Hard diffraction at Tevatron and LHC

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Contents:

- What is diffraction? (experimental definition)
- Diffraction at Tevatron and factorisation breaking
- Look for exclusive events at the Tevatron
- Prospects at the LHC
- Looking for BFKL effects (Mueller-Navelet jets) if time allows...

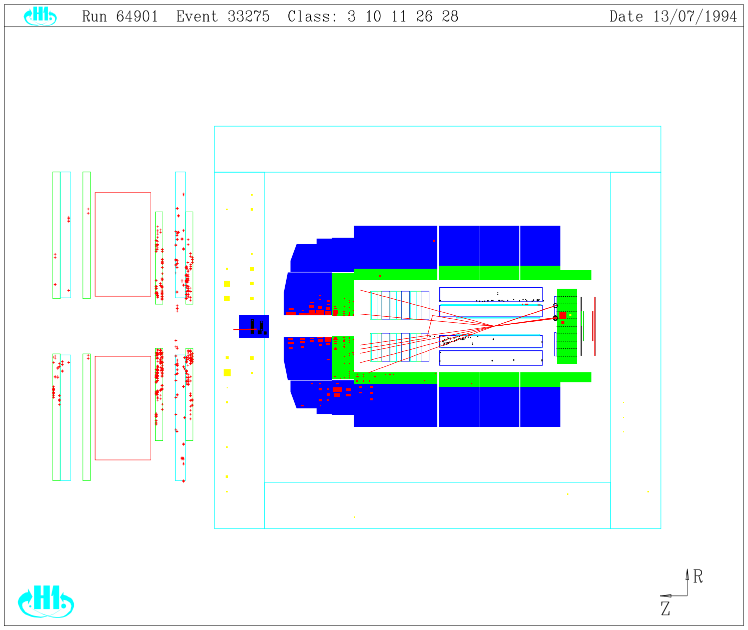
Tevatron

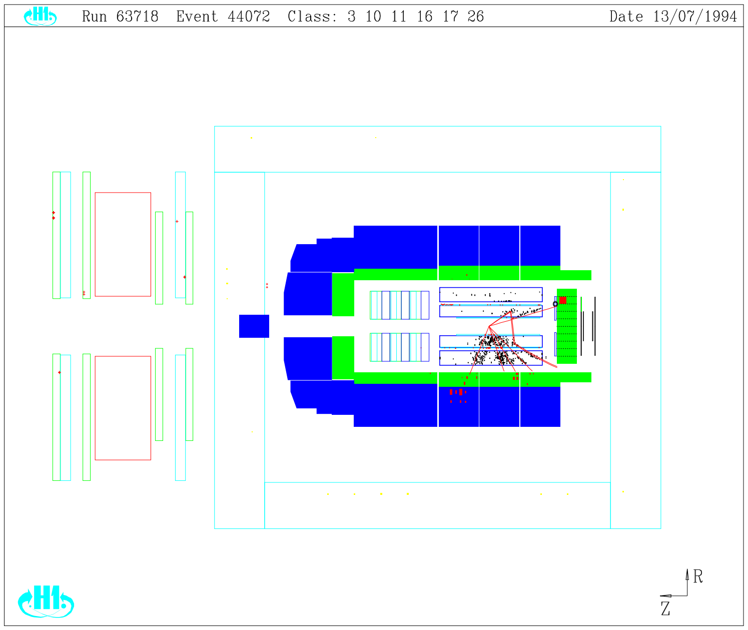
- Tevatron: $p\bar{p}$ collider, $\sqrt{S} = 1.96$ TeV, 2 experiments DØ and CDF
- Luminosity accumulated of the order of 3 fb^{-1} per experiment

Diffraction at HERA

- Typical DIS event: part of proton remnants seens in detectors in forward region (calorimeter, forward muon...)
- HERA observation: in some events, no energy in forward region, or in other words no colour exchange between proton and jets produced in the hard interaction
- Leads to the first experimental definition of diffractive event: rapidity gap in calorimeter
- Second definition of diffraction: tag of scattered proton in roman pots

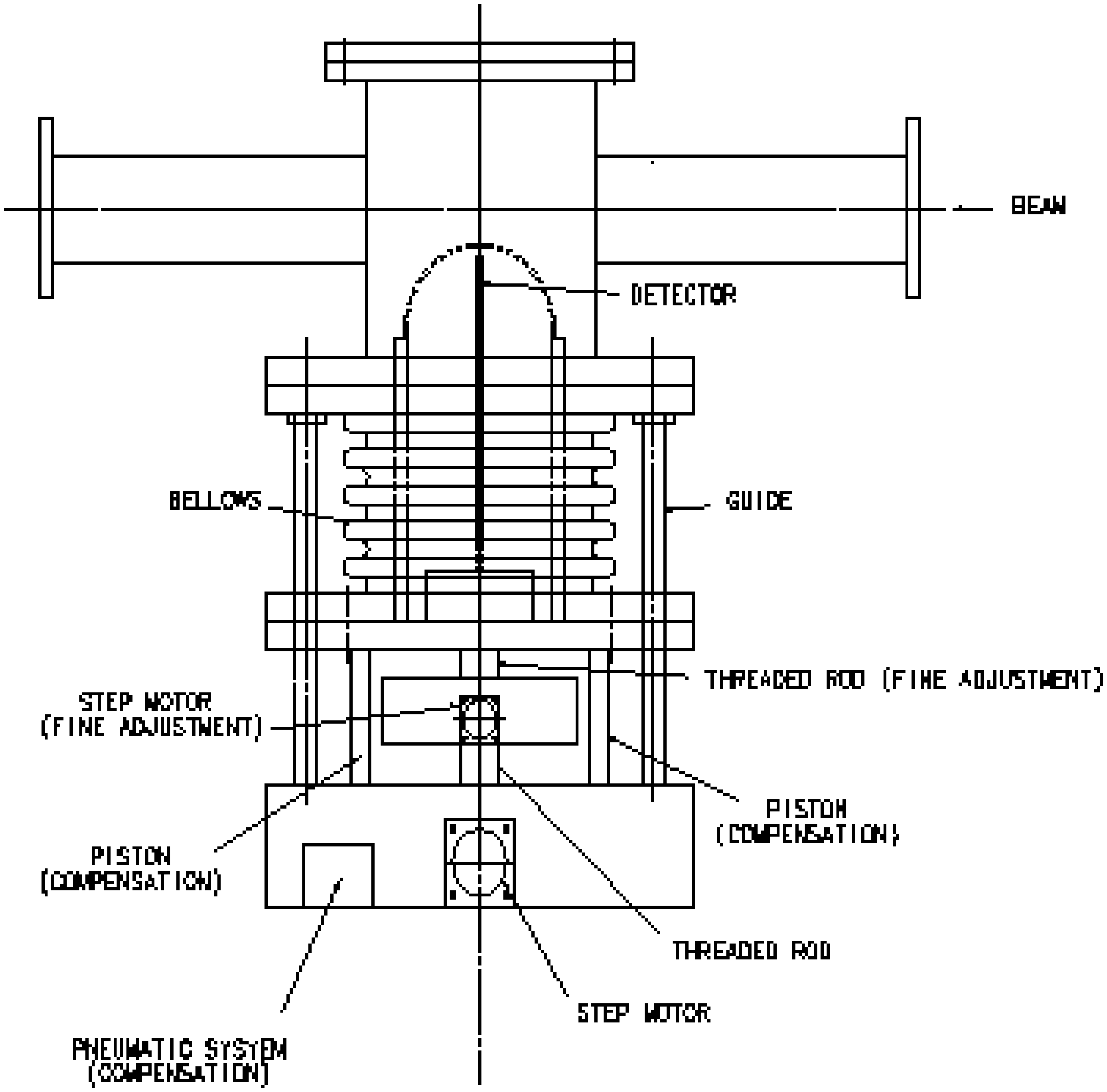
DIS and Diffractive event at HERA





Scheme of a roman pot detector

Scheme of roman pot detector



Diffraction at Tevatron (and LHC)

- Definition of diffraction at Tevatron: colourless exchange (Pomeron)
- As an example: take events at HERA to define experimentally how we detect diffractive events

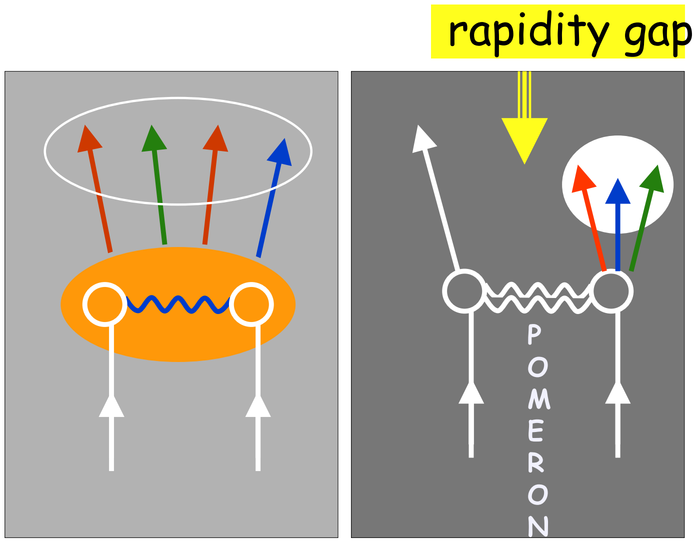
Non-diffractive:

Color-exchange

Diffractive:

Colorless exchange with vacuum quantum numbers

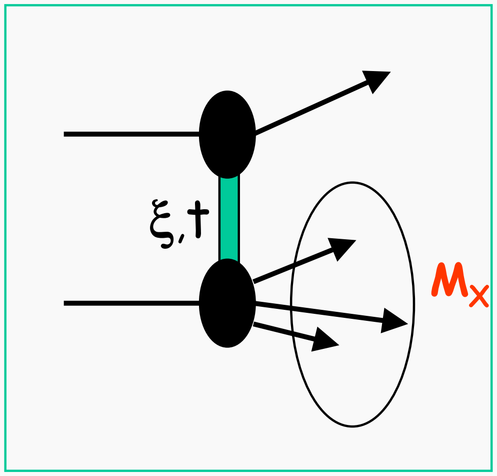
Incident hadrons acquire color and break apart

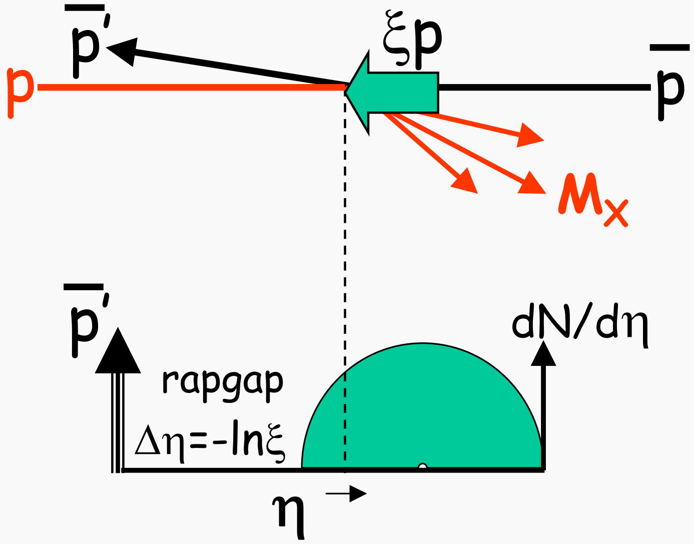


Incident hadrons retain their quantum numbers remaining colorless

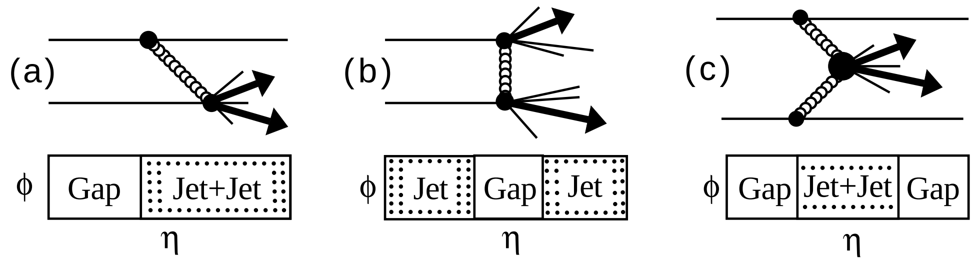
Diffraction at Tevatron

Vision of diffraction from Dino: fireworks





Diffraction at Tevatron/LHC

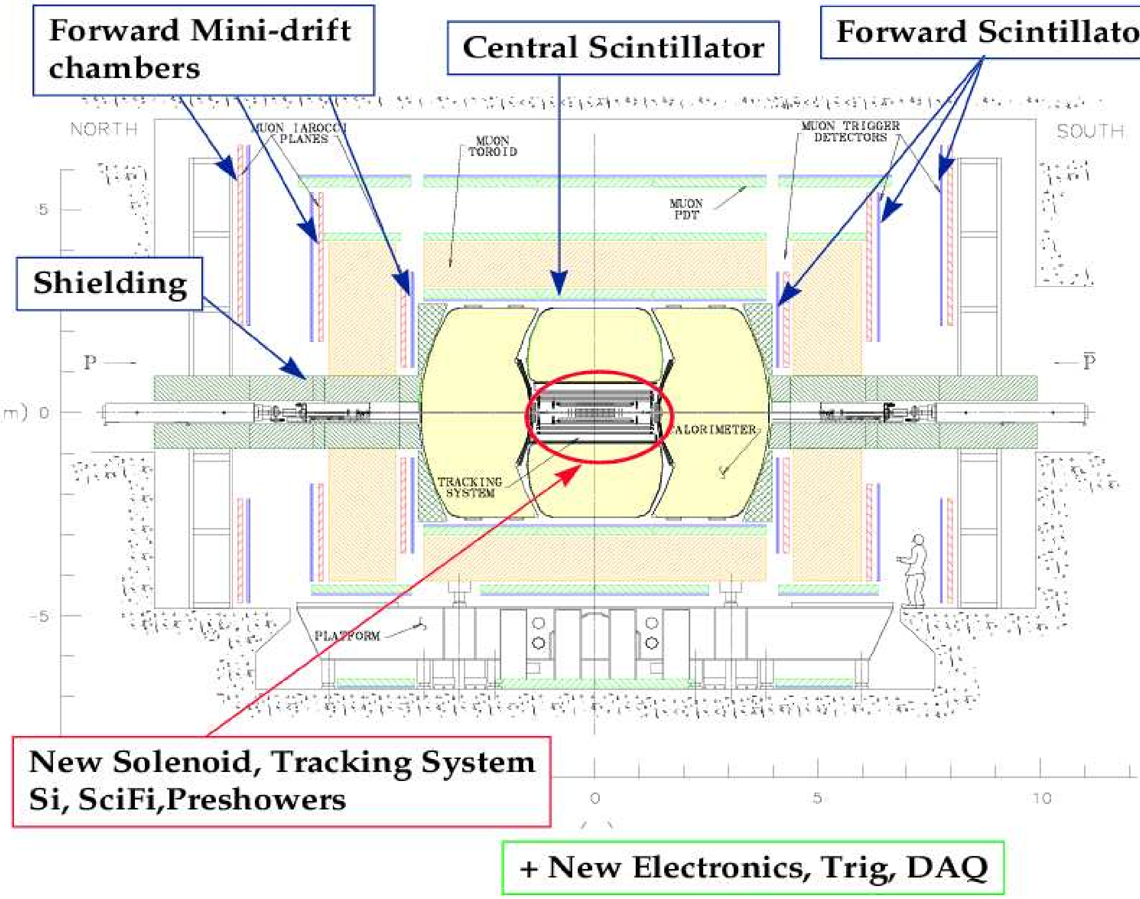


Kinematic variables

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

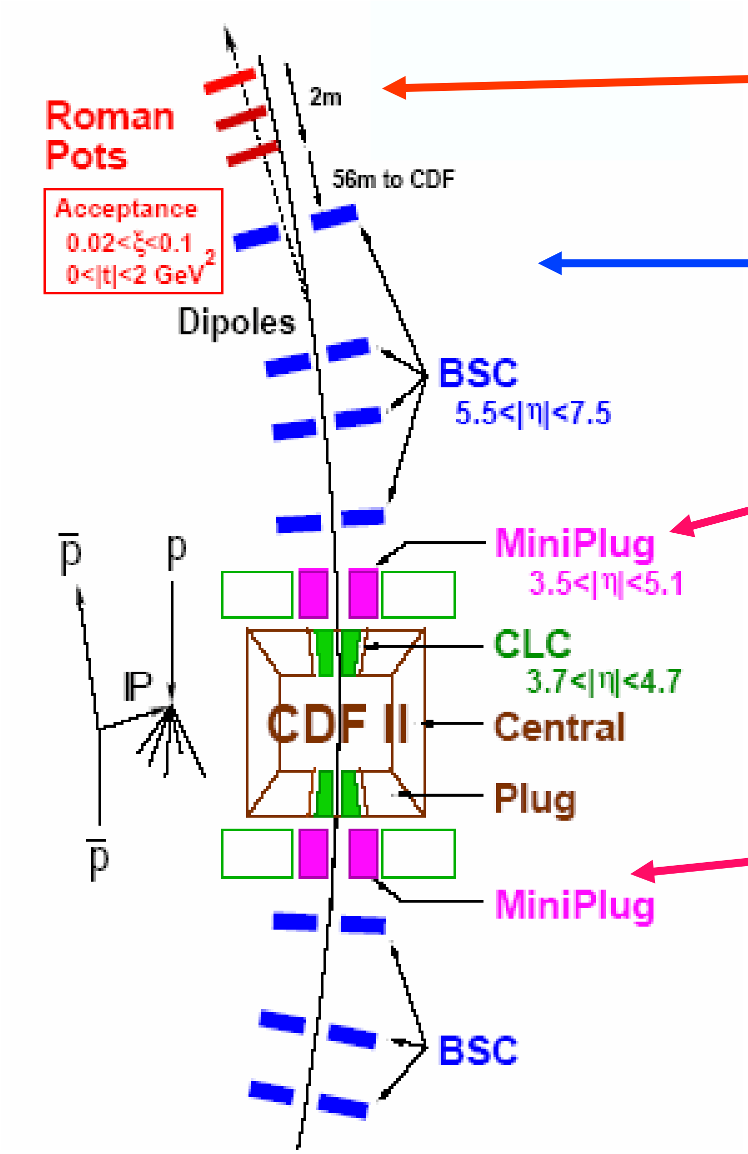
How to find diffractive events at the Tevatron

- First method: Use the rapidity gap technique defined in calorimeter
- Second method: Tag p and/or $\bar{p}$ in final state



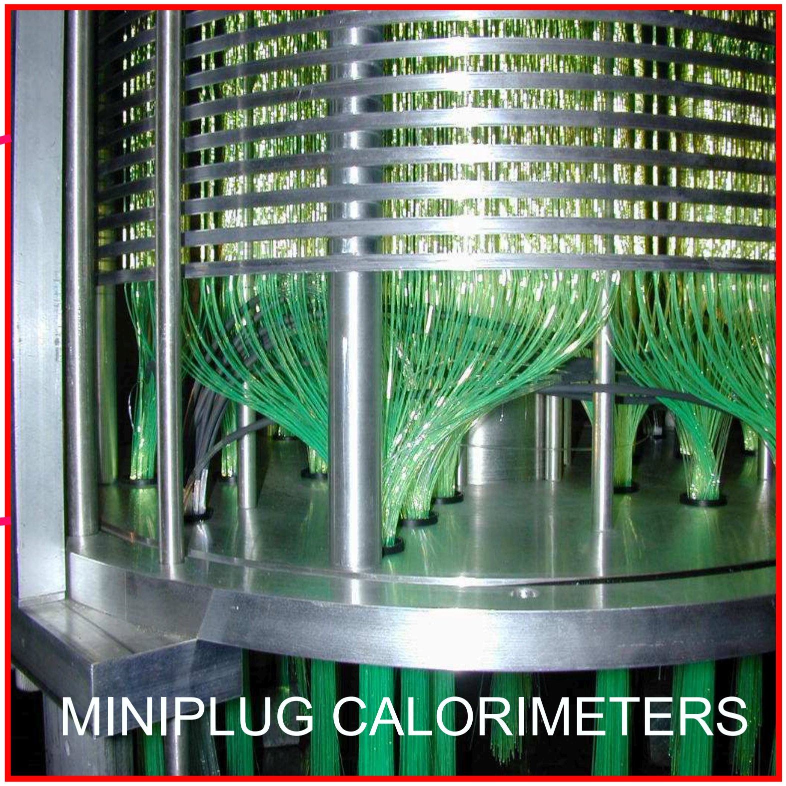
Forward Detectors (CDF)

Use miniplug for rapidity gaps, roman pots for proton tagging

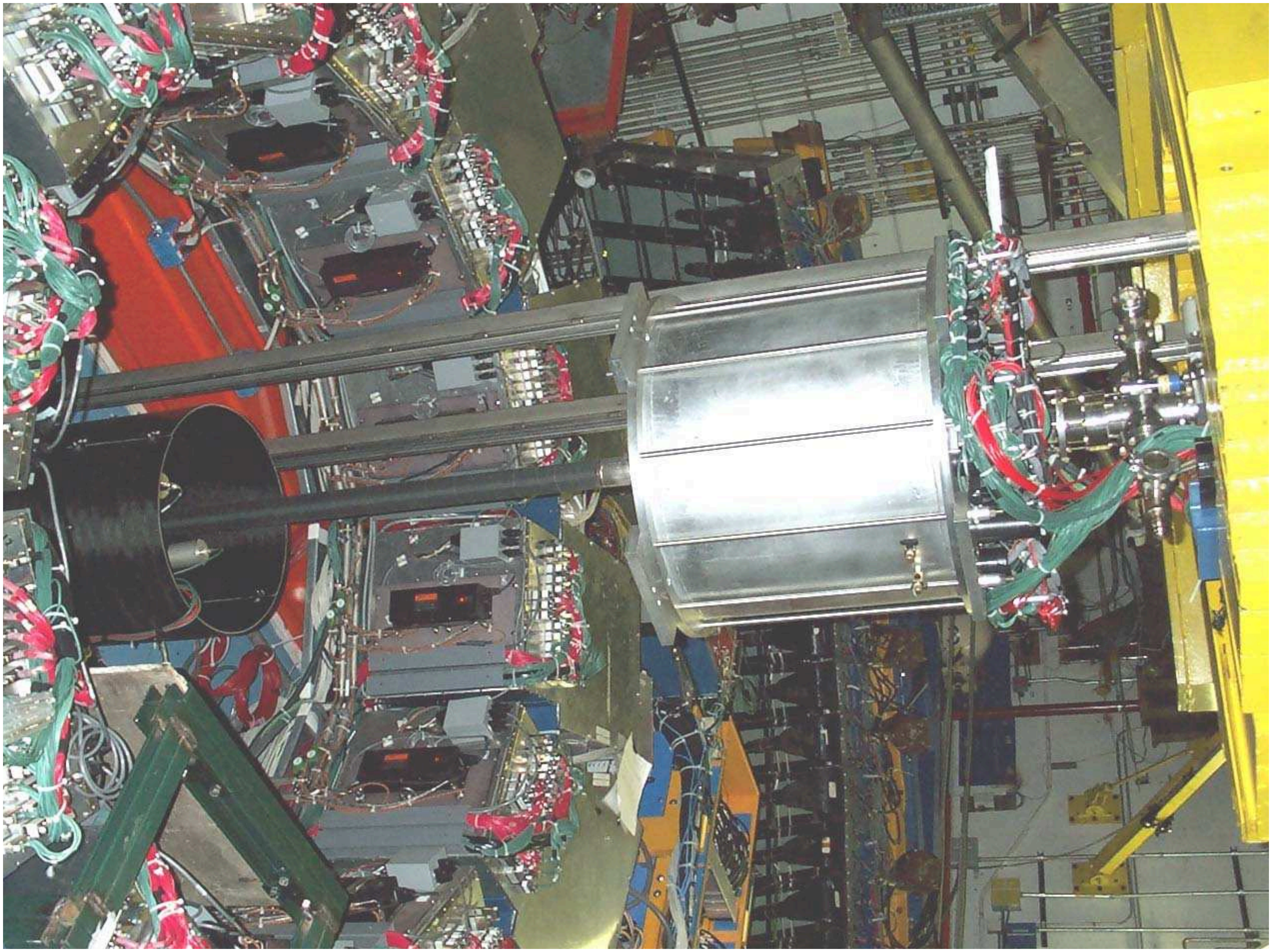


ROMAN POT DETECTORS

BEAM SHOWER COUNTERS: used to reject ND events

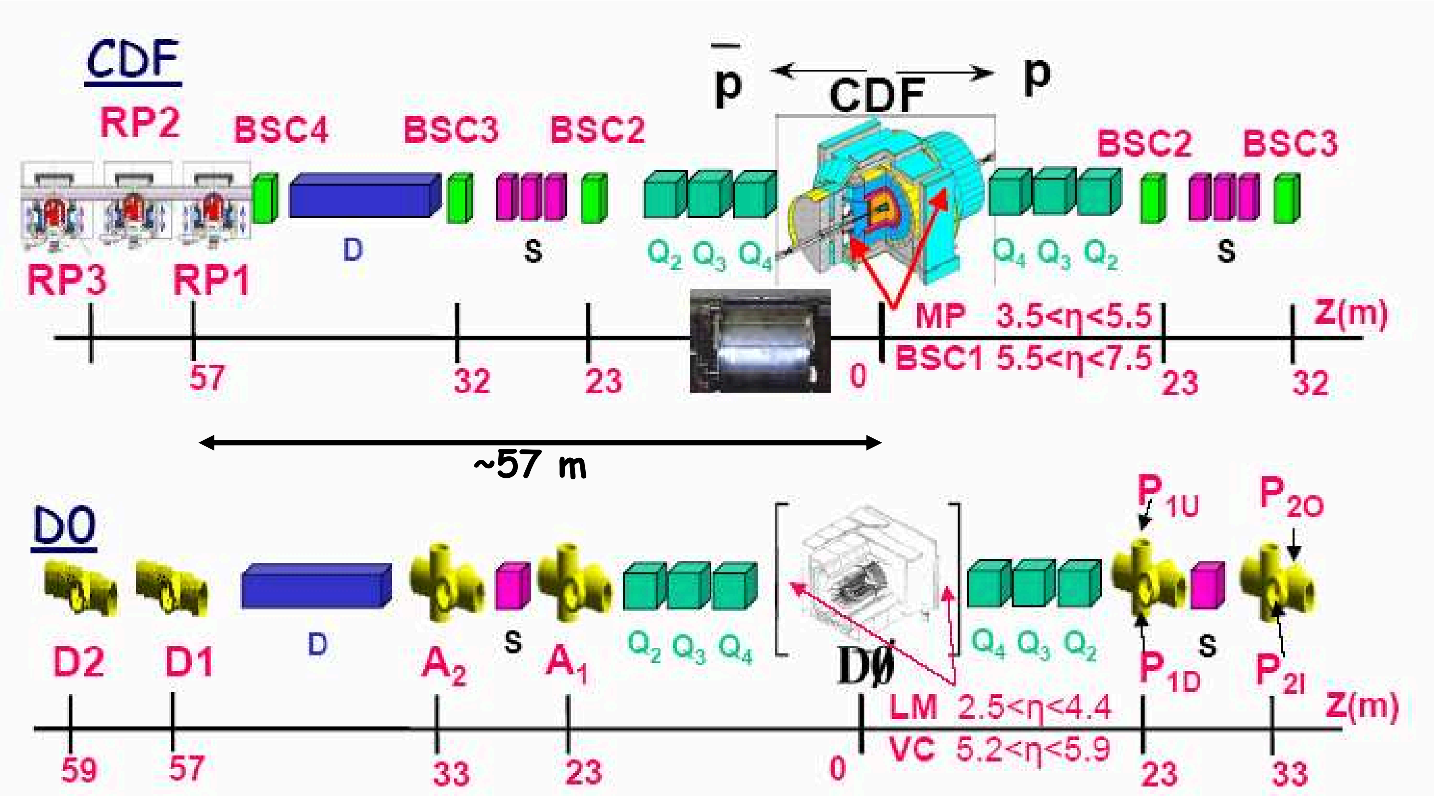


Miniplug (CDF)



Forward Detectors (DØ and CDF)

- CDF: "dipole" roman pots on $\bar{p}$ side only
- DØ :"Roman pot" detectors on each side (p and $\bar{p}$)



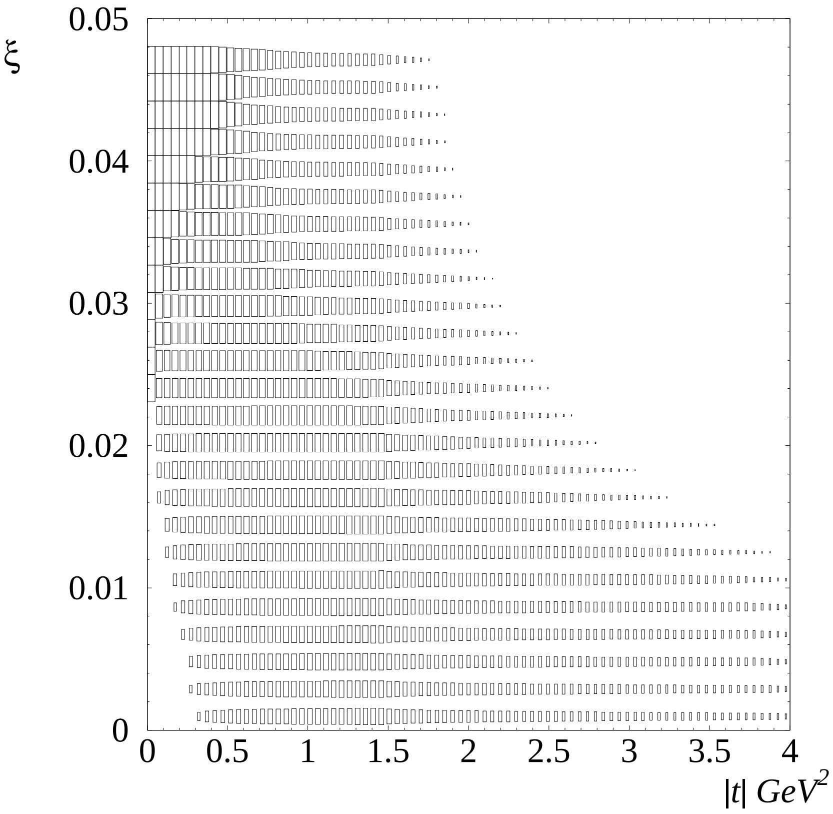
Forward Detectors (DØ)

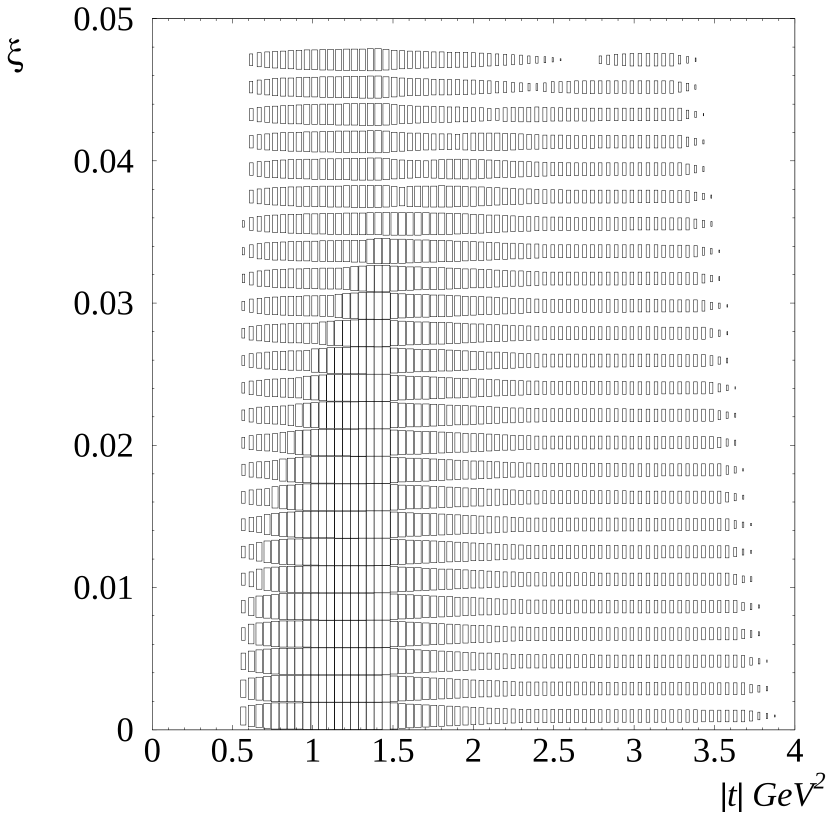
Rapidity gap method: limitation

- Difference in acceptance for proton tagging in roman pots and rapidity gap method
- ξ is the fraction of the proton momentum carried away by the pomeron (colourless object): $gap\ size \sim log 1/\xi$
- Total diffractive mass (energy conservation): $M_X = \sqrt{\xi_p \xi_{\bar{p}} S}$
- Implies that rapidity gaps are only visible for small masses, when ξ is small enough: if masses are large, rapidity gap too small, not visible since at the edge of the detector
- Another limitation (specially at the LHC): Rapidity gaps filled by particles coming from minimum bias interactions if many interactions occur in the same bunch crossing $\rightarrow$ leads to another definition of "gaps" by counting only track pointing to the main vertex (inconvenient: small acceptance of tracking devices)

FPD acceptance (DØ)

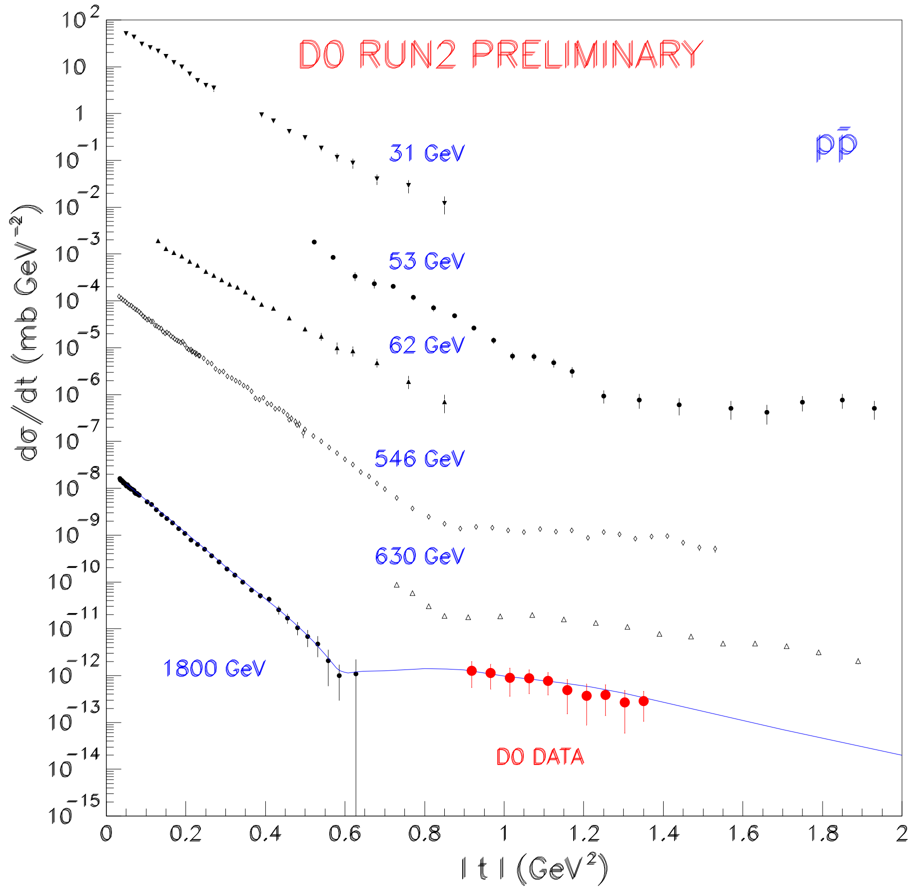
dipoles: acceptance at small t, medium ξ, quadrupole: higher t, small ξ, dipole acceptance similar to CDF pots





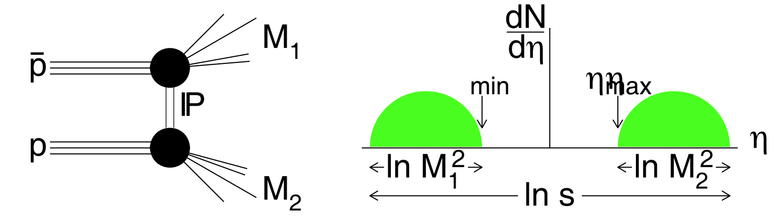
Elastic events

Measurement of the t-slope of the elastic cross section (FPD commissioning)

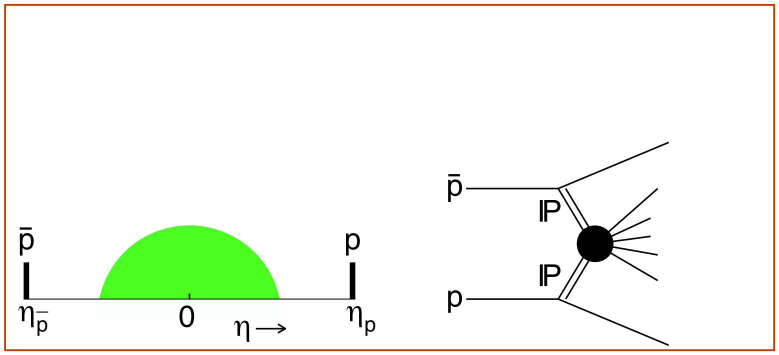


Central and multigap events

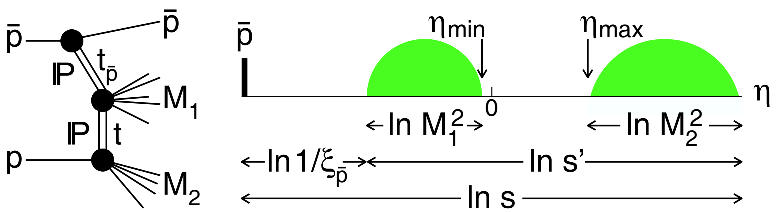
Different kinds of events



- **Double Diffraction Dissociation**
  - **One central gap**



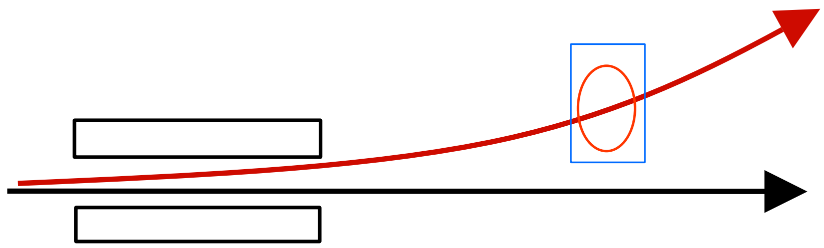
- **Double Pomeron Exchange**
  - **Two forward gaps**



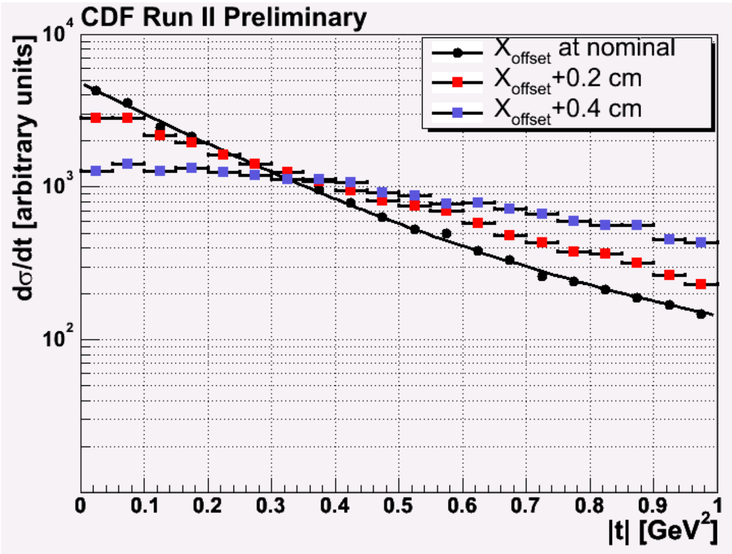
- **SDD: Single+Double Diffraction**
  - **One forward gap+ one central gap**

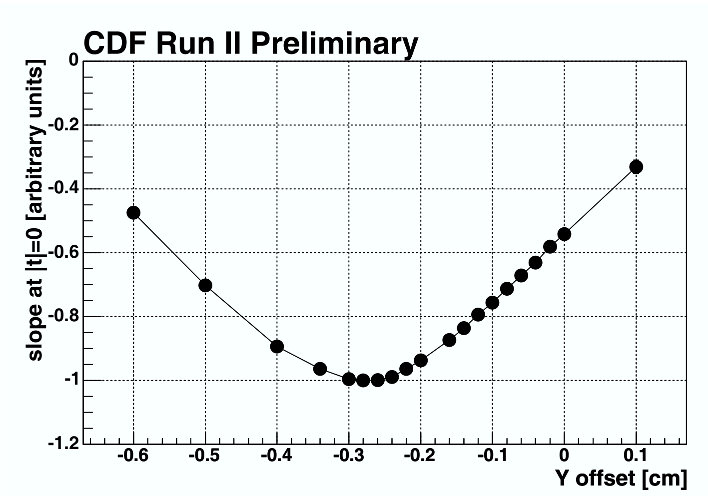
Roman pot alignment

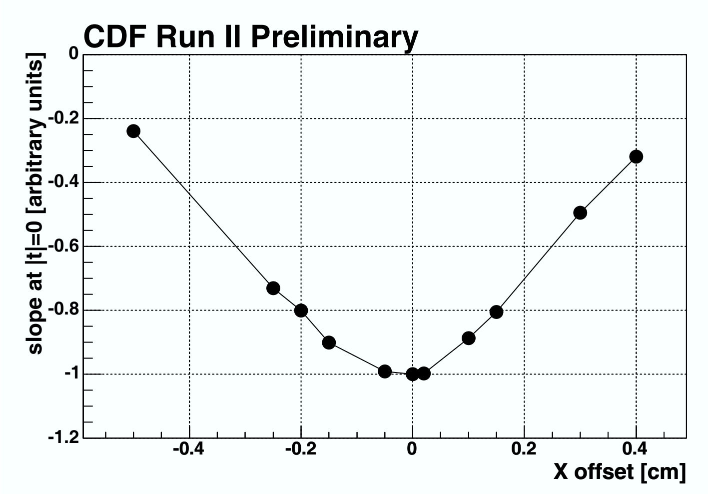
Roman pot alignment using data: maximise the t slope of the cross section



maximize the |t|-slope
⇨ determine X and Y offsets

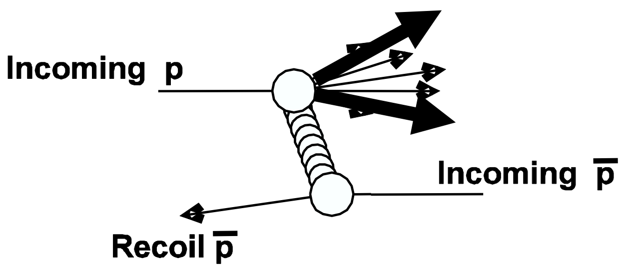


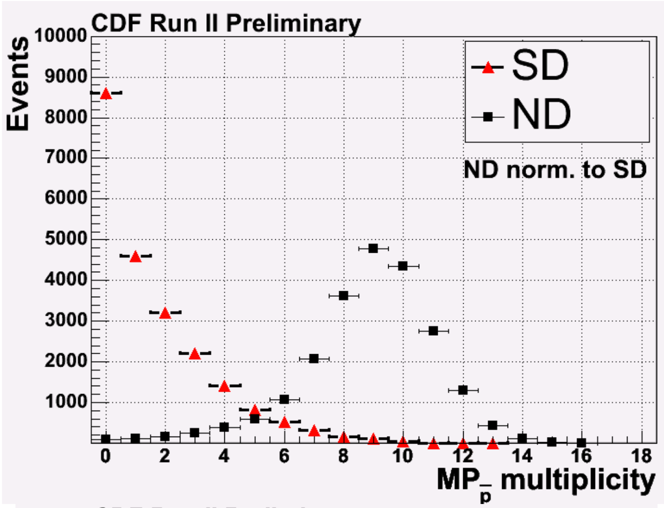




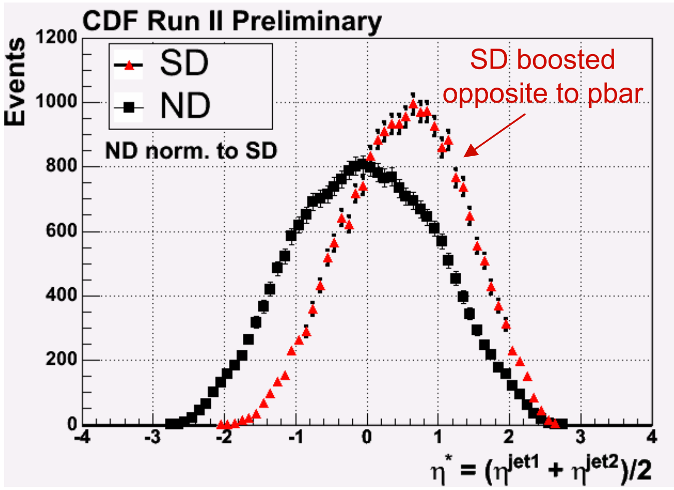
Kinematic properties for diffractive events

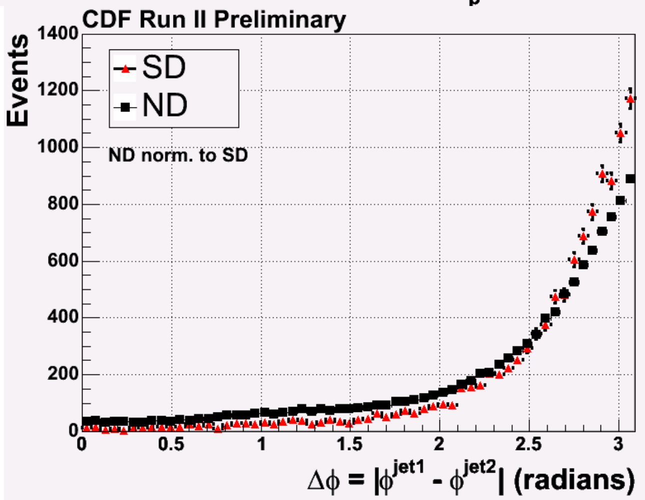
- Compare kinematic properties of single diffractive/non diffractive events when a $\bar{p}$ is tagged
- Diffractive events show less QCD radiation: events more back-to-back





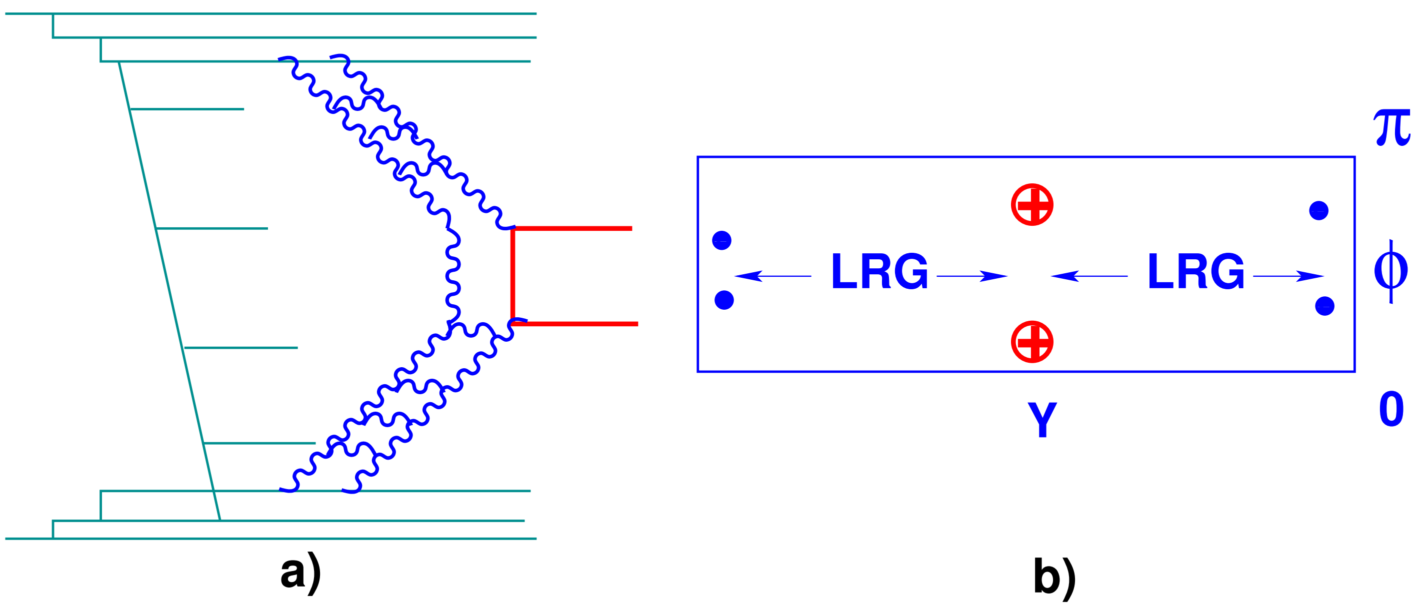
compare ND and SD





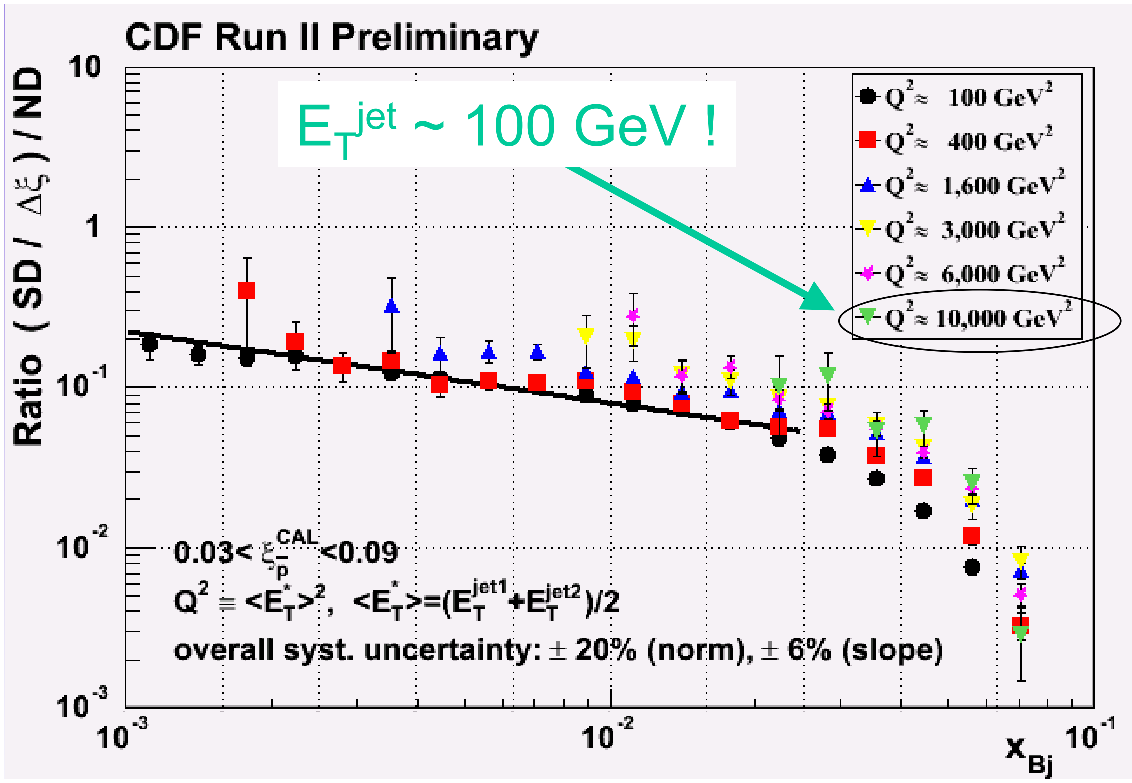
Factorisation at Tevatron?

- Is factorisation valid at Tevatron? Can we use the parton densities measured at HERA to use them at the Tevatron/LHC?
- Factorisation is not expected to hold: soft gluon exchanges in initial/final states
- Survival probability: Probability that there is no soft additional interaction, that the diffractive event is kept



Factorisation within CDF data?

Same x dependence for different kinematical domains $\longrightarrow$
Factorisation holds



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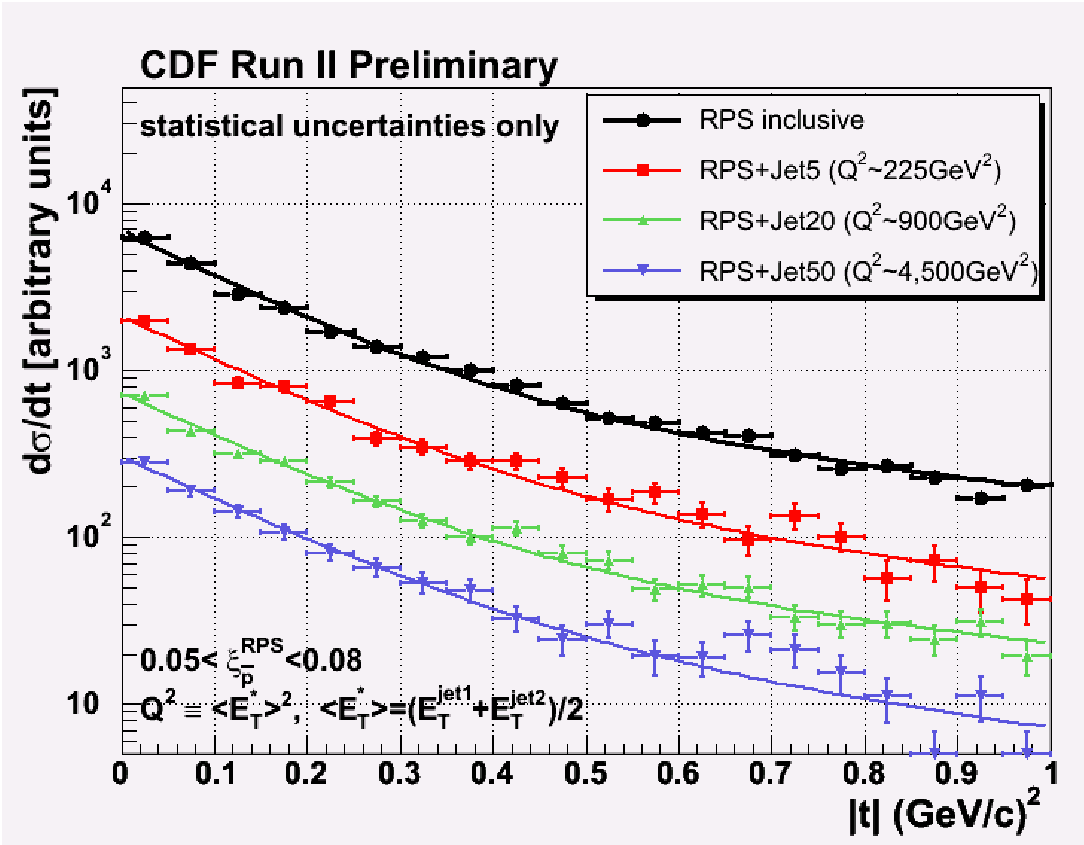
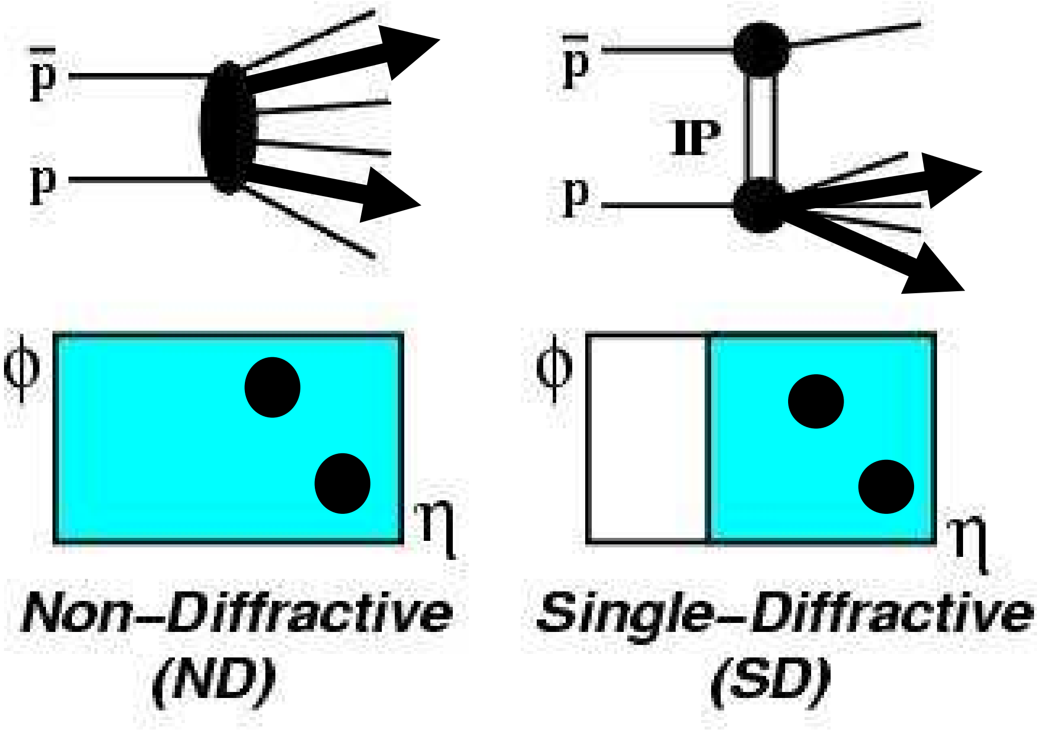


Extraction of xG in pomeron from CDF data

Extraction of gluon in pomeron using diffractive jet rate in CDF data

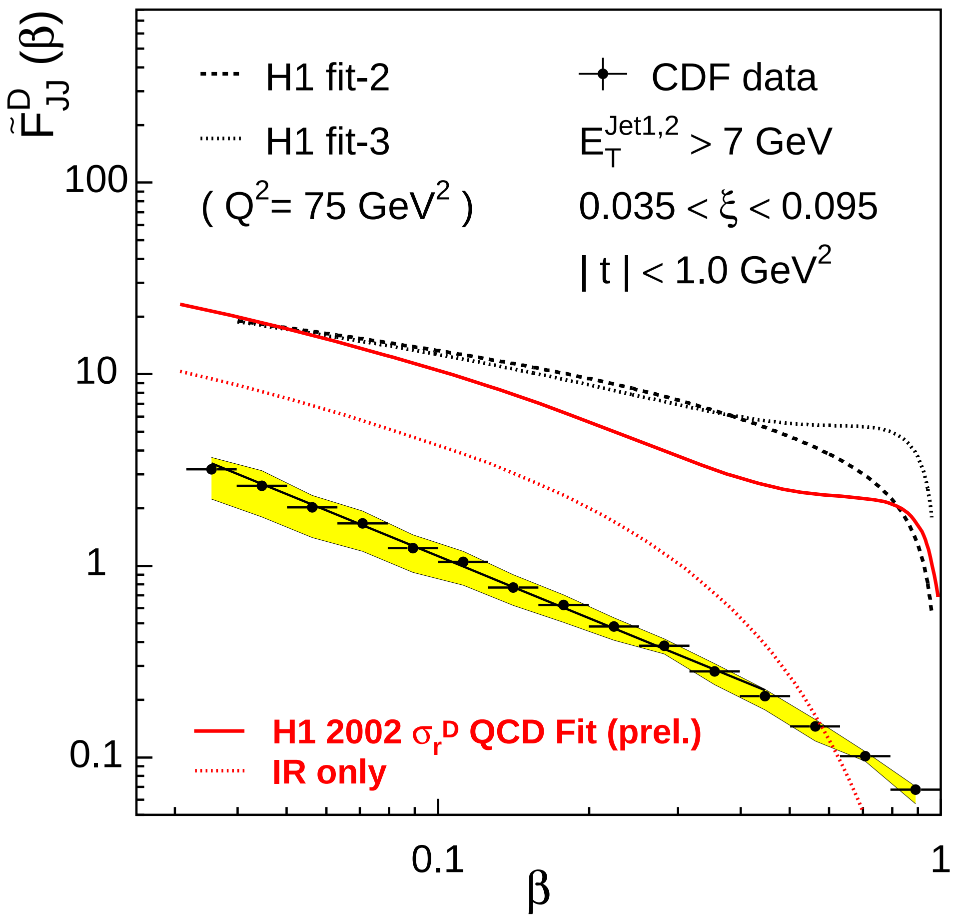


$$R(x_{Bj}) \equiv \frac{\mathrm{Rate}^{SD}_{jj}(x_{Bj})}{\mathrm{Rate}^{ND}_{jj}(x_{Bj})}$$

$$\Rightarrow \quad \frac{F^{SD}_{jj}(x_{Bj})}{F^{ND}_{jj}(x_{Bj})}$$

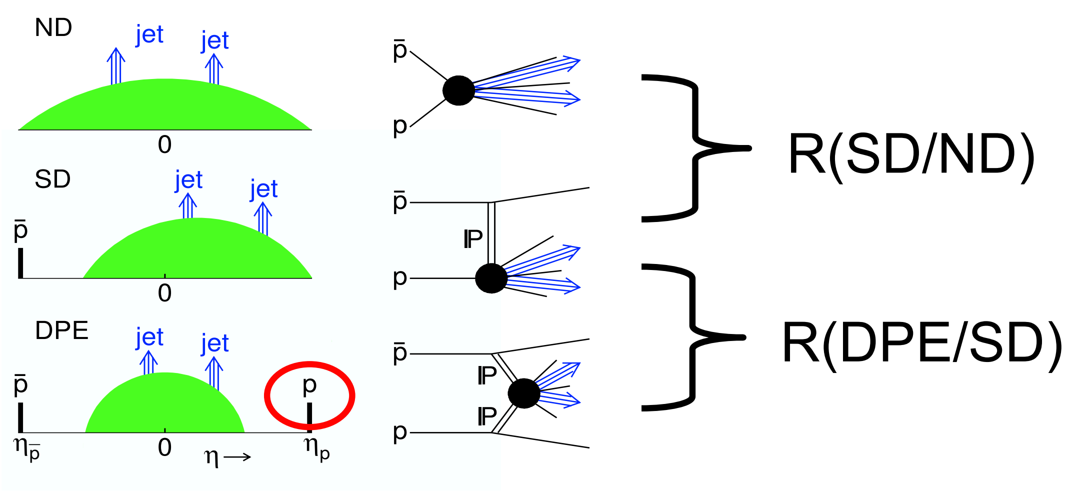
Extraction of xG in pomeron from CDF data

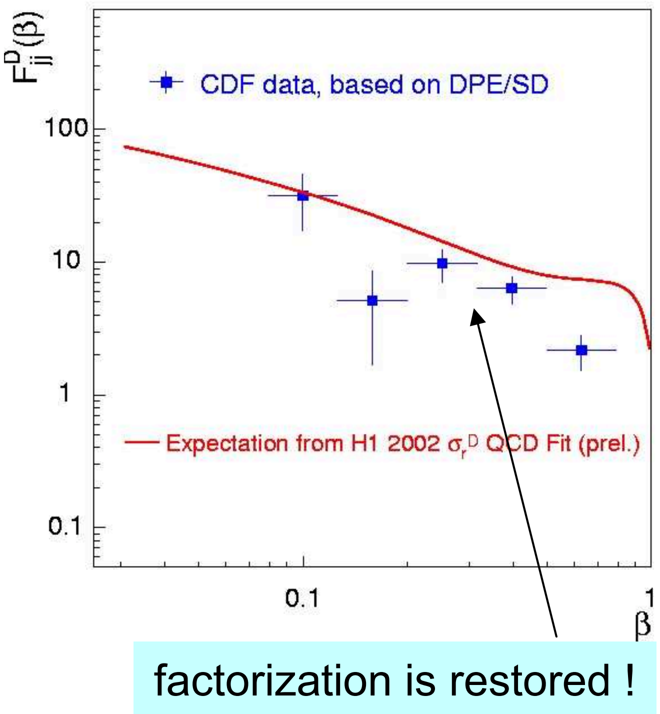
- Measurement of the dijet diffractive cross section leads directly to diffractive structure function: $\frac{\sigma_{jj}(SD)}{\sigma_{jj}(ND)} = \frac{F^D_{jj}}{F_{jj}}$
- Comparison of xG in pomeron from H1 (full red line) compared to CDF measurement:
- Difference in normalisation, shapes similar



Factorisation breaking at Tevatron

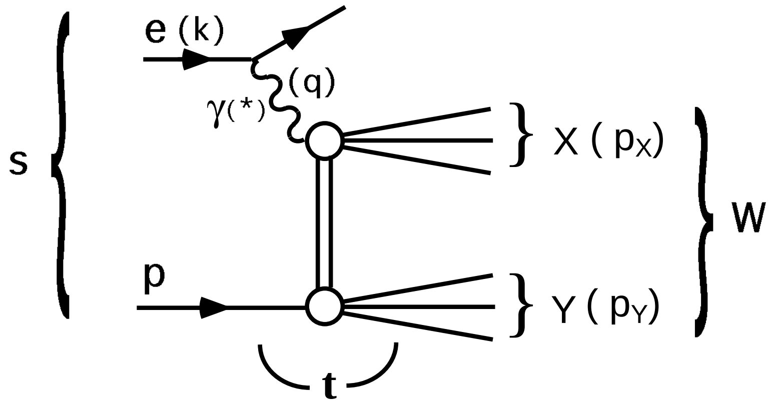
- No factorisation between HERA and Tevatron: survival probability of 0.1 at Tevatron
- Factorisation between double pomeron exchange and single diffraction?
- Is the survival probability a constant or does it depend on kinematic variables? Can we test it at Tevatron?

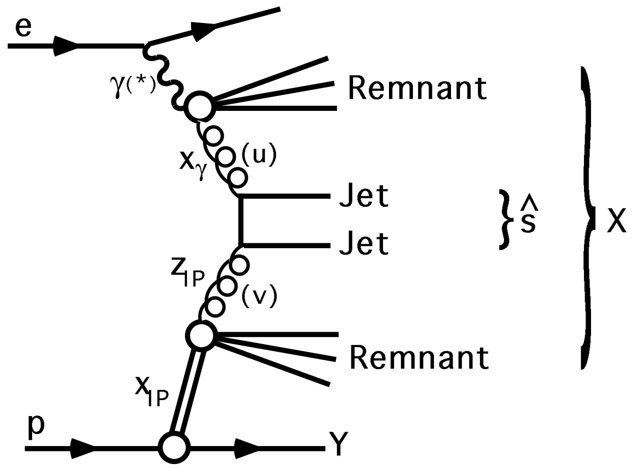




Survival probability studies in H1

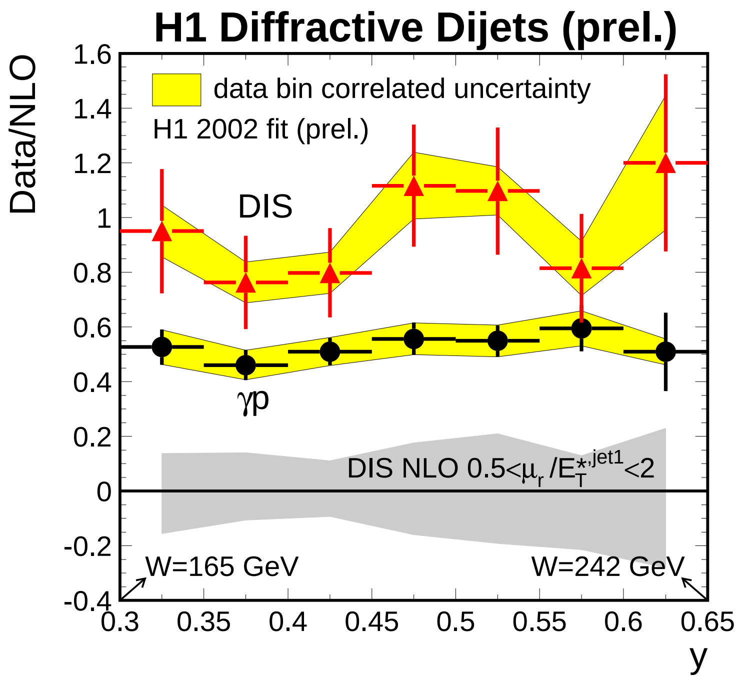
- Find a process where we have diffractive hadron-hadron interaction at HERA: look in resolved photoproduction events
- Look for the proportion of diffractive events and check if it is different from DIS





Survival probability studies in H1

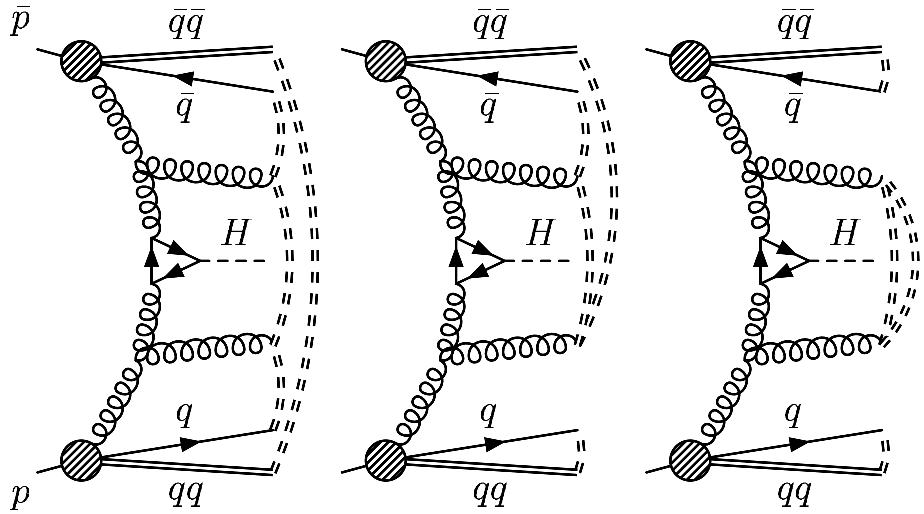
Normalised cross section for the diffractive production of 2 jets in γp



Conclusion: Factor 0.5 needed between DIS and γp data! Evidence for survival probability effects, different from Tevatron.

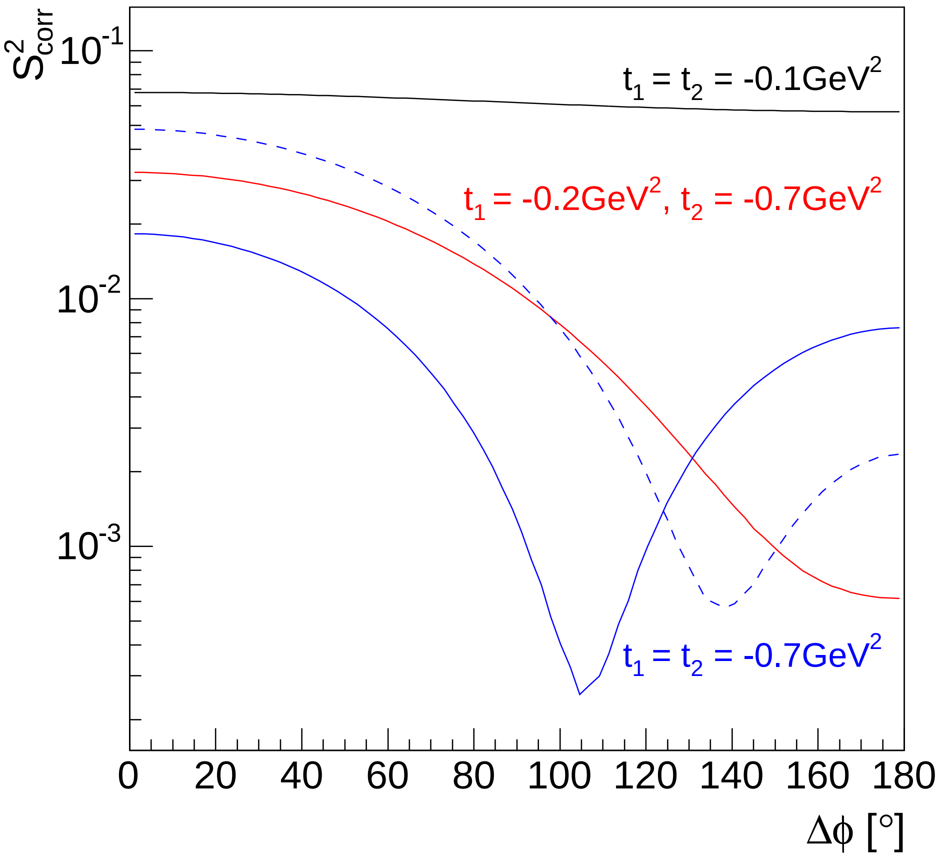
A parenthesis: Soft Colour Interaction Models

- A completely different model to explain diffractive events: Soft Colour Interaction (R.Enberg, G.Ingelman, N.Timneanu, hep-ph/0106246)
- Principle: Variation of colour string topologies, giving a unified description of final states for diffractive and non-diffractive events
- No survival probability for SCI models



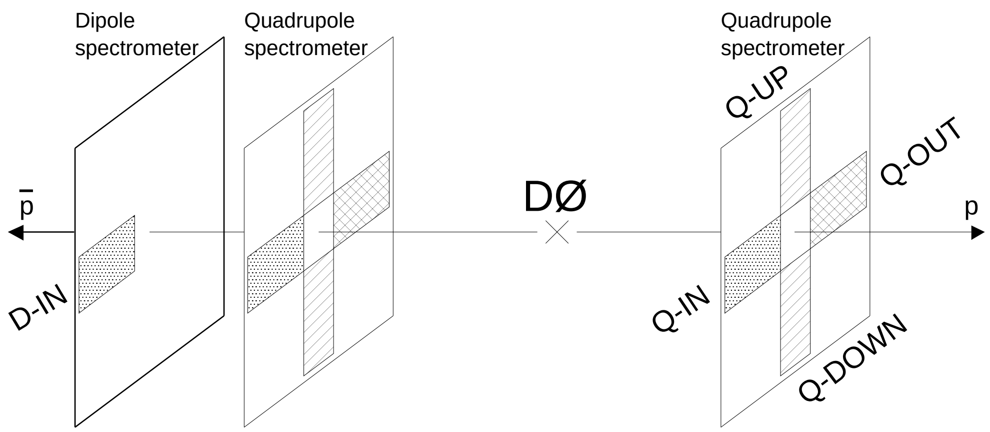
$\Delta\Phi$ dependence of survival probabilities

Survival probability strongly $\Delta\Phi$-dependent where $\Delta\Phi$ is the difference in azimuthal angles between p and $\bar{p}$



Forward Proton Detector in DØ

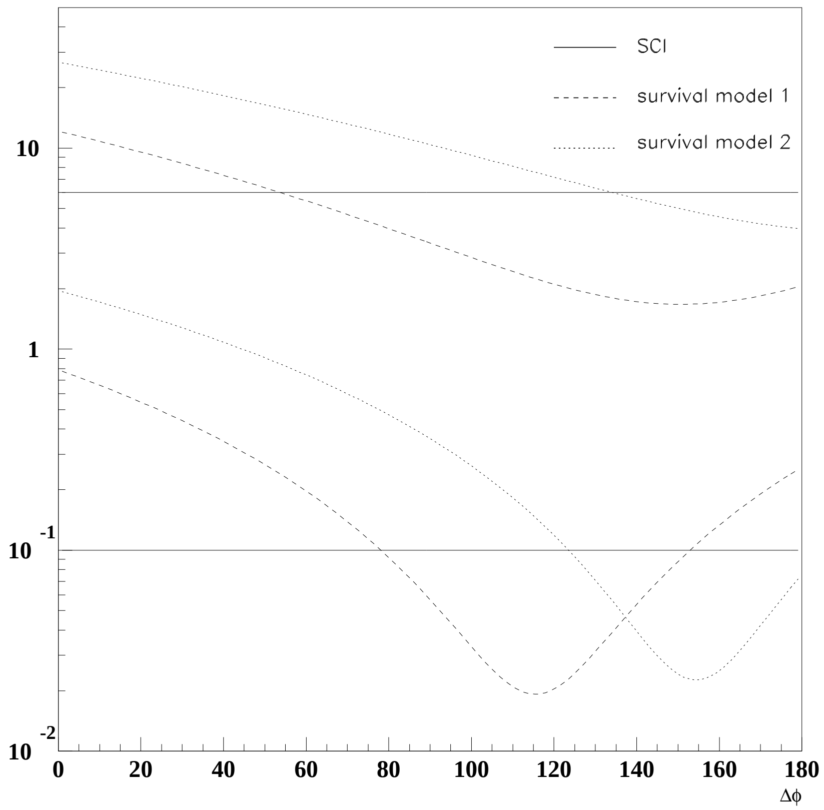
Forward Proton Detector (FPD) installed by DØ allowing to measure directly $\Delta\Phi$



Possibility to combine D-IN with quadrupole on the other side, or two quadrupole detectors (Q-UP and Q-UP, or Q-UP and Q-DOWN...)

Results

Relative $\Delta\Phi$ dependence for SCI and pomeron-based models (upper plots: ($|t_p| > 0.6$, $|t_{\bar{p}}| > 0.1$ GeV^2, lower ones $|t_p| > 0.5$, $|t_{\bar{p}}| > 0.5$ GeV^2)



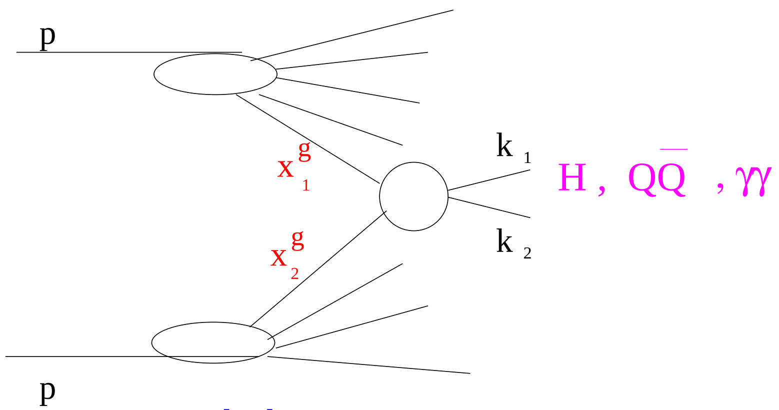
Possible measurement at DØ

- Diffractive cross section ratios in different regions of $\Delta\Phi$ at the Tevatron
- same side: $\Delta\Phi < 45$ degrees, opposite side: $\Delta\Phi > 135$, middle: $45 < \Delta\Phi < 135$ degrees;
- 1st measurement: asymmetric cuts on t (dipole and quadrupole), 2nd measurement: symmetric cuts on t (quadrupole on both sides)
- Possible to distinguish between SCI and pomeron-based models, and test the survival probabilities
- See A. Kupčo, R. Peschanski, C. Royon, Phys. Lett. B 606 (2005) 139

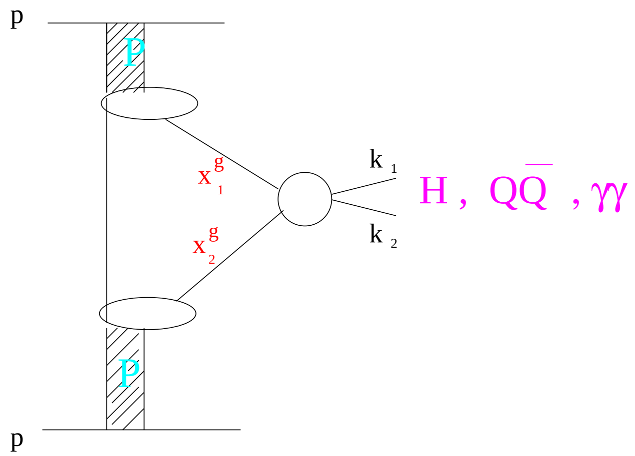
Configuration	model	middle/same	opp./same
Quad.	SCI	1.3	1.1
+ Dip.	Pom.	0.36	0.18
Quad.	SCI	1.4	1.2
+ Quad.	Pom.	0.14	0.31

Look for exclusive events at the Tevatron

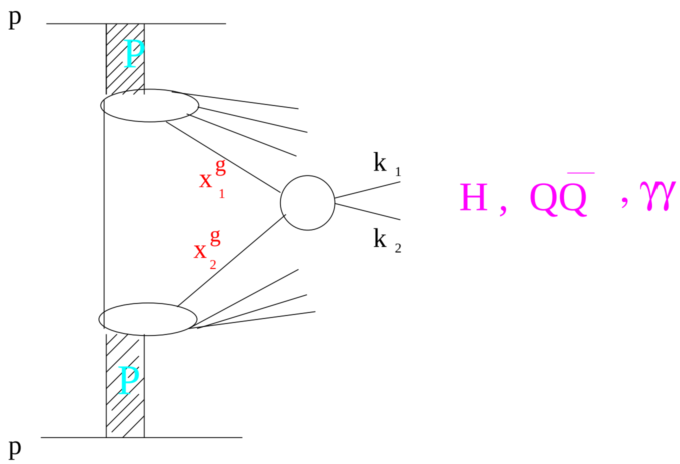
- "exclusive" events: events without pomeron remnant
- The full available energy is used in the hard interaction
- Interesting for LHC...



"Standard"



"Exclusive "



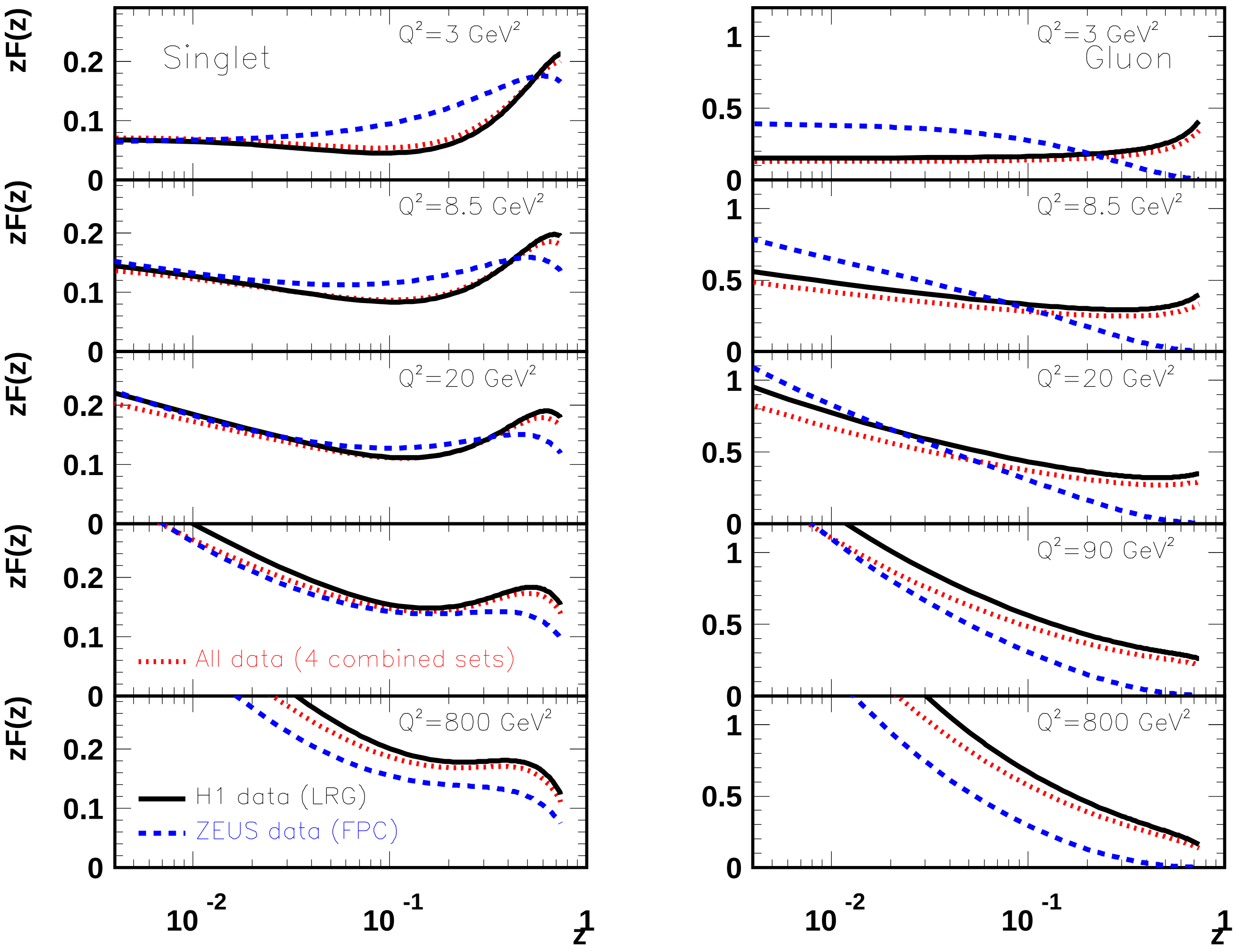
"Inclusive"

How to get predictions for Tevatron/LHC?

- QCD fits to F_2^D data
- Use the most recent F_2^D data published by H1, ZEUS
- DGLAP QCD evolution using MRS-like distributions at the starting scale
- $$zS(z, Q^2 = Q_0^2) = \left[A_S z^{B_S} (1-z)^{C_S} (1 + D_S z + E_S \sqrt{z})\right] \cdot e^{\frac{0.01}{z-1}}$$
  $$zG(z, Q^2 = Q_0^2) = \left[A_G (1-z)^{C_G}\right] \cdot e^{\frac{0.01}{z-1}}$$
- In the fits: $\alpha_S(M_Z) = 0.118$, $Q_0^2 = 3$ GeV^2
- Charm quark contribution computed in the fixed flavour scheme using the photon-gluon fusion prescription
- For H1 data: $\alpha_P = 1.12$, $\chi^2/dof \sim 0.9$

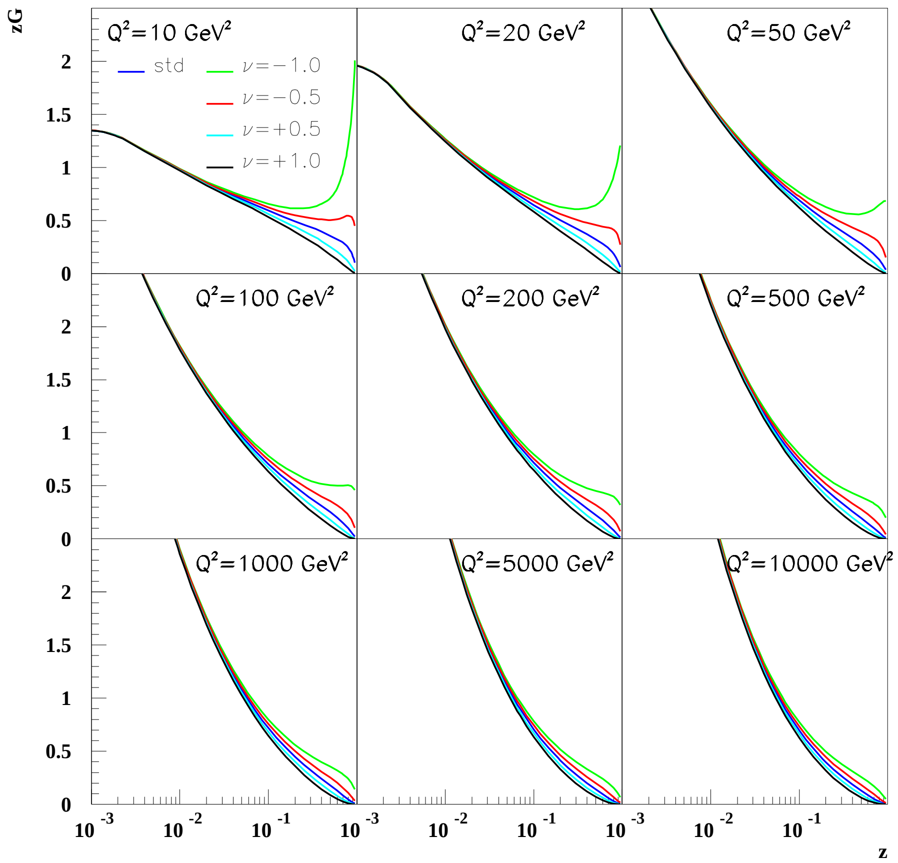
Parton densities in Pomeron

DGLAP fits to most recent H1 and ZEUS data (see: hep-ph/0609291, hep-ph/0602228)



Uncertainty on high β gluon

- Important to know the high β gluon since it is a contamination to exclusive events
- Experimentally, quasi-exclusive events indistinguishable from purely exclusive ones
- Uncertainty on gluon density at high β: multiply the gluon density by $(1-\beta)^\nu$ (fit: $\nu = 0.0 \pm 0.6$)

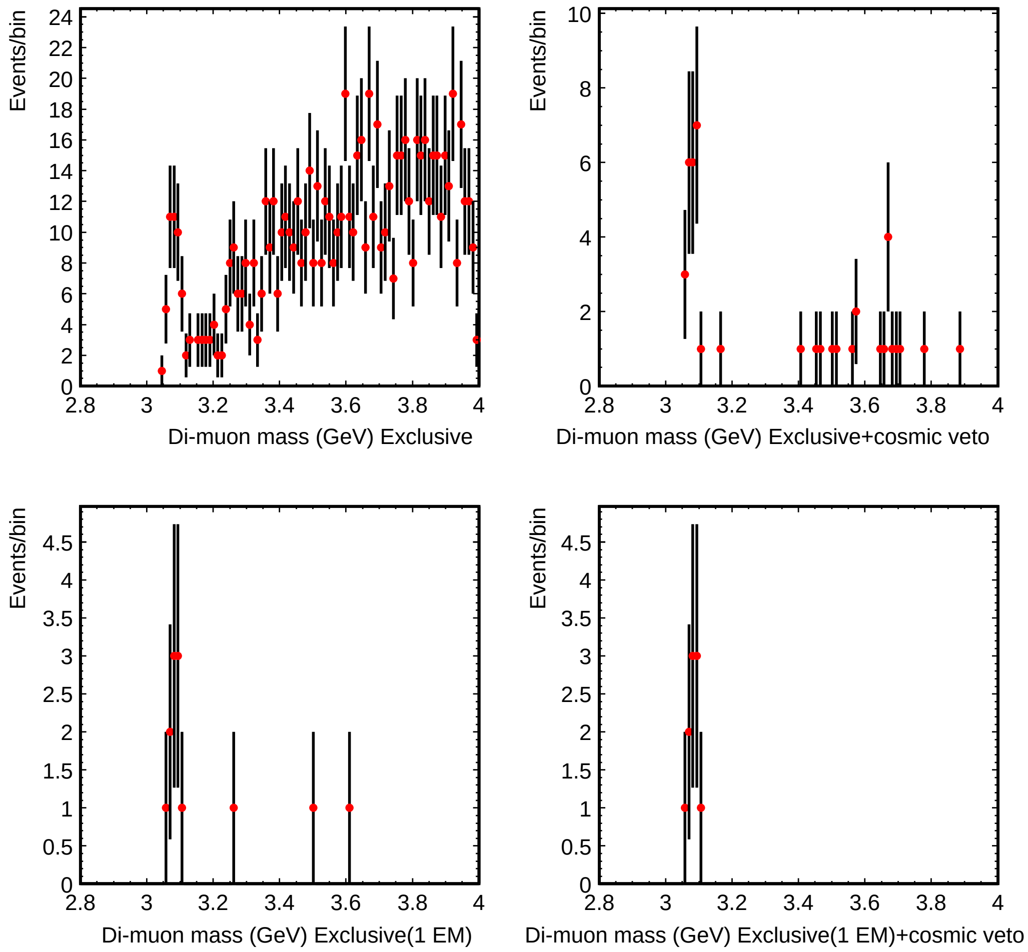


DPEMC Monte Carlo

- DPEMC (Double Pomeron Exchange Monte Carlo): New generator to produce events with double pomeron exchange (contains different models available for inclusive/exclusive diffraction) http://boonekam.home.cern.ch/boonekam/dpemc.htm, paper to be submitted to Comp. Phys. Com.
- Interface with Herwig: for hadronisation
- Exclusive and inclusive processes included: Higgs, dijets, diphotons, dileptons, SUSY, QED, Z, W...
- DPEMC generator interfaced with a fast simulation of LHC (as an example CMS, same for ATLAS) and CDF detectors, and a detailled simulation of roman pot acceptance
- Gap survival probability of 0.03 put for the LHC and 0.1 for Tevatron

Exclusive χ_c production at CDF

- Look for events with two muons and two rapidity gaps ($\chi_C^0 \rightarrow J/\Psi\gamma \rightarrow \mu^+\mu^-\gamma$)
- Problem of cosmics contamination



χ_C **exclusive production at the Tevatron?**

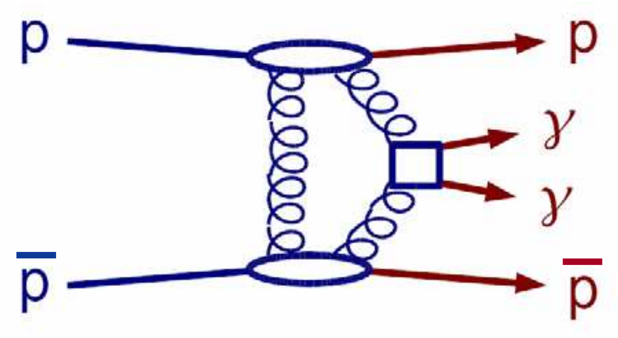
- CDF observation: Upper limit of χ_C exclusive production at the Tevatron in the $J/\Psi\gamma$ channel $\sigma \sim 49$ pb $\pm 18 \pm$ 39 pb for $y < 0.6$ (result not corrected for cosmics, χ_2 contamination)
- Exclusive prediction: 59 pb
- Quasi-exclusive contamination:

mass fraction	$\nu = 0$	$\nu = -1$	$\nu = -0.5$	$\nu = +0.5$	$\nu = +1.0$
$\geq$ 0.8	5.4	119.1	27.2	0.9	0.2
$\geq$ 0.85	2.0	62.0	11.2	0.2	0.0
$\geq$ 0.9	0.3	19.6	2.9	0.0	0.0
$\geq$ 0.95	0.8	1.7	0.8	0.0	0.0

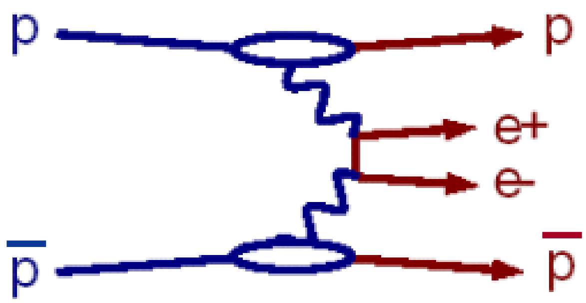
- Contamination of quasi-exclusive events strongly dependent on assumption on high-β gluon density in pomeron (completely unknown...), and also on precision and smearing of dijet mass distribution
- Look now in the diphoton channel
- See: M. Rangel, C. Royon, G. Alves, J. Barreto, R. Peschanski, Nucl. Phys. B 774 (2007) 53

Search for exclusive diphotons (CDF)

- Look for diphoton events: very clean events (2 photons and nothing else), but low cross section (nothing means experimentally nothing above threshold..., quasi-exclusive events contamination)
- Look for dilepton events: produced only by QED processes, cross-check to exclusive $\gamma\gamma$ production



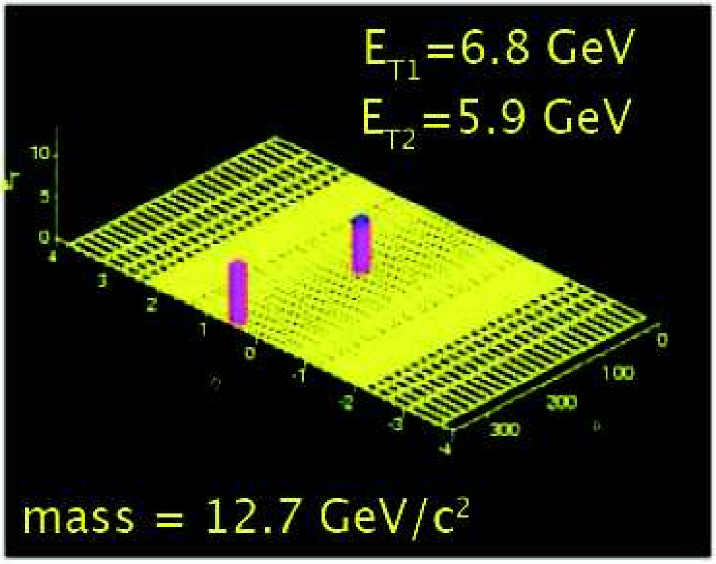
$p\bar{p} \rightarrow p + \gamma\gamma + \bar{p}$

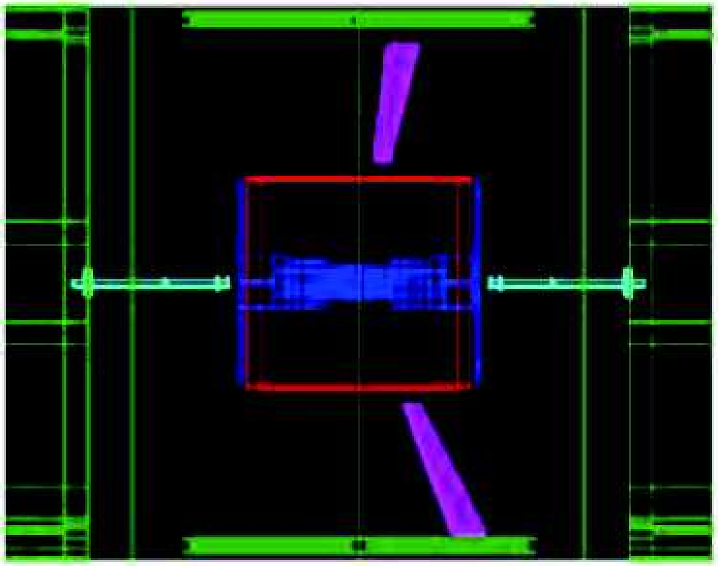


QED process: cross-check to exclusive $\gamma\gamma$

Search for exclusive diphotons (CDF)

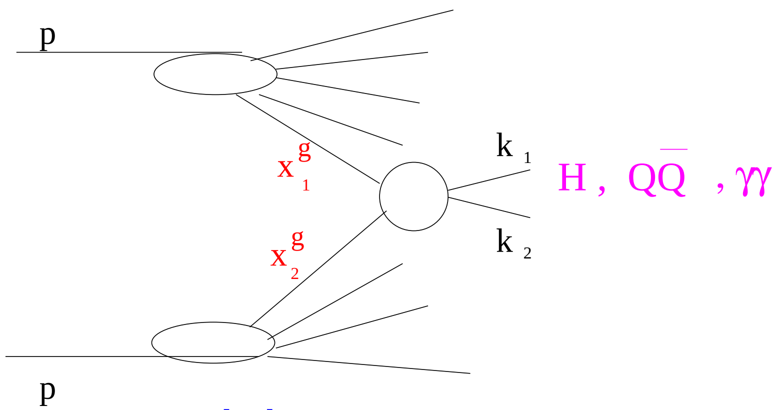
- Look for exclusive diphoton or dilepton production, (dilepton dominated by QED events (photon exchanges) and not from pomeron exchanges)
- Cross section for e^+e^- exclusive production: $N_{candidates} = 16^{+5.1}_{-3.2}$, $N_{background} = 2.1^{+0.7}_{-0.3}$ (mainly dissociation events) in 46 pb^{-1}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



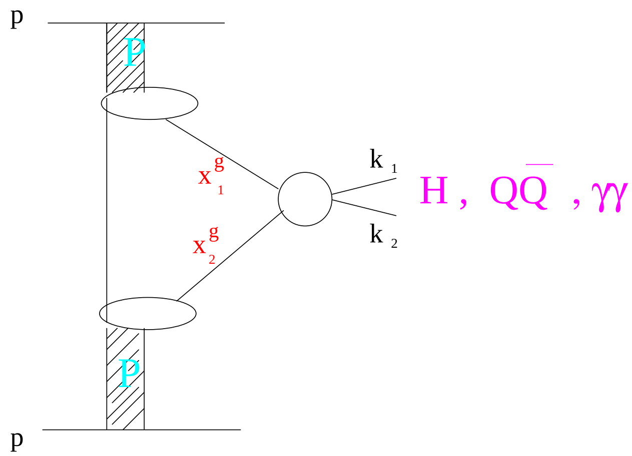


Look for exclusive events at the Tevatron in dijet channel

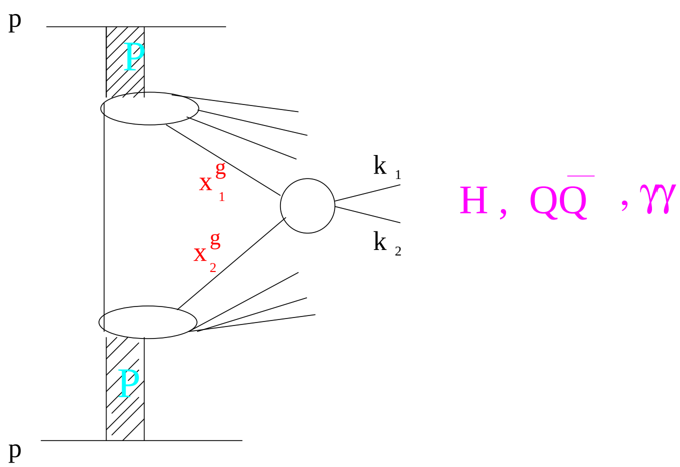
- “exclusive” events: events without pomeron remnant
- The full available energy is used in the hard interaction
- Interesting variable: dijet mass fraction



"Standard"



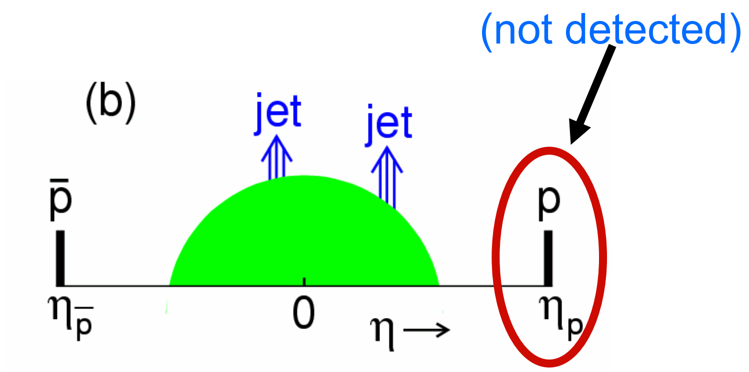
"Exclusive "

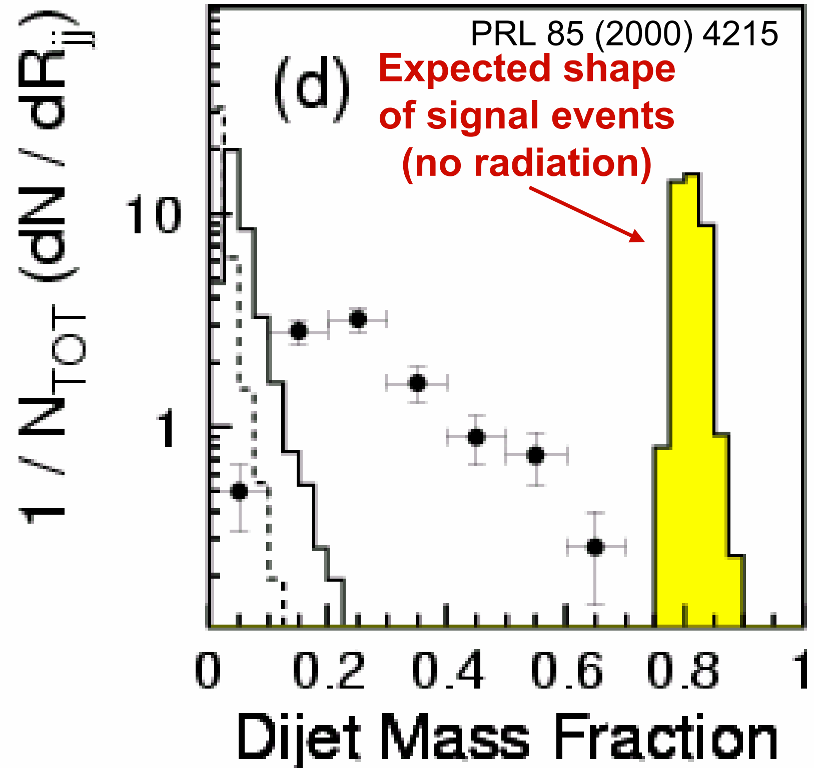


"Inclusive"

Look for exclusive events at the Tevatron

- measurement of the dijet mass fraction
- Expect a peak towards one if exclusive events exist

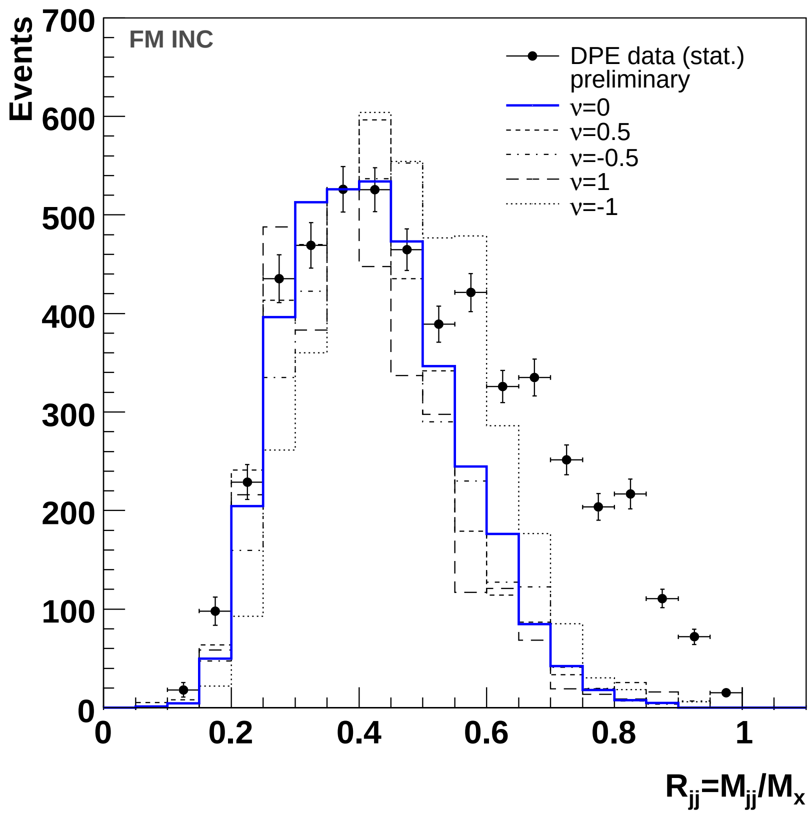




Mass fraction: $R_{jj} = \frac{M_{jj}}{M_x}$

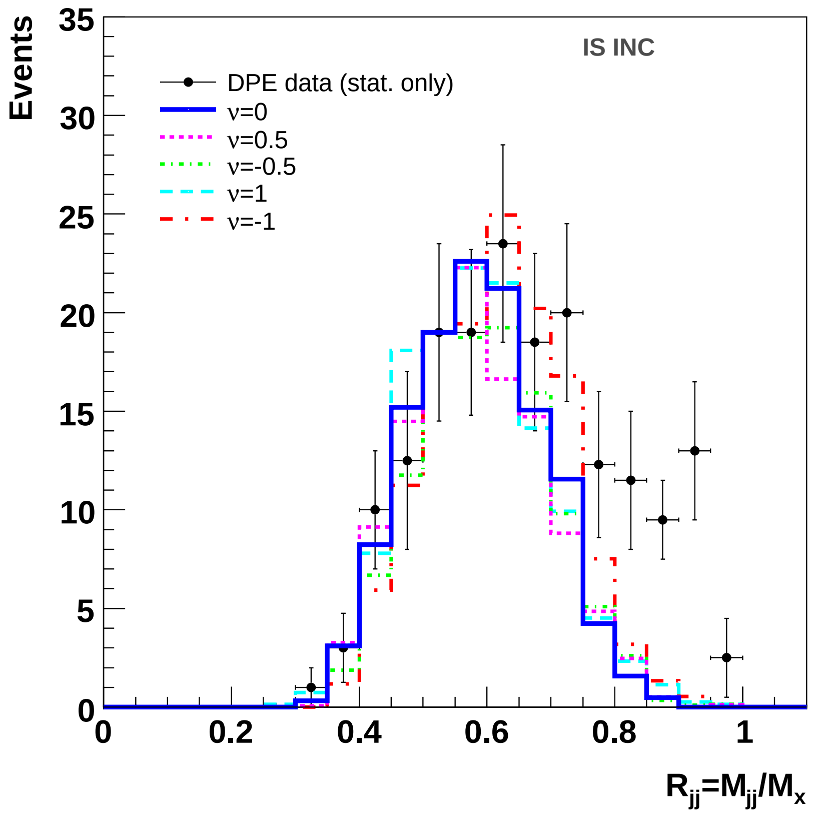
Dijet mass fraction measurement in CDF

- Look for exclusive events (events where there is no pomeron remnants or when the full energy available is used to produce diffractively the high mass object)
- Select events with two jets only, one proton tagged in roman pot detector and a rapidity gap on the other side
- Predictions from inclusive diffraction models for Jet $p_T > 10$ GeV



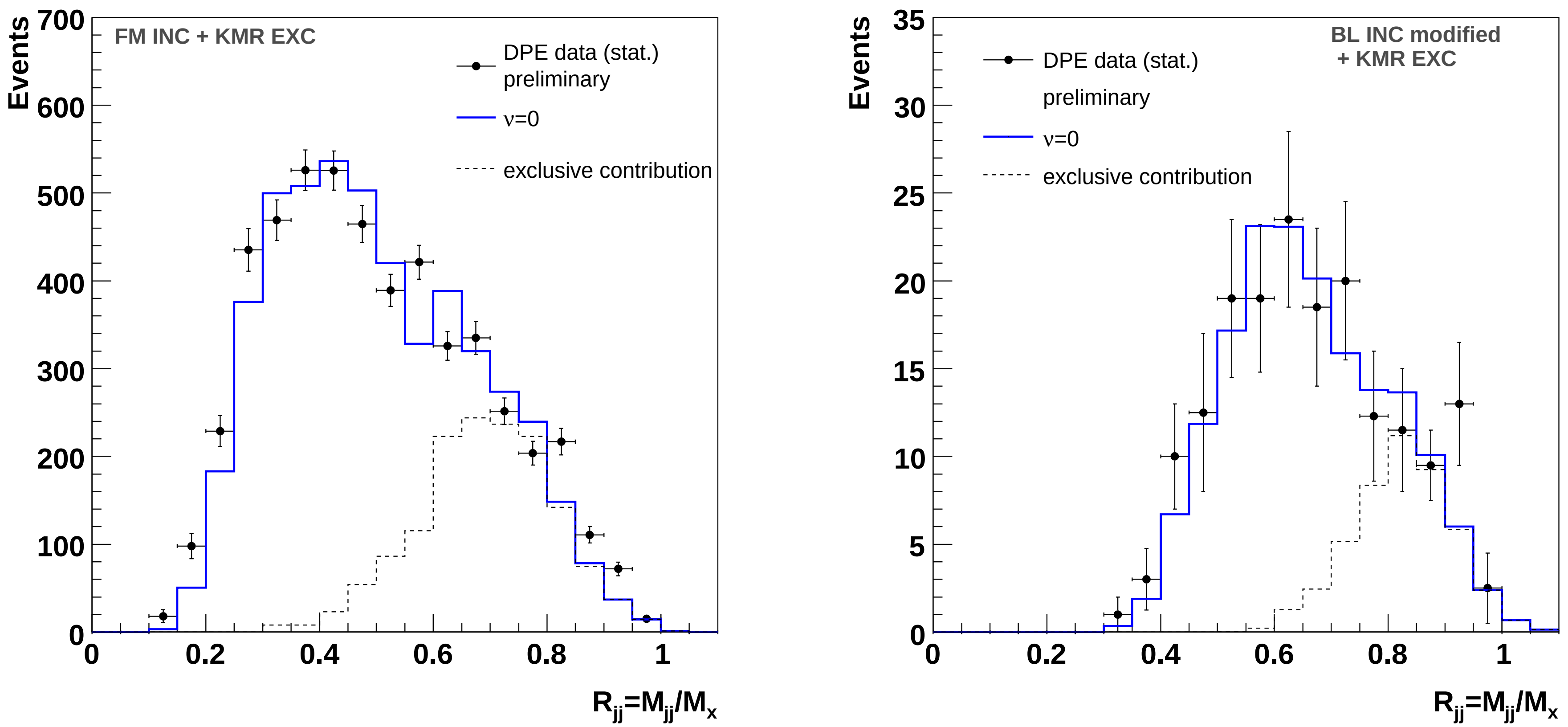
Prediction from inclusive diffraction

- Predictions from inclusive diffraction models: Jet $p_T > 25$ GeV
- Deficit of events at high dijet mass fraction



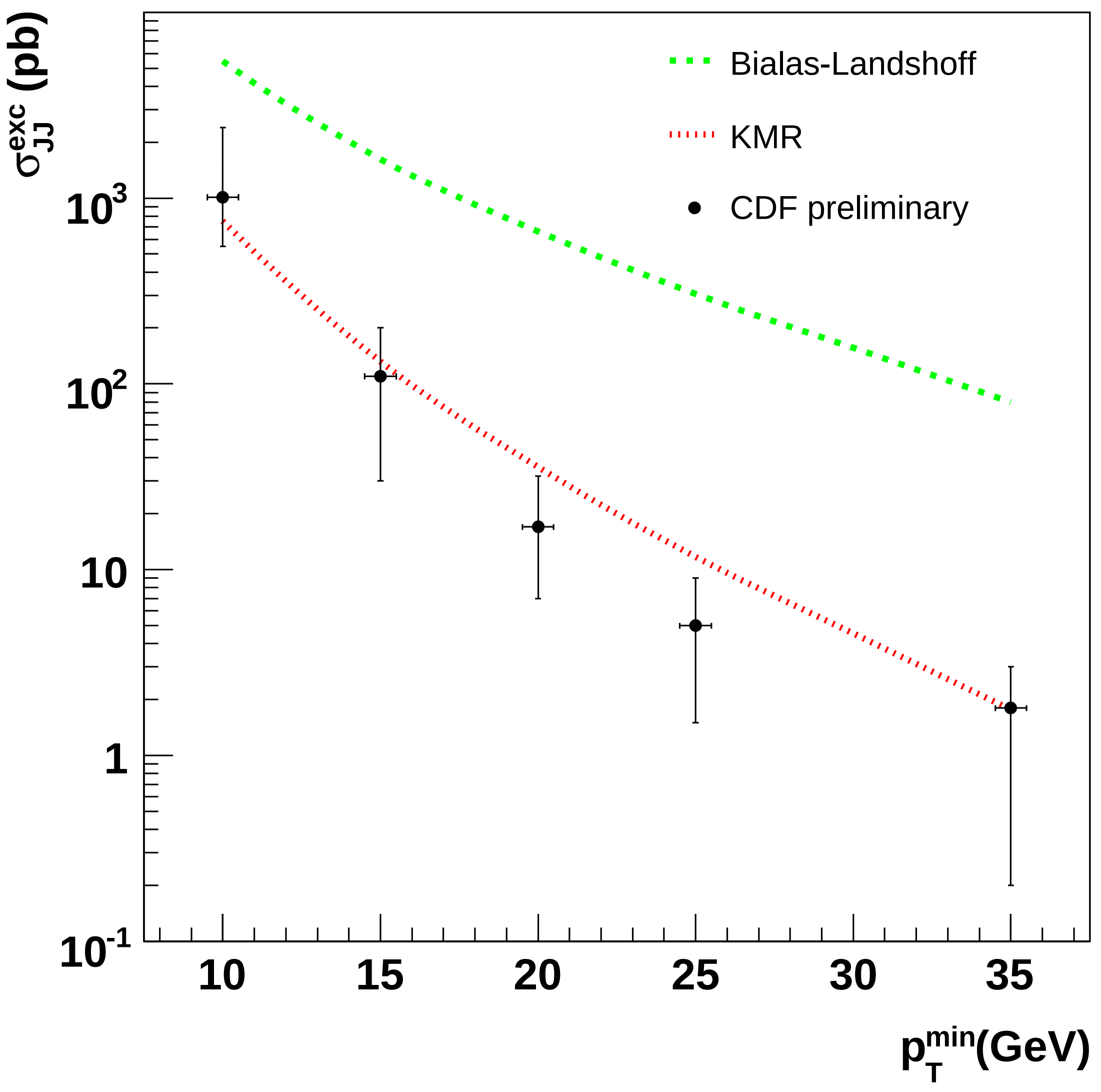
Prediction from inclusive and exclusive diffraction

- Add the exclusive contribution (free relative normalisation between inclusive and exclusive contribution)
- Good agreement between measurement and predictions
- As an example: exclusive and inclusive models for $p_T > 10$ GeV and for $p_T > 25$ GeV
- See O. Kepka, C. Royon, arXiv:0704.19956 accepted by Phys. Rev. D, arXiv0706.1798



Exclusive production cross section

- Measure p_T dependence of exclusive event cross section
- Two kinds of different models for exclusive predictions compared

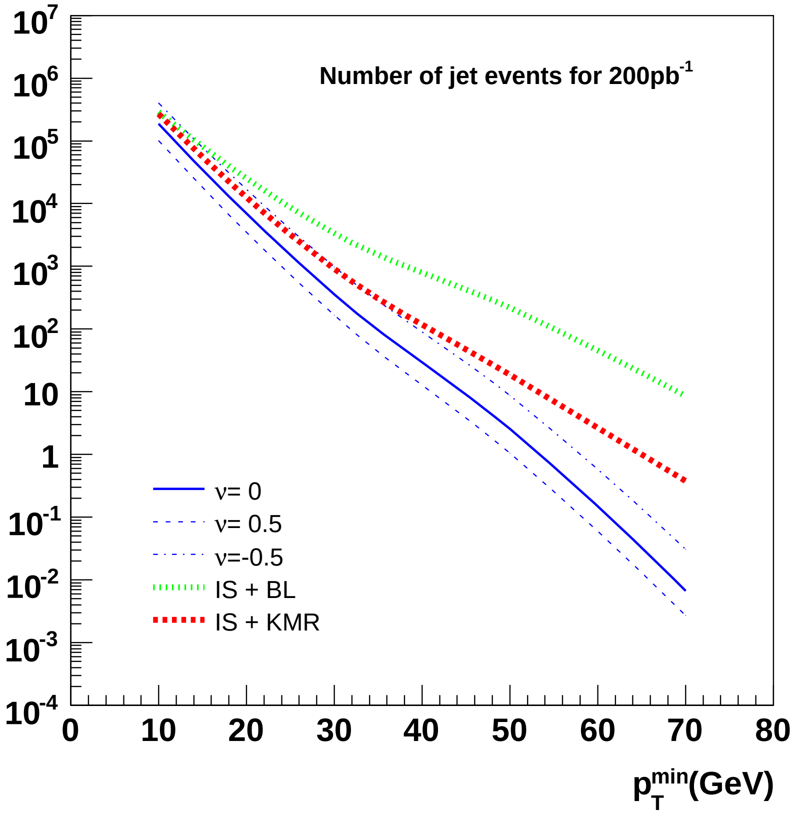


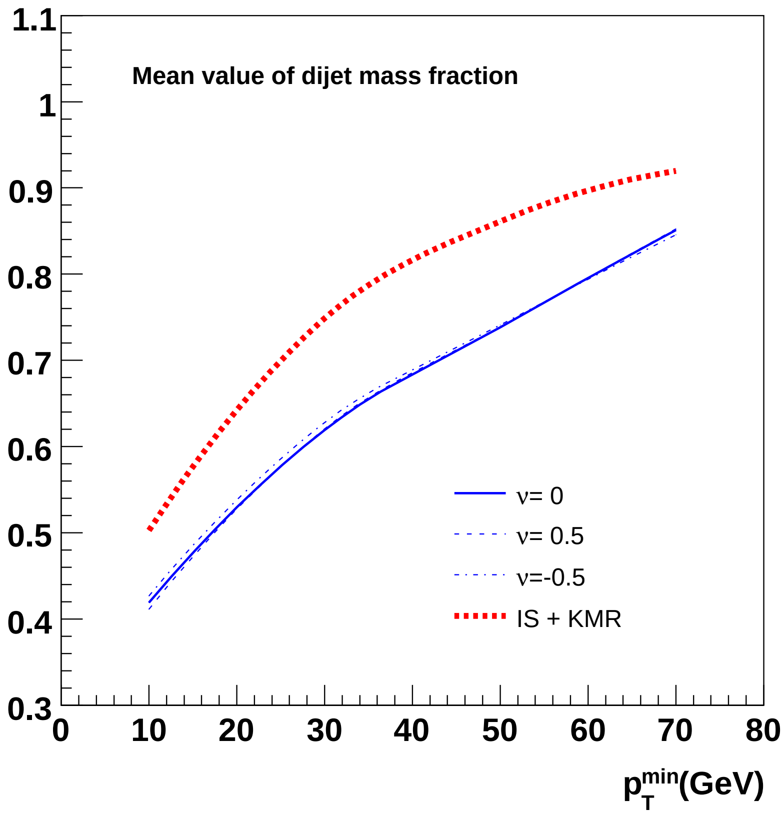
Exclusive events in dijet channel?

- Inclusive diffraction alone cannot explain the dijet mass fraction observable
- If one adds the exclusive events in addition, nice description of dijet mass fraction
- Is there a nicer way to see exclusive events?
- What about soft colour interaction? (another model of diffraction)

A better way to look for exclusive events?

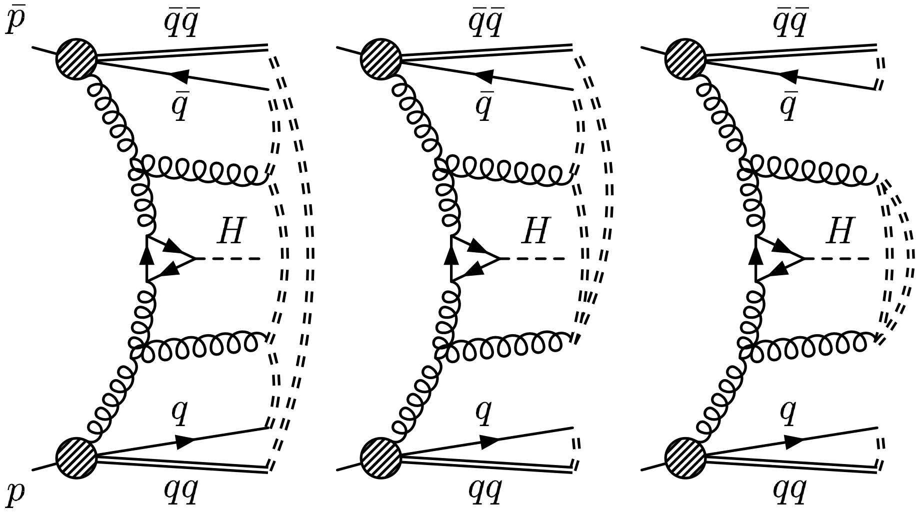
Exclusive contribution more visible at jet p_T of 30-40 GeV





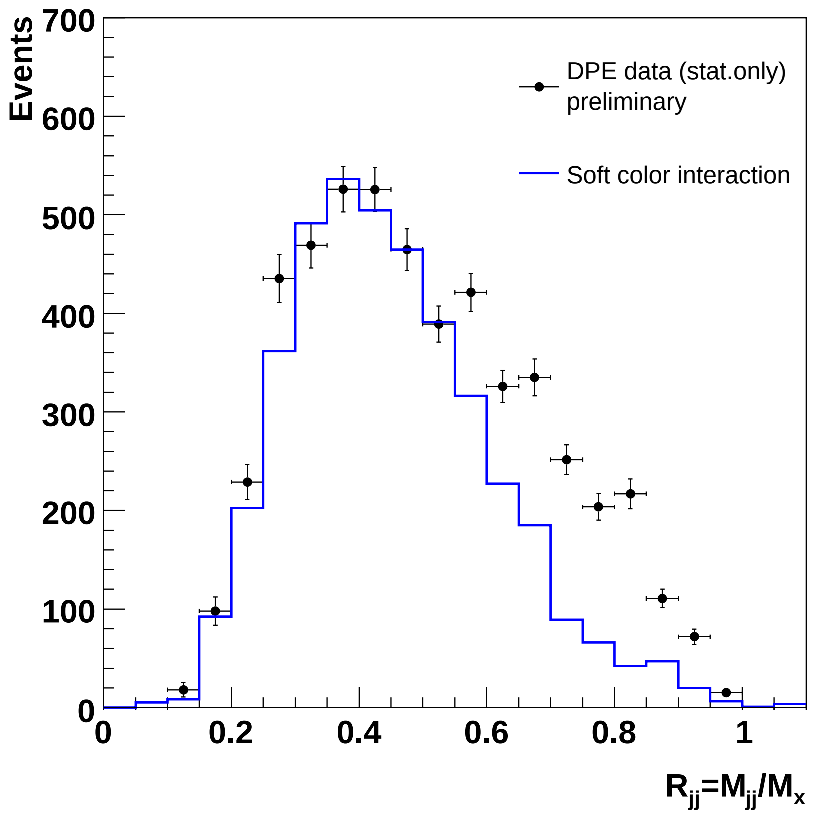
Reminder: Soft Colour Interaction models

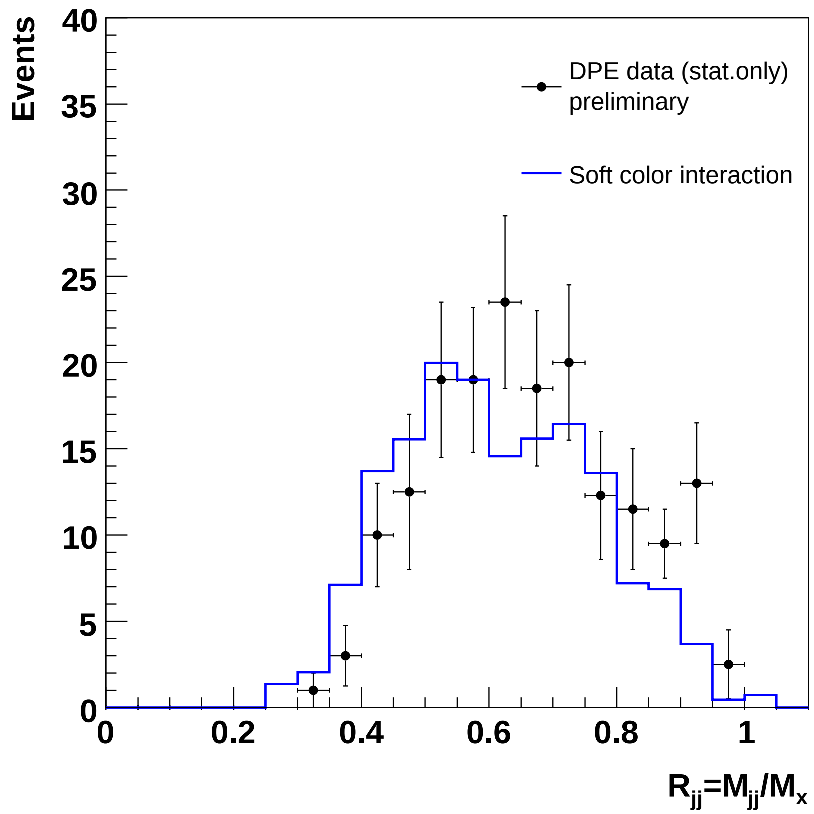
- A completely different model to explain diffractive events: Soft Colour Interaction
- Principle: Variation of colour string topologies, giving a unified description of final states for diffractive and non-diffractive events
- No survival probability for SCI models



What about SCI?

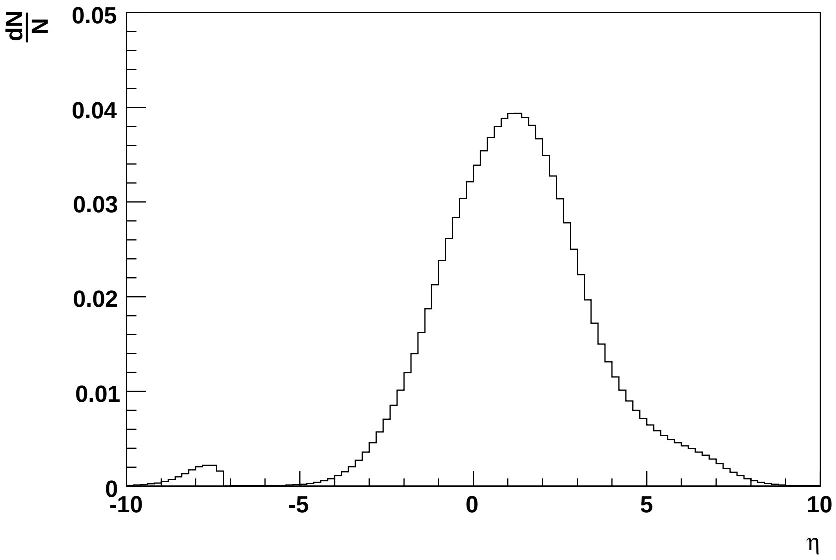
- SCI models give correct normalisation for single diffraction at Tevatron and diffraction at HERA without any additional parameter
- Exclusive events and SCI: Contribution of exclusive events needed much lower compared to Pomeron-like models, even vanishes for jet $p_T > 25$ GeV...

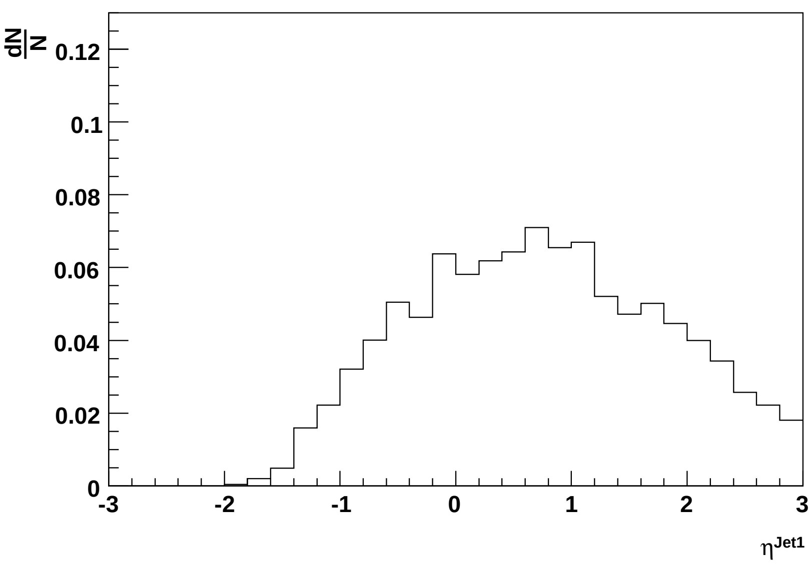




Comments about SCI

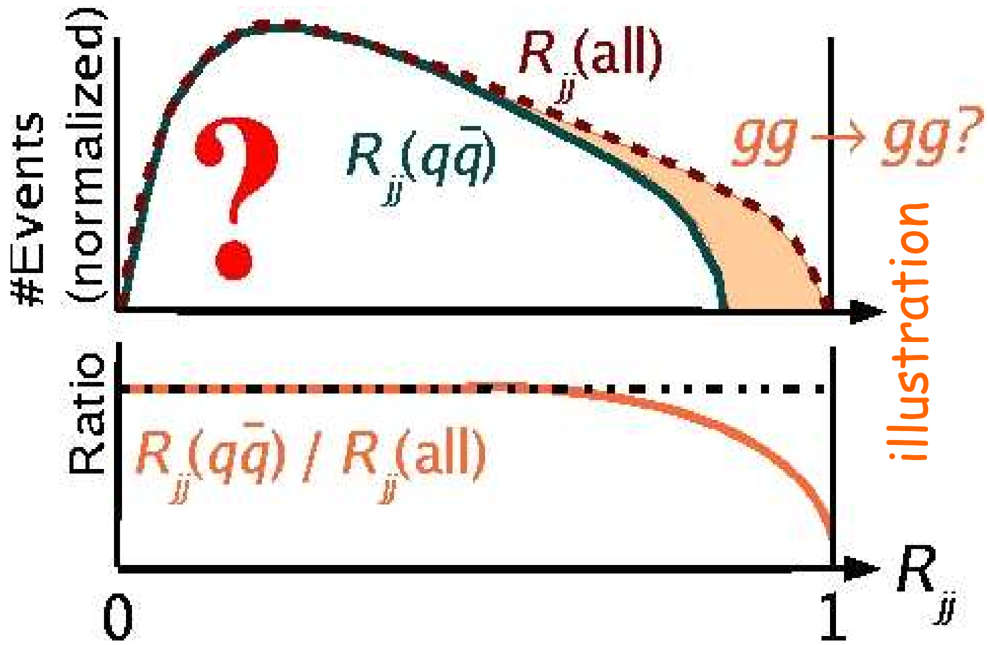
- Contribution of exclusive events much smaller for SCI
- "DPE" exchange in SCI models dominated by the following configuration for CDF events: 1 antiproton tagged in the final state, a bunch of particles going through the beam pipe on the other side (dominated by pions), no proton in the final state, due to the fact that only a rapidity gap is requested
- Jet rapidity boosted towards high rapidity: SCI model worth to be studied in more detail, but needs further improvement





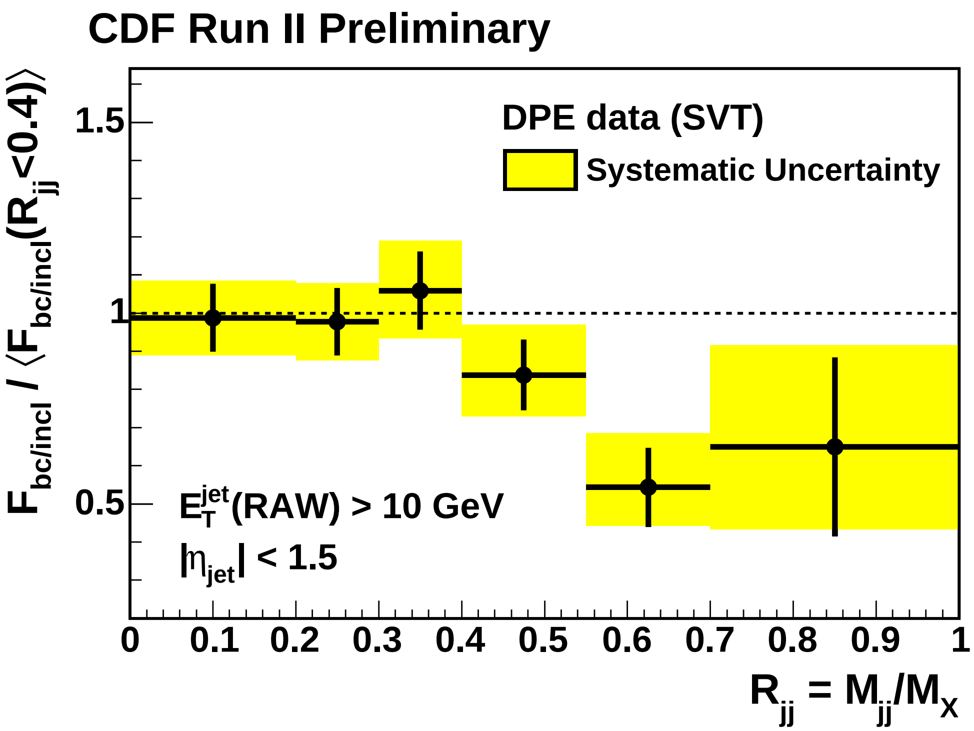
Search for exclusive events (CDF)

- Look for exclusive events in $b\bar{b}$ events production:
- If exclusive events exist the ratio of b jet events should be smaller at high dijet mass faction since exclusive b jet production is suppressed



Search for exclusive events (CDF)

- Look for exclusive events in $b\bar{b}$ events production:
- The ratio of b jet events tends to be smaller at high dijet mass faction, needs more stats

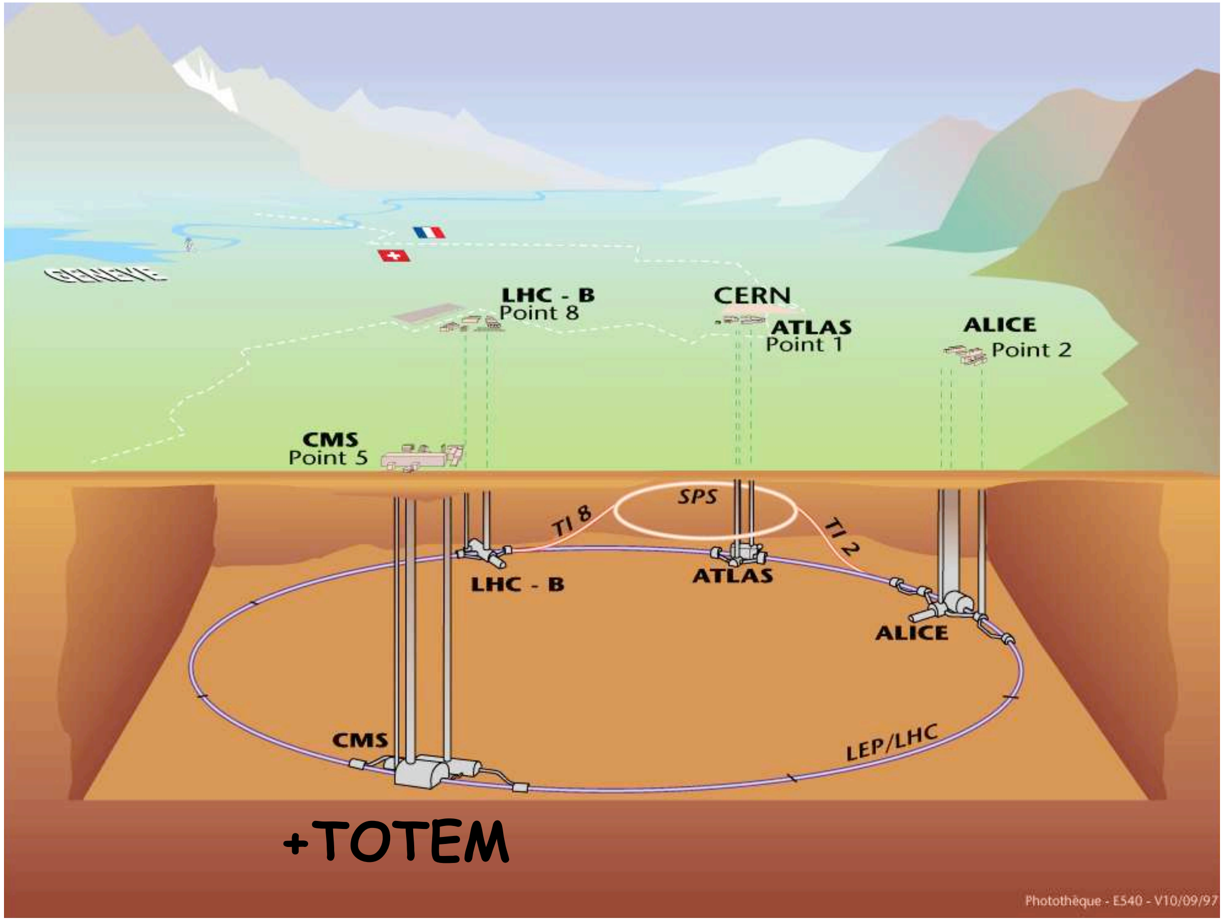


Conclusion on diffraction at Tevatron

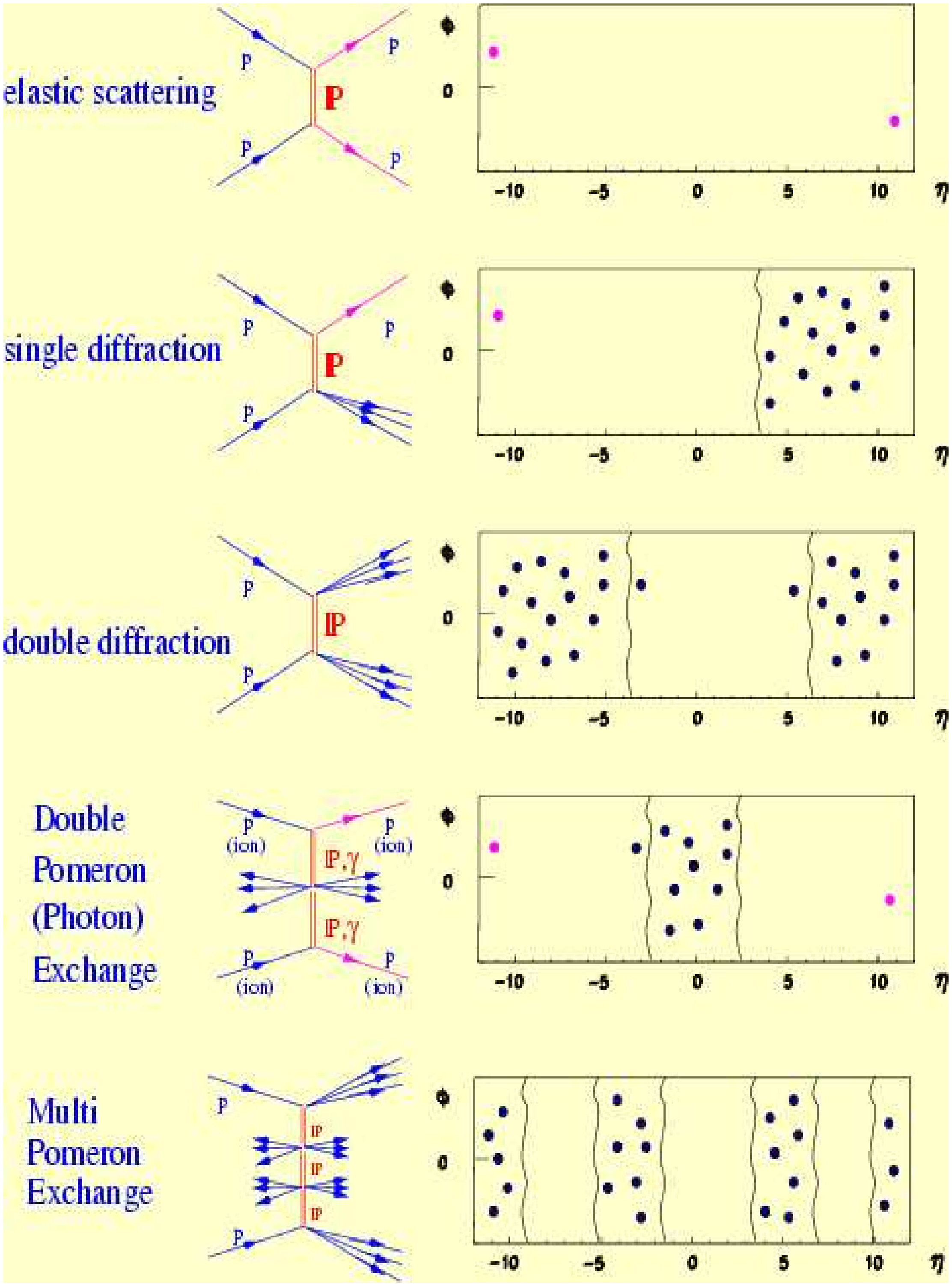
- Hard inclusive diffraction well described using parton densities from HERA provided one introduces a survival gap probability of about 10%
- Further tests of survival probability possible especially in DØ where one can measure the azimuthal angle correlations between p and $\bar{p}$ in final state: important study to be performed to make precise predictions at the LHC
- Existence of exclusive events: not definite in χ_C and diphoton channels, seems more certain in dijet channel
- Importance for the LHC: Pomeron structure (inclusive diffraction), exclusive Higgs production

Diffraction at the LHC

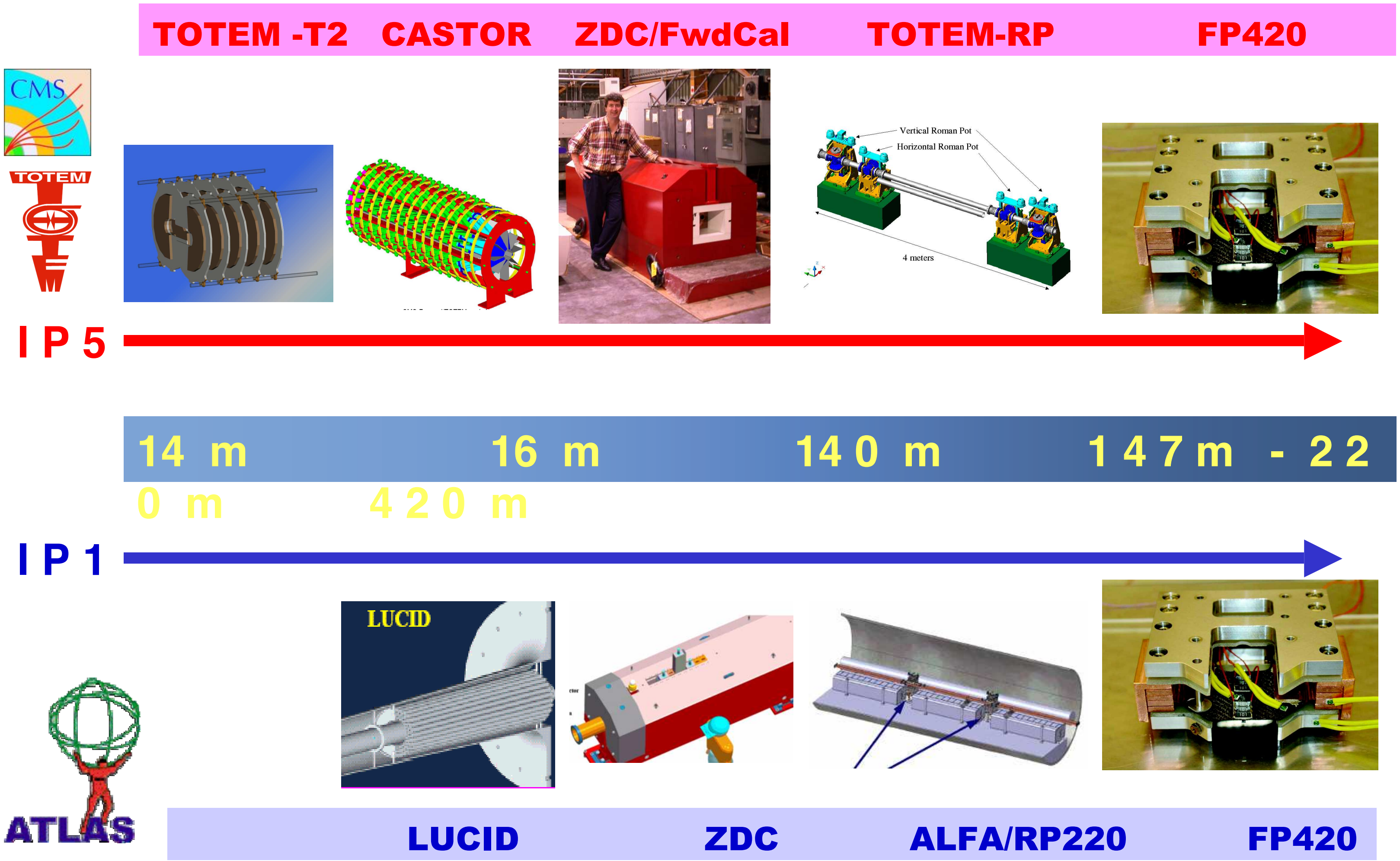
- LHC, $\sqrt{S} = 14$ TeV, allows to reach a completely new kinematical domain, 2 experiments involved in diffraction: ATLAS, CMS-TOTEM
- Diffractive selection: as for the Tevatron, rapidity gap selection at low luminosity (25 interactions expected at the same time at the highest luminosity, will kill the gaps)
- Measurements of hard diffraction and elastic cross sections



Diffraction at the LHC

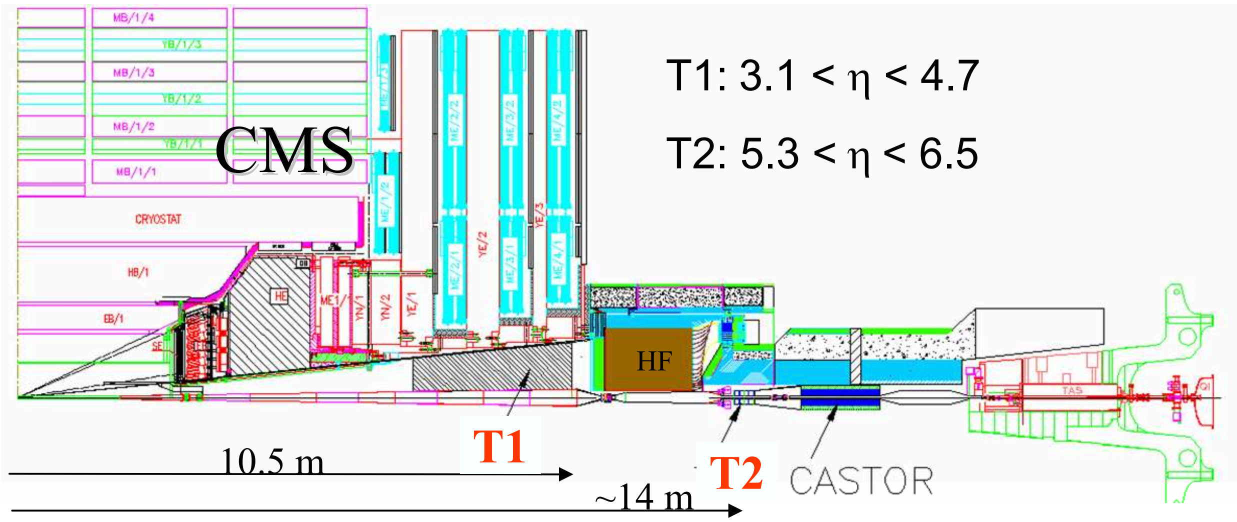


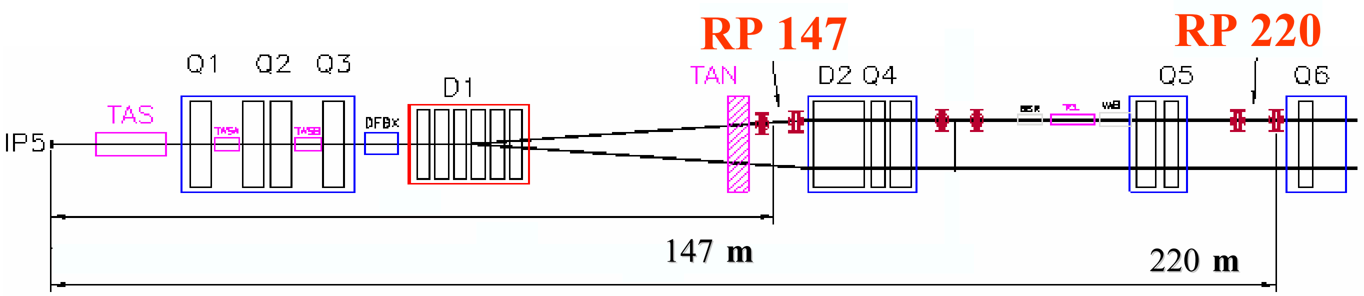
Forward region in CMS/ATLAS



Soft physics at the LHC: Roman pots in TOTEM/ATLAS

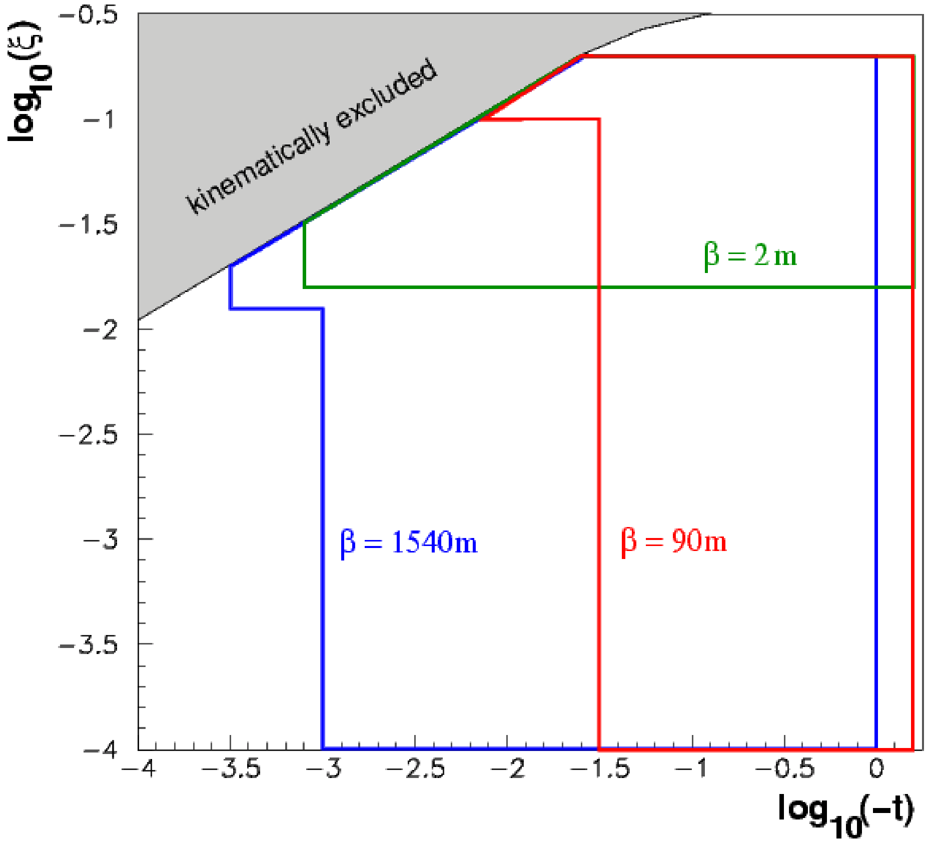
- Roman pots in TOTEM located at 147 m, 220 m
- Possibility to measure the total cross section at the LHC with a special LHC lattice at low luminosity





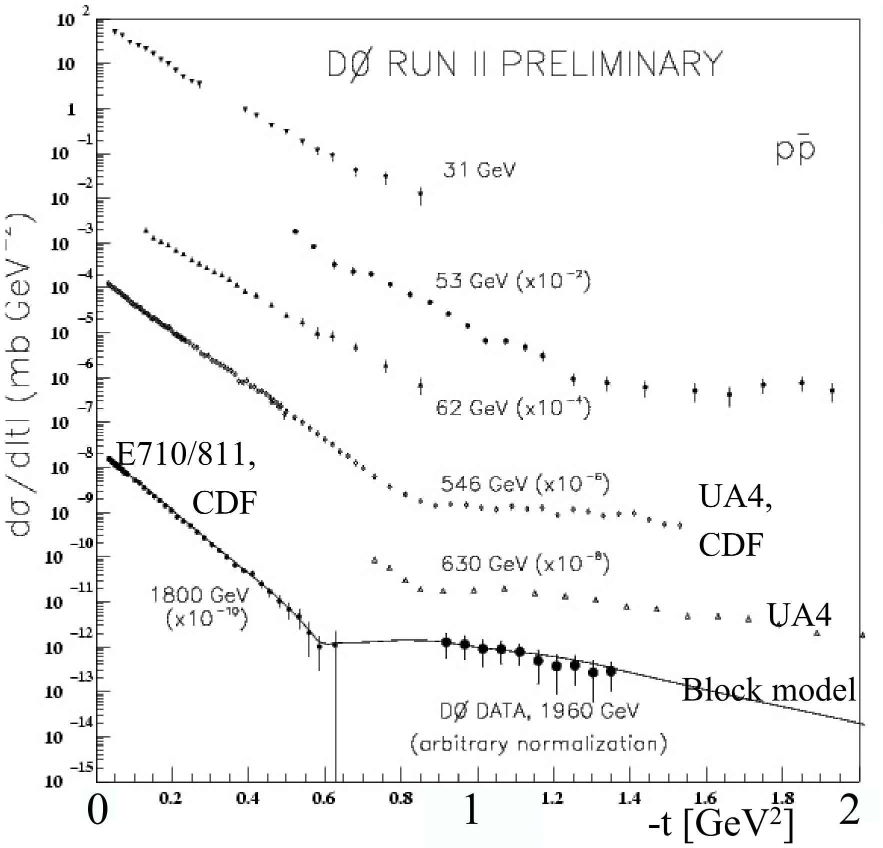
TOTEM acceptance

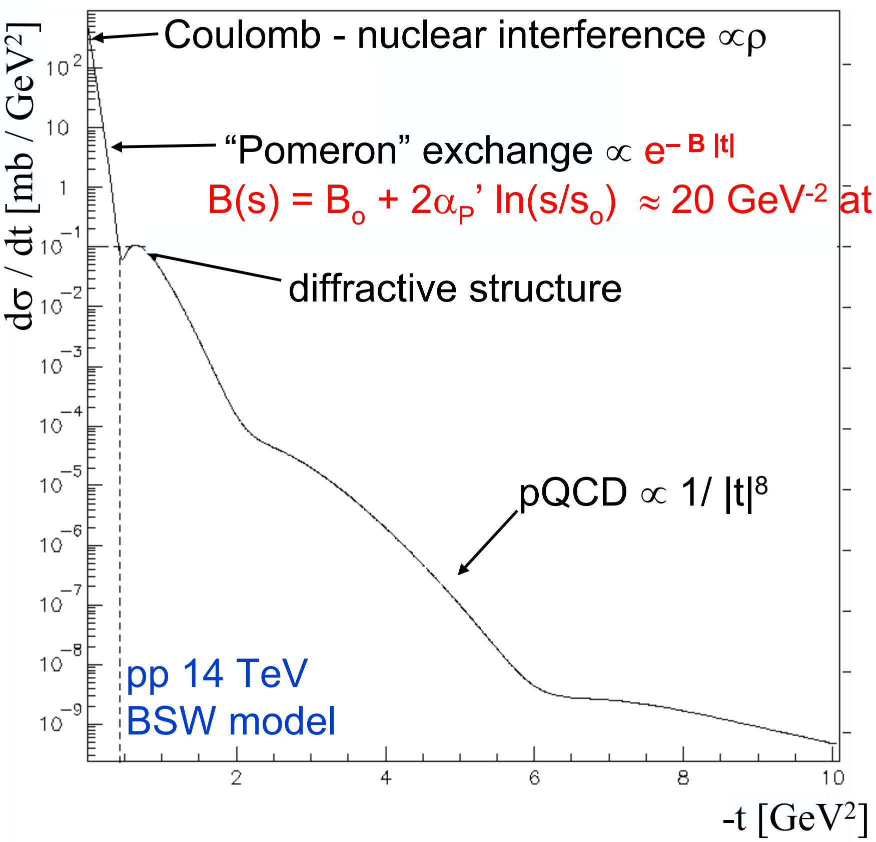
Proton acceptance for TOTEM for different beam configuration



Elastic scattering from ISR to TOTEM

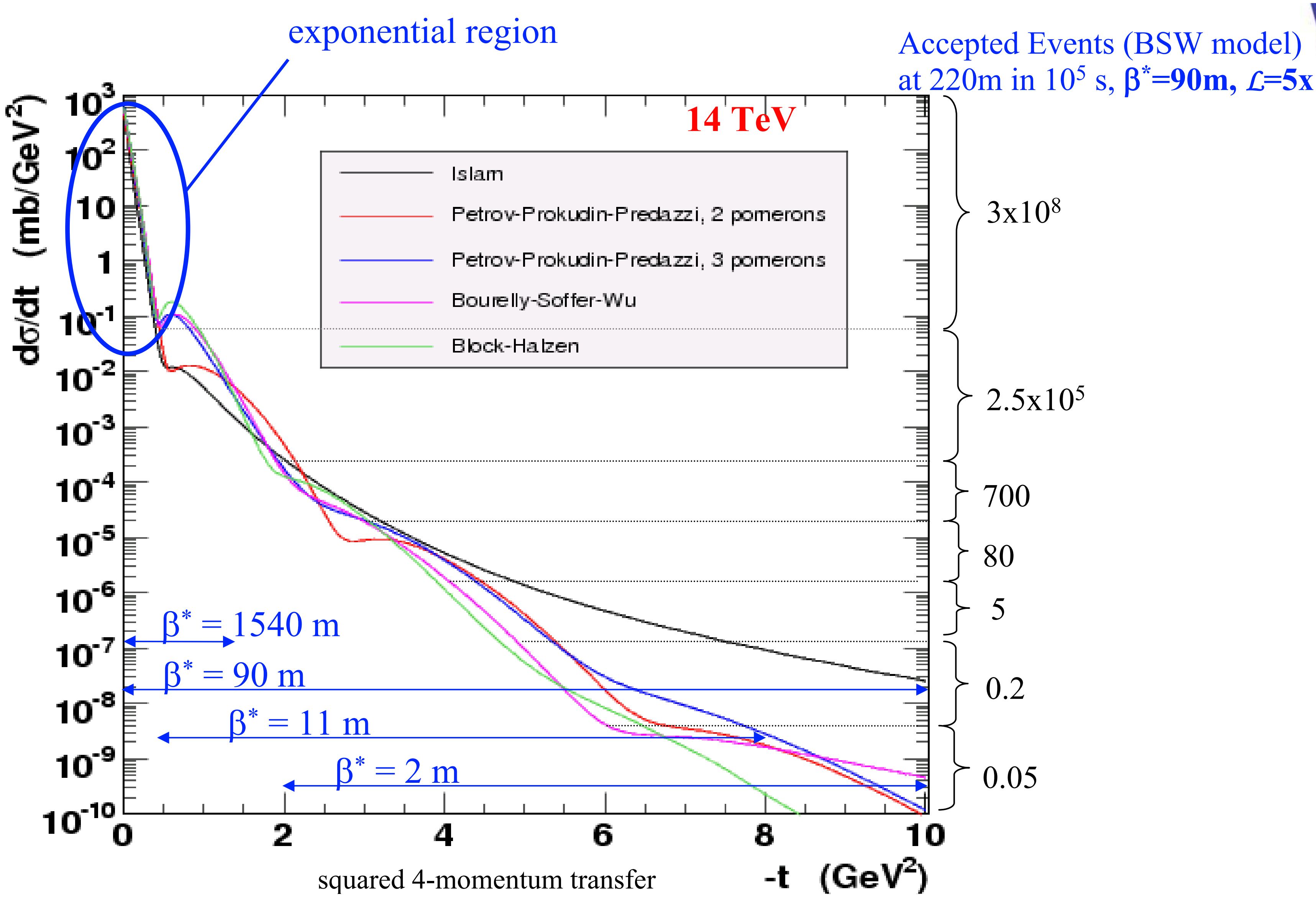
Measurement of the elastic total cross section at the LHC





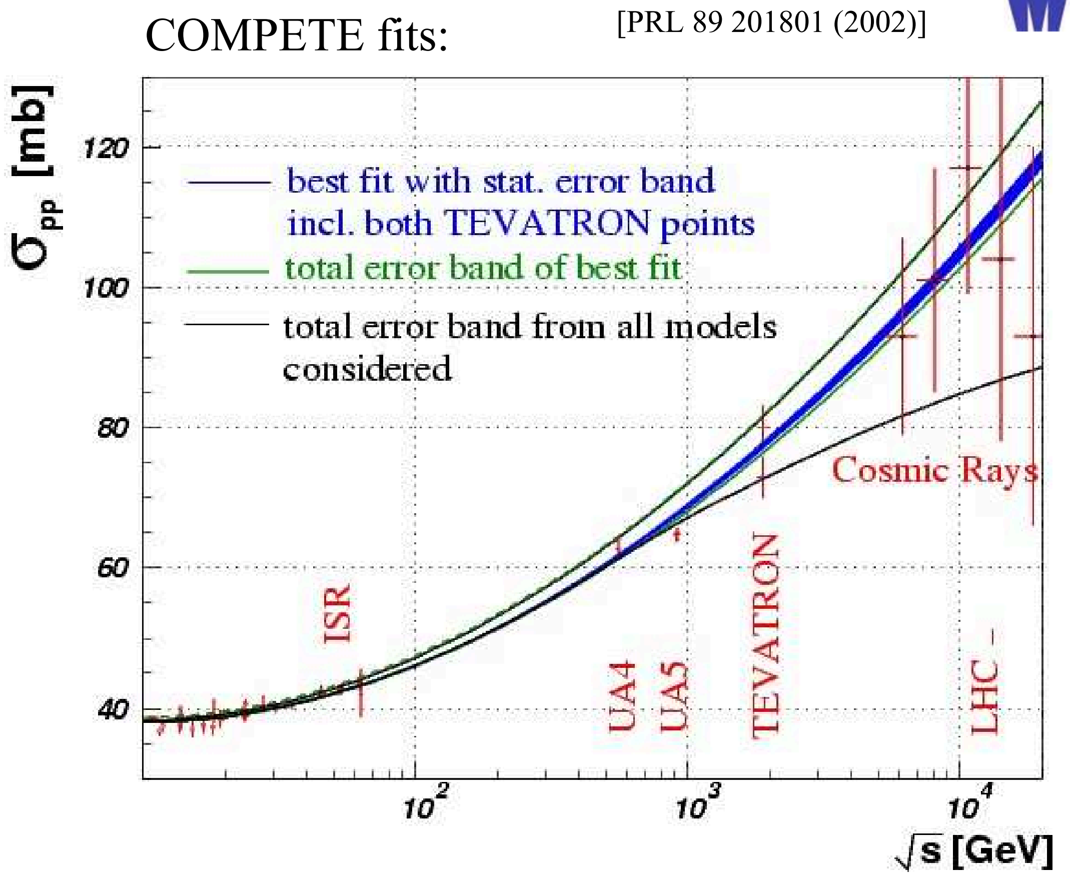
TOTEM physics program : elastic scattering

Physics program for TOTEM for different beam configurations

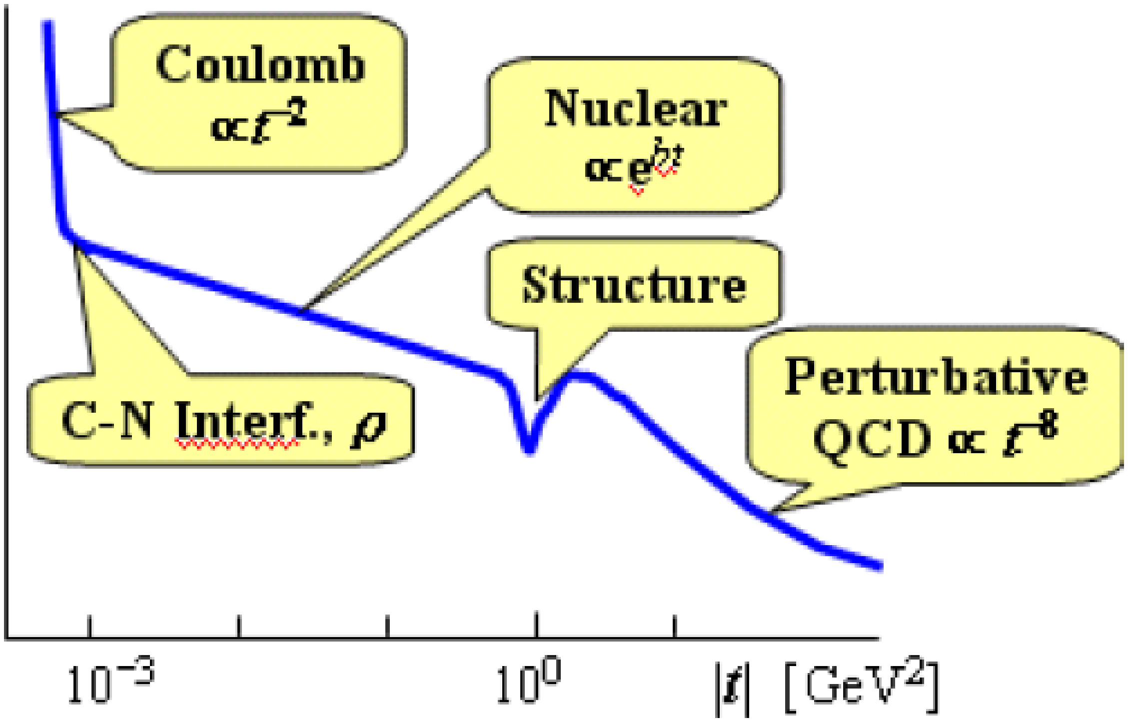


Measurement of the total cross section in TOTEM

- Measurement of the total cross section at the LHC
- Also important for luminosity measurements



Elastic scattering in the Coulomb region (ATLAS)



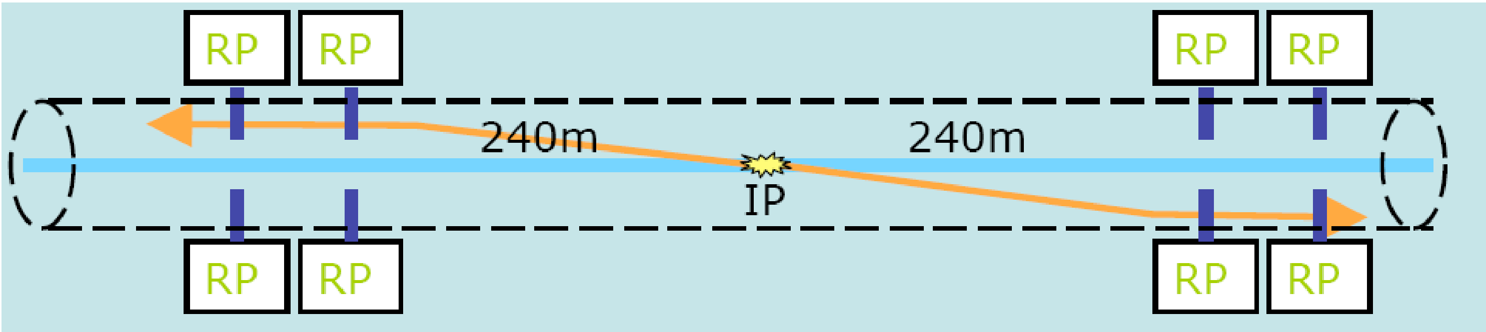
- Measurement of dN/dt:

$$\frac{dN}{dt}(t \to 0) = L\pi \left(\frac{-2\alpha}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-b|t|/2} \right)^2$$

- From the fit, we get σ_{tot}, ρ, b and L

Elastic scattering in the Coulomb region: How technically?

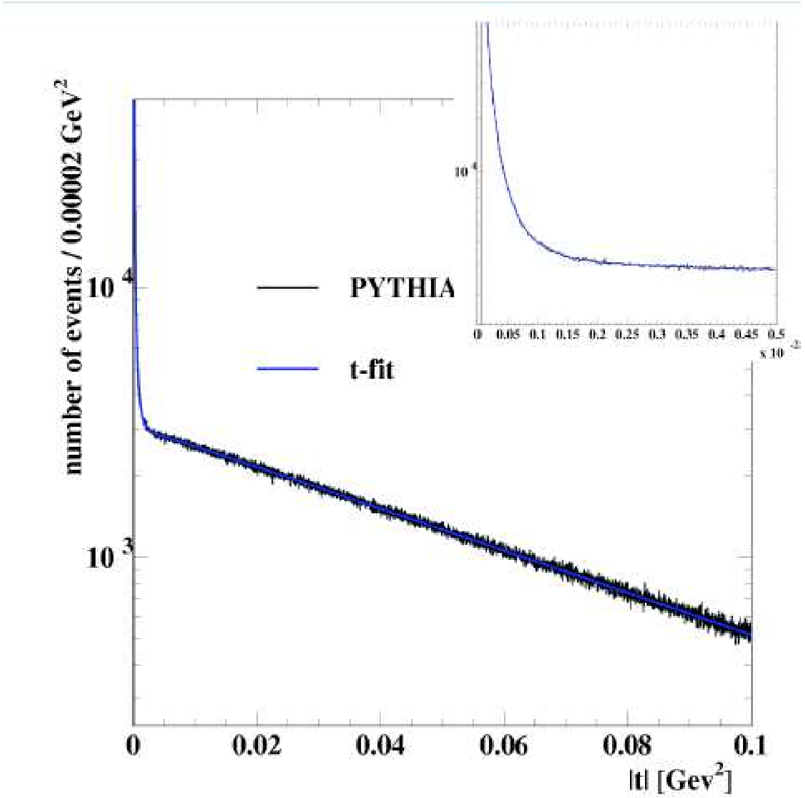
- Goal: Understanding lumi with a precision better of 2-3%
- Measure elastic rate dN/dt in the Coulomb interference region: Necessity to go down to $t \sim 6.5\ 10^{-4}$ GeV^2, or $\theta \sim$ 3.5 μrad (when the strong amplitude equals the electromagnetic one)
- This requires:
  - Special high β^* beam optics
  - Detectors at $\sim$ 1.5 mm from LHC beam axis
  - Spatial resolution well below 100 μm
  - No significant inactive edge ($< 100\mu$m)



Luminosity extraction from a fit to the t-distribution

Aim: showing the feasibility of a fit to dN/dt to extract luminosity information after a full simulation of 10 million events

$$\frac{dN}{dt} = L\left(\frac{4\pi\alpha^2}{|t|^2} - \frac{\alpha\rho\sigma_{tot}e^{-b|t|/2}}{|t|} + \frac{\sigma_{tot}^2(1+\rho^2)e^{-b|t|}}{16\pi}\right)$$



Luminosity extraction from a fit to the t-distribution

Comparison between fitted parameters and input ones

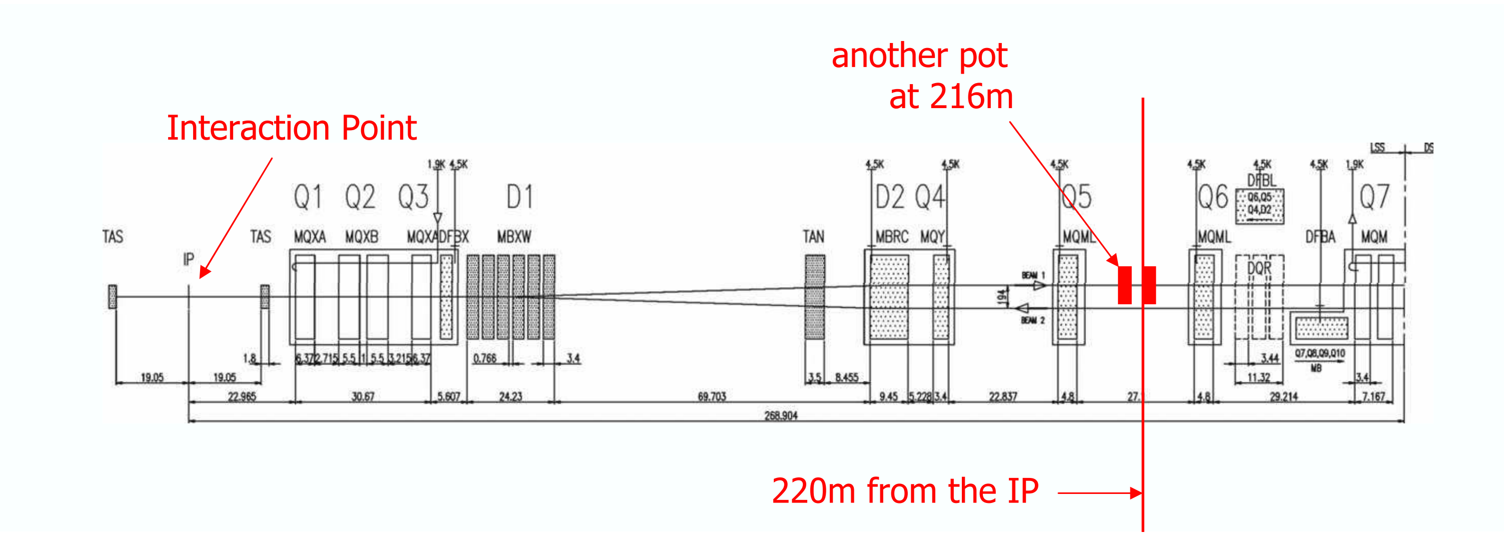
$$\frac{dN}{dt} = L\left(\frac{4\pi\alpha^2}{|t|^2} - \frac{\alpha\rho\sigma_{tot}e^{-b|t|/2}}{|t|} + \frac{\sigma_{tot}^2(1+\rho^2)e^{-b|t|}}{16\pi}\right)$$

Parameters	input	fitted	error	correlation
L	8.124 10^{26}	8.162 10^{26}	1.5%	
σ_{tot}	100 mb	101.1 mb	0.74%	99%
b	18 GeV^{-2}	17.95 GeV^{-2}	0.59%	64%
ρ	0.15	0.1502	4.24%	92%

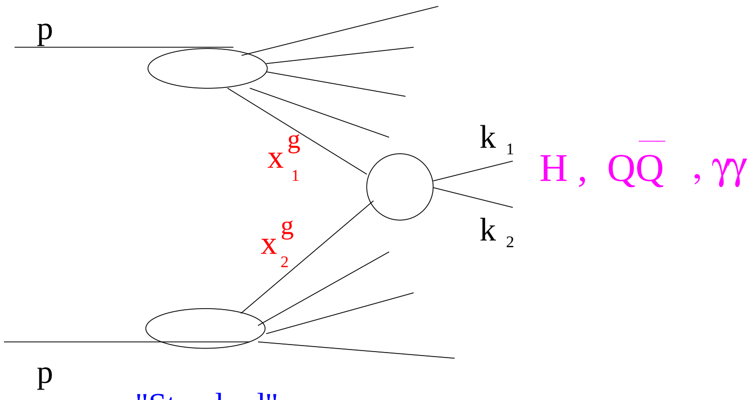
Large statistical correlations between L and other parameters in the fit

Hard diffraction at LHC

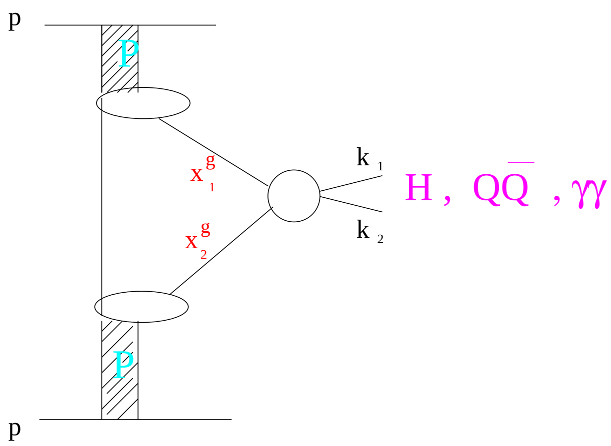
- Two projects of roman pot detectors at the LHC at high luminosity: 220m and 420 m (both for CMS and ATLAS)
- Projects under study, to be installed in 2009-2010
- First study the physics to be done with those detectors, and then the technology of the forward detectors



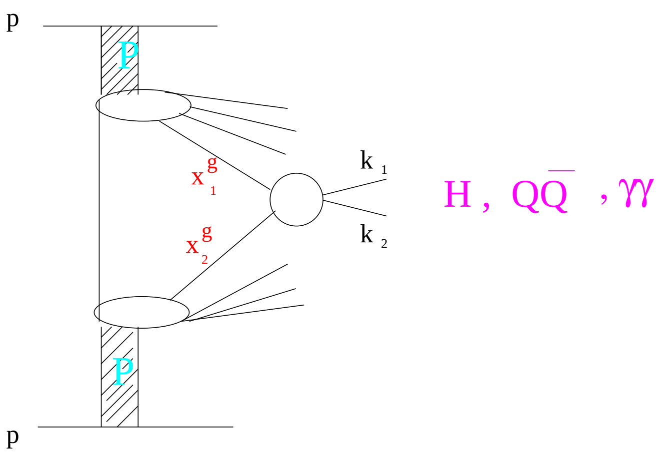
“Exclusive models” (Reminder)



"Standard"



"Exclusive "

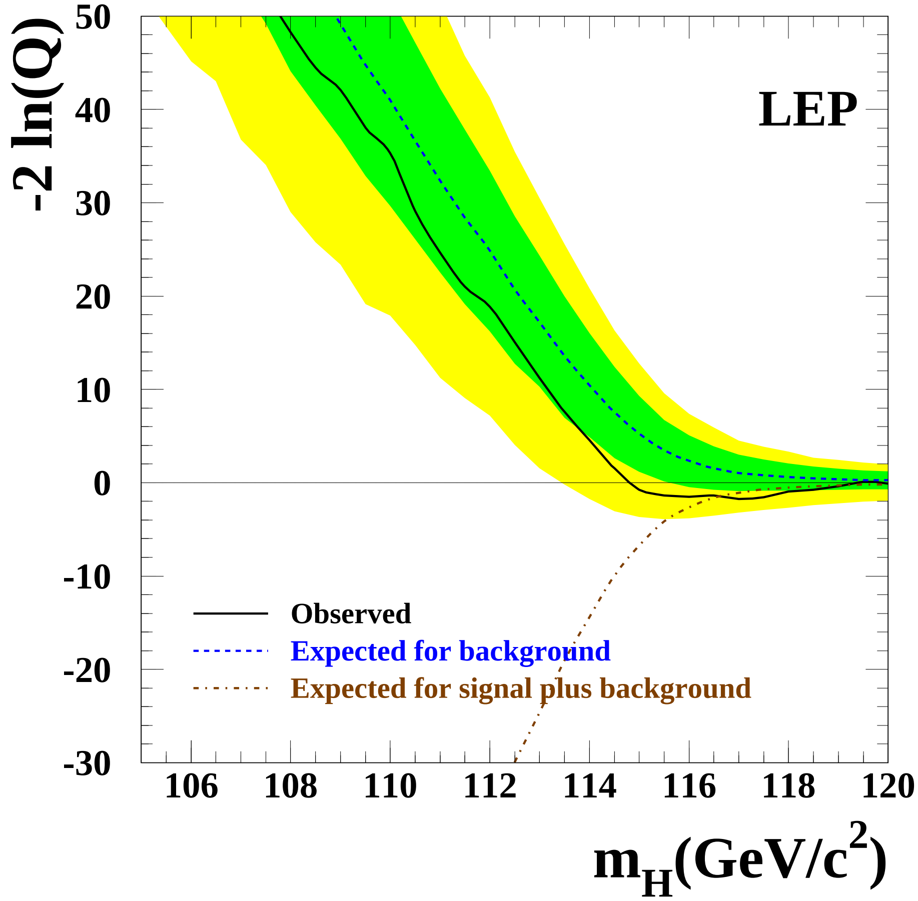


"Inclusive"

All the energy is used to produce the Higgs (or the dijets), namely $xG \sim \delta$

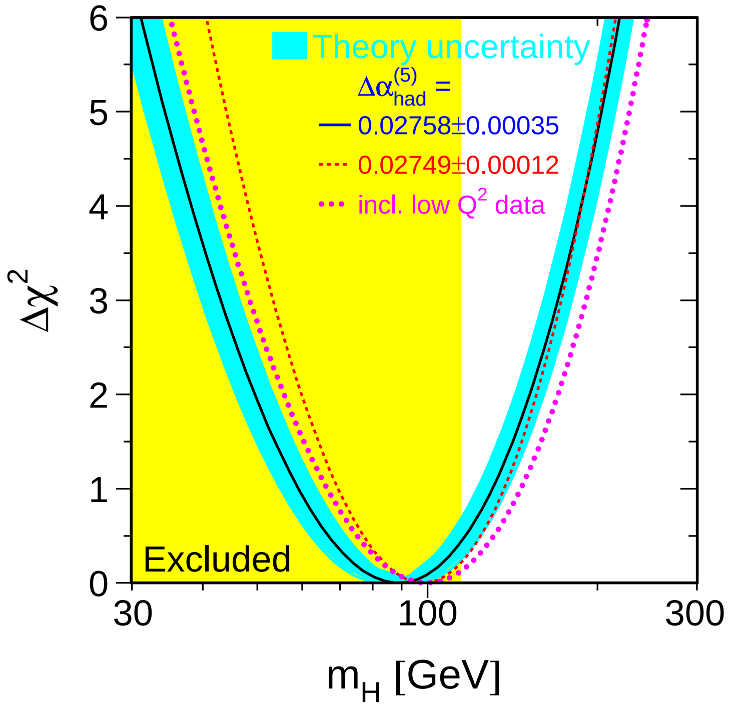
LEP limits on Higgs mass

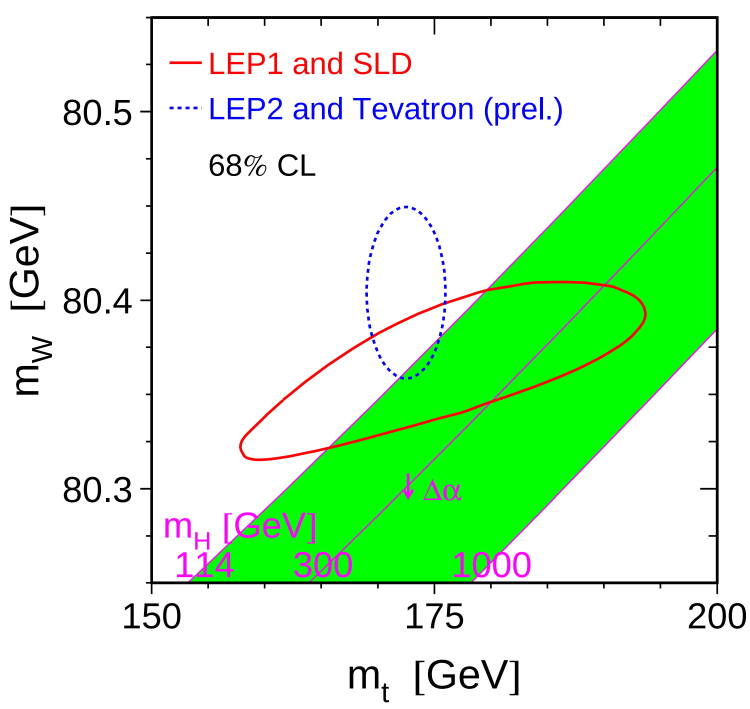
Limit on Higgs mass: 114.4 GeV



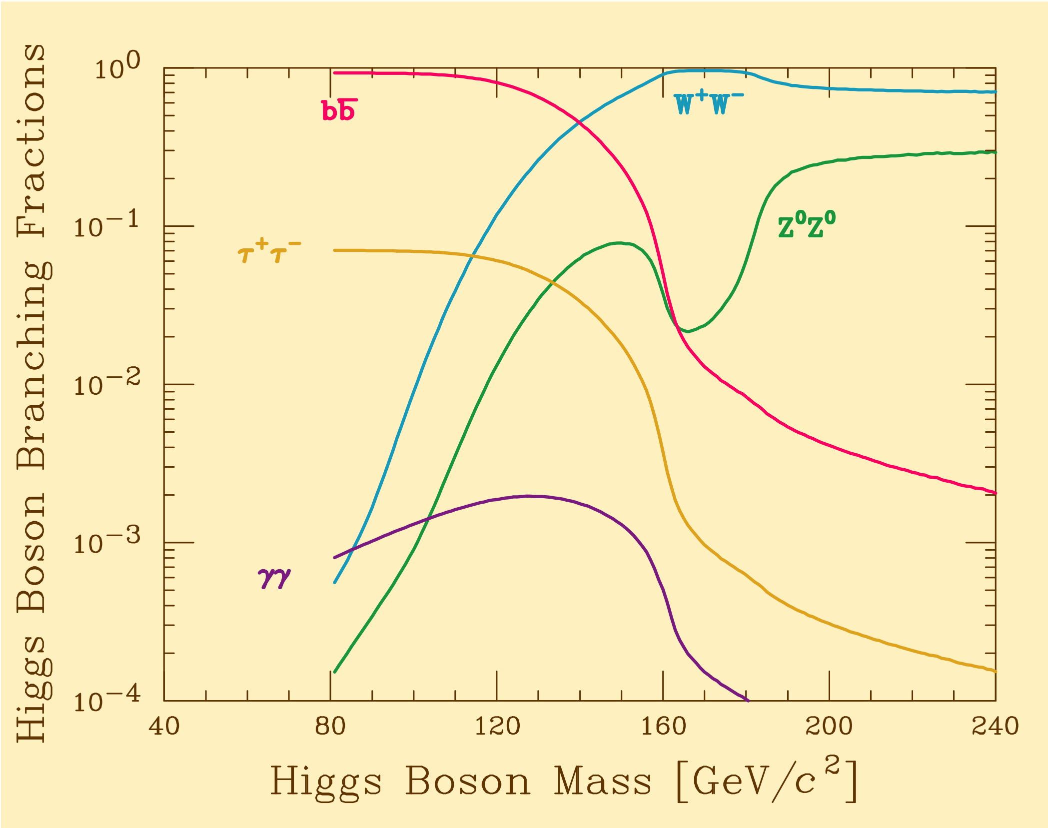
Electroweak fits and mass of Higgs boson

- Use new M_{top}, width of W boson from Tevatron and LEP, and mass of W from LEP
- $M_{Higgs} = 89 + 42 - 30$ GeV (68% CL), and < 175 GeV at 95% CL





SM Higgs decay

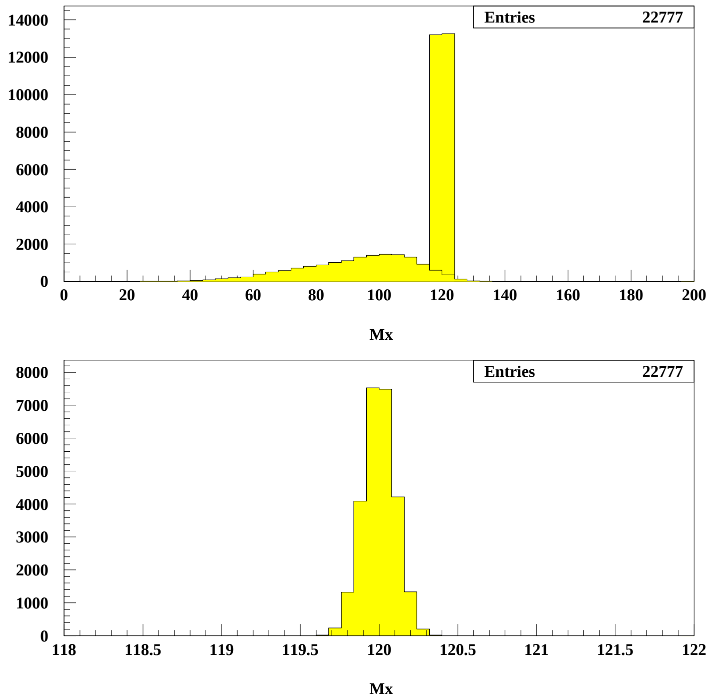


Low masses: $b\bar{b}$ and $\tau\tau$ dominate

High masses: WW dominates

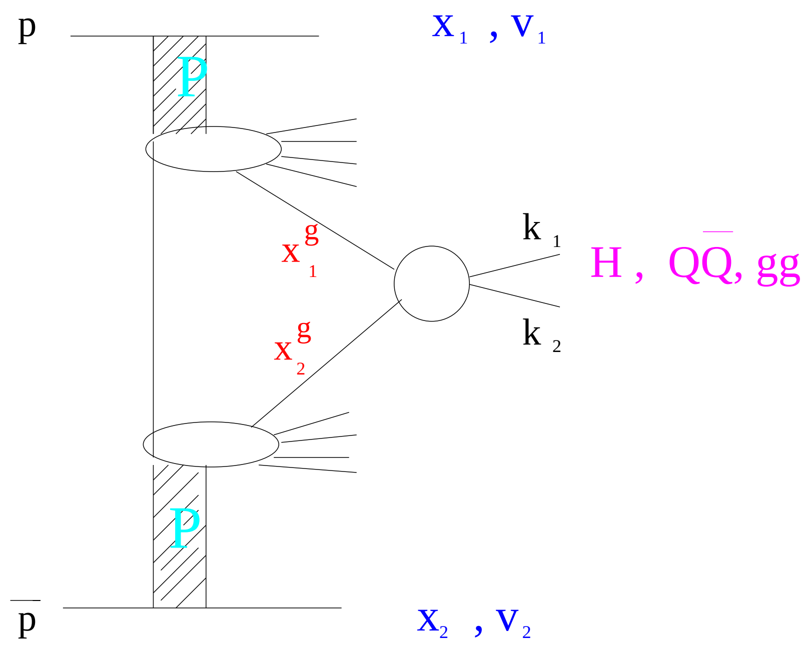
Advantage of exclusive Higgs production?

- Good Higgs mass reconstruction: fully constrained system, Higgs mass reconstructed using both tagged protons in the final state ($pp \to pHp$)
- $M_H = \sqrt{\xi_p \xi_{\bar{p}} S}$
- Contamination to the exclusive Higgs signal due to the tail of inclusive events: important to know the tail of the inclusive distributions at high β



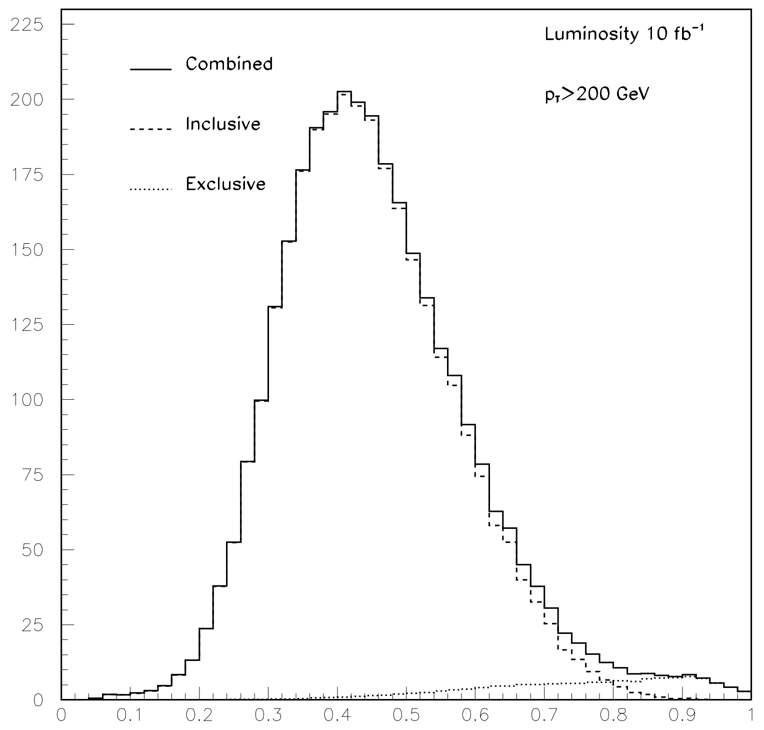
How to make predictions for diffraction at the LHC

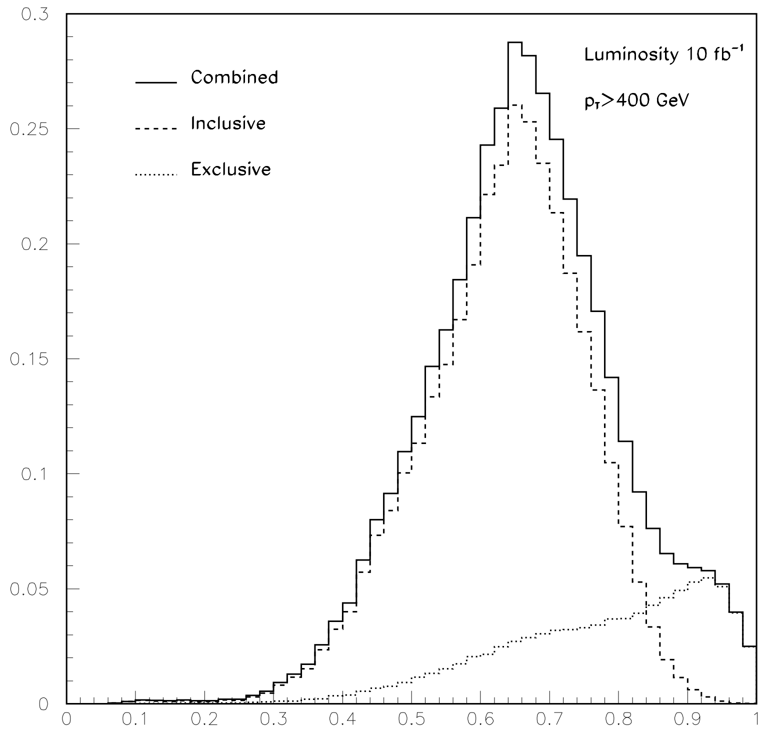
- "Inclusive" models: Take the hadron-hadron "usual" cross section convoluted with the parton distributions in the pomeron
- Take shape of H1 measurement of gluon density
- Normalisation coming from survival gap probability
- Inclusive cross sections need to be known in detail since it is a direct background to search for exclusive events



LHC: Exclusive and inclusive events

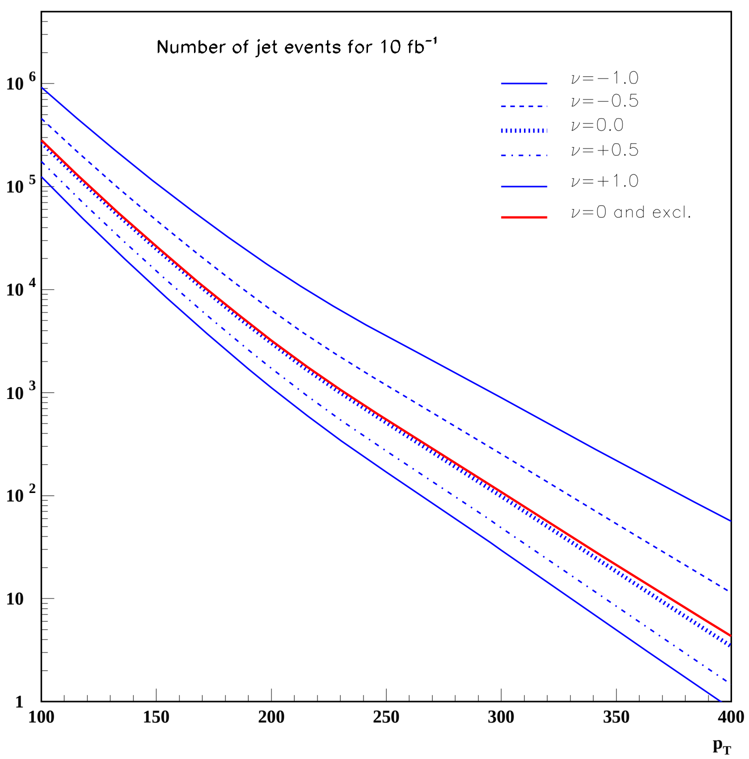
- Study of exclusive and inclusive production to be made at the LHC: study cross section of both components as a function of jet p_T and perform DGLAP QCD fits
- Important to understand background and signal for exclusive production of rare events: Higgs, SUSY...

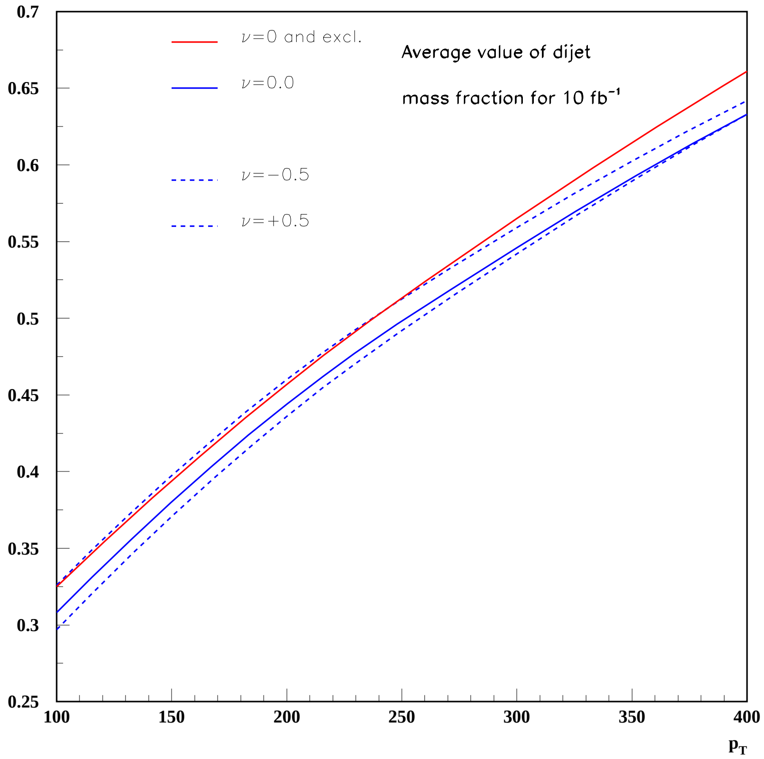




LHC: Exclusive and inclusive events

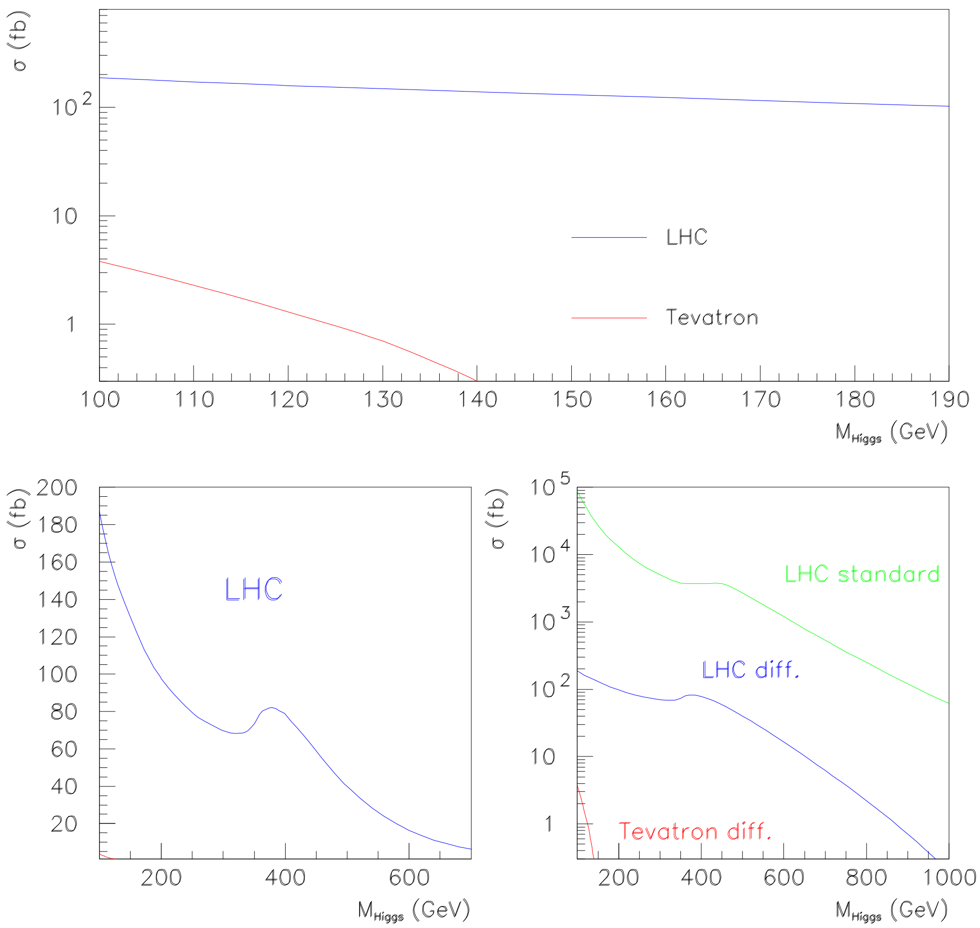
- Number of dijet events as a function of jet p_T: dominated by uncertainty on gluon density
- Dijet mass fraction (average value as an example): sensitive to exclusive production, quite easy to measure
- See O. Kepka, C. Royon, arXiv:0704.1956



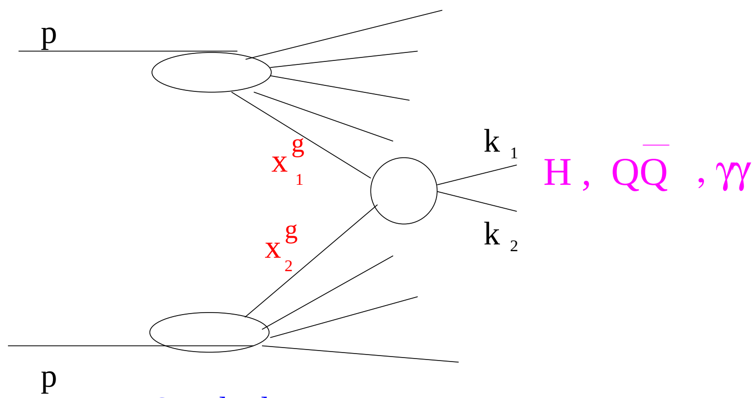


Inclusive Higgs mass production

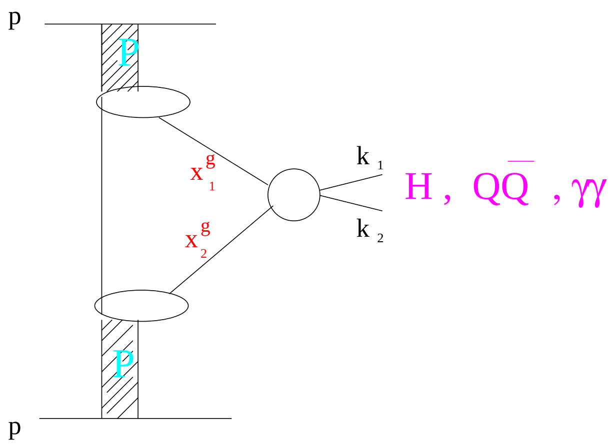
Large cross section, but mass poorly reconstructed since part of the energy lost in pomeron remnants ($M = \sqrt{\xi_1 \xi_2 S}$ ~Higgs + remnant mass)



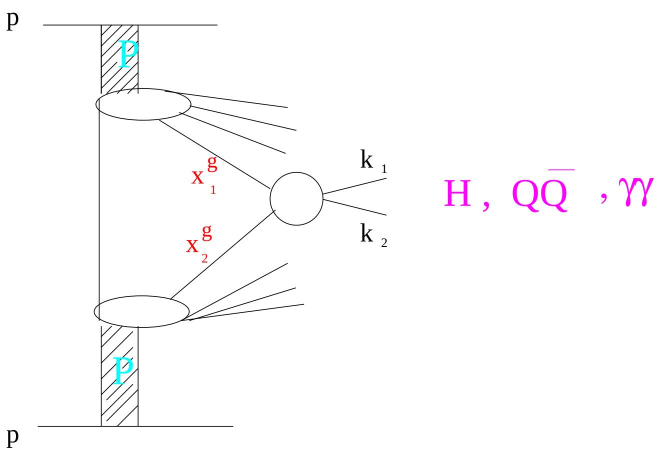
Reminder: “Exclusive” Higgs production



"Standard"



"Exclusive "

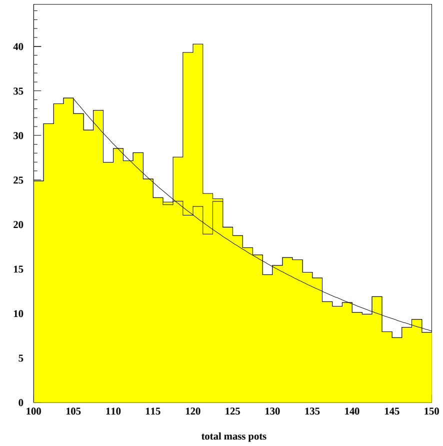


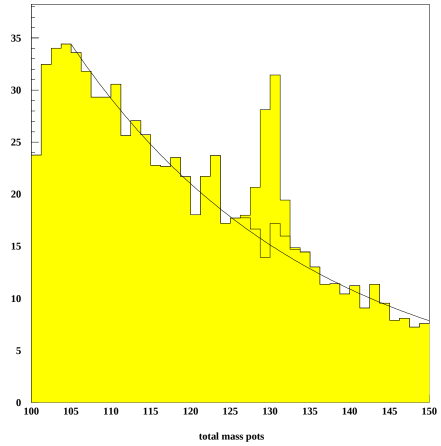
"Inclusive"

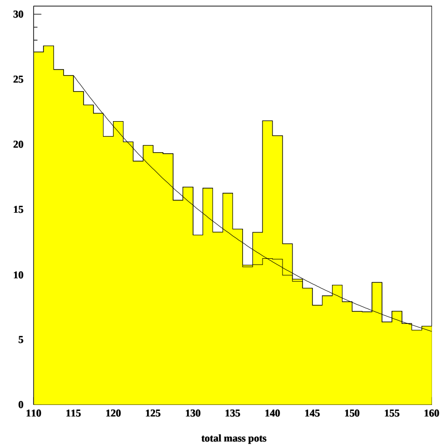
All the energy is used to produce the Higgs (or the dijets), namely $xG \sim \delta$

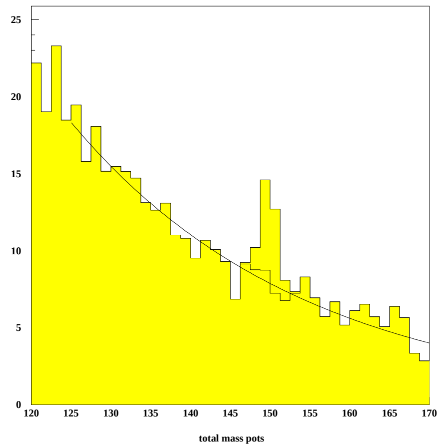
Signal and background

Signal and background for different Higgs masses for 100 fb^{-1}









"Exclusive" production at the LHC

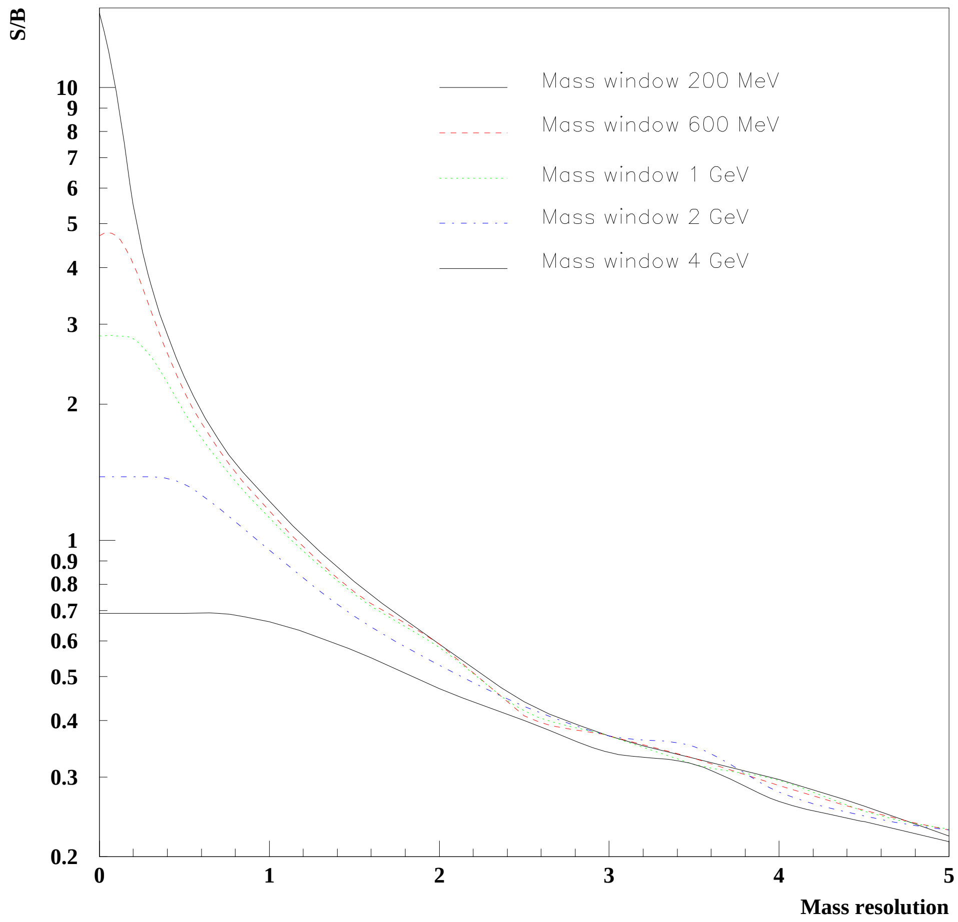
- Higgs decaying into $b\bar{b}$: study S/B
- Exclusive $b\bar{b}$ cross section (for jets with $p_T > 25$ GeV): 2.1 pb
- Exclusive Higgs production (in fb)

M_{Higgs}	σ (fb)
120	3.9
125	3.5
130	3.1
135	2.5
140	2.0

- NB: a survival probability of 0.03 was applied to all cross sections

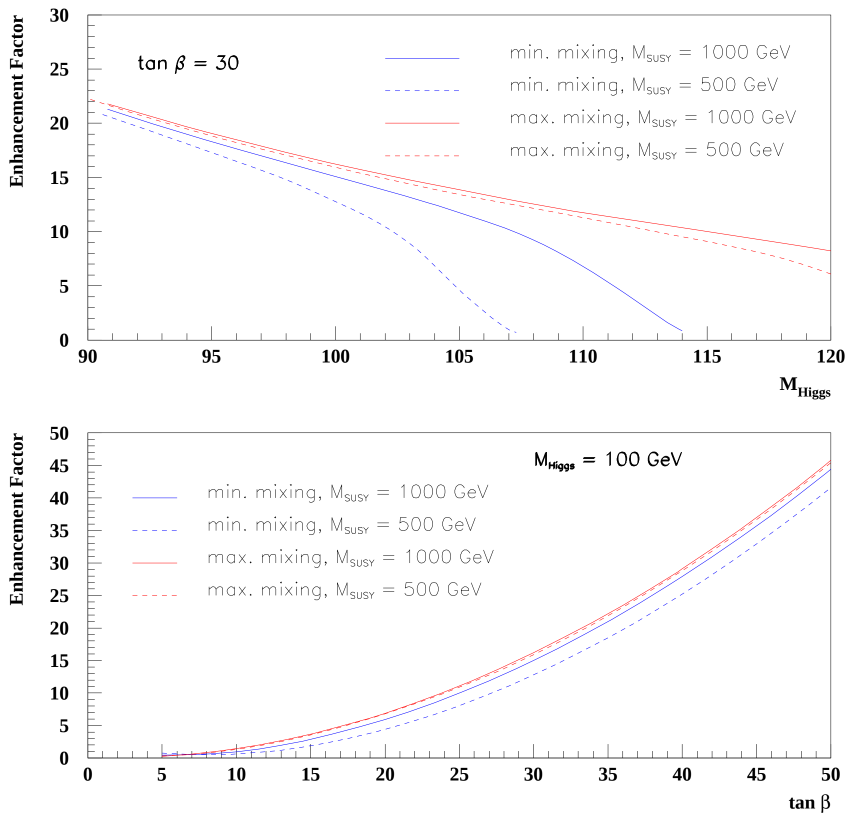
Signal over background: standard model Higgs

- For a Higgs mass of 120 GeV and for different mass windows as a function of the Higgs mass resolution (study after full simulation in progress)
- See: M. Boonekamp, R. Peschanski, C.Royon Phys.Lett. B598 (2004) 243-251, Nucl.Phys. B669 (2003) 277



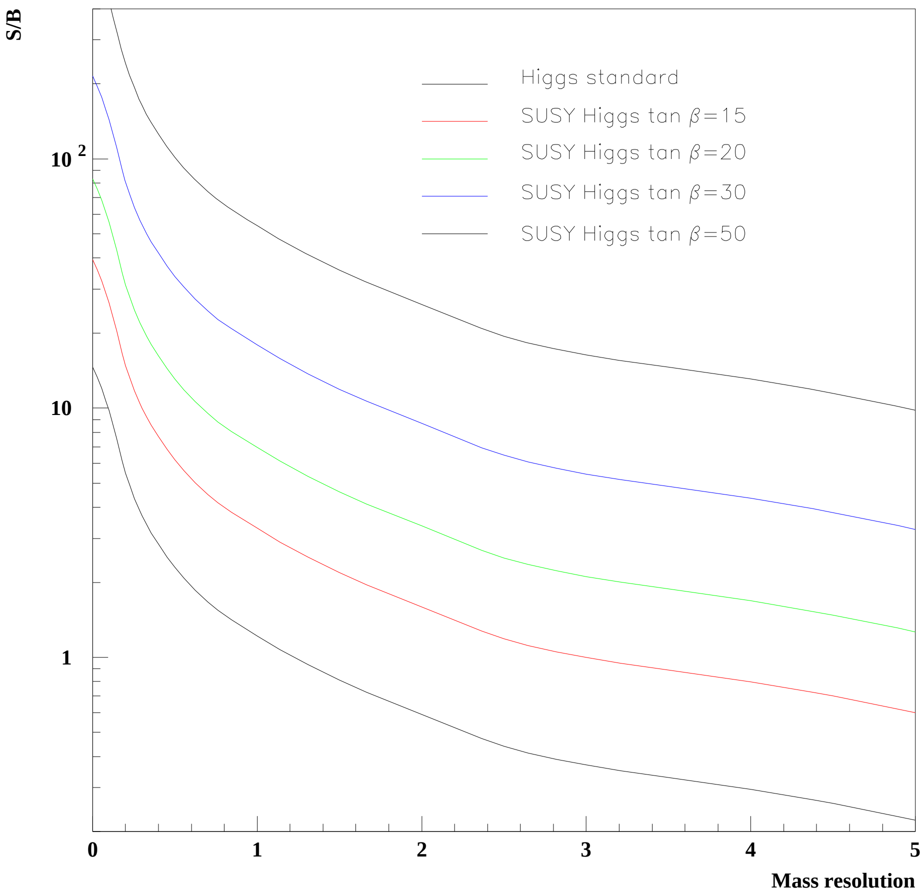
Diffractive SUSY Higgs production

- High $\tan\beta$: top and bottom loops to be considered, enhance the cross section by up to a factor 50
- (worth looking into Higgs decaying into $b\bar{b}$ since branching ratio of Higgs decaying into $\gamma\gamma$ smaller at high $\tan\beta$, standard search in $\gamma\gamma$ does not benefit from the increase of cross section)
- See: M. Boonekamp, J. Cammin, S. Lavignac, R. Peschanski, C. Royon, Phys.Rev. D73 (2006) 115011

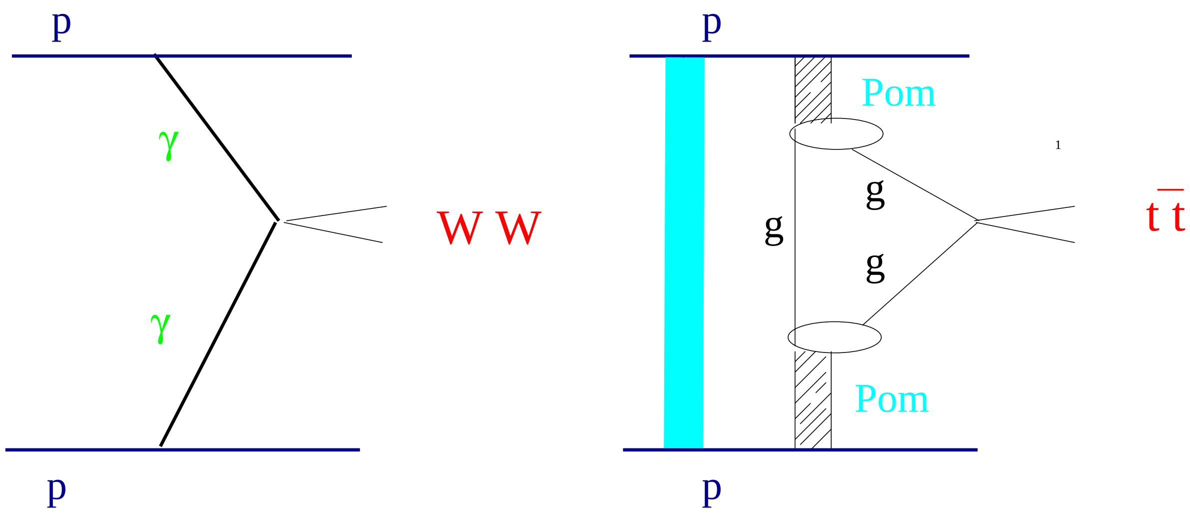


Diffractive SUSY Higgs production

At high $\tan\beta$, possibility to get a S/B over 50 (resp. 5.) for 100 (resp.10) fb^{-1}!

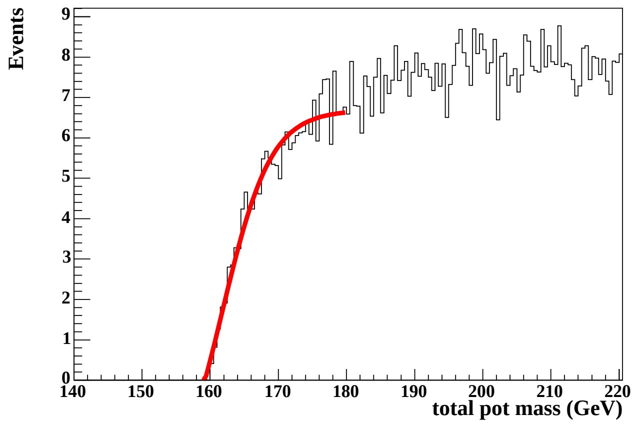


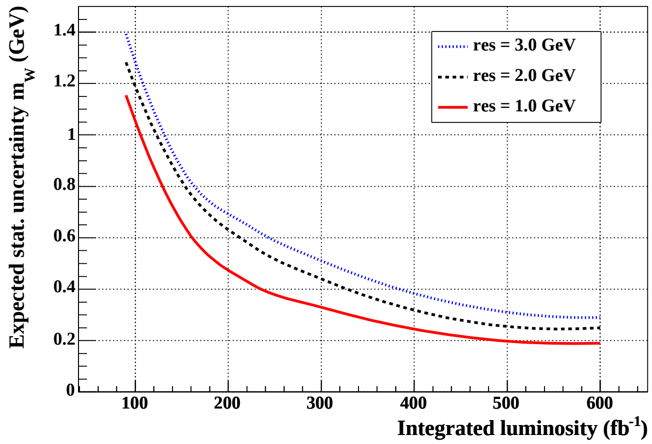
W, top and stops



All the energy is used to produce the W, top (stop) pairs: W: QED process, cross section perfectly known, top: QCD diffractive process

Top and W events





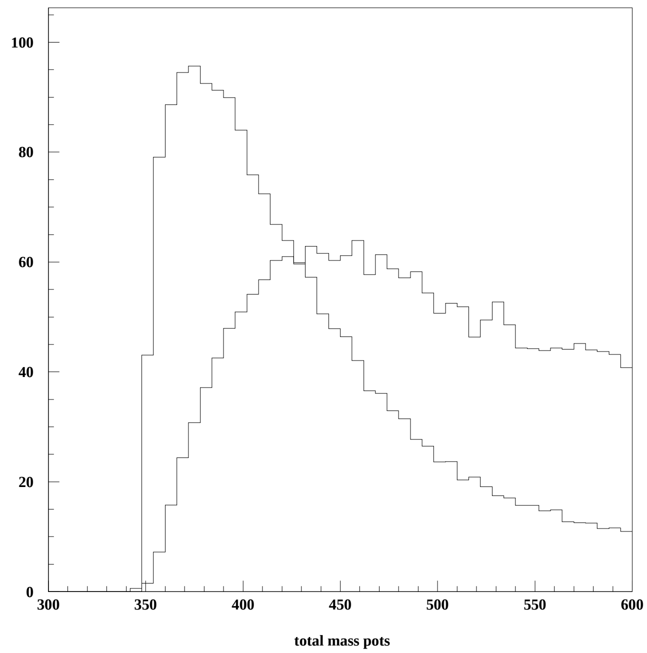
- W boson cross section and acceptance: $\sigma \sim 56$ fb, pots at 420 m needed, about 60%
- Top quark cross section and acceptance: $\sigma \sim 40$ fb, pots at 220 m, about 85%, model dependent
- Reconstruct the W and top mass using the threshold scan method: Fit the increase of the cross section at threshold

Sensitivity on photon anomalous coupling

- WW production cross section perfectly known (QED)
- Any anomalous coupling between γ and W will reveal itself in a modification of the production cross section, and by different anbgular distributions
- The WW production cross section is proportional to the 4th power of the γW coupling $\rightarrow$ GOOD SENSITIVITY
- Quantitative studies in progress

Top and stops

- Cross section for a stop mass of 250 GeV: $\sigma_{tot} = 8$ fb, $\sigma_{acc} = 6$ fb
- Possibility to distinguish between top and stop even if they have about the same mass: using the differences in spin (as an example: $m_{\tilde{t}} = m_{top}$)
- Very fast turn-on for stops



Conclusion on diffractive physics at the LHC

- Inclusive diffractive physics: Measure the pomeron intercept, quark and gluon structure of pomeron, check DGLAP evolution of parton distributions using dijet events
- Exclusive events: Specially interesting for Higgs, W, SUSY... Need also to ensure exclusive jet production in dijet, diphoton channel and measure the cross section as a function of p_T
- Study the detectors which will be dedicated to diffractive measurement at the LHC

Projects in forward direction at LHC

- TOTEM project accepted, close to CMS: dedicated to measurements at low luminosity (total cross section)
- Alfa project in ATLAS: dedicated to measurements at low luminosity (cross section in the Coulomb region)
- FP420: Project of installing roman pot detectors at 420 m both in ATLAS, CMS
- Roman pot detectors at 220 m in ATLAS: hard diffraction in ATLAS
- For more information, see the web pages of FP420, CMS, TOTEM, ATLAS

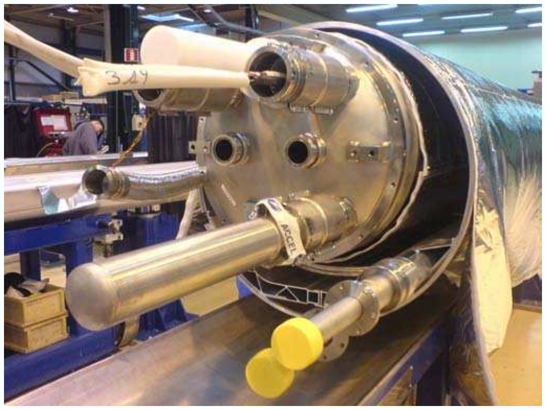
FP420 project

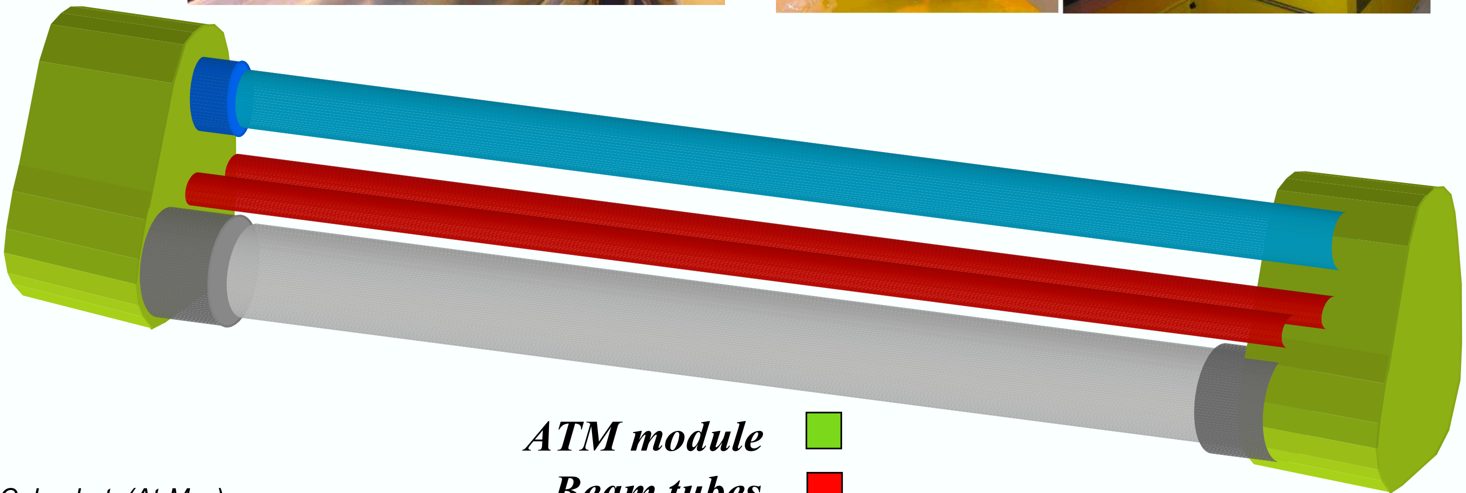
- FP420 project: Project to install forward detectors to measure scattered protons at 420 m on each side of CMS/ATLAS detectors
- Aim of FP420 collaboration: Technological developments and feasibility study of detectors at 420 m, to be followed by a proposal to ATLAS and CMS experiments
- Difficulties of 420 m region: Cold region of the LHC, needs special studies

FP420 location

Full integration of the detectors in the LHC cryogenic system

FP420 Connection Cryostat





ATM module

Beam tubes

Line X vacuum vessel

Connection Module

T. Colombet (At-Mcs)

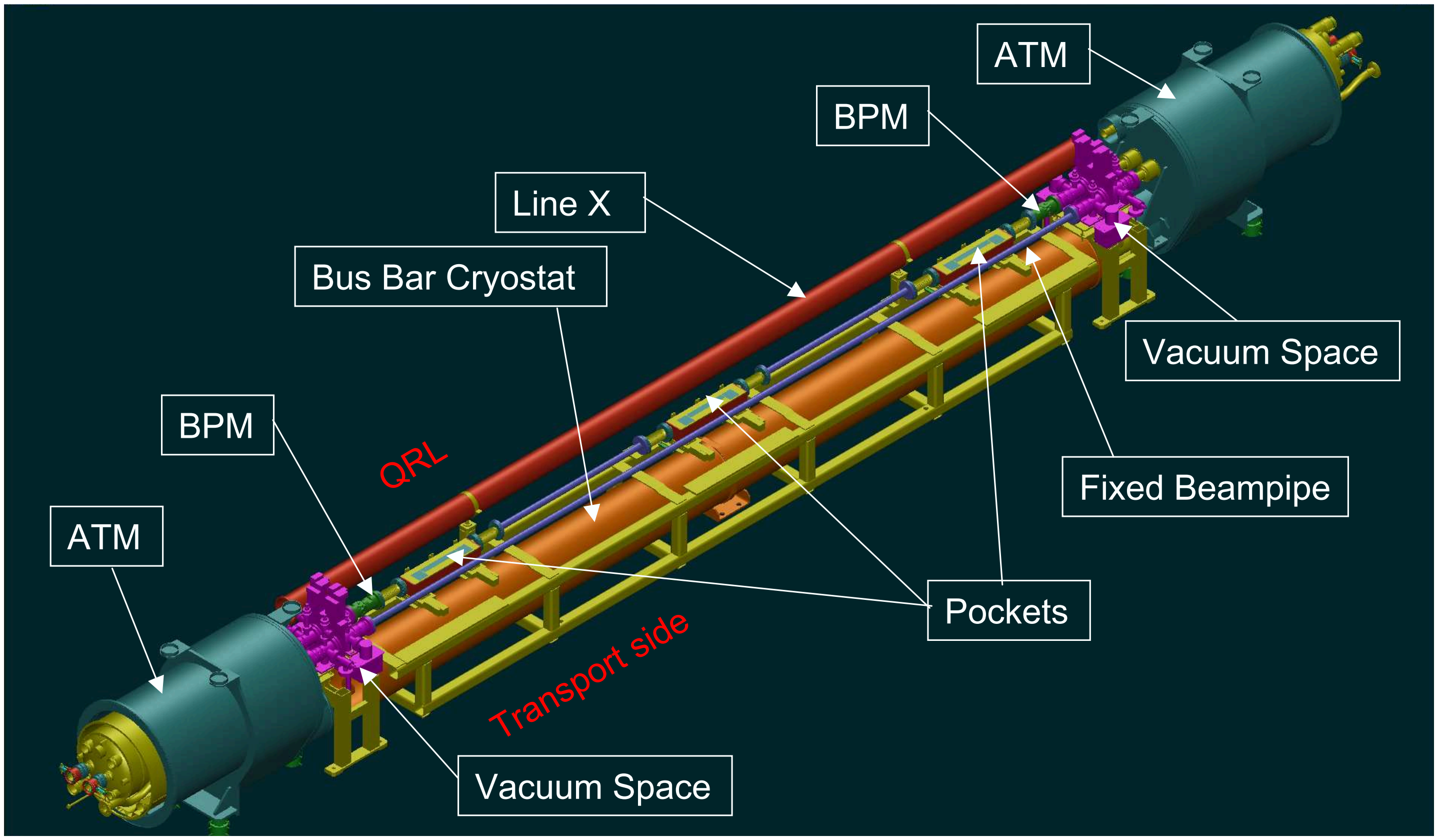
T. Renaglia,

R. Folch

TECHNICAL SUPPORT DEPARTMENT

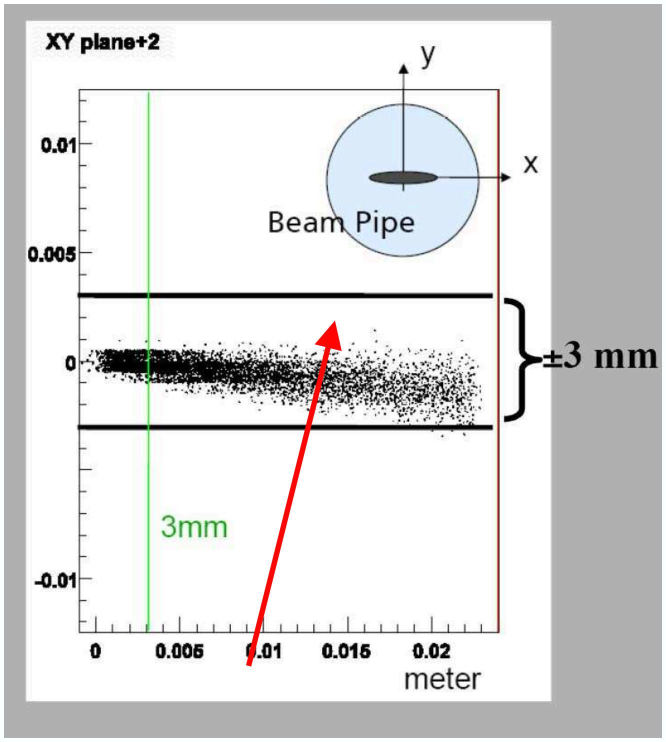
FP420 location

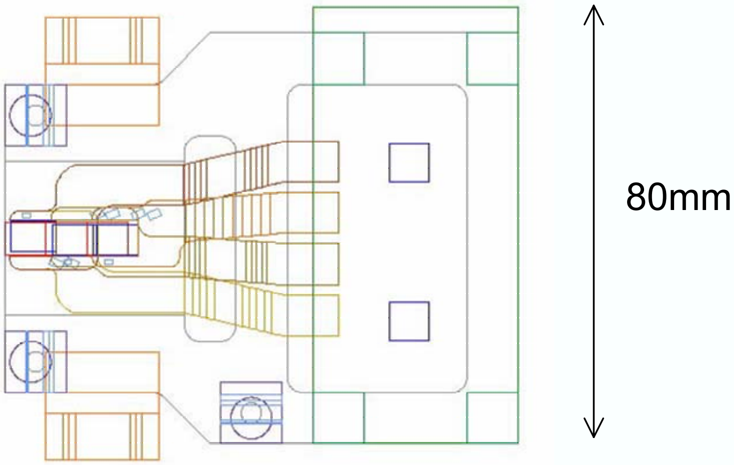
Integration of the moving beam pipe and detector



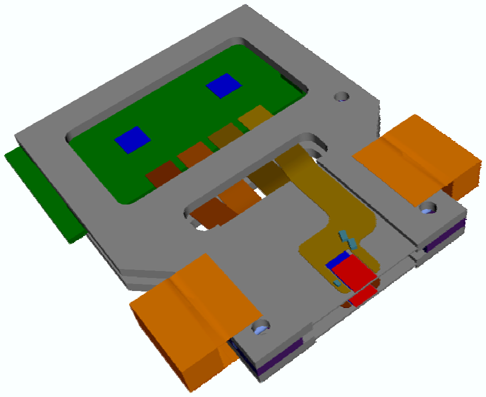
FP420 silicon detector stations

3D silicon option chosen for FP420



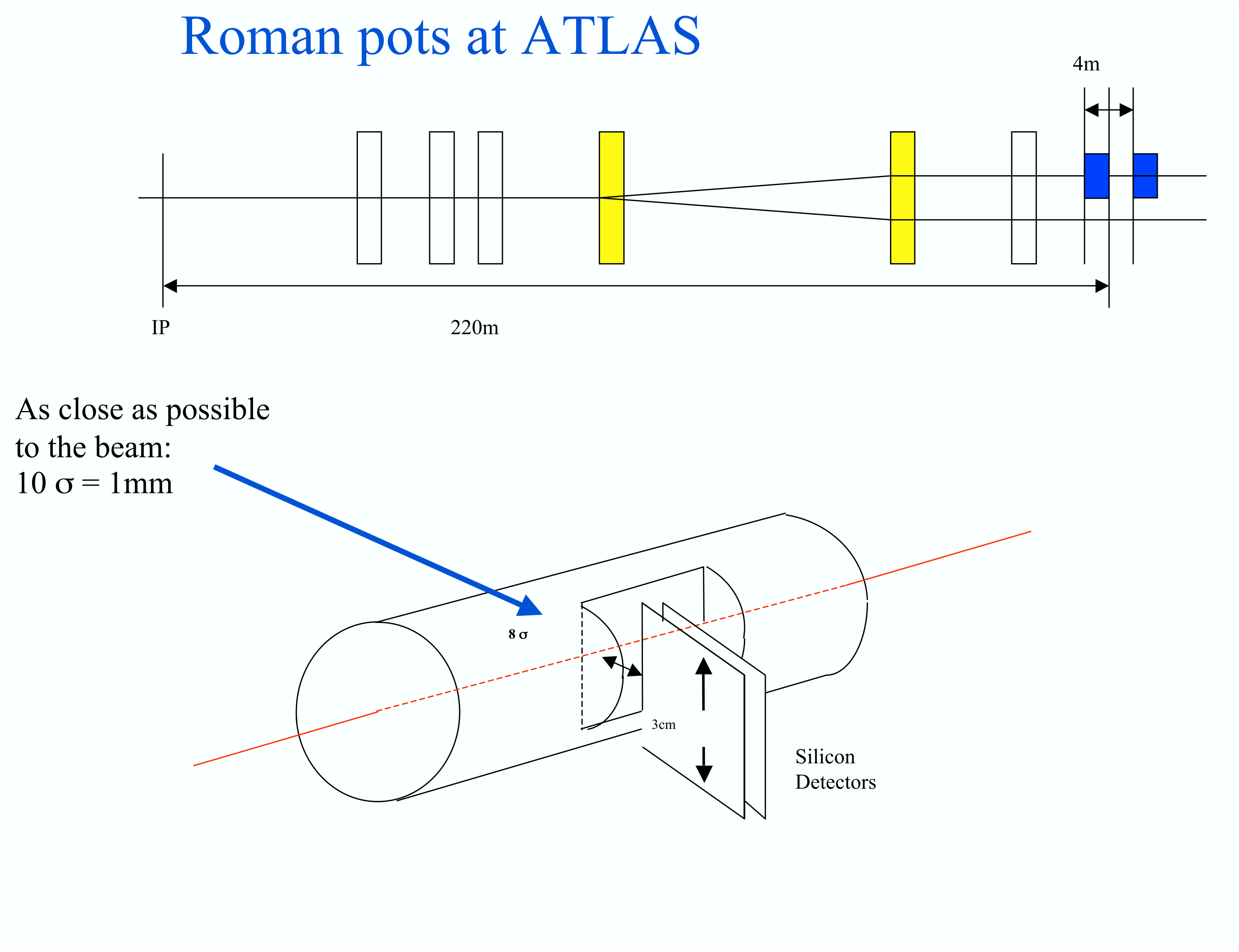


7.2 mm x 24mm (7.2 x 8 mm^2 sensors)



Roman pot project at 220m in ATLAS

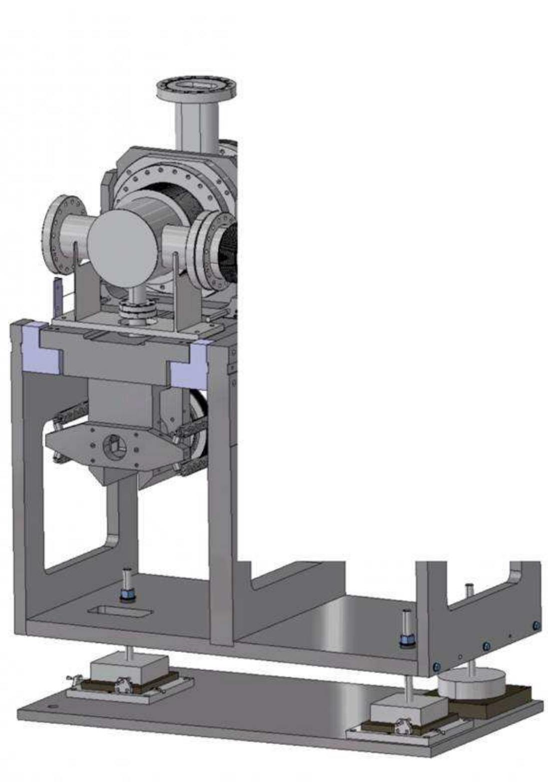
Collaboration between Prague, Cracow, Saclay, Stony Brook, Paris 6, Giessen, Michigan State University, and also Argonne National Lab., University of Chicago for timing detectors

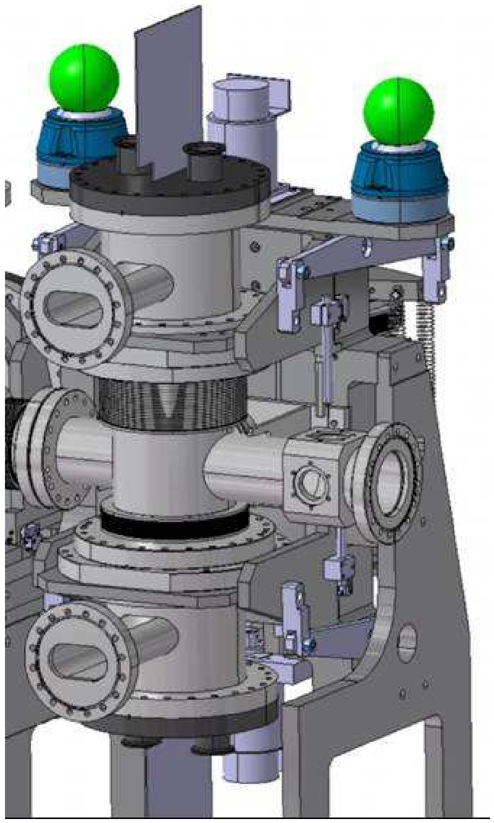


Assume roman pots located at 216 and 224 m

Roman pots at 220 m

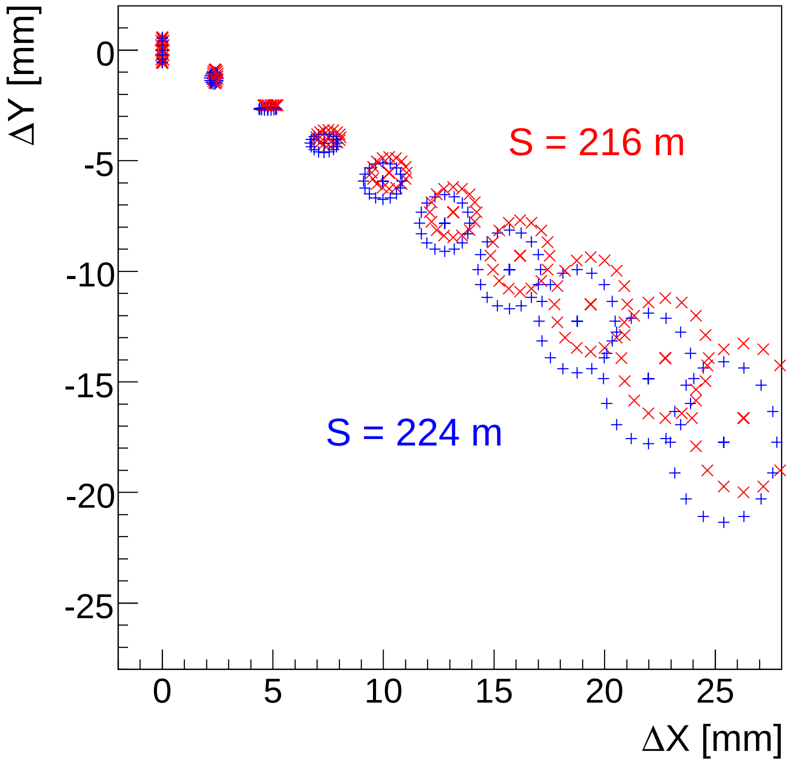
Schematic view of 220 m pots: keep horizontal pots only from the TOTEM pots

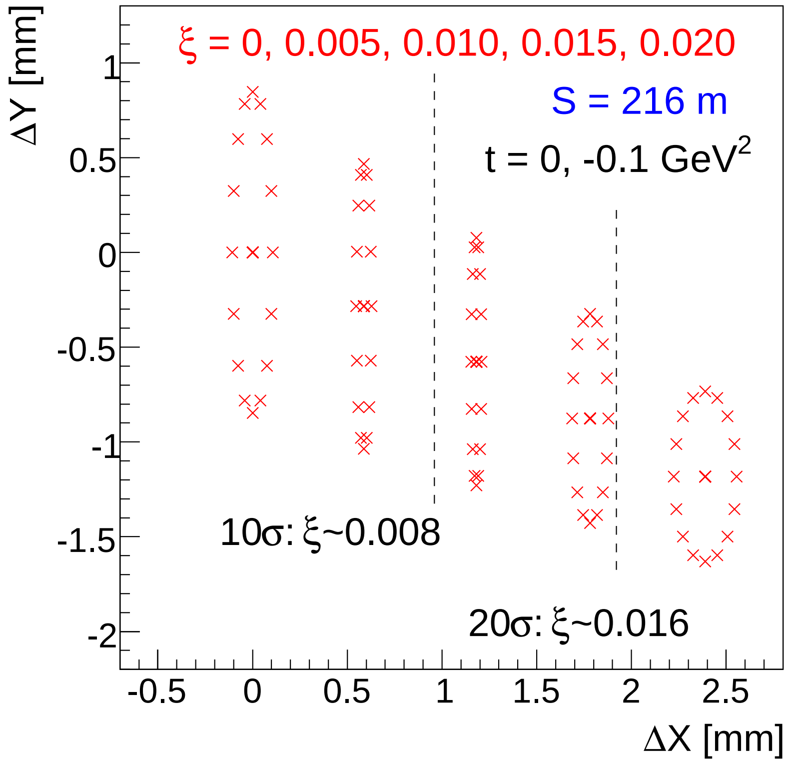




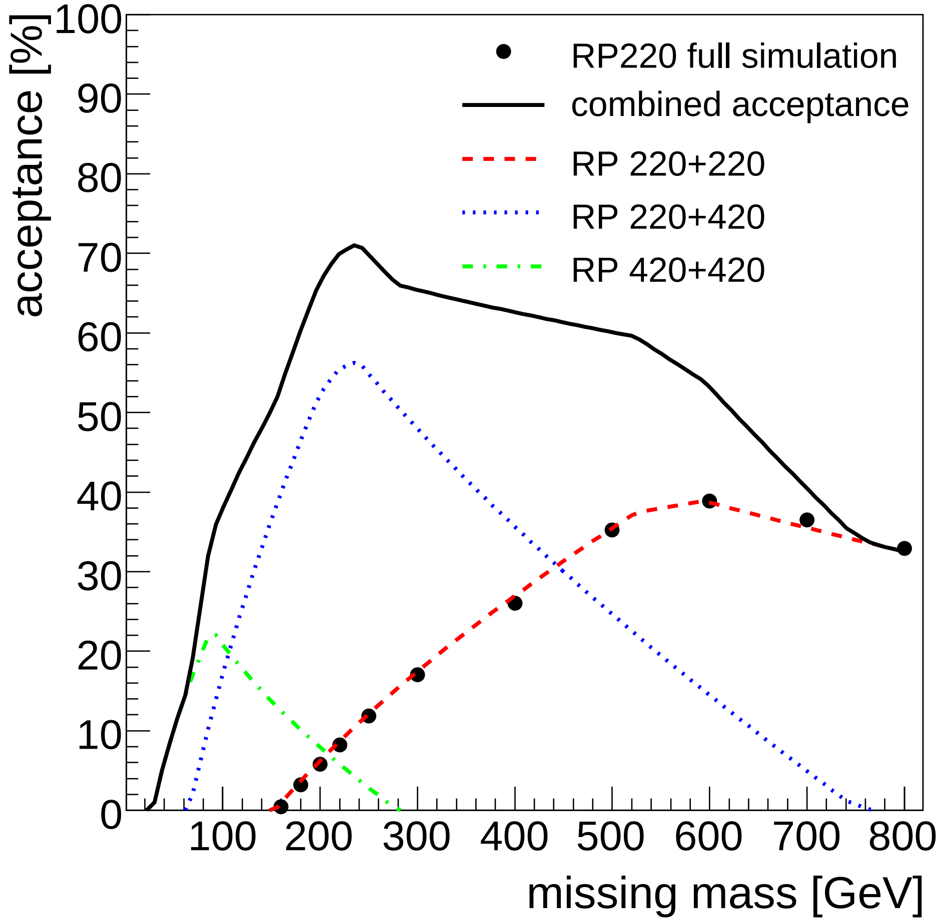
Acceptance for 220 m pots

- Steps in ξ: 0.02 (left), 0.005 (right), $|t|$=0 or 0.05 GeV^2
- Detector of 2 cm $\times$ 2 cm will have an acceptance up to $\xi \sim 0.16$, down to 0.008 at 10 σ, 0.016 at 20 σ
- As an example Higgs mass acceptance using 220 m pots down to 135 GeV and upper limit due to cross section and not kinematics





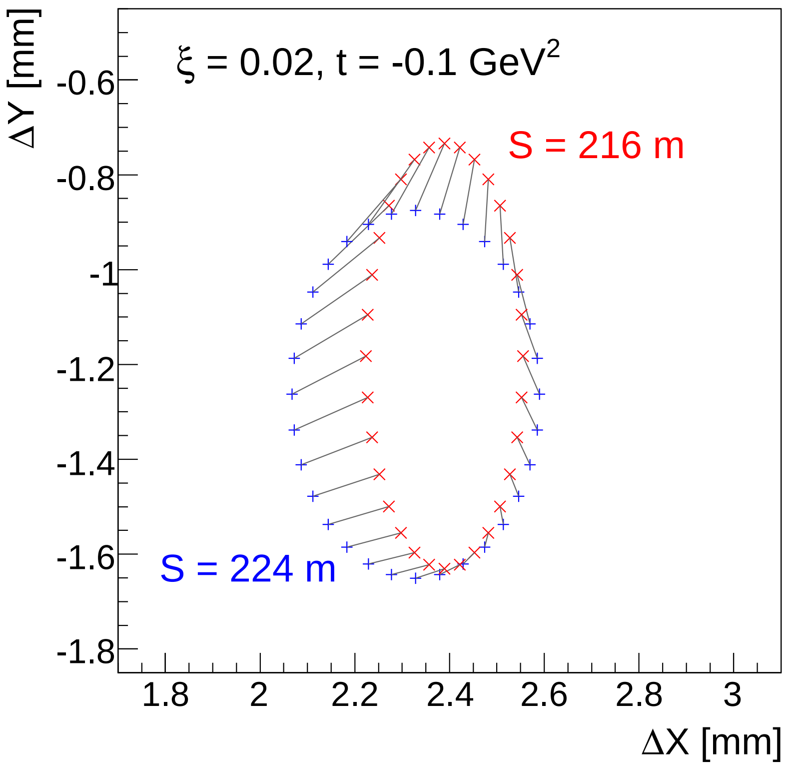
Roman pot projects

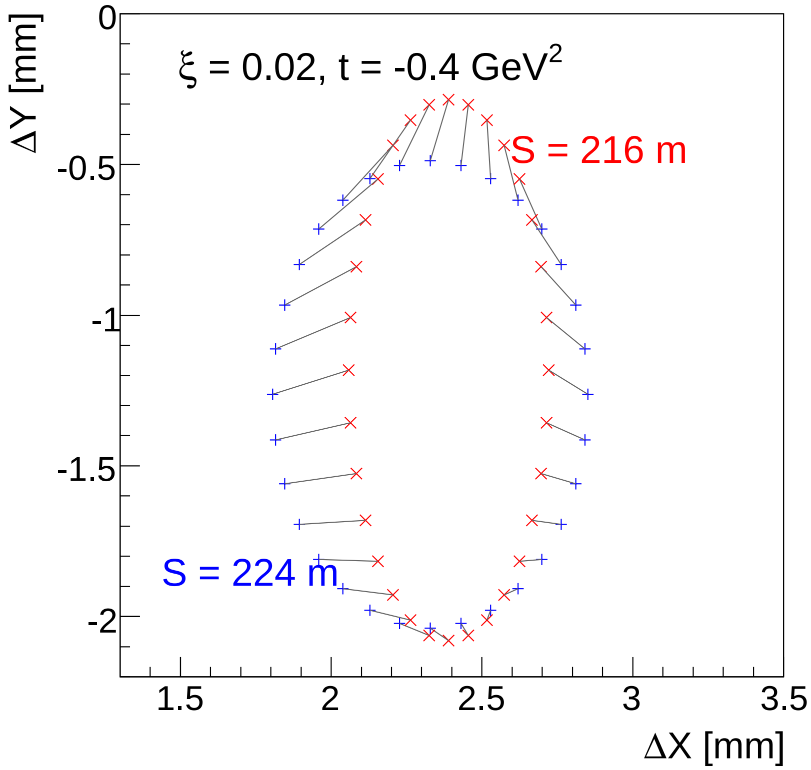


Both FP420 and RP220 needed to have a good coverage of acceptance (NB: acceptance slightly smaller in CMS than in ATLAS)

Hit maps at 216 and 224 m

- Study difference between hit maps at 216 and 224 m: test the idea of using displacement at the trigger level to distinguish with halo
- No unique shift direction between 216 and 224 m

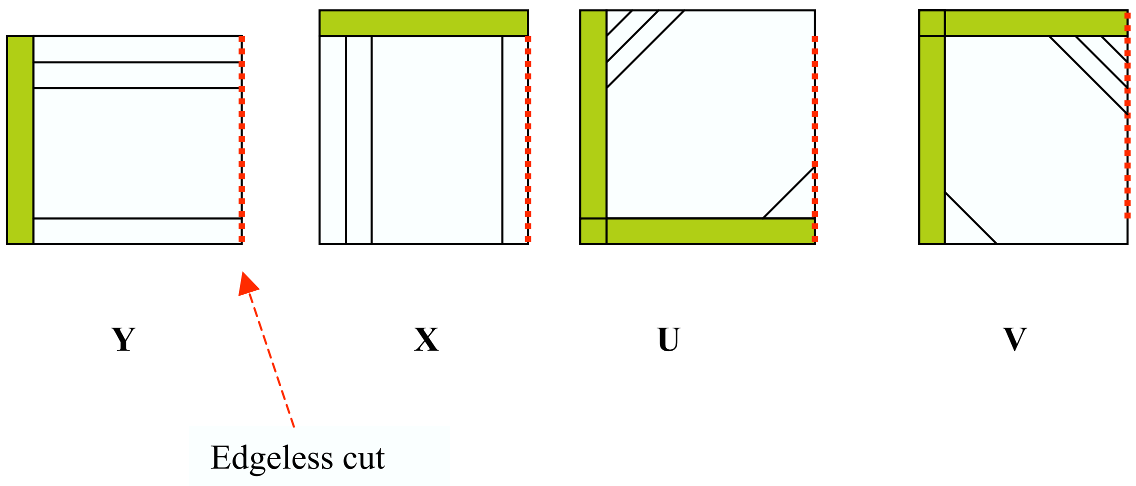




Which kind of detectors?

- Requirement: good resolution in position (good measurement of mass, kinematical propwerties), and in timing
- Position detectors:
  - Size of Si detectors: 2cm $\times$ 2cm
  - Spatial resolution of the order of 10-15 μm: Si strip detectors of 50 μm, as a first proposal: 5 layers, 2 vertical, 1 horizontal, 1 U, 1 V (45 degrees)
  - Edgeless detectors: Between 30 to 60 μm
  - First prototype of detector made by CANBERRA, VTT: test-stand (laser and radioactive source) being installed in Saclay, Prague following the Paris 6 experience
  - 2 additional layers used for the trigger: Strip detectors of 100-200 μm (to be optimised given the fact that we have 1 μs to send the trigger to ATLAS)
  - Readout and trigger chip ABCNext: standard Si readout for ATLAS
  - Other option in collaboration with FP420: 3D Silicon

Different kinds of detectors

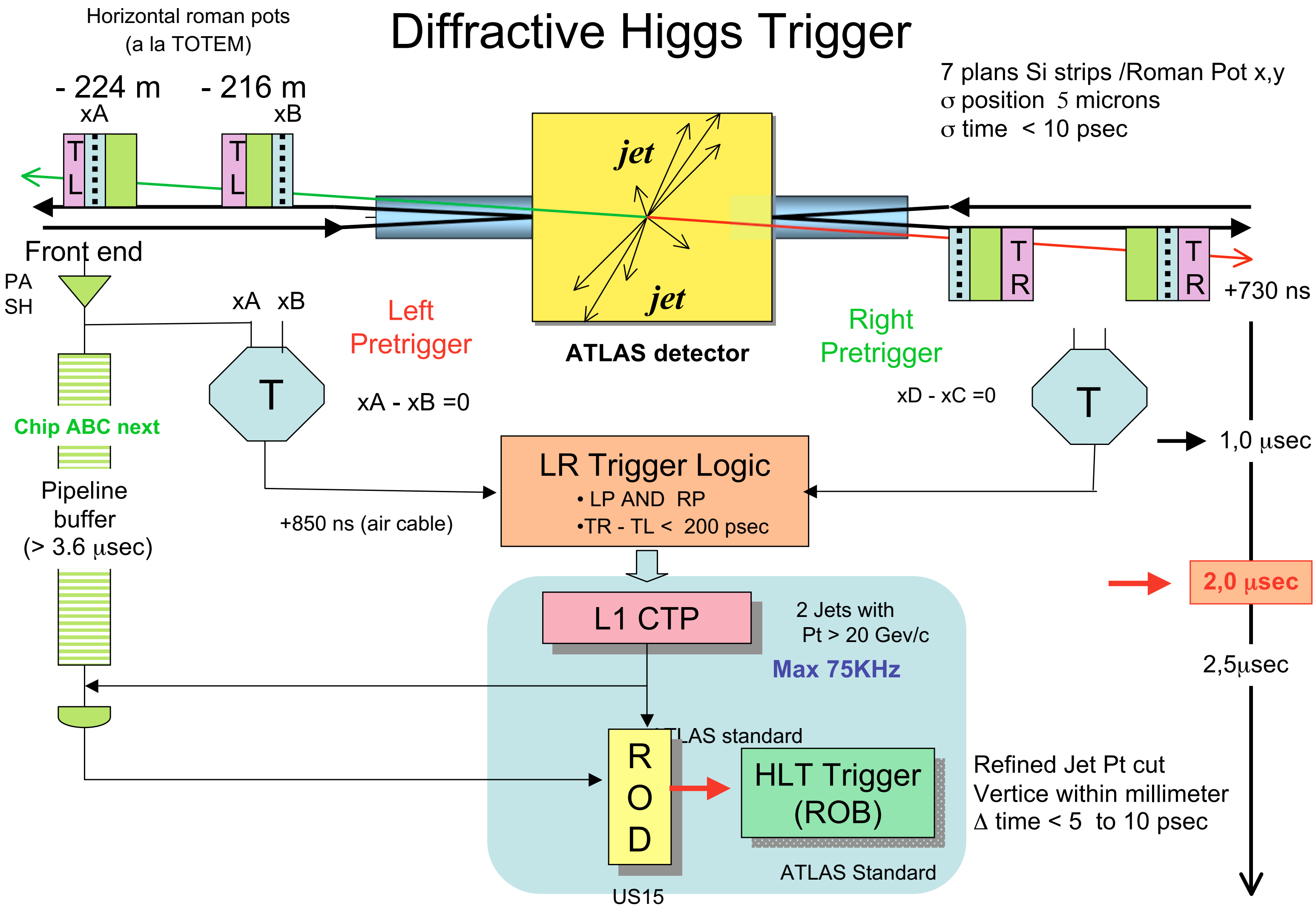


- 5 detectors to be used in readout per pot
- 2 additional detectors to be used for triggering (larger strips)
- Other option: 3D Silicon detectors

Which kind of detectors?

- Timing detectors
  - Why do we need timing detectors? At the LHC, up to 30 interactions by bunch crossing, and we need to identify from which vertex the protons are coming, same problem for FP420
  - Timing detector resolution needed: of the order of 5 picoseconds (space resolution slightly more than 1 mm)
  - Radiation hardness
  - Detector space resolution: few mm, the total width of the detectors being 2.5 cm (4.5 cm available in roman pot)
  - Reference clock: either the LHC clock (resolution of 7-8 ps), or atomic clock (they need to be calibrated on each side)
  - Trigger information: at L1 (rough compatibility between both sides of ATLAS) and specially at L2 (compatibility with vertex position)
  - Development: new timing detectors in collaboration with the Universities of Chicago, Stony Brook, and Argonne, and with Photonis
  - For more information, see: http://www-d0.fnal.gov/ royon/timing/, Saclay workshop on timing detectors on March 8 and 9

Trigger: principle



Trigger: strategy

- L1 trigger when two protons tagged at 220 m
- L1 trigger when only one proton is tagged at 220 m: in that case, cut on acceptance at 220 m corresponding to the possibility of a tag at 420 m
- Cuts used:
  - 2 jets in central detector with $p_T > 40$ GeV
  - Exclusiveness of the process (2 jets carrying 90% of the energy) $(E_{T_1} + E_{T_2})/H_T > 0.9$
  - Kinematics requirement $(\eta_1 + \eta_2) \times \eta_{220} > 0$
  - At least one proton tagged at 220 m with $\xi < 0.05$ (compatible with the eventual presence of a proton at 420 m on the other side) **or** one proton tagged at 220 m on each side
- With those cuts, possibility to get a L1 rate less than 1 kHz for a luminosity less than 3.10^{33}cm^{-2} s^{-1}

Trigger: rates

L1 rates for 2-jet trigger with $E_T > 40\,\mathrm{GeV}$ and additional reduction factors due to the requirement of triggering on diffractive proton in $220\,\mathrm{m}$ Roman Pot, and also on jet properties.

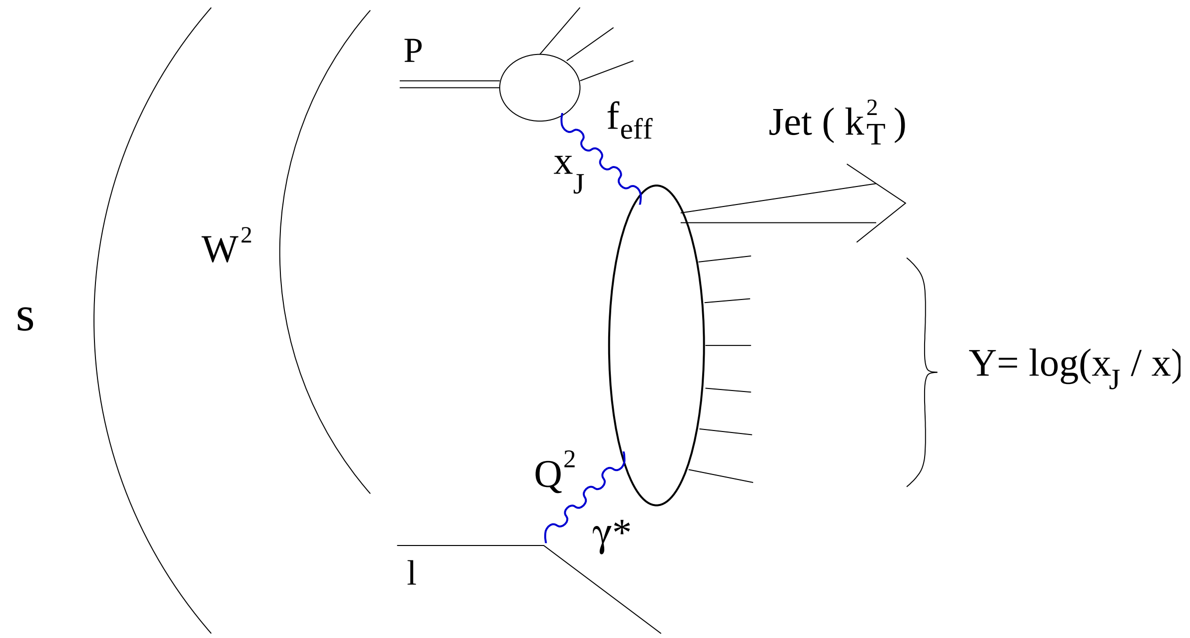
$\mathcal{L}$ $E_T > 40\,\mathrm{GeV}$	n_{pp} per bunch crossing	2-jet rate $[\mathrm{kHz}]$ $[\mathrm{cm}^{-2}\cdot\mathrm{s}^{-1}]$	RP200 reduction factor	$\xi < 0.05$ reduction factor	Jet Prop.
1×10^{32}	0.35	2.6	120	300	1200
1×10^{33}	3.5	26	8.9	22	88
2×10^{33}	7	52	4.2	9.8	39.2
5×10^{33}	17.5	130	1.9	3.9	15.6
1×10^{34}	35	260	1.3	2.2	8.8

Conclusion: Trigger can hold for $Higgs \to b\bar{b}$ up to a lumi of 3.10^{33}

Conclusion on diffraction at LHC

- Rich program of hard diffractive studies at the LHC: standard QCD, understanding of Pomeron structure in terms of quark and gluons, diffractive W and tops, anomalous couplings for W, measurement of exclusive cross section in dijets, diphoton channels...
- Of special interest: Diffractive Higgs production: Very clean events
- Roman pots and forward detectors in progress: Roman pots at 220 m being proposed for ATLAS, FP420 for ATLAS and CMS, both projects are needed to get a good acceptance
- Triggering: Very important aspect, possibility to trigger on $Higgs \rightarrow b\bar{b}$ without prescale almost up to highest luminosity at the LHC

Forward jet measurement at HERA



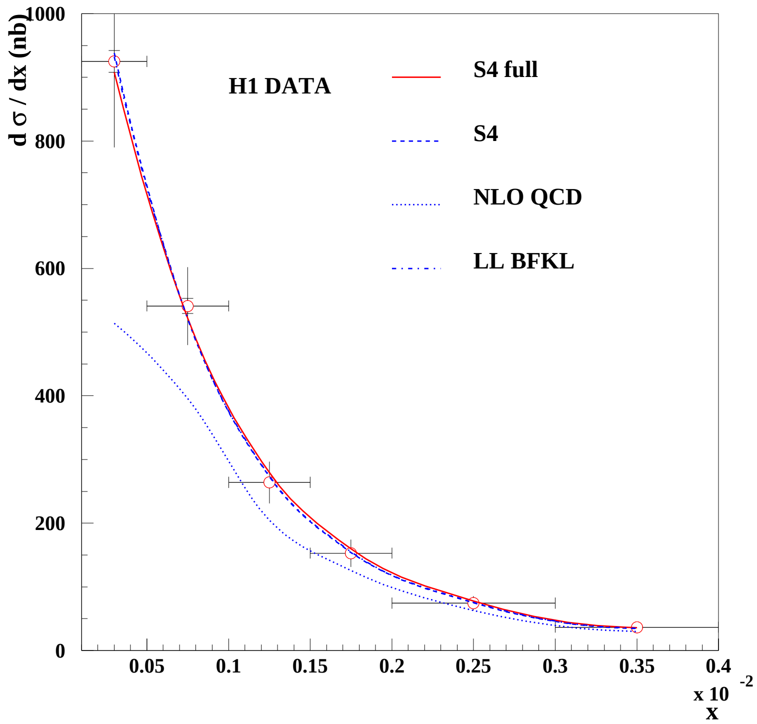
- Typical kinematical domain where BFKL effects are supposed to appear with respect to DGLAP: $k_T^2 \sim Q^2$, and Q^2 not too large
- LO BFKL forward jet cross section: 2 parameters α_S, normalisation
- NLL BFKL cross section: one single parameter: normalisation (α_S running via RGE)

Cross section calculation, comparison with H1

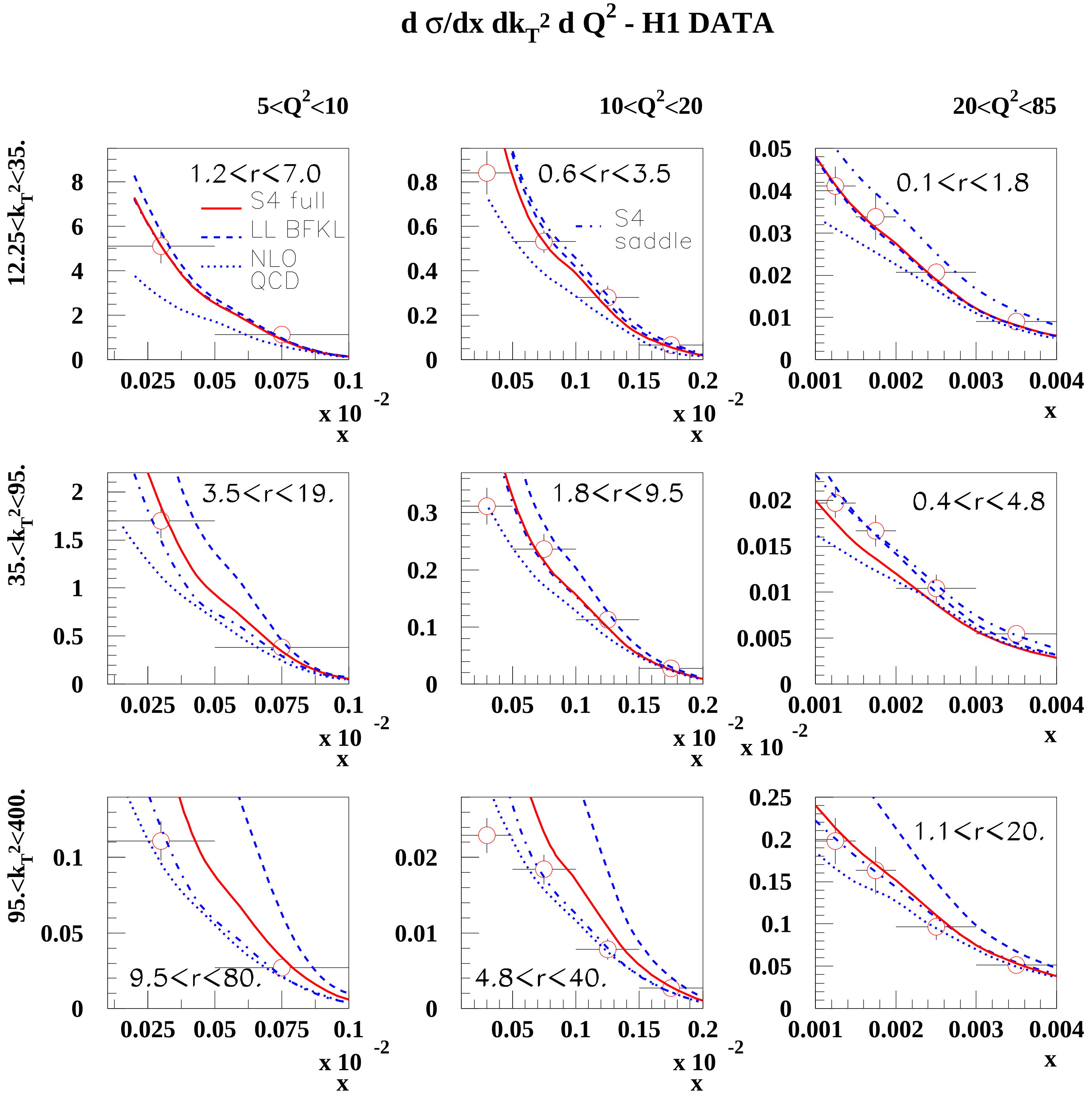
- Two difficulties: We need to integrate over the bin in Q^2, x_{jet}, k_T to compare with the experimental measurement and we need to take into account the experimental cuts (as an example: $E_e > 10$ GeV, $k_T > 3.5$ GeV, $7 \leq \theta_J \leq 20$ degrees....)
- We perform the integration numerically: we chose the variables for which the cross section is as flat as possible to avoid numerical difficulties in precision: k_T^2/Q^2, $1/Q^2$, $log 1/x_{jet}$
- We take into account some of the cuts at the integration level (k_T for instance) and the other ones using a toy Monte Carlo
- For more information, see: C. Marquet, C. Royon, Nucl.Phys. B739 (2006) 131; O. Kepka, C. Marquet, R. Peschanski, C. Royon, hep-ph/0609299

Fit procedure

- Fit to H1 $d\sigma/dx$ data only
- Fit using the 6 data points
- Results at LO: Good fit ($\chi^2 \sim 0.5/5$), but α_S small ($\alpha_S \sim 0.1$)
- $\alpha_S(k_T Q)$ is imposed using the renormalisation group equation at NLL
- Nice description of data using NLL BFKL formalism

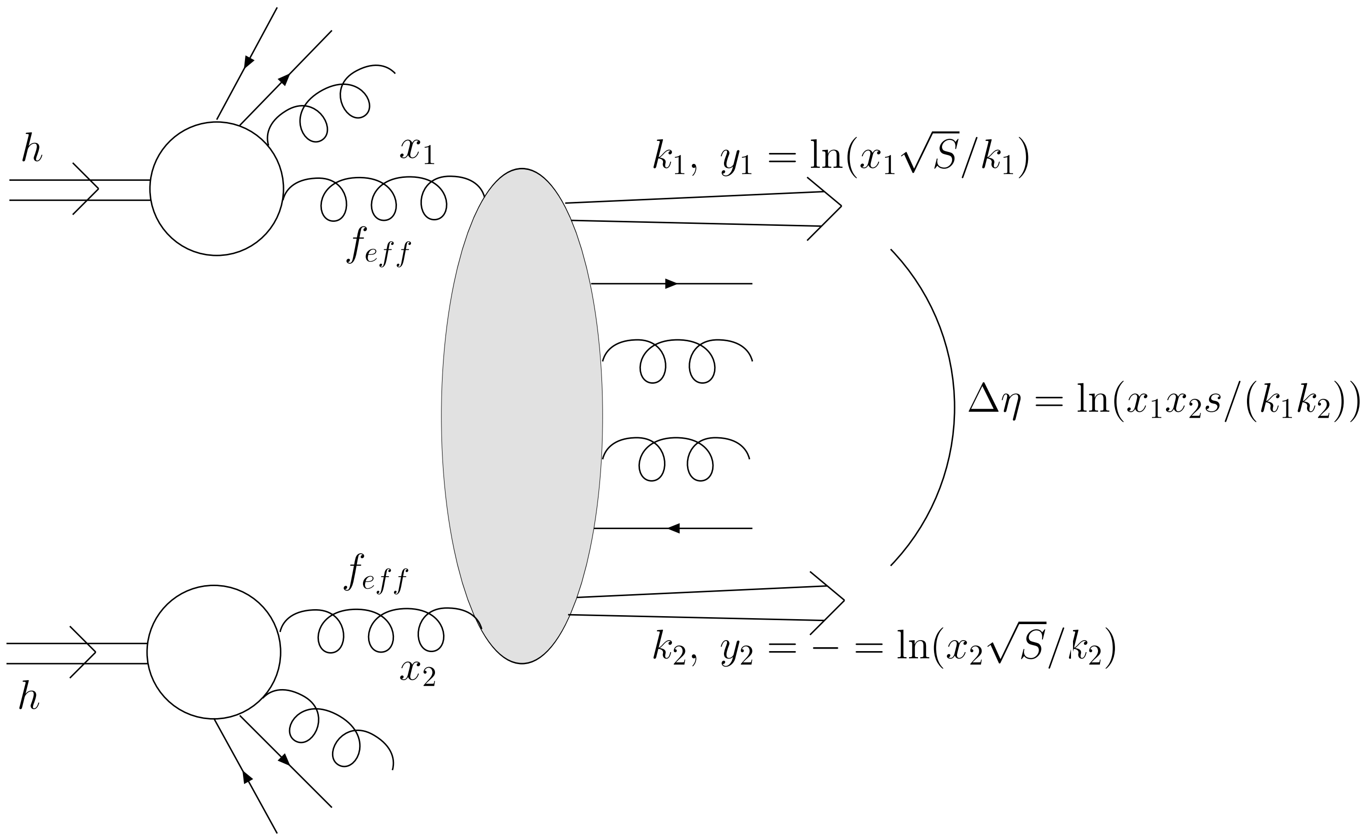


Comparison with H1 triple differential data



Mueller Navelet jets

Same kind of processes at the Tevatron and the LHC



- Same kind of processes at the Tevatron and the LHC: Mueller Navelet jets
- Study the $\Delta\Phi$ between jets dependence of the cross section:
- For more information, see: C. Marquet, C. Royon, arXiv:0704.3409

Mueller Navelet jets: $\Delta\Phi$ dependence

- Study the $\Delta\Phi$ dependence of the relative cross section
- Relevant variables:

$$\begin{aligned} \Delta\eta &= y_1 - y_2 \\ y &= (y_1 + y_2)/2 \\ Q &= \sqrt{k_1 k_2} \\ R &= k_2/k_1 \end{aligned}$$

- Azimuthal correlation of dijets:

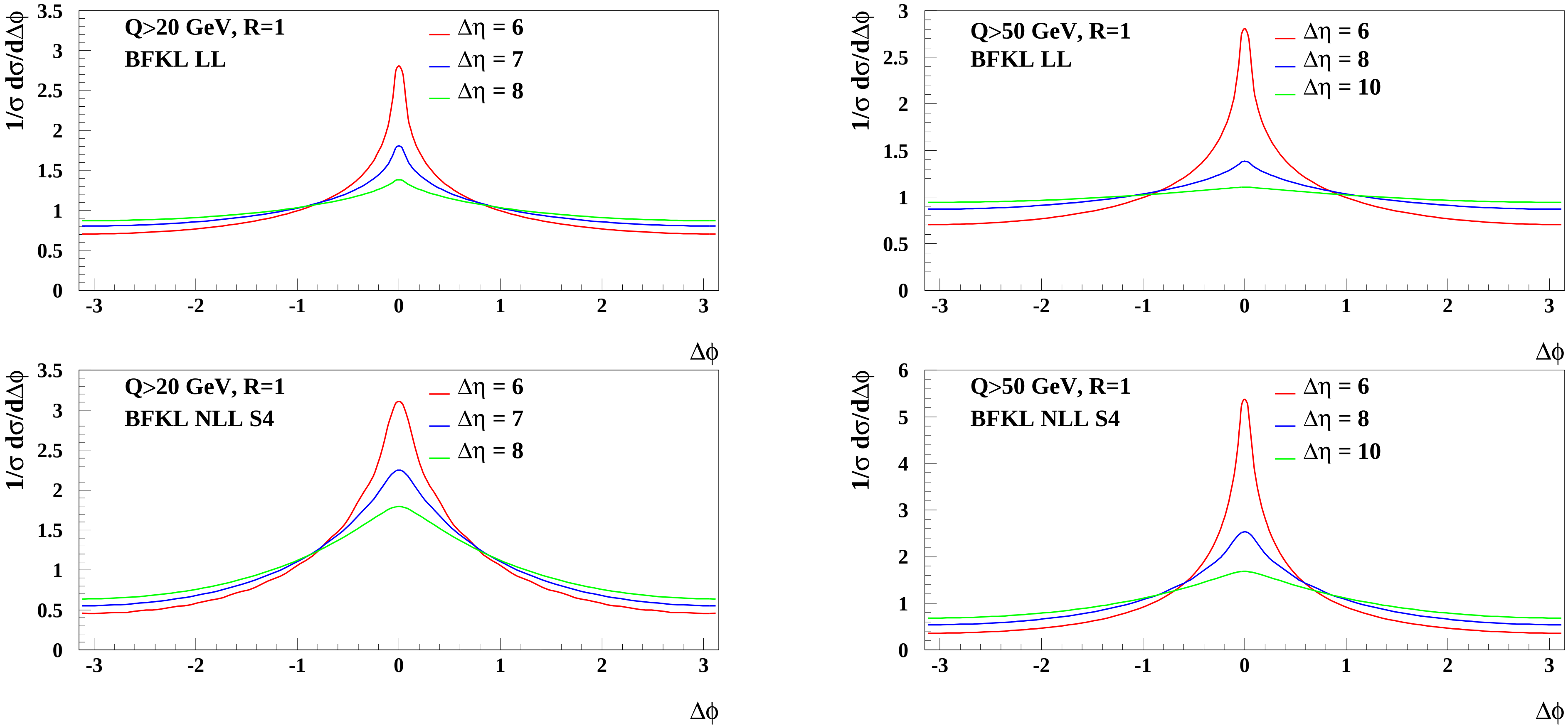
$$2\pi \, \frac{d\sigma}{d\Delta\eta dR d\Delta\Phi} \bigg/ \frac{d\sigma}{d\Delta\eta dR} = 1 + \frac{2}{\sigma_0(\Delta\eta, R)} \sum_{p=1}^{\infty} \sigma_p(\Delta\eta, R) \cos(p\Delta\Phi)$$

where

$$\sigma_p = \int_{E_T}^{\infty} \frac{dQ}{Q^3} \alpha_s(Q^2/R) \alpha_s(Q^2 R) \left(\int_{y_<}^{y_>} dy x_1 f_{eff}(x_1, Q^2/R) x_2 f_{eff}(x_2, Q^2 R) \right) \int_{1/2-\infty}^{1/2+\infty} \frac{d\gamma}{2i\pi} R^{-2\gamma} \; e^{\bar{\alpha}(Q^2)\chi_{eff}\Delta\eta}$$

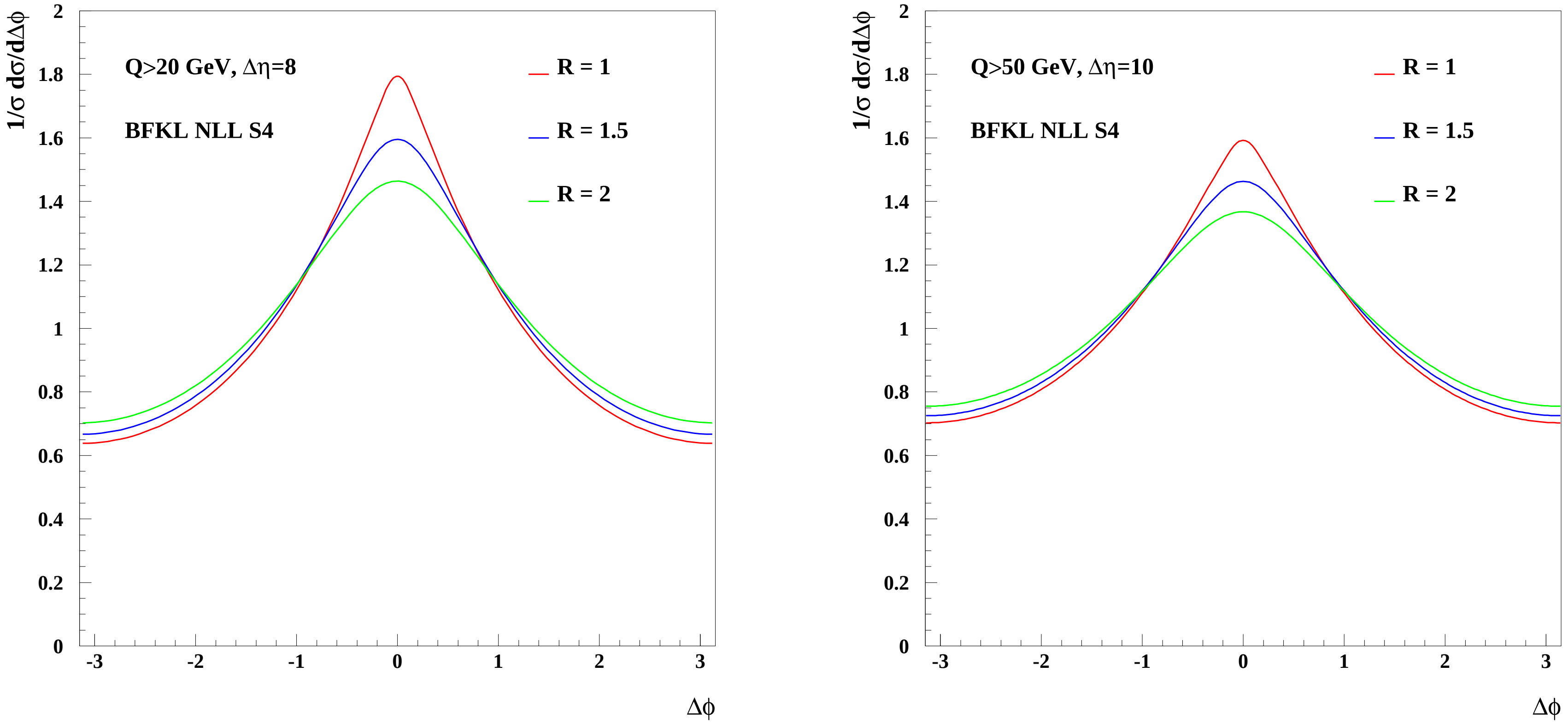
Mueller Navelet jets: $\Delta\Phi$ dependence

- $1/\sigma d\sigma/d\Delta\Phi$ spectrum for BFKL LL and BFKL NLL as a function of $\Delta\Phi$ for different values of $\Delta\eta$
- Measurement to be performed at the Tevatron/LHC



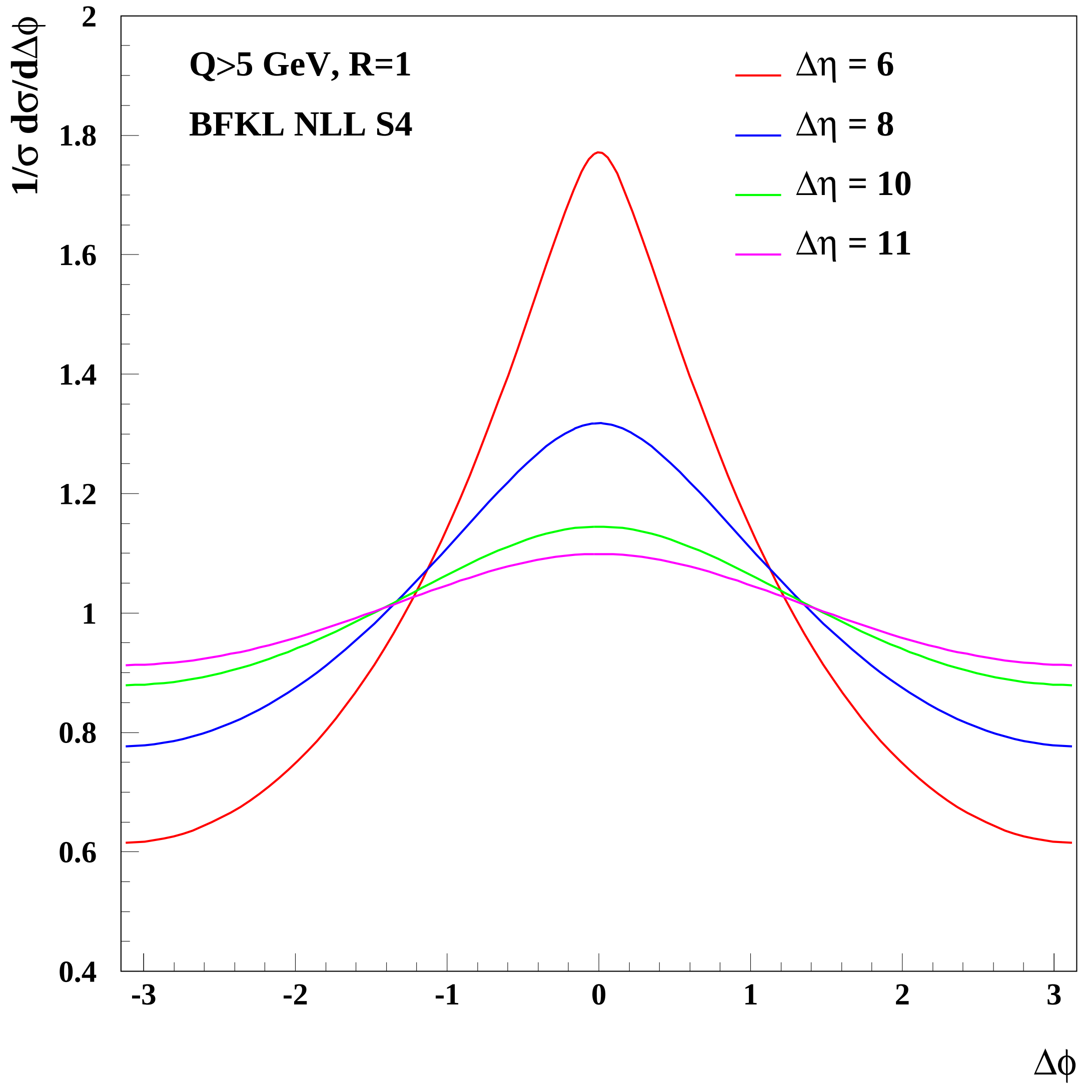
Mueller Navelet jets: R dependence

Weak R dependence, BFKL/DGLAP enhanced if R close to 1



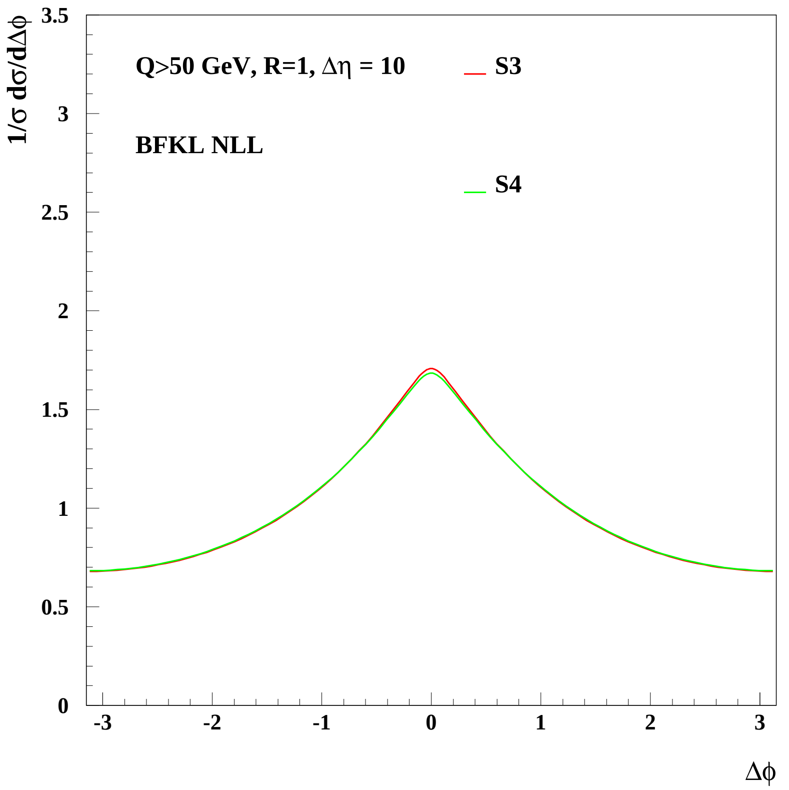
Mueller Navelet jets in CDF

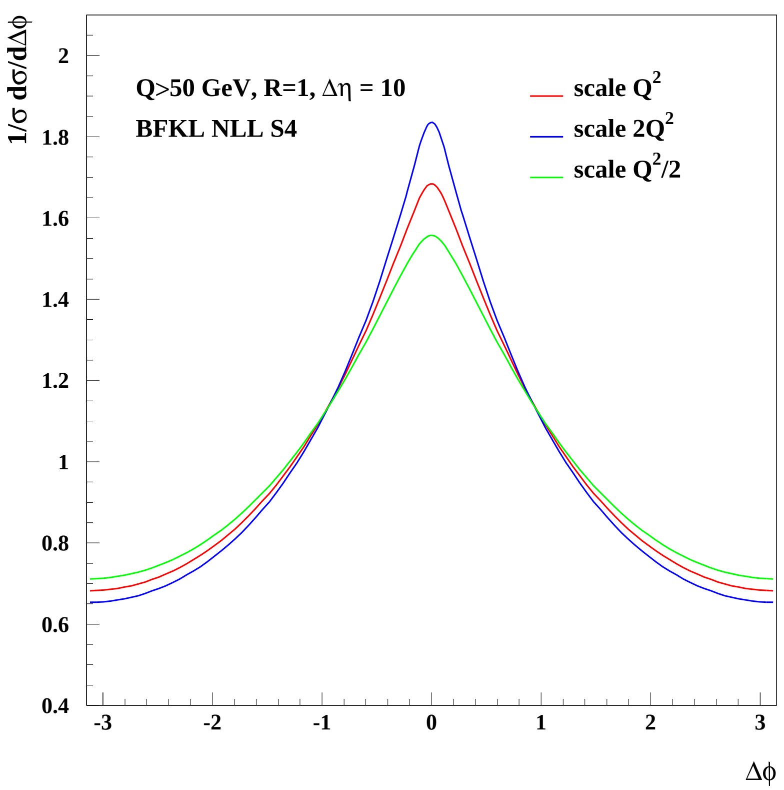
Possibility to measure $\Delta\Phi$ distribution in CDF for large $\Delta\eta$ and low jet p_T ($p_T > 5$ GeV) using the CDF miniPLUG calorimeter



Mueller Navelet jets: S3 and S4, scale dependence

- No difference between S3 and S4 schemes (as an example for LHC)
- Weak scale dependence (given as an example for the LHC): $Q^2/2$, Q^2, $2Q^2$





Conclusion

- Many results from the Tevatron on diffraction: inclusive diffraction (jets...), and search for exclusive events (especially in dijet channel, and also diphoton, χ_C)
- Rich diffractive program at the LHC: Elastic cross section, hard diffraction (Inclusive, exclusive, especially for Higgs diffractive production, photon anomalous coupling, SUSY...
- Many new detectors proposed at the LHC: TOTEM, ALFA (approved), FP420, RP220, also forward coverage of both CMS and ATLAS, Increases by a lot the physics potential of the LHC
- Interesting to study Mueller Navelet jets at Tevatron/LHC to study BFKL resummation effects