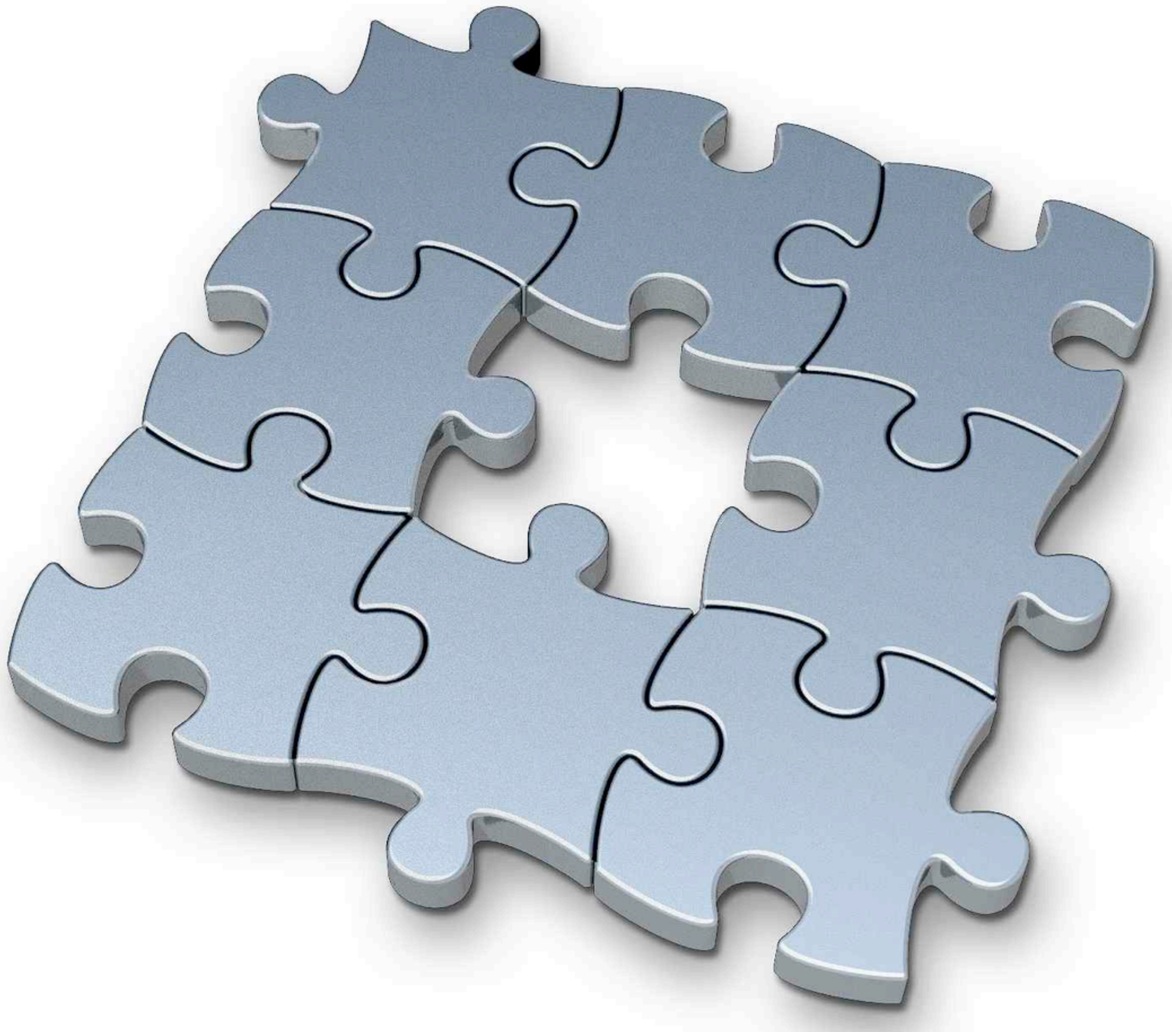


Prospect for $B \to D^* \tau \nu_\tau$ at LHCb

Malcolm John, for the LHCb collaboration
26 November 2012

Intriguing result from BaBar

- In PRL 109, 101802 (2012), BaBar describe an excess of semi-tauonic B decays from measurements of

$$R^{(*)} \rightarrow \frac{\mathscr{B}(B \rightarrow D^{(*)}\tau\upsilon)}{\mathscr{B}(B \rightarrow D^{(*)}\mu\upsilon)} \text{ for both } B^0 \text{ and } B^{\pm}$$

$\mathscr{B}(B \rightarrow D\tau\upsilon)$ ~ 1.0%
$\mathscr{B}(B \rightarrow D^*\tau\upsilon)$ ~ 1.2%

- The SM expectation:

R = 0.297±0.017 R^*= 0.252±0.003

- Their result:

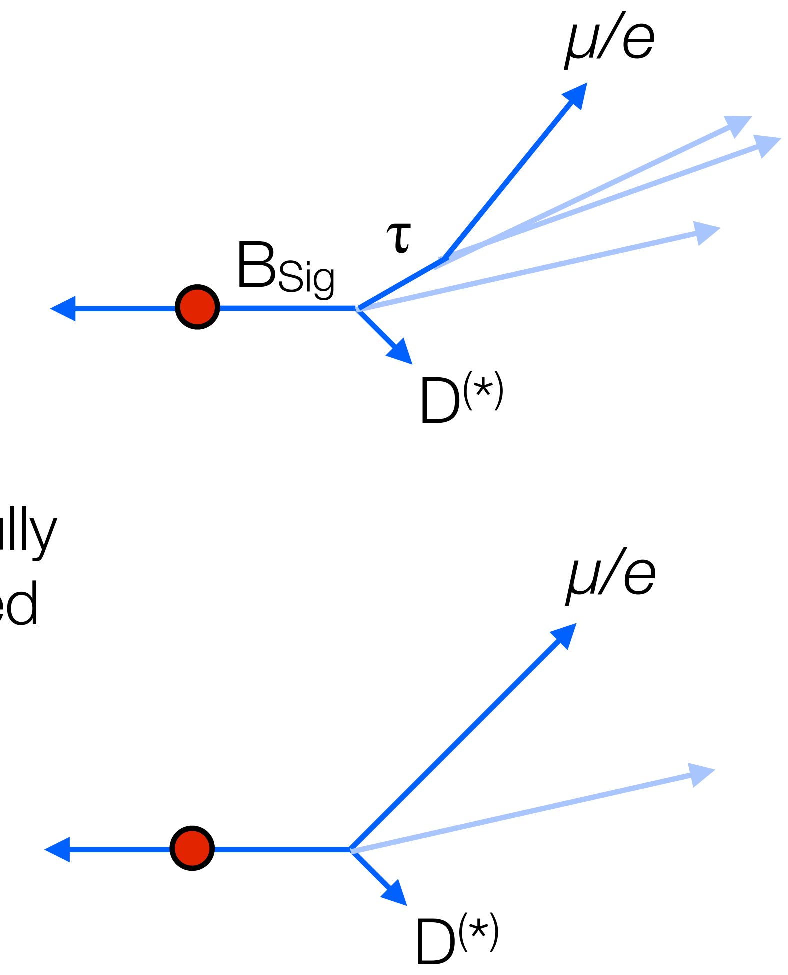
Decay	N_{sig}	N_{norm}	$\varepsilon_{\text{sig}}/\varepsilon_{\text{norm}}$	$\mathcal{R}(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	Σ_{stat}	Σ_{tot}
$B^- \to D^0\tau^-\overline{\nu}_\tau$	314 ± 60	1995 ± 55	0.367 ± 0.011	$0.429 \pm 0.082 \pm 0.052$	$0.99 \pm 0.19 \pm 0.13$	5.5	4.7
$B^- \to D^{*0}\tau^-\overline{\nu}_\tau$	639 ± 62	8766 ± 104	0.227 ± 0.004	$0.322 \pm 0.032 \pm 0.022$	$1.71 \pm 0.17 \pm 0.13$	11.3	9.4
$\overline{B}^0 \to D^+\tau^-\overline{\nu}_\tau$	177 ± 31	986 ± 35	0.384 ± 0.014	$0.469 \pm 0.084 \pm 0.053$	$1.01 \pm 0.18 \pm 0.12$	6.1	5.2
$\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau$	245 ± 27	3186 ± 61	0.217 ± 0.005	$0.355 \pm 0.039 \pm 0.021$	$1.74 \pm 0.19 \pm 0.12$	11.6	10.4
$\overline{B} \to D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	0.372 ± 0.010	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	8.4	6.8
$\overline{B} \to D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	0.224 ± 0.004	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	16.4	13.2

tau yields $R^{(*)}$

- R and R^* are 2.0σ and 2.7σ away from SM respectively

Semi-tauonic reconstruction

- Reconstructing both B mesons and calculate the missing mass, **m_{miss}**
  - only the $\tau \to \mu\nu\nu$ decay mode is used
  - semi-muonic signal is integral. Straight-forward measurement of $R^{(*)}$



$m_{miss} > 0$

$m_{miss} = 0$

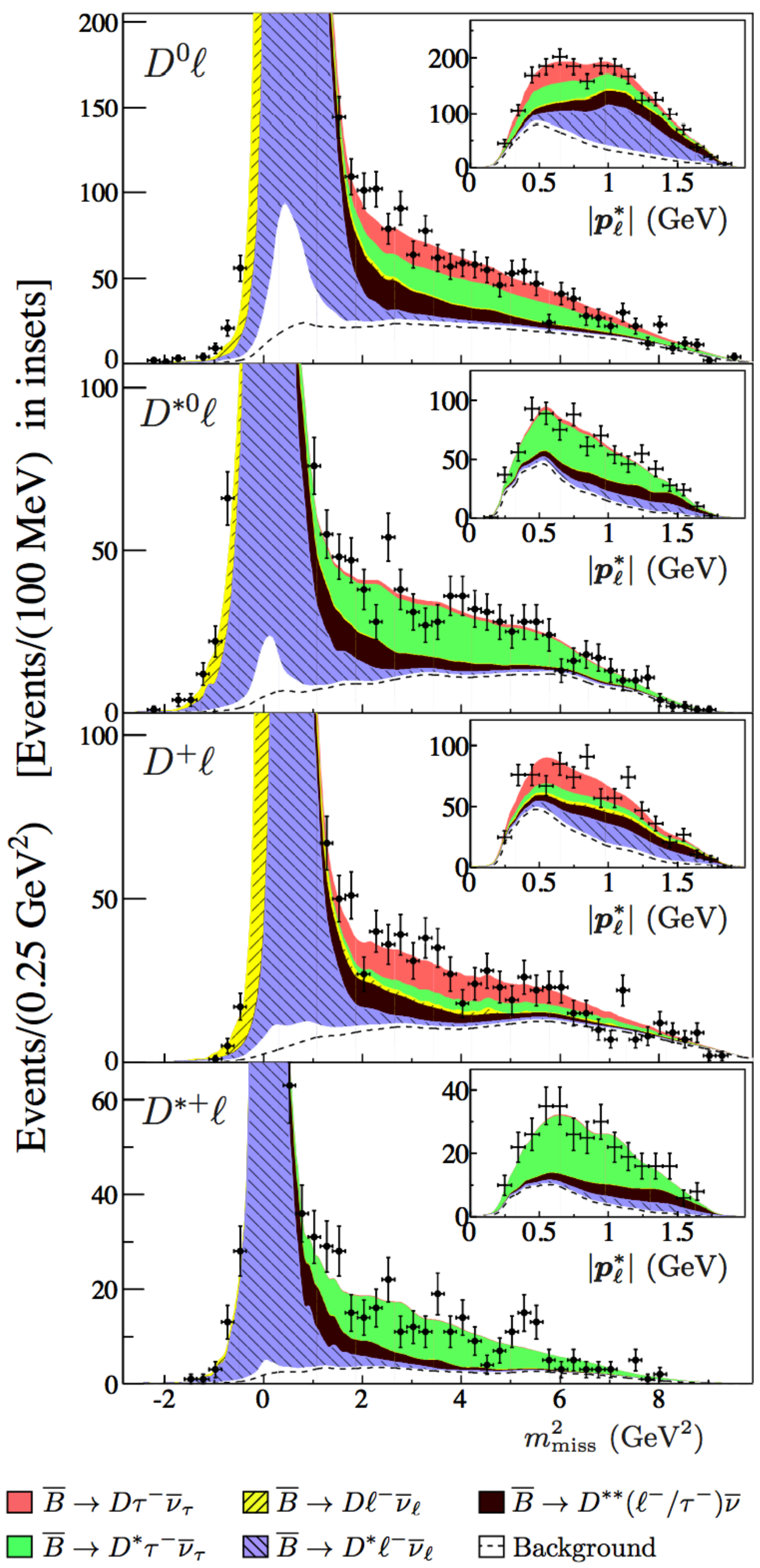
B_{Tag}

Uses 1680 fully reconstructed modes!

m_{miss}

$m^2_{miss} = (p^2_{init} - p^2_{tag} - p^2_D - p^2_{muon})$

BaBar: PRL 109, 101802 (2012)

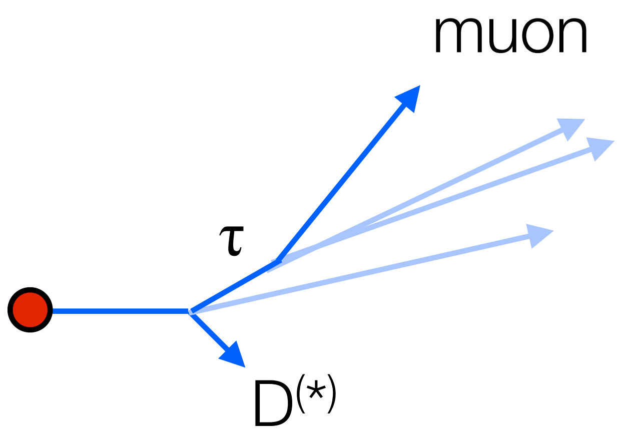


$D^0 \to K\pi, KK, K\pi\pi^0, K\pi\pi\pi, K_S\pi\pi$

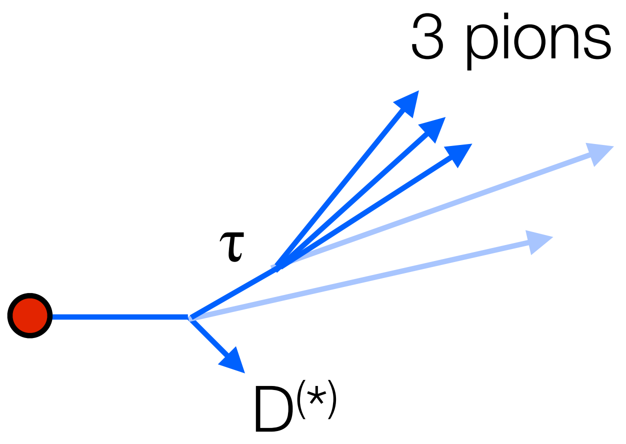
$D^\pm \to K\pi\pi, K\pi\pi\pi^0, K_S\pi, K_S\pi\pi\pi, K_S\pi\pi^0, K_SK$

What can LHCb do?

- Kinematic *B*-tagging is unhelpful as initial state is undefined in pp collisions
- Therefore, despite its advantages (high branching fraction, $\mathscr{B}(\tau\to\mu\nu\nu)$=17.4%, and high reconstruction efficiency), $\tau\to\mu\nu\nu$ mode is difficult, if not impossible from hadronic collisions

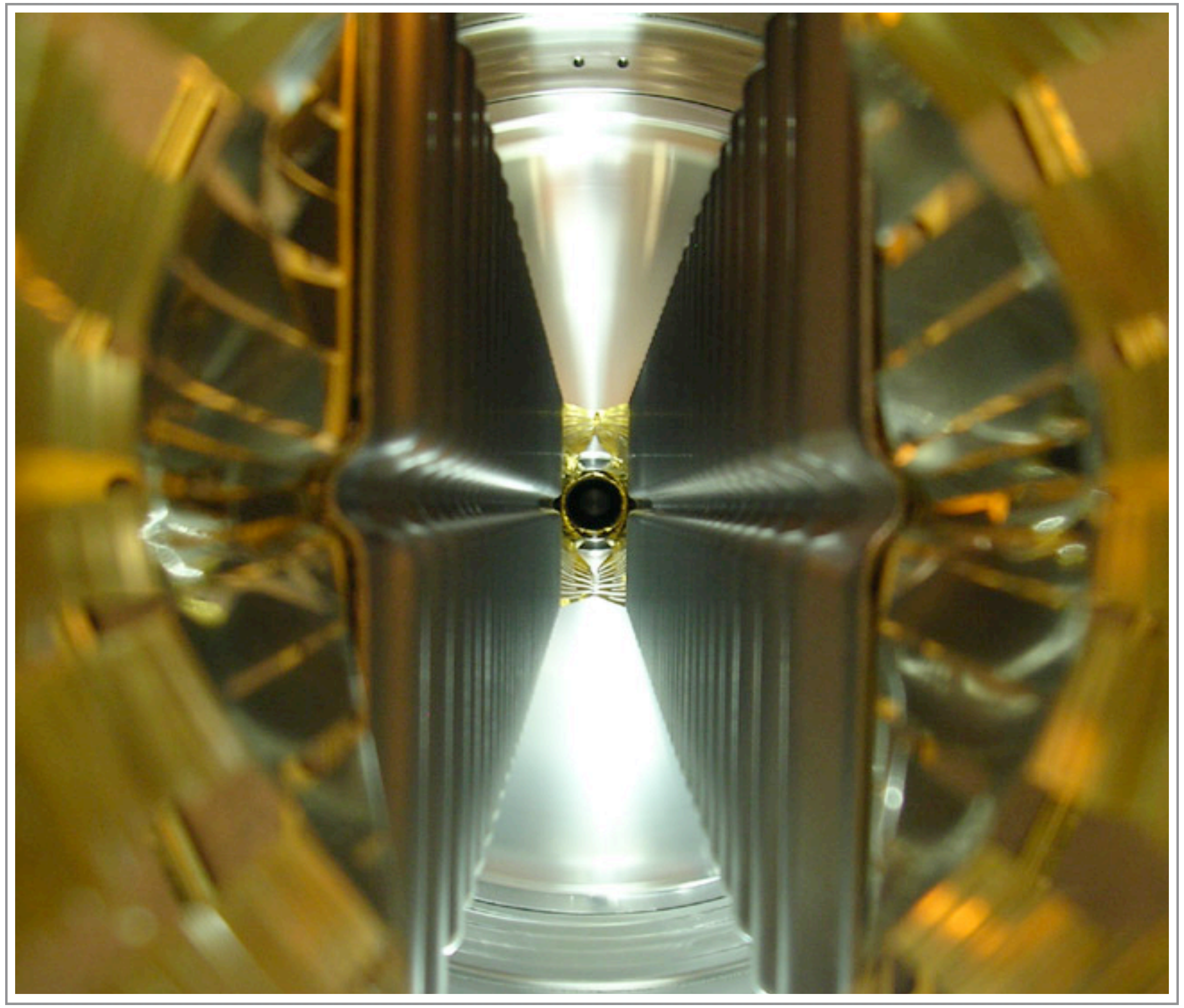


- Hence the $\tau\to\pi\pi\pi\nu$ mode is being investigated
  - Lower branching fraction, $\mathscr{B}(\tau\to\pi\pi\pi\nu)$=9.3% and 3π final state suffers much lower efficiency w.r.t. single muon case
  - But, the 3π defines the tau decay vertex
    - D^0 + 'slow' pion provides the tau birth vertex and the difference is the tau direction vector



- This technique takes advantage LHCb's core strengths
  - Exceptionally high production rate (>10^{11} bb/year)
  - Large boost (separation of secondary and tertiary decays)
  - An intelligent, "topological" (~ pseudo-inclusive) *B* trigger
  - Excellent vertexing...

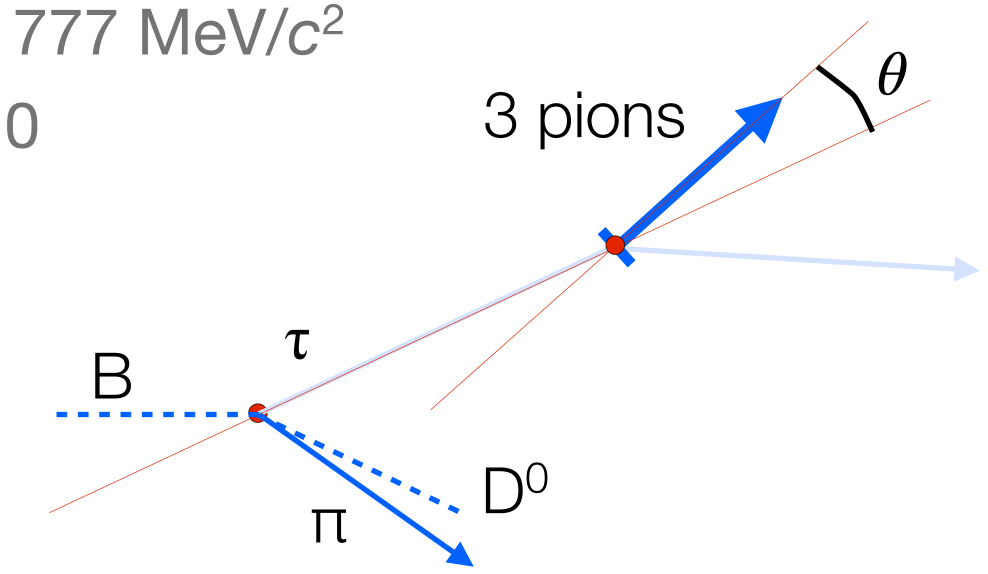
The precise vextexing is provided by the VELO subdetector which brings microstrip sensors to within 8.2 mm from the LHC beams



“*Reconstruction of the tau lepton and the study of $B^0 \to D^{*-}\tau^+\nu_\tau$ at LHCb*”
Anne Keune, Ph.D. thesis, EPFL (2012)

Tau reconstruction

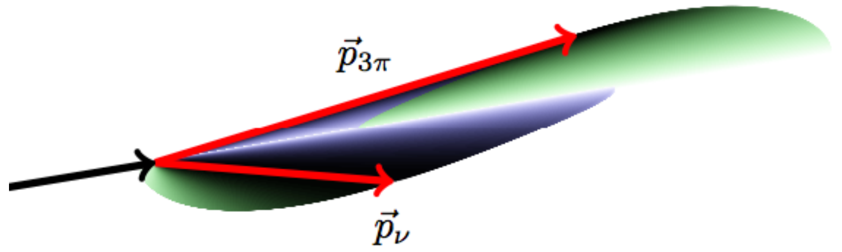
- Fix $m(\tau) = 1777$ MeV/c^2
- and $m(\upsilon) = 0$



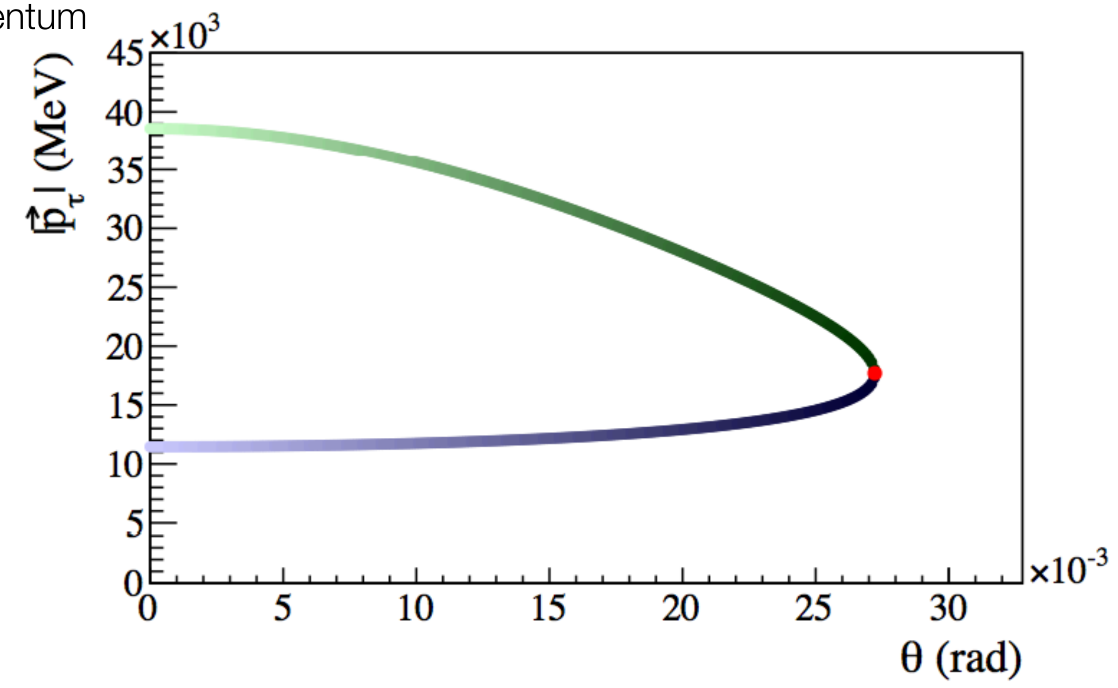
$$|\vec{p}_\tau| = \frac{\left(m_{3\pi}^2 + m_\tau^2\right)|\vec{p}_{3\pi}|\cos(\theta) \pm E_{3\pi}\sqrt{\left(m_\tau^2 - m_{3\pi}^2\right)^2 - 4m_\tau^2|\vec{p}_{3\pi}|^2\sin^2(\theta)}}{2\left(E_{3\pi}^2 - |\vec{p}_{3\pi}|^2\cos^2(\theta)\right)}$$

- Generally, have 2 solutions - unavoidable ambiguity
    - Presumably renders impossible an angular analysis of the tau decay
- Same idea is reapplied to obtain the *B* momentum
    - Up to 4 p(B) x p(τ) solutions

Cartoon and plot shows the kinematic possibilities for one decay
green(blue) displays positive(negative) discriminant solutions



tau momentum

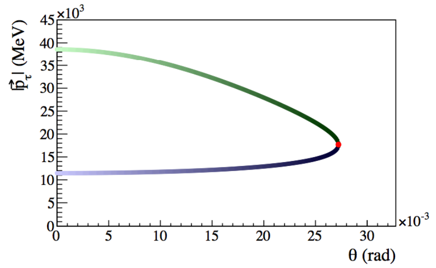


Angle between 3π & τ

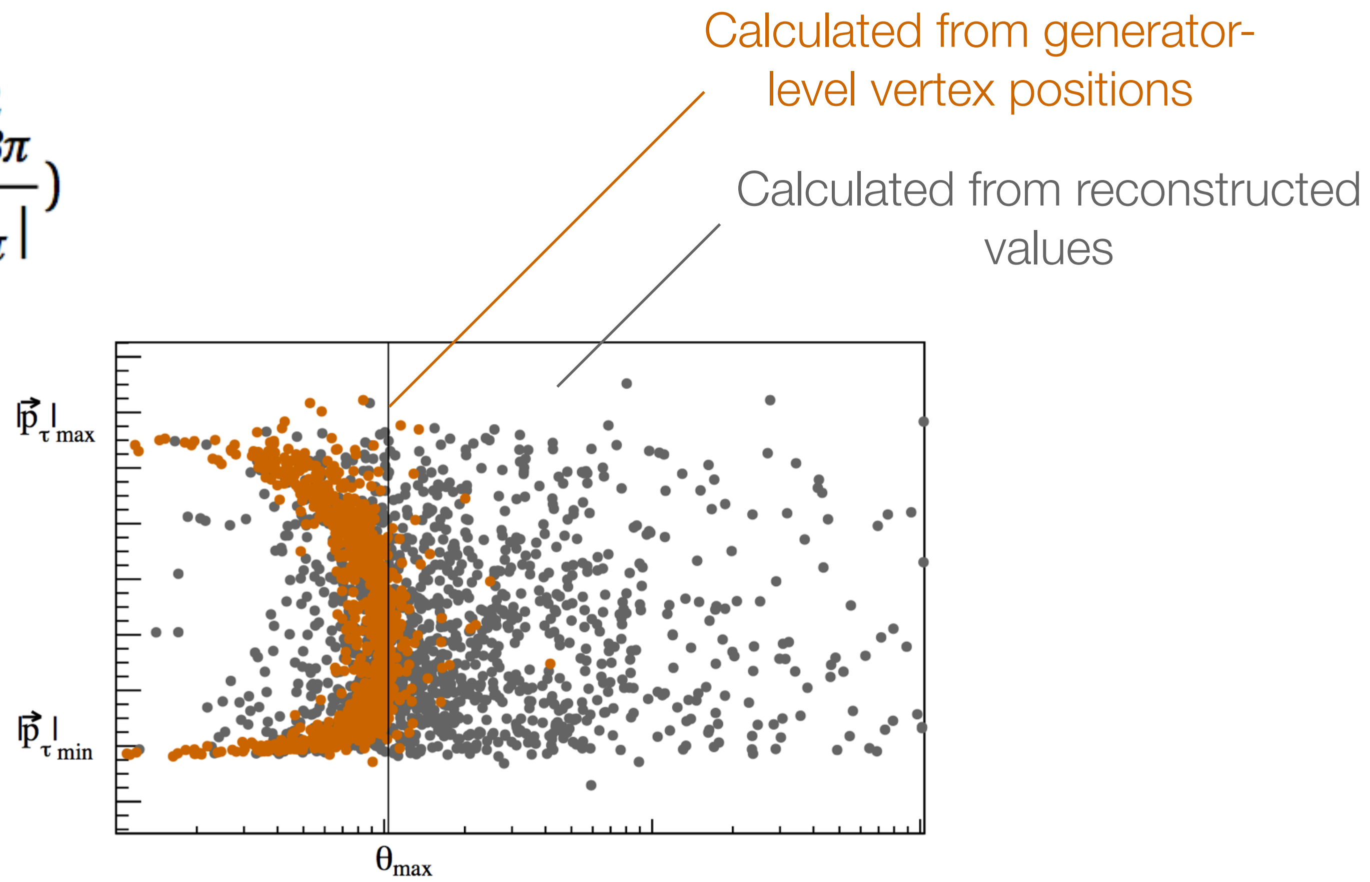
Limitation due to accurate vertexing

- Angle θ has a kinematic upper limit

$$\theta_{\max} = \operatorname{asin}\left(\frac{m_\tau^2 - m_{3\pi}^2}{2m_\tau|\vec{p}_{3\pi}|}\right)$$



Single example → Many events



- Problem! - Due to imprecision of the vertexing and even floating-point rounding, an analytical solution is possible only ~25% of the time.

- Possible solution: move any unphysical points to the single-solution apex (red dot on first plot)
  - OK ... but can do better with a kinematic fit

Refit of the whole B decay

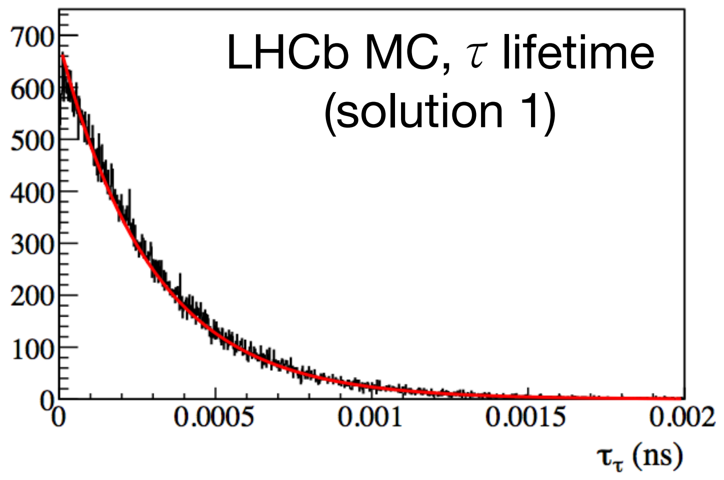
- Minimise a χ^2 taking information from the whole candidate

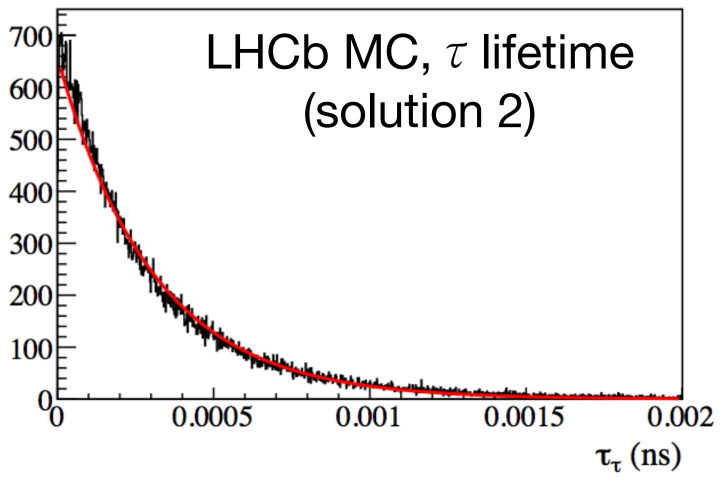
W is the covariance matrix of the measurable quantities

$$\chi^2 = (m - h(x))^T W (m - h(x))$$

$$h(x) = \{\boldsymbol{pV}, \boldsymbol{dV}, \vec{p}_{3\pi}, m^2_{3\pi}, \boldsymbol{bV}, \vec{p}_{D^*}, m^2_{D^*}\}$$

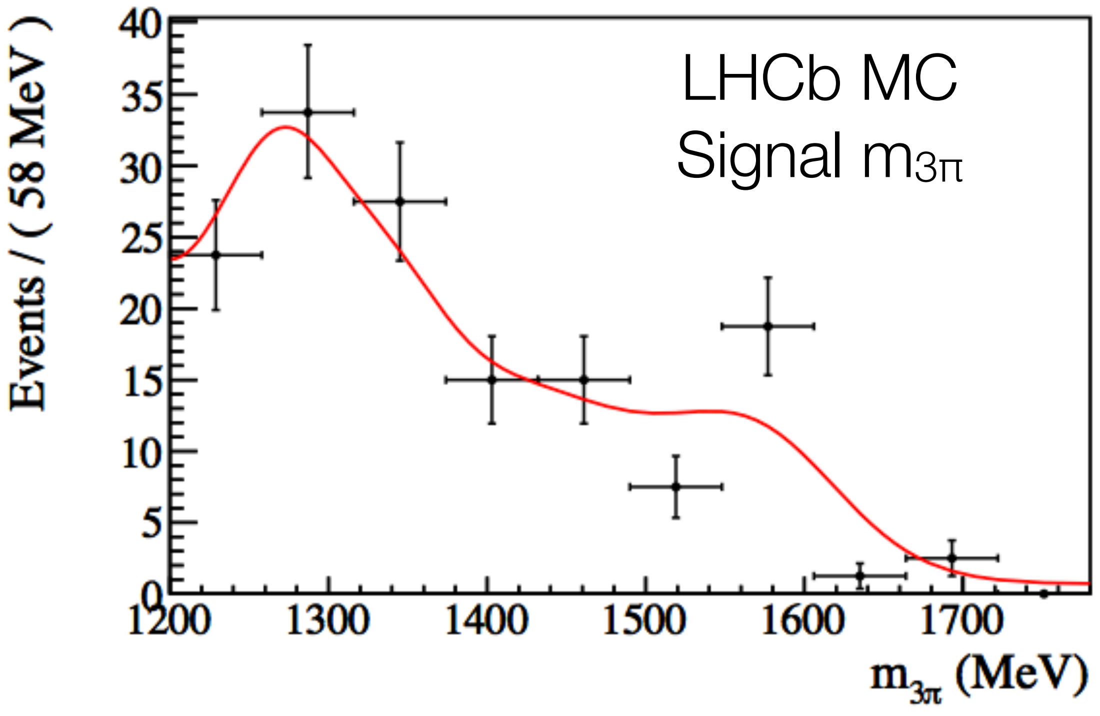
- Seems to work well. BUT: only gives one solution. Analytical calculation still needed to recover other(s)
- Finally, checking properties of the solutions: lifetime distributions seem degenerate

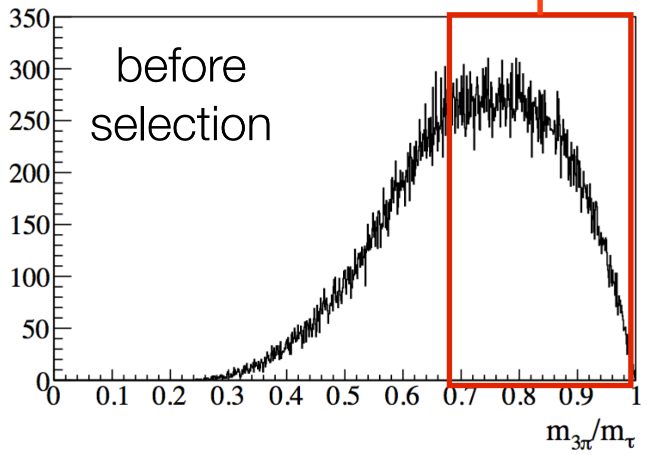




Signal extraction ideas

- Possible fit distributions: τ-lifetime and $m_{3\pi}$
  - *B*-mass, τ-mass, neutrino masses: fixed.





- Very preliminary look at some of the 2011 data is modestly encouraging
  - *Kinematic refit and a tight cut on the m(D*)-m(D) applied*

→ signal PDF →

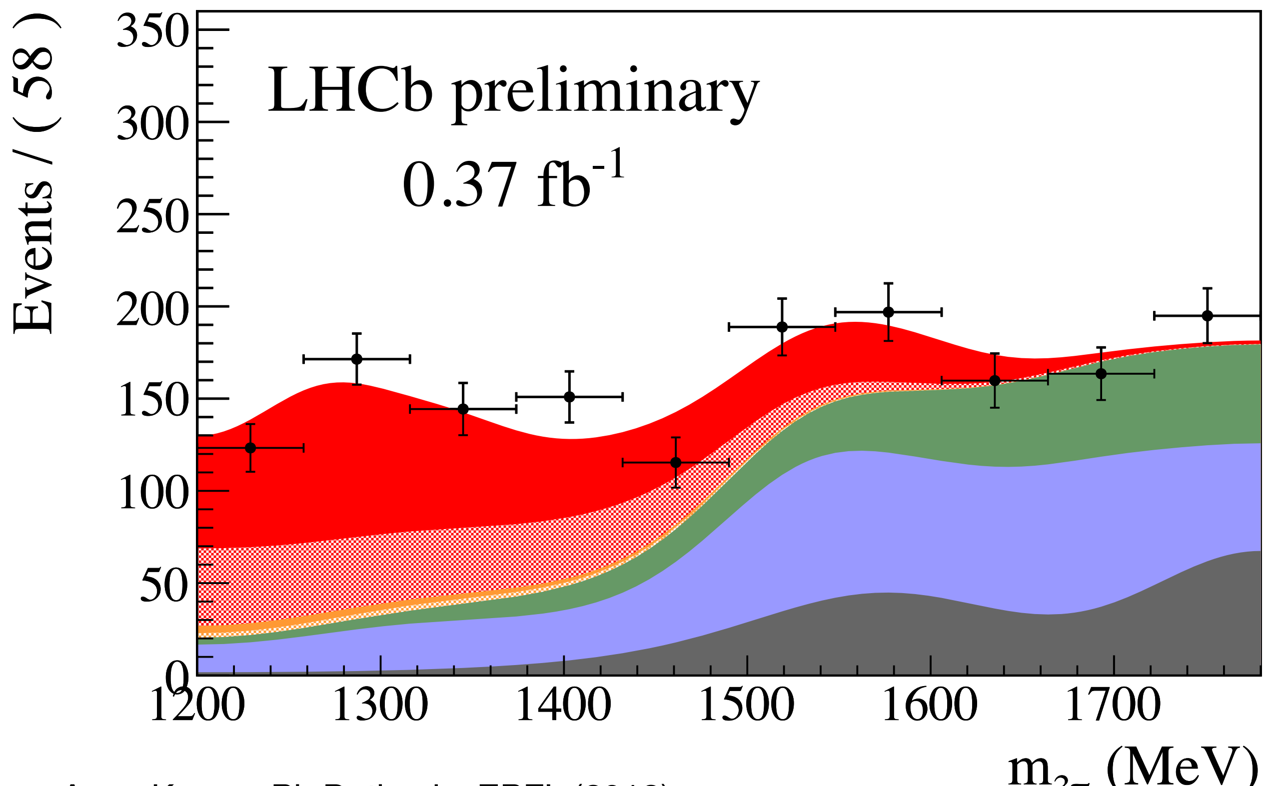
$B_d \to D^* \tau \nu$, $\tau \to \pi\pi\pi\nu$

$B_d \to D^* \tau \nu$, $\tau \to \pi\pi\pi\pi^0\nu$

$B_u \to$ DX inclusive

$B \to D^* \pi\pi\pi\pi^0$

$B_d \to$ DX inclusive



Anne Keune, Ph.D. thesis, EPFL (2012)

Possible yields with the full 2011+2012 sample

- Assume: 3 fb^{-1}, $\sigma(bb)$ = 250μb, f_d=0.4, $\mathscr{B}(B\to D^*\tau\upsilon)_{SM}$ = 1.2% and $\varepsilon_{REC} \cdot \varepsilon_{SEL}$ = 0.010%

estimated at 0.015% in the "first look" analysis

Have the tau birth vertex

- $N(B_d\to D^*\tau\upsilon, D^*\to D^0\pi, D^0\to K\pi, \tau\to\pi\pi\pi\nu)$ ~ **1800** BASELINE ANALYSIS (c.f. N_{Babar} ~ 900)
- $N(B_d\to D^\pm\tau\upsilon, D^\pm\to K\pi\pi, \tau\to\pi\pi\pi\nu)$ ~ **300**
- $N(B_u\to D^0\tau\upsilon, D^0\to K\pi, \tau\to\pi\pi\pi\nu)$ ~ **300**

Early studies suggest about a factor 10 loss in efficiency without the D*

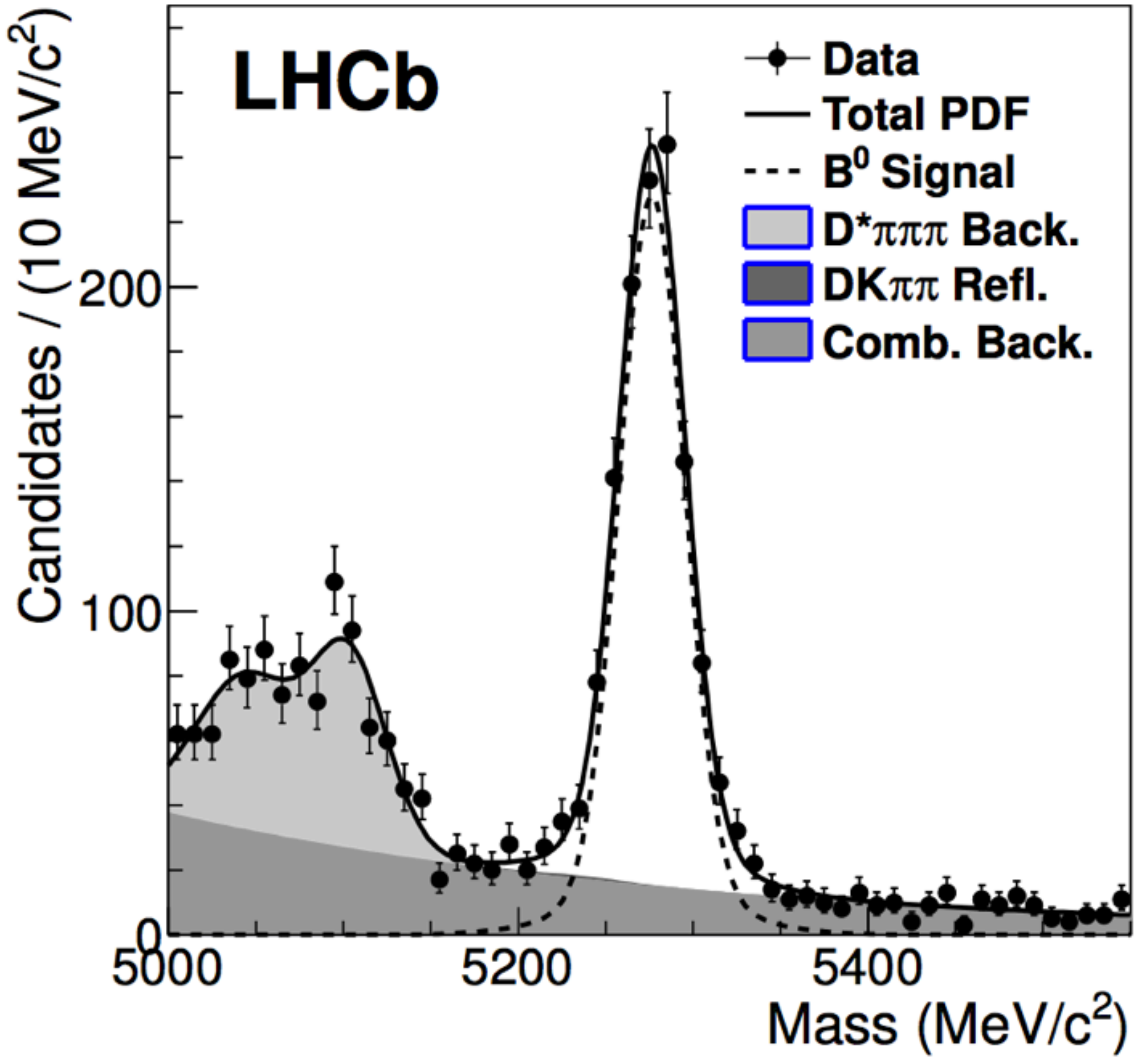
- $N(B_s\to D_s\tau\upsilon, D_s\to KK\pi, \tau\to\pi\pi\pi\nu)$ ~ **50** Bs production is a factor 4 lower than B_u & B_d
- $N(B_c\to J/\psi\tau\upsilon, J/\psi\to\mu\mu, \tau\to\pi\pi\pi\nu)$ ~ **20**

Normalisation

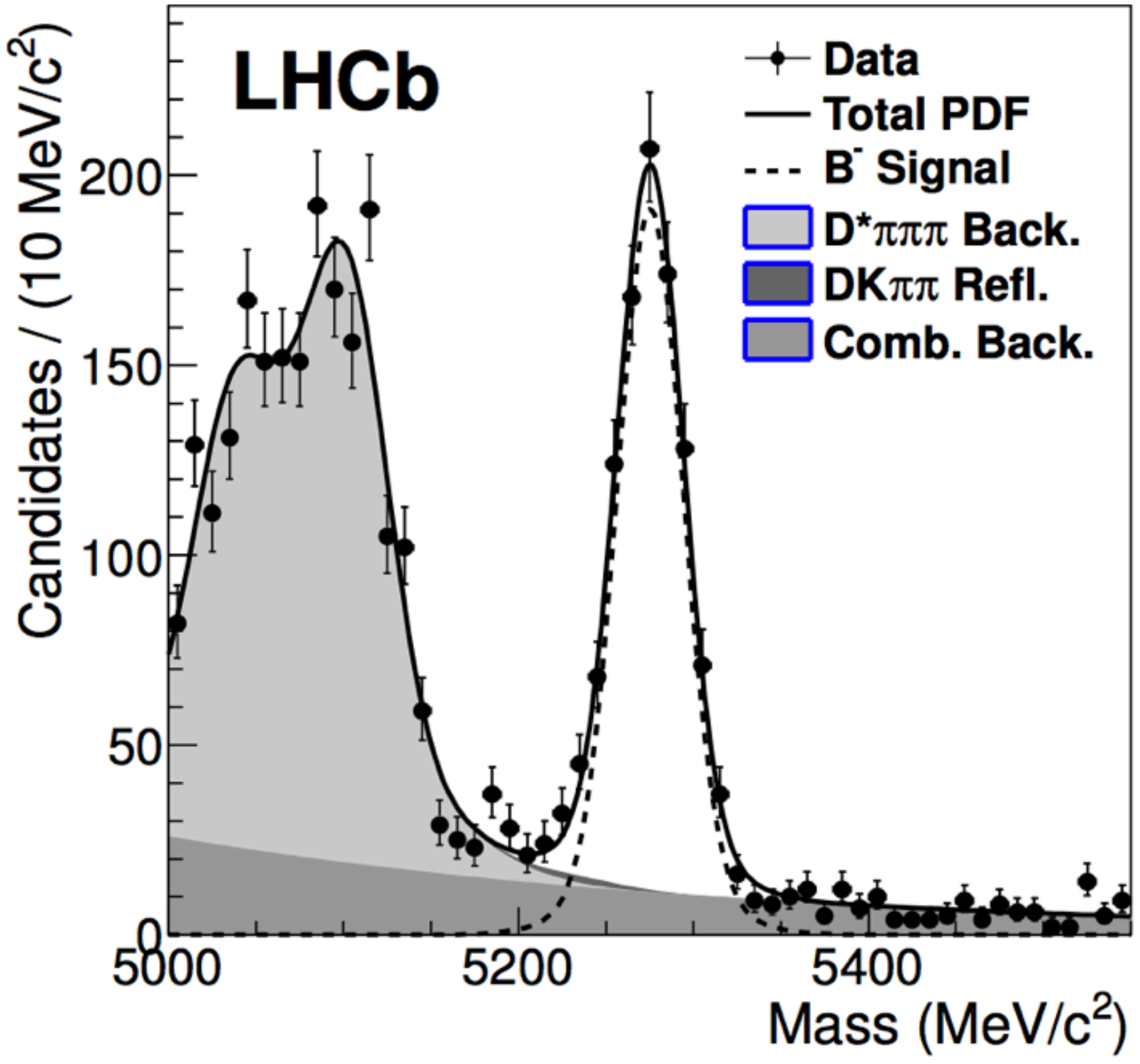
- For $\tau\to\pi\pi\pi\nu$ normalising to $B\to D^{(*)}\pi\pi\pi$ seems reasonable (cross-checking with $D^{(*)} D_s$, $D_s\to\tau\nu$)
- My world averages (PDG + recent LHCb results)
  - $B_d\to D^\pm\pi\pi\pi = (6.4\pm0.5)\cdot10^{-3}$ **7.8% relative error**
  - $B_u\to D^0\pi\pi\pi = (6.1\pm0.6)\cdot10^{-3}$ **10.0% relative error**
  - $B_s\to D_s\pi\pi\pi = (6.3\pm0.9)\cdot10^{-3}$ **14.3% relative error**
  - $B_d\to D^*\pi\pi\pi = (7.0\pm0.8)\cdot10^{-3}$ **13.1% relative error**

- First task! improve $\mathscr{B}(B_d\to D^*\pi\pi\pi)$ with LHCb data (ongoing)

Successful reconstruction of the “normalisation” modes



$B_d \to D^{\pm}\pi\pi\pi$ (0.035 fb^{-1})



$B_u \to D^{0}\pi\pi\pi$ (0.035 fb^{-1})

Conclusion

- A reconstruction of a semitauonic decays at LHCb using the $\tau \to \pi\pi\pi\nu$ mode is postulated

- An analysis of $B \to D^{*}\tau\nu$ with the 3 fb^{-1} has begun
    - The first task is almost complete: an improved measurement of the normalisation mode
    - Investigating the feasibility of $D^{\pm}\tau\nu$, $D_{s}\tau\nu$ or $D^{0}\tau\nu$
    - Expect to provide first public results towards autumn 2013