Forward Physics

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Contents

- Introduction to forward physics
- Forward regions of present LHC detectors
- Physics topics

"Classical forward physics"

  - Total and elastic cross sections cross section
  - Diffractive scattering (general)

"New forward physics"

  - Hard diffractive scattering (HERA/Tevatron/LHC)
  - Exclusive production of the Higgs
    - Including detector upgrades needed (FP420)
  - Low-x QCD
  - Cosmic rays connections
  - (2-photon interactions)

LECTURE 1

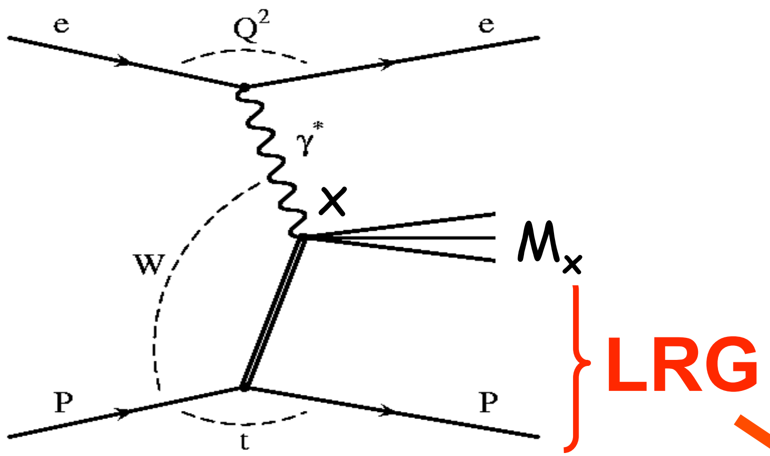
LECTURE 2

Borrowed slides from M. Albrow, D Enterria…

Lecture 2

- Hard diffractive scattering
- Exclusive processes, eg Higgs
- Low-x QCD measurements
- Cosmic ray connection

Diffractive Deep Inelastic Scattering



Q^2 = virtuality of photon =

= (4-momentum exchanged at e vertex)^2

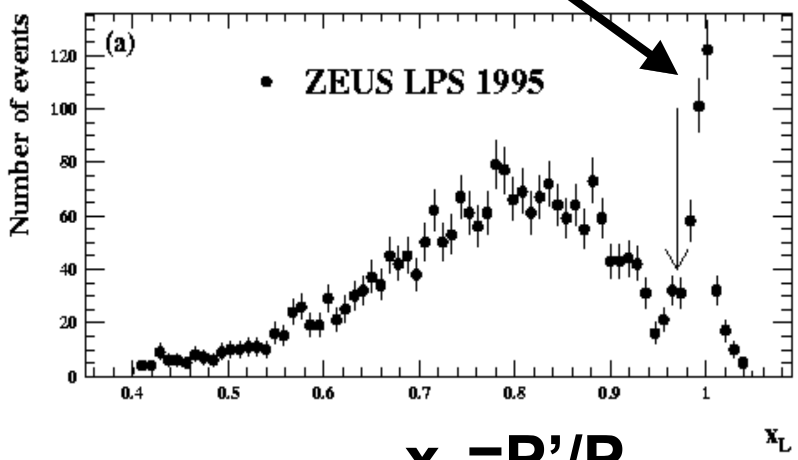
x = momentum fraction of parton in proton

t = (4-momentum exchanged at p vertex)^2

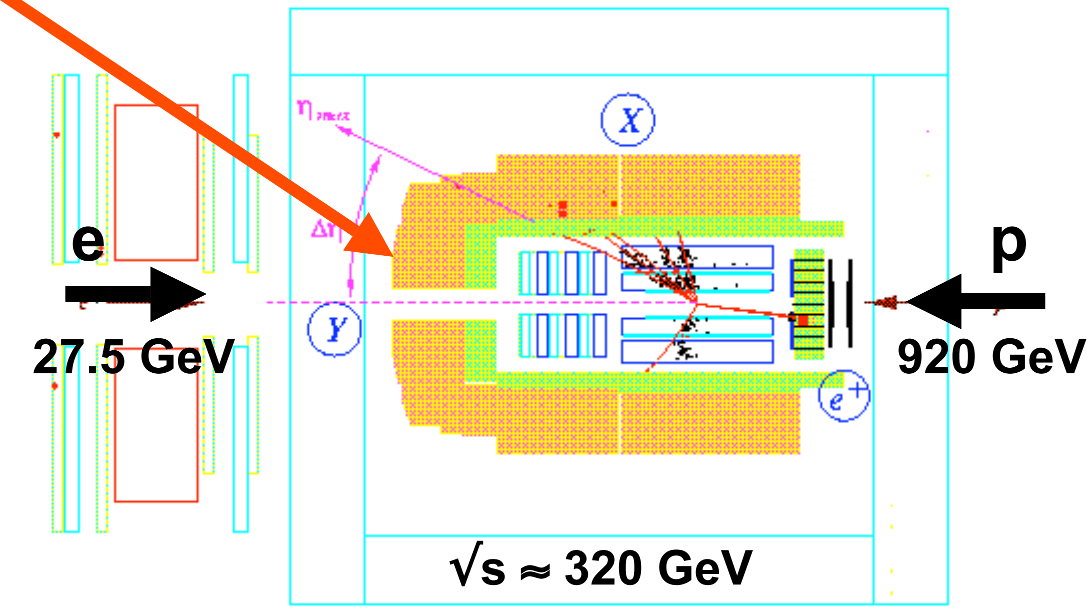
W = invariant mass of photon-proton system

M_X= invariant mass of photon-Pomeron system

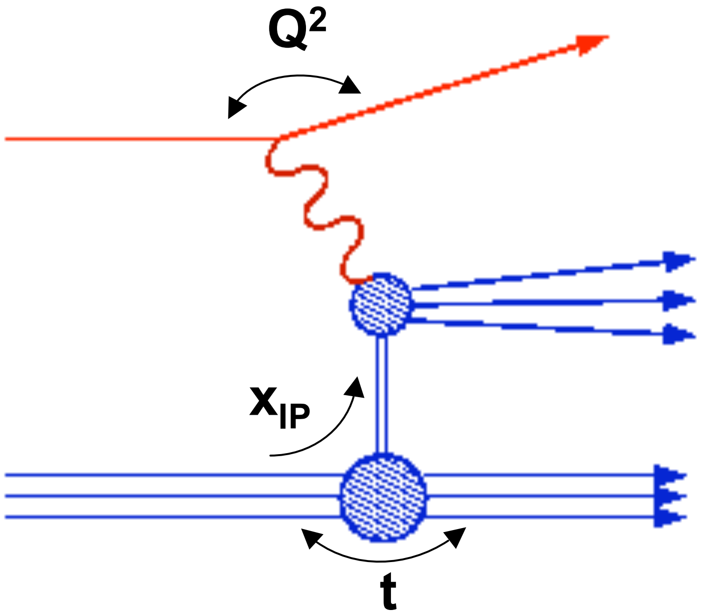
Diffractive peak



$x_L = P'/P_{beam}$



Diffractive Deep Inelastic Scattering



x_{IP} = fraction of proton's momentum taken by Pomeron

β = Bjorken's variable for the Pomeron
= fraction of Pomeron's momentum carried by struck quark
= x/x_{IP}

$$\frac{d^4\sigma}{d\beta dQ^2 dx_{IP} dt} = \frac{4\pi\alpha^2}{\beta Q^4}\left\{1 - y + \frac{y^2}{2(1+\underline{R^{D(4)}})}\right\}\underline{F_2^{D(4)}(\beta, Q^2, x_{IP}, t)}$$

if these were particles: $F_2^{D(4)} \approx f_{IP}(x_{IP}, t)\, F_2^{POM}(\beta, Q^2)$

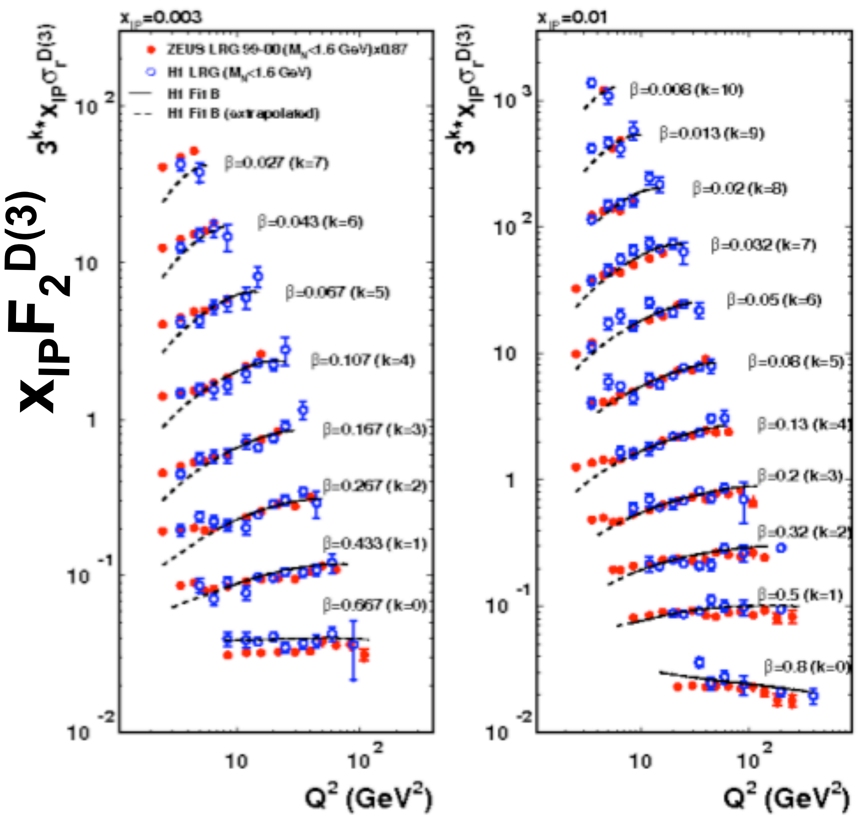
Flux of Pomerons

"Pomeron structure function"

Diffractive Structure Function versus Q^2

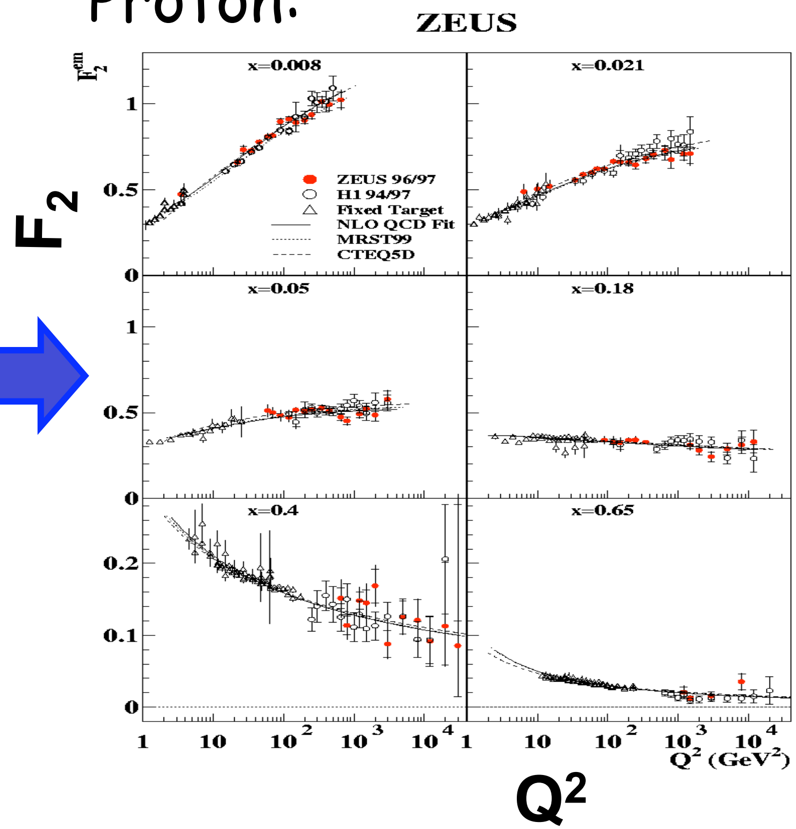
Diffractive exchange (Pomeron):

$\sigma_r^{D(3)}$ at x_{IP}=0.003 and 0.01



Q^2

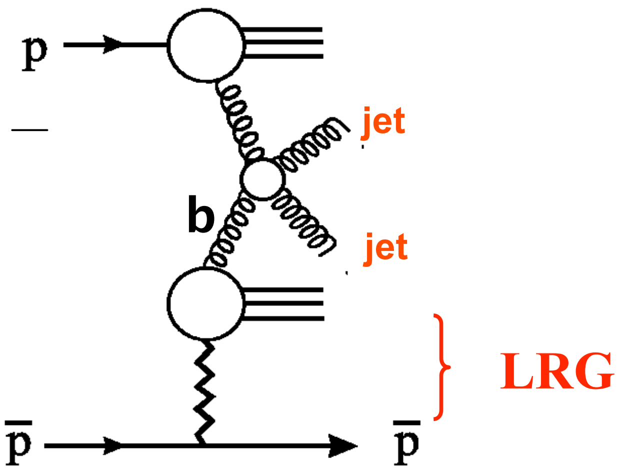
Proton:

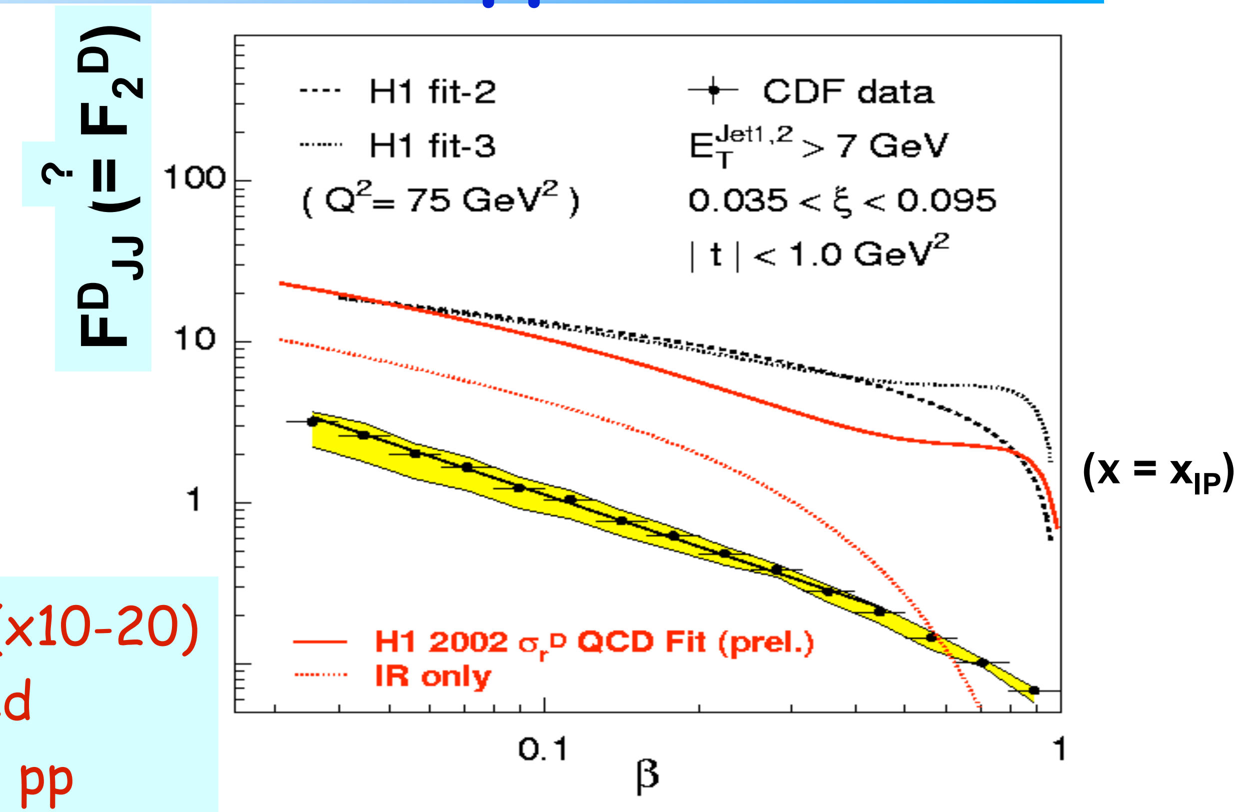


Positive scaling violations: lots of gluons !

QCD analysis: Pomeron is gluon dominated: integrated fraction of exchanged momentum carried by gluons (75 ± 15)%

Test factorization in pp events



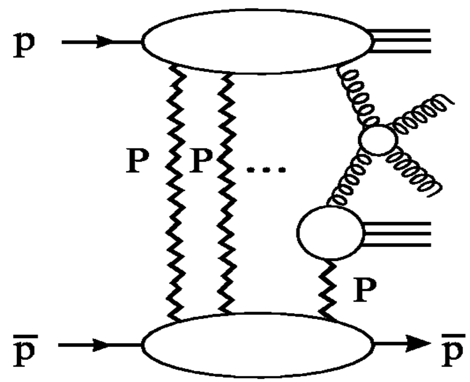


Normalisation discrepancy (x10-20)

⇨ Factorisation violated in "hard diffraction" pp

Violation of factorisation understood in terms of rescattering corrections of the spectator Partons that destroy the gap

Survival probability of the gap ~0.1 for Tevatron and 0.05 for the LHC

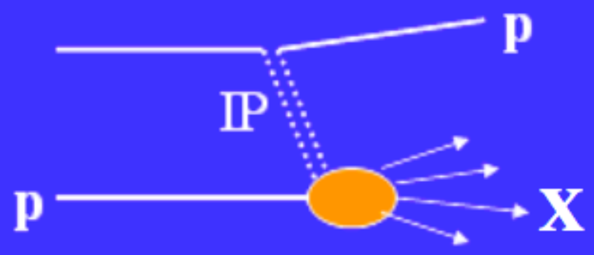


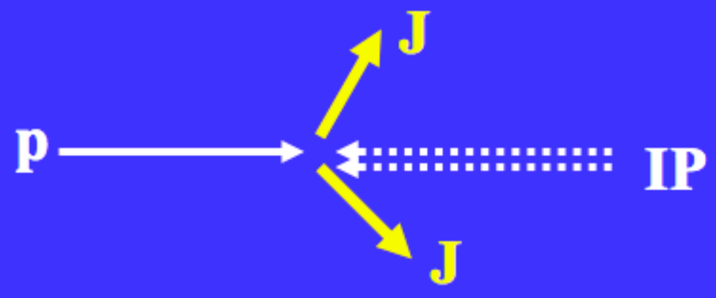
Kaidalov, Khoze, Martin, Ryskin

Hard Diffractive Scattering

<u>Ingelman-Schlein description of high mass diffraction</u>

SDE = Single Diffractive Excitation





Suppose IP has constituent (q,g) structure F(Q2,β=x)
Go into frame of X, and look for jets.
Kinematics tells parton momentum fractions β.

Jets in SDE observed at CERN SppS Collider (not v. high ET)
ET > 20 GeV jets in CDF, D0 at Tevatron.

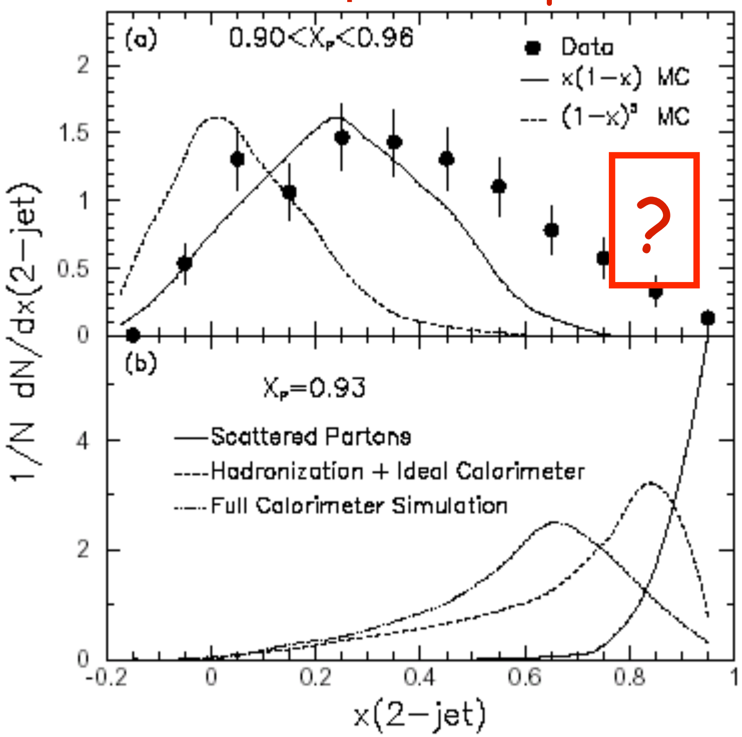
$$x_{Bj} = \frac{1}{\sqrt{s}} \sum_{jets} E_T^J e^{-\eta(J)} \qquad x_{Bj} = \frac{p_{PARTON}}{p_{PROTON}}$$

Diffraction: UA8 superhard pomeron?

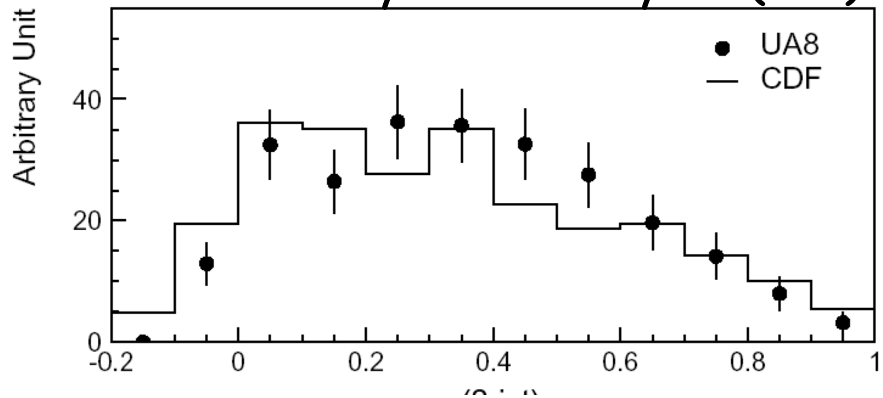
Di-jet data from UA8 at 630 GeV at the SppS at CERN '87
Measure the total longitudinal momentum of the Di-jets in the "pomeron"-proton CMS system, normalized to $(\sqrt{s}\xi)/2$:

$$x(\text{2-jet}) = x(\text{pomeron}) - x(\text{proton}) = \beta - x(\text{proton})$$

~30% of β~1 component

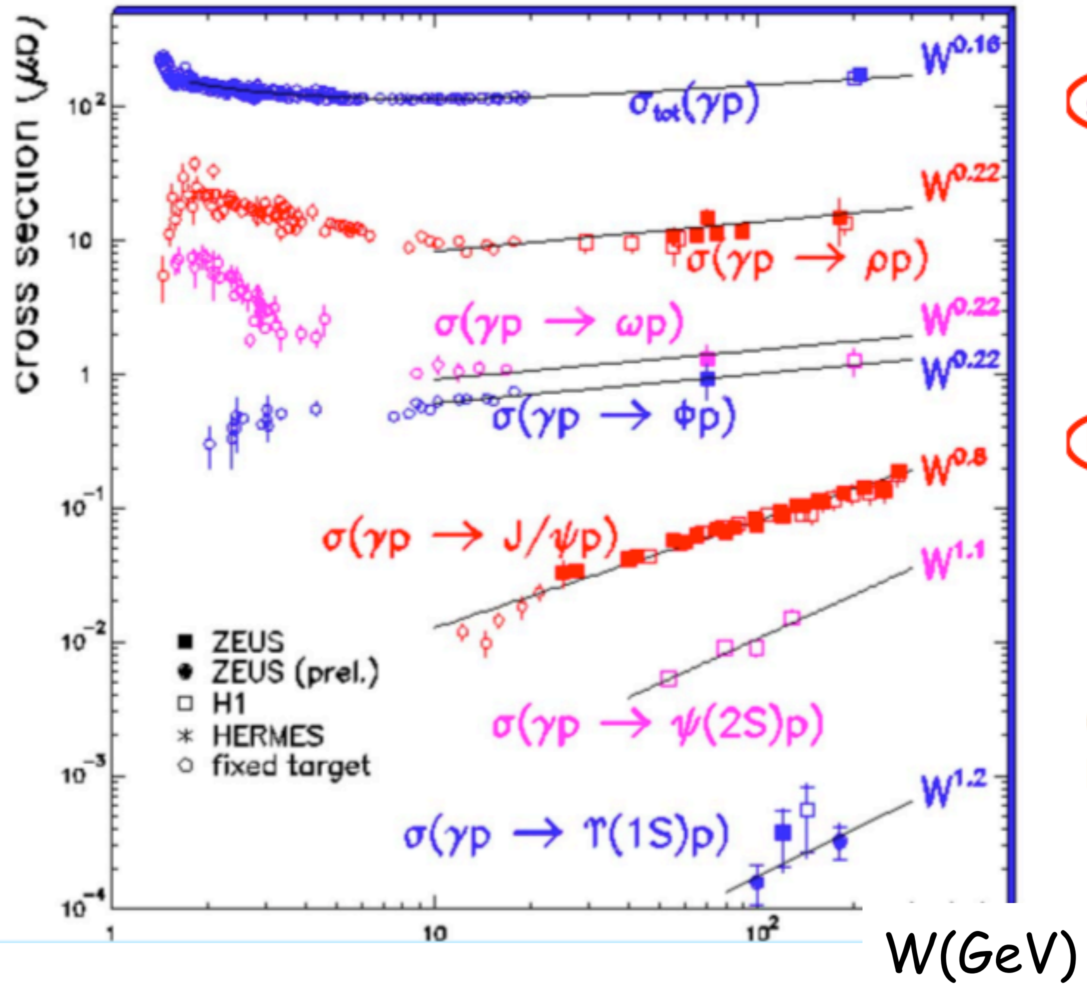


Preliminary CDF analysis ('02)



- $0.04 < \xi < 0.10$
- Jet cone radius $R = 1.0$
- No underlying event or out-of-cone corrections
- $E_T^{jet1,2} > 8$ GeV
- $|\eta^{jet1,2}| < 2$
- $\Delta\phi(jet1,2) > 135°$
- $|t| < 0.2$ GeV^2 (UA8 : $0.9 < |t| < 2.3$ GeV^2)

Vector Meson Production at HERA



$\sigma \propto W^{\delta}$

soft

σ_{tot}

ρ, ω, ϕ

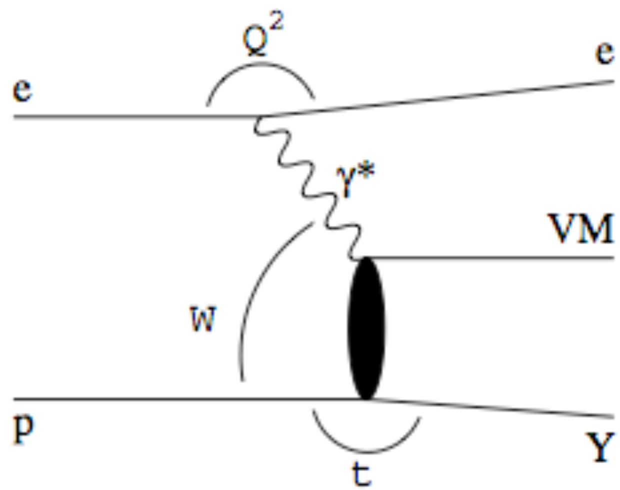
hard

J/Ψ

Υ

(skewing,

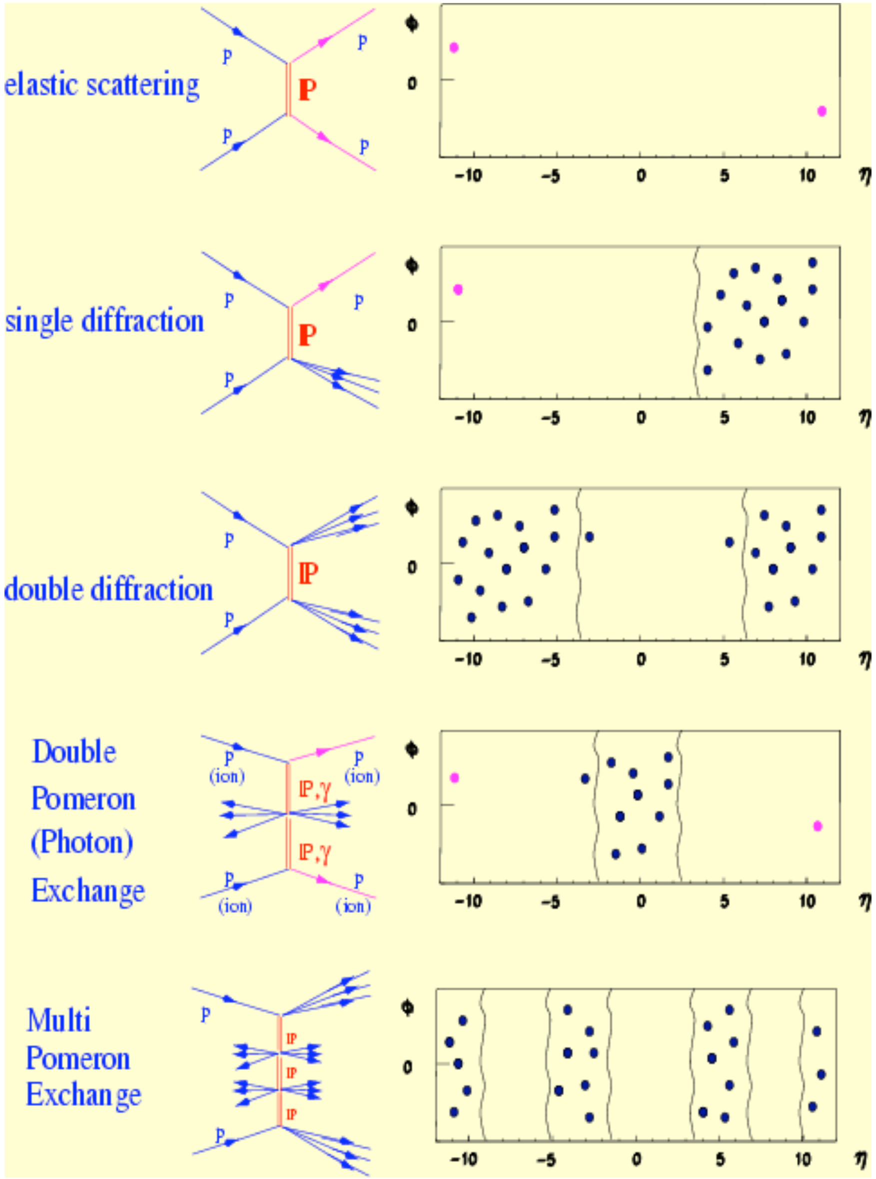
Re →GPD)



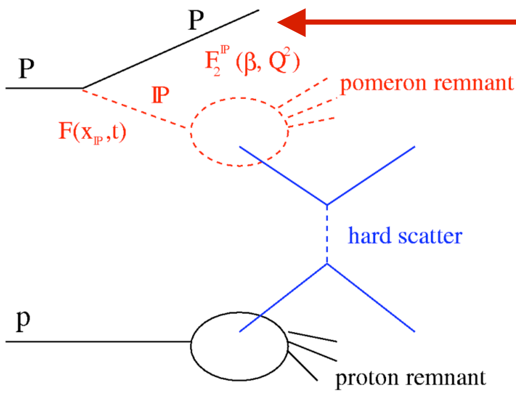
Onset of low-x QCD effects at large |t|?

Wealth of experimental results. Soft⇔Hard transitions

Diffraction at LHC:



- Soft Diffraction at the highest energy & Multi-gap events
- Hard Diffraction ⇒ Structure



ξ = proton momentum loss
Reconstruct ξ with roman pots

$\xi < 0.1 \Rightarrow$ O(1) TeV "Pomeron beams"

E.g. Structure of the Pomeron $F(\beta,Q^2)$

β down to ~ 10^{-3} & Q^2 ~10^4 GeV^2

Can use jets, J/ψ, W,... as hard probes

Diffraction at LHC

Plan to use both rapidity gap and proton tagging techniques

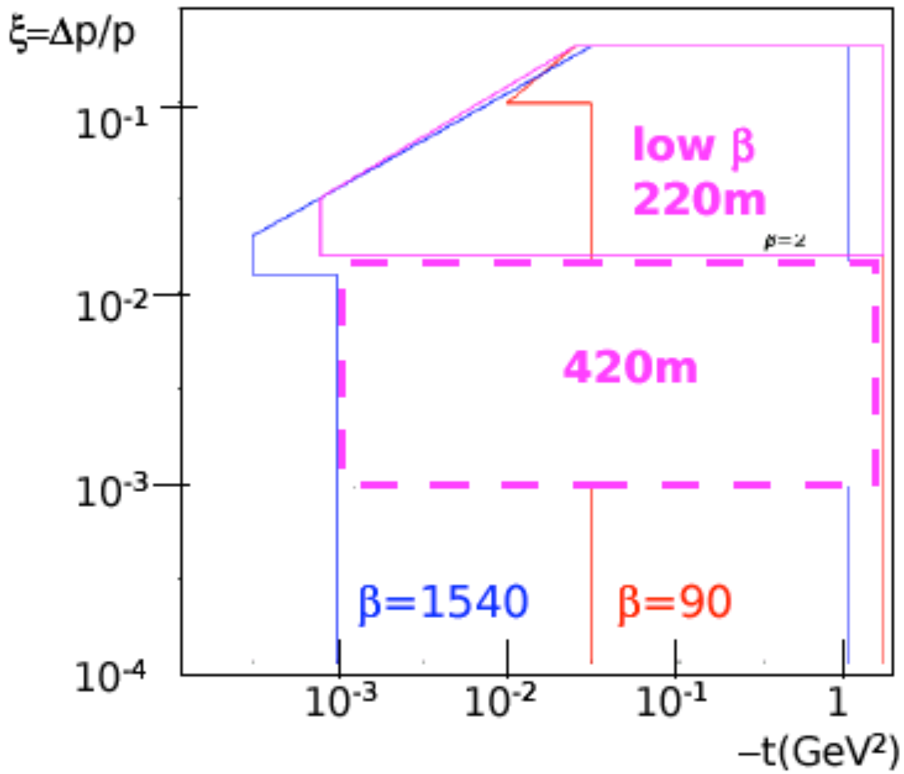
- Rapidity gaps based on the central detector
  - Used extensively at HERA and the Tevatron
  - Uses correlation between the η_{max} and ξ, the momentum loss of the proton
  - Once detector/readout stable, can lead to first results quickly.

    Many significant HERA analyses, like F_2^D, first made with rapgaps
  - Only usable if pile up small and can be controlled
  - Cannot distinguish between outgoing proton or low mass system
  - Need Monte Carlo based corrections
- Tagging protons based on detectors along the beamline
  - Clean measurement for non-dissociative final protons, kinematics!
  - Need to understand positioning, alignment, acceptance corrections…

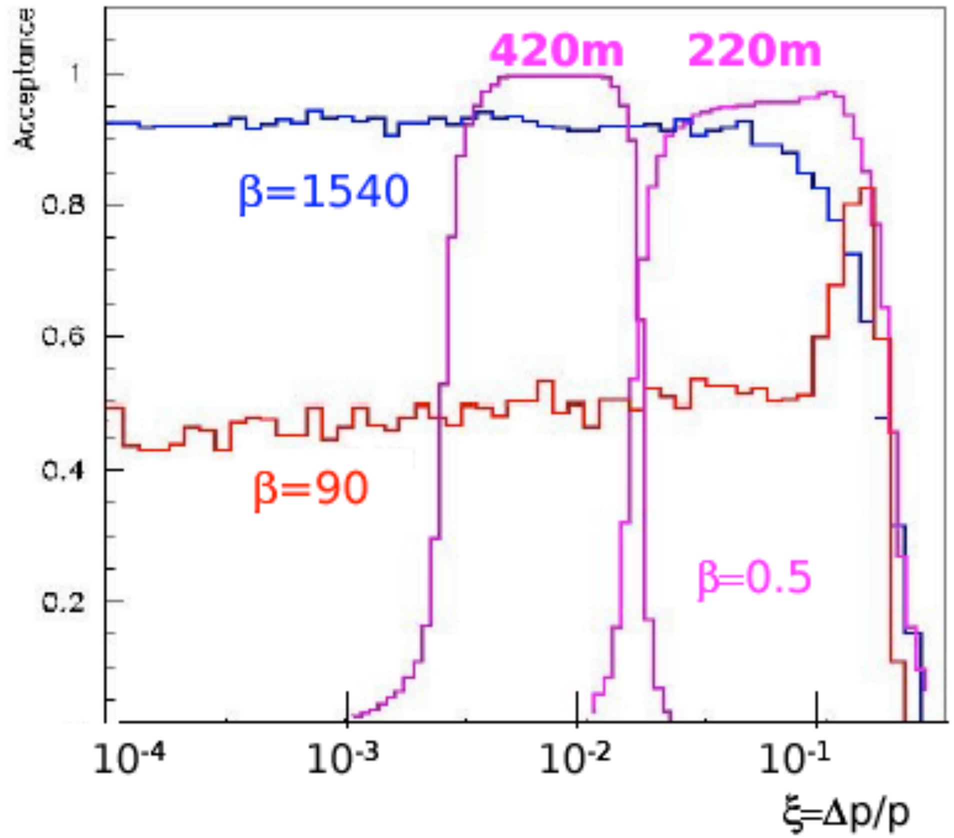
    This can take some time (HERA & Tevatron experience)
  - May have reduced integrated luminosity: can insert RPs only when beams/background low and stable

Experience from both HERA and Tevatron vital

Forward Proton Acceptance

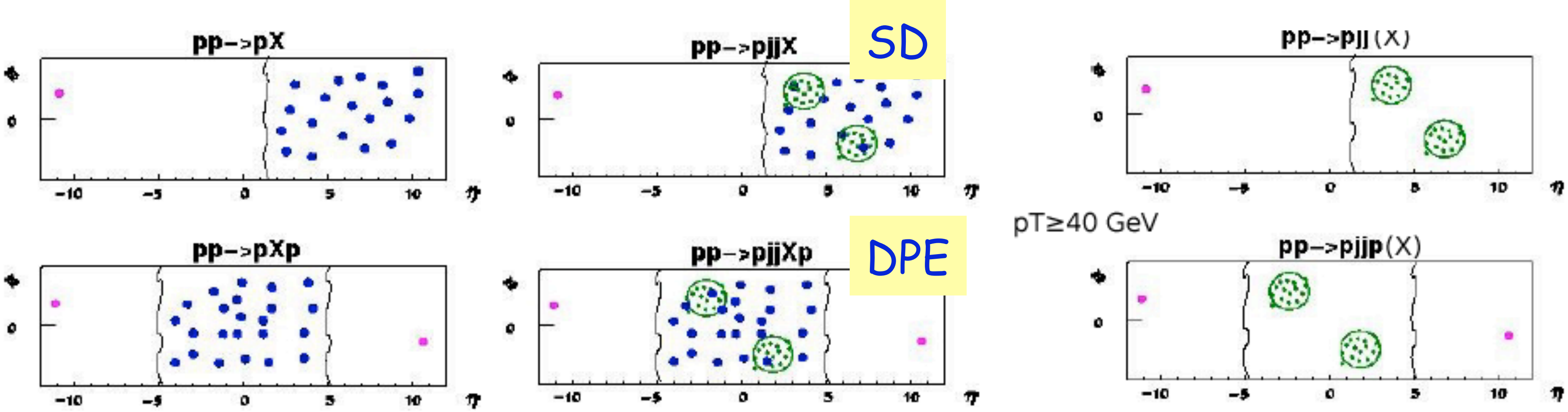


Acceptances as calculated by TOTEM
Similar for ATLAS RPs



- ~ full ξ coverage with special optics and low luminosity
- Coverage down to $\xi = 10^{-2}$ (10^{-3}) at nominal optics and medium/high luminosity

Running Scenarios: Eg:CMS/TOTEM



soft diffraction | (semi)-hard diffraction | hard diffraction/exclusive processes

Cross section ← → Luminosity

σ	mb	μb		nb
L ($cm^{-2}\ s^{-1}$)	10^{28}	10^{30}	10^{32}	10^{34}
β (m)	1540	90	2	0.5
	TOTEM runs		Standard runs	

The accessible physics depends on : luminosity

β (different proton acceptance)*

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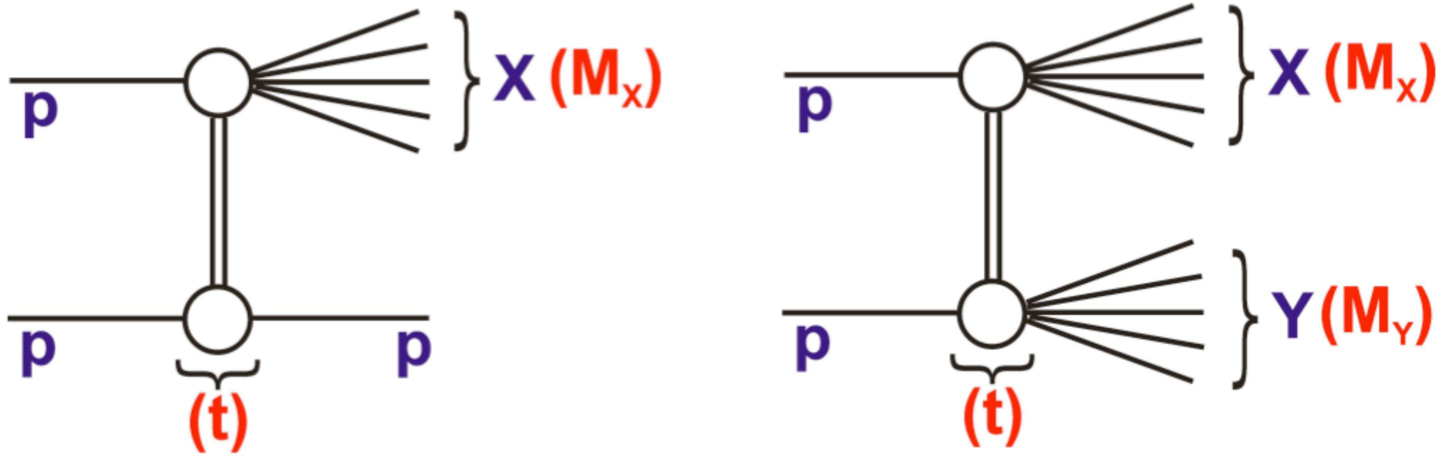
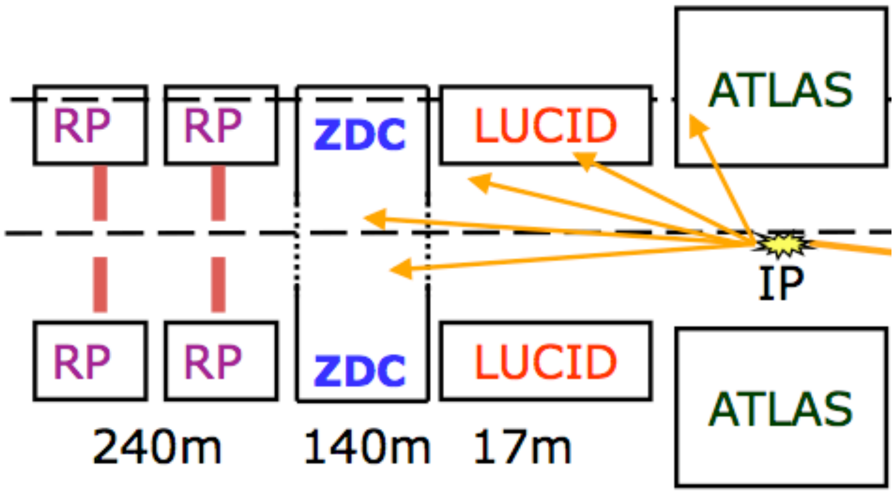
Soft Diffraction Measurements

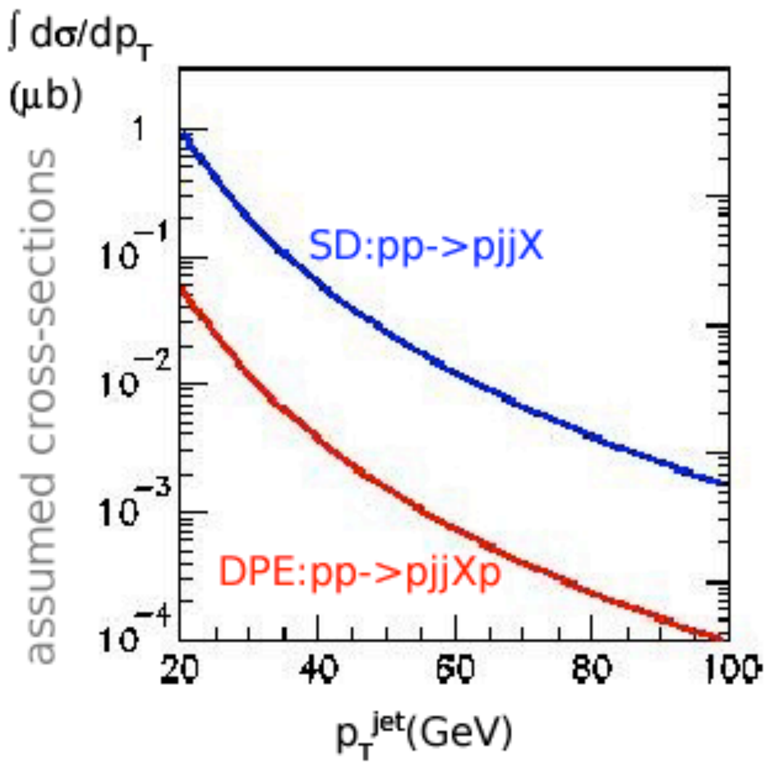


- Single and double diffractive dissociation have large cross section [O(mb)]
- First measurement of rapidity gap processes at LHC – study of underlying event/soft survival. Impacts on understanding pile-up at high luminosity.



Efficiency [%]	Pythia	Phojet
Preselection		
ξ<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

Di-jets at low and medium luminosity



N event collected [acceptance included]

β=90 $\int Ldt$ = 0.3 (pb^{-1})

SD:	pT>20 GeV	$6x10^4$
DPE:	"	2000

β=2 $\int Ldt$ = 100 (pb^{-1})

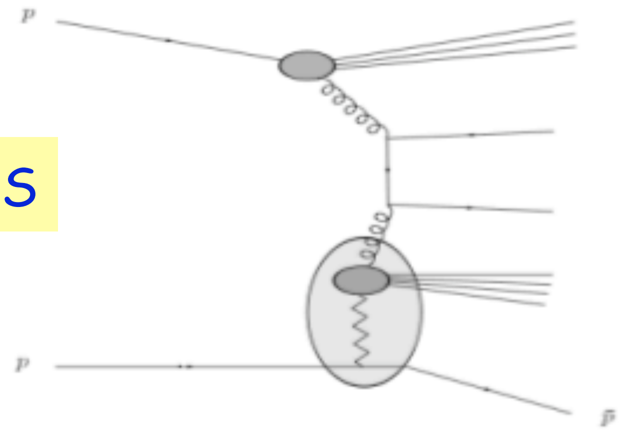
SD:	pT>50 GeV	$5x10^5$
DPE:	"	$3x10^4$

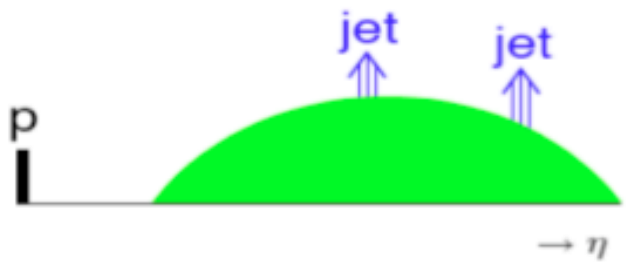
- Modest luminosity sufficient for initial studies at 10/14 TeV
- Medium luminosity (~ $1fb^{-1}$)

⇒ Measure cross sections and the t, M_x, P_t… dependence

Diffractive Dijet Production

ATLAS





- Diffractive di-jet production:
  - Measure single diffractive to non-diffractive di-jet ratio, R(SD/ND).
  - Also look for double pomeron exchange (DPE) di-jet production, measure R(DPE/SD).
  - Allows study of soft-survival, diffractive PDFs.
- Impose one (or two) rapidity gaps in forward detectors to search for SD (DPE).
  - Expect a few thousand SD di-jet events in 100pb^{-1} with E_T>20GeV (after trigger pre-scale and gap requirement).
  - New trigger possibilities being examined to increase rate.

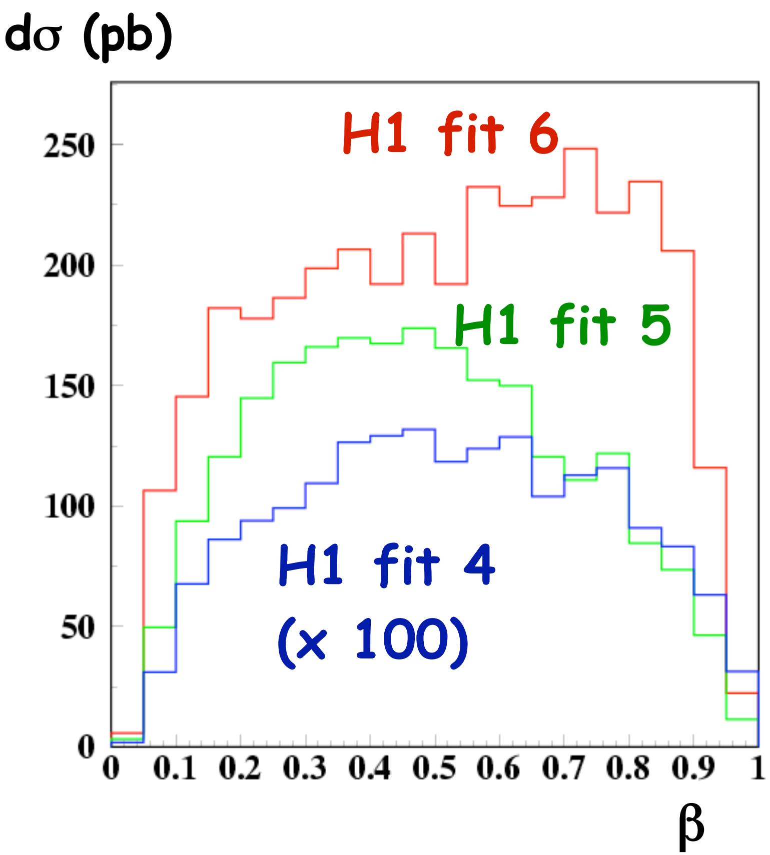
(No trigger prescale)

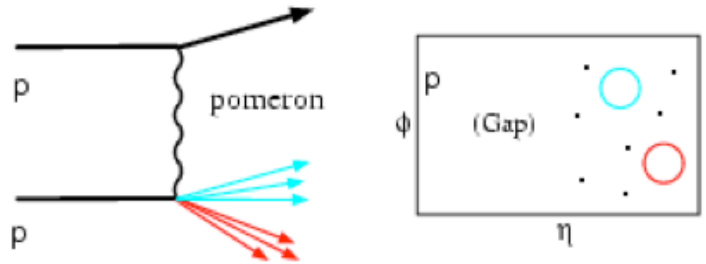
$p_T(GeV)$	x_{pom}	σ (pb)	gap type	efficiency	Events in 100 pb^{-1}
20	< 0.01	7.2×10^5	FCAL	0.4	2.9×10^7
20	< 0.1	3.6×10^6	FCAL	0.08	2.9×10^7
40	< 0.1	2.1×10^5	FCAL	0.05	1.0×10^6
40	< 0.1	2.1×10^5	LUCID,ZDC	0.44	9×10^6

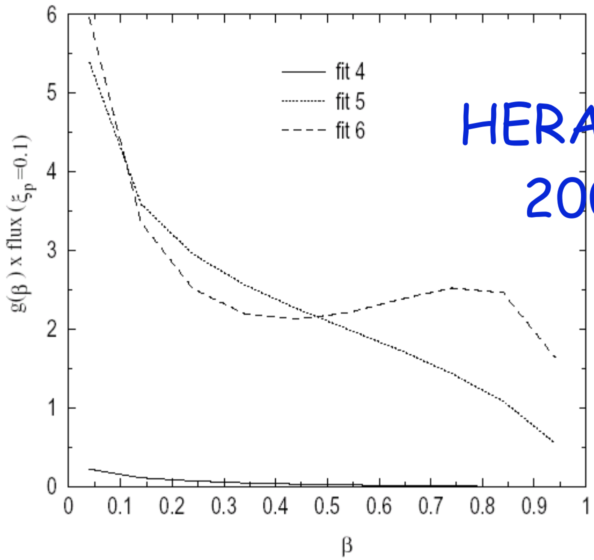
Di-jet events and diffractive structure

2002 study

P_t>100 GeV/c for different structure functions







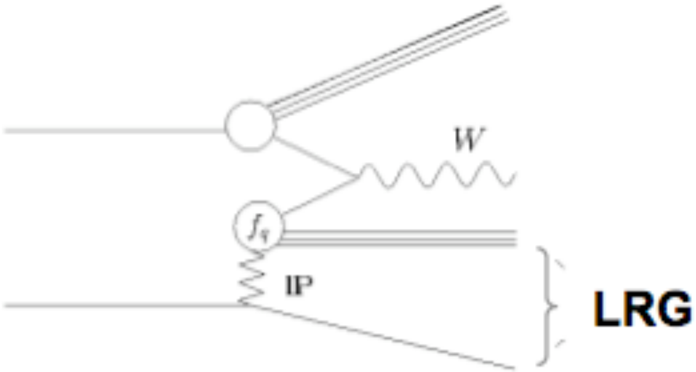
HERA PDFs 2002

$\beta=\Sigma_{jets}\, E_T\, e^{-\eta}/(\sqrt{s}\,\xi)$; ξ from Roman Pots; E_T and η from CMS

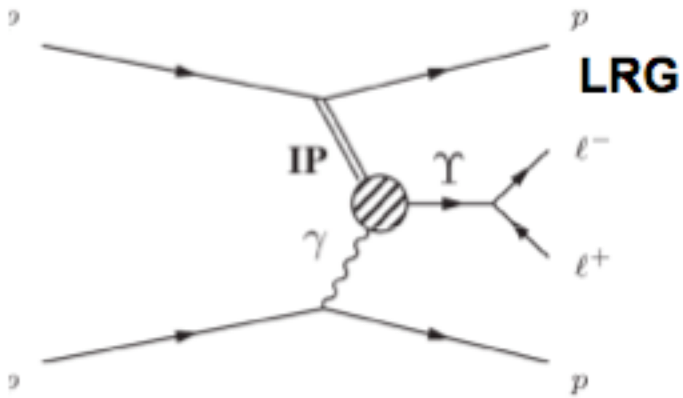
High β region probed/ clear differences between different dSFs

Diffractive W and Upsilon Production

Early measurements at LHC



SINGLE DIFFRACTIVE
W PRODUCTION

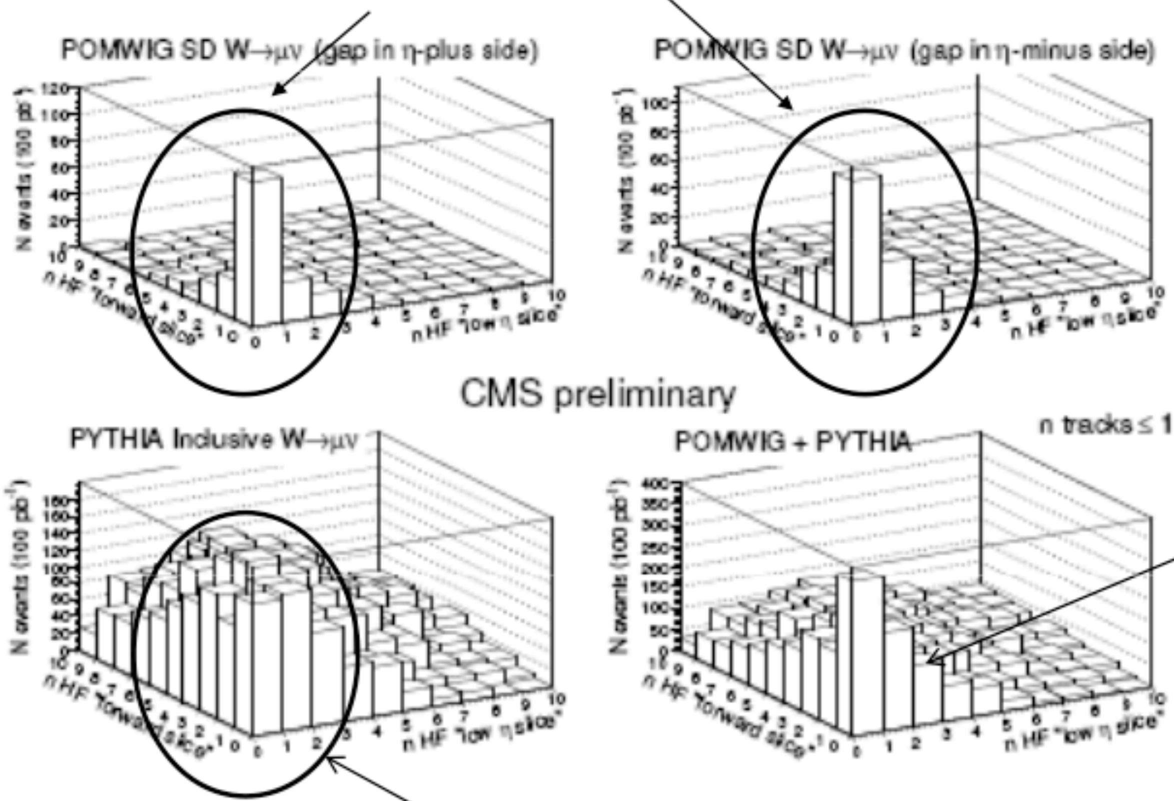


Υ PHOTOPRODUCTION

Studies for 100 pb^{-1} and no pile-up
Use rapidity gap technique

Diffractive W→μν Selection

Clear peak at zero multiplicity



Rapidity gap:
Calorimeter towers in the CMS forward calorimeter (HF)

"low η": $3.0 < |\eta| < 4.0$

"high η": $4.0 < |\eta| < 5.0$

Excess in low multiplicity visible

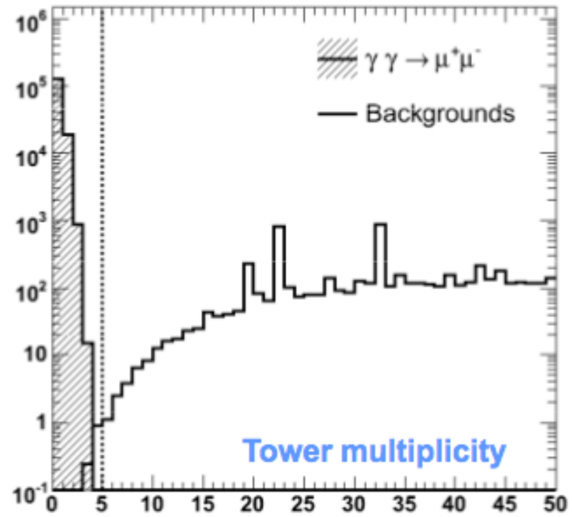
Non-diffractive background clusters in the low multiplicity (signal) region

Expect O(100) signal events for 100 pb^{-1} assuming 0.05 gap survival probability

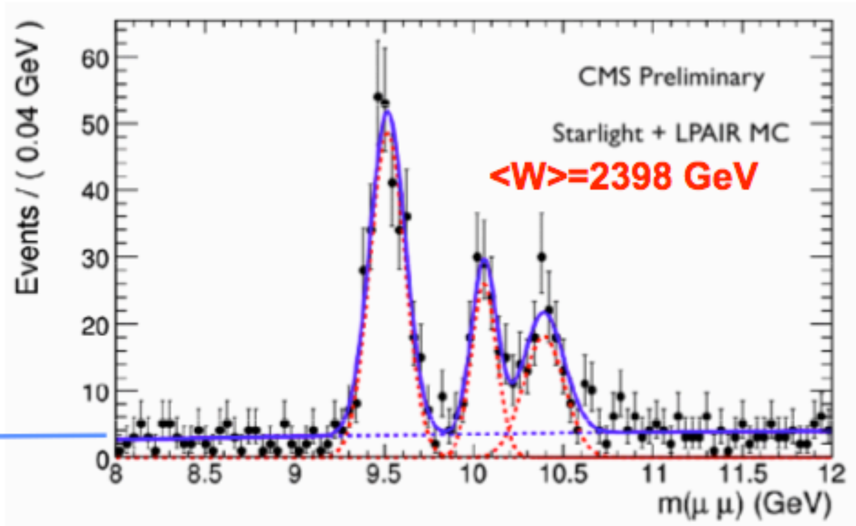
Exclusive Upsilon production

Offline analysis selection:
- Exactly 2 reconstructed opposite-sign muons
- Δp_T $(\mu\mu) < 2.0$ GeV
- $|\Delta\phi(\mu\mu)| > 2.9$

Select events with:
- Number of extra towers < 5
- Number of tracks < 3



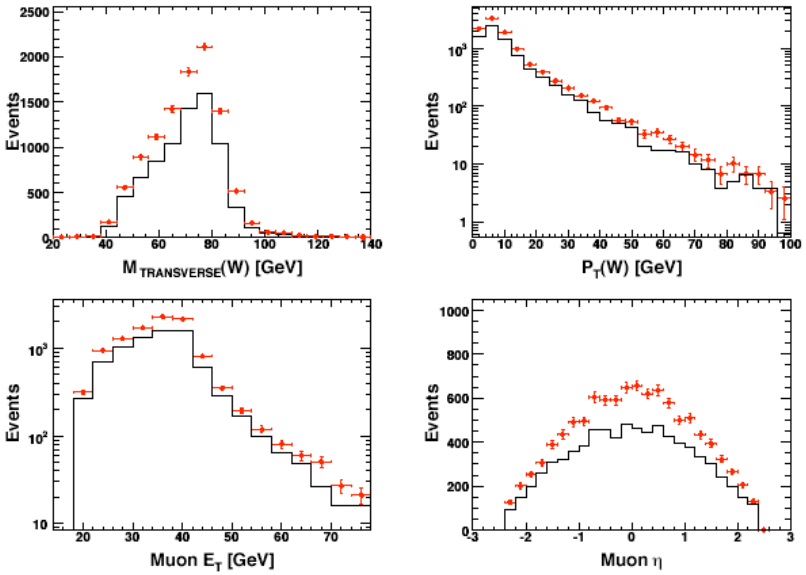
"Extra" towers: E > 5 GeV, isolated from either of the μ candidates by $\Delta R > 0.3$ in the η-ϕ plane



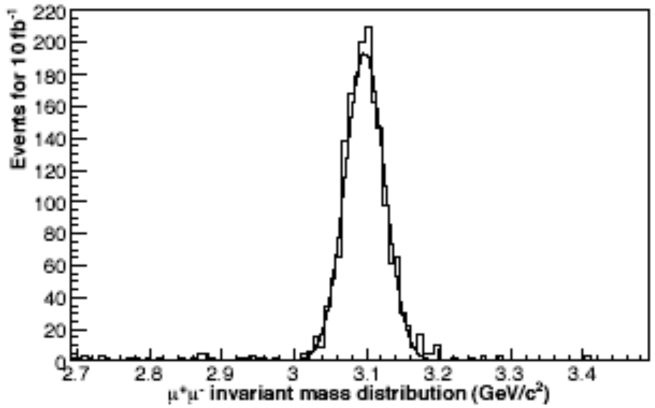
γγ continuum

Observable with 100 pb^{-1} but no survival probability taken into account

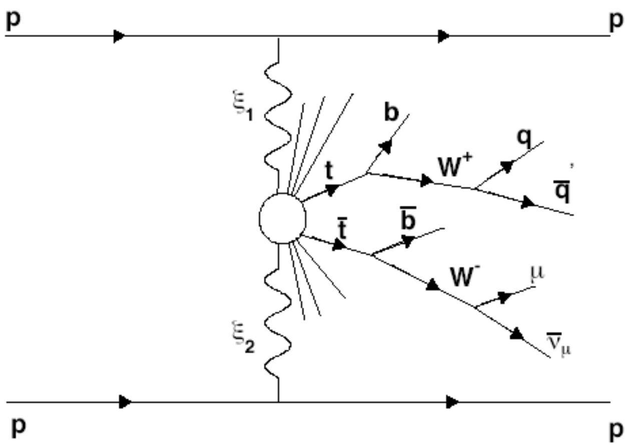
Other Hard Diffraction Studies



Diffractive DPE W-production
Few 1000 events with 1fb^{-1}



Diffractive B production with B→J/ψ
for 1 fb^{-1}



Diffractive top?
Depends on the cross section

+ γγ production, low mass mesons…

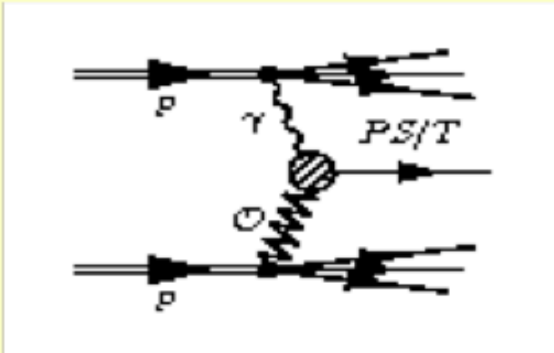
Diffraction @ ALICE

Signature Odderon cross section

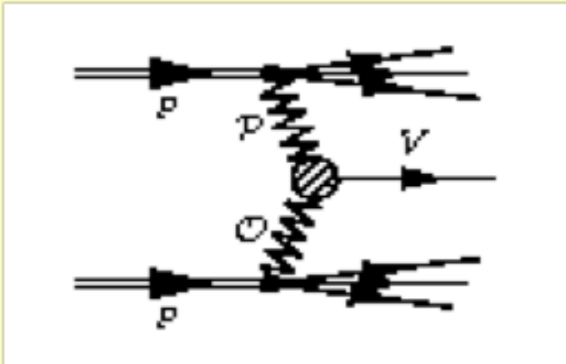
Look at exclusive processes with rapidity gaps

Examples:

diffractive pseudo scalar and tensor meson production: C = +1 states



diffractive vector meson production: C = -1 states



→ *measure cross sections*

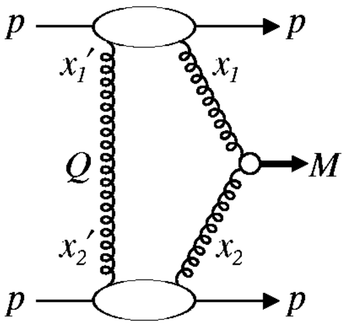
Exclusive Processes

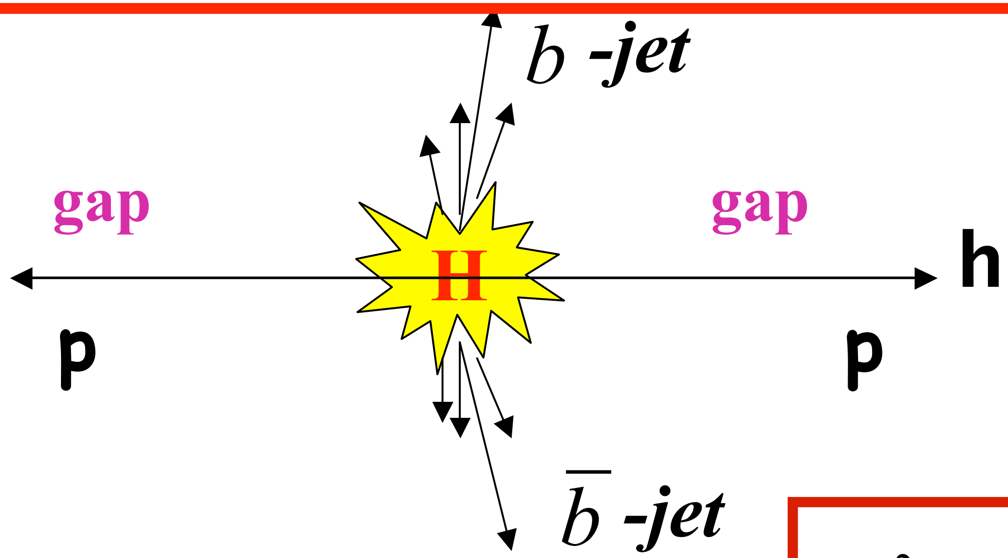
A clean gateway to new physics

Central Exclusive Higgs Production

Central Exclusive Higgs production pp→ p H p : 2-10 fb (SM)

~10-100 fb (MSSM)

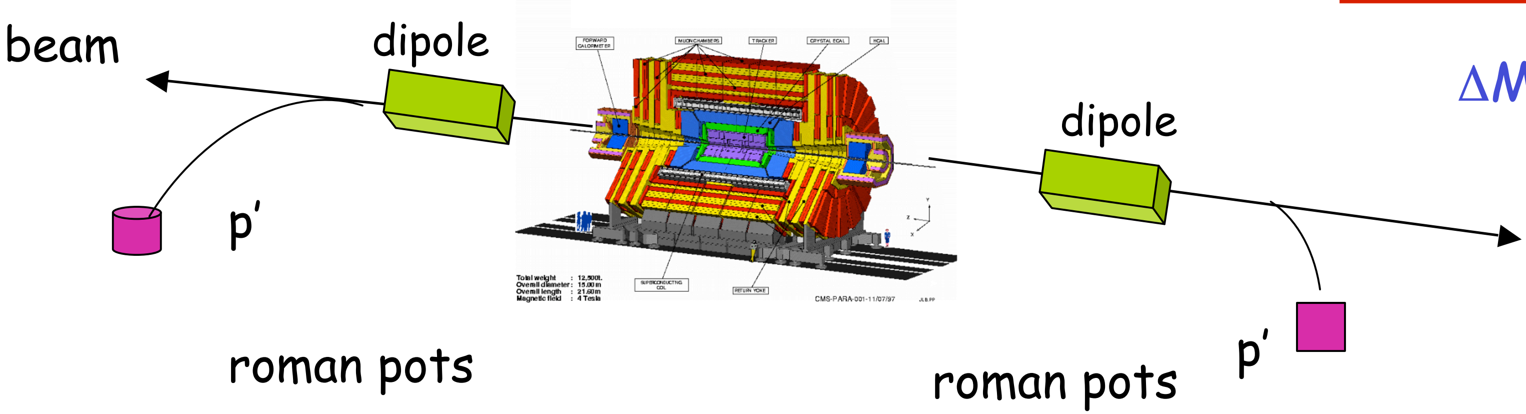




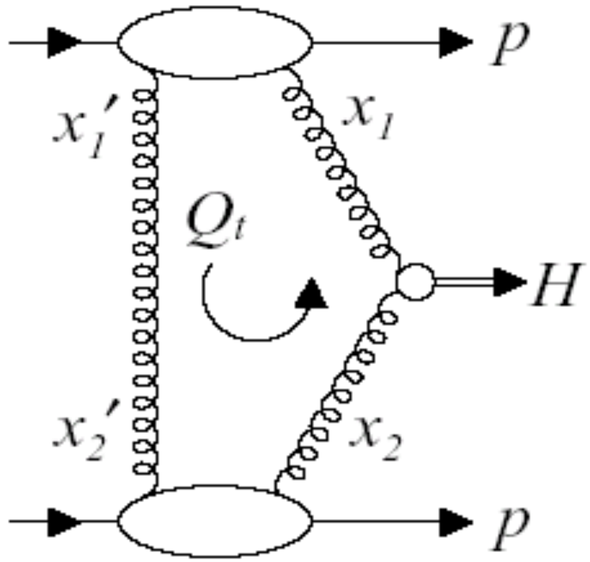
E.g. V. Khoze et al
ADR et al.
M. Boonekamp et al
B. Cox et al.
V. Petrov et al…
Brodsky et al.
Cudell, Dechambre

$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

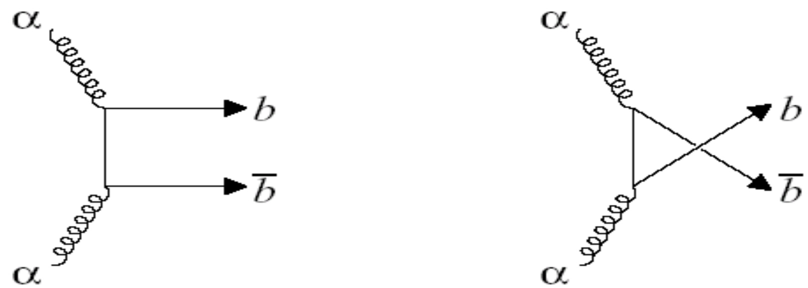
$\Delta M = O(1.0 - 2.0)$ GeV



Exclusive Higgs Production



- For light Higgs, dominant decay mode is $H \longrightarrow b\bar{b}$
- For inclusive production, the QCD $b\bar{b}$ background is overwhelming
- For double diffractive production (2 tagged protons) there is a J_Z = 0, parity even selection rule :



cancel each other in the $m_b \longrightarrow 0$ limit

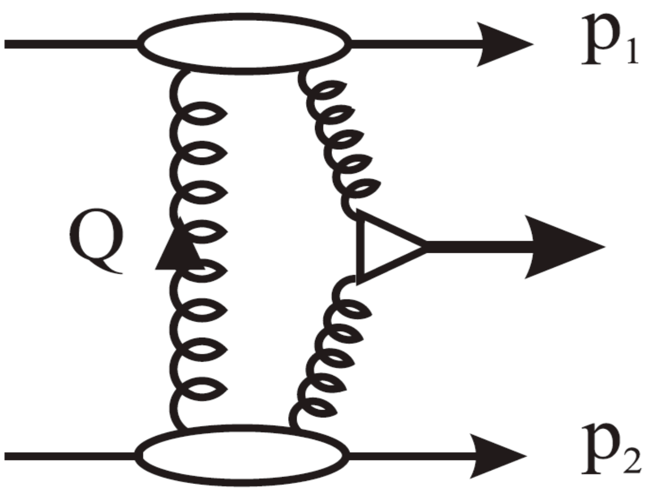
- Cross section suppressed as m_b^2/E_T^2

where $E_T \sim M_H/2$

H →bb measurements may become possible!!

Problem: exclusive production = mixture of perturb.+non-peturb. QCD
⇒Survival probability!!! E.g. S= 0.04 at Tevatron and 0.02 at LHC (estimates)
⇒ Theoretical uncertainties in the cross section…

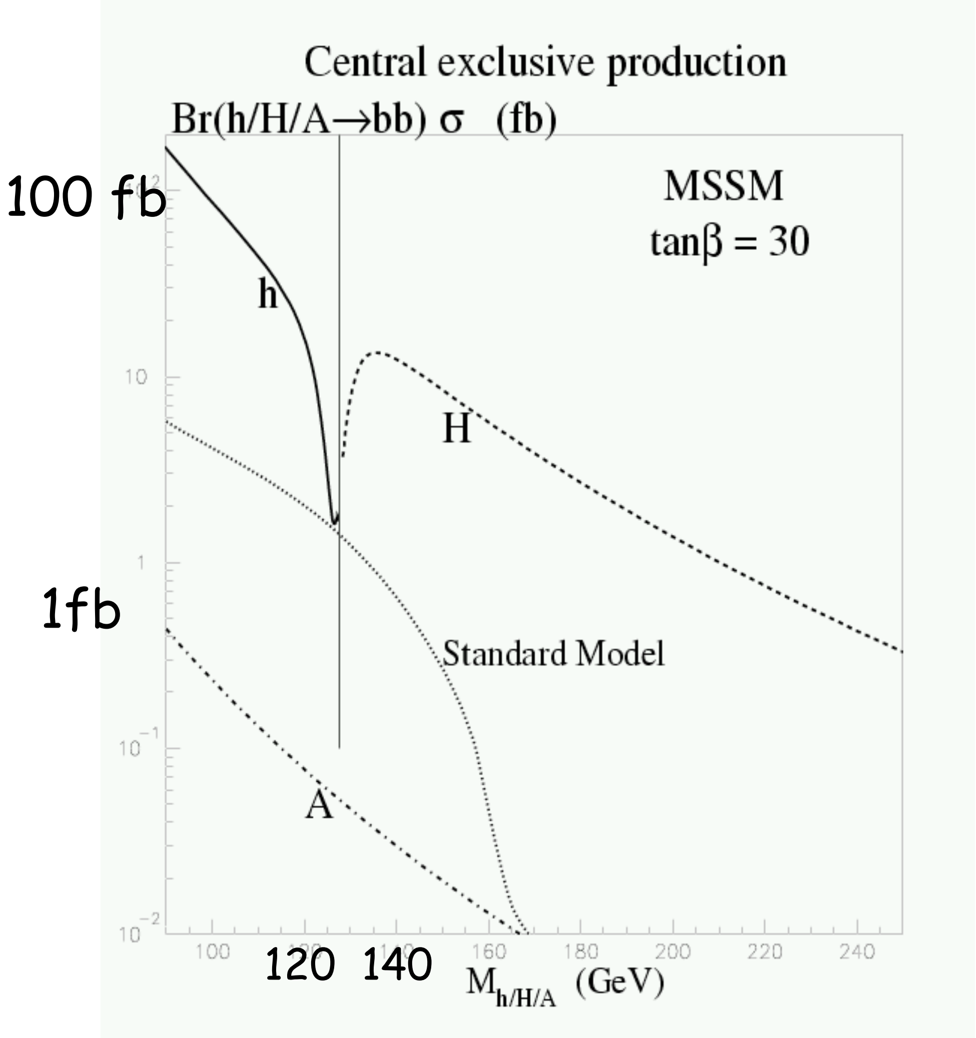
Exclusive Central Production



- Selection rules mean that central system is 0^{++} $\Rightarrow$pinning down the quantum numbers
- CP violation in the Higgs sector shows up directly as azimuthal asymmetries
- Tagging the protons means excellent mass resolution (~ GeV) irrespective of the decay products of the central system. LO QCD backgrounds suppressed
- Proton tagging may be the discovery channel in certain regions of the MSSM.
- Unique access to a host of interesting QCD processes

Very schematically: exclusive central production is a glue – glue collider where you know the beam energy of the gluons - source of pure gluon jets - and central production of any 0^{++} state which couples strongly to glue is a possibility …

Higgs Studies



Cross section SM Higgs ~ 2-3 fb
⇒Few 10 events after experimental cuts with ~ 10 background events for 30 fb^{-1}

~ Factor 10 larger in MSSM (high tanβ)
⇒Few 100 events

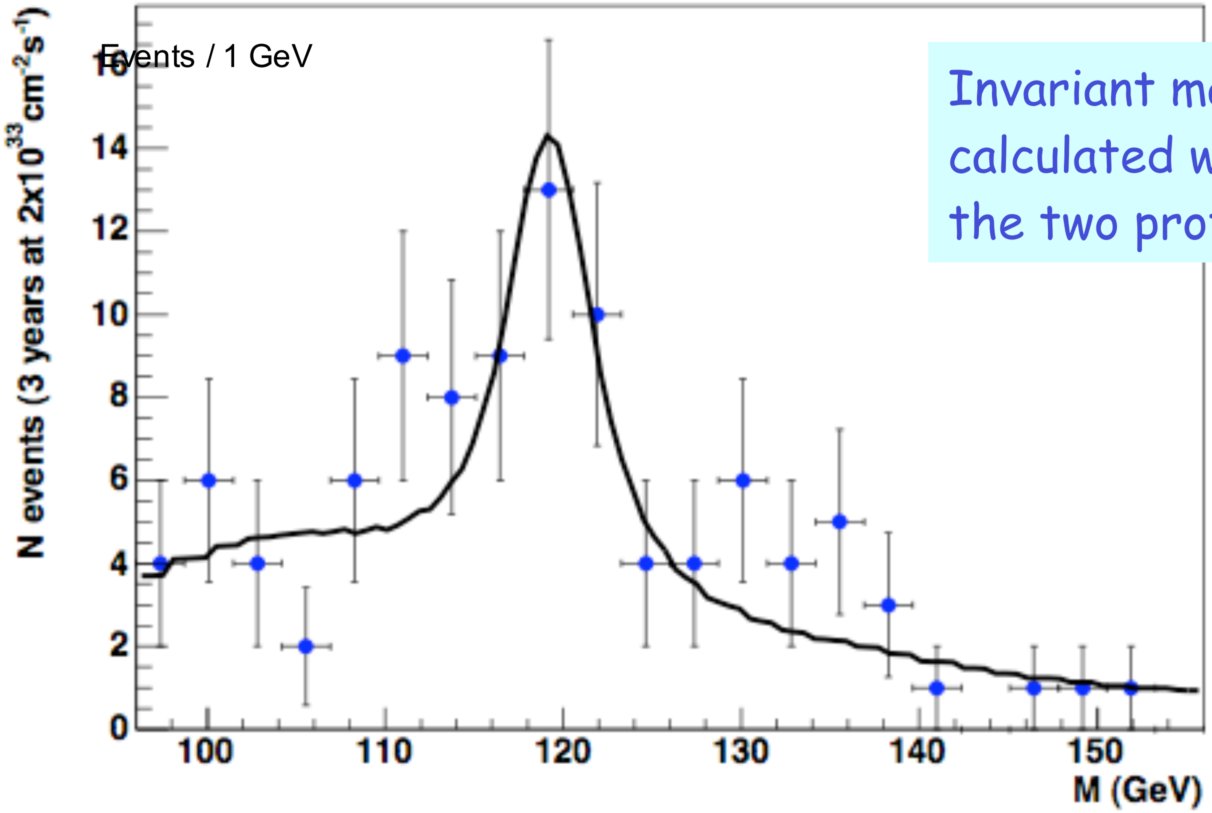
Kaidalov et al., hep-ph/0307064

Note: This cross section calculation has a checkered history(90's, early '00)
Since 2-3 years ago the Durham calculations have been confirmed/verified

H→bb

M_h^{max} MSSM scenario: H→bb

(m_A=120 GeV, tanβ = 40, 60 fb^{-1})   σ= 20 fb



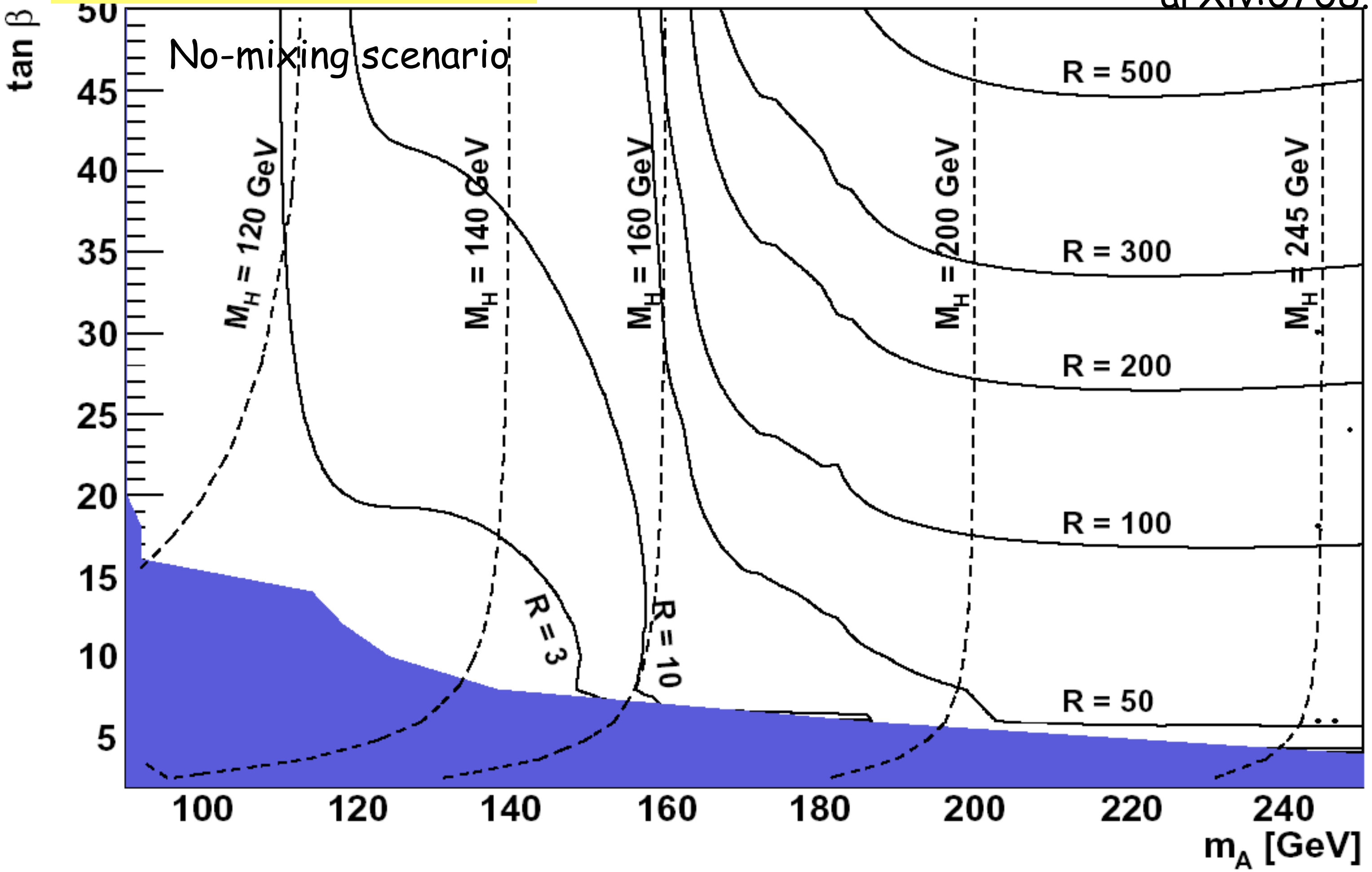
Invariant mass calculated with the two protons

Taking into account acceptance, trigger efficiencies etc.

MSSM Scenario Studies

M_A = 130 GeV $H \to bb$

Heinemeyer et al.
arXiv:0708.3052

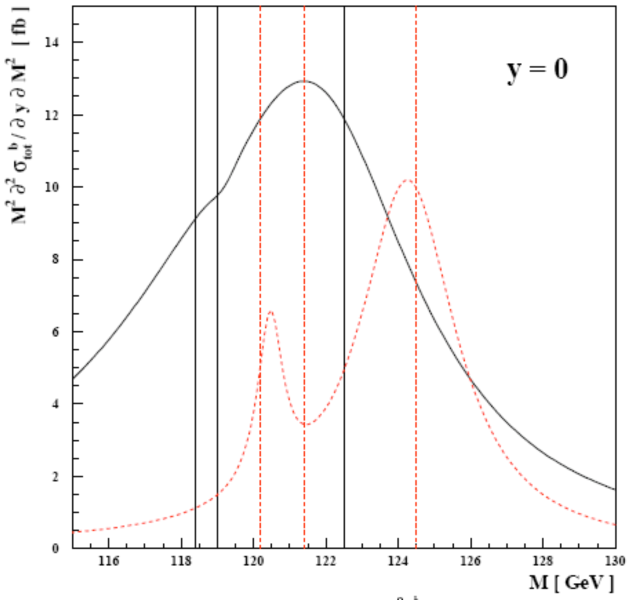


Contours of ratio of signal events in the MSSM over the SM

"lineshape analysis"

J. Ellis et al.
hep-ph/0502251

Scenario with CP violation in the Higgs sector and tri-mixing

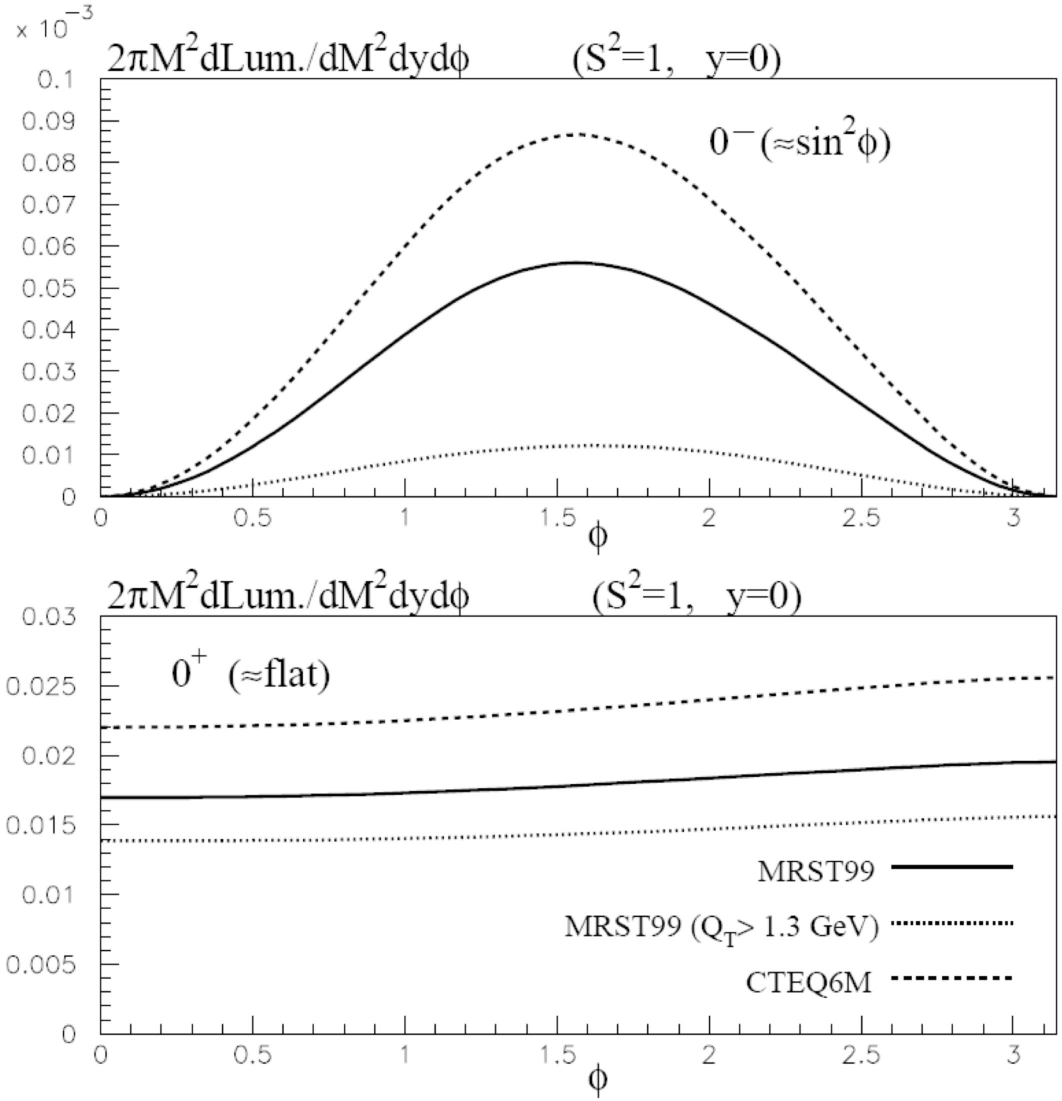


This scenario needs a mass resolution of about 1 GeV and 100 fb-1

Unique

This example shows that exclusive double diffraction may offer unique possibilities for exploring Higgs physics in ways that would be difficult or even impossible in inclusive Higgs production. In particular, we have shown that exclusive double diffraction constitutes an efficient CP and lineshape analyzer of the resonant Higgs-boson dynamics in multi-Higgs models. In the specific case of CP-violating MSSM Higgs physics discussed here, which is potentially of great importance for electroweak baryogenesis, diffractive production may be the most promising probe at the LHC.

Measuring the Azimuthal Asymmetry



Khoze et al., hep-ph/0307064

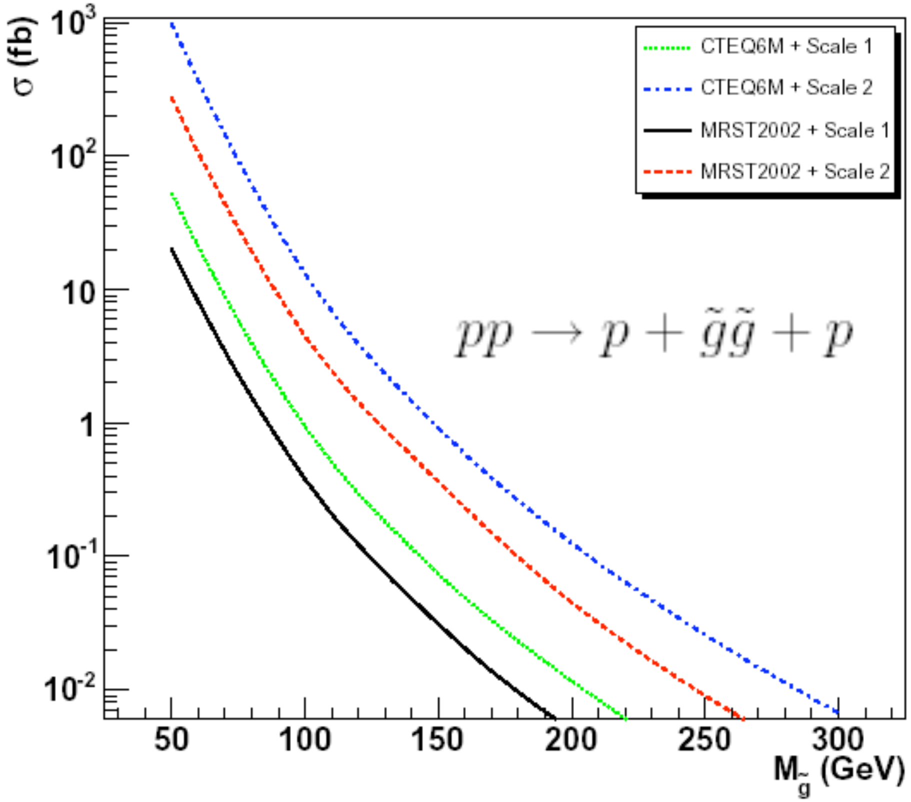
Azimuthal correlation between the tagged protons

Allows to eg to differentiate O^+ from O^-

A way to get information on the spin of the Higgs
⇒ADDED VALUE TO LHC

Long Lived gluinos at the LHC

Gluinos that live long and pass through the detectors (R-Hadrons)



P. Bussey et al
hep-ph/0607264

$m_{\tilde g}$ (GeV)	$\sigma_{m_{\tilde g}}$ (GeV)	$\frac{\sigma_{m_{\tilde g}}}{\sqrt{N-1}}$ (GeV)	N
200	2.31	0.19	145
250	2.97	0.50	35.0
300	3.50	1.10	10.2
320	3.61	1.54	6.5
350	3.87	2.45	3.5

Gluino mass resolution with 300 fb^{-1}
using forward detectors and muon system

The event numbers includes acceptance
in the FP420 detectors and central
detector, trigger…

Added value

Measure the gluino mass with a precision (much) better than 1%

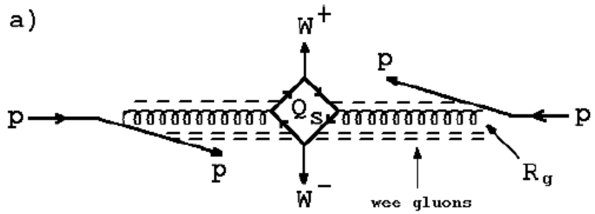
Exotics Anomalous WW Production?

Alan White: theory of supercritical pomeron→ reggeized gluon+many (infinite) wee gluons

- color sextet quarks required by asymptotic freedom, have strong colour charge, (at least) few 100 GeV constituent mass
- Sextet mesons → EWSB
- UDD neutron dark matter candidate
- Explain high energy cosmic rays, Knee?
- Color sextet quarks couple strongly to W and Z and to the pomeron
- Phenomenology: Anomalous production of WW when above threshold ie. At the LHC (with possibly some onset already detectable at the Tevatron

color triplets			color sextets
u	c	t	U
d	s	b	D

Unique for Central Exclusive Production



⇒Measure exclusive WW,ZZ cross sections in DPE at the LHC
Expected cross section to be orders of magnitude larger than in SM

Can we trust theory predicitions? What can we learn Tevatron and early LHC data ?

A lot of measurements performed at the Tevatron in the last years to check central exclusive predictions

Possible Measurements at Tevatron

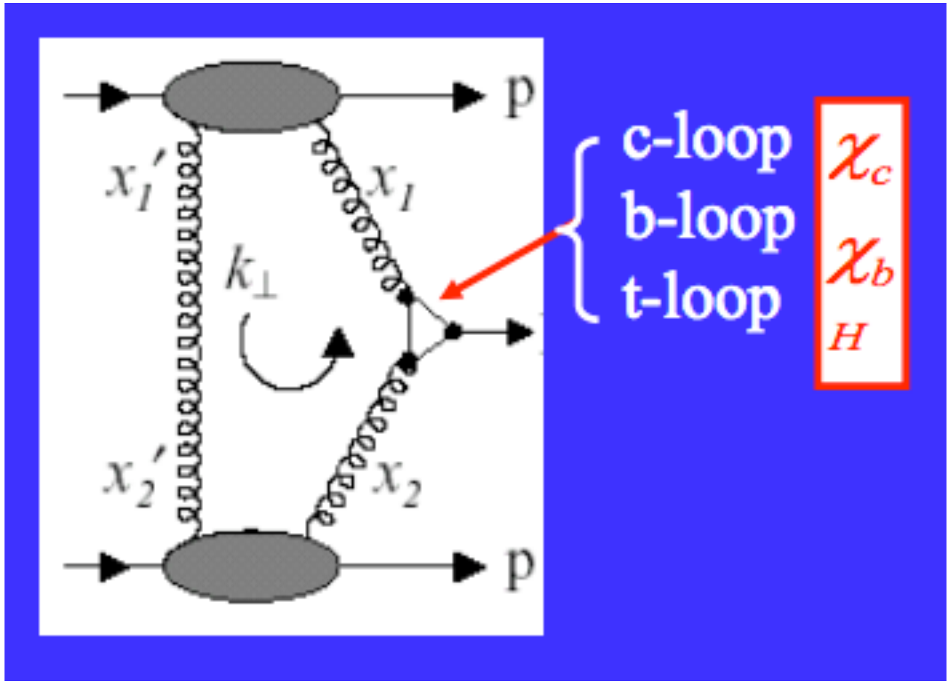
Processes

$g+g \rightarrow$ jet jet

$g+g \rightarrow \gamma\gamma$

$g+g \rightarrow \chi_b$

$g+g \rightarrow \chi_c$

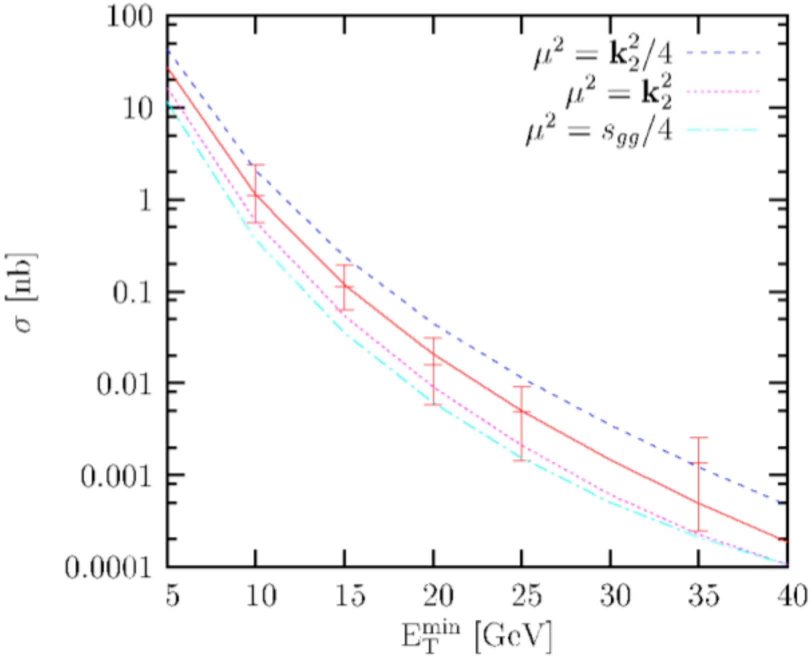


Predictions for these processes at tevatron and LHC energies exist

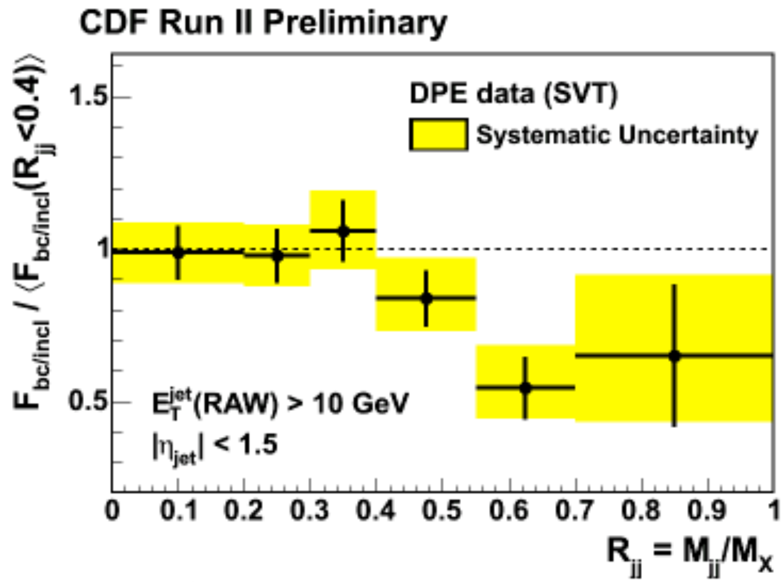
Does High Mass Exclusive Production Exist?

Results from the tevatron

A. Dechambre et al
AIP Conf.Proc.1105 (2006)222



b-tagged dijet fraction



Exclusive b-jets are suppressed by J_Z= 0 selection rule

⇒ Good evidence for exclusive production

⇒ Results agree with the KMR calculations. Gives confidence for the LHC

Di-photon Production at the Tevatron

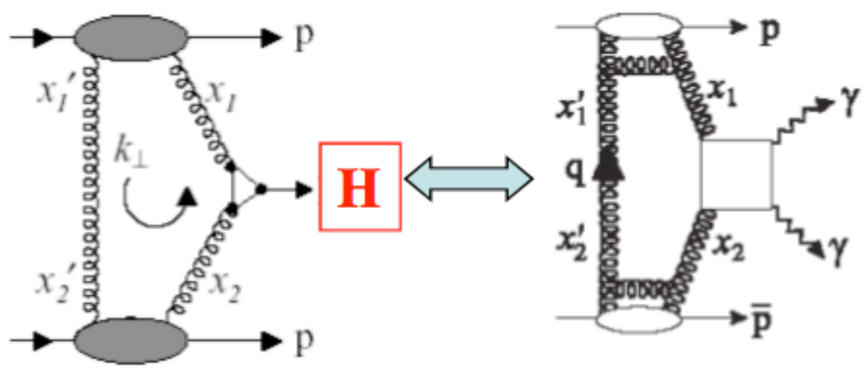
PRL 99, 242002 (2007) PHYSICAL REVIEW LETTERS week ending 14 DECEMBER 2007

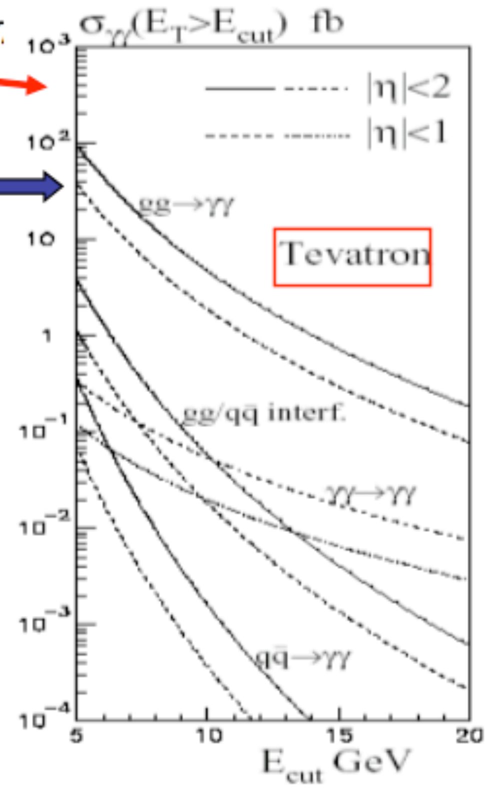
Search for Exclusive $\gamma\gamma$ Production in Hadron-Hadron Collisions

Khoze, Martin and Ryskin, Eur.Phys.J. C23: 311 (2002) ; KMR+Stirling hep-ph/040903?

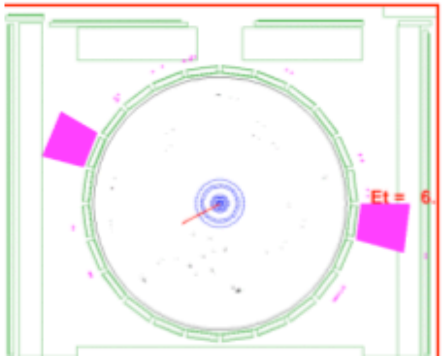
Claim factor ~ 3 uncertainty ; Correlated to p+H+p

36 fb





$\gamma\gamma \to \gamma\gamma \;\&\; q\bar{q} \to \gamma\gamma$ much smaller



$E_T(\gamma) > 5\,\text{GeV}; |\eta(\gamma)| < 1.0$

3 candidates, 2 golden, 1 ? $\pi^0\pi^0$?

36 fb → 0.8 events

$$\boxed{\text{Note}: \sigma_{MEAS} \approx 2\times10^{-12}\sigma_{INEL}\,!}$$

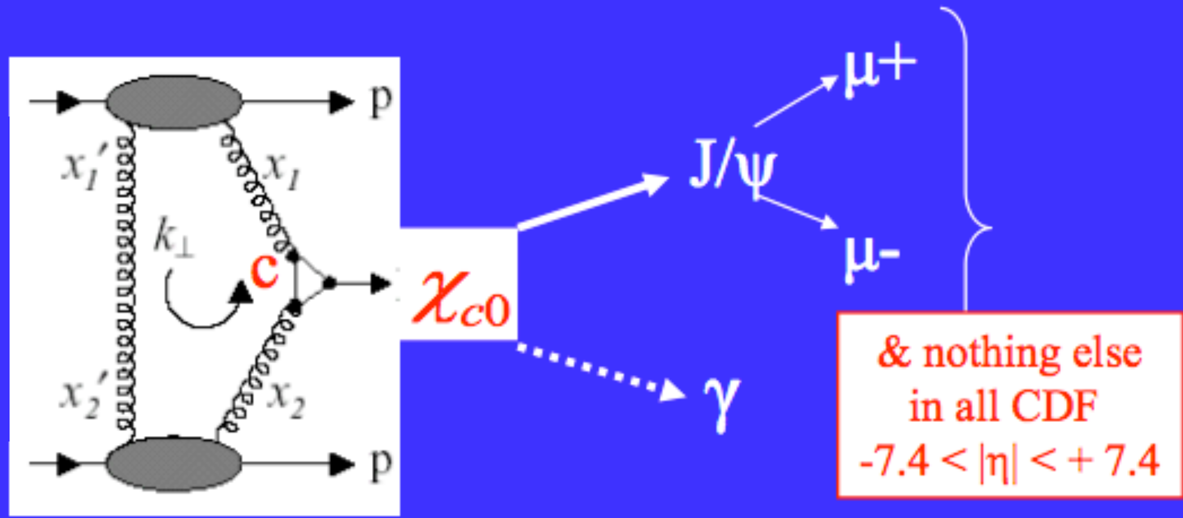
New data, Lower threshold, possible "observation"

CDF measured exclusive $\chi c \rightarrow J/\psi + \gamma \rightarrow \mu+\mu- \gamma$

$$\frac{d\sigma}{dy}\Big|_{y=0} = 78 \pm 10 \pm 10 \text{ nb}$$

KMR (Durham) prediction : 90 nb

Uncertaint y factor "several"



Added to CDF: Beam Shower Counters BSC:
Scintillator paddles tightly wrapped around beam pipes.
Detect showers produced in beam pipes if p or p dissociate.
e.g. $p \rightarrow p\pi^+\pi^-$ 8 + 10 counters

$$5.2 < |\eta| < 7.4$$

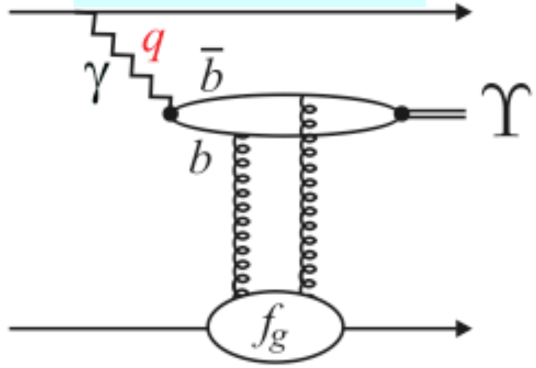
If these are all empty, p and p did not dissociate
(or BSC inefficient, could estimate from data)
but went down beam pipe with small (<~ 1 GeV/c) transverse momentum.

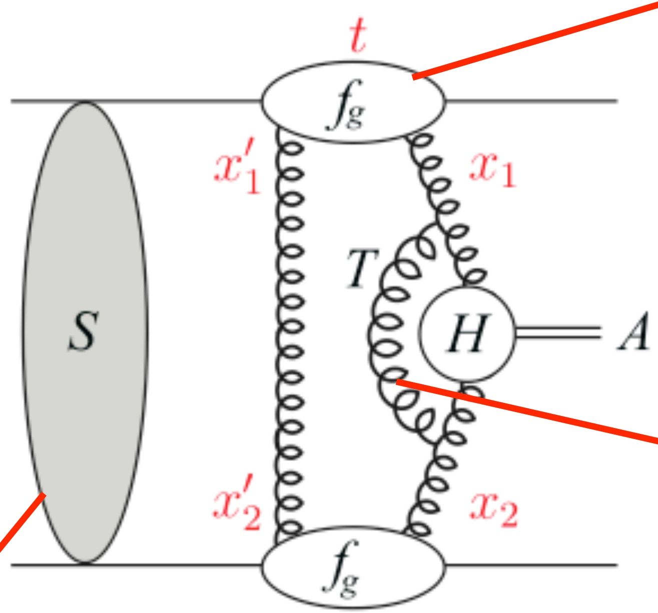
What can we learn from early LHC data?

In fact we can learn a lot when studying events with rapidity gaps
… and more when having access to scattered protons

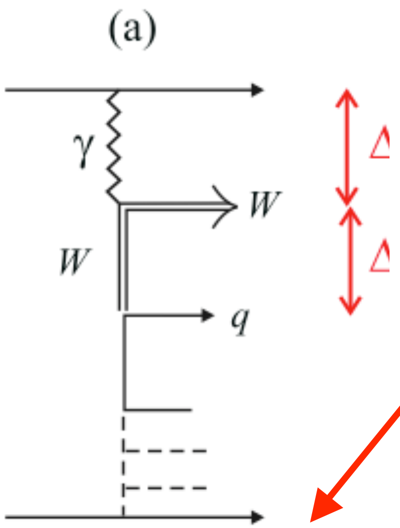
Main uncertaintes
- Unintegrated PDF
- Sudakov suppression T
- Soft gap survival S

Υ production



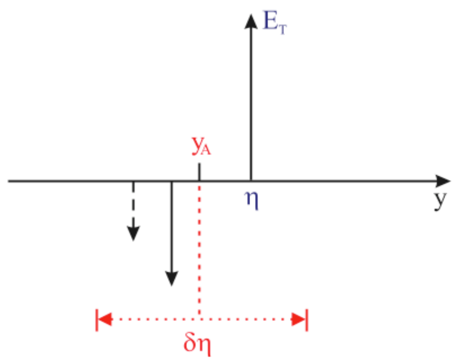


3 jet events measurements



Diffractive W production

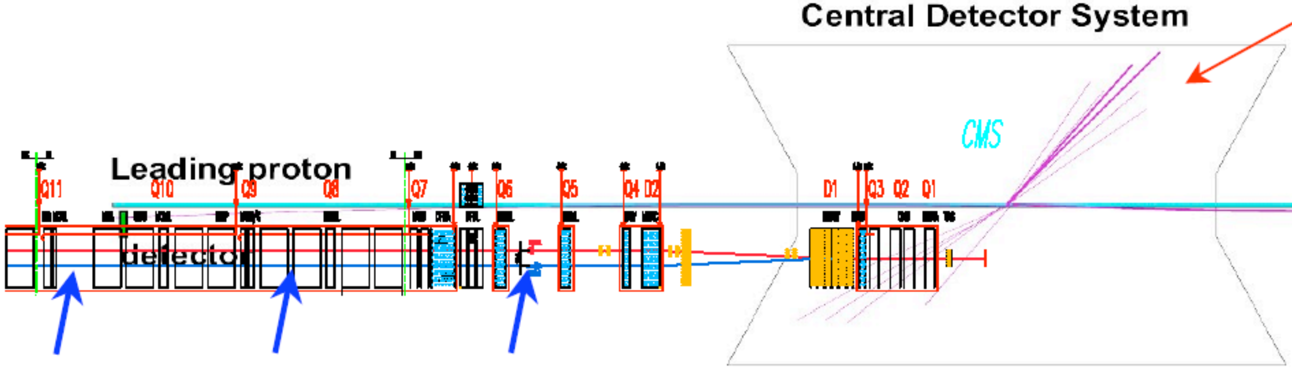
Khoze et al,
arXive:0803.3939



Can we do this experimentally?

The FP420 R&D effort

FP420: Detectors at 420m

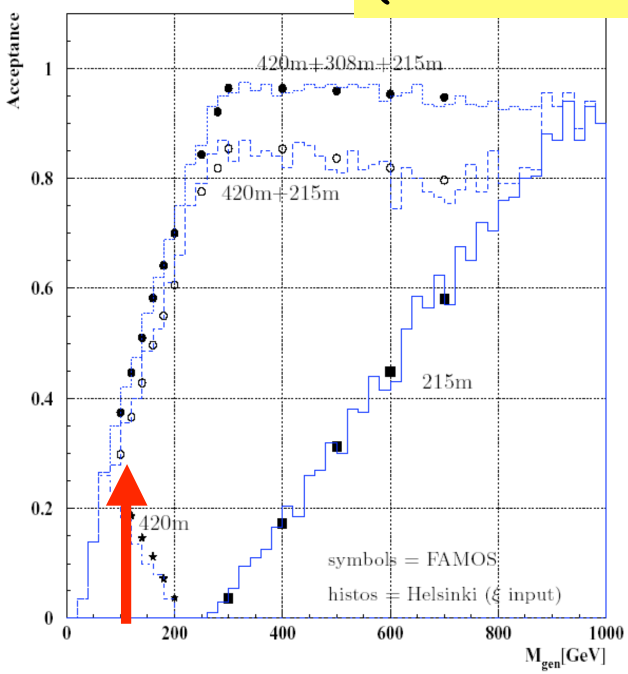


$M^2 = \xi_1 \xi_2 S$

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

FP420

TOTEM (ATLAS/RP220)



Low β^*: (0.5m): Lumi 10^{33}-10^{34} $cm^{-2}s^{-1}$

215m: $0.02 < \xi < 0.2$

300/400m: $0.002 < \xi < 0.02$

Detectors in the cold region are needed to access the low ξ values

FP420 R&D Study

FP420 History

- Higgs prod. with RapGaps: Dokshitzer, Troyan and Khoze '87
- End of the 90's: interest growing in "diffractive Higgs production"
- Expected to be cleaner than incl. production. High cross section predicted by Bialas&Landhoff, and Nachtmann et al.
- Many groups get interested (Tel Aviv, Durham,…) and make calculations of the central exclusive production process. K. Piotrzkowski on exclusive Higgs production in $\gamma\gamma$
- R. Orava, ADR, Khoze,… write in 2002 a paper on the Higgs measurement and experimental issues proposing detectors at 420 m. Cross sections are still used to date.
- December 2003: Forward physics meeting in Manchester
- June 2004; Formation of the FP420 R&D collaboration
- June 2005: LOI to LHCC CERN-LHCC-2005-025 ; LHCC-I-015
- April 2008: R&D report of FP420 ready
- Now in the hands of the CMS/ATLAS collaborations

IPPP/02/29
DCPT/02/58
12 August 2002

Ways to detect a light Higgs boson at the LHC

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[b] Institute for Particle Physics Phenomenology, University of Durham, DH1 3LE, UK
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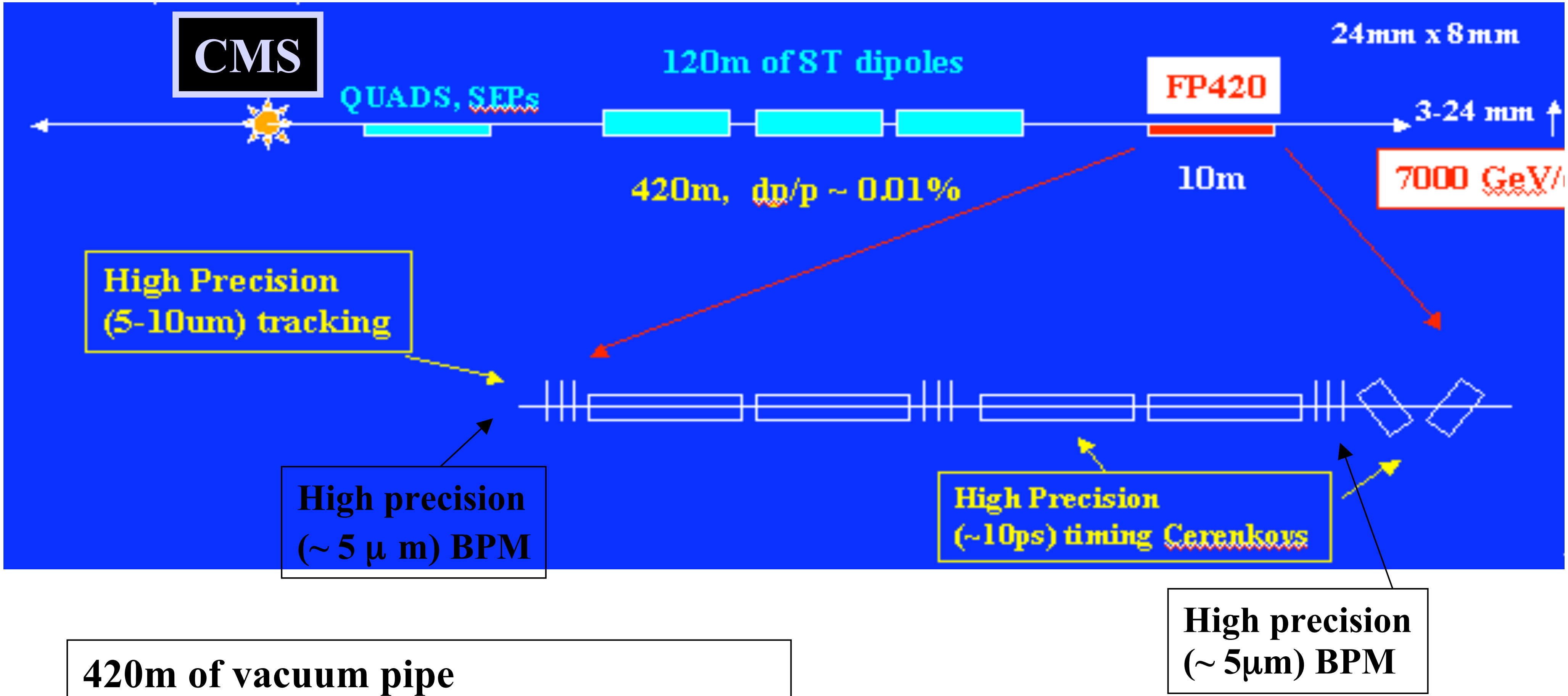
[d] Department of Physical Sciences, University of Helsinki, and Helsinki Institute of Physics, Finland

Abstract

We summarize the possible processes which may be used to search for a Higgs boson, of mass in the range 114–130 GeV, at the LHC. We discuss, in detail, two processes with rapidity gaps: exclusive Higgs production with tagged outgoing protons and production by Weak Boson Fusion, in each case taking $H \to b\bar{b}$ as the signal. We make an extensive study of all possible $b\bar{b}$ backgrounds, and discuss the relevant experimental issues. We emphasize the special features of these signals, and of their background processes, and show that they could play an important role in identifying a light Higgs boson at the LHC.

Schematic of Extremely High Precision Proton Spectrometer

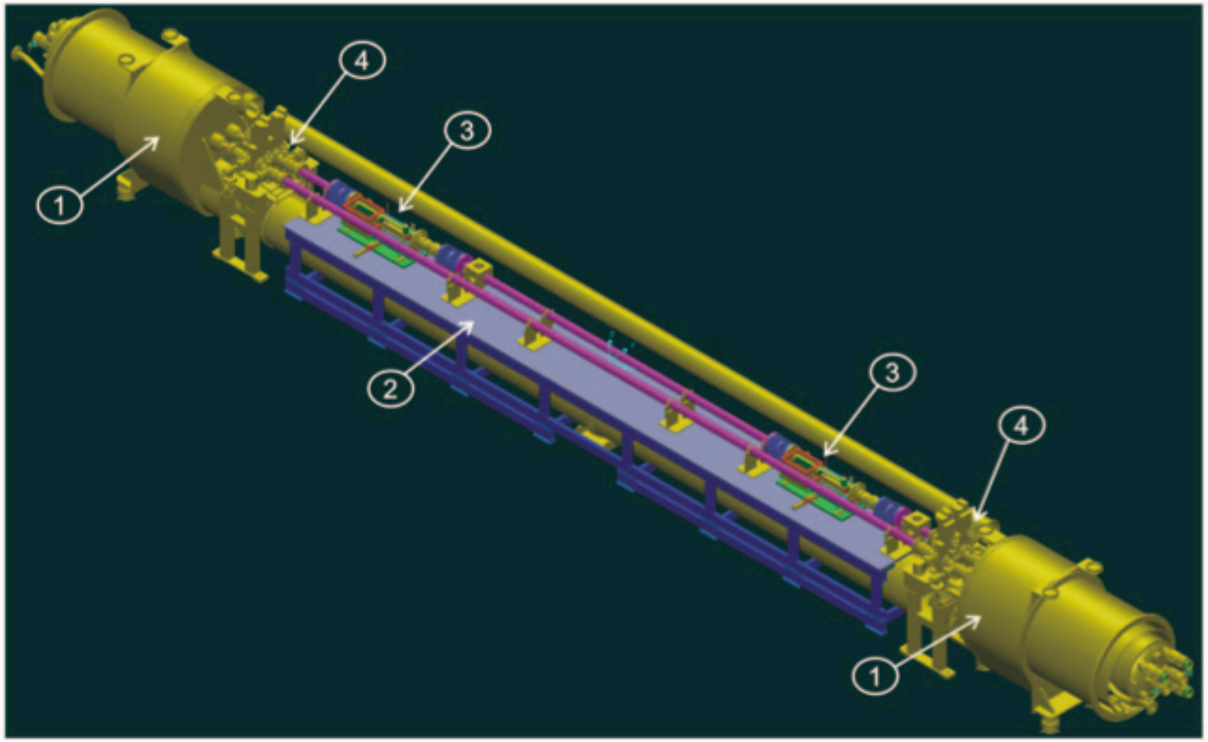


420m of vacuum pipe
120m of 8T dipoles
Precision ~ 5 µ m on track displacement and ~ 1 µ rad on angle w.r.t. beam.

"Small detectors" but huge challenges!!
Also spin-off to other applications

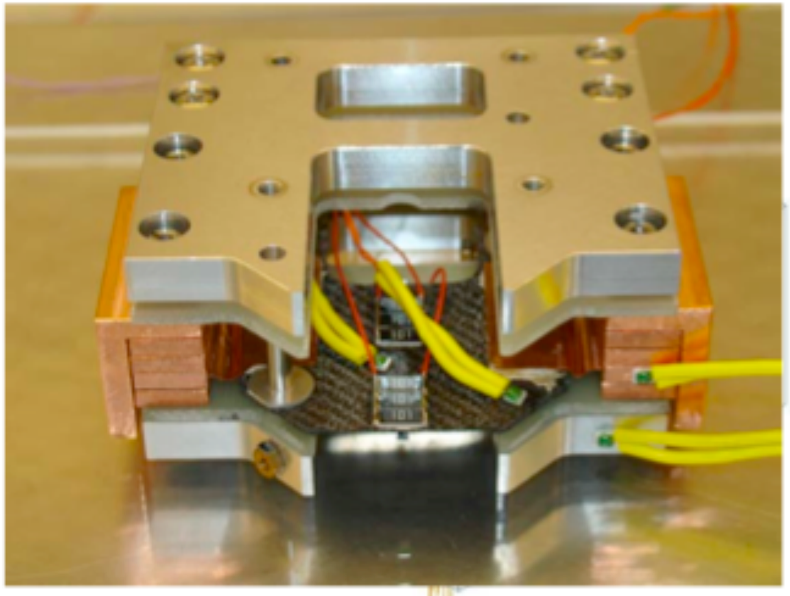
FP420

Detectors at 420 m from the IP to detect forward protons



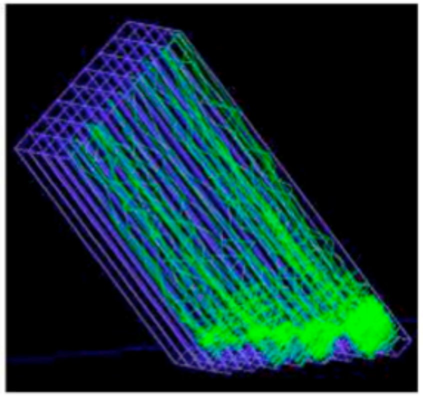
Replace empty cryostat with ATMs and “FP420” beampipe containing tracking (silicon or other) and timing detectors

Detectors: Tracking/Timing



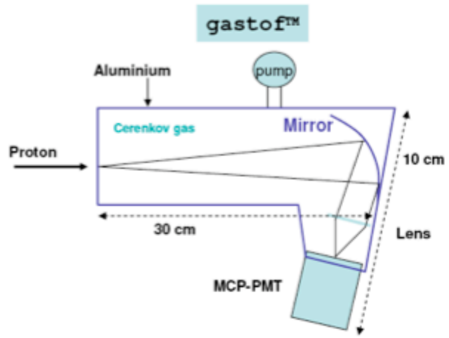
Tracking:
Proposed solution 3D dectors

Quartic (FNAL, Alberta, UTA)



More than 50% of the photons arrive within the first 5 ps.

GASTOF (Louvain)



all the photons arrive within $\approx$ 3 ps

Timing Detectors
Quartic and GASTOF

Burle 85011-501 with 25 μm pores

Hamamatsu R3809U-50 with 6 μm pores

Test beam FNAL March 2007:

δt (G1) = 32ps

δt (G1) = 13ps

δt (Quartic) = 82ps / bar - 13 measurements / detector -> 23ps

CERN test beam July 08 – 40ps / bar Quartic -> 10ps

Fast Timing Detectors

Check that p's came from same interaction vertex
(& as central tracks) ~ 10 ps

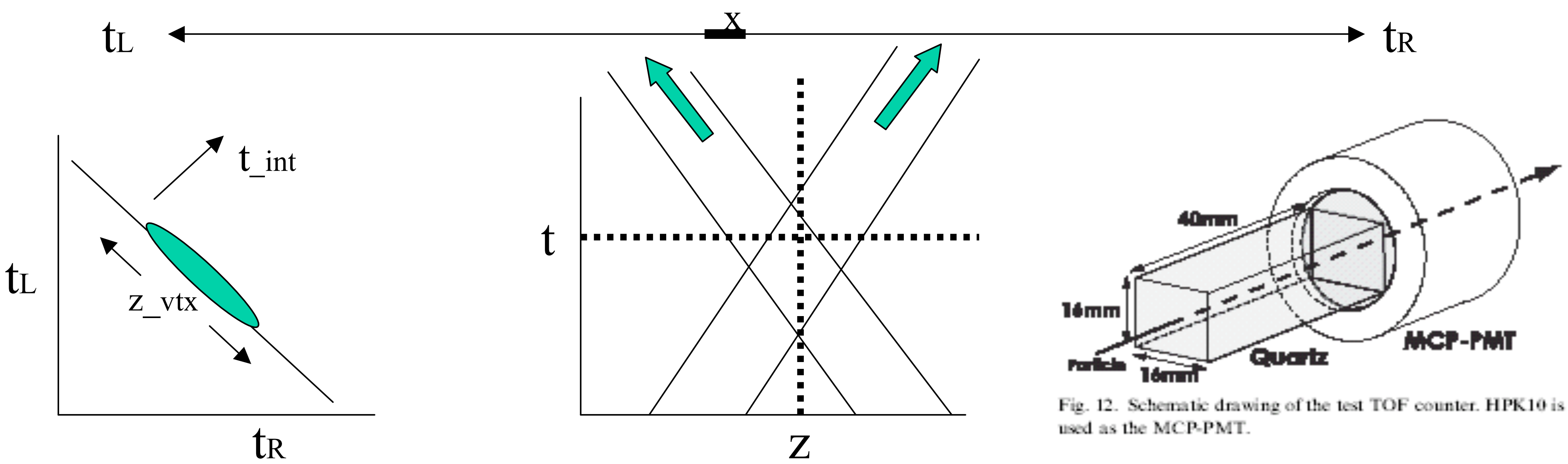
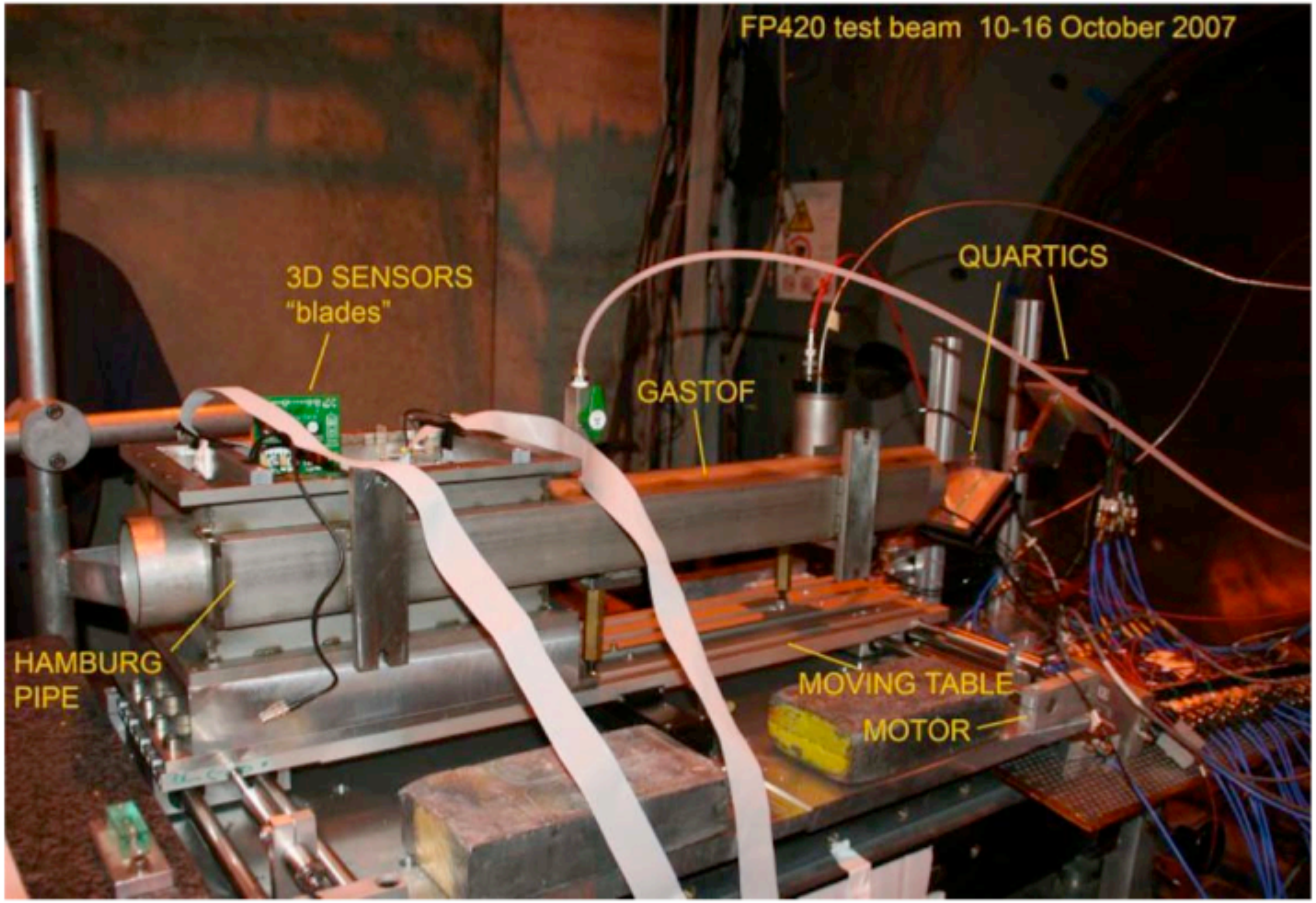


Fig. 12. Schematic drawing of the test TOF counter. HPK10 is used as the MCP-PMT.

Expected to be particularly useful/essential at high luminosity

October 2007 Testbeam at CERN

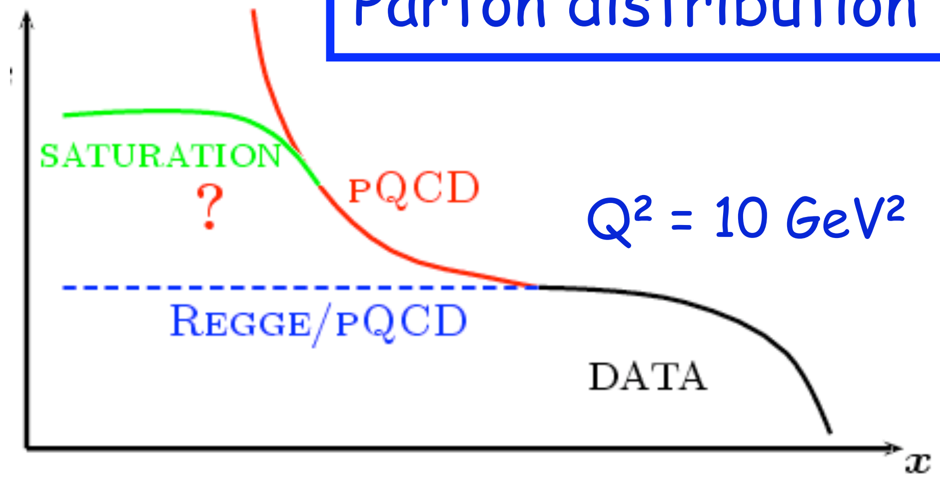


+ testbeam campaigns at FNAL for timing detectors

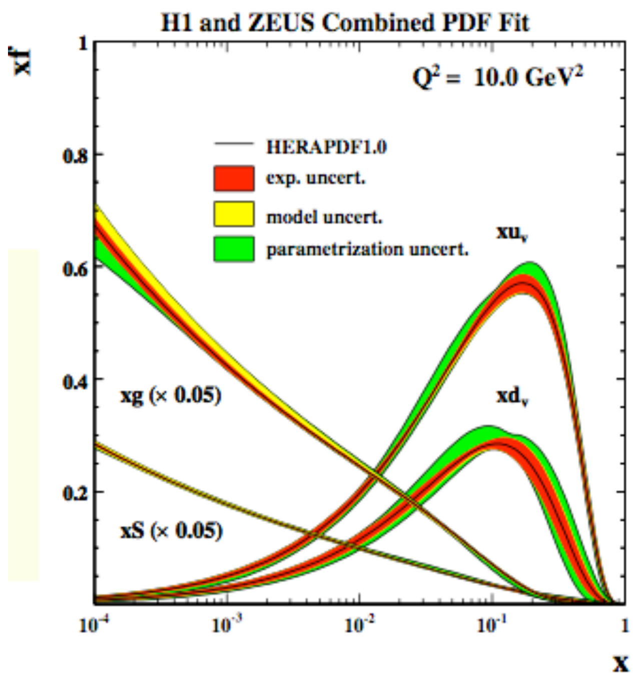
Low-x QCD

Parton Densities and Saturation

Parton distribution in the proton

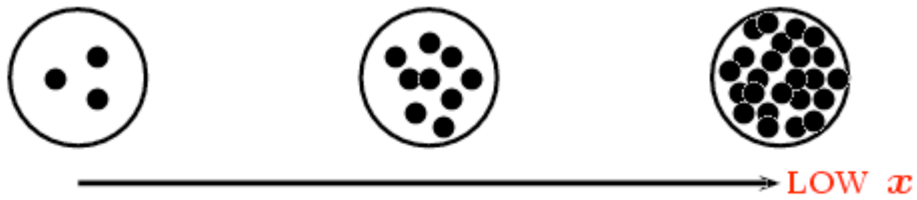


$Q^2 = 10\ GeV^2$



x = Bjorken's variable=
= fraction of proton's momentum carried by struck quark

Q^2 = scale (resolution)



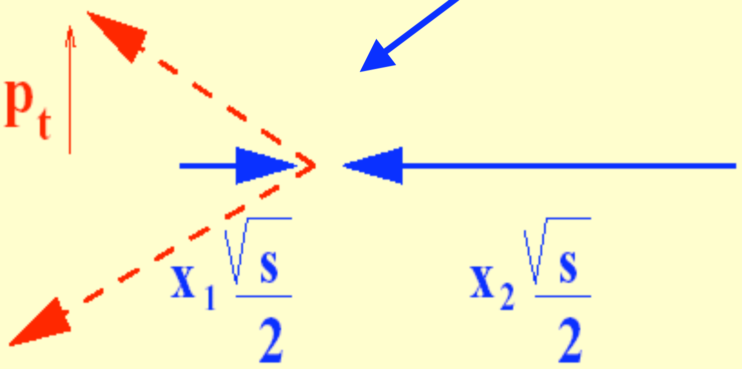
Parton saturation at low x?
Formation of hot-spots in the proton?

Parton distributions

Reconstruct x_1 and x_2

$x_1 = p_t(e^{\eta 1} + e^{\eta 2})/\sqrt{s}$

$x_2 = p_t(e^{-\eta 1} + e^{-\eta 2})/\sqrt{s}$



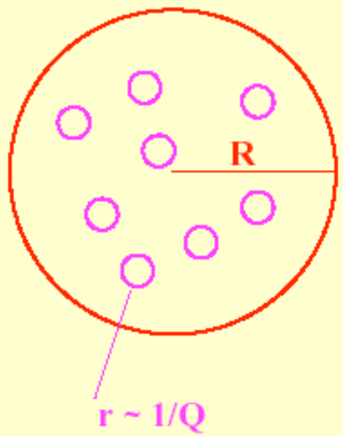
$$x_1 > \frac{4p_t^2}{x_s \cdot s}$$

$$p_t = 10\,\mathrm{GeV} \rightarrow \Theta < 10^{-3}$$

$$\eta \sim 7 - 8$$

saturation:

$$\frac{\alpha_2}{Q^2} xg(x, Q^2) > \pi R^2$$

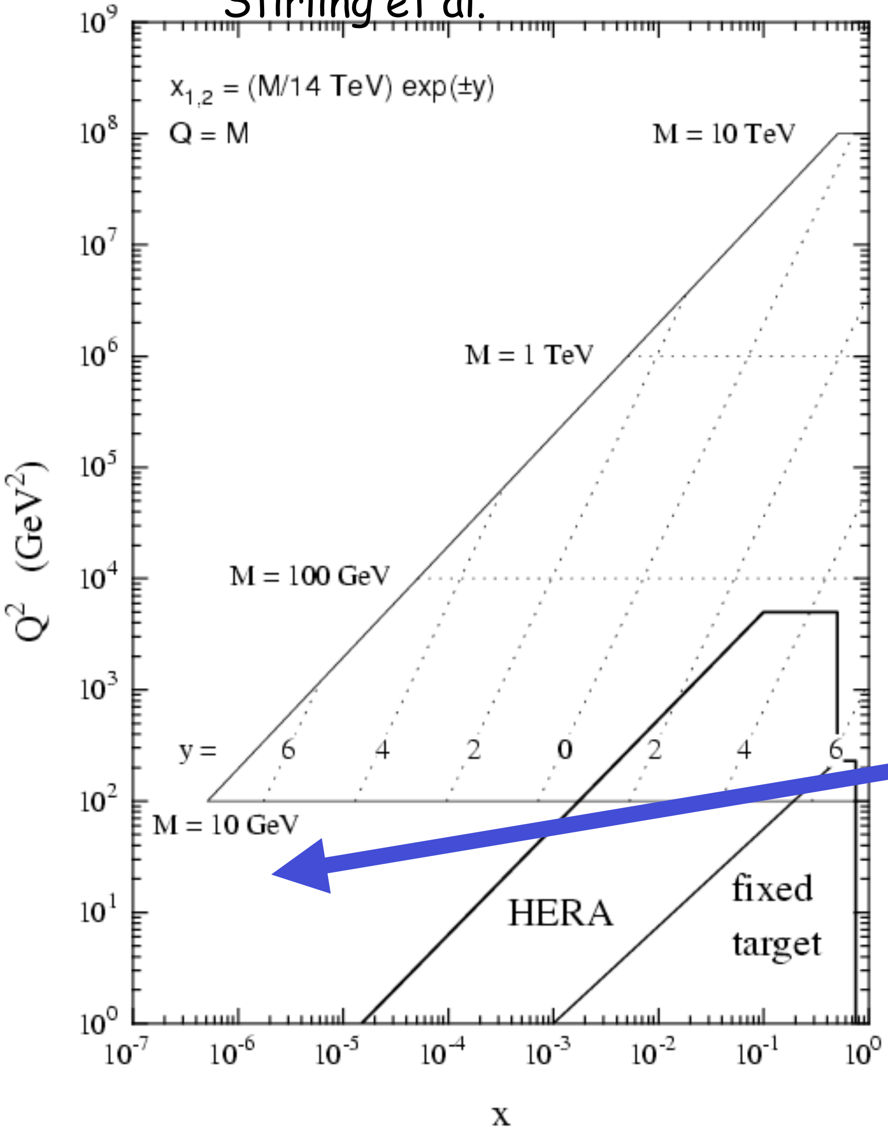


Where will the saturation happen? Naïve argument based on geometry (Mueller)

$\boxed{xG(x,Q^2) \sim 6\, Q^2}$

Low-x at the LHC

Stirling et al.



LHC: due to the high energy can reach small values of Bjorken-x in parton densities $g(x,Q^2)$, $q(x,Q^2)$

Processes:

$p(p_1)+p(p_2)\to \text{jet}+\gamma+\ X$	Prompt photons
$p(p_1)+p(p_2)\to l\bar{l}+\ X$	Drell-Yan
$p(p_1)+p(p_2)\to \text{jet}_1+\text{jet}_2+\ X$	Jets
$p(p_1)+p(p_2)\to Q+\bar{Q}+\ X$	Heavy Flavours
$p(p_1)+p(p_2)\to W/Z+\ X$	W,Z production

If rapidities below 5 and masses below 10 GeV can be covered $\Rightarrow$ x down to 10^{-6}-10^{-7}

Proton structure at low-x !!

High Energy QCD

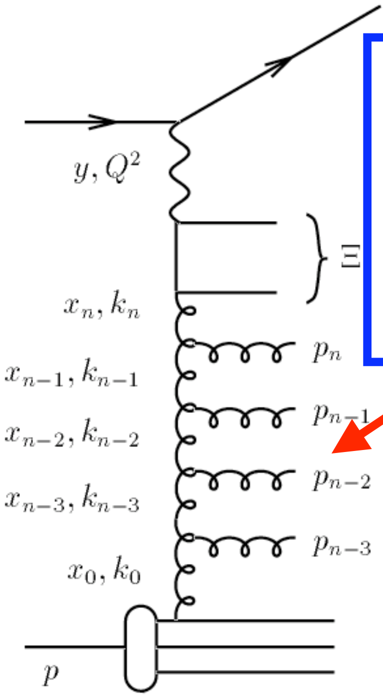
- Strong interactions at large partonic center of mass energy s and momentum transfer t, such that s>>|t| → region of the BFKL theory
  → domain of small x

•BFKL equation resums multiple gluon exchanged in t channel
resums α_s log1/x terms

•It predicts a power increase of the cross section

•BFKL effect not yet unambigeously established in present data

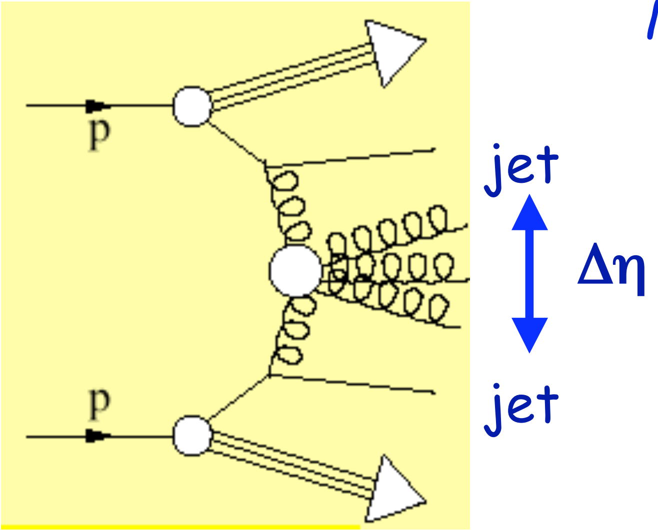
BFKL = Balitski-Fadin-Kuraev-Lipatov



Study of the parton evolution in the ladder

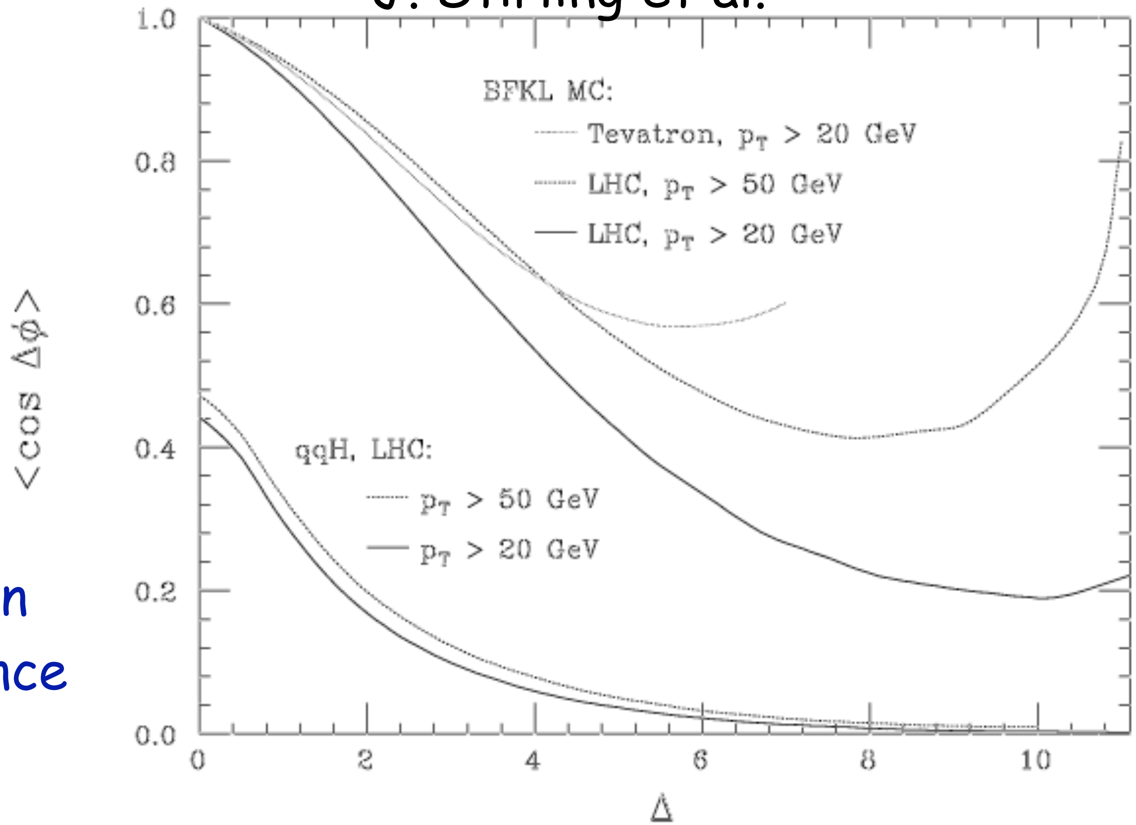
Also called hard / pertubative /BFKL pomeron

Di-jets in pp scattering



Measurements for low-x (BFKL) dynamics

J. Stirling et al.



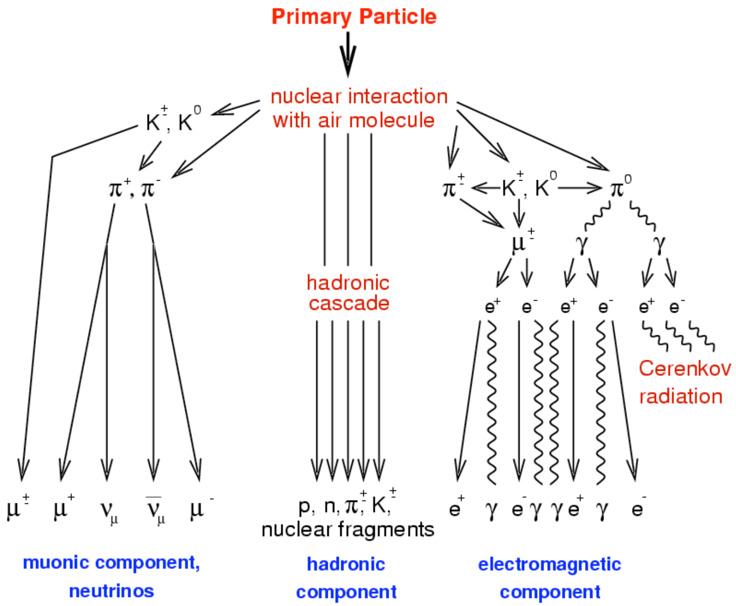
Azimuthal decorrelation between the 2 jets versus rapidity distance between the 2 jets

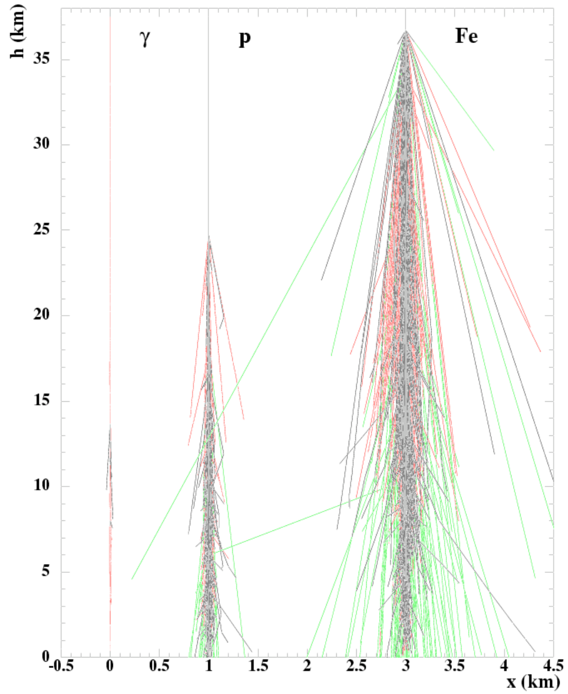
Large Δη range needed

The more forward coverage, the better…

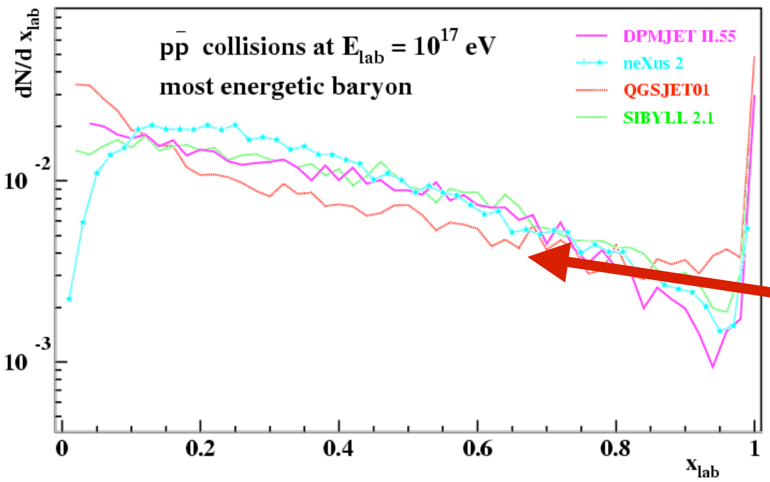
Forward Physics and Cosmic Rays

High Energy Cosmic Rays



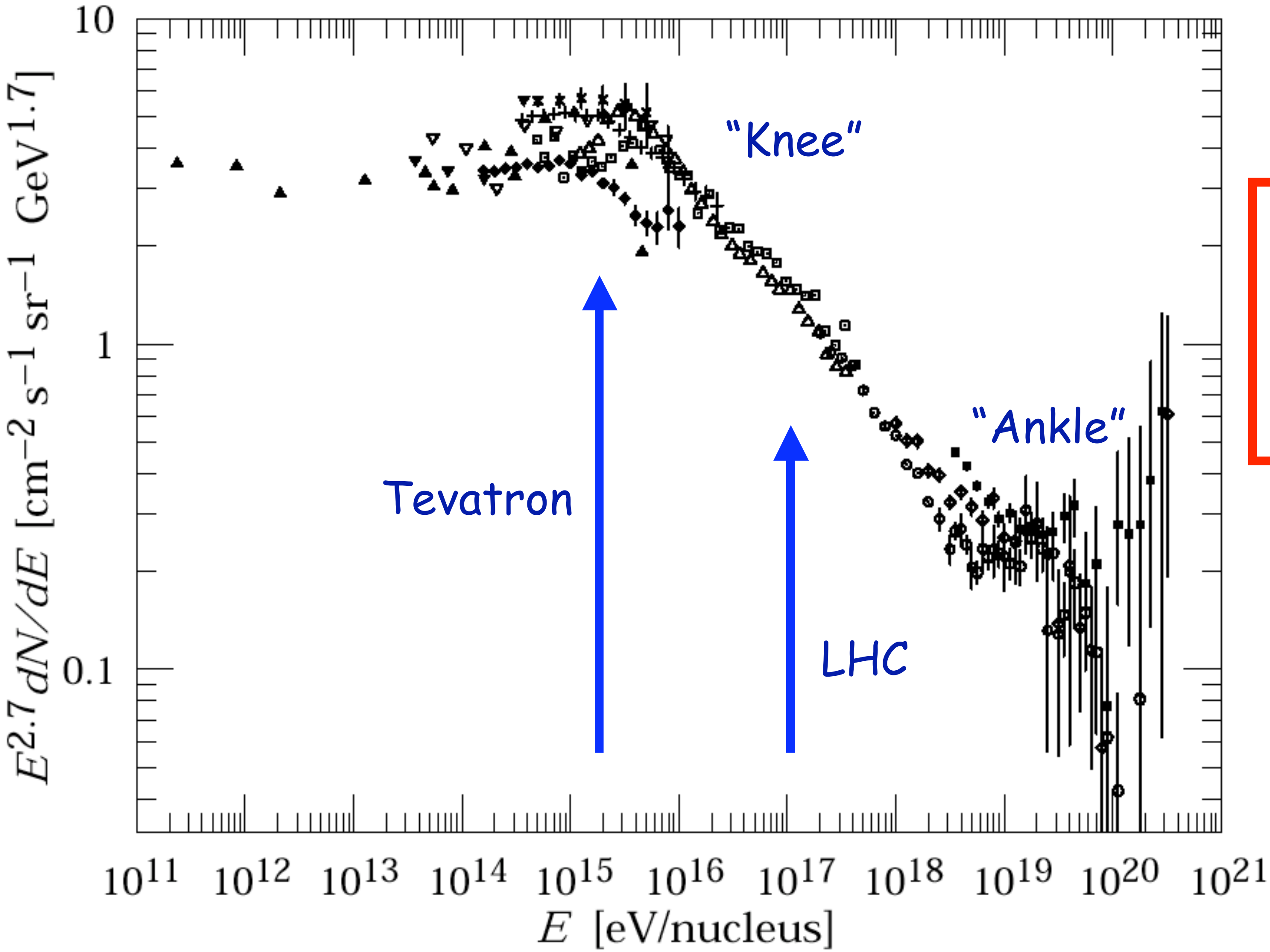


Cosmic ray showers:
Dynamics of the high energy particle spectrum is crucial



Interpreting cosmic ray data depends on hadronic simulation programs
Forward region poorly know/constrained
Models differ by factor 2 or more
Need forward particle/energy measurements
e.g. $dE/d\eta$…

Connection to Cosmic Rays

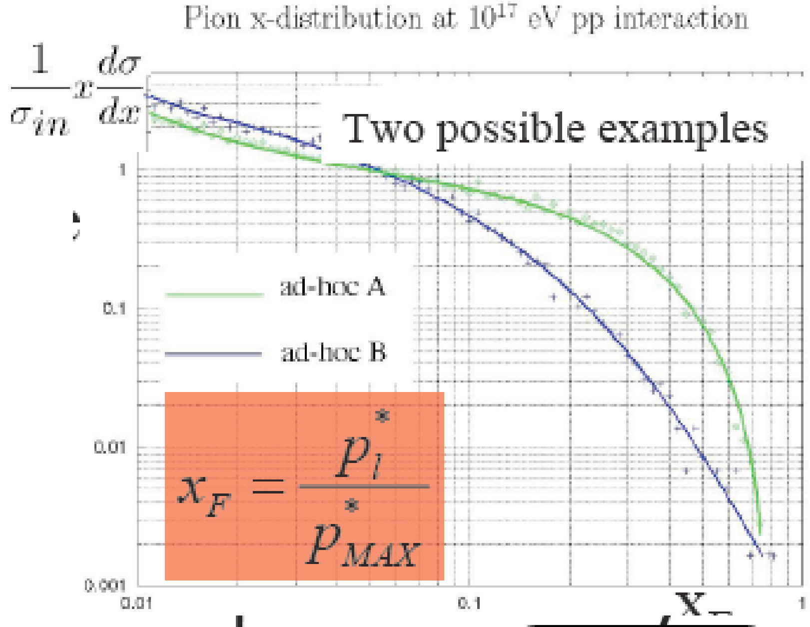


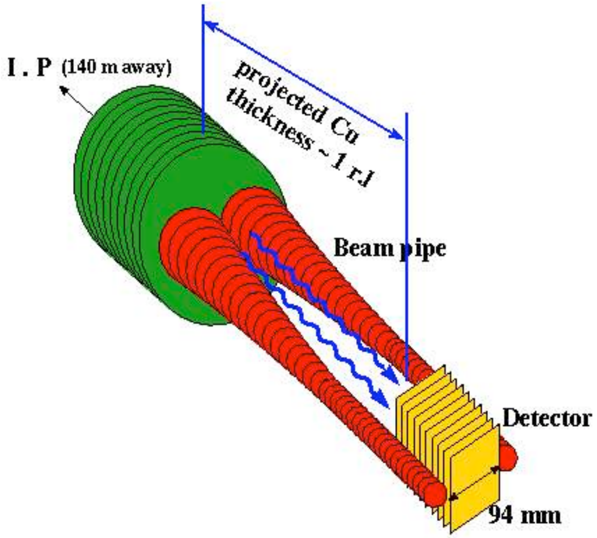
Energy of incident particles in cosmic rays

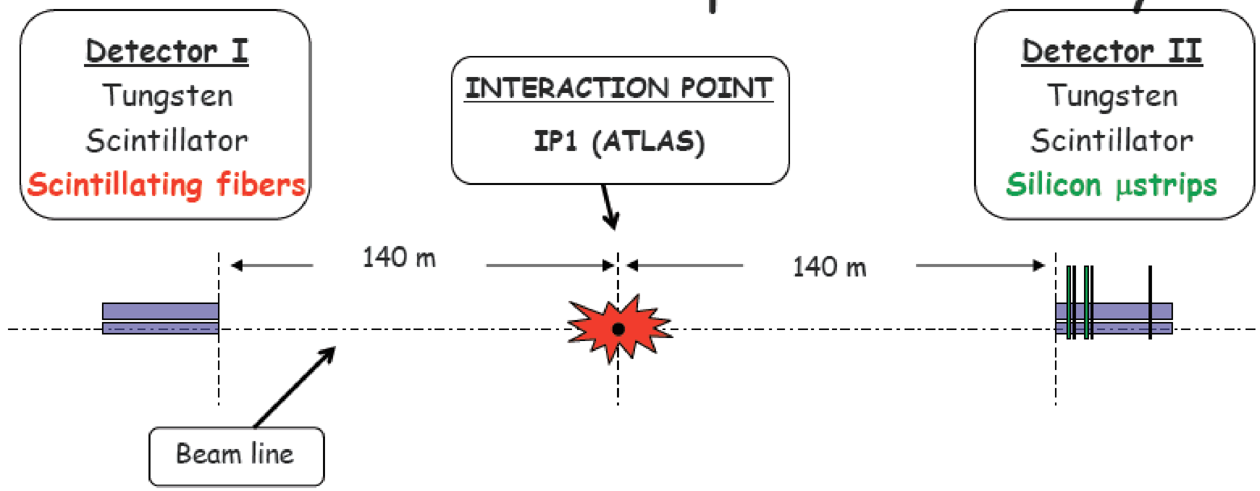
LHCf: an LHC Experiment for Astroparticle Physics

LHCf: measurement of photons and neutral pions and neutrons in the very forward region of LHC

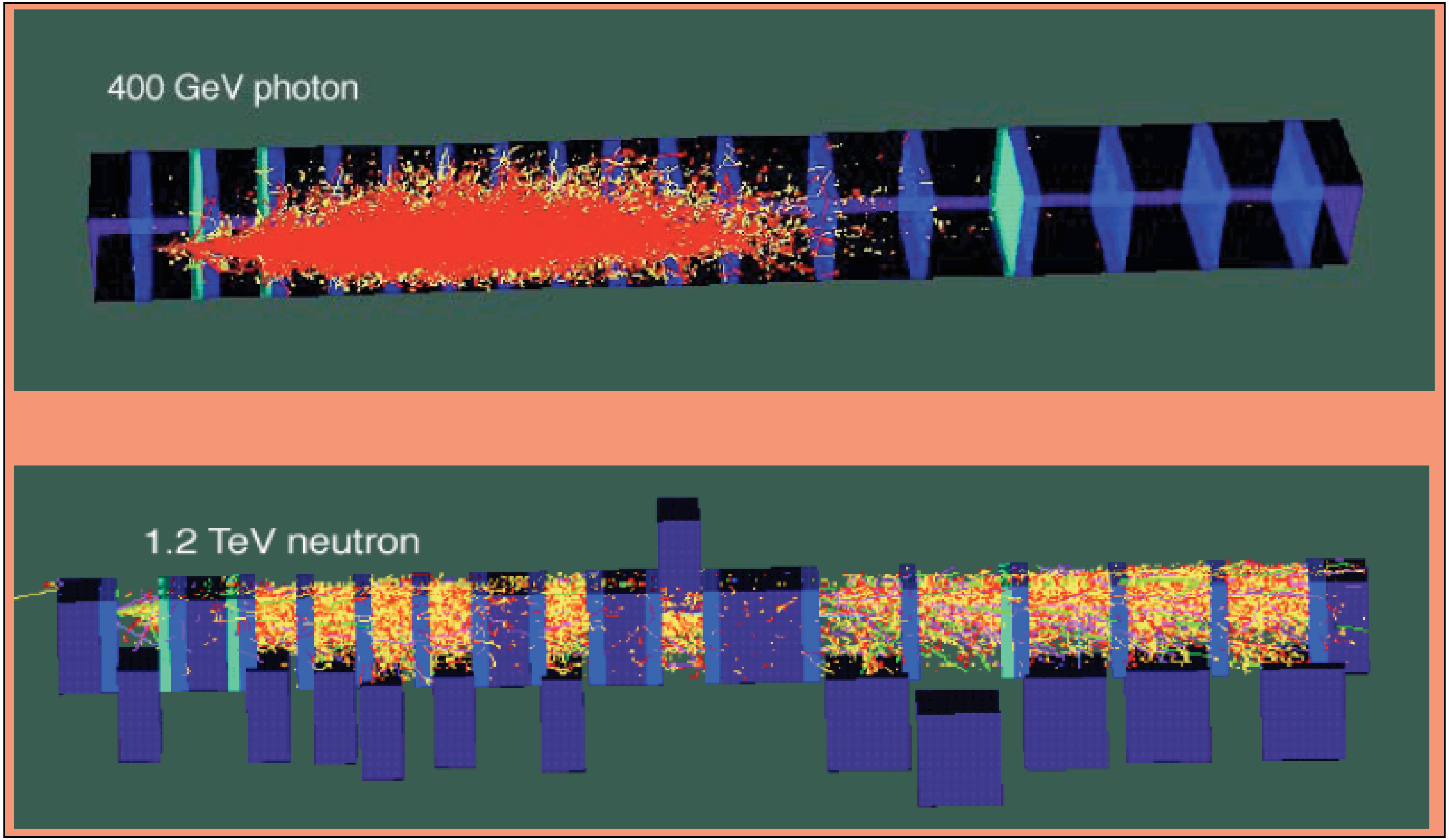
Add an EM calorimeter at 140 m from the Interaction Point (IP1 ATLAS)
For low luminosity running



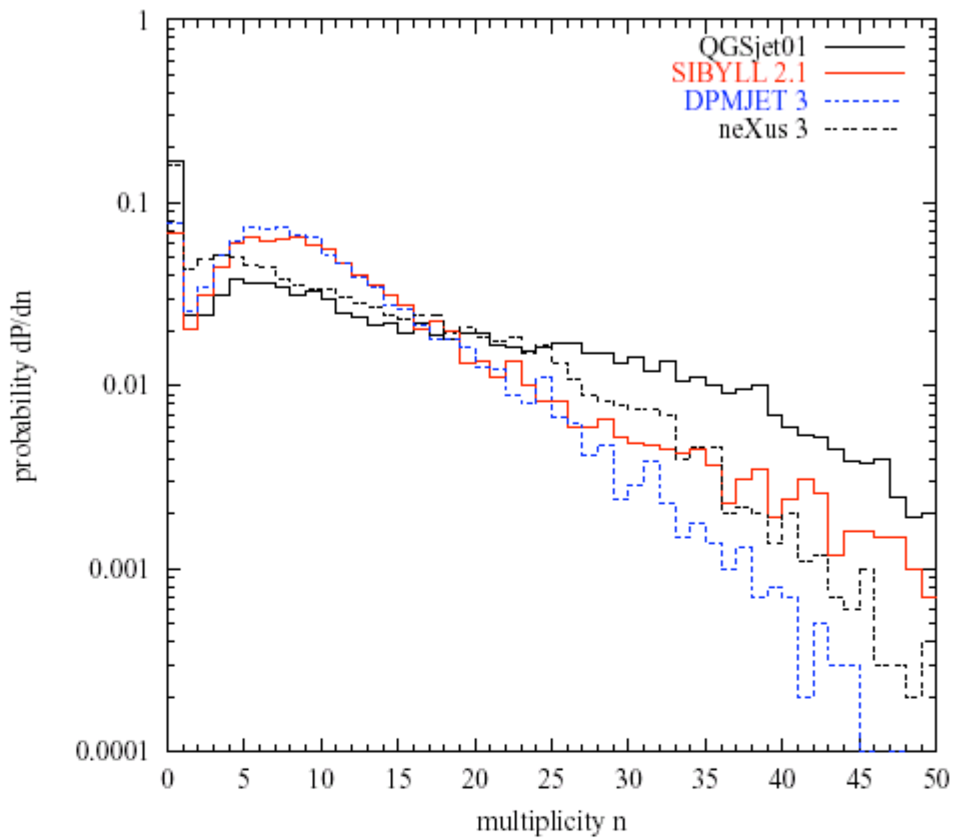




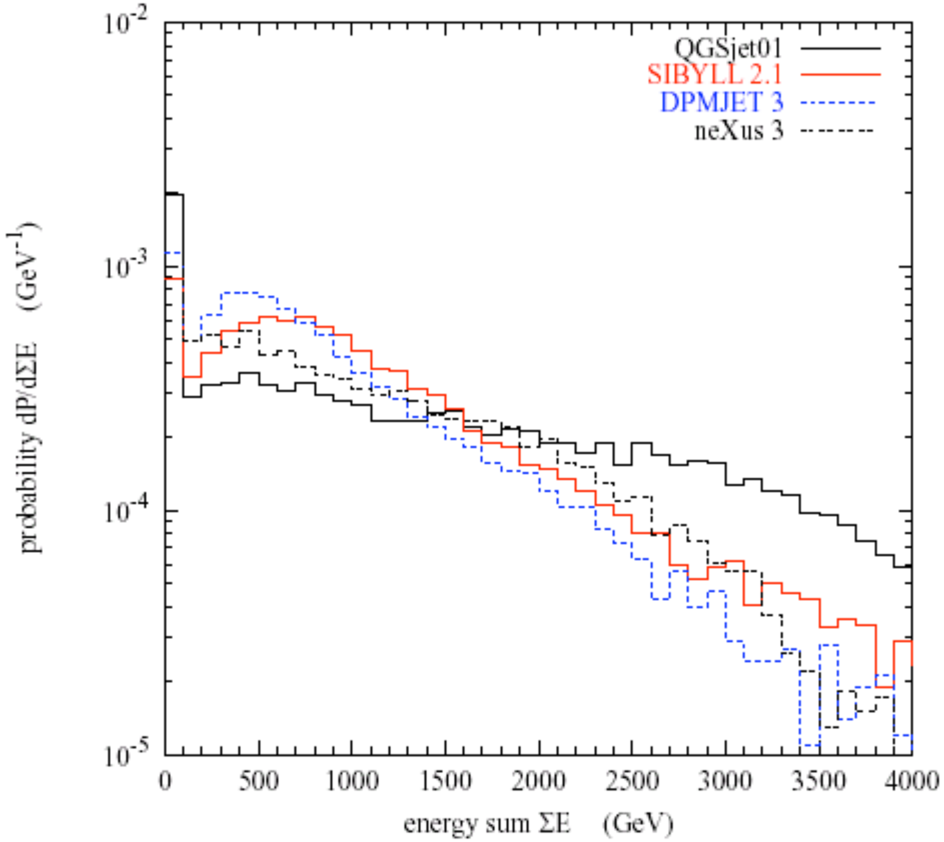
Particle response



Model Predictions: proton-proton at the LHC



total multiplicity in forward detector
$(5 \leq \eta \leq 7)$



total energy in forward detector
$(5 \leq \eta \leq 7)$

Predictions in the forward region within the CMS/TOTEM acceptance
Large differences between models

Wish List from Cosmic Rays

Astro- & cosmic ray physics needs

R. Engel
Blois Workshop '03

- particle combinations p-p, p-A, and A-B
- total, elastic, and diffractive cross sections

$\boxed{\text{Forward}}$

- leading hadron distributions

$\boxed{\text{Forward}}$

  - minimum bias trigger
  - fully inclusive (no need to distinguish between p and n)
  - leading π^0 distribution very important
- general event features

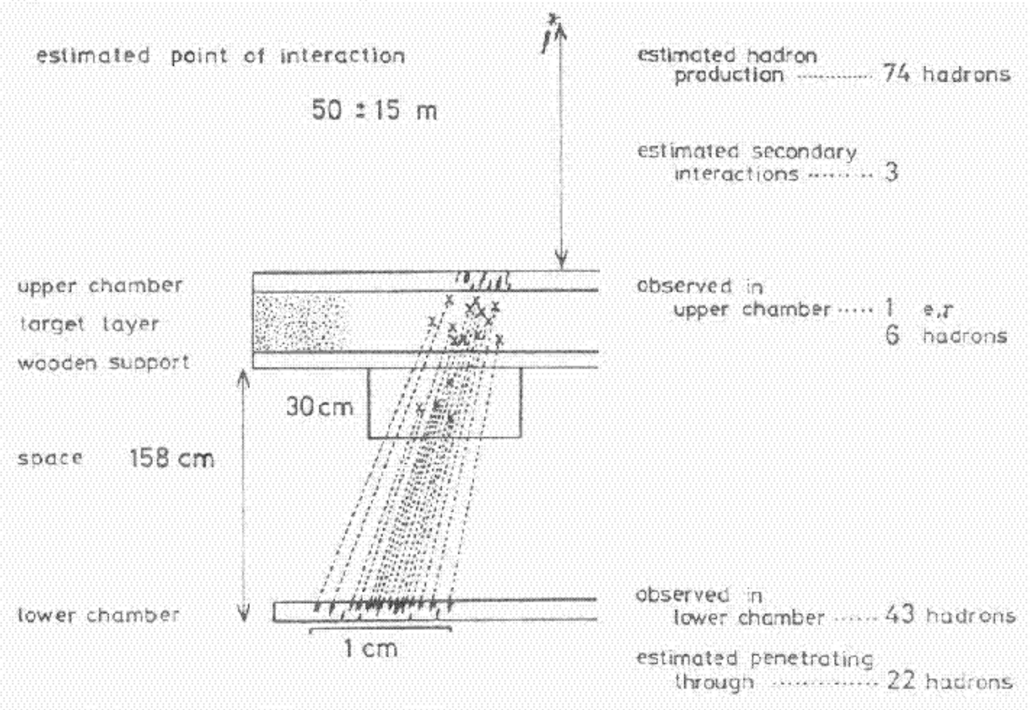
$\boxed{\text{Forward+Central}}$

  - mean multiplicity and multiplicity distribution
  - inclusive $p_\perp$ distributions
  - low-$p_\perp$ jets (inclusive & distribution)
  - correlations: forward/central event features

Still valid requests!

Some Cosmic ray people have joined LHC experiments

Exotica: e.g. Centauros



Chacaltaya experiment

Table 2.2: Characteristics of Chacaltaya Centauros.

CHACALTAYA CENTAUROS					
Centauro no.	I	II	III	IV	V
Chamber no.	15	17	17	17	16
Observed in the chamber					
N_γ	1	-	-	-	-
N_{unid}	-	5	26	61	34
N_h	49	32	37	38	31
$\Sigma E_h^\gamma [TeV]$	222	179	169	144	167
$\Sigma E_{tot} [TeV]$	231	203	270	286	285
Q_h	0.96	0.88	0.63	0.50	0.59
					0.72*

Events with essentially no electromagnetic component (large average pt/particle and long penetrating showers)

Possible explanations

- Exotic extraterestial glob of matter
- Diffractive firebal
- Disoriented chiral condensates
- Strange quark matter

...

Significant???
Never seen at an accelerator
...sofar.

Summary

- LHC is coming on-line: expect the first 10 TeV collisions by early 2010
  - Use the first data to look for soft/hard diffraction signatures
    - W, Jets production
    - Exclusive production eg Υ (and J/ψ) production
    - Measure the gap survival probability at the LHC for several processes
- Exclusive measurements of Higgs/New physics with additional detectors (FP420/RP220)
- Forward physics @ LHC came a long way during the last years!!
  - Detectors are extending the coverage in the forward direction
  - TOTEM and LHCf are special forward physics experiments
  - Common physics program between CMS and TOTEM still in the plan
- Still many open questions in diffraction/forward physics
  - The dynamics of the rapidity gaps
  - The structure and dynamics of diffractive exchange
  - The dynamics of QCD at small x values
  - New phenomena?
- Forward physics and diffraction by now "in the blood" of the experiments.