Measurement of the B^0 lifetime using $B^0 \to J/\psi K^{*0}$ decays with the LHCb detector

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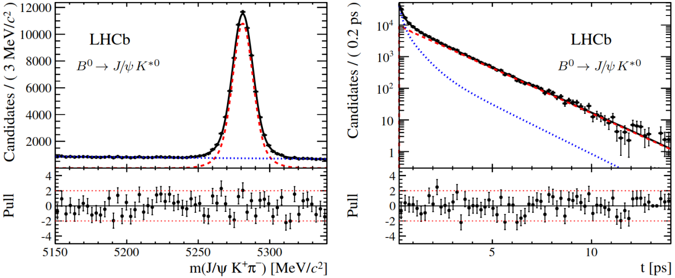
Motivation

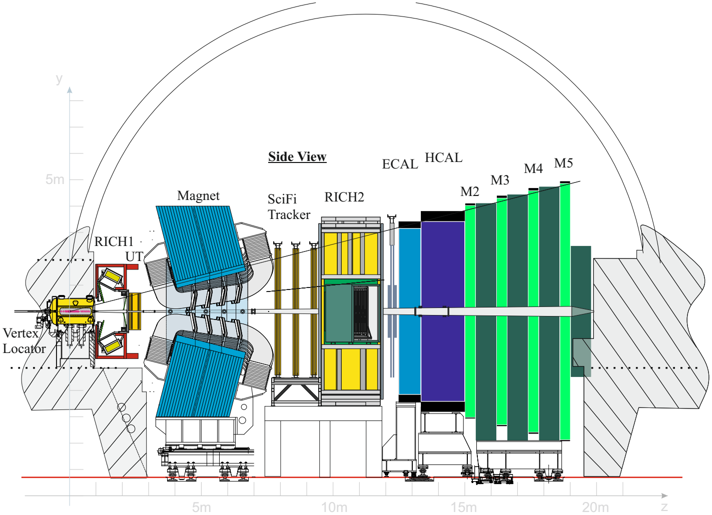
- Lifetime measurements offer precise probe for EW physics
- Precise theory predictions usually limited to lifetime ratios
  $\Longrightarrow$ **Absolute measurements serve as important reference points for theory models**
- $B^0 \to J/\psi K^{*0}$ decays have large branching fraction and are easy to identify
  Large sample for precision measurements
- **Good verification channel for LHCb Upgrade I detector**
- B^0 and B^+ lifetimes are commonly used as calibration for other measurements
- Recent ATLAS measurement [2411.09962]: $\tau_{B^0} = (1.5053 \pm 0.0012 \pm 0.0035)$ ps

LHCb Run 1 measurement [1402.2554]

- Measured value: $\tau_{B^0} = (1.524 \pm 0.004 \pm 0.003)$ ps
- Integrated luminosity: $1.0\,\text{fb}^{-1}$ at $\sqrt{s} = 7\,\text{GeV}$
- Total yield: $70\,500$ B^0 candidates
- Strategy: 2D-fit to $m(J/\psi K^{*0})$ and $t(B^0)$

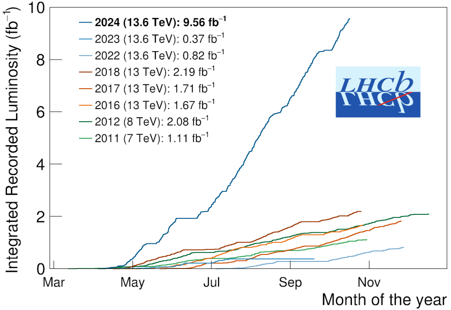


LHCb Upgrade I

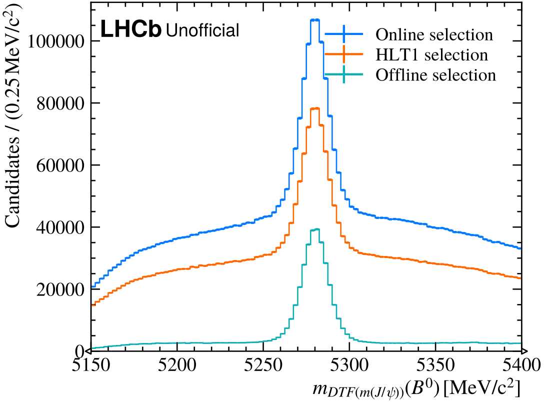


Run 3 expected results

- Detector improvements
  - Five times larger instantaneous luminosity
  - Center of mass energy: $\sqrt{s} = 13.6\,\text{GeV}$
    $\implies$ doubled cross-section
  - Software trigger allows for lifetime unbiased event selection
- Analysis targets
  - Data set of $6.0\,\text{fb}^{-1}$ in 2024
    $\implies$ Expect at least 12x larger yield
  - Statistical uncertainty $\sim 1\,\text{fs}$
  - Improved systematics: $\sim 1\,\text{fs}$



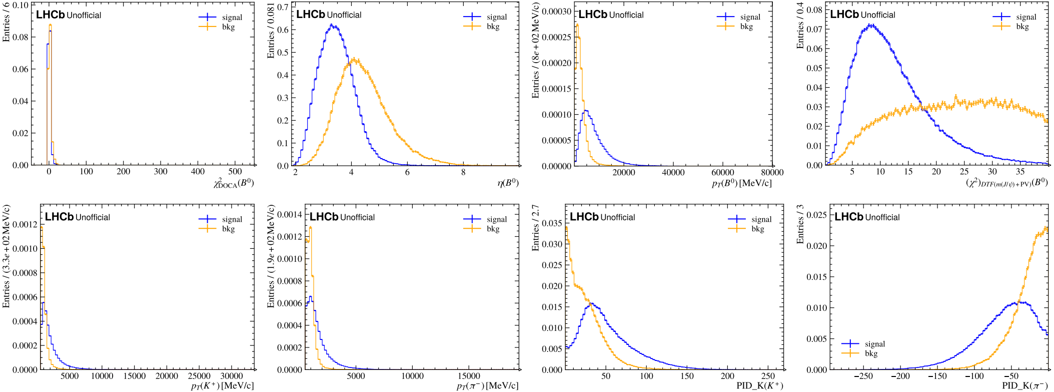
Candidate selection



- Rectangular cuts on kinematic and PID variables
- Decay-tree fit constraining the J/ψ candidate to its nominal mass and the B^0 candidate to its production vertex
- Distorted low mass background due to too tight trigger requirement in data taking

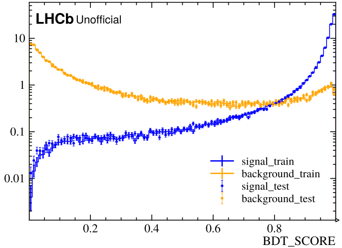
BDT selection

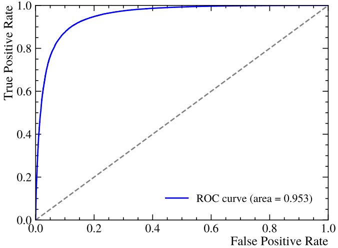
- Train simple BDT to further reduce combinatorial background
- Signal sample from simulation
- Background sample from upper and lower mass sidebands ($m(J/\psi K^{*0}) < 5230$ GeV or $m(J/\psi K^{*0} > 5330$ GeV)

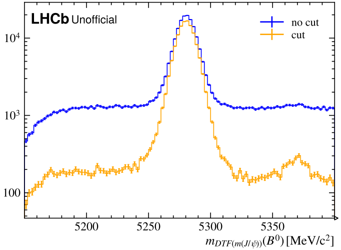


BDT selection

- Train simple BDT to further reduce combinatorial background
- Signal sample from simulation
- Background sample from upper and lower mass sidebands ($m(J/\psi K^{*0}) < 5230$ GeV or $m(J/\psi K^{*0} > 5330$ GeV)
- No signs of overtraining
- Optimize cut value for best significance $\frac{S}{\sqrt{S+B}}$
- Signal efficiency: $92\,\%$; Background rejection: $85\,\%$

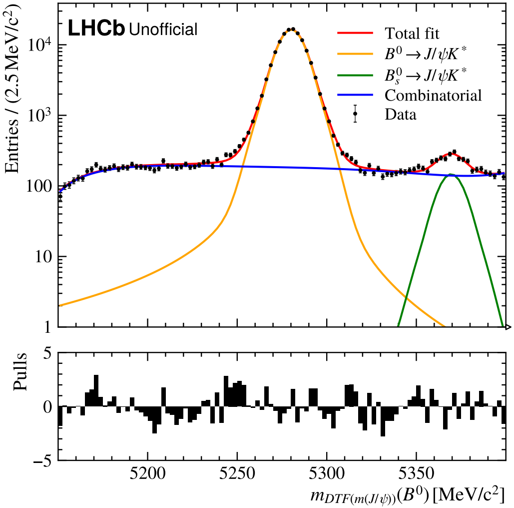






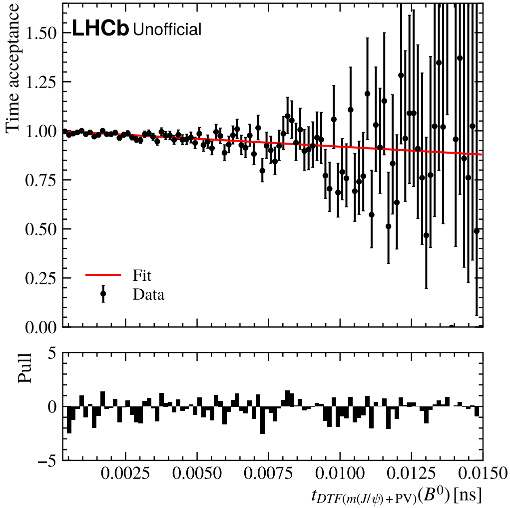
Mass Fit

- Fit mass spectrum to determine signal yield
- Signal modeled by sum of double-sided crystal ball (DCB) and gaussian sharing the mean
- Tail parameters of DCB fixed from simulation
- Combinatorial background modeled by 5th order Bernstein polynomial
- Irreducible $B_s^0 \to J/\psi K^{*0}$ background modeled by same shape as signal
- Yield per fb^{-1}: $\sim 110\,000$



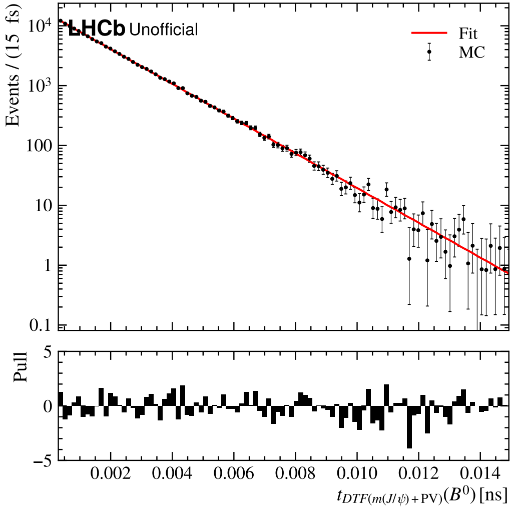
Time acceptance

- Reconstruction efficiency is lower for larger flight distances
- Potentially biases the lifetime fit
- Model time acceptance with linear function: $acc(t) \propto 1 + \beta t$
- Fit Exponential with generated lifetime multiplied by acceptance function
- Exponential convoluted with Gaussian with $\sigma = 45\,\text{fs}$ to model decay time resolution $(\text{Exp}(t; \tau_{B^0,\text{PDG}}) * \text{Gauss}(t; 0, \sigma)) \cdot (1 + \beta t)$



Decay time fit in MC

- Fit decay time in signal MC as cross check
- Time acceptance function fixed from previous fit
- Model signal time distribution by $(\mathrm{Exp}(t;\tau) * \mathrm{Gauss}(t;0,\sigma)) \cdot (1+\beta t)$
- Result: $\tau = (1.514 \pm 0.004)$ ps
- PDG value: $\tau_{B^0,\mathrm{PDG}} = (1.517 \pm 0.004)$ ps



Outlook

- Precision lifetime measurement of $B^0 \to J/\psi K^{*0}$ using 2024 LHCb data ongoing
- Next steps:
  - Investigate origin of decay time acceptance
  - Implement decay time fit for data using COWs
  - Extend to full $6.0\,\text{fb}^{-1}$ dataset
  - Evaluate sytematic uncertainties
- Aim to publish towards the end of this year