Central Exclusive Production in CDF

Mass > 5 GeV (Jim Pinfold's talk for Mass < 5 GeV)

Mike Albrow, Fermilab

$$\gamma\gamma \rightarrow e^+e^-, \mu^+\mu^-$$
$$\gamma + I\!P \rightarrow Y(1S), Y(2S), Y(3S), Z(?)$$
$$I\!P + I\!P \rightarrow \gamma\gamma$$

Introduction

e+e- Mass 10 – 40 GeV (and γγ) … not new, a brief reminder

e+e- and μ+μ- Mass 40 – 100 GeV, and Exclusive Z search (new PRL)

μ+μ- Mass 8 – 40+ GeV, Upsilons Y photoproduction, χ_b ?(prelim.)

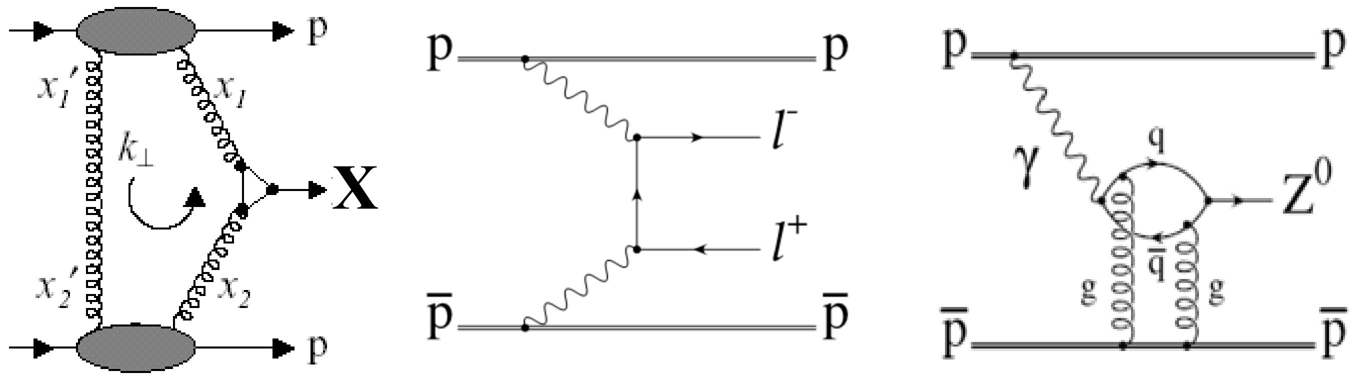
Some LHC-relevant comments

Introduction

Central Exclusive Production $\boxed{p+\bar{p} \to p+X+\bar{p}}$

where X is a simple state fully measured, and no other particles produced.

(Cannot detect p/pbar, down beam pipe, but BSC → η = 7.4 empty)



(& VM)

Motivation:

In CDF, sophisticated tests of QCD with large rapidity gaps Δy

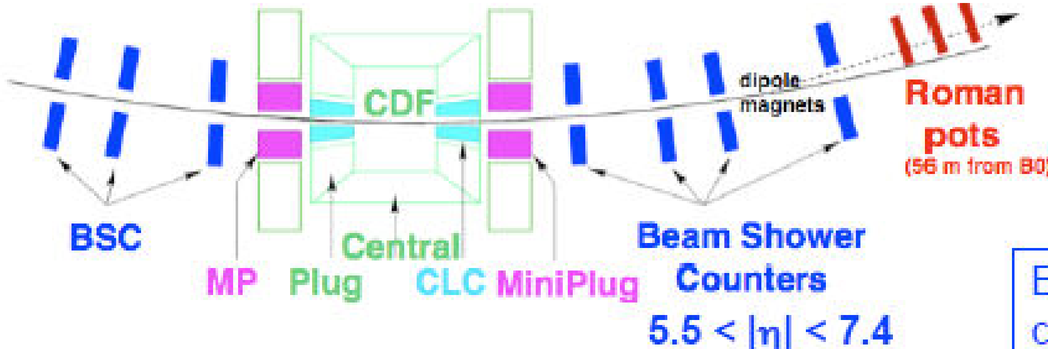
Looking forward to LHC:

Interesting examples → $X = h, H, W^+W^-, \tilde{l}^+\tilde{l}^-, \ldots$

If see h, H : **Mass, width, spin J, C = +1, Couplings H – gg, …**

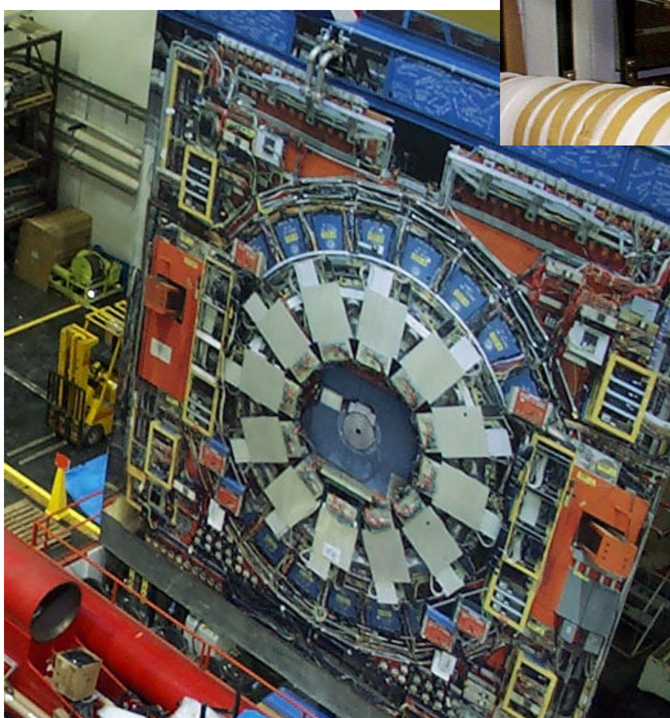
in a unique way, even if e.g. $h(140) \to b\bar{b}$ & $H(150) \to b\bar{b}$

CDF Forward Detectors (see Goulianos talk on Tuesday for more details)



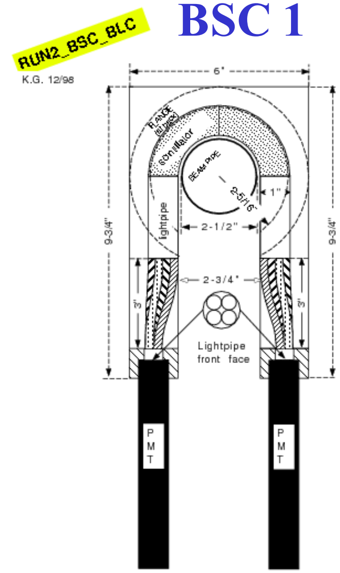
Each BSC consists of 2-4 PMTs

MINIPLUG

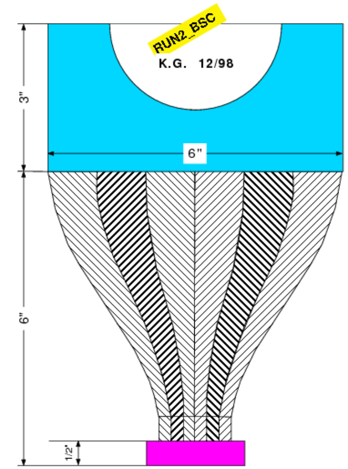


CLC
Cherenkov
Luminosity
Counters

BSC 1



BSC 2,3,4



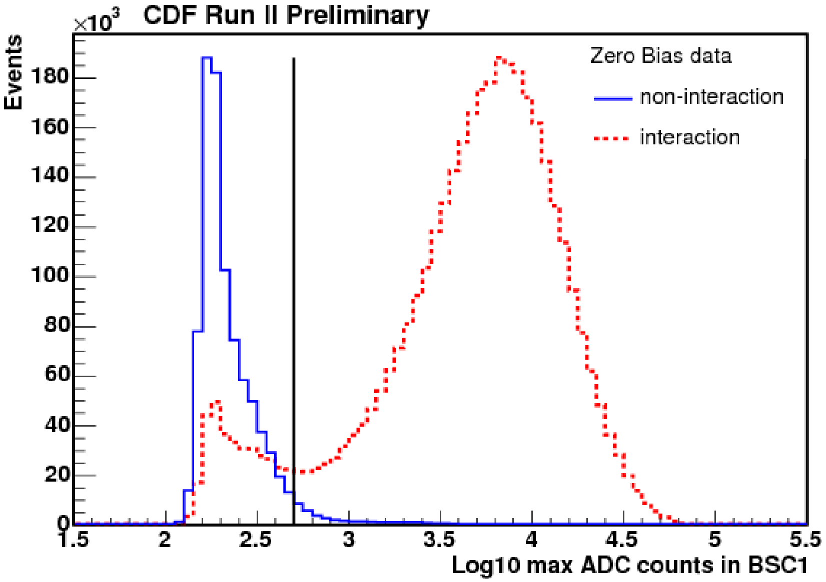
BSC very important as rap gap detectors. All LHC experiments should have them!

FORWARD PHYSICS WITH RAPIDITY GAPS AT THE LHC

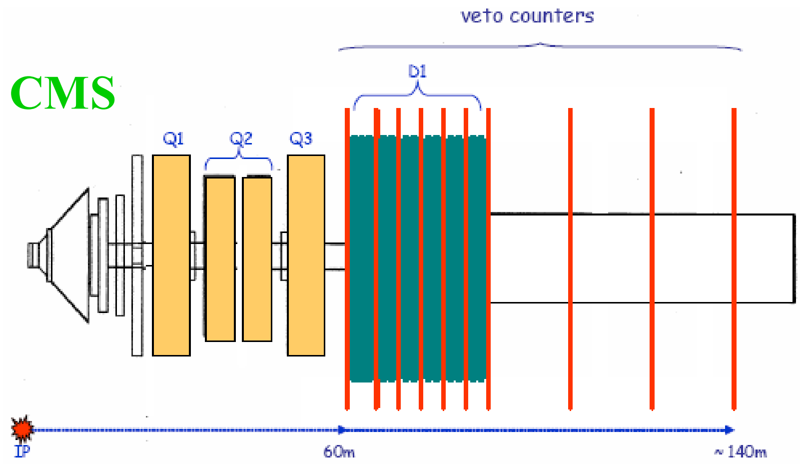
arXiv:0811.0120

Michael Albrow[1], Albert De Roeck[2], Valery Khoze[3], Jerry Lämsä[4,5], E. Norbeck[6], Y. Onel[6], Risto Orava[5], and M.G. Ryskin[7]

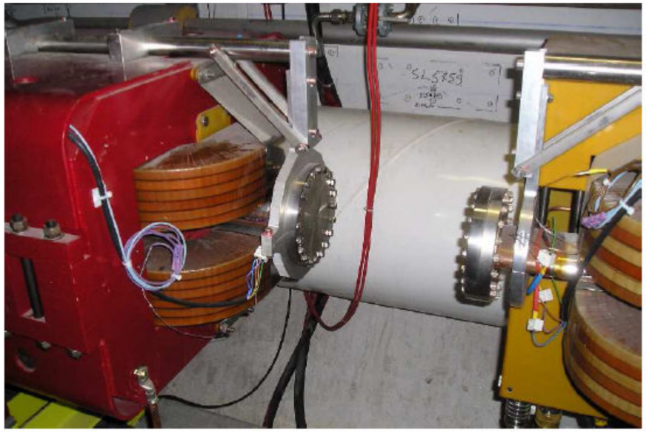
Sunday, November 09, 2008



Warm accessible vacuum pipe (circular – elliptical)
Do not see primary particles, but showers in pipe ++
Simple scintillator paddles: **Gap detectors in no P-U events**



Take 0-bias events (Essential!)
{1} = prob no interaction
{2} = prob >= 1 interaction
Take hottest PMT of 8 BSC1
Plot log max ADC for {1} and {2}
Separates empty / not empty
Repeat for all detectors



A bit of history. LOI to FNAL PAC:

CDF/PHYS/EXOTIC/CDFR/5585

March 26, 2001

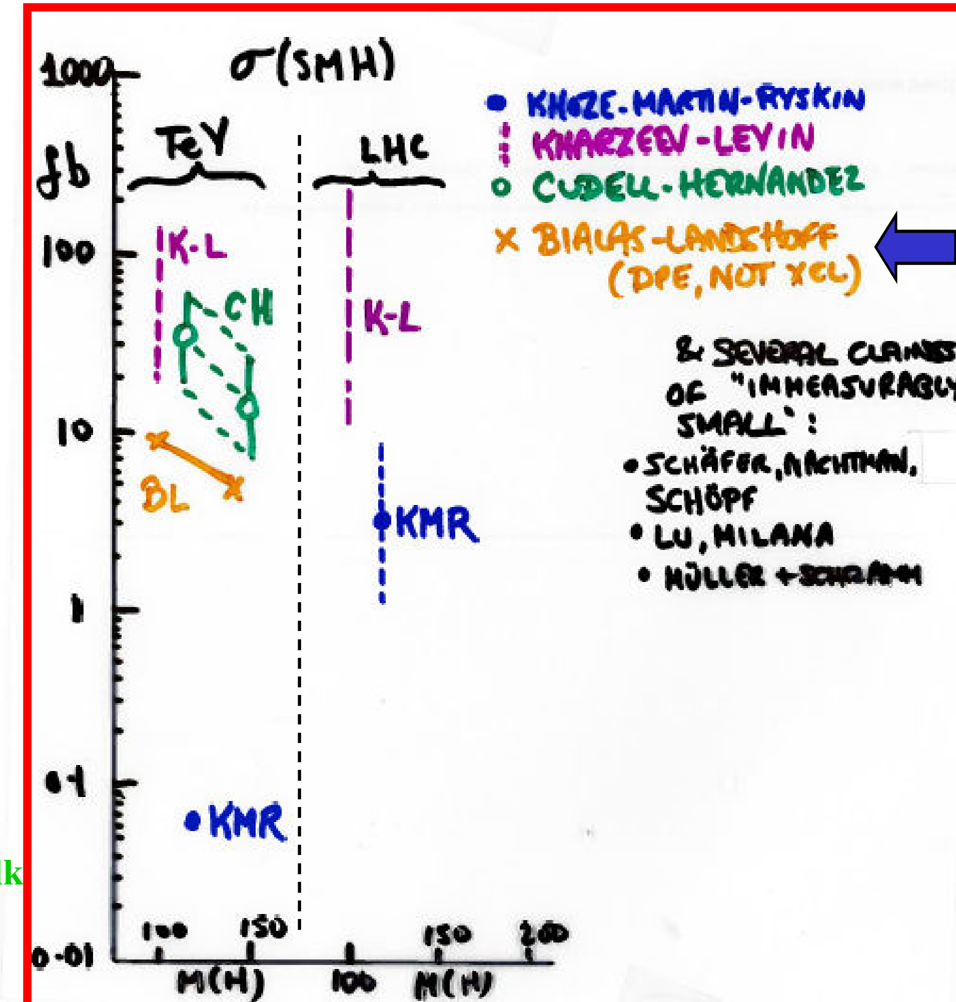
A Search for the Higgs Boson using Very Forward Tracking Detectors with CDF.

M.G.Albrow†,[1] M.Atac,[1] P.Booth,[2] P.Crosby,[3] I.Dunietz,[1] D.A.F
B.Heinemann,[2] M.Lancaster,[3] R.Lauhakangas,[5] D.Litvintsev,[1] T
S.Marti-Garcia,[2] D.McGivern,[3] C.D.Moore,[1] R.Orava,[4,5] A.Rostovtsev,
S.Tapprogge,[5] W.Wester,[1] A.Wyatt,[3] K.Österberg.[4]

Quartz + MCP-PMT

It was great!
So why was it not pursued?
Most people thought it was hopeless
And they were probably right!
(for Tevatron … not for LHC)

σ(p+H+p) was uncertain by a factor > 1000 in 2000



We absolutely needed some experimental input to home in on what to expect!

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

$$p+\bar{p}\rightarrow p+\chi_c+\bar{p} \quad *$$

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

$$p+\bar{p}\rightarrow p+JJ+\bar{p} \quad *$$

Jim Pinfold's talk

* Now measured in CDF

$$p+\bar{p}\to p+\gamma\gamma+\bar{p}$$
$$p+\bar{p}\to p+\chi_c+\bar{p}$$
$$p+\bar{p}\to p+\chi_b+\bar{p}$$
$$p+\bar{p}\to p+JJ+\bar{p}$$

Cleanest (no S.I.) but smallest σ

KMR: 38 pb in our box). 2+1 candidates

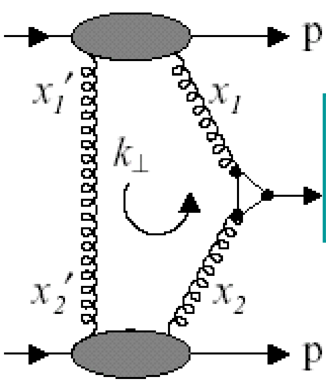
Clean, big σ: $\frac{d\sigma}{dy}(y=0)\sim 100\,\text{nb (KMRS)}$

Jim Pinfold's talk

but M(c) small (non-pert) & hadron

More perturbative, smaller theory uncertainty
But σ ~ 1/500th χc. Also BR's not known!
See next slide.

Big cross section, but least well defined (jets!)
and largest background. ~ 100 pb for M(JJ) > 30 GeV



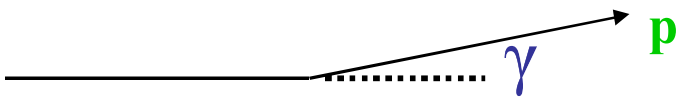
$\sigma(600), f_0(980)$
$\gamma\gamma, \chi_c, \chi_b$, JJ, H

ISR did it

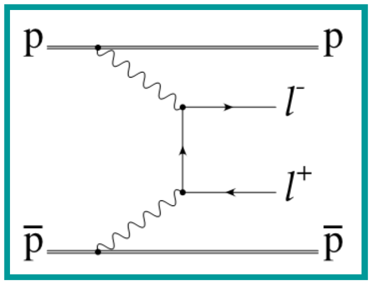
Our 3 measurements are all in good agreement (factor "few") with the Durham group predictions.

PRL 98, 112001 (2007) PHYSICAL REVIEW LETTERS week ending 16 MARCH 2007

Observation of Exclusive Electron-Positron Production in Hadron-Hadron Collisions



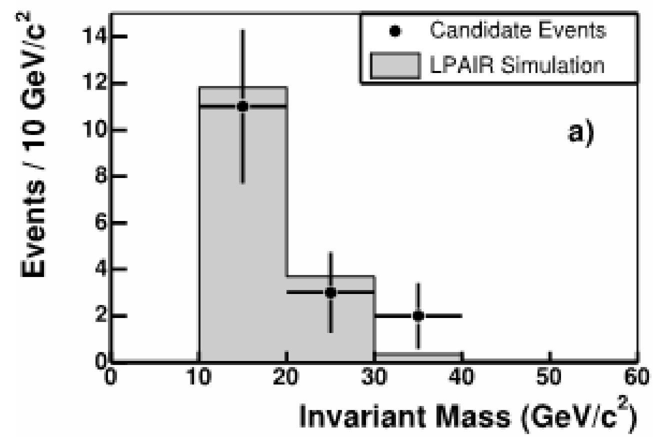
LEP etc: e+e- (~ background free)
HERA: e p Very high b/g … Seen in CDF
pp/ ppbar: Very high b/g … Seen in CDF



Tevatron as a γγ collider!

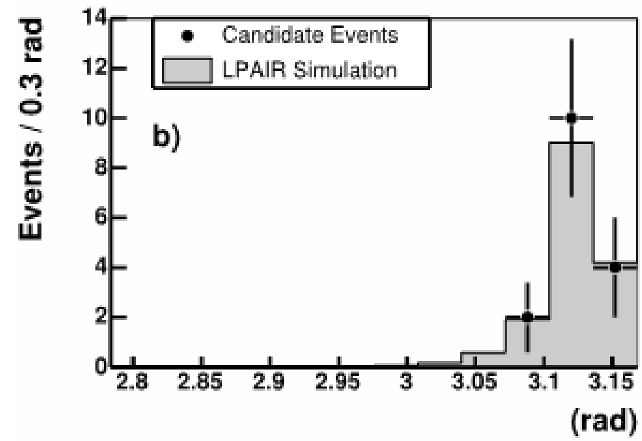
e+e- Mass 10 – 40 GeV

Trigger:
2 EM showers > 4 GeV ET + BSC1 rap.gaps.
Off-line:
All detectors |η| < 7.4 consistent with noise (empty)
2 EM showers |η| < 2.0, ET > 5 GeV
532/pb → 46/pb (no-PU)



16 events with two tracks, all +&-, all back to back,
all same pT within resolution. B/g (diffDiss) ~ 1.9 events.

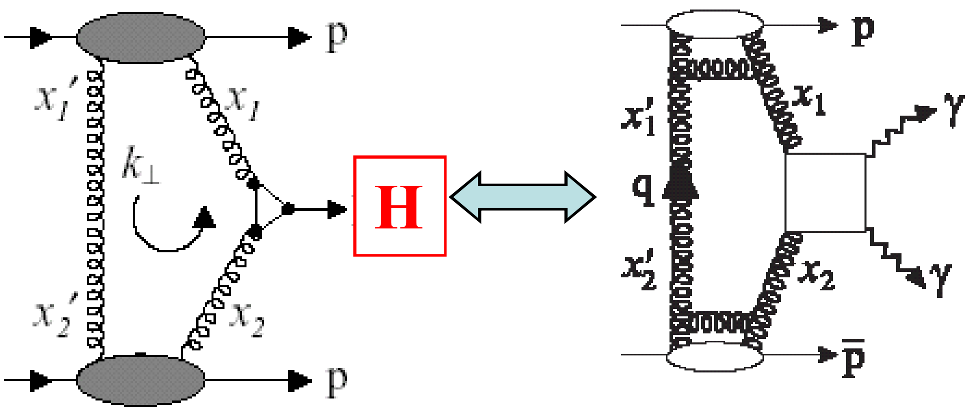
$$\sigma(|\eta|<2, p_T > 5\text{GeV}/c^2):$$
$$\text{CDF}: 1.6^{+0.5}_{-0.3}(\text{stat}) \pm 0.3(\text{syst})\,\text{pb}$$
$$\text{QED(LPAIR)}: 1.71 \pm 0.01\,\text{pb}$$



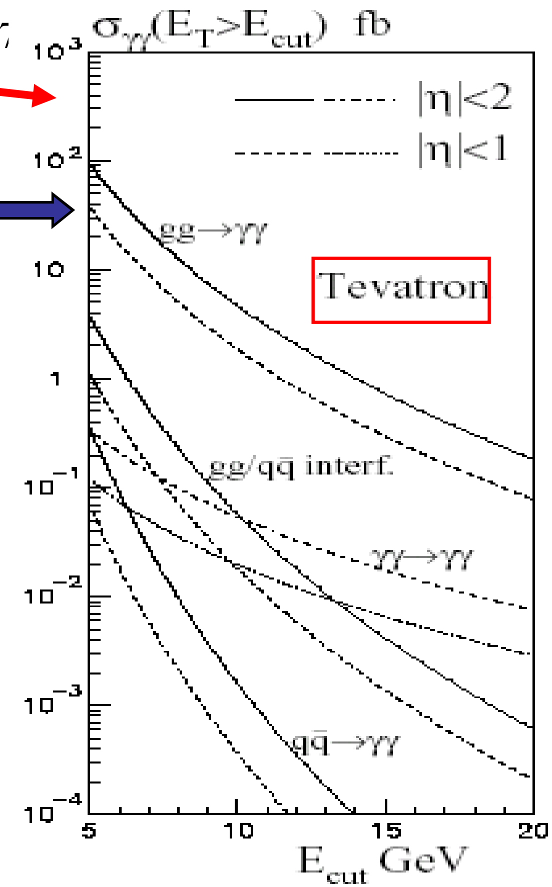
Search for Exclusive $\gamma\gamma$ Production in Hadron-Hadron Collisions

Khoze, Martin and Ryskin, Eur.Phys.J. C23: 311 (2002) ; KMR+Stirling hep-ph/0409037

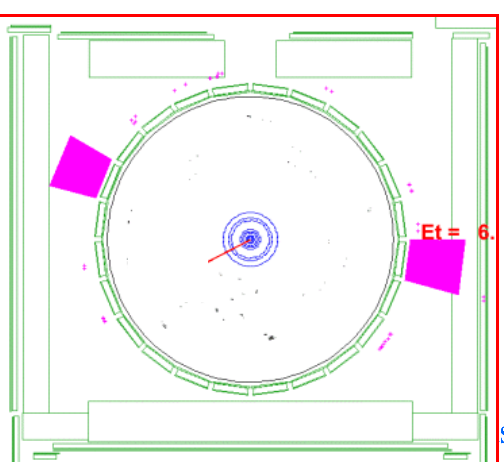
Claim factor ~ 3 uncertainty ; Correlated to p+H+p



36 fb



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



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

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

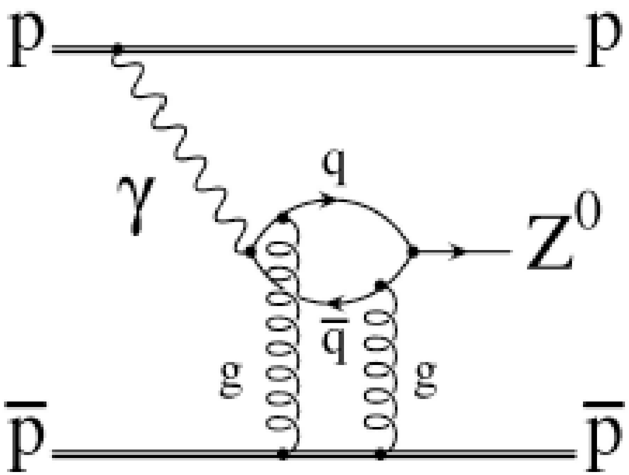
36 fb → 0.8 events

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

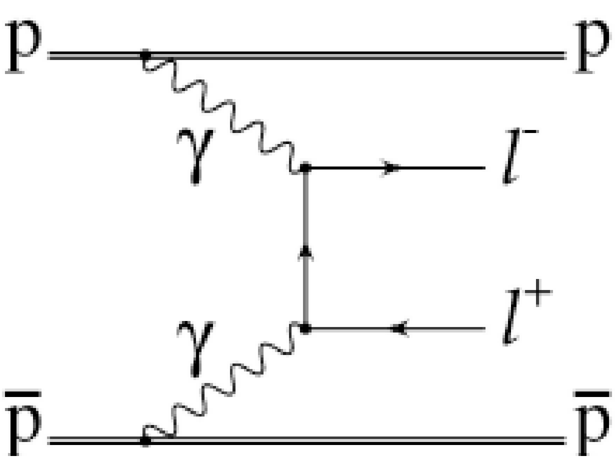
New data, Lower threshold, possible "observation"

PRL 102, 222002 (2009) PHYSICAL REVIEW LETTERS week ending 5 JUNE 2009

Search for Exclusive Z-Boson Production and Observation of High-Mass $p\bar{p} \to p\gamma\gamma\bar{p} \to pl^+l^-\bar{p}$ Events in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV



- Exclusive Z production possible – but σ (SM) = 0.3 fb [Phys. Rev. D78, 014023 (2008)]
- Detection would imply BSM physics - much enhanced σ predicted by A.White [Phys. Rev. D72,036007]



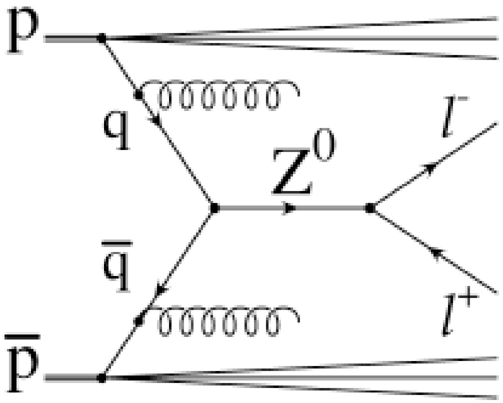
- Final state identical to exclusive dilepton production.
- This "background" is also interesting: could be used to calibrate forward proton detectors [$\xi(\bar{p}) = s^{-1/2}\sum p_T^{\ell} e^{-\eta^{\ell}}$].

Fractional momentum loss of $\bar{p}$

[Some slides from Emily Nurse]

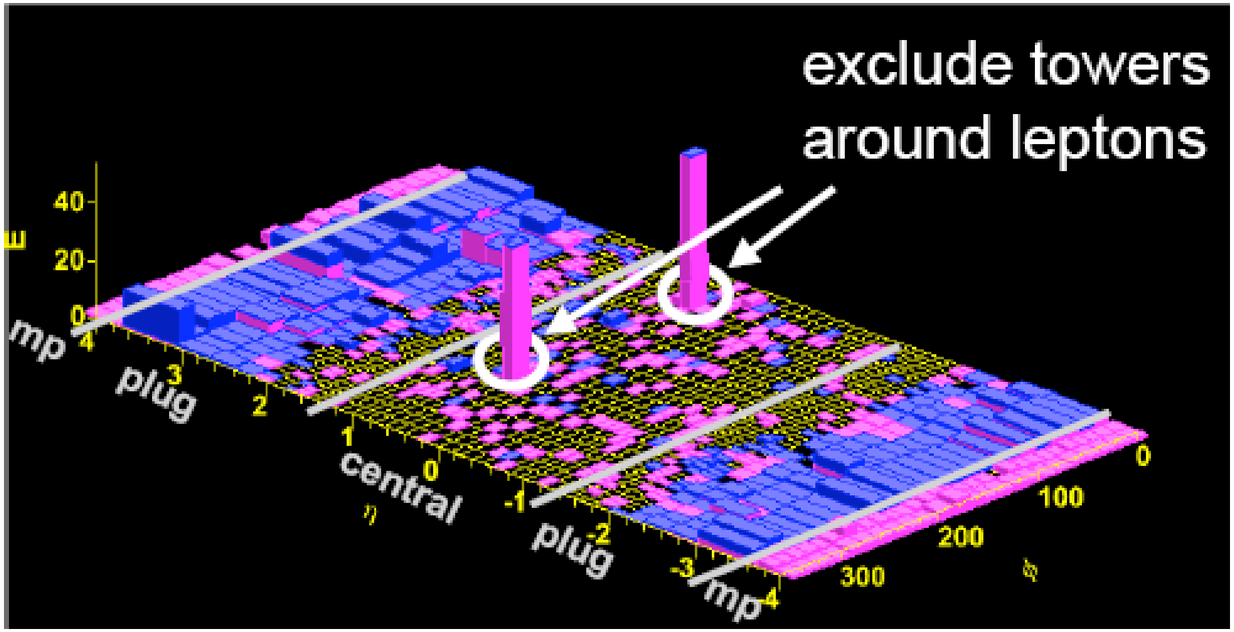
Select $Z \rightarrow \ell\ell$ ($\gamma\gamma \rightarrow \ell\ell$) events:

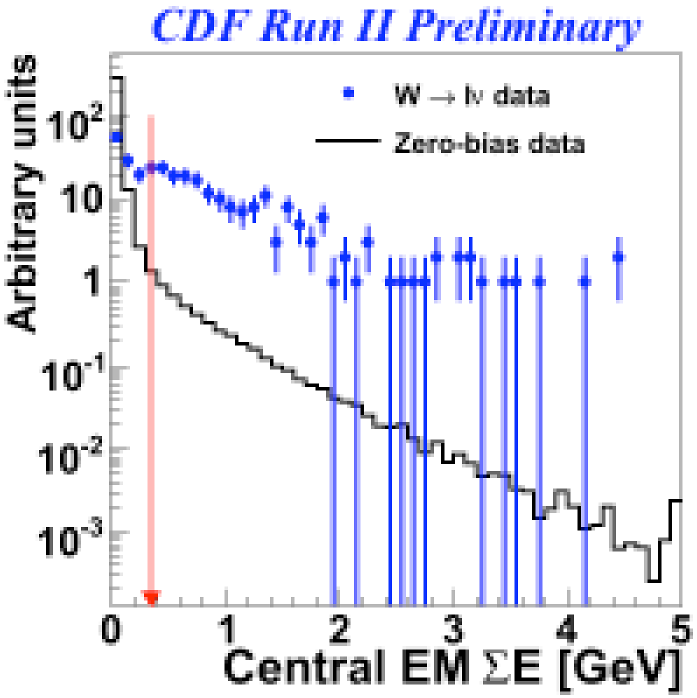
- e^+e^- or $\mu^+\mu^-$ pair with $p_T^\ell > 25(20)$ GeV
- require $82 < M_{\ell\ell} < 98$ ($M_{\ell\ell} > 40$) GeV
- Dominated by *non-exclusive* Z production ($\sigma \sim 250$ pb).
- Require *no other particles* in the event.



1) Require no additional reconstructed tracks.
2) Cut on ΣE in each sub calorimeter:

CENTRAL EM and HAD; PLUG EM and HAD; MINIPLUG EAST and WEST





Exclusivity cuts: Use 0-bias data (important!)
Select events with no tracks,
compare with W→lν in all different detectors

Choose cuts efficient for "noise" = "empty",
inefficient for W events.
Example: **Central EM ΣE < 0.35 GeV**
Not same method as for other studies.
More efficient, maybe more background

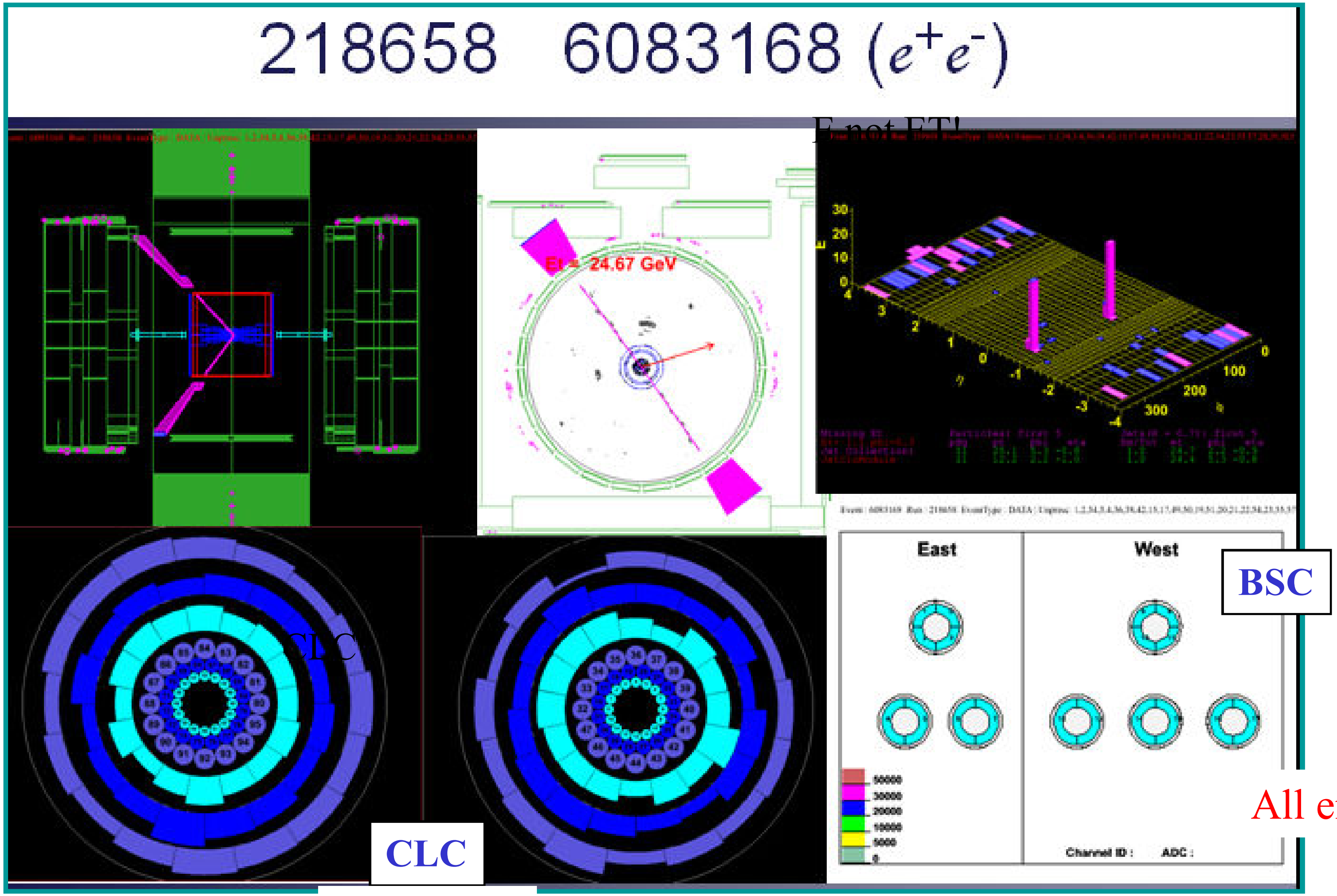
With 2.20(2.03) fb^{-1} in the electron(muon) channels:

	$\gamma\gamma \rightarrow \ell\ell$ [$M_{\ell\ell}$ > 40 GeV]	$Z \rightarrow \ell\ell$ 82 < M < 98 GeV
Inclusive	317,712	183,332
Exclusive	8	0

Measure σ (pp→pℓℓp)

Place upper limit on $\sigma(Z_{excl})$

M(ee) = 49.3 GeV/c2 |Δφ-π| = 6 mrad = 0.34 deg, pT(ee) = 210 MeV



All empty!

All empty!

M reach Tevatron ~ HERA, LEP !

Luminosity

- Exclusivity cuts veto events with *additional* interactions → define $\mathcal{L}_{eff}$ = fraction of $\mathcal{L}$ with zero additional interactions.
- Obtained from fraction of zero bias events passing exclusivity cuts (20.6%).
- Can also be found using Poisson statistics (18.7%)

$\mathcal{L}_{eff}$ = 403 ± 39 ± 24 pb^{-1} ($\mu\mu$)
$\mathcal{L}_{eff}$ = 467 ± 42 ± 28 pb^{-1} (ee)

Details

Acceptance

- Use LPAIR MC + CdfSim for $\gamma\gamma \to \ell\ell$ acceptance.
- Use Pythia (non-exclusive $Z \to \ell\ell$) + CdfSim for exclusive $Z \to \ell\ell$ acceptance:
  - Corrections applied to account for kinematic differences (P_T^Z, y_Z, lepton decay distribution).

Backgrounds to $\gamma\gamma \to \ell\ell$ and $Z \to \ell\ell$

1) Inclusive $Z/\gamma^* \to \ell\ell$

- Assume fraction of $W \to \ell\nu$ events passing exclusivity cuts (0.00009%) is the same for $Z/\gamma^* \to \ell\ell$ events:
- 0.3 ± 0.2 events for $\gamma\gamma \to \ell\ell$; 0.2 ± 0.1 events for $Z \to \ell\ell$

2) $\gamma\gamma \to \ell\ell$ background to $Z \to \ell\ell$

- Found from LPAIR : 0.49 ± 0.06 events

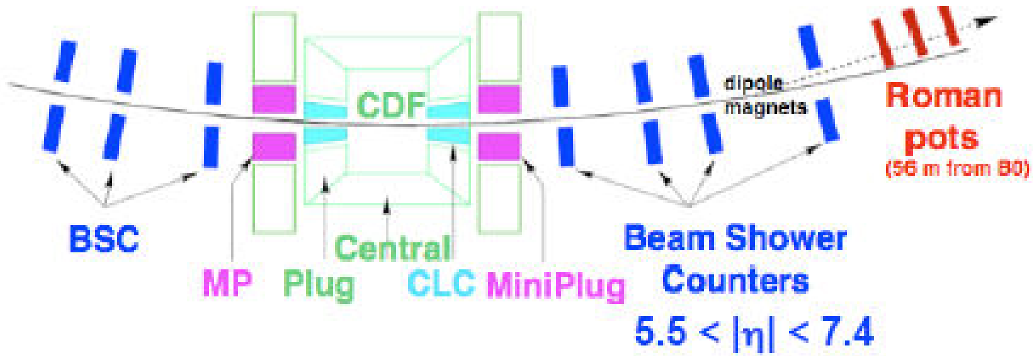
Cosmic ray background is 0

Dissociation "background"

4) $p\bar{p} \to p\gamma\gamma\bar{p} \to p\ell\ell\bar{p}$ events where the p or $\bar{p}$ dissociates:

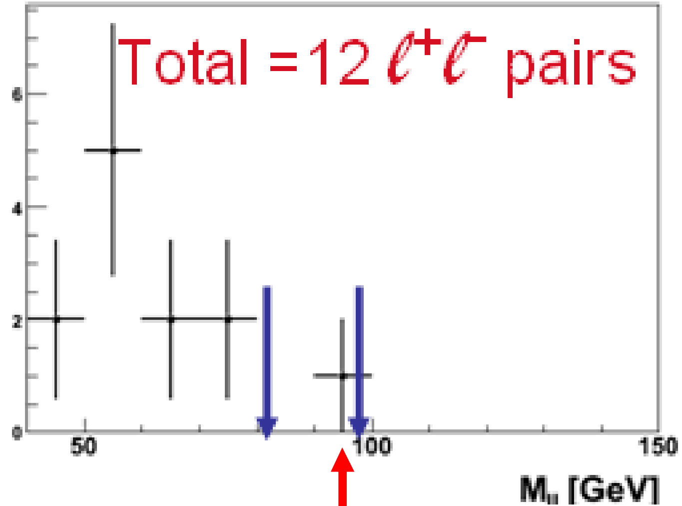
- Will only survive cuts if all dissociation particles have $|\eta|>7.4$ (edge of the BSC acceptance).
- LPAIR runs in inelastic modes to give expected cross section.
- Rockefeller Minimum Bias MC dissociates the p($\bar{p}$) to obtain η distribution of fragmented particles.
- We predict a background of 1.45 ± 0.61 events.

NB: These events are still (probably) $\gamma\gamma \to l^+l^-$ and most detected in BSC = Beam Shower Counters



- BSC cuts required to reduce dissociation "background" (events where the p or $\bar{p}$ dissociates).
- Veto events if *any* BSC PMT has > 700 ADC counts.

Before requiring BSC empty (no dissociation):



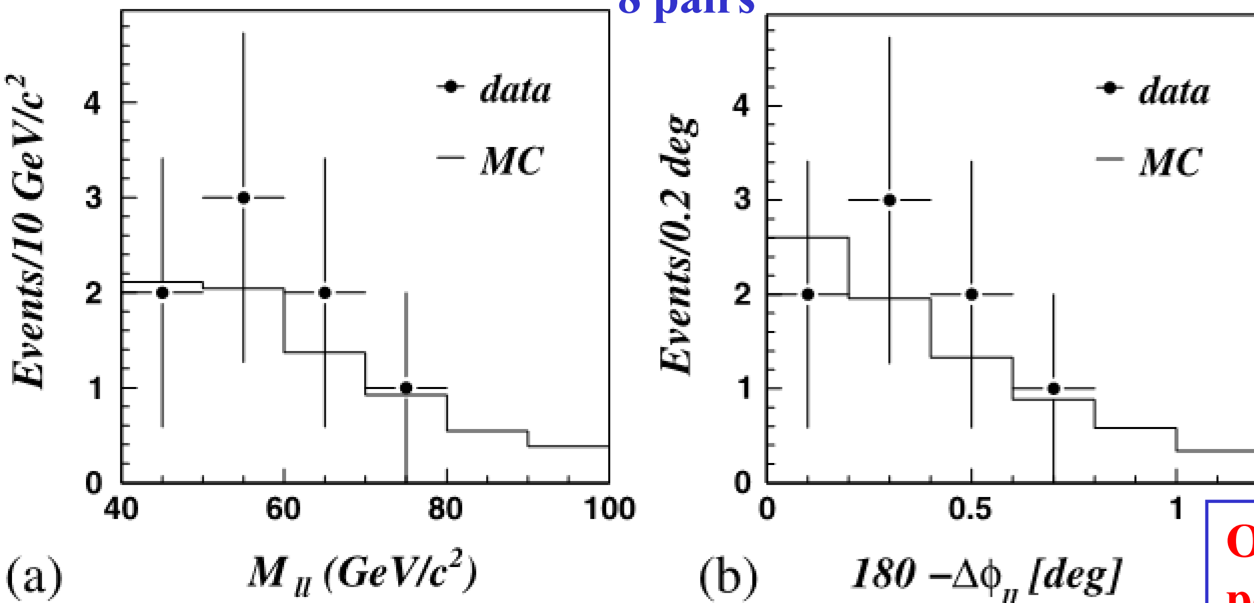
$$\sigma(p+\bar{p}\rightarrow p+e^{+}e^{-}+\bar{p})\ \text{or}\ \mu\mu$$

$$M>40\ \text{GeV/c}^{2}, |\eta|<4$$

$$=0.24^{+0.13}_{-0.10}\ \text{pb}$$

$$\text{cf QED}_{(\text{LPAIR})}=0.256\ \text{pb}$$

8 pairs



Likely a Z, but not exclusive; dissociation? $p_T, \Delta\phi-\pi$ not ~ QED

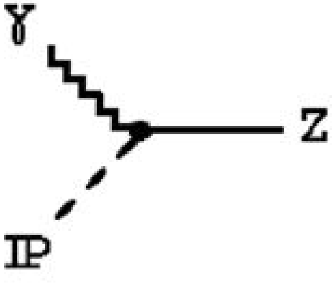
One event has a Roman pot pbar track, others had pbar out of acceptance or R.pots off.

Agrees with LPAIR/QED in shape as well as normalization.
All pairs back-to-back in Ø within 0.8 degrees!

Results : exclusive Z limit

Combining the $\mu\mu$ and ee decay channels:

- 0 candidates
- 0.66 ± 0.11 background
- $\alpha \times BR(\ell\ell) \times \mathcal{L}_{eff} = 3.22 \pm 0.38\ pb^{-1}$



$\sigma(Z_{excl}) < 0.96$ pb @ 95% C.L.

(960 fb)

COOL!

Predictions: Standard Model:

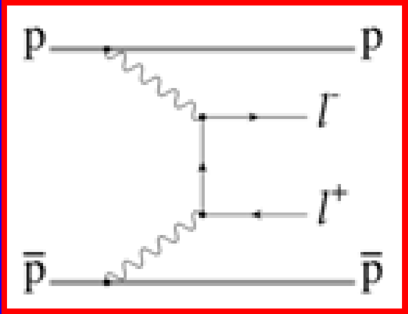
Motyka and Watt, PRD 78, 014023 (2008) : σ(Z,excl) = 0.3 fb

Goncalves and Machado, Eur.Phys.J. C 56, 33 (2008) : σ(Z,excl) = 0.21 fb

Beyond Standard Model (Color sextet quarks):

A.R.White, PRD 72, 036007 (2005): "much bigger" at LHC!

All our dilepton measurements agree with QED: So what?



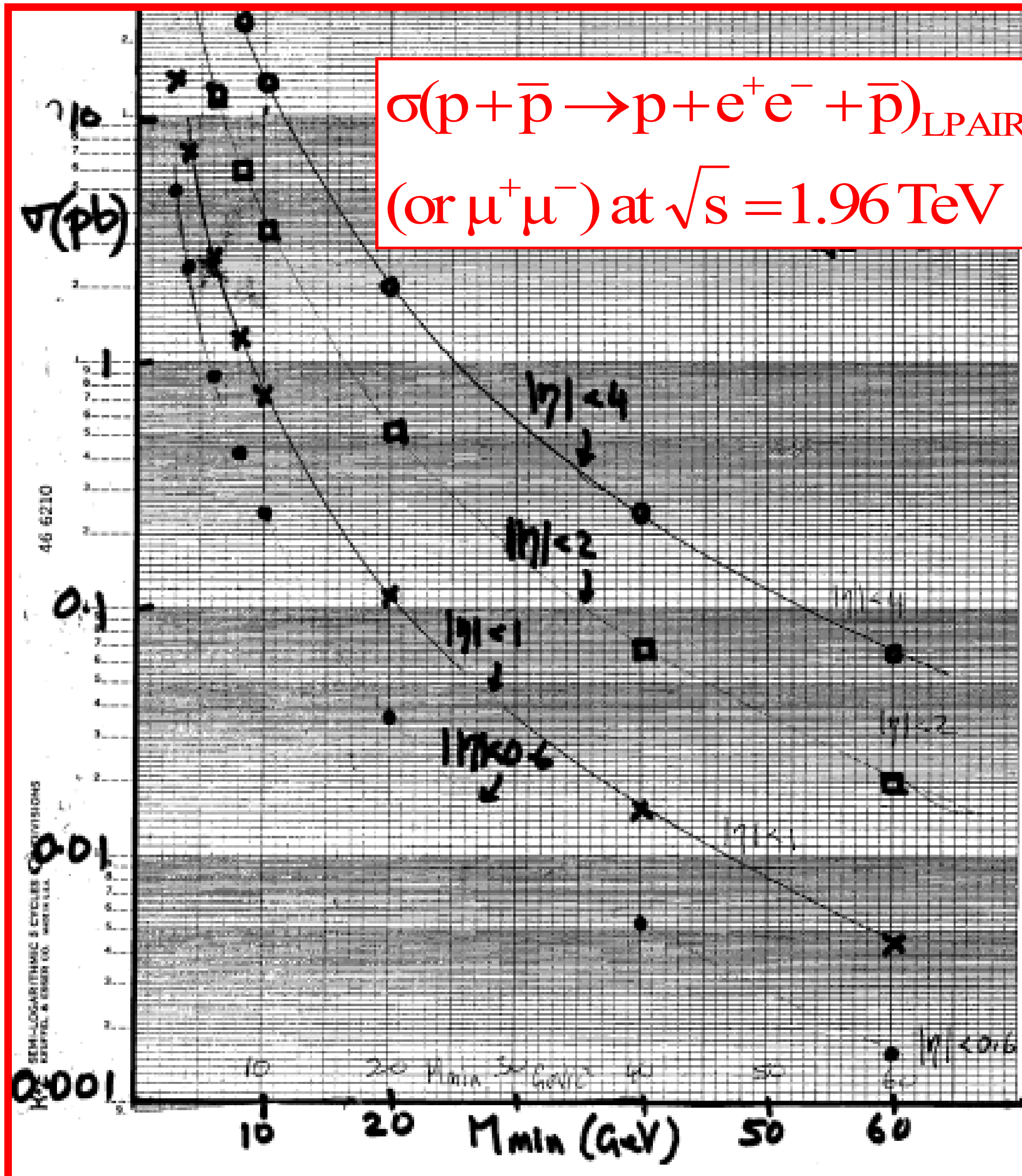
1) It shows we know how to select rare exclusive events in hadron-hadron environment
2) No other h-h cross section is so well known theoretically except Coulomb elastic.
   Possibly excellent **Luminosity calibration** at LHC e.g.
3) Outgoing p-momenta extremely well-known (limited by beam spread). Calibrate forward proton spectrometers.
4) Practice for other $\gamma\gamma$ collisions at LHC: $\gamma\gamma \to W^+W^-, \tilde{l}^+\tilde{l}^-, \ldots$

Luminosity calibration at LHC ➡ 4400 events in 500 pb^{-1} with $M(\mu^+\mu^-) > 10$ GeV and $|\eta| < 2$

$$\sigma(p\bar{p} \rightarrow p + \mu^+\mu^- + \bar{p})_{QED}$$

vs. M(min) for different $|\eta|$(max)

at $\sqrt{s} = 1.96$ TeV, LPAIR



Can "read off" cross section
For any M_min or
M-range, and eta(max).

Purely empirical fit
(no physics, just convenient):

$$\sigma_{\mu\mu}(\text{pb})[M_{min}(\text{GeV}), |\eta_{max}|] = \frac{1}{(1+0.008\times M_{min})} \times \frac{|\eta_{max}|^{2.15}}{M_{min}^{2.5}}$$

Good to few % 4 GeV – 30 GeV
Similar for LHC

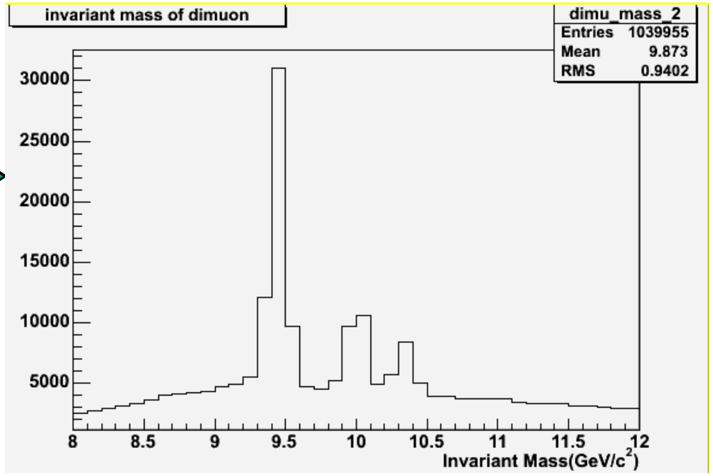
Dimuons: Upsilon Region

Trigger: μ+μ-
|η|<0.6 , pT(μ) > 4 GeV/c

Search for/measurement of photoproduction of Y(1S),Y(2S),Y(3S) (not before seen in hadron-hadron)

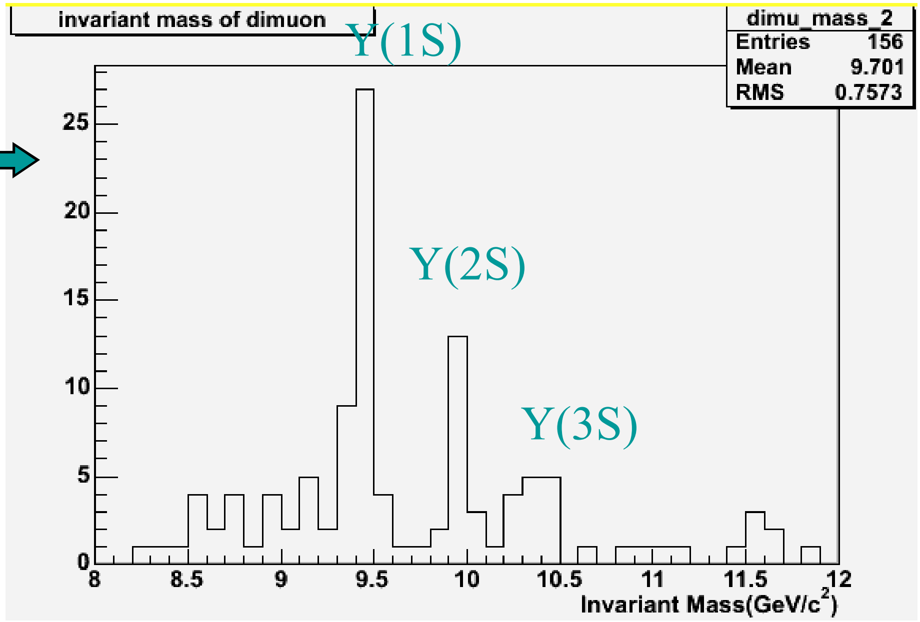
Inclusive

CDF Run II Preliminary



Invariant Mass
0 associated tracks
pT(μμ) < 1.5 GeV/c

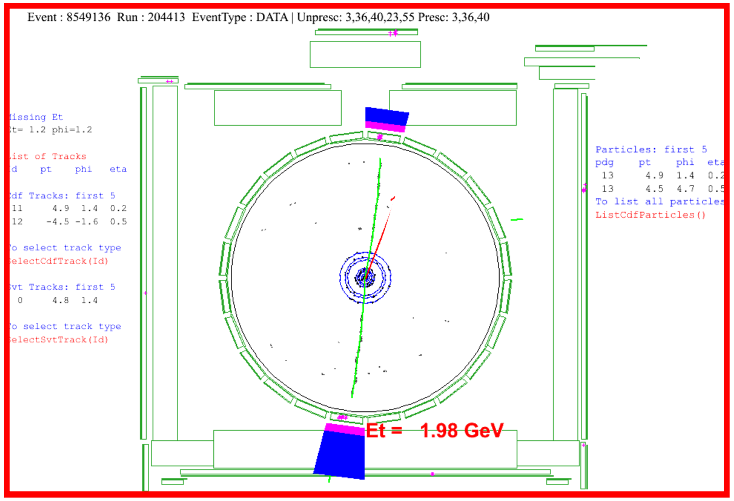
CDF Run II Preliminary

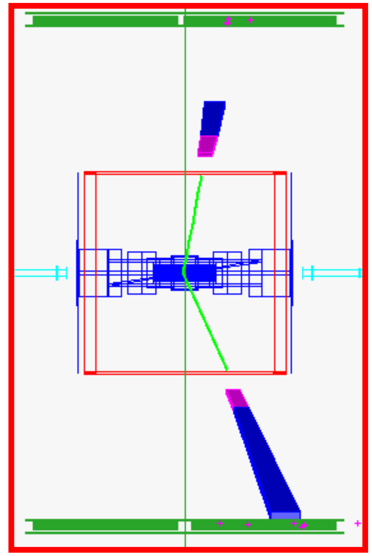


Status:
analysis in progress.
QED continuum check
Y : cf HERA (we resolve states)
Can we see $\chi_b \rightarrow Y+\gamma$?

Exclusive Upsilon Y(1S) candidate

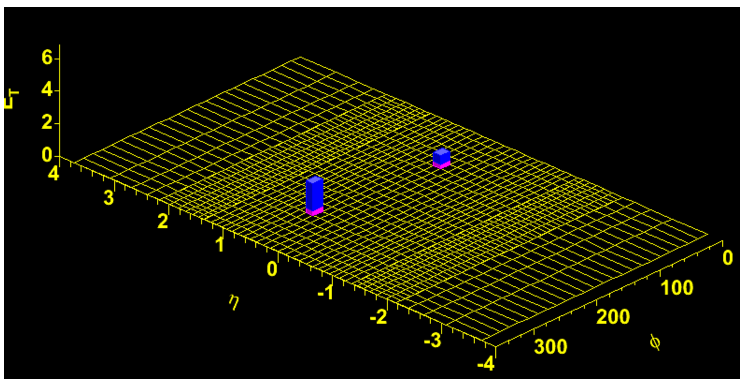
Run/Event: 204413/8549136

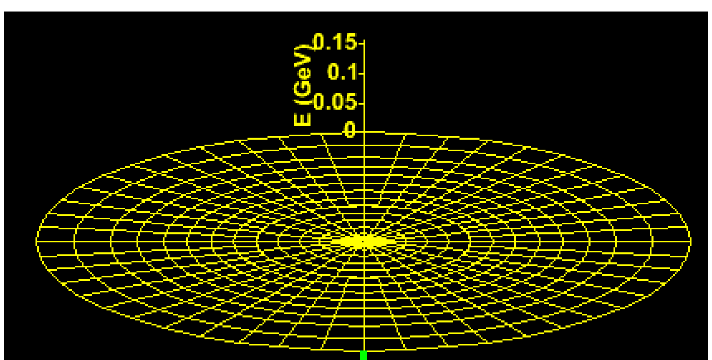




R-z, Muon hits

M ~ 9.4 GeV





Plugs, Miniplugs, CLC, BSC empty

But we will allow P-U,
(except for χb →Y + γ search)
Maybe a few events ???

Branching ratios for μ+μ- channels:	
Y(1s)[9.46 GeV]	: 2.5%
Y(2s)[10.02 GeV]	: 1.3%
Y(3s)[10.36 GeV]	: 1.8%

e.g. A. Szczurek: arXiv:0811.2488

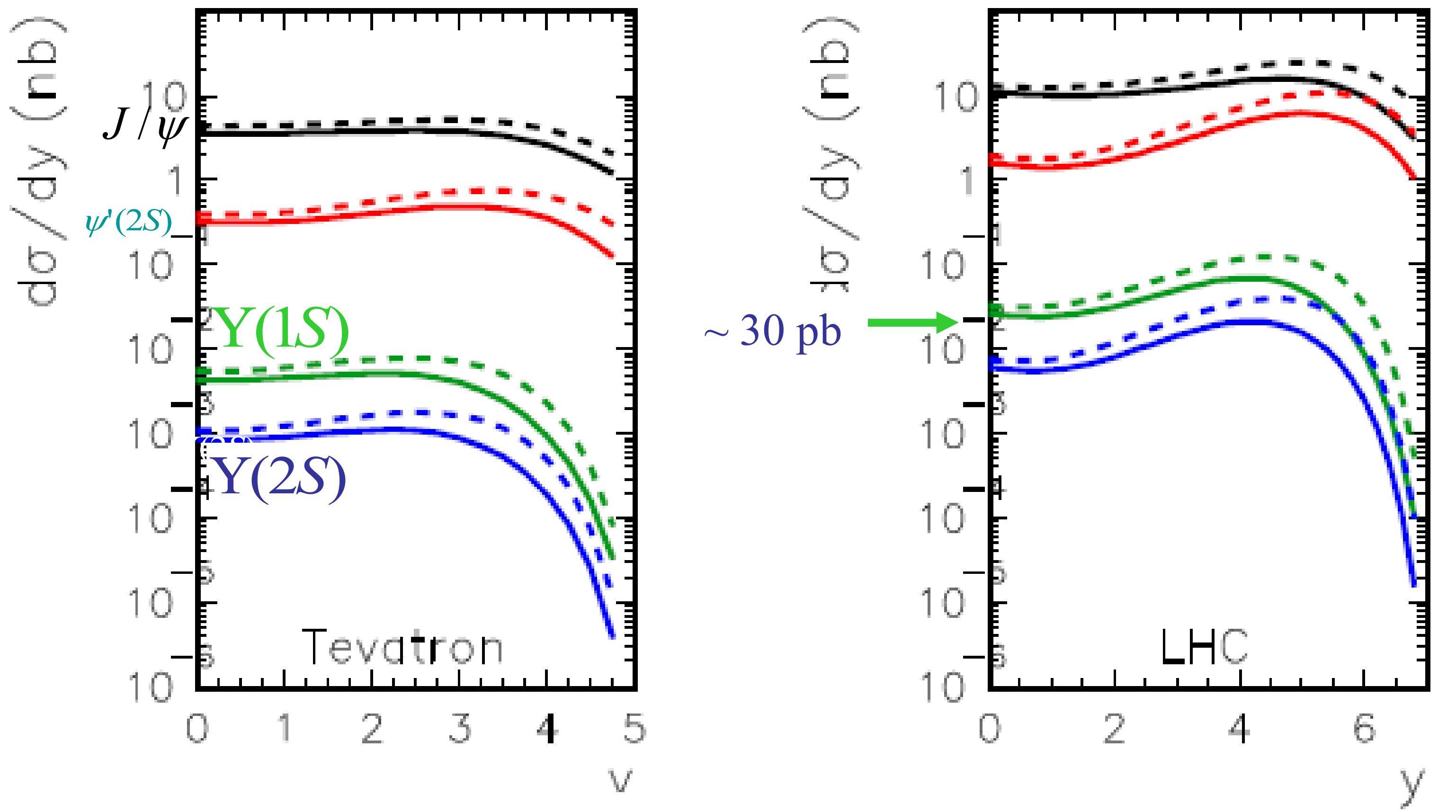


FIGURE 6. Distribution in rapidity of J/Ψ, Ψ', Υ, Υ' (from top to bottom) for Tevatron (left panel) and LHC (right panel). The dashed line corresponds to calculation in the Born approximation and the solid line includes absorption corrections.

$$\frac{d\sigma}{dy}(y=0)\Upsilon(1S) \sim \frac{1}{500}\frac{d\sigma}{dy}(y=0)J/\psi$$

PDG 2008 (latest):

χ_b states are very poorly known!

$\chi_{b0}(1P)$ [f]

$I^G(J^{PC}) = 0^+(0^{++})$
J needs confirmation.

Mass $m = 9859.44 \pm 0.42 \pm 0.31$ MeV

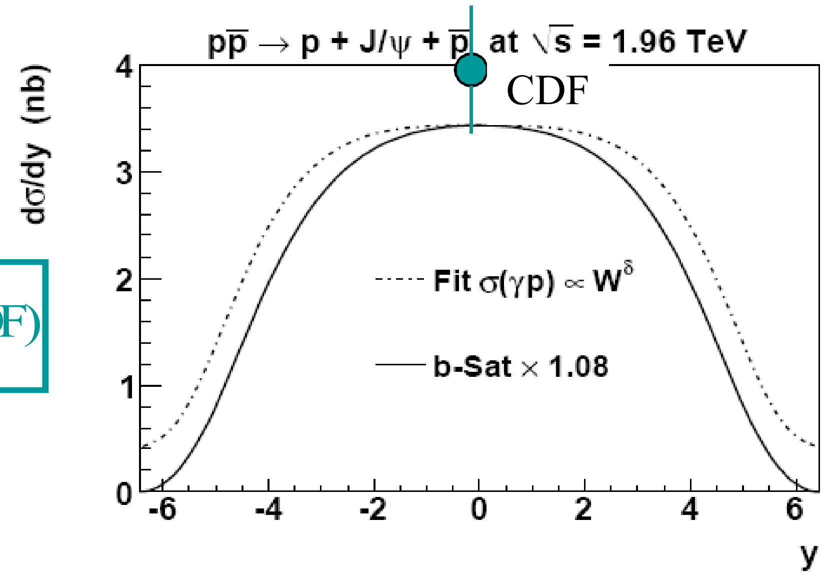
$\chi_{b0}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\gamma\Upsilon(1S)$	< 6 %	90%	391
$D^0 X$	< 10.4 %	90%	–
$\pi^+\pi^-K^+K^-\pi^0$	$< 1.6 \times 10^{-4}$	90%	4875
$2\pi^+\pi^-K^-K^0_S$	$< 5 \times 10^{-5}$	90%	4875
$2\pi^+\pi^-K^-K^0_S 2\pi^0$	$< 5 \times 10^{-4}$	90%	4846
$2\pi^+2\pi^-2\pi^0$	$< 2.1 \times 10^{-4}$	90%	4905
$2\pi^+2\pi^-K^+K^-$	$(1.1\pm0.6) \times 10^{-4}$		4861
$2\pi^+2\pi^-K^+K^-\pi^0$	$< 2.7 \times 10^{-4}$	90%	4846
$2\pi^+2\pi^-K^+K^-2\pi^0$	$< 5 \times 10^{-4}$	90%	4828
$3\pi^+2\pi^-K^-K^0_S\pi^0$	$< 1.6 \times 10^{-4}$	90%	4827
$3\pi^+3\pi^-$	$< 8 \times 10^{-5}$	90%	4904
$3\pi^+3\pi^-2\pi^0$	$< 6 \times 10^{-4}$	90%	4881
$3\pi^+3\pi^-K^+K^-$	$(2.4\pm1.2) \times 10^{-4}$		4827
$3\pi^+3\pi^-K^+K^-\pi^0$	$< 1.0 \times 10^{-3}$	90%	4808
$4\pi^+4\pi^-$	$< 8 \times 10^{-5}$	90%	4880
$4\pi^+4\pi^-2\pi^0$	$< 2.1 \times 10^{-3}$	90%	4850

Perhaps: Dedicated 800 GeV p -Fixed target DPE experiment (χ-factory) ?

Predictions from Motyka and Watt arXiv:0805.2113

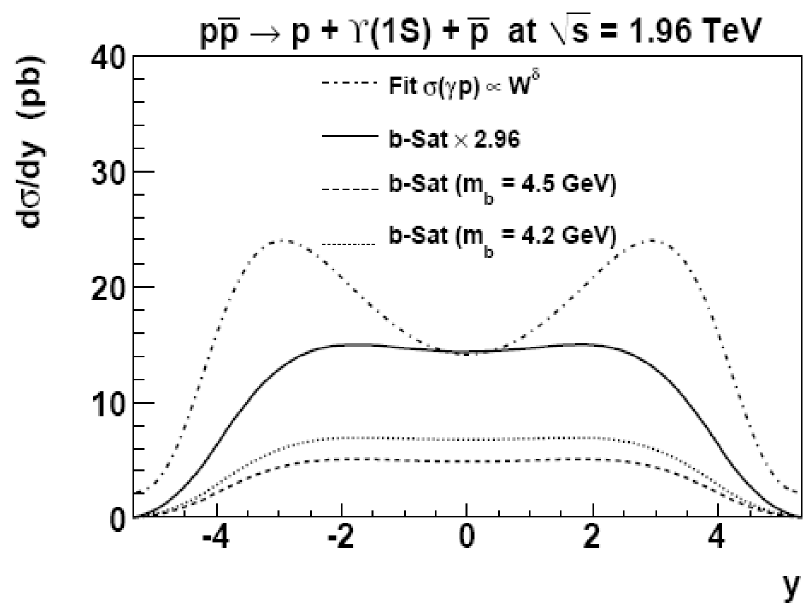
Phys.Rev.D78:014023,2008.

$$\frac{d\sigma}{dy}|_{y=0}\,(J/\psi) = (3.92 \pm 0.25(stat) \pm 0.52(syst)\text{ nb (CDF)}$$



Factor ~ 400

$$\frac{d\sigma}{dy}|_{y=0}\,(Y(1)) = (5-14)\text{ pb (M\&W)}$$

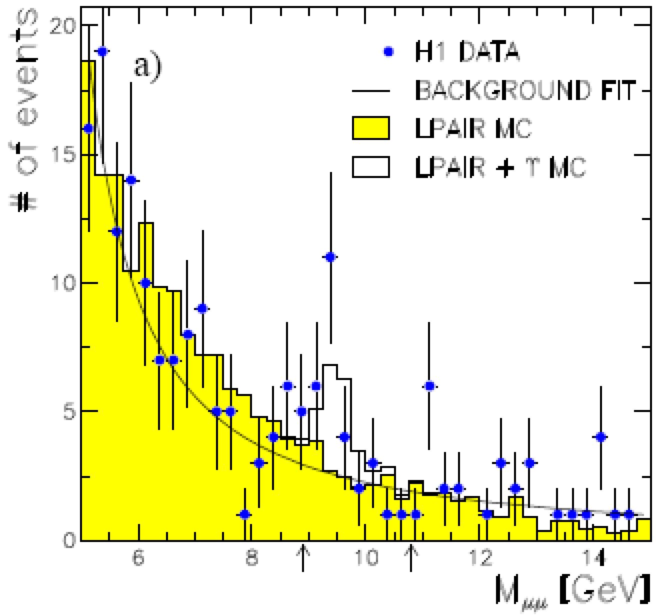


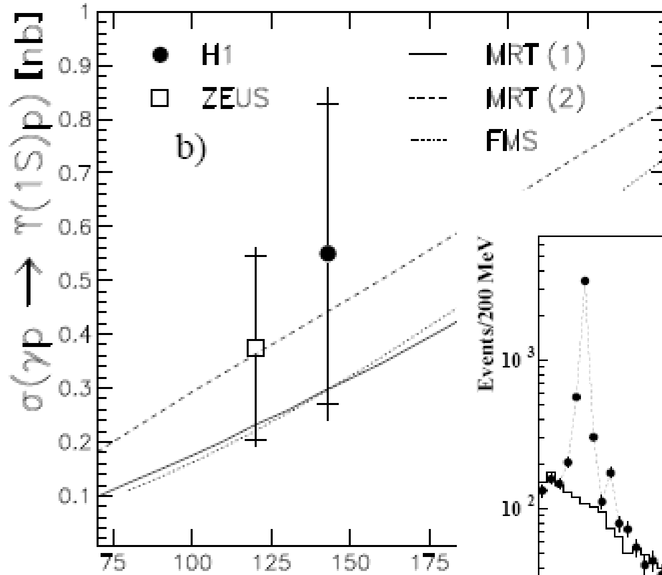
Other predictions:
12 +- 1 pb (Cox,Forshaw,Sandapan)
~12 pb (Klein & Nystrand)
0.8 – 5 – 9 pb
(Bzdak,Motyka,Szymanowski & Cudell)

HERA data little help:
Resolution confuses Y1,2,3, low statistics

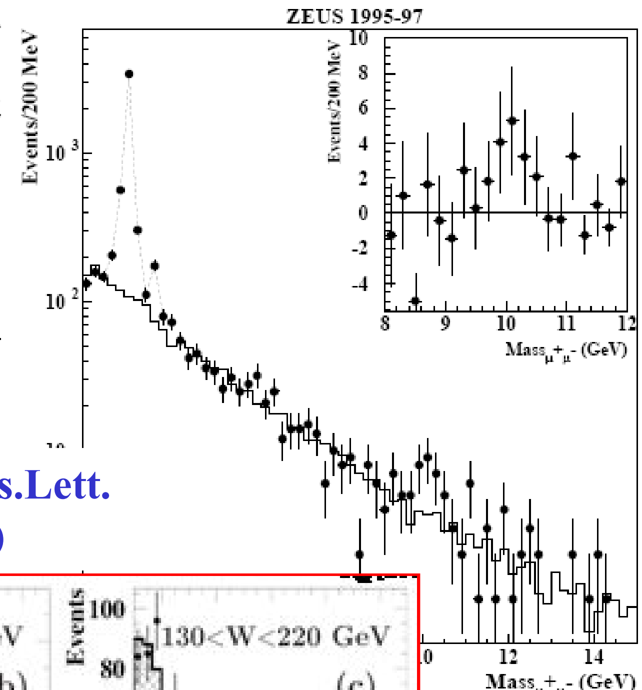
HERA: e + p

H1





ZEUS

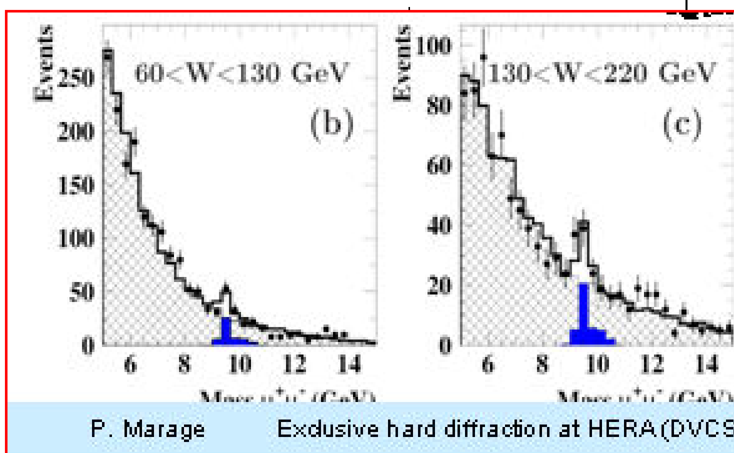


Phys.Lett.B483:23-35 (2000)

J.Breitweg et al.,Phys.Lett. B437: 432-444 (1998)

Y(1),Y(2),Y(3) signals in CDF cleaner than at HERA!
Better mass resolution,
less γγ→μμ background.
BUT χ_b → Y+γ background absent at HERA!

Just saw in Marage talk



ZEUS

Cross sections at HERA

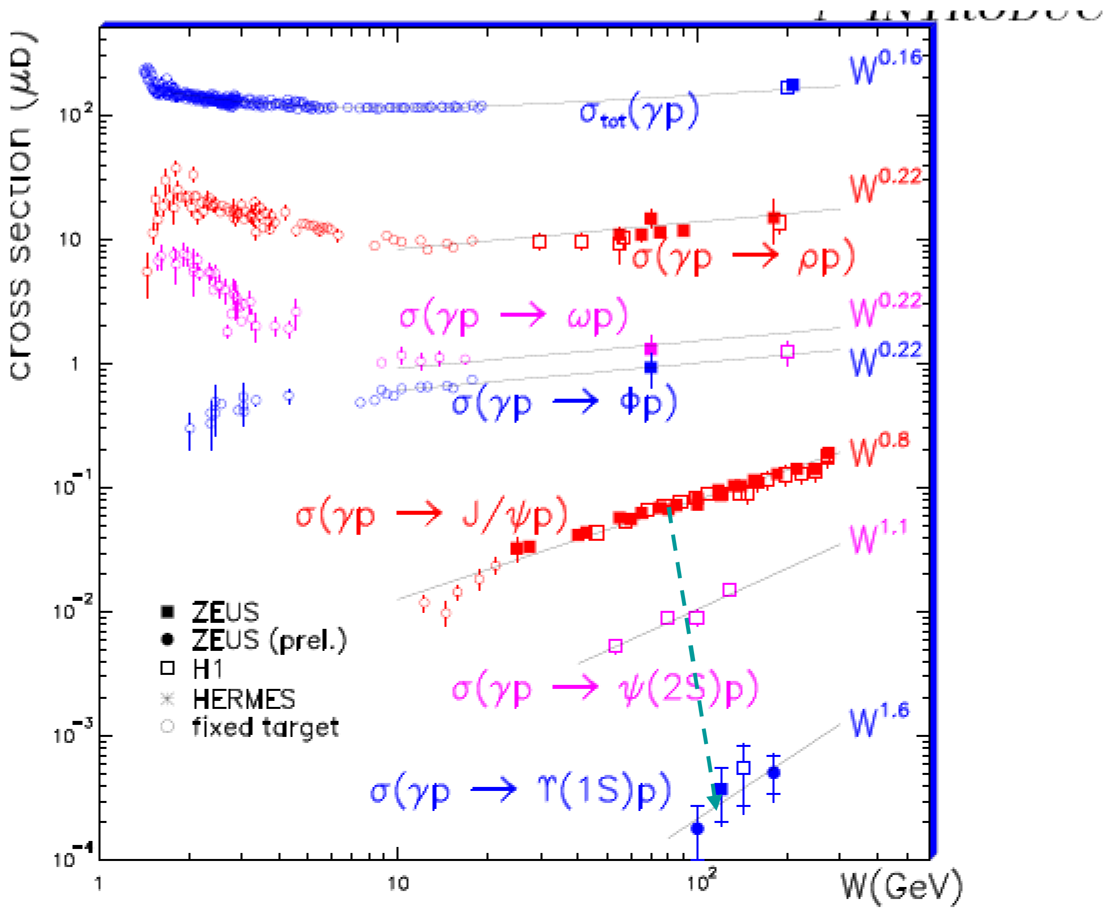


Figure 2: A compilation of HERA data on exclusive vector meson production cross sections vs. W.

Ratio ~ 300!

$$W = \sqrt{s(\gamma p)} = \sqrt{M_V^2 + M_p^2 + 2 M_V . E_p}$$

~ 80 GeV (J/psi), 136 GeV (Y) in CDF, V at y=0

Y and FP420 at LHC

Predictions from Motyka and Watt
arXiv:0805.2113

Phys.Rev.D78:014023,2008.

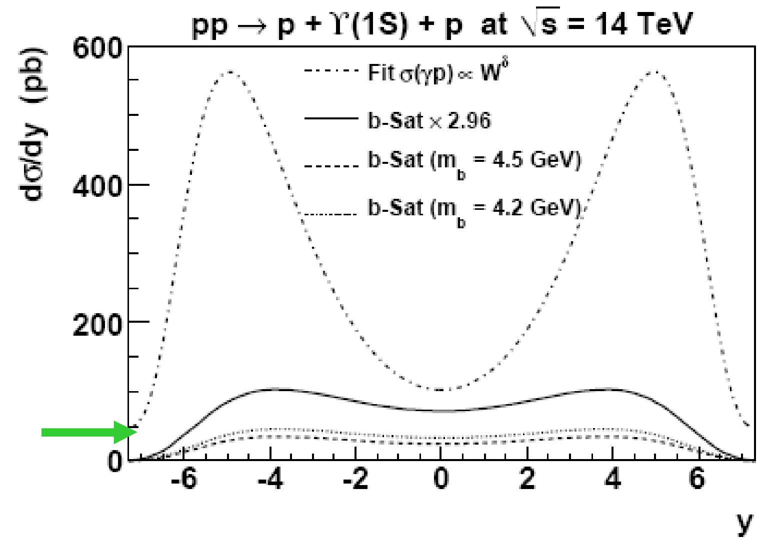


FIG. 8: Rapidity distributions for exclusive photoproduction of Υ mesons at the Tevatron and LHC. The "b-Sat" model predictions with $m_b = 4.5$ GeV are rescaled by a factor 2.96 to give optimum agreement with the HERA data [16, 17, 18]. Also shown is the result of a direct fit to the HERA data of the form $\sigma(\gamma p) \propto W^{\delta}$. No gap survival factor has been applied to these predictions.

Large uncertainty in extrapolation.
No gap survival probability!

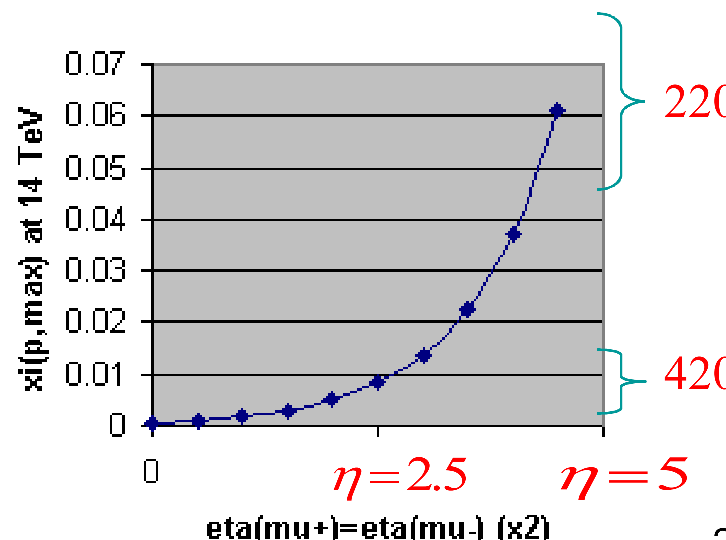
FP420 acceptance?

$$\xi_{1(2)} = \sum_{leptons} p_T e^{+(-)\eta}$$

$$p_{T1} = p_{T2} = 4.75\ \mathrm{GeV/c};\ \eta_1 = \eta_2 = \eta$$

(most likely kinematics)

$\xi_{max}(p)\ vs.\ \eta$



$\xi_{min}(p)$ is always much too small to see.
Fortunately *each* xi(p) is known

Rate for Υ @ LHC:

$$\text{Rate} \sim \frac{d\sigma}{dy}.\Delta y.(\text{BR} \to \mu^+\mu^-).\text{Acc. Eff.}$$

$$\sim 100\,\text{pb} \times 2.0 \times 025 \times 0.25 \sim 1.25 \times 10^{-36}\,\text{cm}^2$$

$$\sim 5/\text{hour at } L = 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$$

Double-diffractive χ meson production at the hadron colliders

V.A. Khoze[a,b], A.D. Martin[a], M.G. Ryskin[a,b] and W.J. Stirling[a,c]

χ_b at Tevatron and LHC

χ_c **predictions down by 1.45 (pdg width change)**

	Tevatron $\sqrt{s} = 2$ TeV χ_c	χ_b	LHC $\sqrt{s} = 14$ TeV χ_c	χ_b
$d\sigma_{\text{excl}}/dy\|_{y=0}$	130	0.2	340	0.6
σ_{excl}	650	0.5	3000	4
$d\sigma_{\text{incl}}/dy\|_{y=0}$	13	0.06	30	0.2
σ_{incl}	70	0.3	200	2

Complex spectrum of radiative decays to Y(1),Y(2):

Here just give DPE allowed states
(J=0 >> J=2)

dσ/dy(KMRS,TeV) = 200 pb
If BR = 4% (?) that's 8 pb -> γ+Y1
Cf ~ 10 pb for ds/dy(Y1)

dσ/dy(KMRS, LHC) = 600 pb
If BR = 4% (?) that's 24 pb -> γ+Y1
cf ~ 30 pb for ds/dy(Y1)

χ_b $I^G J^{PC} = 0^+0^{++}$ and 0^+2^{++} states:

$\chi_{b0}(9859)$ $J = 0$: $\rightarrow \gamma \Upsilon(1S)$ <6% (~3.5%?); $p_\gamma = 391$ MeV

$\chi_{b2}(9912)$ $J = 2$: $\rightarrow \gamma \Upsilon(1S) = (22 \pm 4)\%$ $p_\gamma = 442$ MeV

$\chi_{b0}(10232)$ $J = 0$: $\rightarrow \gamma \Upsilon(2S) = (4.6 \pm 2.1)\%$ $p_\gamma = 207$ MeV

$\chi_{b0}(10232)$ $J = 0$: $\rightarrow \gamma \Upsilon(1S) = (0.9 \pm 0.6)\%$ $p_\gamma = 743$ MeV

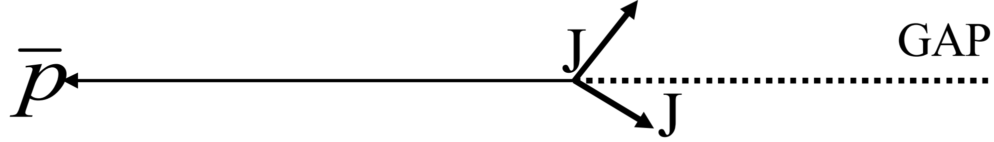
$\chi_{b2}(10269)$ $J = 2$: $\rightarrow \gamma \Upsilon(2S) = (16.2 \pm 2.4)\%$ $p_\gamma = 242$ MeV

$\chi_{b2}(10269)$ $J = 2$: $\rightarrow \gamma \Upsilon(1S) = (7.1 \pm 1.0)\%$ $p_\gamma = 777$ MeV

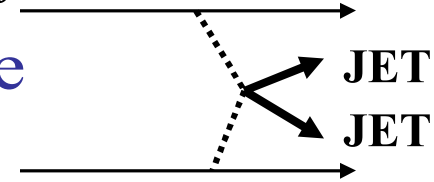
→ Will not get good Y cross sections
without knowing χ_b , and p-calibration is screwed up.
"Soft" photons important. Use QED

Exclusive Di-Jets

Phys Rev D77:052004 (2008)

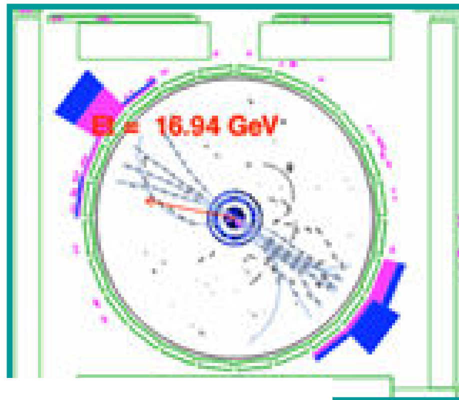


$$p + \overline{p} \rightarrow p + JJ + \overline{p} + \sim \text{nothing else}$$

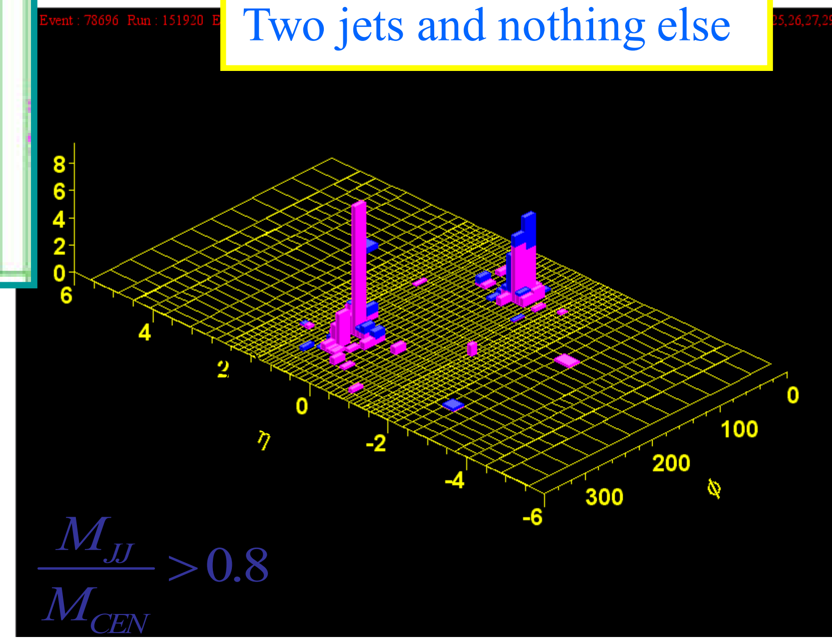


Observed in CDF, QCD tests
& related to p+H+p

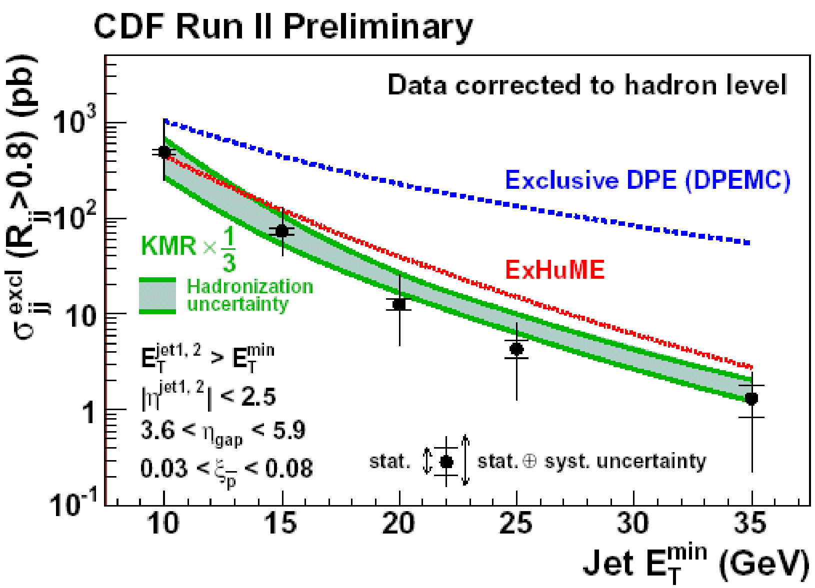
$$R_{JJ} = \frac{M_{JJ}}{M_X} \approx 1.0$$



“Almost” exclusive di-jet,
Two jets and nothing else



$$\frac{M_{JJ}}{M_{CEN}} > 0.8$$



Interesting QCD: gap survival, Sudakov factor
Nearly all jets should be gg …. qq suppressed by M(q)/M(JJ) (Jz=0 rule)

Gluon jet physics.

30

Summary

Programme in CDF to measure central exclusive processes

a) **As interesting QCD physics in its own right**
but especially in a Tev-4-LHC spirit and to understand FP420/240 issues

b) **Measurements to demonstrate that p + H + p must happen (if H)**

c) **Measurements to demonstrate that γγ → ee, μμ can be used in a hadron-hadron collider to calibrate forward spectrometers**

I covered:

$$\gamma\gamma \rightarrow e^+e^-, \mu^+\mu^-$$
$$\gamma + I\!P \rightarrow \Upsilon(1S), \Upsilon(2S), \Upsilon(3S), Z(?)$$
$$I\!P + I\!P \rightarrow \gamma\gamma$$

More to come!

Jim Pinfold will cover:

$$\gamma\gamma \rightarrow \mu^+\mu^-$$
$$\gamma + I\!P \rightarrow J/\psi, \psi(2S)$$
$$I\!P + I\!P \rightarrow \chi_c$$

our star reaction!

Thank You