Exclusive Central $\pi^+\pi^-$ Production in Proton Antiproton Collisions at the CDF

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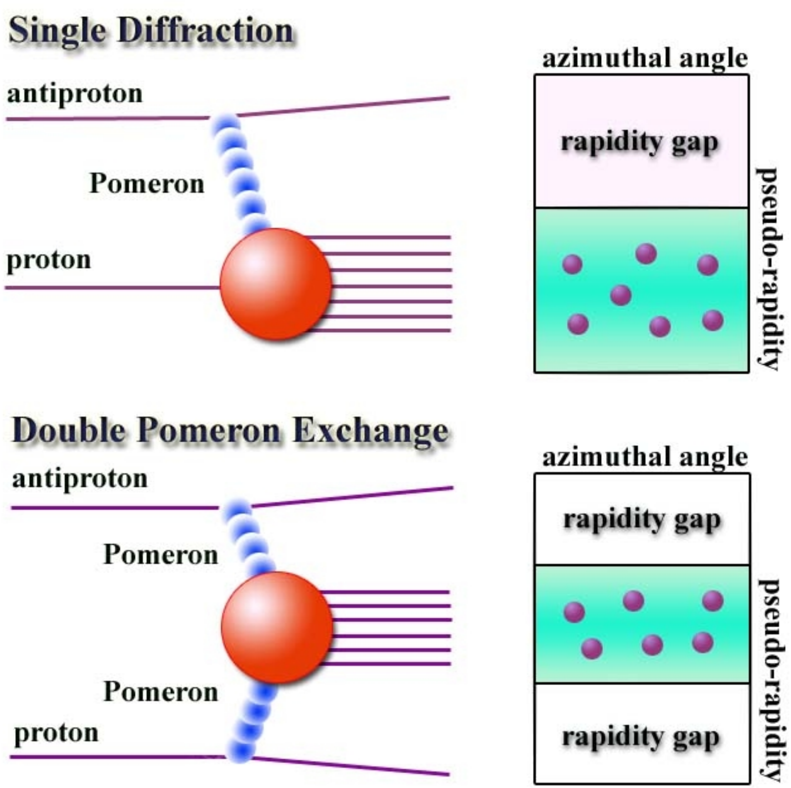
Physics Motivation

Double Pomeron Exchange (DPE)



Pomeron:

- Carrier of 4-momentum between protons
- Strongly interacting color singlet combination of gluons and quarks
- Quantum numbers of vacuum
- LO: P = *gg*

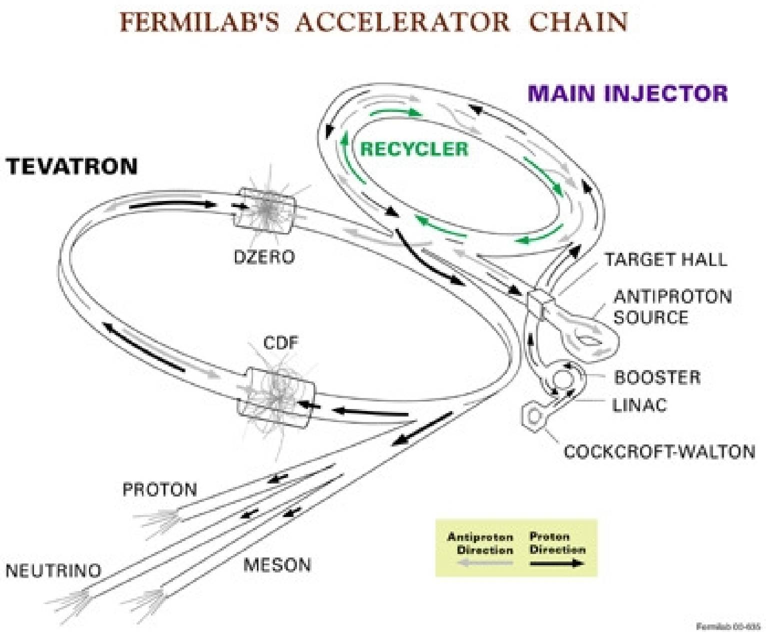
Analysis
GXG reaction

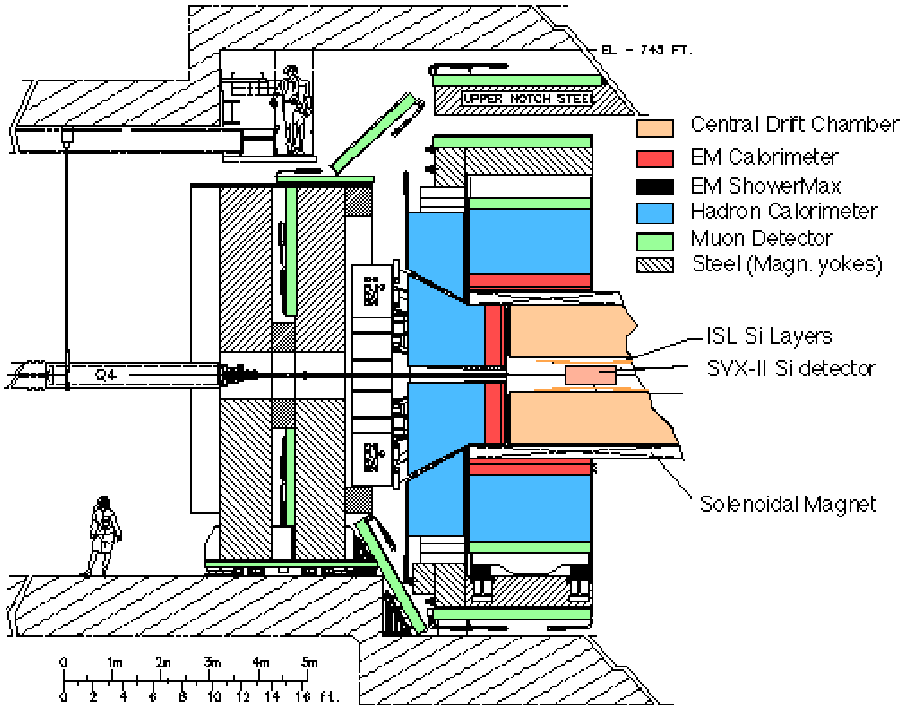
$$\bar{p} + p \rightarrow \bar{p}\,(*) + GAP + X + GAP + p\,(*)$$

- **X** (in this study)**:**
- hadron pair mostly $\pi^+ \pi^-$
- central $|y(\pi^+ \pi^-)| < 1.0$
- between rapidity gaps $\Delta\eta > 4.6$
- Q = S = 0, C = +1, J = 0 or 2, I=0

Expected to be dominated by DPE in the t-channel!

Collider Detector at Fermilab

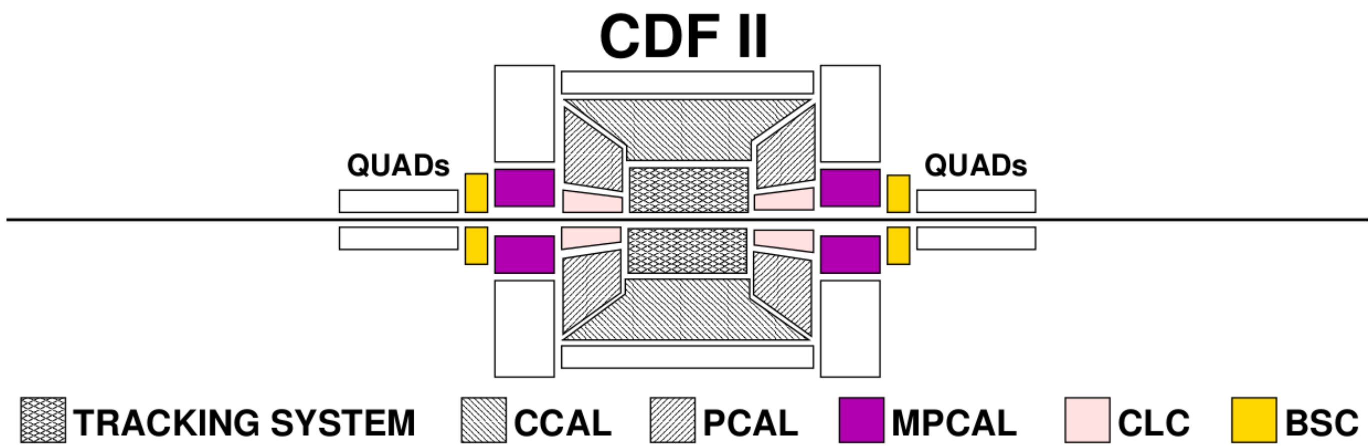




$\sqrt{s}$ = 1960 GeV

$\sqrt{s}$ = 900 GeV

Collider Detector at Fermilab



- We do not detect outgoing protons
- Forward detectors in veto

- BSC – Beam Shower Counters
- CLC – Cherenkov Luminosity Counters
- PCAL – Plug Calorimeter

We require all detectors, $|\eta| < 5.9$, to be empty except for two tracks

Central Hadronic State Analysis

Candidates selection

Trigger requirements:

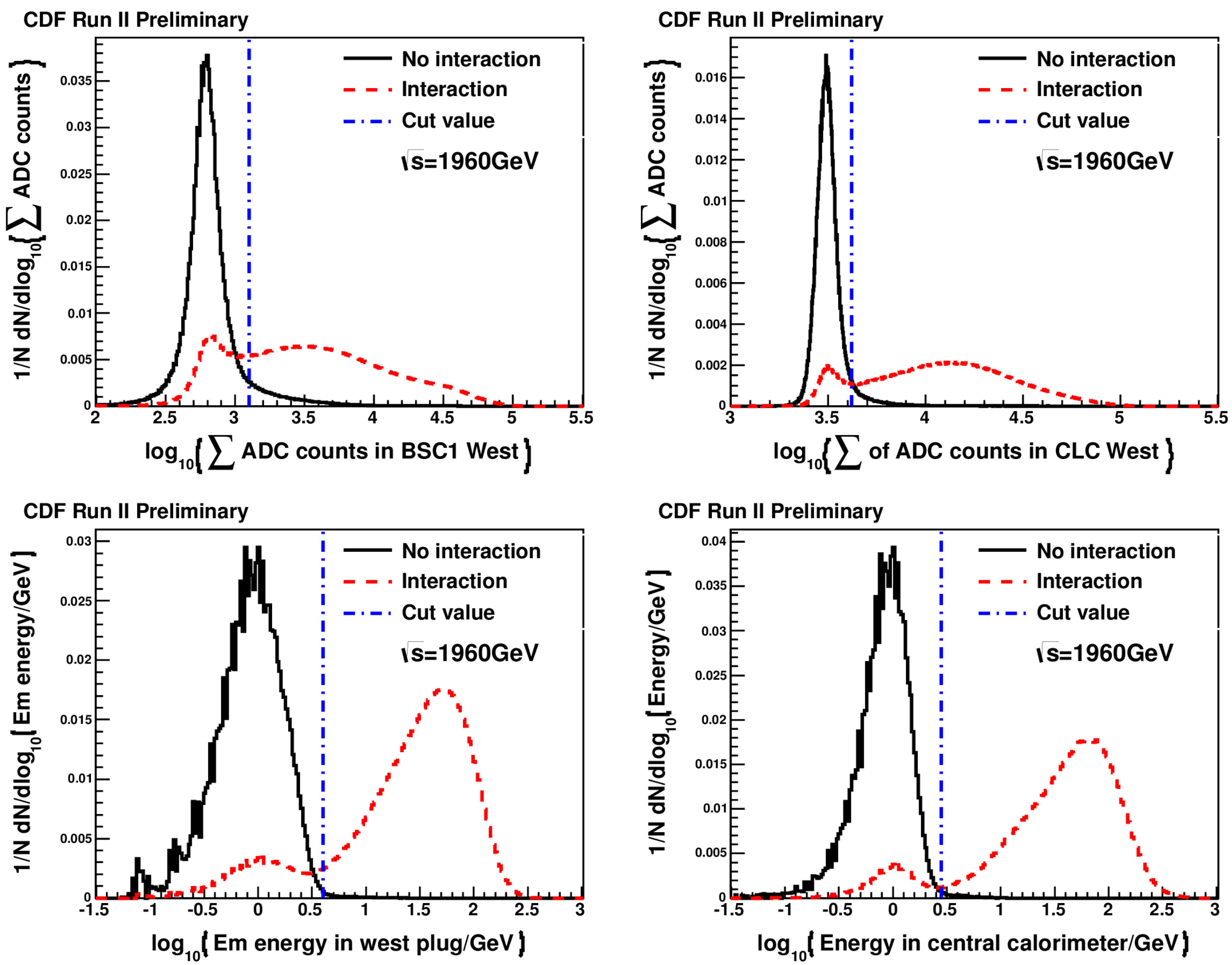
- 2 central ($|\eta|<1.3$) towers with $E_t > 0.5$ GeV
- PCAL ($2.11<|\eta|<3.64$) in veto
- CLC ($3.75<|\eta|<4.75$) in veto
- BSC1 ($5.4<|\eta|<5.9$) in veto

Gap cuts:

To determine noise levels in subdetectors we divide zero-bias sample from same periods into two sub-samples:

No Interaction:	Interaction:
• No tracks and • No CLC hits and • No muon stubs	At least one • Track or • CLC hit or • Muon stub

Exclusivity cuts



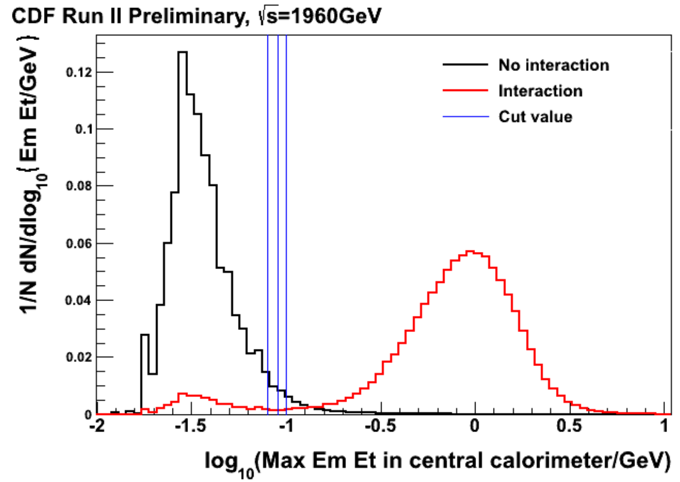
Central Hadronic State Analysis
Candidates selection

Exclusive 2 tracks:

→ Similar technique in region of central calorimeter

→ excluding cones of R=0.3 around each track extrapolation.

$$R=\sqrt{(\Delta\eta)^2+(\Delta\varphi)^2}$$



The “hottest” EM tower must be less than 90 MeV

Additional cuts:

- quality of tracks
- cosmic ray rejection
- 2 oppositely charged tracks

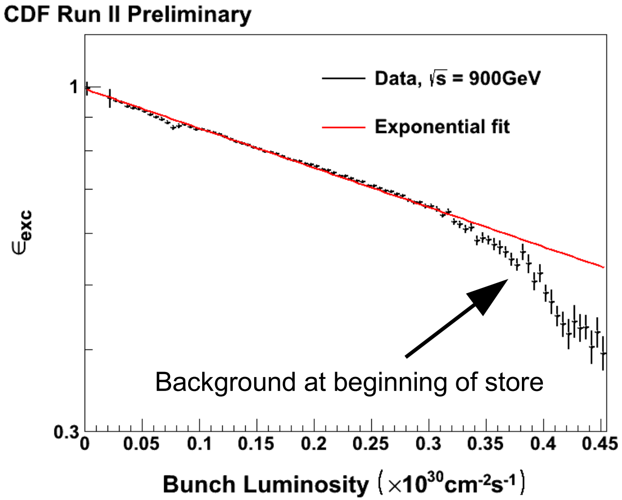
Effective exclusive luminosity

- Determination of efficiency of having no-pileup using zero-bias sample.

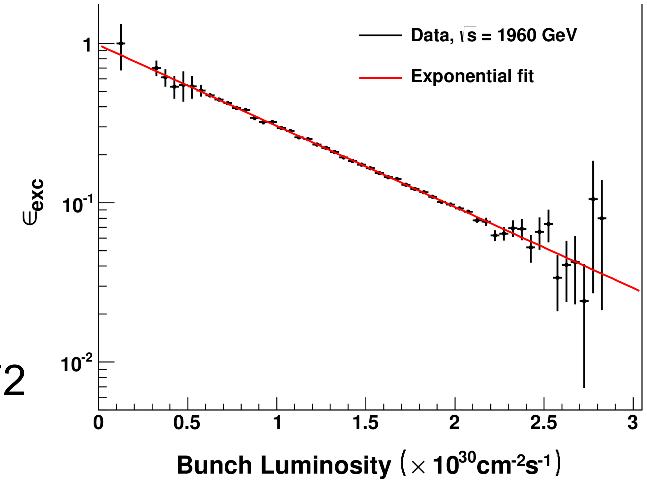
  We measure ratio of empty events (all detectors on noise level) to all events.

- Exponential drop with bunch luminosity.

- Slope corresponds to total 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



L renormalization factor based on σ_{inel} for 900 GeV: 0.72

Higher dissociation masses allowed at 1960 GeV

Central Hadronic State Analysis

Acceptance and cut efficiency

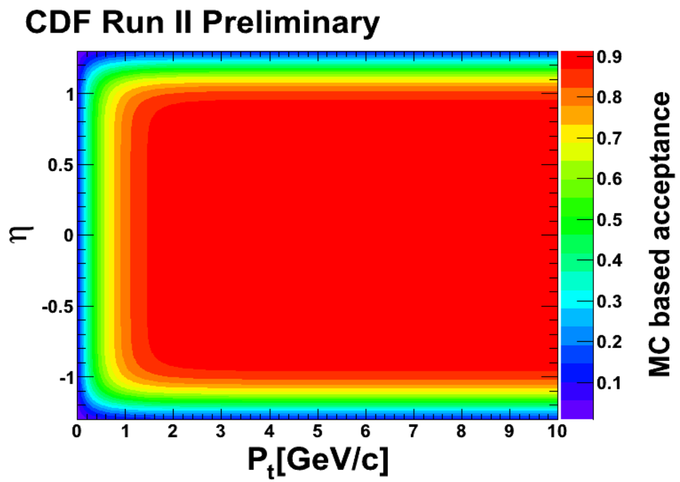
Model independent analysis

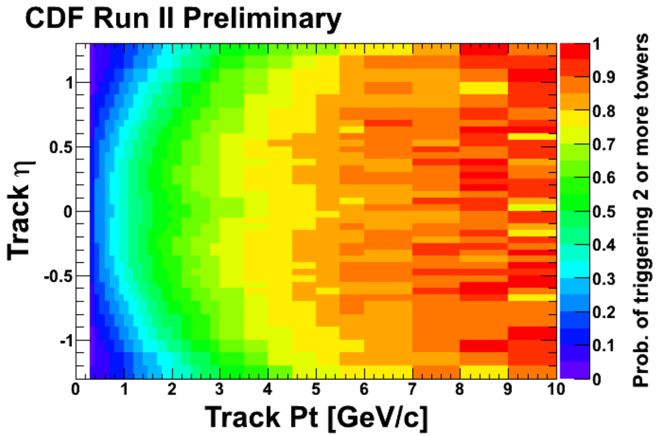
Kinematic cuts:

- $P_t(\pi)>0.4$ GeV/c
- $|\eta(\pi)|<1.3$
- $|y(\pi^+ \pi^-)|<1.0$

3 components:

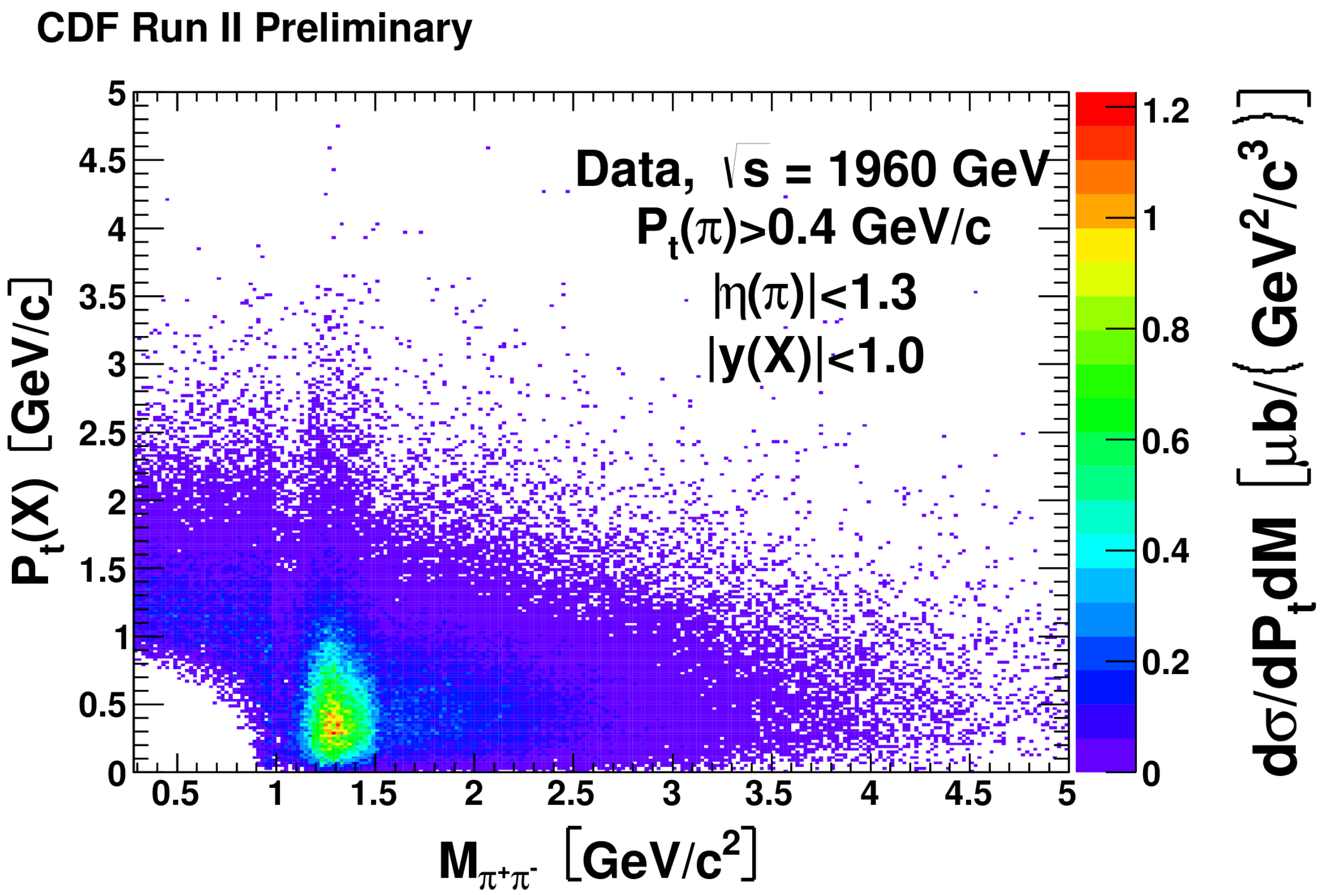
- Trigger efficiency
- Single track acceptance
- 2 tracks acceptance





Central Hadronic State Analysis

$M(\pi^+\pi^-)$ vs $P_t(X)$ for 1960 GeV



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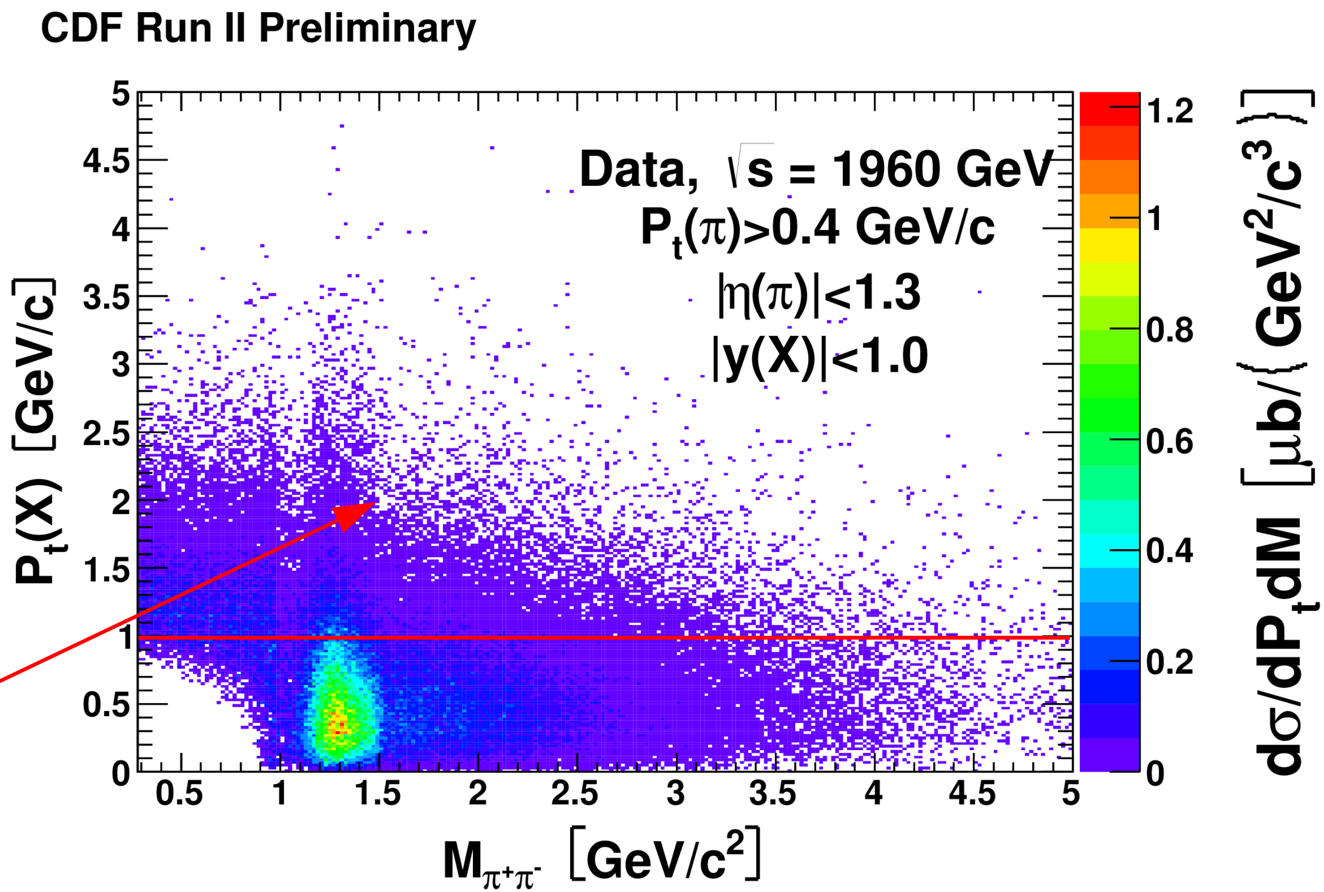

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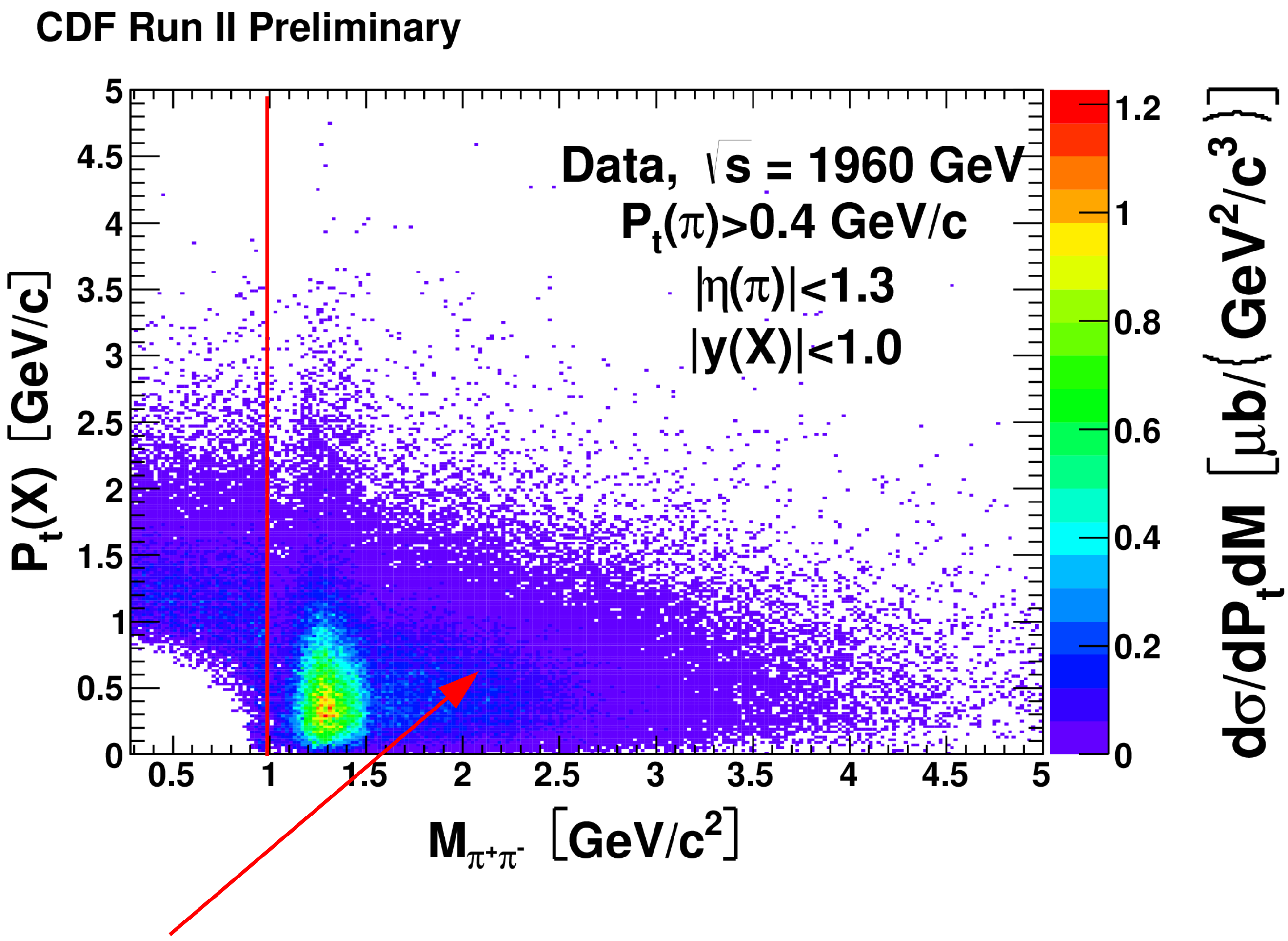

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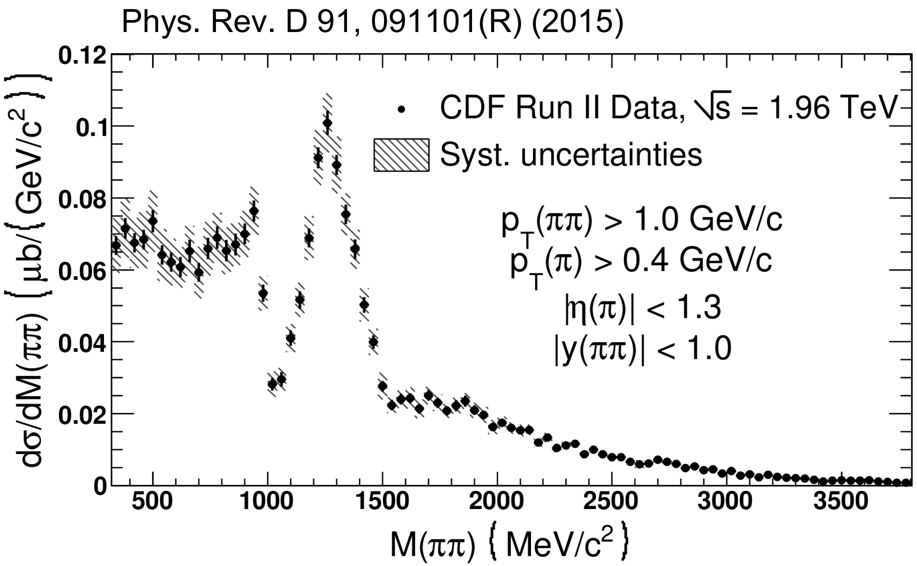
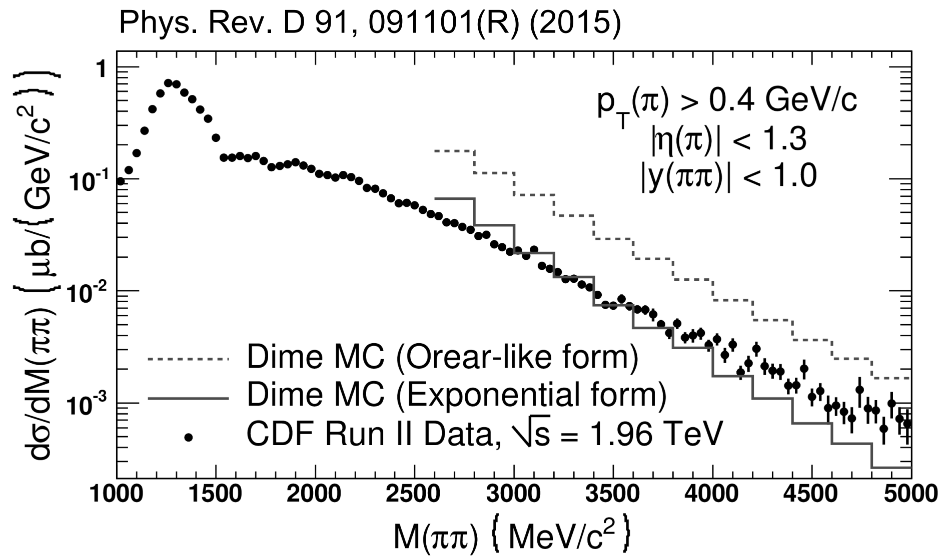




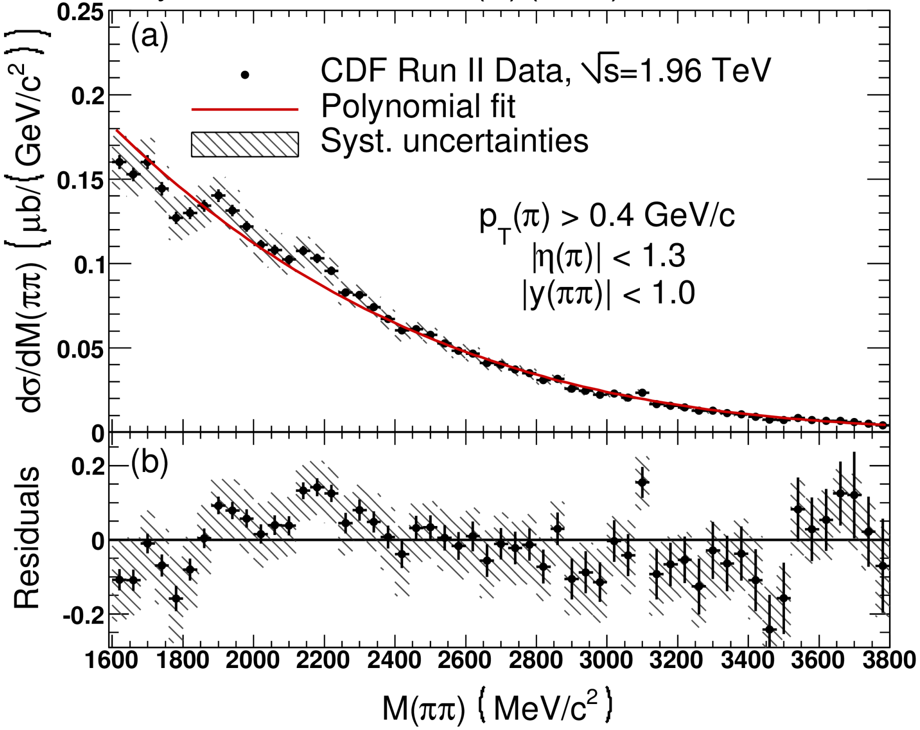
→ Broad continuum below 1 GeV/c^2

→ Cusp at 1 GeV/c^2

→ Resonant enhancement around 1.0 – 1.5 GeV/c^2 dominated by $f_2(1270)$

Central Hadronic State Analysis
$M(\pi^+\pi^-)$ for 1960 GeV and 900 GeV

Phys. Rev. D 91, 091101(R) (2015)



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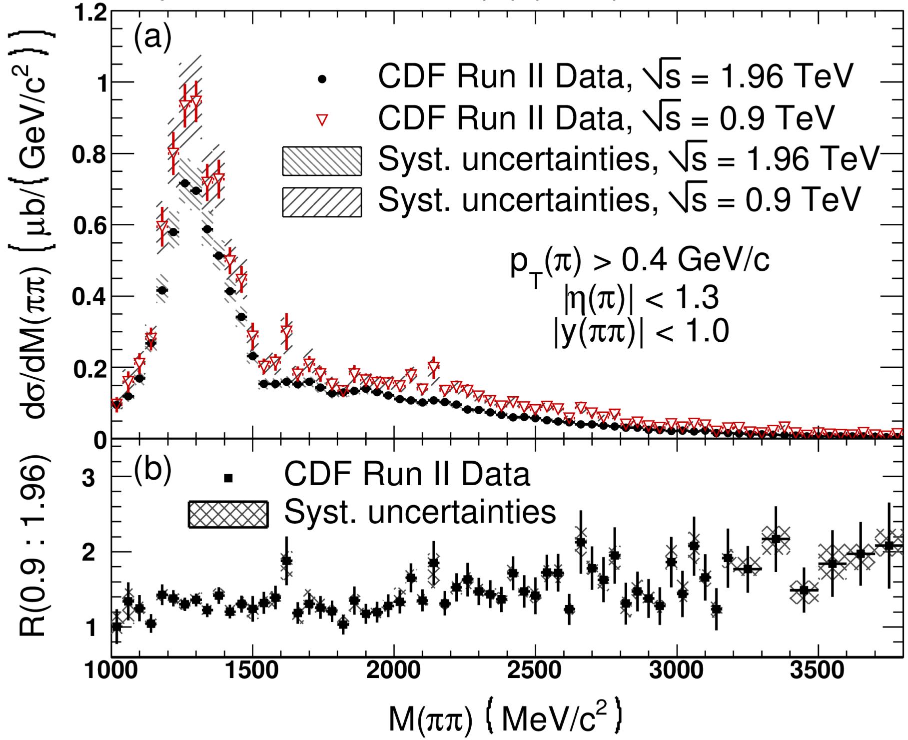
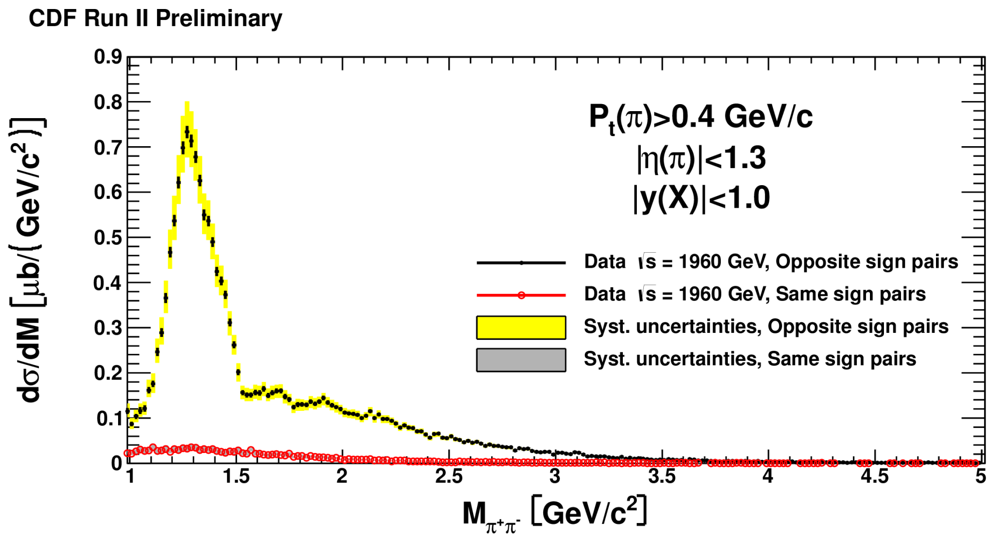


Indications of structure up to 2.4 GeV/c²

Non-exclusive background
Same sign sample

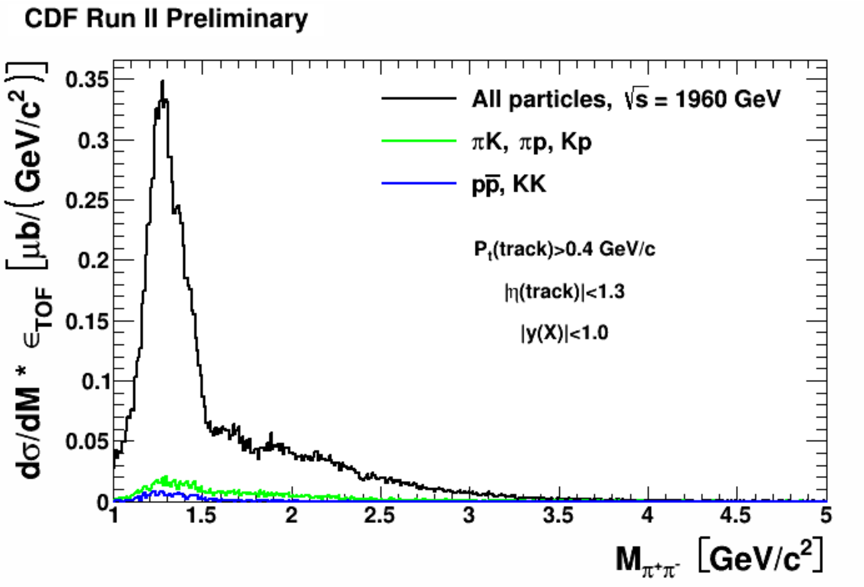
- The events with two same charge tracks: 6.1% (900 GeV) and 7.1% (1960 GeV)
- Sign of non-exclusive background with 2 or more undetected charged particles:

→ very low pT (no reconstructed track and calorimetric E above the noise level)
→ very forward



The M($\pi^+\pi^-$) distribution for ++/- - pairs is featureless
→ But! indication of a similar background from $\pi^+\pi^-\pi^+\pi^-$ events in $\pi^+\pi^-$ sample
→ No subtraction

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



ToF counter information used (coverage in $|\eta|<0.9$)

For $|\eta|<1.3$: 67% of the pairs have both particles identified
→ $\pi^+\pi^-$ pairs – 89%

For $|\eta|<0.7$: 90% of the pairs have both particles identified
→ No significant change in the composition

No non-$\pi^+\pi^-$ background subtraction

Conclusions

- **We have measured $\pi^+\pi^-$ pairs between large rapidity gaps at the Tevatron, which should be dominated by double pomeron exchange.**
- **Contribution of non-$\pi^+\pi^-$ pairs background and non-exclusive background 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.**


MIND THE GAP

Backup slides

Acceptance calculation

Model independent analysis

Kinematics cuts:

- $P_t(\pi)>0.4$ GeV/c
- $|\eta(\pi)|<1.3$
- $|y(X)|<1.0$

3 components:

- Trigger efficiency
- Single track acceptance
- 2 tracks acceptance

Trigger efficiency

1. Sample of min-bias data, good quality isolated (no other tracks in cone with R=0.4) tracks.

2. Checking how often they fired 0, 1, 2 or more trigger towers (>= 4 bits) in 3x3 box around track extrapolation.

3. Trigger efficiency composed from those 3 probability distributions (which are functions of P_t and η)

Trigger efficiency

Probability of triggering 2 or more towers in the central detector by two independent tracks „a” and „b”:

$$\varepsilon = P_2(a)+P_1(a)*[P_1(b)+P_2(b)]+P_0(a)*P_2(b)$$

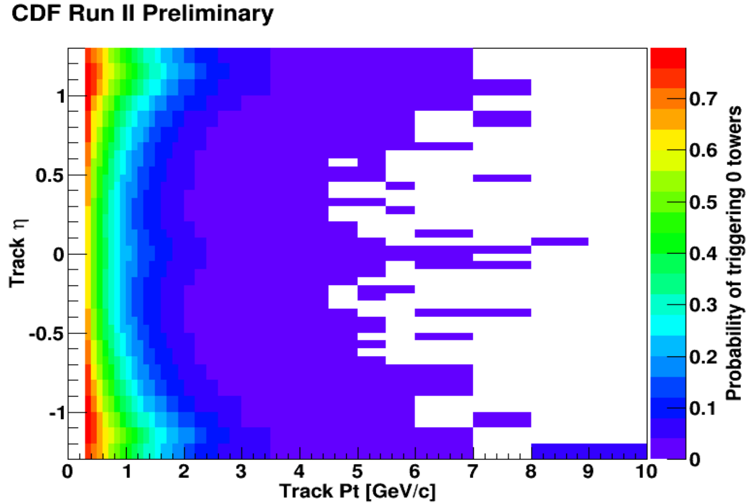
	P_2b	P_1b	P_0b
P_2a	**X**	**X**	**X**
P_1a	**X**	**X**	
P_0a	**X**		

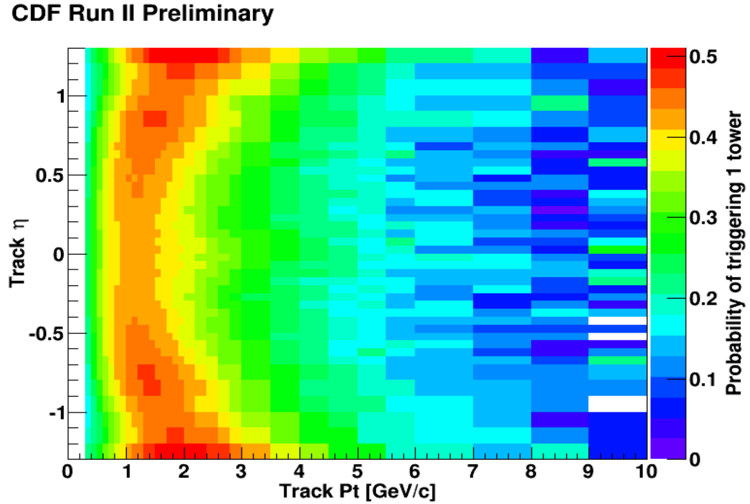
P_0 – probability of triggering no towers

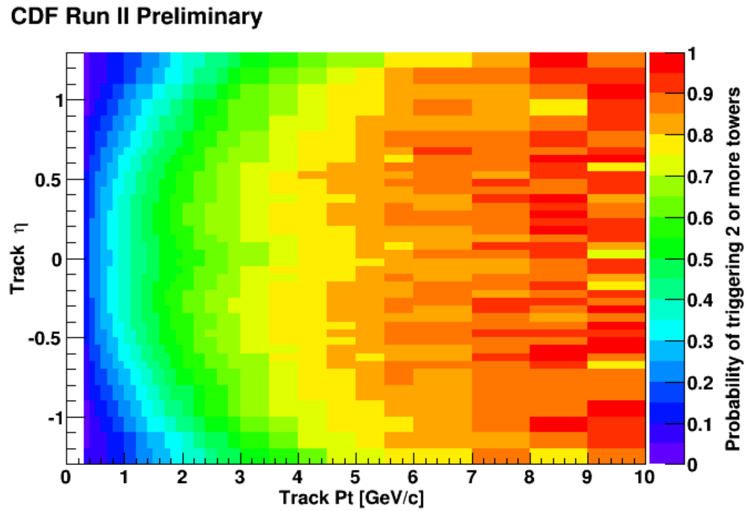
P_1 – probability of triggering one tower

P_2 – probability of triggering two or more towers

Trigger efficiency







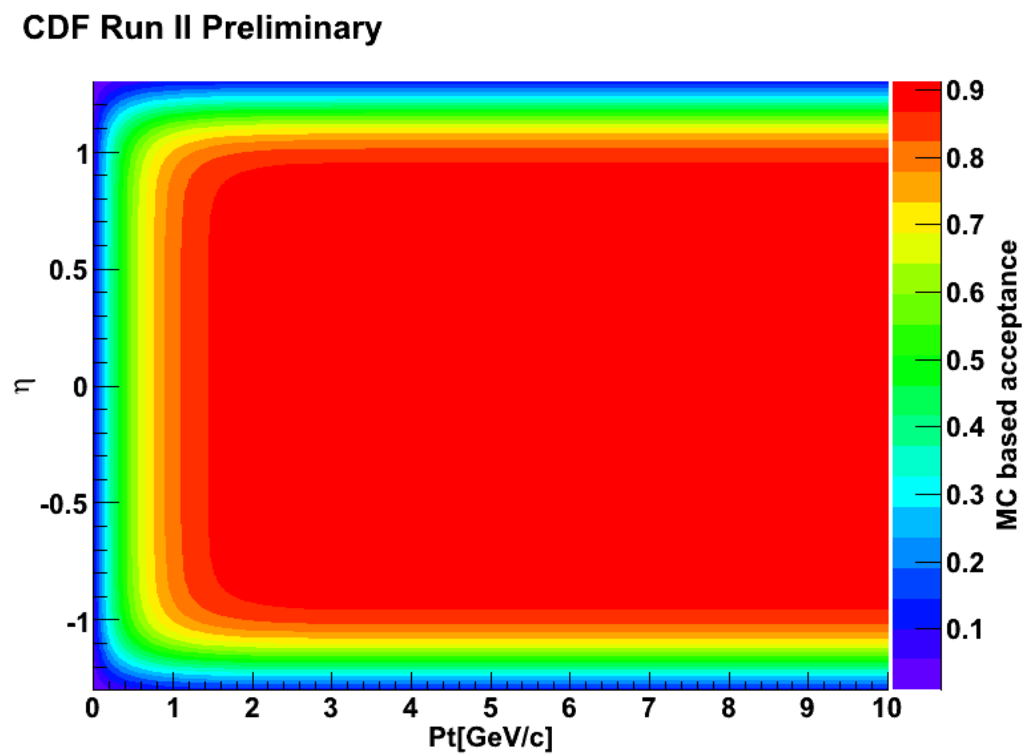
Single track acceptance

1. Single pion generation, flat in phi

2. Acceptance as a function of Pt(track) and eta

- Probability that track will be reconstructed at all

- Probability that track will pass all single track quality cuts



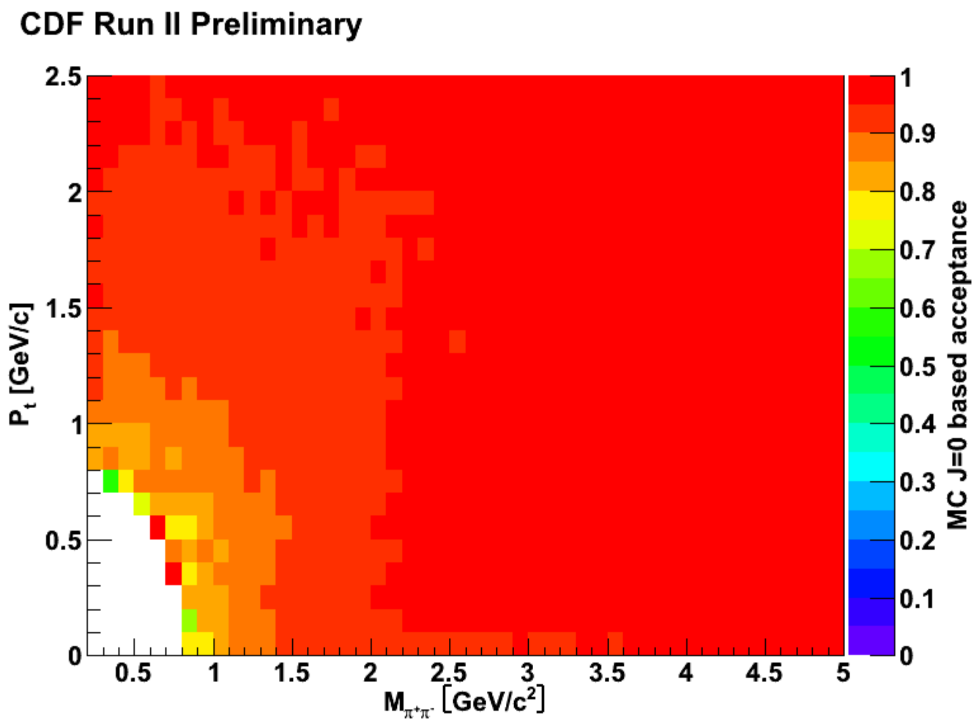
2 tracks cuts acceptance

Cuts:

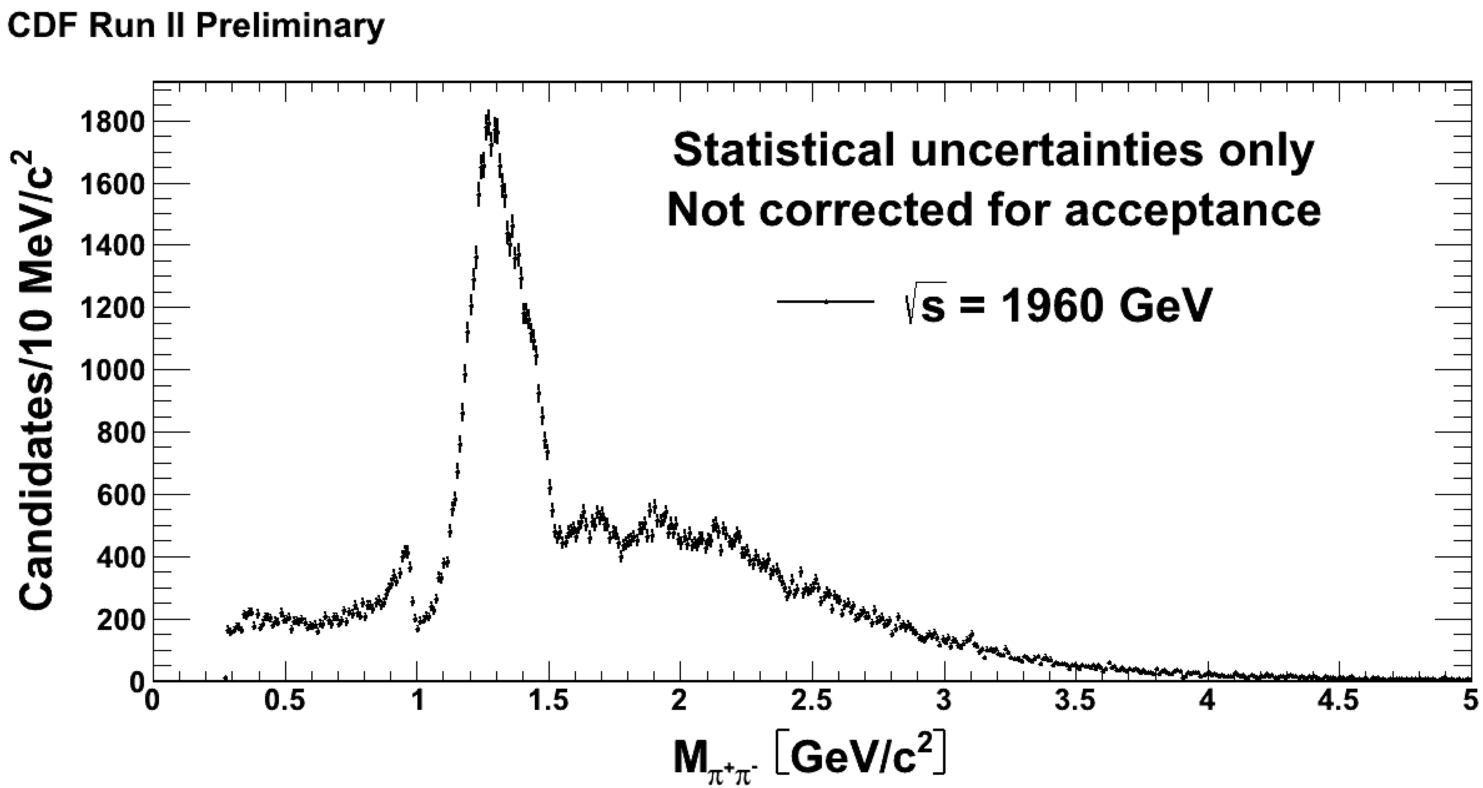
- 3D opening angle
- y of central state
- Separation
- ΔZ_0

Based on J=0 phase space model

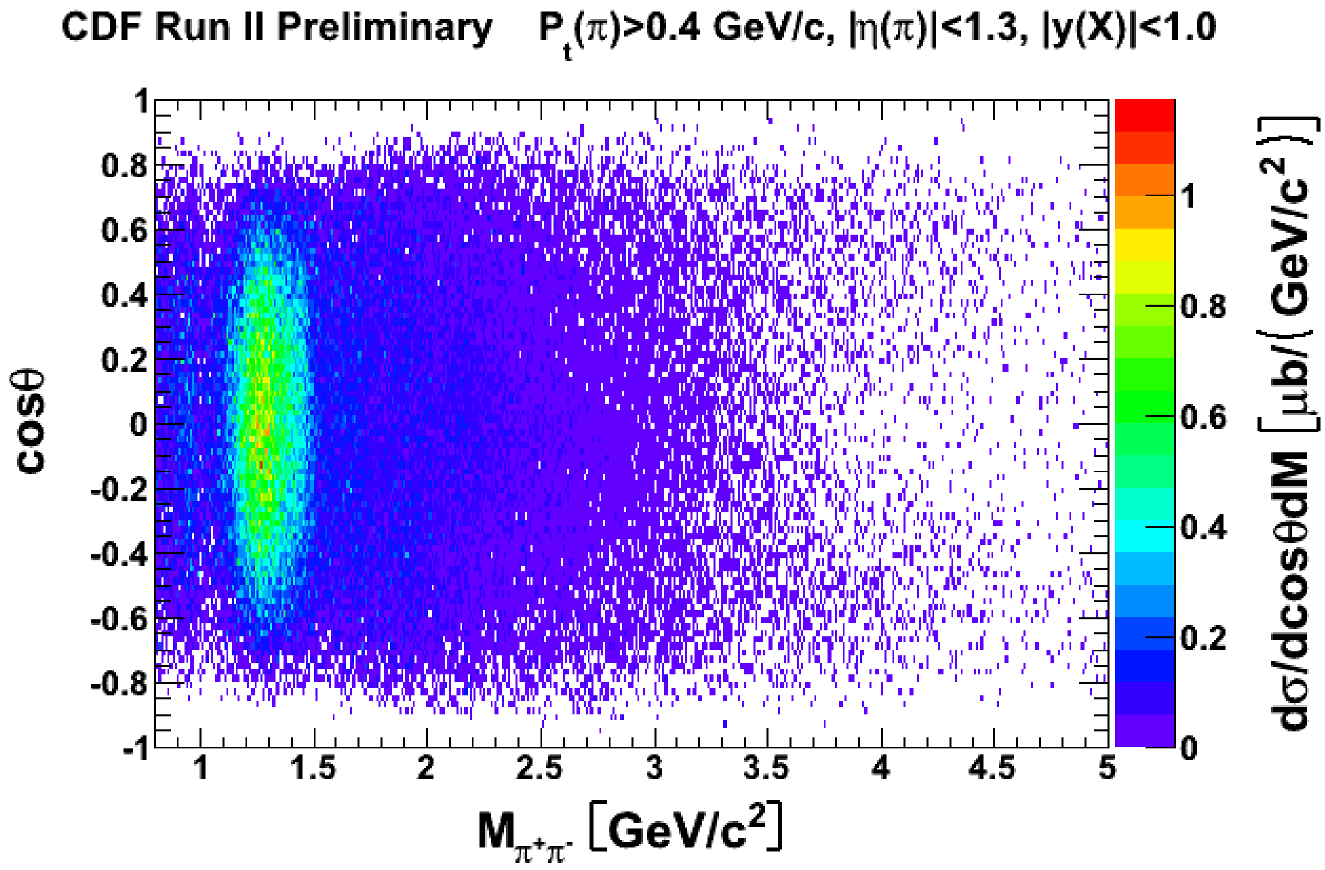
All previous cuts applied before



Invariant mass distribution



Partial wave analysis



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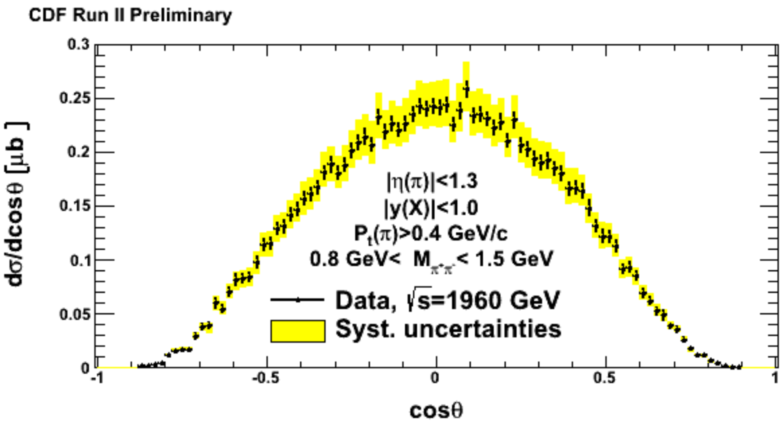

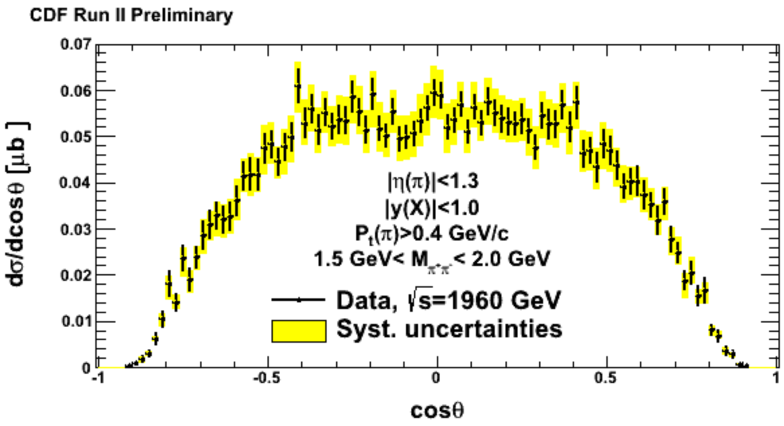

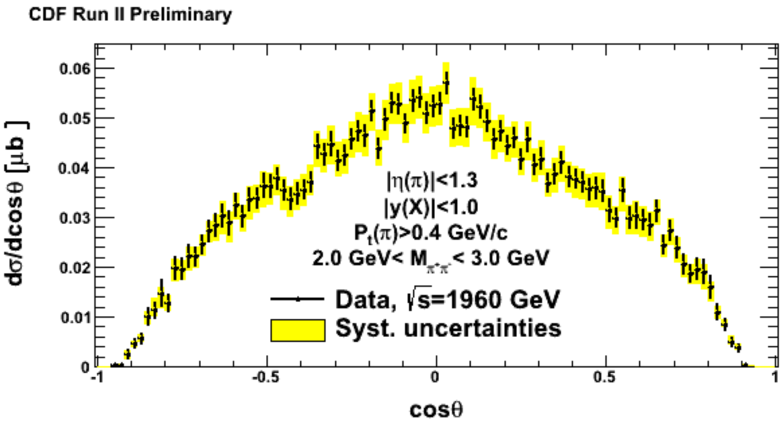

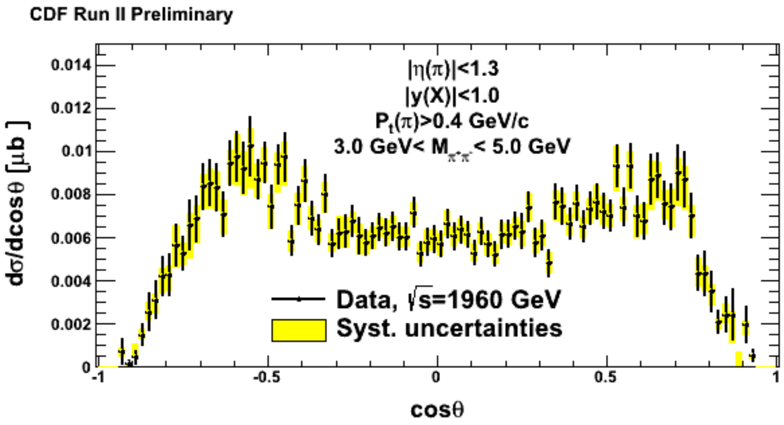

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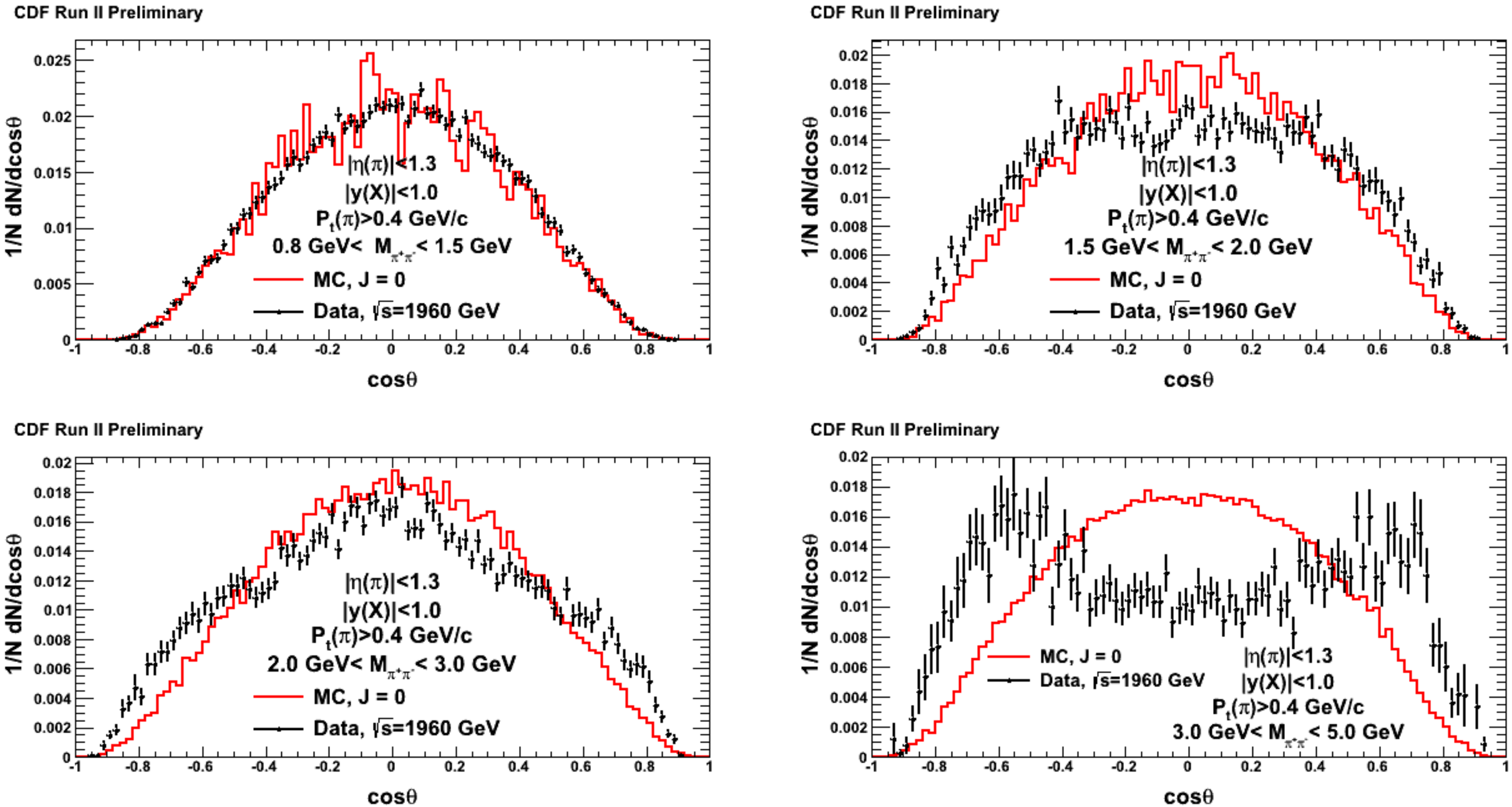


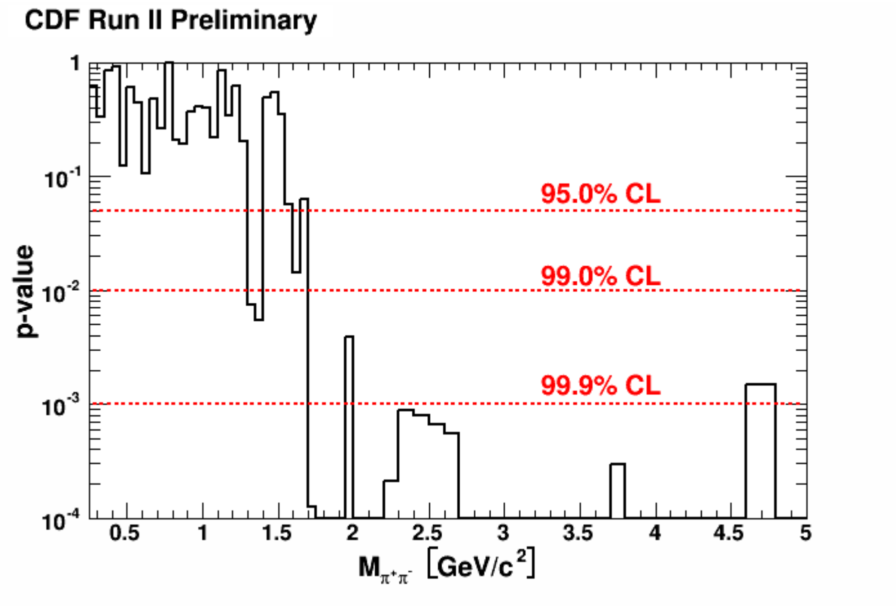
Partial wave analysis

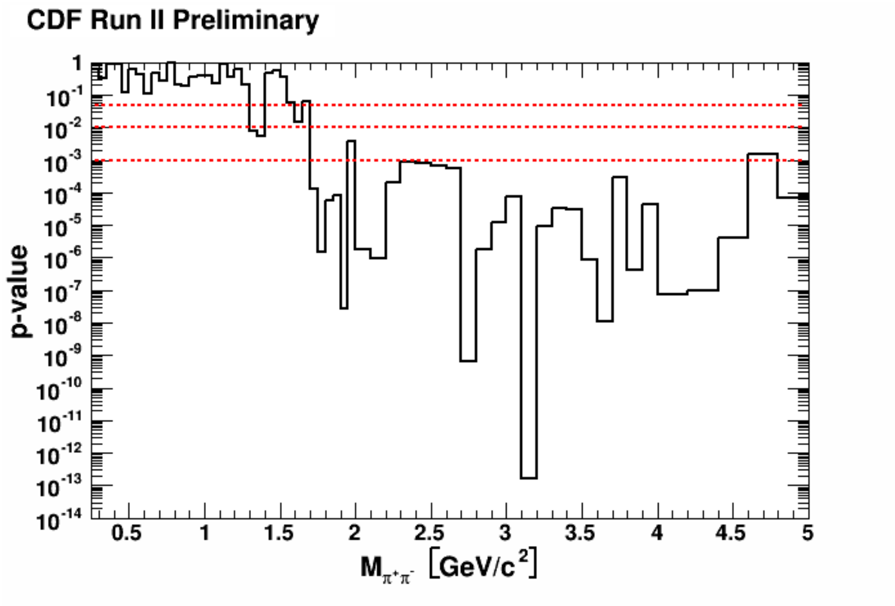
Comparison of data/MC s-wave cos(θ) distributions

H0 : cos(θ) distribuants for data and s-wave MC are the same (in mass bins)

- H1 : not H0.
- Test type: Smirnow
- Test statistics: λ Kolmogorov

Partial wave analysis





If p-value is smaller then 0.05 we reject the H0 (s = 0) in favour of H1 on the 95% CL
If p-value is greater then 0.05 we cannot reject the null hypothesis H0 (s = 0) on the 95% CL