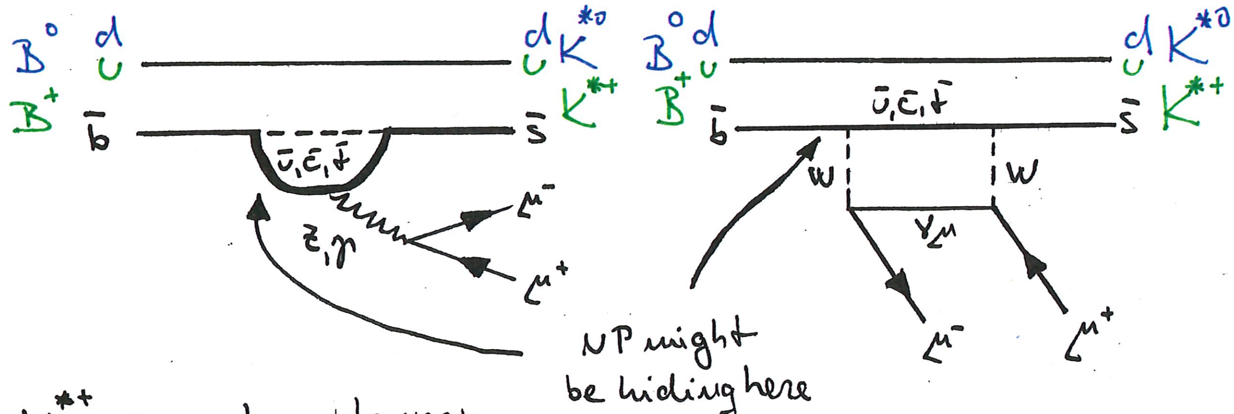
Angular analysis of $B^+ \to K^{*+} \mu\mu^*$

• Motivation

- many measurements show tensions in P_5' in low q^2 ← angular variable
- all LHC measurements done in $B^0 \to K^{*0} \mu\mu$
  - the only $B^+ \to K^{*+} \ell\ell$ done by Belle (1612.05014) together with $B^0 \to K^{*0} \ell\ell$



- $B^+ \to K^{*+} \mu\mu$ probes the very same process as $B^0 \to K^{0*} \mu\mu$, but the spectator quark is different → important cross-check
- B^0 channel measured first because of K^{*0}:

$$K^{*0} \to K^{\pm} \pi^{\mp} \quad \leftarrow \text{2 charged particles in the final state}$$

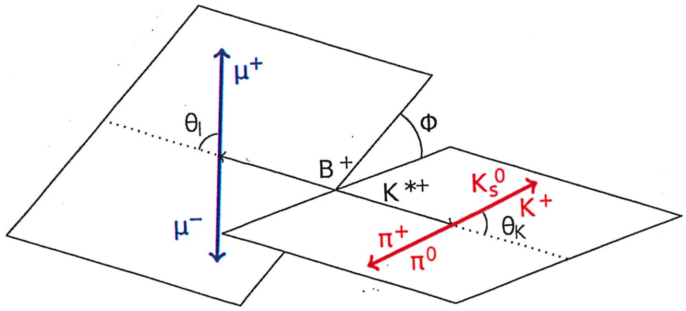
$$K^{*+} \to K^{0}_{+} \pi^{+}_{0} \quad \leftarrow \text{1 charged particles, 1 NEUTRAL particle}$$

• this analysis is the 1^{st} angular analysist of this channel within LHCb!

* footnote: When we talk about $B^+ \to K^{*+} \mu\mu$, we assume including $B^- \to K^{*-} \mu\mu$

Angular description

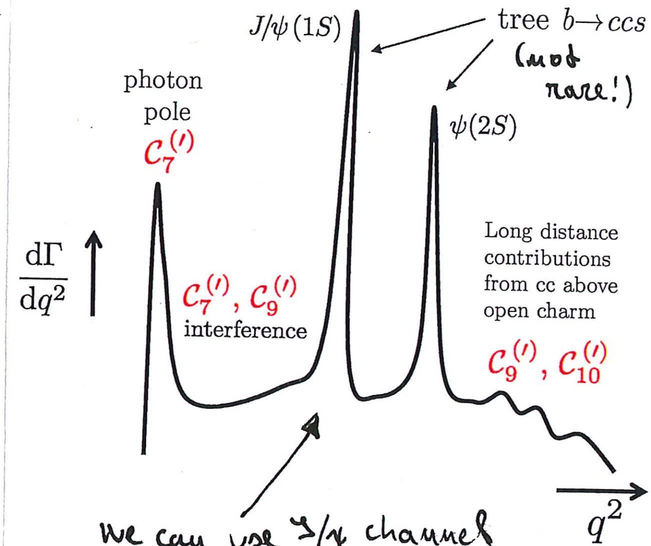
2



- 3 angles $(\theta_\ell, \theta_k, \phi)$ and q^2 (dimuon invariant mass, see first lecture) describe the complete kinematics
- note two subchannels:

$$B^+ \to K^{*+}(\to K_S^0 \pi^+)\mu\mu$$
$$B^+ \to K^{*+}(\to K^+ \pi^0)\mu\mu$$

- different q^2, different physics:



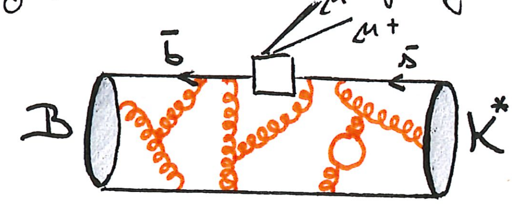
We can use J/ψ channel to validate our methods!

$$\frac{d^4(\Gamma+\bar\Gamma)}{d\cos\theta_K \, d\cos\theta_\ell \, d\phi \, dq^2} = \frac{9}{32}\cdot\Big[$$
$$\tfrac{3}{4}(1-F_L)\sin^2\theta_k + F_L\cos^2\theta_k +$$
$$+\tfrac{1}{4}(1-F_L)\sin^2\theta_k\cos 2\theta_\ell -$$
$$-F_L\cos^2\theta_k\cos 2\theta_\ell +$$
$$+S_3\sin^2\theta_k\sin^2\theta_\ell\cos 2\phi +$$
$$+S_4\sin 2\theta_k\sin 2\theta_\ell\cos\phi +$$
$$+S_5\sin 2\theta_k\sin\theta_\ell\cos\phi +$$
$$+\tfrac{3}{4}A_{FB}\sin^2\theta_k\cos\theta_\ell +$$
$$+S_7\sin 2\theta_k\sin\theta_\ell\sin\phi +$$
$$+S_8\sin 2\theta_k\sin 2\theta_\ell\sin\phi +$$
$$+S_9\sin^2\theta_k\sin^2\theta_\ell\sin 2\phi\Big]$$

Longitudinal K^* polarization

Forward-backward assymetry

- theory prediction challenging due to QCD contributions



- form-factor contribution
  → we can get rid of form-factors in the 1^{st} order by constructing P_j' observables

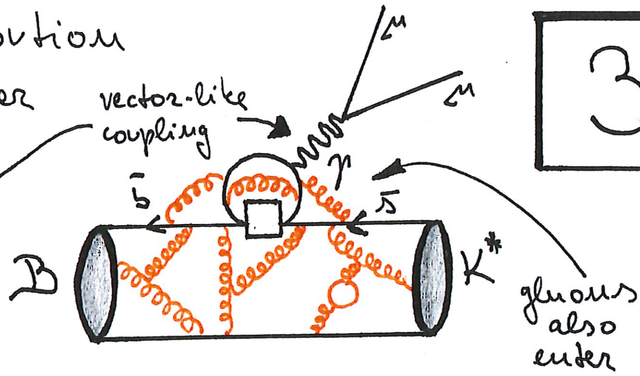
- transforming this in another basis, where:

$$P_1 = \frac{S_3}{1-F_L},\quad P_2 = \frac{\tfrac{4}{3}A_{FB}}{1-F_L},\quad P_3 = \frac{S_9}{1-F_L}$$

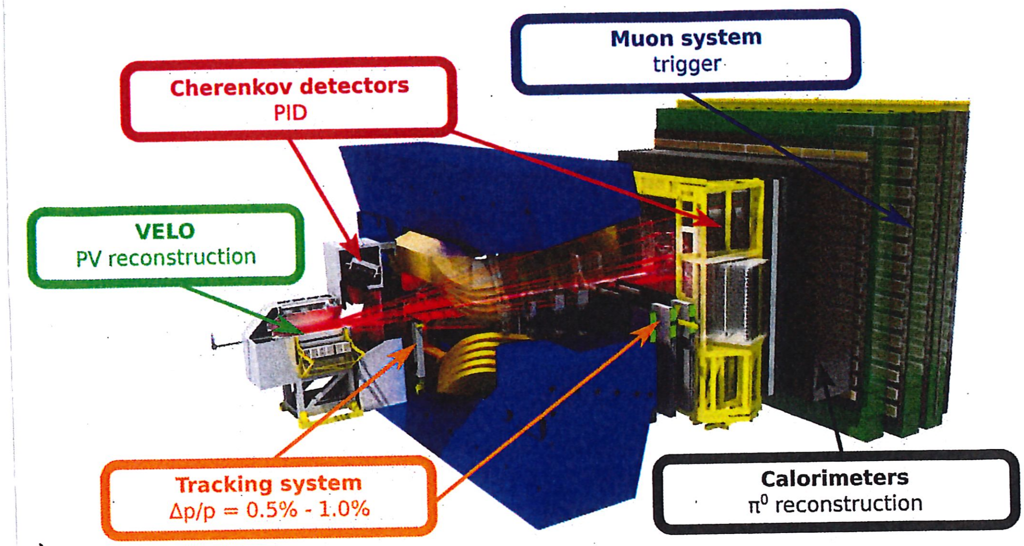
$$P_4' = \frac{S_4}{\sqrt{F_L(1-F_L)}},\quad P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}},\quad P_6' = \frac{S_7}{\sqrt{F_L(1-F_L)}},\quad P_8' = \frac{S_8}{\sqrt{F_L(1-F_L)}}$$

- these parameters depend on q^2 and do not strongly depend on form-factors

• there is also a non-factorizable contribution from charm loops (but it's a smaller contribution than from factors)
- important not to mix it up!



Signal Selection



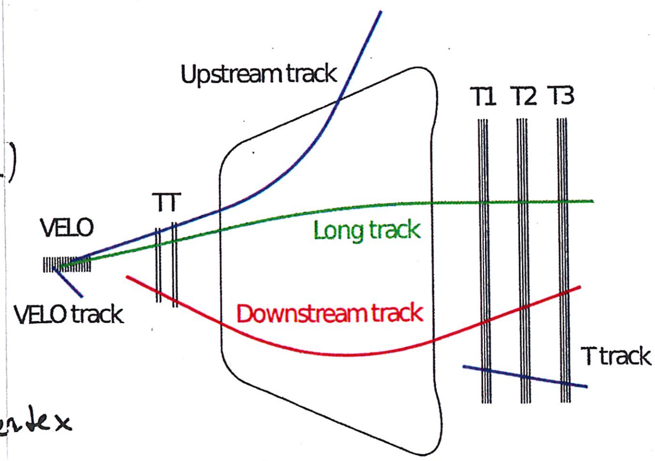
1, $B^+ \to K^{*+}(\to K^0_S \pi^+)\mu\mu$

• we cannot measure K^0_L, since it flies too far in the detector ($\tau_L \sim 5.10^{-8}$)
→ typically stopped in HCAL

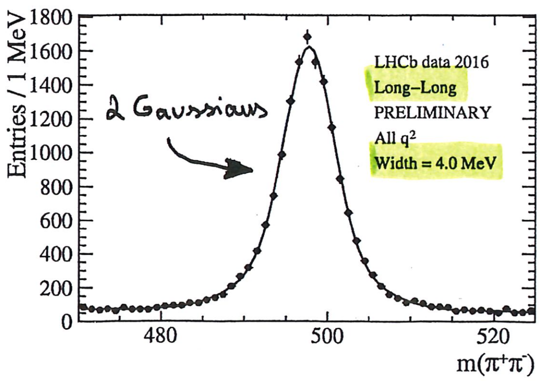
• K^0_S lifetime is ~ 9.10^{-11}s : assuming boost of $\gamma = 20$ ($v/c \simeq 0{,}999$), K_S flies ~ 53 cm before decaying (K_L would fly 300 m)

• K^0_S decays into $\pi^\pm\pi^\mp$ (70%) (or into $\pi^0\pi^0$, but we don't care)

• K_S either decays inside VELO
  • 2 Long tracks are reconstructed (LL)
 or outside of VELO
  • 2 Downstream tracks are reconstructed (DD)



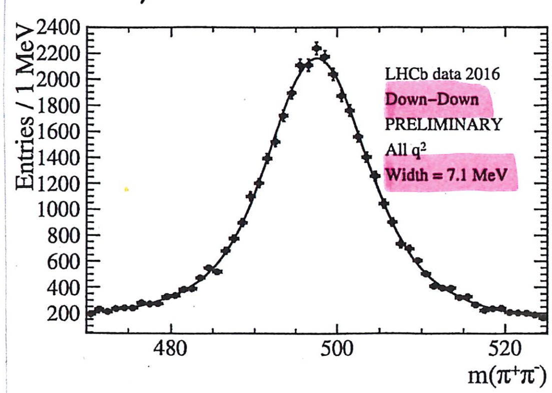
• SINGLE downstream tracks have ~2x worse resolution than a long track
+ we have 2 pions from the same vertex
+ we use a trick
- we have 2 data sub-sets that need separate treatement



2 Gaussians

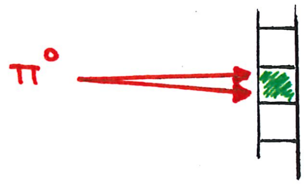
more narrow

more statistics

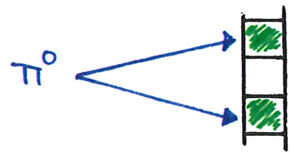


2, $B^+ \to K^{*+}(\to K^+\pi^0)\mu\mu$

- K^+ is a stable particle for LHCb
- π^0 decays into $\gamma\gamma$ in ~ 98,8%
  - ECAL has finite granularity
    - a, both γ hit one cell → merged π^0
    - b, each γ hits a different cell → resolved π^0

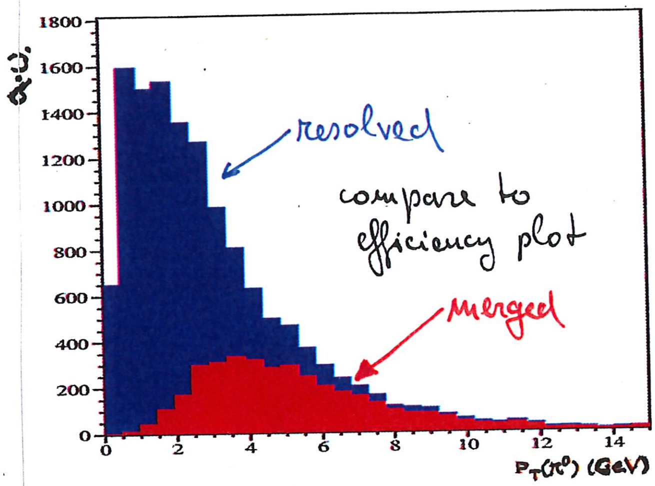


  - for this analysis, we use only resolved π^0
    - better resolution
    - higher statistics
    - better PID



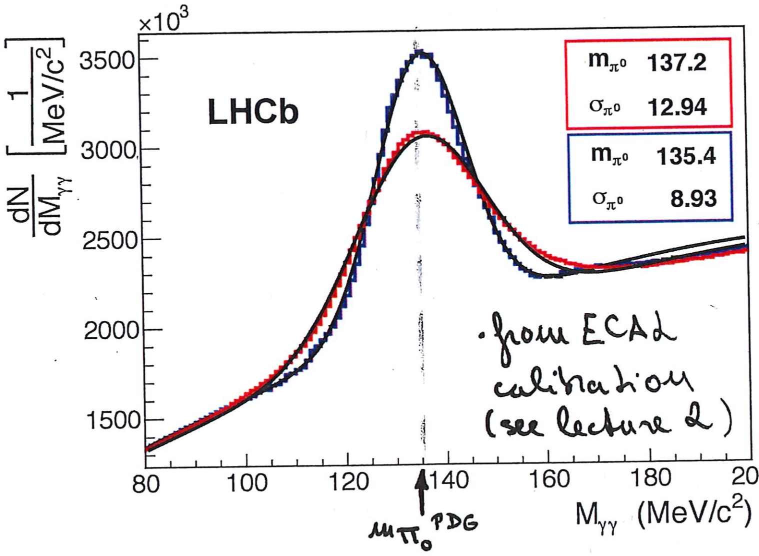
π^0 reconstruction

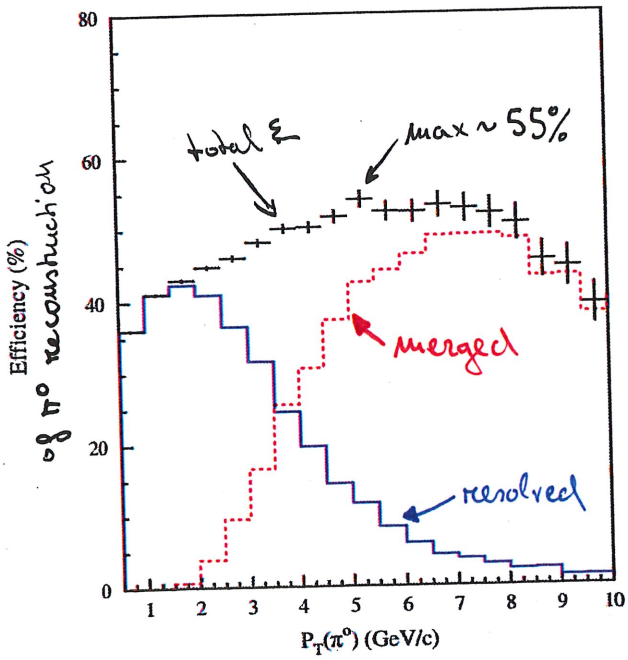
- ECAL resolution $\sigma/E = \frac{0,1}{\sqrt{E}} \oplus 0,01$
- decays into $\gamma\gamma$
  - large combinatorial background
  - large width (= bad resolution)



- efficiency ≲ 40%
- PID:
  π^0 confidence level
  $CL_{\pi^0} = CL_{\gamma}^1 \cdot CL_{\gamma}^2$

information from trackers + CALO, kinda probability it's π^0



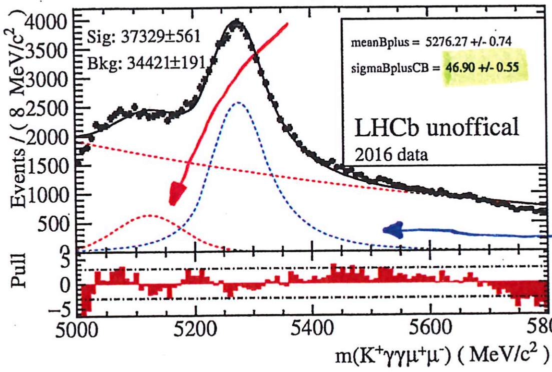


→ We use Decay-Tree-Fitter (DTF)

• Decay-Tree-Fitter

- normally, a decay is reconstructed starting from the top vertex e.g. $B \rightarrow K^* \rightarrow K^+$, $\pi^0 \rightarrow \gamma\gamma$, $\mu\mu$
  and then the tree is build upstream
  → no propagation from the "mother" vertex to the daughter particles
  • this way of reconstruction is fast
  • in the case of <u>charged</u> particles the gain of information by using DTF is negligible
  • in the case of neutrals it becomes important
    - DTF developed by BaBar to reconstruct $K_S^0 \rightarrow \pi^0\pi^0$
- DTF constrains mass (in our case π^0 and K_S^0) and adds this mass information to the decay vertex of mother particle
  • complete decay chain is parametrized in vertex position, decay lenght and momenta
  • simultaneously fitted, taking into account all the constraints (4-momenta conservation, ...)
- in the case of π^0, DTF significantly improves B^+ mass resolution

ExpGauss: accounts for missing E_{π^0} not coming from π^0

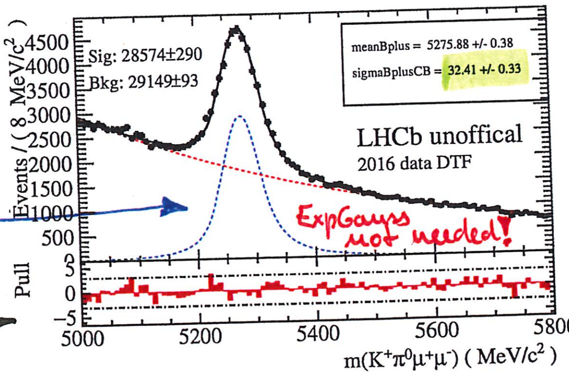


Double-sided CB

← no DTF

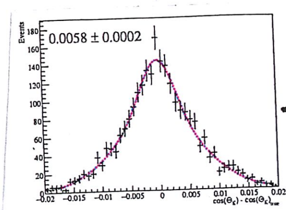
DTF →

ExpGauss not needed!



- in the case of K_S^0,
  B mass resolution is not significantly better (= it's good already before DTF)
  • angle resolution improves significantly, making the analysis more sensitive
  • showing only LL K_S^0, DD very similar

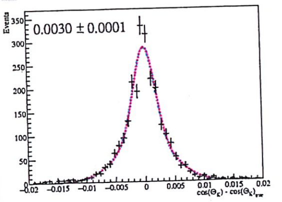
$\cos\theta_K - \cos\theta_K^{true}$



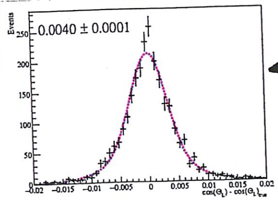
← no DTF

DTF →

$\cos\theta_K - \cos\theta_K^{true}$



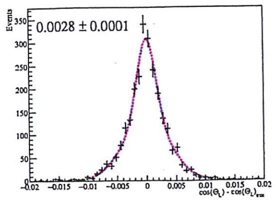
$\cos\theta_L - \cos\theta_L^{true}$



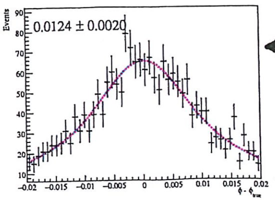
← no DTF

DTF →

$\cos\theta_L - \cos\theta_L^{true}$



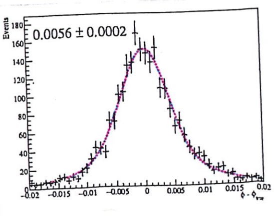
$\phi - \phi_{true}$



← no DTF

DTF →

$\phi - \phi_{true}$



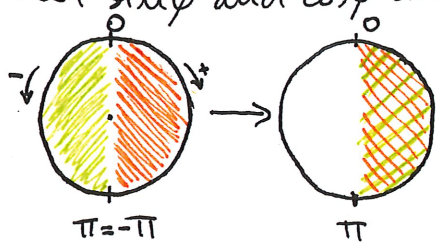
Fit strategy

- Fit of the selected data is fully blinded in order to prevent any biases and is validated using the J/ψ channel
- signal event fit in $\theta_K, \theta_L, \phi, m_{B^+}$ in bins of q^2

- We are looking into a rare decay + our detection efficiency is not the biggest → lower statistics + a lot of fit parameters

⇒ to improve fit stability, we use folding of angles
  - looking at the formula on page $\boxed{2}$, we have a lot of $\sin\alpha$, $\cos 2\alpha$, ...
  - using goniometry, we can 'fold' angles
    - → some terms cancel out
    - → gain stability since we have less parameters
    - – loosing information about correlations between coefficients

- we have 5 different foldings : we still have access to all observables
  - an example folding #2 : $\phi \to \pi + \phi$ for $\phi < 0$
    - access to F_L, S_3, A_{FB} and S_9
    - → all $\sin\phi$ and $\cos\phi$ cancel out



Outlook

- our analysis of $9\,fb^{-1}$ will have similar sensitivity as $B^0 \to K^{0*}\mu\mu$ $3\,fb^{-1}$ analysis
- now the P_5' tension is $\sim 2{,}7\,\sigma$, with this measurement we can have $\sim 1\,\sigma$ added

- Take home messages:
  - Neutrals are hard, but not impossible, to reconstruct
  - Analysis of $B^+ \to K^{*+}\mu\mu$ is an important systematic check to $B^0 \to K^{0*}\mu\mu$
- Once more: different q^2 = different physics