

Angular analysis in rare beauty decays with electrons

LHCb and me

Jamboree, Amsterdam

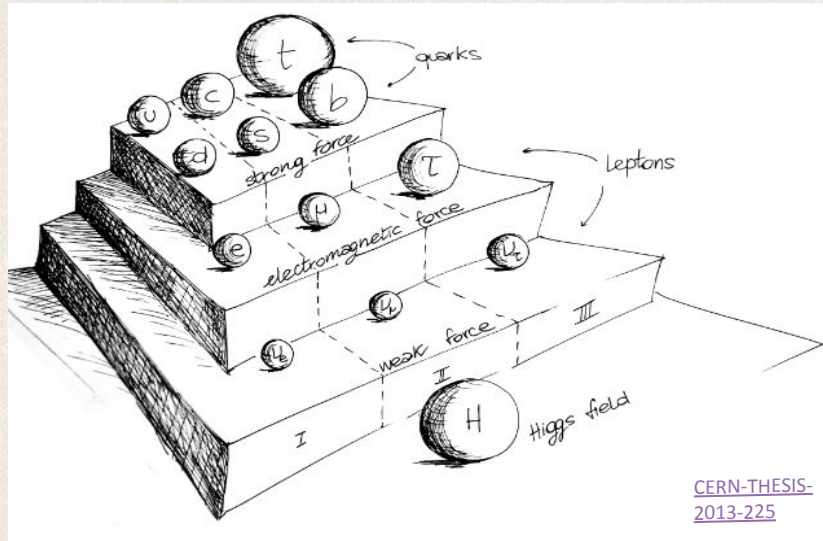
2023 May 16th



R. Magritte, *La Clairvoyance*, 1936

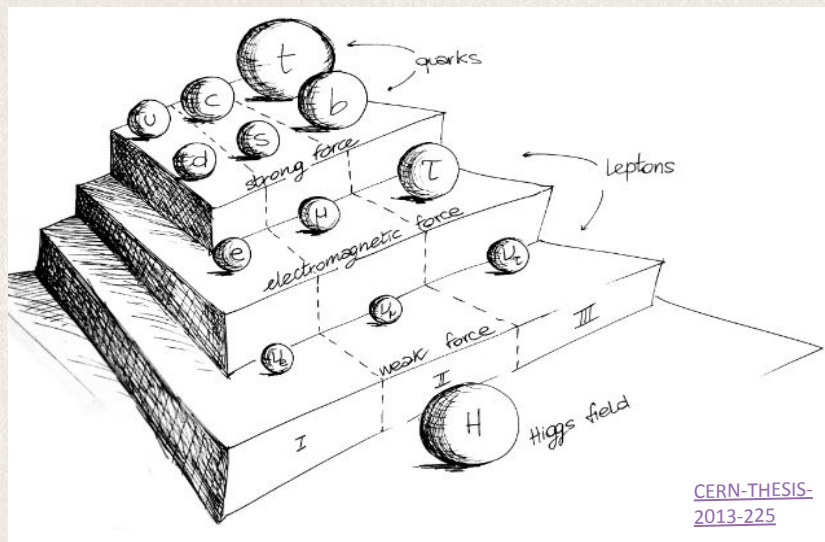
Flavour Physics

Field of particle physics that studies the properties of elementary particles



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Field of particle physics that studies the properties of elementary particles



Why do generation exists?

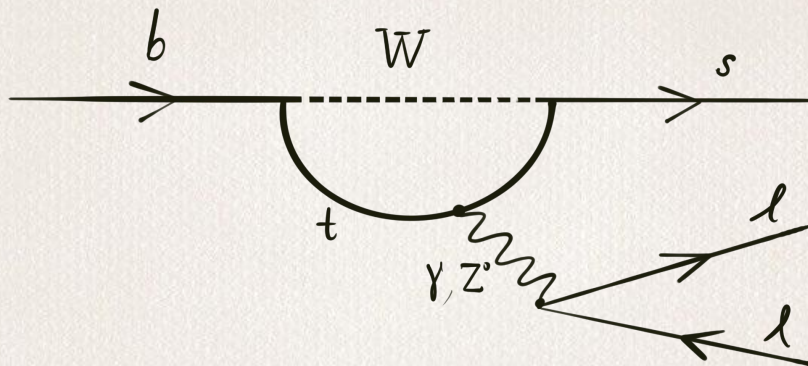
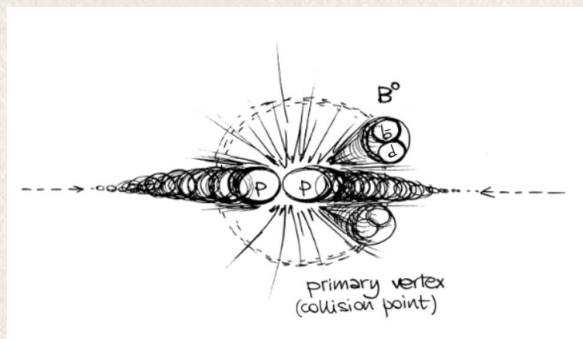
Why are there three of them?

Why the fermions hierarchies are the way they are?

The answer to these questions will open the door to Physics beyond Standard Model

Rare beauty decay

$b \rightarrow sll$ transitions are good laboratory to explore flavour physics



Standard Model Feynman diagram

Rare beauty decay



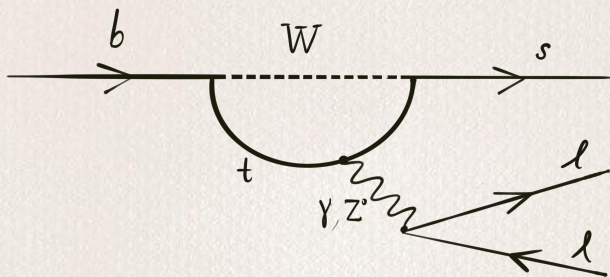
SM Feynman diagram

$$B \sim \mathcal{O}(10^{-6})$$

Sensitive to *New Physics* (**NP**) at the TeV scale

NP can affect the decay rates and angular distributions

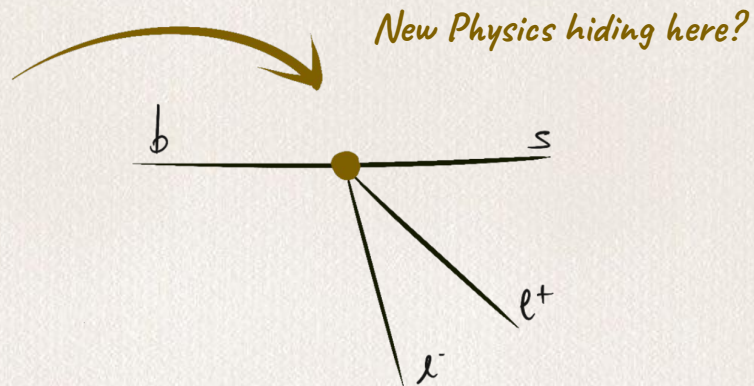
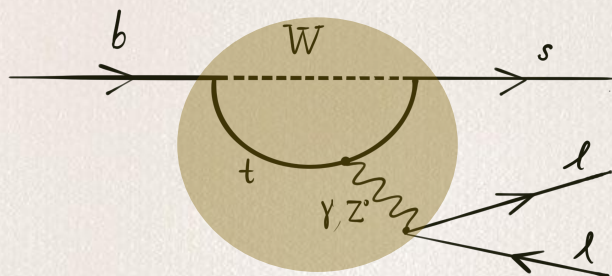
Rare beauty decay



$$\mathcal{H}_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* (\Delta_i^{\text{SM}} + \epsilon_i^{\text{NP}}) \mathcal{O}_i$$

EFFECTIVE FIELD THEORY

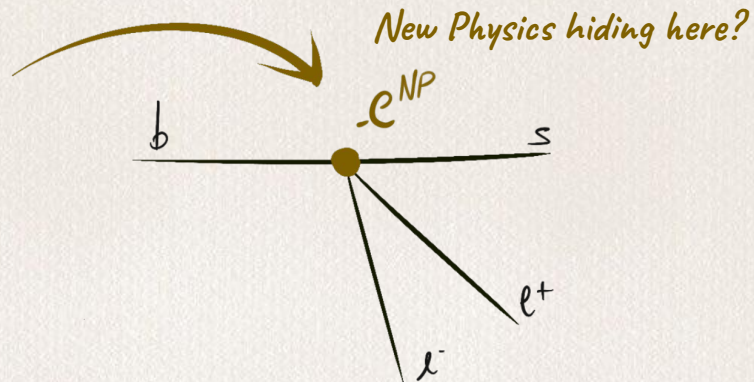
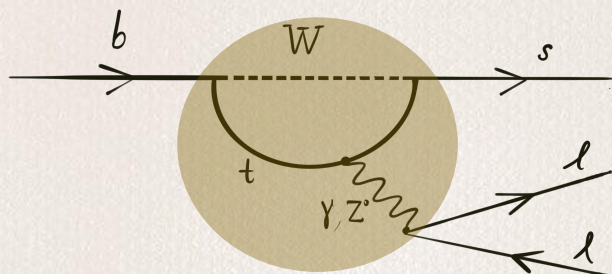
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$$\mathcal{H}_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* (\Delta_i^{\text{SM}} + c_i^{\text{NP}}) O_i$$

EFFECTIVE FIELD THEORY

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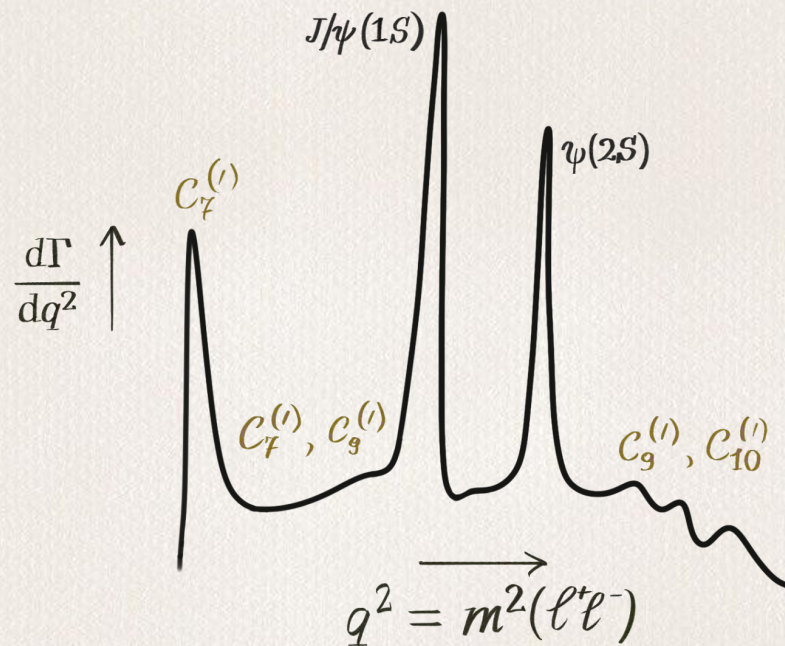
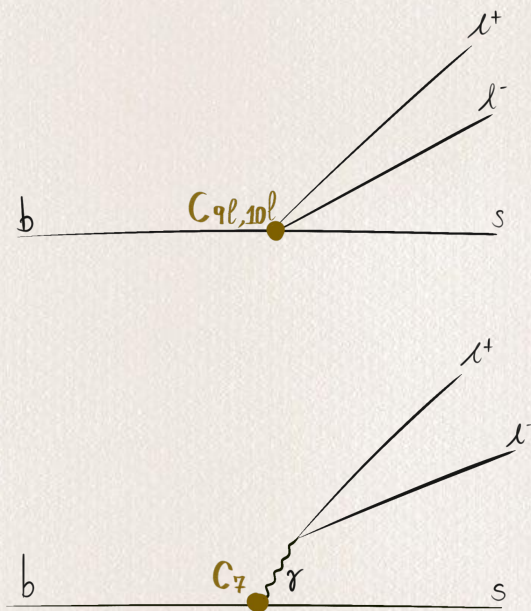


New Physics hiding here?

$$\mathcal{H}_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* (\Delta_i^{\text{SM}} + \underbrace{c_i^{\text{NP}}}_{\text{Wilson coefficients}}) O_i$$

EFFECTIVE FIELD THEORY

Rare beauty decay



Measurements in flavour physics

Ratio between branching fractions

$$R_H = \frac{\mathcal{B}(b \rightarrow s\mu\mu)}{\mathcal{B}(b \rightarrow see)}$$

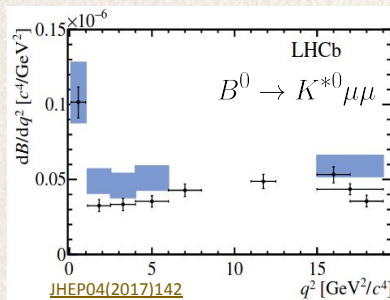
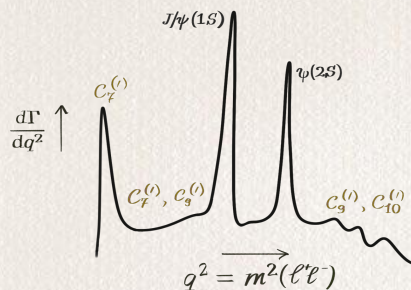


Measurements in flavour physics

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Branching fractions

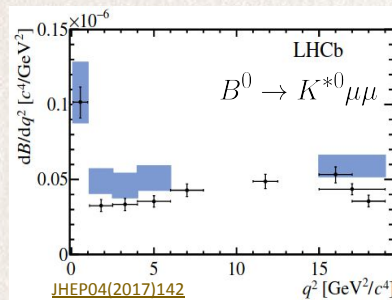
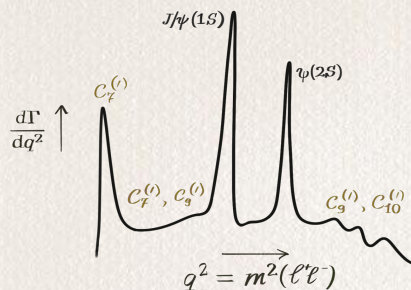


Measurements in flavour physics

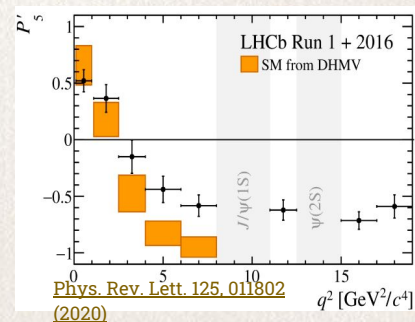
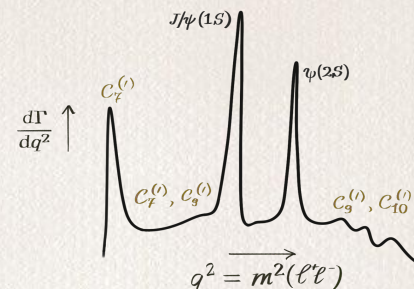
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Branching fractions



Angular Analyses

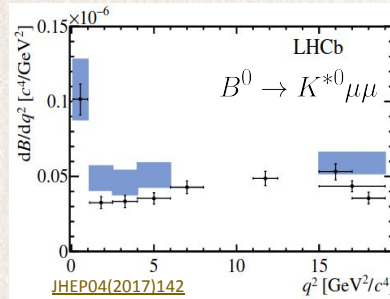
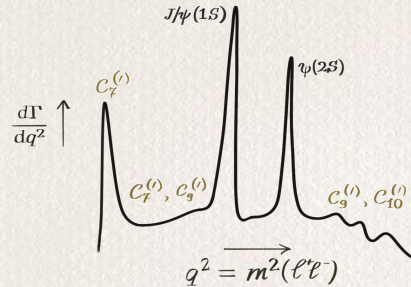


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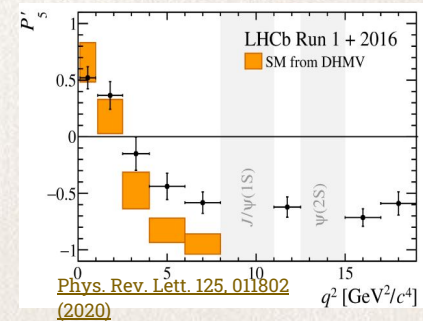
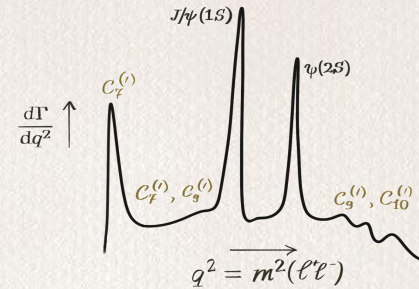
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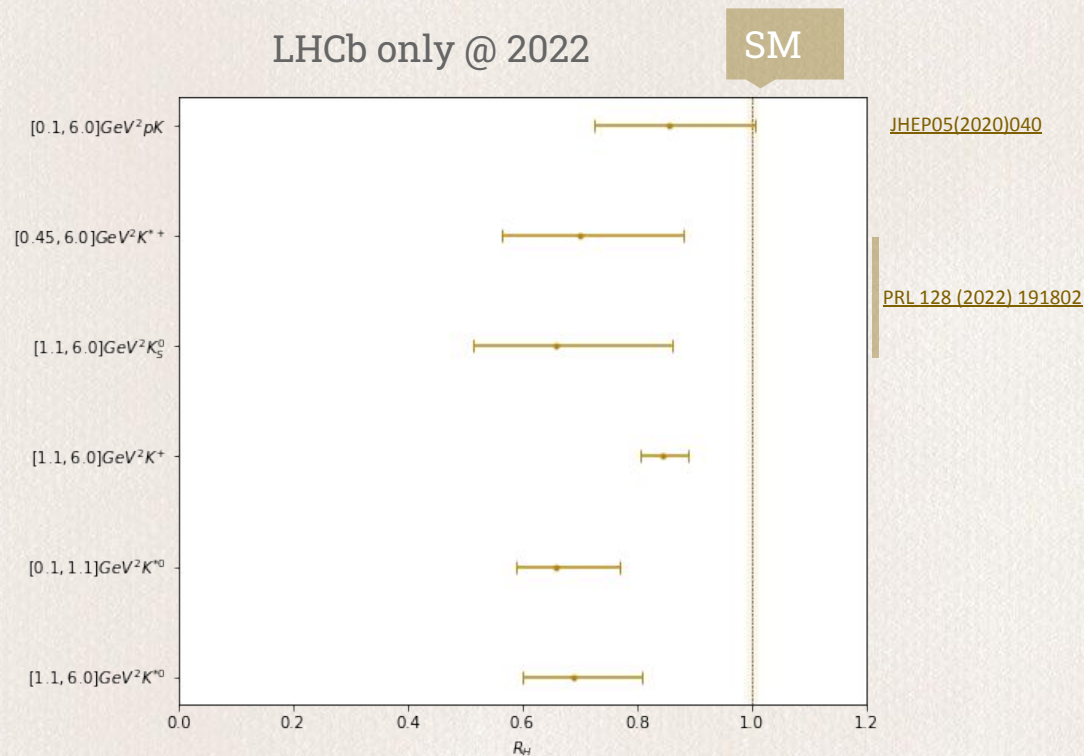


Angular Analyses



Ratio between branching ratio

$$R_H = \frac{\mathcal{B}(b \rightarrow s\mu\mu)}{\mathcal{B}(b \rightarrow see)}$$

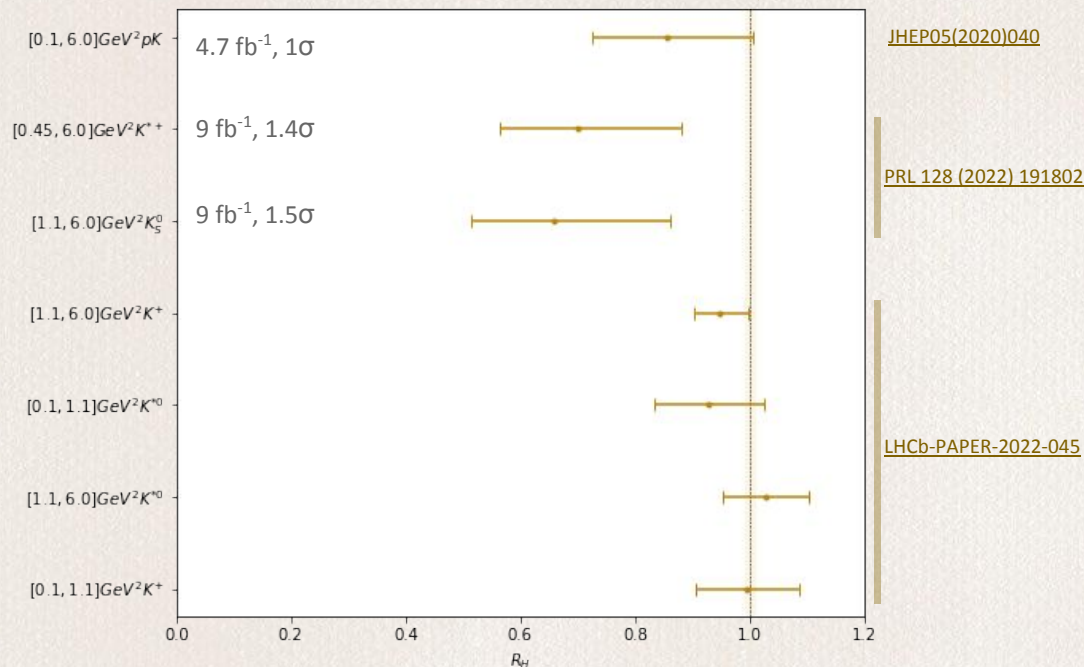


Ratio between branching ratio

$$R_H = \frac{\mathcal{B}(b \rightarrow s\mu\mu)}{\mathcal{B}(b \rightarrow see)}$$

LHCb only @ 2023

SM



R
ANOMALIES

SM



My thoughts

This egg was just an egg.

“V o r w ä r t s .
Und damit vorwärts auf der Bahn der Weisheit,
guten Schrittes, guten Vertrauens! Wie du auch bist, so diene
dir selber als Quell der Erfahrung!”

“F o r w a r d .
**And thus forward on the path of wisdom, good step,
good faith! Whatever you are, serve yourself as a source
of experience!”**

5th section
“Human, all too human”
F. Nietzsche

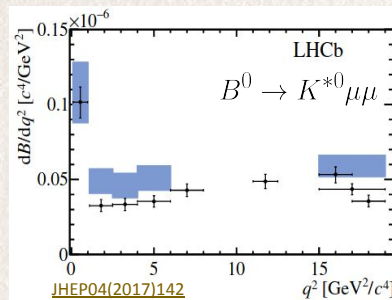
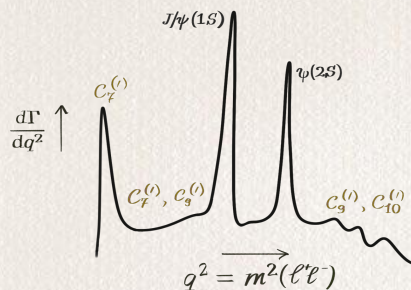


Measurements in flavour physics

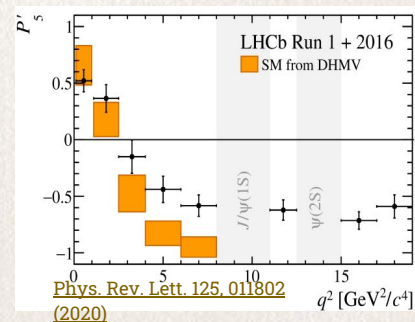
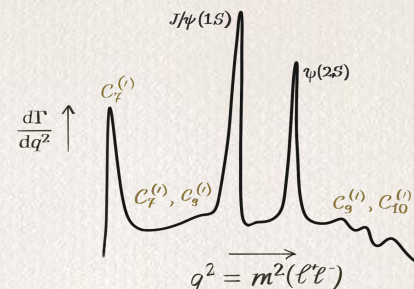
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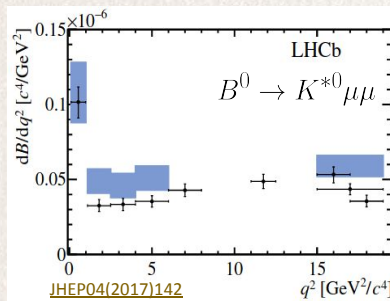
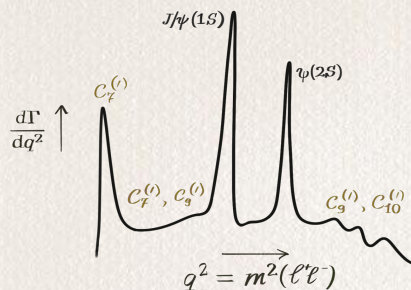


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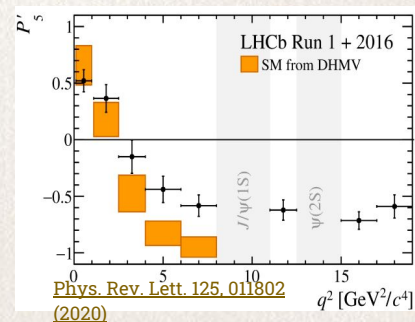
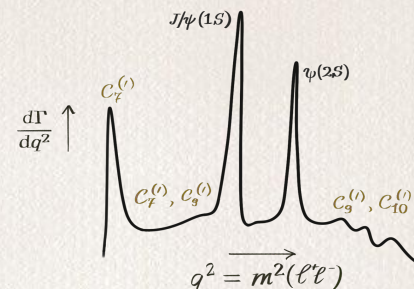
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Angular Analyses

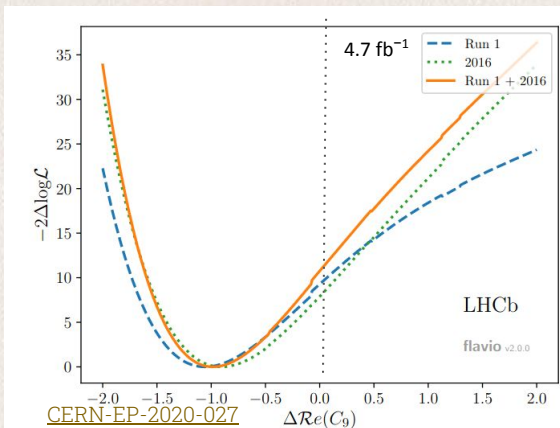


Another puzzle to solve: angular analysis

$$B^0 \rightarrow K^{*0} \mu \mu$$

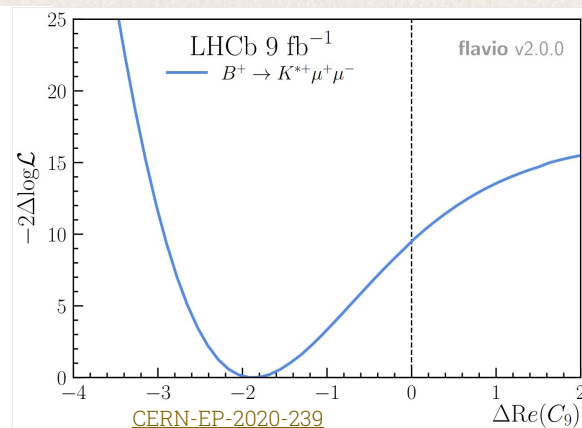
$$B^+ \rightarrow K^{*+} \mu \mu$$

$$B_s^0 \rightarrow \phi \mu^+ \mu^-$$



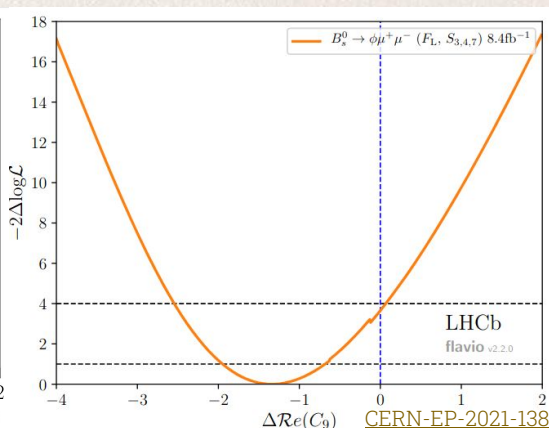
[CERN-EP-2020-027](#)

[PhysRev\(2020\)125](#)



[CERN-EP-2020-239](#)

[PhysRev\(2021\)126](#)



[CERN-EP-2021-138](#)

[JHEP11\(2021\)043](#)

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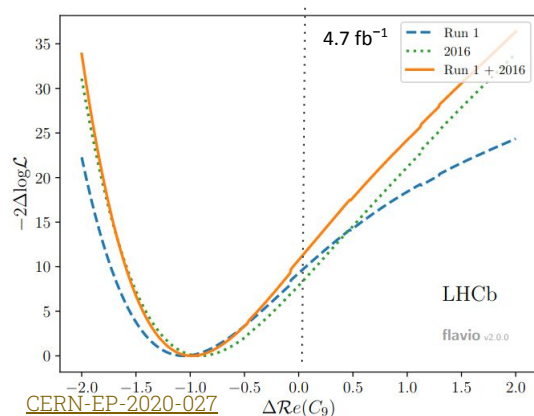
SM

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SM

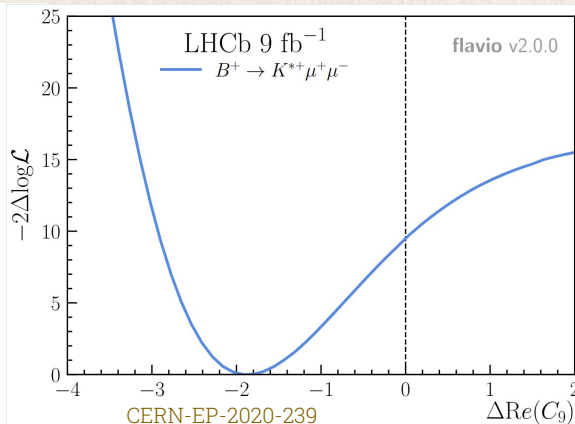
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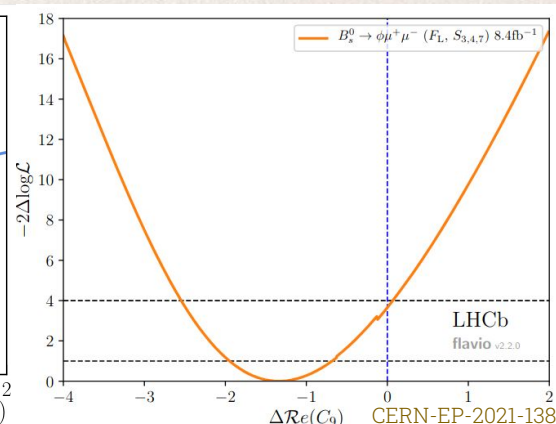
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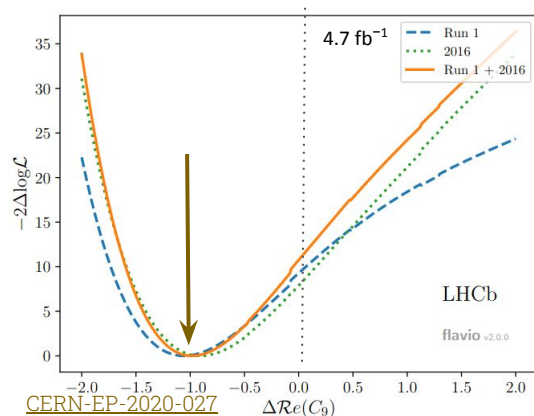
SM

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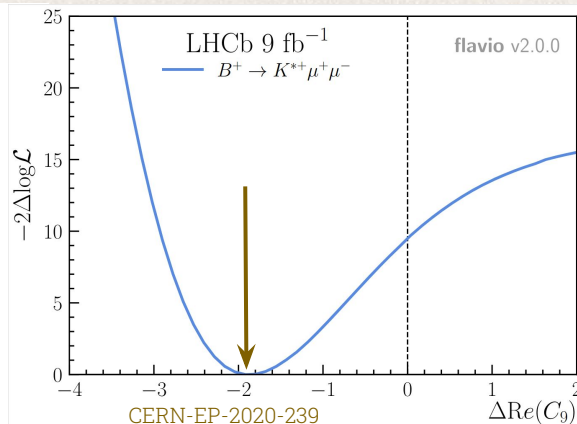
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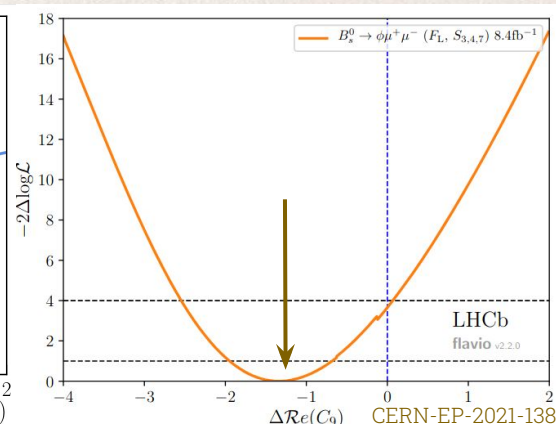
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CERN-EP-2021-138

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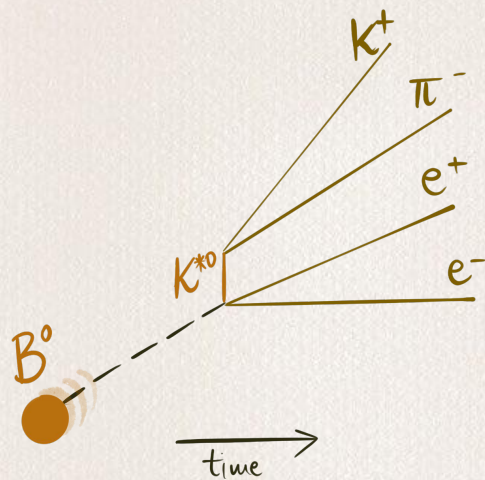
$$\Delta \mathcal{R}e(C_9) = -0.99^{+0.25}_{-0.21}$$

$$\Delta \mathcal{R}e(C_9) = -1.9$$

$$\Delta \mathcal{R}e(C_9) = -1.3^{+0.7}_{-0.6}$$

$B^0 \rightarrow K^{*0} ee$ angular analysis -

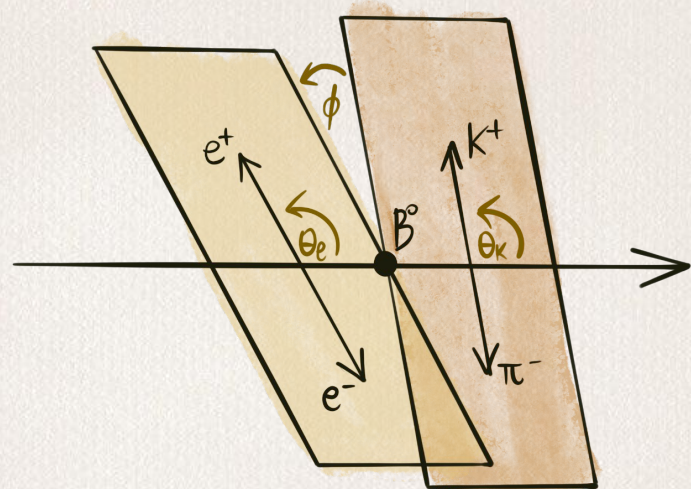
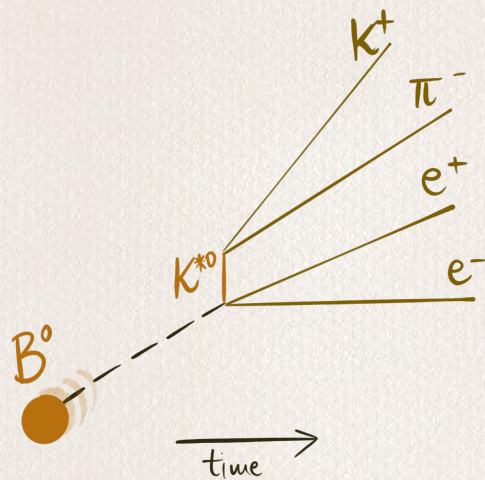
M. Senghi Soares, W. Hulsbergen, M.L. Martinez, A. Snoch, M. Geijsen, N.S. Oskam



$B^0 \rightarrow K^{*0} ee$ angular analysis -

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The decay is described by 3 angles (θ_1 , θ_K and ϕ)

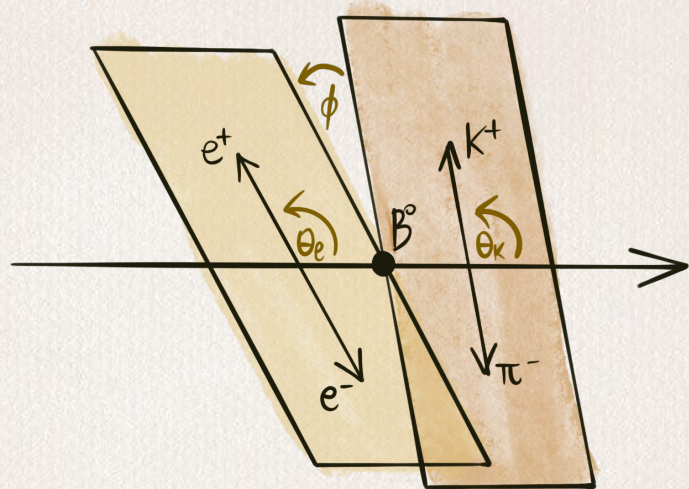


$B^0 \rightarrow K^{*0} e e$ angular analysis -

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The decay is described by 3 angles (θ_l , θ_K and ϕ)

$$\frac{d^3(\Gamma + \bar{\Gamma})}{d\vec{\Omega}} = \mathcal{K} \sum_i^8 p_i f_i(\theta_l, \theta_K, \phi)$$



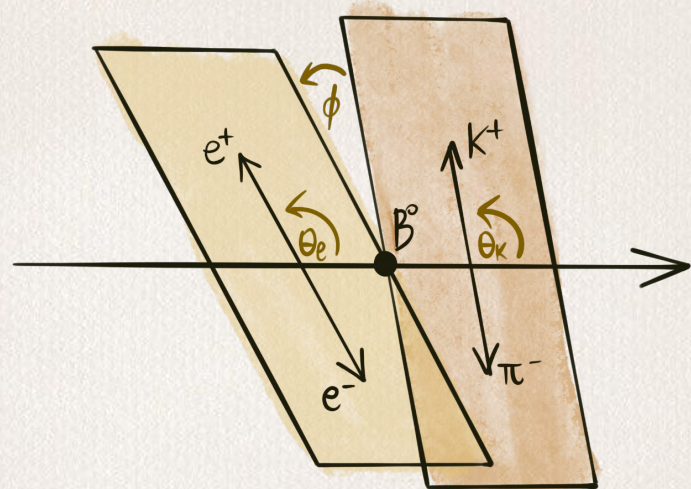
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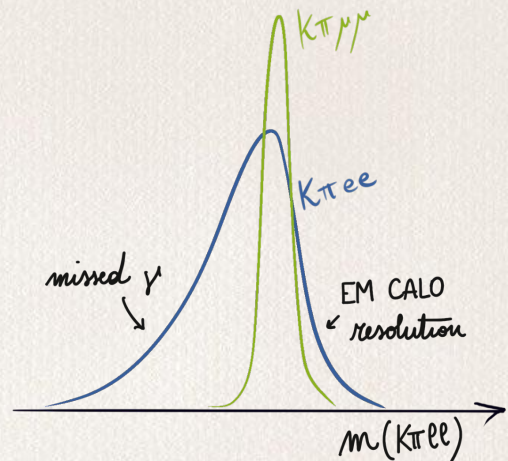
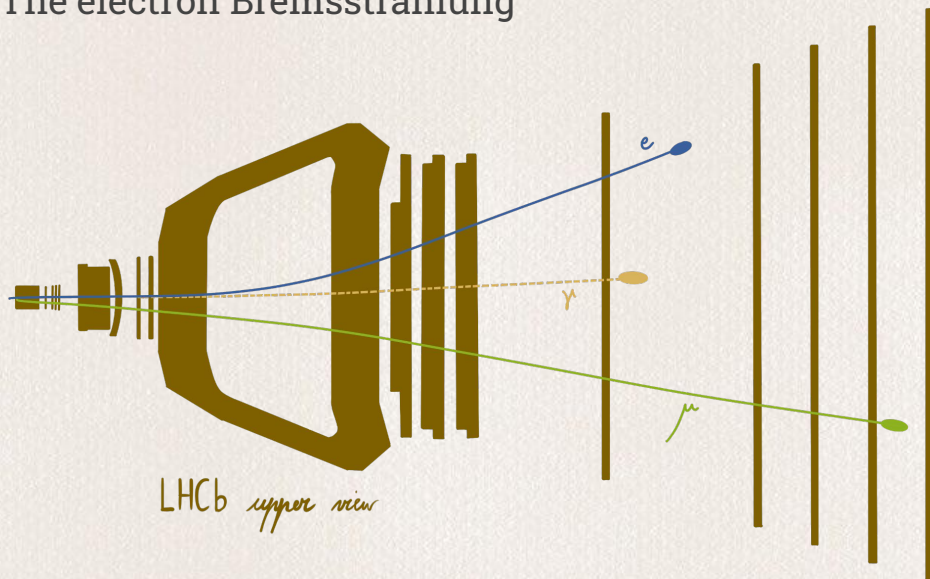
coefficients



THE GOAL: Measure coefficients describing the angular distribution

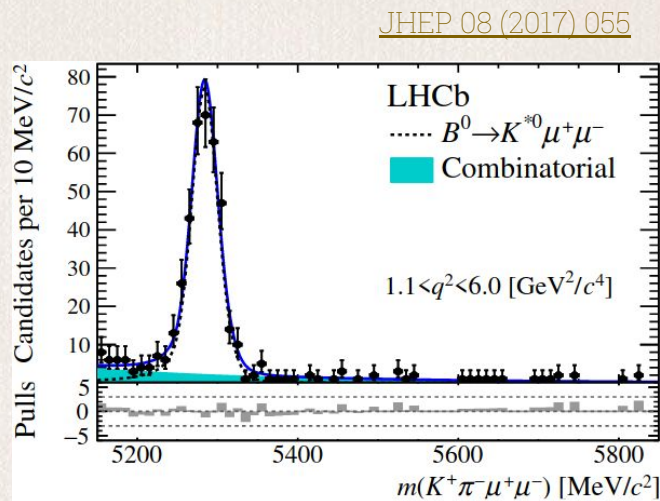
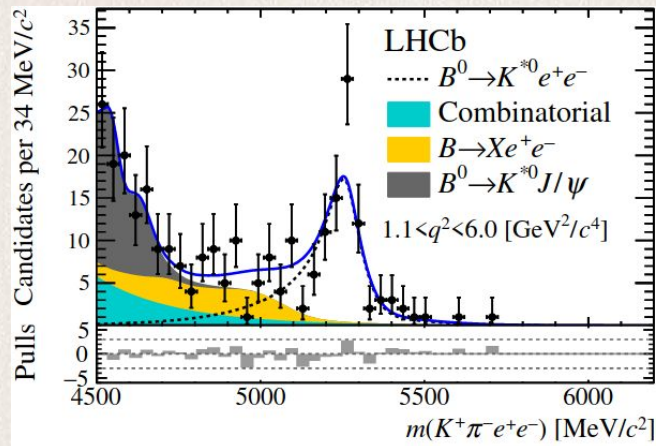
Major challenges

The electron Bremsstrahlung

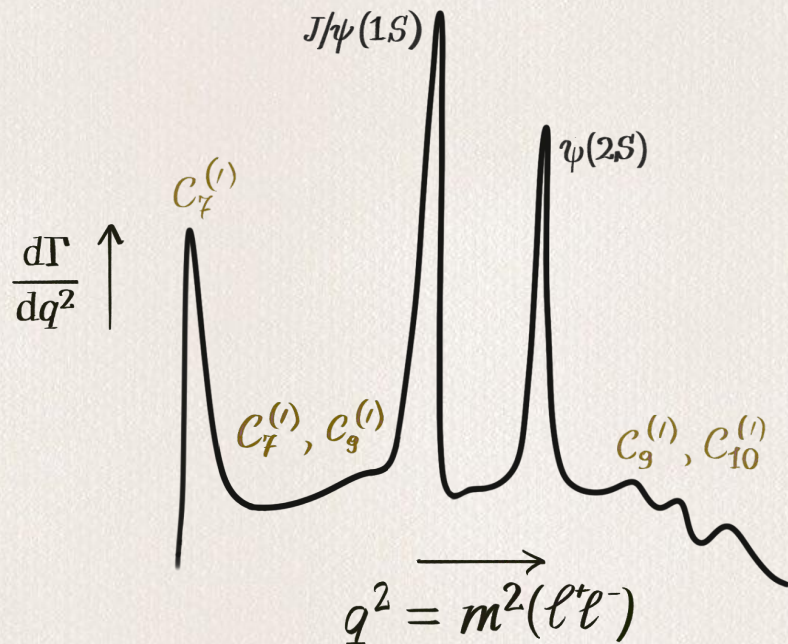


Major challenges

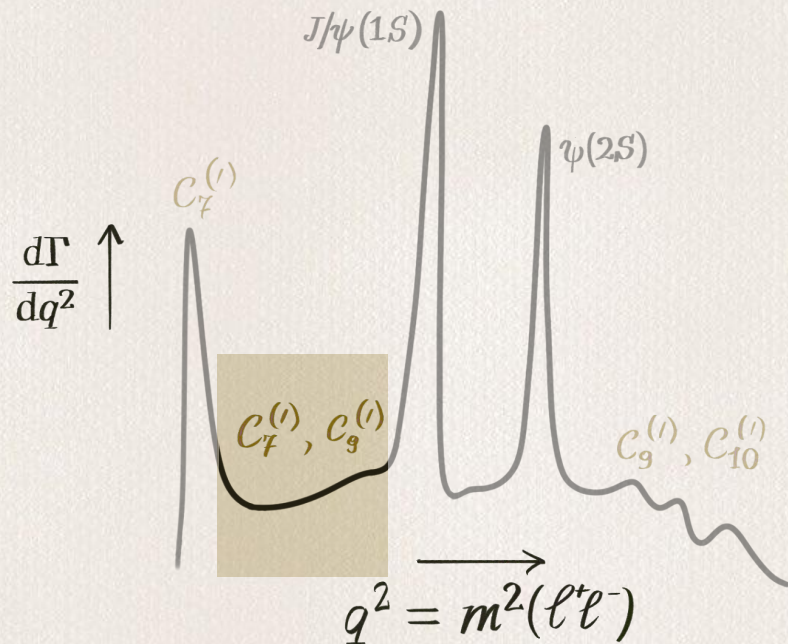
Few signal events and a lot of background



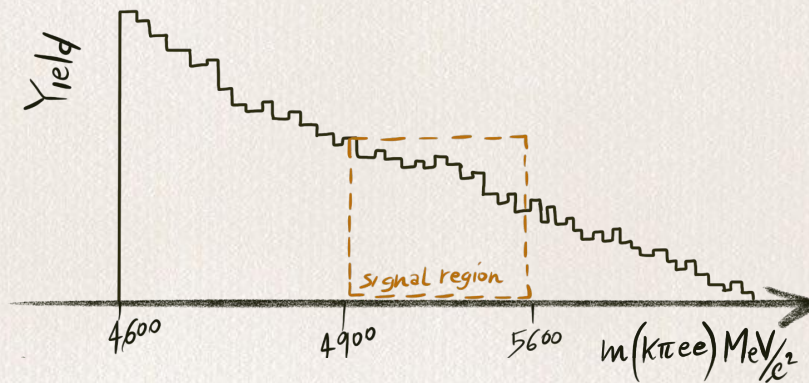
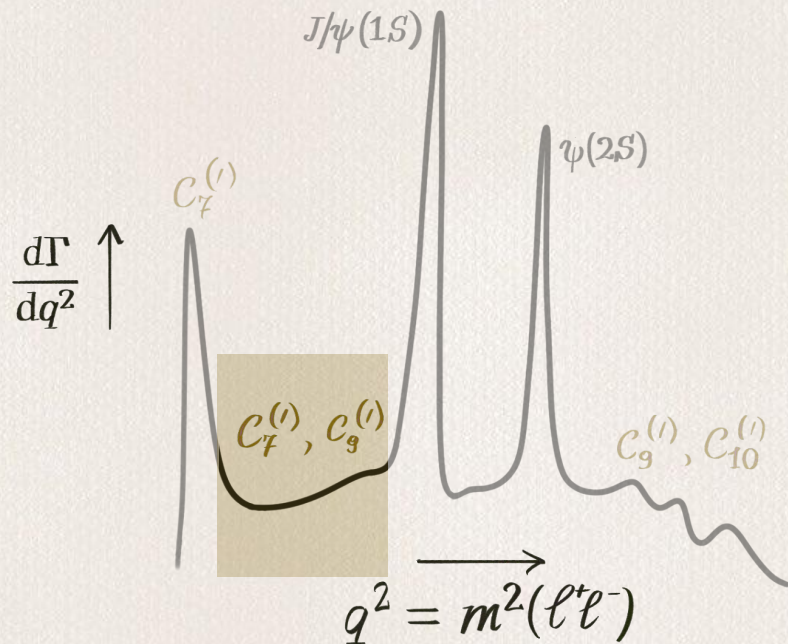
$B^0 \rightarrow K \pi e e$ mass



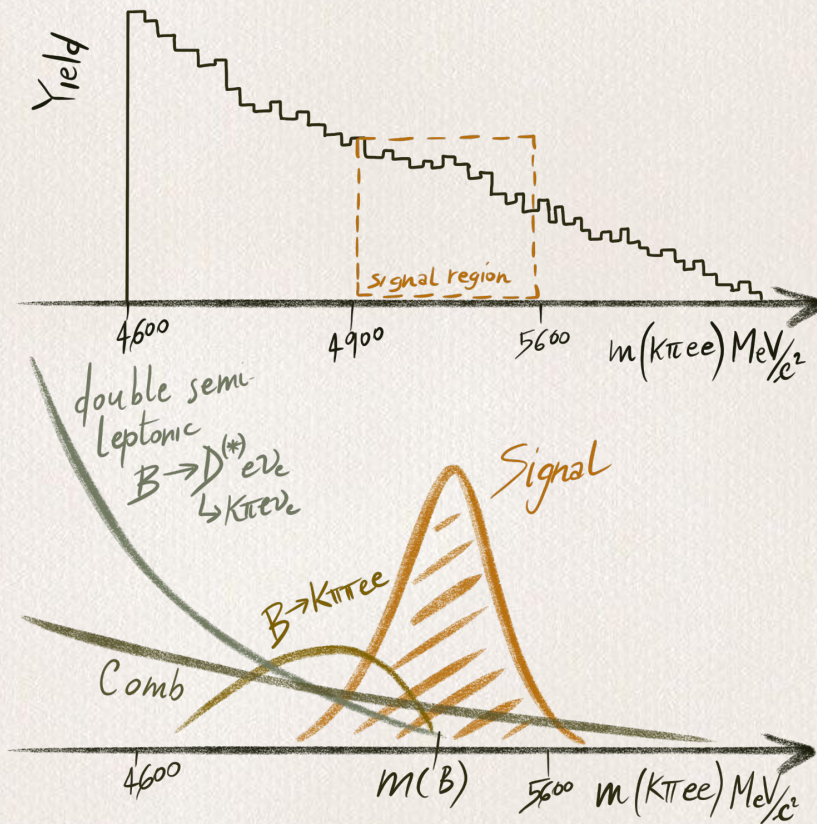
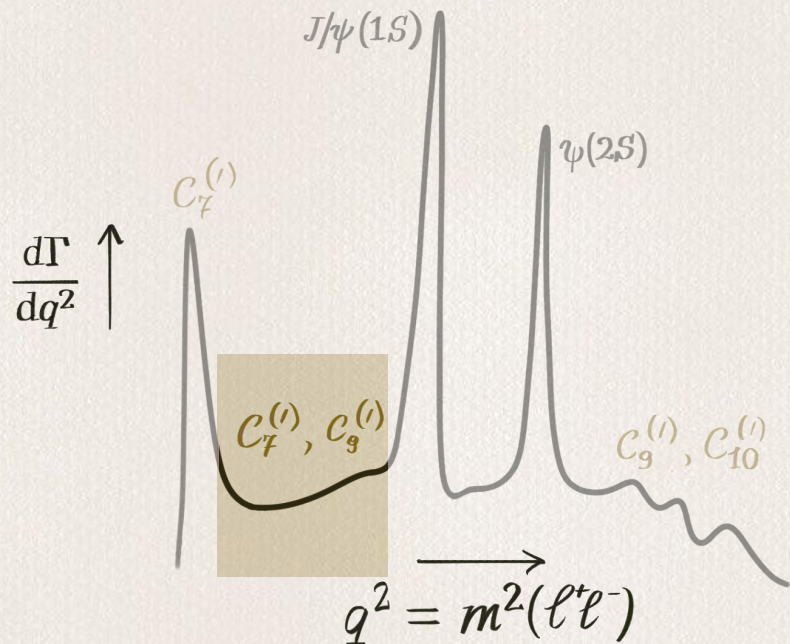
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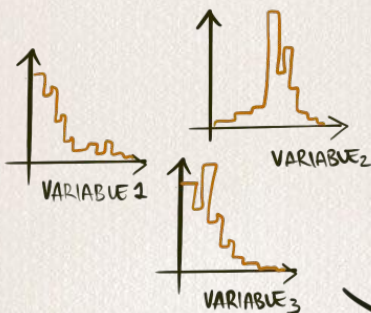


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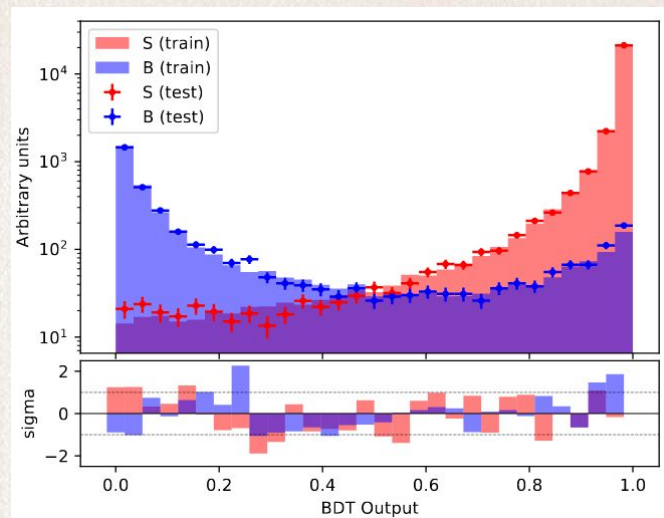
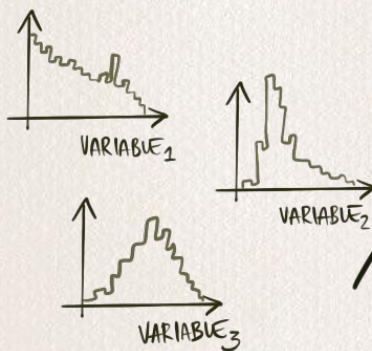


Boosted Decision Tree

Signal distributions

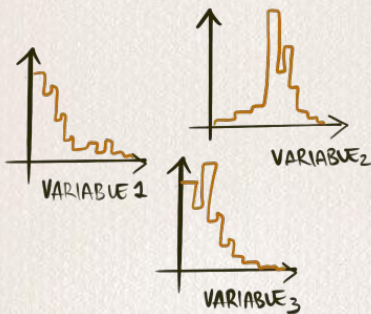


Background distributions

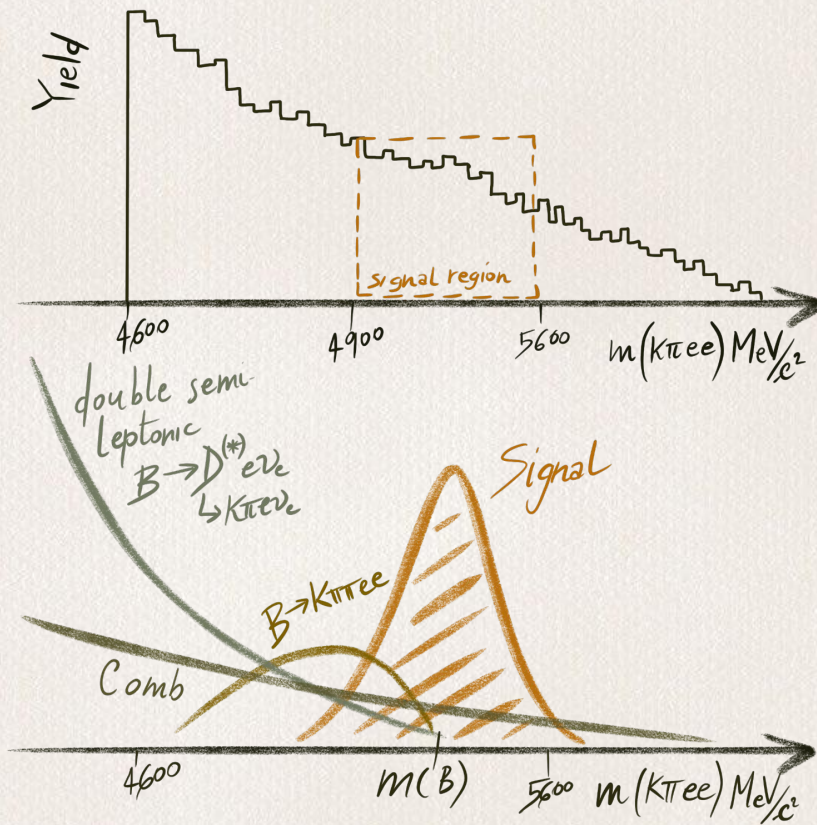
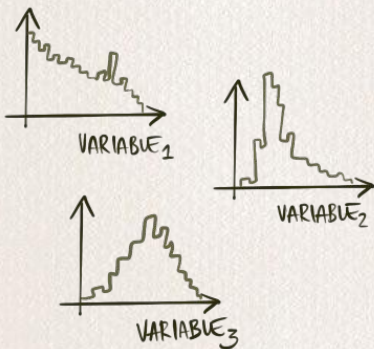


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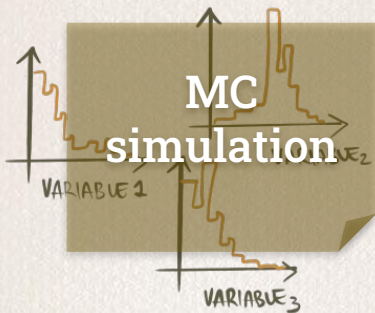


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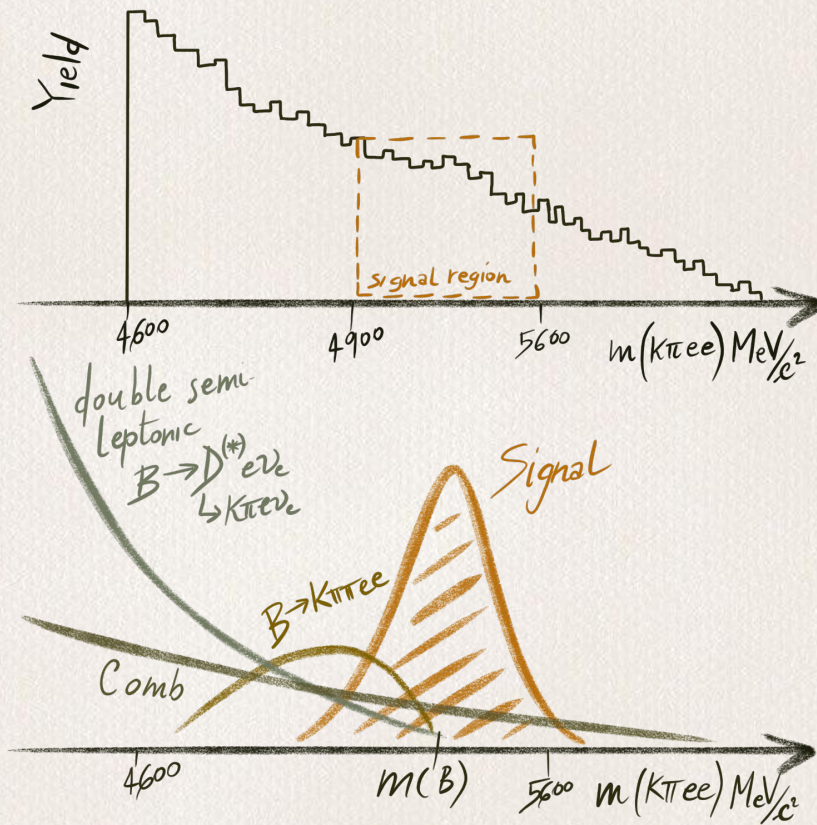
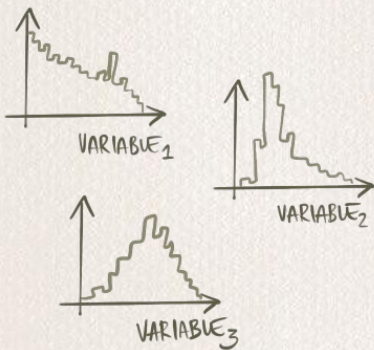


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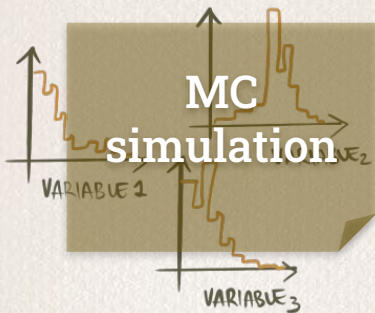


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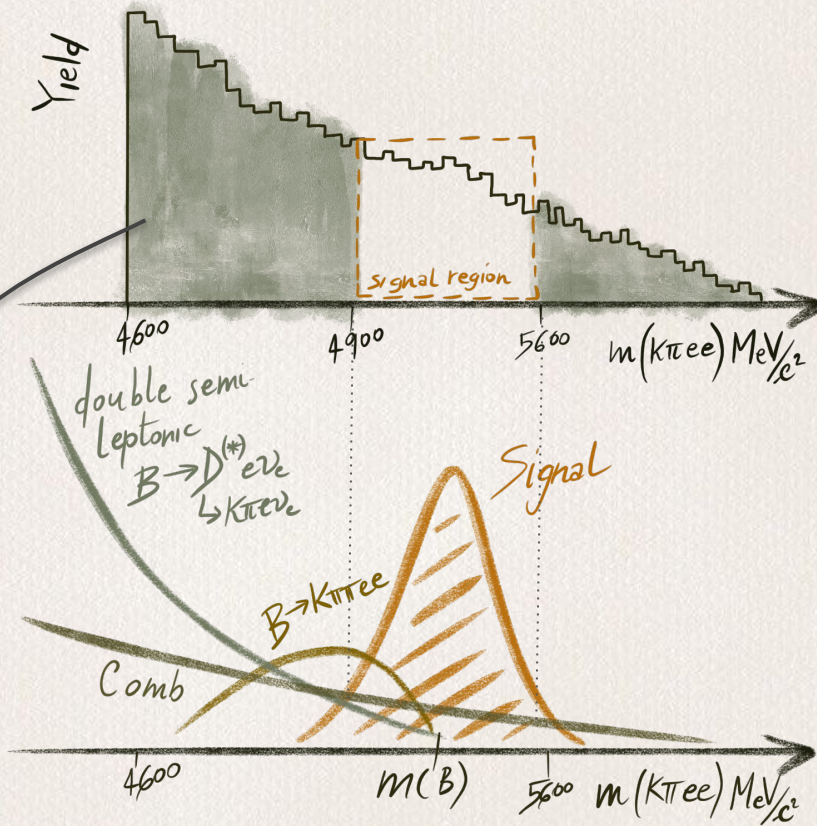
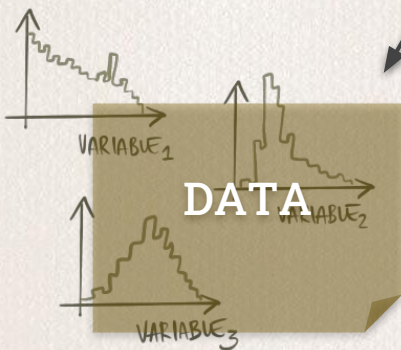


New BDT selection

Signal distributions



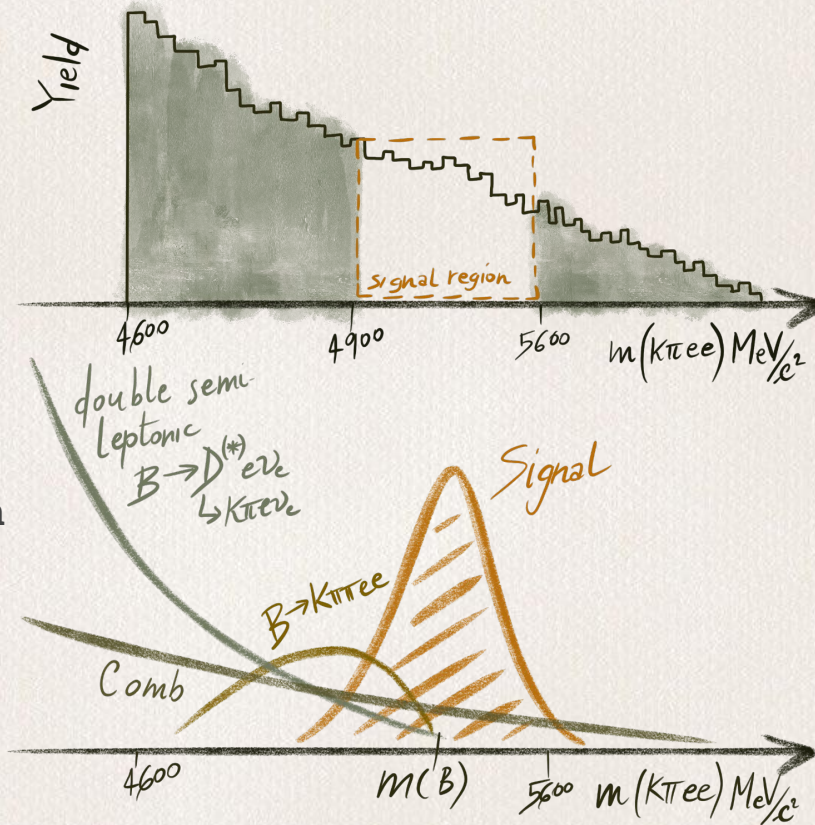
Background distributions



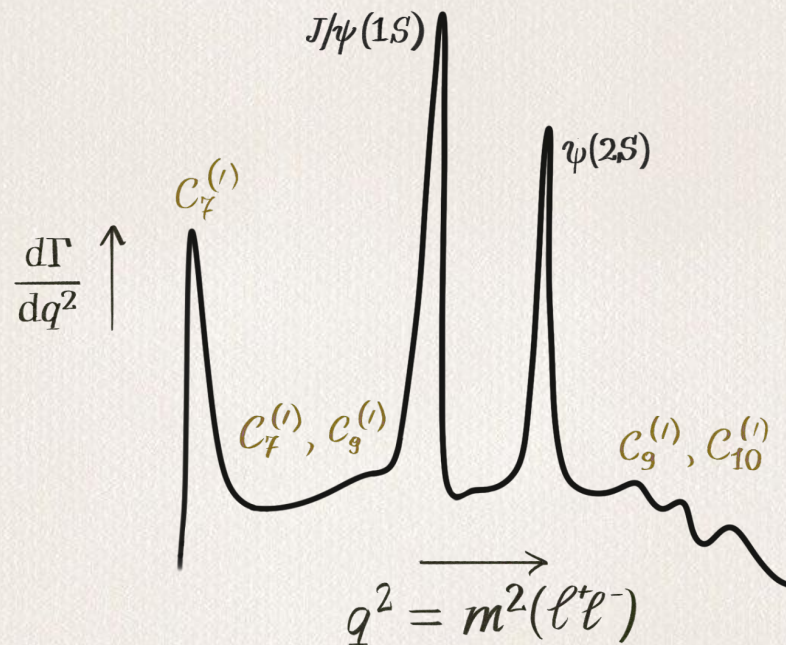
New BDT selection

Validate a new BDT training and selection:

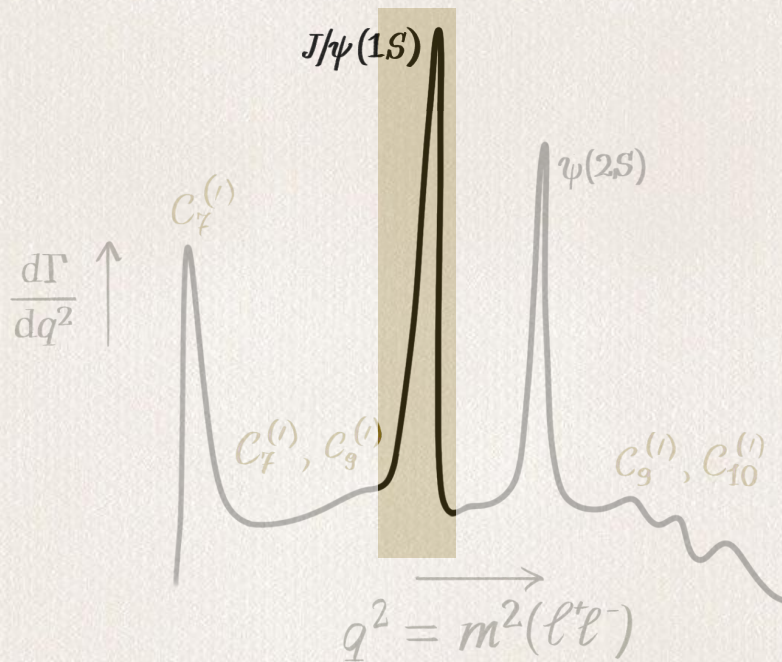
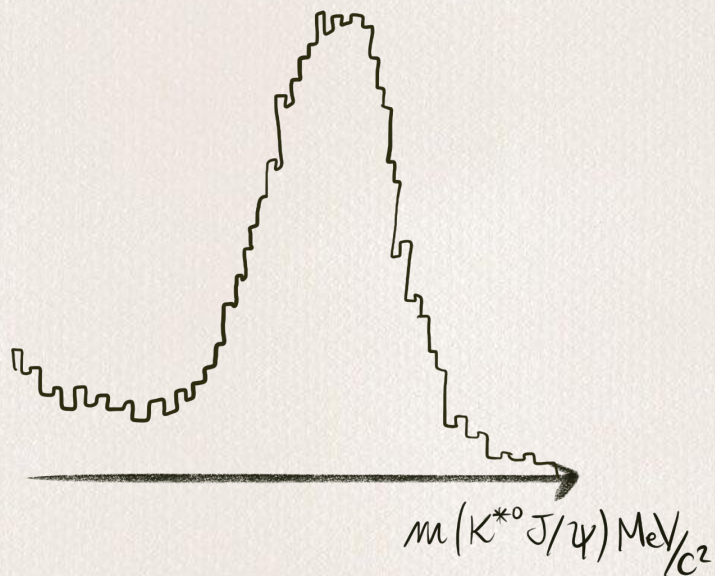
- **Input variables validation**
MC match data in the variables used to train the BDT?
- **Selection validation**
Angles shape not biased from the selection?
- **Signal efficiency & background rejection**



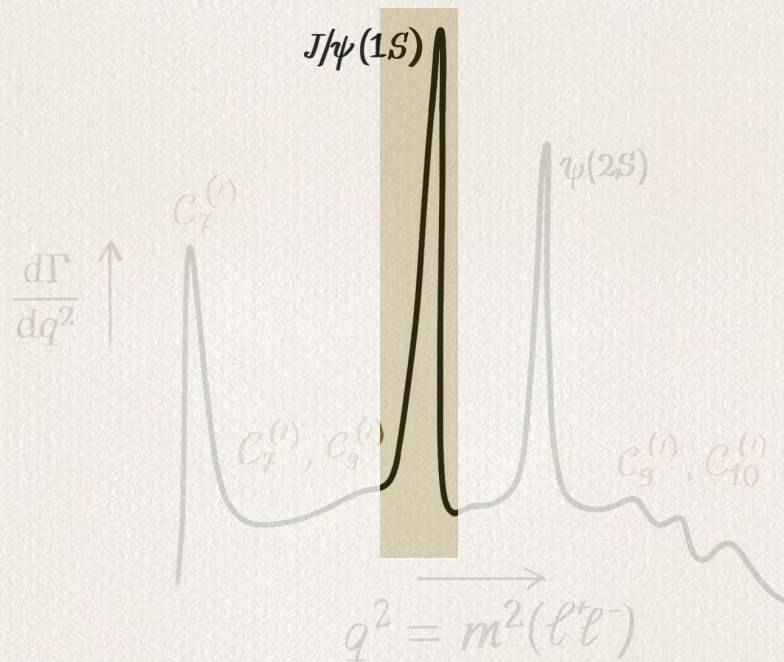
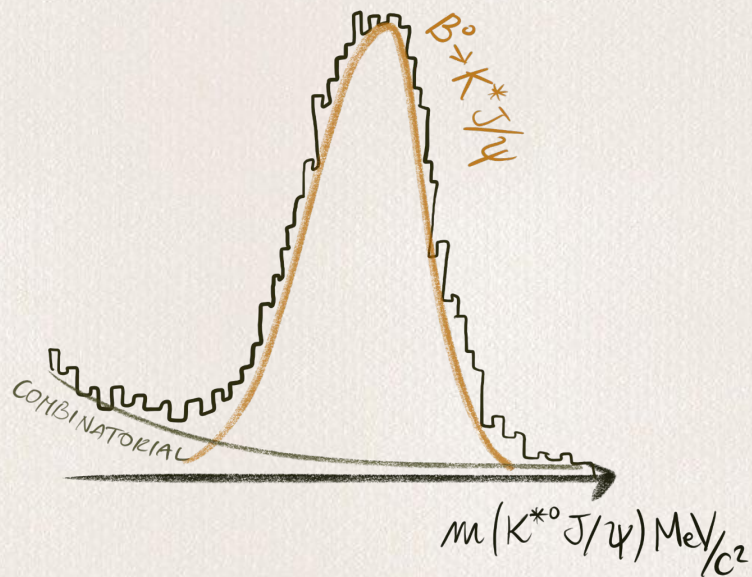
Variables validation



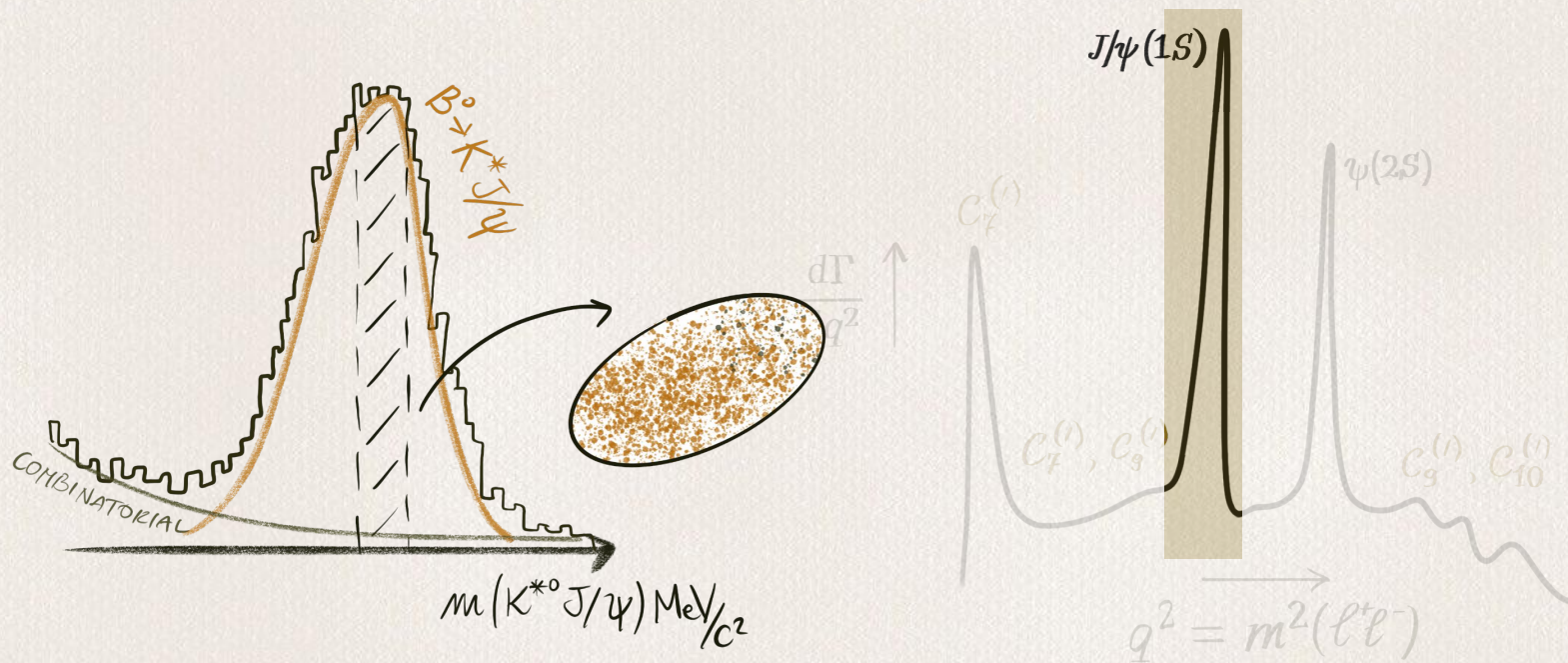
Variables validation



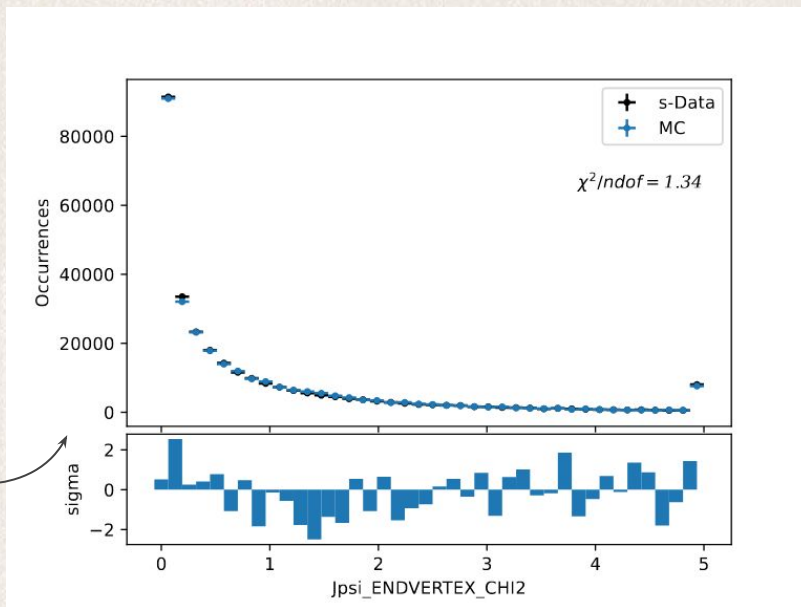
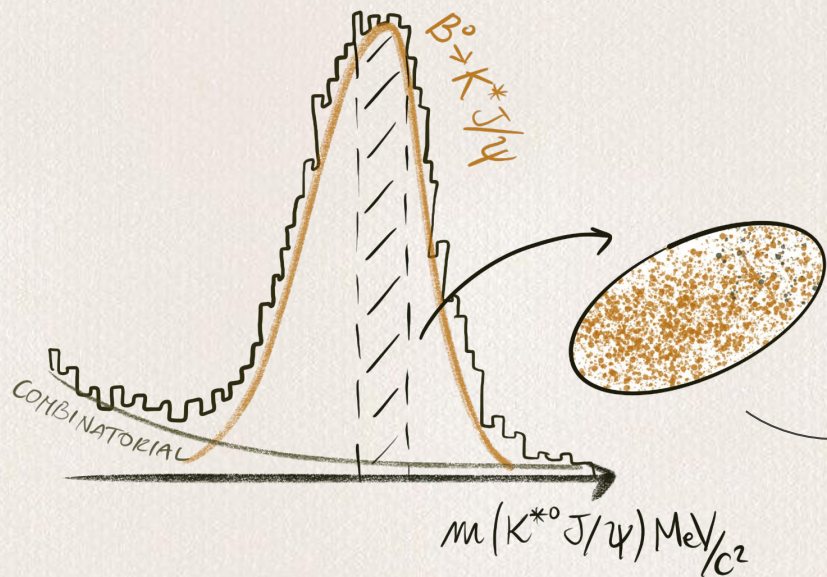
Variables validation



Variables validation

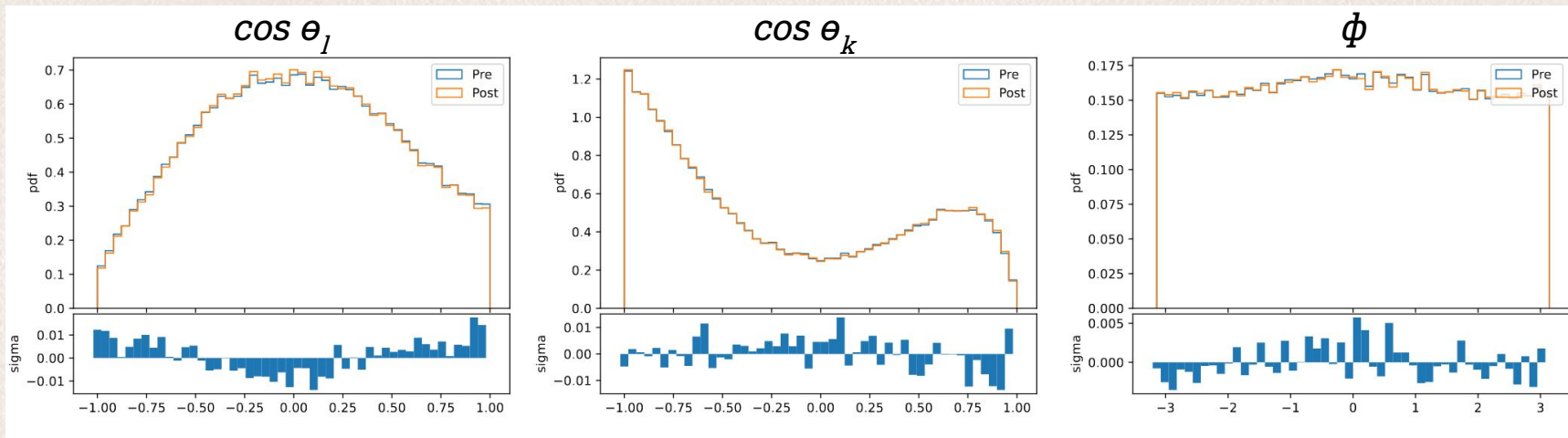


Variables validation



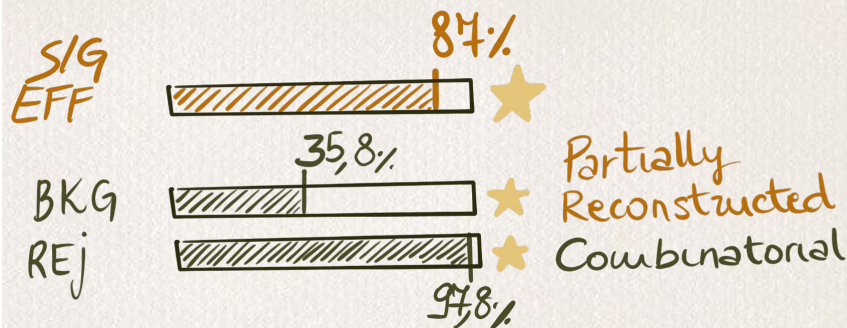
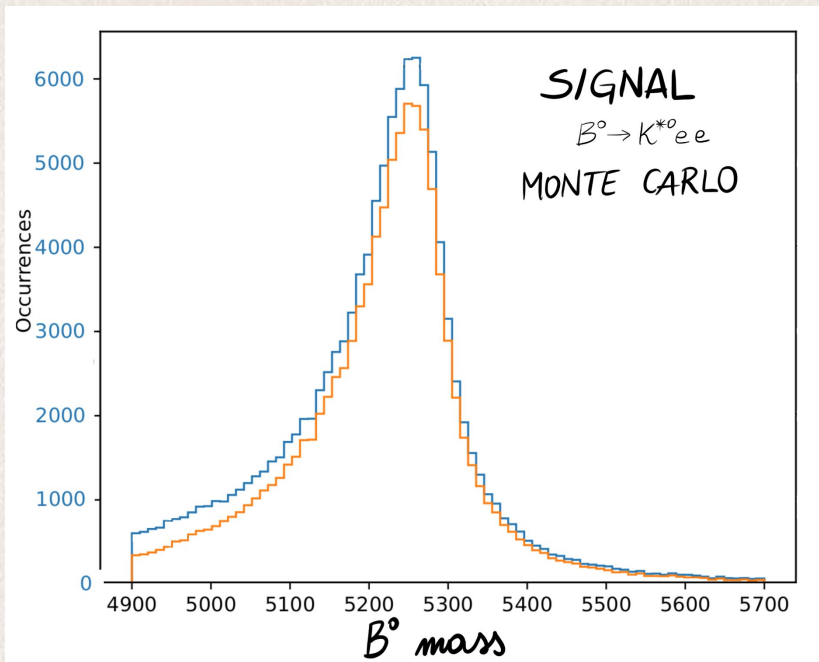
Selection validation on the angles

From the Monte Carlo Simulation of the signal



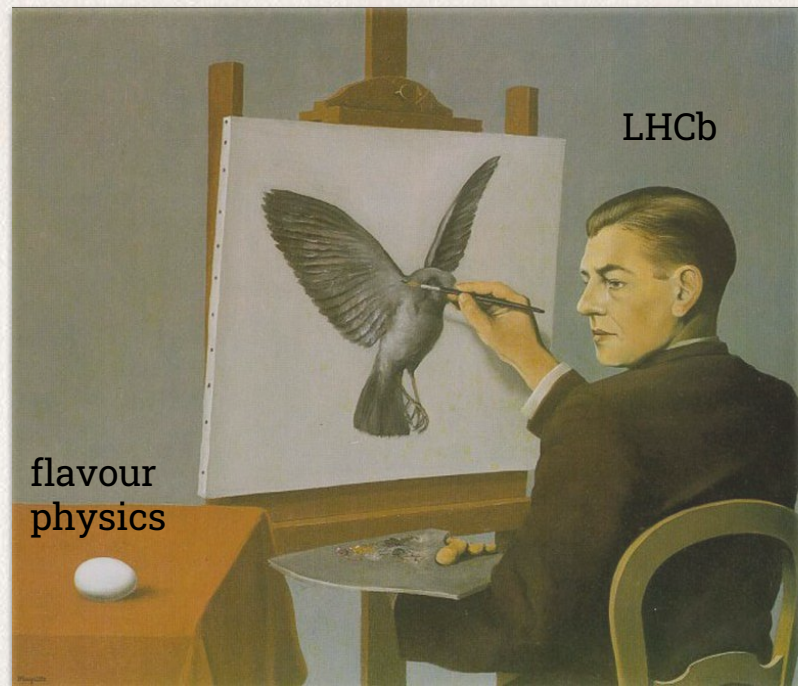
Signal efficiency & background rejection

From the Monte Carlo Simulation of the signal



Conclusions and LHCb and me

- Flavour physics still has intriguing puzzles
- Measurements in the electron sector
 - Experimental orthogonal way to test deviations from theory
 - More info on New Physics structure
- $B^0 \rightarrow K^{*0} e e$ angular analysis
- I feel very lucky contributing the CERN mission
 - Commissioning for VELO
 - Outreach activities

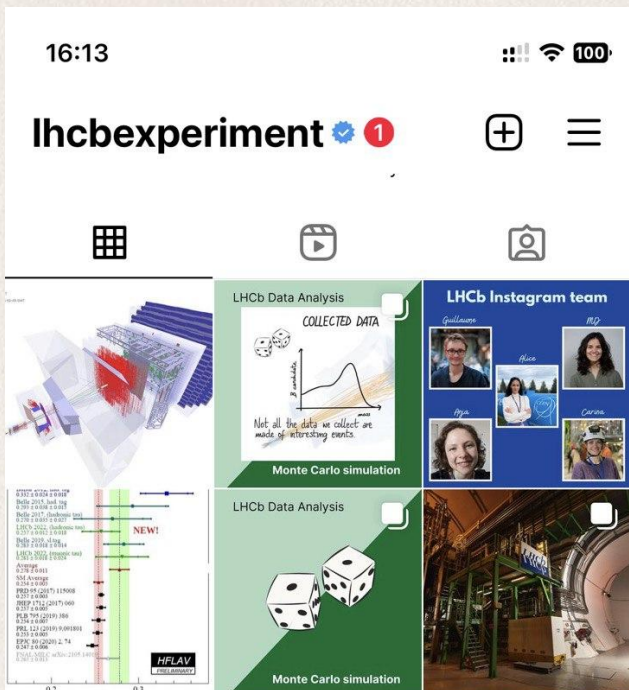


Guide tours @ CERN



LHCb Instagram -

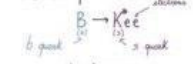
M. D. Galati, G. Pietrzyk, A. Beck, C. Trippi



LHCb Data Analysis

Experimental measurement

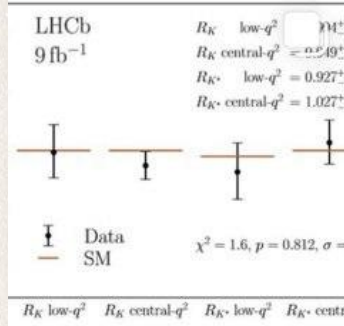
Let's take the following decay as an example:



its diagram



Penguin Diagrams



LHCb Data Analysis

Physics Introduction



Penguin Diagrams



Talk @ my high school

Intensità e raggio di azione



Alice Biolchini - Una passeggiata nel mondo delle interazioni fondamentali - 10/01/2023

2

PARTICLES,



PARTICLES EVERYWHERE

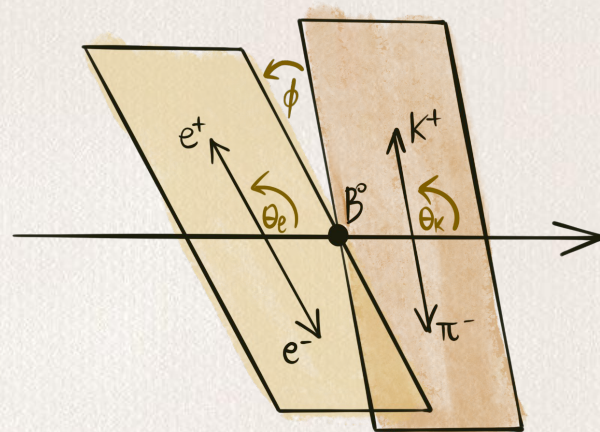
*Thanks for your attention.
Any questions?*

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alice.biolchini@cern.ch

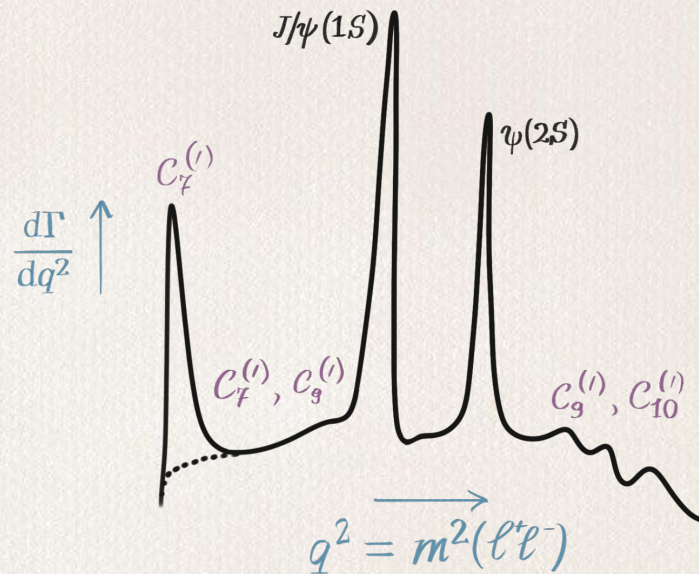
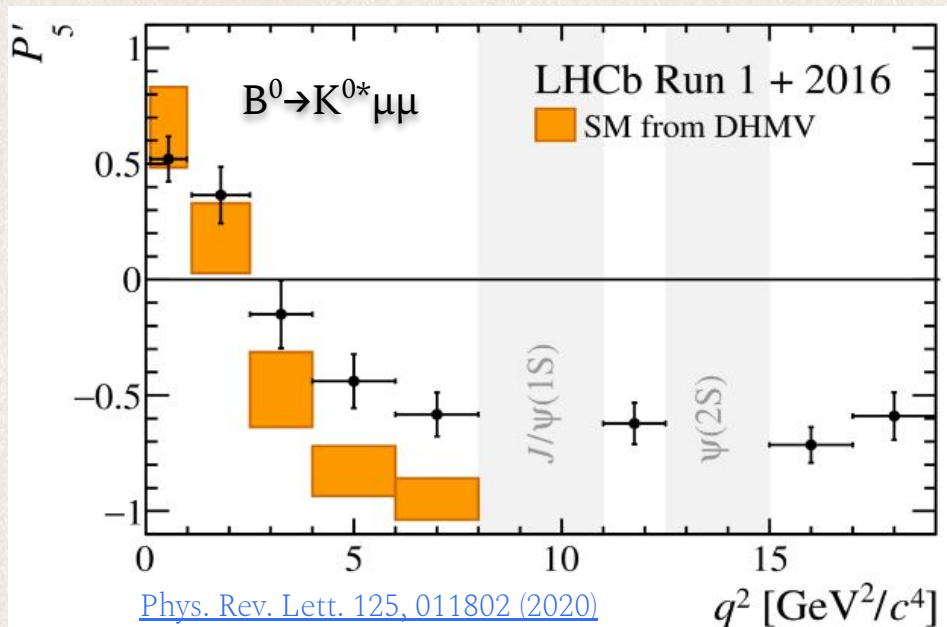
Backup slides: Angular distribution

$$\frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \frac{d^4(\Gamma + \bar{\Gamma})}{dq^2 d\vec{\Omega}} = \frac{9}{32\pi} \left[\begin{aligned} &\frac{3}{4}(1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K \\ &+ \frac{1}{4}(1 - F_L) \sin^2 \theta_K \cos 2\theta_\ell \\ &- \underline{F}_L \cos^2 \theta_K \cos 2\theta_\ell + \underline{S}_3 \sin^2 \theta_K \sin^2 \theta_\ell \cos 2\phi \\ &+ \underline{S}_4 \sin 2\theta_K \sin 2\theta_\ell \cos \phi + \underline{S}_5 \sin 2\theta_K \sin \theta_\ell \cos \phi \\ &+ \frac{4}{3} \underline{A}_{FB} \sin^2 \theta_K \cos \theta_\ell + \underline{S}_7 \sin 2\theta_K \sin \theta_\ell \sin \phi \\ &+ \underline{S}_8 \sin 2\theta_K \sin 2\theta_\ell \sin \phi + \underline{S}_9 \sin^2 \theta_K \sin^2 \theta_\ell \sin 2\phi \end{aligned} \right]$$

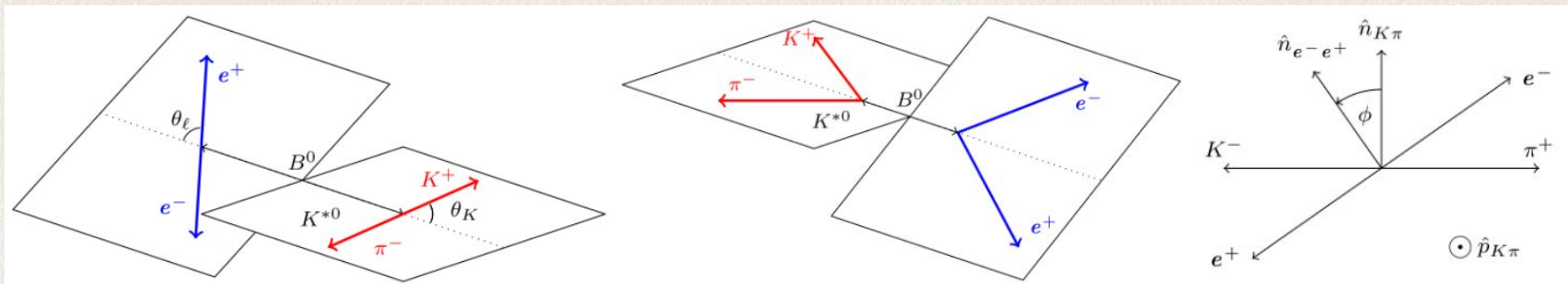


THE GOAL: Measure the coefficients describing the angular distribution

Example: angular coefficients in bin of q^2



Backup slide: Decay angles



$\theta_l \rightarrow$ between the direction of the e^+ and the direction opposite to that of the B^0 in the rest frame of the dimuon system

$\theta_K \rightarrow$ between the direction of the K^+ and the direction of the B^0 in the rest frame of the K^{*0}

$\phi \rightarrow$ between the plane defined by the electrons pair and the plane defined by the kaon and pion in the B^0 rest frame

Backup slide: Optimized base P_i'

Theoretically cleaner angular observables:
 $B^0 \rightarrow K^{*0}$ form-factor uncertainties
largely cancel

$$P_1 = \frac{2S_3}{(1 - F_L)} = A_T^{(2)},$$

$$P_2 = \frac{2}{3} \frac{A_{FB}}{(1 - F_L)},$$

$$P_3 = \frac{-S_9}{(1 - F_L)},$$

$$P'_{4,5,8} = \frac{S_{4,5,8}}{\sqrt{F_L(1 - F_L)}},$$

$$P'_6 = \frac{S_7}{\sqrt{F_L(1 - F_L)}},$$

Backup slide: NP contributions (EFT interpretation)

[Buchalla, Buras, Lautenbacher, Rev. Mod. Phys.68 (1996) 1125]

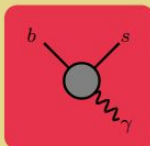
$b \rightarrow sl^+l^-$ OPERATORS

[Go to Patrick's presentation](#)



Operator

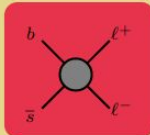
$\mathcal{O}_{7\gamma}$



Effective Hamiltonian \mathcal{H}

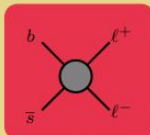
$$A(b \rightarrow sll) = \langle sll | \mathcal{H}_{\text{eff}} | b \rangle$$

\mathcal{O}_{9V}



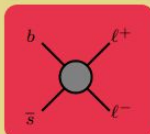
$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{10} C_i(\mu) \mathcal{O}_i(\mu)$$

\mathcal{O}_{10A}



- Operators \mathcal{O}_i : Long-distance effects
- Wilson coefficients C_i : Short-distance effects (masses above μ are integrated out)

$\mathcal{O}_{S,P}$



New physics can show up in new operators or **modified Wilson coefficients**

Nikhef

Patrick Koppenburg

Penguin B decays

19/05/2021 — Santiago [49 / 62]