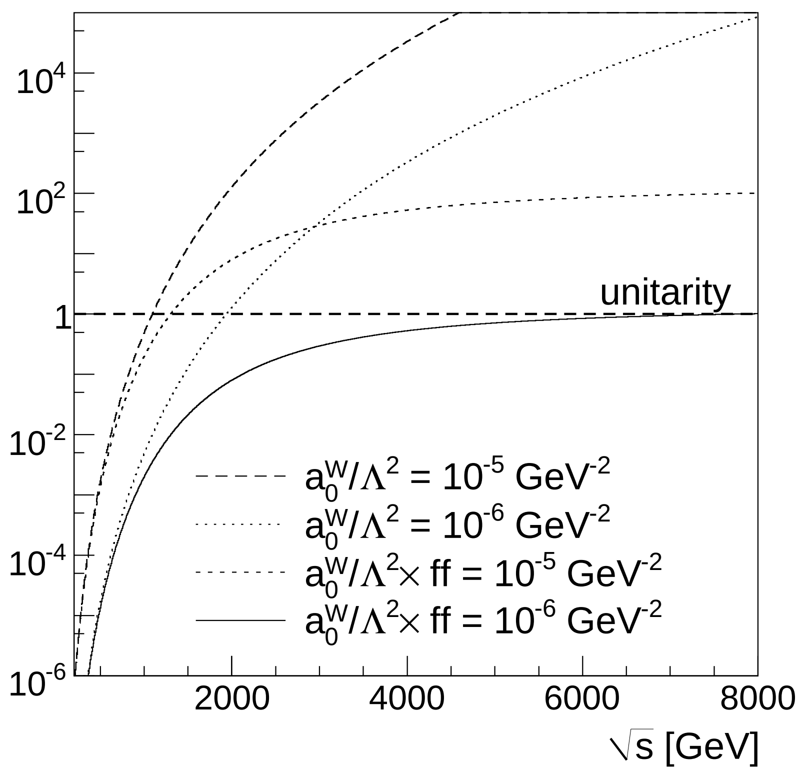
Quartic anomalous gauge couplings: form factors

- Unitarity bounds can be computed (Eboli, Gonzales-Garcia, Lietti, Novaes):

$$4\left(\frac{\alpha a s}{16}\right)^2\left(1-\frac{4M_W^2}{s}\right)^{1/2}\left(3-\frac{s}{M_W^2}+\frac{s^2}{4M_W^4}\right)\leq 1$$

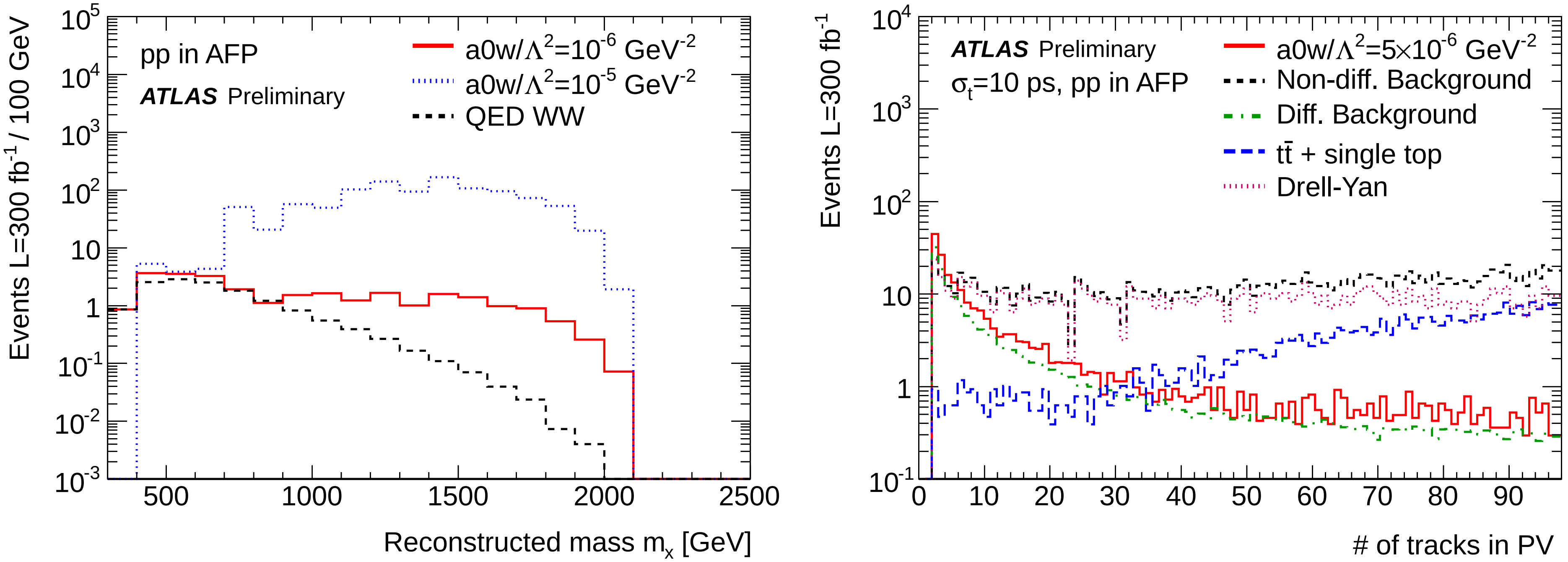
where $a = a_0/\Lambda^2$

- Introducing form factors to avoid quadratical divergences of scattering amplitudes due to anomalous couplings in conventional way: $a_0^W/\Lambda^2 \rightarrow \frac{a_0^W/\Lambda^2}{(1+W\gamma\gamma/\Lambda_{cutoff})^2}$ with $\Lambda_{cutoff} \sim 2$ TeV, scale of new physics
- For $a_0^W \sim 10^{-6}$ GeV^{-2}, no violation of unitarity



Anomalous couplings studies in WW events

- Reach on anomalous couplings studied using a full simulation of the ATLAS detector, including all pile up effects; only leptonic decays of Ws are considered
- Signal appears at high lepton p_T and dilepton mass (central ATLAS) and high diffractive mass (reconstructed using forward detectors)
- Cut on the number of tracks fitted to the primary vertex: very efficient to remove remaining pile up after requesting a high mass object to be produced (for signal, we have two leptons coming from the W decays and nothing else)



Results from full simulation

- Reaches the values expected for extradim models (C. Grojean, J. Wells)

Cuts	Top	Dibosons	Drell-Yan	W/Z+jet	Diffr.	$a_0^W/\Lambda^2 = 5 \cdot 10^{-6}$ GeV^{-2}
timing < 10 ps $p_T^{lep1} > 150$ GeV $p_T^{lep2} > 20$ GeV	5198	601	20093	1820	190	282
M(ll)>300 GeV	1650	176	2512	7.7	176	248
nTracks ≤ 3	2.8	2.1	78	0	51	71
$\Delta\phi < 3.1$	2.5	1.7	29	0	2.5	56
$m_X > 800$ GeV	0.6	0.4	7.3	0	1.1	50
$p_T^{lep1} > 300$ GeV	0	0.2	0	0	0.2	35

Table 9.5. Number of expected signal and background events for 300 fb^{-1} at pile-up $\mu = 46$. A time resolution of 10 ps has been assumed for background rejection. The diffractive background comprises production of QED diboson, QED dilepton, diffractive WW, double pomeron exchange WW.

- **Improvement of "standard" LHC methods by studying $pp \to l^{\pm}\nu\gamma\gamma$ (see P. J. Bell, ArXiV:0907.5299) by more than 2 orders of magnitude with 40/300 fb^{-1} at LHC**

	5σ	95% CL	LEP limit
$\mathcal{L} = 40\ fb^{-1}, \mu = 23$ $\mathcal{L} = 300\ fb^{-1}, \mu = 46$	5.5 10^{-6} 3.2 10^{-6}	2.4 10^{-6} 1.3 10^{-6}	0.02

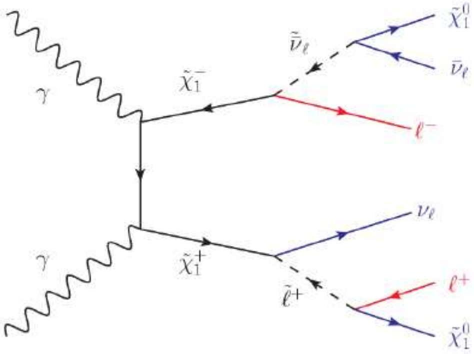
Reach at LHC

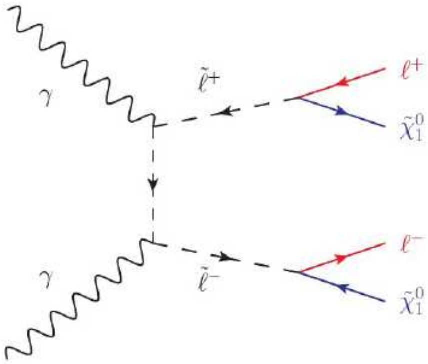
Reach at high luminosity on quartic anomalous coupling

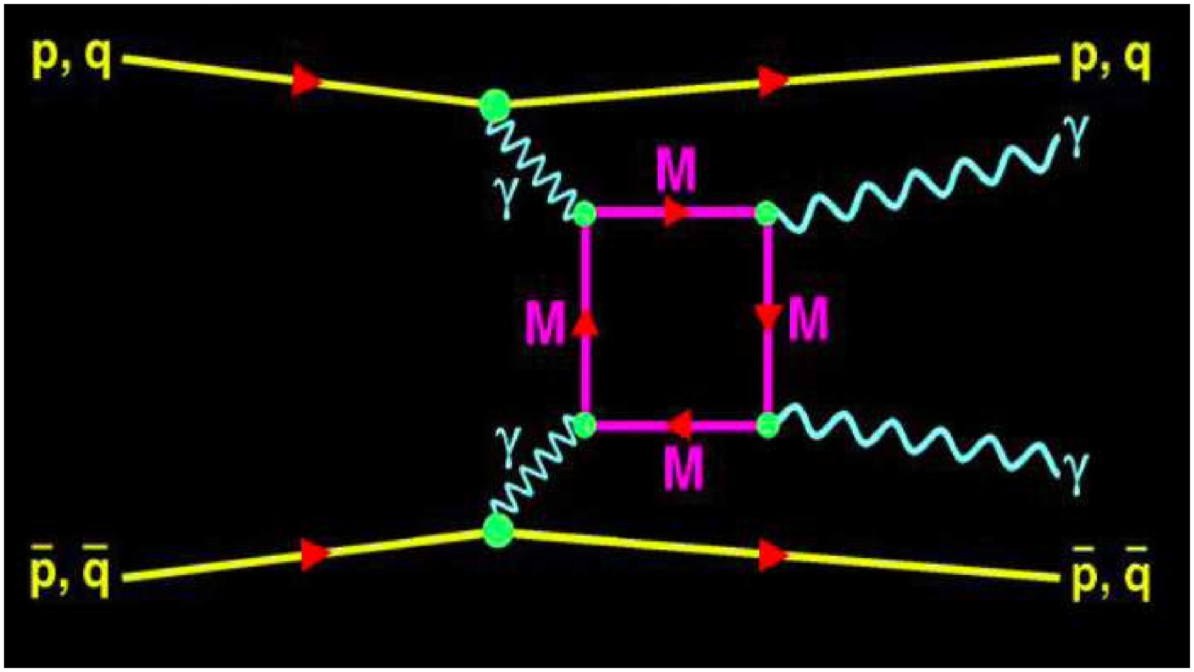
Couplings	OPAL limits [GeV^{-2}]	Sensitivity @ $\mathcal{L} = 30$ (200) fb^{-1} 5σ	95% CL
a_0^W/Λ^2	[-0.020, 0.020]	5.4 10^{-6} (2.7 10^{-6})	2.6 10^{-6} (1.4 10^{-6})
a_C^W/Λ^2	[-0.052, 0.037]	2.0 10^{-5} (9.6 10^{-6})	9.4 10^{-6} (5.2 10^{-6})
a_0^Z/Λ^2	[-0.007, 0.023]	1.4 10^{-5} (5.5 10^{-6})	6.4 10^{-6} (2.5 10^{-6})
a_C^Z/Λ^2	[-0.029, 0.029]	5.2 10^{-5} (2.0 10^{-5})	2.4 10^{-5} (9.2 10^{-6})

- Improvement of LEP sensitivity by more than 4 orders of magnitude with 30/200 fb^{-1} at LHC!!!
- Reaches the values predicted by extradimension models

Additional exclusive event production







- Production of new objects (with mass up to 1.3 TeV) to be produced either by photon or gluon exchanges: magnetic monopoles, KK resonances, SUSY,... (which could be missed in central ATLAS if predominant decays are hadronic)
- Production of SUSY particles: Possibility of measuring the mass of sleptons if cross section high enough

Conclusion

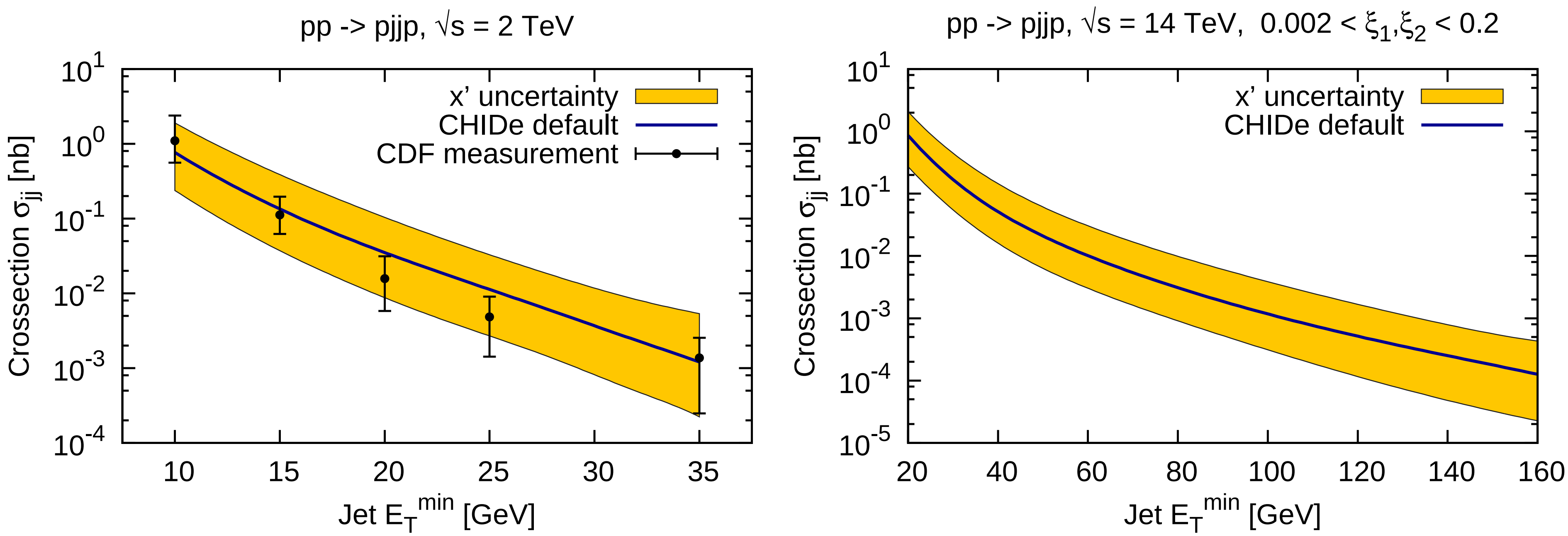
- Many topics in diffraction can be studied using AFP: Diffractive jet production, exclusive event production...
- Measurement of the exclusive jet cross section important to constrain further the exclusive event production mechanism, especially for Higgs production (possible upgrade of phase 1 AFP)
- Exclusive QED production of W, Z pairs: sensitive to extra-dimensions, AFP allows to obtain a sensitivity close to the ones predicted by these models
- Many other topics to be studied in AFP: any particle produced exclusively via gluon-gluon or photon-photon processes can be studied (magnetic monopole, SUSY resonant production, Kaluza Klein...)

Modifying the Sudakov lower limit

- Variation of a factor 2 (0.25-1) of the lower limit x' on the Sudakov factor

$$T(Q_T, \mu) = \exp\left[-\int_{Q_T^2/x'}^{\mu^2/x} \frac{\alpha_S(k_T^2)}{2\pi}\frac{dk_T^2}{k_T^2}\int_0^{1-\Delta} dz\,(zP_{gg}(z) + \Sigma_q P_{qg}(z))\right]$$

- Factor 10-20 difference for high p_T jet cross section at LHC, increases with jet p_T



Impact of CDF data on model uncertainty

- Not all variation of parameters allowed by CDF measurement
- Method to obtain the model uncertainties:
  - For each gluon distribution, obtain a range of lower Sudakov limits (x'_{min} and x'_{max}) which agree within 1 σ with the CDF measurement
  - Use the same (x'_{min} and x'_{max}) values to obtain the uncertainties on LHC dijets and Higgs production
  - The final error band is defined by the largest differences using the 4 gluon densities
- About a factor 10 uncertainty on Higgs production at the LHC