Central Exclusive $\pi^+\pi^-$ Production in $p\bar{p}$ Collisions at $\sqrt{s}$ = 0.9 and 1.96 TeV in CDF

CDF = Collider Detector at Fermilab

Michael Albrow
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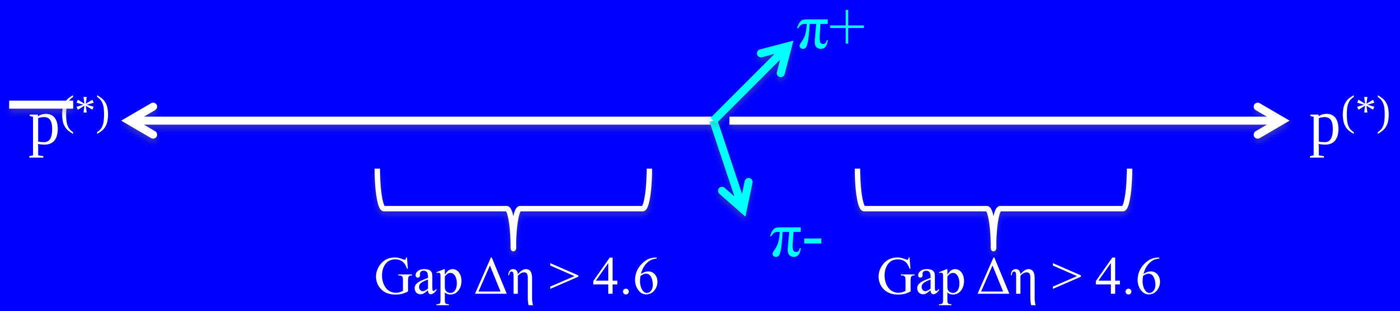
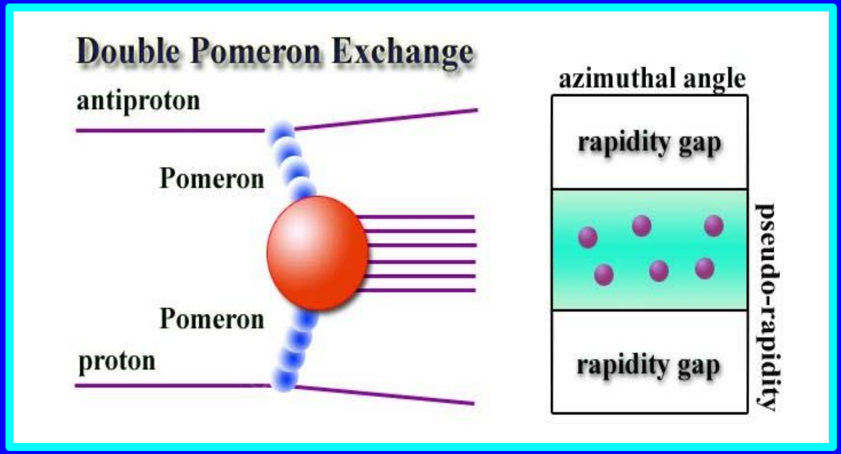
On behalf of the CDF Collaboration





These results submitted to PRL : arXiv:1502.01391 [hep-ex]

CDF Publications on Central Exclusive Production in $p\bar{p}$

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

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

e^+e^-

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

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

$\gamma\gamma$

PHYSICAL REVIEW D **77,** 052004 (2008)

Observation of exclusive dijet production at the Fermilab Tevatron $\bar{p}p$ collider

JJ

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

e^+e^-
$\mu^+\mu^-$

PRL **102,** 242001 (2009) PHYSICAL REVIEW LETTERS week ending 19 JUNE 2009

Observation of Exclusive Charmonium Production and $\gamma\gamma \to \mu^+\mu^-$ in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

$\mu^+\mu^-$
J/ψ
χ_c

PRL **108,** 081801 (2012) PHYSICAL REVIEW LETTERS week ending 24 FEBRUARY 2012

Observation of Exclusive $\gamma\gamma$ Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

$\gamma\gamma$

PHYSICS MOTIVATION

1) Pomeron : Strongly interacting color singlet exchange
   Carrier of 4-momentum (t-channel) in elastic scattering
   and other diffractive – large rapidity gap – interactions.

   Non-perturbative QCD : models required for calculations.
   At leading order gluon pair {gg} in color singlet.
   Vacuum quantum numbers I PC = 0 ++
   s-channel continuation would be a glueball {gg}

2) Double Pomeron Exchange (DPE) : P + P → X
   Excellent channel for meson spectroscopy $I^G J^{PC} = 0^+ \text{even}^{++}$
   Especially for scalar and tensor (J=2) glueballs
   Uniquely produced in isolation (or an isolated pair)

Introduction

$$p + \bar{p} \longrightarrow p(*) + X + \bar{p}(*)$$

In this study $X = \pi^+\pi^-$ and central : $|y(\pi^+\pi^-)| < 1.0$

+ : Rapidity gaps $\Delta\eta > 4.6$ with no detected particles.

Allowed t-channel exchanges only γ or P(dominant)

Quantum numbers of state X have to be Q = S = B = 0

Isospin I = 0, Parity = +1, C-parity = +1, spin J = 0 or 2

Established states (PDG) : f0(500, 980, 1370, 1500, 1710)

f2(1270, 1525, 1950, 2010, 2300, 2340)

$\chi_{c0}(1P)$, $\chi_{c2}(1P)$, $\chi_{c0}(2P)$, $\chi_{c2}(2P)$

$\chi_{b0}(1P)$, $\chi_{b2}(1P)$, $\chi_{b0}(2P)$, $\chi_{b2}(2P)$

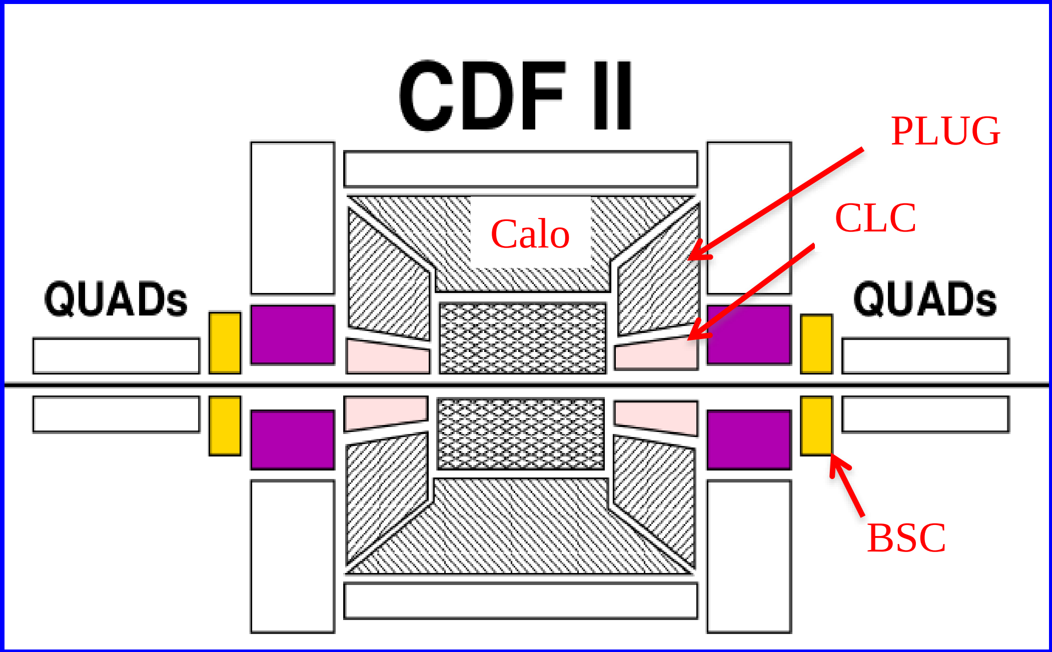
& Higgs(125) ! (@ LHC?)

J = 0, 2 GLUEBALL IN HERE?

Tevatron and CDF

$\sqrt{s}$ = 1960 GeV p-pbar
& $\sqrt{s}$ = 900 GeV
(special run for this & …)

Outgoing protons not detected –
Dissociation e.g. $p\pi\pi$ allowed if all $|\eta| > 5.9$



Level 1 Trigger:
2 Calo towers $|\eta| < 1.3$ with $E_T > 0.5$ GeV

& all these in VETO :

BSC = Beam Shower Counters $|\eta|$ = 5.4 - 5.9
CLC = Cherenkov Lumi Counters $|\eta|$ = 3.75-4.75
Plug Calorimeter $|\eta|$ = 2.11 – 3.64

Only single, no pile-up, interactions usable
Data mostly at end of stores when pile-up is low.

Off-line select exactly two tracks on a common vertex
& excluding cones of R = 0.3 in calo around extrapolated tracks,
full detector $-5.9 < \eta < +5.9$ “empty” = consistent with noise.

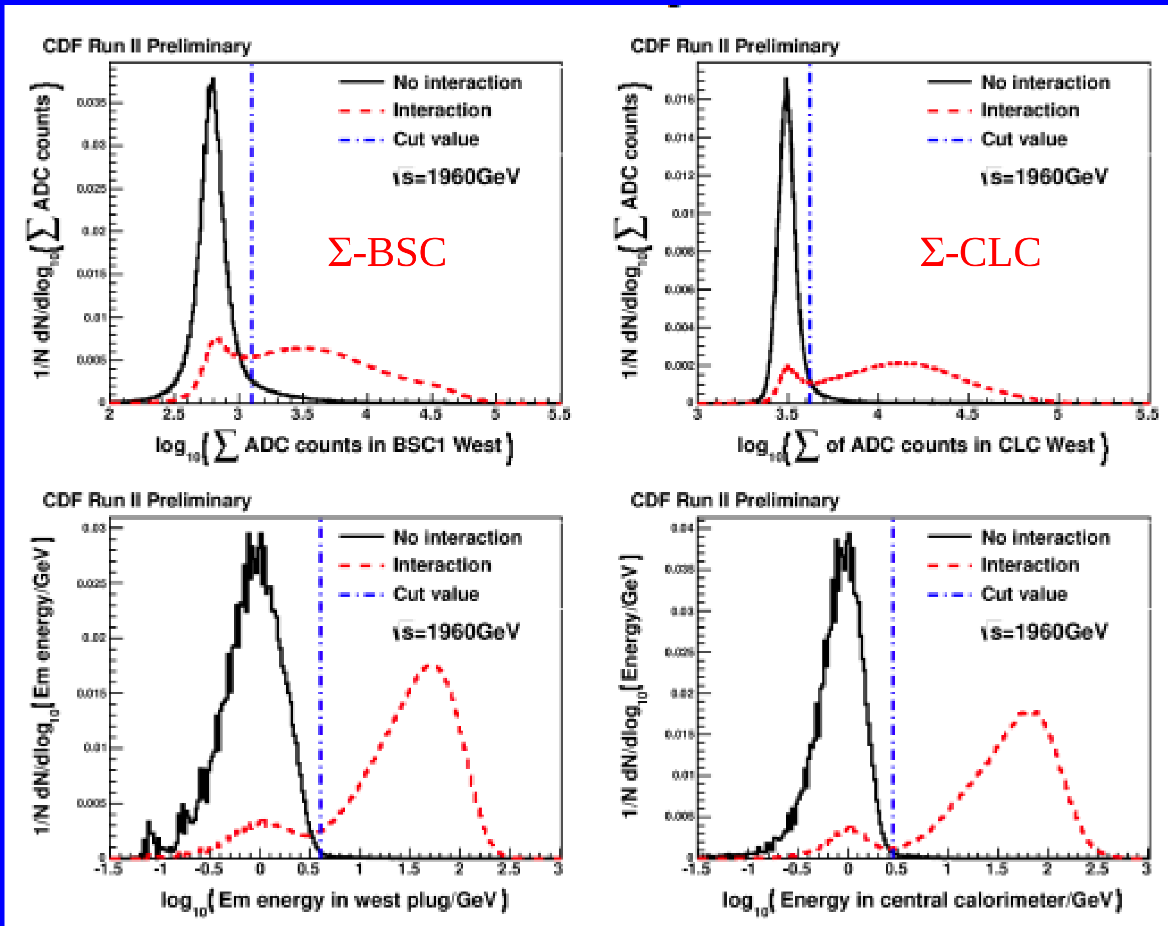
$$R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$

Determining noise levels (exclusivity cuts)

Zero bias (bunch crossing) triggers, same periods
Make two distinct classes:
A)“No Interaction” = no tracks, no CLC hits, no muon stubs
B) “Interaction” = All other events

Plot distributions of A and B for ΣE, ΣADC counts, hottest PMT for each subdetector

Examples of determining noise levels = exclusivity cuts



ΣE PlugEM

ΣE Cen Calo

Good noise-hits separation
Red under noise = genuine gaps

Shift cuts for systematics

These are for the “west” side.
East side plots ~ identical

Applying all exclusivity cuts to zero-bias data →

Probability empty detector fn L_{bunch}

ε(excl) vs L_{bunch}

-- 36 x 36 bunches not all equal

Intercept = 1.0 (no beams no noise!)

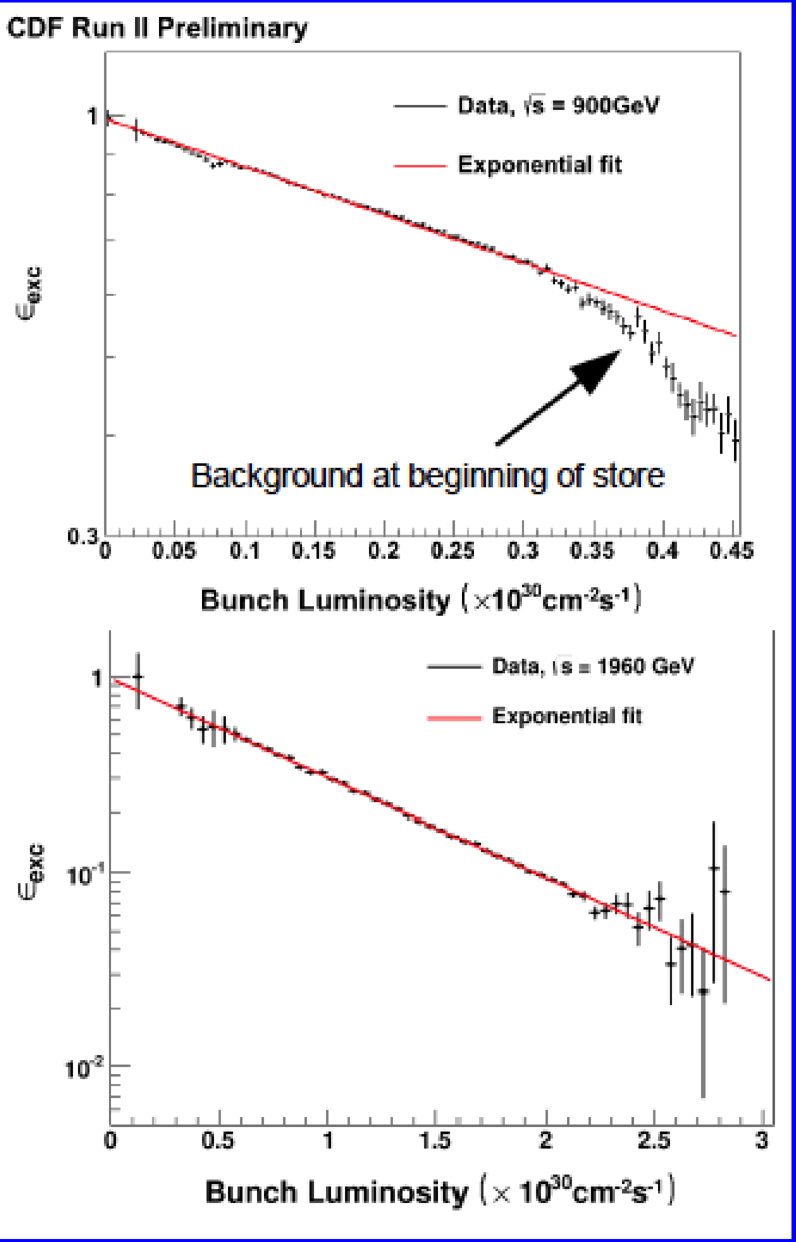
P(0) is exponential

Slope → detected inelastic cross section

	1960 GeV	900 GeV
σ_{obs} (|η|<5.9)	55.9(4) mb	65.8(4) mb
L_{eff}	1.15/pb	0.059/pb

Higher M(diss.) allowed at 1960 GeV

Provides the effective no-pileup luminosity, convoluting L_{bunch} distribution of data



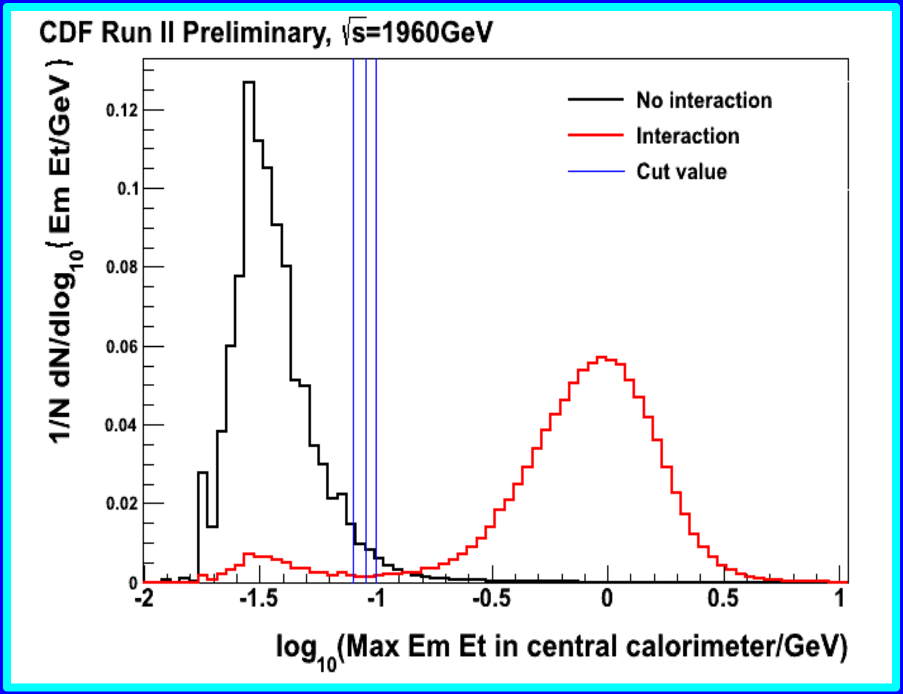
Further analysis:

Exactly two tracks, opposite charge (|Q| = 2 kept for B/G control) on a common vertex in interaction region.

Track quality (χ^2) cuts, and p_T(track) > 0.4 GeV/c, |η(track)| < 1.3

|y(π+π-)| < 1.0

Additional noise cut on hottest EM tower (E_T < 90 MeV) outside track cones.



The "hottest" EM tower must be less than 90 MeV

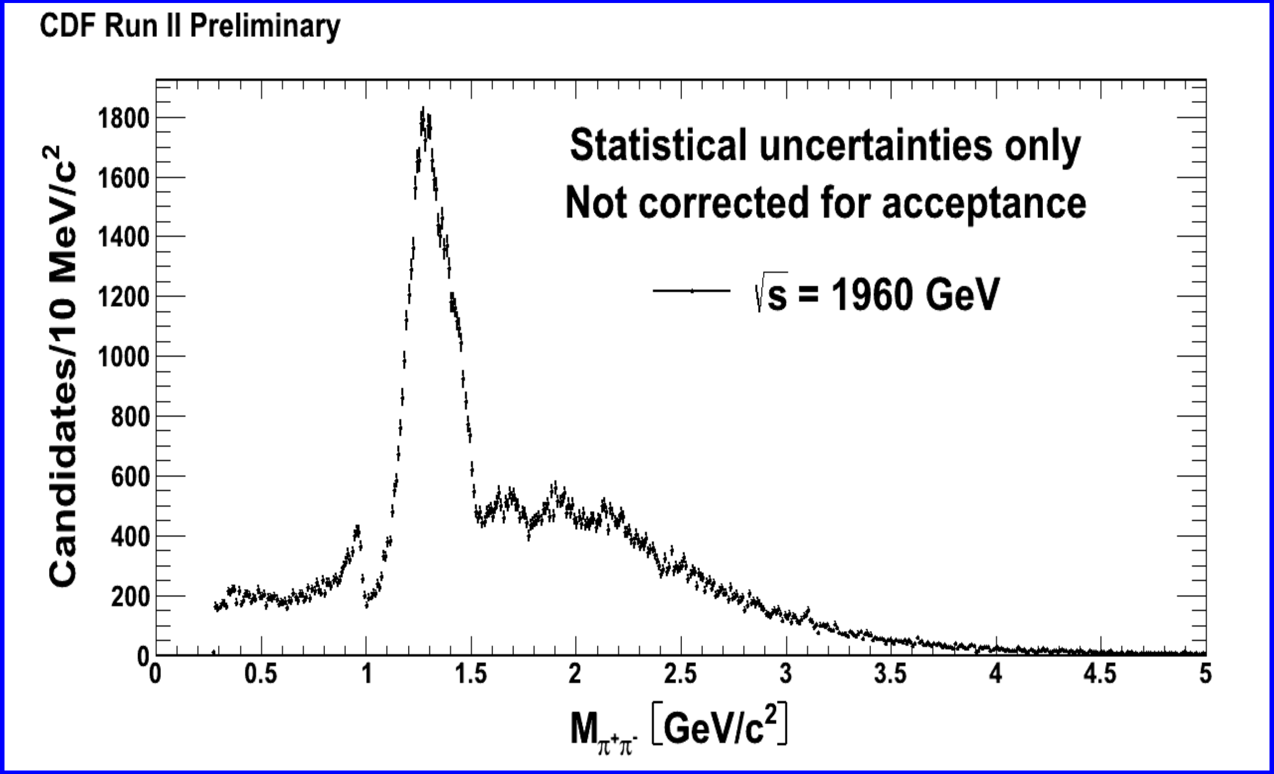
Cosmic ray background = 0 after cuts

Final sample:

127,340 events at $\sqrt{s}$ =1960 GeV

6,240 events at $\sqrt{s}$ = 900 GeV

Invariant mass distribution, not corrected for acceptance



Acceptance very low for $M_{\pi\pi} < 1$ GeV/c^2 (p_T cut)

But no significant ρ (forbidden in DPE)

f0(980)/cusp at KK threshold

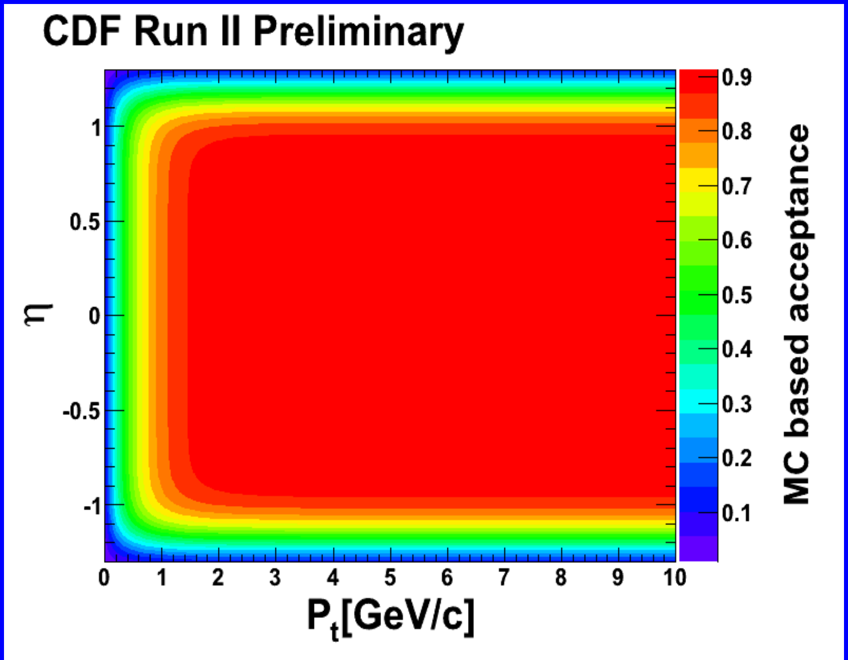
Strong f2(1270) with f0(1300) shoulder

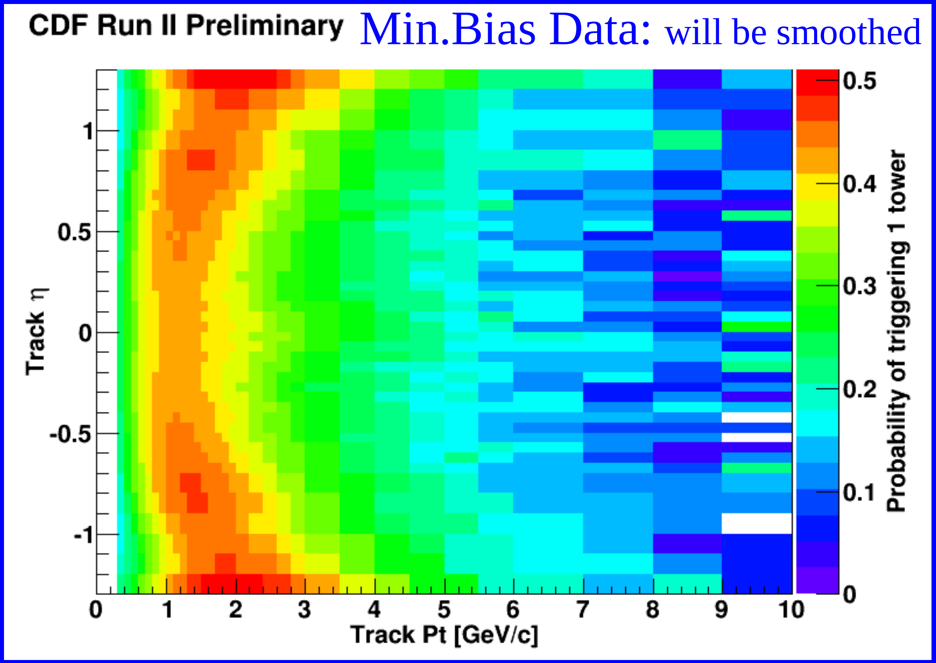
Structures at higher masses

Need to correct for acceptance!

Components to acceptance x efficiency:

Trigger efficiency (p_T, η, ϕ)
Single track acceptance (p_T, η, ϕ)
Two track acceptance ($M_{\pi\pi}$, $p_{T\pi\pi}$ $y_{\pi\pi}$)
… we assume isotropic decay (S-wave): the only model dependence
Will be checked by comparing with data … compatible with isotropic?

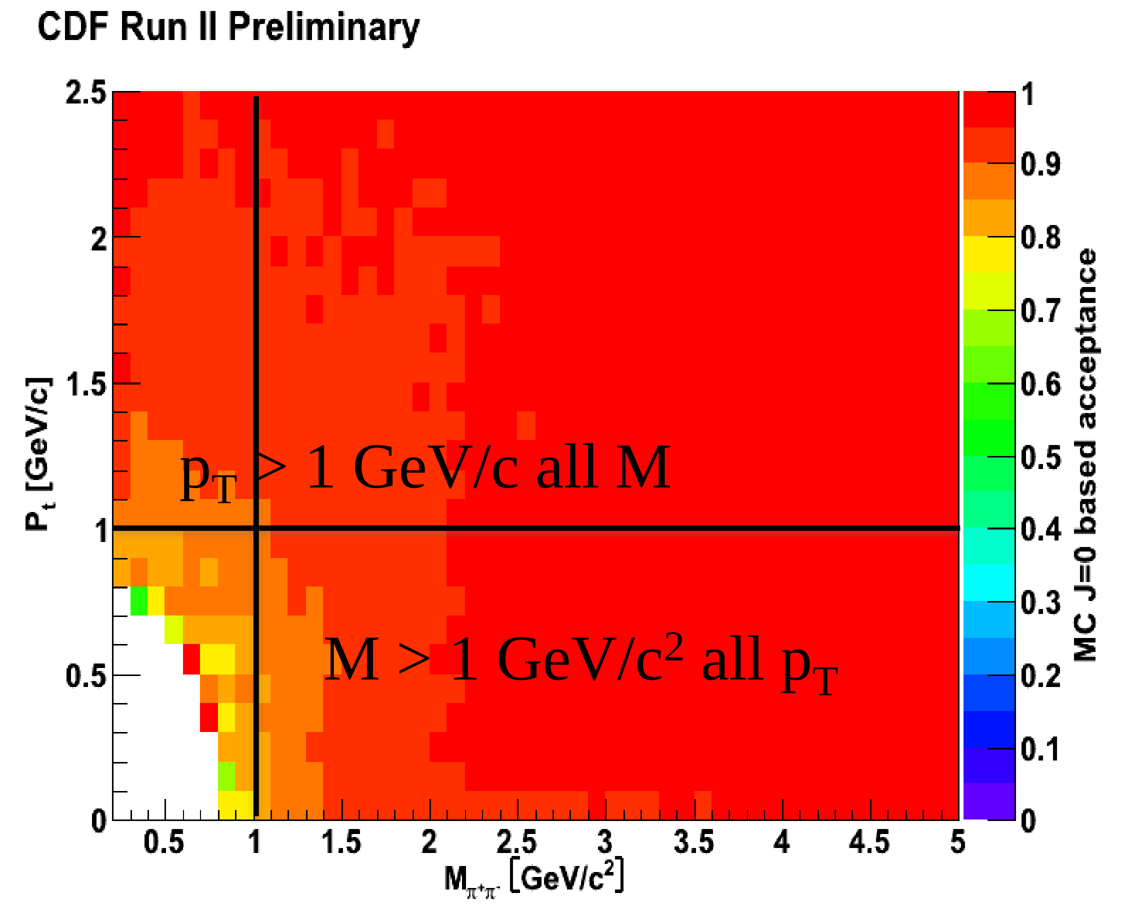




Single track acceptance (p_T, η, ϕ)

Probability of triggering exactly 1 tower
> At high p_T 2 or more towers trigger

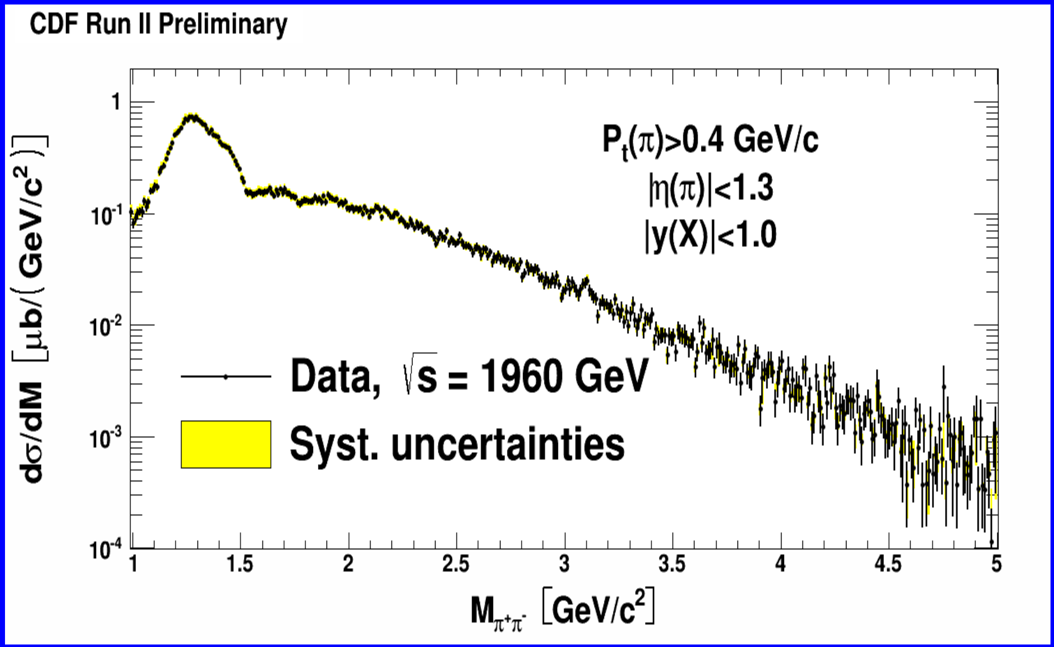
Acceptance x efficiency for $\pi\pi$, function of $M_{\pi\pi}$ and $p_{T\pi\pi}$



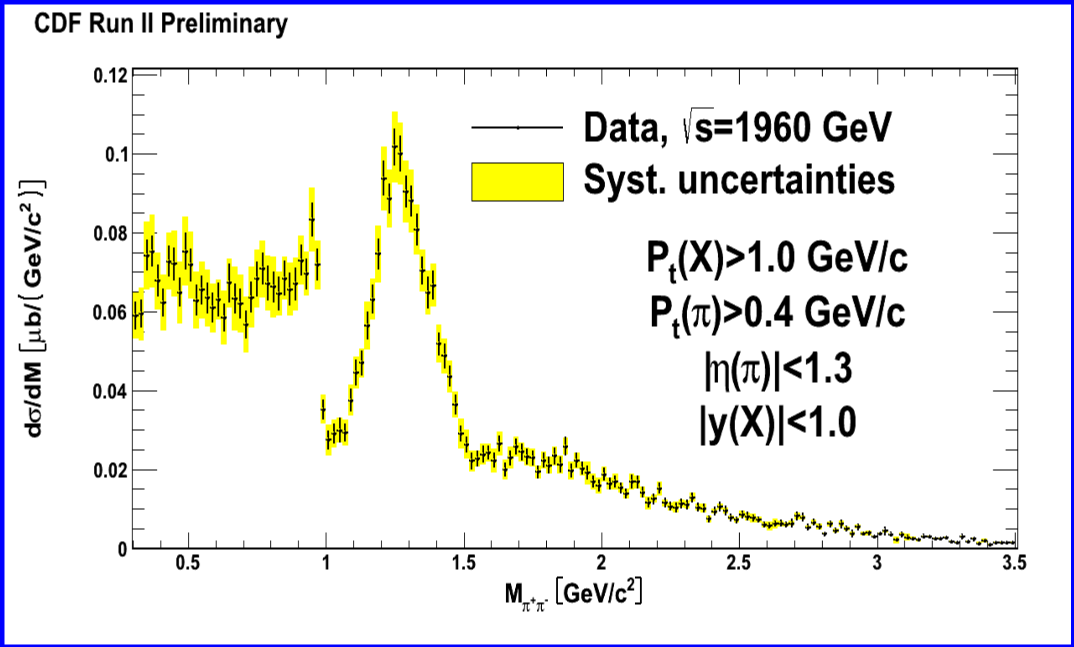
Avoid (low M, low p_T) hole and edges: select two regions

Data, corrected for acceptance and efficiencies in M, p_T and effective luminosity:

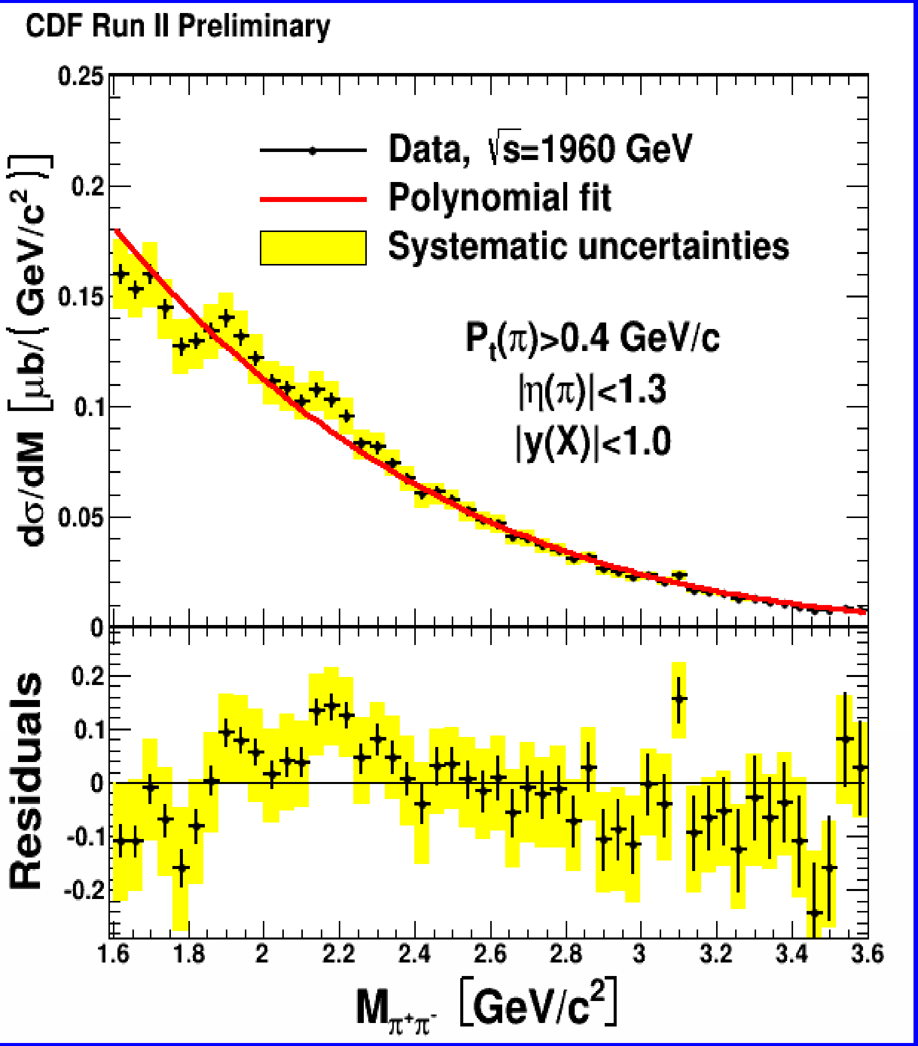
Cross sections, integrated over p_T in two regions (1960 GeV)



Broad continuum below 1 GeV/c^2
"Cusp" at KK threshold/f0(980)
Resonance(s) up to 1500 MeV/c^2
dominated by f2(1270)
…asymmetric: probable f0(1300)
Change (~dip) at 1500 MeV/c^2
Possible higher mass structures

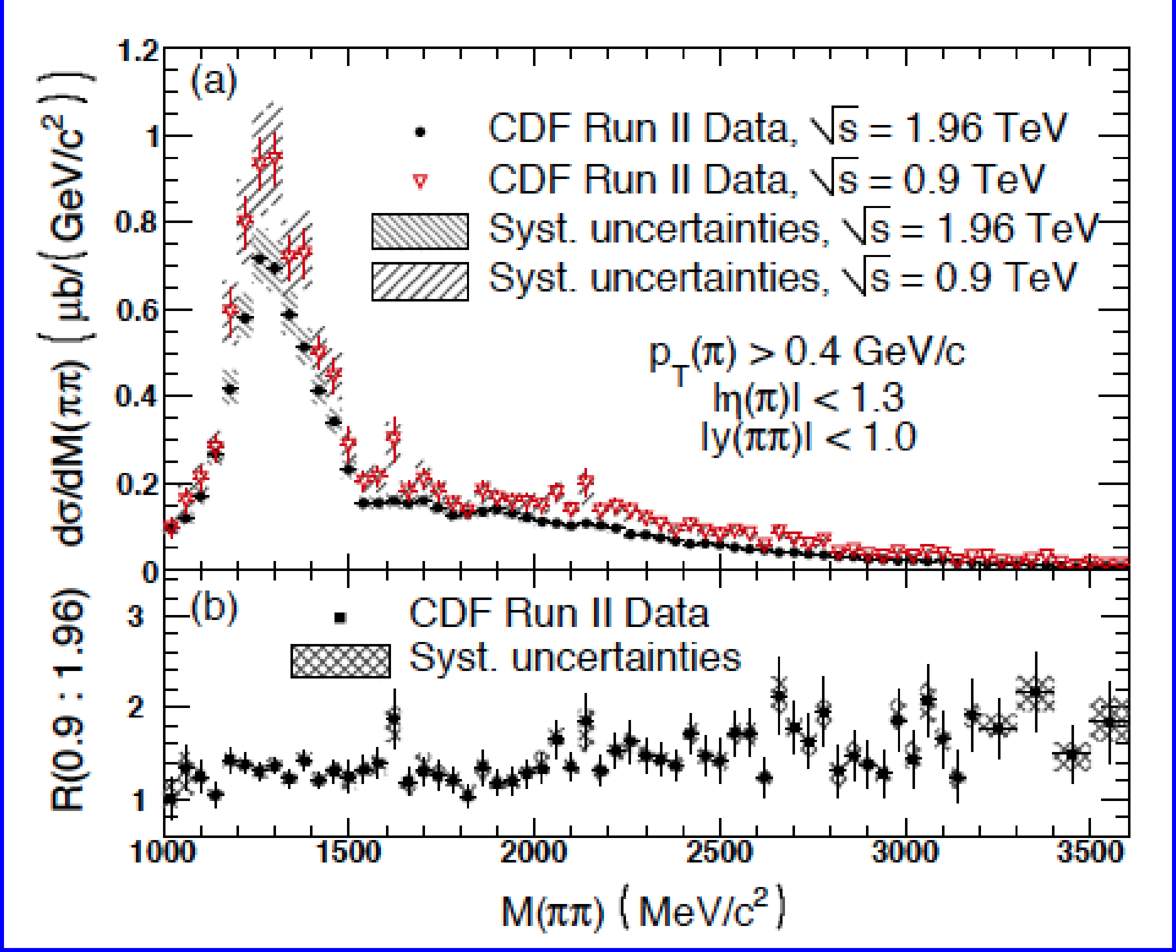


$M_{\pi\pi}$ > 1600 MeV/c^2 structures?
Fit 1600 – 3600 MeV/c^2 to 4th order polynomial



Cannot say more now:
other channels
e.g. KK, KKππ, φφ etc very desirable.
(LHC Low pile-up running?)
Peak at 3100 MeV/c^2 is
consistent with photoproduced
$J/\psi \rightarrow e^+e^-$ (muon stubs were veto'd)

√s dependence 0.9 TeV and 1.96 TeV



R(0.9:1.96) from 1000 – 2000 MeV/c^2 = 1.284 ± 0.039

Consistent with R ~ 1.3 from Regge phenomenology, σ(p+X+p) ~ 1/ln(s) [but p* included]

R(0.9:1.96) from 2000 < M < 3000 MeV/c^2 = 1.560 ± 0.056. Why higher?

Backgrounds

I: Same sign sample (non-exclusive)

- Remove $Q(\pi\pi) = 0$ requirement. Same charge pairs are
- 6.1% (900 GeV) and 7.1% (1960 GeV)
- Some non-exclusive background with 2 or more undetected charged particles. Can be:

→ very low p_T (with no reconstructed track and calorimeter E/E_T below the noise level or in a crack)

→ very forward $|\eta| = 4.75 – 5.40$ or $|\eta| > 5.9$

The $M(\pi\pi)$ distribution for ++/- - pairs is featureless

→ But is indication of a similar background from $\pi^+\pi^-\pi^+\pi^-$ (e.g.) events in $\pi^+\pi^-$ sample

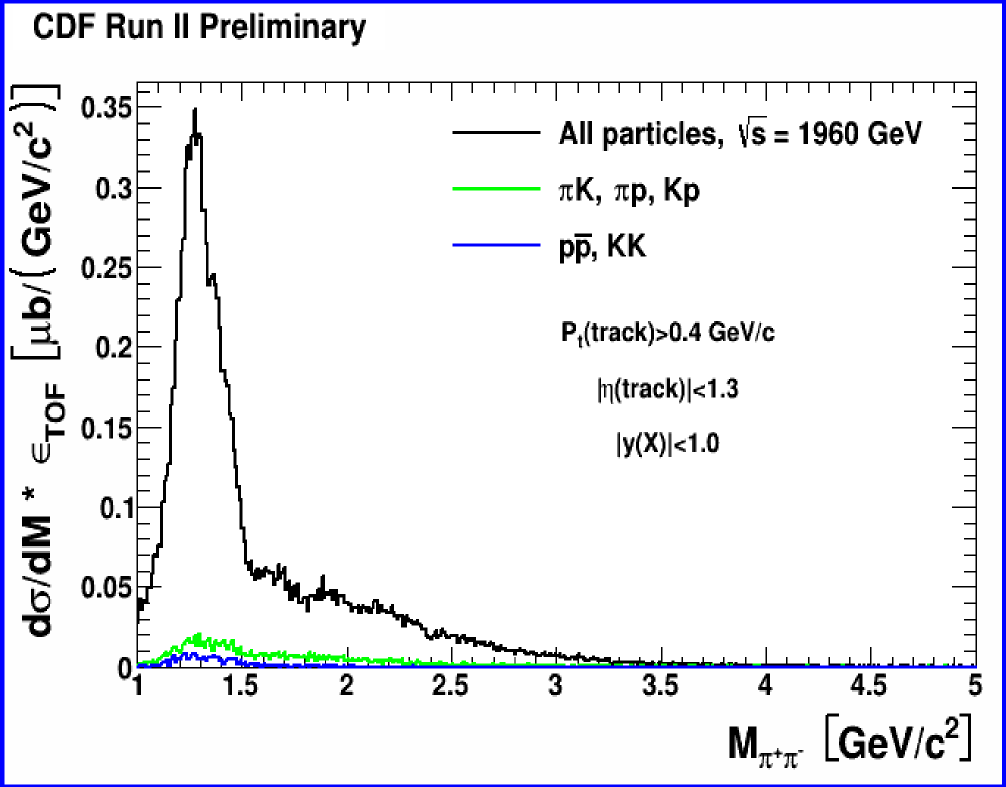
→ We do not subtract.

II: Non-$\pi^+\pi^-$ background

ToF counter hodoscope information used (coverage only |η|<0.9)

For |η|<1.3: 67% of the pairs have both particles identified.
Of those 89% are $\pi^+\pi^-$ pairs

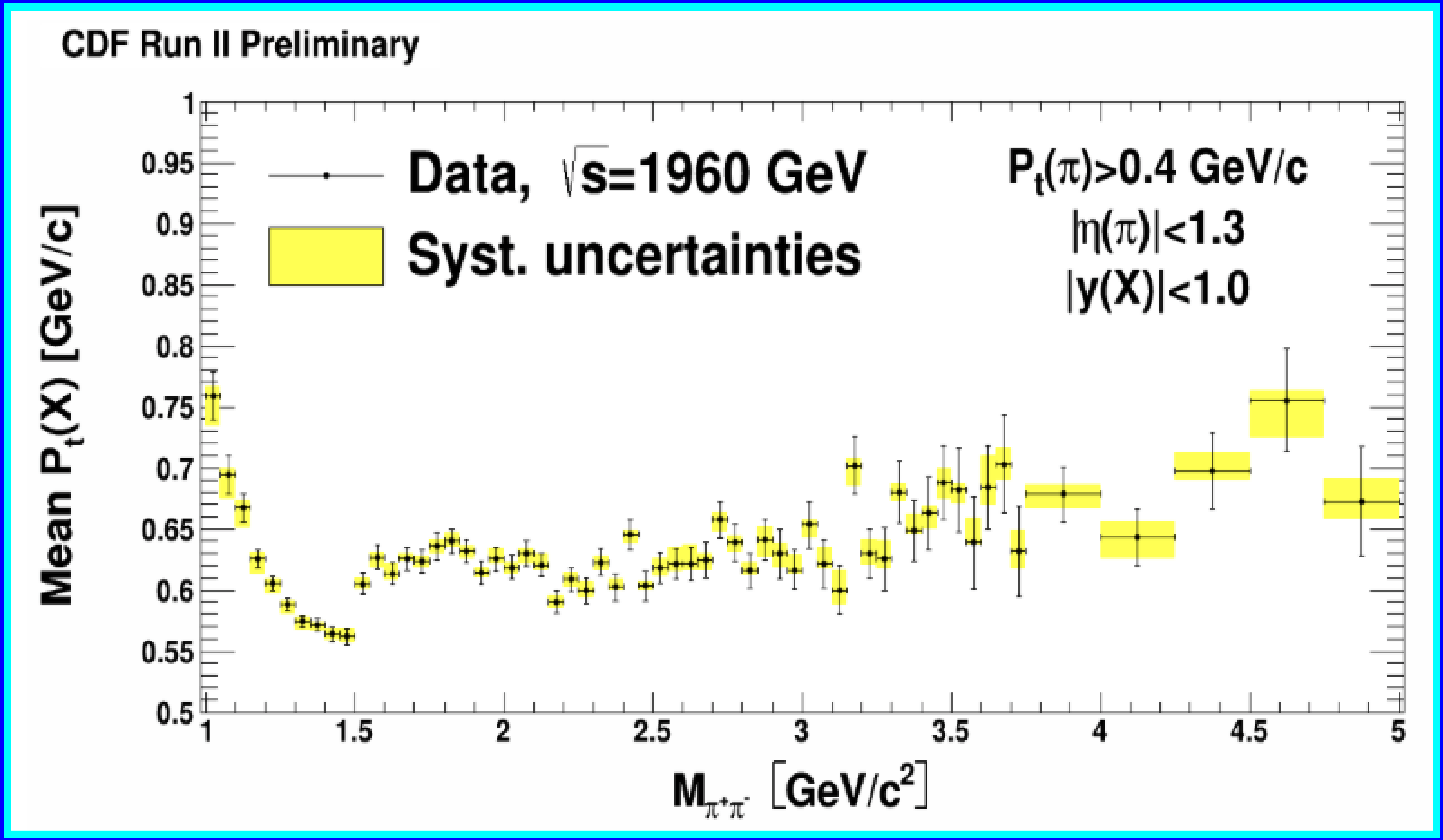
For |η|<0.7: 90% of the pairs have both particles identified (cracks in coverage)
→ No significant change in the composition



Assigning pion masses

We do not subtract non-$\pi^+\pi^-$ backgrounds; systematics would be large.

Mean $p_T(\pi^+\pi^-)$ as a function of $M_{\pi+\pi-}$



Decrease above 1 GeV/c2 can be acceptance effect

Sharp jump at 1.5 GeV/c2 cannot be. Interesting region

Angular distributions (not a full partial wave analysis)

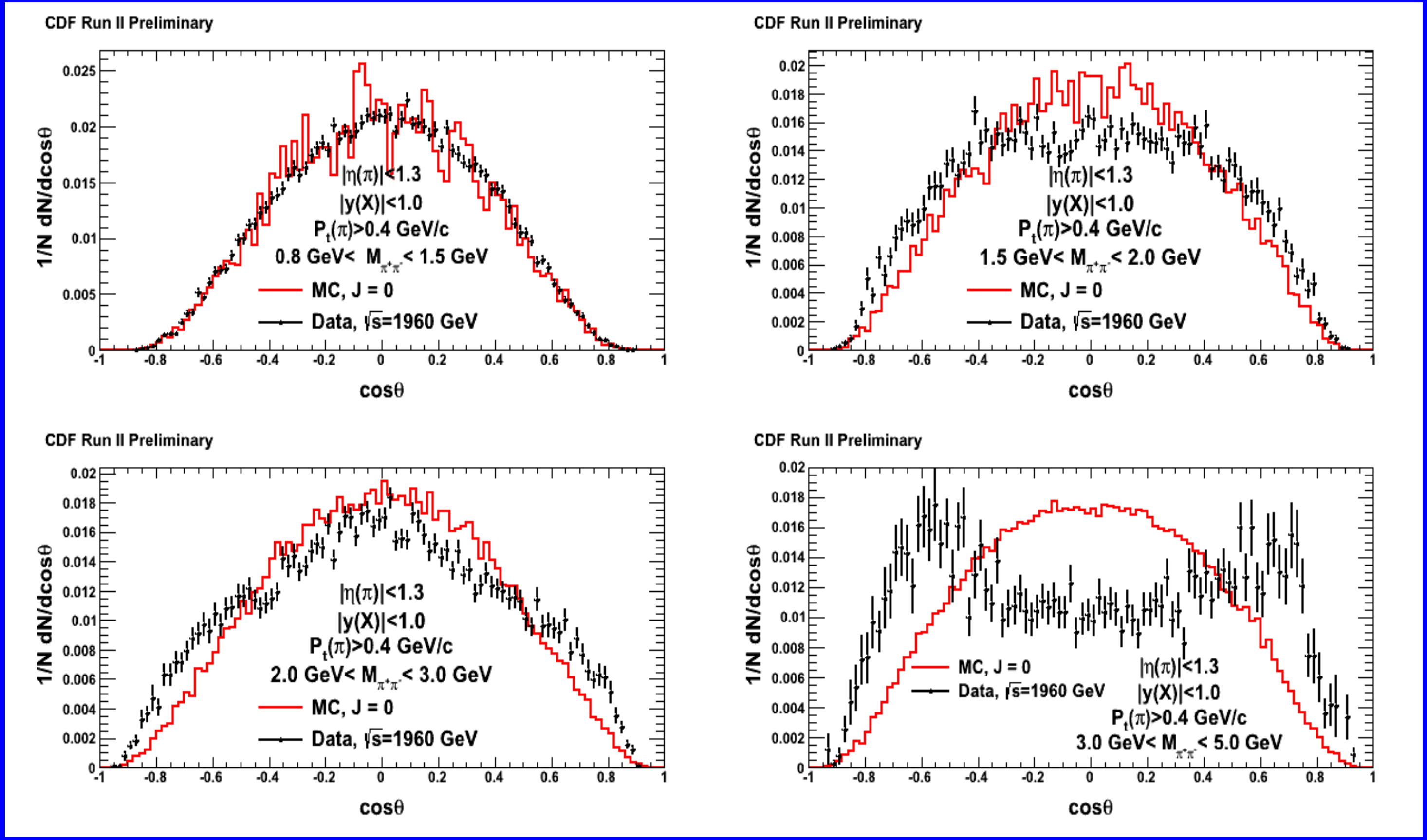
In $\pi^+\pi^-$ frame, cos ϑ distribution of π^+ w.r.t. X direction.

Flat for J = 0 S-wave if 4π coverage, sculpted by central acceptance.

Black points are data, red histogram is S-wave Monte Carlo with acceptance.

Four mass bands: 0.8 < M < 1.5 GeV isotropic (even through f2(1270) peak)

Above 1.5 GeV Forward-Backward peaking.



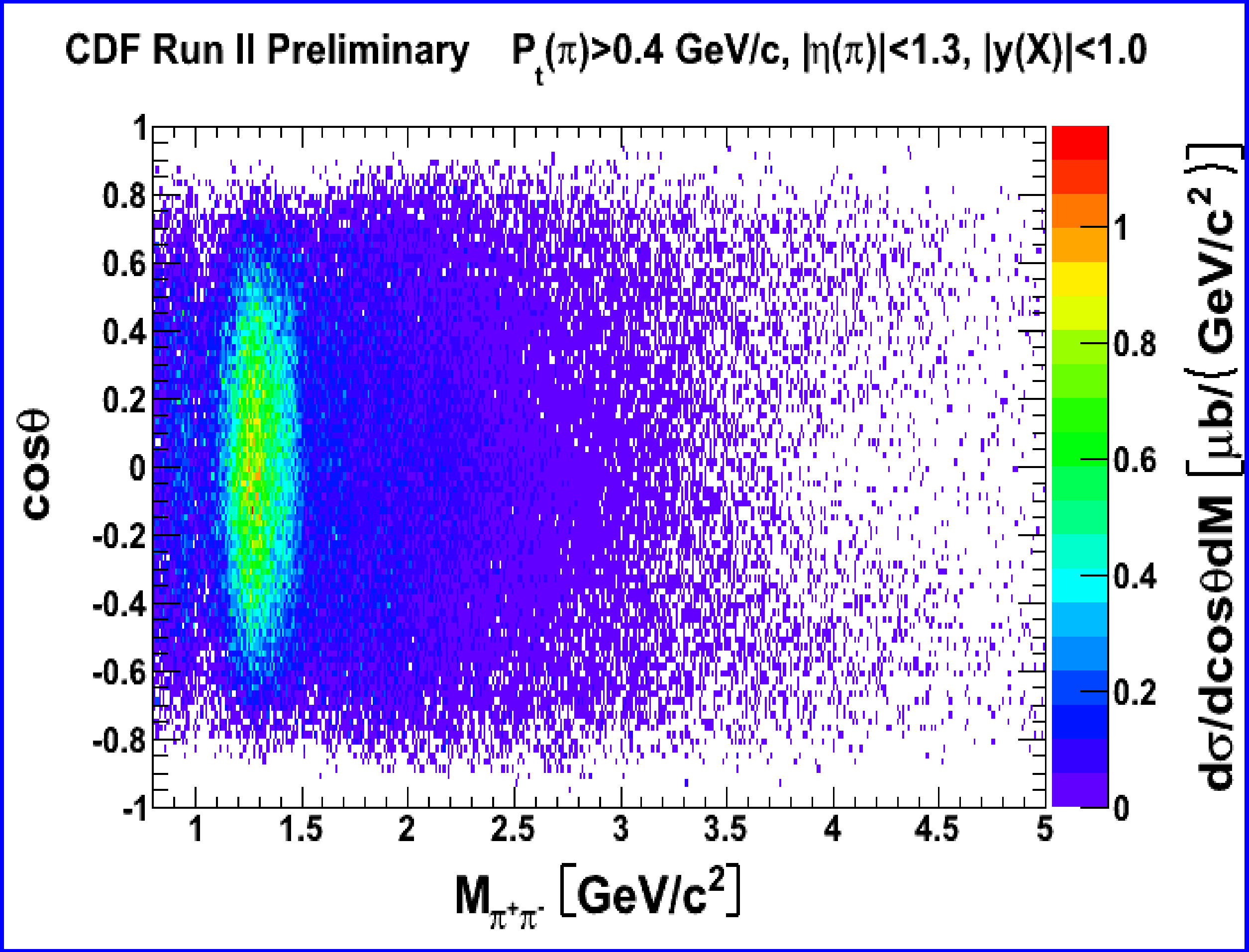
Conclusions

- We have measured $\pi^+\pi^-$ pairs between large rapidity gaps $\Delta\eta > 4.6$ in CDF at the Tevatron, which should be dominated by double pomeron exchange.
- Contribution of non-$\pi^+\pi^-$ pairs background and non-exclusive backgrounds is small
- The mass spectra show several structures:
  - Broad continuum below 1 GeV/c^2,
  - Sharp drop at 1 GeV/c^2
  - Resonant enhancement around 1.0 – 1.5 GeV/c^2.
- This is the only measurement from the Tevatron, and has much higher statistics than preliminary data from the LHC experiments.

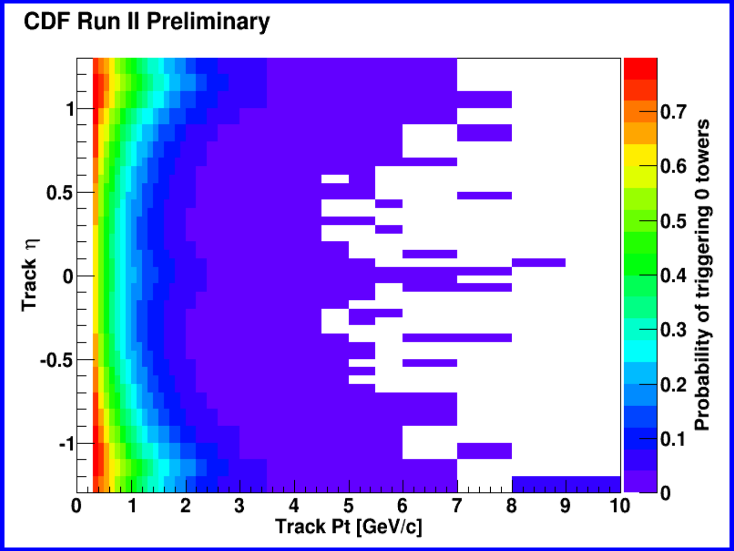
Glueballs remain elusive, but this is a promising channel (LHC!)

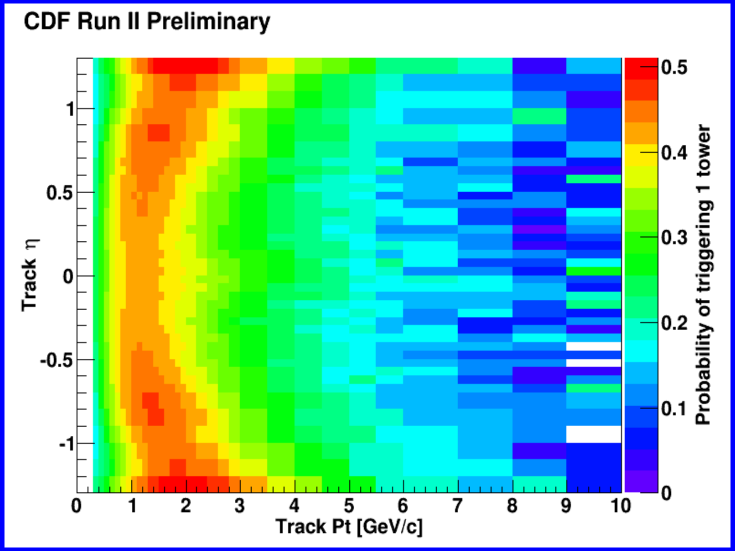
Thank you

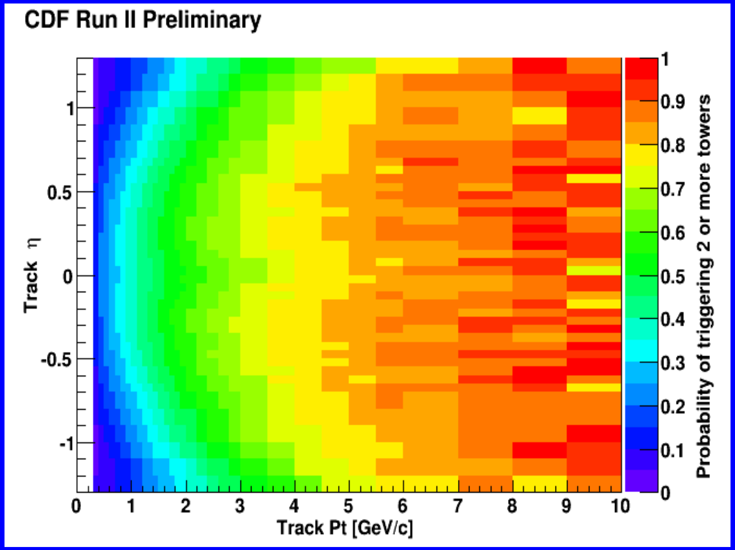
Back Ups


CDF Run II Preliminary
$P_t(\pi)>0.4$ GeV/c, $|\eta(\pi)|<1.3$, $|y(X)|<1.0$
$\cos\theta$
$M_{\pi^+\pi^-}$ [GeV/c^2]
$d\sigma/d\cos\theta dM$ [μb/(GeV/c^2)]
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
1.5
2
2.5
3
3.5
4
4.5
5

Trigger Efficiency

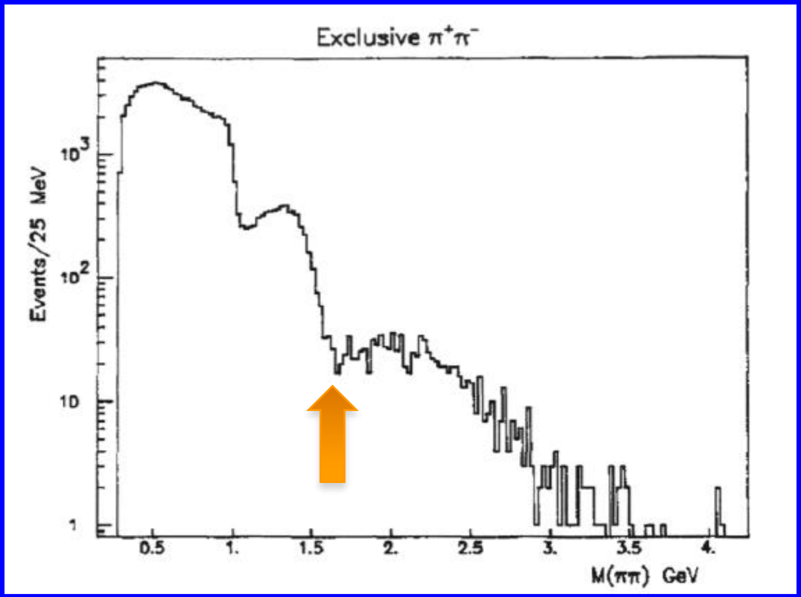


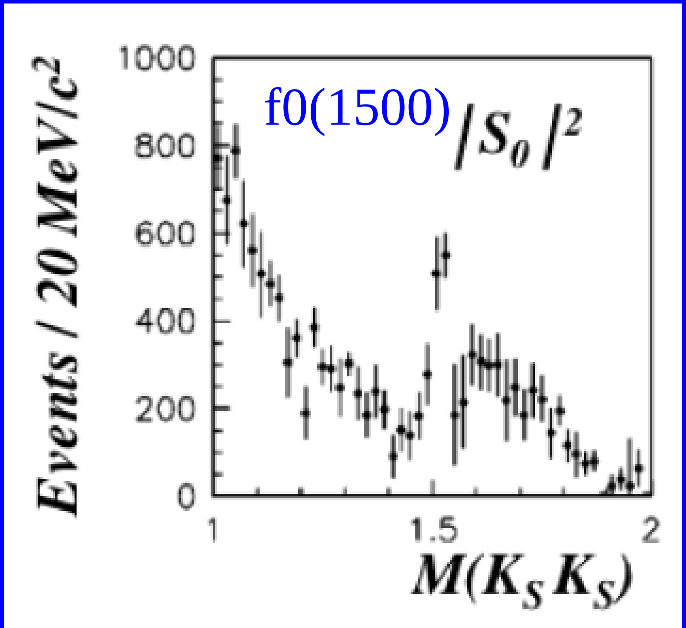




1500 MeV/c^2 region ? f0(1500) as dip in $\pi\pi$, peak in KK, $\sigma\sigma$?

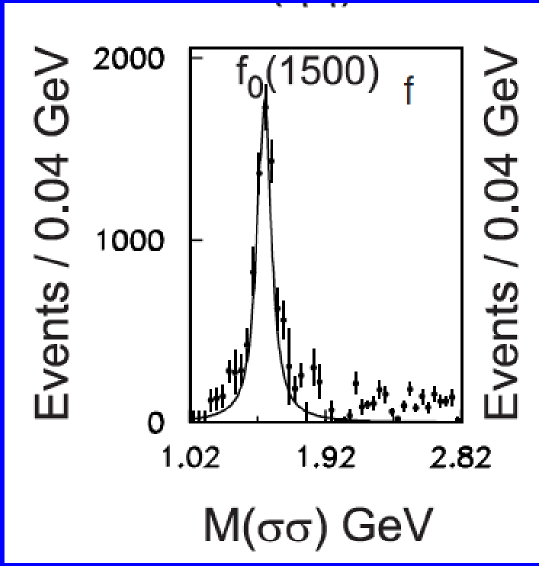
AFS Collaboration (ISR, $\sqrt{s}$ = 63 GeV)





E690 (FNAL) 800 GeV/c $\sqrt{s}$ = 27.4 GeV

p + $K^0_s K^0_s$ + p Gaps Δy > 1.2 & > 3.7



WA102 (Omega)
$\sqrt{s}$ = 29 GeV

26. F.E. Close and A. Kirk, *Phys. Lett.* **B483**, 345 (2000).

$$|f_0(1710)\rangle = 0.42|G\rangle + 0.89|S\rangle + 0.17|N\rangle,$$

$$|f_0(1500)\rangle = -0.61|G\rangle + 0.37|S\rangle - 0.69|N\rangle,$$

$$|f_0(1370)\rangle = 0.65|G\rangle - 0.15|S\rangle - 0.73|N\rangle.$$