Heavy Flavor Production at the Tevatron

Les Rencontres de Physique de la Vallée d'Aoste

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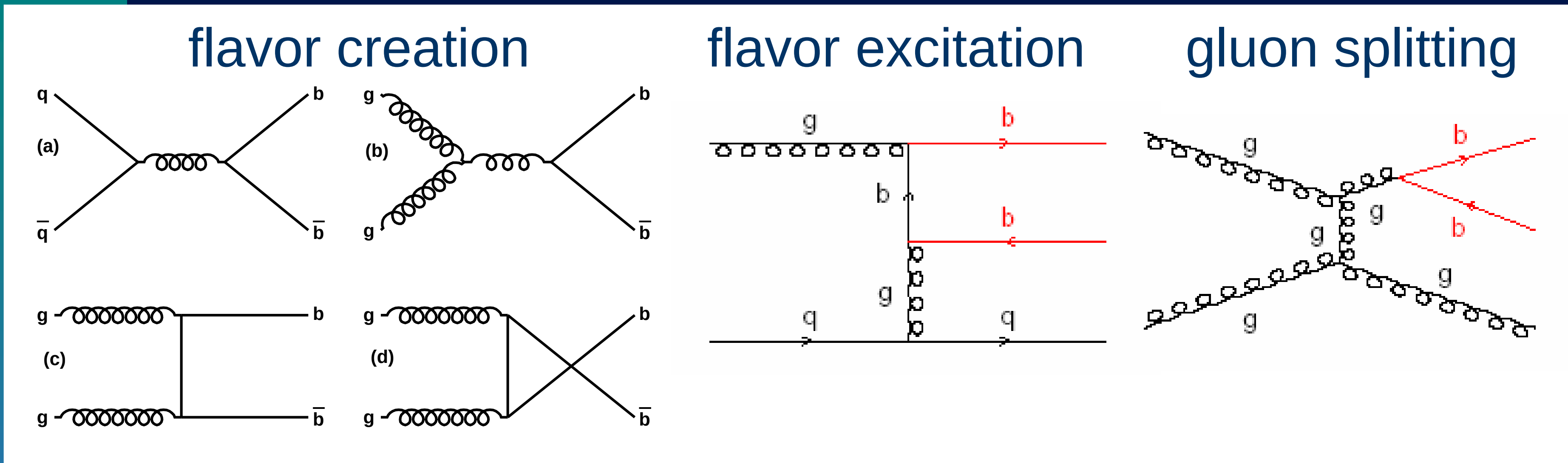
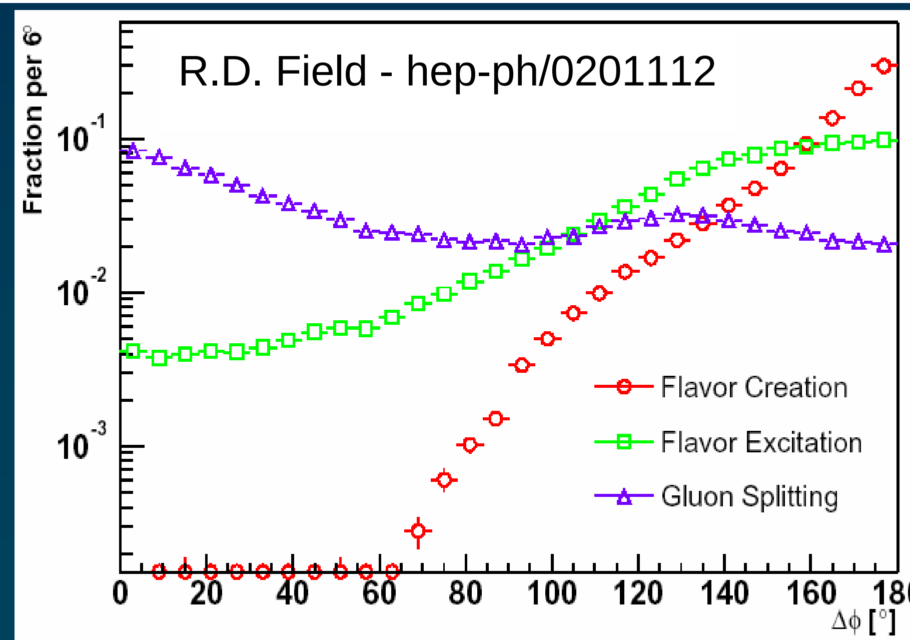
Representing the DØ and CDF collaborations

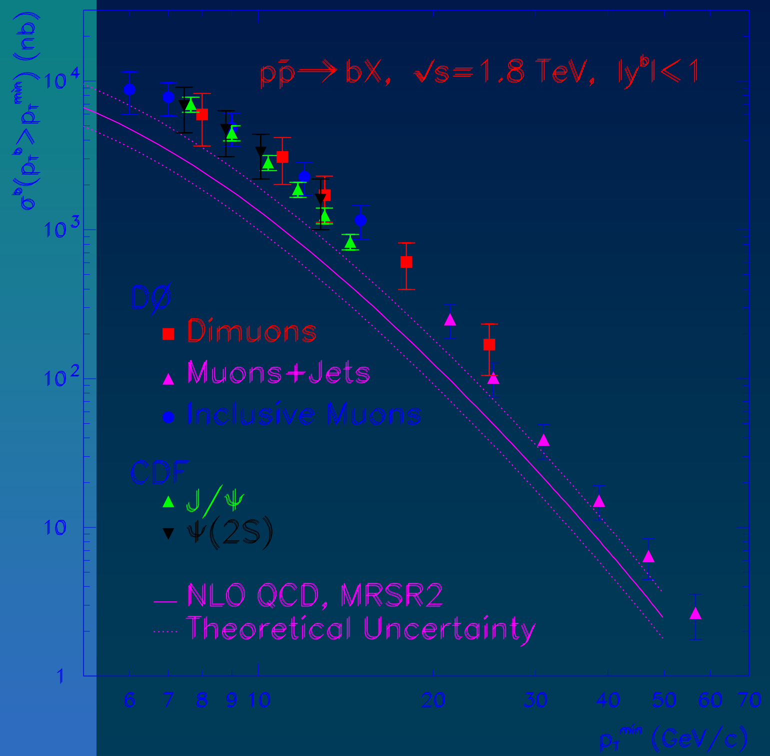
Hadroproduction of heavy quarks

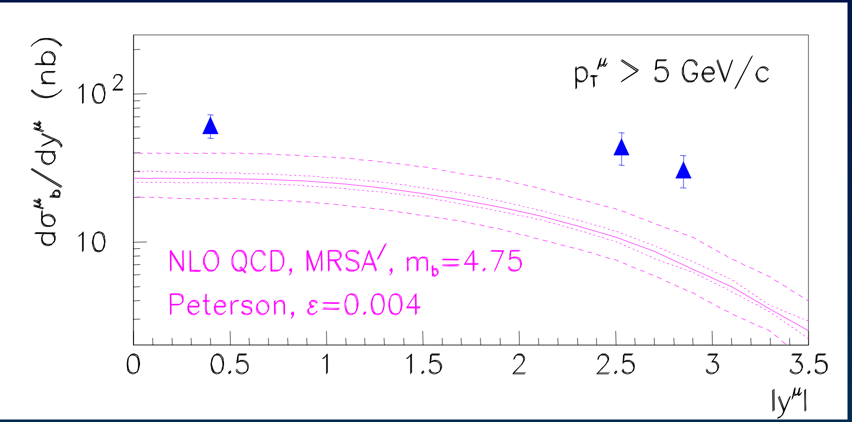


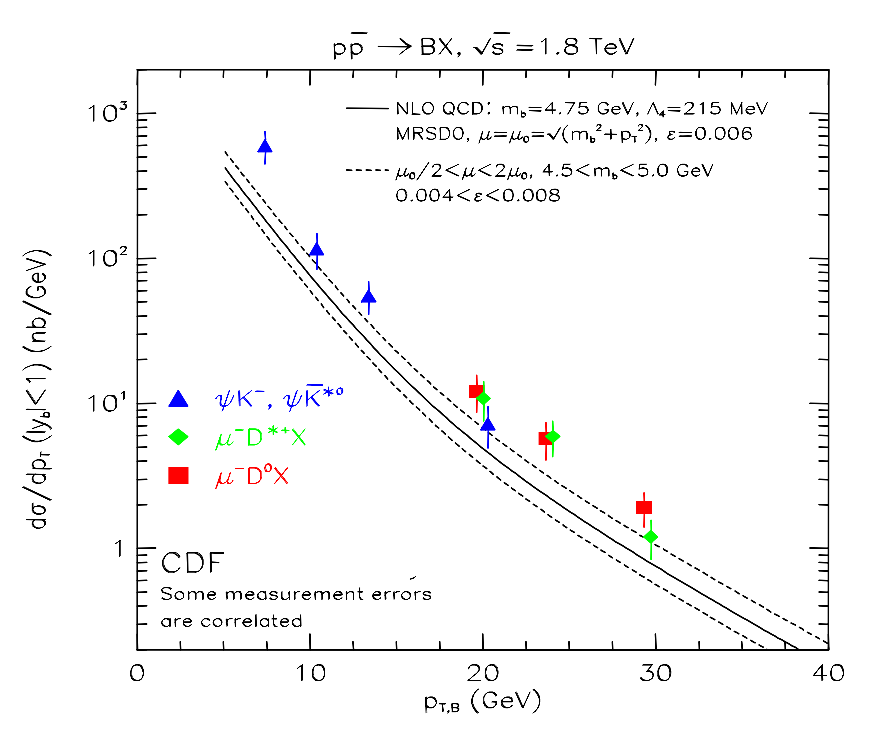
- NLO processes contribute with the same magnitude as LO ones
- Lead to different kinematic correlations
  - ΔR, $\Delta\phi$, pT_1 vs. pT_2



b-quark cross sections at the Tevatron





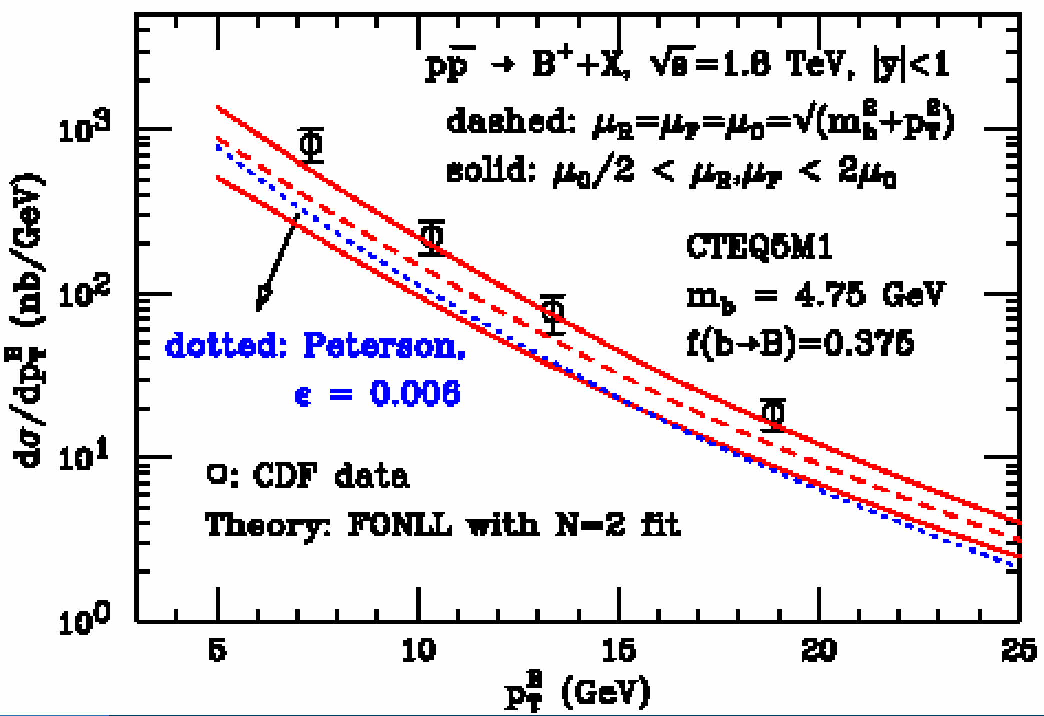


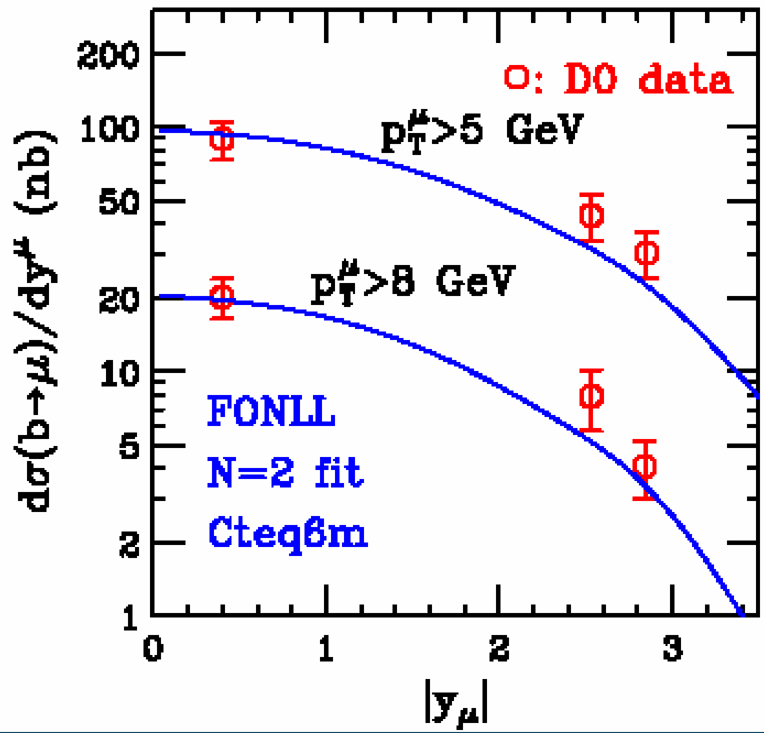
- Run 1 measured x-sections were a factor of two or three higher than the central values of the theory at the time.

Large uncertainties

- Experimental uncertainties
  - We don't measure b-quarks, only B-hadrons
    - Fragmentation uncertainty – Peterson is not correct
  - *B* decay products often not fully reconstructed
    - Must extrapolate to B-hadron, then b-quark pT
- Theoretical uncertainties
  - hard scatter really needs NNLO – scale factors (x2)
  - quark mass (10%), PDF's (20%)
  - kT effects and fragmentation
- Correlations between the above often not included in theory vs. experiment comparisons
  - Was this merely a 2 σ discrepancy? – or more?

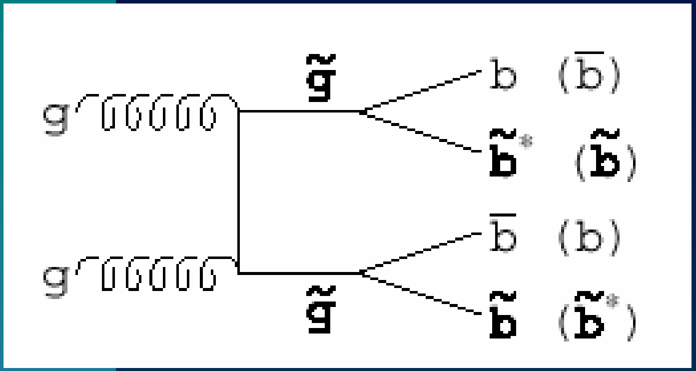
Improvements in theory

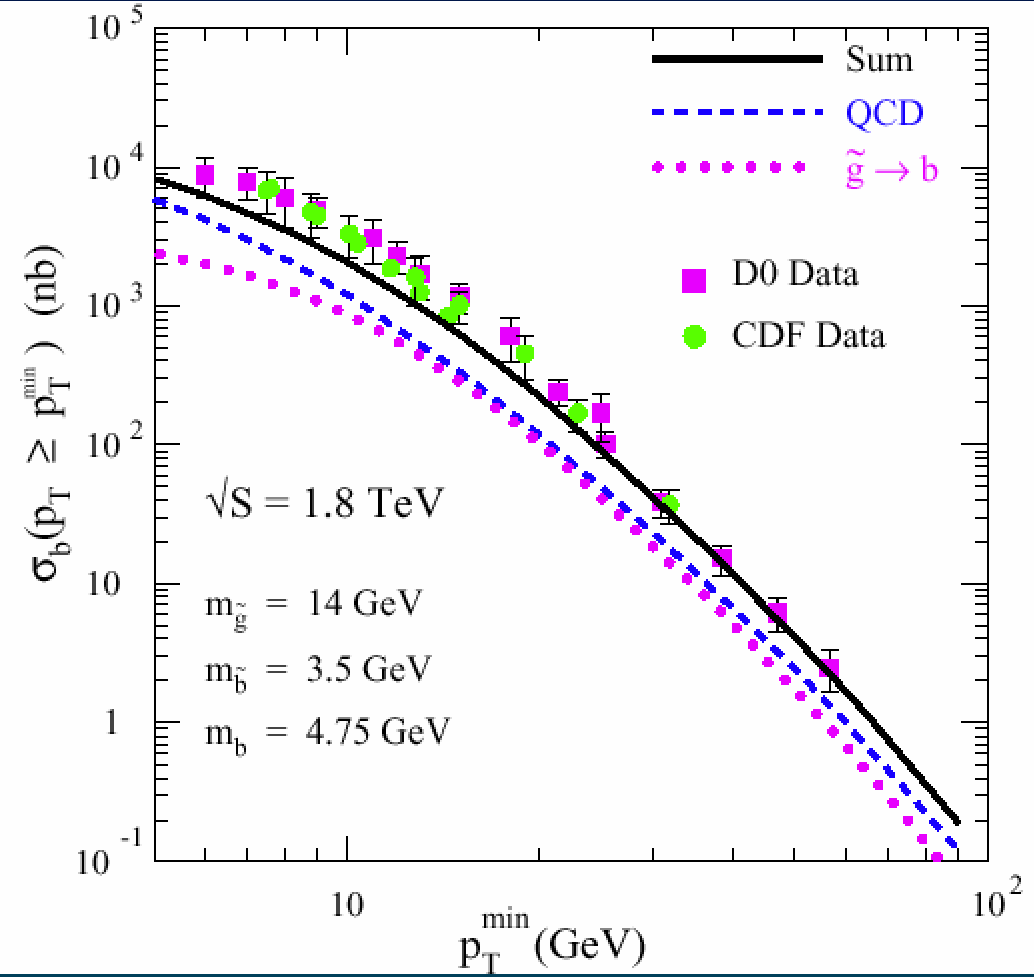




- New LO and NLO B-meson fragmentation functions determined from recent data
  - Binnewies, Kniehl, Kramer
- Next to leading log resumation and re-tuned frag. functions: FONLL
  - Cacciari, Nason

An exotic explanation

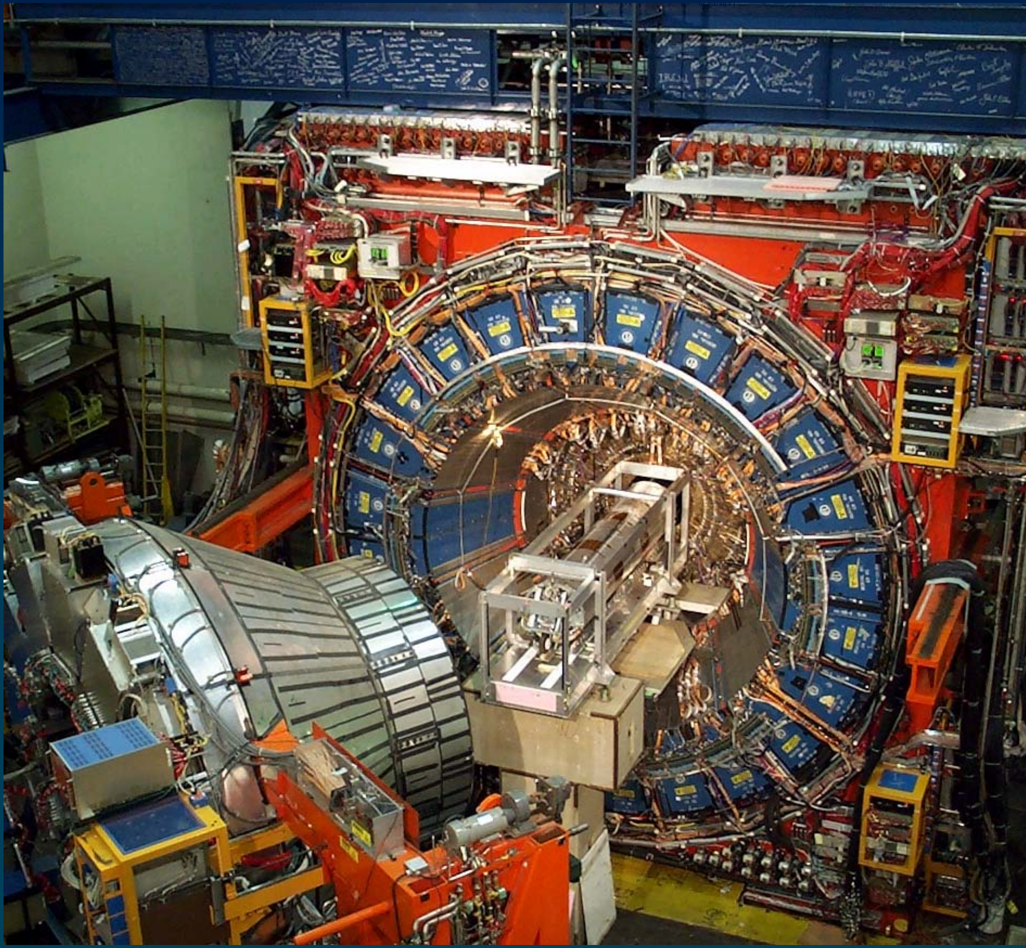




- SUSY gluino production and decay to b-quarks
  - Berger, Tait, Wagner
- Also produce like sign BB hadrons and influence mixing measurements

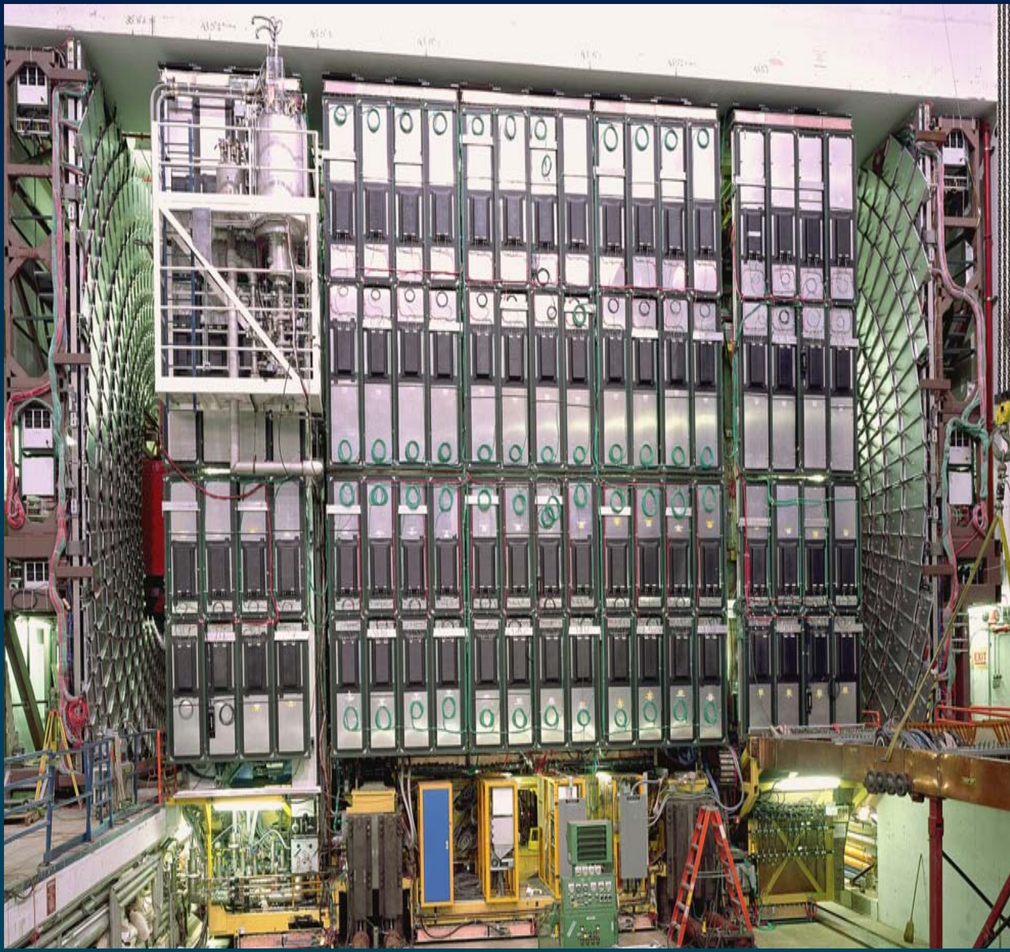
The CDF Run II detector

- The CDF detector has undergone extensive upgrades
  - New silicon vertex detector
    - inner layer at 1.35 cm
  - New central tracker
  - Extended μ coverage
  - Time of flight detector
  - Second level impact parameter trigger
    - Allows all hadronic b triggers

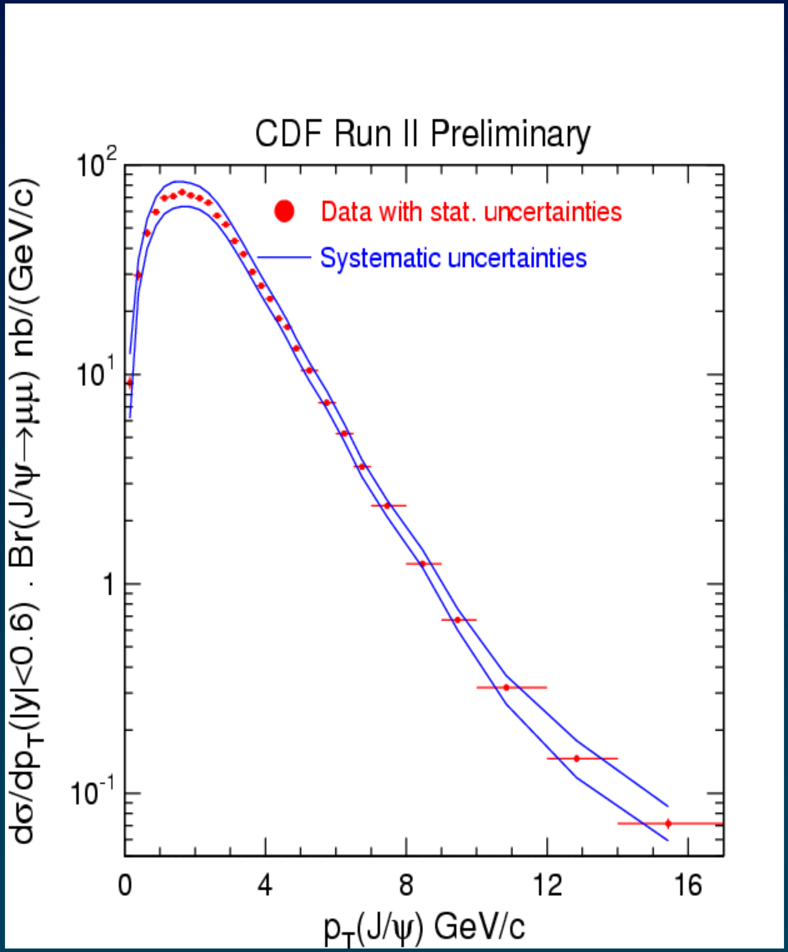


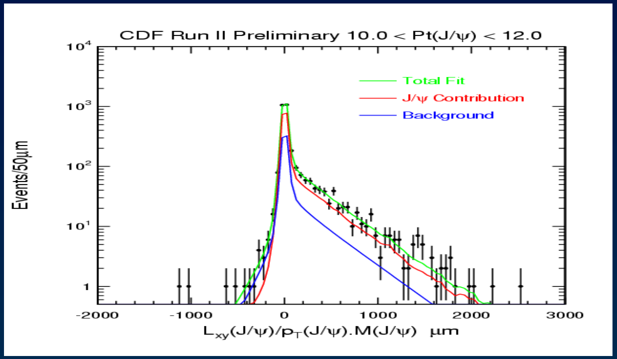
The DØ Run II detector

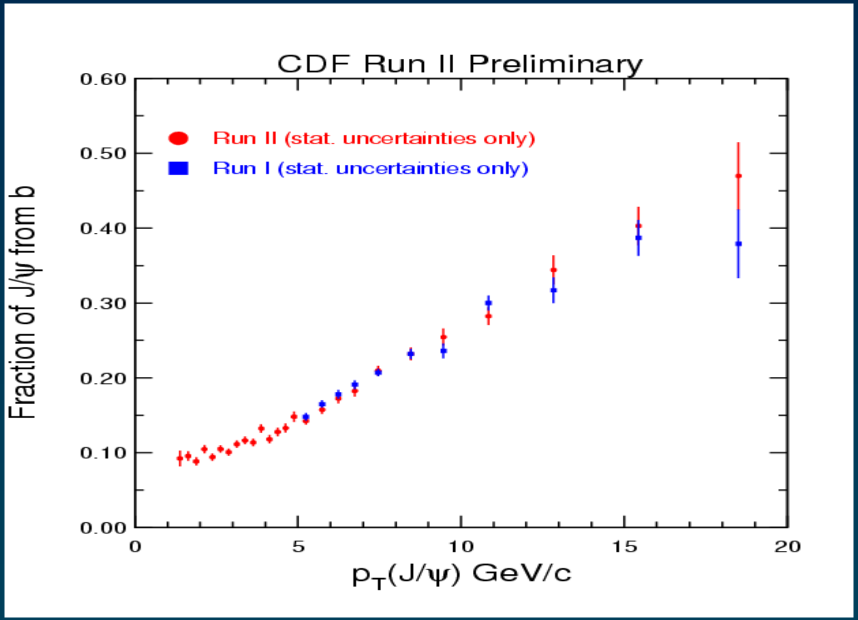
- The DØ detector has undergone very extensive upgrades
  - Silicon vertex detector
    - $|\eta| < 3.0$
  - Central fiber tracker
  - 2 T solenoid magnet
  - Low pT central muon trigger scintilators
  - New forward μ system
  - L2 silicon track trigger coming soon



Inclusive J/ψ cross section







- CDF's new muon trigger capabilities extend the J/ψ p_T acceptance down to 0 – was 5 GeV in Run I.

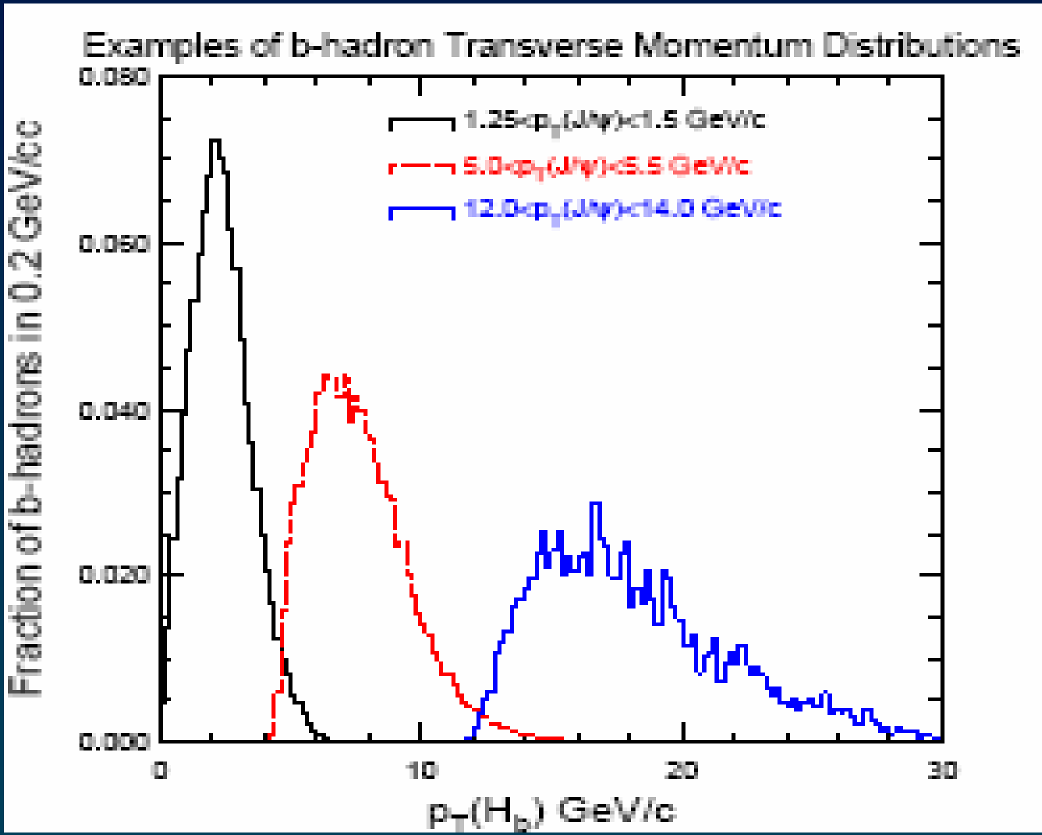
Differential B → J/ψ cross section

Assume a b-hadron pT spectrum

Unfold pT(Hb) from pT(J/ψ) using MC

New b-hadron pT spectrum

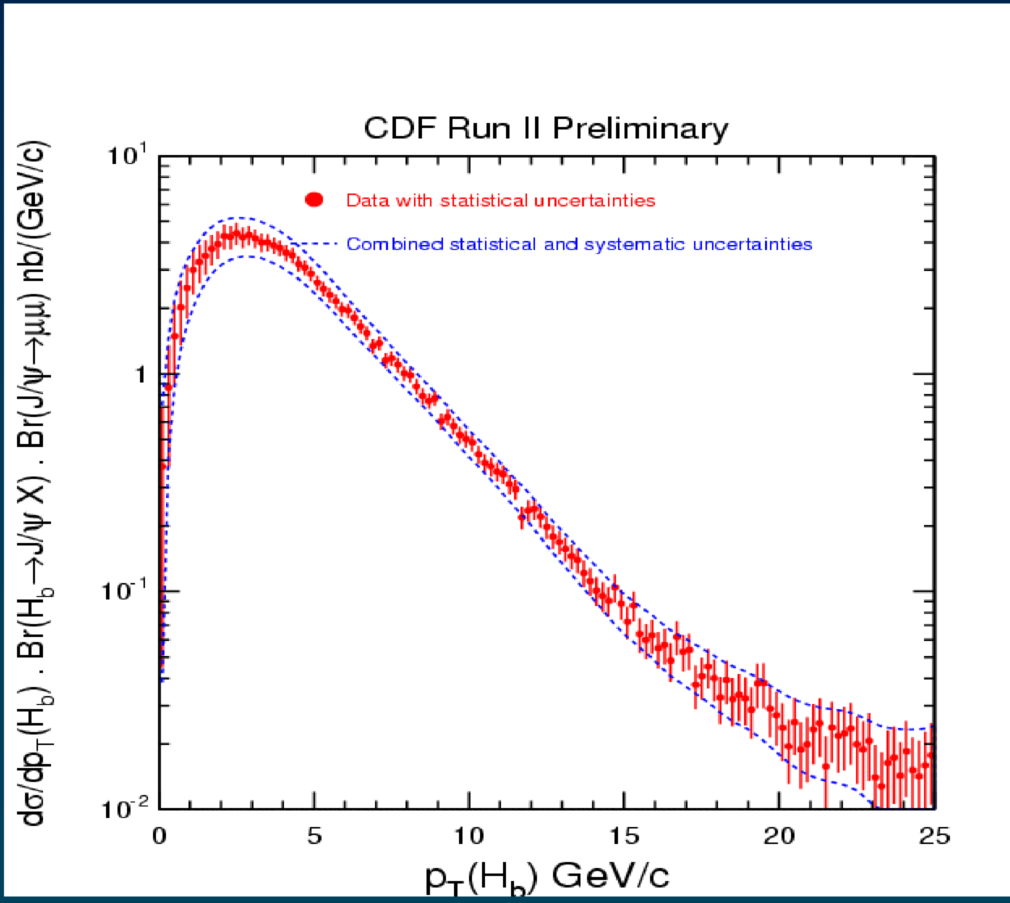
Iterate to obtain the correct pT spectrum



b-hadron x-section $d\sigma/dp_T(H_b)$

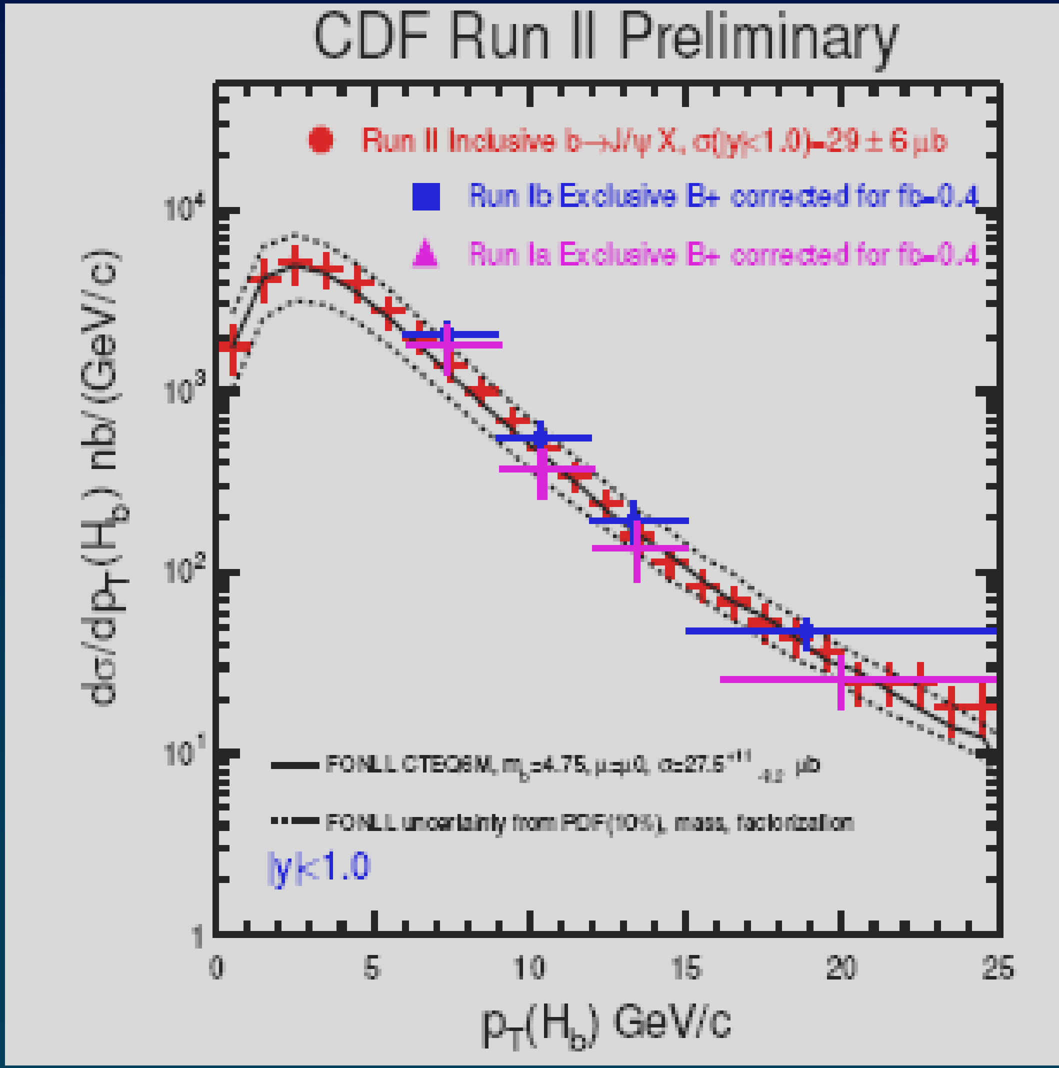
Differential $d\sigma/dp_T(B)$ as function of $p_T(B)$

- $\sigma(pp \rightarrow B, |y|<0.6) * BR(B \rightarrow J/\psi) * BR(J/\psi \rightarrow \mu^+\mu^-)$ $= 24.5 \pm 0.5(\text{stat}) \pm 4.7(\text{syst})$ nb
- $\sigma(pp \rightarrow b, |y|<0.6) =$ $18.0 \pm 0.4 \pm 3.8\ \mu b$



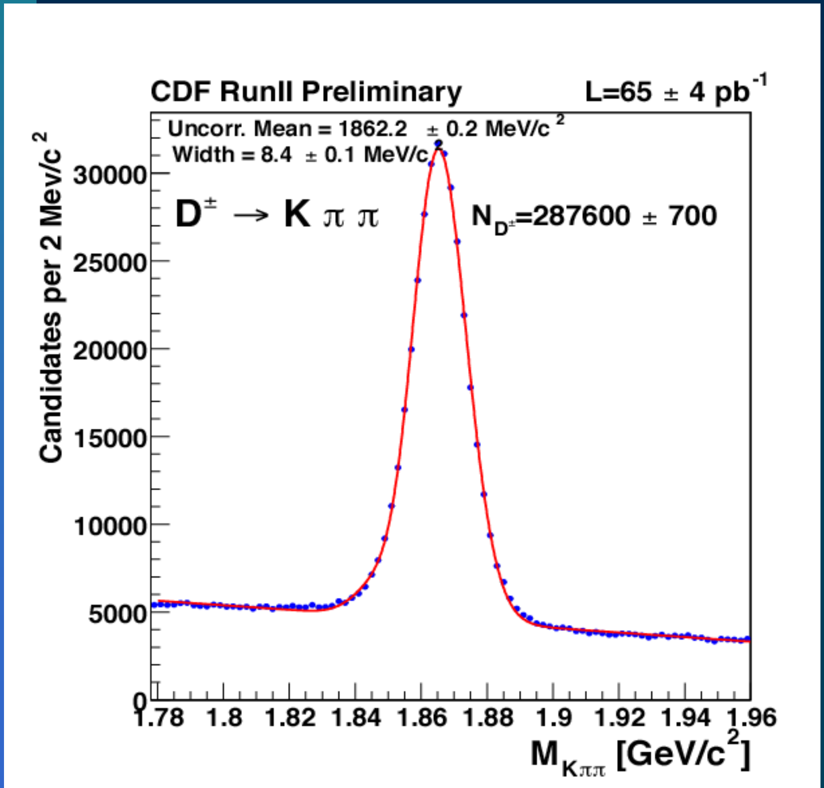
Comparison to theory

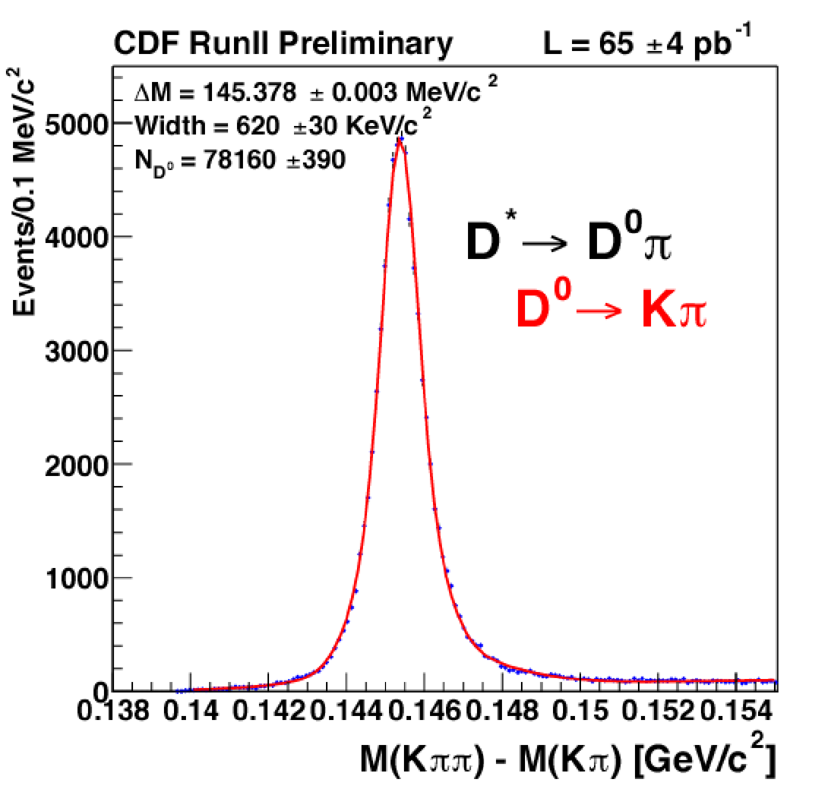
- FONLL, a la Cacciari, Frixione, Mangano, Nason, Ridolfi
- Impressive agreement with new data!
- But…
  the measured inclusive x-section is at the same level as the Run I exclusive one – it should be 10-15% higher, due to the increase in beam energy.



Open charm cross sections

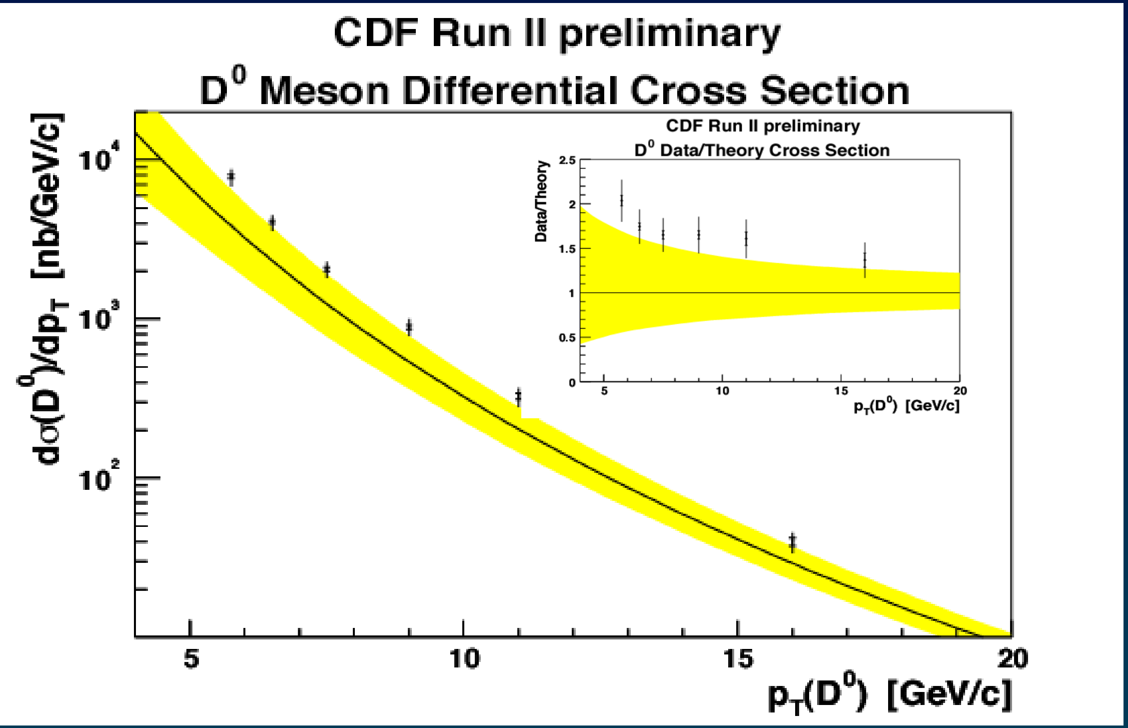
- Charm production probes the same hard scatter processes as beauty, but has different fragmentation – good cross check of theory

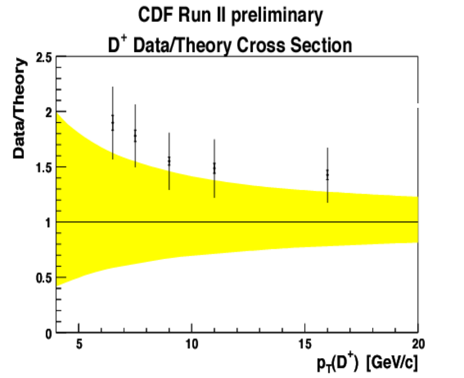


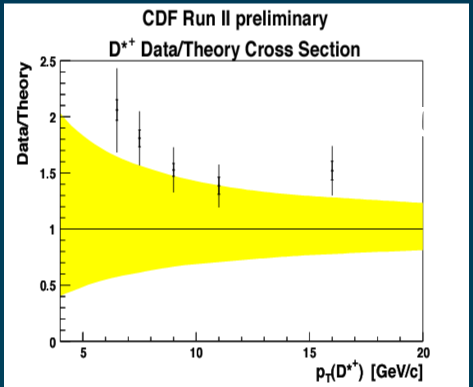


Open charm cross sections

- Same level of agreement or disagreement between data and theory (FONLL) as for beauty



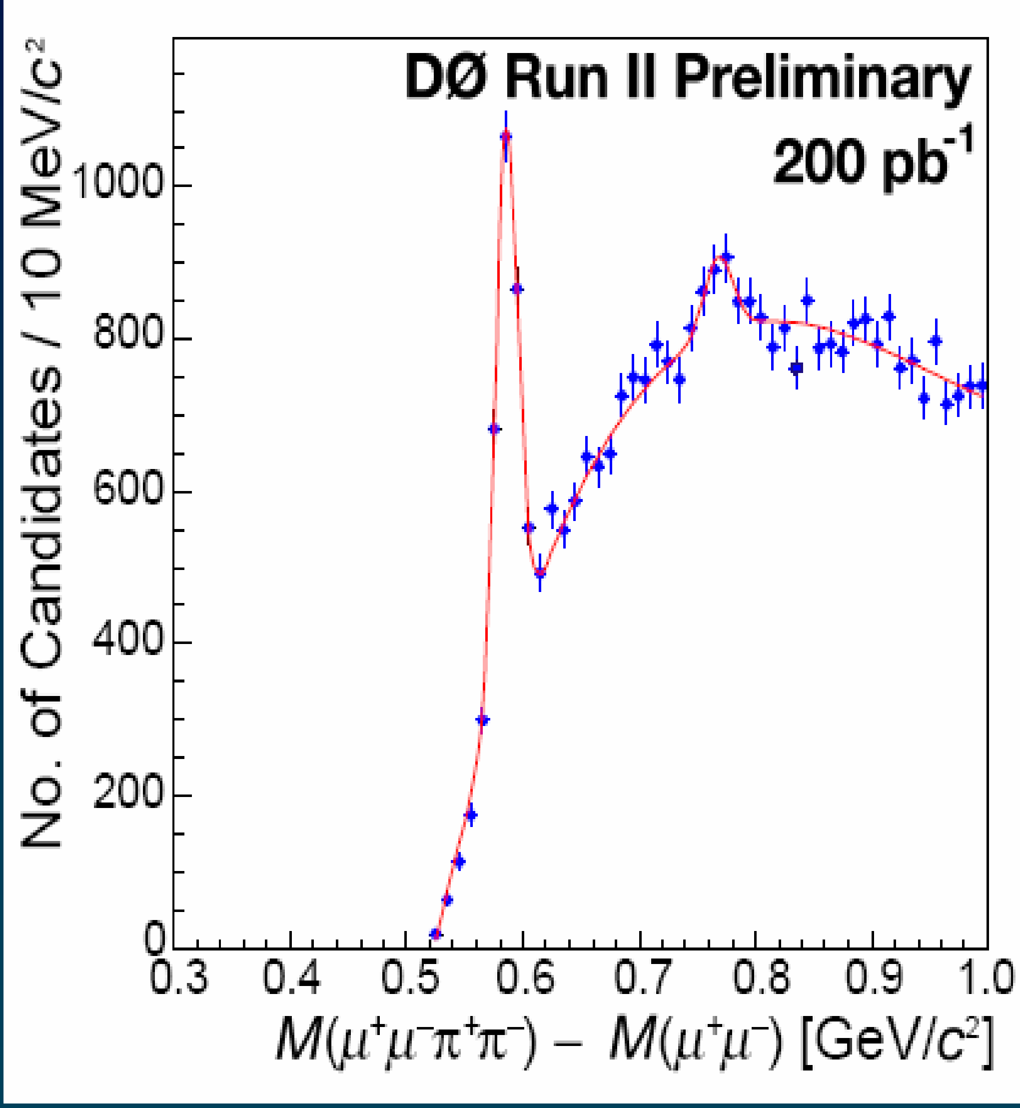




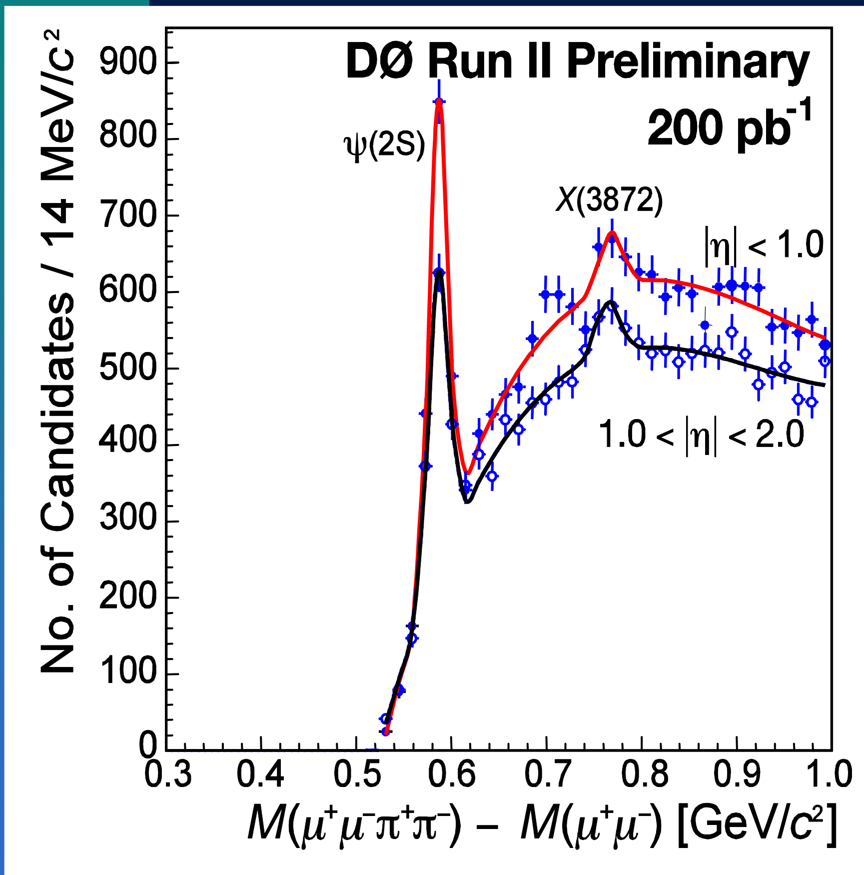
D^0 ($pT \geq 5.5$)	13.3±0.2±1.5 μb
D+ ($pT \geq 6$)	4.3±0.1±0.7 μb
D*+ ($pT \geq 6$)	5.2±0.1±0.8 μb
Ds+ ($pT \geq 8$)	0.75±0.05±0.22 μb

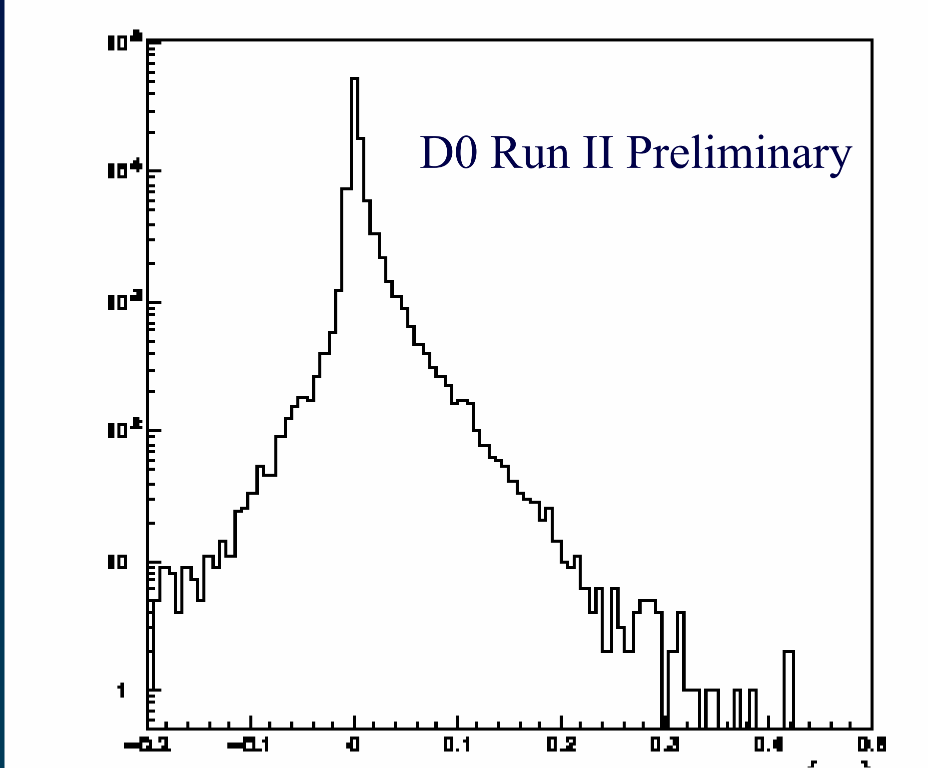
$X(3872) \rightarrow J/\psi\pi^+\pi^-$

- Both CDF and DØ have confirmed BELLE's discovery of the X(3872)
- DØ results:
  - 300 ± 61 candidates
  - 4.4σ effect
  - $\Delta M = 0.768 \pm 0.004$ (stat) ± 0.004 (sys) GeV/ c^2
  - Direct (non-B) production
- See Vaia's charmonium review for CDF results



X(3872) production properties





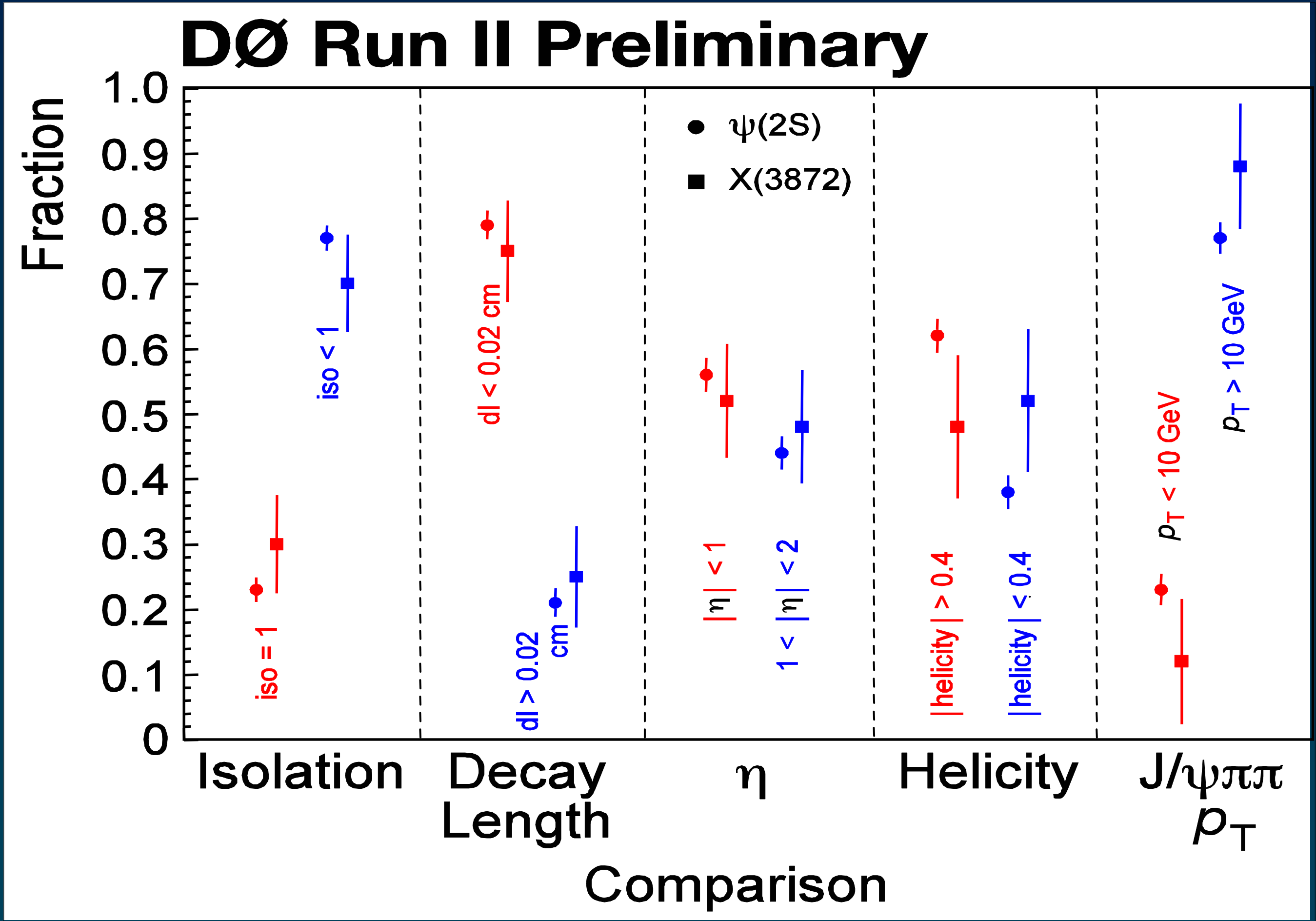
X mass range decay length (cm)

dl < 0.02 cm 230 ± 59 evts

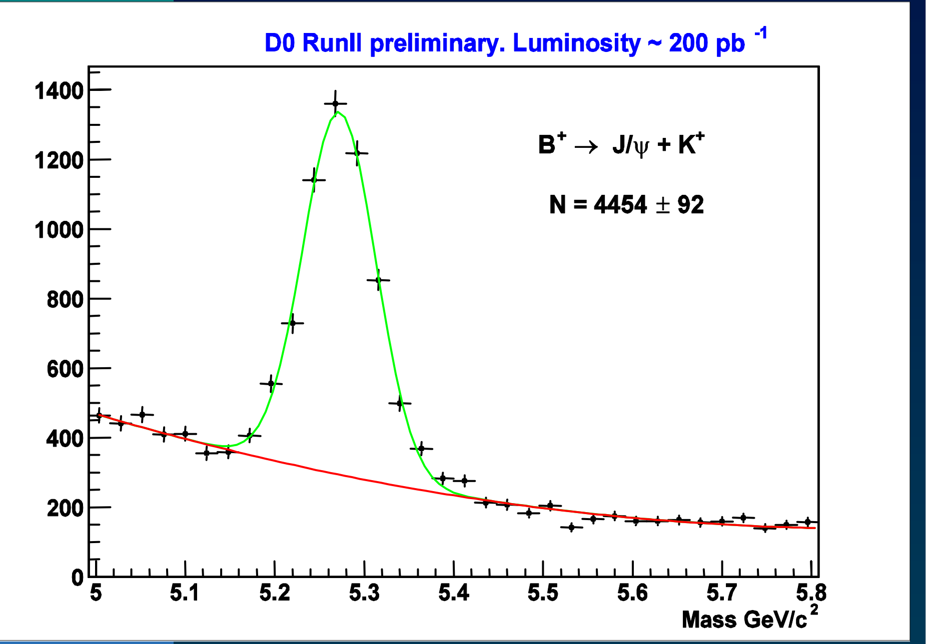
dl > 0.02 cm 77 ± 25 evts

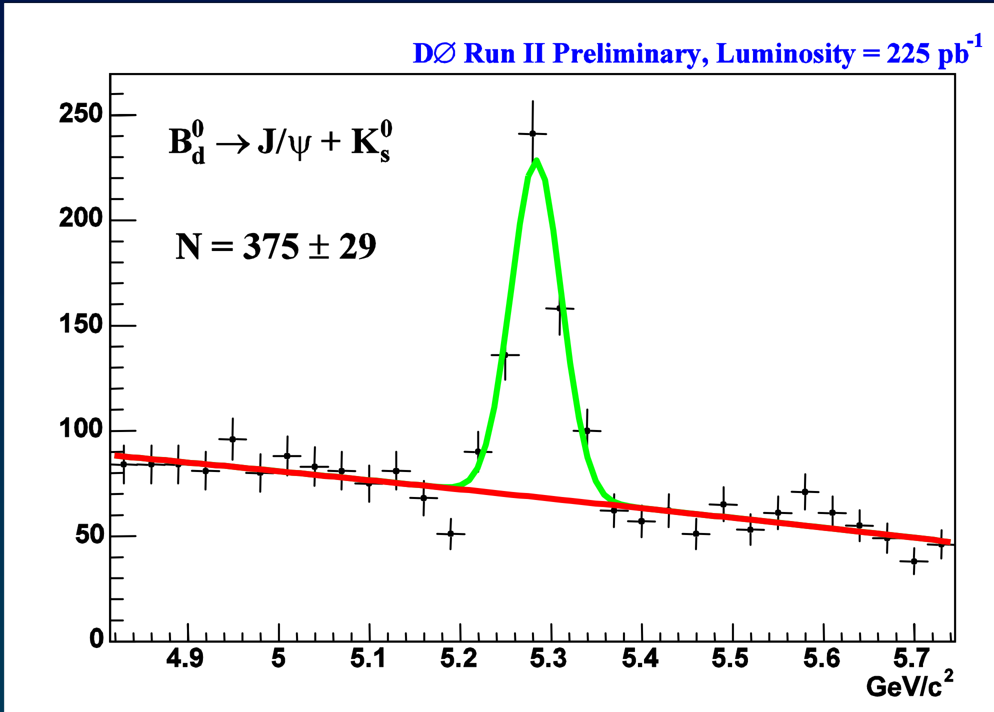
X(3872) – ψ(2S) comparison

- Is the X charmonium, or an exotic meson molecule?
- No significant differences between ψ(2S) and X have been observed yet



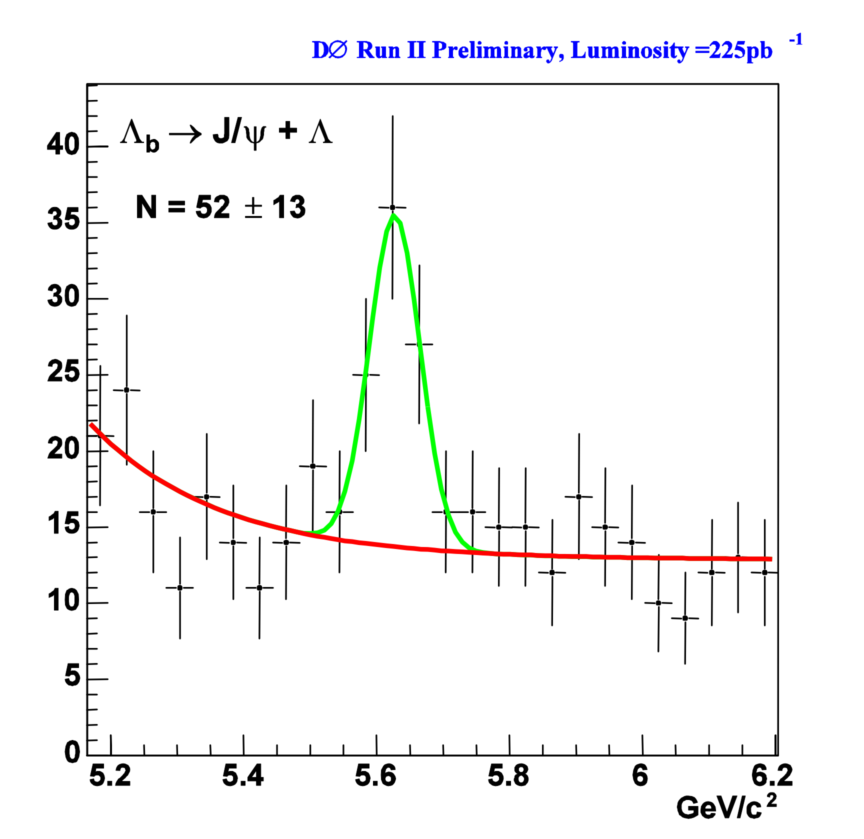
Fully reconstructed B's

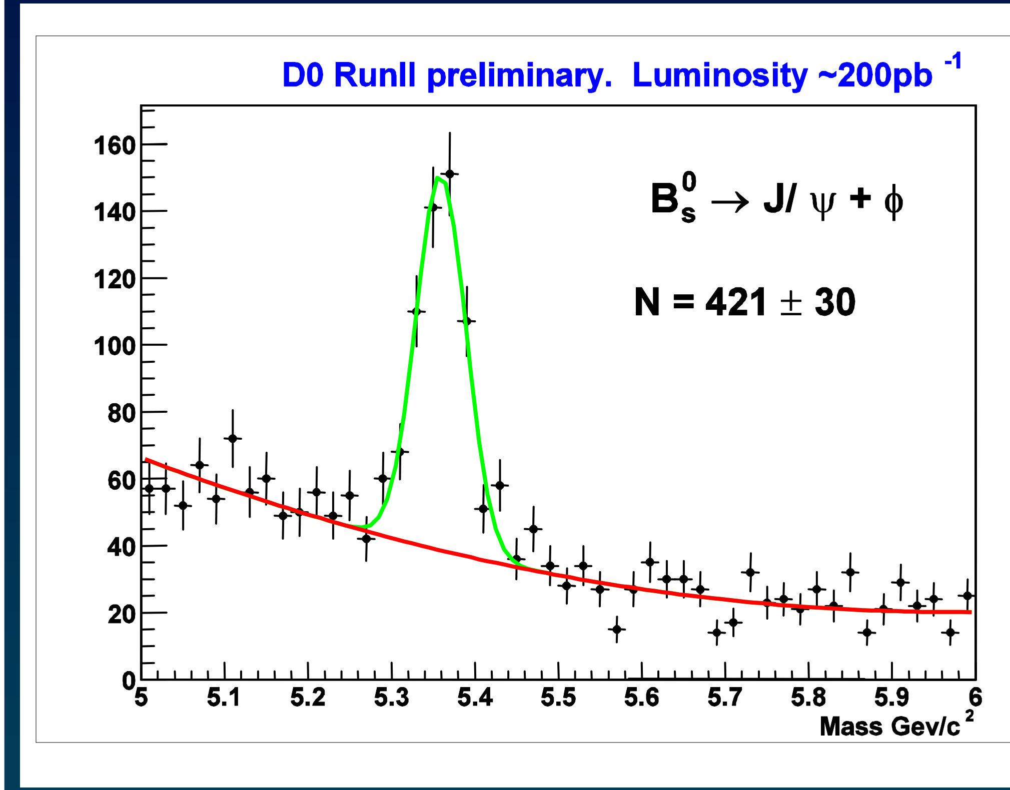




- Better for cross section measurement – no missing decay product extrapolation uncertainties
- Also very nice for correlations – hadron vs. other lepton or jet, or even other hadron!

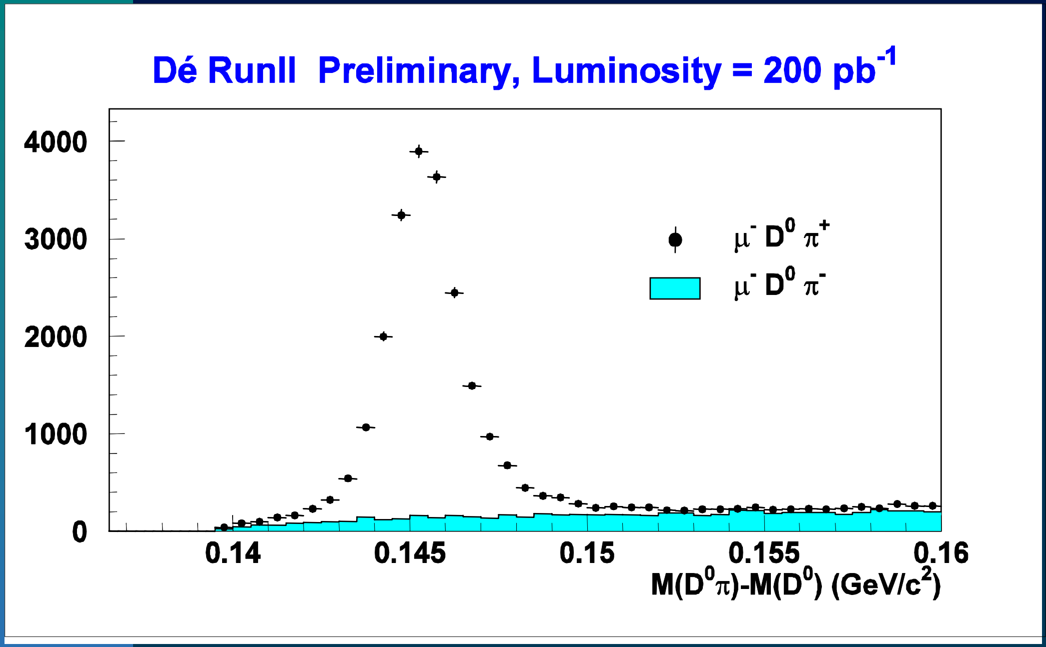
More fully reconstructed B's

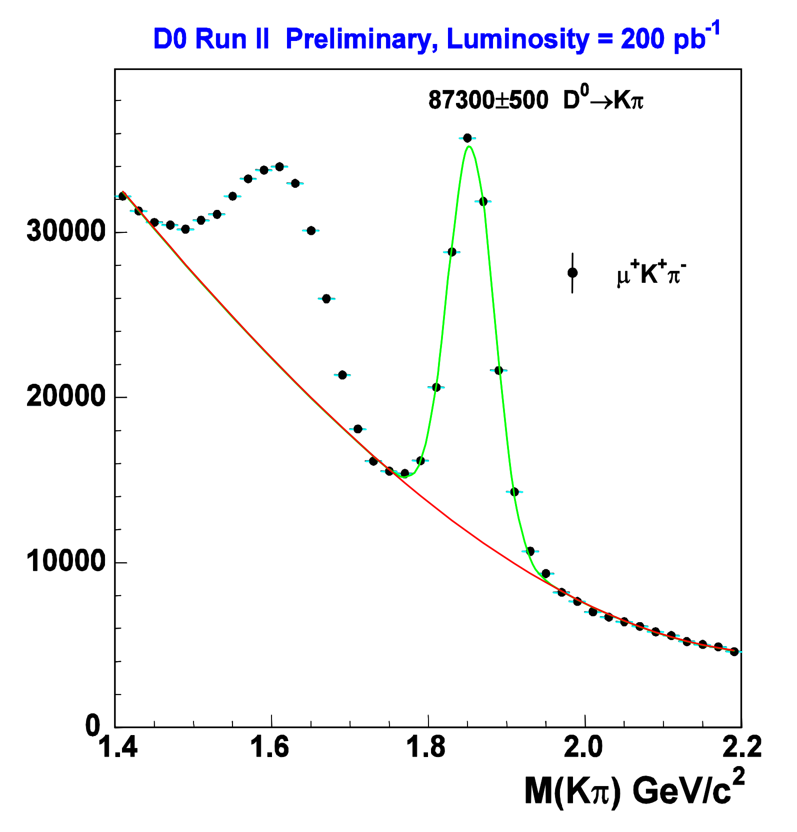




- These states are not accessible at B-factories
  - mass and lifetime measurements (see Todd's talk)
  - CP violation in Bs, very small in SM – good place to look for new physics
  - Bc hopefully coming soon

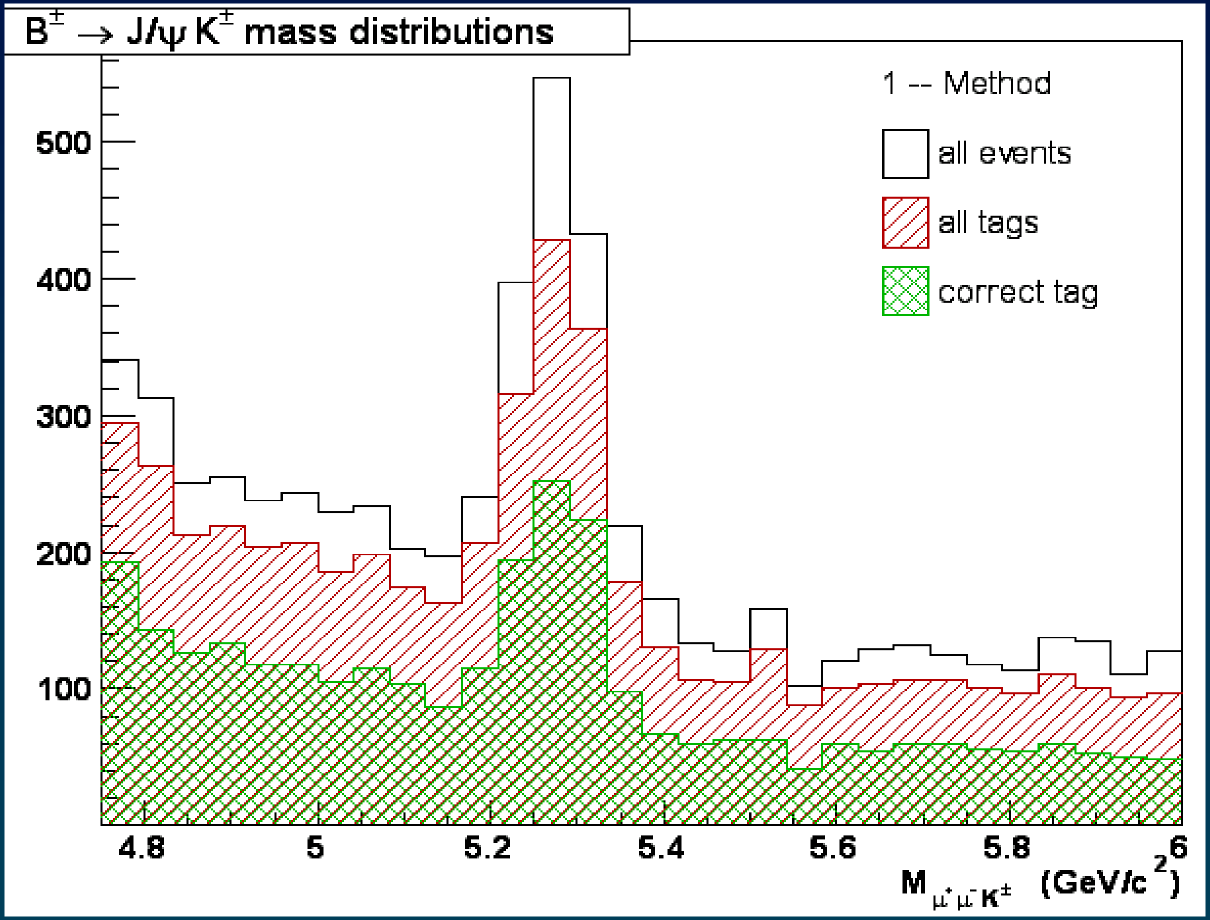
Large B semileptonic samples





- Muon – D charge correlation already in these plots
- B_d mixing measurement based on these signals coming soon

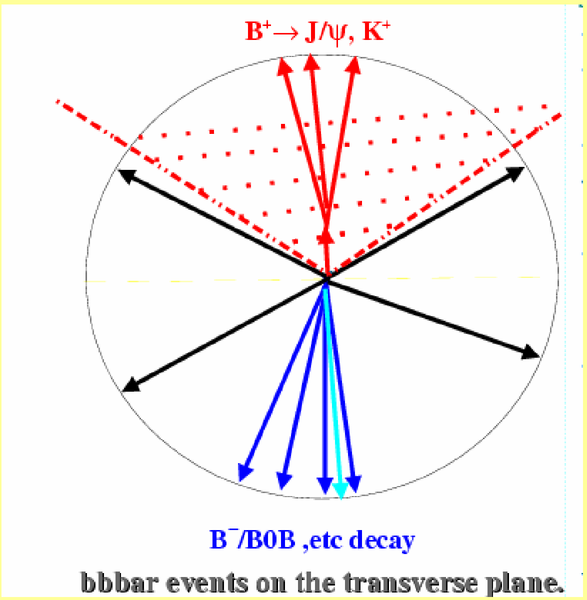
Same side track flavor tag



- Same side tags on 1k B→J/ψK events (update with 4k events coming soon)

Flavor tagging

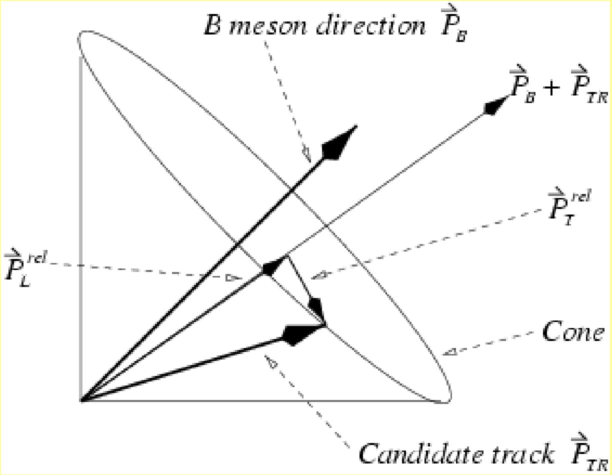
Opposite jet charge



$$\text{Jet Q} = \frac{\Sigma p_T^i . q^i}{\Sigma p_T^i}$$

Require |Q| > 0.2

Same side track charge



Q of the highest pT (or lowest pTrel) track in a cone (dR < 0.7) around the B

Muon charge

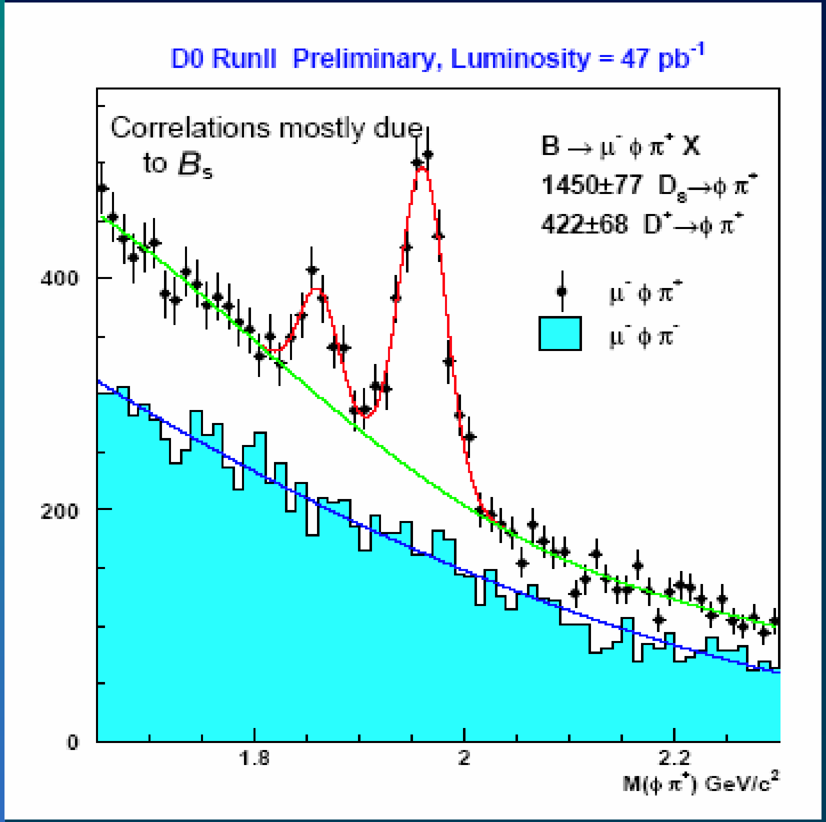
Q of the highest pT muon in the event separated in ϕ from the signal B by 2.2 rads.

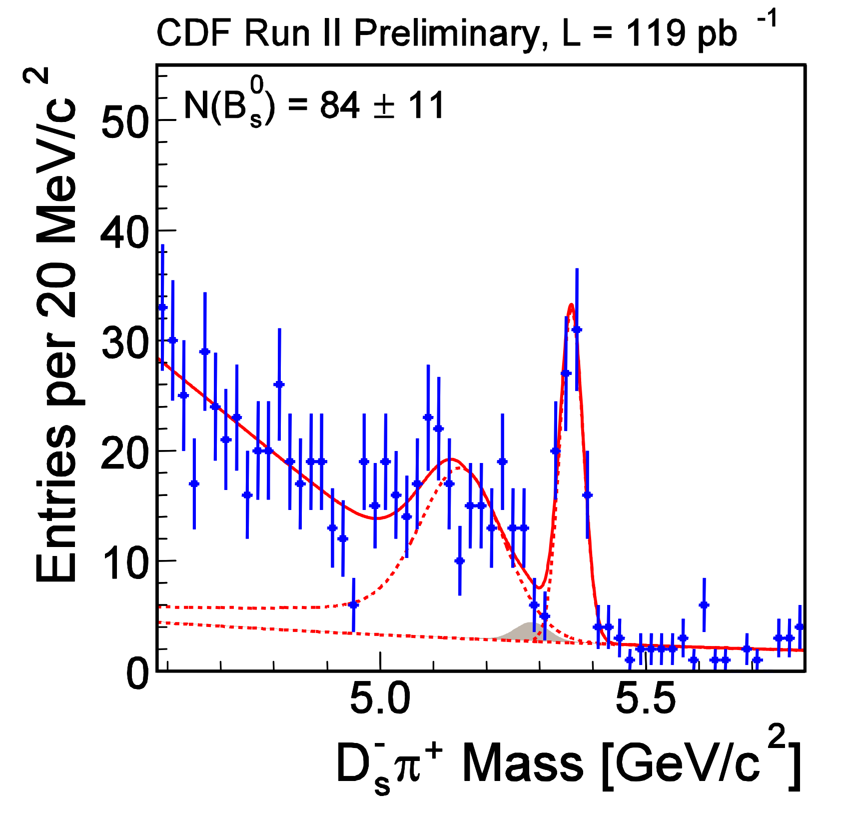
Flavor Tagging

Method	Efficiency ε (%)	Dilution D (%)	Tag Power εD^2 (%)
Jet Charge	46.7±2.7	26.7±6.8	3.3±1.7
Same side track	79.2±2.1	26.4±4.8	5.5±2.0
Muon Tag	5.0±0.7	57.0±19.3	1.6±1.1

- For hadronic final states we trigger on muon from other B – self tagging (ε=1) with even cleaner dilution $\varepsilon D^2 \sim 80\%$
- See Diego's talk for CDF flavor tag results

Bs mixing





- Semileptonic decays
  - Very good statistics
  - Degraded proper time resolution
  - If $\Delta m_s \sim 15 ps^{-1}$ expect a measurement with 500 pb^{-1}
- Hadronic decays – DØ too!
  - Poor statistics
  - Excelent proper time resolution
  - Need a few fb^{-1} of data to reach $\Delta m_s \sim 18 ps^{-1}$

Conclusions

- The Tevatron continues to be an excellent place to study heavy flavor production and properties
  - Improvements in theory have reduced the discrepancy between measurements and predictions
    - Better treatments of fragmentation
    - FONLL
  - Run II measurements starting to come in
    - B $\rightarrow$ J/ψ cross section
    - Open charm cross sections
    - X(3872) studies
  - Exciting measurements to come
    - Exclusive hadron cross sections and correlations
    - Bs mixing, and so much more….