Central Exclusive Production in CDF

Mass > 8 GeV (Jim Pinfold's talk for Mass < 5 GeV)

Mike Albrow, Fermilab, on behalf of CDF

$$\gamma\gamma \rightarrow e^+e^-, \mu^+\mu^-$$

$$\gamma + IP \rightarrow Y(1S), Y(2S), Y(3S), Z(?)$$ Search

$$IP + IP \rightarrow \gamma\gamma$$

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 (recent PRL)

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

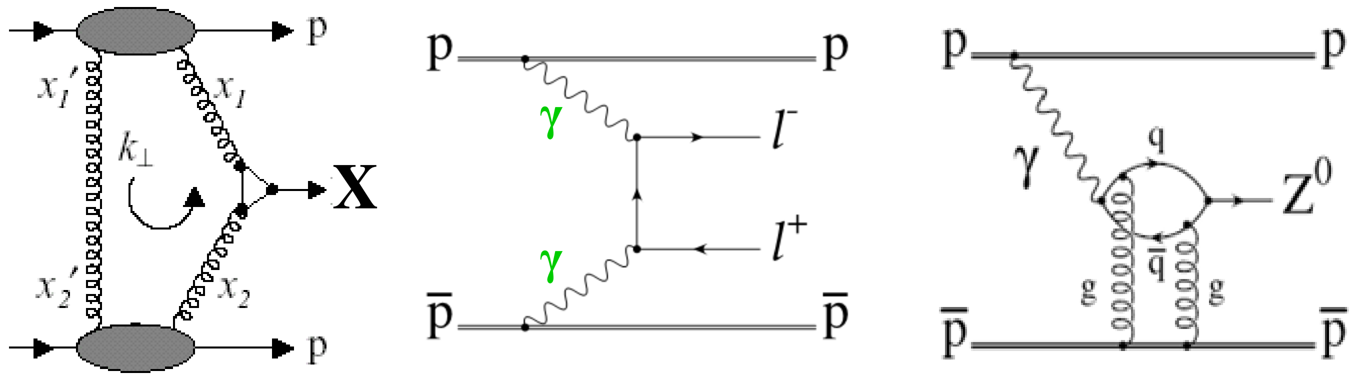
Some LHC-relevant comments

Introduction

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

where X is a simple state fully measured, and <u>no</u> 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 → $\boxed{X = h, H, W^+W^-, H^+H^-, \tilde{l}^+\tilde{l}^-, \ldots}$

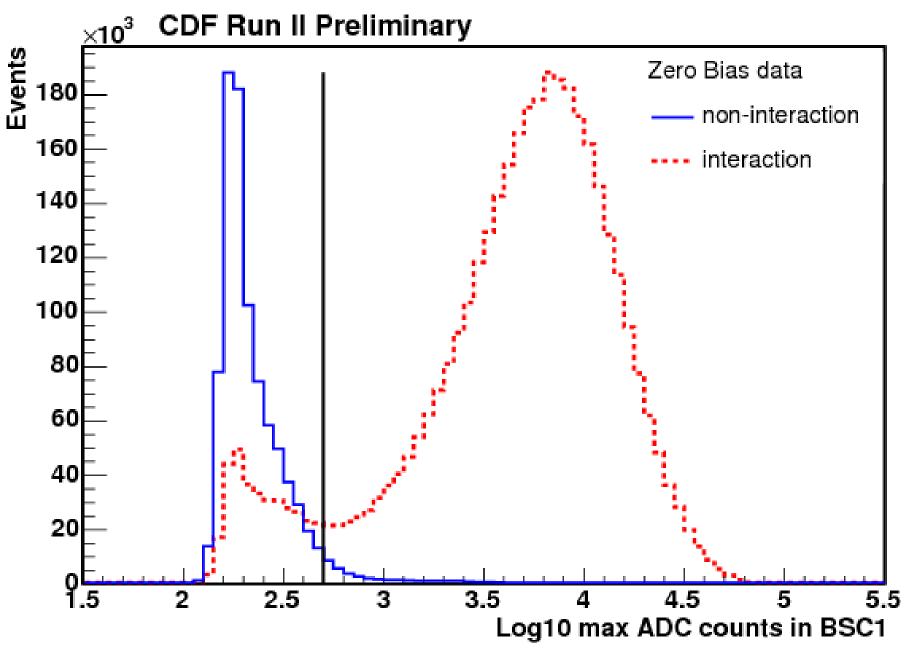
If see h, H : **Mass, width, spin J, C = +1, Couplings H – gg, …**

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

Trigger on X, and off-line require all CDF detectors empty (except X):
Use Zero-bias (bunch crossing) data

{1} = probably no interaction
{2} = probably >= 1 interaction

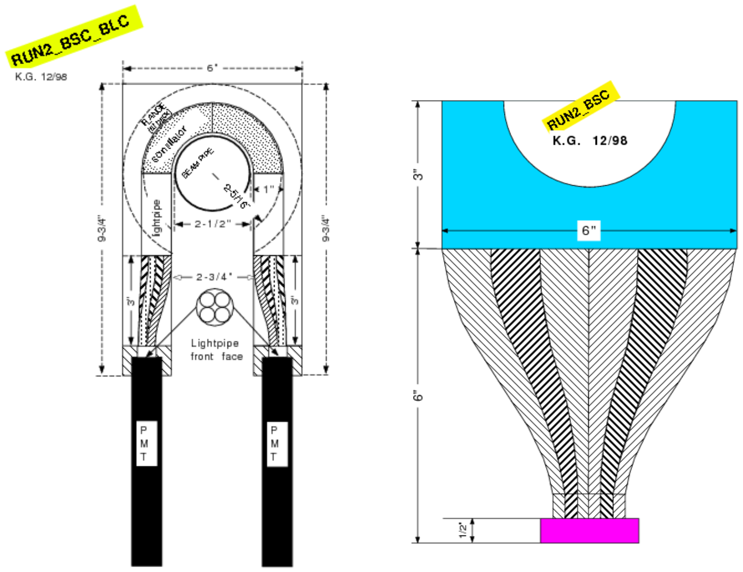
Take hottest PMT of 8 BSC1
Plot log max ADC for {1} and {2}
Separates empty / not empty
Repeat for all detectors



100 1000 10000

Example: forward Beam Shower Counters
BSC (Rockefeller)

BSC 1 BSC 2,3,4



Would be useful in all LHC experiments

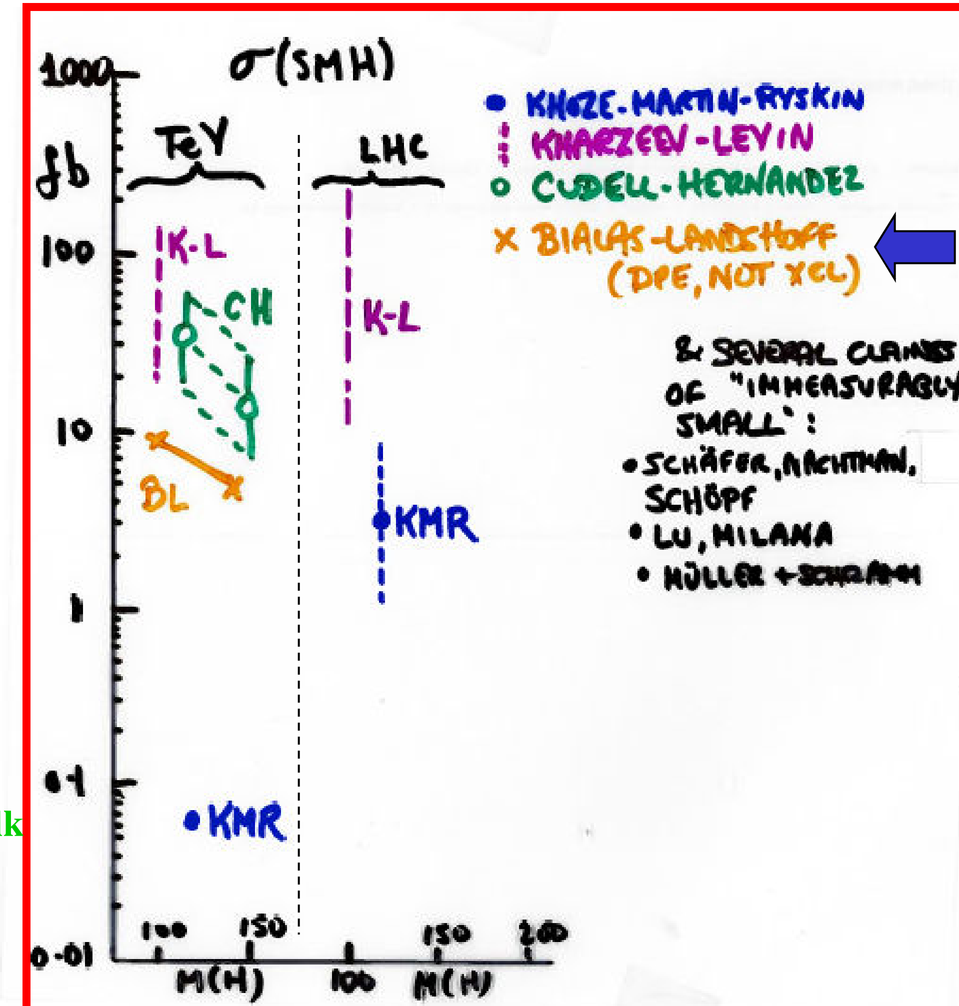
Can also make e.g. ΣET distibutions
in calorimeters.

Exclusive Higgs production?

Letter of Intent 2001
hep-ex/0511057
p+H+p at Tevatron?

Not impossible according to some!

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!

$$p+\bar{p}\rightarrow p+\gamma\gamma+\bar{p}\ \ *$$
$$p+\bar{p}\rightarrow p+\chi_c+\bar{p}\ \ *$$
$$p+\bar{p}\rightarrow p+\chi_b+\bar{p}$$
$$p+\bar{p}\rightarrow p+JJ+\bar{p}\ \ *$$

Jim Pinfold's talk

* Now measured in CDF

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

Cleanest (no S.I.) but smallest σ

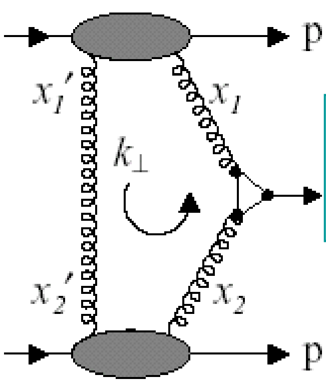
KMR: 36 pb in our box : . 2+1 candidates

Clean, big σ: $\frac{d\sigma}{dy}(y=0) \sim 90\,\text{nb (KMRS)}$

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

More perturbative, smaller theory uncertainty
But σ ~ 1/500th χc. Also BR's not known!
May not be possible at Tevatron.

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



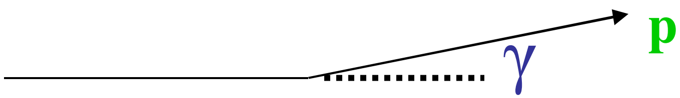
$\sigma(600), f_0(980)$
$\gamma\gamma, \chi_c, \chi_b$, JJ, H

ISR did it

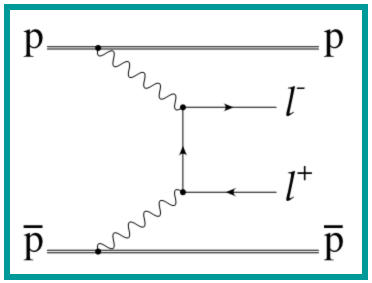
Our 3 measurements are all in good agreement (factor "few") with the Durham group predictions.

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

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

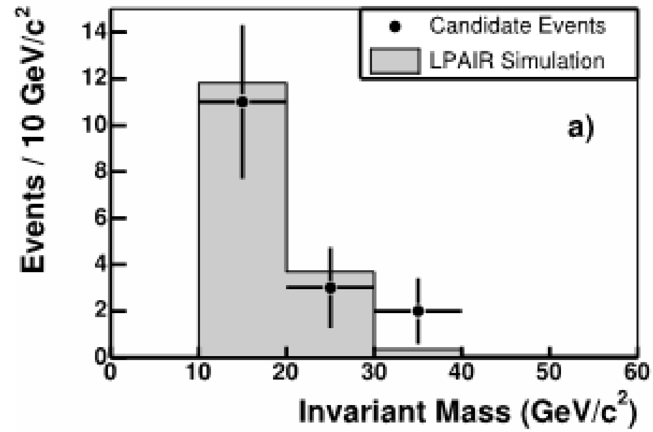


LEP etc: e+e- (~ background free)
HERA: e p High b/g … Seen
pp/ ppbar: Very high b/g … Seen in CDF



Tevatron as a γγ collider!

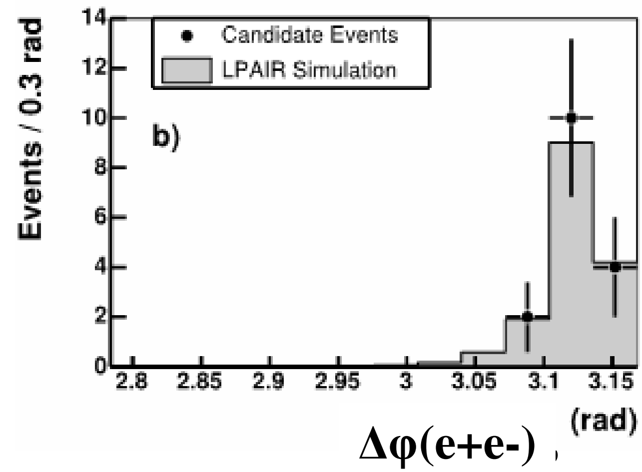
e+e- Mass 10 – 40 GeV



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 (diff Diss) ~ 1.9 events.

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

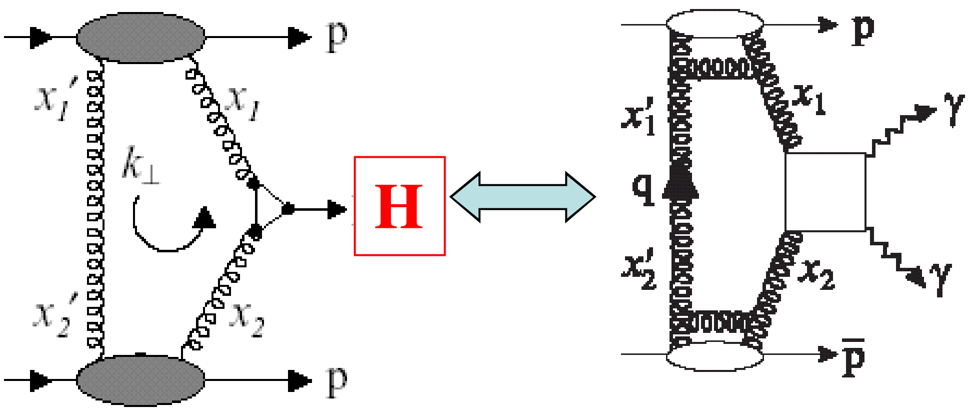


PRL 99, 242002 (2007) PHYSICAL REVIEW LETTERS week ending 14 DECEMBER 2007

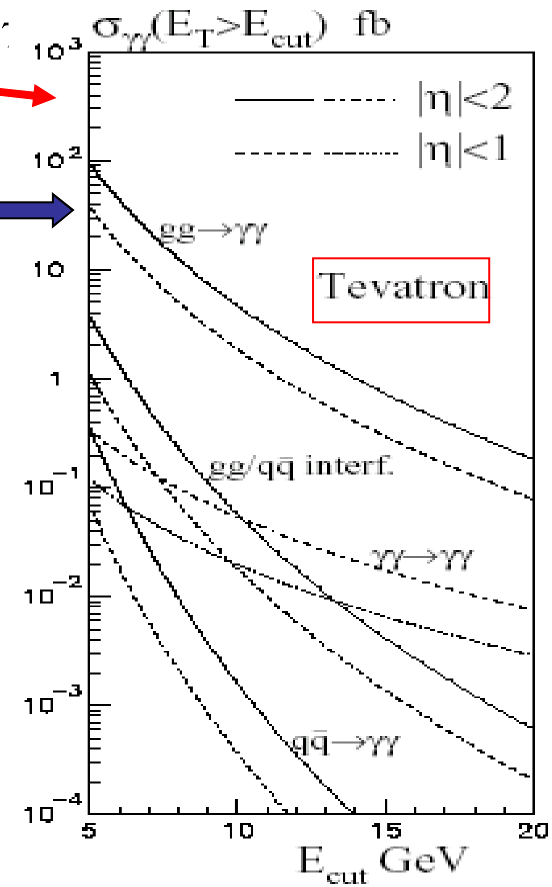
Search for Exclusive $\gamma\gamma$ Production in Hadron-Hadron Collisions

Khoze, Martin and Ryskin, Eur.Phys.J. C23: 311 (2002) ; KMR+Stirling hep-ph/040903

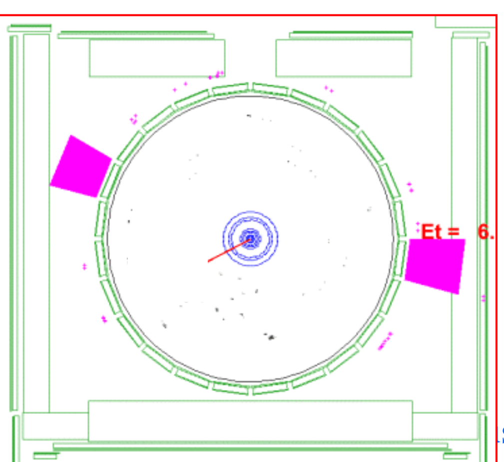
Claim factor ~ 3 uncertainty ; Correlated to p+H+p



36 fb



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



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

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

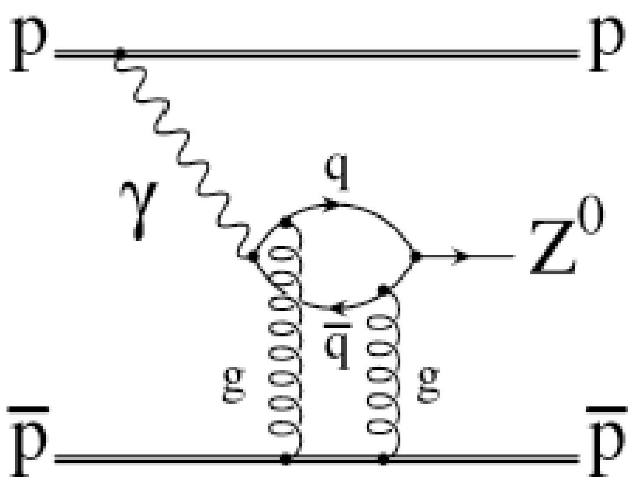
36 fb → 0.8 events

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

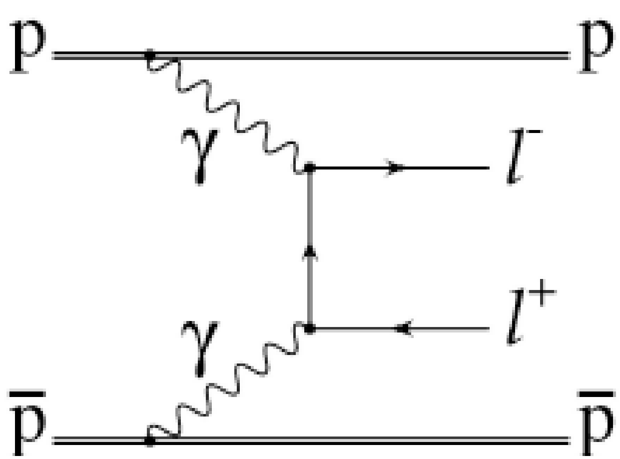
New data, Lower threshold, possible "observation"

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 photoproduction is SM process, but very small cross section at Tevatron:**
- **σ(SM) = 0.3 fb (Motyka & Watt 2008)
  σ(SM) = 0.21 fb (Goncalves & Machado 2008)
  Observation would mean BSM physics:
  example A.R.White Phys Rev D72: 036007**

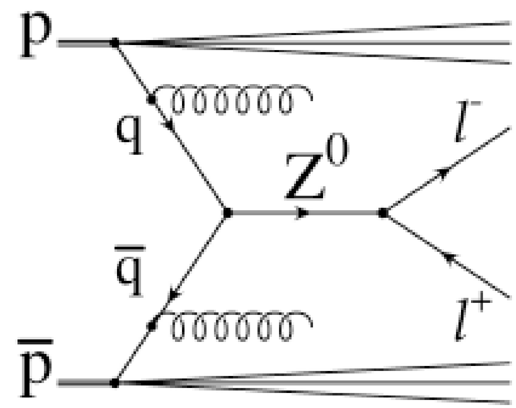


- Final state identical to exclusive dilepton production.
- This "background" is also interesting: could be used to calibrate forward proton detectors [$\xi(\bar{p}) = s^{-1/2}\sum p_T' e^{-\eta'}$].

↑ Fractional momentum loss of $\bar{p}$

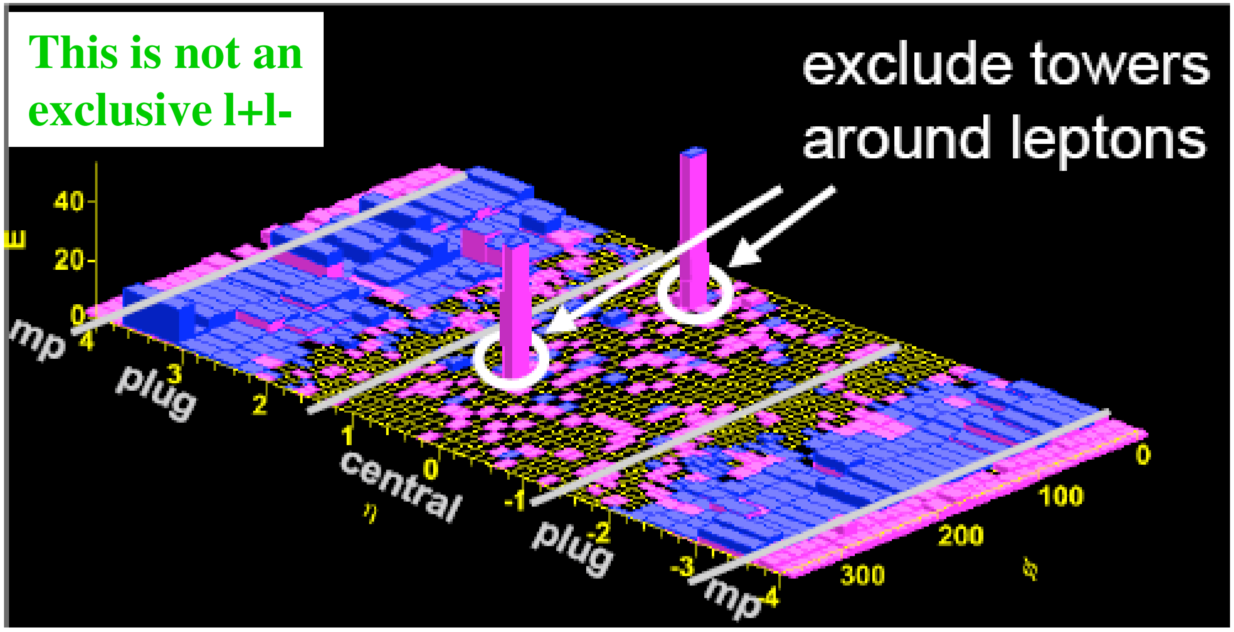
Select $Z \to \ell\ell$ ($\gamma\gamma \to \ell\ell$) events:

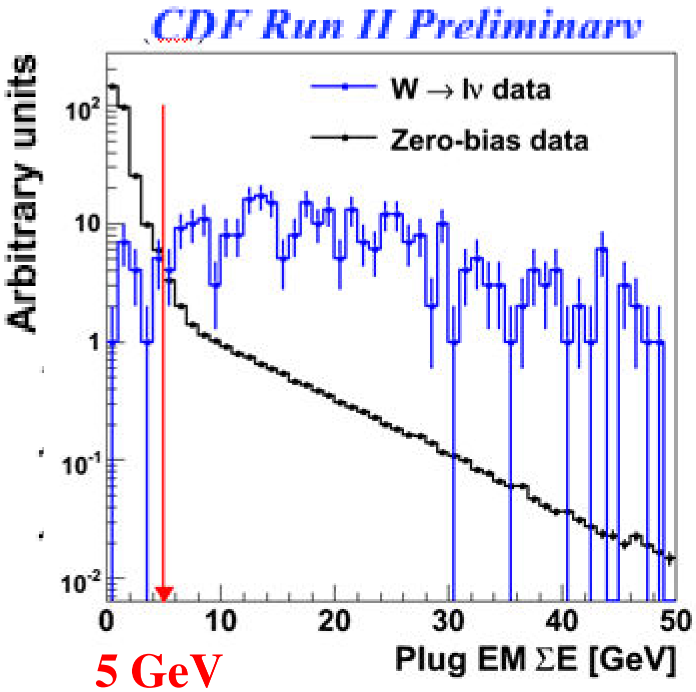
- e^+e^- or $\mu^+\mu^-$ pair with $p_T^{\ell} > 25(20)$ GeV
- require $82 < M_{\ell\ell} < 98$ ($M_{\ell\ell} > 40$) GeV
- Dominated by *non-exclusive* Z production ($\sigma \sim 250$ pb).
- Require *no other particles* in the event.



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
>> W cannot be exclusive
Choose cuts efficient for "noise" = "empty",
inefficient for W events.
Example: **Plug EM ΣE < 5 GeV**
Not same method as for other studies.
More efficient, maybe more background

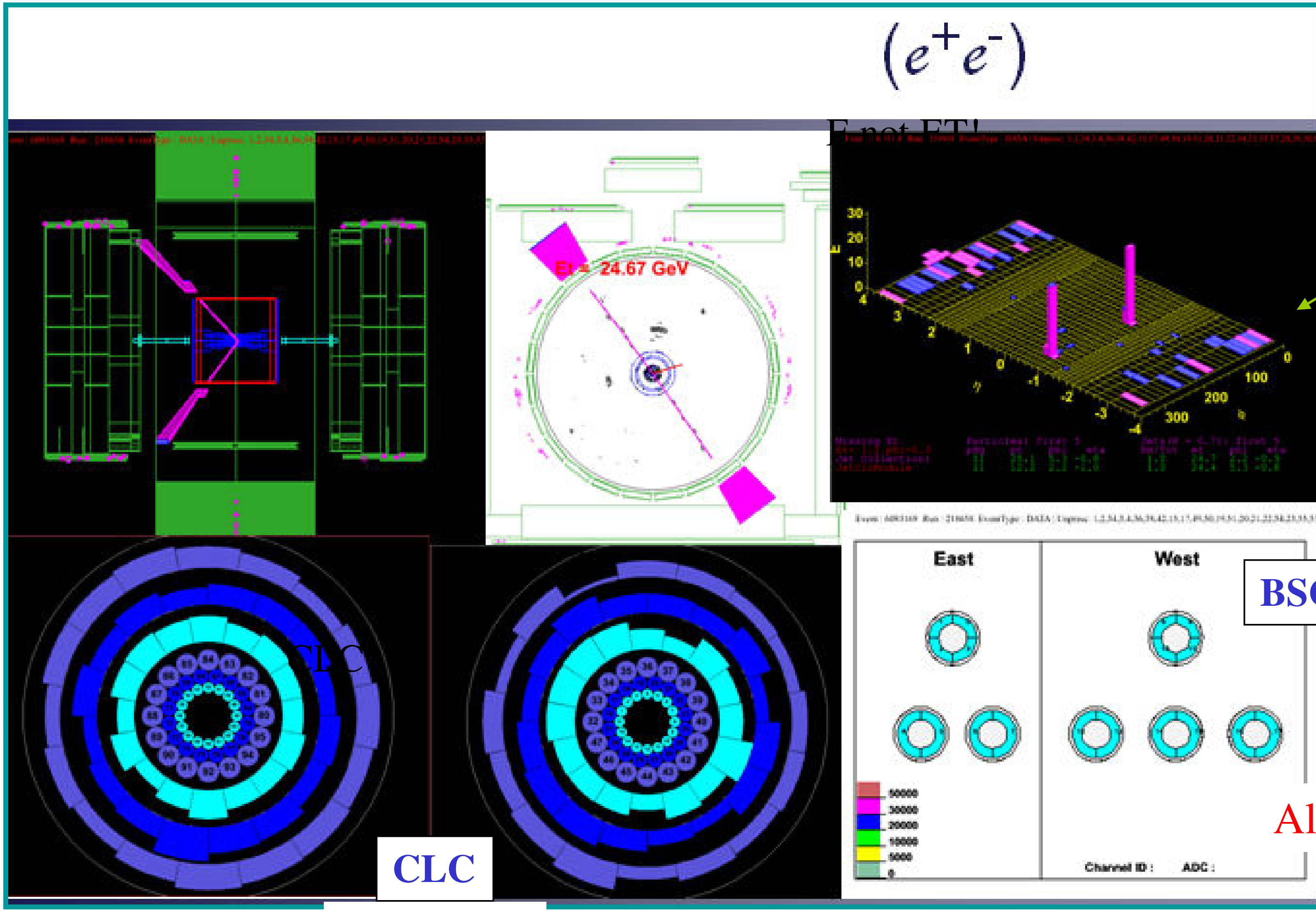
With 2.20(2.03) fb^{-1} in the electron(muon) channels:

	$\gamma\gamma \to \ell\ell$ [$M_{\ell\ell}$ > 40 GeV]	$Z \to \ell\ell$ (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



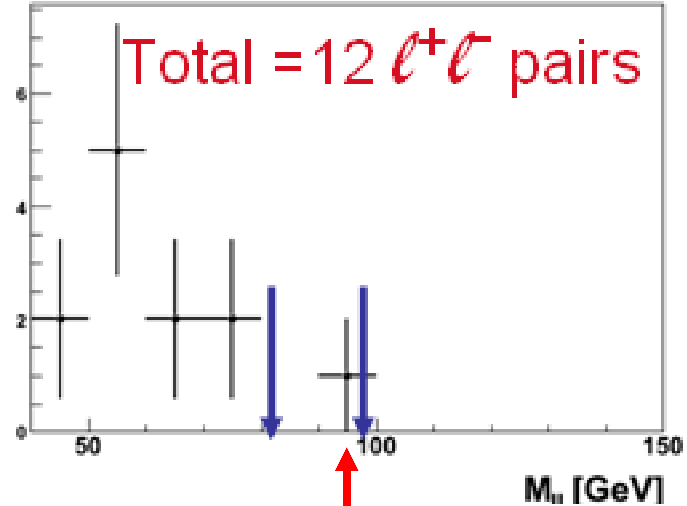
Noise

All empty!

All empty!

Mass reach at Tevatron ~ HERA, LEP !

Before requiring BSC empty (no dissociation):



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

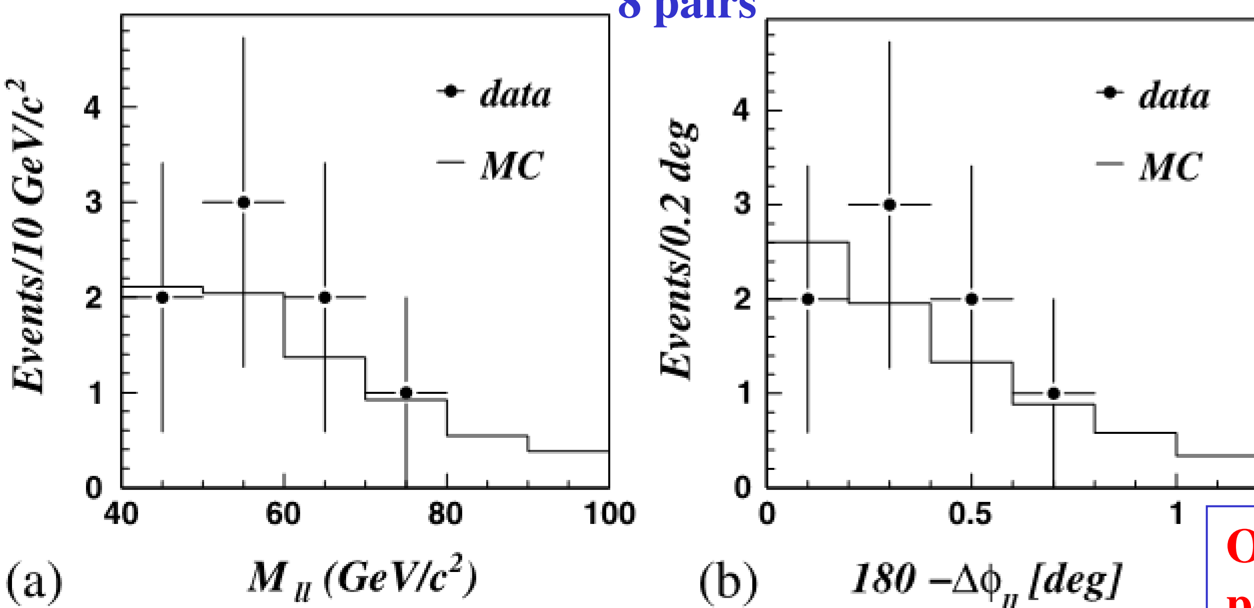
$$M > 40\ \mathrm{GeV/c^2}, |\eta| < 4$$

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

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

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

8 pairs



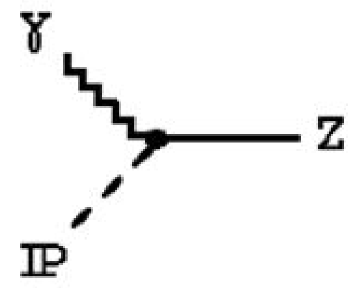
One event has a Roman pot pbar track, others had pbar out of acceptance or Roman pots off.

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 **Mainly from W**
- $\alpha \times BR(\ell\ell) \times \mathcal{L}_{eff} = 3.22 \pm 0.38\ pb^{-1}$



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

(960 fb)

COOL!

Predictions: Standard Model:

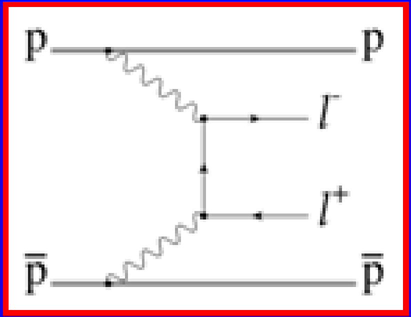
Motyka and Watt, PRD 78, 014023 (2008) : σ(Z,excl) = 0.3 fb

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 γγ 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 $|\eta| < 2$

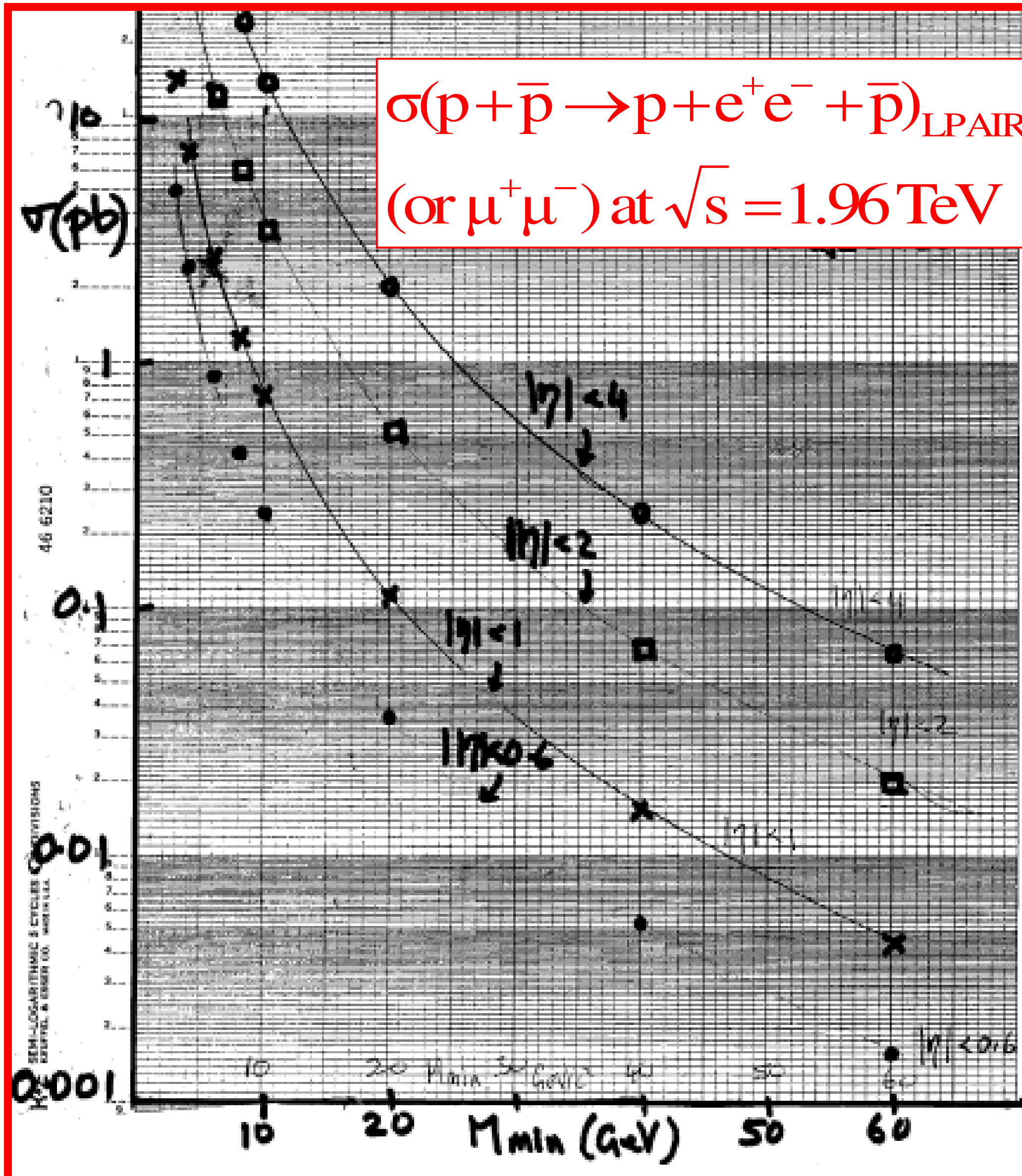
$\sigma(p\bar{p} \rightarrow p + \mu^+\mu^- + \bar{p})_{QED}$
vs. M(min) for different $|\eta|$(max)
at $\sqrt{s} = 1.96$ TeV, LPAIR

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

Purely empirical fit (Tevatron)
(no physics, just convenient):

$$\sigma_{\mu\mu}[M_{min}(\mathrm{GeV}), |\eta_{max}|] \approx \frac{245\,\mathrm{pb}}{(1 + 0.008 \times M_{min})} \times \frac{|\eta_{max}|^{2.15}}{M_{min}^{2.5}}$$

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



$$p+\bar{p} \rightarrow p+\mu^+\mu^- + \bar{p}$$

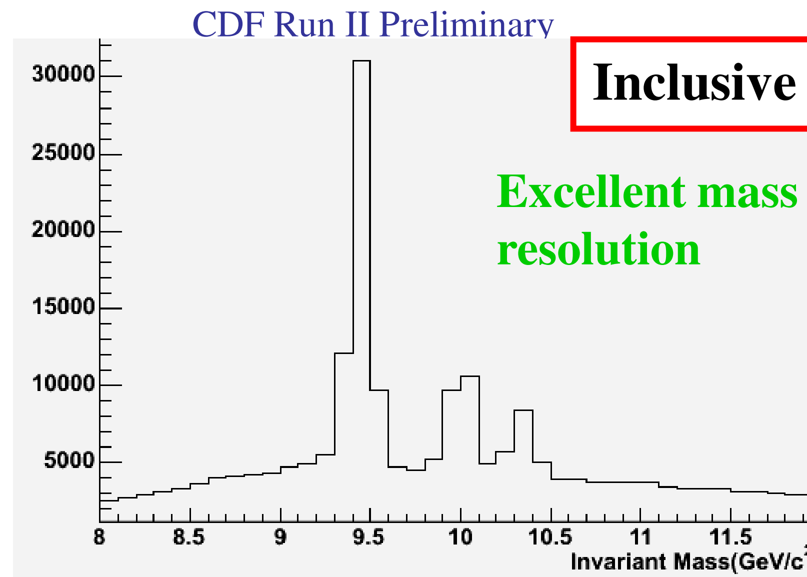
M ~ 8 GeV – 40 GeV

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

$$\frac{d\sigma}{dy}(y=0)Y(1S) \sim (12\pm3)\text{ pb}$$

(Spread in predictions)

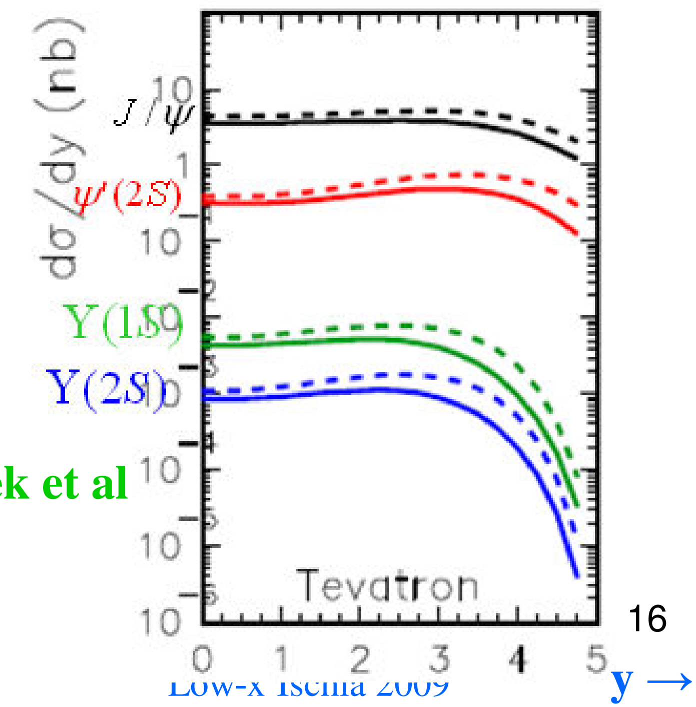
$$\frac{d\sigma}{dy}(y=0)J/\psi = (3.92\pm0.25\pm0.52)\text{ nb (CDF)}$$



$$\frac{d\sigma}{dy}(y=0)\Upsilon(1S) \sim \frac{1}{300-800}\frac{d\sigma}{dy}(y=0)J/\psi$$

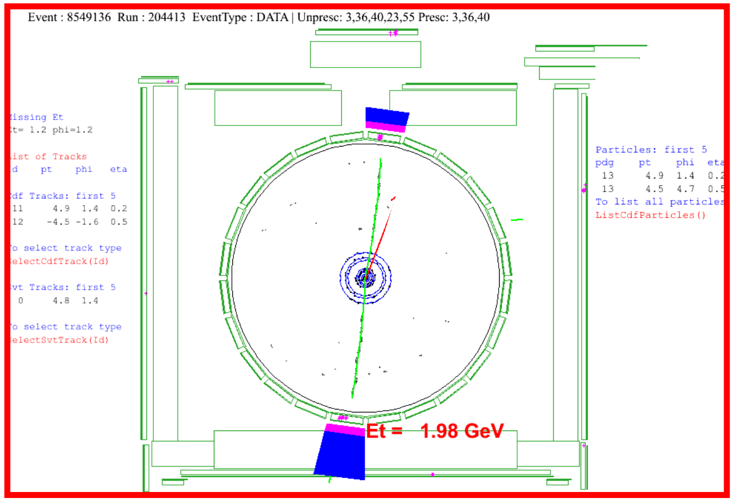
Unlike J/ψ, need to allow pile-up.
Handles: N(ass) = 0, pT(μ+μ-) ~ 0, π-Δφ ~0

e.g. A.Szurek et al



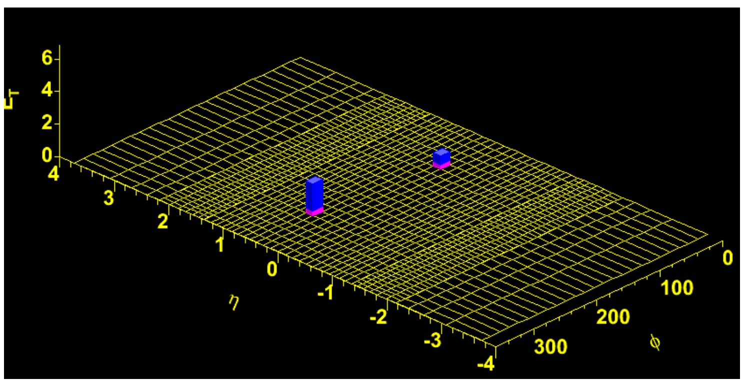
Exclusive Upsilon Y(1S) candidate

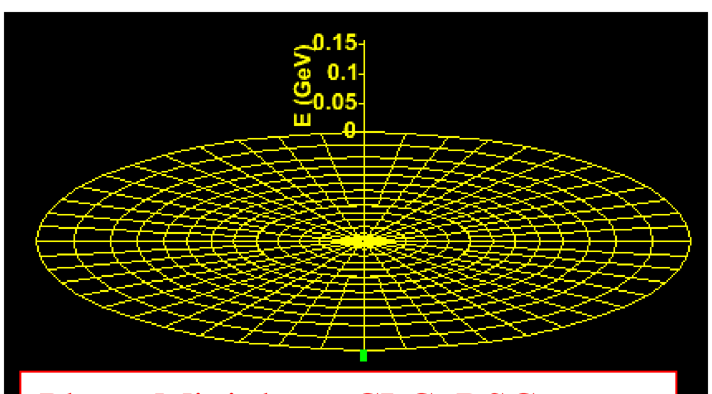
Run/Event: 204413/8549136



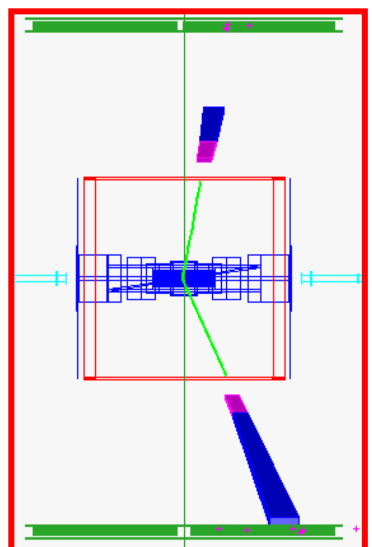
M ~ 9.4 GeV

We have candidates, but will have few without pile-up (< 10% at present L)





R-z, Muon hits



Plugs, Miniplugs, CLC, BSC empty

Exclusive χb production is important (better than χc) but probably impossible with pile-up. But will not get a good Υ cross section without knowing χb !

$\chi_b \rightarrow \Upsilon + \gamma < 6\%$ (PDG)

Use so far:
Run 2 Periods 1-17
L = 2.36 / fb
Will add +50% later

Branching ratios for μ+μ- channels:

Υ(1s)[9.46 GeV] : 2.5%
Υ(2s)[10.02 GeV] : 1.3%
Υ(3s)[10.36 GeV] : 1.8%

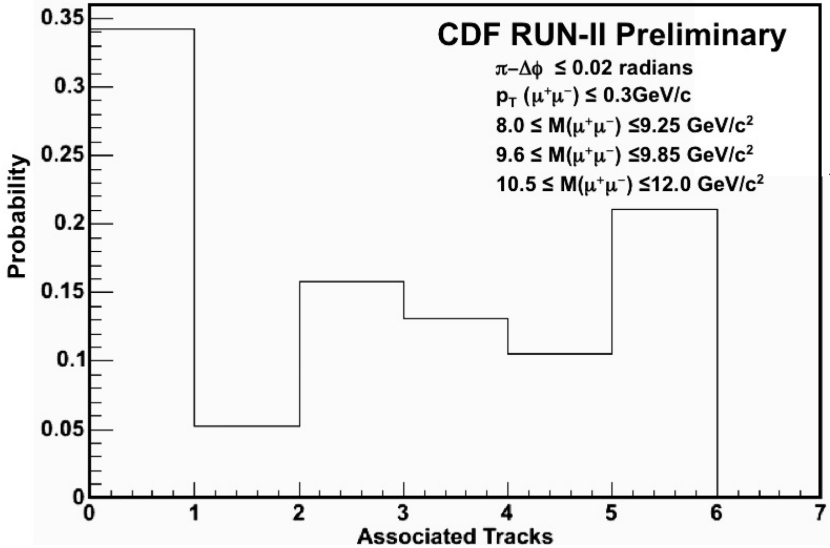
Trigger: μ+μ- |η|<0.6 , pT(μ) > 4 GeV/c

Require two quality muons |η| < 0.6, pT > 4 GeV/c, Δz < 2 mm, z0 < 60 cm. : Then ~ 500K events

Then home in:
N(ass) < 6, pT < 2 GeV/c, (π-Δφ) < 0.2 ("big box") and study distributions
Generate MC QED events (LPAIR) and Υ photoproduction (STARLIGHT) + CDFSIM

Make smaller "boxes" in pT, (π-Δφ) to enhance S:B even with reduced efficiency

Number (0-5) of associated (additional) tracks on dimuon vertex

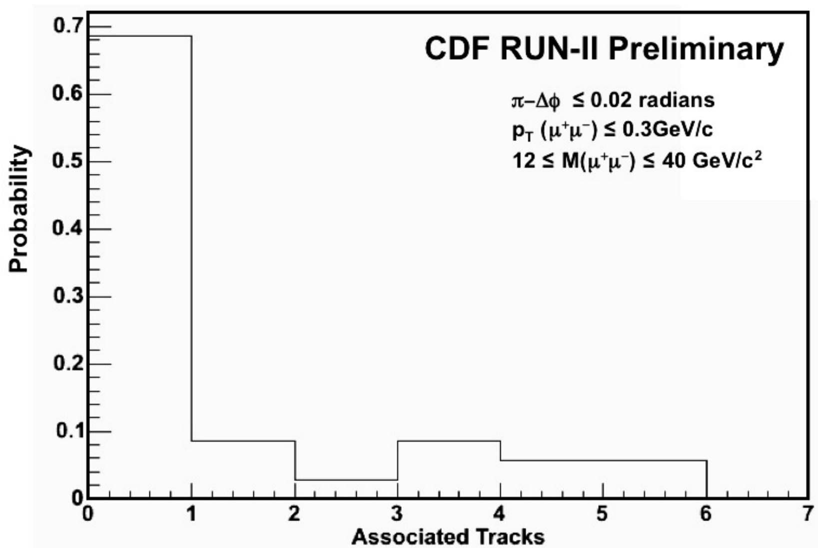


QED regions:

Low mass 8 – 12 GeV excluding Y's

High mass 12 – 40 GeV

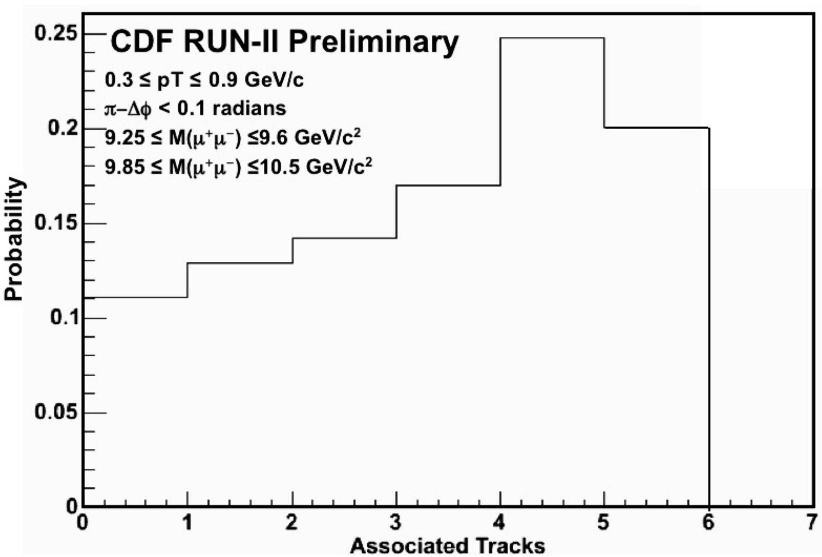
$\pi - \Delta\varphi < 0.02$
$pT < 0.3$ GeV/c
(QED favored cuts)



$\pi - \Delta\varphi < 0.1$
$0.3 < pT < 0.8$ GeV/c
(Y favored)

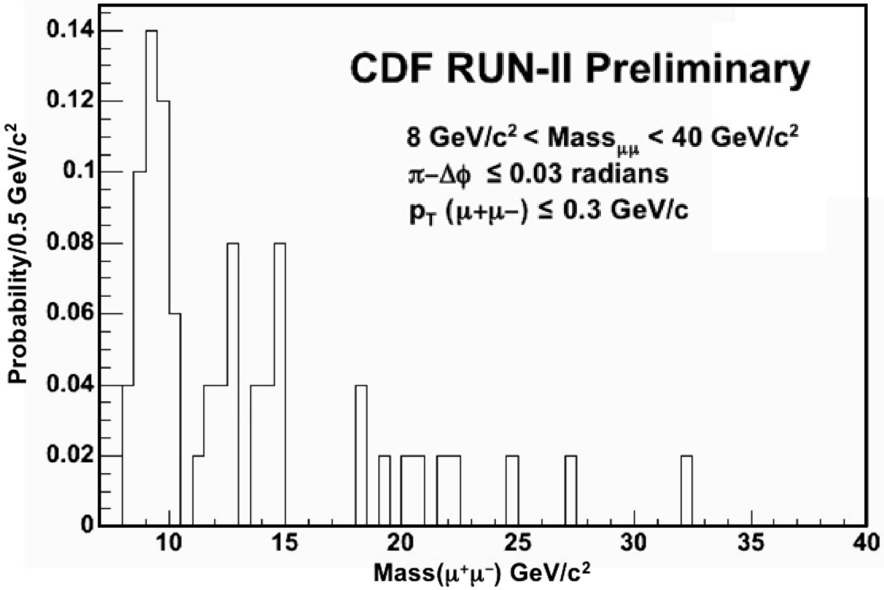
Y mass region:

9.25 – 9.6, 9.85 – 10.5 GeV

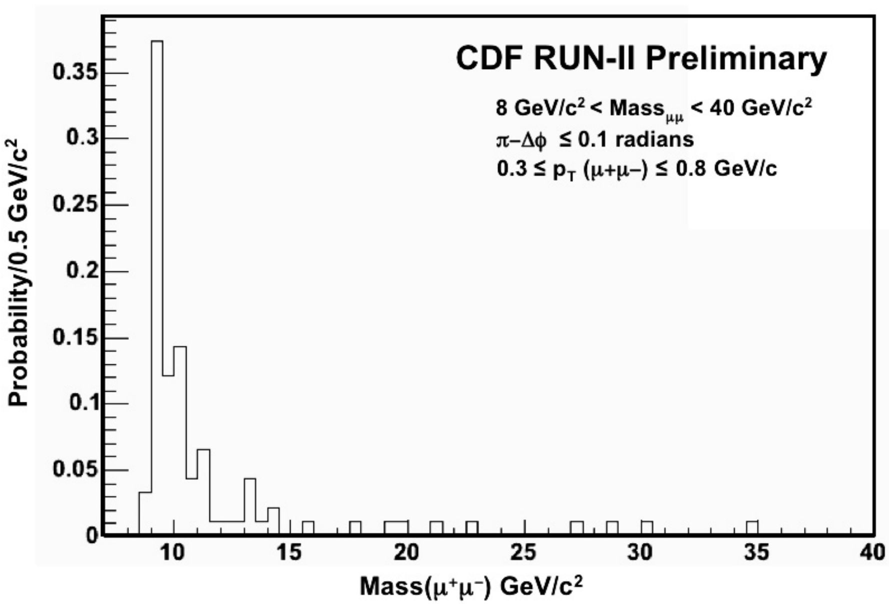


Mass spectra (8 – 40 GeV), N(ass) = 0 and (π-Δφ), pT cuts

QED favoured cuts



Y favoured cuts
(non-overlapping)



Next steps:

Finish acceptance x efficiency → QED cross section (Good?)
+ other triggers + ~ 2 x more data
Y cross section or upper limit (large non-exclusive B/G)
Select no-pile-up events, allowing EM showers.
Any $\chi c \rightarrow Y + \gamma$ candidates? Cross section x BR or limit

Parallel analysis on e+e- (Erik Brucken, Risto Orava, MA) No-PU
Any Y signal? Compare results
Especially look for more exclusive $\gamma\ \gamma$ events

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 exists)

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

I covered:

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

More to come!

Jim Pinfold covered:

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

← **our star reaction!**

Thank You

Back-ups

PDG 2008:

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
$2\pi^+ 2\pi^- K^+ K^-$	$(1.1 \pm 0.6) \times 10^{-4}$		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
$3\pi^+ 3\pi^- K^+ K^-$	$(2.4 \pm 1.2) \times 10^{-4}$		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

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)

$\chi_b \quad I^G J^{PC} = 0^+0^+$ and 0^+2^{++} states:

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

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

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

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

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

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

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