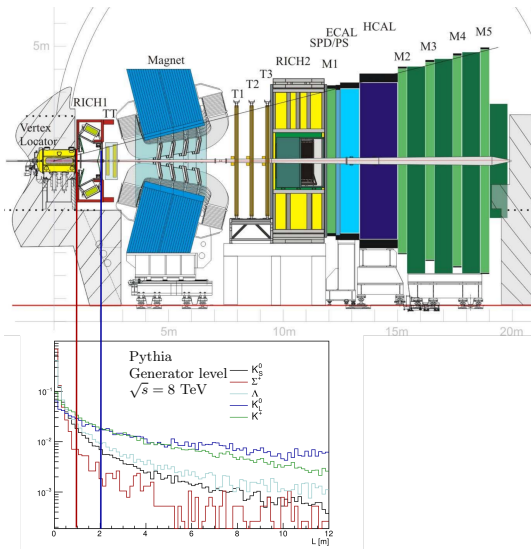# Rare strange decays at LHCb
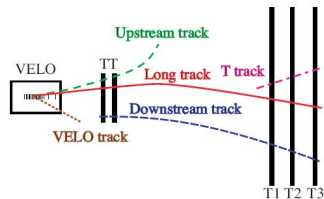
Francesco Dettori
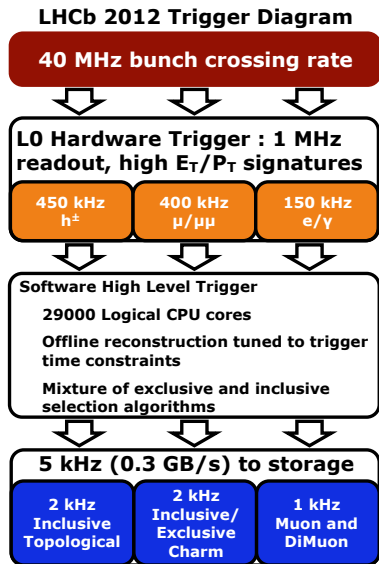
University of Liverpool

UK Flavour 2017
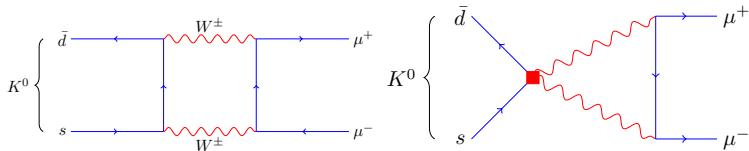4-6 September 2017 IPPP, Durham

- 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 2012 Trigger Diagram

40 MHz bunch crossing rate

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

| 450 kHz $h^{\pm}$ | 400 kHz $\mu/\mu\mu$ | 150 kHz e/γ |

Software High Level Trigger

29000 Logical CPU cores

Offline reconstruction tuned to trigger time constraints

Mixture of exclusive and inclusive selection algorithms

5 kHz (0.3 GB/s) to storage

| 2 kHz Inclusive Topological | 2 kHz Inclusive/ Exclusive Charm | 1 kHz Muon and DiMuon |

- LHCb trigger designed for heavy flavours
- Muon (hadron) L0 trigger require $p_T > [1-5]GeV$
- **Too hard for primary strange hadrons**

- Hlt1 and Hlt2 are software and customizable
- No dedicated triggers in 2011, added a $K_S^0 \to \mu^+\mu^-$ 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

Search for $K_S^0 \to \mu^+ \mu^-$ decays

- $K_L^0 \to \mu^+ \mu^-$ is the "father" of flavour physics motivating the need for charm quark and GIM mechanism
- $K_S^0 \to \mu^+ \mu^-$ in addition suppressed by CPV
- SM prediction $\mathcal{B}(K_S^0 \to \mu^+ \mu^-) = (5.1 \pm 1.5) \cdot 10^{-12}$
  [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
- Best limit before LHCb was $\mathcal{B}(K_S^0 \to \mu^+ \mu^-) < 3.1 \cdot 10^{-7}$ at 90% CL at CERN PS in 1973 [S. Gjesdal et al. PLB44(1973)217]
- Recent theoretical interest following LHCb results: possibility to study the interference of K_L^0 and K_S^0 to two muons [D'Ambrosio et al. hep-ph/1707.06999]
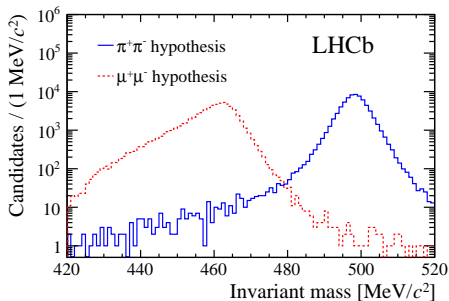
Search for $K_S^0 \to \mu^+ \mu^-$ decays

Selection strategy

- Common selection of $K_S^0 \to \mu^+ \mu^-$ and $K_S^0 \to \pi^+ \pi^-$, control and normalisation channel as well as main background
- Veto for $\Lambda \to p \pi^-$ and particle identification against $K^* \to K\pi$ and other backgrounds
- Two multivariate operators to fight different backgrounds:
  - ⋆ Dedicated multivariate particle identification algorithm developed
  - ⋆ BDT to fight combinatorial background
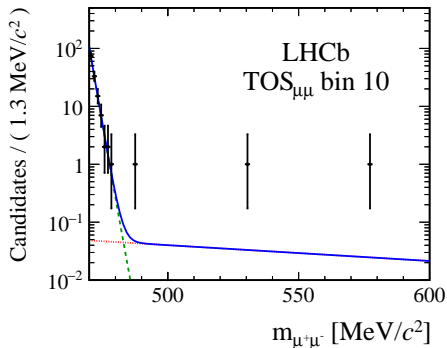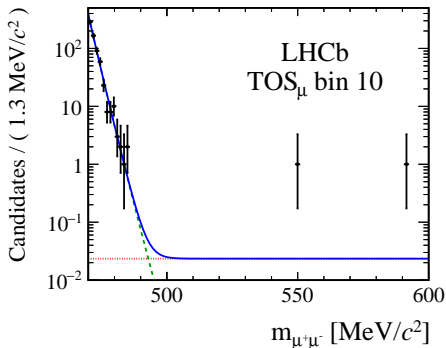
Trigger strategy

- Two categories based different trigger paths

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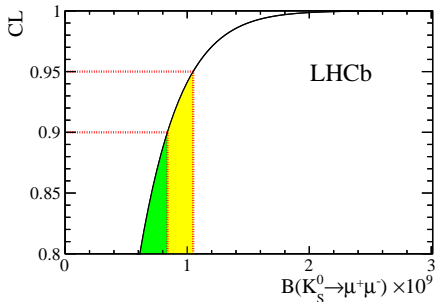- **No excess of events is observed with respect to background expectations**

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

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

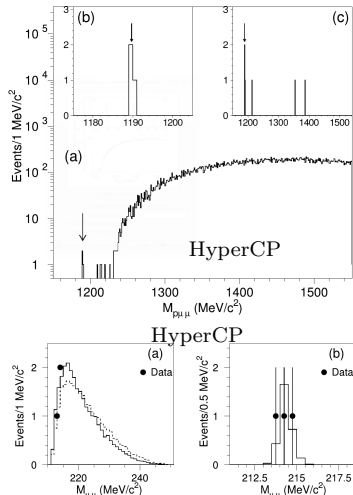$$\mathcal{B}(K_S^0 \to \mu^+\mu^-) < 0.8(1.0) \times 10^{-9} \text{ at } 90 \ (95\%) \text{ CL}$$

- Factor 400 improvement with respect to the best limit before LHCb

- $\Sigma^+ \to p\mu^+\mu^-$ 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]

- 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 $m_X^0 = 214.3 \pm 0.5$ MeV
  $\mathcal{B}(\Sigma^+ \to pX^0(\to \mu\mu)) = (3.1^{+2.4}_{-1.9} \pm 5.5) \cdot 10^{-8}$

- Large theoretical and experimental attention (see backup) but no other direct search for $\Sigma^+ \to p\mu^+\mu^-$

HyperCP

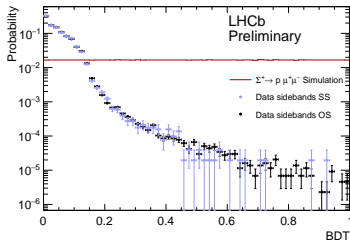HyperCP

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

General analysis strategy

Sample and selection:

- Full 2011+2012 statistics, luminosity 3 fb^{-1}
- Decays reconstructed with long tracks (i.e. decays in VELO)
- Prompt decays (no displacement of the dimuon pair)

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)
- Soft pre-selection to reduce dataset
- Cut on BDT and PID to remove most of the background
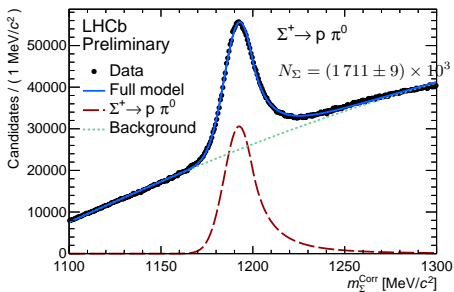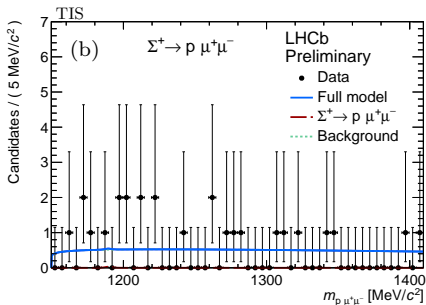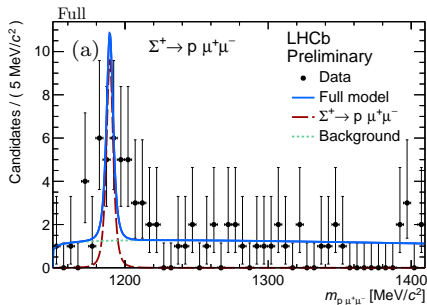- Explicit veto of $\Lambda \to p\pi$ background, no other peaking background contributes

Normalisation

- No fully charged final state available in the Σ^+ to normalize
- Use high branching fraction $\Sigma^+ \to p\pi^0$ ($\mathcal{B} = (51.57 \pm 0.30)\%$)

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

$$= \alpha N_{\Sigma^+ \to p\mu^+\mu^-}$$

- Selection for $\Sigma^+ \to p\pi^0$ with $\pi^0 \to \gamma\gamma$ (resolved clusters) from calorimeter

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 BR)

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

- 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**
- Long-awaited paper with full normalisation is in preparation

LHCb Run II and Upgrade

LHCb 2015 Trigger Diagram

40 MHz bunch crossing rate

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

| 450 kHz $h^{\pm}$ | 400 kHz $\mu/\mu\mu$ | 150 kHz e/γ |

Software High Level Trigger

Partial event reconstruction, select displaced tracks/vertices and dimuons

Buffer events to disk, perform online detector calibration and alignment

Full offline-like event selection, mixture of inclusive and exclusive triggers
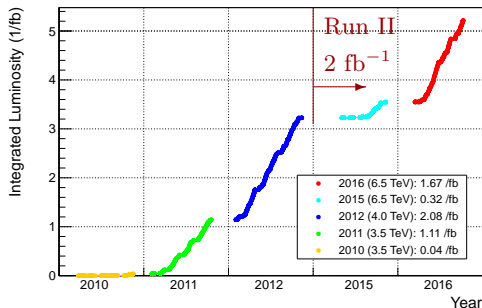
12.5 kHz (0.6 GB/s) to storage

- 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

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
- $K_S^0 \to \mu^+\mu^-$ see later
- Different other rare hyperon decay searches possible ($\Sigma^+ \to pe^+e^-$, $\Lambda^0 \to p\pi^- e^+e^-$, LFV, etc)

LHCb Upgrade data-taking

LHCb Upgrade Trigger Diagram

**30 MHz inelastic event rate
(full rate event building)**

⬇ ⬇ ⬇

Software High Level Trigger

Full event reconstruction, inclusive and
exclusive kinematic/geometric selections

⬇

Buffer events to disk, perform online
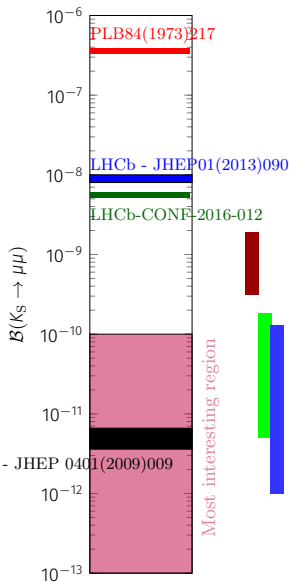detector calibration and alignment

⬇

Add offline precision particle identification
and track quality information to selections

Output full event information for inclusive
triggers, trigger candidates and related
primary vertices for exclusive triggers

⬇ ⬇ ⬇

2-5 GB/s to storage

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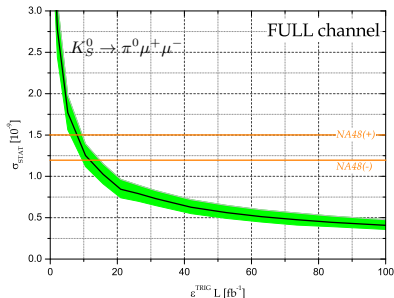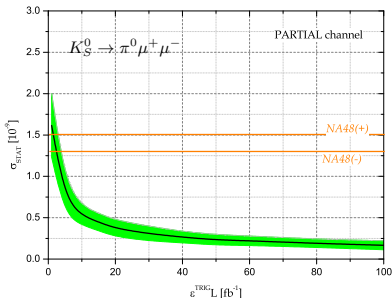
$K^0_S \to \mu^+ \mu^-$ prospects

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

- 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

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LHCb

- $K_L^0 \to \pi^0 \mu^+ \mu^-$ very sensitive to physics beyond the SM, e.g. extra-dimensions [M. Bauer et al. JHEP 09(2010)017]

- SM prediction with large uncertainty
  $\mathcal{B}_{SM}(K_L^0 \to \pi^0 \mu^+ \mu^-) = \{1.4 \pm 0.3, 0.9 \pm 0.2\} \times 10^{-11}$

- Limited by knowledge of ChPT parameter $|a_S|$ extracted from $K_S^0 \to \pi^0 \mu^+ \mu^-$ branching fraction

- $\mathcal{B}(K_S^0 \to \pi^0 \mu^+ \mu^-) = (2.9^{+1.5}_{-1.2} \pm 0.2) \times 10^{-9}$ measured by NA48 Collaboration
  [J.R. Batley et al. PLB599 (2011) 197]

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

- 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
- Statistical uncertainty on $\mathcal{B}(K_S^0 \to \pi^0 \mu^+ \mu^-)$ 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 $\mathcal{A}(K_S^0 \to \ell^+\ell^-\ell^+\ell^-)$ and $\mathcal{A}(K_L^0 \to \ell^+\ell^-\ell^+\ell^-)$ would give a measurement of the sign of $\mathcal{A}(K_L^0 \to \gamma\gamma)$ which is a stringent test of CKM
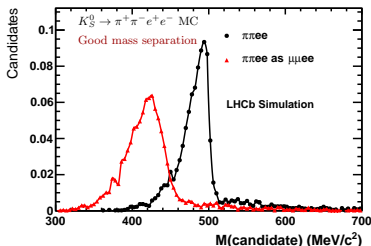 [D'Ambrosio et al - EPJC73(2013)2678]

- $K_L^0 \to \ell^+\ell^-\ell^+\ell^-$ studied by different experiments but no experimental constraints on K_S^0 modes
  $$\mathcal{B}(K_S^0 \to e^+e^-e^+e^-) \sim 10^{-10} \quad \mathcal{B}(K_S^0 \to \mu^+\mu^-e^+e^-) \sim 10^{-11} \quad \mathcal{B}(K_S^0 \to \mu^+\mu^-\mu^+\mu^-) \sim$$

- 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

- 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.

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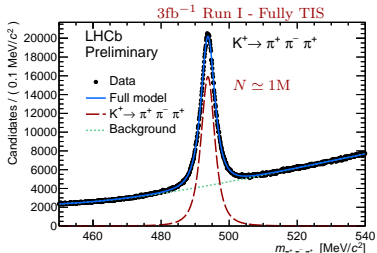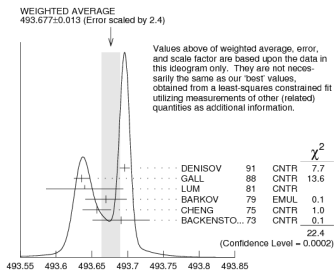
$$N_{exp} = 5 \cdot 10^4 \text{ per fb}^{-1}$$

- Similar efficiencies are expected for the $K_S^0 \to \ell^+ \ell^- \ell^+ \ell^-$ rare channels

- Single event sensitivities of order $9.6 \cdot 10^{-10}$ per each fb^{-1} in Upgrade conditions
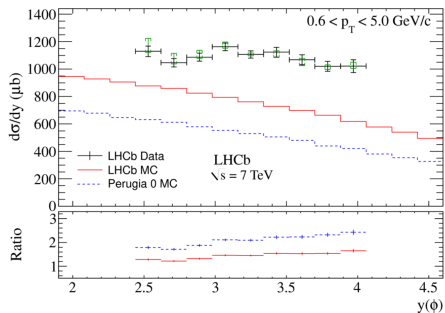
Prospects for charged kaons

- 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 [†]

WEIGHTED AVERAGE
493.677±0.013 (Error scaled by 2.4)

Values above of weighted average, error, and scale factor are based upon the data in this ideogram only. They are not necessarily the same as our 'best' values, obtained from a least-squares constrained fit utilizing measurements of other (related) quantities as additional information.

			χ^2
DENISOV	91	CNTR	7.7
GALL	88	CNTR	13.6
LUM	81	CNTR	
BARKOV	79	EMUL	0.1
CHENG	75	CNTR	1.0
BACKENSTO...	73	CNTR	0.1
			22.4

(Confidence Level = 0.0002)

493.55 493.6 493.65 493.7 493.75 493.8 493.85

3fb^{-1} Run I - Fully TIS

LHCb Preliminary

$K^+ \to \pi^+\pi^-\pi^+$

$N \simeq 1M$

- Data
- Full model
- $K^+ \to \pi^+\pi^-\pi^+$
- Background

[†] A. Contu LHCb-PUB-2014-032

Kaon physics from ϕ decays

- Huge ϕ production at LHC
- Exploit $\phi \to K^+ K^-$ decays in which one of the kaons is fully reconstructed
- Study final state of second kaon, also partially reconstructed thanks to the ϕ constraint
- $O(10^{10})$ tagged $\phi \to KK$ decays per year in the upgrade [*]
- For example study $K^+ \to e\nu$ (tag also initial Kaon leg with RICH1)

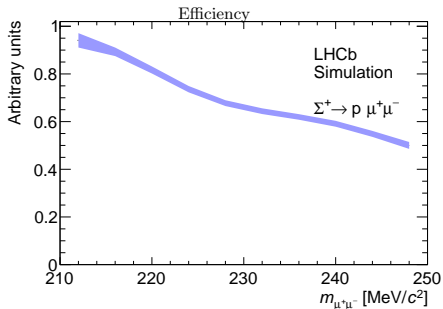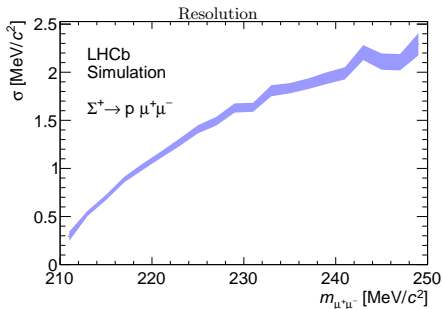[*]See talk by Vava Gligorov, Rare'n'Strange workshop https://indico.cern.ch/event/590880/

- Not really rare but very interesting!
- Determination of V_{us} important for CKM unitarity checks
- Sensitive to new physics at 10 TeV scale
- Large number of observables: branching fractions, asymmetries, lepton universality
- LHCb has huge potential to contribute given the high rates, with the drawback of the open kinematics
- As example: $K_S \to \pi\mu\nu$, $K_S \to \pi\pi\mu\nu$ (no results so far!) and contribute to the charged ones
- Large interest also on hyperon semi-leptonic decays where LHCb could be one in a kind
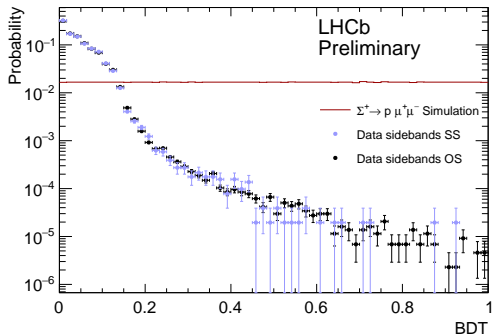
- Bring together LHCb and the theoretical community on these new topics
- Goals:
  - ⋆ boost theoretical interest on measurements in progress
  - ⋆ explain LHCb capabilities
  - ⋆ build up a shopping list
- 1st at CERN, 2nd at Santiago de Compostela with large attendence (https://indico.cern.ch/event/590880/)
- A third workshop will be organized soon

Summary and conclusions

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

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
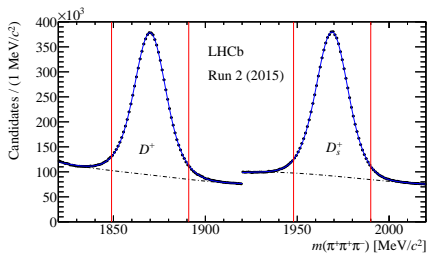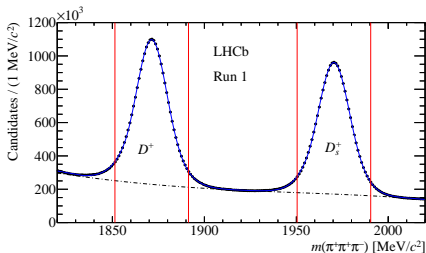
Multivariate selection: BDT

- 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, ...

- 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 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

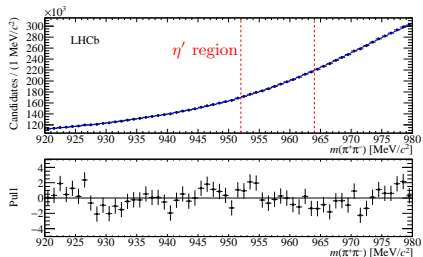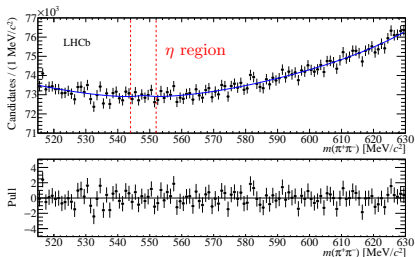# Search for CP violating strong decays $\eta' \to \pi^+\pi^-$

- 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

Search for $K_S^0 \to \mu^+ \mu^-$ decays

- Best limit before LHCb was $\mathcal{B}(K_S^0 \to \mu^+ \mu^-) < 3.1 \cdot 10^{-7}$ at 90% CL at CERN PS in 1973 [S. Gjesdal et al. PLB44(1973)217]

- In Run I about 10^{13} K_S^0 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: $\mathcal{B}(K_S^0 \to \mu^+ \mu^-) < 9 \cdot 10^{-9}$ at 90% CL

- Updated analysis with 2fb^{-1} 8 TeV and combined with the first one
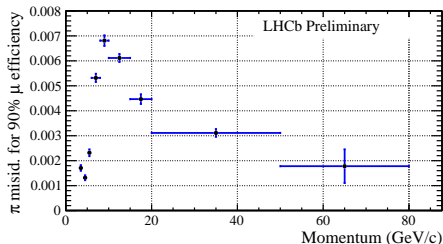
$K_S^0 \to \mu^+ \mu^-$

Two multivariate operators to fight different backgrounds

Dedicated multivariate particle identification algorithm developed

- Trained on $K_S^0 \to \pi^+ \pi^-$ 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 $K_S^0 \to \pi^+ \pi^-$ data proxy for signal and right data sideband for background

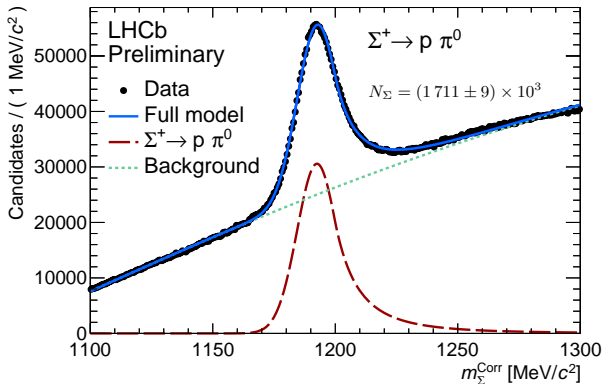- Geometric and kinematic variables as input

- Trained separately per trigger category

- Search performed in bins of BDT and trigger category

$$\mathcal{B}(K^0_S \to \mu^+\mu^-) = \mathcal{B}(K^0_S \to \pi^+\pi^-) \cdot \frac{\varepsilon^{\pi\pi}}{\varepsilon_i^{\mu\mu}} \cdot \frac{N_i^{\mu\mu}}{N^{\pi\pi}} = \alpha_i N_i^{\mu\mu}$$
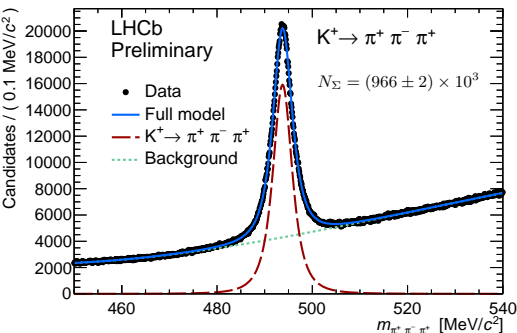
- NoBias trigger used for $K^0_S \to \pi^+\pi^-$ (of known prescale of $\sim 3 \cdot 10^{-7}$)
- Efficiencies from MC but calibrated with data corrections
- Total systematic uncertainty of $4-5\%$ on the normalisation depending on the bin
- Final fit performed with different background shapes for an absolute uncertainty of 4×10^{-11}

- 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

- 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

- 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 $B^+ \to J/\psi K^{*+}$ 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

LHCb Preliminary

$K^+ \to \pi^+\pi^-\pi^+$

$N_\Sigma = (966 \pm 2) \times 10^3$

- Data
- Full model
- $K^+ \to \pi^+\pi^-\pi^+$
- Background

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%