The ATLAS Forward Physics Project (AFP)

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Seminar, Nagoya University, August 20

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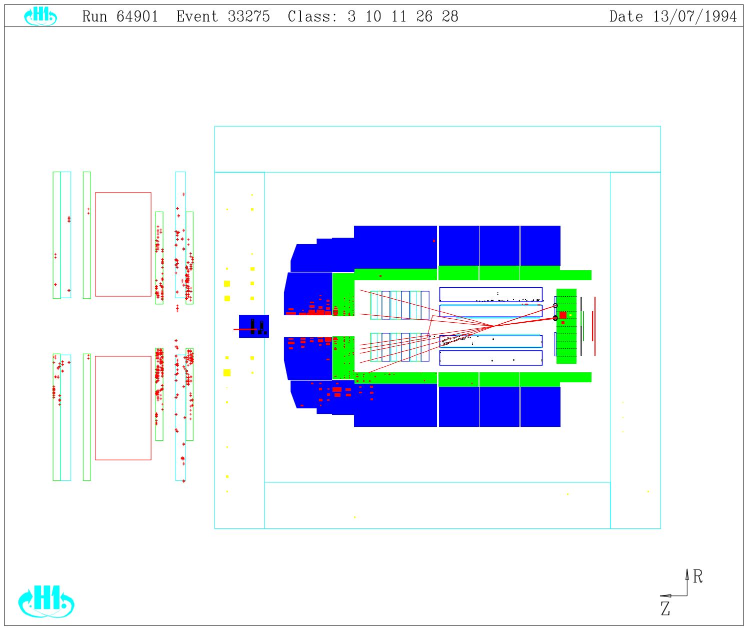
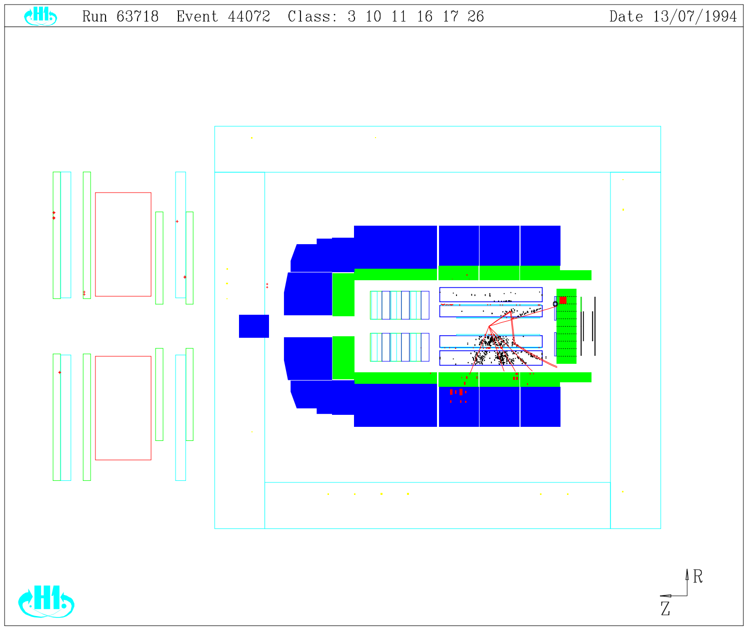
Definition of diffraction: example of HERA

- 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)

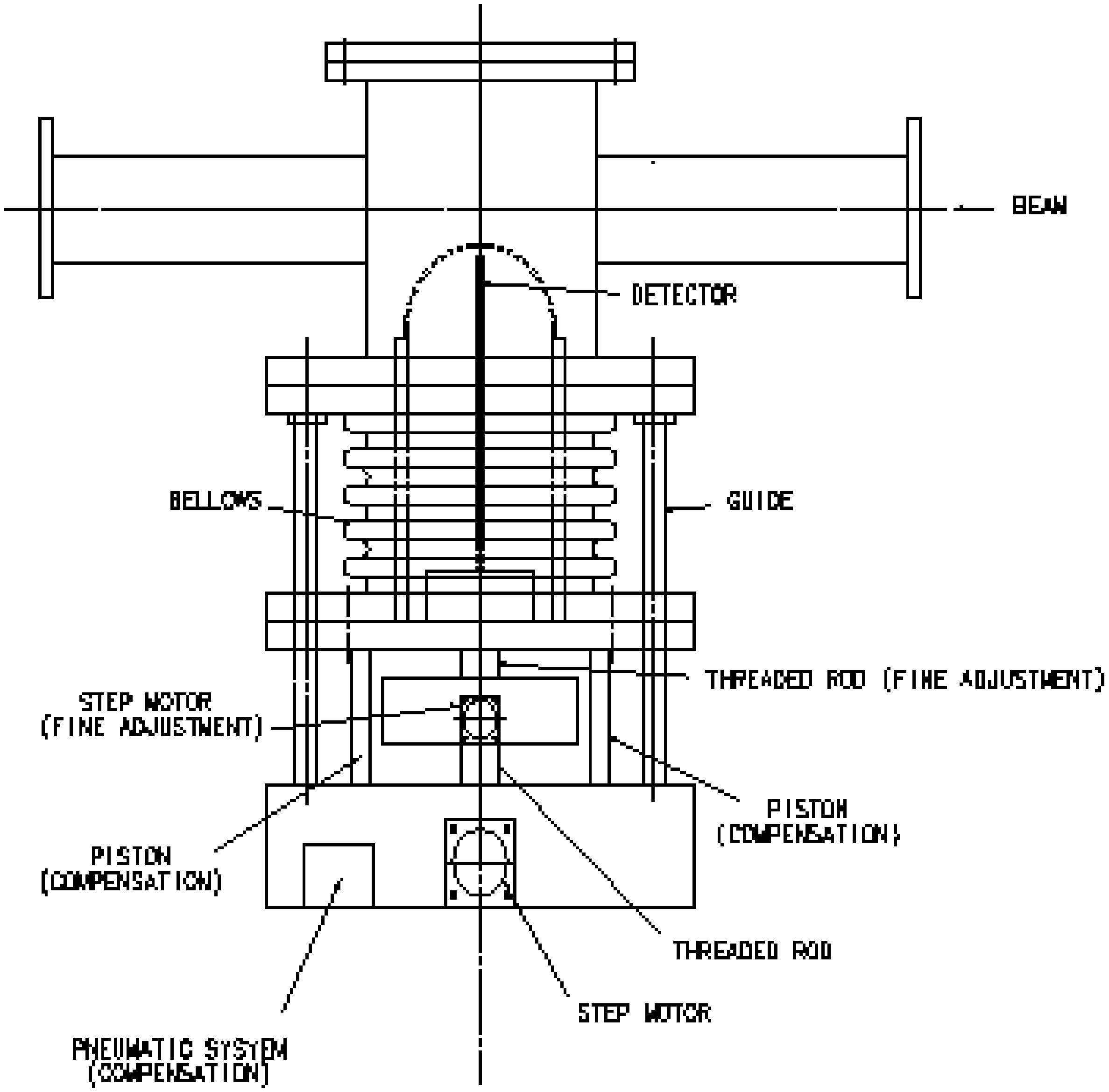
DIS and Diffractive event at HERA



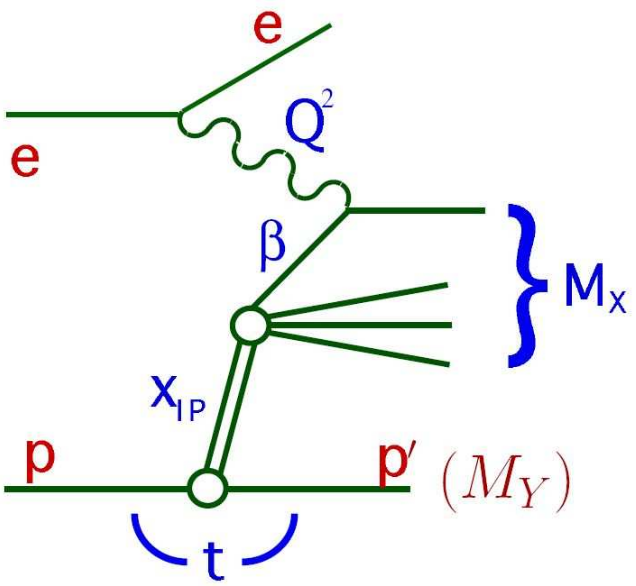


Scheme of a roman pot detector

Scheme of roman pot detector: traditionally used in diffraction



Diffractive kinematical variables



Invariant mass of the diffractive final state

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

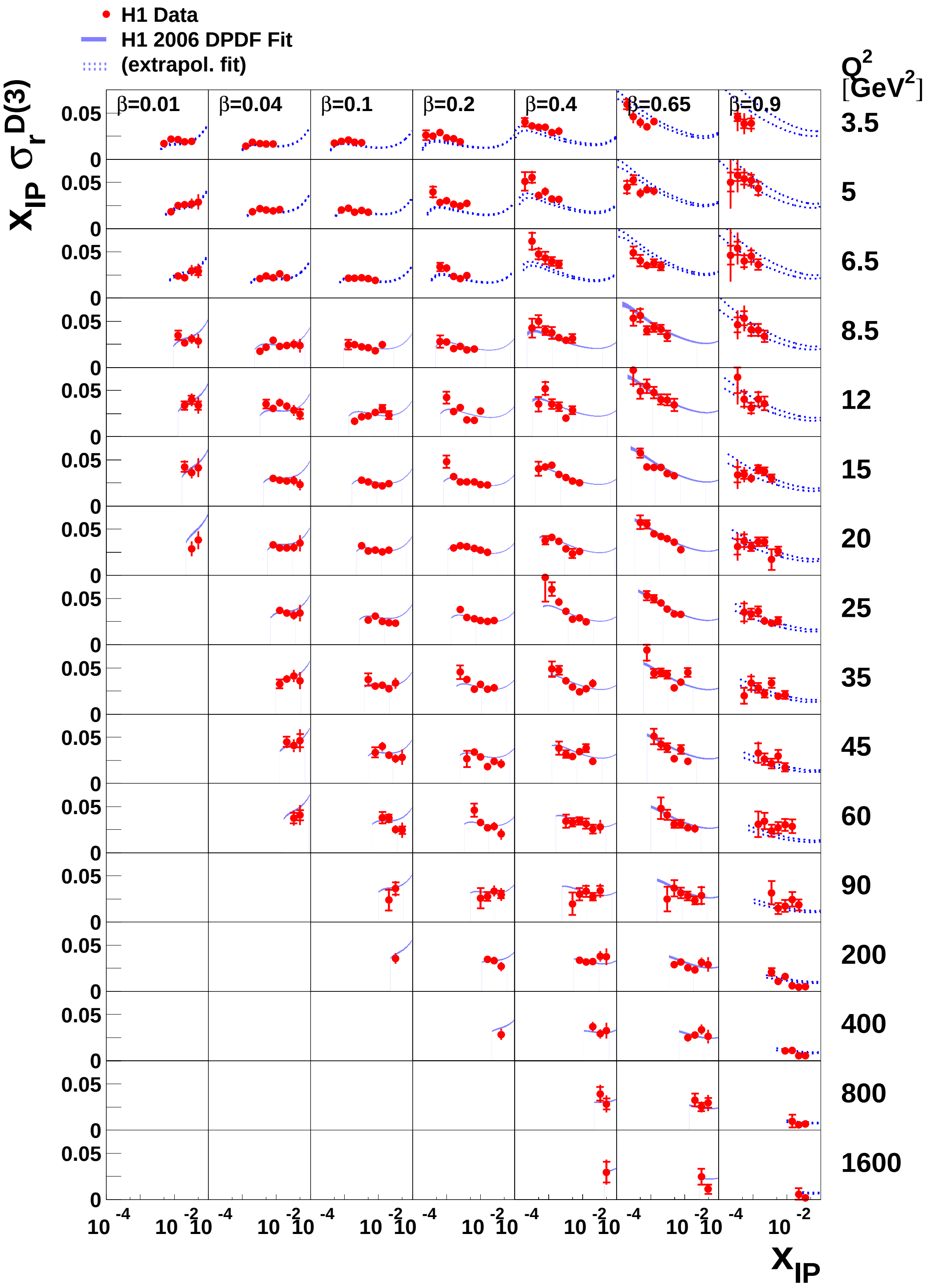
Measurement of the diffractive structure function F_2^D

- Measurement of the diffractive cross section using the rapidity gap selection over a wide kinematical domain in (x_P, β, 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: → 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)

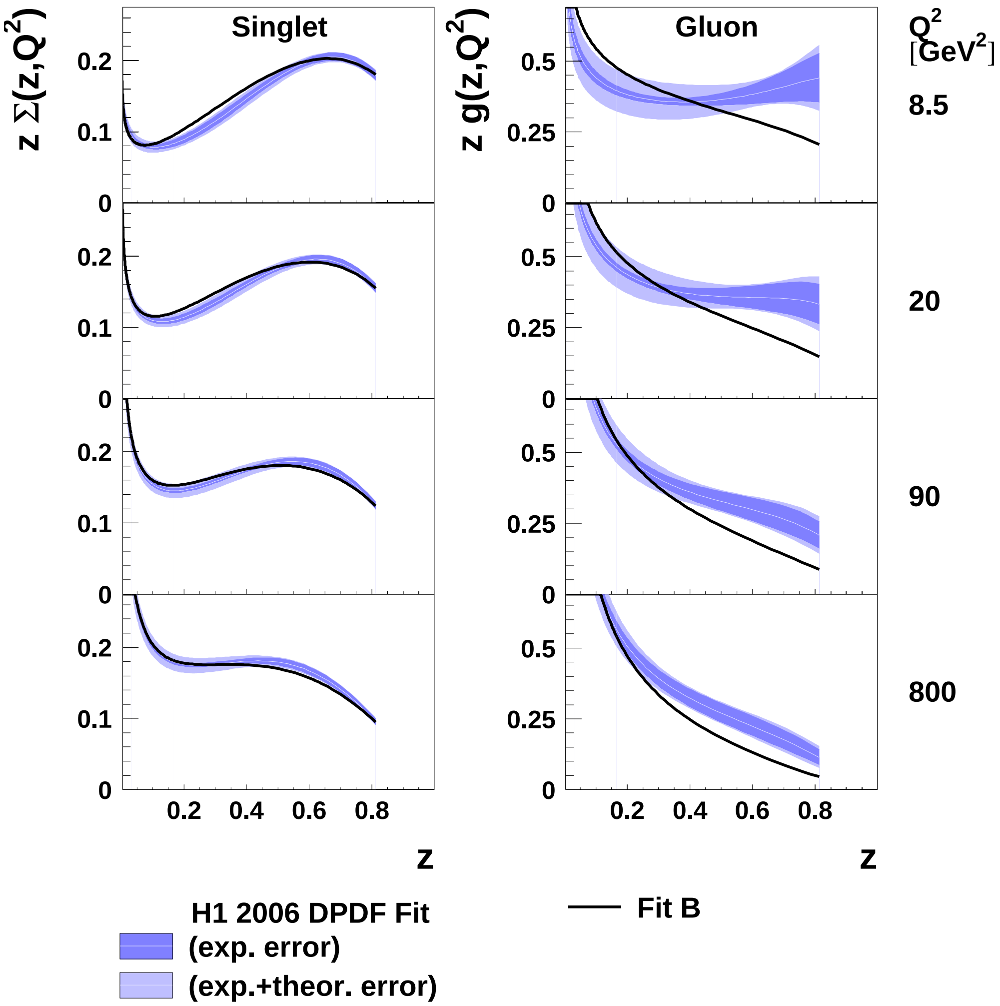
$$\begin{aligned}\beta q &= A_q \beta^{B_q}(1-\beta)^{C_q}\\ \beta G &= A_g (1-\beta)^{C_g}\end{aligned}$$

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

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

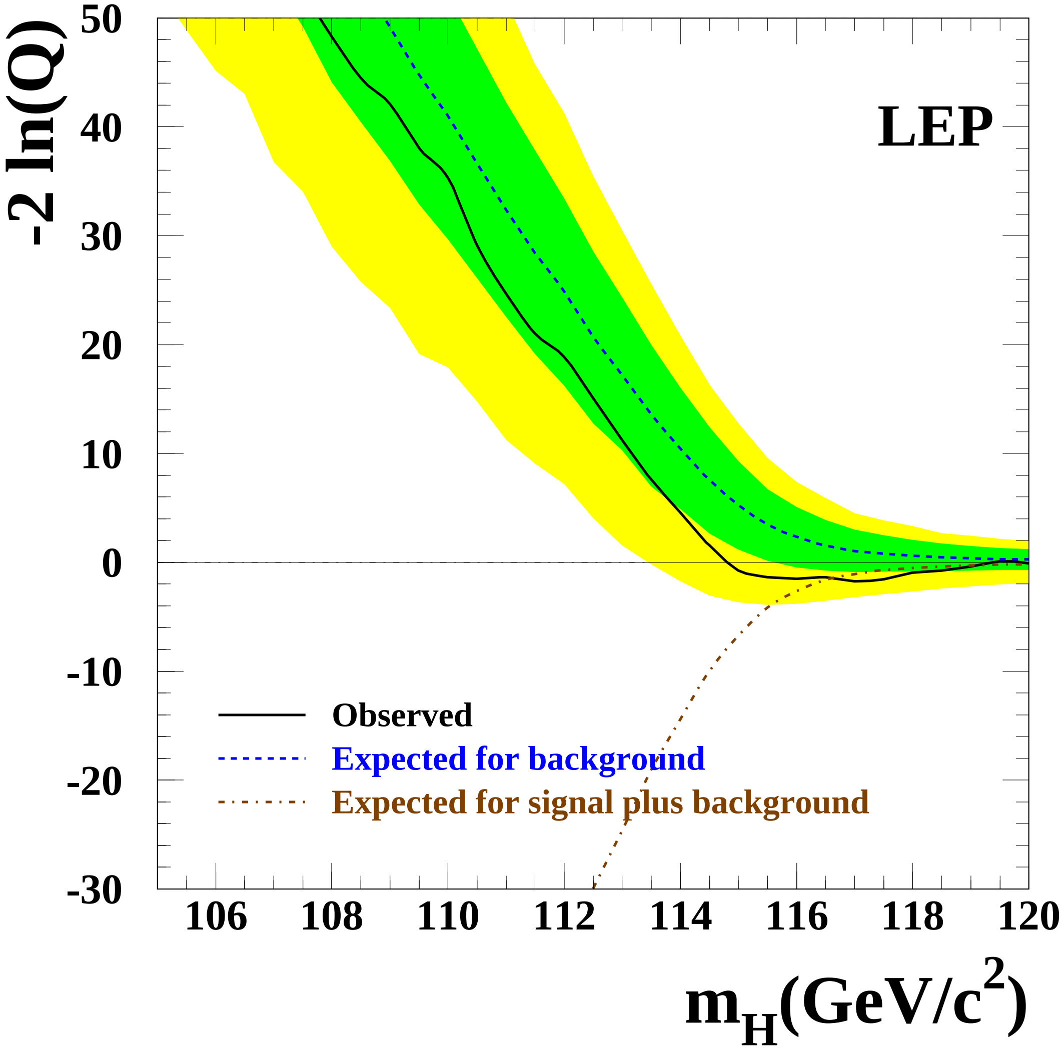
Parton densities in the pomeron (H1)

- 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



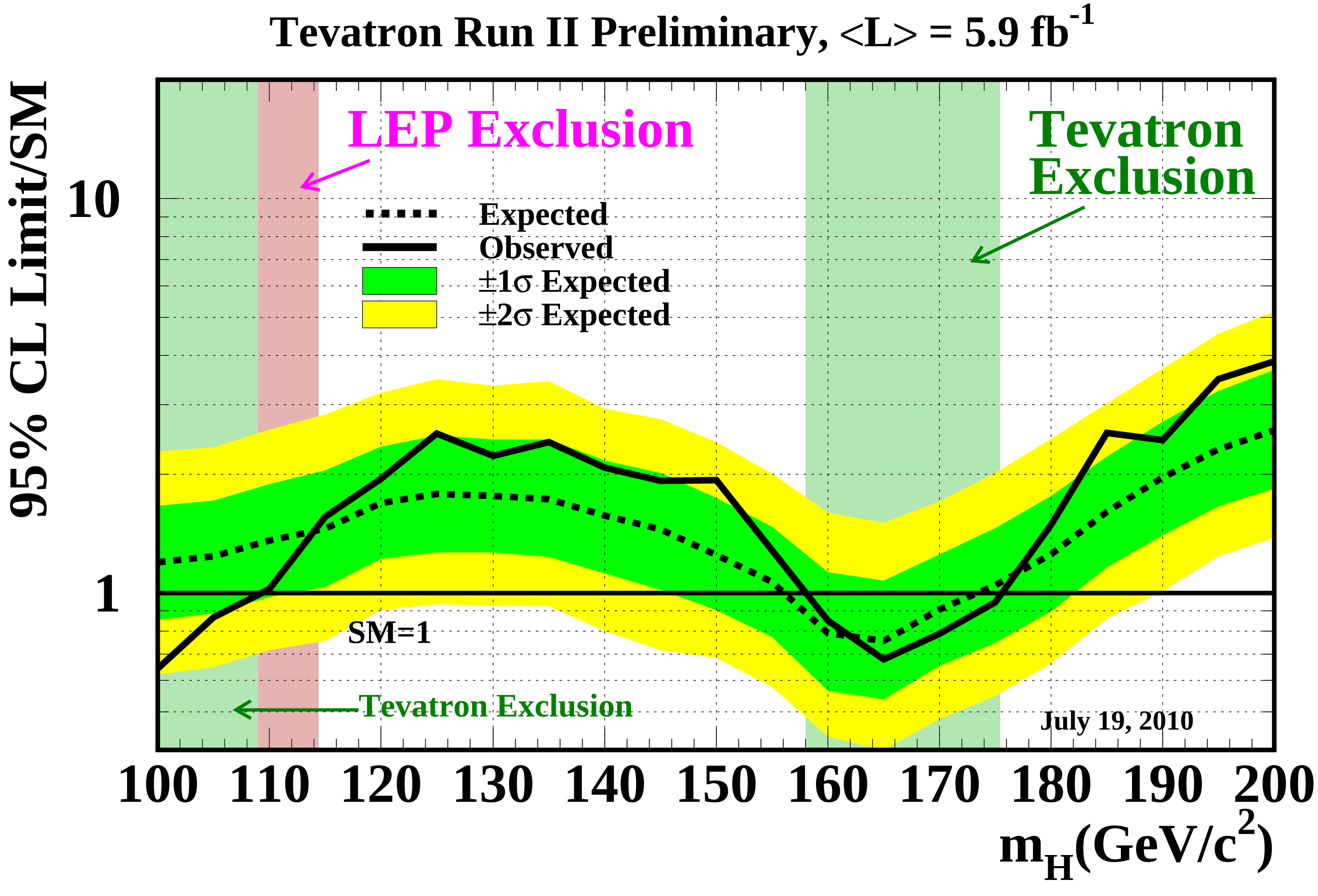
LEP experiments limits on Higgs mass

- 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



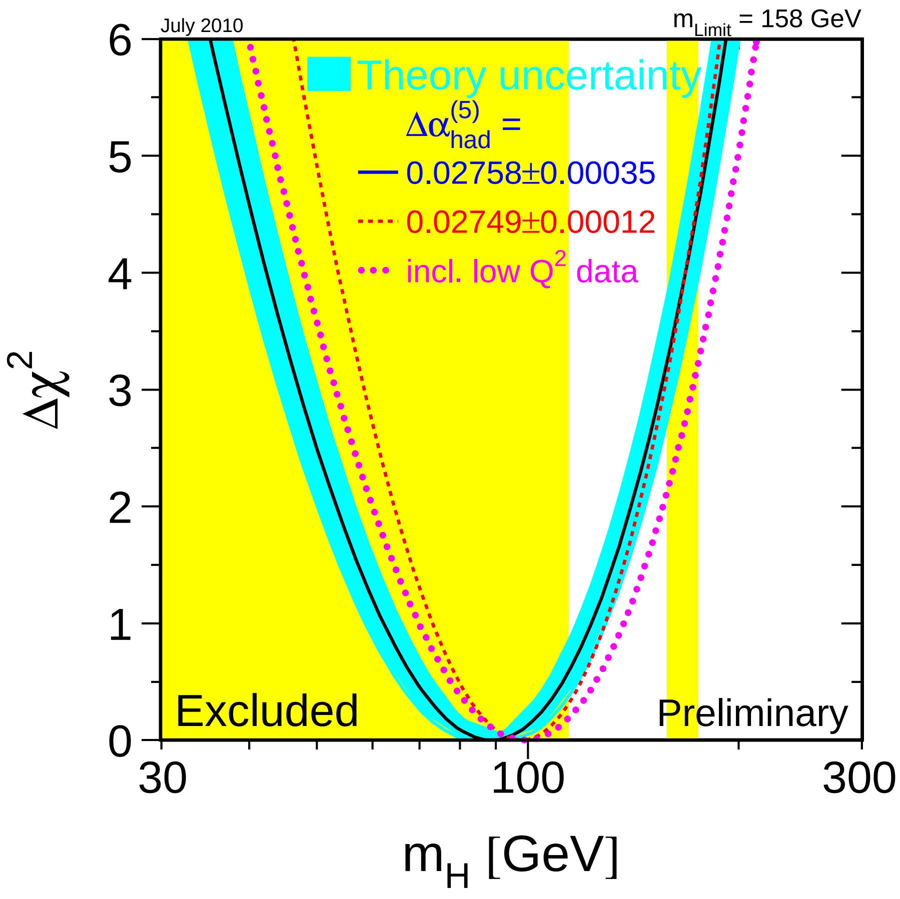
Tevatron limit on Higgs mass

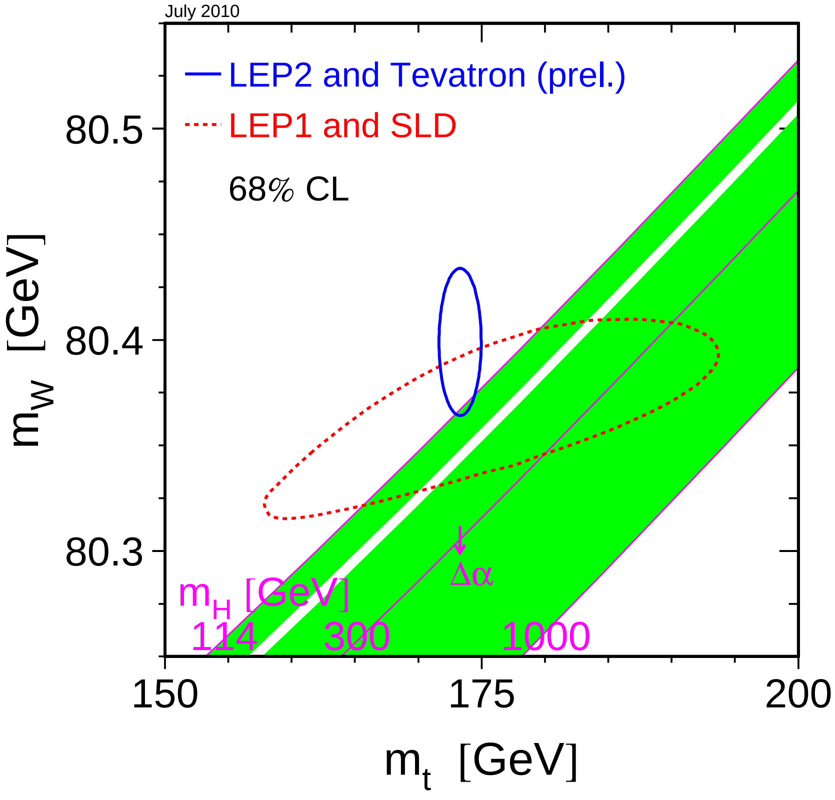
Best sensitivity around 165 GeV; new D0-CDF combination excludes region around 158-175 GeV



Electroweak fits and mass of Higgs boson

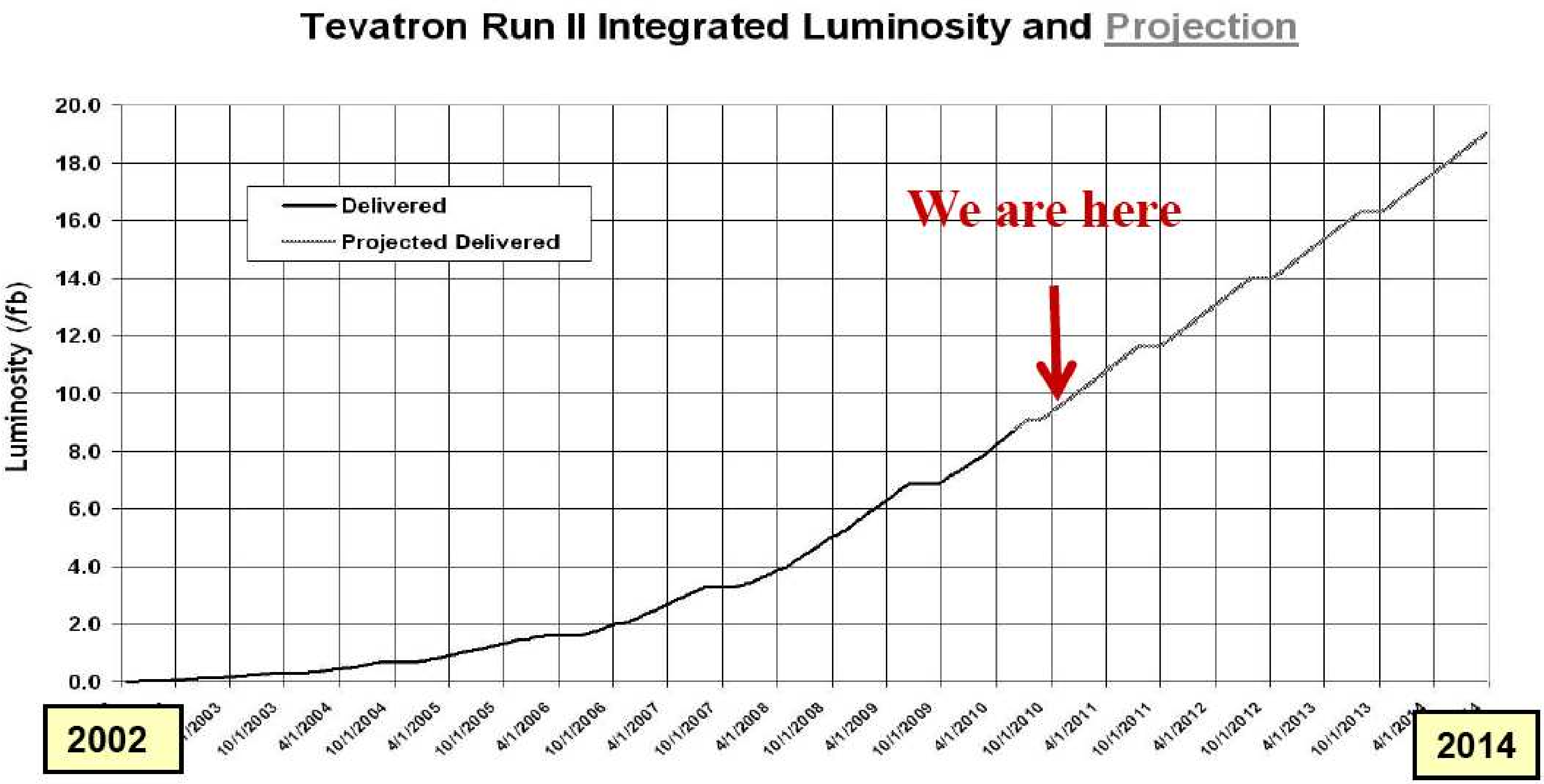
- Use new M_{top}, width of W boson from Tevatron and LEP, and mass of W from LEP and Tevatron
- $M_{Higgs} = 89 + 35 - 26$ GeV (68% CL), and < 158 GeV at 95% CL





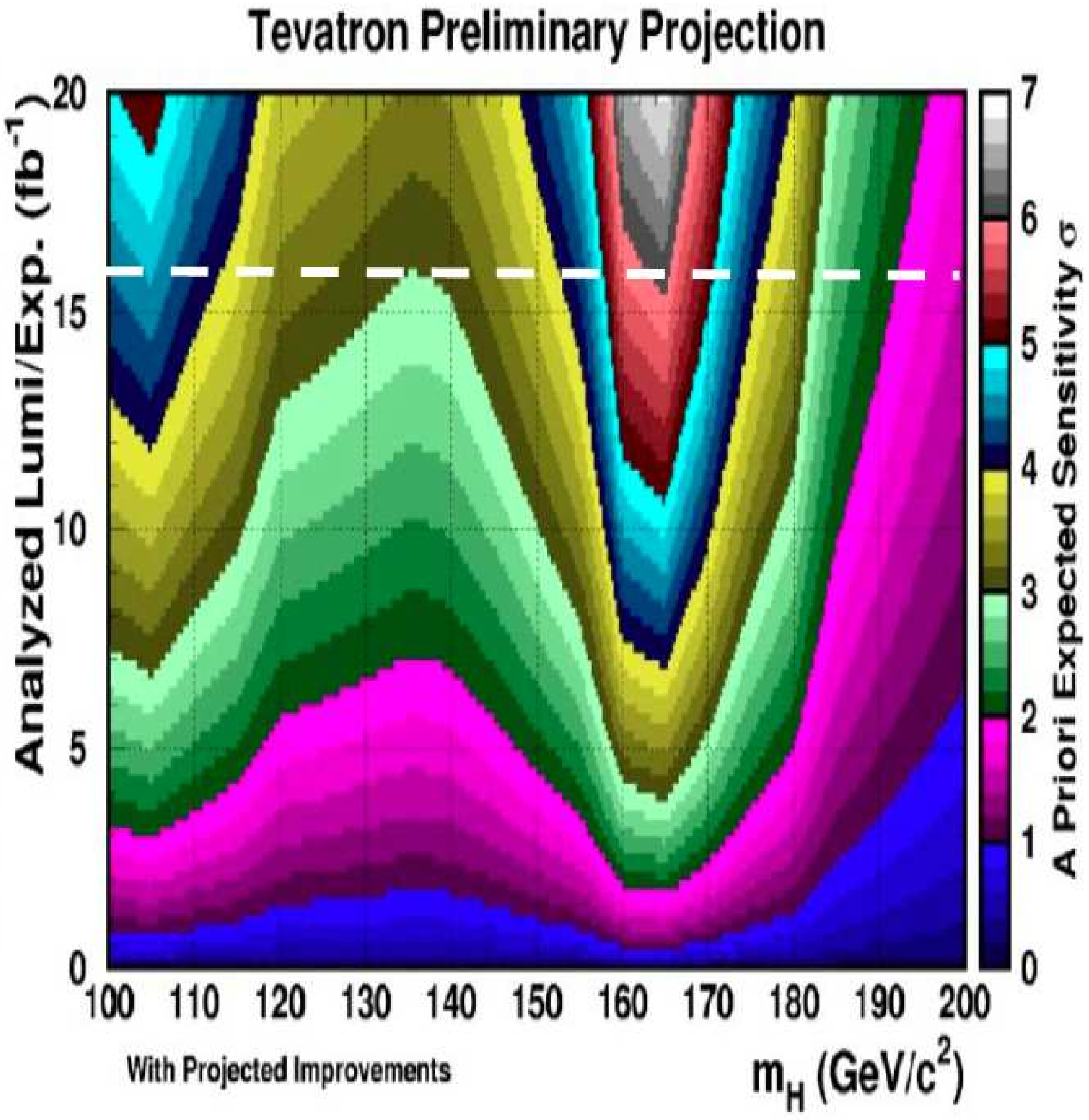
Tevatron running prospects

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



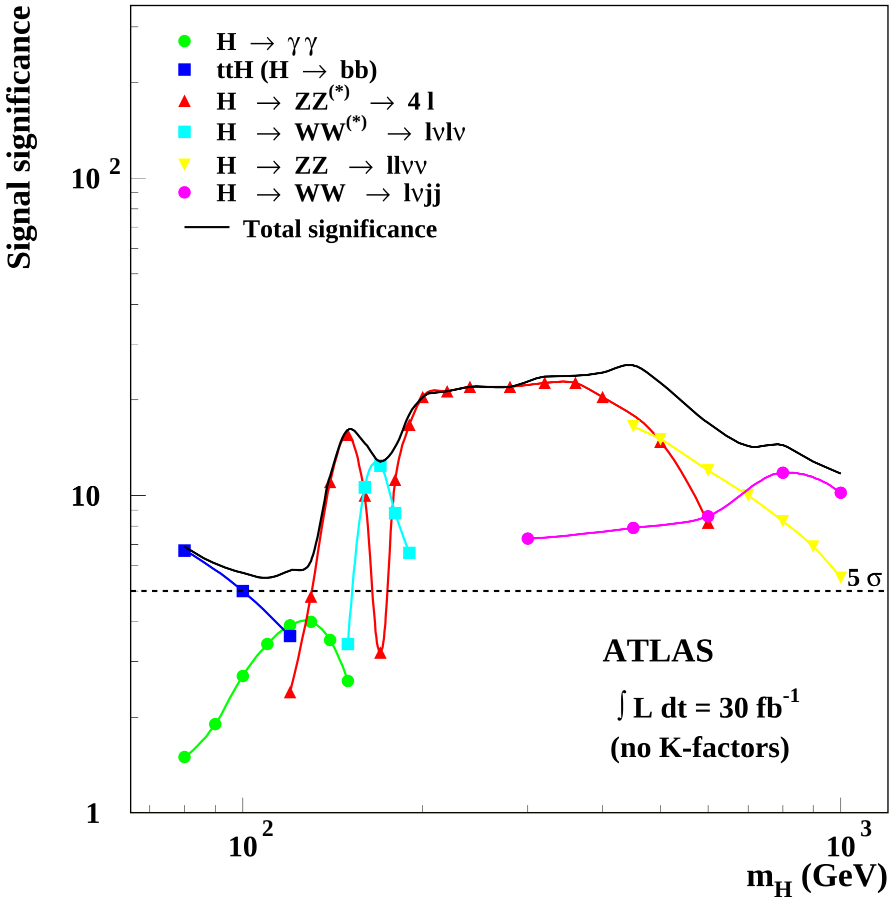
Expectation at the Tevatron

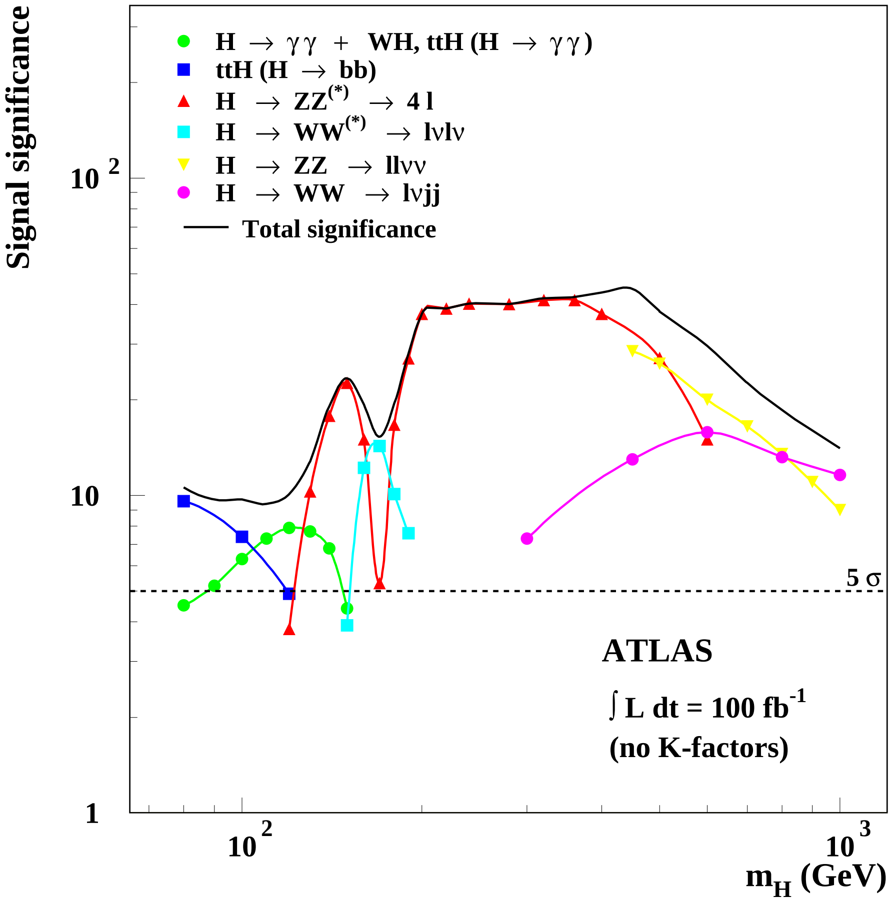
- Low mass region more difficult
- Possibility of 3 σ evidence or exclusion over the full mass range
- Analysis of Higgs boson properties: mass, spin... → LHC



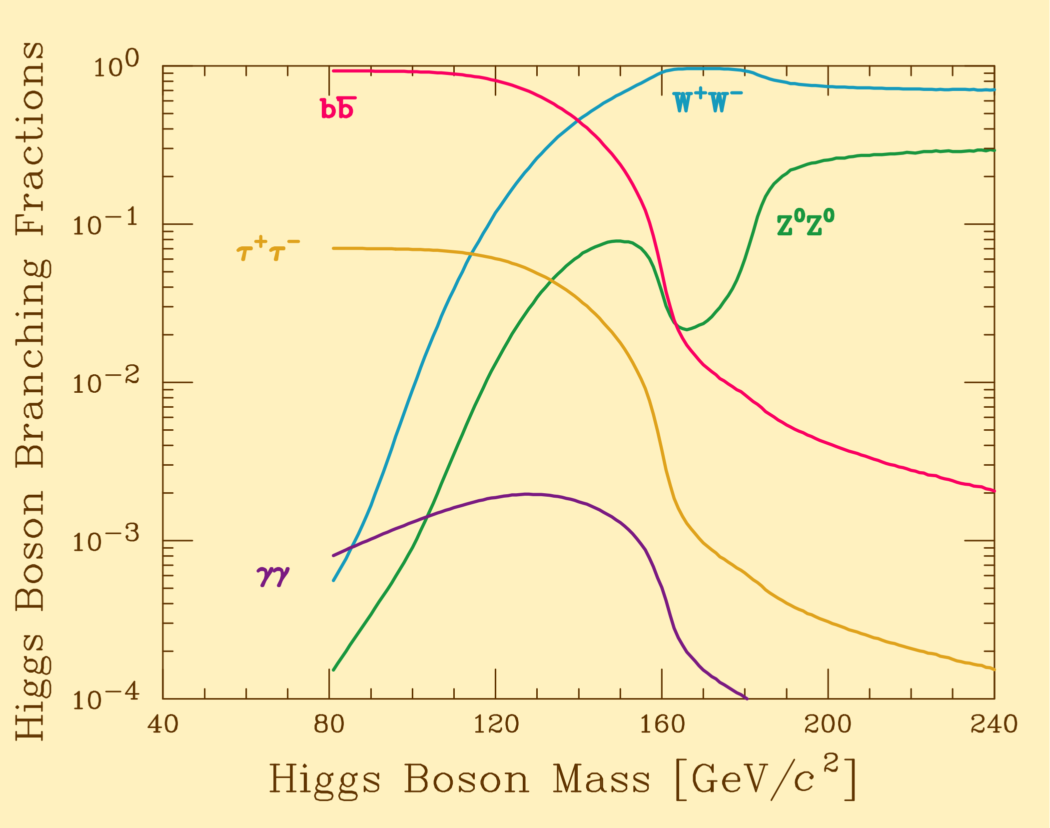
Standard search for Higgs boson at the LHC

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



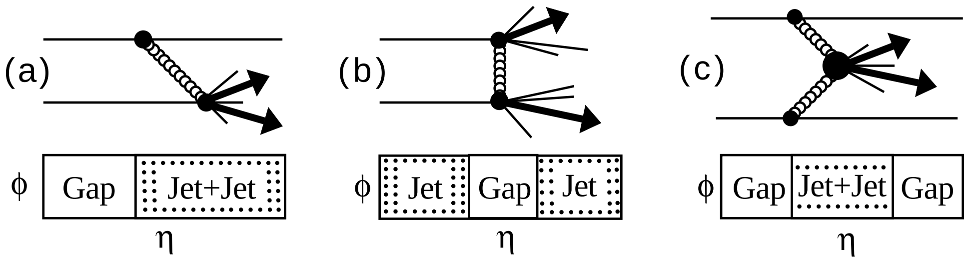


SM Higgs decay



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

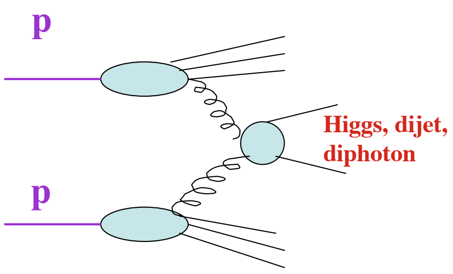
Diffraction at Tevatron/LHC



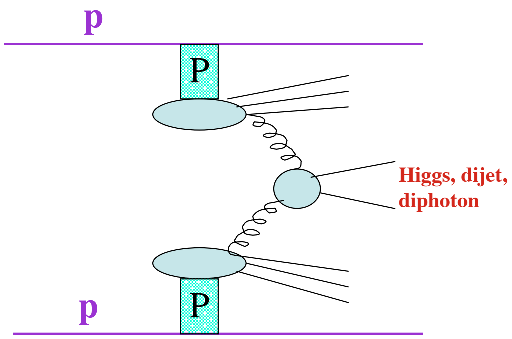
Kinematic variables

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

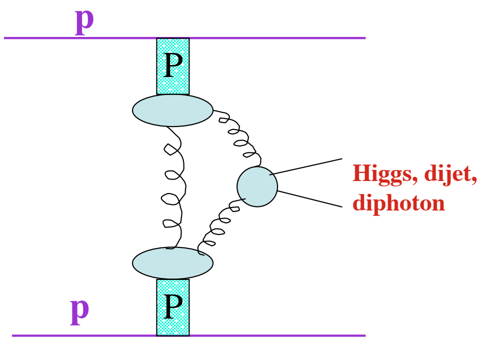
“Exclusive models” in diffraction



Inclusive non diffractive (1)



Inclusive Diffractive (2)

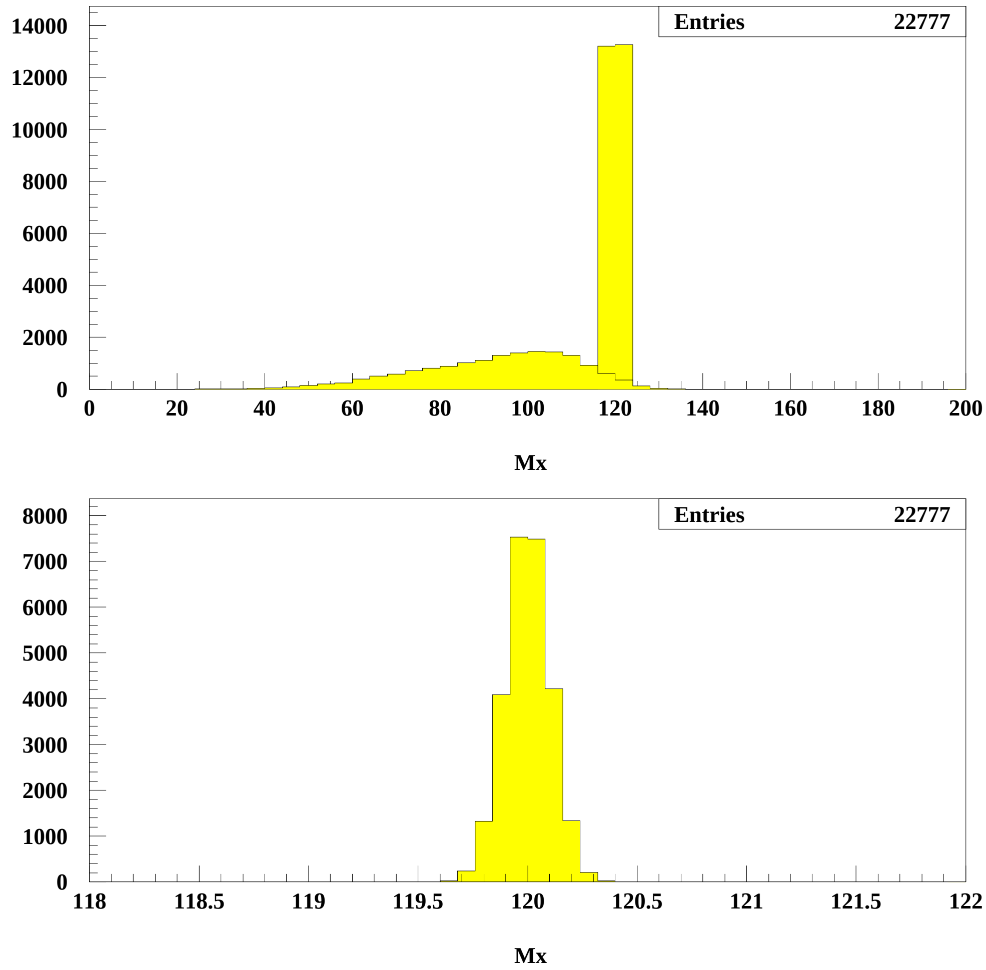


Exclusive Diffractive (3)

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

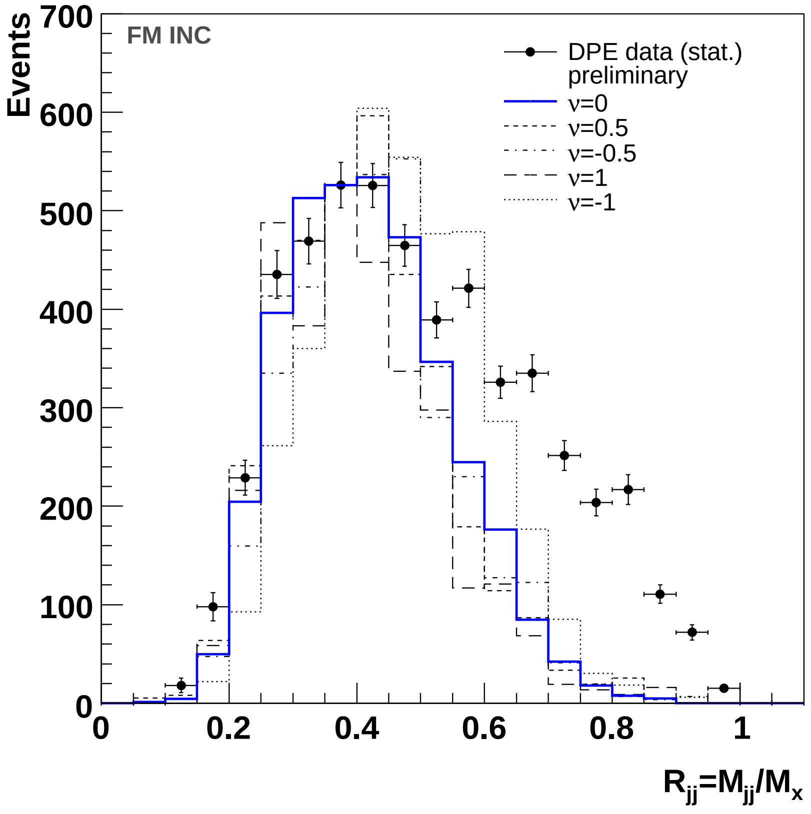
Advantage of exclusive Higgs production?

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



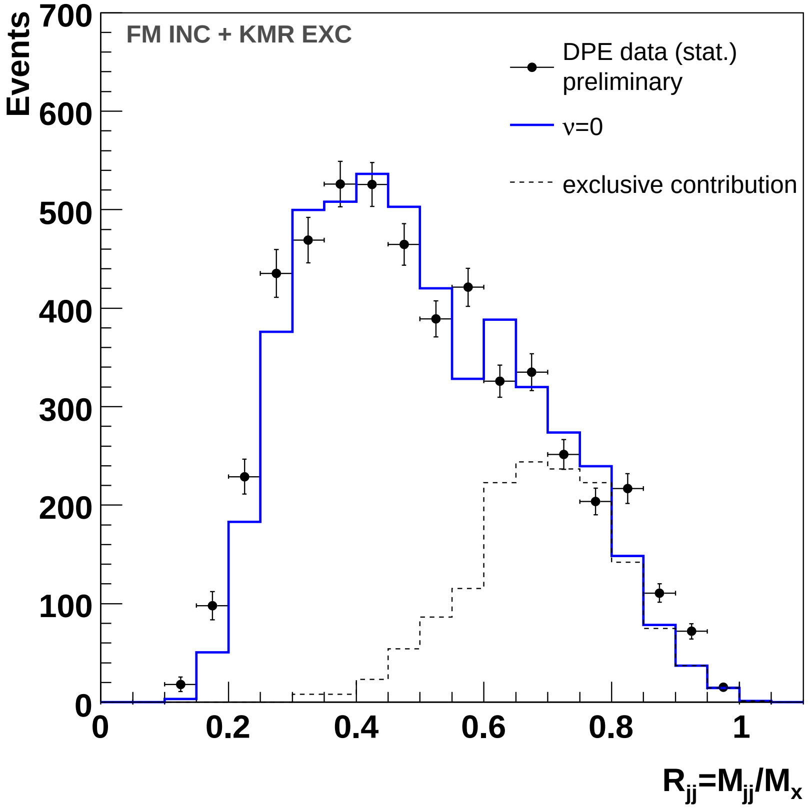
Dijet mass fraction measurement in CDF

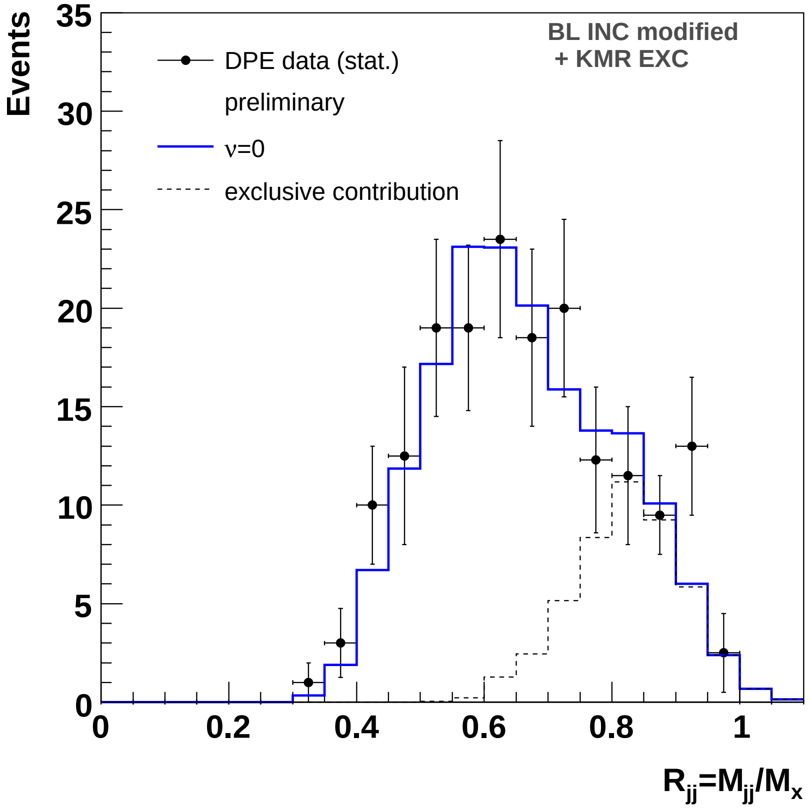
- Look for exclusive events (events where there is no pomeron remnants or when the full energy available is used to produce diffractively the high mass object)
- Select events with two jets only, one proton tagged in roman pot detector and a rapidity gap on the other side
- Predictions from inclusive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





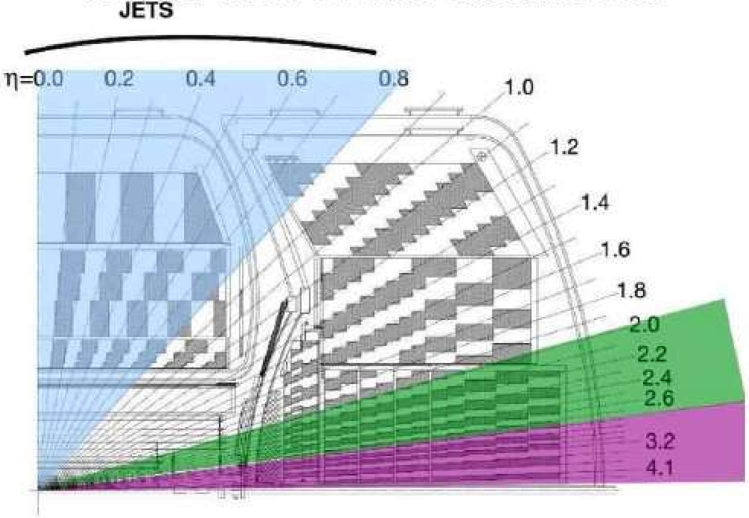
Search for exclusive events at high mass (D0)

- Inclusive jets trigger and $p_{T_1} > 60$ GeV, $p_{T_2} > 40$ GeV, select high mass events $M_{jj} > 100$ GeV
- Separate Exclusive events from background

Separation variable: sum of energy of calorimeter cells

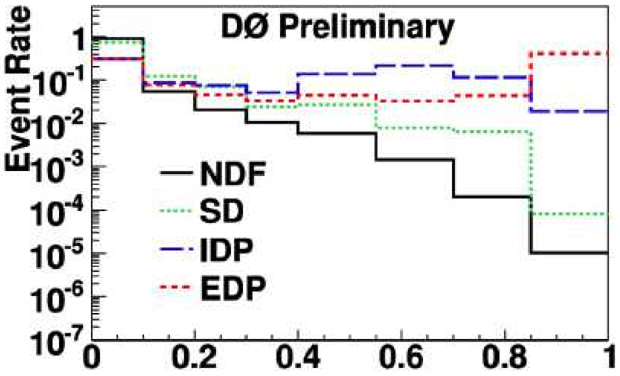
$$\Delta = \frac{1}{2}\exp\left(-\sum_{2.0<|\eta|\leq 3.0} E_T\right) + \frac{1}{2}\exp\left(-\sum_{3.0<|\eta|\leq 4.2} E_T\right)$$

¼ side view of the calorimeter



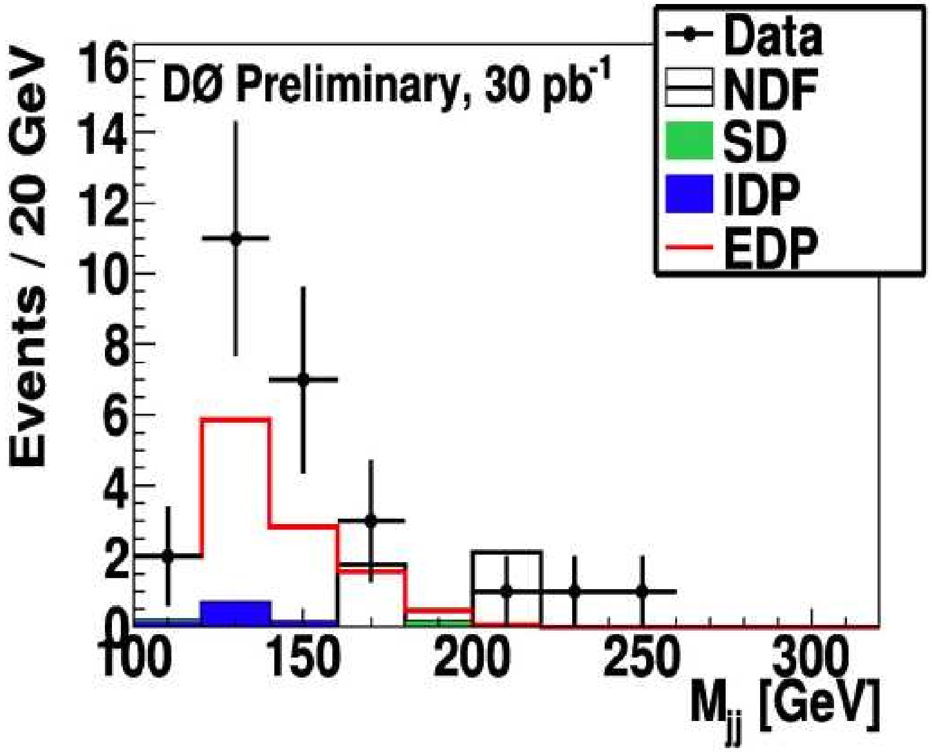
Dijet in the central part of the calorimeter

Rapidity gap – minimum energy in the forward -

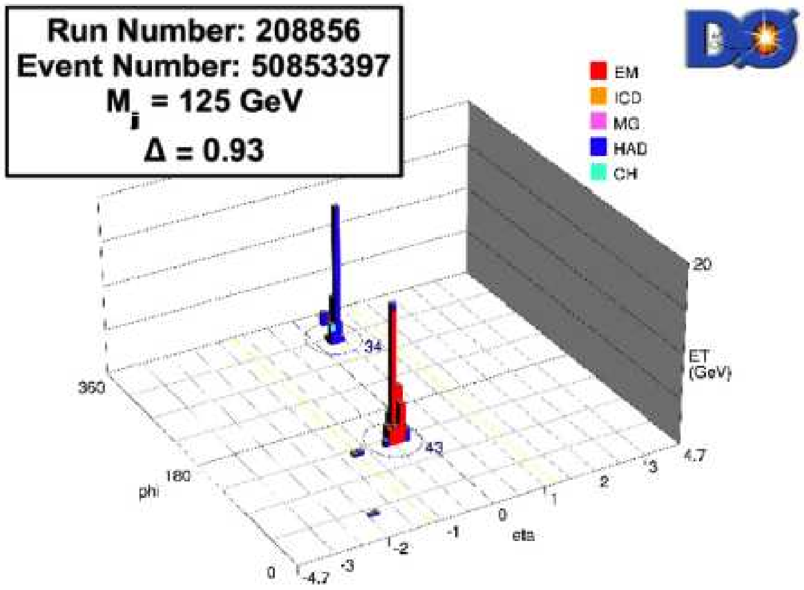


Search for exclusive events at high mass (D0)

- Dijet invariant mass for $\Delta > 0.85$
- 4.1 σ excess in data at high Δ, in the region where exclusive events should be present

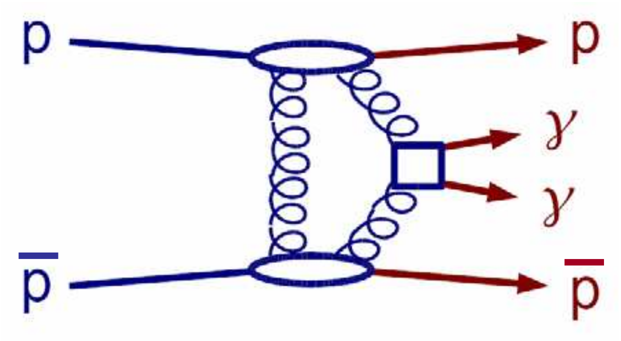


EDP event candidate

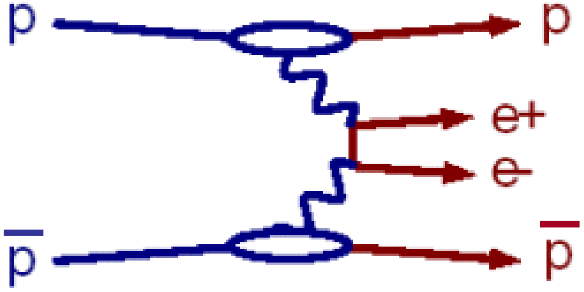


Search for exclusive diphotons (CDF)

- 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



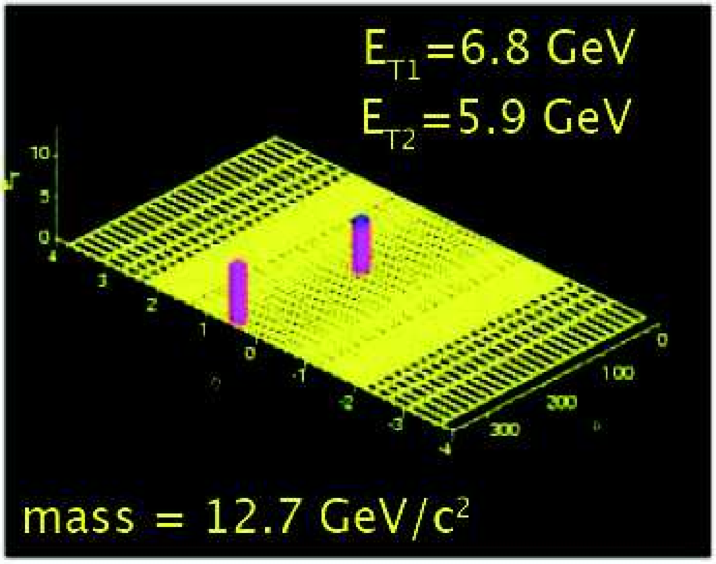
$$p\overline{p} \rightarrow p + \gamma\gamma + \overline{p}$$

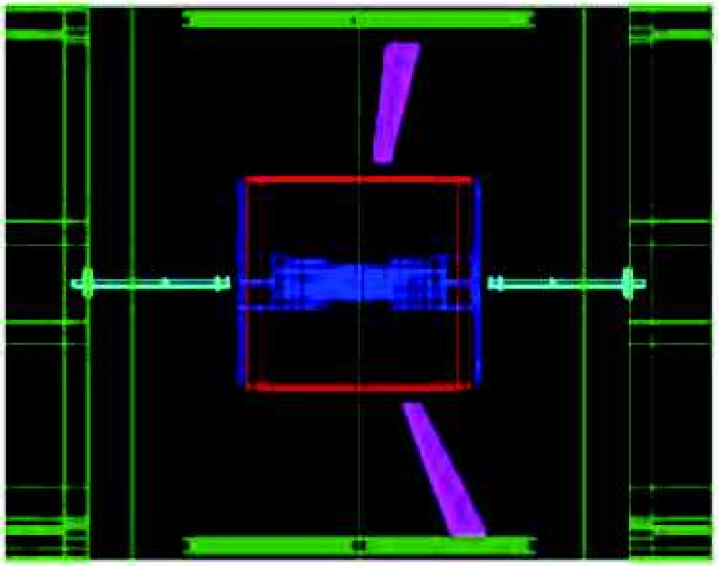


QED process: cross-check to exclusive $\gamma\gamma$

Search for exclusive diphotons (CDF)

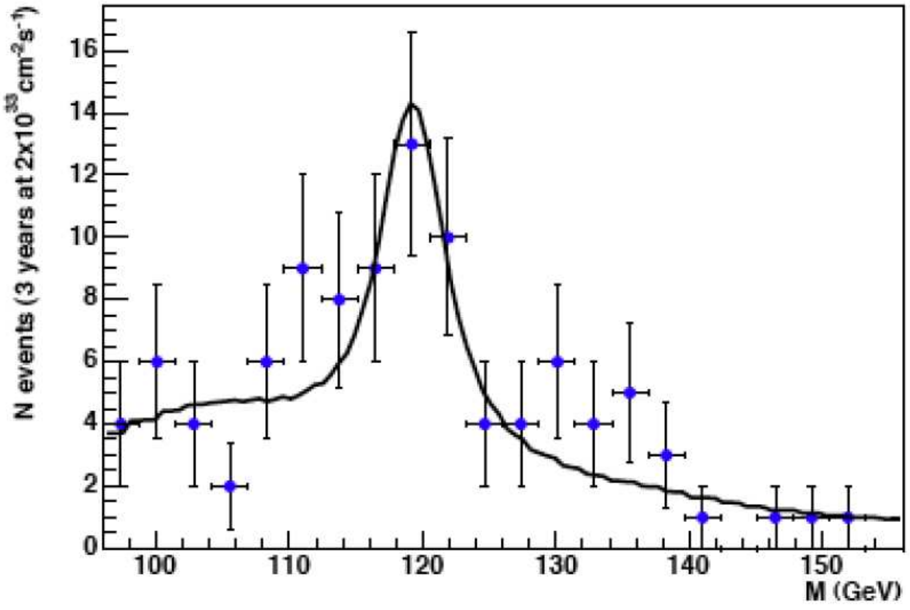
- Look for exclusive diphoton or dilepton production, dominated by QED events (photon exchanges) and not from pomeron exchanges
- Cross section for e^+e^- exclusive production: $N_{candidates} = 16^{+5.1}_{-3.2}$, $N_{background} = 2.1^{+0.7}_{-0.3}$ (mainly dissociation events) in 46 pb^{-1} $\sigma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

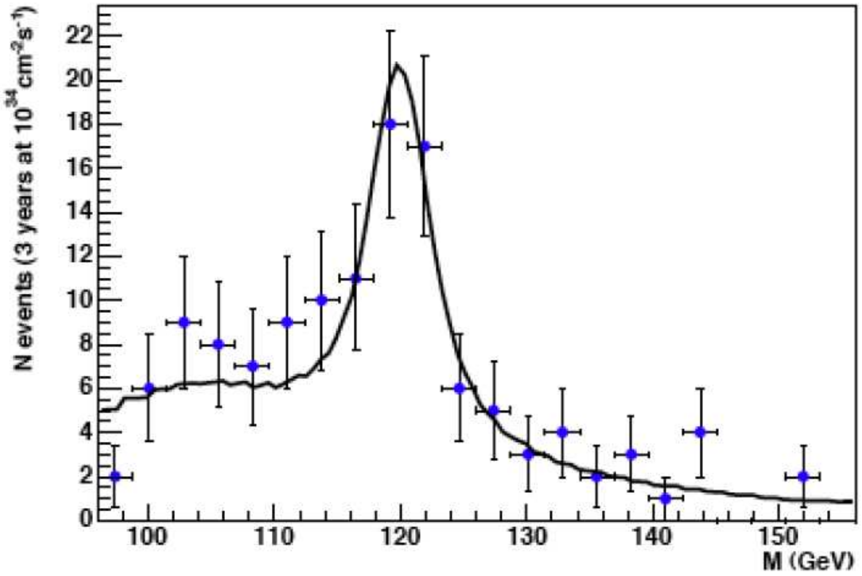




SUSY Signal significance

- 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 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

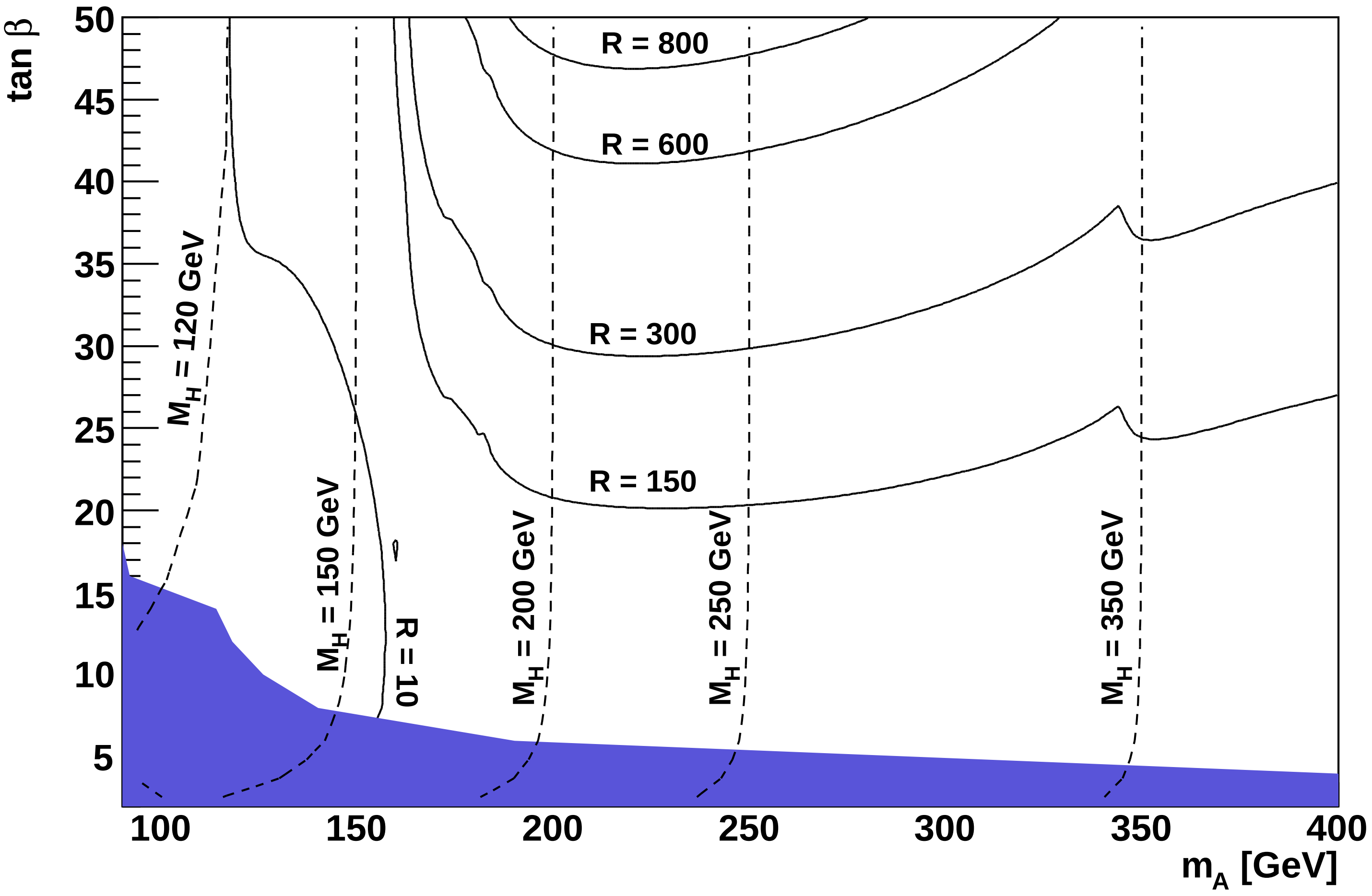




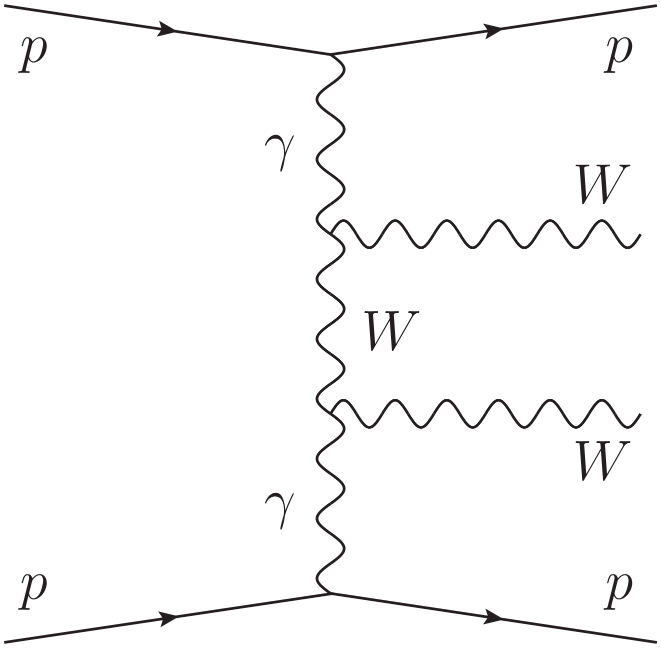
Diffractive SUSY Higgs production

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

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



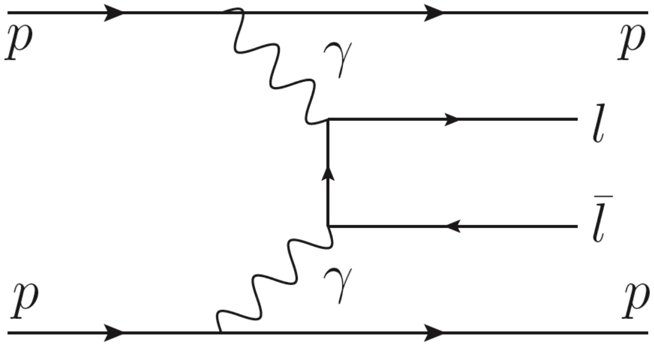
WW production at the LHC



- 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
- $\sigma_{WW} = 95.6$ 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



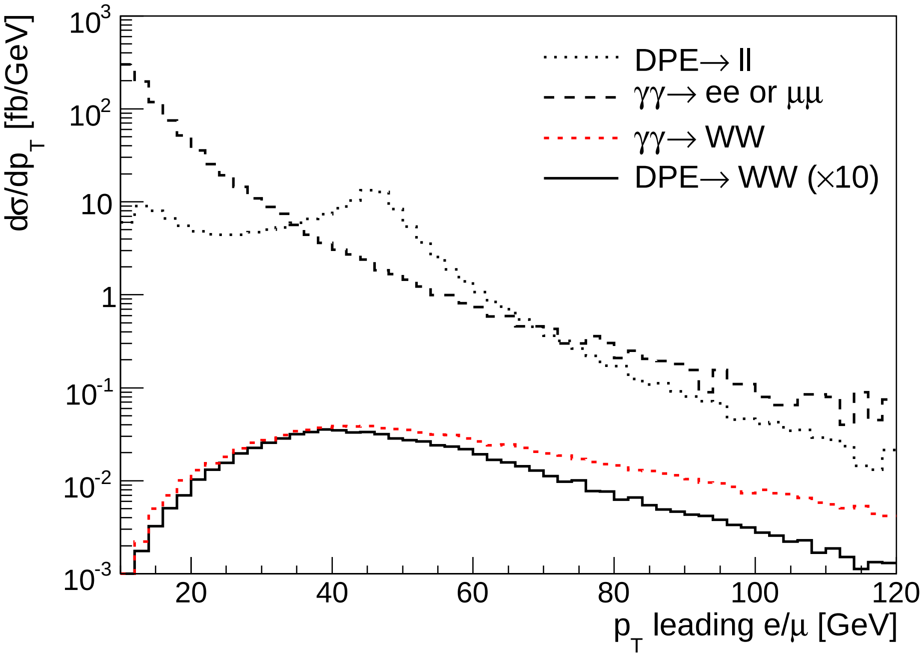
  - Lepton production via double pomeron exchange: activity in the forward region due to pomeron remnants, removed by $\not{E}_T$ cut
  - WW via double pomeron exchange: removed by cut on high diffractive mass

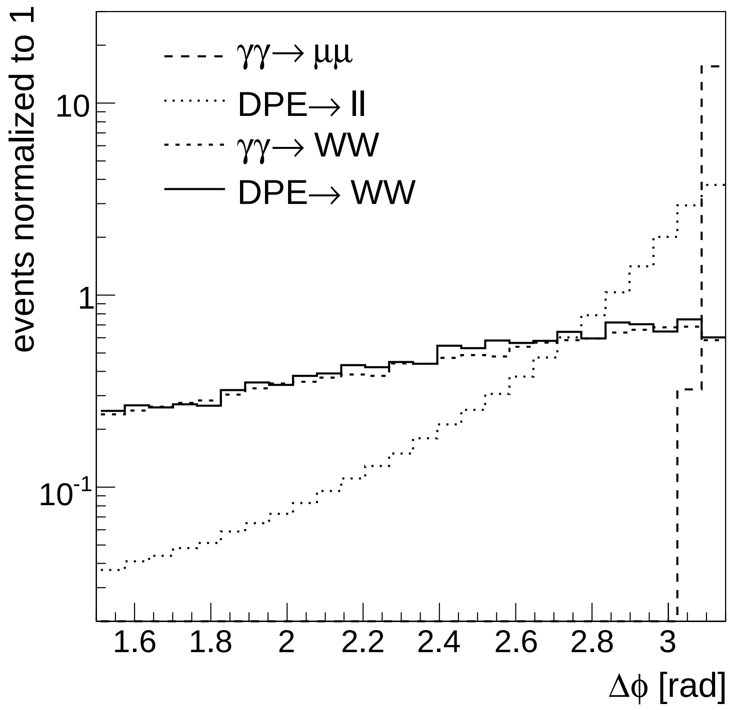
Forward Physics Monte Carlo (FPMC)

- 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 $\gamma\gamma \to WW$ SM cross section

- Require both Ws 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
- $\not{E}_T > 20$ GeV, natural for W decays (get rid of dilepton background produced by photon exchange
- $\Delta\Phi$ between leading leptons allows to remove dilepton background



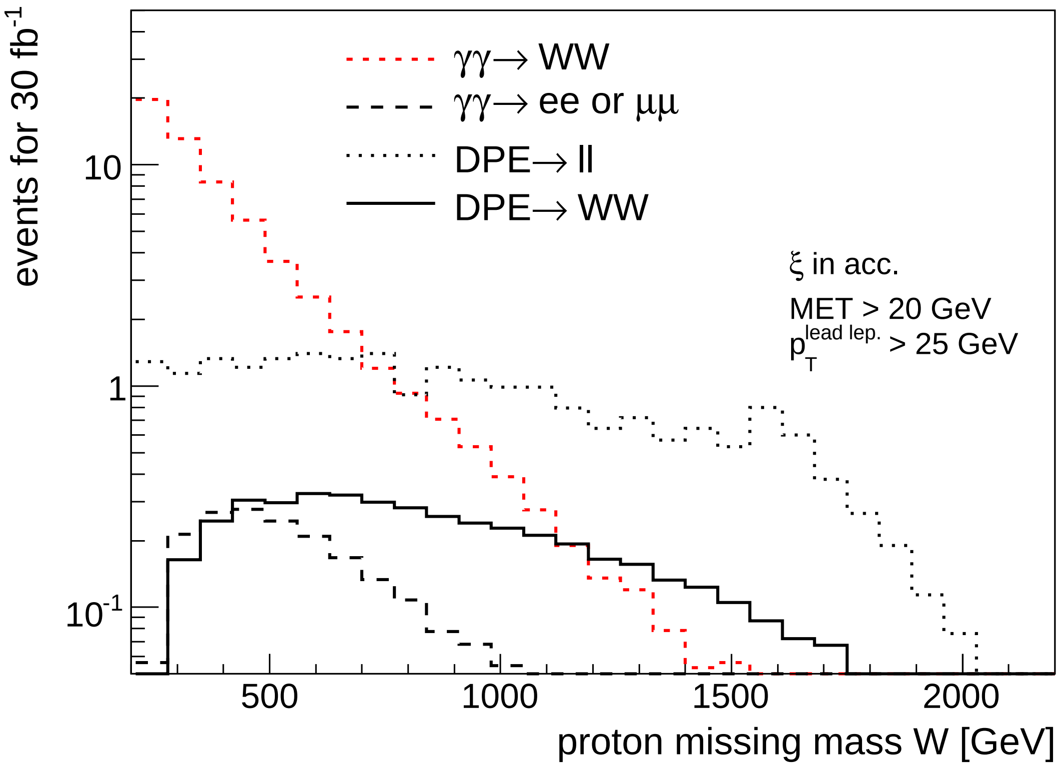


Measuring the $\gamma\gamma \rightarrow WW$ SM cross section

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

cut / process	$\gamma\gamma \rightarrow ll$	DPE$\rightarrow ll$	DPE$\rightarrow WW$	$\gamma\gamma \rightarrow WW$
$p_T^{lep1,2} > 10$ GeV	50620	17931	8.8	95
$0.0015 < \xi < 0.15$	21059	11487	5.9	89
$\not{E}_T > 20$ GeV	14.9	33	4.7	78
$W > 160$ GeV	9.2	33	4.7	78
$\Delta\phi < 2.7$	0	14	3.8	61
$p_T^{lep} > 25$ GeV	0	7.5	3.5	58
$W < 500$	0	1.0	0.67	51

5 σ discovery possible after 5 fb^{-1} (pure leptonic decays of Ws)



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

- Consider both leptonic and semileptonic decays of Ws
- Fast generator level study: 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 σ

ξ_{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

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

- Anomalous parameters equal to 0 for SM
- Non zero anomalous couplings motivated by Higgsless and extra dimension models (under study: Christophe Grojean et al.)
- 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

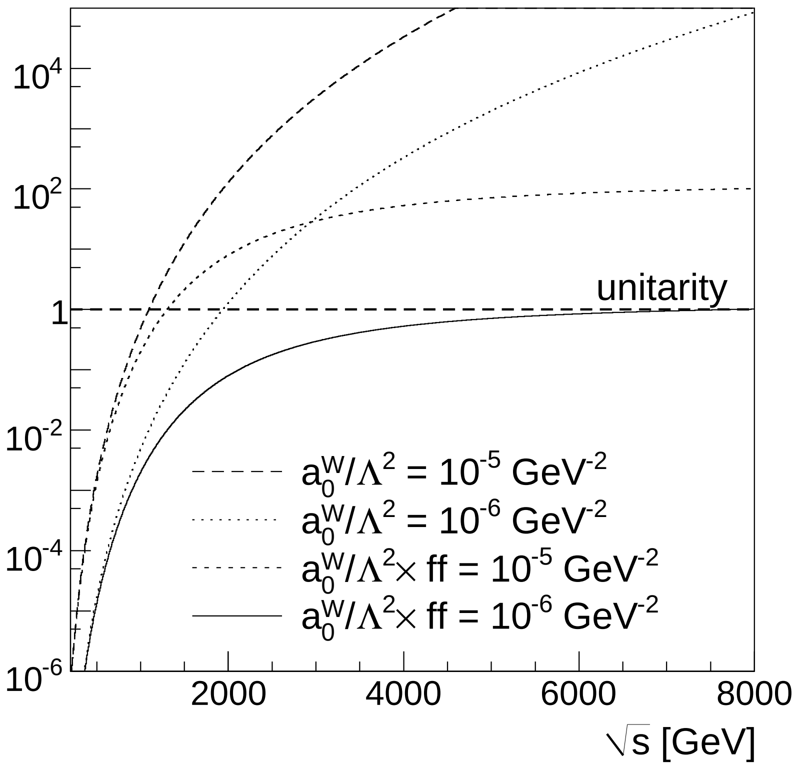
Quartic anomalous gauge couplings: form factors

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

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

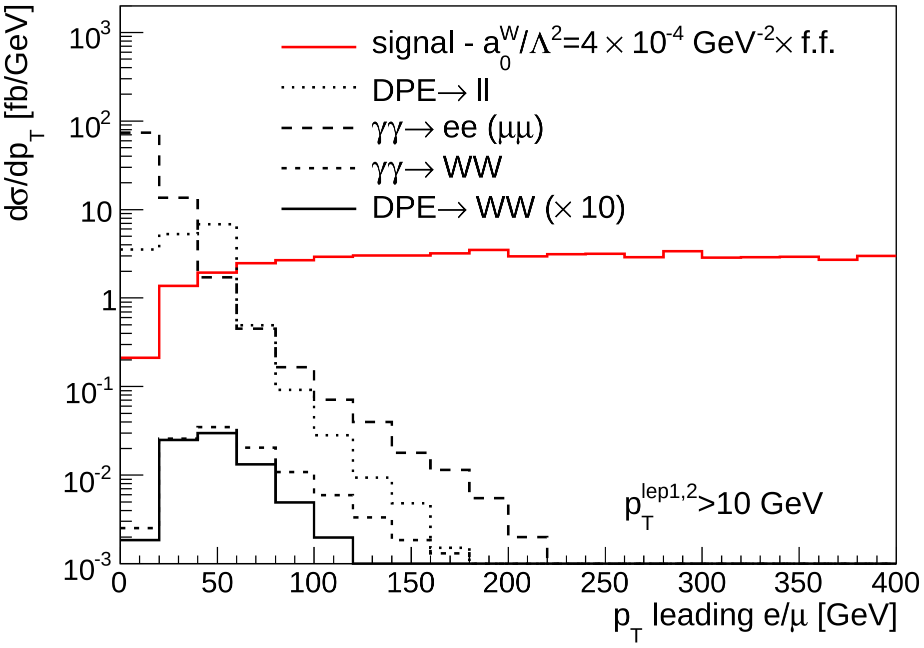
  where $a = a_0/\Lambda^2$

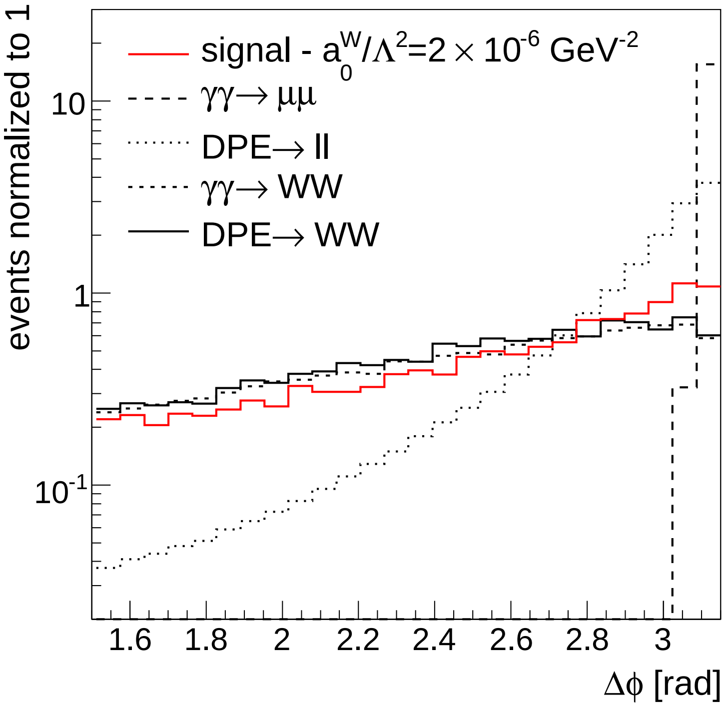
- Introducing form factors to avoid quadratical divergences of scattering amplitudes due to anomalous couplings in conventional way: $a_0^W/\Lambda^2 \to \frac{a_0^W/\Lambda^2}{(1+W\gamma\gamma/\Lambda_{cutoff})^2}$ with $\Lambda_{cutoff} \sim 2$ TeV, scale of new physics
- For $a_0^W \sim 10^{-6}$ GeV^{-2},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



Strategy to select quartic anomalous gauge couplings events

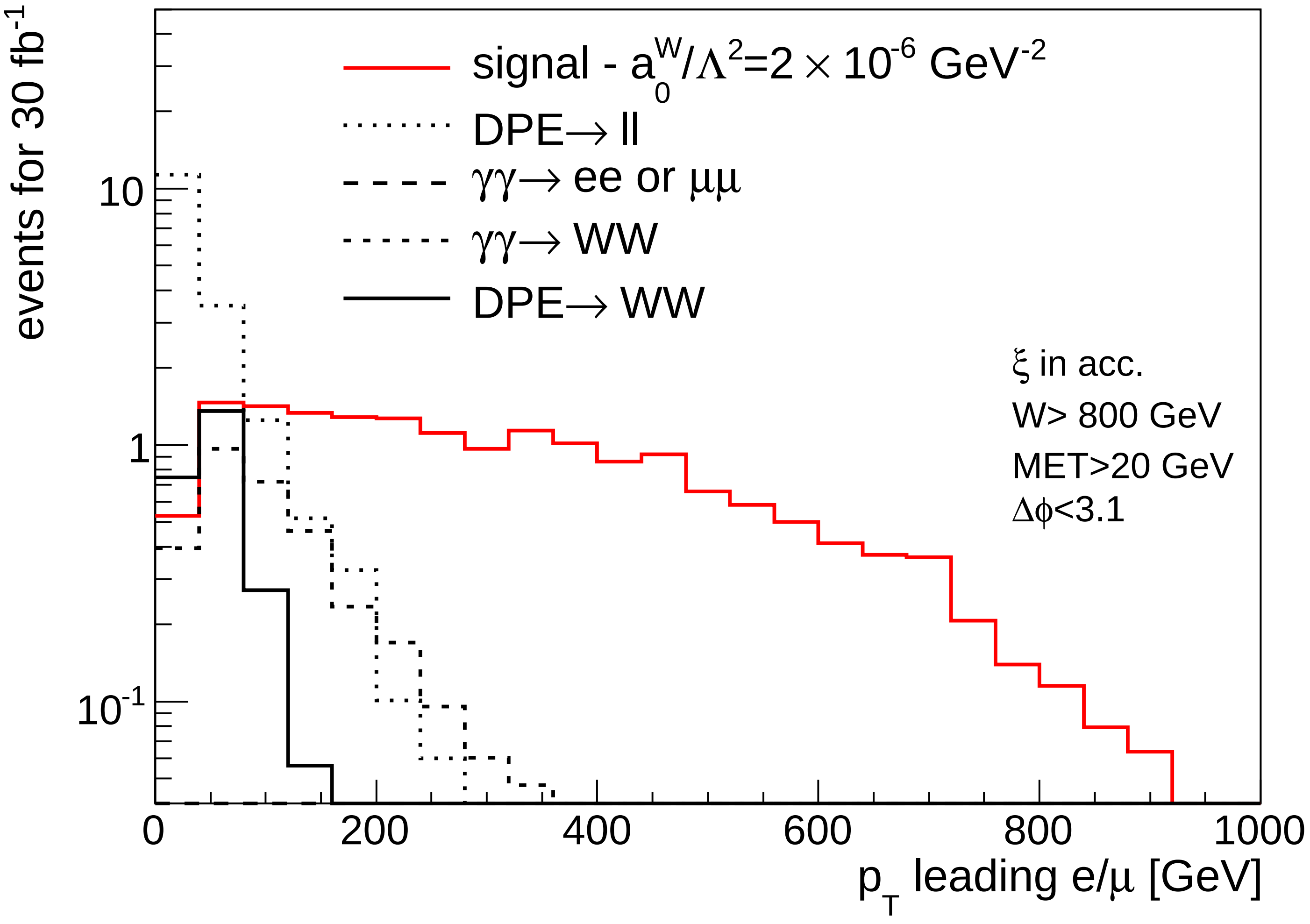
- p_T of the leading lepton: request high p_T lepton to remove background
- Missing E_T distribution: natural to be requested for W pair production
- Diffractive mass computed using the forward proton detectors $\sqrt{\xi_1 \xi_2 S}$: request high mass objects to be produced
- $\Delta\Phi$ between both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

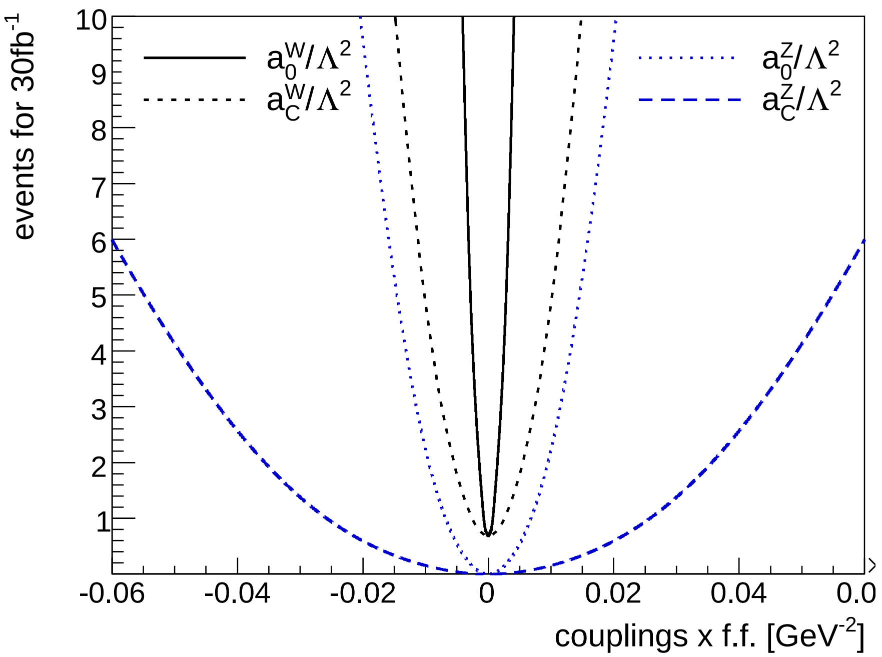
cut / process	$\gamma\gamma \to ll$	$\gamma\gamma \to WW$	DPE$\to ll$	DPE$\to WW$
$p_T^{lep1,2} > 10$ GeV	50619	99	18464	8.8
$0.0015 < \xi < 0.15$	21058	89	11712	6.0
$\not{E}_T > 20$ GeV	14.9	77	36	4.7
$W > 800$ GeV	0.42	3.2	16	2.5
$M_{ll} \notin < 80, 100 >$	0.42	3.2	13	2.5
$\Delta\phi < 3.13$	0.10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

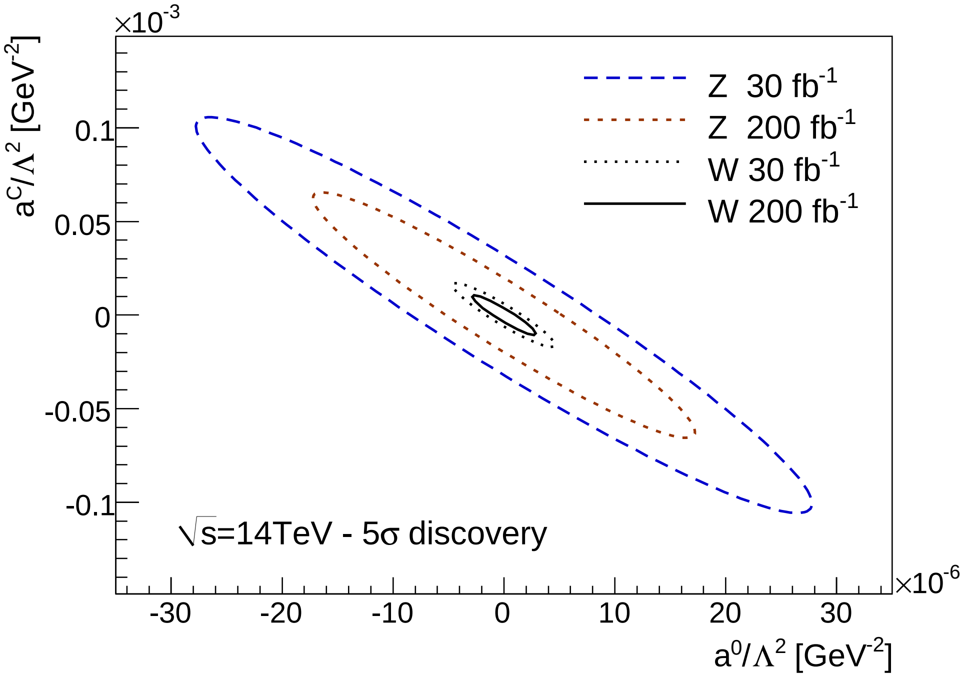
Signal events for 30 fb^{-1}

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

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 fb^{-1} for the different couplings
- 5σ discovery countours for two different luminosities 30 and 200 fb^{-1}
- Present LEP limits can be improved by up to four orders of magnitude





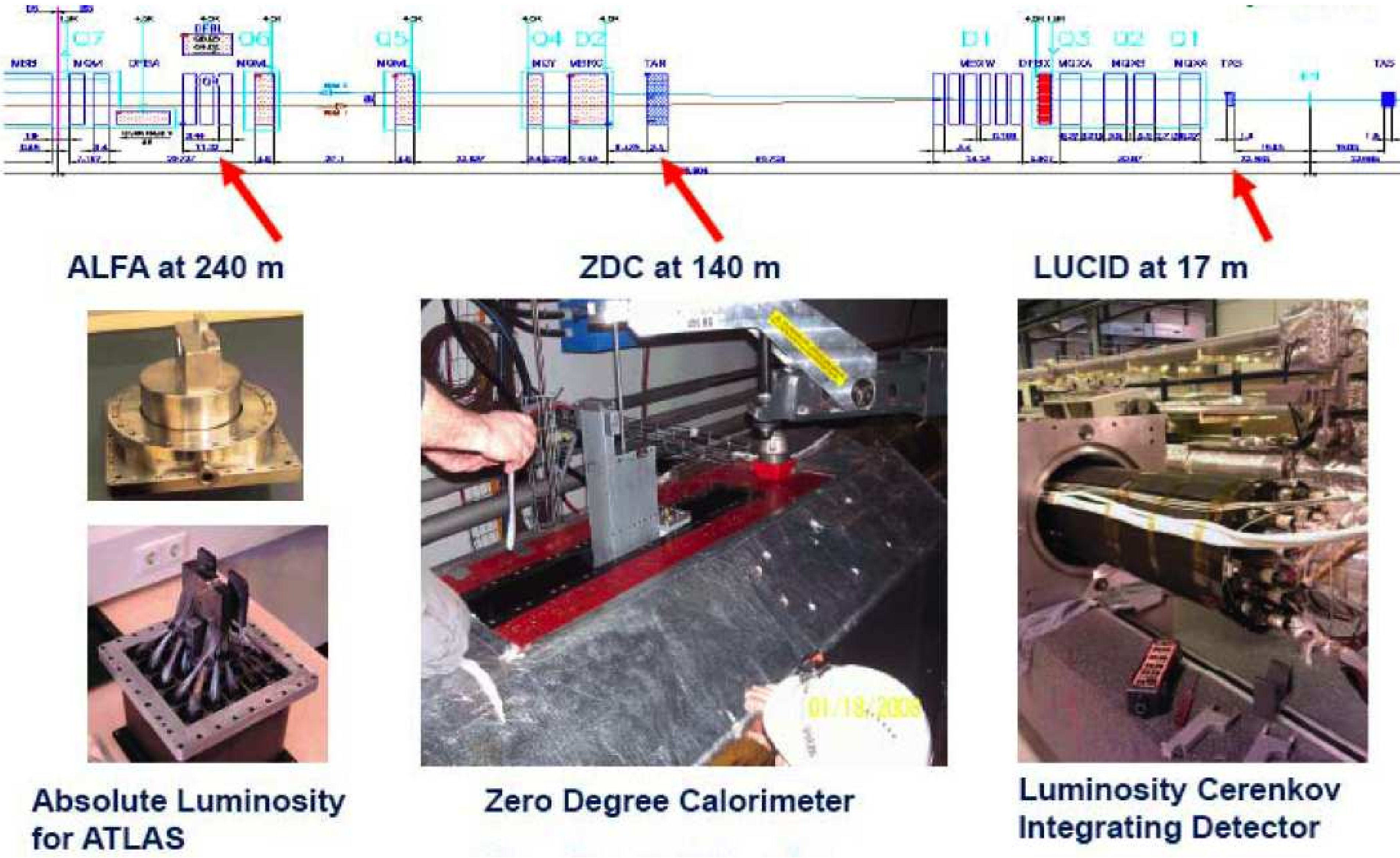
Reach at LHC

Reach at high luminosity on quartic anomalous coupling

Couplings	OPAL limits [GeV^{-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!!!
- Reach the values expected by Higgsless models

Forward detectors in ATLAS



ALFA at 240 m

ZDC at 140 m

LUCID at 17 m

Absolute Luminosity for ATLAS

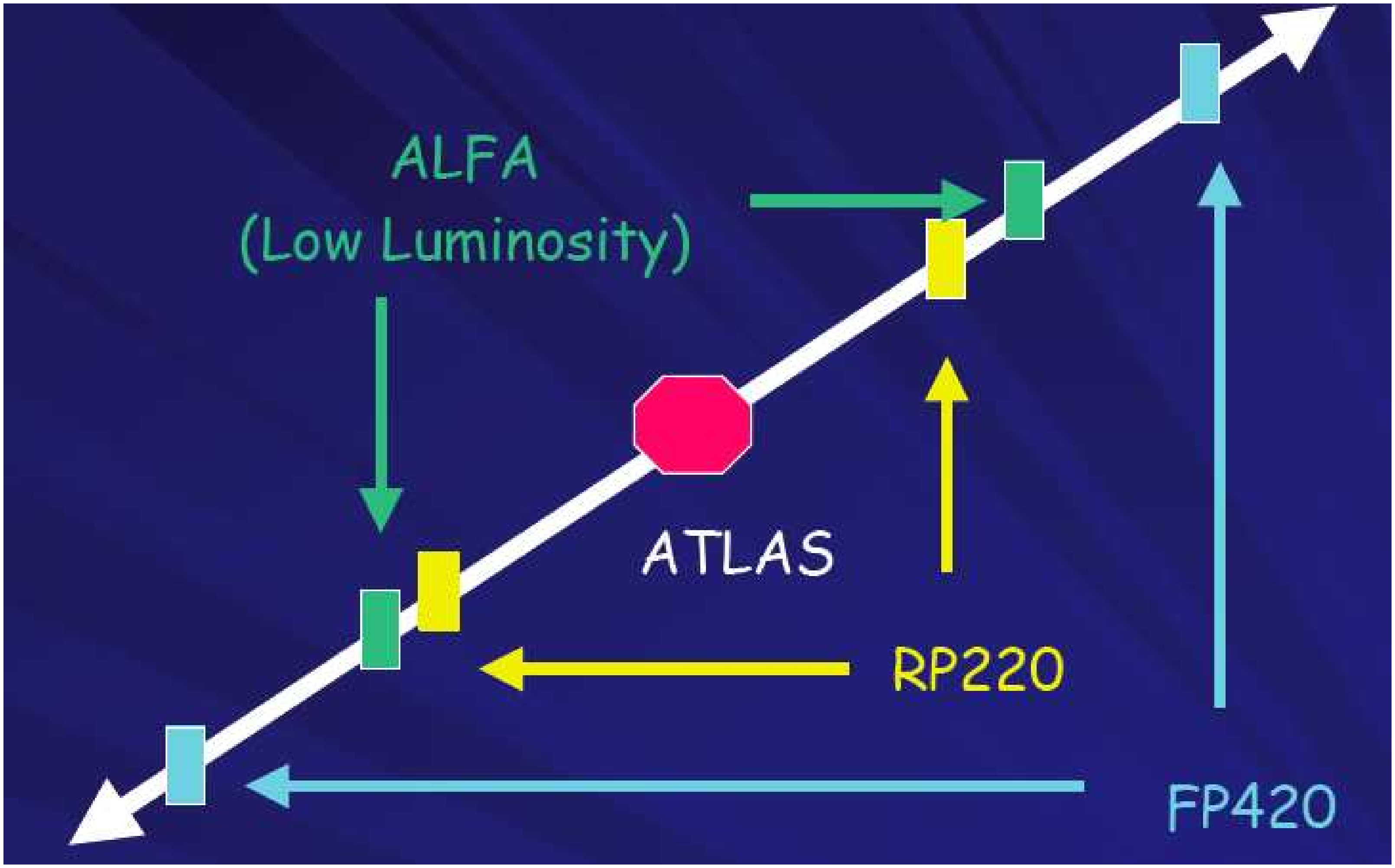
Zero Degree Calorimeter

Luminosity Cerenkov Integrating Detector

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

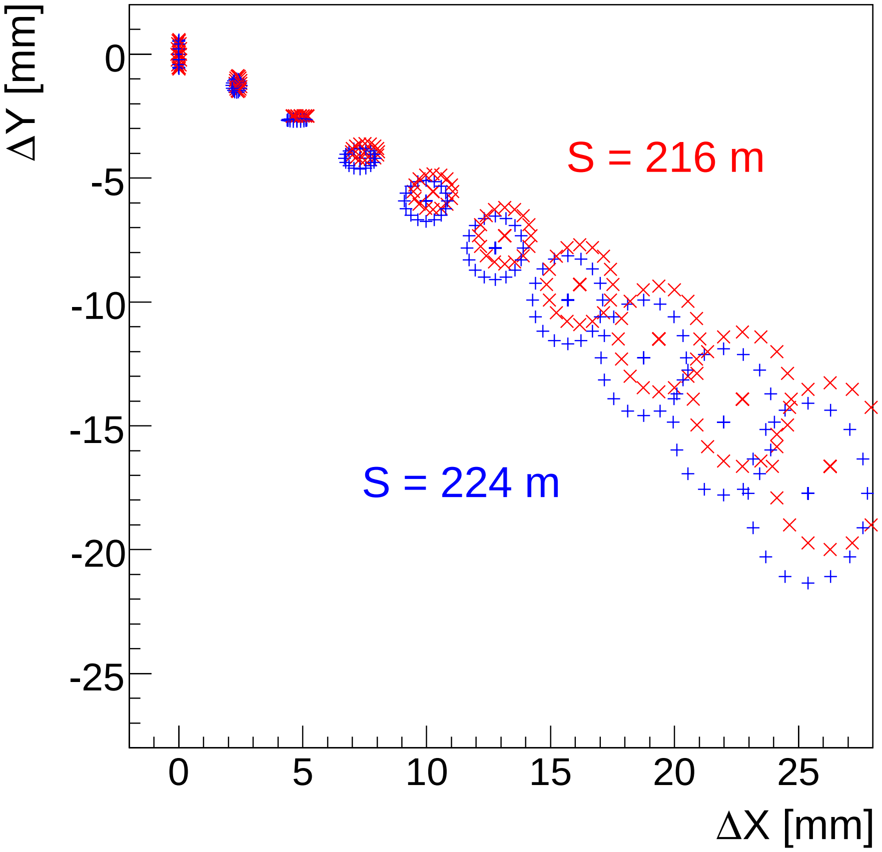
Detector location

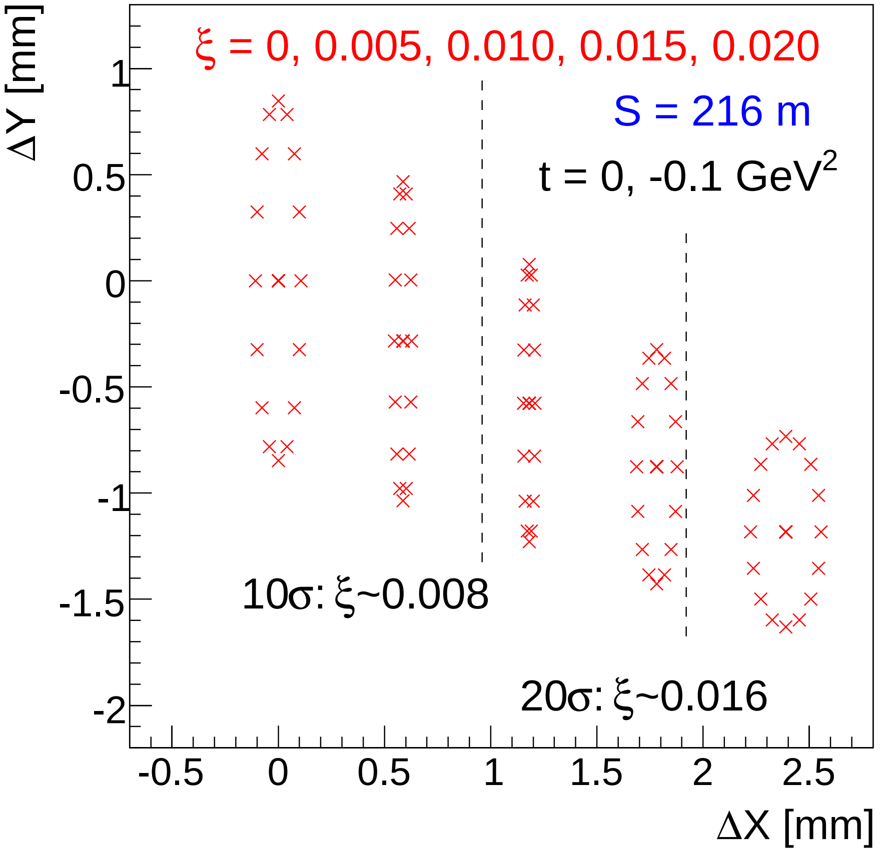
- what is needed? Good position and good timing measurements
- 220 m: movable beam pipes (in addition vertical roman pots for alignment purposes under study)
- 420 m: movable beam pipe (roman pots impossible because of lack of space available and cold region of LHC)



Example: Acceptance for 220 m detectors

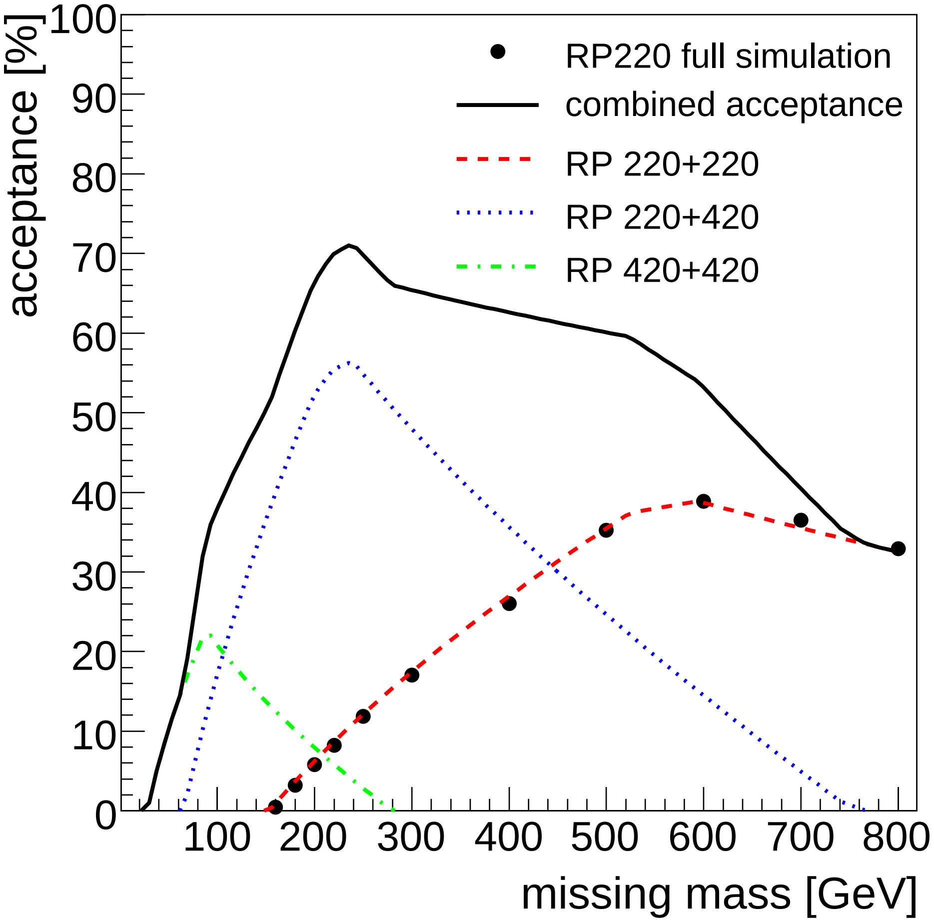
- Steps in ξ: 0.02 (left), 0.005 (right), $|t|$=0 or 0.05 GeV^2
- Detector of 2 cm × 2 cm will have an acceptance up to $\xi \sim 0.16$, down to 0.008 at 10 σ, 0.016 at 20 σ
- Estimate: possibility to insert the detectors up tp $\sim 15\sigma$ from the beam routinely
- Detector coverage of 2 cm × 2 cm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





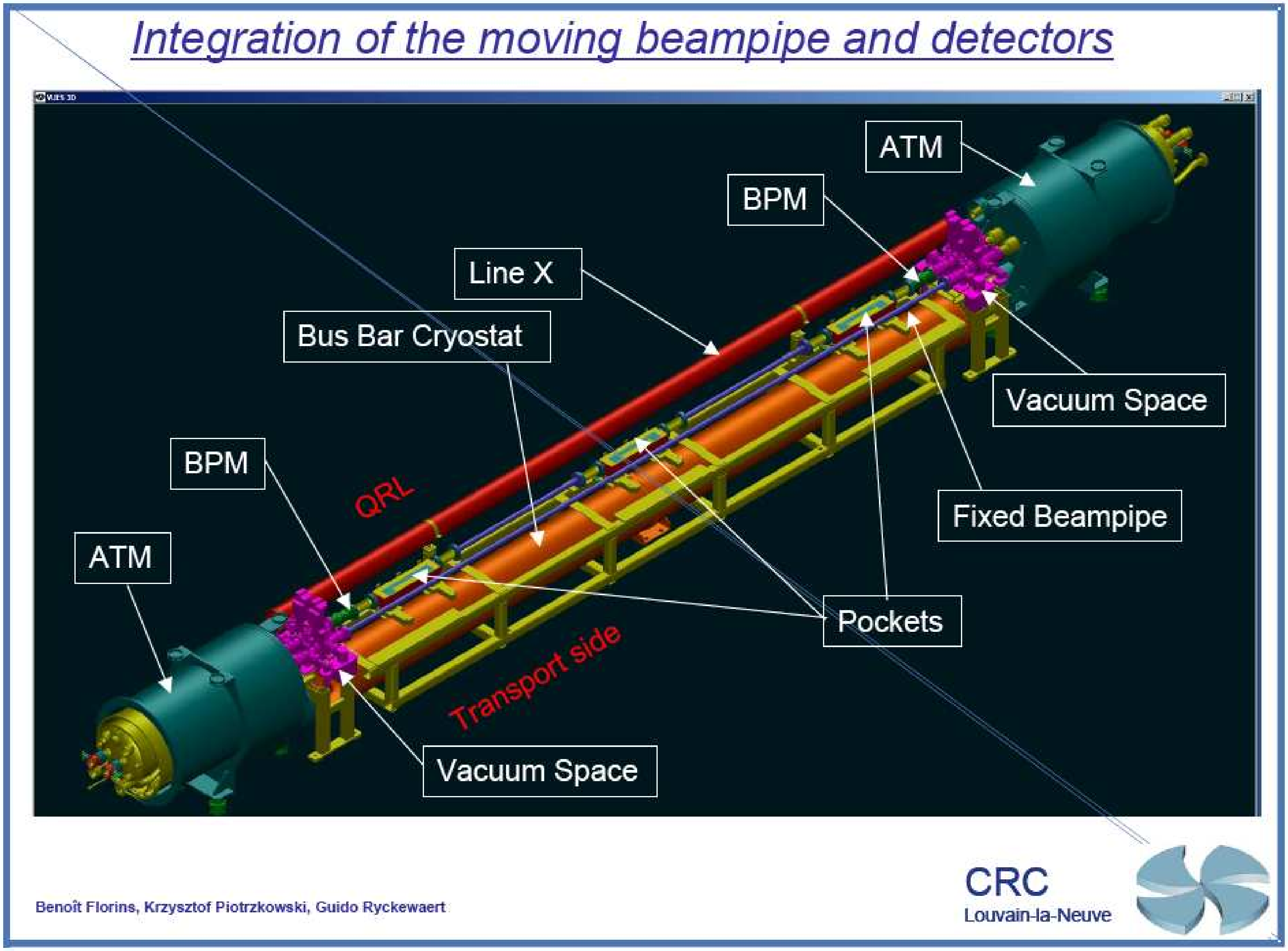
ATLAS Forward Physics detector acceptance

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 μm)

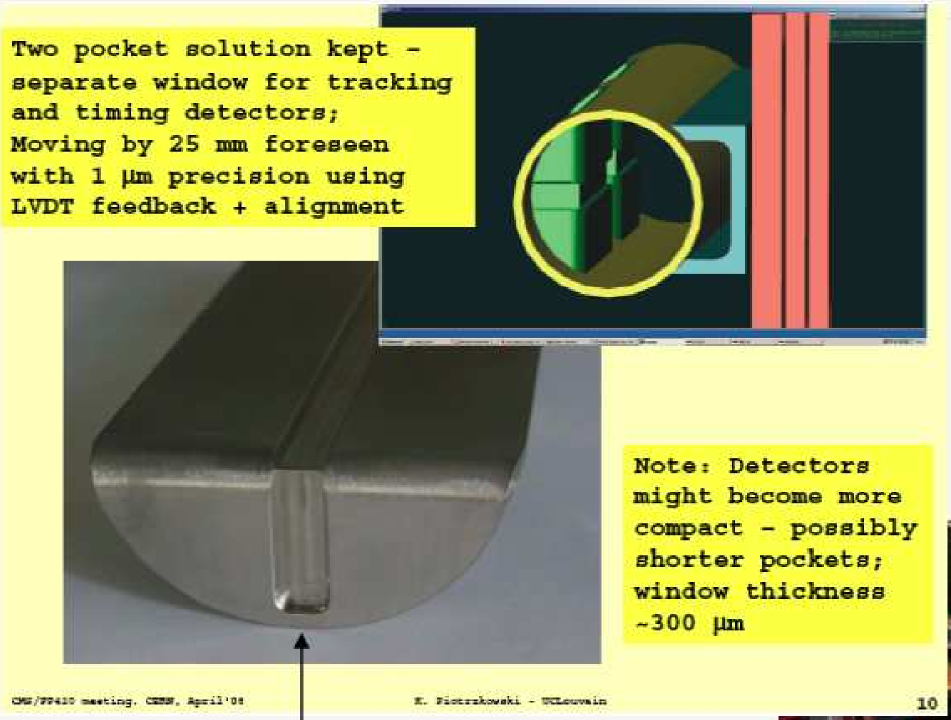


Integration of the moving beampipe and detectors

Benoît Florins, Krzysztof Piotrzkowski, Guido Ryckewaert

CRC
Louvain-la-Neuve

Movable beam pipes and pockets



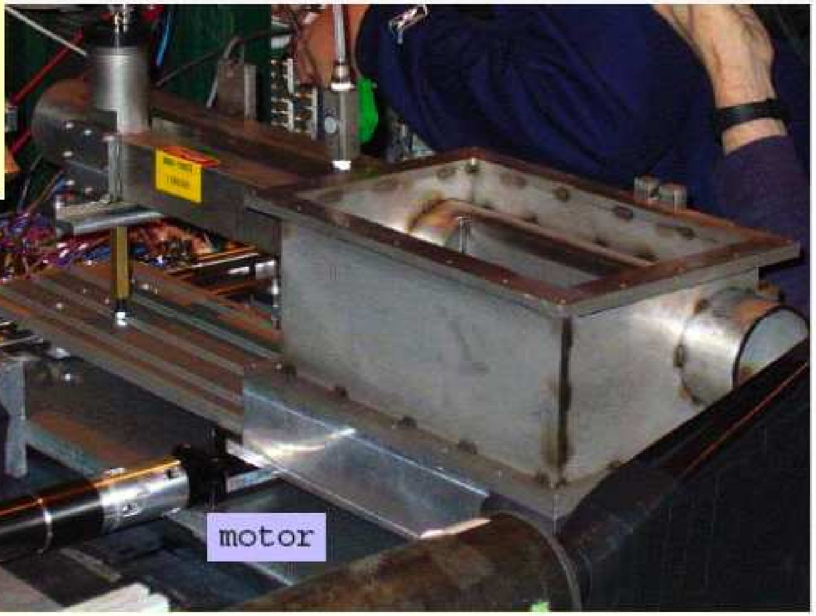
Two pocket solution kept – separate window for tracking and timing detectors;
Moving by 25 mm foreseen with 1 µm precision using LVDT feedback + alignment

Note: Detectors might become more compact – possibly shorter pockets; window thickness ~300 µm

CMS/FP420 meeting, CERN, April'08 K. Piotrzkowski - UCLouvain 10

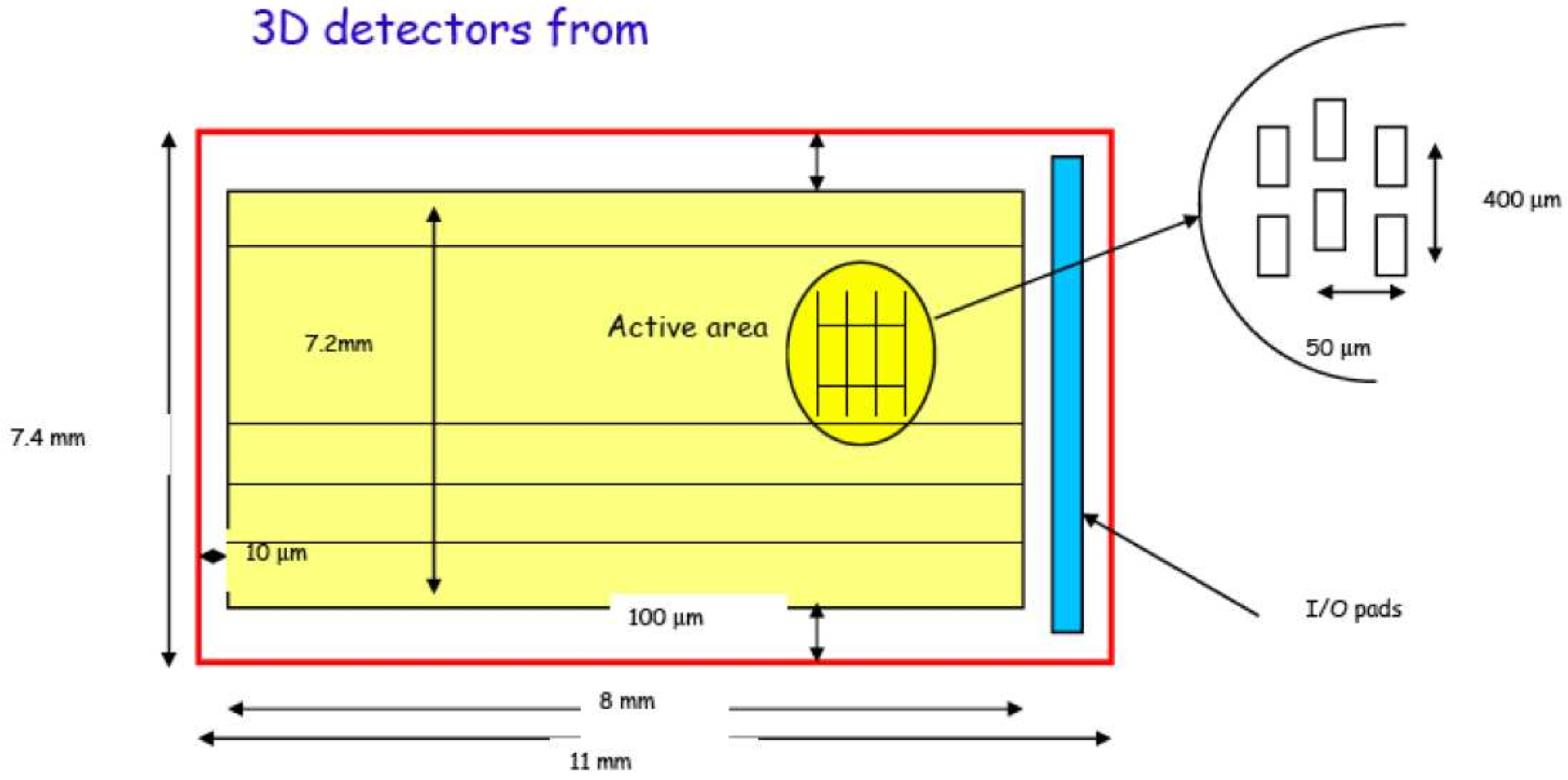
300 µm window
Louvain

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



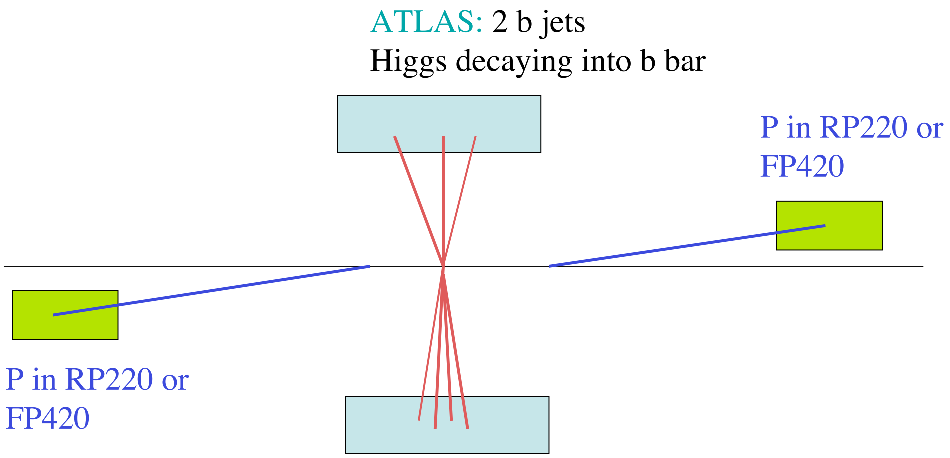
3D Silicon Detectors (Manchester/SLAC)

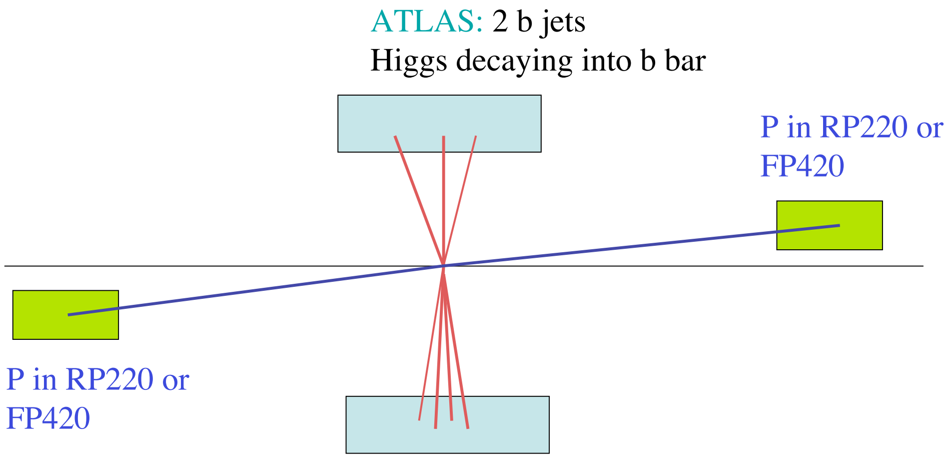
- Precise reconstruction of proton position, and then mass: position resolution of 10-15 μm
- Radiation hardness
- 3D Si detectors: 10 planes per supermodule, pixels of 50 $\times$ 400 μm; 10 layers
- Modification of readout chip to include L1 trigger: address of vertical line hit to know ξ at L1



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!!!!)



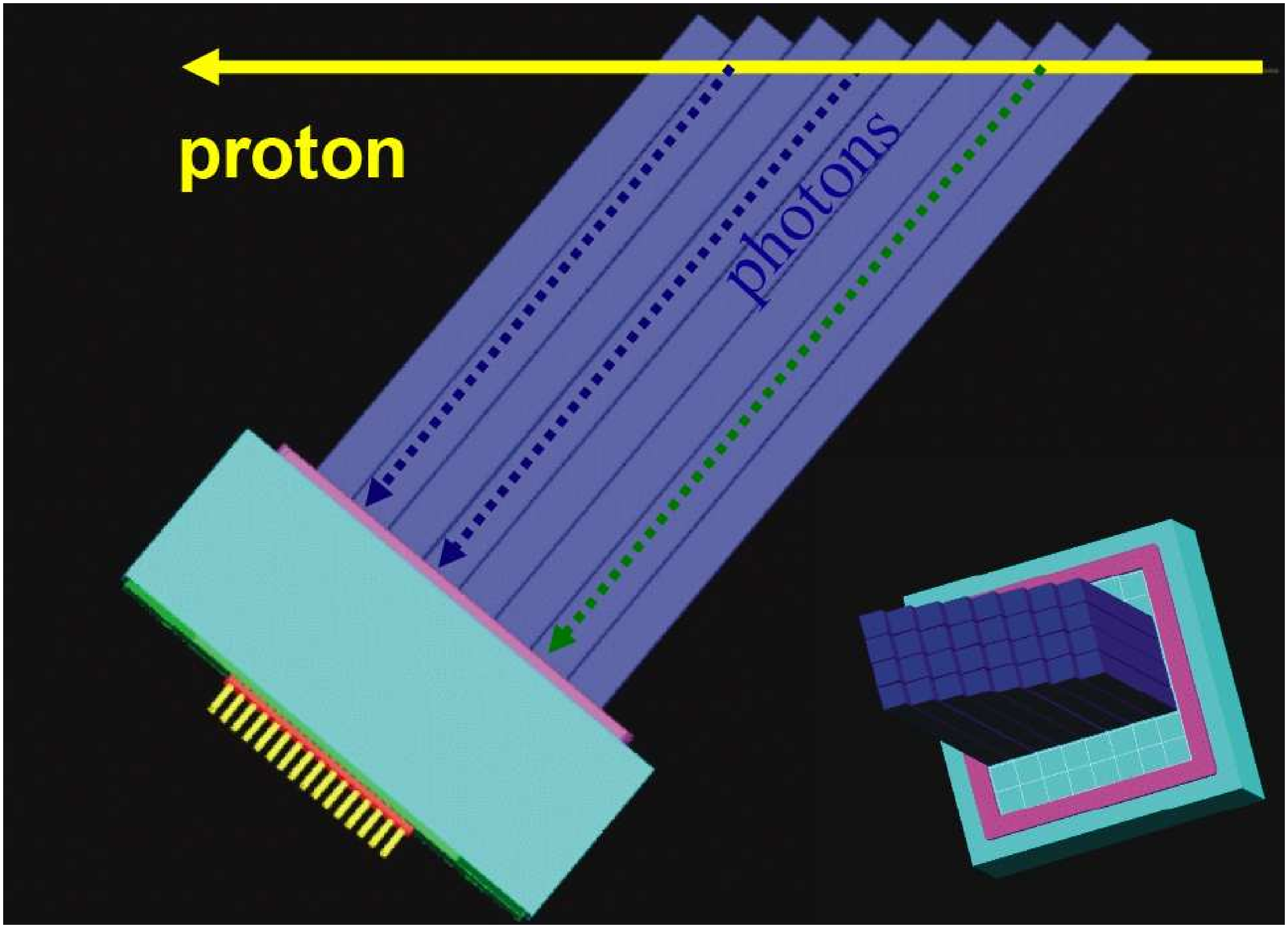


Timing system requirements

- Timing resolution of full system: 5 to 10 ps by 2015-2016 (preliminary detector with best possible resolution by 2012-2013)
- Nearly 100% efficiency, and high rate capability: Issue with phototube lifetime
- Segmentation if possible: in the case multi-protons are detected in the same bunch crossing
- Robust: Need to be operated with minimum intervention (radiation environment)
- Two solutions proposed: QUARTIC and GASTOF (collaboration between many institutes on electronics/detector: University of Chicago, Alberta, Orsay, Saclay, Texas Arlington, Louvain, Fermilab...)

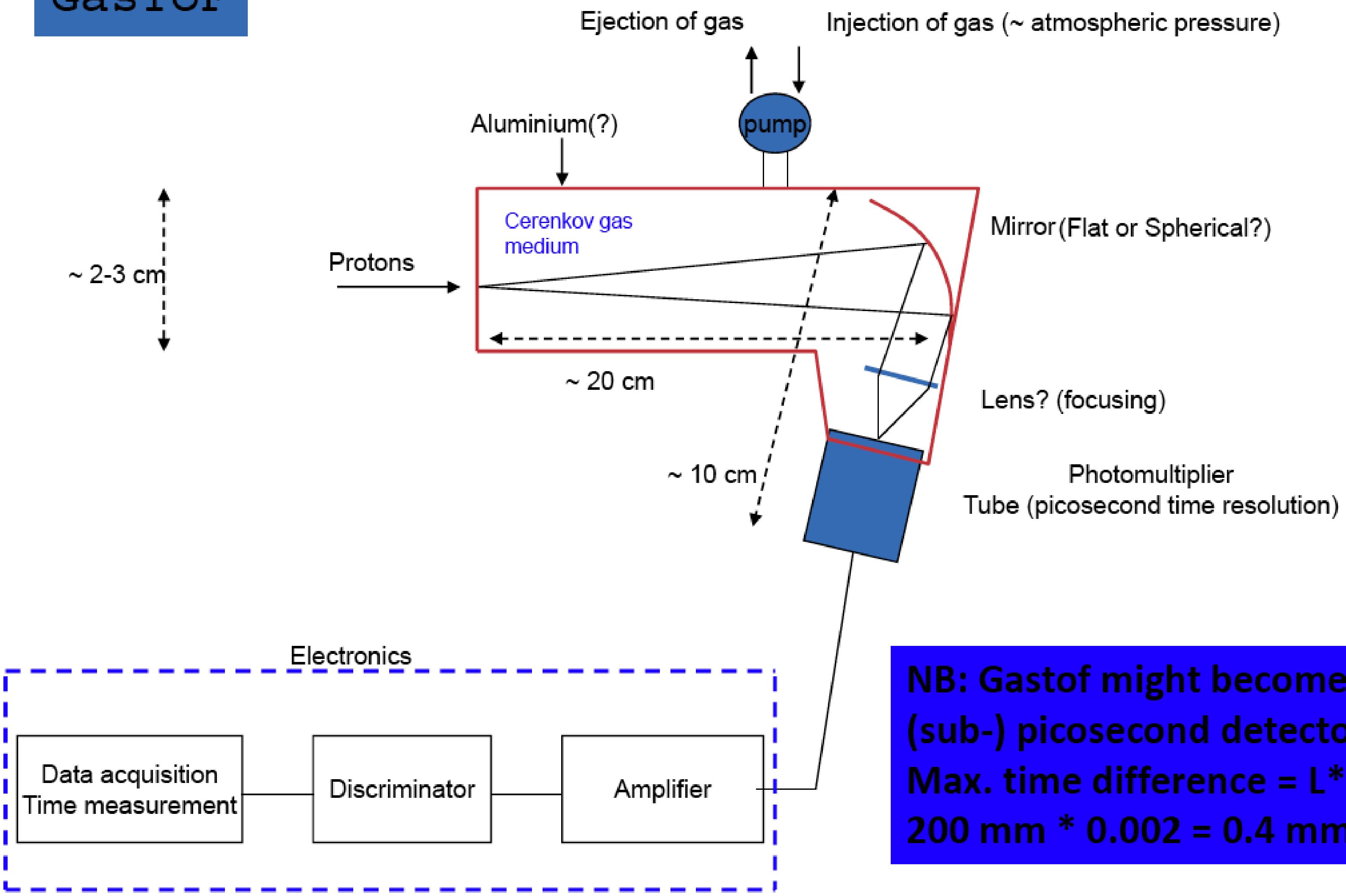
QUARTIC

- 4x8 array of 5-6 mm^2 fused silica bars (Texas Arlington, Alberta, Giessen, Stony Brook, Fermilab)
- only need a 40 ps measurement if we can do it 16 times: 2 detectors with 8 bars each, with about 10 photoelectrons per bar Readout by Micro-Channel Plate Photomultiplier Tube: Burle/Photonis 64 channel, 10 μm pore tube as a default



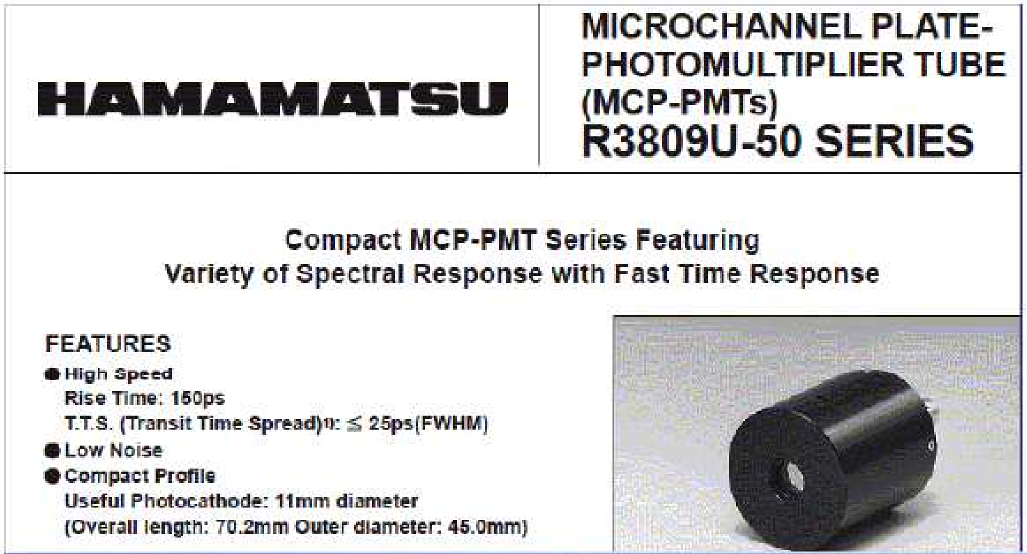
GASTOF detector principle

GasToF



NB: Gastof might become (sub-) picosecond detector! Max. time difference = L*Δn (= 200 mm * 0.002 = 0.4 mm !)

GASTOF using 6 μm pore MCP PMT

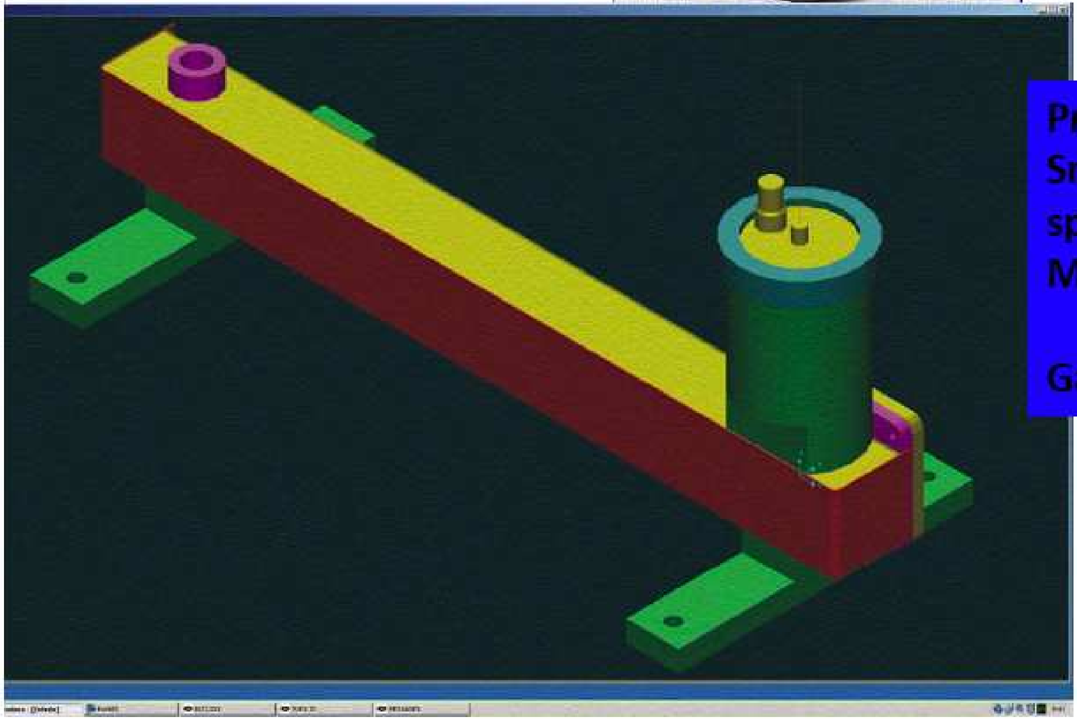


HAMAMATSU

MICROCHANNEL PLATE-PHOTOMULTIPLIER TUBE (MCP-PMTs)
R3809U-50 SERIES

Compact MCP-PMT Series Featuring
Variety of Spectral Response with Fast Time Response

FEATURES
- High Speed
  Rise Time: 150ps
  T.T.S. (Transit Time Spread)1): ≤ 25ps(FWHM)
- Low Noise
- Compact Profile
  Useful Photocathode: 11mm diameter
  (Overall length: 70.2mm Outer diameter: 45.0mm)



Gastof **with 6 μm pore MCP PMT**

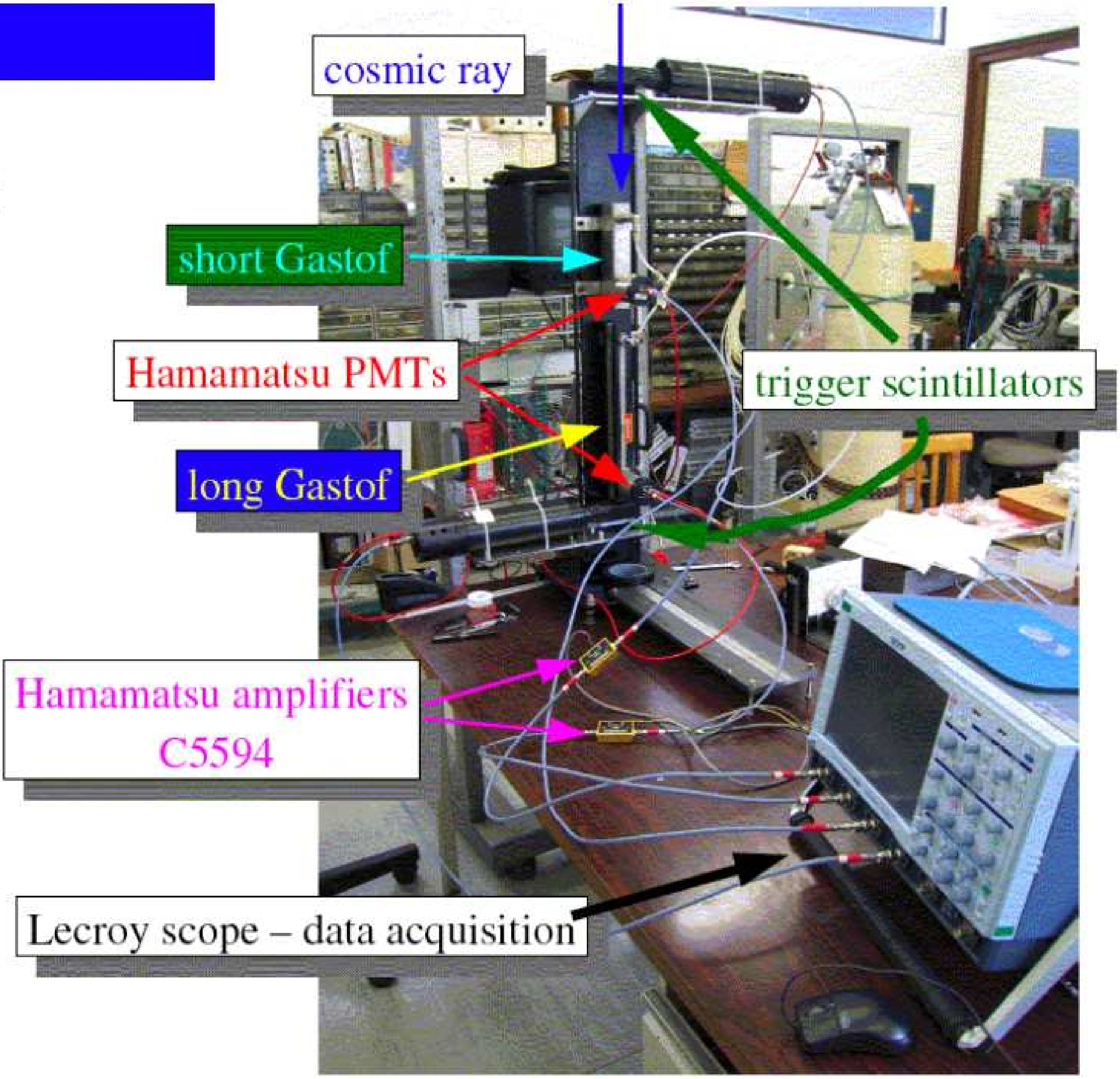
Problems:
Small 11 mm cathode –> use spherical mirror to focus light on MCP-PMT;

Gas tightness – PMT case leaks.

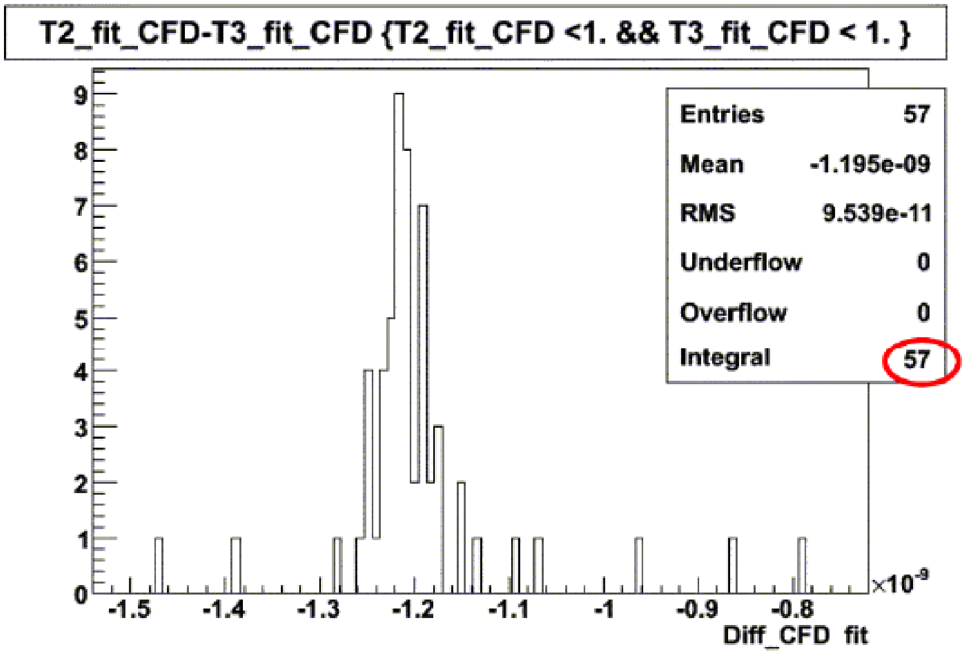
GASTOF cosmics test stand

Tomek Pierzchala

Cosmic rays test stand

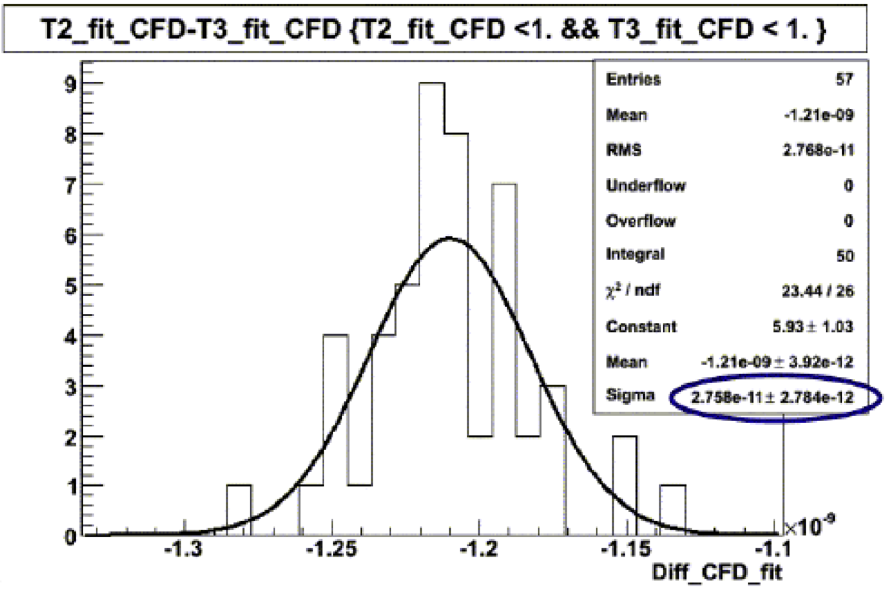


GASTOF performance



Tomek Pierzchala

From CFD algo: Measure spread of time difference (= distance between PMTs)



Single Gastof resolution (for ~1 pe):

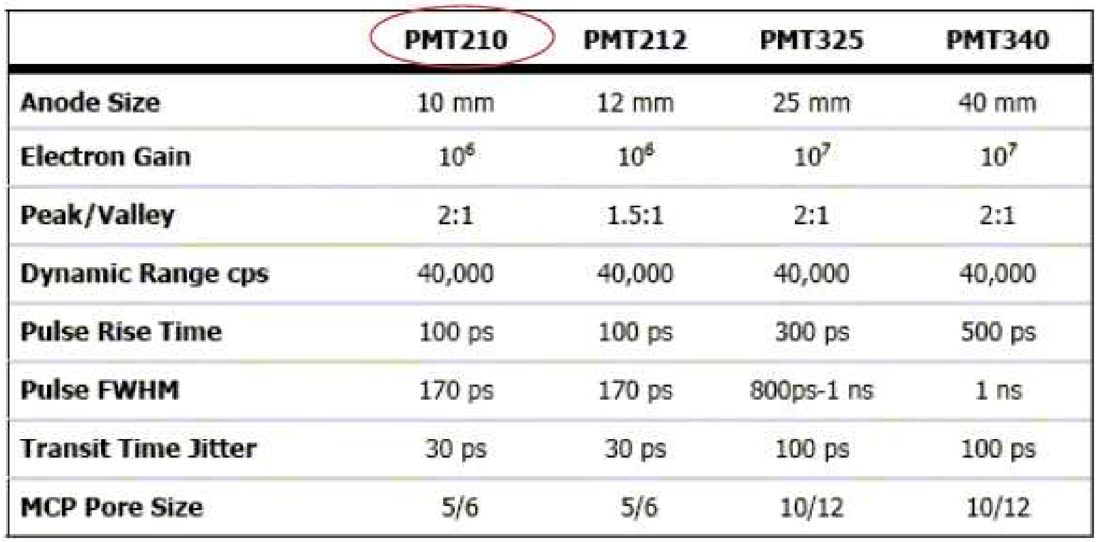
< 28 ps/√2 = 19.5 ± 2 ps

GASTOF using PHOTEK 3 μm pore MCP PMT

ULTRA FAST PHOTOMULTIPLIERS Photek

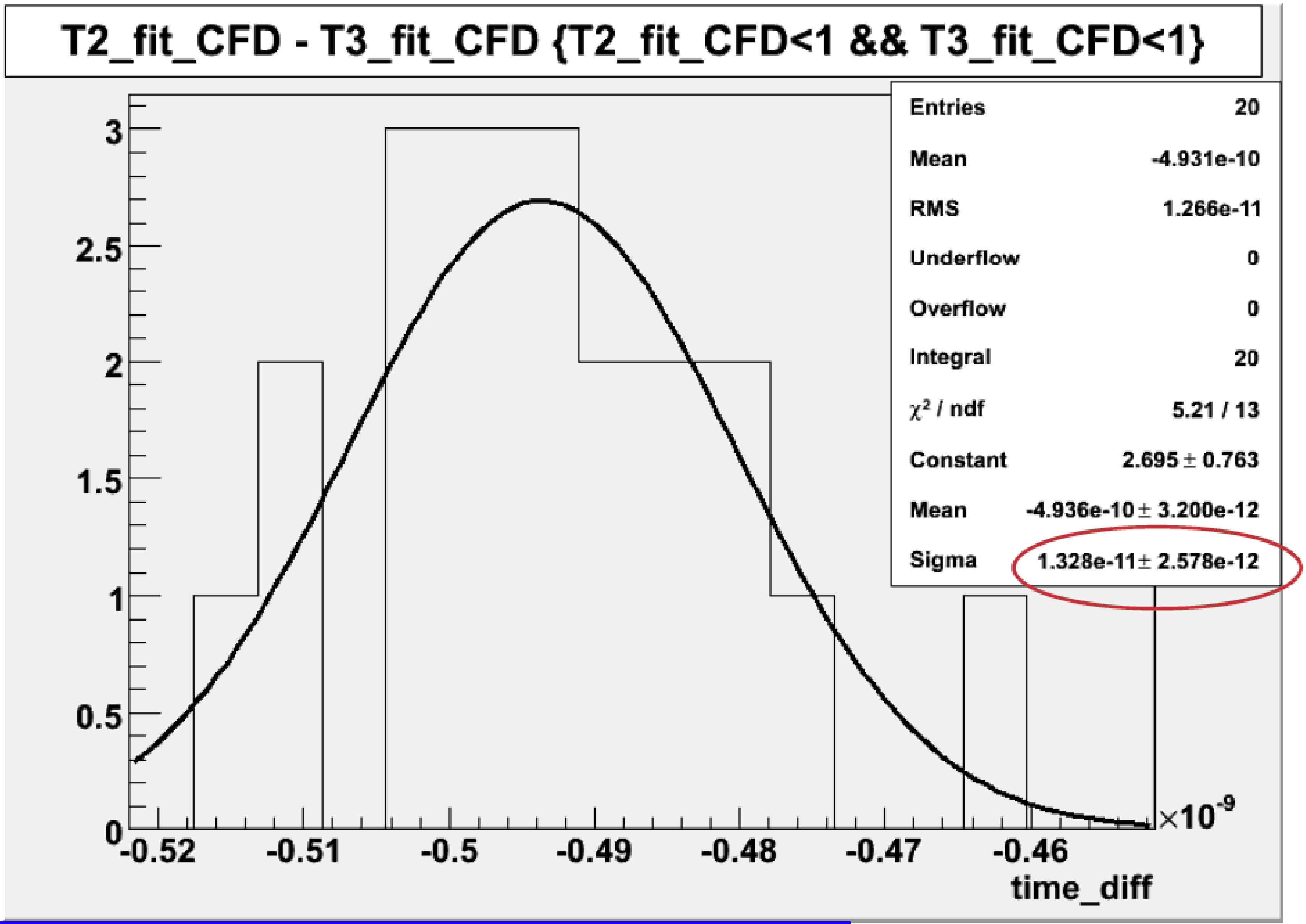
In collaboration with PHOTEK:

- Received two 3 µm pore tubes, with no gas leak!



	PMT210	PMT212	PMT325	PMT340
Anode Size	10 mm	12 mm	25 mm	40 mm
Electron Gain	10^6	10^6	10^7	10^7
Peak/Valley	2:1	1.5:1	2:1	2:1
Dynamic Range cps	40,000	40,000	40,000	40,000
Pulse Rise Time	100 ps	100 ps	300 ps	500 ps
Pulse FWHM	170 ps	170 ps	800ps-1 ns	1 ns
Transit Time Jitter	30 ps	30 ps	100 ps	100 ps
MCP Pore Size	5/6	5/6	10/12	10/12

GASTOF using 6 μm pore MCP PMT

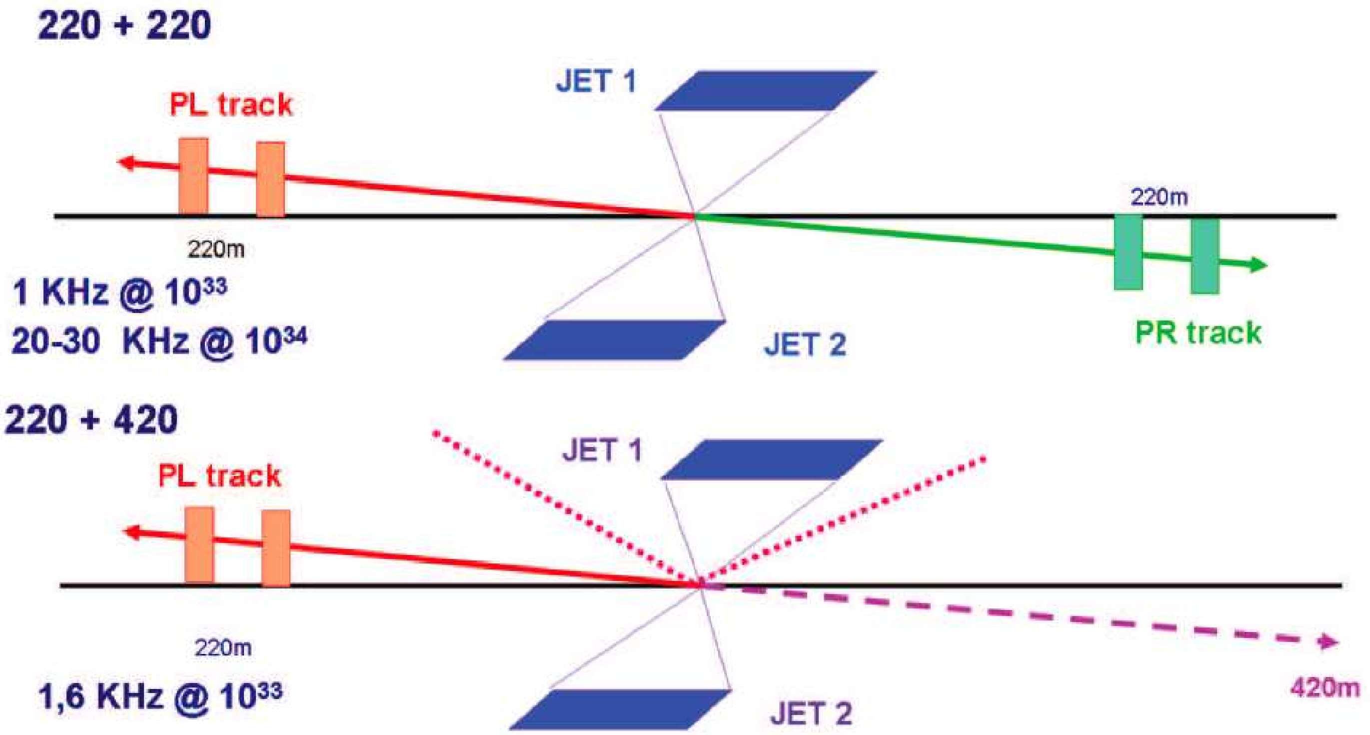


Entries	20
Mean	-4.931e-10
RMS	1.266e-11
Underflow	0
Overflow	0
Integral	20
χ^2 / ndf	5.21 / 13
Constant	2.695 ± 0.763
Mean	-4.936e-10 ± 3.200e-12
Sigma	1.328e-11 ± 2.578e-12

Gastof resolution < 10 ps – we are there!

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 $L < 3.10^{33}$cm^{-2} s^{-1}
- Level 2: 420 m info and timing info: rates of a couple of Hz



Conclusion and timescale

- Diffractive 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, Cockroft 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 devolopments performed/in progress for the project and extremly useful for the future in particle physics or medical applications: 3D Si, timing detectors

Trilinear anomalous gauge couplings

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

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

- 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 γ and Z exchanges in $e^+e^- \to WW$)
  - 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 λ^γ, and $\Delta\kappa^\gamma$ only modifies the normalisation and the low mass events have to be retained:
  - for $\Delta\kappa^\gamma$:

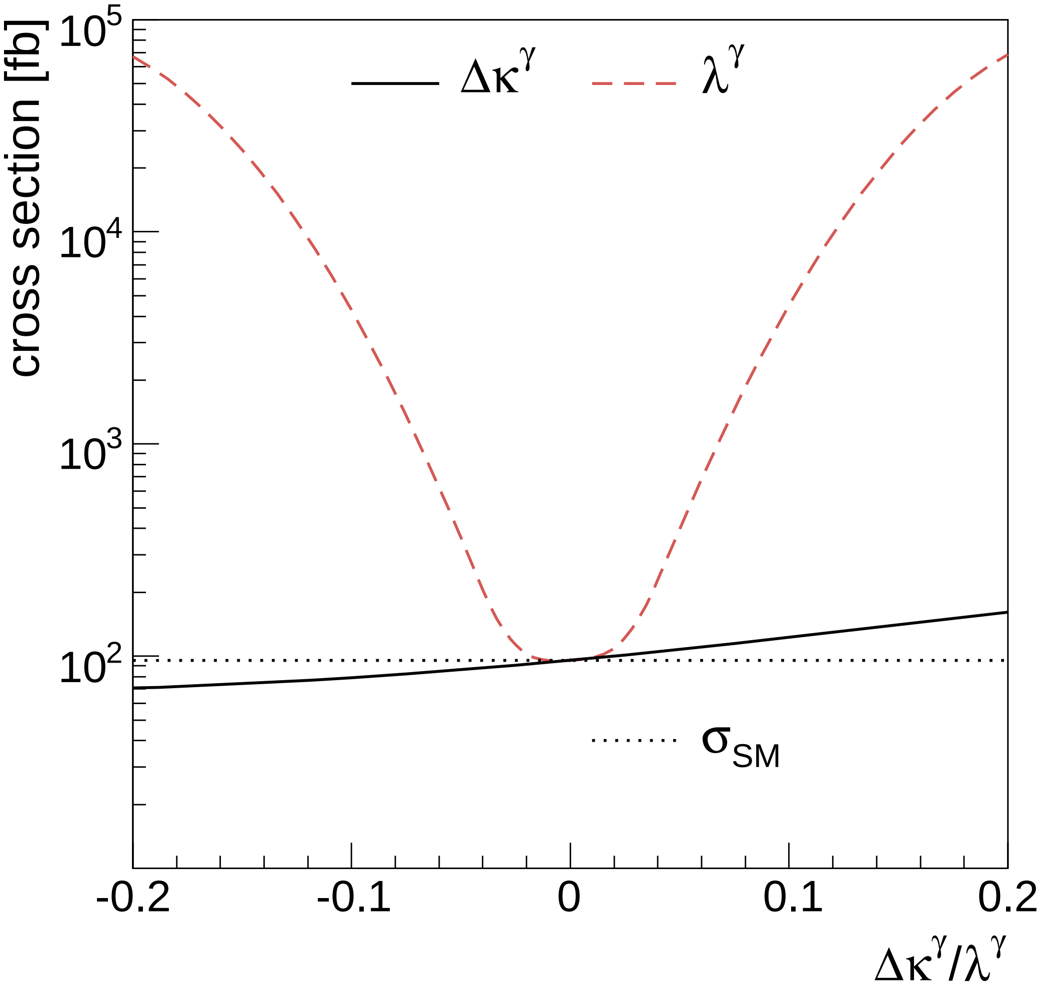
$$p_T^{lep1} > 25 \text{ GeV} \text{ , } p_T^{lep2} > 10 \text{ GeV} \text{ , } 0.0015 < \xi < 0.15, \not{E}_T > 20 \text{ Ge}$$
$$W > 160 \text{ GeV} \text{ , } \Delta\phi < 2.7, W < 500 \text{ GeV}$$

  - for λ^γ:

$$p_T^{lep1} > 160 \text{ GeV} \text{ , } p_T^{lep2} > 10 \text{ GeV} \text{ , } 0.0015 < \xi < 0.15, \not{E}_T > 20 \text{ G}$$
$$W > 800 \text{ GeV} \text{ , } M_{ll} \notin \langle 80, 100 \rangle \, GeV, \Delta\phi < 3.13 rad$$

Anomalous $WW\gamma$ triple gauge coupling

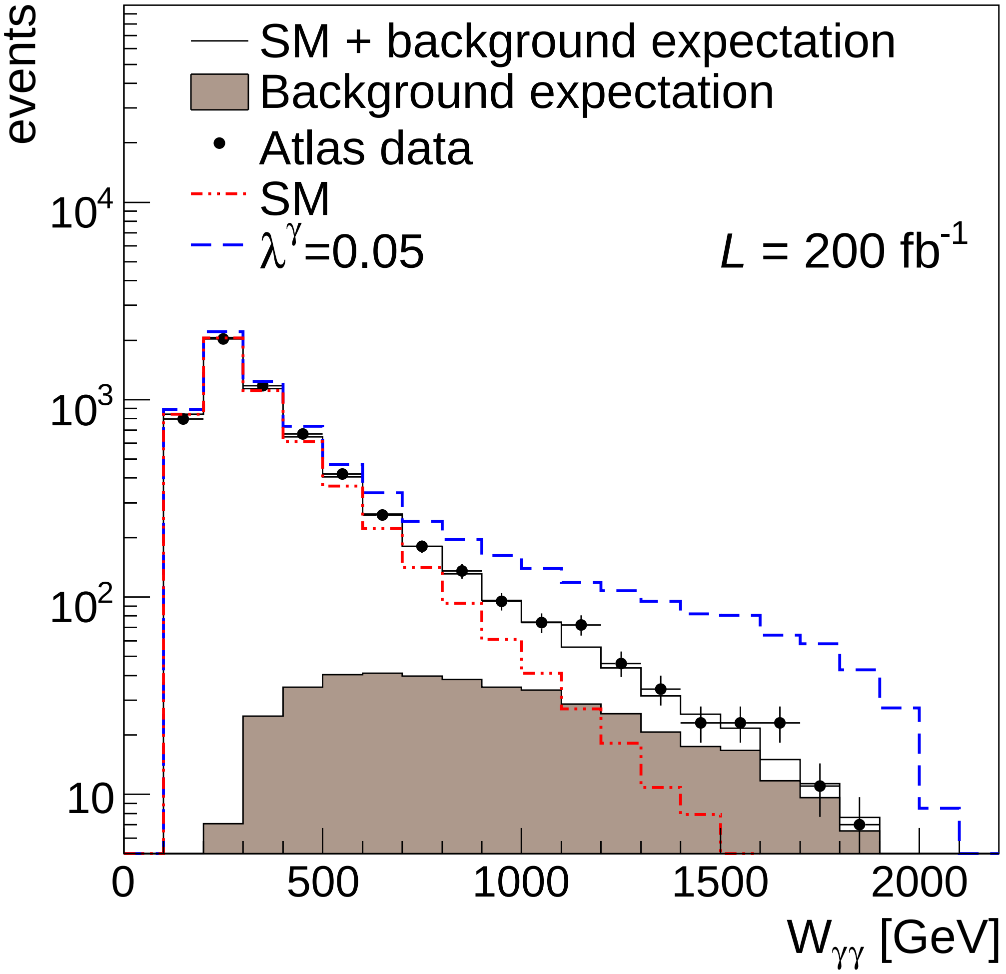
Different behaviour of the cross section as a function of anomalous couplings



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 fb^{-1}
  - 5σ 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 Ws



Forward detector alignement 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 ssction lower (higher mass), can be used only to perfrom 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