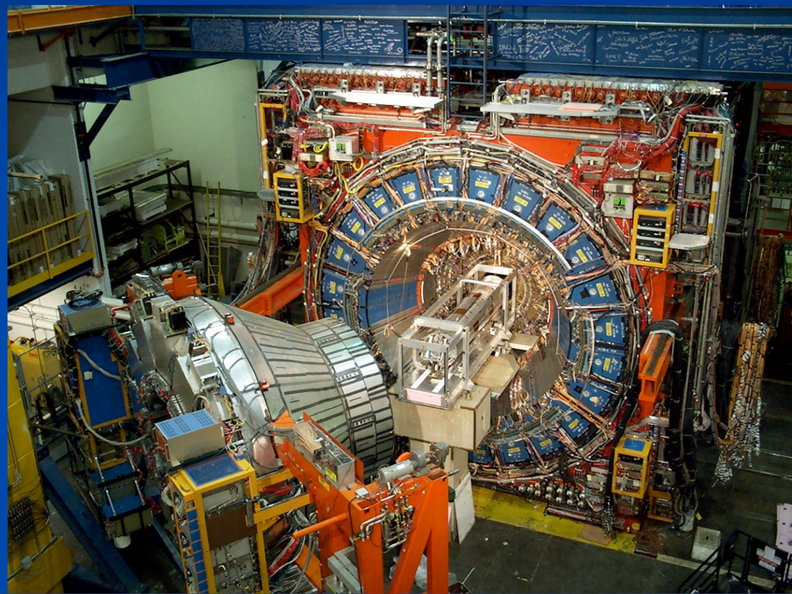
Heavy flavor production in CDF II

Mario Campanelli/ Geneva



Experimental techniques:

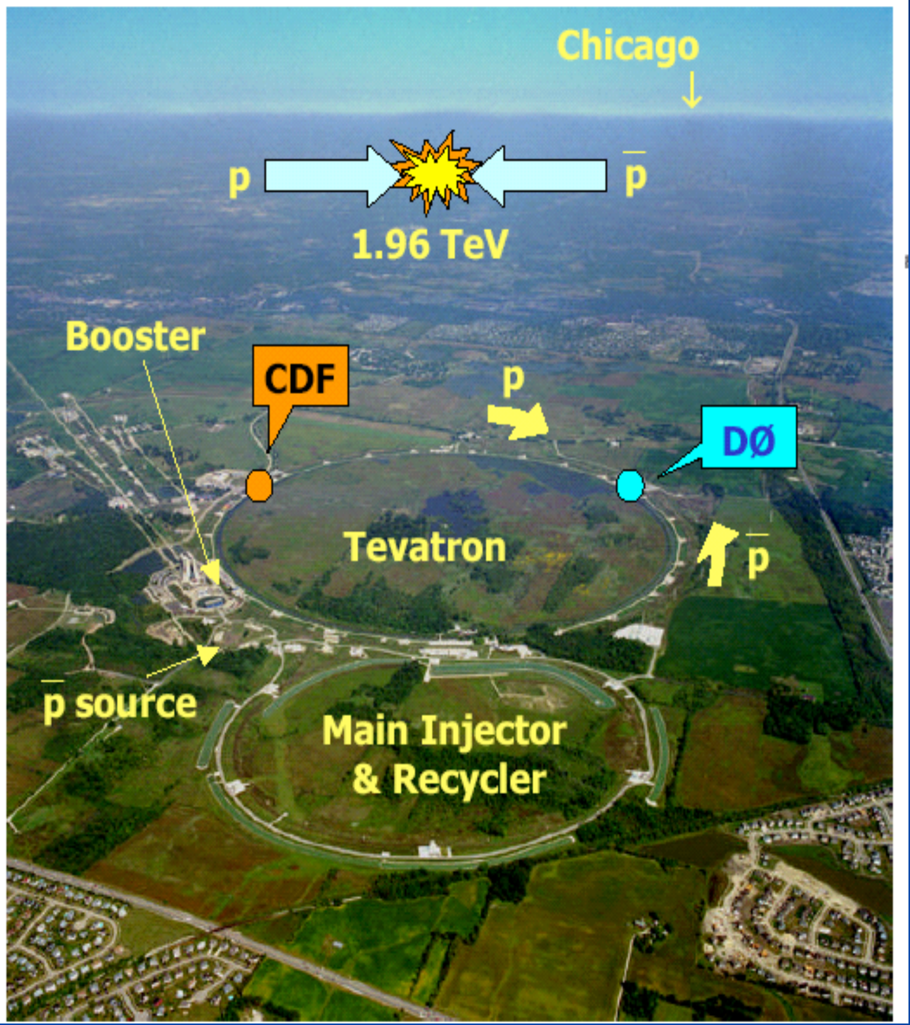
Tevatron and CDF

Triggering on b: SVT

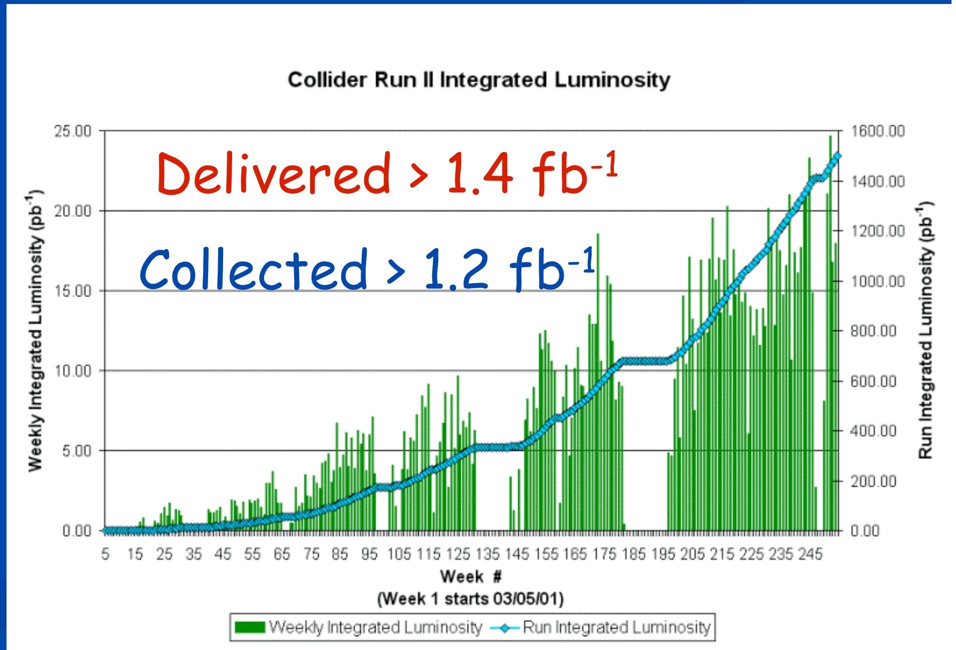
Heavy flavor production

- **High-pt**
- **Low-pt**
- **Search for new physics**

The Tevatron

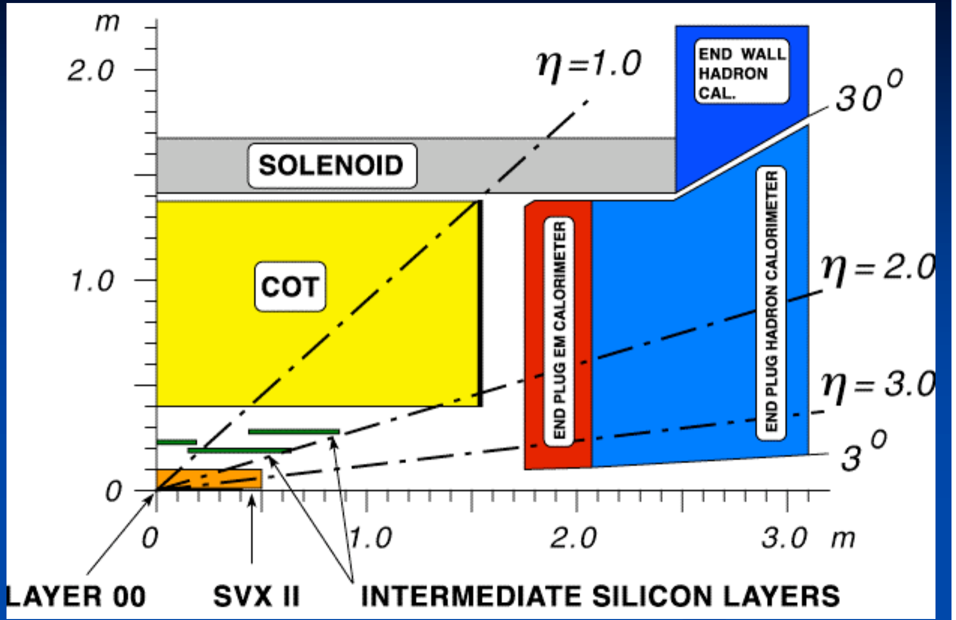


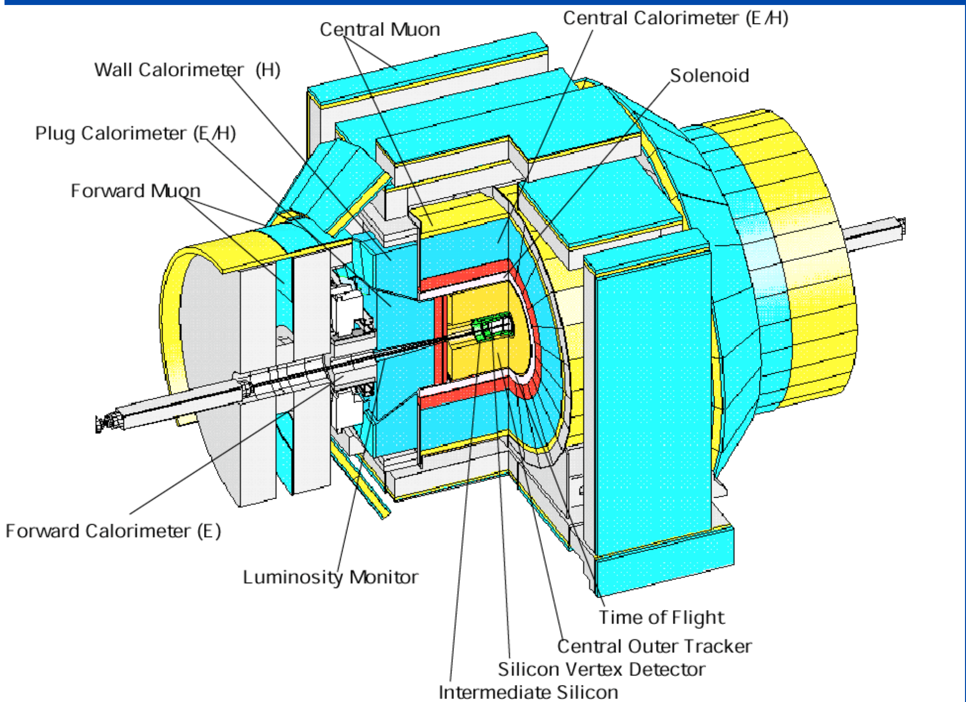
- World's largest hadron collider
- $\sqrt{s}$ = 1.96 TeV
- Peak lum 1.7 10^{32} cm^{-2} s^{-1} (Jan 15, 2006)
- >1 fb^{-1} delivered to experiments
- Analyses ~ 60-400 pb^{-1}



CDF II detector

- CDF fully upgraded for Run II:
  - Si & tracking
  - Extended calorimeters range
  - L2 trigger on displaced tracks
  - High rate trigger/DAQ





Calorimeter

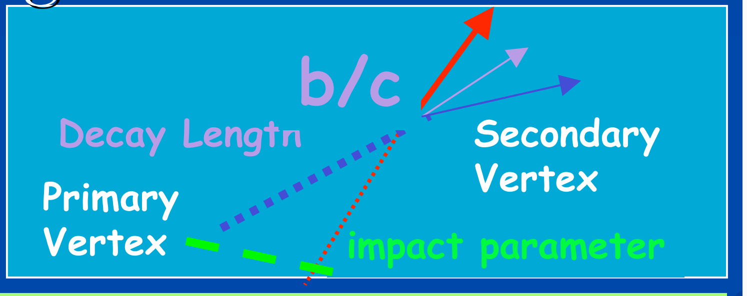
- CEM lead + scint 13.4%/$\sqrt{E_t} \oplus$ 2%
- CHA steel + scint 75%/$\sqrt{E_t} \oplus$3%

Tracking

- σ(d0) = 40μm (incl. 30μm beam)
- σ(pt)/pt = 0.15 % pt

The experimental challenge

- b production 3-4 orders of magnitude smaller than ordinary QCD; selected by longer lifetime
- c slightly higher but more difficult to isolate

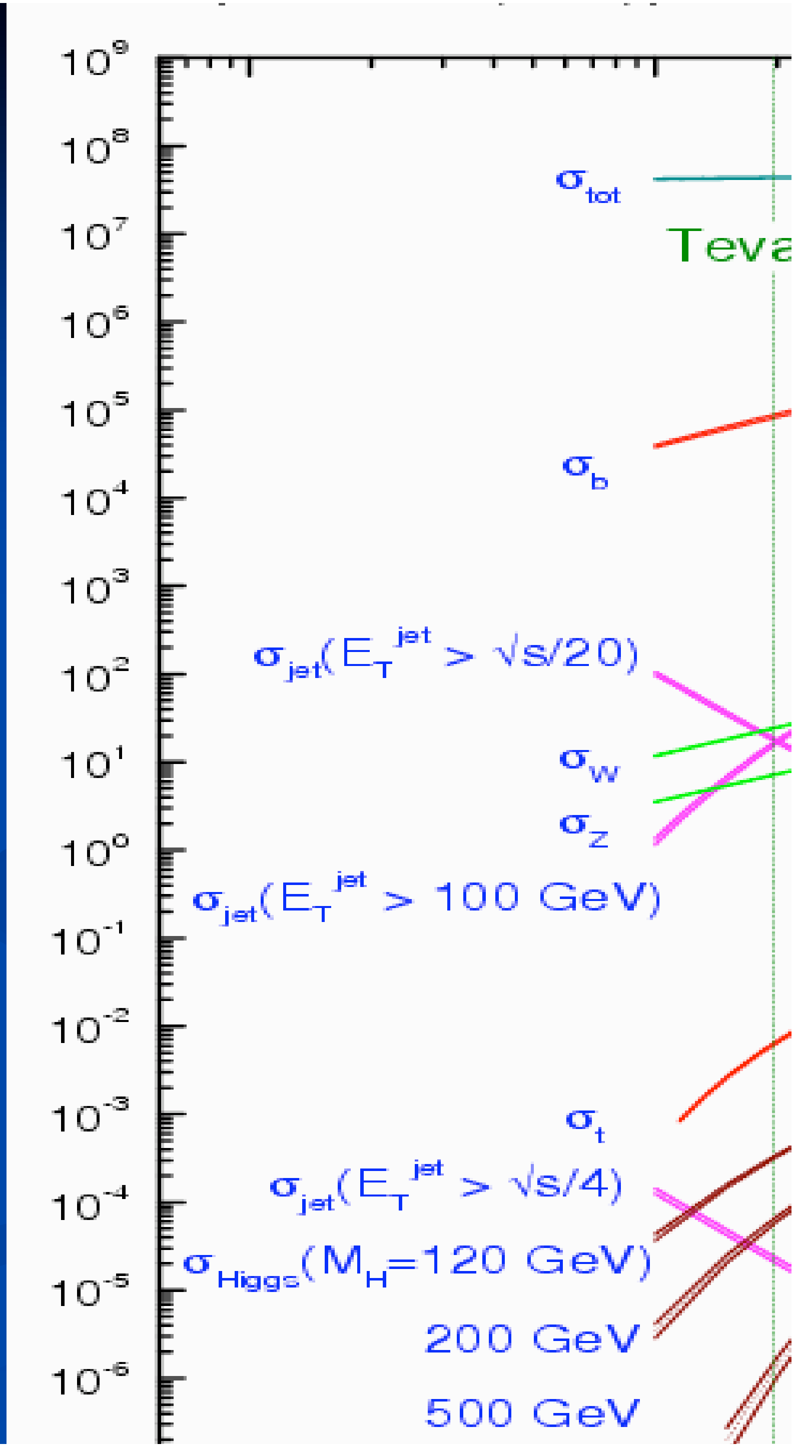


Various strategies:

•High-pt (traditional): take unbiased prescaled triggers, identify b off-line

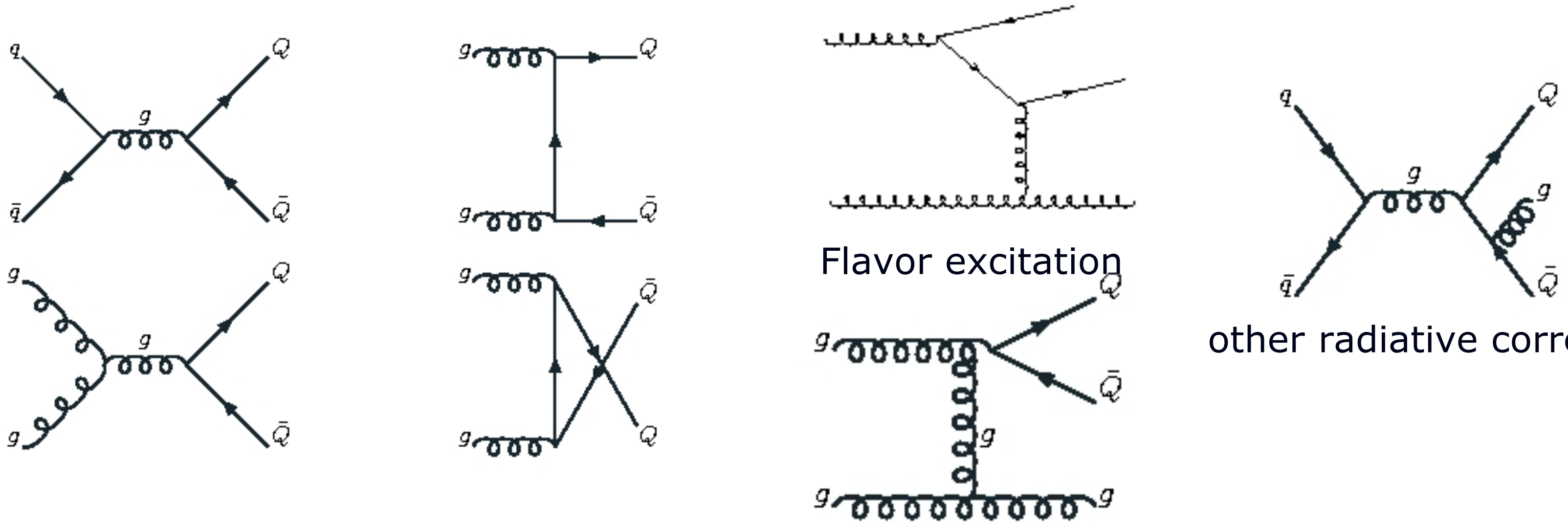
•Low-pt: use on-line impact-parameter information to trigger on hadronic decays

•High-pt (new): b-enriched samples



What's interesting in HF production at colliders

Leading Order | Next to Leading Order



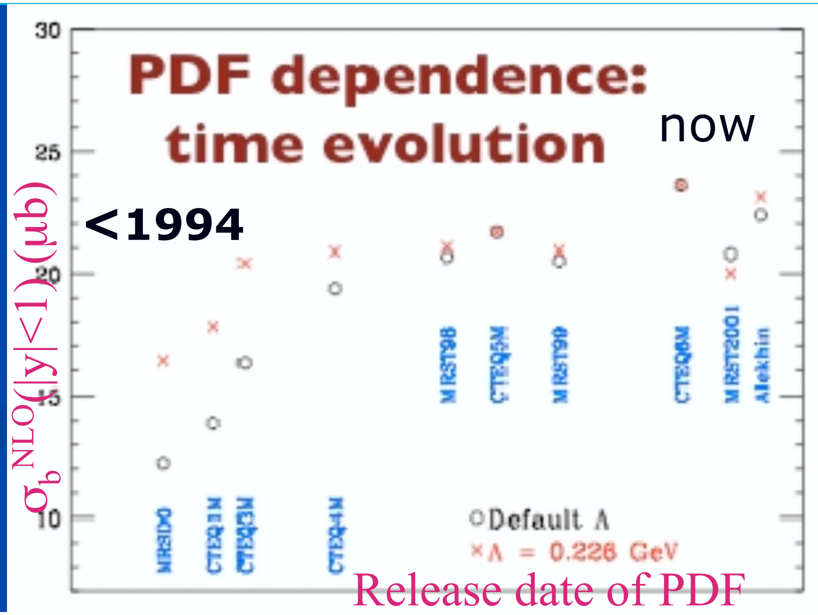
Flavor creation

Flavor excitation

Gluon splitting

other radiative corrections..

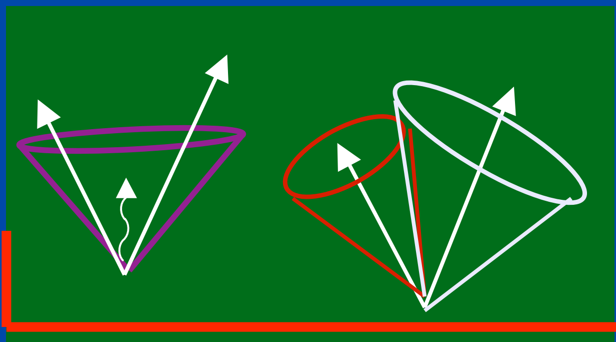
- kHz rates at present Tevatron energy/luminosity
- High mass -> well established NLO calculations, resummation of log(pT/m) terms (FONLL)
- New fragmentation functions from LEP data



Jet algorithms for inclusive studies

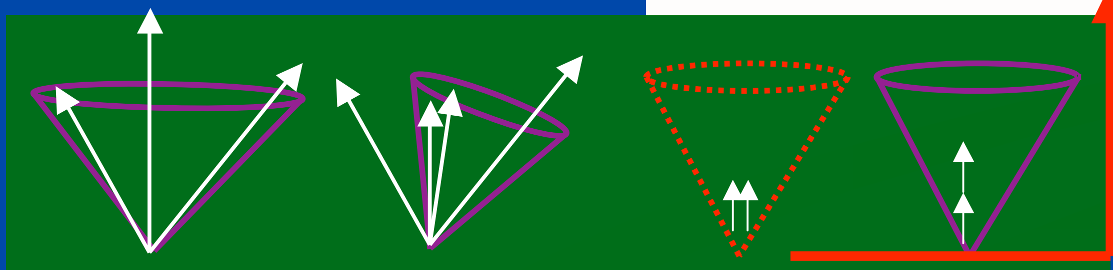
Good jet definition
- Resolve close jets
- Stable, boost invariant
- Reproducible in theory

- Cone based (seeded) algorithms
  - JetClu (RunI)
  - MidPoint (new RunII)
- Merging pairs of particles
  - Kt (recently used @ CDF)



JetClu

- Preclustering
- Uses E_t, η
- Not **infrared** safe
- Not **collinear** safe

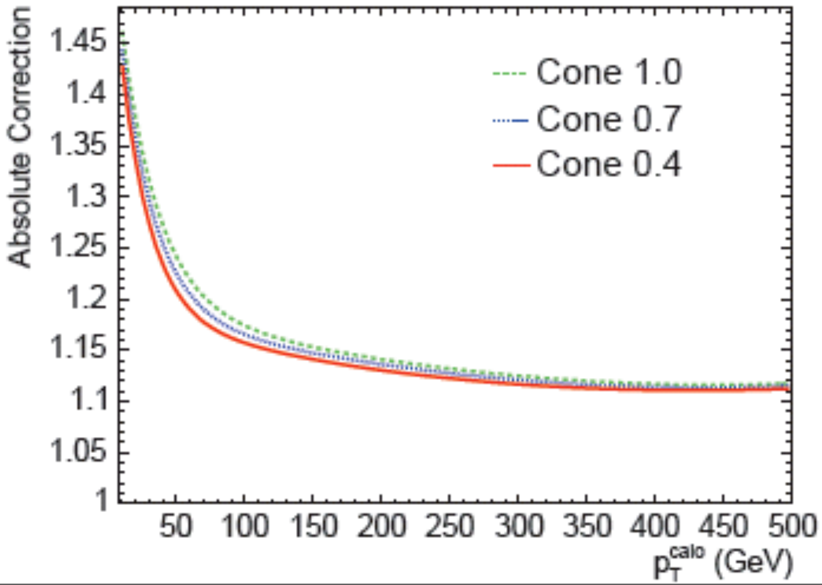


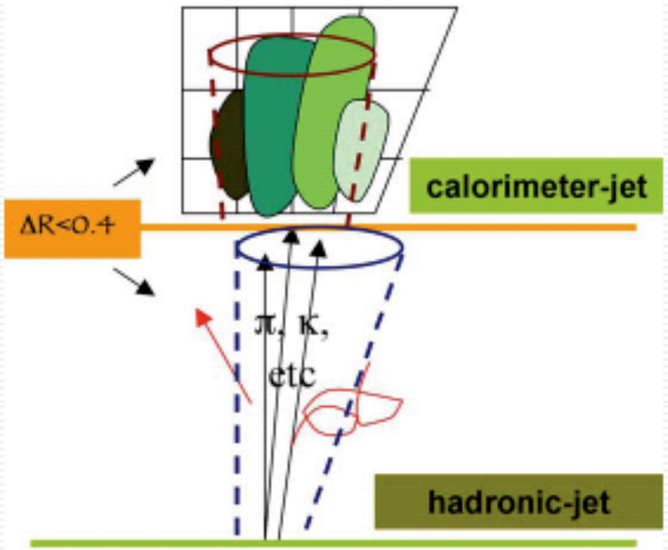
MidPoint

- No preclustering
- Uses p_t, y
- Adds midpoints to original seeds
- Infrared safe

Absolute jet corrections

- The corrections are calculated using two leading jets in PYTHIA dijet events (0 - 800 GeV).
- Map the calorimeter jet P_T to the particle jet P_T and obtain the probability of observing P_T^{Cal} when P_T^{Had} was produced. Use Most Probable Value as the correction.





Corrections for FLAT input spectrum.
Addition correction needed to unsnear.

After this correction, jets are independent of the detector.

Systematics for energy scale

CALORIMETER SIMULATION

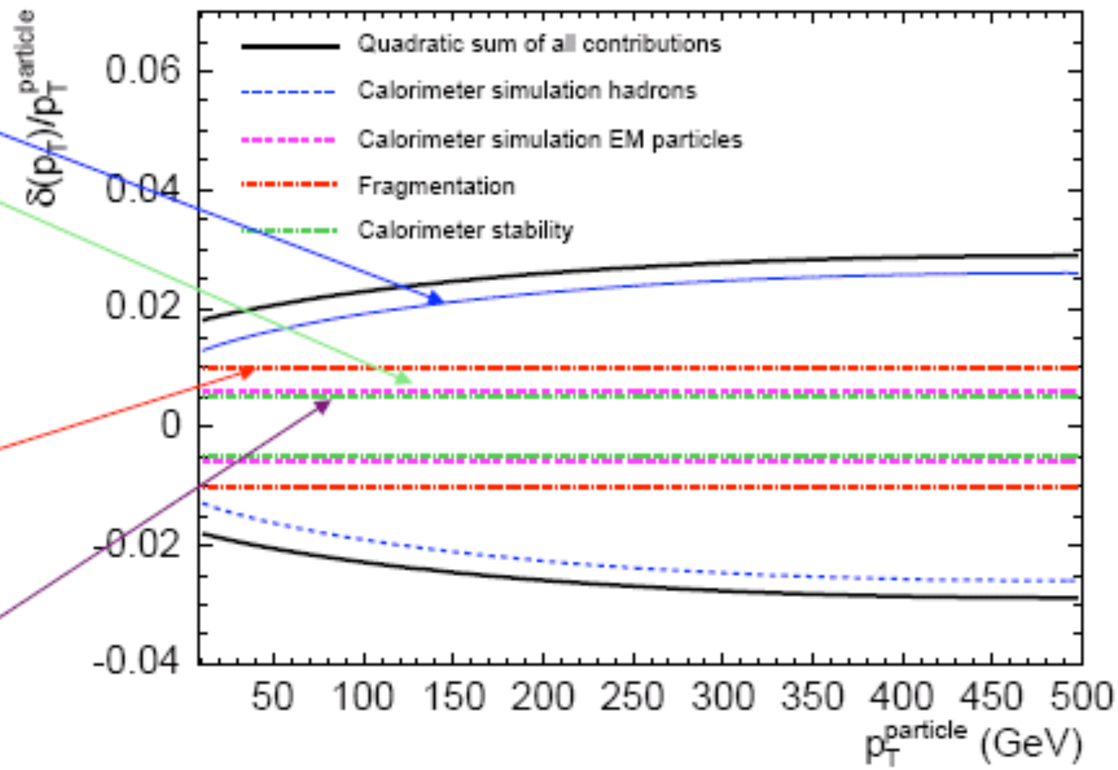
Is the response of the calorimeter to single particles (pions, protons, neutrons, etc) simulated correctly?

FRAGMENTATION(1%)

Does the Monte Carlo describe the particle spectra and densities at all Jet E_T

STABILITY (0.5%)

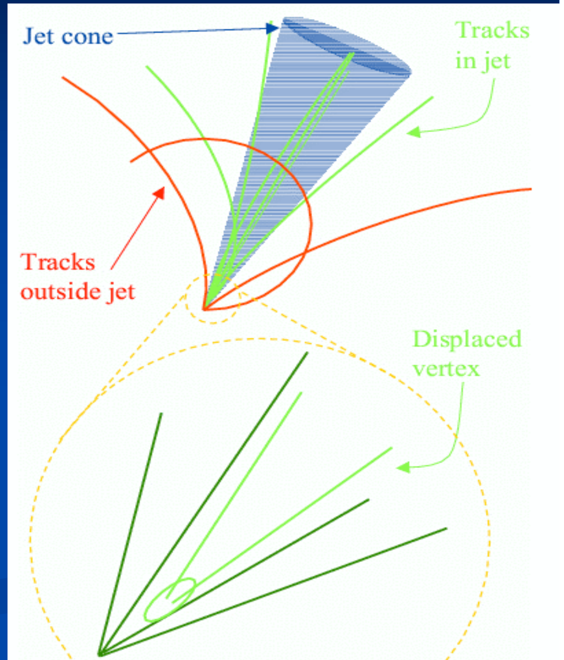
Calorimeter scale variation with time



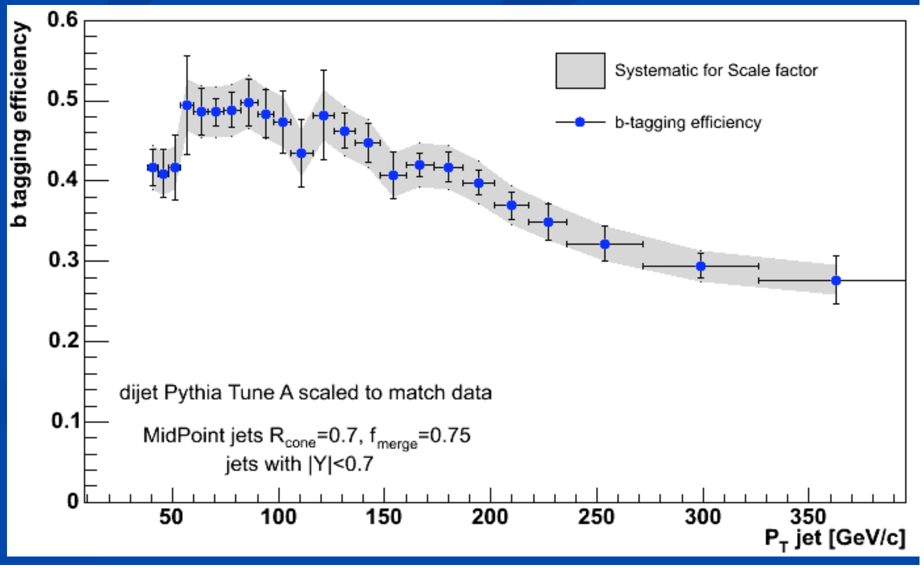
Using test beam data P_T regions (relatively large uncertainty), important for high P_T jets

High-pt identification: search for secondary vertex

- For inclusive studies, instead of trying to identify specific b decay products, we look for a secondary vertex resulting from the decay of the b meson



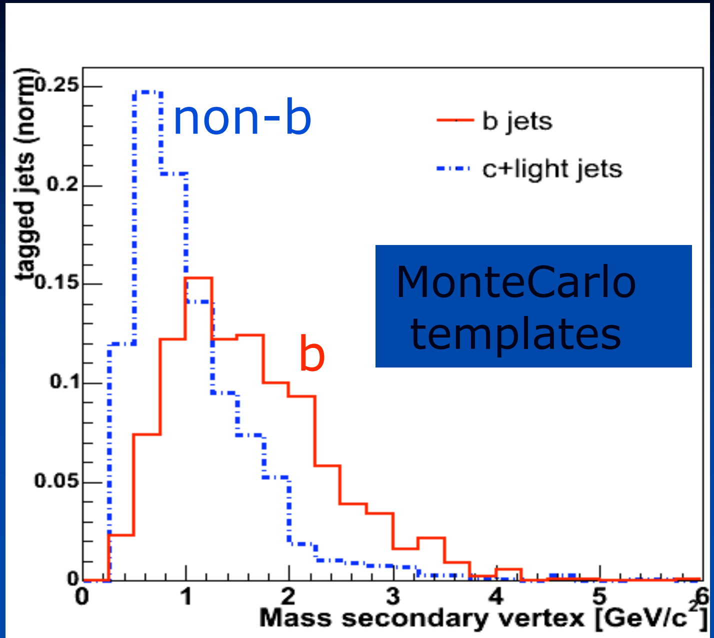
Efficiency of this "b tagging" algorithm (around 40%) is taken from Monte Carlo and cross-checked with b-enriched samples (like isolated leptons)

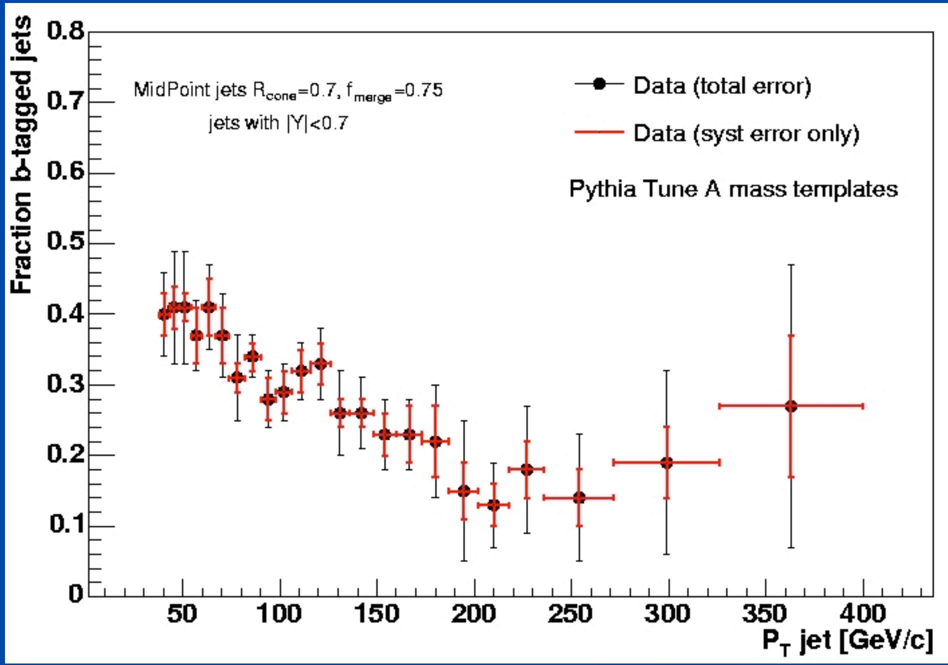


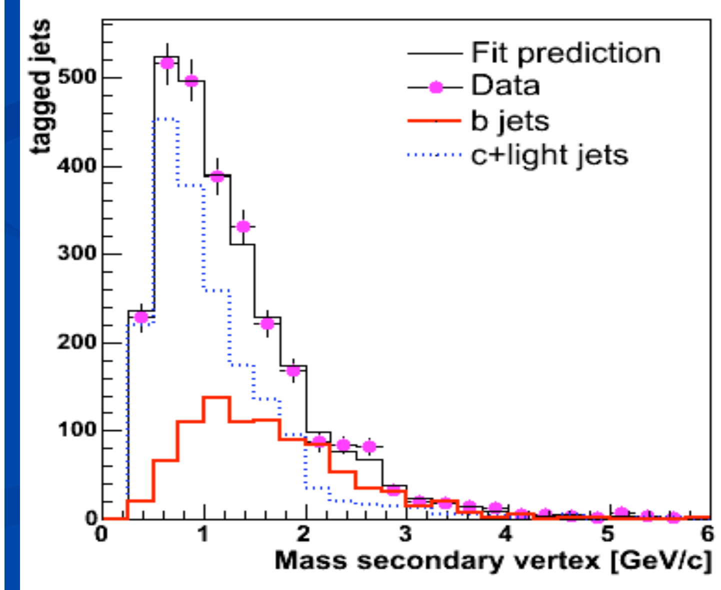
b-jet fraction

Which is the real b content (purity)?
Extract a fraction directly from data

- Use shape secondary vertex mass
  - Different P_t bins to cover wide spectrum
  - Fit data to MC templates



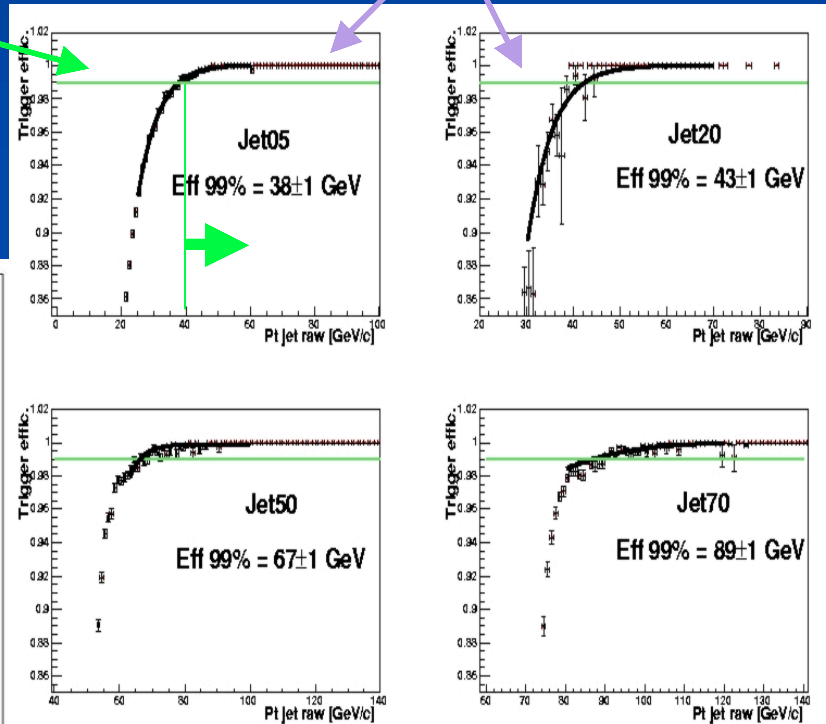


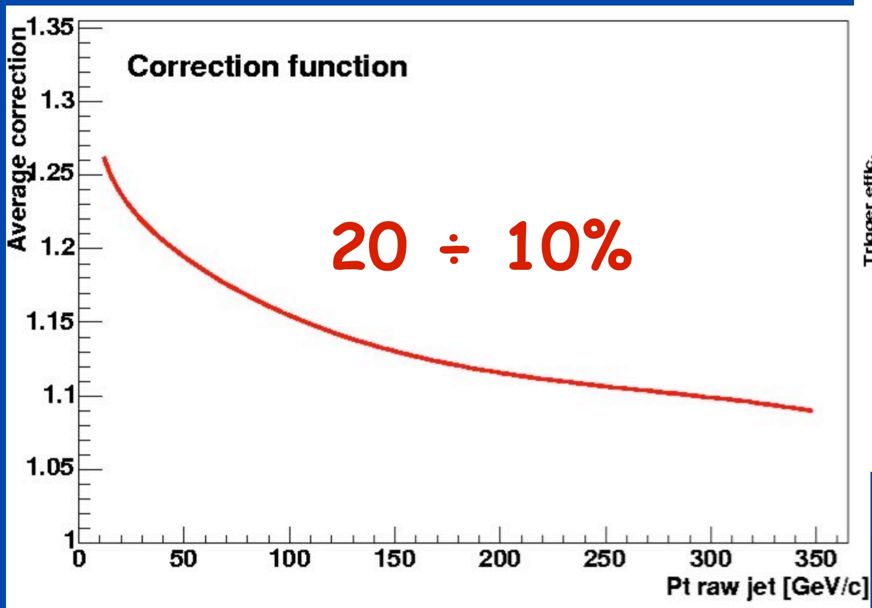


High p_t b jet cross section

- MidPoint R_{cone} 0.7, |Y| < 0.7
- Pt ranges defined to have 99% efficiency (97% Jet05)
- Jets corrected for det effects

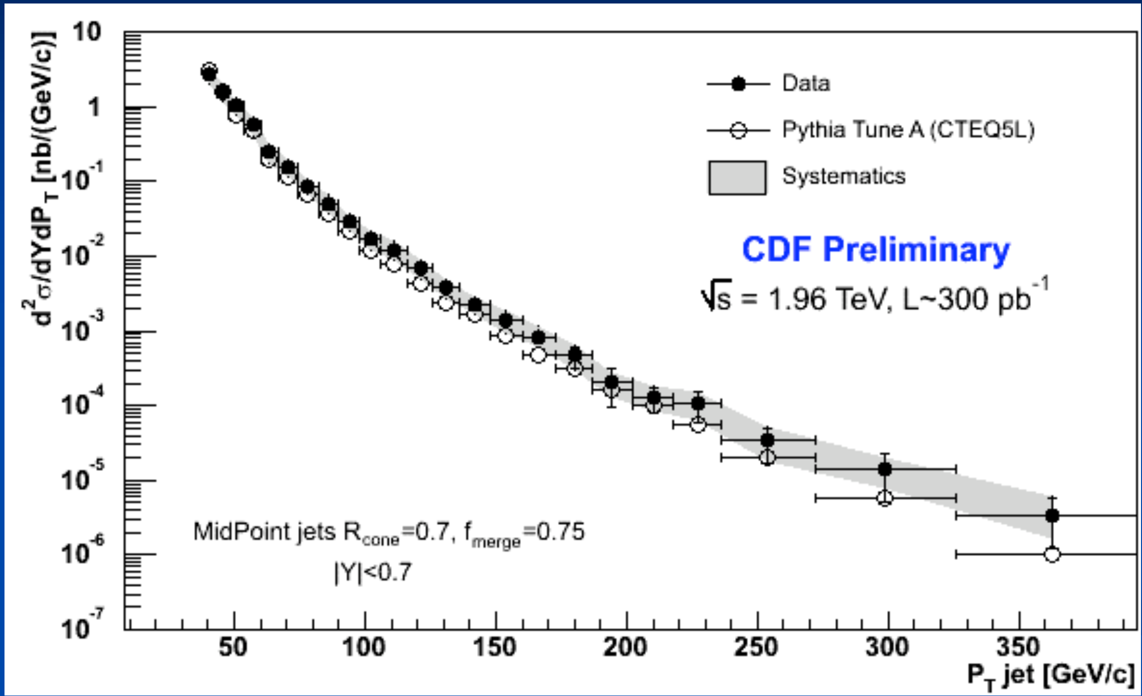
- Inclusive calorimetric triggers
  - L3 Et > x (5,20,40,70,100)

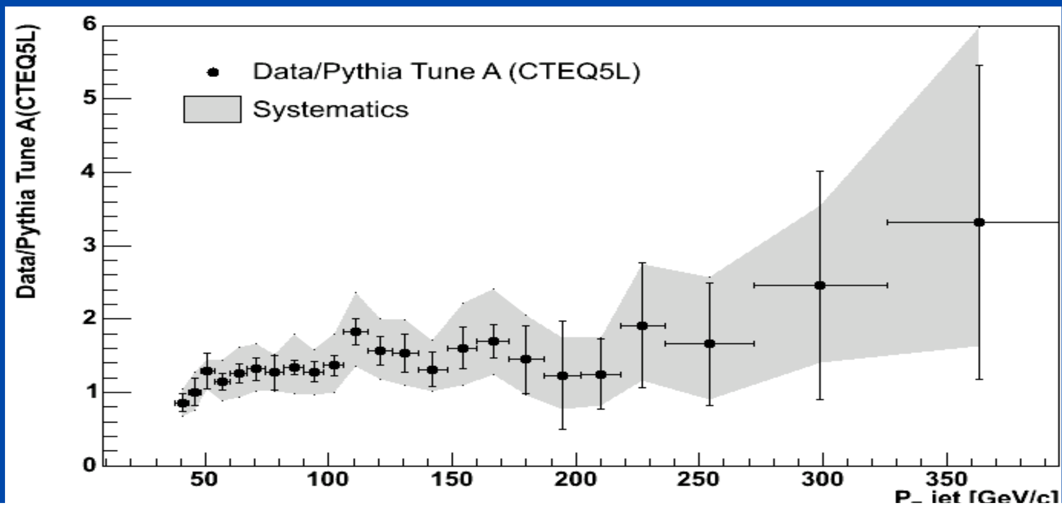




~ 300 pb^{-1}
Pt ~ 38 ÷ 400 GeV

High p_t b-jet cross section



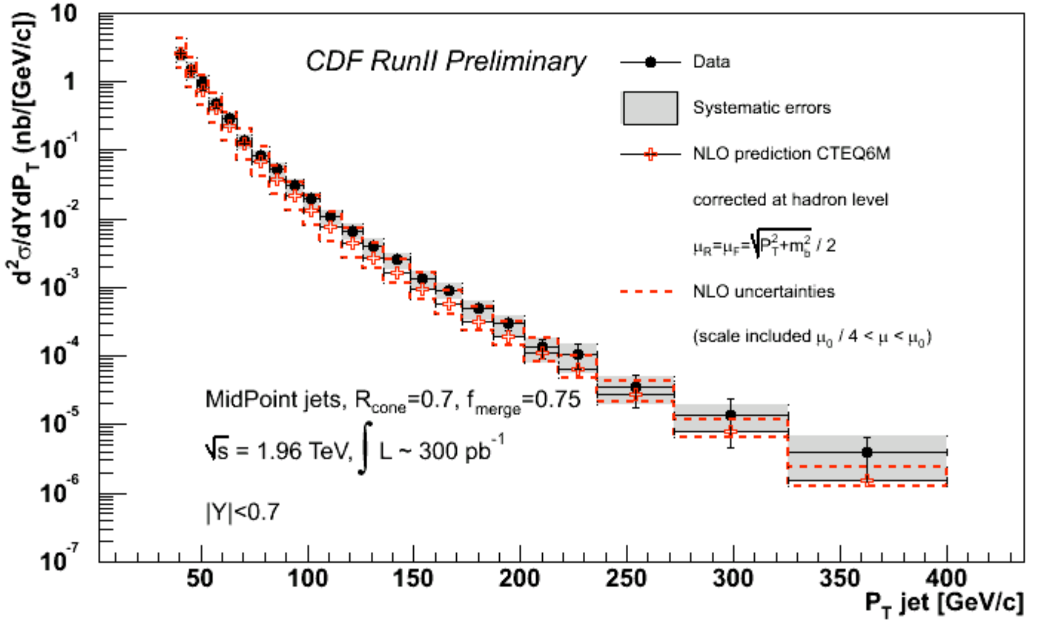


- Main sources of systematics:
  - Absolute energy scale
  - B-tagging

Systematic Error	low P_T	high P_T
Luminosity	6%	6%
Absolute Energy Scale	15-20%	40%
Jet energy resolution	6%	6%
B-tagging efficiency	10%	15%
B-tagged jets fraction	10-15%	40%
Unfolding	8%	8%

Preliminary
Data/Pythia tune A ~ 1.4
As expected
from NLO/LO comparison

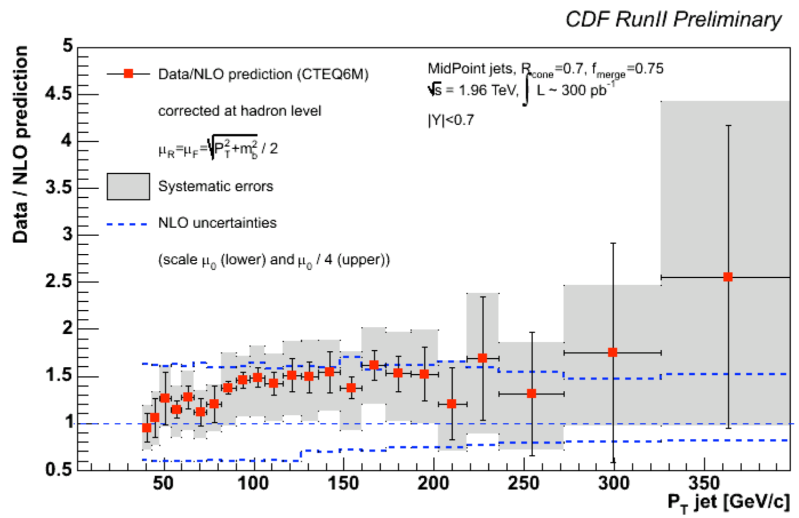
Comparison with NLO



Jets unfolded back to parton level for comparison with NLO cross section (Mangano et al. 1997)

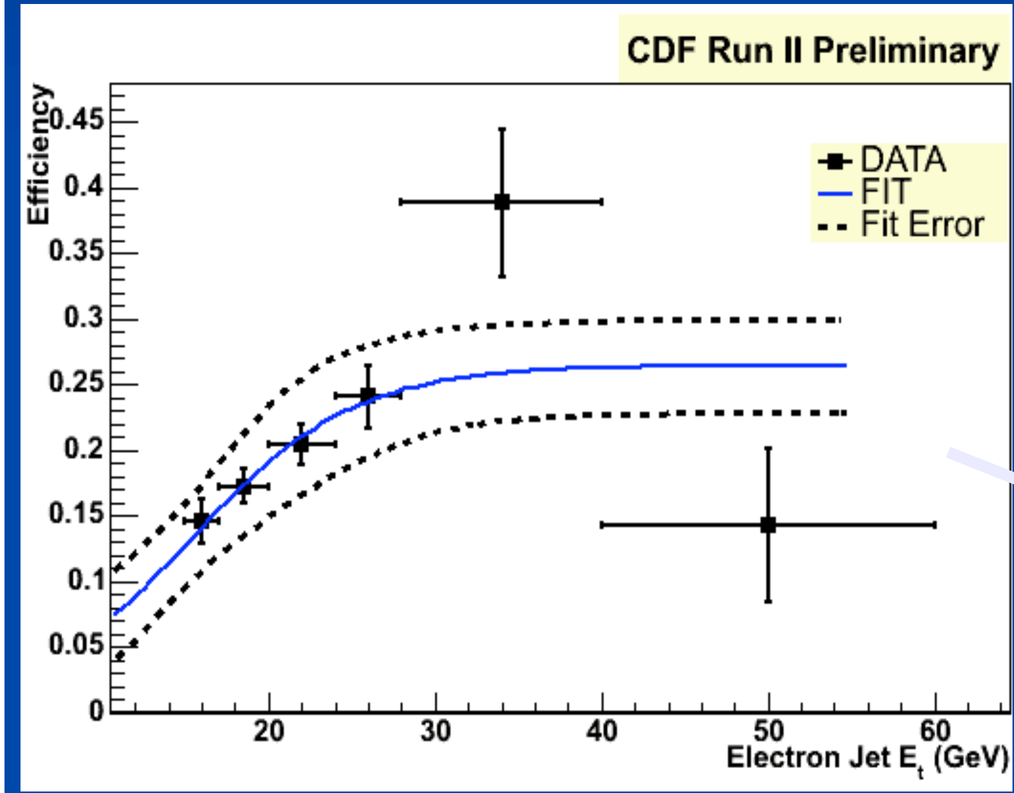
Large uncertainties due to renarmalization scale (default $\mu_0/2$); overall data higher than theory in the high-Pt region (where gluon splitting is more present)

Possible need for higher orders



$b\bar{b}$ cross section

~ 64 pb^{-1}

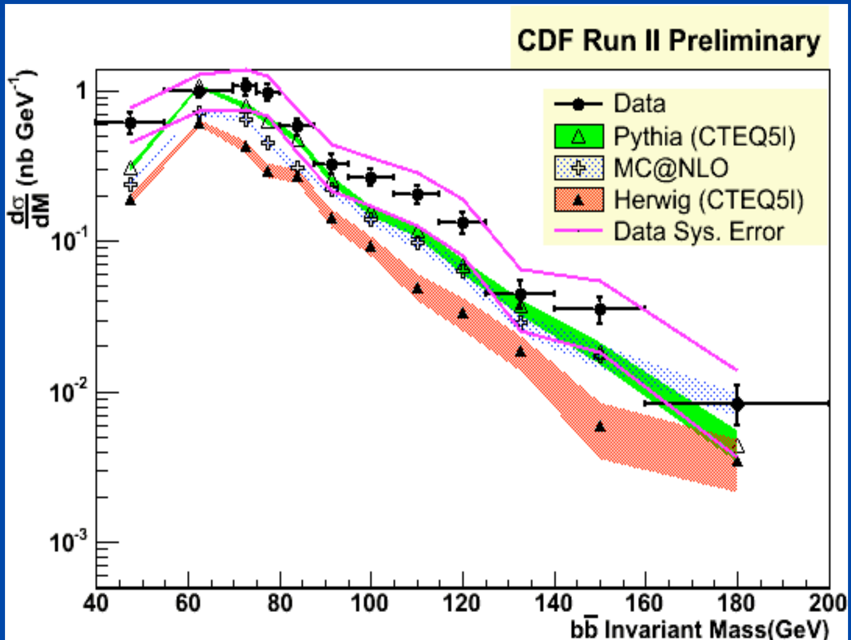


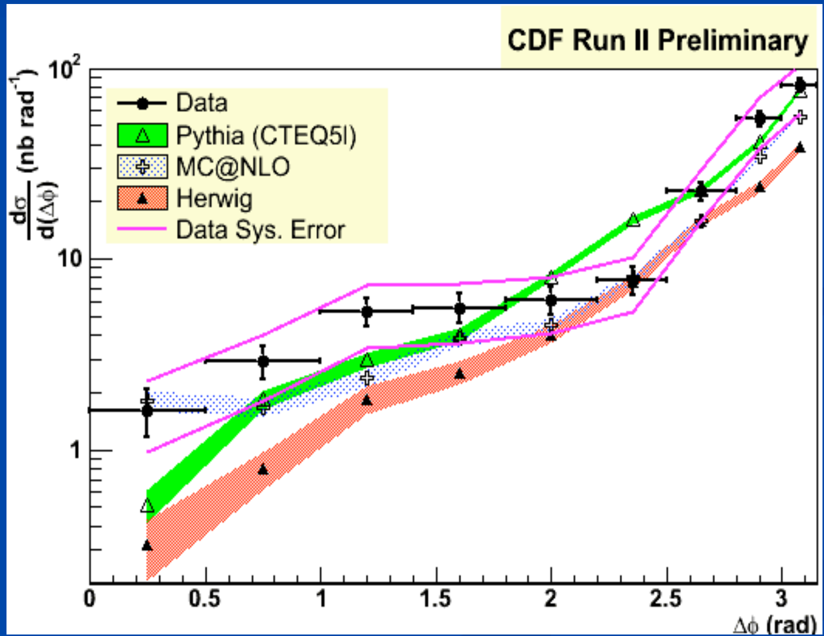
- Calorimetric trigger
  - L3: reconstructed jet E_t>20GeV
- JetClu cone 0.7
- Two central jets $|\eta|$< 1.2
  - $E_t(1)$ > 30 GeV, $E_t(2)$ > 20 GeV
- Energy scale corrected for detector effects
- Acceptance
  - Trigger efficiency folded in
- b tagging efficiency from data
  - Use an electron sample to increase bjets content
- b fraction
  - Fit to secondary vertex mass templates

$b\bar{b}$ cross section

- Main systematics:
  - Jet energy scale (~20%)
  - b tag efficiency (~8%)
- UE description lowers Herwig prediction

Data	34.5 ± 1.8 ± 10.5nb
Pythia(CTEQ5l)	38.71 ± 0.62nb
Herwig(CTEQ5l)	21.53 ± 0.66nb
MC@NLO	28.49 ± 0.58nb



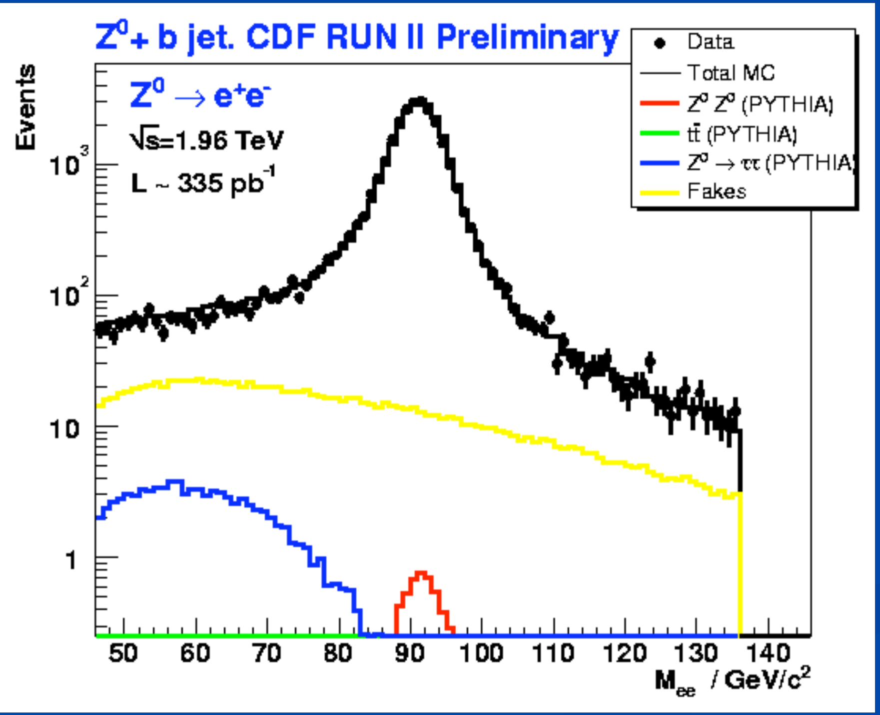


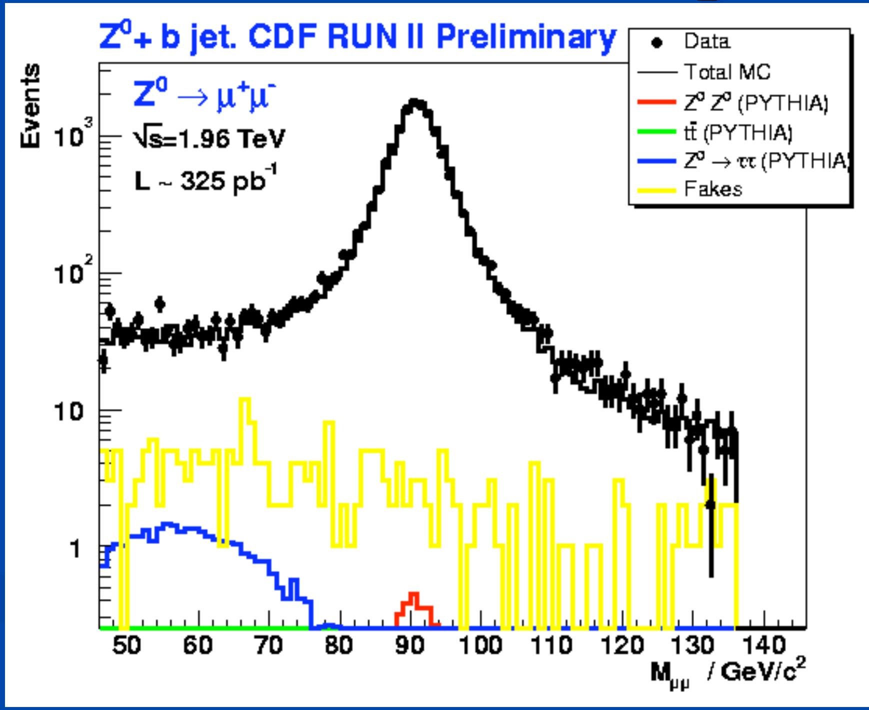
Better agreement with NLO MC can be reached using a multiparton generator (JIMMY) that gives better description of underlying event. Still under investigation.

Further analyses going on using SVT-triggered multi-b datasets

Z+b jets

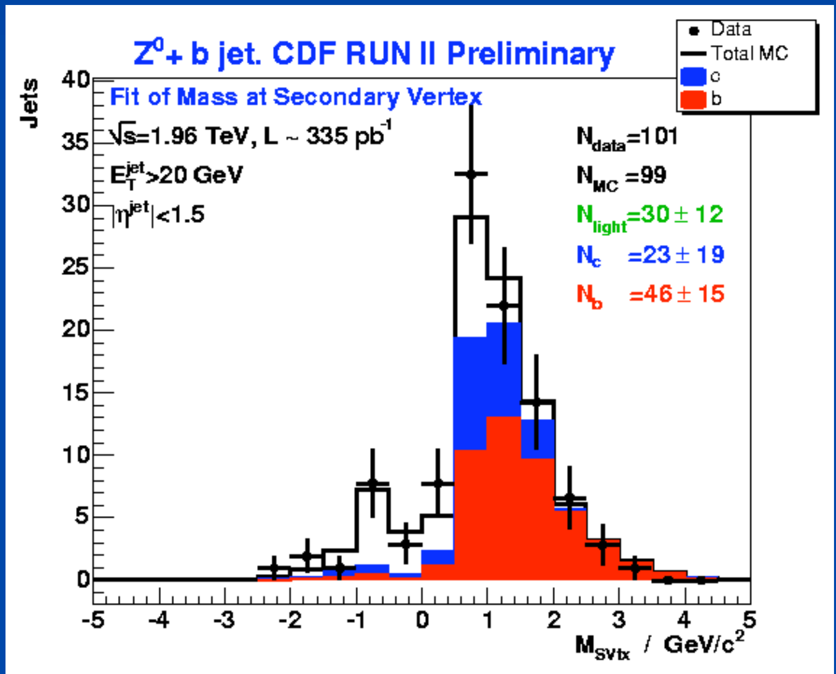
- Associated production of heavy quarks and vector bosons or photons can be used to cross check validity of extrapolation of hq Pdf, presently not measured yet by Hera (see Tev4Lhc write-up).
- In CDF, look for Z decays in electron or muon pairs

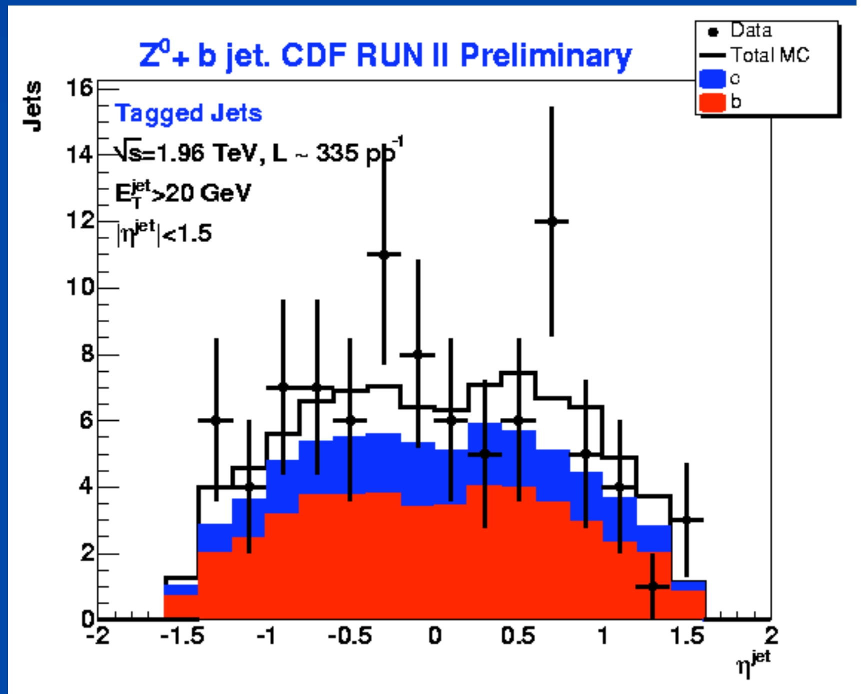




Z+b jets

- Asking for a tagged jet largely reduces the sample. Also in this case, b, c and light fractions are extracted from a fit to the secondary vertex mass

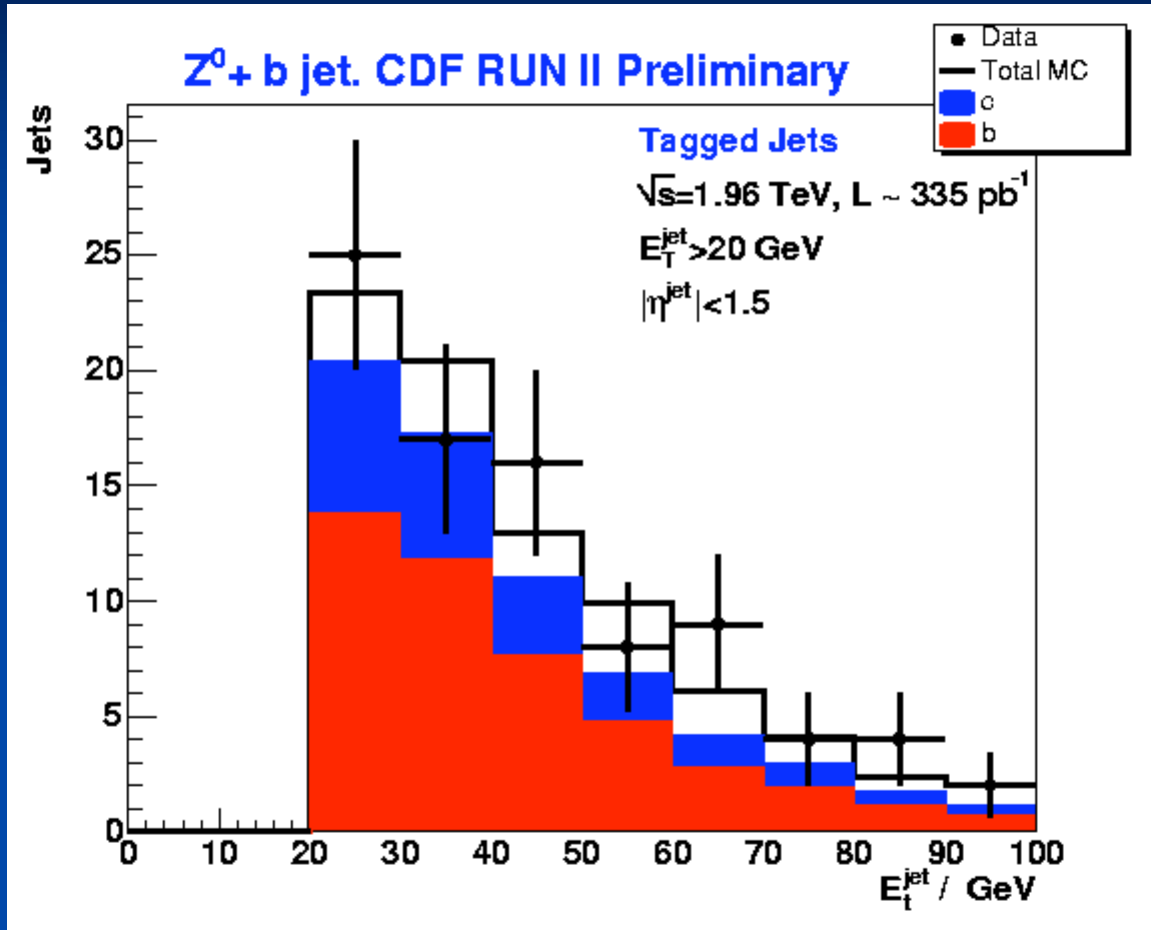




Jet Eta distribution relevant for Pdf determination, but needs more statistics

Z+b jet cross section

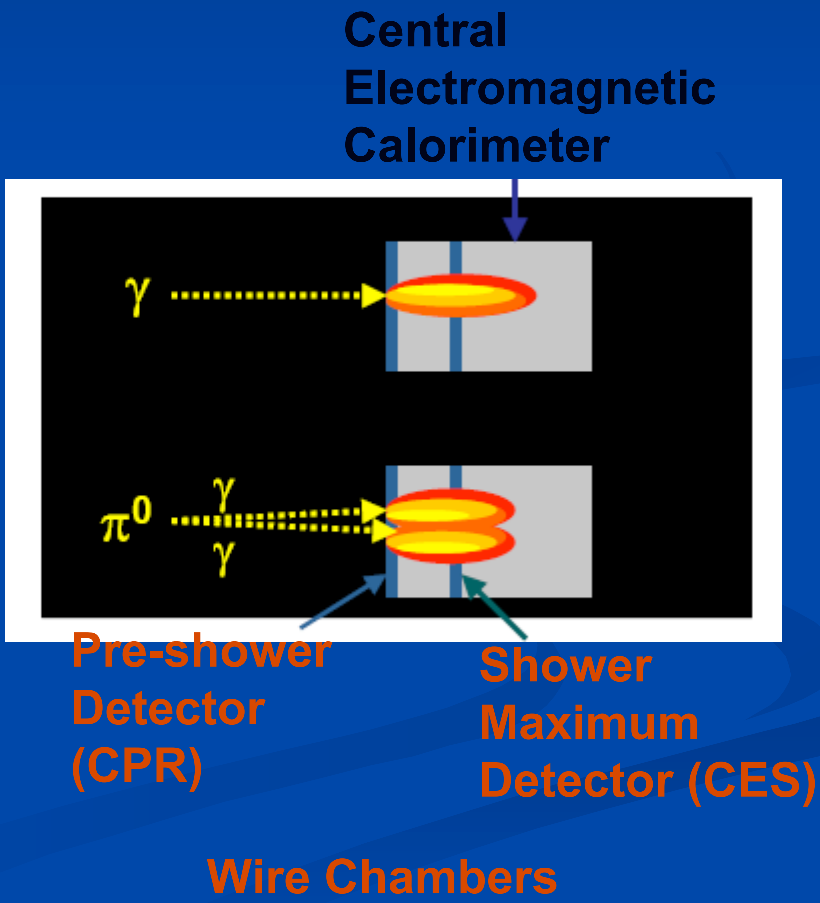
- Also in this case, Pythia seems to agree better than NLO code, probably due to better treatment of UE and fragmentation tuning



Cone0.7, $E_T^{jet} > 20$ GeV, $\lvert\eta^{jet}\rvert < 1.5$, $\sqrt{s} = 1.96$ TeV, $L \sim 335\,\mathrm{pb}^{-1}$	CDF RUN II Preliminary Data	PYTHIA TuneA (CTEQ5L)	NLO J. Campbell	NLO with Had, UE
$\sigma(Z^0 + b\ \mathrm{jet})$	$0.96 \pm 0.32 \pm 0.14$ pb	0.83 pb	0.48 pb	0.52 pb
$\sigma(Z^0 + b\ \mathrm{jet})/\sigma(Z^0)$	$0.0038 \pm 0.0012 \pm 0.0005$	0.0034	0.0019	0.0021
$\sigma(Z^0 + b\ \mathrm{jet})/\sigma(Z^0 + \mathrm{jet})$	$0.0237 \pm 0.0078 \pm 0.0033$	0.0207	0.0185	0.0185

b/c + γ analysis

- Background to Susy searches, will be used used to extract b/c Pdf's
- No event-by-event photon identification possible: only statistical separation based on shower shape in electromagnetic calorimeter

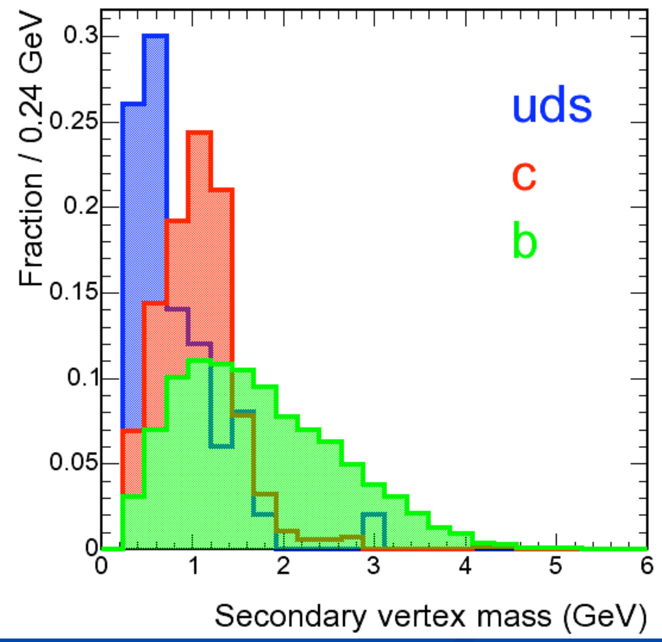


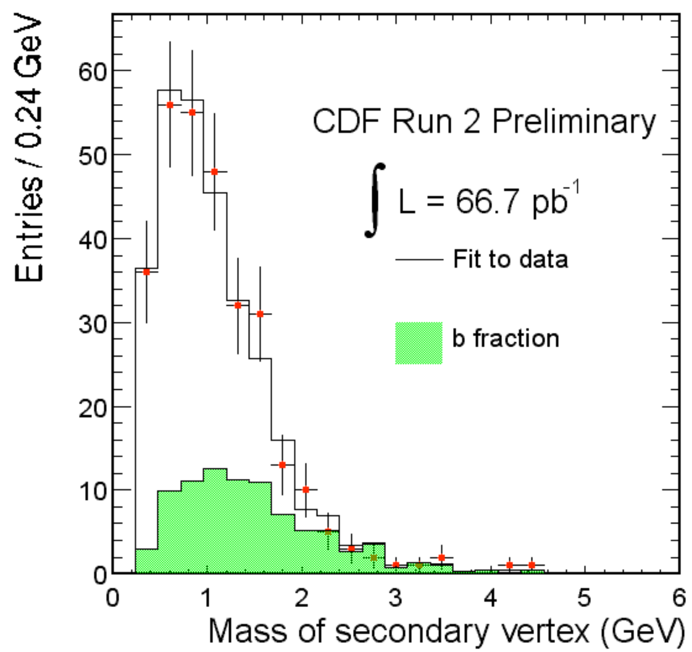
Photon + b/c Analysis

So far, use Et > 25 GeV unbiased photon dataset, without jet requirements at trigger level:

Apply further requirements off-line:

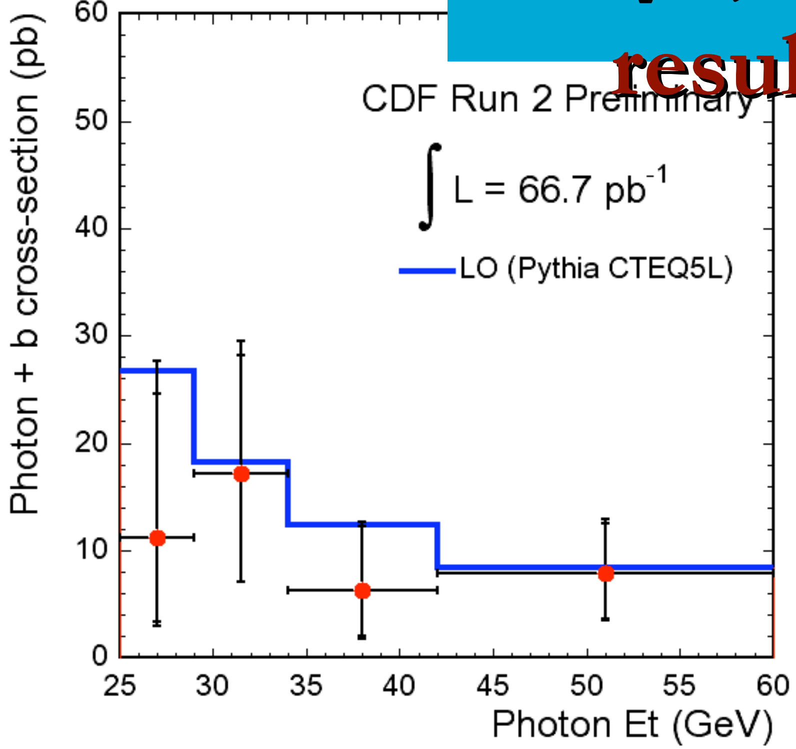
- γ $|\eta|<1.0$
- jet with secondary vertex
- Determine b, c, uds contributions
- Subtract photon background using shower shape fits

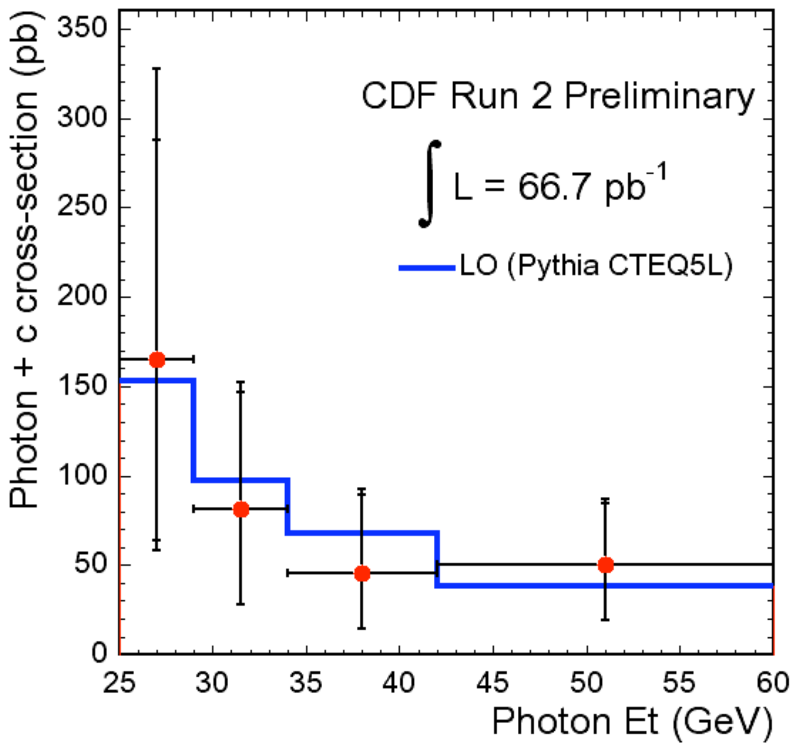


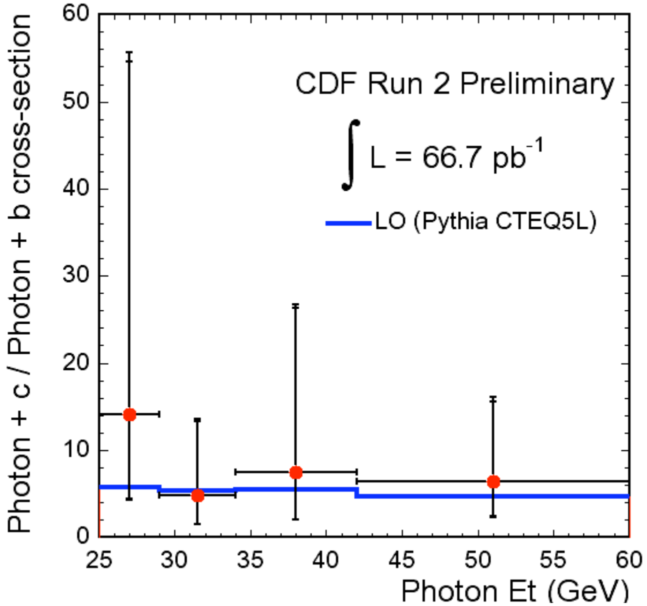


Studies going on using dedicated triggers based on SVT

γb, γc results



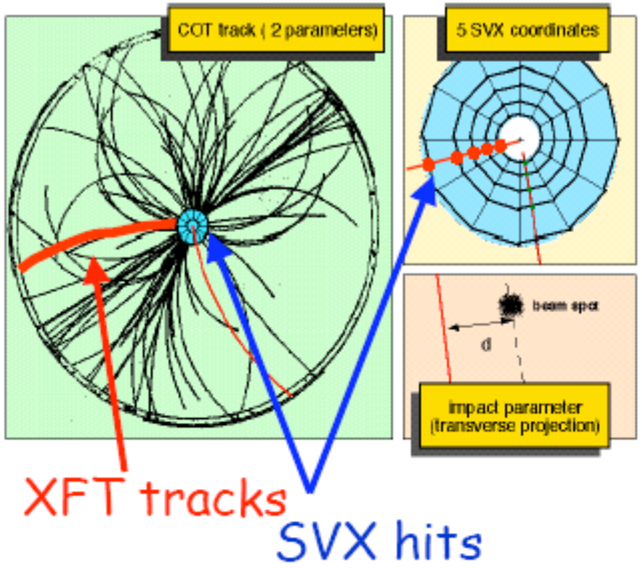




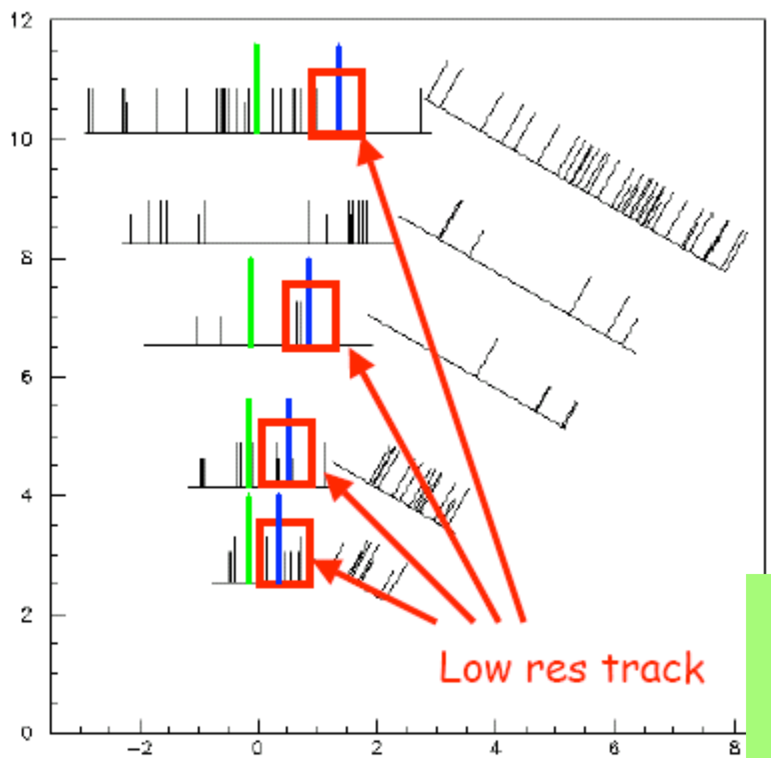
Cross sections and ratio agree with LO predictions from MC.

This measurement still largely statistics-dominated

Silicon Vertex Tracker (SVT)



Finding tracks in the silicon

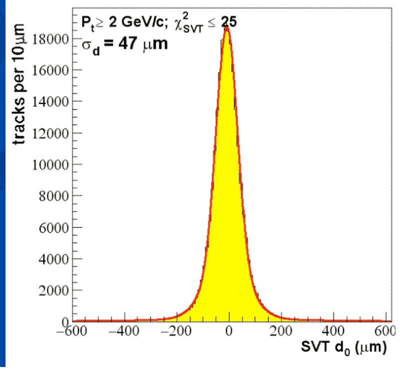


2 steps:

1. Find tracks @ low res: constant time (during readout)
2. Fit hit at full res.: time consuming depending on the number of fits

35 μm ⊕ 33 μm = σ≈47 μm (resolution ⊕ beam)

On-line tracking reconstruction allows design of specific triggers for heavy flavors; widely used in low-pt physics, extension to high-pt under way



Using the SVT at high Pt

- The Geneva group proposed and is presently responsible of two trigger paths that use SVT information to enhance b content in high-Pt events.
- Conceived to search for new physics, we are now analyzing these datasets to measure QCD properties:
  - PHOTON_BJET
    - A photon with Et>12 GeV
    - A track with |d0|>120 μm
    - A jet with Et>20 GeV (eff. about 30% on bγ candidates)
  - HIGH_PT_BJET
    - 2 tracks with |d0|>120 μm
    - 2 jets with Et>20 GeV

Two-track trigger

- Level 1:
  - two XFT tracks with $pT>2$ GeV
  - $pT_1 + pT_2 > 5.5$ GeV
- Level 2:
  - 120 μm < $|d_0|$ < 1 mm for each track
  - Opening angle $2^\circ < |\Delta\varphi| < 90^\circ$
  - Lxy > 200 μm

Fully hadronic decays; other trigger paths still using SVT information exist for semileptonic and leptonic channels

Cross section of exclusive charm states

With early CDF data: $5.8 \pm 0.3 pb^{-1}$

- Measure prompt charm meson production cross section
- Data collected by SVT trigger from 2/2002-3/2002
- Measurement not statistics limited

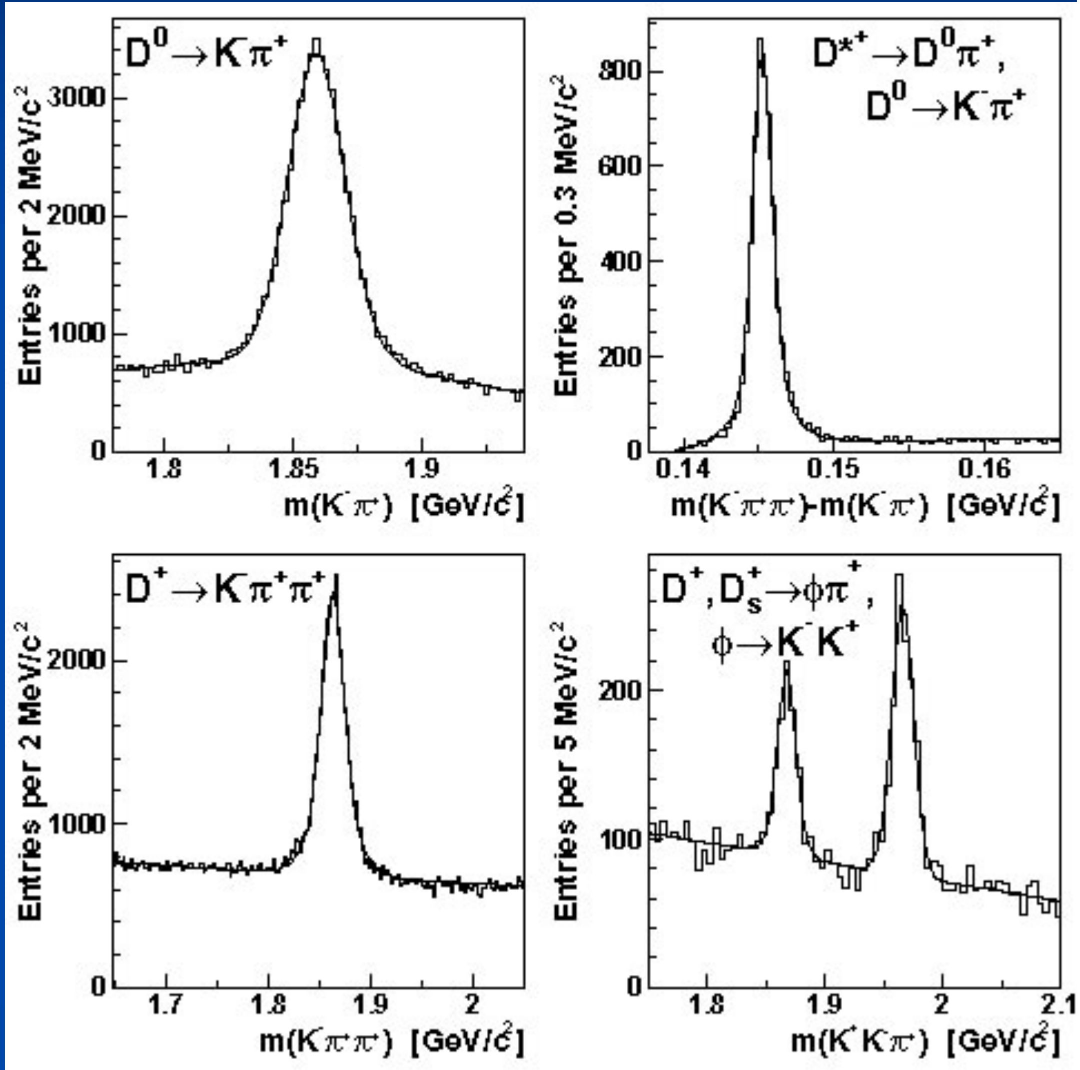
Large and clean signals:

$D^0 \to K^- \pi^+$

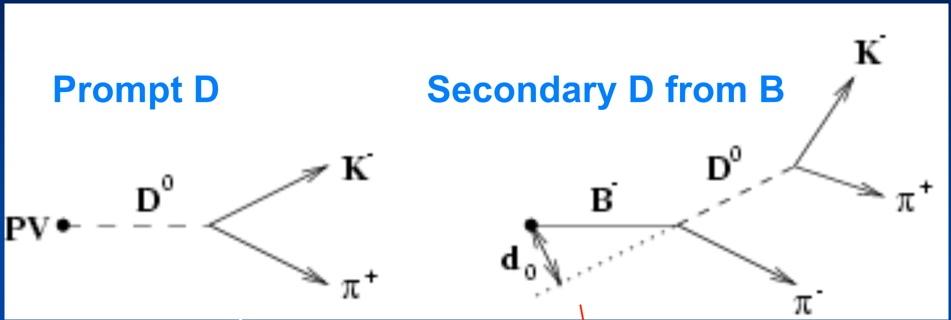
$D^{*+} \to D^0 \pi_s^+$ with $D^0 \to K^- \pi^+$

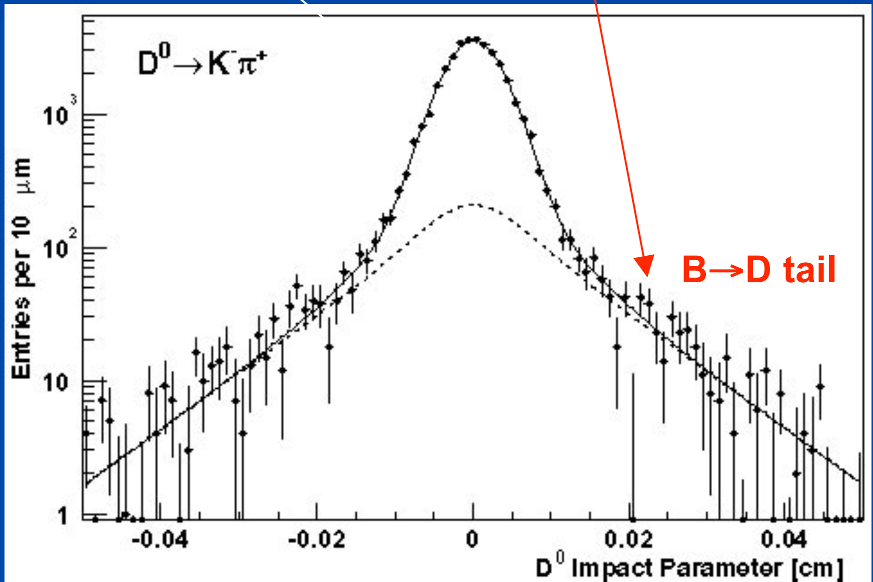
$D^+ \to K^- \pi^+ \pi^+$

$D_s^+ \to \phi \pi^+$ with $\phi \to K^+ K^-$



Separating prompt from secondary Charm





Separate prompt and secondary charm based on their transverse **impact parameter distribution**.

Need to separate direct D and B→D decay

- Prompt D point back to collision point
  I.P.= 0

  Detector I.P. resolution shape measured from data in K^0_s sample.

- Secondary D does not point back to PV
  I.P.≠ 0

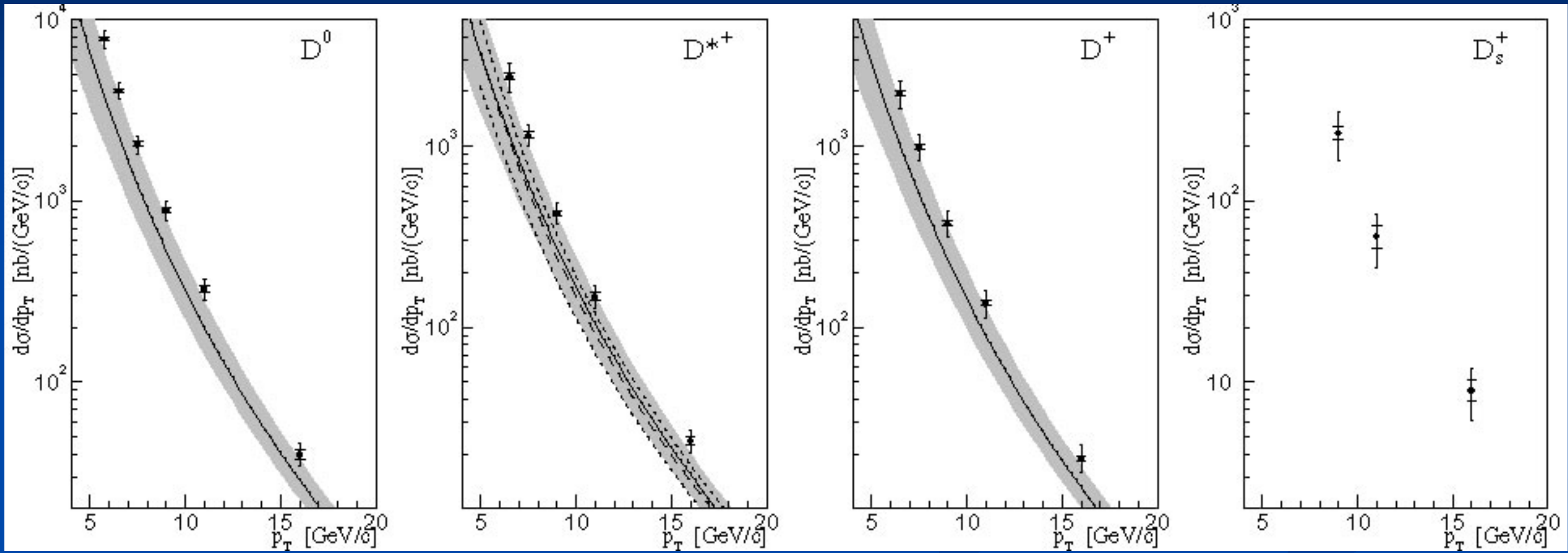
Direct Charm Meson Fractions:

D^0: f_D=86.4±0.4±3.5%
D^{*+}: f_D=88.1±1.1±3.9%
D^+: f_D=89.1±0.4±2.8%
D^+_s: f_D=77.3±3.8±2.1%

Most of reconstructed charm mesons are direct →

Differential Charm Meson X-Section

P_T dependent x-sections:



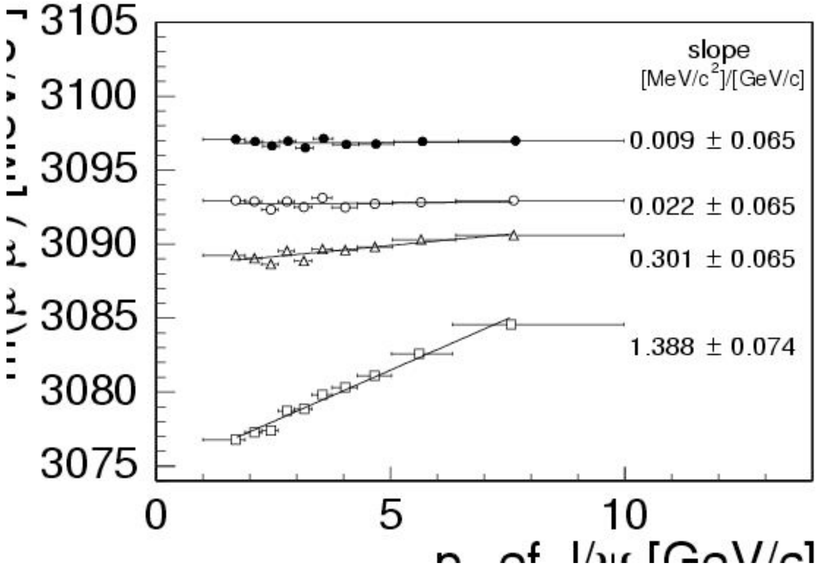
Theory prediction:

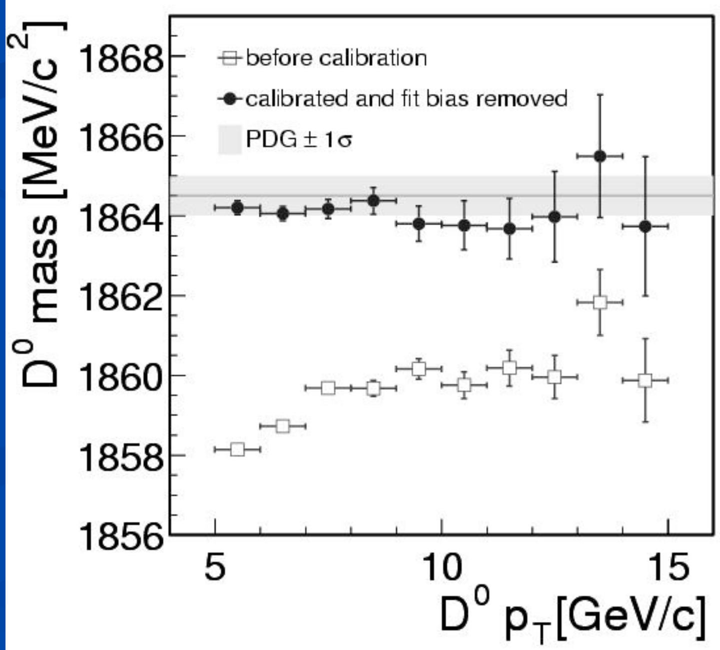
Calculation from M. Cacciari and P. Nason:
Resummed perturbative QCD (FONLL)
JHEP 0309,006 (2003)

CTEQ6M PDF
M_c=1.5GeV,
Fragmentation: ALEPH measurement
Renorm. and fact. Scale:
$m_T=(m_c^2+p_T^2)^{1/2}$
Theory uncertainty: scale factor 0.5-2.0

G3X track calibration (Gen4)

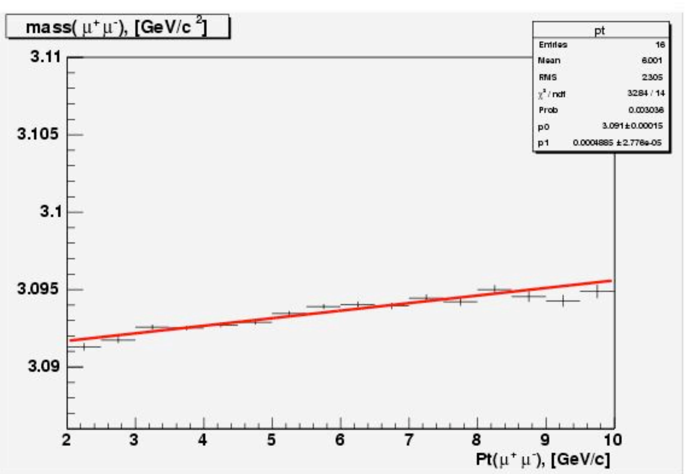
- To perform high-precision spectroscopy measurements energy loss in tracker has to be properly accounted for.
- The GEANT description of the detector material has been used in a first time to correct for energy loss.
- An additional layer, (20% of total passive material in the silicon tracking system) has been added inside the inner shell of the COT to remove the dependence of the J/Ψ on pT.
- Also the value of the magnetic field has been recalibrated
- Calibration tested on D^0



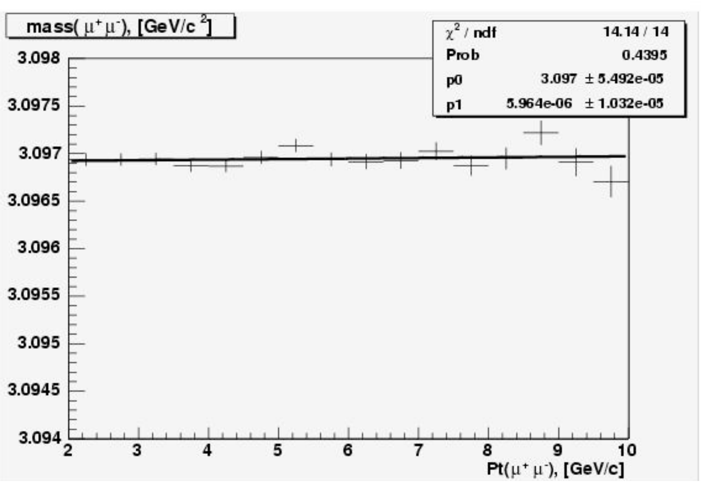


Kalman track calibration (Gen5)

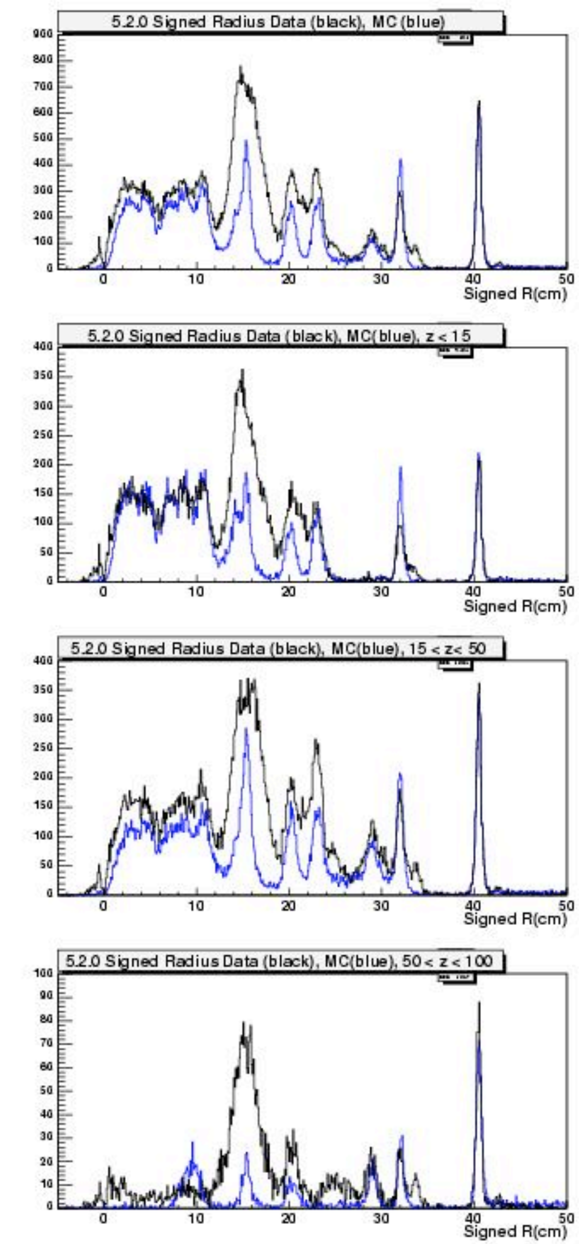
- With tracking reconstruction improvements, it became possible to add the additional material in the much faster Kalman refitter.



Standard material description still inadequate; photon conversion distribution indicates extra material to be z-dependent and in several locations



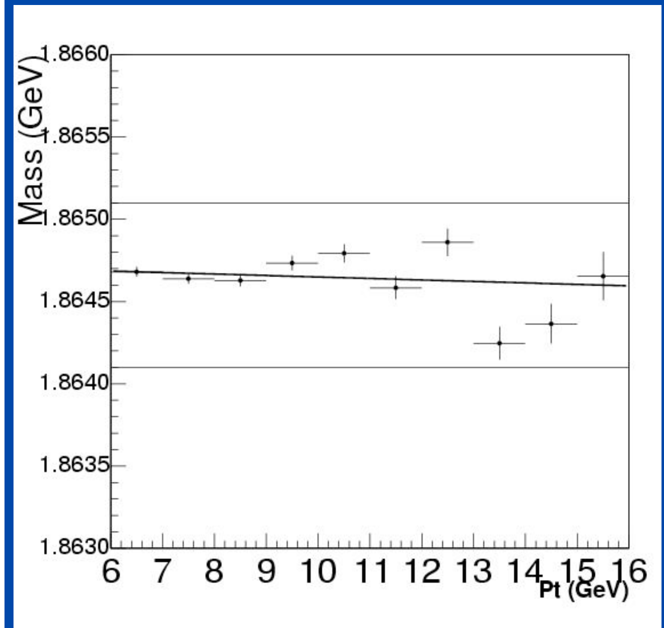
After retuning

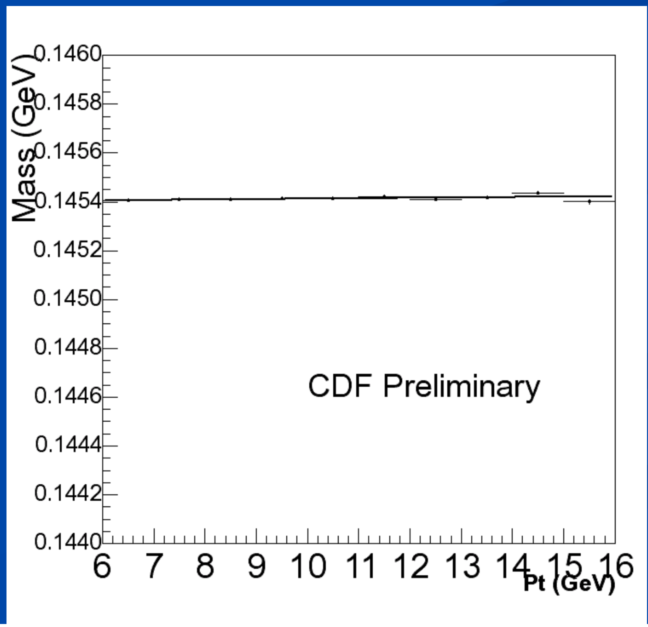


Tests of Kalman calibration

- Calibration performed on J/Ψ, tested on many other channels, also to check for charge asymmetries

Meson	Decay mode	Slope MeV/GeV	Measured mass, MeV	PDG mass, MeV	Mass pull
K^0_S	$\pi^+\pi^-$	-0.07 ± 0.16	$497.63 \pm 0.04 \pm 0.07$	497.672 ± 0.031	-0.48
$B^\pm$	$J/\psi K^\pm$	0.11 ± 0.06	$5278.73 \pm 0.58 \pm 0.7$	5279.0 ± 0.5	0.70
J/ψ	$\mu^+\mu^-$	-0.006 ± 0.01	$3096.87 \pm 0.2 \pm 0.4$	3096.87 ± 0.04	$0.$
$\Upsilon(1S)$	$\mu^+\mu^-$	-0.16 ± 0.21	$9459.6 \pm 1.1 \pm 1.5$	9460.30 ± 0.26	-0.4

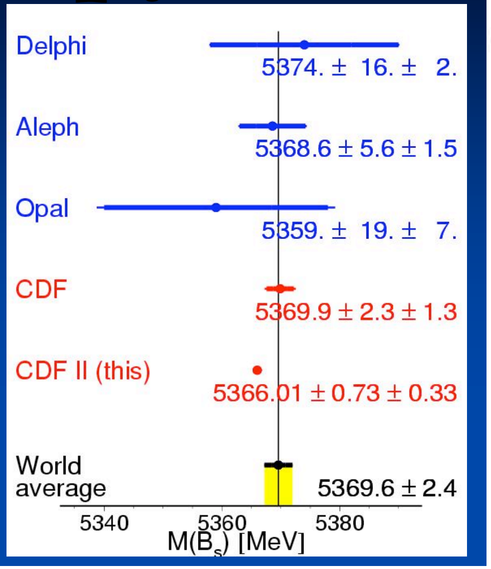


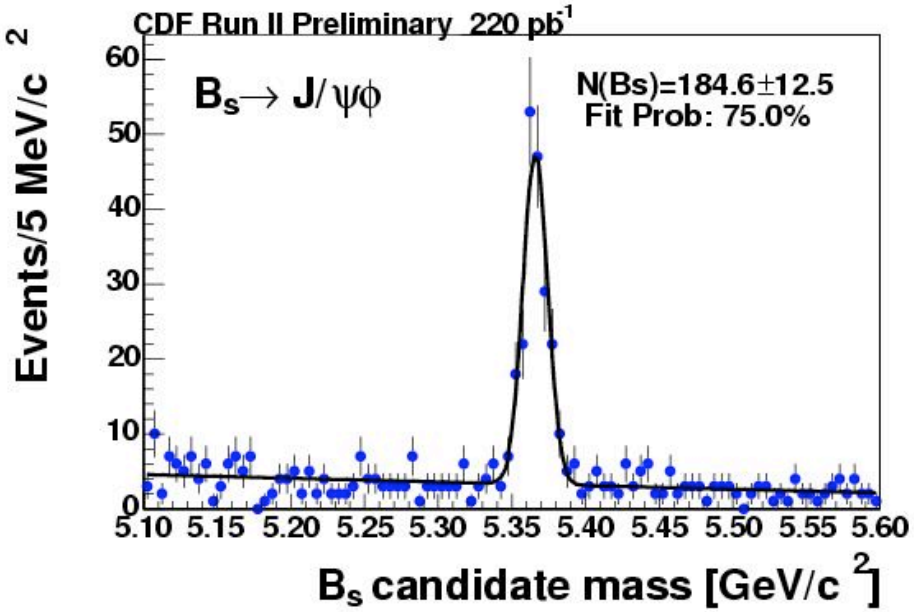


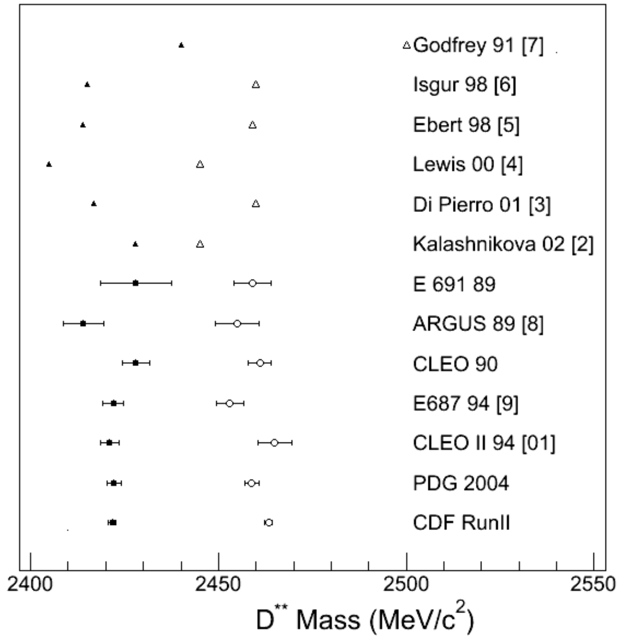
As well as on D^0 and D^*-D^0 mass difference

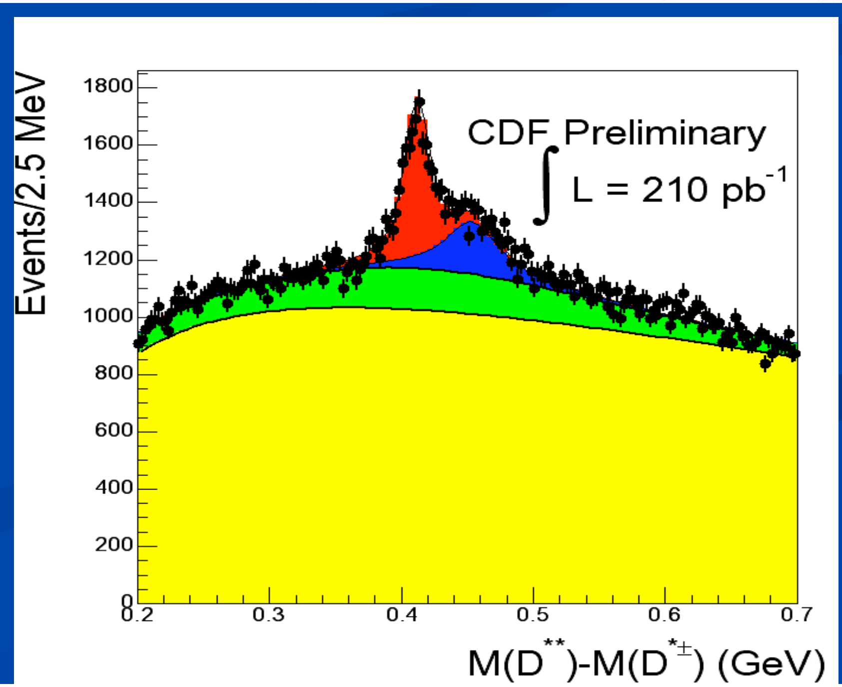
Spectroscopy with SVT datasets

Huge dataset in Bs and hadronic charm, best world spectroscopic measurements for many states







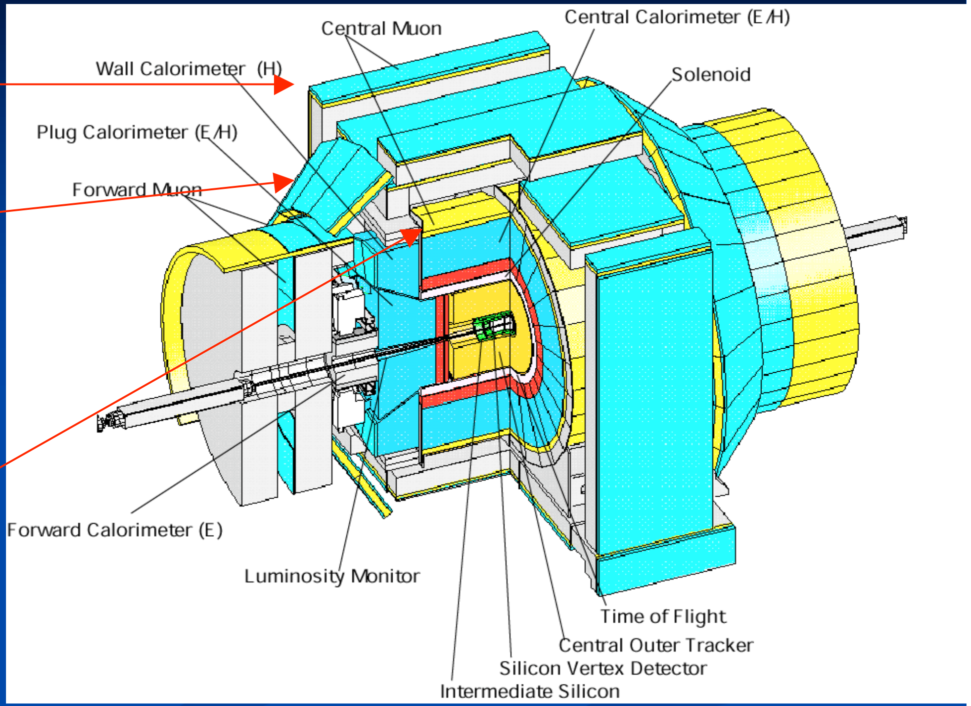


CDF muon system and trigger

External muon chambers (CMP) after magnet

eXtension muon chambers (CMX) for $0.6<\eta<1.0$

Internal muon chambers (CMU) after HCAL



Several muon-based triggers;

- J/ψ with two opposite-sign muons $pT>1.5$ GeV

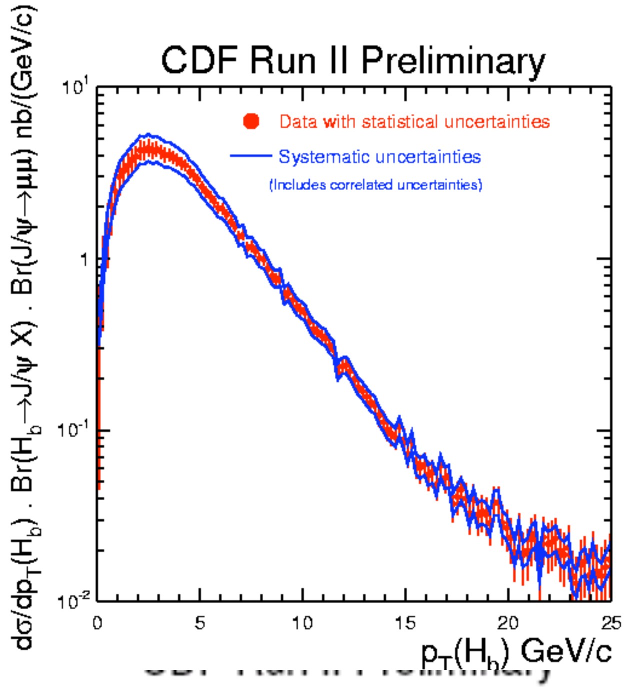
  pT_1+pT_2 down to zero

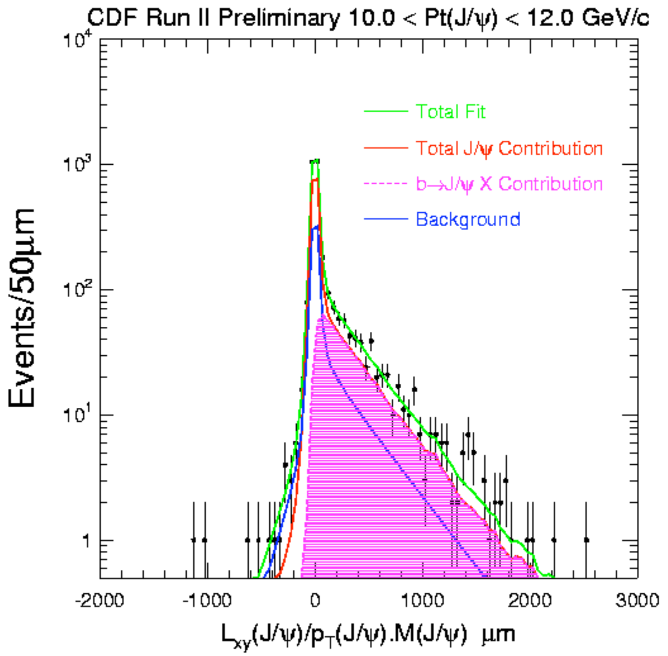
- Exotic triggers for CMU/CMU or CMU/CMX events

B production from J/ψ sample

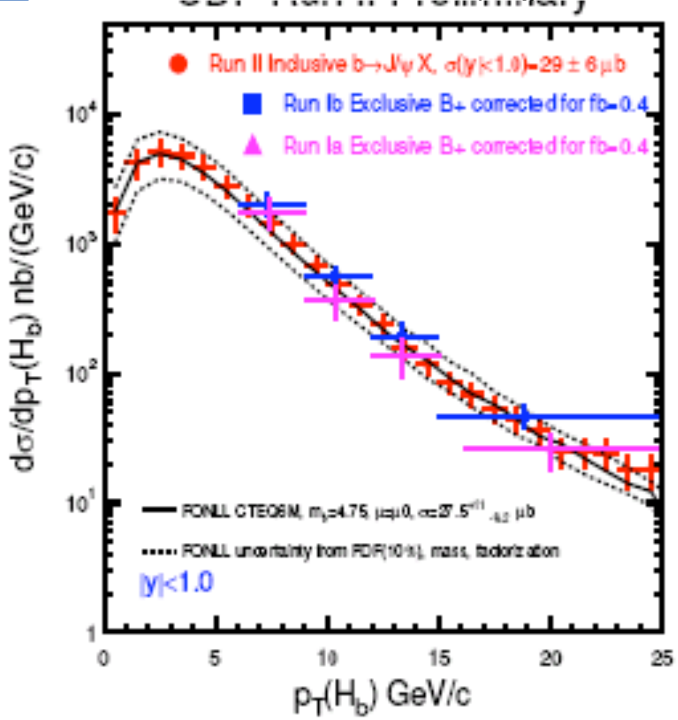
- Triggers μμ in J/ψ mass window down to Σ pT=0
- As for D case, measures both prompt production and b decays

Combined variable of mass pt and impact parameter allows distinction of the two cases



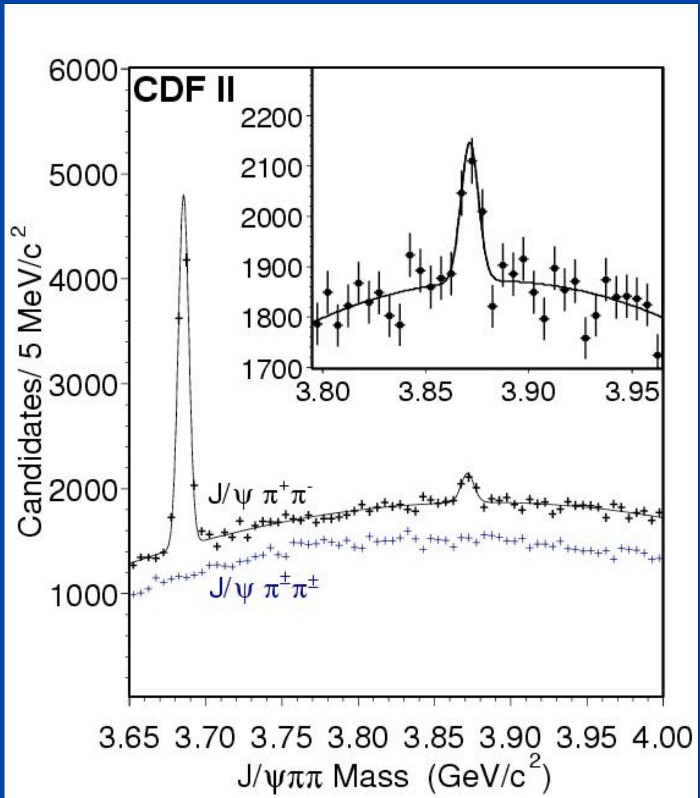


Final b cross section in agreement with NLO calculations



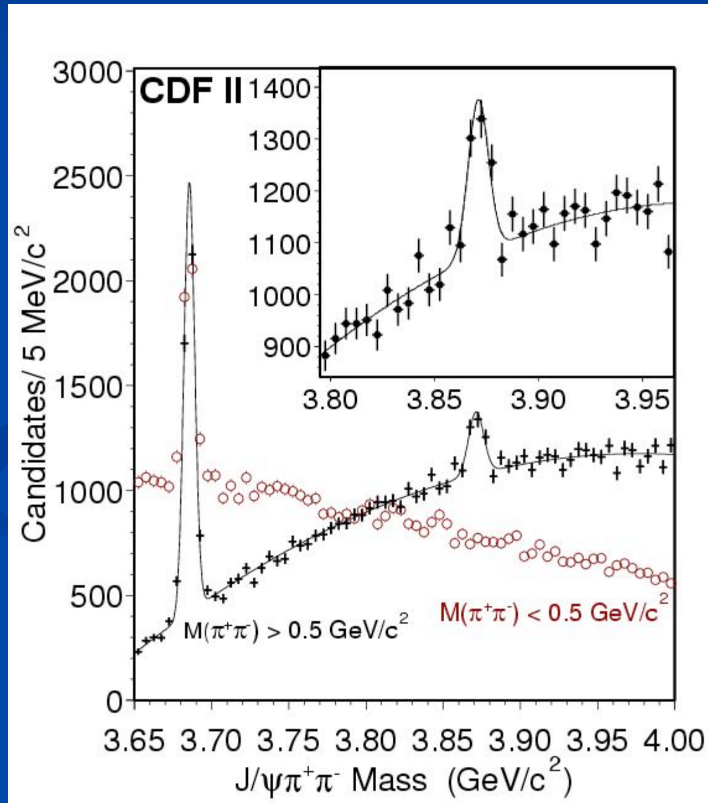
X(3872): observation

- The Belle observation of a mysterious new state X(3872) in $J/\Psi\ \pi^+\pi^-$ pushed CDF to its first confirmation.



730 candidates, M(X) = 3871.3 ± 0.7 (stat) ± 0.4 (sys)

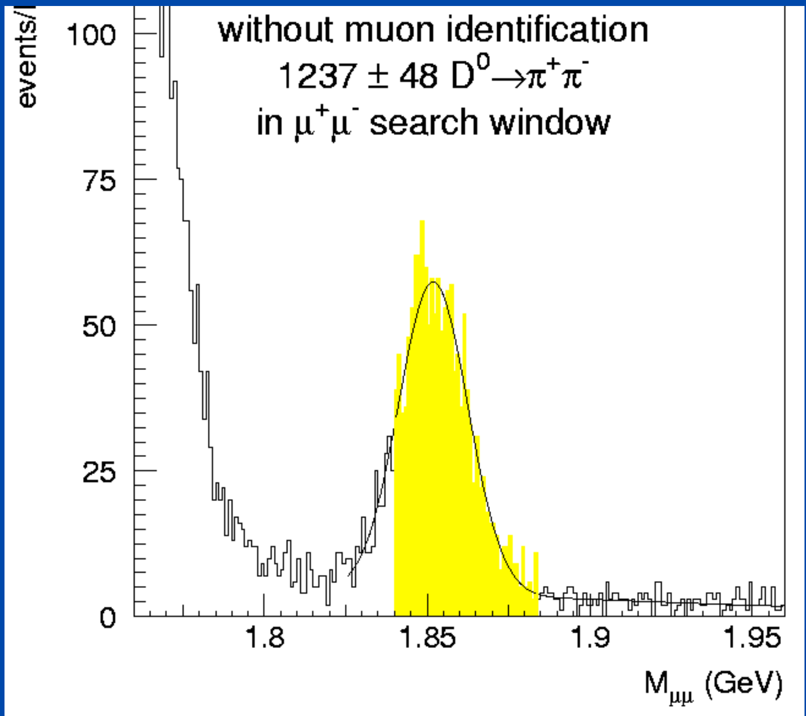
Γ(X) = 4.9 ± 0.7 consistent with detector resolution



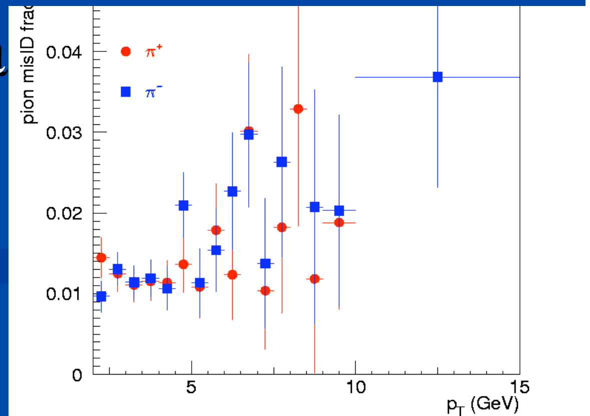
Cut on M(π π)>500 MeV: 659 candidates on 3234 background, signal seen at 11.6σ.

Search for $D^0 \to \mu\mu$ in the TTT dataset

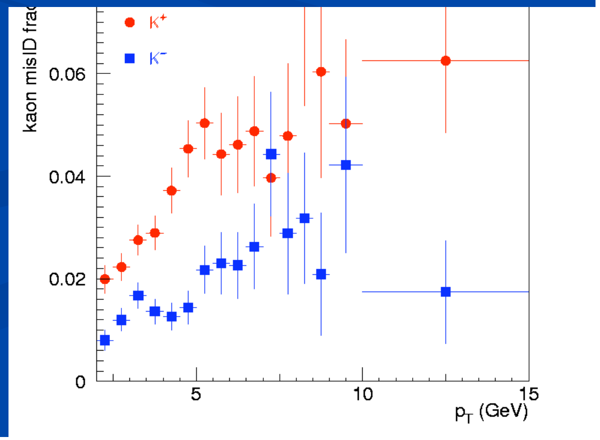
- GIM-suppressed ($BR \approx 10^{-13}$), up to 10^{-8} in SUSY
- No trigger requirement on muons, since analysis uses $D^0 \to \pi\pi$ for normalization, and $D^* \to D^0\pi$, $D^0 \to K\pi$ to determine fake muon ba



Mis-id pions



Mis-id kaons



Results on $D^0 \to \mu\mu$

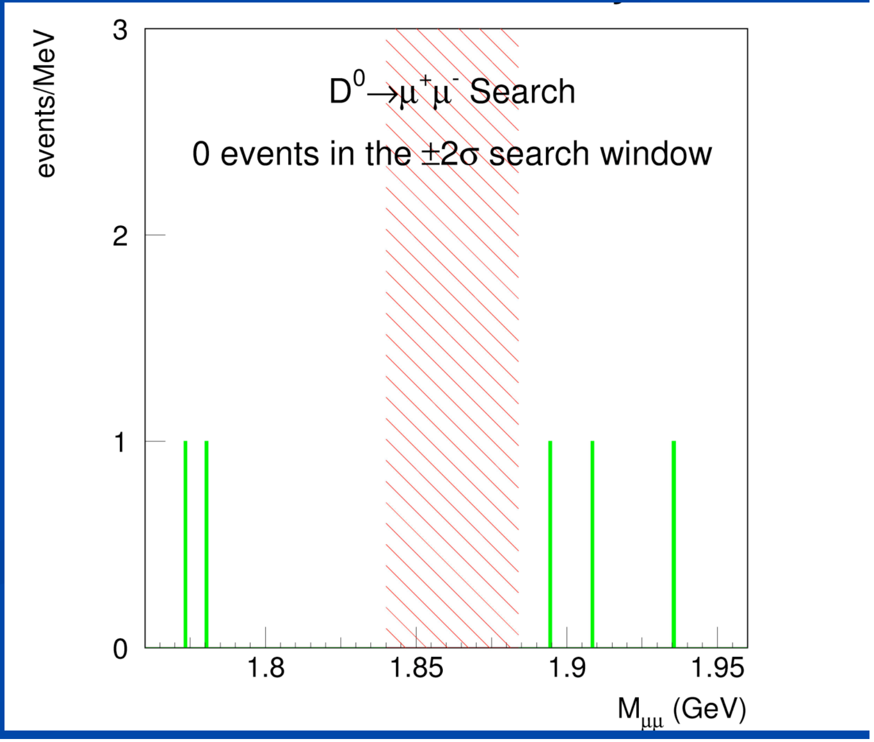
- MC used to derive efficiency and acceptance corrections between pions and muons.

  $\epsilon(\pi\pi)/\epsilon(\mu\mu) = 1.13 \pm 0.04$, $a(\pi\pi)/a(\mu\mu) = 0.96 \pm 0.02$

Additional cuts optimized maximizing Punzi function $S/(1.5+\sqrt{B})$:

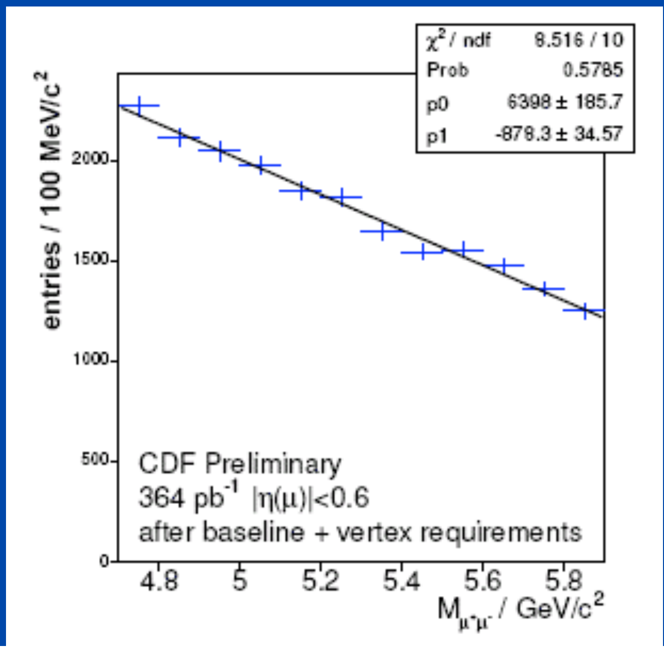
$|\Delta\varphi(\text{CMU})| > 0.085$ rad, $|d_{xy}| < 150\ \mu$m, $L_{xy} < 0.45$ cm

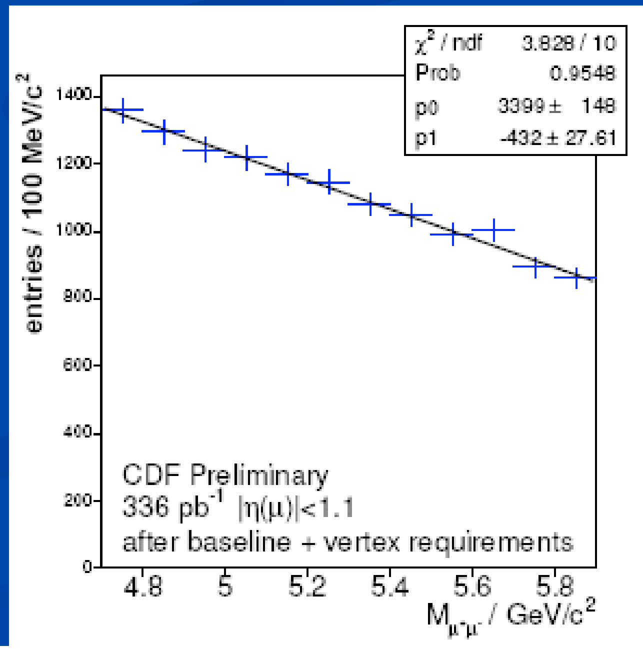
Expected BG 1.8±0.7, observed 0, limit set to $2.5\ 10^{-6}$ at 90% C.L.



Search for Bd,Bs $\rightarrow \mu\mu$

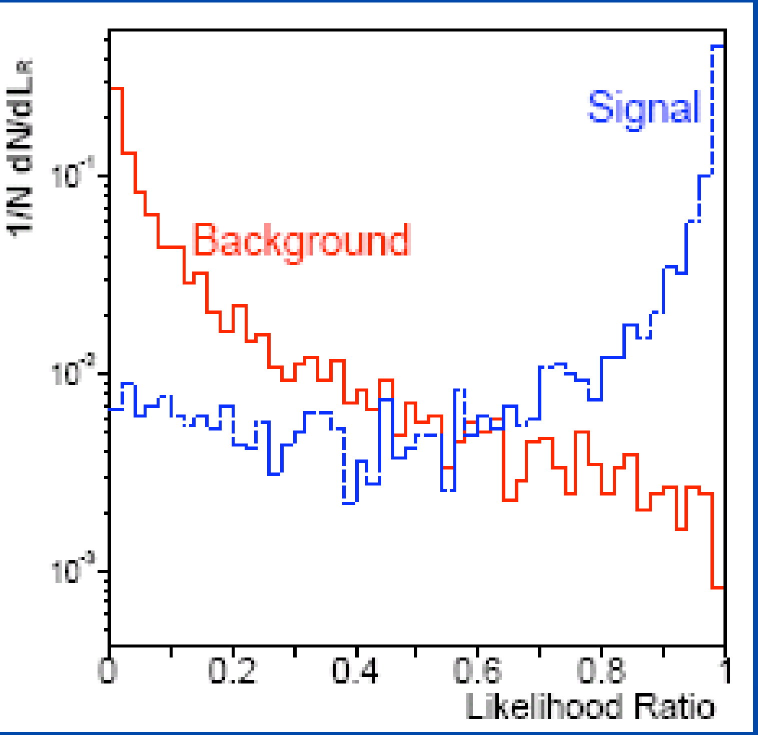
- Expected SM BR: 10^{-10} and 3 10^{-9} respectively. SUSY may enhance by 3 orders of magnitude, $\propto \tan\beta^6$
- Use both CMU-CMU and CMU-CMX events, restricting to pT>2 (2.2) GeV and $|pT_{\mu\mu}|>4$ GeV
- Requiring $L_{3D}<1$ cm, $(L_{3D})<150$ μm, $2c\tau<c\tau<0.3$ cm still leaves a large combinatorial BG:

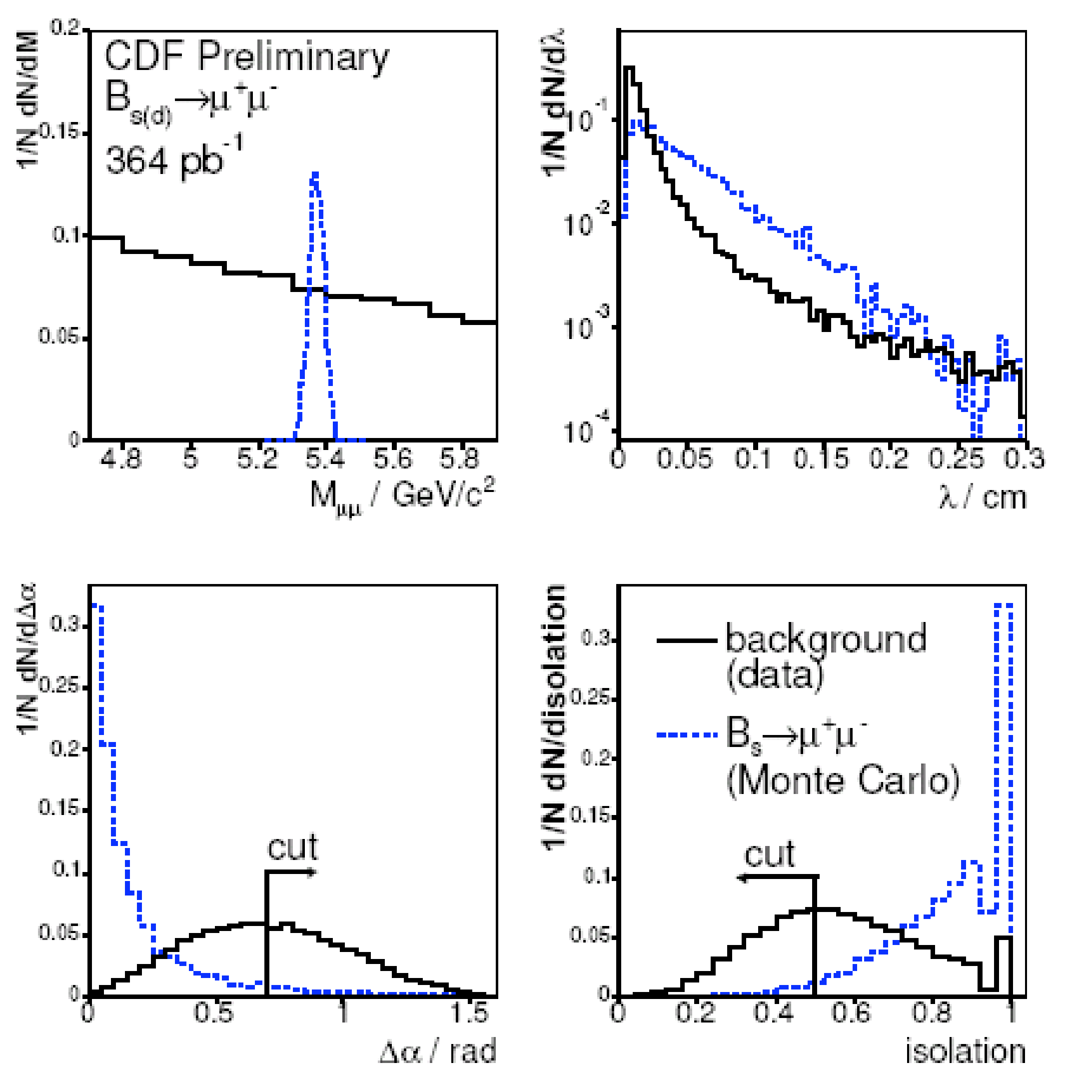




Likelihood method

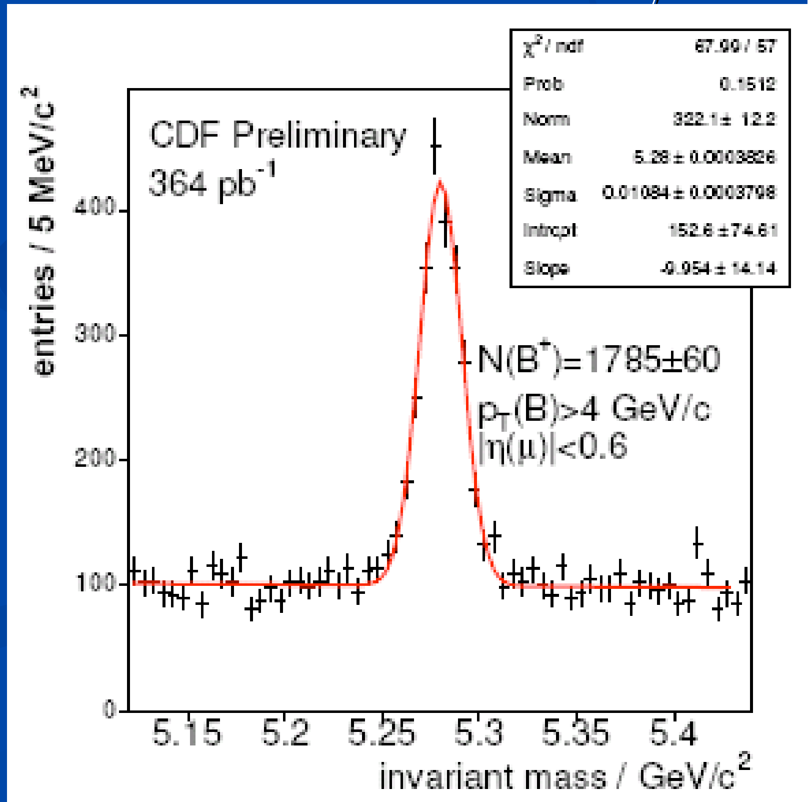
- $\lambda = c\tau$
- $\Delta\alpha$ pointing angle between p and L





Normalization channel

- $B^+ \to J/\psi K^+$ taken with same trigger and same requirements, plus $pT(K) > 1$ GeV.
- Used as normalization and to cross-check MC;
  - Important inacceptance ratio and likelihood efficiency
- Background estimation from
  - Like-sign muons
  - Events with $\lambda<0$
  - Fake-enriched sample



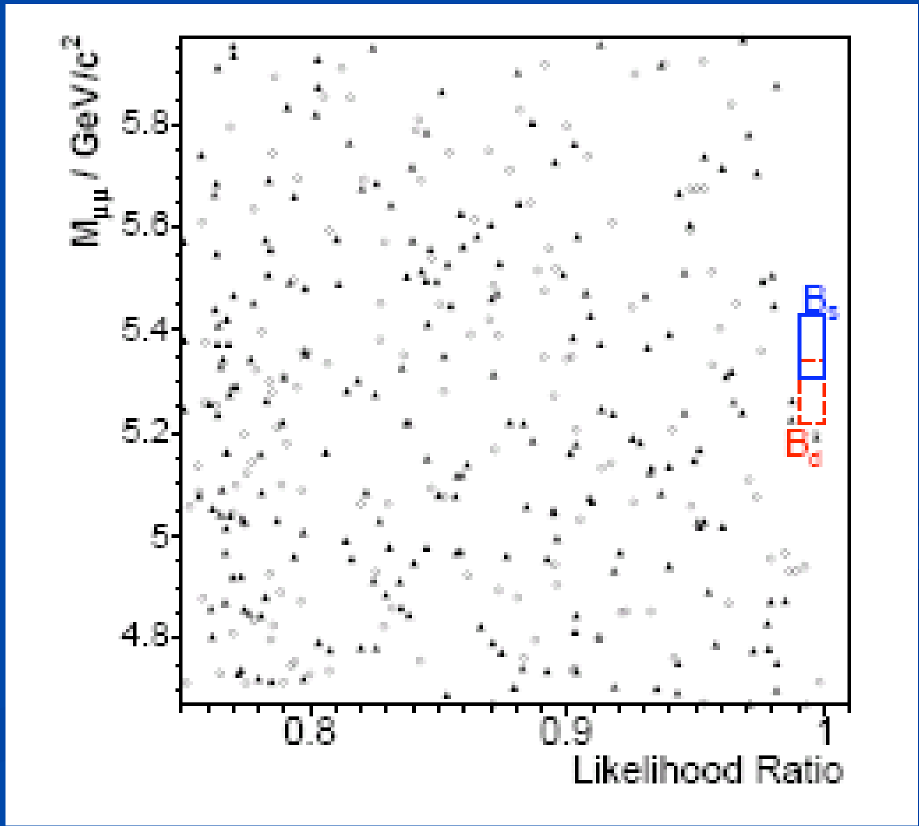
Results

- To optimize a priori 90% C.L. upper limit, the cut chosen is $L_R > 0.99$.
- Expected BG: 0.81±0.12; 0.66±0.13
- No events found in either mass window

Limits sets to

BR(Bs →μμ)< 1.5 10^{-7}

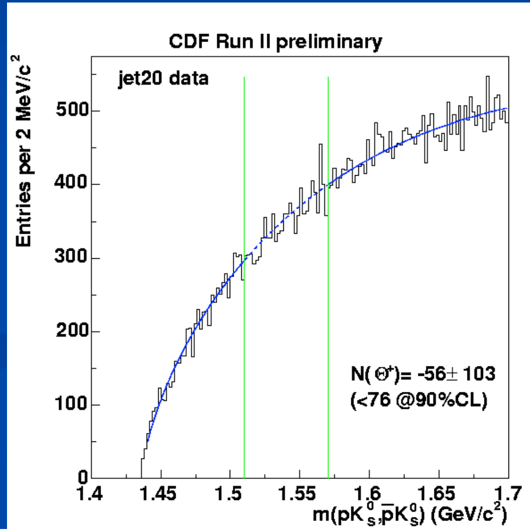
BR(Bd →μμ)< 3.9 10^{-8} at 90% CL

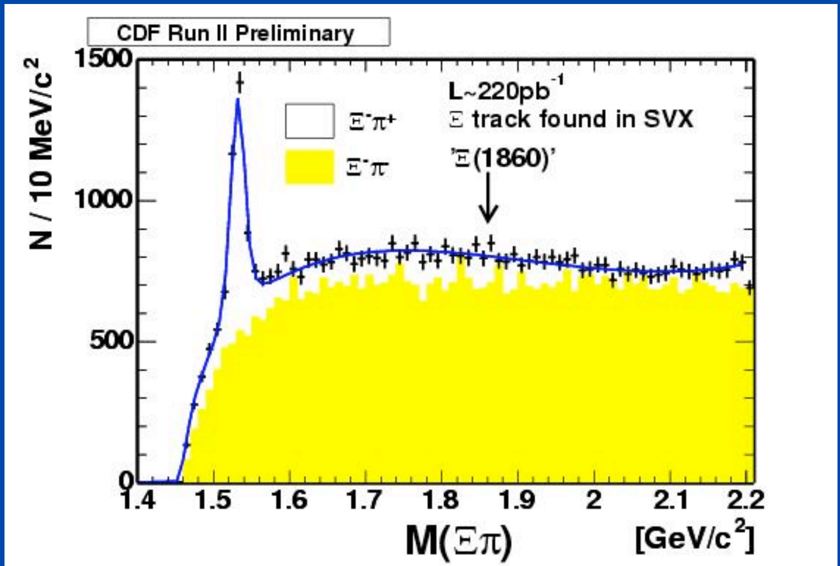


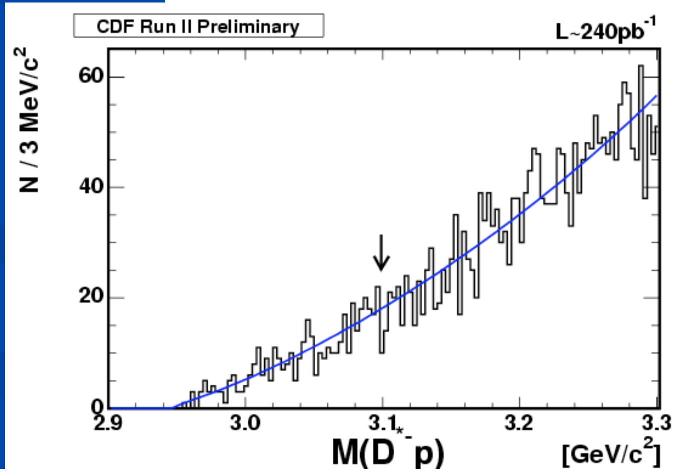
Search for PentaQuarks

Several claims:

- $\Xi_{3/2}^{--}, \Xi_{3/2}^{0} \rightarrow \Xi^{\pm}\pi^{\pm}$; M=1862±2 MeV (NA49)
- $\Theta^{+} \rightarrow nK^{+}, pK^{0}$; M≈1530 MeV (Hermes, Zeus, Diana, CLAS, SVD,COSY-TOF, not HERA-B, Phoenix,BES)
- $\Theta_{c} \rightarrow D^{*}p$; M=3099 MeV (H1)







No confirmation from CDF so far

Conclusions

- Tevatron RunII is proceeding at full steam, many analyses with 1 fb-1 will be presented at this year's winter conferences
- Excellent tracking capabilities allow study of b production in association with multiple final states
- Enormous b-physics program possible thanks to on-line tracking
- Starting to analyze b-enriched datasets also at high-pt
- Not only measurements, also search for new physics, and perhaps surprises (X, PQ, etc.)