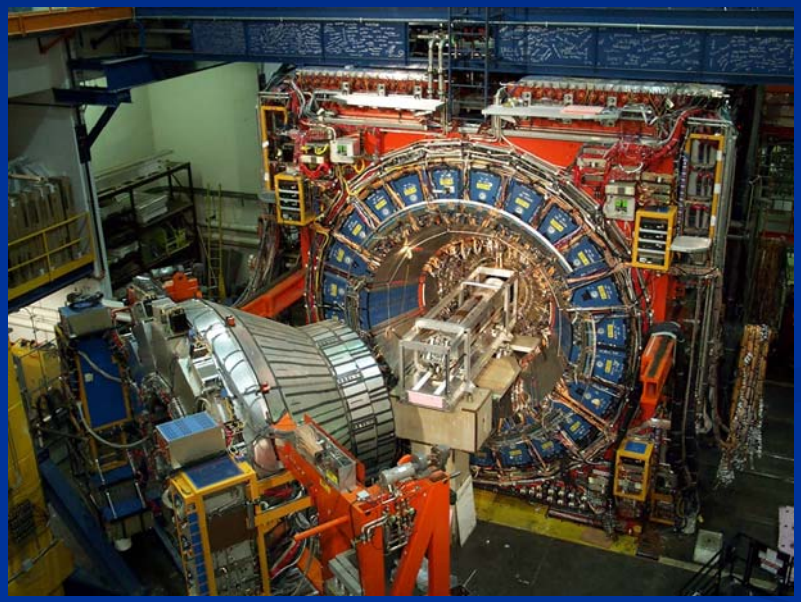
Associated b production in with dedicated trigger

Mario Campanelli/ Michigan State University



Experimental techniques:

Tevatron and CDF

Triggering on b: SVT

Heavy flavor measurements

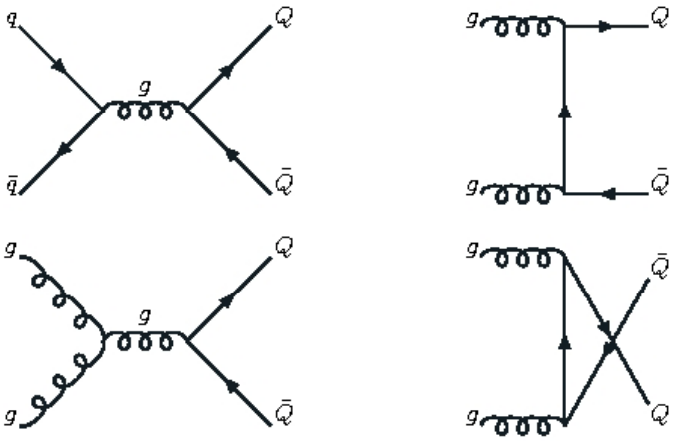
- **Low-pt**
- **High-pt**

Thanks to:

A.Clark, X.Wu, S.Vallecorsa, T.Hoffmann, R.Lefevre, K.Hakateyama etc.

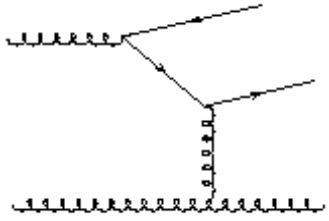
What's interesting in HF production at colliders

Leading Order

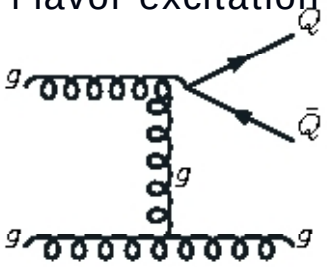


Flavor creation

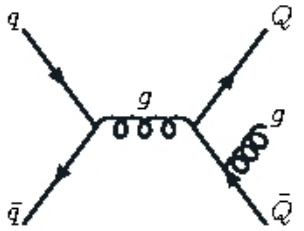
Next to Leading Order



Flavor excitation

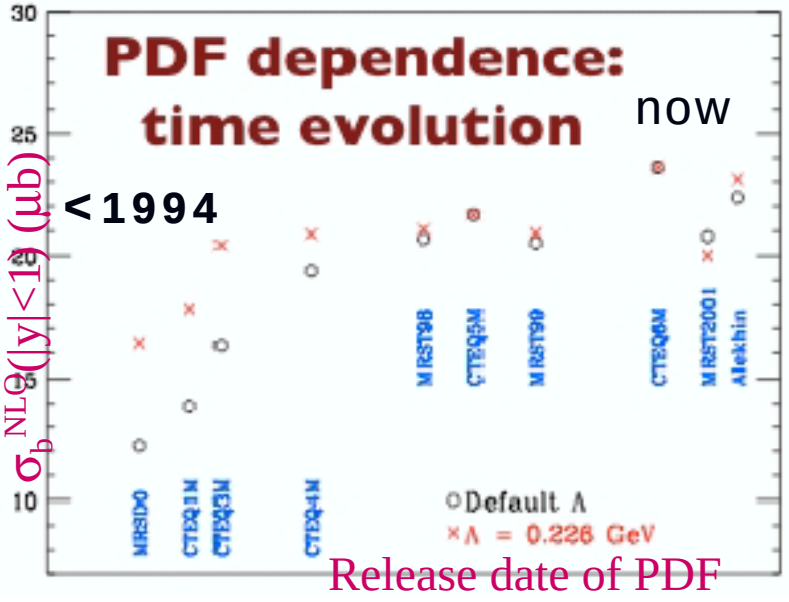


Gluon splitting



other radiative corrections..

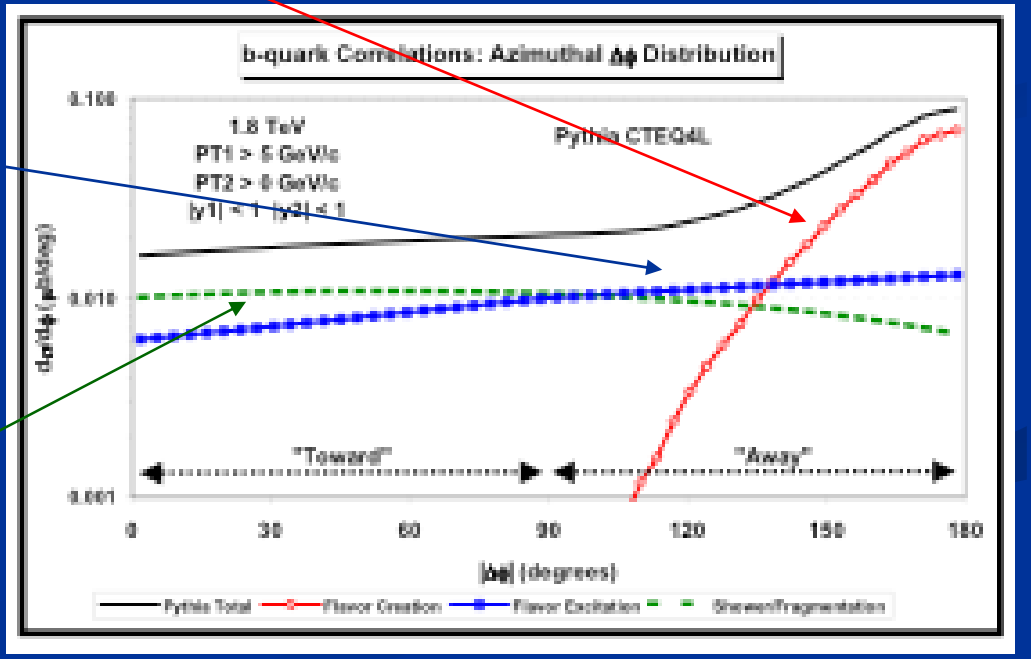
- kHz rates at present Tevatron energy/luminosity
- High mass -> well established NLO calculations, resummation of log(pT/m) terms (FONLL)
- New fragmentation functions from LEP data



B production mechanism and angular correlations

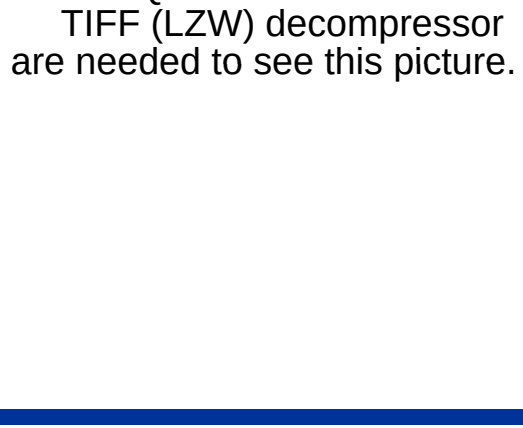
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

The various b production mechanisms result in different angular distributions of the bb pair



Heavy-quark Pdf uncertainties

- QCD: sensitive to Pdf of b extrapolated from gluon (high uncertainty at high x, region probed at Tevatron)

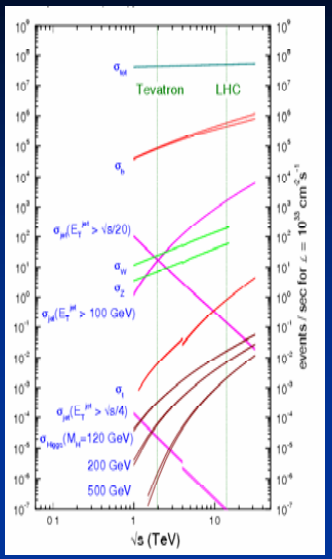


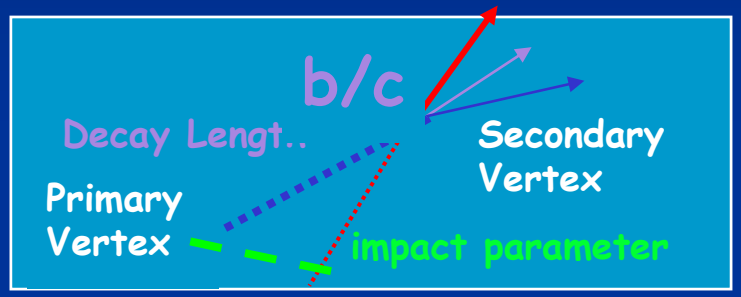
Large uncertainties!

We need better than this for the LHC!

The experimental challenge

- b production 3-4 orders of magnitude smaller than ordinary QCD; selected by longer lifetime





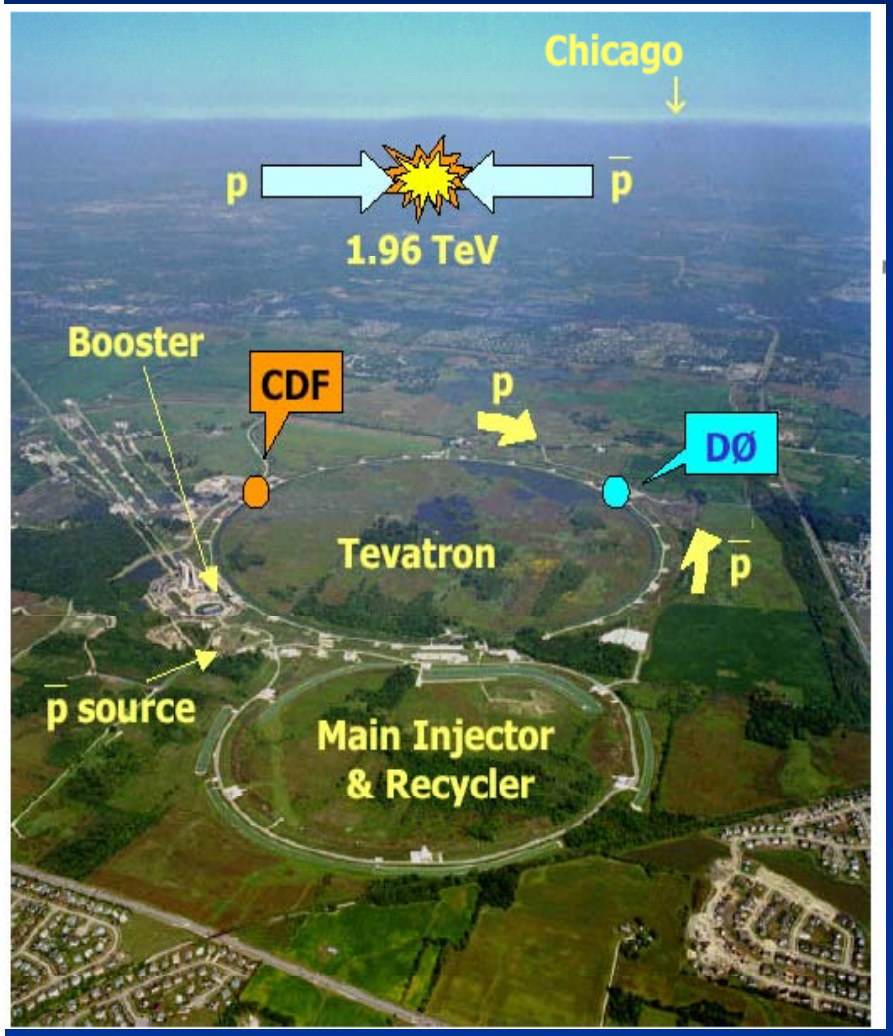
Et (GeV)	L1 ps	L2 ps
5	20/50	300/1000
20	20/50	12/25
50	20/50	1
70	1	8
100	1	1

Traditional strategy: take unbiased prescaled triggers, identify b off-line

•At low-pt prescales are enormous: only decays with leptons are available

•New experimental techniques can largely help

The Tevatron



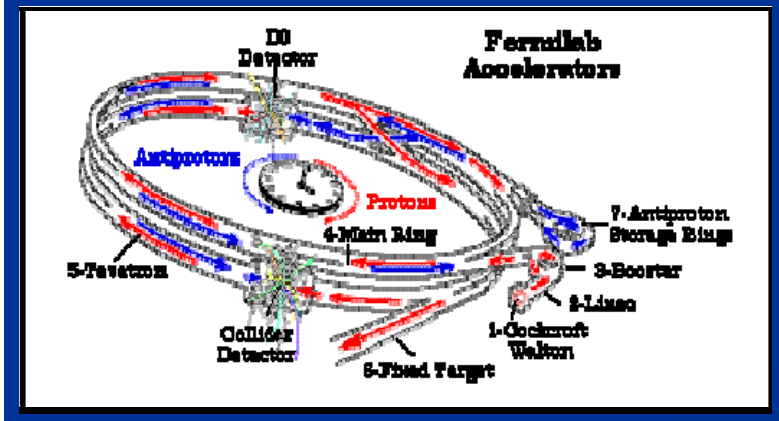
- World's largest hadron collider
- First large-scale super-conducting magnet (4.2 T) accelerator
- 6.28 Km length, theoretical maximum about 1.4 TeV per beam
- $\sqrt{s}$ = 1.96 TeV

- Started operation in 1987 (run 0), then collected about 100 pb^{-1} until 1996 (run I), then a long shutdown until 2000, and Run II between 2001 and 2009

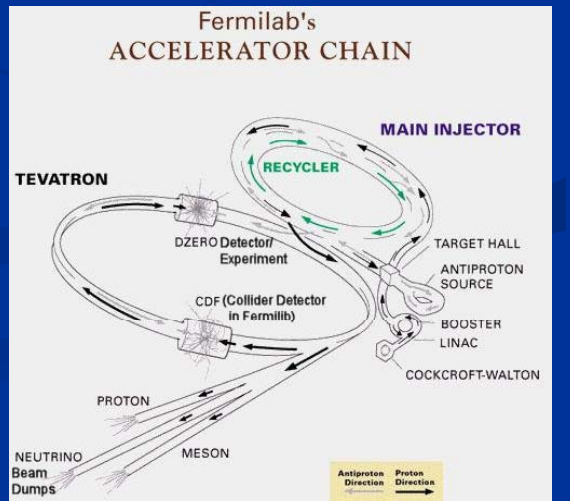
Accelerator upgrade between Run I and Run II

- The Tevatron in itself was designed for much higher luminosities, limitations to the design were coming from the injection, where the old main ring (in the same tunnel) was used

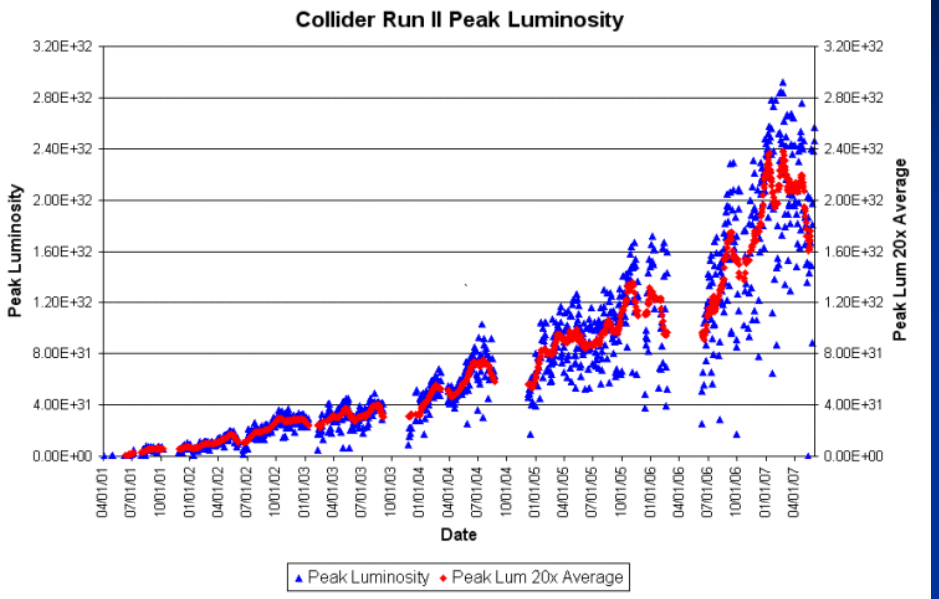
Main ring removed

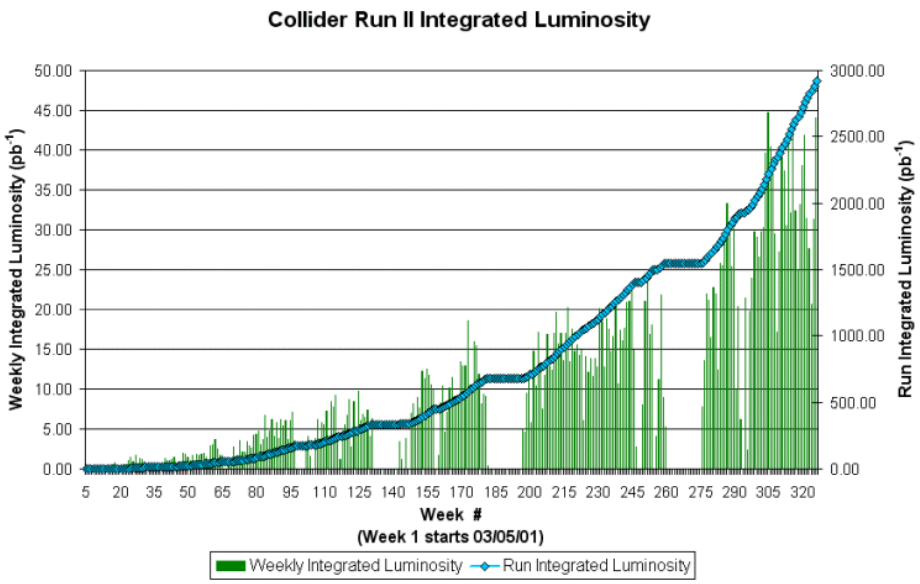


External main injector built



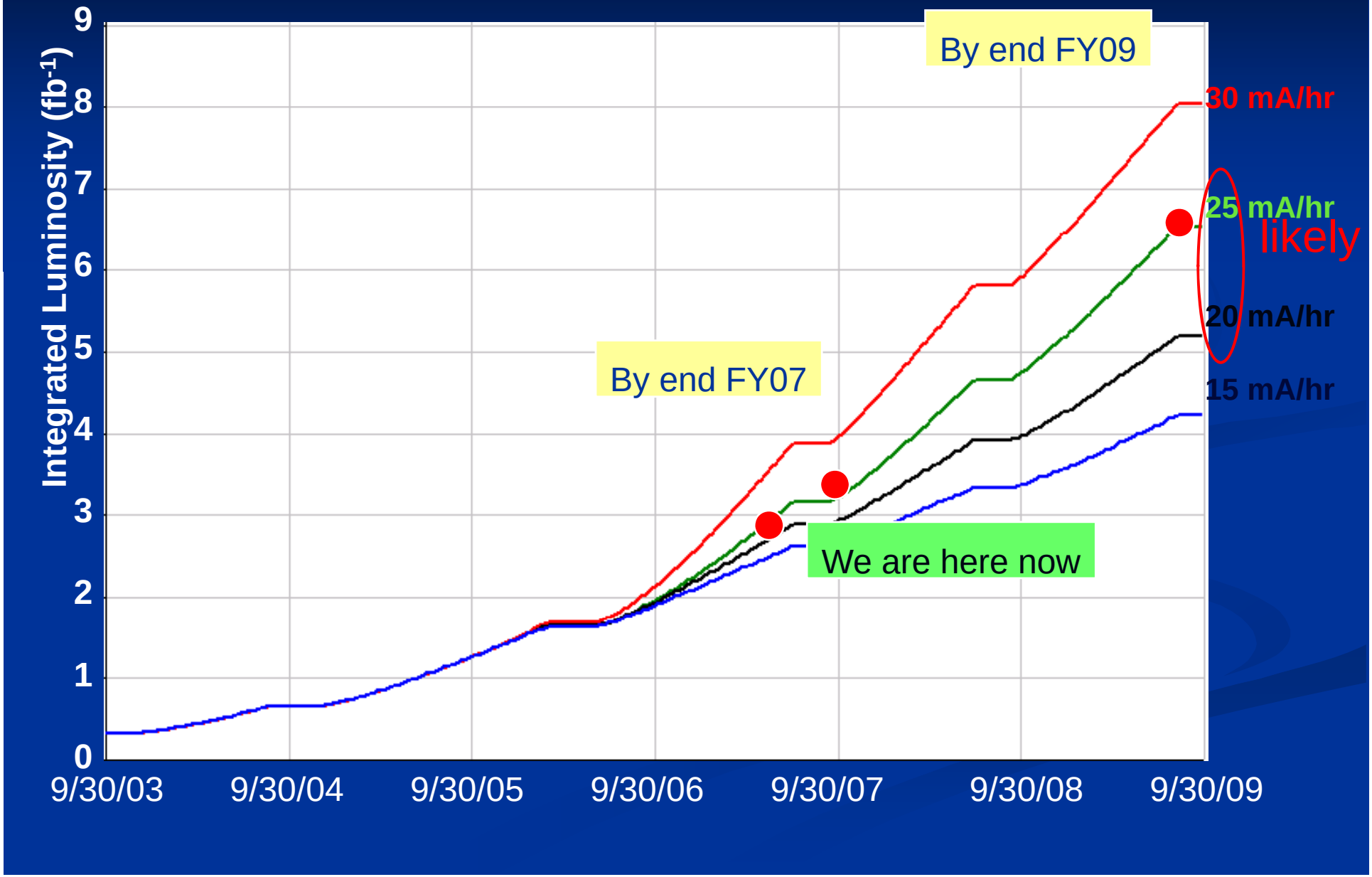
Run II luminosity evolution





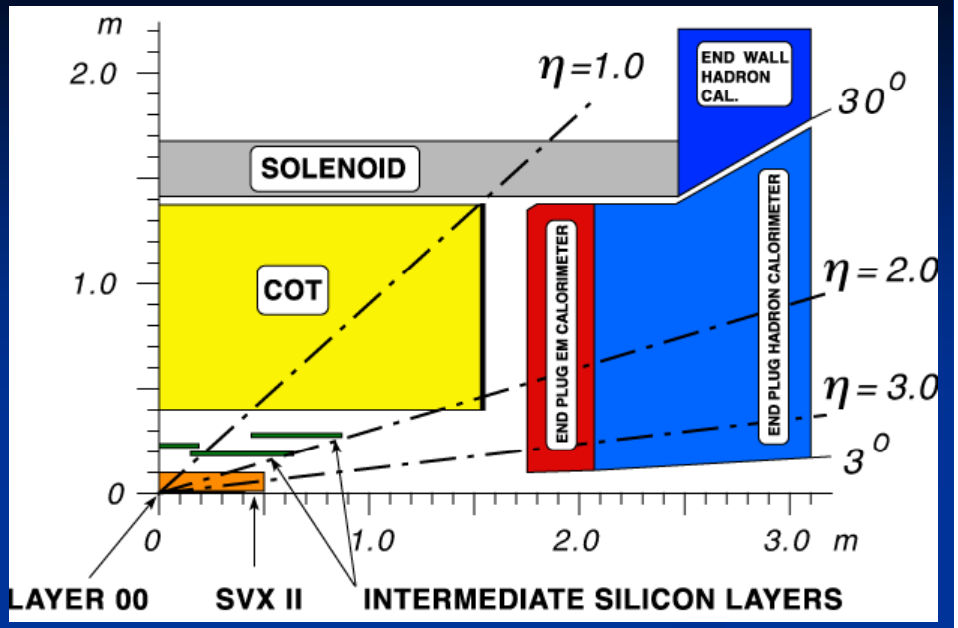
- Highest initial Lum store: $2.90e^{32}$
- Best integrated Lum week: 45 pb^{-1}
- Best integrated Lum month: 165 pb^{-1}
- Almost 3 fb^{-1} already collected
- Shutdown foreseen on October '09

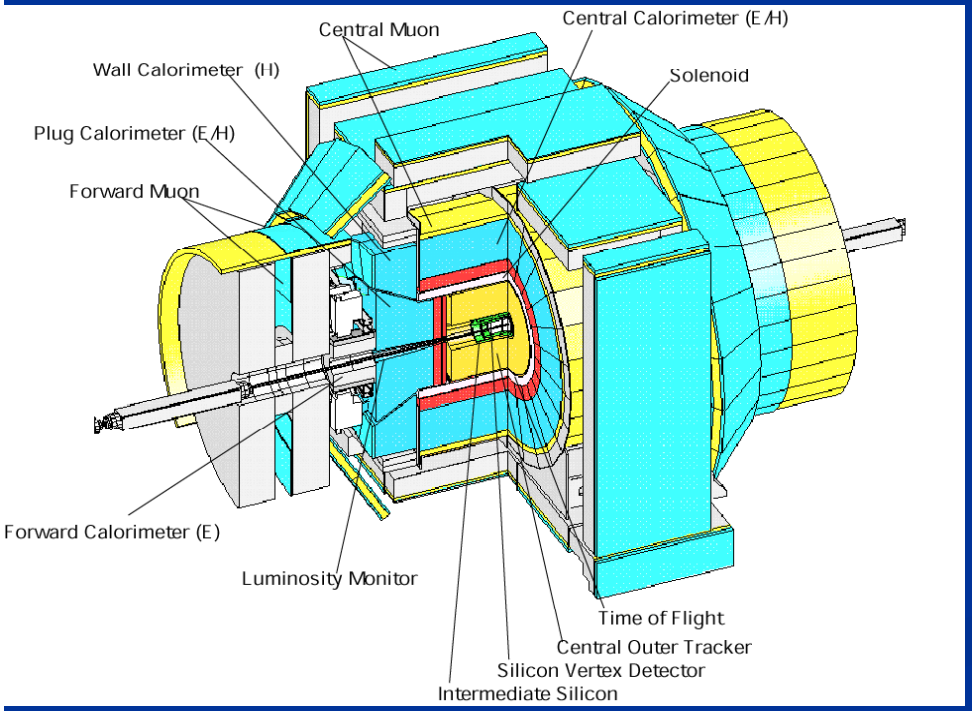
Luminosity projections



CDF II detector

- CDF fully upgraded for Run II:
  - Si & tracking
  - New endcap calorimetry
  - 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

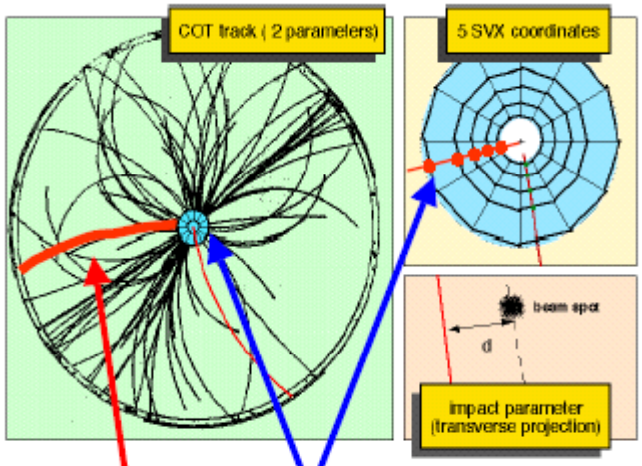
- $\sigma(d0)$ = 40μm (incl. 30μm beam)
- $\sigma(pt)/pt$ = 0.15 % pt

Online tracking

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

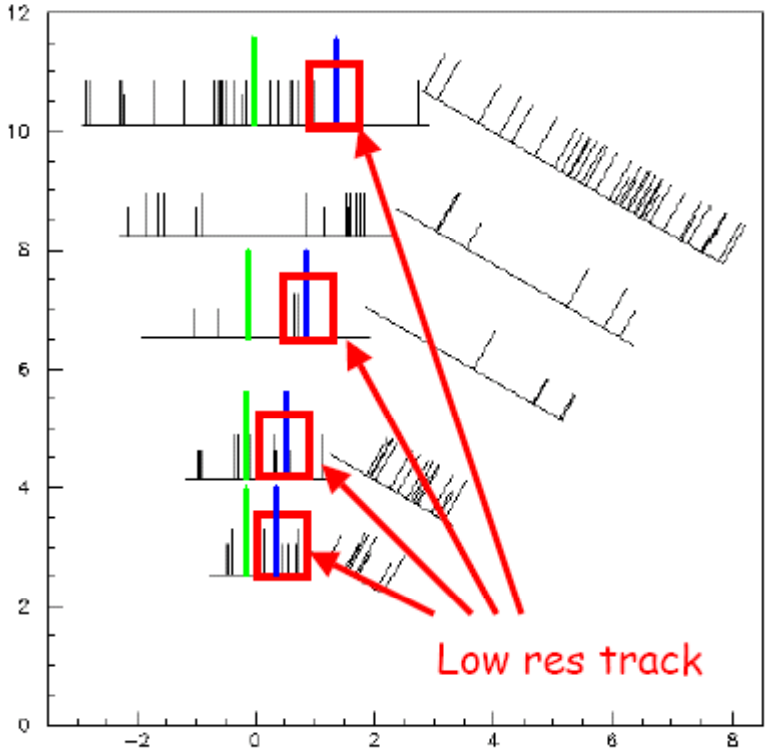
- The SVT is a revolutionary device made of 150 VME boards that measures track parameters in a 15 μs pipeline. Its results can be used at Level 2 trigger

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

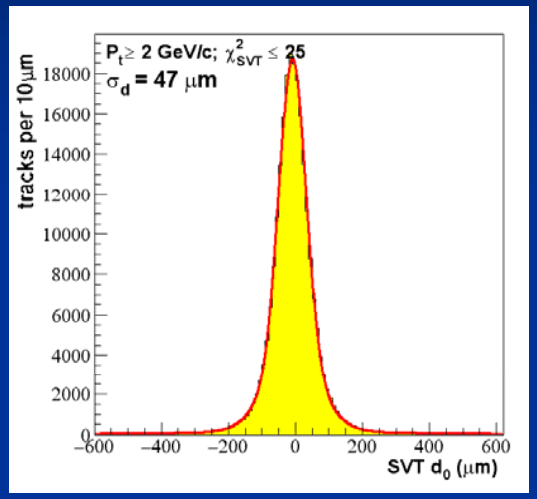


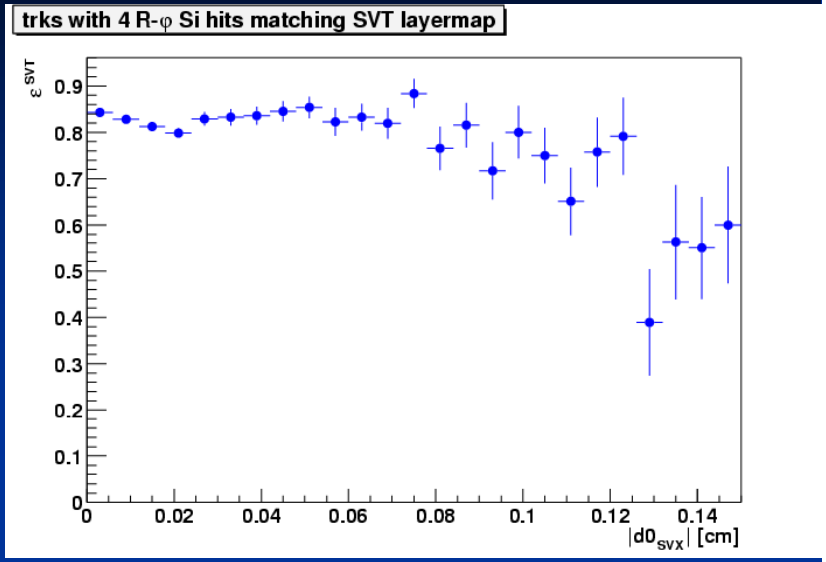
1. Find low resolution track (road) in COT
2. Discretize ϕ, Pt of road and SVX hits
3. Compare with pre-calculated configurations (in associative memory): no fit performed!
4. Track parameters found in few μs

Performances of online tracking

- Hit finding efficiency: 85%
- Impact parameter resolution:

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





This device has greatly changed the way we do b physics at CDF, both at low and high Pt.

In the rest of this talk I will present examples of measurements of b properties, and how the presence of on-line tracking improved them or made them possible

Low-Pt B Physics Triggers

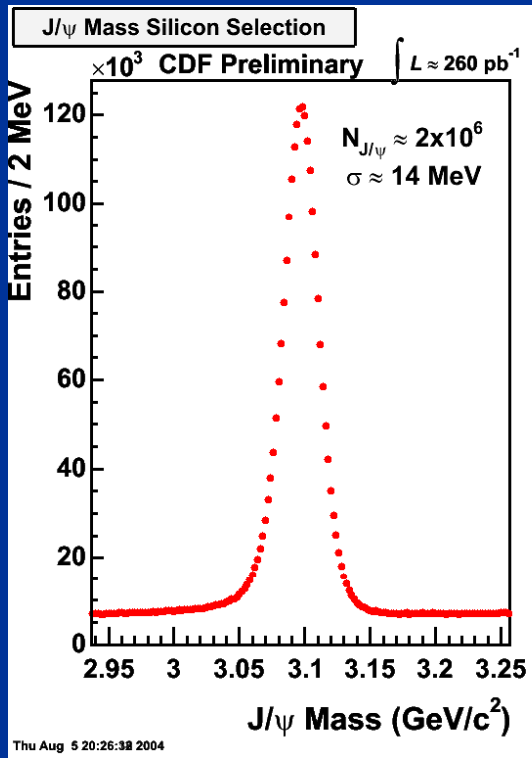
Largely improved

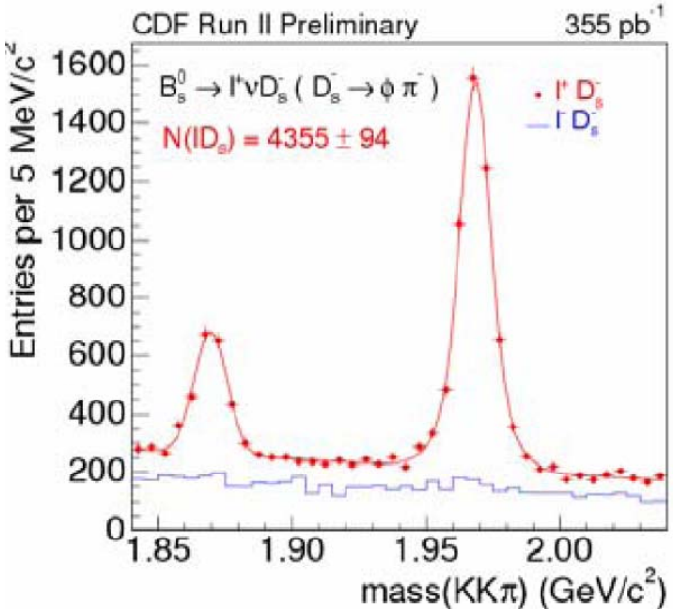
Completely new

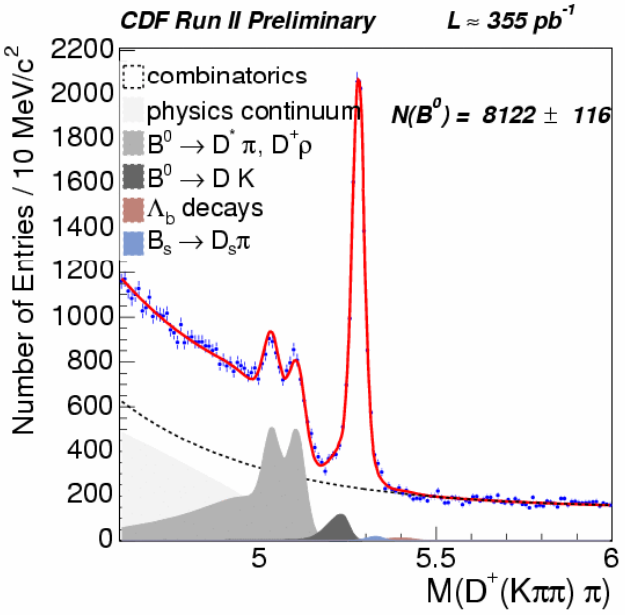
Di-muon
$J/\psi \rightarrow \mu\mu$
$B \rightarrow \mu\mu$
Two muons with:
$p_T(\mu) > 1.5$ GeV/c

One displaced track + lepton (e, μ)
$B \rightarrow l\nu X$
Lepton:
$p_T(l) > 4.0$ GeV/c
Track:
$p_T > 2.0$ GeV/c,
$d_0 > 120$ μm

Two displaced tracks
$B \rightarrow hh$
Two tracks with:
$p_T > 2.0$ GeV/c
$\Sigma p_T > 5.5$ GeV/c
$d_0 > 100$ μm

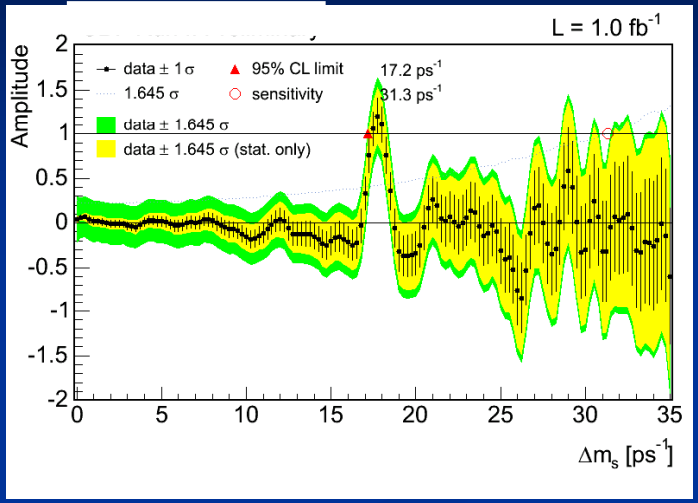


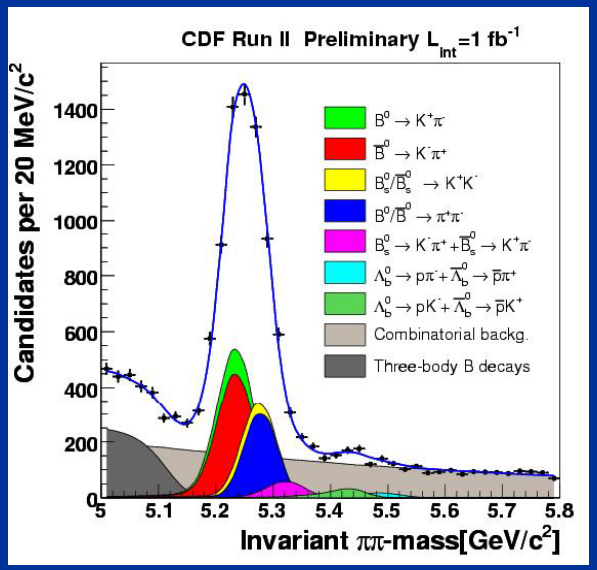


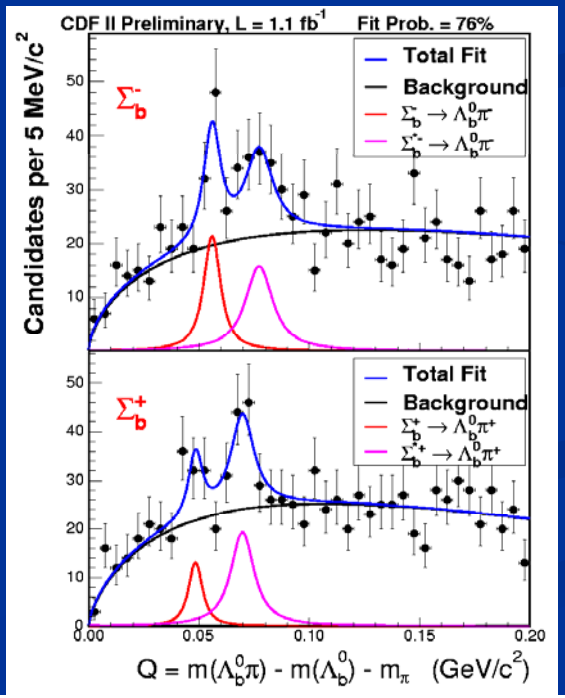


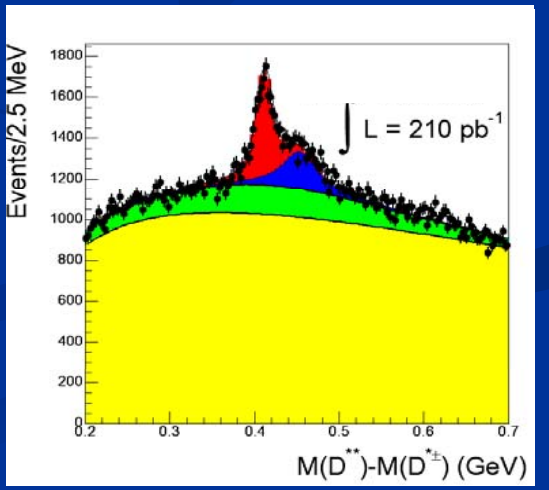
Low-pt b physics in CDF

- Impact parameter trigger responsible for an enormous wealth of results on b physics:
  - Bs oscillations
  - B->hh modes
  - Σ_b discovery
  - Spectroscopy
  - Lifetimes
  - ..and many others









Exclusive/low Pt measurements on charmed mesons

Cross section of exclusive charm states

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

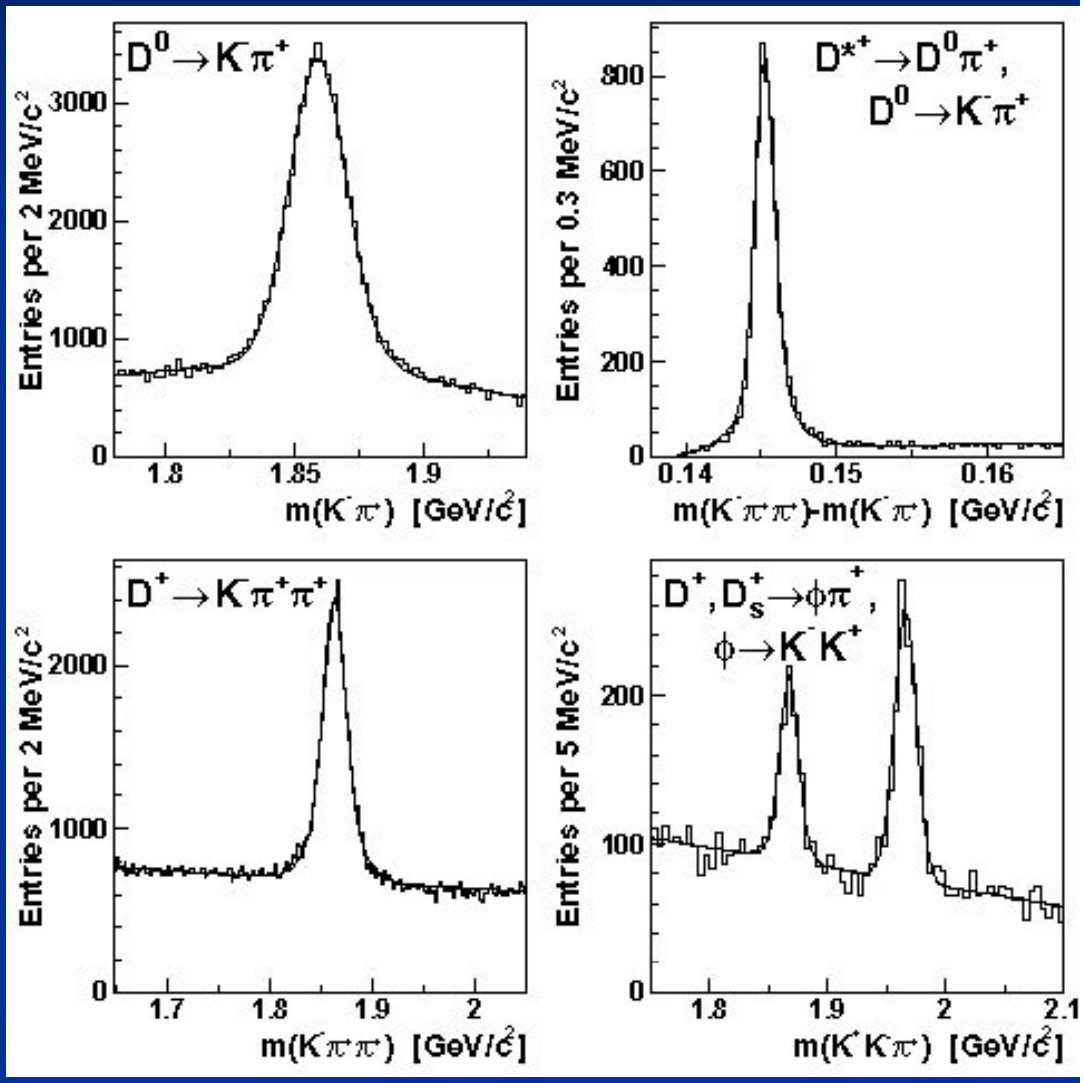
- Measure prompt charm meson production cross section
- Data collected by SVT trigger from 2/2002-3/2002
- Measurement not statistics limited Large and clean signals:

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

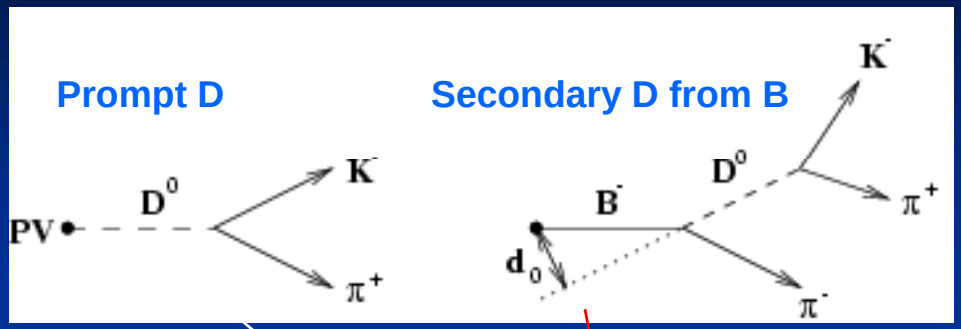
$D^{*+} \to D^0 \pi_s^+$ with $D^0 \to K^- \pi^+$

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

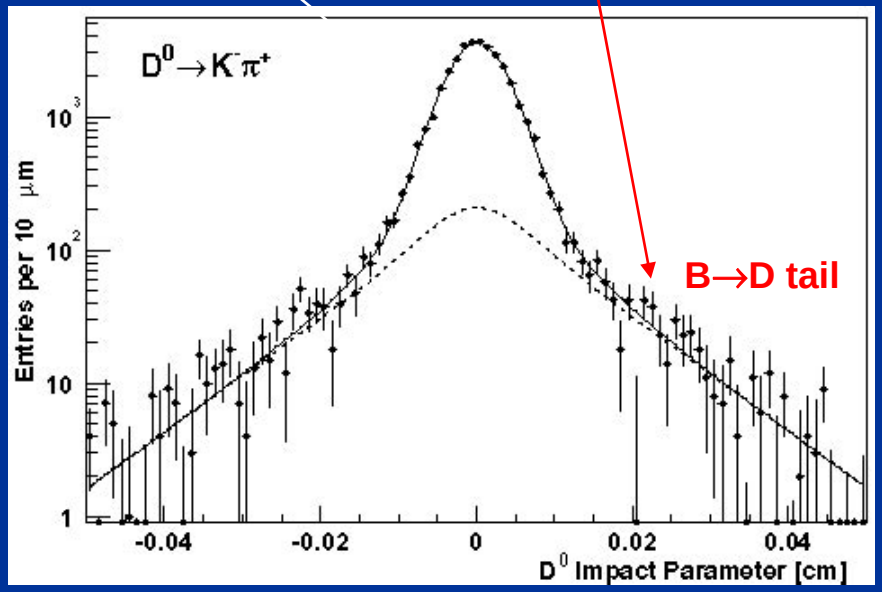
$D_s^+ \to \phi \pi^+$ with $\phi \to K^+ K^-$



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

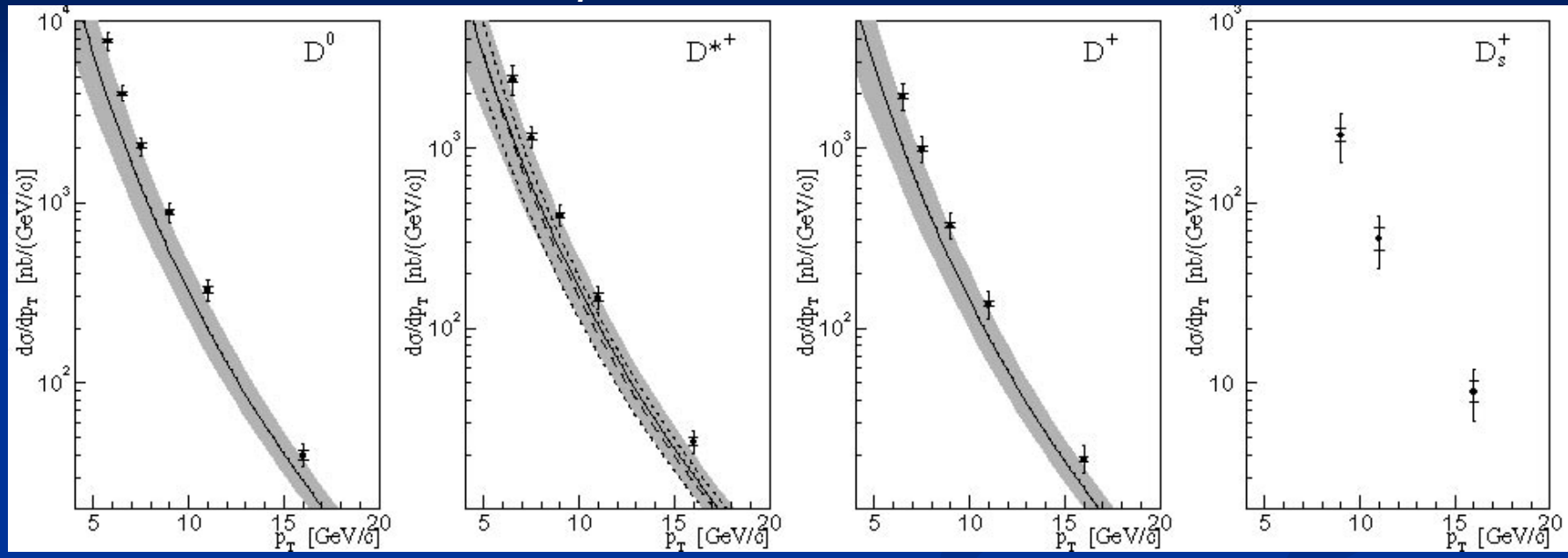
Most of reconstructed charm mesons are direct →

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%

Single Charm Meson X-Section

P_T dependent x-sections:



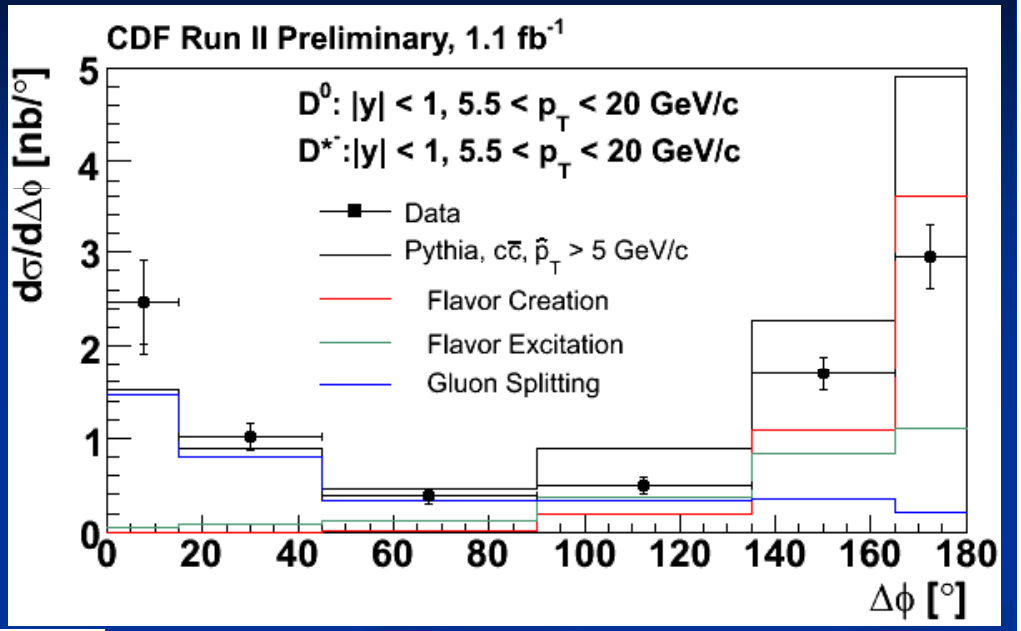
Theory prediction:

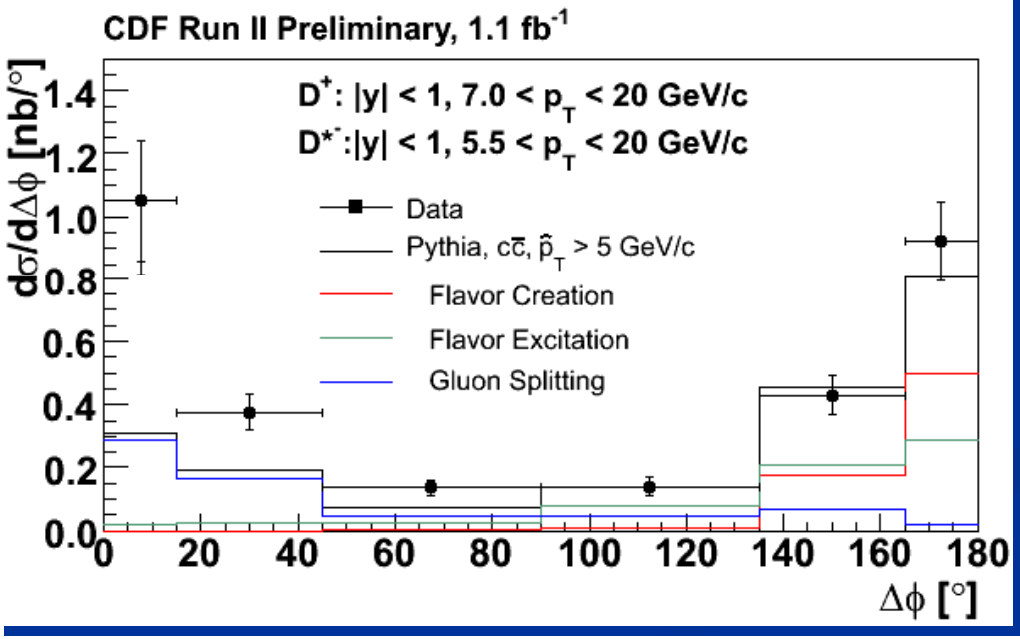
Calculation from M. Cacciari and P. Nason:
Resummed perturbative QCD (FONLL)
JHEP 0309,006 (2003)

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

With more data: charm pair correlations

Single D meson cross section already systematics dominated; more statistics useful to look for angular distributions and discriminate production mechanisms



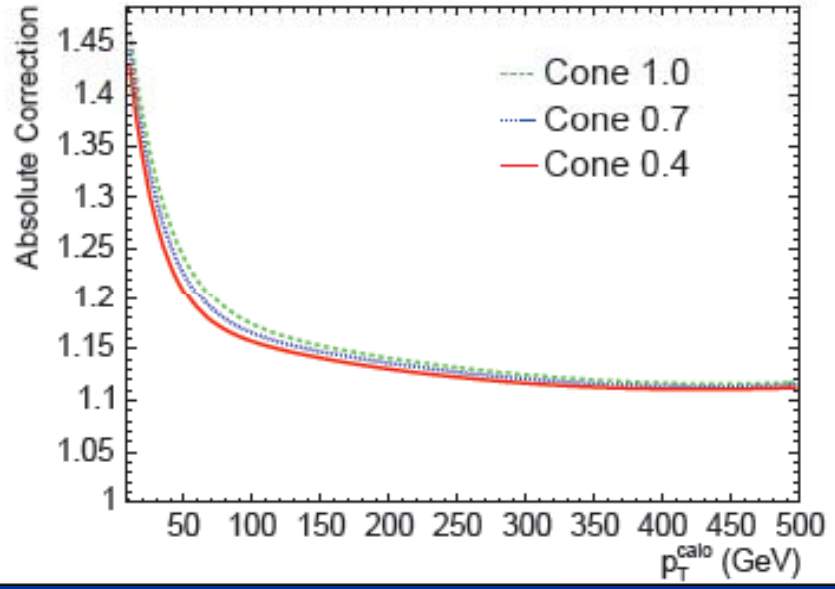


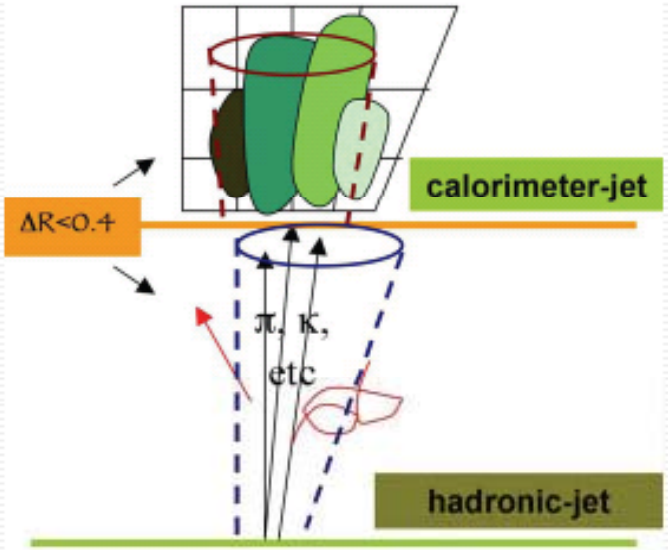
As expected, data favor more gluon splitting than LO Monte Carlo. Use of higher orders should improve the agreement

High-Pt measurements: b production on unbiased datasets

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.





After this correction, jets are independent of the detector.

Systematics for energy scale

Major systematics for most of jet-based measurements

CALORIMETER SIMULATION

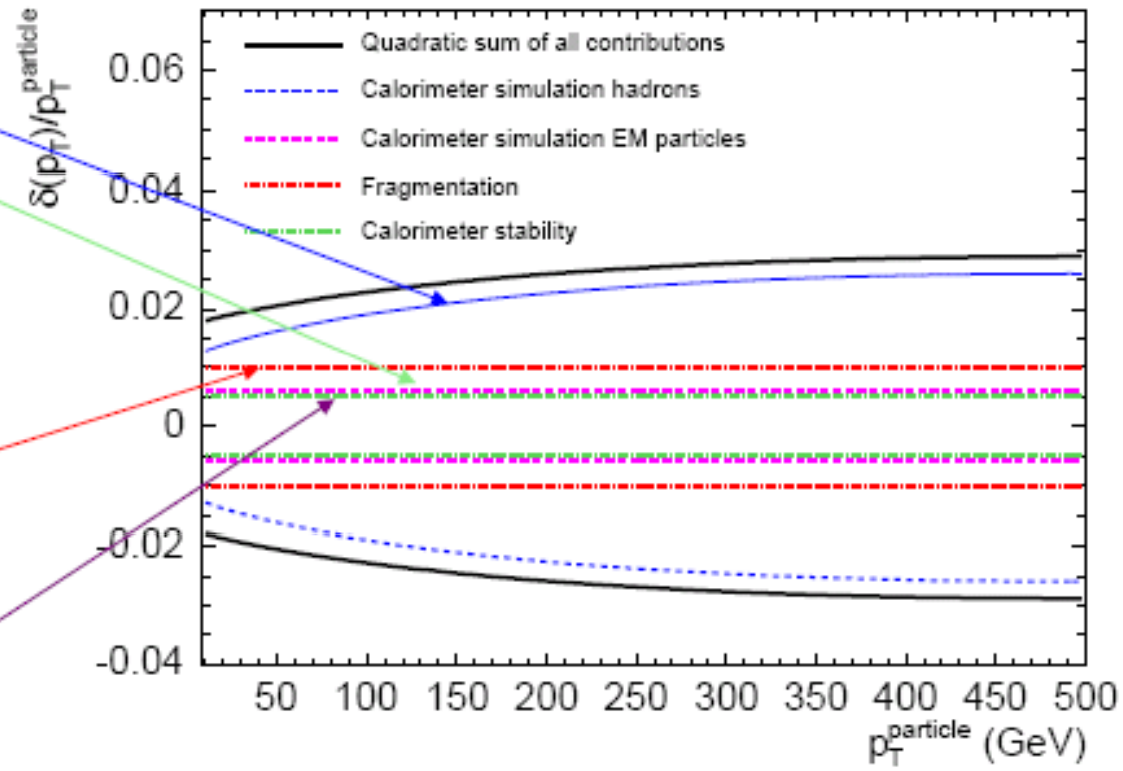
Is the response of the calorimeter to single particles (pions, protons, neutrons, etc) simulated correctly?

FRAGMENTATION(1%)

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

STABILITY (0.5%)

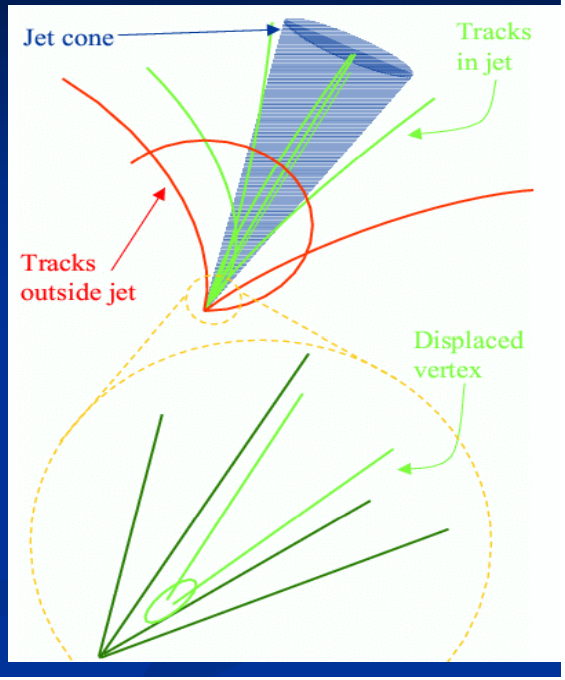
Calorimeter scale variation with time



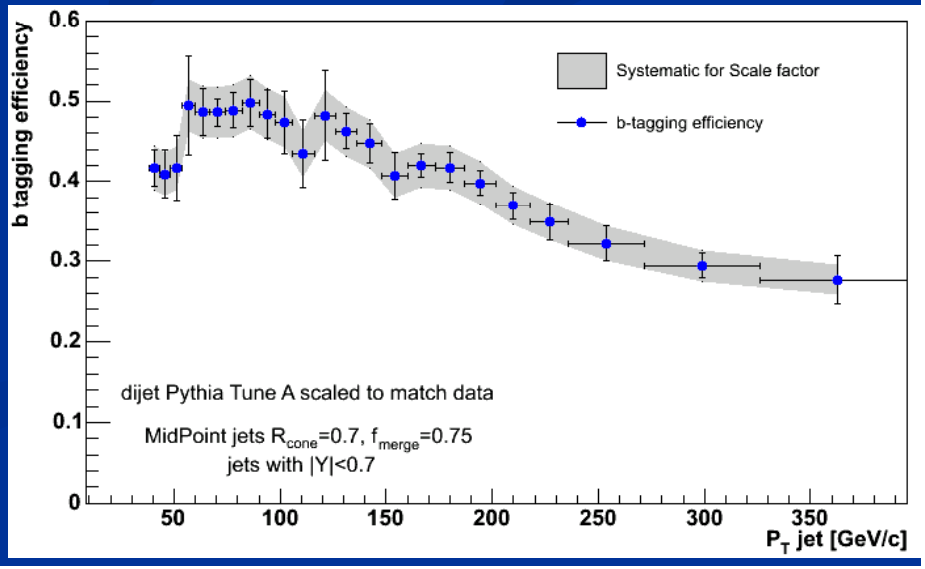
Using test beam data P_T regions (relatively large uncertainty), important for high P_T jets

B-jet 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



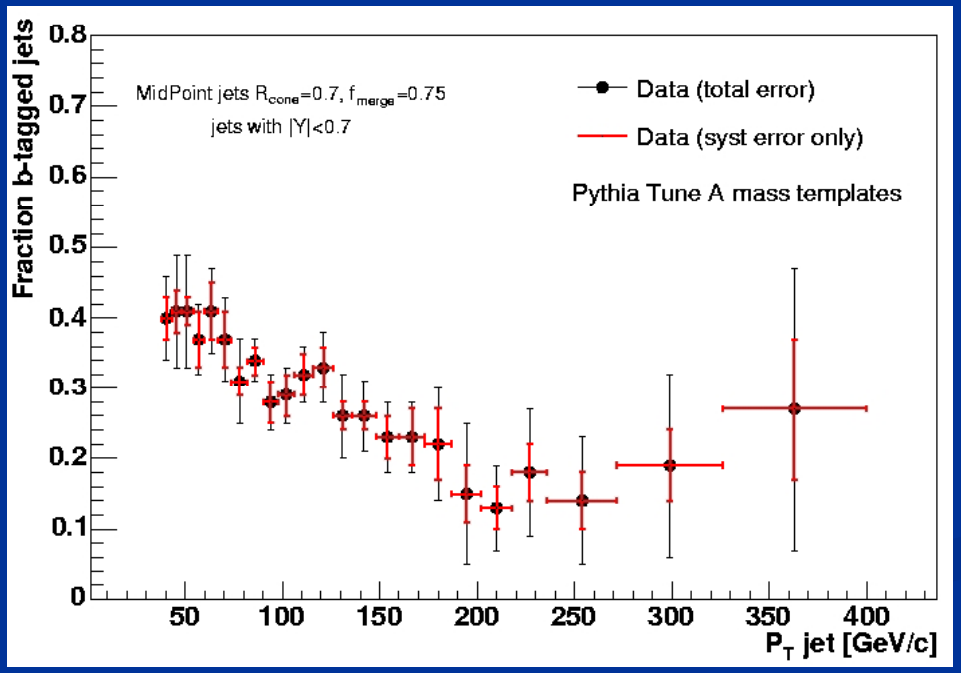
Efficiency of this "b tagging" algorithm (around 40%) is taken from Monte Carlo and cross-checked with b-enriched samples (like isolated leptons)

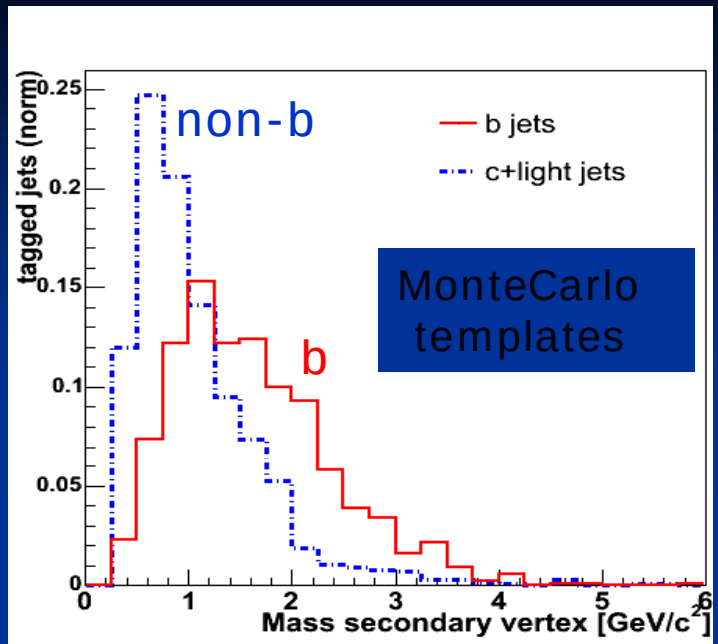


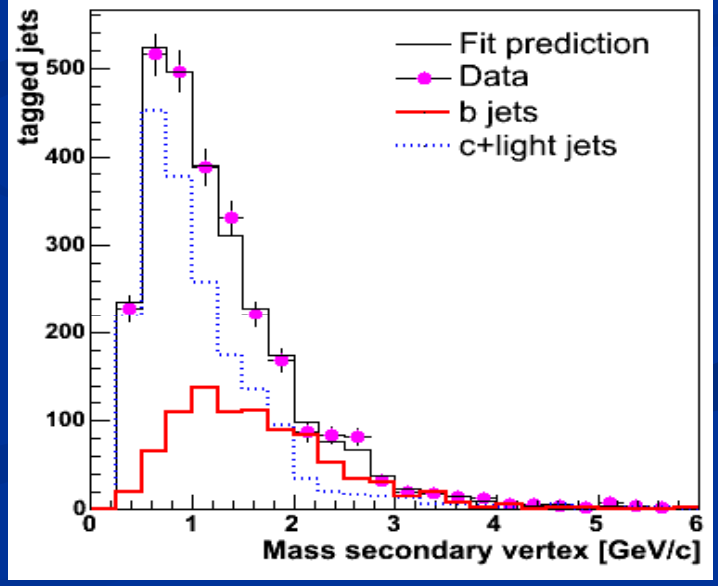
b-jet fraction

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

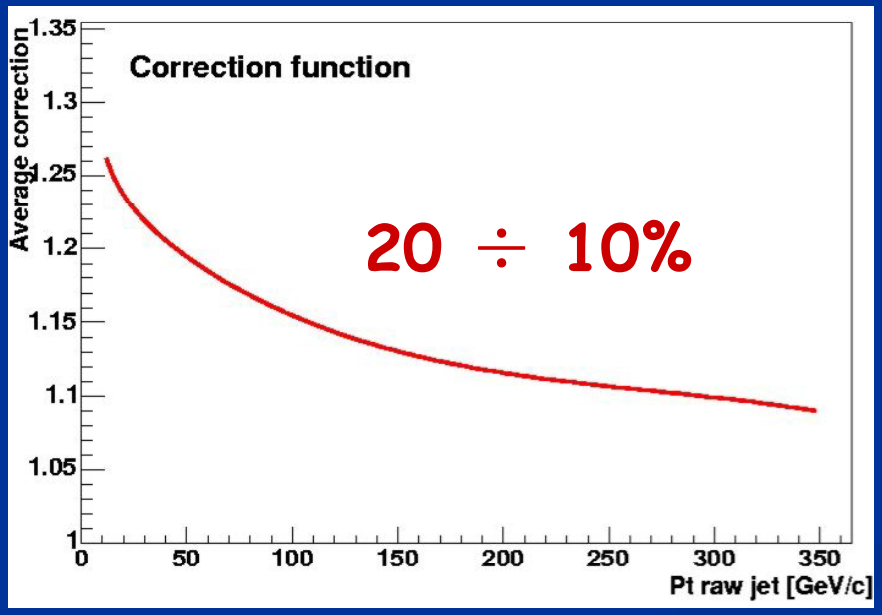




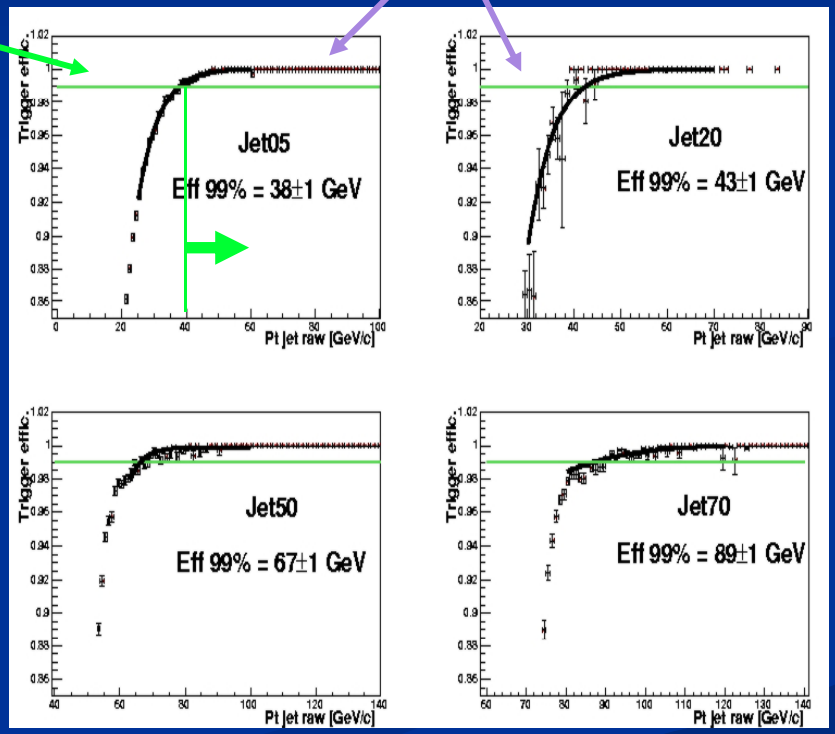


High p_t b jet cross section

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



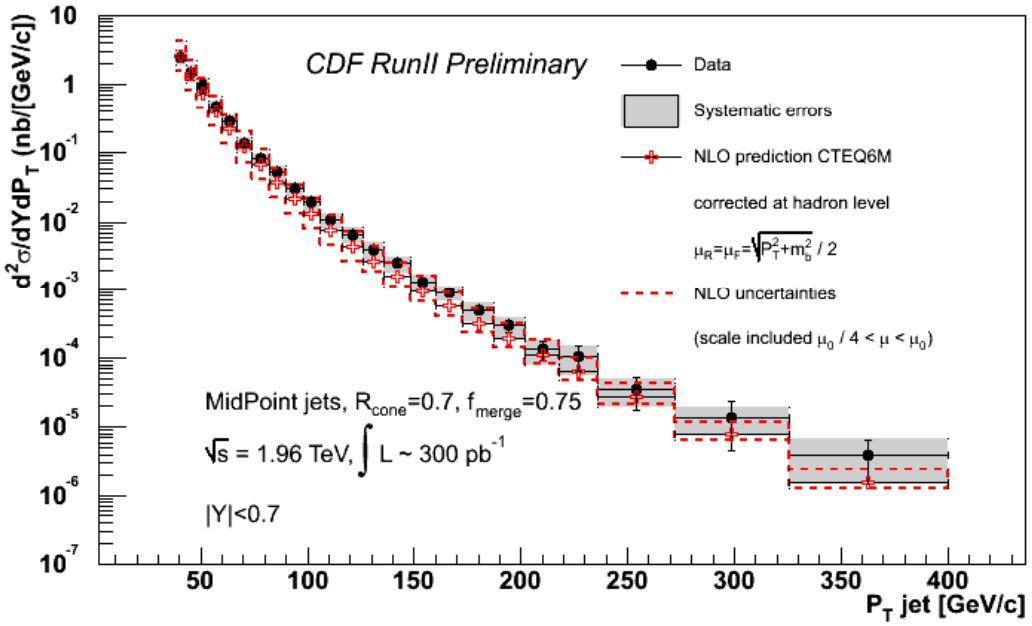
- Inclusive calorimetric triggers
  - L3 Et > x (5,20,40,70,100)



~ 300 pb^{-1}

Pt ~ 38 ÷ 400 GeV

High p_t b-jet cross section

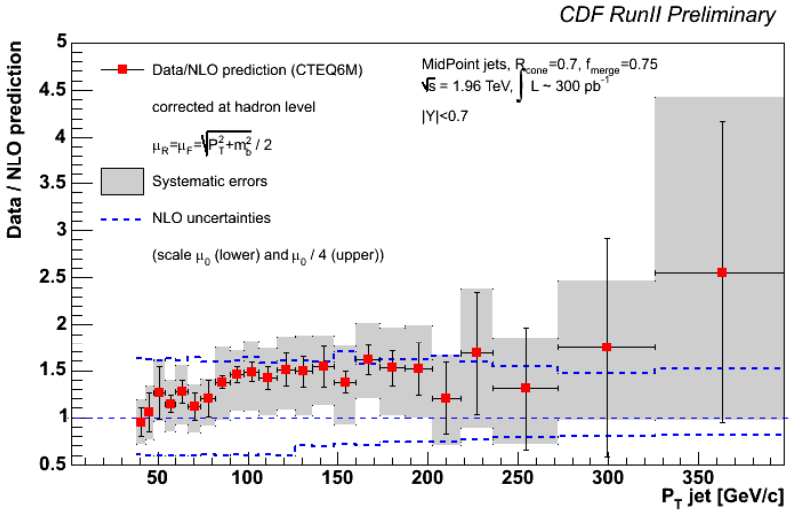


Jets unfolded back to parton level for comparison with NLO cross section (Mangano et al. 1997)

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%

Large uncertainties due to factorization and renormalization scales (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



Using the SVT at high Pt

- Since the beginning of Run II in addition to the low-Pt triggers there are 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 $|d_0|>120$ μm
    - A jet with Et>20 GeV (SVT selects about 50% of tagged jets)
  - HIGH_PT_BJET
    - 2 tracks with |d0|>120 μm
    - 2 jets with Et>20 GeV
  - Z_BB
    - 2 tracks with |d0|>160 μm
    - 2 jets with Et>10 GeV (to have larger BG sidebands)

$b\bar{b}$ cross section

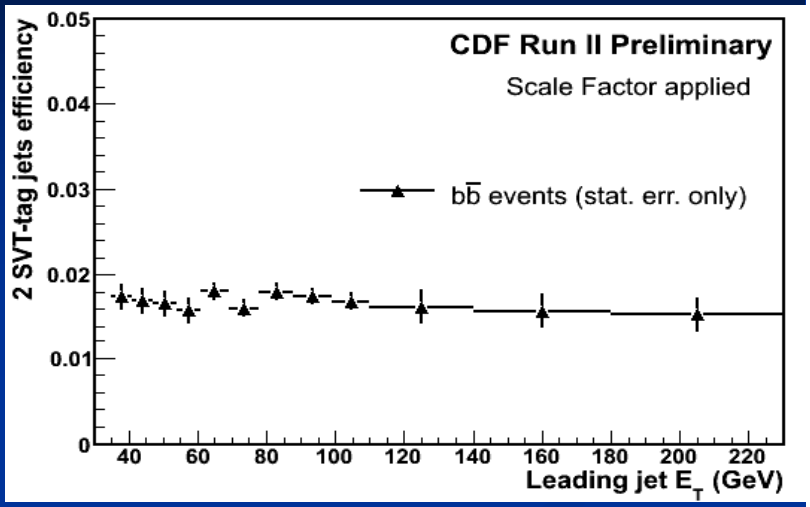
Based on 260 pb^{-1} of data taken with SVT-based trigger- no prescale

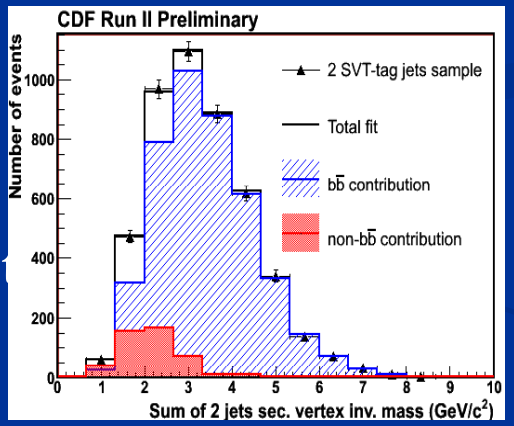
In the absence of a control sample, efficiency computed from MC.

To avoid detailed trigger simulation, offline cuts harder than trigger requirements.

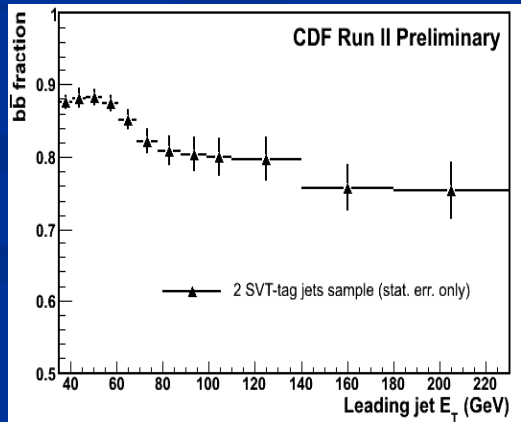
Efficiency about 2% vs 10% of just requiring 2 b-tags

SVT requirement « costs » about a factor 5 (eff. ~50% per jet)





B purity around 90% due to double SVT + offline tag requirement



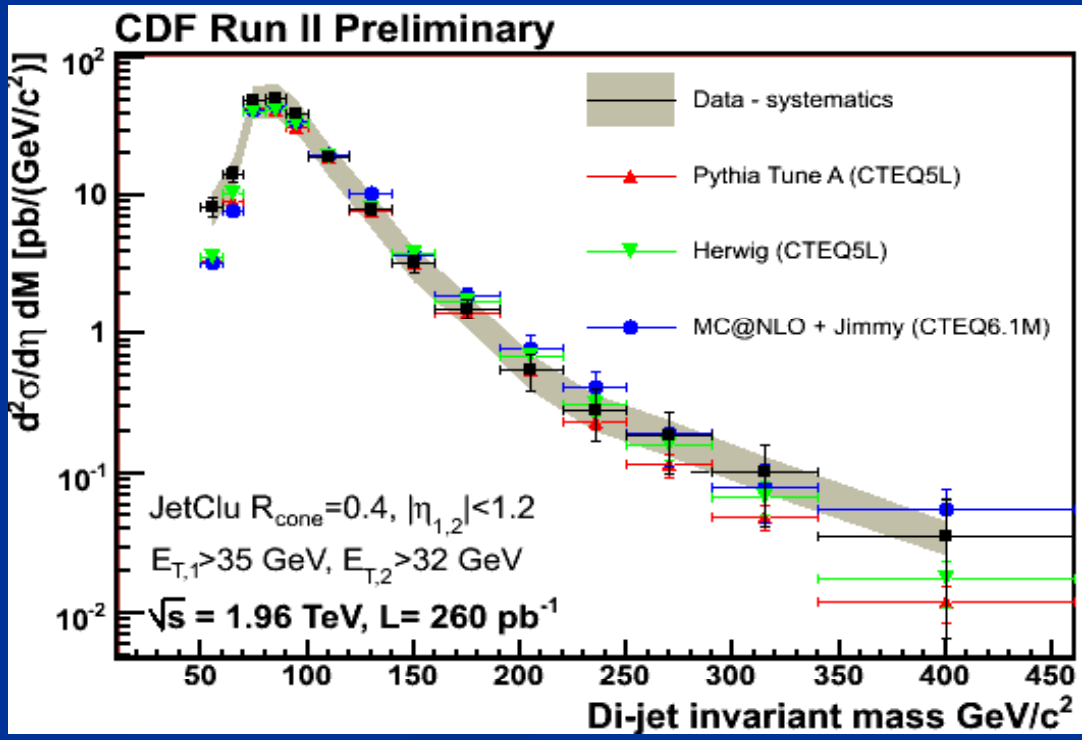
$\bar{b}b$ cross section

Largely dominated by systematics

Dominant systematic uncertainties:

- Jet Corrections 15-20%
- b fraction 7%
- Unfolding 4%

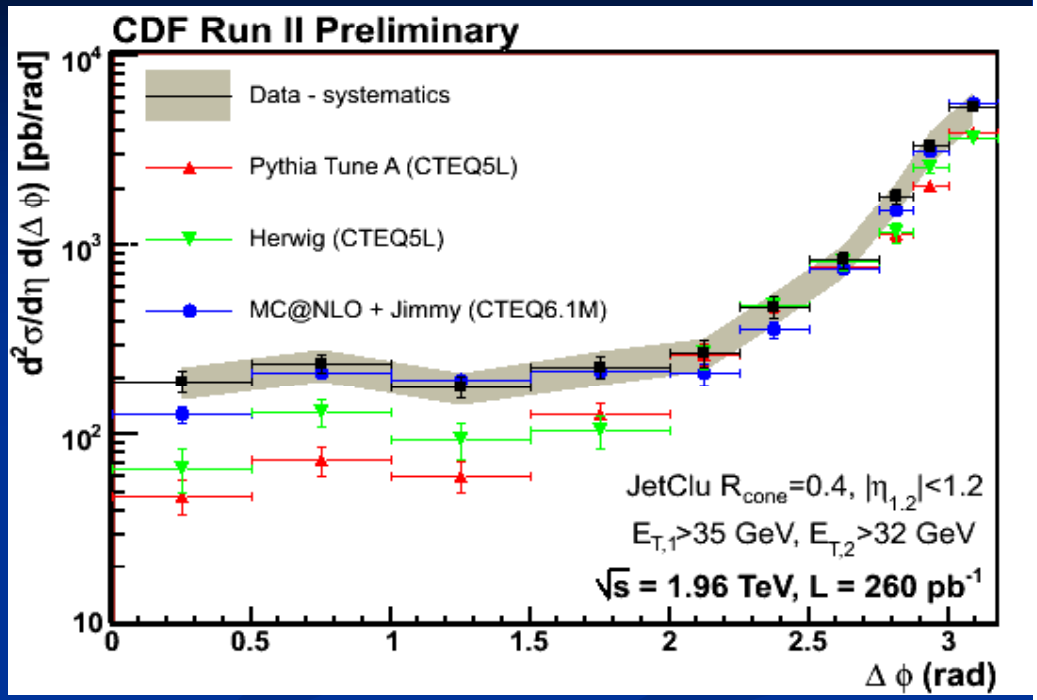
CDF Run II Preliminary	σ [pb] $\lvert\eta_{1,2}\rvert < 1.2$, $E_{T,1} > 35$ GeV, $E_{T,2} > 32$ GeV
Data	$\sigma = 5664 \pm 168$ (stat.) ± 1270 (syst.)
Pythia (CTEQ5L) Tune A	$\sigma = 5136 \pm 52$ (stat.)
Herwig (CTEQ5L) + Jimmy	$\sigma = 5296 \pm 98$ (stat.)
MC@NLO (CTEQ6M) + Jimmy	$\sigma = 5421 \pm 105$ (stat.)

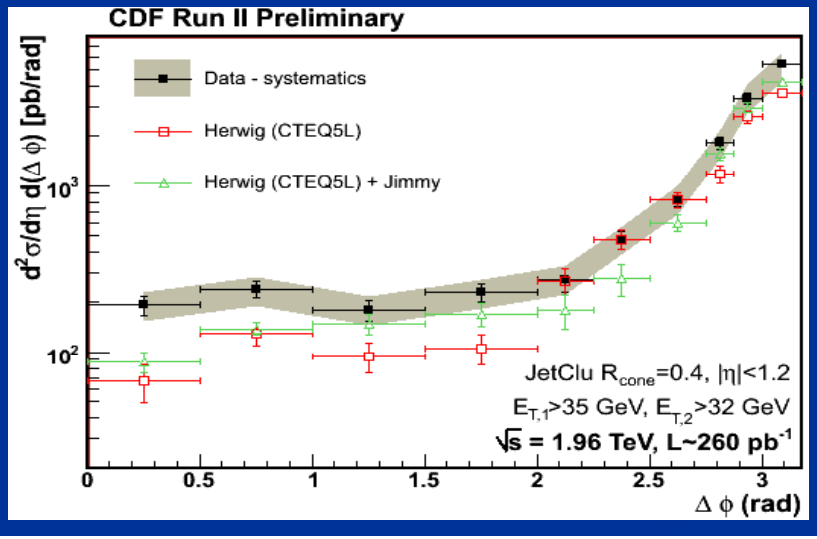


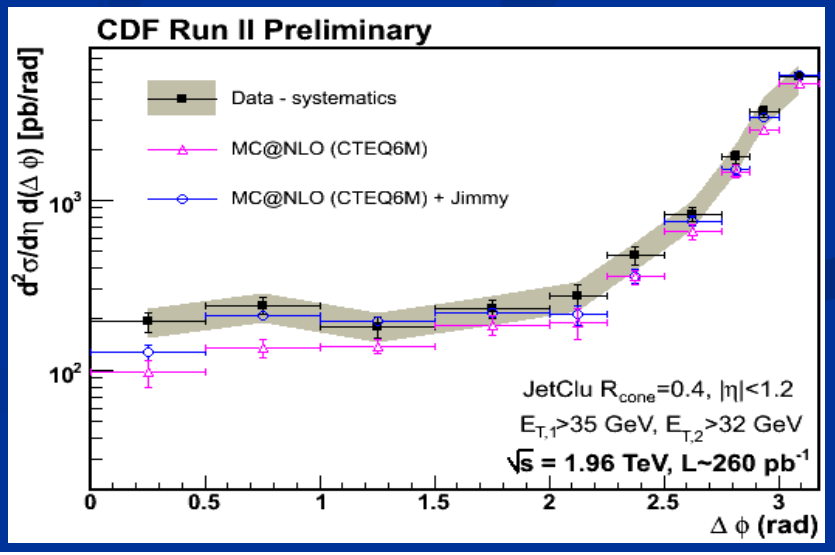
Angular distribution

Confirm excess of events with small angle between the jets wtr leading order MC

Proper treatment of multi-parton interactions is as important as inclusion of next-to-leading order







B jet energy scale using Z->$b\bar{b}$

- Apart from being an interesting challenge per se, finding the Z in the hadronic b decay channel is useful for jet energy scale calibration. Start from very large SVT-based di-jet dataset

Dijet event selection	**Low jet E_t** **Z signal distinct from BG peak**	**Two leading R=0.7 jets:** • **E_t(L5)>22 GeV** • **$\|\eta_{det}\|$<1.0**
Signal optimization	**Back-to-back events with low extra jet radiation**	**$\Delta\Phi_{(jet\ 1,\ jet\ 2)}$>3.0** **$E_t^{(3rd\ jet)}$(corr)<15 GeV**
	Tagging	**both jets are (+) SecVtx tagged**
BG modeling	**Data-driven**	

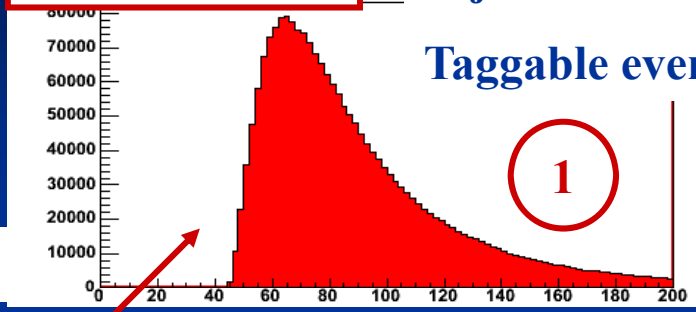
Total analyzed events	39,147,479
Two leading jets with $E_t > 22$ GeV	23,950,515
Pass $\|\eta_d\| < 1.0$ cut	21,420,308
Both jets taggable	18,128,488
One tagged jet	6,205,578
Both jets tagged	699,590
$\Delta\Phi_{12} > 3.0$ and $E_t^{3rd} < 15$ GeV	267,246

Data-driven BG Modeling

Signal Region

Dijets mass

Taggable events



1

$\Delta\Phi_{12}$

3.0

$[\Delta\Phi_{12}]_{BG}$

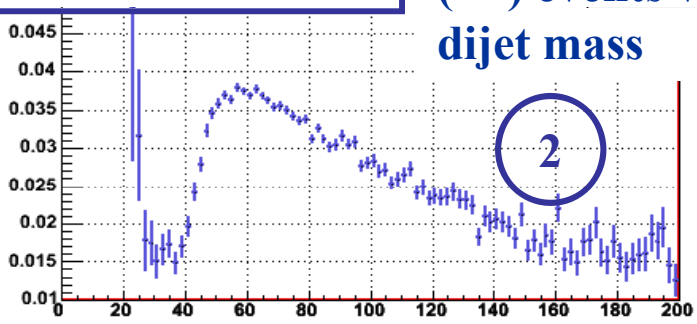
E_T^3

15

$[E_t^3]_{BG}$

Tag ratio: BG Region

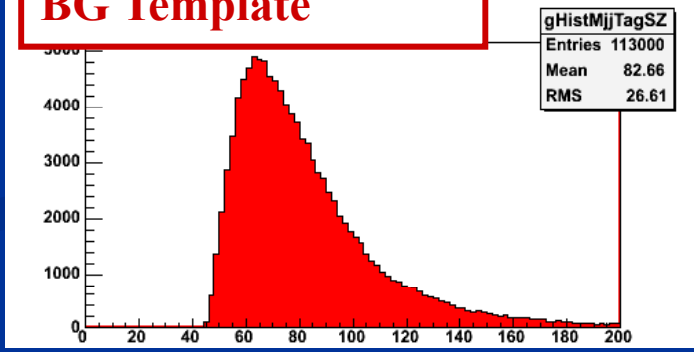
Fraction of (++) events vs dijet mass



2

1 ⊗ 2

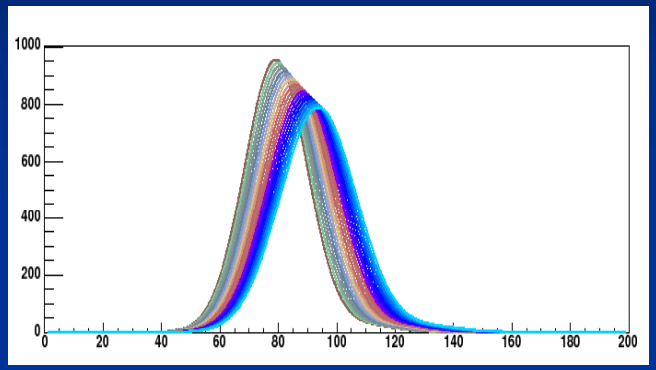
BG Template



Distribution is then parameterized with a p.d.f.

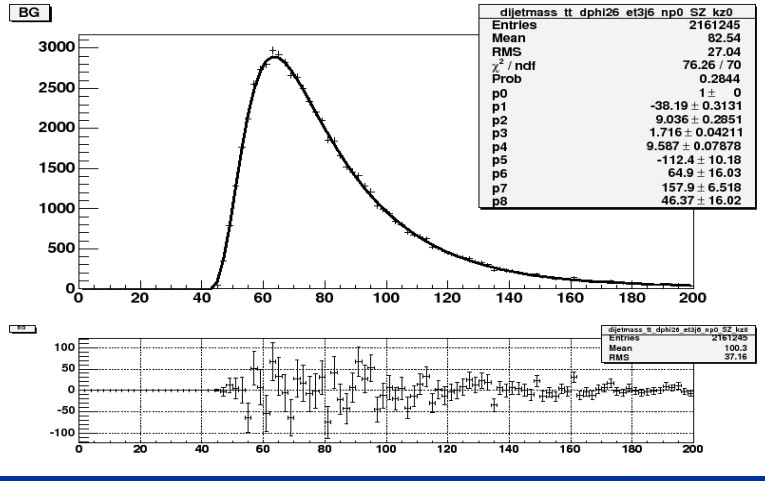
Z->$b\bar{b}$ signal

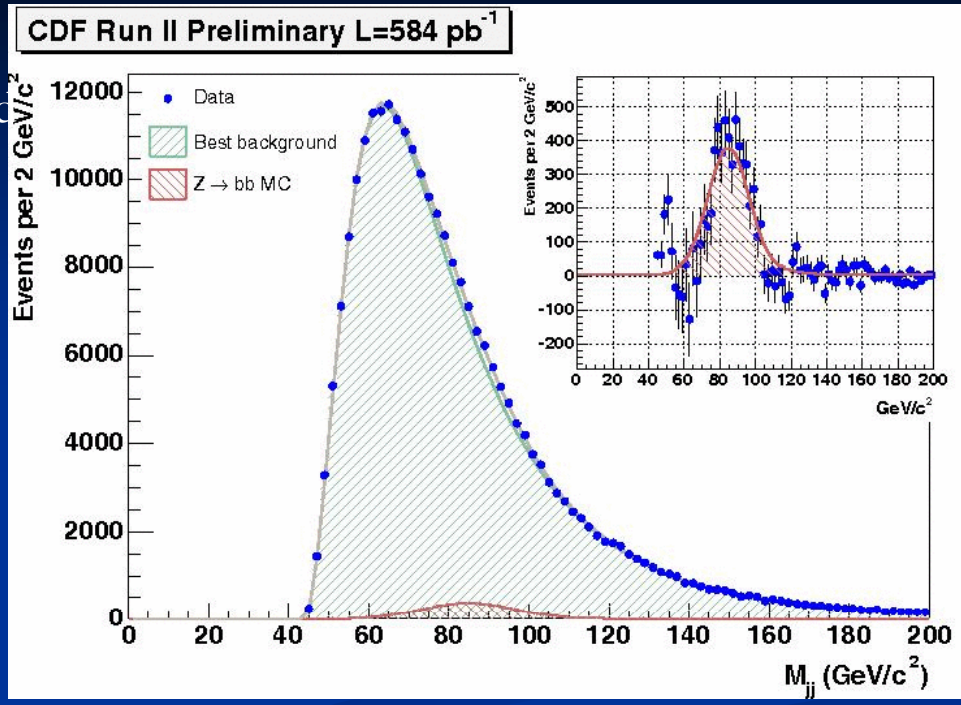
Signal: templates as a function of reconstructed Z mass (energy scale)



Background modeled as sum of Pearson and error function:

$$P_b(m_{jj}) = \beta_0 \left[1 + \left(\frac{m_{jj} - \beta_1}{\beta_2}\right)^2\right]^{-\beta_3} \cdot e^{-\beta_4 \tan^{-1}\left(\frac{m_{jj} - \beta_5}{\beta_2}\right)} + \beta_5 \times Erf\left(\frac{m_{jj} - \beta_6}{\beta_7}\right) + \beta_8$$





b-JES = 0.974 ± 0.011(stat.) + 0.017 - 0.014 (syst.)

Nevents = 5674 ± 448(stat.) + 1473 - 570 (syst.)

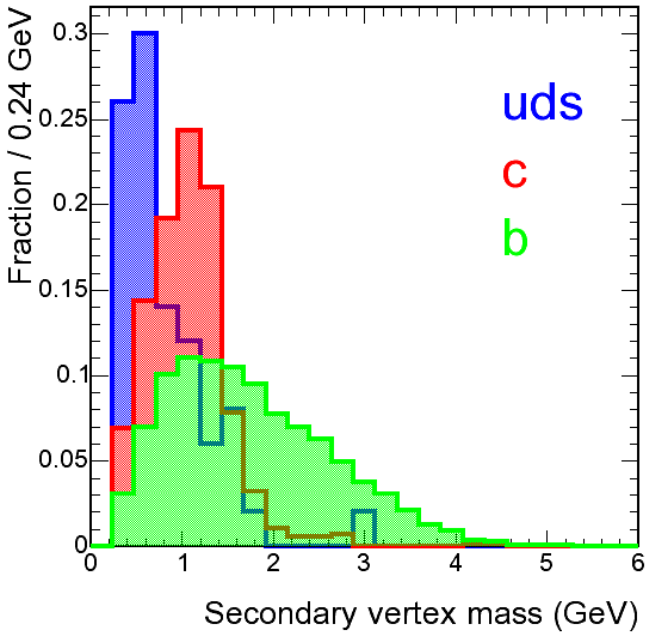
Nexpected (Pythia) = 4630 ± 727

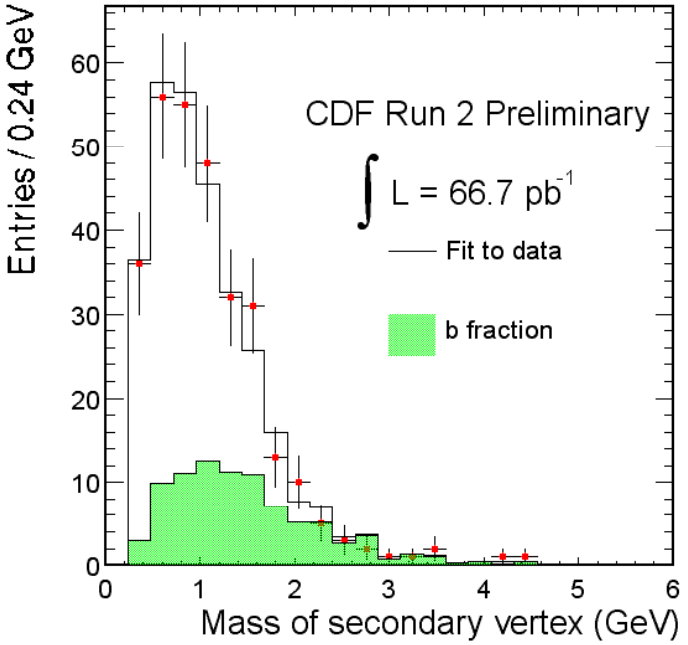
Photon + b Analysis

Use Et > 25 GeV unbiased photon dataset, without jet requirements at trigger level:

Off-line cuts:

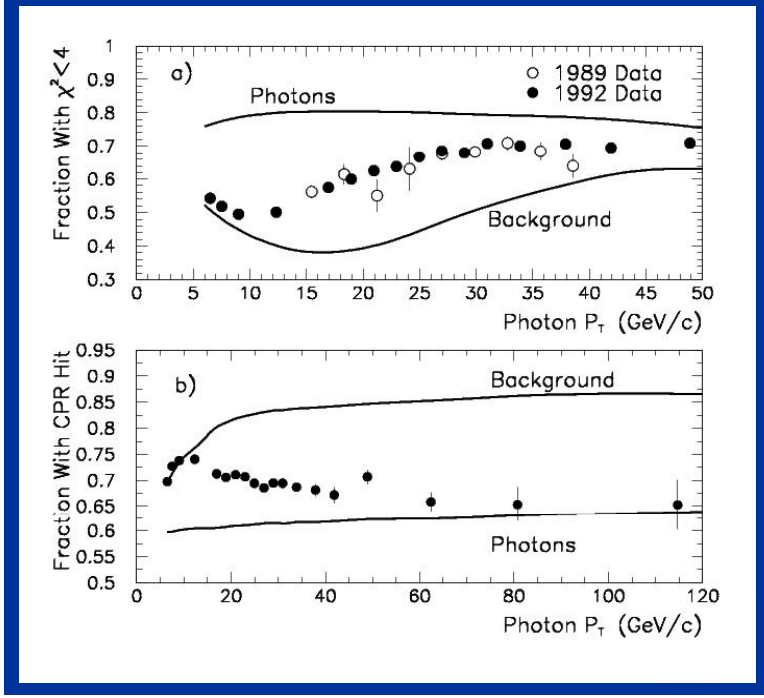
- γ $|\eta|$<1.0
- jet with secondary vertex
- Determine b, c, uds contributions
- Subtract photon background using shower shape fits

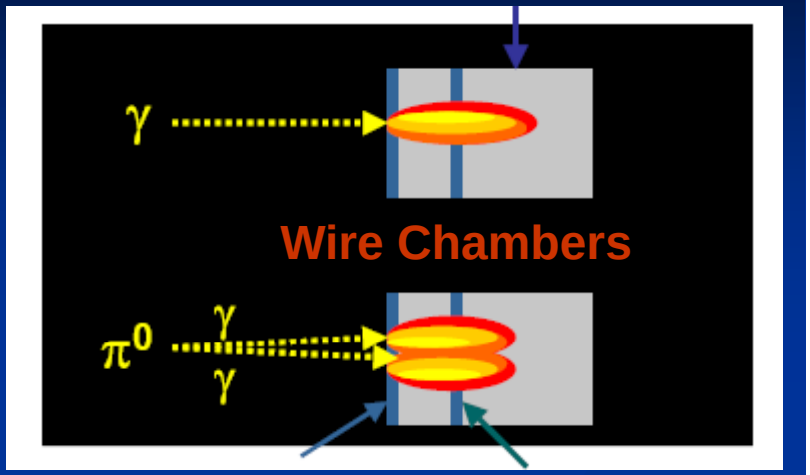


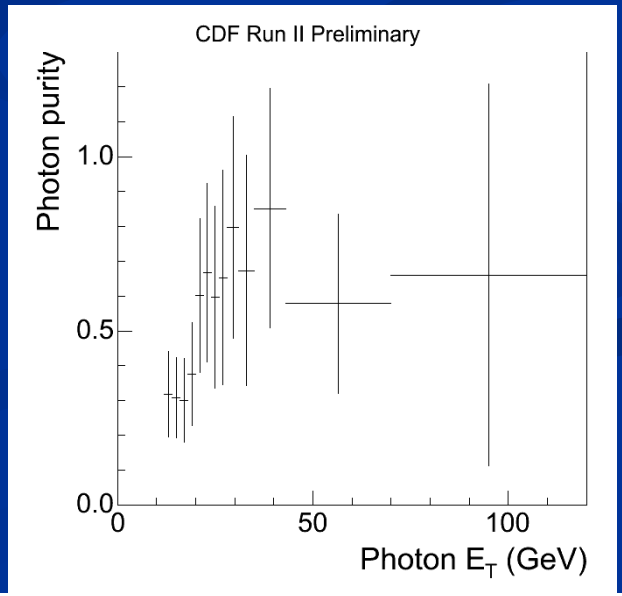


Photon identification

No event-by-event photon identification possible: only statistical separation based on shower shape measured by tracking devices inside the calorimeter



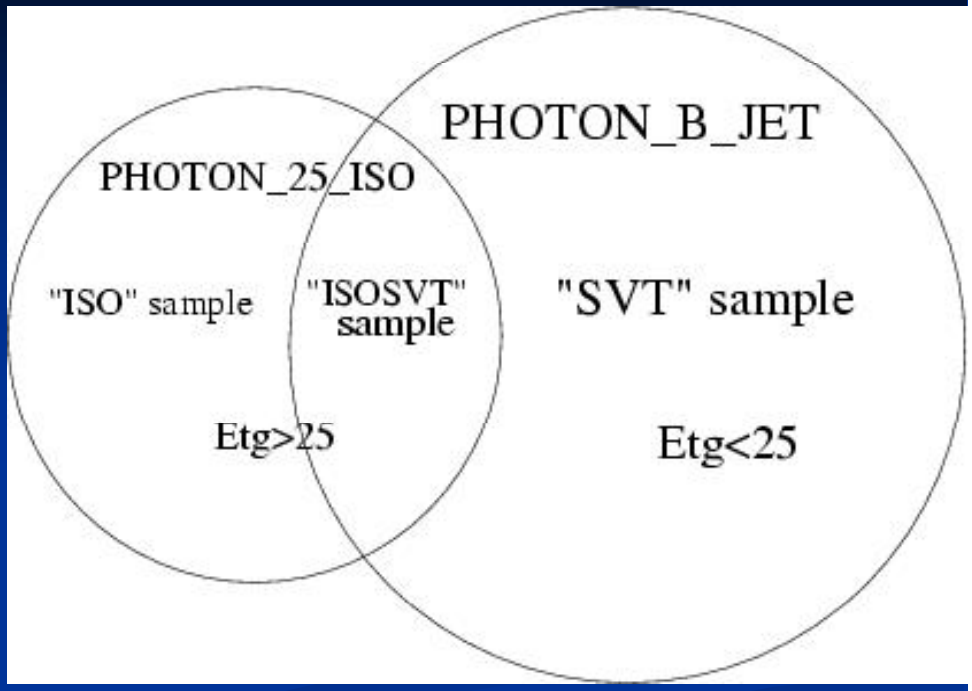




SVT vs unbiased dataset

Two datasets can be used:

- Unbiased with Et(γ)>25
- SVT-based with Et(γ)>12 GeV without prescale!



$$\sigma_{ISO} = N_{ISO} f^{b}_{ISO} / \epsilon^{lag}_{ISO} / \mathcal{L}$$

$$\sigma_{SVT} = N_{SVT} f^{b}_{SVT} / \epsilon^{lag}_{SVT} / \epsilon^{trig}_{SVT} / \mathcal{L}$$

Requires trigger simulation

Hard to calculate

Trigger efficiency can be computed directly from data using the overlap region (ISOSVT), where events have photon Et above 25 GeV and an SVT track

Analysis strategy

What we need in the end is:

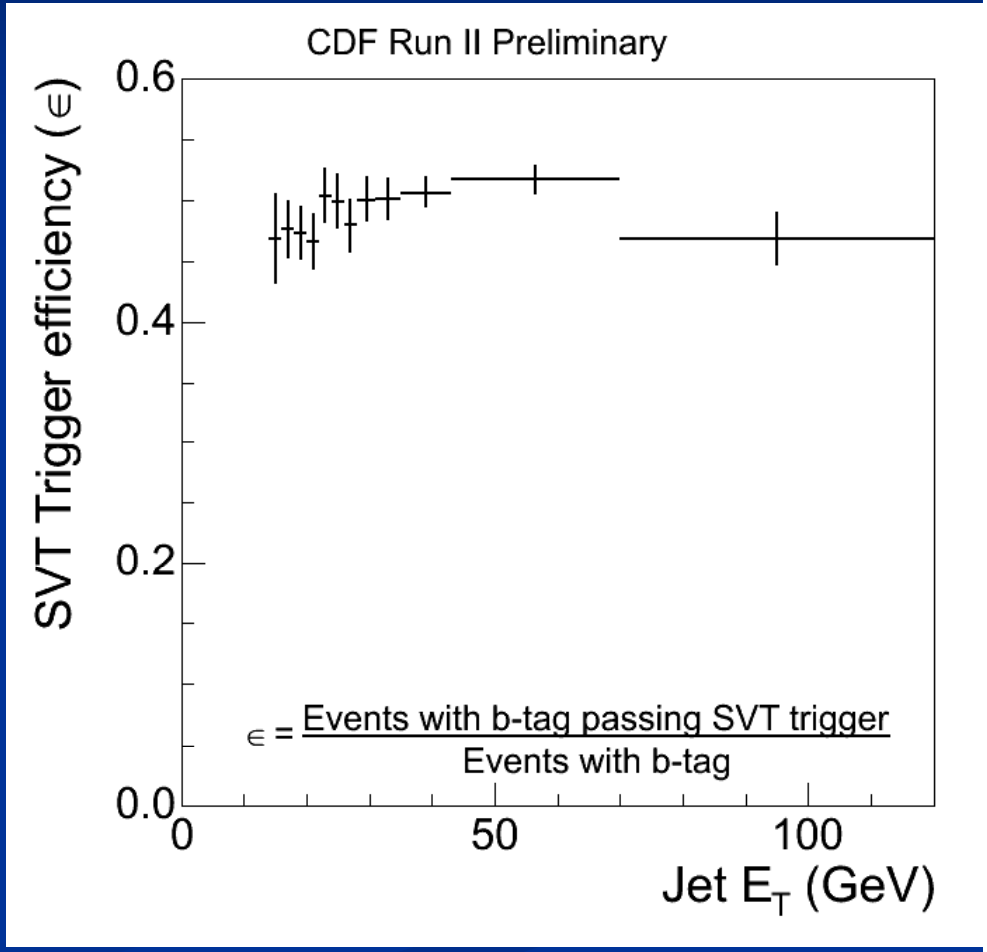
- perform the analysis on the unbiased dataset
- do the same on SVT-based events with E(L3γ)>25 GeV
- use their ratio to extrapolate to the low photon Et region.

This only requires the hypothesis that the jet quantities are independent on the photon energy

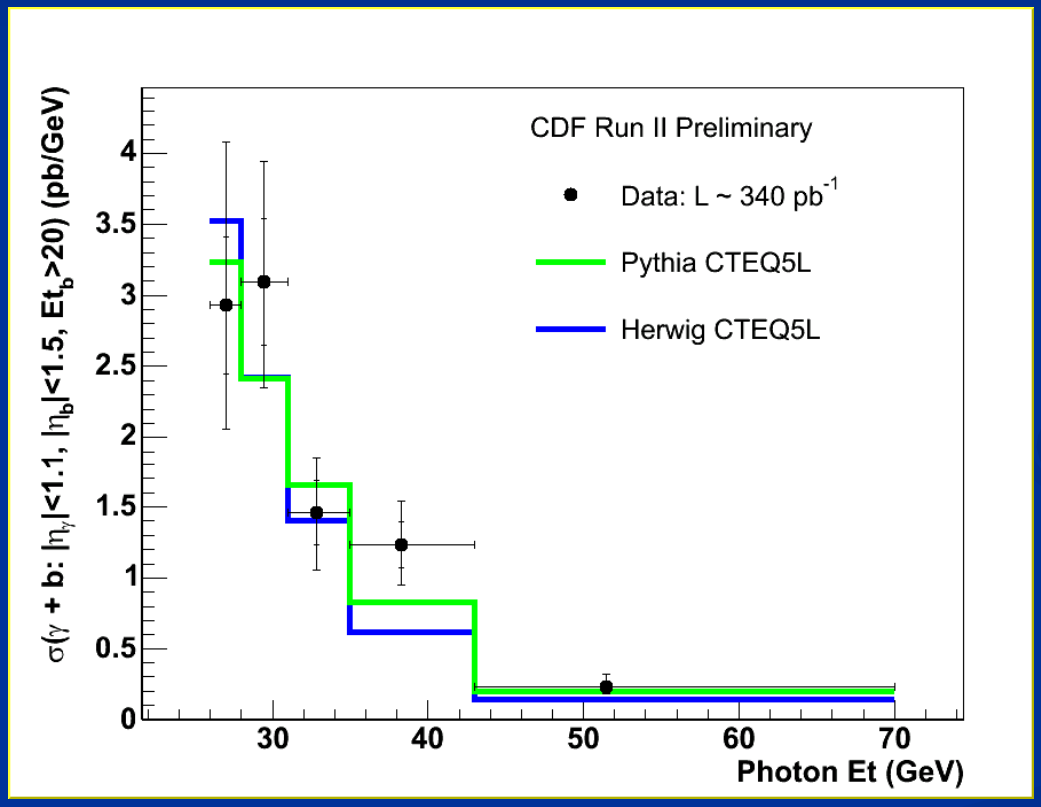
Trigger efficiency: Et dependence

Trigger efficiency was found to be stable with run number, for the different trigger conditions.

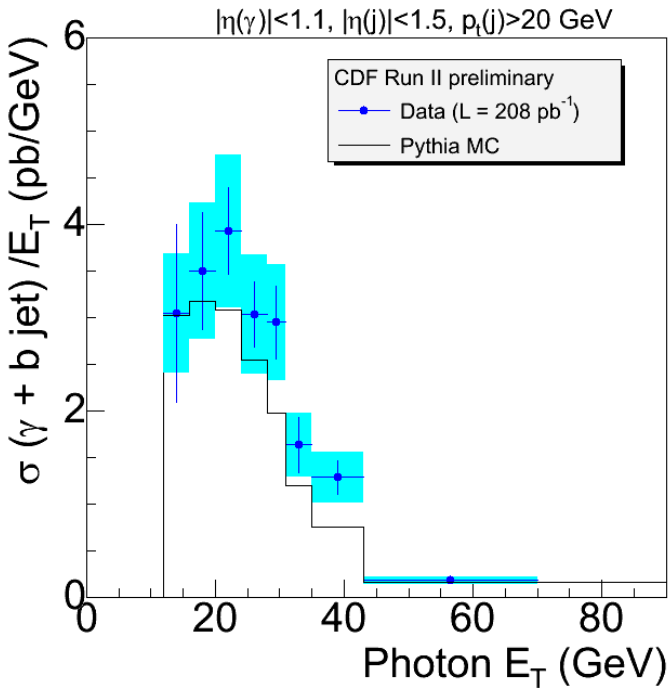
Trigger efficiency is also constant as a function of jet Et (small dependence used in the analysis)

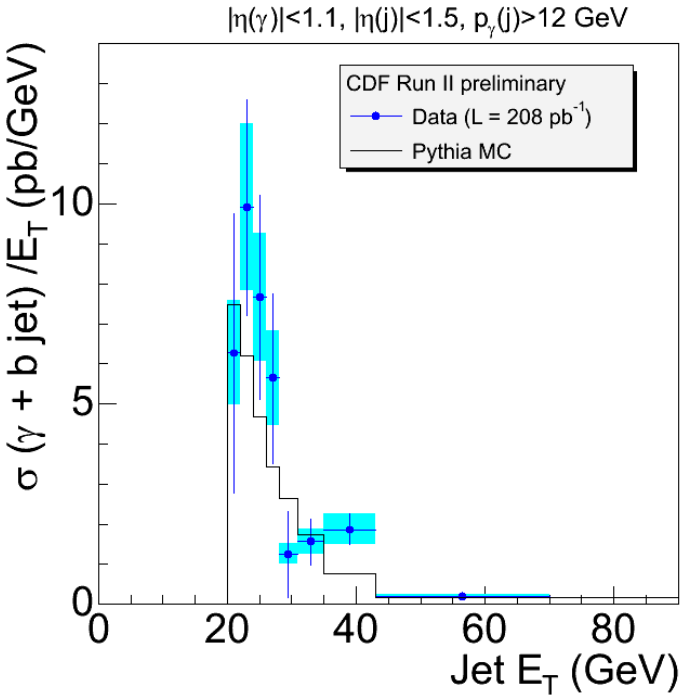


Photon + b result on unbiased dataset



Cross sections and ratio agree with LO predictions from MC, but on the high side





Photon+b cross section on the SVT dataset

Very good agreement with previous measurement based on PHOTON_25_ISO (~45% candidate overlap)

Data:

90.5 ± 6.0 (stat.) +21.7 -15.4 (syst) pb

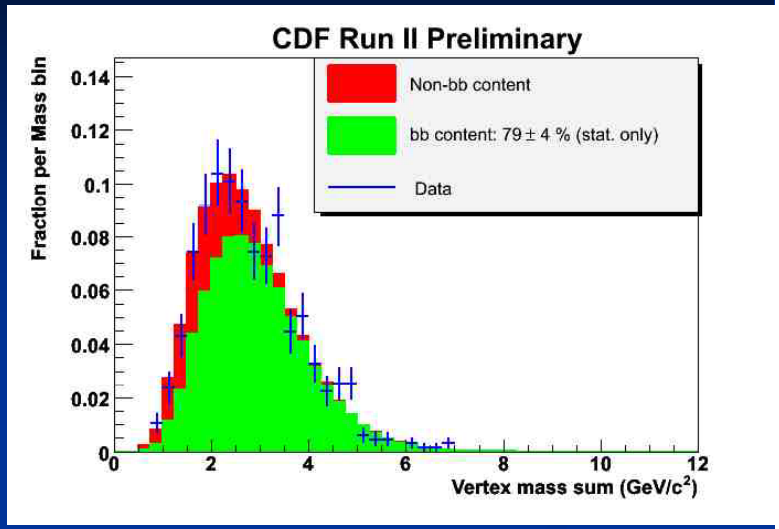
Pythia gen. Level: 69.3 pb

- Luminosity: 6%
- Trigger efficiency extrapolation (from statistics):10%
- Jet energy scale: 4% (from JES group methods)
- B purity templates: +20% -10%

$\bar{b}b$ + photon production

Natural follow-up of the b-photon analysis, using the same dataset and analysis technique, requiring double b-tag

- trigger efficiency is 60%
- bb purity around 80%

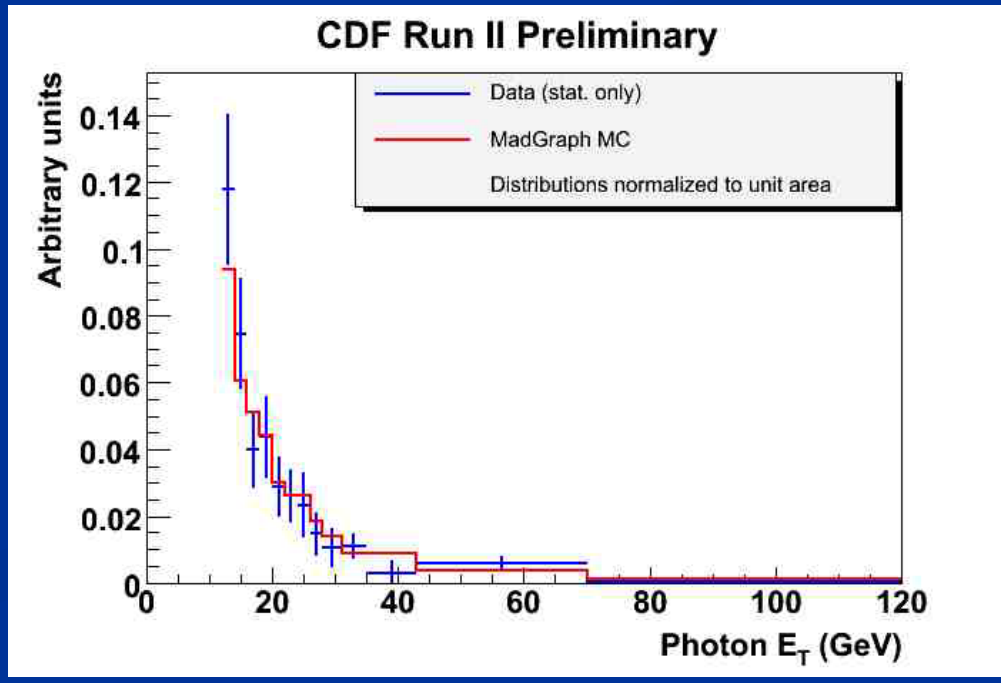


Measurement still preliminary;

Performed on the full 1.2 fb^{-1} sample

About 1 event/pb^{-1}

Angular distributions sensitive to production mechanisms



Conclusions

- Sometimes a breakthrough in hardware technologies opens up a new world of physics opportunities
- The possibility of online tracking allowed CDF to explore an exciting new horizons in heavy-flavor physics
- The first analyses using SVT-based triggers at high-Pt are ready, and show that we can understand these triggers well enough to perform precision measurements
- Now that the method has been tested on known physics, SVT-based triggers start to be used for the purpose they were designed for- a new weapon to look for SUSY and Higgs (H^+->bb analysis out soon)!