CKM physics from B→Kπ decays at LHCb

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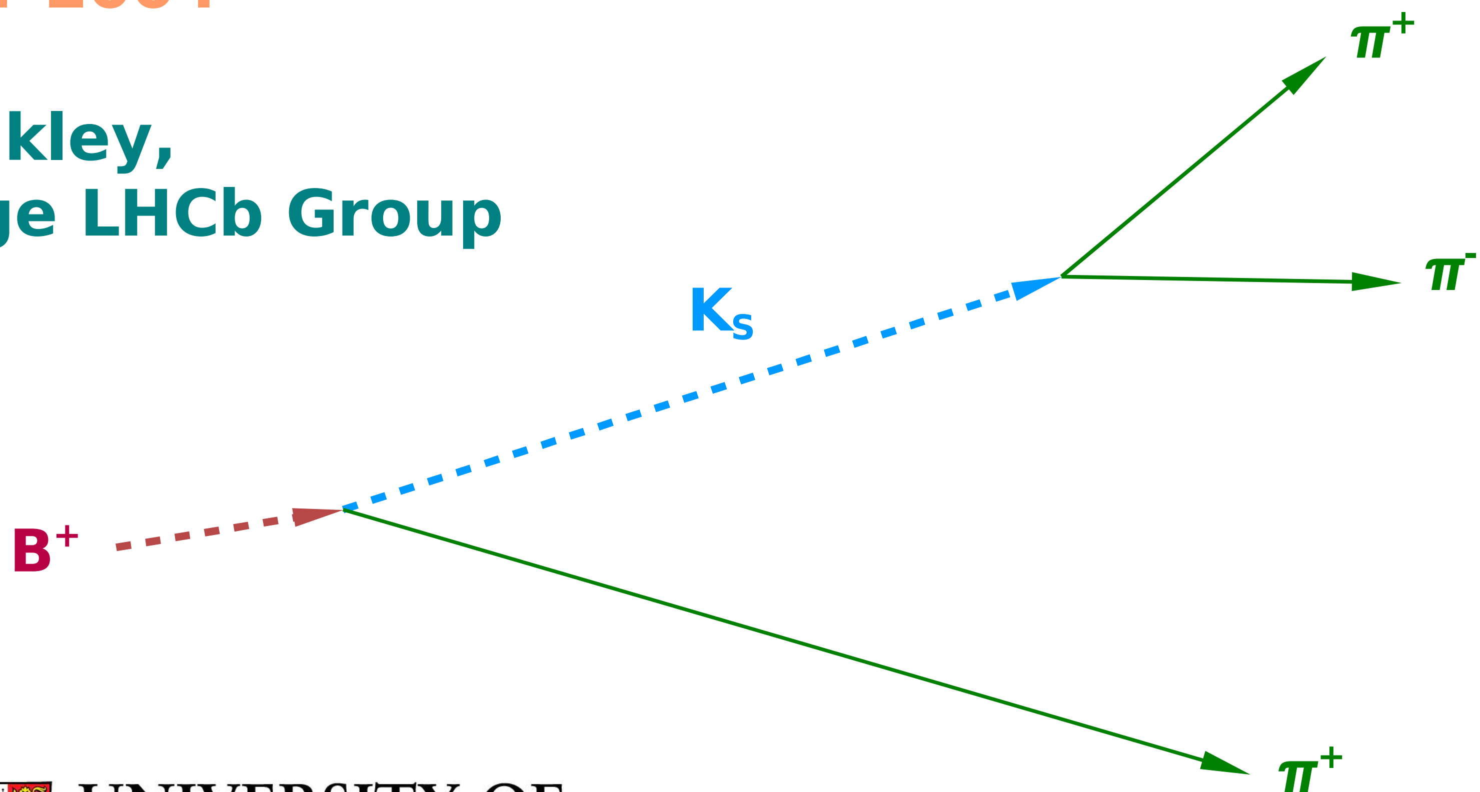
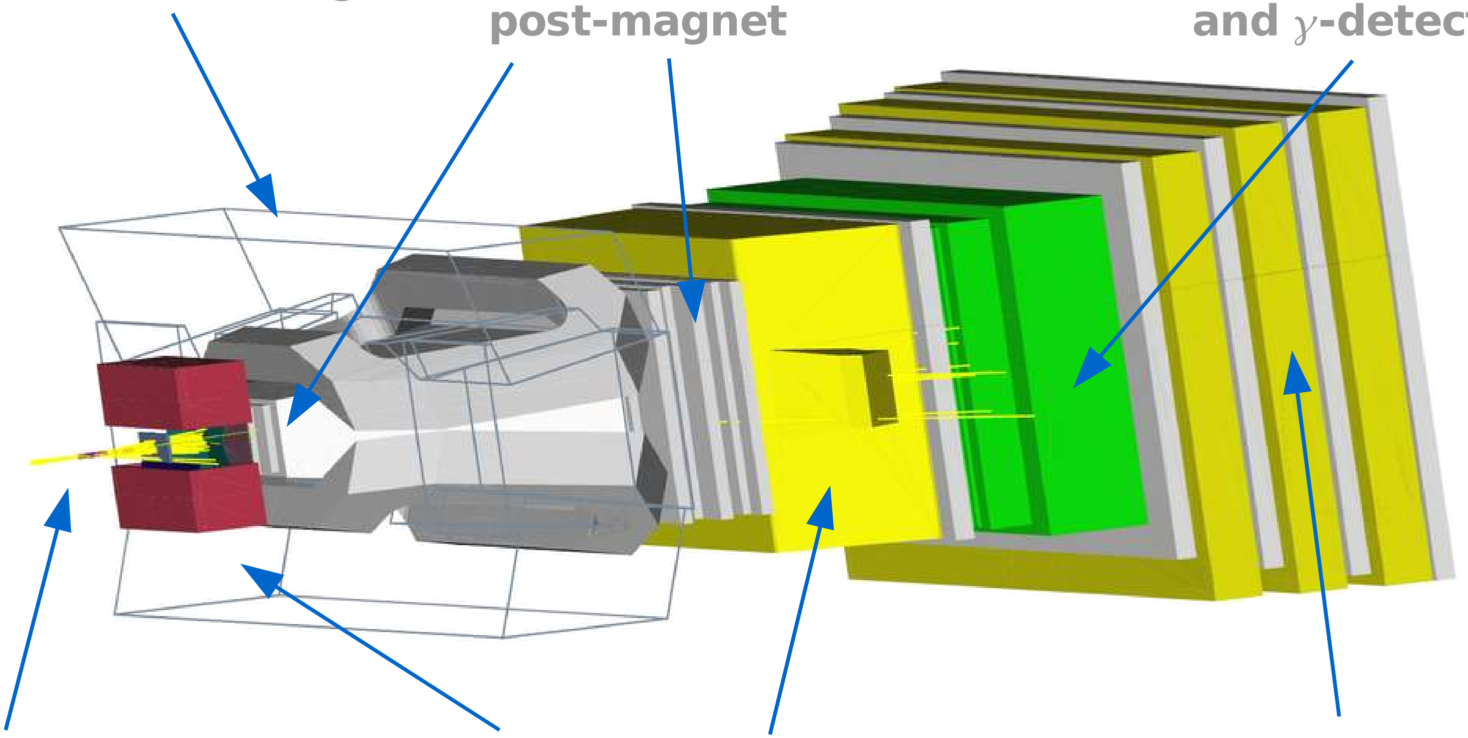


LHCb

UNIVERSITY OF CAMBRIDGE

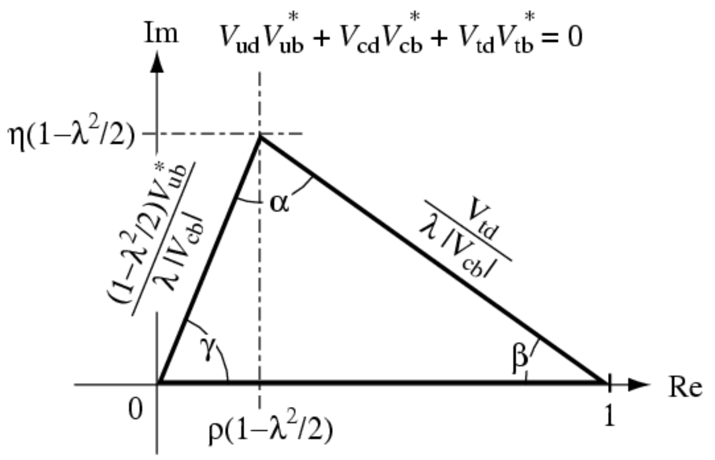
The LHCb Experiment

- LHCb is an LHC experiment for B physics



- Single-sided detector because of bb production correlation

CKM physics from B → K π



- **A major task in B physics is to overconstrain the 2 "main" CKM triangles: γ can be obtained from B→K π decays. Use an isospin argument to cancel strong phase differences.**

- **Construct vars *R* and A_0 from $B_d \to K^+ \pi^-$ and $B_u \to K_S \pi^+$ rates:**

$$\begin{pmatrix} R \\ A_0 \end{pmatrix} \equiv \frac{\mathcal{B}(B_d^0 \to \pi^- K^+) \pm \mathcal{B}(\overline{B_d^0} \to \pi^+ K^-)}{\mathcal{B}(B^+ \to \pi^+ K^0) + \mathcal{B}(B^- \to \pi^- \overline{K^0})}$$

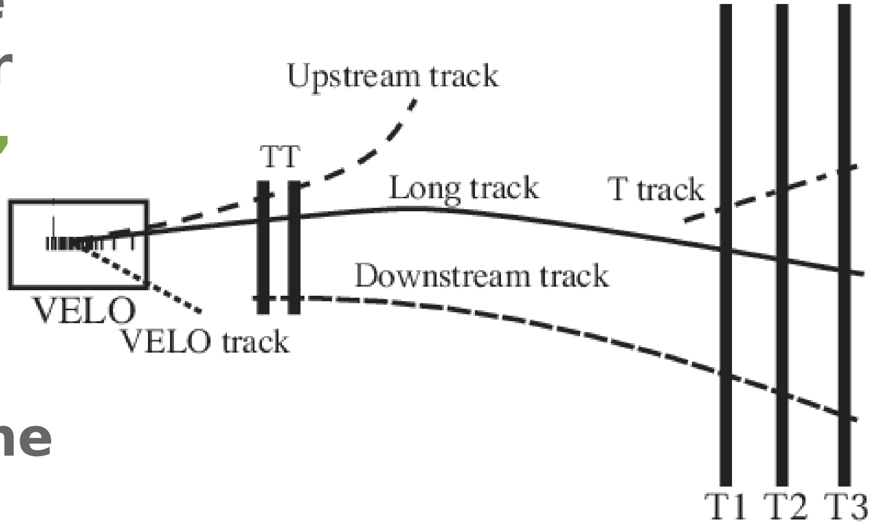
(Note that relative selection efficiencies *are* important.)

- **Define *r* as the tree-penguin amplitude ratio (model dep). Constrain γ via *R* and A_0 contours in r-γ space.**

- **Useful cross-check of γ.**

$B^+ \rightarrow K_S \pi^+$ decays

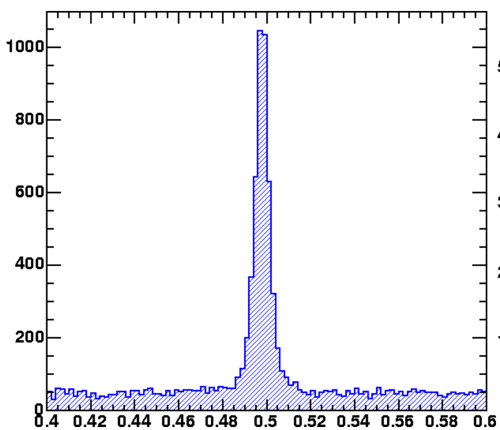
- B_d channel already investigated: predict yield of ~135k/yr.
- $B^+ \rightarrow K_S \pi^+$ channel under investigation. BR = 22.0 x 10^{-6}.
  - K_S propagates a mean distance of 80cm: about 2/3 decay after the VELO. Introduce Upstream, Downstream and Long track type definitions.
  - Pions are assigned nominal π masses after RICH PID: only one kinematic cut (K_S mass).
  - Large pion and K_S populations from bb inclusive decays



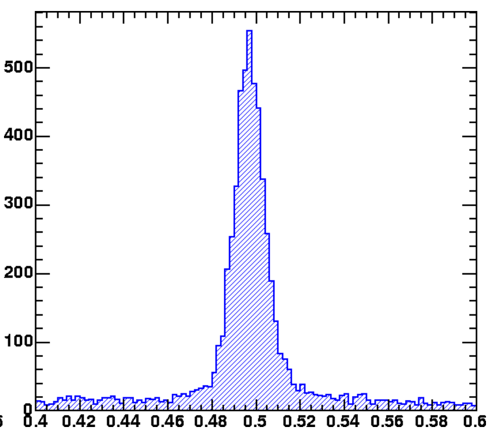
K_S reconstruction

- Reconstruct via $K_S \rightarrow \pi^- \pi^+$ decay chain (BR ~ 68%). Categorise as LL, DD, LU and LD according to π tracks. Pion types are naturally correlated.
- K_S pre-selection cuts are on IP w.r.t. PV, mass, p_T with variations depending on pion track type.
- K_S mass plots (all from 400-600 MeV):

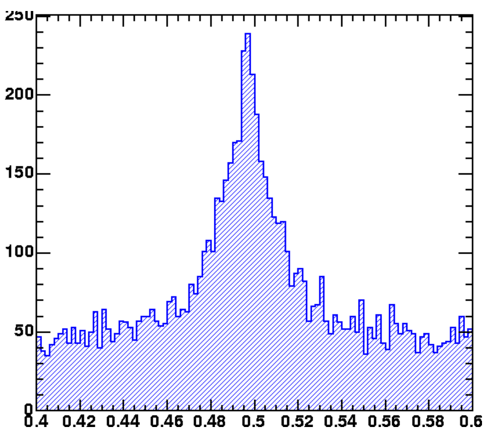
LL:



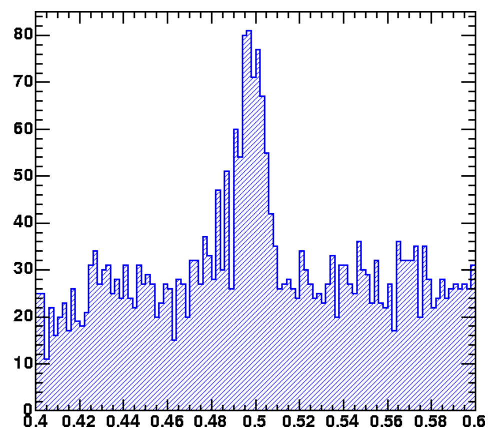
DD:



LU:



LD:

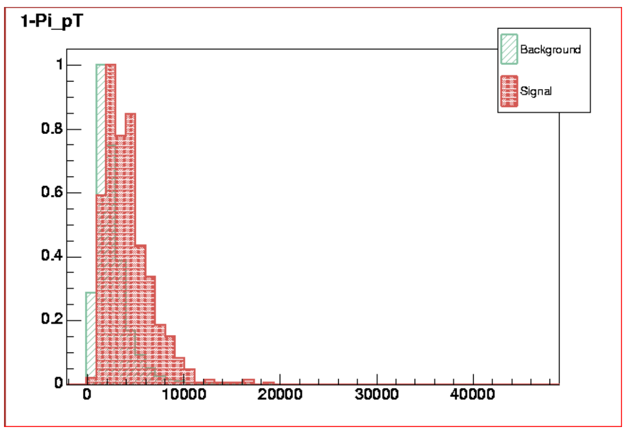


- Just use LL and DD for now to avoid being swamped by background. Categorise whole decay as “LL” or “DD”.

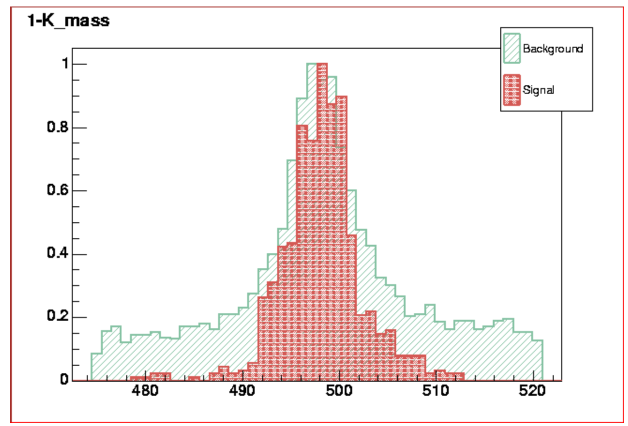
Typical cut variables (LL)

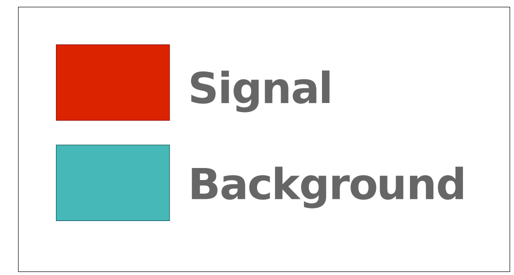
- **Some physical cut variable distributions from reconstructed LL events. Note that S/B are independently normalised; the background is actually much larger than signal:**

Pi *pT*:



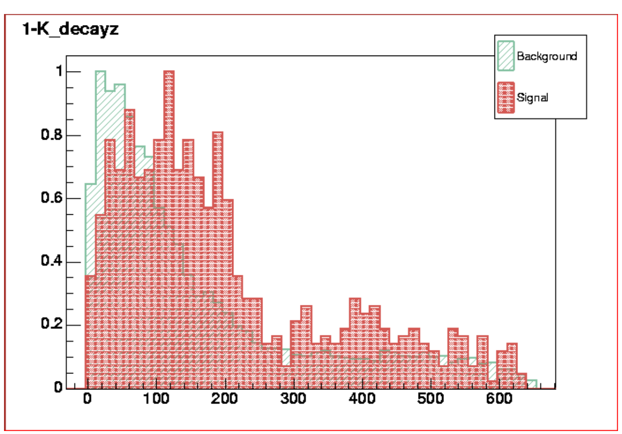
Ks mass:



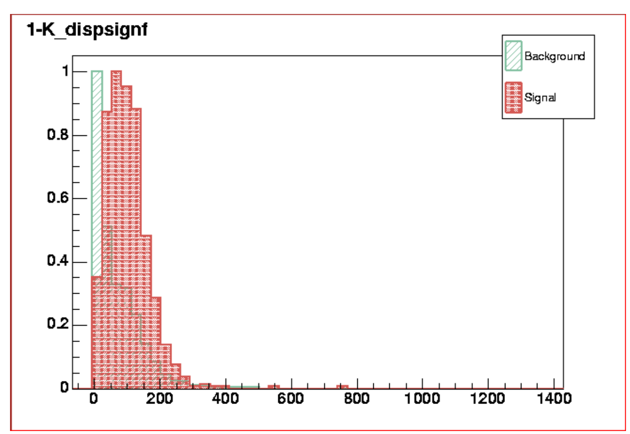


NB. these are the *best* discriminant variables. Others have less S-B separation.

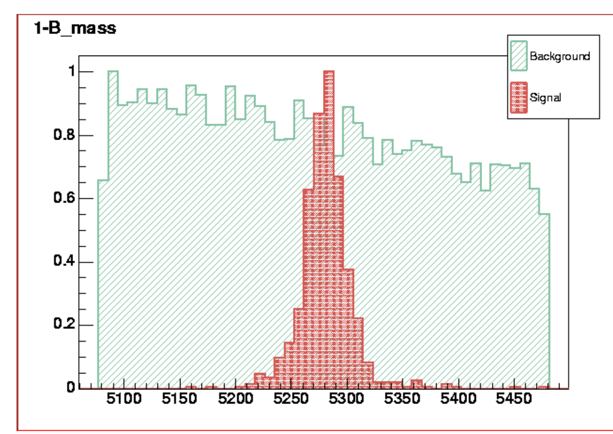
Ks decay *z* position:



Ks disp signf:



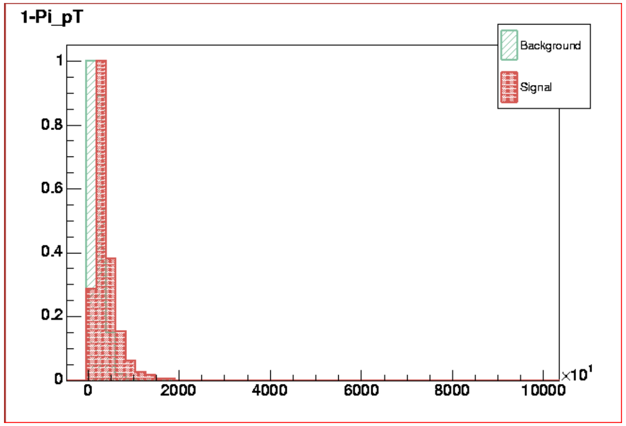
B^+ mass:



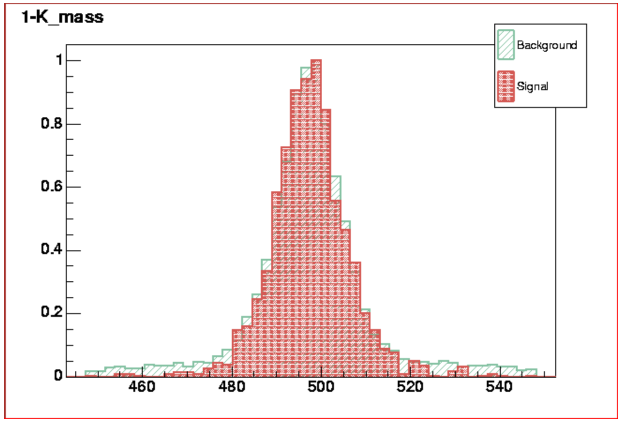
Typical cut variables (DD)

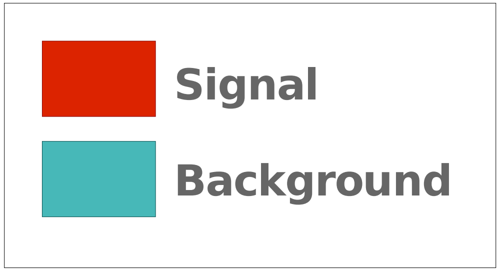
- **And again for the DD events:**

Pi *pT*:

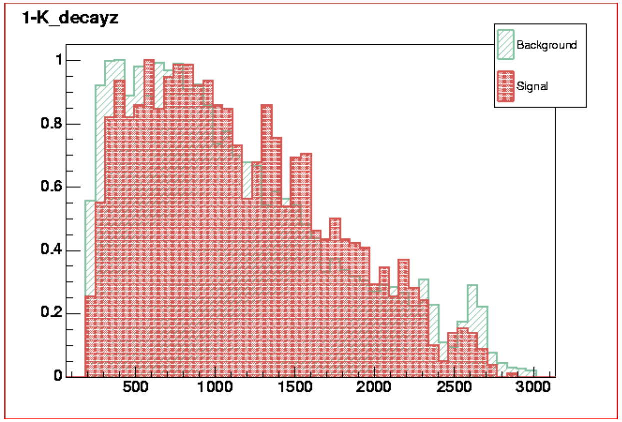


Ks mass:

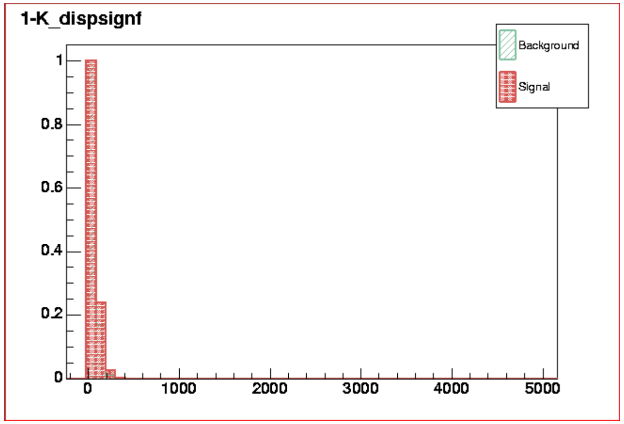




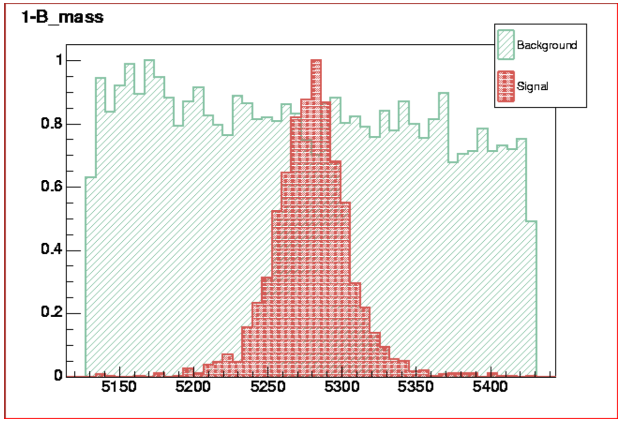
Ks decay *z* position:



Ks disp signf:



B^+ mass:



- **DD has more background and it's more similar to the signal.**

Tuning methods

- **Several approaches attempted with 18 reconstructed vars**
  - **(π and K p, p_T, σ_{IP}; K mass, decay z, lifetime, σ_{disp} and vertex-fit χ^2; B mass, p, p_T, σ_{IP}, lifetime, σ_{disp} & χ^2. Phew!)**

- **No good 2D correlation clustering observed and no outstanding 1D cuts. Make marginal 1D cuts instead.**

- **Naïve approach to tuning cuts: form a 2-parameter window for each variable, position cuts by eye and then tune perturbatively. Rather than a grid scan (not a good idea in n = 36!), use Markov Chain Monte Carlo sampler (MCMC).**

- **Implementation is an OO library based on ROOT and GSL.**
Details: use a Nelder-Mead simplex minimisation sampler (no gradient info). Cut variables are shifted by the means of their signal component, rescaled by its extent and then tuned on the homogenised variables.

- **What are we extremising? Hard to construct a metric which represents the optimal situation for extracting gamma. Typical variables: S/B, S/√B or explicit $\epsilon \times \rho$.**

Statistical issues

- Need to weight bb part of the event sample to match actual relative fractions: account for generator cuts, geometric effects, branching ratios and hadronisation fractions:

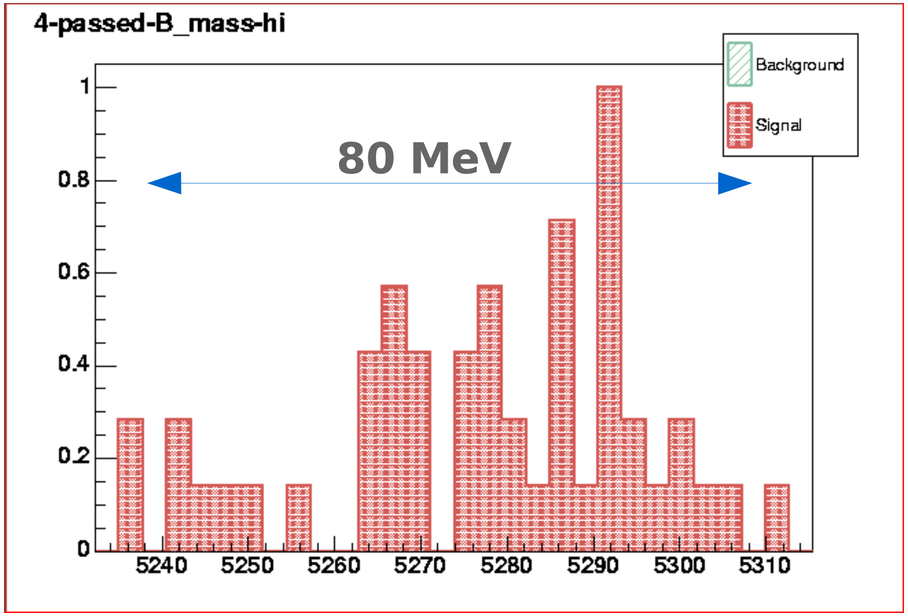
$$w_{\mathrm{bb}} = \frac{S_{\mathrm{tot}}}{B_{\mathrm{tot}}} \times \frac{G_{\mathrm{bb}}}{G_{\mathrm{sig}}} \times \frac{1}{f_{\mathrm{B_u^+}} \times \mathcal{B}(\mathrm{B_u^+} \to \mathrm{K_S^0}\,(\pi^+\pi^-)\,\pi^+)}$$

Net effect is that w_{bb} ~ 780 for 32k signal and ~8M bb. Massive overweighting of single points (i.e. need much more bb data).

- Given this, try to make life easy for sampler: characteristic function is S/√(B+1) for its improved B scaling and lim(S+B→0) regularisation. Additionally, only count S and B *after* L0 & L1 triggers: this hits bb events harder than signal events.

Results (LL)

LL B mass:

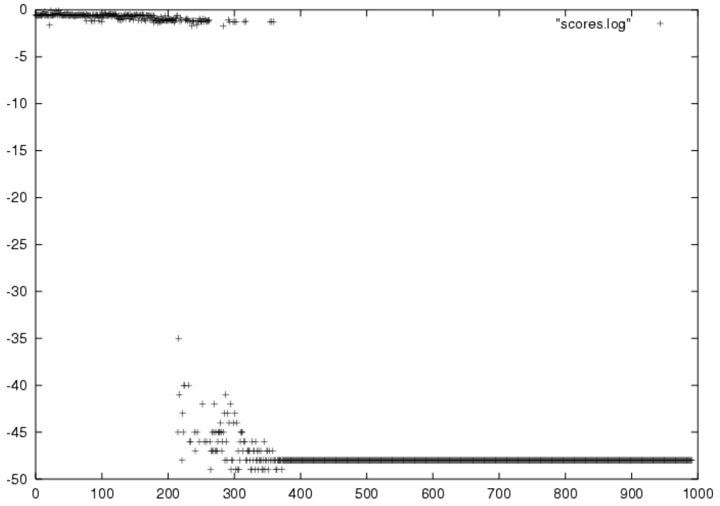


49 events from 32k signal.
Eff = 7.44%, no background.
Mass RMS ~ 30 MeV.

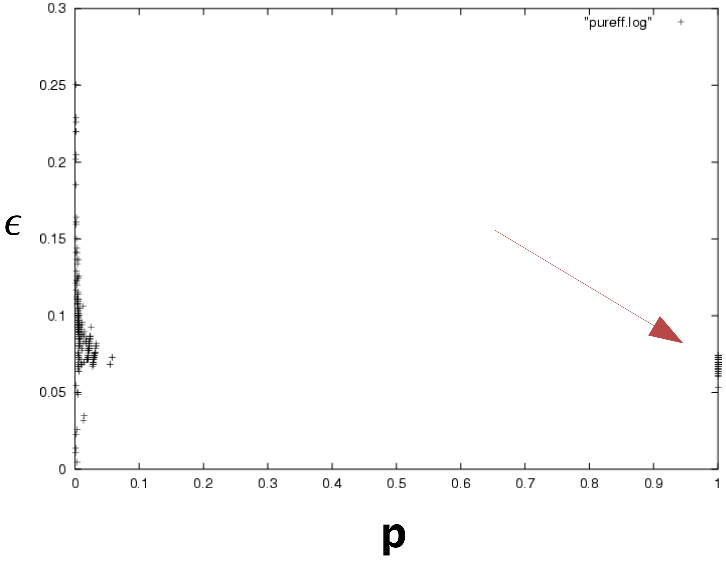
Note score progression and purity-efficiency plots.

Yield ~ 9.4k evt/yr

Score (-S/√(B+1)):

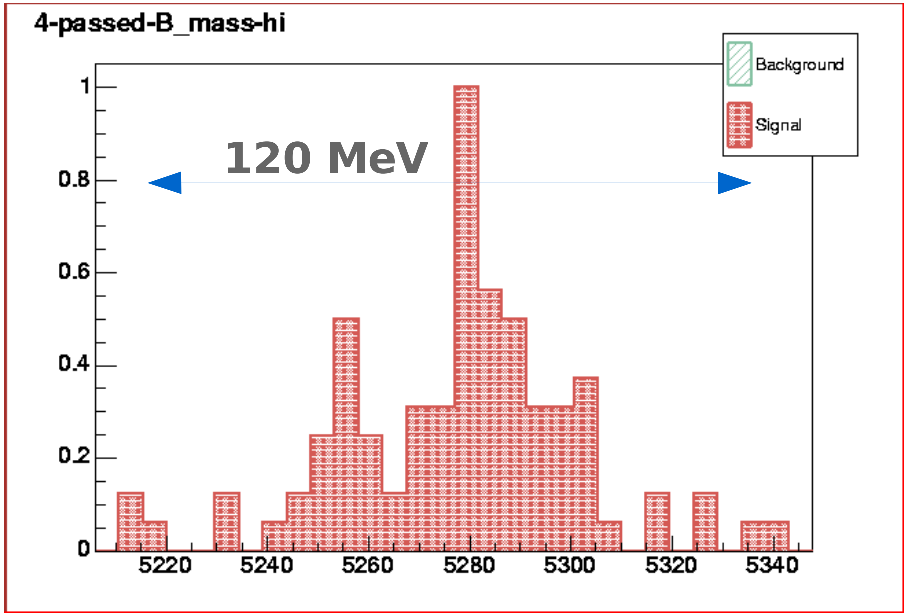


Eff-purity



Results (DD)

DD B mass:

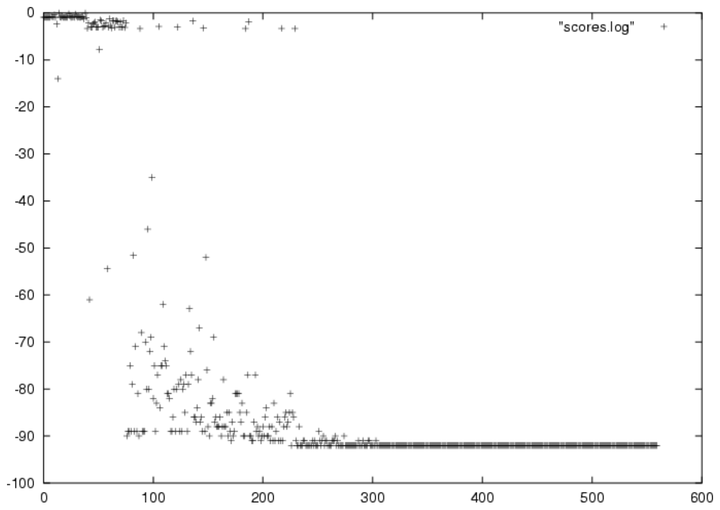


92 events.
Eff = 5.06%, no background.
Mass RMS ~ 50 MeV.

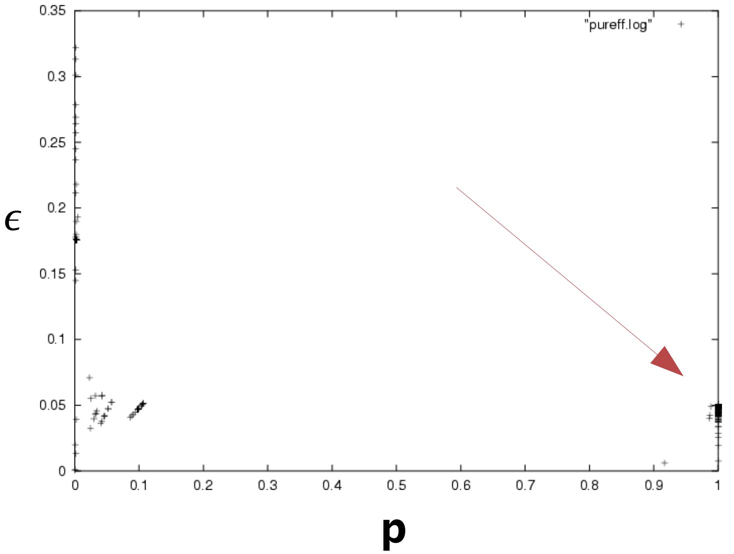
Yield ~ 18.7k evt/yr
so total yield ~ 28k evt/yr.

Need more stats!

Score (-S/√(B+1)):



Eff-purity



Work to come

- Improve statistics: LHCb Data Challenge '04 approaching. Can also use B mass sidebands mapped into pre-sel mass window.

- Using gradient info in sampler?

- Better approaches to discrimination: diagonalised "natural" variables with box cuts or, even better, quadratic discriminants (see right).
  This is partially implemented already.

- Tune/test on different samples.

- And finally, get some real data!

  Hopefully 28k evt/yr for B^+,
  135k evt/yr for B_d: good sensitivity to γ starting 2007...

Optimal QDA cuts on Gaussian populations