Search for $B^0 \rightarrow \rho\gamma$ decay at LHCb

Giulio Gazzoni

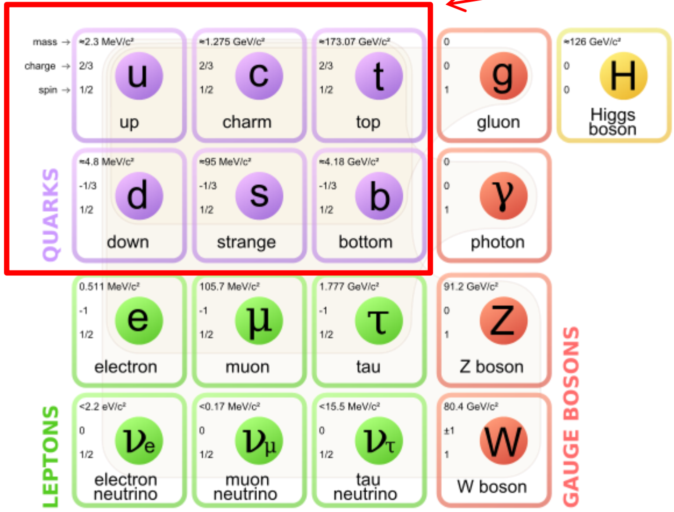
Université Blaise Pascal Clermont-Fd II - Laboratoire de Physique Corpusculaire

8th December 2016

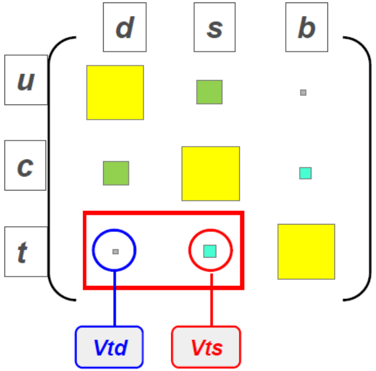
Journées de Rencontres Jeunes Chercheurs 2016

The Standard Model and the CKM Matrix

- The Standard Model (SM) has been successfully confirmed through four decades but still numerous open questions remain to justify the search for New Physics (NP).



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

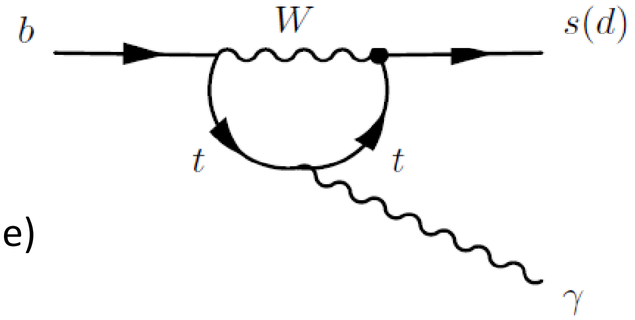


- The Cabibbo-Kobayashi-Maskawa matrix describes the couplings between the up and down-type quarks.

- Quarks form composite objects named hadrons: mesons ($q\bar{q}$) and baryons (qqq).

Introduction and experimental status

- The radiative $B^0 \to \rho\gamma$ decay is a rare decay which corresponds at quark level to a $b \to d\gamma$ transition occurring via Flavour Changing Neutral Current. This transition appear through electroweak penguin diagrams.

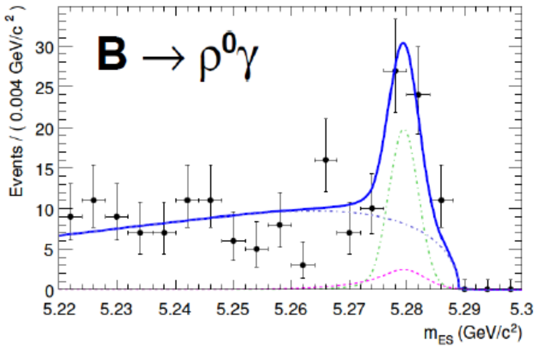


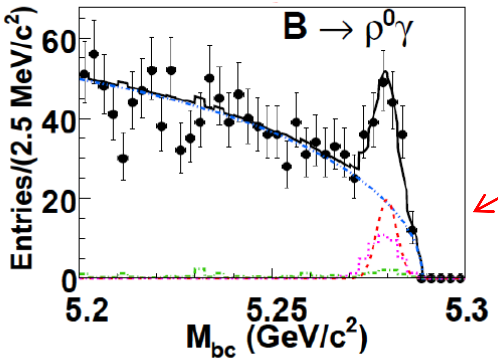
- The branching fraction is:

$$\mathcal{B}(B^0 \to \rho\gamma) = (8.6 \pm 1.5) \cdot 10^{-7}$$

(PDG value)

- This decay has already been observed at BaBar and Belle experiments, but not yet at LHCb.

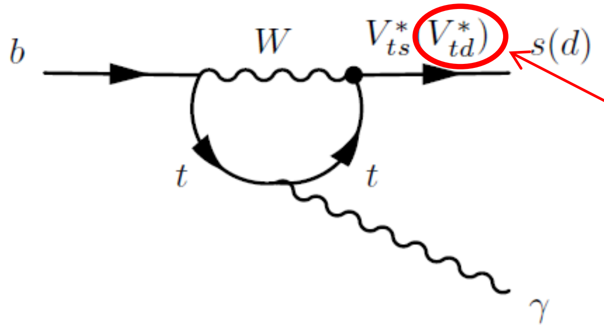


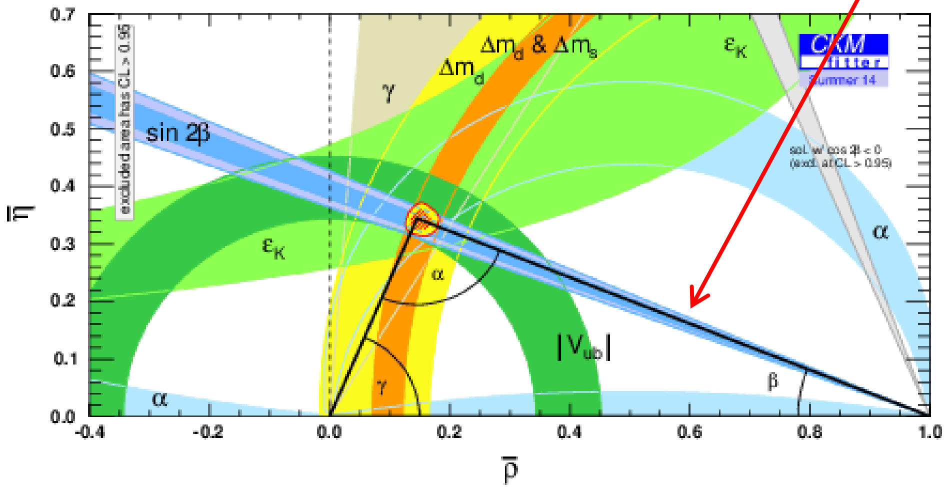


Motivation for the measurement (1)

- This decay provides a way to extract the value of the V_{td} element of the CKM matrix, thus allowing to constrain the unitarity triangle:

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

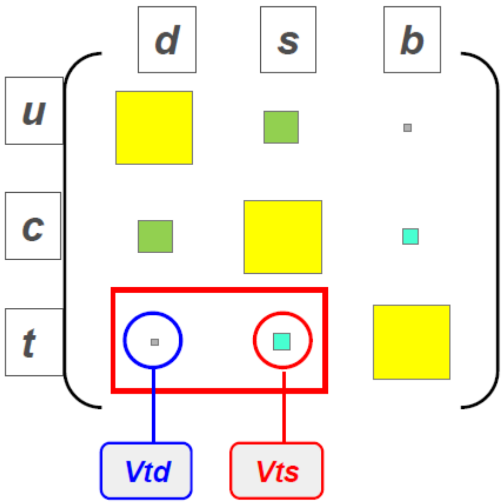


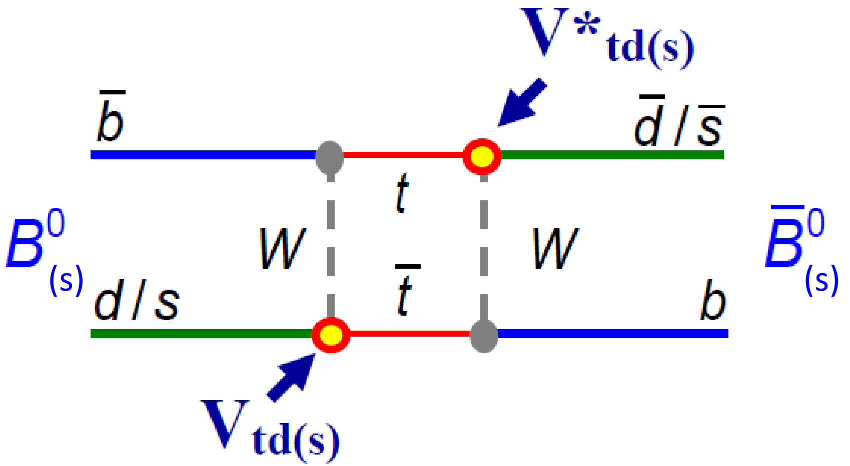


- By measuring $\dfrac{\mathcal{B}(B^0 \to \rho\gamma)}{\mathcal{B}(B^0 \to K^*\gamma)} \propto \left|\dfrac{V_{td}}{V_{ts}}\right|^2$ we can extract the ratio $|V_{td}/V_{ts}|$ as a very interesting test of the SM.

Motivation for the measurement (2)

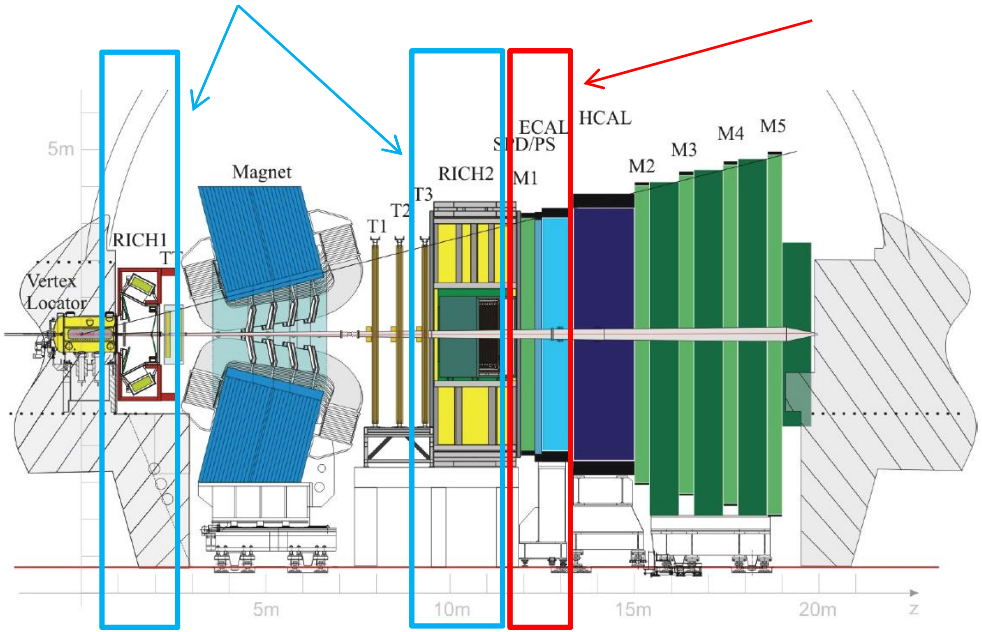
- In particular we can compare the result with those ones arising from the measurement of the oscillation frequencies of $B^0 - \overline{B}^0$ and $B_s^0 - \overline{B}_s^0$ systems.





- This type of measurement, together with the study of $b \to d\gamma$ transitions, is the only way to extract the ratio $|V_{td}/V_{ts}|$.

The LHCb detector at the LHC



The LHCb detector is a single-arm spectrometer with a forward geometry composed by:

- **Tracking System:**
  VELO, Trigger Tracker, Dipole Magnet and 3 Tracking Stations.

- **Particle Identification System:**
  RICH1, RICH2, ECAL, HCAL and Muon Stations (M1-M5).

- The measured cross section for $b\bar{b}$ pairs at $\sqrt{s} = 7\text{TeV}$ and the number of produced pairs for an integrated luminosity of $\mathcal{L} = 3\ \text{fb}^{-1}$ are

$$\sigma(pp \to b\bar{b}X)_{4\pi} = (284 \pm 20 \pm 49)\ \mu\text{b}$$ and $$\boxed{N_{b\bar{b}} = \mathcal{L} \cdot \sigma_{b\bar{b}} \simeq 9.4 \times 10^{11}}$$

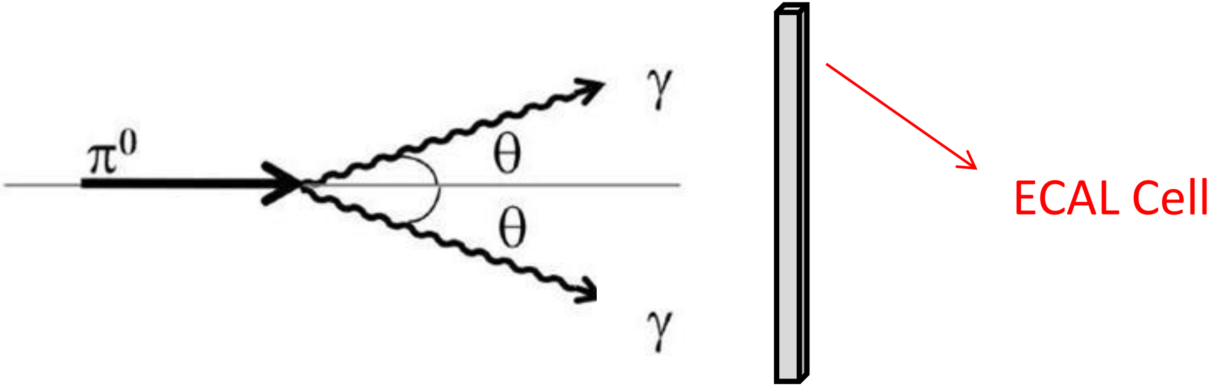
Experimental scenario and issues

- Experimentally we look for this final state:

$$B^0 \rightarrow \rho\gamma \rightarrow (\pi^+\pi^-)\gamma$$

This is something very challenging at LHCb.

- The π^0/γ separation is a crucial point since LHCb has not been specifically designed to accomplish it.



- We have to set up a thorough selection in order to reduce and control the potentially very large background contamination. The analysis is conducted blindly and we can benefit of a nice $B^0 \rightarrow K^*\gamma$ control sample.

A world of backgrounds

- Combinatorial background: one random particle in the decay chain.

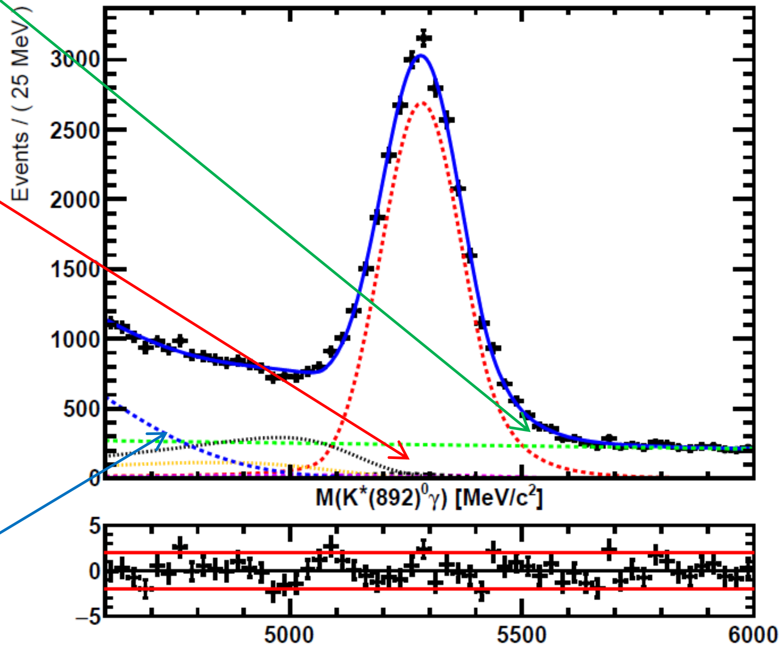
  $\longrightarrow$ MVA

- Peaking backgrounds: other decays peaking under the signal peak (the most dangerous ones).
  - $h^+h'^-\gamma$ decays for which at least one track is misidentified as a pion [$K^*(K\pi)\gamma$, $\Lambda^*(pK)\gamma$]
  - $h^+h'^-\pi^0$ decays for which a high p_T π^0 is misidentified as a photon [$K^+\pi^-\pi^0$, $\pi^+\pi^-\pi^0$]

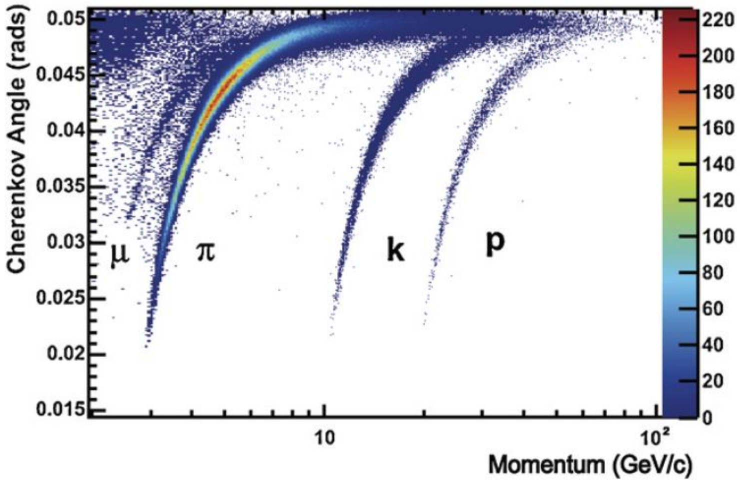
  $\longrightarrow$ Charged and neutral PID cuts

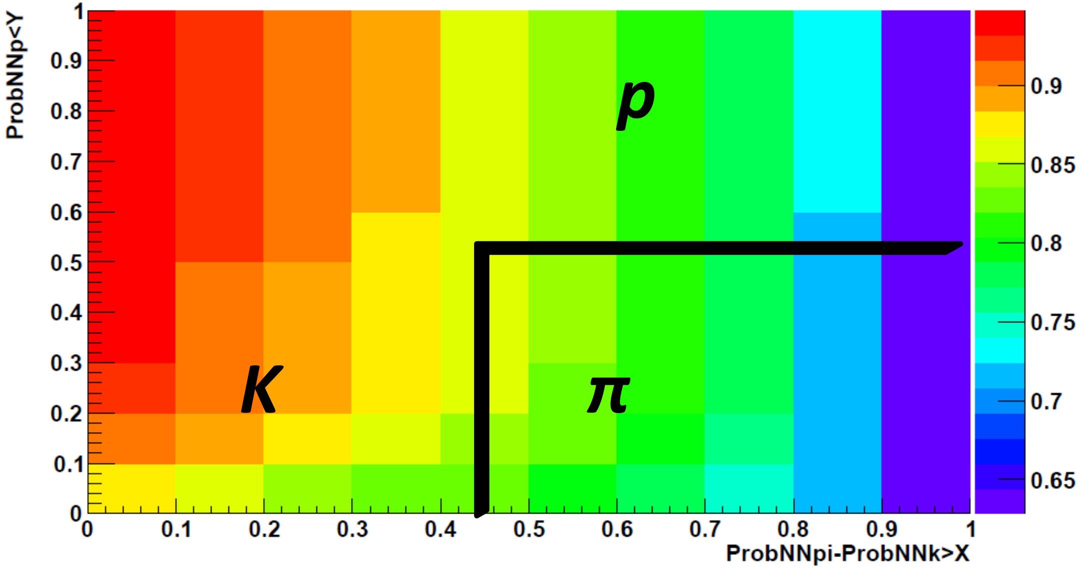
- Partially reconstructed backgrounds: one or more particles missing/misidentified.

  $\longrightarrow$ Charged PID cuts + MVA



Charged tracks PID

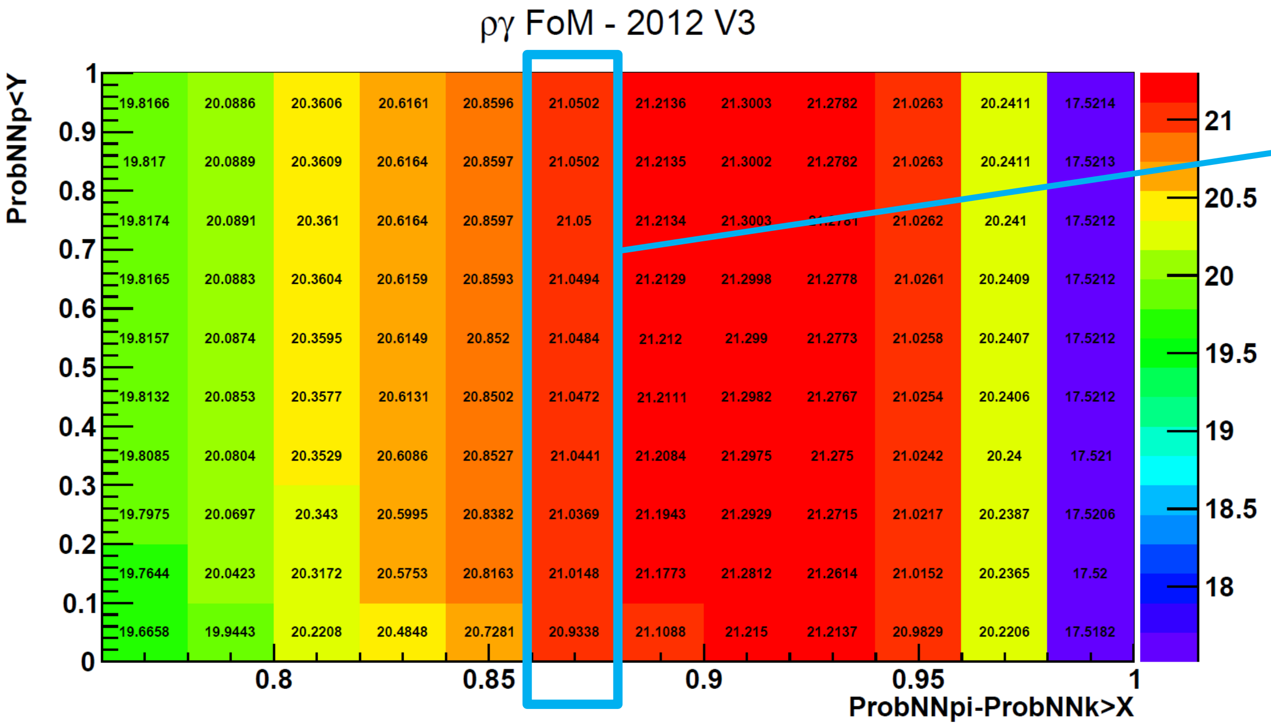




- In order to reduce the peaking backgrounds contamination and having mutually exclusive events in each spectrum we opted for a bi-dimensional cut in the (ProbNNpi-ProbNNk, ProbNNp) plane.

- The goal of this approach is to improve the performances of the simultaneous fit to the $B^0 \to \rho\gamma$ and $B^0 \to K^*\gamma$ spectra.

Optimal cut to select pions



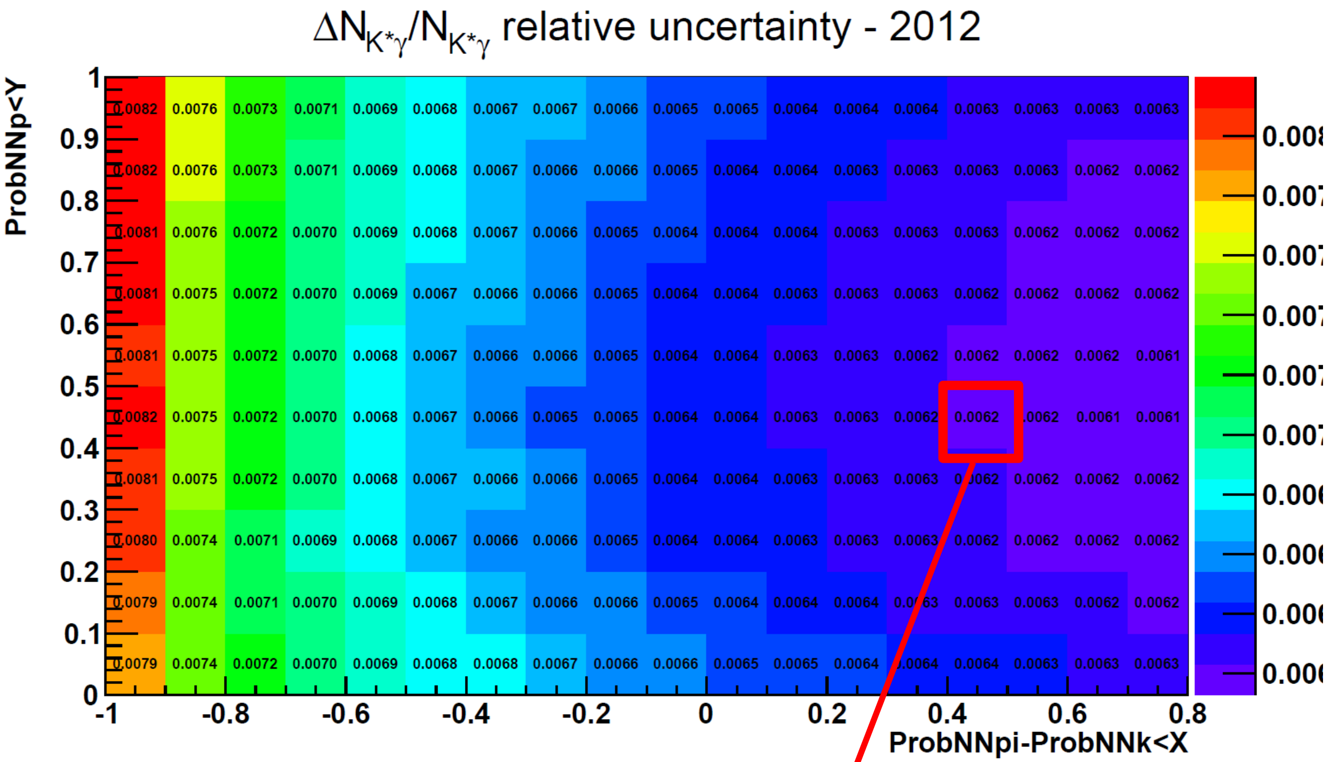
- This region corresponds to ~610 ργ events (2012 only) selected with a 67% efficiency and to an intrinsic contamination of ~220 $K^{*}\gamma$.

- The figure of merit used in the optimization is $S/\sqrt{S+B_i}$ where $B_i =$

$$K^{*}(K\pi)\gamma\,,\ \phi(KK)\gamma\,,\ \Lambda^{*}(pK)\gamma$$

- We fix as optimal value to select pions ProbNNpi-ProbNNK > 0,86.

Optimal cut to select kaons and reject protons



- To optimize the remaining cuts we minimize the relative uncertainty on the $K^*\gamma$ yields.

- $$\Delta N_{K^*\gamma} = \sqrt{\sum_i \Delta N_i^2}$$

  with N_i =

  $$N_T, N_{\rho\gamma}, N_{\phi\gamma}, N_{\Lambda^*\gamma}$$

- We fix as optimal value to select kaons ProbNNpi-ProbNNK < 0,5. In order to reject protons we choose ProbNNp < 0,5.

Towards the MVA classification: Data-MC matching

- We use the $B^0 \rightarrow K^*\gamma$ control channel to check which variables are well reproduced by the MC, only those ones will be used in the TMVA classification.

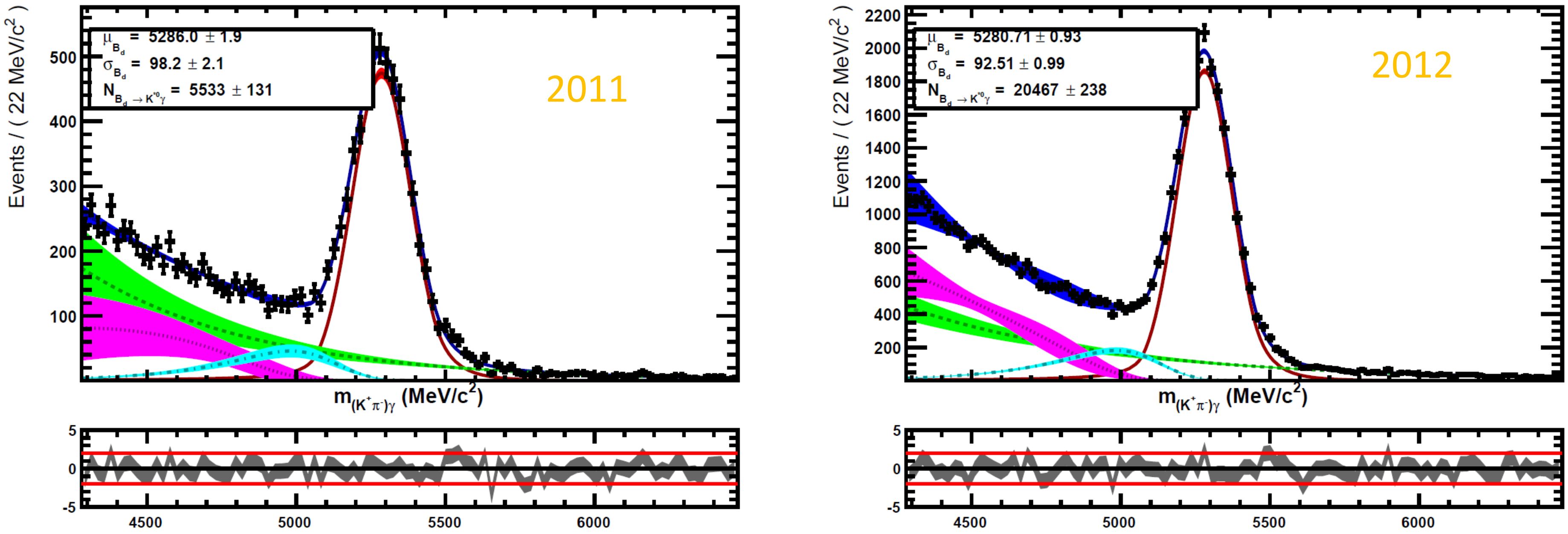
- A cut based approach is used here to select $B^0 \rightarrow K^*\gamma$ events.

- The simulation is then compared to the background subtracted $B^0 \rightarrow K^*\gamma$ data sample.

- The background is statistically subtracted fitting the reconstructed B mass spectrum and applying the *sPlot* technique.

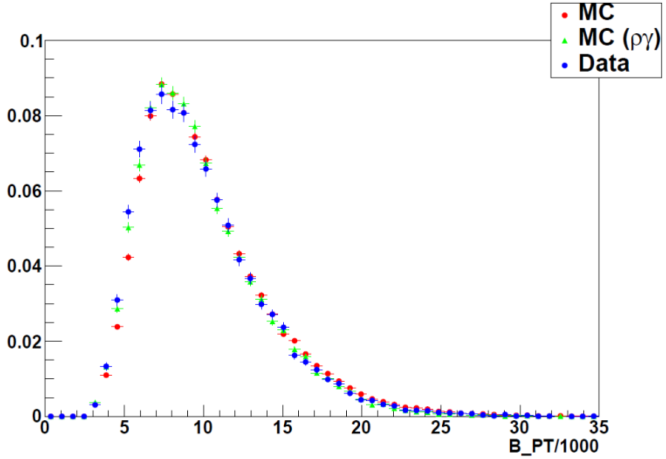
[Nucl. Instrum. Meth. A555, 356-369 (2005)]

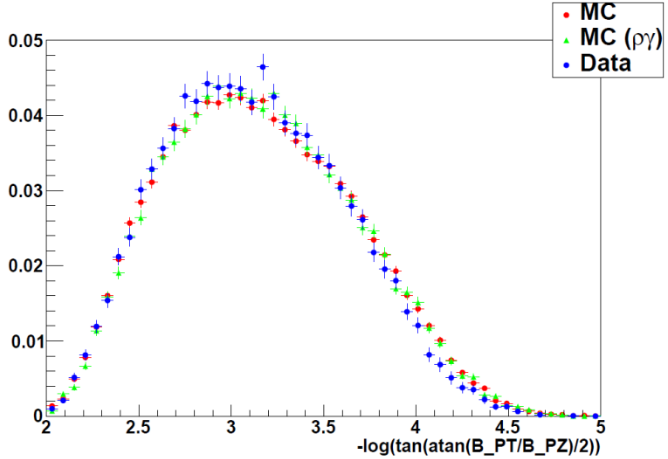
Mass fits

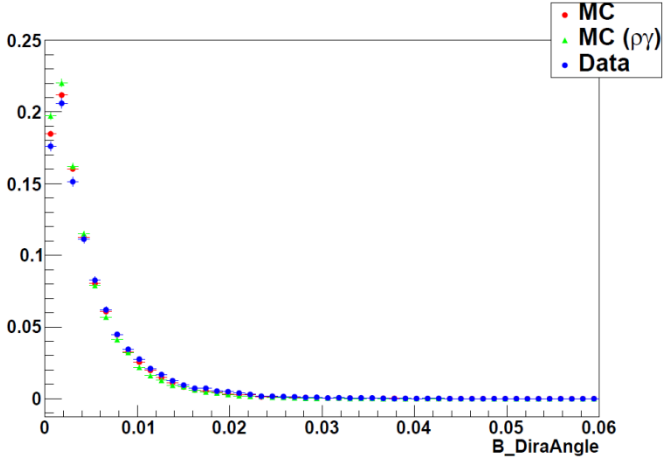


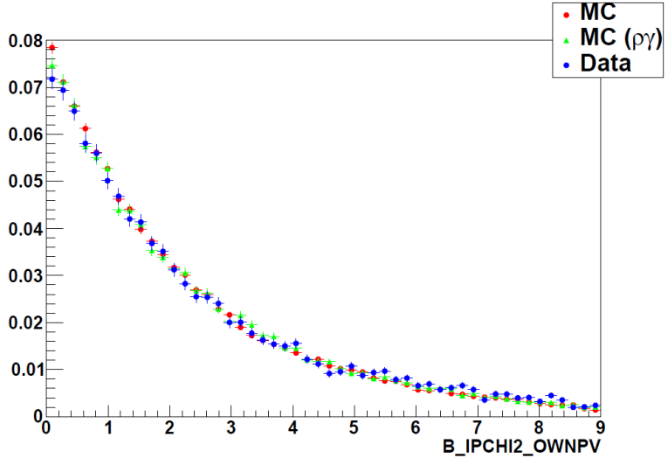
- With Run 1 data (3 fb^{-1}) we can count on ~26k $K^*\gamma$ signal events.

MC matching: good variables

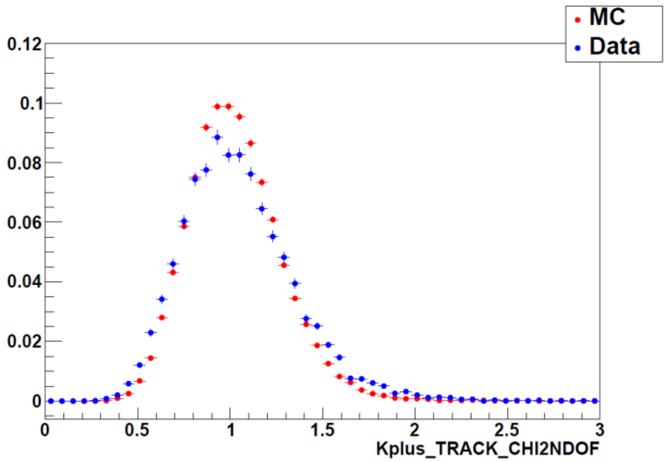


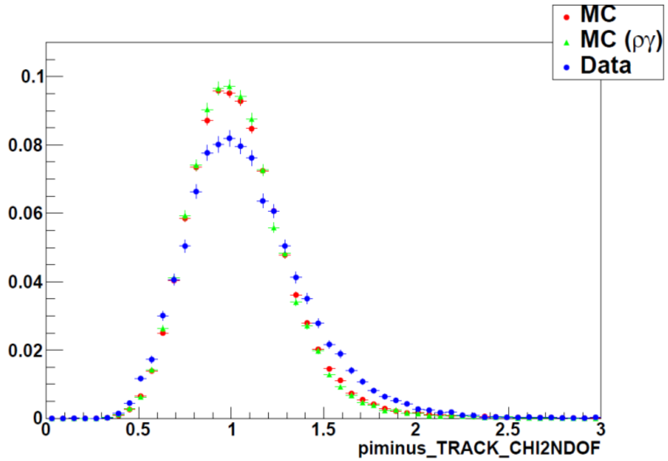


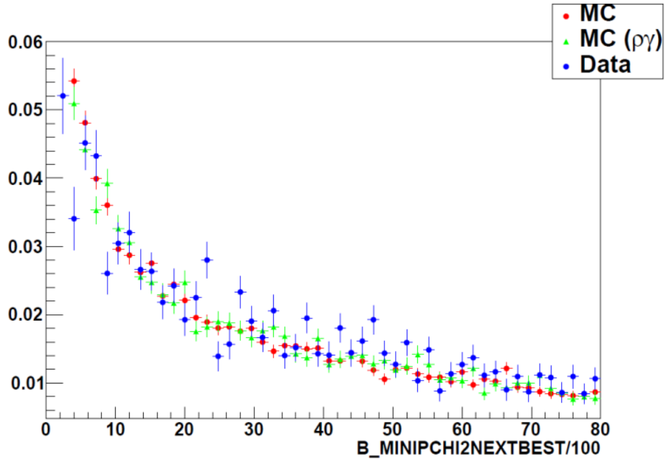




MC matching: poorly modeled variables







Variables used in the classification

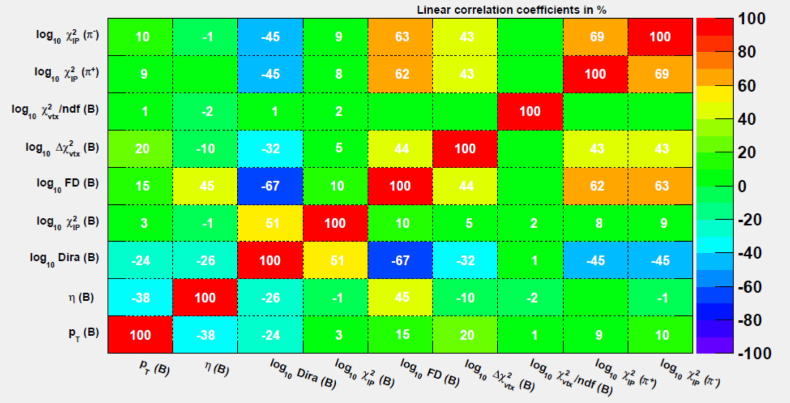
- Then we come to the final set of variables that maximizes the rejection of combinatorial background:

B transverse momentum - $p_T(B)$
B pseudorapidity - $\eta(B)$
B direction angle - log_{10} (B_{DIRA})
B impact parameter chi2 - log_{10} ($\chi^2_{IP}(B)$)
B flight distance - log_{10} (B_{FD})
B vertex isolation - log_{10} (Smallest $\Delta\chi^2_{VTX}(B)$)
B vertex chi2 - log_{10} ($\chi^2_{VTX}/\mathrm{ndf}\ (B)$)
Track 1 impact parameter chi2 - log_{10} ($\chi^2_{IP}(\pi^+)$)
Track 2 impact parameter chi2 - log_{10} ($\chi^2_{IP}(\pi^-)$)

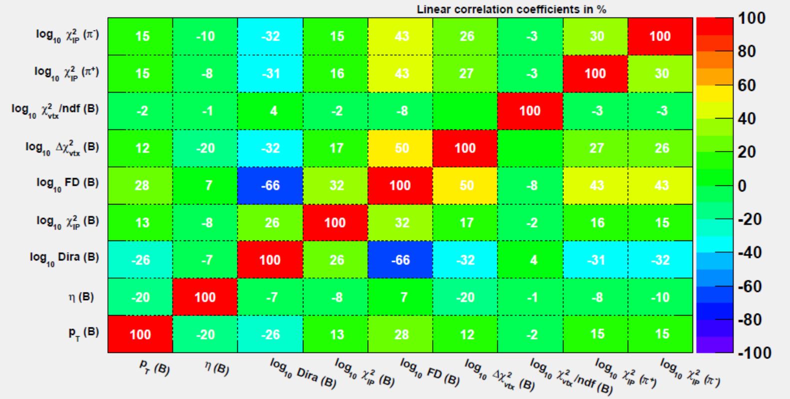
- In the classification training all the events passing some pre-selection requirements (not specified here) for both signal (MC) and background (Data in the high mass sideband region) are used.

Correlation matrices and performance curves (2012)

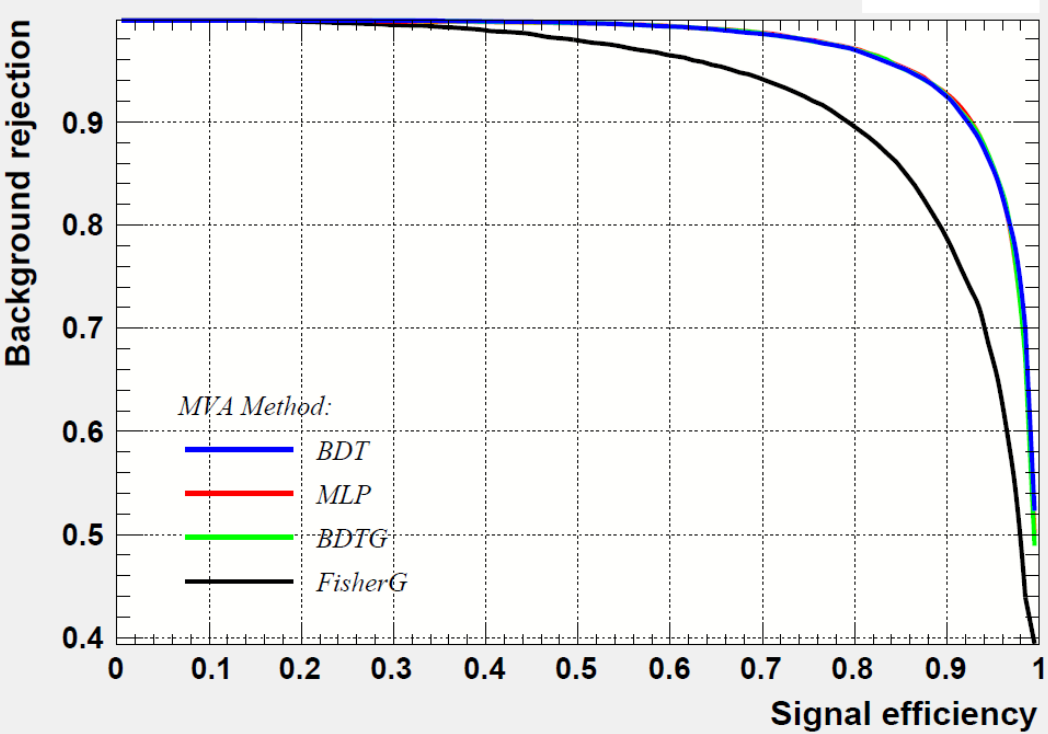
Correlation Matrix (signal)



Correlation Matrix (background)



Background rejection versus Signal efficiency



Summary

- Measurement of the ratio $\frac{\mathcal{B}(B^0 \to \rho\gamma)}{\mathcal{B}(B^0 \to K^*\gamma)}$ in order to extract the ratio $|V_{td}/V_{ts}|$ of the CKM matrix elements. The analysis is performed blindly and by exploiting $B^0 \to K^*\gamma$ as control channel.

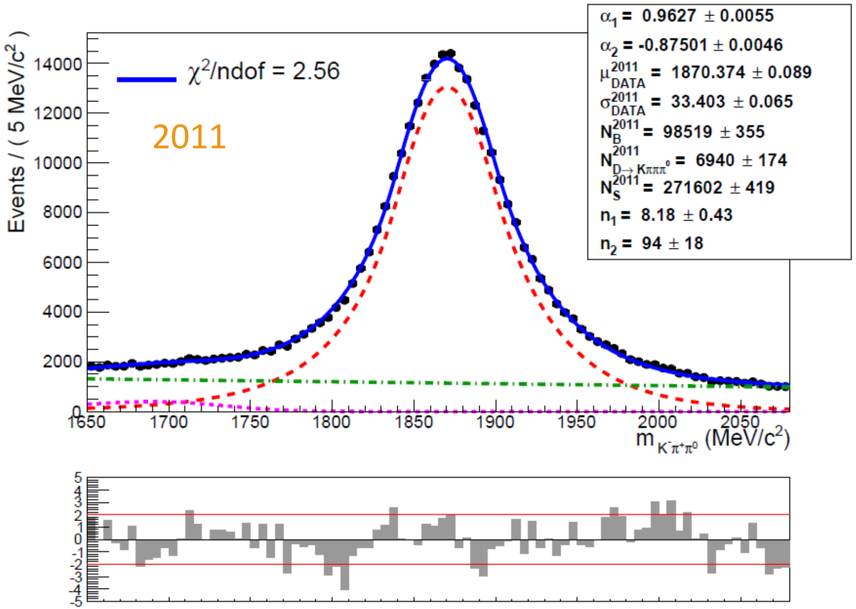
- The main difficulty is the potentially very large background contamination coming from charged and neutral mis-identifications: K to π, p to π and π^0 to γ.

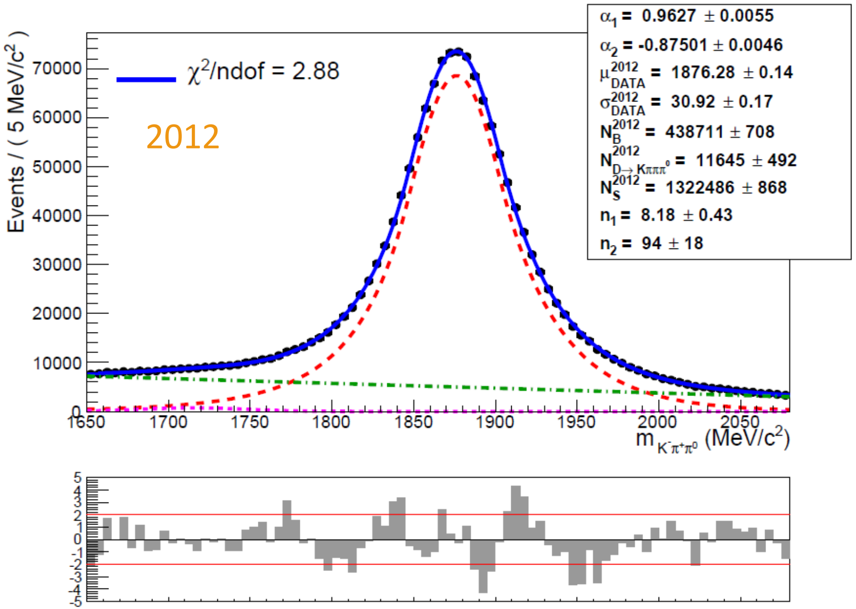
- Baseline PID strategy for charged tracks set up and optimized in two dimensions. Ongoing optimization of neutral PID to reject merged π^0 background.

- We exploited the $B^0 \to K^*\gamma$ reference channel to fix the definitive set of variables to be used in the final TMVA classification. Ongoing optimization of the MVA machinery.

- The precision on the ratio of branching fractions measurement is expected to be around 5-10%.

Backup





- High statistics calibration samples are used to estimate the π^0/γ (mis-)identification efficiencies: for instance $D^{*+} \to D^0(K\pi\pi^0)\pi^+$ samples which I am in charge of.

- With Run1 Data we can count on $\sim 1{,}5 \cdot 10^6$ signal events with merged π^0.