Measurement of $b\bar{b}$ cross section in LHCb

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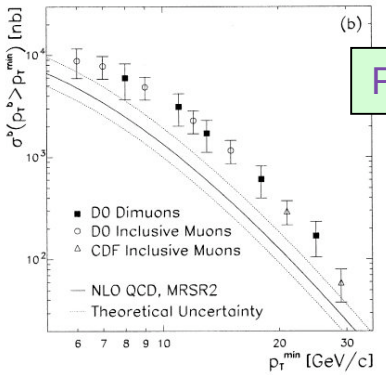
Physics interest of production studies

- Measurements of heavy-quark production are essential for testing predictions based on perturbative QCD, and for constraining fragmentation models
- Significant improvements in theoretical calculations, and their inputs, over past few years
  - Better knowledge of fragmentation, structure functions and α_S
  - Calculations performed fixed-order with next-to-leading log (FONLL)
  - Consequent improved agreement with Tevatron data for central bb production



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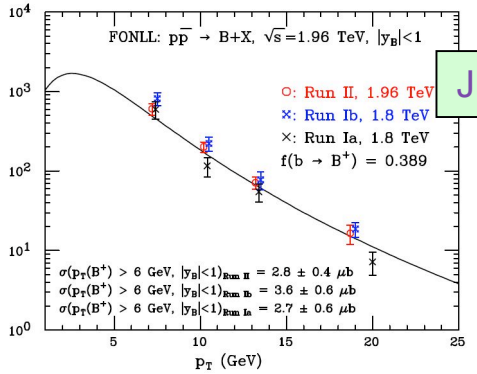

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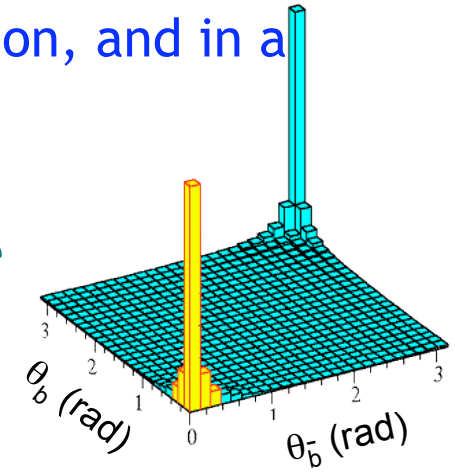
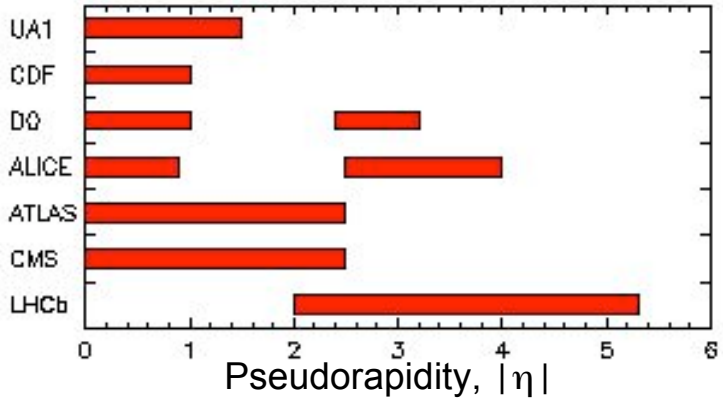
- Need more precise measurments before ruling out contributions from new physics
- Need to improve understanding of forward production
  - D0 measurement for $2.4 < |\eta| < 3.2$ factor 4 higher than suggested by theory

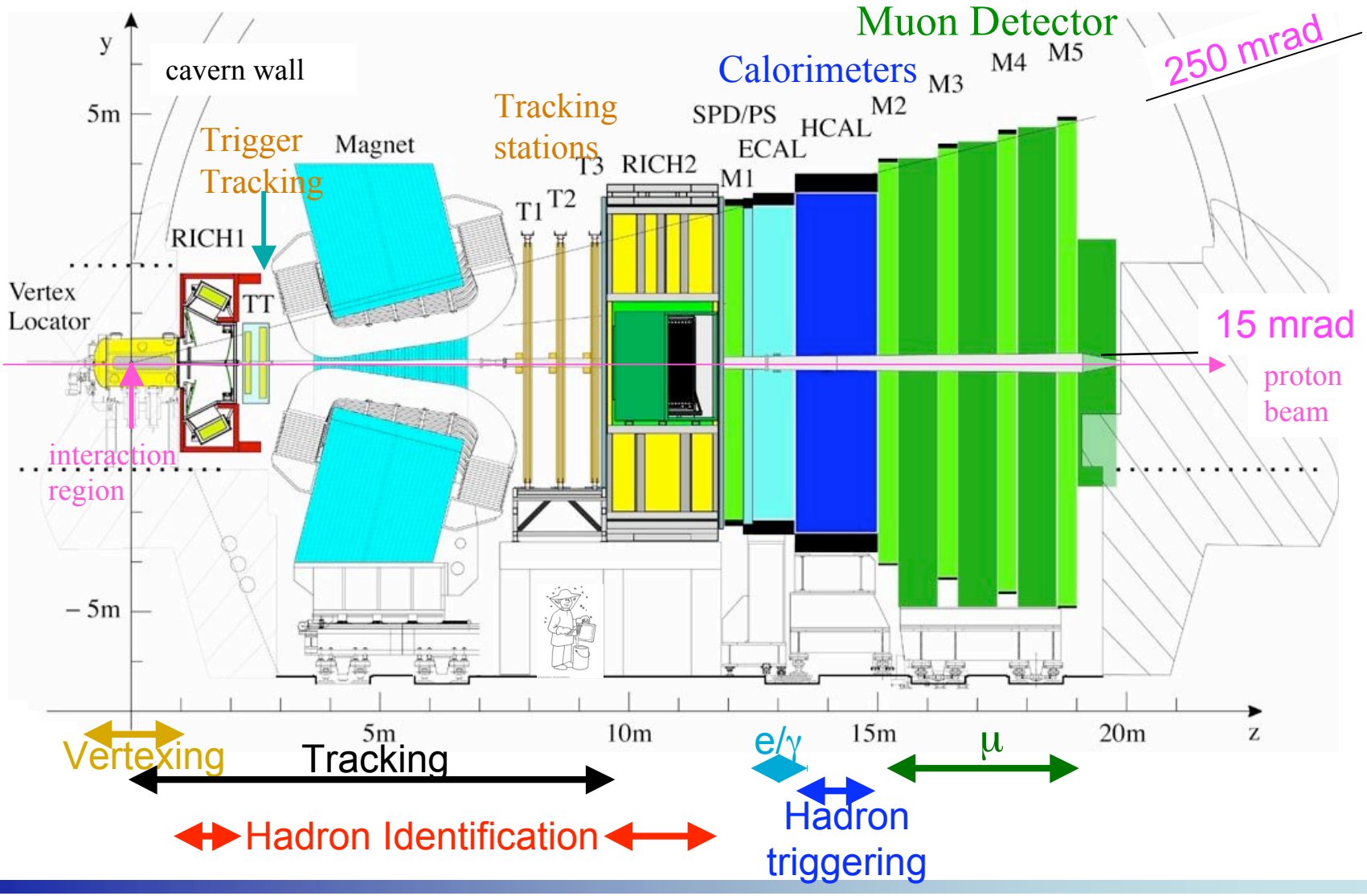
Measuring σ_{bb} in LHCb

- LHCb is designed for high-precision measurements of b-hadron decays
  - Will record enormous data samples useful for bb production studies
- Experiment is optimised for acceptance in forward region, and in a single hemisphere
  - Take advantage of correlation between b and $\bar{b}$
  - Measure σ_{bb} in region of phase space not accessible to previous hadron-collider experiments, or to other LHC experiments
- Measurement of σ_{bb} is complementary to other production measurements
  - Production fractions for different species of b hadron
  - Differential cross sections
  - Correlations between pairs





LHCb detector



Trigger and rates

Average luminosity = 2×10^{32} cm^{-2} s^{-1} $\approx$ 2 fbarn^{-1} per year of data taking (10^7 s)

Approximate cross sections and production rates

≥ 2 charged tracks in VELO

	Cross section (mbarn)	Rate (kHz)
Bunch crossings		40000.
All interactions	100.	20000.
Visible interactions	60.	12000.
bb events	0.5	100.
cc events	3.5	700.

Trigger rates

- Hardware trigger
- High E_T particles
- Partial information

- Software trigger
- High E_T and IP
- Full information

	Rate (kHz)
L0 triggers	1000.
HLT	2.
Exclusive B	0.2
Dimuon	0.6
Single muon	0.9
Inclusive D	0.3

Overall trigger efficiency in range 0.3-0.8 for hadronic and semi-leptonic b decays of interest to LHCb

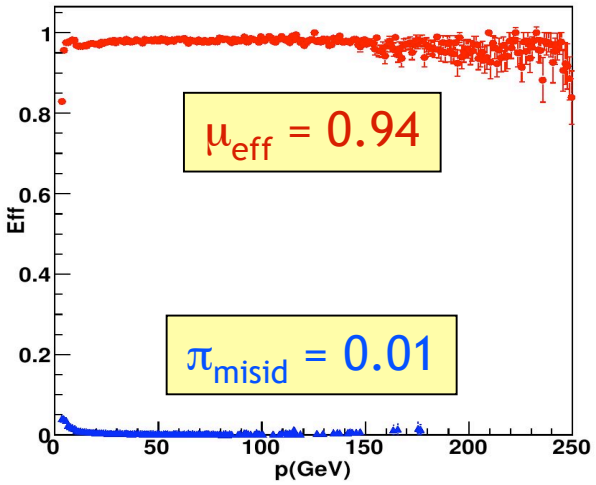
Determination of σ_{bb}

- Measurement of cross section for a process X is conceptually simple
- Use: $\sigma_X = N_X / (L \varepsilon_X)$
  - σ_X: cross section
  - L: integrated luminosity
  - N_X: number of times process is detected
  - ε_X: Detection efficiency
- Outline how each of these will be evaluated in LHCb for measurment of σ_{bb}
  - Deal with general strategy rather than precise numbers, as studies are still at an early stage
- Note that work to measure σ_{bb} is work to understand the detector (acceptances) and the environment (luminosity)
  - Essential for all LHCb physics studies

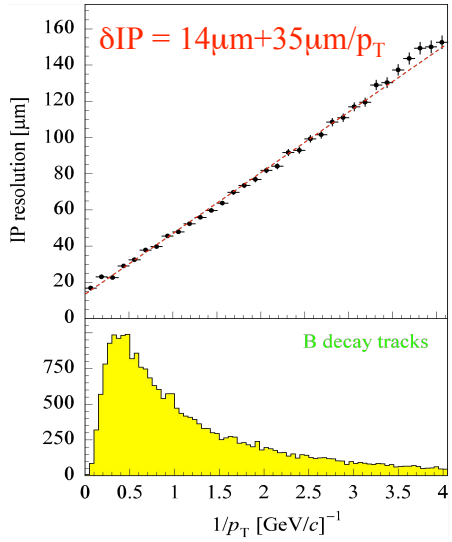
Number of bb pairs using inclusive muons

- Approaches based on analysis of inclusive muon samples have historically been very successful
  - Used by UA1, CDF and D0 in their first measurements of σ_{bb}
- LHCb has dedicated muon stream in trigger, and good muon identification in offline reconstruction
- Aim to identify muons from b using cuts on P_T and impact parameter

Muon identification for $B^0 \rightarrow J/\psi\,(\mu^+\mu^-)\,K_S^0$



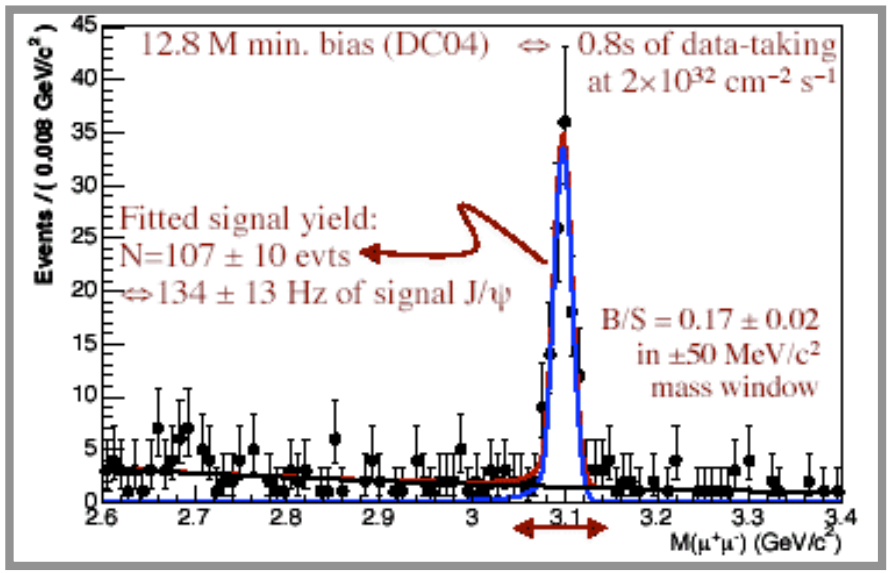
Impact-parameter resolution



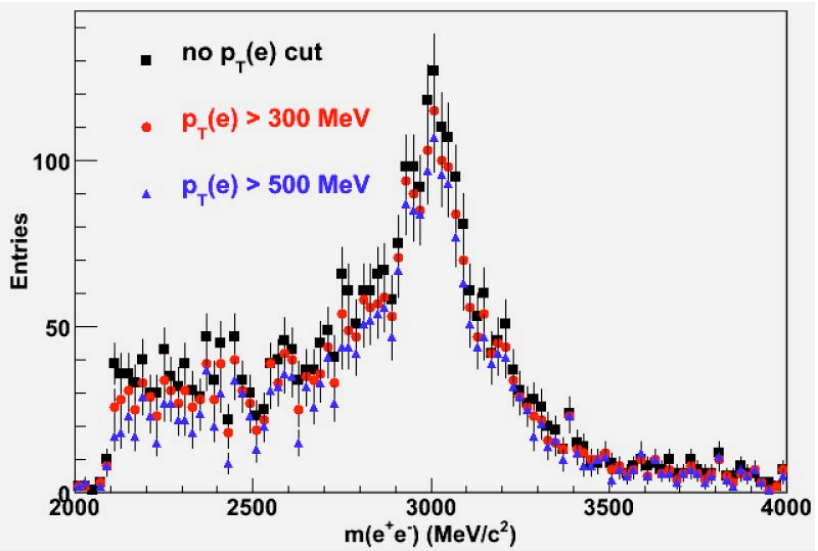
Number of bb pairs using inclusive J/ψ

- LHCb is able to reconstruct J/ψ decays both to muons and to electrons
- In addition to cuts on P_T and impact parameter, will use cuts on separation between primary vertex and J/ψ vertex to identify J/ ψ from b

$J/\psi \rightarrow \mu^+\mu^-$ in minimum-bias events



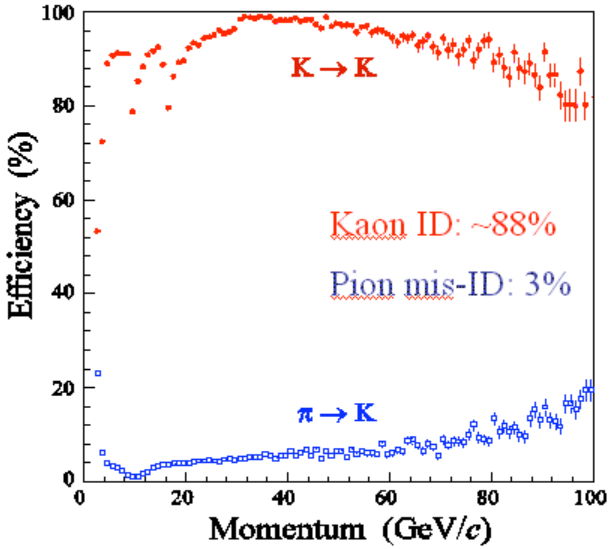
$J/\psi \rightarrow e^+e^-$ in inclusive J/ψ events



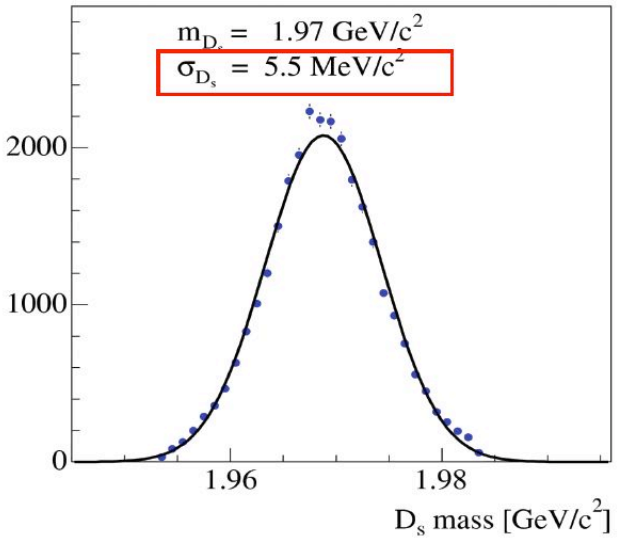
Number of bb pairs using inclusive D mesons

- Reconstruct $D \rightarrow K\pi\pi$, $D \rightarrow K\pi$, $D \rightarrow K\pi\pi\pi$, $D_S \rightarrow KK\pi$, then identify D mesons from b by again using cuts on P_T, impact parameter and vertex separation
- D-meson reconstruction uses RICH for kaon identification

Kaon identification with RICH



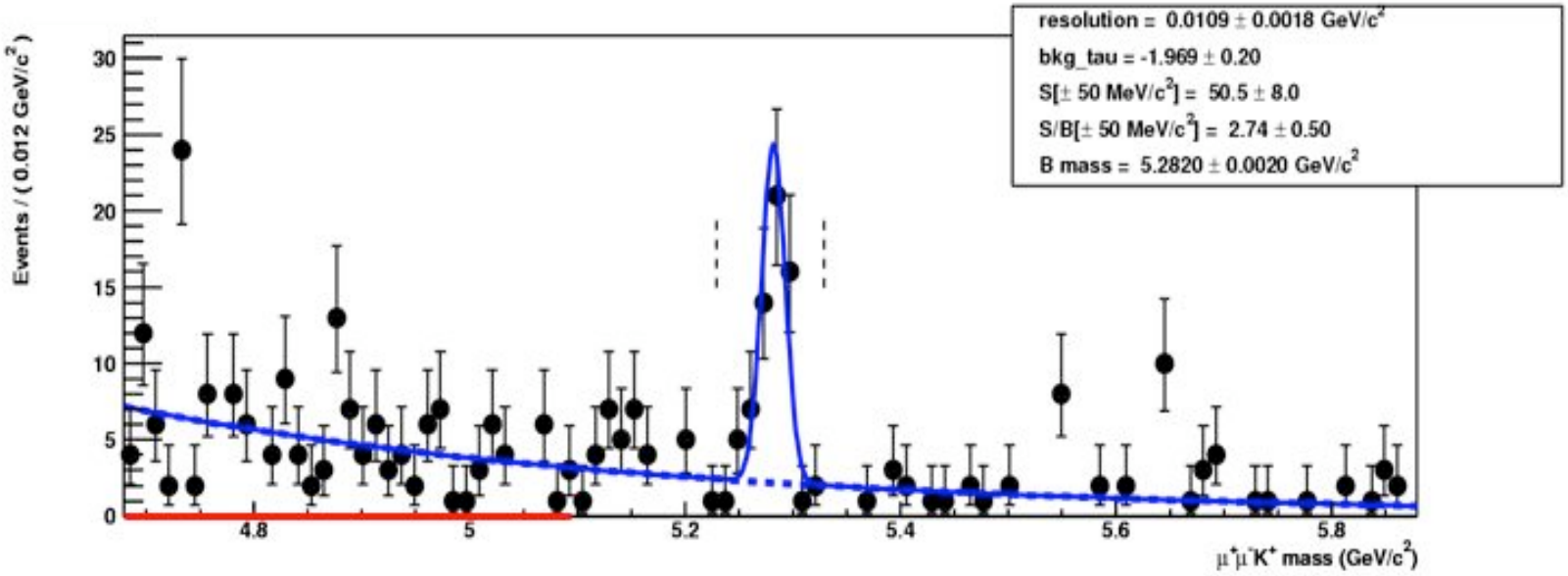
$D_S \rightarrow KK\pi$ in $B_S \rightarrow D_S(KK\pi)K$ events



Number of bb pairs using exclusive B decays

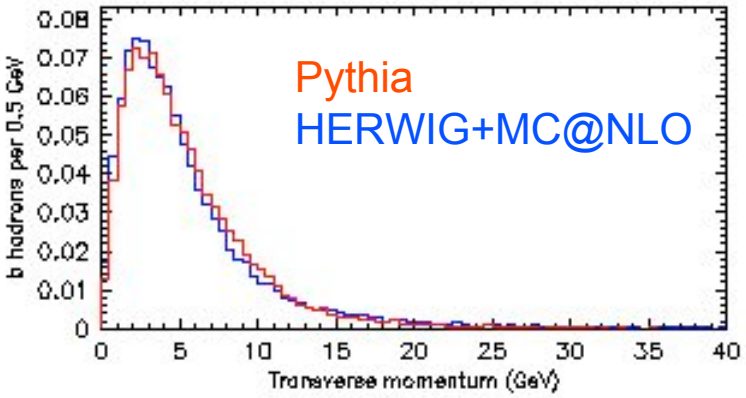
- Use channels with well-measured branching fractions, for example: $B^+ \rightarrow J/\psi K^+$ (3.5% uncertainty), $B^0 \rightarrow J/\psi K^0$ (3.8% uncertainty)
- For these channels, expect to reconstruct >100k decays per year

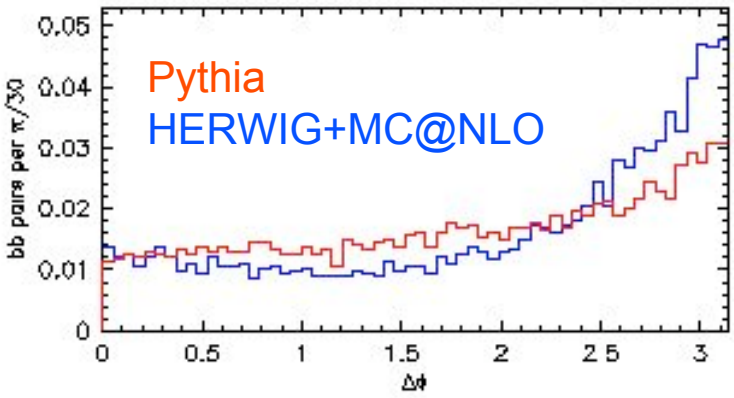
$B^+ \rightarrow J/\psi K^+$



Efficiency estimates

- Efficiency estimates rely heavily on simulation studies
- Most LHCb studies to date have used Pythia for particle production
- Studies for b production based on other packages also
  - HERWIG/MC@NLO/Jimmy, Sherpa, etc
  - Essential for understanding systematic uncertainties
    - Two generators can give same inclusive distributions, but different correlations
- Use EvtGen for particle decays, and Geant 4 for detector simulation

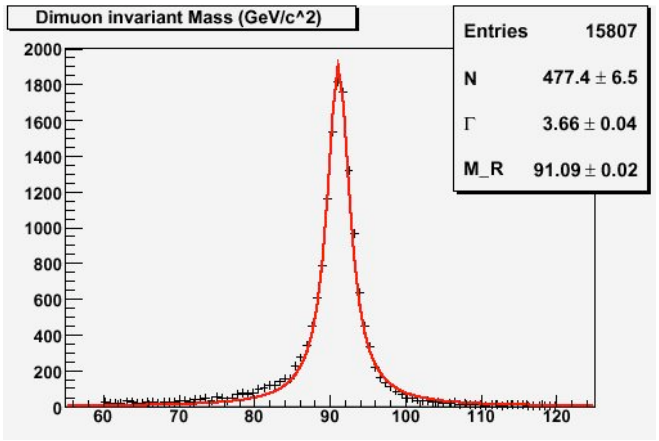




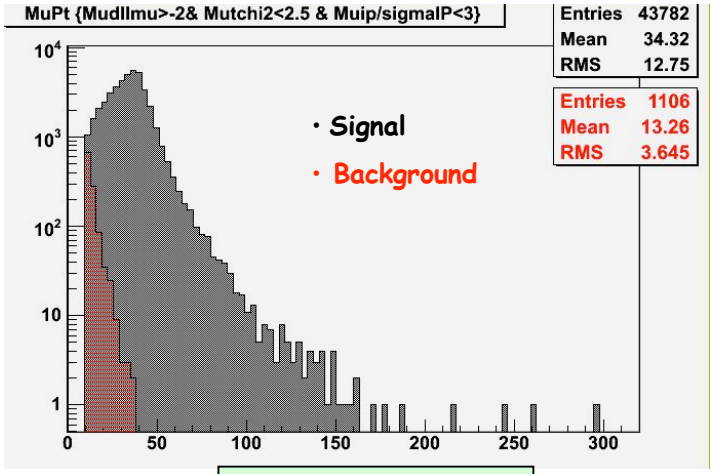
Luminosity from decays of Z^0 and $W^{\pm}$

CERN-THESIS-2006-013

- Take theoretical predictions for Z and W cross sections and muonic branching fractions
  - Theoretical uncertainty of ~4%
- Measure yields of $Z \rightarrow \mu\mu$ and $W \rightarrow \mu\nu$, and correct for experimetal acceptance
  - Detection rate, after selection cuts, of about 0.05 Hz for $Z \rightarrow \mu\mu$, and 0.25 Hz for single μ from Z or W
  - To match theoretical uncertainty, require data taking for about 3.75 hours for $Z \rightarrow \mu\mu$ and 45 minutes for single μ
- Combine numbers from theory and experiment to determine luminosity



Dimuon mass (GeV/c^2)



Muon P_t (GeV/c)

Luminosity from beam profiles

NIM A553 (2005) 388

- Consider two counter-rotating bunches, with velocity ~*c* in beams with crossing angle ϕ and revolution frequency *f*
- Bunches have populations N_1, N_2, and are described by normalised density functions $\rho_1(x,t)$, $\rho_2(x,t)$
- Luminosity obtained as:

$$L = f\, N_1\, N_2\, 2c\, \cos^2(\phi/2) \int_{4-\text{fold}} \rho_1(\mathbf{x},t)\, \rho_2(\mathbf{x},t)\, d^3x\, dt$$

Measured by AB-BI

Measured by the experiments

- Use residual gas into region of vertex locator, or inject additional gas
- Reconstruct beam-gas interaction to determine vertices beam angles, profiles and relative positions, and so evaluate overlap integral
  - Use Hijing to generate beam-gas interactions

Conclusions

- LHCb is designed for high-precision measurements of b-hadron decays, and will have large data samples for studies of b production characteristics
- To keep systematic uncertainties under control, each of the quantities contributing to the measurement of σ_{bb} will be evaluated in more than one way
  - Determine number of bb pairs using inclusive muons, inclusive J/ψ, inclusive D mesons, and exclusive B decays
  - Determine efficiencies using different packages for particle production
  - Determine absolute luminosity using decays of Z^0 and $W^{\pm}$, and using beam-gas interactions in region of vertex locator
- LHCb will measure σ_{bb} in the forward region, where the only previous measurement suggests disagreement with predictions based on perturbative QCD