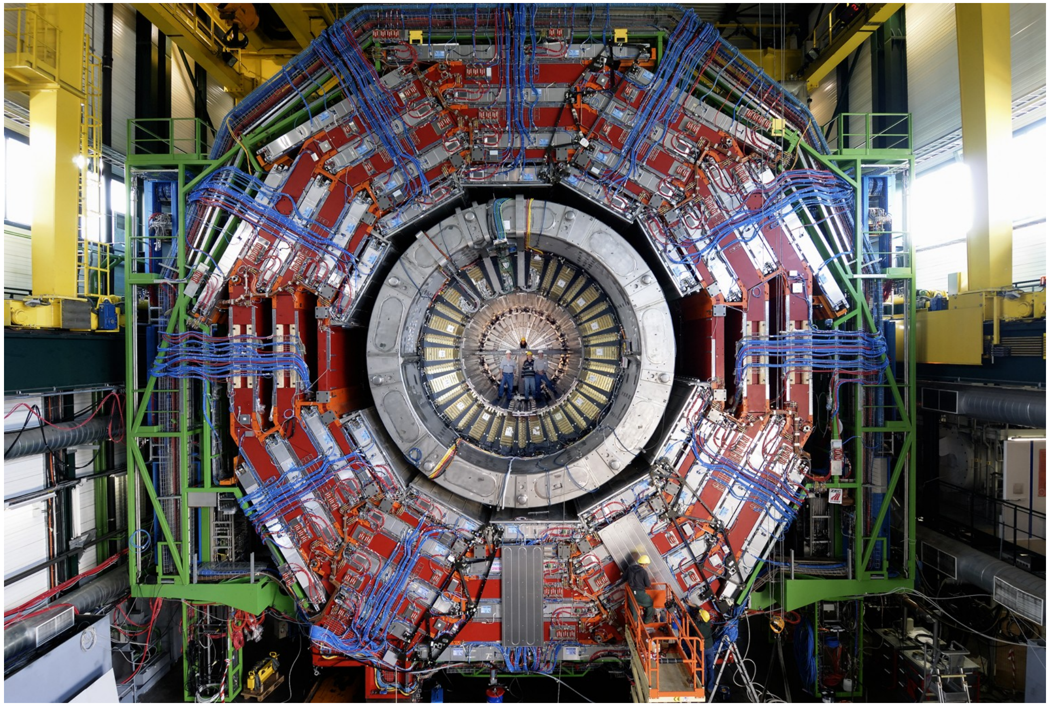


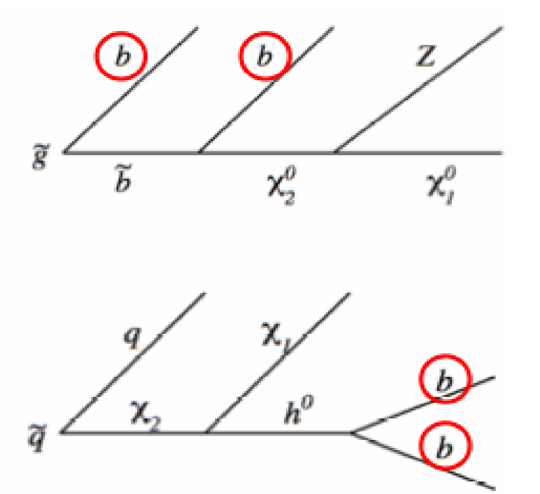
b Production Studies With Early Data At CMS

David Lopes Pegna
(Princeton University)
On behalf of the CMS Collaboration

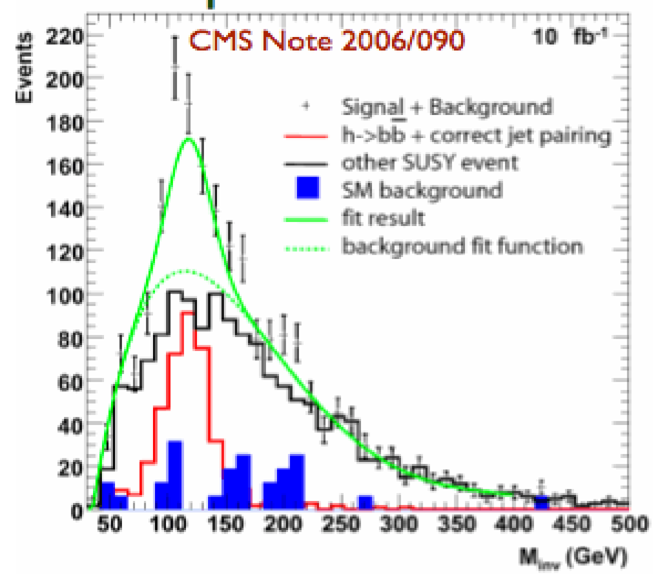
Berkeley Workshop
May, 7th 2009

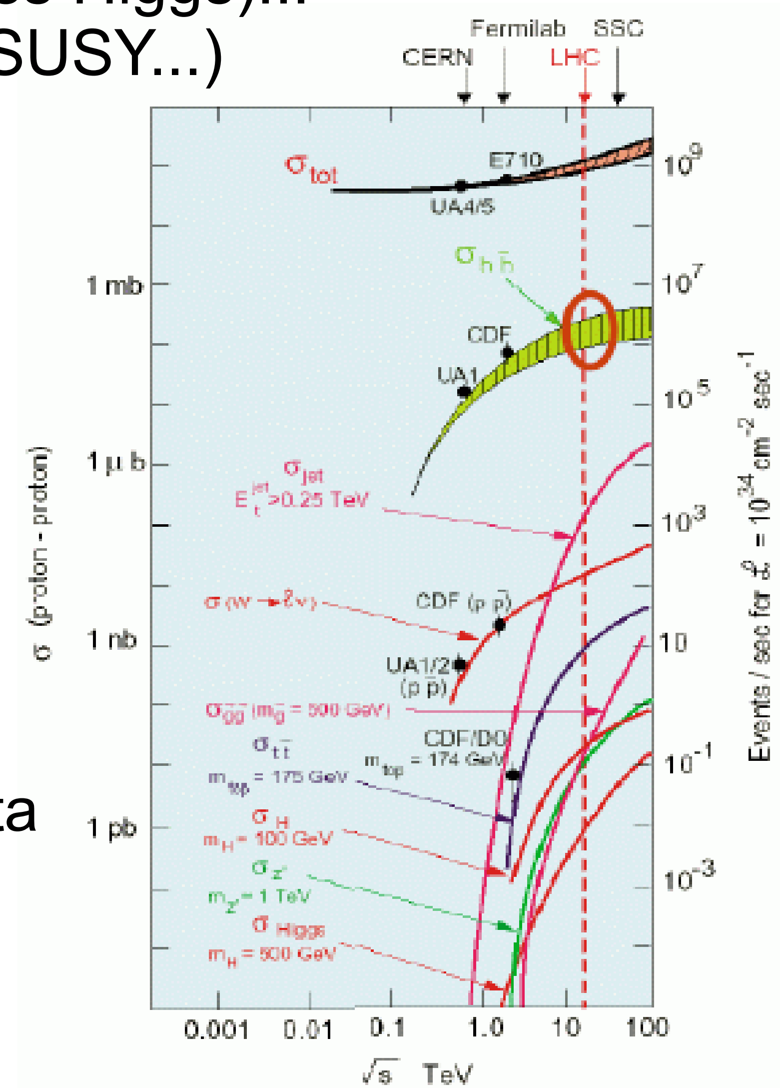
Why study b production at LHC?

- b quarks are a key ingredient at LHC
  either as direct signal (top physics, low mass Higgs)...
  Or background to New Physics searches (SUSY...)



example h^0 at LM5:

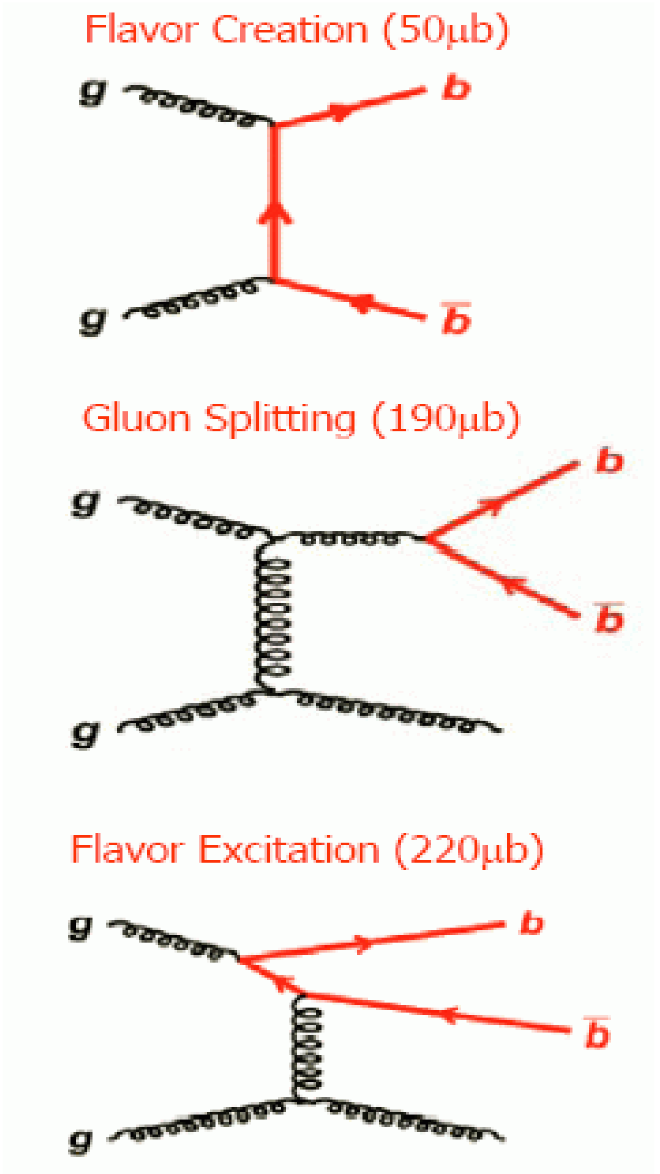




- Large bb cross-section allow study of b production and bb correlations with early data
- Test of QCD predictions at LHC energy
- Test detector performance: help with calibration, alignment, trigger

b production mechanisms

- Three dominant production mechanisms:
  LO:
  Flavor Creation (FC): gluon fusion (dominant) and qq annihilation
  NLO:
  Flavor Excitation (FE): $b\bar{b}$ from the sea, only one b participates to the hard scatter, asymmetric p_T for the b's
  Gluon Splitting (GS): $g \rightarrow b\bar{b}$ in initial or final state, b at low p_T and close in the azimuthal angle ($\Delta\phi$)



- Measurement of b production:
  Differential cross-section $d\sigma/dp_T$, $d\sigma/d\eta$
- $b\bar{b}$ correlations:
  Azimuthal correlation between the two b's (high sensitivity to NLO/LO ratio)

b production at the Tevatron

- Studied since the first data in late 80s
- Single b production

Exclusive, fully reconstructed $B \to J/\Psi K$ — CDF PRL 75, 1451(1995)

Inclusive $b \to J/\Psi X$ (lifetime) — CDF PRL 79, 572(1997)

Inclusive $b \to (e,\mu)X$ (impact parameter) — CDF PRL 71, 2396(1993), D0 PRL 74, 3548 (1995)

Inclusive $b \to \mu$+jet — D0 PRL 85, 5068(2000)

- Correlated $b\bar{b}$ production

Dimuons (impact parameter) — CDF PRD 55, 2546(1997), D0 PLB 487, 264 (2000)

J/Ψ +lepton (lifetime + impact parameter)

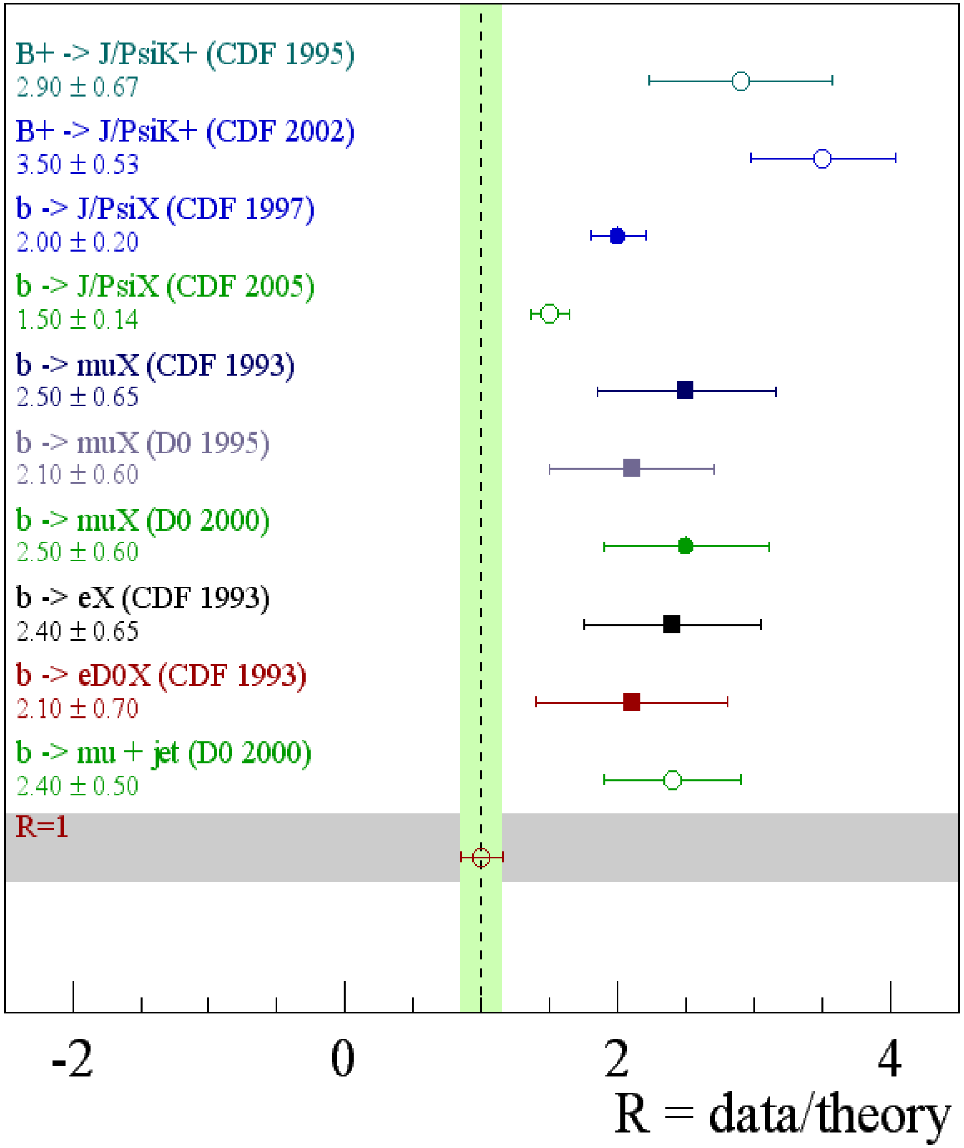
μ + b-tagged jet (secondary vertex) — CDF PRD 53, 1051(1996)

Two b-tagged jet — CDF PRD 69, 072004(2004)

Results have been compared with "classic" NLO QCD (MNR), and newer FONLL (Cacciari et al., JHEP 0407,033) to determine If QCD correctly predicts the data

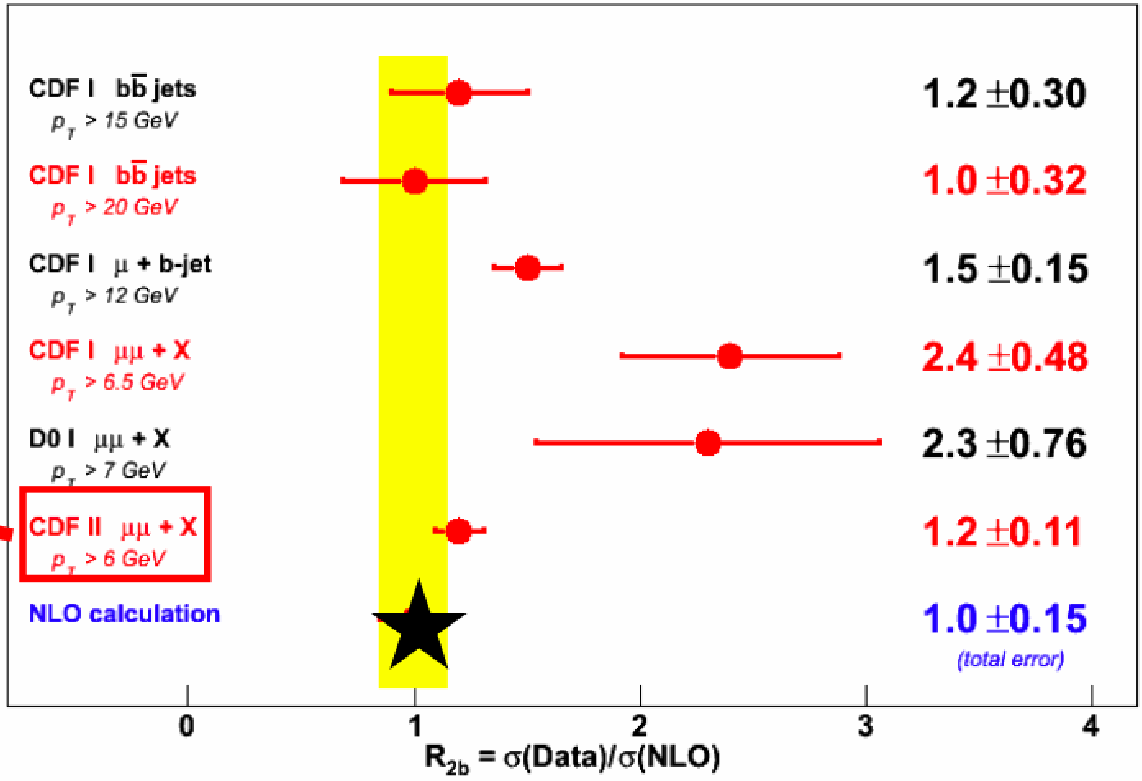
b production at the Tevatron

- We quote the ratio R=data/theory, as reported by Happacher *et al.* (PRD 73, 014026), who performed a consistent evaluation of all existing data as of 2006 using a common theory benchmark
- Data consistently above simulation
- Agreement improves slightly at large p_T
- Problem even in D0 μ+jet that should be less sensitive to the exact features of the b fragmentation



$b\bar{b}$ correlation at the Tevatron

- Similar situation for $b\bar{b}$ correlation measurements with μ, but not for only-jet analysis!
- Recent measurement from CDF with tighter cuts on muon in good agreement with NLO
- Problem with μ in old analysis ("Ghost muon" puzzle)? Similarly, single b analysis with μ yields larger R values...



Analysis Examples:

- Cross-section for bottom, charm and quarkonia
  Inclusive J/Ψ, Exclusive B decays ($J/\Psi K^{(*)}$) — $O(10\ pb^{-1})$
- Quarkonia studies: polarization, production mechanisms
- bb correlations: — $O(100\ pb^{-1})$
  - $J/\Psi+\mu$
  - μ + jet
  - jet + jet
- Lifetime and properties of b hadrons: $B_u, B_d, B_s, B_c, \Lambda_b$
- B_s oscillations, CP violation — $O(1\ fb^{-1})$
- FCNC rare decays: $B \to K^{(*)}\mu\mu$, $B_s \to \Phi\mu\mu$
- FCNC very rare decays: $B_{s/d} \to \mu\mu$ — $O(10\ fb^{-1})$
- $\tau \to 3\mu$ LFV

$\int \mathcal{L} dt$

Trigger @ CMS

Level 1 Triggers:
Hardware based
Muons and Calorimeters
40 MHz → 200 kHz

High Level Triggers (L2,L3):
Software based
Fast (local) reconstruction in the tracker included
200 kHz → 100 Hz

- Different trigger menu under study, depending on the luminosity (e.g. 8E29, 1E31...)

Relevant Triggers for heavy flavor physics:

- Dimuon triggers

  L1: 2 muons p_T > 3 GeV/c (2μ3)

  HLT:Normal dimuon trigger: 2 muons p_T>3 GeV/c

  Displaced dimuon vertex trigger

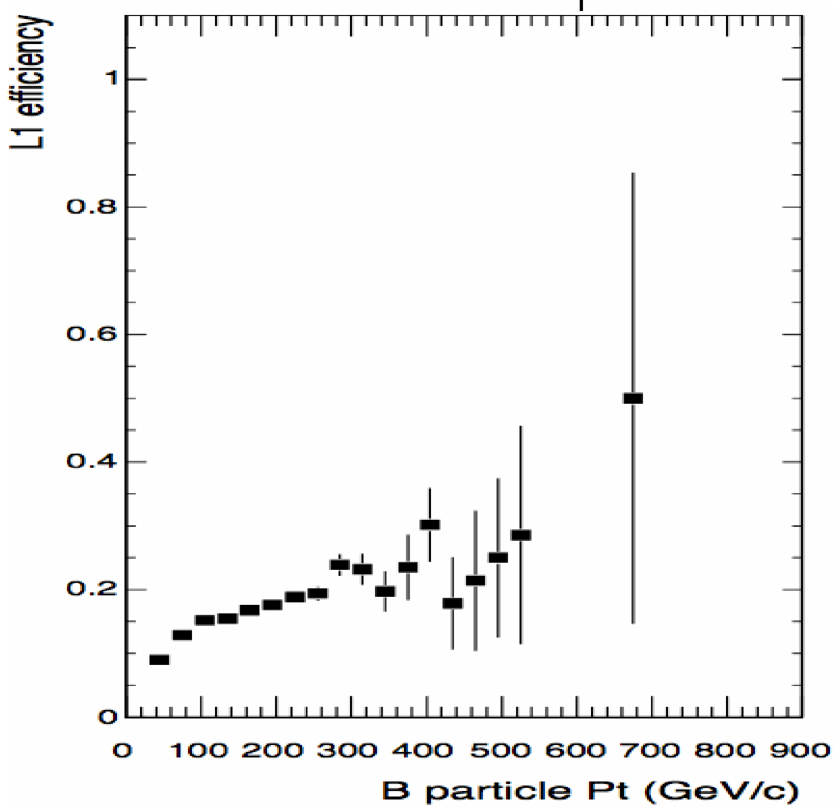
- Single muon triggers

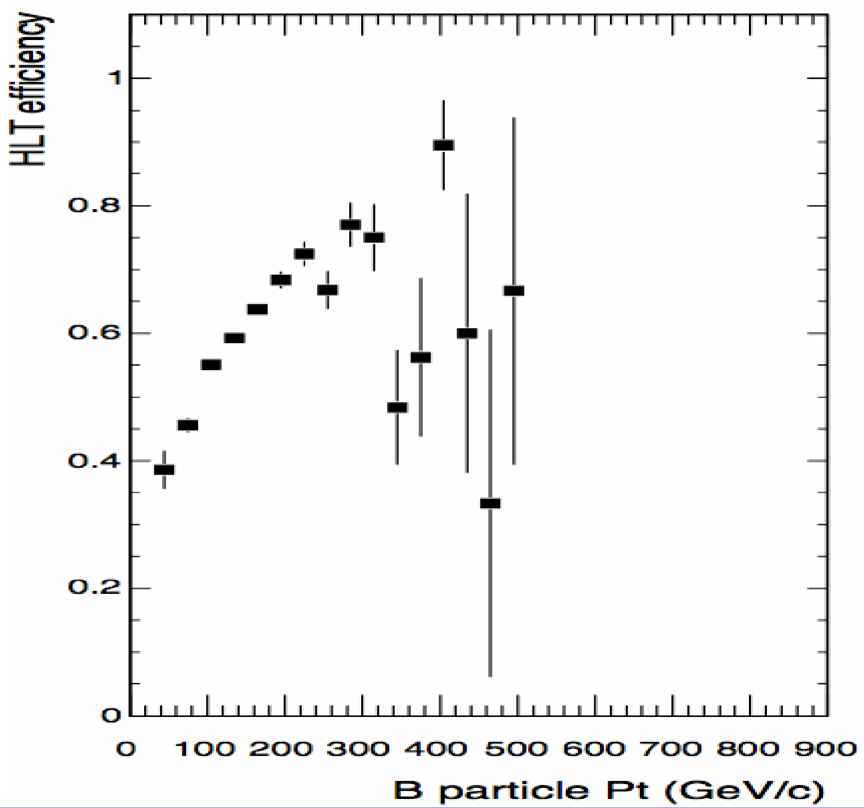
  L1 & HLT: 1 muon with p_T> 9 GeV/c (other threshold available, with different pre-scaling factors)

Inclusive b production

Measure inclusive differential b cross-section: $d\sigma/d\eta$, $d\sigma/dp_T$

- Study performed at 14 TeV collisions and high lumi
- L1 Trigger: single μ with p_T>14 GeV/c
- HLT: μ + b-jet: 1 non isolated μ (with p_T>19 GeV/c) plus a b-tagging requirement on a jet (E_T>50 GeV and $|\eta|$<2.4, Track counting from pixel tracks)



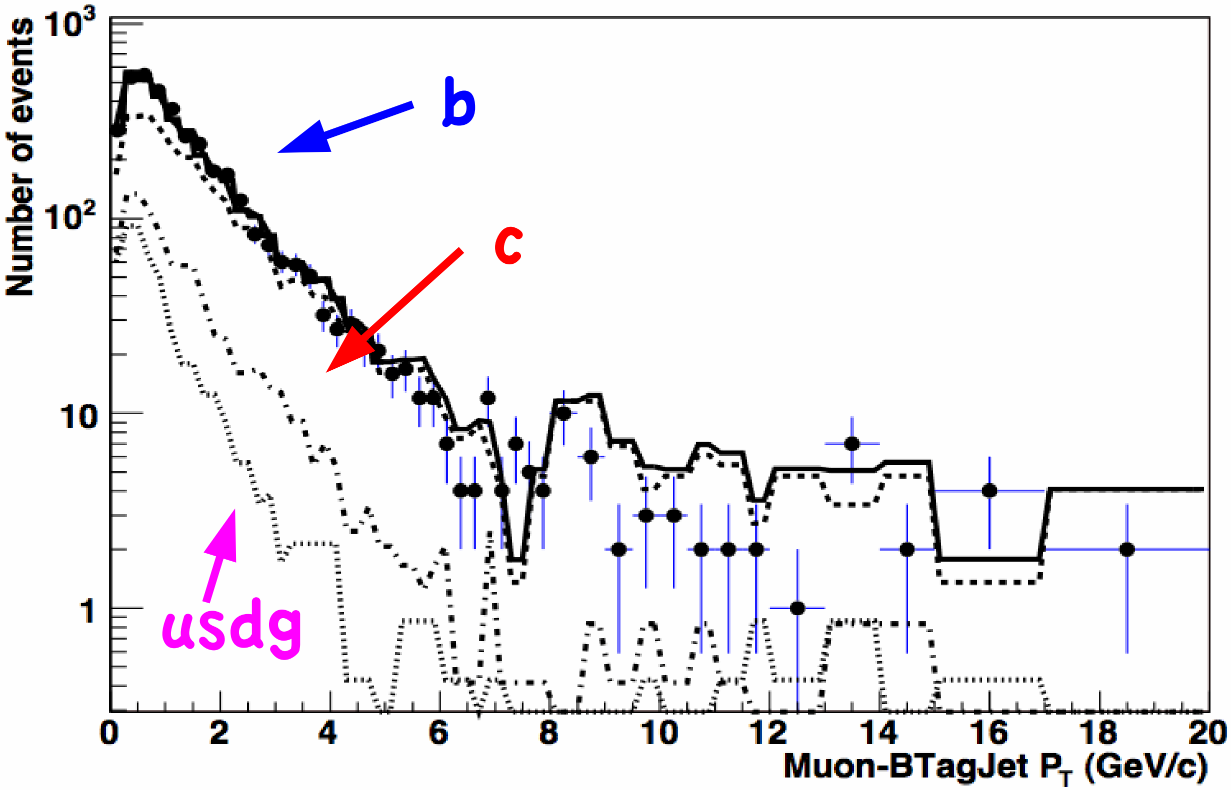


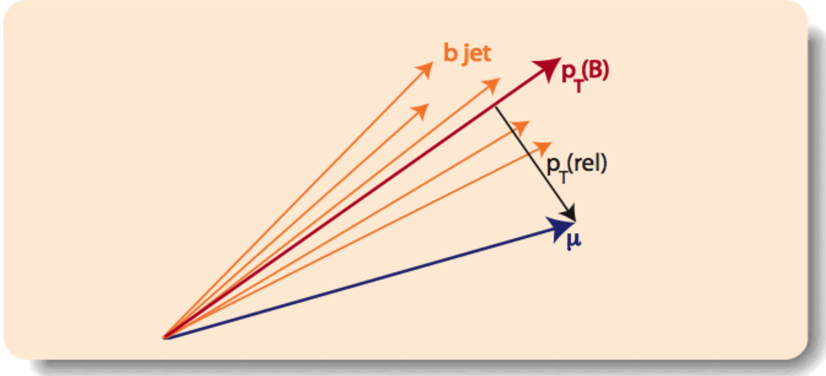
Inclusive b production

- Select events with at least one b-tagged jet and one μ
- Select b-tagged jet with highest p_T, μ associated to jet (ΔR)

B-tag efficiency is about 65%(55%) in barrel (end-caps),Total efficiency ~25%

- Use p_T(Rel) to distinguish between b,c, and light quark events





	MC Gen, $120 < \hat{p}_t < 170$	Fit
$N_{b\bar{b}}$	2503	2750 ± 346
$N_{c\bar{c}}$	965	702 ± 513
N_{uds}	299	329 ± 235

b purity between 55 and 70%

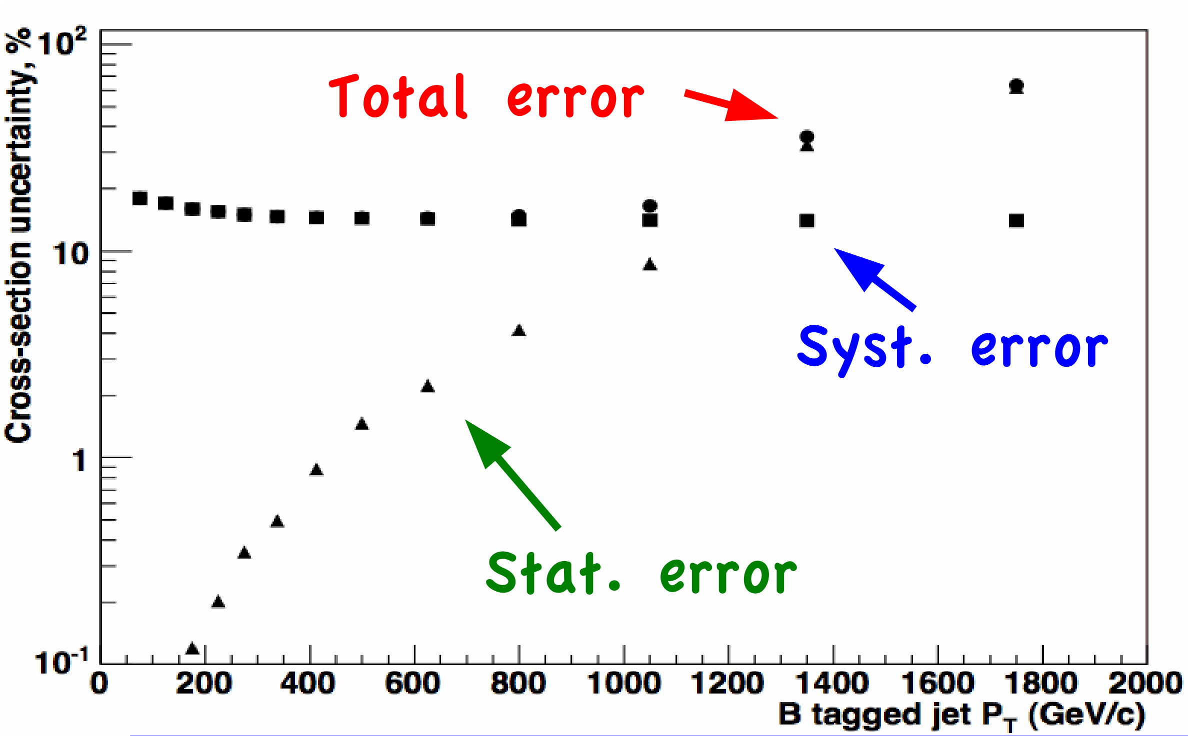
b-hadron p_T range accessible up to 1.5 TeV/c

$t\bar{t}$ contamination <1%

Inclusive b production

- Systematics uncertainties at 14 TeV dominated by:
  - JES uncertainty
  - b-quark fragmentation
  - MC modeling
  - B-tagging, luminosity, trigger, etc.

Source	uncertainty, %
jet energy scale	12
event selection	6
B tagging	5
luminosity	5
trigger	3
muon Br	2.6
misalignment	2
muon efficiency	1
$t\bar{t}$ background	0.7
fragmentation	9
total	18

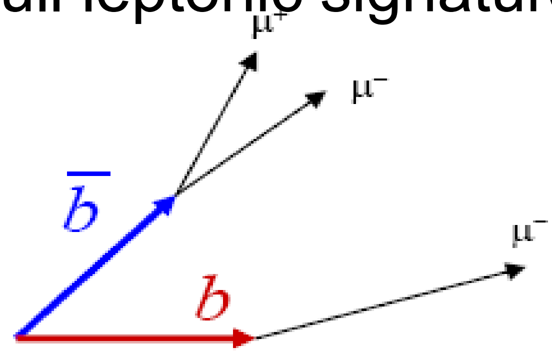


Prospects:
$\int \mathcal{L}dt$ 1fb^{-1} 1.6 M

$b\bar{b}$ Correlations using $J/\Psi + \mu$

- Strategy

  Measure $b\bar{b}$ azimuthal correlation using clean full leptonic signature in final state



- Goal

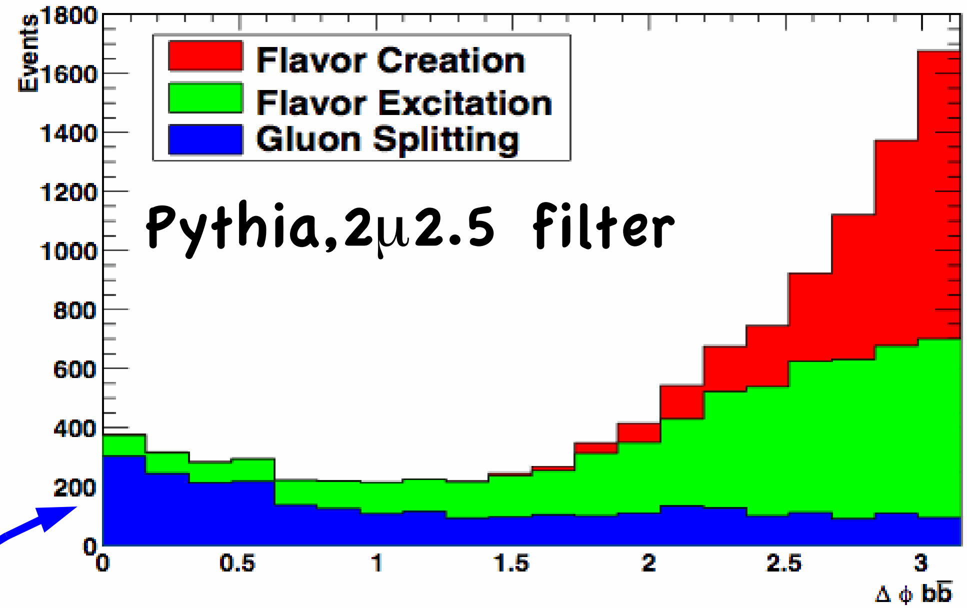
  Measure $b\bar{b}$ cross-section, estimate NLO contribution

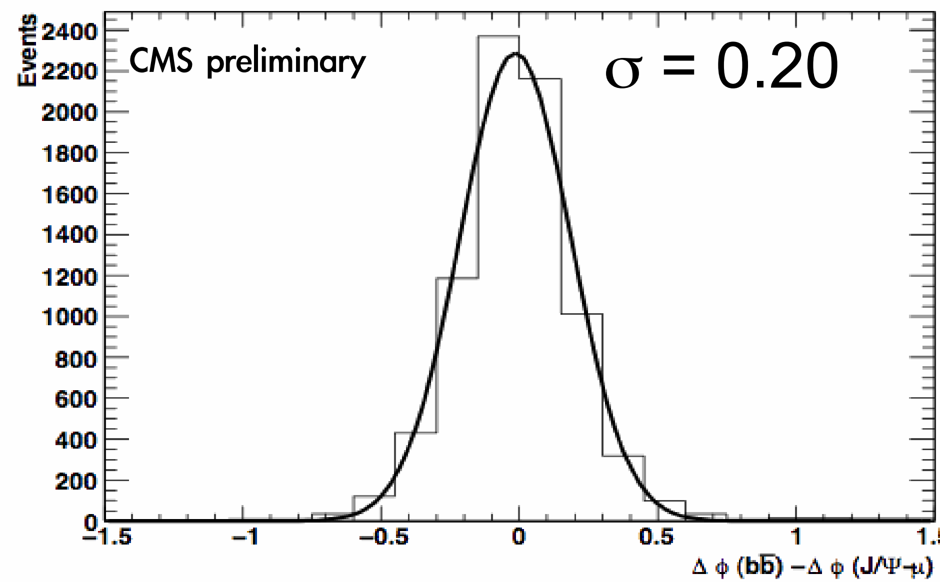
- Sensitive to $\Delta\phi$ region ~0

  Allow measurement of GS contribution

- Commissioning with early data (first $\mathcal{O}(10)$ pb^{-1})

  Complementary to charmonium inclusive study for lifetime/IP fits





bb Correlations using $J/\Psi + \mu$

Event Selection:

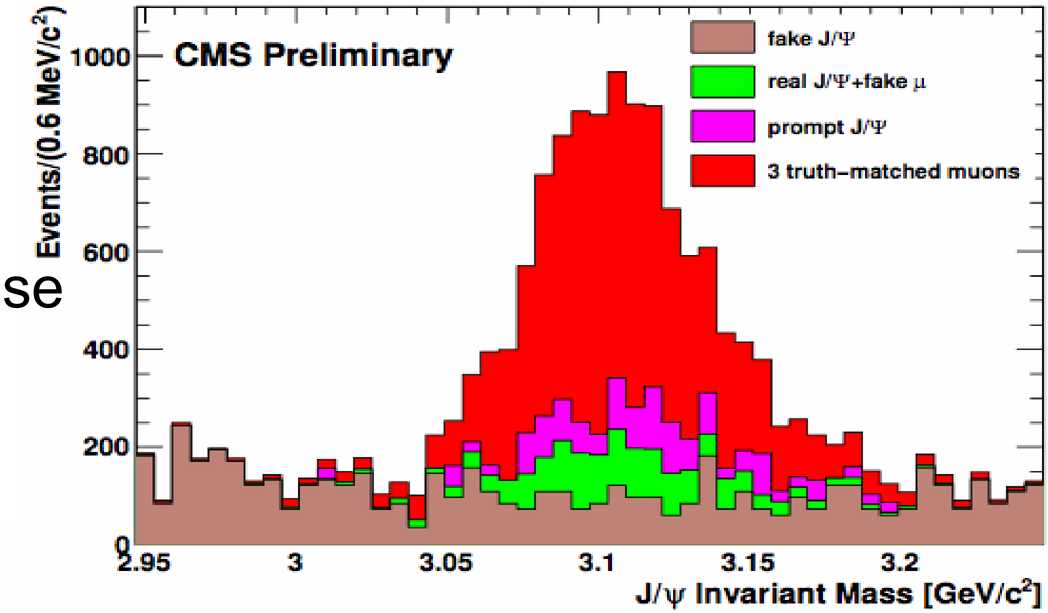
Trigger: $2\mu3$

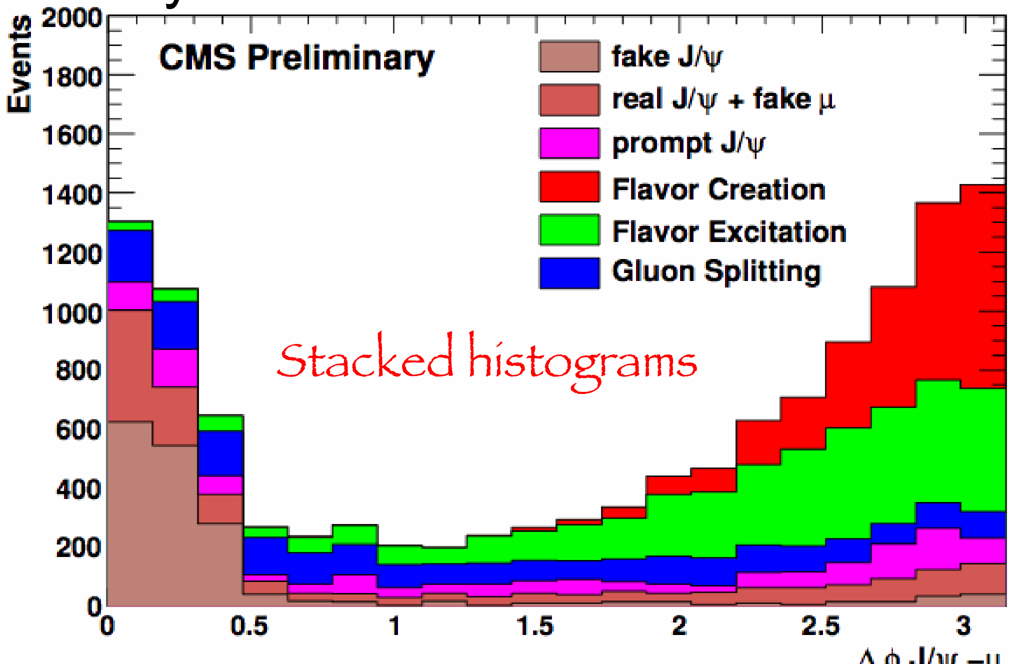
Vertex $\mu\mu$ pairs to build J/Ψ candidate

Require only match between pixel track and one muon segment to increase Sensitivity at low p_T

Look for a third μ in the event

Quality cuts on the third muon track





Backgrounds:

Misassigned muons

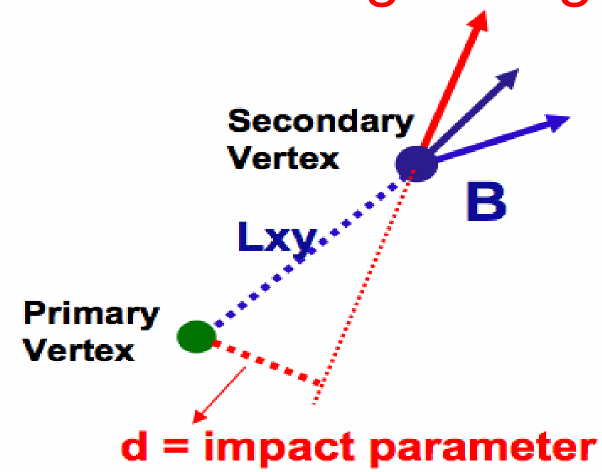
Real J/Ψ and Fake 3rd muon (hadronic punch-through/Decay in flight),

Real J/Ψ from prompt decays

Irreducible background from Bc $J/\Psi X\mu$ decays

Signal Extraction

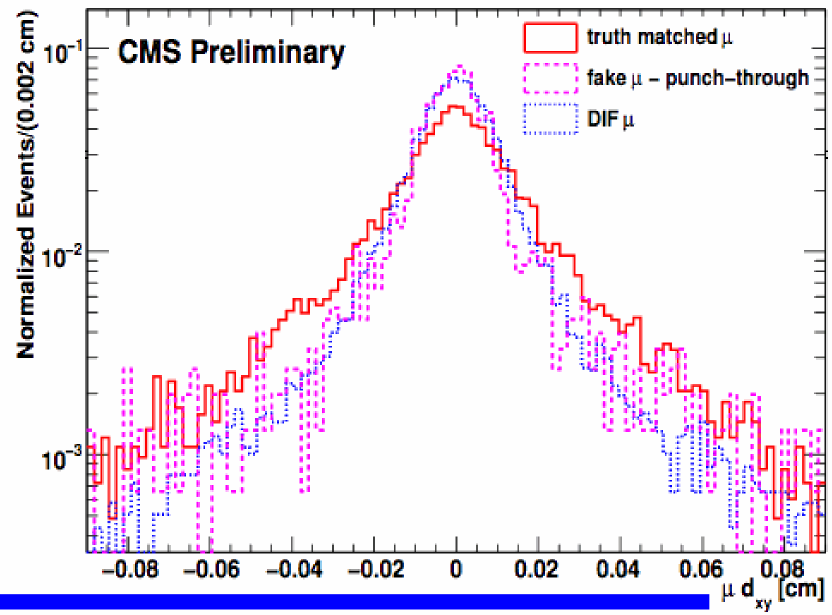
Extract signal in several $\Delta\phi$ bins by simultaneous 3-d unbinned maximum LH fit to J/Ψ invariant mass, L_{xy} transverse flight length, soft μ Impact Parameter



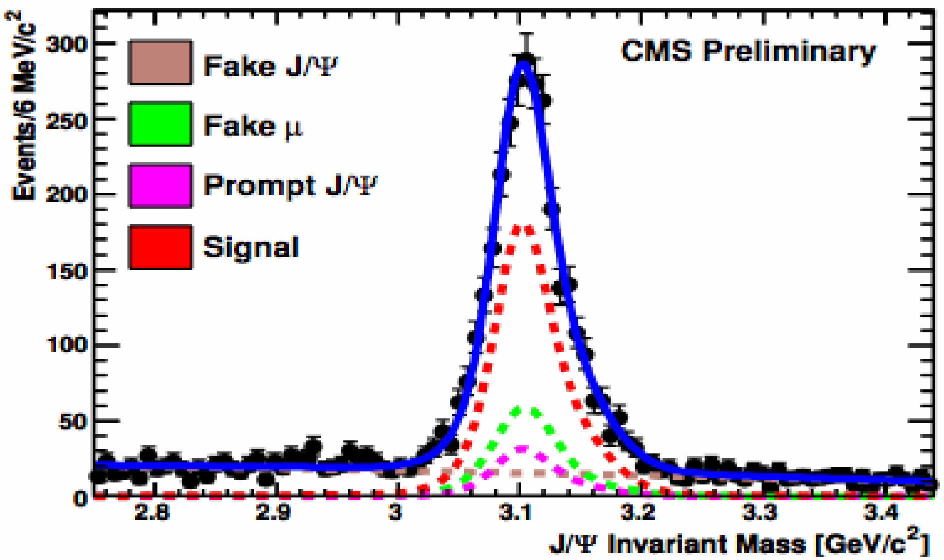
PDF shapes fixed on MC sample, yields for signal, real J/Ψ+ fake μ, prompt J/Ψ, and fake J/Ψ floated PDF Shapes:

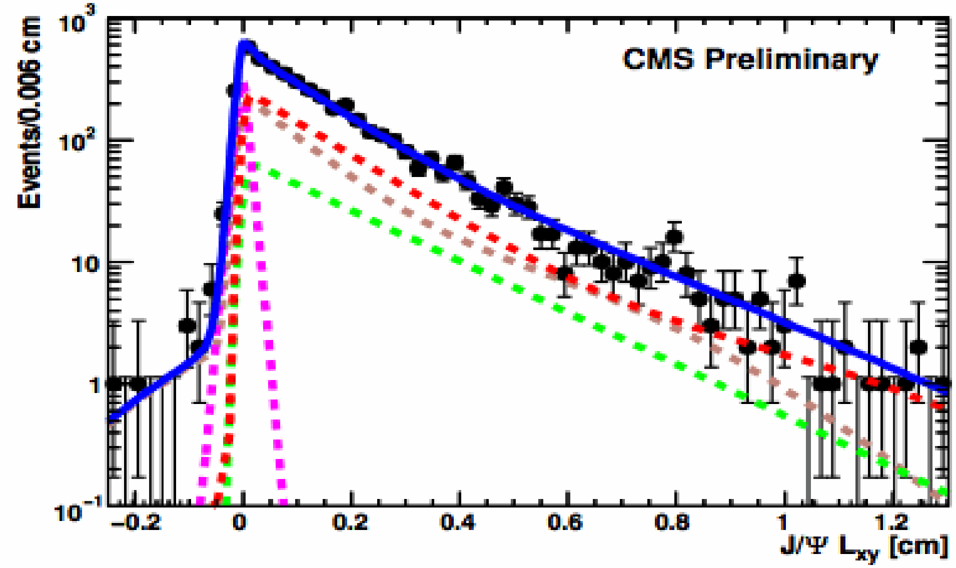
- Triple Gaussian for J/Ψ invariant mass
- Single(double) tail exponential convoluted with 2 Gaussians for J/Ψ L_{xy} (μ Impact Parameter)
- Use error/event for gaussian resolution

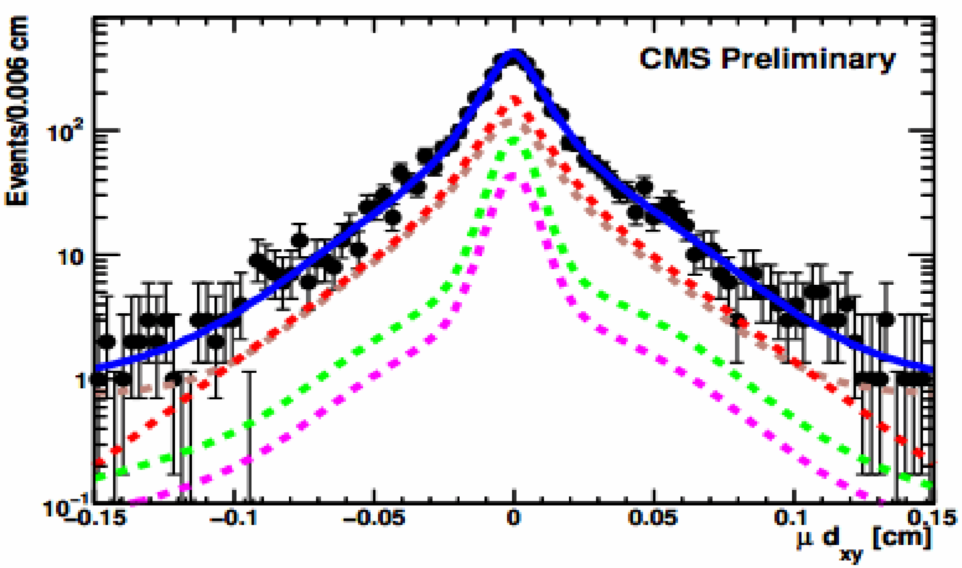
Validate Fit by fitting independent MC samples, and by using a toy MC study



bb Signal Yield Fit Example







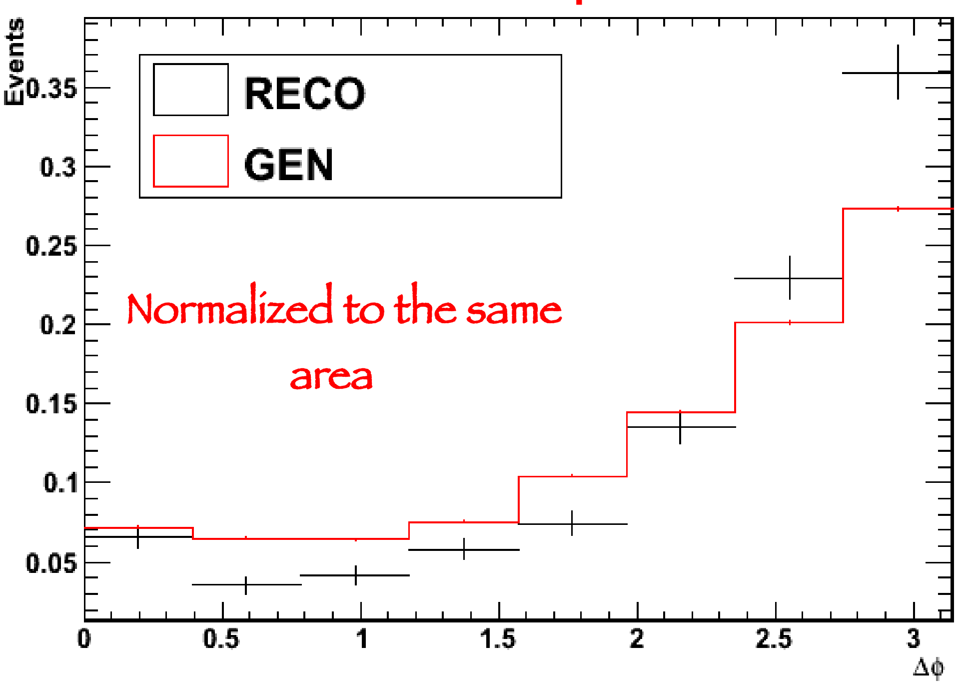
Integrated luminosity ~ 13 pb^{-1}

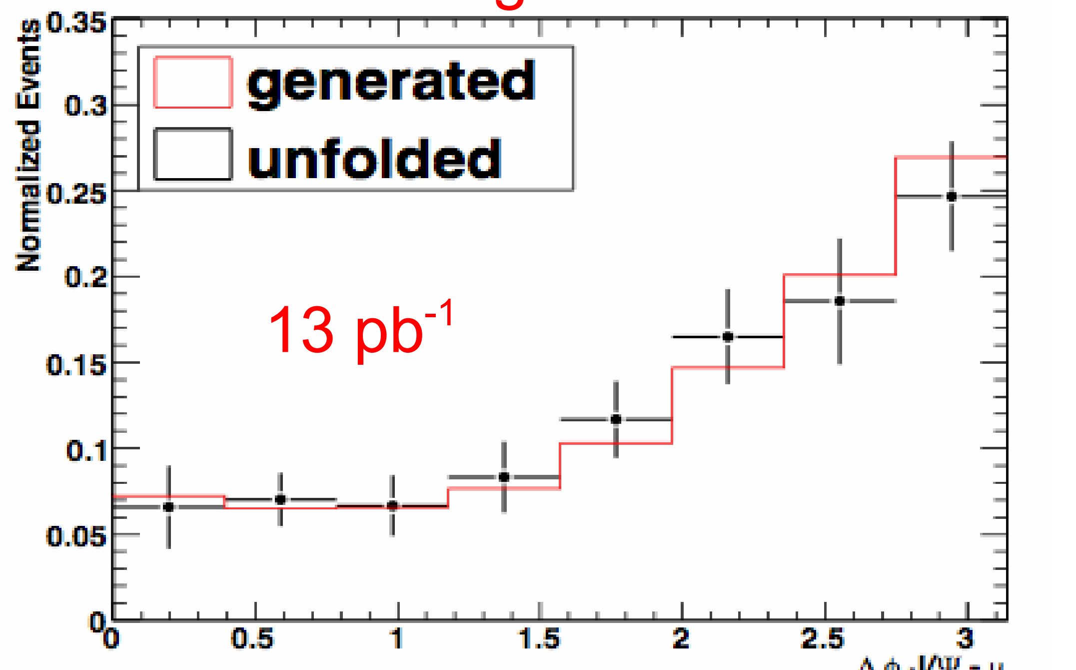
Category	Gen Yield	Fitted Yield
Signal	1865	1924 ± 147
Fake μ	674	642 ± 140
Fake J/ψ	1576	1543 ± 47
Prompt J/ψ	330	334 ± 25

Unfolding the $\Delta\phi$ Distribution

- Acceptance sculpts reconstructed $\Delta\phi$ distribution
  How to get the true spectrum (a) from the measured spectrum (b)?
  A:detector/resolution matrix → must be inverted:
  $\hat{A}\vec{a}=\vec{b}$ (problems: statistical fluctuations,oscillatory solutions..)

- Use Singular Value Decomposition (SVD) (A.Hocker et al, hep-ph/9509307)
  Comparison before and after unfolding





Differential Cross-Section

Sources of systematic uncertainty (estimated in each $\Delta\phi$ bin):

Luminosity, tracking and trigger efficiency

Fraction of muons produced in cascade decays $b \to cX \to \mu X'$

b-quark fragmentation

Uncertainty in the PDF shapes

J/Ψ polarization and misalignment effects

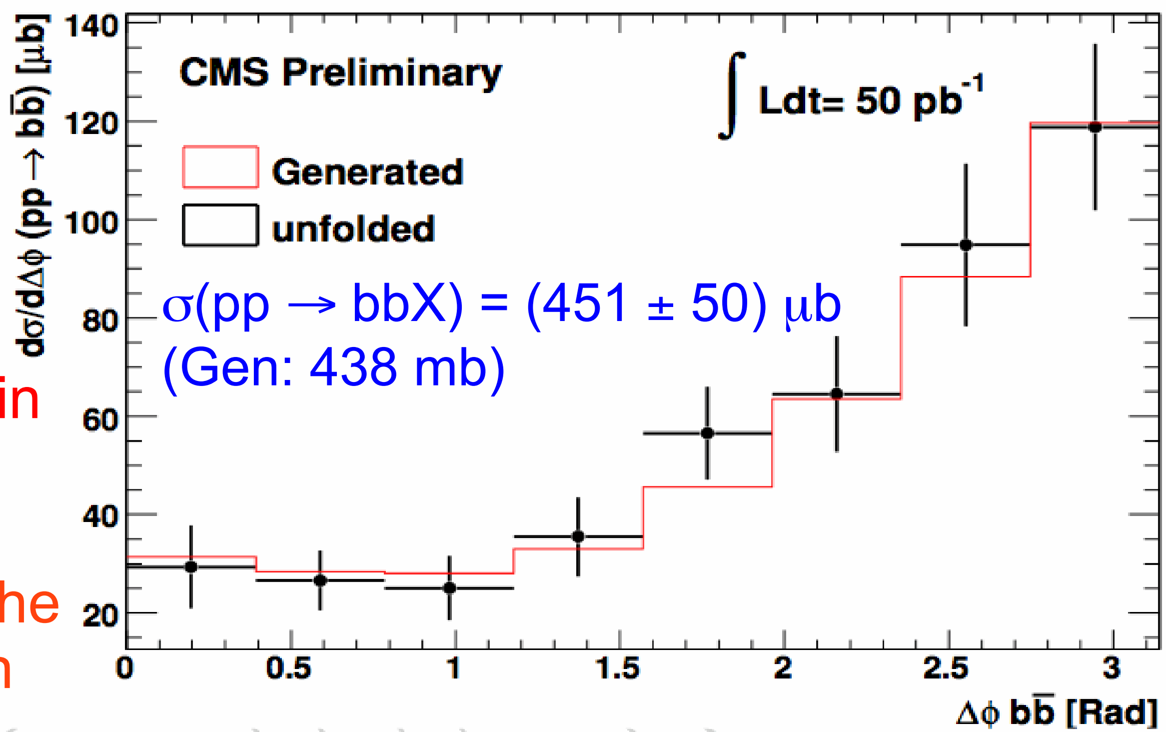
Compute $pp \to b\bar{b}X$ cross-section

According to

$$\frac{d\sigma}{d\Delta\phi} = \frac{N_{\rm fit}}{\mathcal{L}\cdot\epsilon_{\rm trg}\cdot\epsilon_{\rm reco}}$$

Uncertainty between 15 and 25% in each $\Delta\phi$ bin, for an integrated luminosity of 50 pb^{-1}

Expect an uncertainty of 10% for the integrated $pp \to bbX$ cross-section



$\sigma(pp \to bbX) = (451 \pm 50)\ \mu b$

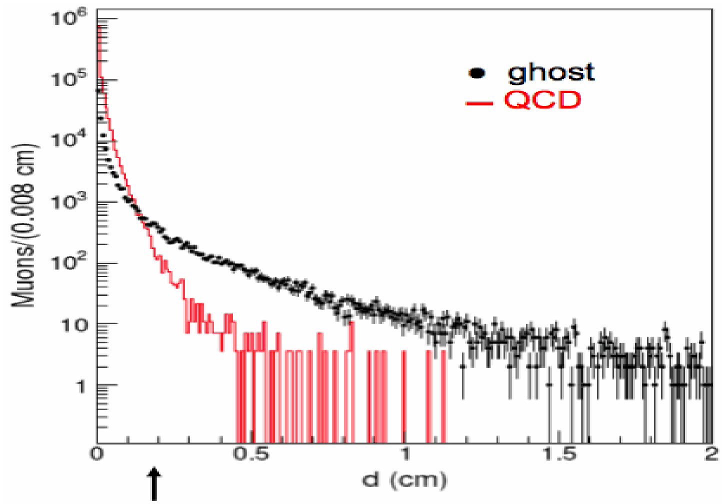
(Gen: 438 mb)

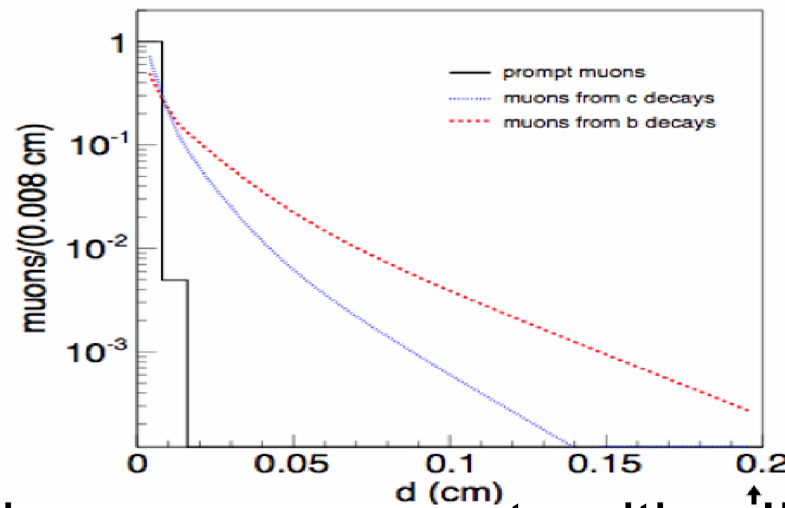
Conclusions

- b-quark crucial ingredient for LHC goals
- Large $b\bar{b}$ cross-section makes b production studies ideal test for LHC first run
  - Better understanding of the detector
  - Competive results with the Tevatron with O(10 pb^{-1}) data
- Tevatron data on b production and quarkonium still need to be reconciled with theory
- Measurement of b production and $b\bar{b}$ correlations is an important test of QCD
  - Important to disentangle vanilla QCD effects from real new physics Signatures
- We are all waiting for LHC run at the end 2009!

Backup Slides

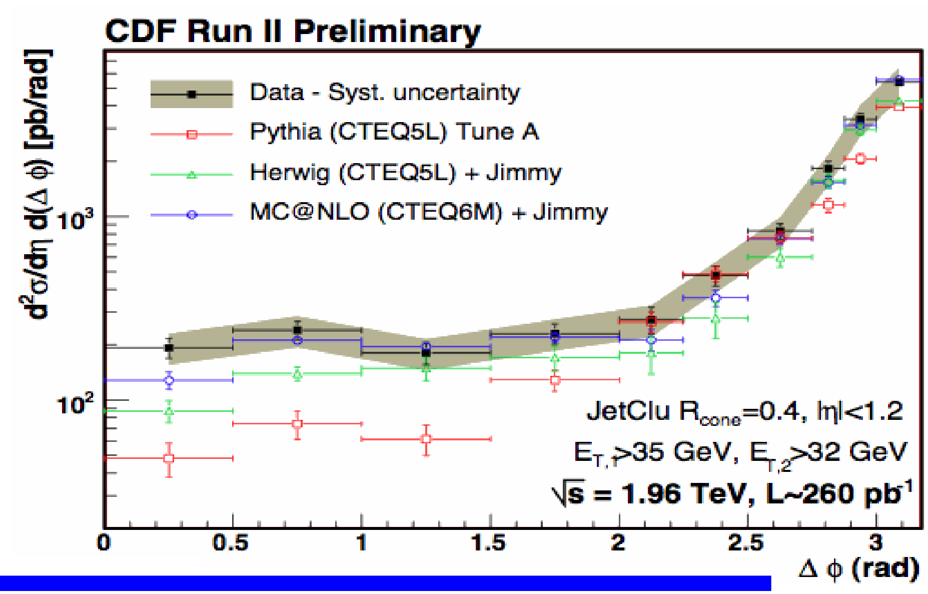
$b\bar{b}$ correlation at the Tevatron





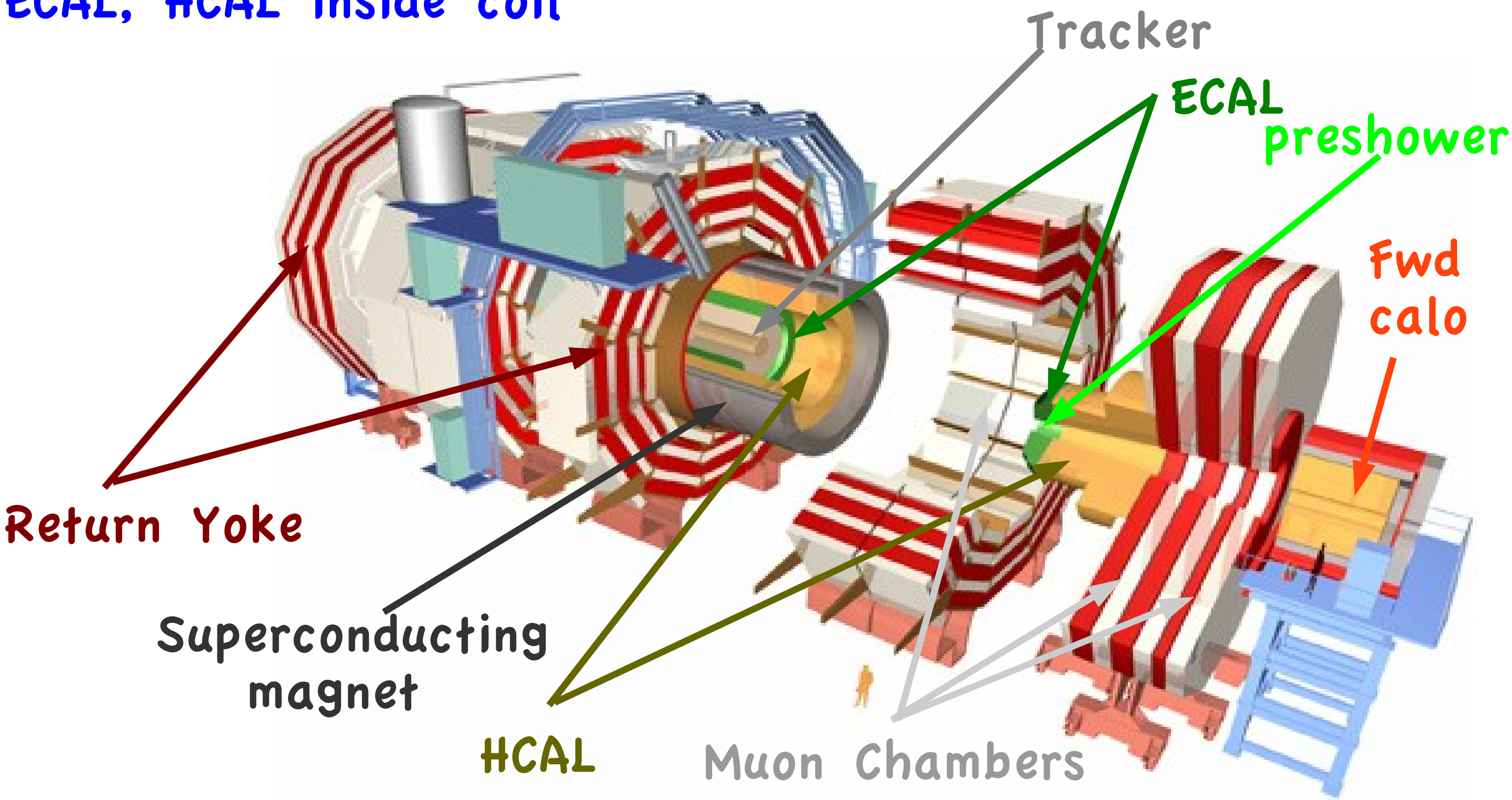
- Requiring tight SVX selection removes events with μ IP > 1.5 cm, Old CDF results suffered from large bkg (1:1) of long-lived real (fake) μ

- Most recent CDF results on single b and $b\bar{b}$ correlation using jets close to NLO prediction

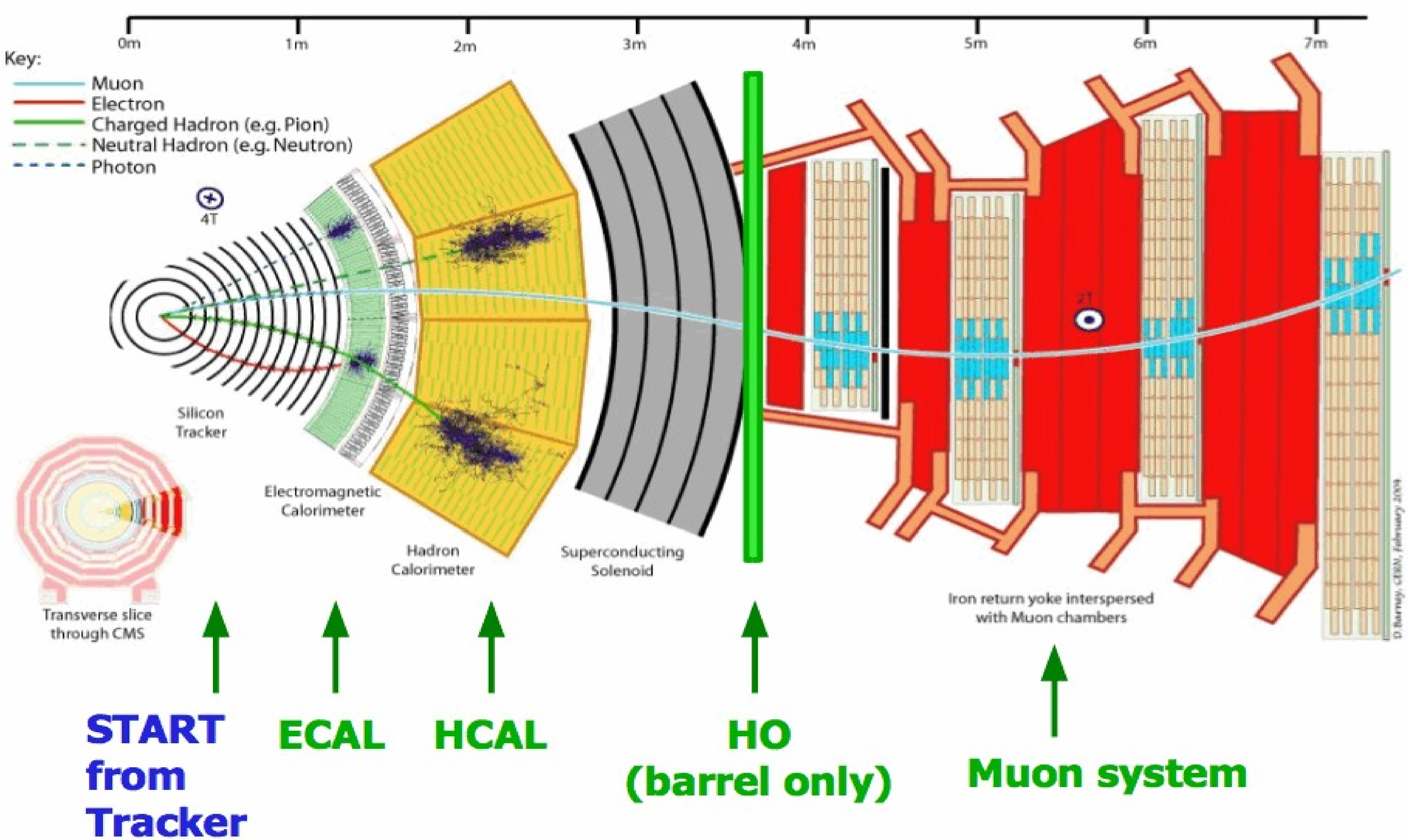


The CMS Detector

Diameter = 15m, length =21.6 m, Weight = 12000 t
3.8 T solenoidal magnetic field
Steel Return Yoke (2T) instrumented with Muon spectrometer
Tracker, ECAL, HCAL inside coil



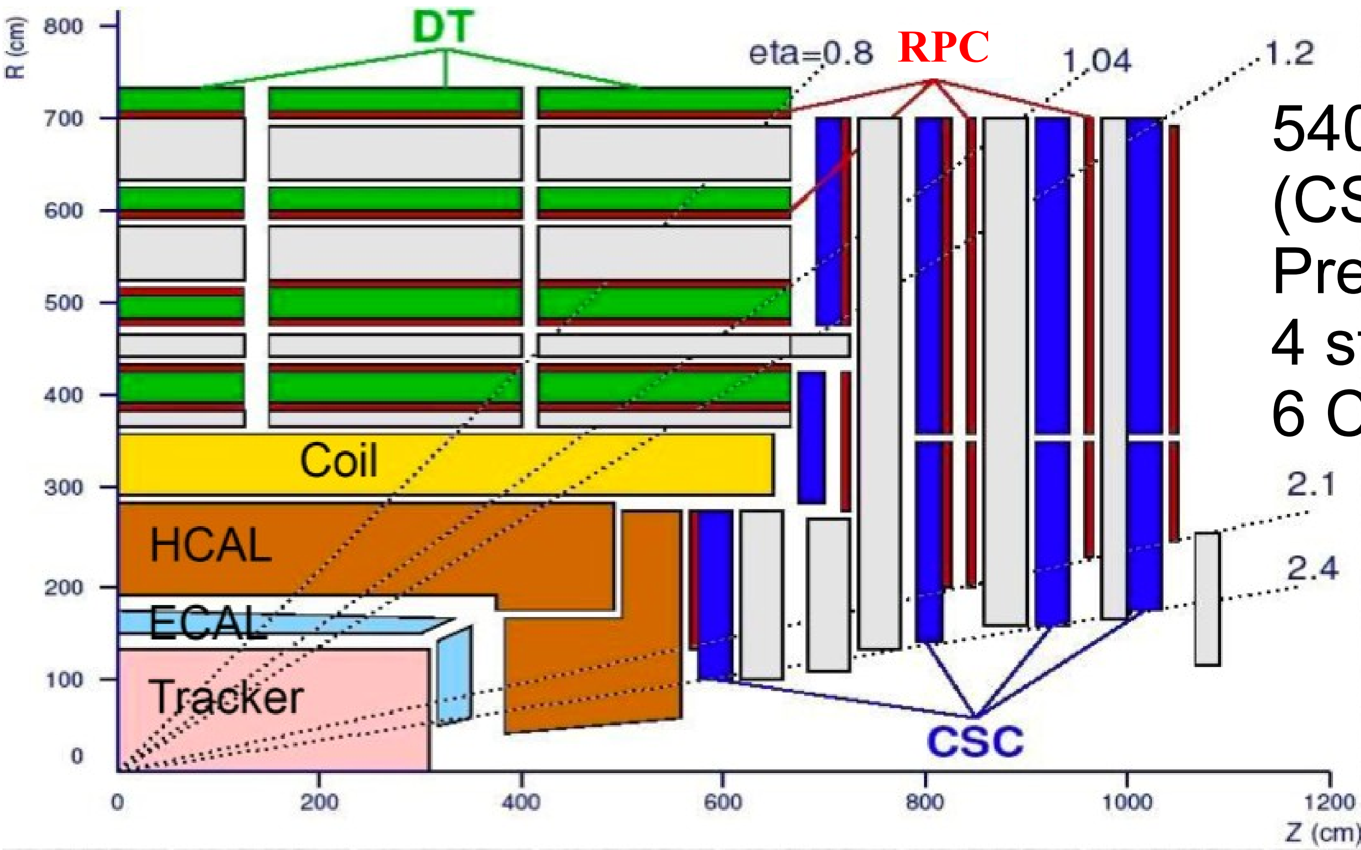
CMS Detector Slice



The CMS Muon System

250 Drift Tube Chambers (DT)
Precise tracking
4 stations in the muon barrel
8-12 DT layers/station

Resistive Plate Chambers (RPC)
Fast response < 10 ns
6 layers in muon barrel
4 layers in muon endcap



540 Cathode Strip Chambers (CSC)
Precise tracking
4 stations in muon endcap
6 CSC layers/station

CMS Muon Reconstruction

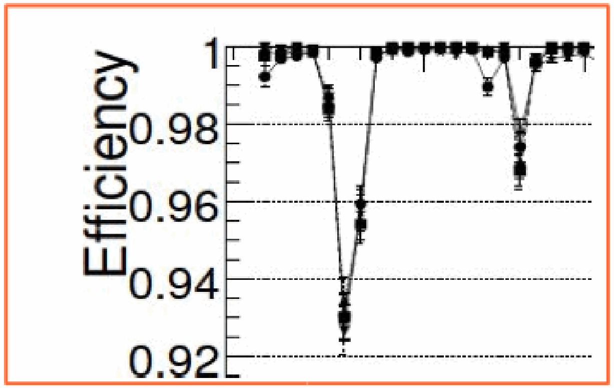
Standard approach: Outside-in

- Local Reconstruction
  Combine hits in muon chambers into segments (2-d projections and then 3-d segments)

- Standalone muon reconstruction
  Build muon seeds from segments in DT,CSC, RPC hits
  Backward Kalman filter to innermost muon station, followed by fit with vertex constraint

- Global muon reconstruction
  Extrapolate back to tracker surface
  Look for compatible tracks in region of interest
  Perform global fit, select final candidates based on χ^2

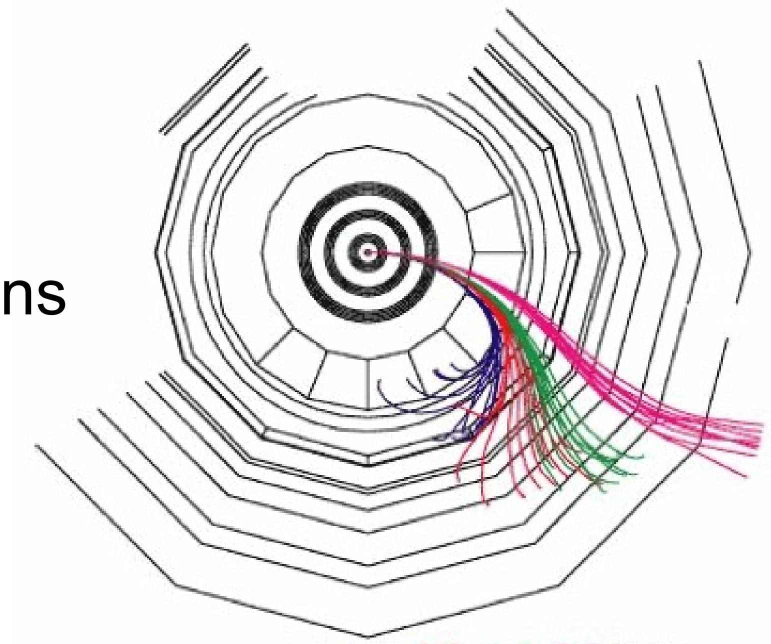
CMS Muon Reconstruction



Alternative approach: Inside-out

- Extrapolate every track outward
- Find compatible deposits in ECAL,HCAL,HO, muon hits
- Determine muon “compatibility”

Recover muon inefficiencies at muon chamber boundaries and low p_T (e.g. muons which only reach the first muon station)



Systematic Uncertainties

Relative Errors (in %)

Source	$\Delta\phi$ Bin 1	$\Delta\phi$ Bin 2	$\Delta\phi$ Bin 3	$\Delta\phi$ Bin 4	$\Delta\phi$ Bin 5	$\Delta\phi$ Bin 6	$\Delta\phi$ Bin 7	$\Delta\phi$ Bin 8
	Relative Error (in %)							
cascade decay rate	1.1	0.7	1.2	1.	0.4	1.2	0.7	1.
bottom hadron rate								
$J/\psi L_{xy}$	4.8	2.6	4.1	2.6	2.6	0.9	1.8	0.7
μ IP	3.7	2.9	0.6	1.5	1.8	2.2	1.9	2.6
PDF shape								
J/ψ invariant mass	0.7	0.4	0.4	0.1	0.1	0.2	0.2	0.1
$J/\psi L_{xy}$	2.8	1.9	0.3	1.1	0.9	0.7	0.4	0.7
μ IP	7.6	4.4	5.	4.5	3.3	3.6	2.8	3.
Fit Bias	0.7	0.5	1.4	0.3	0.3	0.1	0.1	0.2
Unfolding Bias	1.1	0.02	0.2	5.8	3.1	2.4	0.3	1.2
$B_c \to J/\psi\mu X$	3.5	1.5	-	-	-	-	-	-
Trigger/Muon Efficiency	5.	5.	5.	5.	5.	5.	5.	5.
Tracking Efficiency	9.	9.	9.	9.	9.	9.	9.	9.
MC Statistics	3.2	3.4	3.6	3.5	2.9	2.1	1.7	1.3
J/ψ Polarization	4.3	4.3	4.2	4.3	4.3	4.3	4.2	4.3
Misalignment	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Luminosity	10	10	10	10	10	10	10	10
Total	18.9	16.8	17.0	17.6	16.4	16.2	15.7	15.8