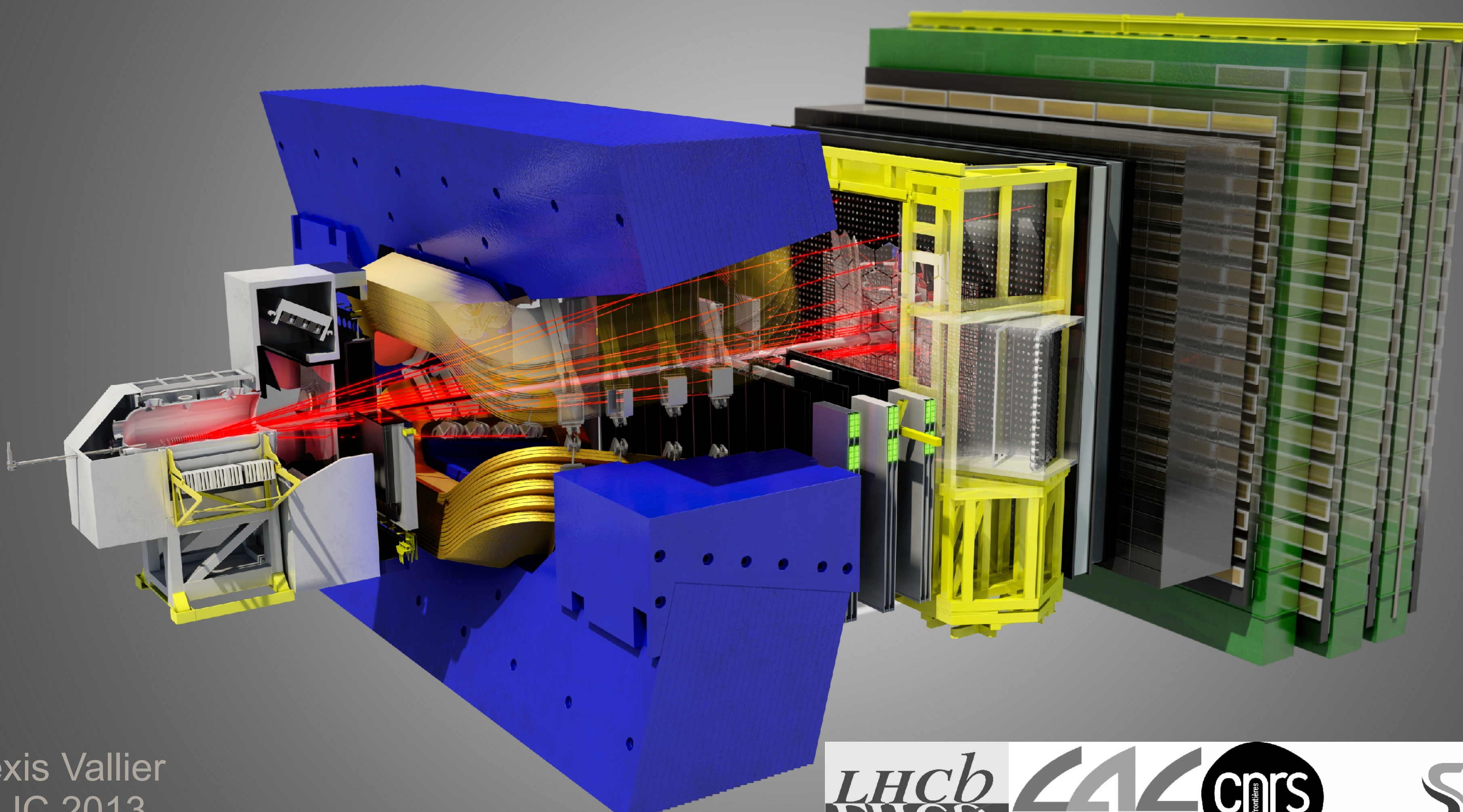
Measurement of the CKM angle γ in the $B^0 \to D(K^0_s\pi\pi)K^{*0}$ decay at LHCb



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JRJC 2013

LHCb
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cnrs IN2P3 Les deux infinis
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Outline

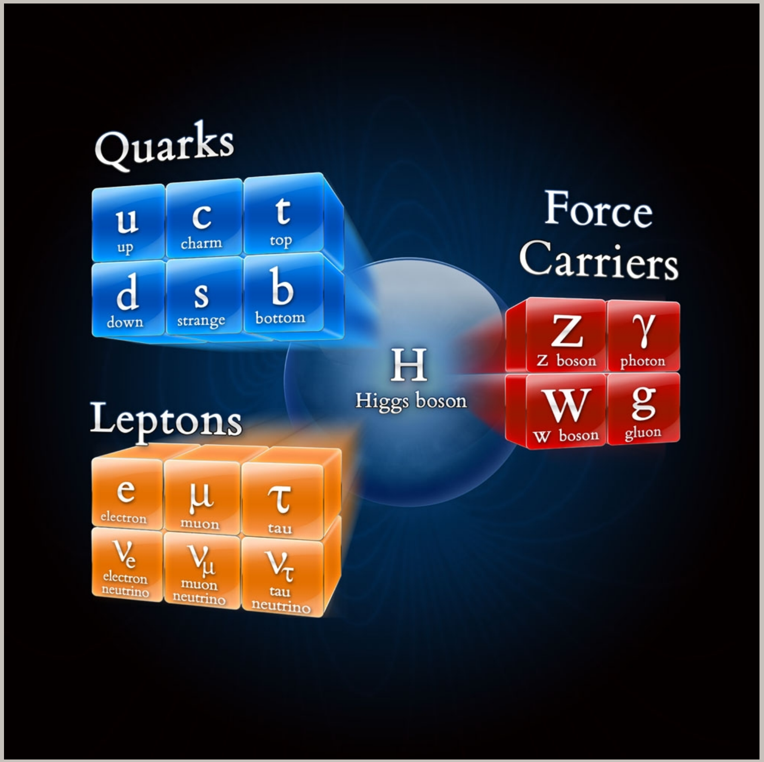
1) Flavour Violation in the Standard Model (SM).

2) $B^0 \to D(K^0_s \pi\pi)K^{*0}$ decay and CKM angle γ measurement.

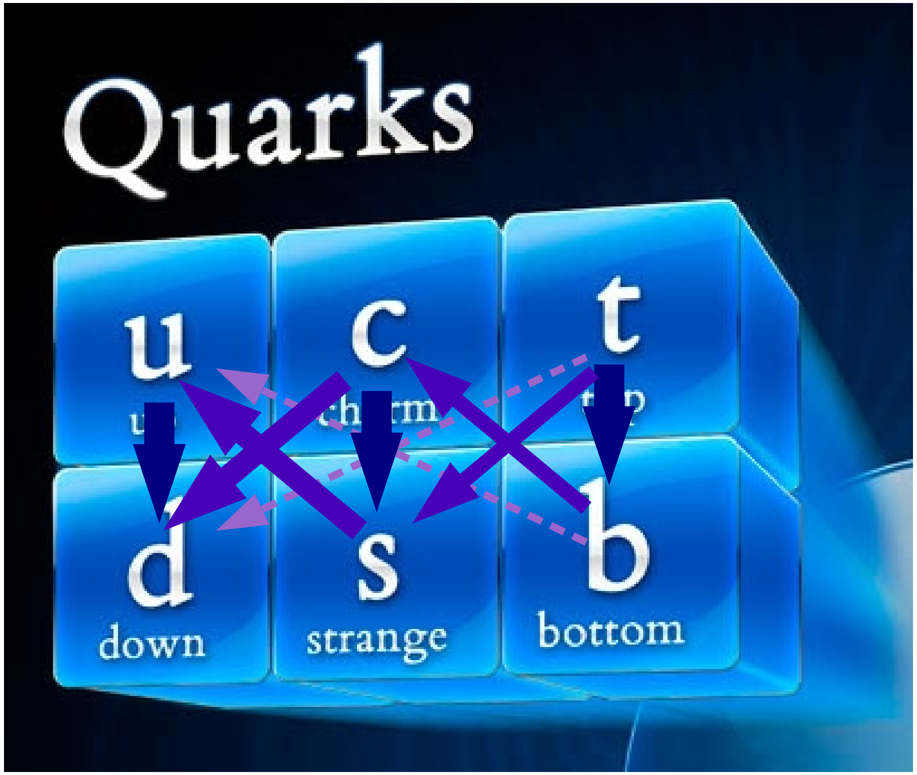
3) Tracking system of the LHCb detector.

4) $B^0 \to D(K^0_s \pi\pi)K^{*0}$ analysis.

Flavour Violation in the Standard Model



Quarks Flavour Mixing



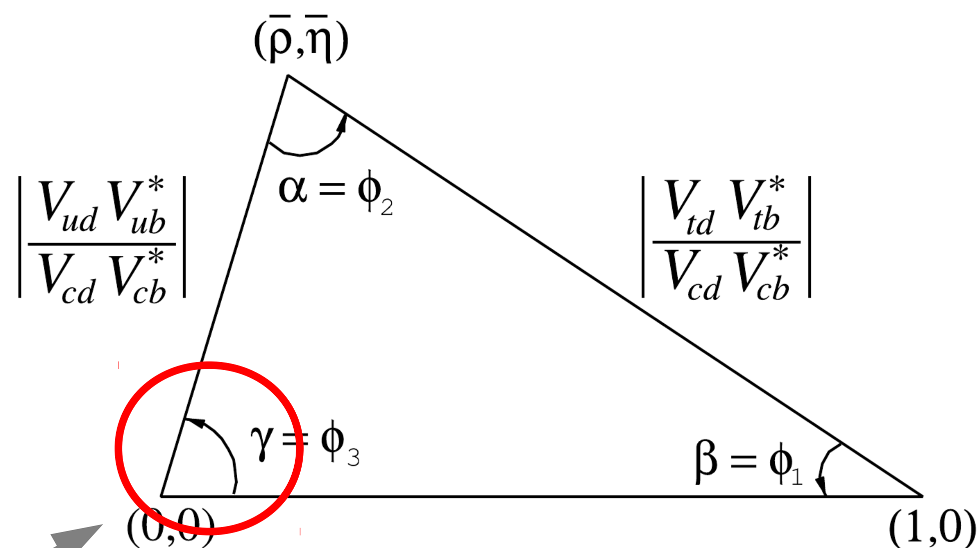
- The quark flavour is not conserved:
  - s→u
  - c→s or d
  - b→c or u
  - t→b or s or u
- Transitions inside a same family are the most probable, then family 2→1, family 3→2 and 3→1.
- This mixing is describe by the Cabibbo-Kobayashi-Maskawa (CKM) mechanism.

CKM mechanism

- | Weak eigenstates > ≠ | Mass eigenstates >
- Rotation in quark space: CKM matrix

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx$$

Unarity Triangle

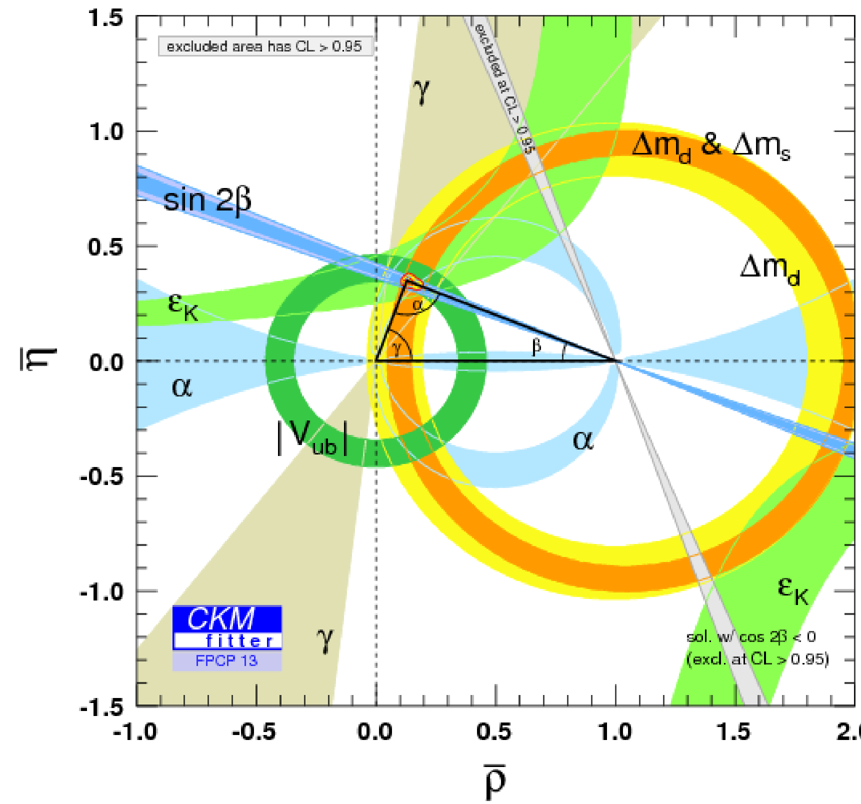


- Each term encode the amplitude of the $q_i \rightarrow q_j$ transition.
- The matrix must be unitary:

$$\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} + 1 + \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} = 0$$

γ angle

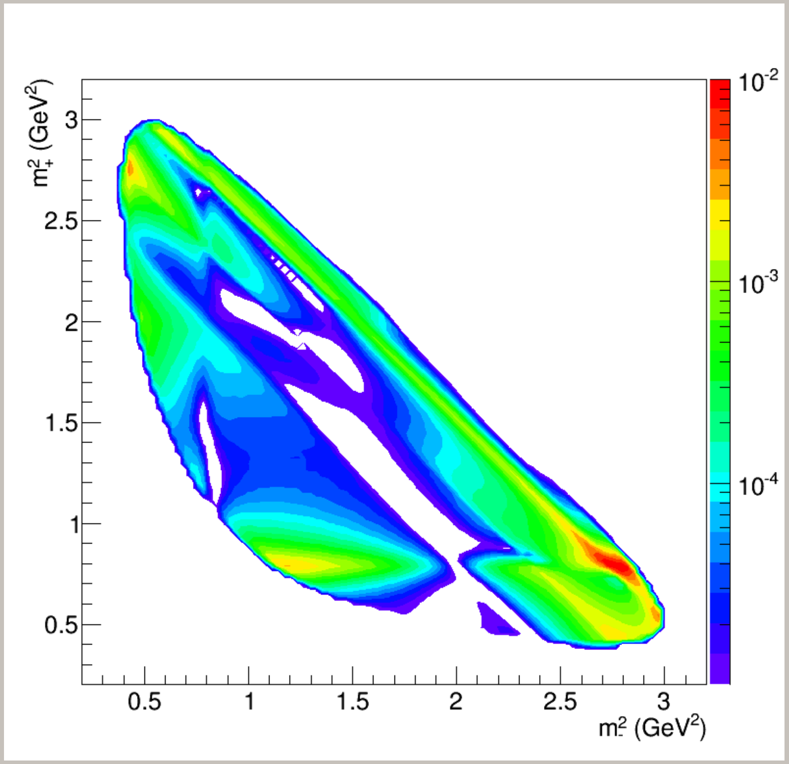
- γ is one of the free parameters of the SM.
- **Check the consistency of CKM paradigm**:
  - Measure α, β, γ separately.
  - Measure side length of the triangle.
  - Look if it makes a closed triangle.
- γ is the least none CKM parameter:
  - $\gamma = 68^{+10}_{-11}$ ° (PDG 2012)



$$\boxed{\gamma = \arg\left(-\frac{V_{ud}V_{ub}^{*}}{V_{cd}V_{cb}^{*}}\right)}$$

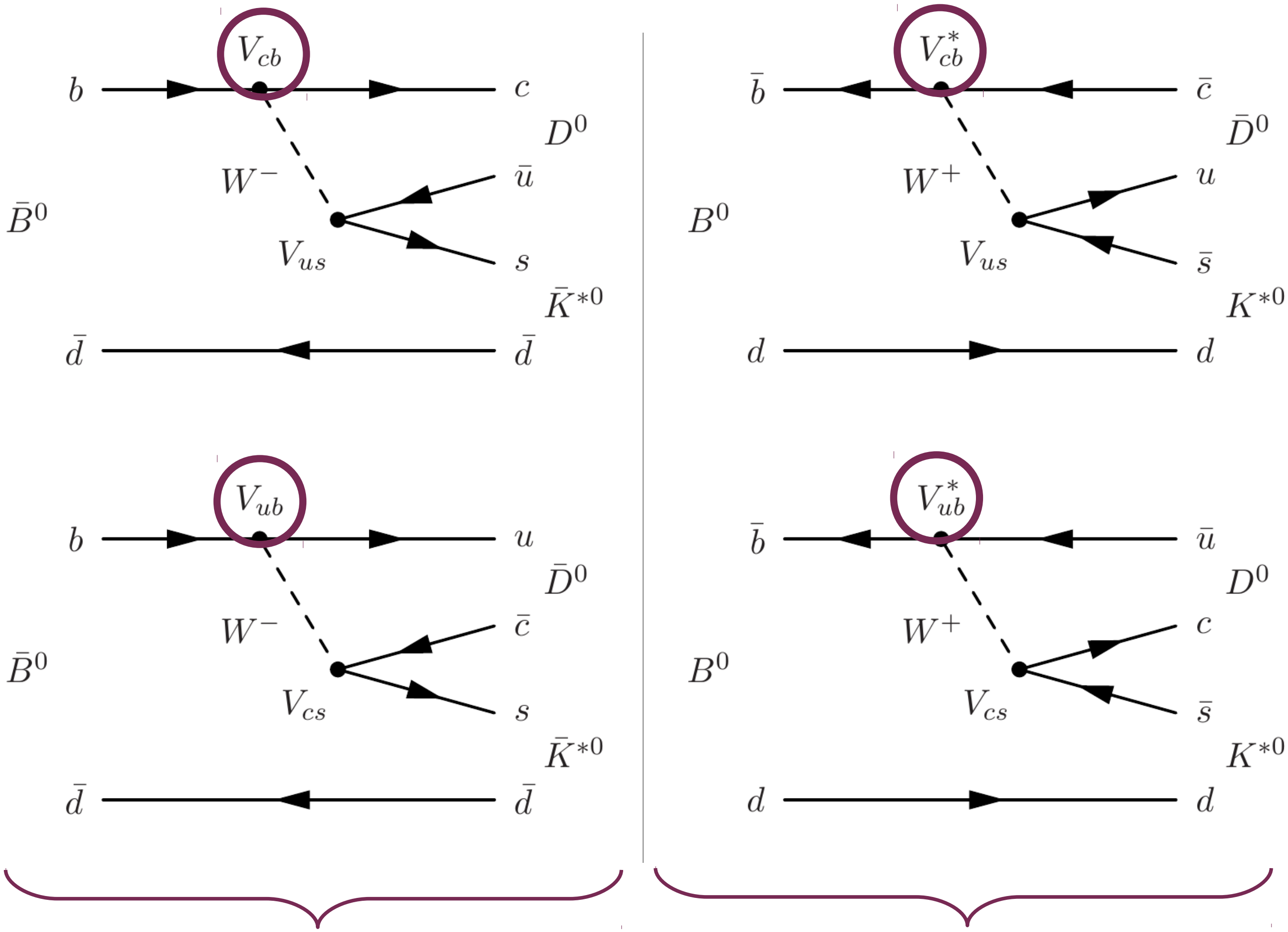
γ ≈ phase of V_{ub}

$B^0 \rightarrow D(K^0_s\pi\pi)K^{*0}$ decay and CKM angle γ measurement



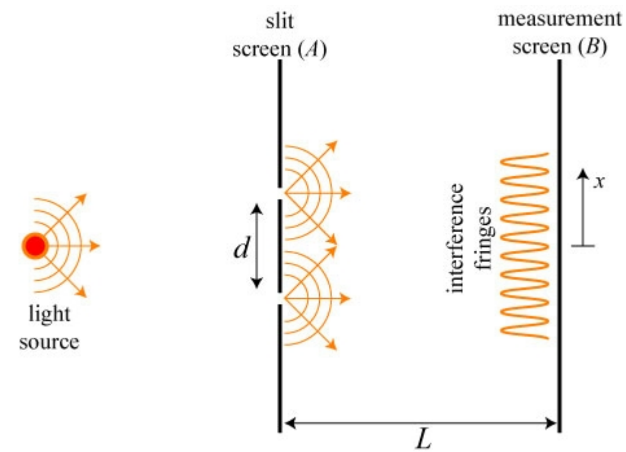
b→u / b→c Interference

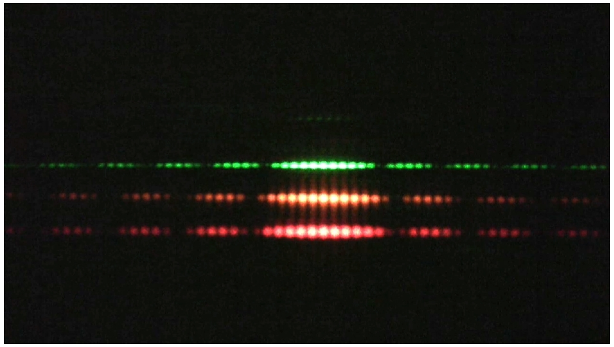
γ = phase difference between V_{ub} and V_{cb}



b→u / b→c or $\bar{b}$→$\bar{u}$ / $\bar{b}$→$\bar{c}$ interferences sensitive to γ

Analogy with Young's slits experiment:





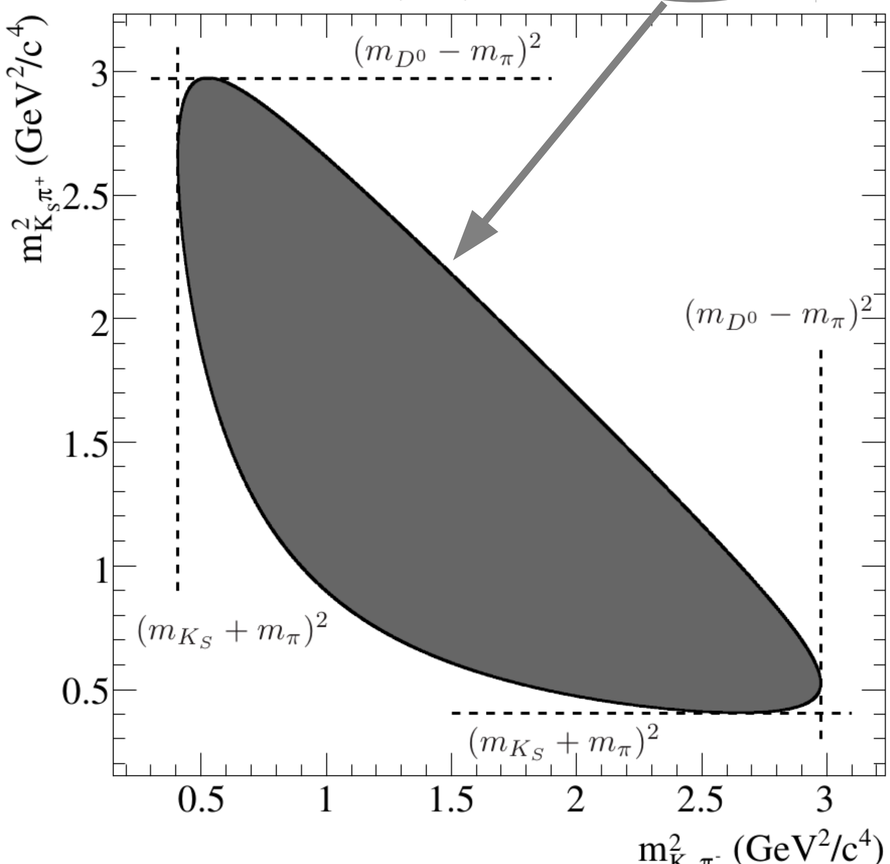
Interference sensitive to d

How to see the interference?

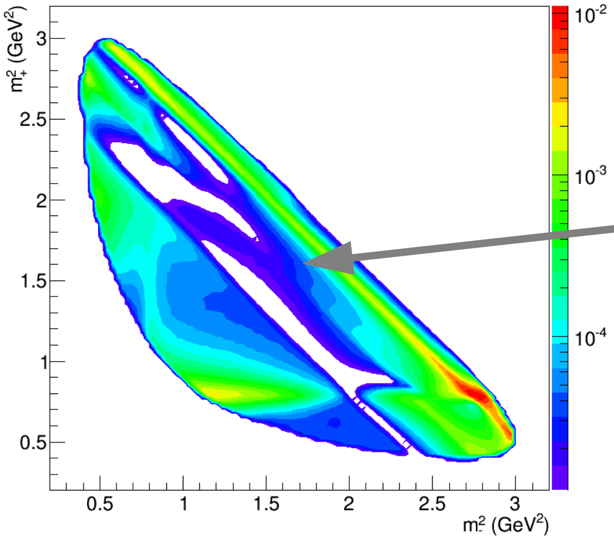
- To make the interference between $B^0 \to D^0 K^{*0}$ and $B^0 \to \overline{D}^0 K^{*0}$ we look at a **common $D^0/\overline{D}^0$ final state**: $D \to K^0_s \pi\pi$

- Since it is a 3 bodies decay, the phase-space can be described by only 2 invariant masses: $\mathbf{m^2(K^0_s\pi^+) = m^2_+}$ and $\mathbf{m^2(K^0_s\pi^-) = m^2_-}$

$$d\Gamma = \frac{|\mathcal{M}|^2}{32(2\pi)^3 m_D^3} dm_+^2 dm_-^2$$



Interference between $B^0 \to D^0 K^{*0}$ and $B^0 \to \overline{D}^0 K^{*0}$



$$d\Gamma = \frac{|\mathcal{M}|^2}{32(2\pi)^3 m_D^3} dm_+^2 dm_-^2$$

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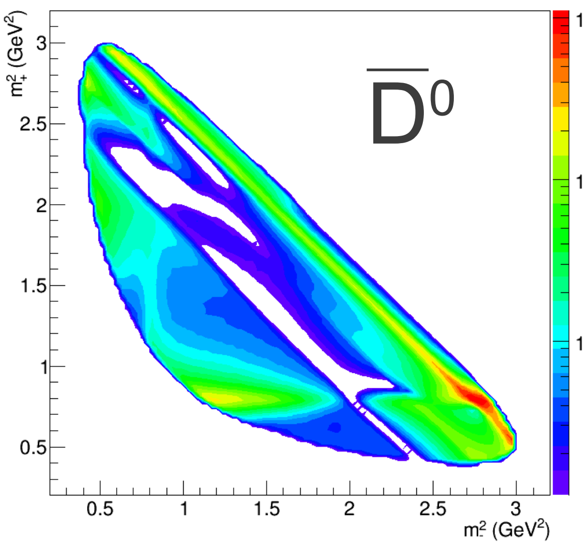
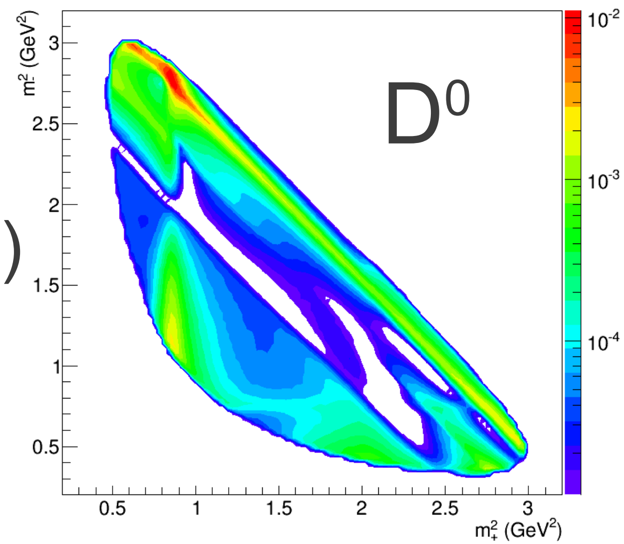
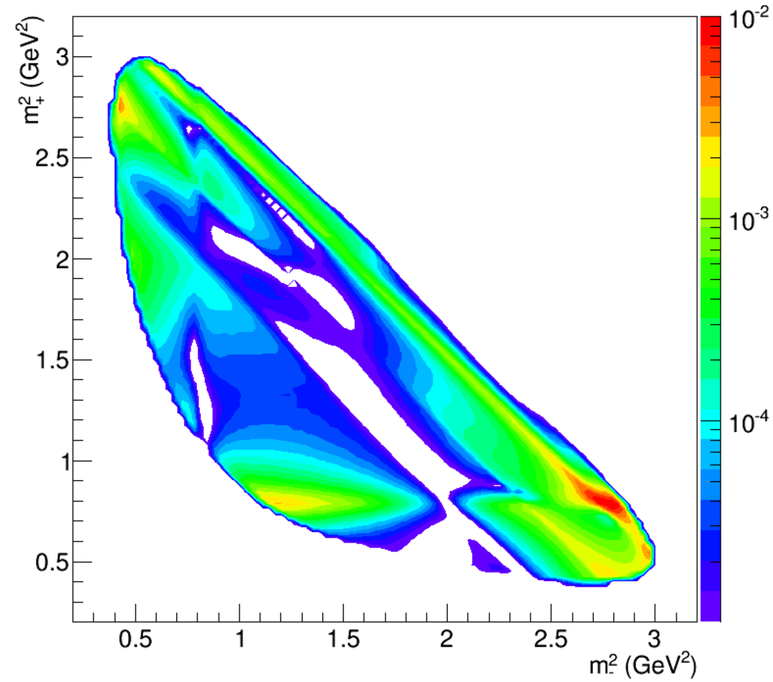


$+ \; r_B e^{-i(\delta+\gamma)}$



$|^2$

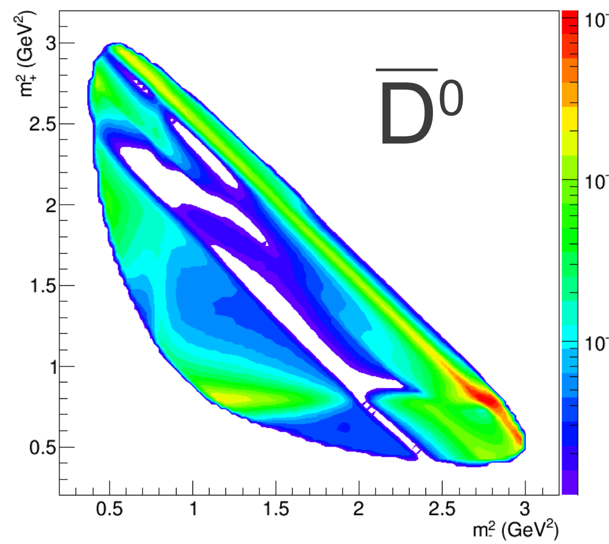
$=$



Distributions function of γ :

→ 2D fit to extract its value

Interference between $B^0 \to D^0 K^{*0}$ and $B^0 \to \overline{D}^0 K^{*0}$



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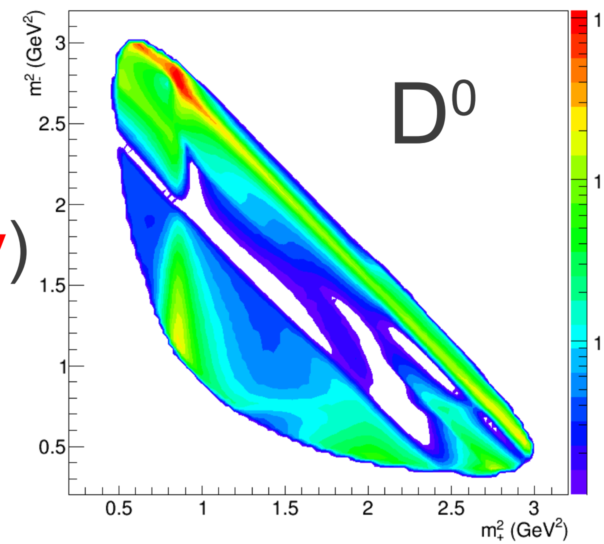
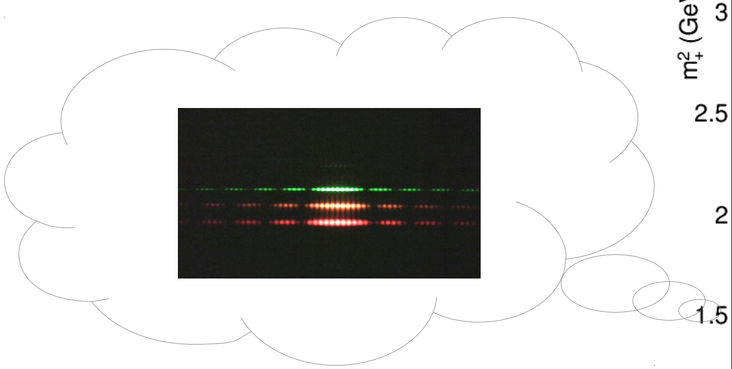
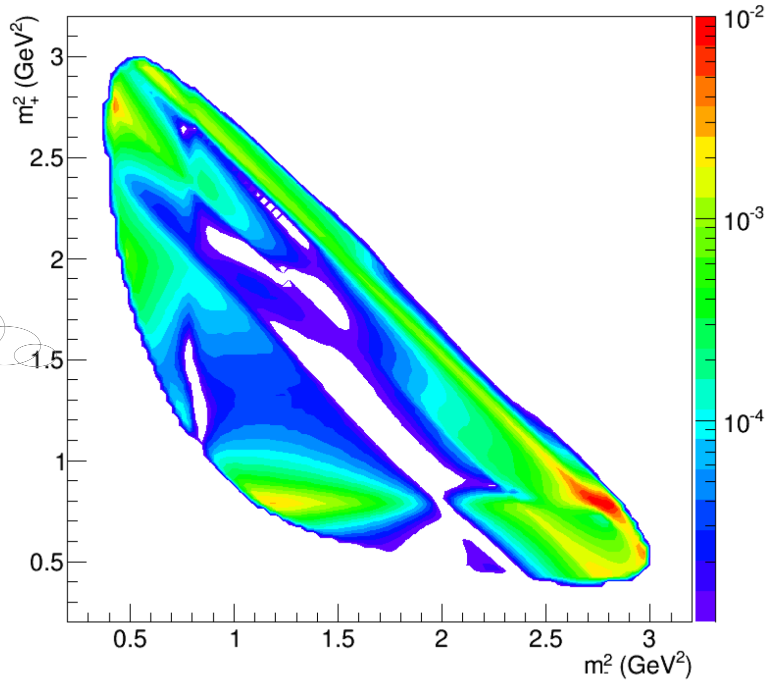


$\Big|\ \ldots\ \Big|^2$

=

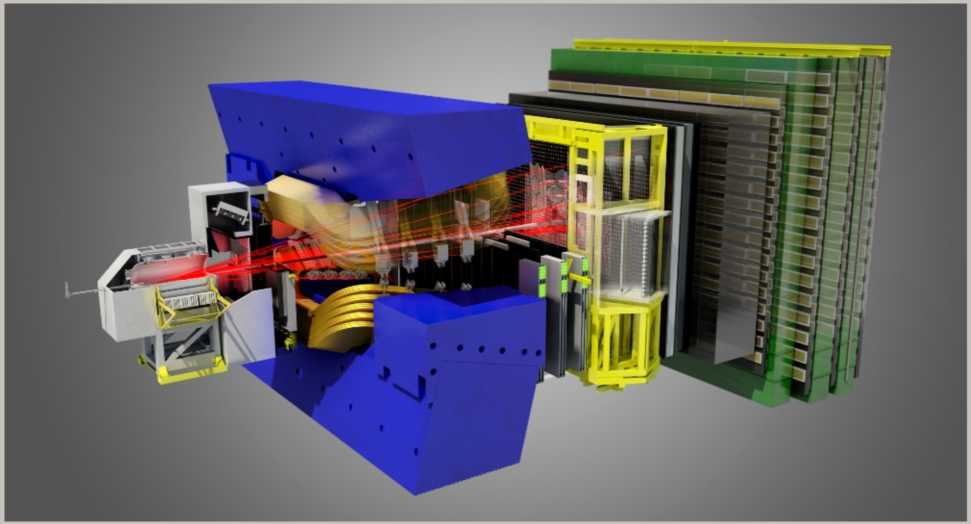




Distributions function of γ :

→ 2D fit to extract its value

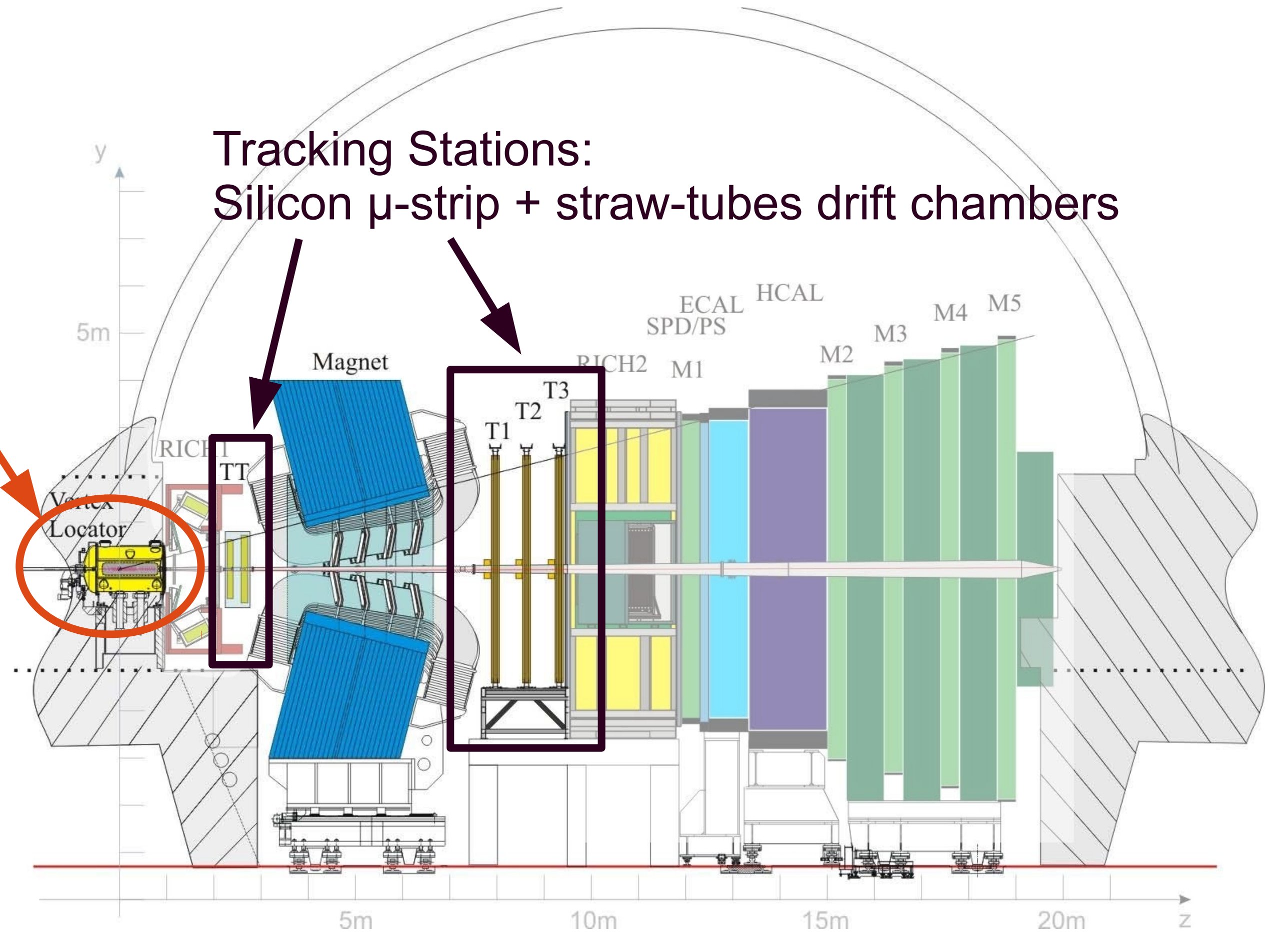
Tracking system of the LHCb detector



How do we measure particles trajectories ?

Vertex Locator:
Silicon µ-strip

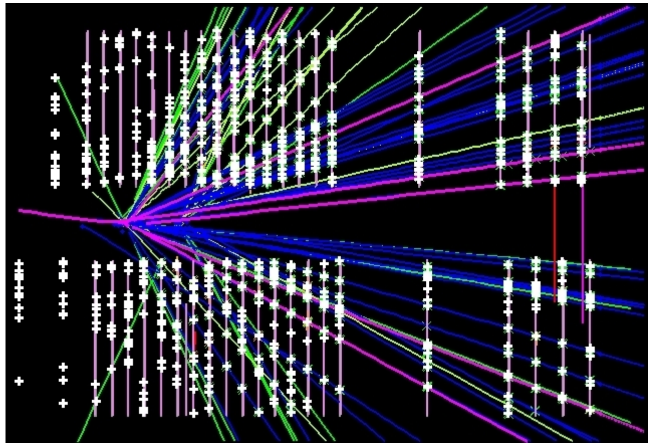
Tracking Stations:
Silicon µ-strip + straw-tubes drift chambers

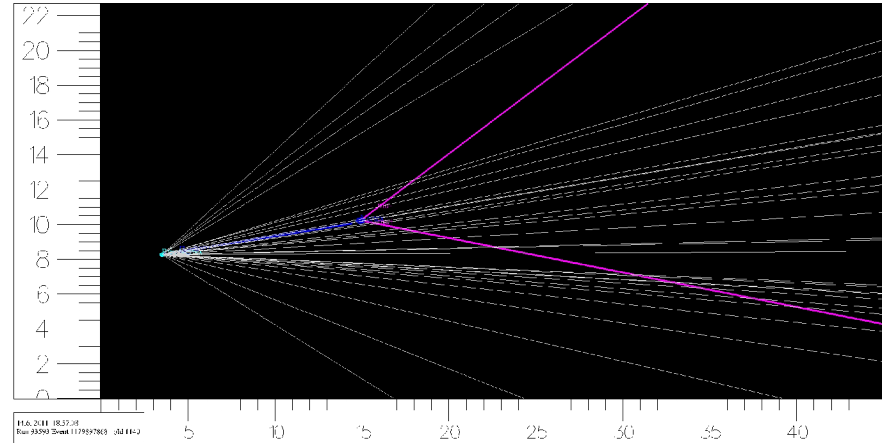


When a **charged particle** go through the µ-strips or the straw-tubes, it make a "**hit**".

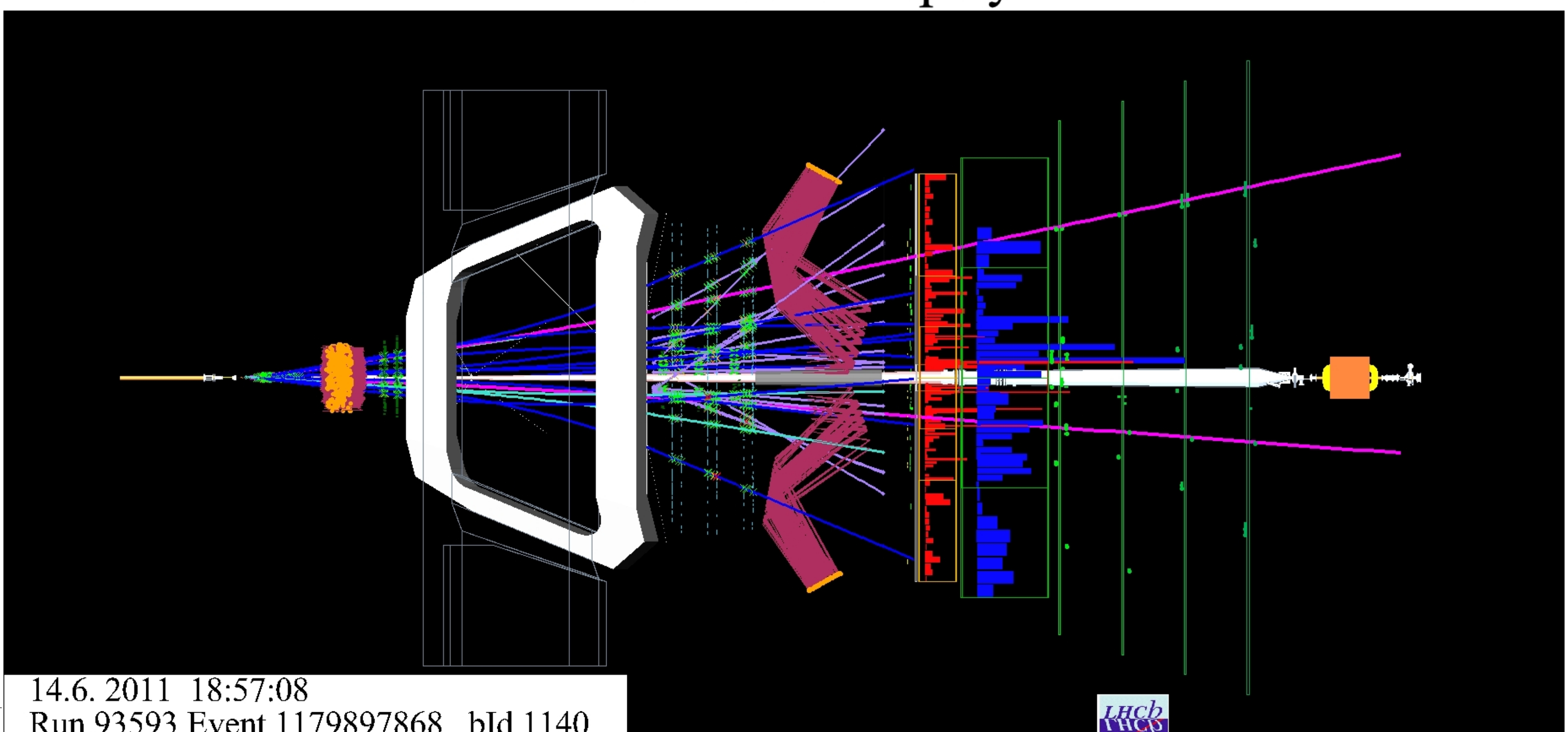
Hit Machine

In the Velo →

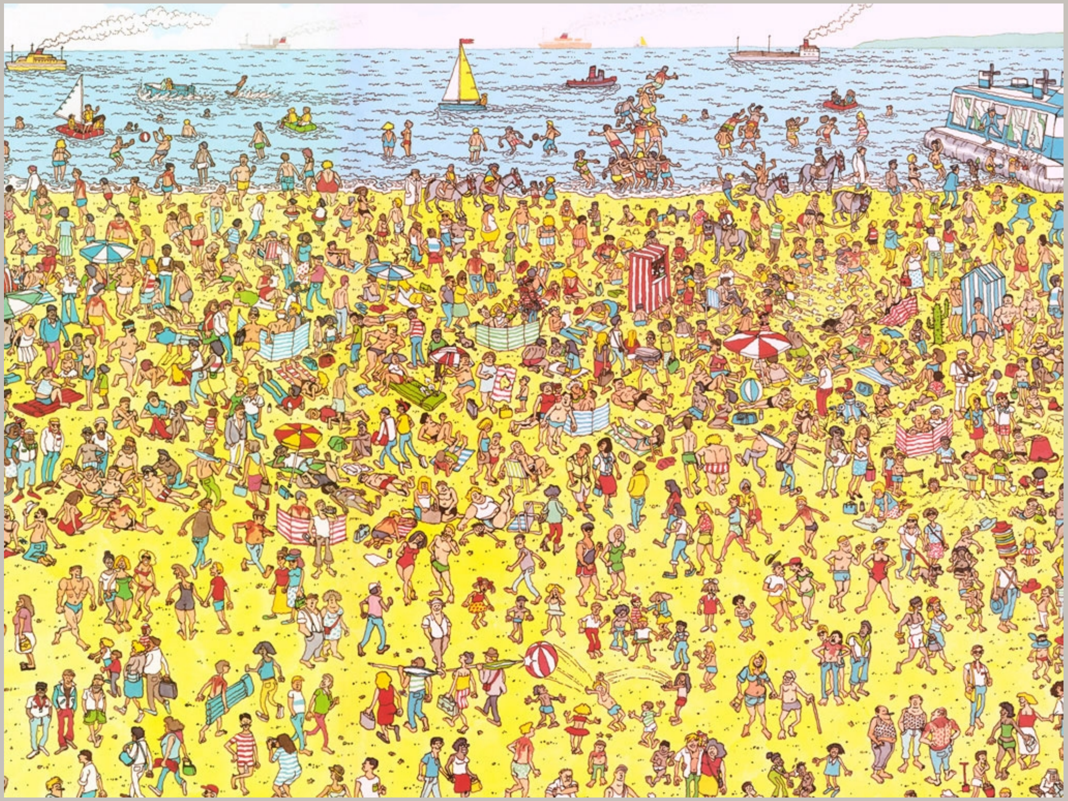




LHCb Event Display



$B^0 \to D(K^0_s\pi\pi)K^{*0}$ analysis



$B^0 \to D(K^0_s\pi\pi)K^{*0}$ analysis

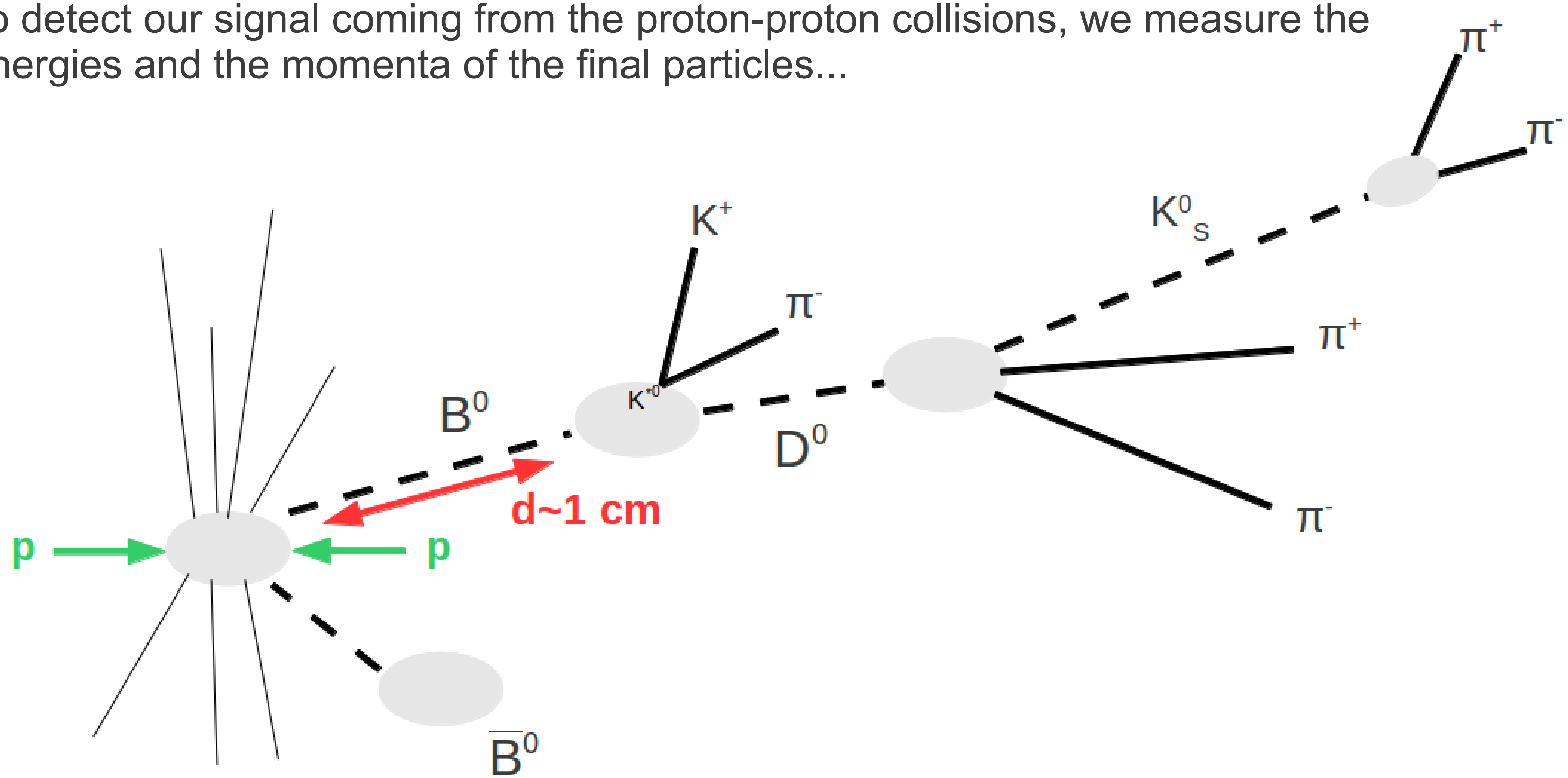
- Analysis strategy:
  - Signal selection
  - Background characterisation
  - 2D fit to estimate the γ value

Presented today

Handled in near futur

$B^0 \to D(K^0_s\pi\pi)K^{*0}$ topology

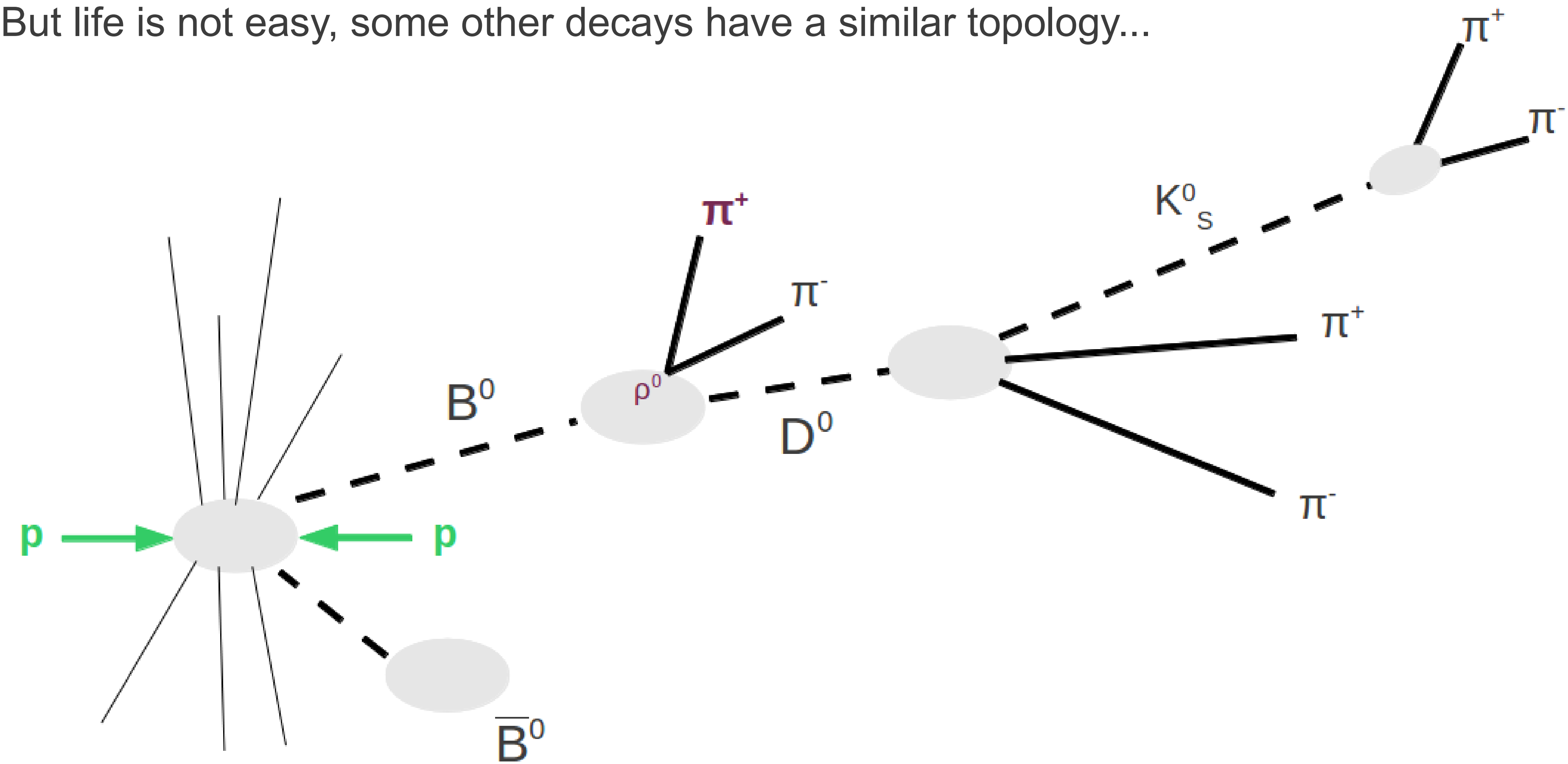
To detect our signal coming from the proton-proton collisions, we measure the energies and the momenta of the final particles...



… and reconstruct the B^0 invariant mass : $m_{B^0} = \sqrt{\left(\sum p_i\right)^2}$

$B^0 \to D(K^0_s\pi\pi)\rho^0$ background

But life is not easy, some other decays have a similar topology...

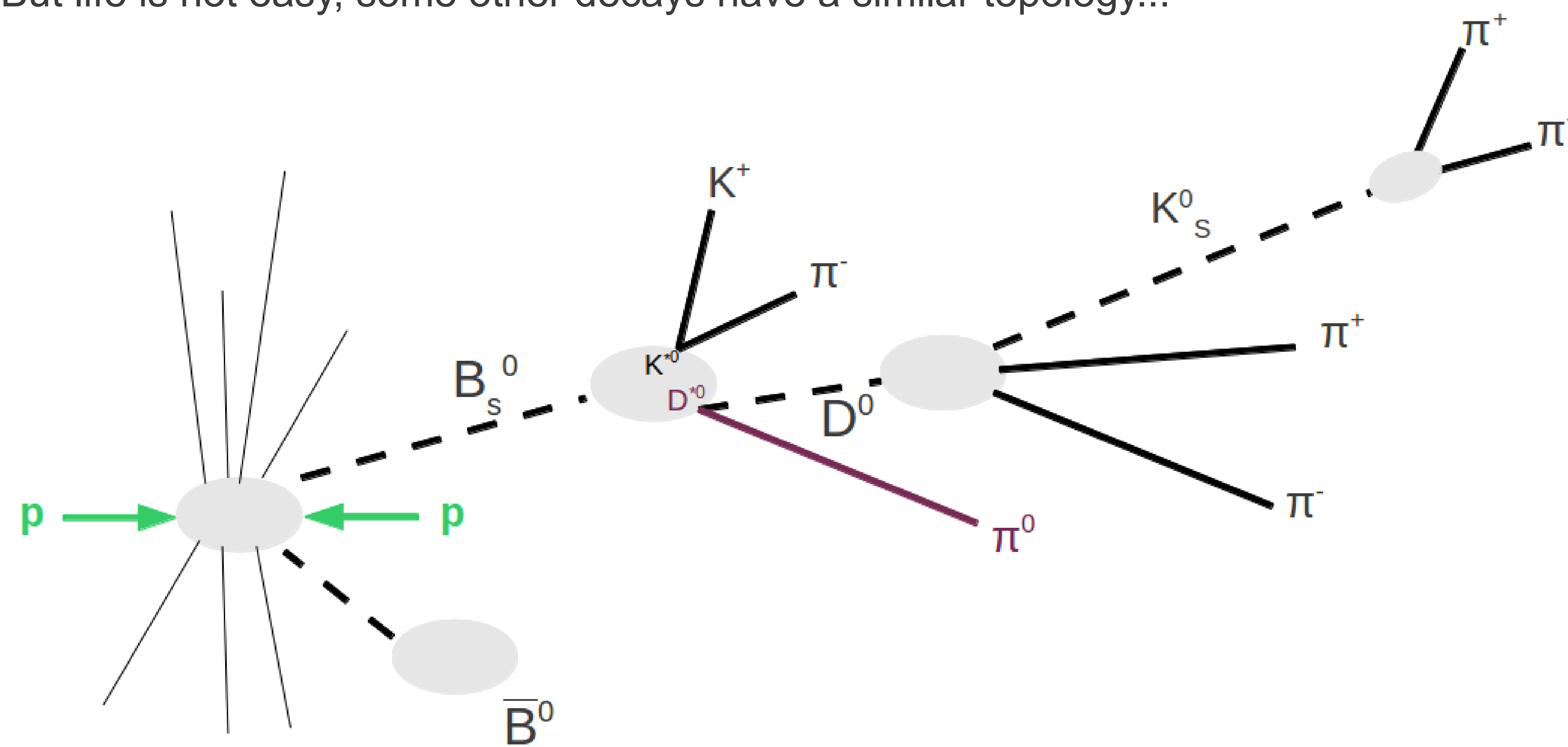


If we detect the **π⁺ as a K⁺**, we will think that the detected event is our $B^0 \to D(K^0_s\pi\pi)K^{*0}$ signal !

But the **reconstructed m(B^0)** will be a little bigger than the true B mass value: **K is heavier than π**

$B_{(s)}^0 \to D^*(D^0\pi^0)K^{*0}$ background

But life is not easy, some other decays have a similar topology...

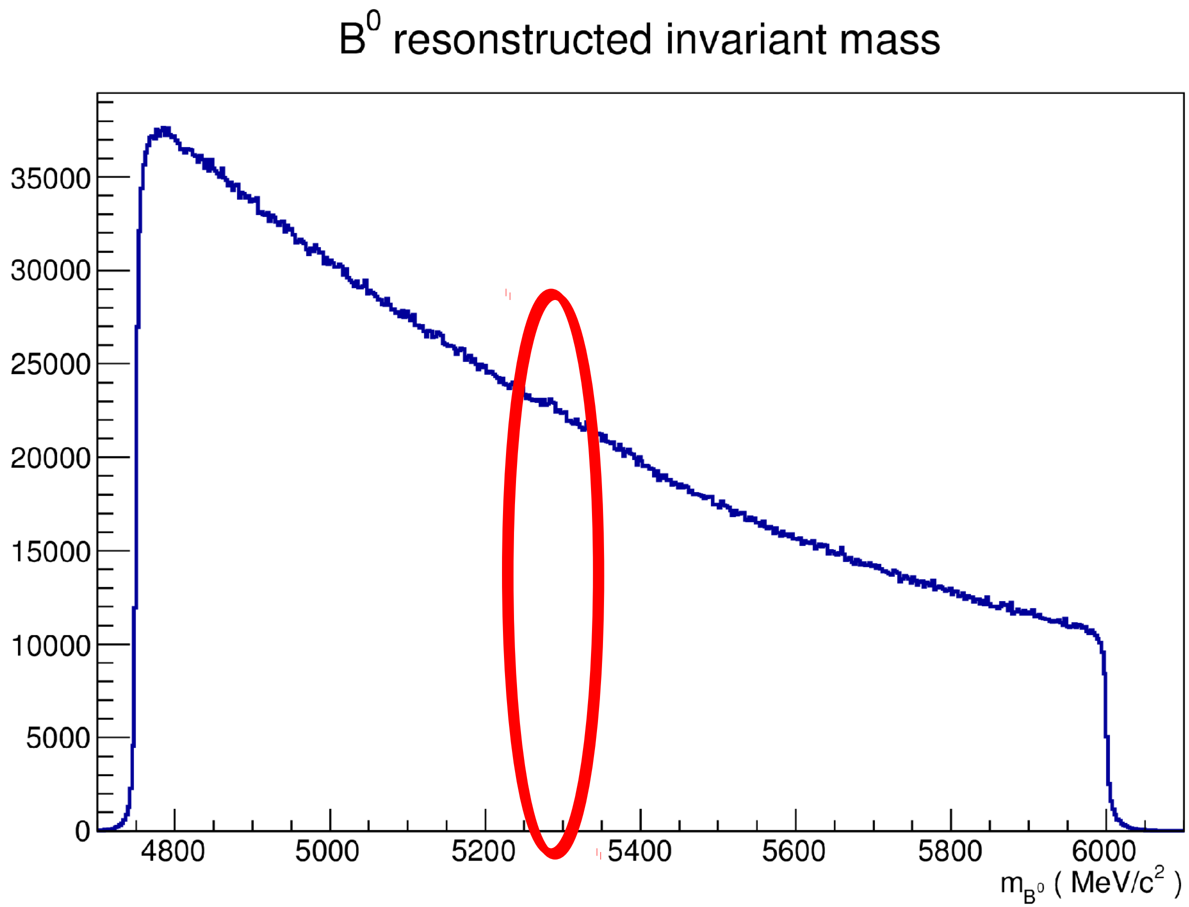


If we miss the **π^0**, we will think that the detected event is our $B^0 \to D(K^0_s\pi\pi)K^{*0}$ signal !

But the **reconstructed $m(B^0)$** will be smaller than the true B mass value: **some energy is missing**

Output of the pp collisions

Indeed, if we look at the reconstructed B mass obtained with the pp collisions at the LHC...

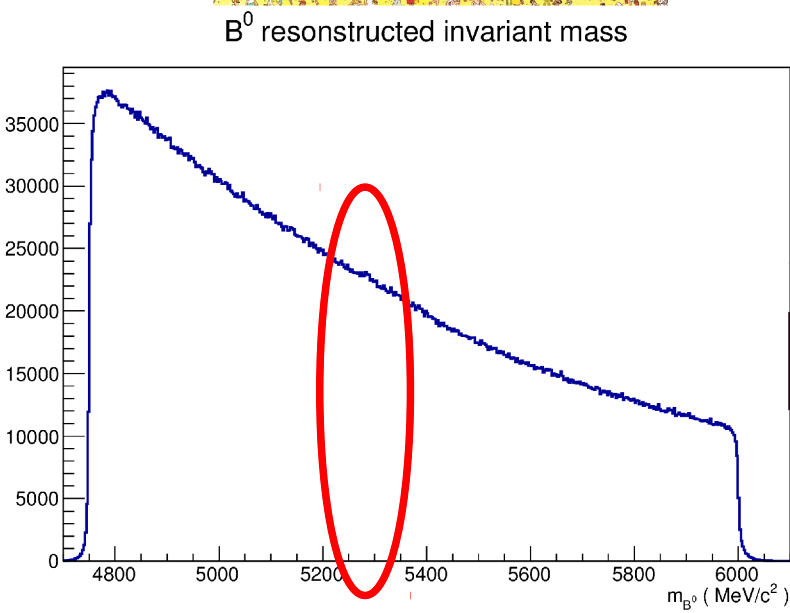


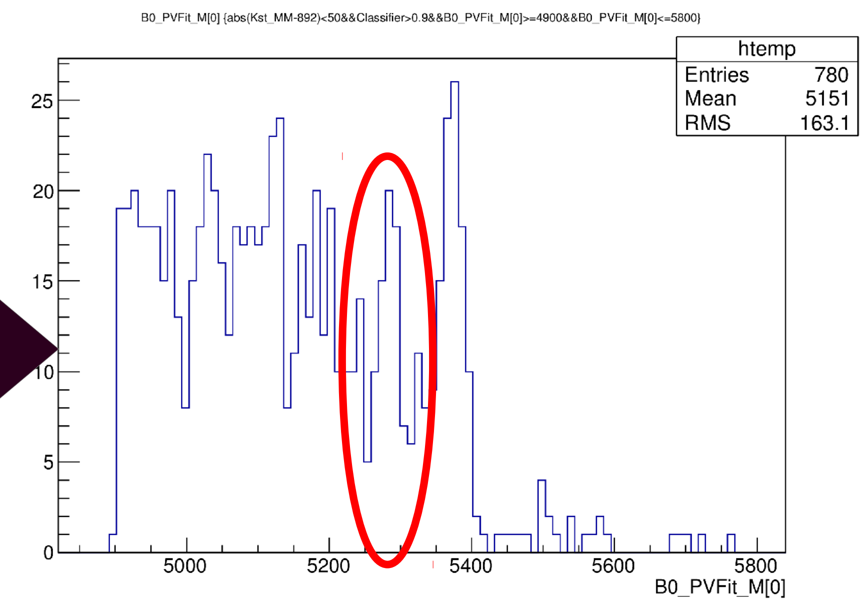
PDG:
m_{B0}=5279 MeV/c^2

…there is **A LOT OF** background ^^

Signal Selection

There is a lot of background, so we need to select our signal:





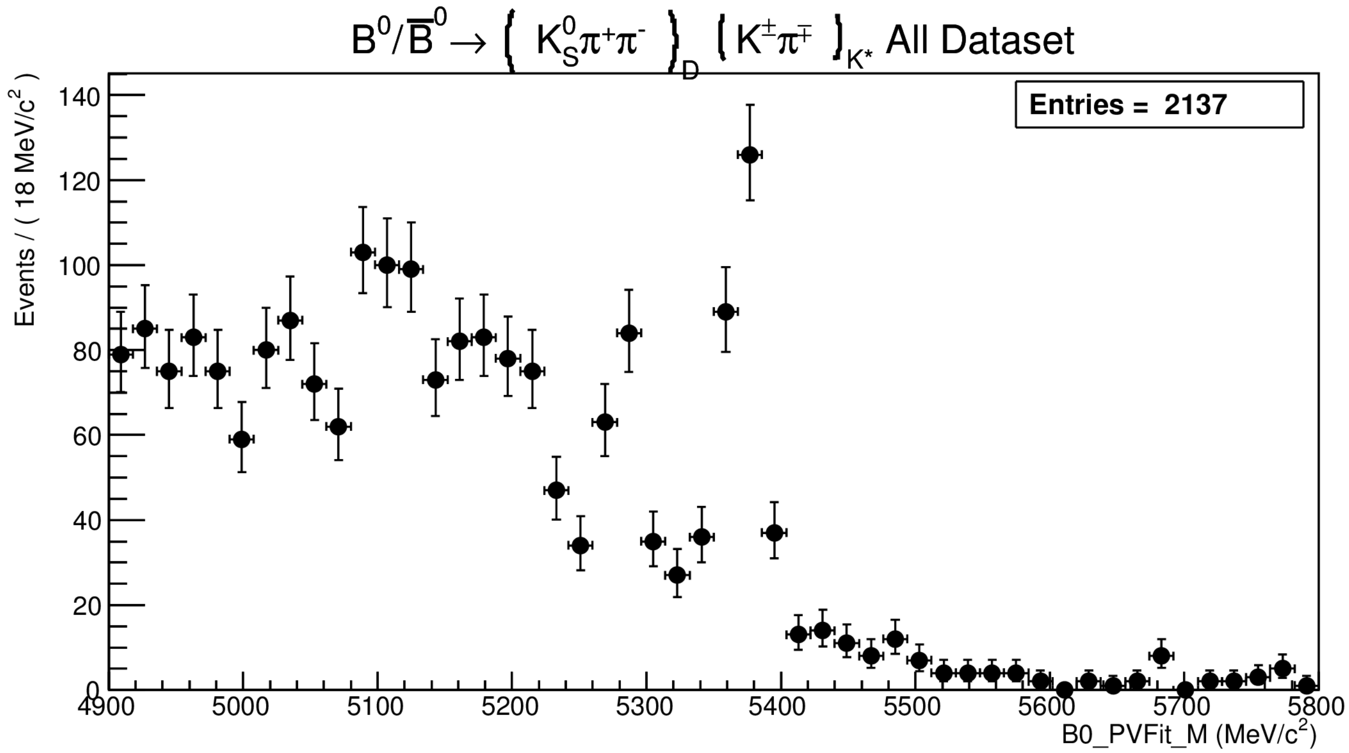
We reject some events which does not fulfill some criteria on:

- invariant masses
- transverse momenta
- flight distances
- vertex reconstruction quality

(Multivariate selection)

Estimation of numbers of events

To know the **numbers of signal and background events** it remains after the selection: Maximum Likelihood estimation (fit) of the m(B^0) distribution.



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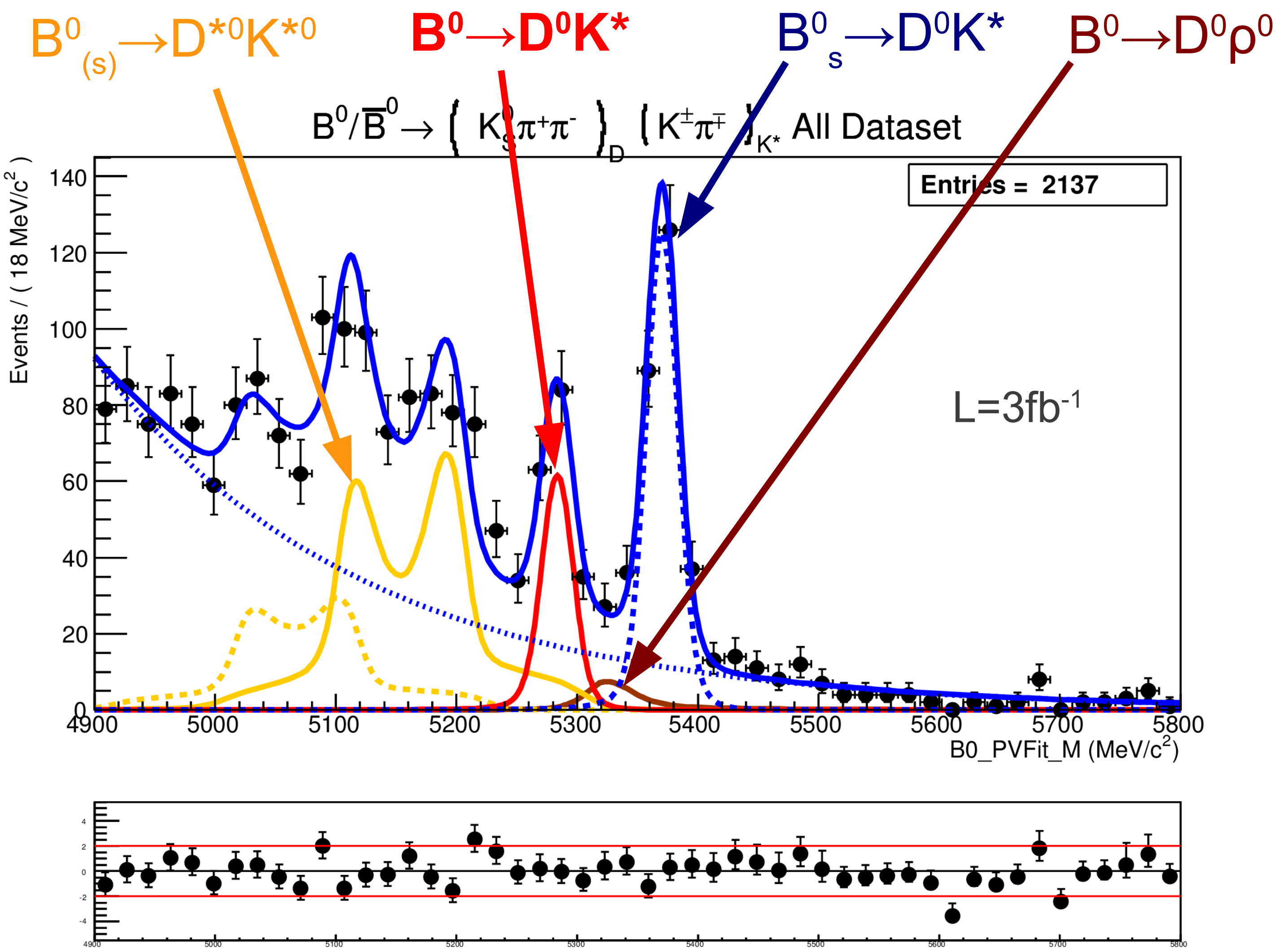
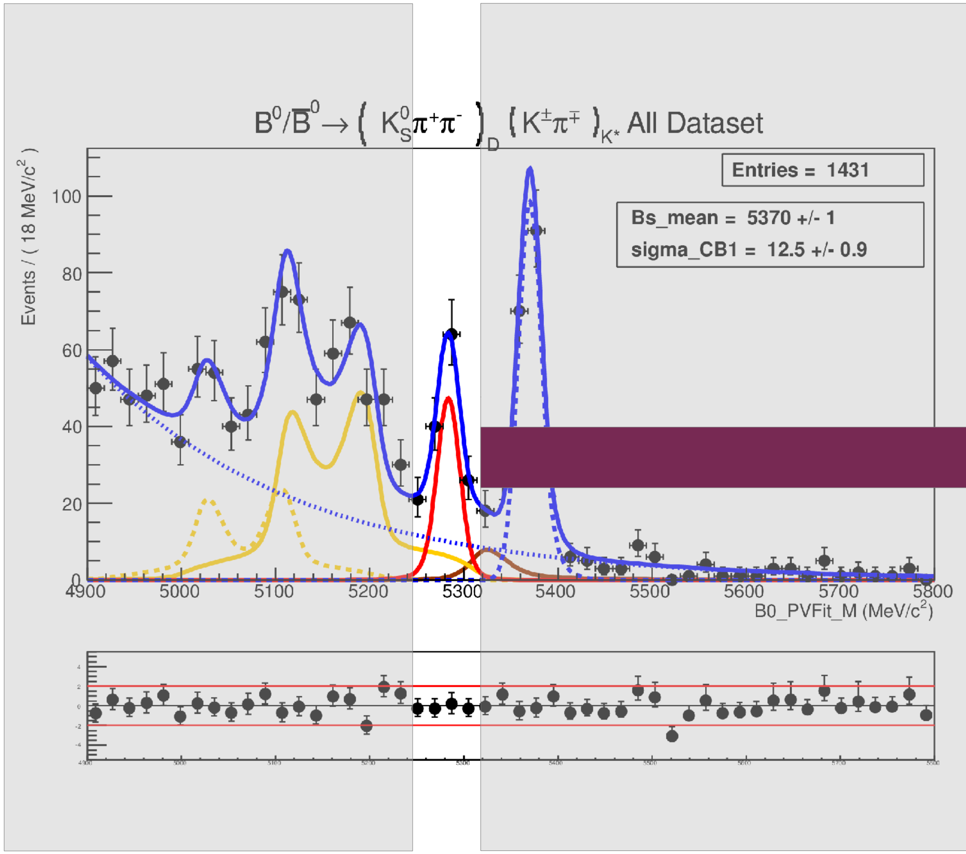
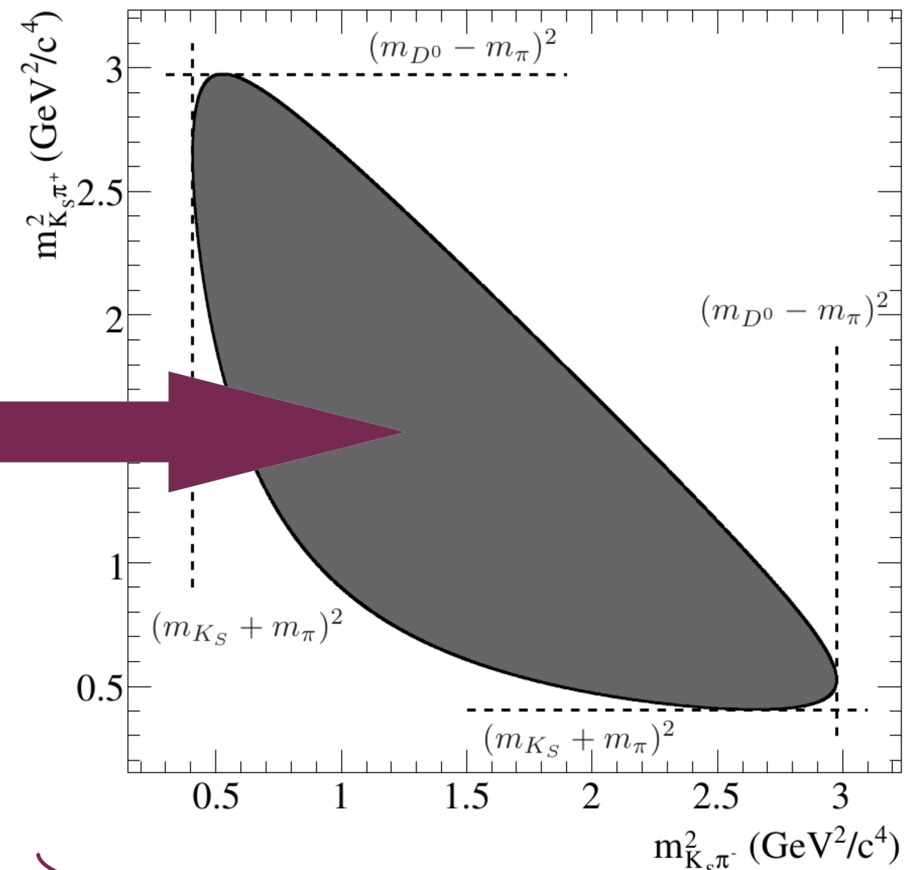


Nsig ≈ 80

Estimation of the γ value





1D fit of m(B^0) to know numbers of signal and backgrounds.

2D fit of (m^2_+, m^2_-) to estimate the value of γ

Just start working on it!

Conclusion

- The **quark flavour mixing** is described by the **CKM mechanism**.
- The **CKM angle γ** corresponds to the **phase difference between b→u and b→c** transitions.
- We will measure this phase difference with the **interference between $B^0 \to D^0(K^0_s\pi\pi)K^{*0}$ and $B^0 \to \overline{D}^0(K^0_s\pi\pi)K^{*0}$.**
- It will be the **first γ measurement with the neutral B**.

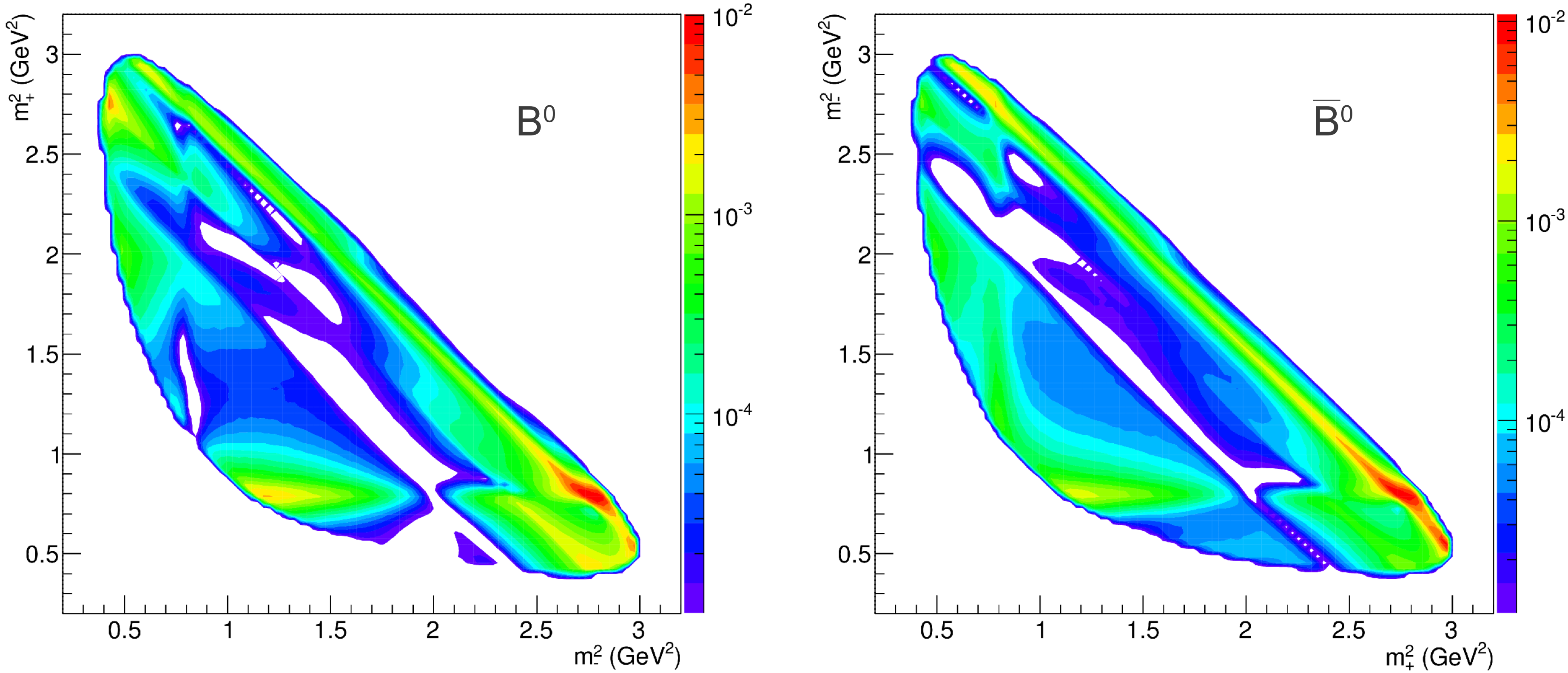
Quiz

- **Why the B^0 meson have the time to flight before decaying?**

BACKUP

$B^0 \to D(K^0_s\pi\pi)K^{*0}$ and $\bar{B}^0 \to D(K^0_s\pi\pi)\bar{K}^{*0}$ Dalitz plots

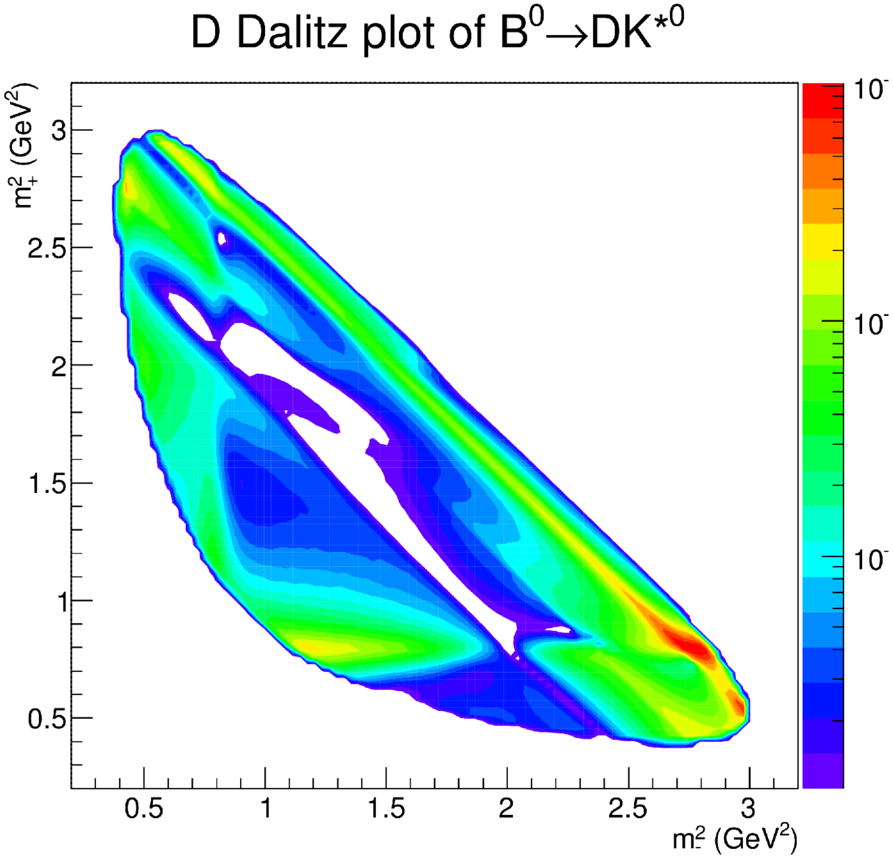
γ=68°

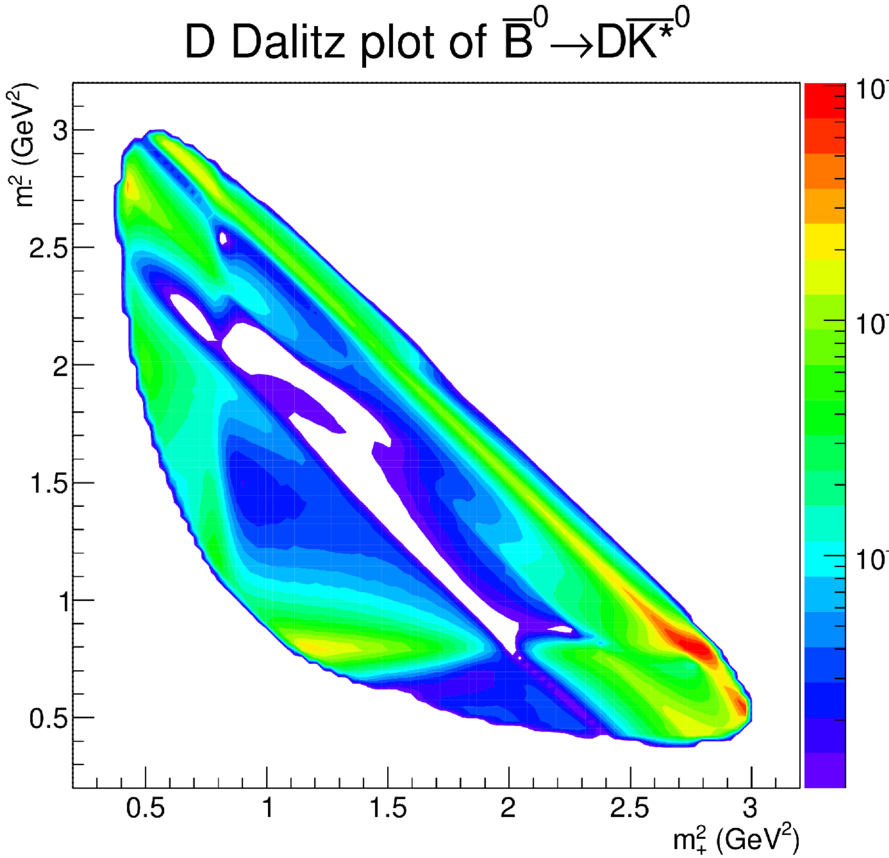


$$\mathcal{P}_{B^0/\bar{B}^0} \propto \left|A_D(m_\mp^2, m_\pm^2)\right|^2 + r_{B^0}^2\left|A_D(m_\pm^2, m_\mp^2)\right|^2 + 2\kappa r_{B^0}\mathcal{R}e\left[A_D(m_\pm^2, m_\mp^2)A_D^*(m_\mp^2, m_\pm^2)e^{-i(\delta_{B^0}\pm\gamma)}\right]$$

$B^0 \to D(K^0_s\pi\pi)K^{*0}$ and $\bar{B}^0 \to D(K^0_s\pi\pi)\bar{K}^{*0}$ Dalitz plots

γ=0°





$$\mathcal{P}_{B^0/\bar{B}^0} \propto \left|A_D(m^2_\mp, m^2_\pm)\right|^2 + r^2_{B^0}\left|A_D(m^2_\pm, m^2_\mp)\right|^2 + 2\kappa r_{B^0}\mathcal{R}e\left[A_D(m^2_\pm, m^2_\mp)A^*_D(m^2_\mp, m^2_\pm)e^{-i(\delta_{B^0}\pm\gamma)}\right]$$