WE-Heraeus-Summerschool

Diffractive and electromagnetic processes at high energies

Heidelberg, September 2 - 6, 2013

Diffraction at the Tevatron

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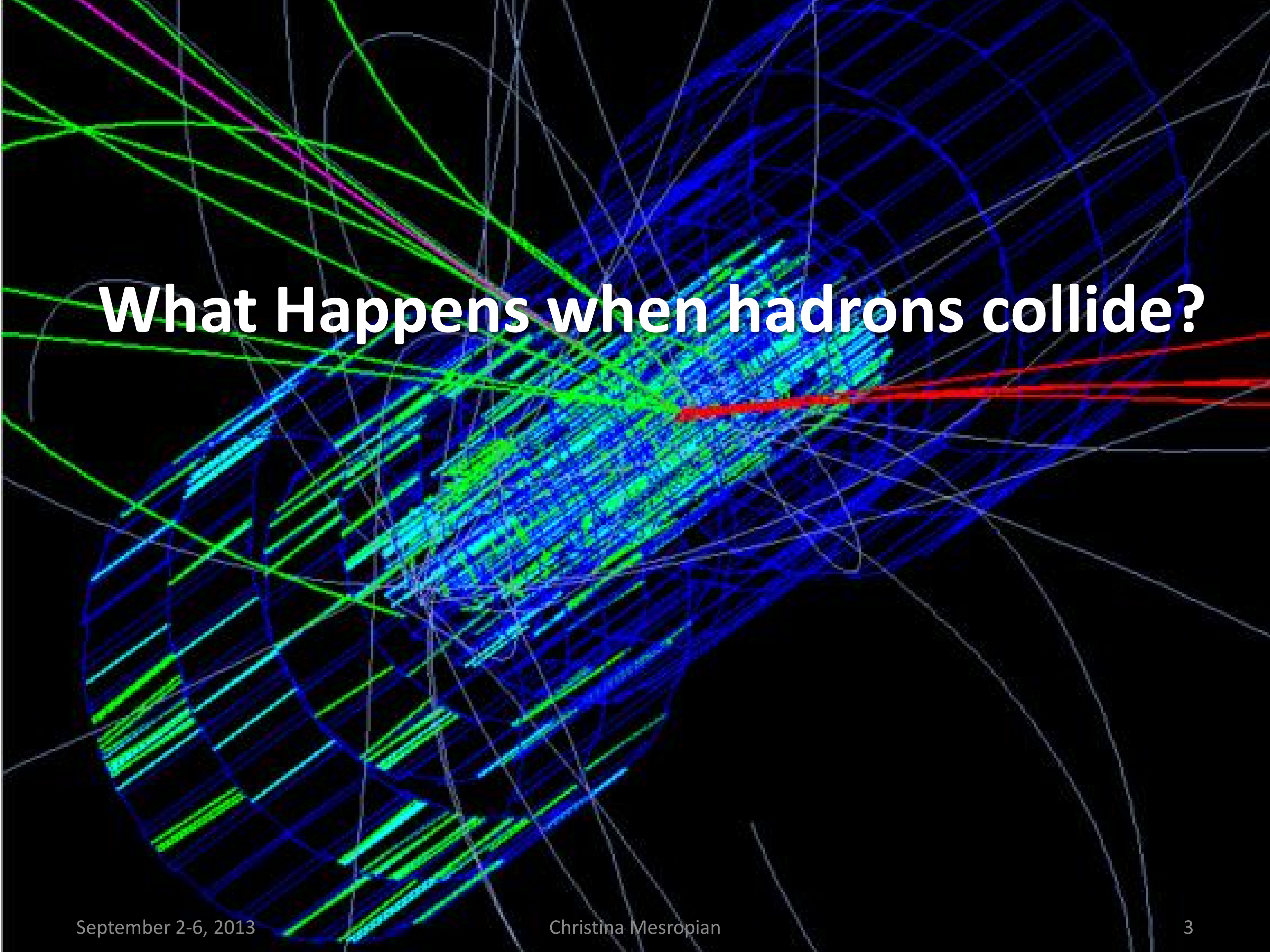
Contents:

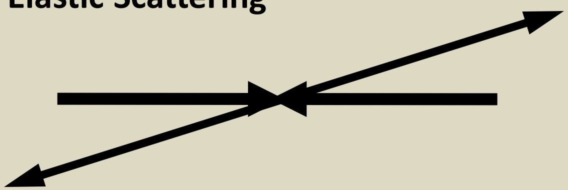
- Introduction
- Detectors
- Total and Elastic Scattering
- Single Diffraction Processes
- Double Diffraction Processes
- Double Pomeron Exchange Processes

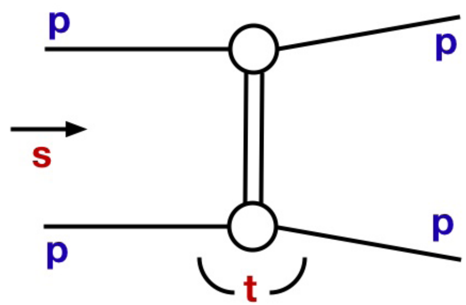
What Happens when hadrons collide?



Proton-(anti)Proton Collisions

Elastic Scattering





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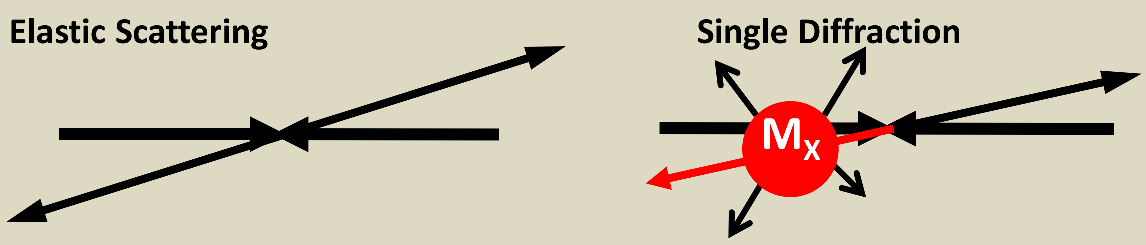

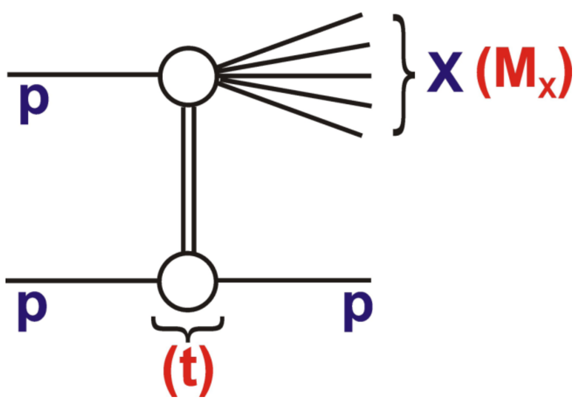

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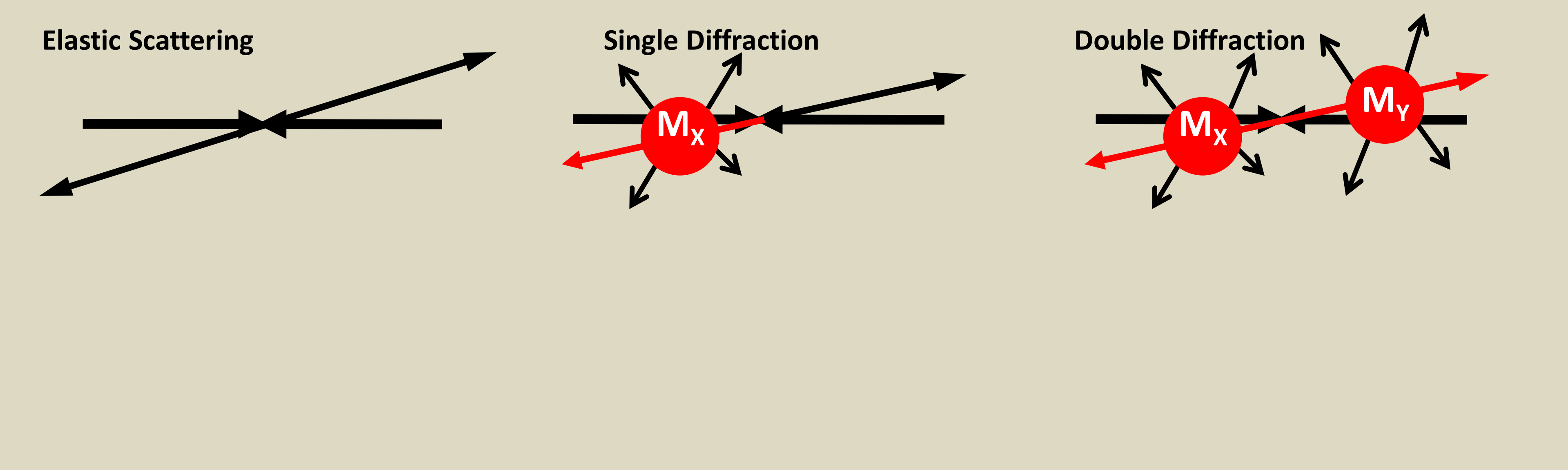

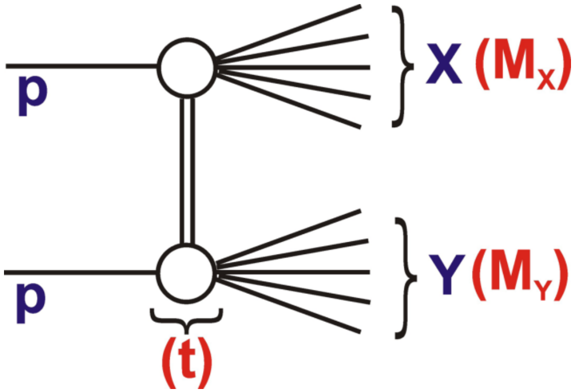

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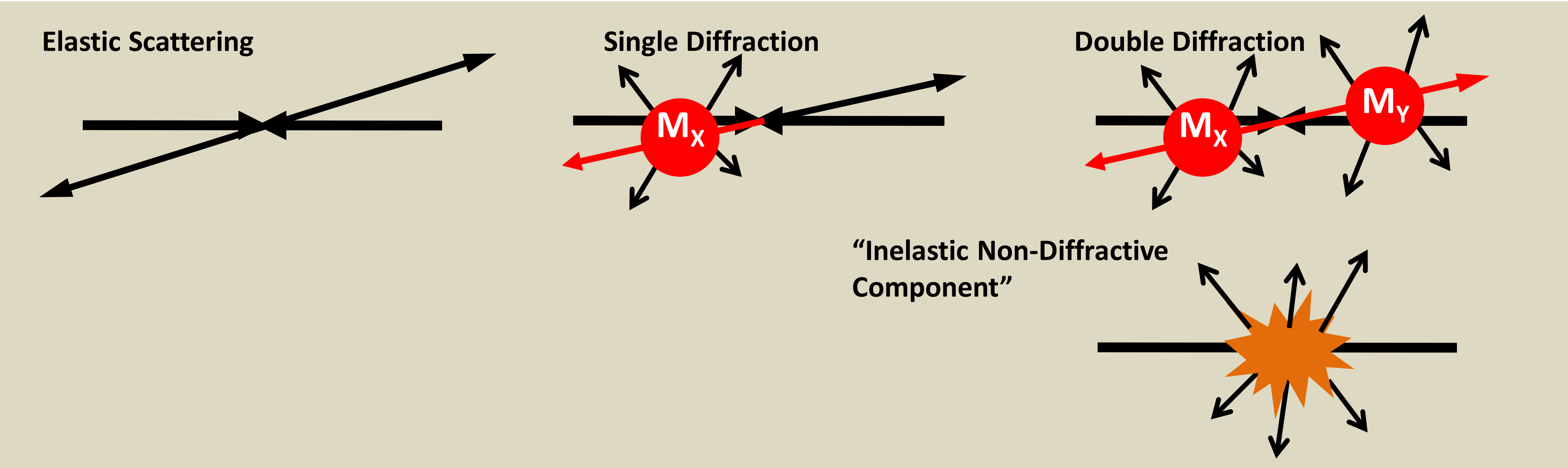
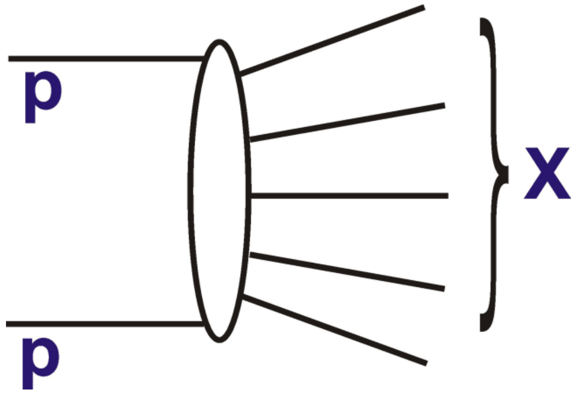
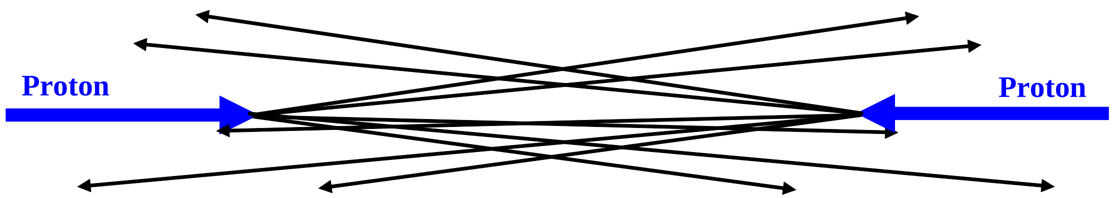
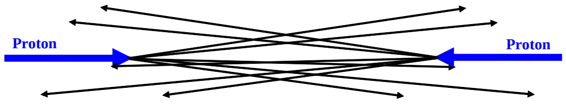




The Inelastic Non-Diffractive Cross-Section





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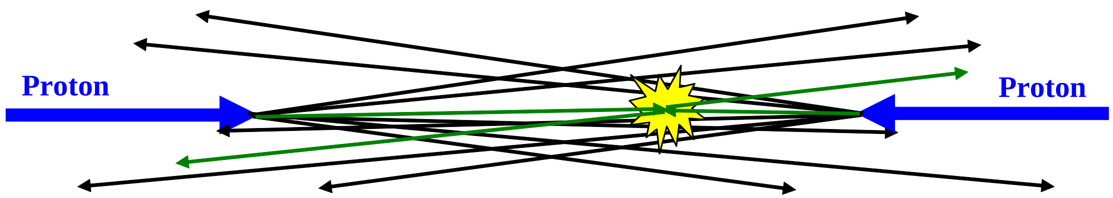
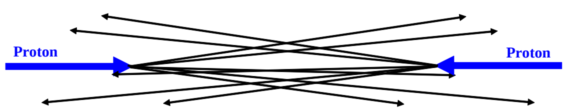
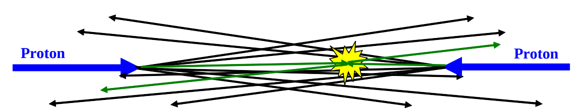


"Semi-hard" parton-parton collision (p_T < ≈2 GeV/c)



+



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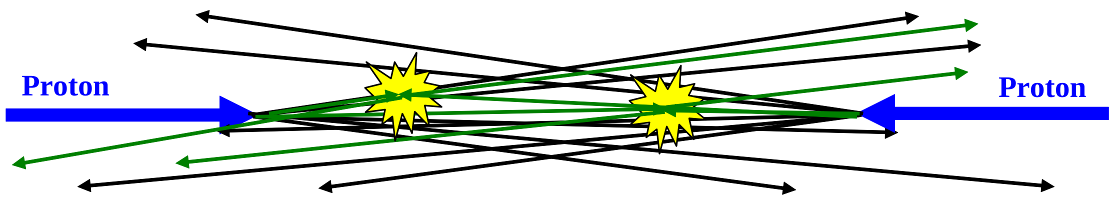

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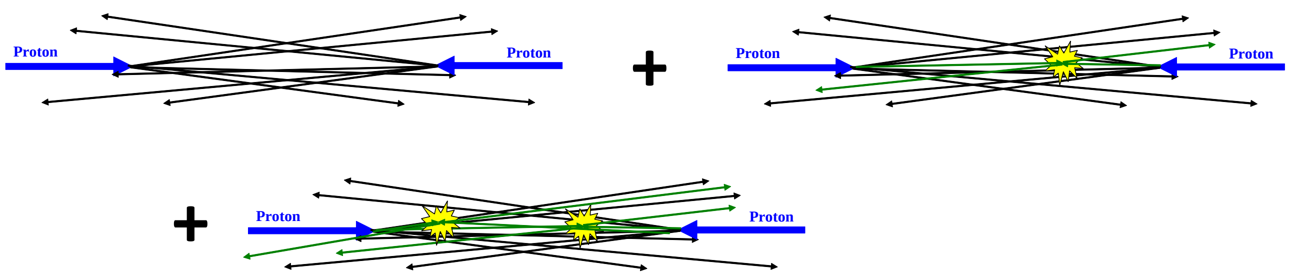

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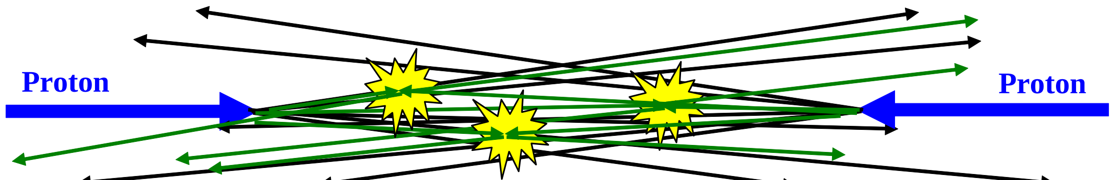

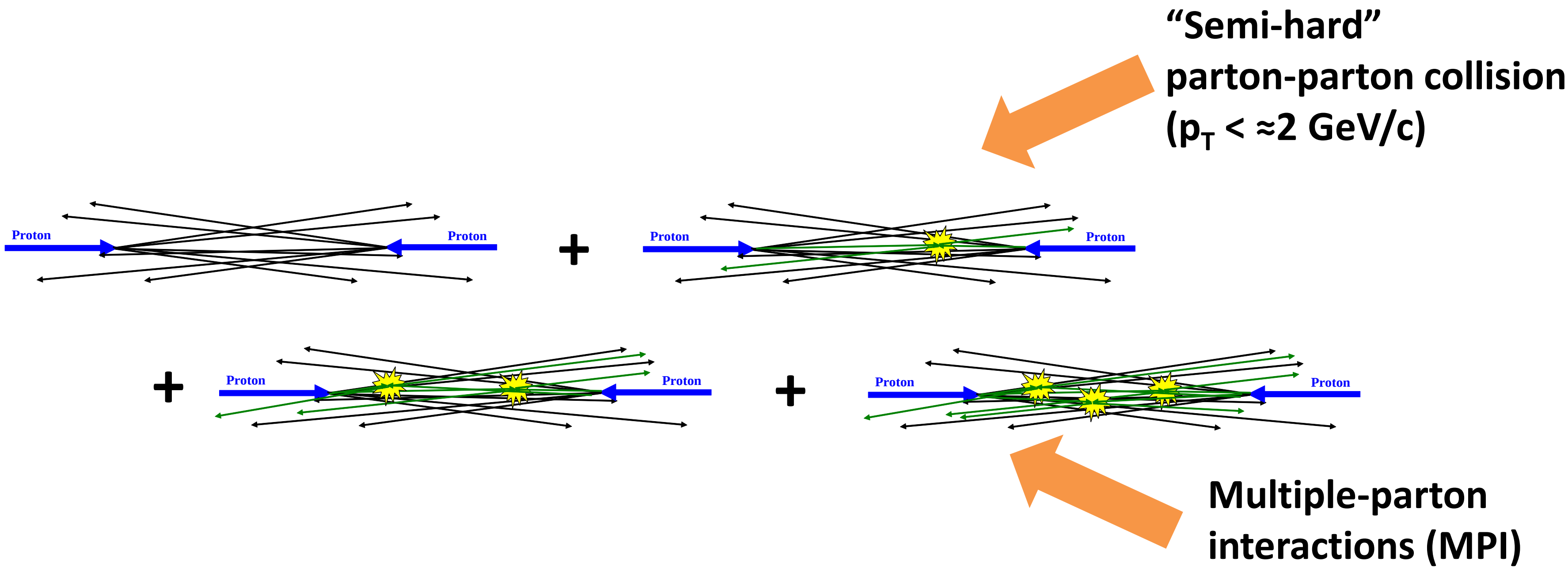

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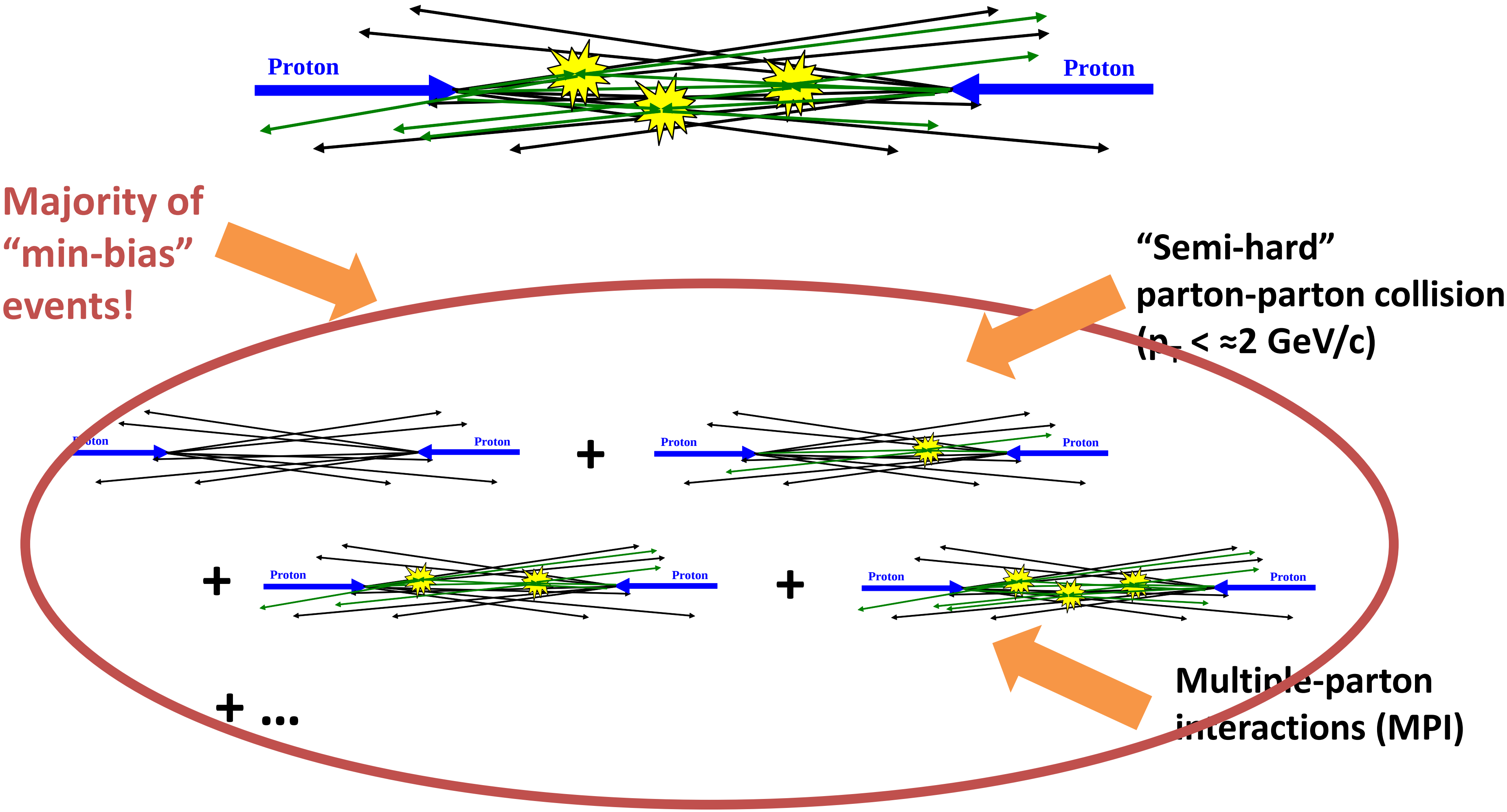

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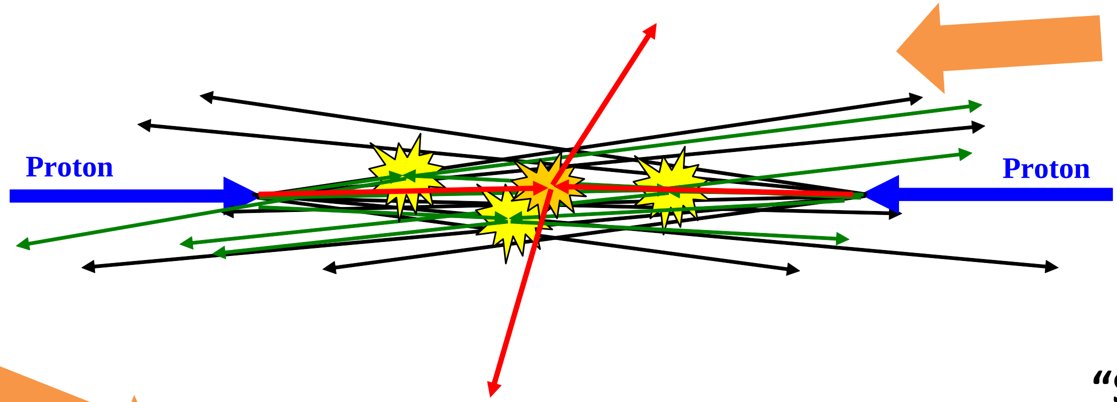
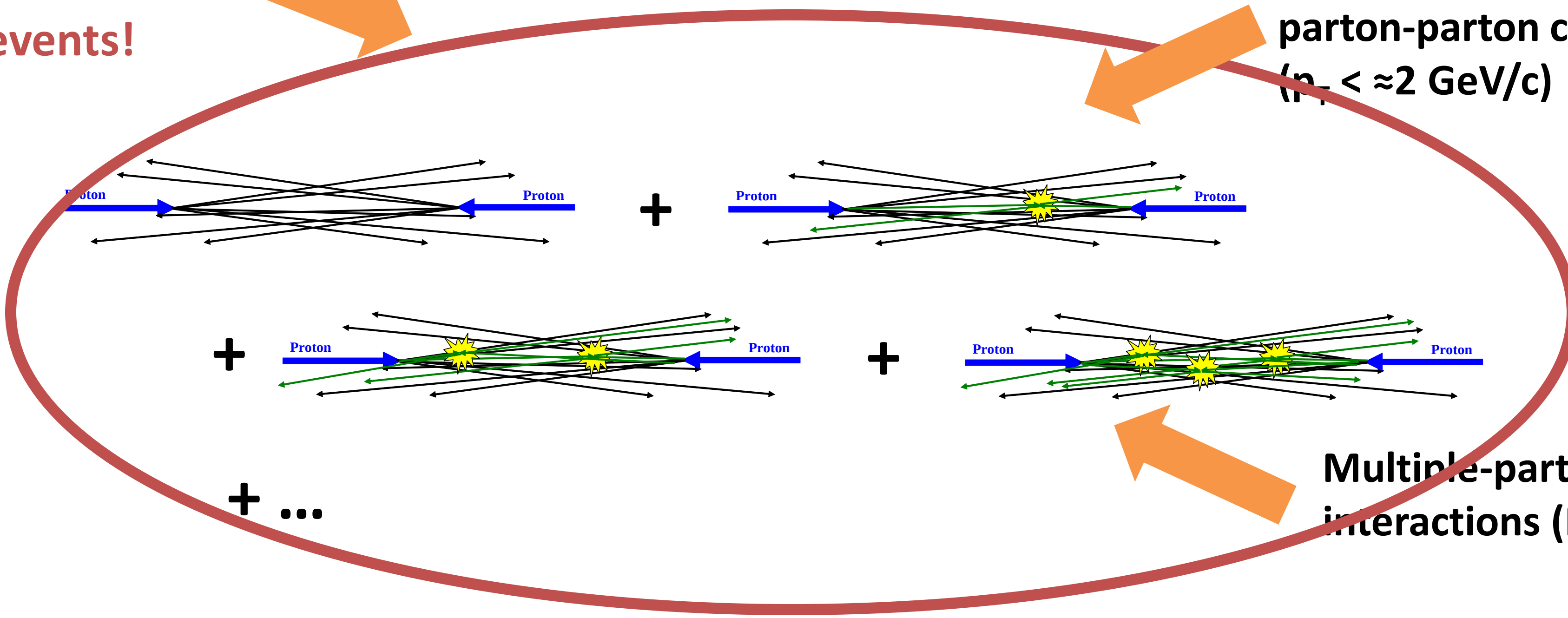


Occasionally one of the parton-parton collisions is hard (p_T > ≈2 GeV/c)

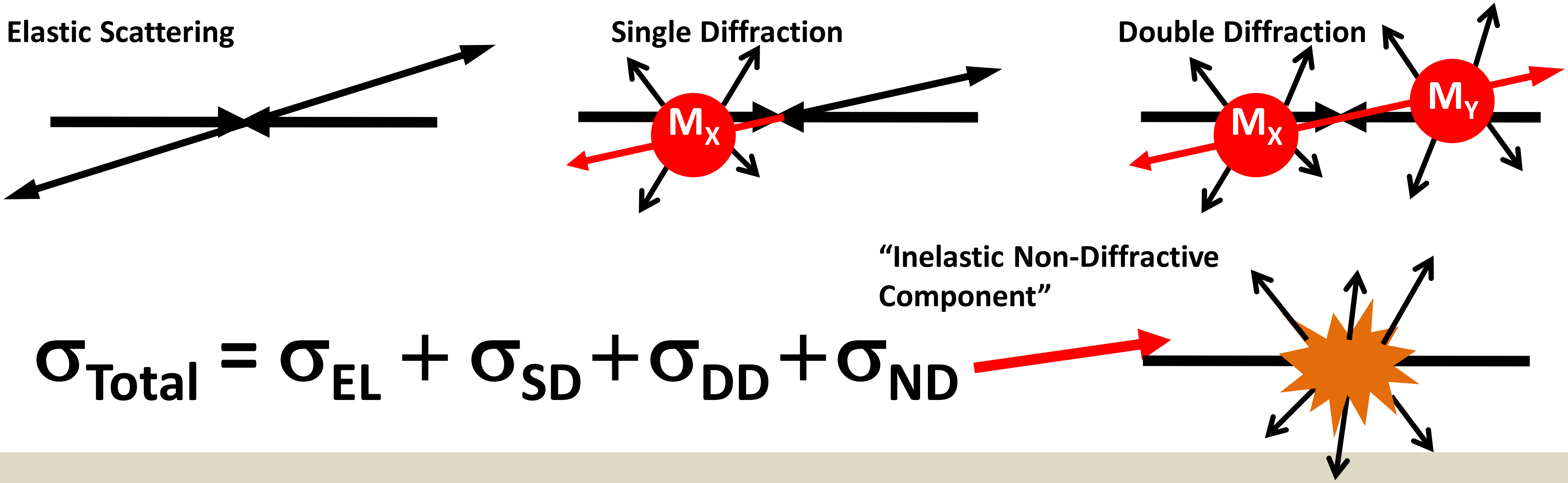
Majority of “min-bias” events!

“Semi-hard” parton-parton collision (p_T < ≈2 GeV/c)

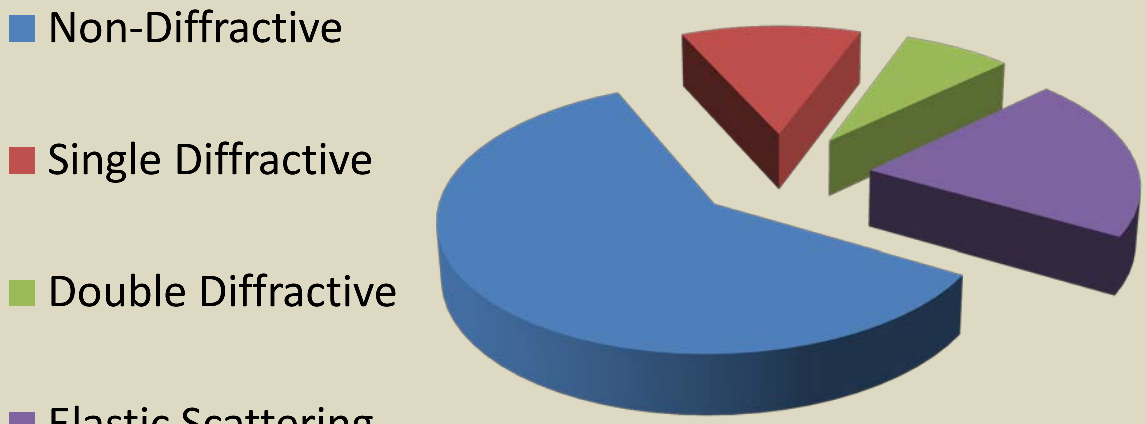


Multiple-parton interactions (MPI)

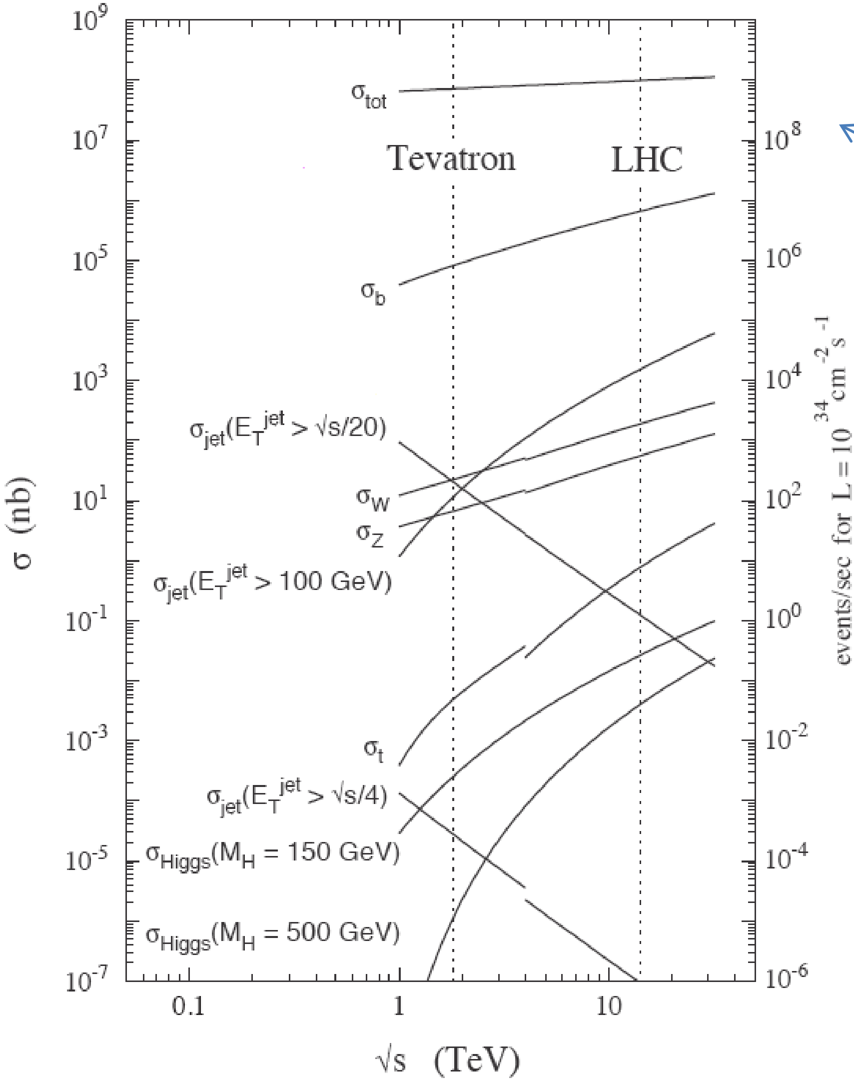
Proton-(anti)Proton Collisions



$$\sigma_{Total} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{ND}$$



Proton-(anti)Proton Collisions

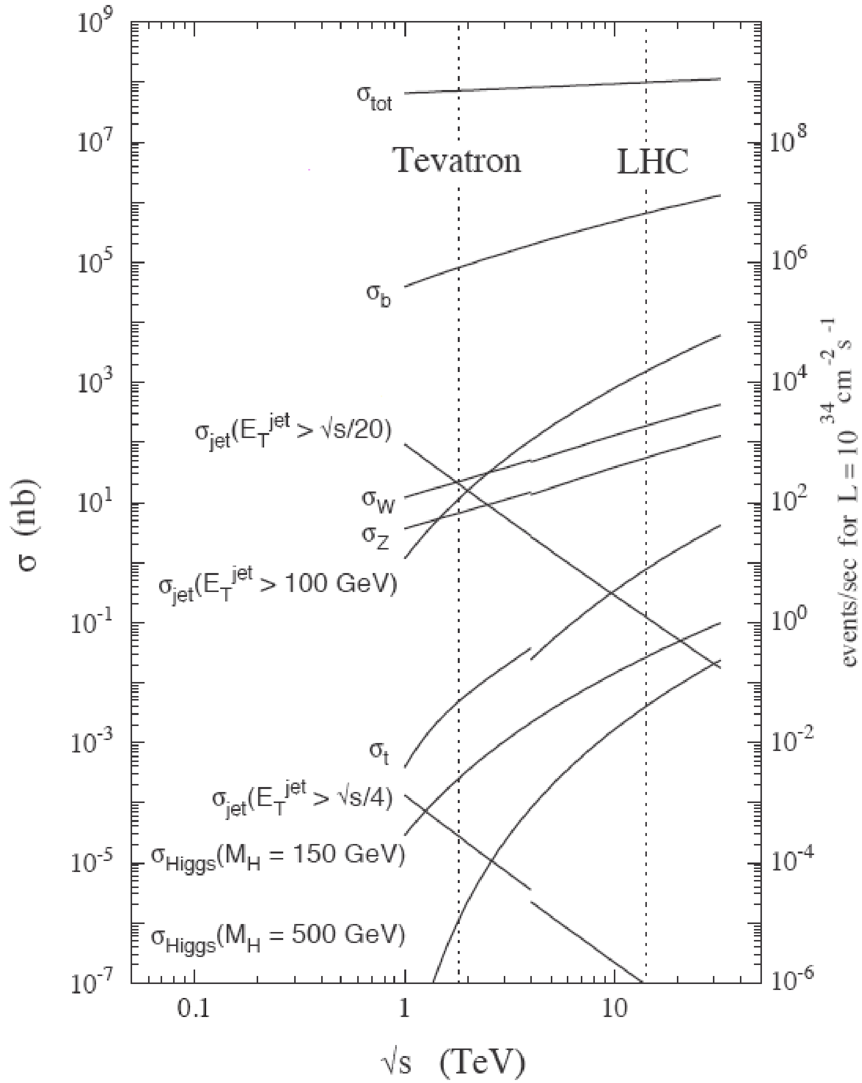


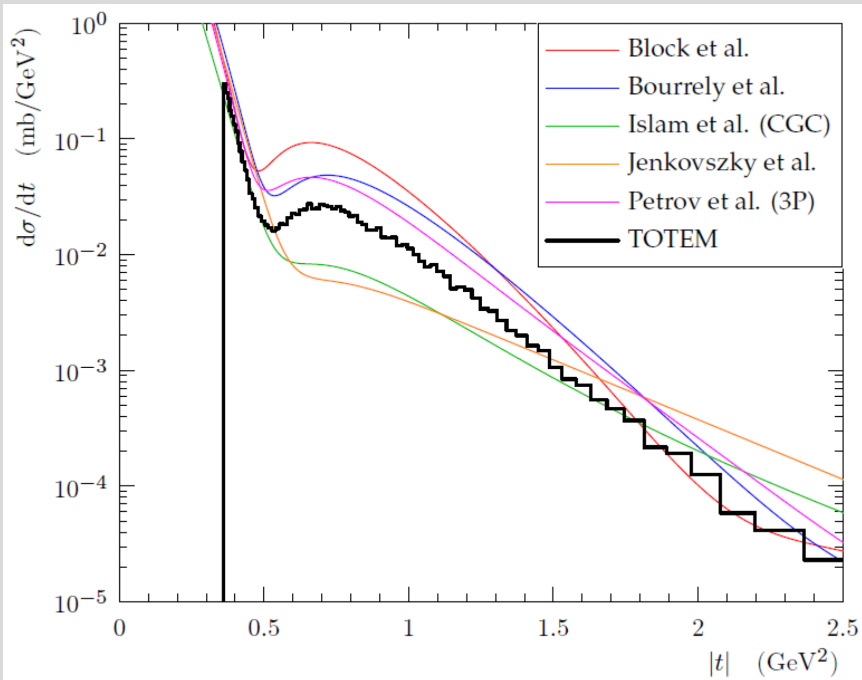
much harder to calculate this

than

this

Proton-(anti)Proton Collisions



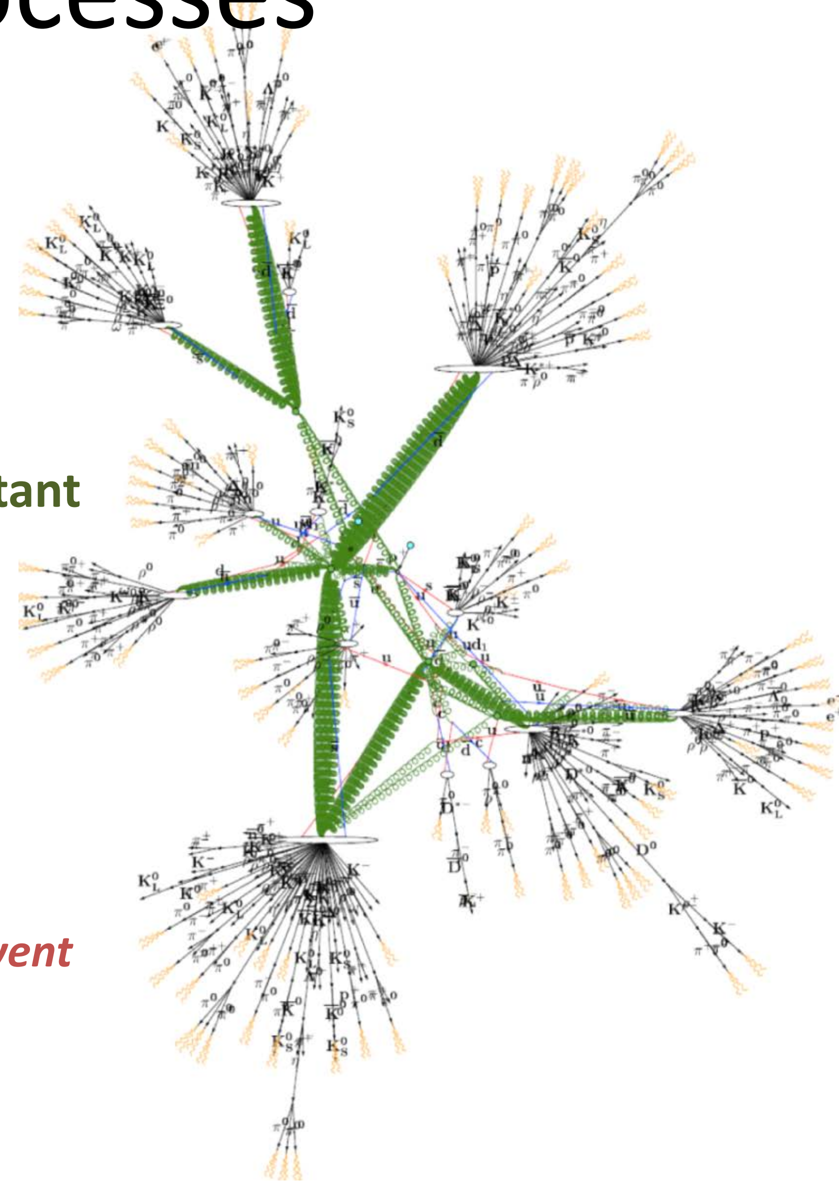


Comparison of recent TOTEM results on the total cross section with several theoretical models

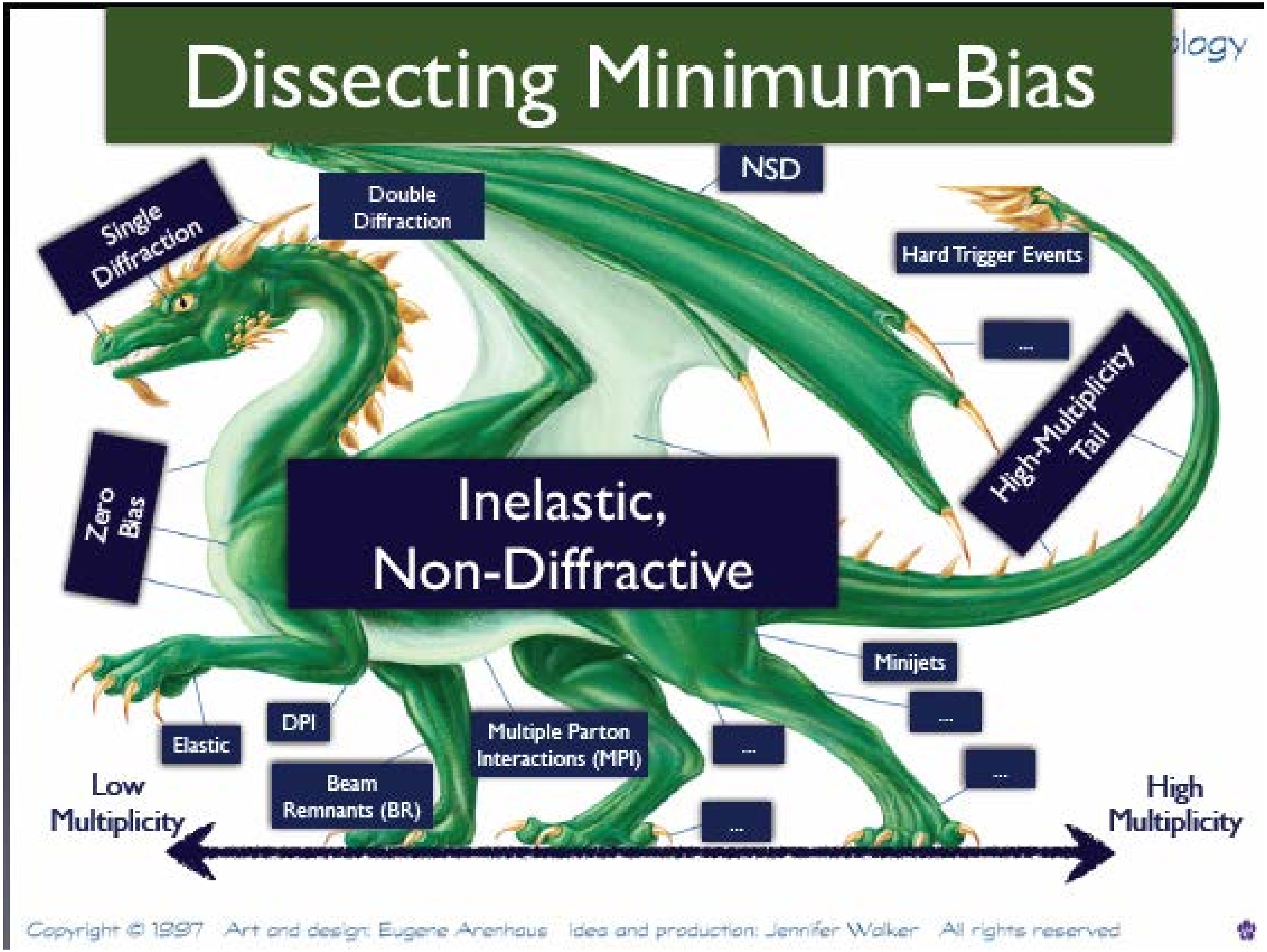
Soft Processes

It's complicated:

- data often ahead of phenomenology
- non-perturbative contributions important even for hard-scattering studies

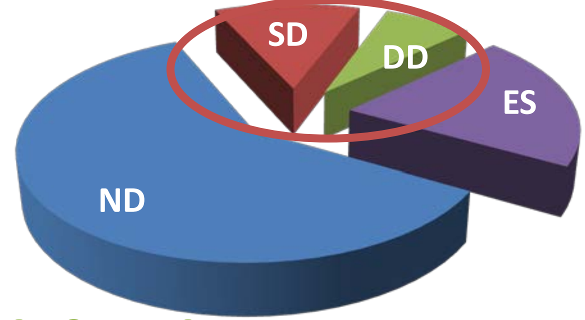


visualization of "minimum bias" event
in pp $\sqrt{s}$=7 TeV collisions
in PYTHIA8 with MCViz



slide from talk by Peter Scands at "MB & UE Workshop" at CERN, March 2010

Definitions: Diffraction



- **Diffractive reactions at hadron colliders are defined as reactions in *which no quantum numbers* are exchanged between colliding particles**

Identified by presence of:

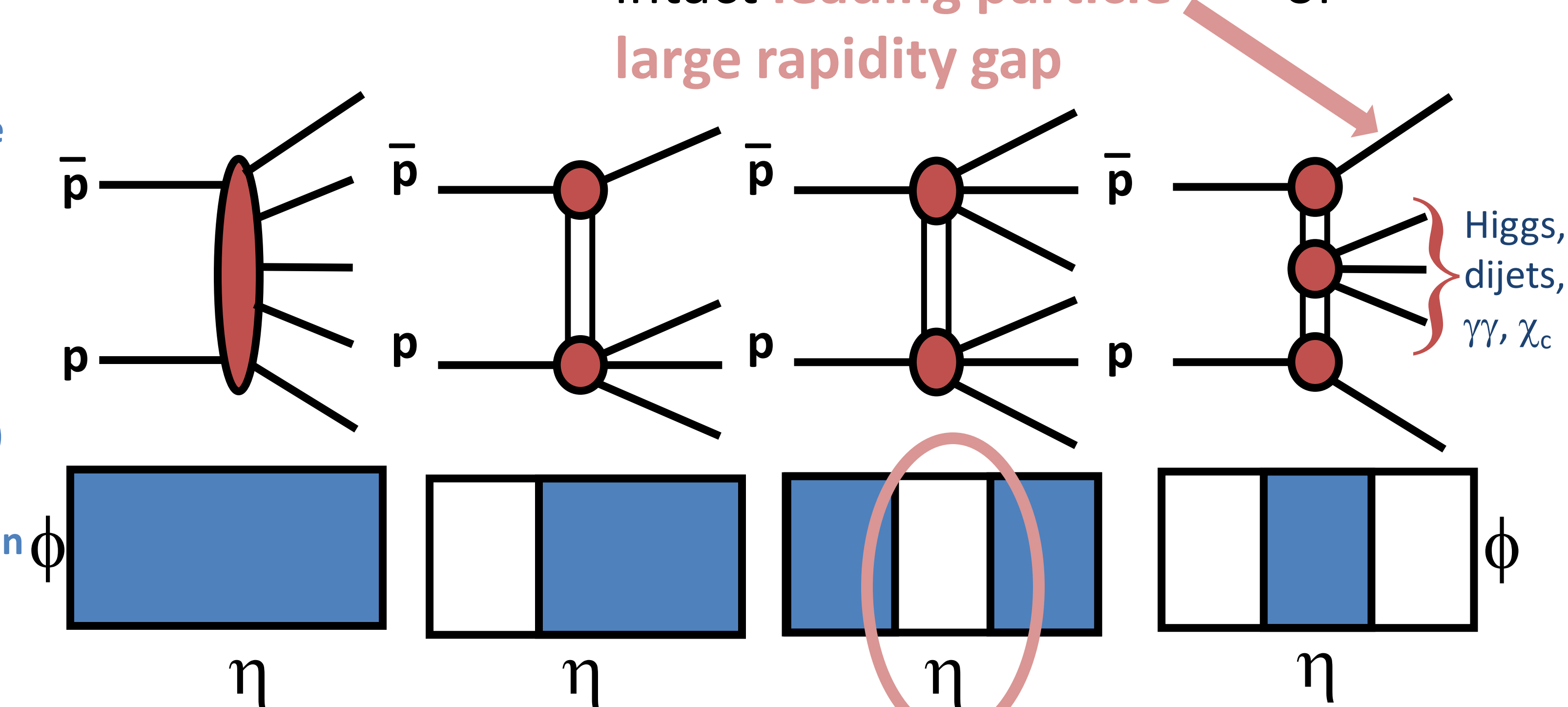
intact **leading particle** or **large rapidity gap**

Non- Diffractive (ND)

Single Diffraction (SD)

Double Diffraction (DD)

Double Pomeron Exchange (DPE)



Diffractive Processes

Hadronic processes can be characterized by an energy scale:

***soft processes* -** energy scale of the order of the hadron size (~ 1 fm)
pQCD is inadequate to describe these processes

hard processes – "hard" energy scale (> 1 GeV^2)
can use pQCD,
"factorization theorems" - can separate perturbative part
from non-perturbative

Diffractive processes mostly belong to "soft processes" , however
discovery of ***hard diffraction*** - jet production in ppbar collisions
with a leading proton in the final state (1988 UA8)

Hard diffractive processes allow to study diffraction in the pQCD framework.

At the Tevatron we study both soft and hard diffractive processes.

Diffraction: definitions

y - rapidity

η - pseudorapidity

$y = 1/2 \ln((E+p_z)/E-p_z))$

$\eta \equiv y|_{m=0} = -\ln \tan(\vartheta/2)$

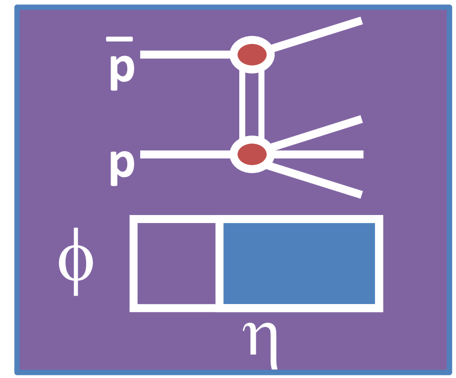
t - four-momentum transfer squared

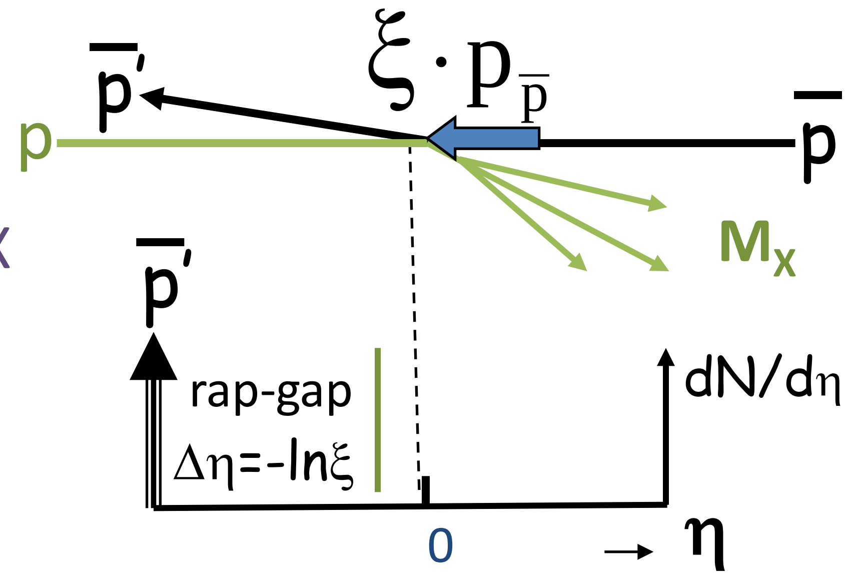
ξ - fractional momentum loss of pbar

M_X - mass of diffractive system X

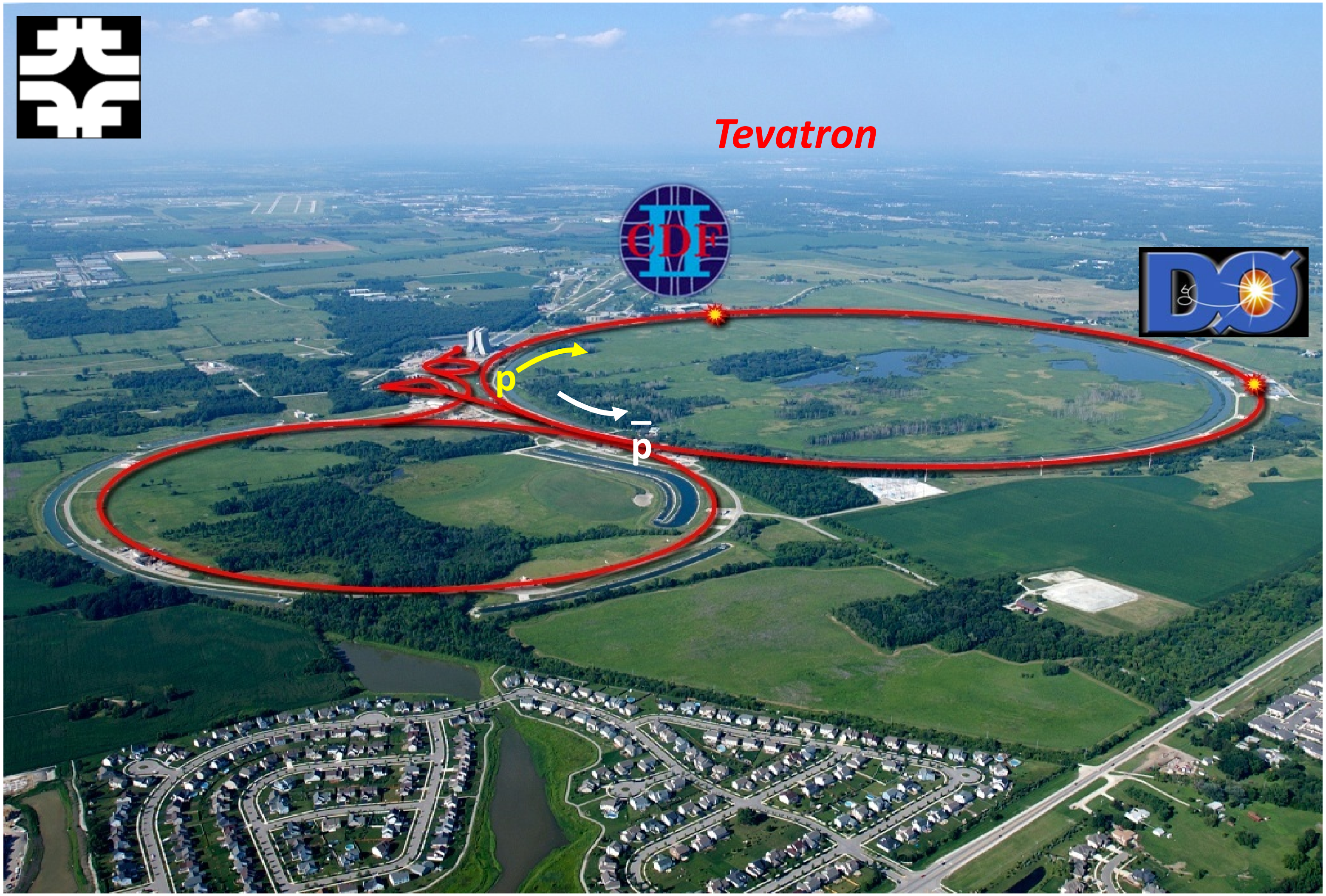
$\xi = M_X^2/s$

$\Delta\eta \approx \ln(s/M_X^2)$





Tevatron $\bar{p}p$ Collider at FNAL



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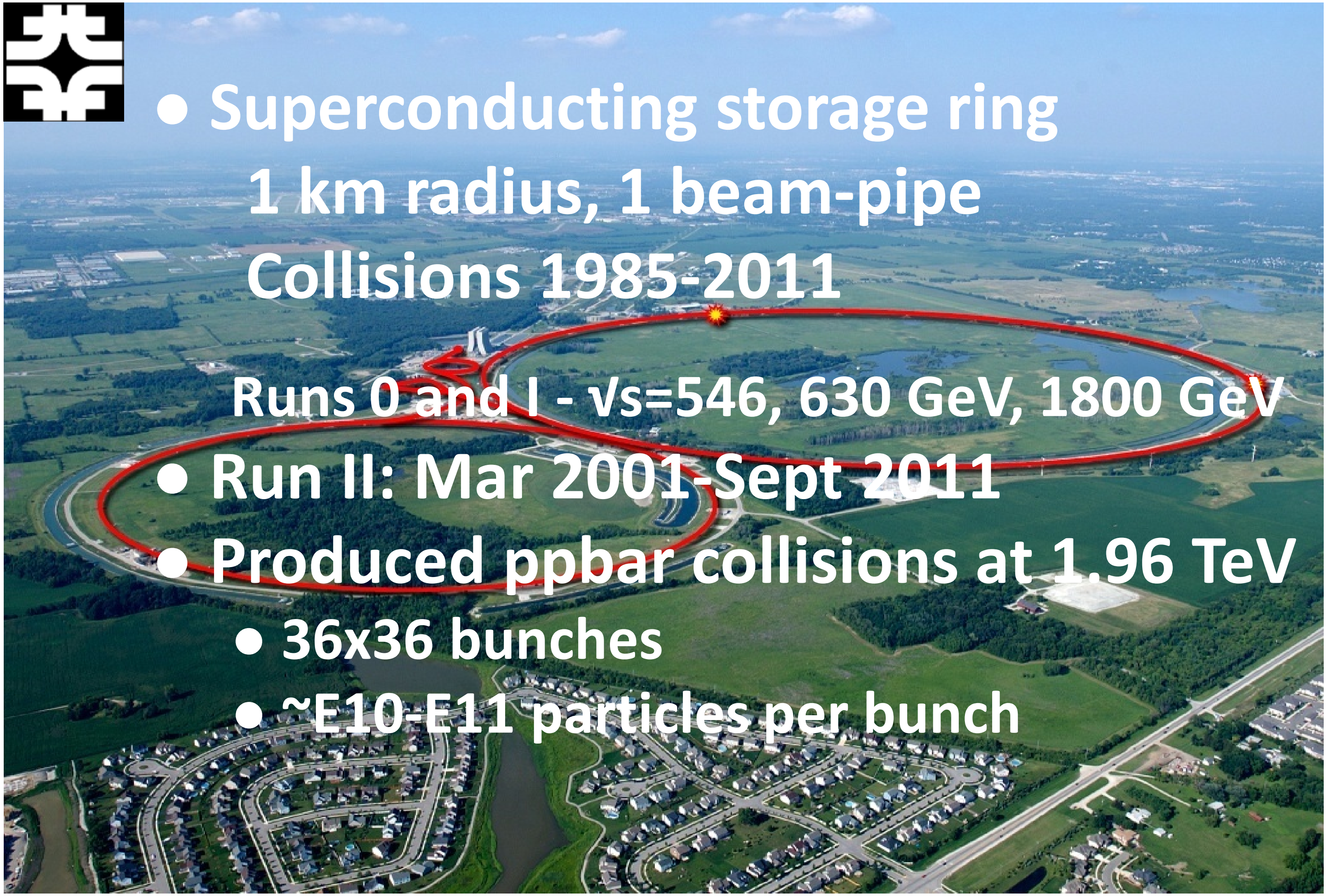
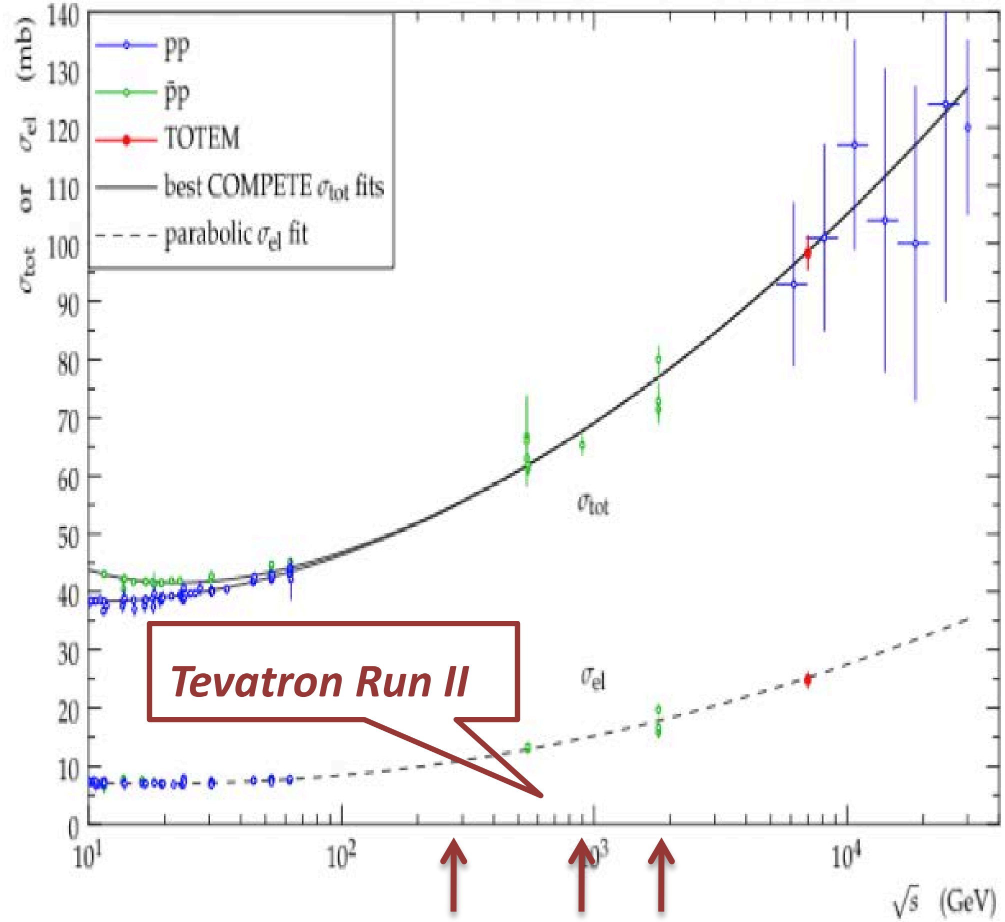


- Superconducting storage ring
  1 km radius, 1 beam-pipe
  Collisions 1985-2011
  Runs 0 and I - √s=546, 630 GeV, 1800 GeV
- Run II: Mar 2001-Sept 2011
- Produced ppbar collisions at 1.96 TeV
  - 36x36 bunches
  - ~E10-E11 particles per bunch

Tevatron energy scan

Study s-dependence of high cross-sections physics

...mostly non-pQCD



1.Study of MinBias events:

2.Study of Underlying Events

3.Gap-X Gap events

Tevatron energy scan - data

September 8 – 16, 2011

- 3x3 bunches
- Special trigger
- 1 interaction per crossing (no pile-up)

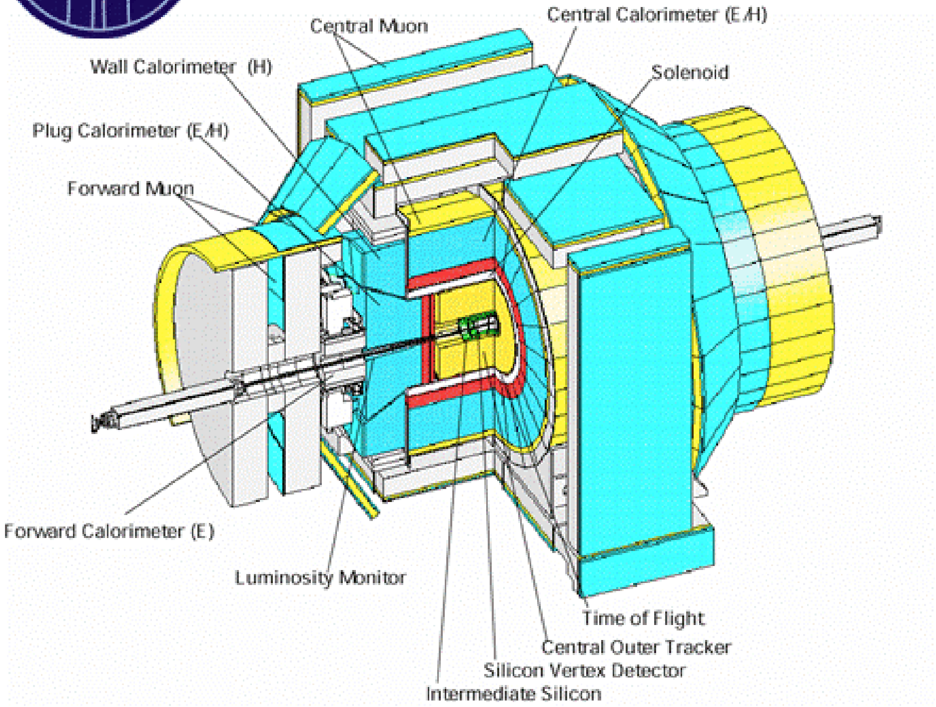
Total data taking time :

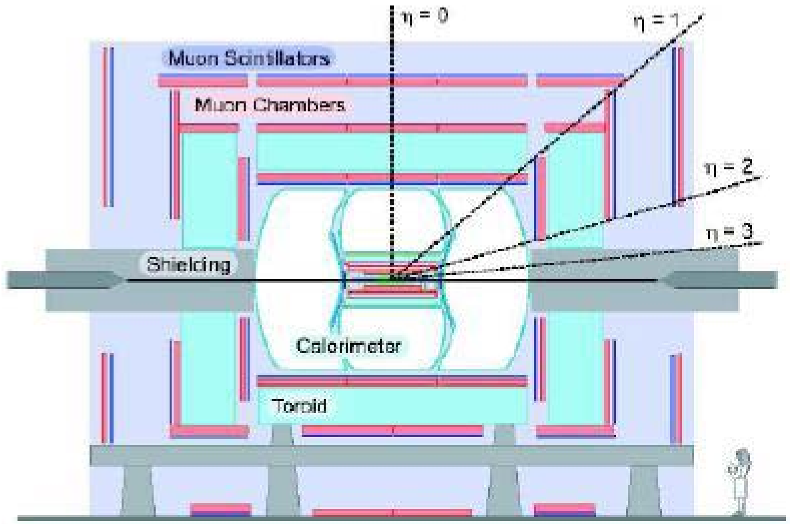
10 h at 300 GeV and 39 h at 900 GeV

$\sqrt{s}$	0-bias	Minbias	Gap-X-Gap	Jets	e,μ,ν	Total # events
300	1.89 M	12.1 M	9.2 M	8.3 K	352	23.2 M
900	8.0 M	54.3 M	21.8 M	550 K	16 K	84.7 M

CDF and DØ Detectors

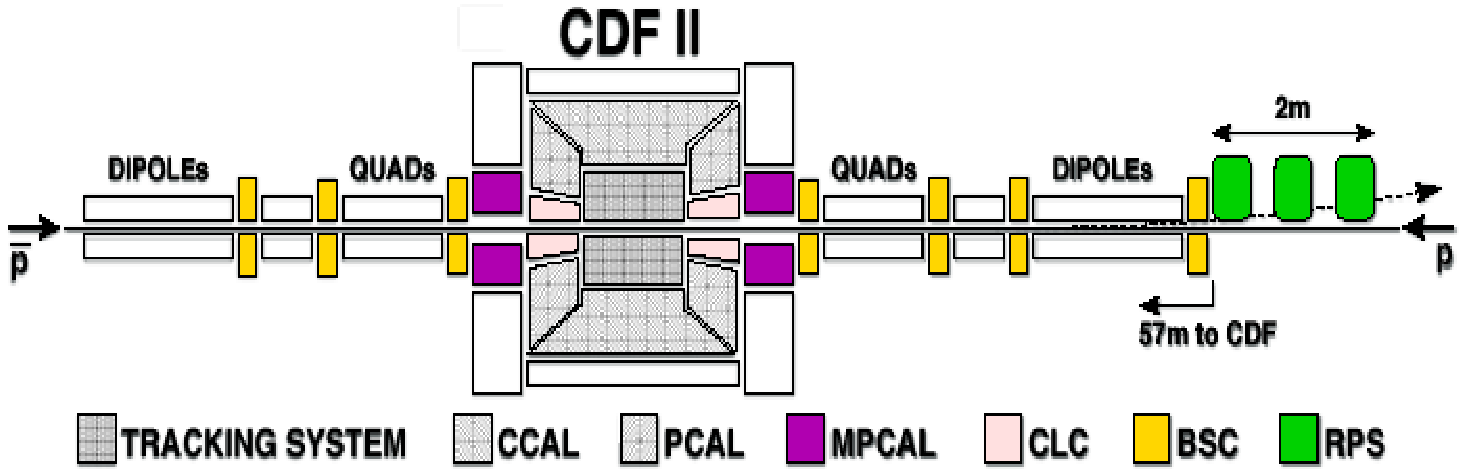
General purpose detectors





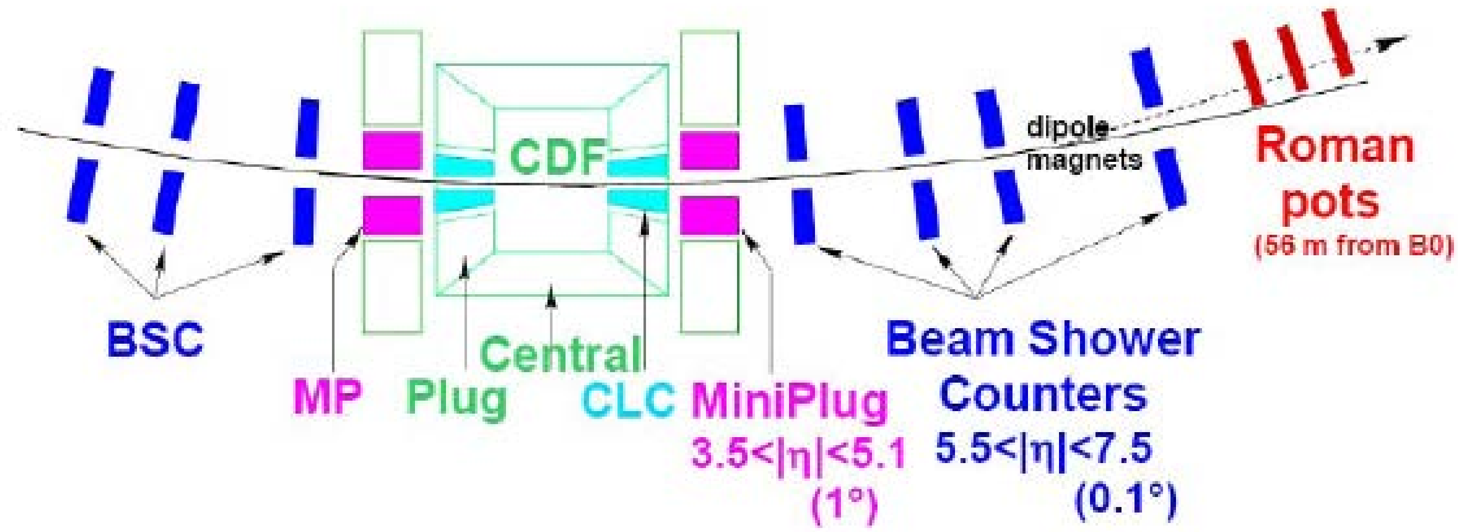
- ❑ Top performance (>85% data taking efficiency)
- ❑ ~10 fb^{-1} per experiment

CDF II Detectors



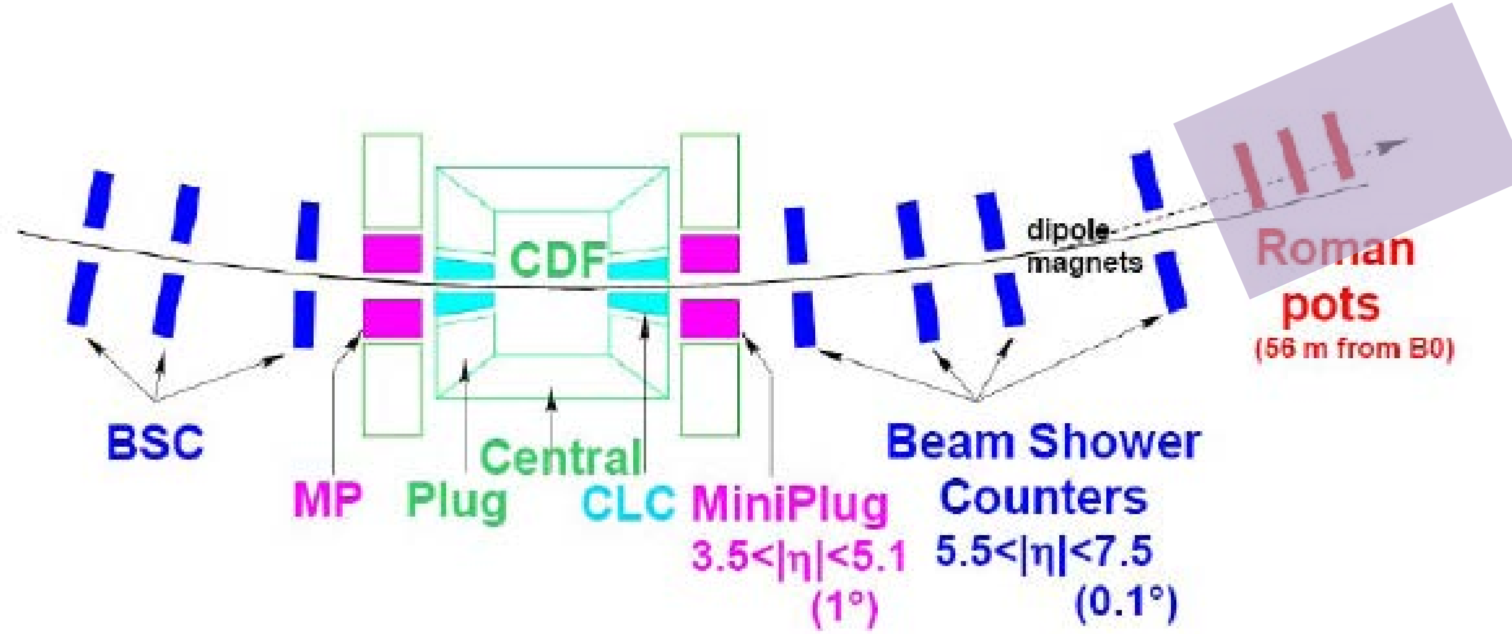
- Tracking – Tracking Detectors $|\eta| < 2.0$
- CCAL, PCAL – Calorimeters (15°(in φ)x0.1(in η)) $|\eta| < 3.6$
- RPS – Roman Pot Spectrometers $0.02 < \xi < 0.1$, $0 < |t| < 2\ GeV^2$
- BSC – Beam Shower Counters $5.4 < |\eta| < 7.4$
- MPCAL – MiniPlug Calorimeters $3.5 < |\eta| < 5.1$

Forward Detectors



Forward Detectors are crucial for diffractive studies

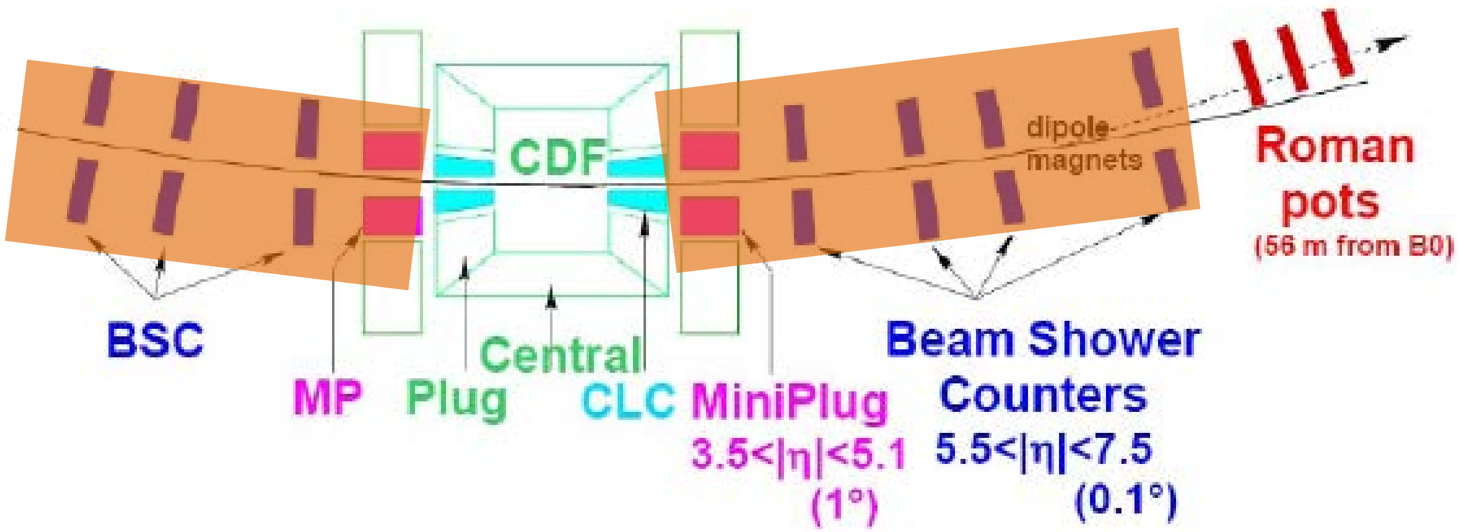
Forward Detectors



Forward Detectors are crucial for diffractive studies

use Roman Pots for antiproton tagging

Forward Detectors

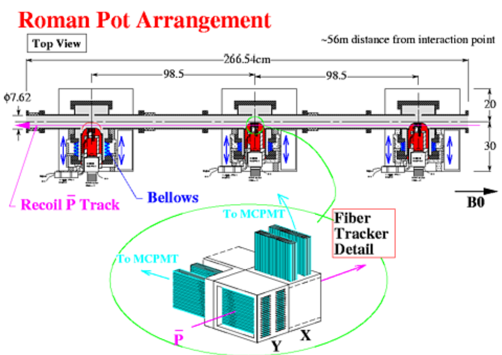


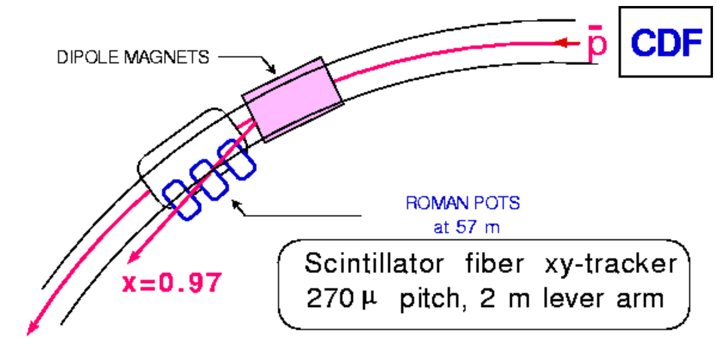
Forward Detectors are crucial for diffractive studies

use Miniplugs and BSCs for rapidity gaps

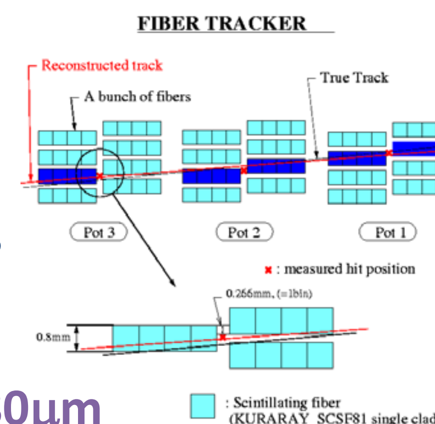
Forward Detectors at CDFII:
Roman Pot Spectrometers (RPS)

Fiber Tracker
- 3 stations
- 57 meters from IP

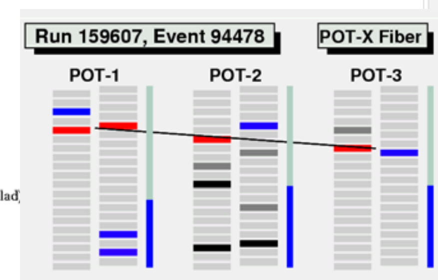


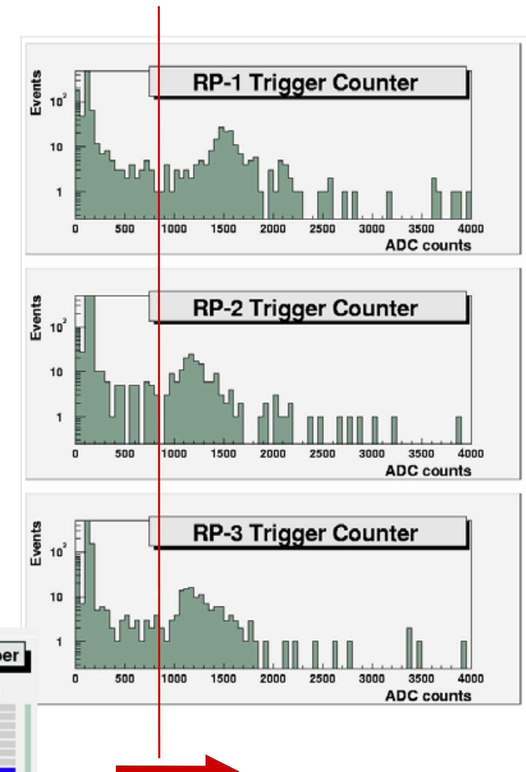


Acceptance: $0 < |t| < 2$, $0.03 < \xi < 0.1$



- 3 trigger counters
- 240 channels





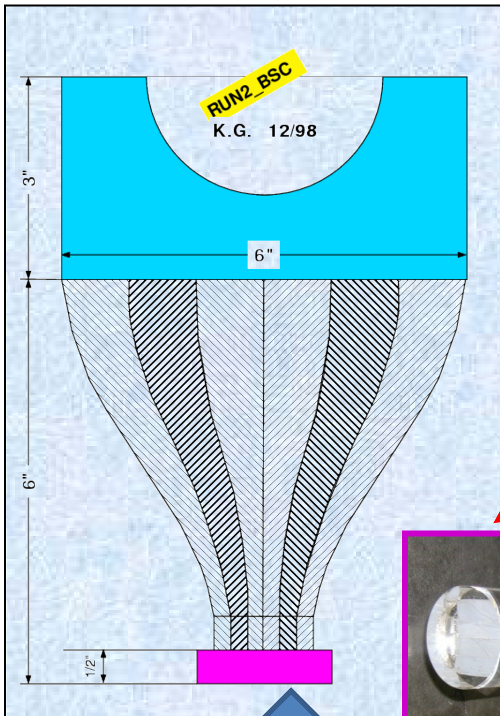
MIPs (>1000 counts)

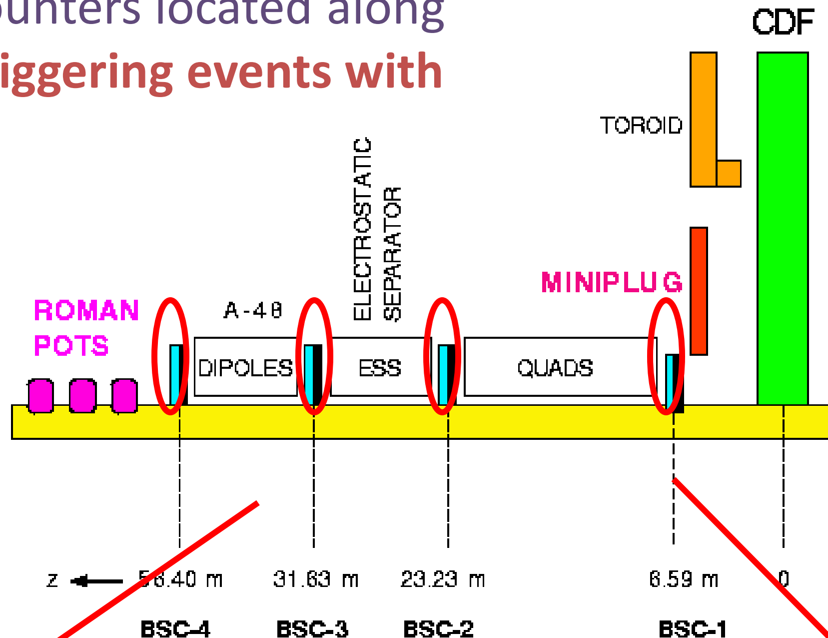
position resolution ±80μm
typical resolutions
in ξ $\delta\xi = \pm 0.001$; in t $\delta t = \pm 0.07 GeV^2$

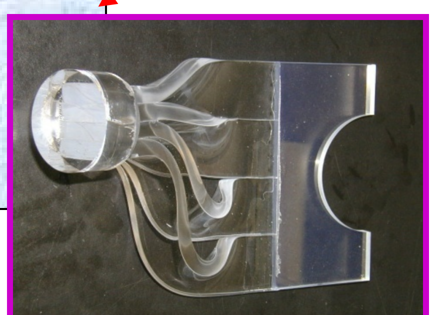
Forward Detectors at CDFII:

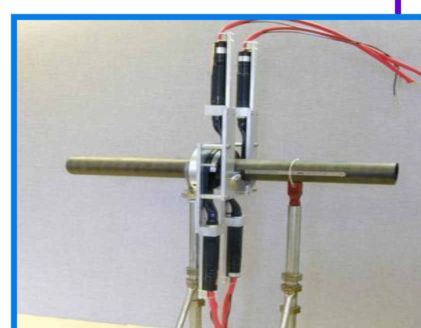
Beam Shower Counters (BSCs)

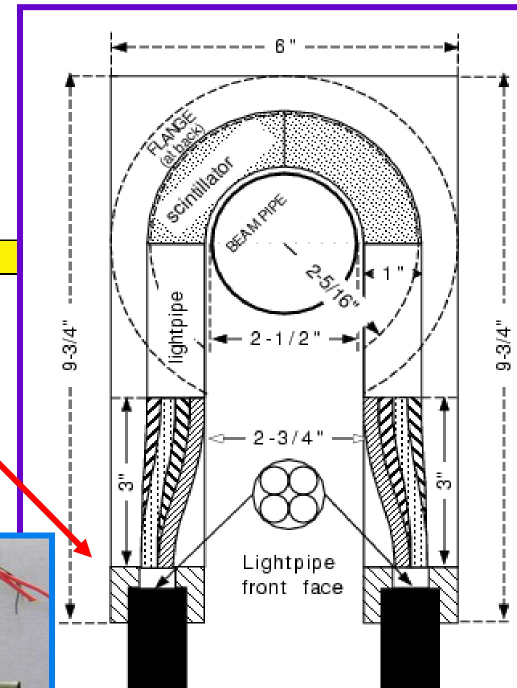
BSCs are scintillator counters located along beam pipe used for **triggering events with forward rapidity gaps**











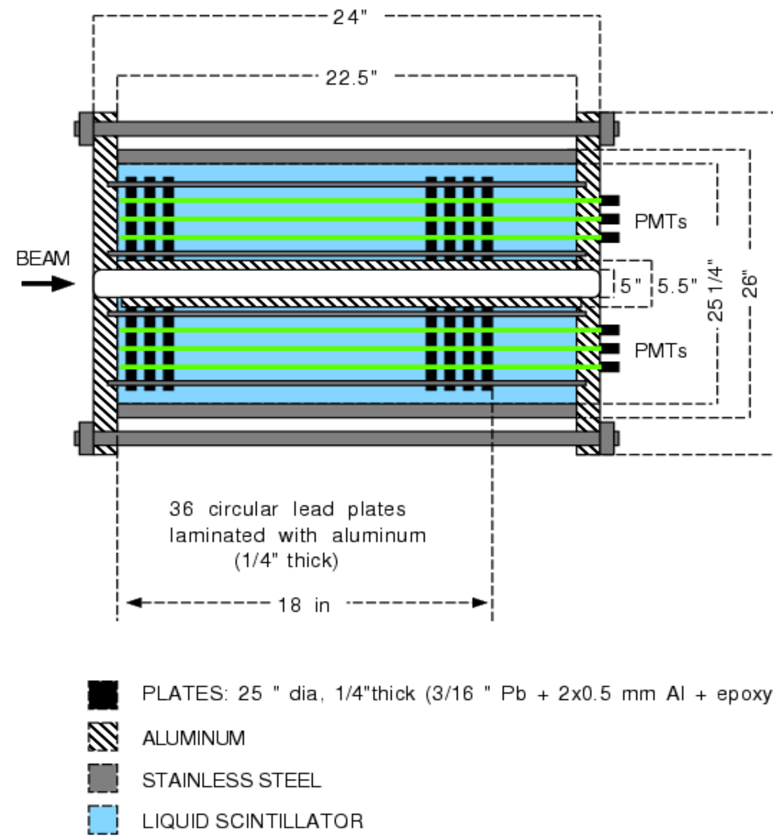
BSC-2,3,4

BSC-1

Forward Detectors at CDFII: MiniPlug Calorimeters (MPs)

*Nucl. Instrum. Meth. **A**518 (2004) 42*

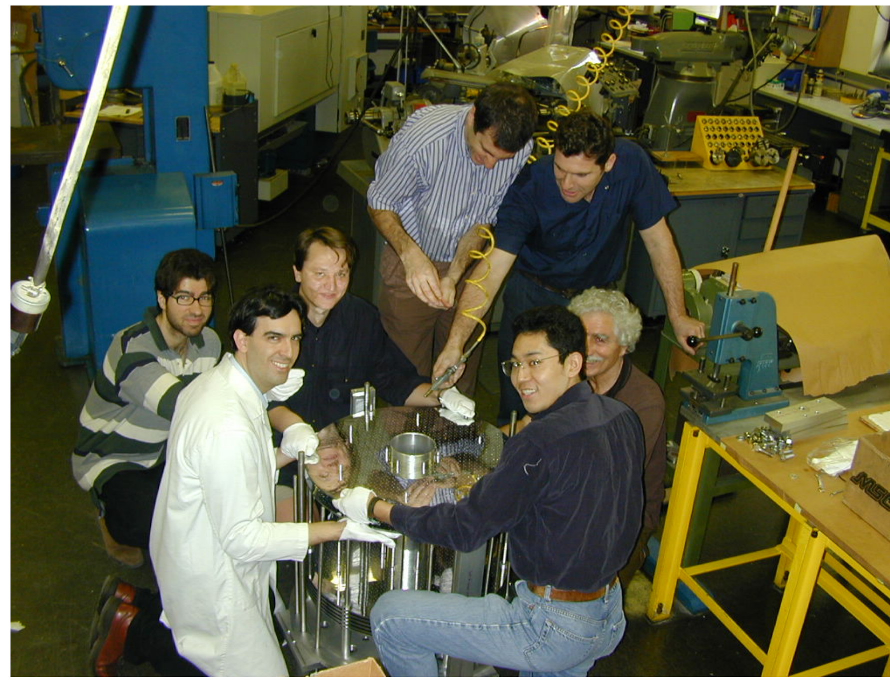
*Nucl. Instrum. Meth. **A**496 (2003) 333*



designed to **measure the energy and lateral position** of both electromagnetic and hadronic showers

“towerless” geometry – no dead regions

MiniPlug Calorimeters: Assembly



***Still** can design and build important detectors by rather small group!*

Methods

Results are mostly MC free

ξ variable can be determined two ways

- Determine ξ using Roman Pots tracking
- Also can determine ξ from E_T in calorimeters

important to have MiniPlugs ↗

$$\xi^{cal} = \sum_{towers} \frac{E_T}{\sqrt{s}} e^{-\eta}$$

Main challenge: multiple interactions spoiling diffractive signatures

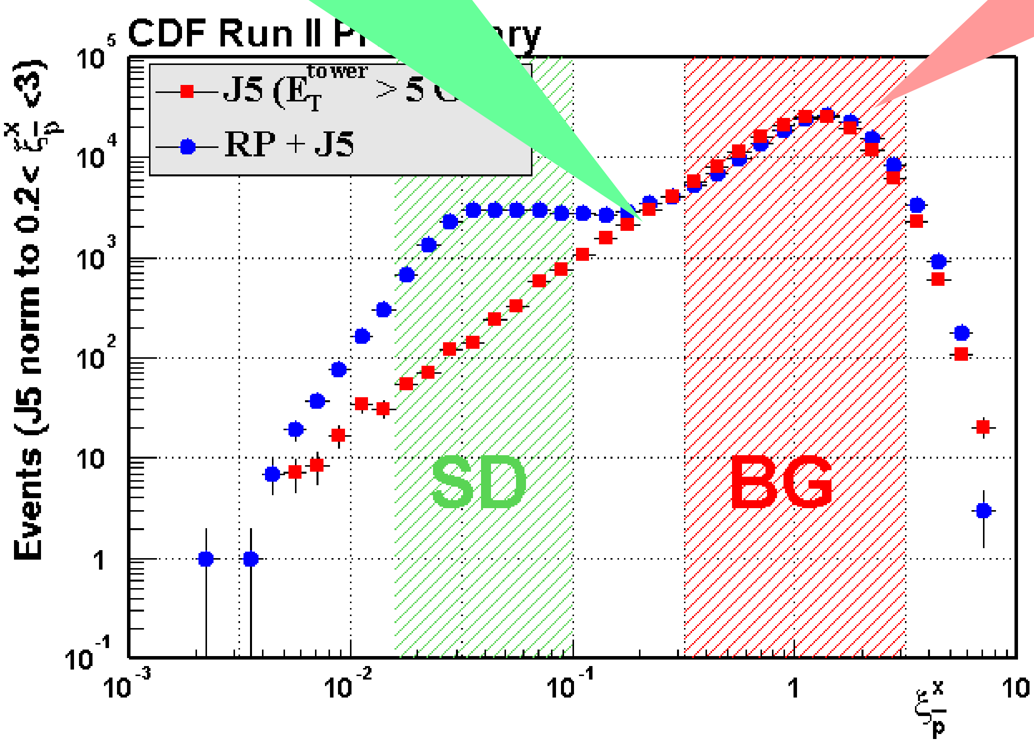
use $\xi^{cal} < 0.1$ to reject overlap events → non-diffractive contributions

Methods:
ξ distributions

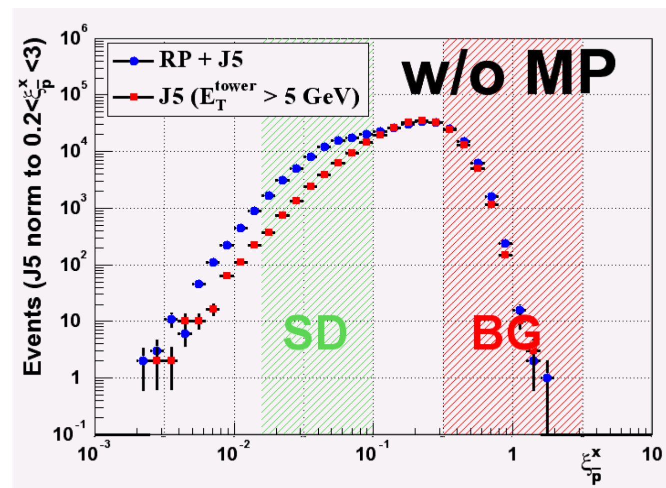
Flat part at ξ < 0.1

$$\frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \rightarrow \frac{d\sigma}{d(\log\xi)} = const$$

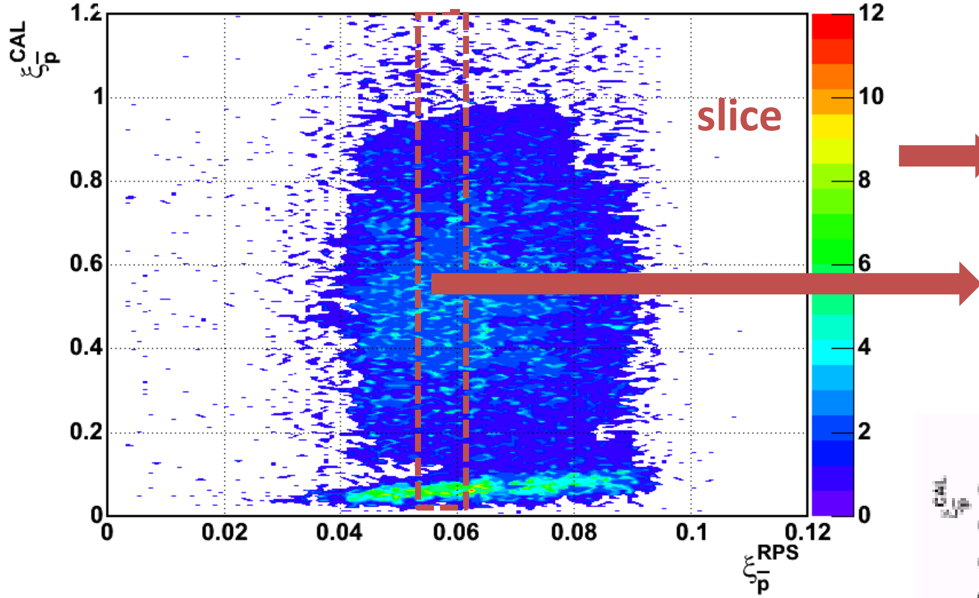
Peak at ξ= 1
-overlap events from
multiple interactions

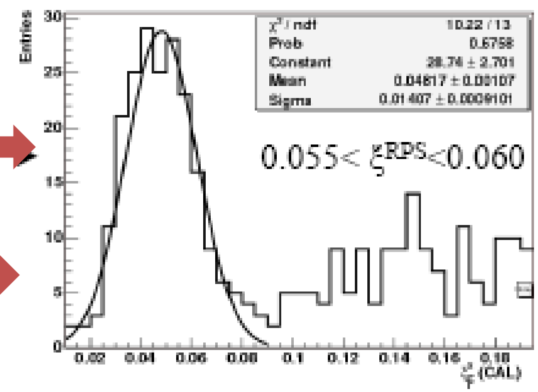


MP calorimeters allow to separate diffractive and non-diffractive parts

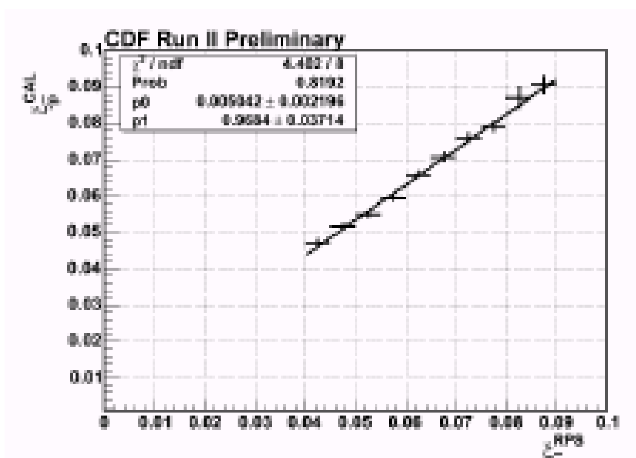


Methods and Challenges:
ξ with RPS and calorimeter info



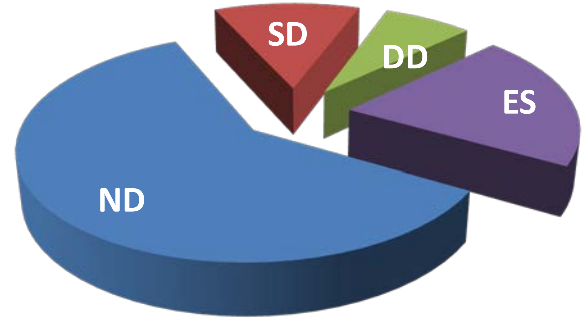


pile-up events



calibration of ξ from calorimeter with ξ from RPS

Elastic Scattering



- The particles after scattering are the same as the incident particles
  $\xi=\Delta p/p=0$ for elastic events; $t = -(p_i-p_f)^2$

- The cross section can be written as:

$$\frac{d\sigma/dt}{(d\sigma/dt)|_{t=o}} = e^{bt} \cong 1-b(p\theta)^2$$

$\sqrt{s}$	Exp.	t-range [GeV^2]	B[GeV^{-2}], ρ
546 GeV	CDF	$0.025 \div 0.08$	$B = 15.28 \pm 0.58$
1.8 TeV	CDF	$0.04 \div 0.29$	$B = 16.98 \pm 0.25$
	E710	$0.034 \div 0.65$	$B = 16.3 \pm 0.3$
		$0.001 \div 0.14$	$B = 16.99 \pm 0.25$
			$\rho = 0.140 \pm 0.069$
	E811	$0.002 \div 0.035$	using $\langle B \rangle_{\mathrm{CDF,E710}}$
			$\rho = 0.132 \pm 0.056$
1.96 TeV	DØ	$0.9 \div 1.35$	–

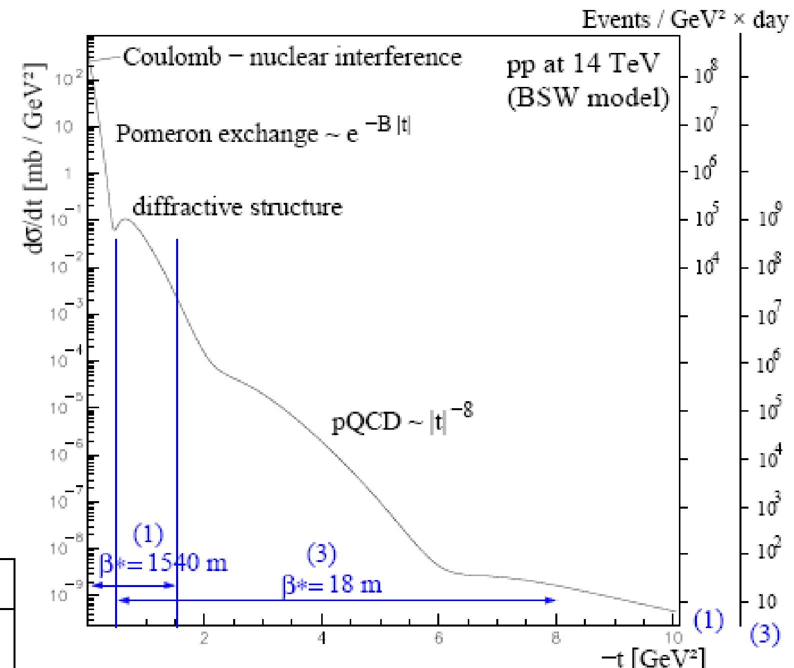
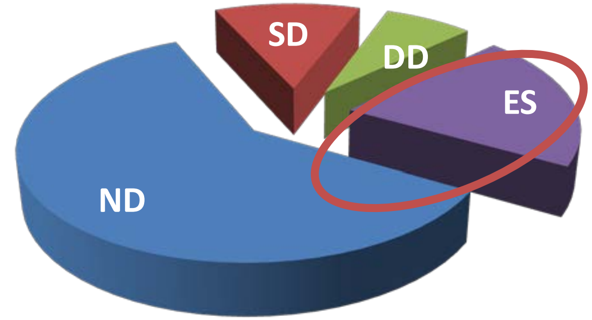


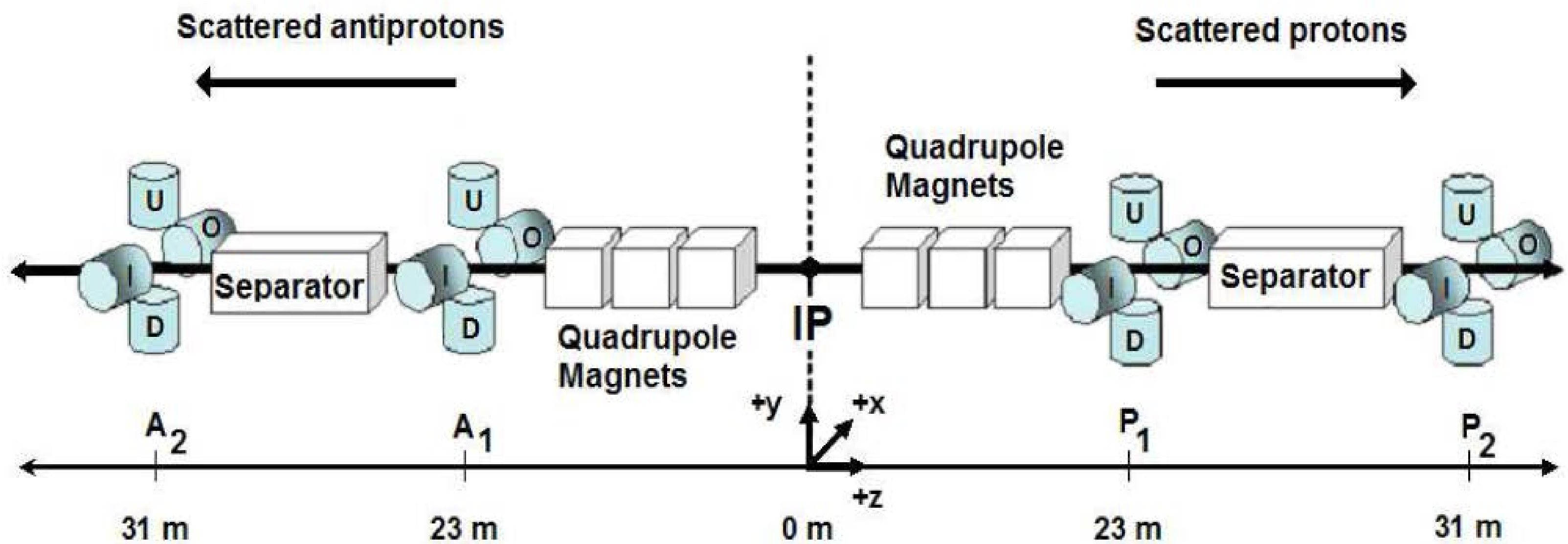
Fig. fromTOTEM publications

Elastic Scattering at $\sqrt{s}$=1.96



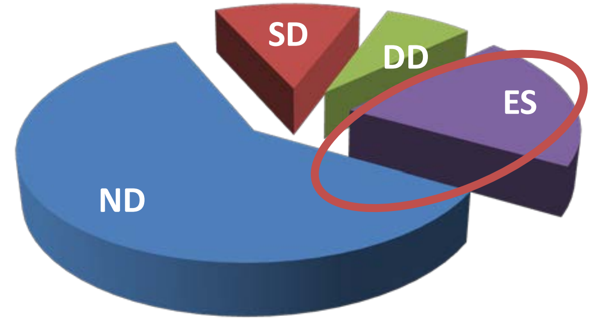
Forward Proton Spectrometer

Phys. Rev. D 86, 012009 (2012)



- ❑There are eight quadrupole spectrometers (Up, Down, In, Out) on the outgoing proton (P) and anti-proton (A) sides each comprised of two detectors (1, 2)
- ❑Use Tevatron lattice and scintillating fiber hits to reconstruct ξ and |t| of scattered protons (anti-protons)
- ❑The acceptance for |t|>|tmin| where t_{min} is a function of pot position: for standard operating conditions |t| > 0.8 GeV^2

Elastic Scattering at $\sqrt{s}$=1.96



Phys. Rev. D 86, 012009 (2012)

- In 2005 DØ proposed a store with special optics to maximize the |t| acceptance of the FPD

- In February 2006, the accelerator was run with the injection tune, β* =1.6m (instead of nominal 0.35 m)

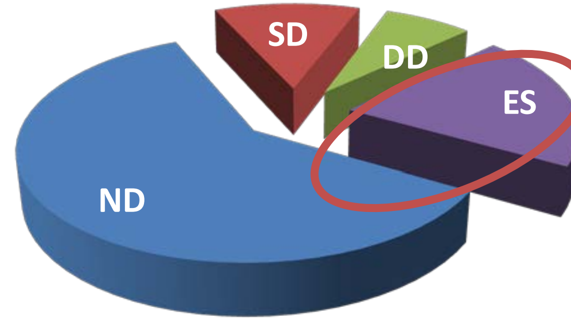
- Only 1 proton and 1 anti-proton bunch were injected

- Separators OFF (no worries about parasitic collisions with only one bunch)

- Integrated Luminosity (**30 ±4 nb-1**) was determined by comparing the number of jets from Run IIA measurements with the number in the Large β*store

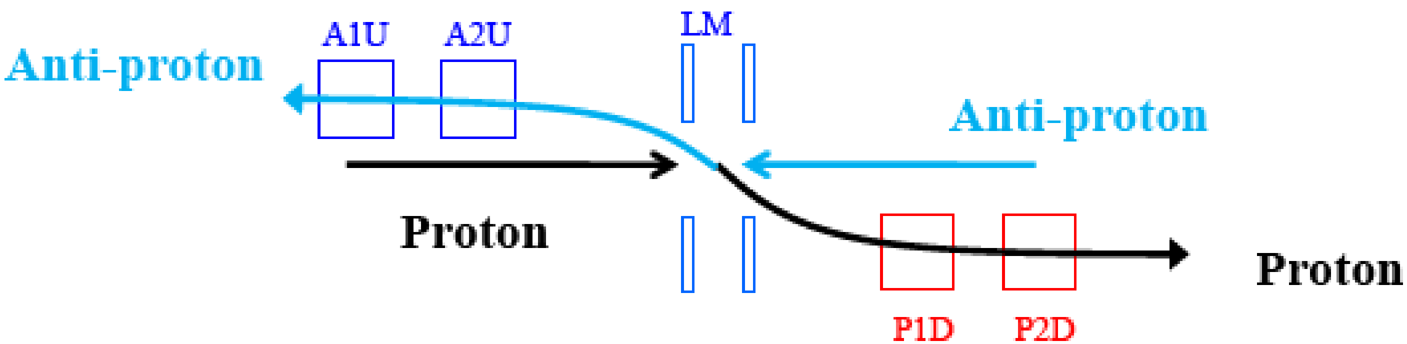
- A total of 20 million events were recorded with a special FPD trigger list

Elastic Scattering at $\sqrt{s}$=1.96



Phys. Rev. D 86, 012009 (2012)

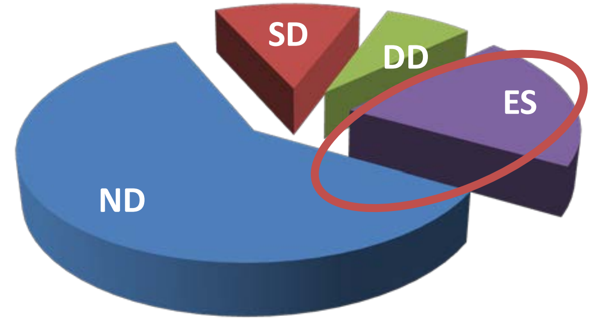
Elastic events have tracks in diagonally opposite spectrometers

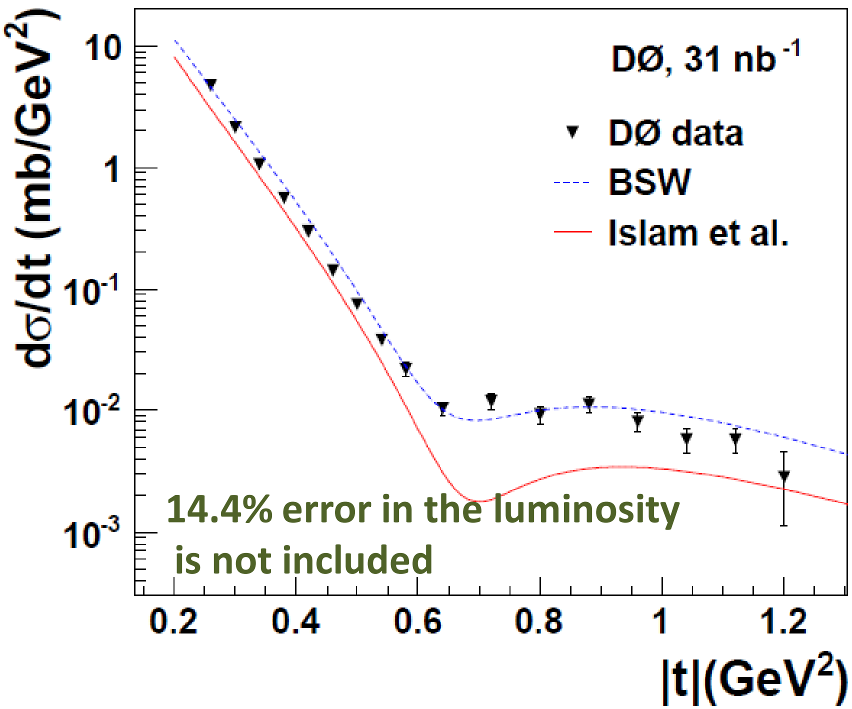


Momentum dispersion in horizontal plane results in more halo (beam background) in the IN/OUT detectors, so concentrate on vertical plane AU-PD and AD-PU to maximize |t| acceptance while minimizing background

AU-PD combination has the best |t| acceptance

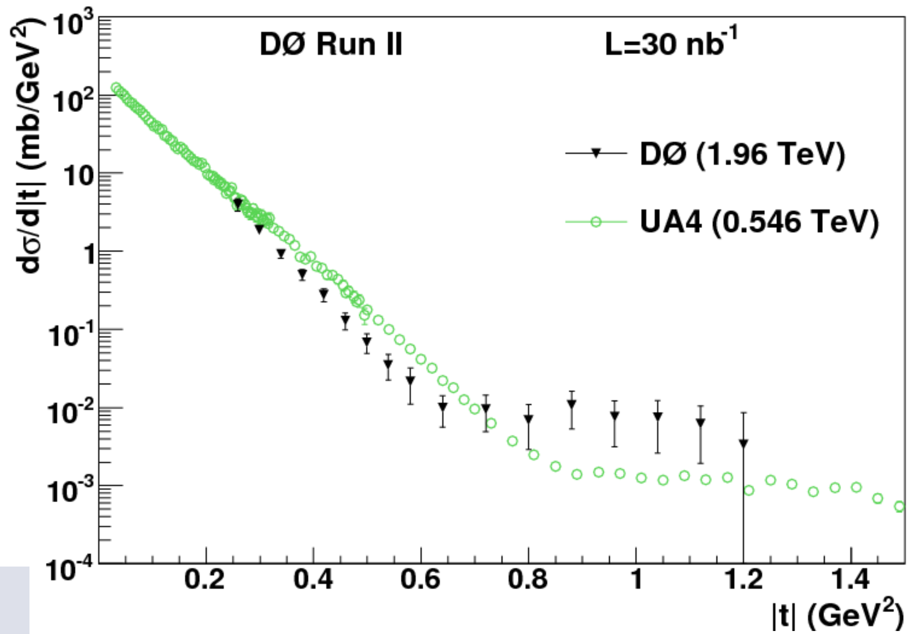
Elastic Scattering at √s=1.96





Phys. Rev. D 86, 012009 (2012)

Comparison with UA4



Fit $Ae^{-b|t|}$ yields slope **b**

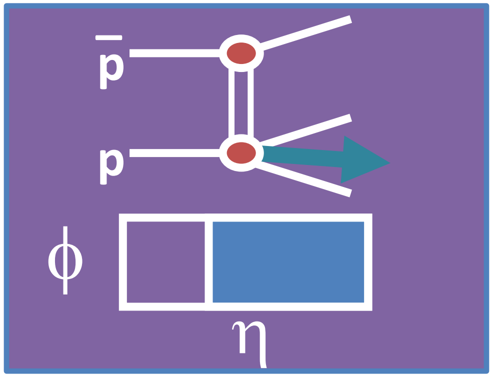
$$b = 16.86 \pm 0.10\ (\text{stat}) \pm 0.20\ (\text{syst})\ \text{GeV}^{-2}$$

Syst. error dominated by trigger eff. correction

Second biggest uncertainty- alignment =±0.3GeV^2

Slope steeper and slope change earlier for higher √s (shrinkage)

Hard Single Diffraction



Diffractive signature:

- large rapidity gap
- intact pbar detected in RPS

Can study diffractive production of high p_T objects:

jets, W, J/Ψ, b

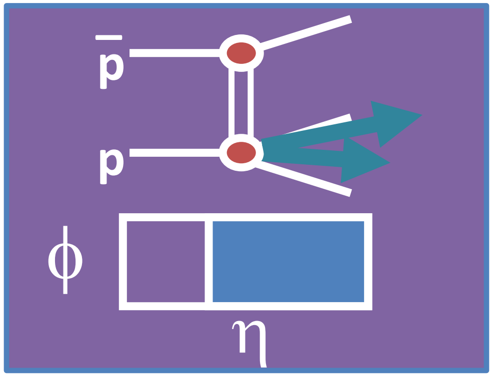
different insight into the nature of Pomeron

Method: measure ratio of diffractive to non-diffractive production

Diffractive Structure Function

Diffractive dijet cross section

$$\sigma(\bar{p}p \to \bar{p}X) \approx F_{jj} \otimes F^{D}_{jj} \otimes \hat{\sigma}(ab \to jj)$$



Study the diffractive structure function $F^{D}_{jj} = F^{D}_{jj}(x, Q^2, t, \xi)$

Experimentally determine diffractive structure function F^{D}_{jj}

at LO $$R_{\frac{SD}{ND}}(x,\xi) = \frac{\sigma(SD_{jj})}{\sigma(ND_{jj})} = \frac{F^{D}_{jj}(x, Q^2, \xi)}{F_{jj}(x, Q^2)}$$

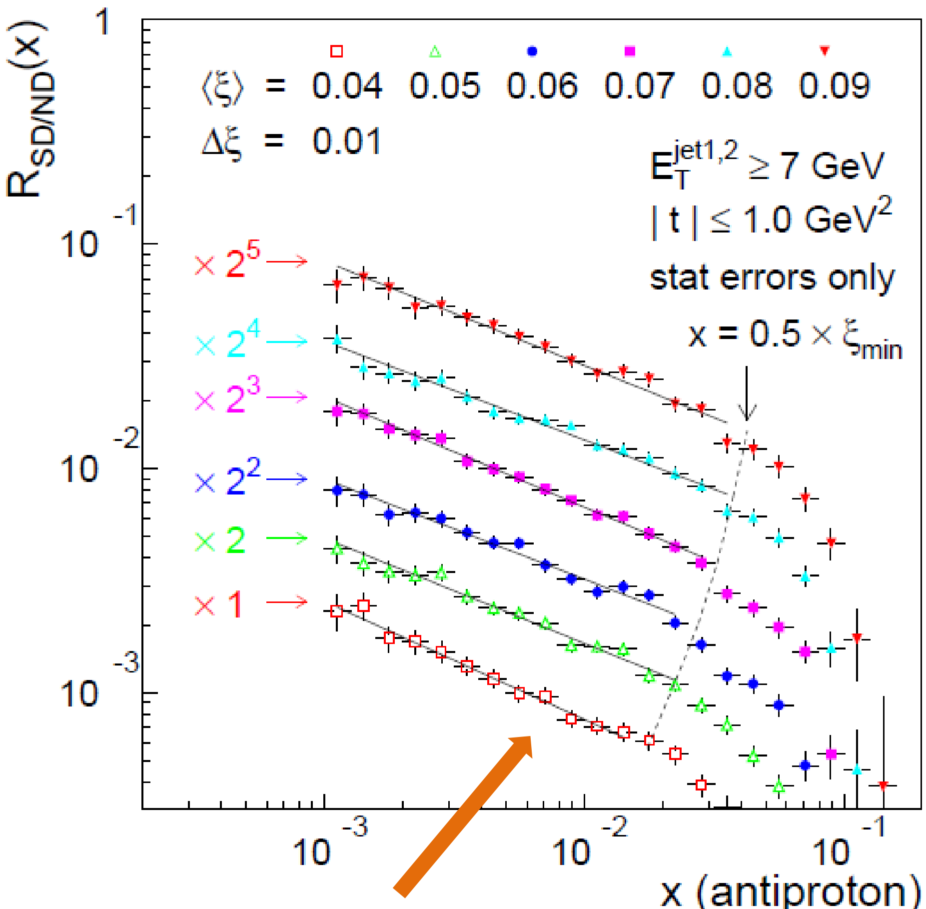
Data known PDF

Will factorization hold at the Tevatron?

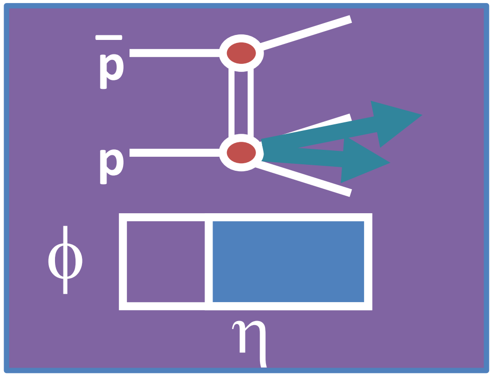
Diffractive Structure Function
Diffractive dijets

PRL 84, 5043 (2000)

$\sqrt{s}$= 1.8TeV



no ξ dependence



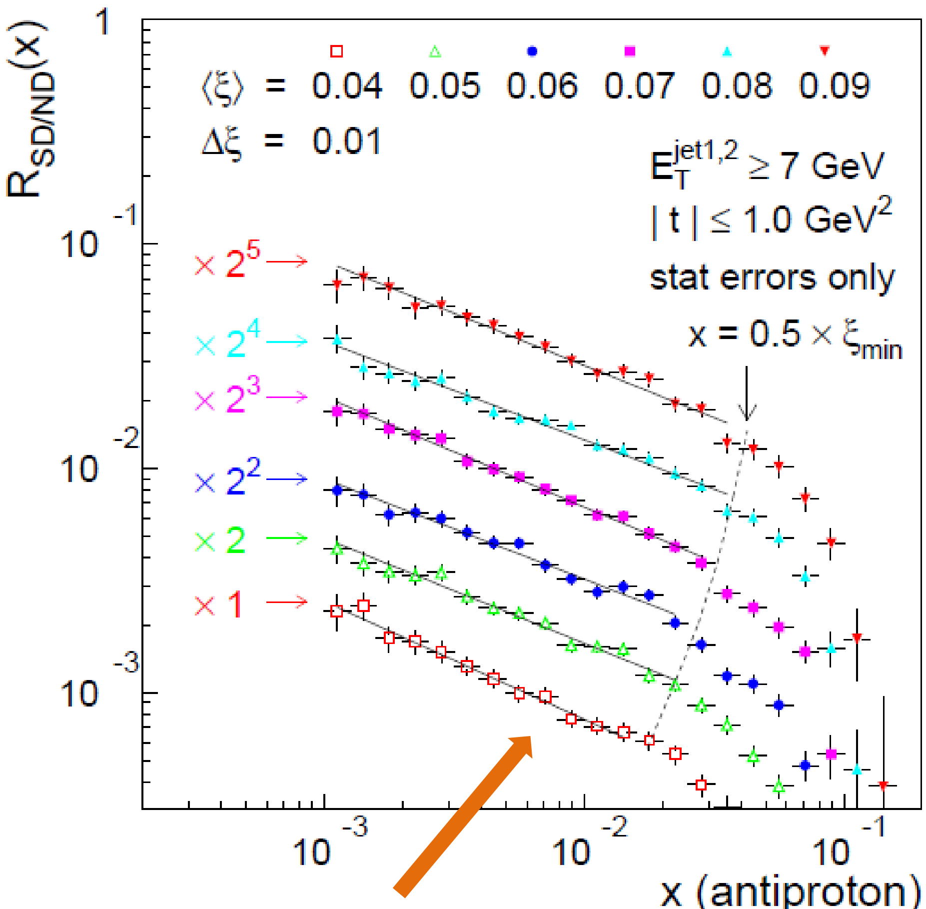
Diffractive signature:

intact pbar detected in RPS

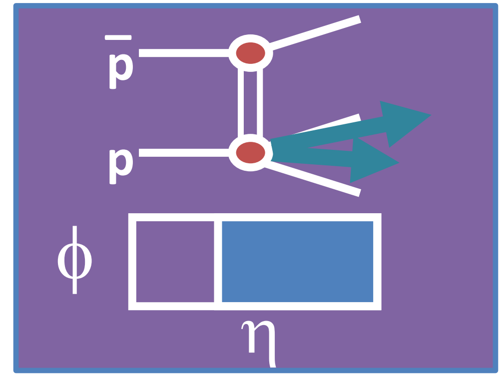
Diffractive Structure Function
Diffractive dijets

PRL 84, 5043 (2000)

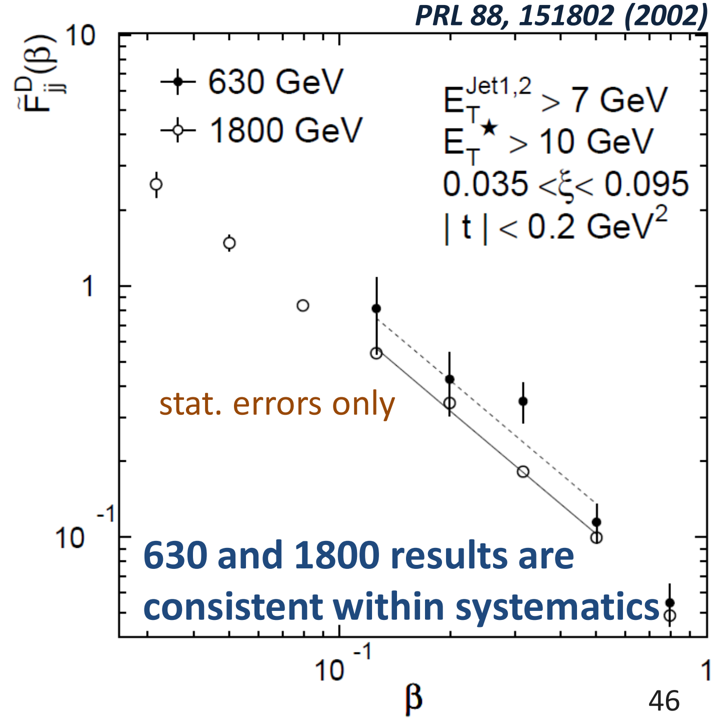
$\sqrt{s}$= 1.8TeV



no ξ dependence

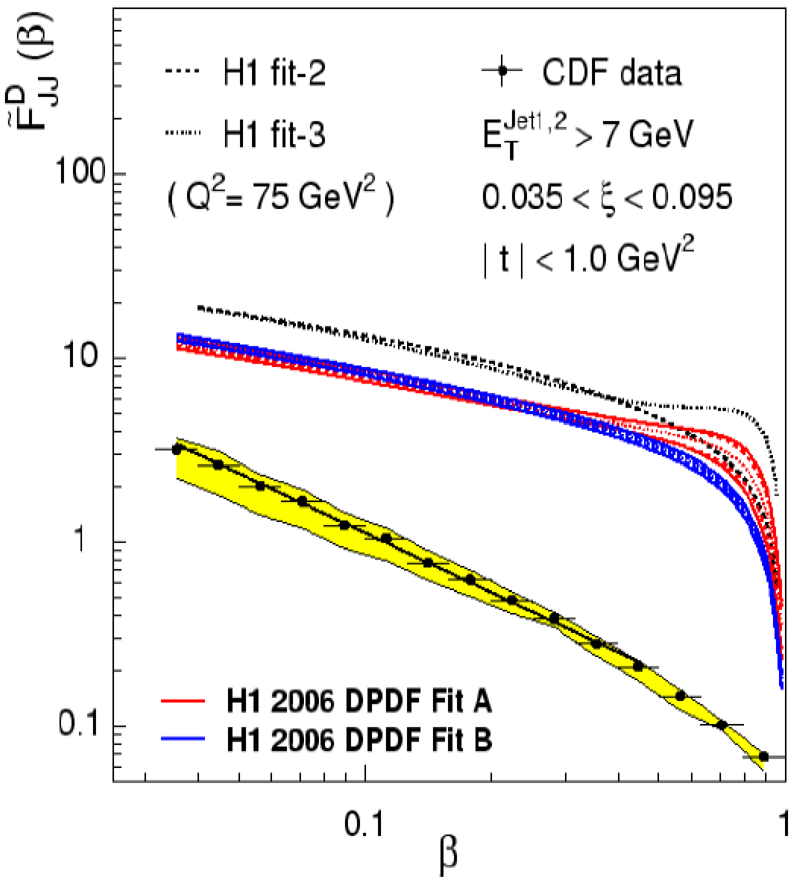


PRL 88, 151802 (2002)

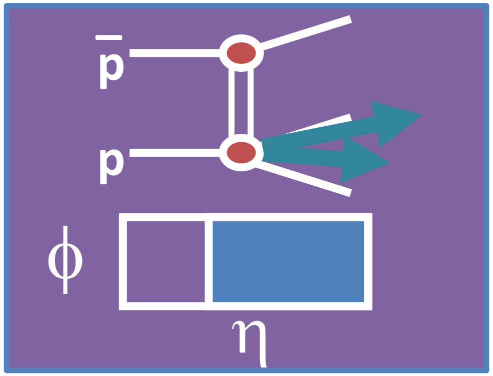


630 and 1800 results are consistent within systematics

Diffractive Structure Function
Diffractive dijets



$\sqrt{s}$= 1.8TeV



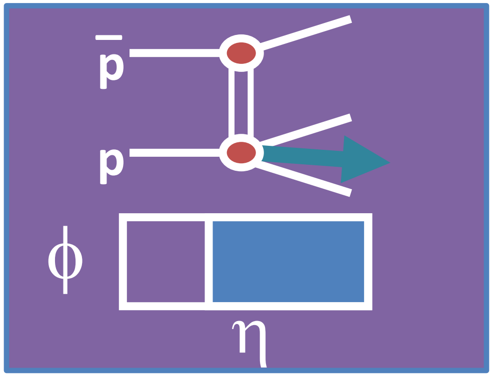
Diffractive signature:

intact pbar detected in RPS

β - momentum fraction of parton in pomeron

Factorization breakdown between HERA and Tevatron

Hard Single Diffraction – example diffractive b production

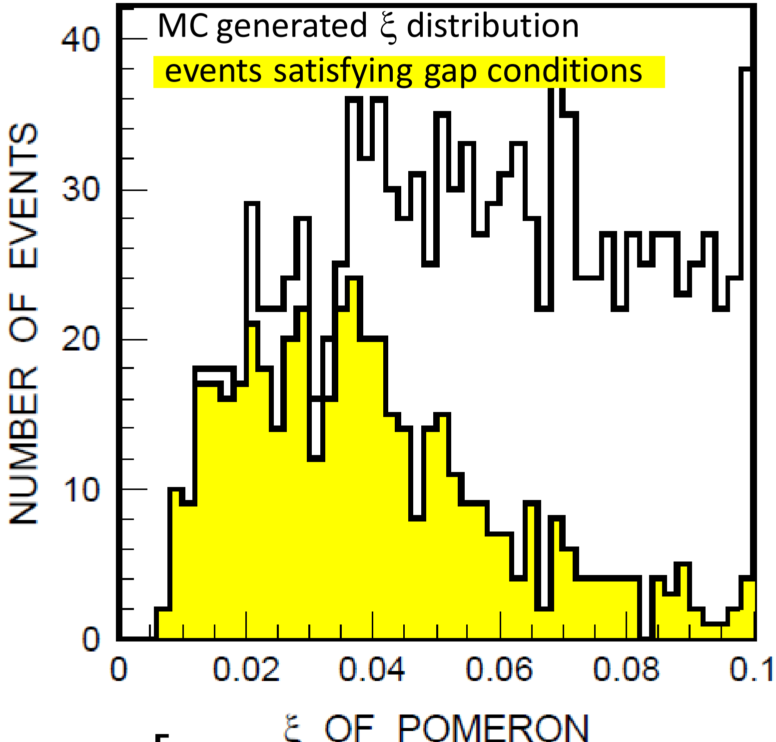


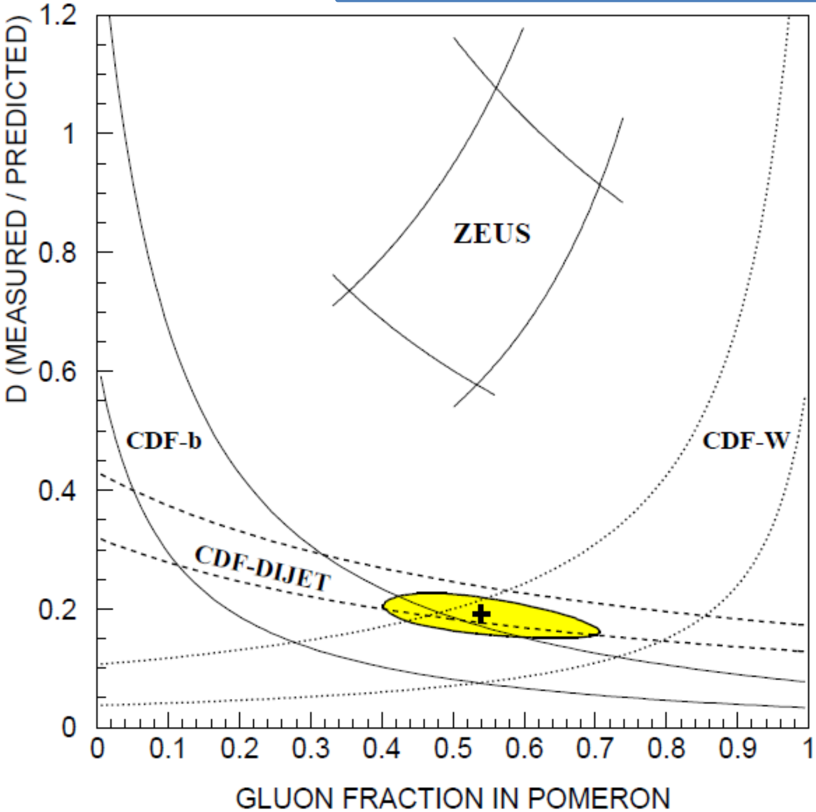
PRL 84, 232-237 (2000)

9.5< p_T^e <20 GeV/c
|η|<1.1

$$\bar{p}p \to p/\bar{p} + b(\to e + X') + X$$

Diffractive signature:
large rapidity gap





$$R_{b\bar{b}} = [0.62 \pm 0.19(stat) \pm 0.16(syst)]\%$$

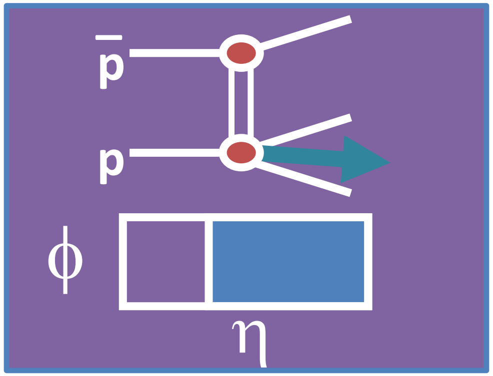
Hard Single Diffraction – example – diffractive $J/\psi(\rightarrow\mu^+\mu^-)$

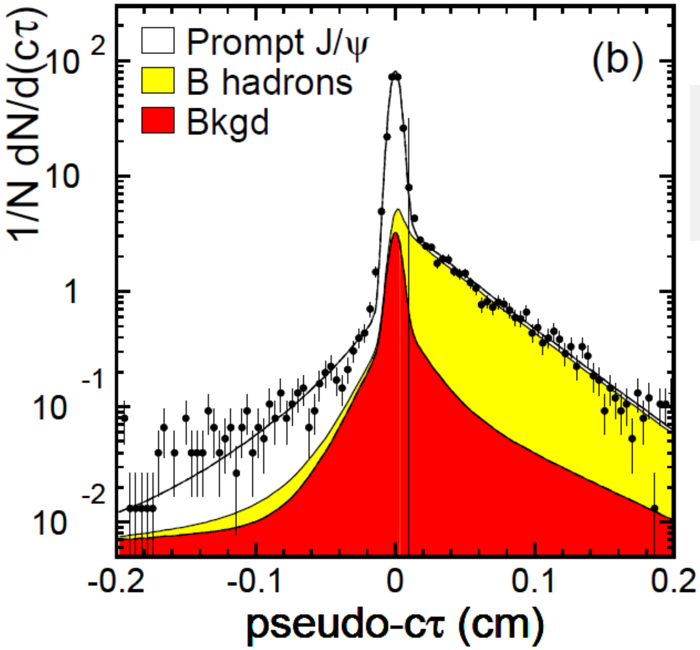
PRL 87, 241802 (2001)

$p_T^\mu > 2$ GeV/c
$|\eta| < 1.0$
$3.05 < M_{\mu\mu} < 3.15$ GeV/c^2

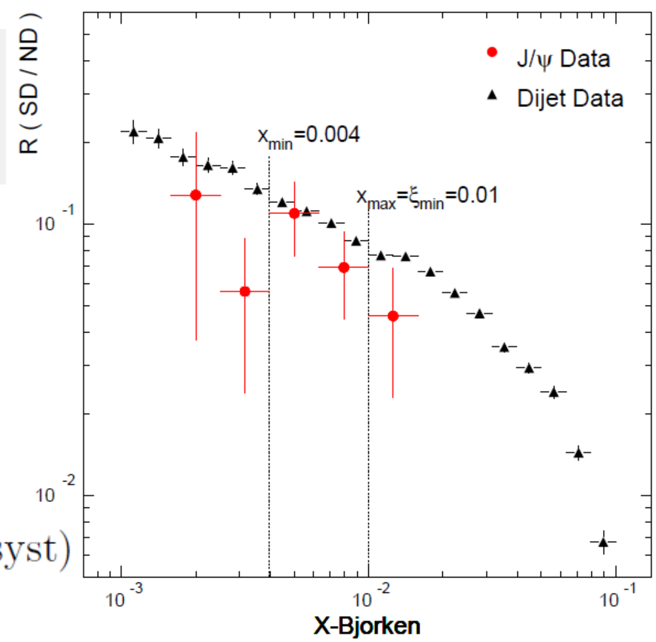
$\sqrt{s}$= 1.8TeV

Diffractive signature:
large rapidity gap





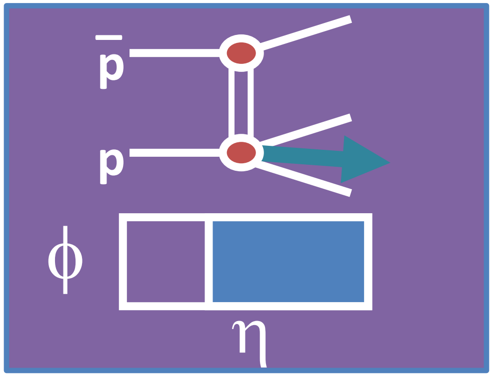
Both J/ψ and b quark productions are mainly sensitive to the gluon content of Pomeron



$$f_g^D = 0.59 \pm 0.14(\mathrm{stat}) \pm 0.06(\mathrm{syst})$$

$$R_{J/\psi} = [1.45 \pm 0.25]\%$$

Hard Single Diffraction



Diffractive signature:

large rapidity gap –
slightly different
gap definitions

method used as a model for LHC analyses

Fraction:
R≡SD/ND ratio
@ 1800 GeV

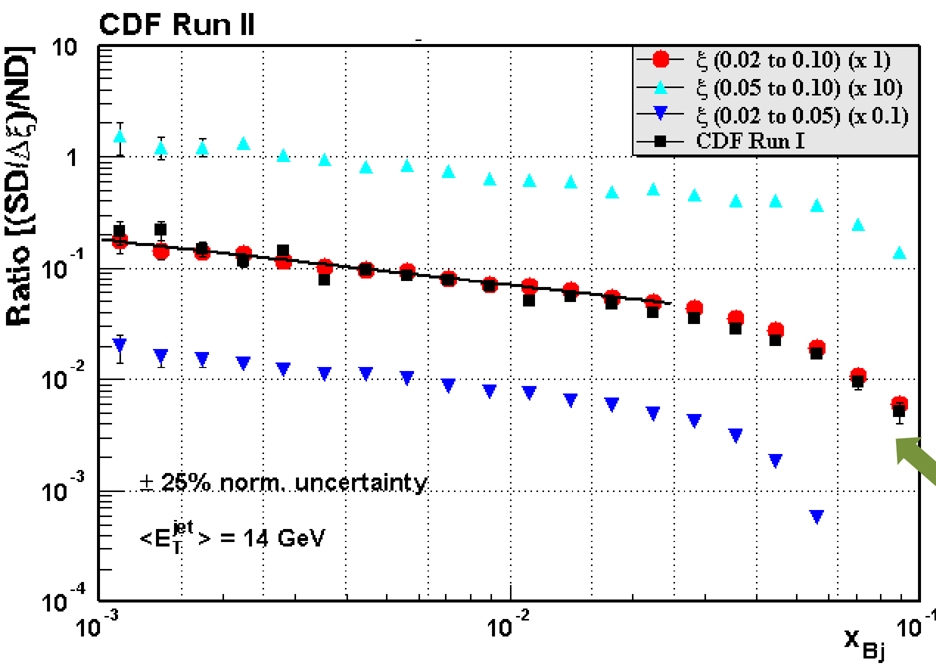
Hard component	Fraction (R) %
Dijet	0.75 ± 0.10
W	1.15 ± 0.55
b	0.62 ± 0.25
J/ψ	1.45 ± 0.25

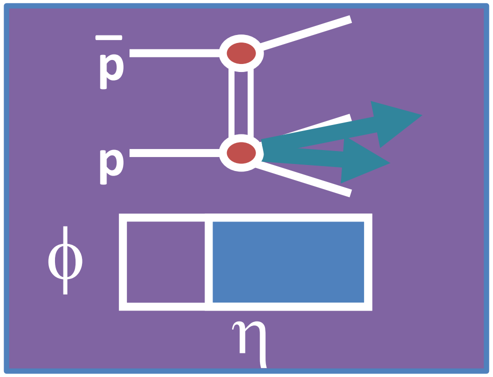
All fractions ~ 1%
(differences due to kinematics)
➢ ~ uniform suppression

The Diffractive Structure Function diffractive dijets

√ s= 1.96 TeV

PRD 86, 032009 (2012)





Diffractive signature:

intact pbar detected in RPS

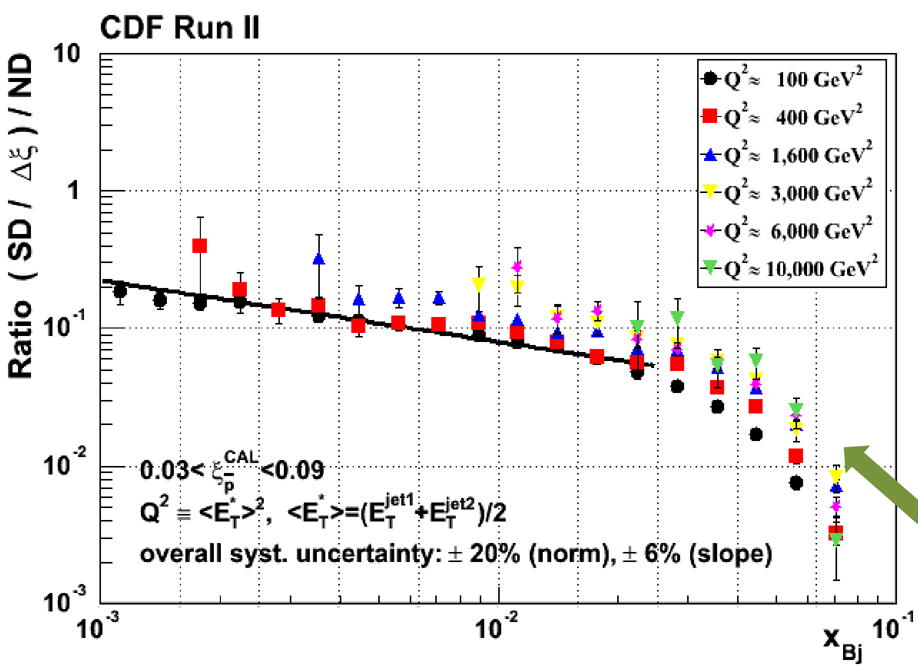
Good agreement with Run I

same behavior for different ξ values

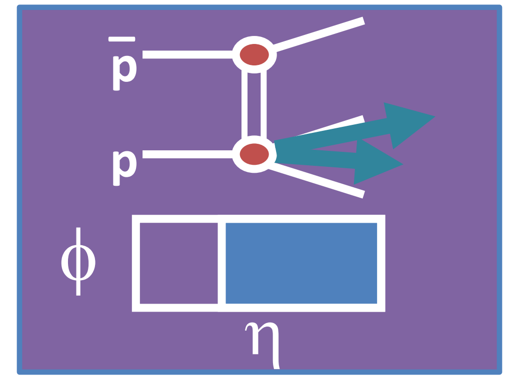
The Diffractive Structure Function diffractive dijets

√ s= 1.96 TeV

[PRD 86, 032009 (2012)]



same behavior for different Q^2

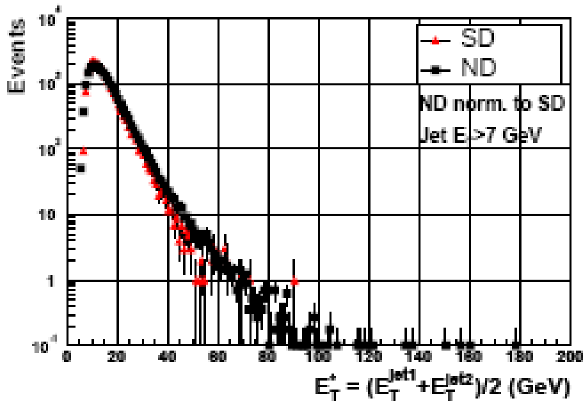


Diffractive signature:

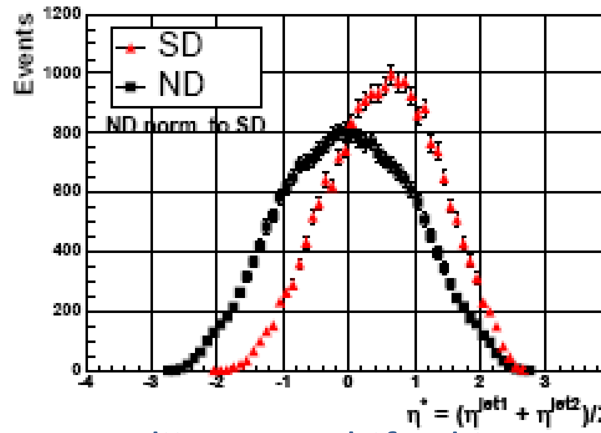
intact pbar detected in RPS

Q^2 varies from 100-10,000 GeV^2

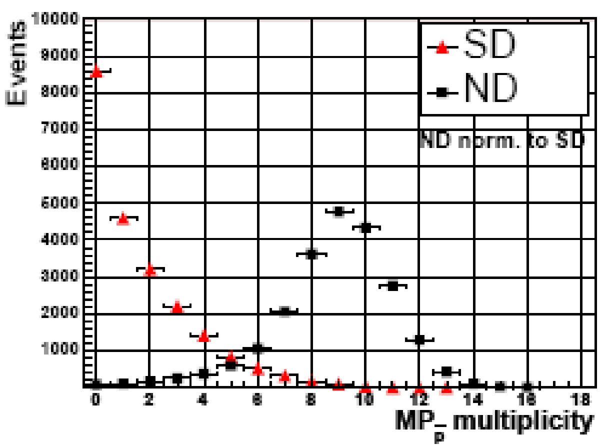
Kinematic Distributions for SD dijets



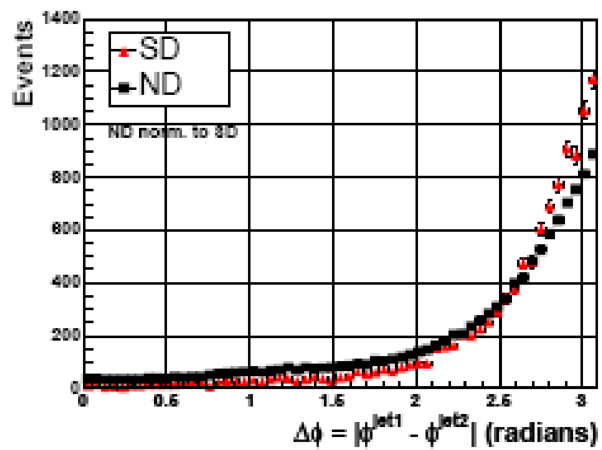
SD and ND dijets have similar E_T distributions



SD dijets are shifted in + η



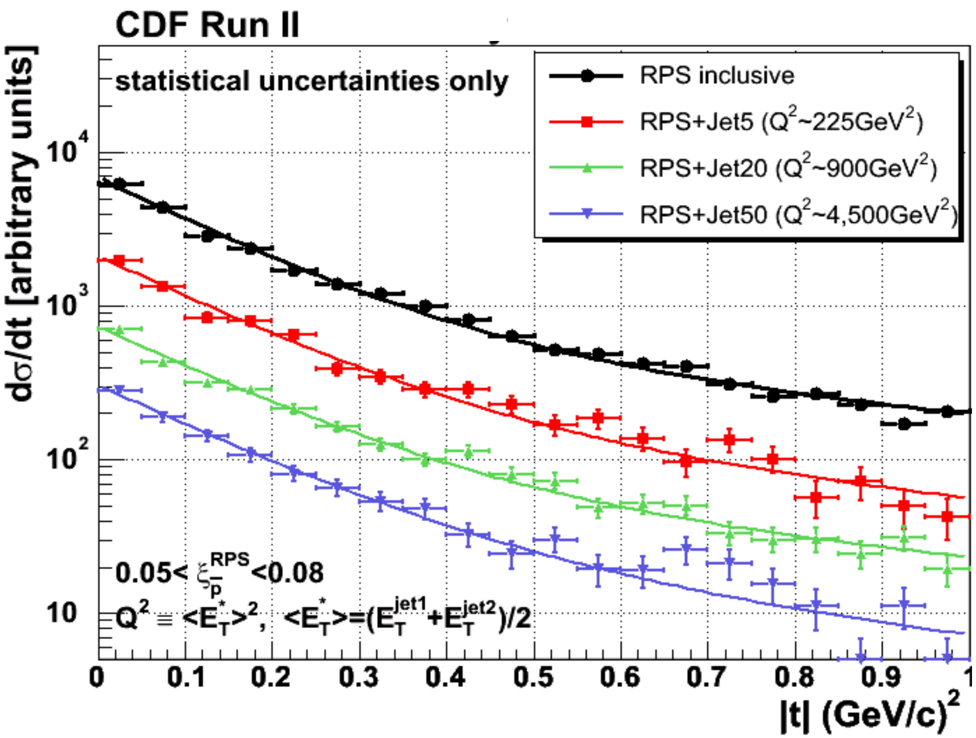
The multiplicity distributions in MP



SD dijets are more back to back

t distribution

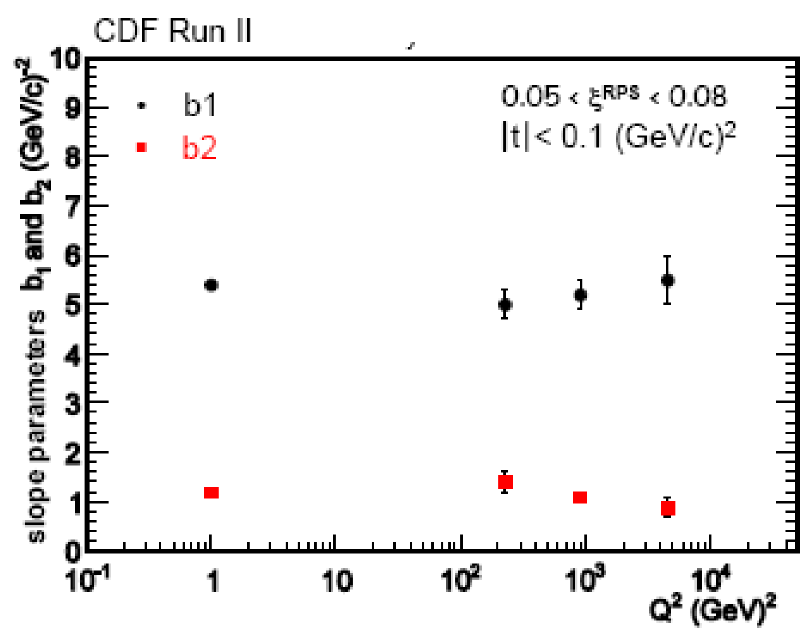
[PRD 86, 032009 (2012)](#)



antiproton |t| distribution

- **no diffractive dips**
- **no Q^2 dependence**

  in slope from inclusive to $Q^2 \sim 10^4$ GeV^2



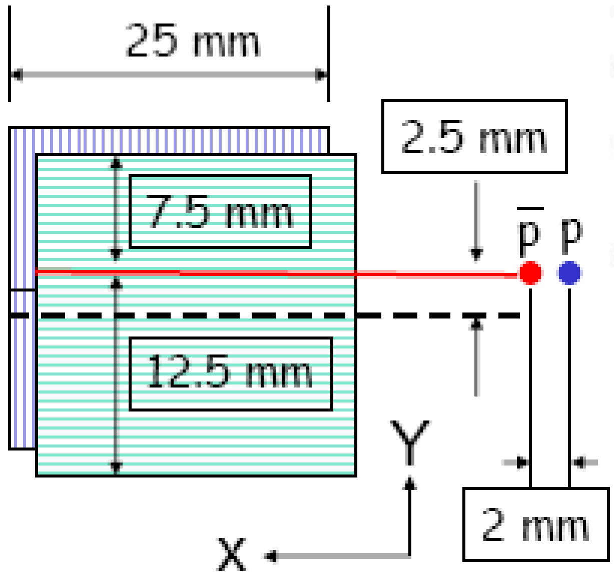
Fit to double exponential function:

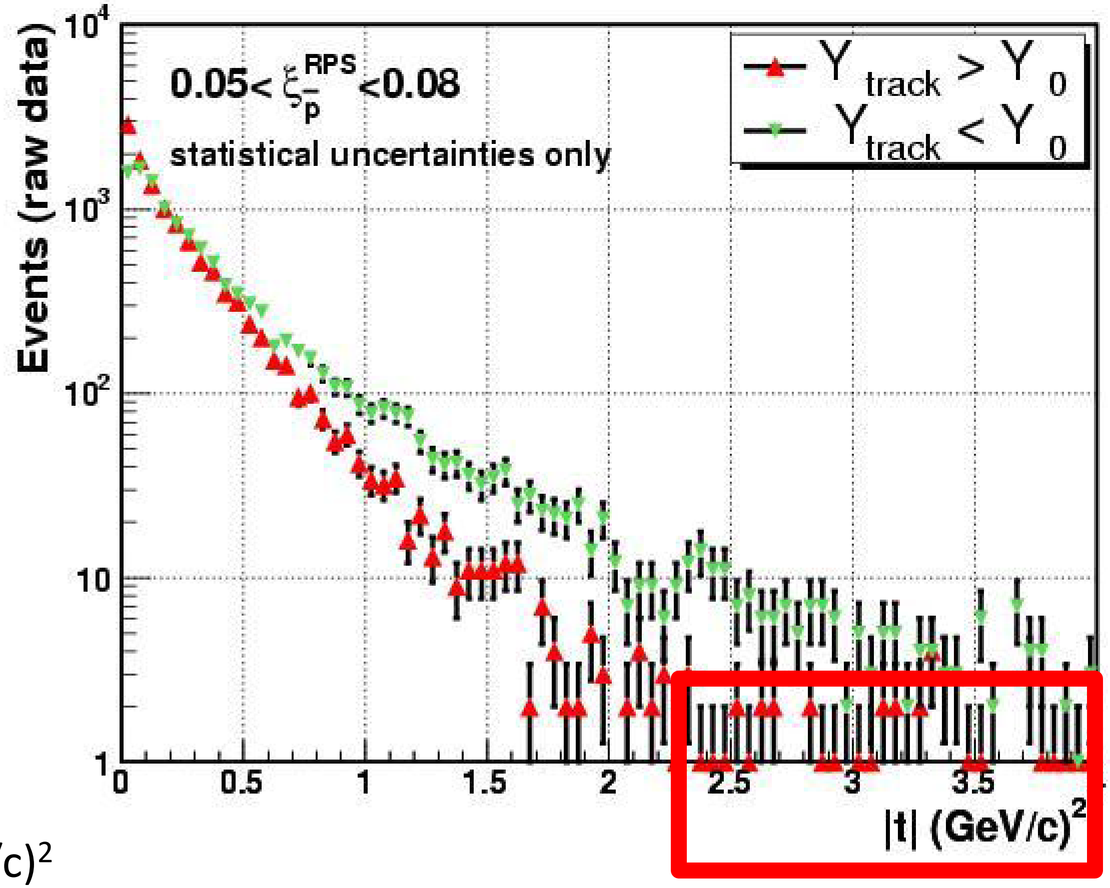
$d\sigma/dt \propto 0.9\, e^{b1 \times t} + 0.1\, e^{b2 \times t}$

Background evaluation

Taking advantage of asymmetrical position of RPS

schematic view of
fiber tracker

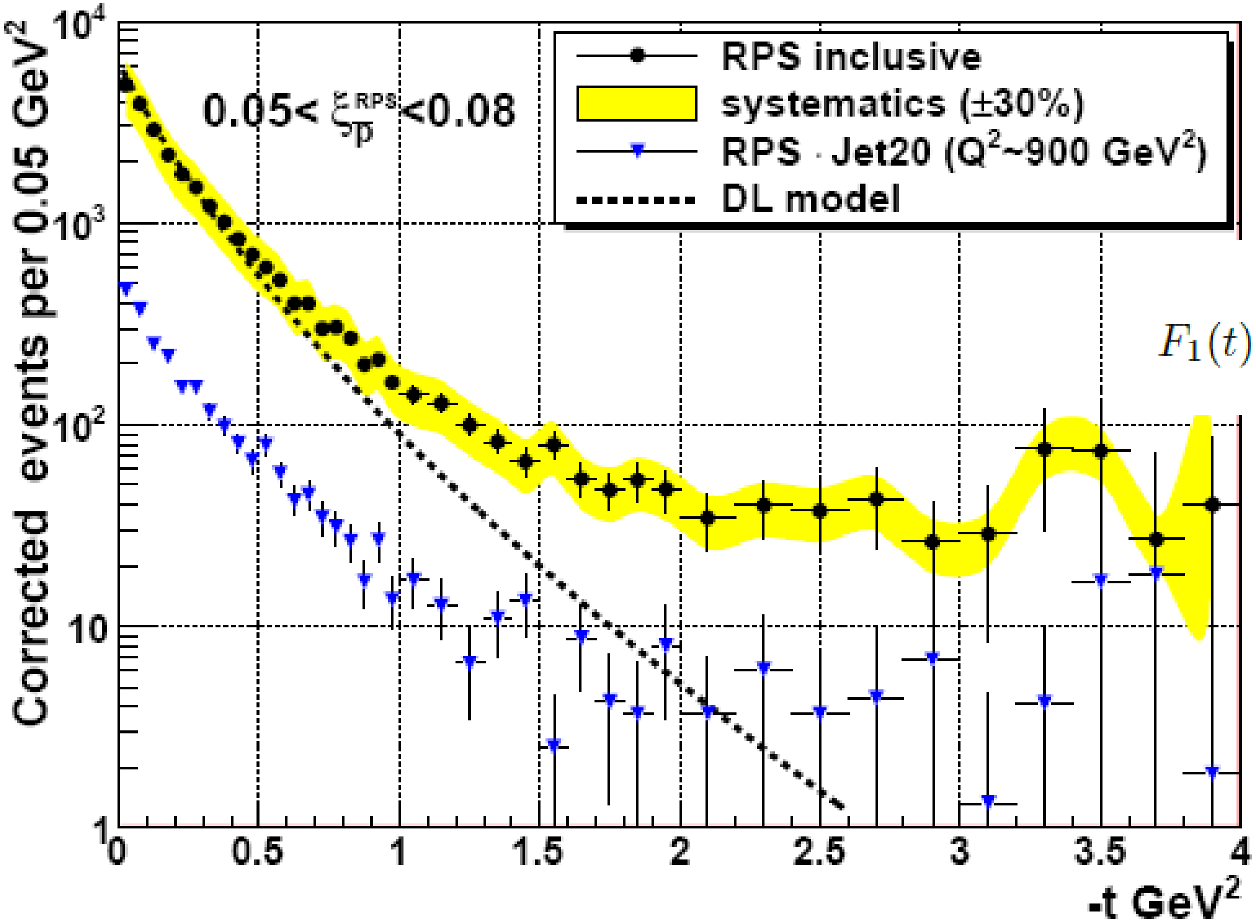




- tracker's upper edge: |t|=2.3 $(GeV/c)^2$
- the lower edge is at |t|= 6.5 $(GeV/c)^2$ (not shown)
- background level: region of Y_{track}>Y_o data for |t|>2.3 $(GeV/c)^2$

t distributions for SD

[PRD 86, 032009 (2012)](#)



Fitted with electromagnetic form factor squared $F_1(t)^2$

$$F_1(t) = \frac{4m_p^2 - 2.8t}{4m_p^2 - t} \cdot \left(\frac{1}{(1 - t/0.71)}\right)^2$$

from

$$\frac{d\sigma^{SD}}{dt} = N_{norm} \cdot F_1(t)^2 \cdot \exp\left[2\alpha' \cdot \ln\frac{1}{\xi} \cdot t\right]$$

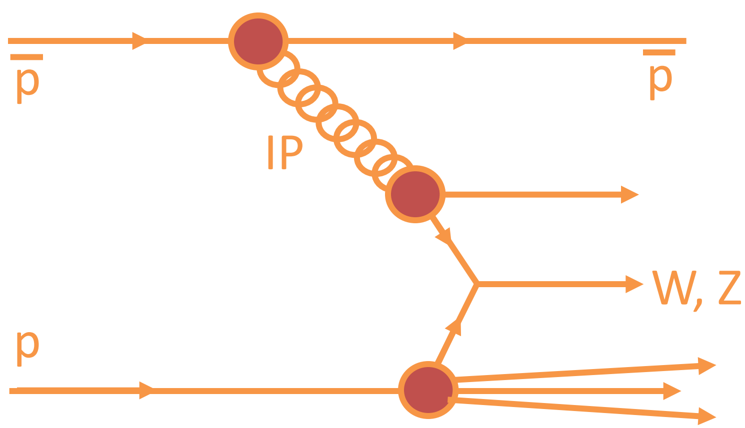
where $\alpha' \approx 0.25\ (\mathrm{GeV}/c)^{-2}$ is the slope of the the $I\!P$- trajectory

Search for diffraction minimum around *t* of 2.5 GeV^2?

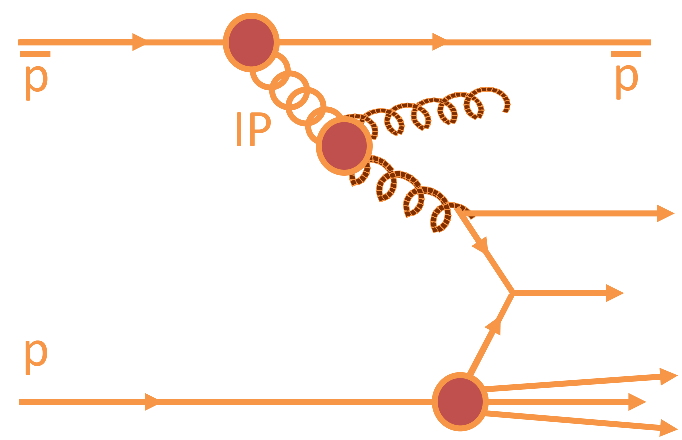
Example:
Diffractive W/Z Production

Diffractive W/Z production probes the quark content of the Pomeron

- to Leading Order the W/Z are produced by a **quark** in the Pomeron



- production by gluons is suppressed by a factor of α_s and can be distinguished by an associated jet



Diffractive W Production

Identify diffractive events using Roman Pots:

accurate event-by-event ξ measurement
no gap acceptance correction needed
can still calculate ξ^{cal}

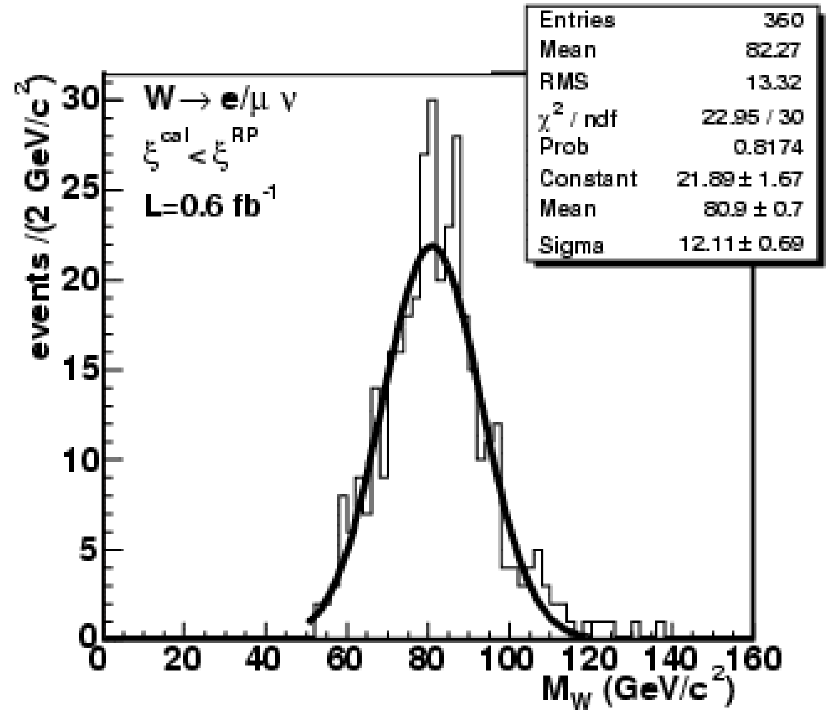
$$\xi^{cal} = \sum_{towers} \frac{E_T}{\sqrt{s}} e^{-\eta}$$

In W production, the difference between ξ^{cal} and ξ^{RP} is related to missing E_T and η_ν

$$\xi^{RP} - \xi^{cal} = \frac{E_T}{\sqrt{s}} e^{-\eta_\nu}$$

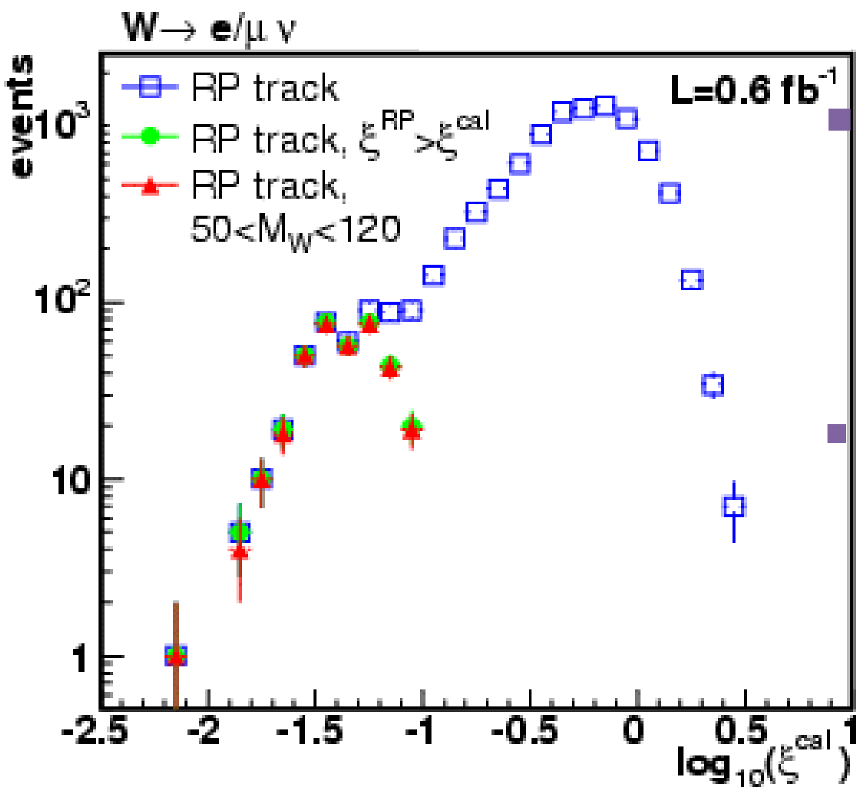
allows to determine:
neutrino and W kinematics
x_{bj}

Phys. Rev. D 82, 112004, 2010



reconstructed diffractive W mass

Diffractive W Production



$\xi^{cal} < \xi^{RP}$ requirement removes most events with multiple pbar-p interactions

$50 < M_W < 120$ GeV/c^2 requirement on the reconstructed W mass cleans up possible mis-reconstructed events

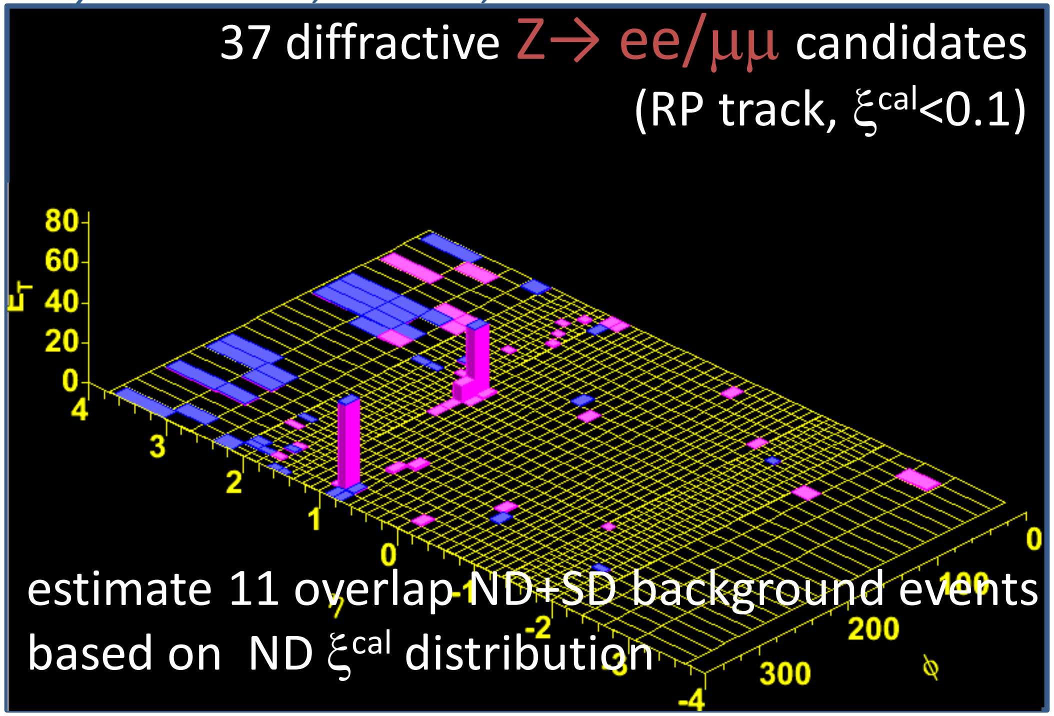
Fraction of diffractive W

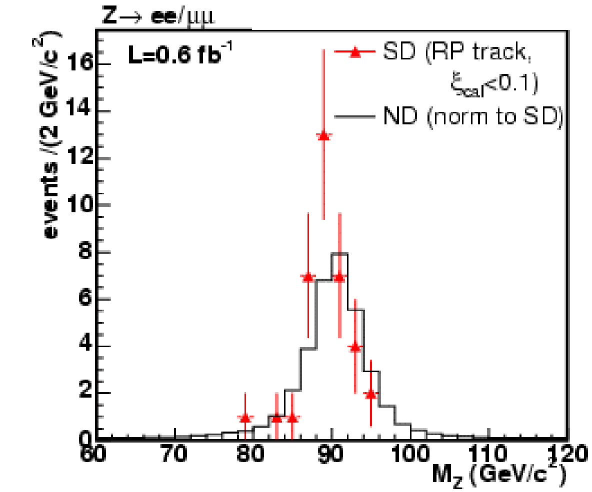
R_W (0.03<ξ<0.10, |t|<1)= [0.97 ±0.05(stat) ±0.10(syst)]%

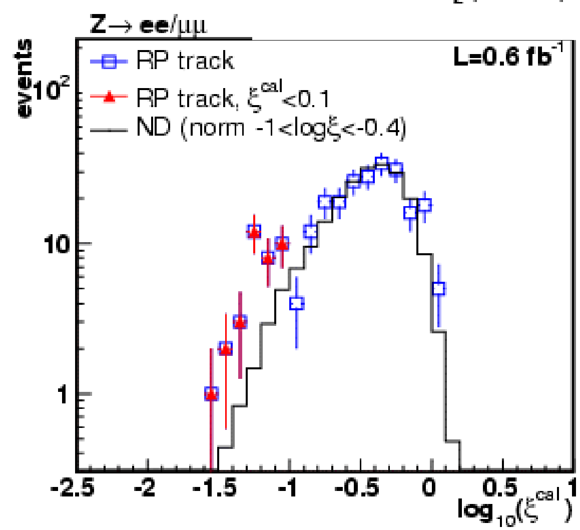
consistent with Run I result, extrapolated to all ξ

Diffractive Z Production

Phys. Rev. D 82, 112004, 2010







Fraction of diffractive Z

R_Z (0.03< ξ <0.10, |t|<1)=

[0.85±0.20(stat) ±0.08(syst)]%

W/Z Results

R^W ($0.03 < \xi < 0.10$, $|t|<1$)= [0.97 ± 0.05(stat) ± 0.11(syst)]%

Run I: R^W ($\xi<0.1$)=[1.15±0.55] % → **0.97±0.47 %** in **$0.03 < \xi < 0.10$ & $|t|<1$**

R^Z ($0.03 < x < 0.10$, $|t|<1$)= [0.85 ± 0.20(stat) ± 0.11(syst)]%

CDF/DØ Comparison – Run I ($\xi < 0.1$)

CDF PRL 78, 2698 (1997)

R^W=[1.15±0.51(stat)±0.20(syst)]%

gap acceptance A^{gap}=0.81

Uncorrected for A^{gap}

R^W=(0.93±0.44)%

DØ Phys Lett B **574**, 169 (2003)

R^W=[5.1±0.51(stat)±0.20(syst)]%

gap acceptance A^{gap}=(0.21±4)%

Uncorrected for A^{gap}

R^W=[0.89+0.19-0.17]%

R^Z=[1.44+0.61-0.52]%

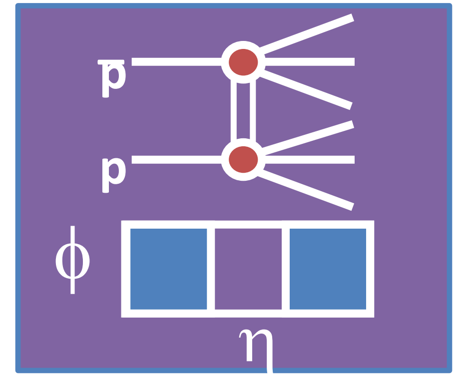
This analysis is a good example of agreement between RPS and large rapidity gap identification methods

Double Diffraction

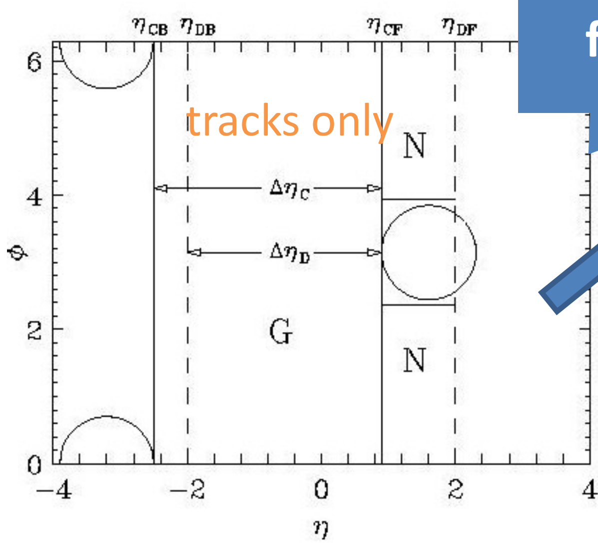
Diffractive signature:

large central rapidity gap – slightly different gap definitions

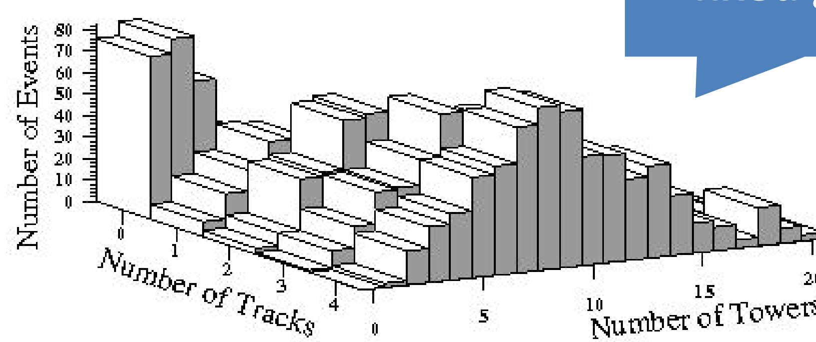
Bjorken's estimate of gap "survival" probability $\langle S \rangle \sim 0.1$
PRD 47, 101, 1993



floating gap



fixed gap



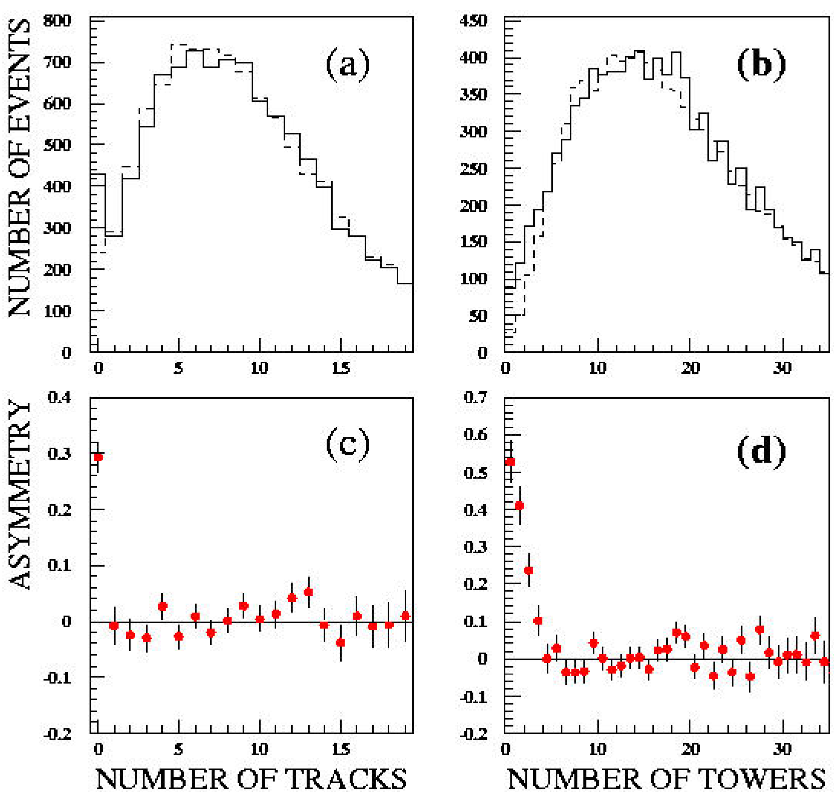
PRL 72, 2332, 1994 (D0)
PRL 74, 855, 1995 (CDF)
PRL 80, 1156, 1998 (CDF)

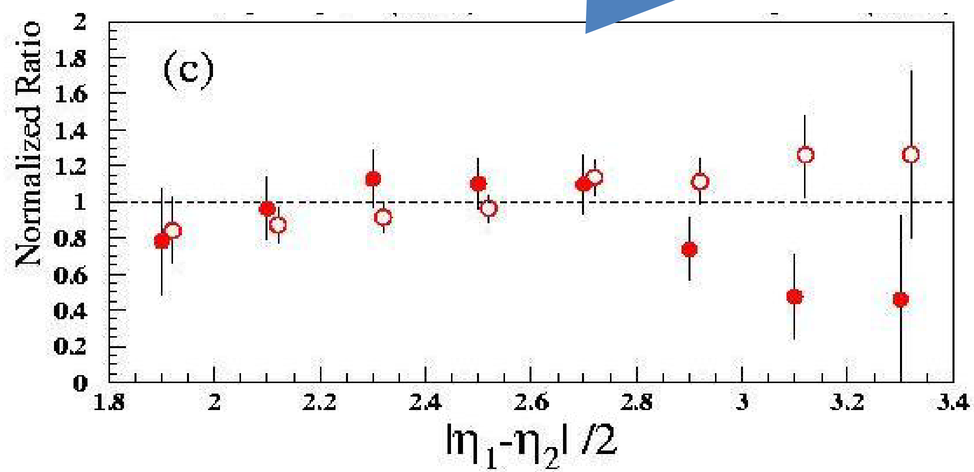
Central Gaps in Run I

PRL 80, 1156, 1998

R=[1.13±0.12(stat) ±0.11(syst)]% @ 1800 GeV
R=[2.7±0.7(stat) ±0.6(syst)]% @ 630 GeV

floating jets
fixed central gap





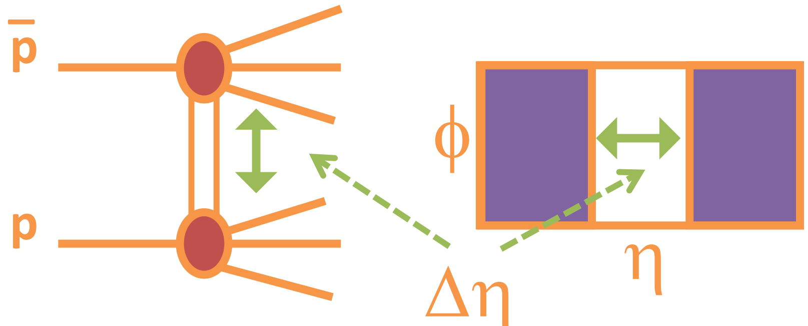
R is estimated using OS jets as signal and SS jets as a control sample

- look for events with rapidity gap in $|\eta|<1$ when jets are at $1.8<|\eta|<3.5$
- both track and tower multiplicities produce similar results

Rapidity Gaps in Minbias Events

PRL 87, 141802 (2001)

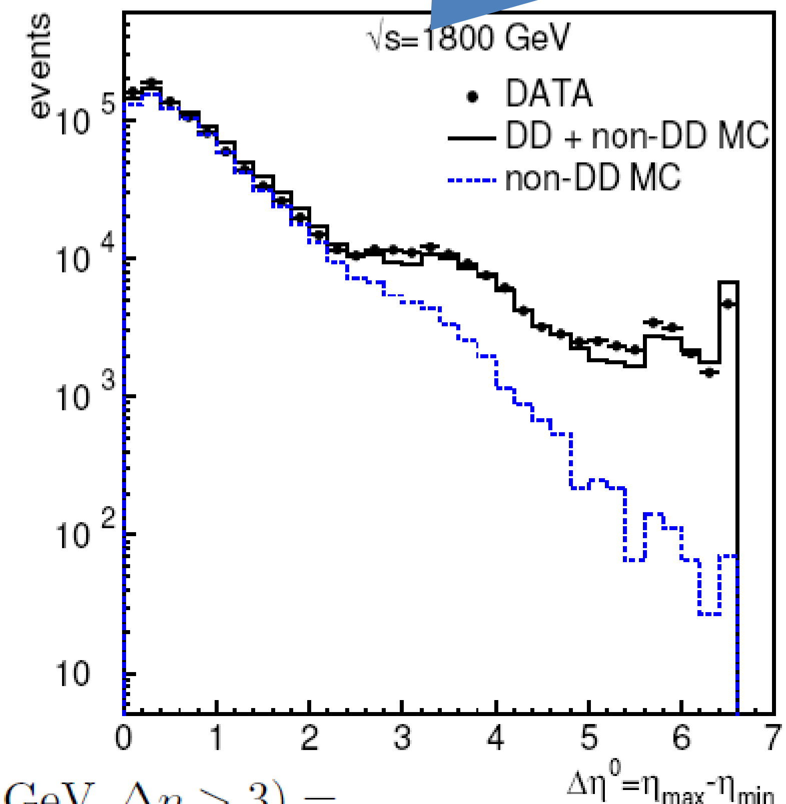
Soft Double-Diffraction (DD)

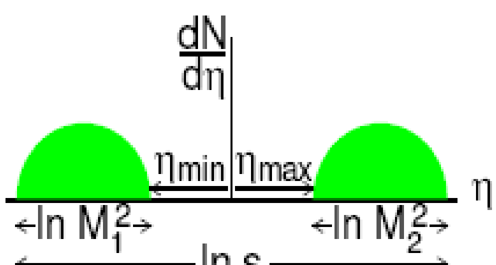


Strategy of analysis:

look for "experimental gaps" defined as
$\Delta\eta \equiv \eta_{max} - \eta_{min}$
$\eta_{max}(\eta_{min})$- "particle" closest to η=0
in the p(p) direction

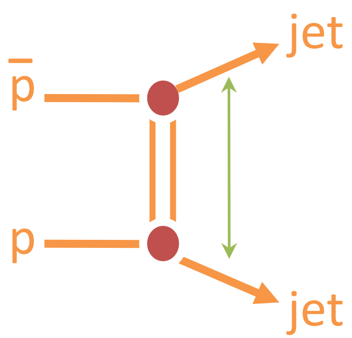
floating gap

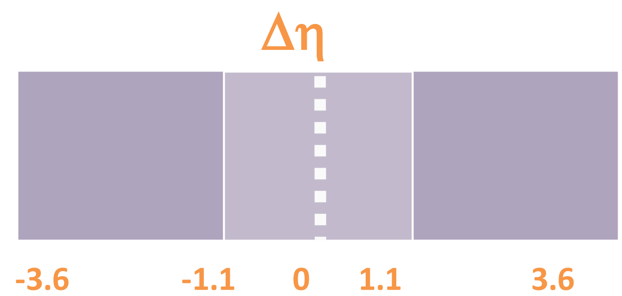


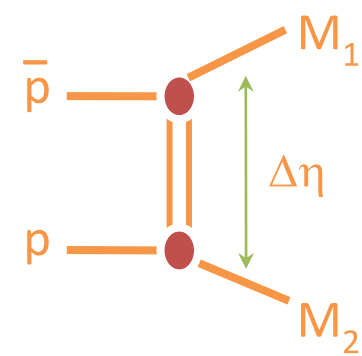


$$\sigma_{DD}(\sqrt{s} = 1800\ [630]\ \text{GeV}, \Delta\eta > 3) =$$
$$6.32 \pm 0.03(\text{stat}) \pm 1.7(\text{syst})\ \text{mb}$$
$$[4.58 \pm 0.02(\text{stat}) \pm 1.5(\text{syst})\ \text{mb}]$$

Central Gaps in Soft and Hard DD







To **compare gap probability** in soft and hard DD dissociation:

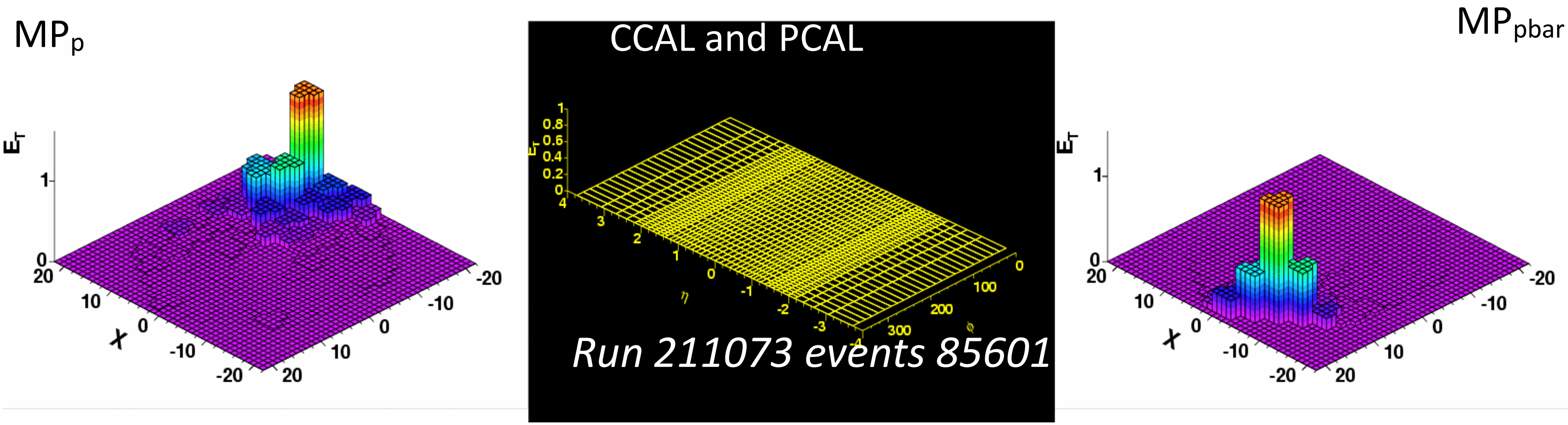
reconstruct $\Delta\eta$ in both cases
require events to have gap in CCAL
$|\eta| < 1.1 \rightarrow \Delta\eta > 2 \quad \rightarrow$
significant DD contribution

require opposite side MP jets for hard DD,
with E_T>2 GeV

For this analysis we use "floating" – not-necessarily central gap

Direct comparison of the results is relatively free of syst. uncertainties.

Forward Jets and Rapidity Gaps

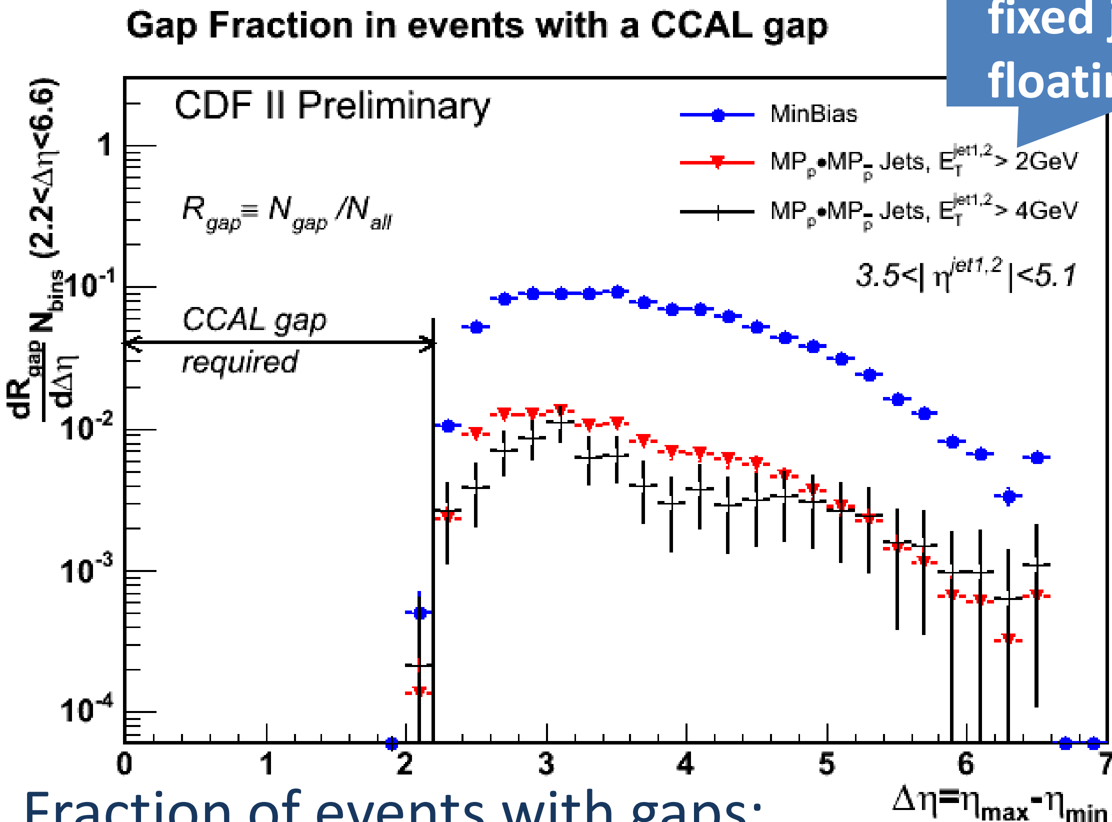


Gaps:

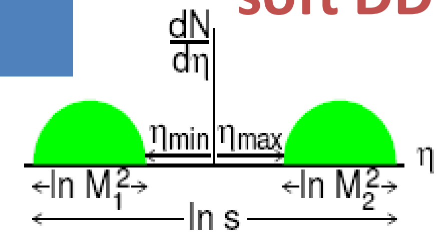
- what is under the "carpet"? - detector noise etc…

Central Gaps in Soft and Hard DD

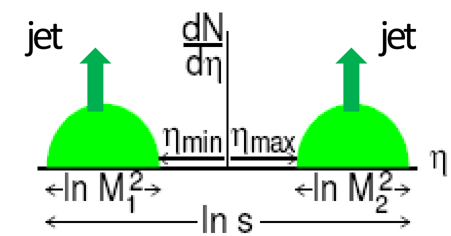
Pub. Proceedings Diffraction 2008,
Sep 9-14,La Londe-les Maures, France



soft DD



compare with



hard DD

Fraction of events with gaps:

~10% in soft DD events and ~1% in jet events

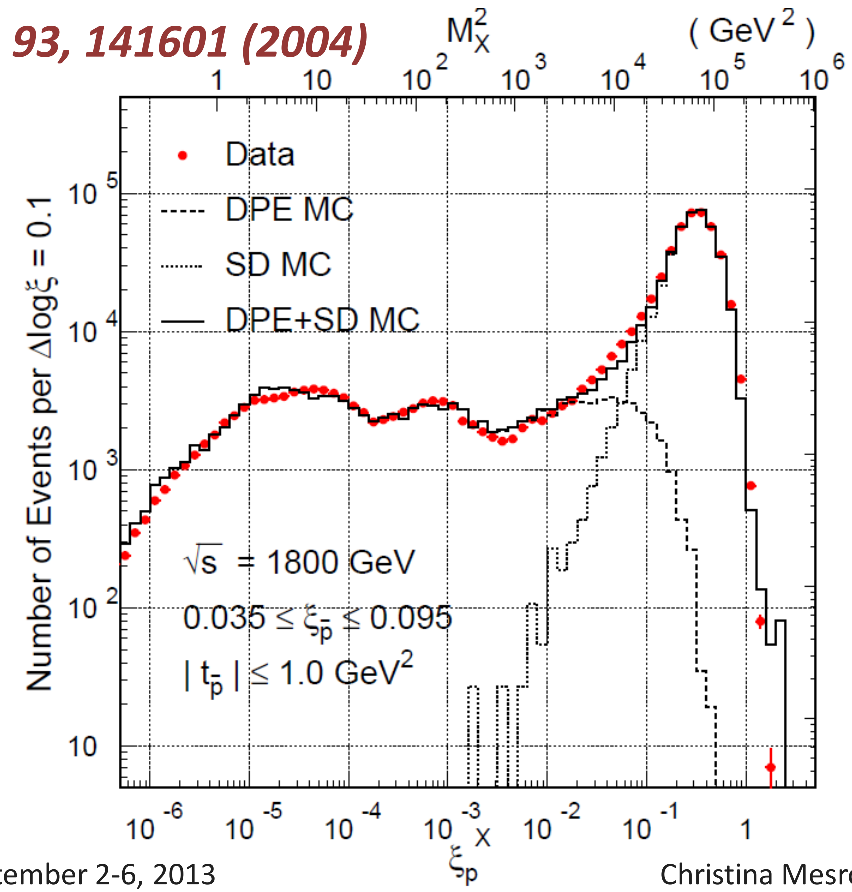
The distributions are similar in shape within the uncertainties

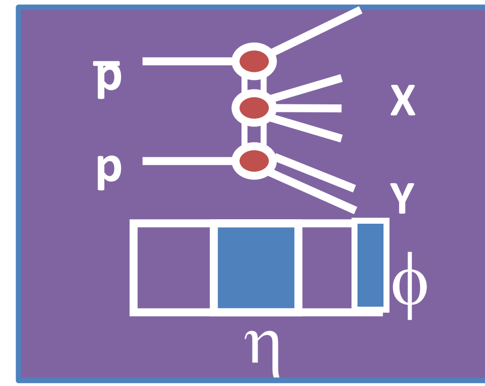
Double Pomeron Exchange

Diffractive signature:

recoil pbar /large rapidity gap **AND**
large rapidity gap on proton side

PRL 93, 141601 (2004)





Inclusive DPE ξ and M_X^2 distribution

M_Y<8 GeV/c^2

$R_{DPE/SD}$ = 0.194±0.001(stat)±0.012(syst)
↓
production of the second gap is relatively un-suppressed

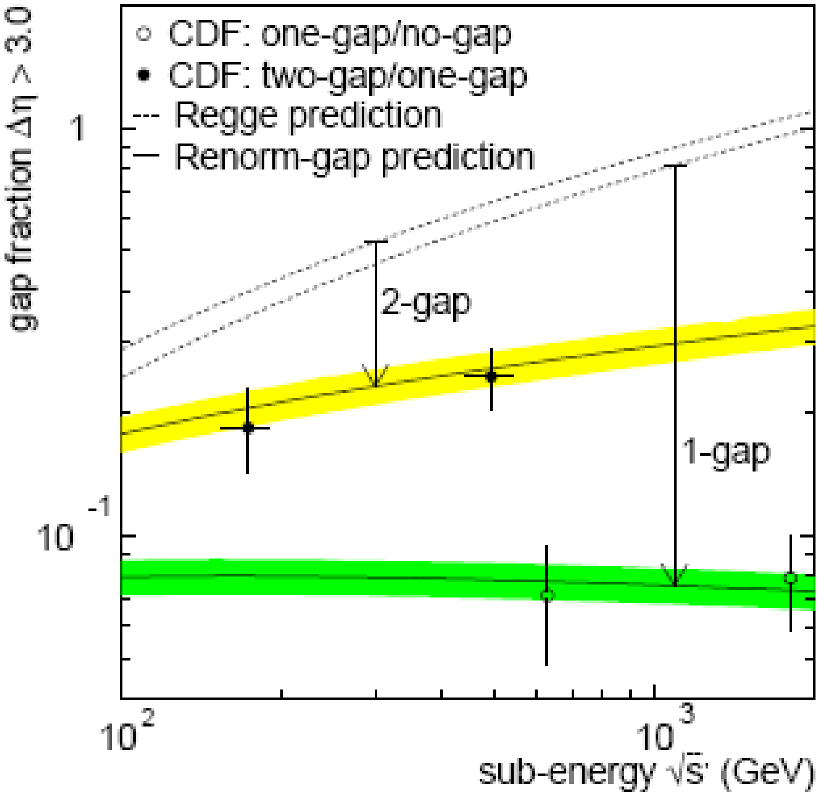
Multi Gap events

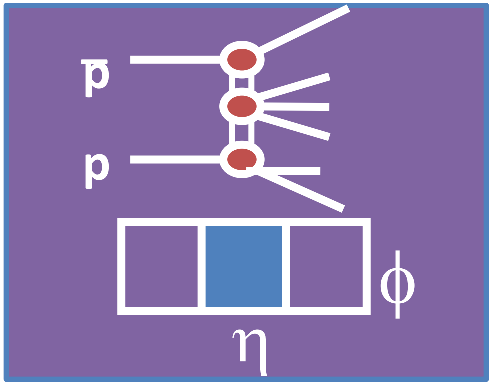
PRL 91, 011802 (2003)

Diffractive signature:

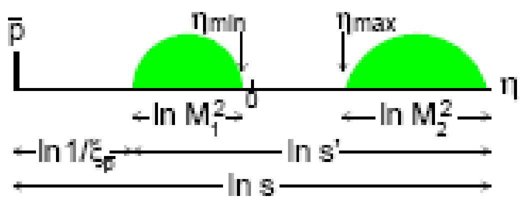
recoil pbar **AND**

large rapidity gap on proton side





would be interesting to study at LHC

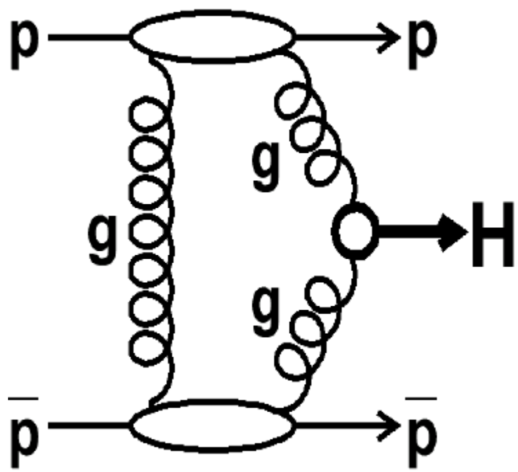


second gap production is not suppressed

Central Exclusive Production

See very nice review by Mike Albrow on Tuesday

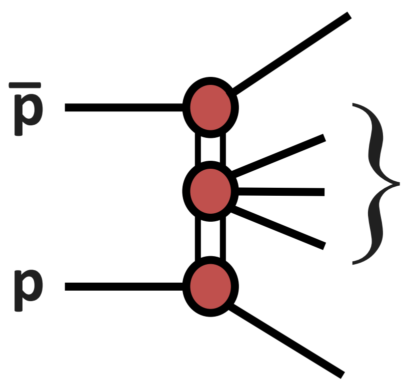
LHC



- suppression at LO of the background sub-processes (J_z=0 selection rule)
- "exclusive channel" → clean signal (no underlying event)

- At the Tevatron we use similar processes with larger cross sections to test and calibrate theor. predictions

CDF



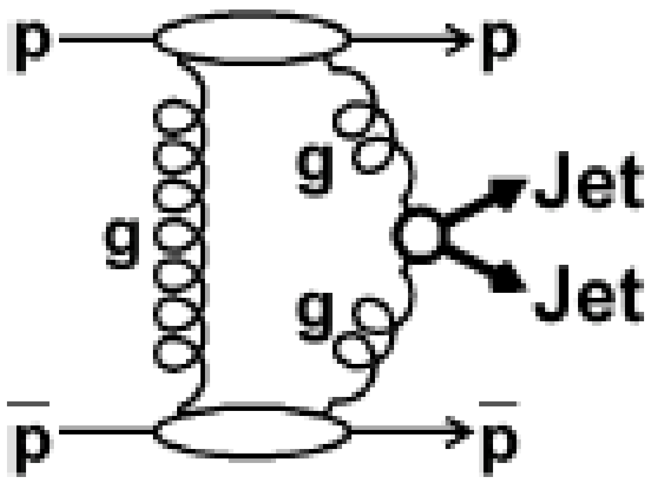
Dijets,

$\gamma\gamma$,

χ_c

Exclusive Dijet Production

Run I



CDF limit of

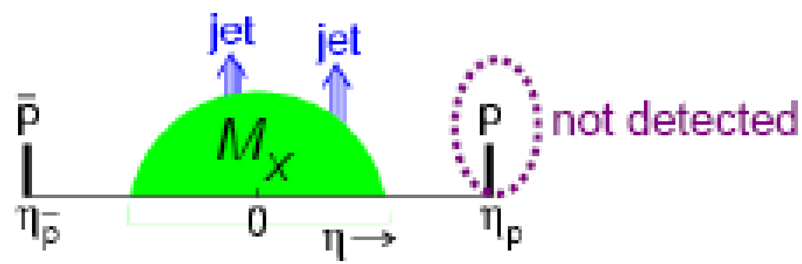
σ_{excl}<3.7 nb(95% CL)

Run II

Method:

Select inclusive diffractive dijet events produced by DPE

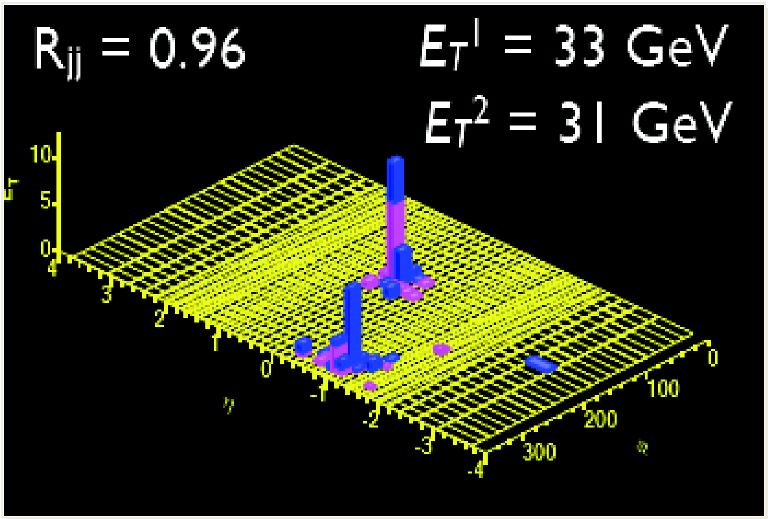
$$p+\bar{p} \rightarrow I\!P + I\!P \rightarrow \bar{p} + X(\geq 2 \text{ jets}) + gap$$

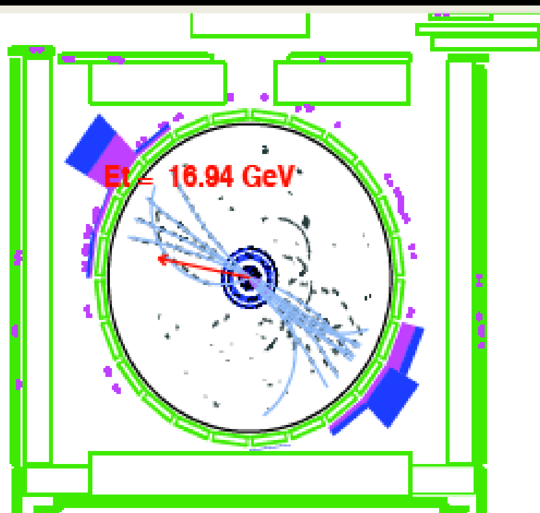


Reconstruct $R_{jj} = \frac{M_{jj}}{M_X}$, where

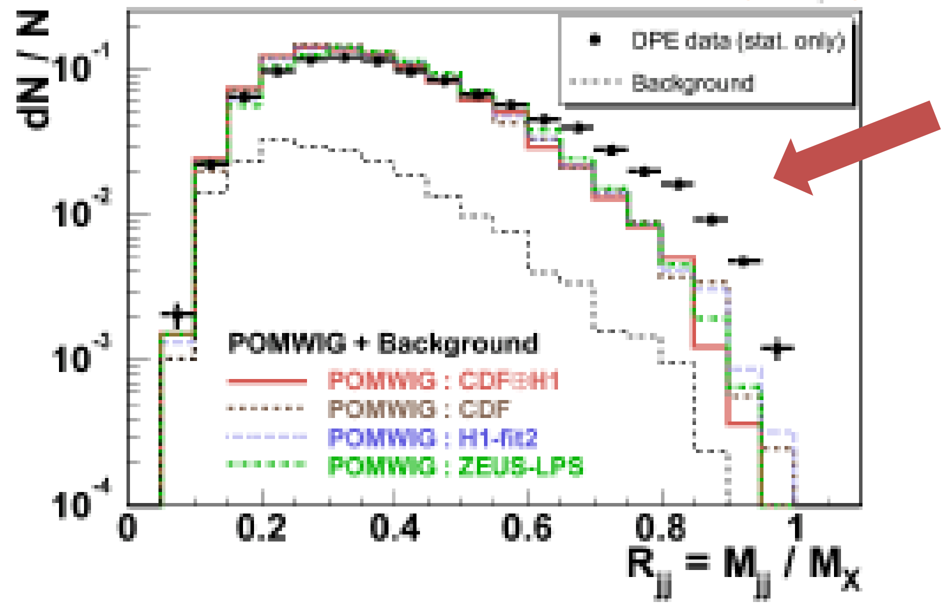
M_{jj} - dijet mass, M_X - mass of system X

Observation of Exclusive Dijet Production





PRD 77, 052004 (2008)

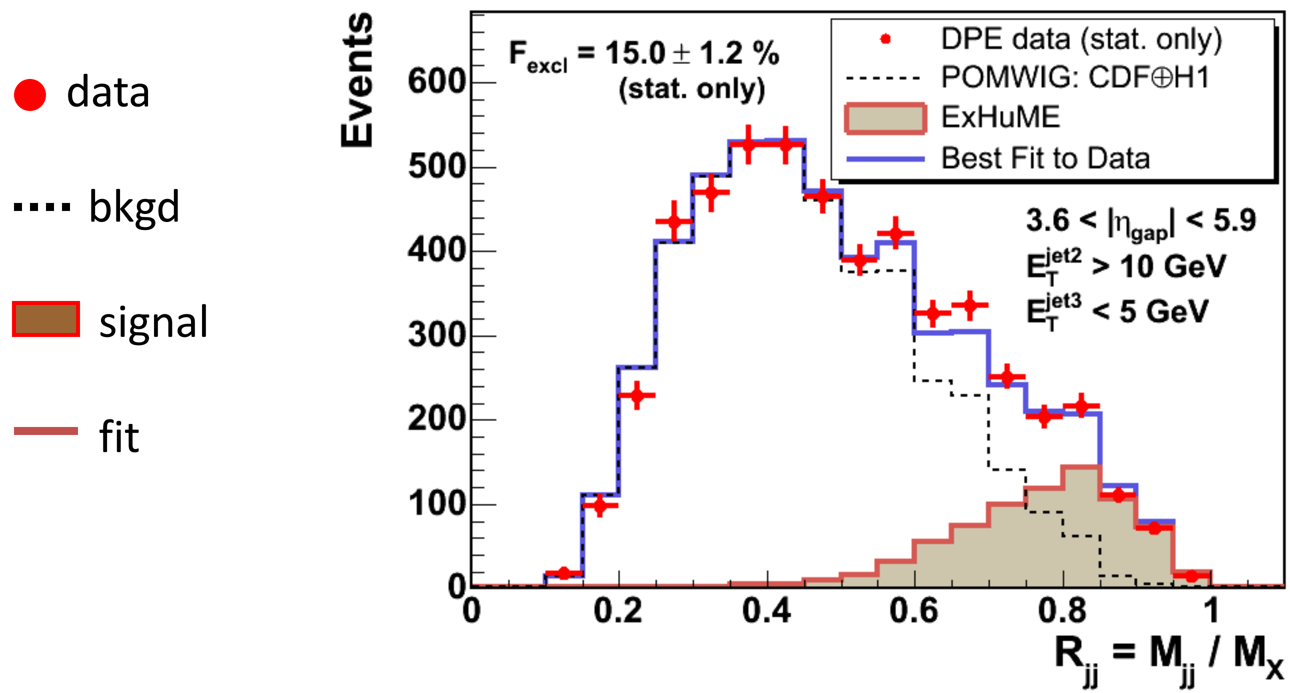


Observe excess over inclusive DPE dijet MC's at high dijet mass fraction

Signal at R_{jj}=1 is smeared due to shower/hadronization effects, NLO $gg \to ggg, q\bar{q}g$ contributions

Exclusive Dijets

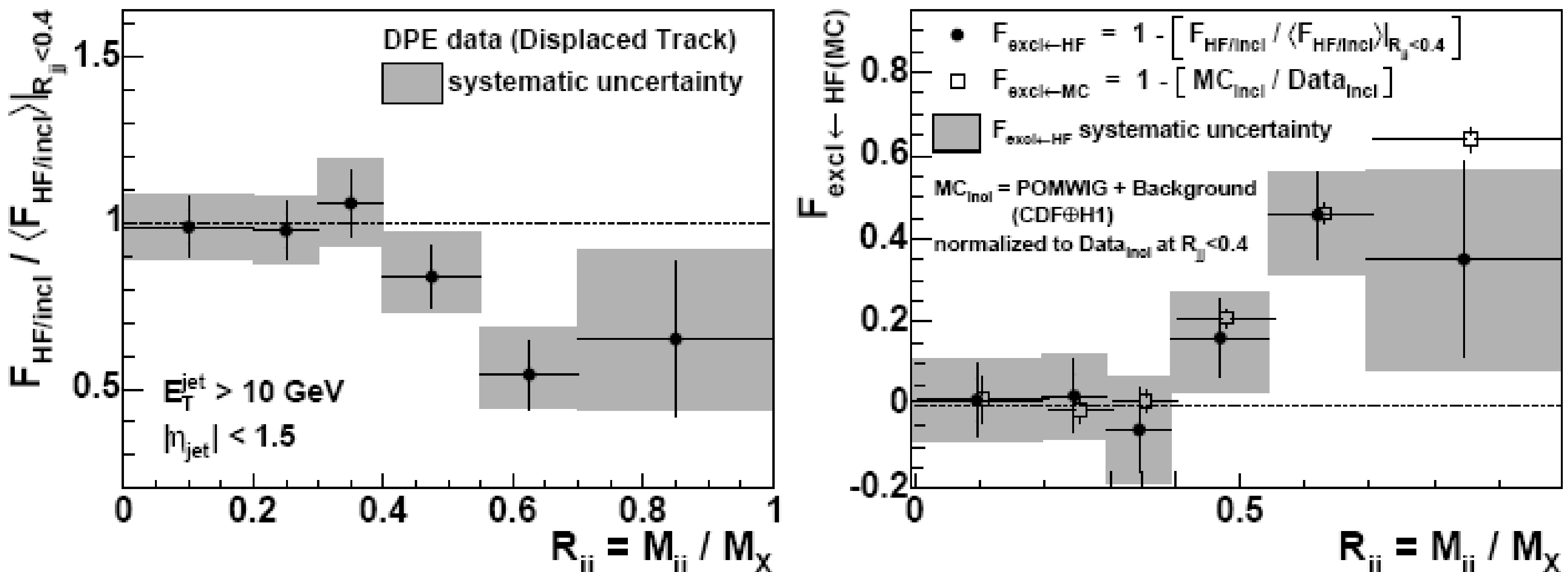
Signal MC ExHuME *CPC 175,232 (2006)*



➔ Shape of excess described by exclusive dijet MC (ExHuME) shows good agreement

Heavy Flavor Suppression

- LO exclusive $gg \rightarrow q\bar{q}$ suppressed ($J_Z = 0$ rule)
- Look for **heavy flavor jet suppression** relative to inclusive dijets at high Rjj



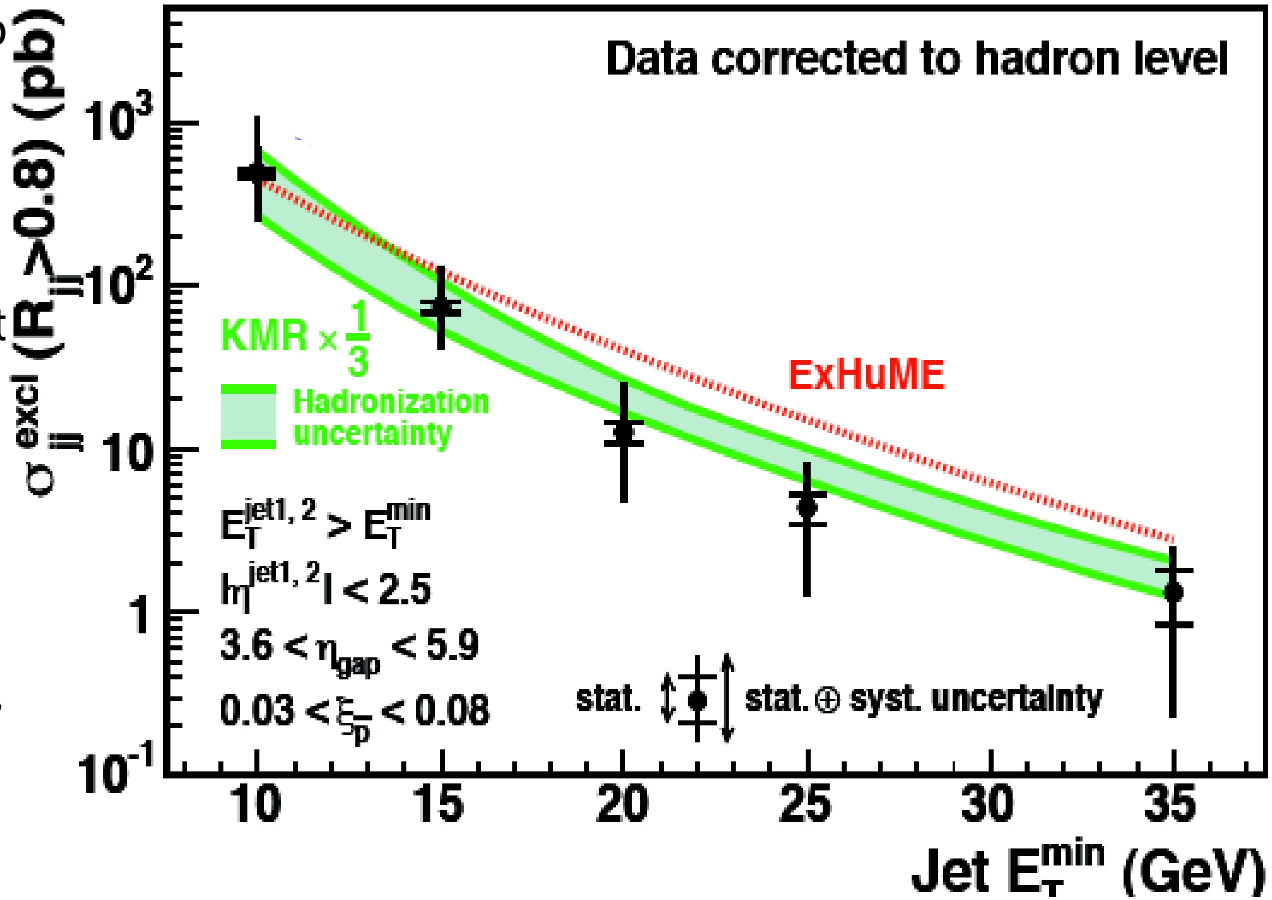
Suppression of heavy flavor for R_{jj}> 0.4 is consistent in shape and magnitude with the results based on MC based extraction of exclusive dijet signal.

Exclusive Dijet Cross Section

Exclusive dijet cross sectio
compared
with MC ExHuME

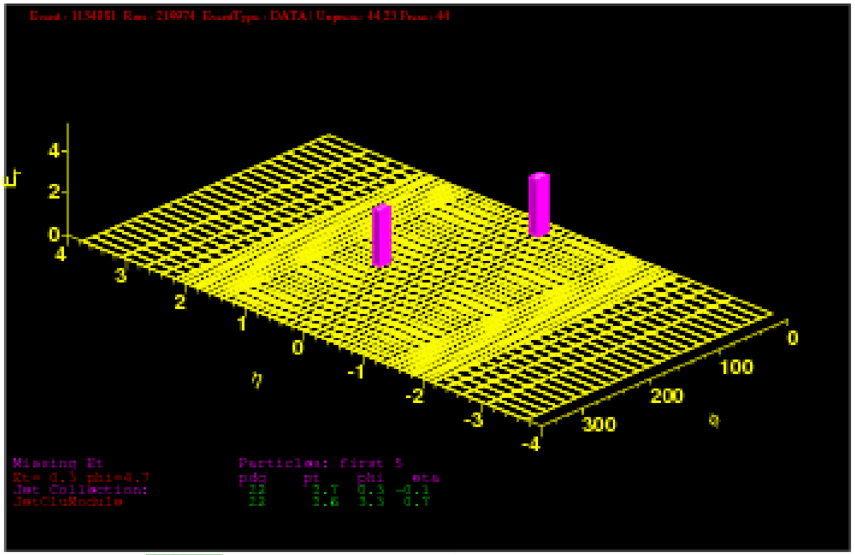
Calculation by Khoze, Mart
and
Ryskin consistent
within its factor
of 3 uncertainty.

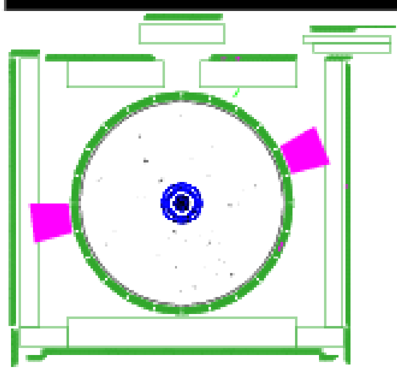
*Eur. Phys J C**14, 525(2000).***

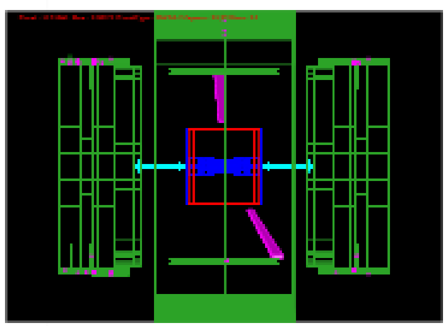


Exclusive Di-photon Production

PRL 108, 081801 (2012)



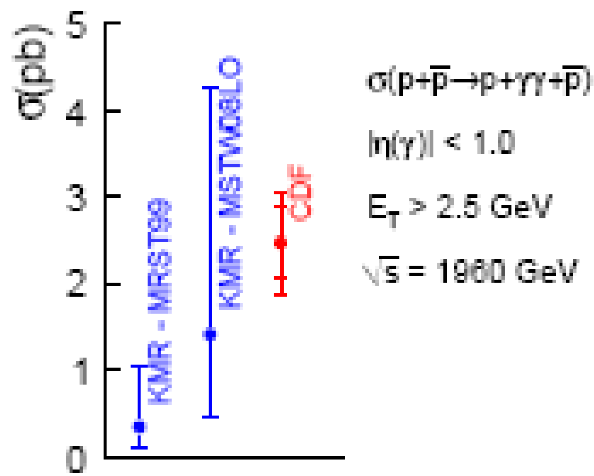




Observed 43 events >> 5 σ

$$\sigma^{|\eta|<1, E_T>2.5\text{GeV}}_{\gamma\gamma\text{excl.}} = 2.48 \pm 0.42(\text{stat}) \pm 0.41(\text{sys})\ \text{pb}$$

Good agreement with
the theoretical predictions



CONCLUSIONS

We have very extensive program of diffractive studies at the Tevatron – new forward detectors R&D, new methodologies developed, many pioneering measurements performed.

So what is in the **future?**

- ✓ expect more results on central exclusive production!
- ✓ more diffractive measurements from the Tevatron energy scan data – soft DD production(?)
- ✓ new types of measurements - MPI in Diffractive events?
- ✓ new MC tools became available – can apply to existing data…

Ref: Papers on diffraction at CDF

Soft Diffraction

Double Pomeron Exc.
PRL 93,141603 (2004)

Multi-Gap Diffraction
PRL 91, 011802 (2003)

Single Diffraction
PRD 50, 5355 (1994)

Double Diffraction
PRL 87, 141802 (2001)

Hard Diffraction

Dijets:
1.8 TeV PRL 85, 4217 (2000)
1.96 TeV PRD 77, 052004 (2008)
1.96 TeV PRD 86, 032009 (2012)

Di-photons
1.96 TeV PRL 108, 081801 (2012)
1.96 TeV PRL 99, 242002 (2007)

Charmonium
1.96 TeV PRL 102, 242001 (2009)

Rapidity Gap Tag
W PRL 78, 2698 (1997)
Dijets PRL 79, 2636 (1997)
b-quark PRL 84, 232 (2000)
J/Ψ PRL 87, 241802 (2001)

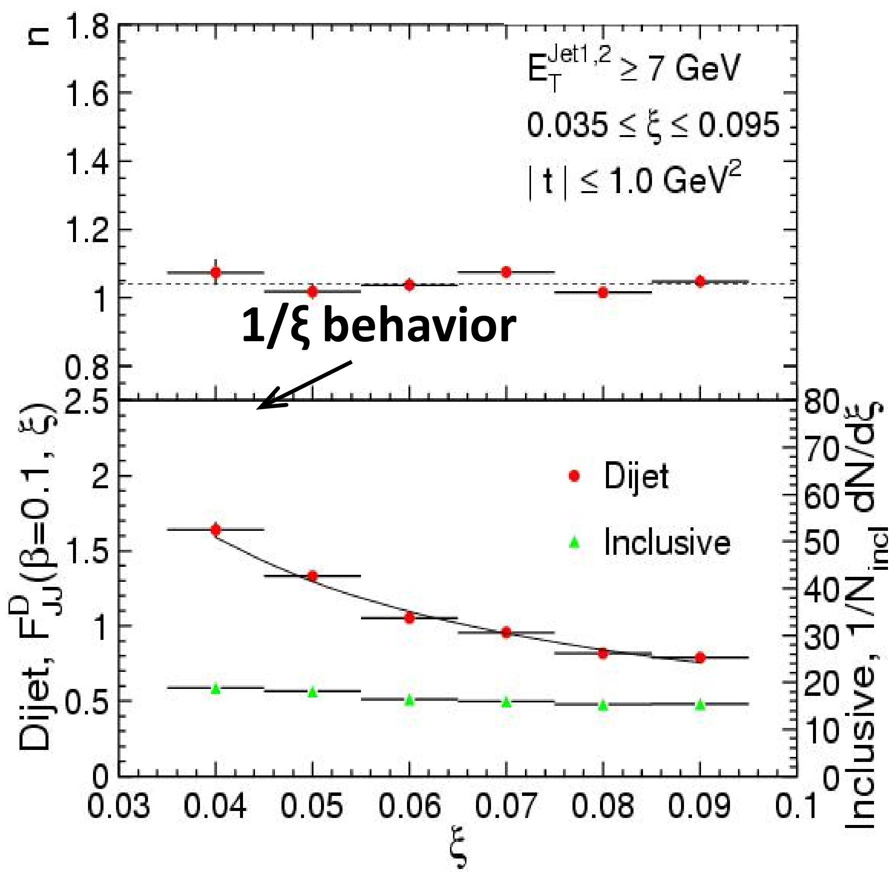
Roman Pot Tag

Dijets:
1.8 TeV PRL 84, 5043 (2000)
630 GeV PRL 88, 151802 (2002)

W/Z:
1.96 TeV PRD 82,112004 (2010)

Jet-Gap-Jet
1.8 TeV PRL 74, 855 (1995)
1.8 TeV PRL 80, 1156 (1998)
630 GeV PRL 81, 5278 (1998)

The Diffractive Structure Function



But, do we have a pomeron exchange?

reggeon contribution ~ ξ
pomeron contribution ~ $1/\xi$ $\rightarrow$

SD dijets – pomeron only,
though ξ values are moderately large

$$F^D_{jj} = C\beta^{-n}\xi^{-m}$$

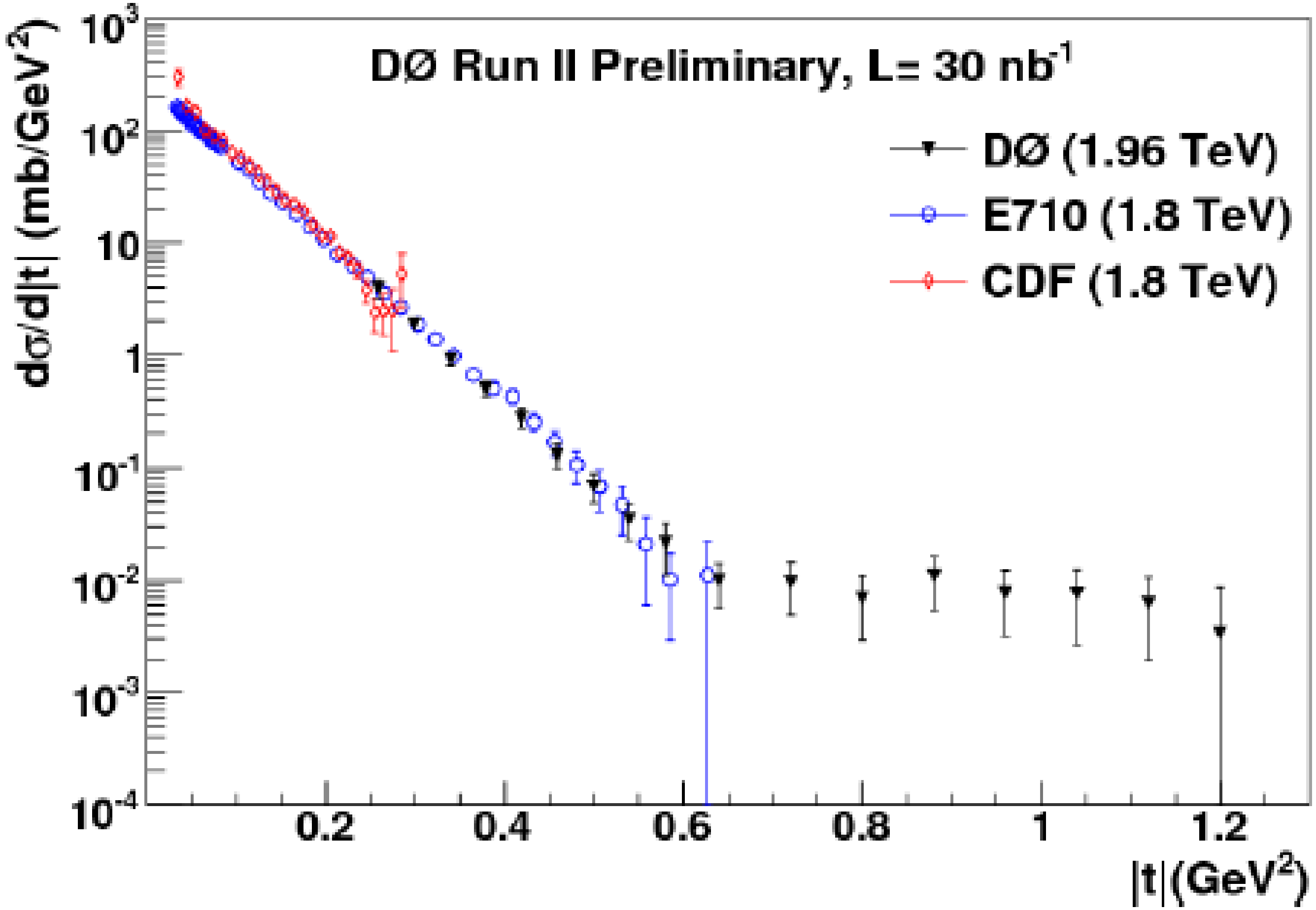
Regge factorization holds

pomeron exchange

$for\ \beta < 0.5$
$n = 1.0 \pm 0.1$
$m = 0.9 \pm 0.1$

Elastic Scattering at √s=1.96

Comparison with CDF and E710



Dynamic alignment of the RPS

Method: iteratively adjust the RPS X and Y offsets from the nominal beam axis until a maximum in the b-slope is obtained at t=0.