Muon Selection at low Pt: An user case Example

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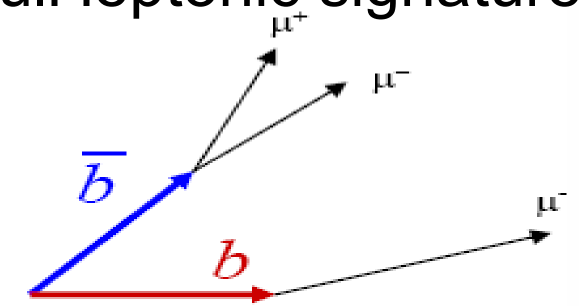
Outline

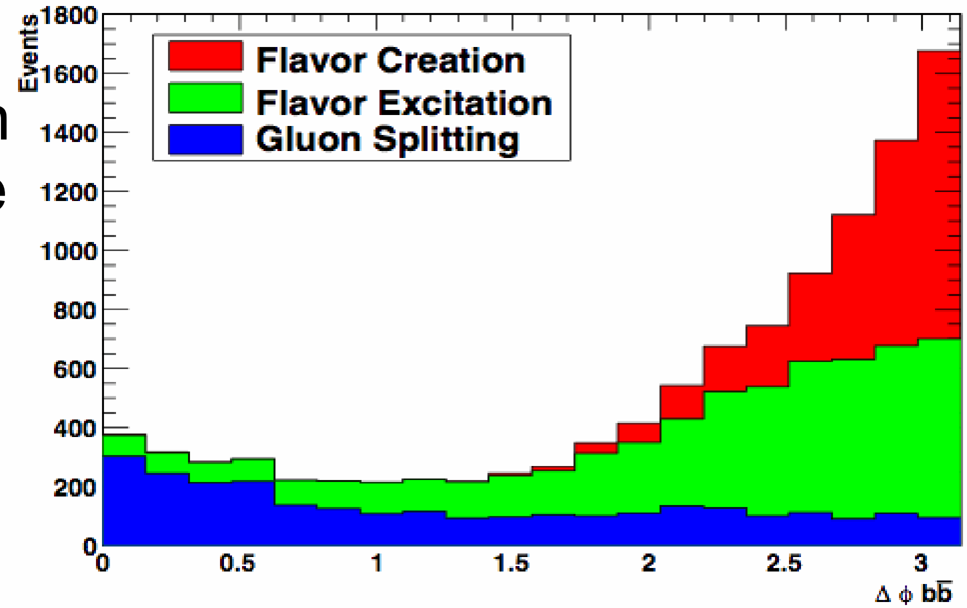
- Brief Analysis Overview
- Monte Carlo Samples
- Muon selection: optimization
- Conclusions

Analysis Overview

- **Strategy**

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





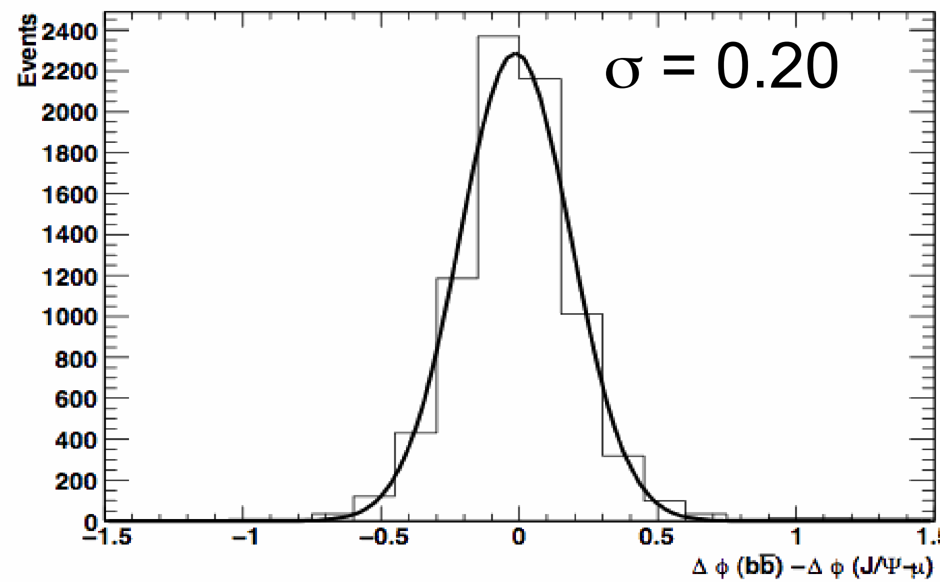
- **Event reconstruction**

  Tag $b\bar{b}$ events by reconstructing $b\bar{b} \rightarrow (J/\Psi X)(\mu X')$, $J/\Psi \rightarrow \mu\mu$

- **Commissioning with early data (first O(10) pb)**

  Help μ reco, trigger eff, tracker alignment

  Complementary to charmonium inclusive study for lifetime/IP fits



Monte Carlo Samples

Summer 2008 Production

- Inclusive $b \to J/\Psi X$, $J/\Psi \to \mu\mu$ analyzed with CMMSW_2_1_12
- EvtGen with inclusive $b \to J/\Psi X$, $J/\Psi \to \mu\mu$
- Filter on 2 μ with p_T>2.5 GeV/c, $|\eta|$<2.5

σ_{gen} = 51.56 mb (@10TeV),
BF($b \to J/\Psi X$) = 0.0116,
BF($J/\Psi \to \mu\mu$) 0.0593
σ=3.547 · 10^7 pb

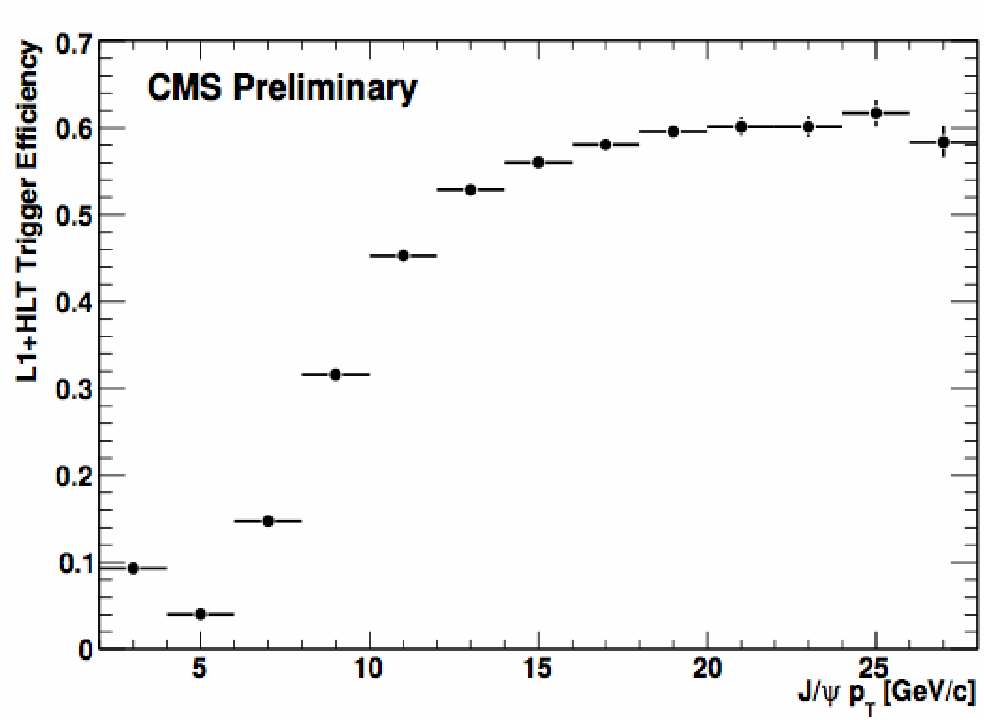
Process	MC sample	# of events	Filter Eff.	σ (pb)	$\int \mathcal{L} dt$ (pb^{-1})
$b \to J/\psi X$	/BtoJpsiMuMu/Summer08_IDEAL_V9_v2/GEN-SIM-RECO	2434076	6.44E-4	35467000.	106.6
$pp \to \mu X$	/InclusivePPmuX/Summer08_IDEAL_V9_v4/GEN-SIM-RECO	5232662	0.002305	51.56E9	0.044
$pp \to J/\psi X$	/JPsi/Summer08_IDEAL_V9_v1/GEN-SIM-RECO	1847135	0.0074	0.2861E9	14.7

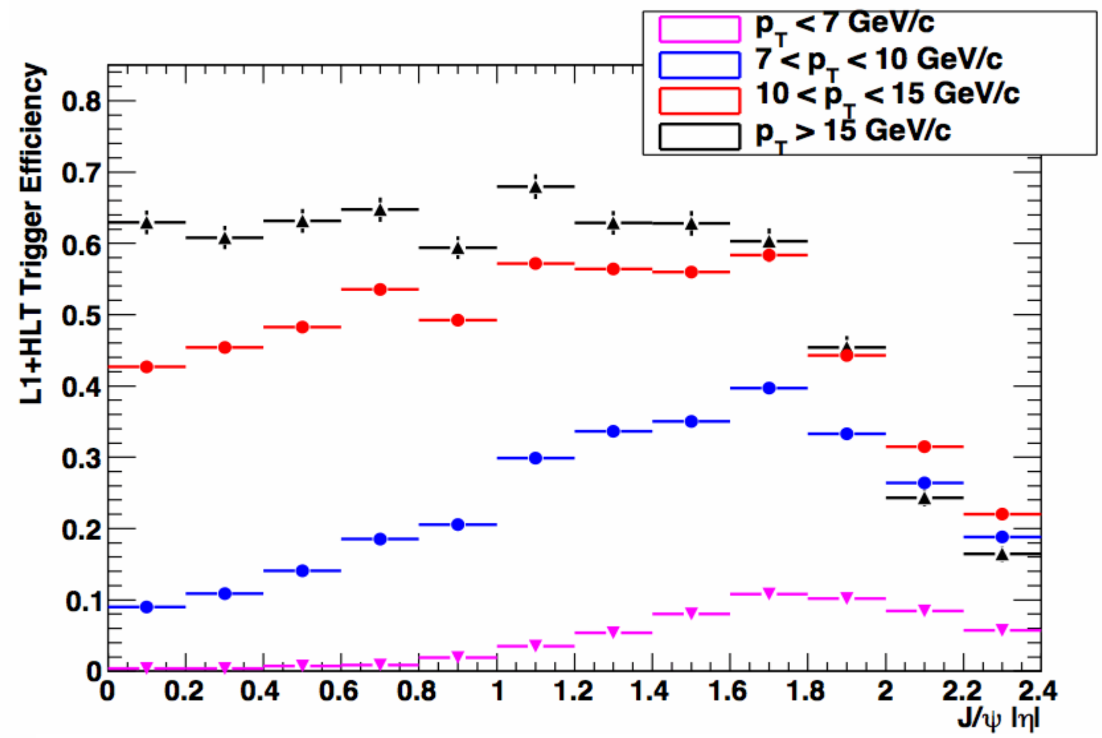
- Prompt J/Ψ: small contribution due to 3 lepton in final state
- Inclusive $pp \to \mu X$: background cross-check and correct treatment of decay-in-flight

Trigger Efficiency

- Due to clean signature of final state, loose mu trigger selection
- Require HLT_DoubleMu3

$$\epsilon_{J/\psi}(p_T,\eta,\phi,\Delta\phi) = \frac{N_{J/\psi}(p_T^{J/\psi},\eta_{J/\psi},\phi_{J/\psi},\Delta\phi_{J/\psi-\mu})}{N_{J/\psi}^{gen+filter}((p_T^{J/\psi},\eta_{J/\psi},\phi_{J/\psi},\Delta\phi_{J/\psi-\mu})}$$





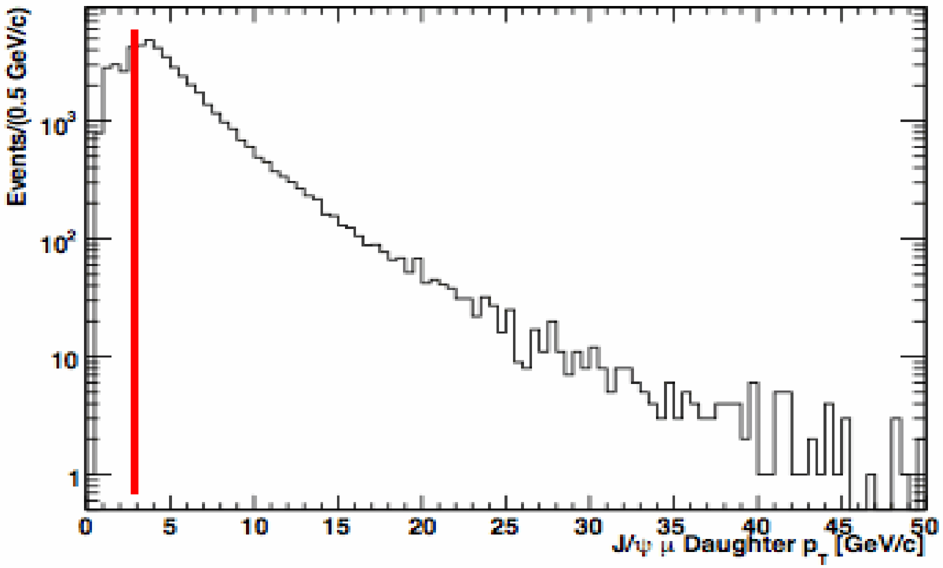
- HLT_DoubleMu3 unprescaled up to Lumi=10E32

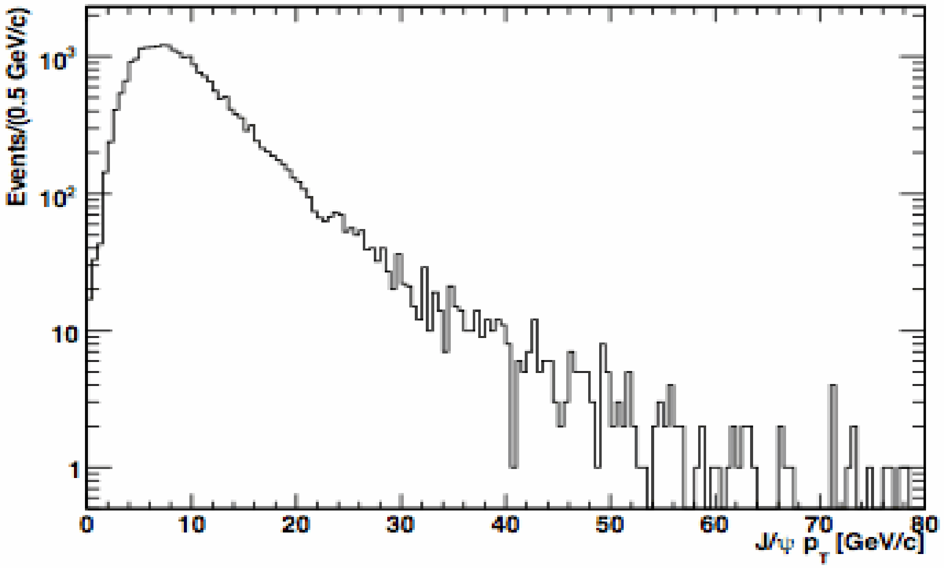
Event Reconstruction

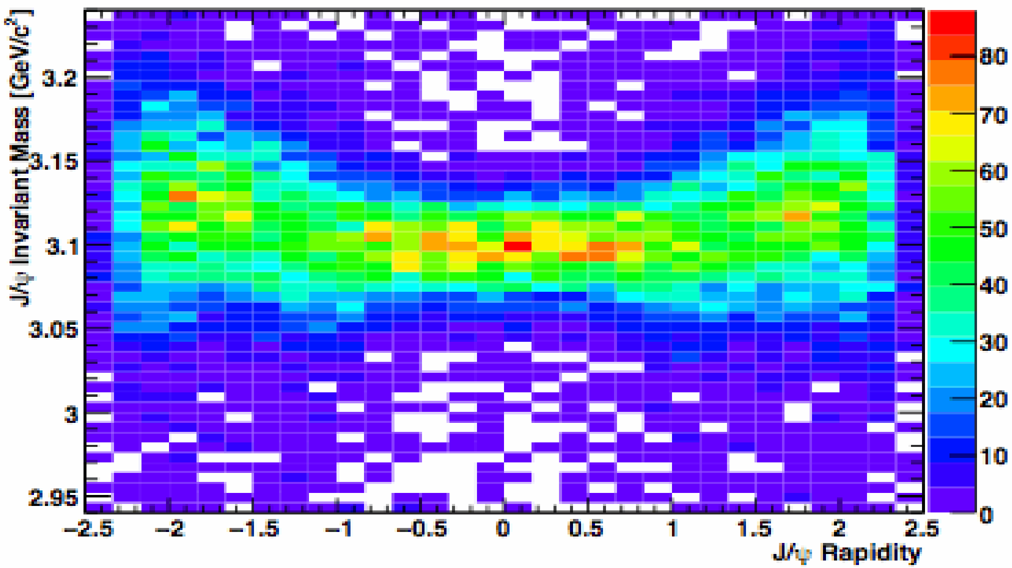
- KalmanVertexFitter on μμ pairs, best J/Ψ from vertex quality
  - $2.75 < m_{J/\Psi} < 3.45$ GeV/c^2
  - μ daughters $p_T > 3$ GeV/c, $|\eta|<2.4$
- Look for (additional) highest p_T μ from B SL (or cascade) decay
  - μ: $p_T > 3$ GeV/c, $|\eta|<2.4$
- Detailed study of global vs tracker muon
  - 40% efficiency gain if using 3 tracker vs 3 global muons, but decrease in purity

Relative Efficiencies w.r.t. HLT_Mu3				
	ϵ_{reco}(%)	Truth J/ψ(%)	Truth soft μ (%)	Purity
3 global μ	1.07	1.06	0.90	0.84
2 tracker +1 global μ	1.48	1.44	1.17	0.79
3 tracker μ	3.82	3.74	1.35	0.35
Relative Efficiencies w.r.t. HLT_DoubleMu3				
	ϵ_{reco}(%)	Truth J/ψ(%)	Truth soft μ (%)	Purity
3 global μ	2.73	2.72	2.35	0.86
2 tracker +1 global μ	3.34	3.26	2.78	0.83
3 tracker μ	7.54	7.42	3.11	0.41

J/Ψ→μμ Distributions

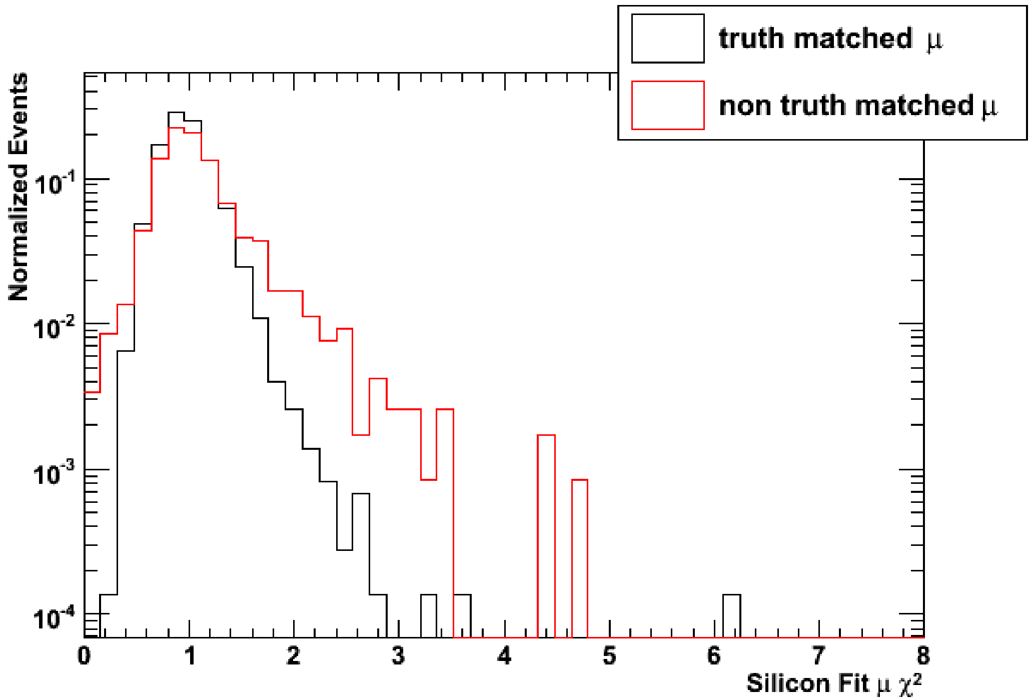


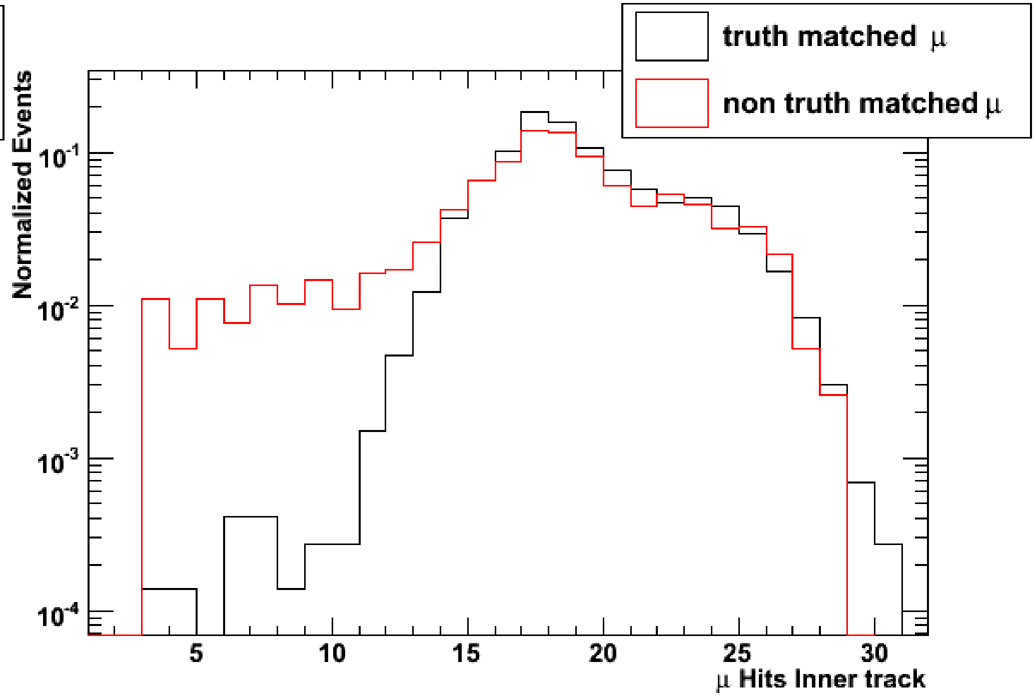




SL Muon Selection

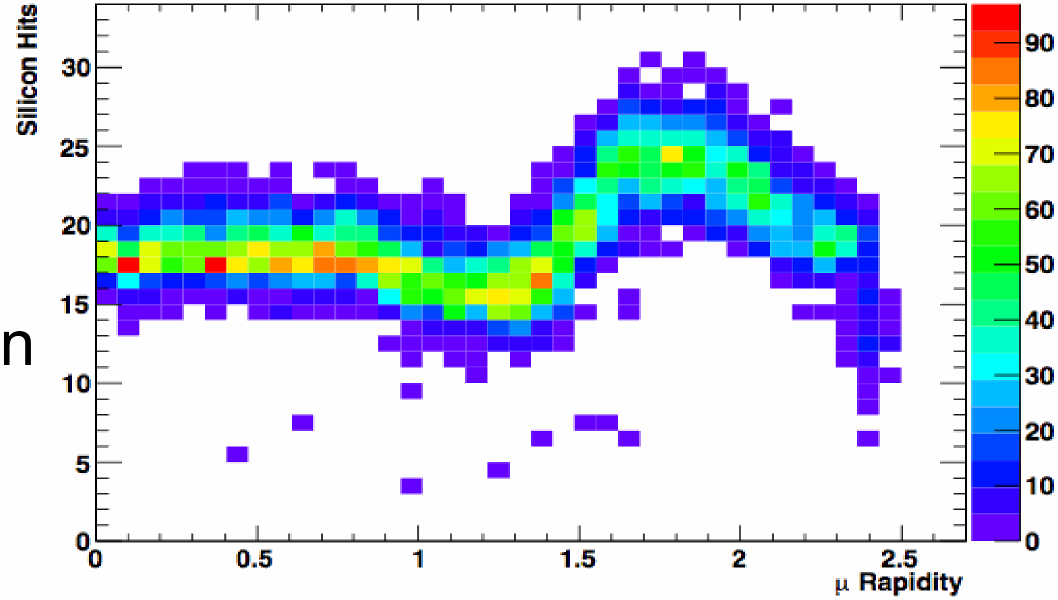
- Additional cuts optimized to maximize significance:
  - Signal is defined as 3 reconstructed muons truth-matched
    - Truth-Matching by-hand using ΔR (ΔR_{truth}<0.02)
    - Require one and only one generator-reco matching
  - Background is defined as truth-matched J/Ψ and not truth-matched third muon (punch-through/DIF)

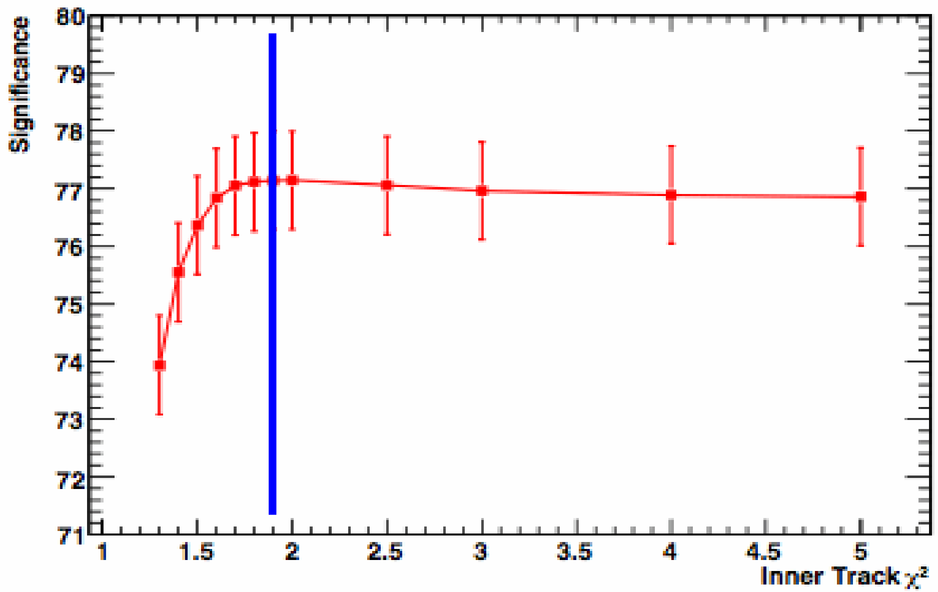


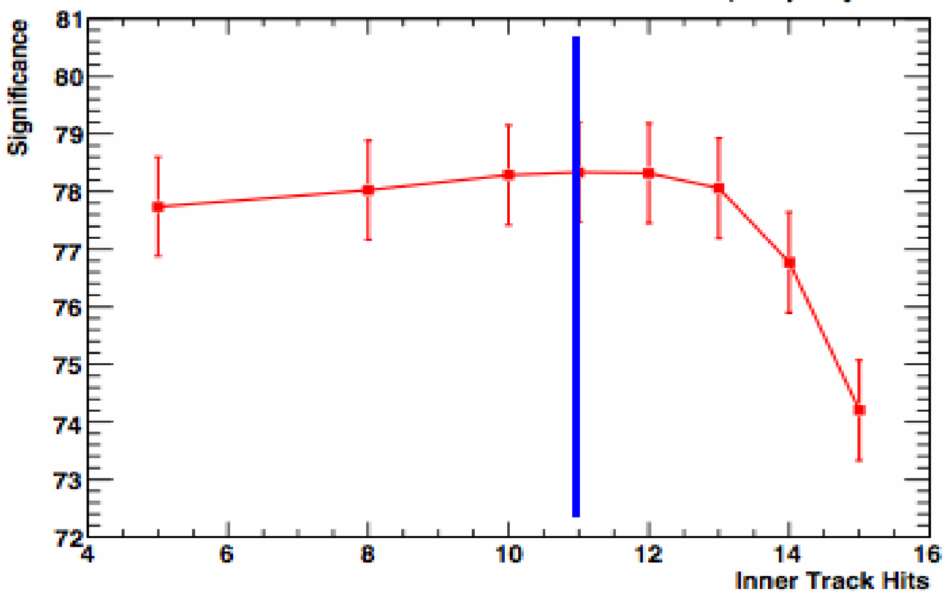


SL Muon Selection

- Track Quality Cuts:
  - $\mu\ \chi^2$ silicon fit < 1.9
  - μ inner hits > 11
- Also tried a separate optimization for the inner track hits in the two regions $|\eta|<1.479$ ($>=1.479$)

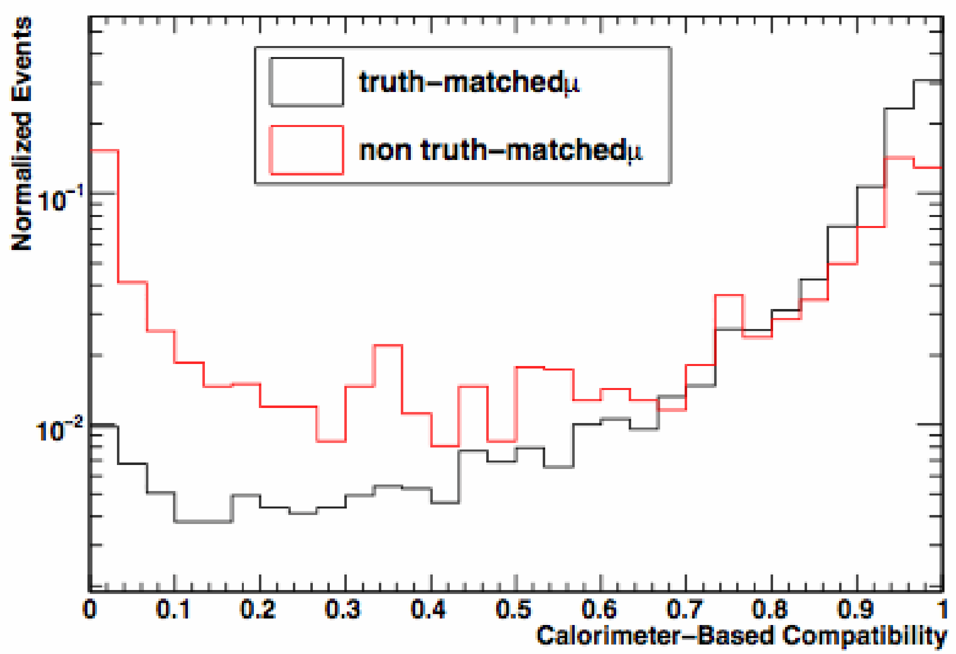


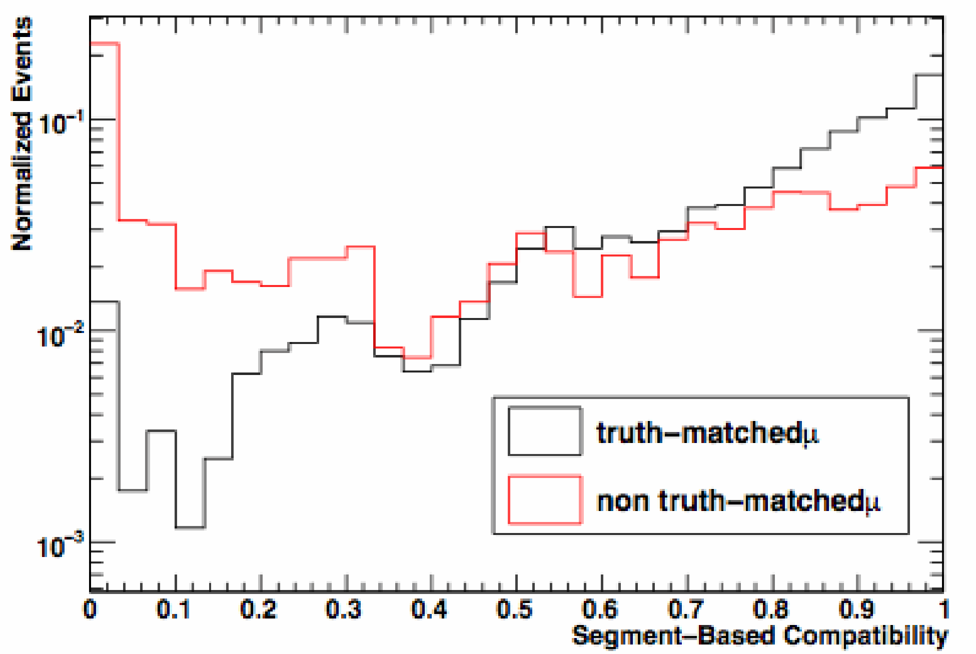




SL Muon Selection

Additional selection criteria on third tracker muon (look at reco::muon methods):





SL Muon Selection

Additional selection criteria on third tracker muon
(look at reco::muon methods):

Arbitration

TM2DCompatibilityLoose (combined segment-calo log-compatibility)

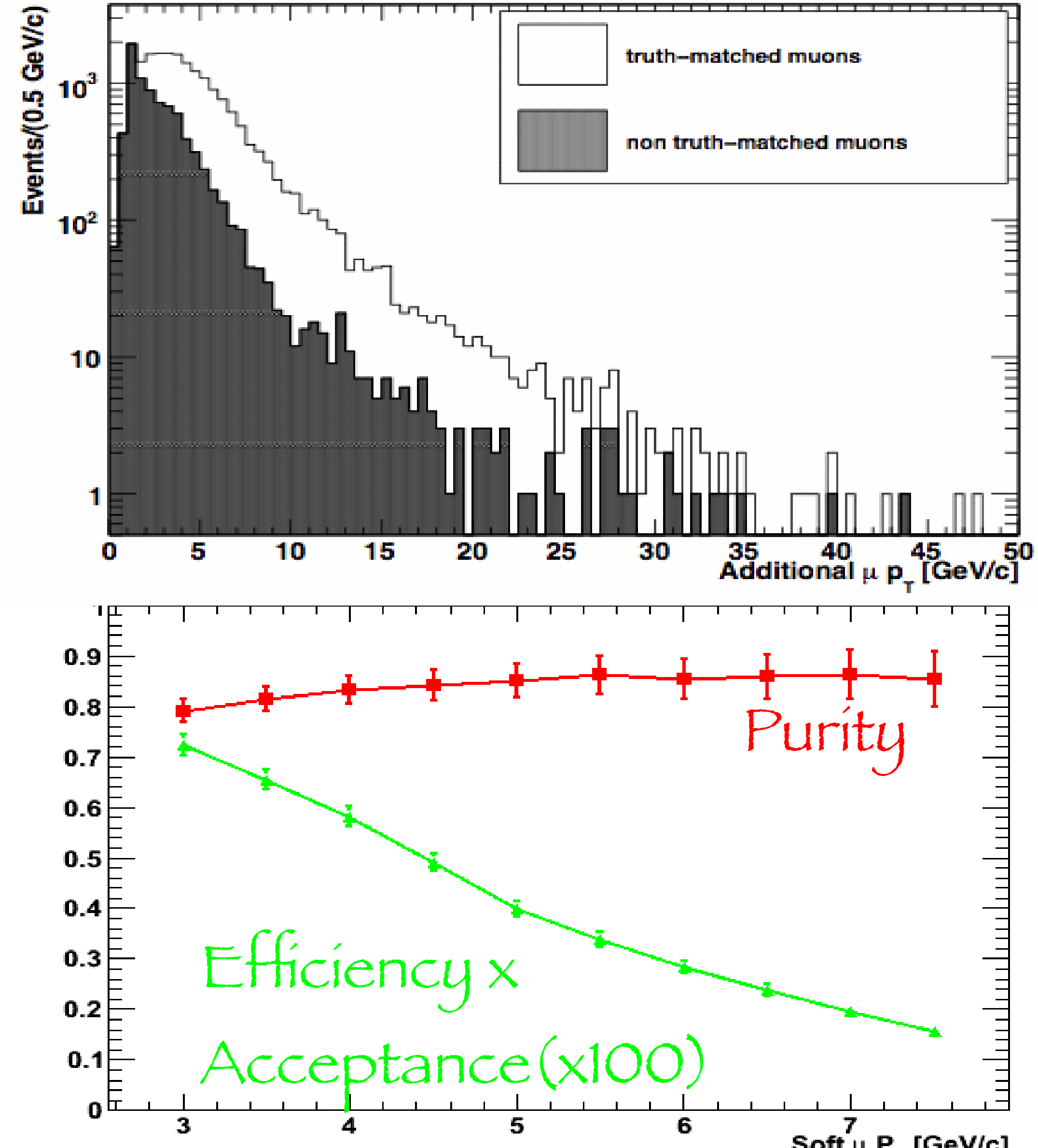
OneStationTight (penetration depth in muon stations)

Cut	Relative Efficiency	Purity (%)	Change in Significance (%)
No cut	1.	48.4	-
Arbitration	0.987	75.1	23.7
Last Station - Loose	0.875	89.0	1.9
Last Station - Tight	0.866	89.7	1.1
Calo-Seg compatibility - Loose	0.993	81.7	4.
Calo-Seg compatibility - Tight	0.966	85.7	5.
One Station - Loose	0.993	77.2	1.
One Station - Tight	0.985	82.7	4.
Last Station- low Pt - Loose	0.974	85.2	5.
Last Station- low Pt - Tight	0.963	86.4	5.

Table 5: Effect of the muon algorithms: relative efficiency of the algorithm, purity of the sample and relative variation in the significance. The significance changes for the other flags are computed with respect the sample for which the arbitration algorithm has already been applied.

$b \rightarrow \mu + X$: μ Pt cut

- Background from fake μ concentrated at low Pt
- Efficiency drops quickly with μ Pt cut: choose Pt>3 GeV/c

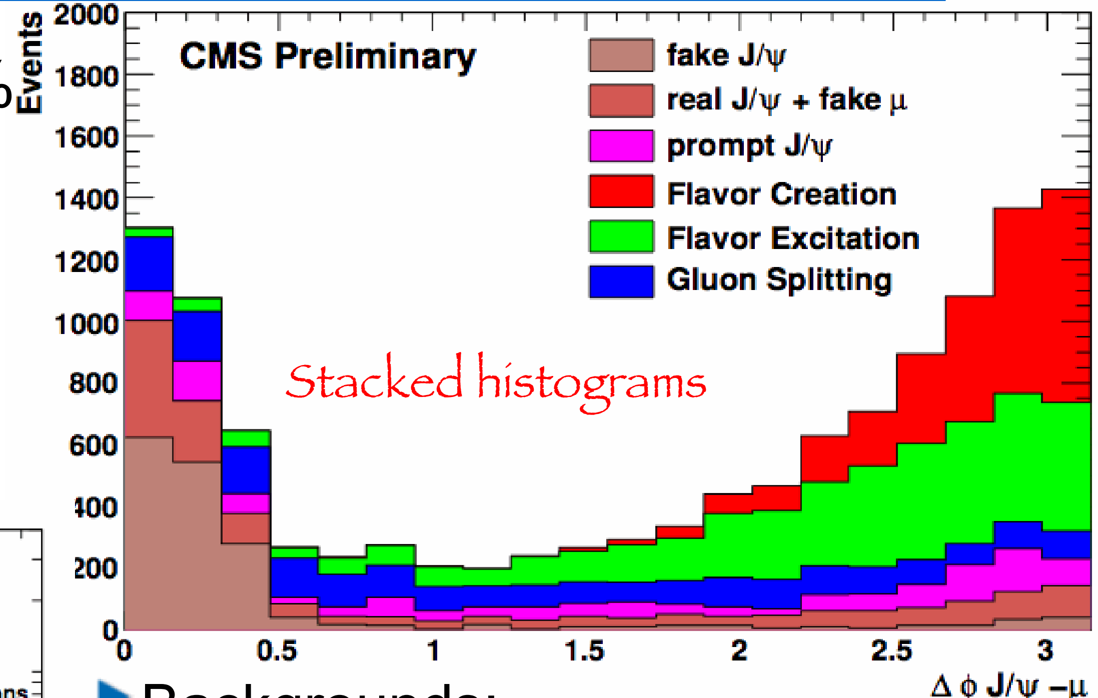


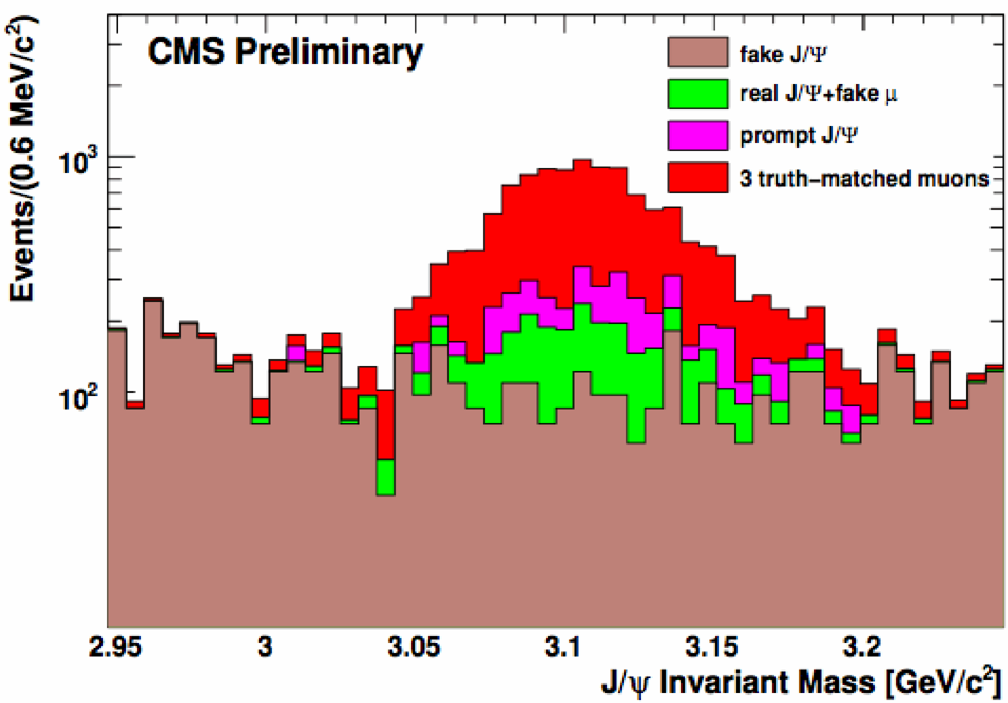
$b \rightarrow J/\Psi + X$ Sample

- Total Selection Efficiency ~1.9% with Purity ~ 85%
- Estimate σ_{eff} ~ 150 pb

2000 evts in $\mathcal{O}$(15 pb^{-1})

8000 evts in $\mathcal{O}$(60 pb^{-1})

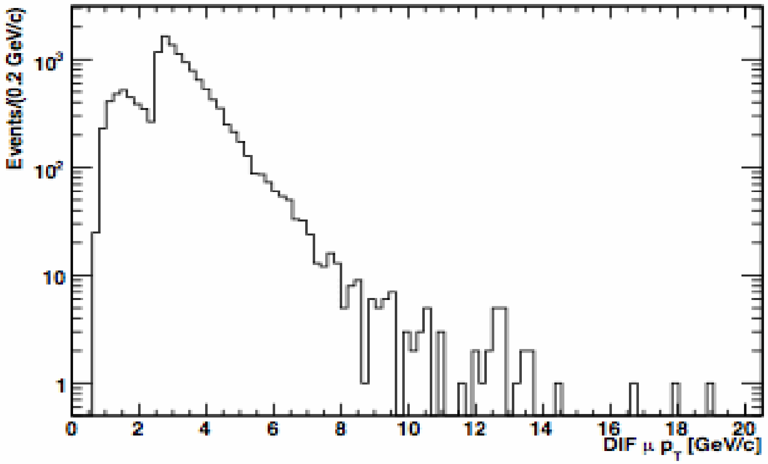


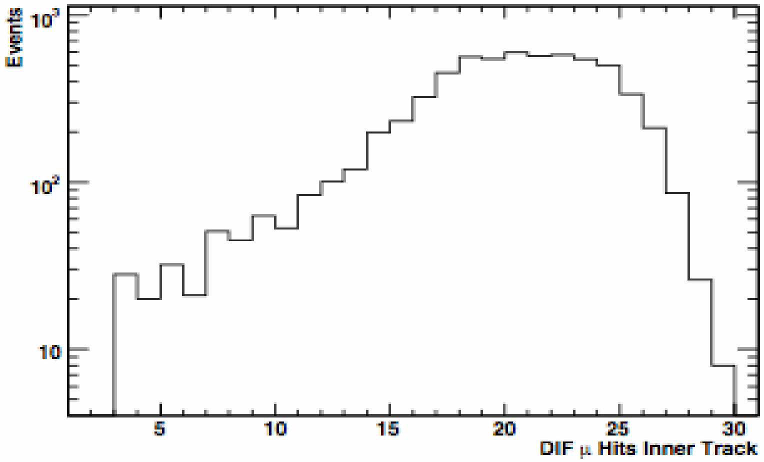


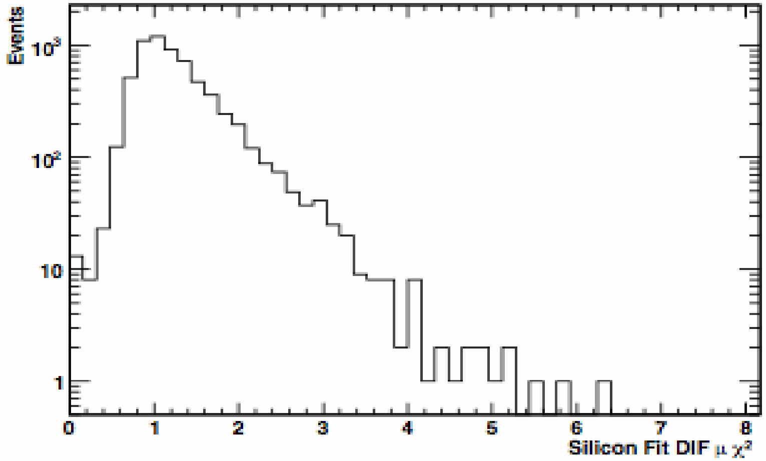
- Backgrounds:
  - Misassigned muons (brown)
  - Fake muons (hadronic punch-through/DIF), dominating at low p_T (orange)
    - DIF background underestimated in inclusive J/ΨX sample due to known muon filter problem

Decay-in-Flight muons

- We use the Inclusive pp → μX sample
  /InclusivePPmuX/Summer08_IDEAL_V9_v2/GEN-SIM-RECO
  to characterize the background from DIF muons

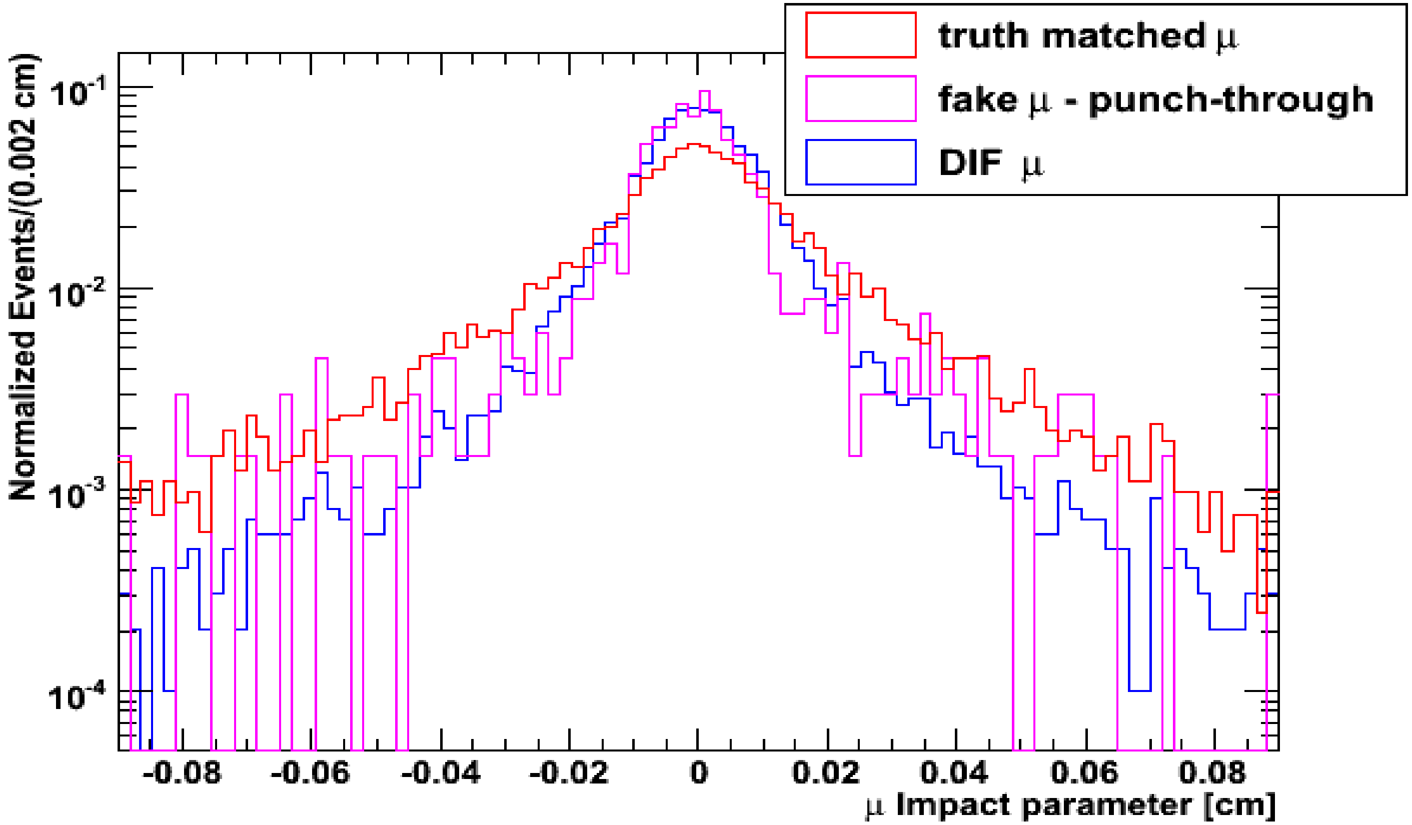






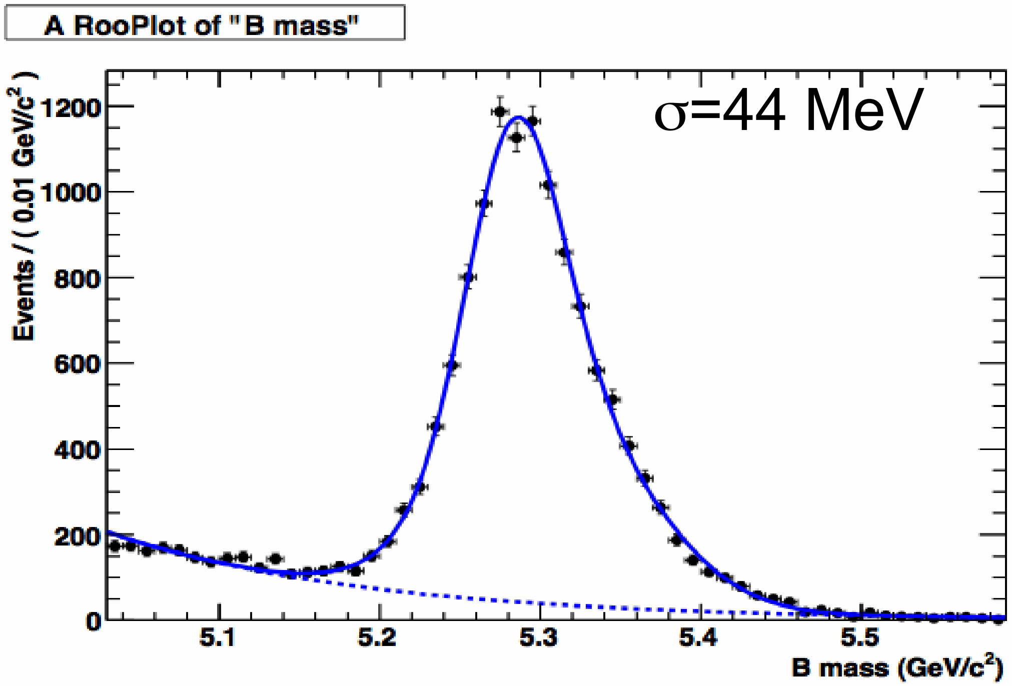
Decay-in-Flight muons

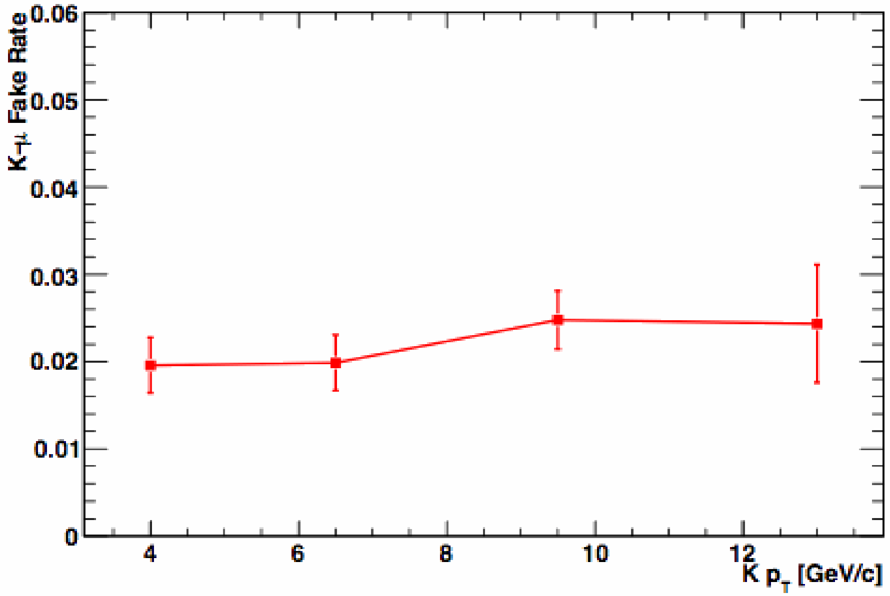
- Background from DIF or hadronic punch-through can be further reduced by tighter cuts, however in this analysis the fake μ background can be directly estimated in the fit to the μ impact parameter



$B \to J/\Psi K$ Control Sample

- Can use $B \to J/\Psi K$ control sample to cross-check J/Ψ reconstruction efficiency and K fake rate
- Start from $J/\Psi X$ sample, vertex J/Ψ+track combinations and choose the one with highest probability
- Expect about 11000 signal events in 100 pb
- It would also be possible to use $D^0(K\pi)\mu X$





Conclusions

- Use of tracker muons and standard reco::muon objects gives a reasonable clean sample of muons at low pT
  - Penetration depth cuts very promising to remove bkg from punch-through but need to be careful on the efficiency
  - Combined calo-muon segment likelihood can be further optimized (analysis-dependent)
- Looking forward to comments/suggestions!!

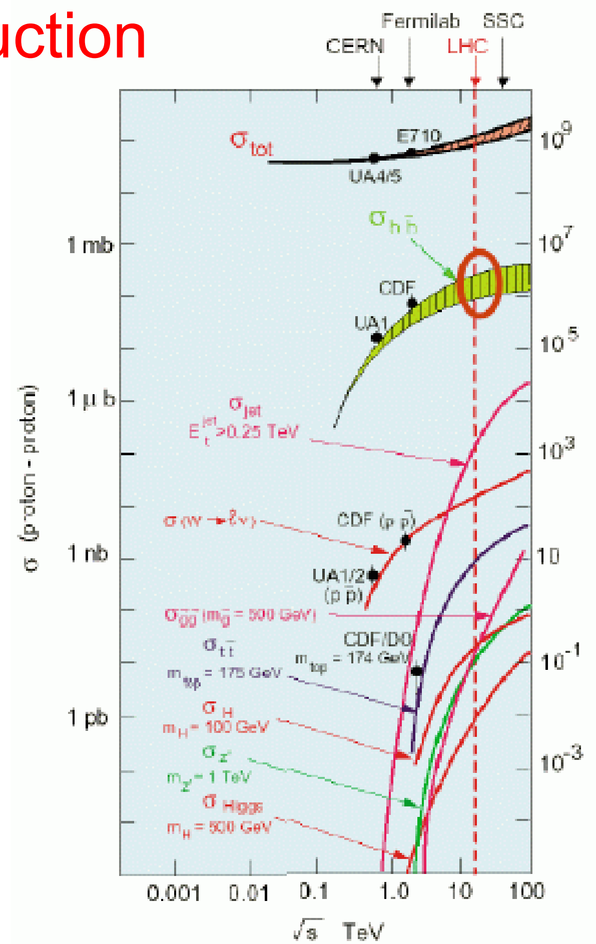
Backup Slides

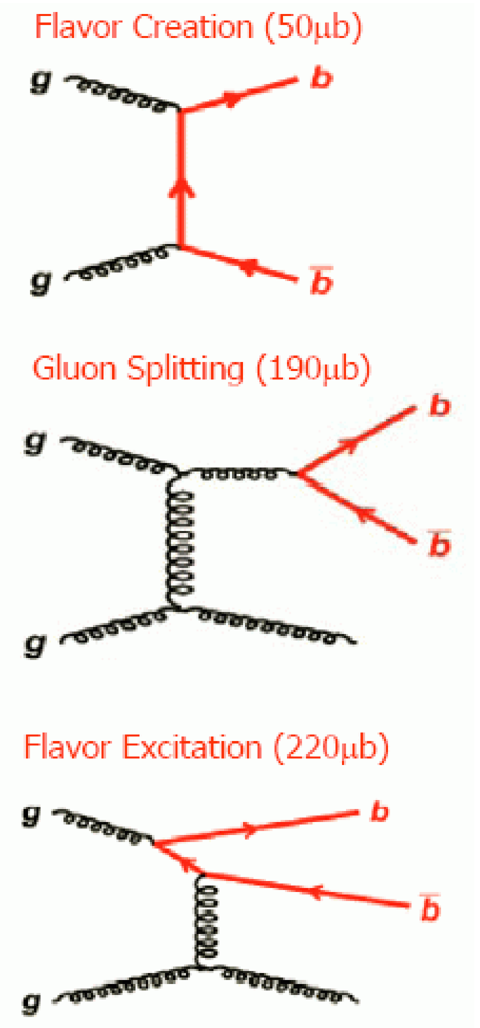
Motivations

- b quarks are a key ingredient at LHC
  Top physics, low mass Higgs, SUSY....

- Measurements of b-quark production and $b\bar{b}$ correlations in hadronic collisions test QCD
- Investigate production mechanisms with early data:

- Correlated $b\bar{b}$ production sensitive to LO and NLO production mechanism

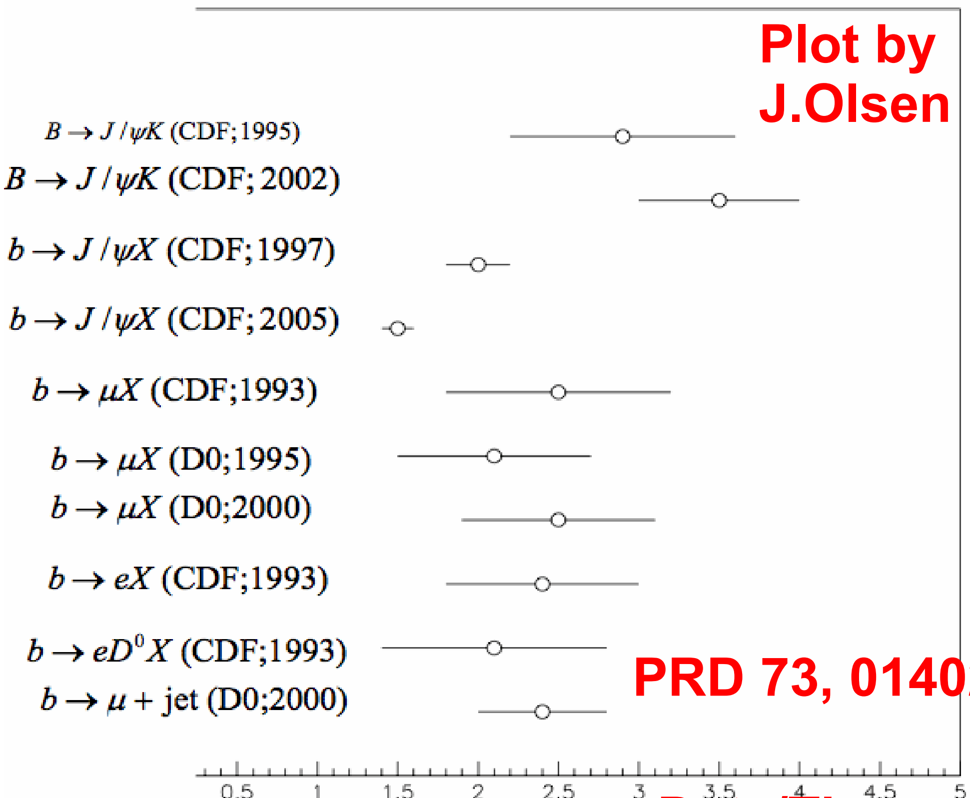


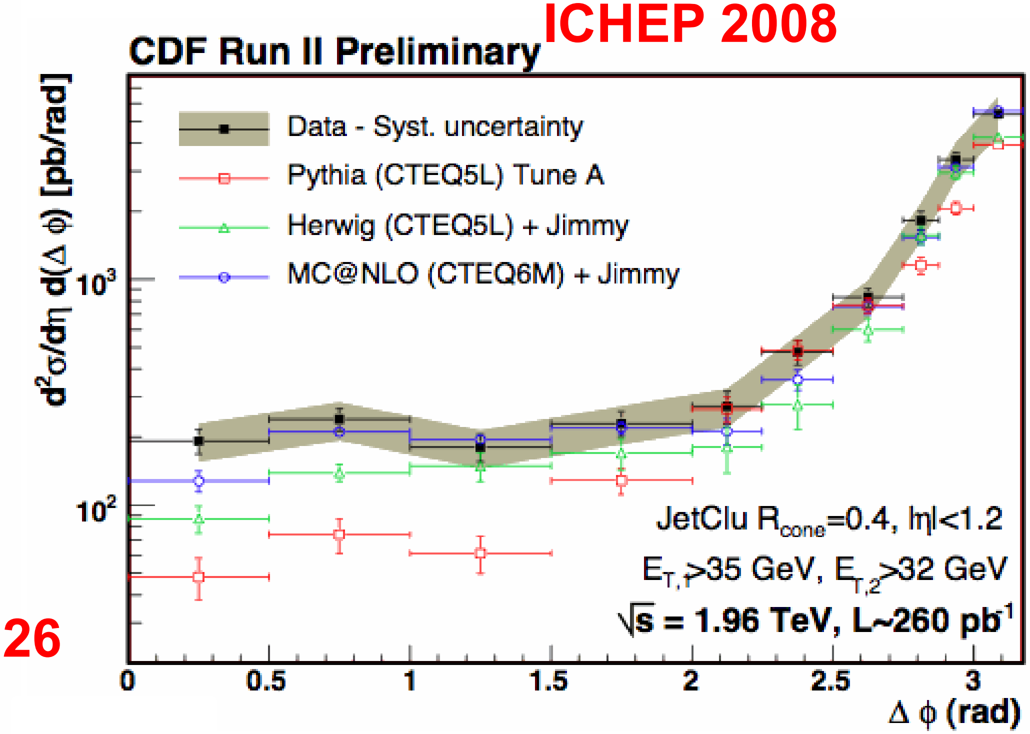


B Production at the Tevatron

- Studied since the first data in late 80s

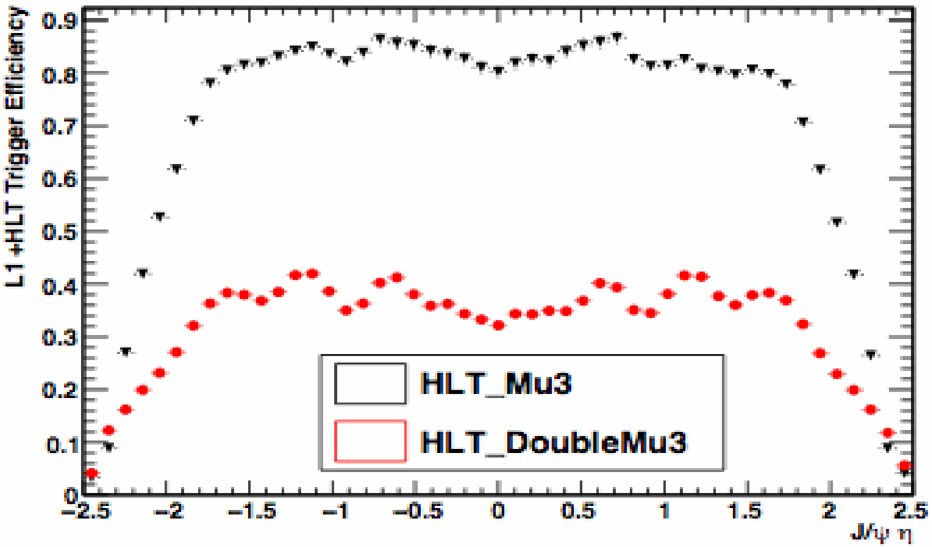
  Consistent cross-section excess in single b and $b\bar{b}$ correlation measurements

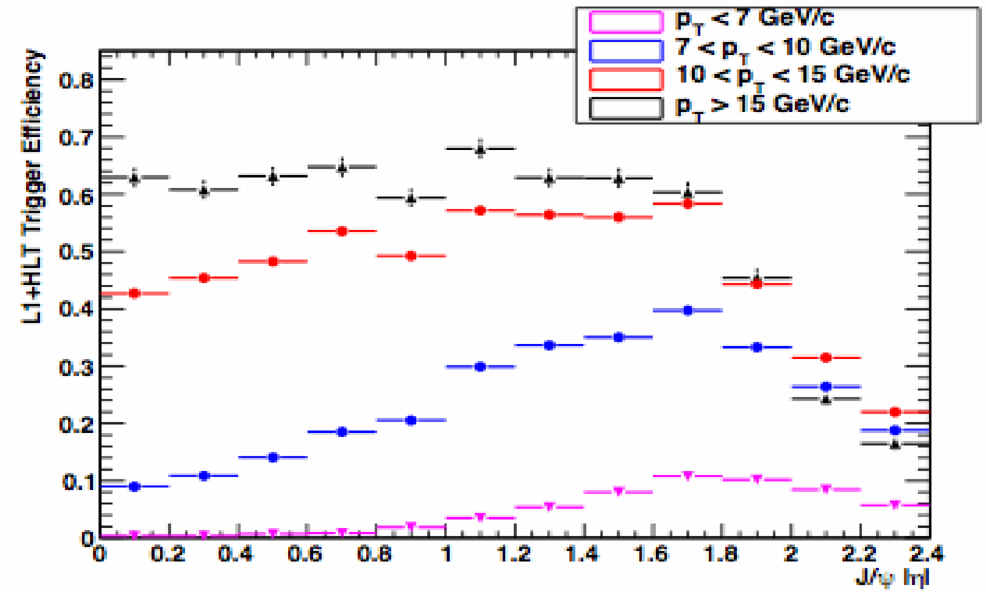


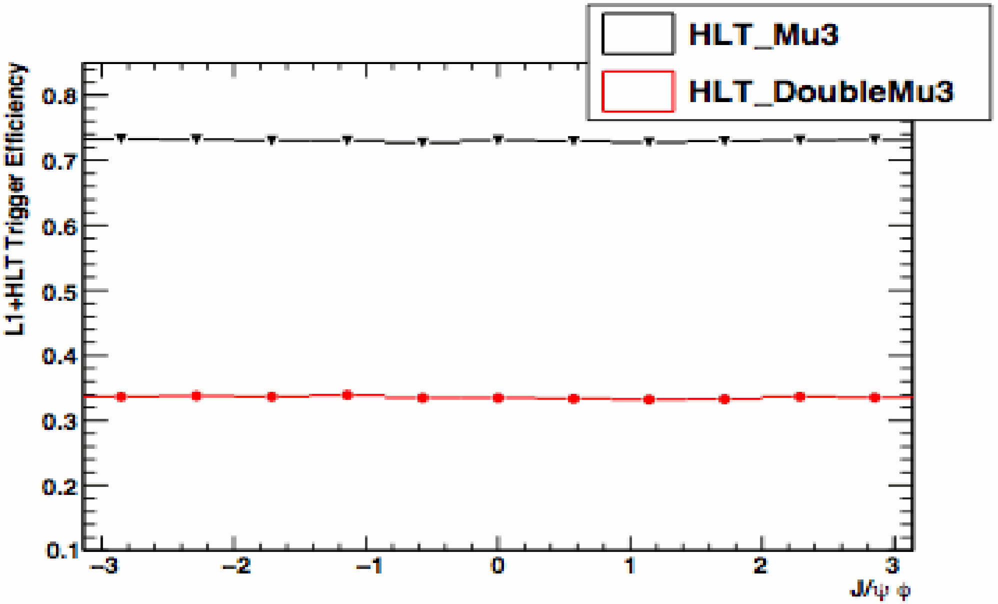


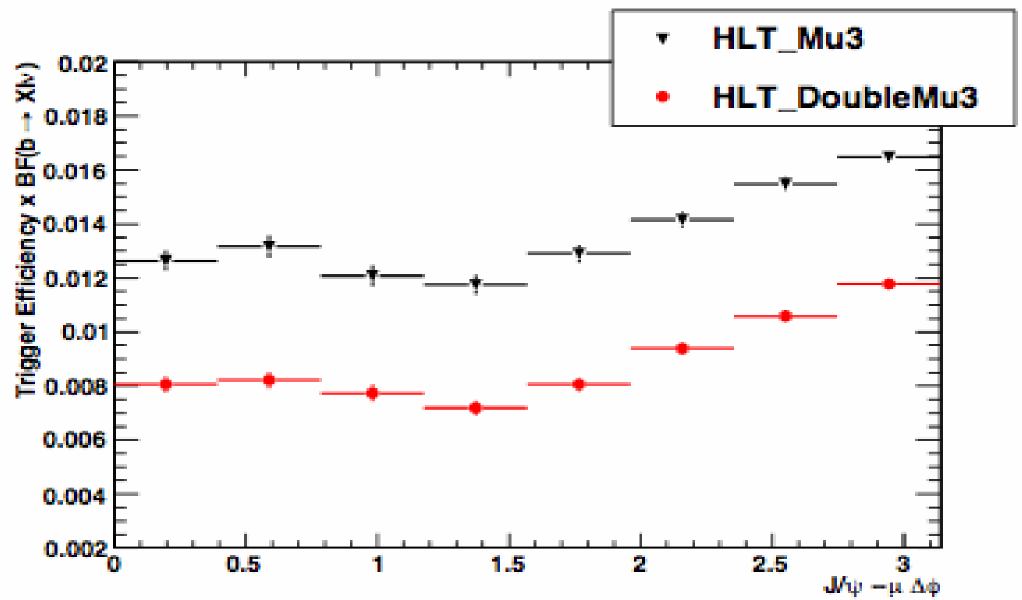
- New data from LHC will hopefully cast new light on this puzzle

Trigger Efficiency

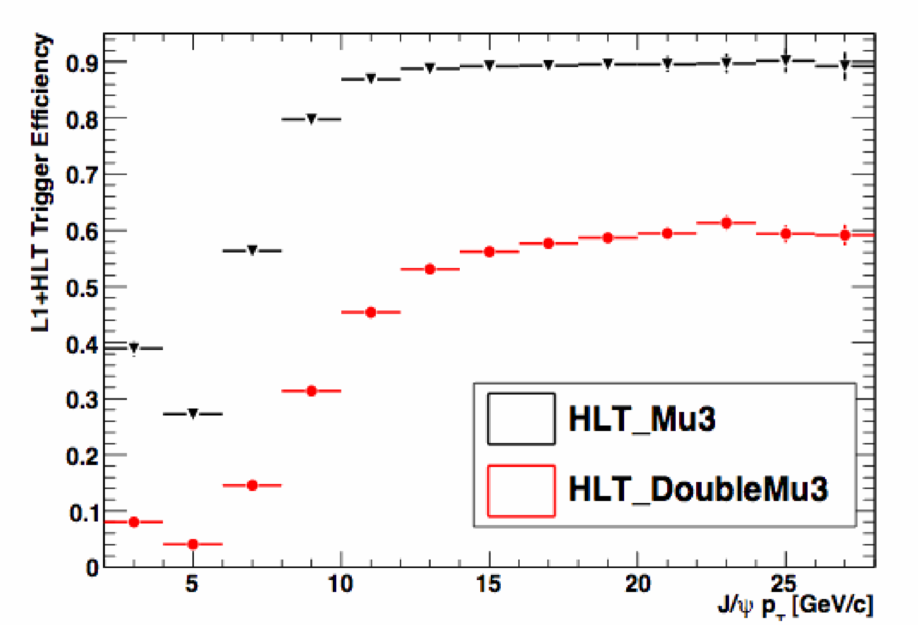


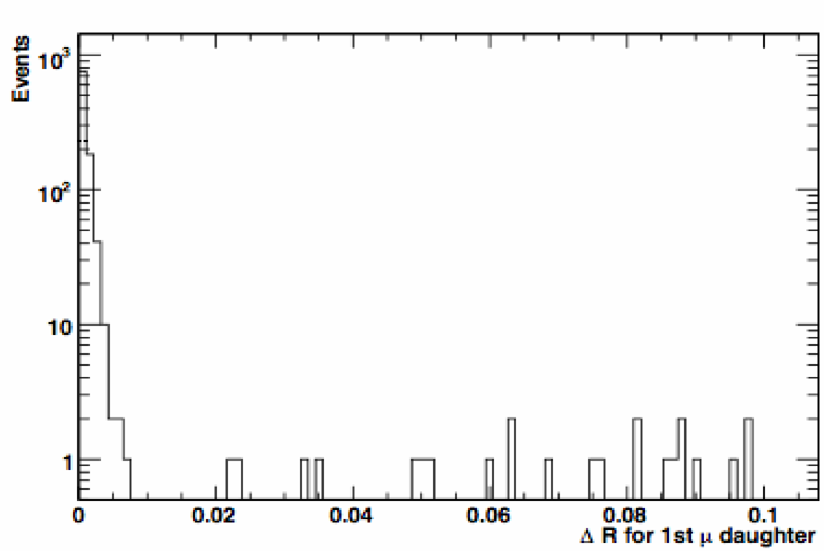


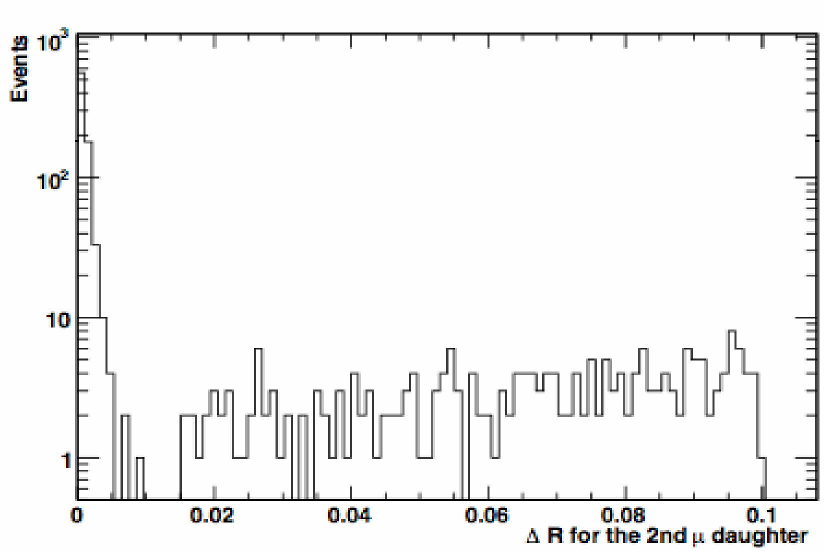




Trigger Efficiency







Samples analyzed:

- Inclusive pp → μX sample

  /InclusivePPmuX/Summer08_IDEAL_V9_v4/GEN-SIM-RECO

Correct number of decays in flight

Generator conditions:

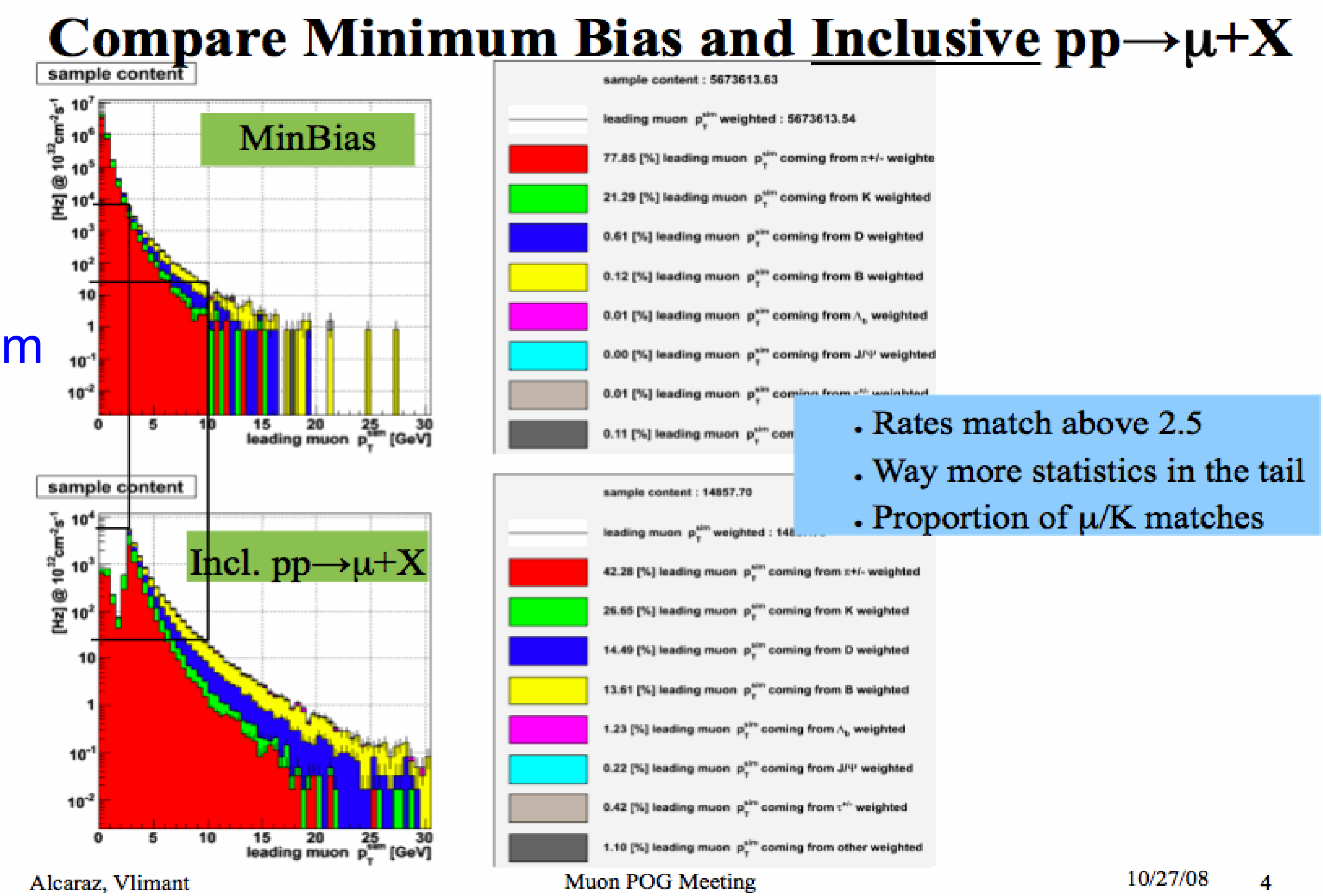
Muons from hadronic decays in r < 1.5 m, |z|<3 m

pt(muon) > 2.5 GeV

at generator level

filter_eff = 0.002305,

σ_{gen} = 51.56 mb



Backgrounds-II

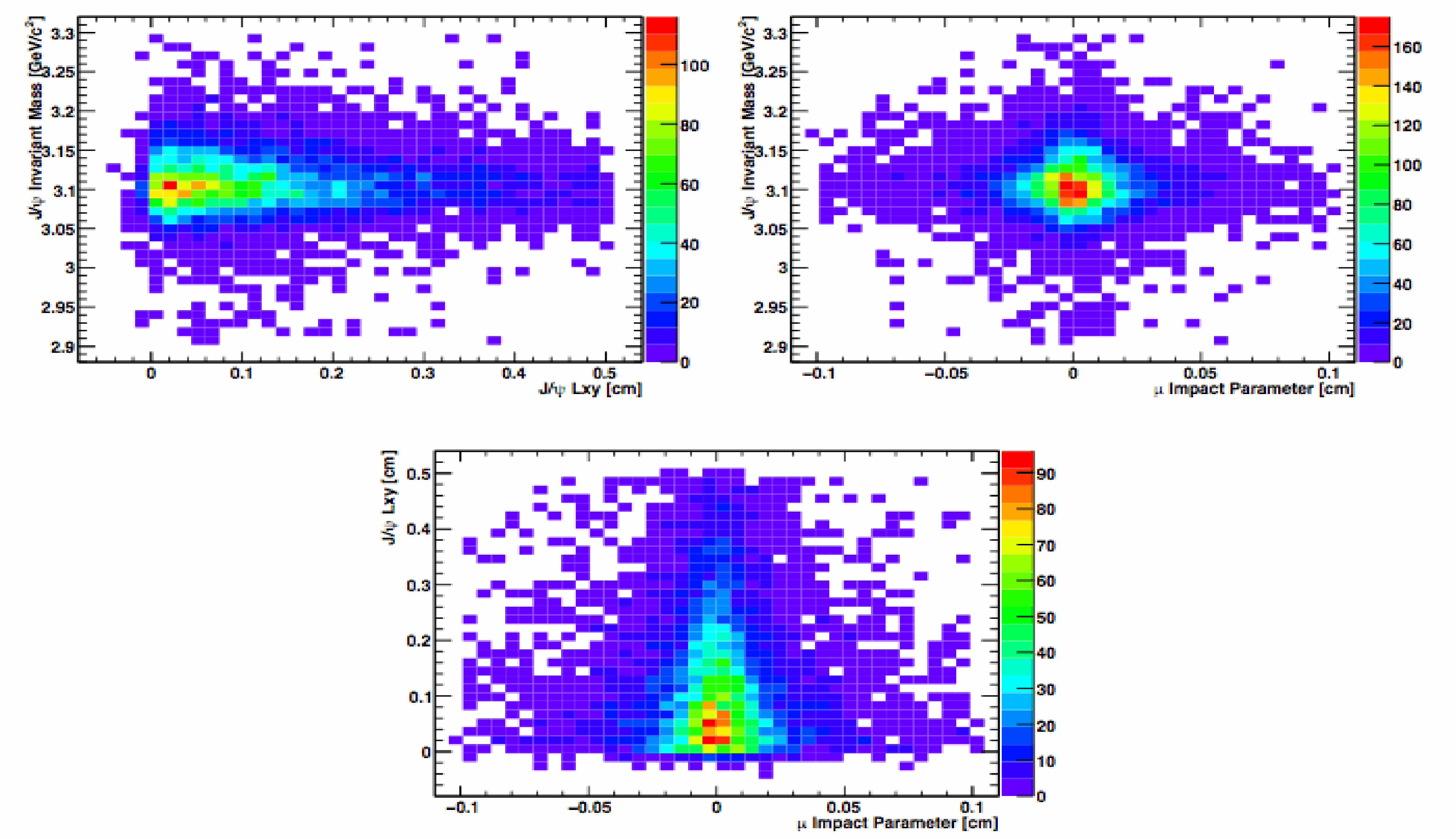
Samples analyzed:

- Inclusive pp → μX sample
  /InclusivePPmuX/Summer08_IDEAL_V9_v2/GEN-SIM-RECO
- $5.2 \cdot 10^6$ events,
  HLT_Mu3 Efficiency: 16.3%
  HLT_DoubleMu3 Efficiency: 0.14%
- After all cuts 29 events in (2.94,3.24) GeV/c^2 J/Ψ mass window
- 3 events from non bb σ_{eff}: ~70 pb
- σ_{eff} for signal (18 events fully truth matched): ~400 pb (!!)
  bb hadronization through pythia, large differences w.r.t. EvtGen for Decay branching fractions
- 1 event with truth-mached J/Ψ and fake μ, 1 event with truth-mached J/Ψ and DIF μ from π decay

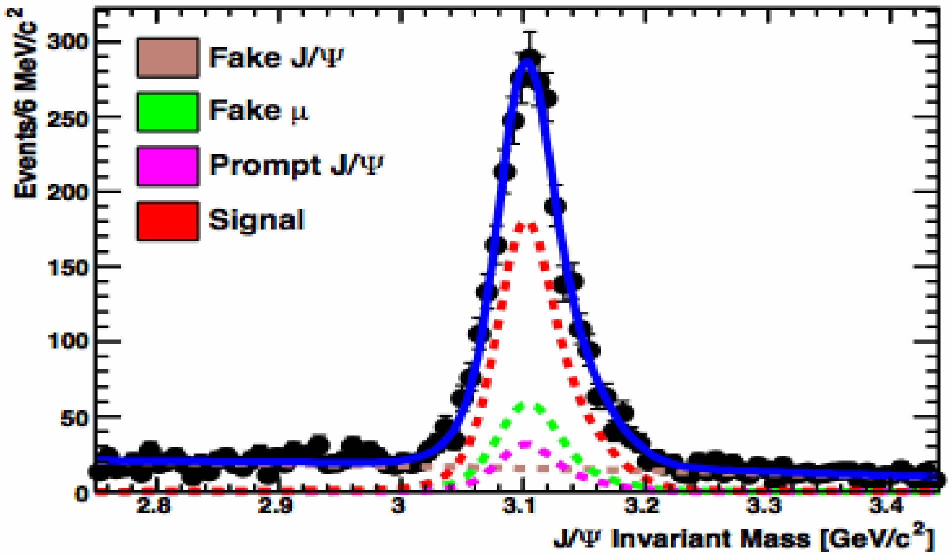
Signal Extraction

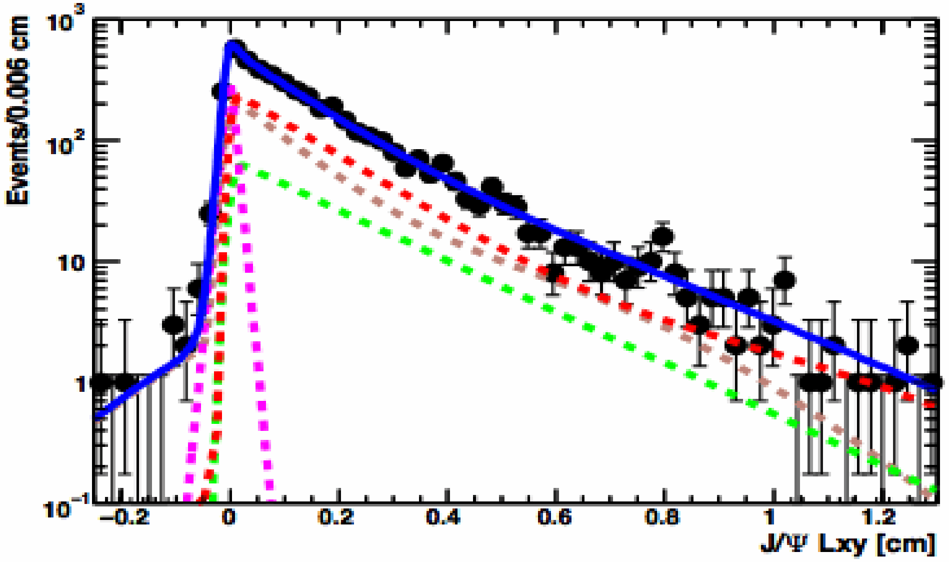
- Extract signal in several $\Delta\phi$ bins by simultaneous unbinned maximum LH fit to J/Ψ invariant mass, L_{xy} transverse flight length, soft μ IP
  - 4 components: signal, real J/Ψ+ fake μ, prompt J/Ψ, and fake J/Ψ
- Build PDF shapes using one half of MC, fixed in the final fit
  PDF Shapes:
  - Triple Gaussian for J/Ψ invariant mass
  - Single(double) tail exponential convoluted with 2 Gaussians for J/Ψ L_{xy} (μ IP)
  - Use error/event for gaussian resolution
  - L_{xy} computed w.r.t. primary vertex, L_{xy} error for now only include J/Ψ vtx contribution
- Non-parametric PDF for fake J/Ψ L_{xy} (Replace with single tail exponential convoluted with 2 Gaussian)
- Validate Fit by fitting independent MC sample

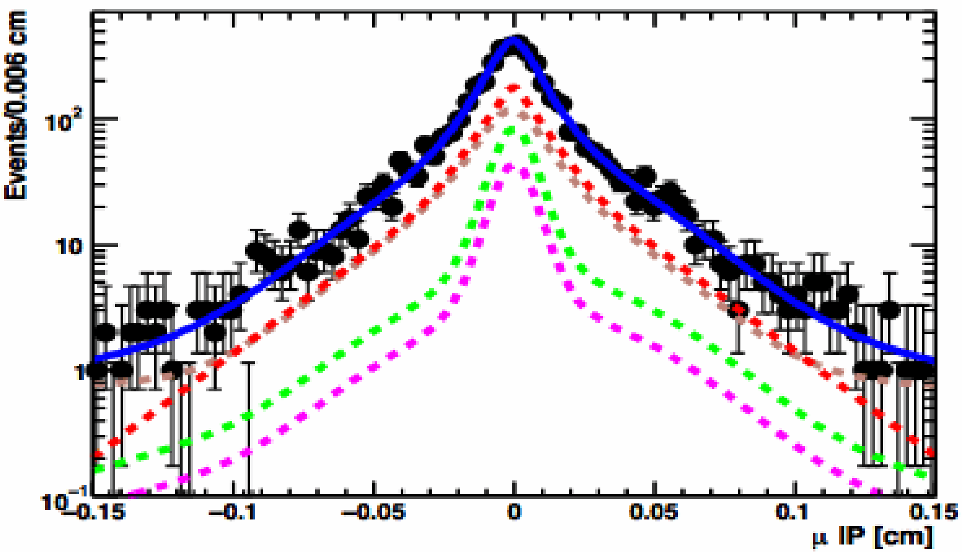
2D-Distributions: Signal



Fit Validation







Integrated luminosity ~ 13 pb
Using "realistic" bkg estimates

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

Systematic Uncertainties

- Systematic Uncertainties under consideration:
  - Impact parameter shape for direct bottom lepton and cascade decays $b \to c \to$ lepton: consider relative rate variation
  - Transverse flight length and impact parameter for different bottom hadrons: consider lifetime and relative rate variation
  - PDF shape: ensemble of fits in which each PDF parameter is varied within its Gaussian uncertainty
  - Fit bias: use toy results, cross-check with full sim
  - Unfolding: use toy bias as systematic uncertainty
  - J/Ψ polarization and residual misalignment: use approved inclusive Charmonium systematics
  - Trigger and Muon Efficiency: use Tag and Probe approach
  - Tracking Efficiency: assume 3%/track
  - $B_c \to J/\Psi \mu X$ background: concentrated at $\Delta\phi \sim 0$
  - Luminosity: could in principle measure rate w.r.t. $\Delta\phi$ peak at π

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
$B_c \rightarrow J/\psi\mu X$	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