Perspectives on the search of $\Sigma^+ \to p\mu^+\mu^-$ at LHCb

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Rare'n'Strange
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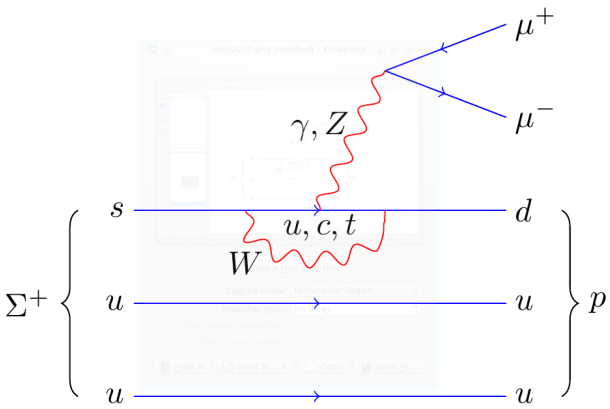
Introduction

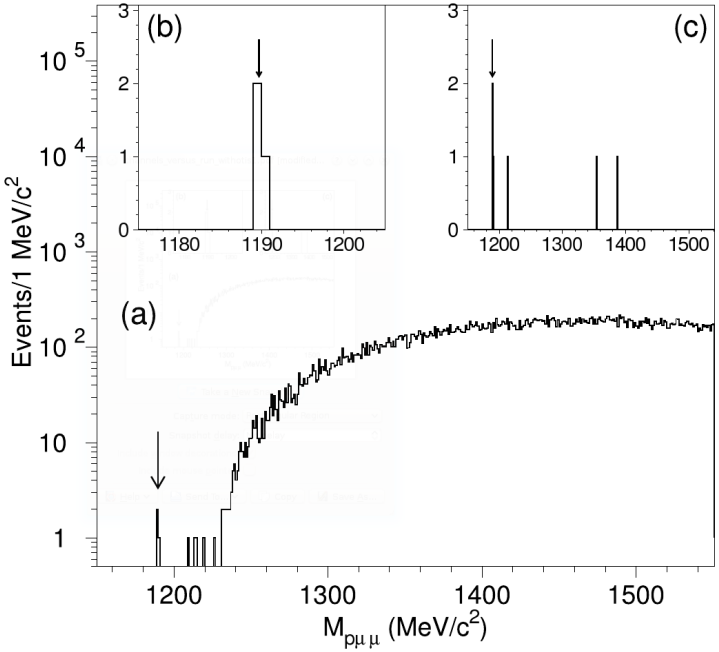
$\Sigma^+ \to p\mu^+\mu^-$ in the Standard Model

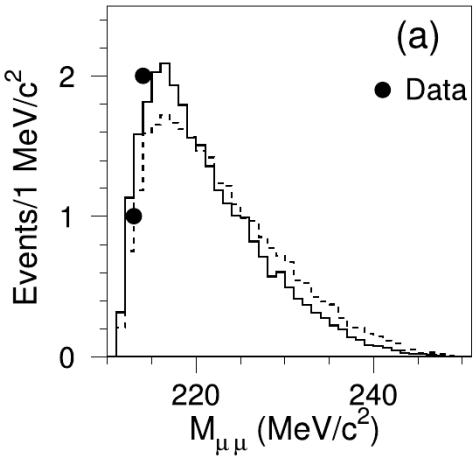
- $\Sigma^+ \to p\mu^+\mu^-$ is a very rare FCNC
- Short distance SM branching fraction is $O(10^{-12})$
- Dominated by long distance contributions:
  $1.6 \cdot 10^{-8} < \mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) < 9.0 \cdot 10^{-8}$ [Phys.Rev. D72 (2005) 074003]

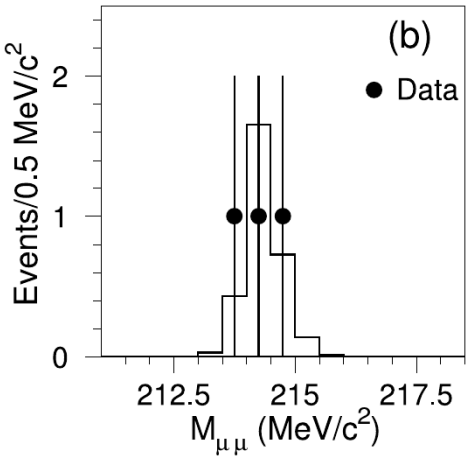


The HyperCP evidence

- 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 had wide relevance since all the **3** observed signal events have the same dimuon invariant mass: pointing towards a $\Sigma^+ \to pX^0(\to \mu\mu)$ decay







Interpretations

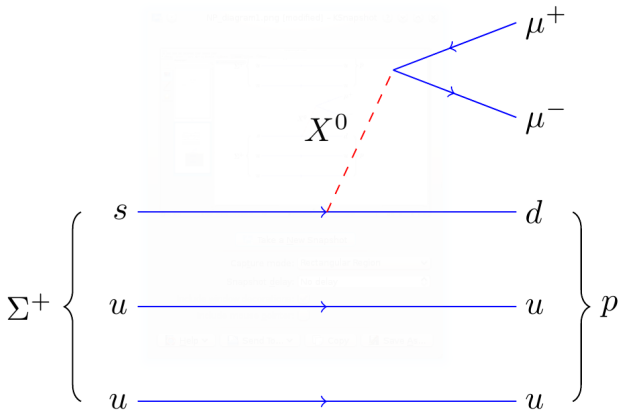
Model independent:

- Assumed existence of X^0 particle of mass 214 MeV
- Scalar and vector couplings exluded by $K^+ \to \pi^+\mu^+\mu^-$
- Bounds from K^0 mass difference and other strange processes
- Dominated by pseudo-scalar coupling

[N. G Deshpande et al. Phys.Lett. B632 (2006) 212-214] [X. He et al. - Phys.Lett. B631 (2005) 100-108]

Particular models:

- Light pseudoscalar or scalar sgoldstinos [Gorbunov and Rubakov Phys. Rev. D 73, 035002 (2006)]
- Light pseudoscalar Higgs [X. He et al Phys. Rev. Lett. 98, 081802 (2007)]



Tests of the X^0 hypothesis

- The existence of a light neutral particle decaying into two muons would be striking and have consequences everywhere
- Specific tests of this hypothesis:
  - ⋆ CLEO Collaboration: "Search for Very Light CP-Odd Higgs Boson in Radiative Decays of Upsilon(S-1)" [Phys.Rev.Lett. 101 (2008) 151802]
  - ⋆ Searches for $K^0(L) \to \pi^0\pi^0 X$ at KTeV and E391a [Phys.Rev.Lett. 107 (2011) 201803] [Phys.Rev.Lett. 102 (2009) 051802]
- Also: Babar, Belle, D0 searches for $A^0 \to \mu\mu$
- Within LHCb: search for $B \to \mu\mu\mu\mu$ [Phys. Rev. Lett. 110, 211801 (2013)]
- The final word is to search for the $\Sigma^+ \to p\mu^+\mu^-$ itself

Why searching for $\Sigma^+ \to p\mu^+\mu^-$ at LHCb

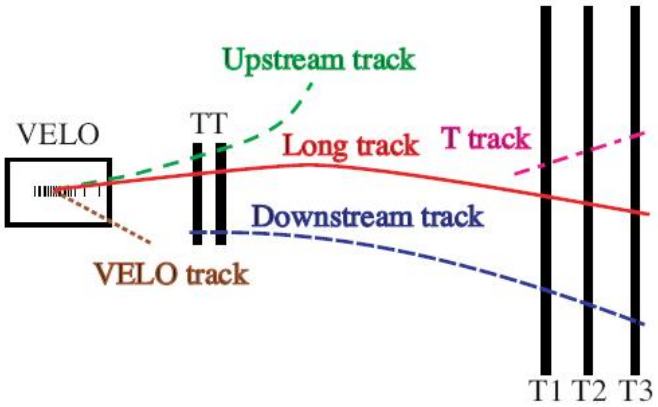
- Huge Σ production at LHC pp collisions (40% of events contain one)
- Forward production with very little transverse momentum
- $c\tau = 2.4$ cm and large boost: large separation from primary interaction
- Very good PID for both muons and protons
- Small resolution

$\Rightarrow$ Some of these "pros" are also "cons"

Note: search at LHCb also directly suggested in [H. Park - JHEP10(2010)052]

Analysis goals and strategy

- Main goal is to confirm or disprove the HyperCP evidence for the decay and to study the dimuon invariant mass
- Signal channel signature is very clear but very difficult to trigger and reconstruct due to low momenta
- Secondary goal is to measure the branching fraction:
  - Only possible normalisation channel: $\Sigma^+ \to p\pi^0(\to e^+e^-\gamma)$
    $\mathcal{B} = 51.57\% \times 1.174\% = 6 \times 10^{-3}$ (with undetected photon)
- Preselection common to signal, control and norm channels
- Reconstruction based on Long tracks, but also Dowstream approach is feasible: see talk by A. Contu.



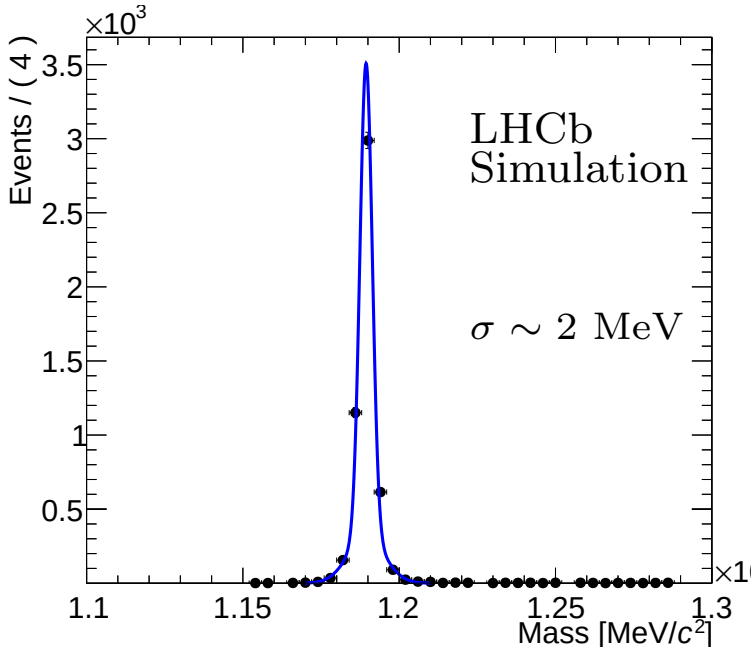
Trigger

- Particles from strange hadrons decays can be very soft, in particular in the transverse direction
- Presently no dedicated trigger is present (See also C. Fitzpatrick talk)
- However at LHC kaons and sigmas are produced copiously in the underlying event
- Events triggered independently of the signal (TIS) will be exploited

Preselection

- Aim is to reduce the sample to a manageable level
- Further multivariate selection is under development

μ, p	Track $\chi^2 < 3$, GhostProb< 0.3
μ	minIP$\chi^2 > 4$
p	PIDp > 5
e	PIDe > 2
	min IP $\chi^2 > 9$
$p\mu\mu$, pee	$\lvert m_{p\mu\mu} - m_{\Sigma^+}\rvert < 500$ MeV
	DOCA< 2mm
	Vtx $\chi^2 < 25$
	$p_{\mathrm{T}} > 500$ MeV
	DIRA> 0.9
	IP $\chi^2 < 36$
	Vtx $\chi^2 < 36$
	$\tau > 6$ ps
	$p_{\mathrm{T}} > 500$ MeV

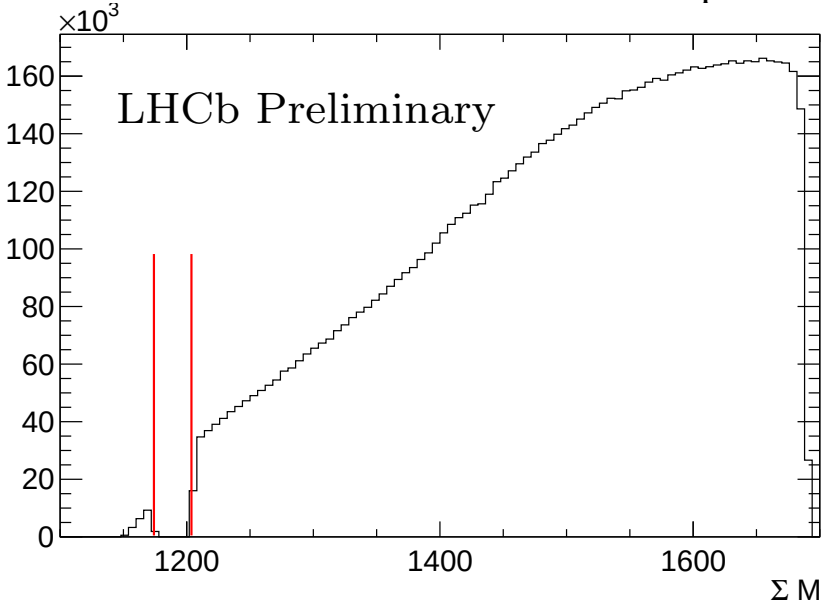


Note: mass resolution is very good as daughter particles basically saturate the Σ mass.

Backgrounds

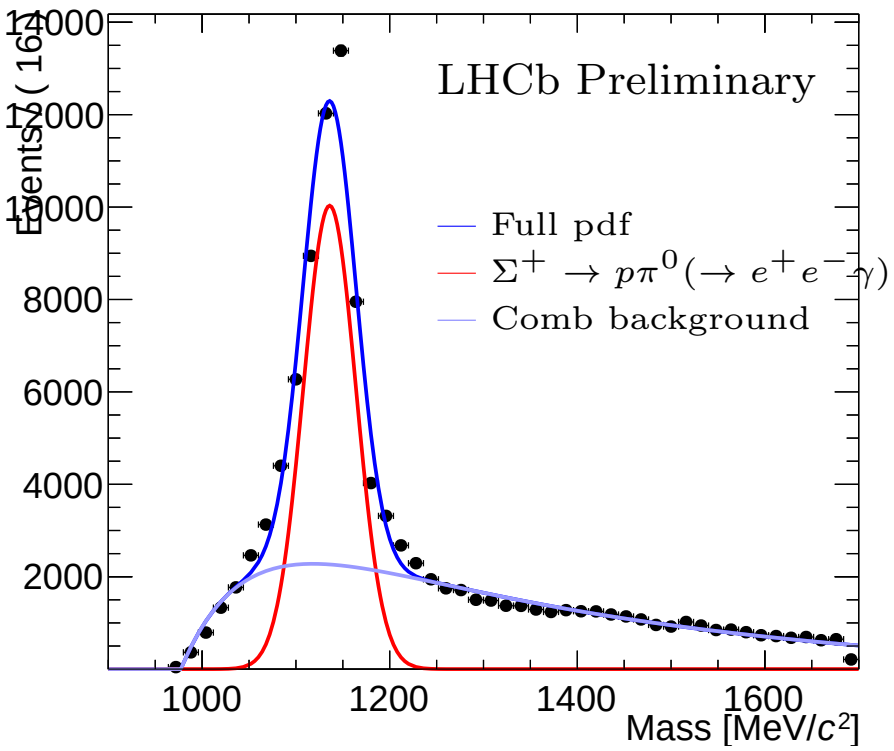
- Combinatorial background:
  - Largely reduced by particle identification cuts
  - To be estimated by fit to the invariant mass sidebands
- Background with two of the particles coming from the same decay:
  - $\Lambda^0 \to p\pi^-$
  - $K^0_S \to \pi^+\pi^-$
  - $\rho^0, \omega \to \pi^+\pi^-$
- Background from exclusive channels
  - $K^+ \to \pi^+\pi^-\pi^+$
  - $K^+ \to \pi^+\pi^-\mu^+\nu$
  - $K^+ \to \pi^+\mu^-\mu^+$

$p\mu\mu$ invariant mass distribution after preselection with signal region blind



Normalisation

- Considering the 2011+2012 LHCb dataset
- Additional cleaning cuts but not optimised final selection



$N_{\Sigma^+ \to p\pi^0(\to e^+e^-\gamma)} = 45\text{k}$ for about $3 fb^{-1}$

Sensitivity

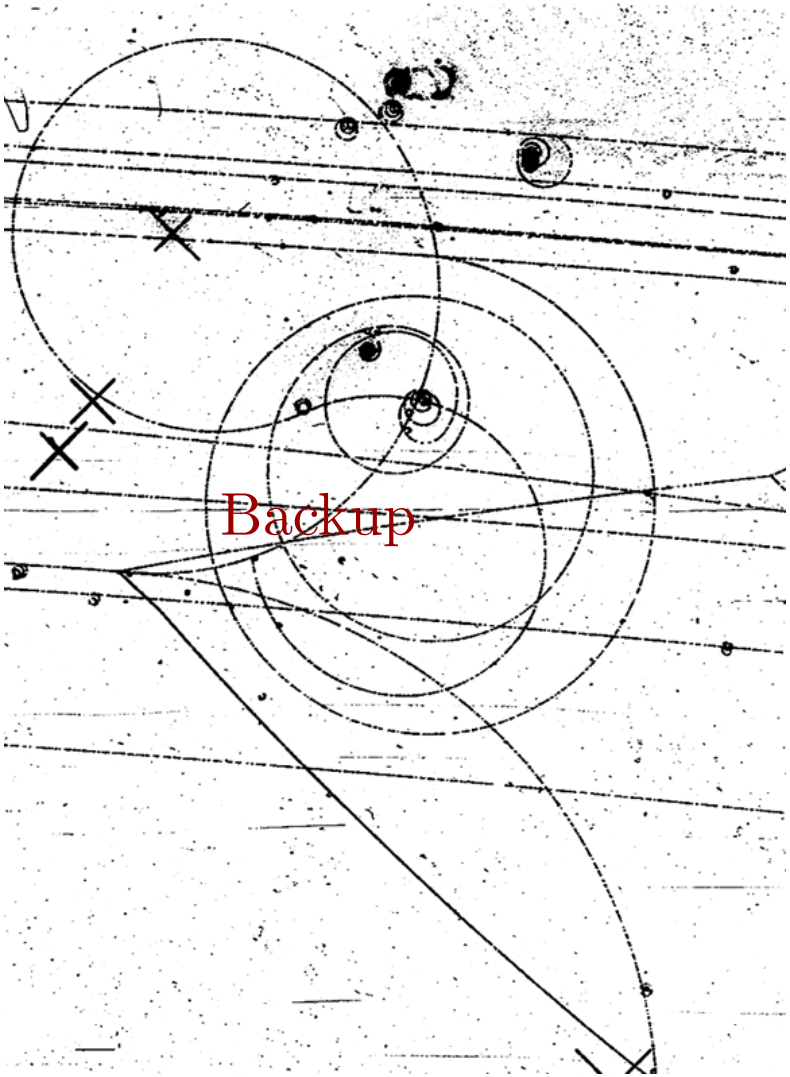
$$\mathcal{B} = \frac{\varepsilon_{\text{norm}}}{\varepsilon_{\Sigma^+\to p\mu^+\mu^-}} \frac{\mathcal{B}(\Sigma^+ \to p\pi^0(\to e^+e^-\gamma))}{N_{\Sigma^+\to p\pi^0(\to e^+e^-\gamma)}} \times N_{\Sigma^+\to p\mu^+\mu^-} = \alpha \times N_{\Sigma^+\to p\mu^+\mu^-}$$

- Assuming same trigger efficiency
- Assuming phase space signal
- The reconstruction and selection efficiency ratio is about 0.04 due to the difficult reconstruction of very soft electrons
- Without optimisation of final selection

A single event sensitivity of $\sim 5 \times 10^{-9}$ can be reached

Conclusions

- Search for $\Sigma^+ \to p\mu^+\mu^-$ at LHCb just started
- Optimisation of analysis and specific background evaluations to be done
- Normalisation channel is clearly observed with large yield
- Single event sensitivity could be as low as $\sim 5 \times 10^{-9}$



Backup

- Generated MC is phase space: the q^2 distribution could be different, but it cannot change much as kinematically very limited.
- SM distribution: