ATLAS Diffractive Physics Program

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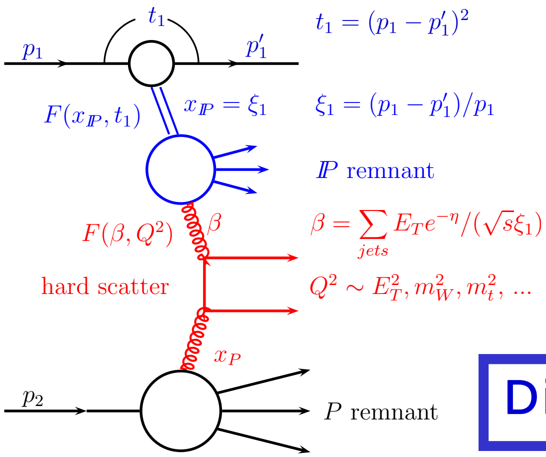
Workshop on HE Photon Collisions at LHC - CERN 24/04 2008

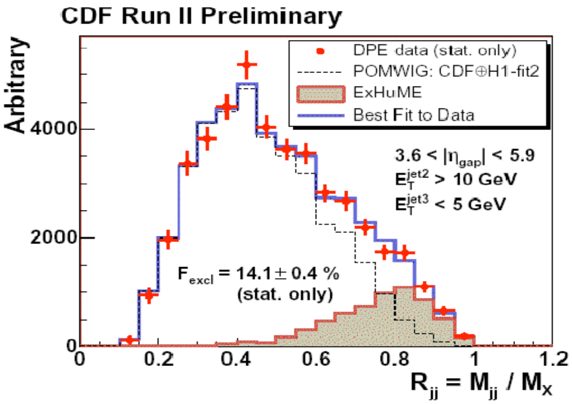
Diffraction at low luminosities

Diffraction at high luminosities

Rich program for Forward Physics at LHC

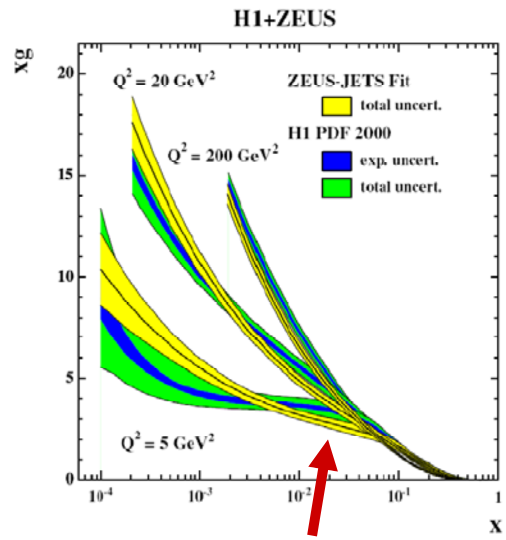


Diffraction

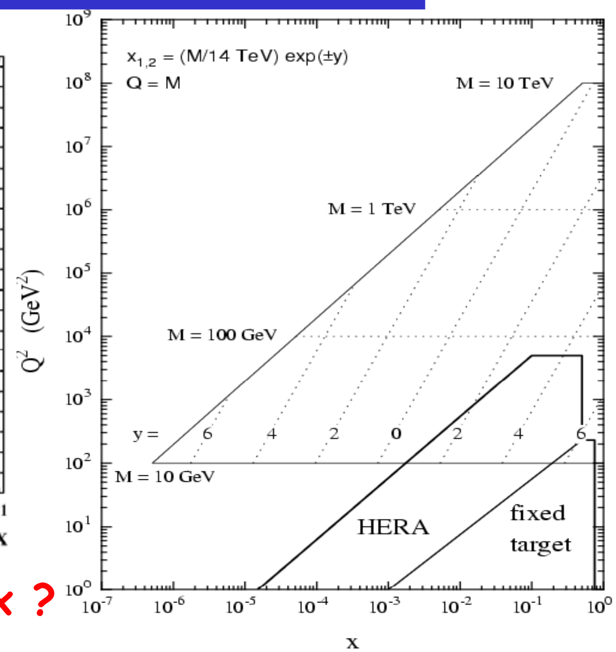


Evidence for CEP?

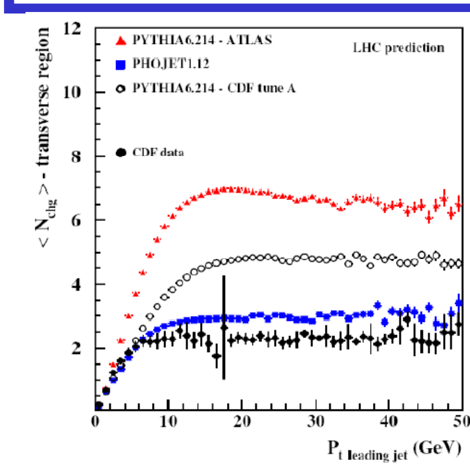
F_2^p at very low x



Saturation at very low x ?



Underlying event/Multiple interactions



Long dist. Correl. in rap. (need to cover fwd region)

Huge differences for diff. generators and diff. tunes

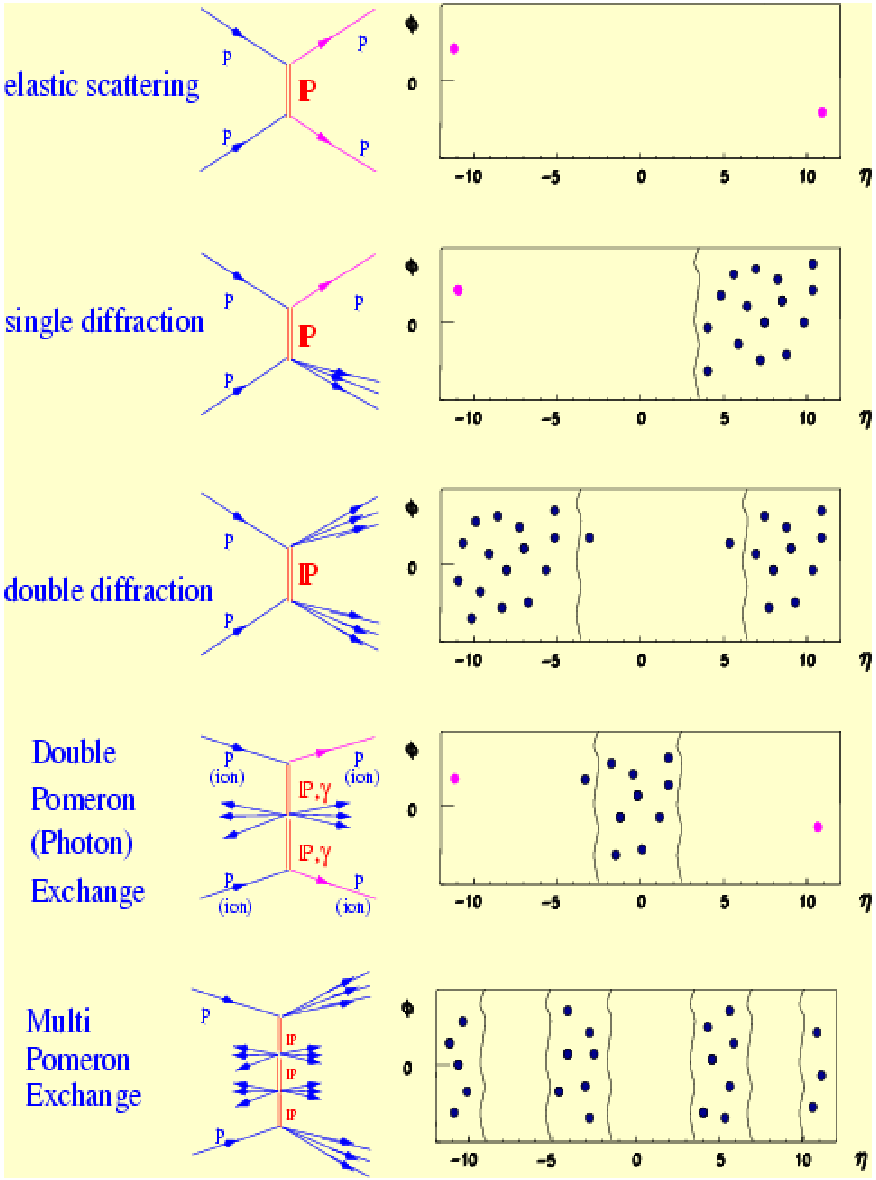
Average mult. transv. to leading jet at LHC

[C.Buttar et al., HERA-LHC proc.]

Two-photon interactions

- **Absolute lumi calibration**
- **Calibration, resolution for FPS**
- **Factorization breaking in hard diffr.**

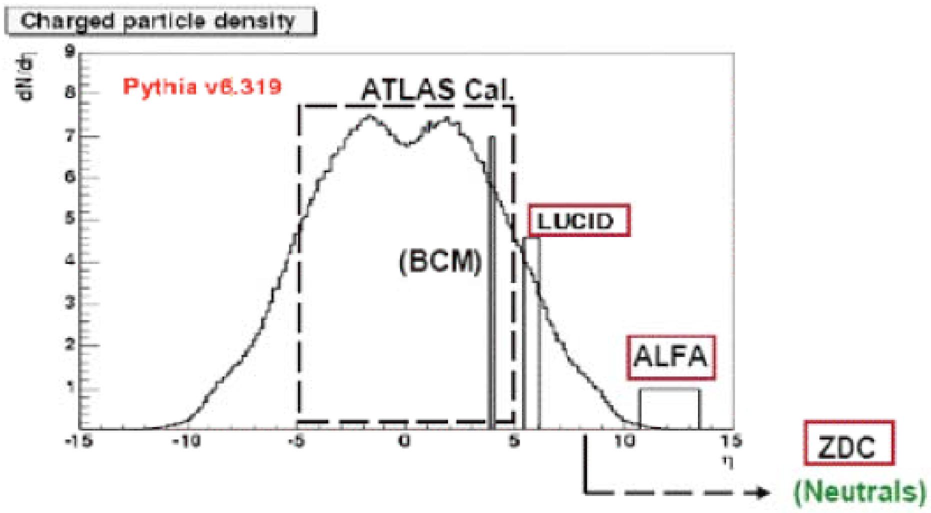
Diffraction at LHC:



- Forward proton tagging in special runs with ALFA

- Combined tag of proton in ALFA on one side and remnants of dissociated proton in LUCID/ZDC on the other side

- Central rapidity gap in EM/HAD calorimeters (|η|<3.2) and inner detector (|η|<2.5)



Diffraction Physics Measurements – Low Lumi

WITHOUT PROTON TAGGING	WITH PROTON TAGGING
Low luminosity	or Early data
L1 trigger: rapgap, low E_T (20-30 GeV)	ALFA, LUCID or ZDC
Start with ratios X+gaps/X(incl.),	X=W,Z,jj,μμ -> get information on S^2
pp → RG + W/Z + RG	**Info on soft survival S^2** (γ-exch. dominates for W)
pp → RG + W	**Info on soft survival S^2**
pp → RG + jj + RG	**Combined effect of all basic ingredients to CED** (**S^2**, Sudakov suppr., unintegr. f_g, enhanced absorpt)
pp → RG + Y + RG	**Info on unintegrated f_g** (γ- or Odderon exchange)
	P-tagging = info on proton p_T, i.e. dσ/dt
Hard SD, Hard DD	**High rate soft diffraction:**
	ALFA: σ_{tot}, $d\sigma_{el}/dt$, σ_{SD}(low M), **$d^2\sigma_{SD}/dtd\xi$, $d^2\sigma_{DPE}/d\xi_1 d\xi_2$**
	- tests model assumptions,
	- governs rates of Pile-up bg
	- Strongly restricts S^2 (info on enhanced absorption), not sensitive to higher-order (Sudakov) effects
	pp → p + jj + p:
	Advantages: rel. high rate
	separate different effects in one process
	High rate γp and γγ processes

With proton tagging

V.Khoze, DIS08

Without proton tagging

$$\sigma(RG + W + RG) \simeq 2 * (0.2-1)\, pb * S^2$$

S^2 ~0.6-0.7

$t_{\min}(\xi_p)$ - effects

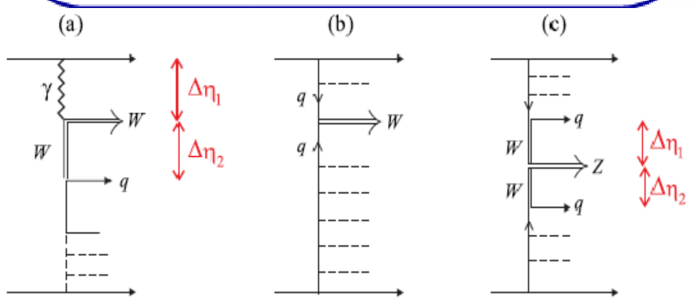
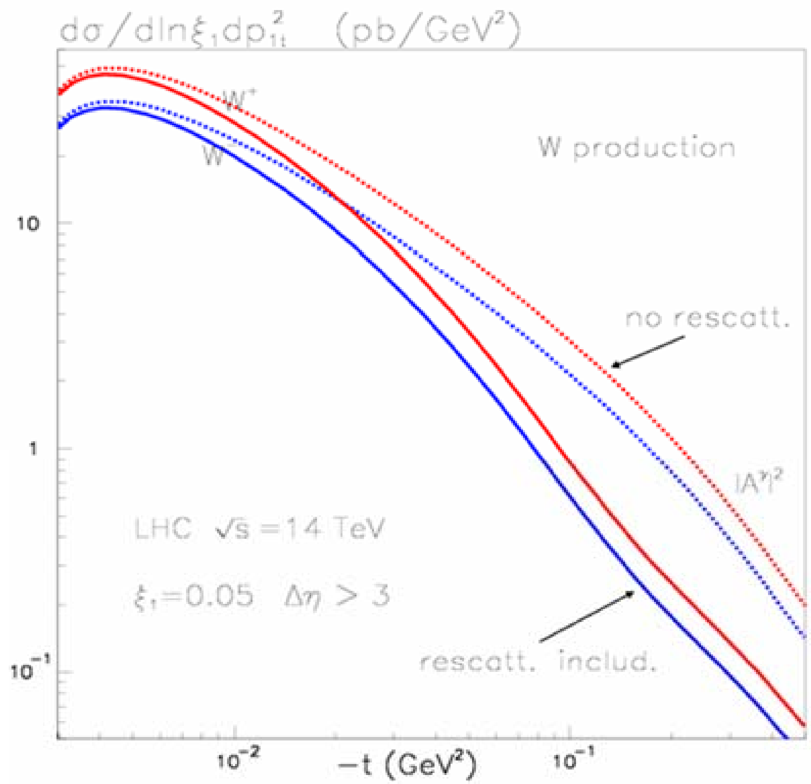
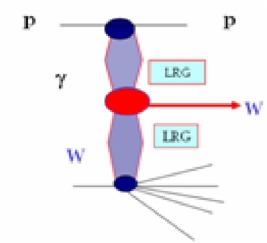
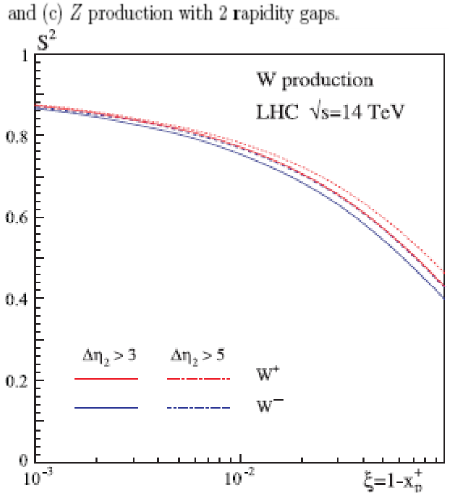


Figure 2: Diagrams for (a) W production with 2 rapidity gaps, (b) inclusive W production, and (c) Z production with 2 rapidity gaps.







The differential cross section for $pp \to p + W^{\pm} + X$ at the LHC. The dotted and ntinuous curves correspond, respectively, to the predictions without and with the rescattering ects of Figs. 8(b,c). In each case W^+ production corresponds to the upper one of the pair curves. The rapidity gap between the quark recoil jet and the W boson is taken to satisfy $\eta > 3$.

Possible dijet study strategy

V.Khoze, DIS08

❶ Measurement of E_T dependence of inclusive dijets (NLO DGLAP calculations).
Mainly tests of efficiencies etc

❷ Ratio of $\sigma_{jj}^{SD} / \sigma_{jj}^{incl}$ (similar to the CDF studies).

With known pdfs (HERA data) we test models for/measure the survival factor S^2

❸ Ratio $\sigma_{jj}^{DPE} / \sigma_{jj}^{incl}$ with different gap sizes allows to probe Sudakov effects and the possible role of 'enhanced absorption'
Variation of the gap size and jet E_T → various quantitative tests
(e.g. absorption is higher for low-p_t particles)

❹ When/if proton tagging is operational, then the studies of proton momentum correlation should come. pt-spread in the beams ?

Scanning of proton opacity.
Can also pave the way to direct measurements of CP violation
In the Higgs sector.

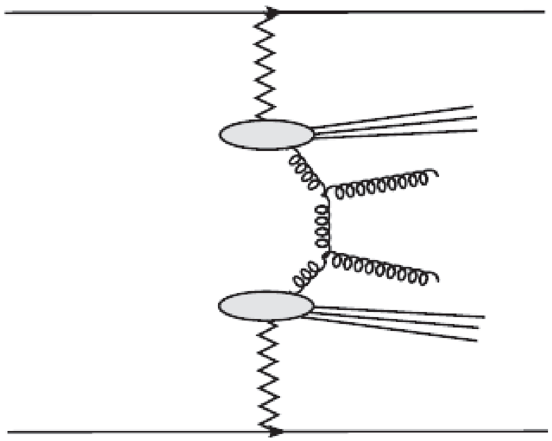
All these measurements are interesting on their own right: diffractive (soft QCD) physics is still not fully understood !

Advantages: - comparatively high rate (3 orders higher than Higgs with the same E_T), $\sigma_{jj}^{DPE}(E_T>20)$~10nb
- possibility to separate different effects by studying one process

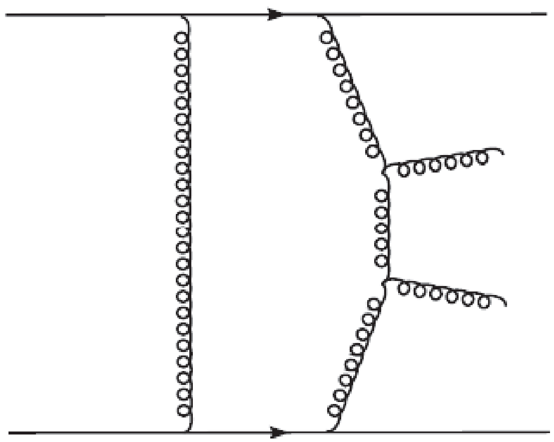
DPE/CED measurements using rapgaps

A.Pilkington, DIS08

DPE

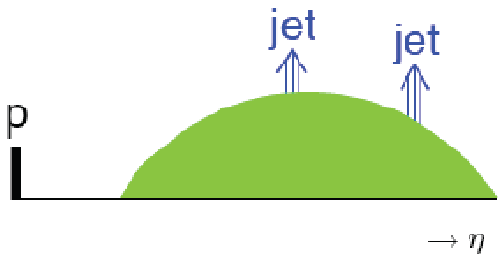


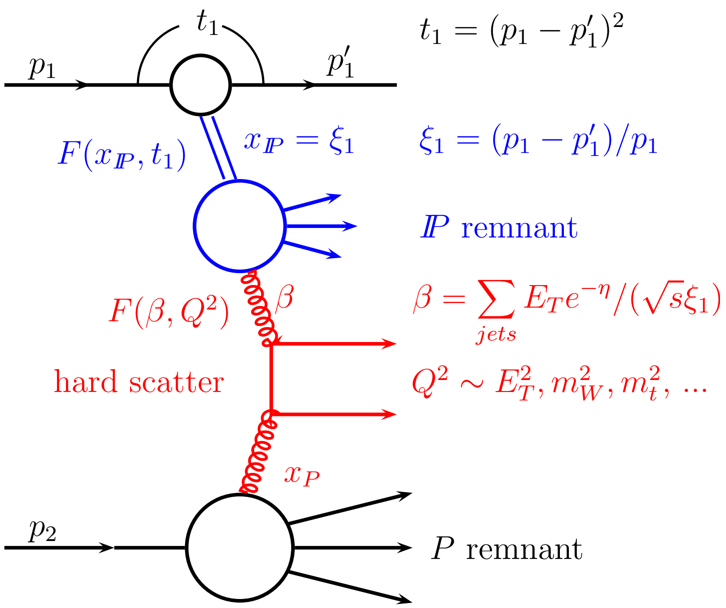
CED



- Two central jets with |η|<2.5.
- Gap imposed on both sides of IP in FCAL, LUCID, ZDC.
- Expect CEP cross section to be 50 times larger than DPE for these criteria.
- Measurement of CEP dijet production at 14TeV. Compare with CDF measurement to constrain theoretical model.

Hard Single Diffraction using rapgap





- Look for hard scatter event with gap on one side of the detector. Compare gap/non-gap ratio to determine soft-survival.
- Gap defined by LUCID/ZDC + FCAL
- FCAL gap needed to restrict event to diffractive region (x_{pom}<0.01).
- e.g. di-jet production (MC Truth):

A.Pilkington, DIS08

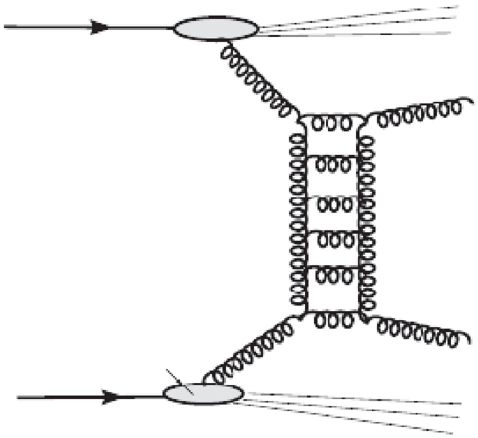
$p_T(GeV)$	x_{pom}	σ (pb)	gap type	efficiency	Events in 100 pb^{-1}
20	< 0.01	7.2×10^5	FCAL	0.4	2.9×10^7
20	< 0.1	3.6×10^6	FCAL	0.08	2.9×10^7
40	< 0.1	2.1×10^5	FCAL	0.05	1.0×10^6
40	< 0.1	2.1×10^5	LUCID,ZDC	0.44	9×10^6

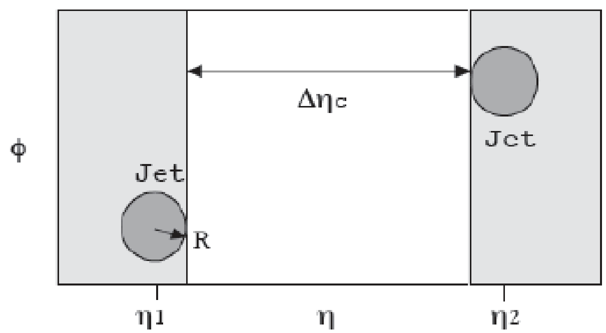
ξ < 0.1 $\Rightarrow$ O(1) TeV "Pomeron beams"
e.g. Structure of the Pomeron F(β,Q**2**)
β down to ~ 10^{-3} & Q^2 ~10^4 GeV**2**

- Approximately 5000 (8000) SD di-jet events in 100 pb^{-1} with jet transverse energy > 20 (40) GeV after trigger pre-scale.

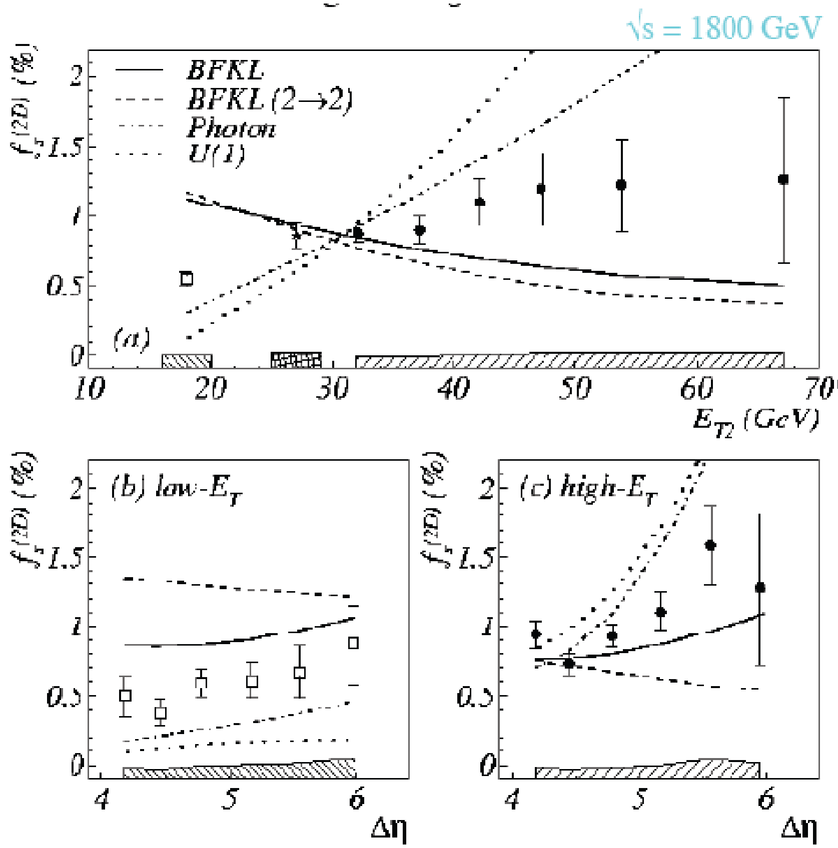
Gaps between jets

A.Pilkington, DIS08





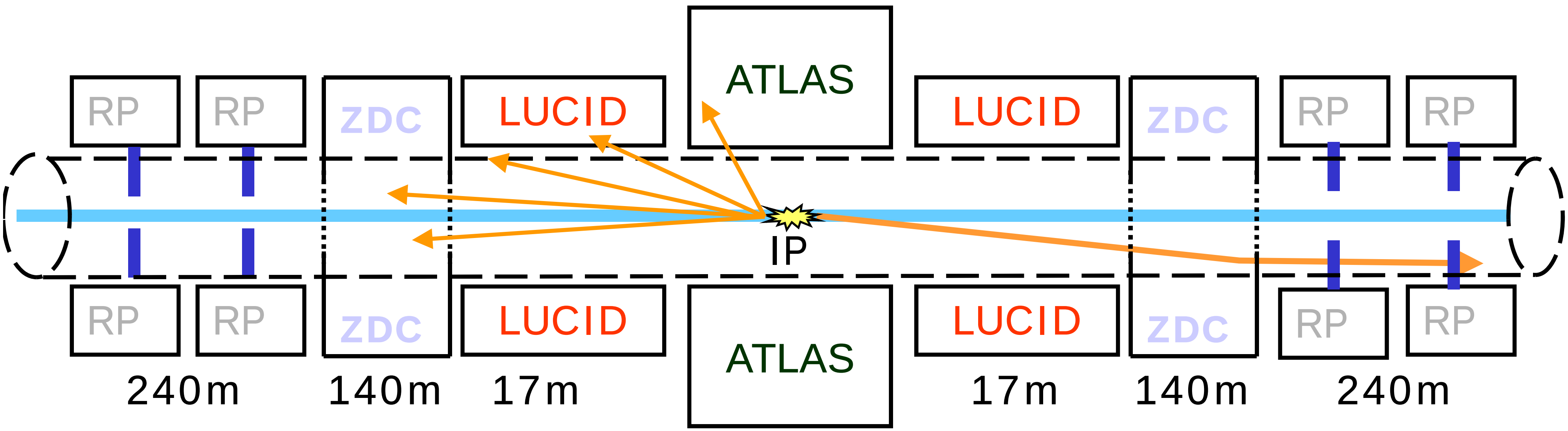
D0 data (PLB 440, 189 (1998))



- Di-jet production via colour singlet exchange (background from single gluon exchange process).
- Require two jets, one in each forward calorimeter.
- Require gap in central calorimeter.
- ATLAS can make an improved measurement with increased COM energy and available phase space.

Soft SD measurement with ALFA

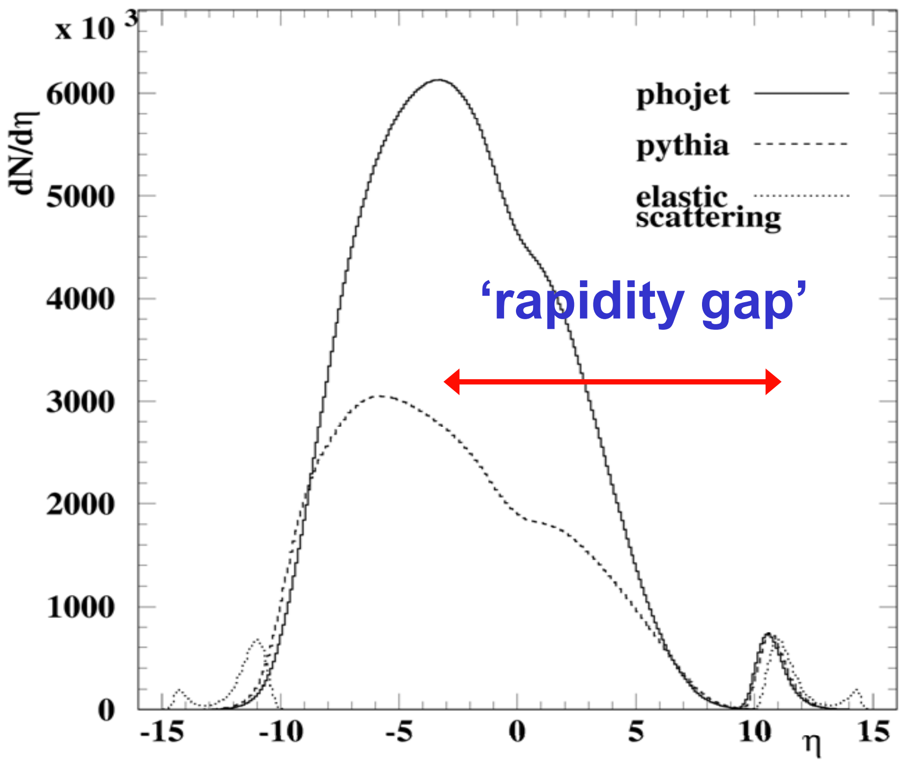
- soft single diffraction pp→X+p: motivation
  - fundamental process for which cross section and distributions should be measured
  - large model uncertainties, background to other processes
  - relevant for luminosity calibration in case the coulomb region for elastic scattering can't be reached

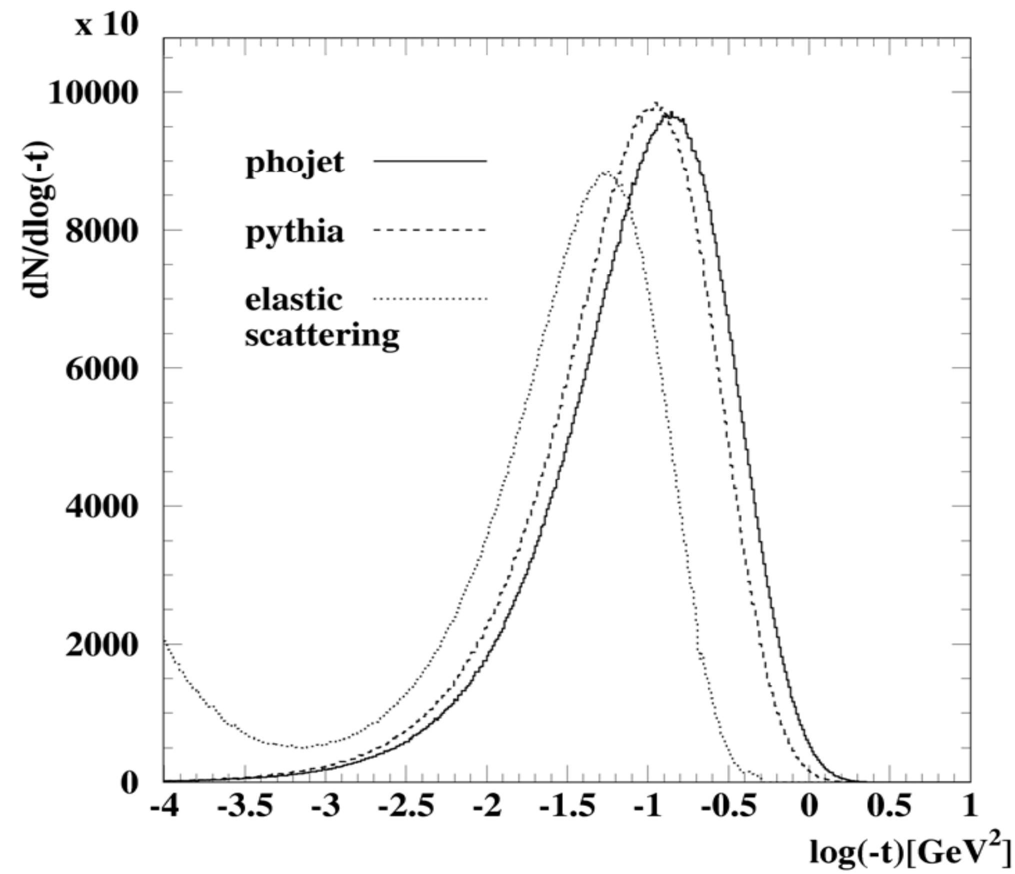


Soft SD measurement with ALFA

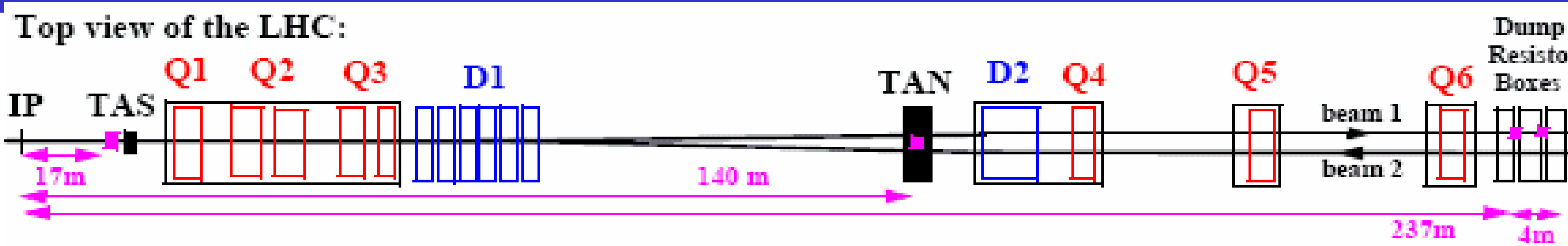
Huge differences between Pythia and Phojet:

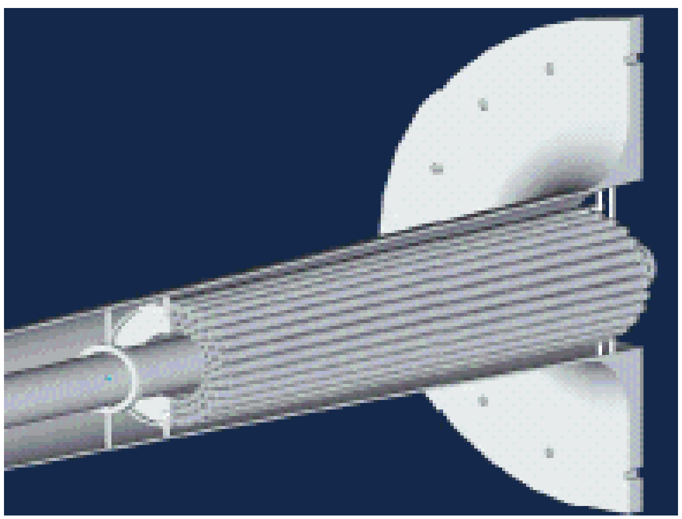
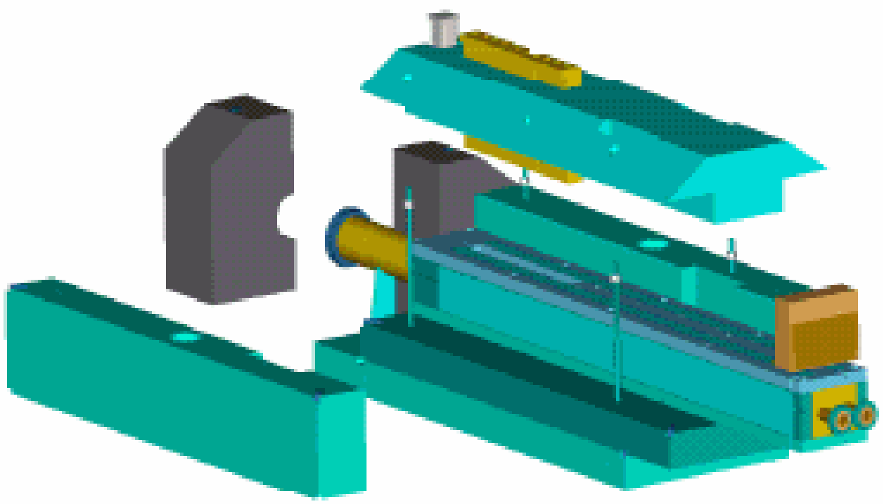
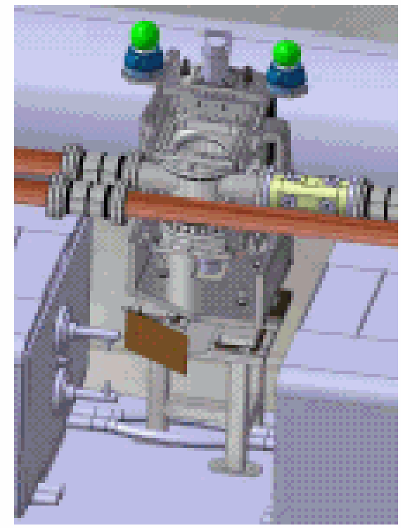
particle multiplicity and t -distribution





Forward detectors for single diffraction



LUCID	ZDC	ALFA
		
Cherenkov tubes Relative luminosity monitoring.	**Tungsten/Quartz calorimeter** Forward physics in both pp and heavy ion collisions.	**Scintillating fibres in Roman Pots** Absolute luminosity in dedicated LHC runs with
$5.4 \leq \|\eta\| \leq 6.1$ E > 2.7 GeV acceptance ≈ 80%	$\|\eta\| \geq 8.3$ E > 1 TeV n, > 60 GeV γ acceptance ≈ 90%	$10 \leq \|\eta\| \leq 14$ efficiency > 99% acceptance ≈ 67% (elastic)

Soft SD with ALFA: Trigger conditions

- For the special run, high β* optics, (~100 hrs, $L=10^{27} cm^{-2} s^{-1}$)

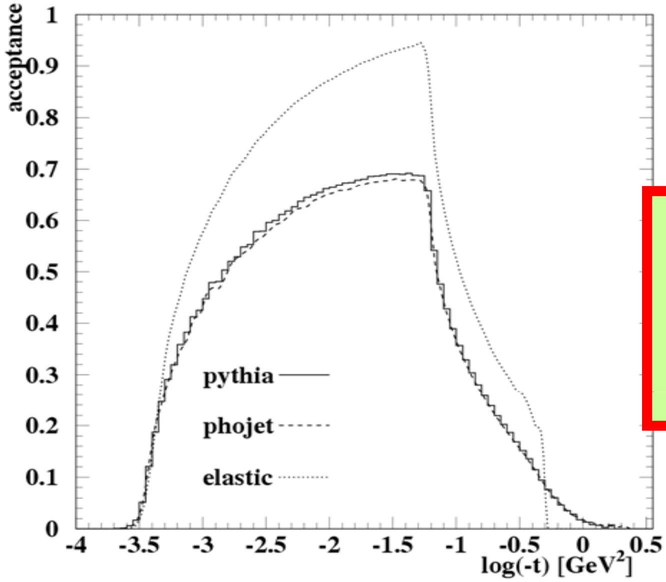
- 1. ALFA trigger
  - coincidence signal left-right arm (elastic trigger)
  - each arm must have a coincidence between 2 stations
  - rate about 30 Hz

- 2. LUCID trigger
  - coincidence left-right arm (luminosity monitoring)
  - single arm signal: one track in one tube

- 3. ZDC trigger
  - single arm signal: energy deposit > 1 TeV (neutrons)

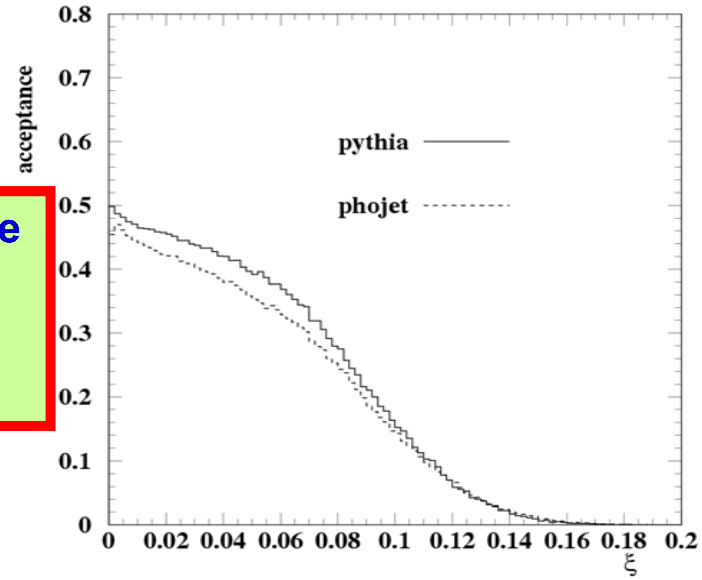
- 4. Single diffraction trigger
  - ALFA.AND.(LUCID.OR.ZDC)
  - central ATLAS detector not considered for now
  - using the MBTS would be an asset

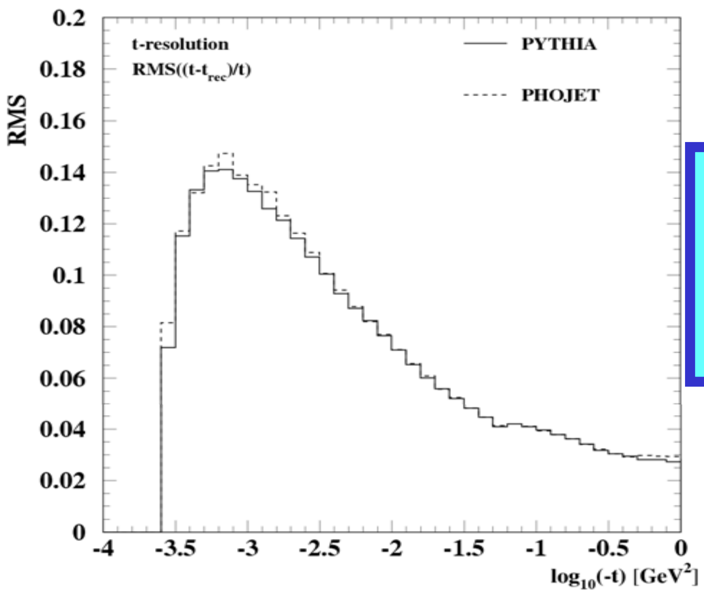
ξ- and t-acceptance and resolutions for SD with ALFA



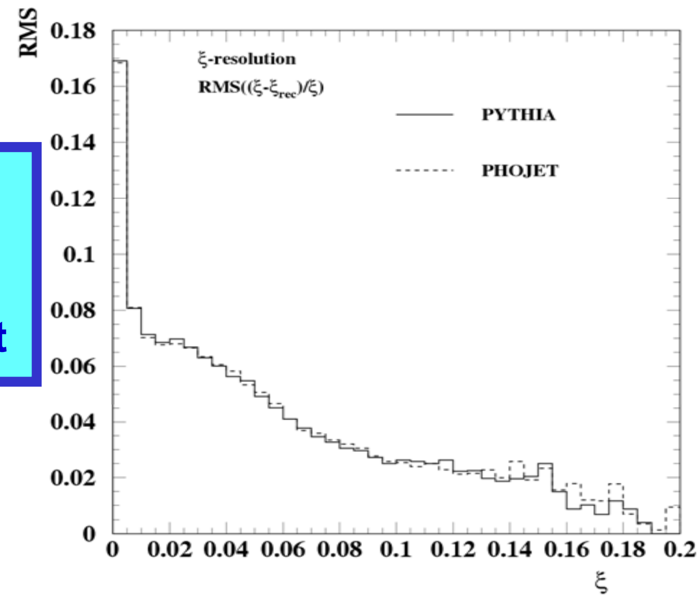
Global acceptance

Pythia 45%
Phojet 40%





Good agreement for resolutions between Pythia and Phojet



Soft SD with ALFA: Summary

Single diffraction can be measured during the special elastic calibration run provided that ALFA can be combined with LUCID/ZDC.

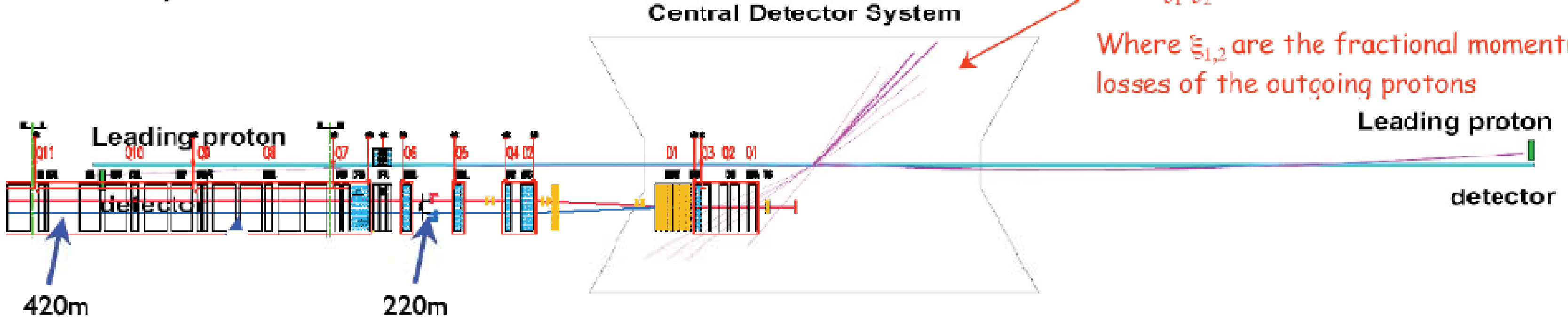
- combined analysis of forward detectors
- measurement of cross section and t-, ξ-distributions
- SD cross section measurement with ≈ 15 % syst. uncertainty ?
- improve model predictions and background estimates for central

Efficiency [%]	Pythia	Phojet
Preselection		
$\xi<0.2$	97.1	94.8
ZDC [E>1 TeV]	53.9	38.7
LUCID [1 track]	45.2	57.3
Total preselection	75	74
RP selection		
ALFA **(Relative to preselection)**	60.1	54.2
Total acceptance	45.0	40.1

Expect 1.2-1.8 M accepted events in 100 hours at $10^{27}cm^{-2}s^{-1}$

ATLAS Forward Physics Upgrade for High Lumi

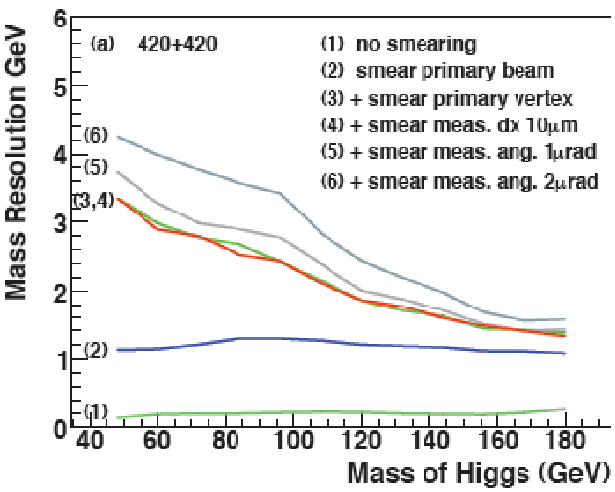
Measure forward protons from DPE/CEP.



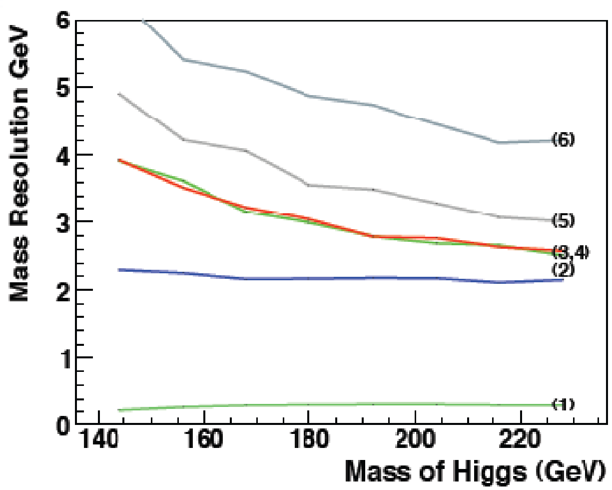
$M^2 = \xi_1 \xi_2 S$

Where $\xi_{1,2}$ are the fractional momentum losses of the outgoing protons

Very good mass resolution from forward protons

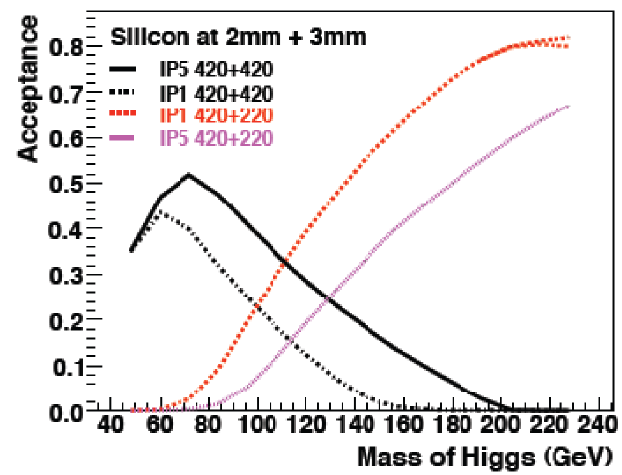


420+420

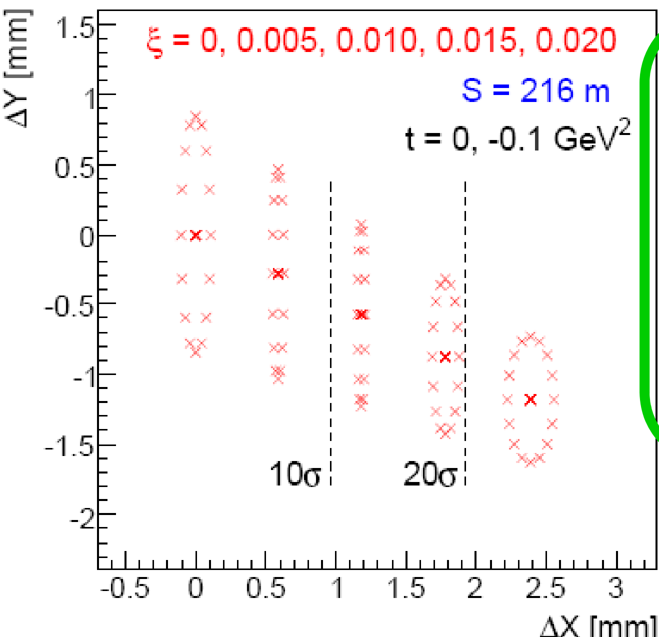


220+420

Good acceptance for combined detectors at 420m and 220m

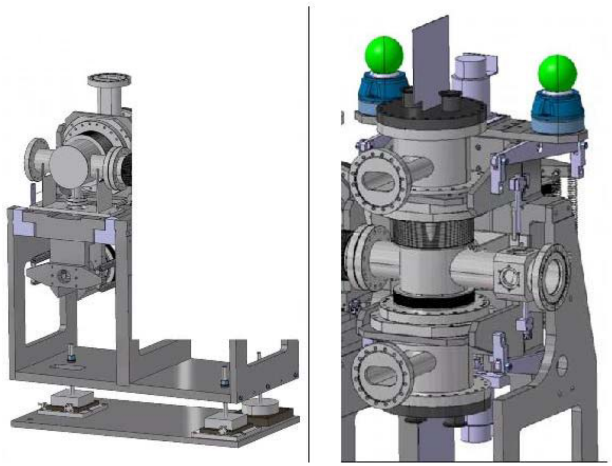


Integration into LHC structure



Roman pots at 220 m

Schematic view of 220 m pots: keep horizontal pots only from the TOTEM pots

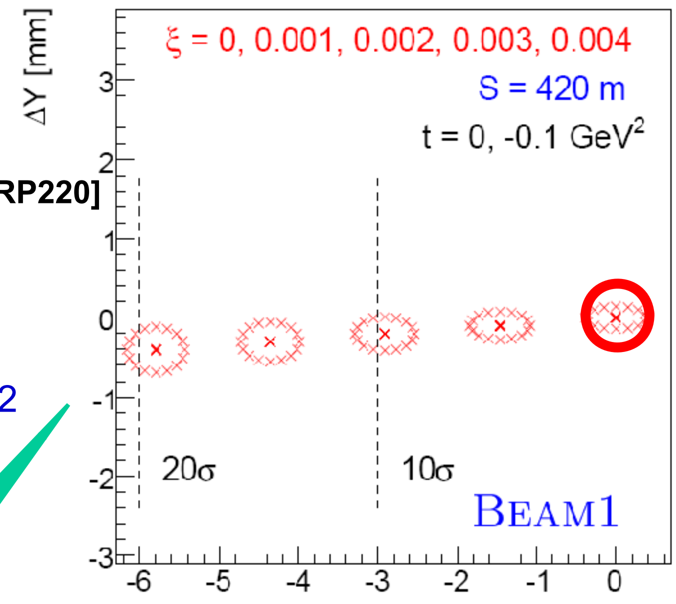


Diffraction protons deflected horizontally and away from the ring

Only horizontal pots from outside needed!

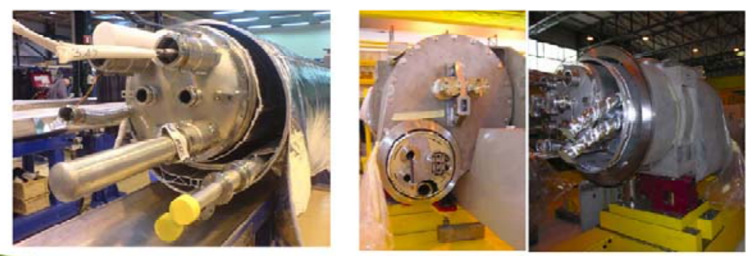
[A.Kupčo, RP220]

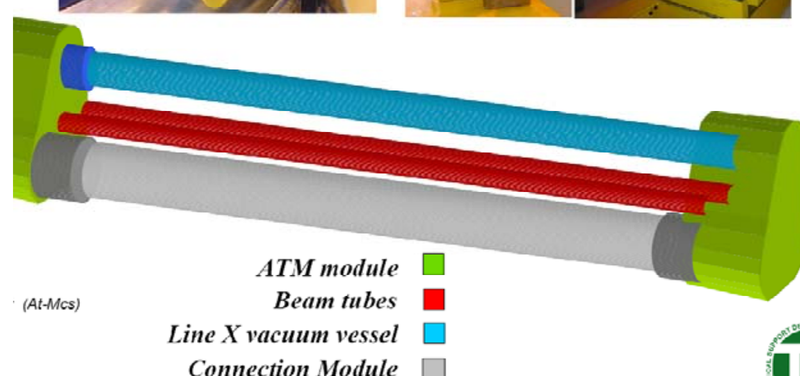
BEAM 2



Diffraction p's deflected horizontally but inside the ring

FP420 Connection Cryostat





Physics with Forward Proton Tagging at High Lumi

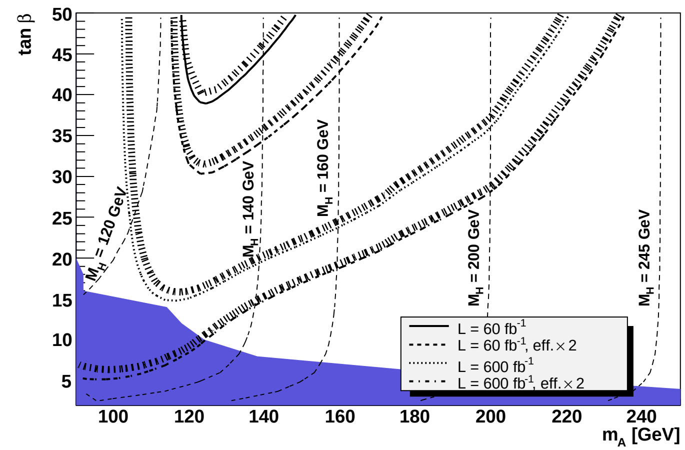
CED Higgs production (Higgs mass, quantum numbers, discovery in certain regions of MSSM/NMSSM):

SM $h \rightarrow WW^*$, $140 < M_h < 180$ GeV

MSSM $h \rightarrow bb$, $h \rightarrow$ tautau for $90 < M_h < 140$ GeV

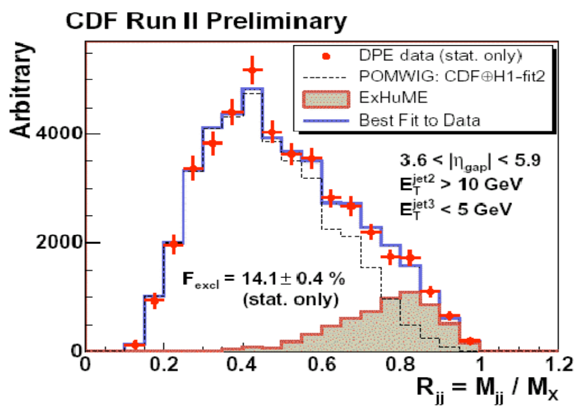
MSSM $H \rightarrow bb$ ($90 < M_h < 300$), $H \rightarrow \tau\tau$ ($90 < M_h < 160$)

NMSSM $h \rightarrow aa \rightarrow \tau\tau\tau\tau$ for $90 < M_h < 110$ GeV

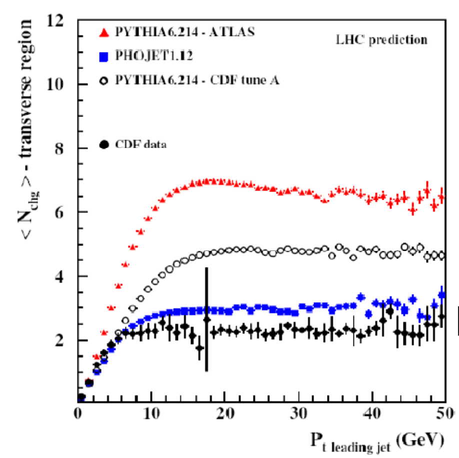


[EPJC 53 (2008) 231]

CED dijets: a la CDF



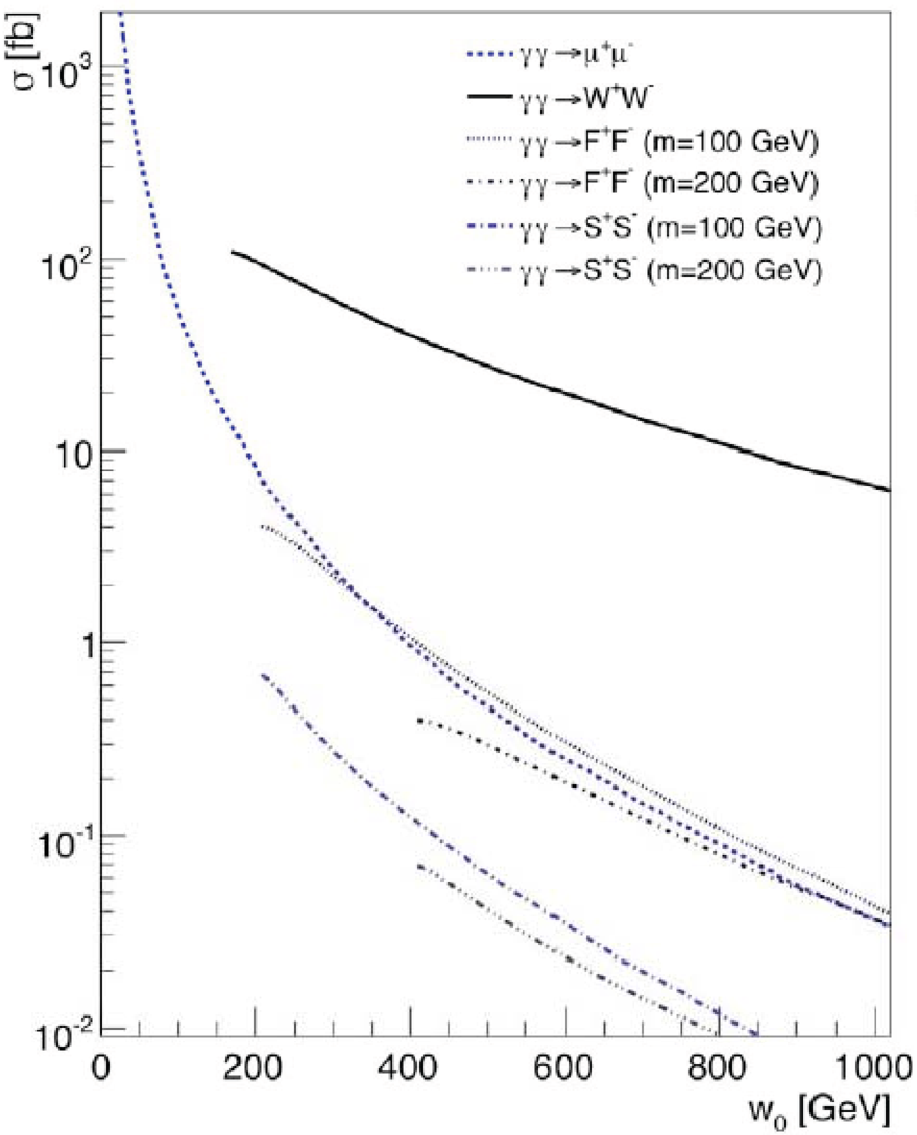
- **Gamma-proton**
- **Gamma-Gamma**
- **SD, DD**
- **Gap survival / Underlying event**
- **Study of gluon jets**

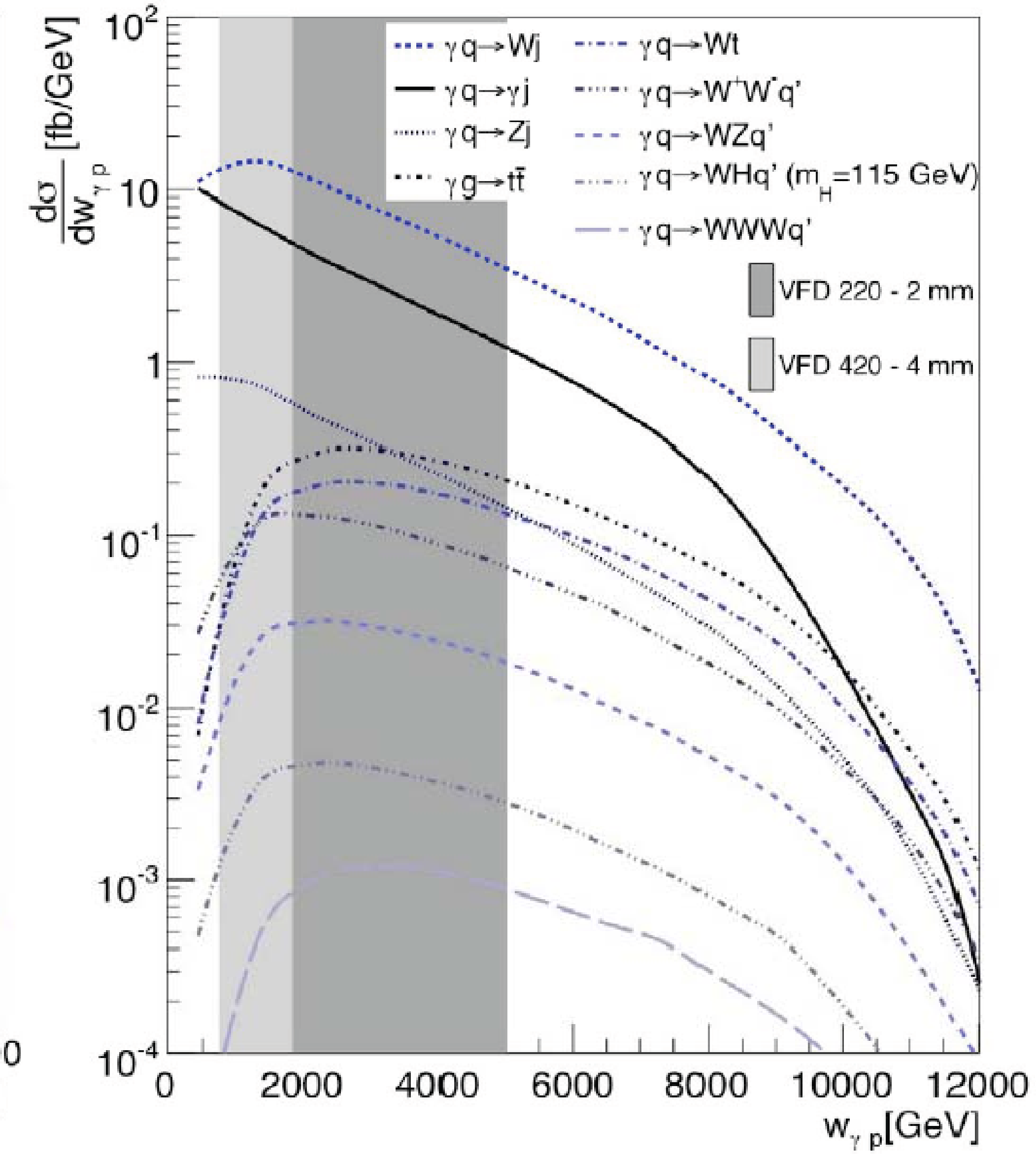


Average mult. transv. to leading jet

[C.Buttar et al., HERA-LHC proc.]

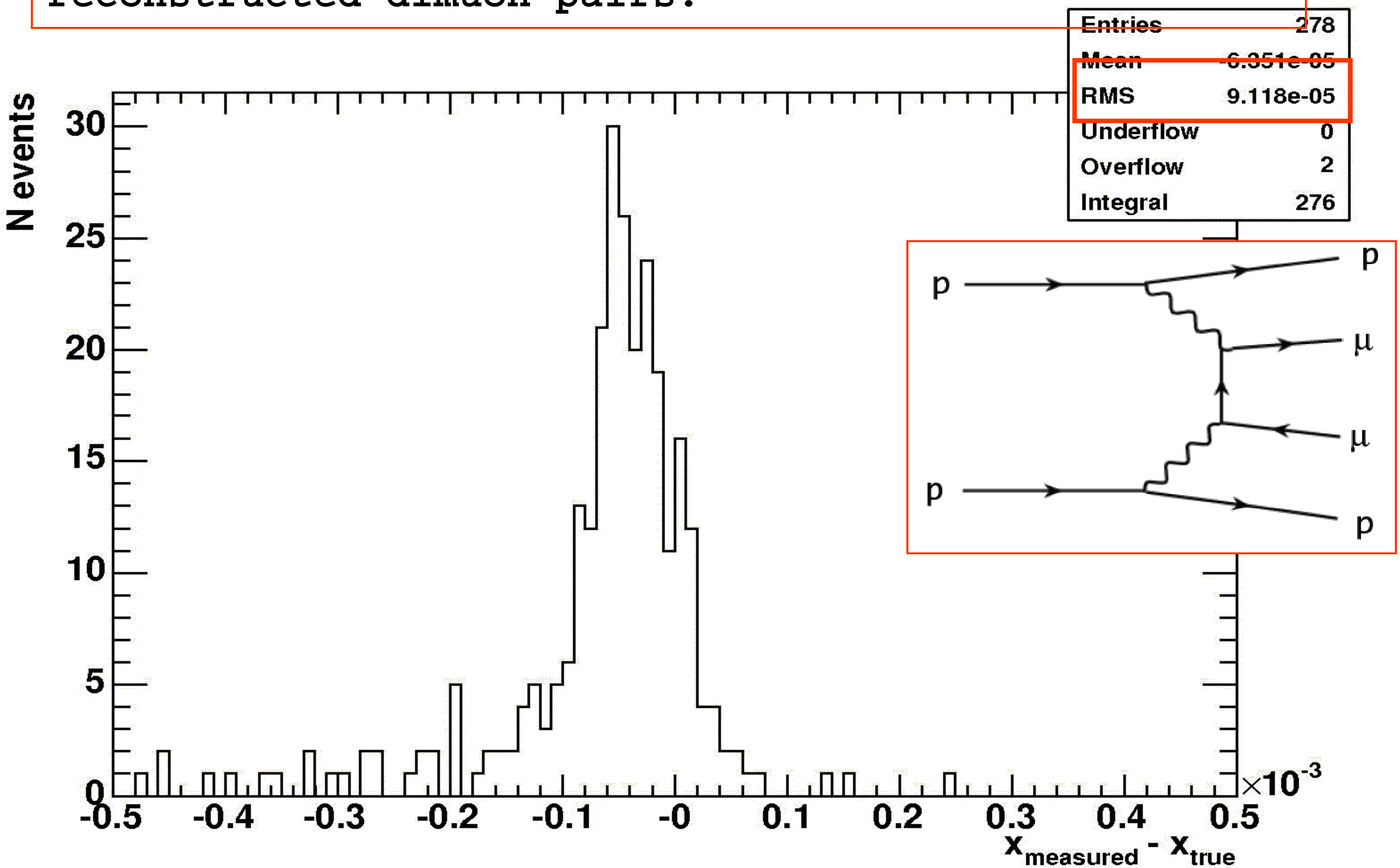
Rich γp and pp physics via forward proton tagging





γγ→μμ excellent tool for FP420 calibration

Resolution of the proton energy loss for the reconstructed dimuon pairs:



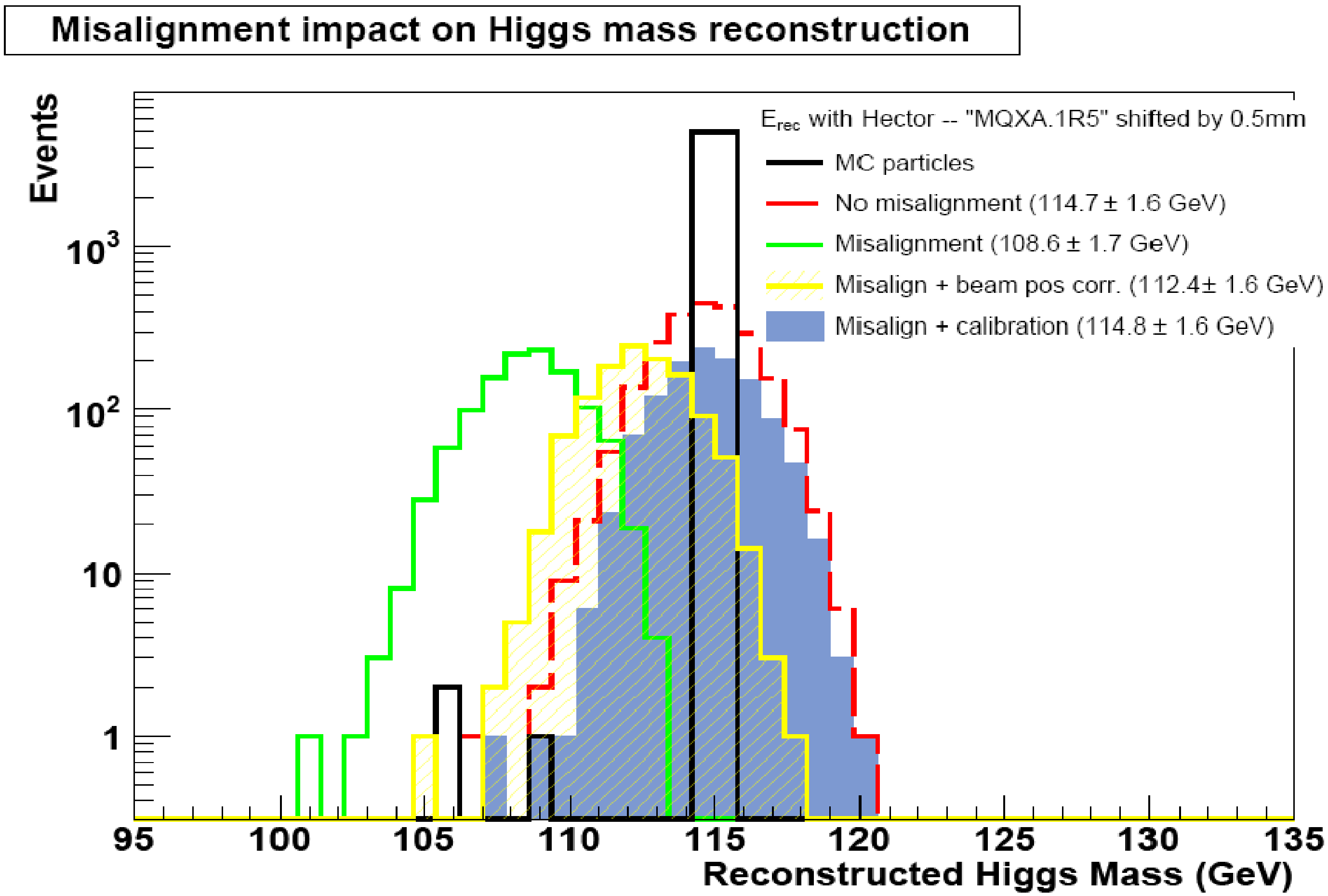


Figure 20: Illustration of the effects in the energy reconstruction due to the misalignment of LHC quadrupoles. The graphs show the reconstructed Higgs boson mass in the two-photon exclusive production, using energy of two forward scattered protons. In the upper plot, a quadrupole (MQM9R5, $s = 347$ m) close to the detector has been shifted by 100 μm. Misaligning an optical element (MQXA1R5, $s = 29$ m) close to the IP leads to a loss of acceptance (lower plot). The reconstructed values including the correction due to the dimuon calibration is also plotted. In brackets, the average reconstructed mass and its resolution are given, without including the beam energy dispersion.

Exclusive Υ production as a probe of f_g

V.Khoze, DIS08

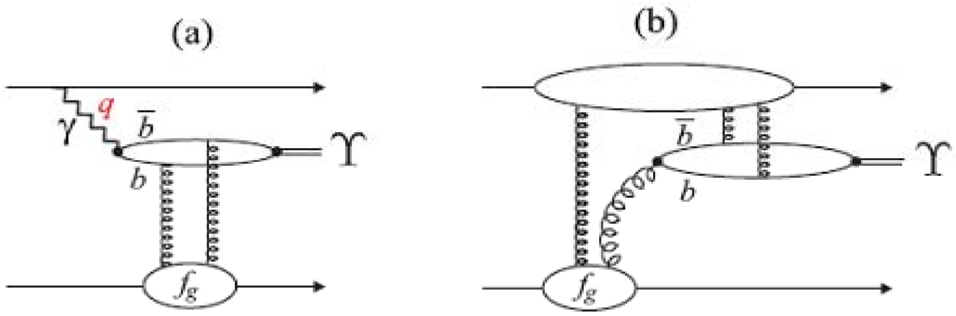


Figure 6: Exclusive Υ production via (a) photon exchange, and (b) via odderon exchange.

$$d\sigma / dy(pp \to p + \Upsilon + p) \sim 50\, pb$$

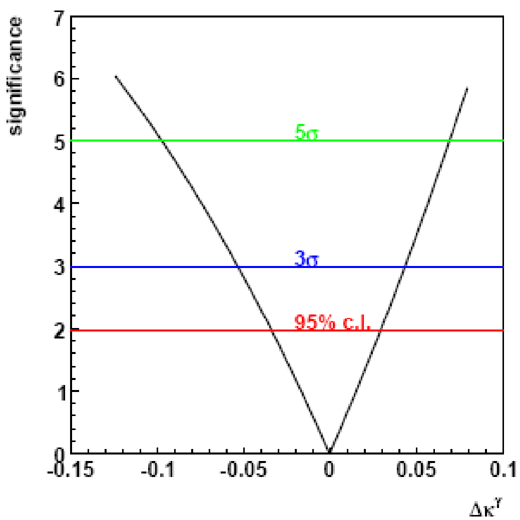
The cross section for γ +p→Y +p is given in terms of the same generalized gluon distribution fg that occurs in the CED Higgs production.

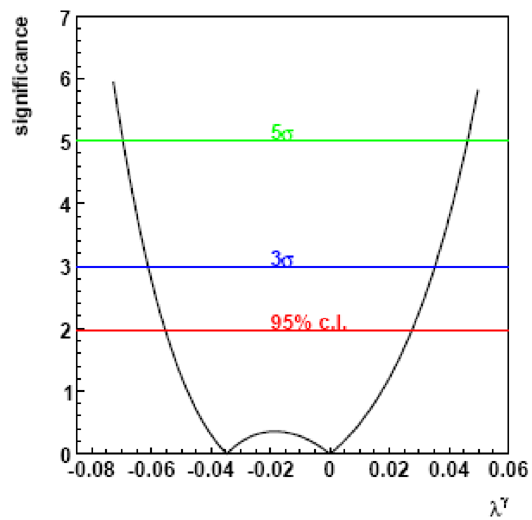
The odderon contribution (if it exists) can be separated and measured.

Tagging the lower proton will be very useful.

Anomalous WWγ

- anomalous $WW\gamma$ changes the SM expectation
- effective Lagrangian can be parameterized with 2 CP-even parameters $\Delta\kappa^\gamma, \lambda^\gamma$ (SM values 0)
- SM cross section $\sigma = 86\,\text{fb}$, without acceptance
  - 0.9 survival probability factor applied





- limits for $\mathcal{L} = 30\,\text{fb}^{-1}$
- $0.0015 < \xi < 0.15$
- 840 SM signal events

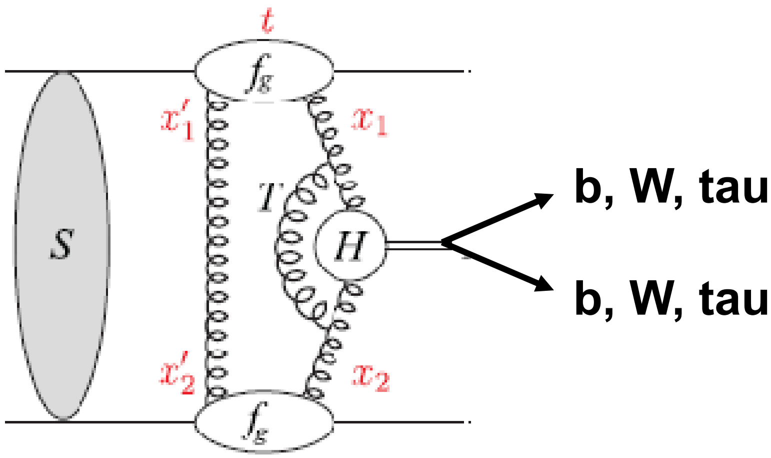
$-0.035 < \Delta\kappa^\gamma < 0.030 \qquad -0.054 < \lambda^\gamma < 0.028$

- current best limits (95% c.l.) from Tevatron - non-diffractive channel $W\gamma$

$-0.51 < \Delta\kappa^\gamma < 0.52 \qquad -0.12 < \lambda^\gamma < 0.13$

- improvement by factor 15 and by 2-5 for $\Delta\kappa^\gamma$ and λ^γ, respectively

Central Exclusive Diffraction: Higgs production



1) Protons remain undestroyed and can be detected in forward detectors

2) Rapidity gaps between leading protons and Higgs decay products

Advantages:

I) Roman Pots give much better mass resolution than central detector

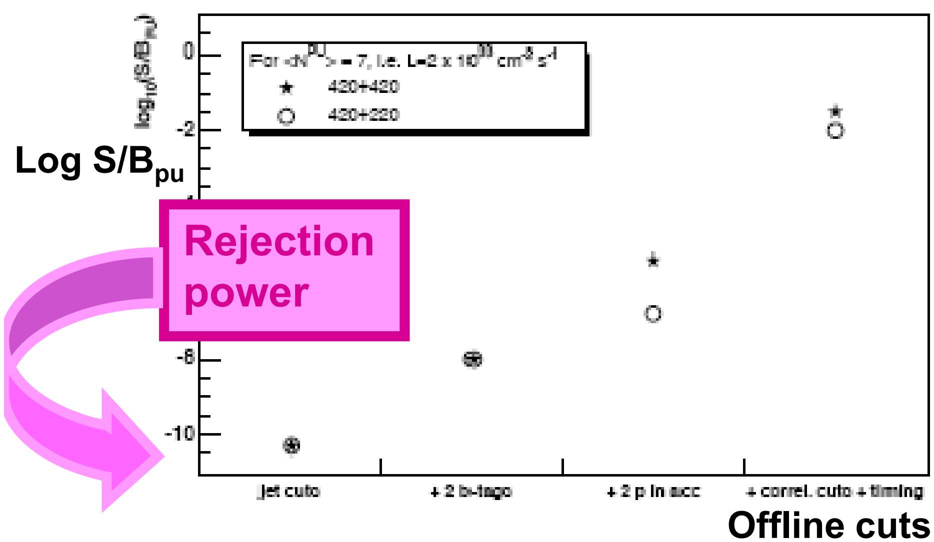
II) $J_Z = 0$, CP-even selection rule:

- strong suppression of QCD bg
- produced central system is 0^{++}

III) Access to main Higgs decay modes: bb, WW, tautau → information about Yukawa coupling

Pile-up is issue for Diffraction at LHC!

[CMS-Totem : Prospects for Diffractive and Fwd physics at LHC]



But can be kept under control !

Disadvantages: Large Pile-up + Irreducible BG, Low signal x-section

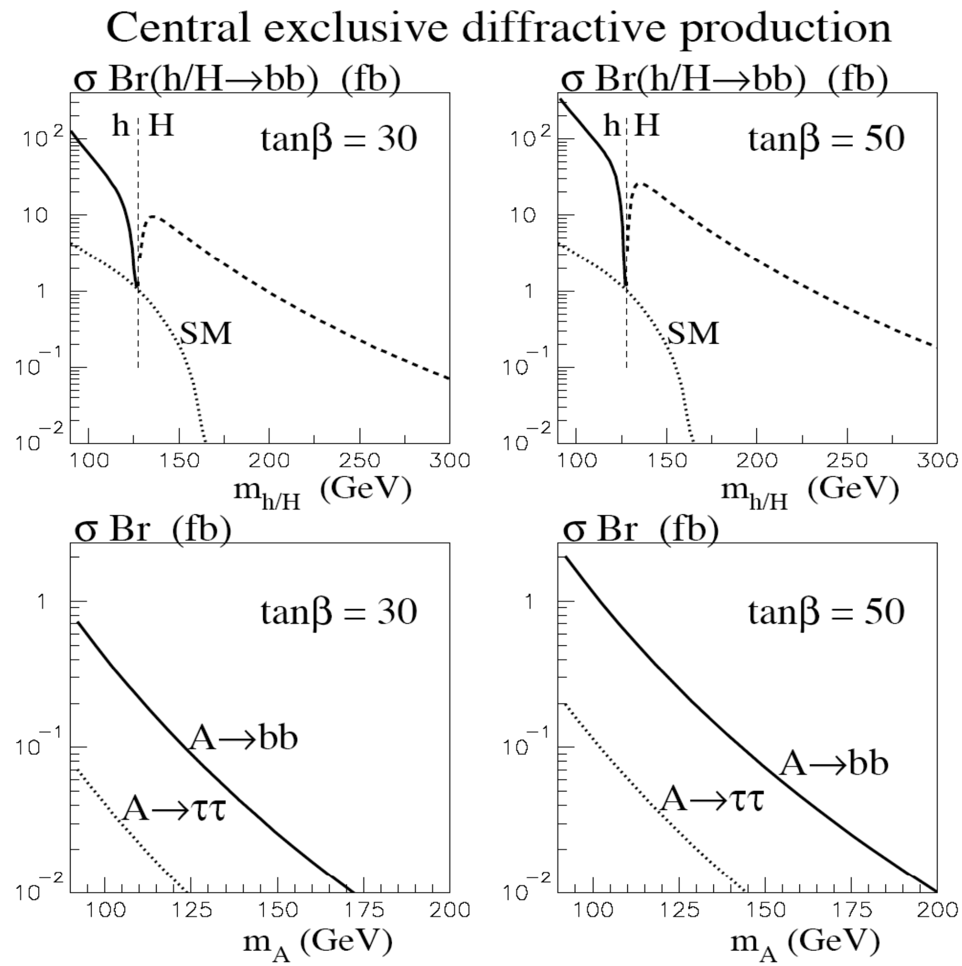
SM Higgs discovery challenging: low signal yield ⟶ try MSSM

MSSM and CED go quite well together

SM: Higgs discovery challenging

MSSM:
1) higher x-sections than in SM in certain scenarios and certain phase-space regions
2) the same BG as in SM

MSSM: Possibility to measure total Higgs width (high tanβ) and to distinguish between nearly degenerate Higgs states
[J. Ellis, J-S. Lee, A. Pilaftsis, ’05]

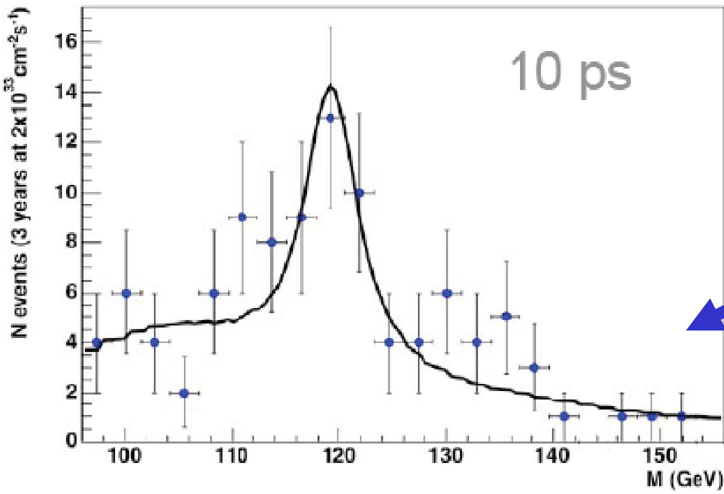


Well known difficult region for conventional channels, tagged proton channel may well be the *discovery channel* and is certainly a powerful *spin/parity filter*

CED H→bb using Forward Proton Tagging

h→bb, mhmax scenario, standard ATLAS L1 triggers, 420m only, 5 mm from beam

Huge Pile-up bg for diffractive processes: overlap of three events (2* SD + non-diffr. Dijets). Can be reduced by Fast Timing detectors: t-resol. required: 2 ps for high lumi!



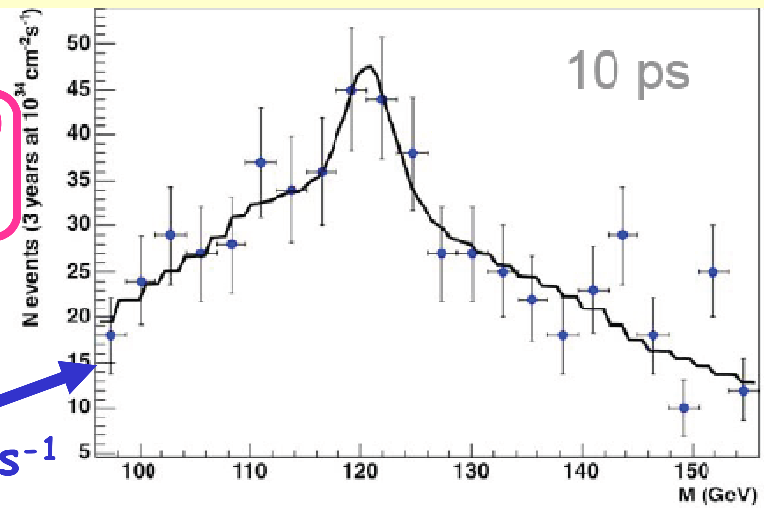
JHEP 0710:090,2007

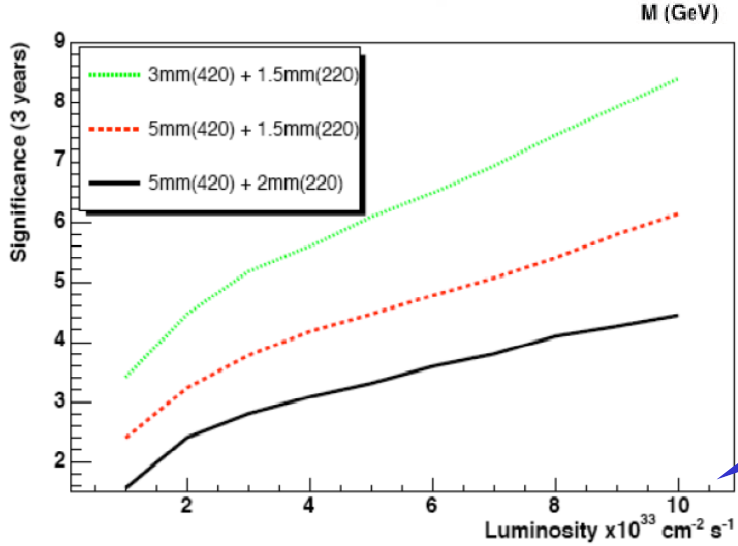
m_A=120 GeV, tanβ=40

$\sigma_{h\to bb}$=17.9 fb

3 years at $2\times10^{33}cm^{-2}s^{-1}$

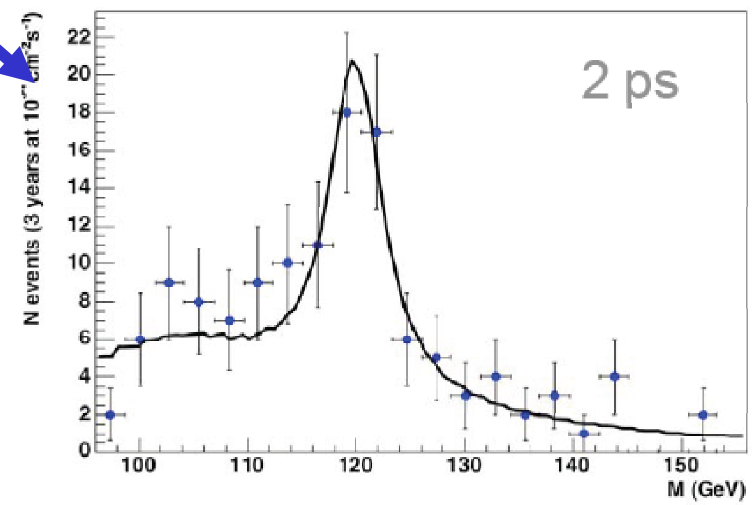
3 yrs at $10^{34}cm^{-2}s^{-1}$





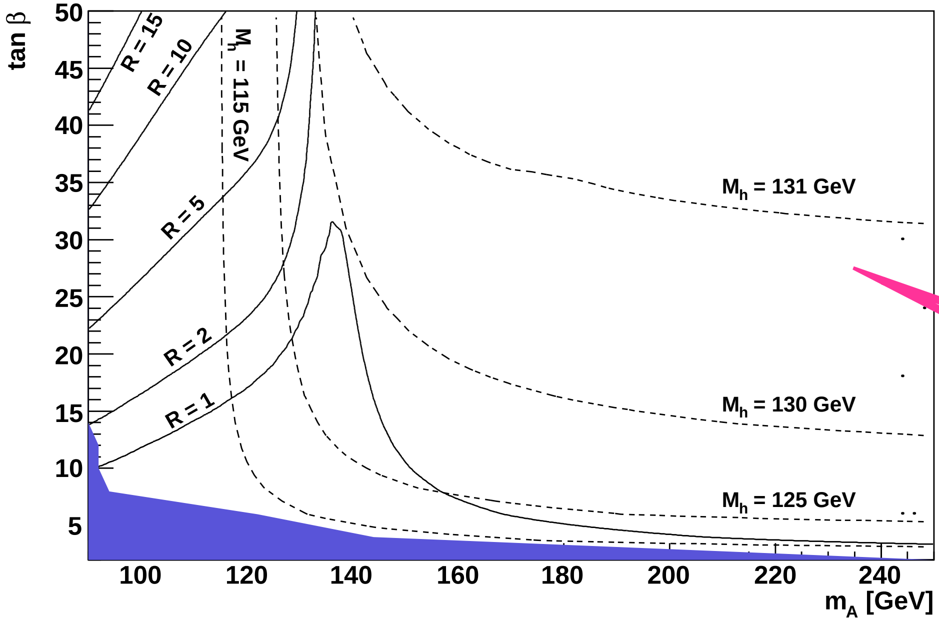
Assume 220m Pots at L1

High signific. for detectors close to beams



CED H→bb using Forward Proton Tagging

The same results found by CMS/Totem

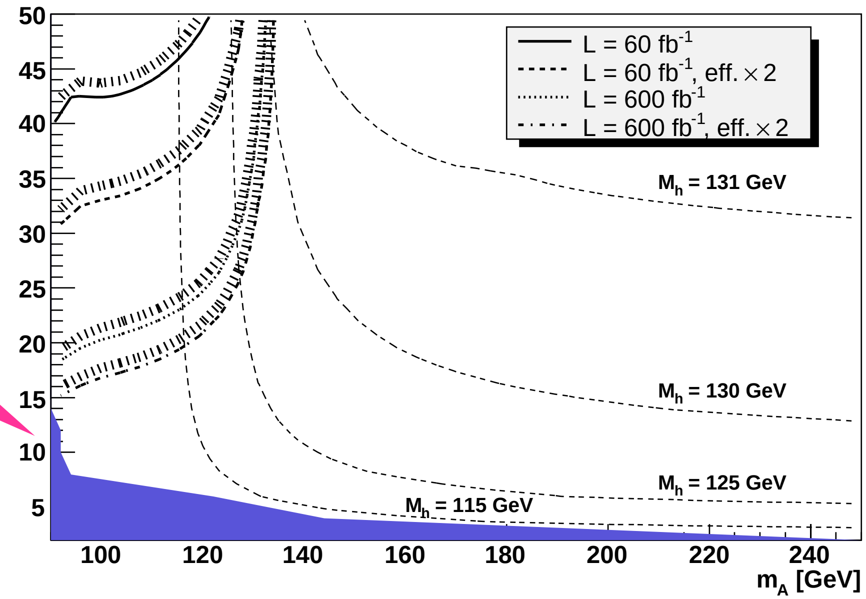


H→bb, mhmax scenario, μ=200 GeV

EPJC 53 (2008) 231, CMS/Totem Note CERN-LHC 2006-039/G-124

Ratio MSSM/SM

5σ significance contours for 4 lumi scenarios
CMS-Totem: 420+420, 420+220
220m RP at L1



Level 1 Trigger for CED

FP420: cannot be put directly into L1 – only in special runs with larger L1 latency

available triggers: 2j, μ (L1 threshold for 2μ is 3 GeV), e, j+lepton

- μ-triggers can save up to 20% of bb signal
- WW signal saved by lepton triggers

Luminosity ($\times 10^{33}$)	Non-diffractive reduction by FP420 without QUARTIC	with QUARTIC
1	2.7×10^{-4}	6.8×10^{-6}
3	5.8×10^{-3}	1.5×10^{-4}
5	1.8×10^{-2}	4.6×10^{-4}
10	8.1×10^{-2}	2×10^{-3}

[A.Pilkington, FP420]

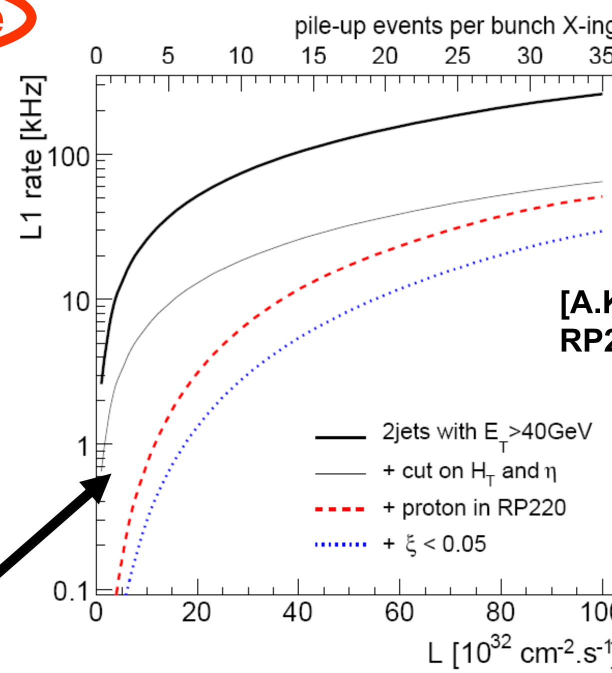
RP220: Can be put into L1: A BIG added value to FP420! Very similar trigger rates as for foreseen CMS-TOTEM L1 trigger:

CMS-TOTEM L1 trigger STUDY

E_T^{jet} > 40 && RP220-1side

Luminosity [$cm^{-2}s^{-1}$]	# Pile-up events per bunch crossing	L1 2-jet rate [kHz] for $E_T > 40$GeV per jet	Total reduction needed	Reduction when requiring track in RP detect: at 220 m	at 220 m, $\xi < 0.1$	at 420 m	at 220 m & 420 (asymmetric)	at 220 m & 420 (asymmetric), $\xi < 0.1$
1×10^{32}	0	2.6	2	370				
1×10^{33}	3.5	26	20	7	15	27	160	380
2×10^{33}	7	52	40	4	10	14	80	190
5×10^{33}	17.5	130	100	3	5	6	32	75
1×10^{34}	35	260	200	2	3	4	17	39

RP220 L1 trigger study



[A.Kupčo, RP220]

Total reduction: 10 (RP) x 2 (jet isol) x 2 (2 jets same hemisph as p) = 40

[M.Grothe et al., CMS Note 2006-054]

Trigger strategies

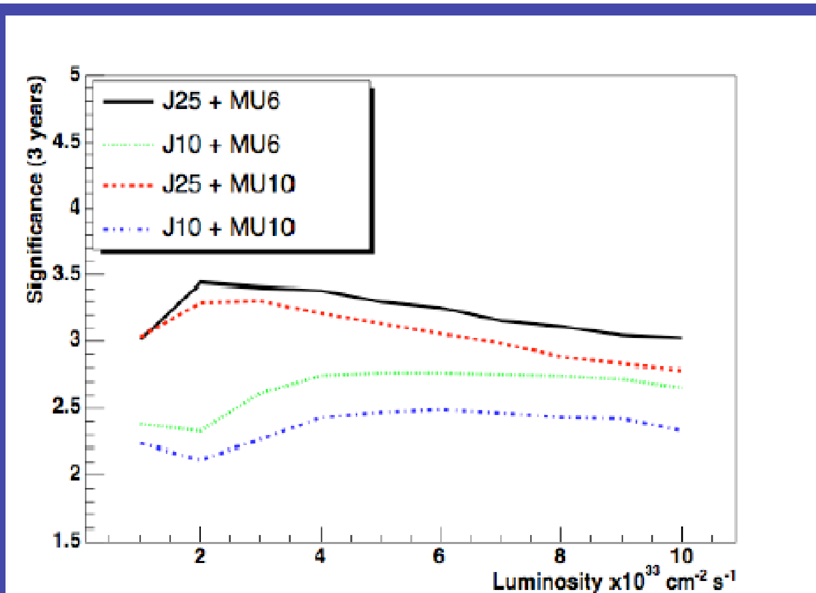
- 420m detectors too far away to be included in level 1, but information can be used at level 2 to substantially reduce the non-diffractive background by requiring two proton hits plus vertex matching from time-of-flight.

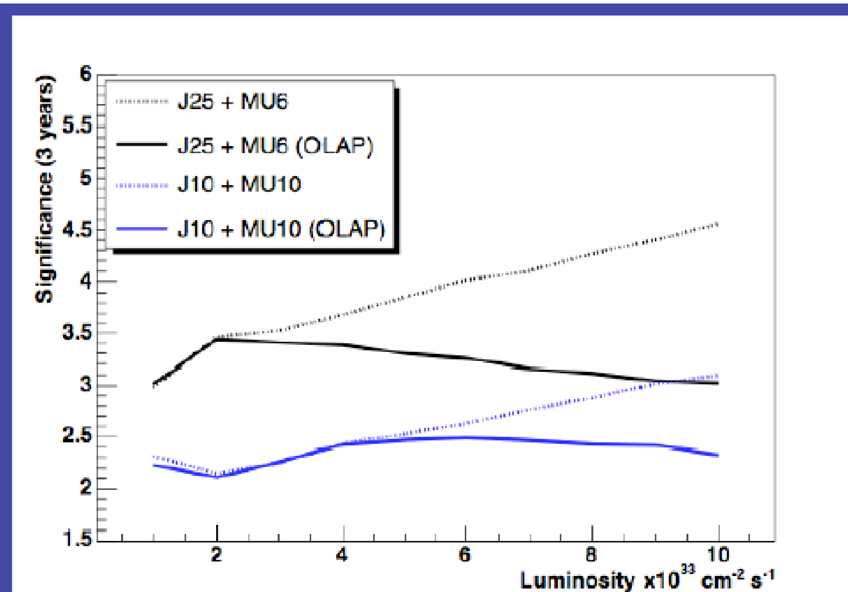
- Two triggers:
  - Low transverse momentum muon in conjunction with a 40 GeV jet (jet requirement to reduce rate at high luminosity). Notation MU6 = muon with $p_T > 6$ GeV.

  - Fixed L1 jet rate (pre-scaled if necessary) for jets that satisfy $E_T > 40$ GeV. Notation J10 = 10kHz rate at level 1.

- Efficiencies:
  - MU6 approximately 11%. MU10 approximately 6%.
  - J10 is 40% efficient at $L=10^{33}cm^{-2}s^{-1}$ and 4% efficient at $L=10^{34}cm^{-2}s^{-1}$.
  - J25 is 100% efficient at $L=10^{33}cm^{-2}s^{-1}$ and 10% efficient at $L=10^{34}cm^{-2}s^{-1}$.

Significance for CED h→bb for 420+420





Summary

Low Luminosity:

- Elastic and σ_{tot} using ALFA
- Start with ratios X+gaps/X(incl), X=W,Z,jj,μμ …. Get S^2
- Soft Diffraction using ALFA
- SD dijet and W production, dijets in DPE and CED
- Gaps between jets as a probe of color singlet exchange
- Exclusive dimuon production in γγ collisions tagged with forward rapgaps
- Photon-induced processes useful for checks of CED predictions

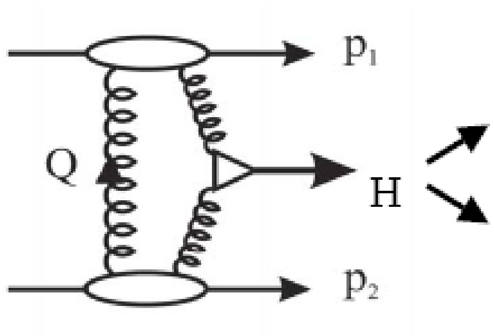
High Luminosity Upgrade:

Possible upgrade to install forward proton taggers at 220 and 420 m from IP

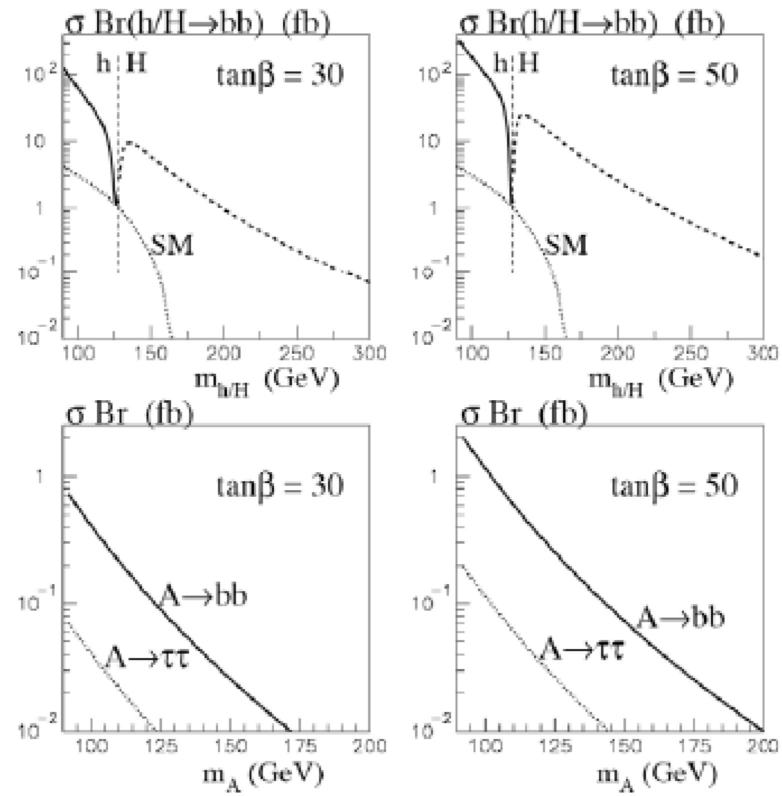
- Provides a good mass measurement of new physics
- $pp \to p+(\gamma\gamma \to \mu\mu)+p$ as excellent tool for absolute calibration of FP420
- $p\gamma \to \Upsilon p$ will help to calibrate and align forward taggers

B A C K U P   S L I D E S

Prime Motivation : Higgs Production



Central exclusive diffractive production



0^{++} Selection rule

QCD Background ~ $\frac{m_b^2}{E_T^2}\,\frac{\alpha_S^2}{M_{b\bar{b}}^2 E_T^2}$

Higgs Quantum Numbers / mass resolution

WW* : M_H = 120 GeV σ = 0.4 fb

M_H = 140 GeV σ = 1 fb

M_H = 200 GeV σ = 0.5 fb

M_H = 140 GeV : 5 (10) signal (1 (2) "gold platted" dl), very small backgrounds in 30 fb^{-1}

B.E. Cox. et al, Eur. Phys. J. C 45, 401-407 (2006)

M_A = 130 GeV, tan β = 50

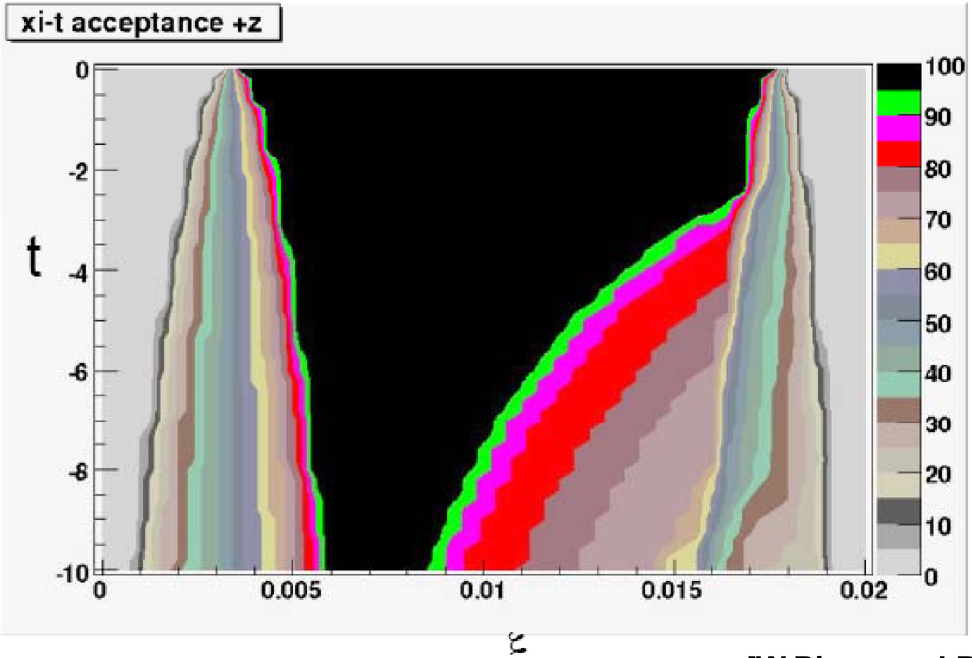
M_h = 124 GeV : 71 signal in 30 fb^{-1}

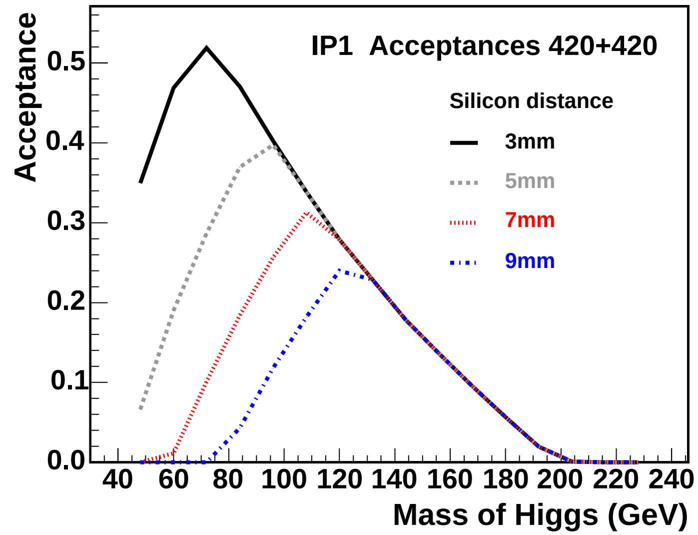
M_H = 135 GeV : 124 signal in 30 fb^{-1}

M_A = 130 GeV : 1 signal in 30 fb^{-1}

A. B. Kaidalov. et al, Eur.Phys.J. C33 (2004) 261-271

Acceptance for RP220 and FP420 at ATLAS





[W.Plano and P.Bussey, FP420]