

Diffraction at HERA, Tevatron and LHC

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Dedicated to Jan Kwiecinski

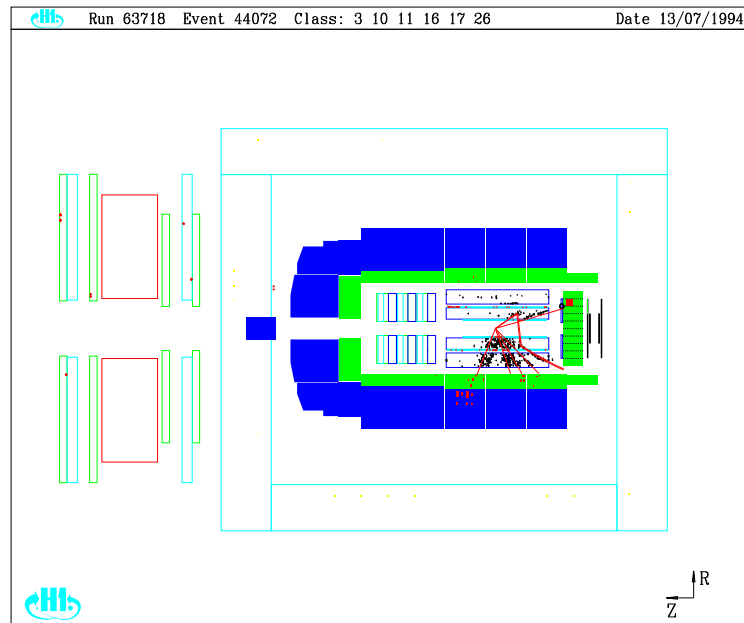
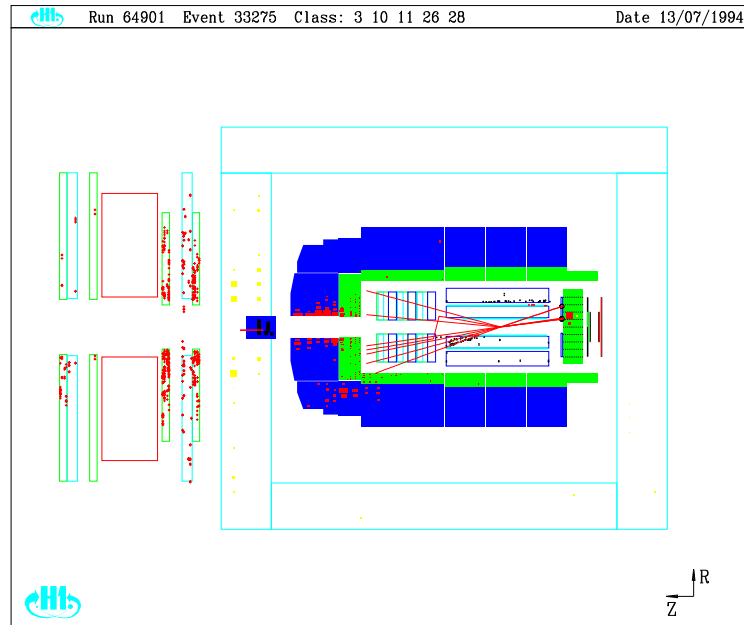
Contents:

- Inclusive diffraction at HERA
- Hard diffraction at the LHC
- Search for exclusive diffraction at Tevatron
- Diffractive Higgs production at the LHC
- Photon physics at the LHC
- AFP project: ATLAS Forward Physics

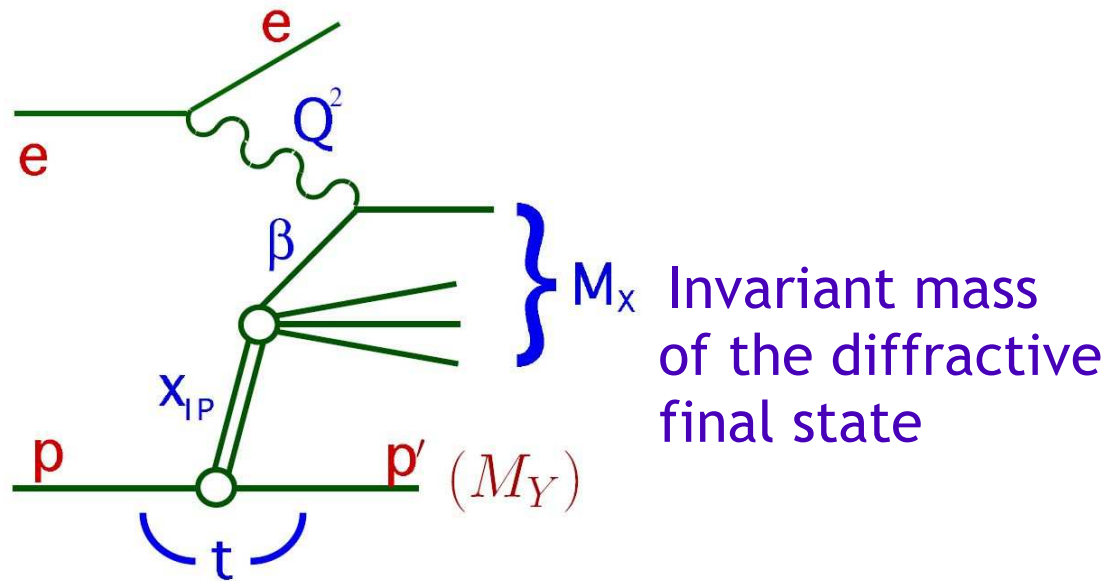
Definition of diffraction: example of HERA

- **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

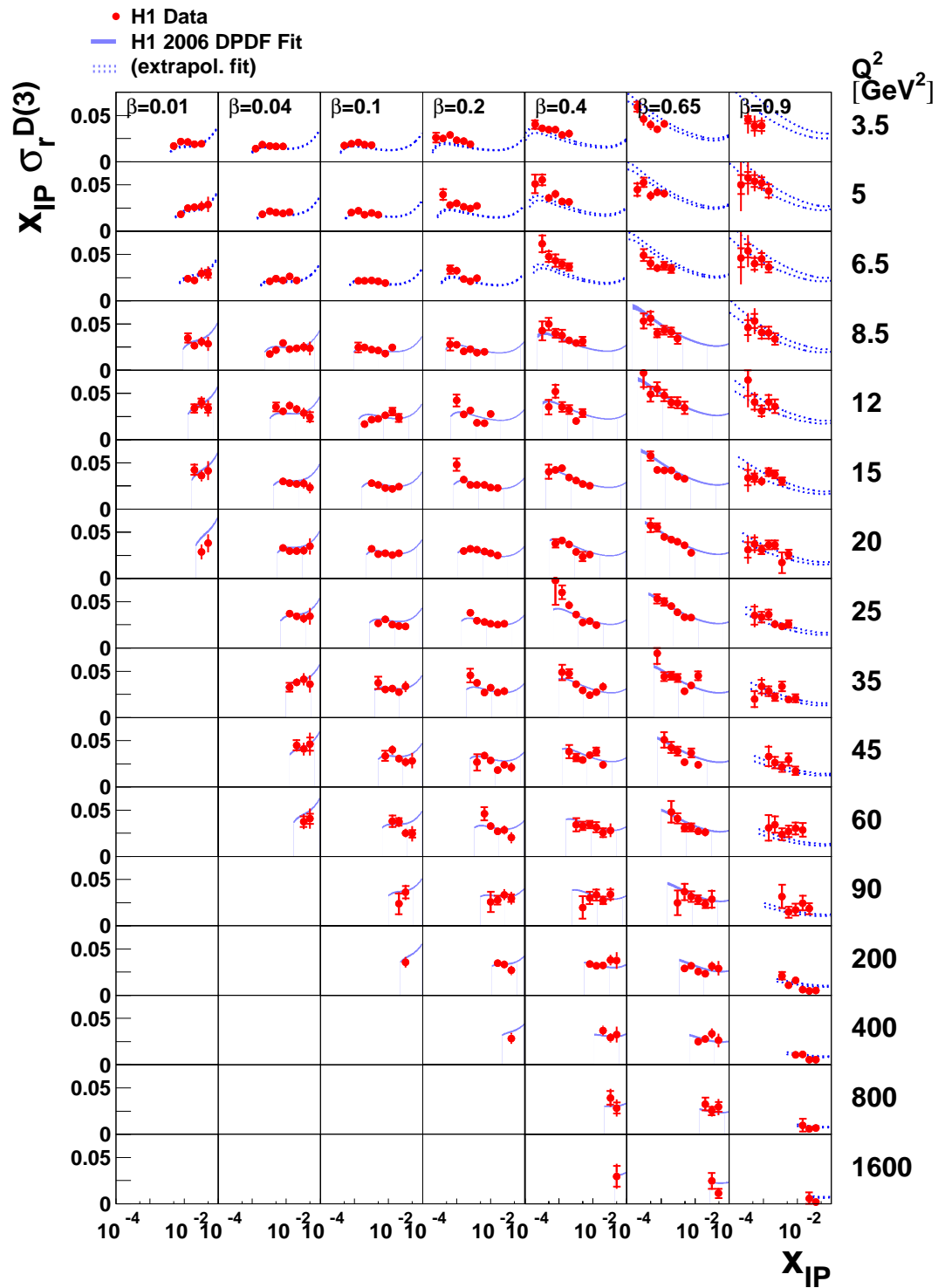


Diffractive kinematical variables



- 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



Extraction of the parton densities in the pomeron (H1)

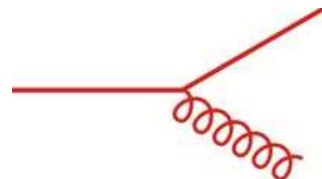
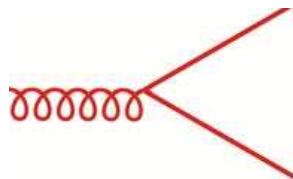
- Assume pomeron made of quarks and gluons: perform QCD DGLAP fits as for the proton structure function starting from xG and xq distributions at a given Q_0^2 , and evolve in Q^2 (the form of the distributions is MRS like)

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

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

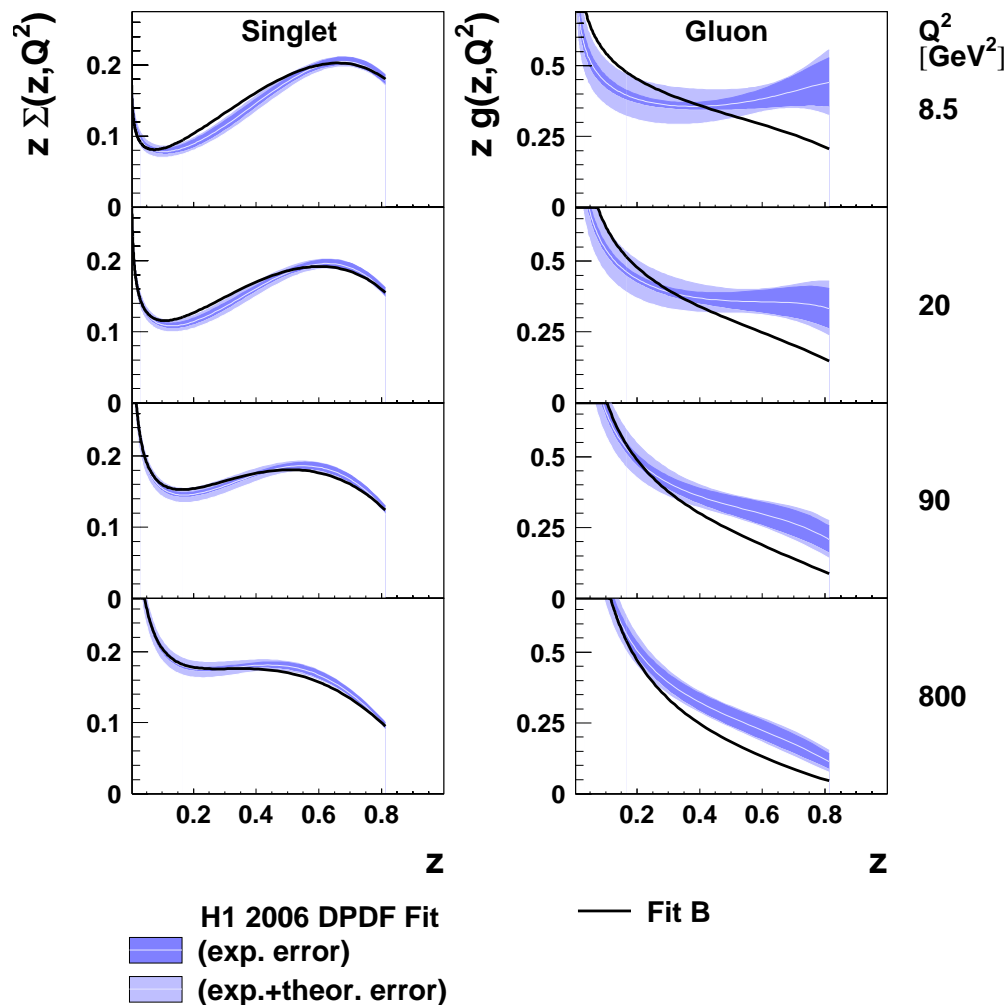
- At low β : evolution driven by $g \rightarrow q\bar{q}$, at high β , $q \rightarrow qg$ becomes important
- Take all data for $Q^2 > 8.5 \text{ GeV}^2$, $\beta < 0.8$ to be in the perturbative QCD region and avoid the low mass region (vector meson resonances)

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

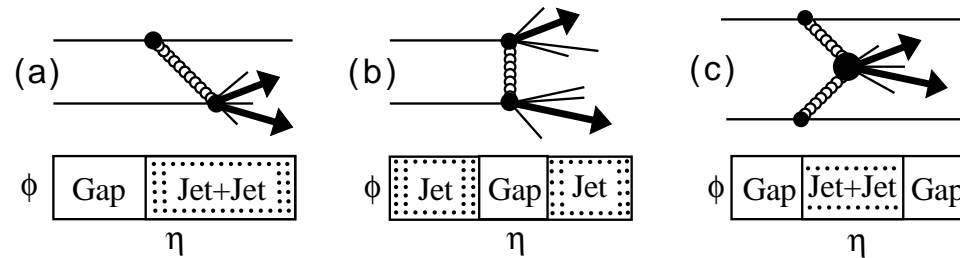


Parton densities in the pomeron (H1)

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



Diffraction at Tevatron/LHC

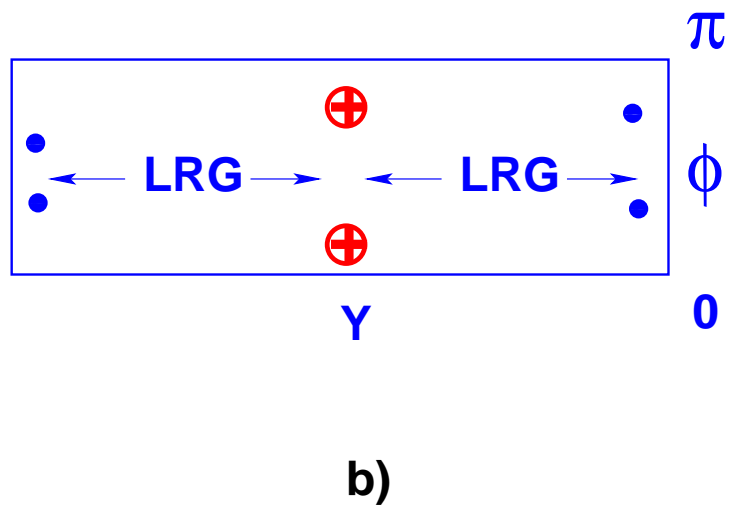
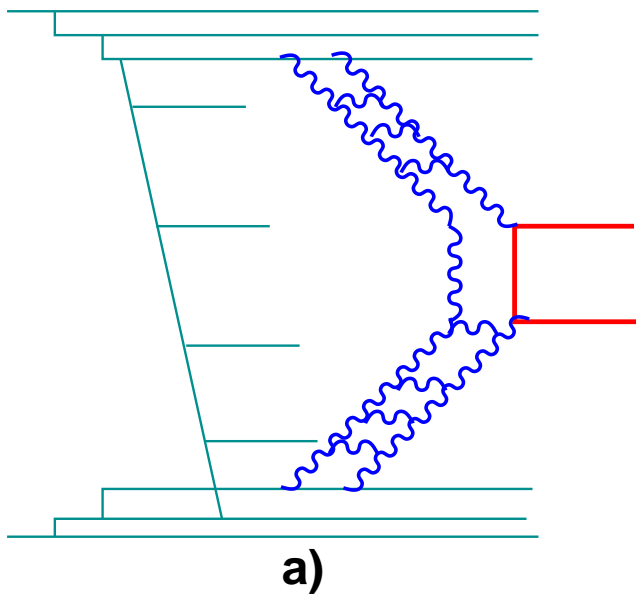


Kinematic variables

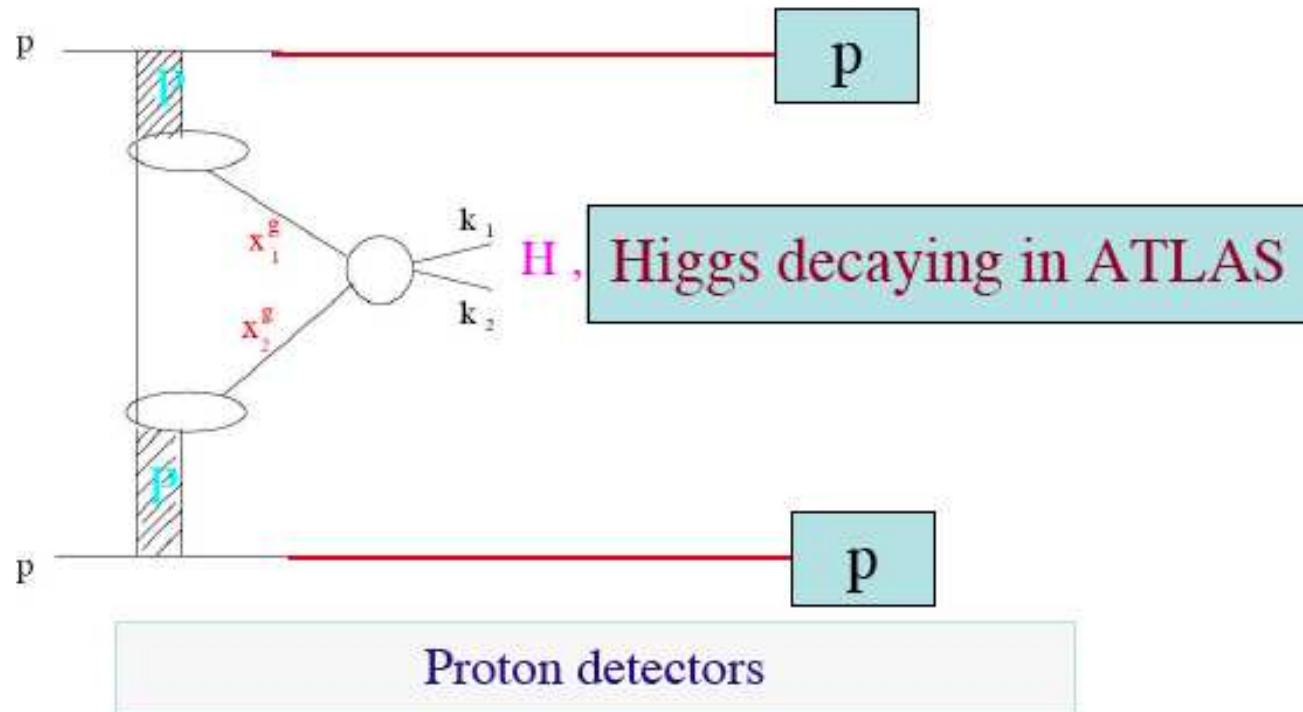
- t : 4-momentum transfer squared
- ξ_1, ξ_2 : proton fractional momentum loss (momentum fraction of the proton carried by the pomeron)
- $\beta_{1,2} = x_{Bj,1,2}/\xi_{1,2}$: Bjorken- x of parton inside the pomeron
- $M^2 = s\xi_1\xi_2$: diffractive mass produced
- $\Delta y_{1,2} \sim \Delta\eta \sim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

Concept of survival probability

- Understanding of factorisation breaking at Tevatron/LHC? 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, independent of hard scattering
- Survival probability: Probability that there is no soft additional interaction, that the diffractive event is kept
- Measurement of survival probability using first data: J/Ψ , Υ ...



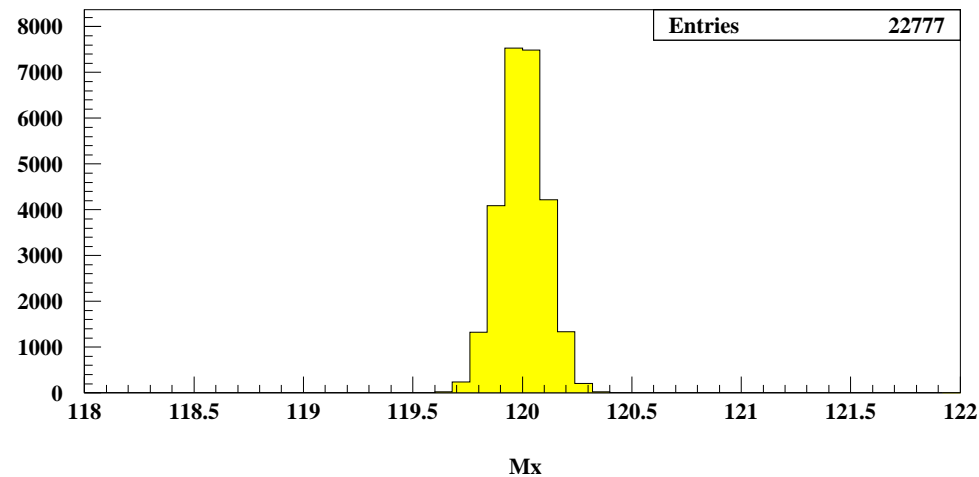
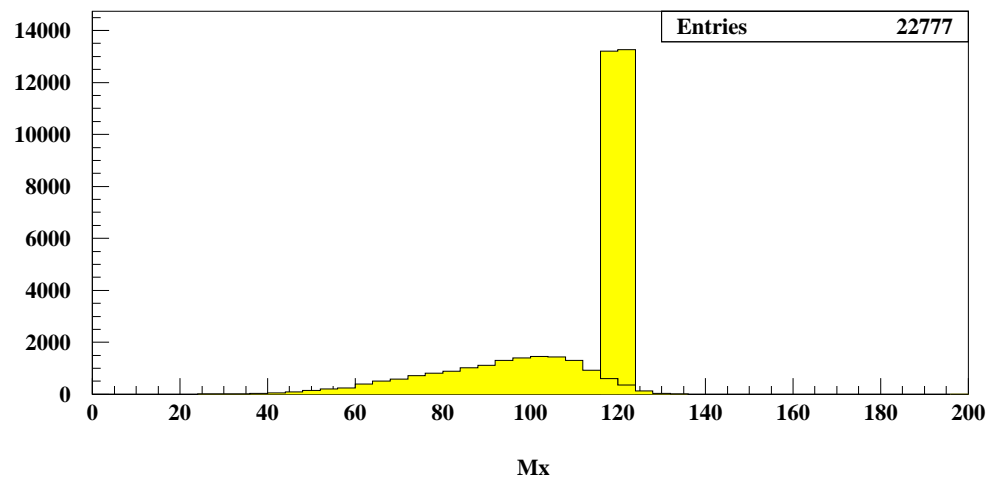
“Exclusive models” in diffraction



- 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...

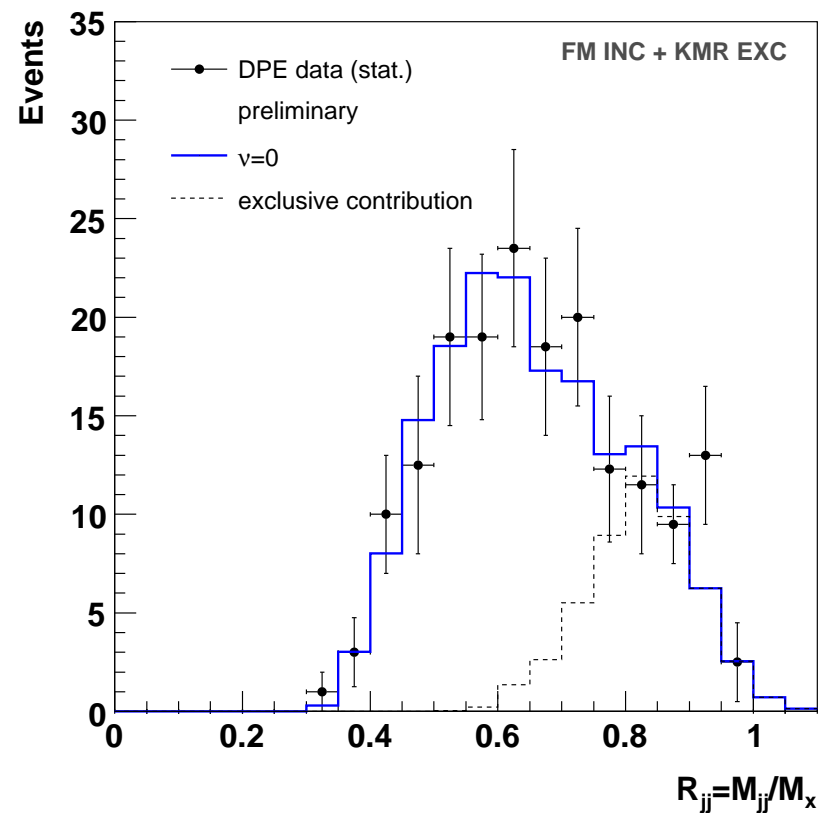
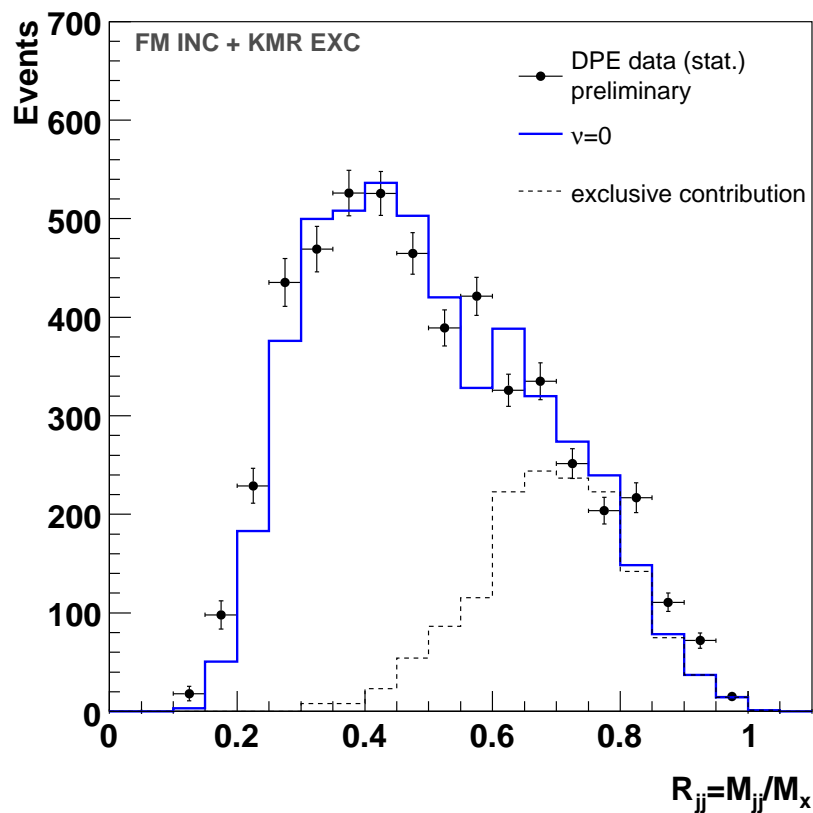
Advantage of exclusive Higgs production?

- 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



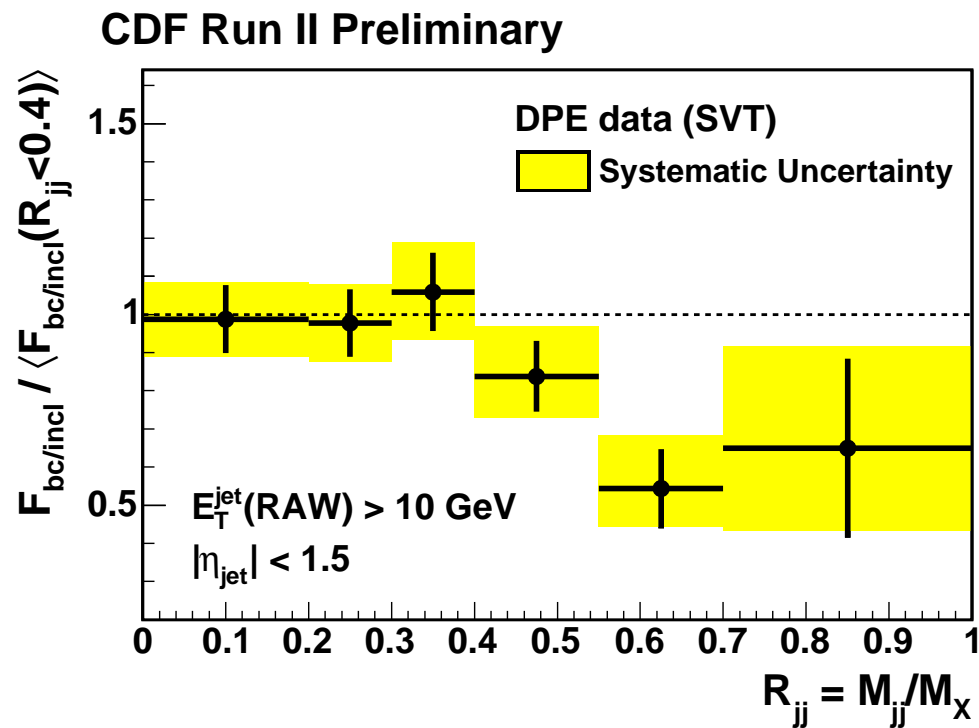
Search for exclusive events in CDF

- Inclusive diffraction cannot explain CDF measurement of dijet mass fraction
- Measurements compatible with inclusive and exclusive diffraction (Khoze Martin Ryskin) added
- See O. Kepka, C. Royon, Phys.Rev.D76 (2007) 034012; arXiv0706.1798



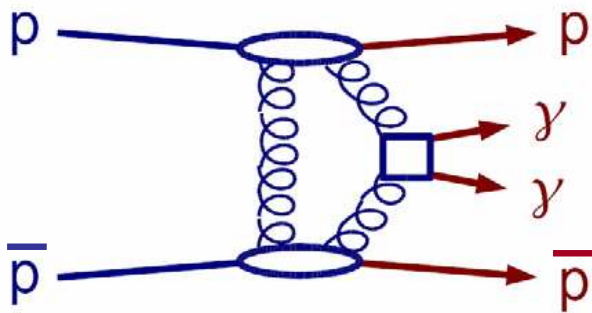
Search for exclusive events (CDF)

- 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

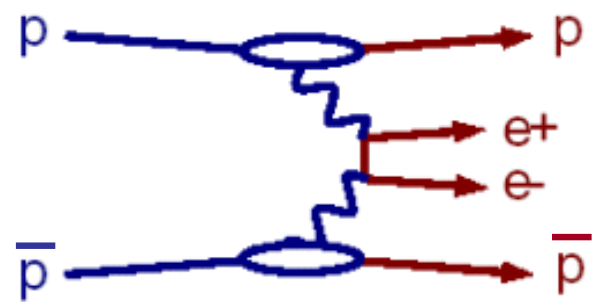


Search for exclusive diphotons (CDF)

- 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



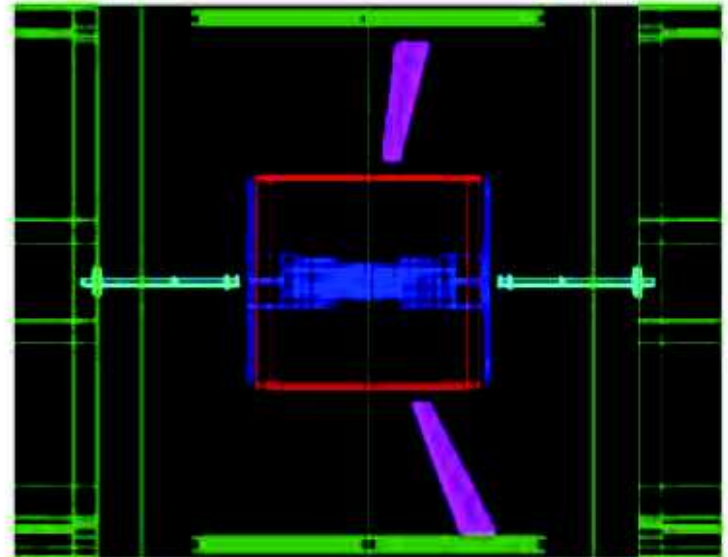
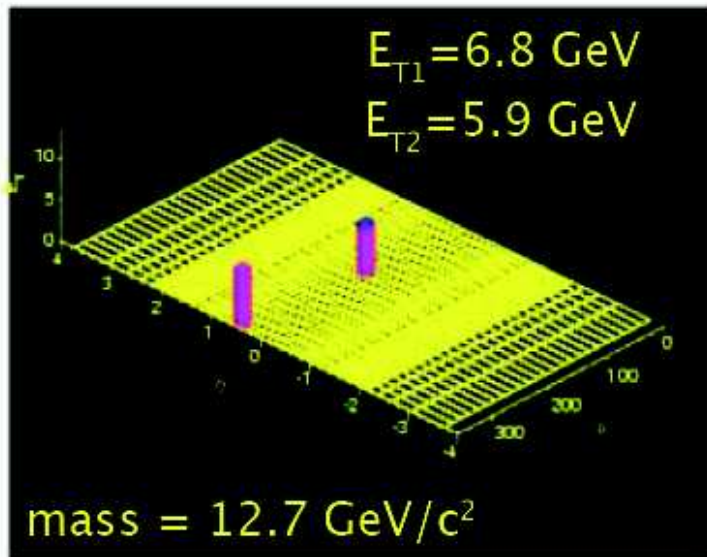
$$p\bar{p} \rightarrow p + \gamma\gamma + \bar{p}$$



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

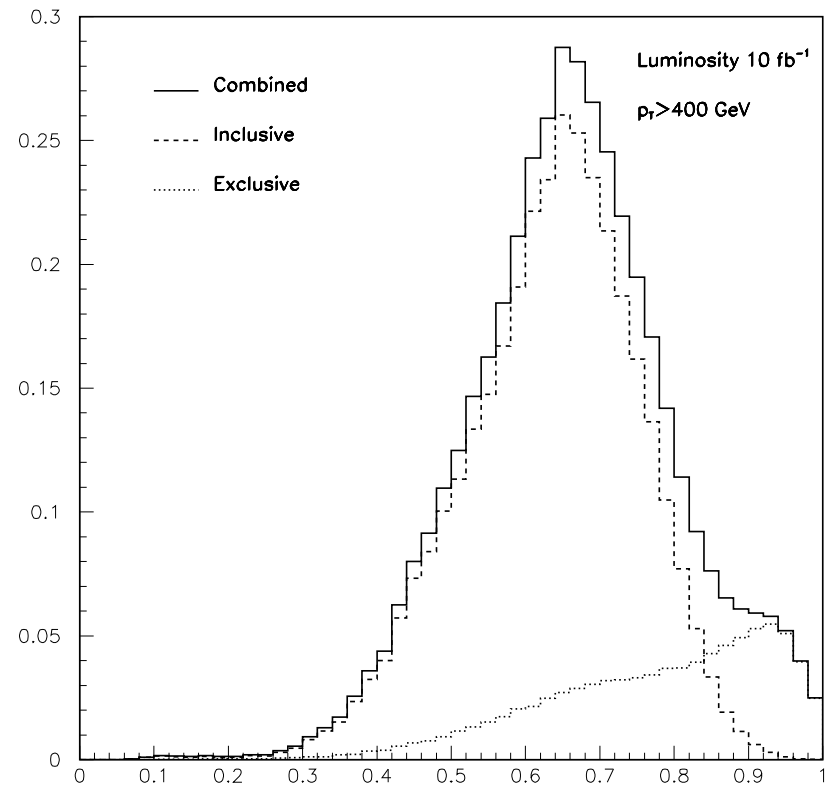
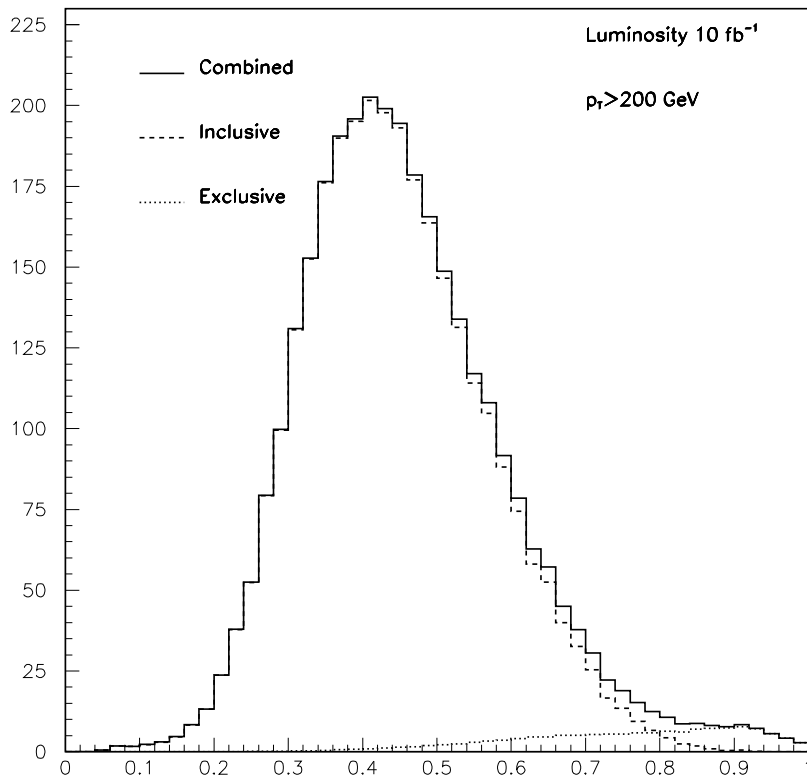
Search for exclusive diphotons (CDF)

- 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 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 pb^{-1} $\sigma = 0.14_{-0.04}^{+0.14}(stat) \pm 0.03(syst) \text{ pb}$



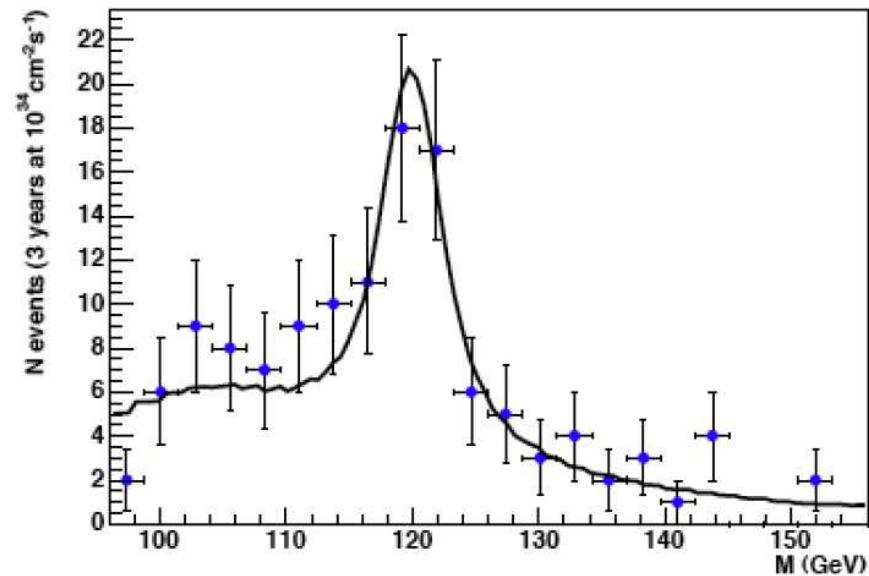
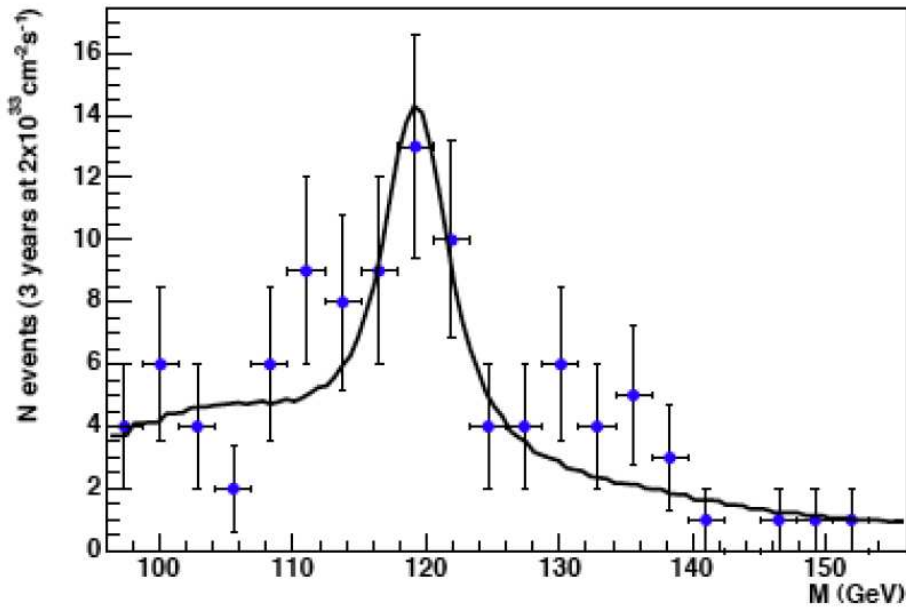
LHC: Exclusive and inclusive events

- Study of exclusive and inclusive production to be made at the LHC: study cross section of both components as a function of jet p_T and perform DGLAP QCD fits
- Important to understand background and signal for exclusive production of rare events: Higgs, SUSY...



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
- **Diffraction Higgs boson production complementary to the standard search**

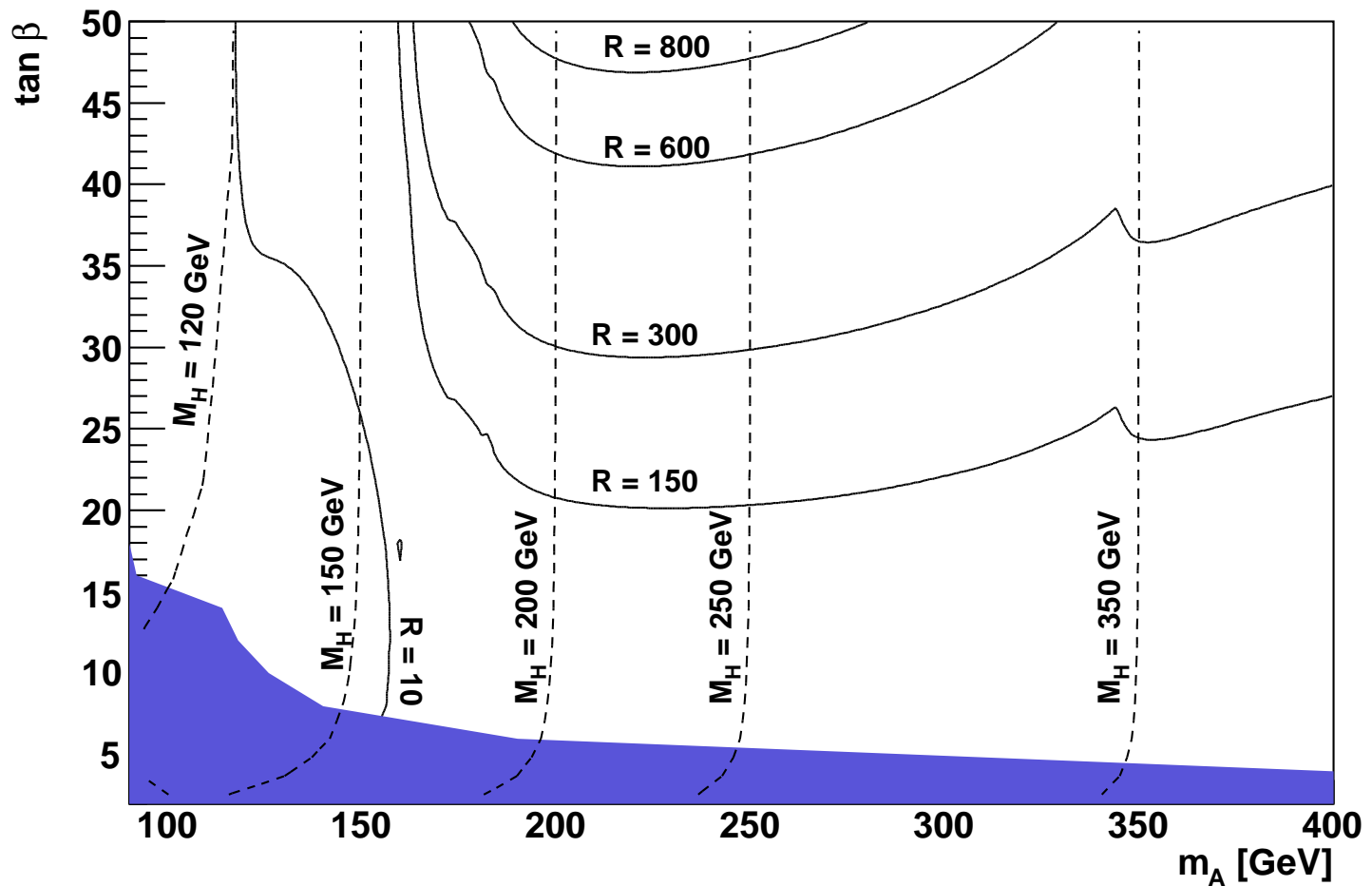


Diffractive SUSY Higgs production

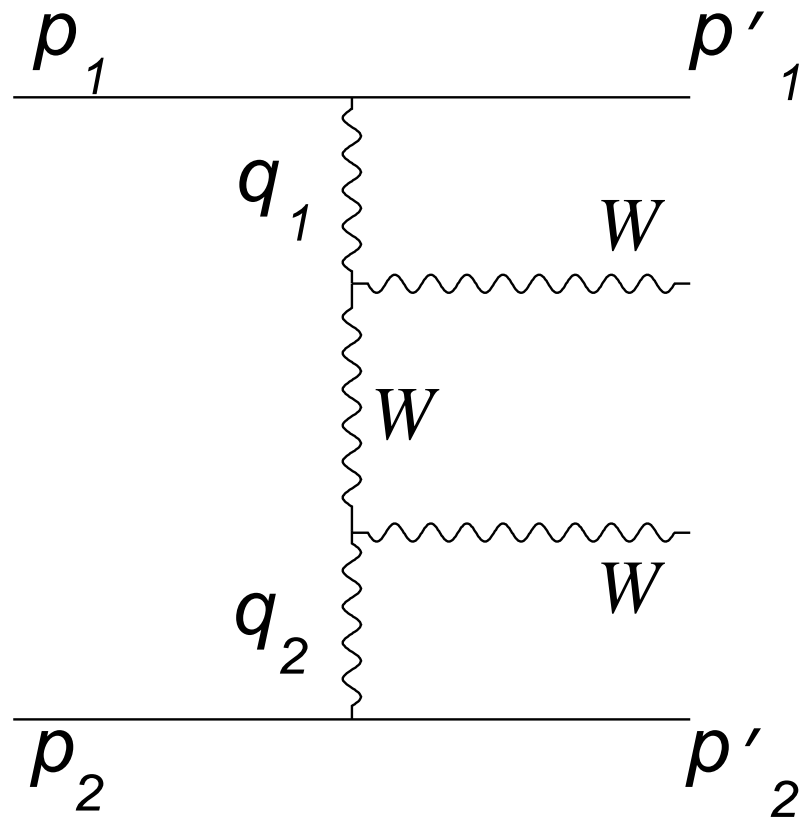
Contour for the ratio of signal events in the MSSM and SM scenarios for

$$H \rightarrow b\bar{b}$$

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



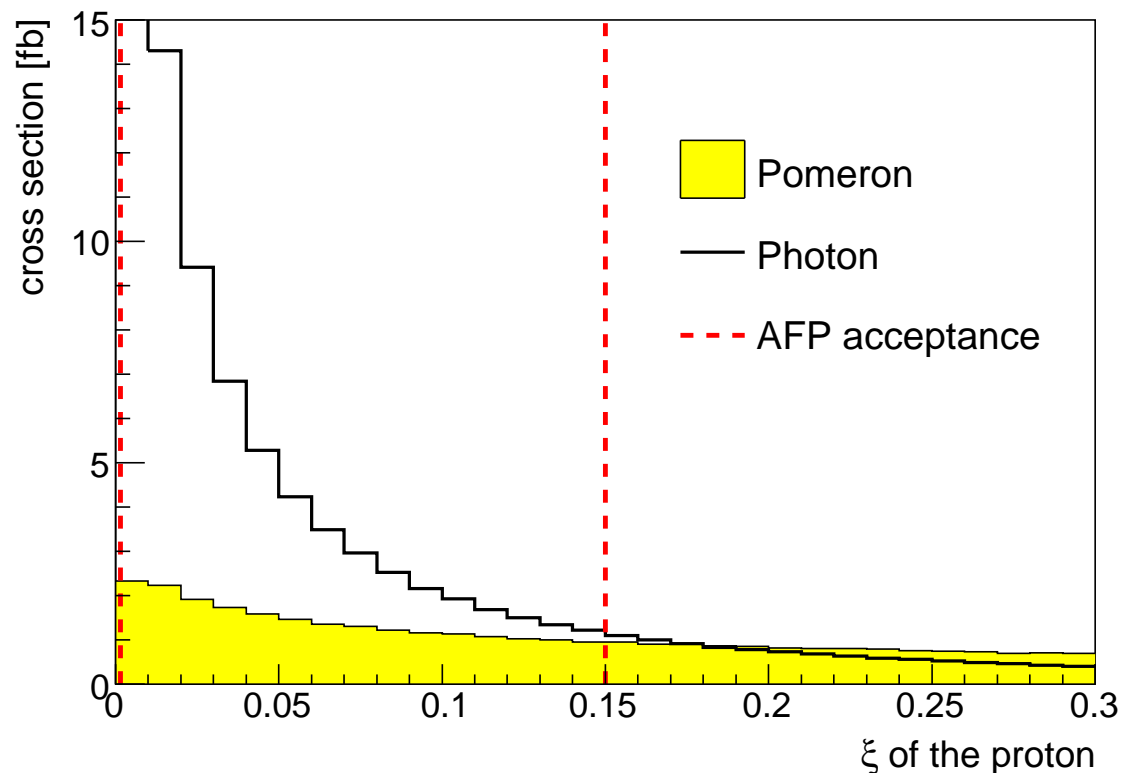
WW production at the LHC



- Study of the process: $pp \rightarrow ppWW$
- Exclusive production of W pairs via photon exchange: QED process, cross section perfectly known
- Two steps: SM observation of WW events, anomalous coupling study
- $\sigma_{WW} = 95.6 \text{ fb}$, $\sigma_{WW}(W > 1\text{TeV}) = 5.9 \text{ fb}$
- See: O. Kepka, C. Royon, arXiv:0808.0322, in press in Phys. Rev. D

Experimental study of WW production at the LHC

- ATLAS/CMS-TOTEM: Proton taggers at 220 and 420 m:
 $0.0015 < \xi < 0.15$
- W detected in main ATLAS/CMS detector: electron or muon detected with $p_T > 30$ GeV and $|\eta| < 2.5$
- Higher cut on ξ allows to remove part of the double pomeron exchange background: cross section of 14 fb for $0.0015 < \xi < 0.05$ (double pomeron exchange background: 0.2 fb)
- For a luminosity of 200 pb^{-1} , observation of 5.6 W pair events for a background less than 0.4, which leads to a signal of 8.6σ



Anomalous $WW\gamma$ triple gauge coupling

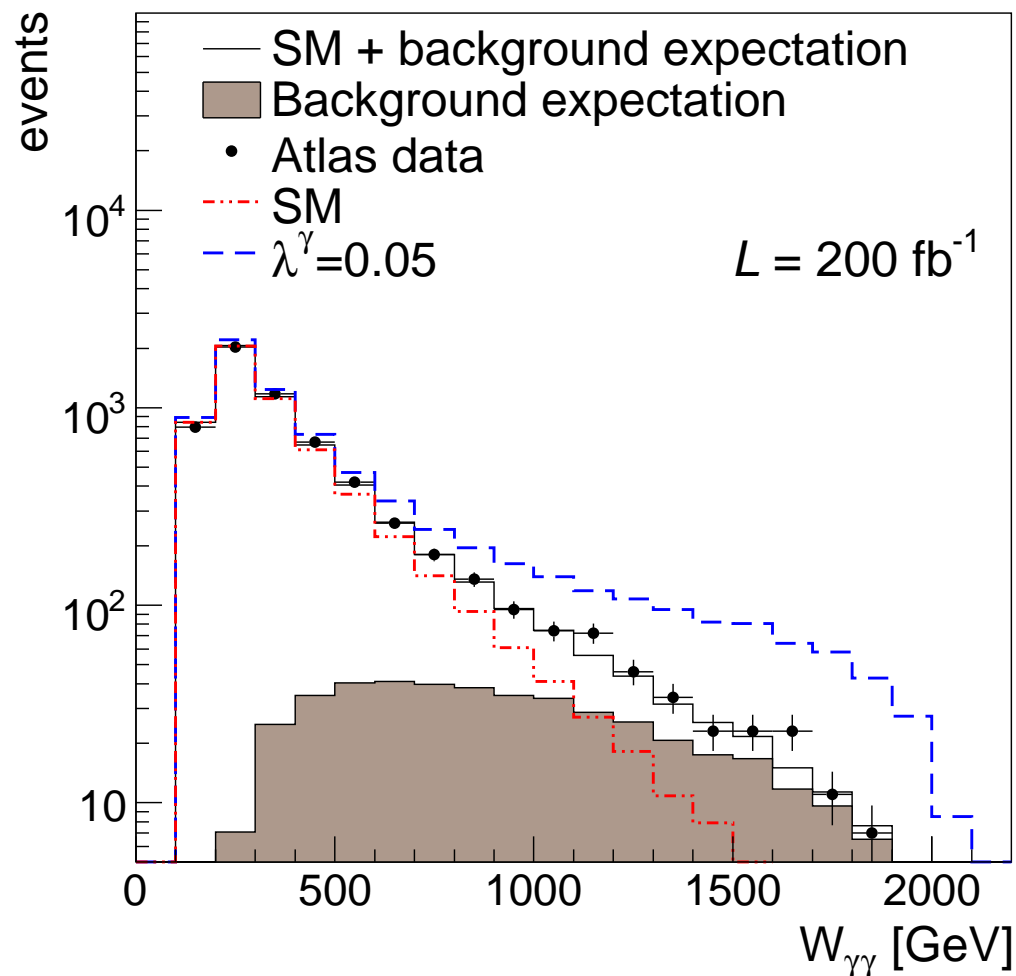
- Lagrangian with anomalous couplings λ^γ

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

- Anomalous coupling matrix elements obtained using OMEGA interfaced with FPMC (Forward Physics Monte Carlo to get DPE (inclusive and exclusive KMR) and Photon exchanges at the LHC, and also single diffraction in the same framework)
- Present limits on anomalous couplings:
 - From Tevatron: $-0.51 < \Delta\kappa^\gamma < 0.51$; $-0.12 < \lambda^\gamma < 0.13$ (direct limits)
 - NB: Indirect limits from LEP: $-0.098 < \Delta\kappa^\gamma < 0.101$; $-0.044 < \lambda^\gamma < 0.047$ (Inconvenient: mixture of γ and Z exchanges in $e^+e^- \rightarrow WW$)
- Reach on anomalous coupling at the LHC using a luminosity of 30 fb^{-1} : gain of a factor 20 on $\Delta\kappa^\gamma$ and λ^γ

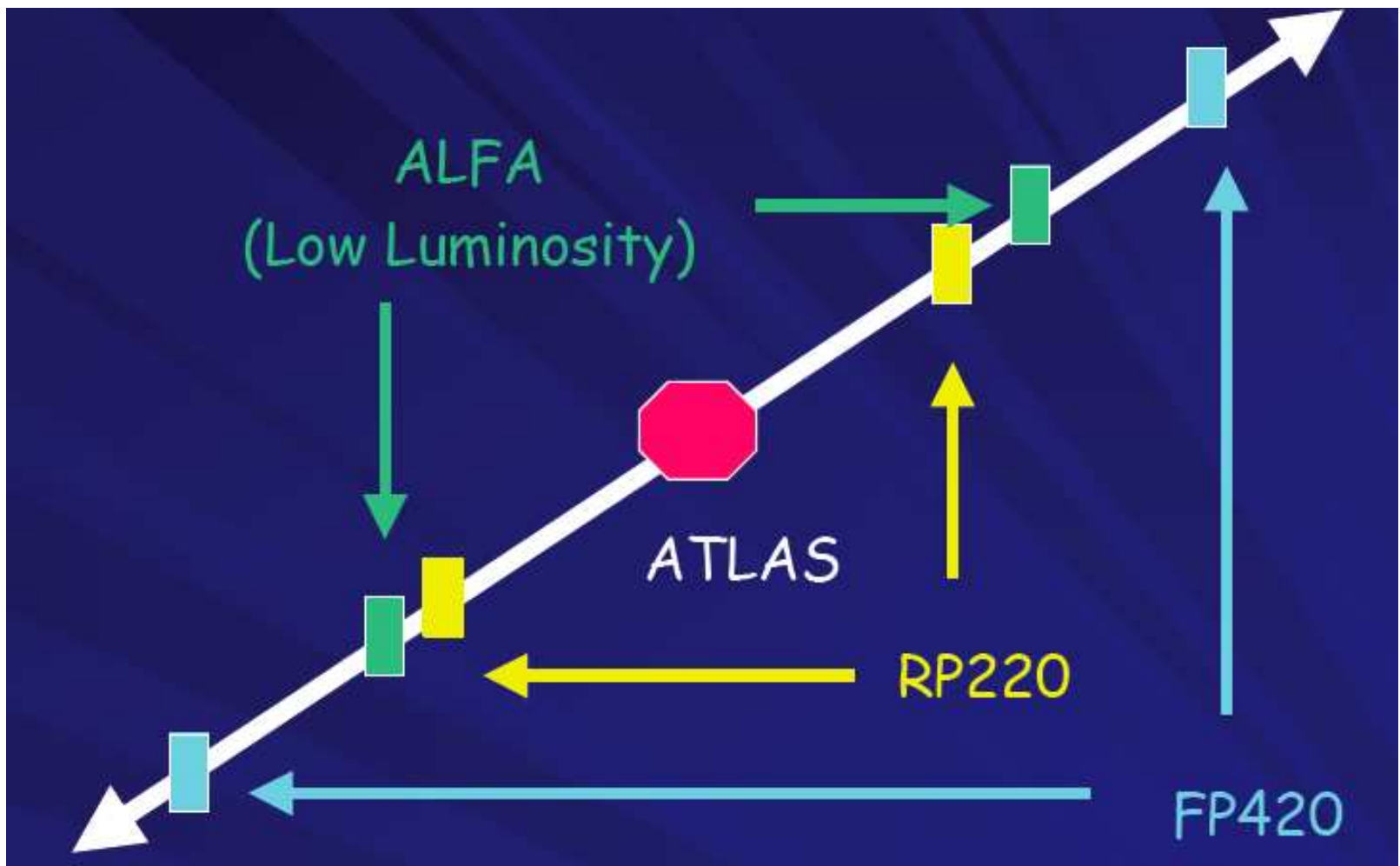
Reach on anomalous coupling

- Distribution of the $\gamma\gamma$ invariant mass $W_{\gamma\gamma}$:
- Specially interesting at high $W_{\gamma\gamma}$ where about 400 events are expected above 1 TeV for 200 fb^{-1}
- Sensitive to anomalous coupling but also to SUSY, new strong dynamics at the TeV scale



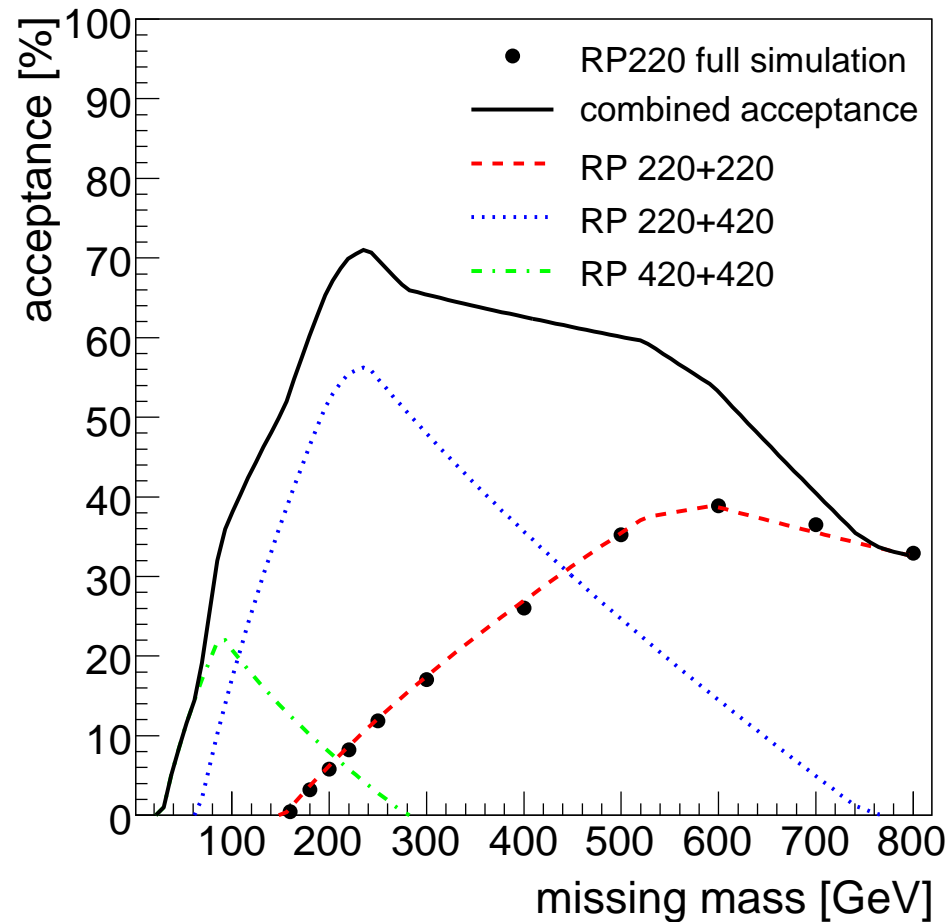
Detector location

- **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)



ATLAS Forward Physics detector acceptance

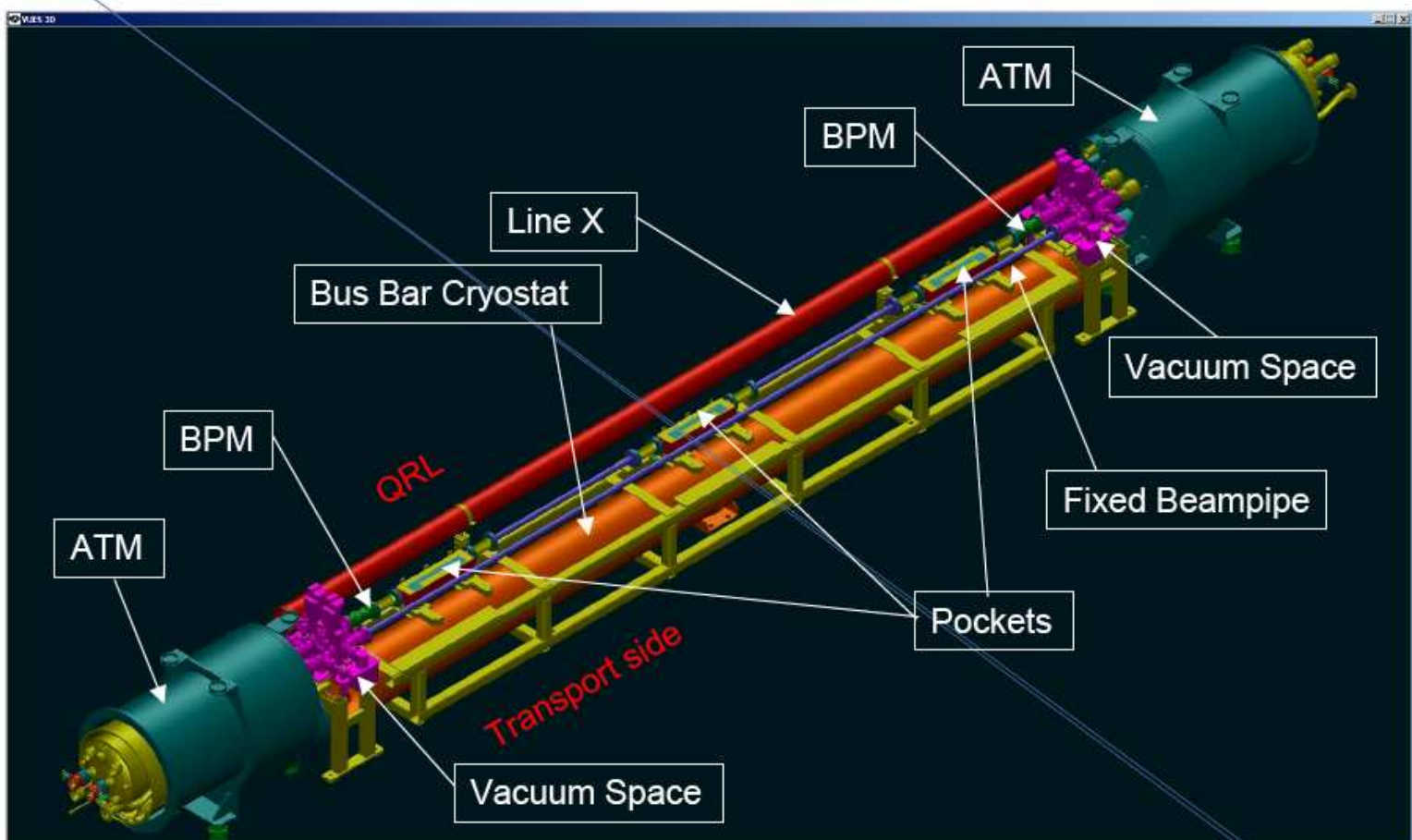
Both detectors at 420 and 220 m needed to have a good coverage of acceptance (NB: acceptance slightly smaller in CMS than in ATLAS)



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 ($5 \mu\text{m}$)

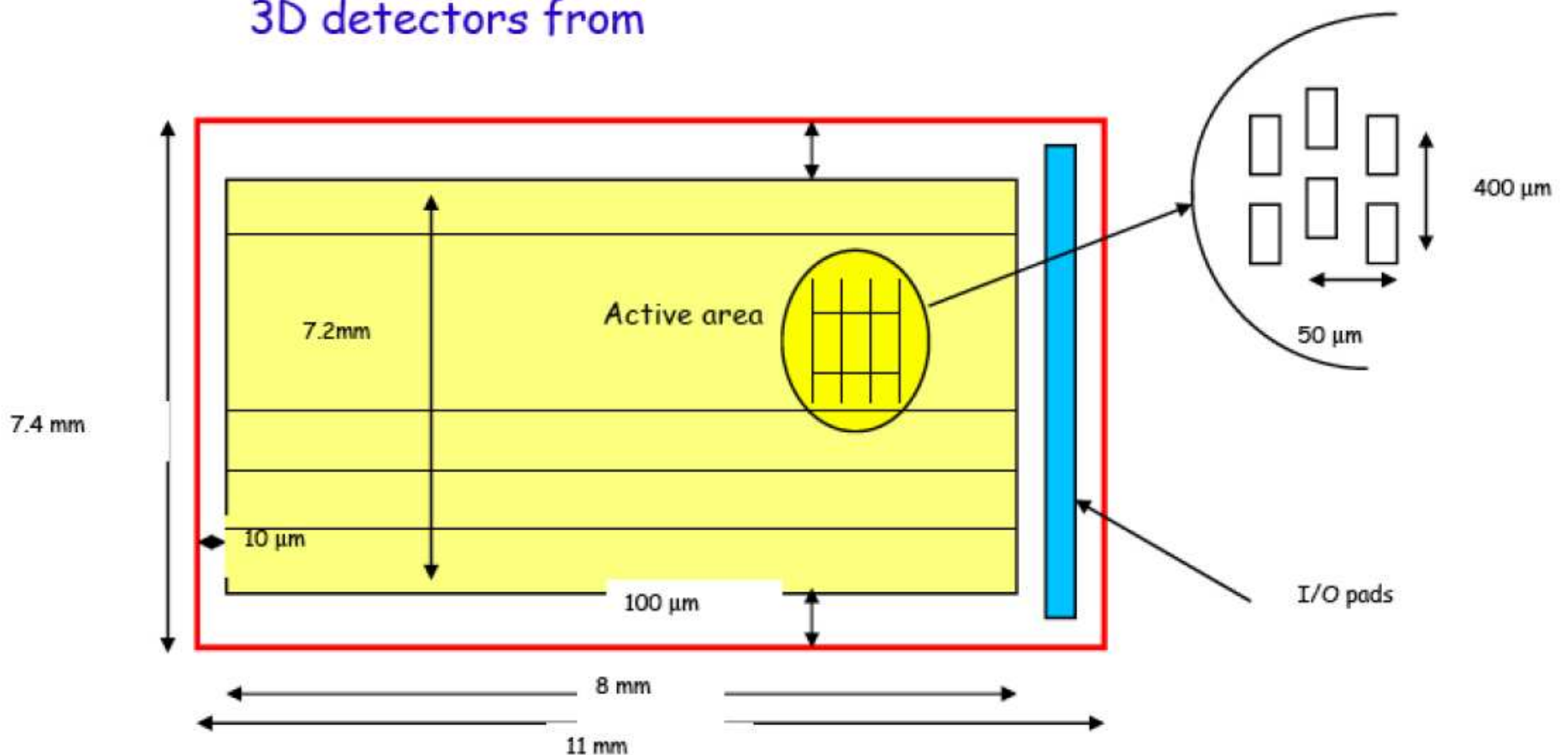
Integration of the moving beampipe and detectors



3D Silicon Detectors (Manchester/SLAC)

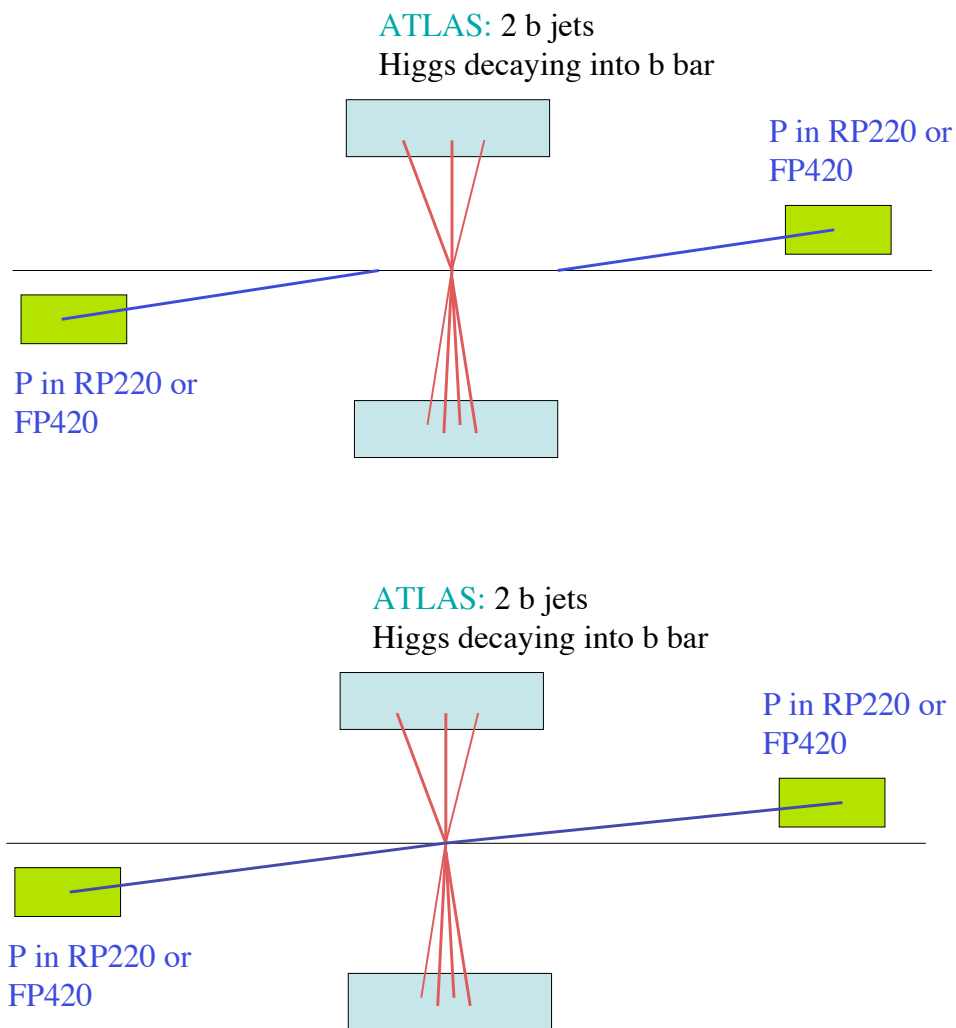
- Precise reconstruction of proton position, and then mass: position resolution of 10-15 μm
- Radiation hardness
- 3D Si detectors: 10 planes per supermodule, pixels of $50 \times 400 \mu m$; 10 layers
- Modification of readout chip to include L1 trigger: address of vertical line hit to know ξ at L1

3D detectors from



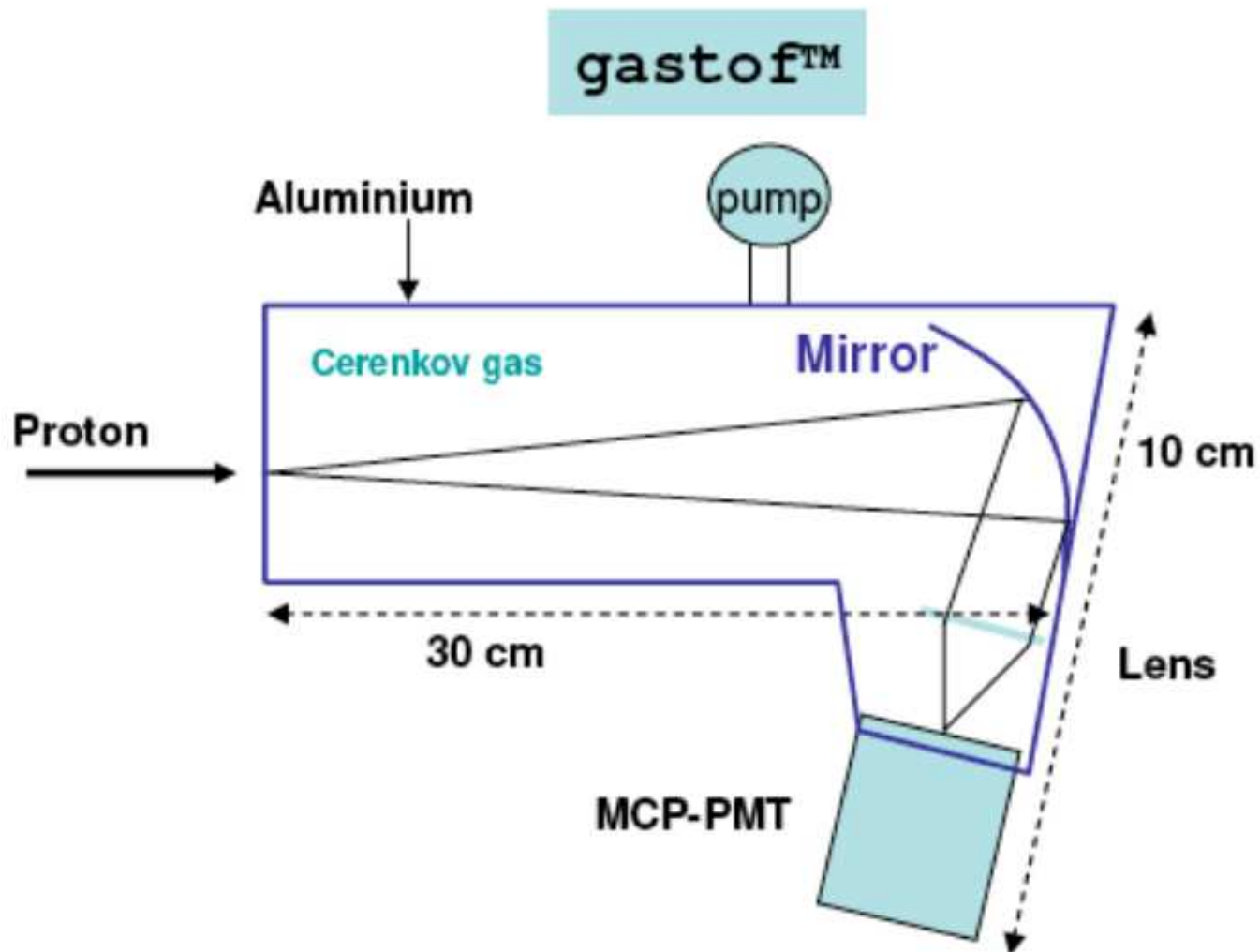
Why do we need timing detectors?

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!!!!)



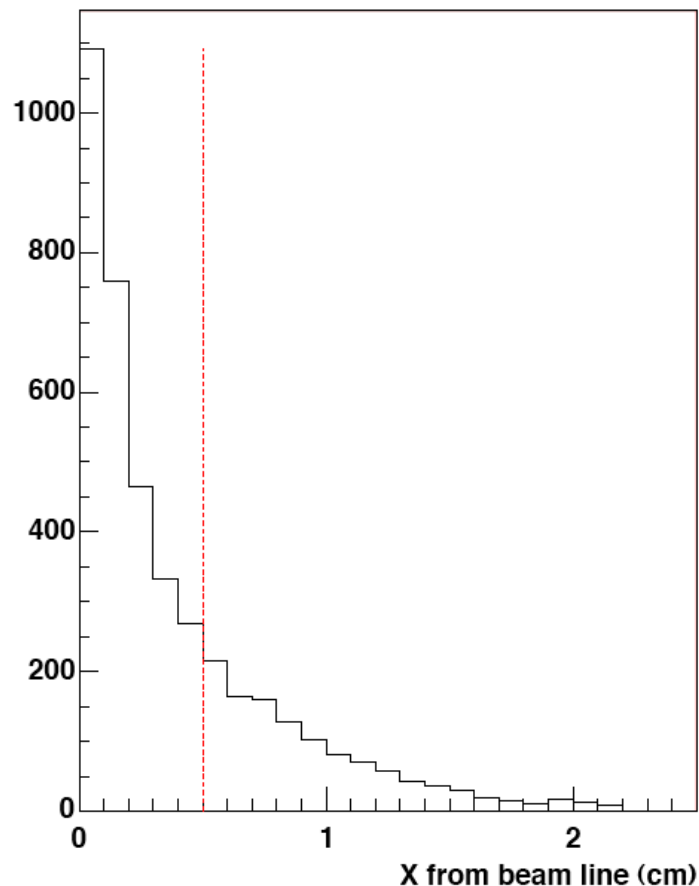
Timing measurements

- Possibility to get presently a timing resolution of 10 – 15 ps using gas based detectors, and 30 – 40 ps per plane using quartz detector (Louvain, UTA, Alberta, Fermilab)
- Inconvenient of present gas detectors: no space resolution
- Upgrades under study: quartz in front of GASTOF, reconstruct Cerenkov light cone



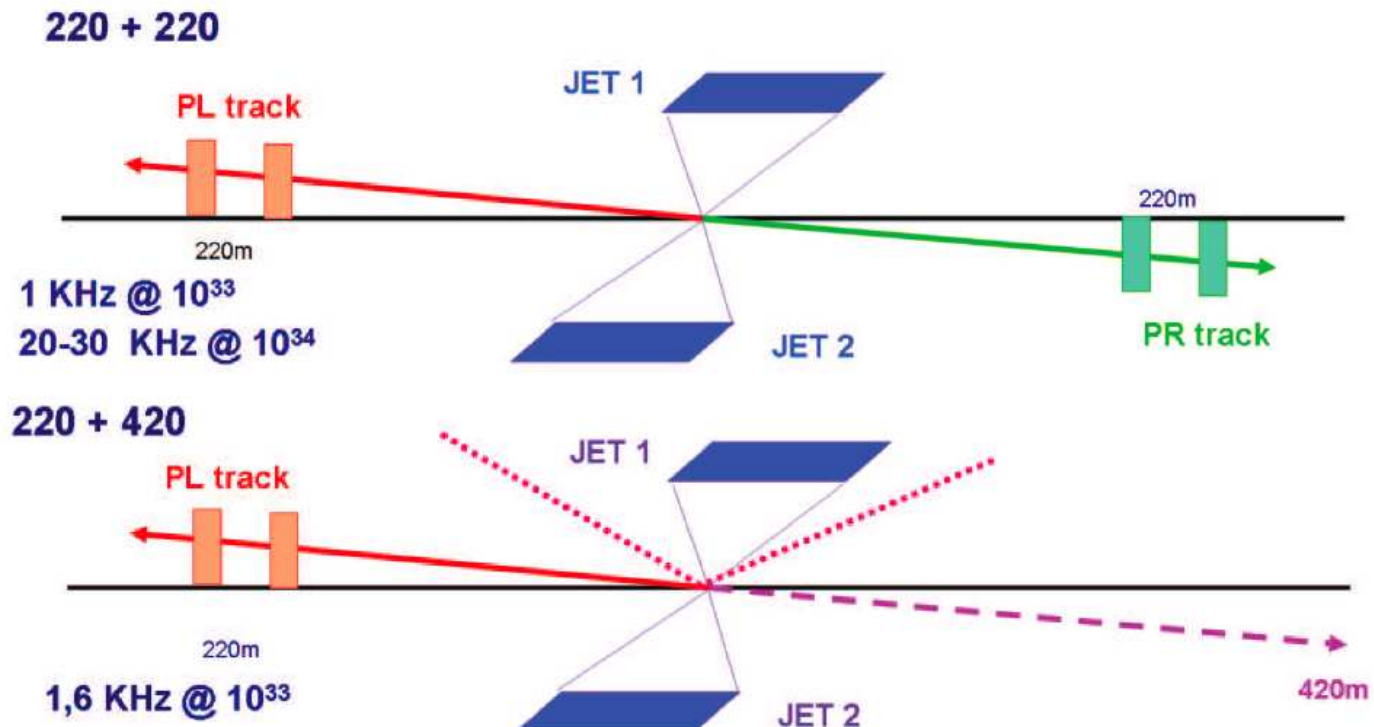
Forward detector alignment using exclusive muons

- 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 μm , can be used to get a store-by-store calibration



Trigger: principle

- 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

- **Diffraction at HERA:** QCD fits allowing to determine the gluon and quark components of the pomeron
- **Diffraction at Tevatron/LHC:** need survival probability, measurement to be done at LHC
- **Exclusive events:** many indications at Tevatron, especially in dijet channel
- **Exclusive events at LHC:** diffractive Higgs production, almost all kinematical plane covered with 30 fb^{-1}
- **Photon anomalous coupling studies:** high sensitivity
- **AFP project:** movable beam pipes needed at 220/420 m, 3D Silicon for position measurement (ξ), timing detectors
- **Timescale:** LOI presented in ATLAS in September, ATLAS answer in February, TDR submission to ATLAS/LHCC by the end of 2009
- **Management structure in progress:** Brian Cox and Christophe Royon, 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