PHENIICS FEST 2026:
Inclusive production of charmonium states in b-hadron decays via their decay into $\phi\phi$ with LHCb

Raoul Henderson

Laboratoire Irène Joliot-Curie

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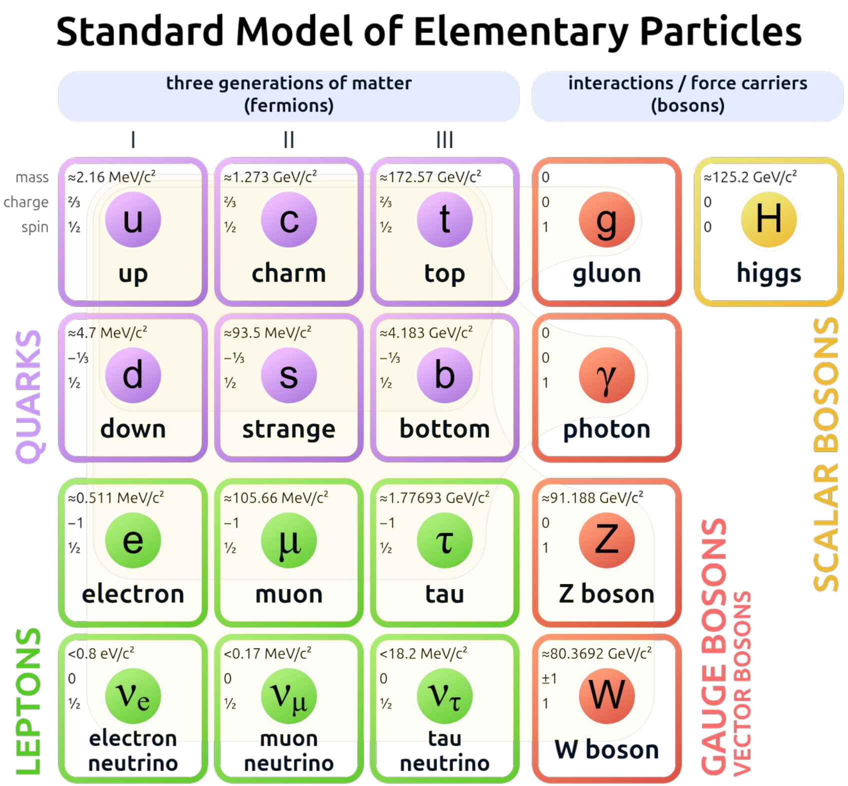

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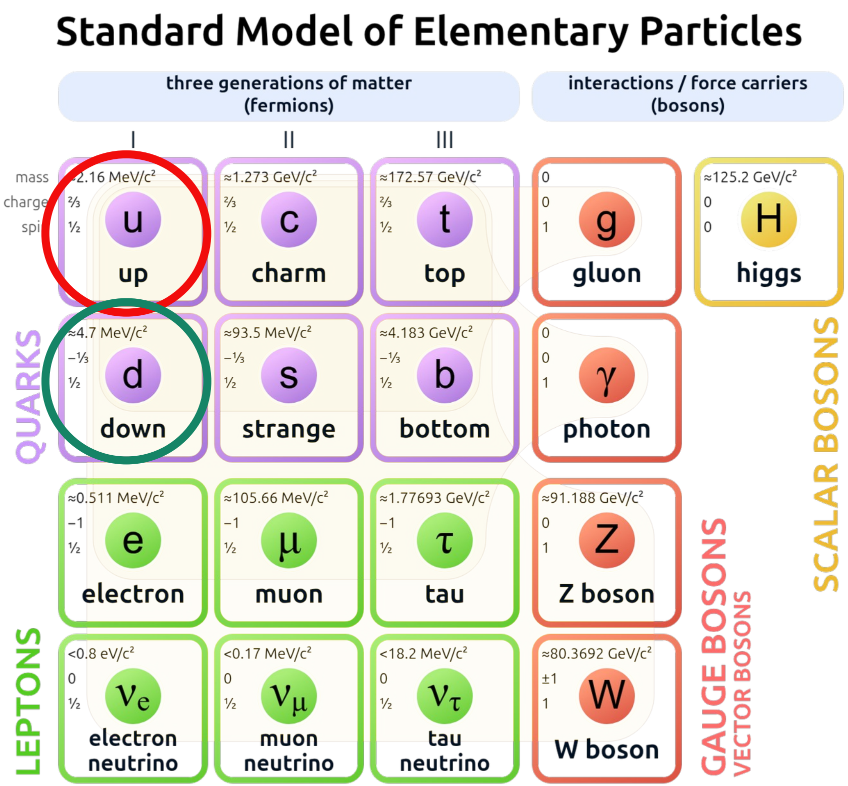

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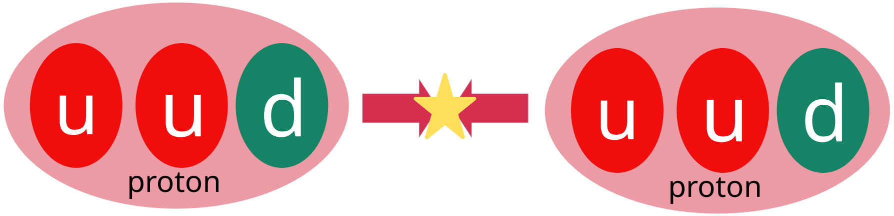

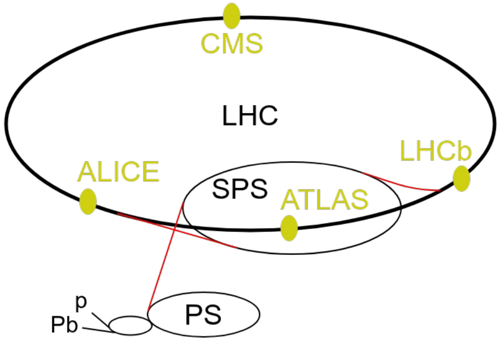

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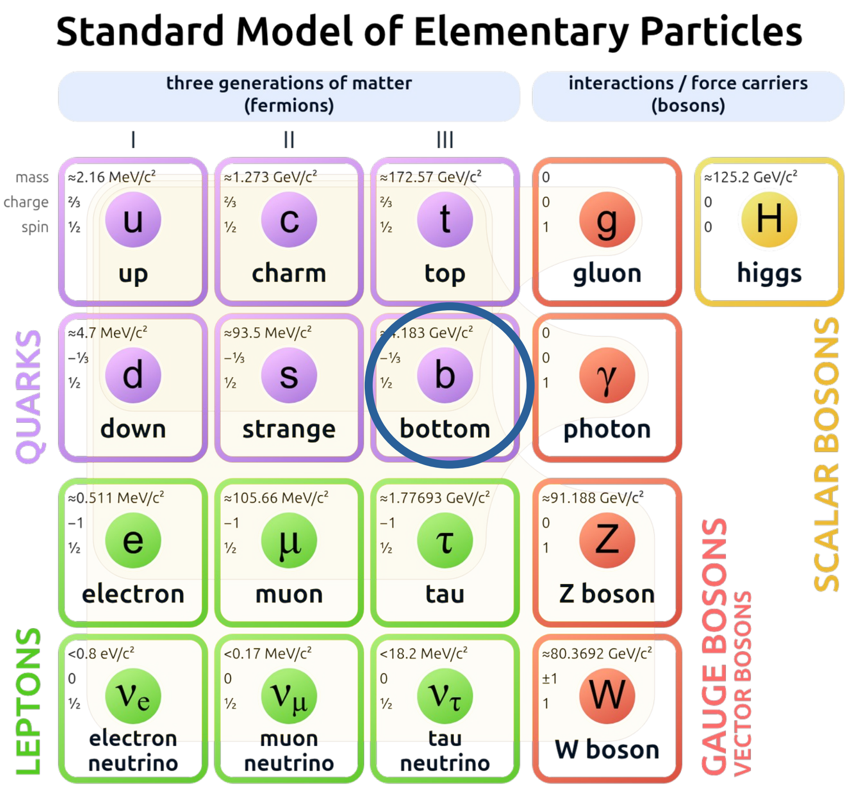

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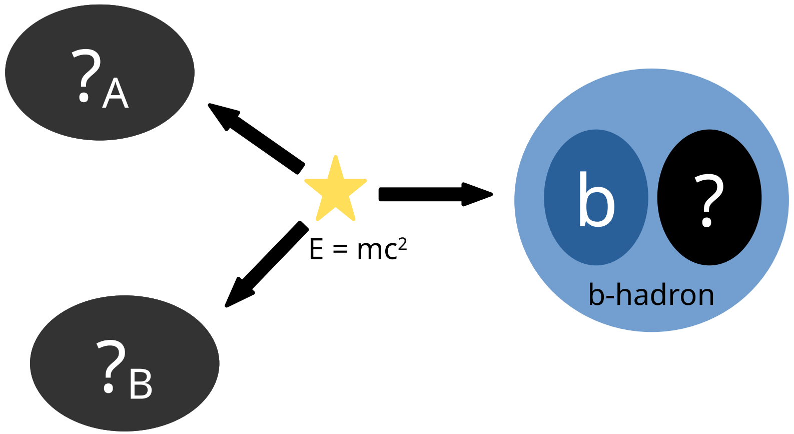

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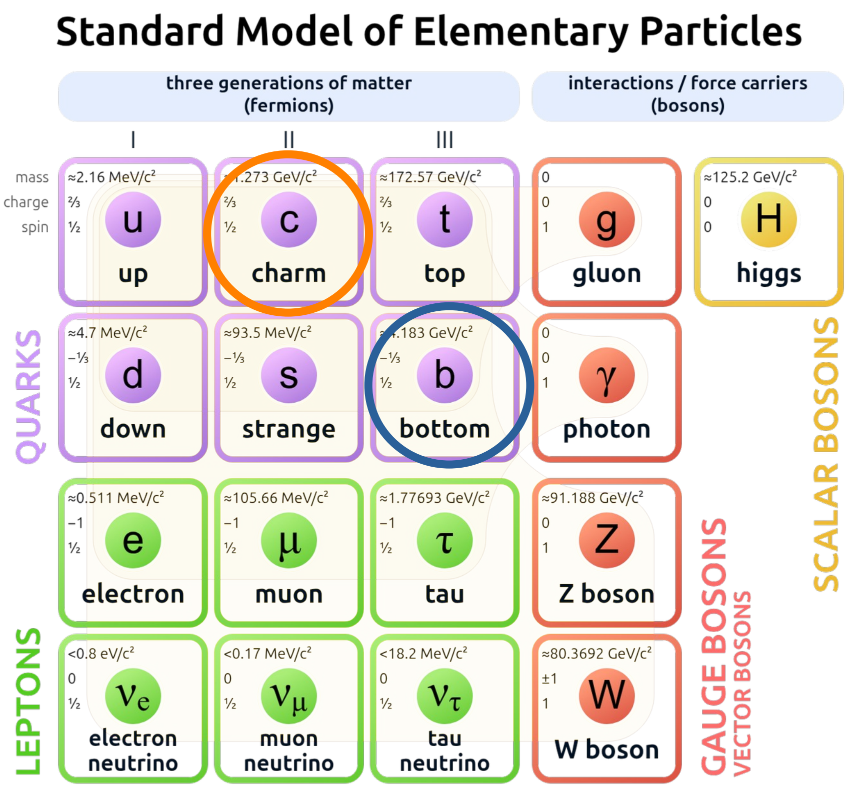

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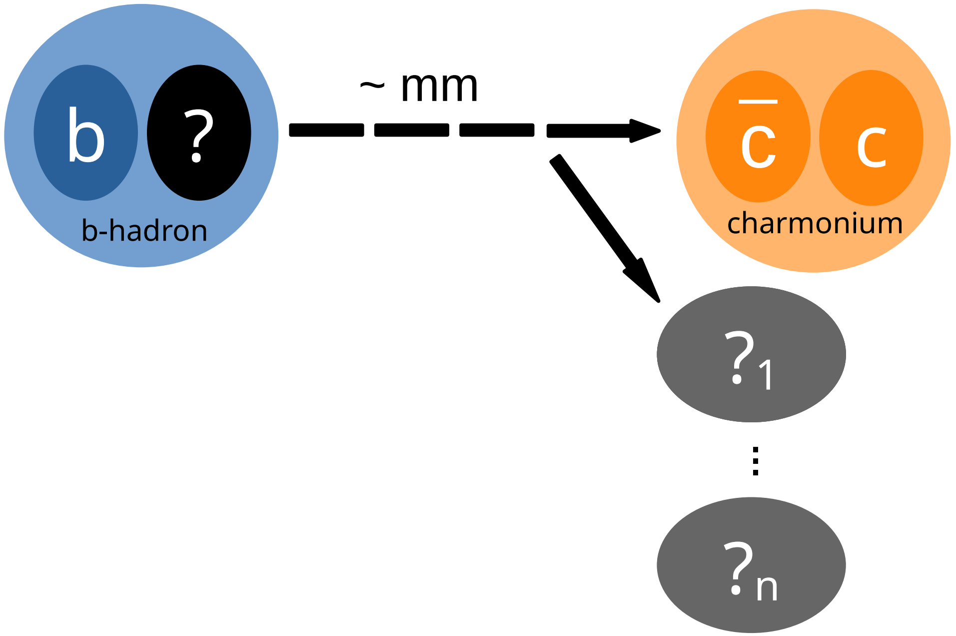

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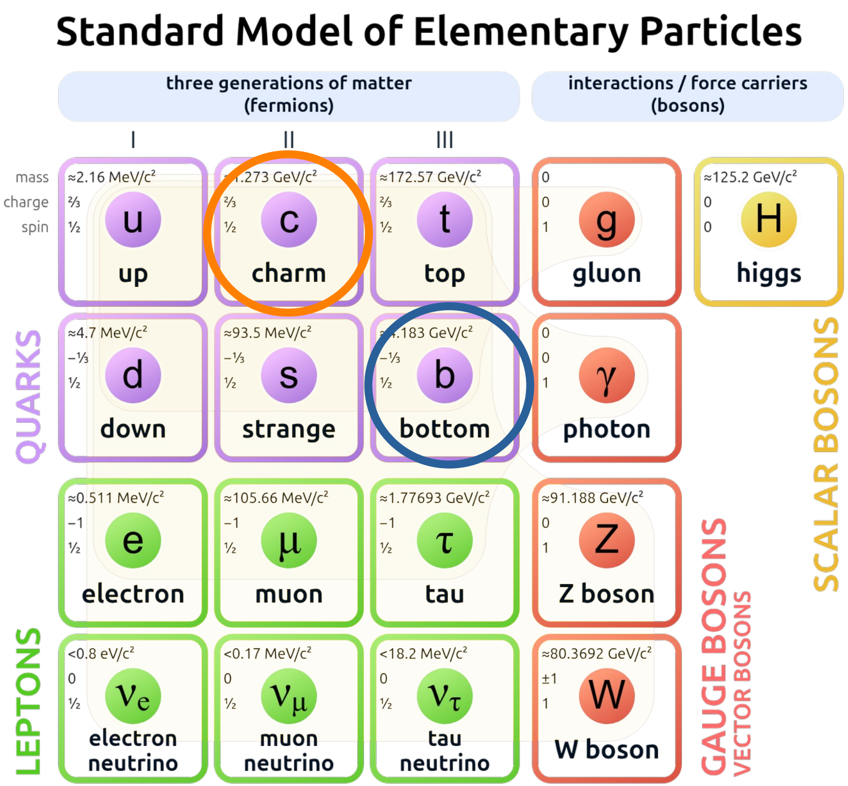

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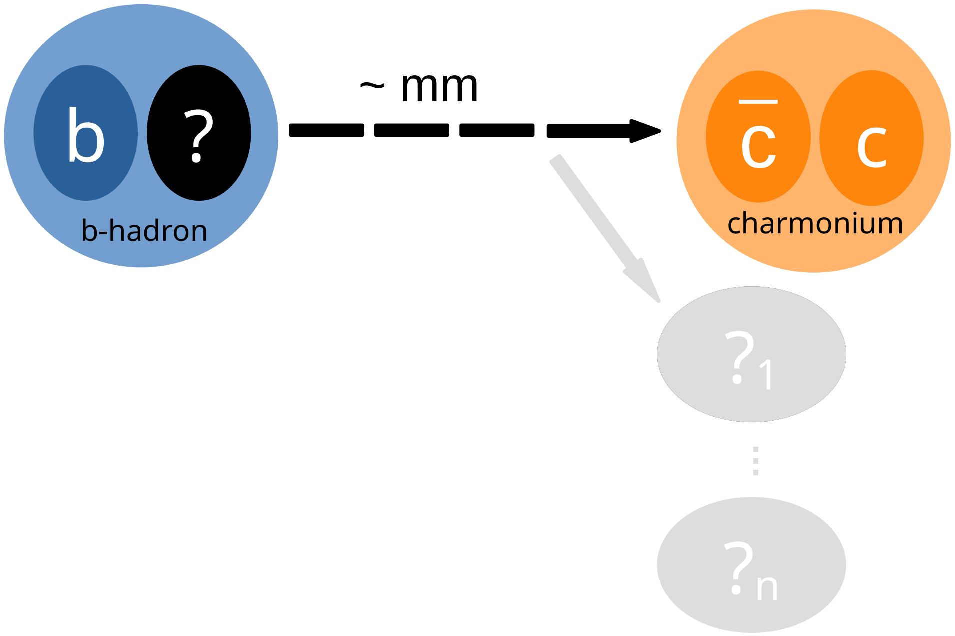

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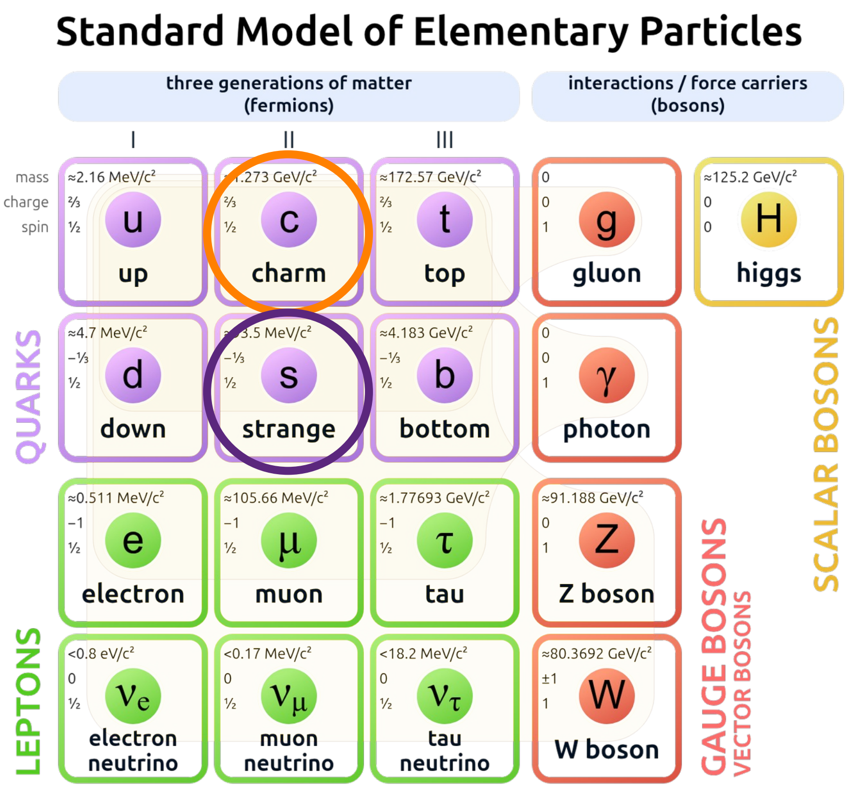

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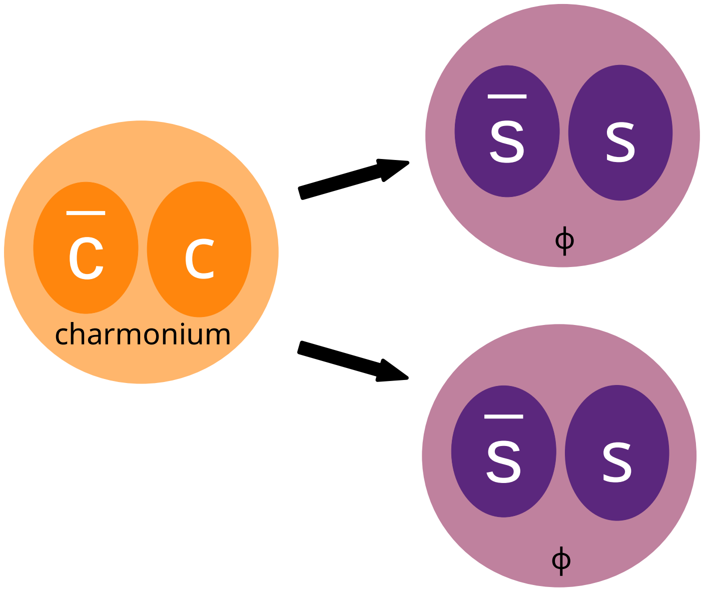

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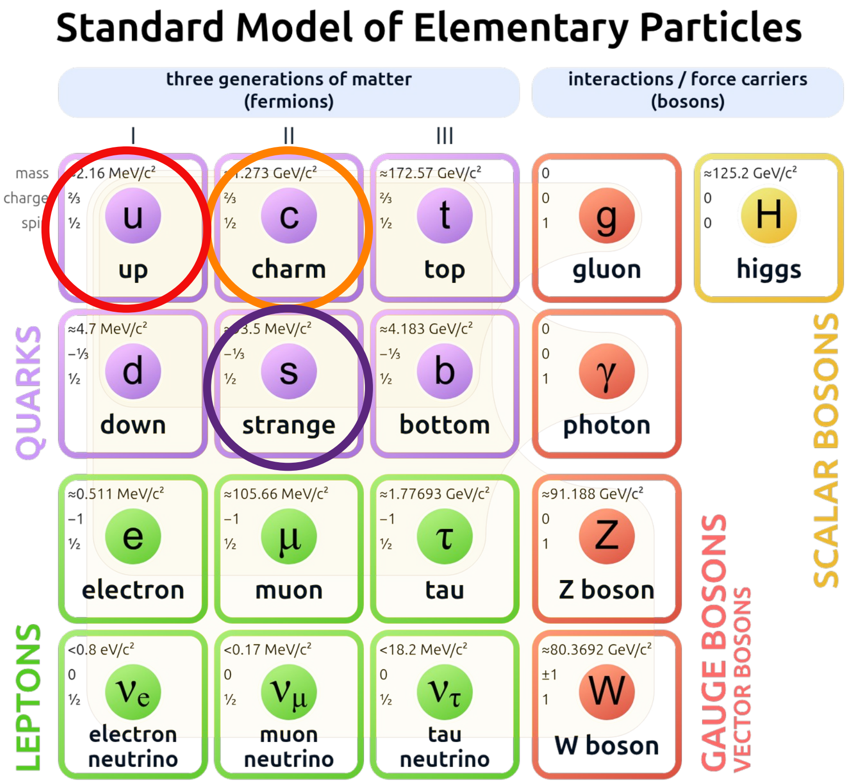

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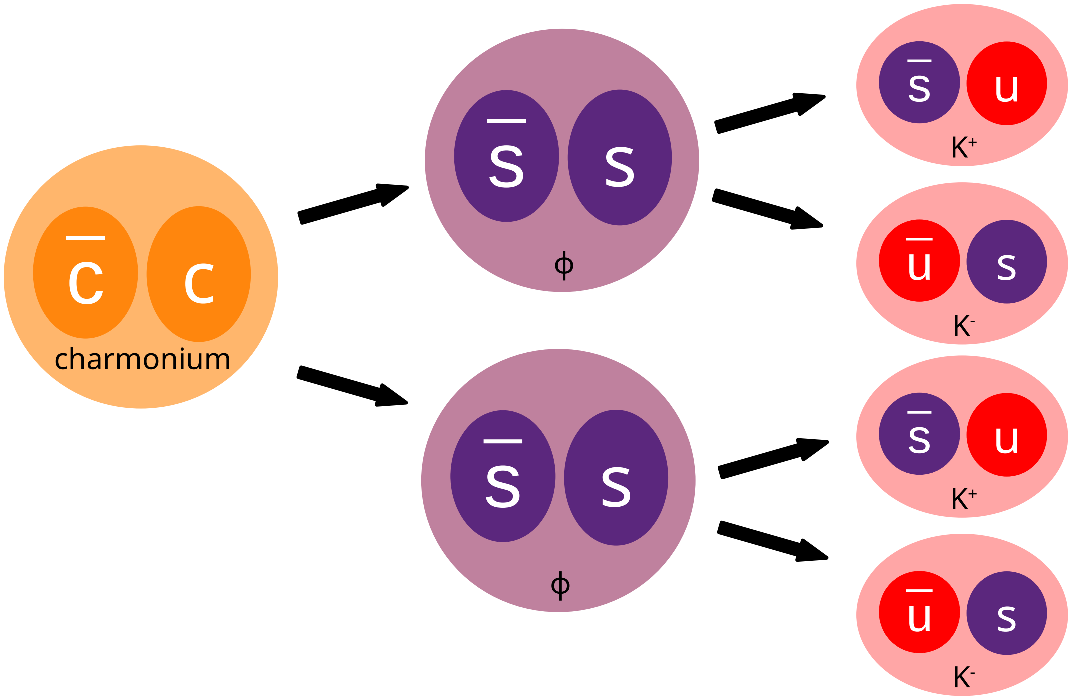

Objective

Measuring $\mathcal{B}(b \to c\bar{c}X)$ for states χ_{c0}, χ_{c1}, χ_{c2}, $\eta_c(2S)$

And ratios between χ_{cJ} states

Using
$$\frac{\mathcal{B}(b \to AX) \times \mathcal{B}(A \to \phi\phi)}{\mathcal{B}(b \to BX) \times \mathcal{B}(B \to \phi\phi)} = \frac{\sum_{\text{year}} N_A^{\text{year}} / \varepsilon_A^{\text{year}}}{\sum_{\text{year}} N_B^{\text{year}} / \varepsilon_B^{\text{year}}}$$

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From fit to data

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Selection efficiencies from simulation

From fit to data

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- $\mathcal{B}(A \to \phi\phi)$, $\mathcal{B}(B \to \phi\phi)$: From world average
- N_A^{year}, N_B^{year}: From fit to data
- $\varepsilon_A^{\text{year}}$, $\varepsilon_B^{\text{year}}$: Selection efficiencies from simulation

Objective

Measuring $\mathcal{B}(b \to c\bar{c}X)$ for states $\chi_{c0},\ \chi_{c1},\ \chi_{c2},\ \eta_c(2S)$

And ratios between χ_{cJ} states

Using

$$\frac{\mathcal{B}(b \to AX) \times \mathcal{B}(A \to \phi\phi)}{\mathcal{B}(b \to BX) \times \mathcal{B}(B \to \phi\phi)} = \frac{\sum_{\text{year}} N_A^{\text{year}} / \varepsilon_A^{\text{year}}}{\sum_{\text{year}} N_B^{\text{year}} / \varepsilon_B^{\text{year}}}$$

Selection efficiencies from simulation

From world average ($\eta_c(1S)$ as normalisation)

Normalisation for absolute branching fraction measurement

From world average

From fit to data

Objective

Measuring $\mathcal{B}(b \to c\bar{c}X)$ for states χ_{c0}, χ_{c1}, χ_{c2}, $\eta_c(2S)$

And ratios between χ_{cJ} states

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$$\frac{\mathcal{B}(b \to AX) \times \mathcal{B}(A \to \phi\phi)}{\mathcal{B}(b \to BX) \times \mathcal{B}(B \to \phi\phi)} = \frac{\sum_{\text{year}} N_A^{\text{year}} / \varepsilon_A^{\text{year}}}{\sum_{\text{year}} N_B^{\text{year}} / \varepsilon_B^{\text{year}}}$$

From world average ($\eta_c(1S)$ as normalisation)

Normalisation for absolute branching fraction measurement

From world average

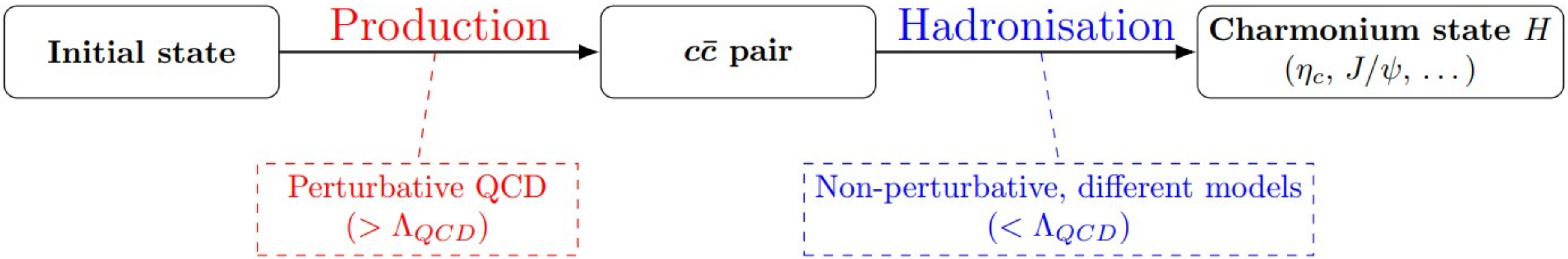
From fit to data

Selection efficiencies from simulation

Also extracting masses and widths from fit

How to make a charmonium ?

$$d\sigma_{A+B\to H+X} = \sum_n d\sigma_{A+B\to c\bar{c}(n)+X} \times \langle \vartheta^H(n) \rangle$$ **(Factorisation)**



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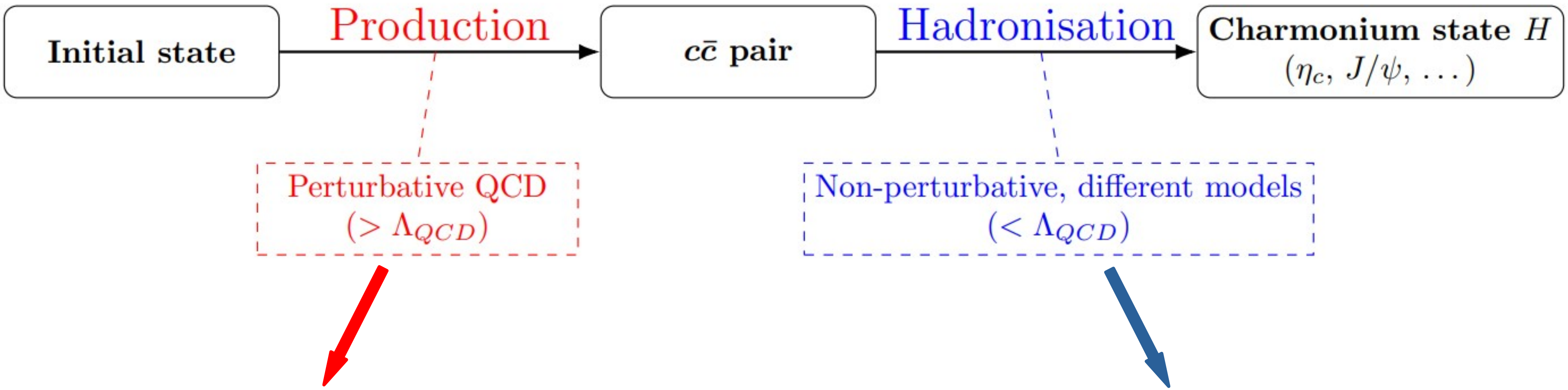


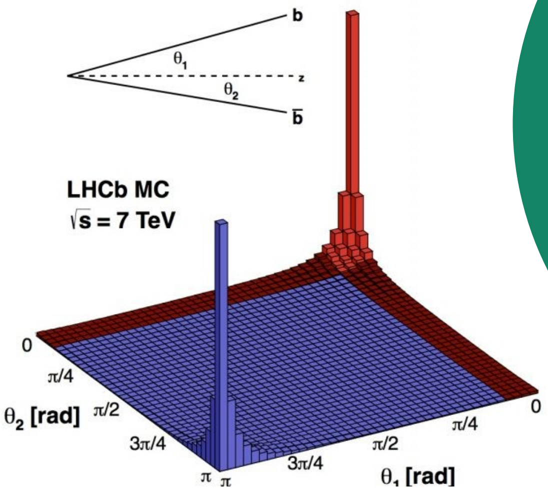
Theory computations

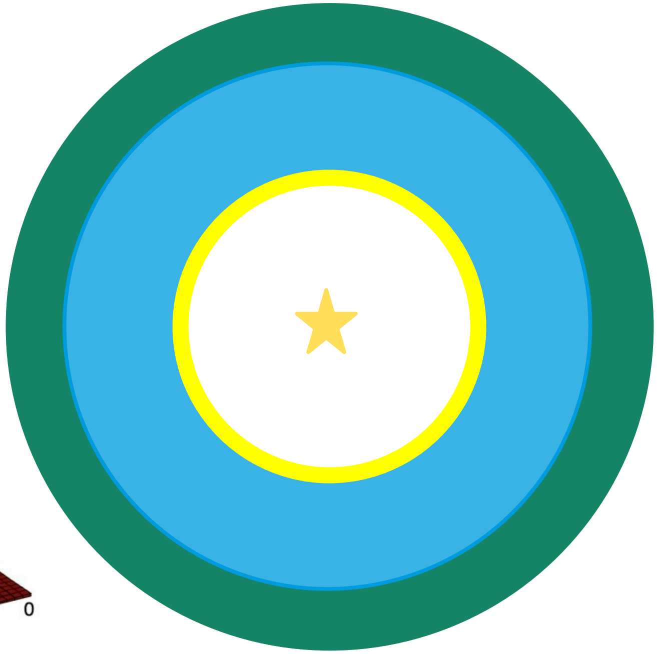
Experimental measurements

The LHCb detector

What detector do we want ?

Forward peaked correlated
b quark production

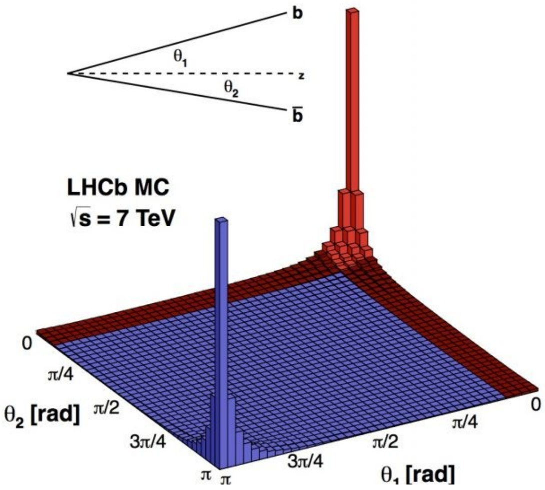




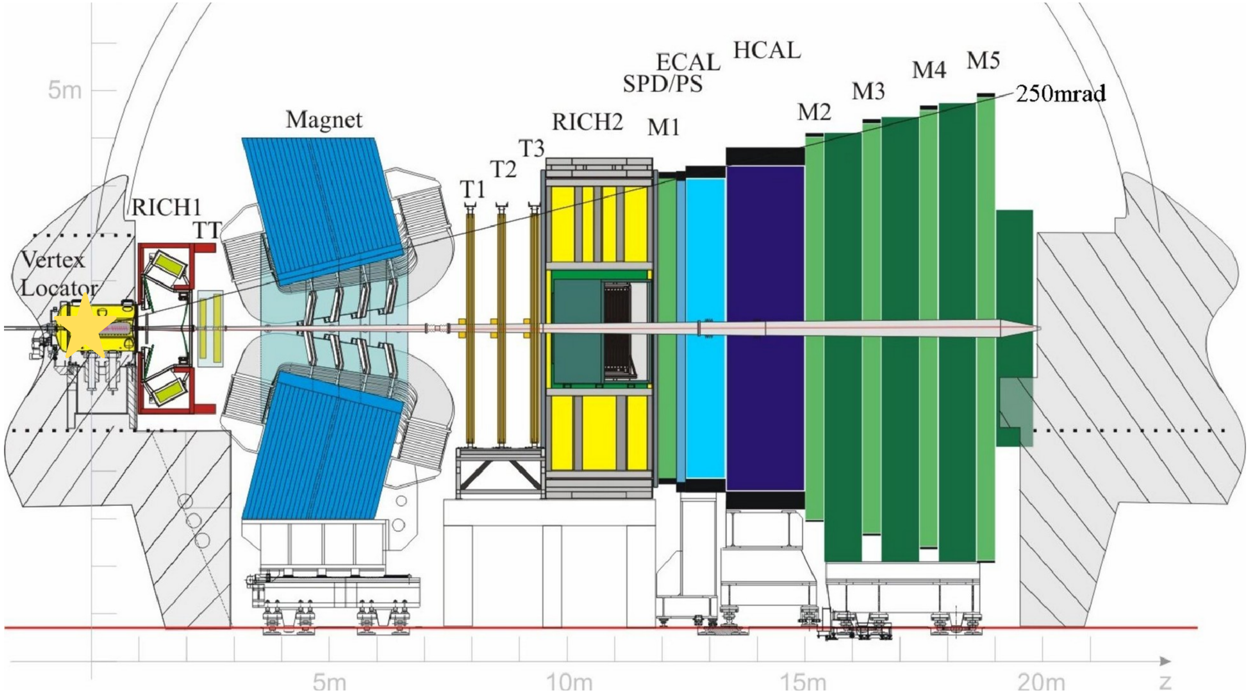
The LHCb detector

2 < η < 4.5

4% of solid angle, 25% of b quark pairs

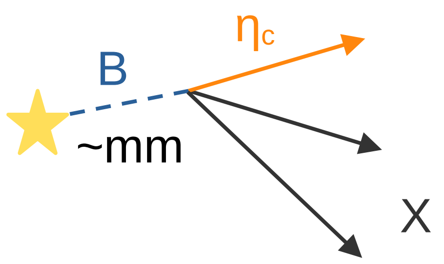


Single arm spectrometer



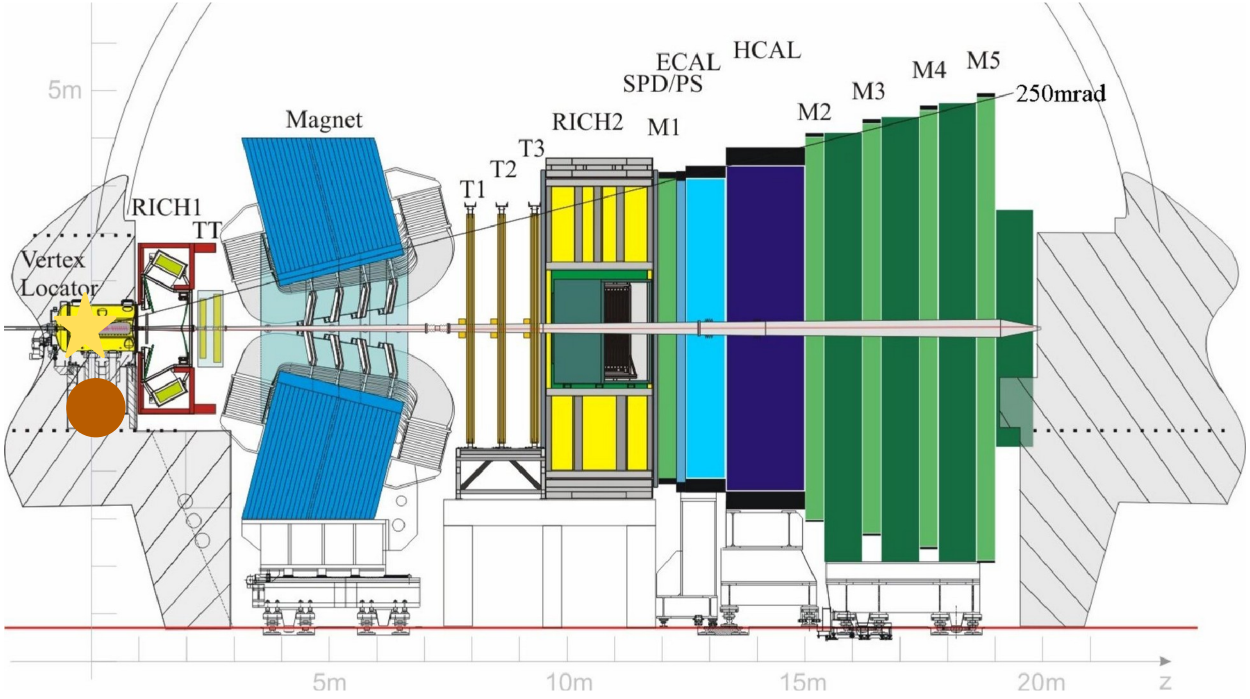
The LHCb detector

Need to reconstruct displaced vertices



Vertex Locator near collision point

Single arm spectrometer



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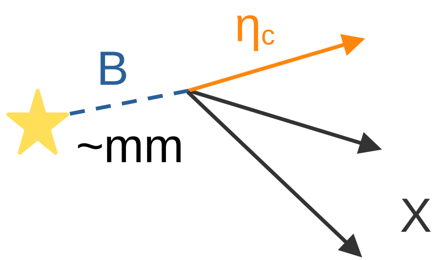
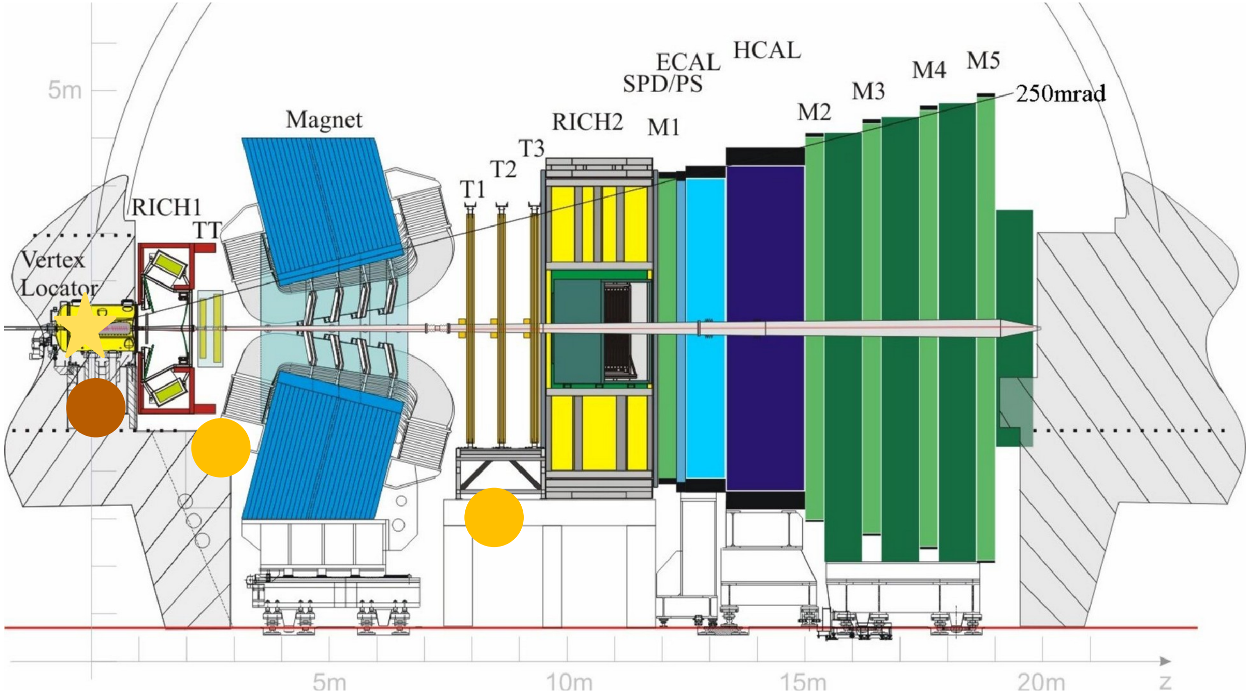


Vertex Locator near collision point

Part of tracking system to get trajectory and momentum

Single arm spectrometer

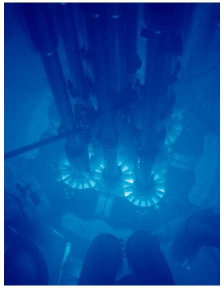


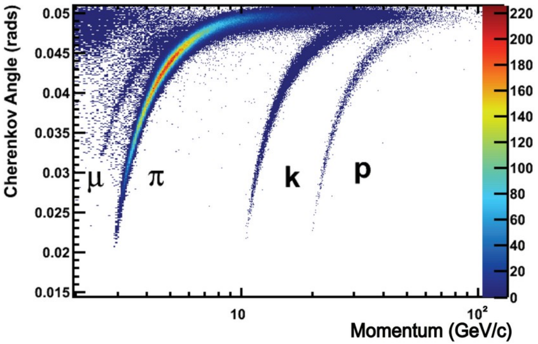
The LHCb detector

How to identify particles ?

Mass with p = mv

Obtained with Cherenkov effect





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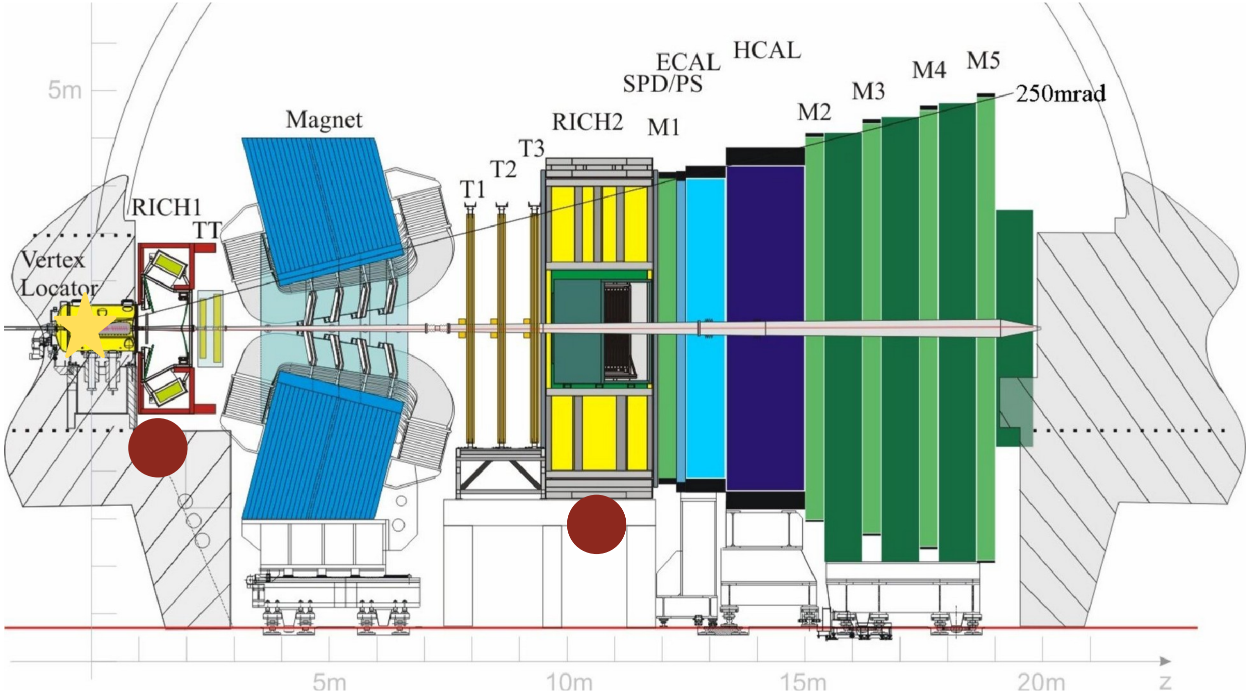


Analysis strategy

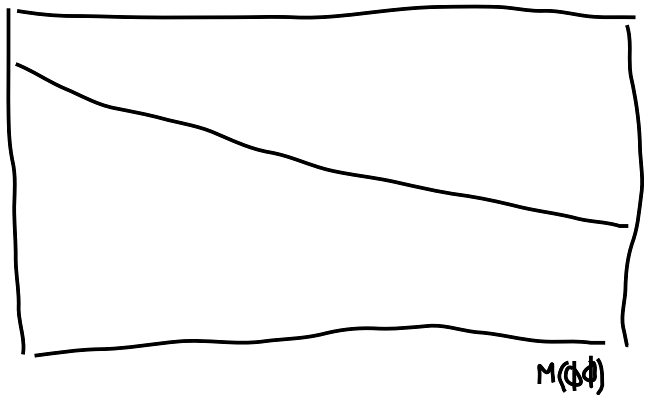
Selection

↓

True ϕϕ

↓

Final fit



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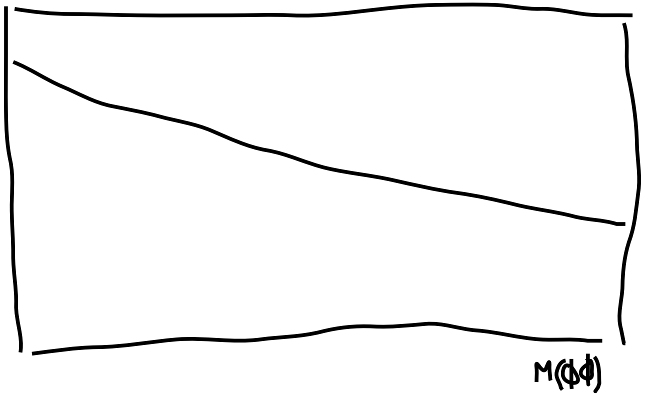
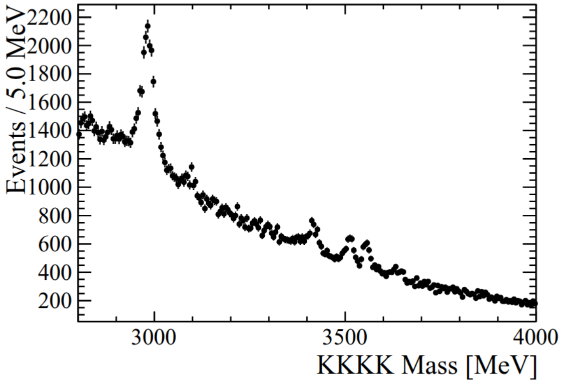


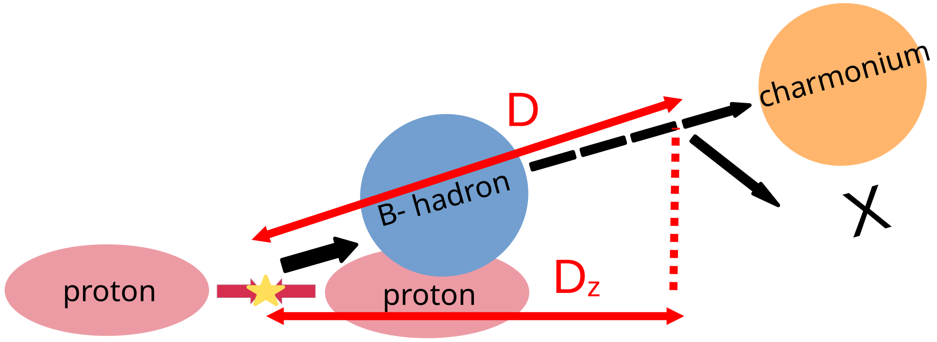
Keep “good” events



Selection

Using several variables:

- Quality of the tracks
- Quality of the vertices
- Relevant mass range
- Identification variables
- Momentum
- **Pseudo time of flight t_z**



$t = D/v = D\ m/p$

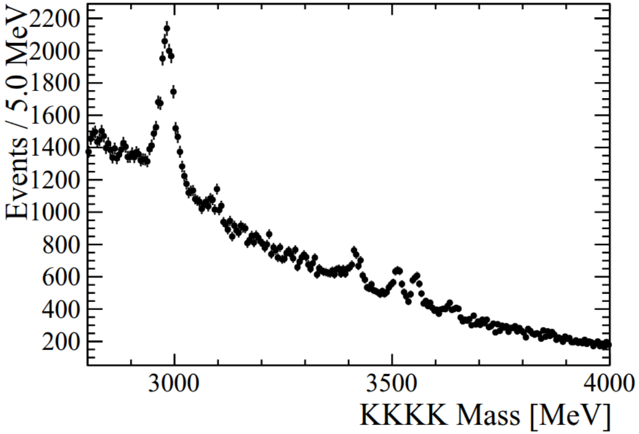
$\Rightarrow t_z = D_z\ m/p_z$

Analysis strategy

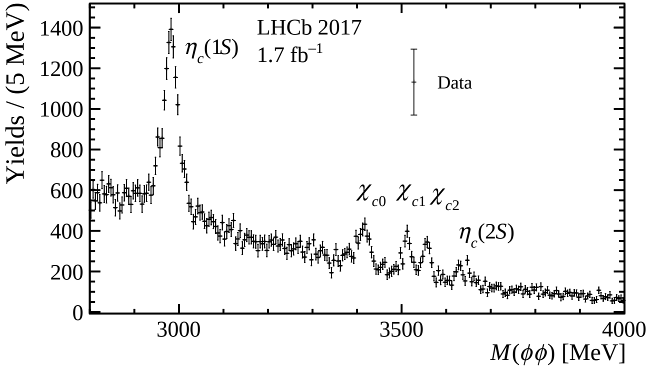
Selection

True ϕϕ

Final fit



Eliminate random kaon pairs

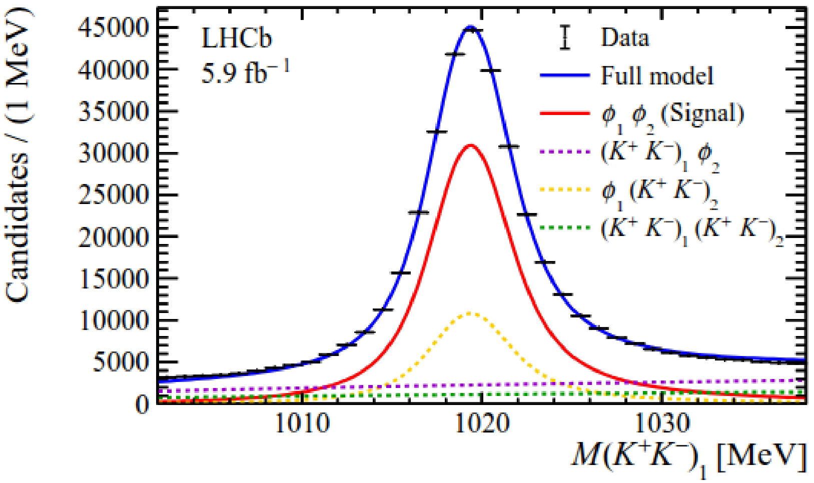


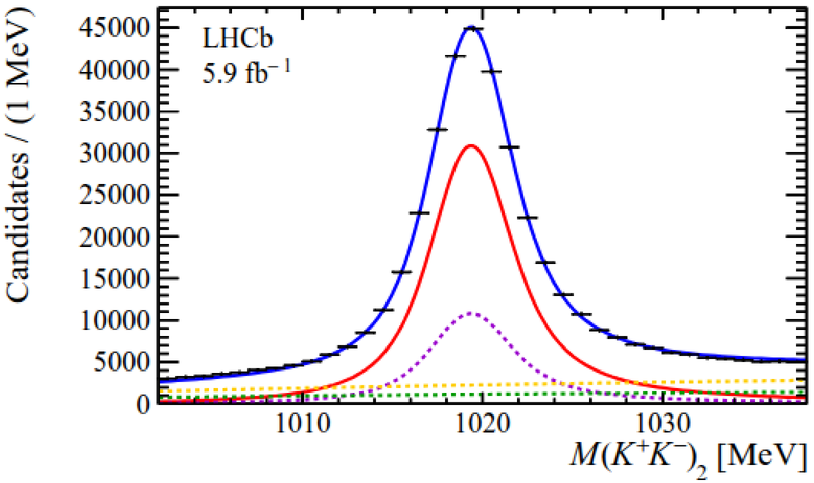
Getting true ϕϕ

Splitting data in bins of M(ϕϕ)

2D fit in each bin => Building histogram with true ϕϕ component

Fixing ϕ mass, ϕ width, resolution in 2D fit of M(KK)M(KK) to full dataset





Analysis strategy

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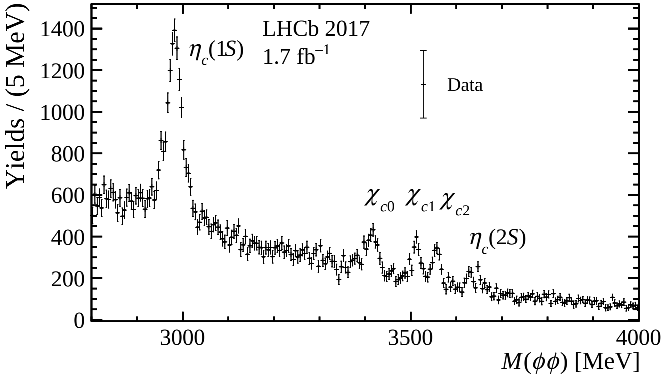
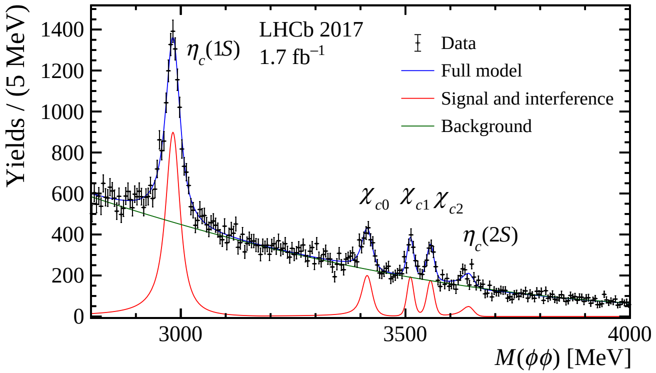




Final fit

Simultaneous binned χ^2 fit on all years

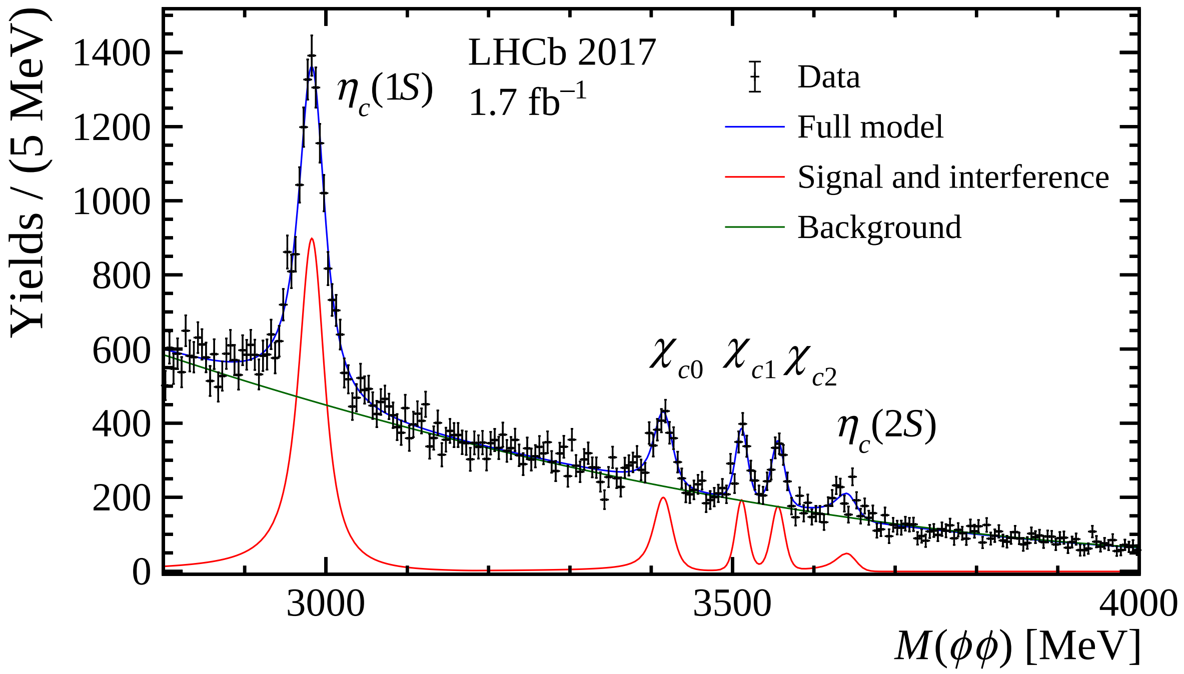
Extracting yield for all states

Also mass for all, and width for $\eta_c(1S)$, χ_{c0} and $\eta_c(2S)$

Signal as Relativistic Breit-Wigner

Background as 2nd order Chebychev polynomial

Including interference between signal and non-resonant $\phi\phi$



Branching ratios

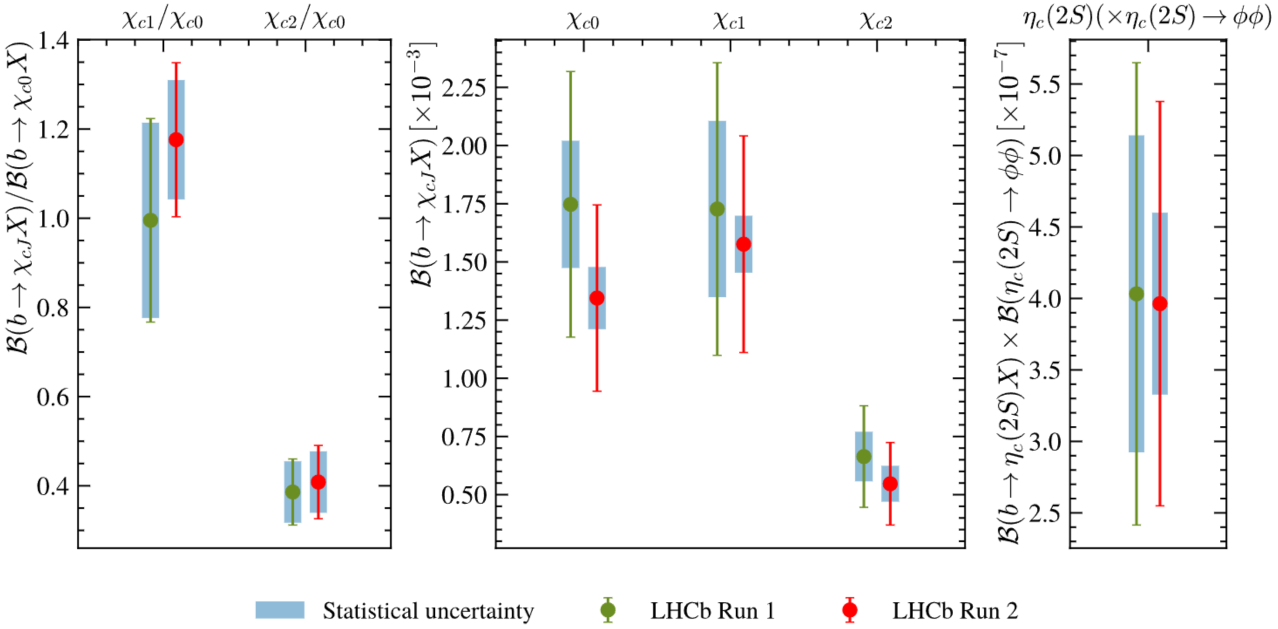
Branching ratios then extracted

Results compatible with Run 1

Improvement limited for χ_{c2} by interference addition

Results to be improved with better $\mathcal{B}(\eta_c(1S) \rightarrow \phi\phi)$ measurement

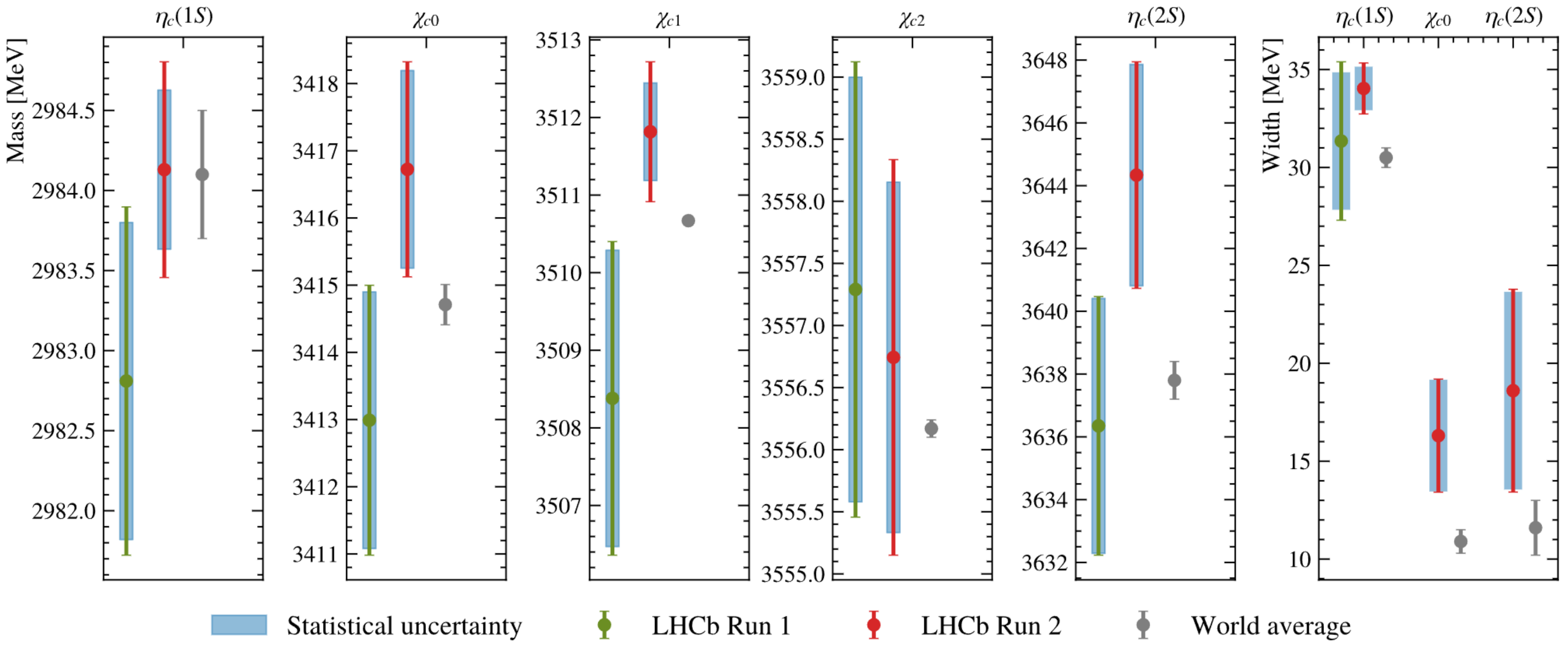
χ_{cJ} production confirmed to be incompatible with current models



Masses and widths

Single best measurement of $\eta_c(1S)$ mass

Other measurements not competitive with world average



Conclusion

Measurement of the production of the χ_{cJ} states and $\eta_c(2S)$ in b-decays with charmonium to $\phi\phi$

Including potential interference with $\phi\phi$ background, some good indication for $\eta_c(1S)$ at least

χ_{cJ} production results incompatible with model predictions (already observed before)

Most precise mass measurement of $\eta_c(1S)$

Next analysis on production of pairs of charmonia

Thank you for listening