B_c & Upsilon at D0

Leah Welty-Rieger
Indiana University
Quarkonium Workshop 2007
DESY, Hamburg

Outline

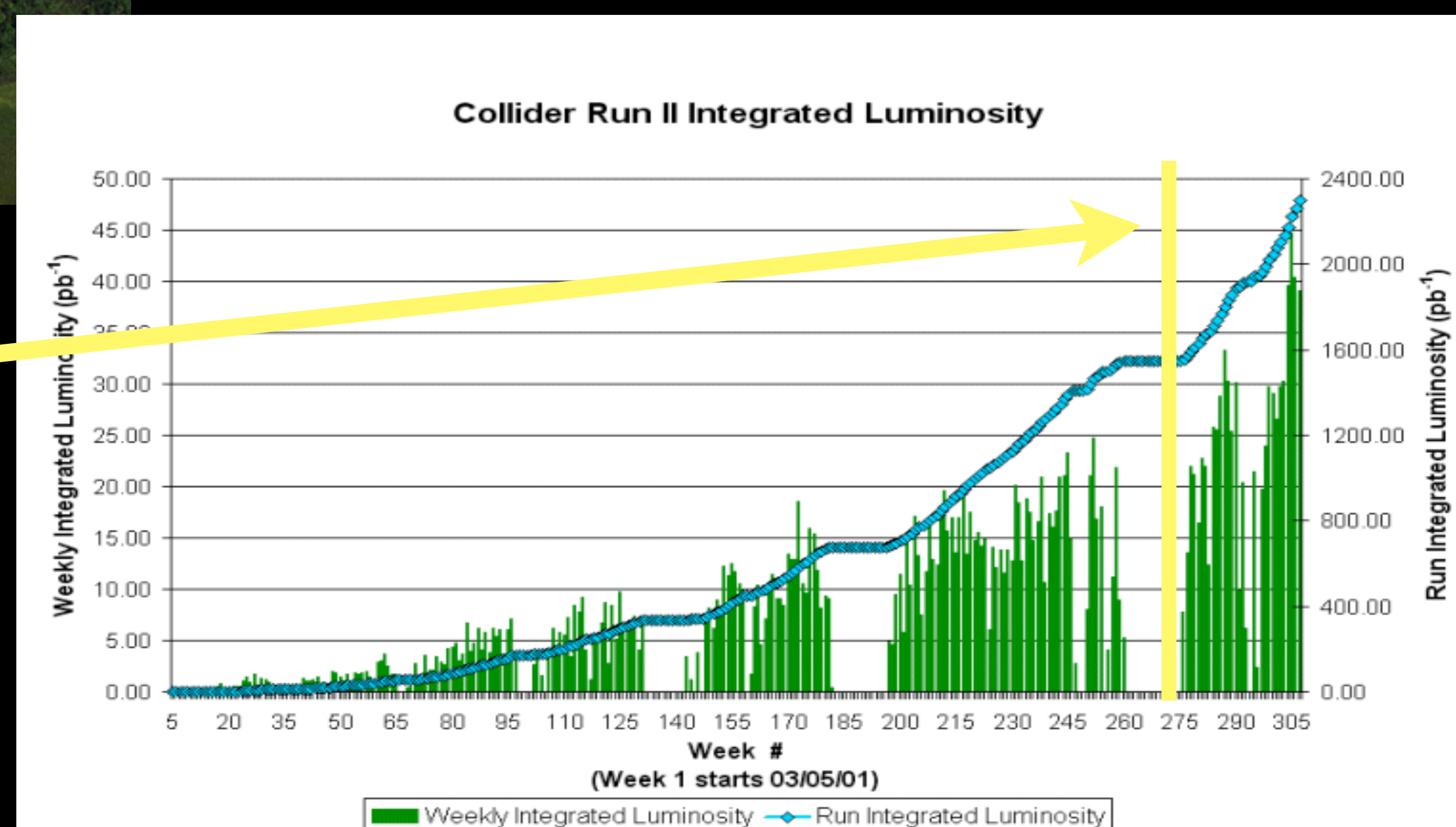
- The Apparatus
  - The Tevatron
  - D0
- Upsilon physics and results
  - Polarization
- B_c physics & results
  - NEW! Lifetime

The Tevatron

D0
Experiment

- ppbar collider
- 1.96 TeV energy
- 45 mi west of Chicago
- Delivered > 3.0 fb^{-1}
- Great location to train for a marathon, 6.5 miles around both rings

- The two analyses presented here cover 1.3 fb^{-1}



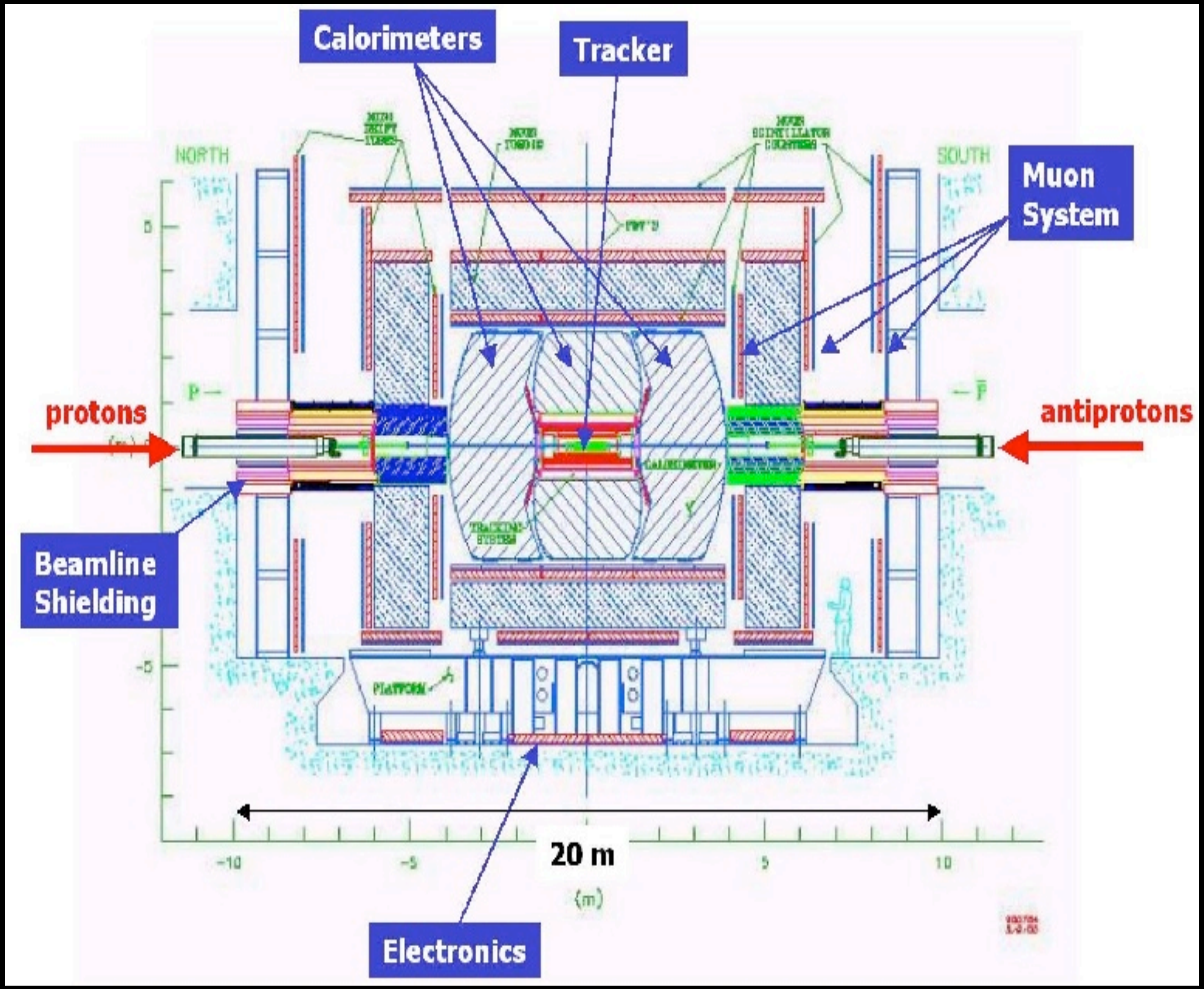
The D0 Detector

~600 scientists
~80 Institutions
20 countries

wear bright colors to show up!

The D0 Detector

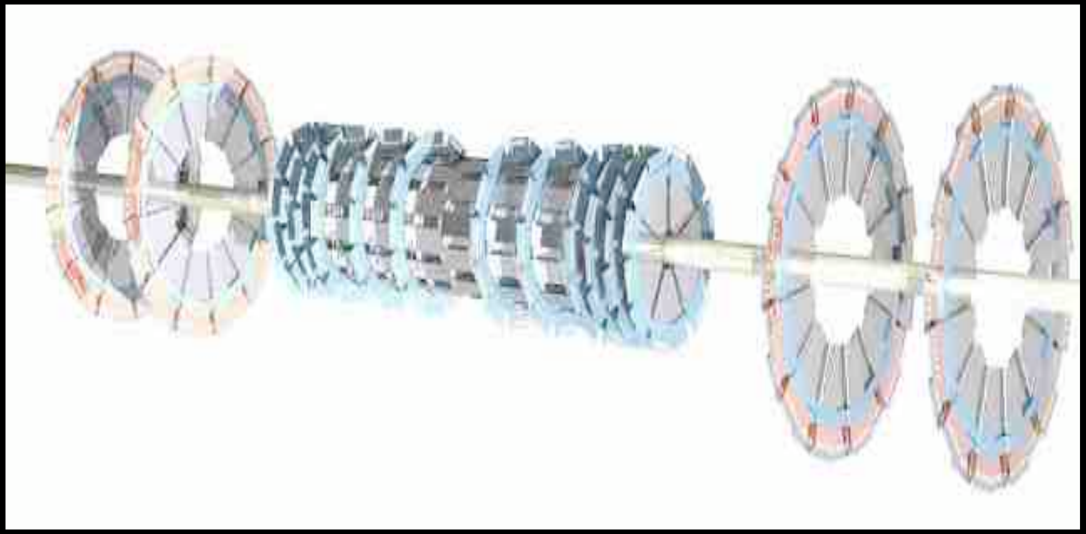
- 2 Tesla Solenoidal Magnetic Field
- Excellent coverage
  - Muon system |η|<2
  - Tracking system |η|<3
- Uranium liquid Argon calorimeter
- Robust muon triggers

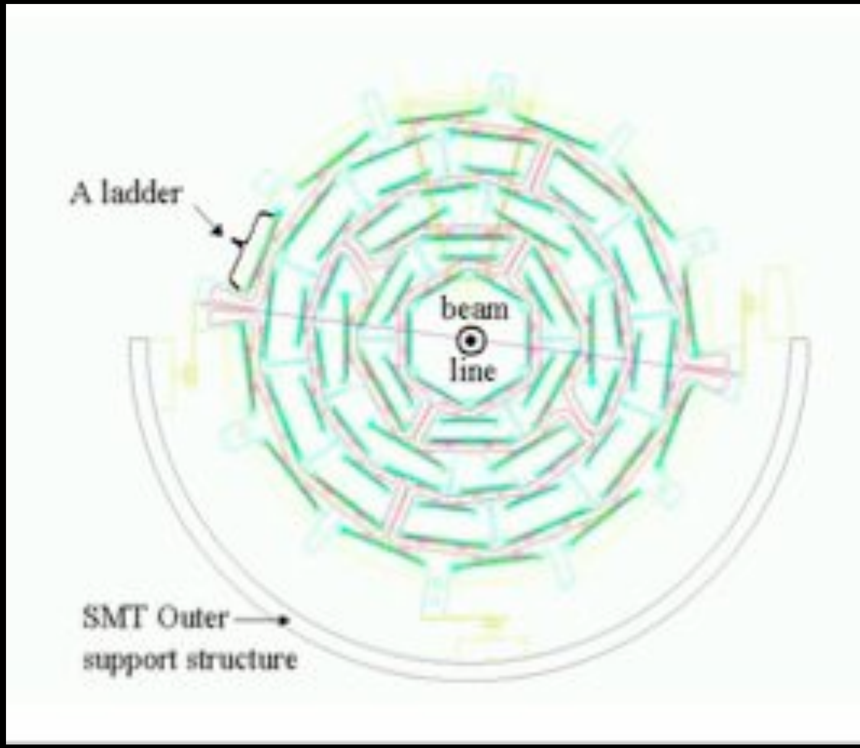


Silicon Microvertex Tracker

- 6 Central Barrels
  - 8 Layers of Ladders
  - Inner 4 barrels
    - All double-sided for 3D reconstruction
  - Outer 2 barrels
    - Half of the layers double-sided
- 12 Central 'F' Disks
  - Double-sided
  - Radius : 2.6cm -10.0 cm
- 4 Forward 'H' Disks
  - Single-sided
  - Radius : 9.5cm - 26 cm
  - Tracking out to ~η=3

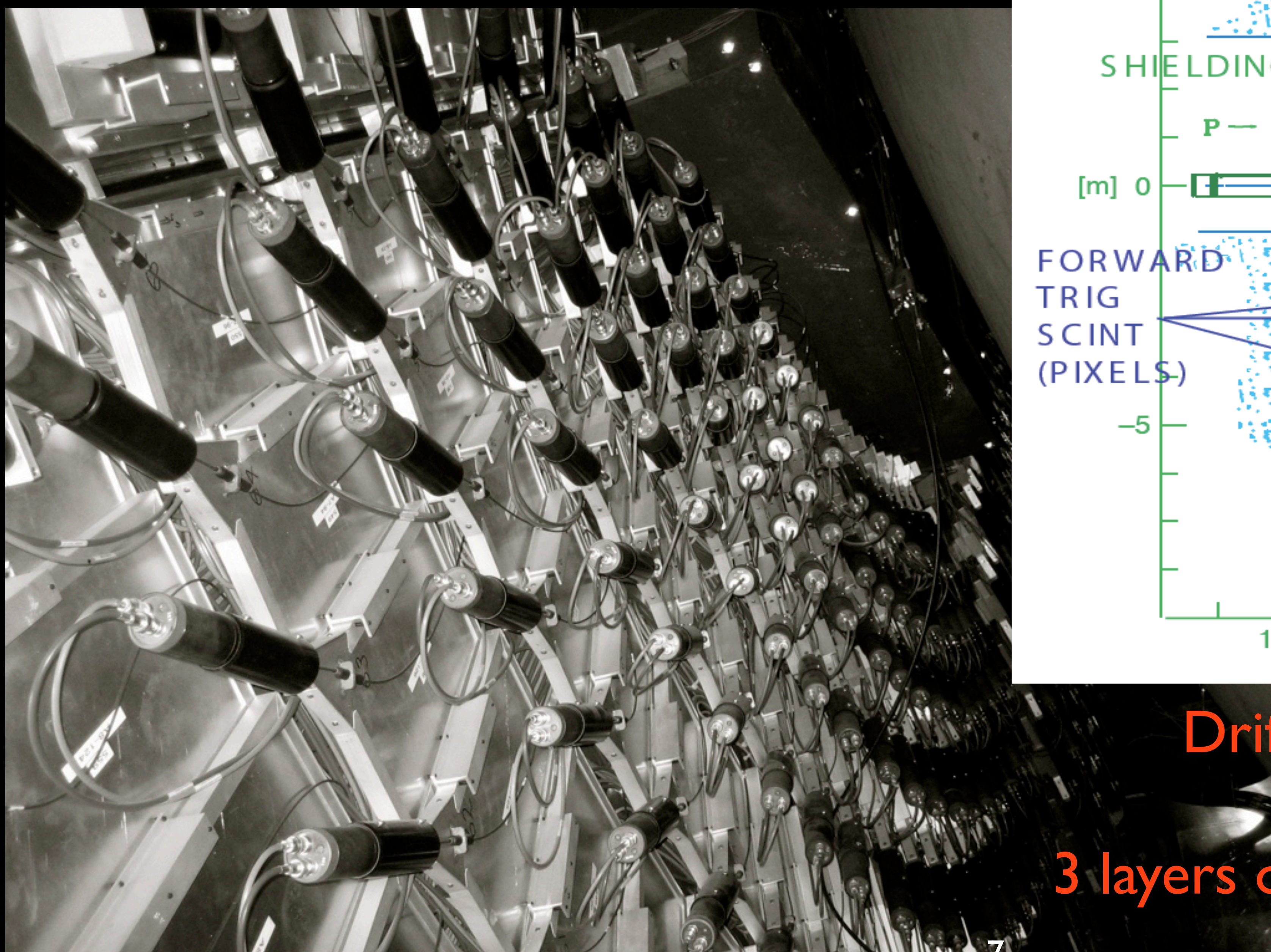
5 micron point resolution

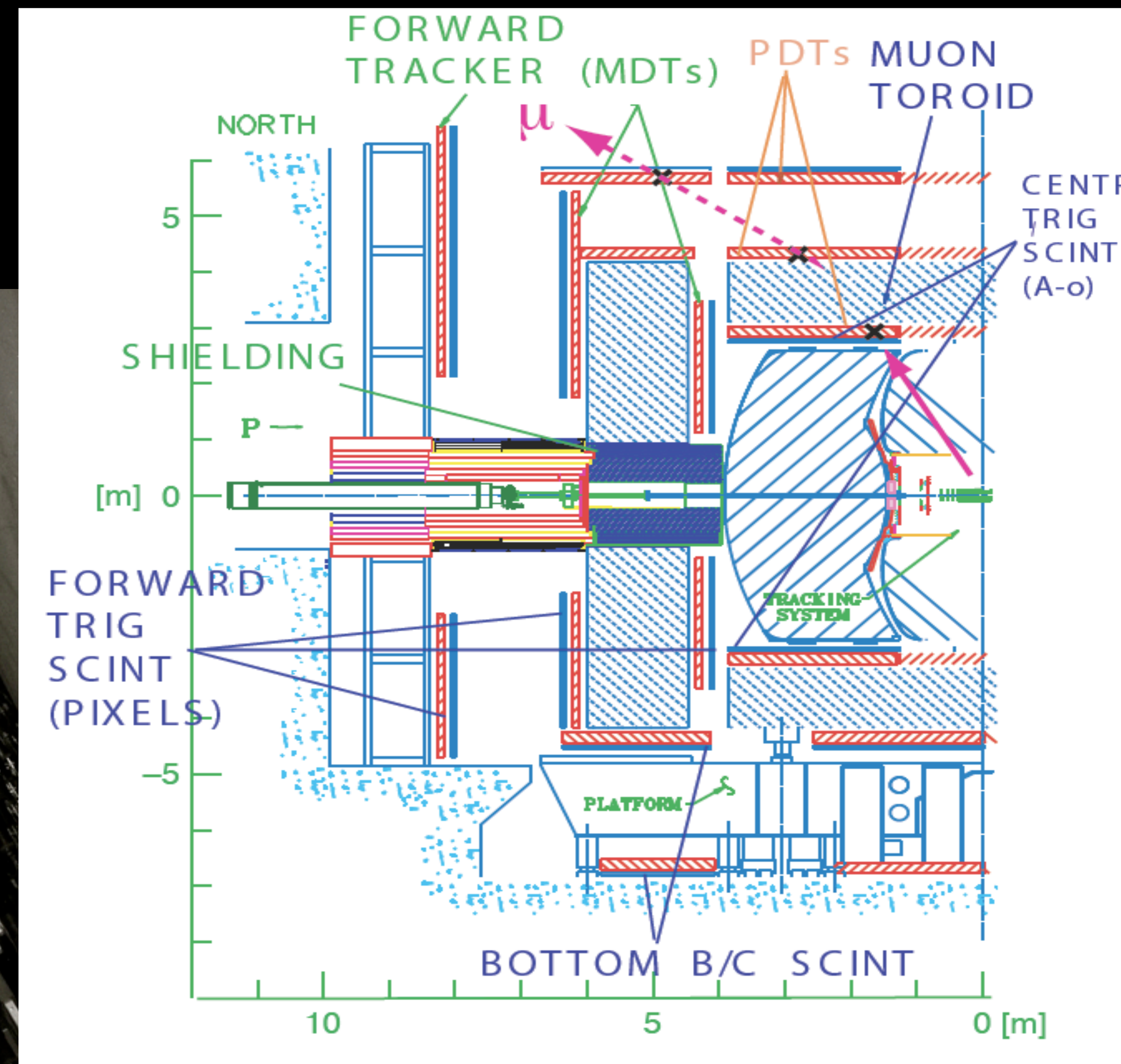




The Heart and Soul of B-Physics

Excellent large angle muon spectrometer and trigger





Drift tube tracking (slow)

&

3 layers of scintillators for triggering (fast)

Upsilon Physics Outline

- Motivation
- Data Selection
- Extraction of Υ signal in $\cos\theta^*$ bins
- Polarization of $\Upsilon(1S)$
- Polarization of $\Upsilon(2S)$
- Conclusions

Motivation

- NRQCD factorization developed to describe inclusive quarkonium production and decay
- Prediction of NRQCD is S-Wave quarkonium produced in *p*$\bar{p}$ collisions should be transversely polarized at high p_T
  - Dominance of gluon fragmentation into quarkonium production at high p_T
  - Approximate heavy-quark symmetry of NRQCD

Motivation

- Convenient measurement of polarization :

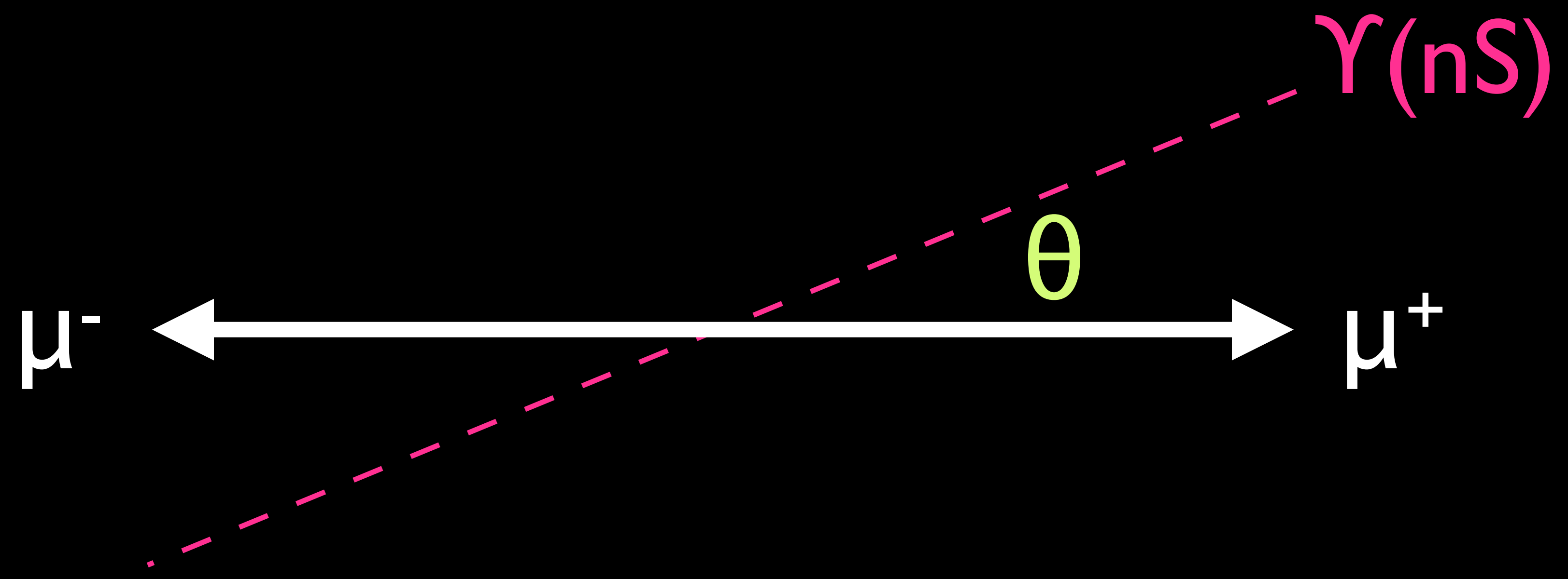
$$\alpha = \frac{(\sigma_T - 2\sigma_L)}{(\sigma_T + 2\sigma_L)}$$

- σ_T : transverse polarized component of the cross section
- σ_L : longitudinal polarized component of the cross section
- When transverse polarization dominates, $\alpha \rightarrow +1$
- When longitudinal polarization dominates, $\alpha \rightarrow -1$

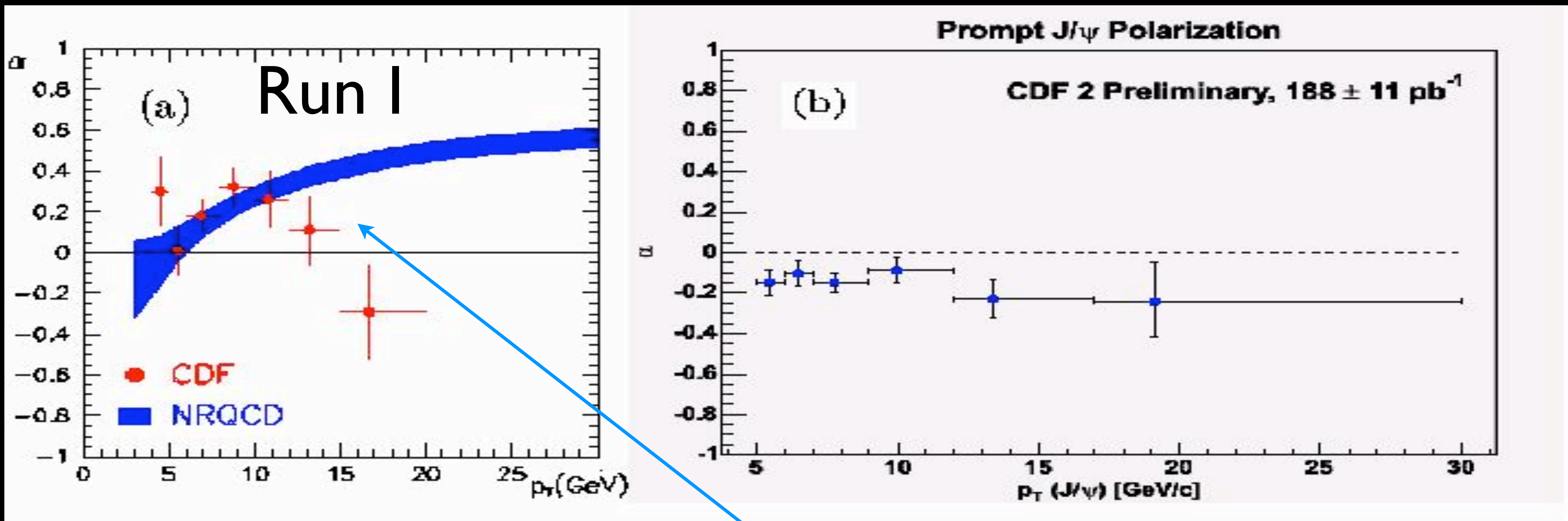
Motivation

- The variable 'α' fitted to the angular distribution of the positive lepton in the center of mass frame w.r.t. the momentum of decaying particle in the lab system :

$$\sim 1 + \alpha \cos^2(\theta^*)$$

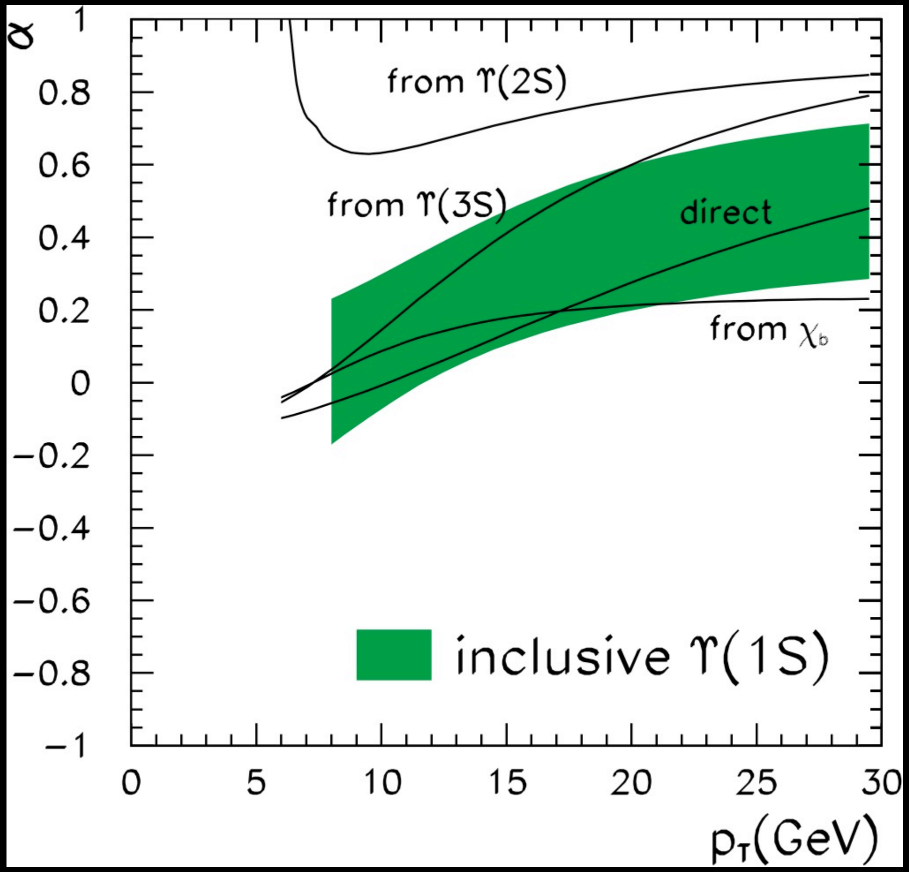


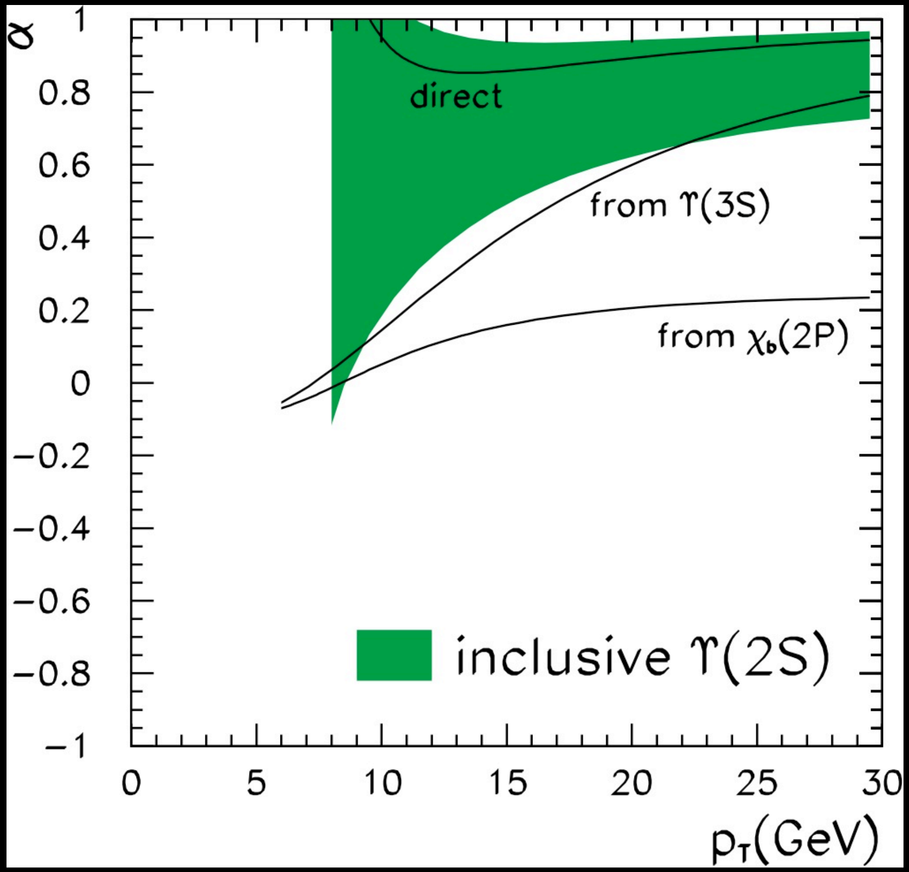
J/ψ Polarization



CDF measurements of prompt *J*/ψ, disagrees with NRQCD predictions in the high p_T region

Υ(nS) Polarization Predictions



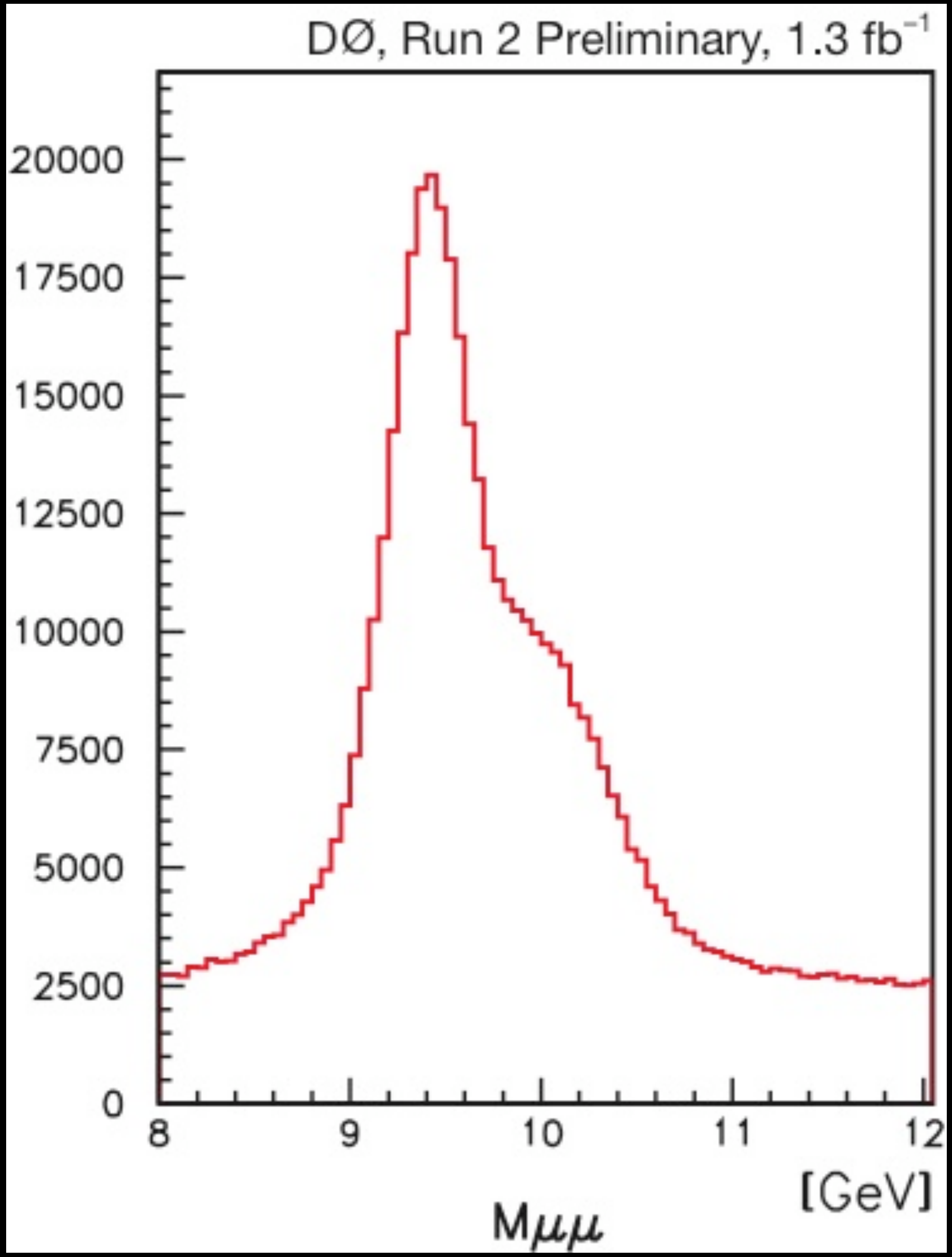


Quantitative calculations of the polarization for inclusive Υ(nS) mesons by NRQCD predictions for direct bottomonium production

(1)Transverse Polarization of Υ(1S) should increase steadily for p_T greater than 10GeV
(2) The Υ(2S) and Υ(3S) should be even more strongly transversely polarized.

Data

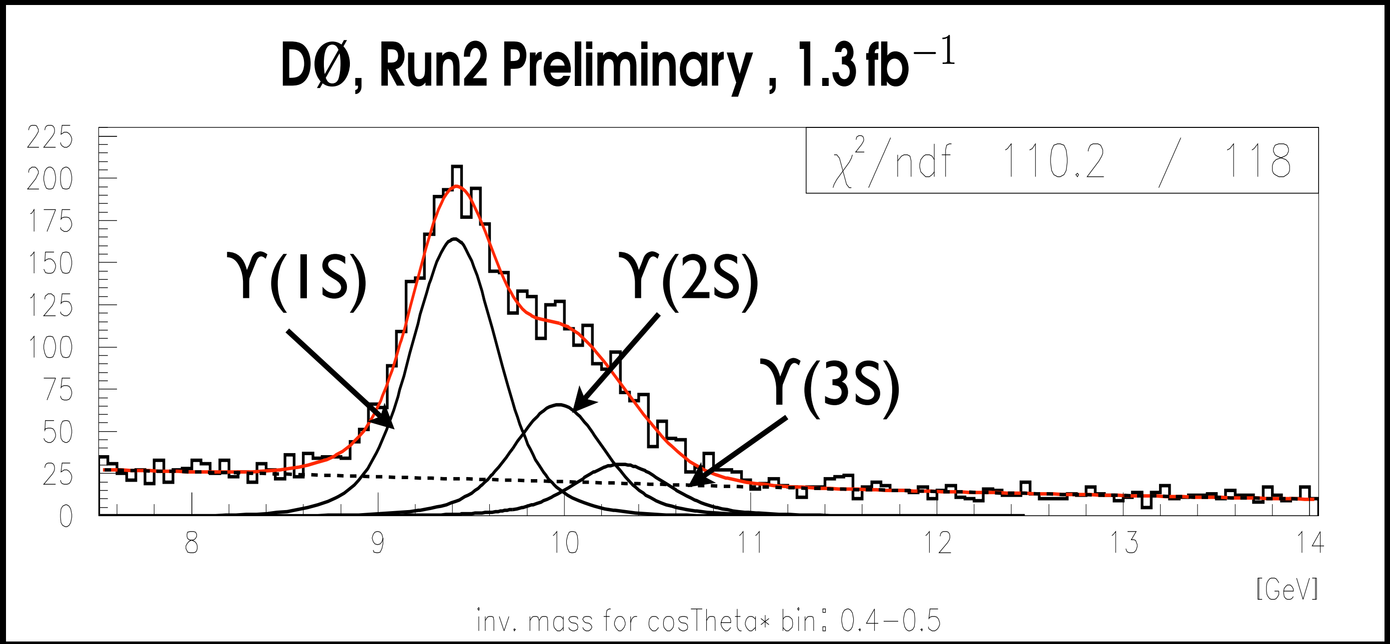
- Full RunIIa Data set
  - 1.3 fb^{-1}
- Base selection cuts
  - Two muons of opposite charge
  - Associated track in central tracking system with hits in both the SMT and CFT
  - Each muon was observed in 3 layers of the muon system
  - $p_T(\mu) > 3.5$ GeV



Extraction of Υ signal

- Mass differences, $\Delta M_{\Upsilon(nS)}$, were fixed and taken from PDG.

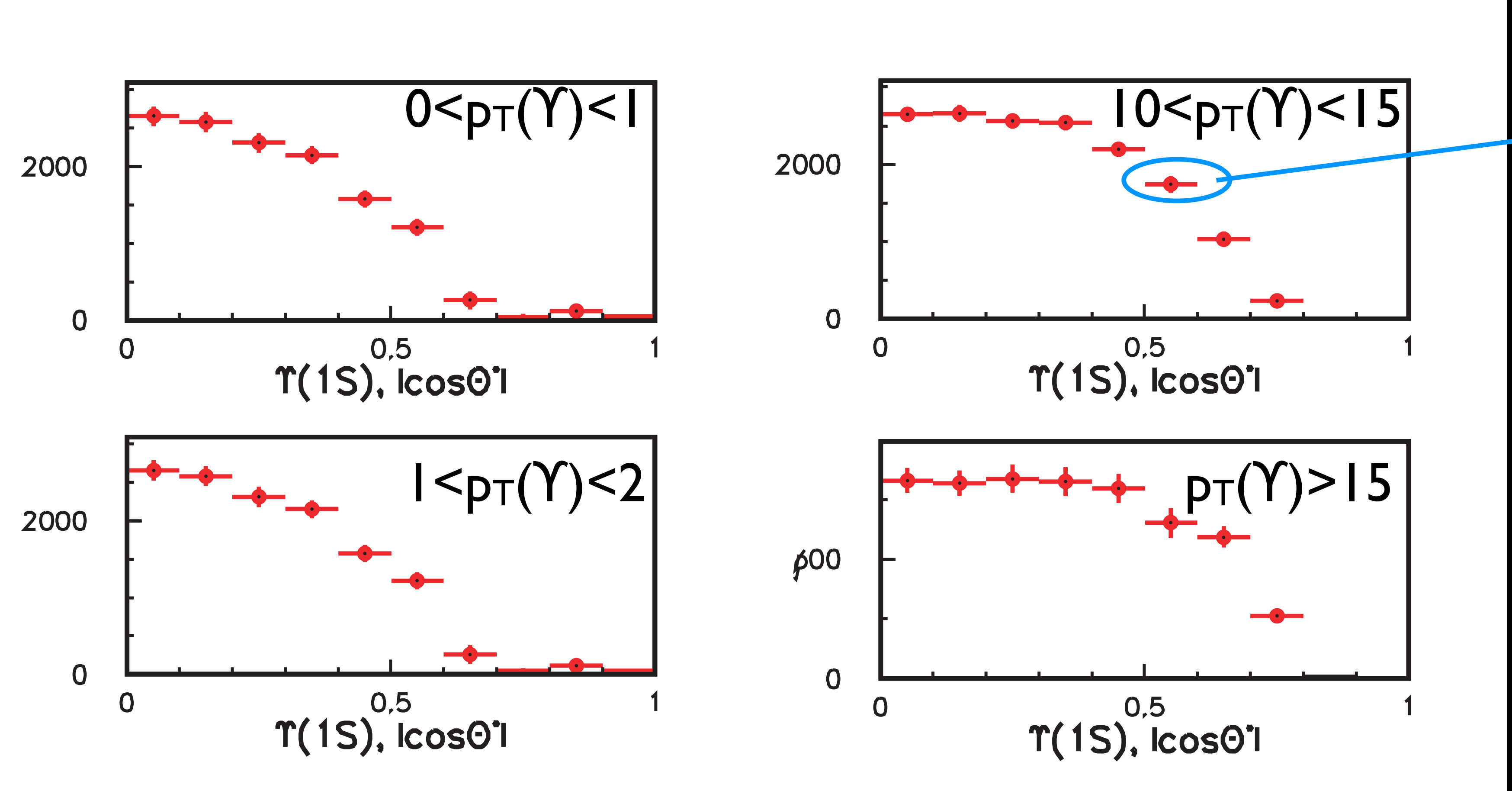
- Background model is convolution of an exponential and a polynomial function.
  - Degree of the polynomial was chosen between 1 to 6 depending on the complexity of the background shape.



$10 < p_T(\Upsilon) < 15$ GeV

$0.4 < \cos\theta^* < 0.5$

Extraction of Υ Signal

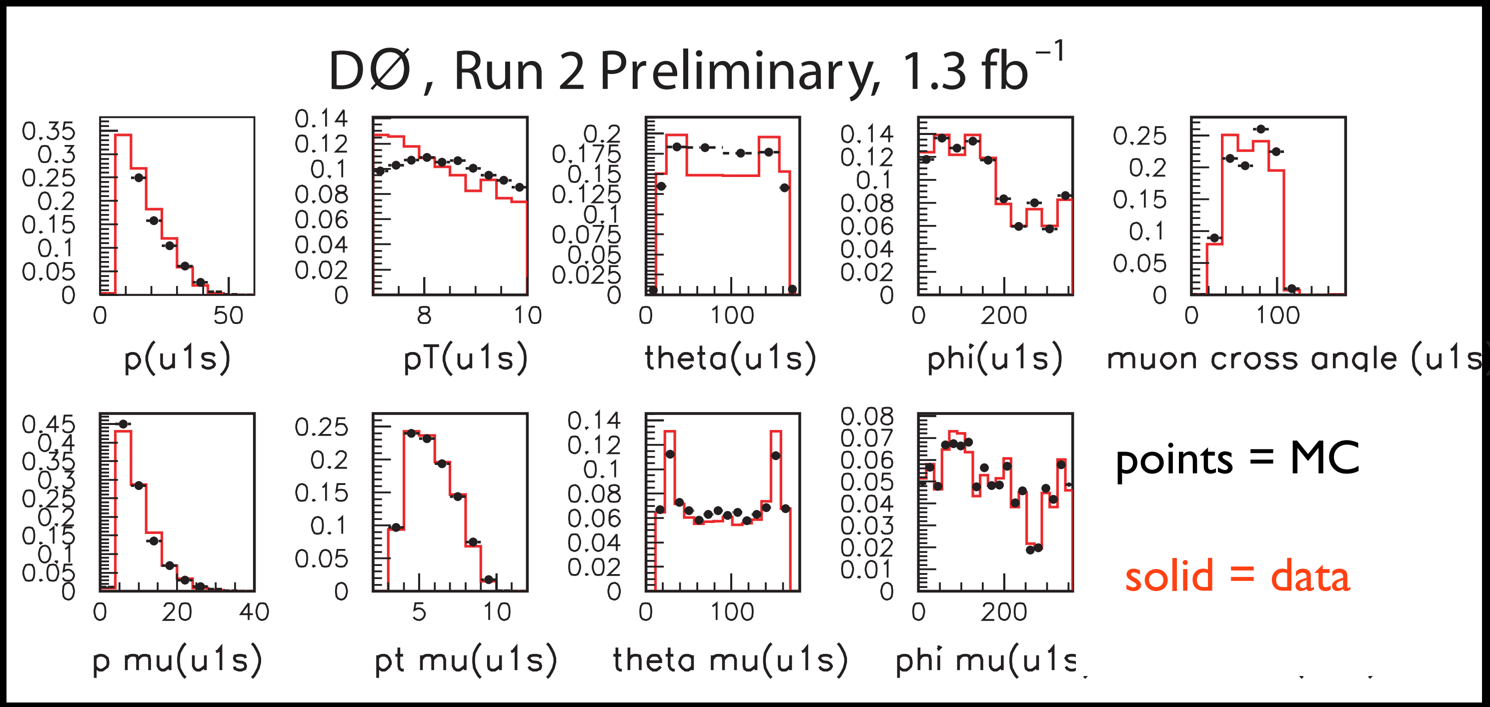


Each bin of histogram is separate fit in the data.

Binned in $p_T(\Upsilon)$

Correct Production of Υ

7<p_T(Υ)<10 GeV



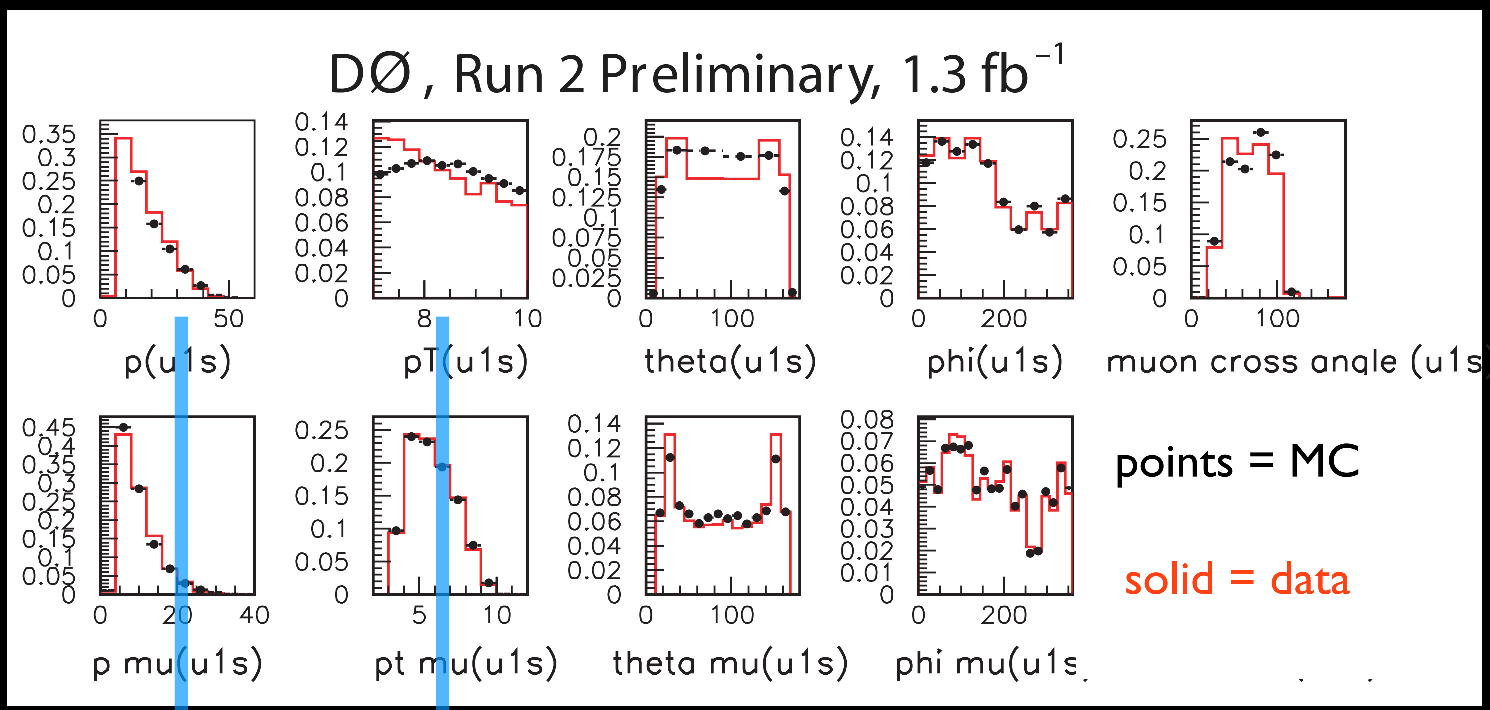
Monte Carlo does not correctly model p_T of Υ production

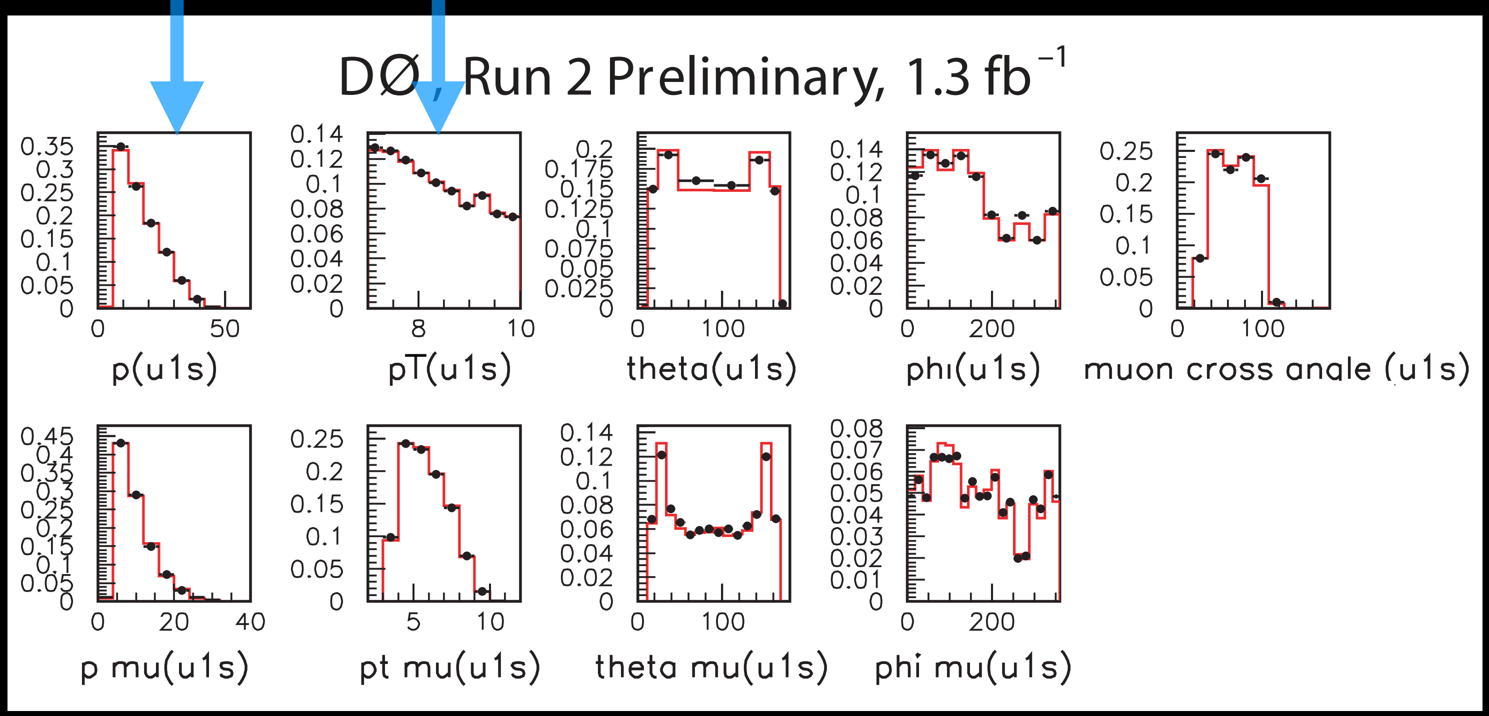
Weight p(Υ) & pT(Υ) separately for agreement of data and MC.

Apply these weighting functions also to all other distributions

Correct Production of Υ

$7<p_T(\Upsilon)<10$ GeV





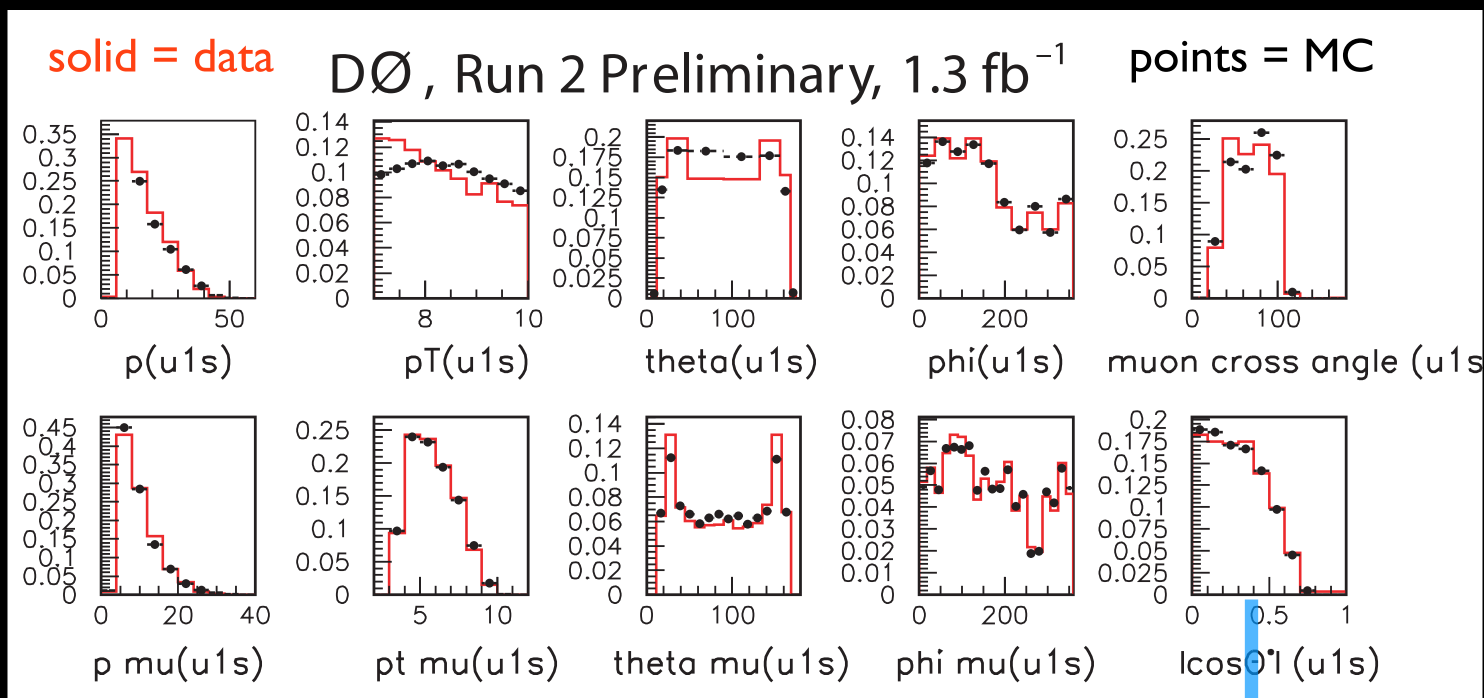
Monte Carlo does not correctly model p_T of Υ production

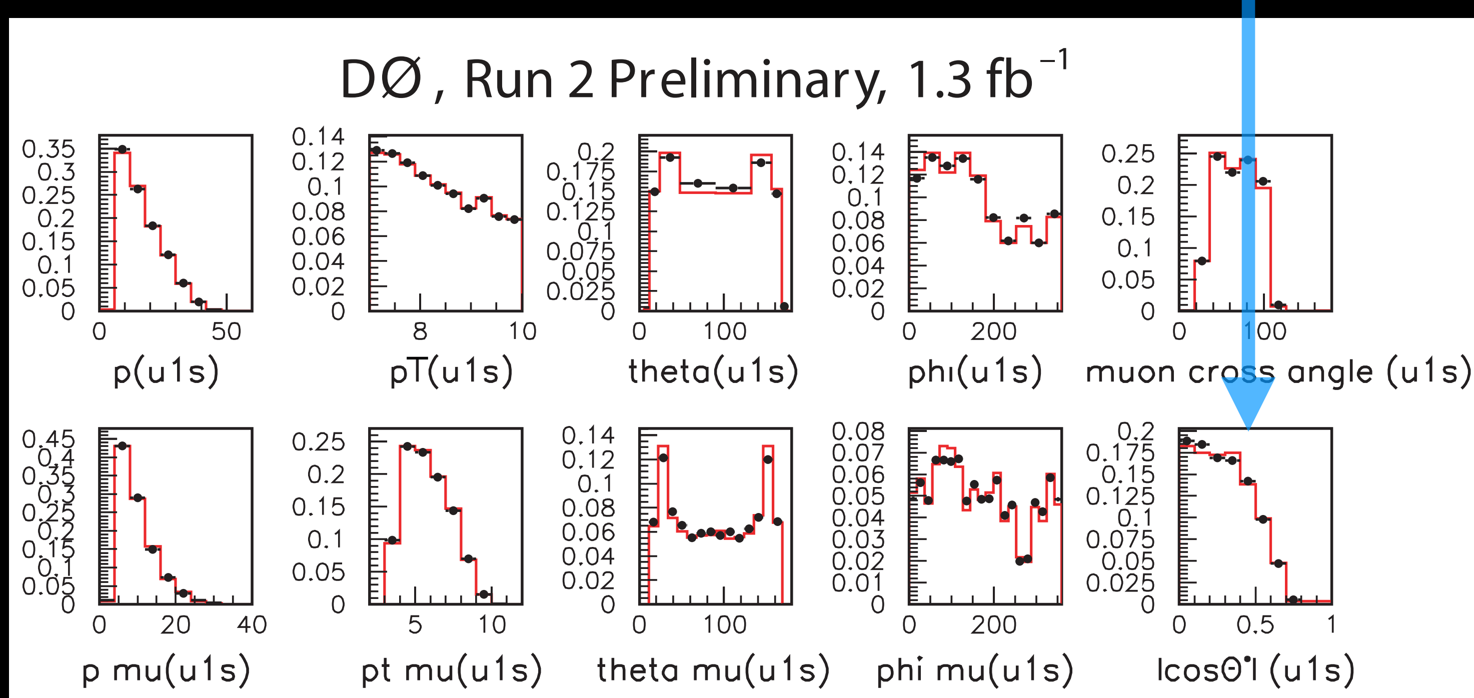
Weight $p(\Upsilon)$ & $pT(\Upsilon)$ separately for agreement of data and MC.

Apply these weighting functions also to all other distributions

Determining α

7<p_T(ϒ)<10 GeV





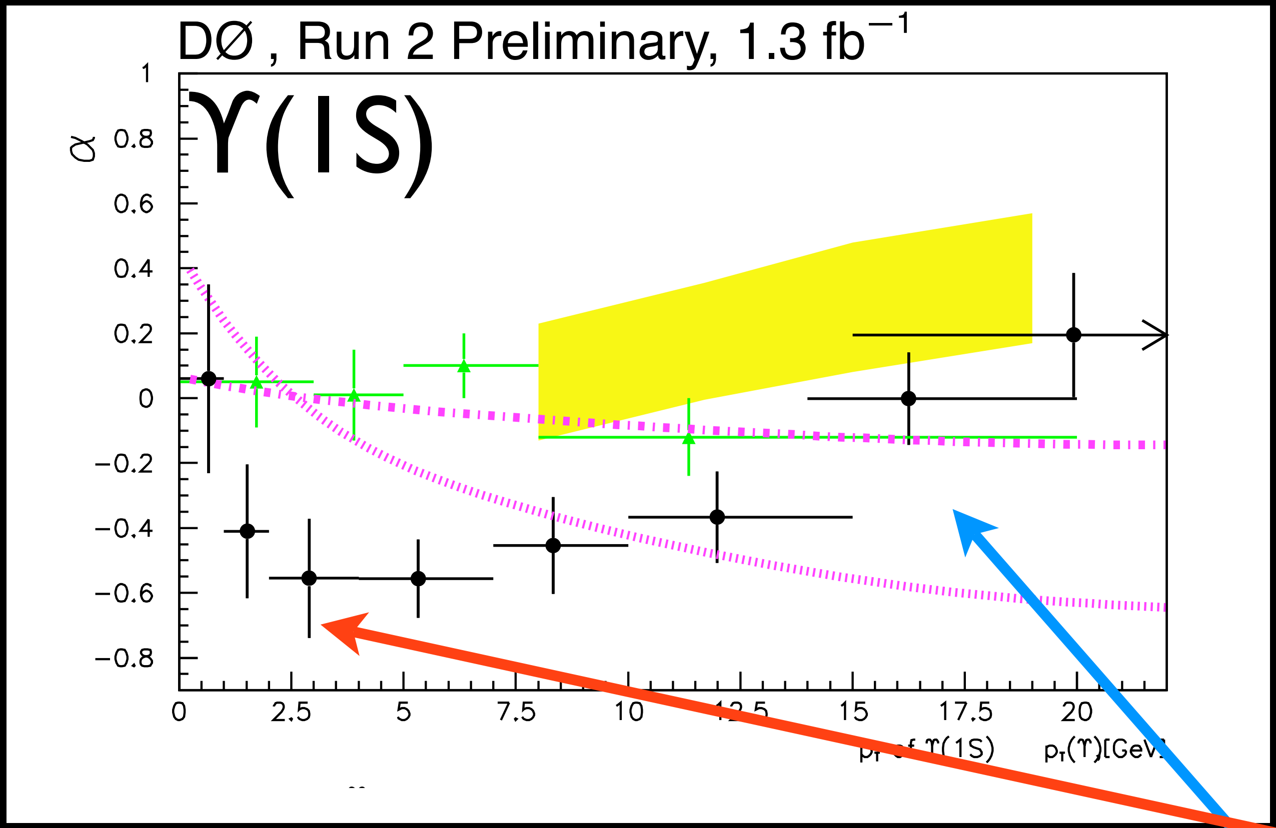
After kinematic reweighting, scan different values of α in MC (original α=0) and minimize the χ^2 between the data and MC to obtain best value of α.

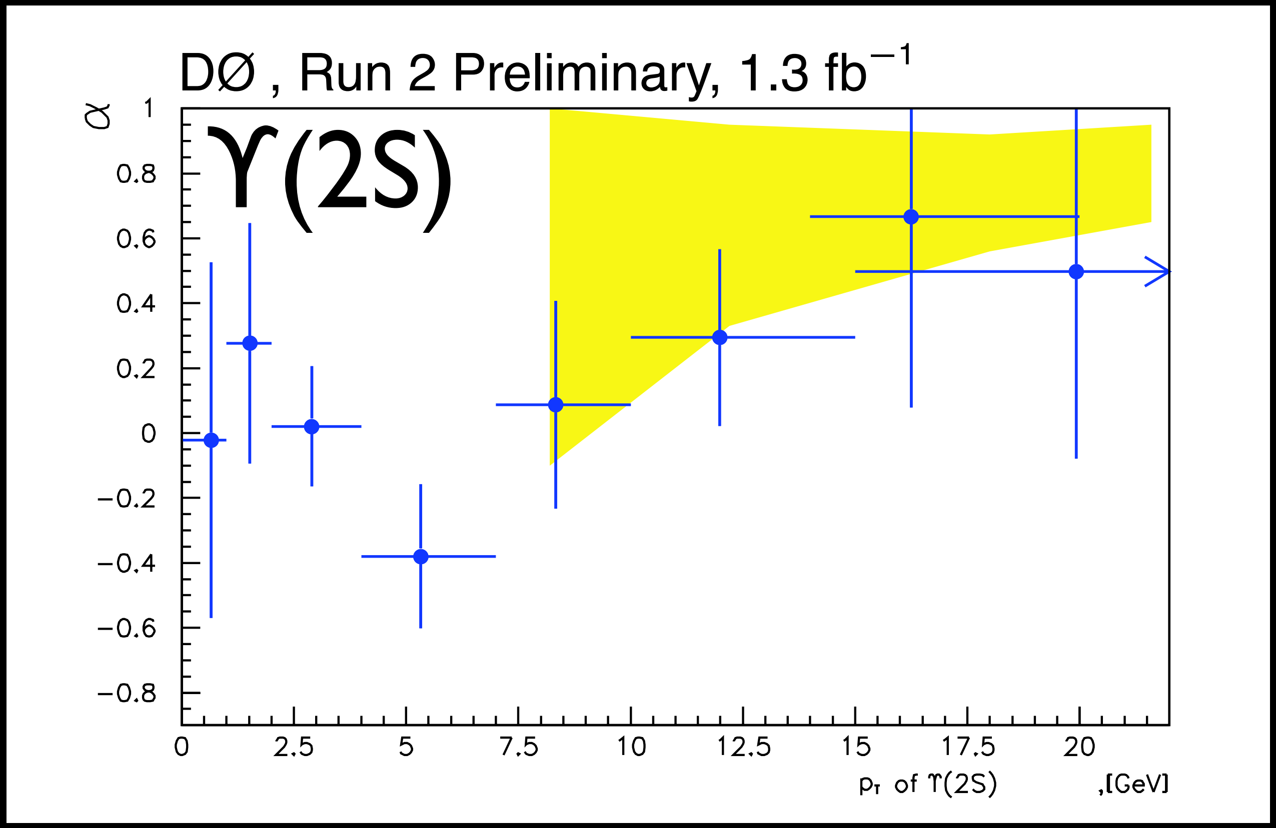
In this specific p_T bin, α = -0.42

Υ Systematics

Source	Error(α), all p_T intervals	p_T interval with the maximal error, [GeV]
Background approximation	0.04 - 0.21	0 - 1
Signal Model	0.01 - 0.15	1 - 2
MC (α dependence on Pt)	0.00 - 0.06	>15
MC (muon momentum reconstruction)	0.00 - 0.06	0 - 1
MC (trigger efficiency)	0.03 - 0.12	0 - 1

Results





Yellow band is NRQCD prediction

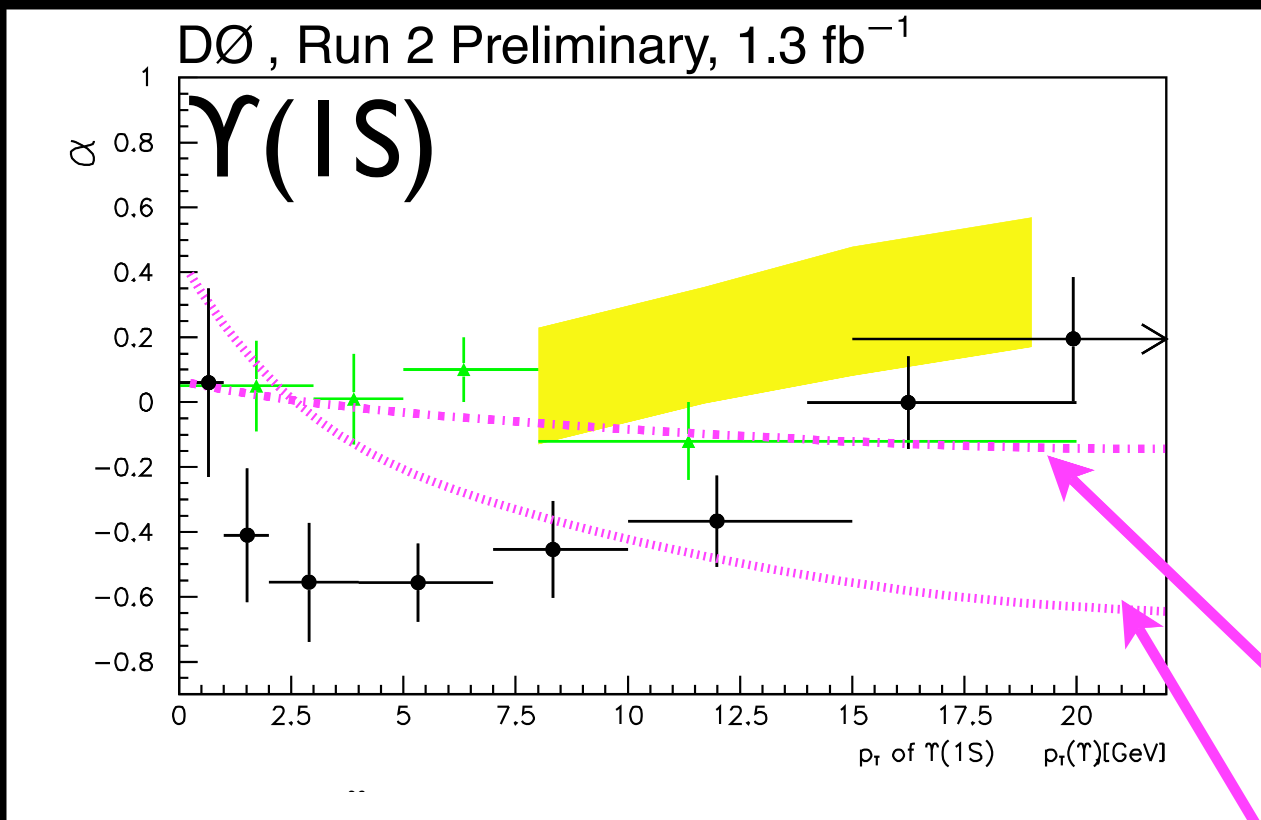
Strong longtudinal polarization at low p_T.

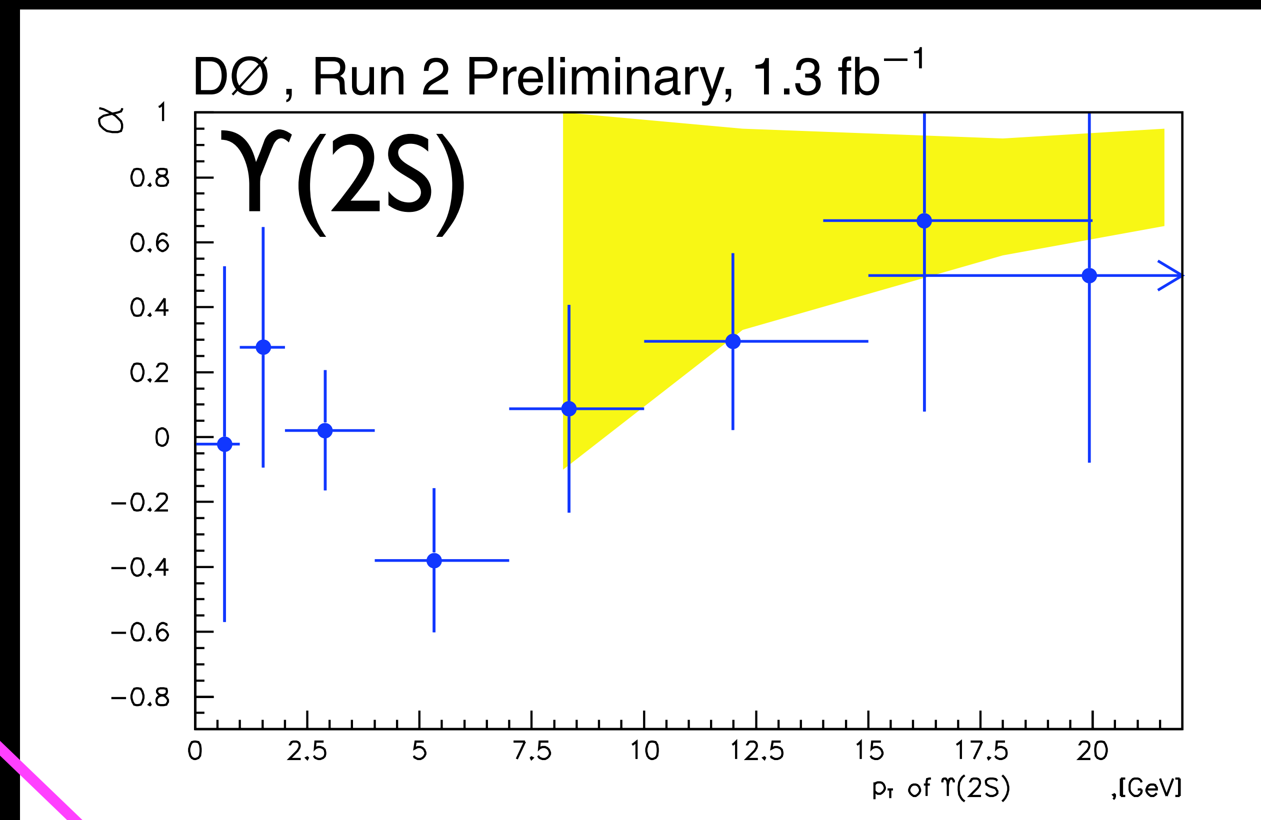
As p_T increases, α increases, but not up to the NRQCD Predictions

Points : D0 Data

Green Triangles : CDF Results

Results





Magenta Curves : Two limit cases of kt-factorization model

full quark-spin depolarization hypothesis

quark-spin conservation hypothesis

Points : D0 Data
Green Triangles : CDF Results

Υ-Polarization Results

- Presented a measurement of the polarization of the Υ(1S) and Υ(2S) as a function of p_T from 0-20 GeV
- Significant *longitudinal (not transverse)* polarization that is dependent on p_T is observed for the Υ(1S) that is *inconsistent with NRQCD Predictions*
- No contradiction to the NRQCD predictions for the Υ(2S) are observed

B_c Physics

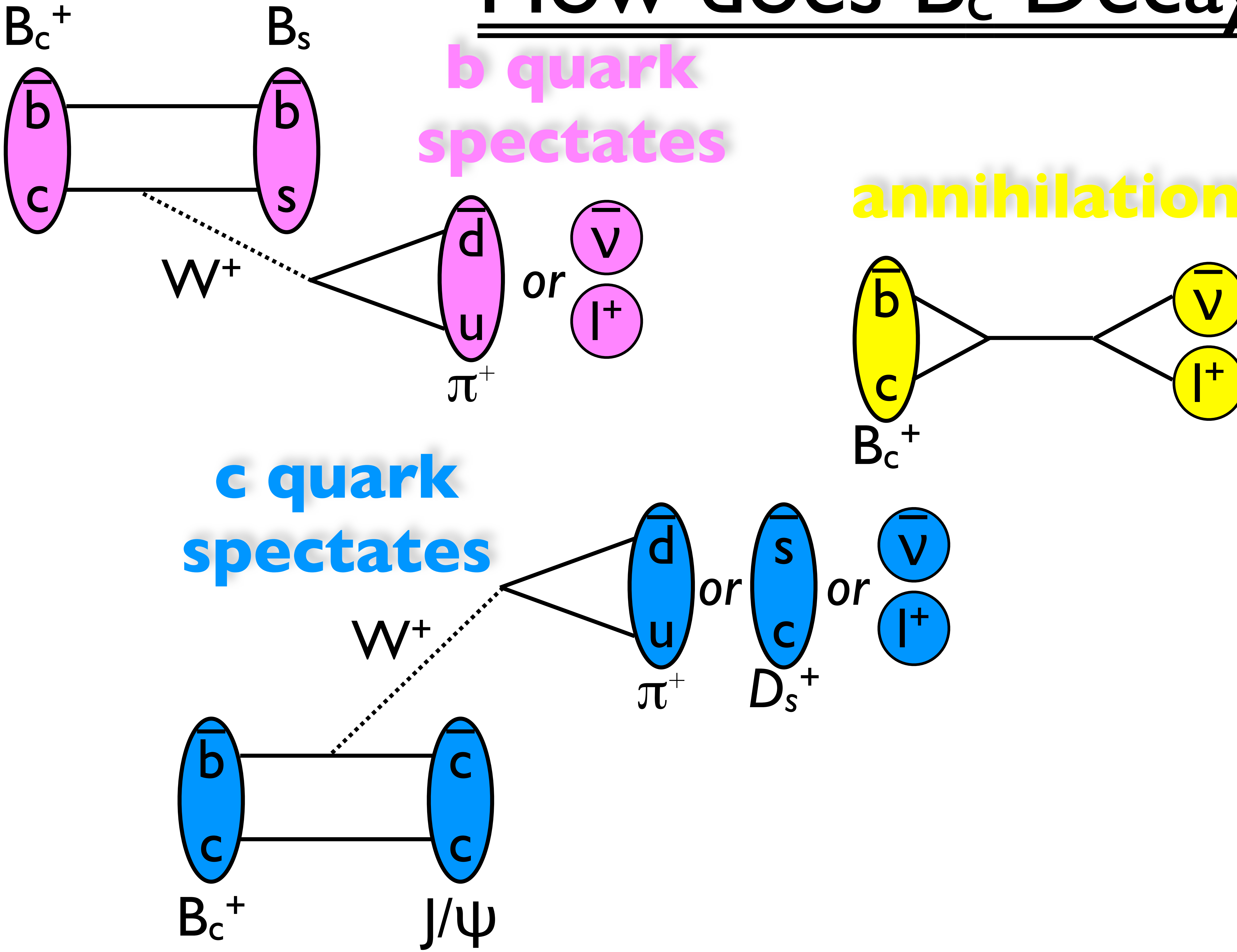
- The B_c meson is the ground state of the *bc* system
- Unique in that it carries two heavy quarks
  - Each can decay quickly
  - Interesting System for HQET predictions
  - Charmonium & Upsilon have two of the same, where as B_c has one of each
- Flavor carrying particle → Study Heavy Quark Dynamics
- Predicted to have a shorter lifetime than other B hadrons

$CDF : \tau(B_c) = 0.463^{+0.073}_{-0.065}(stat) \pm 0.036\ ps$ ⟶ PRL 97, 012002 2006

$D0 : \tau(B_c) = 0.448^{+0.123}_{-0.096}(stat) \pm 0.121\ ps$ ⟶ Preliminary Only D0 Note 4483

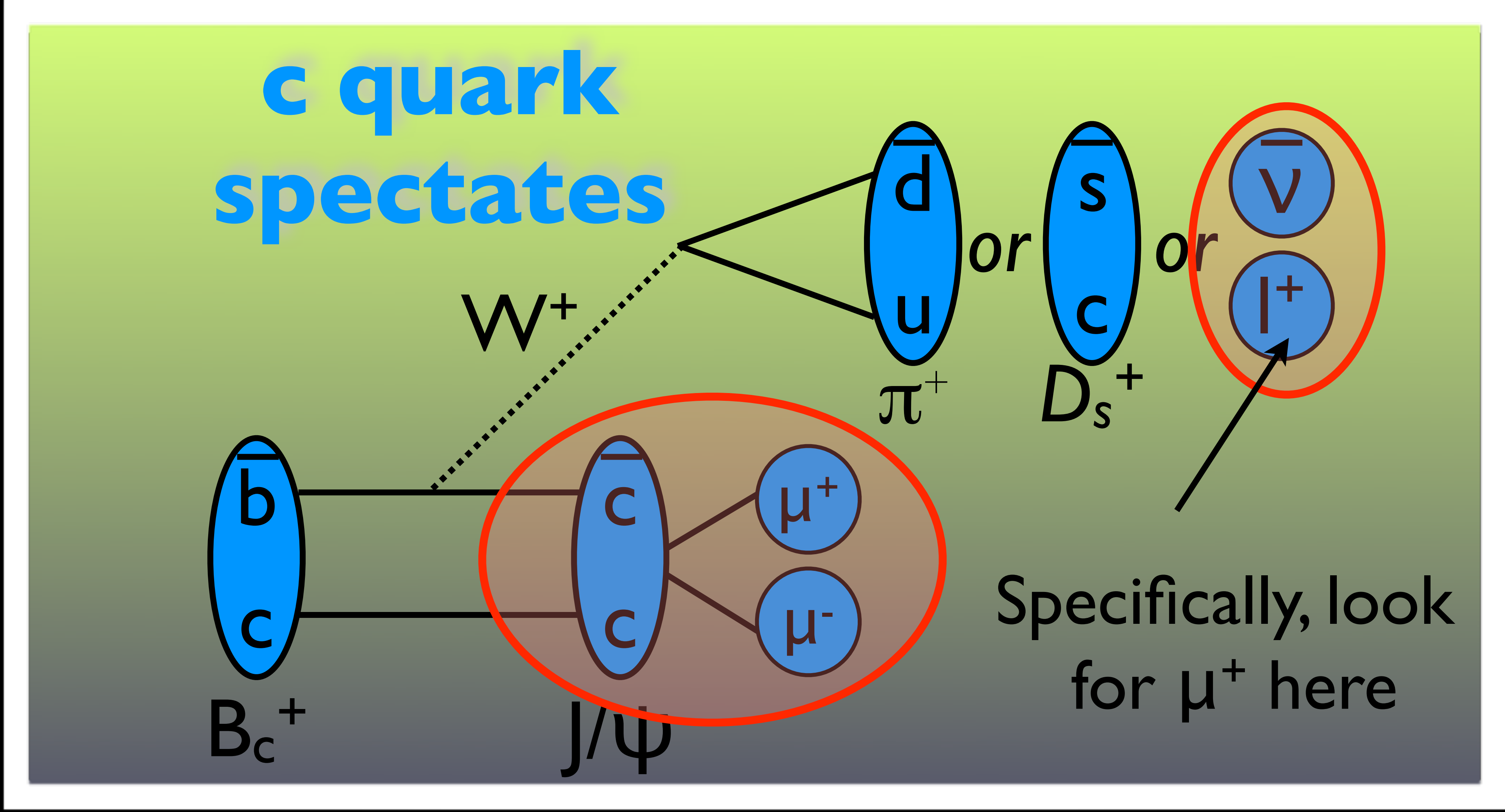
Theory, e.g., 0.48 +/- 0.05 ps (QCD Sum Rules)

How does B_c Decay?



B_c Meson Lifetime

- Lifetime measurement in the $J/\psi+\mu$ channel :

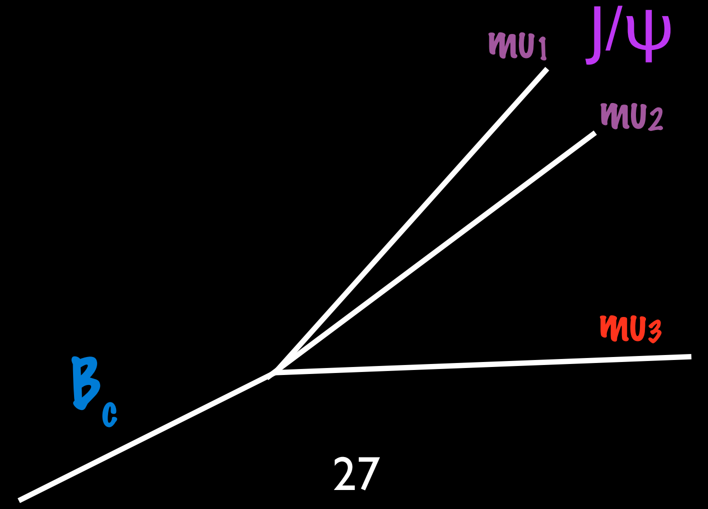


Lifetime Analysis Outline

- Data
  - Sample
  - Event Selection
- Contributions to the Data sample
- Demonstration of the B_c Signal
  - Presence of B_c
  - Demonstration of short signal lifetime
- Lifetime Analysis
  - Process
  - Results
- Conclusions

Data Sample

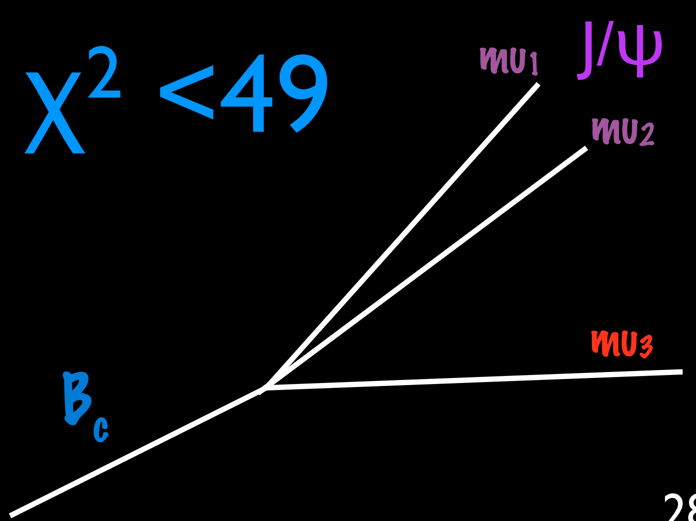
- Use all of the RunIIa data set taken between 2002-2006
    - Corresponds to ~1.3 fb^{-1} of data
- General Idea - Two Sets of Data pulled out
    - J/ψ associated with any other track
    - J/ψ associated with a muon
        - Notice that this is a subset
- Then apply more stringent cuts on each sample



Event Selection

Preselection

- $p(J/\psi) > 4$
- Each muon must have 1 hit in the SMT
  - μ_3 must have two
- $p_T(\mu_3)>2GeV$
- $SV(\chi^2)<100$
- $J/\psi + \mu\ \chi^2 <49$



Selection

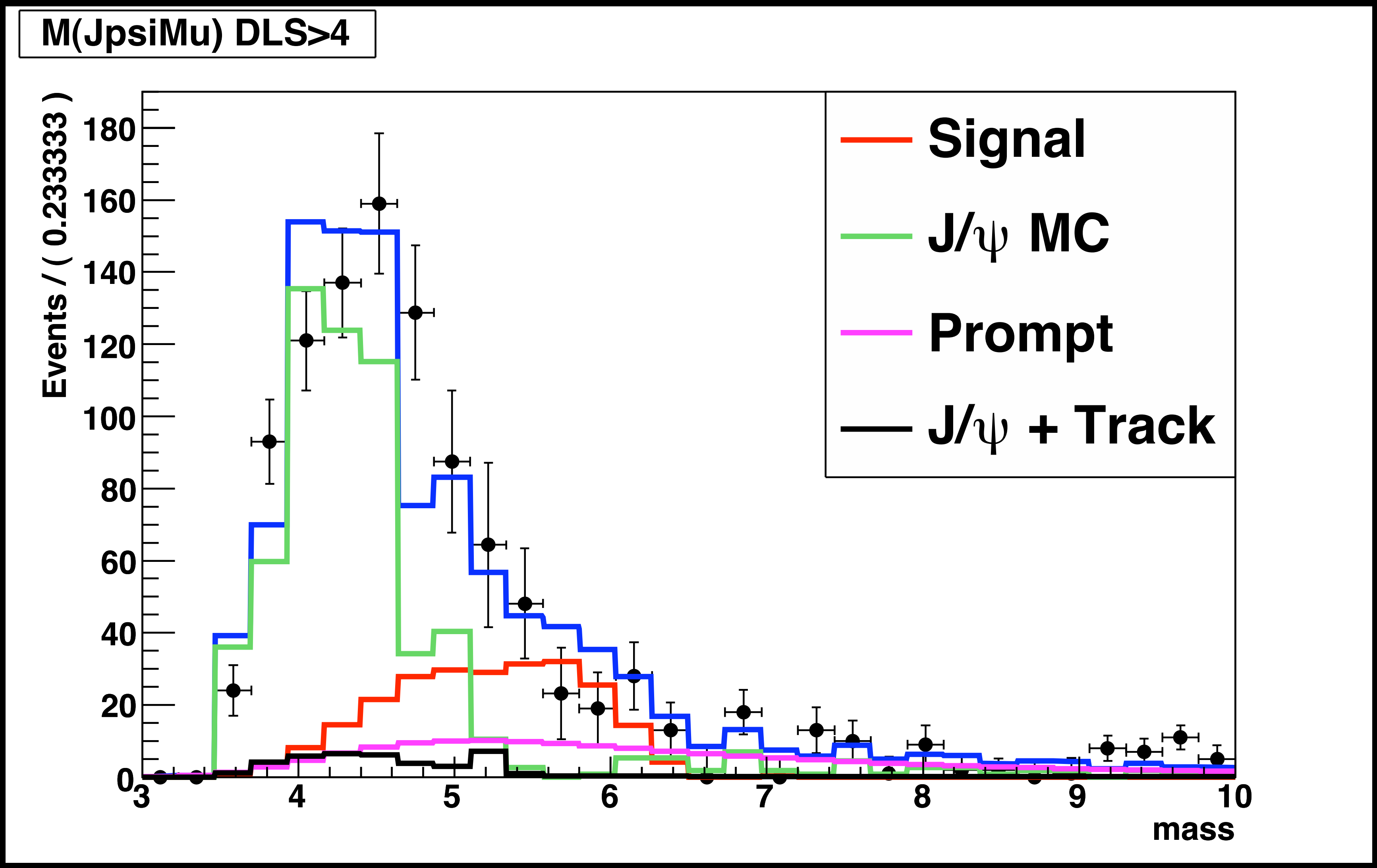
- $p_T(\mu_3) > 3$ GeV
- $p(\mu_3)>4$ GeV
- $p_T(J/\psi\mu) > 5$ GeV
- $\chi^2 <16$
- $nseg(\mu_3)=3$
- $Cos(\theta)$ btwn any two muons <0.99
- |sctime(A)|<10ns
- IP Biased Removed
- Angle btwn J/ψ & $\mu < 1$ rad

Contributions

- Real J/ψ + Fake μ
  - J/ψ + Track Data
- Fake J/ψ + Real μ
  - J/ψ Sideband Data
- Real J/ψ + Real μ
  - But each coming from different particle decays
  - J/ψ QCD Monte Carlo
- Prompt (i.e. J/ψ from cc(bar))
  - Negative Decay length J/ψ + μ Data
- B+
  - $B^+ \rightarrow J/\psi + K^+$
    - $(K^+ \rightarrow \mu^+ \nu)$ ← *decay in flight*
- Signal
  - B_c Signal Monte Carlo

Demonstration of Signal

Cutting on Decay Length Significance

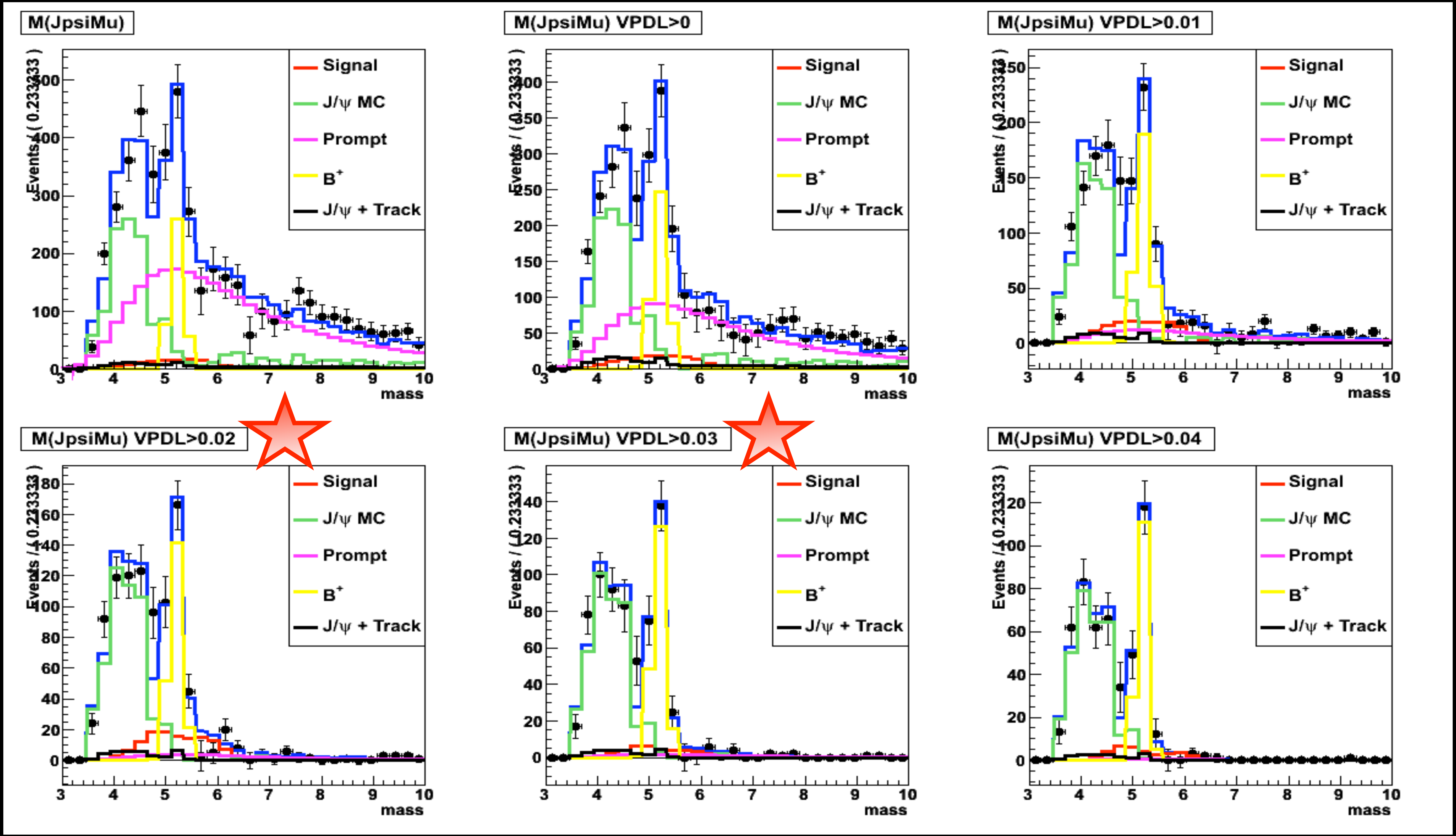


Prob of sig. to fluctuate down to bkg = 6.4σ

Prob. of bkg to fluctuate up to signal or more > 5σ

Demonstration of Short Decay Length

Cutting on Proper Decay Length



Lifetime Analysis

Minimize the Log-Likelihood!

$$\mathcal{L} = \prod_i \left(f_{jtrk} F^i_{Jtrk} + (1 - f_{jtrk}) F^i_{Jmu} \right)$$

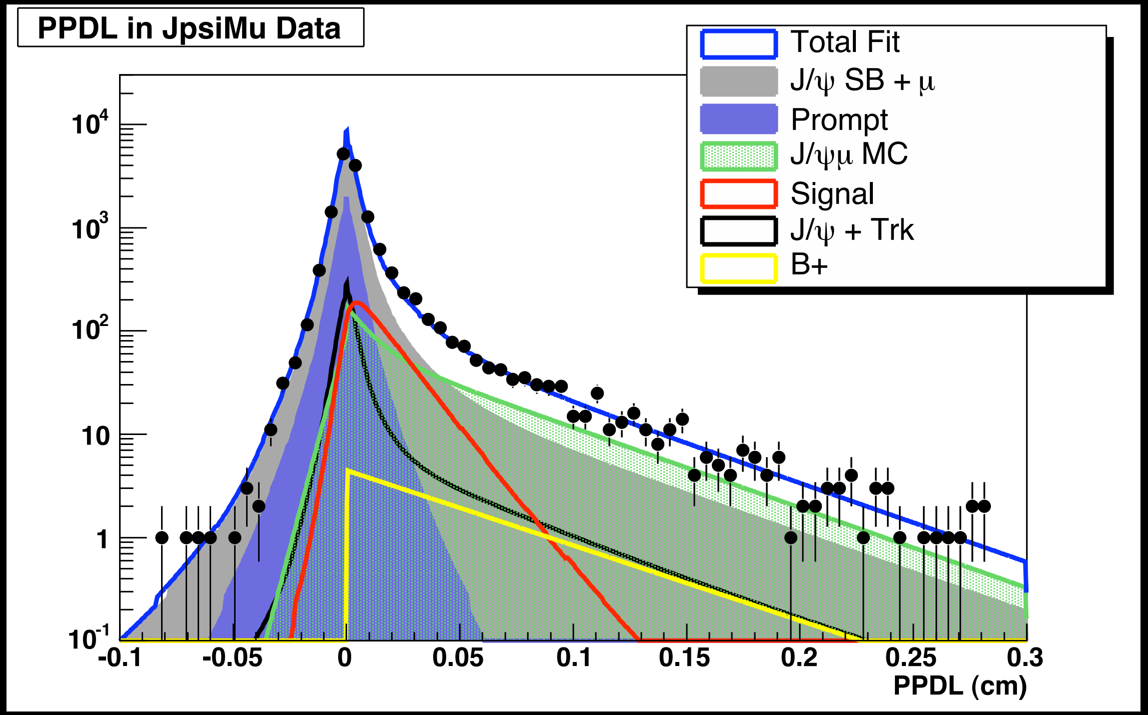
$$F^i_{Jmu} = f_{SB} F^i_{SB} + (1 - f_{SB})(f_{sig} F^i_{sig} + f^i_{JMC} F^i_{JMC} + f_{Bp} F^i_{Bp} + (1 - f_{sig} - f_{JMC} - f_{Bp}) F^i_{PR})$$

Each component consists of a normalized PDF of lifetime and mass multiplied together and the total is minimized

Lifetime Analysis

$$\tau(B_c) = 0.444^{+0.039}_{-0.036}(stat)^{+0.039}_{-0.034}(sys)\ ps$$

N(Signal Events) = 856 ± 85 (stat)

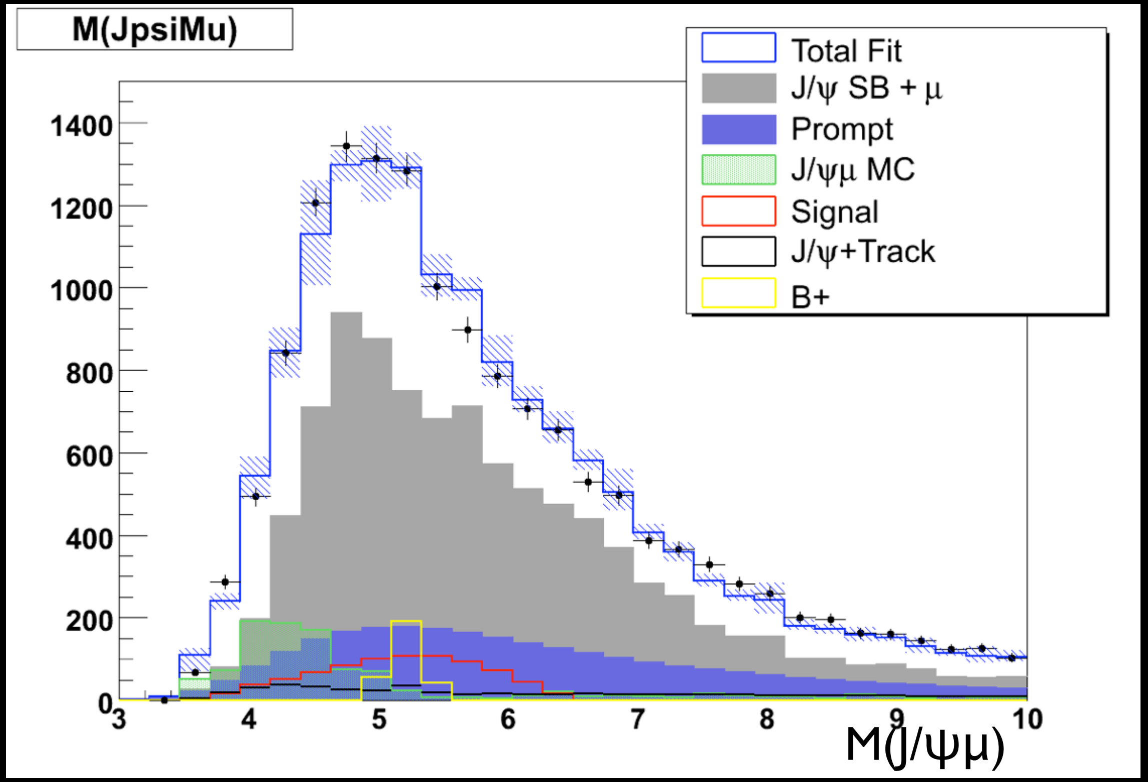


Previous D0 Result

$$\tau(B_c) = 0.448^{+0.123}_{-0.095}(stat) \pm 0.121(sys)\ ps$$

Current CDF Result

$$\tau(B_c) = 0.463^{+0.073}_{-0.065}(stat) \pm 0.036(sys)\ ps$$



Systematics

- Decay model of Signal
  - Phase space instead of Isgur-Wise (ISGW2)
  - Changes signal mass model & K factor
- MC weighting
  - Changes signal, ψ(2S), J/ψ MC mass model & K factor
  - Vary $p_T(B_c)$ within theoretical uncertainties (vary scale μ)
- Alignment
  - Reconstruct the MC using a new geometry file where silicon sensors are moved around within alignment uncertainty (as in the B_s lifetime)
  - Measure the lifetime in each sample and find the difference between the two.
- J/ψ MC mass distribution
  - Use only events which originated from a B^0 or B^+
    - i.e. rough equivalent of large composition variations
    - Also covers uncertainty in g→bb(bar) measured by CDF
- B^+ Mass distribution
  - Vary the background fit in the B^+ fit

- Sideband Mass distribution
  - Only left SB or only right SB
- Lifetime Models
  - Signal
    - Fix 's' at 1.2
  - Prompt
    - Single Gaussian instead of Double Gaussian
  - Sideband
    - Fix to $\pm 1\sigma$
  - J/ψ MC
    - Values which are fixed within a Gaussian penalty function get new starting point at $\pm 1\sigma$
  - B+
    - Fixed by Gaussian penalty function same as J/ψ MC
    - Let lifetime fully float → fitted value consistent with PDG B^+ lifetime. Giving a further check on the lifetime extraction
- Feed down
  - 0%
  - 13% (worst case)

Full List of Systematics

Test	*+Δ(τ) ps*	*-Δ(τ) ps*
Central Value		
Phase Space	0.0104	0.0104
s=1.2	0.0060	0.0060
Single Gaussian Prompt	0.0069	0.0069
J/ψ SB +1σ	0.0096	
J/ψ SB -1σ		0.0114
J/ψ MC +1σ	0.0036	
J/ψ MC -1σ		0.0042
B^+ Lifetime +1σ	0.0002	
B^+ Lifetime -1σ		0.0002
B^+ Lifetime Float	0.0067	0.0067
B+ Mass Distribution	0.0040	0.0040
J/ψ MC Mass Distribution	0.0197	0.0197
Prompt Mass +1σ	0.0050	
Prompt Mass -1σ		0.0048
Remove Weighting	0.0086	0.0086
Alignment	0.0059	0.0059
B_c p_T 2*μ	0.0219	
B_c p_T μ/2		0.0025
J/ψ SB Left Mass	0.0131	
J/ψ SB Right Mass		0.0144
0% Feed Down		0.0032
13% Feed Down	0.0037	
TOTAL	**0.0392**	**0.0338**

B_c Lifetime Conclusions

- Using 1.3 fb^{-1} of data, a measurement on the B_c lifetime has been made in the semileptonic channel : $B_c \to J/\psi + \mu + X$
- An unbinned likelihood simultaneous fit to the $J/\psi+\mu$ invariant mass and lifetime distributions giving 856 ± 85 signal events and a lifetime of :

$$\tau(B_c) = 0.444^{+0.039}_{-0.036}(stat)^{+0.039}_{-0.034}(sys)\ ps$$

- <u>World's most precise measurement</u>
- Consistent with previous measurements and theoretical predictions
  - QCD Sum Rules : 0.48 +/- 0.05 ps