Status and prospects for strange physics at LHCb

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CERN European Organization for Nuclear Research

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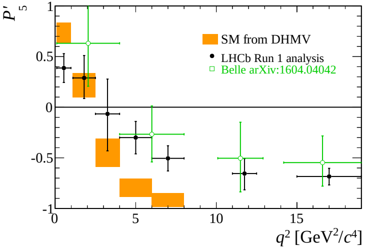
Outline

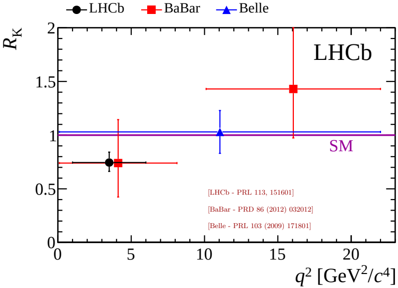
- Flavour anomalies and strange physics
- Searches for rare strange hadron decays at LHCb
  - $\Sigma^+ \to p\mu^+\mu^-$
  - $K^0_S \to \mu^+\mu^-$
  - $\eta^{(\prime)} \to \pi^+\pi^-$
- Prospect for selected channels
  - Run II
  - Upgrade
- Conclusions

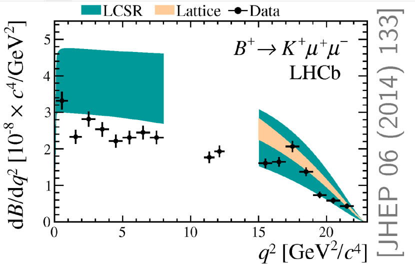
Status of flavour physics anomalies (1)

Several measurements showing discrepancies with respect to SM

- $B_d^0 \to K^* \mu^+ \mu^-$ angular distributions
- Low $b \to s \mu^+ \mu^-$ branching fractions
- Hints of lepton non-universality in $B \to K \ell \ell$ and $B \to D \ell \nu$ decays
- Ratio of $B^0 \to \mu^+ \mu^-$ / $B_s^0 \to \mu^+ \mu^-$ branching fractions

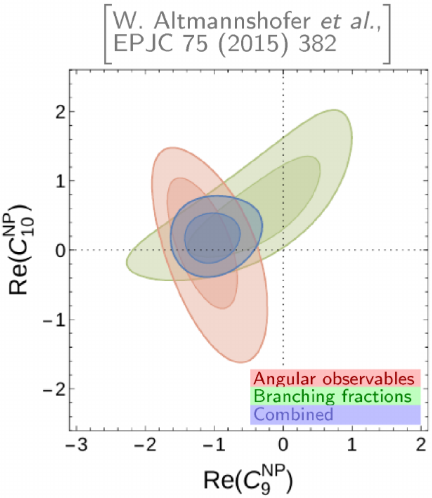






Status of flavour physics anomalies (2)

- All points to the presence of an additional interaction
- Several global fits to Wilson coefficients agree [Buttazzo et al - 1604.03940] [Bauer et al - PRL116,141802(2016)] [Crivellin et al - PRL114,151801(2015)] [Altmannshofer et al - PRD89(2014)095033]...
- Possible underestimated contributions from $c\bar{c}$ loops [Lyon et al - 1406.0566] [Altmannshofer et al -1503.06199] [Ciuchini et al - JHEP06(2016)116]
- Possible explanation is new high mass boson (Z')
- Can be **out of reach for direct production at LHC**
- Fundamental to be confirmed with Run II data



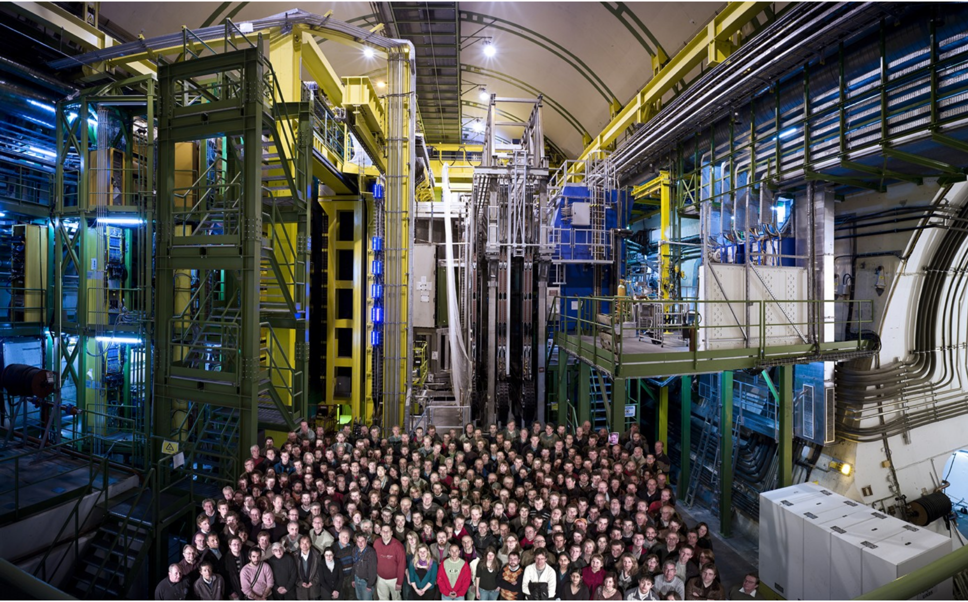
Importance of strange physics

- LHC confirmed SM even more:
  a light Higgs boson and nothing else up to TeV energies
- Motivations for NP are still there but no clear indication of possible NP directions
- Need to search for NP in a broad spectrum
- Unique role of strange physics
  - ⋆ Unique probe of fundamental SM parameters
  - ⋆ Extremely suppressed FCNC $A(s \to d) \sim \lambda^5 \sim 5 \cdot 10^{-4}$
  - ⋆ Largest sensitivity to non-MFV dynamics
  - ⋆ Useful probe of very light (weakly coupled) NP dynamics

	d	s	b
u	$1-\lambda^2/2$	λ	$A\lambda^3(\rho - i\eta)$
c	$-\lambda$	$1-\lambda^2/2$	$A\lambda^2$
t	$A\lambda^3(1-\rho-i\eta)$	$-A\lambda^2$	1

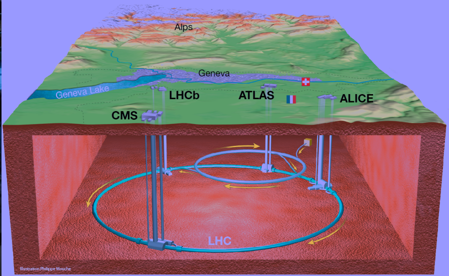
See G. Isidori at KAON 2016 [talk]

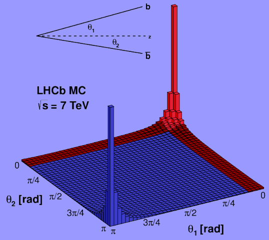
LHCb experiment



LHCb experiment

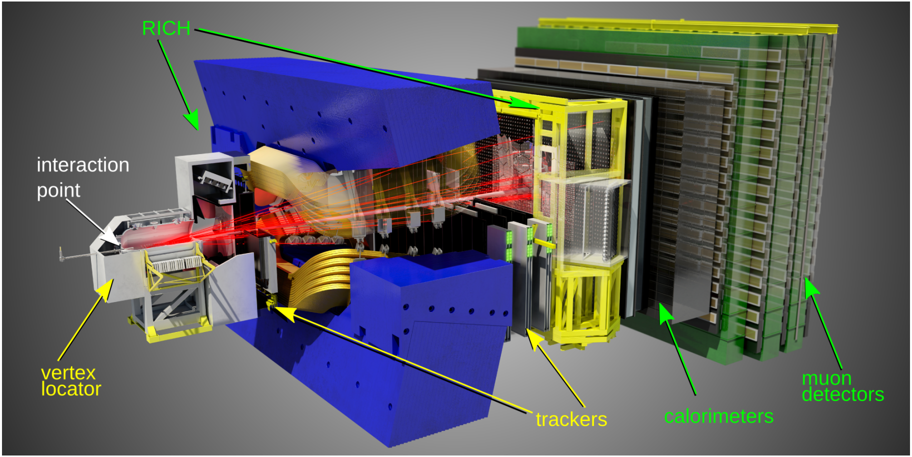
- 1150 members, from 69 institutes in 16 countries
- Dedicated experiment for precision measurements of CP violation and rare decays
- *Beautiful*, *charming*, *strange* physics program





- pp collisions at $\sqrt{s} = 7, 8(13)$ TeV in Run I (Run II)
- $b\bar{b}$ quark pairs produced correlated in the forward region
- Luminosity leveled at $4 \times 10^{32} cm^{-2} s^{-1}$

LHCb detector



Excellent vertex and IP resolution

- $\sigma(IP) \simeq 24\mu\text{m}$ at $p_T = 2$ GeV/c
- $\sigma_{BV} \simeq 16\mu\text{m}$ in x, y

Very good momentum resolution

- $\sigma(p)/p = 0.4\% - 0.6\%$ for $p \in (0, 100)$ GeV/c
- $\sigma(m) \sim 24(4)$ MeV for two body $B(K_S)$ decays

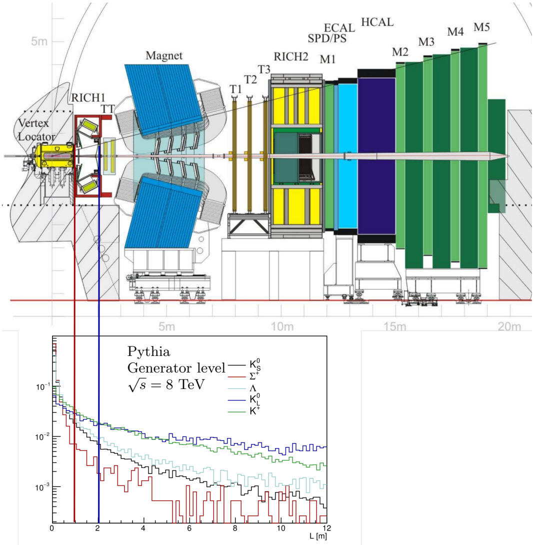
Muon identification

- $\varepsilon_\mu = 98\%$, $\varepsilon_{\pi\to\mu} = 0.6\%$, $\varepsilon_{K\to\mu} = 0.3\%$, $\varepsilon_{p\to\mu} = 0.3\%$

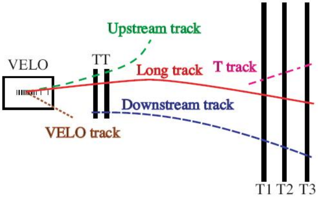
Trigger

- $\varepsilon_\mu = 90\%$ for B decays

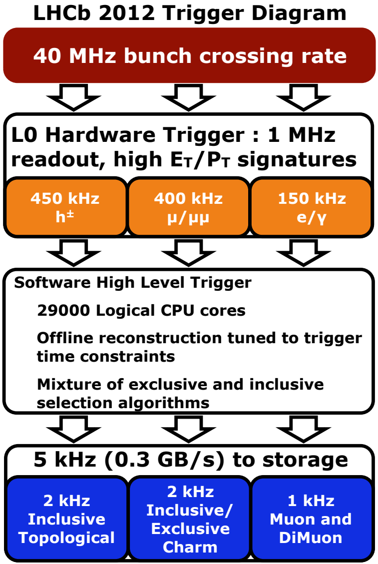
Setting the (long) stage



- Huge strange hadrons production cross-section at LHCb: O(1) strange hadron per minbias event
- Large lifetimes for LHCb... but the peak of an exponential is at zero!



LHCb Run I data-taking



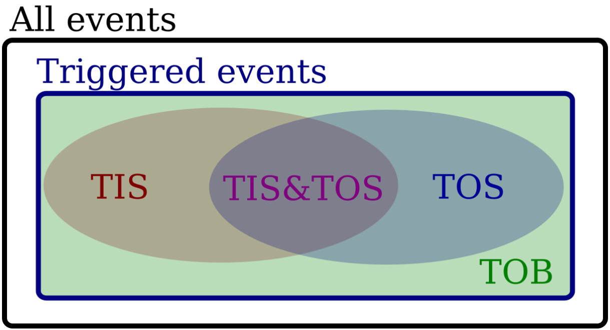
- LHCb trigger designed for heavy flavours
- Muon (hadron) L0 trigger require $p_{\mathrm{T}} > [1-5] GeV$
- **Too hard for primary strange hadrons**

- Hlt1 and Hlt2 are software and customizable
- No dedicated triggers in 2011, added a $K^0_{\mathrm{S}} \to \mu^+\mu^-$ dedicated trigger in 2012
- Several generic (topological) triggers allowed good efficiencies

- Typical events contain more than one strange hadron
- ⇒ Strange physics Run I analyses mostly based on data triggered by the rest of the event

TIS events and the TISTOS method

- Triggered events can be
  - ⋆ Triggered On the Signal (TOS) - the signal is sufficient to trigger
  - ⋆ Triggered Independently of the Signal (TIS) - the signal is not necessary to trigger
  - ⋆ Triggered on both (TOB=!TIS&!TOS)



- Events can be TIS and TOS
- Overlap can be used to measure trigger efficiencies

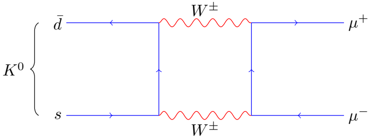
Tolk, S et al. LHCb-PUB-2014-039

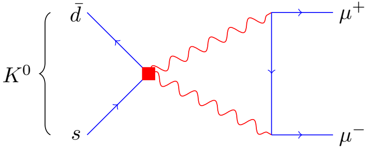
Strange physics at LHCb with Run I

Search for $K^0_S \to \mu^+\mu^-$ decays

- $K^0_L \to \mu^+\mu^-$ is the "father" of flavour physics motivating the need for charm quark and GIM mechanism
- $K^0_S \to \mu^+\mu^-$ in addition suppressed by CPV
- SM prediction $\mathcal{B}(K^0_S \to \mu^+\mu^-) = (5.1 \pm 1.5) \cdot 10^{-12}$

  [Ecker, Pich - Nucl Phys B366 (1991)] [Isidori, Unterdorfer - JHEP 01 (2004) 009]
- Dominated by long distance contributions
- Sensitive to NP, e.g. light scalars with CP-violating Yukawa couplings





Search for $K^0_S \to \mu^+\mu^-$ decays

- Best limit before LHCb was $\mathcal{B}(K^0_S \to \mu^+\mu^-) < 3.1 \cdot 10^{-7}$ at 90% CL at CERN PS in 1973 [S. Gjesdal et al. PLB44(1973)217]
- In Run I about 10^{13} K^0_S in LHCb acceptance per fb^{-1} of luminosity 40% of which decaying inside the VELO
- Limit obtained by LHCb with 1fb^{-1} at 7 TeV: $\mathcal{B}(K^0_S \to \mu^+\mu^-) < 9 \cdot 10^{-9}$ at 90% CL
- Updated analysis with 2fb^{-1} 8 TeV and combined with the first one

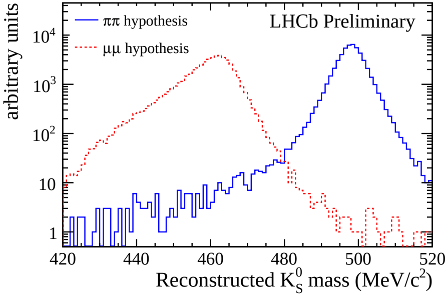
Search for $K^0_S \to \mu^+\mu^-$ decays

Selection strategy

- Search for $K^0_S \to \mu^+\mu^-$ from two well identified muons
- Common selection of $K^0_S \to \mu^+\mu^-$ and $K^0_S \to \pi^+\pi^-$, control and normalisation channel as well as main background
- Armenteros-Podolanski veto for $\Lambda \to p\pi^-$ and particle identification against $K^* \to K\pi$ and other backgrounds

Trigger strategy

- Three categories based on TIS / TOS information at the different levels



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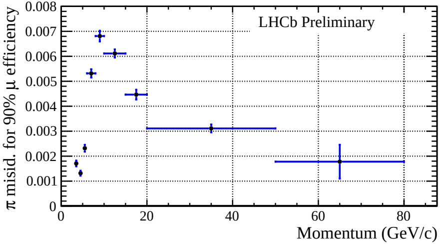
$K^0_S \to \mu^+\mu^-$

Two multivariate operators to fight different backgrounds

Dedicated multivariate particle identification algorithm developed

- Trained on $K^0_S \to \pi^+\pi^-$ and $B^+ \to J/\psi K^+$ reweighted to match kinematics
- 21 variables using Muon detector information and 14 variables related to RICH information
- Fourfold improvement in misID with respect to previous analysis



BDT to fight combinatorial background

- Trained on $K^0_S \to \pi^+\pi^-$ data proxy for signal and right data sideband for background
- Geometric and kinematic variables as input
- Trained separately per trigger category

$K^0_\mathrm{S} \to \mu^+\mu^-$

Normalisation

- Search performed in bins of BDT and trigger category

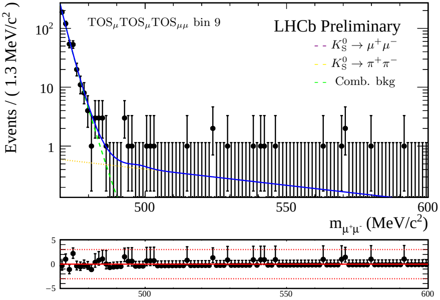
$$\mathcal{B}(K^0_\mathrm{S} \to \mu^+\mu^-) = \mathcal{B}(K^0_\mathrm{S} \to \pi^+\pi^-) \cdot \frac{\varepsilon^{\pi\pi}}{\varepsilon_i^{\mu\mu}} \cdot \frac{N_i^{\mu\mu}}{N^{\pi\pi}} = \alpha_i N_i^{\mu\mu}$$

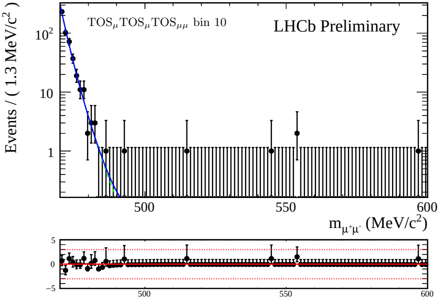
- NoBias trigger used for $K^0_\mathrm{S} \to \pi^+\pi^-$ (of known prescale of $\sim 3 \cdot 10^{-7}$)
- Efficiencies from MC but calibrated with data corrections
- Total systematic uncertainty of $4 - 5\%$ on the normalisation depending on the bin
- Final fit performed with different background shapes for an absolute uncertainty of 4×10^{-11}

$K^0_S \to \mu^+\mu^-$

Results

- $K^0_S \to \mu^+\mu^-$ distribution fitted in the [470,600] MeV range
- Simultaneous maximum likelihood fit performed over the 30 bins
- Combinatorial and misID $K^0_S \to \pi^+\pi^-$ background components included
- **No excess of events is observed with respect to background expectations**





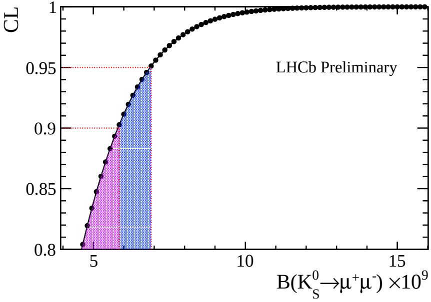
$K^0_S \to \mu^+\mu^-$

Results

- The upper limit of the previous search is reinterpreted as posterior on the branching fraction and included as prior in this search
- The new upper limit on the branching fraction is

$$\mathcal{B}(K^0_S \to \mu^+\mu^-) < 5.8(6.9) \times 10^{-9} \text{ at } 90\ (95\%)\ \text{CL}$$

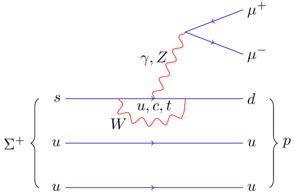
- Factor 50 improvement with respect to the best limit before LHCb



Search for $\Sigma^+ \to p\mu^+\mu^-$ decays

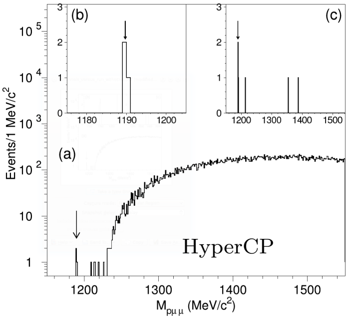
Standard Model

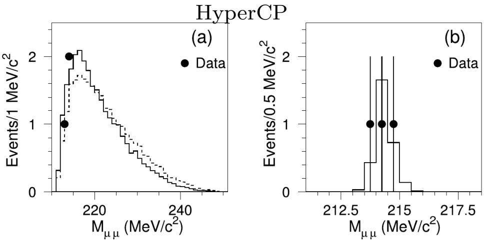
- $\Sigma^+ \to p\mu^+\mu^-$ is a very rare FCNC
- Short distance SM branching fraction is $O(10^{-12})$
- Dominated by long distance contributions:
  $1.6 \cdot 10^{-8} < \mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) < 9.0 \cdot 10^{-8}$ [He et al. - Phys.Rev. D72 (2005) 074003]



The HyperCP evidence

- An evidence for this decay was found by the HyperCP experiment with 3 events in absence of background
- Measured branching fraction is:
  $\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = (8.6^{+6.6}_{-5.4} \pm 5.5) \cdot 10^{-8}$
  [Phys.Rev.Lett. 94 (2005) 021801]
- This evidence attracted large attention since all the **3** observed signal events have the same dimuon invariant mass: pointing towards a
  $\Sigma^+ \to pX^0(\to \mu\mu)$ decay
  with $m^0_X = 214.3 \pm 0.5$ MeV
  $\mathcal{B}(\Sigma^+ \to pX^0(\to \mu\mu)) = (3.1^{+2.4}_{-1.9} \pm 5.5) \cdot 10^{-8}$





Theoretical interpretations and experimental status

- Several interpretations were proposed
  - ⋆ Light Higgs boson [He, Tandean, Valencia, PRL.98.081802 (2007)]
  - ⋆ Sgoldstino [Gorbunov, Rubakov PRD 73 035002] [Demidov, Gorbunov PRD73(2006)035002]
  - ⋆ Many others [He et al - PLB631 (2005) 100] [Geng, Hsiao - PLB632(2006) 215] [Deshpande et al - PLB632 (2006) 212] [Mangano, Nason - Mod. Phys. Lett. A22 (2007)] [Chen et al - PLB663 (2008) 400] [Xiangdong et al - EPJC55 (2008) 317] [Pospelov - PRD80 (2009) 095002]
  - ⋆ In general pseudoscalar favoured over scalar and lifetime of order 10^{-14}s
- Many experimental searches for low mass resonances in dimuons:
  - ⋆ CLEO, E391a, D0, BaBar, Belle, KTeV, BESIII
  - ⋆ Searched also at LHCb in $B^0 \to \mu^+\mu^-\mu^+\mu^-$ and $B^0 \to K^{*0}\mu^+\mu^-$
  - ⋆ Not confirmed nor disproved
- No other search in $\Sigma^+ \to p\mu^+\mu^-$ decays

$\Sigma^+ \to p\mu^+\mu^-$ at LHCb

General analysis strategy

Sample and selection:

- Full 2011+2012 statistics, luminosity 3 fb^{-1}
- Selections for final states: $\Sigma^+ \to p\mu^+\mu^-$, $\Sigma^+ \to \bar{p}\mu^+\mu^+$, $\Sigma^+ \to p\pi^0$, $K^+ \to \pi^+\pi^-\pi^+$
- Decays reconstructed with long tracks (i.e. decays in VELO)
- Prompt decays

Datasets strategy

- Very soft signal to be triggered
- Two trigger strategies:
  1. Full - all events are retained, for search purposes, no normalisation
  2. TIS - for normalization purposes (sub sample)

$\Sigma^+ \to p\mu^+\mu^-$ at LHCb

General analysis strategy

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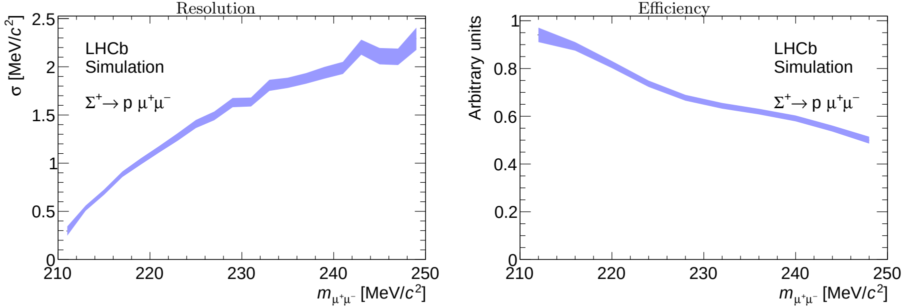
1. Soft pre-selection to reduce dataset
2. Cut on BDT and PID to remove most of the background
3. Explicit veto of $\Lambda \to p\pi$ background, no other peaking background contributes
4. Search for $\Sigma^+ \to p\mu^+\mu^-$ decays:
   - Search around Σ mass window for signal
     $\rightarrow$ If peak is found, look at $\mu\mu$ invariant mass
5. Normalize branching fraction to $\Sigma^+ \to p\pi^0$ decays

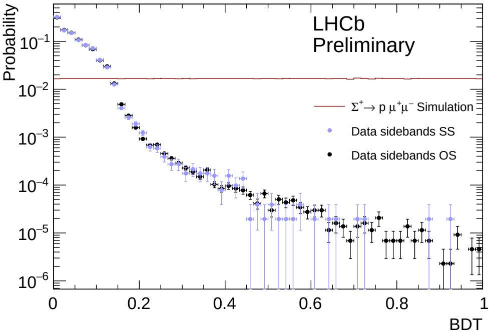
Search for an Hyper-CP like signal

- Hyper-CP signal is consistent with $\Sigma^+ \to p X^0 (\to \mu\mu)$, with $m_{X^0} = 214.3 \pm 0.5$ MeV
- Mass resolution in LHCb:
  - ⋆ Raises with $m_{\mu^+\mu^-}$ departing from threshold
- Study efficiency versus $m_{\mu^+\mu^-}$: higher efficiency at small mass due to higher minimum p_T



Multivariate selection: BDT

- BDT aiming at rejecting combinatorial background
- Training on signal MC sample and background from data same-sign sidebands ($\Sigma^+ \to \bar{p}\mu^+\mu^+$)
- Common geometric and kinematic variables: pointing, IP, p_{T} and isolations, ...



Normalisation

- No fully charged final state available in the Σ^+ to normalize the branching fraction
- Use high branching fraction $\Sigma^+ \to p\pi^0$

$$\begin{aligned}\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) &= \frac{\varepsilon_{\Sigma^+\to p\pi^0}}{\varepsilon_{\Sigma^+\to p\mu^+\mu^-}} \frac{\mathcal{B}(\Sigma^+ \to p\pi^0)}{N_{\Sigma^+\to p\pi^0}} N_{\Sigma^+\to p\mu^+\mu^-} \\ &= \alpha N_{\Sigma^+\to p\mu^+\mu^-}\end{aligned}$$

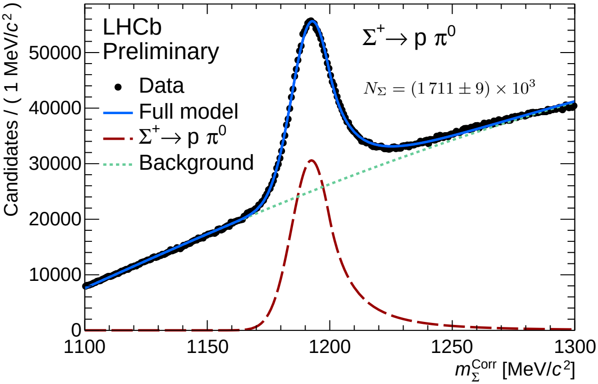
- Selection for $\Sigma^+ \to p\pi^0$ with $\pi^0 \to \gamma\gamma$ (resolved clusters) from calorimeter
- Branching fraction $\mathcal{B} = (51.57 \pm 0.30)\%$

For full Run I dataset, only TIS:

- Single event sensitivity $\alpha_{TIS} = (1.1 \pm 0.6) \times 10^{-8}$
- Correspondent to 4.6 ± 4.2 expected events in the TIS sample with a SM branching fraction

Normalisation with $\Sigma^+ \to p\pi^0$

- Fit to corrected mass: $m_\Sigma - m_{\pi^0} + m_{\pi^0}^{PDG}$
- Single Crystal-Ball pdf with right tail for the signal
- Modified ARGUS function for the background



Normalisation systematics

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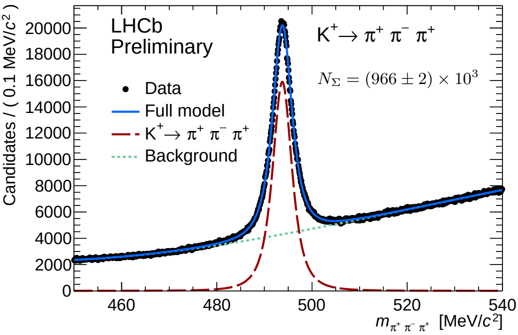
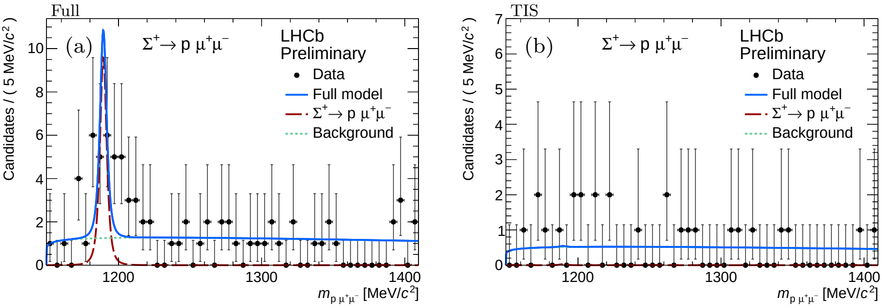
- TIS Trigger efficiency calibrated with large $K^+ \to \pi^+\pi^-\pi^+$ sample and TISTOS method
- Reconstruction of the π^0 calibrated with ratio of ratio of $B^+ \to J/\psi K^{*+}(\to K^+\pi^0)$ and $B^+ \to J/\psi K^+$ decays reconstructed in data.
- Particle identification calibrated with control channels in data ($\Lambda \to p\pi^-$ and J/ψ)
- BDT classifier calibrated with $K^+ \to \pi^+\pi^-\pi^+$ channel in data



Systematic uncertainties

Selection Data-MC differences	1.4%
Calibration of BDT efficiency	6.4%
Calibration of PID efficiency	20%
Calibration of the π^0 efficiency	10%
Calibration of the TIS efficiency	30%
Total	43%

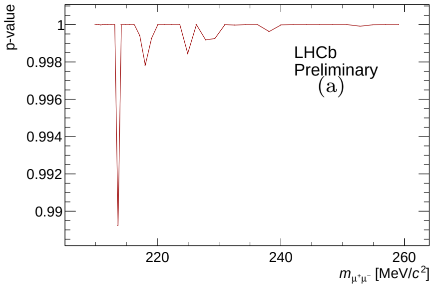
Results

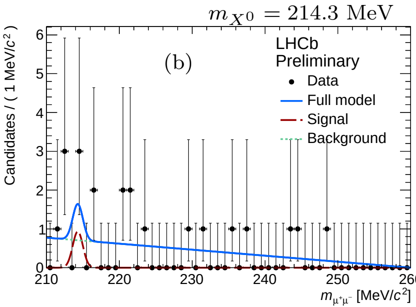


- Excess of events w.r.t. background with a significance of $4.0\,\sigma$
- Fitted signal yield: $12.9^{+5.1}_{-4.2}$
- No excess of events in the TIS sub-sample for which normalisation is performed
- Upper limit with CLs method: $\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) < 6.3 \times 10^{-8}$ at 95% CL

Results: analysis of the dimuon mass

- Consider candidates within $2\,\sigma$ from the Σ mass in the full selection
- Scan dimuon invariant mass for possible peaks
- Fit with gaussian of known mass and resolution
- No significant peak found
- Most pronounced at 213.7 MeV (but not significant)
- Fit at $m_{X^0} = 214.3$ MeV yields 1.6 ± 1.9 events corresponding to a fraction 0.078 ± 0.092 of the total seen signal



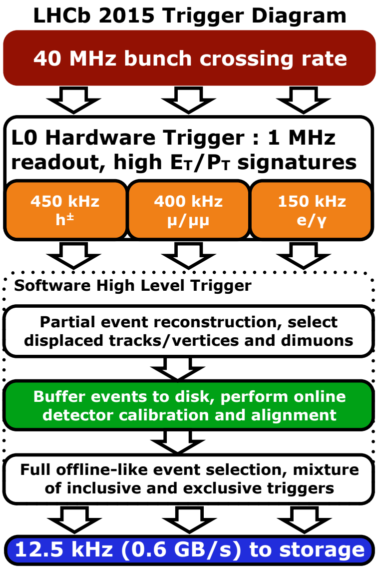


Discussion of the results

- Found signal only in the full sample:
  most of the seen events have only one of the three trigger layers not being TIS
- Full detailed study of $\Sigma^+ \to p\mu^+\mu^-$ trigger efficiency is under way
- The main conclusions are anyway independent of absolute normalisation:
  1. Evidence of $\Sigma^+ \to p\mu^+\mu^-$ decay
  2. SM-like distribution of the dimuon invariant mass
  3. **Contribution from putative X^0 particle consistent with zero**

LHCb Run II and Upgrade

LHCb Run II data-taking

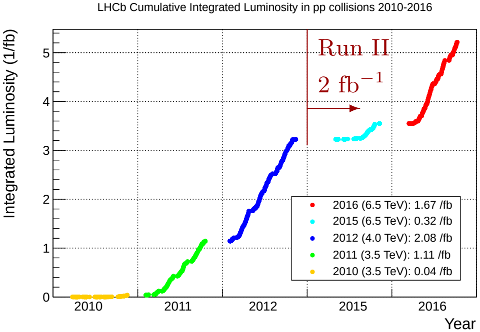


- Higher bandwidth from improved farm and algorithms allows higher yields
- Real time calibration between Hlt1 and Hlt2
- **L0 trigger still limiting factor for strange hadrons**
- *Turbo* stream allows high rate channels to be stored: [Aaij et al. JCPC208(2016)35] important for non rare strange physics

Software improvements for strange

- Complement forward tracking for very soft muons implemented
- New Hlt1 inclusive lines developed with focus on strange physics
- Various novel Hlt2 inclusive and exclusive lines written, dedicated to strange

Prospects for strange physics with Run II data



Already 2 fb^{-1} on tape at $\sqrt{s} = 13$ TeV

- Analysis of $\Sigma^+ \to p\mu^+\mu^-$ with dedicated triggers
  - ⋆ Probable observation
  - ⋆ Precise branching fraction measurement
  - ⋆ Possible differential branching fraction
- $K^0_S \to \mu^+\mu^-$ see later
- Different other rare hyperon decay searches possible ($\Sigma^+ \to pe^+e^-$, $\Lambda^0 \to p\pi^-e^+e^-$, LFV, etc)

Search for CP violating strong decays $\eta^{(\prime)} \to \pi^+\pi^-$

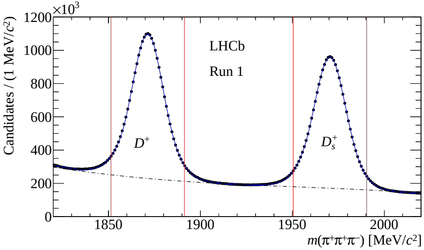
LHCb-PAPER-2016-046

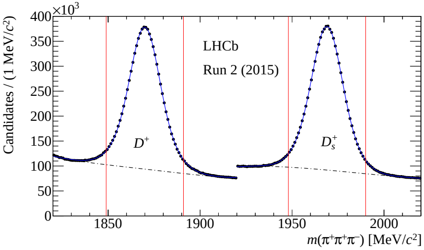
- QCD should violate CP symmetry (with a term $\mathcal{L}_\theta = -\frac{\theta}{64\pi^2}\epsilon^{\mu\nu\rho\sigma}F_{\mu\nu}F_{\rho\sigma}$) but none is observed experimentally
- $\theta < 10^{-10}$ from neutron electric dipole moment (**strong CP problem**)
- $\eta^{(\prime)} \to \pi^+\pi^-$ would be strong CP violating decays
- nEDM limit constraints SM branching fractions to $< 3 \cdot 10^{-17}$ any evidence higher than this would be NP
- Best limits at 90% CL
  $\mathcal{B}(\eta \to \pi^+\pi^-) < 1.3 \cdot 10^{-5}$ (KLOE $\phi \to \eta\gamma$ [PLB606 (2005) 276])
  $\mathcal{B}(\eta' \to \pi^+\pi^-) < 5.5 \cdot 10^{-5}$ (BESIII $J/\psi \to \gamma\pi^+\pi^-$ [PRD84(2011)032006])

Search for CP violating strong decays $\eta' \to \pi^+\pi^-$

LHCb-PAPER-2016-046

- LHCb strategy:
  look for peaks in $\pi\pi$ mass from $D^+_{(s)} \to \pi^+\pi^-\pi^+$ decays (*i.e.* $D^+_{(s)} \to \pi^+\eta^{(\prime)}$)
- MVA operator to reduce background
- Normalisation: $\mathcal{B}(\eta^{(\prime)} \to \pi^+\pi^-) = \frac{N_{\eta^{(\prime)}}}{N_{D^+_{(s)}\to\pi^+\pi^-\pi^+}} \frac{1}{\varepsilon_{\eta^{(\prime)}}} \frac{\mathcal{B}(D^+_{(s)}\to\pi^+\pi^-\pi^+)}{\mathcal{B}(D^+_{(s)}\to\pi^+\eta^{(\prime)})}$
- Constrained D masses and origin vertex improves resolution significantly
- $\varepsilon_{\eta^{(\prime)}}$ small correction to efficiency versus $m_{\pi\pi}$
- 3 fb^{-1} of Run I and 0.3 fb^{-1} of Run II data from Turbo stream
- Run II contribution enhanced by larger cross-section and trigger efficiency





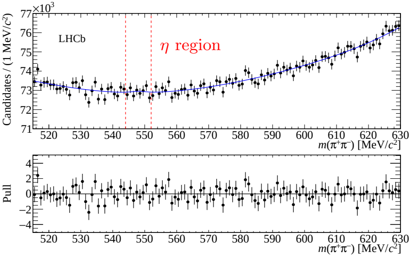
Search for CP violating strong decays $\eta' \to \pi^+\pi^-$

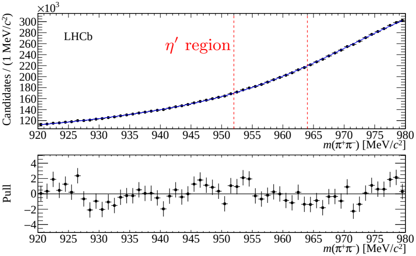
LHCb-PAPER-2016-046

- No excess on top of the background (signal phase space plus combinatorial)
- Upper limit on branching fractions with CLs method at 90% CL:

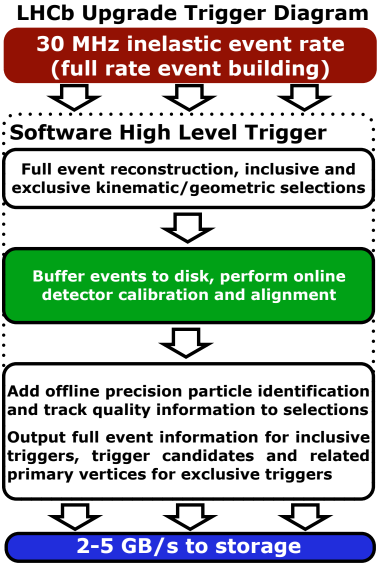
$$\mathcal{B}(\eta \to \pi^+\pi^-) < 1.6 \cdot 10^{-5}$$
$$\mathcal{B}(\eta' \to \pi^+\pi^-) < 1.8 \cdot 10^{-5}$$

- η limit compatible with previous results, η' limit improved by factor three





LHCb Upgrade data-taking

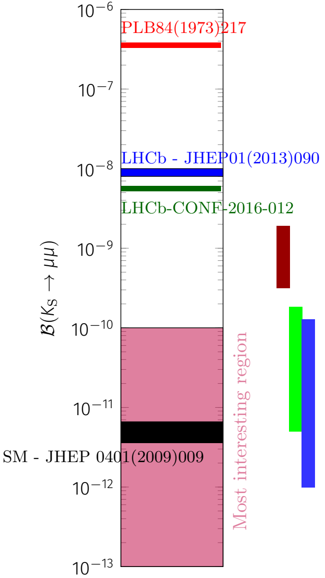


- Upgraded detector for 40 MHz full readout
- $\mathcal{L} = 10^{33} cm^{-2} s^{-1} \Rightarrow$ about 5 fb^{-1} per year

- L0 hardware trigger is removed in Upgrade
- Hlt1 run directly on collision data

Fundamental step forward for strange physics!

$K_S^0 \to \mu^+\mu^-$ prospects



Future sensitivity to $K_S^0 \to \mu^+\mu^-$

- 8 fb^{-1} Run II - $[4 \cdot 10^{-10}, 2 \cdot 10^{-9}]$
- 23 fb^{-1}- $[4 \cdot 10^{-12}, 2 \cdot 10^{-10}]$
- 100 fb^{-1}- $[10^{-12}, 10^{-10}]$

- Possible change towards higher value of SM expectation
- Approach interesting region in Run II
- Probe SM in Upgrade

Sensitivity to $K^0_\mathrm{S} \to \pi^0\mu^+\mu^-$

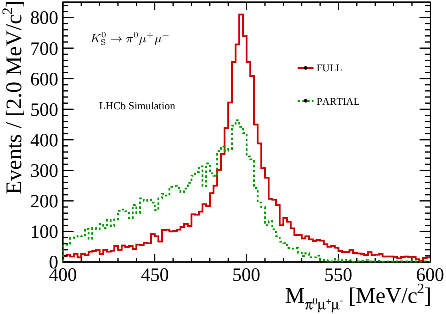
LHCb-PUB-2016-017

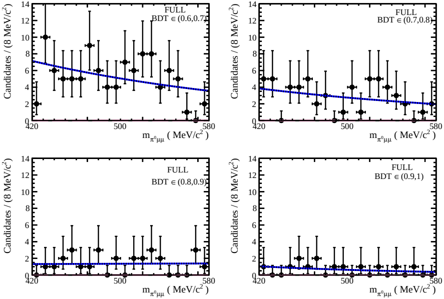
- $K^0_\mathrm{L} \to \pi^0\mu^+\mu^-$ very sensitive to physics beyond the SM, e.g. extra-dimensions [M. Bauer et al. JHEP 09(2010)017]
- SM prediction with large uncertainty
  $\mathcal{B}_{SM}(K^0_\mathrm{L} \to \pi^0\mu^+\mu^-) = \{1.4 \pm 0.3, 0.9 \pm 0.2\} \times 10^{-11}$
- Limited by knowledge of ChPT parameter $|a_S|$ extracted from $K^0_\mathrm{S} \to \pi^0\mu^+\mu^-$ branching fraction
- $\mathcal{B}(K^0_\mathrm{S} \to \pi^0\mu^+\mu^-) = (2.9^{+1.5}_{-1.2} \pm 0.2) \times 10^{-9}$ measured by NA48 Collaboration
  [J.R. Batley et al. PLB599 (2011) 197]

Sensitivity to $K^0_S \to \pi^0 \mu^+ \mu^-$

LHCb-PUB-2016-017

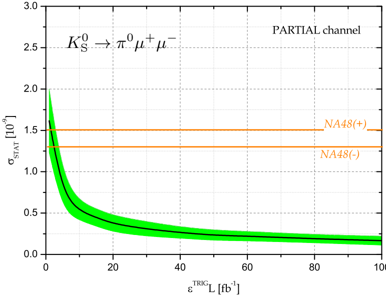
- Studied sensitivity of LHCb to this channel in Run II and Upgrade scenarios
- Difficult reconstruction due to soft π^0
- Double strategy: without π^0 (Partial) and with π^0 reconstructed from γ pairs
- Combinatorial background estimated with real data TIS events
- Peaking backgrounds studied with MC: none found to contribute in LHCb

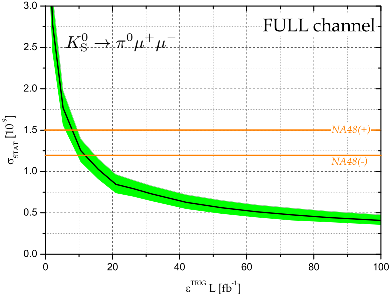




Sensitivity to $K^0_S \to \pi^0\mu^+\mu^-$

- Statistical uncertainty on $\mathcal{B}(K^0_S \to \pi^0\mu^+\mu^-)$ as a function of luminosity times trigger efficiency
- LHCb will be competitive with NA48 for trigger efficiencies of $\sim 50\%$ or larger





$K^0 \to \ell^+\ell^-\ell^+\ell^-$

- $K^0 \to \ell^+\ell^-\ell^+\ell^-$ short distance sensitive to NP
- Dominated by the long distance contribution uncertainty
- Interference of $\mathcal{A}(K^0_\mathrm{S} \to \ell^+\ell^-\ell^+\ell^-)$ and $\mathcal{A}(K^0_\mathrm{L} \to \ell^+\ell^-\ell^+\ell^-)$ would give a measurement of the sign of $\mathcal{A}(K^0_\mathrm{L} \to \gamma\gamma)$ which is a stringent test of CKM

  [D'Ambrosio et al - EPJC73(2013)2678]
- $K^0_\mathrm{L} \to \ell^+\ell^-\ell^+\ell^-$ studied by different experiments
- No experimental constraints on K^0_S modes
- K^0_S four lepton decays very suppressed in SM

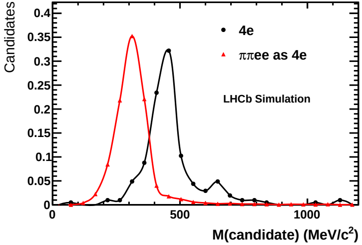
$$\mathcal{B}(K^0_\mathrm{S} \to e^+e^-e^+e^-) \sim 10^{-10}$$
$$\mathcal{B}(K^0_\mathrm{S} \to \mu^+\mu^-e^+e^-) \sim 10^{-11}$$
$$\mathcal{B}(K^0_\mathrm{S} \to \mu^+\mu^-\mu^+\mu^-) \sim 10^{-14}$$

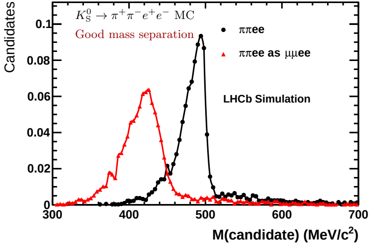
- Sensitive to NP at same order of SM

Sensitivity to $K_S^0 \to \pi^+\pi^-e^+e^-$

- $K_S^0 \to \pi^+\pi^-e^+e^-$ is normalisation, control and background channel for $K_S^0 \to \ell^+\ell^-\ell^+\ell^-$
- Sensitivity study at LHCb with MC simulations
- Standard selection with four displaced good quality tracks
- Particle identification and geometry requirements to suppress the background
- Both TIS and TOS trigger strategy devised: $\varepsilon \sim 0.2\%$, limited by L0 trigger
- $\mathcal{B}(K_S^0 \to \pi^+\pi^-e^+e^-) = (4.79 \pm 0.15) \times 10^{-5}$ (PDG average)

With Run I conditions expected $N = 120^{+280}_{-100}$ events per fb^{-1} of 8 TeV data on top of about $3 \cdot 10^3$ background events. No multivariate selection applied.





LHCb-PUB-2016-016

Sensitivity to $K^0_S \to \pi^+\pi^- e^+ e^-$

- Dedicated Hlt2 trigger line deployed in Run II
- Still limited by Hlt1 and L0

- Upgrade trigger will improve the efficiency on this and related channels sensibly
- In the ideal scenario of $\sim 100\%$ w.r.t. offline selection

$$N_{exp} = 5 \cdot 10^4 \text{ per fb}^{-1}$$

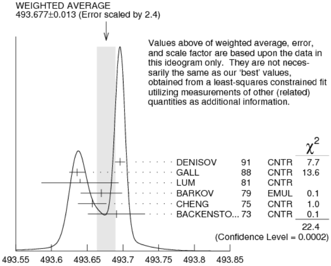
- Similar efficiencies are expected for the $K^0_S \to \ell^+\ell^-\ell^+\ell^-$ rare channels
- Single event sensitivities of order $9.6 \cdot 10^{-10}$ per each fb^{-1} in Upgrade conditions

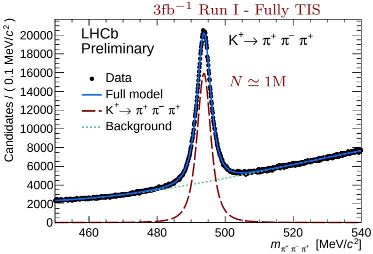
Prospects for charged kaons

- Enormous K^+ production but small acceptance
- Run I has 1 M $K^+ \to \pi^+\pi^-\pi^+$ fully TIS
- Measurement of the charged kaon mass is under way to solve long standing disagreement
- With full software trigger $O(10^{-10})$ single event sensitivity per fb^{-1} obtainable
- $K^+ \to \pi^+\mu^-\mu^+$ and $K^+ \to \pi^+e^-e^+$ with $\mathcal{B} \sim 10^{-7}$ become accessible

Still possible improvements

- Use of downstream tracks increasing decay length acceptance
- Use of K^+ track in VELO to constrain partially reconstructed decays †





† A. Contu LHCb-PUB-2014-032

Summary and conclusions

- *LHCb expanding its physics reach towards strange physics complementary to the core program*
- Encouraging Run I results on $K^0_S \to \mu^+\mu^-$, $\Sigma^+ \to p\mu^+\mu^-$ and $\eta^{(\prime)} \to \pi^+\pi^-$
- Large samples available already on tape
  fully exploiting existing data
- **LHCb major player for K^0_S and hyperons rare decays**
- Complementary to K^0_L and K^+ dedicated experiments
- Run II giving new results with improved trigger
- Upgrade trigger will allow unprecedented sensitivities on many channels

Backup

Fit to the invariant mass distribution

- Signal shape described as Hypatia function used with fixed parameters (only mean and resolution floating)*
  - Resolution and mean calibrated with $K^+ \to \pi^+\pi^-\pi^+$ Data/MC ratio
  - Signal resolution left free to vary in the fit with gaussian constraint in final fits

- Background described as modified ARGUS function

$$f(m, m_0, p, c) = m \left(\frac{m^2}{m_0^2} - 1 \right)^p e^{c \frac{m}{m_0}} \quad (1)$$

where m_0 is the threshold mass typically of the order of the sum of the daughters masses; p and c are free parameters.

*D. Martinez Santos, F. Dupertuis, Nucl.Instrum.Meth. A764 (2014) 150-155