

# The ATLAS Forward Physics Project (AFP)

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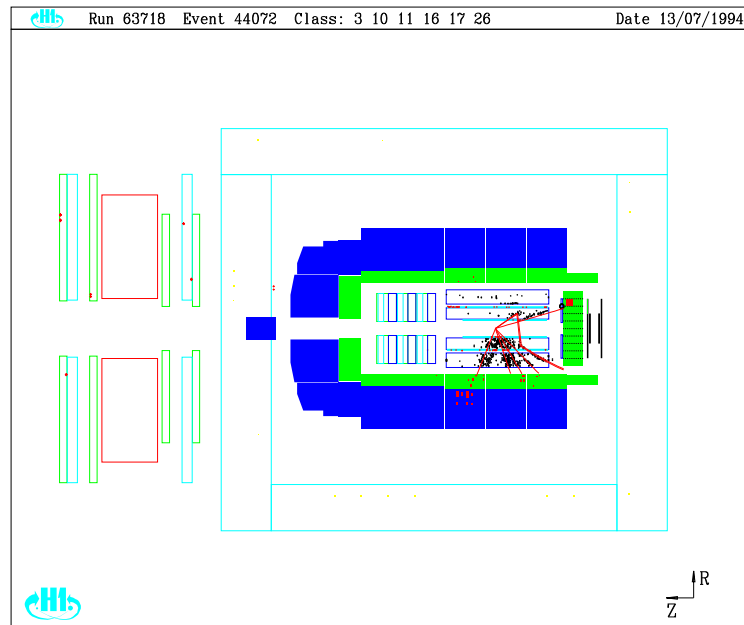
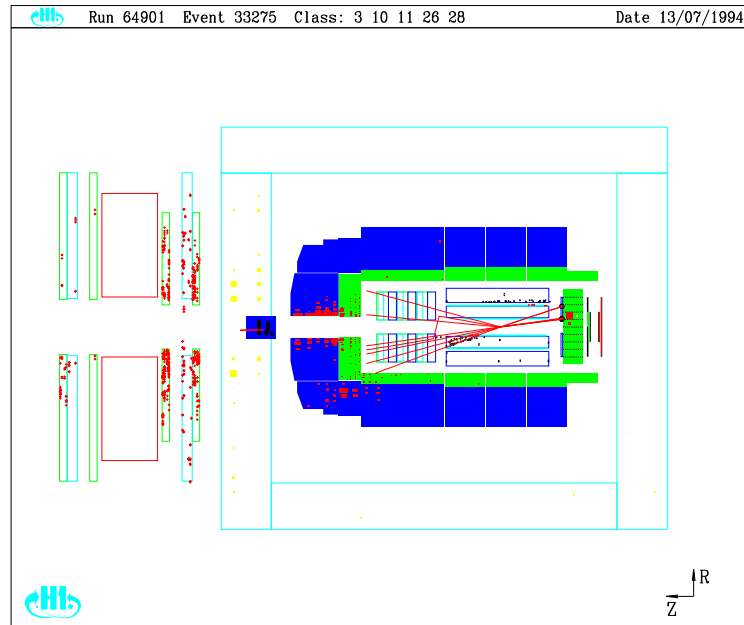
## Contents:

- Definition of diffraction: the example of HERA
- Standard search for the Higgs boson at the Tevatron/LHC
- Hard diffraction at the LHC
- Diffractive Higgs production at the LHC
- Anomalous  $W\gamma$  couplings at the LHC
- ATLAS Forward Physics (AFP) project

## Definition of diffraction: example of HERA

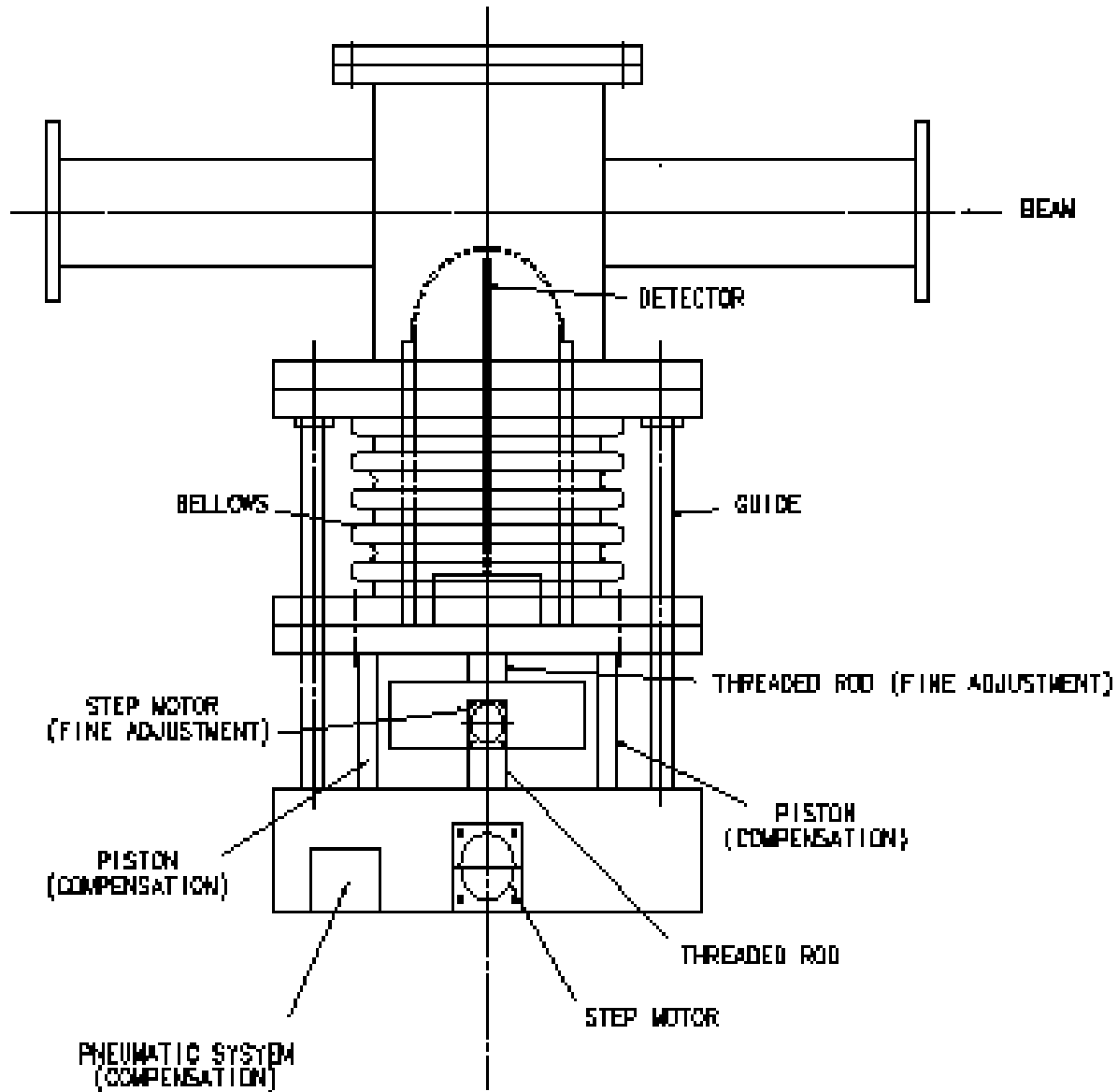
- **Typical DIS event:** part of proton remnants seen in detectors in forward region (calorimeter, forward muon...)
- **HERA observation:** in some events, no energy in forward region, or in other words no colour exchange between proton and jets produced in the hard interaction
- **Leads to the first 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)

# DIS and Diffractive event at HERA

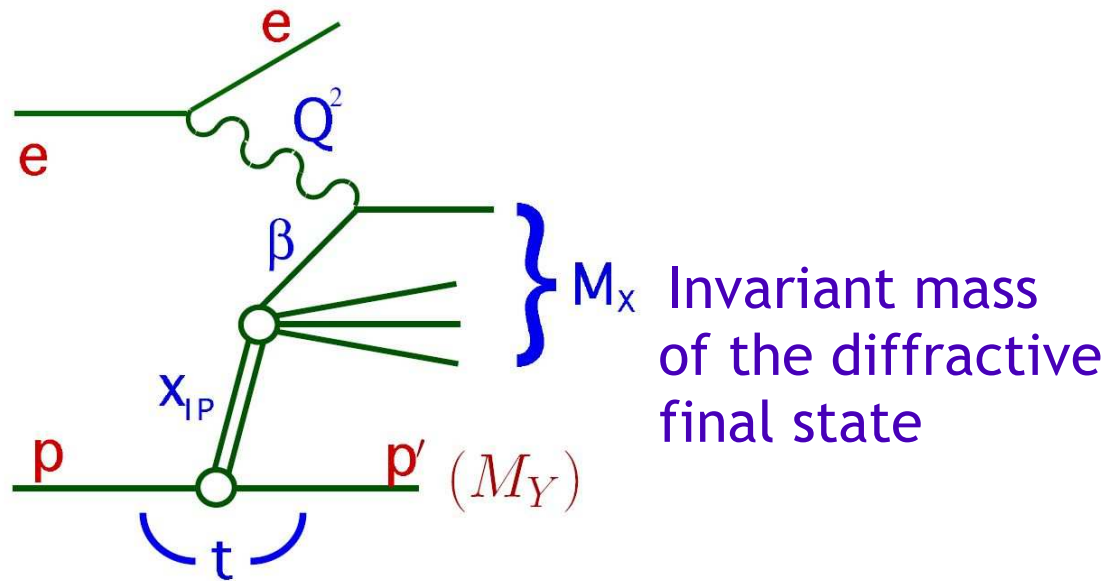


## Scheme of a roman pot detector

Scheme of roman pot detector: traditionally used in diffraction



## 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:  $t = (p - p')^2$

## Measurement of the diffractive structure function $F_2^D$

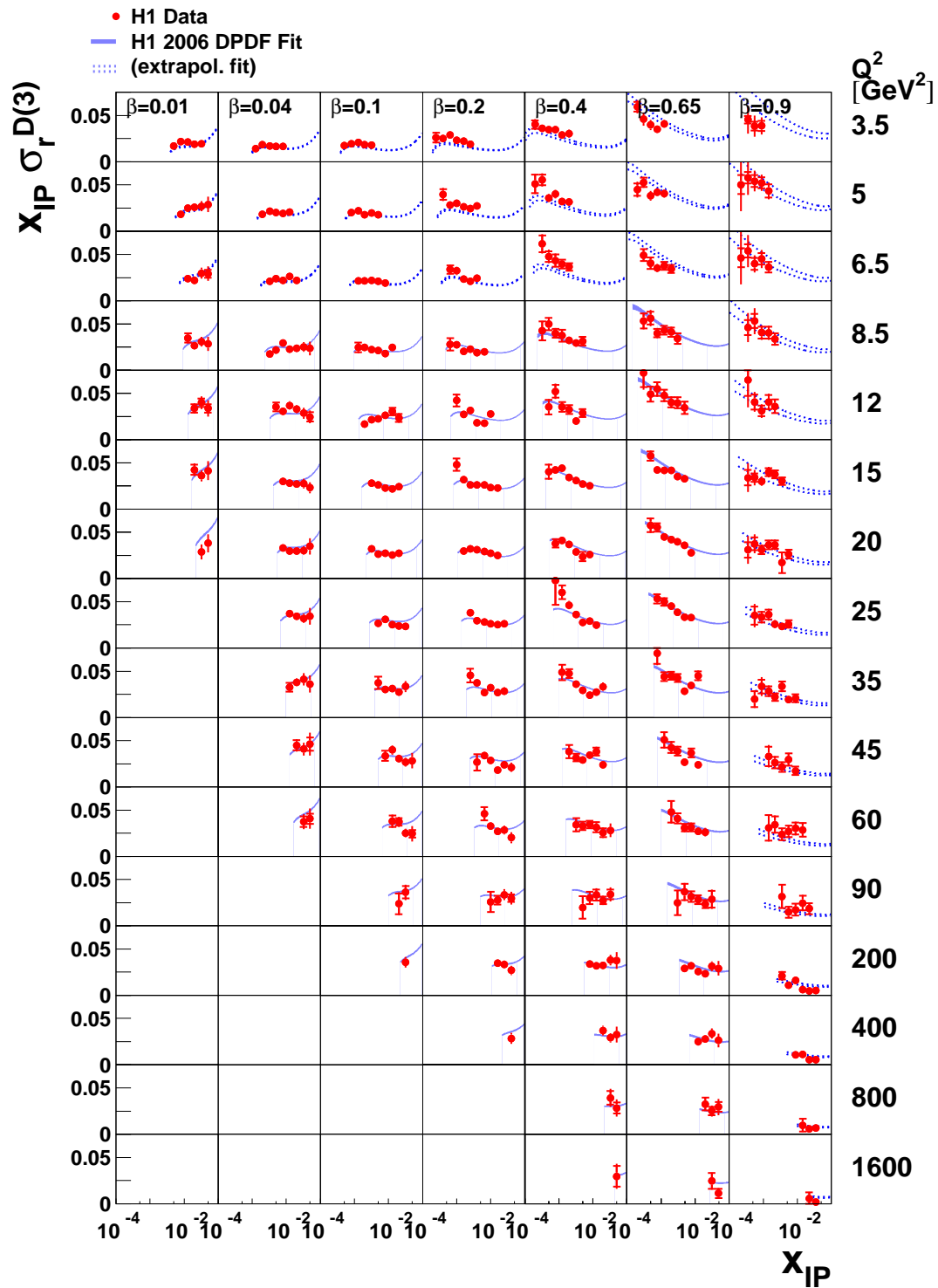
- Measurement of the diffractive cross section using the rapidity gap selection over a wide kinematical domain in  $(x_P, \beta, Q^2)$  (same way as  $F_2$  is measured, there are two additional variables for diffraction,  $t$  is not measured)

- Definition of the reduced cross section:

$$\frac{d^3\sigma^D}{dx_P dQ^2 d\beta} = \frac{2\pi\alpha_{em}^2}{\beta Q^4} \left(1 - y + \frac{y^2}{2}\right) \sigma_r^D(x_P, Q^2, \beta)$$

- As an example: H1 data
- Use these data to make QCD fits and determine the pomeron structure in quarks and gluons:  $\rightarrow$  allows to predict inclusive diffraction at Tevatron/LHC introducing the concept of survival probability

# Measurement of the diffractive structure function $F_2^D$



## Extraction of the parton densities in the pomeron (H1)

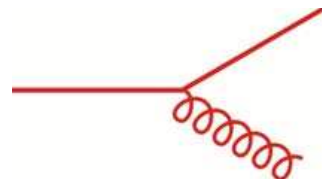
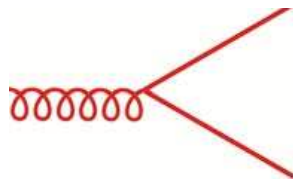
- Assume pomeron made of quarks and gluons: perform QCD DGLAP fits as for the proton structure function starting from  $xG$  and  $xq$  distributions at a given  $Q_0^2$ , and evolve in  $Q^2$  (the form of the distributions is MRS like)

$$\beta q = A_q \beta^{B_q} (1 - \beta)^{C_q}$$

$$\beta G = A_g (1 - \beta)^{C_g}$$

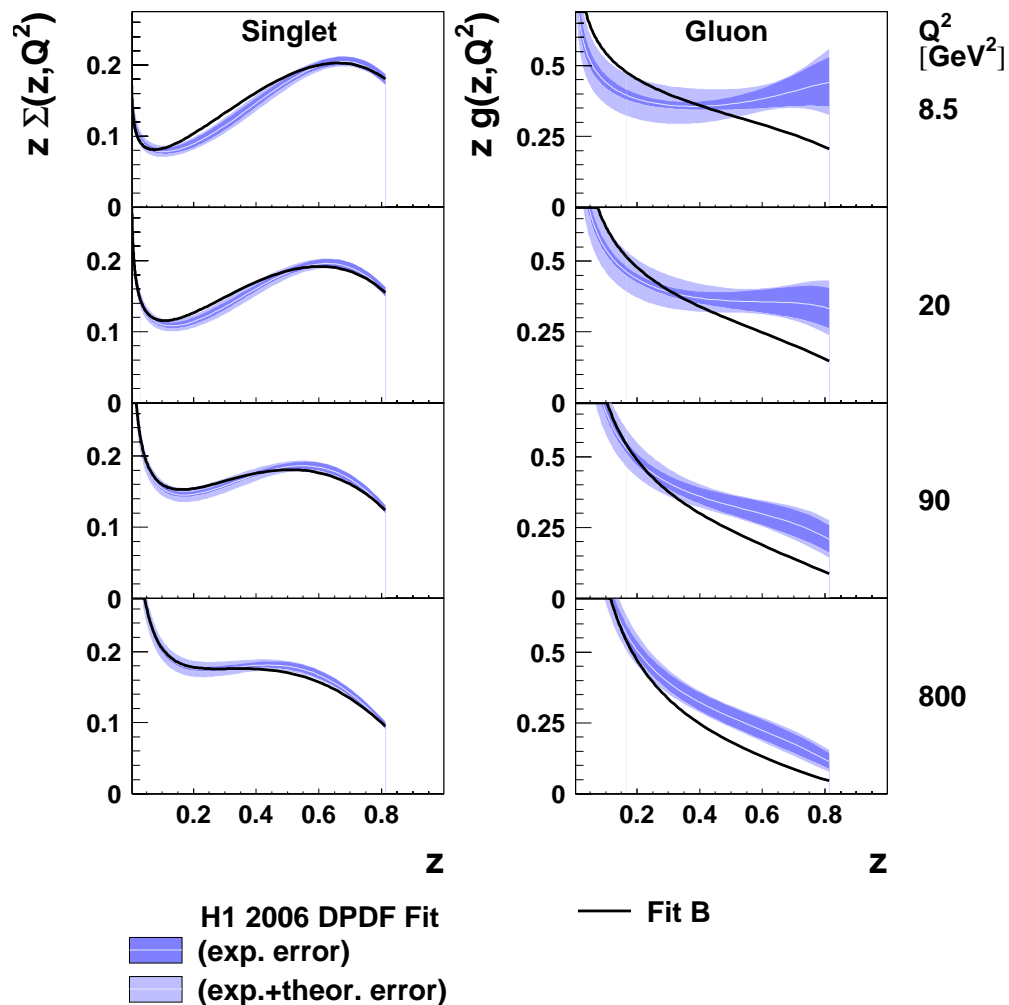
- At low  $\beta$ : evolution driven by  $g \rightarrow q\bar{q}$ , at high  $\beta$ ,  $q \rightarrow qg$  becomes important
- Take all data for  $Q^2 > 8.5 \text{ GeV}^2$ ,  $\beta < 0.8$  to be in the perturbative QCD region and avoid the low mass region (vector meson resonances)

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



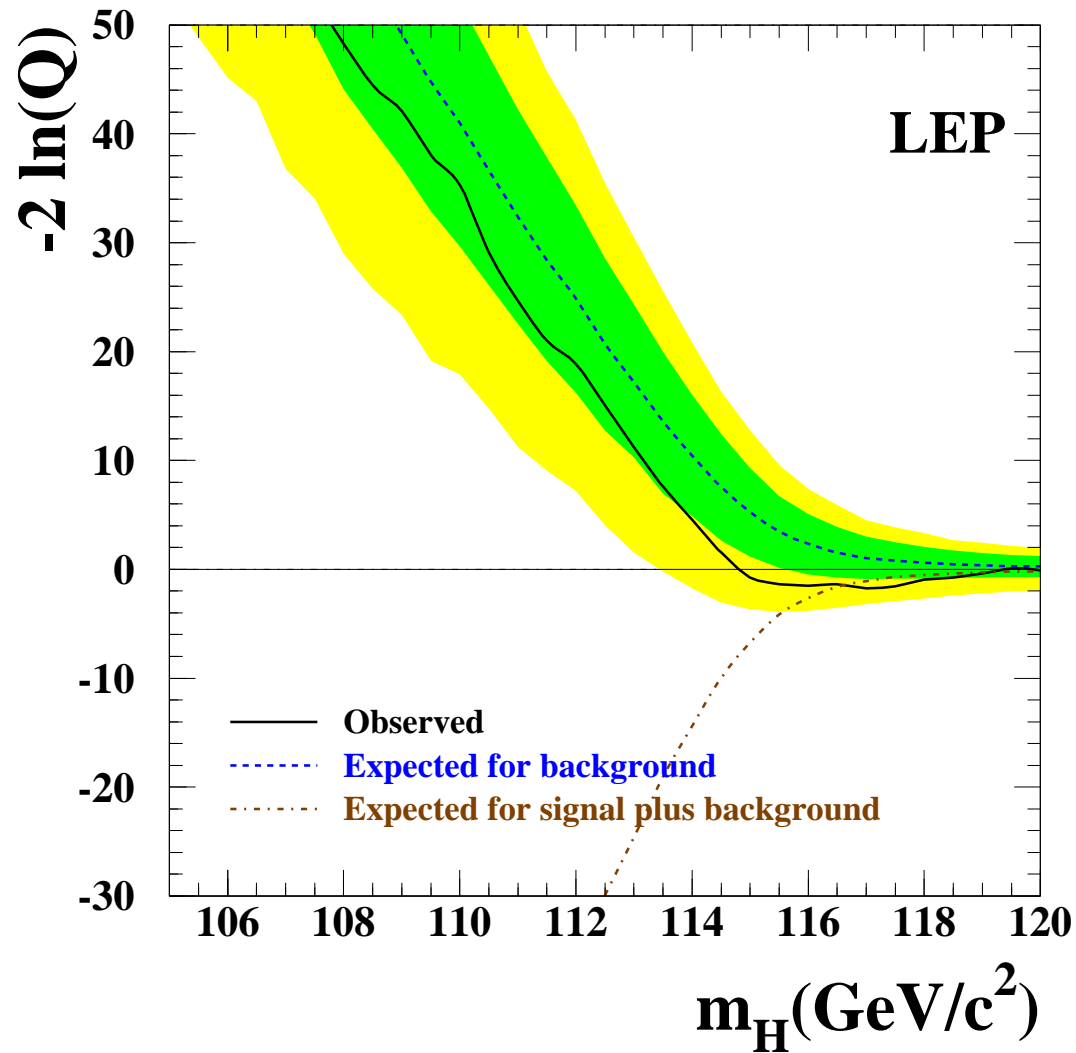
## Parton densities in the pomeron (H1)

- Extraction of gluon and quarks densities in pomeron: gluon dominated
- Gluon density poorly constrained at high  $\beta$  (imposing  $C_g = 0$  leads to a good fit as well, Fit B)
- Good description of final states



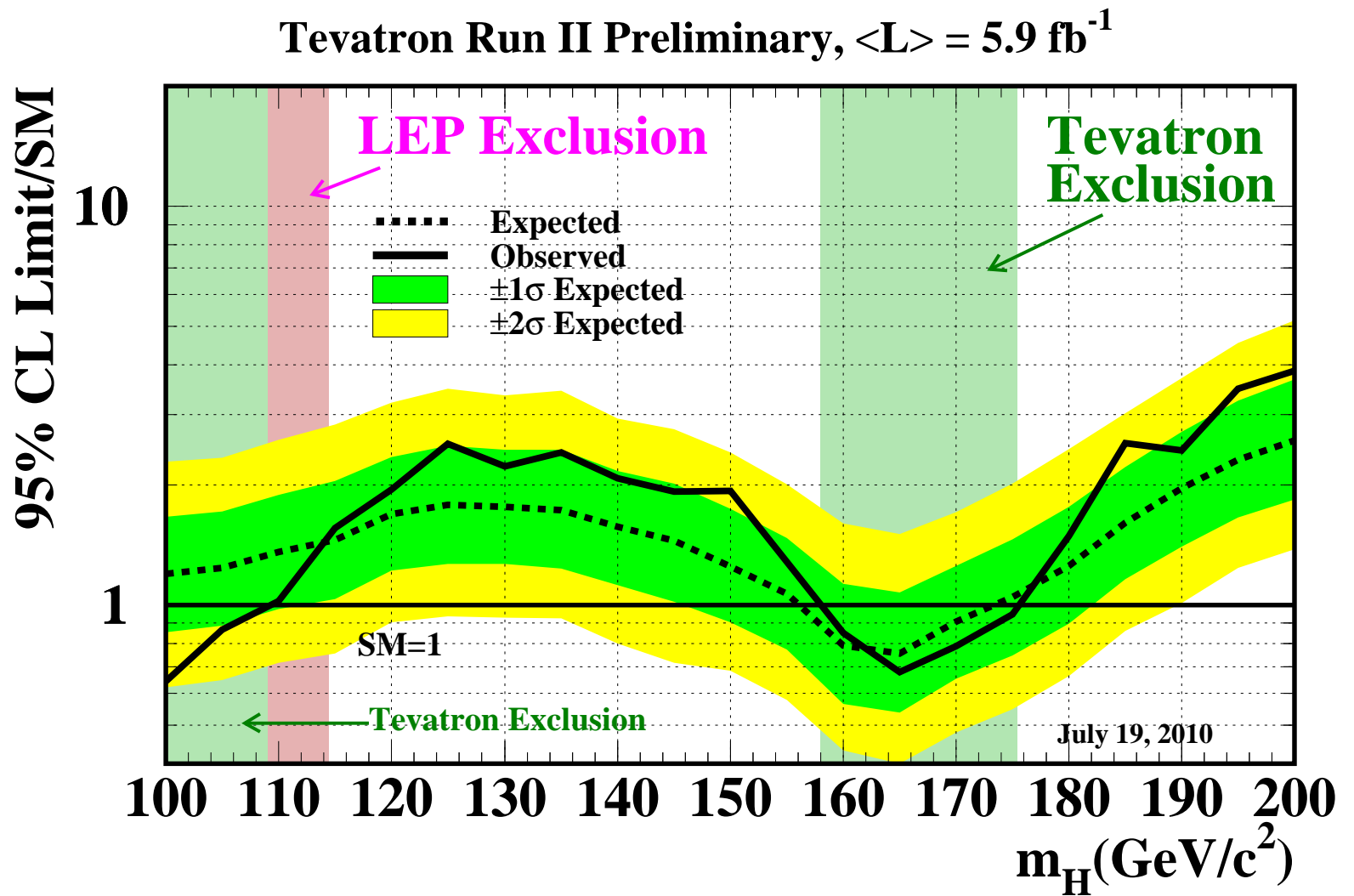
## LEP experiments limits on Higgs mass

- Q: ratio of the probability to observe what has been seen if it is a Higgs signal by the probability to observe the same if it is only background
- Limit on Higgs mass: 114.4 GeV



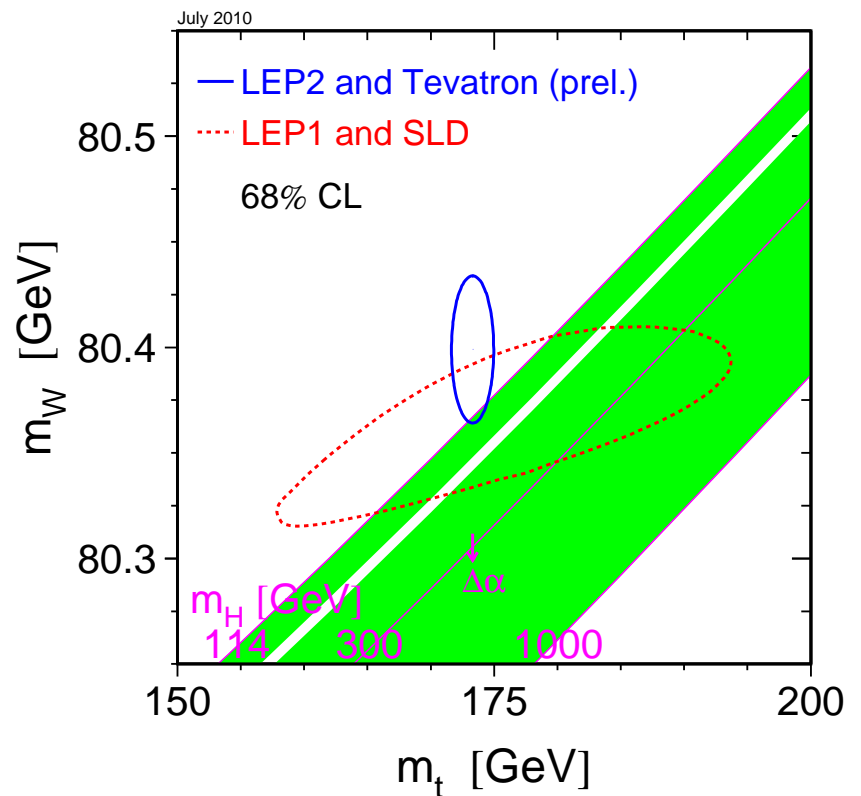
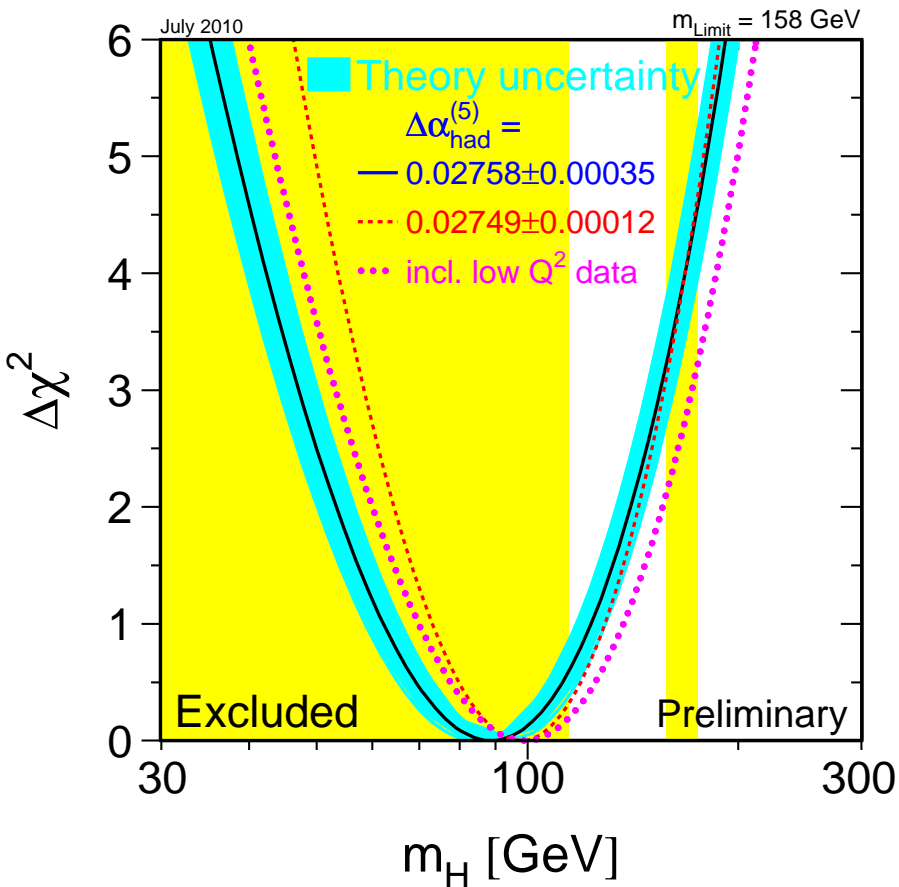
## Tevatron limit on Higgs mass

Best sensitivity around 165 GeV; new D0-CDF combination excludes region around 158-175 GeV



## Electroweak fits and mass of Higgs boson

- Use new  $M_{top}$ , width of  $W$  boson from Tevatron and LEP, and mass of  $W$  from LEP and Tevatron
- $M_{Higgs} = 89 + 35 - 26$  GeV (68% CL), and  $< 158$  GeV at 95% CL



## Tevatron running prospects

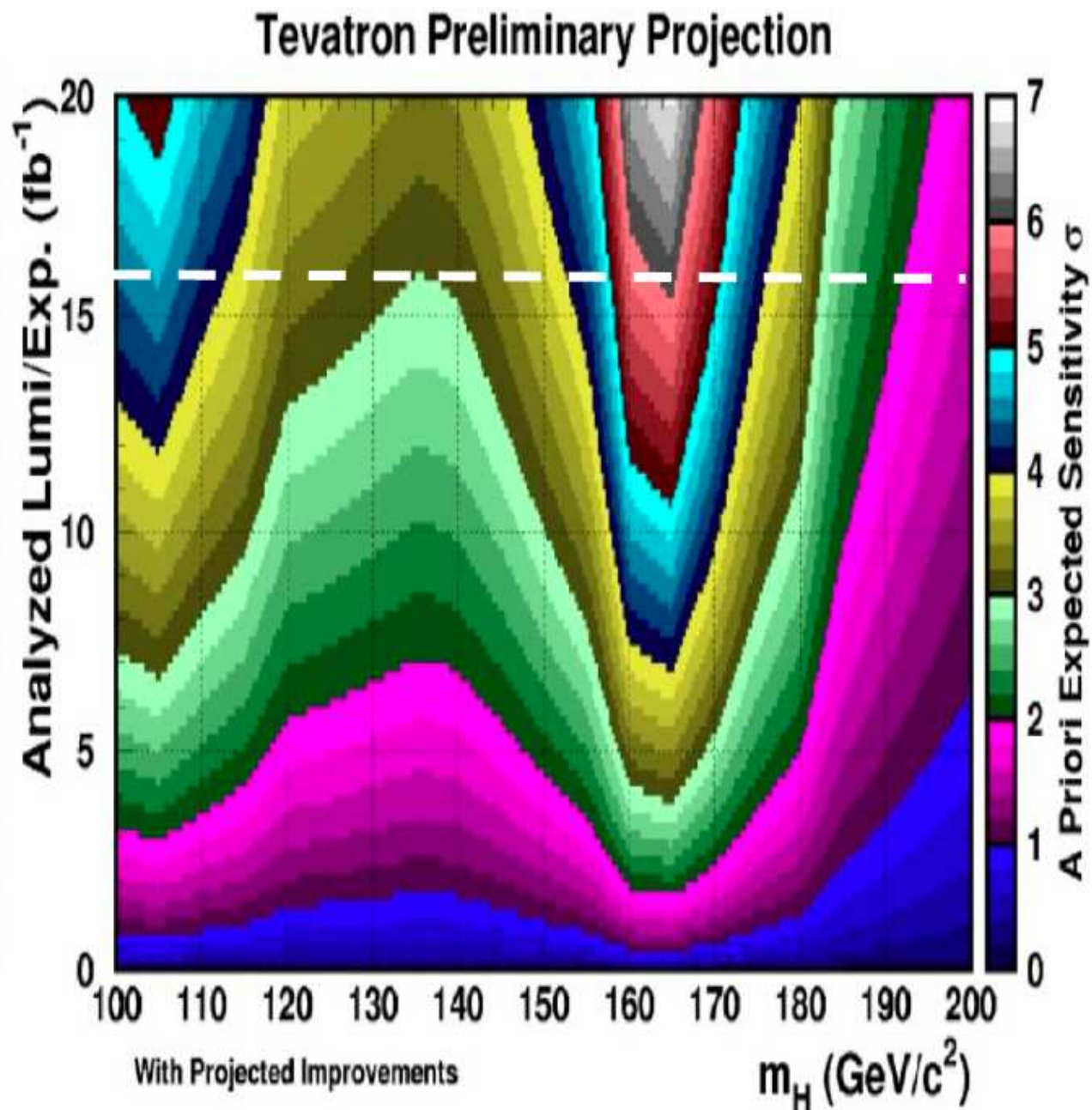
- Prospects of  $10 \text{ fb}^{-1}$  of accumulated luminosity (12 delivered) per experiment by FY2011
- Accumulated luminosity of  $16 \text{ fb}^{-1}$  if running until 2014

Tevatron Run II Integrated Luminosity and Projection



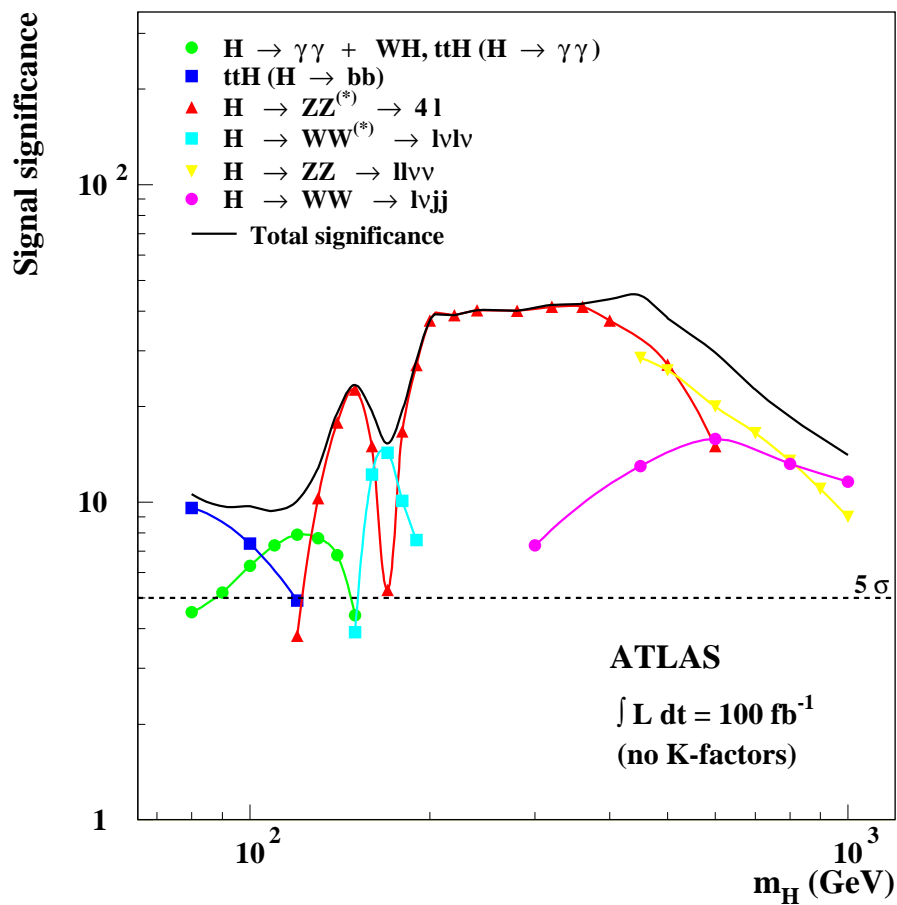
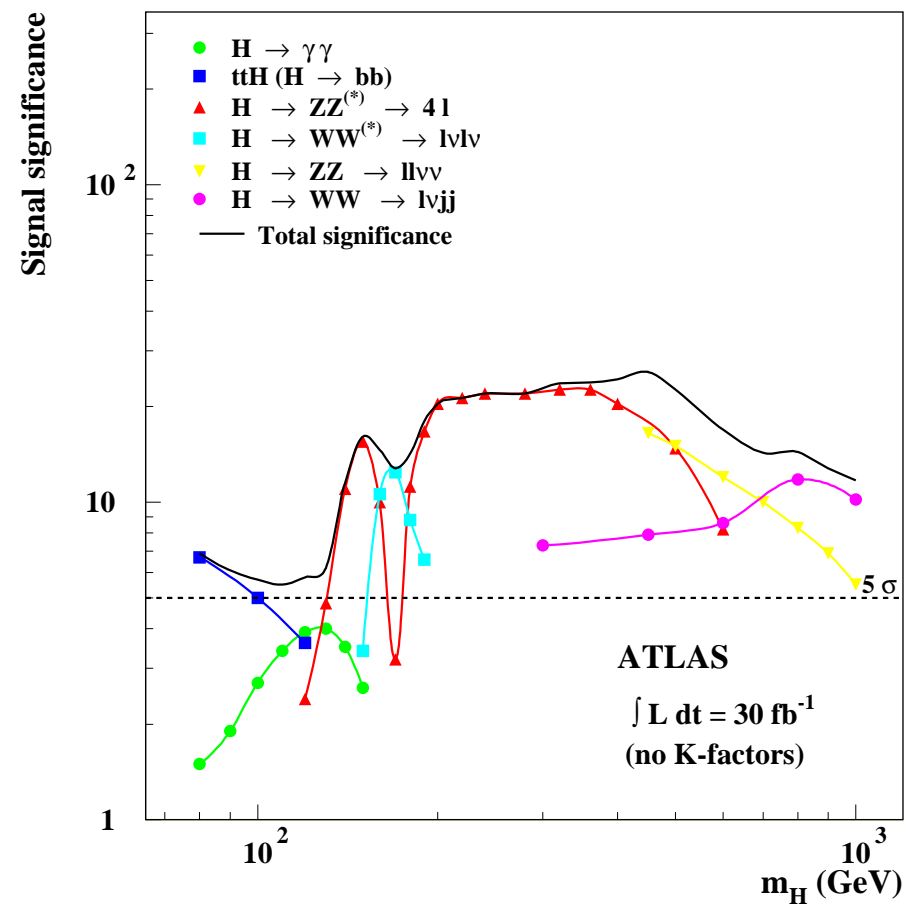
## Expectation at the Tevatron

- Low mass region more difficult
- Possibility of  $3\sigma$  evidence or exclusion over the full mass range
- Analysis of Higgs boson properties: mass, spin... → LHC

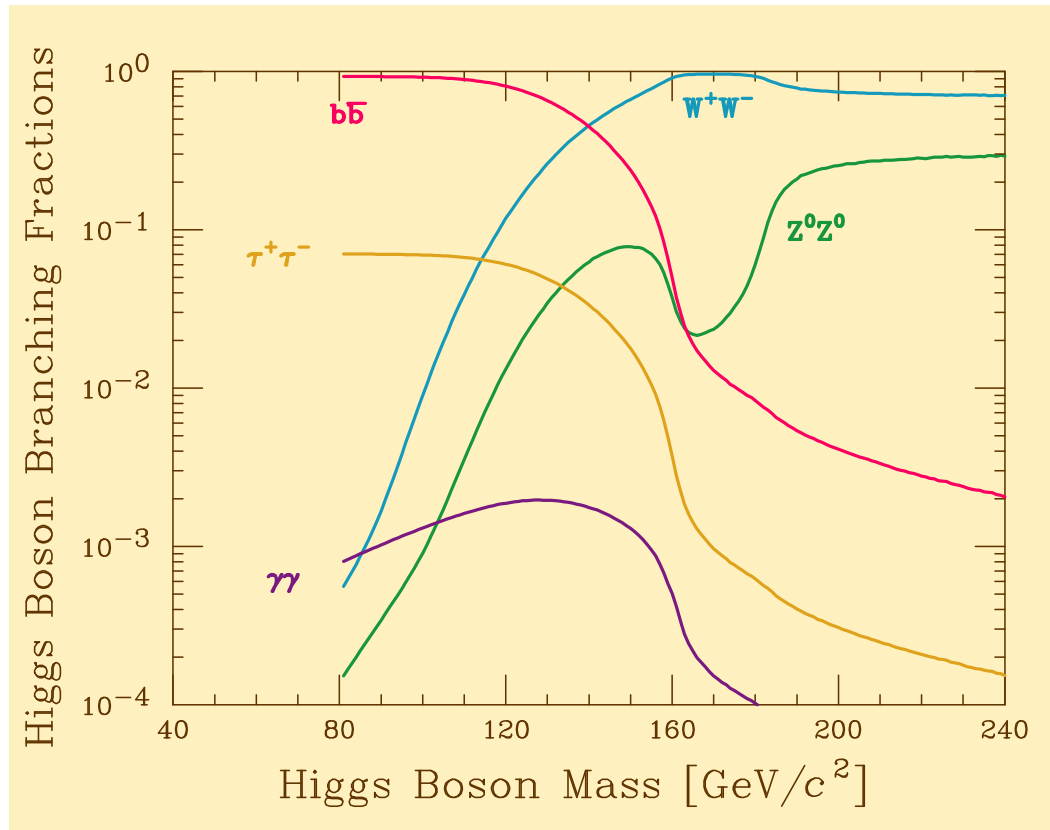


# Standard search for Higgs boson at the LHC

Low masses: difficult region at the LHC: other ways of finding the Higgs boson

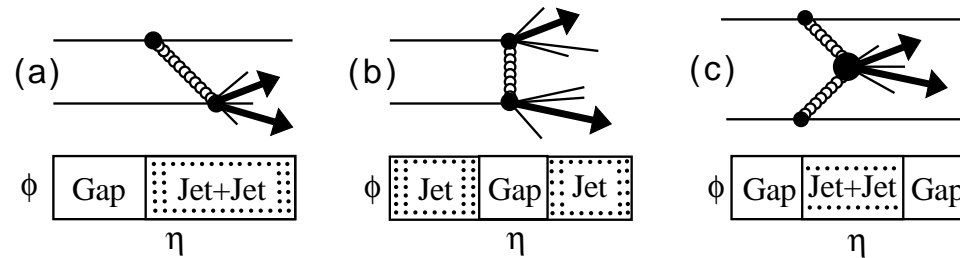


## SM Higgs decay



Low masses:  $b\bar{b}$  and  $\tau\tau$  dominate  
High masses:  $WW$  dominates

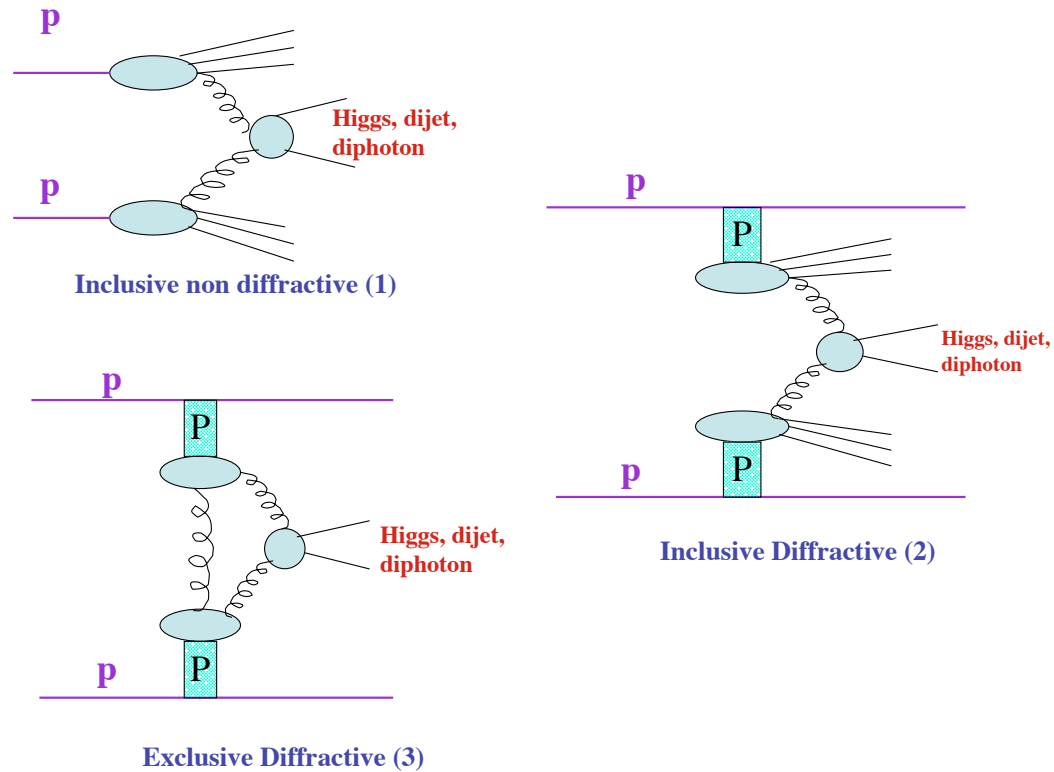
## Diffraction at Tevatron/LHC



### Kinematic variables

- $t$ : 4-momentum transfer squared
- $\xi_1, \xi_2$ : 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

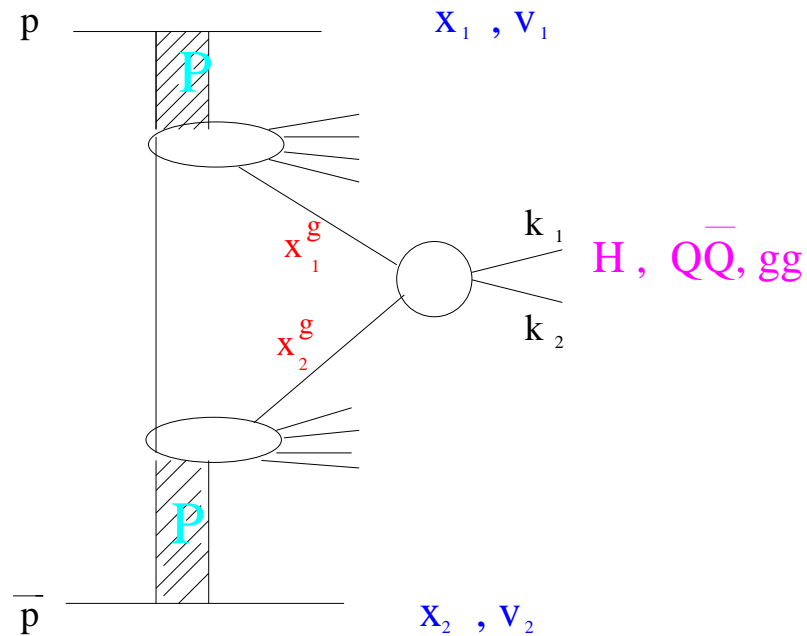
## “Exclusive models” in diffraction



- All the energy is used to produce the Higgs (or the dijets), namely  $xG \sim \delta$
- Possibility to reconstruct the Higgs boson properties from the tagged proton: system completely constrained
- See papers by Khoze, Martin, Ryskin; Boonekamp, Peschanski, Royon...

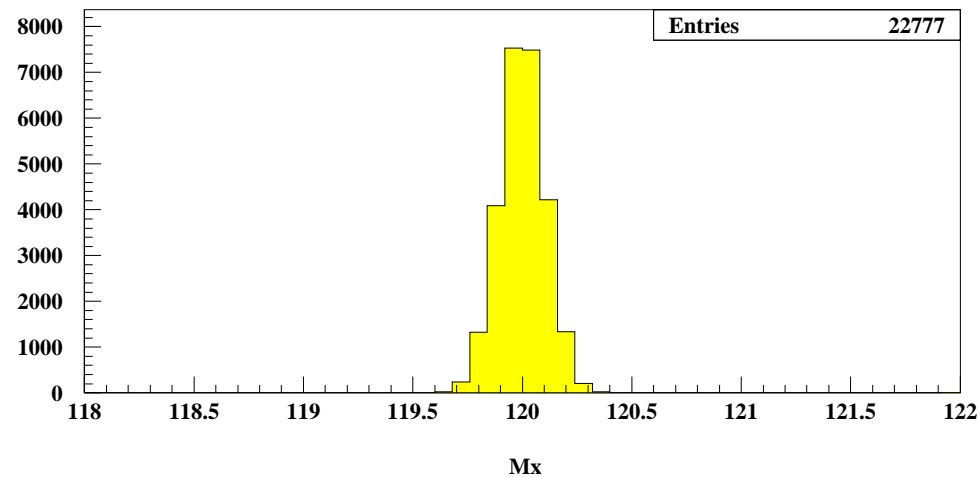
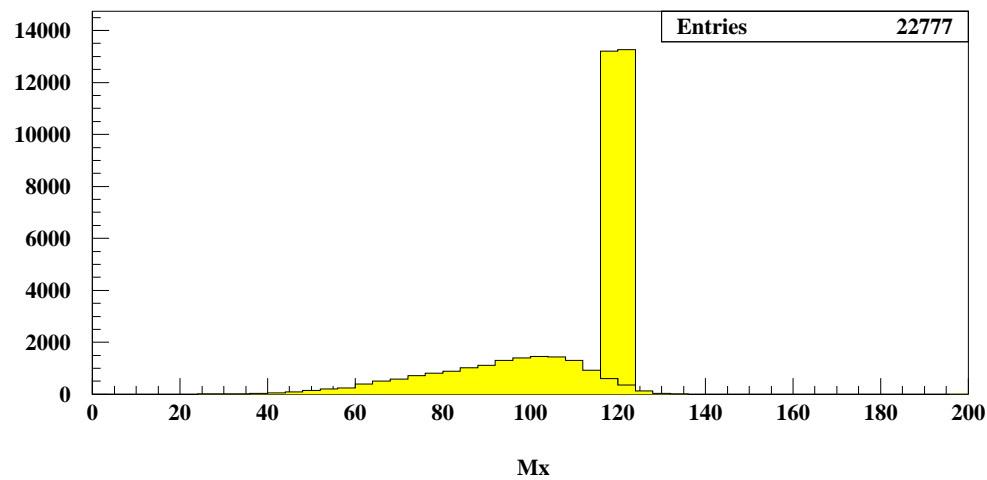
## “Inclusive” models

- “Inclusive” models: Take the hard matrix element convoluted with the parton distributions in the pomeron
- Take shape of H1 measurement of gluon/quark density in pomeron
- Survival probability introduced for normalisation
- Inclusive cross sections need to be known in detail since it is a direct background to search for exclusive events



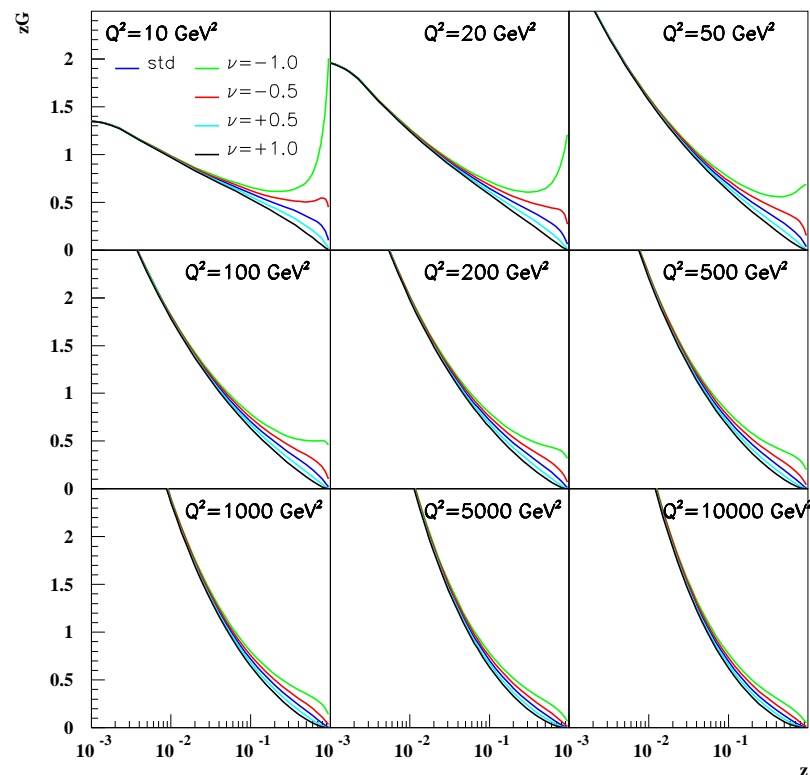
## Advantage of exclusive Higgs production?

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



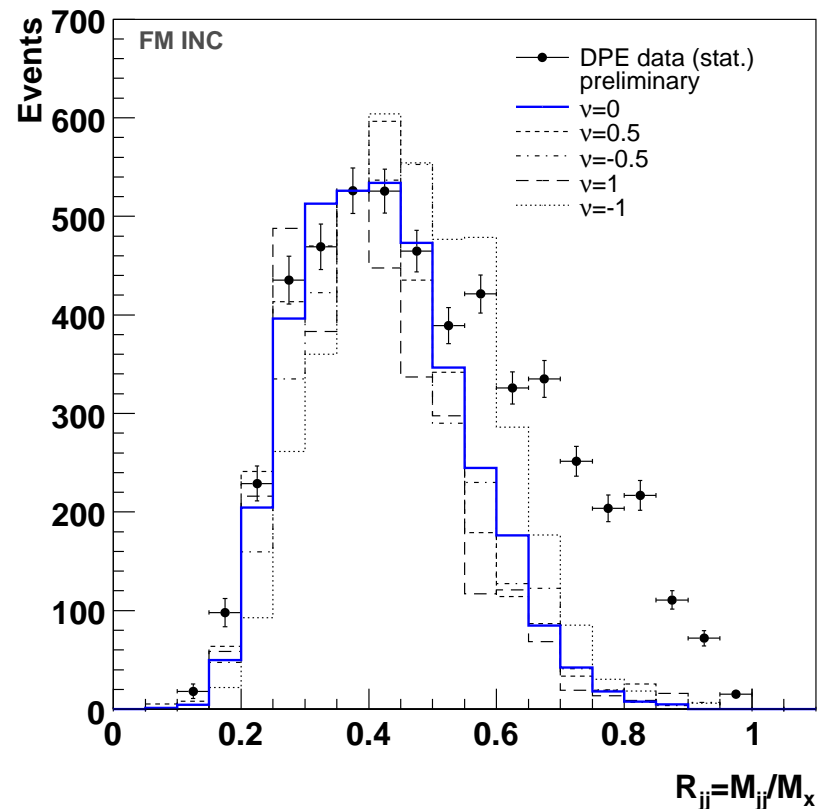
## Looking for exclusive events: uncertainty on high $\beta$ gluon

- Important to know the high  $\beta$  gluon since it is a contamination to exclusive events
- Experimentally, quasi-exclusive events indistinguishable from purely exclusive ones
- Uncertainty on gluon density at high  $\beta$ : multiply the gluon density by  $(1 - \beta)^\nu$  (fit:  $\nu = 0.0 \pm 0.6$ )



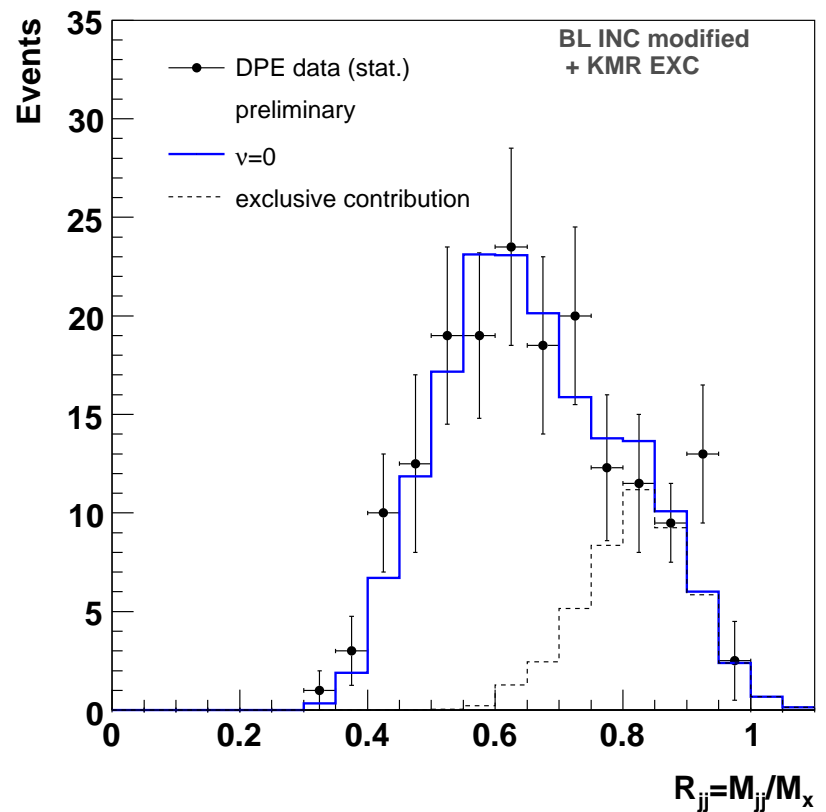
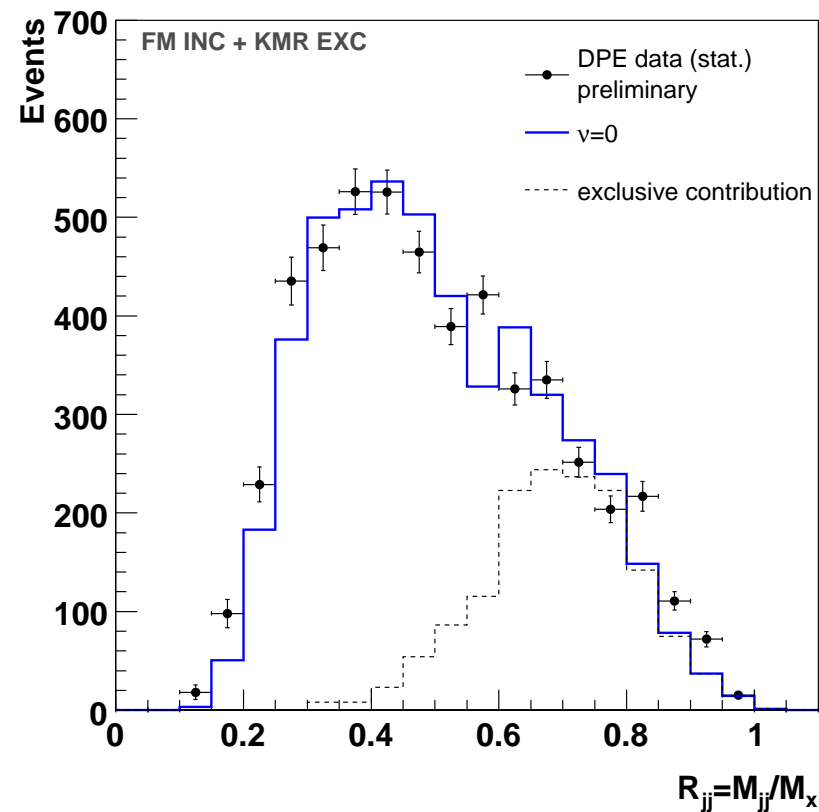
## Dijet mass fraction measurement in CDF

- Look for exclusive events (events where there is no pomeron remnants or when the full energy available is used to produce diffractively the high mass object)
- Select events with two jets only, one proton tagged in roman pot detector and a rapidity gap on the other side
- Predictions from inclusive diffraction models for Jet  $p_T > 10$  GeV



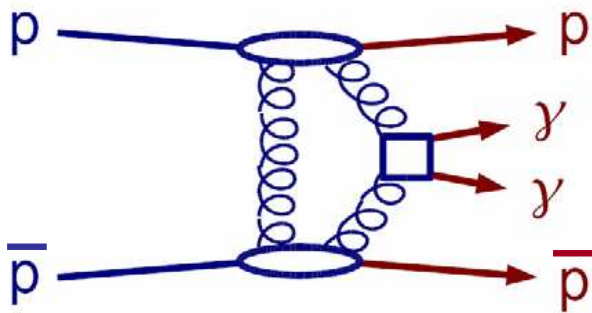
## Prediction from inclusive and exclusive diffraction

- Add the exclusive contribution (free relative normalisation between inclusive and exclusive contribution)
- Good agreement between measurement and predictions
- As an example: exclusive and inclusive models for  $p_T > 10$  GeV and for  $p_T > 25$  GeV
- See CDF papers; O. Kepka, C. Royon, Phys.Rev.D76 (2007) 034012; arXiv0706.1798

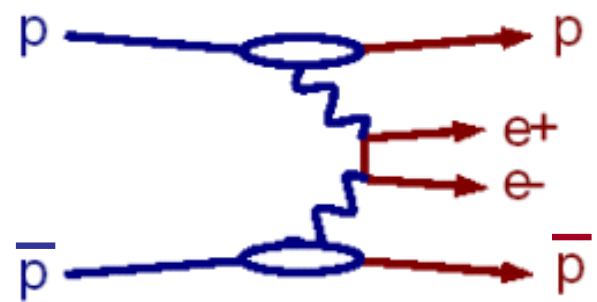


## Search for exclusive diphotons (CDF)

- Look for diphoton events: very clean events (2 photons and nothing else), but low cross section (nothing means experimentally nothing above threshold..., quasi-exclusive events contamination)
- Look for dilepton events: produced only by QED processes, cross-check to exclusive  $\gamma\gamma$  production



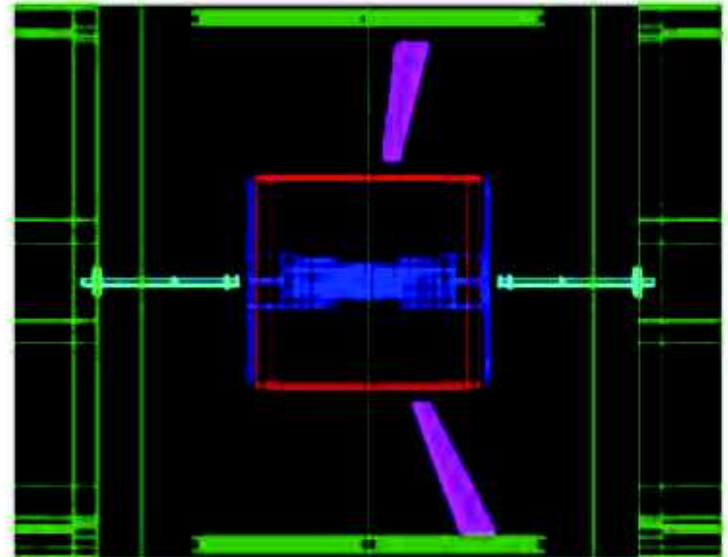
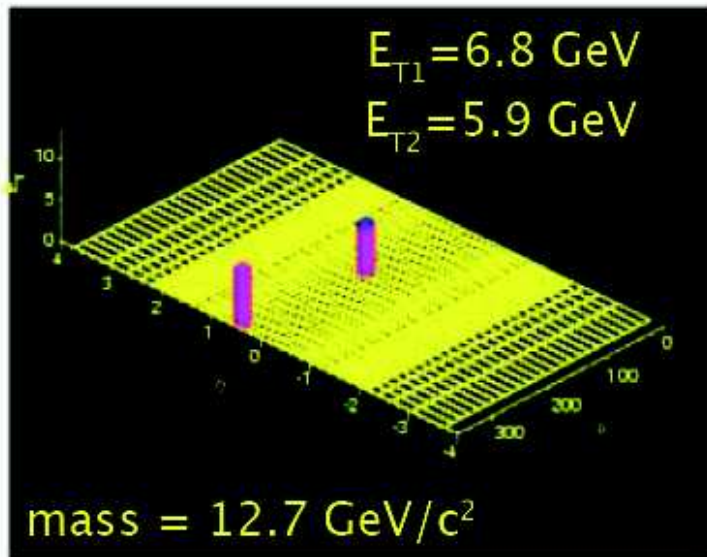
$$p\bar{p} \rightarrow p + \gamma\gamma + \bar{p}$$



QED process: cross-check to exclusive  $\gamma\gamma$

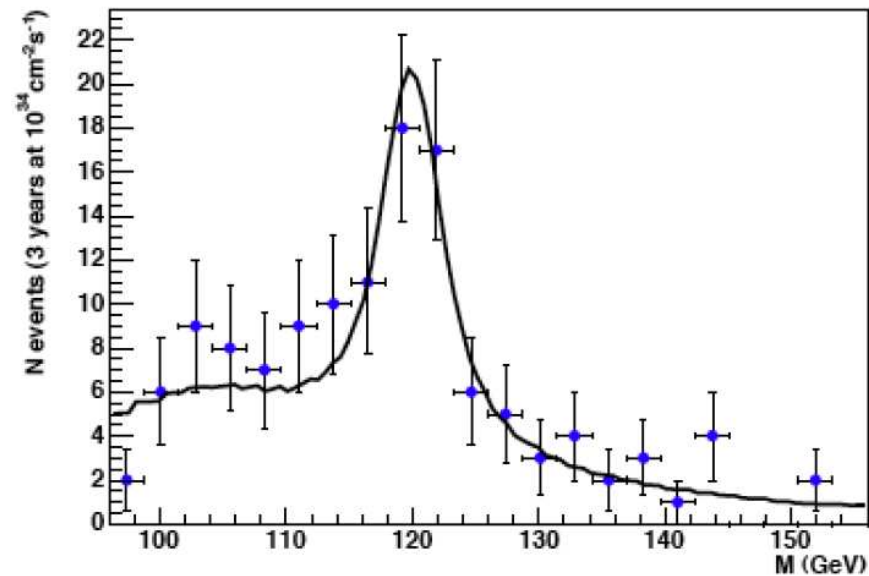
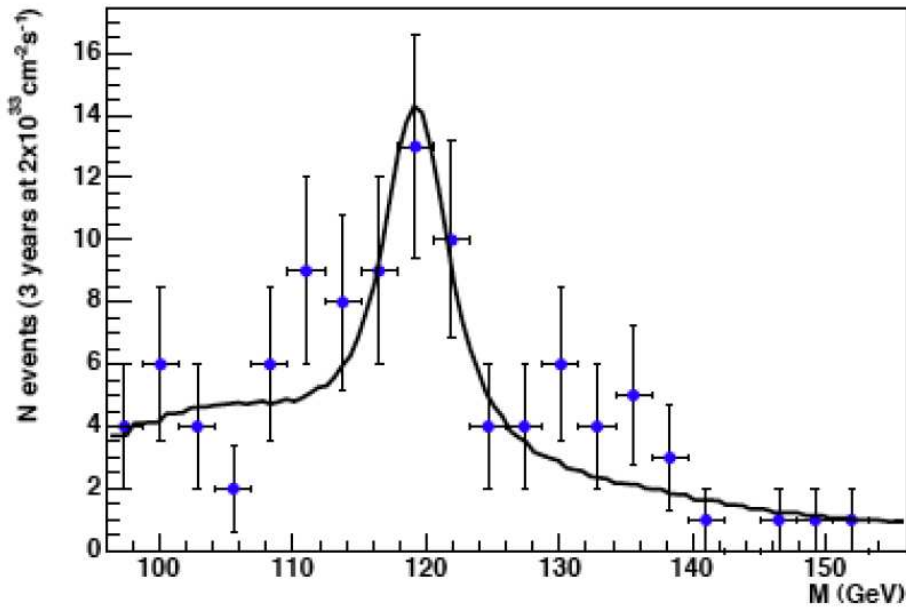
## Search for exclusive diphotons (CDF)

- Look for exclusive diphoton or dilepton production, dominated by QED events (photon exchanges) and not from pomeron exchanges
- Cross section for  $e^+e^-$  exclusive production:  
 $N_{candidates} = 16_{-3.2}^{+5.1}$ ,  $N_{background} = 2.1_{-0.3}^{+0.7}$  (mainly dissociation events)  
in  $46 \text{ pb}^{-1}$   $\sigma = 1.6_{-0.3}^{+0.5}(stat) \pm 0.3(syst) \text{ pb}$
- Cross section for  $\gamma\gamma$ - exclusive production:  
 $N_{candidates} = 3_{-0.9}^{+2.9}$ ,  $N_{background} = 0_{-0.0}^{+0.2}$  (mainly dissociation events) in  
 $46 \text{ pb}^{-1}$   $\sigma = 0.14_{-0.04}^{+0.14}(stat) \pm 0.03(syst) \text{ pb}$



## SUSY Signal significance

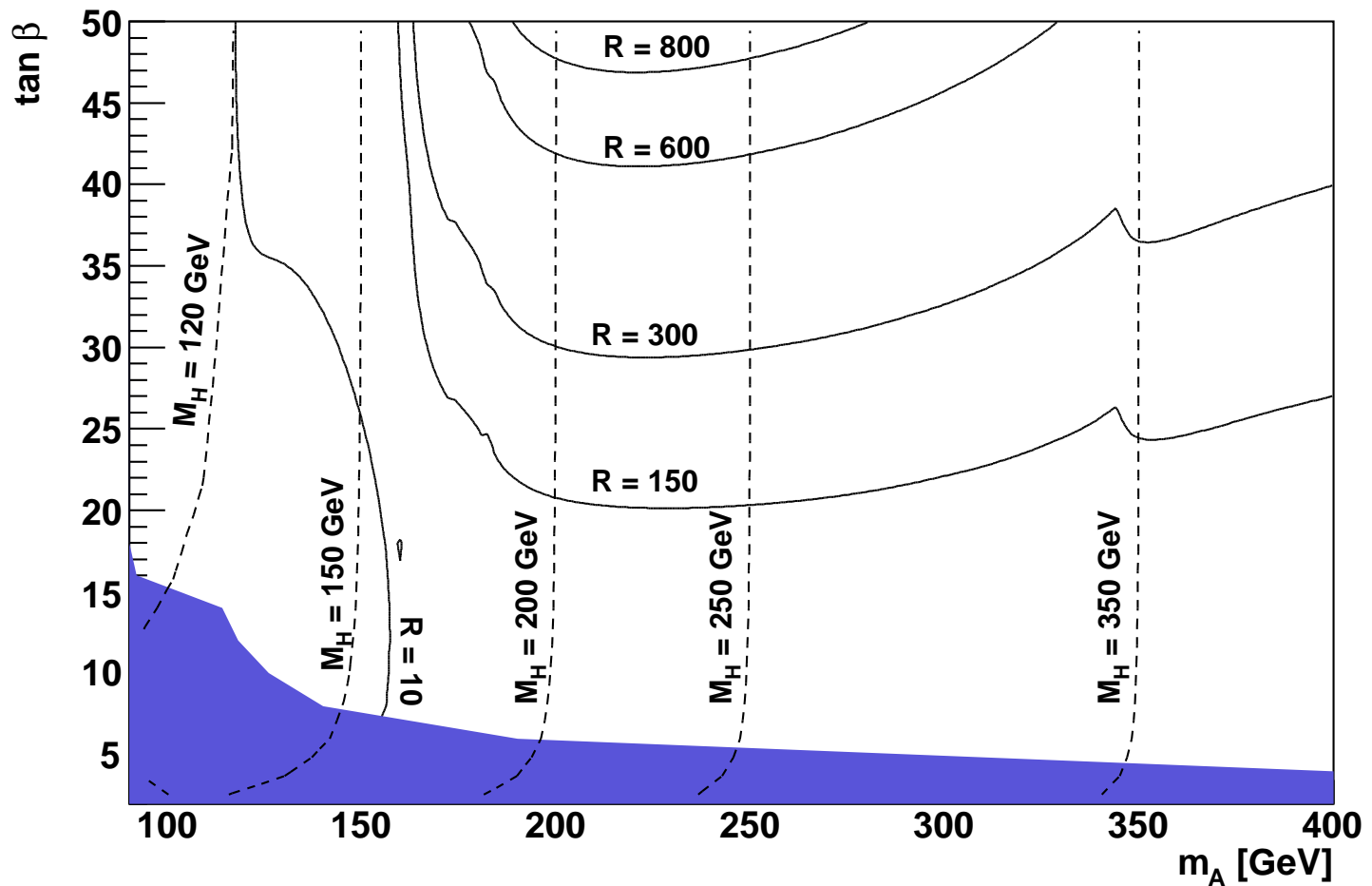
- Signal and background full simulation, pile up effects taken into account: see B. Cox, F. Loebinger, A. Pilkington, JHEP 0710 (2007) 090 for  $h$  production at  $\tan\beta \sim 40$ , 8 times higher cross section than SM
- Significance  $> 3.5\sigma$  for  $60 \text{ fb}^{-1}$  after detector acceptance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



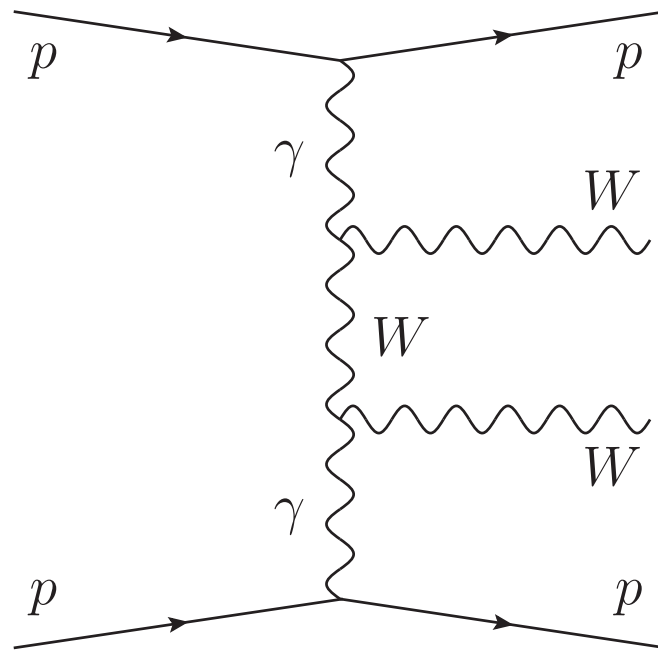
## Diffractive SUSY Higgs production

Contour for the ratio of signal events in the MSSM and SM scenarios for  
 $H \rightarrow b\bar{b}$  for heavy CP-even Higgs bosons

S. Heinemeyer et al., Eur.Phys.J.C53:231-256,2008



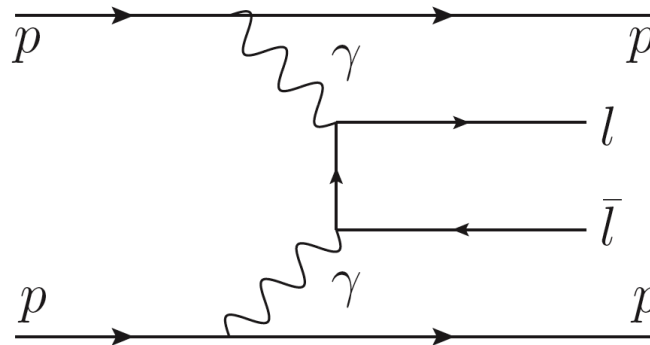
## WW production at the LHC



- Study of the process:  $pp \rightarrow ppWW$
- 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
- $\sigma_{WW} = 95.6 \text{ fb}$ ,  $\sigma_{WW}(W > 1\text{TeV}) = 5.9 \text{ fb}$
- 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



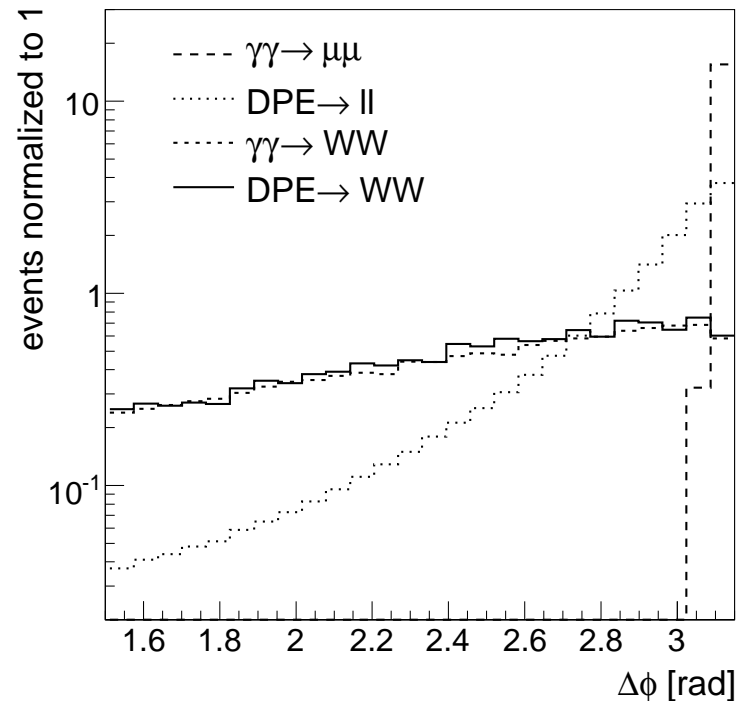
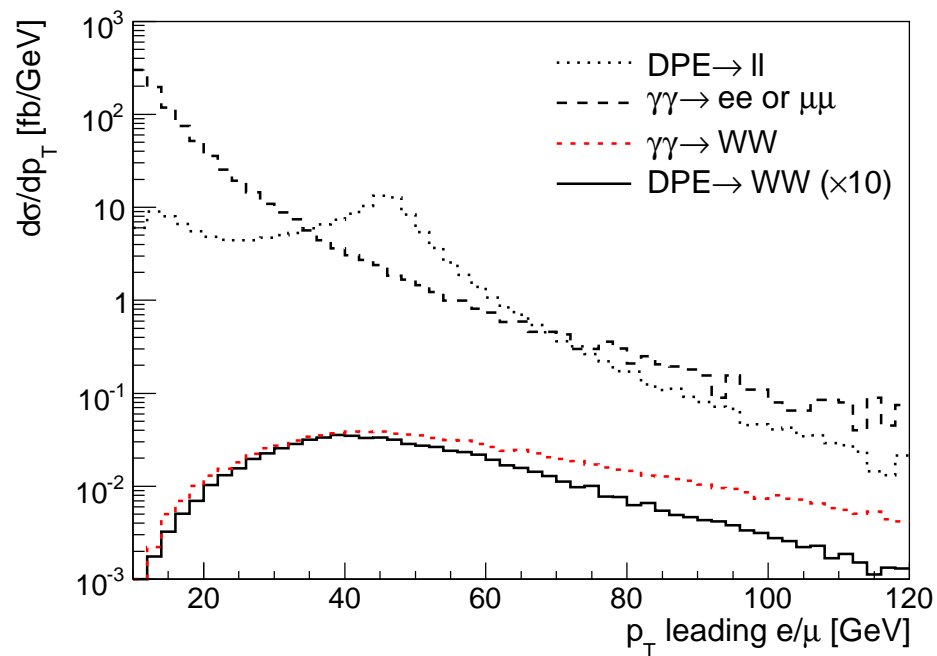
- **Lepton production via double pomeron exchange:** activity in the forward region due to pomeron remnants, removed by  $\cancel{E}_T$  cut
- **WW via double pomeron exchange:** removed by cut on high diffractive mass

## 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 in preparation (M. Boonekamp, O. Kepka, V. Juranek, C. Royon, R. Staszewski...)
- Output of FPMC generator interfaced with the fast simulation of the ATLAS detector in the standalone ATLFast++ package

## Strategy to measure the $\gamma\gamma \rightarrow WW$ SM cross section

- Require both  $W$ s to decay leptonically (as a starting point to avoid jet background) with  $p_T$  of leading (2nd leading) lepton above 25, 10 GeV
- Require both protons in the ATLAS Forward Proton (AFP) detector
- $\cancel{E}_T > 20$  GeV, natural for  $W$  decays (get rid of dilepton background produced by photon exchange)
- $\Delta\Phi$  between leading leptons allows to remove dilepton background

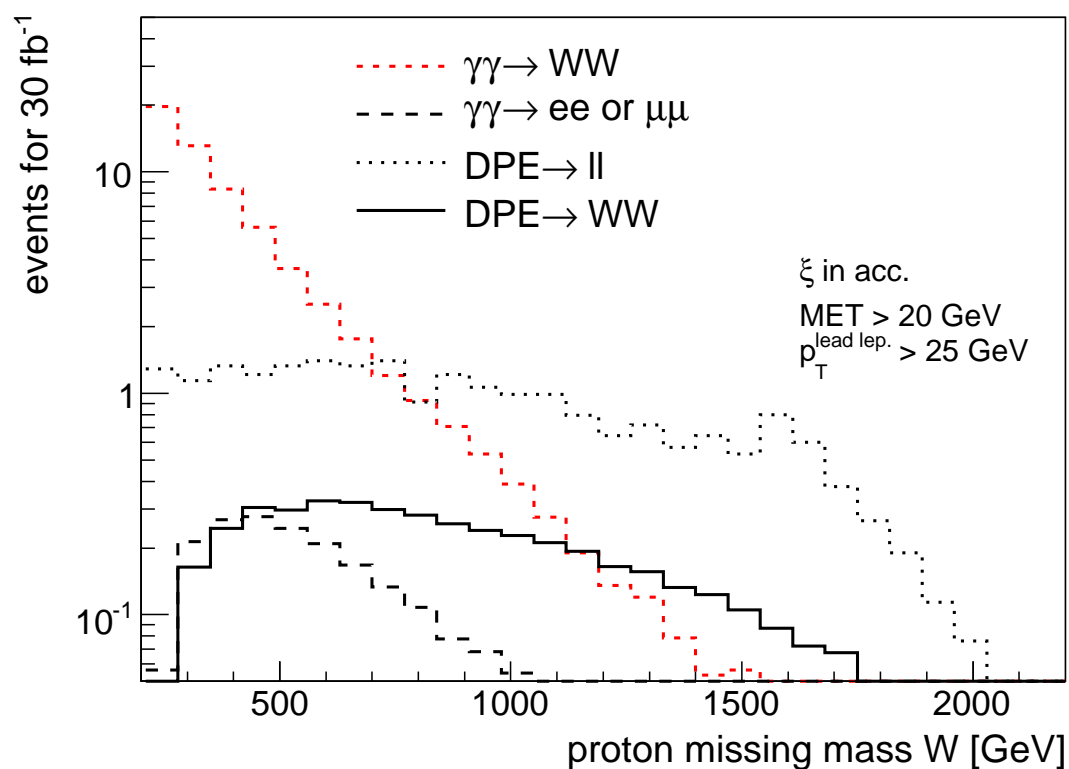


## Measuring the $\gamma\gamma \rightarrow WW$ SM cross section

Number of events for  $30 \text{ fb}^{-1}$  after successive cuts

cut / process	$\gamma\gamma \rightarrow ll$	DPE $\rightarrow ll$	DPE $\rightarrow WW$	$\gamma\gamma \rightarrow WW$
$p_T^{\text{lep}1,2} > 10 \text{ GeV}$	50620	17931	8.8	95
$0.0015 < \xi < 0.15$	21059	11487	5.9	89
$\cancel{E}_T > 20 \text{ GeV}$	14.9	33	4.7	78
$W > 160 \text{ GeV}$	9.2	33	4.7	78
$\Delta\phi < 2.7$	0	14	3.8	61
$p_T^{\text{lep}} > 25 \text{ GeV}$	0	7.5	3.5	58
$W < 500$	0	1.0	0.67	51

5  $\sigma$  discovery possible after  $5 \text{ fb}^{-1}$  (pure leptonic decays of  $W$ s)



## Measuring the $\gamma\gamma \rightarrow WW$ SM cross section: semi-leptonic decays

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- Consider both leptonic and semileptonic decays of  $W$ s
- Fast generator level study: For a luminosity of  $200 \text{ pb}^{-1}$ , observation of 5.6  $W$  pair events for a background less than 0.4, which leads to a signal of  $8 \sigma$

$\xi_{max}$	signal (fb)	background (fb)
0.05	13.8	0.16
0.10	24.0	1.0
0.15	28.3	2.2

- Study needs to be redone considering the simulation of all backgrounds: especially when one of the quarks radiates a  $W$  boson, which is being implemented in FPMC

## Quartic anomalous gauge couplings

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

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

- 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  $-0.02 < a_0^W < 0.02 \text{ GeV}^{-2}$
- 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):

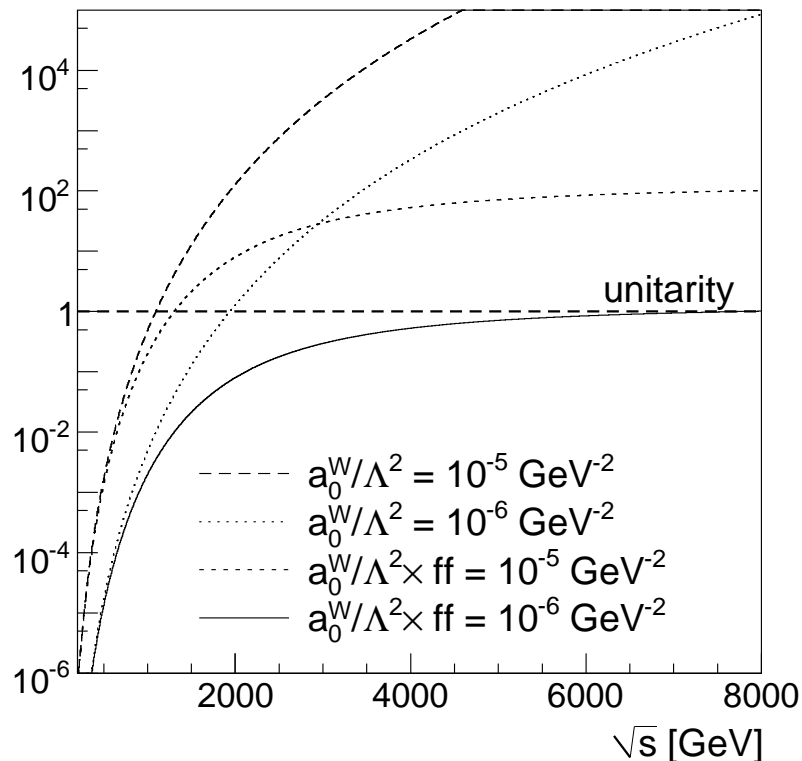
$$4 \left( \frac{\alpha a s}{16} \right)^2 \left( 1 - \frac{4M_W^2}{s} \right)^{1/2} \left( 3 - \frac{s}{M_W^2} + \frac{s^2}{4M_W^4} \right) \leq 1$$

where  $a = a_0/\Lambda^2$

- Introducing form factors to avoid quadratical divergences of scattering amplitudes due to anomalous couplings in conventional way:

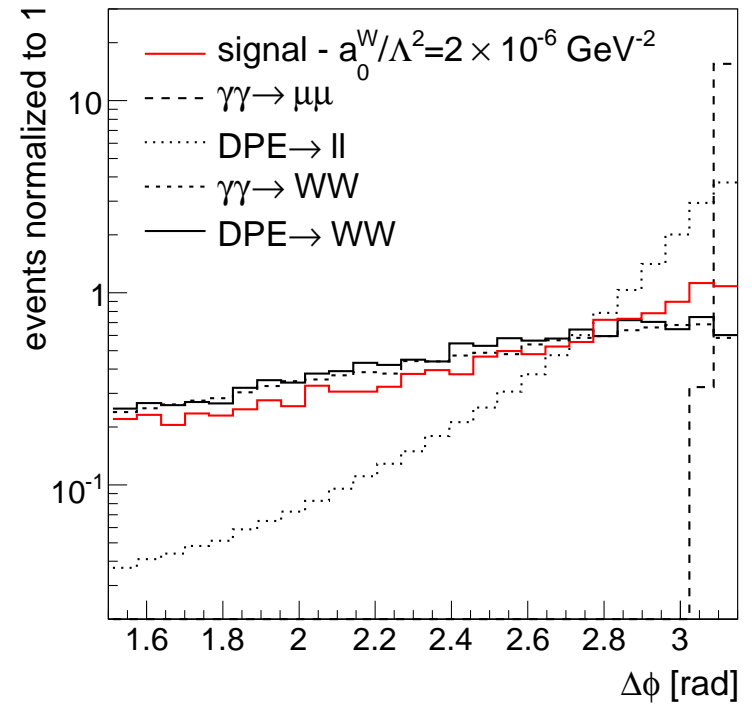
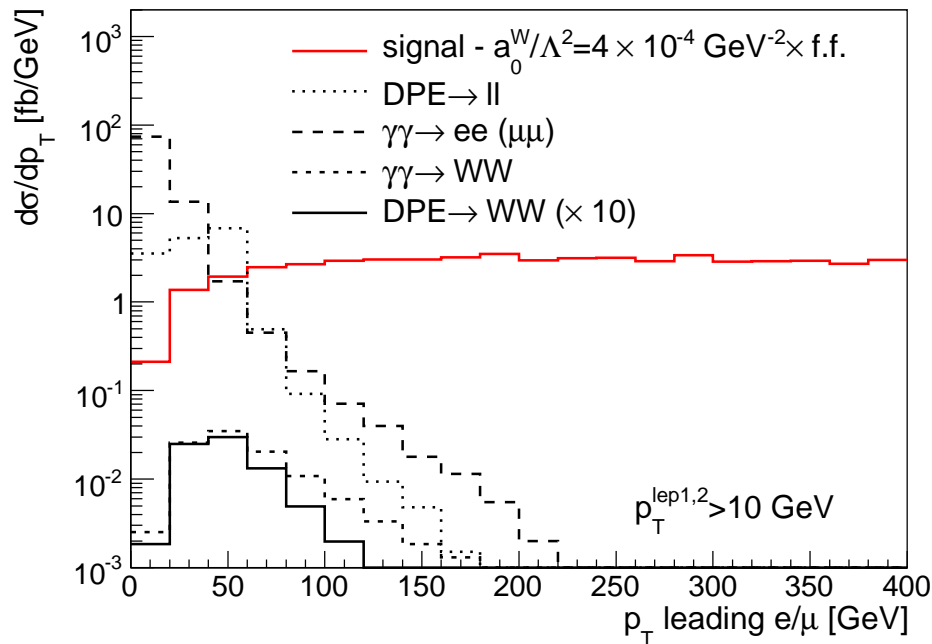
$$a_0^W/\Lambda^2 \rightarrow \frac{a_0^W/\Lambda^2}{(1+W\gamma\gamma/\Lambda_{cutoff})^2} \text{ with } \Lambda_{cutoff} \sim 2 \text{ TeV, scale of new physics}$$

- For  $a_0^W \sim 10^{-6} \text{ GeV}^{-2}$ , no violation of unitarity



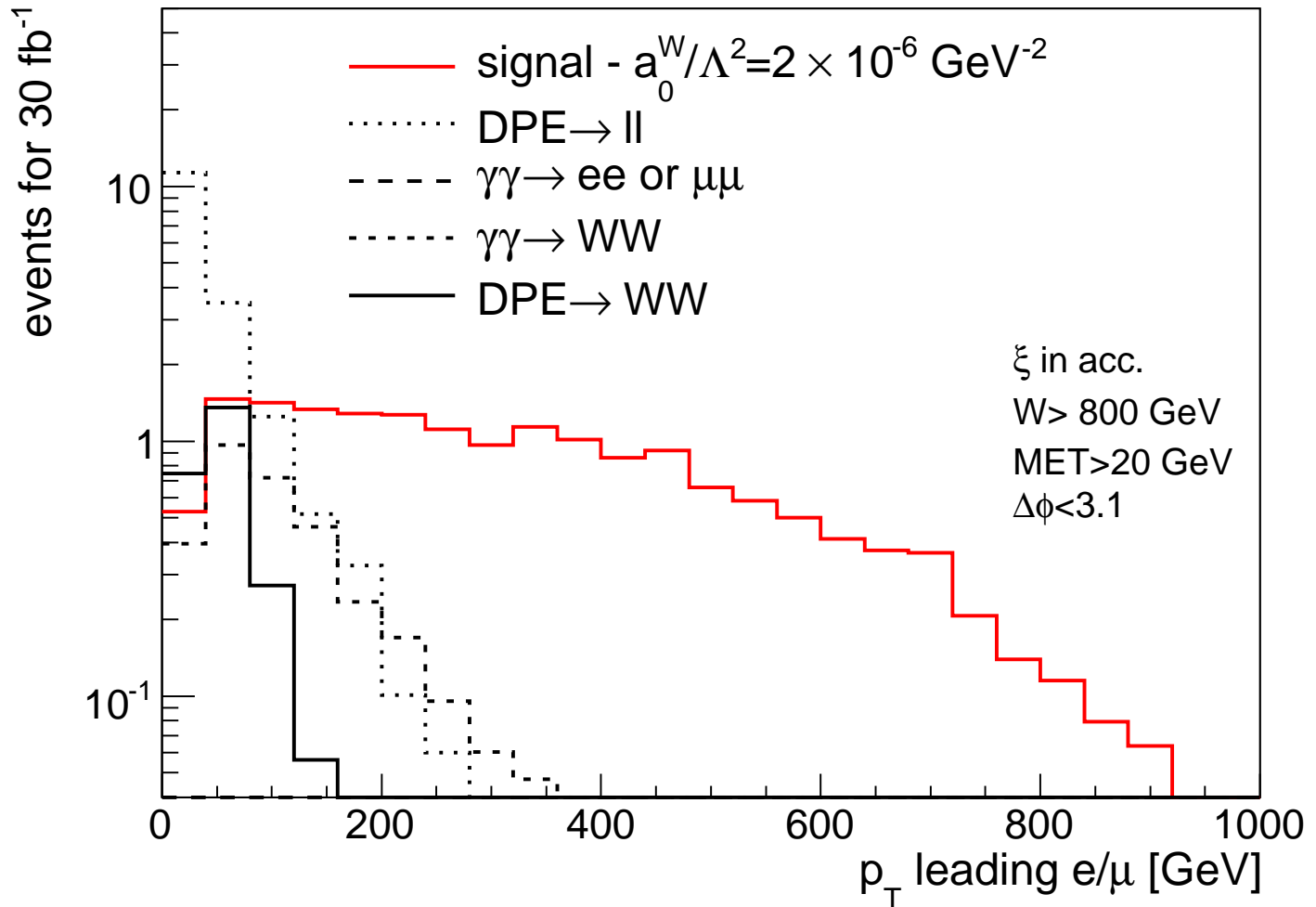
## Strategy to select quartic anomalous gauge couplings events

- $p_T$  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,  $\cancel{E}_T$ , diffractive mass,  $\Delta\Phi$ ) except the cut on leading lepton  $p_T$



## Quartic anomalous gauge couplings

### Background events for $30 \text{ fb}^{-1}$

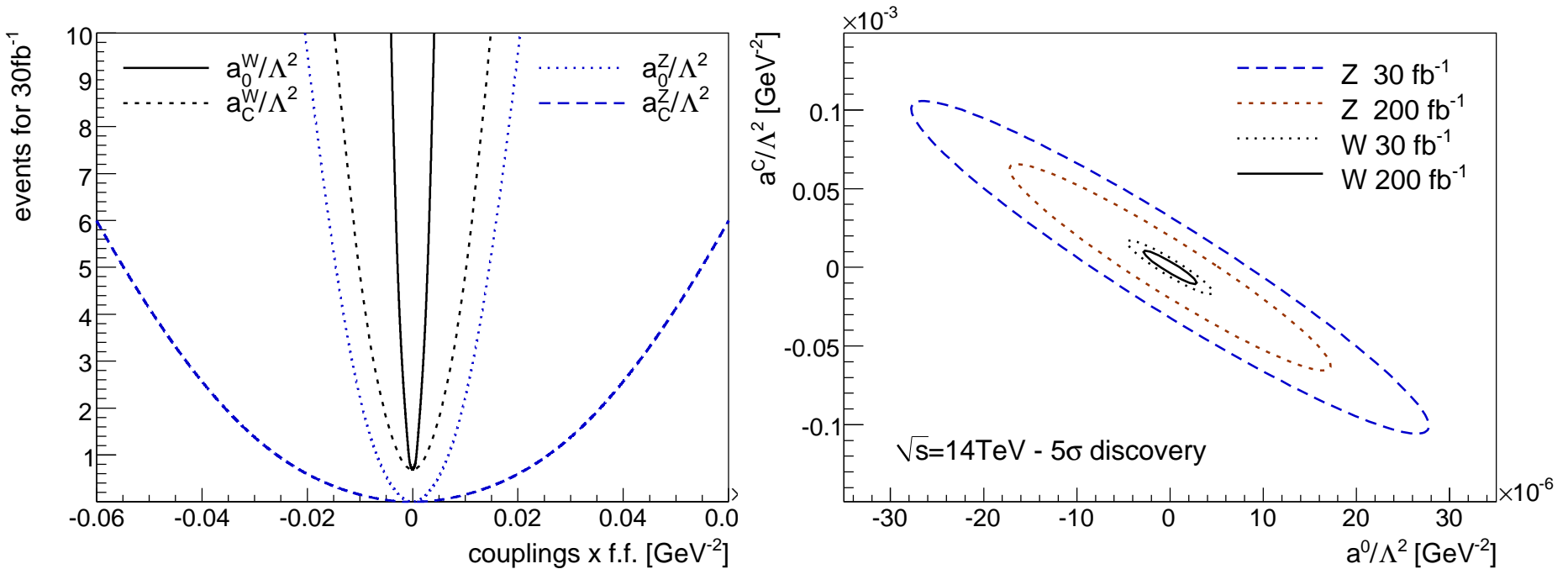
cut / process	$\gamma\gamma \rightarrow ll$	$\gamma\gamma \rightarrow WW$	DPE $\rightarrow ll$	DPE $\rightarrow WW$
$p_T^{lep1,2} > 10 \text{ GeV}$	50619	99	18464	8.8
$0.0015 < \xi < 0.15$	21058	89	11712	6.0
$\cancel{E}_T > 20 \text{ GeV}$	14.9	77	36	4.7
$W > 800 \text{ GeV}$	0.42	3.2	16	2.5
$M_{ll} \notin \langle 80, 100 \rangle$	0.42	3.2	13	2.5
$\Delta\phi < 3.13$	0.10	3.2	12	2.5
$p_T^{lep1} > 160 \text{ GeV}$	0	0.69	0.20	0.024

### Signal events for $30 \text{ fb}^{-1}$

cut / couplings (with f.f.)	$ a_0^W / \Lambda^2  = 5.4 \cdot 10^{-6}$	$ a_C^W / \Lambda^2  = 20 \cdot 10^{-6}$
$p_T^{lep1,2} > 10 \text{ GeV}$	202	200
$0.0015 < \xi < 0.15$	116	119
$\cancel{E}_T > 20 \text{ GeV}$	104	107
$W > 800 \text{ GeV}$	24	23
$M_{ll} \notin \langle 80, 100 \rangle$	24	23
$\Delta\phi < 3.13$	24	22
$p_T^{lep1} > 160 \text{ GeV}$	17	16

## Quartic anomalous gauge couplings

- Strategy for  $ZZ$  events similar: Request either three leptons or two leptons of the same sign, protons tagged in forward detectors,  $p_T$  of leading leptons greater than 160 GeV
- Number of events for  $30 \text{ fb}^{-1}$  for the different couplings
- $5\sigma$  discovery contours for two different luminosities 30 and  $200 \text{ fb}^{-1}$
- Present LEP limits can be improved by up to four orders of magnitude



## Reach at LHC

Reach at high luminosity on quartic anomalous coupling

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

- Improvement of LEP sensitivity by more than 4 orders of magnitude with 30/200 fb<sup>-1</sup> at LHC!!!

## Trilinear anomalous gauge couplings

- Lagrangian with trilinear gauge  $WW\gamma$  anomalous couplings  $\lambda^\gamma$  and  $\Delta\kappa^\gamma$

$$\mathcal{L} \sim (W_{\mu\nu}^\dagger W^\mu A^\nu - W_{\mu\nu} W^{\dagger\mu} A^\nu) + (1 + \Delta\kappa^\gamma) W_{\mu\nu}^\dagger W_\nu A^{\mu\nu} + \frac{\lambda^\gamma}{M_W^2} W_{\rho\mu}^\dagger W_\nu^\mu A^{\nu\rho}$$

- Present limits on trilinear gauge anomalous couplings:
  - From LEP:  $-0.098 < \Delta\kappa^\gamma < 0.101$ ;  $-0.044 < \lambda^\gamma < 0.047$   
(Inconvenient: mixture of  $\gamma$  and  $Z$  exchanges in  $e^+e^- \rightarrow WW$ )
  - From Tevatron:  $-0.51 < \Delta\kappa^\gamma < 0.51$ ;  $-0.12 < \lambda^\gamma < 0.13$  (direct limits)
- Same strategy as for quartic anomalous couplings with the caveat that the signal appears at high mass for  $\lambda^\gamma$ , and  $\Delta\kappa^\gamma$  only modifies the normalisation and the low mass events have to be retained:
  - for  $\Delta\kappa^\gamma$ :

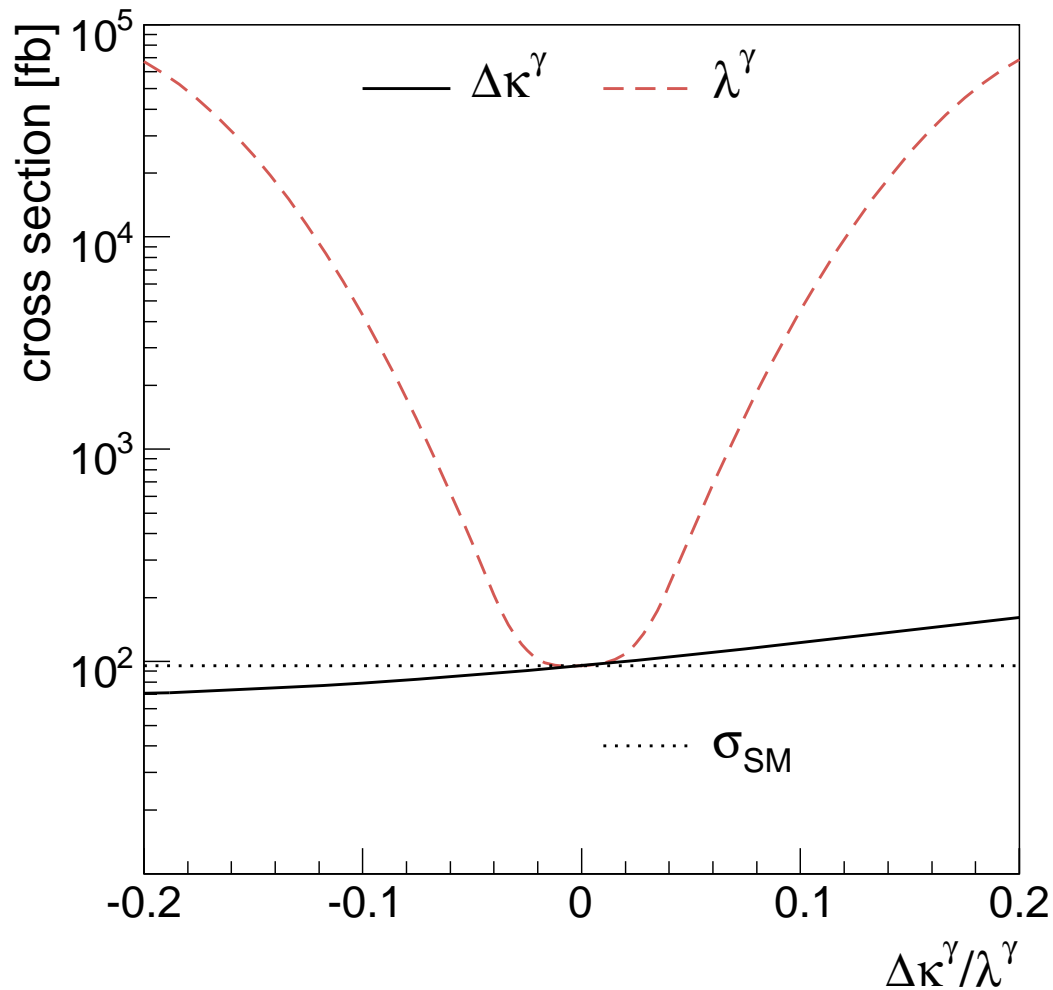
$$p_T^{lep1} > 25 \text{ GeV}, p_T^{lep2} > 10 \text{ GeV}, 0.0015 < \xi < 0.15, \cancel{E}_T > 20 \text{ GeV}, W > 160 \text{ GeV}, \Delta\phi < 2.7, W < 500 \text{ GeV}$$

- for  $\lambda^\gamma$ :

$$p_T^{lep1} > 160 \text{ GeV}, p_T^{lep2} > 10 \text{ GeV}, 0.0015 < \xi < 0.15, \cancel{E}_T > 20 \text{ GeV}, W > 800 \text{ GeV}, M_{ll} \notin \langle 80, 100 \rangle \text{ GeV}, \Delta\phi < 3.13 \text{ rad}$$

## Anomalous $WW\gamma$ triple gauge coupling

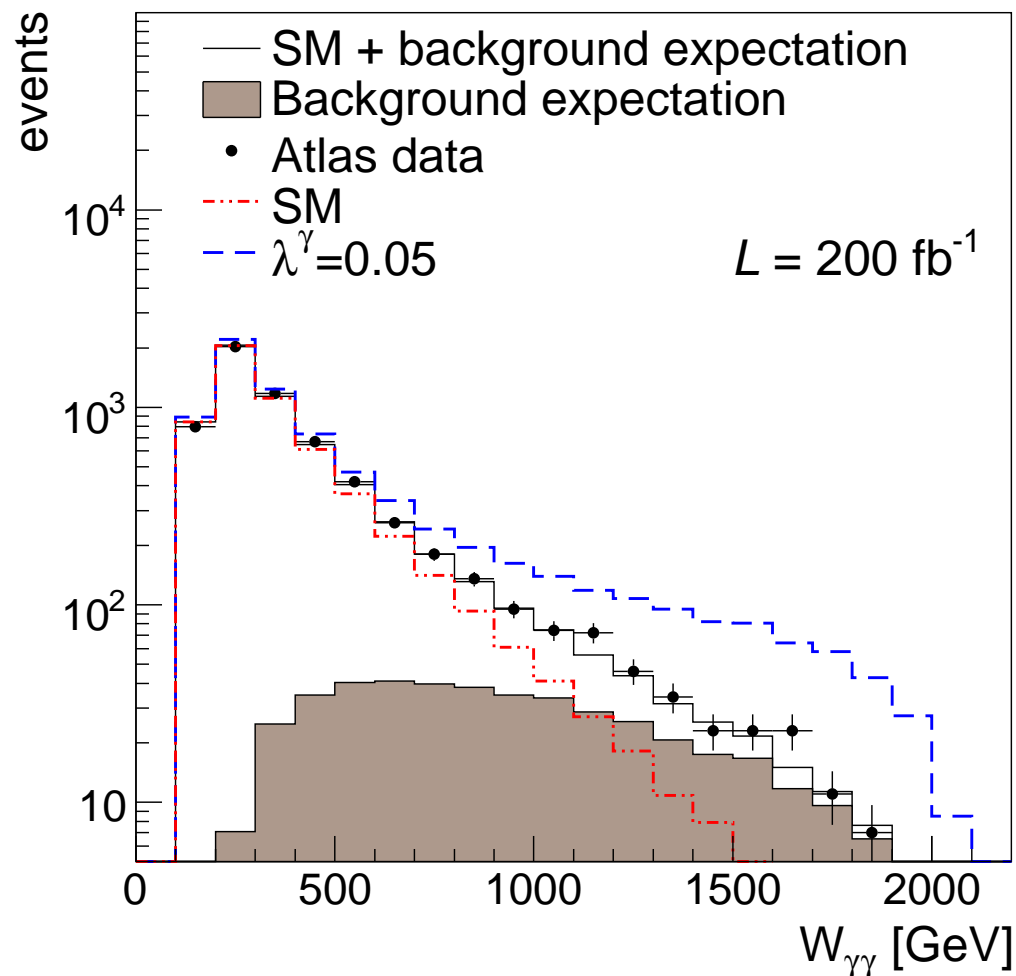
Different behaviour of the cross section as a function of anomalous couplings



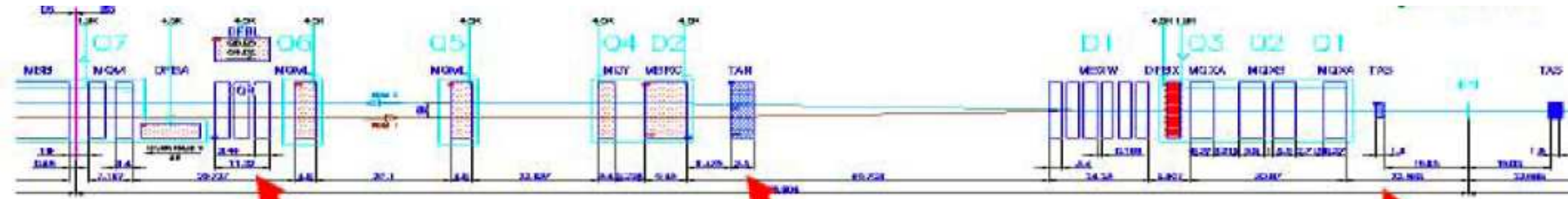
Measurement of  $WW$  events at high luminosities at LHC,  $2W$  events and protons tagged in forward detectors

## Reach on anomalous coupling

- Reach on anomalous coupling at the LHC using a luminosity of  $200 \text{ fb}^{-1}$ 
  - $5\sigma$  discovery:  $-0.26 < \Delta\kappa^\gamma < 0.16$ ;  $-0.053 < \lambda^\gamma < 0.049$
  - 95% CL limit:  $-0.096 < \Delta\kappa^\gamma < 0.057$ ;  $-0.023 < \lambda^\gamma < 0.027$ ,
- One of the best reaches before ILC, which can be improved using semi-leptonic decays of  $W$ s



## Forward detectors in ATLAS

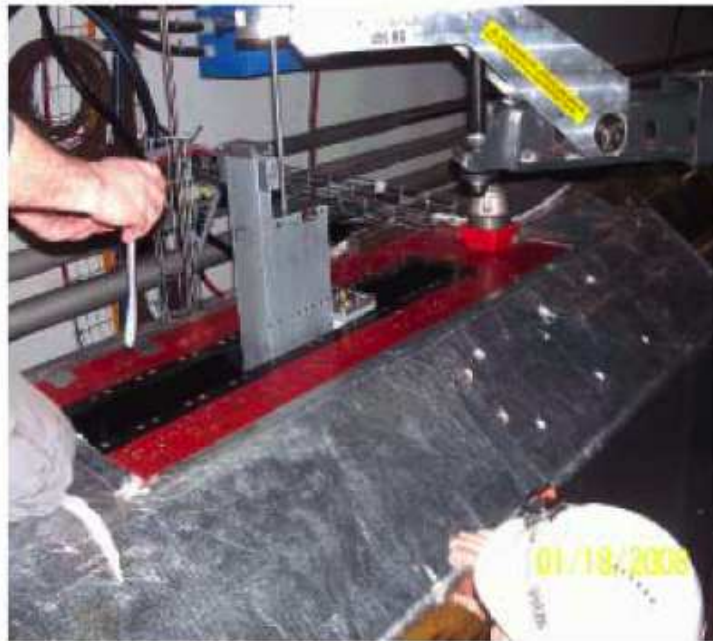


ALFA at 240 m



Absolute Luminosity  
for ATLAS

ZDC at 140 m



Zero Degree Calorimeter

LUCID at 17 m

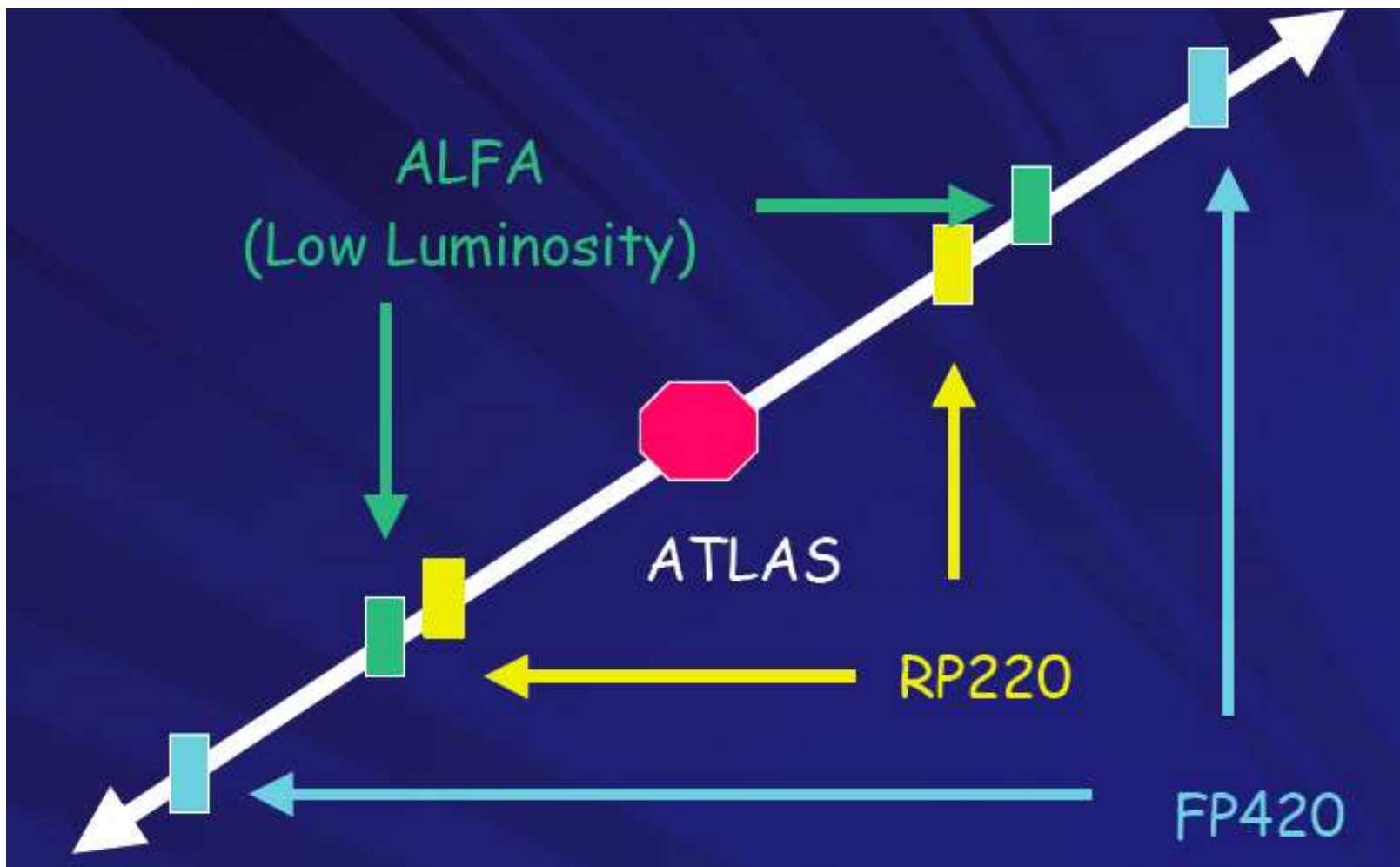


Luminosity Cerenkov  
Integrating Detector

- ALFA: TDR submitted, CERN/LHCC/2008-004, 1 roman pot installed
- ZDC: Detector installed
- LUCID

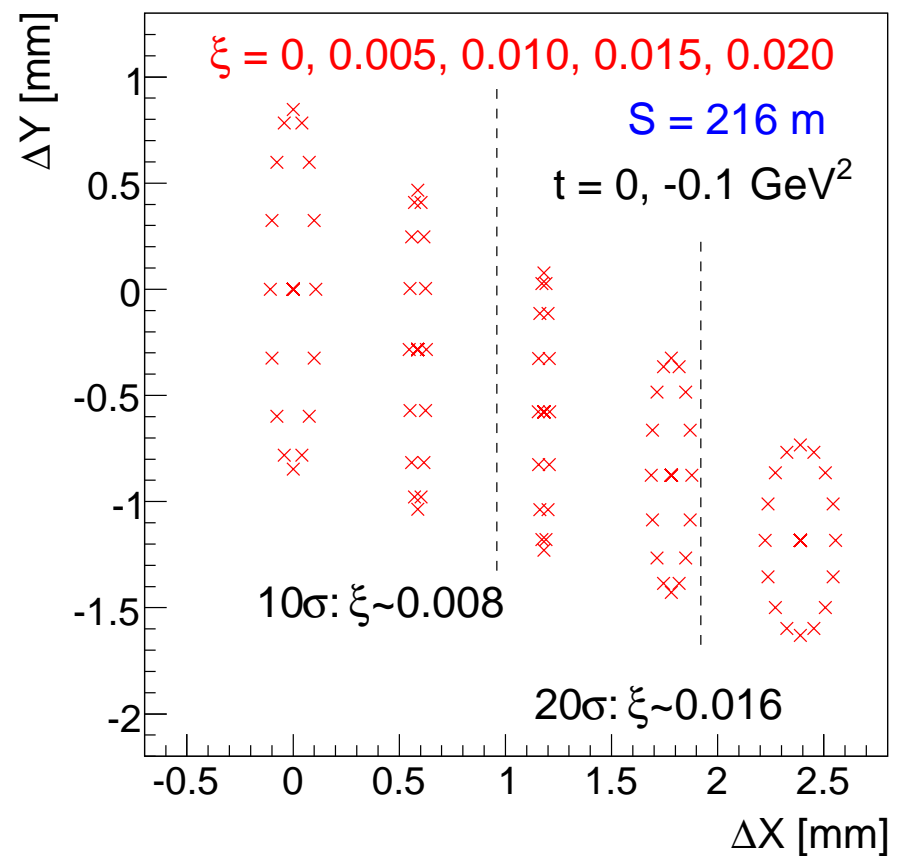
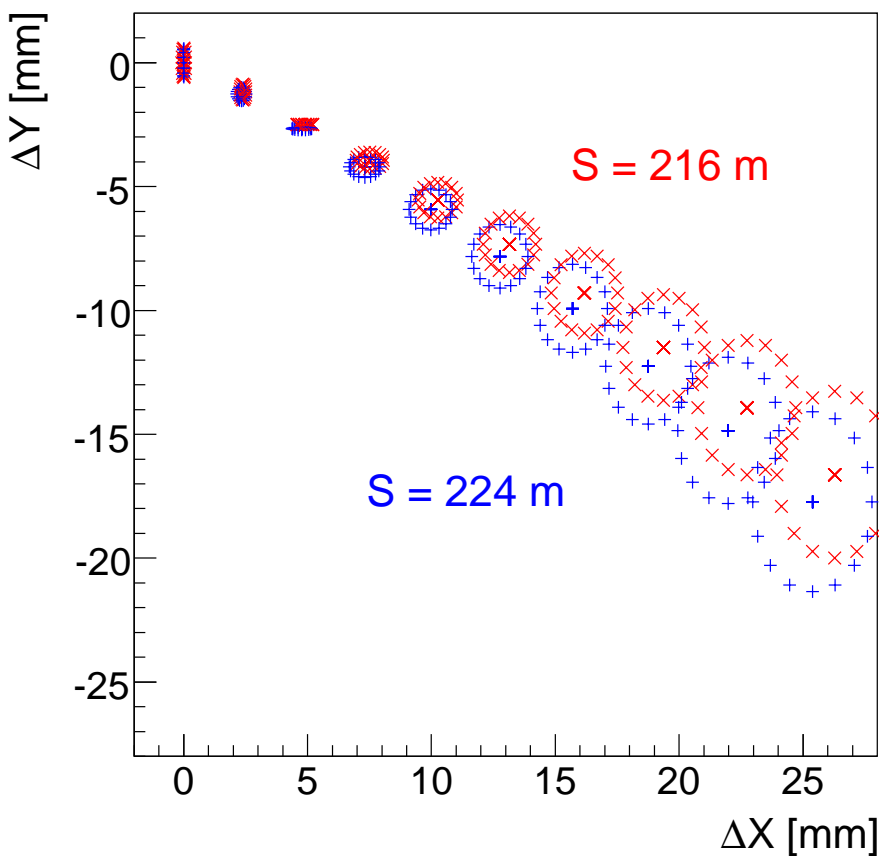
## Detector location

- **what is needed?** Good position and good timing measurements
- **220 m:** movable beam pipes (in addition vertical roman pots for alignment purposes under study)
- **420 m:** movable beam pipe (roman pots impossible because of lack of space available and cold region of LHC)



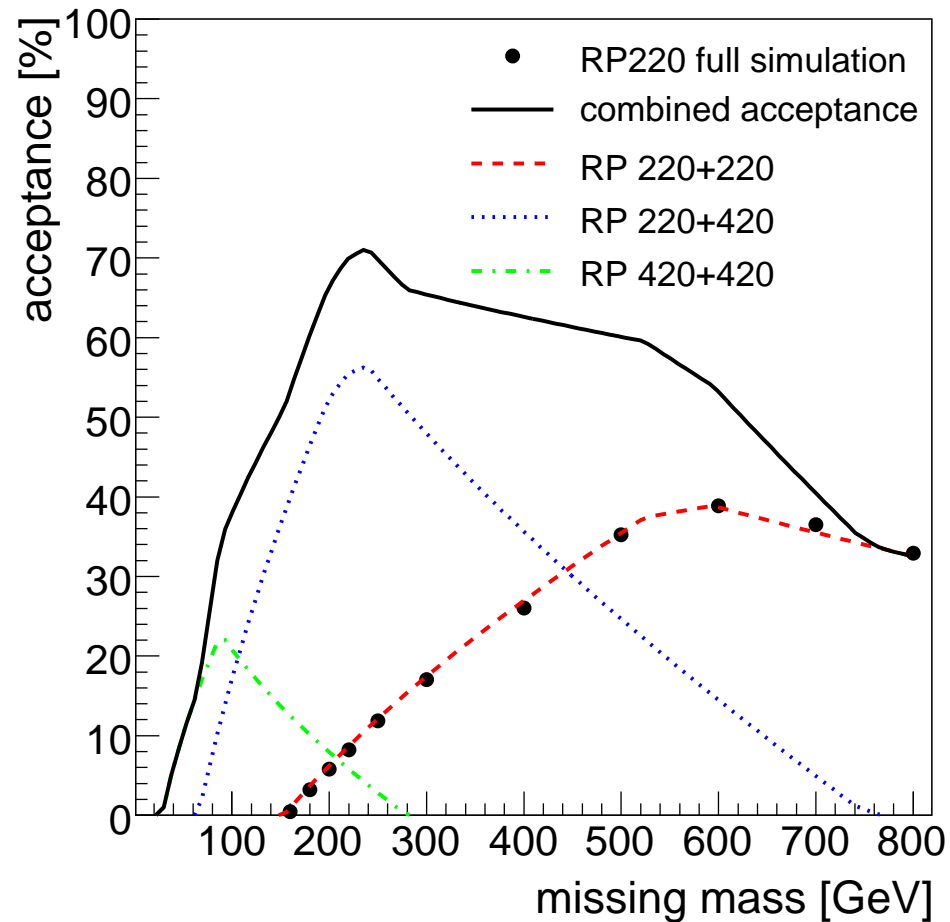
## Example: Acceptance for 220 m detectors

- Steps in  $\xi$ : 0.02 (left), 0.005 (right),  $|t|=0$  or  $0.05 \text{ GeV}^2$
- Detector of  $2 \text{ cm} \times 2 \text{ cm}$  will have an acceptance up to  $\xi \sim 0.16$ , down to  $0.008$  at  $10 \sigma$ ,  $0.016$  at  $20 \sigma$
- Estimate: possibility to insert the detectors up to  $\sim 15\sigma$  from the beam routinely
- Detector coverage of  $2 \text{ cm} \times 2 \text{ cm}$  needed



## ATLAS Forward Physics detector acceptance

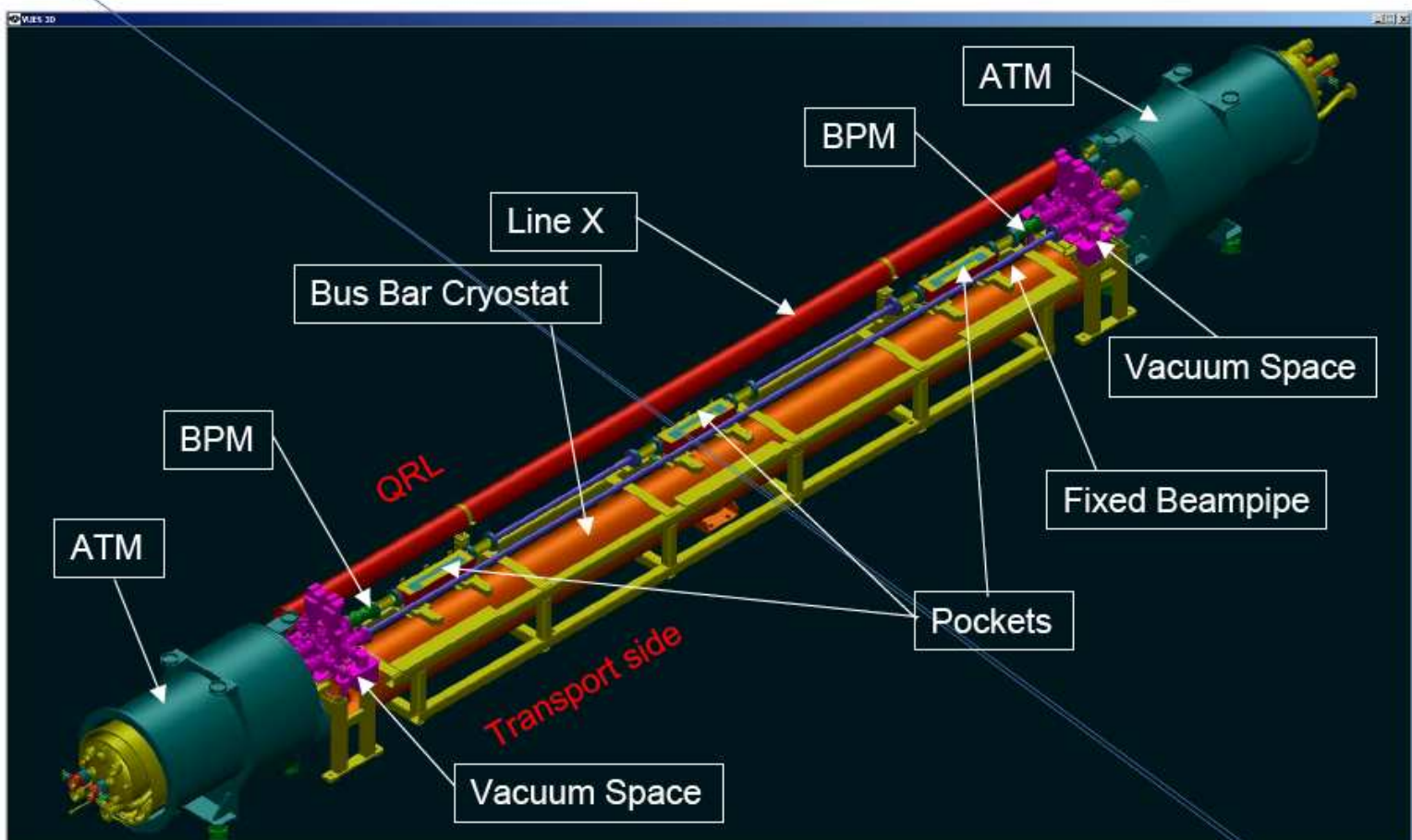
Both detectors at 420 and 220 m needed to have a good coverage of acceptance (NB: acceptance slightly smaller in CMS than in ATLAS)



## Which detectors: Movable beam pipe at 220-420 m

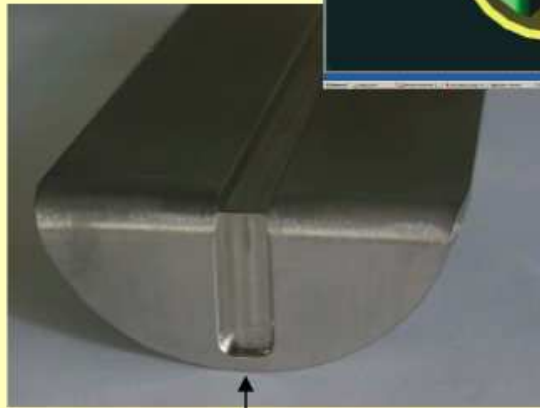
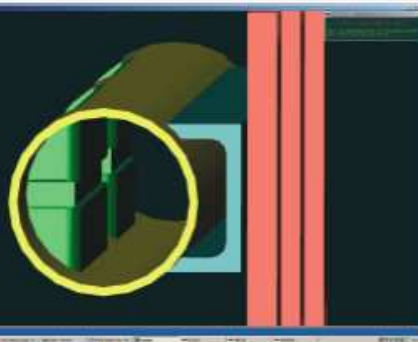
- Simple idea: use movable beam pipe to locate detectors, takes less space than roman pots
- Use movable beam pipes at 220 and 420 m to host position (3D silicon) and timing detectors
- Beam position known with very precise Beam Position Monitors ( $5 \mu\text{m}$ )

### Integration of the moving beampipe and detectors



## Movable beam pipes and pockets

Two pocket solution kept -  
separate window for tracking  
and timing detectors;  
Moving by 25 mm foreseen  
with 1  $\mu\text{m}$  precision using  
LVDT feedback + alignment



Note: Detectors  
might become more  
compact - possibly  
shorter pockets;  
window thickness  
~300  $\mu\text{m}$

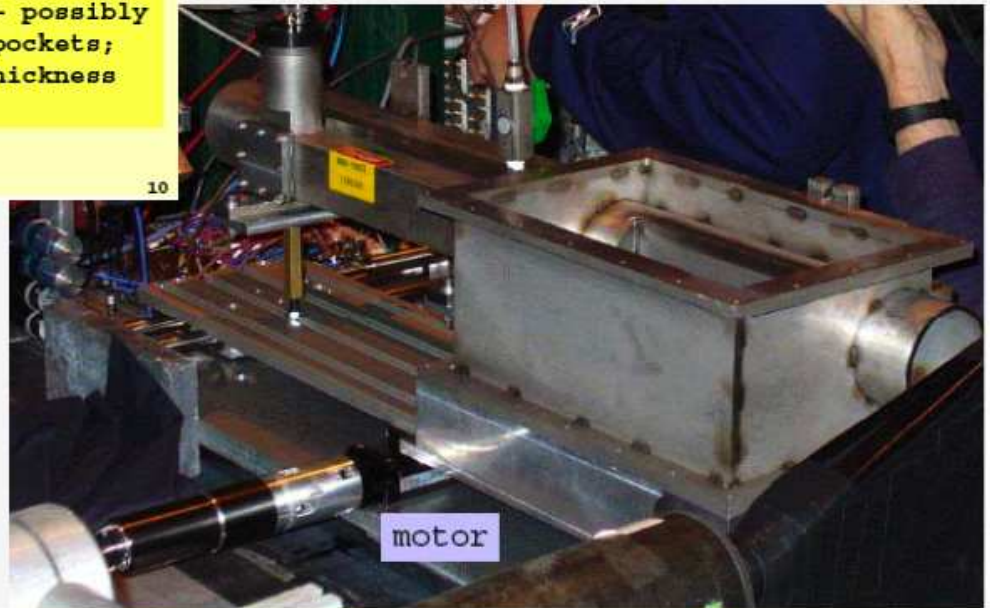
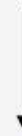
CMG/PP420 meeting, CERN, April '08

K. Piotrowski - UCLouvain

10

300  $\mu\text{m}$  window  
Louvain

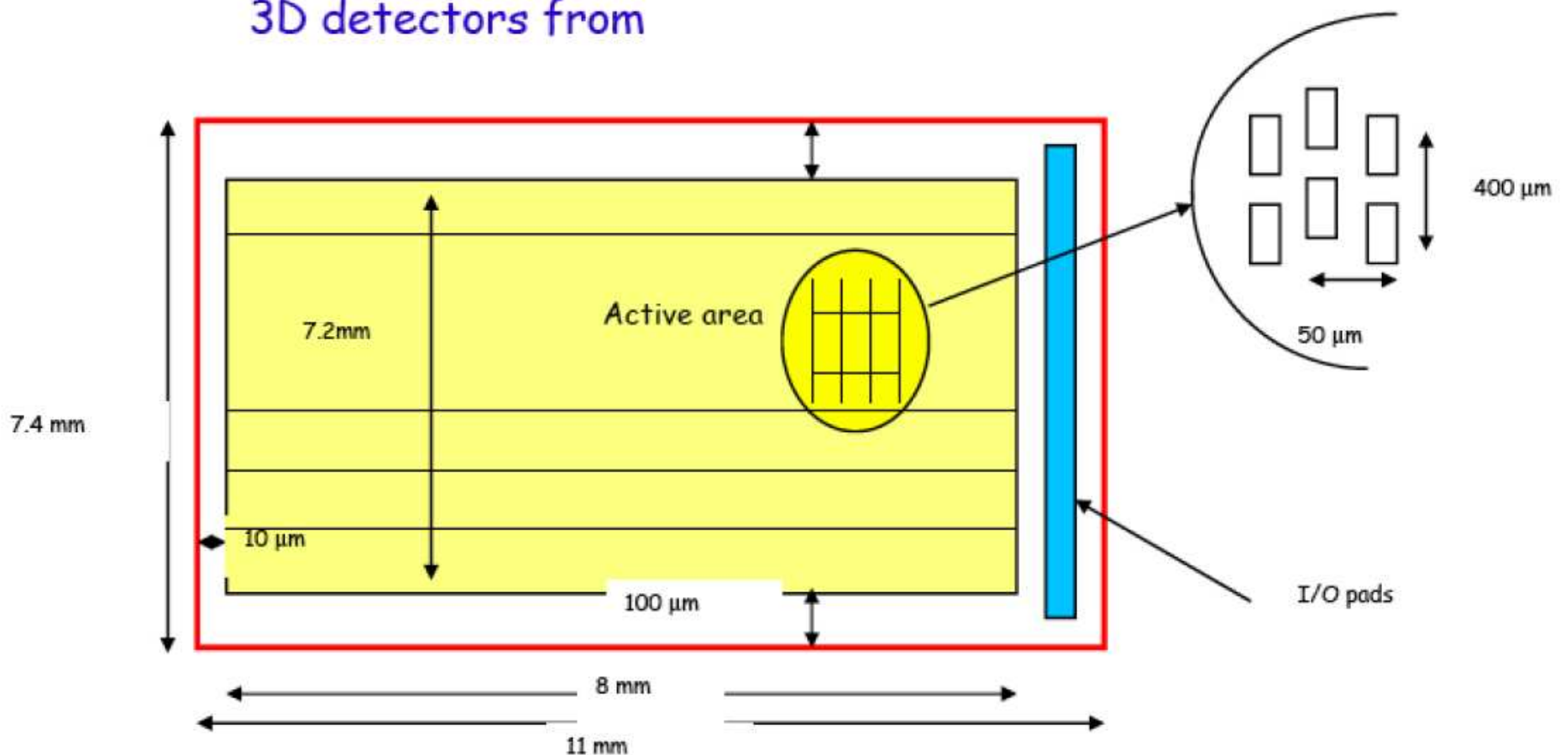
Details of the movable  
Beam-pipe during the 2007  
test beam



## 3D Silicon Detectors (Manchester/SLAC)

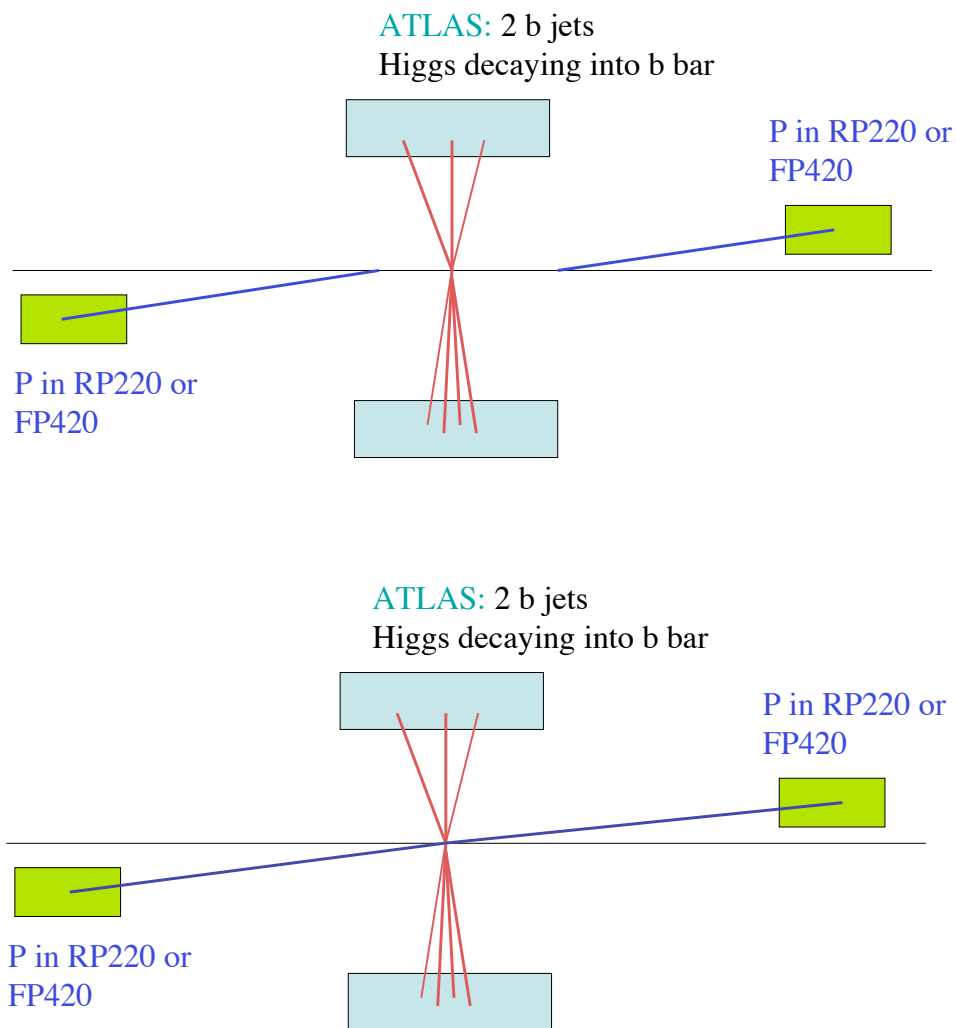
- Precise reconstruction of proton position, and then mass: position resolution of 10-15  $\mu\text{m}$
- Radiation hardness
- 3D Si detectors: 10 planes per supermodule, pixels of  $50 \times 400 \mu\text{m}$ ; 10 layers
- Modification of readout chip to include L1 trigger: address of vertical line hit to know  $\xi$  at L1

### 3D detectors from



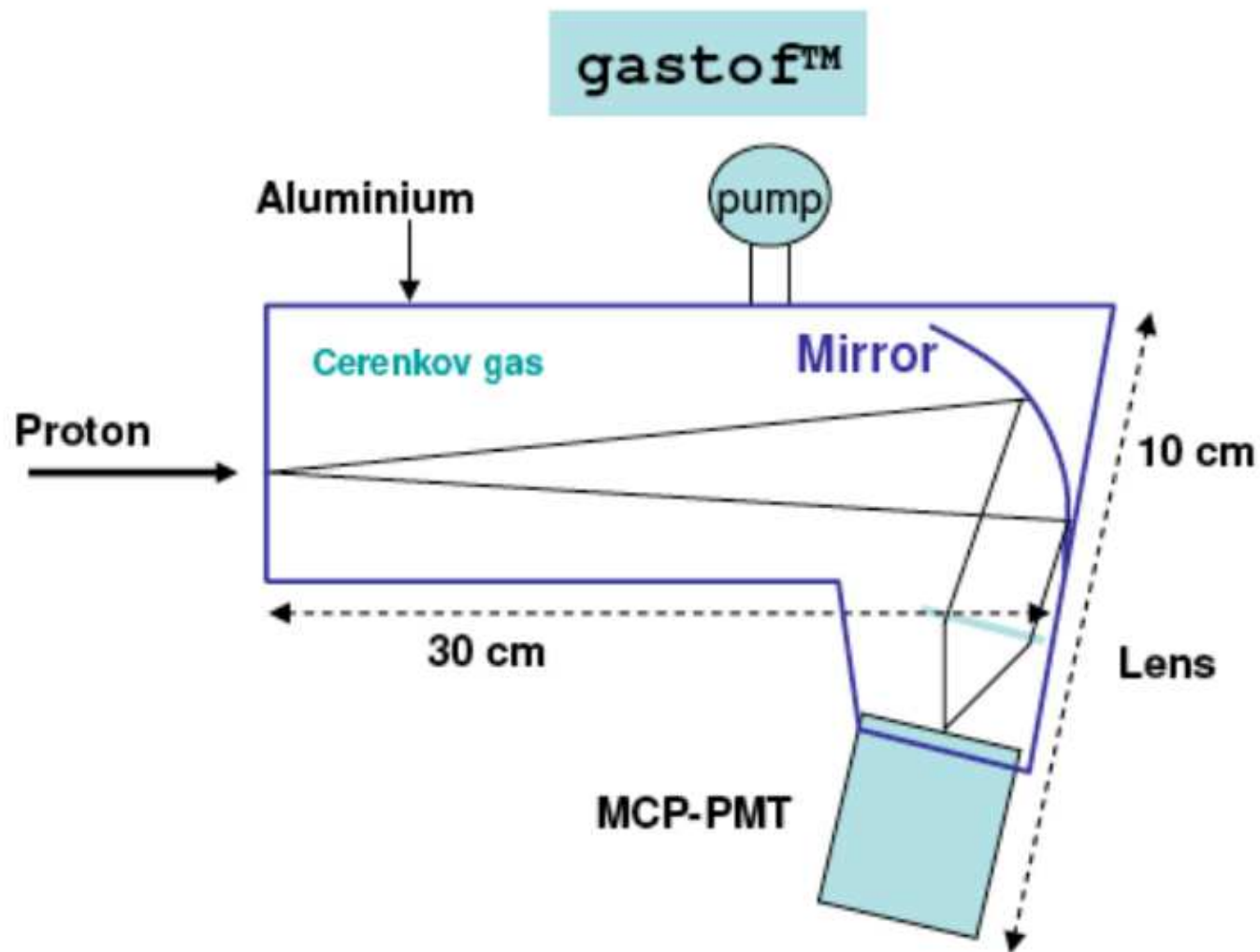
## Why do we need timing detectors?

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



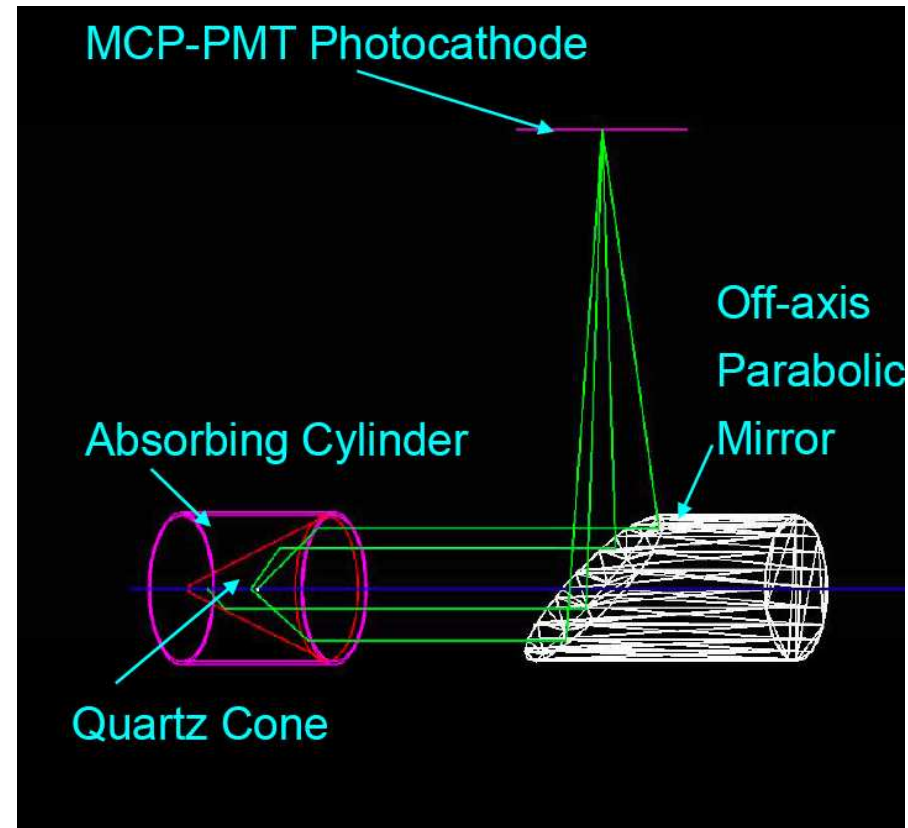
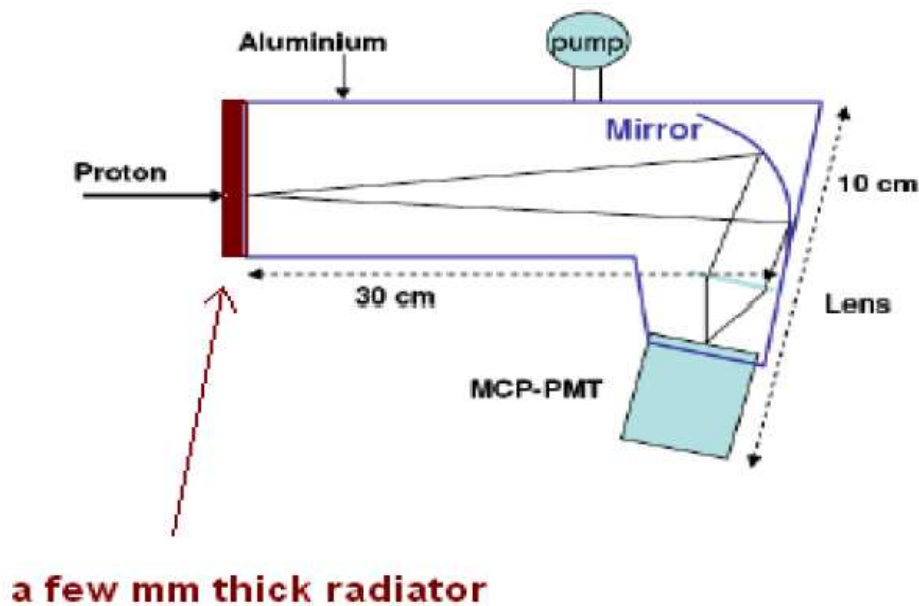
## Timing measurements

- Possibility to get presently a timing resolution of 10 – 15 ps using gas based detectors, and 30 – 40 ps using quartz detector (Louvain, UTA, Alberta, Fermilab, Brookhaven, Chicago, Stony Brook, Saclay, Orsay)
- Inconvenient of present gas detectors: no space resolution



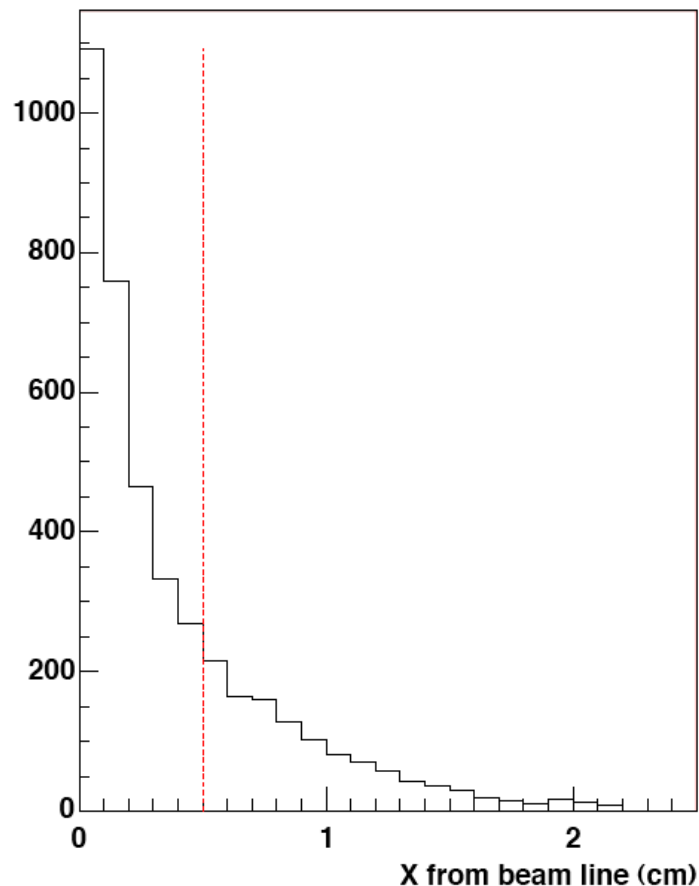
## Future timing detectors: towards 5 ps

- Aim: reach a couple of picosecond precision
- Issue: number of photoelectrons to be produced to get enough resolution
- Solution: combination of GAS and QUARTZ detectors? new concept with absorptive cylinder and off-axis parabolic mirror (Fermilab, Argonne, Chicago, Stony Brook, Brookhaven, Saclay, Orsay...)



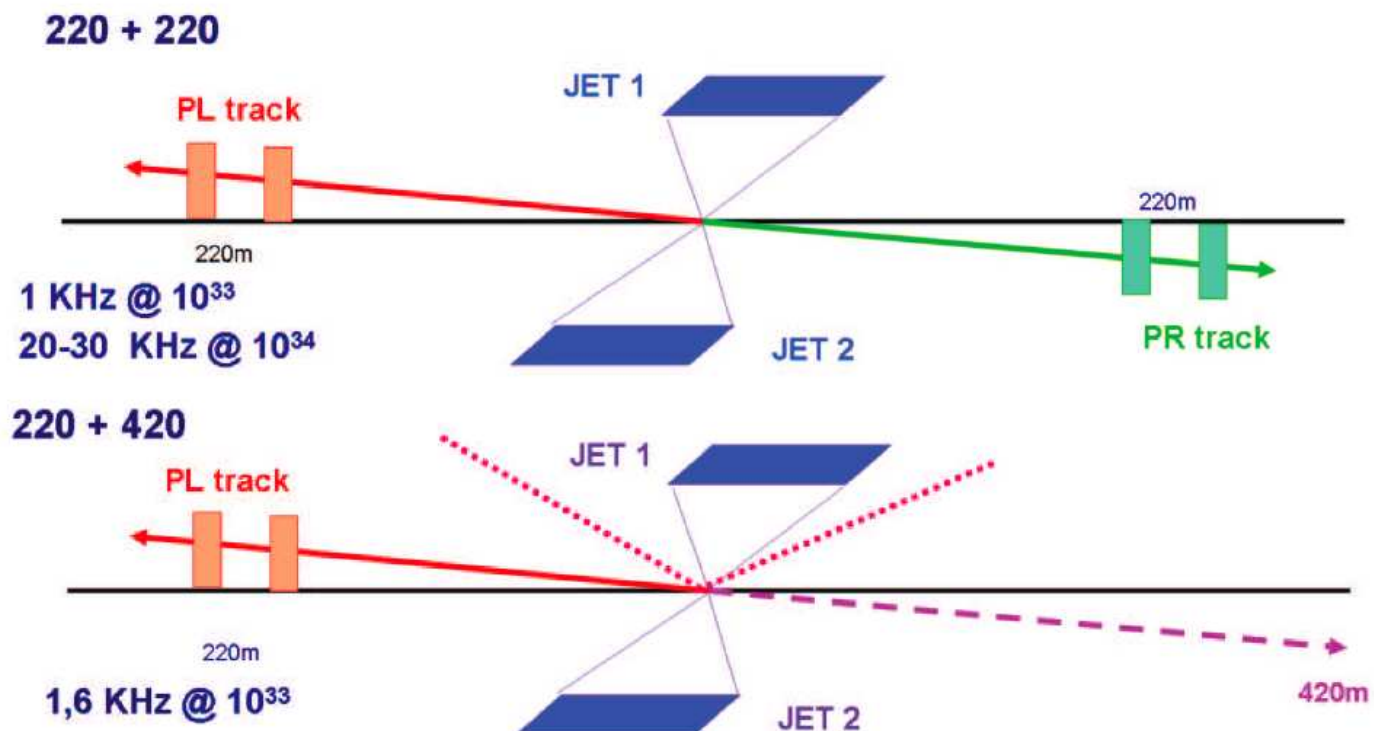
## Forward detector alignment using exclusive muons

- Alignment using dimuon events at 420 m: Compare exclusive dimuon mass reconstructed using muon detectors and forward detectors, possibility to perform a store-by-store calibration
- Same method at 220 m? More difficult since dimuon cross section lower (higher mass), can be used only to perform a measurement every 2 weeks or so
- Beam Position Monitors: high precision of 5-10  $\mu\text{m}$ , can be used to get a store-by-store calibration



## Trigger: principle

- All L1 ATLAS triggers:  $W$ ,  $b$  decaying on leptons...
- 420 m detectors cannot make it to ATLAS L1 (decision time too short)
- Level 1 trigger: Either two tags at 220 m (easy..., possibility to cut on diffractive mass), or one single tag at 220 m (difficult...)
- In that case, cut on acceptance at 220 m corresponding to the possibility of a tag at 420 m: 2 jets  $p_T > 40$  GeV; one proton at 220 m ( $\xi < 0.05$ , compatible with the presence of a proton at 420 m on the other side); Exclusiveness  $(E_{T_1} + E_{T_2})/H_T > 0.9$ ; Kinematics requirement  $(\eta_1 + \eta_2) \times \eta_{220} > 0$  (requires modif of L1 ATLAS trigger)
- L1 rate  $< 1$  kHz for  $L < 3 \cdot 10^{33} \text{cm}^{-2} \text{s}^{-1}$
- Level 2: 420 m info and timing info: rates of a couple of Hz

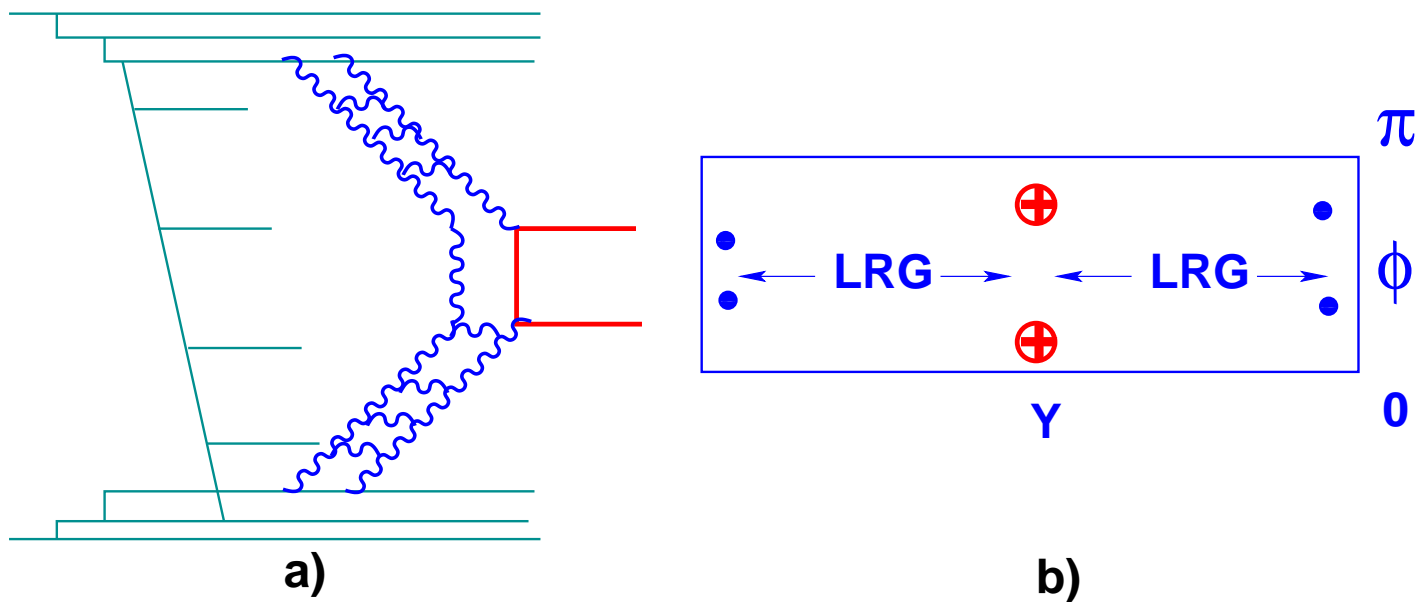


## Conclusion and timescale

- **Diffraction physics at the LHC:** QCD, Higgs,  $WW$ , anomalous coupling...
- **AFP project:** movable beam pipes needed at 220/420 m
- **Position detectors to be used:** 3D Silicon
- **Timing detectors:** High precision needed especially for high luminosity at the LHC ( $\sim 5$ -10 picoseconds)
- **Timescale:** physics project approved by ATLAS, technical proposal submission to ATLAS/LHCC in Winter timescale; many groups involved: UK (Manchester, London UCL, Glasgow, Cockcroft Institute, RAL), France (Saclay, Marseille), Poland (Cracow), Czech Republic (Prague), USA (Texas Arlington, Stony Brook), Canada (Alberta), Germany (Giessen)
- **Management structure in progress:** Stephen Watts, Christophe Royon, Andrew Brandt, ATLAS Forward Physics Project Coordinators
- **Many developments performed/in progress for the project and extremely useful for the future in particle physics or medical applications:** 3D Si, timing detectors

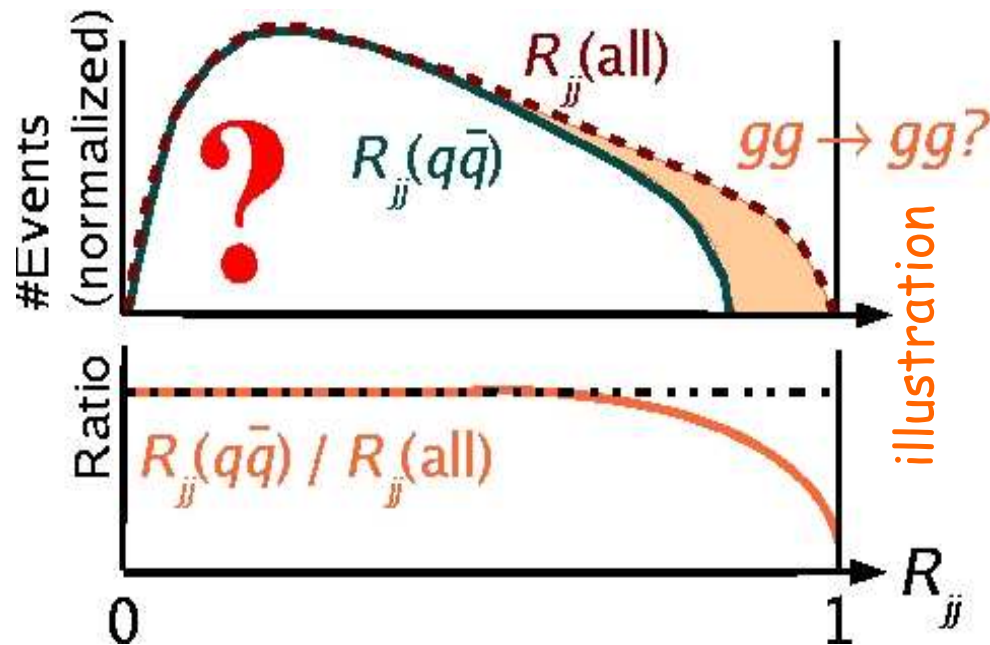
## Factorisation at Tevatron?

- Is factorisation valid at Tevatron? Can we use the parton densities measured at HERA to use them at the Tevatron/LHC?
- Factorisation is not expected to hold: soft gluon exchanges in initial/final states
- Survival probability: Probability that there is no soft additional interaction, that the diffractive event is kept



## Search for exclusive events (CDF)

- Look for exclusive events in  $b\bar{b}$  events production:
- If exclusive events exist the ratio of  $b$  jet events should be smaller at high dijet mass fraction since exclusive  $b$  jet production is suppressed



## Search for exclusive events (CDF)

- Look for exclusive events in  $b\bar{b}$  events production:
- The ratio of  $b$  jet events tends to be smaller at high dijet mass fraction, needs more stats

