Summary of WG4 second meeting

Eric Laenen

NIKHEF

1.	B_c and double heavy baryons	4 talks
2.	Quarkonium production	5 "
3.	B production	3 "
4.	Fragmentation	4 "

+ much discussion

B_c and double heavy baryons

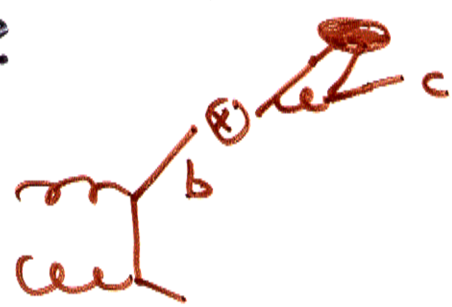
$B_c\,[\bar{b}c]$ observed by CDF in '98

$m \simeq 6.4$ GeV, $\tau \simeq 0.4$ ps

Chen and Likhoded presented studies of the B_c production mechanism.

Both did full α_s^4 calc'n →

Question: how well approximated by much simpler fragmentation approx.?



Answer: only ok for $p_T^{B_c} \gg m$ (30 GeV)

- δ(Normalization) ~ × 2-4
- Codes available

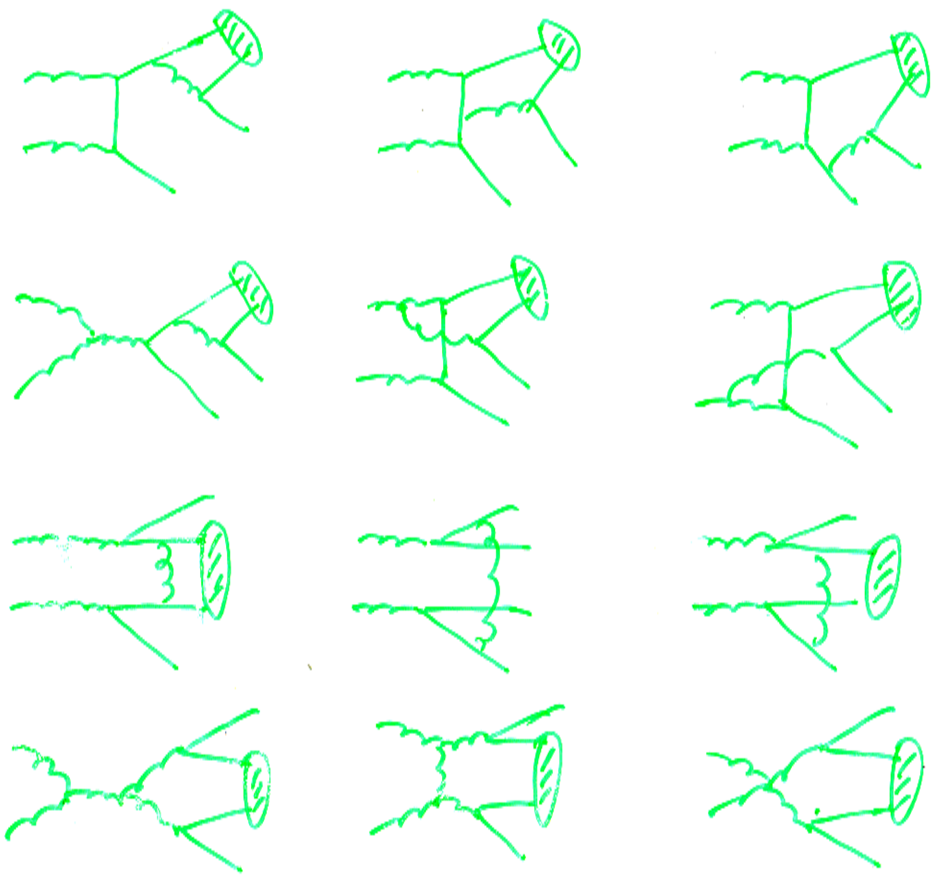
II. α_s^4 full QCD calculation

subprocess

$$g + g \to B_c^+ + b + \bar{c}$$

tree level α_s^4

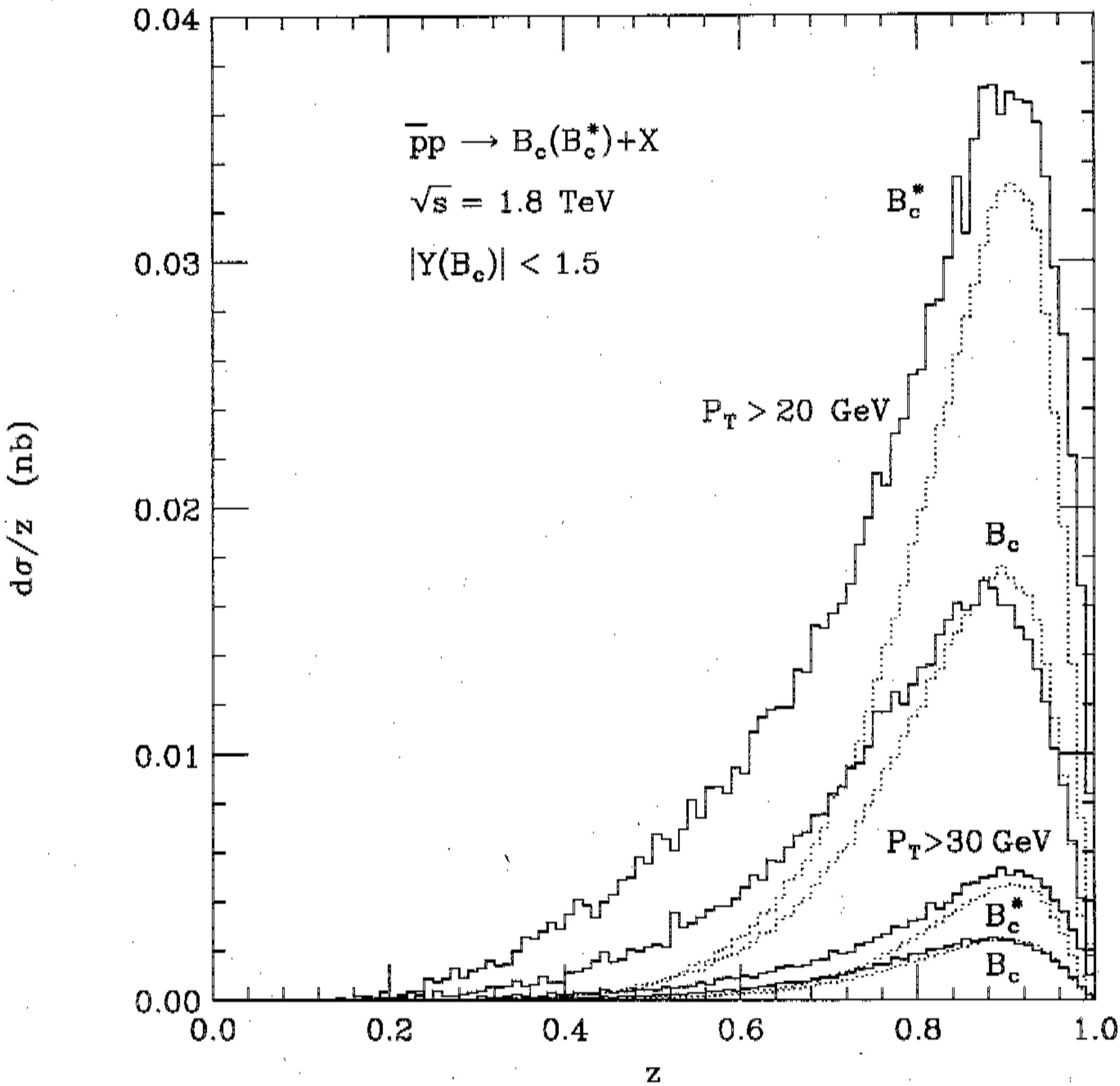
36 Feynman diagrams



color factor $T^a T^b T^c T^d$

gluon vertex $f^{abc} T^c = [T^a, T^b]$

Chen



$z = \frac{E_{B_c}}{\sqrt{s}}$

FIGURE 3b

Rick van Kooten looked at triggering & reconstruction of B_c's @ DØ

- used 450 fully GEANT simulated events (from PYTHIA) [for trigger simulator]

- reweighted PYTHIA with Likhoded calculation

- dimuon trigger ≃ 15% eff.

- electron trigger ≈ 13% eff [bkgd]

- vertex trigger [tough, short B_c lifetime] "to do"

Expects: 600 fully reconstructed $B_c^{\pm} \to J/\psi\, \ell^{\pm} \nu$ in $2 fb^{-1}$

Doubly Heavy Baryons

[Likhoded]

$[QQ'q]$ quark-diquark

Production mechanism ~ B_c

except · QQ' must bind to $\bar{3}$

· Prob ($QQ' \to$ Baryon)

Estimate:

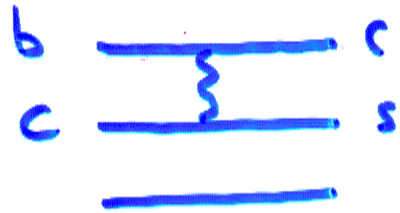
$m_{\Xi_{bc}} \simeq 6.8$ GeV ?

$$\frac{\sigma[B_c]}{\sigma[\Xi_{bc}]} \simeq 2$$

opt $\to 10^5$ Ξ_{bc} @ run I

pess $\to$ 100 "

Decays



or

or..

Keith Ellis (+ RvK + AL) are hoping to estimate branching fractions (cf. Bjorken), and promising decay modes [especially involving J/ψ's → triggerable]

"Best buys" ⇝

Rick van Kooten is studying kinematic aspects of $\Xi_{QQ'}$ decays

⇝

Tentative QQq baryon best buys

No estimate of Branching Ratios, trigger efficiencies yet! Decays with J/ψ are easy to trigger and J/ψ eats Q-value which would otherwise end up in additional π's. Firstly the Cabibbo suppressed (C.S.) decay

$$\Xi_{cb}^{+}(ucb) \rightarrow \Lambda_c^{+}(udc)\; J/\psi(c\bar{c})$$

$J/\psi \hookrightarrow \mu^+\mu^-$

$\Lambda_c^+ \hookrightarrow p^+\; K^+\; \pi^-$

$$\Xi_{cb}^{0}(dcb) \rightarrow \Xi_c^{0}(dsc)\; J/\psi(c\bar{c})$$

$J/\psi \hookrightarrow \mu^+\mu^-$

$\Xi_c^0 \hookrightarrow \Lambda^0 \bar{K}^0(\rightarrow \pi^- p^+ \pi^+ \pi^-)$

$$\Xi_{cb}^{+}(ucb) \rightarrow \Xi_c^{+}(usc)\; J/\psi(c\bar{c})$$

$J/\psi \hookrightarrow \mu^+\mu^-$

$\Xi_c^+ \hookrightarrow \Xi^- \pi^+ \pi^+ (\rightarrow \pi^- \Lambda^0 \pi^+ \pi^+)$

For the ubb we have

$$\Xi_{bb}^{0}(ubb) \rightarrow \Xi_{cb}^{+}\; \pi^-$$

$\Xi_{cb}^+ \hookrightarrow$ as above

and the (C.S.) decays

$$\Xi^0_{bb}(ubb) \quad \to \quad \Lambda^0_b(udb)\ J/\psi(c\bar{c})$$

$$J/\psi \hookrightarrow \mu^+\mu^-$$

$$\Lambda^0_b \hookrightarrow \Lambda_c^+\pi^-(\to p^+\ K^-\ \pi^+\ \pi^-)$$

$$\Xi^-_{bb}(dbb) \quad \to \quad \Xi^-_b\,(dsb) + J/\psi(c\bar{c})$$

If production favorable, bcq may be easier to find than ccq.

Decays without a J/ψ may be still accessible due to cascading decays. A double-heavy baryon with a short (i.e., "charm-like") lifetime can decay into a charm meson with reasonably long lifetime such as the $D^\pm$ ($\tau = 1.06$ ps). These decays are the good for BTeV.

The best *ubc*-baryon decay mode in this class may be:

$$\begin{aligned} \Xi_{cb}^{+}(ucb) \quad &\rightarrow \quad D^{*+}\, pK^- \\ &\qquad \hookrightarrow K^-\pi^+\pi^+ \end{aligned}$$

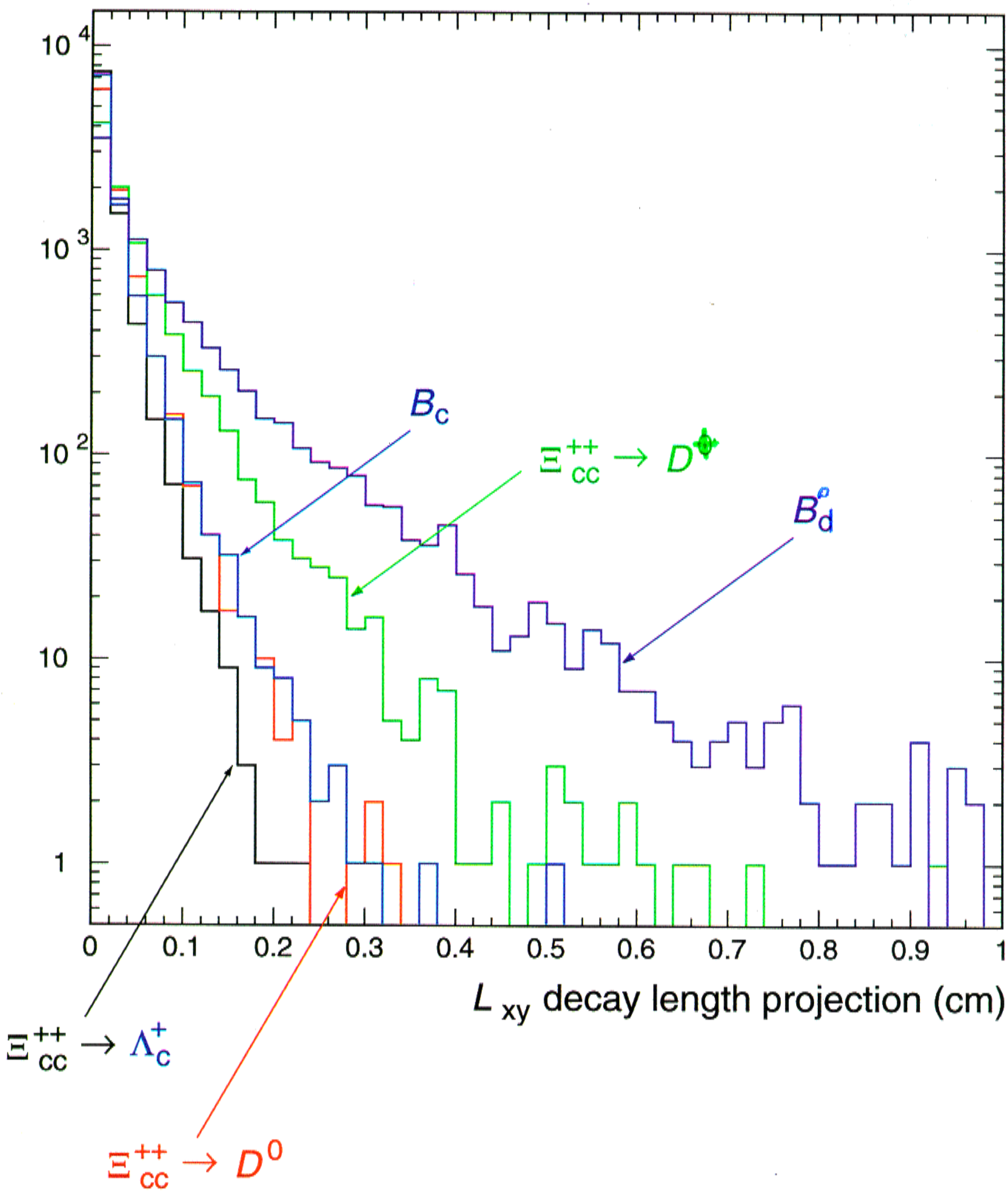
The best *dcb*-baryon decay without a J/ψ may be:

$$\begin{aligned} \Xi_{cb}^{0}(dcb) \quad &\rightarrow \quad D^{*+}\, p\,\pi^-\, K^- \\ &\qquad \hookrightarrow K^-\pi^+\pi^+ \end{aligned}$$

and the analogous:

$$\begin{aligned} \Xi_{cc}^{++}(ucc) \quad &\rightarrow \quad D^{*+}\, p\bar{K}^0 \\ &\qquad\qquad\quad \hookrightarrow \pi^+\pi^- \\ &\qquad \hookrightarrow K^-\pi^+\pi^+ \end{aligned}$$

or



- Redo (oops) with impact parameter
- Smear
- Assess chances of silicon track trigger

Quarkonium production and polarization

Qiu-Sterman

Geoff Bodwin discussed (proof of) factorization of $d\sigma[\text{onium}]$

$$\frac{d\sigma}{dp_T^{J/\psi}} = \sum_{\substack{ij \\ n}} \int \phi_i \otimes \phi_j \otimes d\sigma_{ij \to Q\bar{Q}_n} \otimes \langle O_n^{J/\psi} \rangle \quad (**)$$

"NRQCD"

Sean Fleming analyzed bottomonium production @ Tevatron in NRQCD.

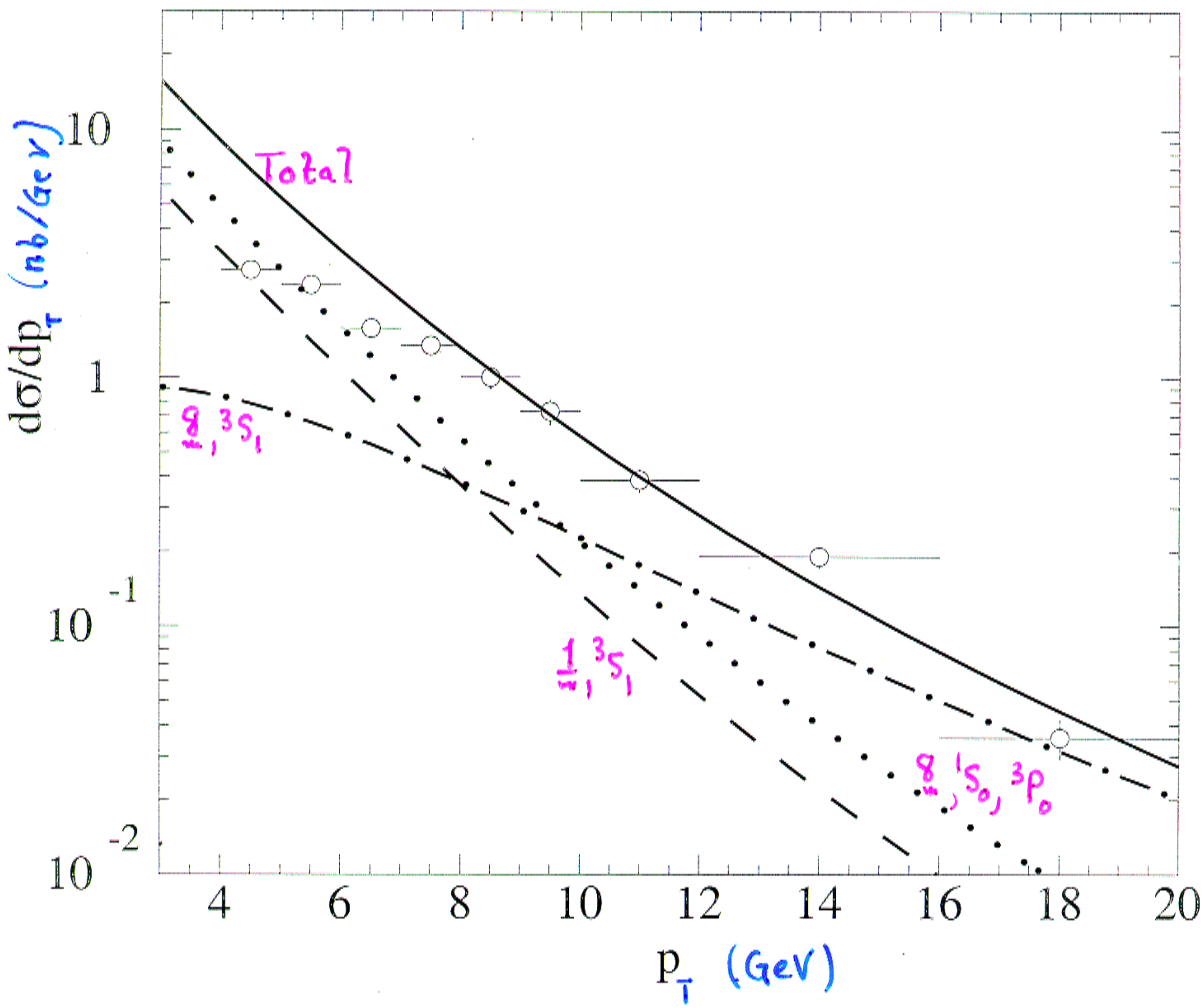
- Fitted $\langle O_n^{\Upsilon} \rangle_{total} \equiv \sum_H B_{r_{H \to \Upsilon}} \langle O_n^H \rangle$

via (**) to CDF $\Upsilon(1S,2S,3S)$ data

⇒

More input to determine the many ⟨O's⟩ required for NRQCD

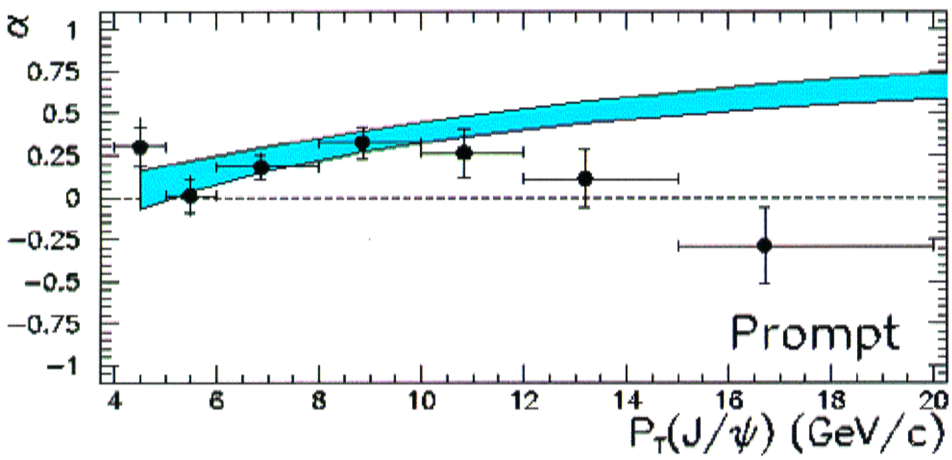
Υ(1S)

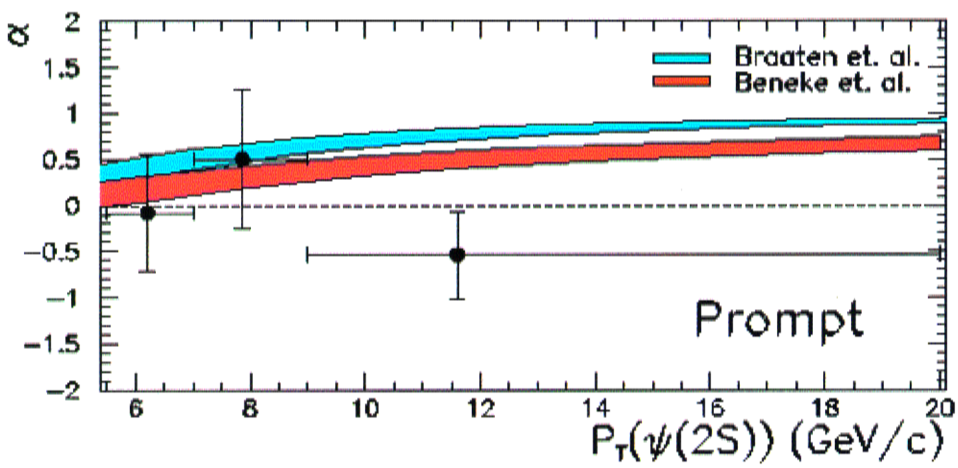


Total
8, ³S₁
1, ³S₁
8, ¹S₀, ³P₀
dσ/dp_T (nb/GeV)
p_T (GeV)
10
1
10⁻¹
10⁻²
4
6
8
10
12
14
16
18
20

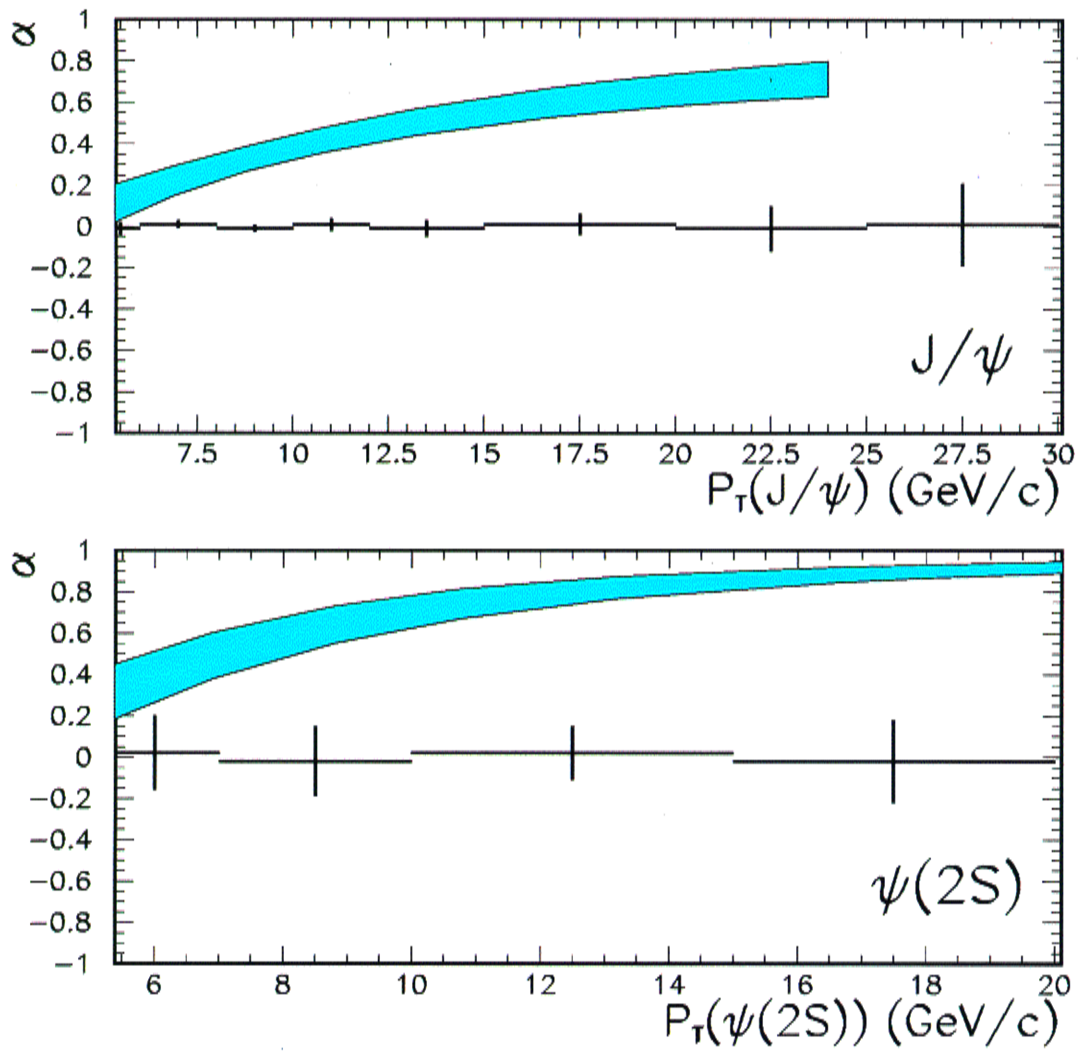
ψ/ψ' Polarisation Results from Run-I

- Hope to publish these in next couple of months





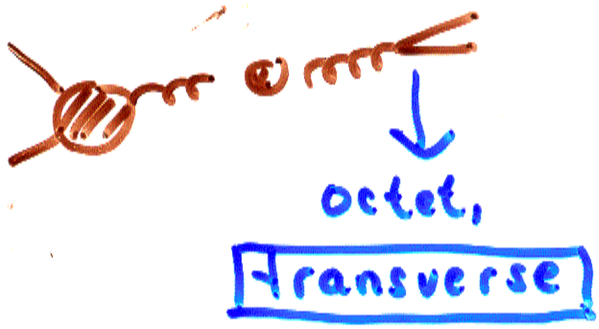
Predictions for ψ/ψ' in Run-II



√N SCALING

Next, polarized onium production.

Idea: at large enough p_T, onium should be due to



William Trischuk showed current results for CDF & issued expectations and warnings for Run II.

- ψ's → Run I → Run II
  Run II: no current plan for ψ' triggers
- Υ's no evidence for polarization
  " + more high-p_T events enough?

Eric Braaten [+ Jungil Lee] discussed (polarized) onium production in NRQCD @ Tevatron

Get $\langle O_1^{J/\psi}(^3S_1)\rangle$ from $\Gamma_{J/\psi \to e^+e^-}$

$\frac{1}{50}$ ↱ $\langle O_8^{J/\psi}(^3S_1)\rangle$ from CDF data

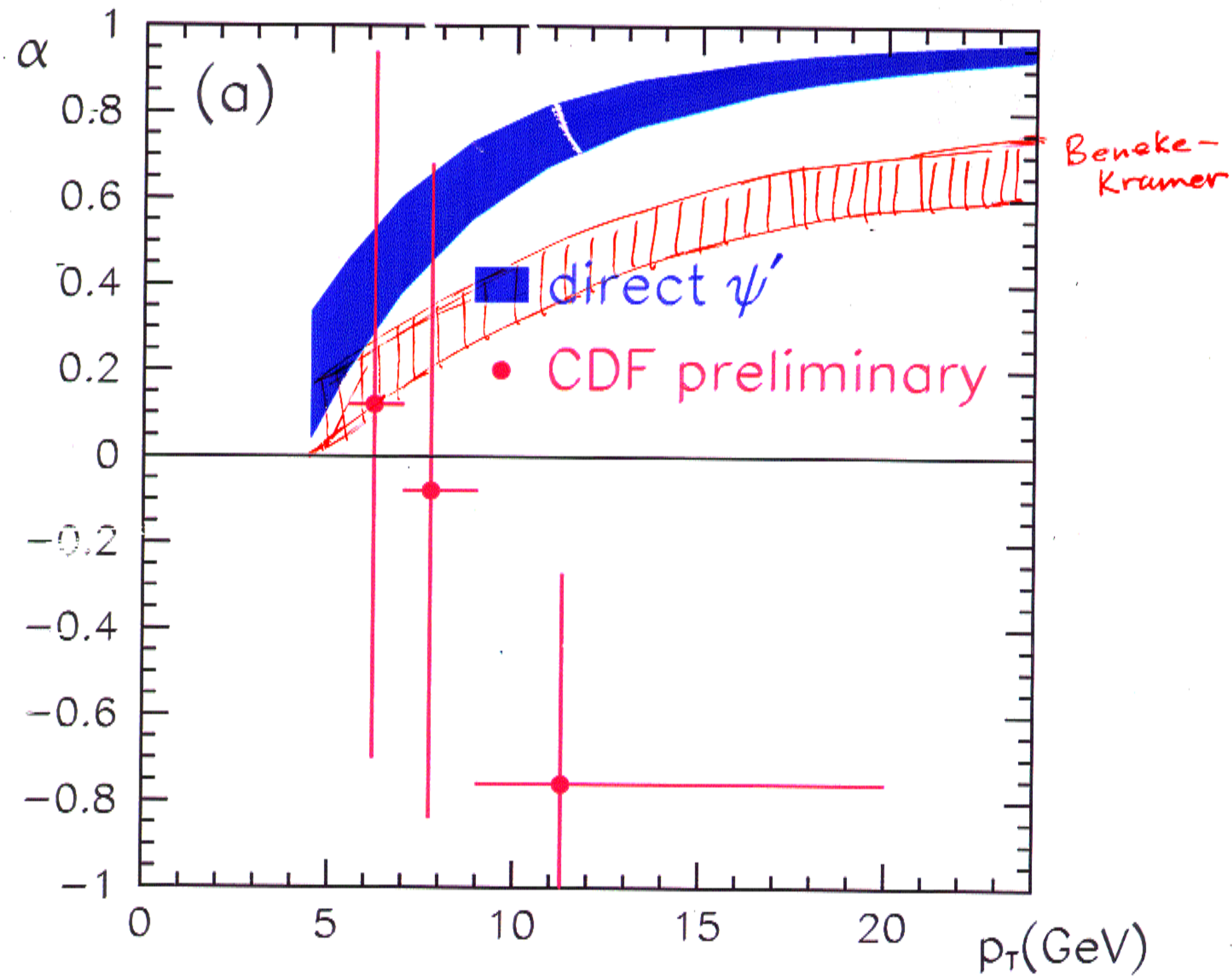
Redid J/ψ polarization calc'n

cf. Beneke Krämer

$\Rightarrow$

- ψ' Pol^n still disagree w/ CDF
- Prompt J/ψ also

? ? ?? → puzzle for Run II


α
(a)
direct ψ′
CDF preliminary
Beneke-Kramer
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0
5
10
15
20
p_T(GeV)

Vassili Papavassiliou showed E866 results on J/ψ polarization.

[proton-on-beamdump (Cu)]

10^7 J/ψ's in special run

Beneke Rothstein

- Expected Pol^n: $0.15 < \alpha < 0.44$

- Find: $\alpha = \int dx_F \, dp_T \, \frac{d^2\alpha}{dx_F \, dp_T} \simeq 0$

  - but $\alpha \neq 0$ in x_F, p_T bins ↷

$\Rightarrow$ more input for $\langle O\text{'s} \rangle$

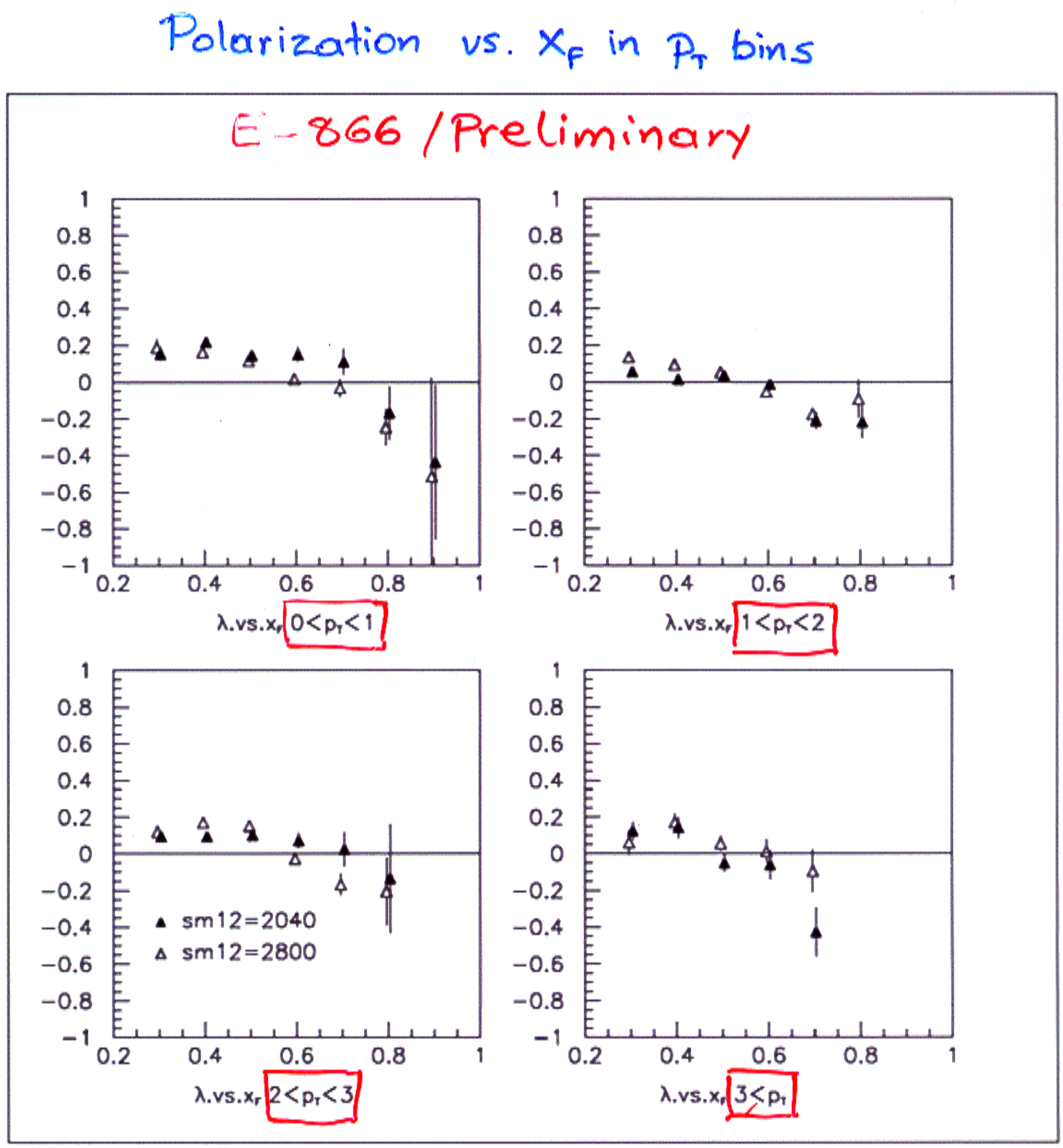


Figure 5.4: J/ψ polarization parameter λ in x_F and p_T bins. The errors shown here are statistical only.

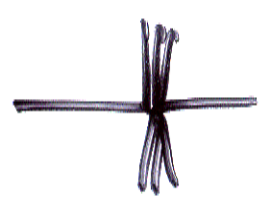
B production

exp'L $\dfrac{d\sigma^b}{dp_T^{min}} \simeq 2\times$ theory (NLO)

(well-known). Arthur Maciel looked at b-containing jets : $\dfrac{d\sigma}{dE_T(\text{jet-b})}$ for 5 pb^{-1} @ DØ. (Mangano, Frixione)

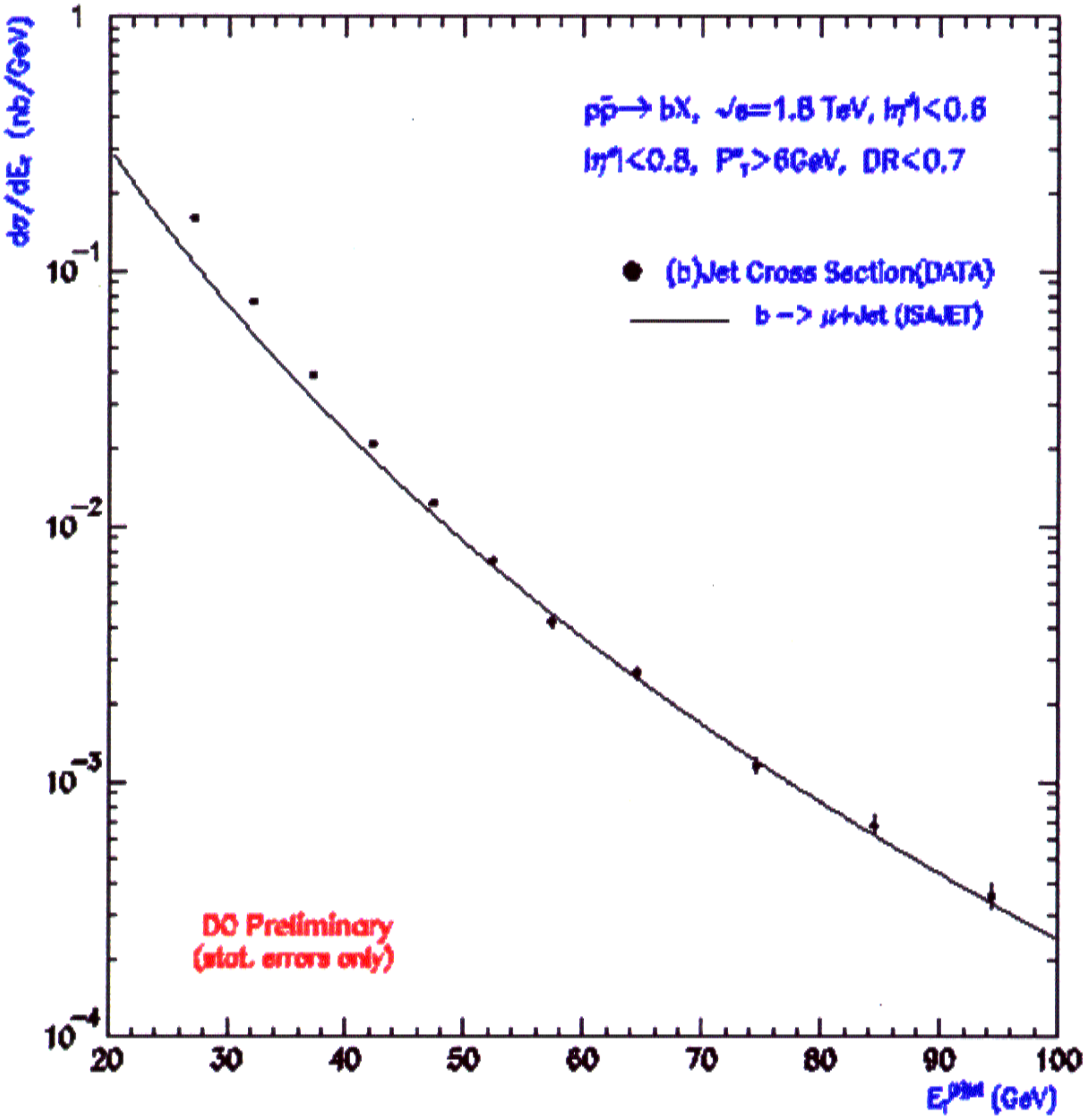
- better behaved observable
- valuable additional tool to understand B-production.
- with μ-tag gets worse @ high p_T
- Run II : more statistics

  DØ: silicon. (high p_T benefit)

  → restrict to  small theory uncertainty

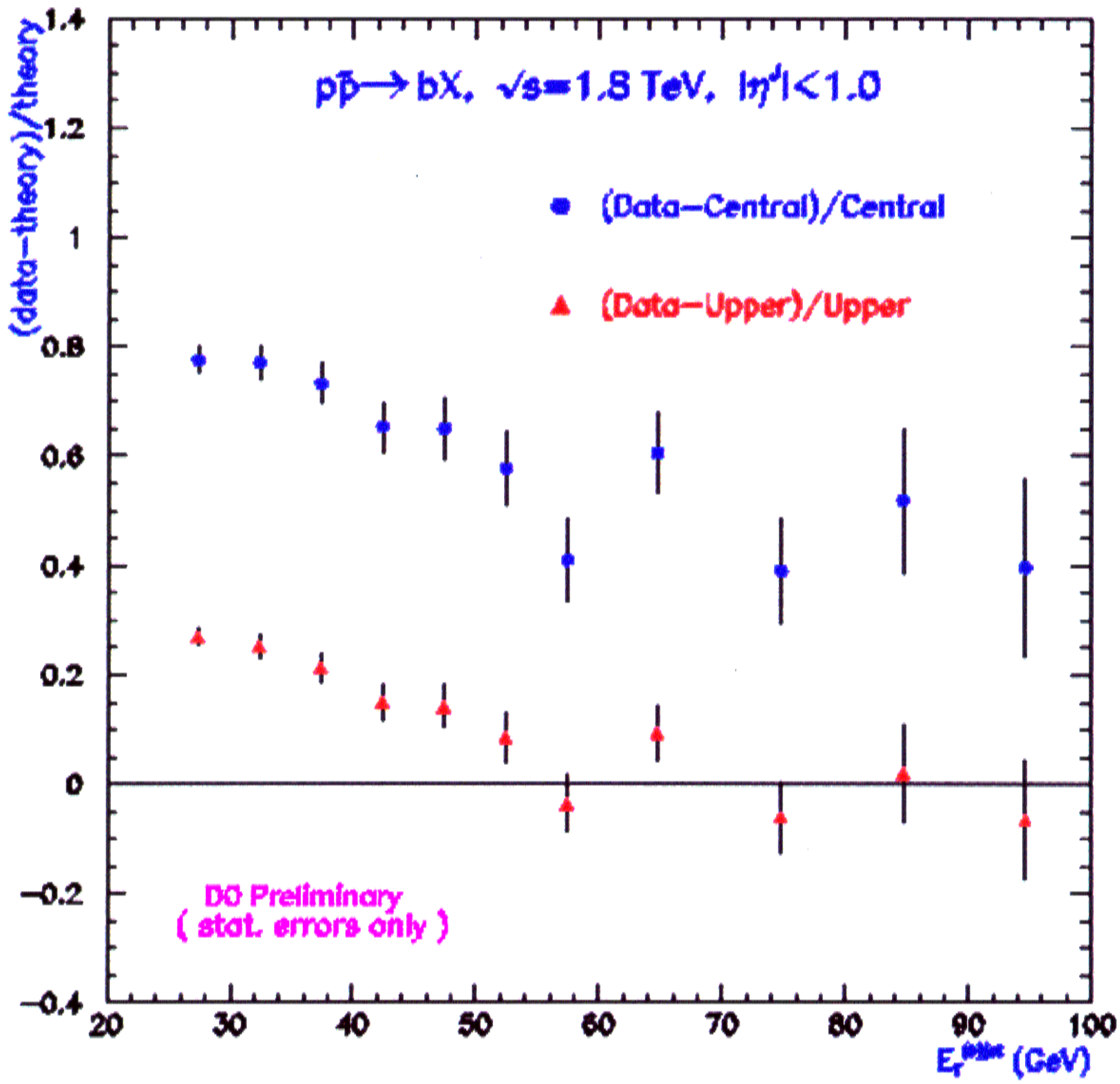
b-Jets Spectrum

b-Tagged Jets



A.Maciel
FNAL b-Wshop
Feb. 24-26, 2000

(Data-Theory) / Theory



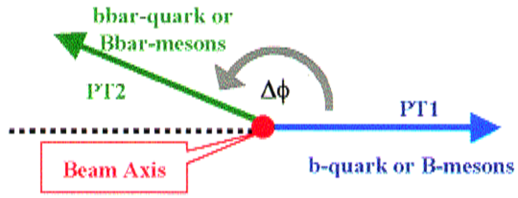
Systematic errors and their correlations confer 80% C.L. to theory higher edge

Rick Field is doing an exhaustive study of B-$\bar{B}$ production with PYTHIA, HERWIG, ISAJET

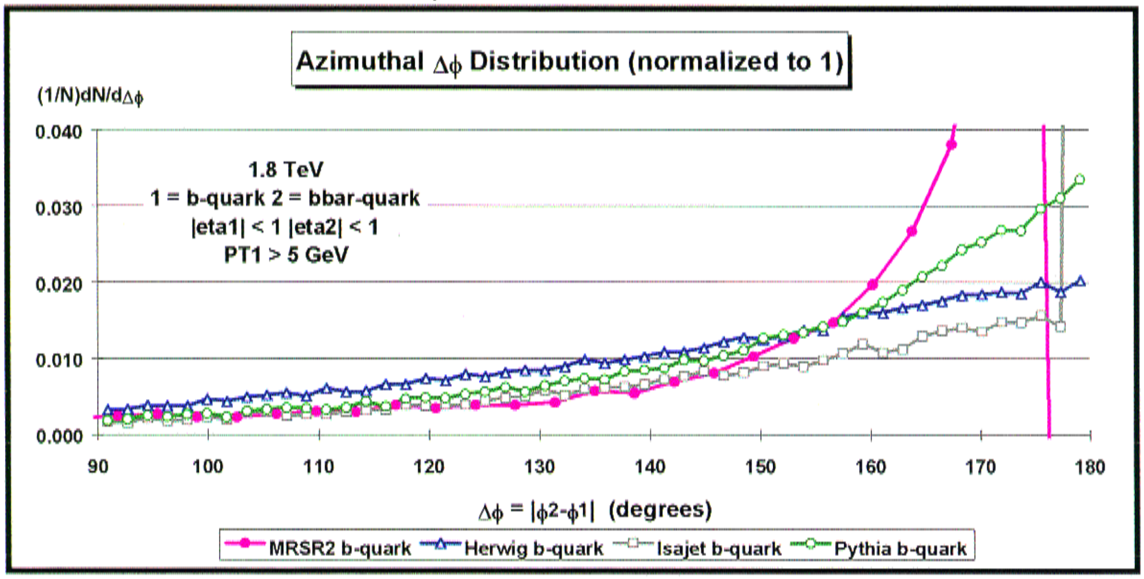
- $\Delta \Phi$ correlations →

- $$\frac{\sigma(2\ TeV)}{\sigma(1.8\ TeV)}\bigg|_{p_T > p_T^{min}}$$

B Physics: Azimuthal Correlations



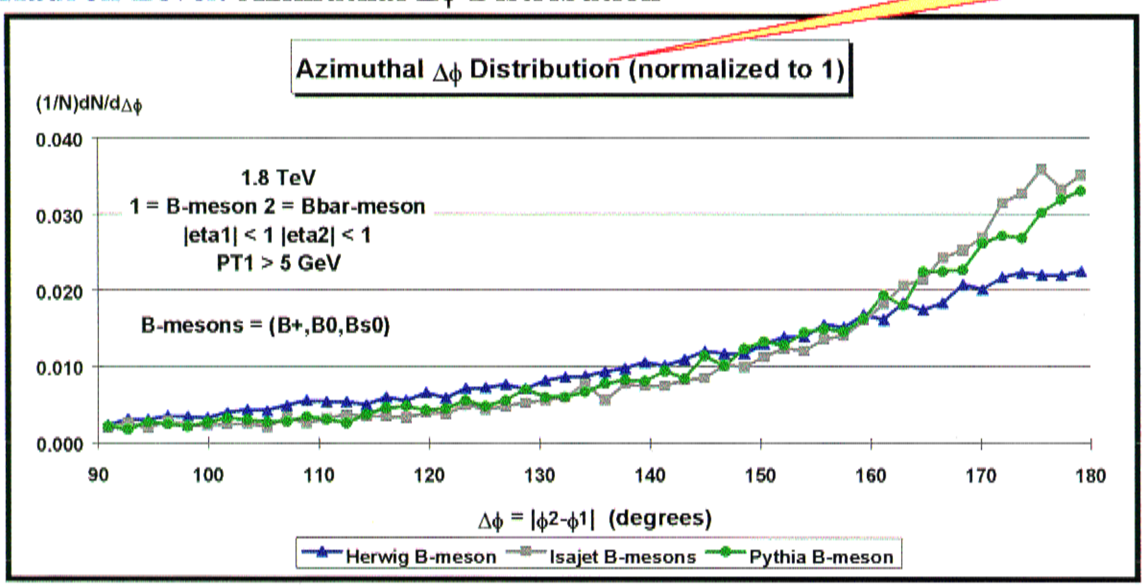
Parton Level: Azimuthal Δφ Distribution



Plot shows $(1/N)dN/d\Delta\phi$ (normalized to 1), where $\Delta\phi = |\phi_2-\phi_1|$ for 1 = b-quark and 2 = bbar-quark at 1.8 TeV with $|\eta_1| < 1$, $|\eta_2| < 1$, and $PT_1 > 5$ GeV.

Measures intrensic PT, gluon radiation, fragmentation.

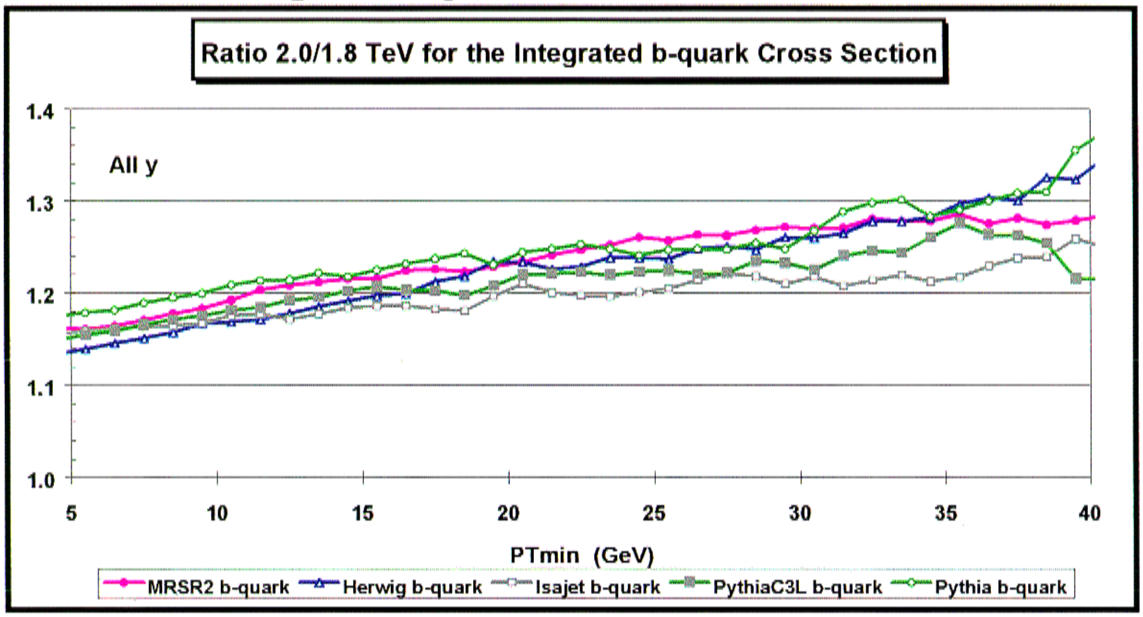
Hadron Level: Azimuthal Δφ Distribution



Plot shows $(1/N)dN/d\Delta\phi$ (normalized to 1), where $\Delta\phi = |\phi_2-\phi_1|$ for 1 = B-mesons (B^+,B^0,B_s^0) and 2 = Bbar-mesons at 1.8 TeV with $|\eta_1| < 1$, $|\eta_2| < 1$, and $PT_1 > 5$ GeV.

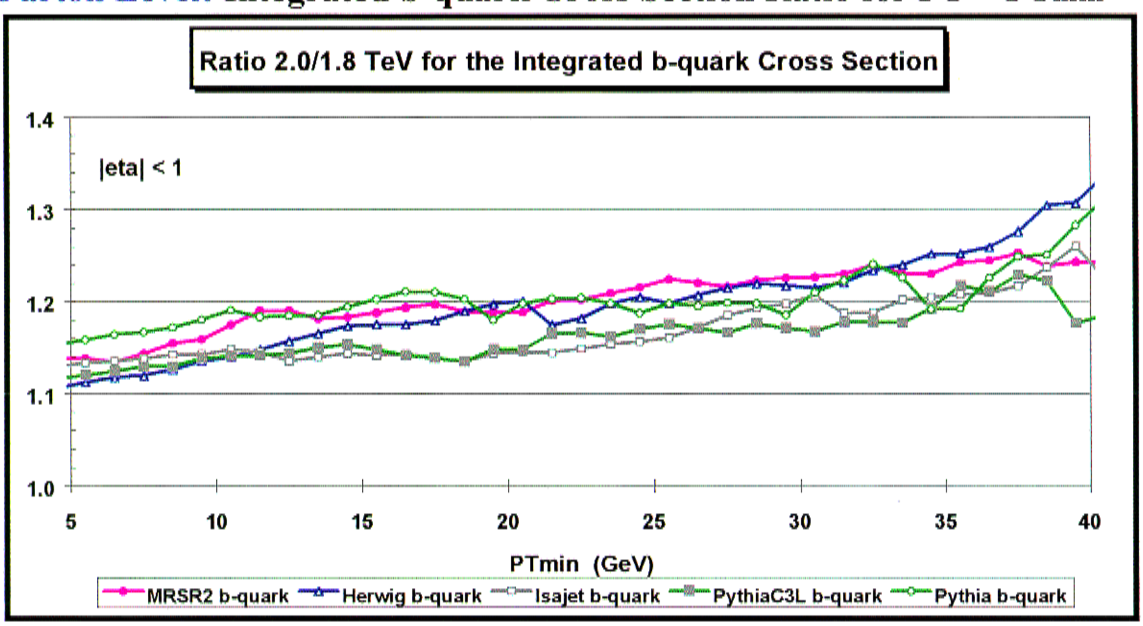
B Physics: 2.0/1.8 TeV Cross Section Ratio

Parton Level: Integrated b-quark Cross Section Ratio for PT > PTmin



Plot shows the 2.0/1.9 TeV ratio of σ(PT>PTmin) for b-quarks (all Y).

Parton Level: Integrated b-quark Cross Section Ratio for PT > PTmin

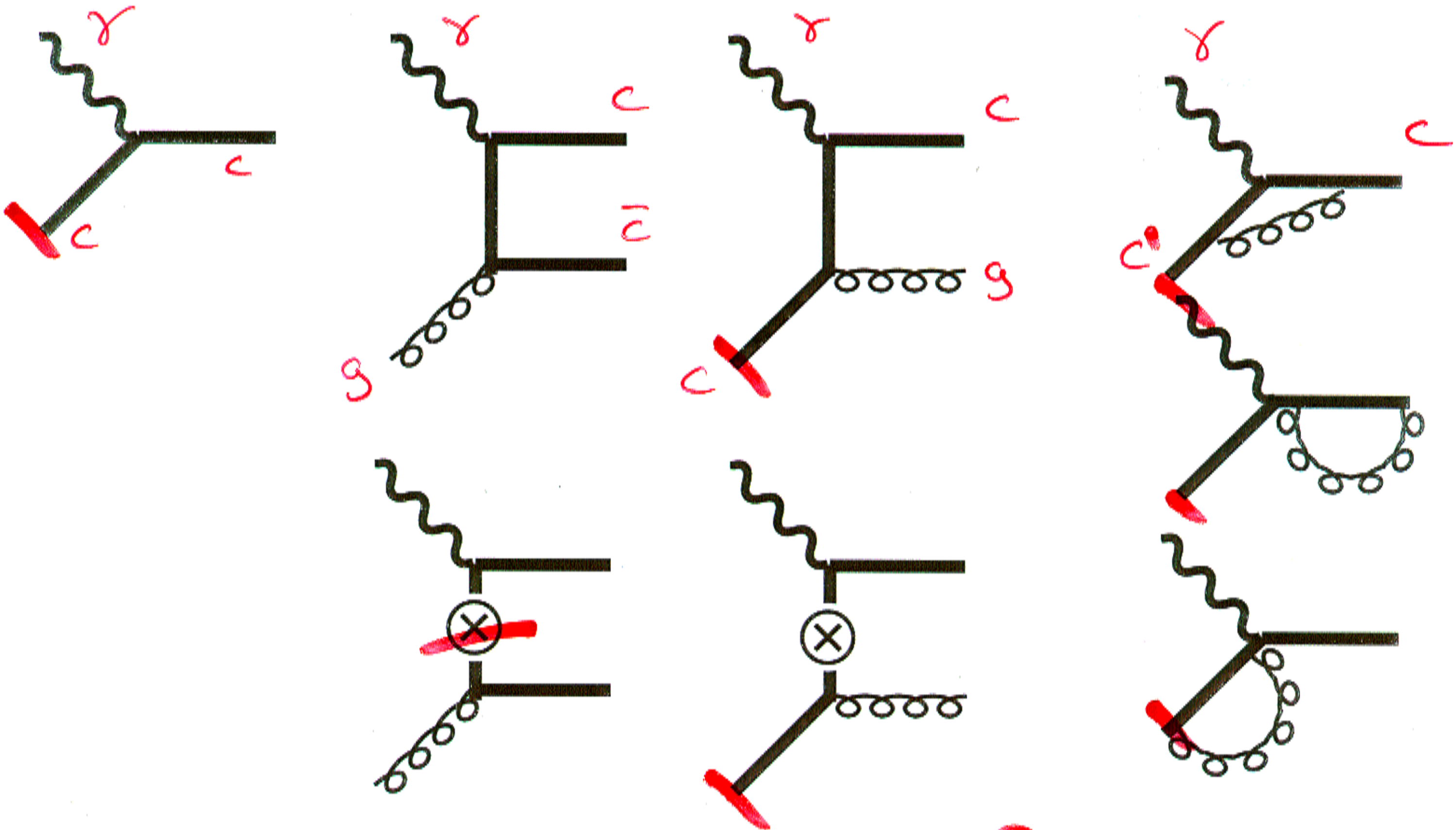


Plot shows the 2.0/1.9 TeV ratio of σ(PT>PTmin) for b-quarks (|eta|<1).

Fred Olness explained simplified (S-ACOT) scheme for higher-order b-quark calculations

- DIS production of heavy quarks does well here $\nearrow$
- Hadroproduction:
  - improved μ-dependence at large p_T $\nearrow$
  - enhancement due to extra graphs at large y

S-ACOT Scheme for Heavy Quarks



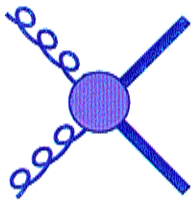
Heavy Excitation: $f_{p\to c}(m_c) \otimes \hat{\sigma}_{s\to c}(m_c)$

Subtraction: $\tilde{f}_{p\to c}(m_c) \otimes \hat{\sigma}_{s\to c}(m_c)$

For heavy quark initiated graphs, set $M_Q=0$

Combine Again

HE
Heavy Excitation

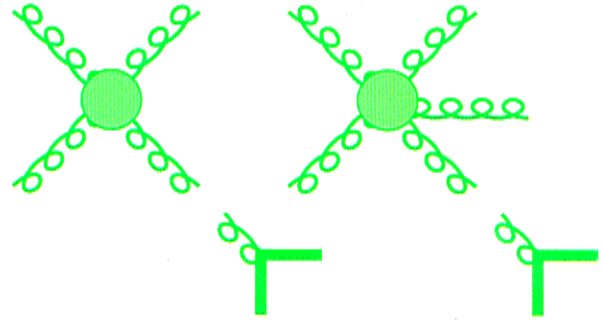


HC
Heavy Creation

Nason, Dawson, Ellis, Nucl.Phys.B303, 607 (1988)
Nucl.Phys.B327, 49 (1989) Phys.Rev.D40, 54(1989)

Olness, Scalise, Tung. PRD 59, 014506 (99)

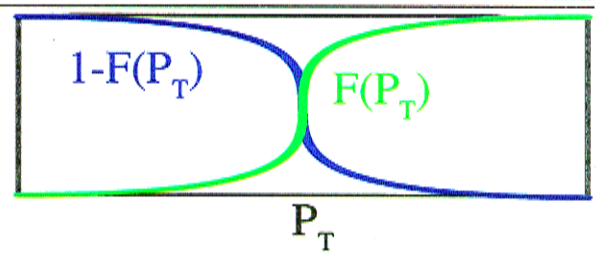
Fragmentation Function



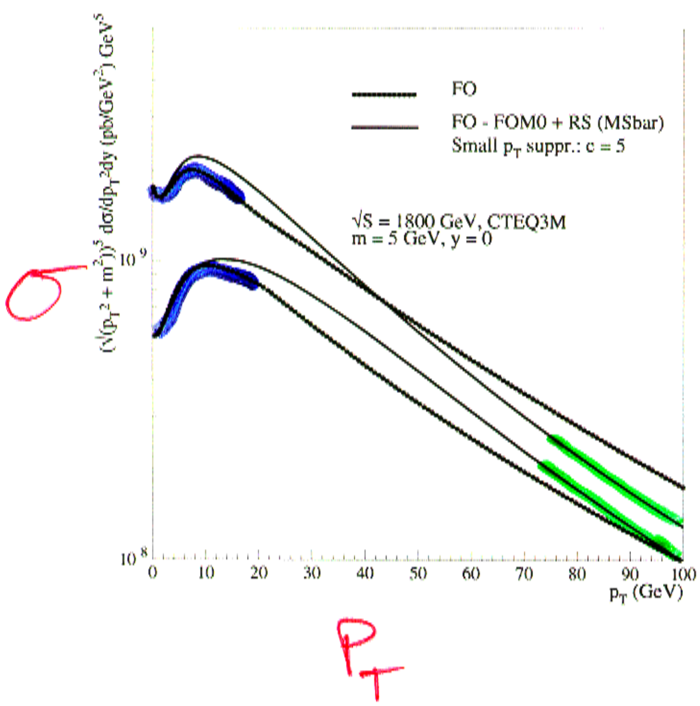
Cacciari & Greco, Nucl.Phys.B421, 630 (1994)

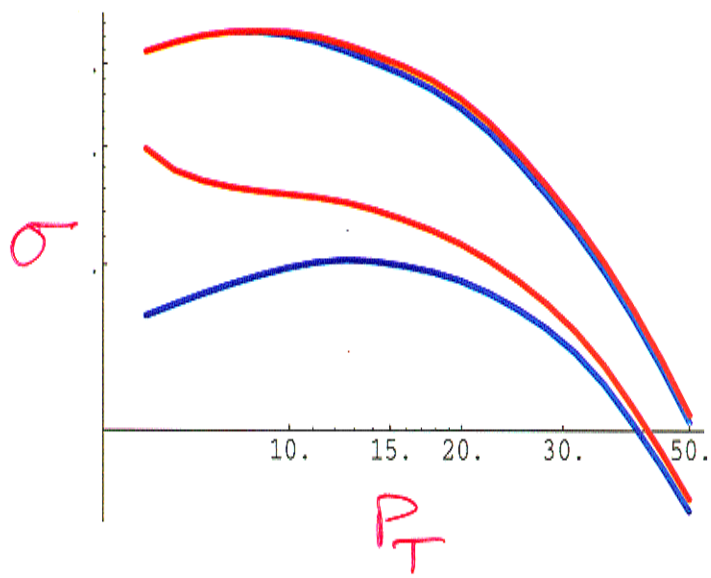
Note: Heavy Excitation contribution does not vanish for finite P_T

- For $\mu = \xi \sqrt{M_H^2 + P_T^2}$, HE can contribute for $P_T < M_H$
- Include Heavy Excitation process (with appropriate subtractions)
- Improved μ dependence at large P_T



Cacciari ,Greco, Nason, JJEP 05, 007 (98)





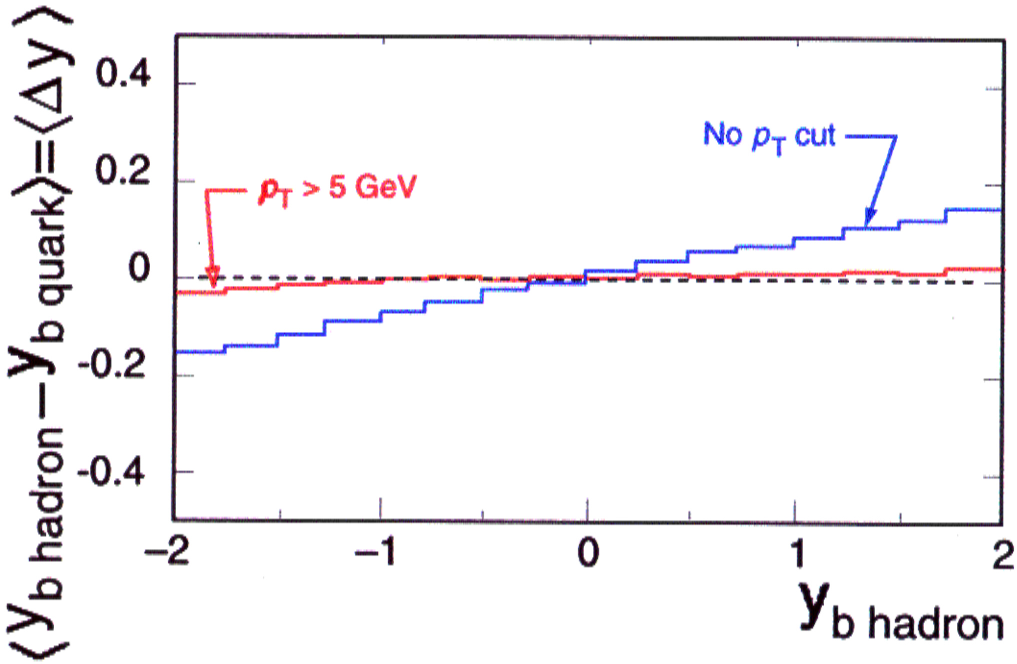
Fragmentation

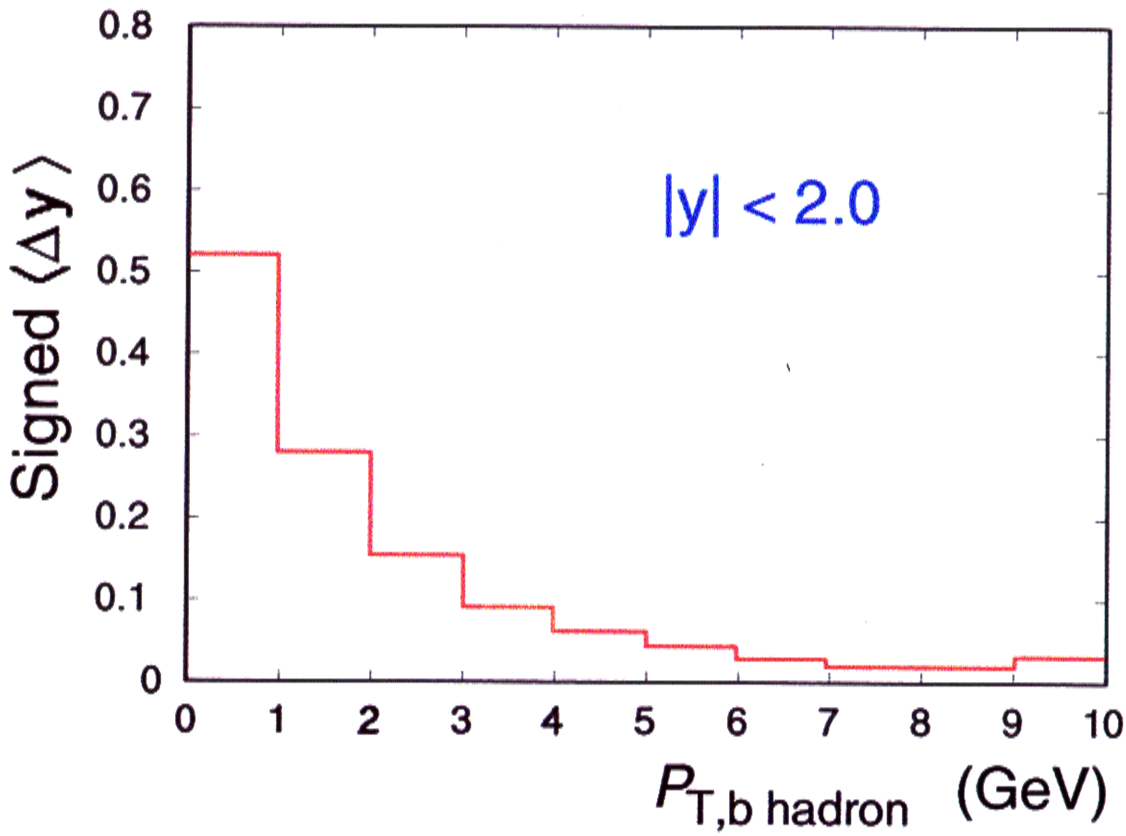
Rick van Kooten showed his studies of the presence and impact of a beam-drag effect on B-mesons. @ Tevatron.

Beam drag: forward produced particles accelerated by beam remnant via string

- Important for BTeV?
- Rick Field will take over baton.

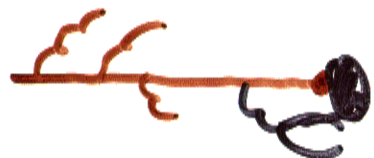
For Tevatron:





- Michelangelo Mangano discussed interplay of perturbative & NP fragmentation.

  At end-stage of evolution

  heavy quark may, in transition to B, be reaccelerated

  $\Rightarrow D(z>1) \neq 0$. (higher twist)

  Noticeable in HERWIG study. (problem?)

- E.L., Brian Harris + Carlo Oleari:

max 10% ambiguities in fragmentation

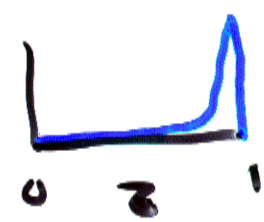
- fragm. frame
- " scheme

Oleari fitted excellent SLD $e^+e^- \to B\bar{B}X$ data to

$$\sigma = \left(\begin{array}{c}\text{best}\\ \text{pert. calc}^{n}\end{array}\right) \otimes D_{NP}$$

↑ fit

2→

- Peterson does not work well at all
- data prefer $D_{NP}^{(z)} \sim$ 

⟨ • Not clear that LEP & SLD do the same thing ⟩

- Do these uncertainties matter for CDF/DØ/BTeV?

uses a fixed order α_s^2 calculation with masses explicit Nason, Oleari '98; Rodrigo '96; Bernreuther, Brandenburger, Uwer '97. Two NP fragmentation models used to compare to SLD data

- Peterson
- "Euler" $(z^\alpha(1-z)^\beta)$

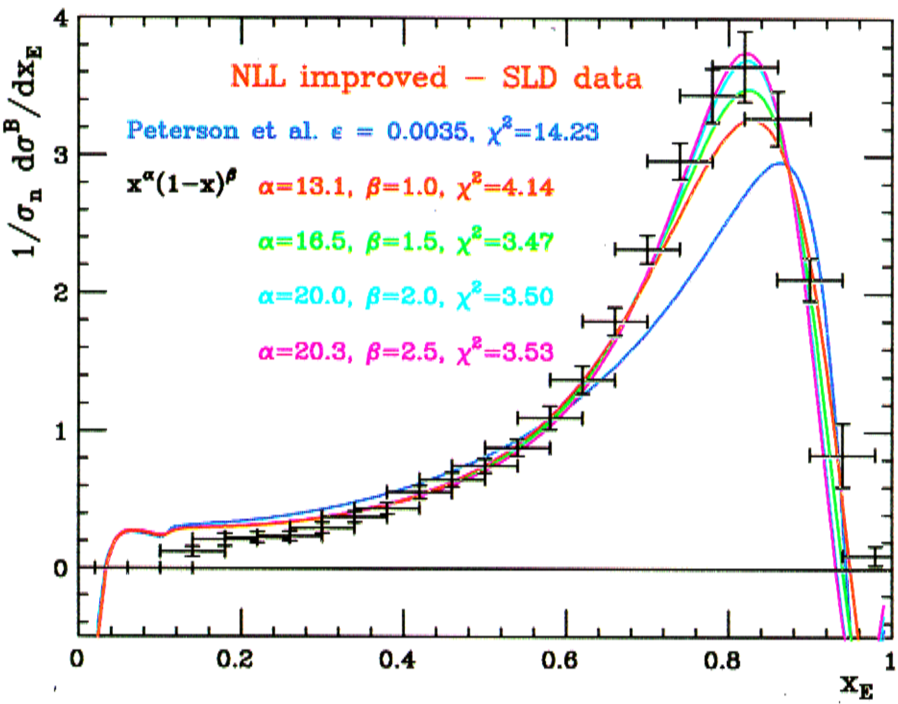


Figure 1:
Fit to SLD data of Peterson and "Euler" nonperturbative fragmentation function via NLL improved calculation.

Conclusions

15

- good, active group
- to do list manageable
- we all have our orders

→ writing can begin