Towards a measurement of the photon polarisation in $b \to s\gamma$ at LHCb

Michelle Nicol, 3rd year PhD, LSD seminar, 8 June 2012

Towards a measurement of the photon polarisation in $b \to s\gamma$ at LHCb

and why it is a pain in the ass to study electrons at LHCb

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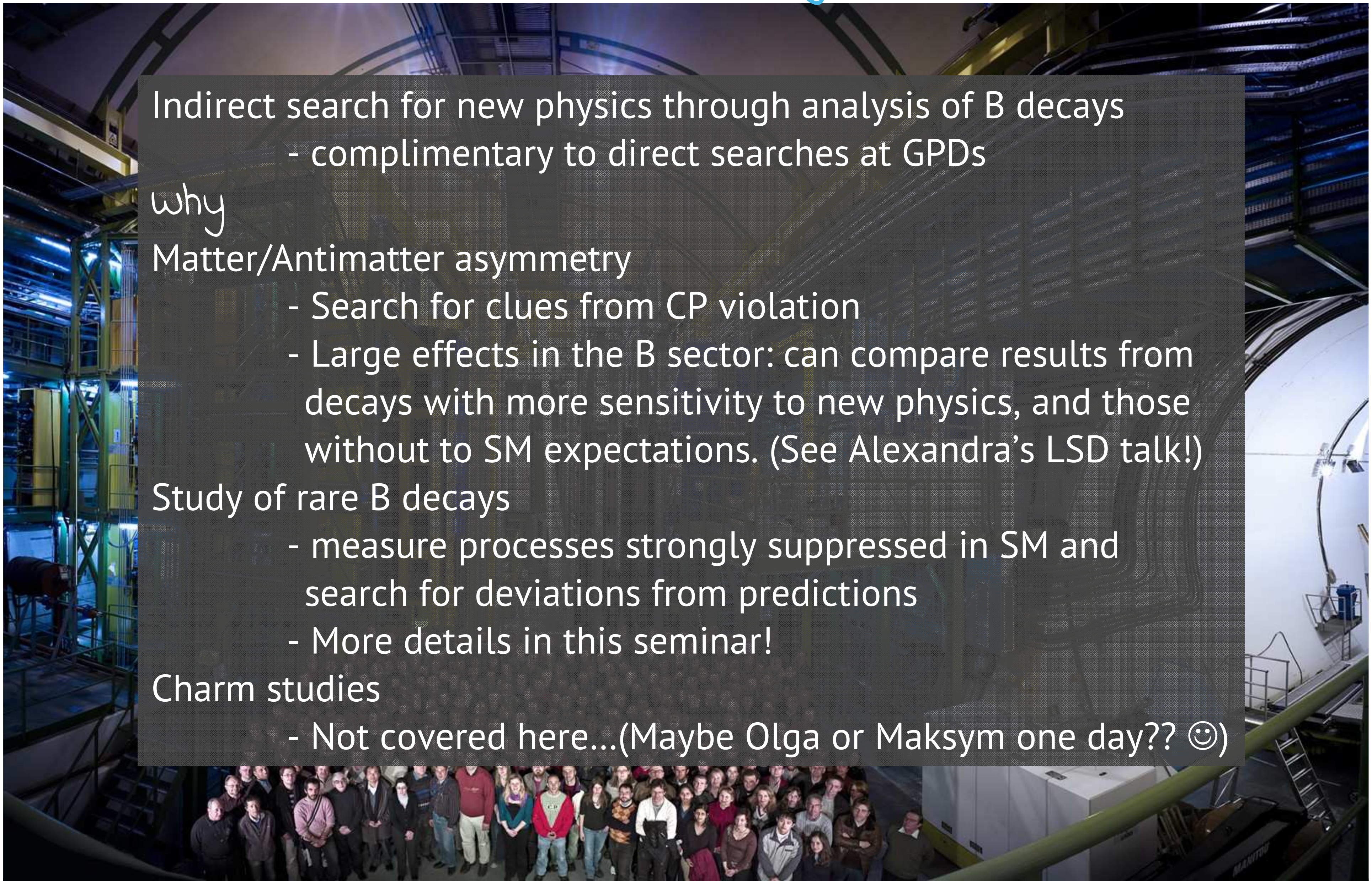
The LHCb detector: Dedicated B Physics experiment



Indirect search for new physics through analysis of B decays
- complimentary to direct searches at GPDs

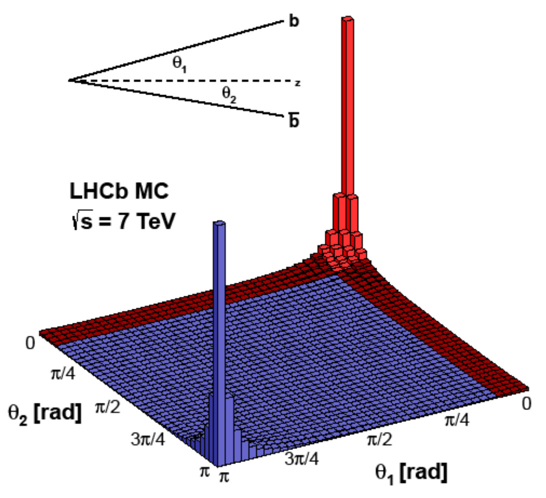
Why

Matter/Antimatter asymmetry
- Search for clues from CP violation
- Large effects in the B sector: can compare results from decays with more sensitivity to new physics, and those without to SM expectations. (See Alexandra's LSD talk!)

Study of rare B decays
- measure processes strongly suppressed in SM and search for deviations from predictions
- More details in this seminar!

Charm studies
- Not covered here…(Maybe Olga or Maksym one day?? ☺)

The LHCb detector: optimised for B physics

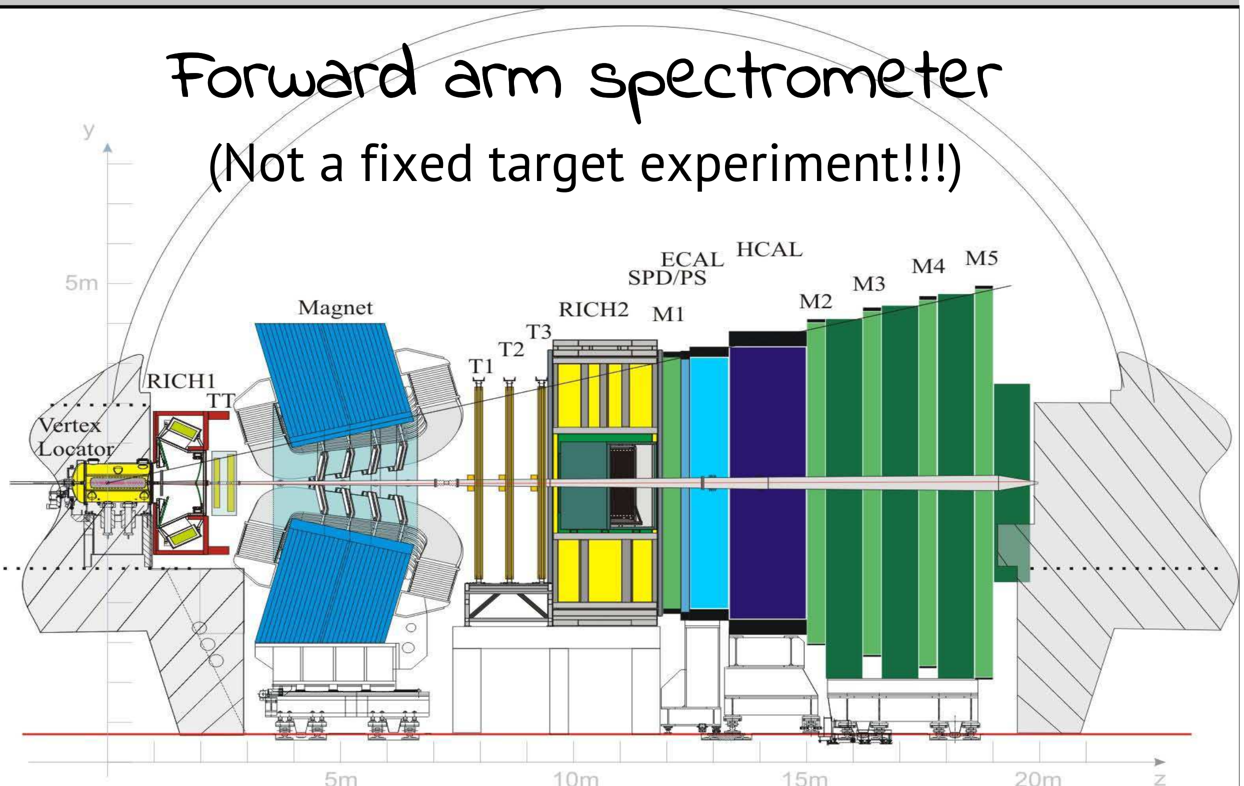


$b\bar{b}$ pairs at LHC produced in same forward/backward cone

2x10[11] B hadrons in LHCb acceptance in 2011

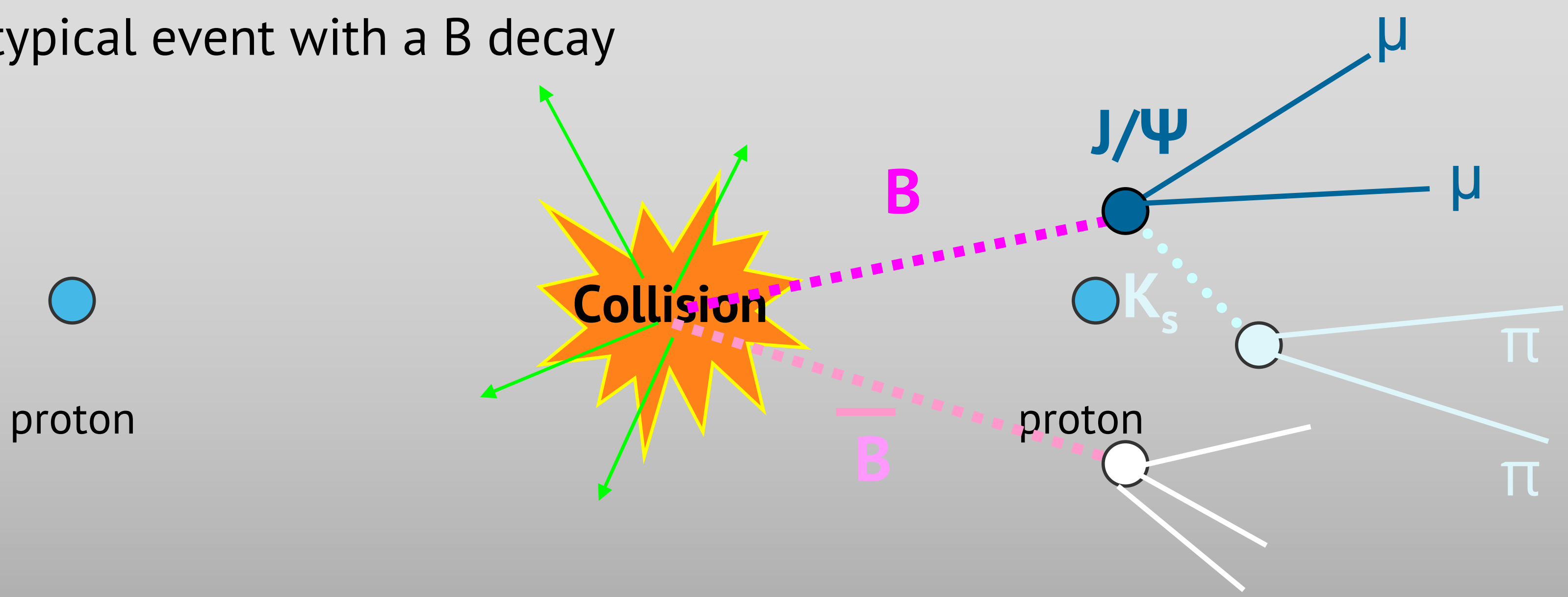
Forward arm spectrometer

(Not a fixed target experiment!!!)



The LHCb detector: optimised for B physics

A typical event with a B decay



Looking for displaced vertices- much easier with one pp interaction per crossing!
-LHCb runs at lower luminosity than GPDs

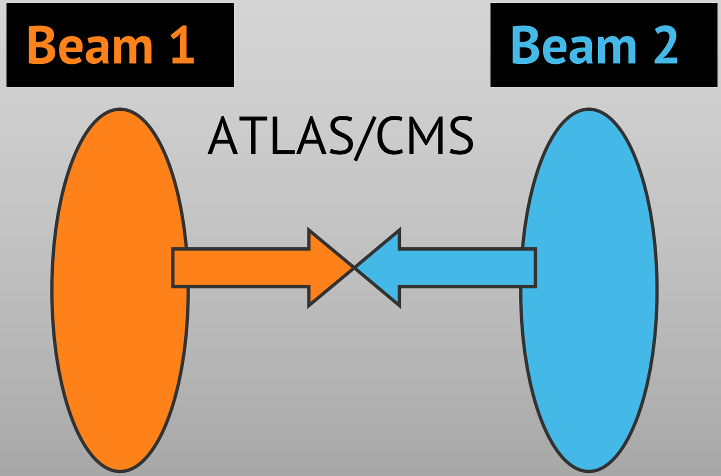
LHCb: peak luminosity **$4\text{x}10^{32}$ cm^{2}s^{-1}**, **~ 1.5 pp** interactions (2.5 in 2010!)

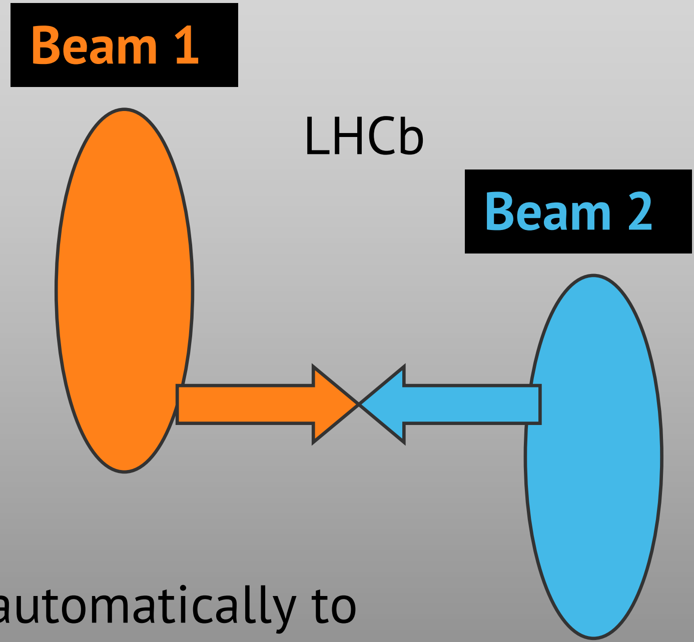
ATLAS/CMS: peak luminosity **$6\text{x}10^{33}$ cm^{2}s^{-1}**, **~ 25 pp** interactions

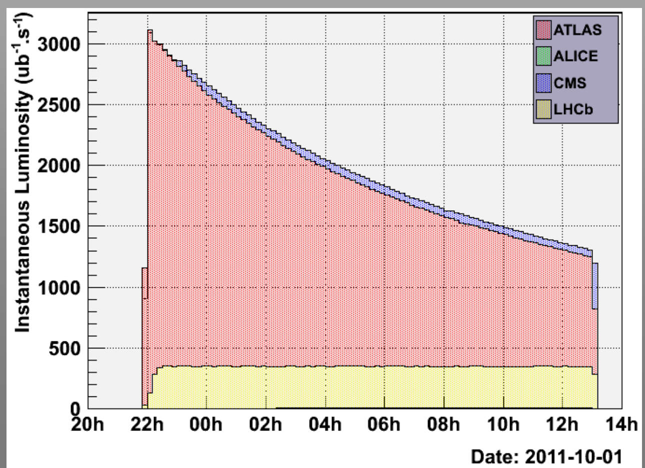
The LHCb detector: luminosity stuff

Achieved by luminosity leveling

~Reduces the interaction area where the bunches pass through







Adjusted automatically to keep constant luminosity

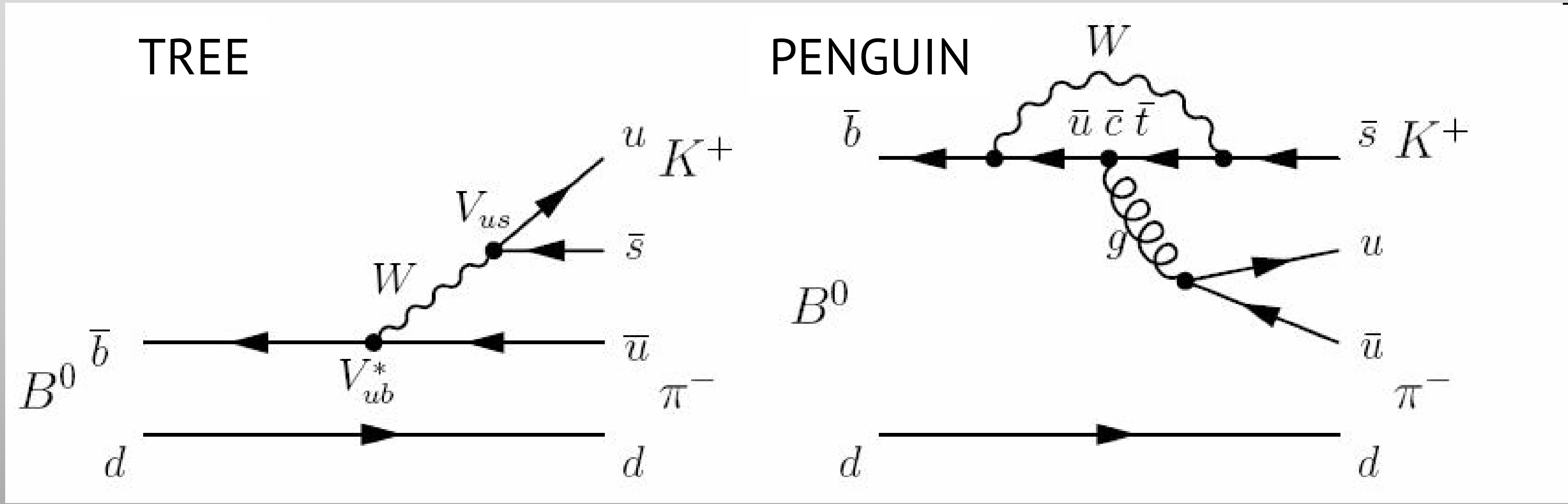
Total integrated luminosity in 2011: $1 fb^{-1}$

Planned integrated luminosity in 2012: $1.5 fb^{-1}$

$b \rightarrow s\gamma$

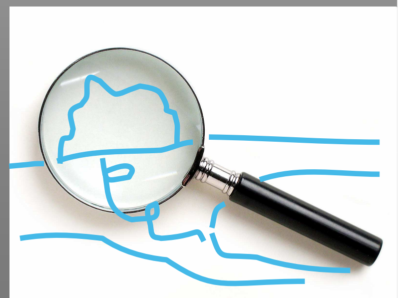
Few words on rare B decays

The rare decays searched for at LHCb are Flavour Changing Neutral Currents (FCNC)



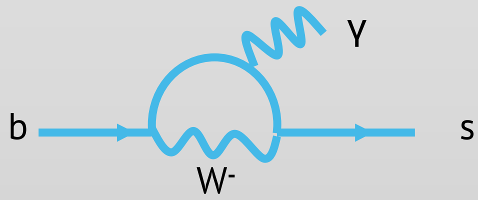
- FCNC are forbidden at tree level in the SM

- Sensitive to new physics, as new particles could manifest in the loop, and cause deviations from standard model predictions. Can change branching fractions, angular distributions, CP violation.



$b \rightarrow s\gamma$ proceeds via FCNC loop.

BR consistent with SM predictions

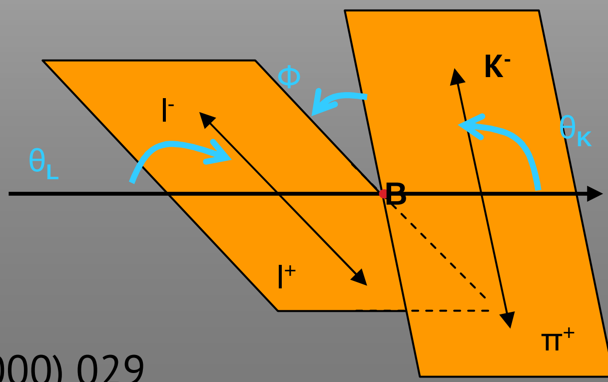


BUT could still be new physics present and detectable via details of the decay process…

In SM, due to the chiral structure of W couplings to quarks, the photon from b is predominantly left handed (right handed component suppressed by m_s/m_b)

- Can imagine new physics scenarios with enhanced right handed current whilst keeping SM BR.

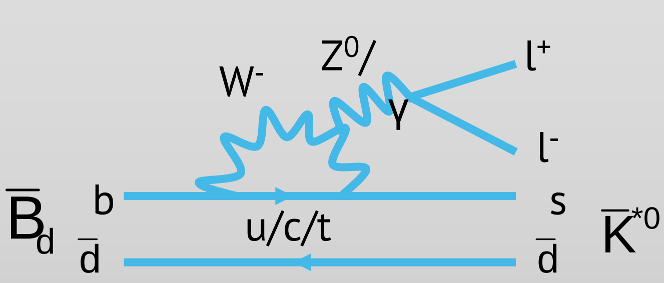
One method [1] to measure the photon polarisation come from the angular analysis of $\mathbf{B_d \rightarrow K^* l^+ l^+}$

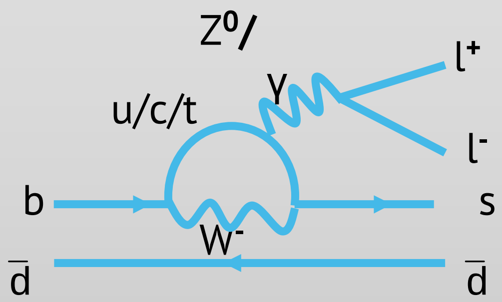


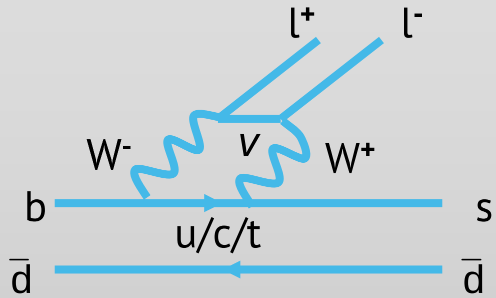
[1] Y. Grossman and D. Pirjol, J. High Energy Phys. 06 (2000) 029

$B \to K^*ll$: to measure the photon polarisation

$B_d \rightarrow K^*ll$







At low $q^2=(M(ll))^2$, lepton pair more likely to come from virtual photon

- sensitive to the photon polarisation

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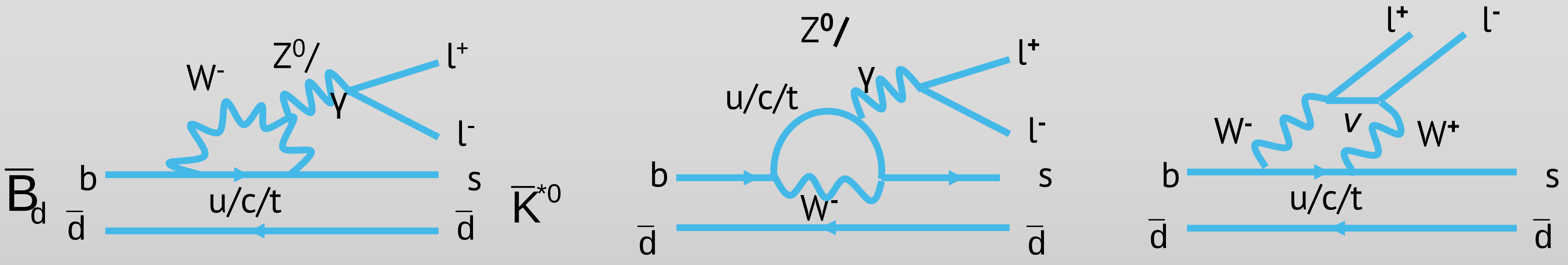
$B_d \to K^* ll$



At low $q^2=(M(ll))^2$, lepton pair more likely to come from virtual photon

- sensitive to the photon polarisation

At LHCb, can measure using electrons or muons...

- muons: experimentally cleaner=> a lot more stats!
- electrons: formalism is simpler-can neglect the lepton mass
- electrons have access to lower q^2 => more sensitive region...

[1] Y. Grossman and D. Pirjol, J. High Energy Phys. 06 (2000) 029

$B_d \to K^* ll$ formalism, to cut a long story short...

Basically can write the differential decay distribution, as a function of the three angles (which you measure), in terms of 3 parameters (which you fit for).

$$F_L = \frac{|A_0|^2}{|A_0|^2 + |A_\perp|^2 + |A_{||}|^2}$$

$$A_T^{(2)} = \frac{|A_\perp|^2 - |A_{||}|^2}{|A_\perp|^2 + |A_{||}|^2}$$

$$A_{Im} = \frac{\Im\left(A^*_{||L} A_{\perp L}\right) - \Im\left(A^*_{||R} A_{\perp R}\right)}{|A_0|^2 + |A_\perp|^2 + |A_{||}|^2}$$

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In helicity amplitudes, $A_T \sim -2A_R/A_L$ (BINGO)

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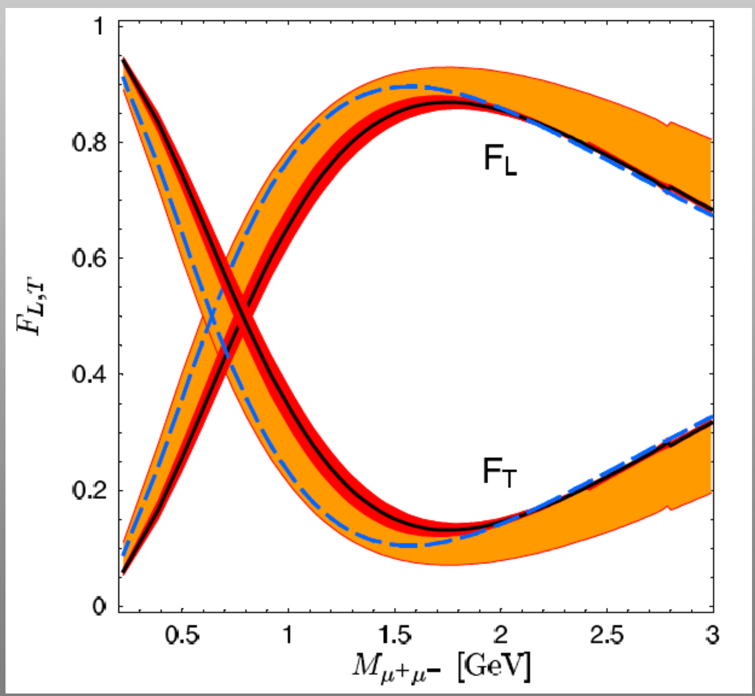
In helicity amplitudes, $A_T \sim -2A_R/A_L$ (BINGO)

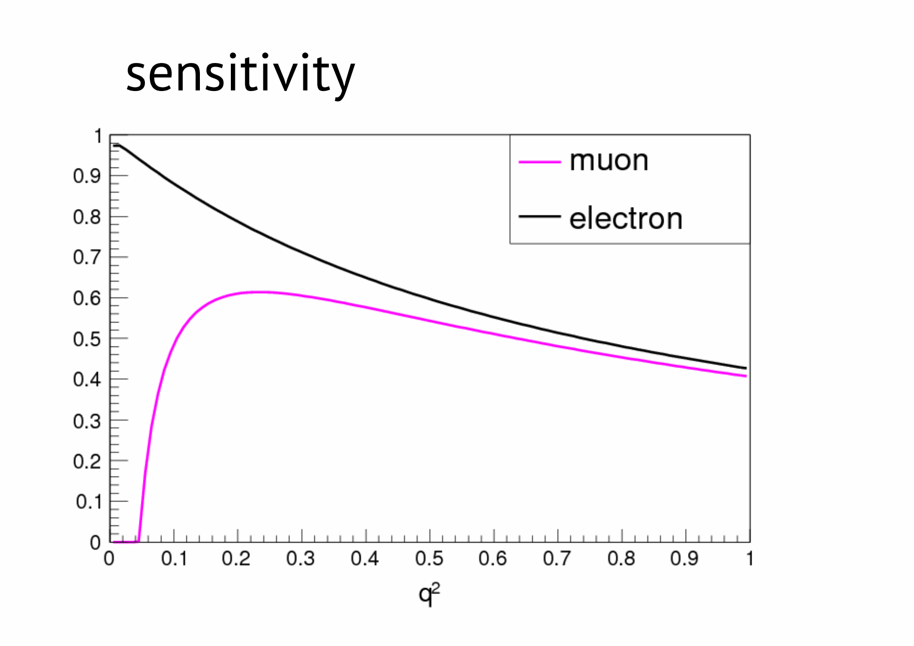
$$\frac{1}{2}(1 - F_L) \times A_T^{(2)} \times (1 - \cos^2\theta_K)$$

If FL=1, no sensitivity



http://arxiv.org/abs/hep-ph/0502060v2
Frank Krüger, Joaquim Matias

$B_d \to K^{*}ll$ electrons...win???



Threshold effects worsen muon sensitivity at low q^2

So, my thesis is based on analysis of $B \to K^{*}ee$ for $30 < M(ll) < 1000$ MeV

Measuring $B \to K^* ee$ at LHCb

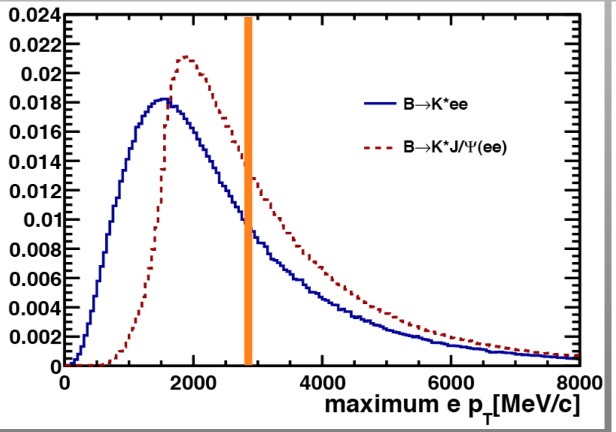
People keep telling me a challenging analysis is fun... ☺

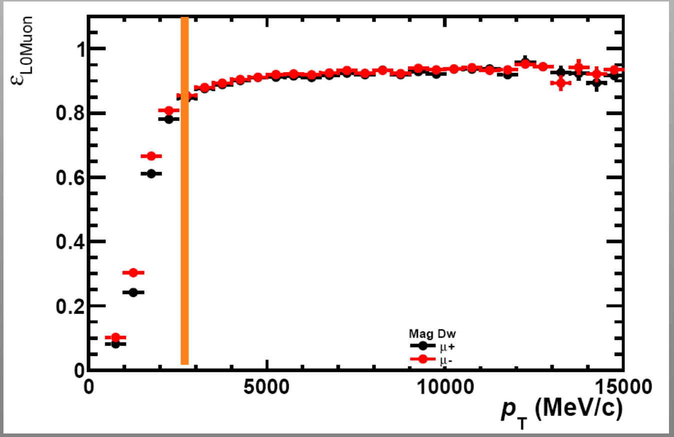
Particular challenges of $B_d \rightarrow K^*ee$

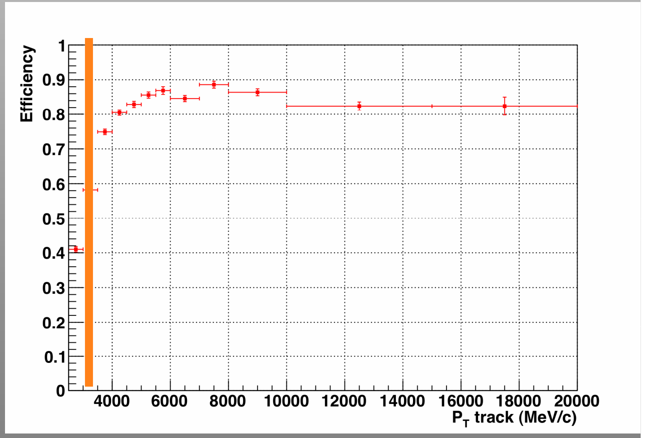
- small BR- 2.2×10^{-7} predicted in mass range
- small q^2 means low p_T electrons means lots of background!
- trigger inefficient on low p_T electrons
- Bremsstrahlung means worse mass resolution

\+ ...

Necessary to develop Multivariate analysis to find optimal selection!





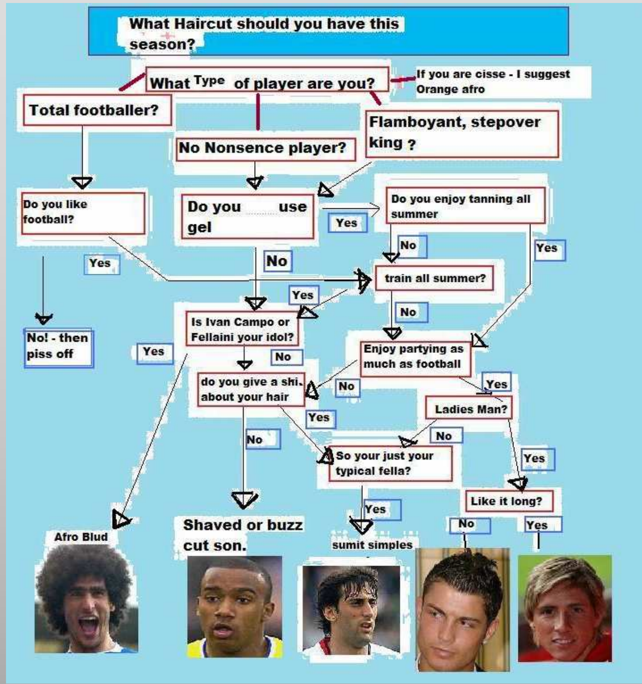


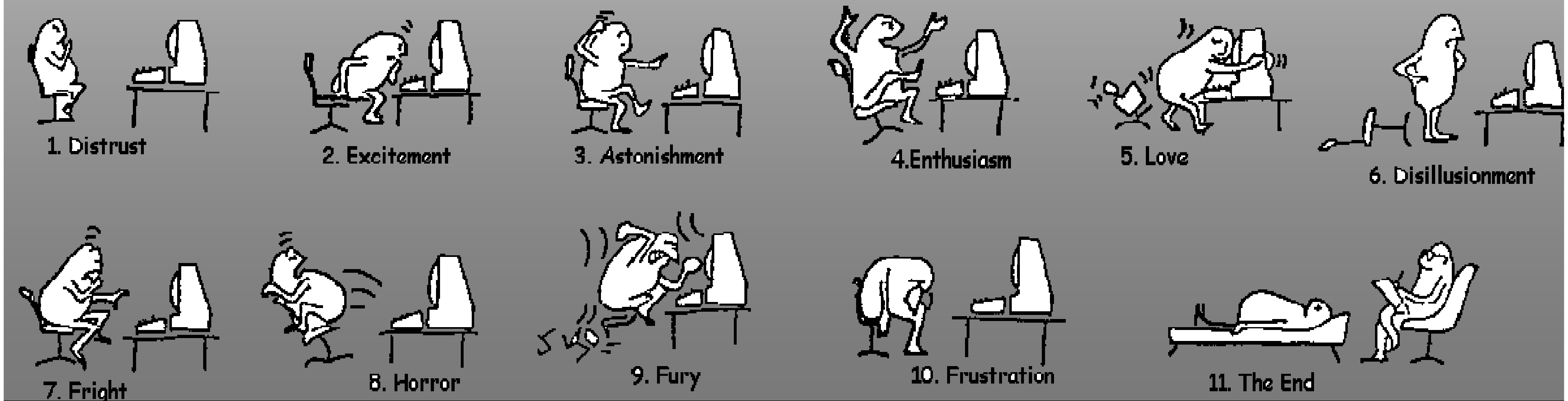
Multivariate selection

BDT is the fashionable MVA at LHCb
(was indeed the one that worked best straight out of the TMVA box for me…)

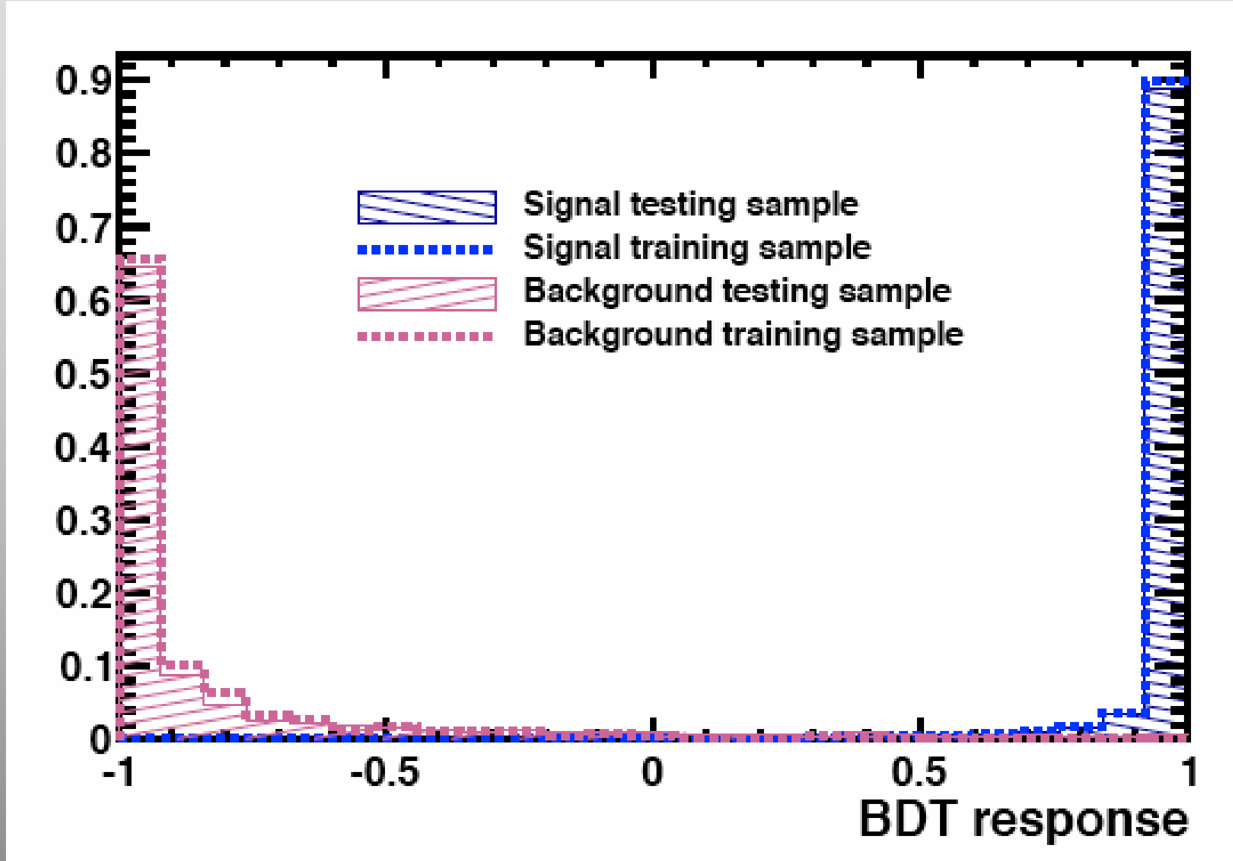
Trained to separate $B \to K^{*}ee$ MC from sidebands of the data collected (BMass>5600 MeV)

Uses kinematic and geometric variables such as PT, flight distance etc





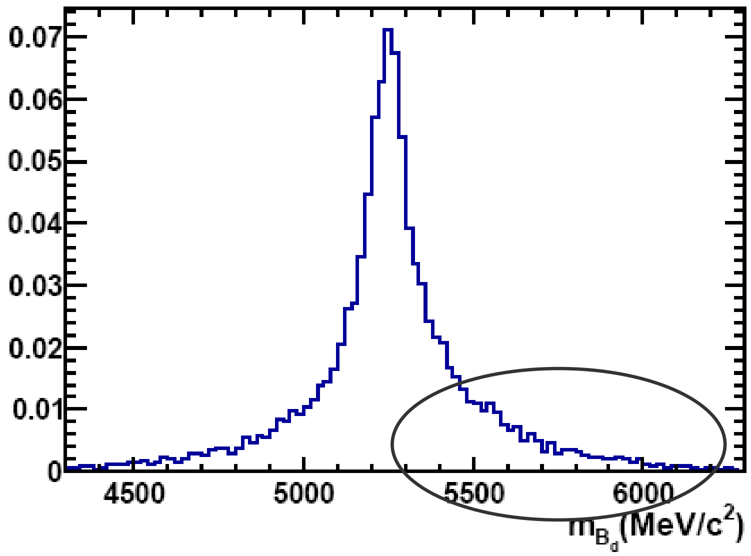
Multivariate selection



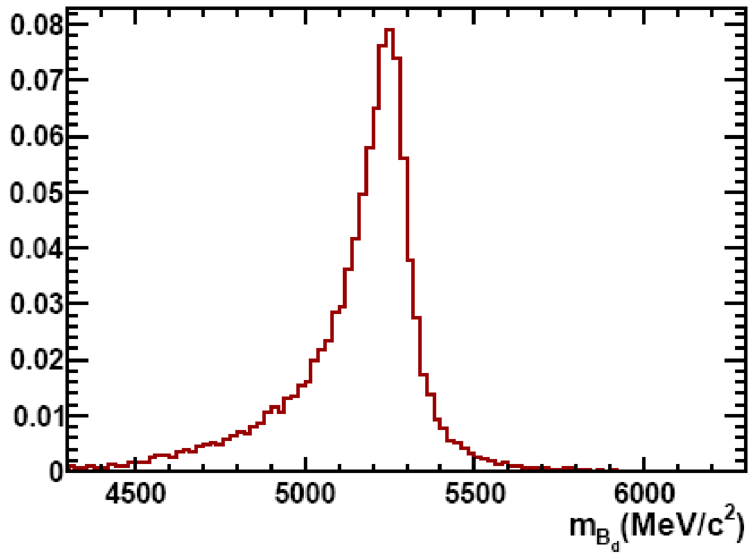
Then 2D optimisation of BDT response and PID performed to maximise $S/\sqrt{(S+B)}$ to set BDT cut value.

Signal shape after selection

After applying the BDT selection, the eeK* mass on MC had a strange shape...



(a) $B^0 \rightarrow K^{*0} e^+ e^-$ MC



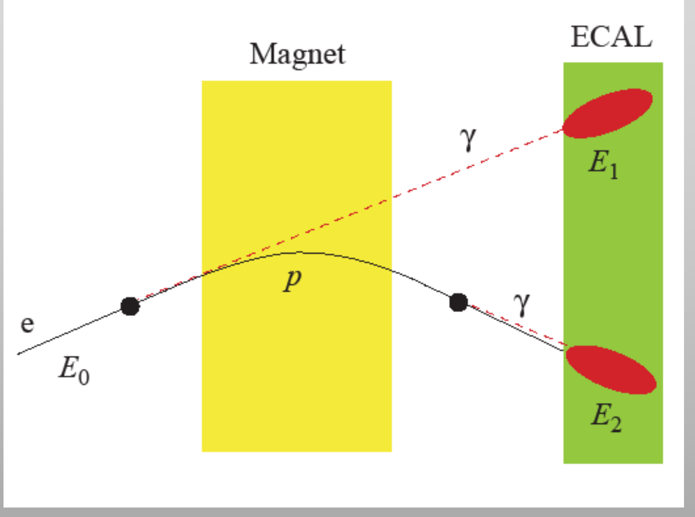
(b) $B^0 \rightarrow J/\psi(ee) K^{*0}$ MC

Expect low mass tail from missing Bremsstrahlung photons, but what are the high mass events??

-Problems with the Brem recovery tool...

Bremsstrahlung recovery

Try to recuperate as much of the missing Brem energy as possible



Search for any Brem emitted before magnet

- Extrapolate track from before magnet to calorimeter
- Form Chi2 between all neutral clusers in calo and this predicted brem position
- If Chi2< 300, add brem to electron

Bremsstrahlung recovery

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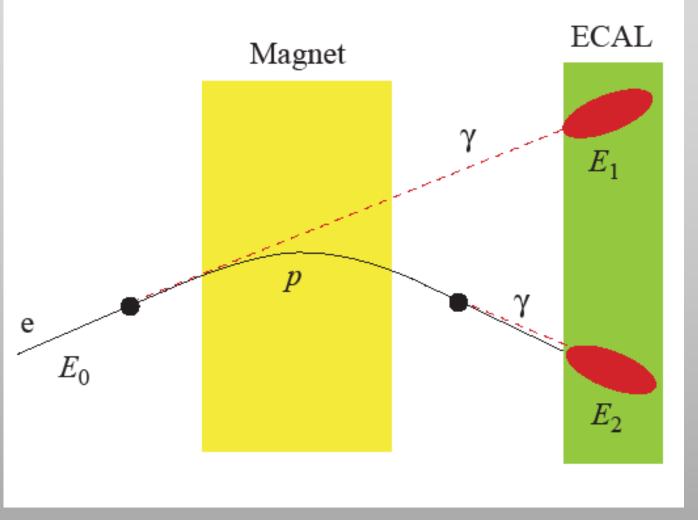

Search for any Brem emitted before magnet
- Extrapolate track from before magnet to calorimeter
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- If Chi2< 300, add brem to electron

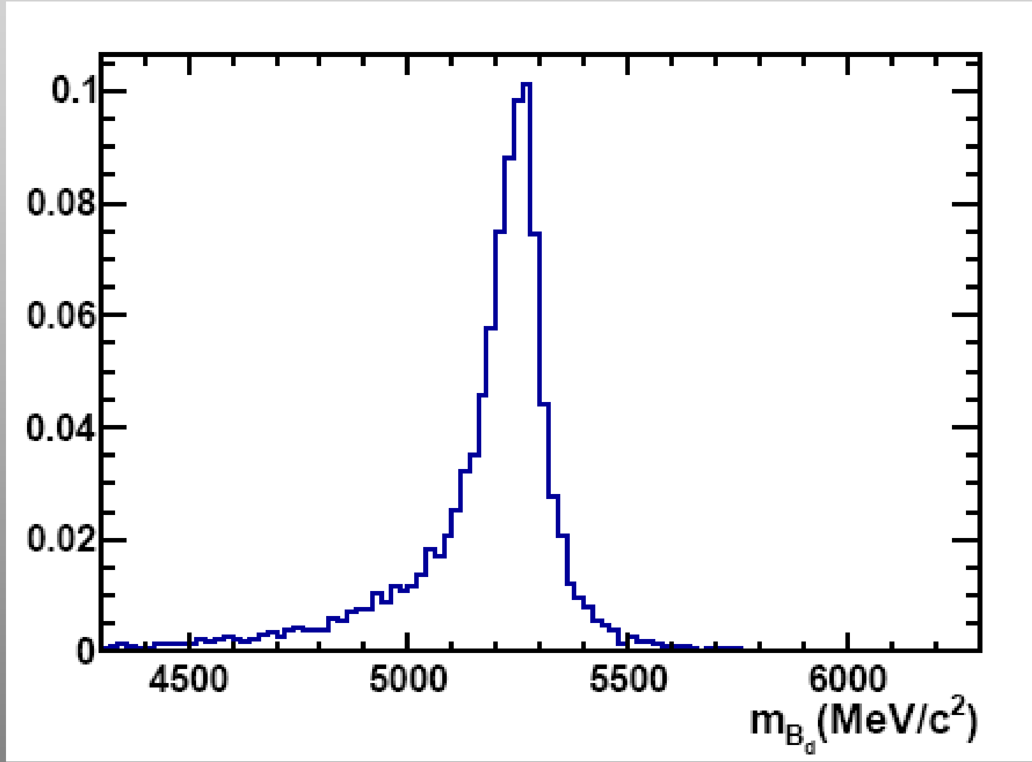
However, for the small q^2 eeK*, the angle between the two electrons is small
Turned out the Brem was being added to both electrons erronously

-extra energy=> high mass events

Bremsstrahlung un-recovery

Fixed in a hurry just now

- If the difference between the Brem added to each electron < 5MeV one of the Brem is removed (randomly) and the B mass is recalculated



(Claire is working on doing this in a nicer way!)

From MC, predict 60 events in 2011 data (1fb-1)

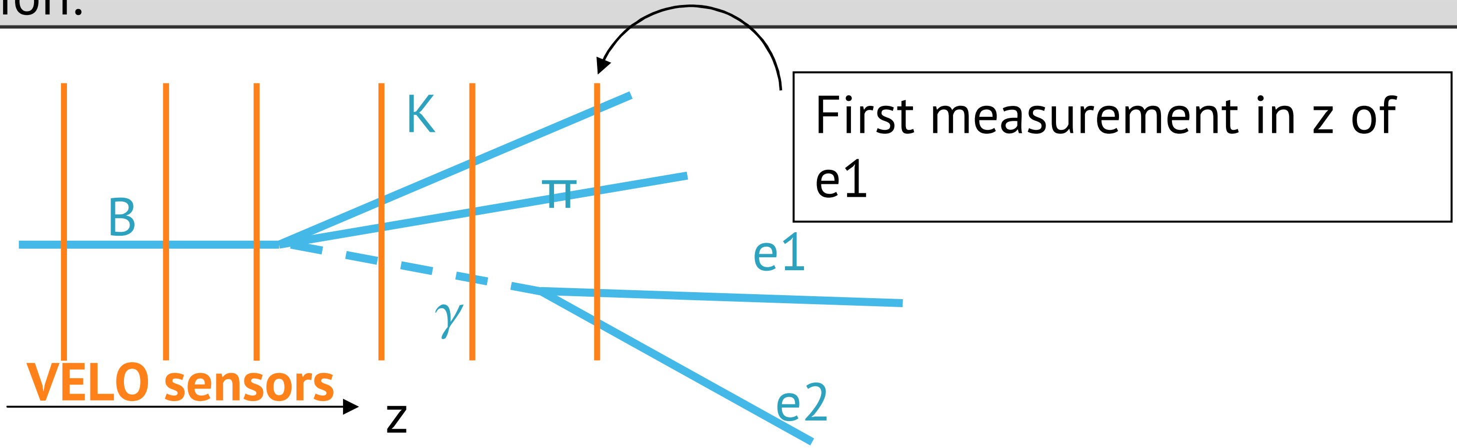
Background

BDT good at separating combinatorial background (when the selection has combined things that aren't all from the same B decay) from signal, but it doesn't do so well with partially reconstructed events, or specific backgrounds with properties similar to signal

Important background for is comes from $B \to K^* \gamma$ with $\gamma \to ee$ (BR 200x larger!)

Background from B→K*γ

Converted photons can have different hit distributions in the VELO station:



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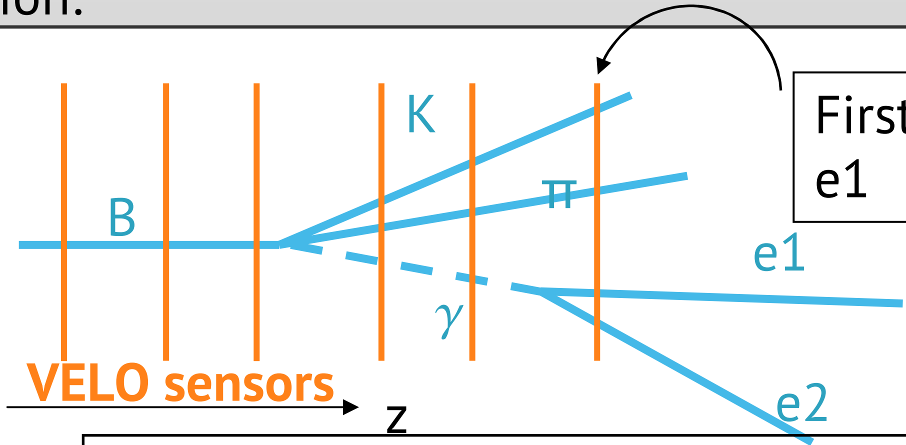
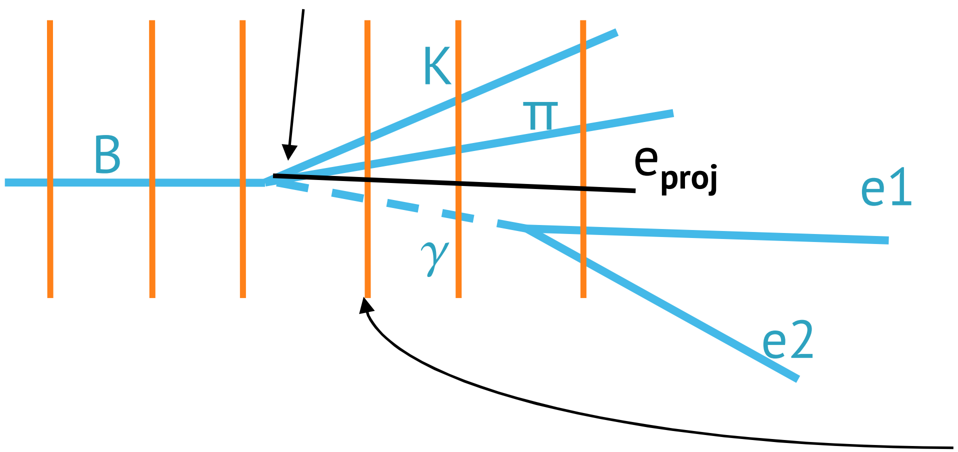


First measurement in z of e1

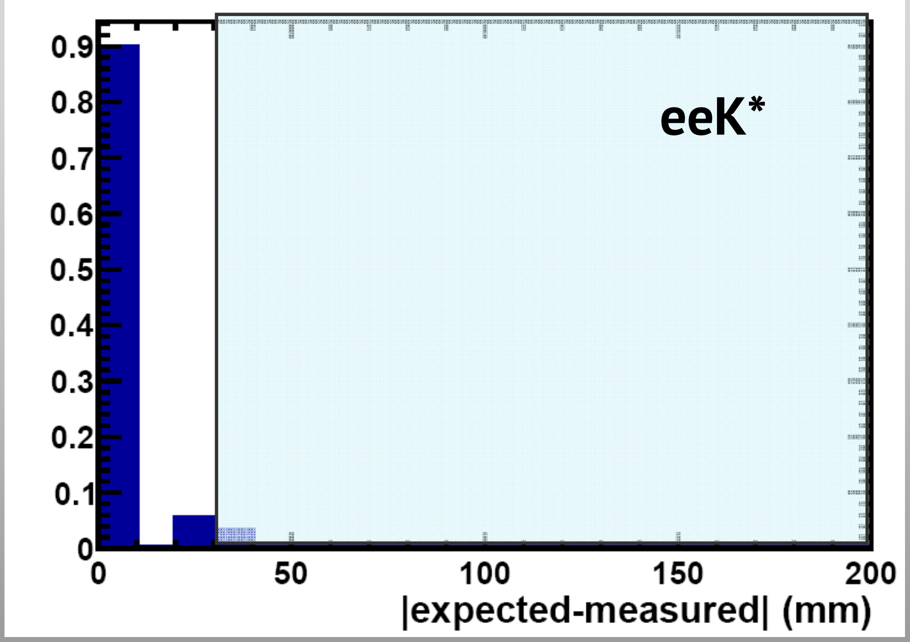
Project the track in the direction of the lepton p from K* vertex.

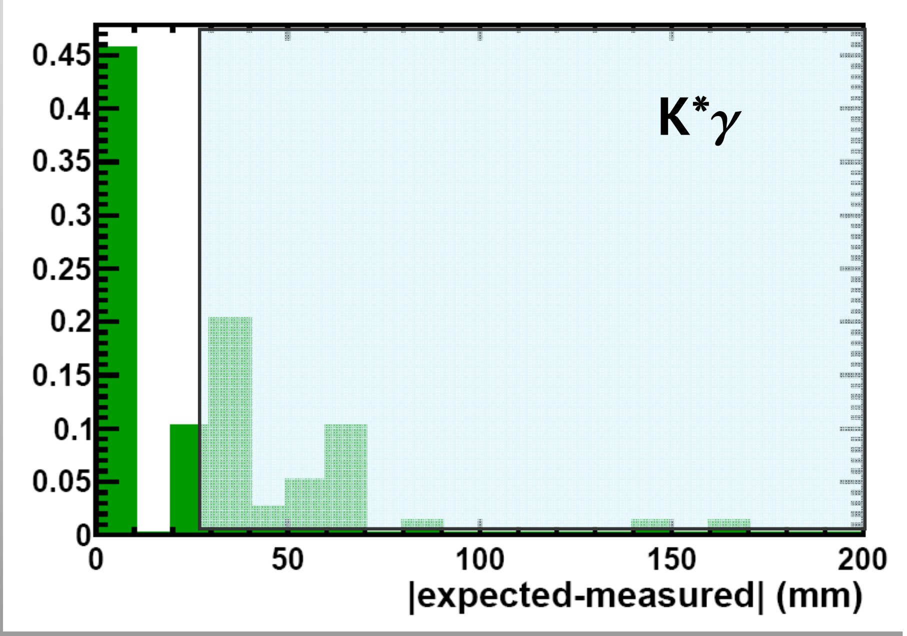


Obtain the expected x and y position at the z position of each VELO sensor If it is within the active VELO region, take that sensor plane as the first expected measurement in z of e1

Background from B→K*γ

Cutting on the difference between the expected and actual measurement removes most of this background

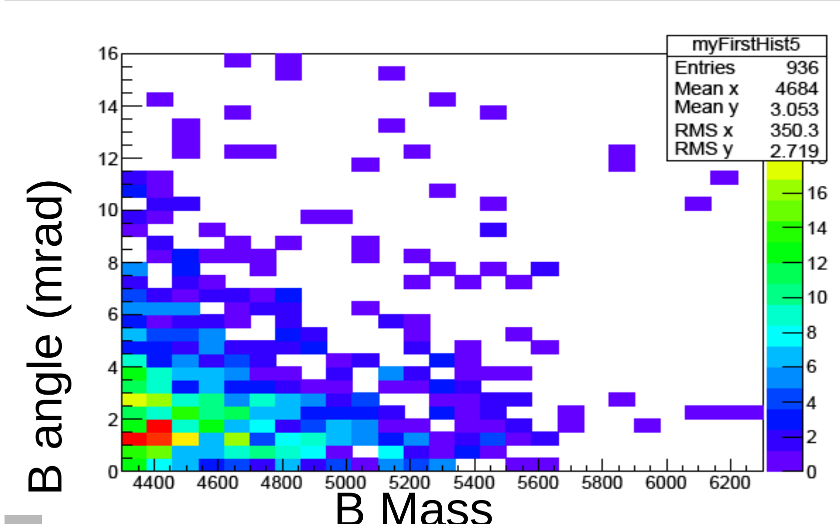




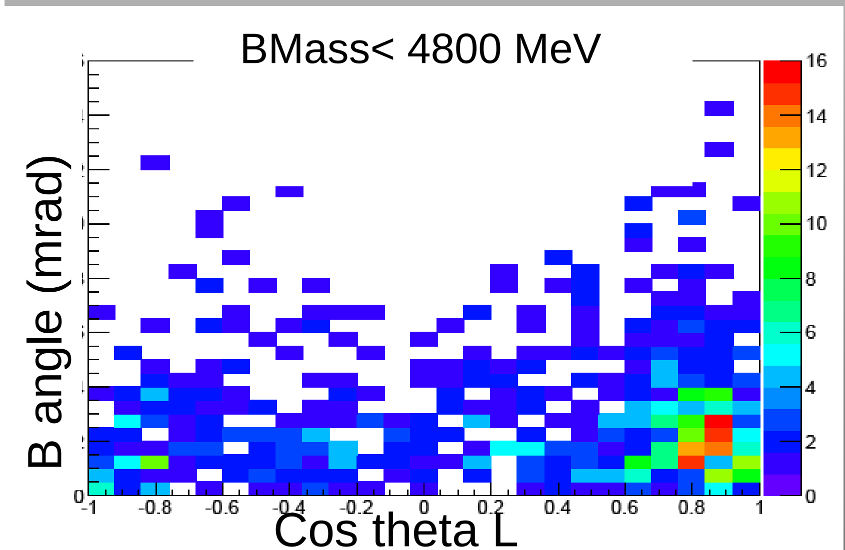
eeK* efficiency 92%

K*γ events expected in data: 5

More specific background-lower sidebands



Look real B decays that aren't losing much momentum.

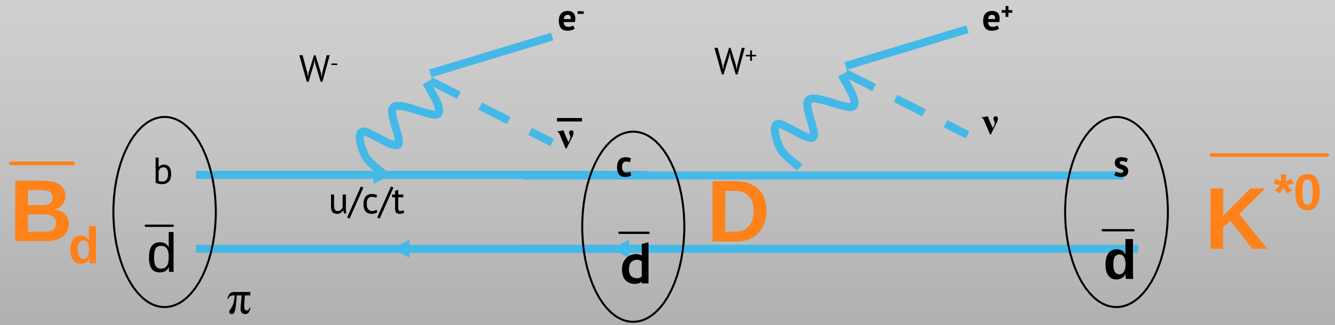


CosΘ_L= angle between e^+ and the direction opposite the B_d in the rest frame of the ee and is symmetric for signal.

More specific background-B->Deν

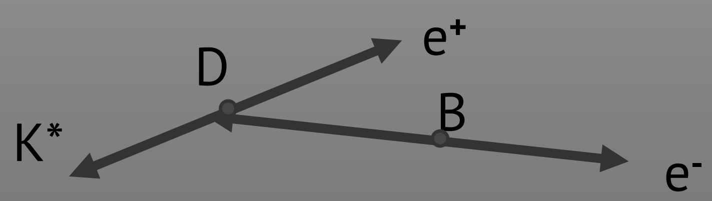
Looking for a background that is peaking at high values of cos theta L, and is a B decay without much missing momentum.

Idea: B->Deν with D->K*eν, (BR~2.17%)



The neutrino energies must be small for good b angle.

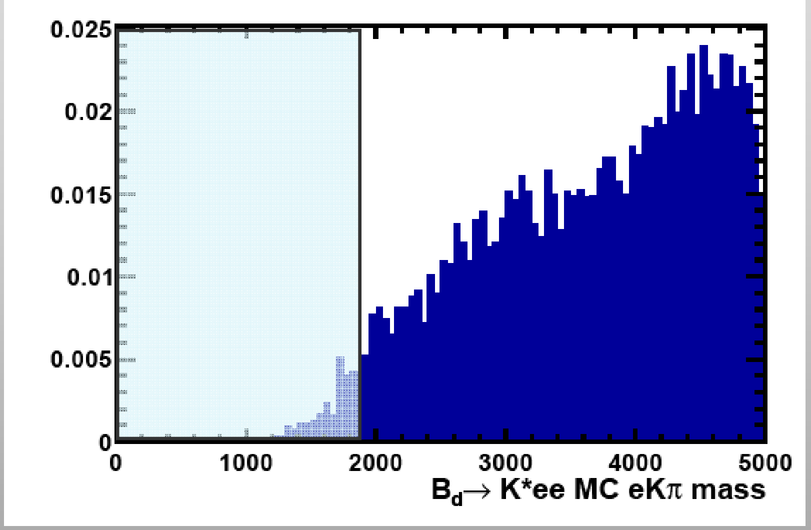
→ back to back D and e in B rest frame
then back to back K* and e in D rest frame.

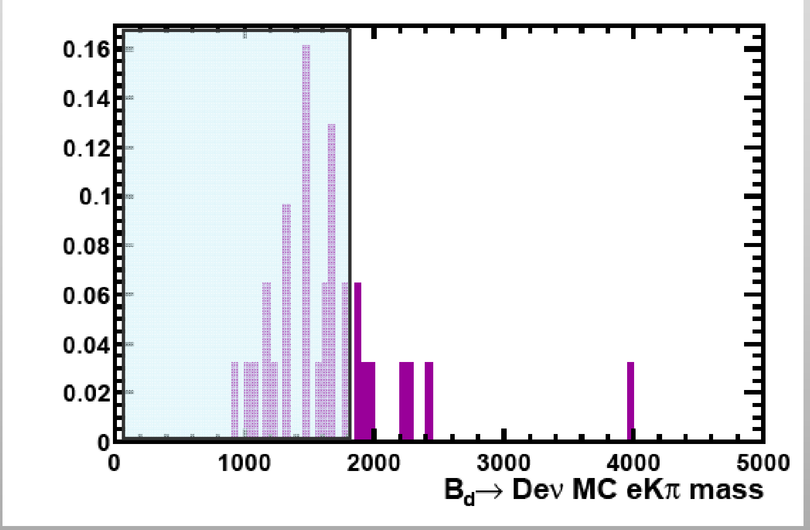


Small ee mass
$Cos\Theta_L$ asymmetry

More specific background-lower sidebands

Easy to kill- K*e should combine to form D mass





eeK* efficiency 97%

Deν events expected in data: 5

Fitting to data

Control sample: Bd→J/Ψ(ee) K*

B_d→J/Ψ(ee) K* branching ratio ~350 times bigger than Bd→eeK* in 30MeV-1GeV dilepton mass range.

Use as a control channel to test fit, and get a handle on the expected ration of signal to partially reconstructed background

NB: Not the same background for the two samples.

B_d→J/Ψ(ee) K*

2 components to partially reconstructed background: incomplete events due to the K* part or due to the J/Ψ part

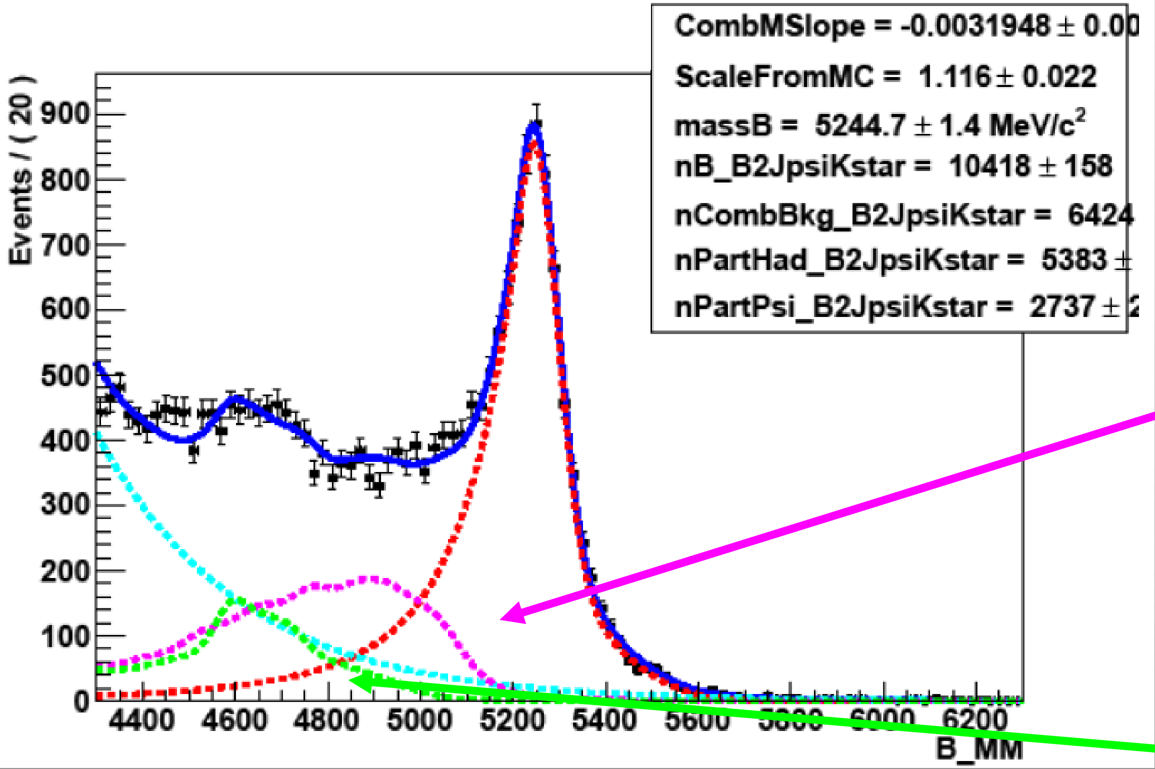
Higher pt electrons= less combinatorics

Bd→eeK*

Partially reconstructed events made up from incomplete hadronic decays.

→ Expect lower ratio of signal to partially reconstructed Low pt electrons=more combinatorics

Fit to $B_d \to J/\Psi K^*$ data



B_u $B_d \to J/\Psi(ee)K^*X$ MC was produced in order to study the real shape of the partially reconstructed background.

Incomplete events from the hadronic part (ratio of this to signal should be the same for eeK*)

Incomplete events from the J/Psi part

Fit to $B_d \to eeK^*$ data

Fit strategy:

- Signal shape from MC with a scaling factor to take into account data/MC differences (scaling obtained from JPsiK* data MC comparison)
- Combinatorial background : fitted on data
- Partially reconstructed background (Hadronic part):
  - shape from inclusive MC JPsiK*X MC
  - ratio to signal fixed to JPsiK* fit on data

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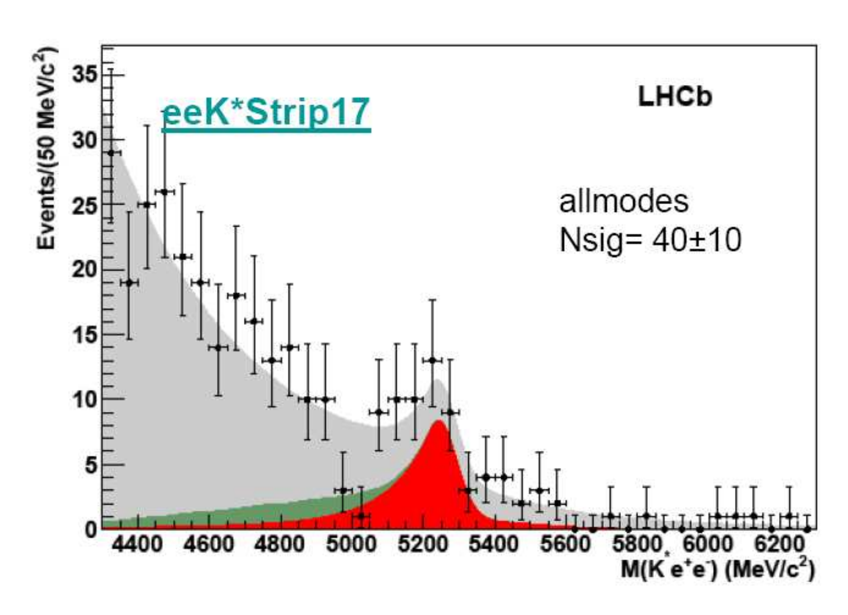
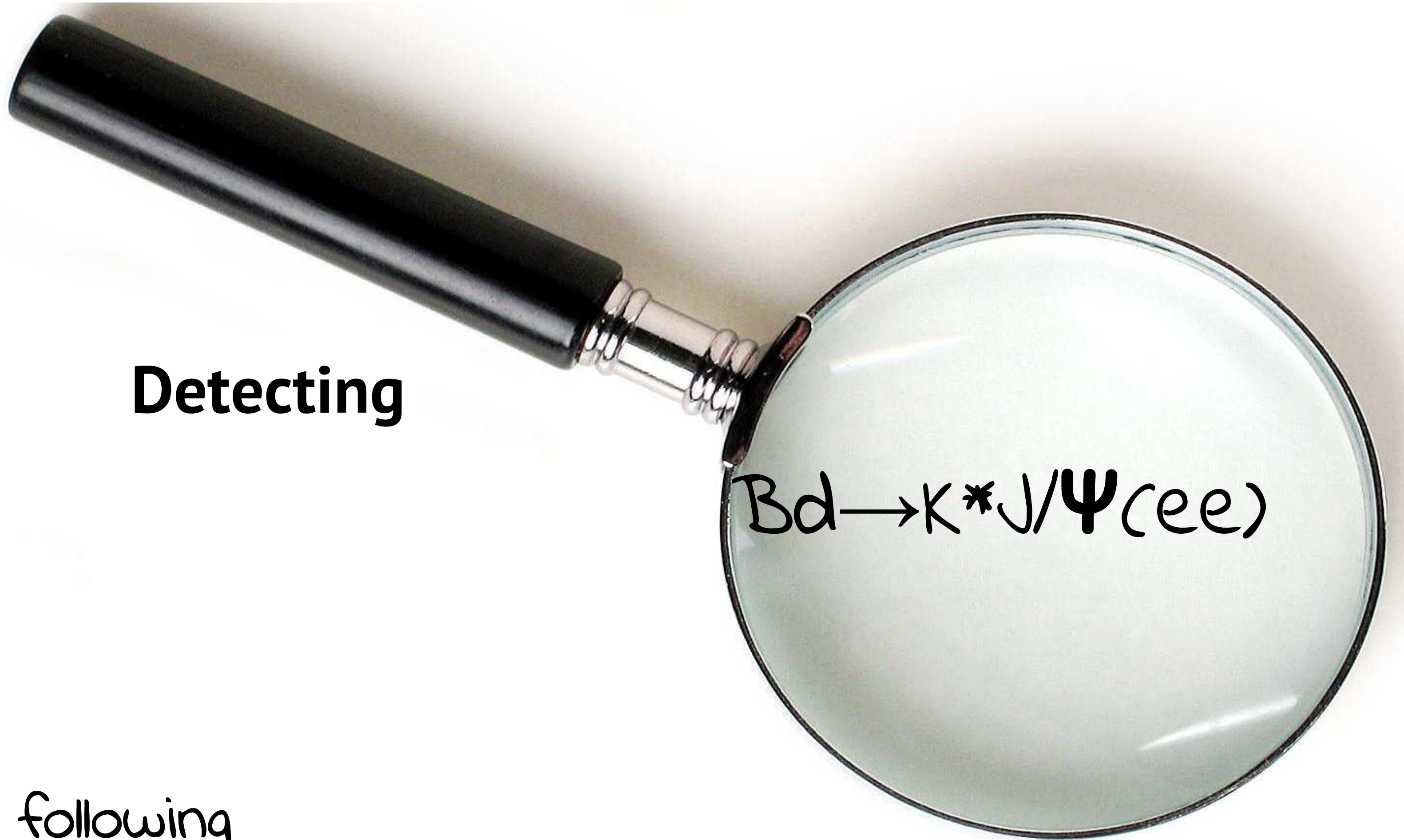


signal

Part reco backgroun

combinatorics



Detecting

$Bd \to K^*J/\Psi(ee)$

following

clues

$Bd \to K^*J/\Psi(\mu\mu)$

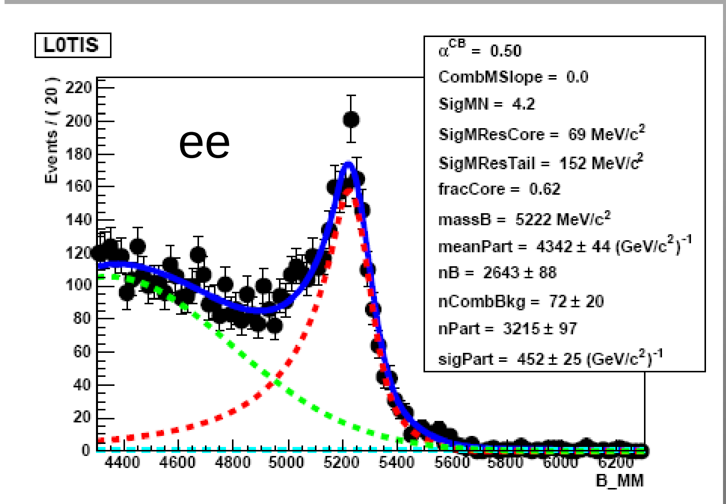
Fit to $B_d \to eeK^*$ data

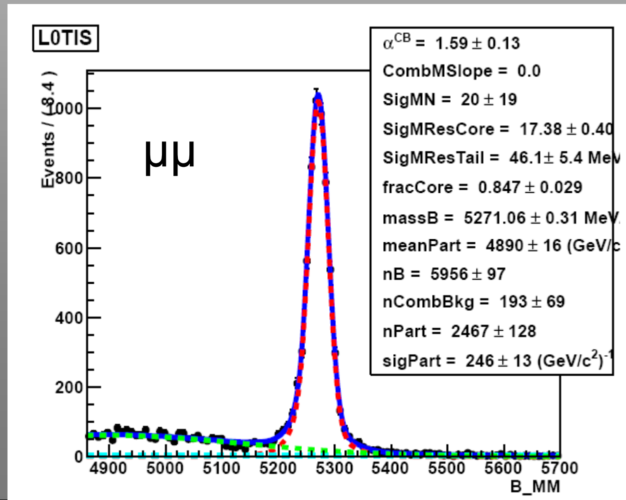
Historically, did a comparison with the muons to validate yields- MC predictions were always a factor 2 below those observed. Now understood, but I show you for fun. (All these plots are with an old subset of the data)

- Major difference in yields comes from trigger. (Less than 30% efficiency for K*ee, and more than 90 for K*mumu.)

- Secondly, tighter cuts are needed on K*ee due to the poorer mass resolution

Even applying the same cuts, and using an independent trigger (so same yields?)





Fit to $B_d \rightarrow eeK^*$ data

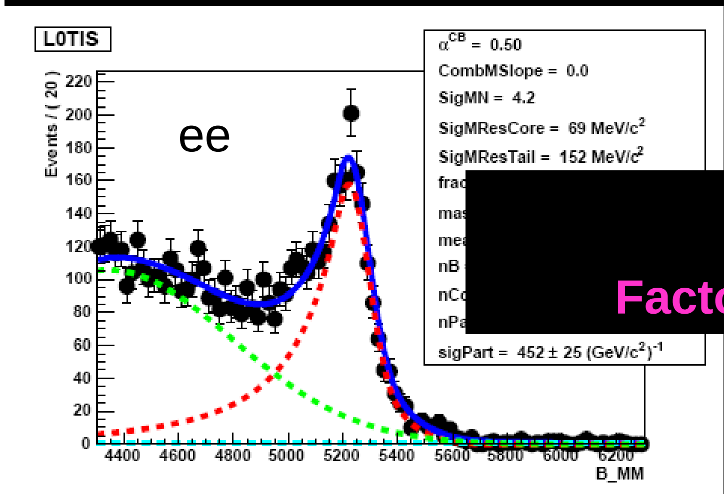
Historically, did a comparison with the muons to validate yields- MC predictions were always a factor 2 below those observed. Now understood, but I show you for fun. (All these plots are with an old subset of the data)

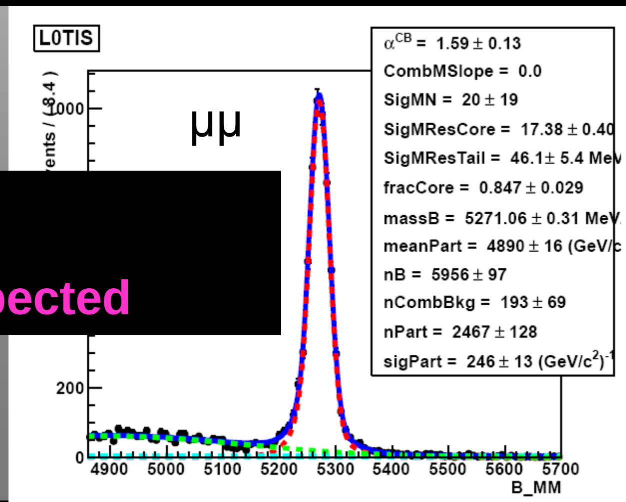
- Major difference in yields comes from trigger. (Less than 30% efficiency for K*ee, and more than 90 for K*mumu.)
- Secondly, tighter cuts are needed on K*ee due to the poorer mass resolution

Even applying the same cuts, and using an independent trigger (so same yields?)

$B \rightarrow J/\Psi(ee)K^*$ nSig= 2643 ± 88

$B \rightarrow J/\Psi(\mu\mu)K^*$ nSig= 5956 ± 69



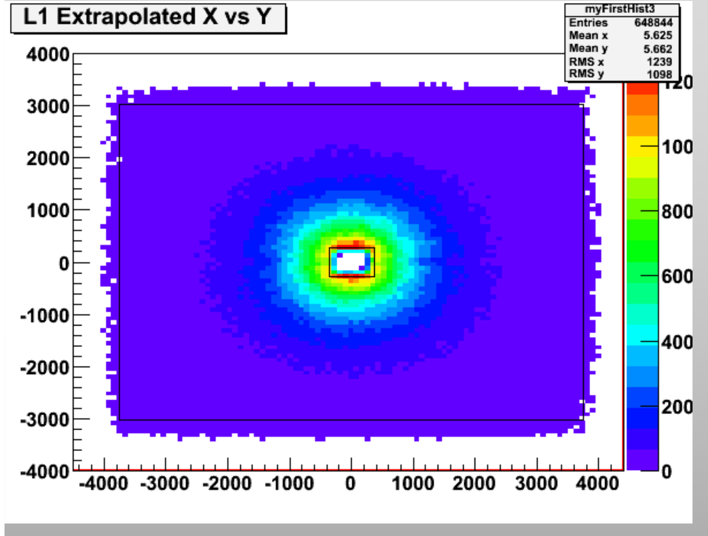


NO!

Factor 2.3 less than expected

other effects on electron efficiency

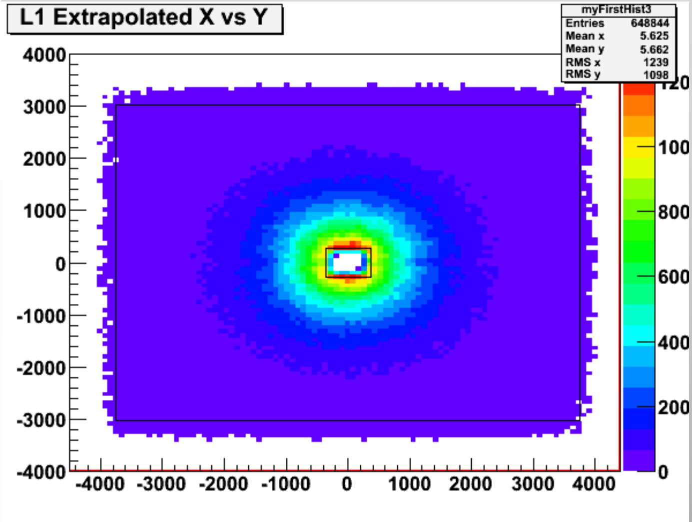
Electron acceptance



The muons have a larger acceptance than electrons:
12% of the muon events have one muon in the ECAL 'hole'

other effects on electron efficiency

Electron acceptance



The muons have a larger acceptance than electrons:
12% of the muon events have one muon in the ECAL 'hole'

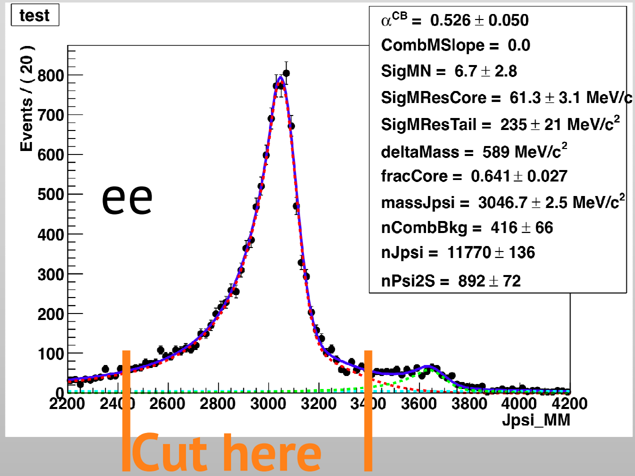
PIDe

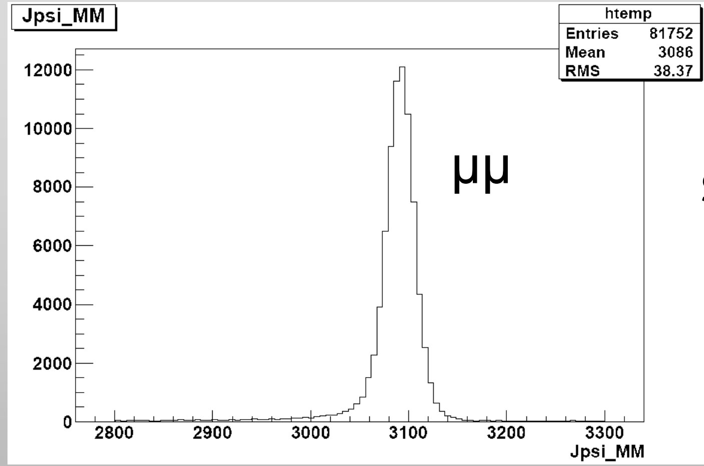
Using the tag and probe method, can test PIDe efficiency for TIS events. (Assume PIDmu>0 is 100% efficient)

PIDe Cut	>0	>1	>2	>3	>4	>5
Efficiency %	93 ± 0.5	89 ± 0.6	84 ± 0.7	78 ± 0.8	71 ± 0.9	60 ± 1.5

Effects (cont.)

Bremsstrahlung effect on J/Ψ shape





Note the different scales!

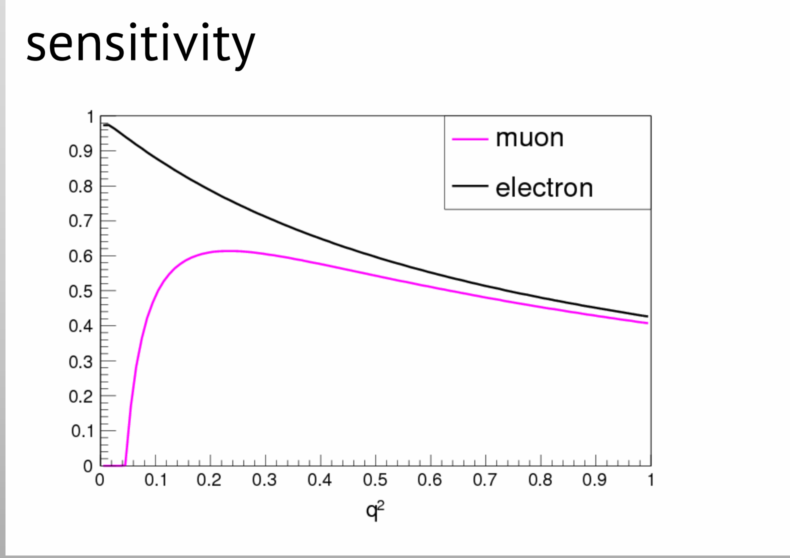
lose ~17% signal ee

Putting it all together and assuming PIDmuon efficiency=100%:
0.88 (CaloHole) x 0.83(JPsiMass cut) x 0.93^2(PIDe) x 0.94(MCμμ vs MCee) = 0.6

	Muon observed	*0.6=electron predicted	Electron observed	nPred/ nObser
Independent trigger	482 ± 31	289 ± 19	252 ± 26	**1.15 ± 0.1**

what was the point again

However, despite the gazillions more muons…



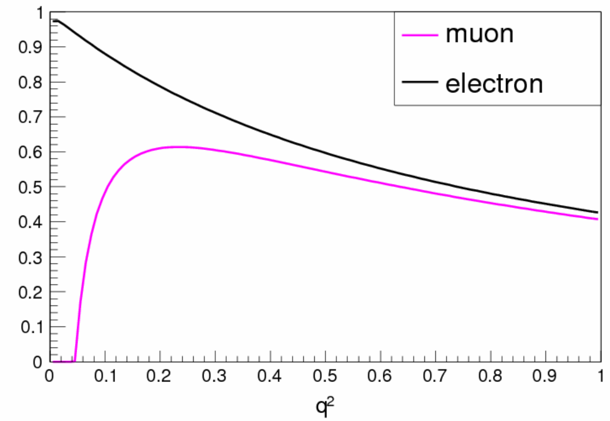
With 2011+2012 data (2.5 fb-1) :

- 100 clean K*ee signal events ?
- precision on AT(2) of the order of 0.15 for a yield of 100 events.
- K*mumu in 0-2 GeV2 region (1 fb-1) : .38

what was the point again

However, despite the gazillions more muons...

sensitivity



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But everyone agrees, unless there is a clear physics case to use electrons over muons, (and usually, there isn't) Don't bother!