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

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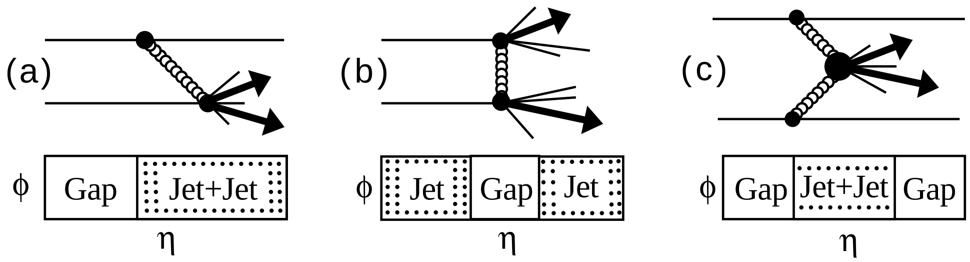
Contents:

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

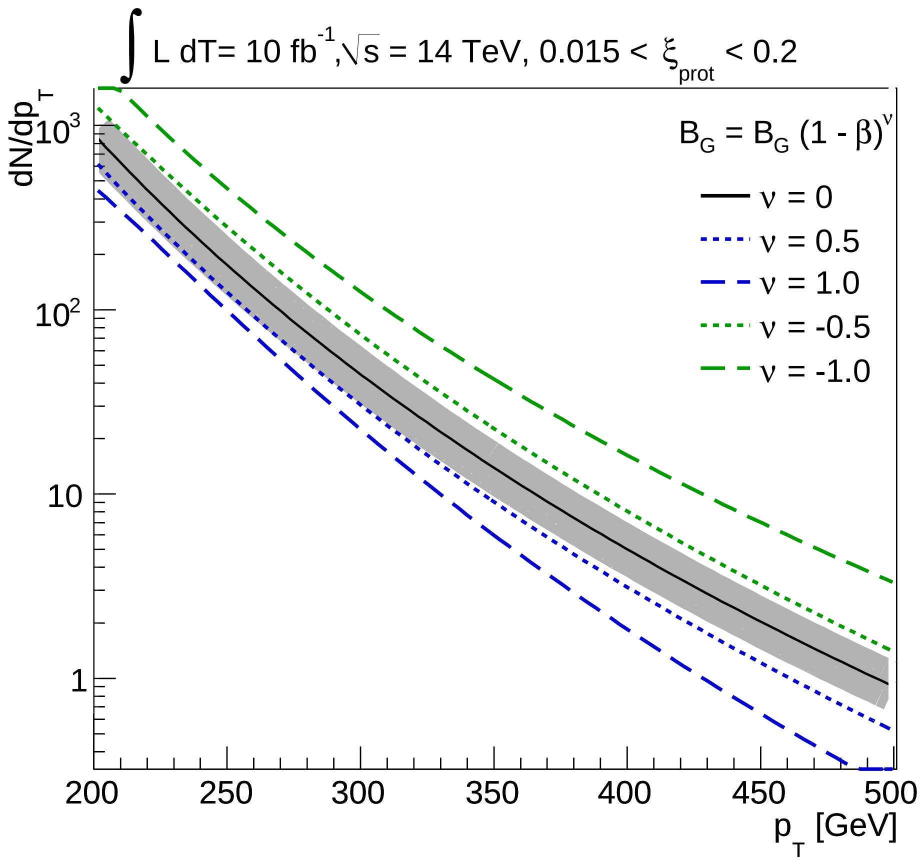
Diffraction at Tevatron/LHC



Kinematic variables

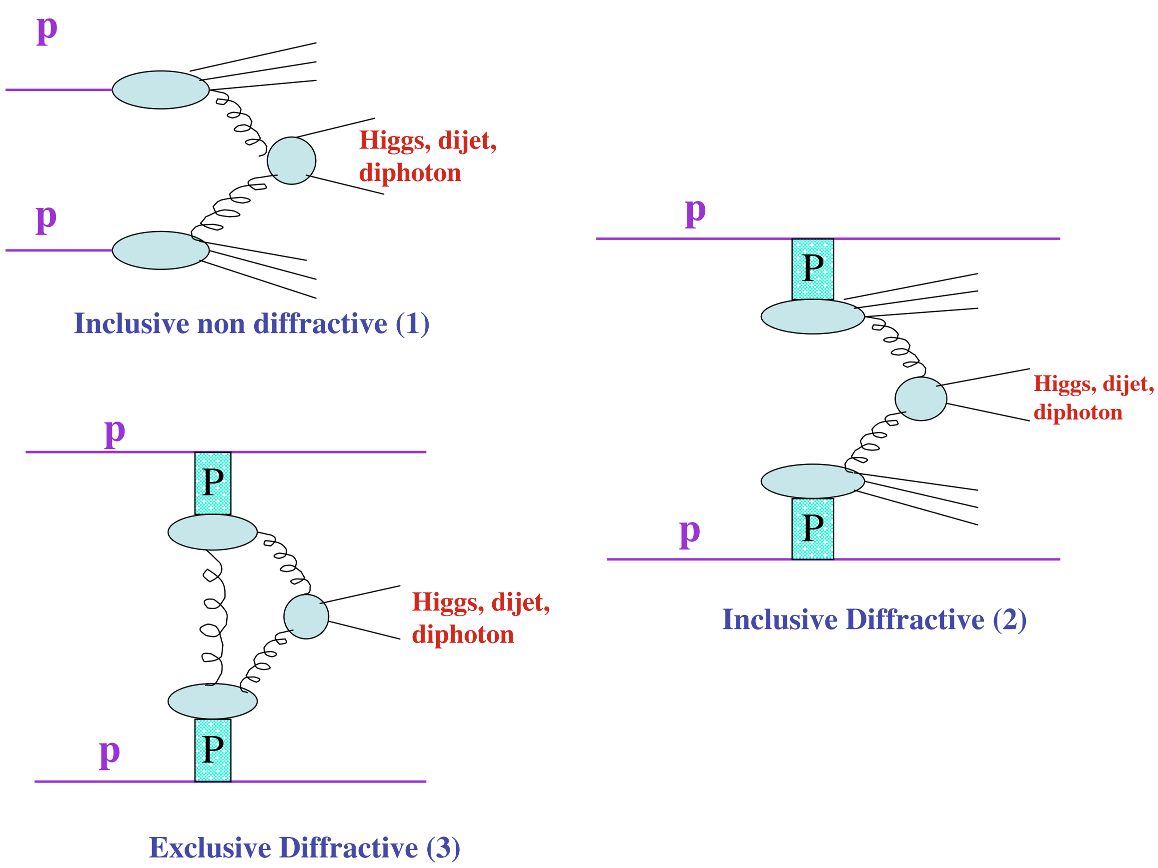
- t: 4-momentum transfer squared
- ξ_1, ξ_2: proton fractional momentum loss (momentum fraction of the proton carried by the pomeron)
- $\beta_{1,2} = x_{Bj,1,2}/\xi_{1,2}$: Bjorken-x of parton inside the pomeron
- $M^2 = s\xi_1\xi_2$: diffractive mass produced
- $\Delta y_{1,2} \sim \Delta\eta \sim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

Jet measurements at the LHC



- Jet cross sections sensitive to gluon content in Pomeron
- Multiply the gluon density in the pomeron by $(1-\beta)^\nu$ with ν=-1, -0.5, 0, 0.5, 1. to show the effect of the gluon uncertainty at high β
- ATLAS data with 10 fb^{-1} will allow to probe QCD an a completely new kinematical domain (test DGLAP evolution, determination of gluon density in Pomeron)

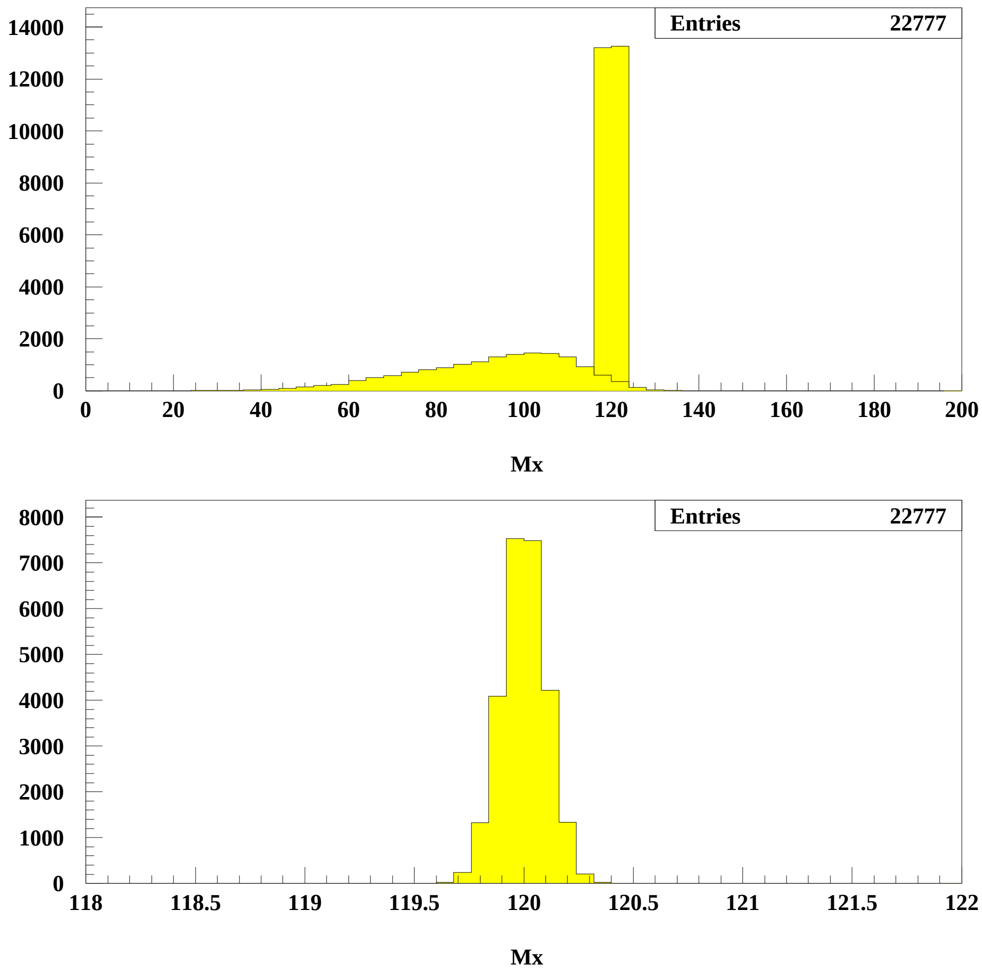
"Exclusive models" in diffraction



- 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

Advantage of exclusive Higgs production?

- Good Higgs mass reconstruction: fully constrained system, Higgs mass reconstructed using both tagged protons in the final state ($pp \to pHp$)
- No energy loss in pomeron "remnants"
- Mass resolution of the order of 2-3% after detector simulation

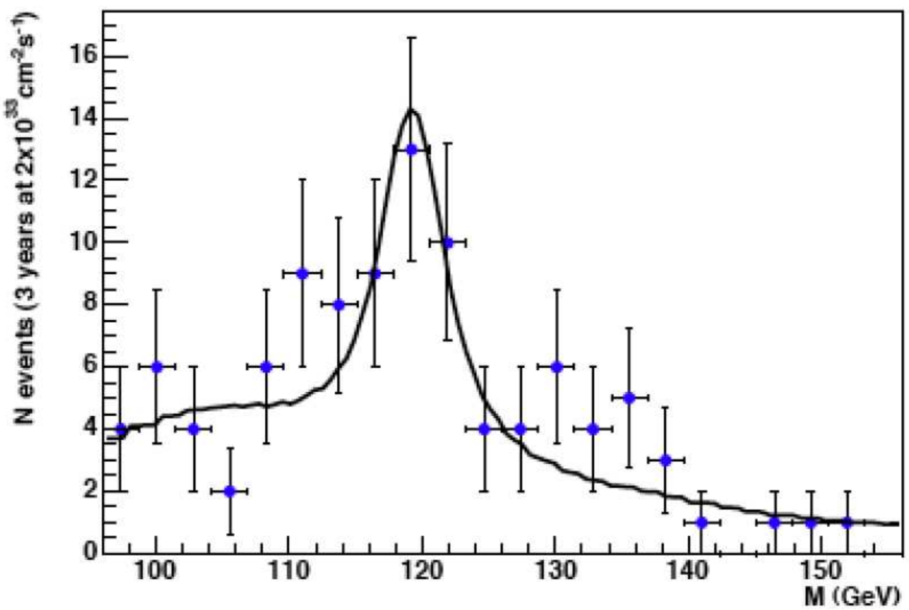


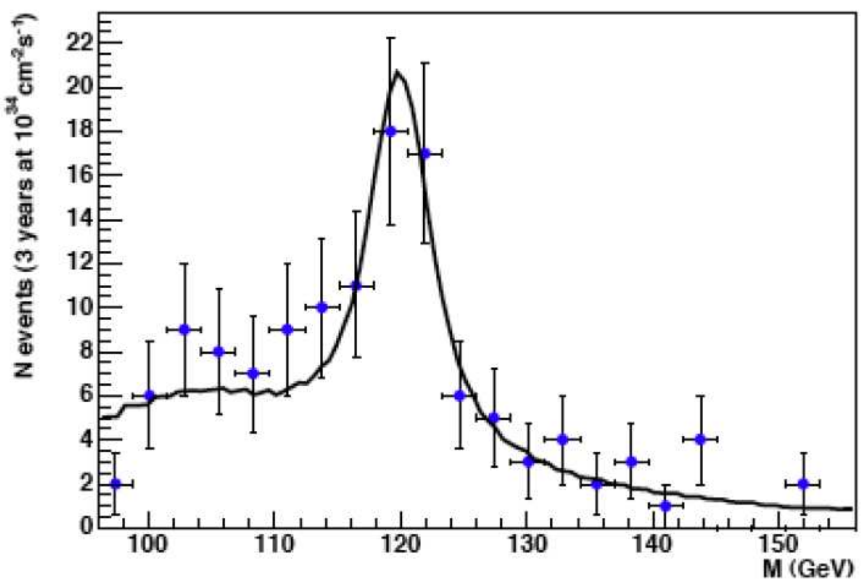
Forward Physics Monte Carlo (FPMC)

- 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

SUSY Signal significance

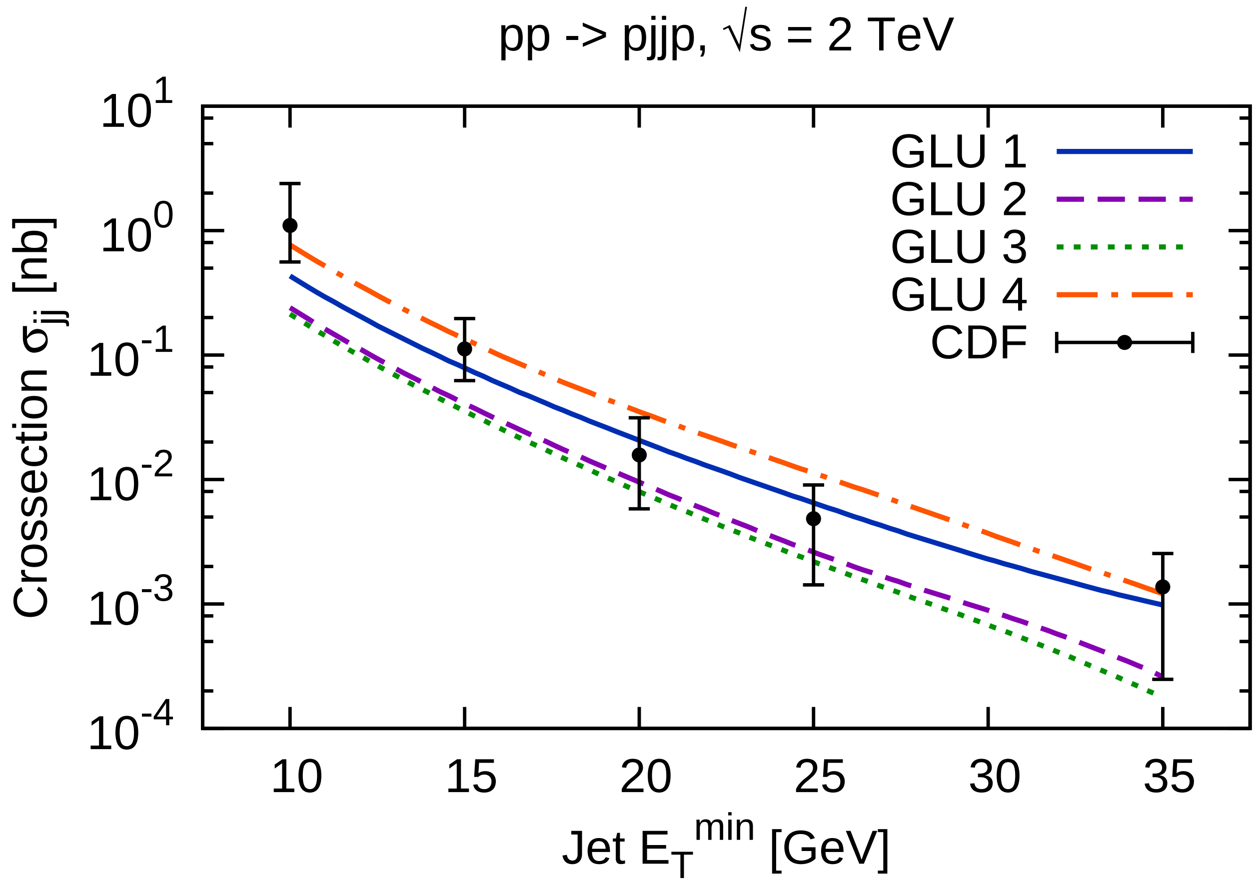
- Signal and background full simulation, pile up effects taken into account: see B. Cox, F. Loebinger, A. Pilkington, JHEP 0710 (2007) 090 for h production at $\tan\beta \sim 40$, 8 times higher cross section than SM
- Significance $> 3.5\sigma$ for 60 fb^{-1} after detector acceptance
- Significance $> 5\sigma$ in 3 years at 10^{34} with timing detectors
- Diffractive Higgs boson production complementary to the standard search, see talk by Marek
- Needs S/B studies for SM and SUSY Higgs with full simulation, including triggers





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)

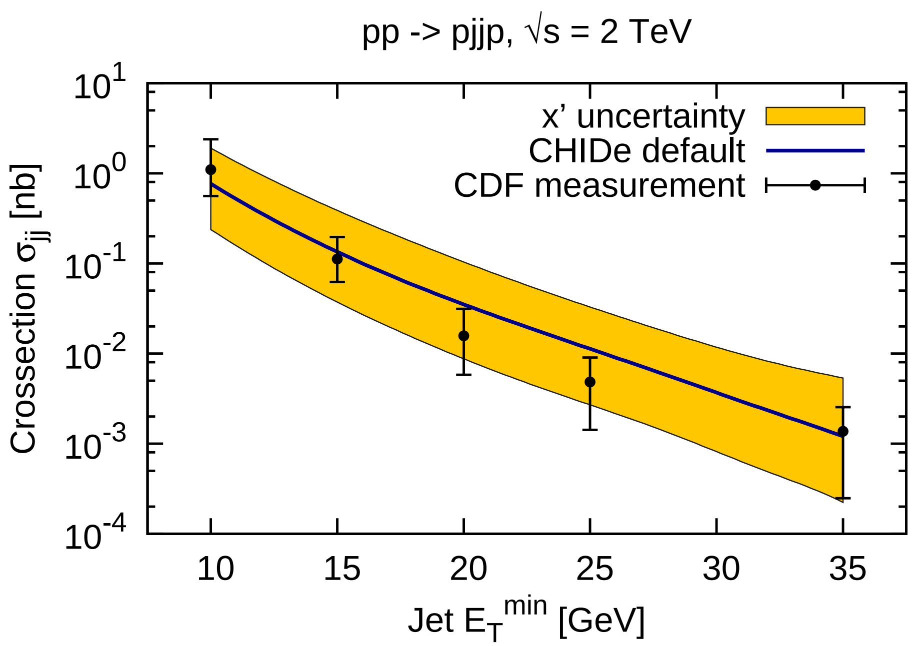


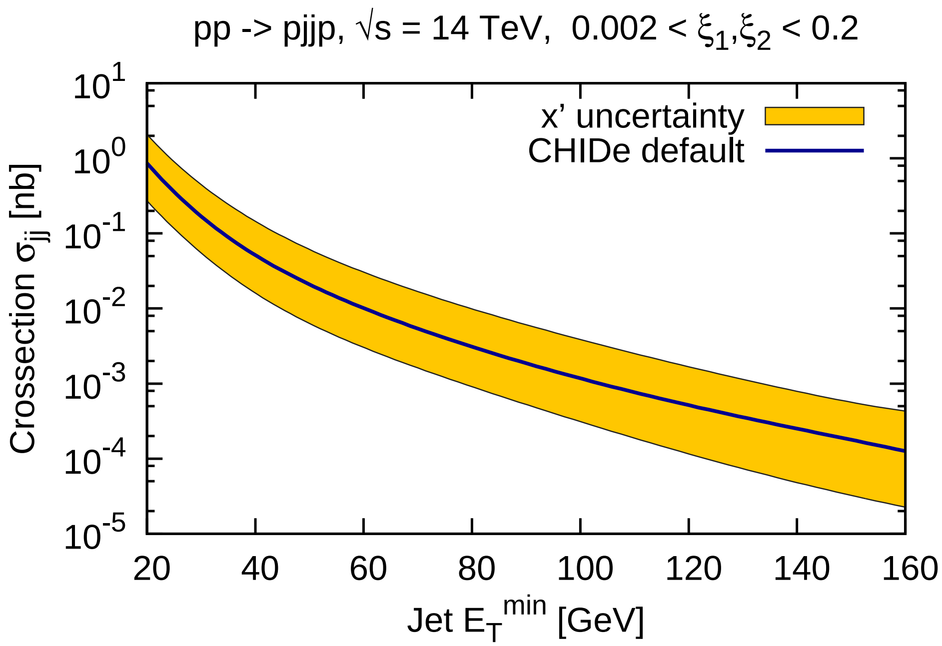
Modifying the Sudakov lower limit

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

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

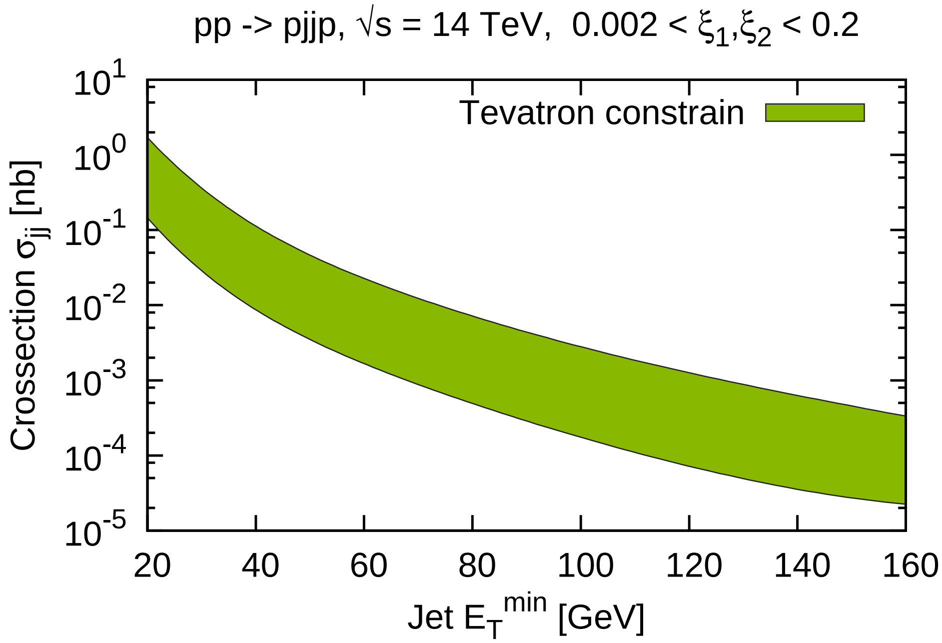
- Factor 10-20 difference for high p_T jet cross section at LHC, increases with jet p_T

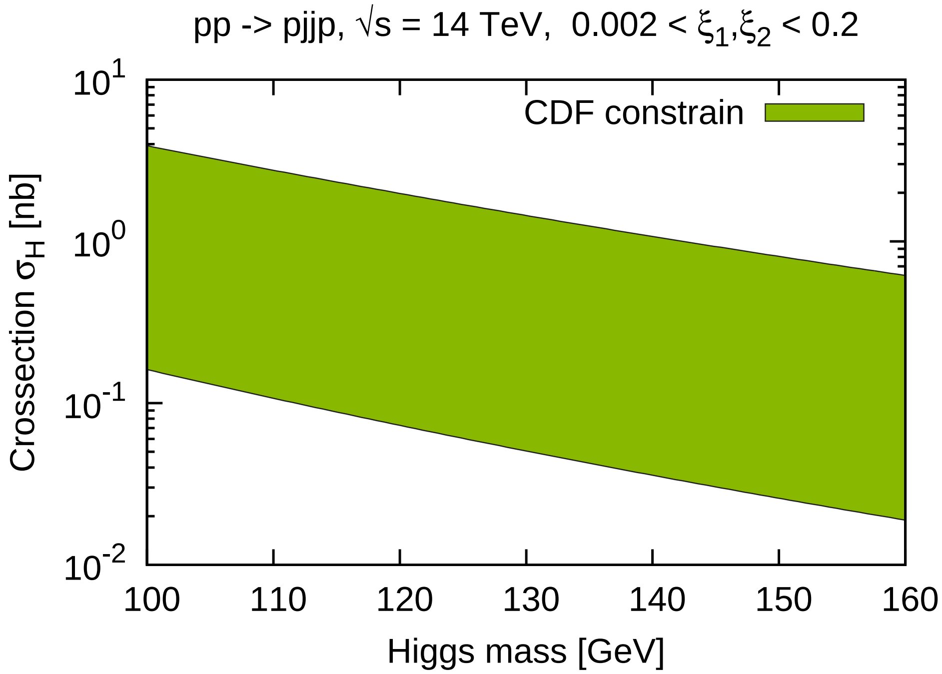




Impact of CDF data on model uncertainty

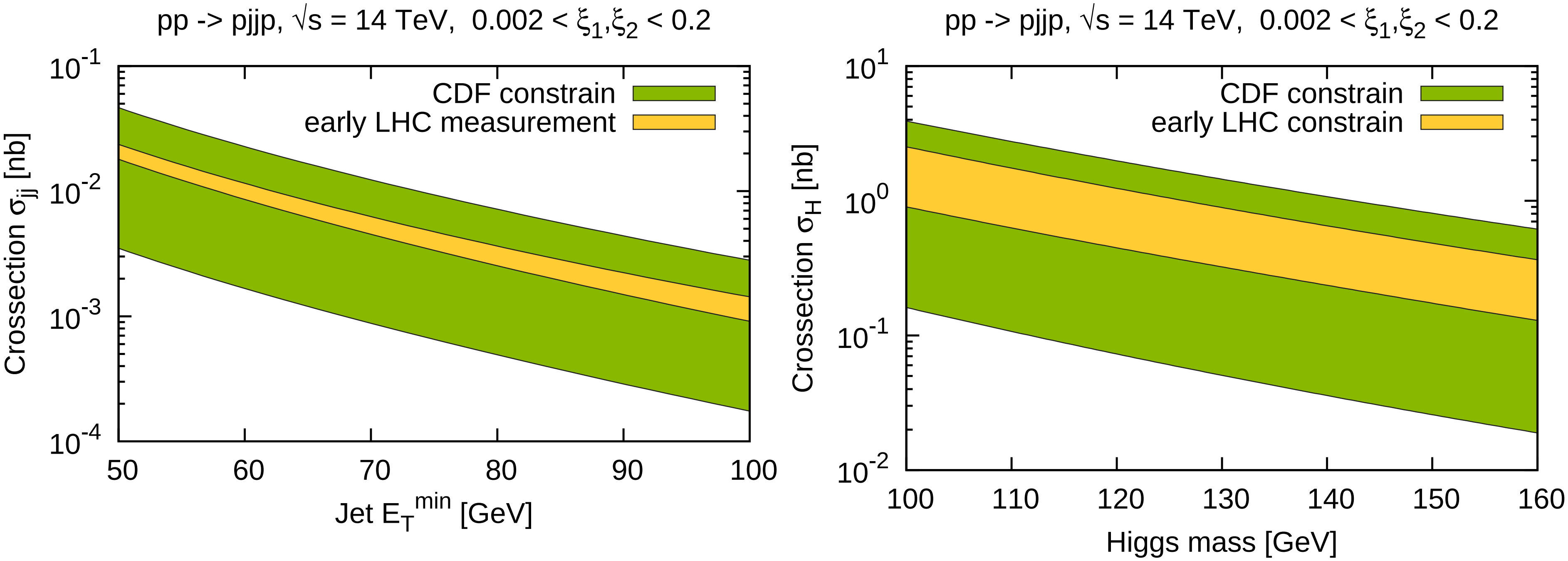
- Not all variation of parameters allowed by CDF measurement
- Method to obtain the model uncertainties:
  - For each gluon distribution, obtain a range of lower Sudakov limits (x'_{min} and x'_{max}) which agree within 1 σ with the CDF measurement
  - Use the same (x'_{min} and x'_{max}) values to obtain 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



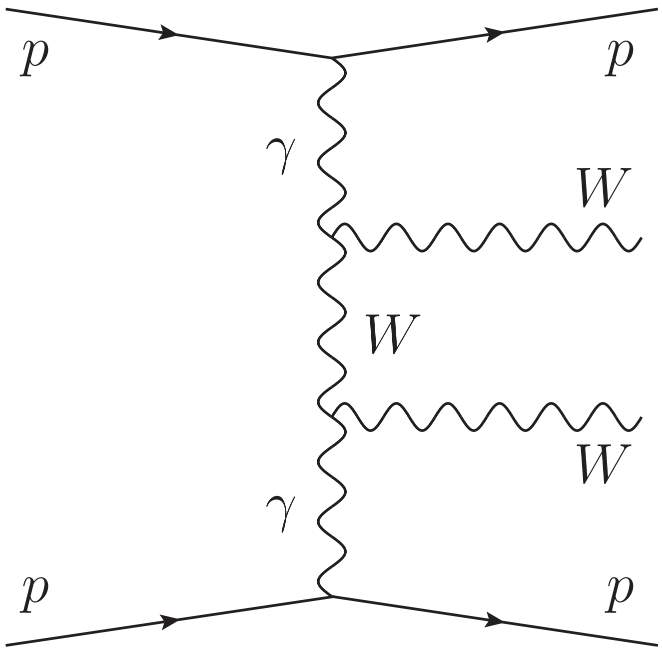


Impact of future LHC measurements on model uncertainty

- 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



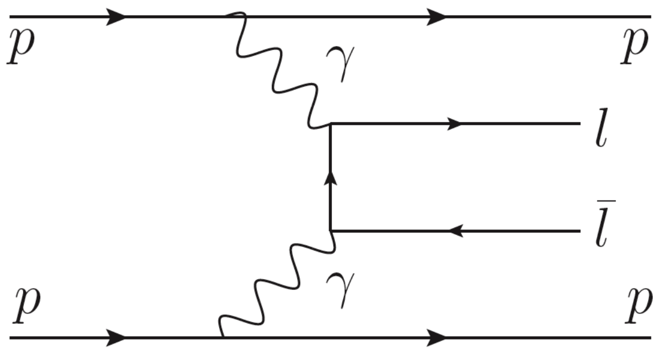
WW production at the LHC



- Study of the process: $pp \to ppWW$
- Clean process: W in central detector and nothing else, intact protons in final state which can be detected far away from interaction point
- Exclusive production of W pairs via photon exchange: QED process, cross section perfectly known
- Two steps: SM observation of WW events, anomalous coupling study
- $\sigma_{WW} = 95.6$ fb, $\sigma_{WW}(W > 1TeV) = 5.9$ fb
- Rich $\gamma\gamma$ physics at LHC: see E. Chapon, O. Kepka, C. Royon, Phys. Rev. D78 (2008) 073005; Phys. Rev. D81 (2010) 074003; T J. De Favereau et al., arXiv:0908.2020; Nicolas Schul, Trento 2010, http://diff2010-lhc.physi.uni-heidelberg.de/Talks/, and arXiv:0910.0202

WW production at the LHC

- Signal: We focus on leptonic signals decays of WW and ZZ, the protons are tagged in the forward proton detectors; fast simulation of the ATLAS detector (ATLFast++)
- Backgrounds considered:
  - Non diffractive WW production: large energy flow in forward region, removed by requesting tagged protons
  - Two photon dileptons: back-to-back leptons, small cross section for high p_T leptons



  - Lepton production via double pomeron exchange: activity in the forward region due to pomeron remnants, removed by $\not{E}_T$ cut
  - WW via double pomeron exchange: removed by cut on high diffractive mass

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

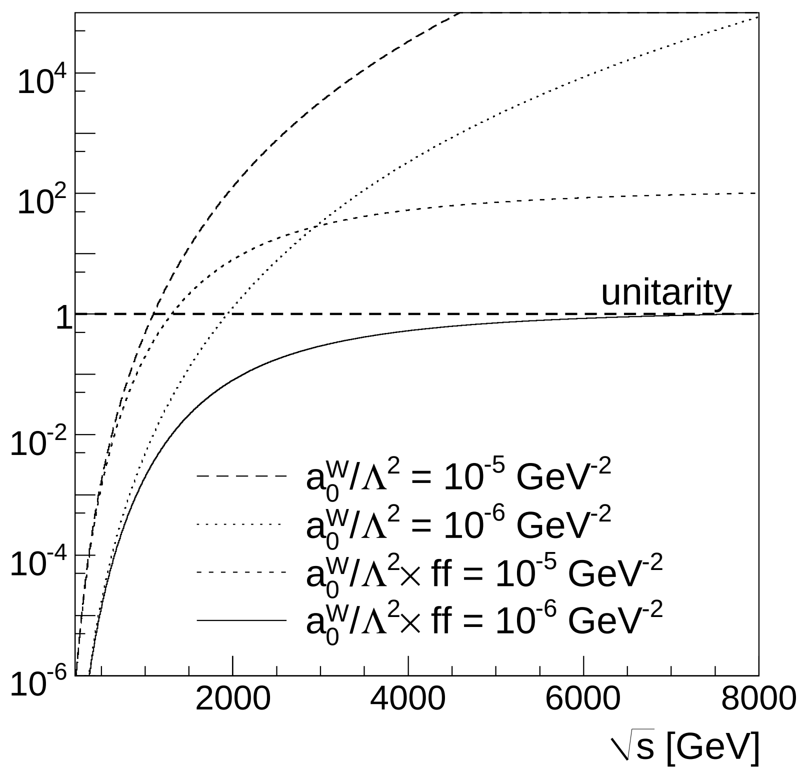
Quartic anomalous gauge couplings: form factors

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

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

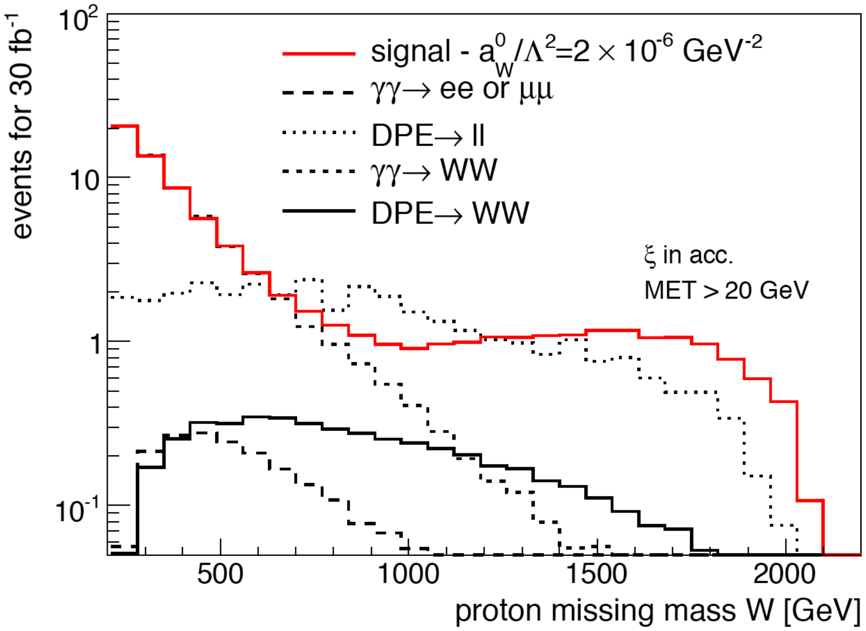
where $a = a_0/\Lambda^2$

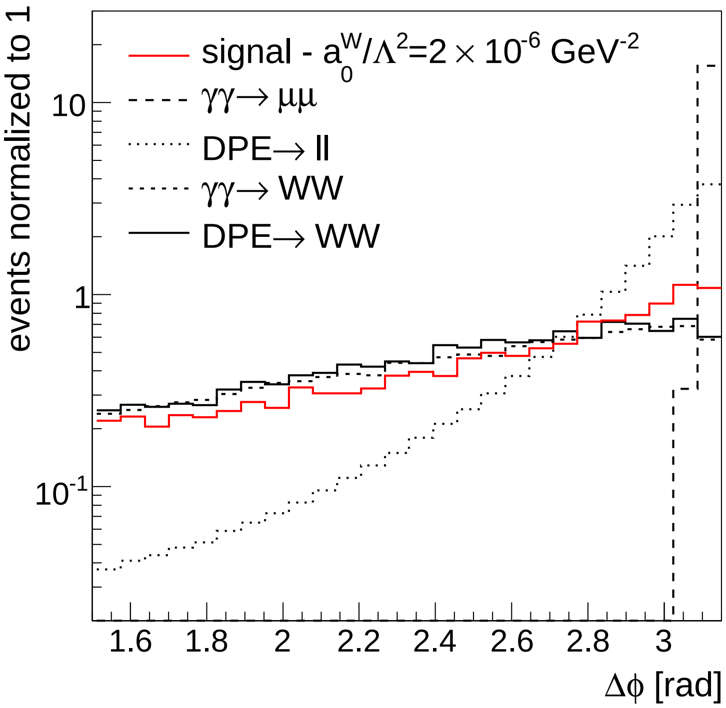
- Introducing form factors to avoid quadratical divergences of scattering amplitudes due to anomalous couplings in conventional way: $a_0^W/\Lambda^2 \to \frac{a_0^W/\Lambda^2}{(1+W\gamma\gamma/\Lambda_{cutoff})^2}$ with $\Lambda_{cutoff} \sim 2$ TeV, scale of new physics
- For $a_0^W \sim 10^{-6}$ GeV^{-2},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



Strategy to select quartic anomalous gauge couplings events

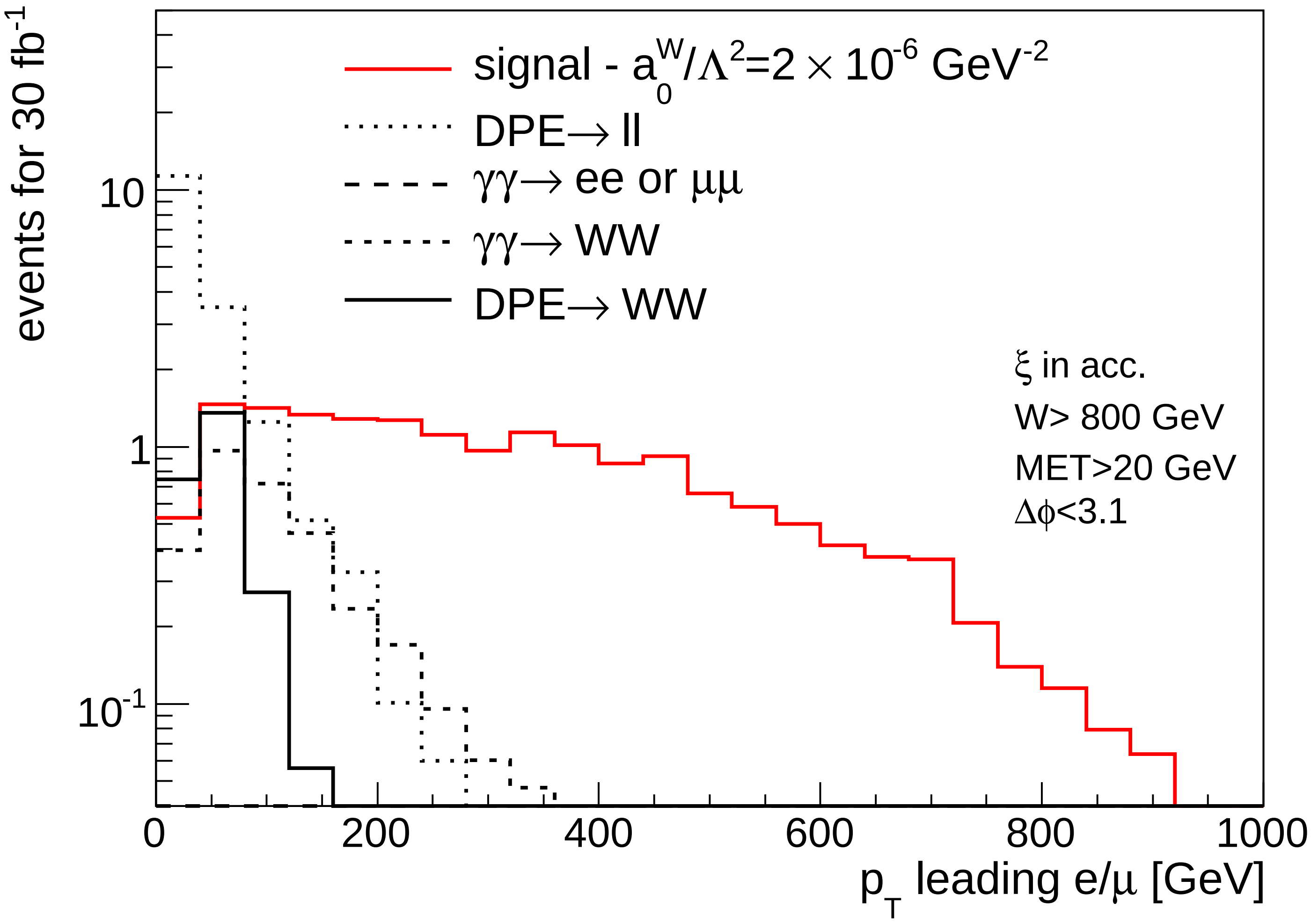
- p_T of the leading lepton: request high p_T lepton to remove background
- Missing E_T distribution: natural to be requested for W pair production
- Diffractive mass computed using the forward proton detectors $\sqrt{\xi_1 \xi_2 S}$: request high mass objects to be produced
- $\Delta\Phi$ between both leptons: avoid back-to-back leptons





Quartic anomalous gauge couplings

Distribution of the leading lepton p_T after all cuts (proton tagged, $\not{E}_T$, diffractive mass, $\Delta\Phi$) except the cut on leading lepton p_T



Quartic anomalous gauge couplings

Background events for 30 fb^{-1}

cut / process	$\gamma\gamma \to ll$	$\gamma\gamma \to WW$	DPE$\to ll$	DPE$\to WW$
$p_T^{lep1,2} > 10$ GeV	50619	99	18464	8.8
$0.0015 < \xi < 0.15$	21058	89	11712	6.0
$\not{E}_T > 20$ GeV	14.9	77	36	4.7
$W > 800$ GeV	0.42	3.2	16	2.5
$M_{ll} \notin < 80, 100 >$	0.42	3.2	13	2.5
$\Delta\phi < 3.13$	0.10	3.2	12	2.5
$p_T^{lep1} > 160$ GeV	0	0.69	0.20	0.024

Signal events for 30 fb^{-1}

cut / couplings (with f.f.)	$a_0^W/\Lambda^2 = 5.4 \cdot 10^{-6}$	$a_C^W/\Lambda^2 = 20 \cdot 10^{-6}$
$p_T^{lep1,2} > 10$ GeV	202	200
$0.0015 < \xi < 0.15$	116	119
$\not{E}_T > 20$ GeV	104	107
$W > 800$ GeV	24	23
$M_{ll} \notin < 80, 100 >$	24	23
$\Delta\phi < 3.13$	24	22
$p_T^{lep1} > 160$ GeV	17	16

Reach at LHC

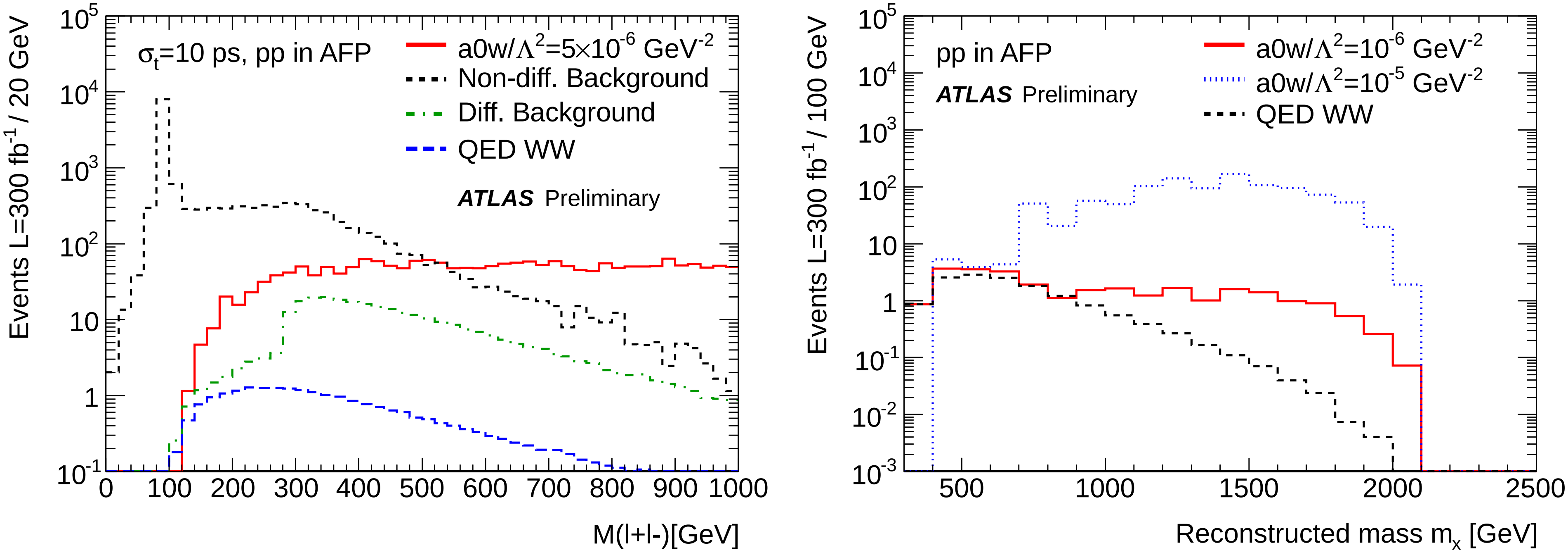
Reach at high luminosity on quartic anomalous coupling

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 Higgsless/extradimension models

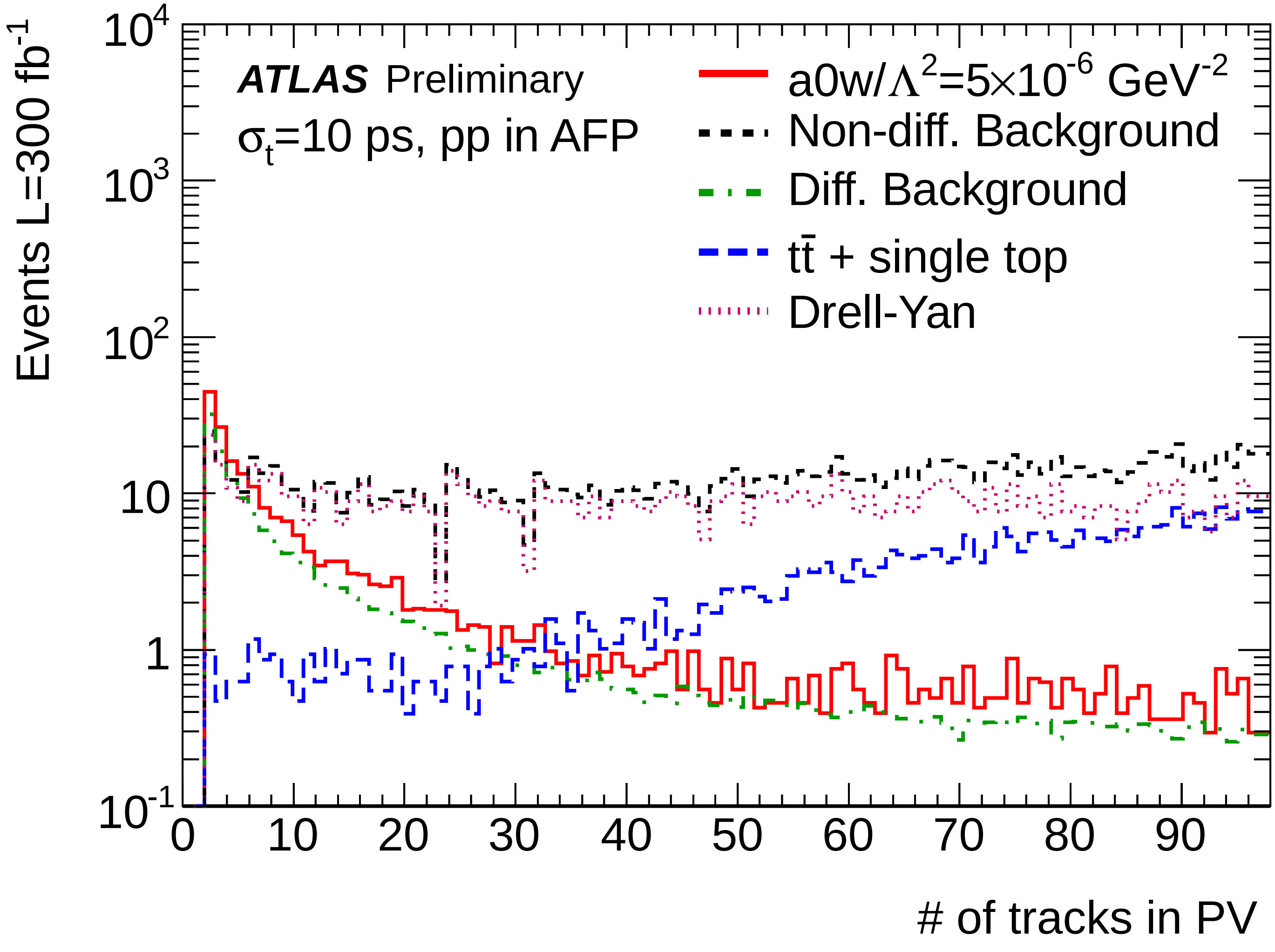
Possible results from the first phase of AFP

- First phase of AFP (ATLAS Forward Physics): installation of forward proton detectors (movable beam pipes, Si and timing detectors) by 2013-14 shutdown
- Reach on anomalous couplings studied using a full simulation of the ATLAS detector, including all pile up effects
- Pile up considered: 23 up to 2017 (40 fb^{-1} accumulated), 46 after 2017 (300 fb^{-1} accumulated)
- Signal appears at high dilepton mass and higgs diffractive mass reconstructed using forward detectors ($\sqrt{\xi_1 \xi_2 S}$)



Rejecting pile up in full simulation

- Cut on the number of tracks fitted to the primary vertex: very efficient to remove pile up (for signal, we have two leptons coming from the W decays and nothing else)
- Need full simulation for these studies (tracking not perfect in fast simulation)



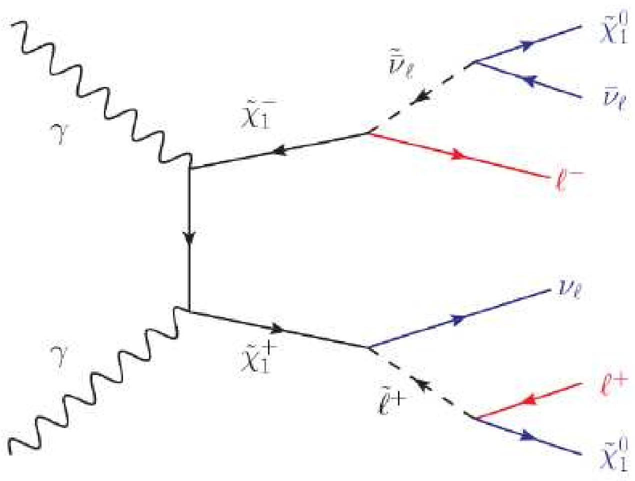
Results from full simulation

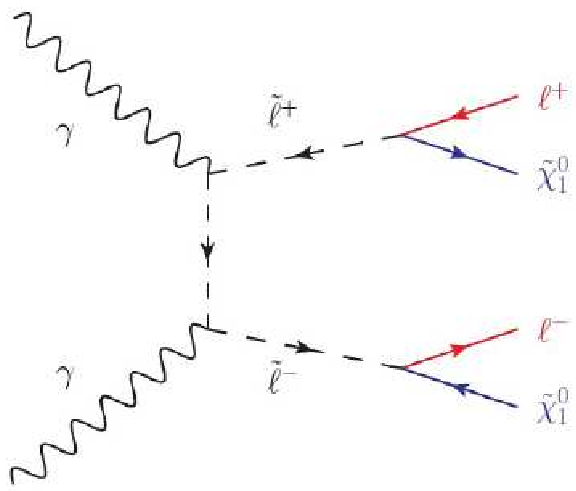
Cuts	Top	Dibosons	Drell-Yan	W/Z+jet	Diffr.	$a_0^W/\Lambda^2 = 5 \cdot 10^{-6}$ GeV^{-2}
timing < 10 ps $p_T^{lep1} > 150$ GeV $p_T^{lep2} > 20$ GeV	5198	601	20093	1820	190	282
M(ll)>300 GeV	1650	176	2512	7.7	176	248
nTracks ≤ 3	2.8	2.1	78	0	51	71
$\Delta\phi < 3.1$	2.5	1.7	29	0	2.5	56
$m_X > 800$ GeV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

	a_0^W/Λ^2 Sensitivity	
	5σ	95% C.L.
$\mathscr{L} = 40\ fb^{-1}, \mu = 23$	$5.5\ 10^{-6}$	$2.4\ 10^{-6}$
$\mathscr{L} = 300\ fb^{-1}, \mu = 46$	$3.2\ 10^{-6}$	$1.3\ 10^{-6}$

Detection of exclusive SUSY pairs





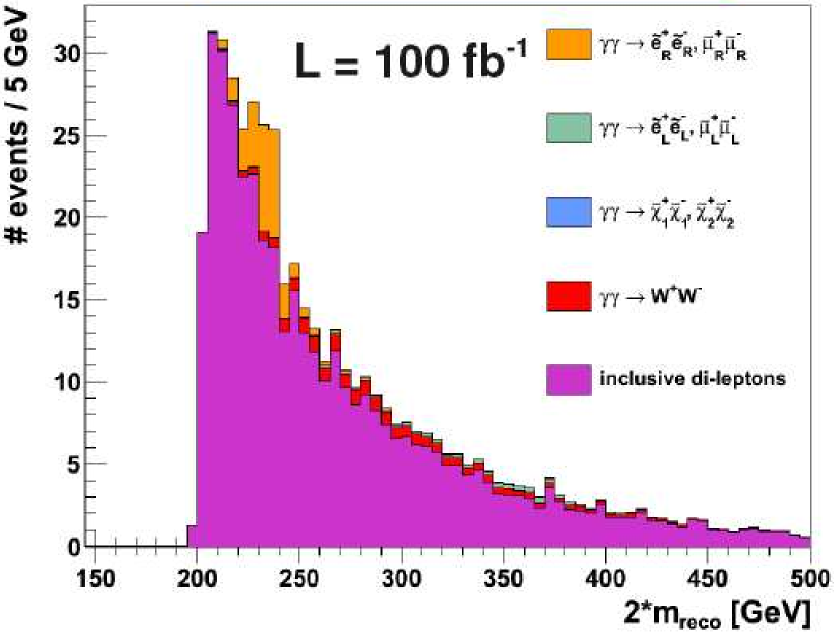
- Low mass SUSY and choice of LM1 benmarch point: mass of right sleptons: 118 GeV (masses of left sleptons, staus higher), charginos: 178 and 60 GeV, σ=2.2 fb
- Only one irreducible background: $\gamma\gamma \to WW \to l\nu l\nu$, $\gamma\gamma \to ll$ suppressed by $\not{E}_T$ and acoplanarity cuts
- Apply cuts: $W_{miss} > 194$ GeV, $W_{\gamma\gamma} > 236$ GeV, $\Delta p_T > 1.5 GeV$, $\Delta\Phi/\pi < 0.9$
- Compute slepton masses using:

$$(2m)^2 = W_{\gamma\gamma}^2 - \left([W_{miss}^2 - 4m_{\tilde{\chi}_1^0}^2]^{1/2} + [W_{lep}^2 - 4m_{lep}^2]^{1/2}\right)^2$$

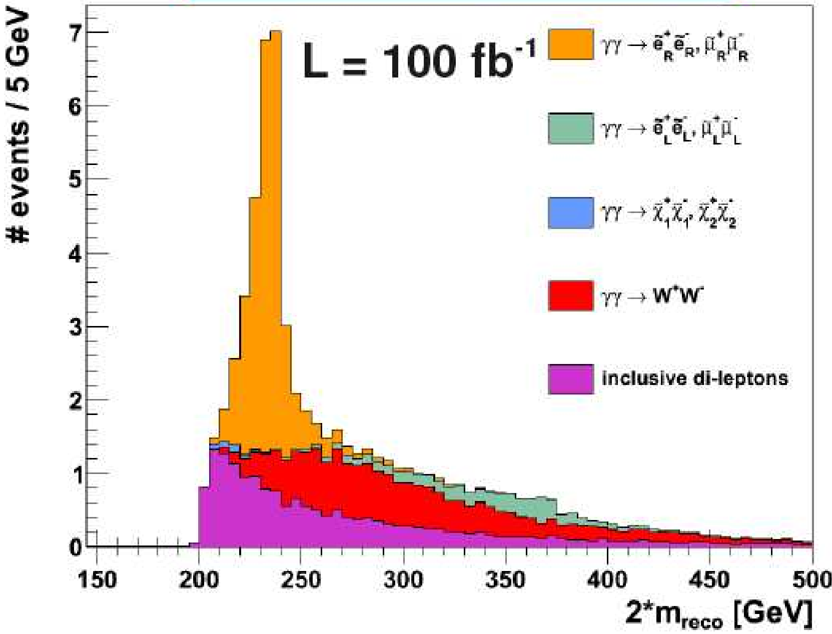
Reconstructed mass

- Result at high luminosity: 10^{34} cm^{-2} s^{-1}, 25 events pile up
- Needs o be redone using full simulation of ATLAS

--> Exclusivity conditions:

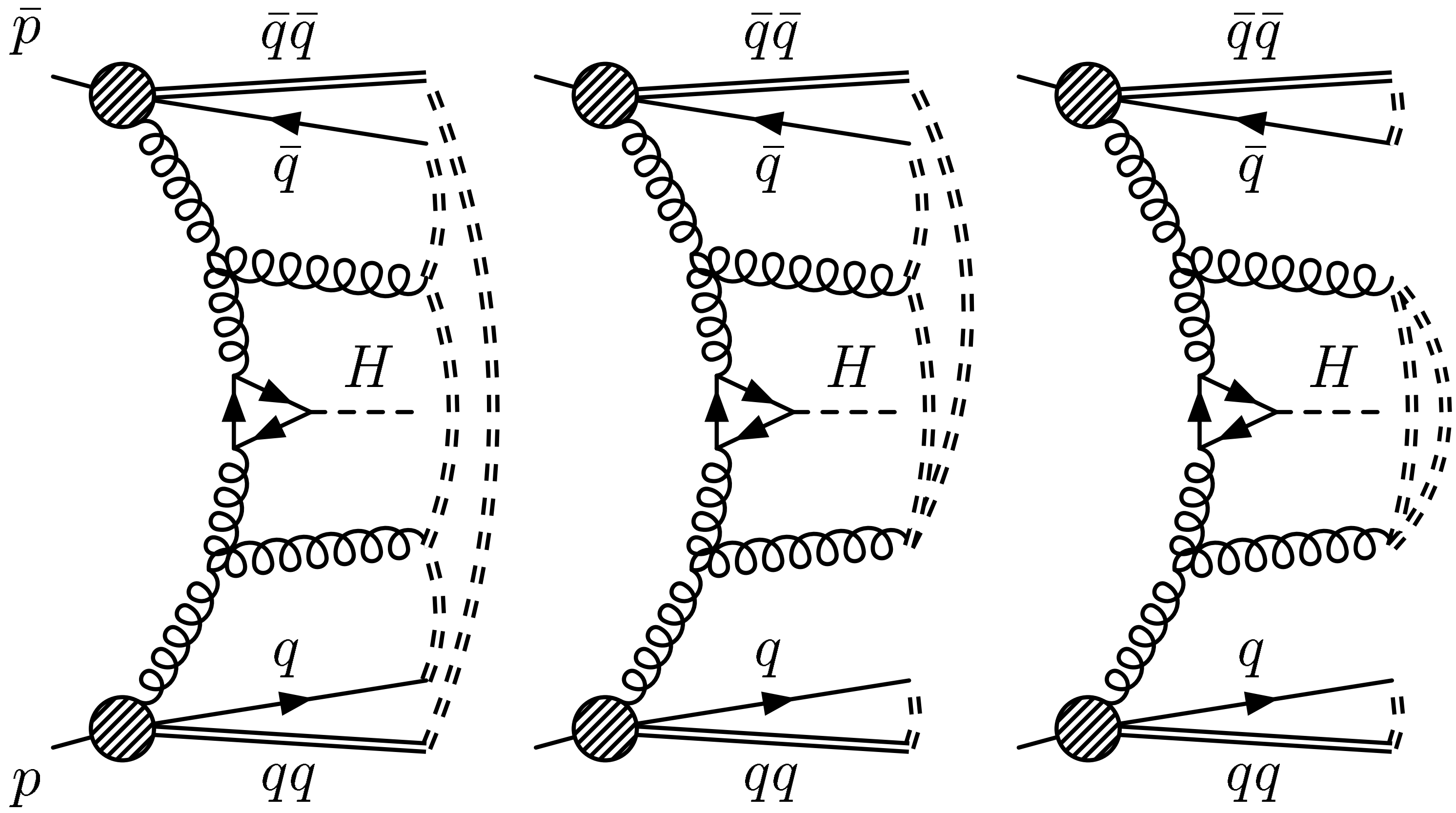


--> Exclusivity conditions + 10ps timing detector:

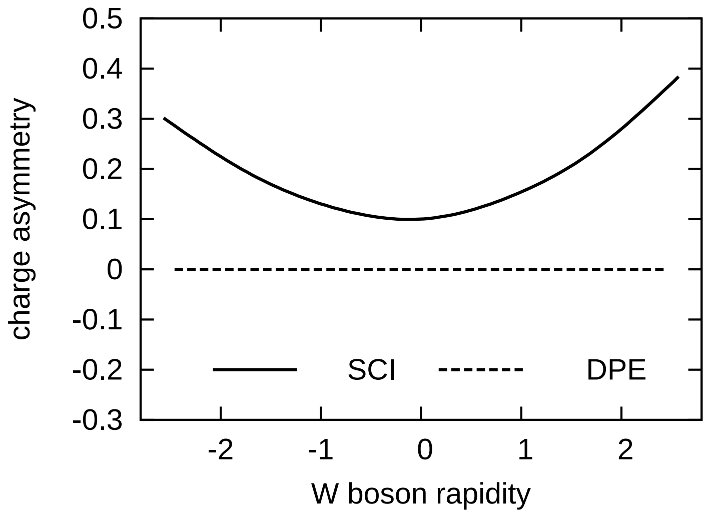


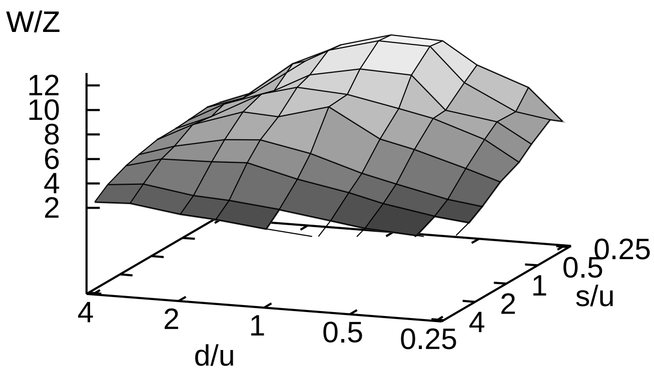
Soft Colour Interaction models

- A completely different model to explain diffractive events: Soft Colour Interaction (R.Enberg, G.Ingelman, N.Timneanu, hep-ph/0106246)
- Principle: Variation of colour string topologies, giving a unified description of final states for diffractive and non-diffractive events
- No survival probability for SCI models



New ideas in W/Z production at the LHC





- New simple idea to probe QCD: K. Golec-Biernat, C. Royon, L. Schoeffel, R, Staszewski, Phys. Rev. D84 (2011) 114006.
- Measure W asymmetry: should be 0 if diffraction due to Pomeron exchanges (made of quark and gluons, since $u = \bar{u}$, $d = \bar{d}$), non-zero if due to soft colour exchanges (diffraction explained through soft colour exchanges at the hadronisation phase, same asymmetries expected as for the proton)
- If aymmetry is 0, measure u/d quark density ratio in the Pomeron: first possible measurement ever, important to test QCD evolution which assumes $u = d = \bar{u} = \bar{d}$

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
- Diffractive DPE W production: sensitive to diffraction mechanism (SCI, pomeron...)
- 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...)