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

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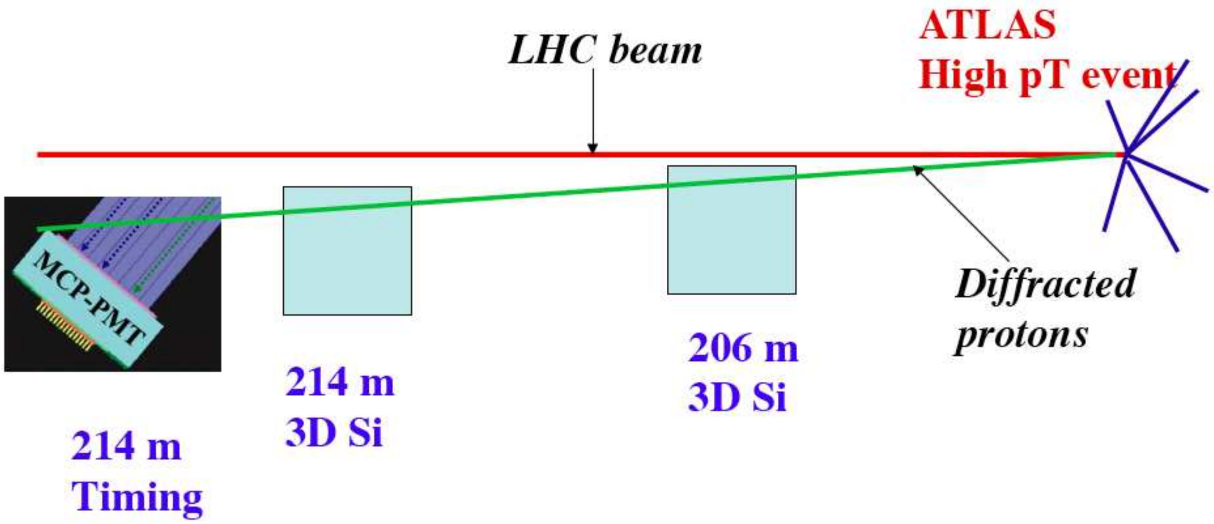
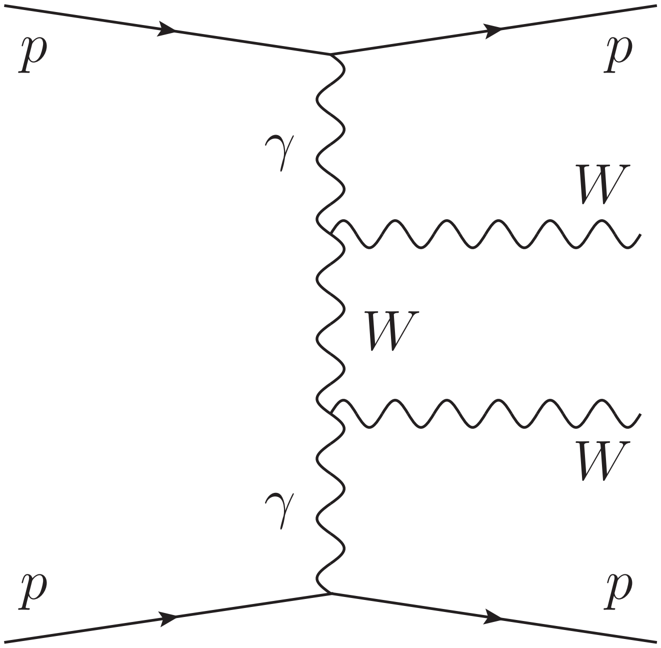
Contents:

- Anomalous $W\gamma$ couplings at the LHC
- Exclusive diffractive Higgs production at the LHC



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



- Study of the process: $pp \to ppWW$
- 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 anomalous couplings to be studied (dimension 6 and 8 operators) if Higgs boson is discovered; $\gamma\gamma$ specially interesting
- 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

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

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

- 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 → violation of unitarity at high energies

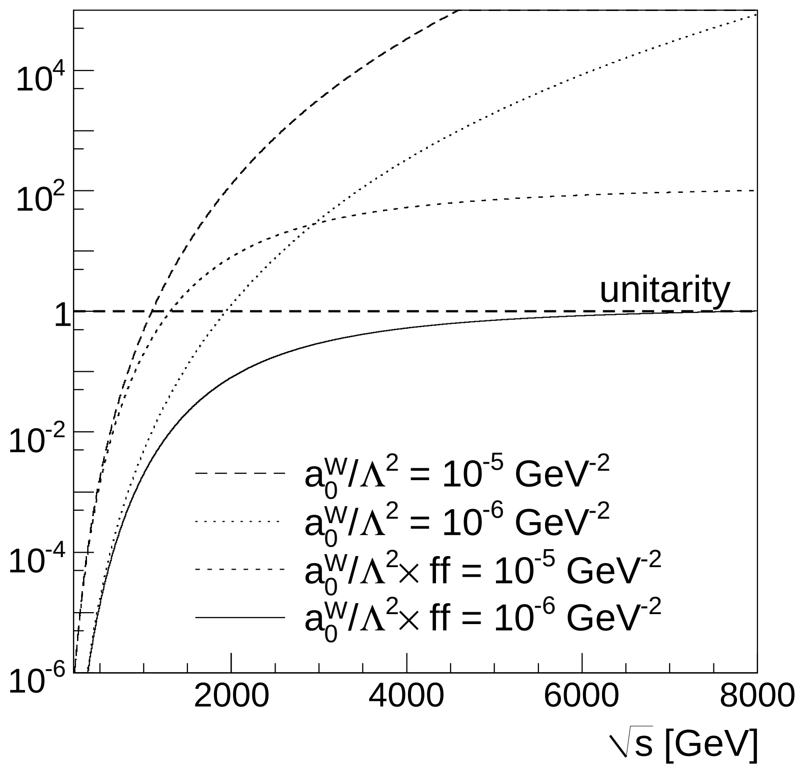
Quartic anomalous gauge couplings: form factors

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

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

  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

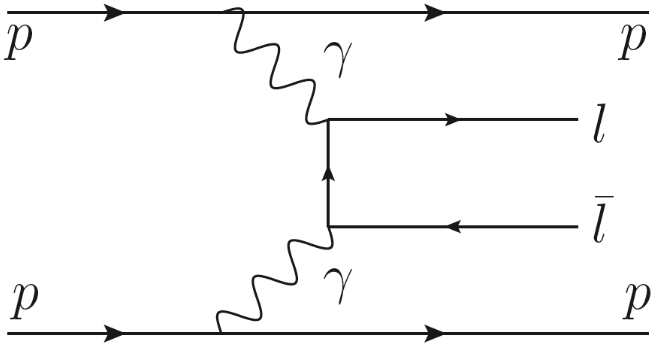


Forward Physics Monte Carlo (FPMC)

- 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
- 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

WW production at the LHC

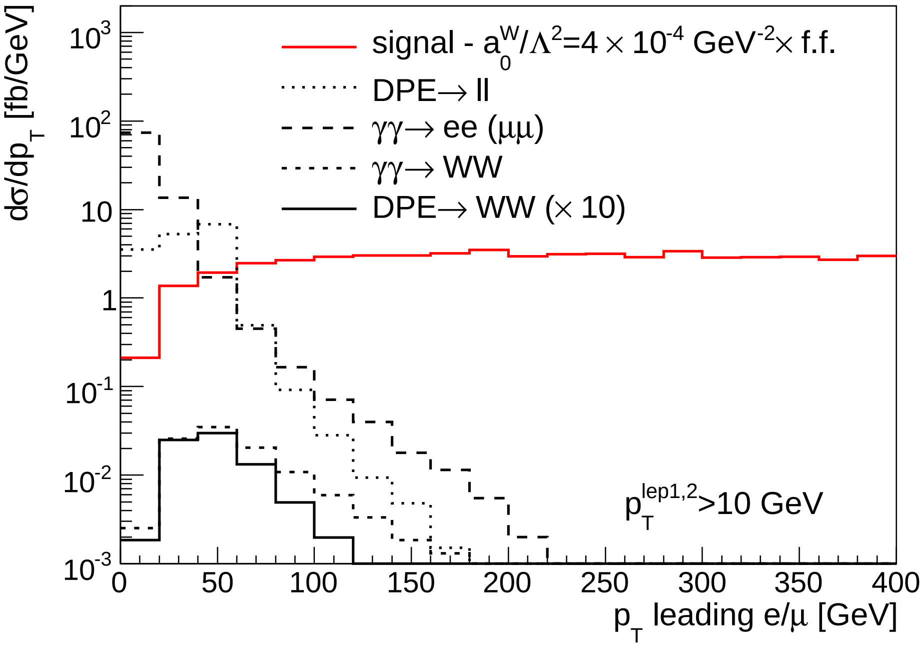
- Signal: We focus on leptonic signals decays of WW and ZZ, the protons are tagged in the forward proton detectors; fast simulation of the ATLAS detector (ATLFast$++$)
- Backgrounds considered:
  - Non diffractive WW production: large energy flow in forward region, removed by requesting tagged protons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

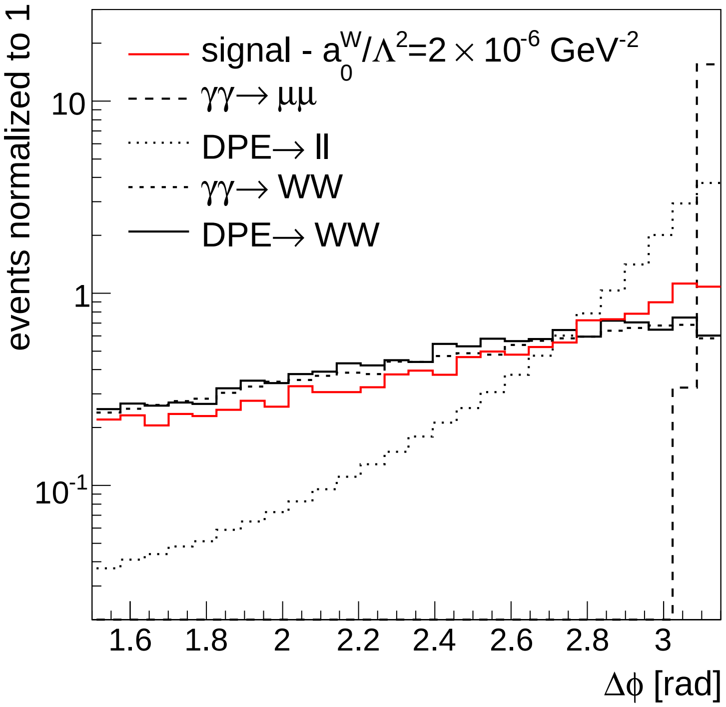


  - Lepton production via double pomeron exchange: small cross section at high dilepton mass
  - WW via double pomeron exchange: removed by cut on high diffractive mass

Strategy to select quartic anomalous gauge couplings events

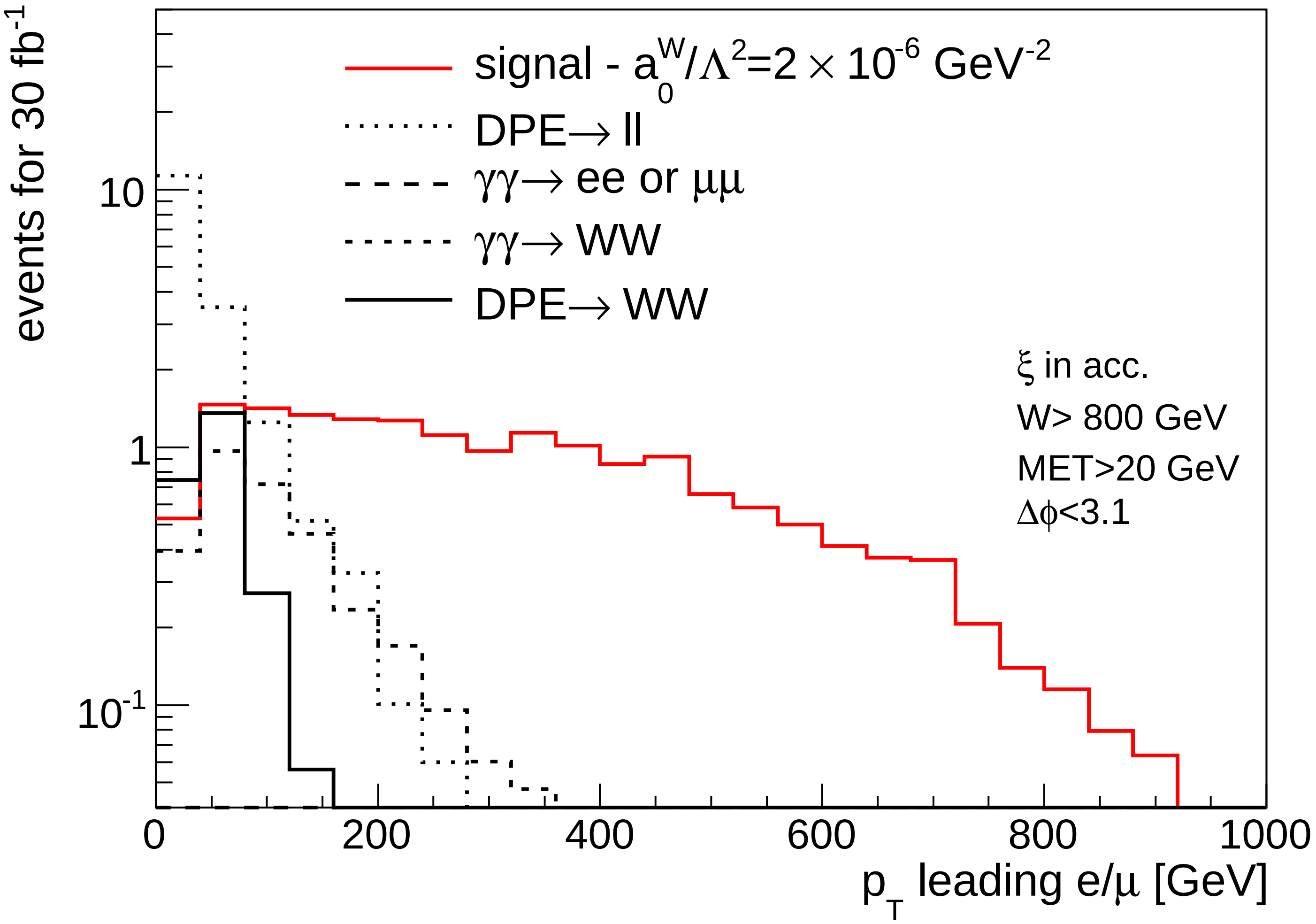
- p_T of the leading lepton: request high p_T lepton to remove background
- Missing E_T distribution: natural to be requested for W pair production
- Diffractive mass computed using the forward proton detectors $\sqrt{\xi_1 \xi_2 S}$: request high mass objects to be produced
- $\Delta\Phi$ between both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



Reach at LHC

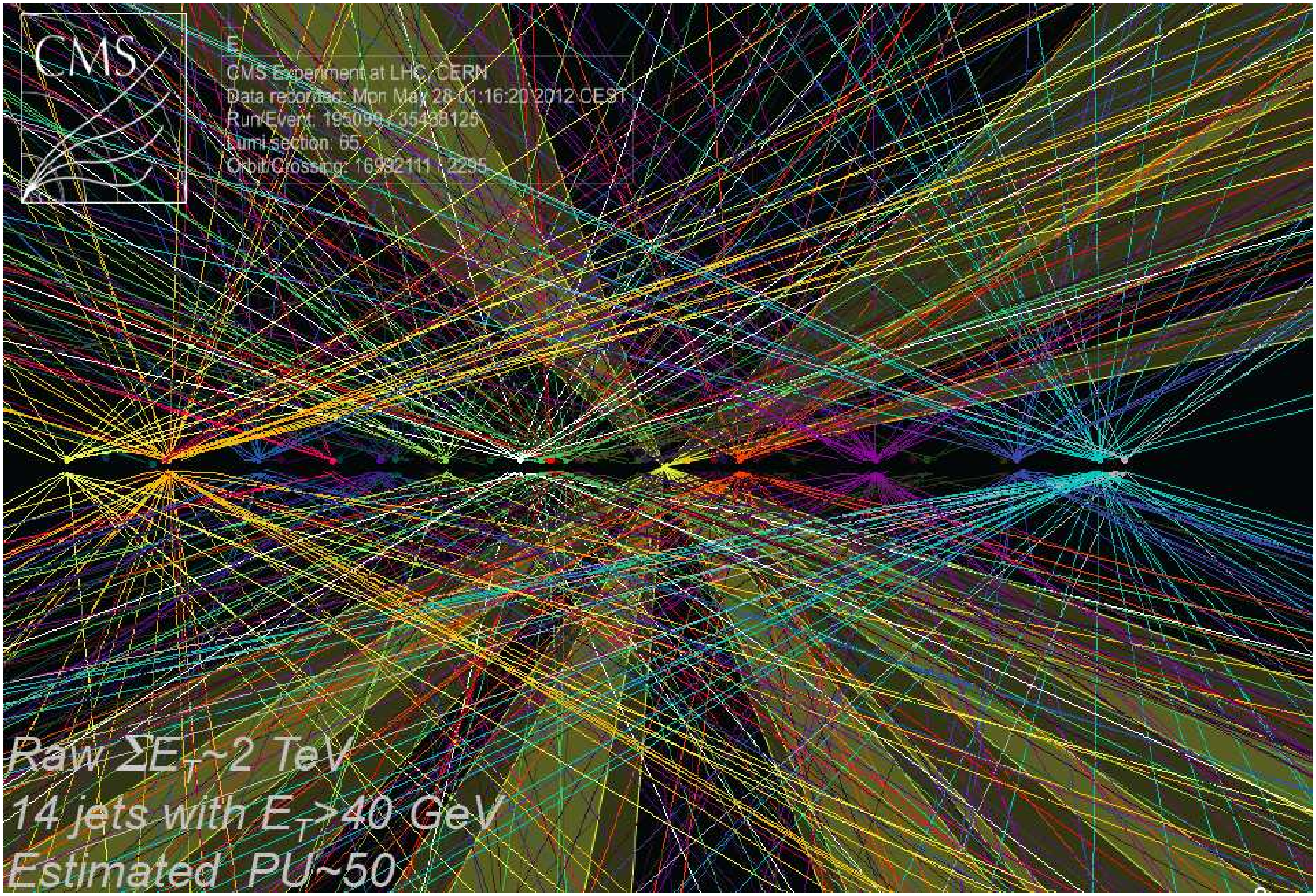
Reach at high luminosity on quartic anomalous coupling

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

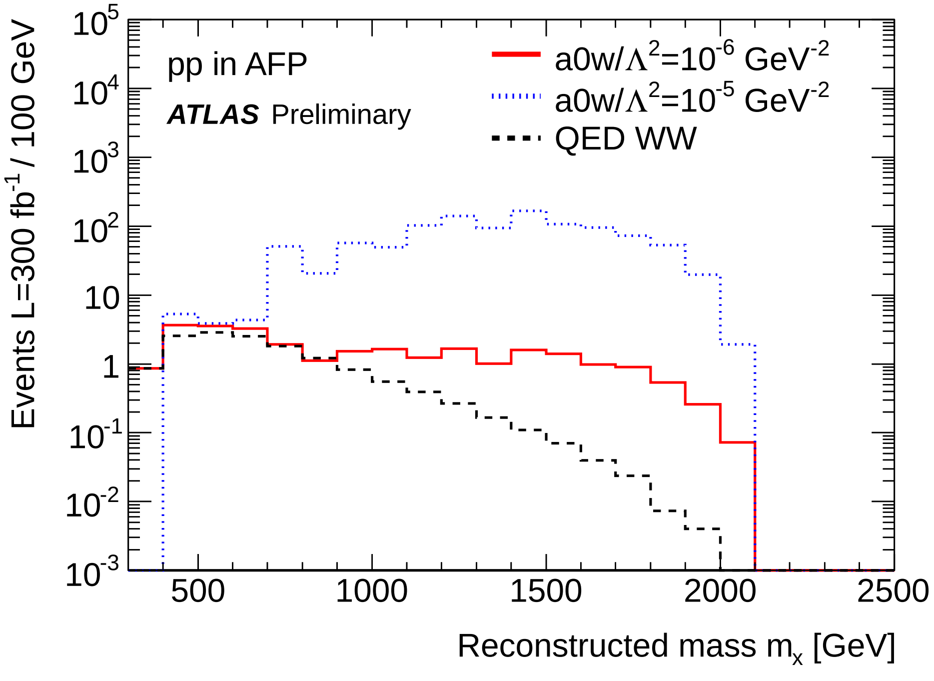
Life is not that easy: LHC reality, high pile up!

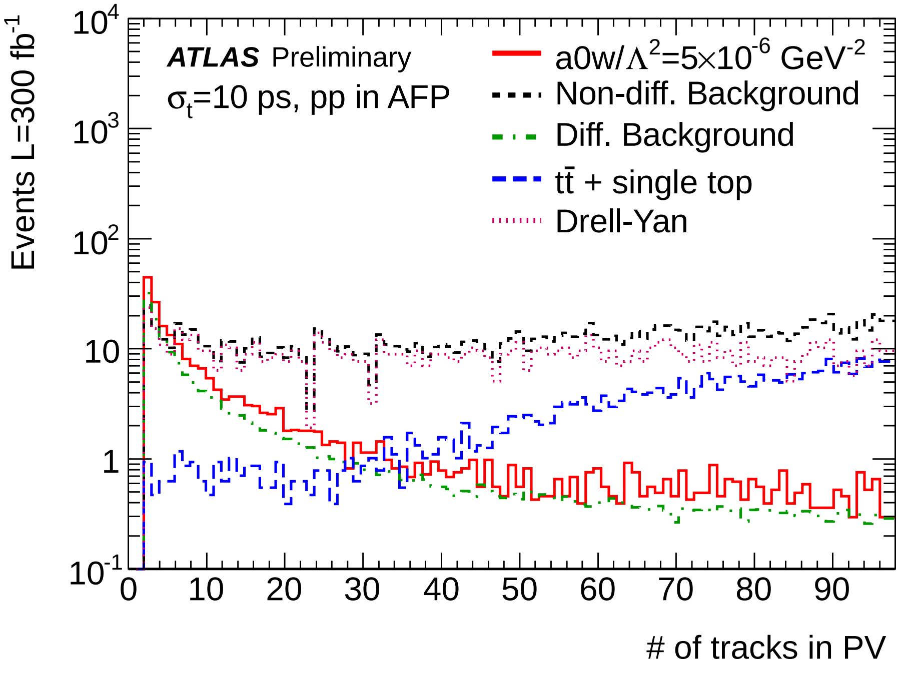
- Many interactions occur in the same bunch crossing, up to 50 at the LHC
- Intact protons can originate from pile up! (nothing to do with WW production)



Anomalous couplings studies in WW events

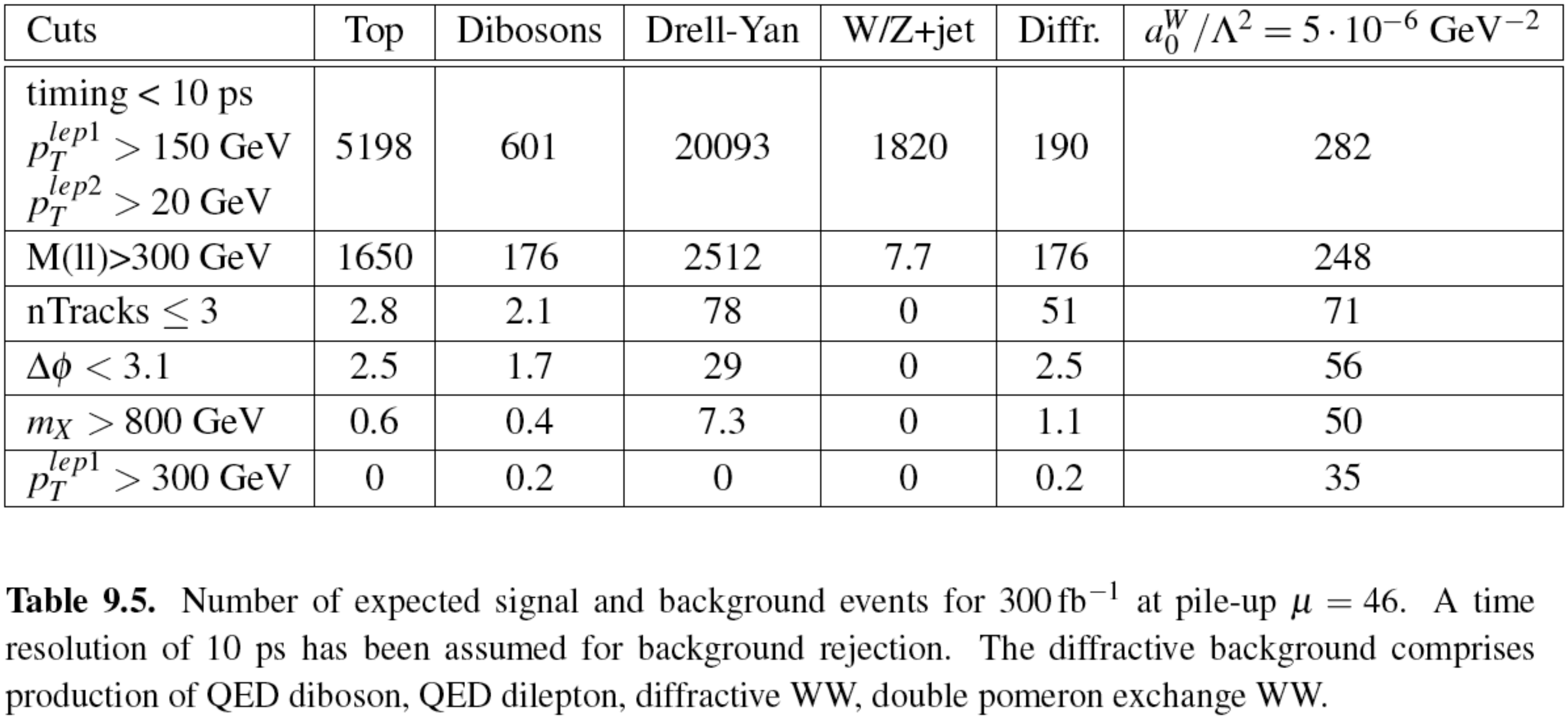
- Reach on anomalous couplings studied using a full simulation of the ATLAS detector, including all pile up effects; only leptonic decays of Ws are considered
- Many backgrounds considered: $t\bar{t}$, single top, Drell Yan, diboson (WW, ZZ, WZ)... and pile up
- Signal appears at high lepton p_T and 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)



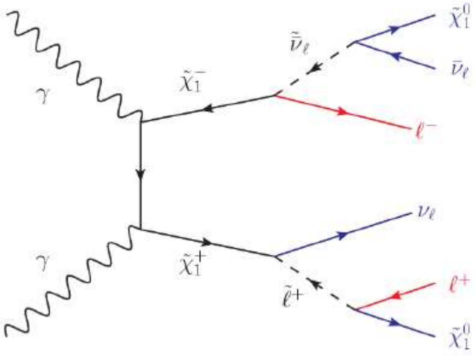
Cuts	Top	Dibosons	Drell-Yan	W/Z+jet	Diffr.	$a_0^W/\Lambda^2 = 5 \cdot 10^{-6}$ GeV^{-2}
timing < 10 ps $p_T^{lep1} > 150$ GeV $p_T^{lep2} > 20$ GeV	5198	601	20093	1820	190	282
M(ll)>300 GeV	1650	176	2512	7.7	176	248
nTracks ≤ 3	2.8	2.1	78	0	51	71
$\Delta\phi < 3.1$	2.5	1.7	29	0	2.5	56
$m_X > 800$ GeV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

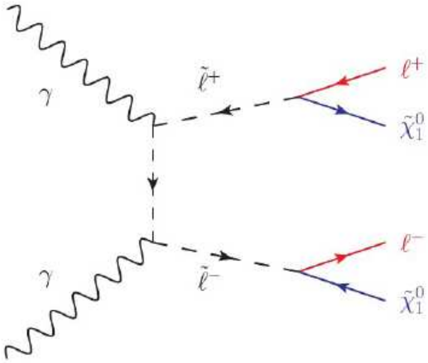
Table 9.5. Number of expected signal and background events for 300 fb^{-1} at pile-up $\mu = 46$. A time resolution of 10 ps has been assumed for background rejection. The diffractive background comprises production of QED diboson, QED dilepton, diffractive WW, double pomeron exchange WW.

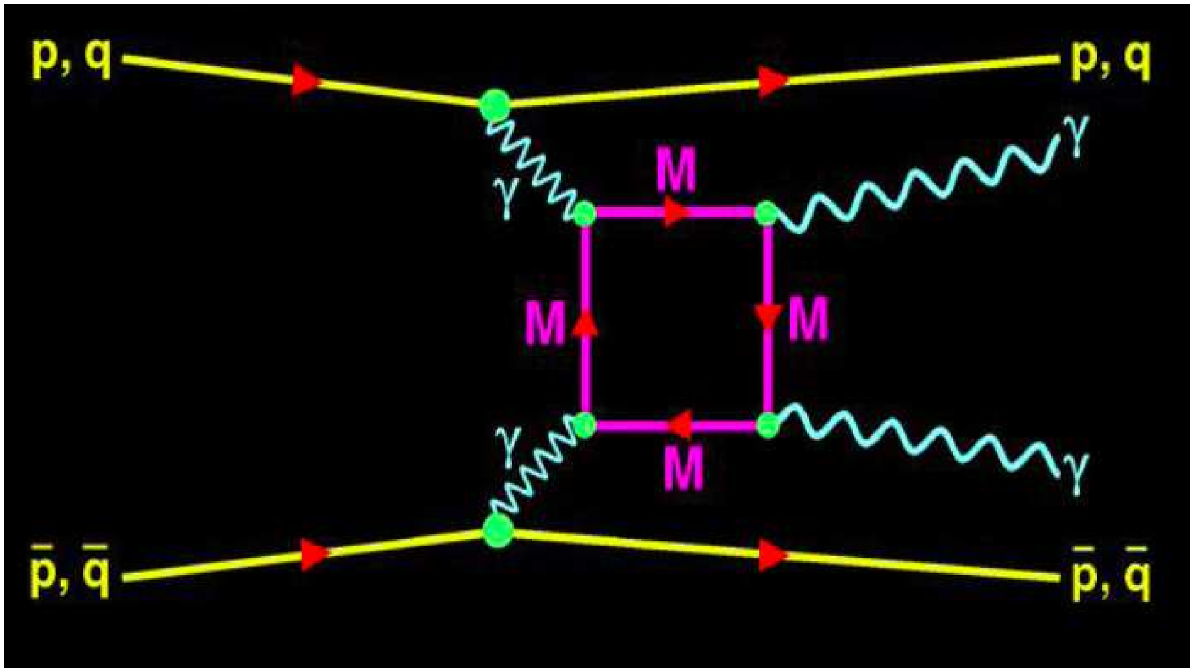
- **Improvement of "standard" LHC methods by studying $pp \to l^{\pm}\nu\gamma\gamma$ (see P. J. Bell, ArXiV:0907.5299) by more than 2 orders of magnitude with 40/300 fb^{-1} at LHC**

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

Additional exclusive event production

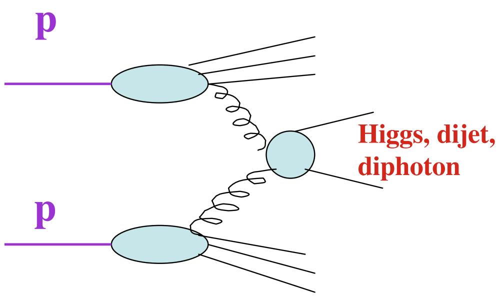




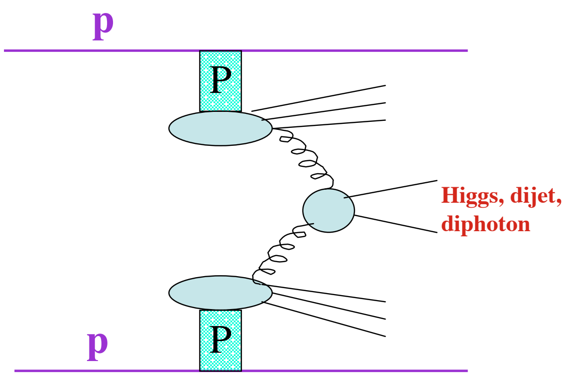


- Production of new objects (with mass up to 1.3 TeV) to be produced either by photon or gluon exchanges: magnetic monopoles, KK resonances, SUSY,... (which could be missed in central ATLAS if predominant decays are hadronic)
- Production of SUSY particles: Possibility of measuring the mass of sleptons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

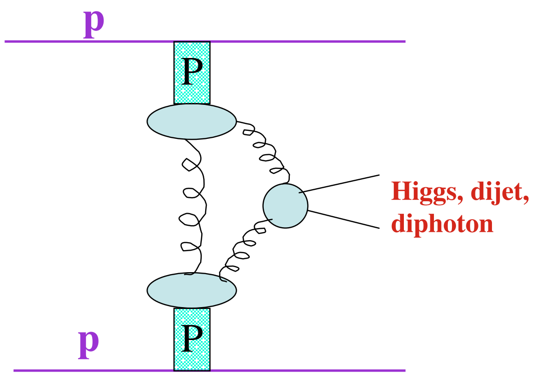
“Exclusive models” in diffraction



Inclusive non diffractive (1)



Inclusive Diffractive (2)

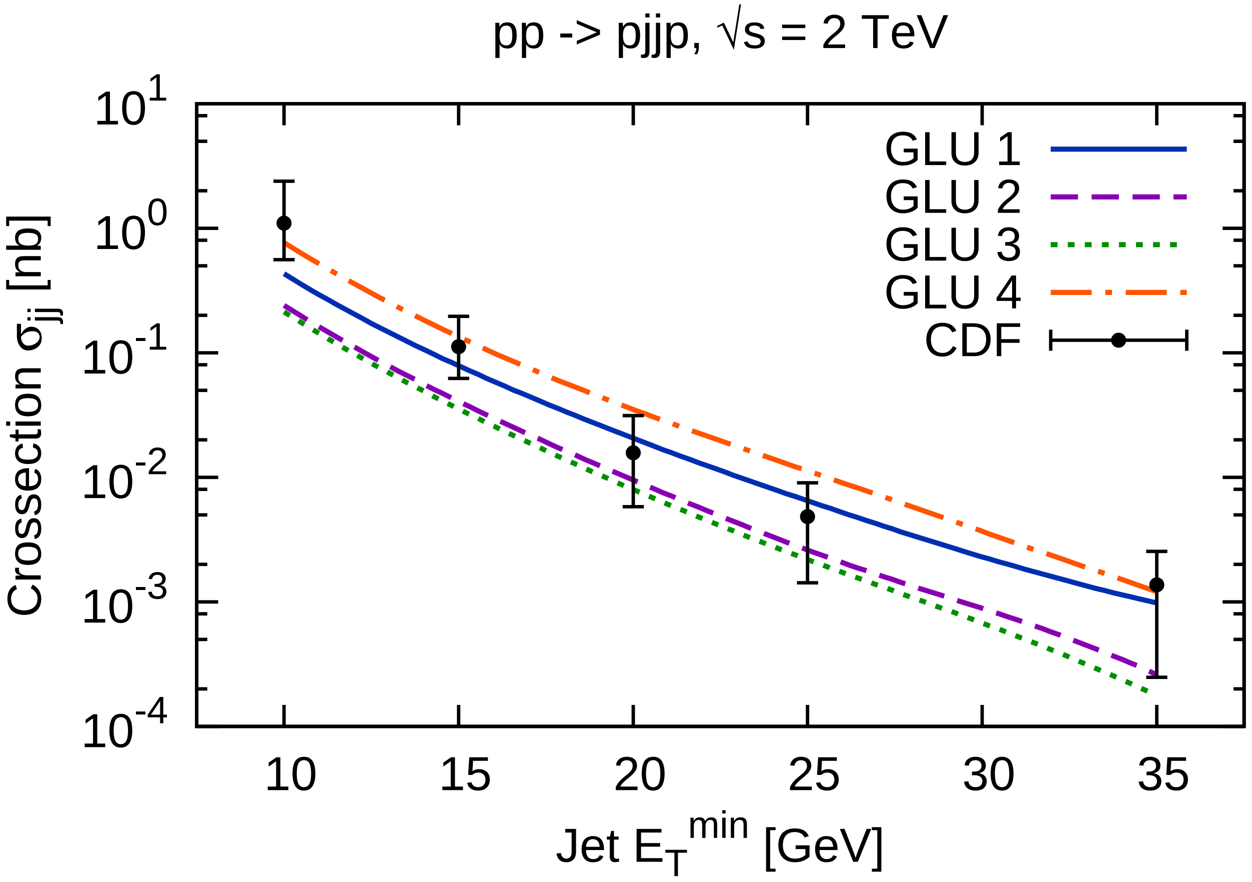


Exclusive Diffractive (3)

- 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., Levin, Maor et al...

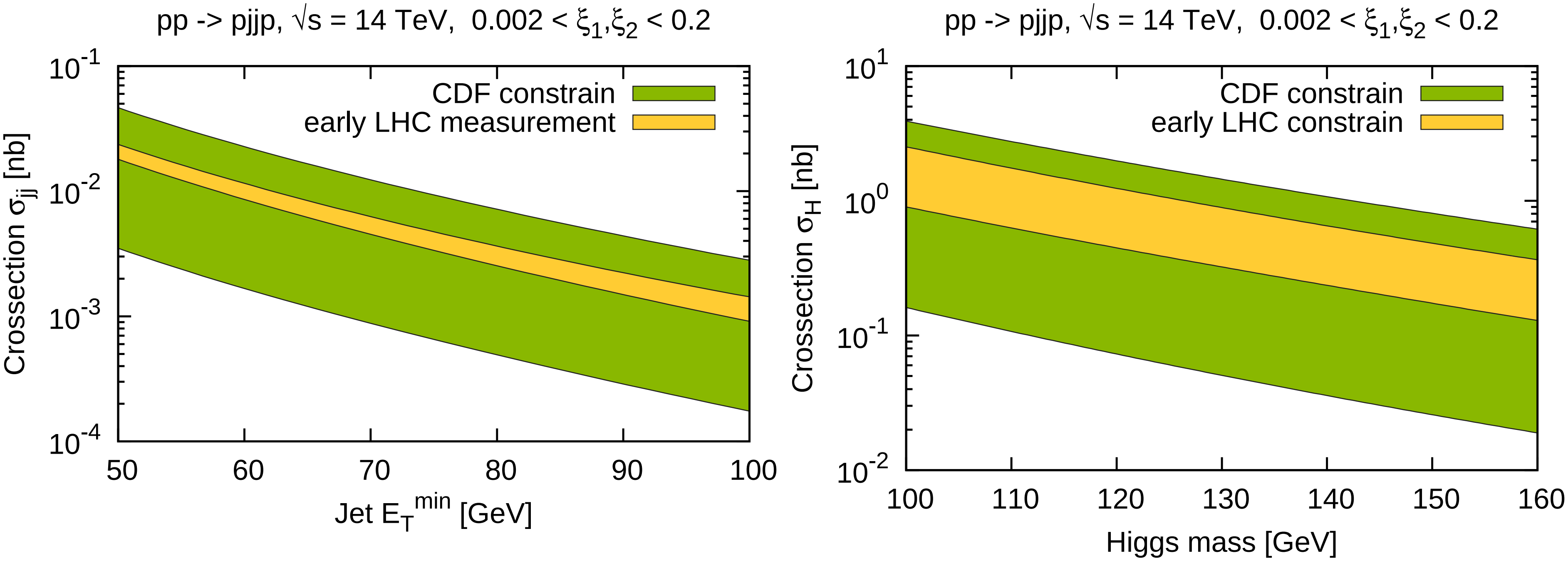
Exclusive model uncertainties - unintegrated gluon

- Study model uncertainties by varying the parameters in KMR model for instance
- 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)



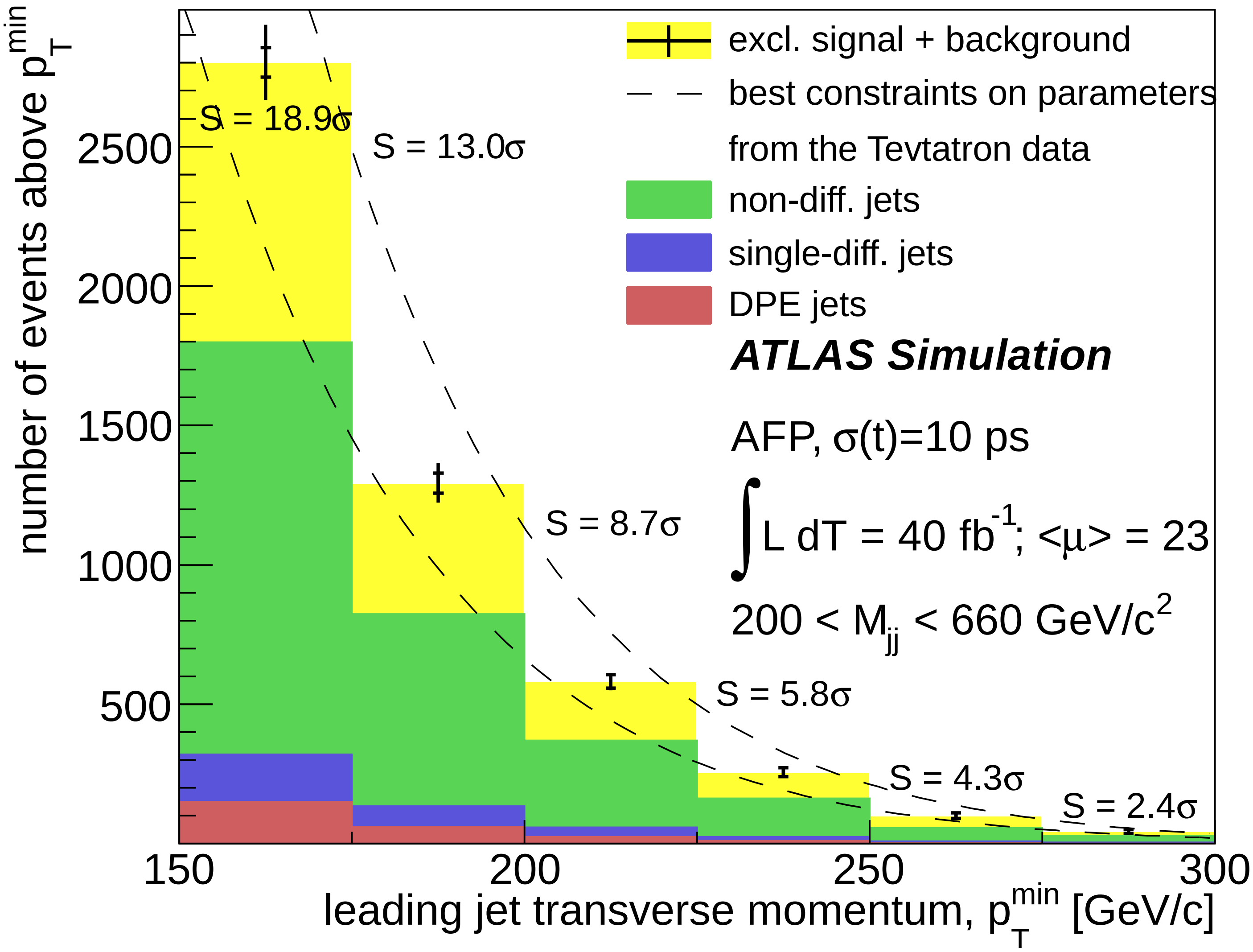
Impact of future LHC measurements on model uncertainty

- 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
- Exclusive Higgs boson cross section: $\sim$ 3 fb for $m_H =$120 GeV, possibility to look for $b\bar{b}$ decay channel



Exclusive jet production at the LHC

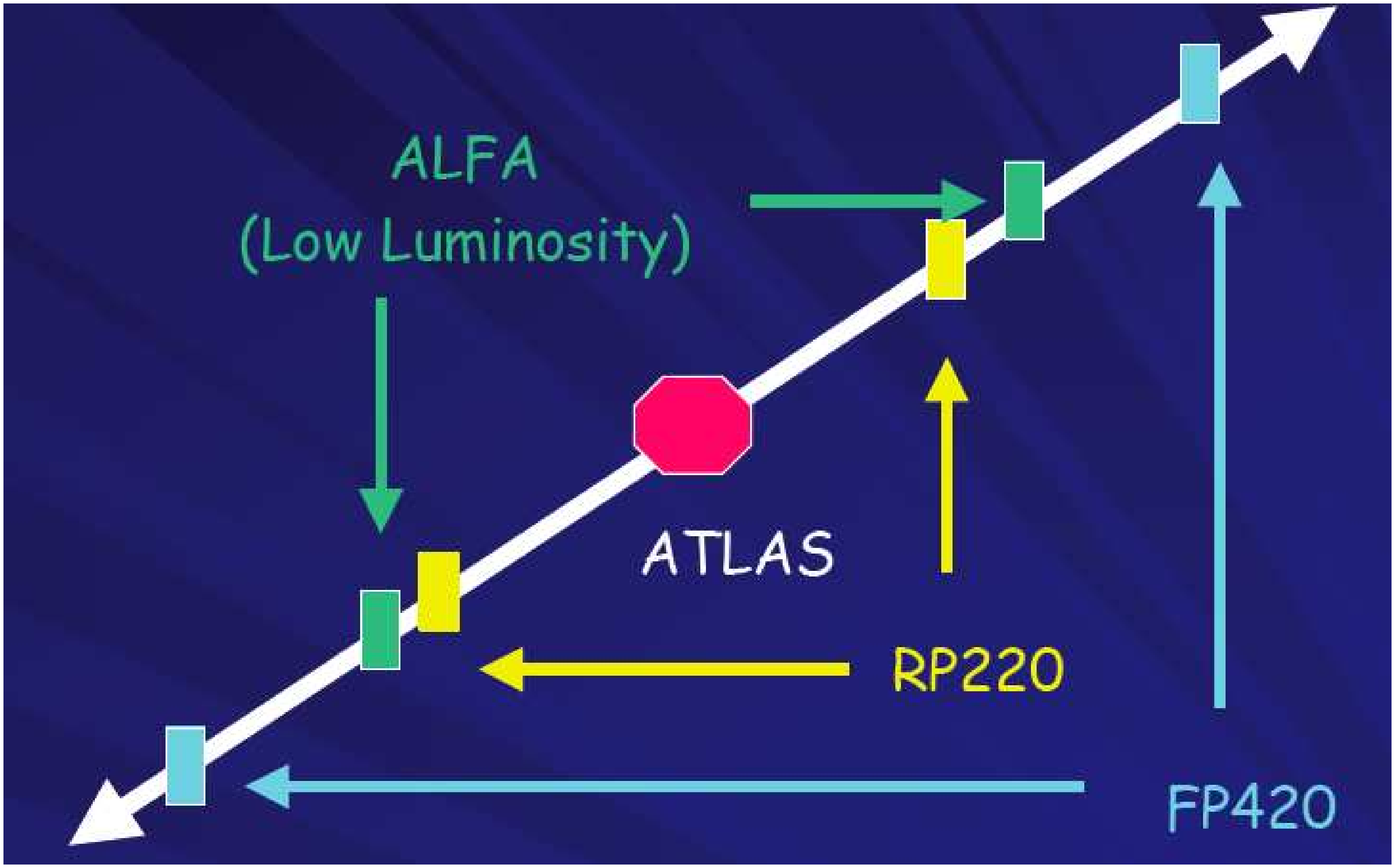
- Jet cross section measurements: up to 18.9 σ for exclusive signal with 40 fb^{-1} ($\mu = 23$): highly significant measurement in high pile up environment, improvement over measurement coming from Tevatron (CDF) studies using $\bar{p}$ forward tagging by about one order of magnitude



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

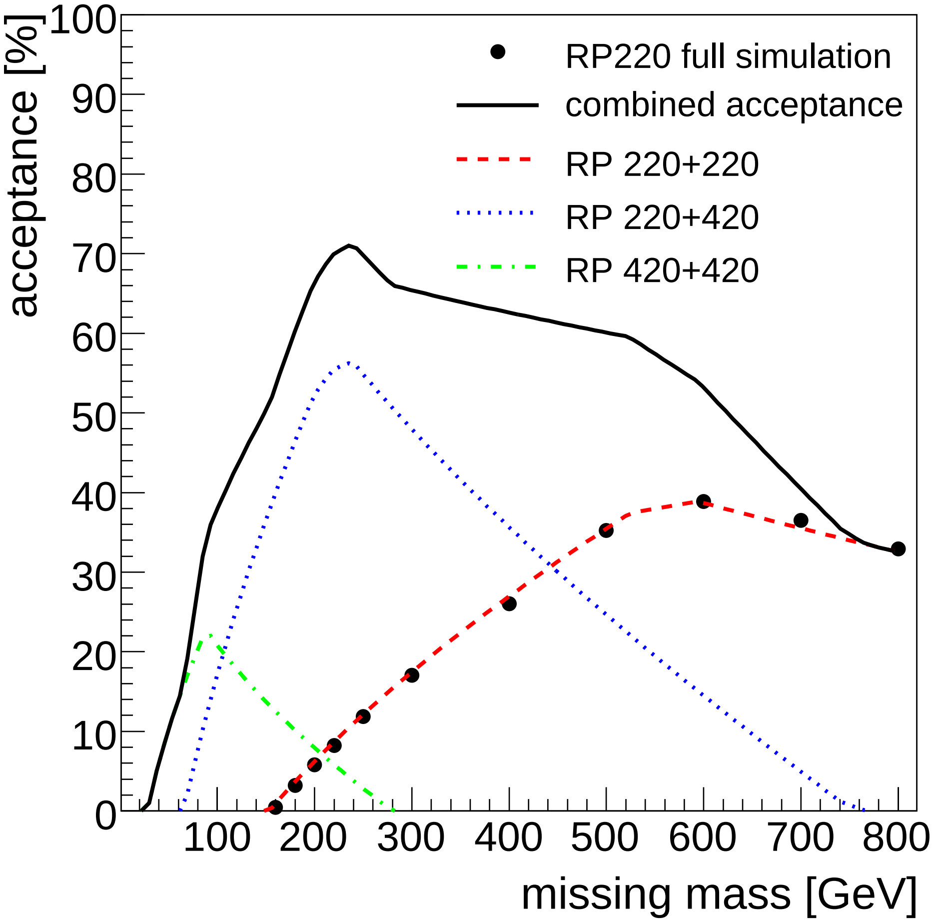
ATLAS and CMS Forward detector projects

- what is needed? Tag the protons intact after interaction, good proton position and good timing measurements (use Si pixel and picosecond quartz/gas detectors
- ATLAS: Detectors at 210 and 420 m (220 m only by 2015)
- CMS: Detectors at 240 and 420 m



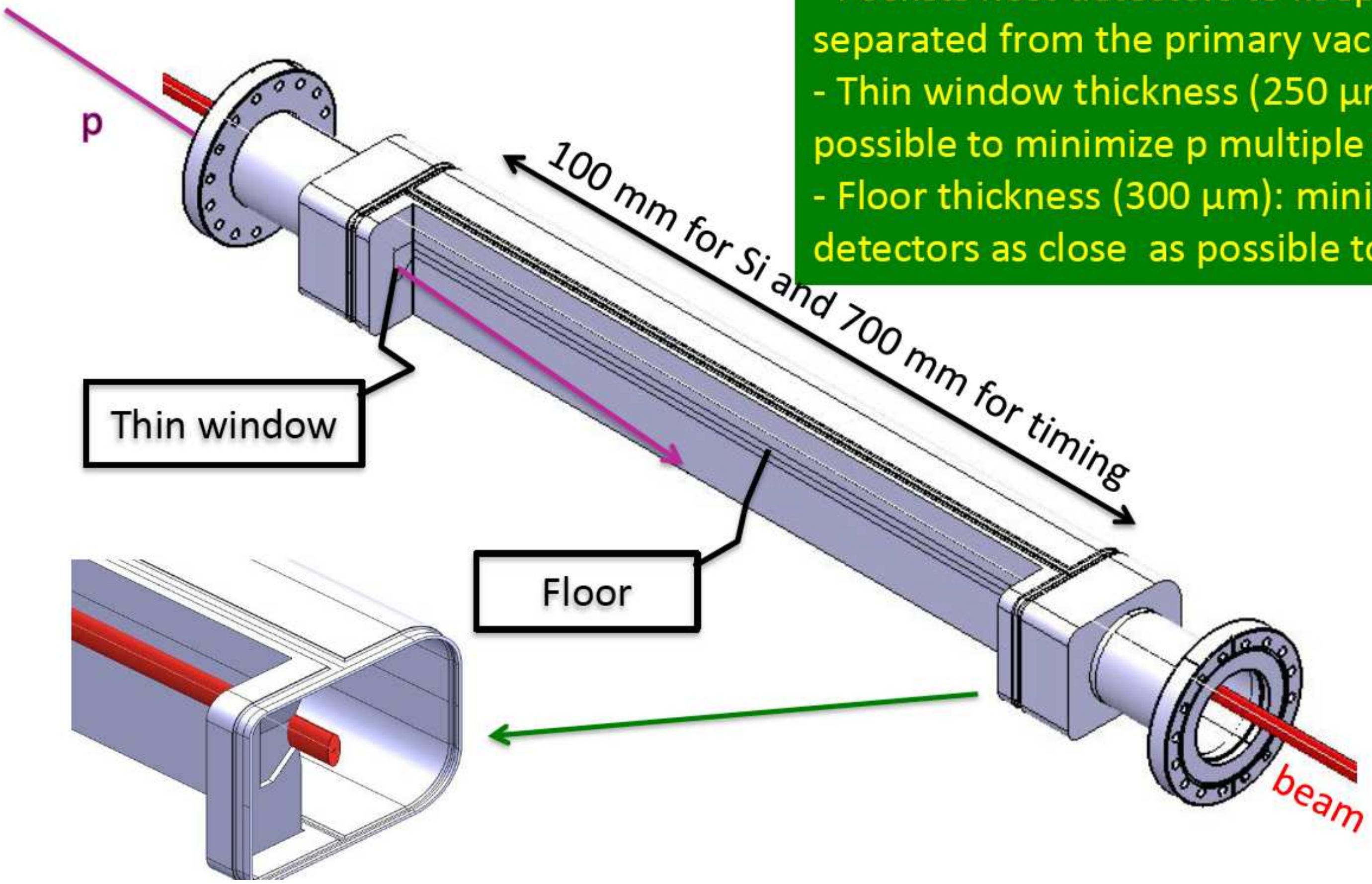
ATLAS Forward Physics detector acceptance

Both detectors at 420 and 220 m needed to have a good coverage of acceptance; 210 m detectors give the high mass acceptance needed for anomalous coupling studies (up to 1.4 TeV) (NB: acceptance slightly smaller in CMS than in ATLAS)



Movable beam pipes

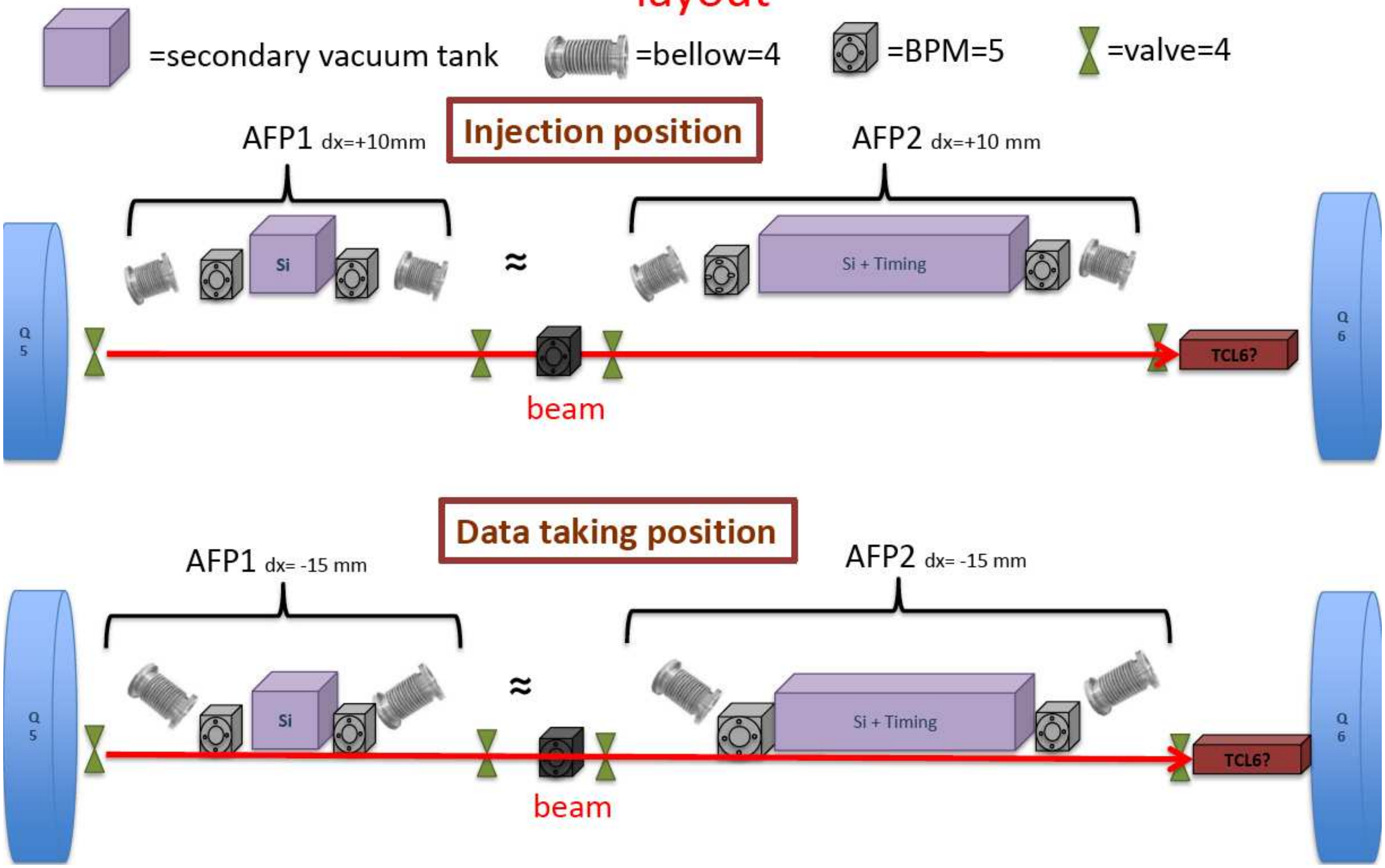
- Allow precise and repeatable movement of detectors close to the beam by $\sim$ 25 mm (HERA, Louvain, CERN)
- Minimum deformation, thin vacuum window (detector a few mm from the beam), small RF impact
- Use standard LHC components (bellows...)



- Pockets host detectors to keep them separated from the primary vacuum
- Thin window thickness (250 µm): as thin as possible to minimize p multiple scattering
- Floor thickness (300 µm): minimized to get the detectors as close as possible to the beam

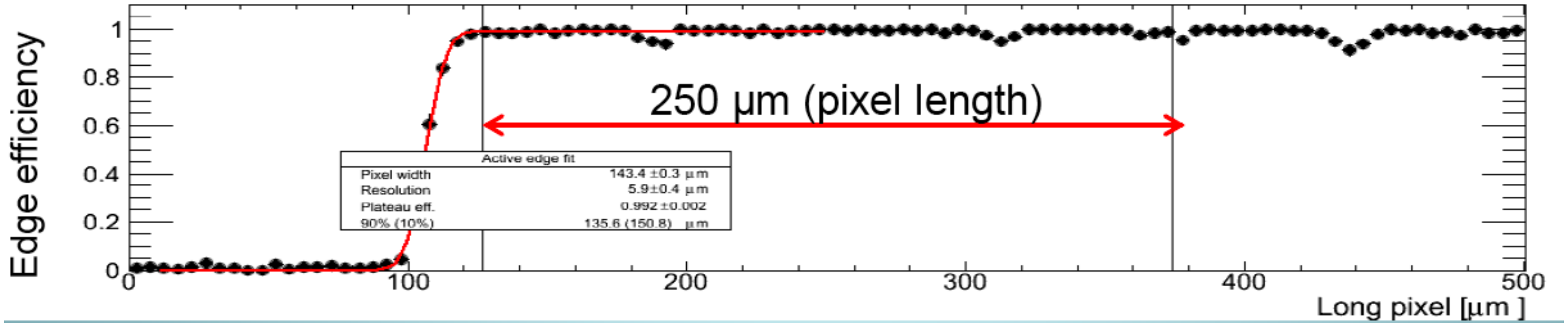
Movable beam pipe: functional specifications

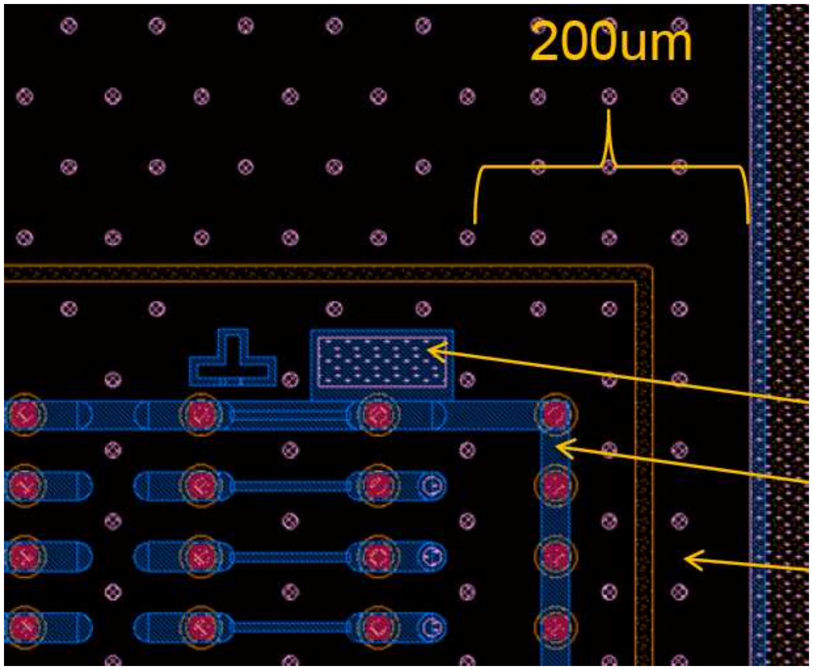
layout



Detector I: 3D Si detector

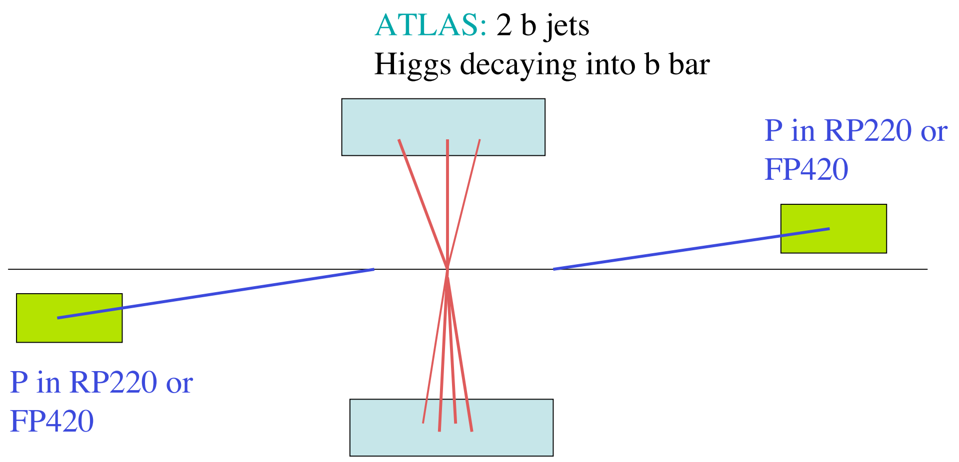
- Key requirements for the Si detector
  - Spatial resolution of 10 (30) μm in x (y) direction over the full detector coverage (2 cm × 2 cm); Angular resolution of 1 μrad
  - Minimal dead space at the edge and radiation hardness

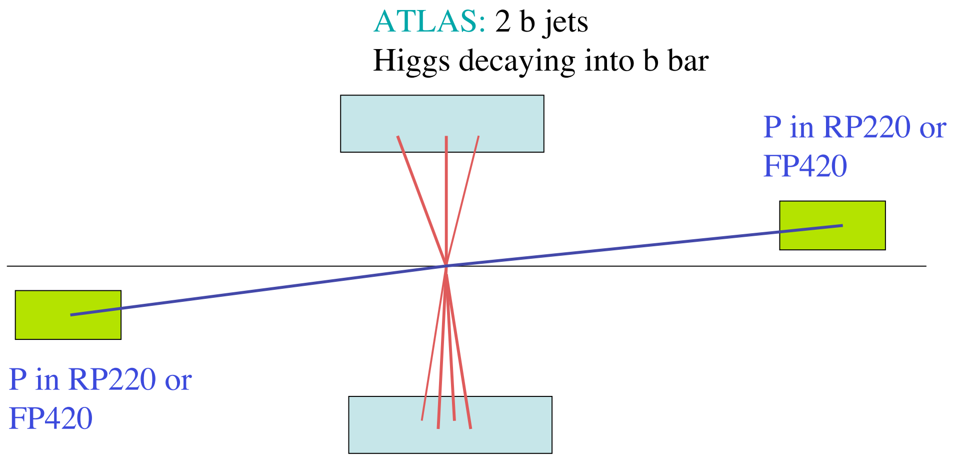




Why do we need timing detectors?

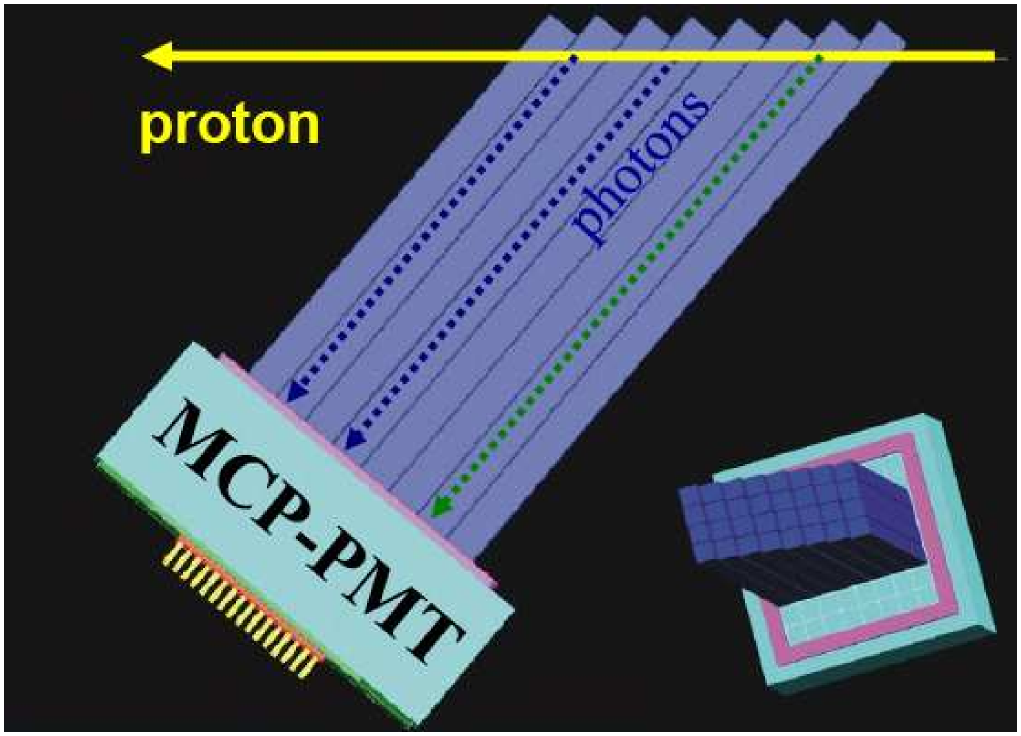
We want to find the events where the protons are related to Higgs production and not to another soft event (up to 35 events occuring at the same time at the LHC!!!!)





Detector II: timing detectors

- Measure the vertex position using proton time-of-flight: suppresses high pile up events at the LHC (50 events in the same bunch crossing), allows to determine if protons originate from main interaction vertex
- Requirements for timing detectors
  - 10 ps final precision (factor 40 rejection on pile up)
  - Efficiency close to 100% over the full detector coverage
  - High rate capability (bunch crossing every 25 ns)
  - Segmentation for multi-proton timing
  - level 1 trigger capability
- 1st version: QUARTIC has 4×8 array of quartz bars; Each proton passes through eight bars in one of the four rows and one only needs a 30-40 ps measurement/bar since one can do it 8 times



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...)
- Many applications in medicine from the timing detectors in PET impaging (new readout chip built in Saclay with a few picoseconds resolution)