Evidence for the Rare Decay $\Sigma^+ \to p\mu^+\mu^-$

JC116 Paper

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ABSTRACT

1. A search for the rare decay $\Sigma^+ \to p\mu^+\mu^-$ is performed using pp collision data recorded by the LHCb experiment at center-of-mass energies $\sqrt{s} = 7$ and $8TeV$, corresponding to an integrated luminosity of $3fb^{-1}$.
2. An excess of events is observed with respect to the background expectation, with a signal significance of 4.1 standard deviations.
3. NO significant structure is observed in the dimuon invariant mass distribution, in contrast with a previous result from the HyperCP experiment.
4. The measured $\Sigma^+ \to p\mu^+\mu^-$ branching fraction is $(2.2^{+1.8}_{-1.3} \times 10^{-8})$, where statistical and systematic uncertainties are included, which is consistent with the standard model prediction.
5. Charge-conjugate process is implied in this search.

LHCb Detector

LHCb detector is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$

Figure: LHCb Detector

Analysis Strategy

1. The online event selection is performed by a trigger system, which consists of a hardware stage, based on information from the calorimeter and muon systems, followed by the two software stages
2. The final-state particles from the signal decay involved i this analysis typically have insufficient transverse momenta to satisfy the requirements of one or more trigger stages.
3. A trigger decision can thus be ascribed to the reconstructed candidate, the rest of the event or a combination of both; events triggered as such are defined respectively as triggered on signal (TOS), triggered independently of signal (TIS), and triggered on both.
4. While all the candidates passing the trigger selection are used in the search for $\Sigma^+ \to p\mu^+\mu^-$ decays, only the TIS candidates are used in the normalization channel $\Sigma^+ \to p\pi^0$.

Analysis Strategy

1. Candidate $\Sigma^+ \to p\mu^+\mu^-$ decays are selected by combining two good-quality oppositely charged tracks identified as muons with a third track identified as a proton.
2. The three tracks are required to form a secondary vertex (SV) with a good vertex-fit quality.The short lifetime estimated for the X^0 particle would result in a prompt signal in this search; hence, no attempt is made to distinguish the dimuon origin vertex from the SV of the Σ^+ baryon.
3. The measured Σ^+ candidate proper decay time is required to be greater than 6 ps, ensuring that the SV is displaced from any pp interaction vertex (primary vertex, PV).
4. The final-state particles are required to be inconsistent with originating from any PV in the event.
5. Only Σ^+ candidates with transverse momentum $(p_T >)0.5GeV/c$ and a decay topolgy consistent with a particle originating from the PV are retained.

Analysis Strategy

1. A candidate $\Sigma^+ \to p\mu^+\mu^-$ decay is considered only if its invariant mass,$m_{p\mu^+\mu^-}$, satisfies $|m_{p\mu^+\mu^-}| < 500 MeV/c^2$ where m_{Σ^+}, is the known mass of Σ^+ particle.

Source	Uncertainty
Selection efficiency	1%
BDT efficiency	6%
PID efficiency	28%
$\pi^0 efficiency$	10%
Trigger efficiency ratio	40%
Total	50%

Table: Relative systematic uncertainties associated with the normalization

Xin's Question

Could you explain how the conclusion of "no significant peak consistent with an intermediate particle is found" is drawn from the paper? (i.e. the logic, evidence, etc)?

Answer: The answer of this question is related with the Fig-2. The plot shows the peak for the decay $\Sigma^+ \to p\mu^+\mu^-$ in which the peak for the invariant mass of $m_{p\mu^+\mu^-}$ has been shown by reconstruction of the decay process. I think this is the reason they are saying that there is no significant peak consistent with an intermediate particle is found.

Ryuta's Question

Among the components of relative systematic uncertainties, contribution from the trigger efficiency ratio is largest (in Table.1) and we can find corresponding description in the middle of page 3.
Could you explain a bit about, why the number is so large ?

Answer: The ratio of the trigger efficiencies for the signal and normalization channels is estimated with simulated samples and cross-checked in data: the trigger efficiency is obtained for selected trigger lines from the overlap of TIS and TOS events in the normalization channel and is compared between data and simulation.
The small size of this overlap induces a 40% relative systematic uncertainty associated with the trigger efficiency ratio.

Kai's Suggestions

(1)[comment] this paper shows the sensitivity of searching similar rare decays at LHCb, based on this, many other similar channels could be done at LHCb, and other experiments such as BESIII, could not compete with LHCb.
(2)[suggestion] single-event sensitivity.
This concept is interesting and important, could you discuss more details on this, such as on the following aspects:
- why it is called single-event sensitivity, what is the meaning of it.?
- try to explain how they get the value 2.2×10^{-9} of single-event sensitivity on page 3 (right col. para. 2.)

Answer:

Suyu's Question

I have a statistical question here, How could we get different error for + and - ?

Answer: I think We can have asymmetric errors. I have found the answer on this website.
https://physics.stackexchange.com/questions/61228/asymmetric-uncertainties

The End