Exclusive production and the Higgs boson

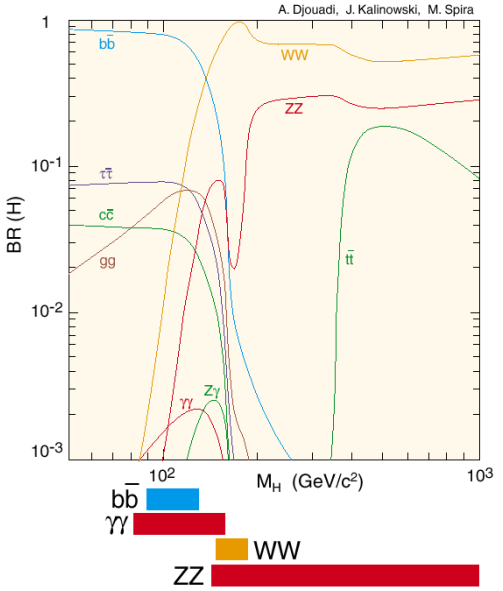
Angela Wyatt (UCL)

- Why look at exclusive Higgs production?
- How might it be measured?
- What measurements should we be making now at the Tevatron?

Search for the Higgs Boson

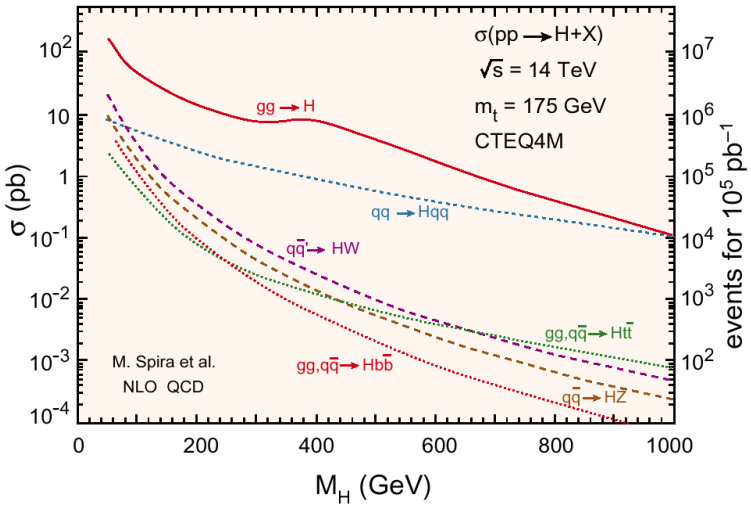
One of the main tasks of the LHC is to search for evidence of the Higgs boson

•A light Higgs is preferred:
- precison EW measurements
  $\Rightarrow M_H < 196$ GeV (95% C.L.)
- direct search at LEP
  $\Rightarrow M_H > 114$ GeV (95% C.L.)
- MSSM - lightest Higgs <135 GeV



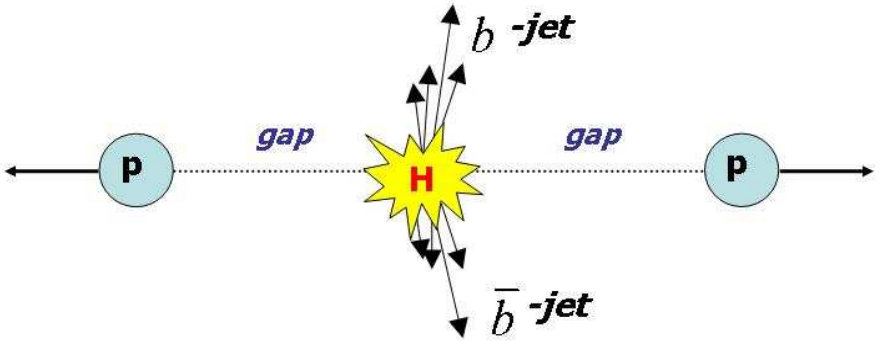
•Number of interesting channels
- For light Higgs either large backgrounds or few events
- worthwhile to consider all possible options

The dominant production and decay are $gg \rightarrow H$ and $H \rightarrow bb$ v. high background
$\Rightarrow$ lower cs processes eg $H \rightarrow \gamma\gamma$



Exclusive Higgs production

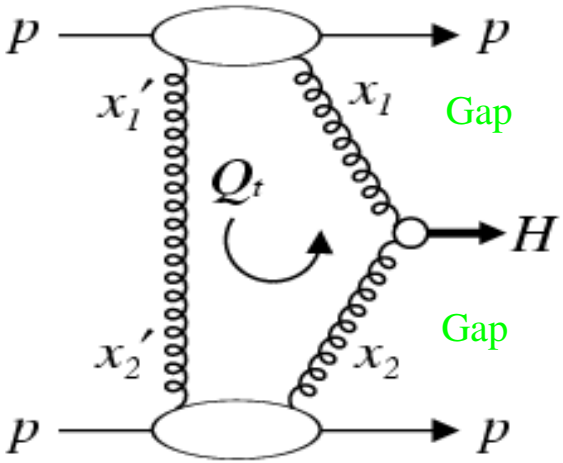
The Higgs boson has vacuum quantum numbers
⇒ could be produced exclusively: *pp*→ *pHp*



➔ Outgoing protons scattered by a small angle
➔ The Higgs decays centrally
➔ Large rapidity gaps between the protons and the Higgs

LO QCD: $gg \rightarrow H$ via a *t*-quark loop
plus an additional gluon exchange that cancels colour ⇒ colour singlet

Colour singlet exchange (diffraction) is also seen as the exchange of a pomeron
⇒ rapidity gap formed.
Very distinct from standard QCD processes



What is the appeal of this process?

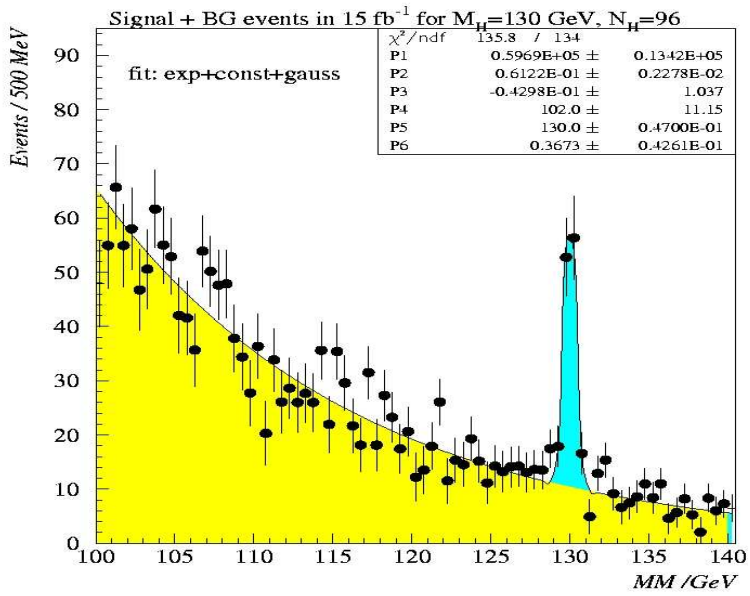
Reconstruct Higgs mass just from the protons missing mass:

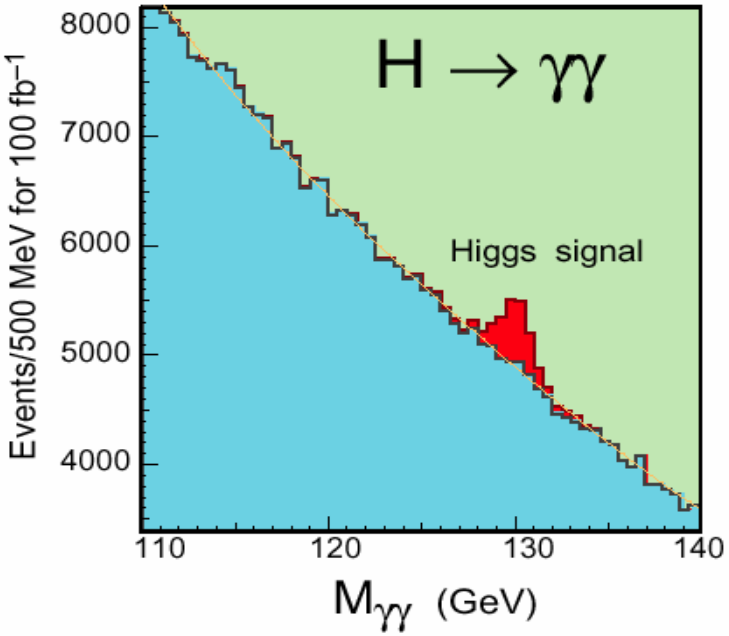
$$M_H^2 = MM^2 = (p_1 + p_2 - p'_1 - p'_2)^2$$

$$M_H^2 = \xi_1 \xi_2 s, \quad \xi = \text{frac mmtm loss of proton}$$

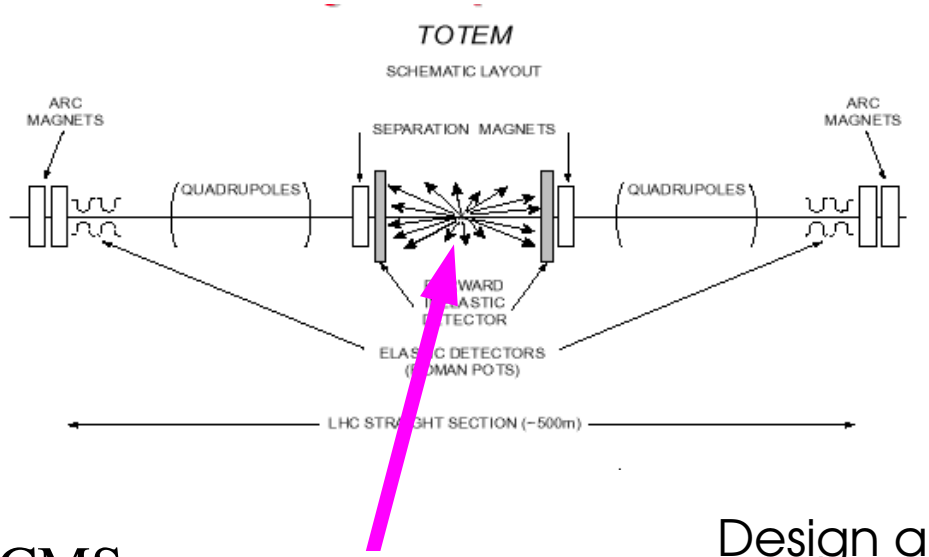
$\Rightarrow$ NEED PROTON TAGGERS

Not affected by central mass resolution
Good S/B





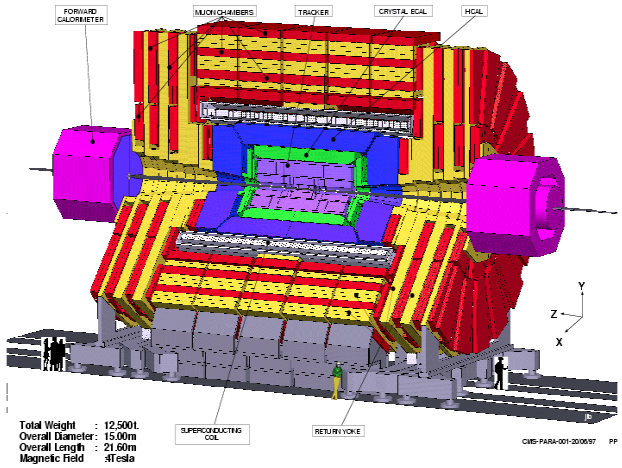
The TOTEM Experiment



Initally designed to run in early low-luminosity phase to measure

- Total Cross Section
- Elastic Scattering
- Diffraction Dissociation

CMS



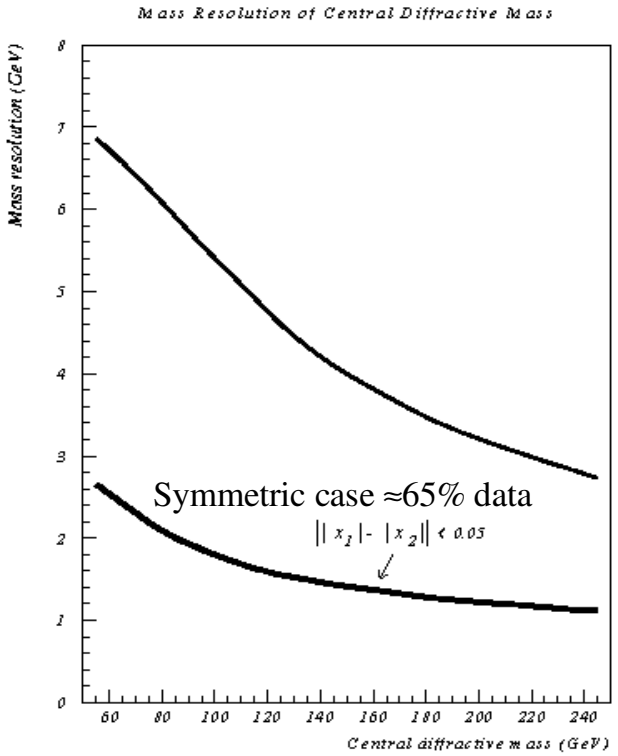
Design allows integration with CMS

Additional proton taggers may be added at 300m, 420m that would have acceptance for exclusive Higgs

Could be used in medium-luminosity phase

Missing Mass Resolution

R. Orava, J. Lamsa, Helsinki group



Range of proton taggers with acceptance at different ξ

$M_H^2 = \xi_1 \xi_2 s \Rightarrow$ need low ξ to detect light

Higgs $\Rightarrow$ proposal for tagger at 425m (or 300m)

Assuming $\Delta X_F / X_F = 10^{-4}$

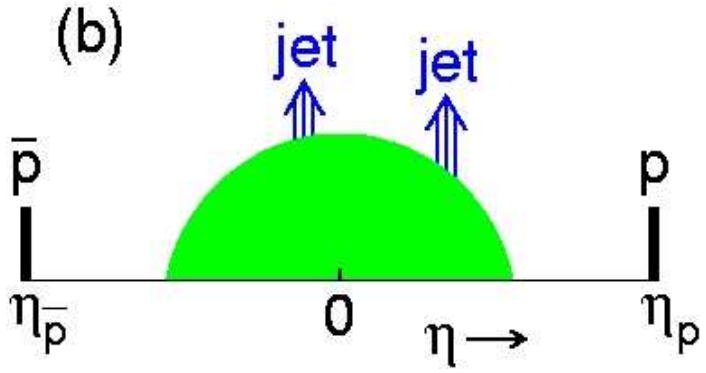
$\Rightarrow \Delta M$ 1-2 GeV

20 GeV < M_X < 160 GeV

M_{xmin} set by minimum deflection (4mm)

M_{xmax} set by last dipole's aperture

CDF Run I Double pomeron exchange dijets



$p\bar{p} \rightarrow pJJX\bar{p}$

Tagged $\bar{p}$: $0.035 < \xi < 0.095$, $|t| < 1\text{GeV}^2$

rapidity gap p side: $0.01 < \xi_p < 0.03$

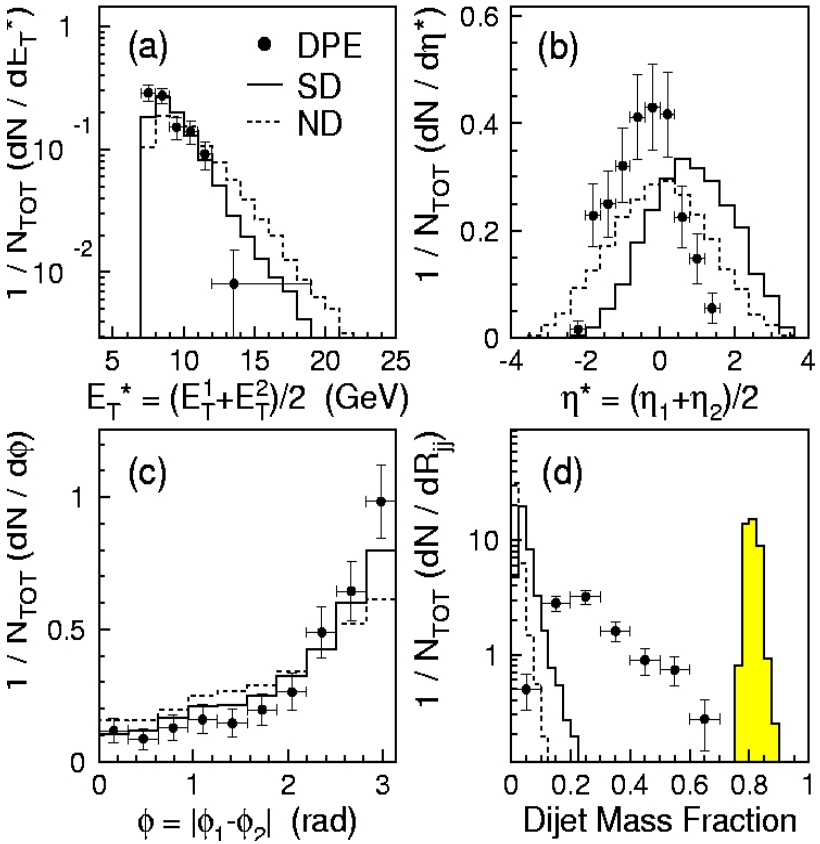
2 jets $E_T > 7$ GeV, $-4.2 < \eta < 2.4$

$\Rightarrow$ around 130 events

Mass Fraction:

$$R_{jj/X} = \frac{M_{jj}^{cone}}{M_X}$$

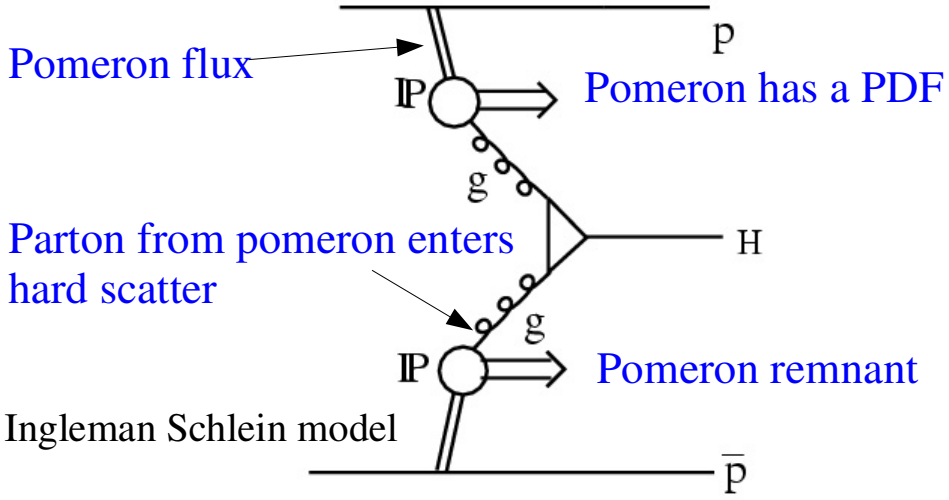
exclusive: $0.7 < R_{jj/X} < 0.9$



Inclusive $\sigma = 43.6 \pm 4.4$ (stat) ± 21.6 (syst) nb

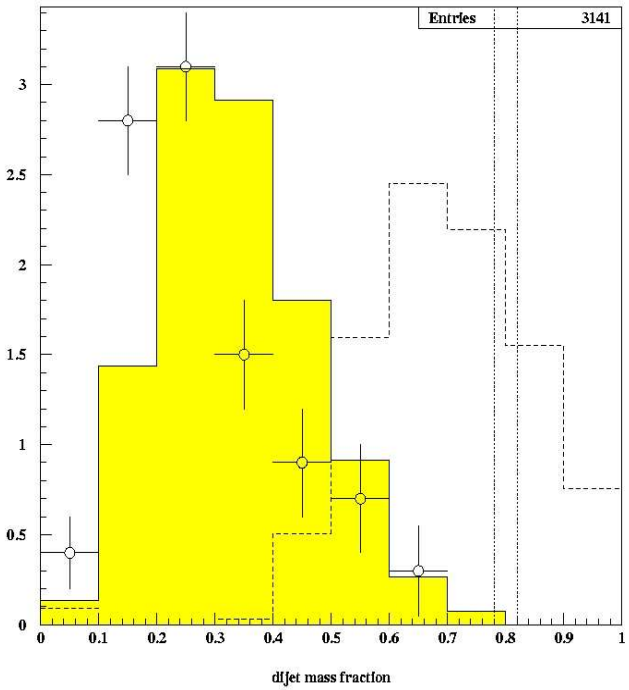
Exclusive $\sigma < 3.7$nb (95% C.L)

Pomeron-pomeron interaction



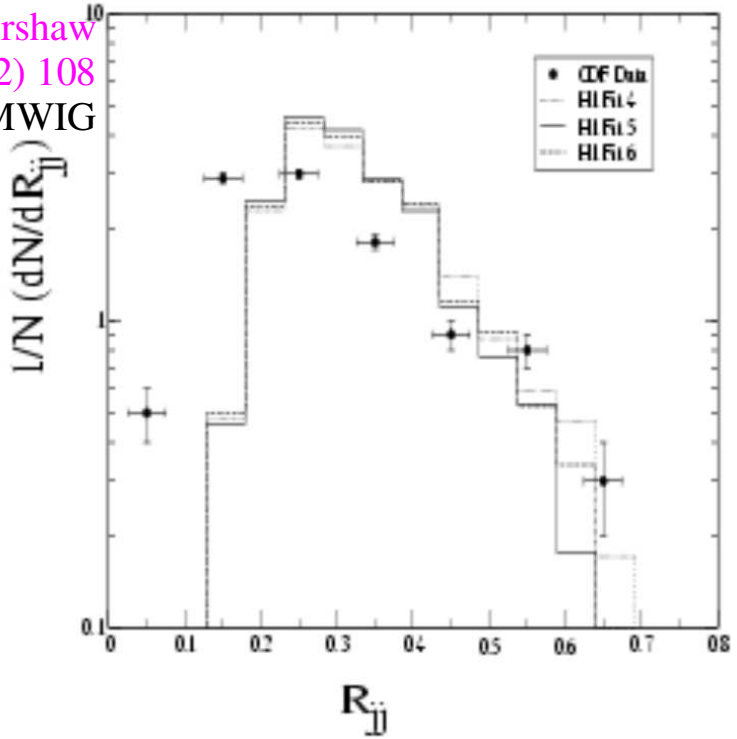
Additional gap survival factor needed to allow for probability that the gap is destroyed by additional soft interactions.

Predictions made using this model use the data to fix the normalisation



Boonekamp, Peschanski, Royon.
Phys Lett 87 (201) 251806

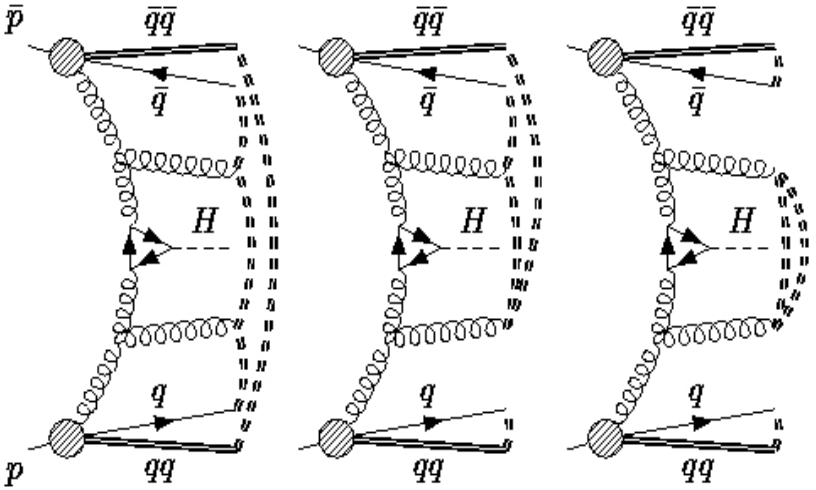
Appleby, Forshaw
Phy. Lett B541 (2002) 108
POMWIG



Soft Colour Interaction model

Enberg, Ingelman and Timneanu

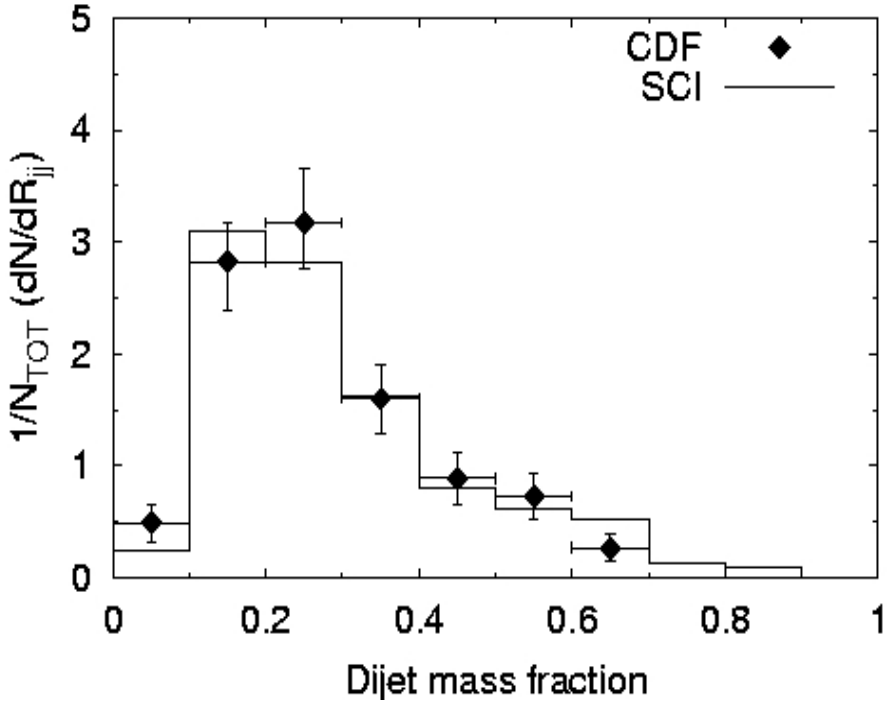
Soft colour exchanges alter topology of colour fields



Standard perturbative matrix elements and parton showering (e.g PYTHIA).

Soft colour exchange (non-perturbative) then effects final colour state.

Phys Rev Lett 89 (2002) 081801

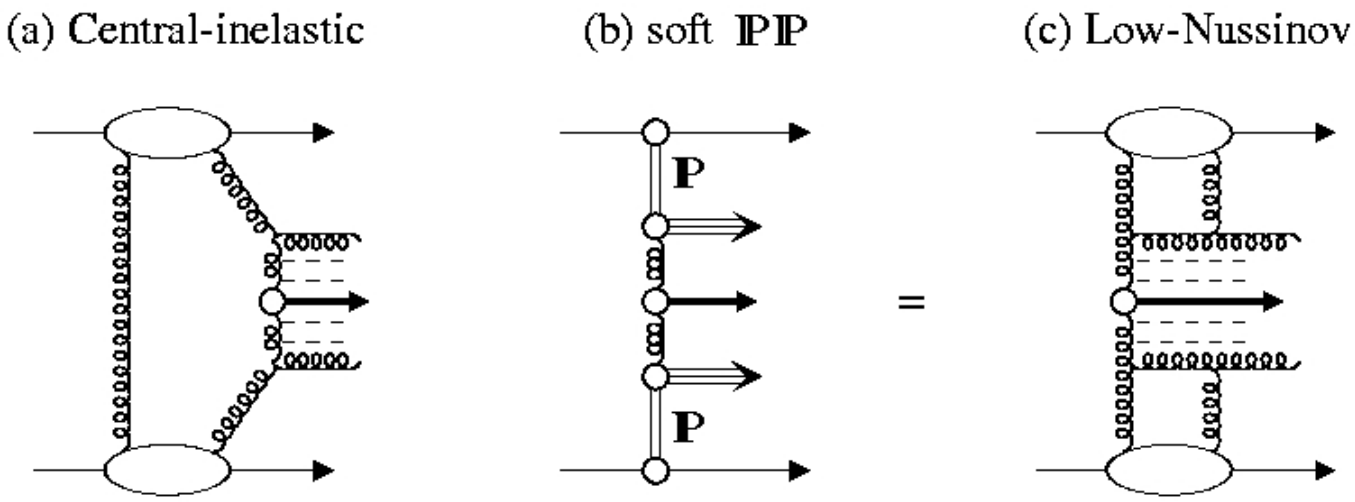


Good agreement with DPE dijet data - shape and cs

also other non-exclusive measurements

QCD Interpretation

Khoze, Martin and Ryskin E. Phys. J C23 (2002) 211



LO HO

HO has similar mass distribution ⇒ gets distributions shape right (normalised to dijet data)

inelastic dijets: 40nb (factor 2 uncertainity)
- good agreement

exclusive dijets: 1nb - not expect to see in run I - should in run II

Is exclusive Higgs observable at the LHC?

DeRoeck, Khoze, Martin, Orava, Ryskin E. Phys. J C25 (2002) 391

Signal

Author	excl σ_H (fb)
Cudell, Hernandez	300
Levin	20
Khoze, Martin,Ryskin	3
Enberg et al.	0.19

Doesn't disagree with CDF dijets

Model for inelastic processes

Backgrounds (for tagged b-jets)

Exclusive *bb*: supressed by Jz = 0 selection rule
Exclusive *gg*: if fake b-jets
HO processes - reduced by $M_{missing} = M_{bb}$

Tevatron:

1. Search for exclusive production
   - Measure exclusive dijets (gg)
   - Look for exclusive bb
   - Test predictions
2. Study inelastic processes
   - Measure background
   - Test models

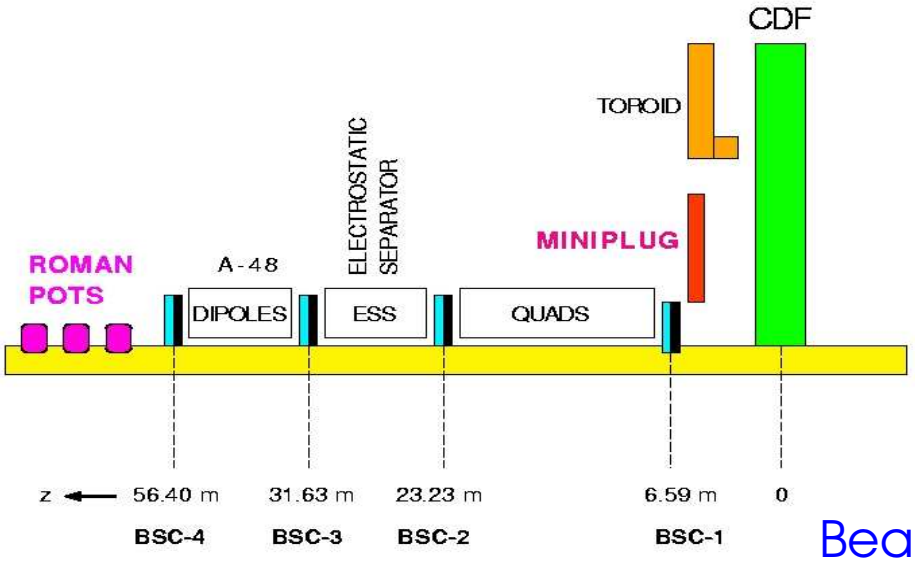
Could be a competitive channel.

DeRoeck, Khoze, Martin, Orava, Ryskin E. Phys. J (2002) 391

30 fb^{-1} at LHC

Higgs signal		number of events: signal	number of events: background	S/B	significance $S/\sqrt{S+B}$
a) $H \to \gamma\gamma$	CMS	313	5007	$0.06 \left(\frac{1\,\text{GeV}}{\Delta M_{\gamma\gamma}}\right)$	4.3σ
	ATLAS	385	11820	$0.03 \left(\frac{2\,\text{GeV}}{\Delta M_{\gamma\gamma}}\right)$	3.5σ
b) $t\bar{t}H$, $H \to b\bar{b}$		26	31	$0.8 \left(\frac{10\,\text{GeV}}{\Delta M_{b\bar{b}}}\right)$	3σ
c) $gg^{PP} \to p + H + p$, $H \to b\bar{b}$		11	4	$3 \left(\frac{1\,\text{GeV}}{\Delta M_{\text{missing}}}\right)$	3σ

Double Pomeron Exchange at CDF Run II



Miniplug calorimeter (new)

high transverse granularity

$3.6 < |\eta| < 5.1$

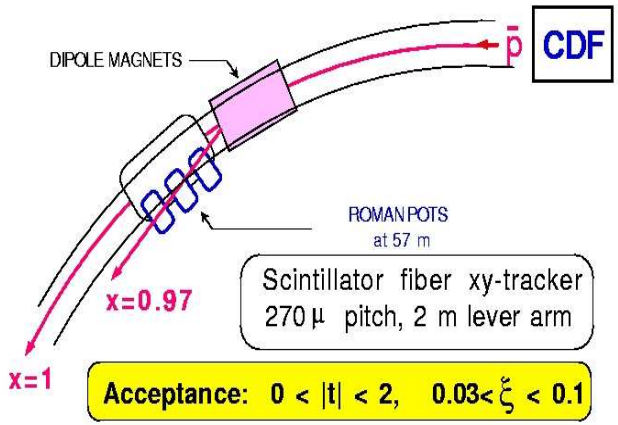
allows larger rapidity gaps to be measured - lower values of ξ_p

Beam Shower Counters (new)

tag forward rapidity gaps

$5.5 < |\eta| < 7.5$

scintillation counters around the beam pipe

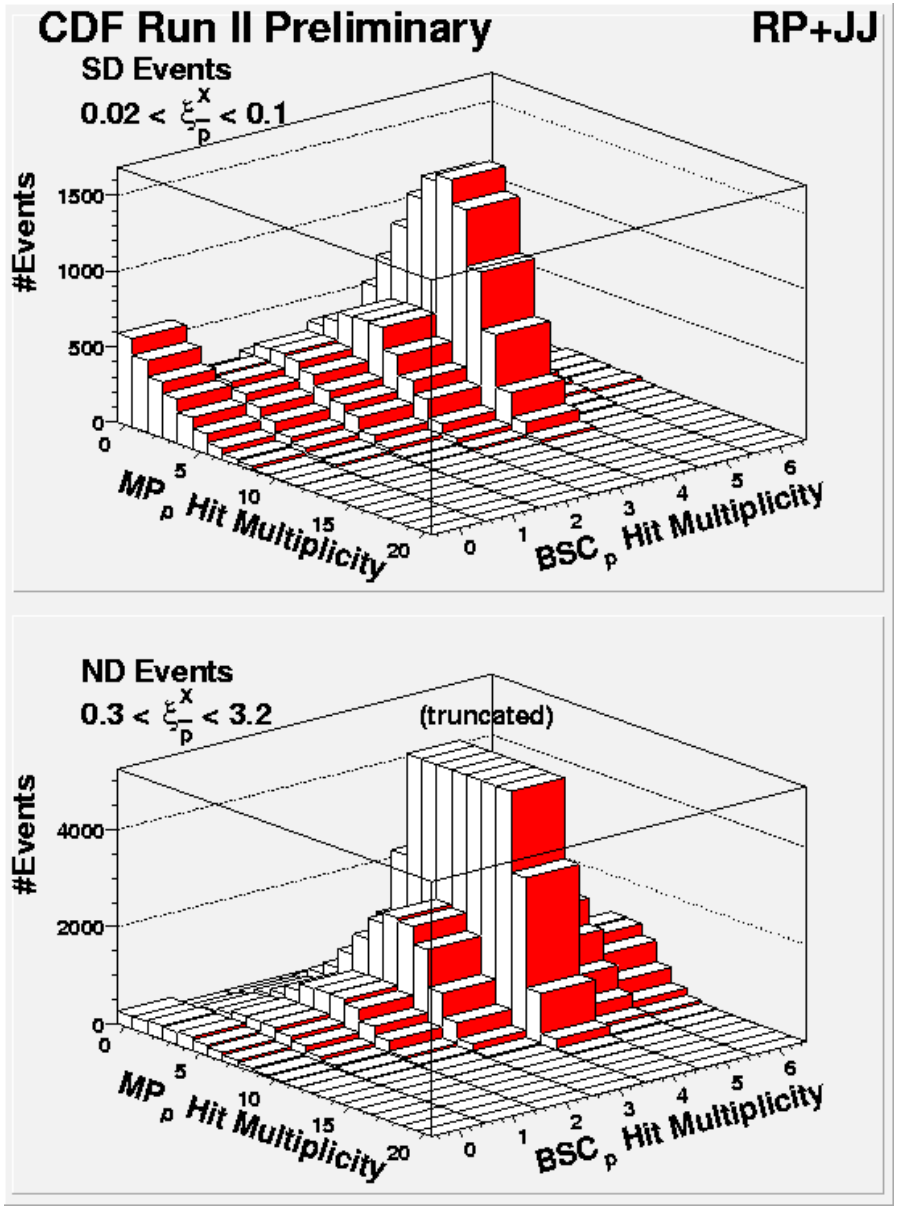


Roman Pot Fibre Tracker (new readout)

tags outgoing anti-proton

$0.02 < \xi < 0.1$, $0 < |t| < 2$.

Double Pomeron Exchange at CDF Run II

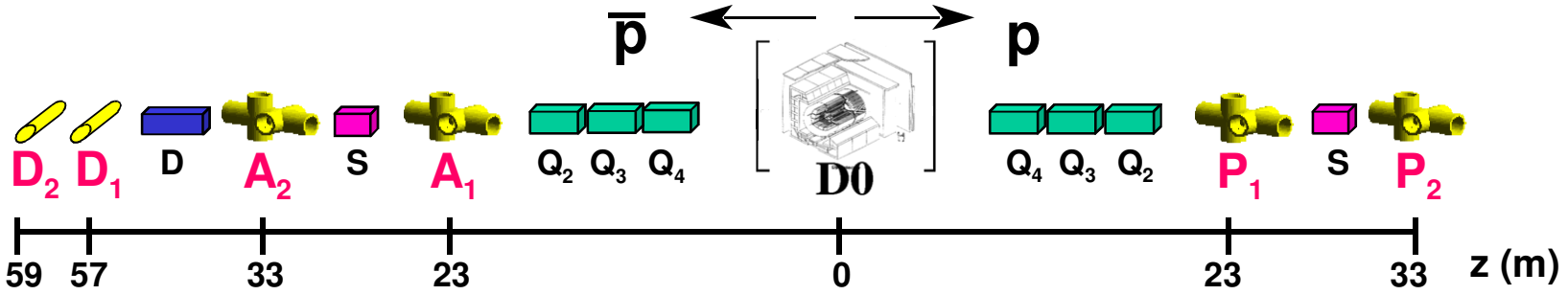


- Single diffractive events are selected using the anti-proton tagger.

- Double pomeron exchange events selected:
  - beam shower counter veto
  - zero multiplicity in east mini-plug

- Dedicated DPE trigger so lots more events than run I already!

Double Pomeron Exchange at D0 Run II



9 Momentum Spectrometers composed of 18 Roman Pots

Scintillating fiber detectors installed in Roman Pots can track the scattered protons and antiprotons

The reconstructed track is used to calculate the momentum and scattering angle of protons and antiprotons

Cover a t region ($0 < t < 4.5$ GeV^2) that was never explored before at Tevatron energies

Allows combination of proton tracks with high p_T scattering in the central detector

$$0 < \xi < 0.08$$

PHYSICS PROGRAM

Hard Double Pomeron reactions

Diffractive jet production

Diffractive heavy quark (c, b and t) production

Diffractive W and Z production

Glueball searches

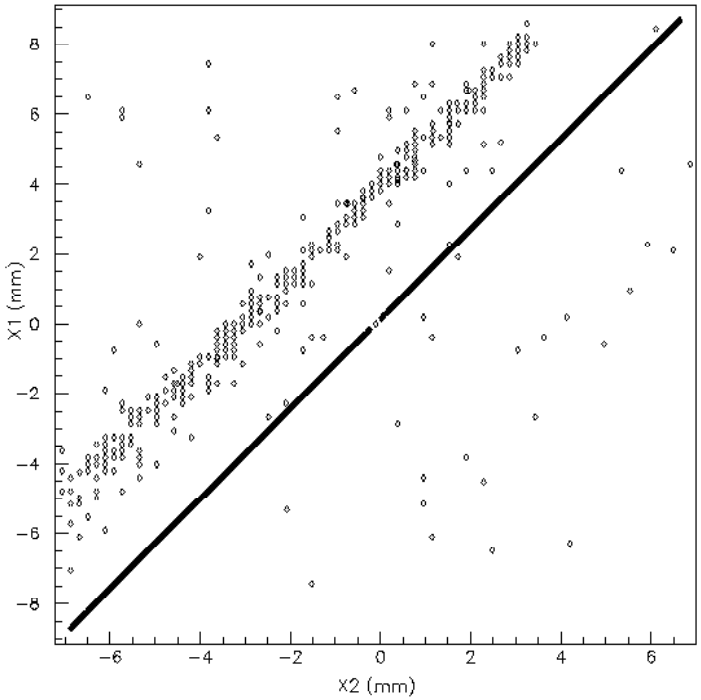
Elastic and Total proton-antiproton cross section

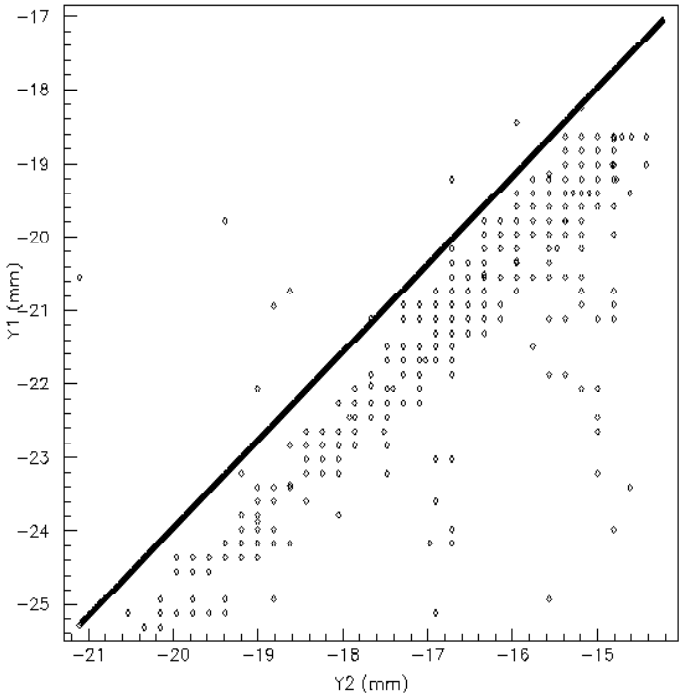
Inclusive Single Diffraction

Inclusive Double Pomeron reactions

D0 Proton Spectrometer - Alignment

P1D-P2D Alignment: Data X MC

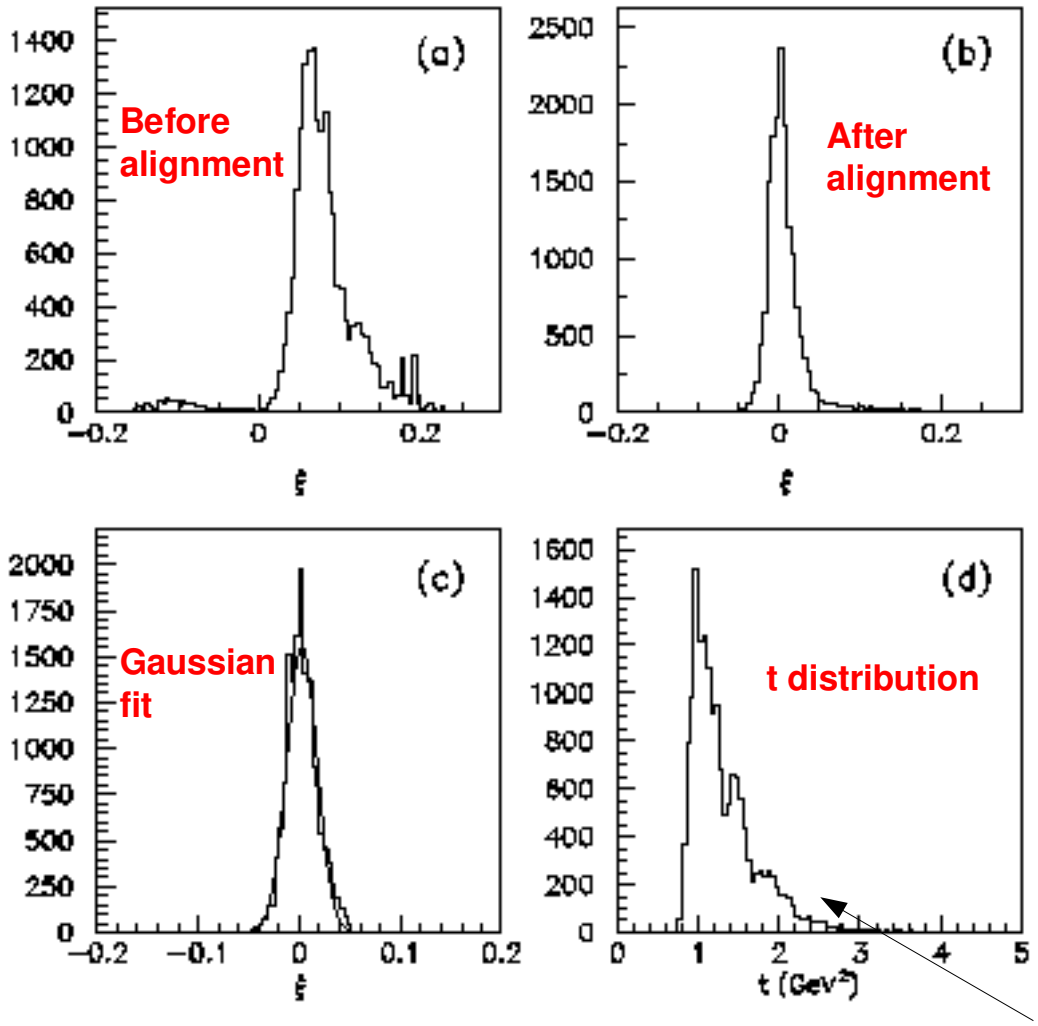




Good correlation between x1,x2 and y1,y2 in data but shifted from MC expectation: (3 mm in x and 1 mm in y)

D0 Proton Spectrometer - Alignment

ξ and t Distributions for Elastic Events (After alignment)



AU-PD Configuration

~20K events are reconstructed

· Experimental ξ-resolution is larger than expectation (MC).

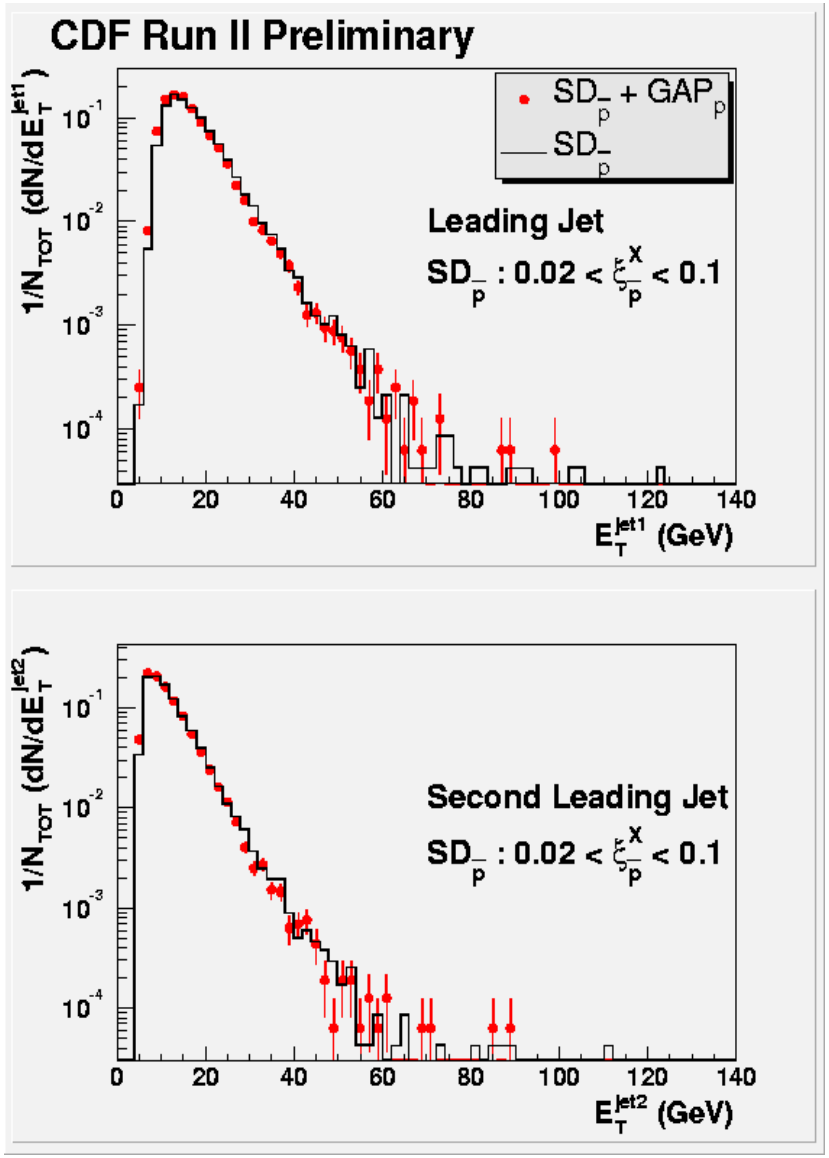
• Shape of t distribution in agreement with expected angular acceptance (MC).

Elastic *t* range 0.55 - 4 GeV

Dijet production from DPE

Have started to collect a large sample of DPE dijets.

What questions do we need to answer?



Search for (and hopefully measure) exclusive dijet production

- test exclusive Higgs predictions

Improve inelastic measurement and test models

- exclusive process background
- may also be useful for Higgs

Search for inelastic bb

- exclusive process background
- maybe around 1 % of inelastic dijets
- exclusive bb should be supressed

Dijet production from DPE

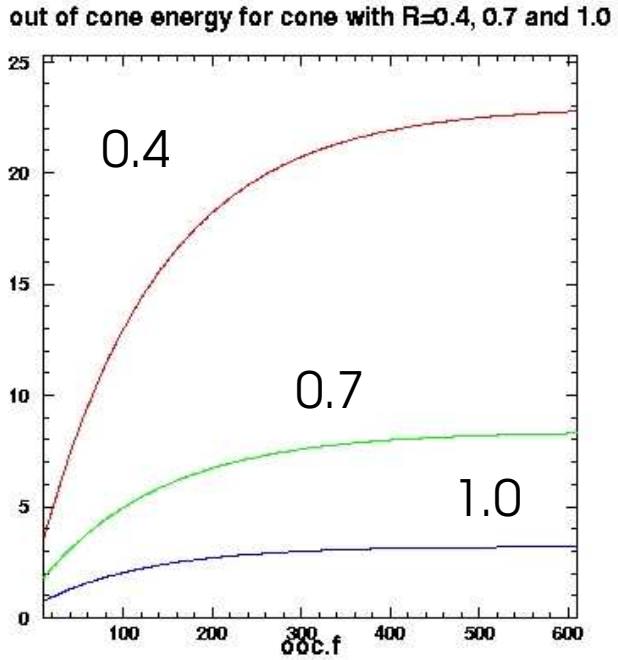
Does exclusive production occur?

-dijet production should have biggest c.s.
- Khoze et al. Predict around 1nb run I cuts
  & 60pb $25 < E_t < 35$ GeV, $\Delta\eta < 1$.

How should we define exclusive dijet production??
- need to measure nothing but the jets

Hadronisation has big effect
- apply corrections?
- affect choice of jet algo, cone size?

Correction for underlying event
- Inelastic events: jet Et is corrected for this run I: 0.37 GeV (c.f 0.54 GeV SPE, 1.16 GeV ND)
- Exclusive events: correction = 0. GeV
- $R_{jj/x}$ dependant correction

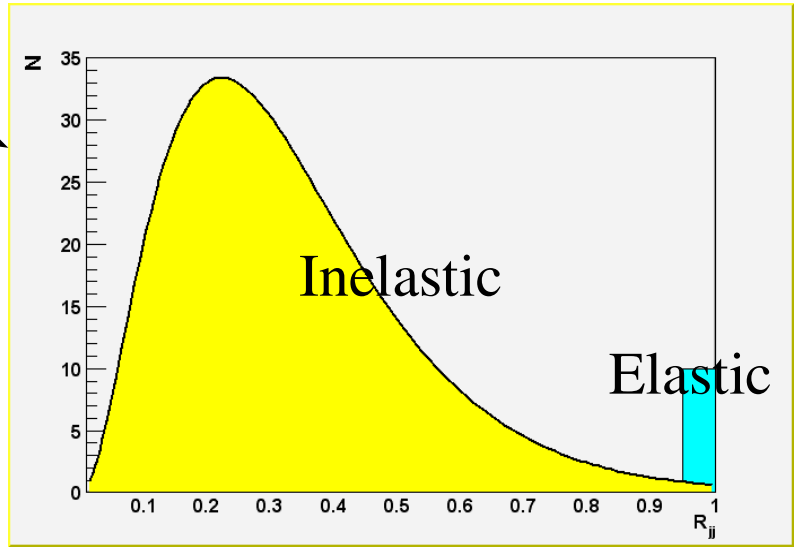


R= 0.7, E_t = 7GeV: corr =1.6GeV

Need to study how significant these effects are:
- inelastic: use pomwig MC to model
- elastic: need MC – could use pomwig tail

Dijet production from DPE

In what kinematic range should we look??
- would be nice to see a signal like this



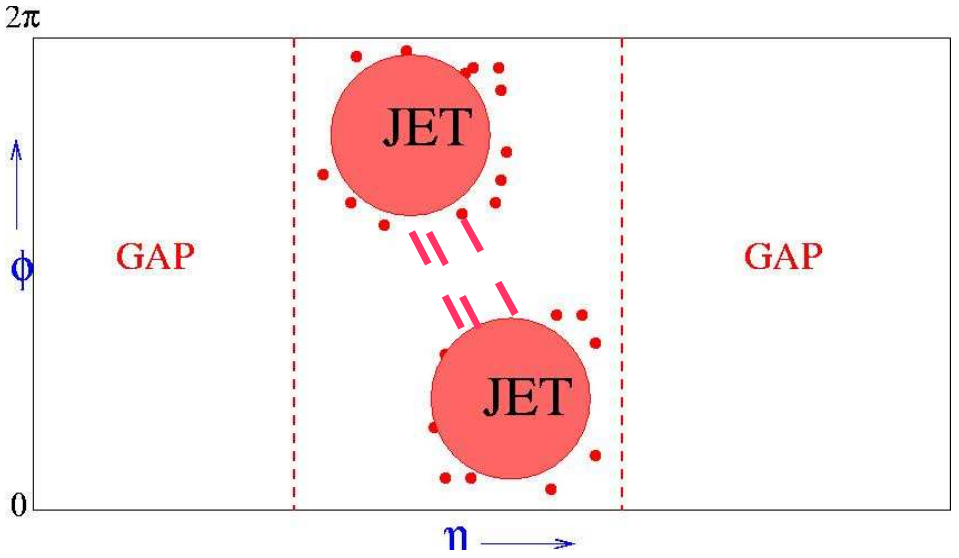
- what are inelastic predictions in high R_{jj}
- look in different mass and E_t ranges

- also important to measure exclusive dijet cs in Higgs mass range (test predictions)

Are there other variables as well as R_{jj}?

-avoid jets
- but depends on where pomeron remnants are

- look at **bb/jj** ratio
  - many uncertaintys cancel exclusive production would cause a supression at large R_{jj}



DPE Diphoton production

Much cleaner than dijets -search exclusive production.

- easier to test inelastic predictions

Colourless like Higgs - see if this effects gap survival probability

Low pt $gg \rightarrow \gamma\gamma$ via a quark loop, bit like Higgs coupling

High pt $qq \rightarrow \gamma\gamma$, sensitive to quark distribution (complementary to dijet (gg))

Exclusive $\gamma\gamma$ Khoze, Martin, Ryskin Eur.Phys.J.C23:311-327,2002

σ: 0.5 (0.008) fb M($\gamma\gamma$) ~ 50 (120) GeV

Inelastic $\gamma\gamma$

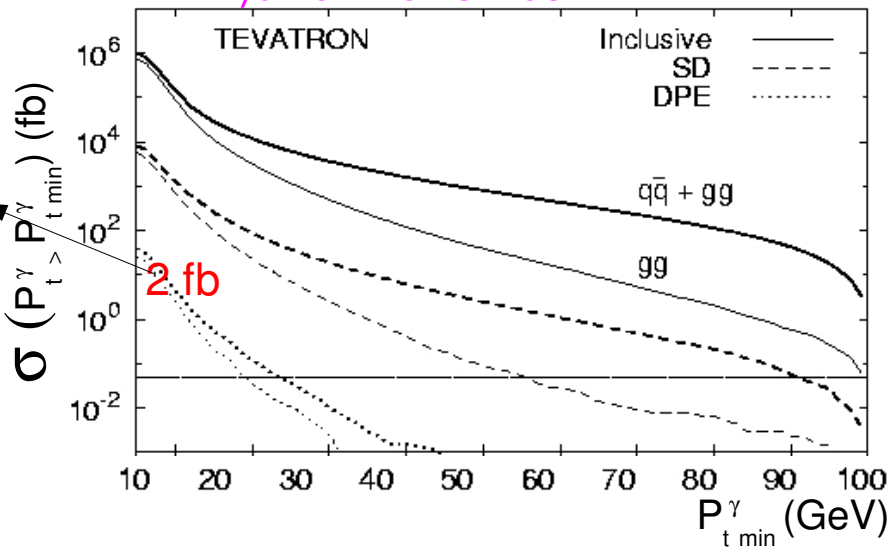
process	σ/fb (inclusive)	σ/fb $I\!P$	σ/fb $I\!R$	σ/fb $(I\!P + I\!R)$	σ/fb $(\times S^2)$
2 γ, $E_t > 12$ GeV, $\eta < 2$	72477	265.6	1009.8	1275.4	128
2 γ, $E_t > 20$ GeV, $\eta < 1$	6345	19.6	63.2	82.8	8.3
2 γ, $E_t > 7$ GeV, (CDF cuts)		684	567	1251	125

Cox, Forshaw, Heinemann (pomwig) Phys.Lett.B540:263-268,2002

Boonekamp, Peschanski, Royon hep-ph/0301244

E_t (γ) > 12 GeV, $\eta(\gamma)$ < 1(2) 71 (9) fb

SCI: Enberg, Ingelman Timneanu Phys.Rev.D67:011301



DPE Diphoton production

Exclusive $\gamma\gamma$

KMR predict 1 event in $2fb^{-1}$, larger at lower M($\gamma\gamma$)

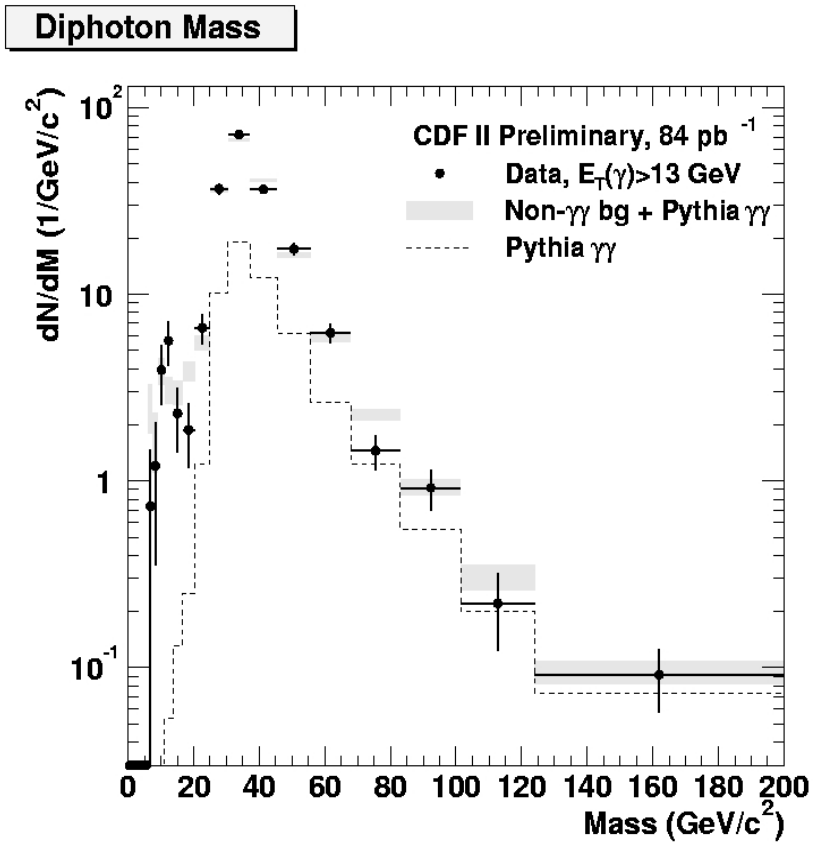
CDF: no p-tagger efficiency M($\gamma\gamma$) < 40 GeV but can trigger on 2 gaps or $\gamma\gamma$

D0 has some acceptance down to elastic events

CDF currently 84 pb^{-1} of diphoton data, $E_t(\gamma) > 13$ GeV, $|\eta(\gamma)| < 1.0$

$\Rightarrow M(\gamma\gamma) > 15$ GeV

Can extend to $E_t(\gamma) > 7$ GeV, $|\eta(\gamma)| < 2.5$



Inelastic $\gamma\gamma$

CFH (pomwig):

250 (12.5) events in $2fb^{-1}$ ($100pb^{-1}$)

EIT (SCI): 2 events in $2fb^{-1}$

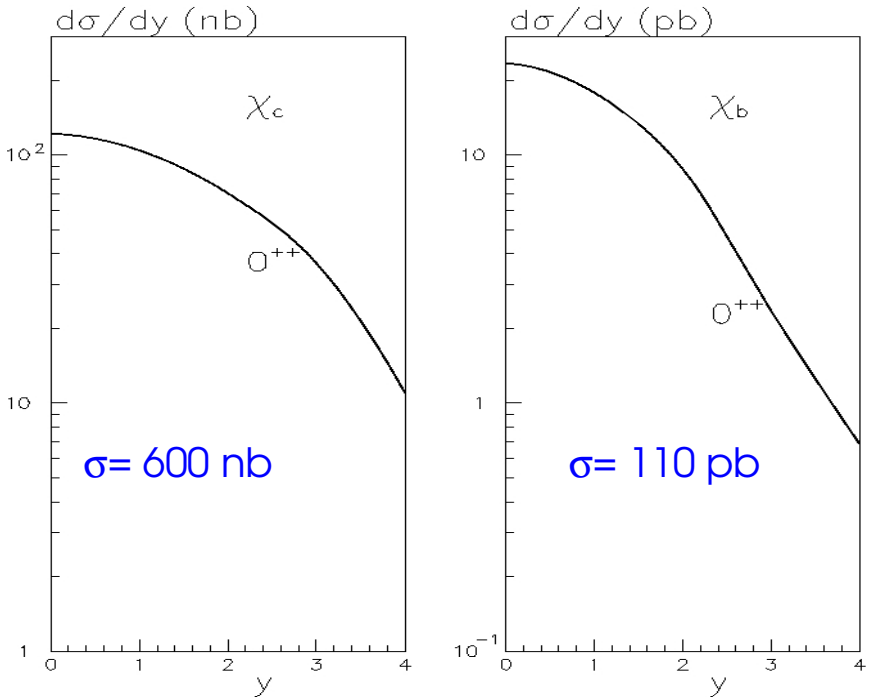
CDF run I efficiency 50%

-should be able to differentiate

- also look at single diffraction

Exclusive χ production

Clearer way of looking for exclusive production



Khoze, Martin, Ryskin, Eur. Phys. J. C19 (2001) 477

$pp \rightarrow p\chi p$ $\quad (0^+(0^{++}))$

$\chi_c \rightarrow J/\psi\,\gamma \rightarrow \mu\mu\gamma$

$\chi_b \rightarrow \Upsilon\,\gamma \rightarrow \mu\mu\gamma$

$M(\chi_c) = 3.4$ GeV, $M(\chi_b) = 9.9$ GeV

assume symmetric

$\rightarrow \xi = 0.002, 0.005$

NOT in CDF acceptance but in D0 acceptance

- Can trigger on the muons:
  CDF: 1.5-2 GeV, $|\eta| < 1$.
- Look for 'empty' detector
  - mini-plug, BSC, central detectors

Exclusive χ production

$\chi_c(0^{++})$	Factor	Cross section
total cross-section		600nb
BR($\chi_{c0} \to \gamma J/\psi$)	0.0066	4 nb
BR($J/\psi \to \mu^+\mu^-$)	0.0588	233 pb
P($\gamma \to e^+e^-$)	0.12	28 pb
acceptance ($\|\eta_\mu\| < 1.0$) (GUESS)	0.3	8.4 pb
photon efficiency est. (Run I)	0.7	6 pb
events in 2 fb^{-1} (100 pb^{-1})	12,000 (600)	

Indication of c.s. size

Low E_T γ - best mass resoln from conversions

Should be visible!

Although $\chi_c(2^{++})$ supressed - much larger BR and easier to measure

$\chi_b(0^{++})$	Factor	Cross section
total cross-section		110 pb
BR($\chi_{b0} \to \gamma\Upsilon$) NOT MEASURED	0.01	1.1pb
BR($\Upsilon \to \mu^+\mu^-$)	0.025	27 fb
P($\gamma \to e^+e^-$)	0.12	3.3fb
acceptance($\|\eta_\mu\| < 1.0$) (GUESS)	0.3	1 fb
photon efficiency est. (Run I)	0.7	0. 7 fb
events in 2 fb^{-1}	1.4	

B.R. < 6% at 90% C.L.

Not so promising

Summary

Exclusive Higgs production may be a competitive channel in which to search for the Higgs boson.

At the Tevatron we need to search for exclusive production, test models and measure the backgrounds.

New detectors at D0 and CDF are working well and ready to make some of these measurements.

Dijet measurements, in particular, need a better understanding in order to observe exclusive production.

The measurements at CDF/D0 contribute to a wider set of measurements help understand diffraction and QCD better.