Search for Lepton Flavor Violating decay $Bs \to Ks(\pi^+\pi^-)\mu^\pm e^\mp$

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Introduction

Lepton Flavor violating(LFV) decays are forbidden in Standard Model(SM). In SM, neutrinos are massless and there is no mixing between lepton families. However, since the observation that neutrino species are massive and exhibit lepton mixing between different generations, the subject of LFV has received considerable interest and a lot of searches have been done looking for such LFV decays

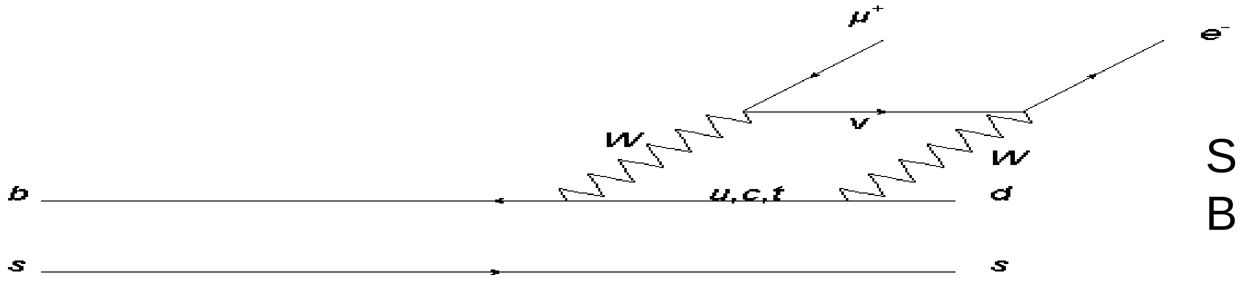
Many Extensions of the SM like SUperSymmetry (SUSY) model, Lepto-Quark (LQ) model allow lepton flavor violating decays. For example, in LQ model, the assumption of the existence of local gauge symmetry between quarks and leptons could lead to tree-level couplings between quarks and leptons and hence allow the decays that violate lepton flavor.

Clearly LFV is a channel to search for new physics beyond SM

Many searches for LFV have been going on in different sectors like muon, kaon, charm etc. The access to B-mesons adds new possibilities for LFV observation as the higher mass of the b-mesons could enhance the decay rate compared to lighter mesons.

Model dependence examples

LFV in SM extended to include neutrino masses plus lepton mixing

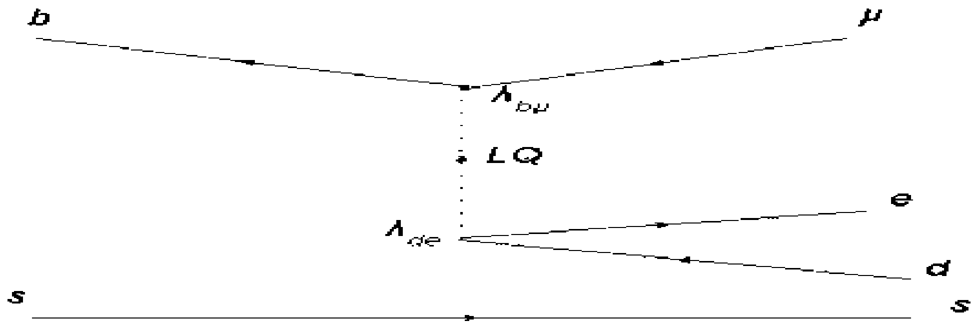


Suppressed :
Br ~ 10^{-54}

LQ tree-level coupling: the decay could couple the b-quark to the second generation muon, and the down quark to the first generation electron.

LQ 's are believed to be spin 1 gauge bosons that carry both color and lepton quantum numbers.

LQ model is a model based on SU(4) where the lepton carry the fourth "color"



Mass LQ ~ 200 TeV

Current status

•CDF Run I published limits @ 90 (95) % C.L. [PRL (81) 1998]

$B(B_s^0 \to e^{\pm}\mu^{\mp}) < 6.1(8.2) \times 10^{-6}$
$B(B_d^0 \to e^{\pm}\mu^{\mp}) < 3.5(4.5) \times 10^{-6}$

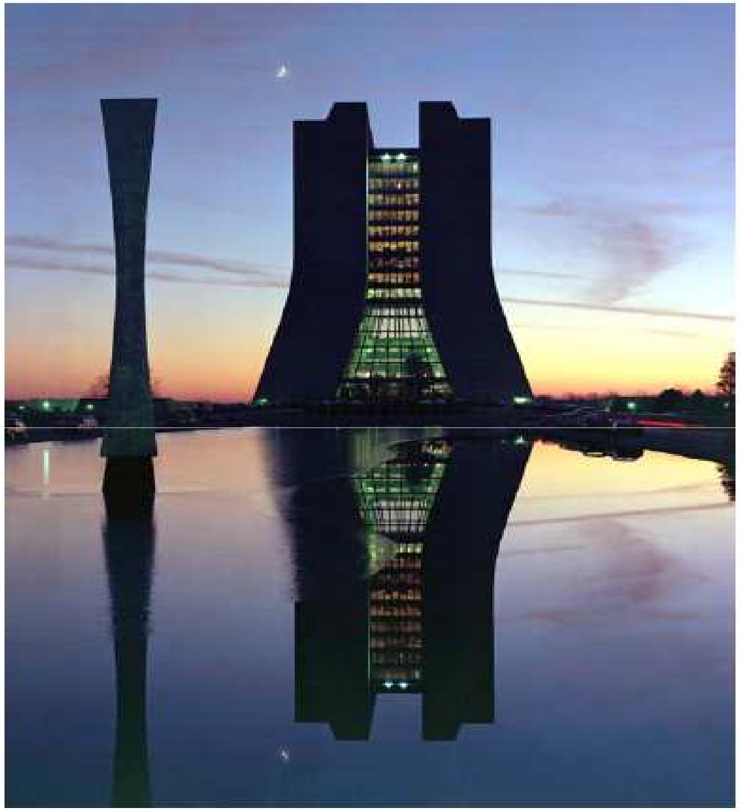
$M_{LQ}(B_s^0) > 20.7(19.3)$ TeV $/c^2$
$M_{LQ}(B_d^0) > 21.7(20.4)$ TeV $/c^2$

•B-factories (90% CL):

$Br(B_d^0 \to e^+\mu^-) < 9.2 \times 10^{-8}$ at 90 % C.L. (BABAR)
$Br(B_d^0 \to e^+\mu^-) < 1.7 \times 10^{-7}$ at 90 % C.L. (BELLE)
$Br(B_d^0 \to e^+\mu^-) < 1.5 \times 10^{-6}$ at 90 % C.L. (CLEO2)

MLQ (Bd) > 53.1 TeV/c2 (BABAR 2007)

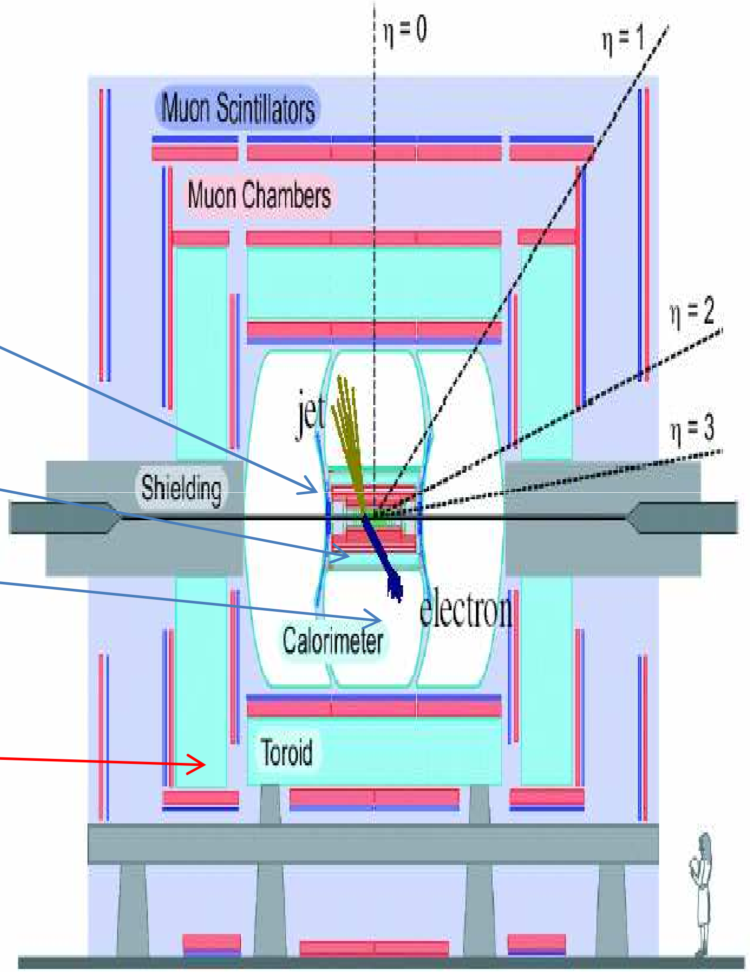
Tevatron proton anti-proton collider



- $\sqrt{s}$=1.96 TeV
- $\mathcal{L} = 2.5\times10^{32}cm^{-2}\ s^{-1}$
- $\int \mathcal{L}dt = 50\ pb^{-1}$ per week

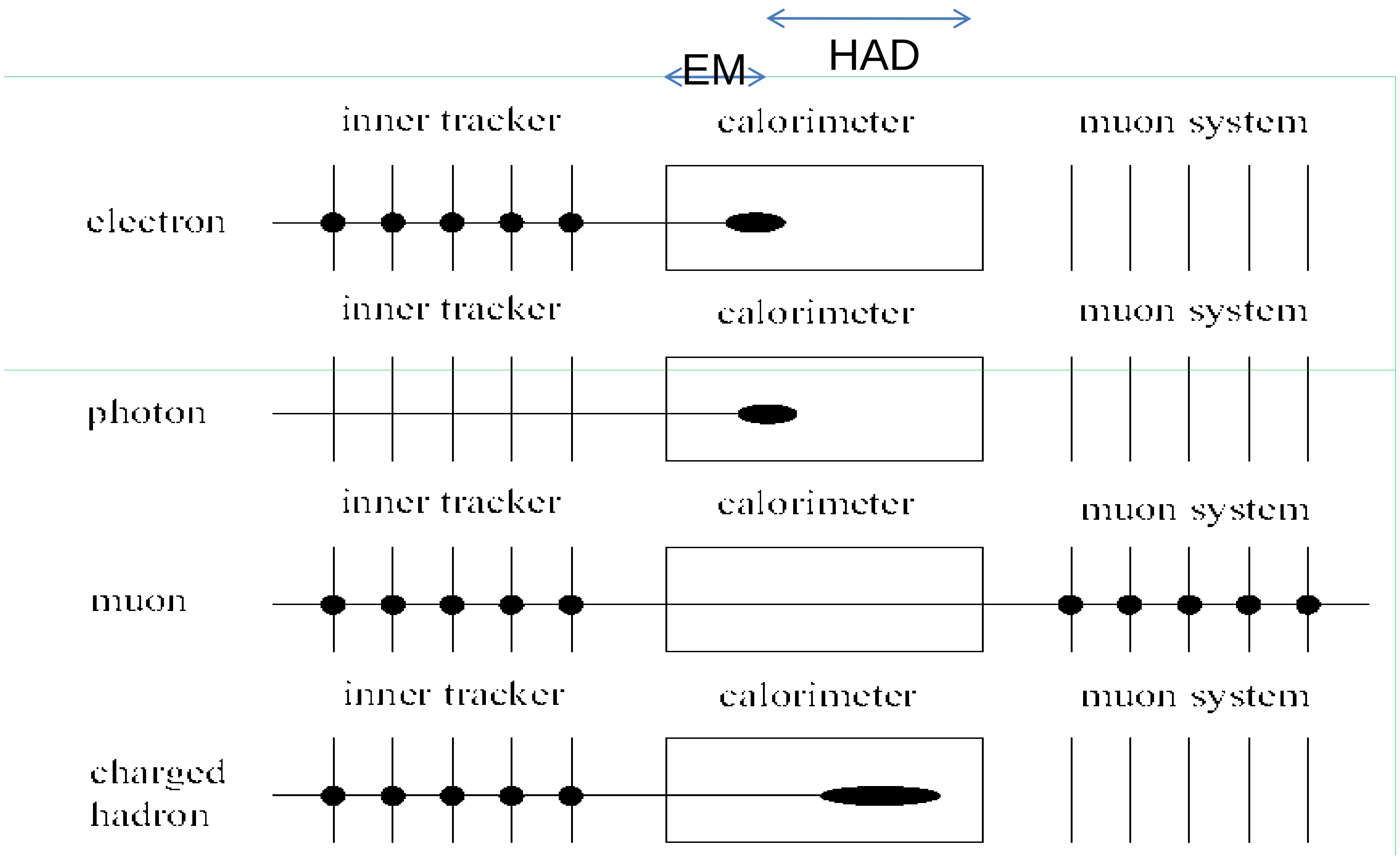
D0 Detector at Tevatron

- Tracking system:
  - Silicon Micro-chip Tracker (SMT):
    radiation hardness plus accurate vertexing
  - Central Fiber Tracker(CFT):
    - Fiber scintillators to measure multiple points on a track's trajectory
- Central Pre-shower
  - Enhance identification of low energy electrons
- Calorimeter
  - Measure the energy of particles
  - Composed of two parts, electromagnetic and hadronic
- Muon system
  - Situated outside the calorimeter
  - Made of three layers of drift chambers and scintillators that help to identify muons
- Trigger system
  - Fast electronics and computers used to decide which event to be recorded on tape



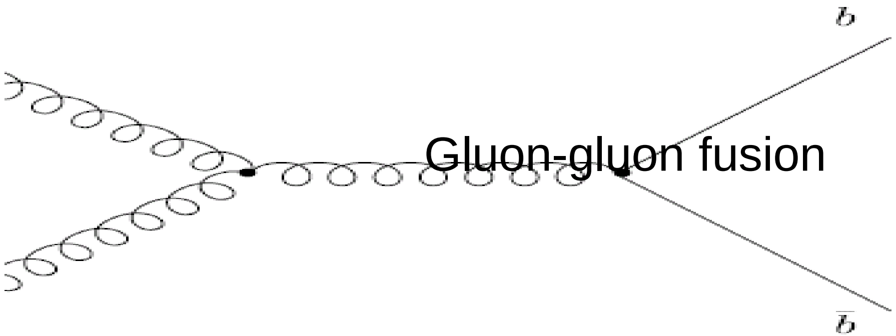
Signature of different particles in D0 detector

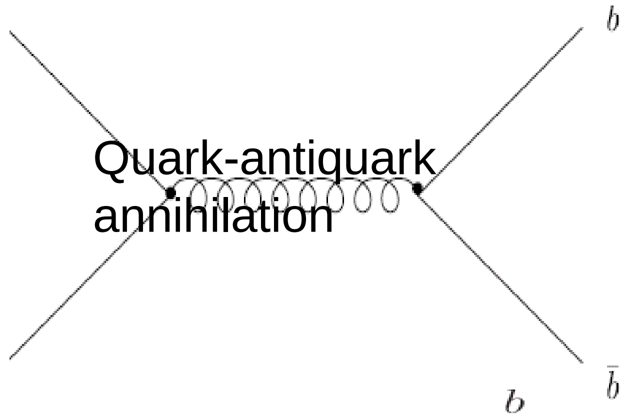
- Different signatures in different subdetectors helps to differentiate particles



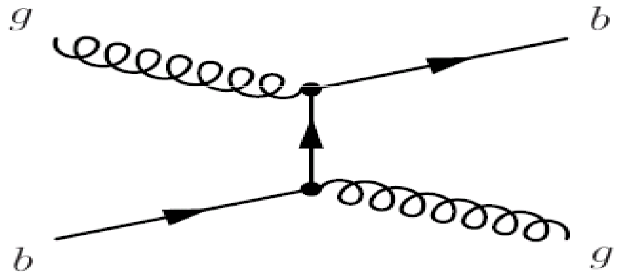
B mesons production at Tevatron

- Leading order(LO) of b-quark production: "Flavor creation"





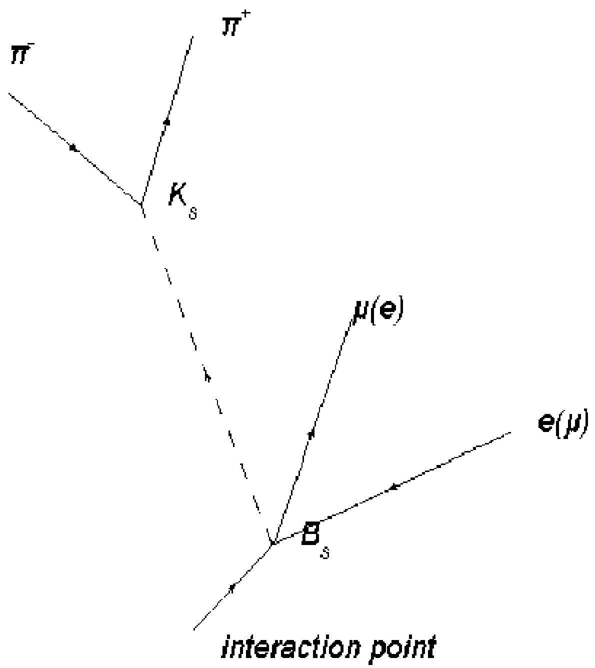
- Next-to-leading order (NLO): "Flavor excitation"



- Hadronization : B-mesons are formed by binding a b-quark with a quark or anti-quark from the proton(anti-) remnant or drawn from vacuum (One of the least understood processes in particle physics)
- Production rates : B*d*(40%), B*u*(40%) , B*s*(10%) and remaining b-quarks hadronize into other b-hadrons. Lower masses of *d* and *u* quarks leads to higher rates of production of B*d* and B*u* mesons

Decay topology

- The experimentally observed topology of the decay $Bs \rightarrow Ks(\pi^{+}\pi^{-})\mu^{\pm}e^{\mp}$ would include the following features;
  - Displaced Bs vertex with decay length consistent with the B meson lifetime
  - Two oppositely charged tracks (muon and electron) with muon identified by a muon system and electron by calorimeter
  - A good signal of a Ks whose displacement points back to the Bs vertex



B-Analysis(BANA) package

- Bana package is software used at D0 to provide an infrastructure for developing analyses in B-physics. It performs the following tasks:
  - Combination of many particles into one
  - Reconstruct primary and secondary vertices
  - Definition of jets
  - Reconstruction of long lived particles like Ks, Lambda etc
  - Accessing the recorded data
  - etc

Search Strategy

The results will be given by the branching fraction equation given below and we use a well known decay $Bd \to J/\psi(\mu^+\mu^-)Ks(\pi^+\pi^-)$ for normalization process

The Result

Events (or Events @ Limit) surviving all selection criteria

World average

B meson fragmentation ratio

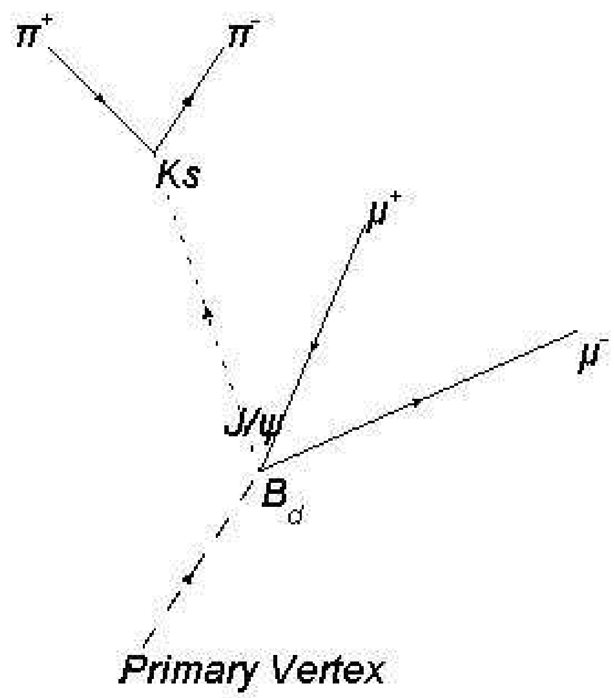
$$Br(B_s \to K_s(\pi^-\pi^+)\mu^\pm e^\mp) = \frac{N_{signal}}{N_{norm}} \bullet \frac{\varepsilon_{norm}}{\varepsilon_{signal}} \bullet Br(B_d \to K_s(\pi^-\pi^+)J/\psi(\mu^+\mu^-)) \bullet \frac{f_{B_d}}{f_{B_s}}$$

Number of events from the fit of Bd-> K0s(pipi) J/psi(mumu)

Acceptances and Reconstruction efficiencies for signal and normalization mode (include muon and electron ID efficiency)

Normalization channel

- The decay $Bd \rightarrow J/\psi(\mu^{+}\mu^{-})Ks(\pi^{+}\pi^{-})$ is used for normalization process because it has same decay topology as our signal channel .
- Systematics arising from Ks selection cancel each other
- Its branching fraction has well been measured



Data and triggers

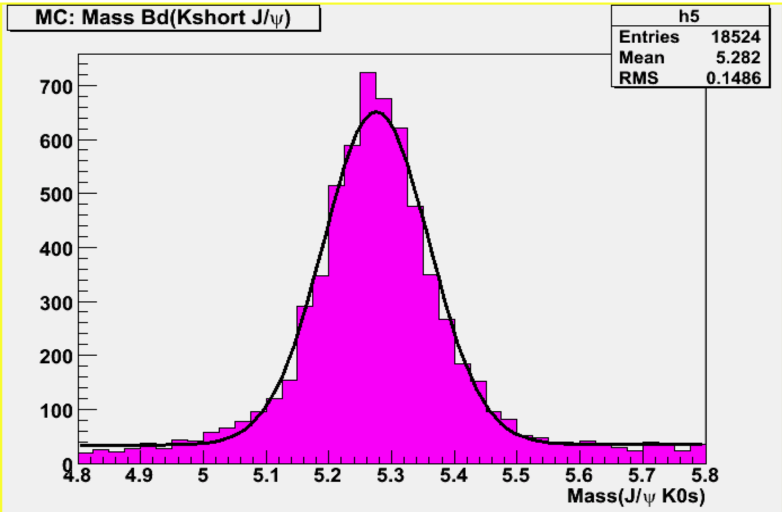
- Data and Monte Carlo used:
  - RunIIa data (1.3 fb $^{-1}$) only was used in this analysis report (all data to be used soon)
  - All data recorded so far by D0 detector amounts to 6.1 fb $^{-1}$
  - 190,000 MC events for signal channel : $Bs \rightarrow Ks(\pi^{+}\pi^{-})\mu^{\pm}e^{\mp}$
  - 200,000 MC events for normalization channel : $Bd \rightarrow J/\psi(\mu^{+}\mu^{-})Ks(\pi^{+}\pi^{-})$
- Trigger selection:
  - Trigger system for B-physics events contains at least one muon particle, hence all events passing single-muon triggers were used in this analysis update.
  - To minimize systematics due to trigger selection, same triggers were applied for both signal and normalization channel event selection.

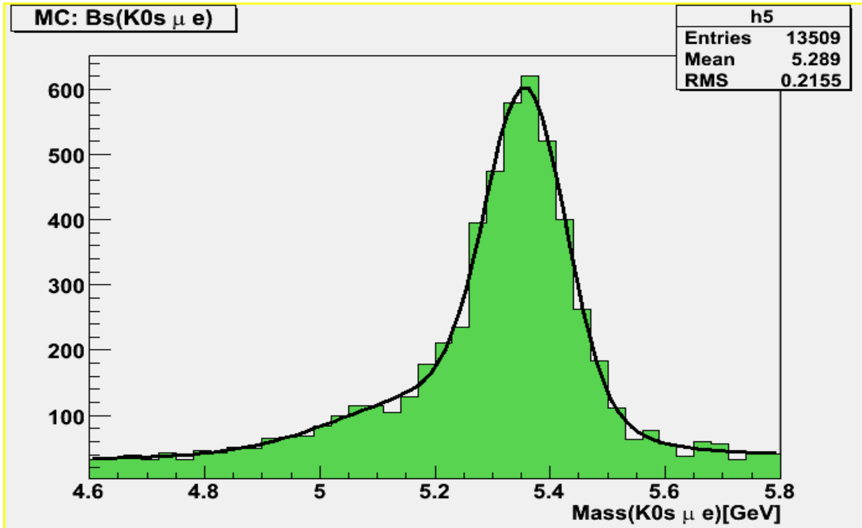
Monte Carlo (MC) simulations

Monte Carlo simulation chain:

- generation of events b bar and hadronization (PYTHIA)
- B hadrons created in PYTHIA are decayed to the desired daughter particles (EVTGEN)
- Make generator level kinematical cuts(pT, $|\eta|$ etc) (D0Mess)
- simulate the effects of the detector material on MC events (DOGSTAR)
- event reconstruction (D0Reco)

– Reconstructed mass plots from MC events



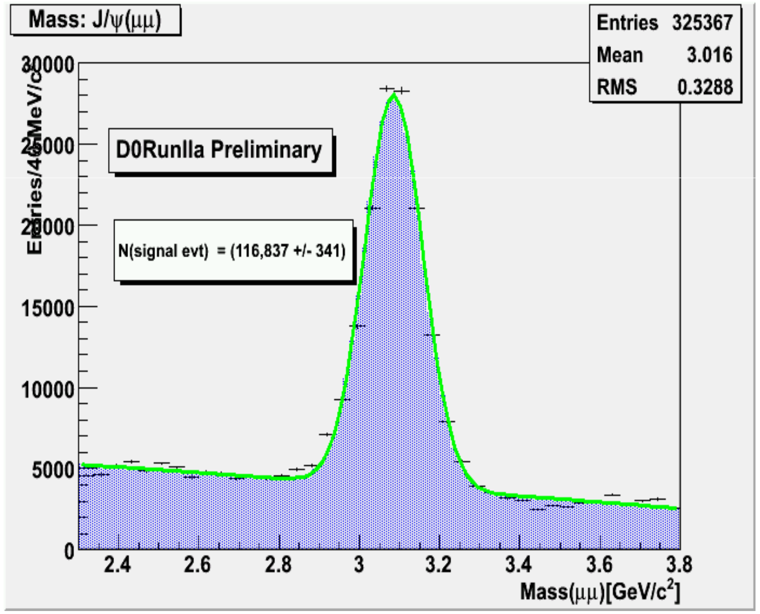


Analysis procedure

- Number of normalization channel:
  - Obtained from the fit of the invariant mass of the decay $Bd \to J/\psi(\mu^+\mu^-)Ks(\pi^+\pi^-)$
- Optimization process we used MC events as signal sample and sidebands as background sample to optimize the cuts. Figure of merit being $S/\sqrt{S+B}$
- Use blind analysis procedure to avoid bias during $Bs \to Ks(\pi^+\pi^-)\mu^\pm e^\mp$ event selection by blinding signal region until when we have an optimal set of cuts to be applied in our event selection.
- Use MC events to calculate detector acceptances and re-weighted MC events to calculate reconstruction efficiency.
- Particle identification efficiency using tag and probe method using the decays $J/\psi(e^+e^-)$ and $J/\psi(\mu^+\mu^-)$
- Tag and probe method is a method applied to a two-body decay whereby;
  - Tagged candidate (muon or electron) has to pass tight set of identification cuts and probe candidate (muon or electron) passes a weak set of cuts
  - both tag and probe candidates must reconstruct an invariant mass of a J/ψ (3.096 GeV)
  - Identification efficiency is calculated as an efficiency for probe candidate to pass identification cuts

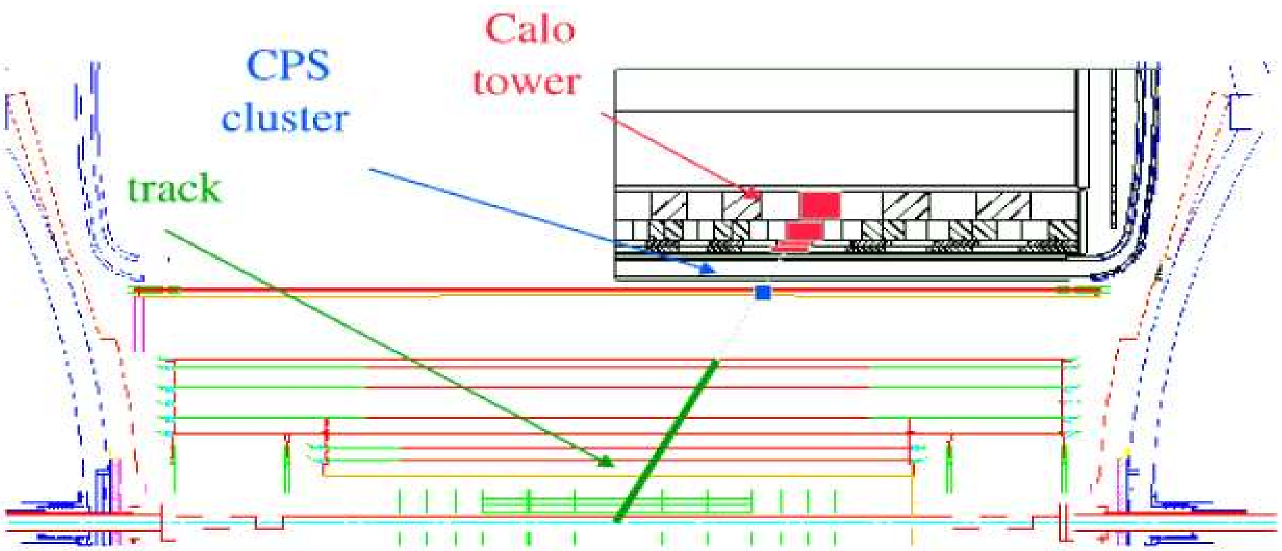
Muon identification efficiency

- Tag and probe method was applied by one of my colleagues at D0 to calculate muon identification efficiency.
- The calculated efficiency is : 80 +/- 0.39)%
- The plot of $J/\psi(\mu^{+}\mu^{-})$ is shown below



Electron identification

- Identification of soft electrons(~ 1 GeV) involves three steps:
  - Find a charged track
  - Match tracks to Central Pre-Shower detector
  - Calculate energy deposited in the electromagnetic calorimeter.
- Calorimeter is divided into two parts; electromagnetic and hadronic.
  - electrons deposit almost all their energies in electromagnetic part
  - charged hadrons like pions, kaons deposit all their energies in hadronic part



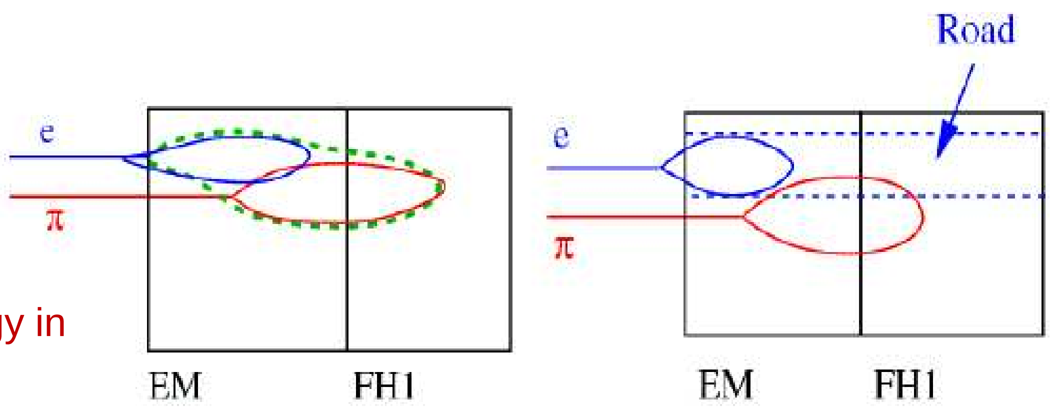
Road Method

- Low energy electron(~ 1 GeV) shower and hadron showers overlap in the electromagnetic calorimeter.
- To minimize this background from light charged hadrons like pions, a method called "road method" is used. The principle of this method is that for a given track, only the energy contained in a narrow tube, or "road", along the track extrapolation is considered.
- The electromagnetic calorimeter contains four floors, and as the charged hadrons are more likely to deposit their energies in the upper floor, only the energy deposited in the first three floors is taken in the calculation of energy deposited by the electrons.

The Road energy is ~ 89% of all energy deposited in the first 3 floors

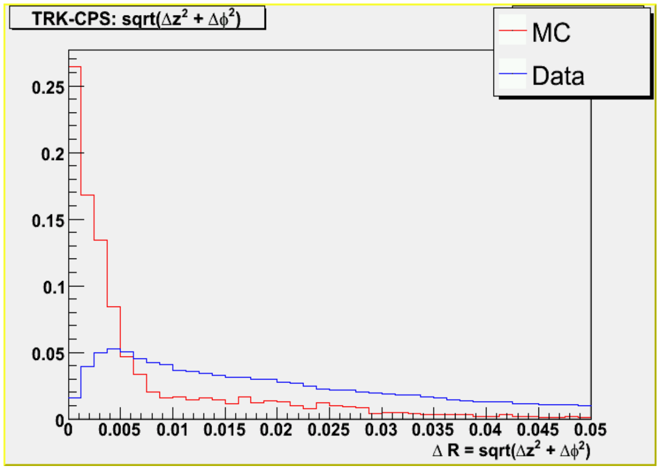
Road electron deposits ~90% of its energy in the first 3 floors.

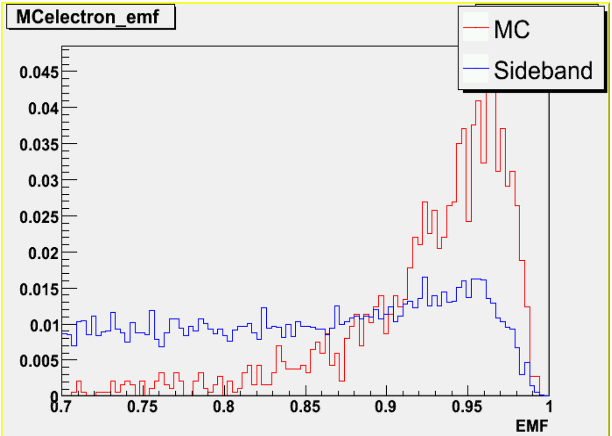
Therefore E/p ~80% and Electromagnetic fraction ~90

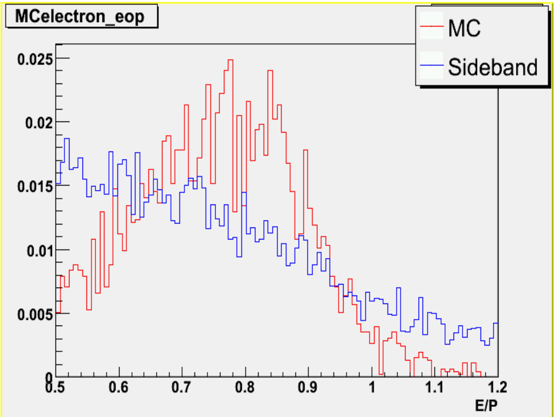


Variables used in electron identification

- The main discriminanting variables used in identifying soft electrons are:
  - $\Delta R = \sqrt{\Delta z^2 + \Delta\phi^2}$ Matching between Track and Central Pre-Shower.
  - Energy over Momentum (E/P), $\frac{E}{p} = \frac{\sum_{i=1,2,3} E_i}{p}$: ratio of total energy in 3 first floors of calorimeter to the momentum of the track.
  - Electromagnetic Fraction(EMF), $EMF = \frac{\sum_{i=1,2,3} E_i}{E_{Tot}}$ fraction of total energy in 3 first floors of EM calorimeter to total energy deposited in the calorimeter.
- Other variables used are: pT, $|\eta|$, hits on tracking system, energy deposit in CPS and Calorimeter





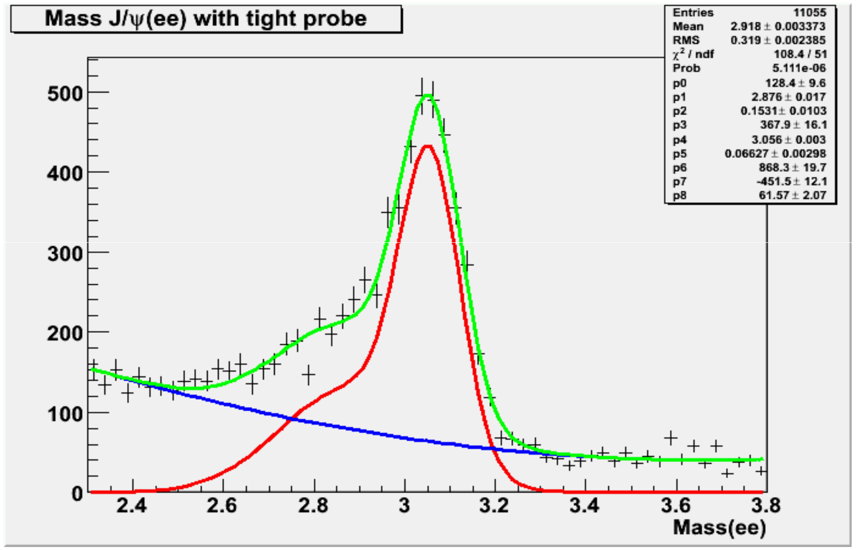


Tag and probe on $J/\psi(e^+e^-)$

- I worked on electron identification efficiency using the decay $J/\psi(e^+e^-)$

- The efficiency was calculated as the efficiency for a probe electron to pass the following tight cuts that had been applied to a tagged electron:
  - pT > 2 GeV
  - $|\eta| < 1.1$ (CPS acceptance)
  - At least 2 hits on CFT and SMT
  - CPS-Track matching: $|\Delta R| < 0.01$
  - CPS energy deposit > 0
  - Road electron transverse energy

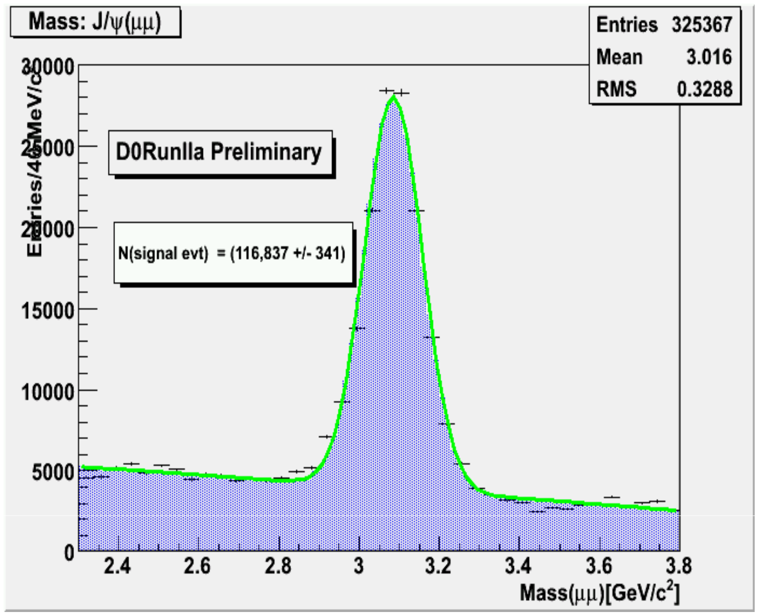
    (floor = 1,23) > 0
  - EMF > .9
  - 0.65 < E/P < 1



- The electron identification efficiency is : 65 +/-0.58)%

$J/\psi(\mu^+\mu^-)$ event selection

- The event $J/\psi(\mu^+\mu^-)$ was reconstructed as follows:
  - Two charged tracks identified as muons
  - Transverse momentum(pT) > 2 GeV
  - $|\eta|$ < 2 : muon system coverage
  - two hits in Silicon Micro-chip Tracker
  - two hits in the Central Fiber Tracker
  - one hit on muon system
  - Invariant mass range (2.3 – 3.8 GeV)



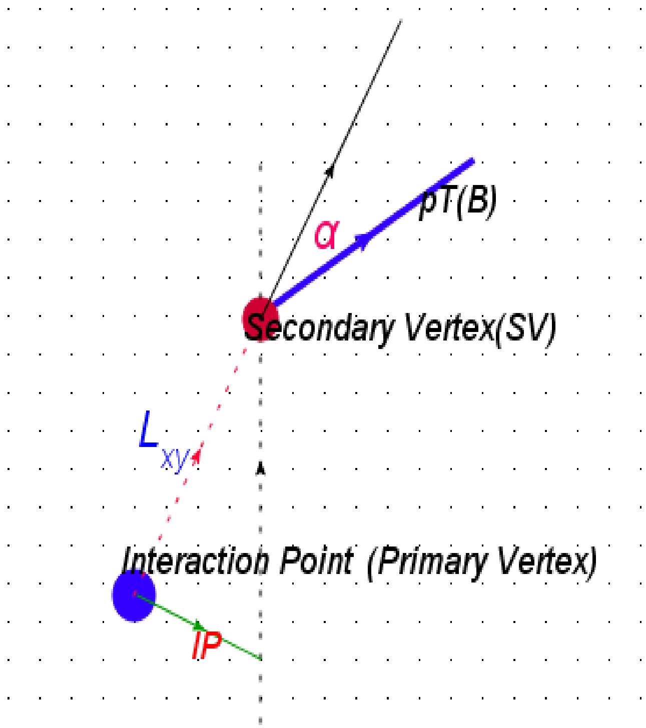
Variables used in B-hadrons reconstruction

- "BANA" package provides a framework of reconstructing B-hadrons by applying different variables like:
  - Transverse momentum: consistence with mass of b-quark (~5 GeV)
  - Vertex chi-square : ensure good vertexing
  - Transverse decay length significance , $L_{xy} / \delta L_{xy}$: consistence with lifetime of b-hadrons(~1 ps)
  - Impact parameter significance (IP/σ)
  - Isolation: $I = \dfrac{|pT(B)|}{|pT(B)| + \sum_{i \neq B} p_i(\Delta R < 1)}$,

    with

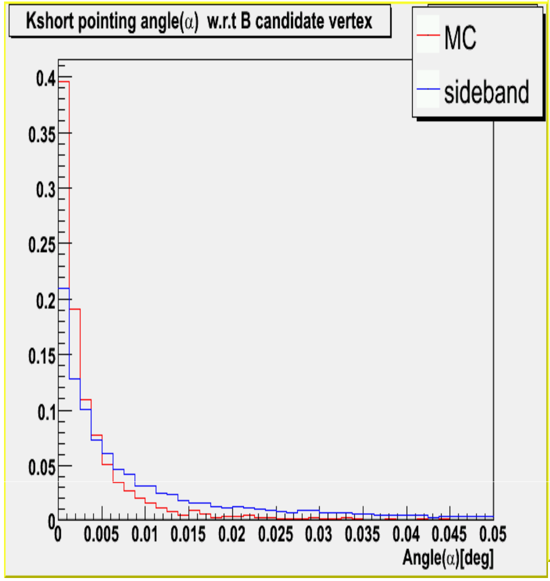
    $$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

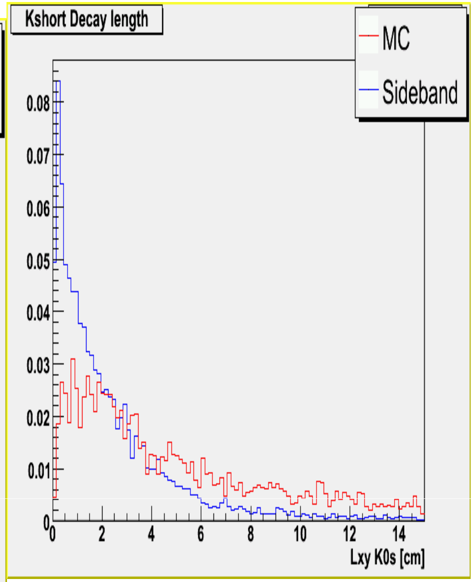
  - Pointing angle , α : consistence between pT of B-hadron and the vector line joining PV and SV

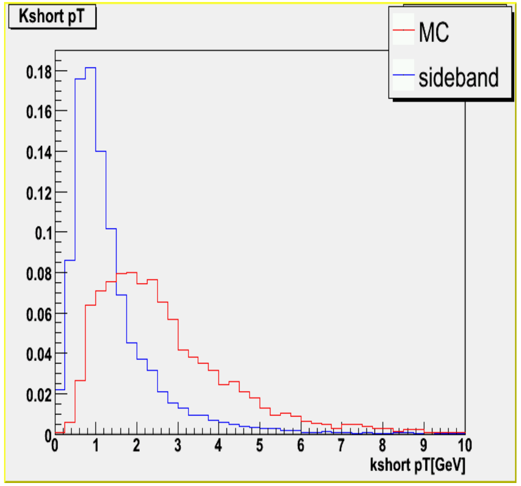


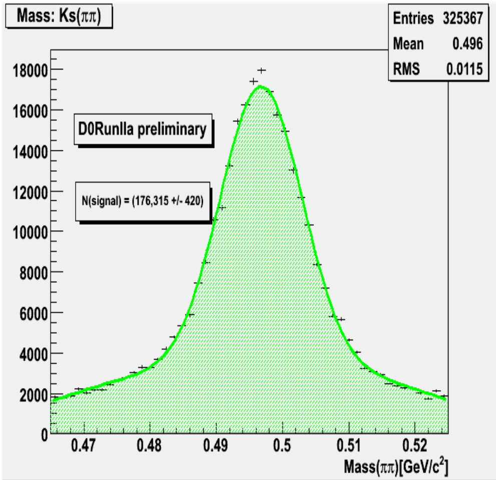
Ks selection

- Kshort reconstruction:
  - look for a long lived neutral particle formed of a vertex of two charged tracks each assigned mass of a pion.
  - the invariant mass of this neutral particle to be in the range 0.48 – 0.52 GeV.
  - Transverse decay length (Lxy) > 2.5 cm (long lived particle)
  - pT > 1 GeV
  - pointing angle with respect to B candidate vertex to be less than 0.012 deg



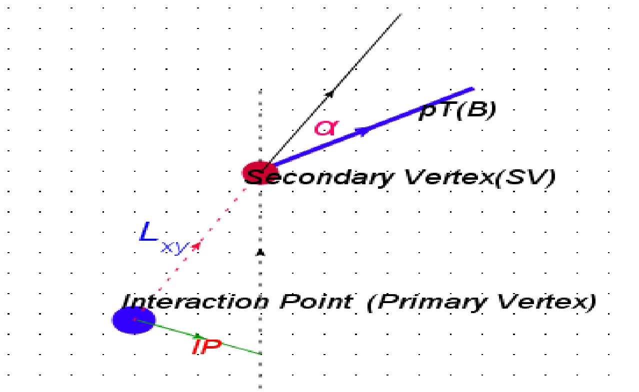


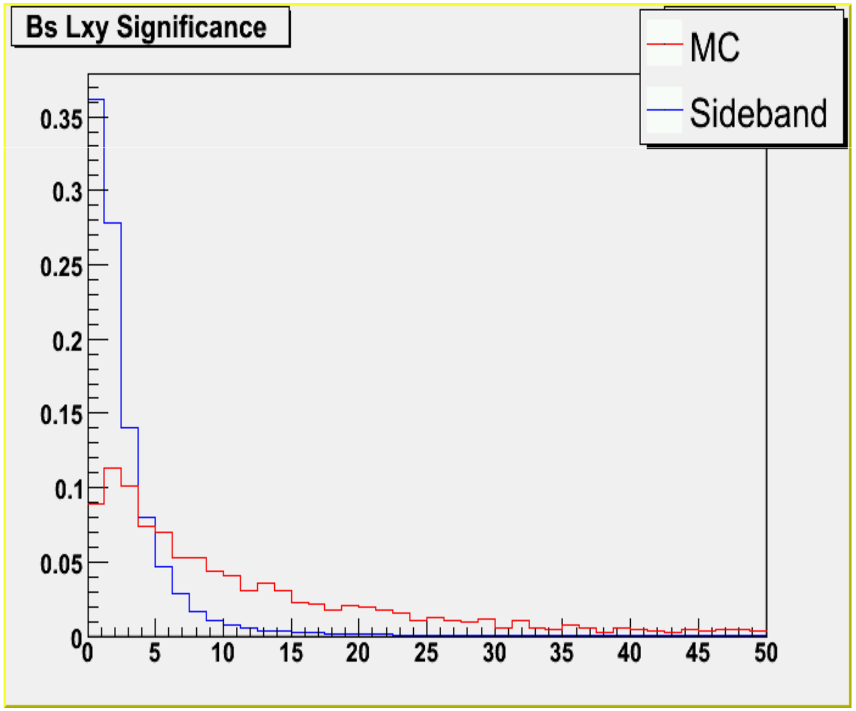


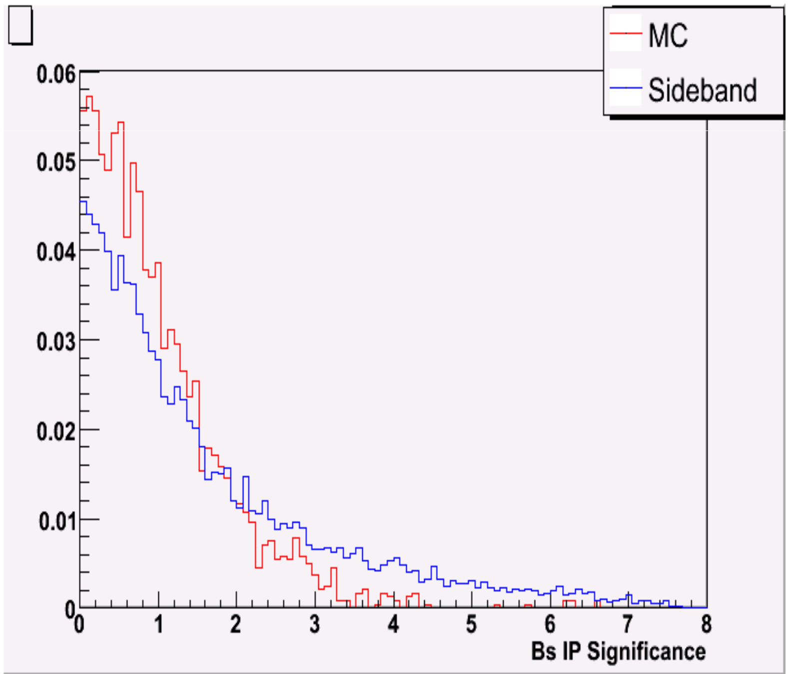


Discriminating variables(1)

- Bs candidate IP significance
  - Optimized cut: < 1.8
- Bs candidate decay length significance
  - Optimized cut: > 8

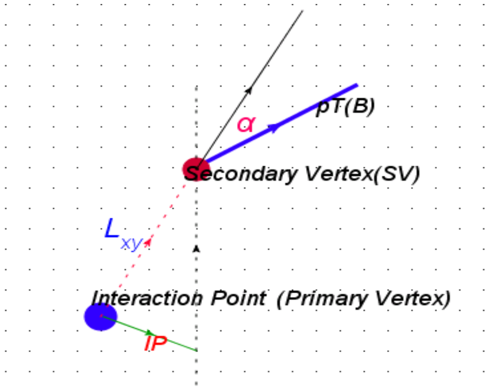


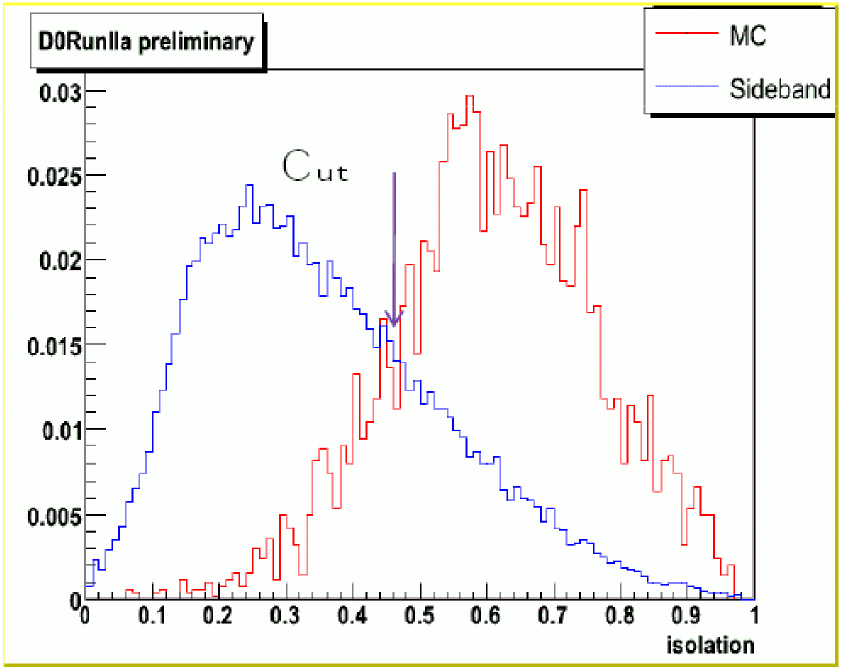


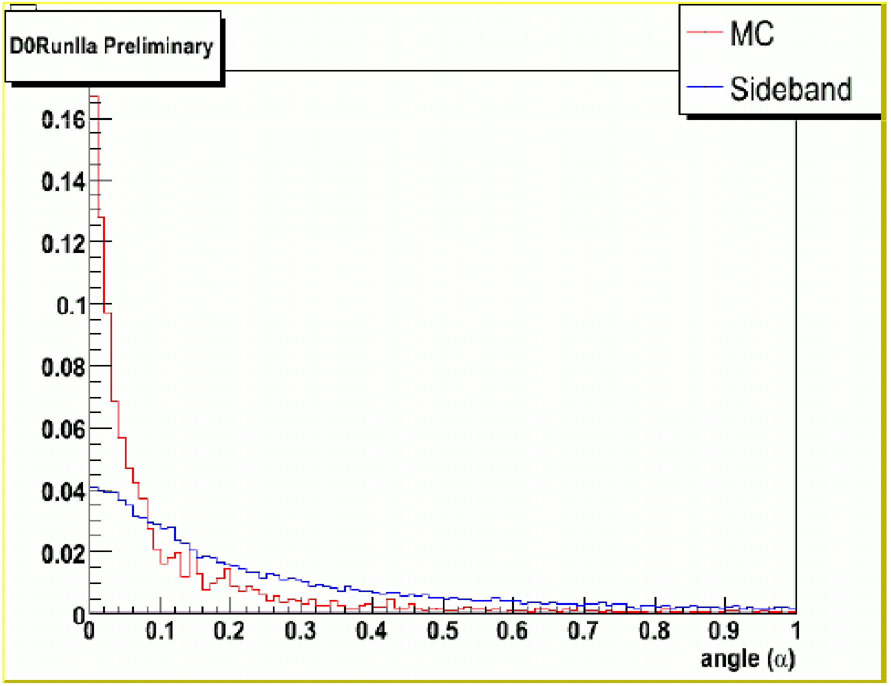


Discriminating variables(2)

- Bs candidate isolation
  - Optimized cut > 0.5
- Bs candidate Pointing Angle
  - Optimized cut < 0.1 deg

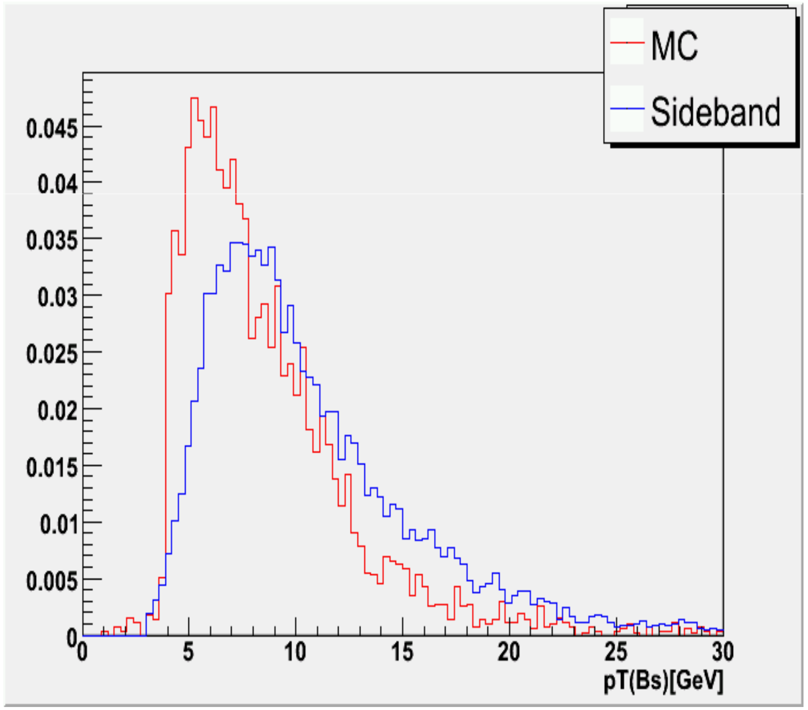


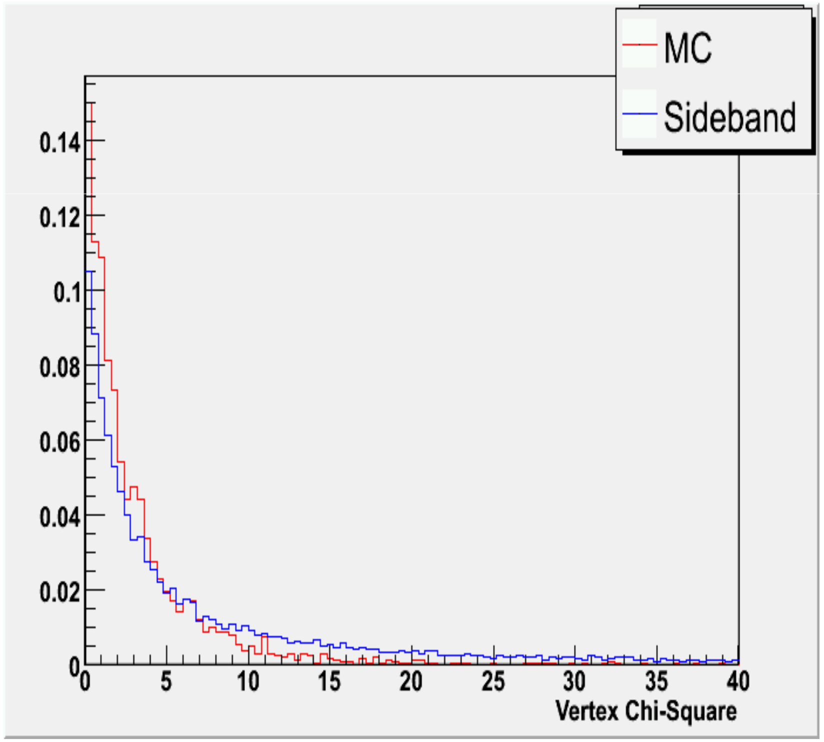




Discriminating variables(3)

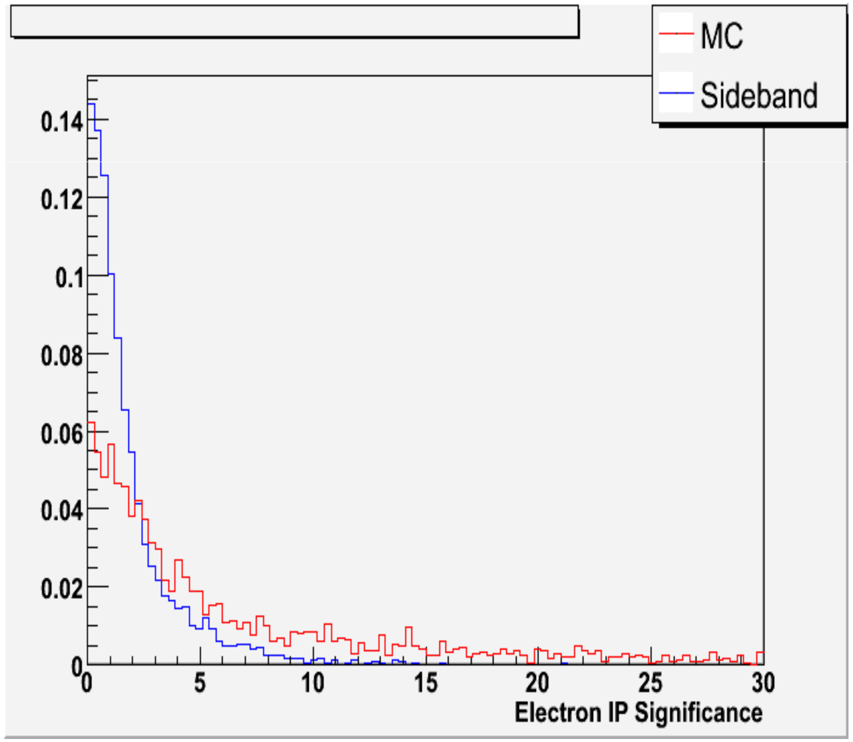
- Bs candidate transverse momentum
  - cut > 6 GeV
- Bs candidate Vertex Chi-Square
  - cut < 16





Discriminating variables(4)

- Muon and electron IP significance:
  - reduce the prompt background,
  - ensures that muon and electron are originating from secondary vertex not primary vertex
  - The cut applied is that IP significance of each lepton is greater than 3.



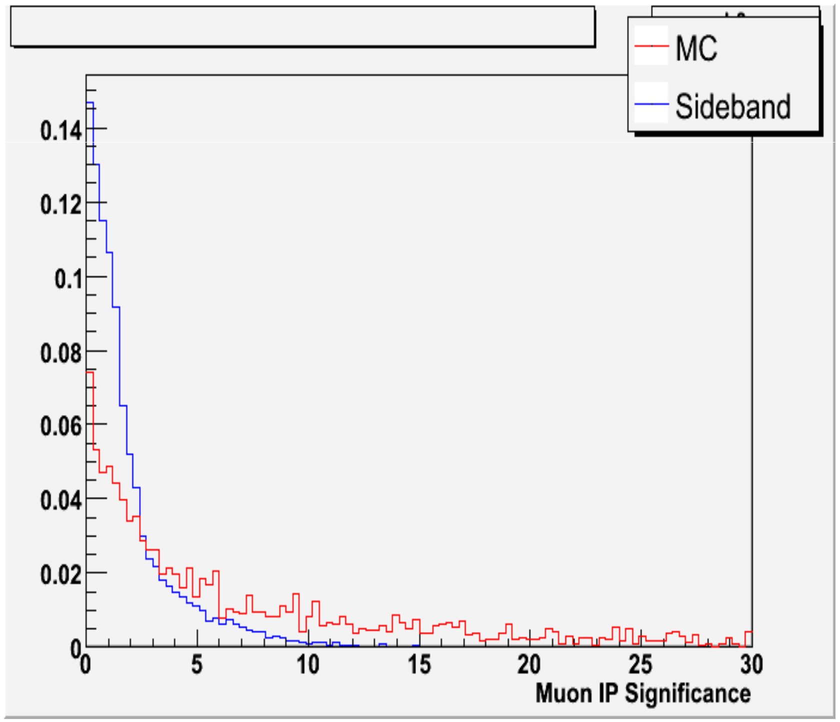


Table of cuts

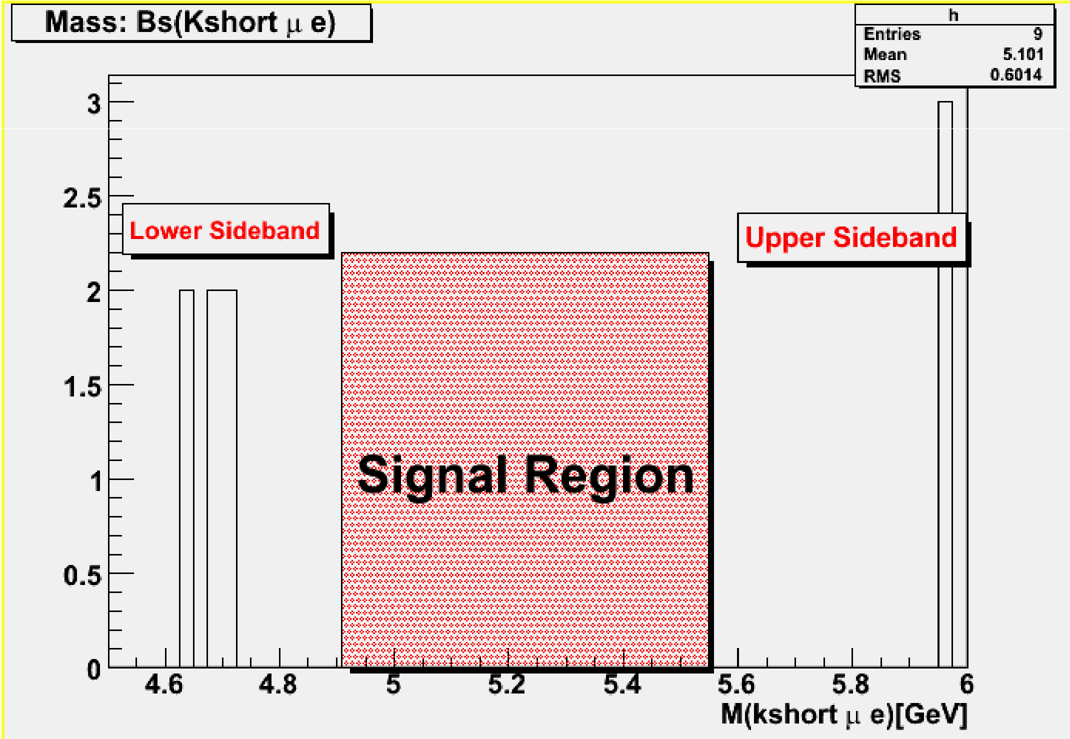
CUT	Background Rejection	Signal rejection
EMF > 0.92	48.7%	87.2%
0.65 < E/P < 1	46.4%	75.2%
|Del R| < .006	81.6%	68%
Muon IP signif > 3	77.1%	62.7%
Electron IP signif > 3	81.8%	56.7%
Ks Pointing Angle < 0.01 deg	42%	89.3%
Ks pT > 1 GeV	44.5%	90.1%
Ks Lxy > 2.5 cm	56.8%	73.6%
Bs Isolation > 0.5	78.6%	77.1%
Bs pT > 6 GeV	14%	76.4%
Bs Pointing angle < 0.1	66.6%	68%
Bs Lxy signif > 8	97.2%	50.2%
Bs Vertex chi-2 < 16	16.4%	93%
TOTAL	99.7%	1.65%

$Bs \rightarrow Ks(\pi^+\pi^-)\mu^\pm e^\mp$ Event reconstruction

- Reconstruct daughter particles
  - Muon
  - Electron
  - Ks
- Form a vertex
- Calculate invariant mass of $Bs \rightarrow Ks(\pi^+\pi^-)\mu^\pm e^\mp$ in the range (4 – 6 GeV)

Mass Plot (box still closed)

- Expected background events in signal region is (6.75 +/- 0.38)
- Signal region(-6σ, +3σ) (4.943 – 5.582 GeV)
- Lower sideband(6 σ wide) (4.914 -4.514 GeV)
- Upper sideband(6 σ wide)(5.582 – 6 GeV)
- With σ = 70 MeV (obtained from MC)



Normalization channel reconstruction

$J/\psi(\mu^+\mu^-)$

- Mass range (2.9 -3.2 GeV)
- pT > 3 GeV
- Vertex chi-square < 20

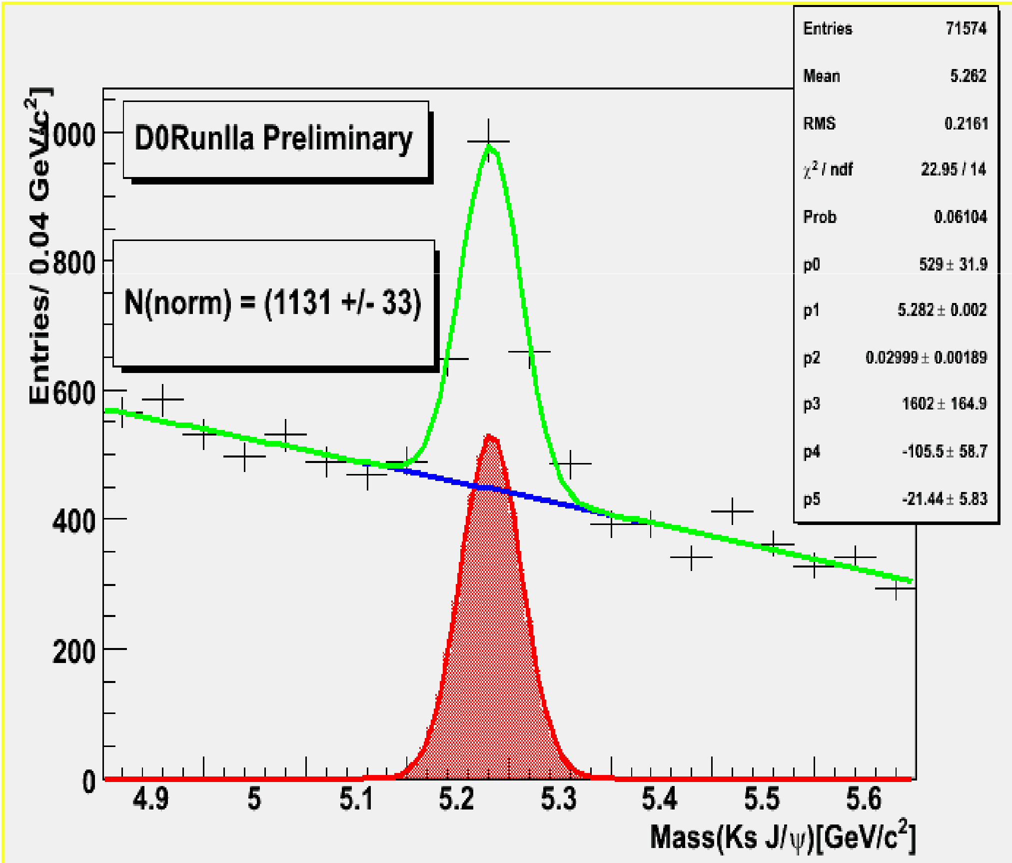
$Ks(\pi^+\pi^-)$

- pT > 1 GeV
- Mass range(0.47 – 0.52 GeV)
- Ks pointing angle < 0.01 deg
- Ks transverse decay length > 2.5 cm

Bd candidate

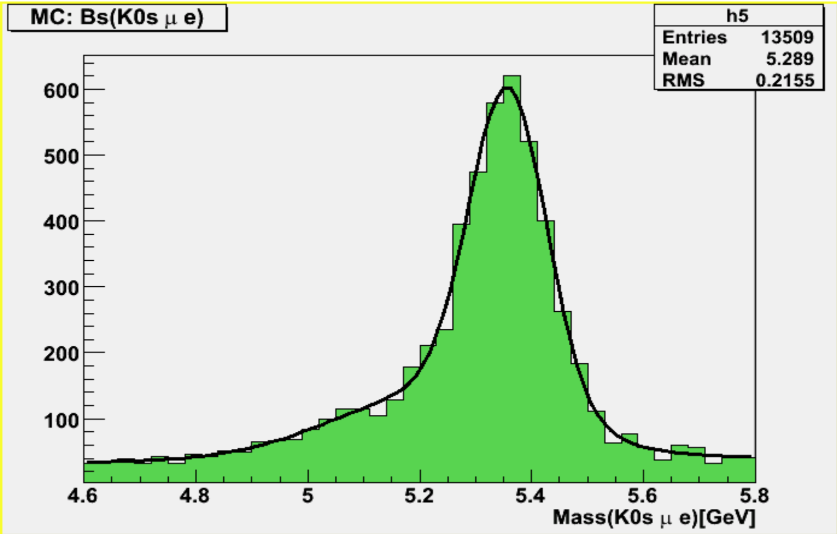
- Transverse momentum > 5 GeV
- Vertex chi-square < 16
- Isolation > 0.46
- Pointing Angle < 0.1
- Decay length significance > 4

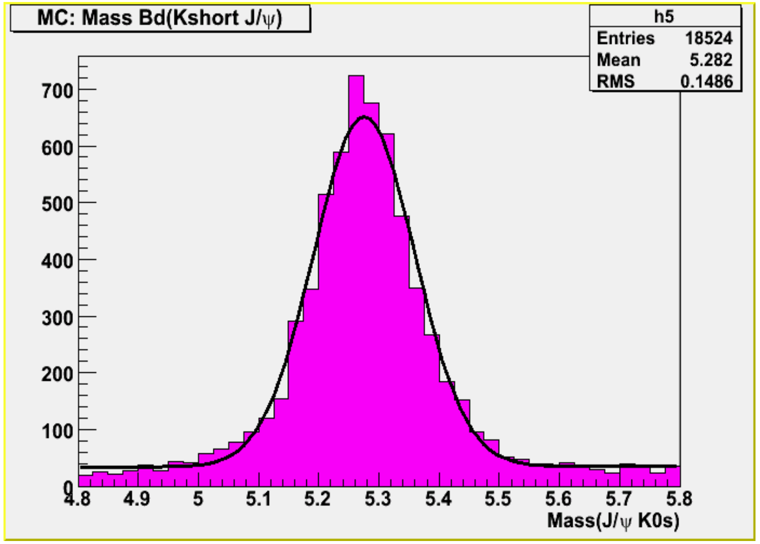
Mass Plot of normalization channel



Acceptance and Reconstruction efficiency

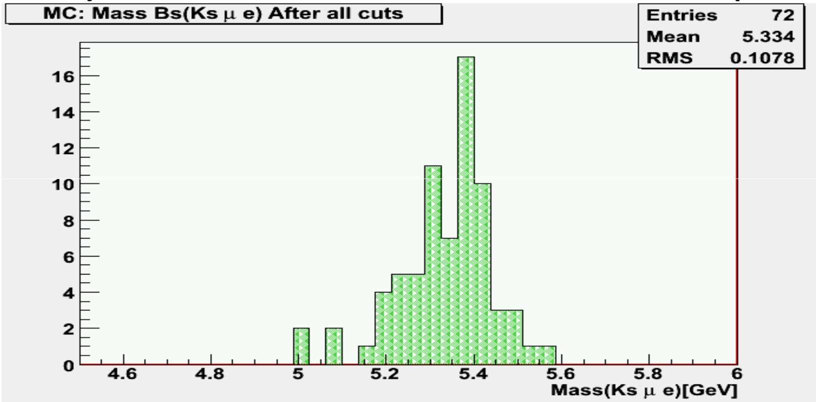
- Generated events
  - signal mode: 190k
  - normalization mode: 200k
- Reconstructed events
  - signal mode : 4358 +/- 66 evts
  - Normalization mode : 5272 +/- 72 evts

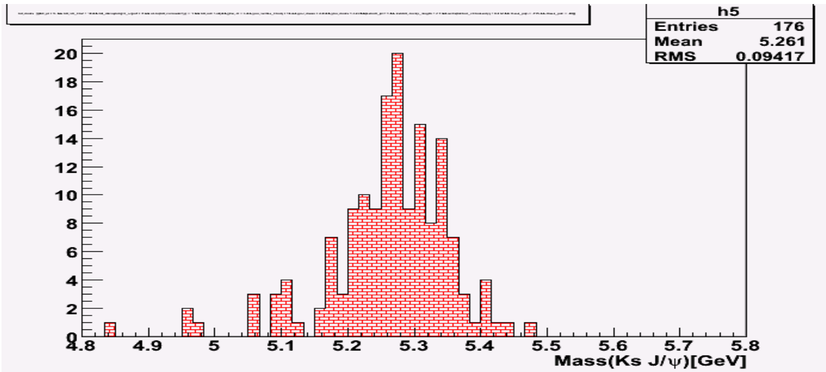




Acceptance and reconstruction efficiency

- The acceptance is calculated as an efficiency for generated events passing generator level cuts (D0mess efficiency)
- Calculated acceptances
  - Signal mode: (4.93 +/- 0.15) %
  - Normalization Mode : (15.37 +/- 0.44) %
- Event selection efficiency is calculated as an efficiency for the reconstructed events to pass the cuts applied in the event selection
  - Signal mode evts: 72 +/- 8.48
  - Normalization mode evts : 176 +/- 13.26
- Calculated event selection efficiencies
  - Signal mode: (1.65 +/- 0.15) %
  - Normalization mode: (3.3 +/- 0.25) %
- Efficiency ratio, $\frac{\varepsilon_{norm}}{\varepsilon_{signal}}$: 6.23 +/- 0.26





Preliminary results for Parameters of branching fraction

Parameter	Value
$Br(Bd \to J/\psi Ks)$	$(8.71 \pm 0.32) \times 10^{-4}$
Efficiency ratio, $\frac{\varepsilon_{norm}}{\varepsilon_{signal}}$	6.23 +/- 0.26(stat.)
N($Bd(J/\psi Ks)$)	1131 +/- 33(stat.)
Fragmentation ratio, f_{Bd}/f_{Bs}	3.51 +/- 0.39 (syst.)
N($Bs \to Ks(\pi^+\pi^-)\mu^{\pm}e^{\mp}$)	Box still closed

Conclusion/summary

- We managed to utilize a $J/\psi(e^{+}e^{-})$ channel that had been previously ignored in B-Physics analyzes.
- Work is still going on selecting and optimization of cuts applied in the event selection, calculation of acceptances and reconstruction efficiency
- Full data sample will be analyzed as soon as we have satisfactory results obtained from RunIIa data sample.
- Evidence for new physics beyond SM is obtained by observing a deviation between prediction and observation or by observing a new phenomena that doesn't exist in the framework of the SM;

LETS HOPE THE BOX CONTAINS THE SIGNAL!!!!!

THANK YOU!!!!!!