WARNING WARNING WARNING

This is an outline...

Not a talk.

B and QCD Physics Results at CDF

Presented for the CDF Collaboration

by

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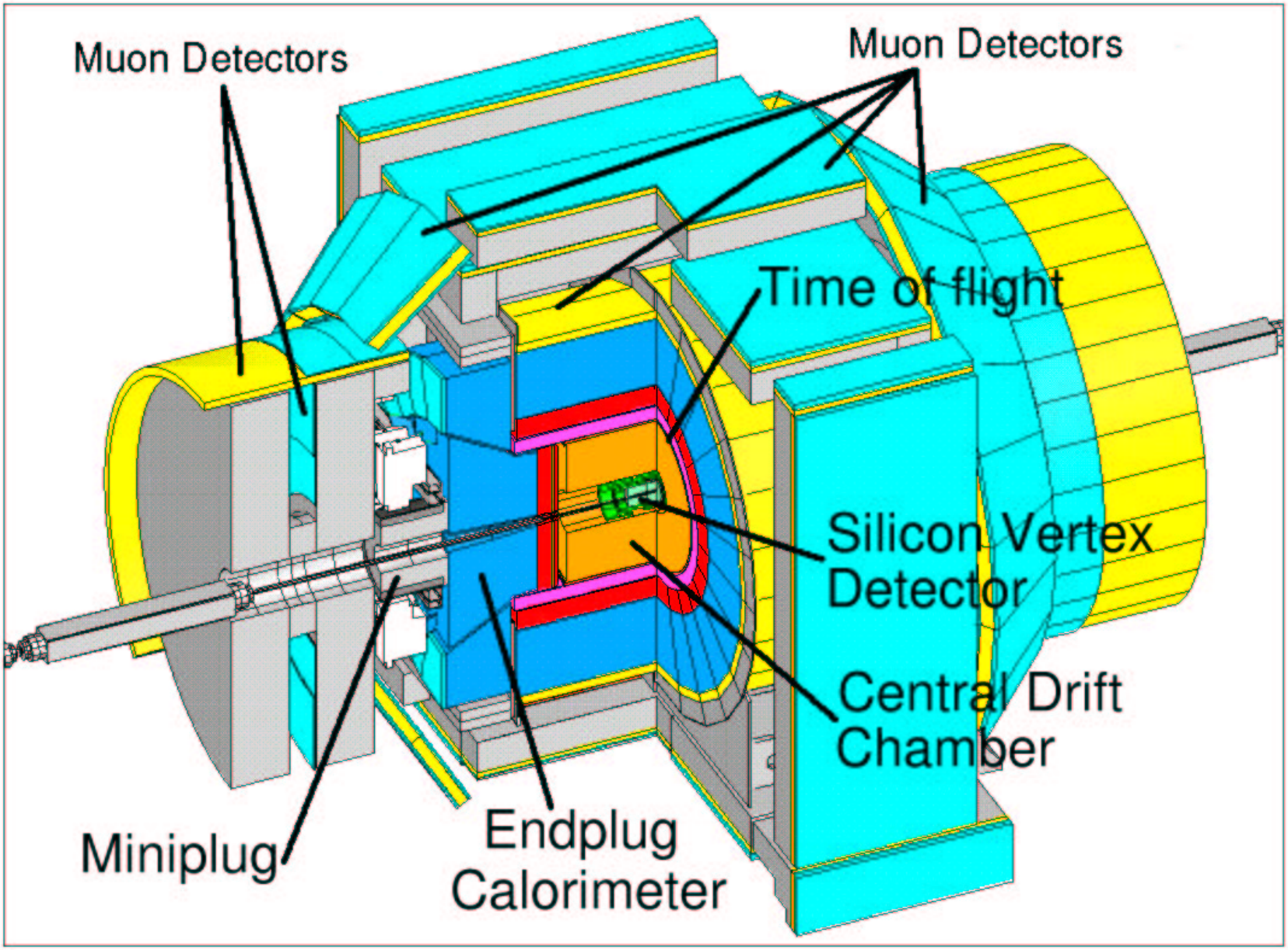
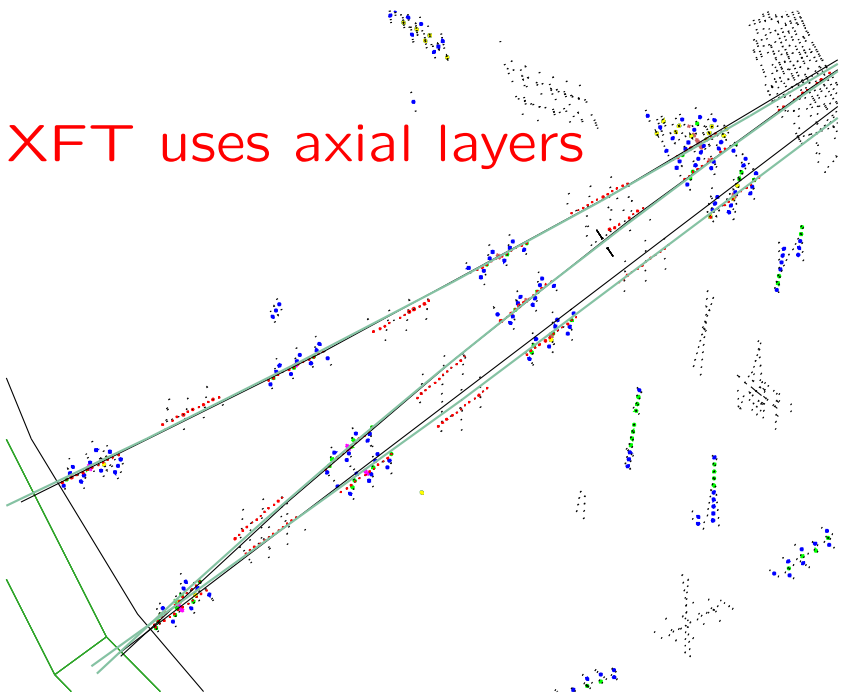
CDF Detector Upgrades for Run II

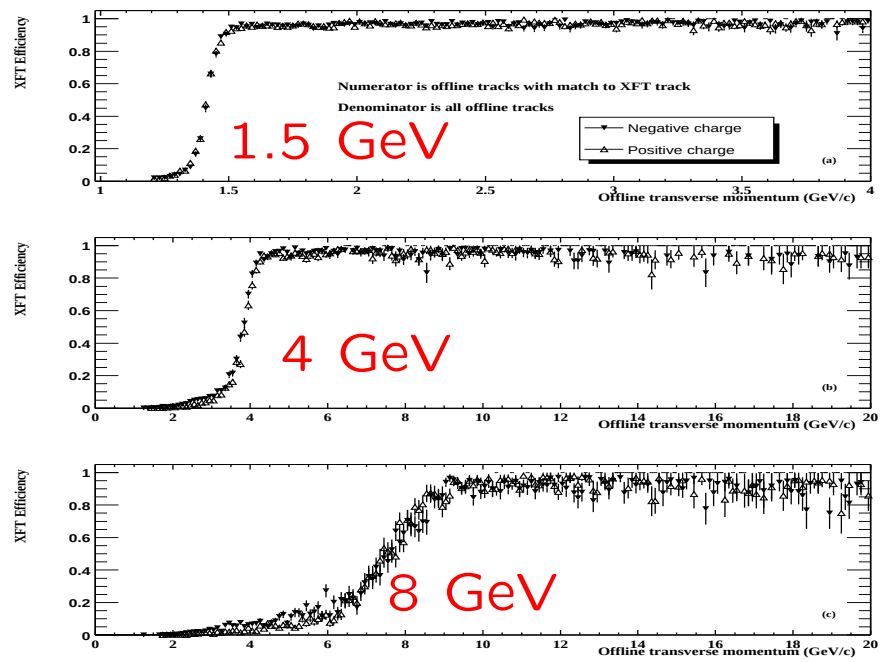


Extremely Fast Tracker (XFT Trigger)

Tracking trigger at L1! Enhances our physics capabilities, able to collect large samples used for in situ calibration.

XFT uses axial layers





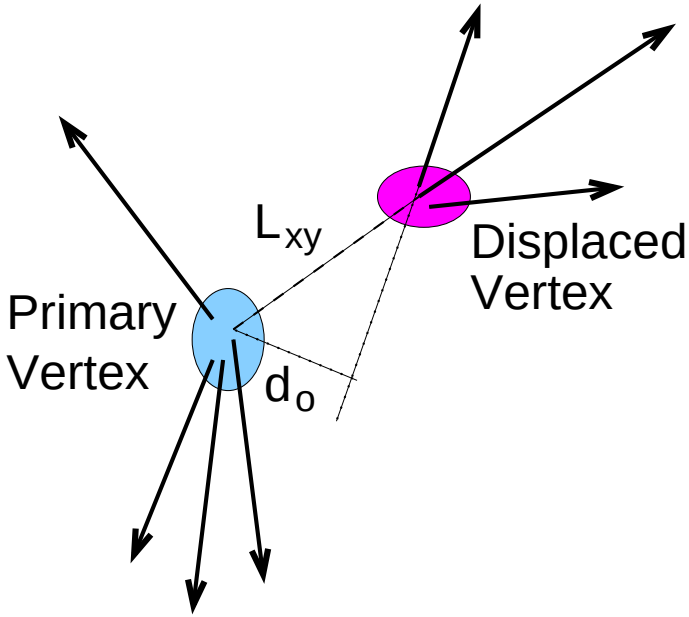
XFT tracks (green) compared with offline tracks (black).

Performance exceeds design specification.

→ Measured momentum resolution $(\Delta p_T/p_T^2) = 1.65\%$.

→ Measured angular resolution 5.1 mR.

Silicon Vertex Tracker (SVT Trigger)



Many important physics signatures involve b quarks: Higgs searches, top studies, constraining CKM matrix...

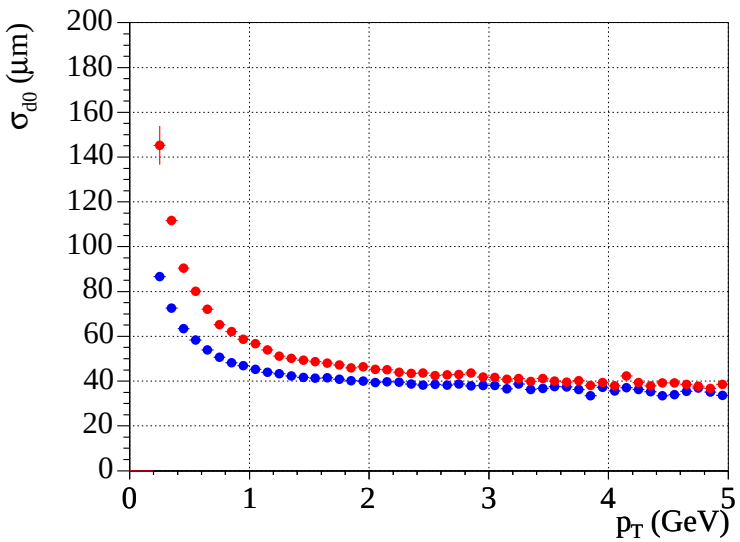
b quarks have lifetimes
$\tau(b) \sim 1.5ps \quad (c\tau \sim 450\mu m)$

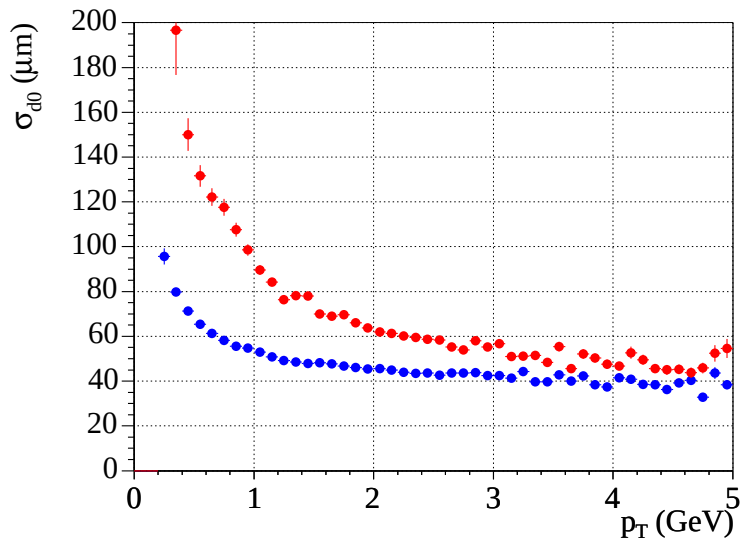
Combine silicon hits with L1 tracks (XFT)

Using impact parameter (d_o) to detect secondary vertexes at the Level 2 trigger significantly increases both our physics potential and calibration sample.

Improvements in alignment allow us to include hits from the innermost silicon layer (L00) in tracking

Results in an improved $d0$ resolution for tracks with low p_T (< 3 GeV) and for tracks that traverse more material





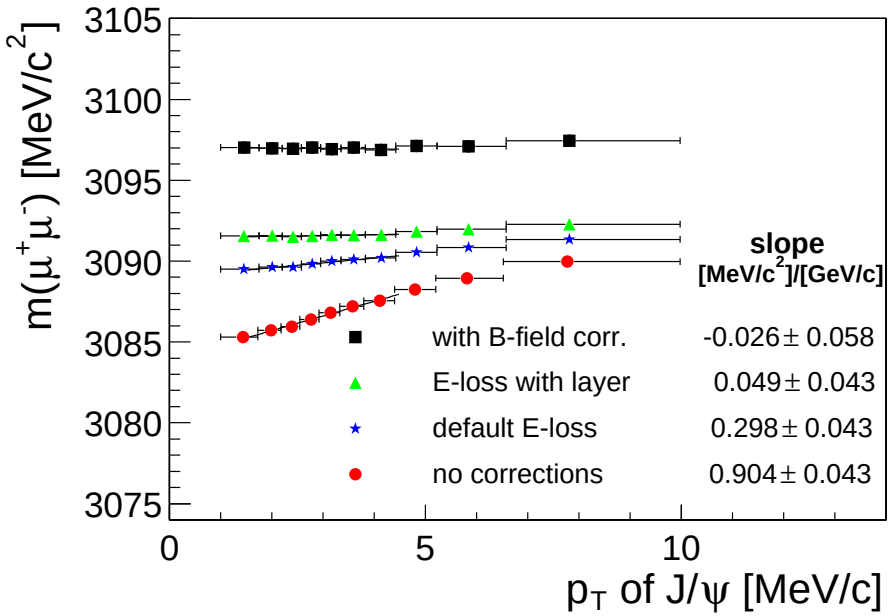
Silicon only regions: Tracks with $|\eta| < 1$ and $|z| < 8$cm

SVX bulkhead region: $11 < |z| < 19$cm

Essential for B_s mixing measurements

Improvements in the trigger allow us to collect large calibration samples that are used to understand the performanc of the tracking chambers.

Tracking Calibration using the *huge* J/ψ sample



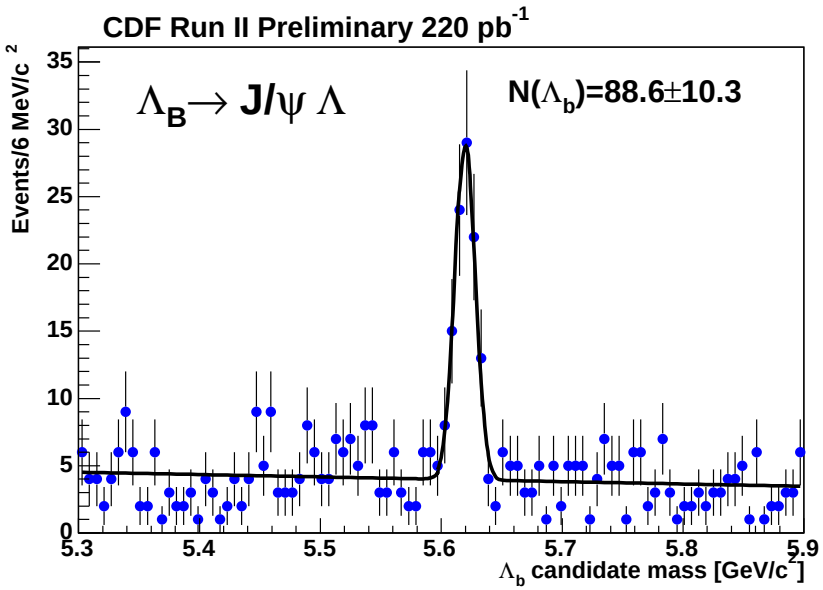
→ Apply GEANT dE/dx corrections
→ Measure missing material from $m_{J/\psi}(P_T)$
→ Magnetic field correction

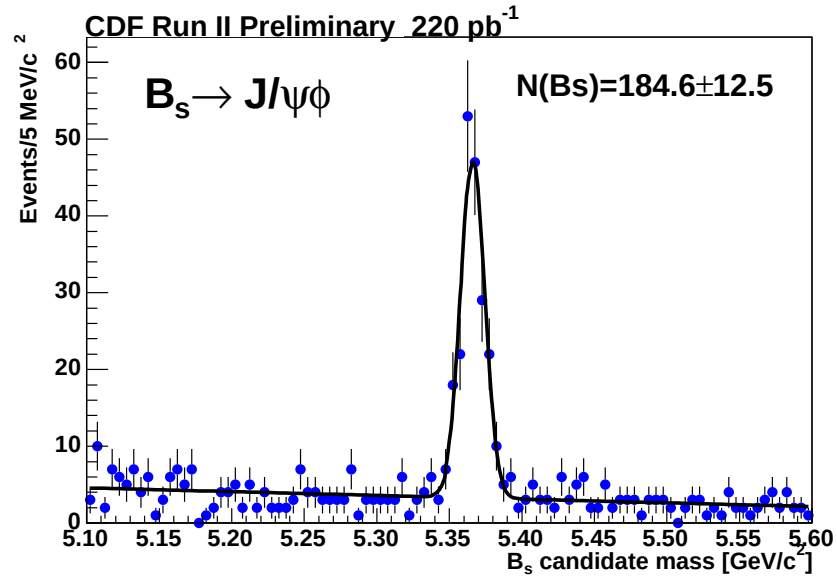
Tune to the J/ψ mass

Check against other particles

Agrees at the sub MeV level...

Measurement of the B hadron masses in exclusive J/ψ channels





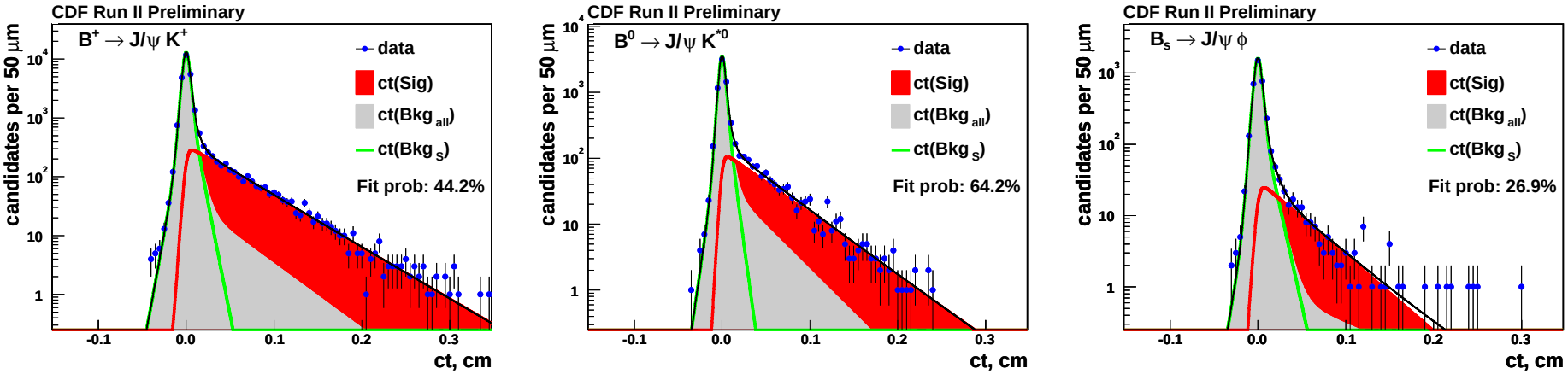
$$m(B^+) = 5279.10 \pm 0.41(stat) \pm 0.36(sys) MeV/c^2$$

$$m(B^0) = 5279.63 \pm 0.53(stat) \pm 0.33(sys) MeV/c^2$$

$$m(B_s^0) = 5366.01 \pm 0.73(stat) \pm 0.33(sys) MeV/c^2$$

$$m(\Lambda_b) = 5619.7 \pm 1.2(stat) \pm 1.2(sys) MeV/c^2$$

B Meson Lifetimes



$$\tau_B^+ = 1.662 \pm 0.033(stat) \pm 0.008(sys)ps$$

$$\tau_B^0 = 1.539 \pm 0.051(stat) \pm 0.008(sys)ps$$

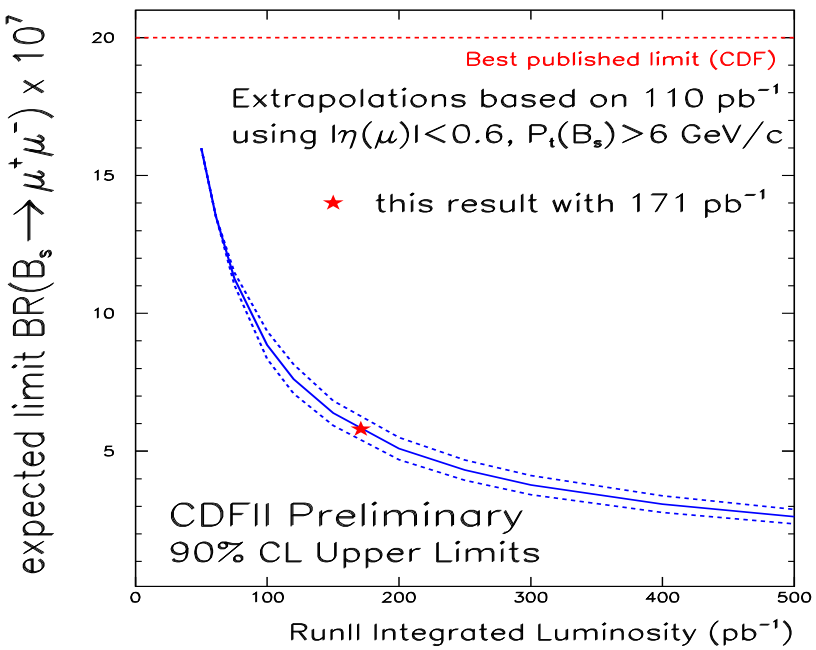
$$\tau_{B_s} = 1.369 \pm 0.100(stat)^{+0.008}_{-0.010}(sys)ps$$

Search for Rare decays $B_{d,s} \to \mu^+\mu^-$

Standard Model expectation for BR($B_s \to \mu\mu$) is $\sim 3.8 \times 10^{-9}$

Extensions to the standard model predict an enhancement of the BR by 1 to 3 orders of magnitude $\to$ *Deviation of the muon (g-2), Higgs Boson, Neutrino oscillations, Dark matter/energy*

Run I limits: BR($B_s \to \mu\mu$) $< 2.6 \times 10^{-6}$ at the 95% CL



Search region centered on world average $B^0_{s,d}$ mass

One event passes selection, consistent with background

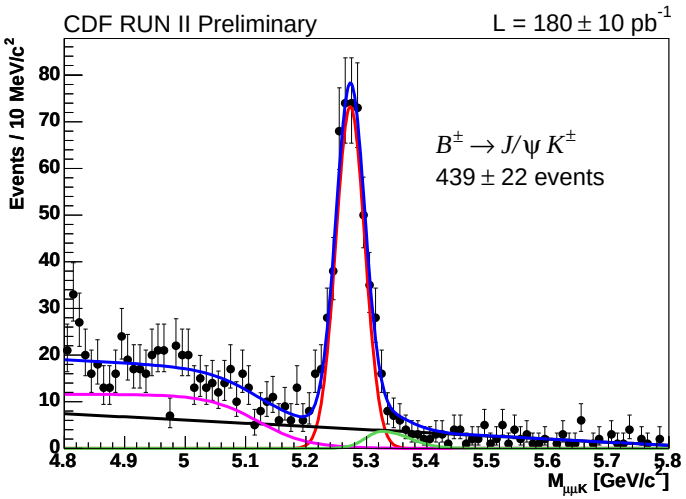
$$\mathrm{BR}(B^0_s \to \mu^+\mu^-) < 5.8 \times 10^{-7}$$

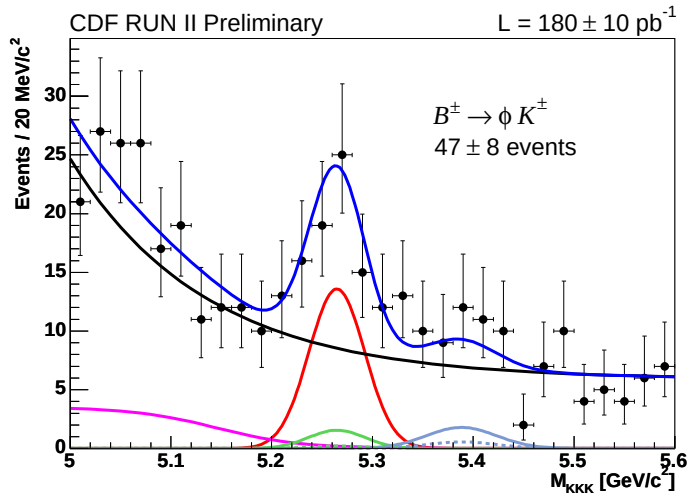
$$\mathrm{BR}(B^0_d \to \mu^+\mu^-) < 1.5 \times 10^{-7}$$

Relative Branching Ratio and Charge Asymmetry

Makes use of the two track trigger

Most systematic errors cancel in the ratio

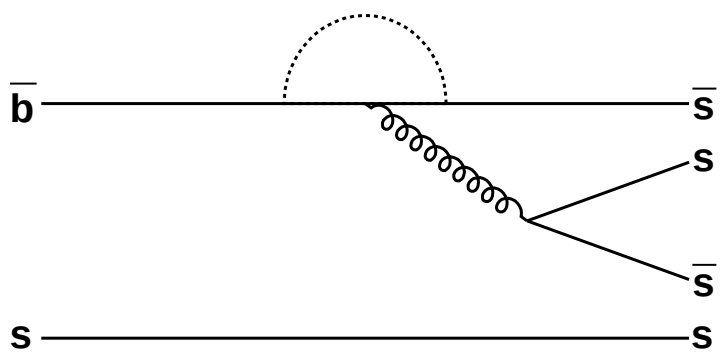




$$\frac{\mathrm{BR}(B^{\pm} \to \phi K^{\pm})}{\mathrm{BR}(B^{\pm} \to J/\psi K^{\pm})} = 0.0072 \pm 0.0013(stat) \pm 0.0007(sys)$$

$$A_{CP}(B^{\pm} \to \phi K^{\pm}) = -0.07 \pm 0.17(stat)^{+0.06}_{-0.05}(sys)$$

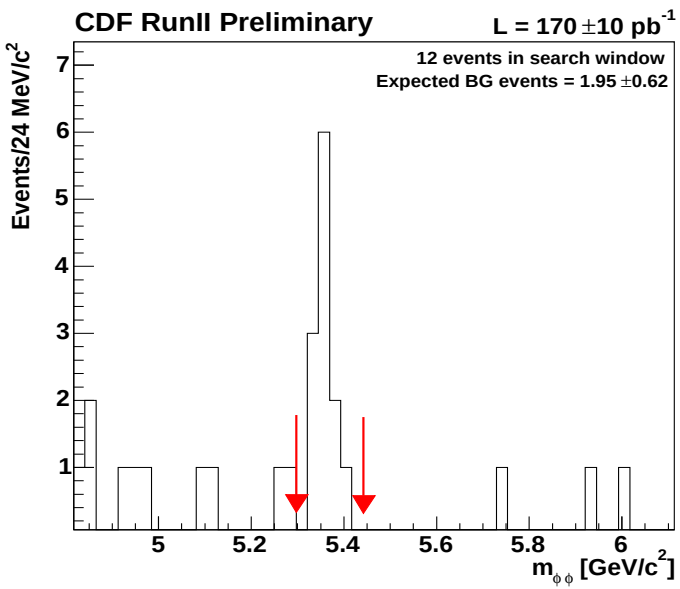
First Observation of $B_s \to \phi\phi$



Makes use of the two track trigger

The main contribution is through the gluonic penguin diagram

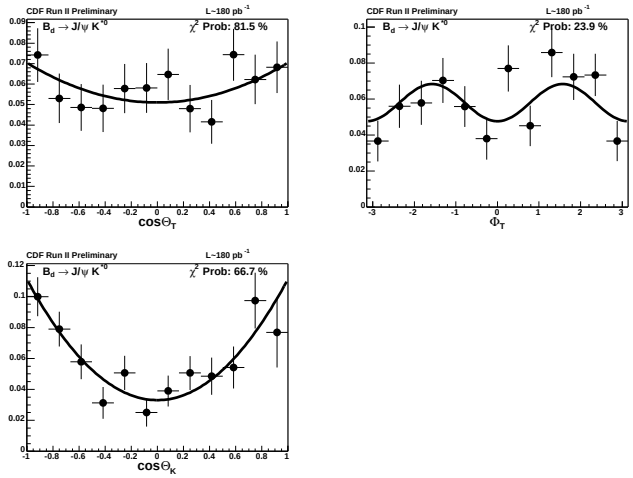
Decay through $b \to s\bar{s}s$



Signal has a significance of 4.7 σ

$$\mathrm{BR}(B_s \to \phi\phi) = (1.4 \pm 0.6(stat) \pm 0.2(sys) \pm 0.5(\mathrm{BR})) \times 10^{-5}$$

$B \to VV$ Polarization Amplitudes

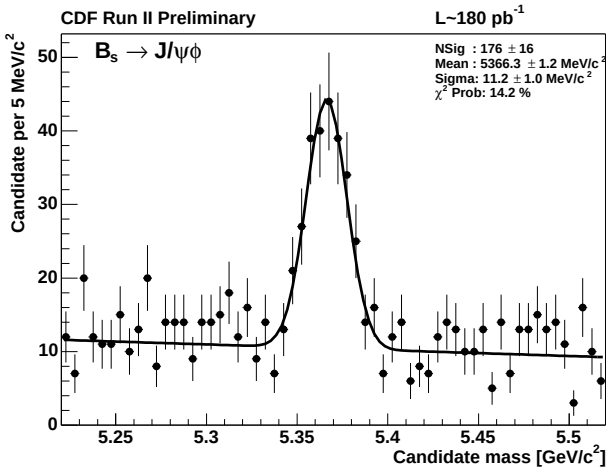


$B_d \to J/\psi K^*$

$A_0 = 0.792 \pm 0.024 \pm 0.016$

$A_\parallel = (0.436 \pm 0.057 \pm 0.016)e^{(3.07 \pm 0.40 \pm 0.07)i}$

$A_\perp = (0.428 \pm 0.059 \pm 0.063)e^{(0.11 \pm 0.23 \pm 0.06)i}$



$B_s \to J/\psi\phi$ (Worlds Best Results)

$A_0 = 0.767 \pm 0.045 \pm 0.017$

$A_\parallel = (0.424 \pm 0.118 \pm 0.013)e^{(2.11 \pm 0.55 \pm 0.29)i}$

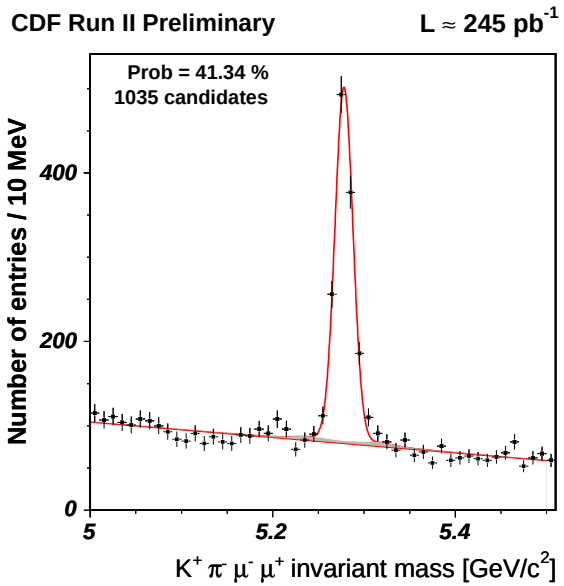
$|A_\perp| = 0.428 \pm 0.104 \pm 0.014$

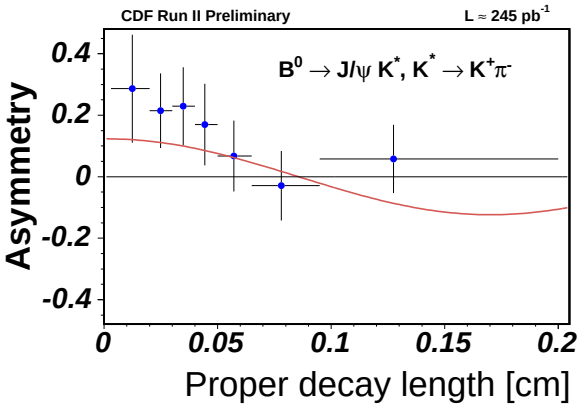
Measurement of B^0 Oscillations Using Same-Side Tagging

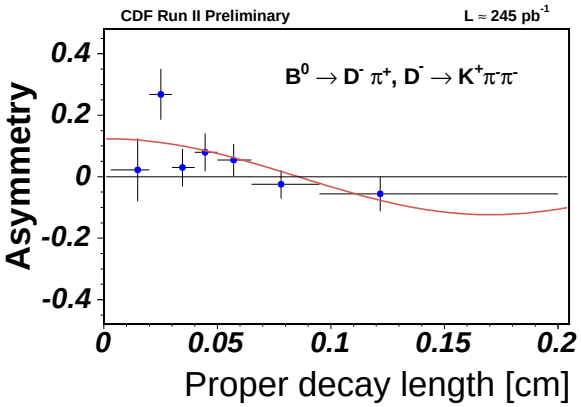
First steps in measuring B_s mixing

$$B^0 \to J/\psi K^{*0} \quad (J/\psi \to \mu^+\mu^-, K^{*0} \to K^+\pi^-)$$
$$B^0 \to D^-\pi^+ \quad (D^- \to K^+\pi^-\pi^-)$$

$$\Delta m_d = 0.55 \pm 0.10 \pm 0.01 \mathrm{ps}^{-1}$$

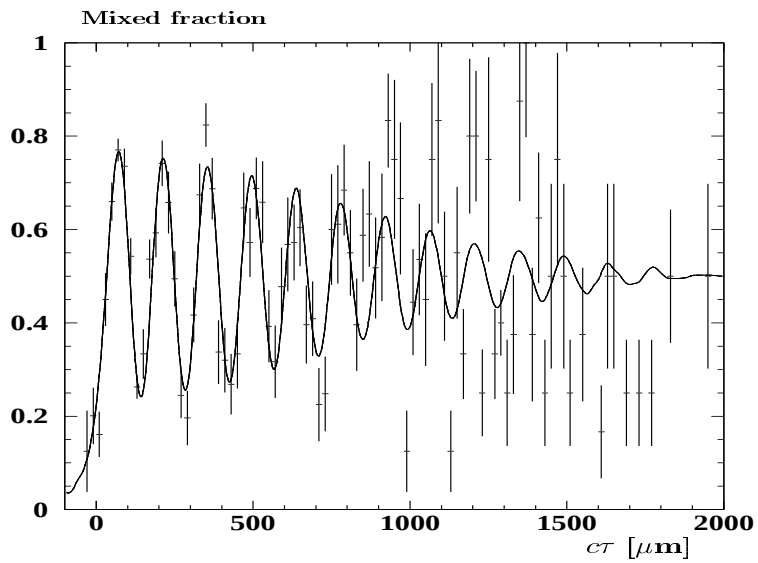






One of the main goals of the B physics program is to test the Standard (Cabibbo-Kobayashi-Maskawa) Model of weak quark mixing and CP violation.

Measurements of B hadron decay rates, observation of $B^0 - \bar{B}^0$ mixing and CP asymmetry in the B and K sectors provide the most precise measurement of the CKM matrix elements.



Simulation of B_s mixing signal

Require excellent mass resolution, vertex determination and specialized triggers.

$D\emptyset$ and CDF at the Tevatron are currently the only places where B_s mesons and Λ_b baryons can be studied.

Publications in Progress

- Search for $B_{d,s} \to \mu^+\mu^-$ decays in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$TeV. Submitted to Phys. Rev. Lett.

- $D^0 \to \pi^-\pi^+/K^-K^+$ Relative Branching Ration and Charge Asymmetry. First Draft released, under GP review.

- Measurement of the J/ψ meson and b quark production cross sections in $p\bar{p}$ collision at $\sqrt{s} = 1.96$TeV. Under GP review.

- $\Lambda_b \to \Lambda_c\pi$ Relative Branching Ratio. Under GP review.

- B Hadron Masses. Under GP review.

- $B_s \to D_s\pi$ Relative Branching Ratio. Under GP review.

- Search for Exotic $S = 2$ Pentaquark decaying to $\Xi\pi$ Under GP review.

In addition to the many mature analyses there are many more analyses in progress

Preliminary results already shown at recent conferences

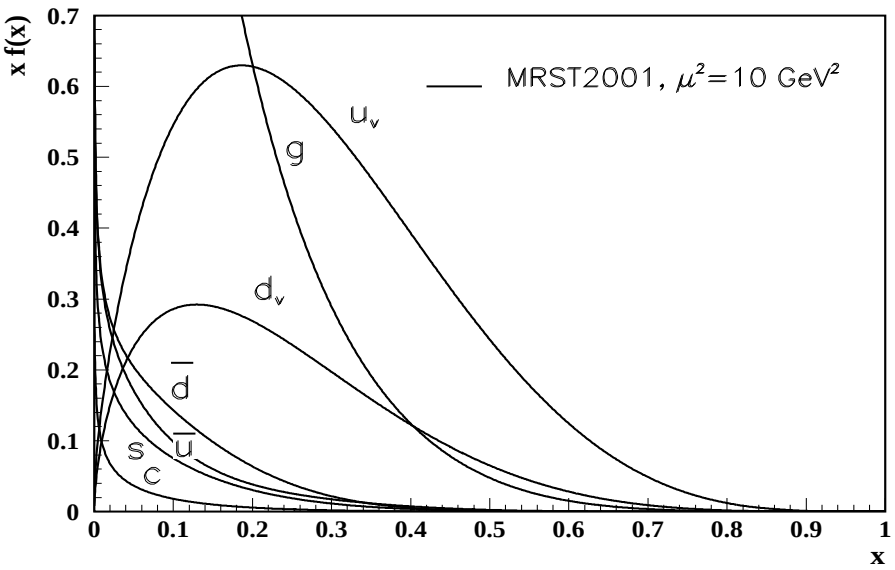
Providing the training ground for Scientists and Professors...

Work In Progress

- Polarization Amplitudes in $B \to VV$
- Branching Ratio and A_{CP} in $B^+ \to \phi K$
- B^0 Mixing with Same Side Tracks in Fully Reconstructed Decays
- Pentaquark Search in $\theta^+ \to pKs$
- Pentaquark Search in $\theta_c \to pD^*$
- $B_s \to VV$ lifetimes
- Moment Analysis
- B Hadron Masses
- $B^+ \to J/\psi\pi$ Branching Ratio
- Observation and Branching Ratio of $B_s \to \phi\phi$
- $B_c \to J/\psi\mu X$
- Soft electron reconstruction for $B_c \to J/\psi eX$
- Branching Ratio and Charge Asymmetry in $D^+ \to \pi^+\pi^-\pi^+$

The Tevatron is the world's highest energy $p\bar{p}$ collider, allowing the study of the fundamental building blocks of matter at distance scales of $\sim 10^{-17}$ cm.

The building blocks of everything from people to planets to consciousness



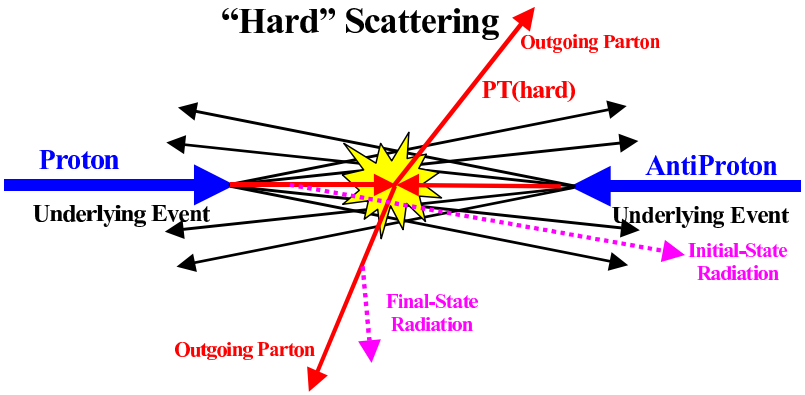
The quark-parton model is used to describe lepton-lepton, lepton-hadron, hadron-hadron collider phenomenology.

Parton Density Functions are fundamental inputs to calculations describing

Studying high energy interactions is way to search for new physics....

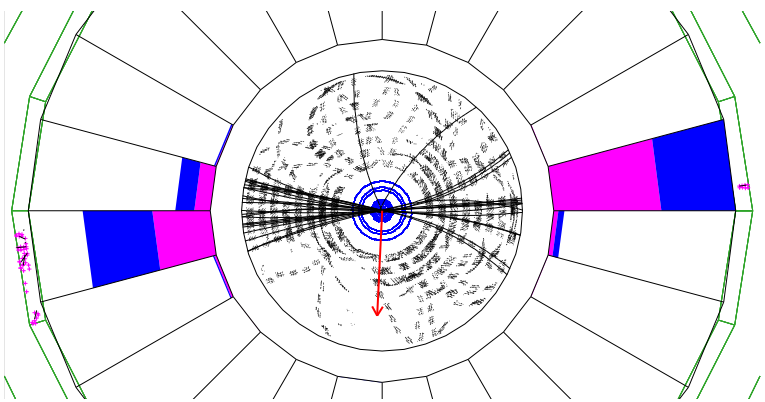
Also refines our understanding of the PDFs allowing more precise calculations that will be needed not only at the Tevatron by also at future experiments.

Reconstructing Jets

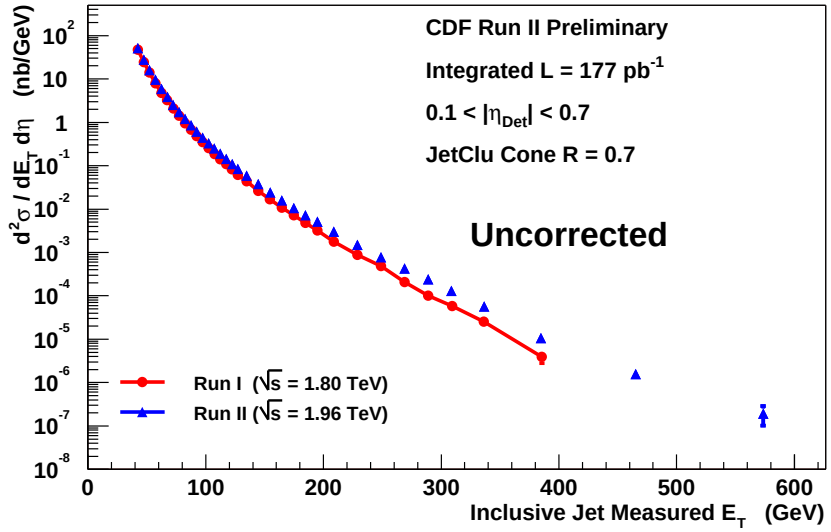


Different "cone based" Jet Reconstruction algorithms are available.

Exploring jet algorithms (MidPoint, KtClustering) that are easier to compare with to theory.

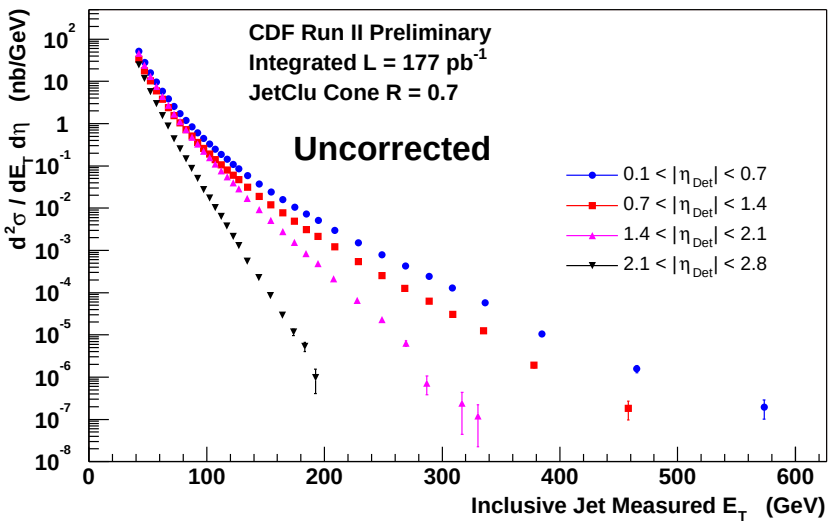


In order to simplify comparisons between CDF and DØ have agreed to present results using the "midpoint" algorithm



Increased center-of-mass energy allows us to extend the Run I reach by about 200 GeV

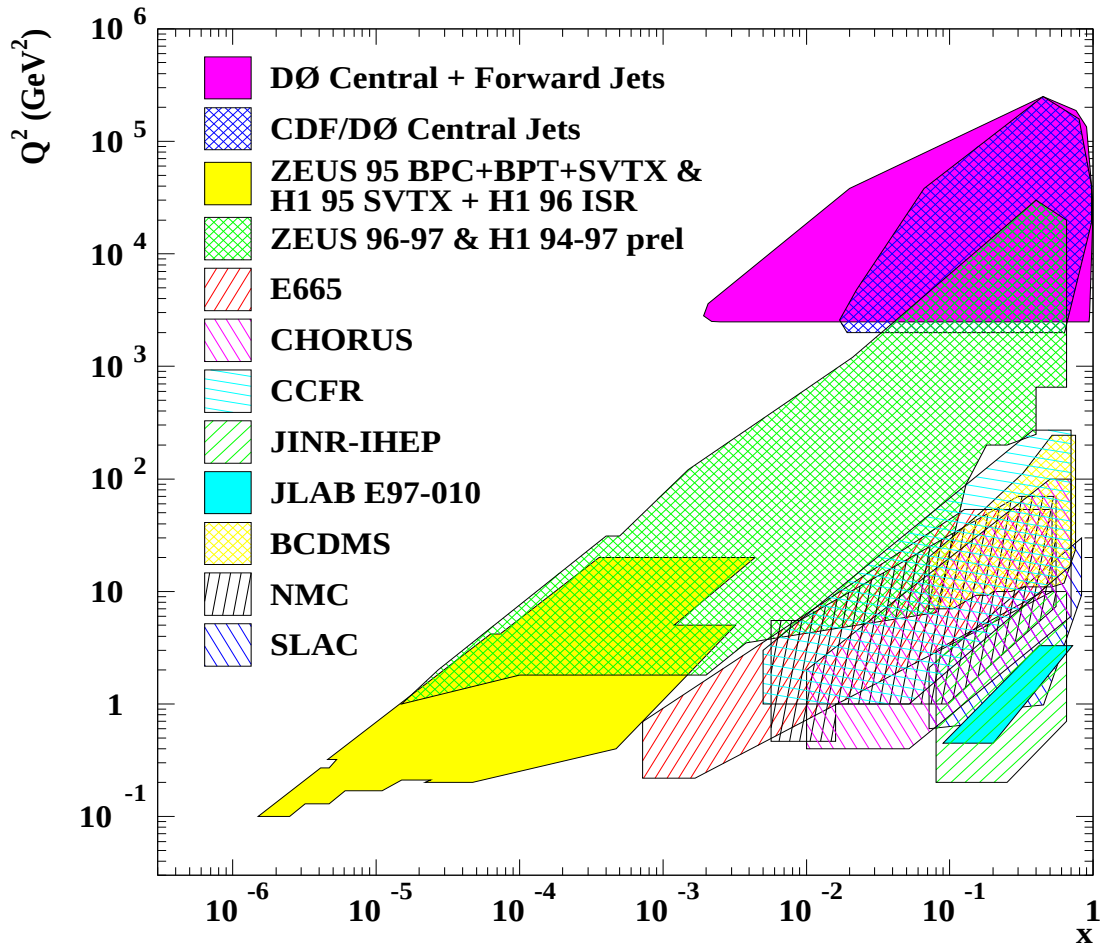
Probing smaller distances with higher precision



Detector upgrades allow us to measure in the forward η region

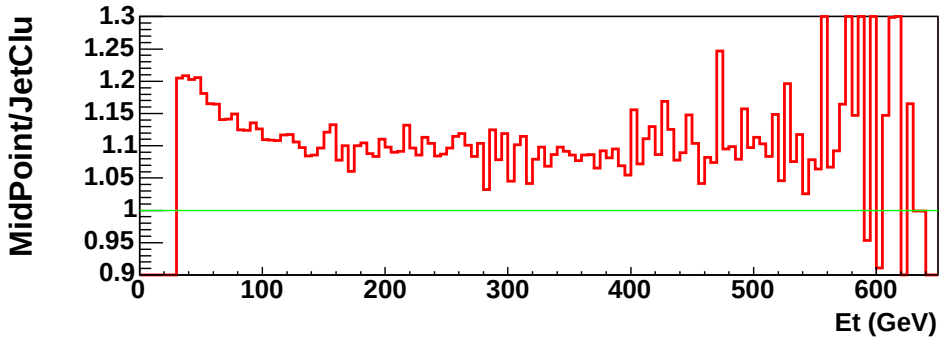
Maximizing the physics potential by exploring the available kinematic region

The Tevatron operates in a kinematic region which compliments existing and previous experiments

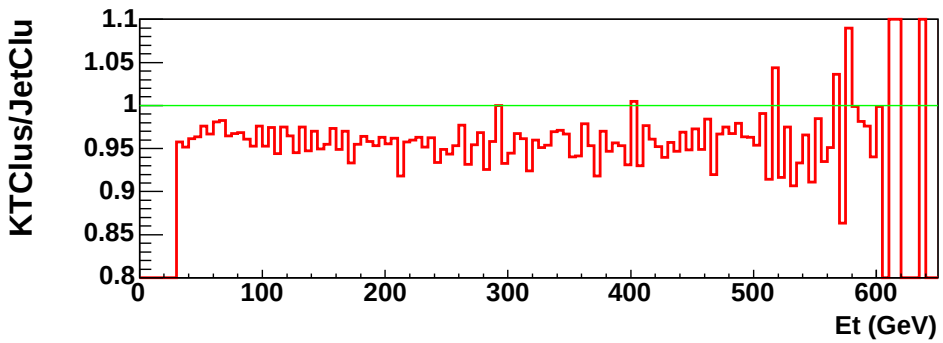


Unique and complimentary physics capabilities
Adding to the world knowledge base

Ratio of the "measured" inclusive jet cross section for KtClus and MidPoint over JetClu.



MidPoint finds more jets at lower E_T.

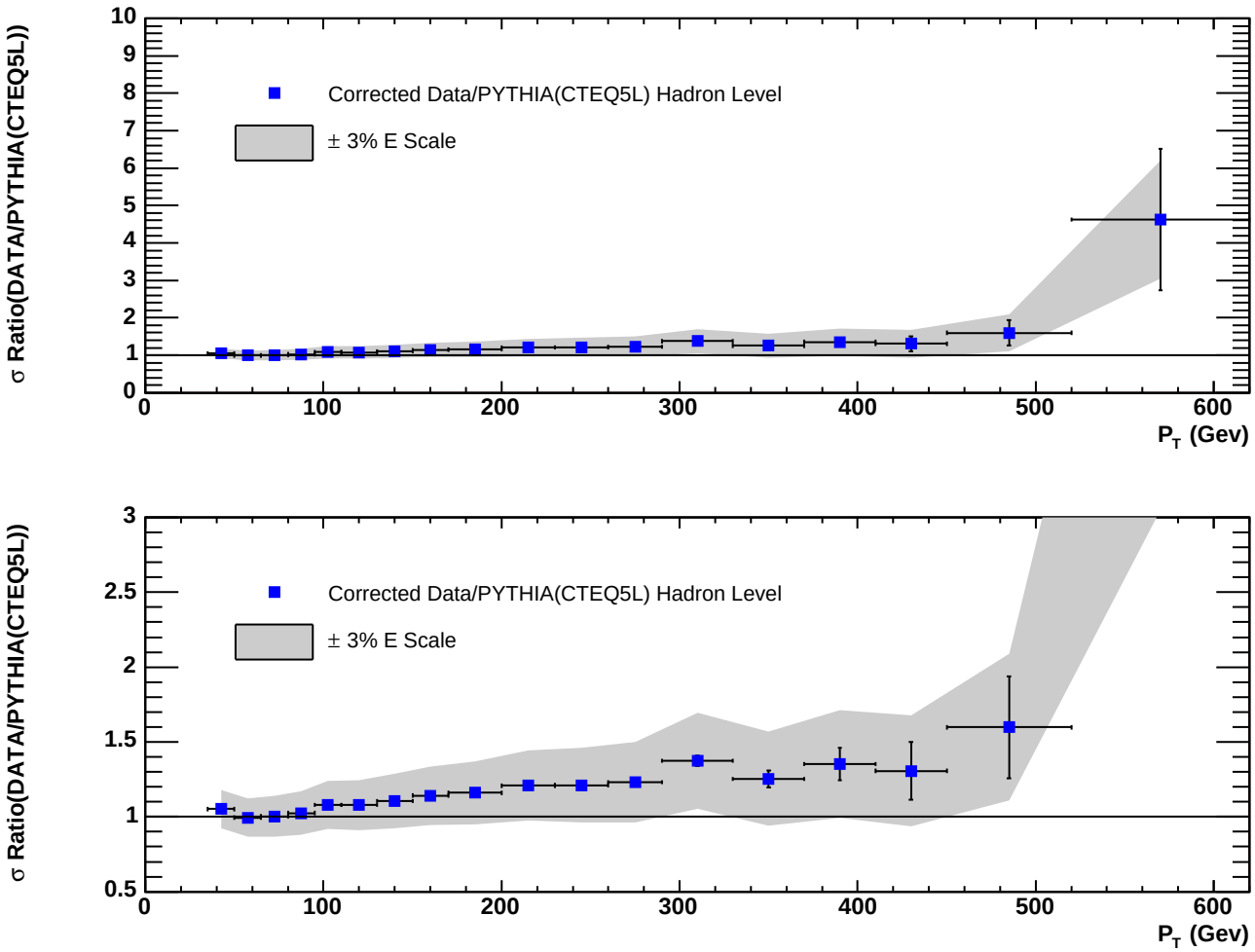


JetClu, KtClus and MidPoint have the same shape at high E_T

Using the MC to correct the data allows us more flexibility in exploring different jet algorithms and PDFs.

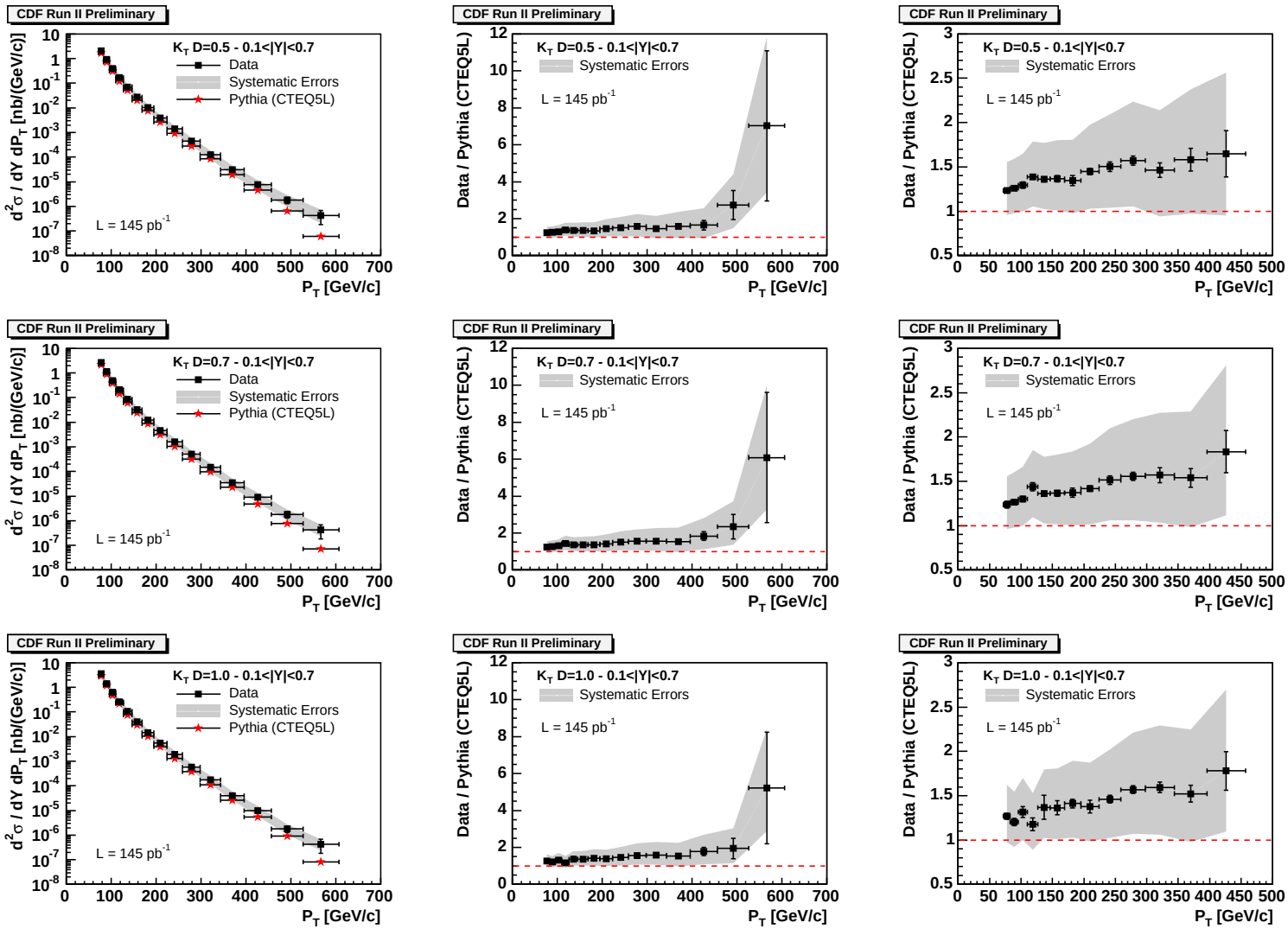
→ Don't need to derive specific corrections for different jet algorithms, cone sizes...

Inclusive Jet Cross Section (MidPoint)



Data compared to PYTHIA using the MidPoint jet algorithm

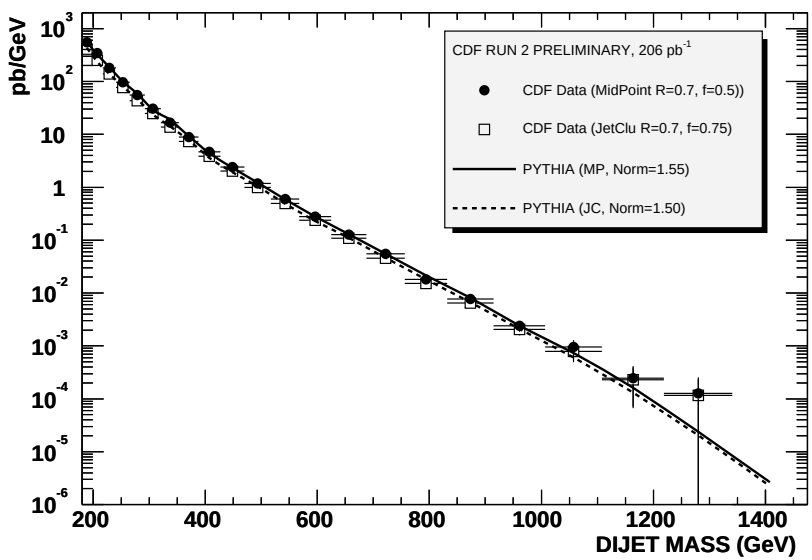
Inclusive Jet Cross Section using Kt Clustering



Search for Dijet Resonances

Many classes of new particles are predicted to have a larger branching fraction into just two partons than modes that contain a lepton or electroweak gauge boson.

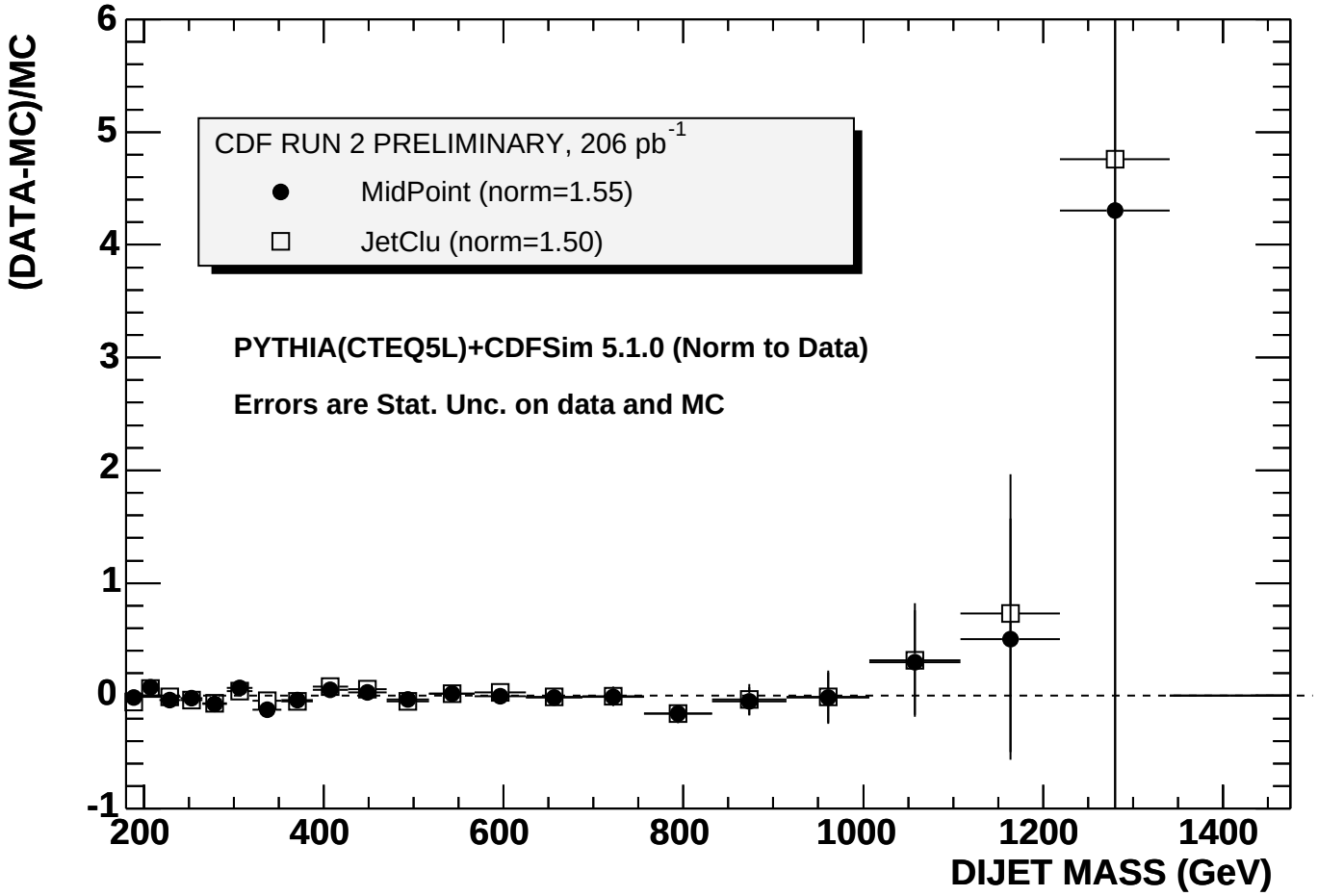
New particles would show up as fluctuations in the Dijet mass distribution



Fully Corrected Dijet Mass Distribution Compared with PYTHIA

JetClu and MidPoint results are in good agreement

Dijet Mass Distribution agrees with QCD

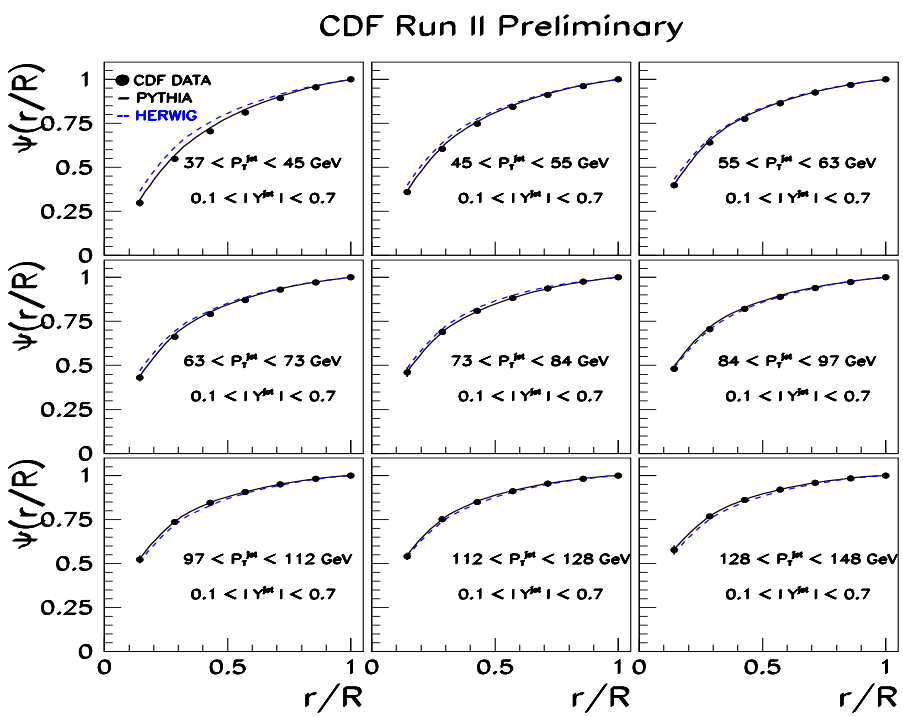


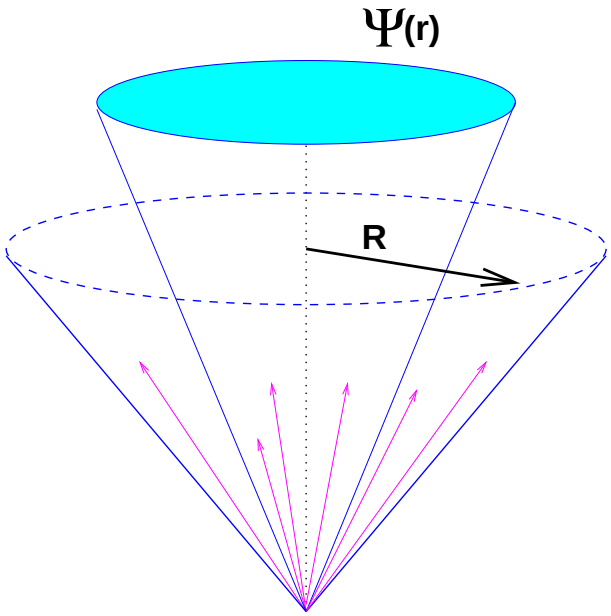
Study of Jet Shapes In Inclusive Jet Production

Jet shape governed by multigluon emission from struck parton

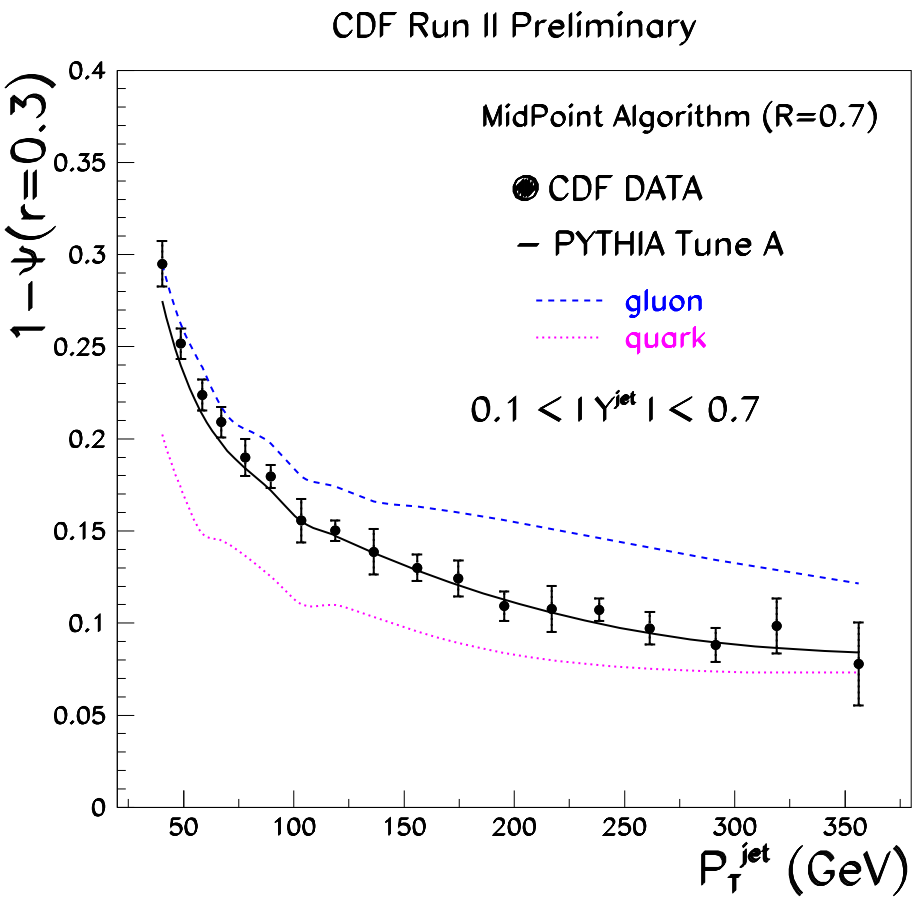
→ Provides tests of multiparton shower models.

→ Sensitive to the quark/gluon final state mixture and underlying event



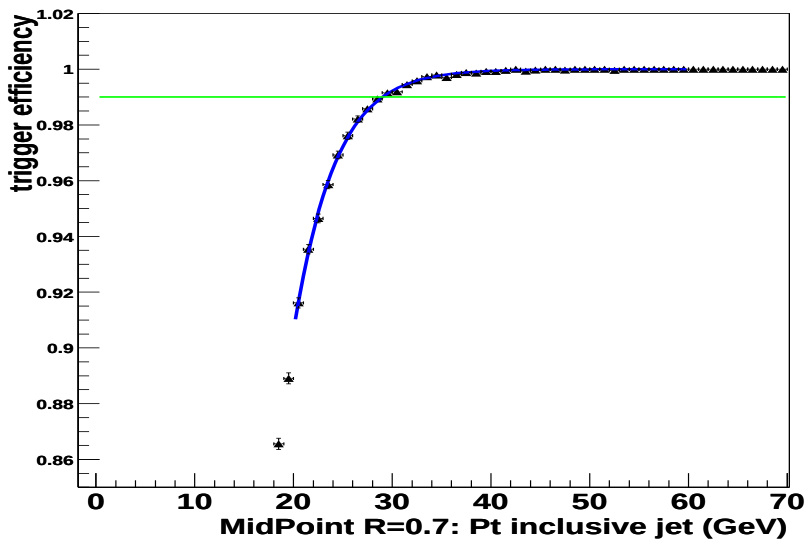


Results extending to 380 GeV.



Evolution with P_T contains information about the running of α_s and quark/gluon fractions.

Extending Measurements to Lower E_T



The Single Tower 5 (ST5) trigger will allow us to extend measurements to lower E_T.

Allows use to have high efficiency down to $E_T = 30$ GeV

But why stop there?

Have the capability to explore the transition to perturbative QCD

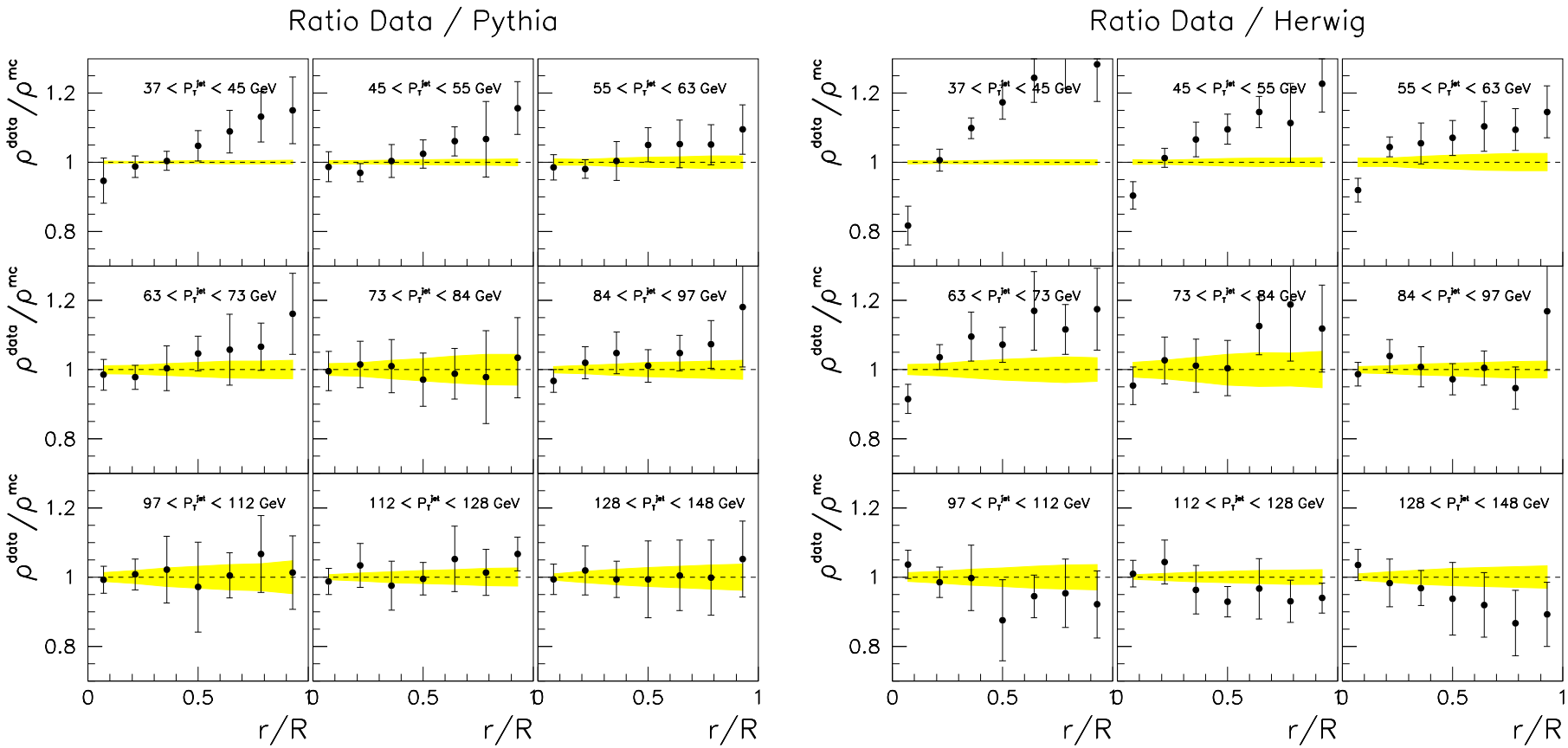
→*Special runs....*

→*New Triggers...*

→*Detailed understanding of the trigger efficiency*

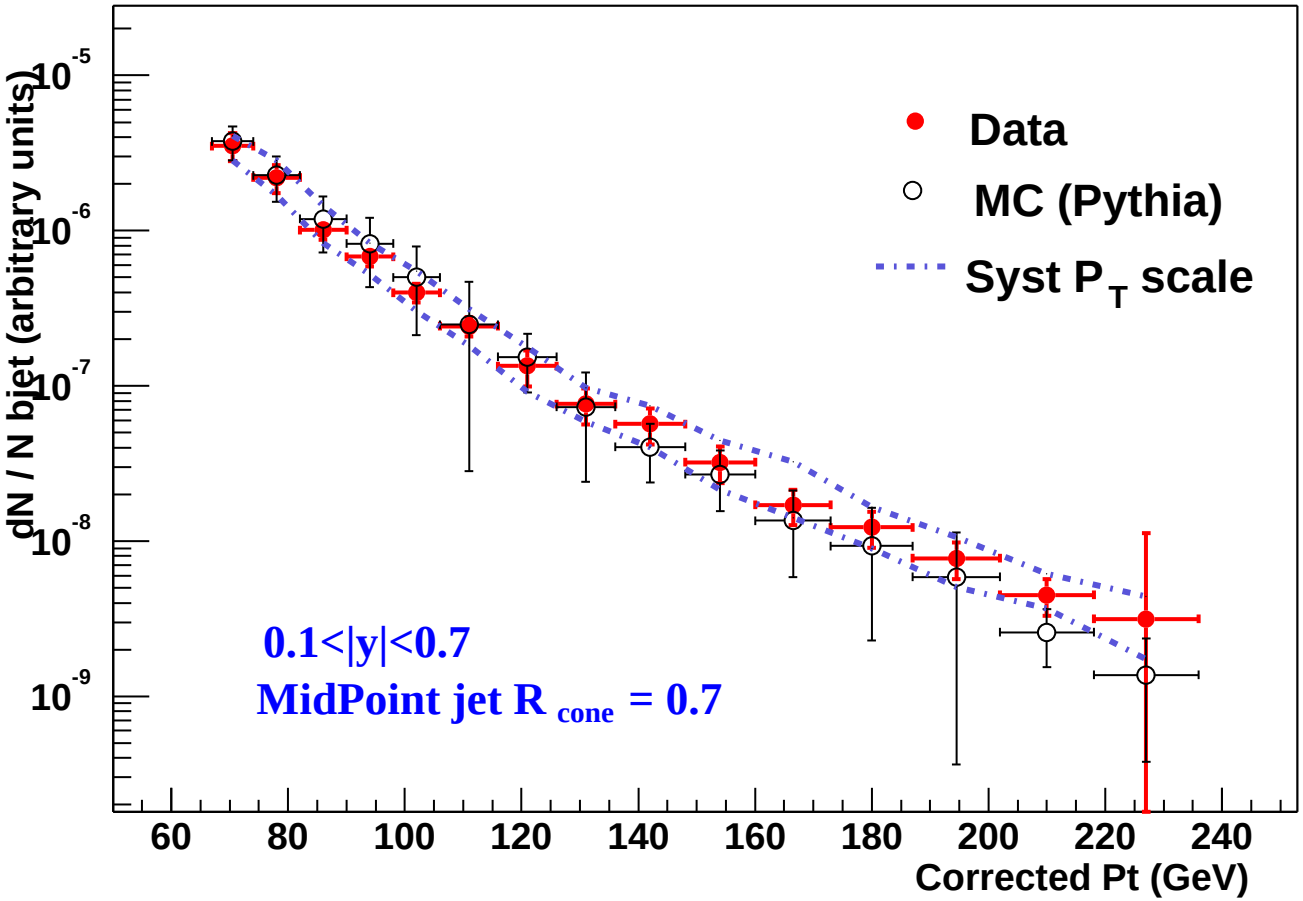
ST5 trigger allows use to reach as low as 30 GeV

$\rightarrow$ Need to understand how good the simulation is at low E_T

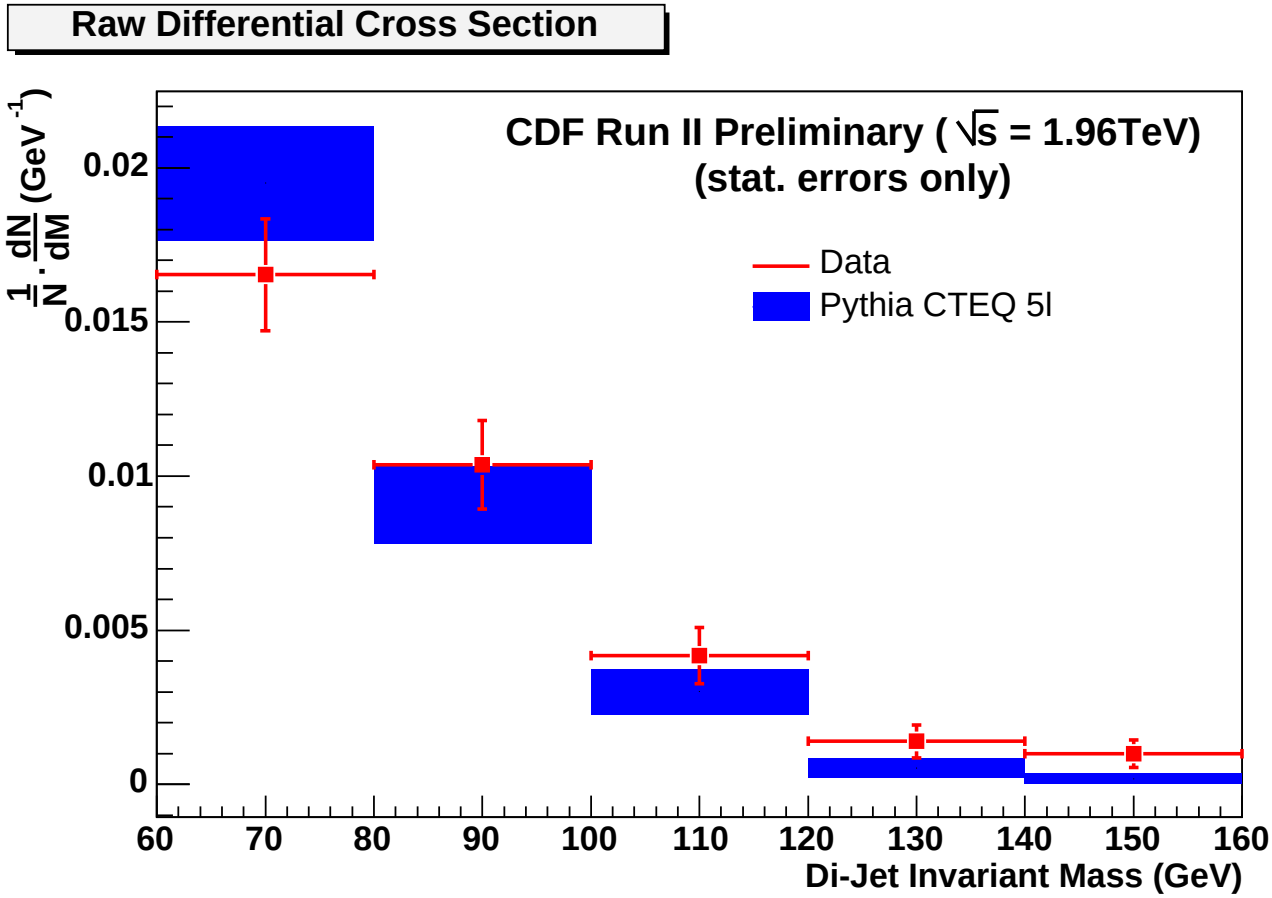


Jets are well described using PYTHIA for $p_T > 70 GeV$

Corrected b-jet dN/N Distribution



$b\bar{b}$ Jet Production Cross Section

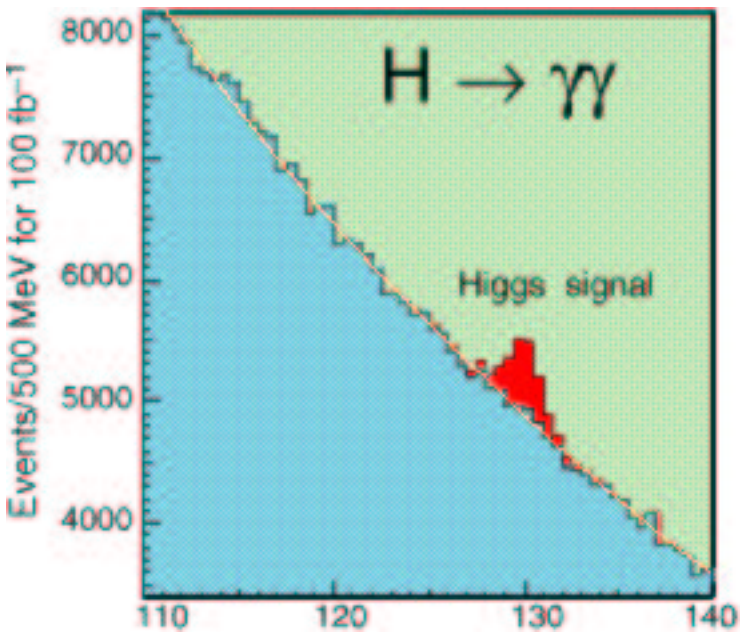


Two positively tagged 2D SecVtx jets within $|\eta| < 1.2$

Lead jet with corrected $E_T > 30$ GeV

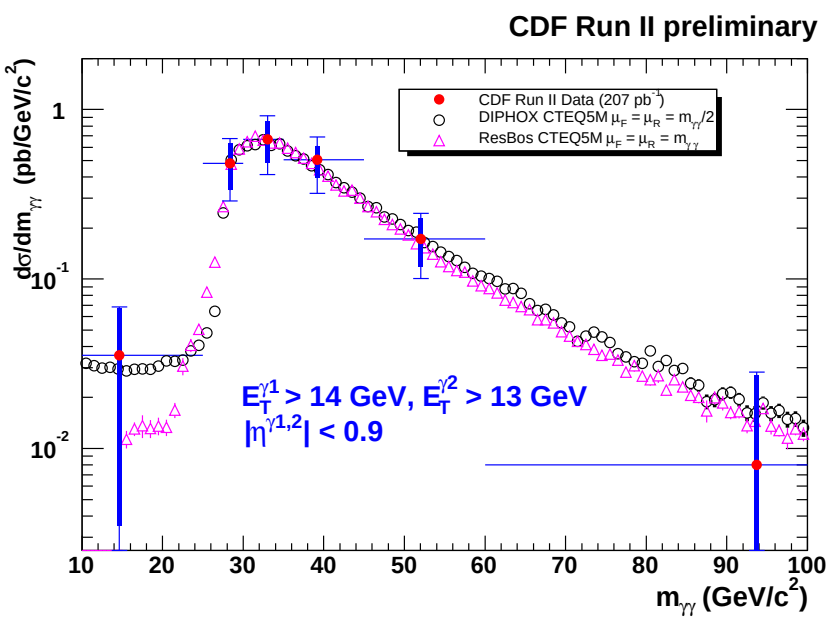
Second jet with raw $E_T > 10$ GeV

DiPhoton Mass Distribution



Higgs to two photons is one of the more promising channels in Higgs production

Also provides tests of QCD
→ Soft gluon resummation
→ Fragmentation



Data compared to the next-to-leading order QCD predictions of DIPHOX and ResBos

Soft gluon emission and NLO fragmentation are important

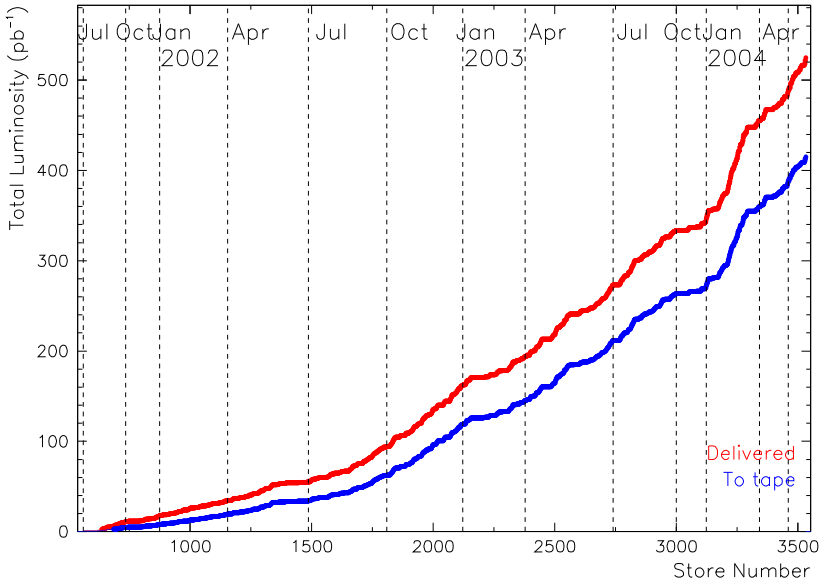
Publications in Progress

- Study of Jet Shapes in Inclusive Jet Production First draft released, under GP review.

- Diphoton Production Cross Section Under GP review.

Work In Progress

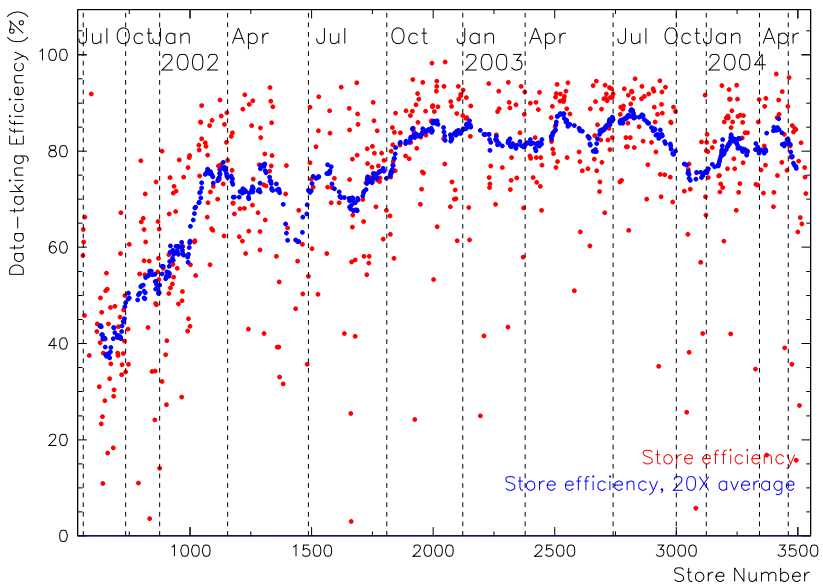
- Inclusive Jet Cross Section using Cone Algorithms
- Inclusive Jet Production using Kt Algorithm
- Inclusive B-Jet Production
- bb-bar pair Production
- Gamma+heavy Quark Production
- W+jets Production Cross Section
- Diffractive Dijet Production
- Search for New Particles Decaying into DiJets
- Exclusive J/Psi Production
- Jet Evolution and Underlying Event Studies
- PYTHIA MC Tuning



Tevatron is performing well

(05/26/04 18:18) Store 3534 set a new record with a luminosity of $73 \times 10^{30} cm^{-2} s^{-1}$

Approaching $3 - 4\times$ the Run I usable dataset size.



CDF is collecting data with good efficiencies 80 - 90%

Very flexible trigger:

```
 56 triggers at L1
117 triggers at L2
172 triggers at L3
```

Conclusions

Run II upgrades build on the experience from Run I

→ *Improved acceptance*

→ *New trigger capabilities*

→ *Better detectors*

→ *More precise measurements*

Making good use of the upgrades to the CDF detector and the new trigger capabilities: Tracking trigger at Level 1 Vertex trigger at Level 2

CDF is collecting data with high efficiencies and the Tevatron has been achieving record luminosities

Many results are mature and on track for publication. More results are well underway...

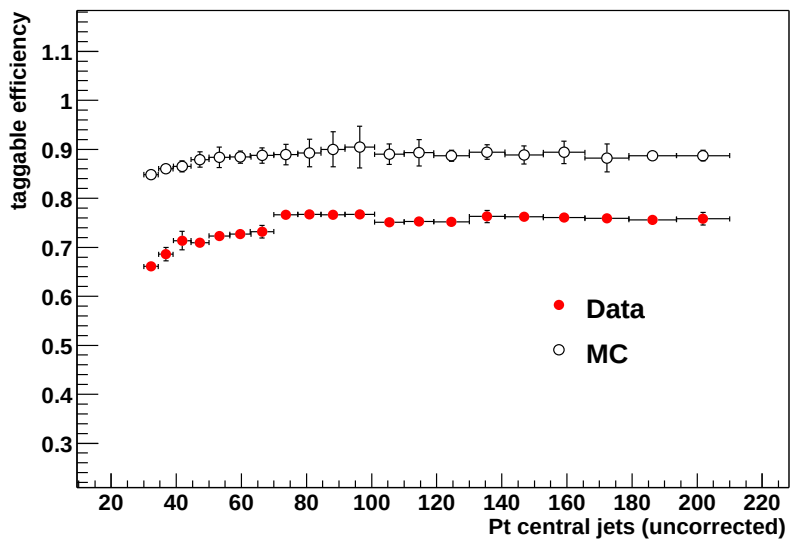
A dynamic and energetic group able to adapt to changing conditions and working around the clock to make CDF a success

Inclusive b-jet Cross Section

$$\sigma_i \text{bjet} = \frac{N_{tagged} \cdot f_b}{\epsilon_{btag} \cdot \epsilon_{taggable} \cdot \Delta\eta \cdot \Delta P_T^i \cdot \mathcal{L}}$$

N_{tagged}	Number of tagged jets using SecVtx
f_b	Fraction of b's among tagged jets
ϵ_{btag}	B tagging efficiency, probability that a b-jet is tagged ($N_{bjettagged}/N_{bjet}$)
$\epsilon_{taggable}$	Taggable efficiency, probability to find a jet with at least two good tracks
$\Delta\eta$	Rapidity range = 1.2
ΔP_T^i	Bin in transverse momentum
$\mathcal{L}$	Integrated luminosity

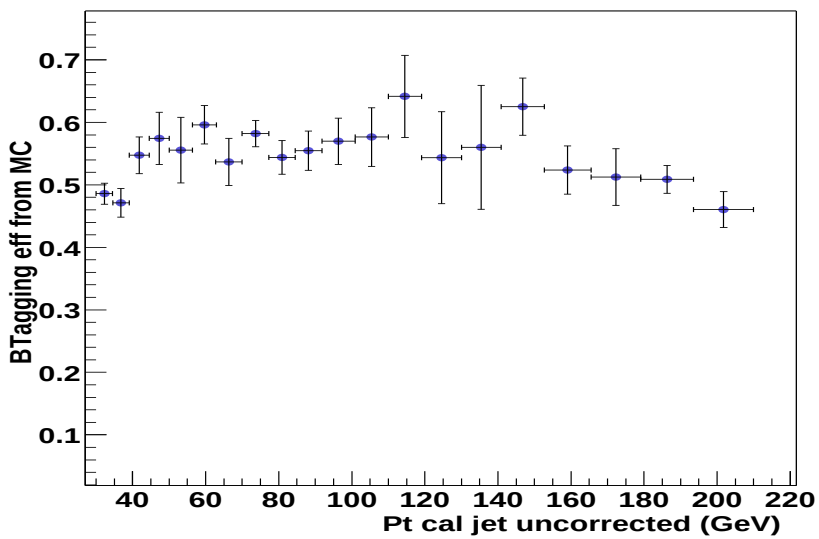
Tagging Efficiency



Taggable efficiency, $\epsilon_{taggable}$, Probability to find a jet with at least two good tracks

Data and MC have different efficiencies.

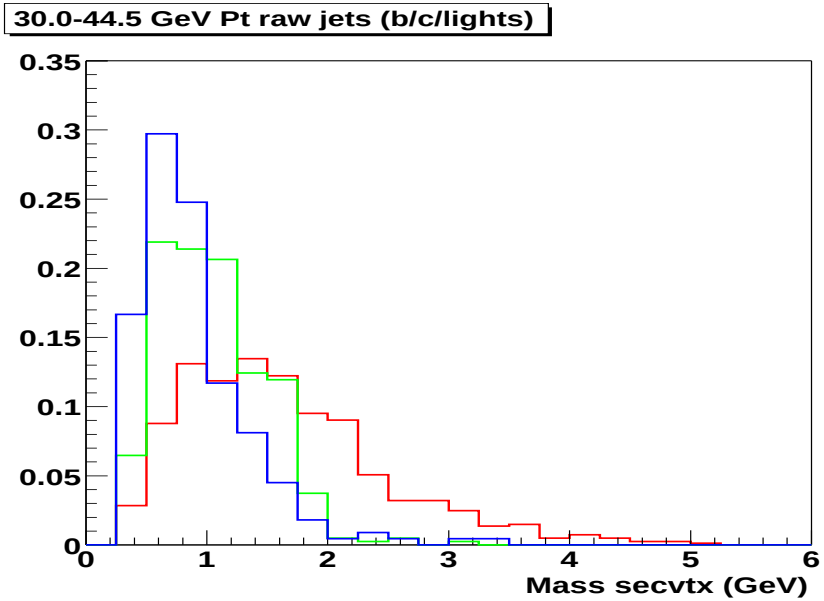
F(Data/MC) = 0.83 ± 0.03



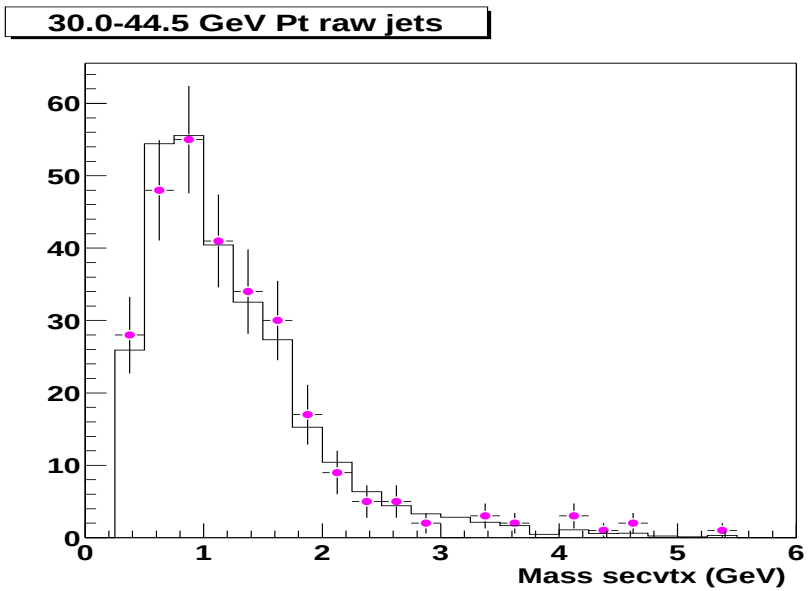
B Tagging efficiency, probability that a b-jet is tagged

$$\epsilon_{btag} = \frac{N_{\text{bjettagged}}}{N_{\text{bjet}}}$$

MC Templates used to determine the B fraction



B fraction determined from the MC using the secondary vertex mass as a discriminant.

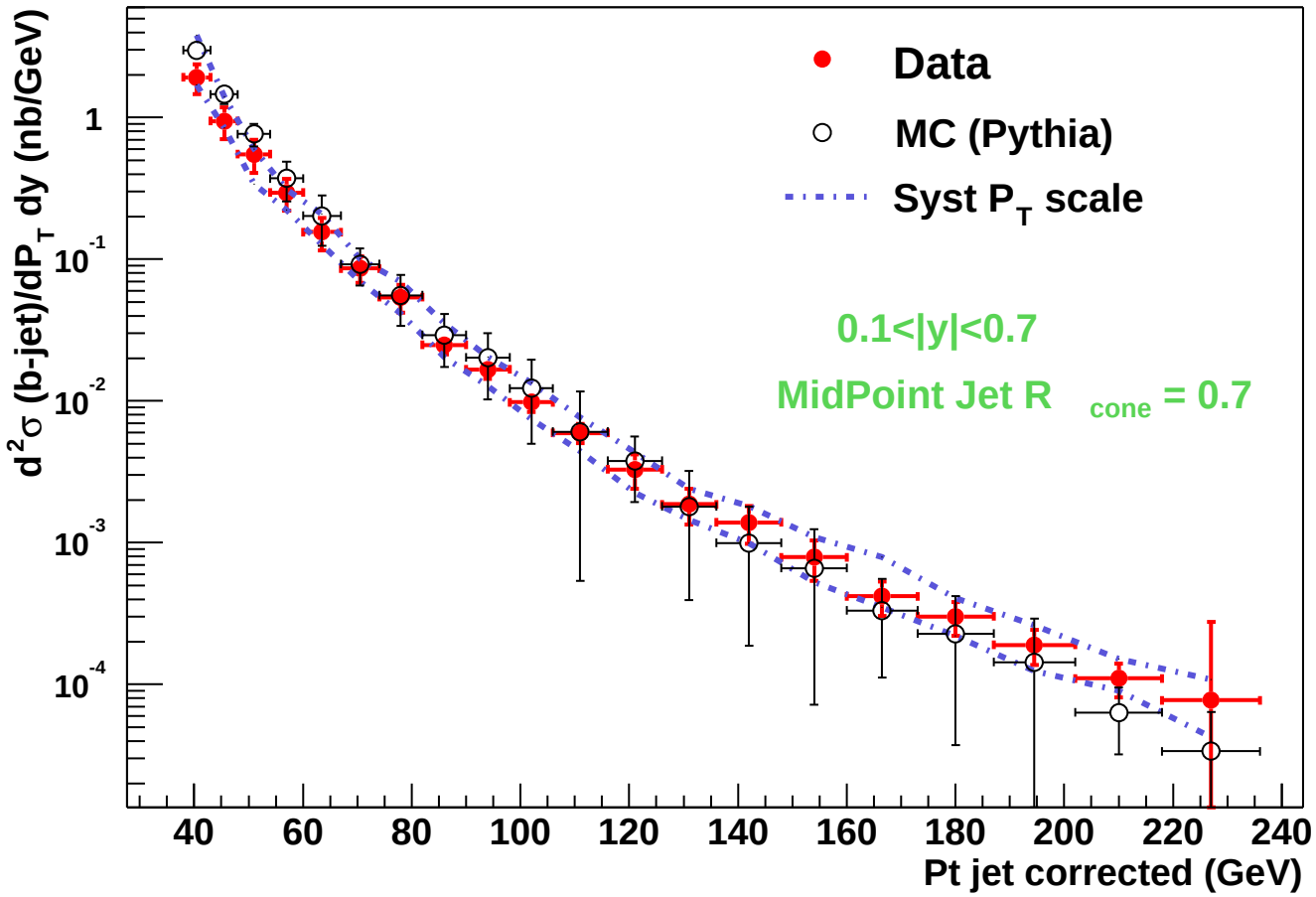


B Fraction Fits Result

Need to combine bins due to limited MC statistics

Effect of different tagging efficiencies in the Data and MC not included

Corrected b-jet Differential Cross-Section



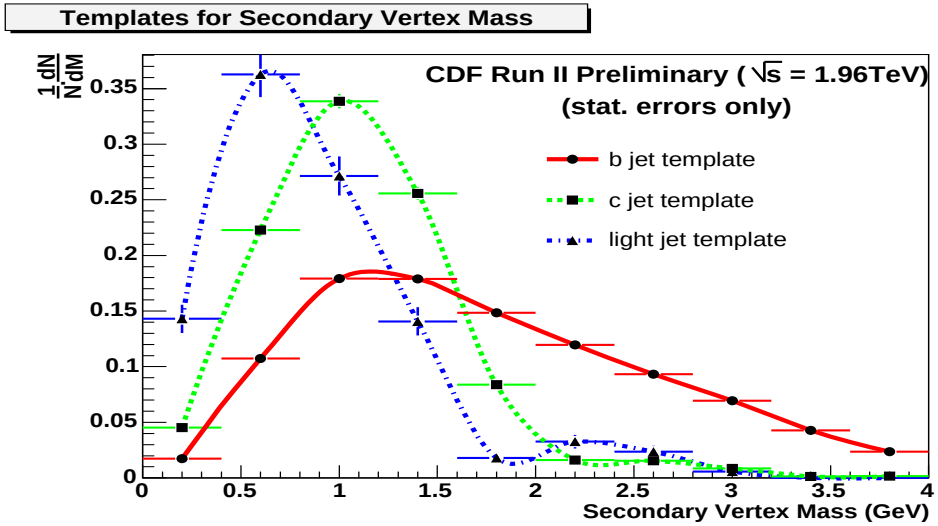
Measured p_T range 30 - 210 GeV

To go from Jet Rate to Cross Section:

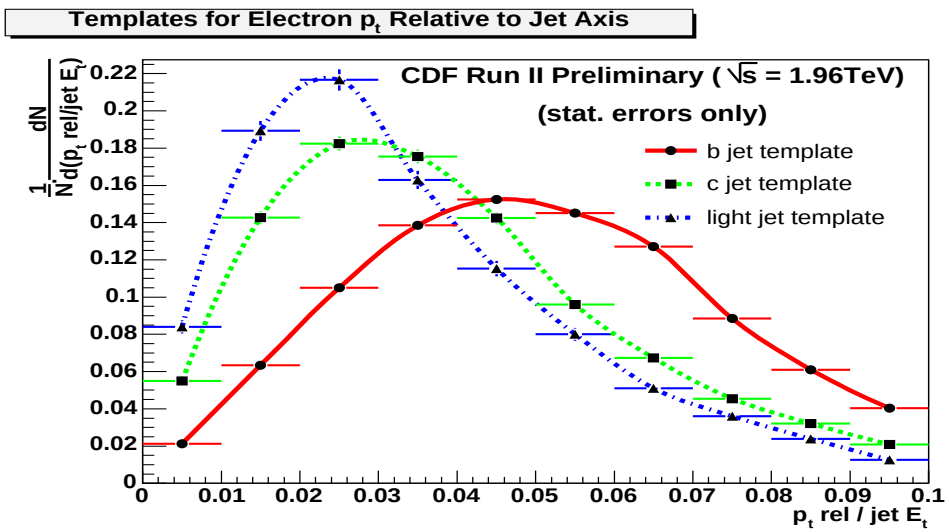
$$\sigma_{b\bar{b}} = \frac{N \cdot p}{\epsilon_b^2 \cdot \epsilon_{jet} \cdot \epsilon_{trig} \cdot \mathcal{L}}$$

N	Number of tagged events using 2D SecVtx
p	Purity
ϵ_b	B tagging efficiency (require two tagged jets)
ϵ_{jet}	Jet reconstruction efficiency determined from the MC
$\mathcal{L}$	Integrated Luminosity

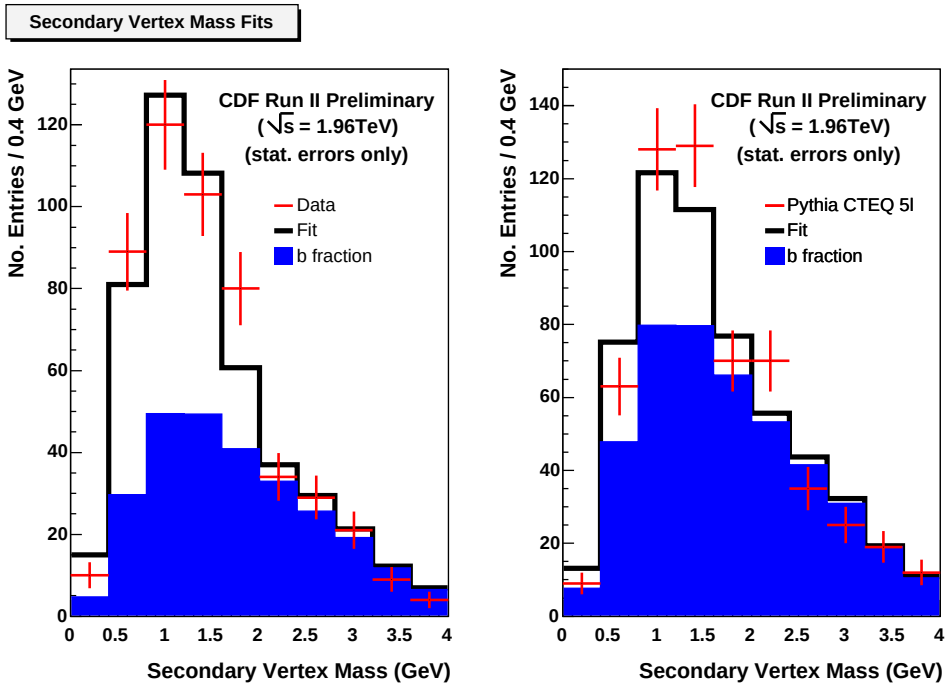
MC templates used to determine purity and B tagging efficiency



Invariant mass of tracks associated with the secondary vertex.



Transverse momentum of electron in a jet relative to the jet axis, p_T^{rel}



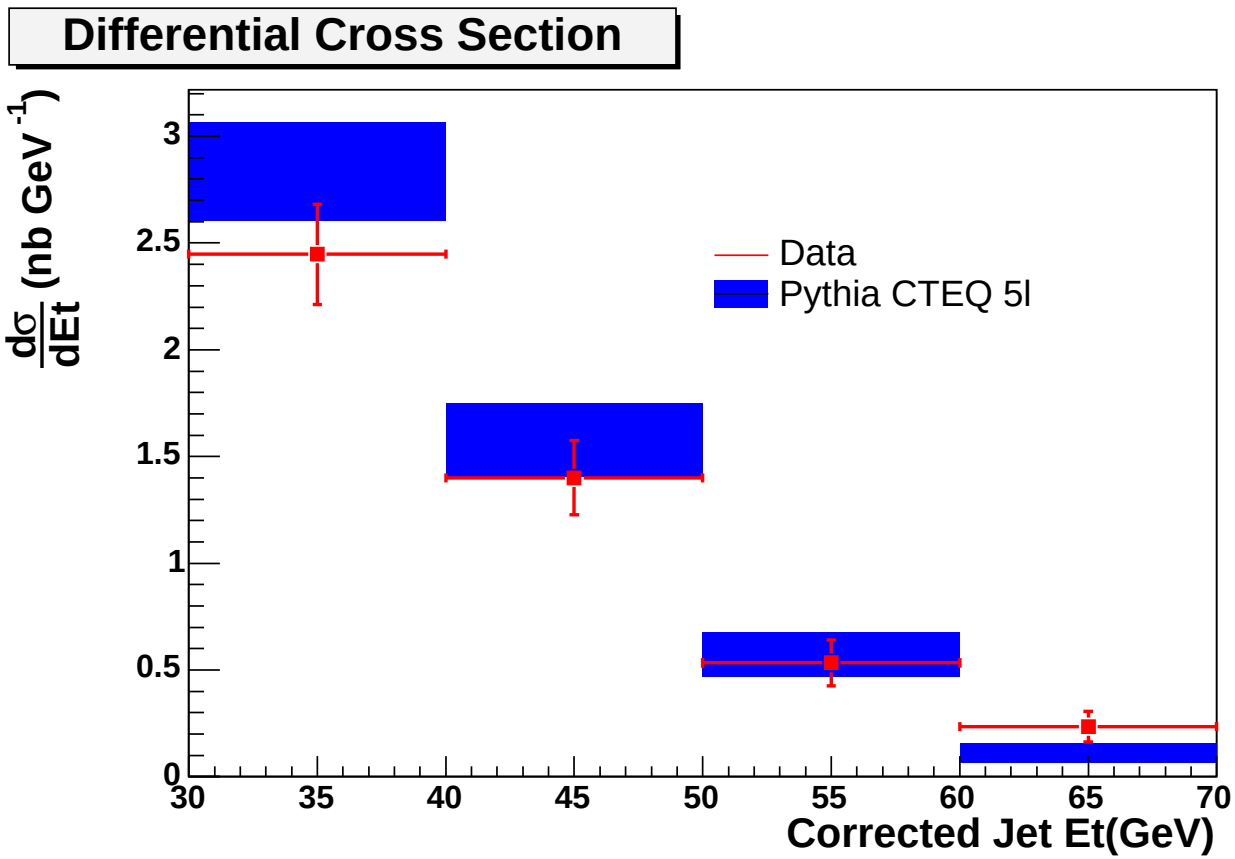
Purity determined from a fit to the mass spectrum from particles associated with the secondary vertex

Purity $= 0.55 \pm 0.06\%$

Vary combinations of b, c and light used in the template spectrum to estimate the systematic uncertainty on the SecVtx b tagging efficiency.

Systematic Uncertainty on $\epsilon_b = 13.5\%$

Total production cross section:

$$\sigma_{b\bar{b}} = 54.1 \pm 5.6 \; ^{+13.8}_{-15.2} \text{ nb}$$

Differential Inclusive $b\bar{b}$ Jet Production Cross Section