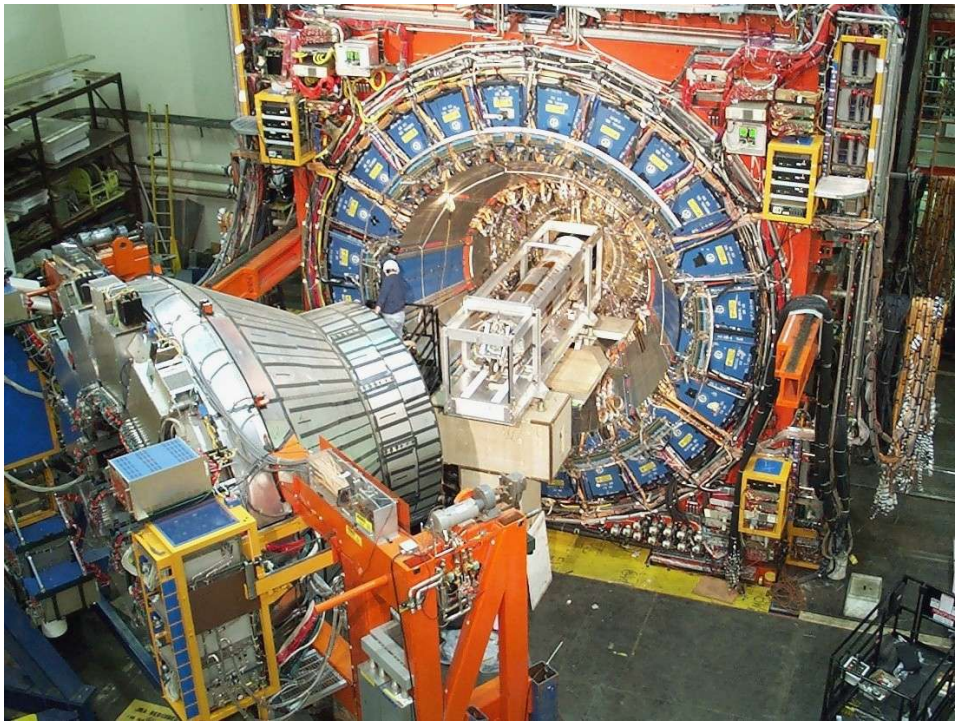
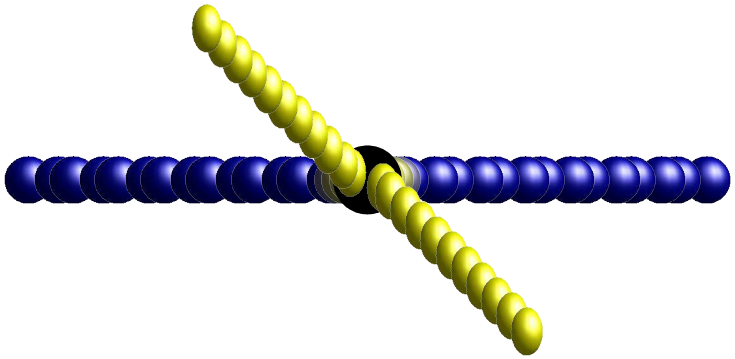
Exclusive Interactions at CDF

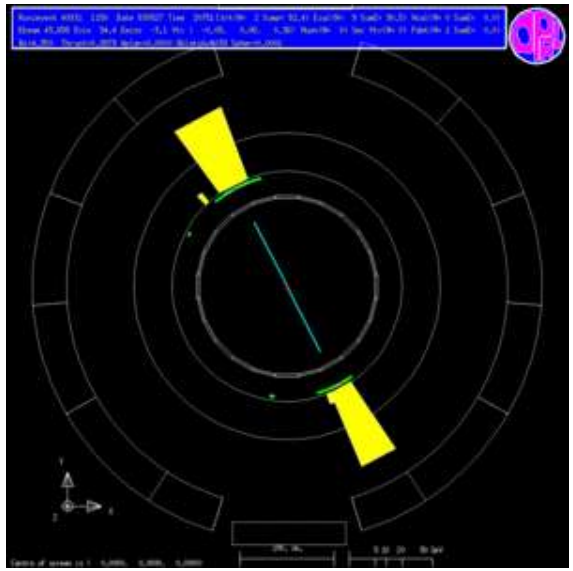


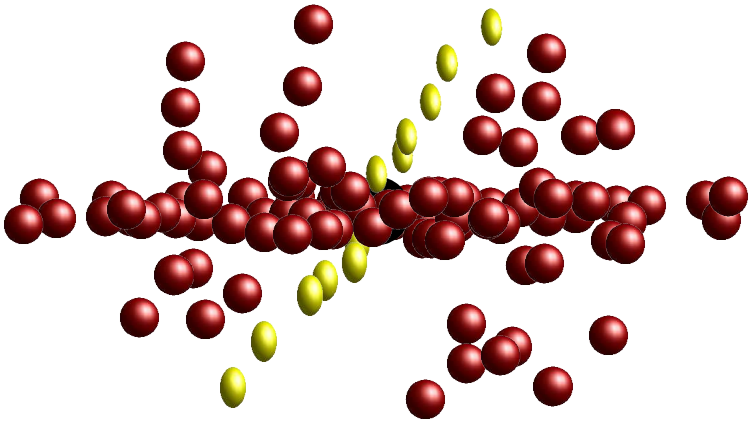
- What is an exclusive interaction?
- Why do we want to observe them?
- Have we observed them at CDF?

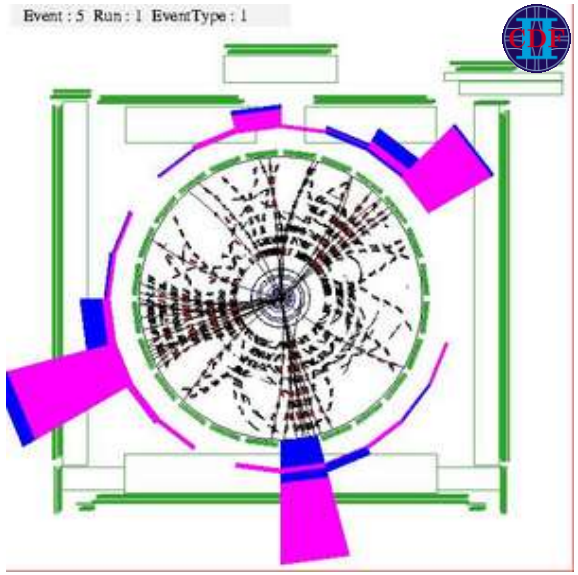
Andrew Hamilton
University of Alberta – Centre for Subatomic Research

Lepton vs. Hadron Colliders









Lepton vs. Hadron Colliders

What are the advantages of a lepton collider?

- beam energy gives extra information about collision
- 'clean' collision environment

Why would we build a hadron collider?

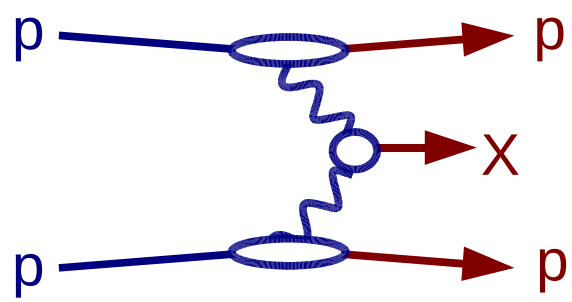
- higher beam energy
- but we suffer with a messy environment and unknown parton collision energy

Exclusive interactions can give us both a clean environment and the parton collision energy in hadron-hadron collisions!

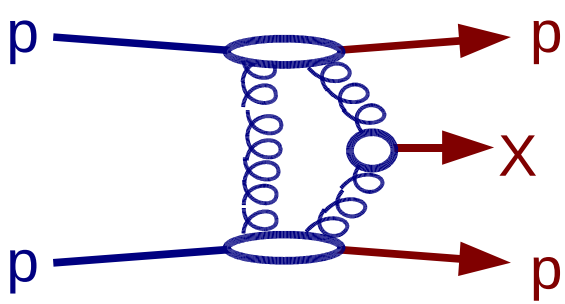
What is an exclusive interaction?

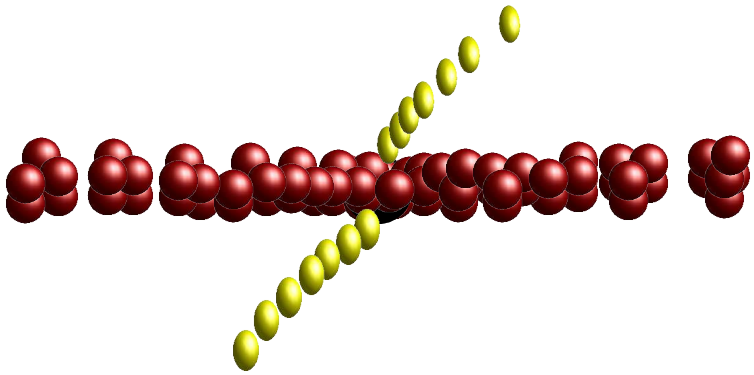
- An exclusive interaction is an ***inelastic*** collision in which the hadrons do not break apart.
- By measuring the outgoing protons' momenta the mass of central system, X, can be determined
- Exchanging colorless objects means the hadrons do not need to break apart, resulting in a ***clean collision environment.***

QED



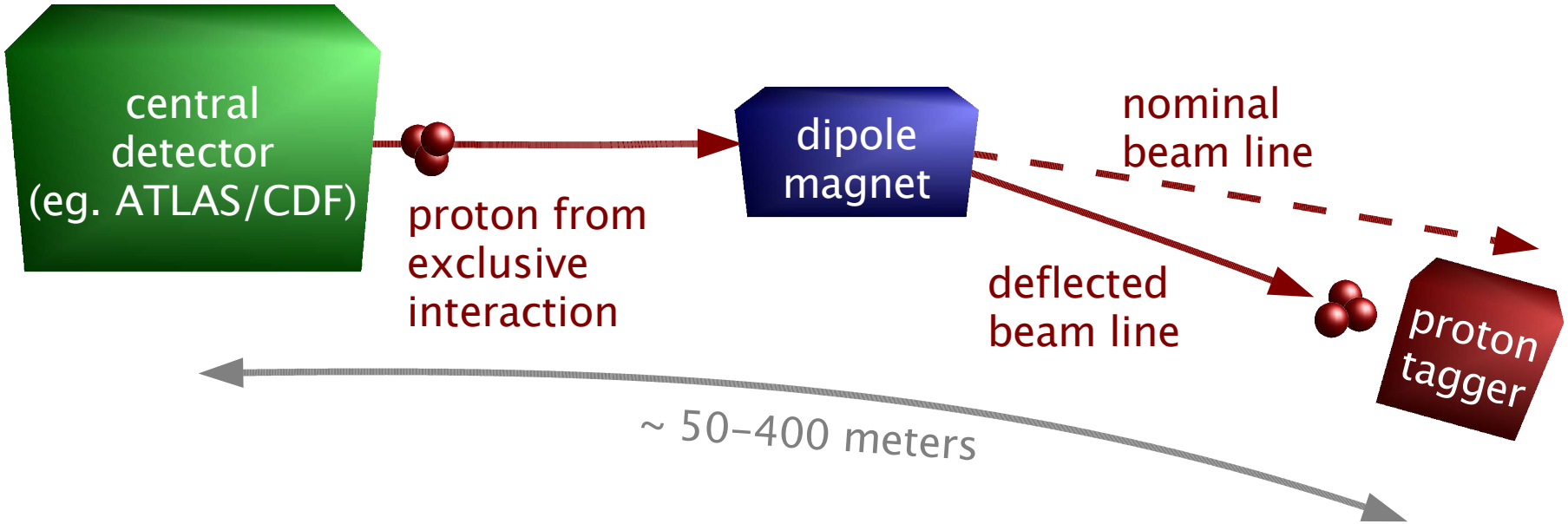
QCD





How to measure proton momentum

- The outgoing proton's momentum can be measured with ***Forward Proton Taggers*** (also called Roman Pots)

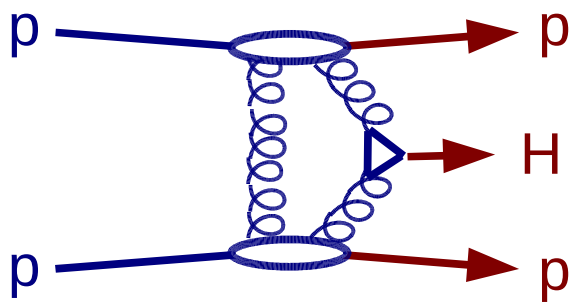


- Basically, we turn the accelerator into a very large spectrometer

QCD exclusive interactions

Advantages of QCD exclusive interactions:

- mass of central system can be determined independently of central detector
- spin selection rule ($J^{PC}=0^{++}$) of central system applies to QCD interactions



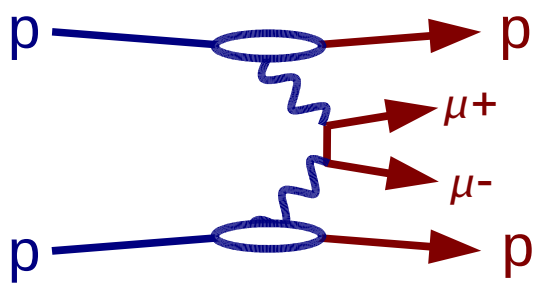
Examples of measurements:

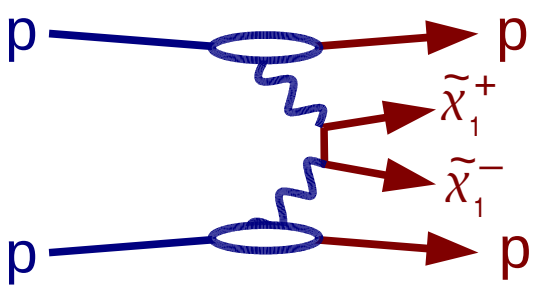
- exclusive SM Higgs:
  - improved mass resolution
  - quantum number determination
  - H→bb branching ration can be measured
- in some beyond SM scenarios exclusive Higgs gives much higher S:B ratio
- mass determination for any 0^{++} SUSY particle that couples to quarks or gluons
- channel independent 'bump' hunting in pp missing mass spectrum
- measure states that decay to unobservable particles

QED exclusive interactions

Advantages of QED exclusive interactions:

- mass of central system can be determined independently of central detector
- cross section can be calculated to high precision





Examples of measurements:

- QED interactions can measure luminosity at LHC
- mass determination for any SUSY particle that couples to photons
- calibrate the measurement of the outgoing protons' momenta
- channel independent 'bump' hunting in pp missing mass spectrum
- measure states that decay to unobservable particles

Sounds Good?

Why aren't they being exploited in the ATLAS physics plans?

- exclusive QED interactions never been observed in hadron-hadron collisions
- exclusive QCD interactions not been observed since the ISR (1983)
- theoretical predictions for QCD interactions have not been experimentally confirmed in ~TeV hadron-hadron collisions

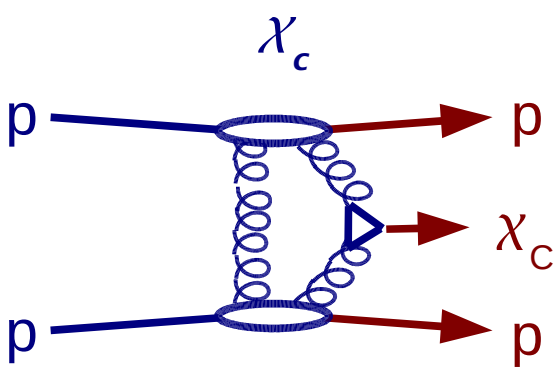
What can we do at CDF to change this?

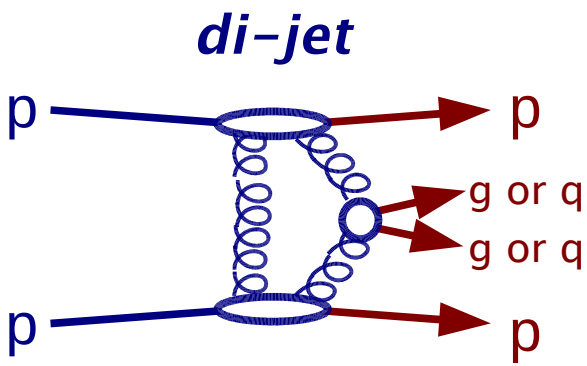
- observe some exclusive interactions!
- QED is expected to be there, not many people doubt that
- QCD exclusive interactions are not as well understood, some in the field think they might not be possible at ~TeV center of mass energy

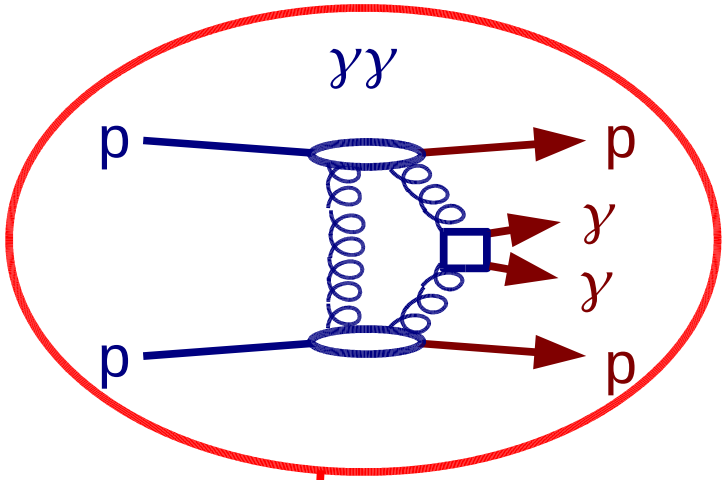
What interaction to search for?

What interactions are expected to be observable at CDF?

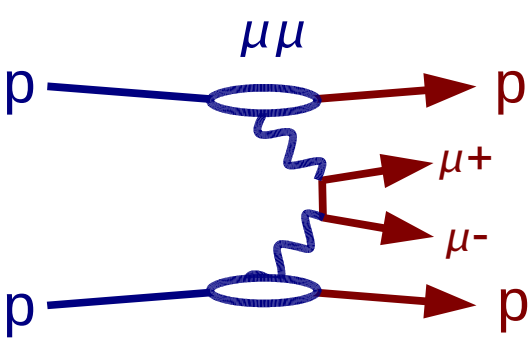
QCD Mediated:

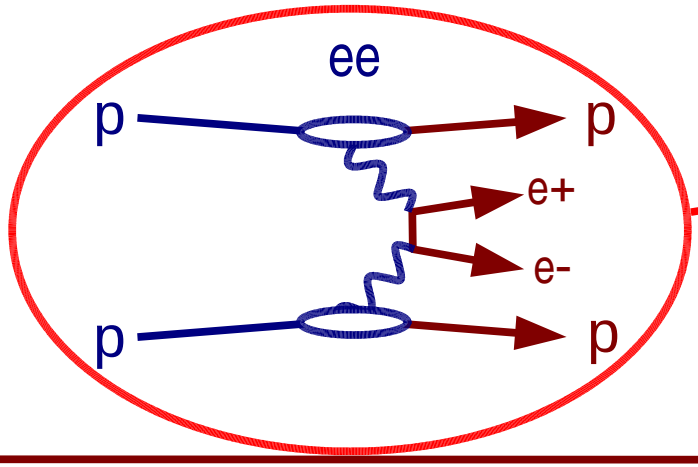






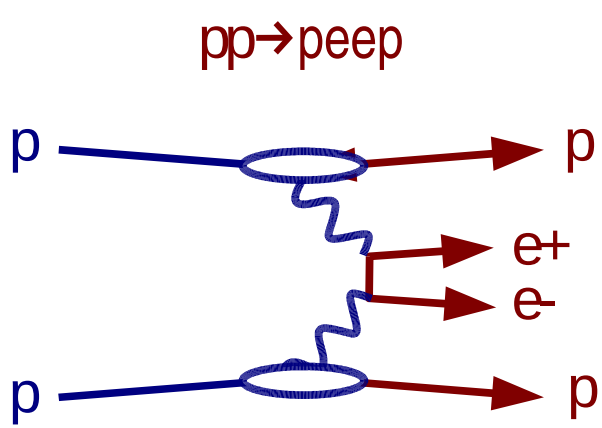
QED Mediated:

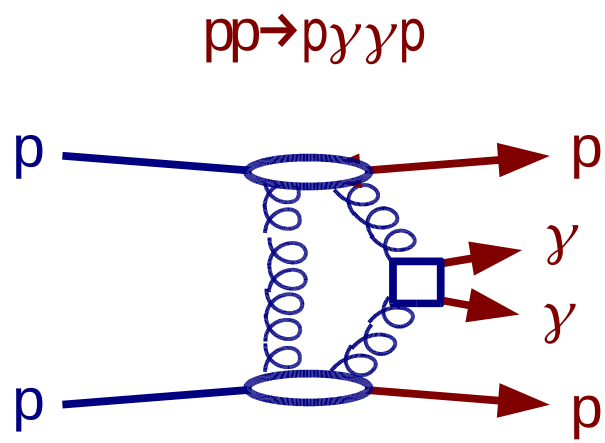




let's take a closer look at these two

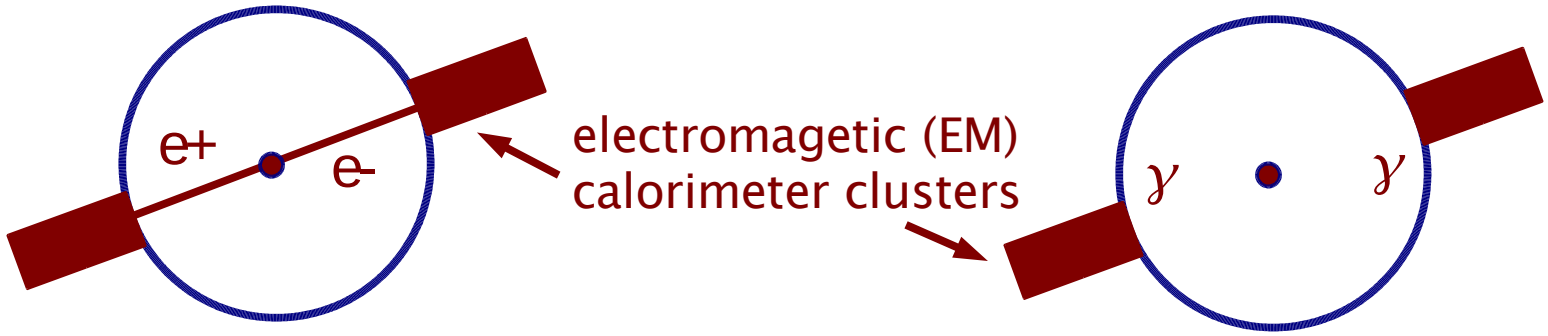
Exclusive e^+e^- and $\gamma\gamma$





Fundamentally different production mechanisms (QED vs. QCD), but the detector signatures are nearly identical, yet easily distinguishable.

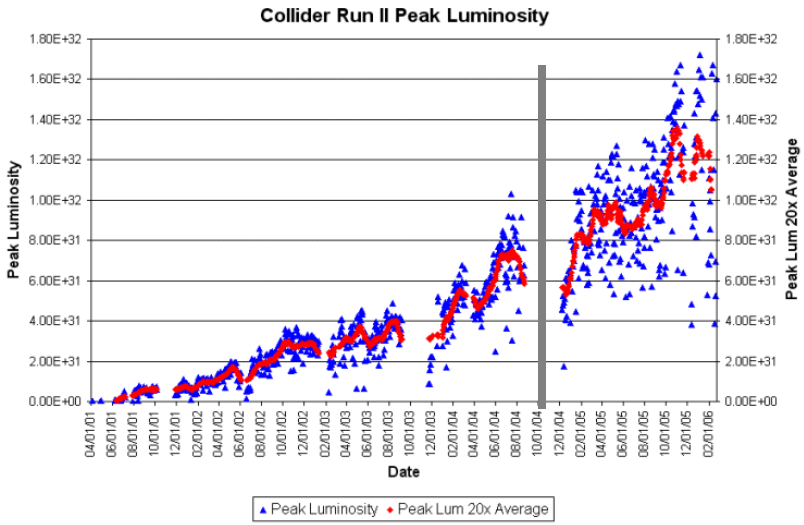
rϕ–view of detector



The Tevatron

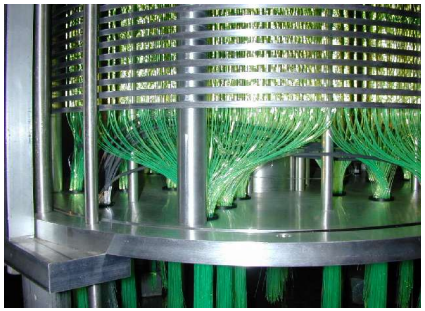
$p\bar{p}$ collisions @ $\sqrt{s} = 1.96 \ TeV$

$\mathscr{L}_{inst} = 20 \text{ to } 160 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$



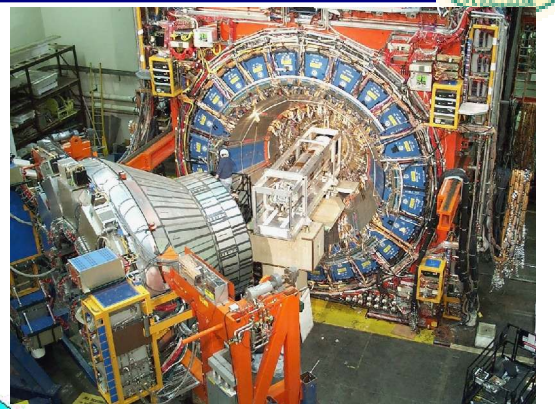
~ 1 to 6 interactions per crossing

The CDF Detector



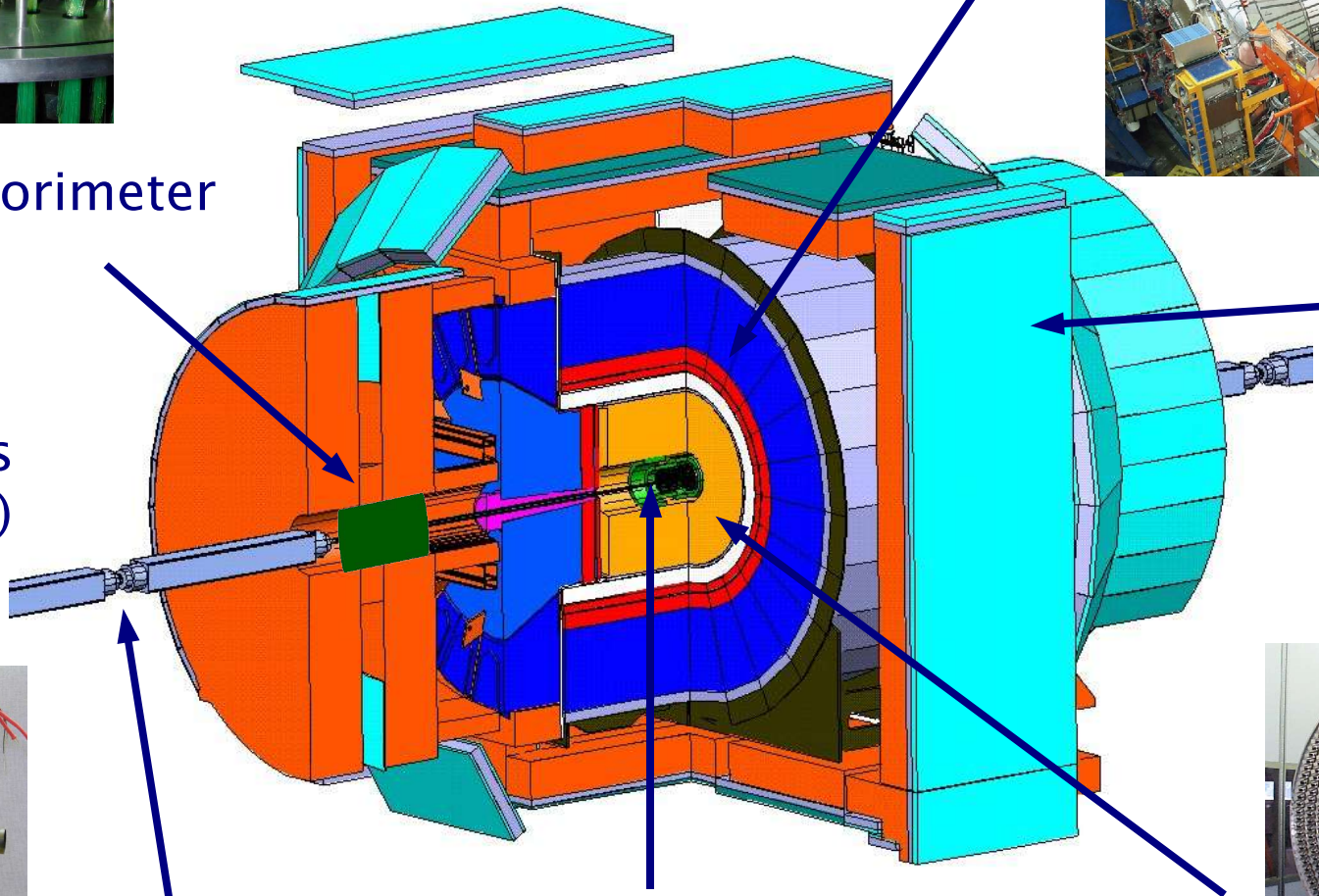
Plug and Central Calorimeters

$|\eta| < 3.5$



MiniPlug Calorimeter

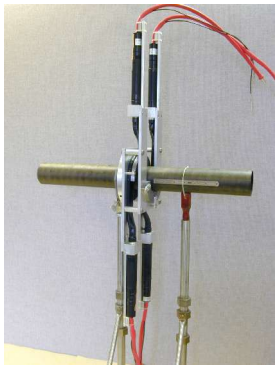
$3.5 < |\eta| < 5.5$



Muon System

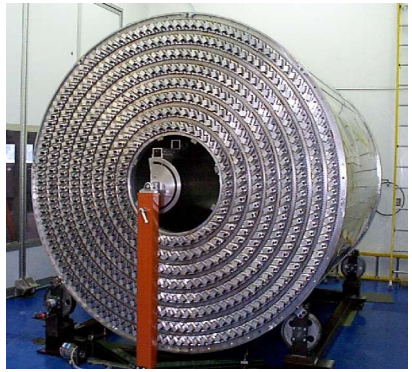
Roman Pots
(not shown)

COT Tracker
$|\eta| < 1\ (2)$



BSC $5.5 < |\eta| < 7.4$

Silicon Vertex Detector



How to make the measurement

Event selection:

- Select events with 2 electromagnetic calorimeter clusters (this will include both e^+e^- and $\gamma\gamma$ events)
- Apply selection criteria to eliminate any cosmic ray events from the sample
- ***Require that there be no other calorimeter activity in the event***
- Differentiate e^+e^- and $\gamma\gamma$ events by separating clusters with tracks from clusters without tracks

Why don't we use the Roman Pots:

- ideally, we would use the Roman Pots to ensure the proton stayed in tact
- but the roman pot acceptance does not cover our kinematic region
- ***we must infer that the proton stayed in tact by the observation that there was nothing except the 2 electrons (photons) in the detector***

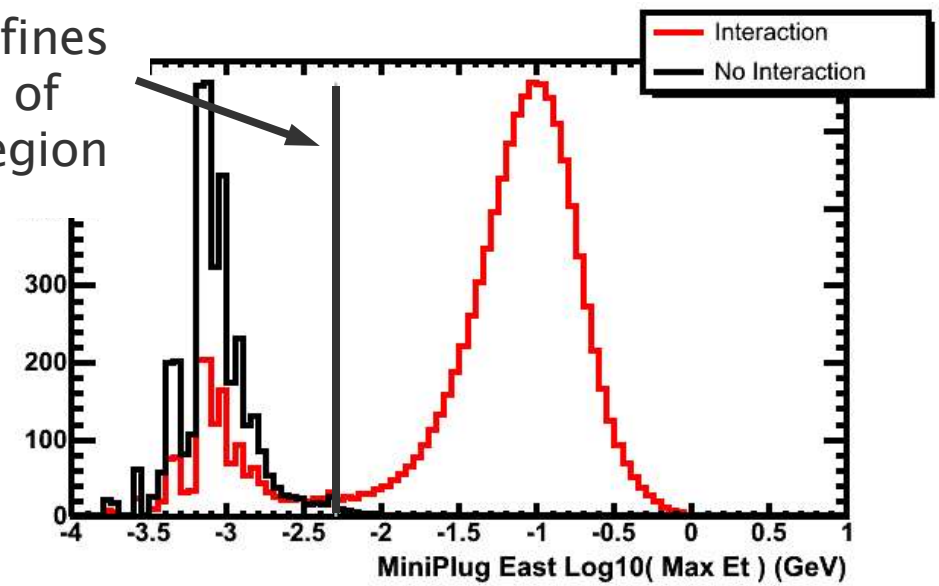
Looking for Nothing

How do you show there is "nothing" in the detector:

- divide the calorimeters into 8 regions base on detector response
- divide an un-biased data sample into ***interaction*** and ***no interaction*** samples (using criteria not based on calorimeters)
- determine the noise level of each calorimeter region based on the comparison between the interaction and no interaction samples

Region	η range
Central	0.00 – 0.66
End Wall	0.66 – 1.32
Mid Plug	1.32 – 2.11
Fwd Plug	2.11 – 3.64
Mini Plug	3.6 – 5.2
BSC 1	5.4 – 5.9
BSC 2	6.4 – 7.1
BSC 3	6.7 – 7.4

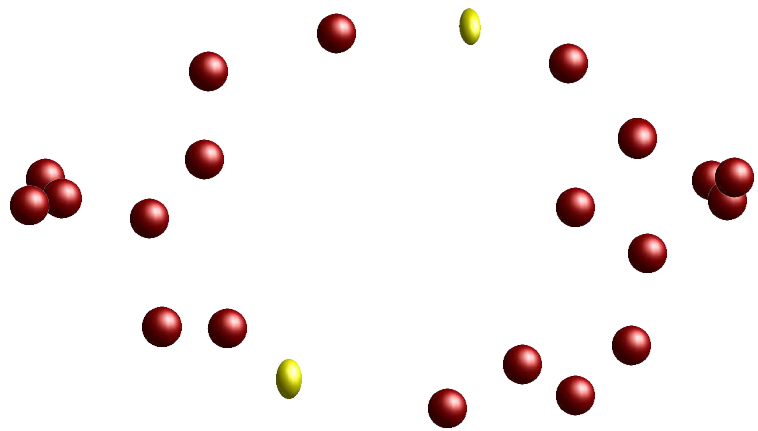
this cut defines noise level of detector region



What about pile-up?

Pile-up: more than one $p\bar{p}$ collision in the beam crossing

- When not using Roman Pots to observe the outgoing protons, pile-up prevents us from observing an exclusive interaction

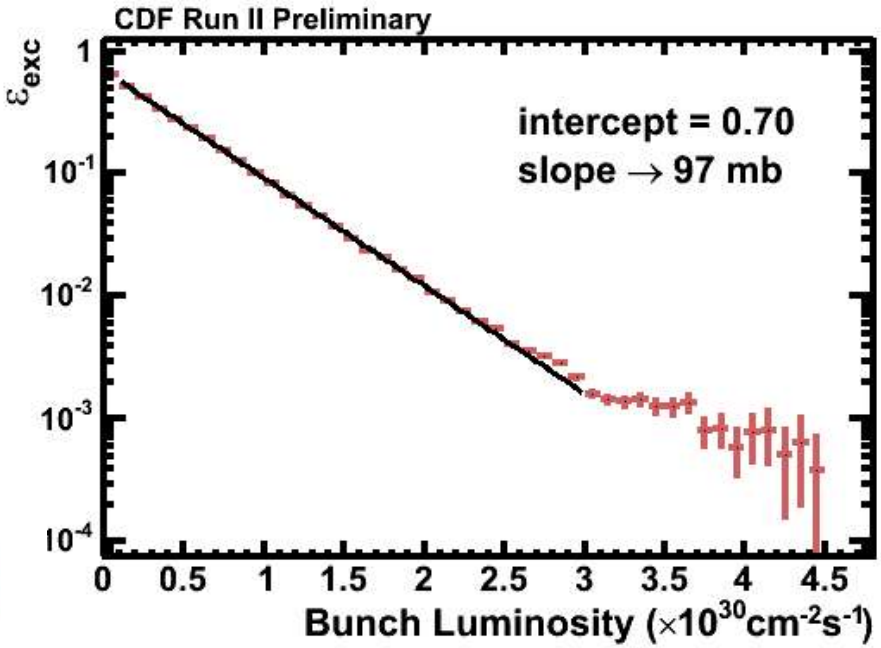


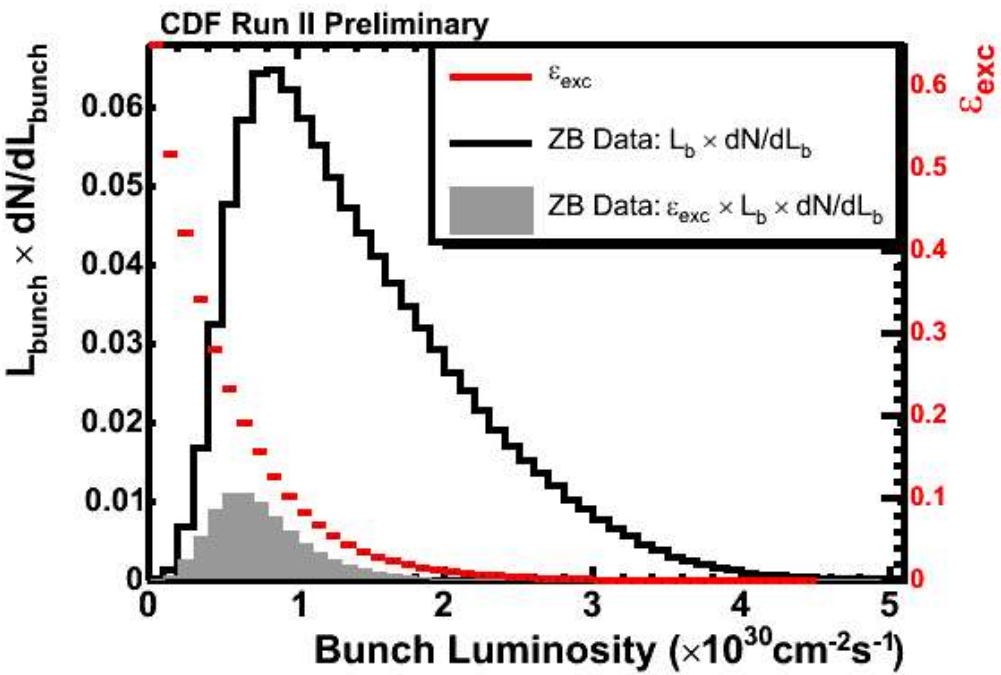
- Since the Tevatron has only ~1-6 interactions per crossing, we still get some events with no pile-up.
- To measure a cross section, we need to carefully calculate the number of events we lose due to pile-up

Exclusive Efficiency

Exclusive efficiency is the probability that the detector is in a state that an exclusive event can be observed. That means there is no pile-up or detector noise above threshold.

→





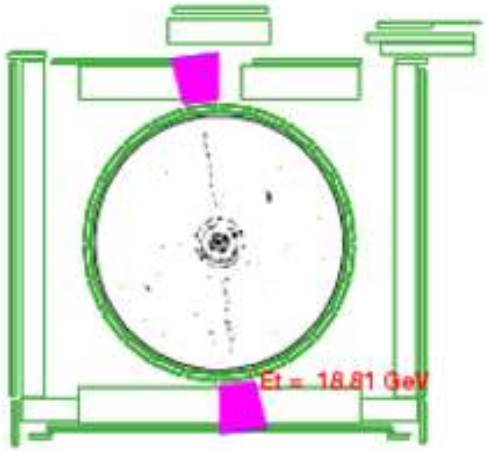
←

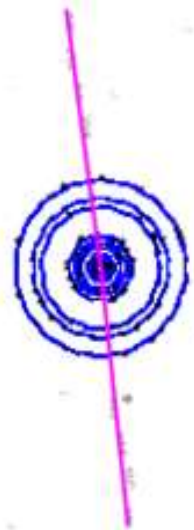
Integrated over the data taking period, the exclusive efficiency is only ***8.56%***

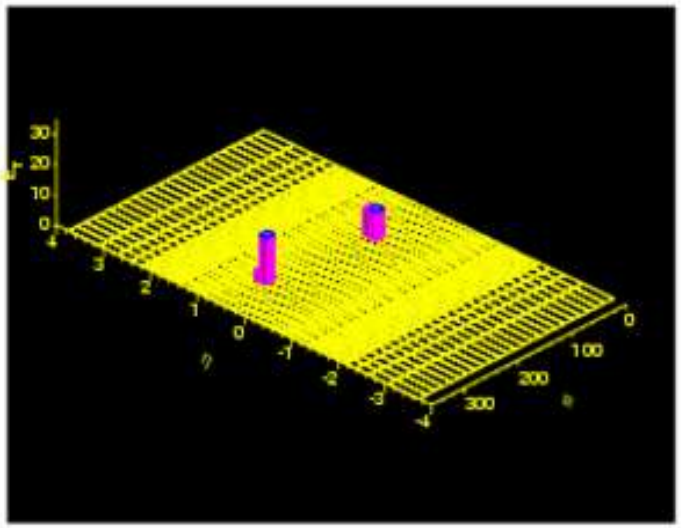
We lose over 90% of these events because we don't have acceptance in the Roman Pots

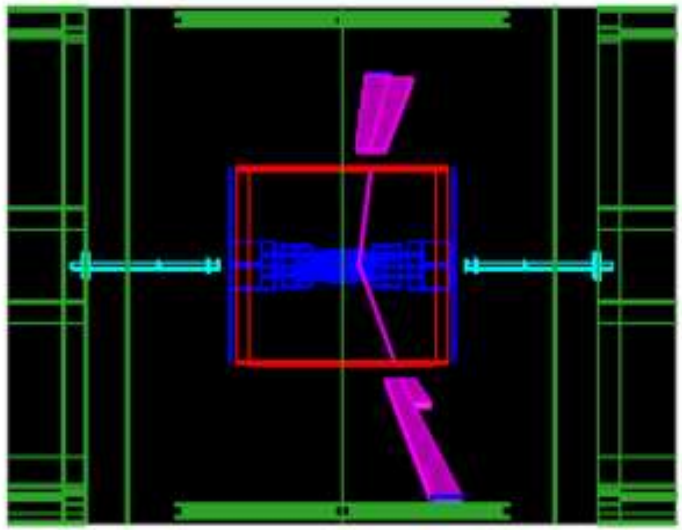
How many e^+e^- events do we find?

There are ***16*** e^+e^- events...

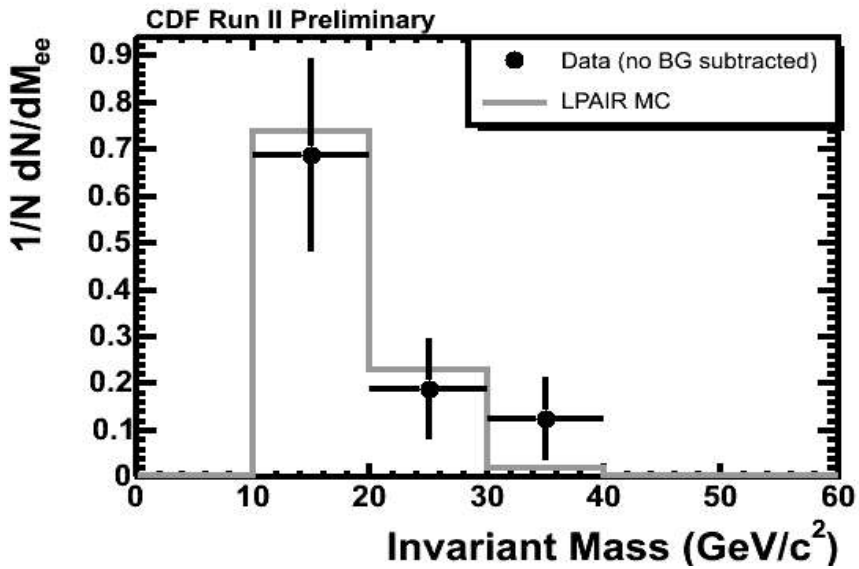


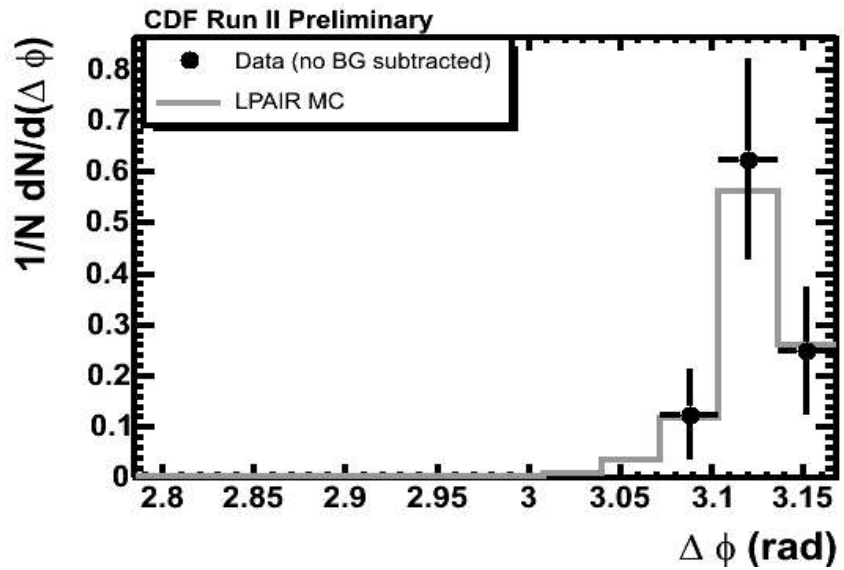


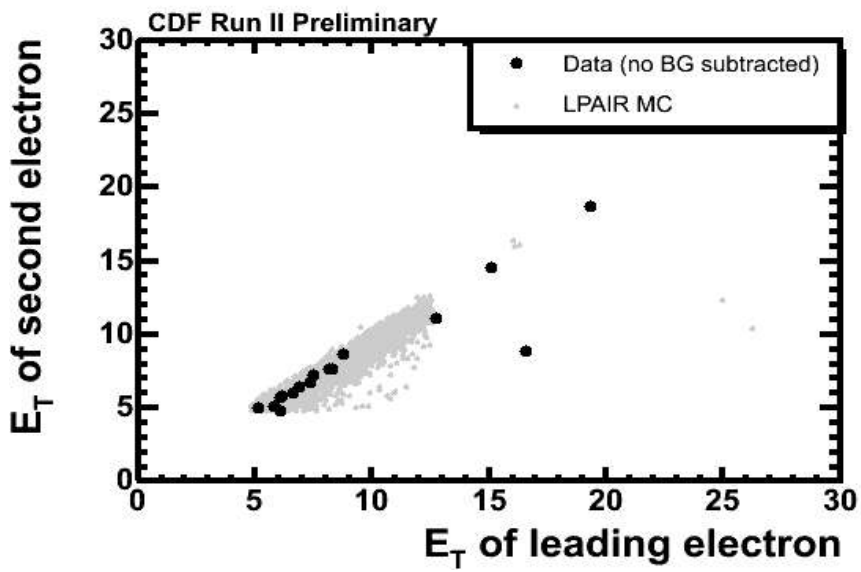


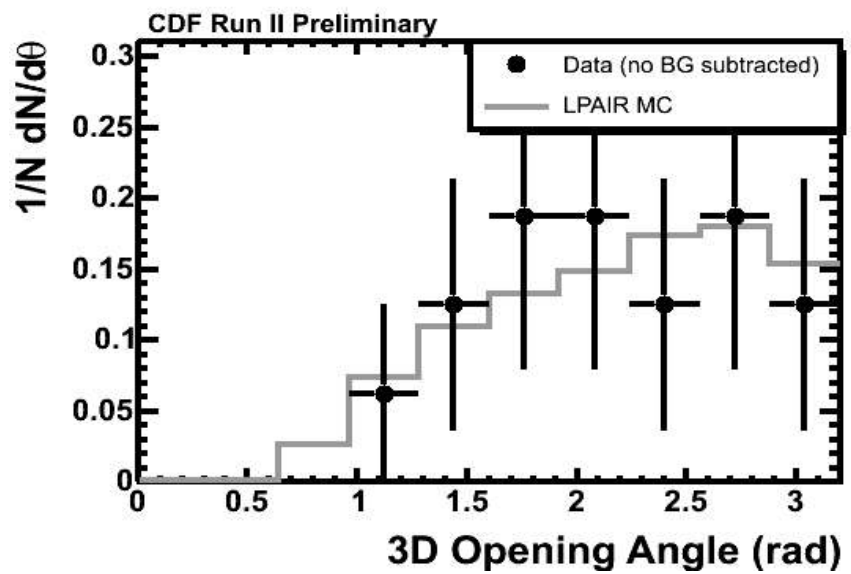


e^+e^- Comparison to Monte Carlo

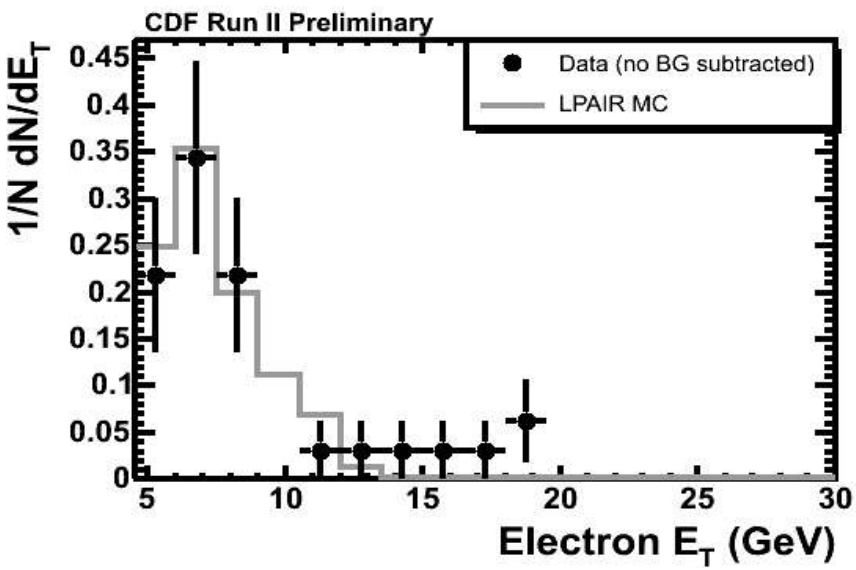


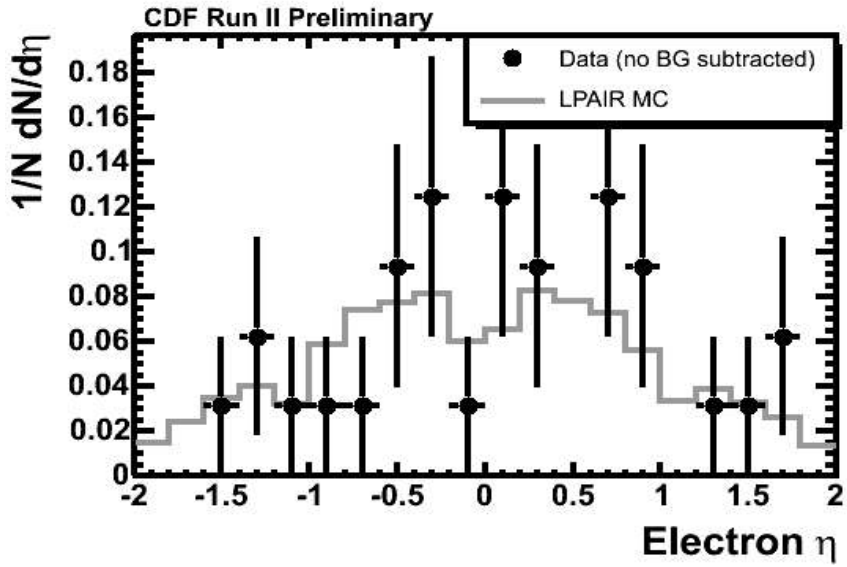


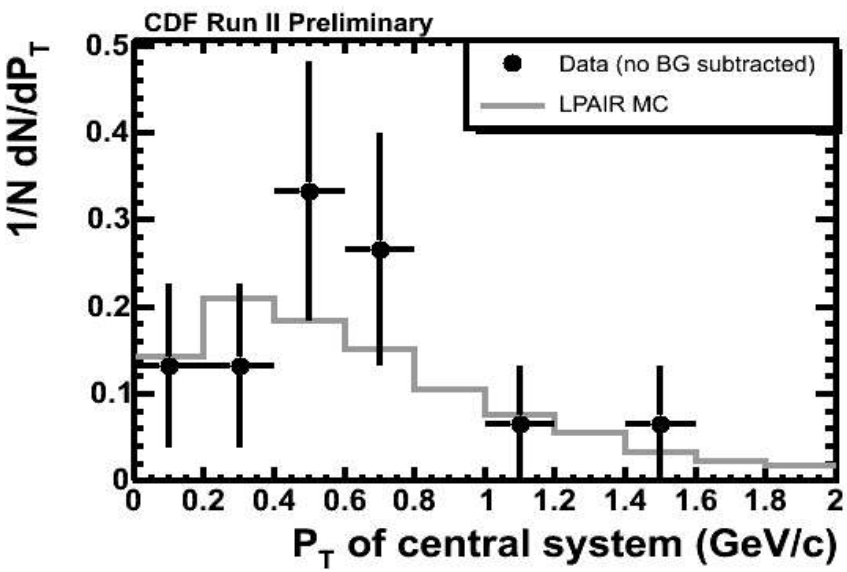


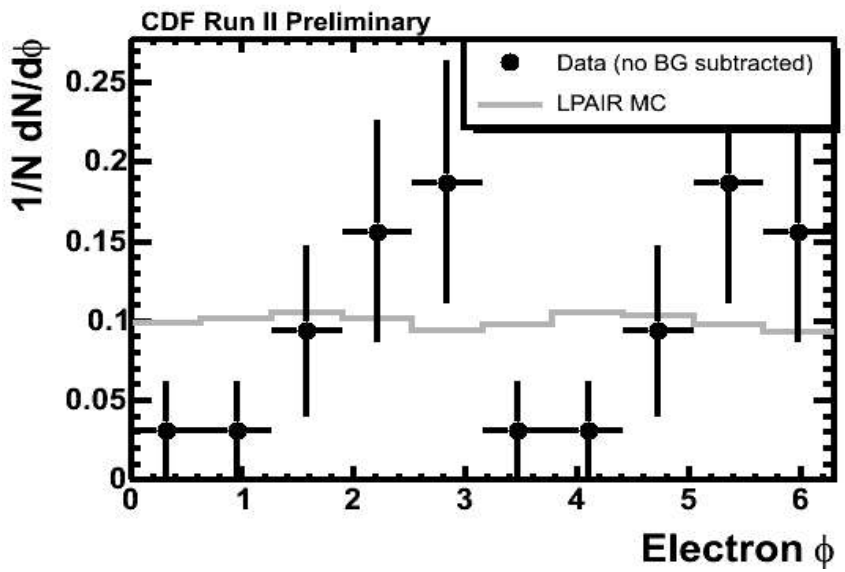


e^+e^- Comparison to Monte Carlo



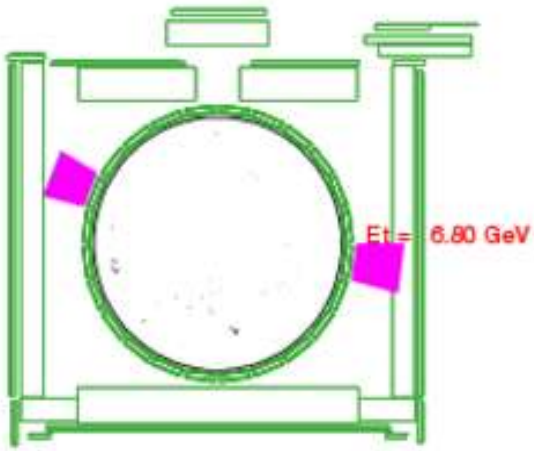


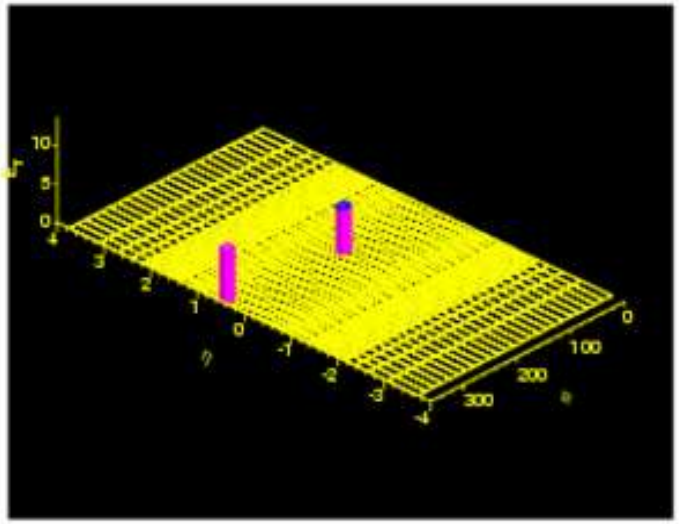


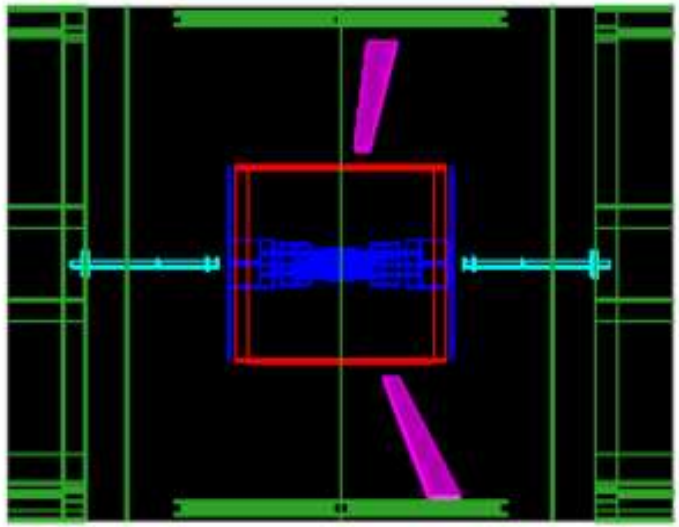


How many $\gamma\gamma$ events do we find?

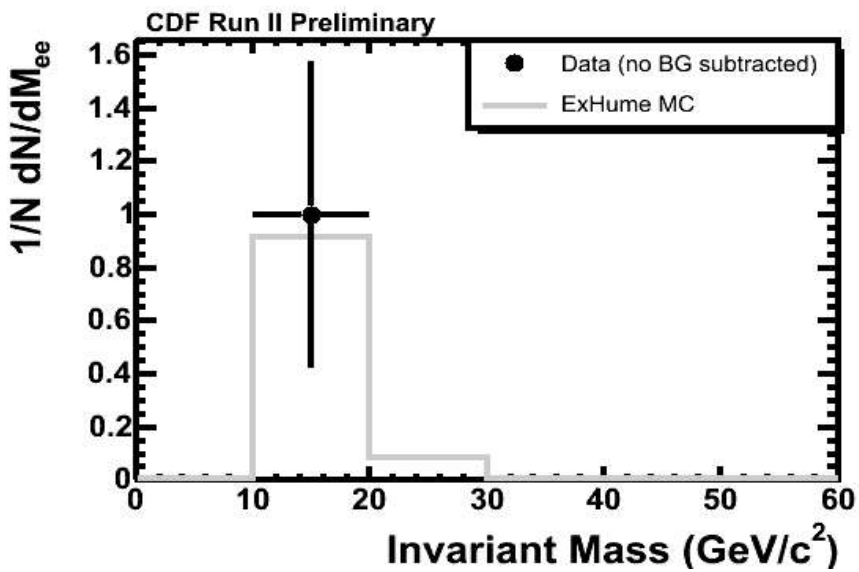
There are ***3*** $\gamma\gamma$ events...

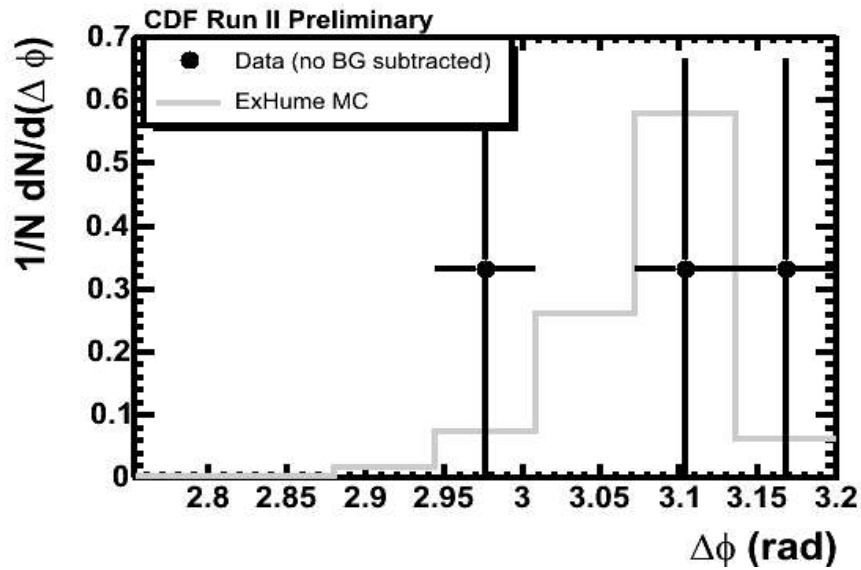


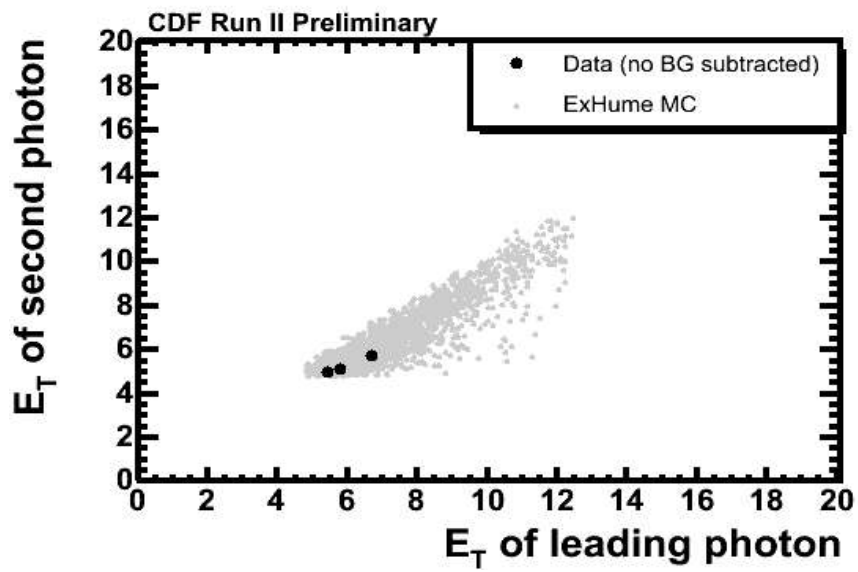


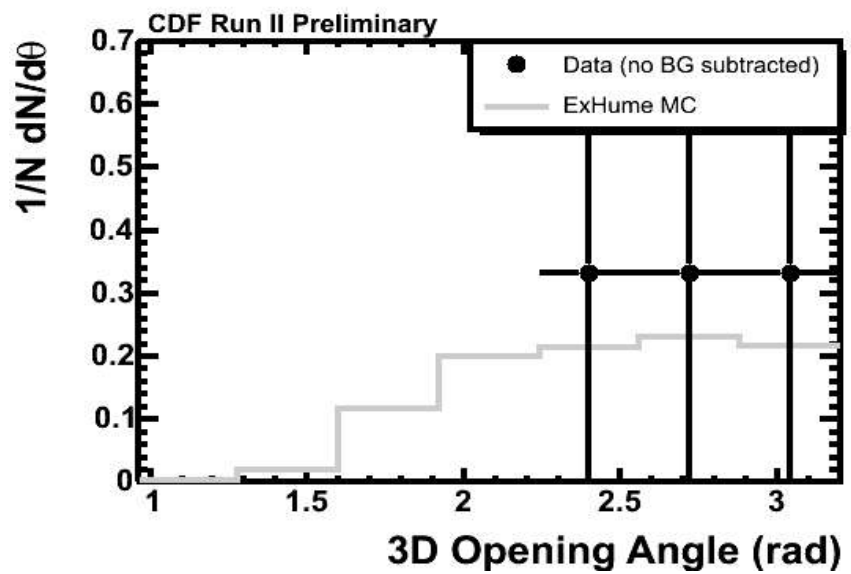


$\gamma\gamma$ Comparison to Monte Carlo

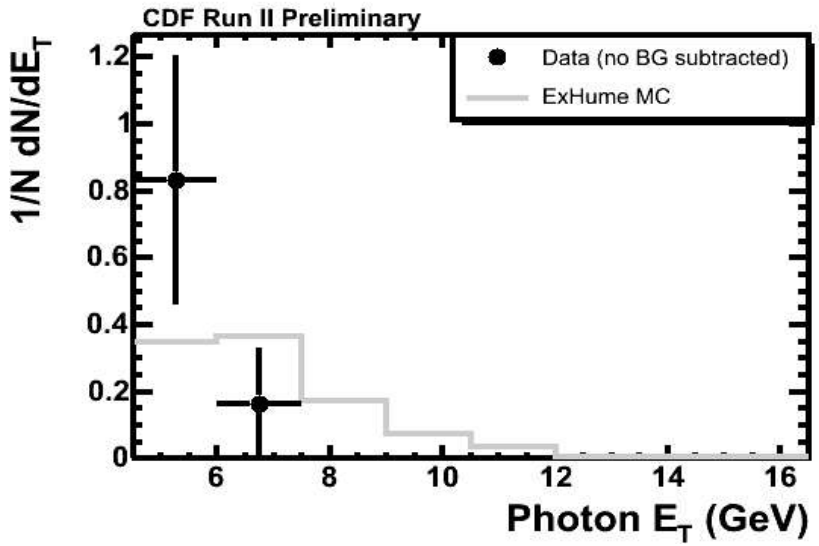


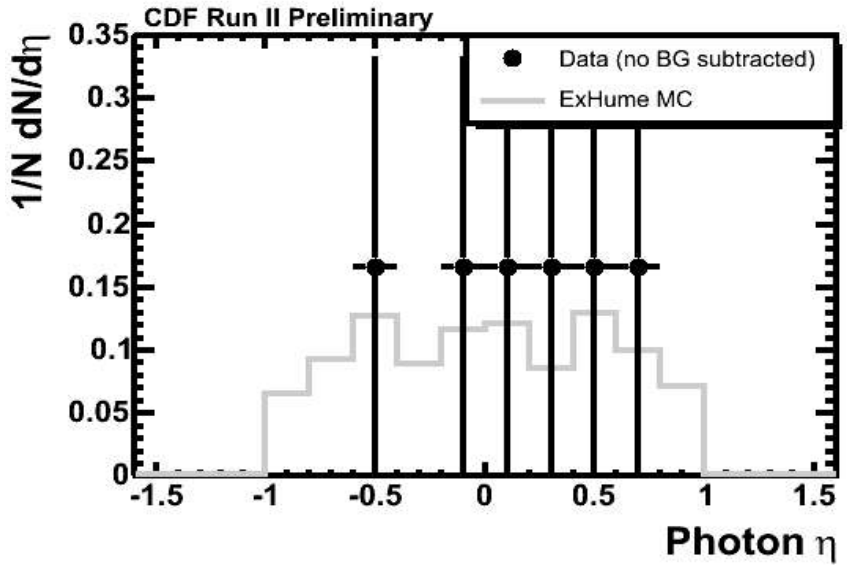


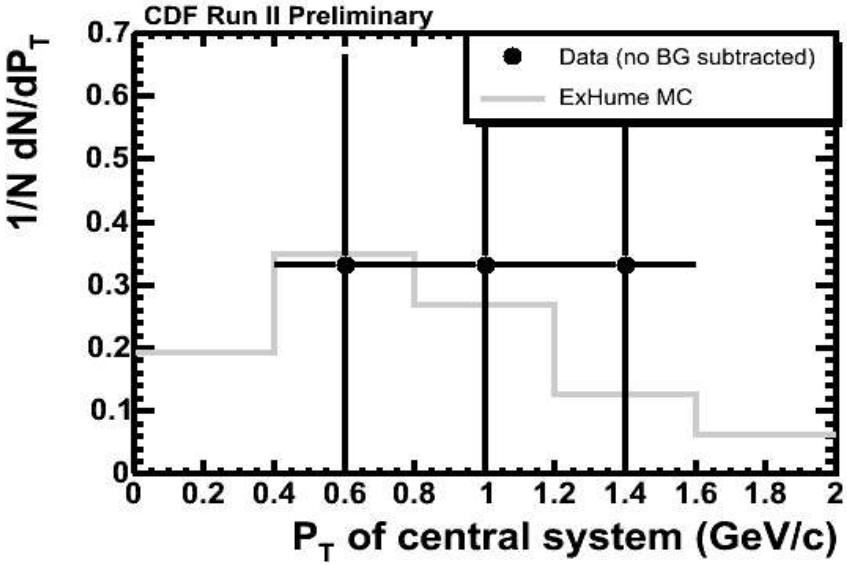


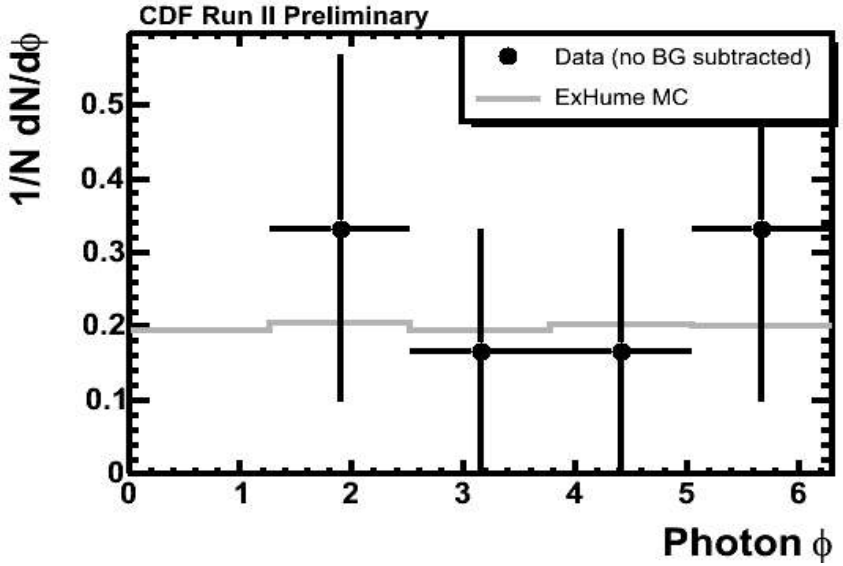


$\gamma\gamma$ Comparison to Monte Carlo





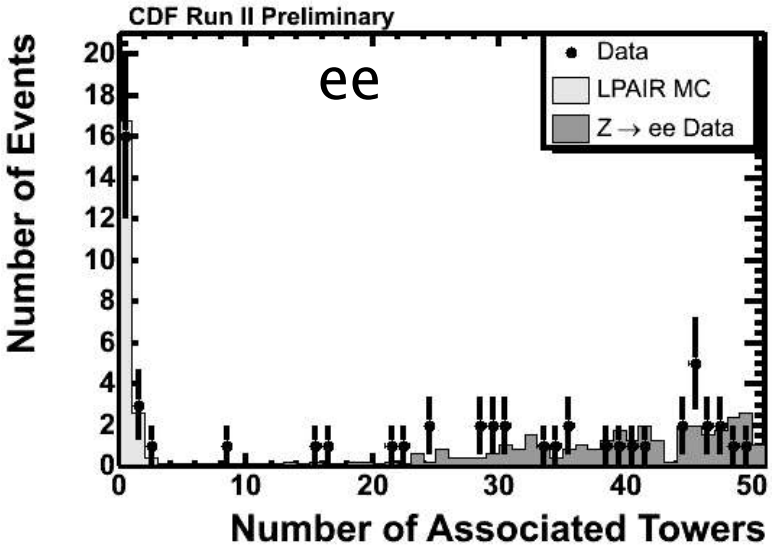


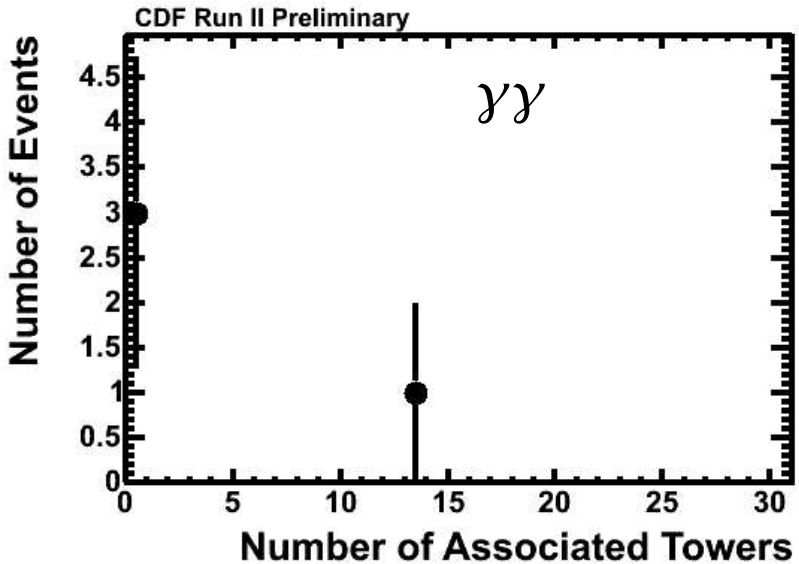


What about backgrounds?

Are they the tail of the inclusive distribution?

No, there is a very small background from inclusive events





Other backgrounds: ***'Jet' Fakes:*** hadron faking an e/γ
Cosmic: cosmic ray creating 2 EM clusters
Dissociation: probability of proton excitation

Total Background Estimates: ***ee:*** $2.1^{+0.6}_{-0.3}$ $\gamma\gamma$***:*** $0.0^{+0.2}_{-0.0}$

How do cross sections compare to theory?

ee

$$\sigma_{MEASURED} = 1.6\ ^{+0.5}_{-0.3}\ (stat) \pm 0.3\ (sys)\ pb$$

Agrees with LPAIR theory: $\sigma_{LPAIR} = 1.711 \pm 0.008\ pb$

Poisson probability of 2.7 → 16 = 3.0×10^{-8}
Corresponds to 5.5σ "observation"

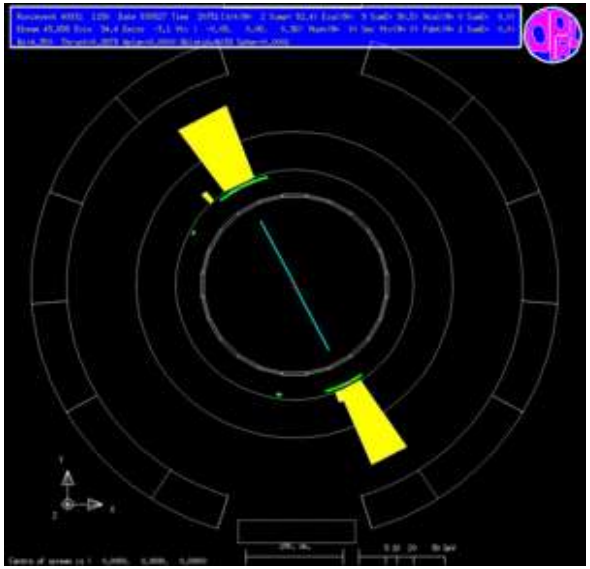
$\gamma\gamma$

$$\sigma_{MEASURED} = 0.14^{+0.14}_{-0.04}\ (stat) \pm 0.03\ (sys)\ pb$$

Agrees with Durham theory: $\sigma_{Durham} = 0.04 \pm (\times 3\text{–}5)\ pb$

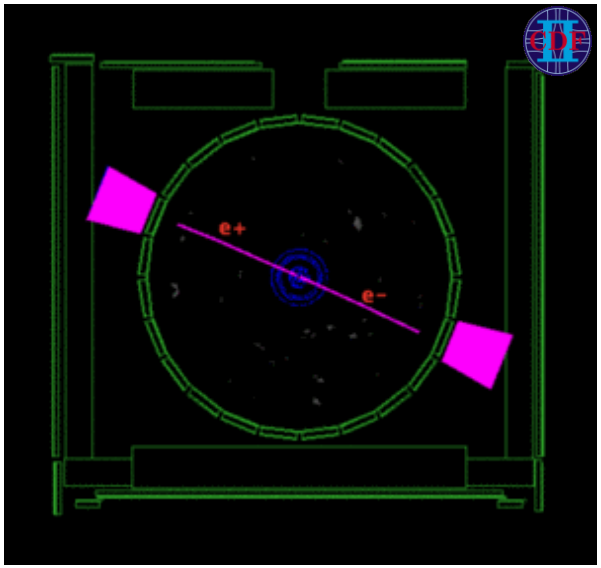
Poisson probability of 0.2 → 3 = 1.1×10^{-3}
Corresponds to 3.3σ "evidence"

What does this mean?



Exclusive interactions are a feasible mechanism to study high p_T physics in hadron-hadron colliders!

By measuring the outgoing protons' momentum, we can determine the parton collision energy.



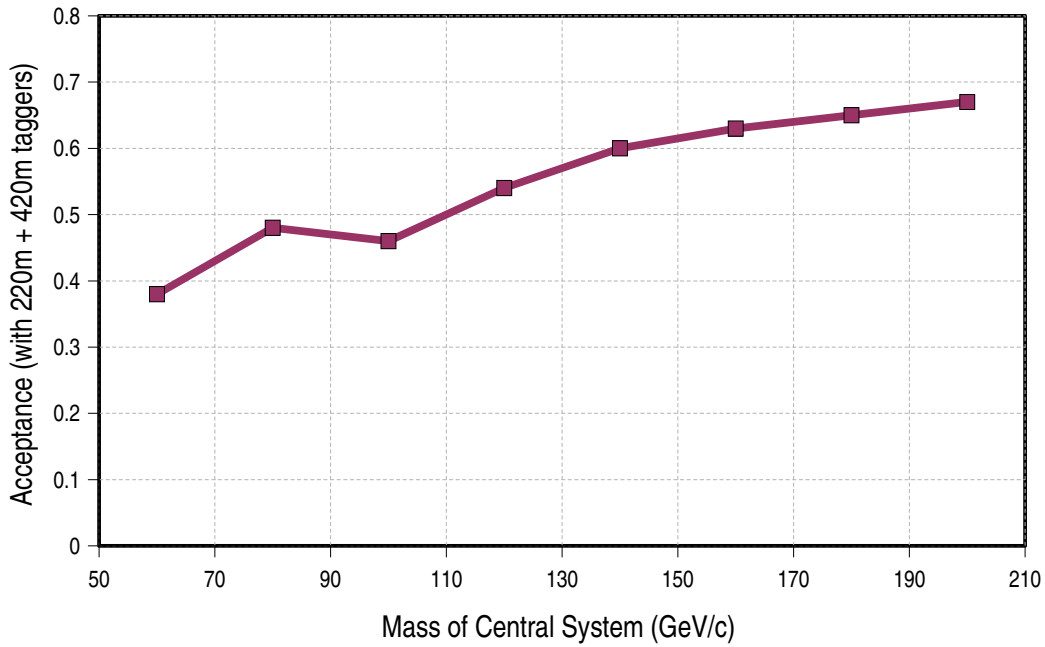
One can do channel independent 'bump' hunting with the outgoing proton missing mass

The exclusive interactions may be used to determine Higgs mass, quantum numbers, and bb branching ratio

What's being done at LHC?

The FP420 Project:

A research and development project, headed by University of Manchester, to install ***Forward Proton Taggers*** at 420m on either side of the ATLAS and CMS detectors.



When combined with the 220m Roman Pots, they will have reasonable acceptance over the 60 to 200 GeV mass region.

LHC studies

Exclusive Higgs:

- The Durham group's prediction of exclusive $\gamma\gamma$ is correct (within the current statistics).
- Their prediction of the exclusive Higgs cross section at the LHC is 3 fb (120 GeV Higgs) and 1 fb (200 GeV).
- Therefore, Standard Model Higgs should be observable in exclusive interactions in ~10's of fb^{-1} at both ATLAS and CMS

Luminosity Monitoring:

- The University of Alberta group is heading the LUCID detector construction.
- LUCID will help monitor luminosity, but more is needed.
- QED mediated exclusive $\mu\mu$ is being studied as a luminosity monitor.

Concluding Remarks

- Both QED and QCD mediated exclusive interactions have been observed at CDF.
- This is the first observation of QED mediated interactions in hadron-hadron collisions
- It is the first evidence of QCD mediated interactions in hadron-hadron collisions near TeV center of mass energies.
- These are very important observations that could have a significant impact on the physics reach of the LHC.

Thank-you