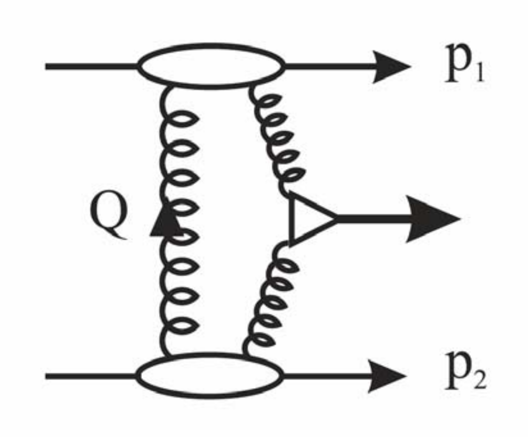
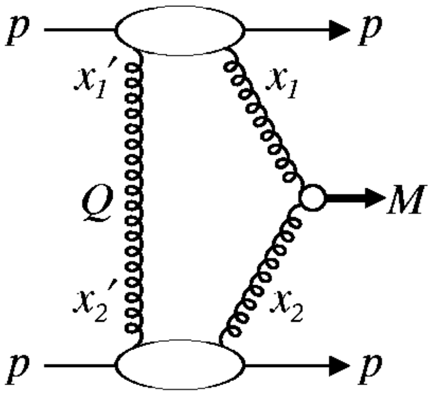
Measurement of Hard and Soft Diffraction at the LHC

Towards a DESY LOI

Henri Kowalski



Exclusive Hard and Soft Diffraction



low *x* reactions:

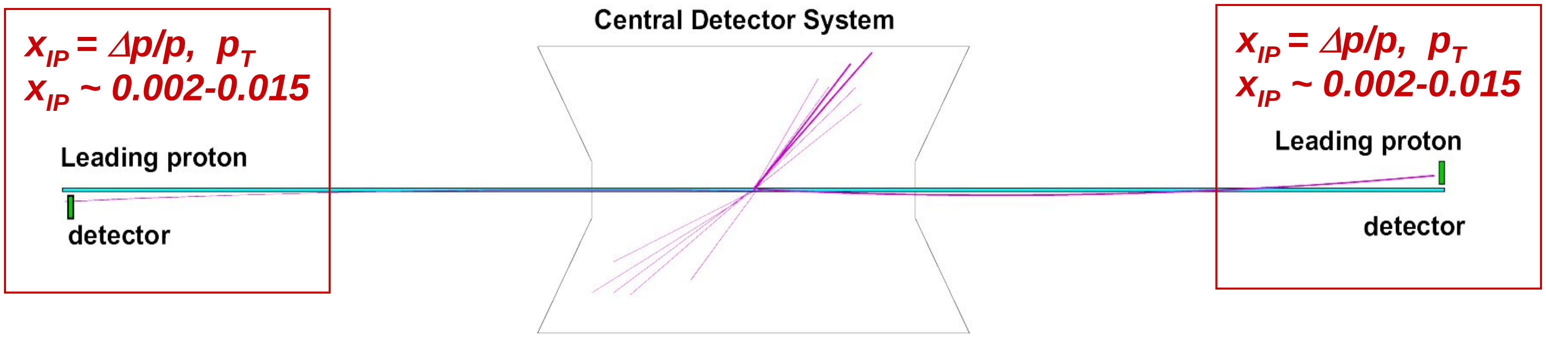
pp => pp + $g_{JET}\,g_{JET}$ $\sigma \sim$ 1 nb for $E_T > 20$ GeV , M(jj) ~ 50 GeV
$\sigma \sim 0.5$ pb for $E_T > 60$ GeV , M(jj) ~ 200 GeV
$|\eta_{JET}| < 2$

pp => pp + M(soft) $\sigma \sim 1\ \mu$b **KMR Eur. Phys J. C23, p 311**

clean study of QCD gluon radiation processes in a much larger Q2 and *t* domain than at HERA. *(Theoretical analysis of HERA data: infinite order radiation or even saturation processes present at low x)*
Study of the <u>transition</u> from <u>small</u> to <u>large</u> distances which is especially interesting in the <u>*t* distributions</u> *(t is a Fourier Trans. of a distance)*

ideal way to search for new resonances and threshold behavior phenomena

pp => pp + Higgs $\sigma \sim 3$ fb
pp => pp + exotics $\sigma \sim$??



$x_{IP} = \Delta p/p$, p_T
$x_{IP} \sim 0.002\text{-}0.015$

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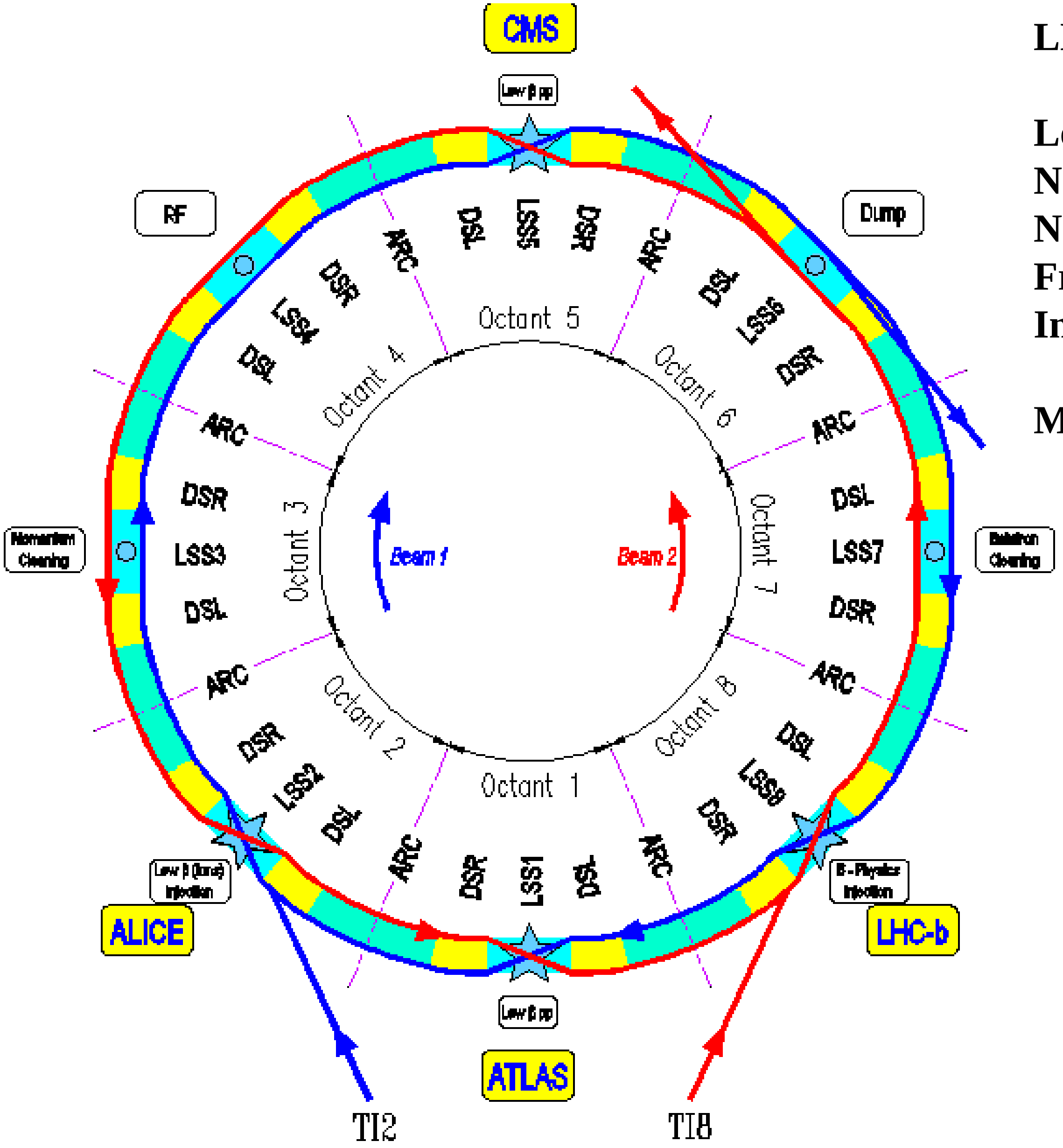


LHC parameters

Length	26.6 km
Nr. of bunches	2808
Nr. of particle/bunch	$1.15\ 10^{11}$
Frequency	40 MHz
Inter-bunch distance	25 nsec

Maximal Luminosity 10^{34} cm^{-2} s^{-1}

LHC High Luminosity Optics

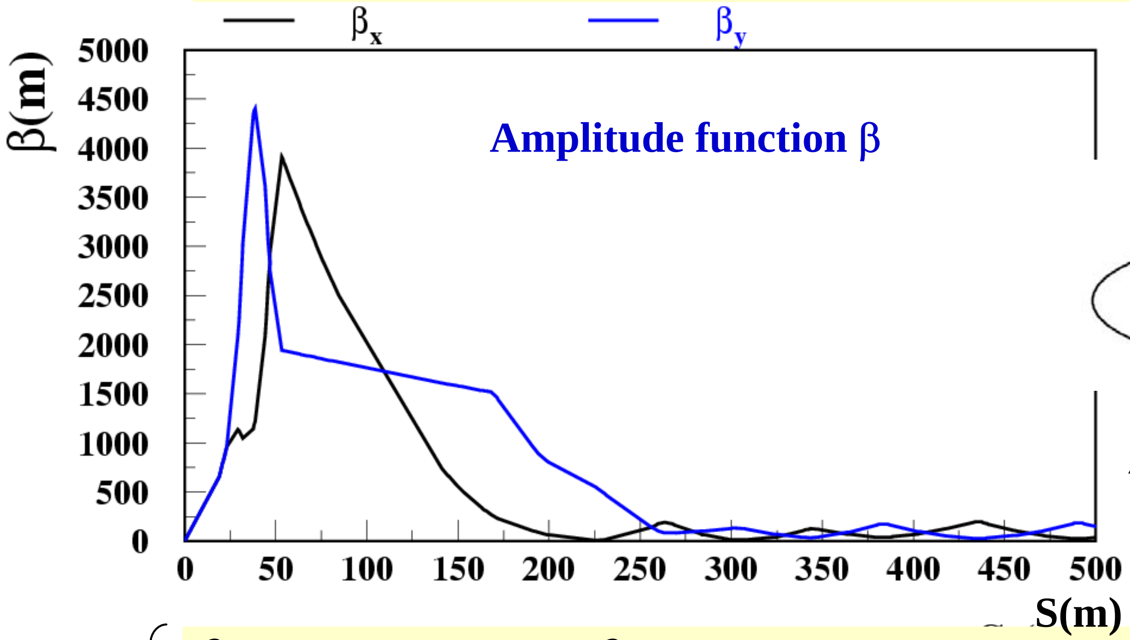
Interaction point

$$\beta_x = \beta_y = 0.55\,\mathrm{m} \qquad \varepsilon_N = 3.75\,\mu\mathrm{rad}\cdot\mathrm{m}$$

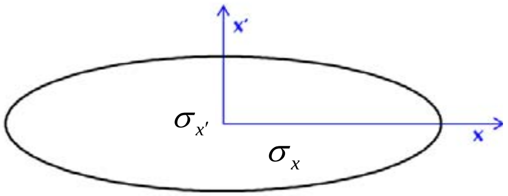
$$\sigma_x = \sigma_y = \sqrt{\varepsilon\beta} = 16.6\,\mu\mathrm{m} \qquad \varepsilon = \varepsilon_N / \gamma$$

$$\sigma_{x'} = \sigma_{y'} = \sqrt{\frac{\varepsilon(1+\alpha^2)}{\beta}} = 30.2\,\mu\mathrm{rad}$$

=> p_T~ 200 MeV



Phase Ellipse



$$\beta x'^2 + \frac{x^2}{\beta} = \varepsilon = \frac{Surface}{\pi}$$

420 m point

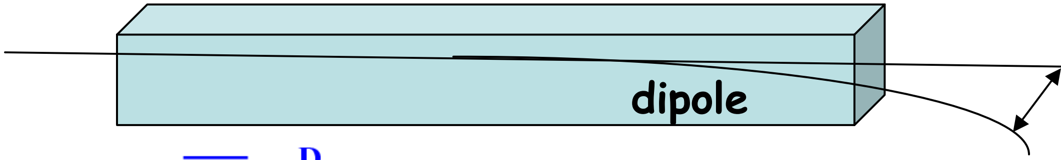
$$\beta_x = 127\,\mathrm{m} \qquad \beta_y = 52\,\mathrm{m}$$

$$\sigma_x = 253\,\mu\mathrm{m} \qquad \sigma_y = 161\,\mu\mathrm{m}$$

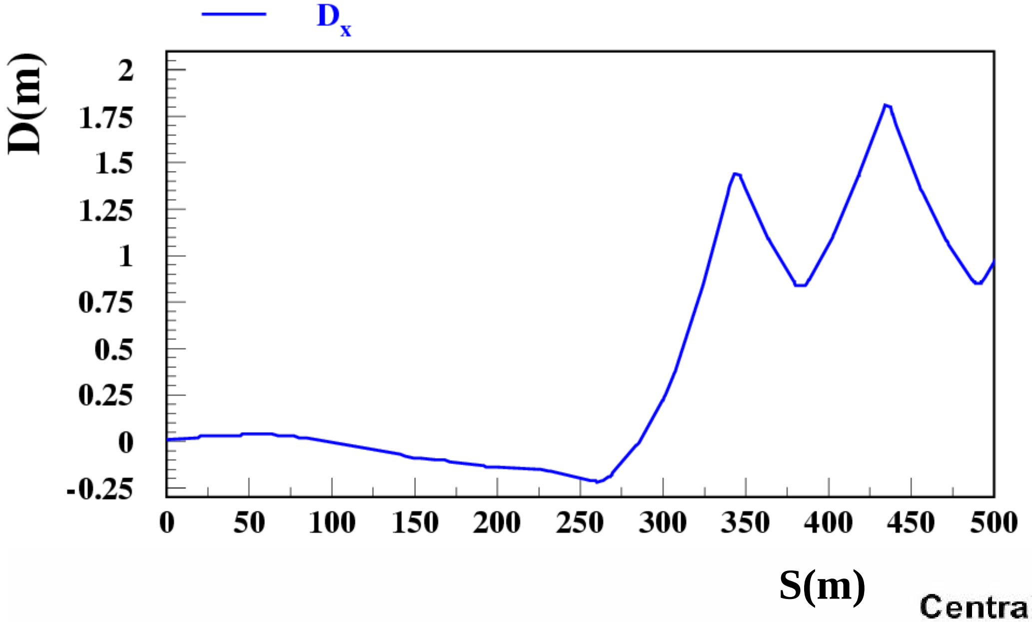
$$\sigma_{x'} = 4.4\,\mu\mathrm{rad} \qquad \sigma_{y'} = 4.7\,\mu\mathrm{rad}$$

LHC HL Optics:
transverse deviations are magnified
angular deviations are diminished

Dispersion



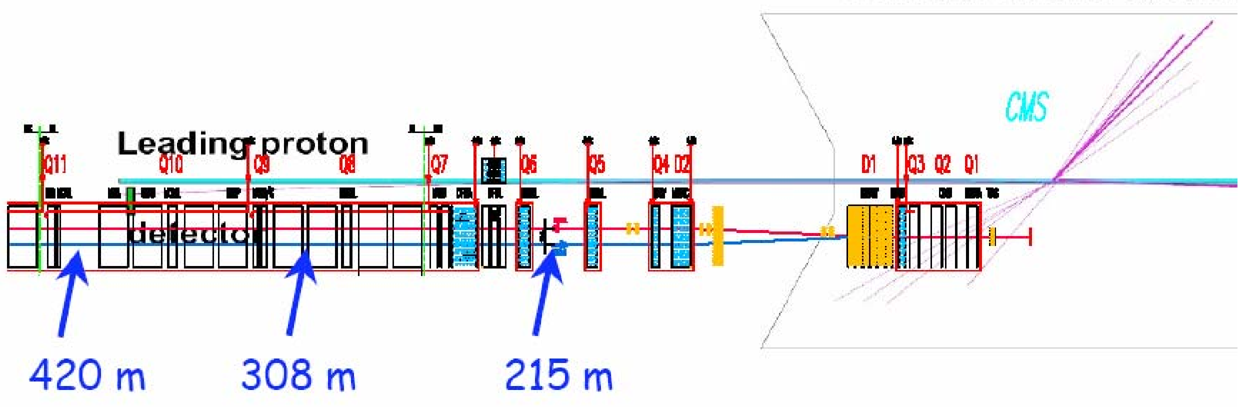
$$x = D_x \frac{\Delta p}{p}$$



At 420 m

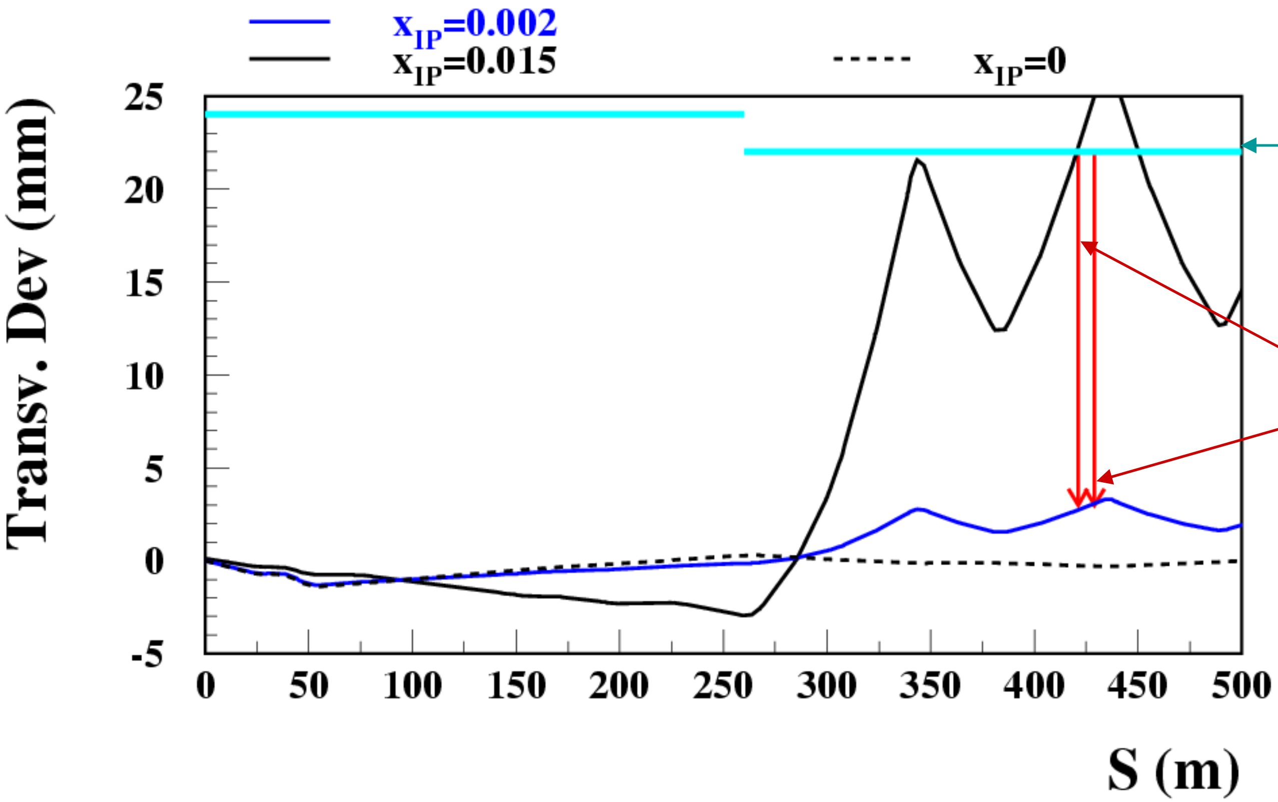
$$\frac{\Delta p}{p} = 0.01 \quad \Rightarrow \quad x = 1.5\,\text{cm}$$

$$\frac{\Delta p}{p} = 0.001 \quad \Rightarrow \quad x = 1.5\,\text{mm}$$



picture from
A. De Roeck

Transverse Deviations from the Nominal Orbit for Diffractive Protons with $t = 0$



Beam Pipe limits

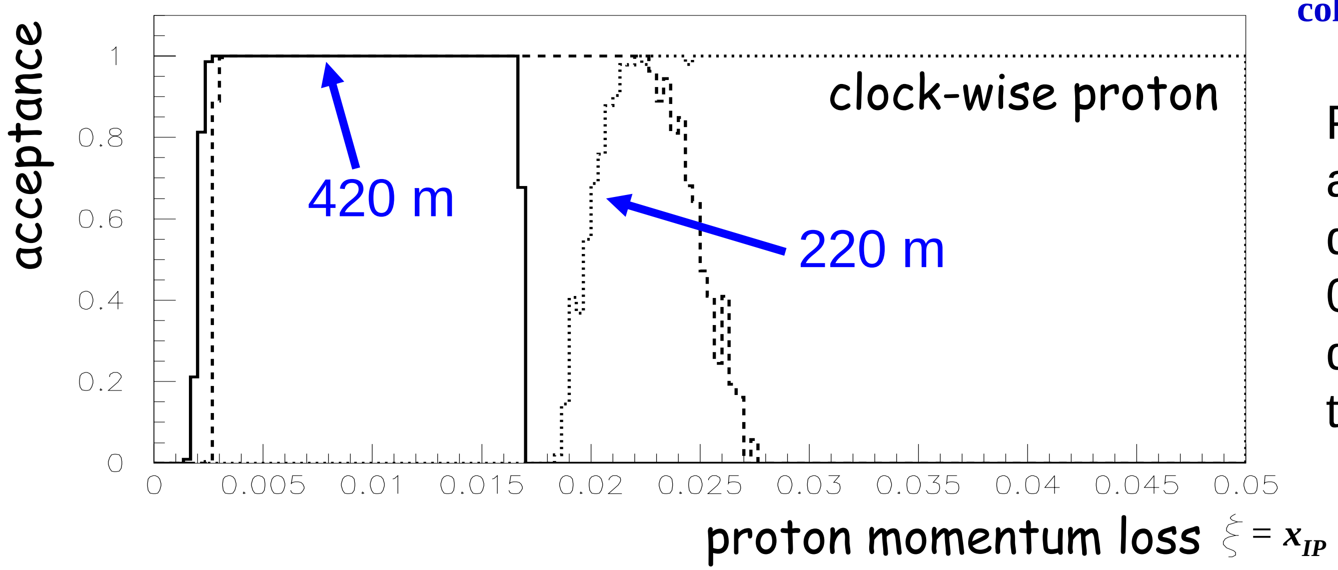
Detector area

closest approach 12 σ ~3mm

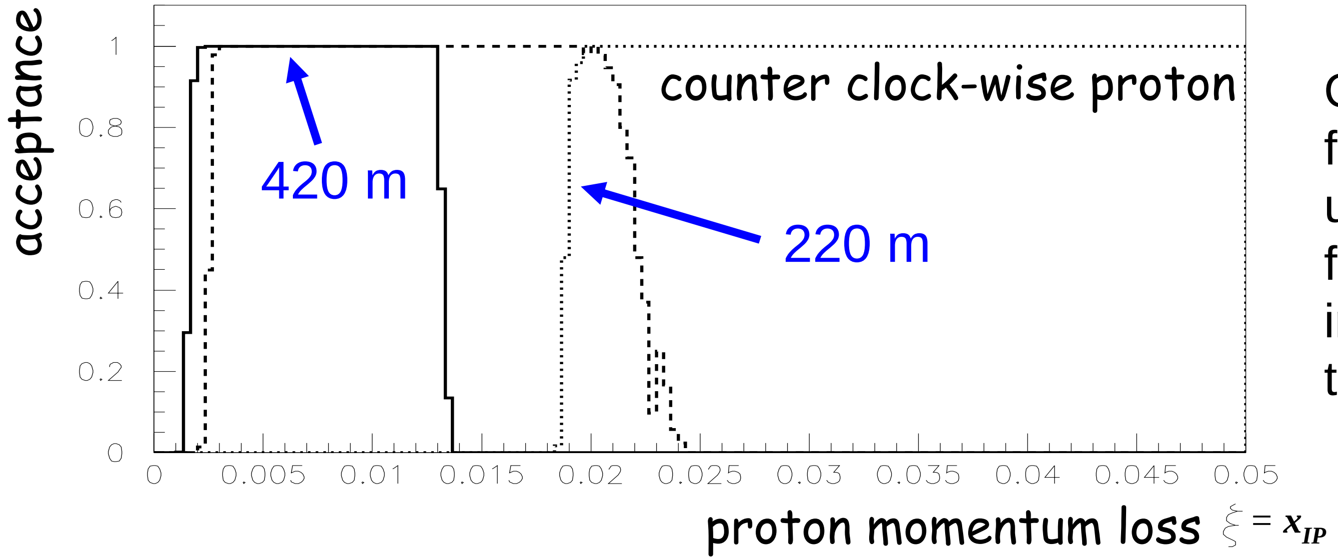
Leading proton acceptance ($\beta^* = 0.5$ m)

March 2003

from the talk of K. Österberg, Manchester for the TOTEM collaboration

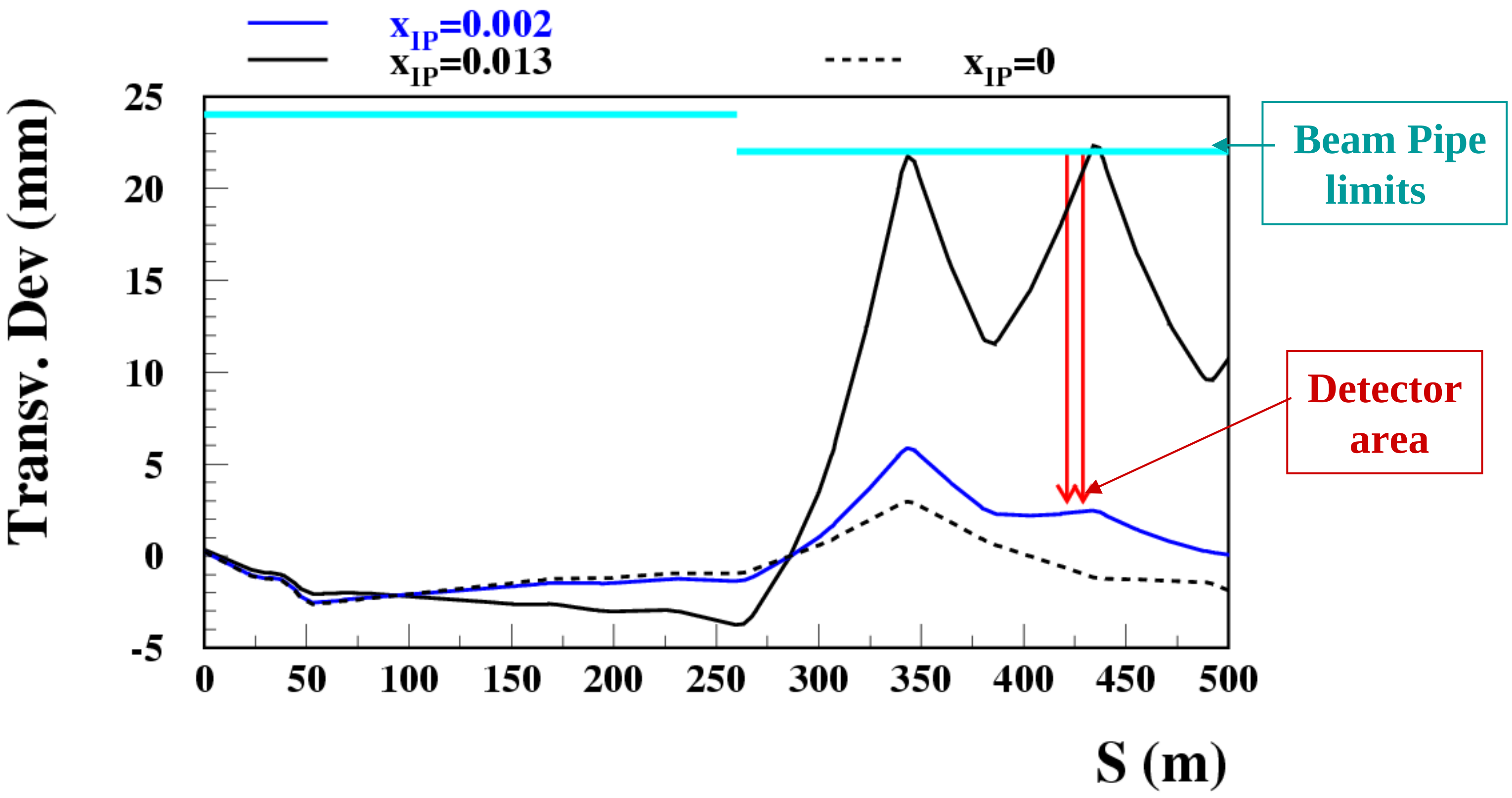


Proton acceptance down to x_{IP} = 0.2 % if detectors in the cold region



Only proton info from detectors up to 220 m from IP arrive in time for L1 trigger decision

Transverse Deviations from the Nominal Orbit for Diffractive Protons with p_T = 3 GeV



Beam Pipe limits

Detector area

420 m Detectors

Missing dipole in the lattice – 14 m space . With a bypass ~8 m space remains for warm detectors sitting in Roman Pots

detector resolution should be better than the beam spread at 420 m

$\sigma_x \approx 250\ \mu\text{m} \qquad \sigma_y \approx 160\ \mu\text{m}$

$\sigma_{x',y'} \approx 4.5\ \mu\text{rad}$

angular measurement can be performed with silicon detectors spaced 8 m apart, with ~10 μm resolution. Size of the detectors: ~30 mm $*$ 20 mm

alignment with physics reactions (much easier than at HERA, high statistics)

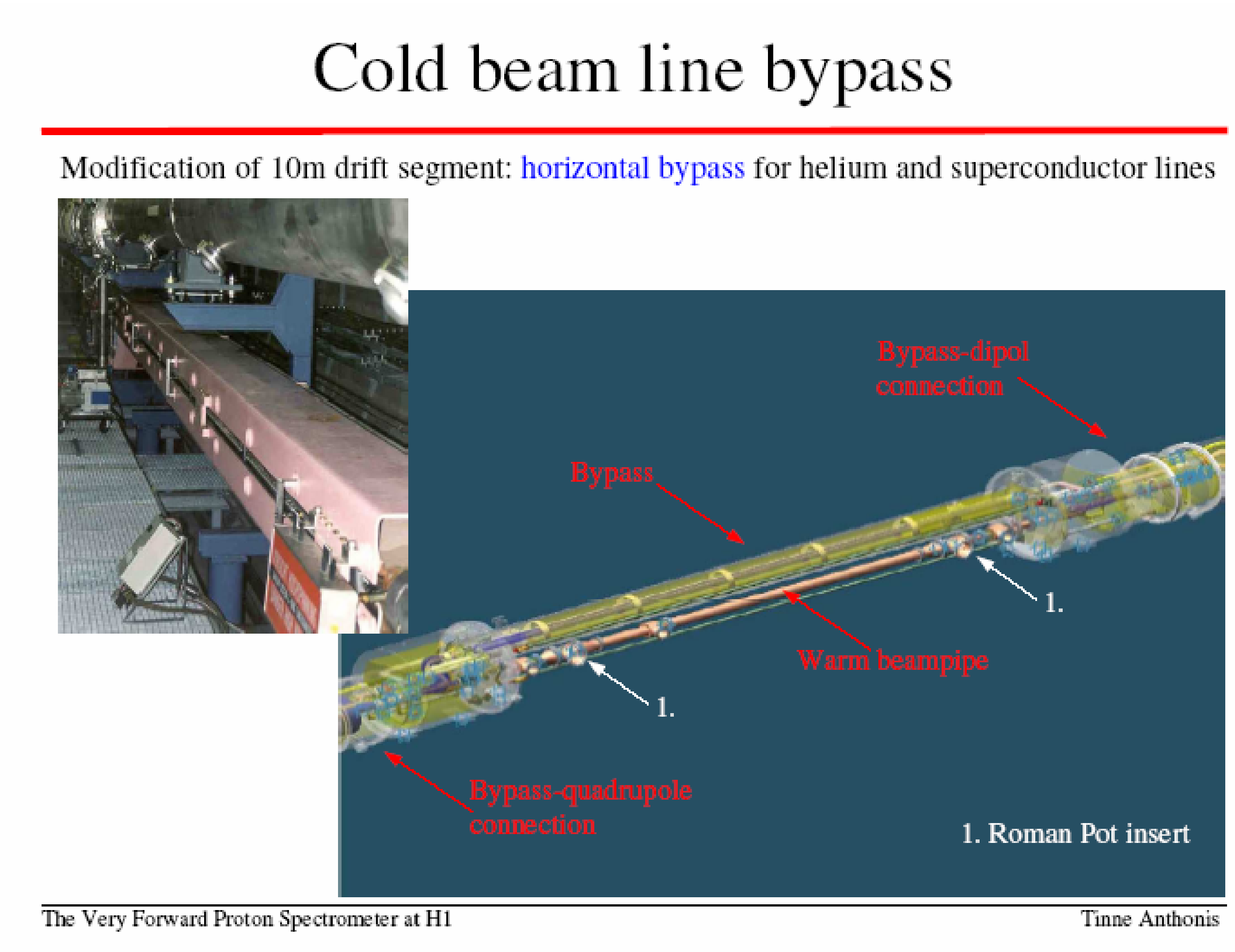
simple estimate of the proton momentum resolution:

$\Delta x_{IP} / x_{IP} \sim 8\% \quad \text{for} \;\; x_{IP} \approx 0.002 \qquad \sigma_x / 3mm$

$\Delta x_{IP} / x_{IP} \sim 1.5\% \quad \text{for} \;\; x_{IP} \approx 0.01 \qquad \sigma_x / 15mm$

$\Delta p_T \sim 200\ \text{MeV}$

H1 VFPS at HERA



Cold beam line bypass

Modification of 10m drift segment: horizontal bypass for helium and superconductor lines

The Very Forward Proton Spectrometer at H1 Tinne Anthonis

LHC No Pileup Measurement Scenarios

The no pileup situation allows to apply rapidity gap, primary single vertex and energy matching requirements to select diffractive events.

inclusive and single diffractive events with $\sigma = 70$ mb produce,
at $L = 10^{34}\ s^{-1}\ cm^{-2}$ => ~ 20 events per bunch crossing

$L = 10^{33}$ => ~ 2 events per bunch
probability to have only one vertex is ~ 30%
effective $L \sim 3*10^{32}$ or $0.3\ nb^{-1}\ s^{-1}$

$L = 2*10^{33}$ => ~ 4 events per bunch
probability to have only one vertex is ~ 7%
effective $L \sim 1.4*10^{32}$

$L = 4*10^{33}$ => ~ 8 events per bunch
probability to have only one vertex is ~ 0.25%
effective $L \sim 1*10^{31}$

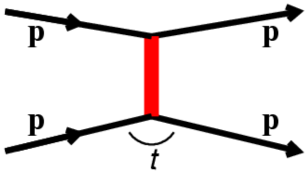
Background Reactions

Main limits on the beam lifetime at LHC is due to strong interactions **σ_{tot} ~ O(100) mb**

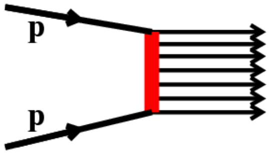
$$(L = 10^{34}\ \text{cm}^{-2}\ \text{sec}^{-1})\cdot(\sigma = 100\cdot 10^{-3}\cdot 10^{-24}\ \text{cm}^{2}) = 10^{9}\ \text{events/sec}$$

σ_{tot} ~ O(100) mb

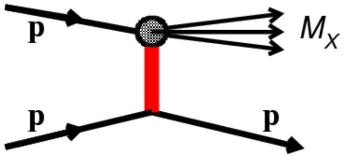
Beam lifetime $2808\cdot 1.15\cdot 10^{11}/(2\cdot 10^{9}\cdot 3600)$ **~ O(40) hours**



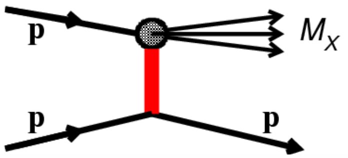
Elastic scattering – σ_{el} ~ O(30) mb small angular and momentum deviations. Protons stay inside the acceptance of the ring



Inclusive scattering – σ_{inc}~O(50) mb - most of the outgoing particles have low momentum and large emission angle. All of them will be either seen in the central detector or captured by the TAN and TAS absorbers.



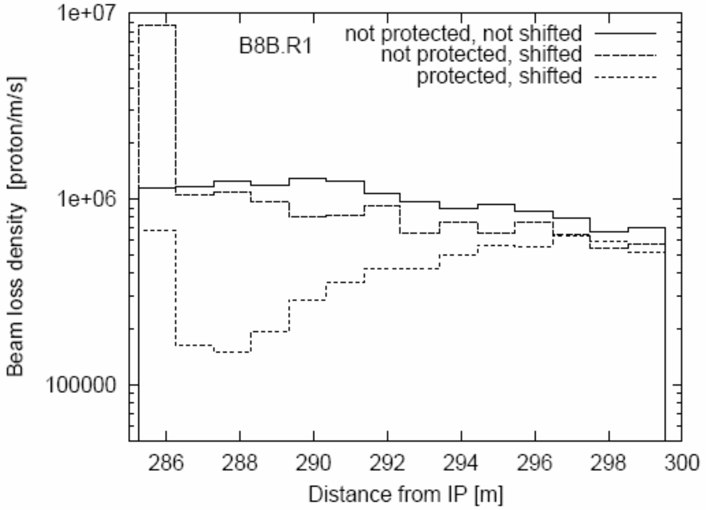
Proton dissociation – σ_{el} ~ 2 O(10) mb for x_{IP} ~ *0.01 – 0.3*
Main source of the machine background. Leads to a rate of O(10^8) forward protons/sec.
Attention!!! It is above the magnet quench limit of 8 10^6 protons/m/sec

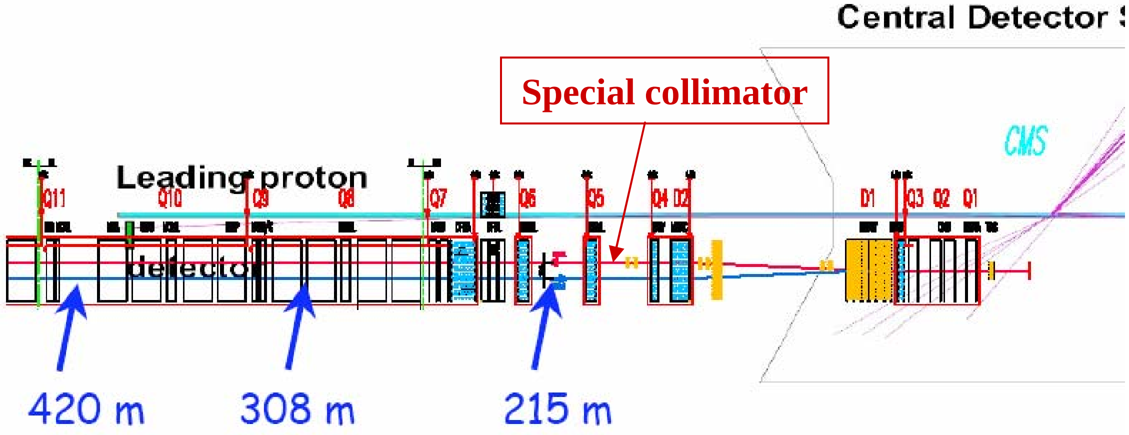


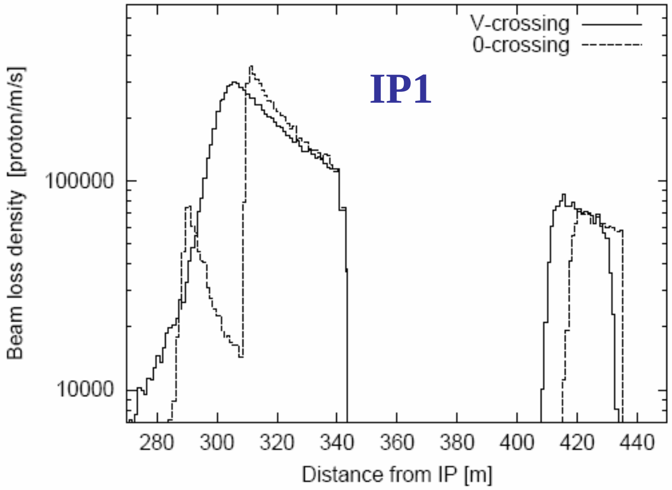
Machine background from proton dissociation reactions

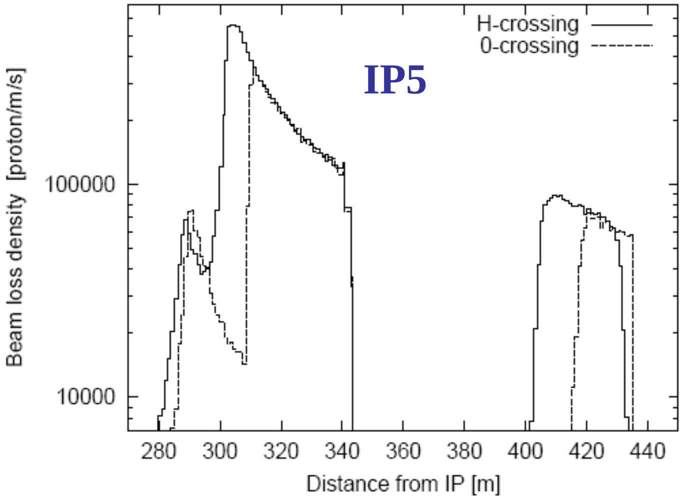
LHC Project Note 240, 208

I. Baishev, J.B. Jeanneret, G.R. Stevenson

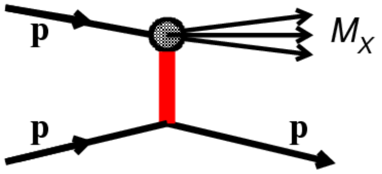






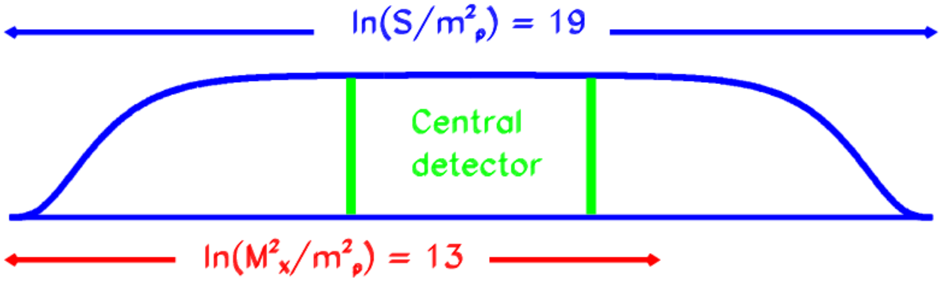


Physics background from proton dissociation reactions



420 m detector sees protons with $x_{IP} \sim 0.002 - 0.015$ and $\sigma_{\text{dis}} \sim 3$ mb ~
At luminosity of 10^{34} s^{-1} cm^2 there will be ~3 10^7 protons/sec ~ 1 proton per bunch crossing

However, these protons are produced in a soft interaction together with a particle cloud of a mass $M_X \sim 700 - 1700$ GeV. Such a large mass cannot escape undetected in the central detector.

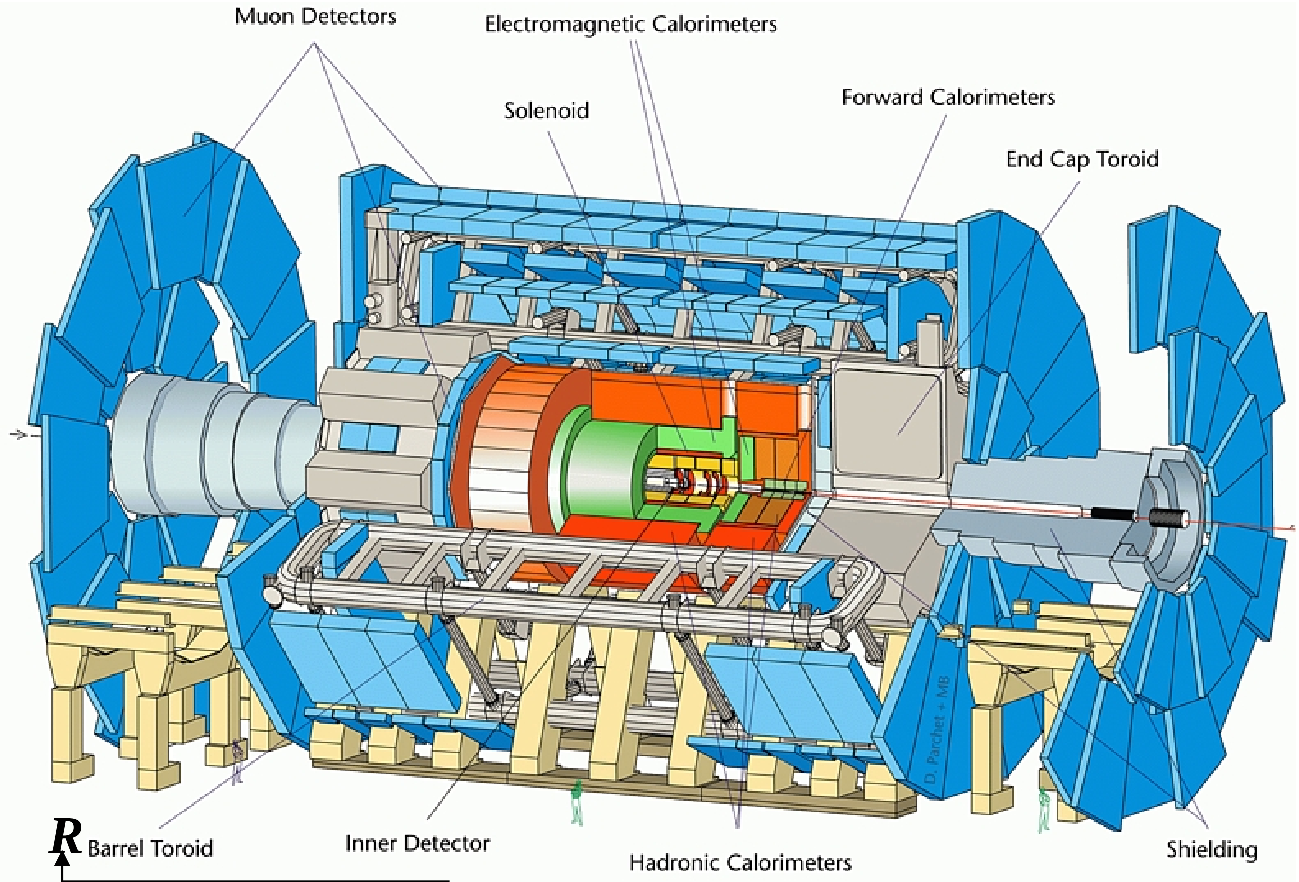


Single diffractive proton dissociation suppression factors:

rapidity gap ~ exp(-$\lambda\Delta$y) ~ 0.006 for $\lambda = 1.7$ and $\Delta y = 3$
no second event vertex O(1/100)

Total suppression factor ~ 6 10^{-5}

The ATLAS Detector



Calorimetry:

$$\frac{\sigma_E}{E}(e,\gamma) = \frac{10\%}{\sqrt{E\,/\mathrm{GeV}}} \oplus 0.3\%$$

$$\sigma_\theta = \frac{60\,\mathrm{mrad}}{\sqrt{E\,/\mathrm{GeV}}}$$

$$\sigma_t = \frac{4\,\mathrm{ns}}{E\,/\mathrm{GeV}}$$

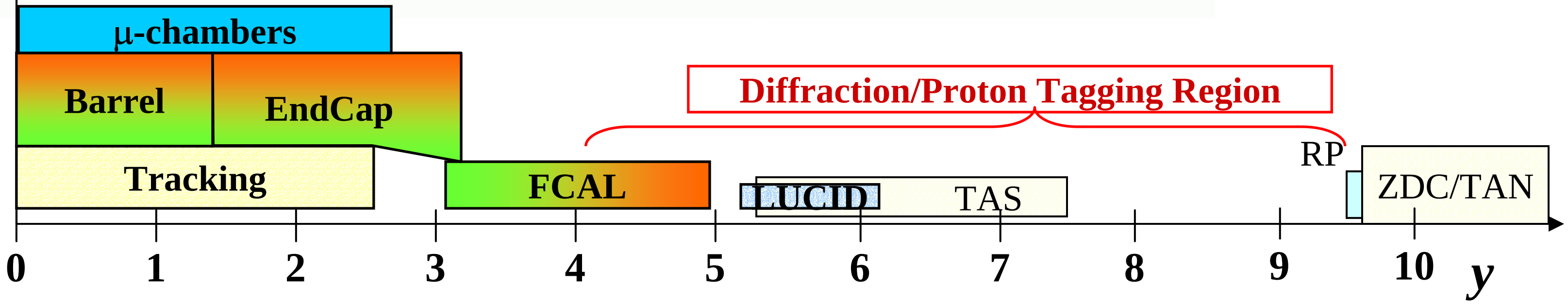
$$\frac{\sigma_E}{E}(\pi^\pm) = \frac{50\,\%}{\sqrt{E\,/\mathrm{GeV}}} \oplus 3\%$$

$$\frac{\sigma_E}{E}(\mathrm{jet}) = \frac{50\,\%}{\sqrt{E\,/\mathrm{GeV}}} \oplus 2\%$$

Tracking:

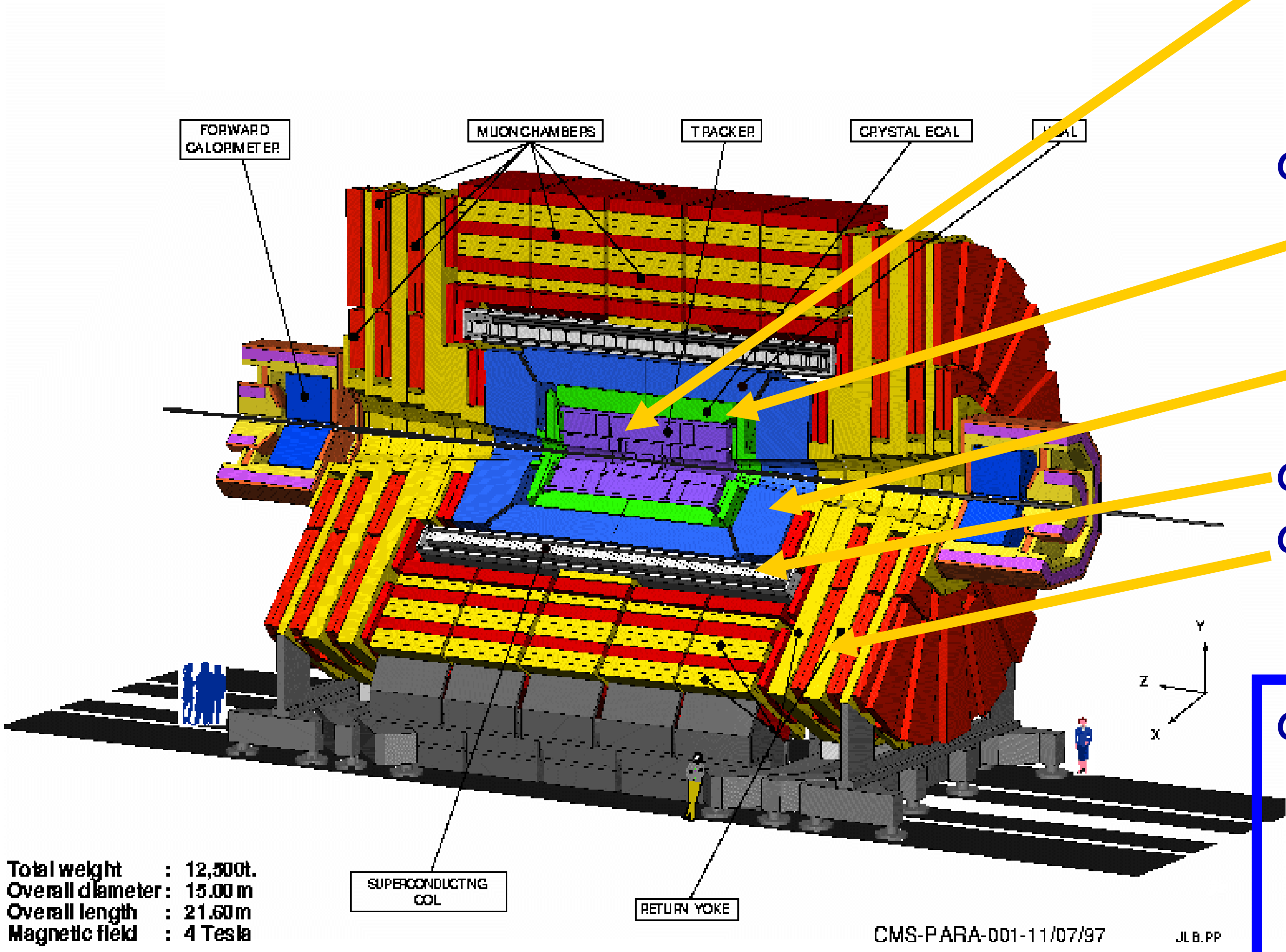
$$\frac{\sigma}{p_T}(\text{Inner Det}) \approx (0.03\,p_T\,/\mathrm{GeV} + 1.2)\%$$

$$\frac{\sigma}{p_T}(\text{IDet+}\mu) \approx (0.009\,p_T\,/\mathrm{GeV} + 1.4)\%$$



The CMS experiment

from the talk of
A. De Roeck



- o Tracking
  - o Silicon pixels
  - o Silicon strips
- o Calorimeters
  - o PbW04 crystals for Electro-magn.
  - o Scintillator/steel for hadronic part
- o 4T solenoid
- o Instrumented iron for muon detection

- o Coverage
  - oTracking
    $0 < |\eta| < 2.5\text{-}3$
  - o Calorimetry
    $0 < |\eta| < 5$

Main program: EWSB, Beyond SM physics…

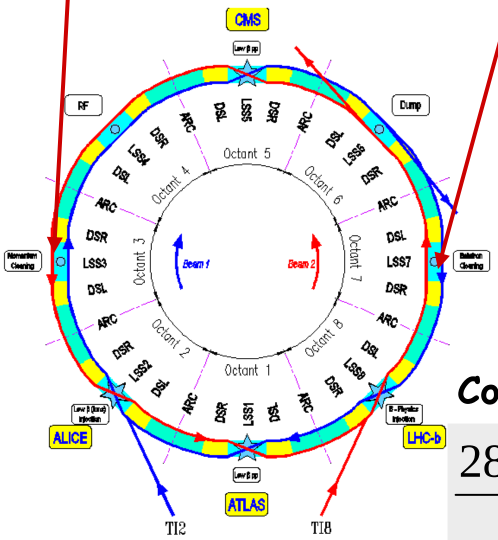
Beam Halo background from beam-beam tune shift

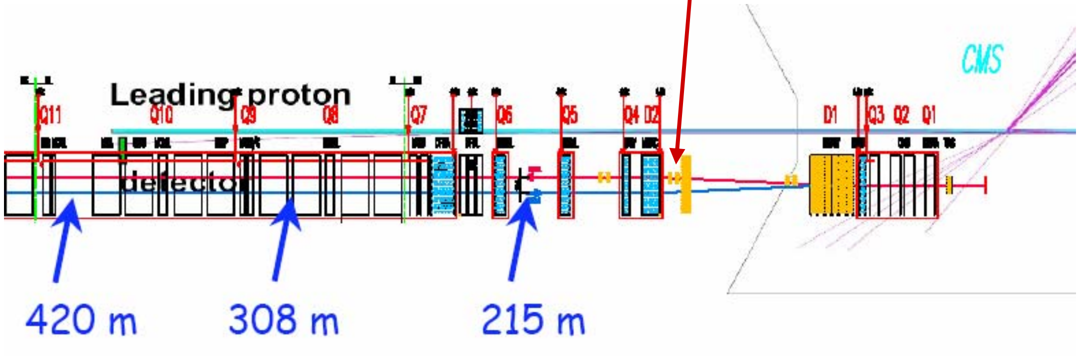
In bunch-bunch collision the particle of one bunch see the other bunch as a nonlinear lens.
Focusing properties are changing => protons of large amplitude
are getting out of tune after many crossings

Estimate of the proton loss: # protons / beam lifetime (40h)

Primary and secondary collimators
beam scratched to 6 and 7 σ

New tertiary collimators





Collimator cleaning inefficiency after 10 σ ~ 4 10^{-4}

$$\frac{2808\cdot 1.15\cdot 10^{11}\cdot 0.63\cdot 4\cdot 10^{-4}}{40\cdot 3600}=0.5\cdot 10^{6}\ \text{protons/sec}$$

1 proton per ~80 bunches at the top luminosity
Presumably even considerably smaller in the 420m region,
in the shadow of the incoming collimator, after D2 (R. Assmann)

Background Estimation

Example:

pp => pp + $g_{JET}\, g_{JET}$ $\sigma \sim 1$ nb for $E_T > 20$ GeV , M(jj) ~ 50 GeV
Signature:
2 forward protons + 2 central jets at $|\eta| < 2$ + 2 rapidity gaps at $2 < |\eta| < 5$
acceptance ~ 100%

Background:
non-diffractive jet production: $\sigma \sim 10^4$ nb at the same E_T and M(jj)
+ 2 accidental beam halo protons

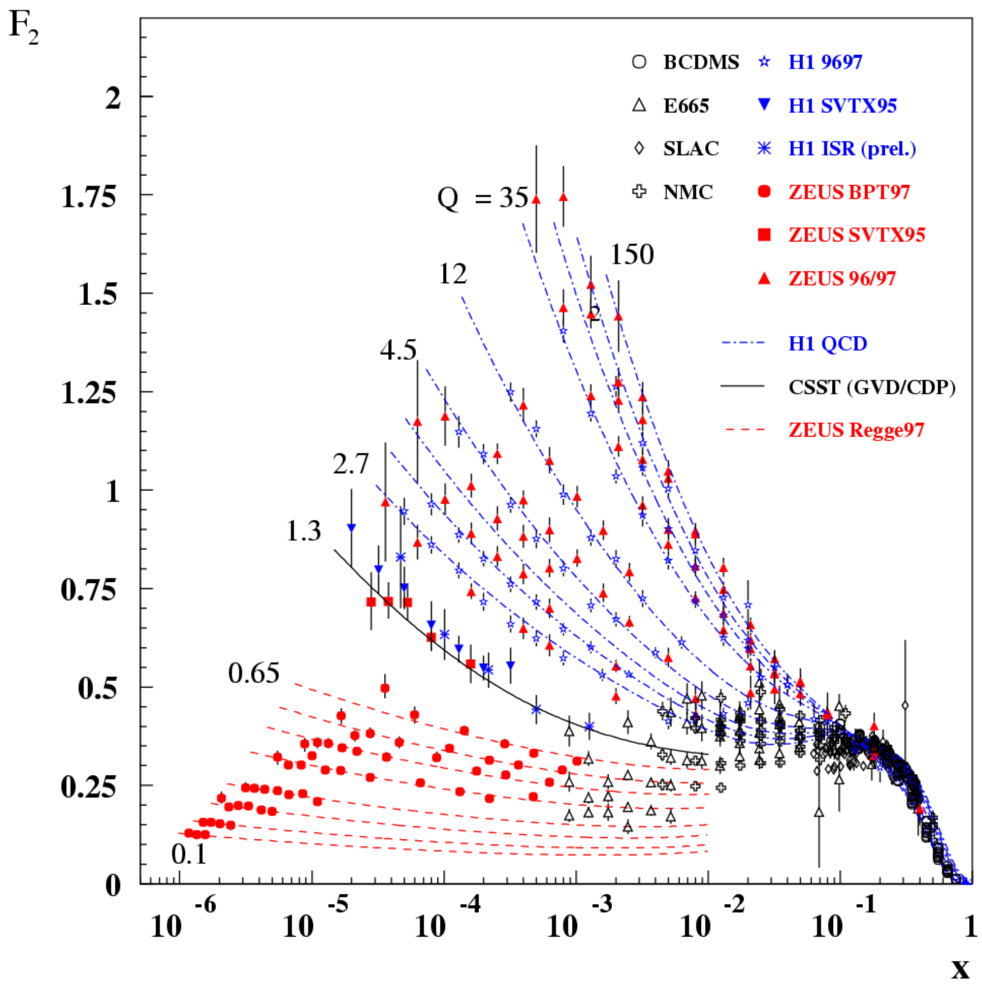
Non-diffractive jet production can be suppressed by:

rapidity gaps ~ exp($-\lambda\Delta y$) ~ 0.006 per gap for $\lambda = 1.7$ and $\Delta y = 3$
probability to have an accidental beam halo proton O(1/80)
matching of energies between the forward proton and CD measurements O(1/10)

Background / Signal ratio = $(0.006/800)^2 \sim O(10^{-6})$

accidental protons rate is (presumably) overestimated in the 420 m region
further study necessary

PHYSICS MOTIVATION



Determination of the Gluon Density and its evolution is the main highlight of HERA physics

=> boost to the QCD understanding:

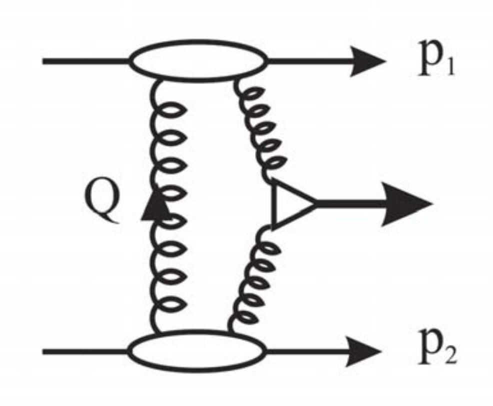
possible saturation effects

infinite resummation ….

Can diffractive measurements at LHC significantly extend the knowledge of the gluon density?

Computation of Diffractive Processes at LHC

Khoze – Martin - Ryskin Approach



$$\sigma = L \cdot \hat{\sigma}$$

$$M^2 \frac{\partial L}{\partial y \partial M^2} = S^2 L$$

Gluon Luminosity

$$L^{exclusive} = \left(\frac{\pi}{(N_c^2 - 1)b} \int \frac{dQ_t^2}{Q_t^4} f_g(x_1, x_1', t, Q_t, \mu) f_g(x_2, x_2', t, Q_t, \mu) \right)^2$$

f_g unintegrated (skewed) gluon densities

obtained from low-x data of HERA

gg ->Jet+Jet

$$\frac{d\hat{\sigma}}{dt} \approx \frac{9}{4} \frac{\pi \alpha_s^2}{E_T^4}$$

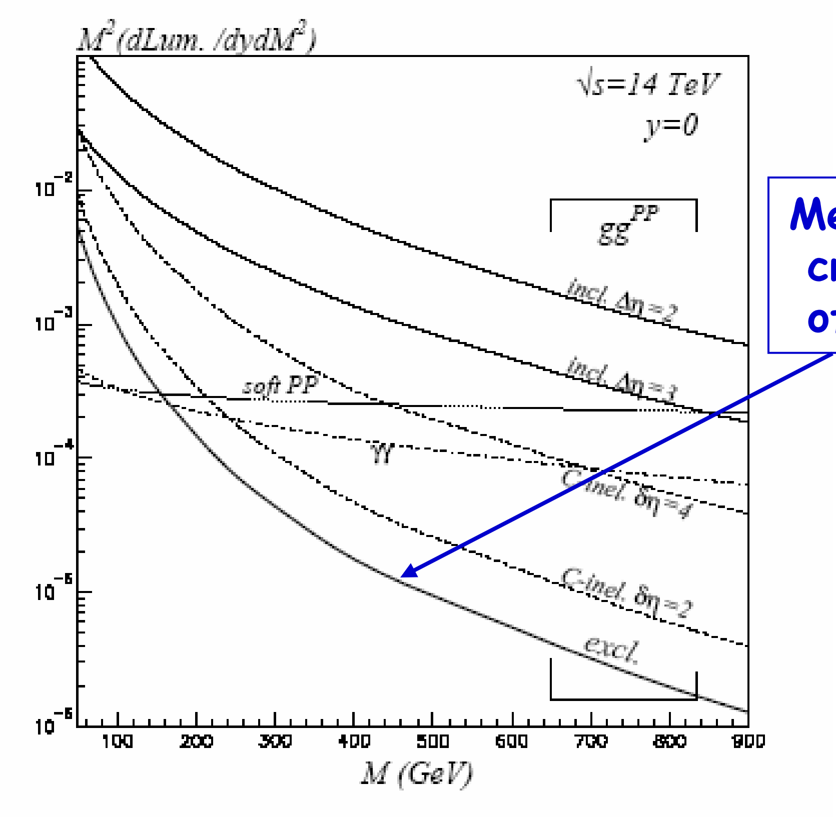
$$f_g(x, x', t, Q_t, \mu) = \beta(t) \cdot R_g \cdot \frac{\partial}{\partial \ln Q_t^2} [\sqrt{T(Q_t, \mu)} \cdot xg(x, Q_t^2)]$$

$$T(Q_t, \mu) = \exp\left(- \int_{Q_t^2}^{\mu^2} \frac{\alpha_S(k_t^2)}{2\pi} \frac{dk_t^2}{k_t^2} \int_0^{k_t/(\mu + k_t)} z P_{gg}(z) dz \right)$$

$$f_g(x_1, x_1', t, Q_t, \mu) = \beta(t) f_g(x_1, x_1', t = 0, Q_t, \mu) \qquad b(t) = \exp(Bt/2)$$

Note: *xg(x,.)* and *P_{gg}* drive the rise of *F_2* at HERA and Gluon Luminosity decrease at LHC

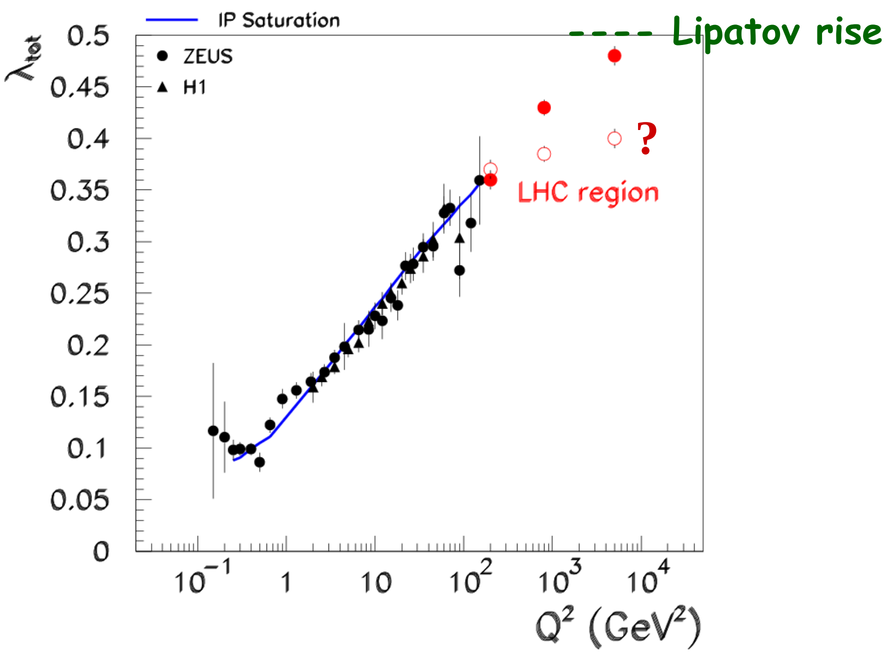
Gluon Luminosity -KMR



Measurement of exclusive Jet-Jet diffractive cross sections determines the low-x evolution of gluon densities in the new Q^2 region

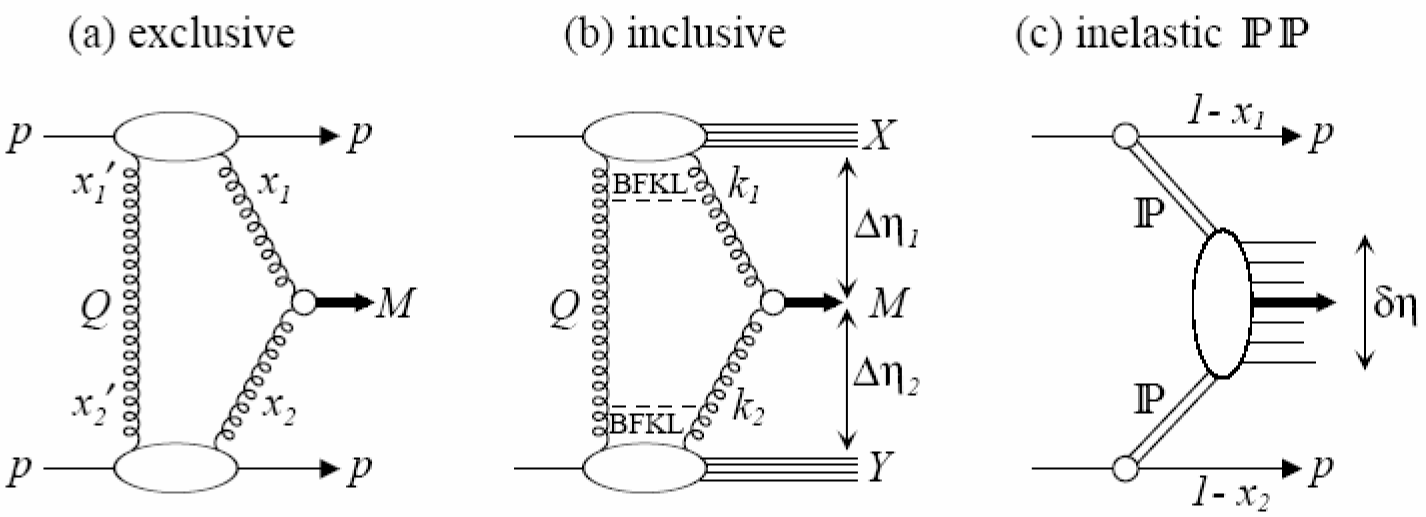
λ – Rate of rise of the Gluon Density

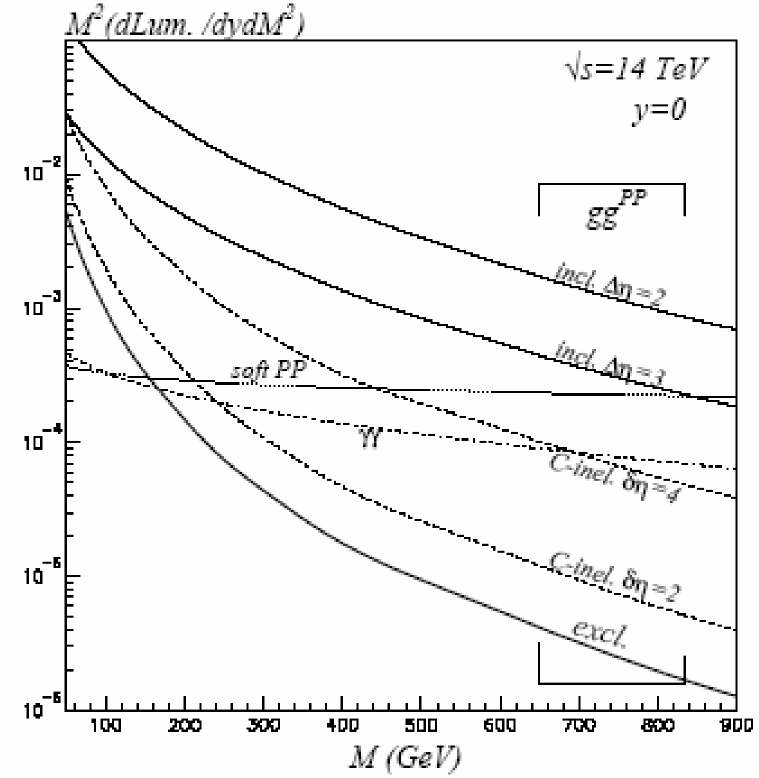
$$xg(x,Q^2) \sim (1/x)^{\lambda_{tot}}$$

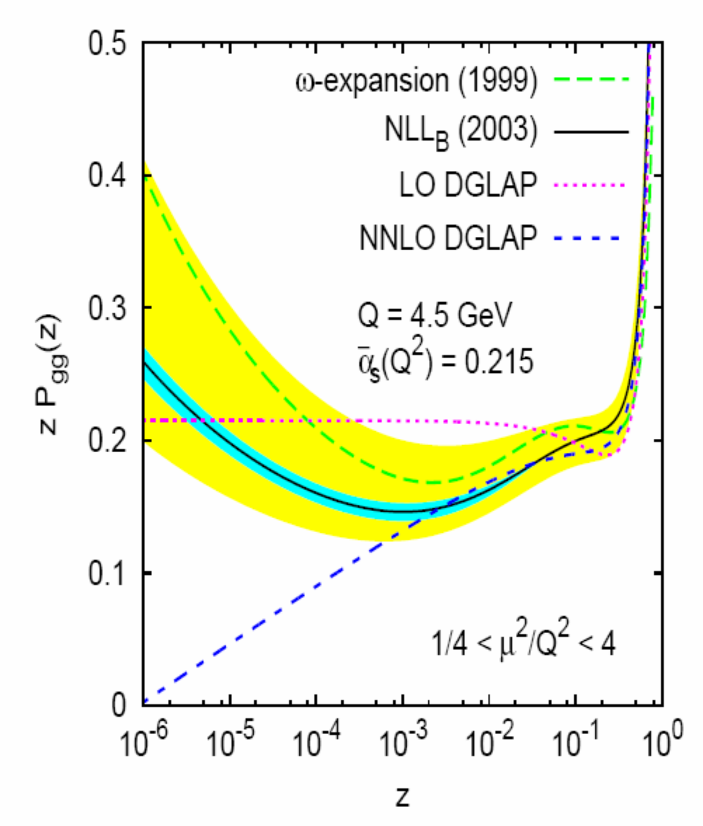


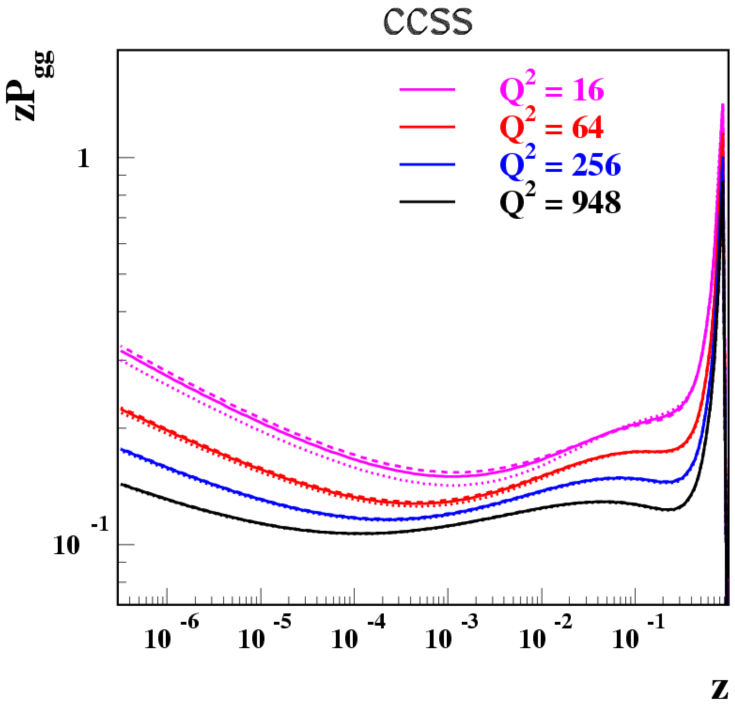
Will we reach the Lipatov rise?

$$\sigma \sim \sum_{n=0} \alpha_s^n \ln^n s \sim s^{4\ln 2\frac{\alpha_s N_C}{\pi}} \sim s^{0.5}$$


(a) exclusive
(b) inclusive
(c) inelastic ℙℙ
p
p
p
p
x_1'
x_1
x_2'
x_2
Q
M
X
Y
BFKL
BFKL
k_1
k_2
$\Delta\eta_1$
$\Delta\eta_2$
M
$1-x_1$
$1-x_2$
ℙ
ℙ
$\delta\eta$


$M^2(dLum./dydM^2)$
$\sqrt{s}=14$ TeV
y=0
gg^{PP}
incl. $\Delta\eta=2$
incl. $\Delta\eta=3$
soft PP
$\gamma\gamma$
C-inel. $\delta\eta=4$
C-inel. $\delta\eta=2$
excl.
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
100
200
300
400
500
600
700
800
900
M (GeV)





Low-x infinite re-summation effects

Ciafaloni, Colferai, Salam, Stasto
Altarelli, Ball, Forte, Thorn

Comment by G. Altarelli:
The puzzle of HERA data is why gluon densities are rising so slowly and not, as usually stated, so quickly

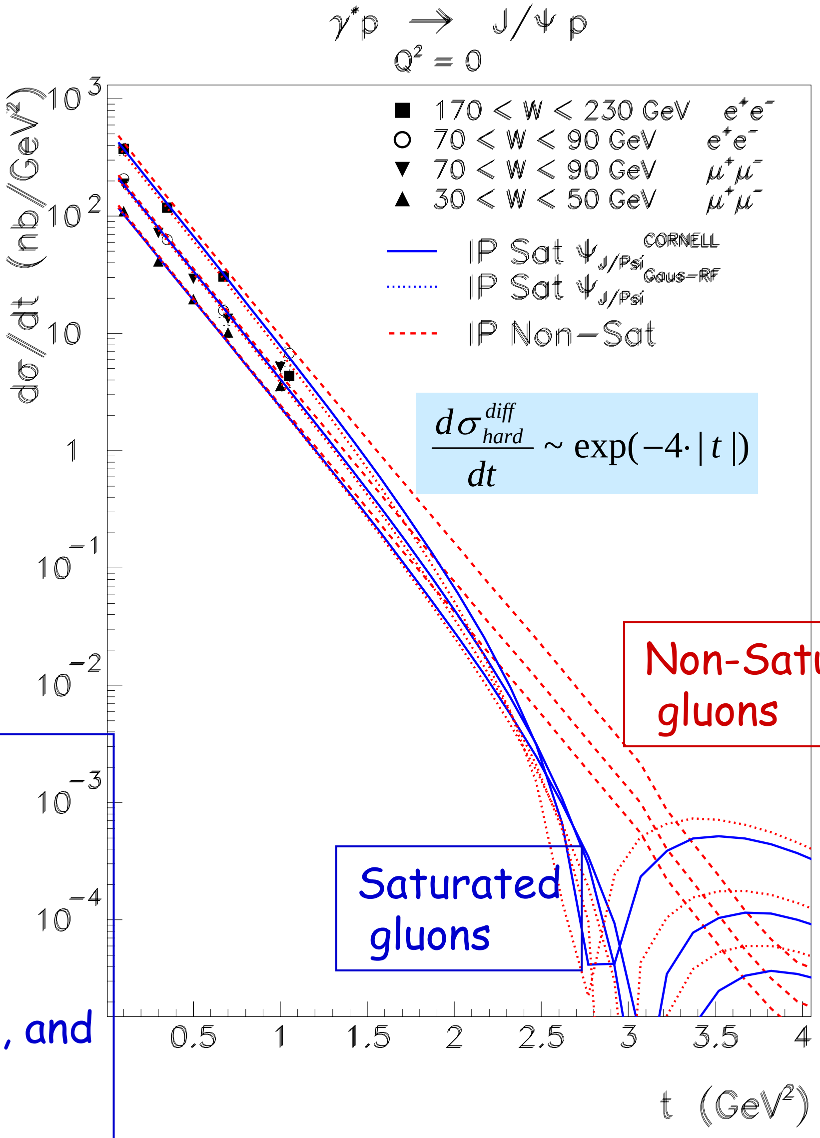
t – distributions at LHC

with the cross-sections of the O(1) nb and $L \sim 1\ \text{nb}^{-1}\ \text{s}^{-1}$ =>
O(10^7) events/year are expected.

For hard diffraction this allows to follow the *t* – distribution to
$t_{max} \sim 4\ \text{GeV}^2$

For soft diffraction $t_{max} \sim 2\ \text{GeV}^2$

t – distributions at HERA



$$\frac{d\sigma^{diff}_{hard}}{dt} \sim \exp(-4\cdot|t|)$$

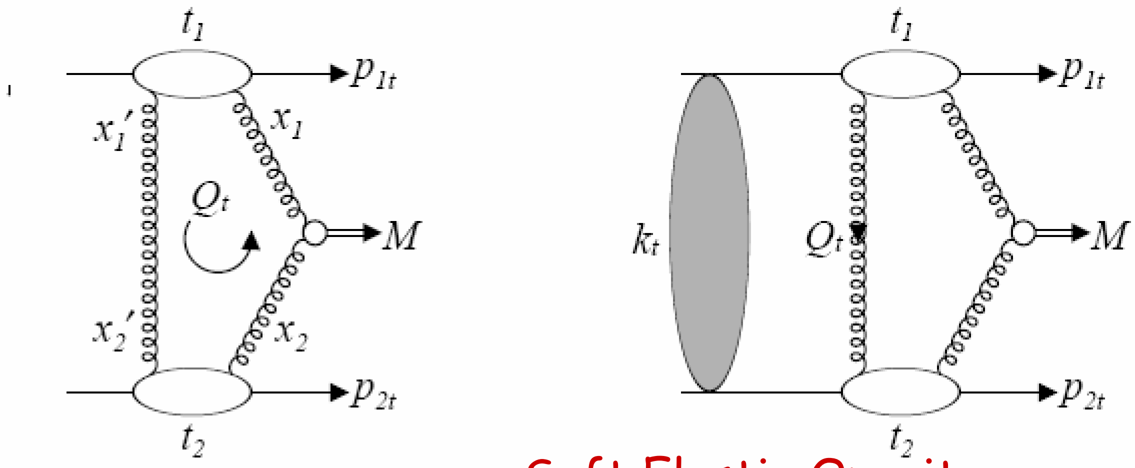
Non-Saturated gluons

Saturated gluons

t-distribution of hard processes should be sensitive to the evolution and/or saturation effects

see:
Al Mueller dipole evolution, BK equation, and the impact parameter saturation model for HERA data

Survival Probability



Soft Elastic Opacity

$$S^2 = \frac{\int M^2(s,b)\boxed{e^{-\Omega(s,b)}}d^2b}{\int M^2(s,b)d^2b}$$

hard impact parameter

$$\frac{d\sigma}{dt_1dt_2}\bigg|_{ppM} = \int M^2\boxed{(b)}e^{-\Omega(s,b)}e^{i\vec{b}\vec{\Delta}}d^2b \qquad F(\vec{p}_{1t},\vec{p}_{2t}) = \frac{\beta^2(t_1)\beta^2(t_2)}{<S^2>\pi^2/b_0^2}\frac{\partial S^2(\vec{p}_{1t},\vec{p}_{2t})}{\partial^2 p_{1t}\partial^2 p_{2t}}$$

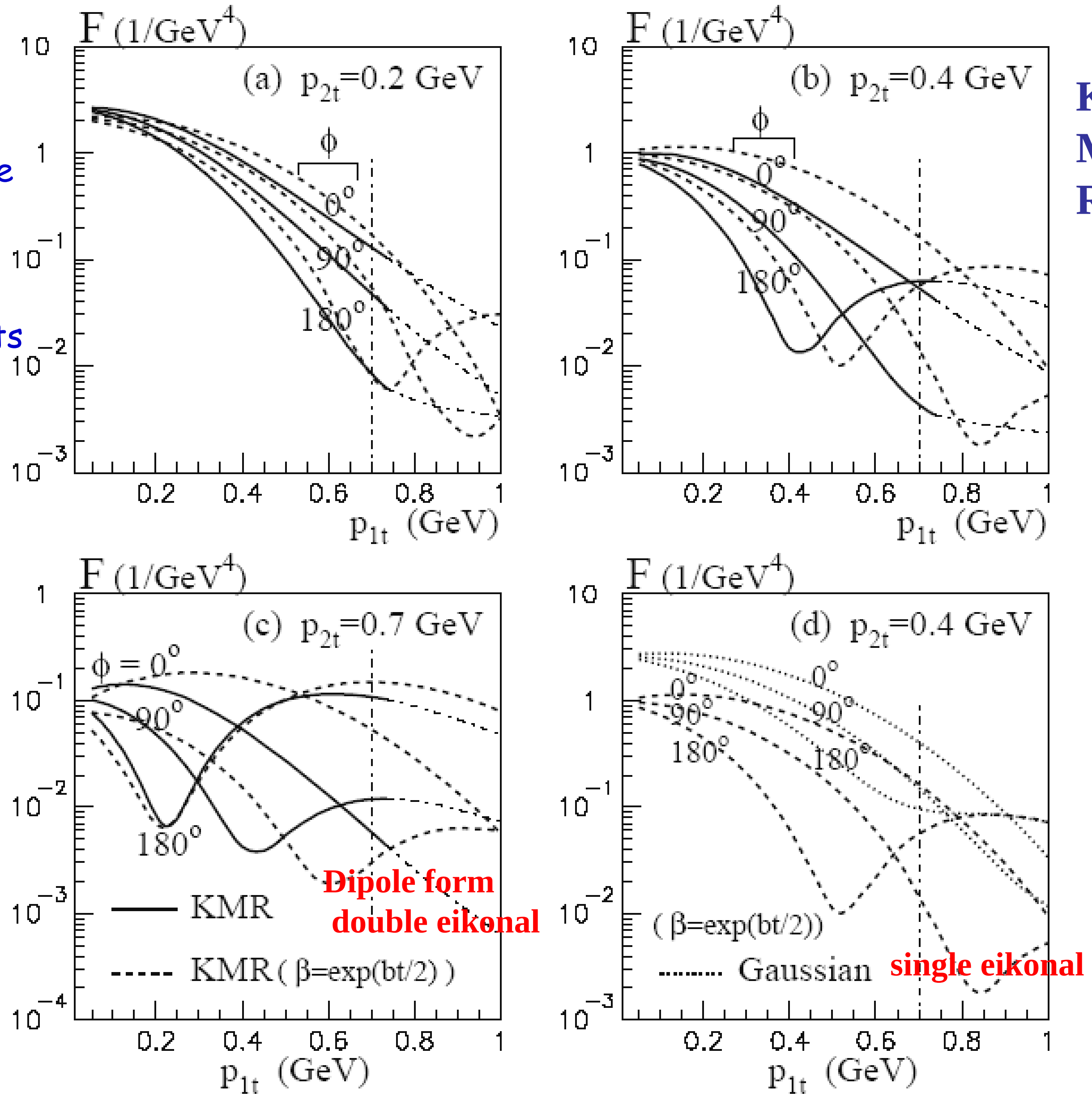
$$t_1 = -(\vec{\Delta}-\vec{p}_{1t})^2 \qquad t_2 = -(\vec{\Delta}+\vec{p}_{2t})^2$$

t – distributions
at LHC

Effects of soft proton absorption modulate the hard *t* – distributions

t-measurement will allow to disentangle the effects of soft absorption from hard behavior

p_{1t}, p_{2t} - dependence of the diffractive cross section



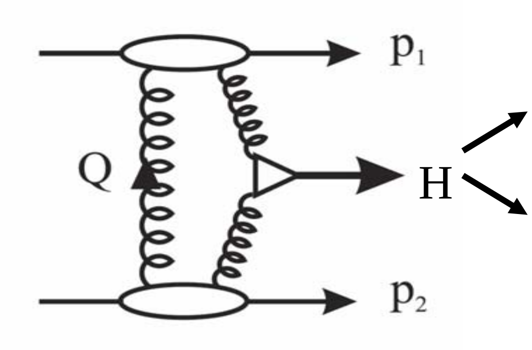
Dipole form double eikonal

single eikonal

Khoze
Martin
Ryskin

Brian Cox talk at
Manchester Conf.

Standard Model Higgs



b jets : M_H = 120 GeV $\sigma = 2$ fb (uncertainty factor ~ 2.5)

M_H = 140 GeV $\sigma = 0.7$ fb

M_H = 120 GeV : 11 signal / 3? background in 30 fb^{-1}

WW* : M_H = 120 GeV $\sigma = 0.4$ fb

M_H = 140 GeV $\sigma = 1$ fb

M_H = 140 GeV : 8 signal / 1? background in 30 fb^{-1}

0^{++} Selection rule

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

- The b jet channel is possible, with a good understanding of detectors and clever level 1 trigger
- The WW* (ZZ*) channel is extremely promising : no trigger problems, better mass resolution at higher masses (even in leptonic / semi-leptonic channel)
- If we see Higgs + tags - the quantum numbers are 0^{++}

Higgs Search

Properties of soft inclusive and single diffraction reactions will be known with high precision from background studies of the QCD reactions and comparison of Monte-Carlos with data

Lund approach , Multi-pomeron approach

They are characterized by *low-p_T* particle production and for sd - *one side rapidity gaps*

High diffractive proton measurement resolution in the Higgs region (~1.5% instead of ~8% and known M_{Higgs})

This should make possible to recognize diffractive events with at least one (two) additional background vertices

=> effective luminosity increase at $L = 10^{33}$ by factor 2 (2.6)

at $L = 4*10^{33}$ by factor 5 (17)

=>

Effective Luminosity for diffractive Higgs search O(30-100) fb^{-1}

Summary

Large luminosity can be collected in the no-pileup mode, O(10) fb^{-1}

420m Roman Pot silicon counters together with the central detector
allow clean and precise measurement of double-diffractive exclusive processes

background/signal - $O(10^{-6})$
x_{IP} resolution ~ 10 – 2 %
p_T resolution ~ 200 MeV

Alignment of forward counters with single diffractive reactions, $\sigma \sim O(1)$ mb

Diffractive LHC ~ pure Gluon Collider

pp -> pp jet+jet - $O(10^7)$ events under no pileup conditions are expected
Events are fully contained in the detector => high measurement precision

Low-x QCD phenomena can be studied at large $Q^2 \sim O(10000)$ GeV^2
and large *t*

Non-trivial QCD region - SOLVE QCD!!!!

ideal way to search for new resonances and threshold behavior phenomena

Luminosity for DPE Higgs measurements O(100) fb^{-1} => Higgs measurements