

Measurement of B_c differential cross-section and lifetime

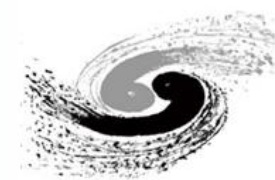
Xianyou Wang, Guoming Chen, Xiangwei Meng, Zhenxia Zhang

Institute of theoretical physics, CQU, CQ
Institute of High Energy Physics, CAS, Beijing

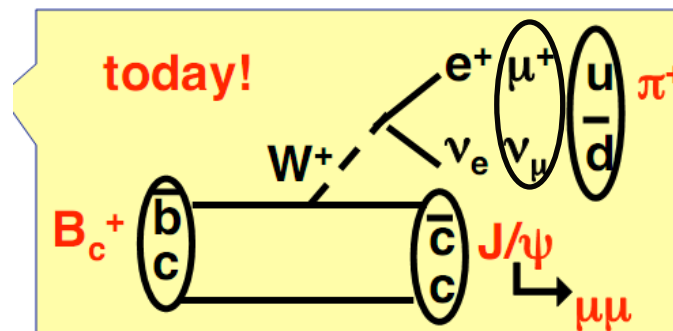


- Motivation
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- Event generation
- Theoretical cross-section parameters
- New approach (estimate the cross-section of B_c)
- Analysis strategy
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- Latest analysis result
- Next steps...

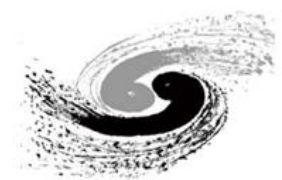
Motivation



- Measure the differential cross-section of $B_c \rightarrow J/\psi \mu \nu$ and $B_c \rightarrow J/\psi \pi$ in 100 pb^{-1} .
- Test the theory-predictions:
- B_c production in hadron collider: many theoretical uncertainties!
- $\sigma(B_c) \sim 10^{-3} \sigma(\text{other B-mesons})$ [E.g: Chang&Wu, EPJC38,267]
- B_c mass
- Potential: $6.2\text{-}6.4 \text{ GeV}/c^2$
- pQCD: $6326^{+29}_{-9} \text{ MeV}/c^2$
- Lattice QCD: $6278(6)(4) \text{ MeV}/c^2$
- PDG'08: $6276 \pm 4 \text{ MeV}/c^2$
- Measure the mass and life time through $B_c \rightarrow J/\psi \pi$.

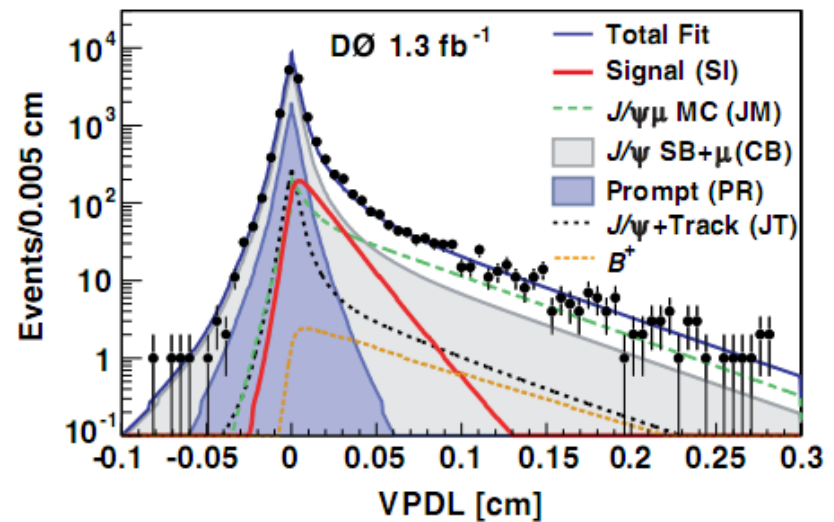
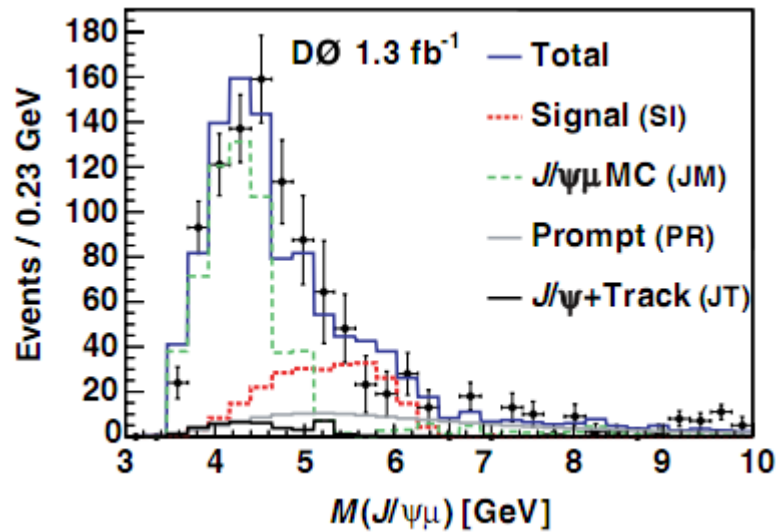
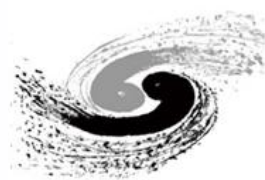


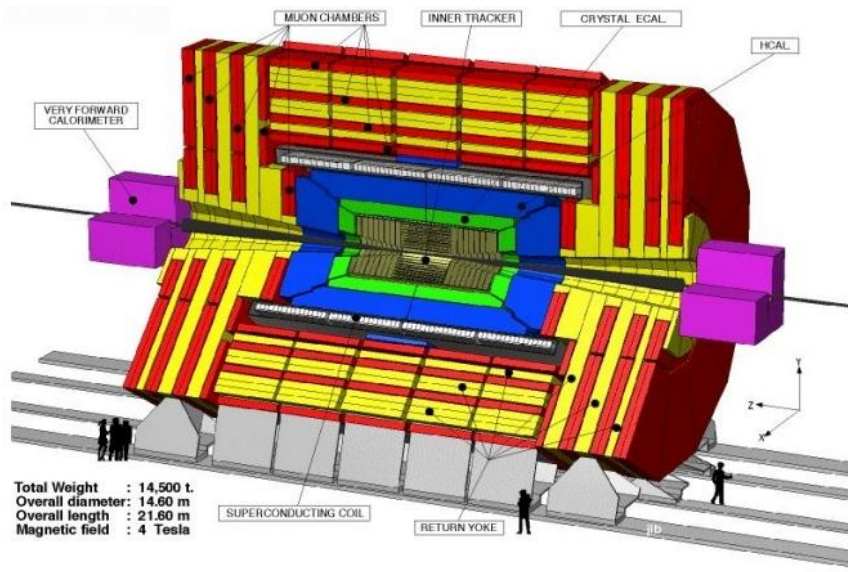
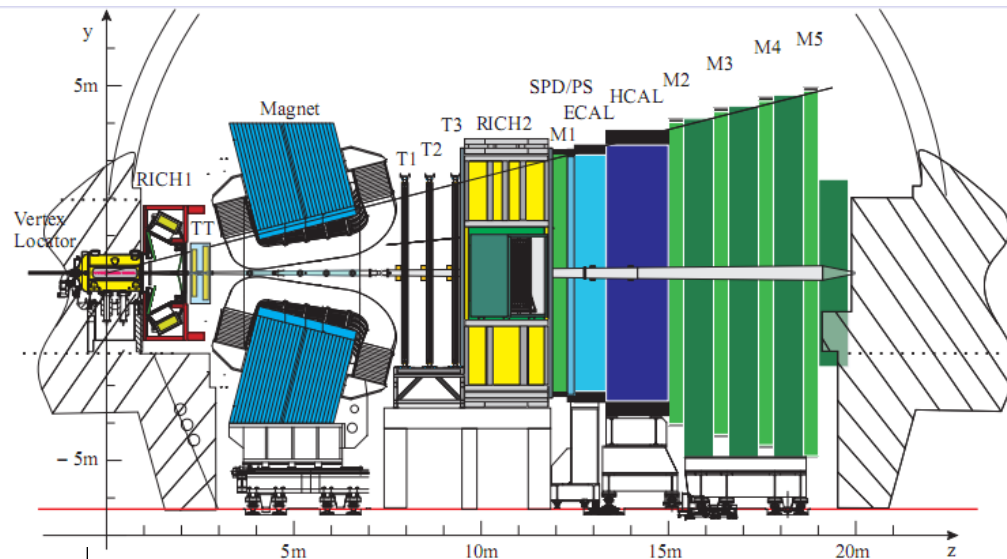
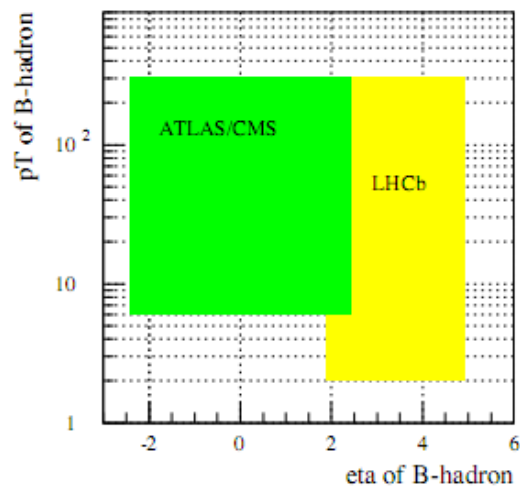
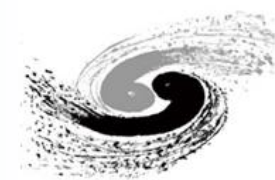
Experimental status



Collab.	$L_{\text{int}}[\text{pb}^{-1}]$	Mode	Signal event	Mass[MeV/c ²]	Lifetime[ps]
CDF	110	$J/\psi l^+ \nu$	$20.4^{+6.2}_{-5.5}$	$6400 \pm 390 \pm 130$	$0.46^{+0.18}_{-0.16} \pm 0.03$
D0	210	$J/\psi \mu^+ X$	$95 \pm 12 \pm 11$	$5950^{+140}_{-130} \pm 340$	$0.45^{+0.12}_{-0.10} \pm 0.12$
CDF	360	$J/\psi \pi^+$	14.6 ± 4.6	$6285.7 \pm 5.3 \pm 1.2$	—
CDF	360	$J/\psi e^+ \nu_e$	238	—	$0.463^{+0.073}_{-0.065} \pm 0.36$
CDF	2400	$J/\psi \pi^+$	108 ± 15	$6275.6 \pm 2.9 \pm 2.5$	—
D0	1300	$J/\psi \pi^+$	54 ± 12	$6300 \pm 14 \pm 5$	—
D0	1300	$J/\psi \mu^+ X$	881 ± 80	—	$0.448^{+0.038}_{-0.036} \pm 0.032$

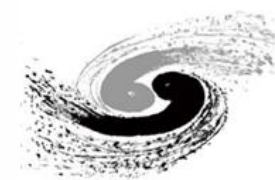
D0 Result





CMS: Competition complement with LHCb
CMS Most analyses here based on
medium and high P_T muons

Event generation



- Signal: $B_c \rightarrow J/\psi \mu$, $J/\psi \rightarrow \mu\mu$ generated with BCVEGPY 2.1 generator

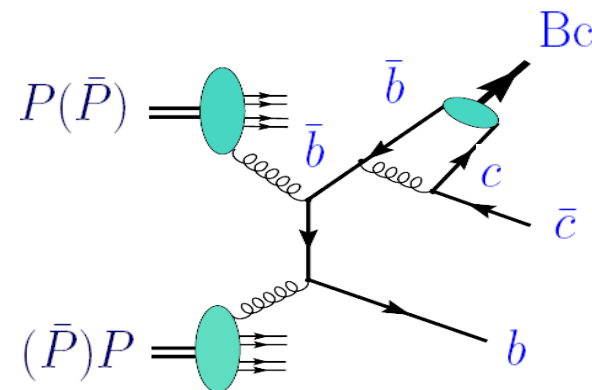
[Chang&Wu, EPJC38:267,2004]

GeneratorInterface/GenExtension(BCVEGPY 2.1) in CMSSW_3_1_x

<https://twiki.cern.ch/twiki/bin/view/CMS/BcGenerator>

<http://indico.cern.ch/getFile.py/access?contribId=8&resId=0&materialId=slides&confId=52322>

- Generator cuts:
 - μ pair (from J/ψ) $p_T \geq 2.5 \text{ GeV}$ $|\eta| \leq 2.5$
 - Third μ (μ from B_c) $p_T \geq 2.5 \text{ GeV}$ $|\eta| \leq 2.5$



Bc theoretical cross-section



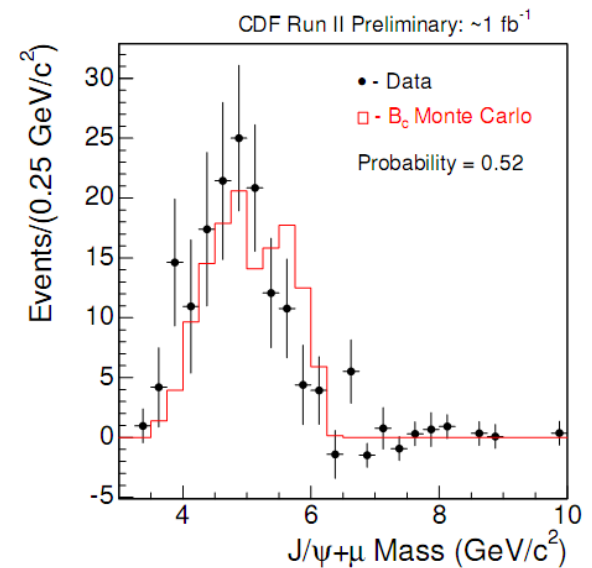
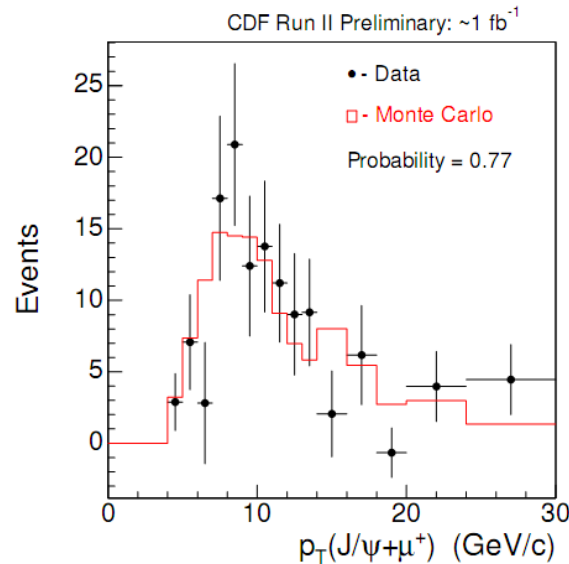
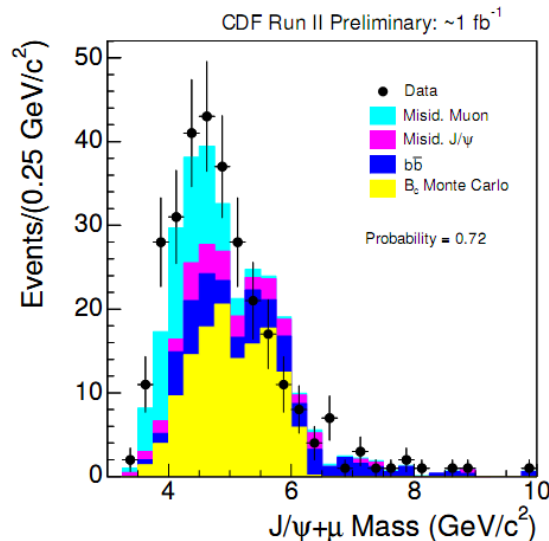
- $\text{Br}(b \rightarrow Bc) = 1.3 \cdot 10^{-3}$ [from HERWIG. Phys. Lett. B 266, 142 (1991).]
- $\text{Br}(\text{QCD} \rightarrow b\bar{b}) = 1.16\%$
- Bc cross section $51.56 \text{ mb} \cdot 0.0116 \cdot 0.001 \cdot 2 = 0.00119619 \text{ mb} \approx 1000 \text{ nb}$
- $\text{Br}(Bc2J\psi\mu\nu) = 1.9 \%$
- $\text{Br}(J2\mu\mu = 6 \%) = 6 \%$
- so three muon Branch = $6 \% \cdot 2 \% = 0.0012$
- $1000 \text{ nb} \cdot 0.0012 = 1.2 \text{ nb} (\sigma Bc \rightarrow J/\psi\mu\nu)$
- This result is come from the fragment mechanics
- The Bc cross-section calculated by [Bcvegpy2.1](#) is different from this result , it's about 360nb when $\sqrt{s} = 10\text{eV}$ ($\sigma Bc \rightarrow J/\psi\mu\nu$ is 0.4nb).

CDF Latest Result(1 fb⁻¹)



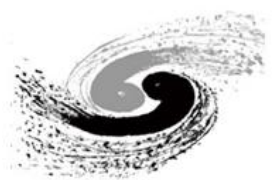
CDF [Public Note 9740](#) 09-03-05

Final results	$p_T(B) > 4 \text{ GeV}/c$	$p_T(B) > 6 \text{ GeV}/c$
$N(B_c^+ \rightarrow J/\psi + \mu^+ + \nu)$	$117.6 \pm 17.2 \text{ (stat)} \quad {}^{+8.3}_{-6.4} \text{ (sys)}$	$107.1 \pm 16.7 \text{ (stat)} \quad {}^{+7.9}_{-6.1} \text{ (sys)}$
$N(B^+ \rightarrow J/\psi + K^+)$	$2333 \pm 55 \text{ (stat)}$	$2299 \pm 53 \text{ (stat)}$
ϵ_{rel}	$5.867 \pm 0.068 \text{ (stat)}$ $+0.554 \text{ (sys)} \pm 0.720 \text{ (spectrum)}$	$4.872 \pm 0.060 \text{ (stat)}$ $+0.420 \text{ (sys)} \pm 0.298 \text{ (spectrum)}$
$\sigma(B_c^+) * BR(B_c^+ \rightarrow J/\psi + \mu^+ + \nu)$	$0.295 \pm 0.040 \text{ (stat)}$	$0.227 \pm 0.033 \text{ (stat)}$
$\sigma(B^+) * BR(B^+ \rightarrow J/\psi + K^+)$	$+0.033 \text{ (sys)} \pm 0.036 \text{ (spectrum)}$	$+0.024 \text{ (sys)} \pm 0.014 \text{ (spectrum)}$



The monte carlo simulation generator is Bcvegpy1.0(only s-wave)

New approach (estimate the cross-section of B_c^+)



- The “signal” events are then passed through the detector and trigger simulation with all analysis cuts applied and a requirement that $p_T(J/\psi + \mu^+) > 4$ (6) GeV/c.

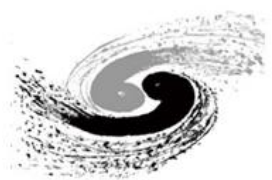
Efficiencies	$p_T(B) > 4 \text{ GeV}/c$	$p_T(B) > 6 \text{ GeV}/c$
$\epsilon_{B_c^+} (\%)$	0.0551	0.1232
$\epsilon_{B^+} (\%)$	0.3231	0.6005

For $p_T > 4 \text{ GeV}/c$ we obtain

$$\sigma^{CDF}(B_c^+) * BR(B_c^+ \rightarrow J/\psi(\mu^- \mu^+) + \mu^+ + \nu) = \frac{N_{\text{signal}}}{\int L dt \times \epsilon_{B_c^+}}$$

$$= \frac{117.6}{1 \text{ fb}^{-1} \times 0.000551} = 213\,430 \text{ fb} \pm 30\,583 \text{ fb} (\text{stat})_{-12549.0 \text{ (fb)}}^{+16274.5 \text{ (fb)}} (\text{sys})$$

This result was calculated by us, the uns



$$\sigma_{\sqrt{s}=10\text{TeV}}^{\text{Est}}(B_c^+) * BR(B_c^+ \rightarrow J/\psi(\mu^+ \mu^-) + \mu^+ + \nu)$$

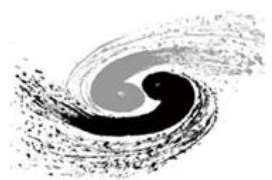
$$= \sigma^{\text{CDF}}(B_c^+) * BR(B_c^+ \rightarrow J/\psi(\mu^+ \mu^-) + \mu^+ + \nu) * \frac{\sigma_{\sqrt{s}=10\text{TeV}}^{\text{MC}}(B_c^+)}{\sigma_{\sqrt{s}=1.96\text{TeV}}^{\text{MC}}(B_c^+)}$$

$\sigma_{\sqrt{s}=10\text{TeV}}^{\text{MC}}(B_c^+)$ $\sigma_{\sqrt{s}=1.96\text{TeV}}^{\text{MC}}(B_c^+)$ are the cross-section calculated by Bcvegy2.1 in whole phase space.

$$\sigma_{\sqrt{s}=10\text{TeV}}^{\text{MC}}(B_c^+) = 184671.84 \text{ pb} \quad \sigma_{\sqrt{s}=1.96\text{TeV}}^{\text{MC}}(B_c^+) = 8984.48 \text{ pb}$$

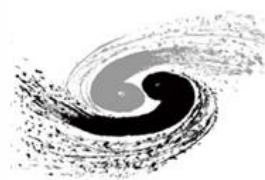
So at last the cross-section of $B_c^+ \rightarrow J/\psi(\mu\mu^+) + \mu^+ + \nu$

$$\sigma_{\sqrt{s}=10\text{TeV}}^{\text{Est}}(B_c^+) * BR(B_c^+ \rightarrow J/\psi(\mu^+ \mu^-) + \mu^+ + \nu) = 213.43 \text{ pb} * 20.55 \approx 4000 \text{ pb}$$



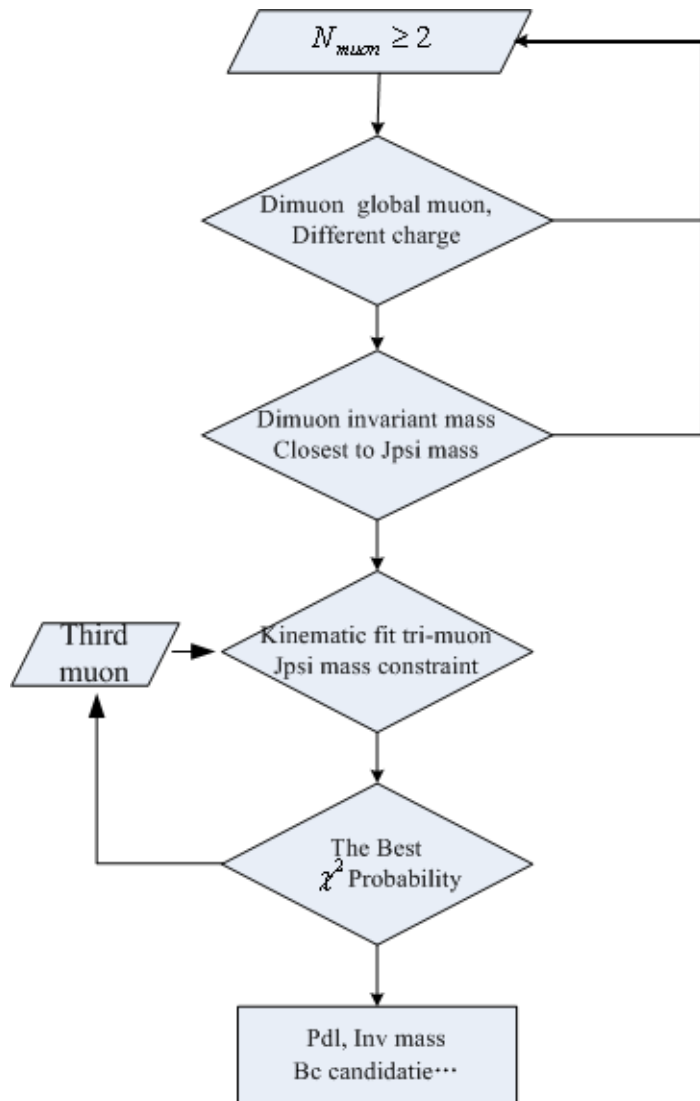
- Cross-section of $B_c^+ \rightarrow J/\psi(\mu^+\mu^-)\mu^-$ in theoretical it should be 1.2 nb.
- After filtrate(muon $P_T > 2.5 \text{ GeV}/c$, $|\eta| < 2.5$).
- Signal cross section $1.2 \text{ nb} * \underline{0.057} = 68.4 \text{ pb}$
- In 100 pb^{-1} there will be 6840 events.
- From the way we used above Cross-section of $B_c \rightarrow J / (\mu^+\mu^-)\mu^-$ should be 8.0 nb.
- After filtrate(muon $P_T > 2.5 \text{ GeV}/c$, $|\eta| < 2.5$).
- Signal cross section $8.0 \text{ nb} * \underline{0.057} = 456 \text{ pb}$
- In 100 pb^{-1} there will be 45600 events.
- There will be 1/3 events be Reconstructed.

Data sample



- Signal(muon $P_T > 1 \text{ GeV}/c$, $|\eta| < 2.5$):
- Bc2JpsiMuNu(signal) 502 972 $\sim 200 \text{ pb}^{-1}$
- Background:
- B2JpsiMuMu(Inclusive B) 10 778 551 $\sim 100 \text{ pb}^{-1}$
- Jpsi2MuMu(Prompt Jpsi) 11 369 136 $\sim 10 \text{ pb}^{-1}$
- ppmumux (QCD) 1016158 $\sim 1 \text{ pb}^{-1}$

Analysis strategy

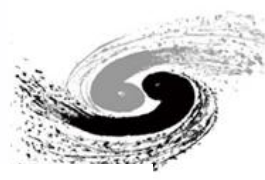


- Calculate the trigger efficiency $\varepsilon_{Trigger}$
- Calculate the efficiency of the selection strategy.
- Add different cut and calculate the efficiency.
- Product select efficiency and the cuts efficiency as the Reconstructed efficiency

$$\varepsilon_{Reco} \cdot \frac{d\sigma}{dp_T} \times Br(Bc \rightarrow J/\psi \mu \nu) \times Br(J/\psi \rightarrow \mu \mu)$$

$$= f(\Delta P_T) \times \frac{N_{\Delta P_T}^{Bc}(A, \varepsilon_{Trigger}, \varepsilon_{Reco}, \lambda_{Trigger}^{corr}, \lambda_{Reco}^{corr})}{\int L dt \cdot \Delta P_T}$$

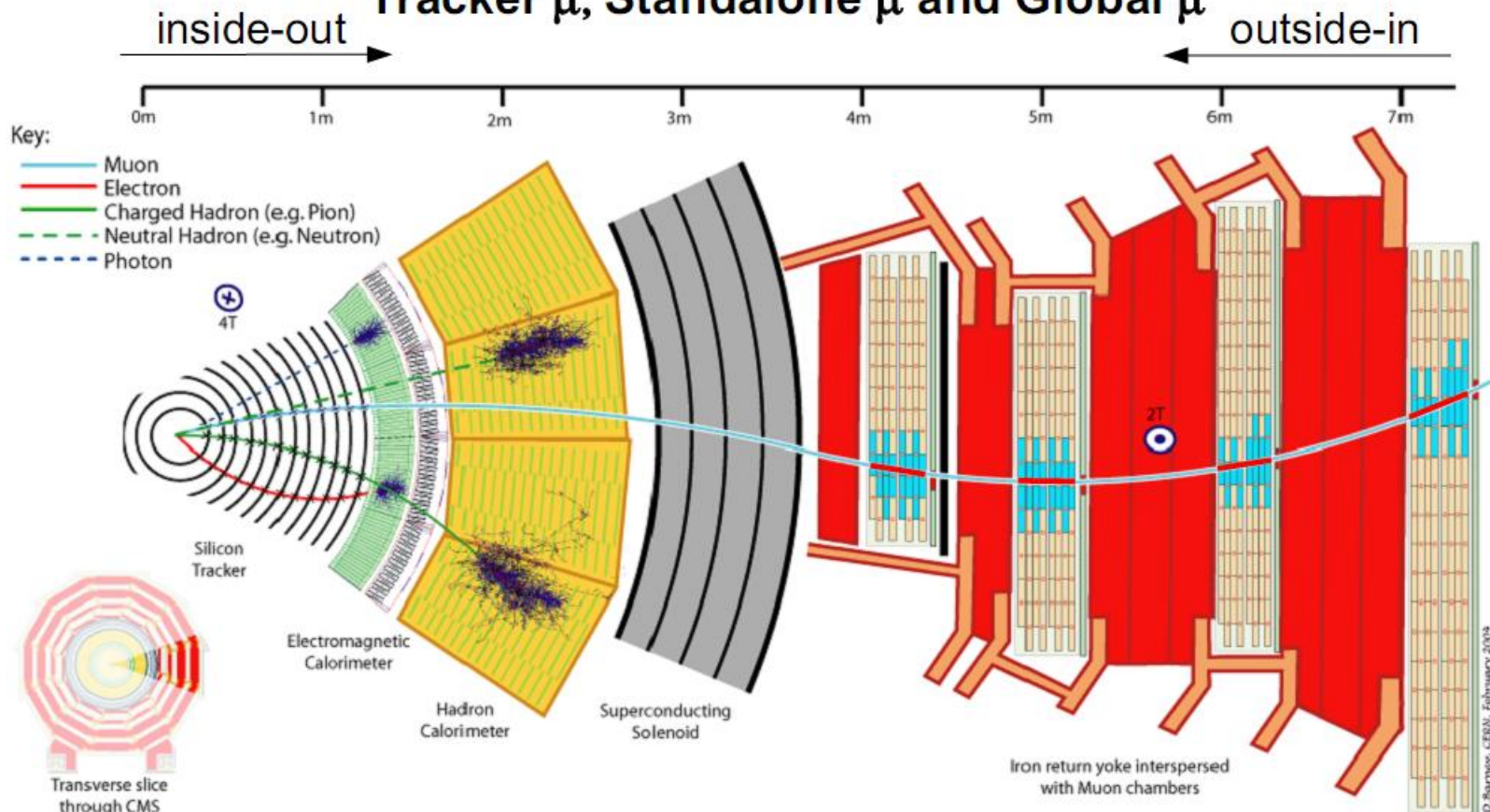
- $\int L dt$ Integral luminosity.
- f fraction for $Bc \rightarrow J/\psi \mu \nu$
- $\lambda_{Trigger}^{corr}, \lambda_{Reco}^{corr}$ correction on trigger and reco efficiency from Tag&probe



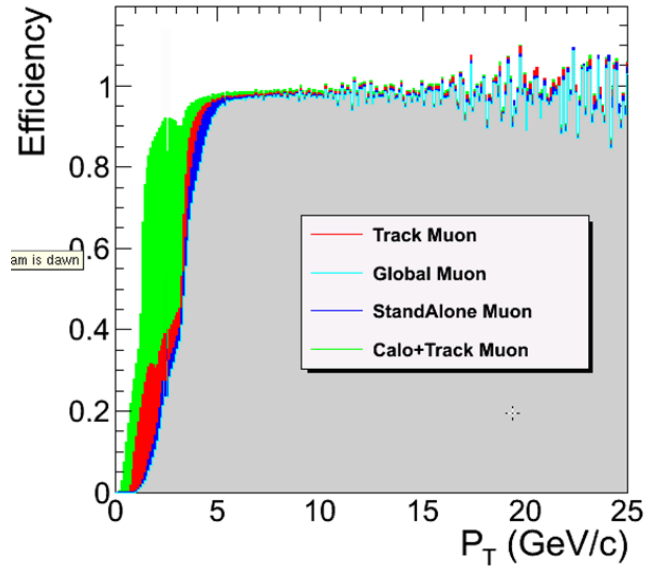
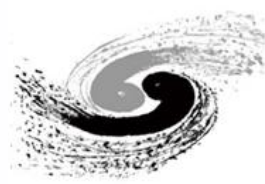
3 Muon types in CMSSW

Two independent approaches for muon reconstruction leading to **three different types of muon candidates**:

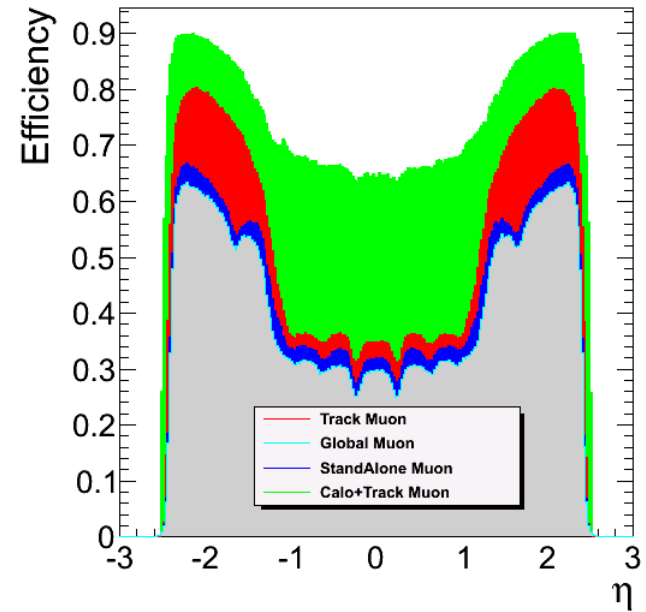
Tracker μ , Standalone μ and Global μ



Muon reconstruction efficiency

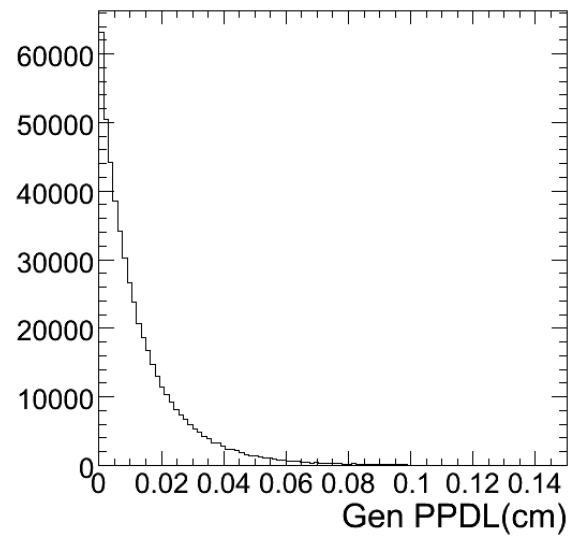
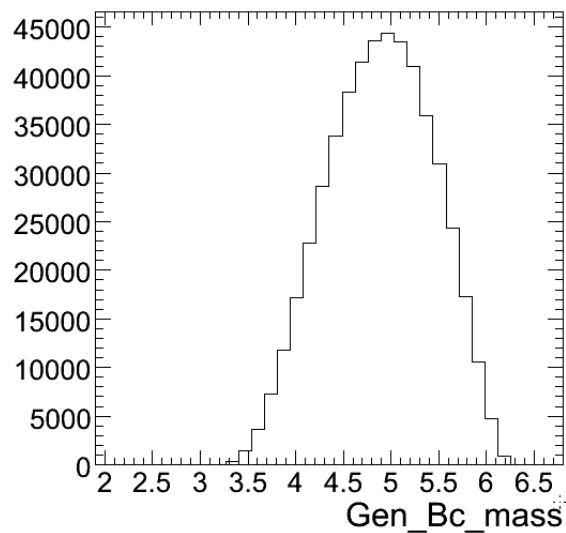
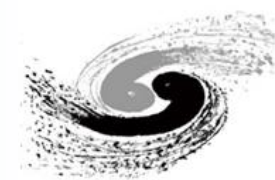


$$\mathcal{E}_{acc} = N_{Re-matched}(p_t) / N_{Gen}(P_t)$$

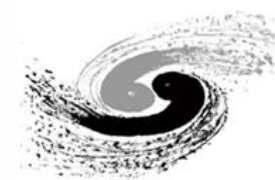


$$\mathcal{E}_{acc} = N_{Re-matched}(\eta) / N_{Gen}(\eta)$$

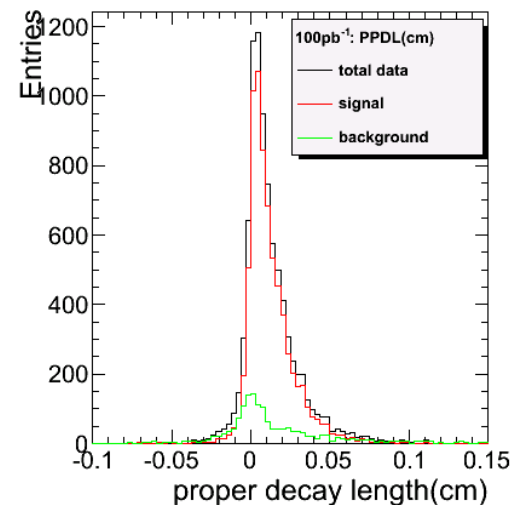
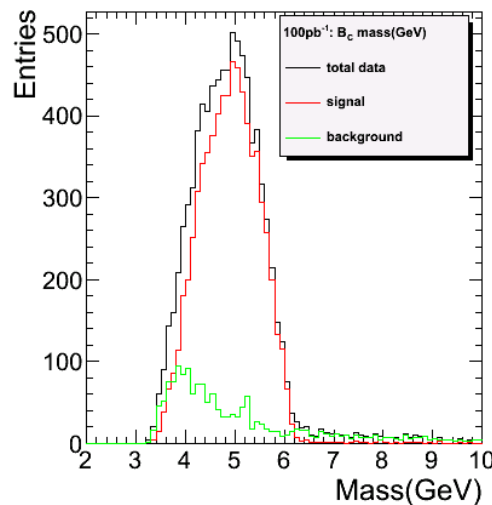
Invariant mass and decay length distribution



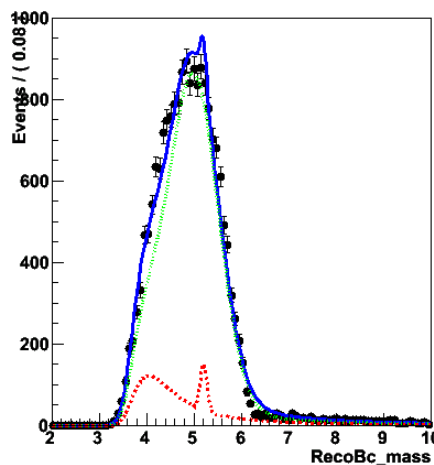
Reconstruction and fit result



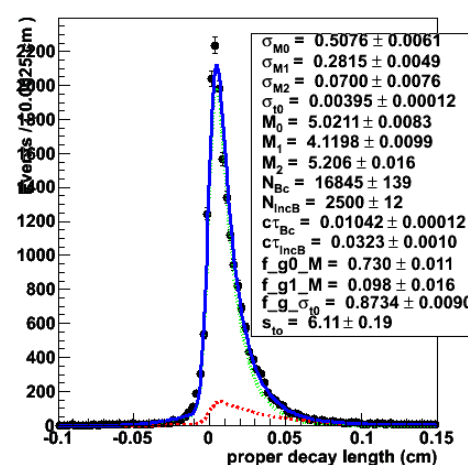
- Event selection
- All global muon
- $pt(>2\text{Gev}/c)$
- Trigger: HLTDoubleMu0
- Final states:
Mass (2,10)
 $\chi^2/\text{ndf}(<10)$
- Jpsi selection
- $Pt(>2.0\text{Gev}/c)$
mass (2.85,3.35)
- The third muon:
 $\chi^2/\text{ndf}(<1.9)$
Nhits (>10)
- ΔR between J/ψ and Third muon (<1.5)



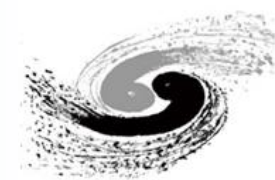
A RooPlot of "RecoBc_mass"



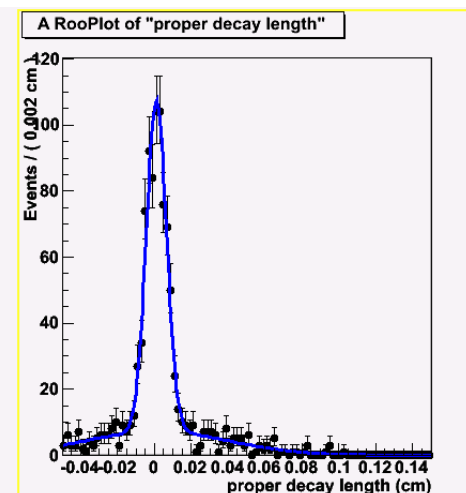
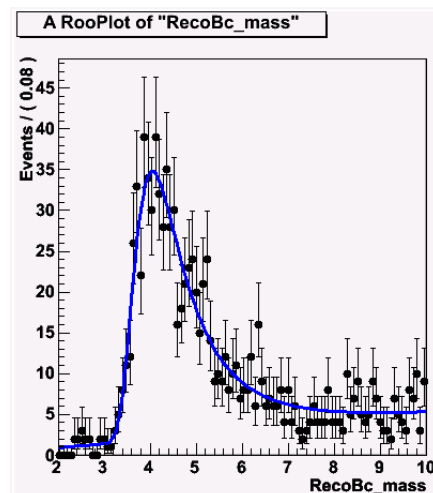
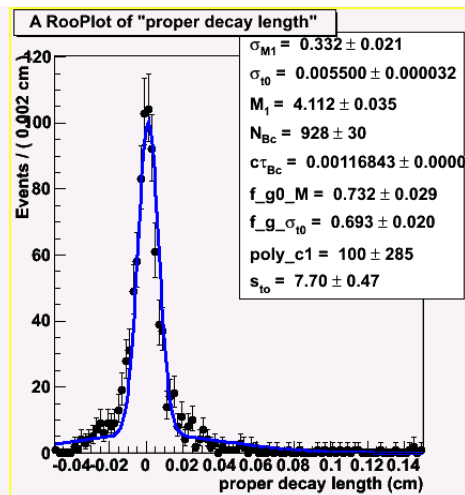
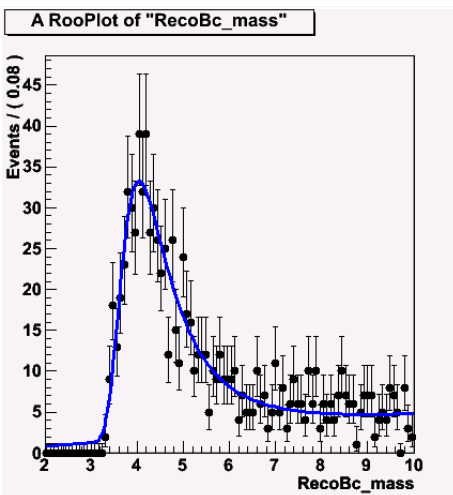
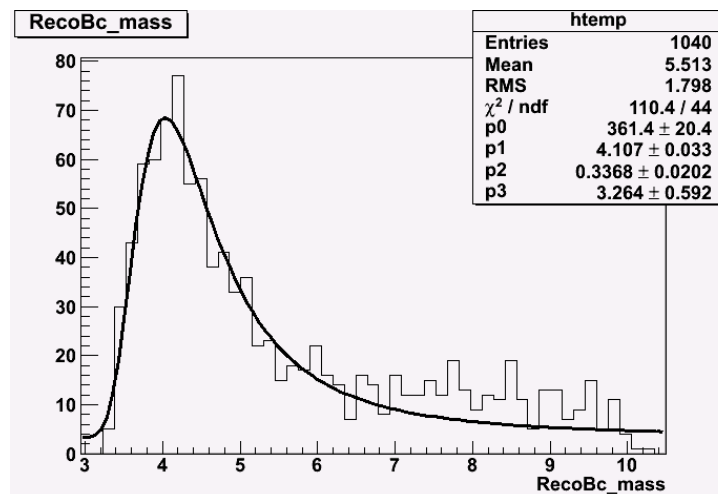
A RooPlot of "proper decay length"



Prompt J/ψ background toy mc



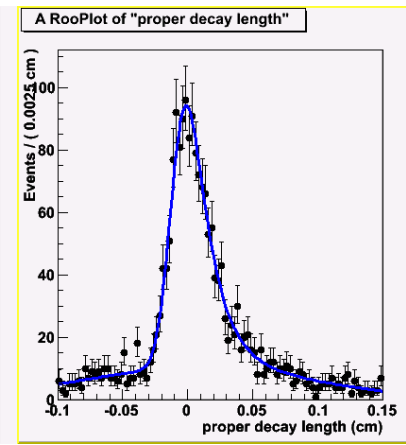
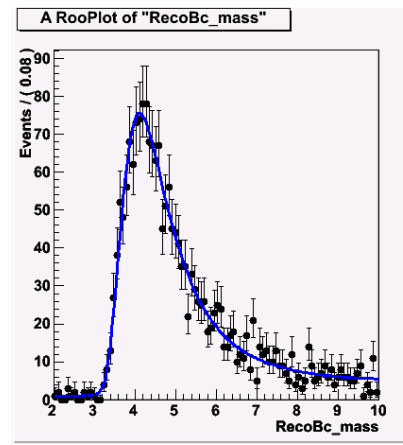
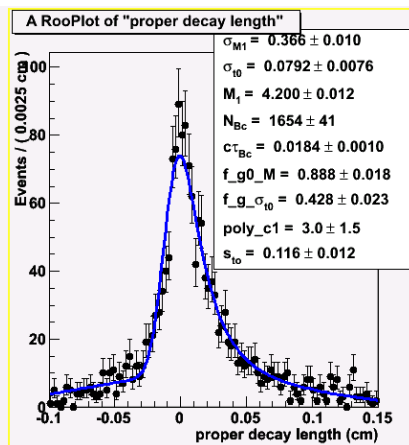
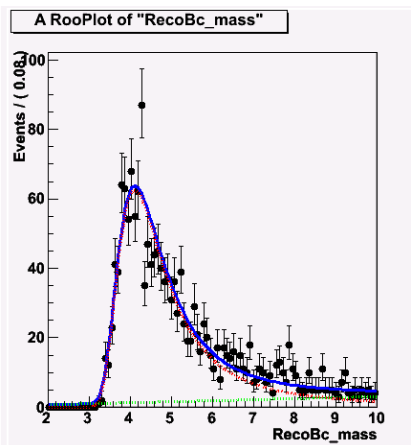
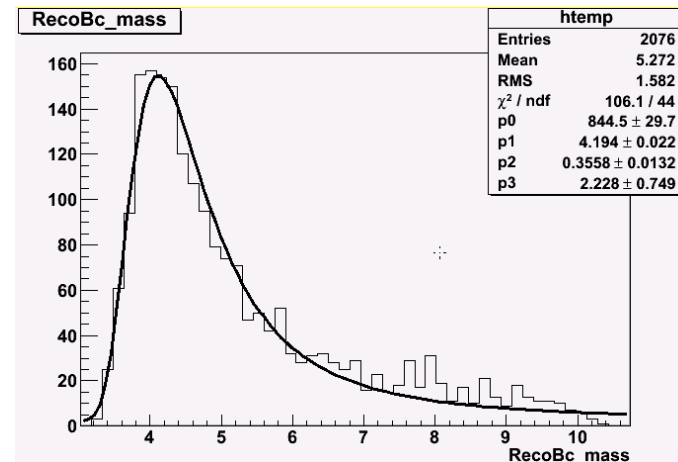
- Event selection
- All global muon
- Trigger: HLTDoubleMuOpen
- Final states: Mass (2,10)
- J/ψ selection
- $Pt(>2.0\text{Gev}/c)$ mass (2.85,3.35)
- The third muon:
- $Pt(>1.3\text{Gev}/c)$



Roofit fit result

After Toy MC(1000)

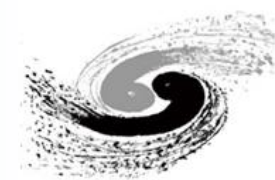
- Event selection
- One tracker muon
- Trigger: HLTDoublMuOpen
- Final states: Mass (2,10)
- Jpsi selection
- $P_t(>2.0\text{Gev}/c)$ mass (2.85,3.35)



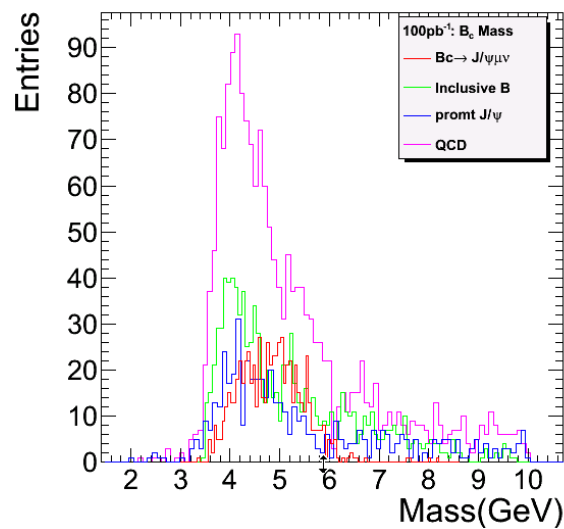
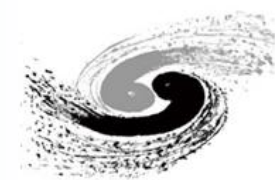
Roofit fit result

After Toy MC(2000)

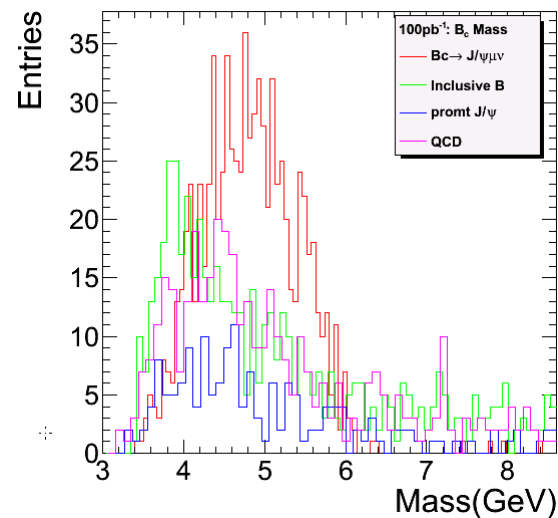
Number of Signal and background in different Pt bin



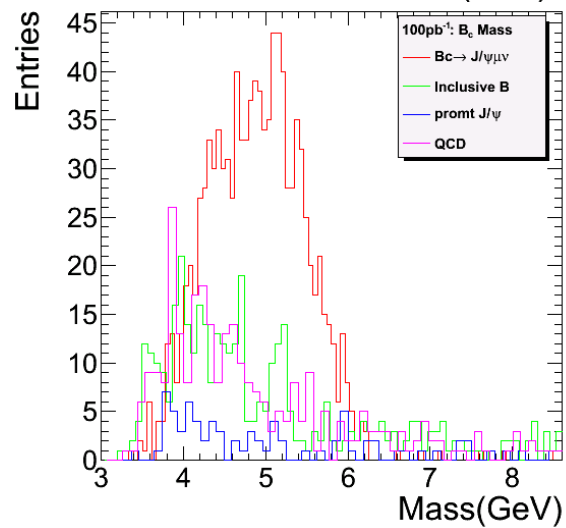
Pt(GeV/c)	Signal	Inclusive B	Prompt $J/\psi(\times 10)$	QCD ($\times 100$)
(5,12)	673	966	52	18
(12,15)	822	570	19	4
(15,18)	1072	411	9	3
(18,21)	970	275	6	4
(21,25)	1051	213	5	3
(25,30)	927	115	3	1
(30,36)	603	93	0	0
(36---)	653	80	1	0



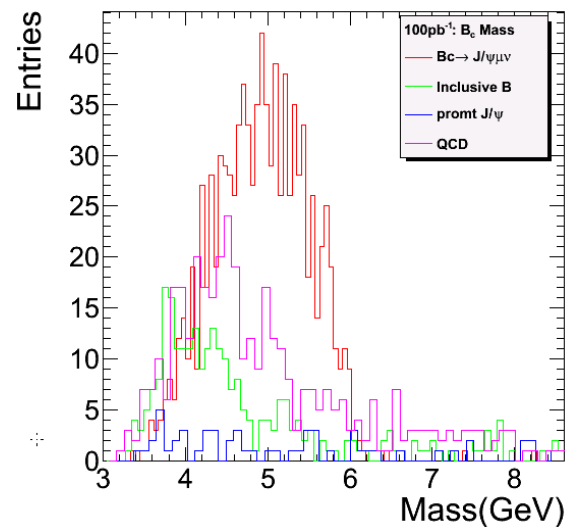
Pt(5,12)



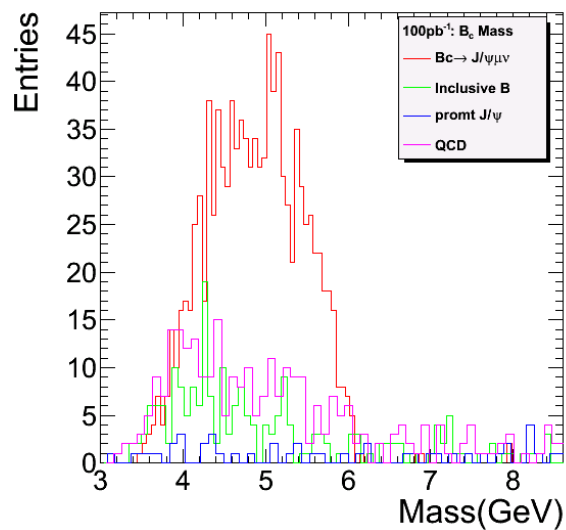
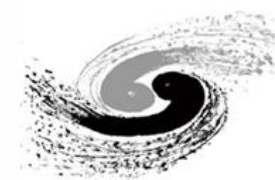
Pt(12,15)



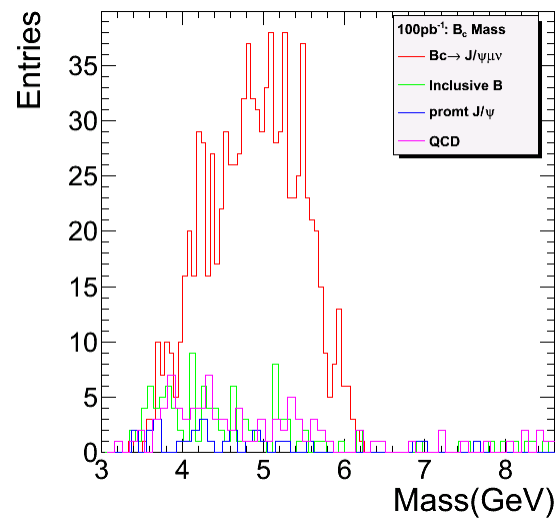
Pt(15,18)



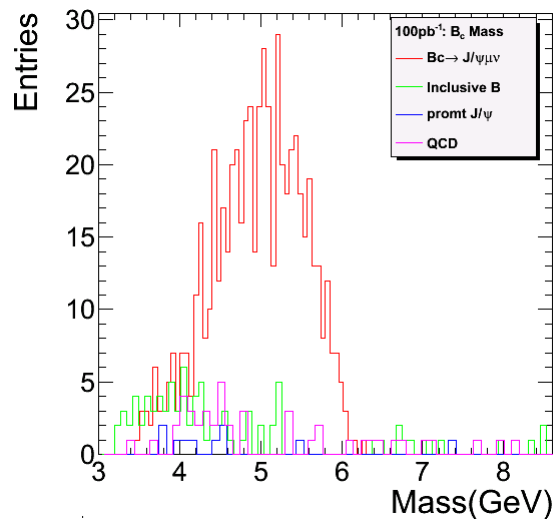
Pt(18,21)



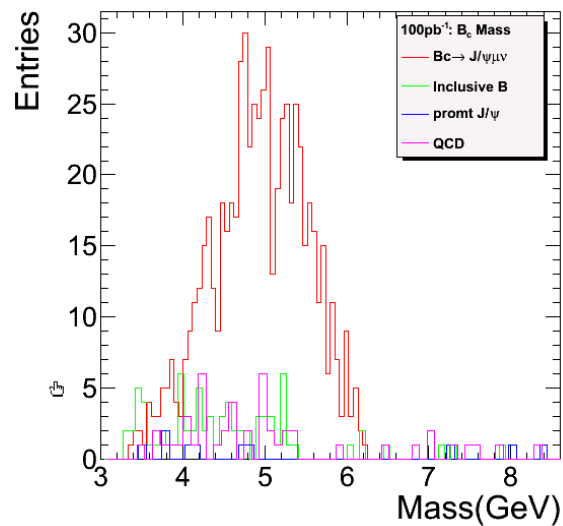
Pt(21,25)



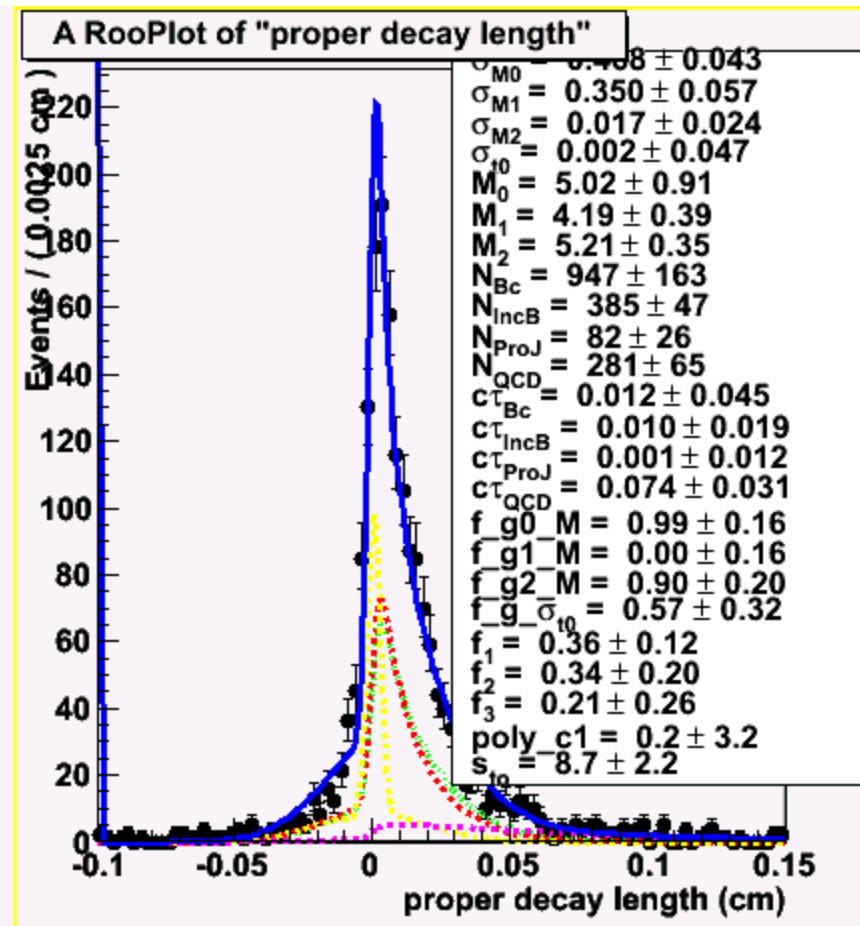
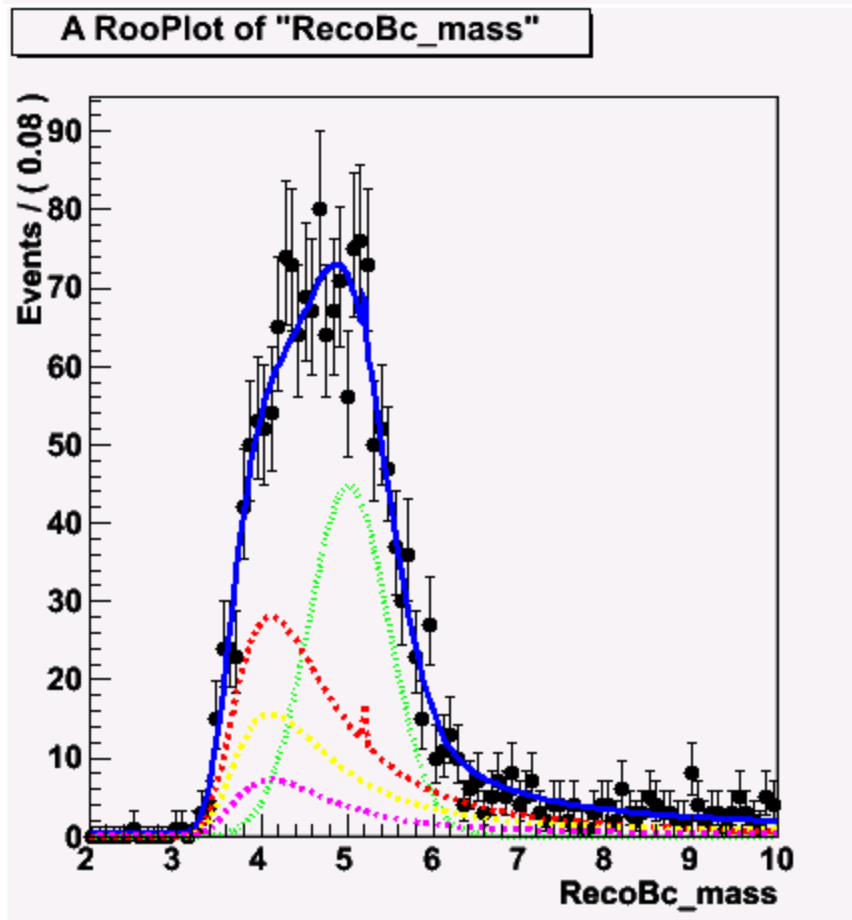
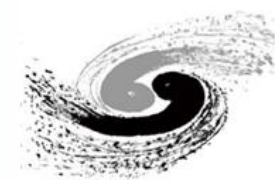
Pt(25,30)



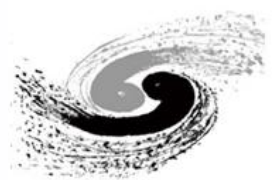
Pt(30,36)



Pt(36---)



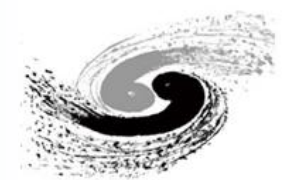
Next step



- Two dimensional fit the mass and decay length in different pt bin.
- Fit validation.
- Tag-probe method based on the real data.
- Real data analysis strategy.

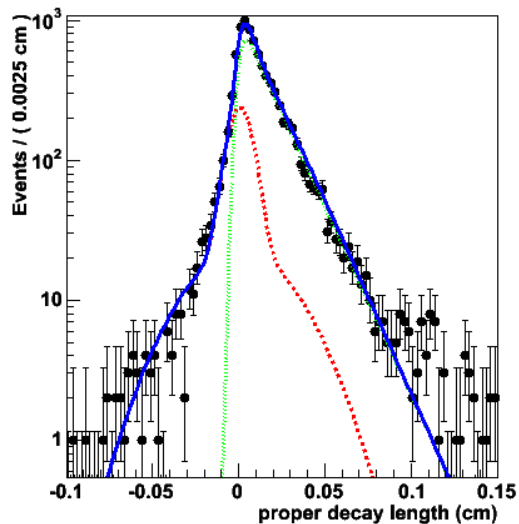
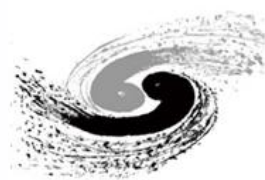


Thank you!

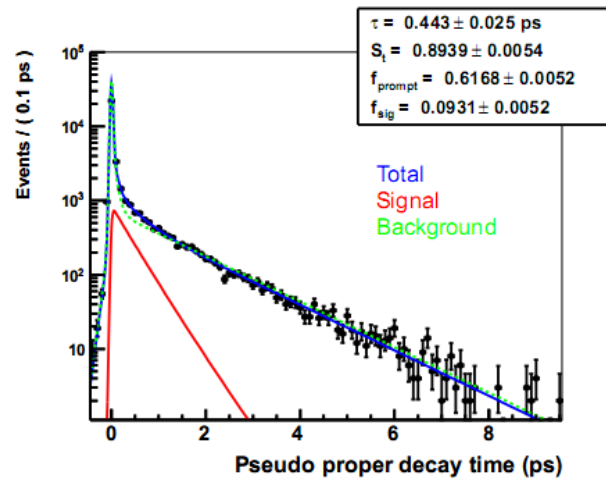


Backup

Decay length



- Our result on cms



- (MC)Analysis result on LHCb