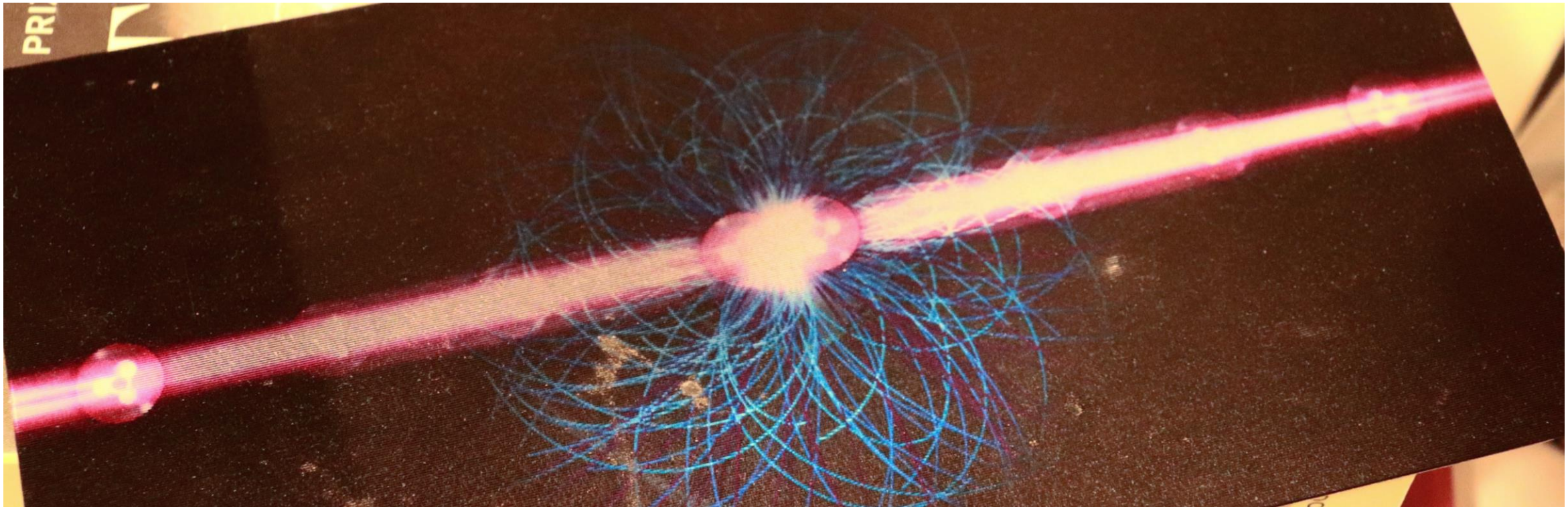

Search for multiquark states decaying to neutral strange particles in the ATLAS detector

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Introduction

- Ordinary matter consists of two quarks (mesons) or three quarks (baryons).

- However, particles consisting of more than three quarks are not forbidden by the Standard Model of Particle Physics. Searches are being carried out by various collaborations.[1]

- Search for possible multiquark states decaying to neutral kaon mesons (K_s^0) and lambda baryons (Λ^0) or its antiparticle ($\overline{\Lambda}^0$) with a data-driven approach using Minimum Bias Run 2 data (2015 for now), as no trigger exists for possible multiquark signals.

Tetraquark $\longrightarrow K_s^0 + K_s^0$

Pentaquark $\longrightarrow K_s^0 + \Lambda^0$

Hexaquark $\longrightarrow \Lambda^0 + \Lambda^0$

1. M. Karliner et al. "*Multiquark States*", Annual Review of Nuclear and Particle Science (2018), DOI: 10.1146/annurev-nucl-101917-020902

Background information

- Kaons decay channel: $K_s^0 \rightarrow \pi^+\pi^-$; Lambda decay channel: $\Lambda^0 \rightarrow p^+ \pi^-$

- Particle identification can be ambiguous, e.g, between p^+ and π^+ which contributes to ambiguity between K_s^0 and Λ^0. Thus, there is a large combinatorial background.

- Cuts are applied to the following parameters

for each reconstructed particle to reduce background:

  - pointing angle ($\cos\theta$)
  - distance travelled (d)
  - Transverse momentum (p_T)
  - Invariant masses of K_s^0 and Λ^0

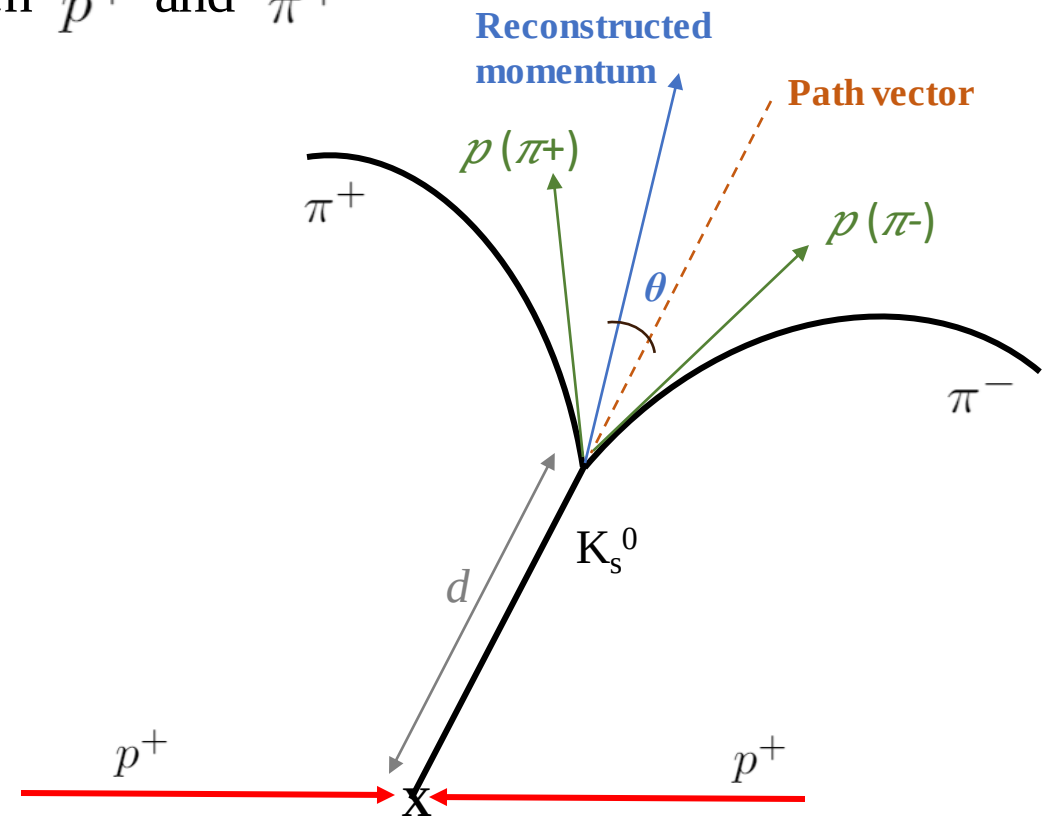


Fig: Representation of a K_s^0 decay

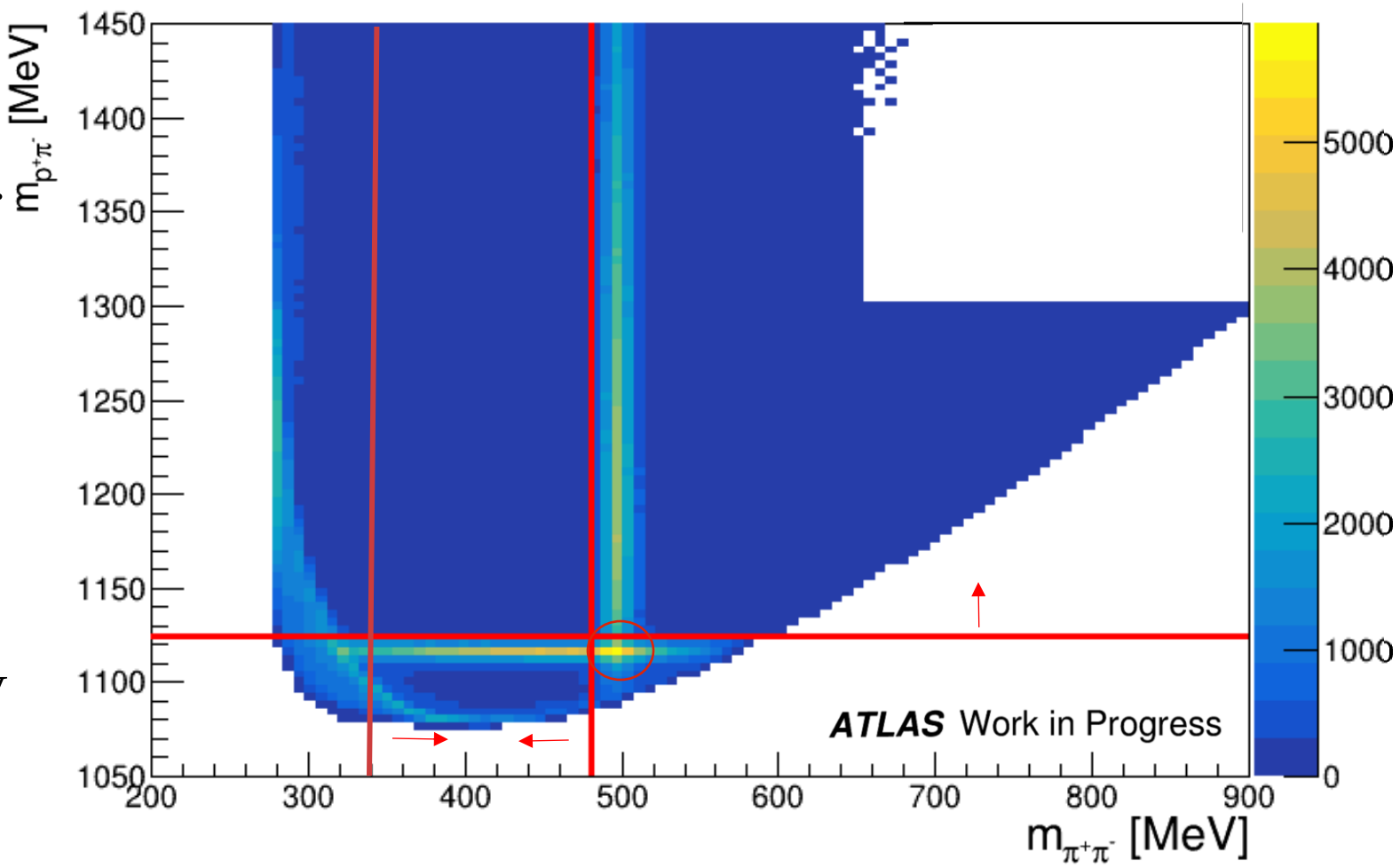
Mass correlation plot between K_S^0 and Λ^0

- Mass correlation between K_s^0 and Λ^0 plotted to determine mass cuts.

- Required to remove the ambiguity (circled in plot) of identification of the particles.

For K_s^0, $m(\Lambda^0) > 1125$ MeV

For Λ^0, 340 MeV < $m(K_s^0)$ < 480 MeV



Initial selection cuts

PARAMETER	K^0_s - MINIMUM	K^0_s - MAXIMUM	Λ^0 - MINIMUM	Λ^0 - MAXIMUM
$cos\,\theta$	0.9998	-	0.9998	-
d [mm]	3	-	13	-
p_T [MeV]	300	-	400	-
K^0_s invariant mass [MeV]	300	700	340	480
Λ^0 invariant mass [MeV]	1125	-	900	1300

Lifetime Analysis

- First step: to verify particle identification of K_s^0 and Λ^0
- Mean lifetime calculated using momentum (p) and distance travelled (d) of each datapoint.

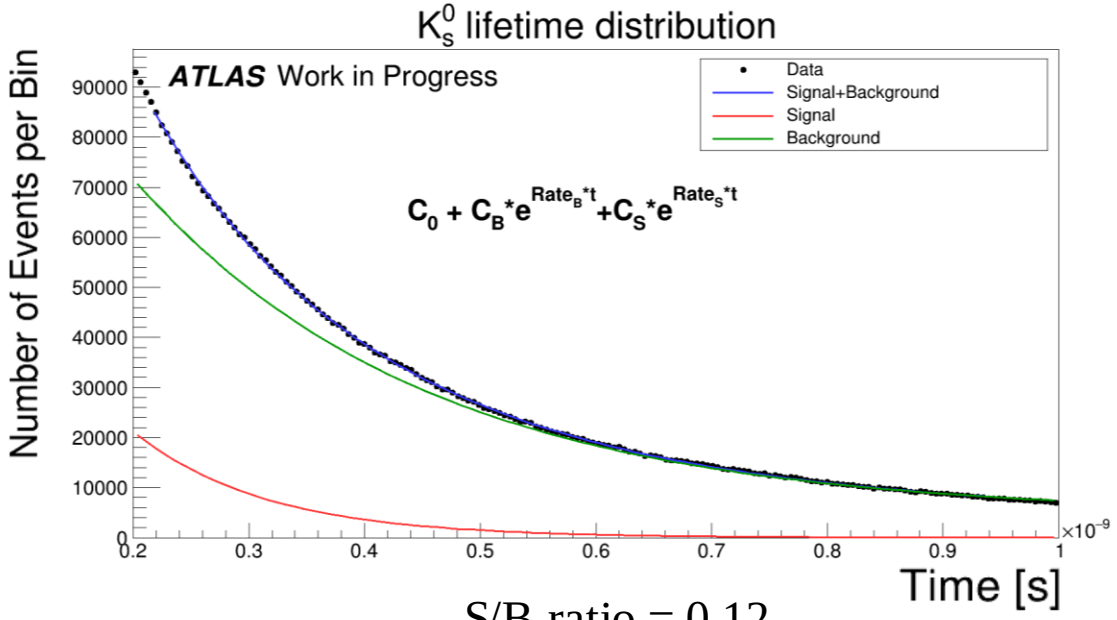
$$t = \frac{d}{v} = d \cdot \frac{\sqrt{(mc)^2 + p^2}}{pc}$$

- Each value is arranged in a histogram which is fit with the following function:

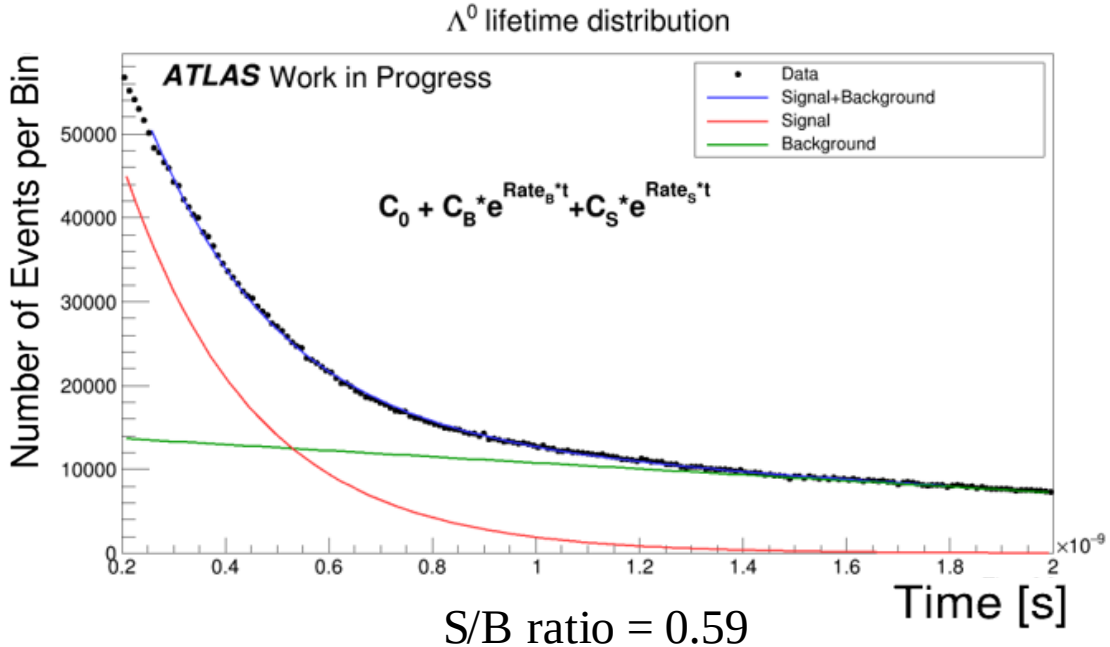
$$f(t) = C_0 + C_B \cdot e^{Rate_B \cdot t} + C_S \cdot e^{Rate_S \cdot t}$$

Background (B) Signal (S)

- K_s^0 lifetime, fit = (11.285 ± 0.278)*10^{-11} s
  PDG value[2] = (8.954 ± 0.0004)*10^{-11} s
- Λ^0 lifetime, fit = (2.495 ± 0.014)*10^{-11} s
- PDG value[2] = (2.632 ± 0.02)*10^{-11} s



S/B ratio = 0.12

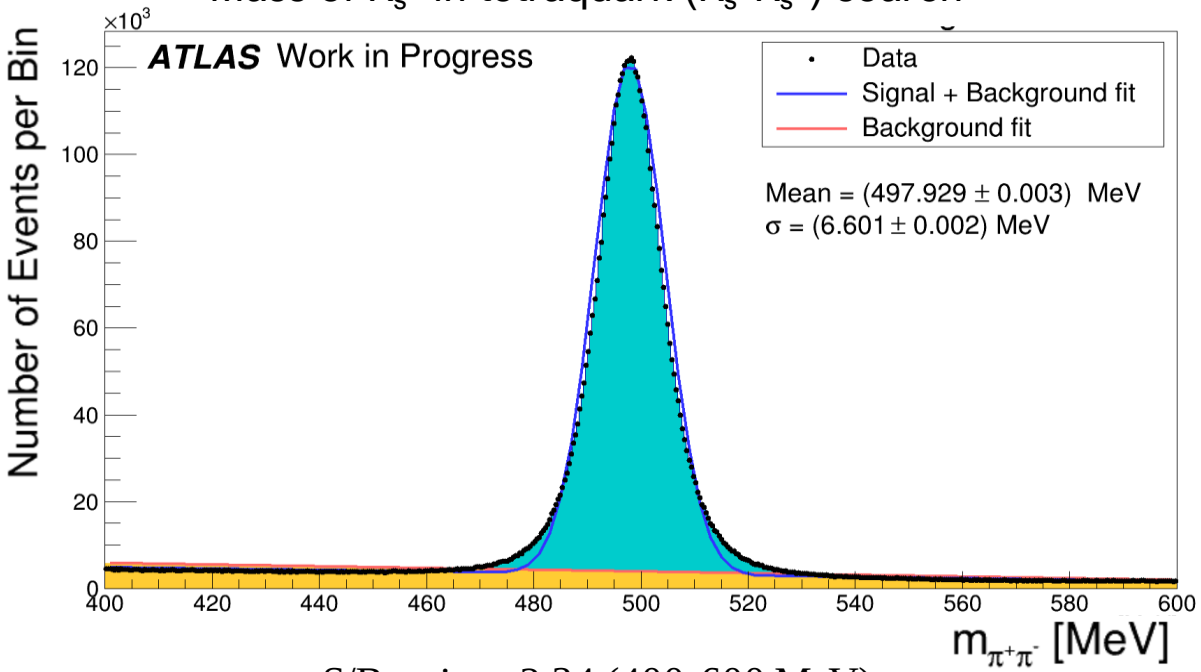


S/B ratio = 0.59

[2] P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

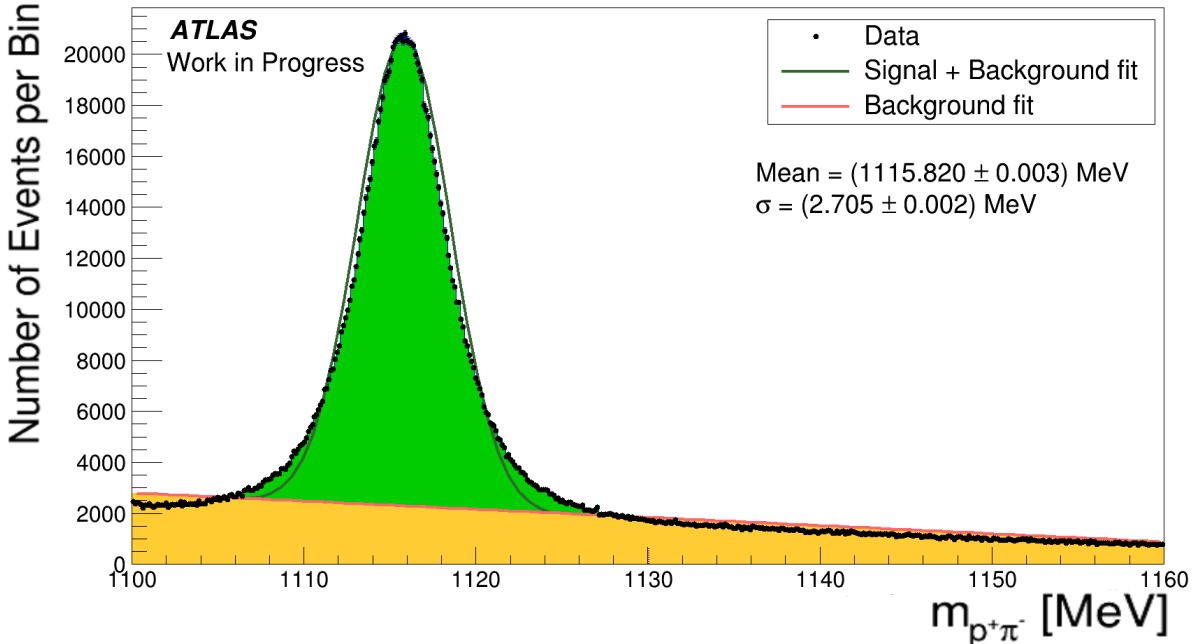
K_s^0 and Λ^0 mass peaks

Mass of K_s^0 in tetraquark ($K_s^0K_s^0$) search



S/B ratio = 2.34 (400-600 MeV)

Mass of Λ^0 in hexaquark ($\Lambda^0\Lambda^0$) search



S/B ratio = 1.07 (1100-1600 MeV)

- K_s^0 mass, fit = (497.929 ± 0.003**) MeV
  PDG value[2] = (497.611 ± 0.013) MeV
- Λ^0 mass, fit = (1115.820 ± 0.003**) MeV
- PDG value[2] = (1115.683 ± 0.006) MeV

**statistical errors only

- K_s^0 mass of the $K_s^0K_s^0$ combination dataset and Λ^0 mass of $\Lambda^0\Lambda^0$ combination dataset have been plotted, after applying tighter cuts ($cos\ \theta$, d, p_T) obtained from lifetime analysis.
- Fit not critical here; gives an estimation of the sigma of mass peaks, which allow for tighter cuts on the mass.

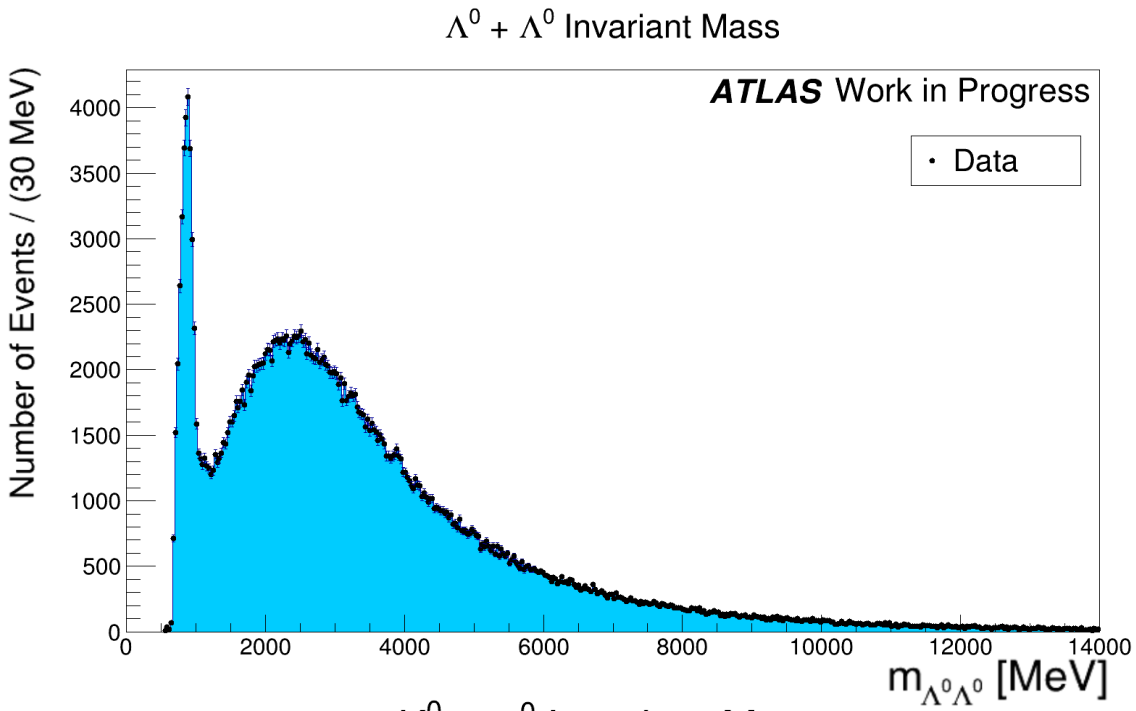
[2] P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

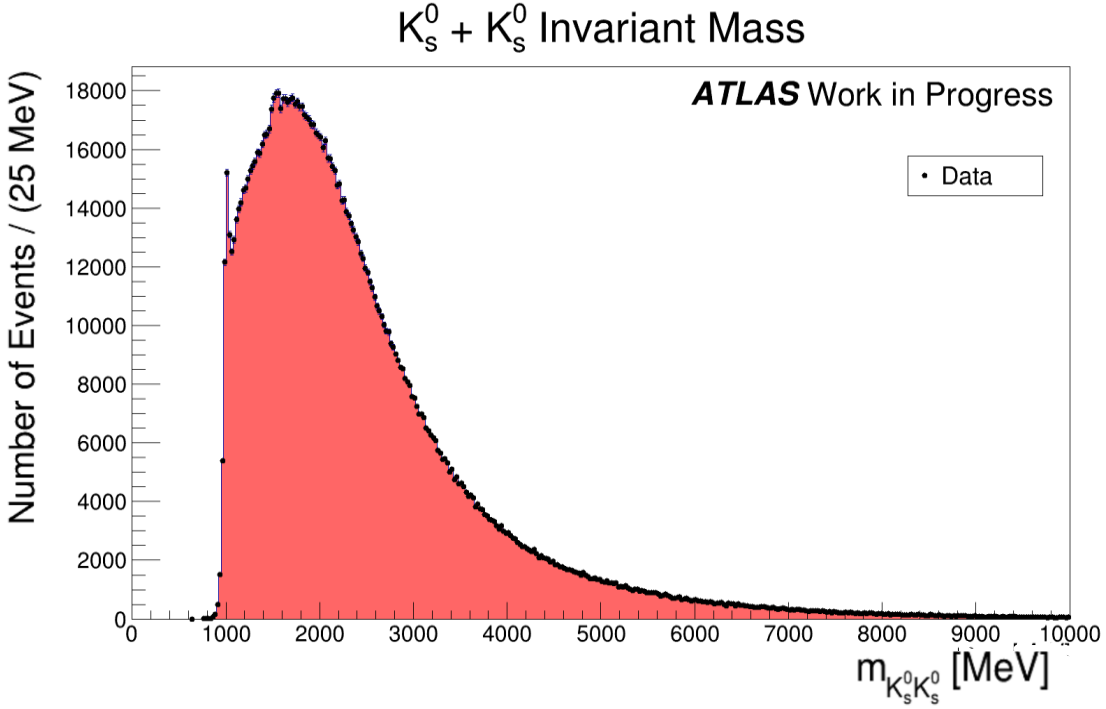
Final (tighter) cuts applied

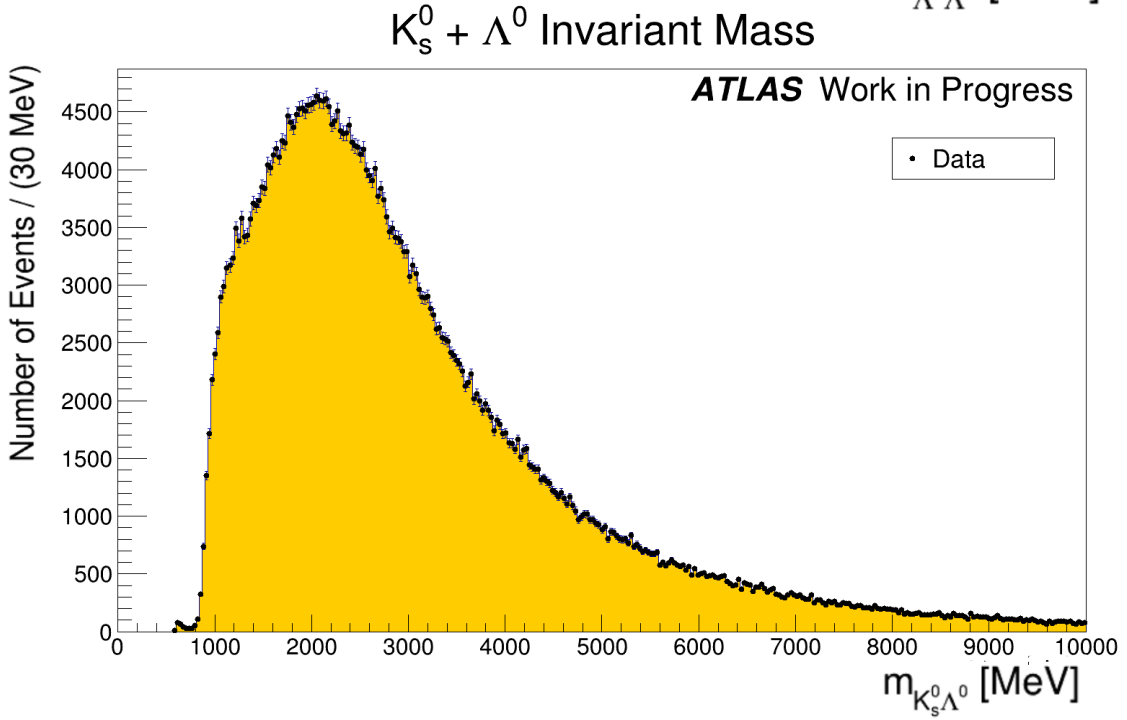
PARAMETER	K^0_s - MINIMUM	K^0_s - MAXIMUM	Λ^0 - MINIMUM	Λ^0 - MAXIMUM
$cos\,\theta$	0.9999	-	0.9999	-
d [mm]	4	300	25	600
p_T[MeV]	300	2000	500	-
K^0_s invariant mass [MeV]	478	518	340	480
Λ^0 invariant mass [MeV]	1125	-	1107	1124

Invariant mass of $K_s^0K_s^0$, $K_s^0\Lambda^0$ and and $\Lambda^0\Lambda^0$

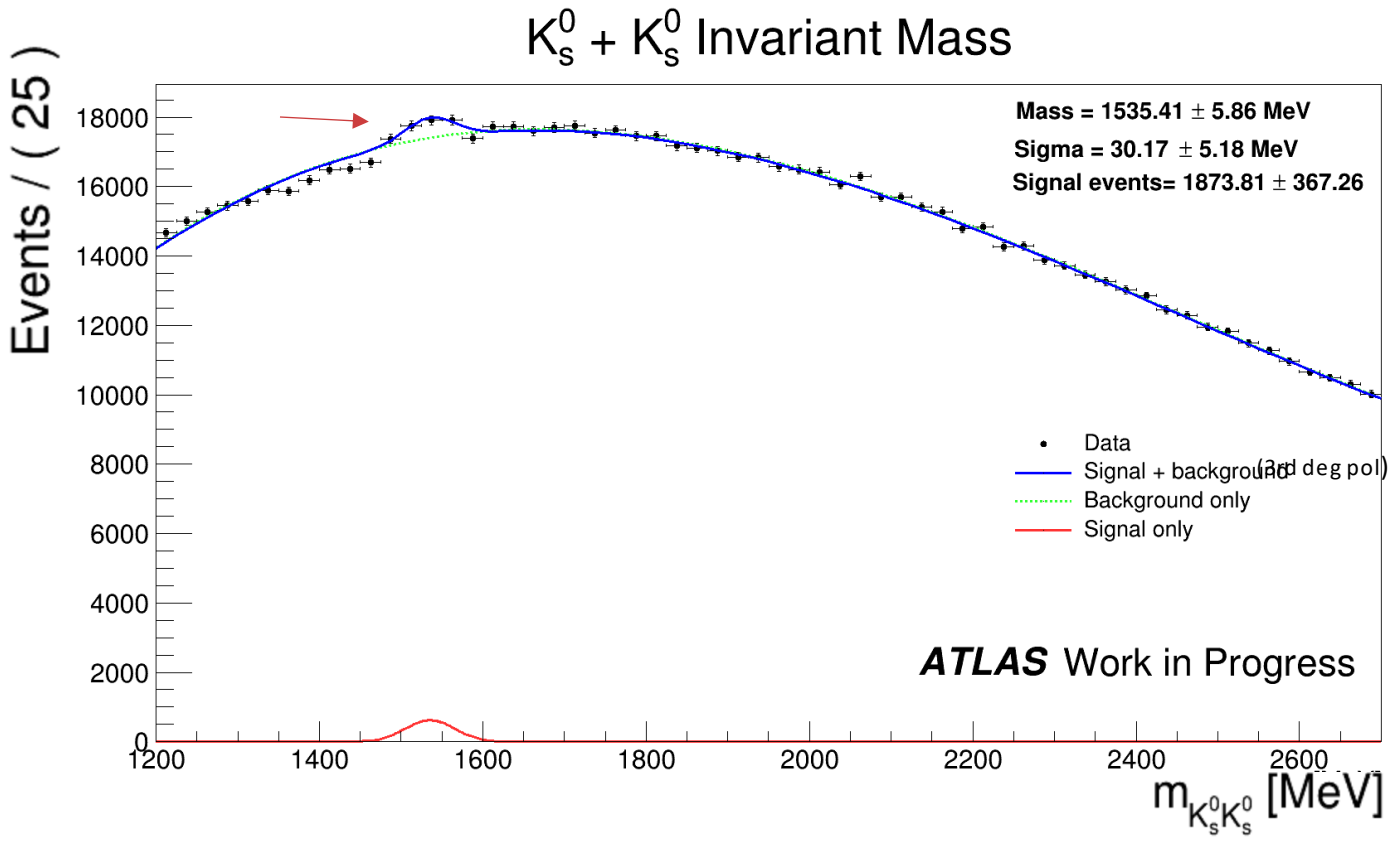
- Invariant mass plots obtained after applying final cuts on K_s^0 and Λ^0.



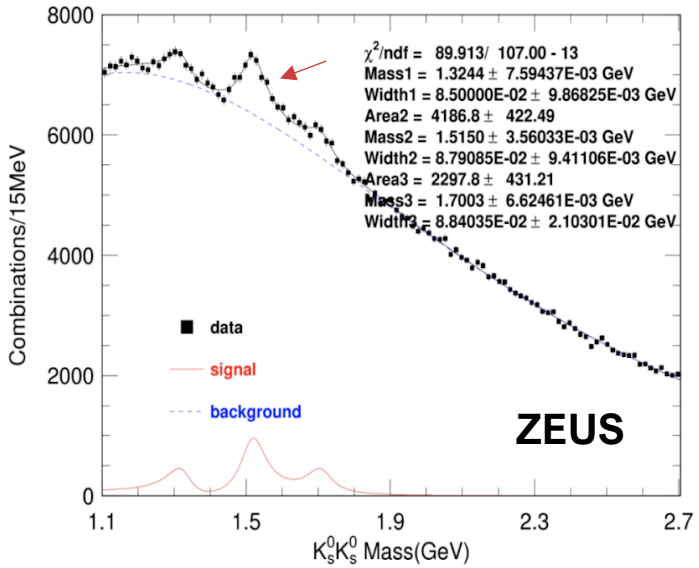




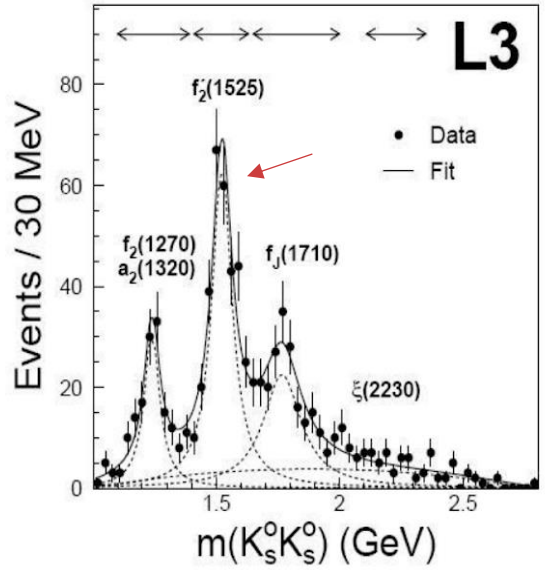
$K_s^0 K_s^0$ mass lower range – peak previously observed



- Peak observed at ~1535 MeV with a width 30 MeV, assumed to be f'_2 (1525). Significance = 1873.81/367.26 = 5.1σ



ZEUS (Mass 1523 MeV, Width 71 MeV) [3]



L3 (Mass 1523 MeV, Width 100 MeV) [4]

[3] C. Zhou Inclusive *KS0KS0 Resonance Production in Electron-Proton Collisions at HERA*, McGill University (2010).
[4] M. Acciarri et al. [L3 Collaboration], Phys. Lett. B 501, 173 (2001) [arXiv:hep- ex/0011037].

Significance studies (in progress)

- Spectrum is scanned by fixing the background and fitting gaussian of width 3σ at each bin.
- Significance (signal events/uncertainty on signal) plots are being currently plotted for varying bin widths for higher range of m_{KK} (shown for bin width of 40 MeV here).
- Currently estimating parameters for fits. Dip from 5750 MeV-6200 MeV presumably because of background parameters.
- Better parametrisation required for fitting.

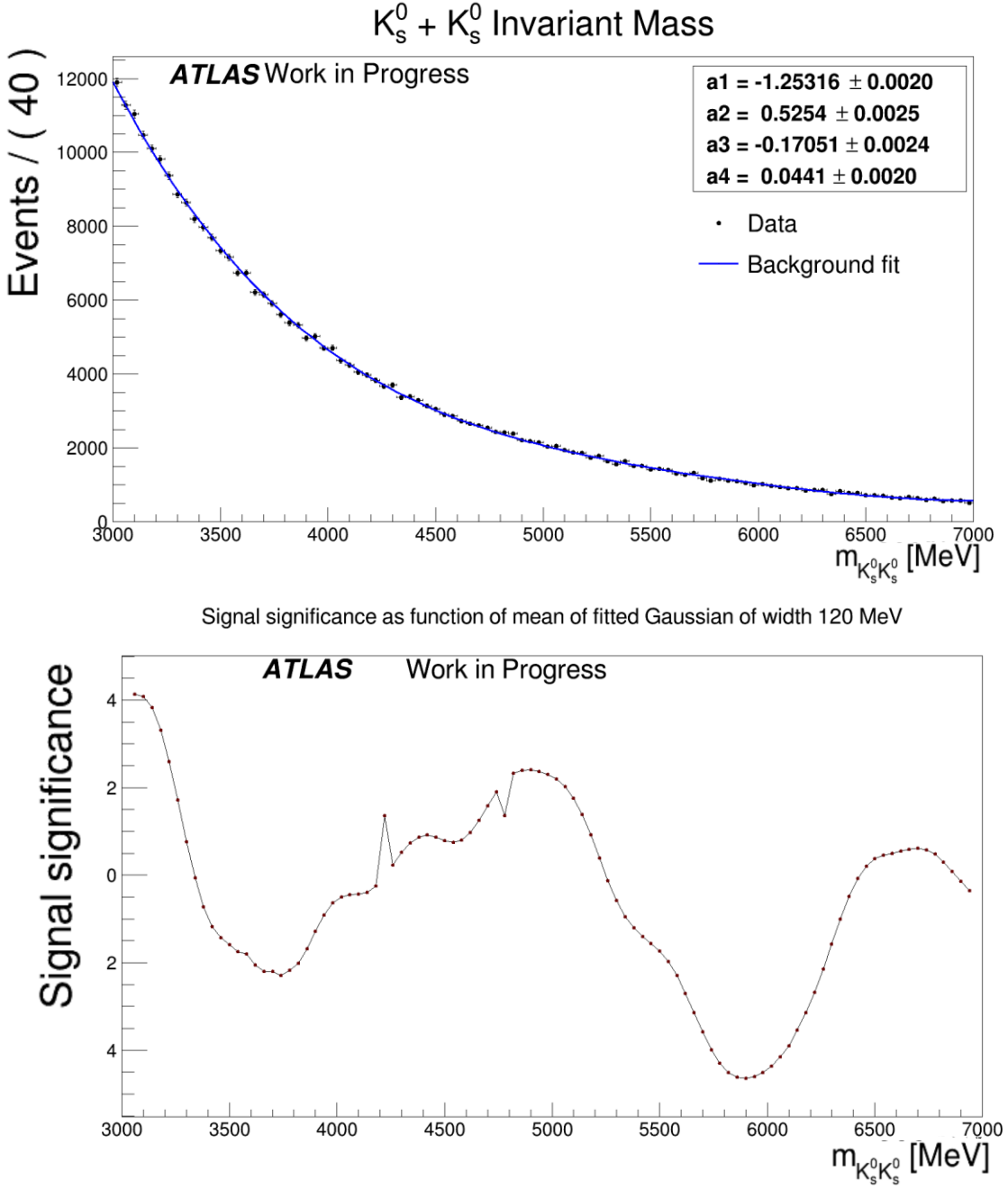


Fig: Significance plotted for 40 MeV

Summary

- Searching for possible multiquark states decaying to neutral strange particles: kaons and lambdas.
- K_s^0 and Λ^0 reconstructed from pions and protons.
- Analysis of lifetime and invariant mass distributions to study the systematics.
- Invariant mass plots for $K_s^0 K_s^0$, $K_s^0 \Lambda^0$ and $\Lambda^0 \Lambda^0$ plotted.
- Low energy resonance observed in $K_s^0 K_s^0$ mass spectrum provides calibration and proof of priniciple.
- Looking for signal in excess of background in higher energy range.

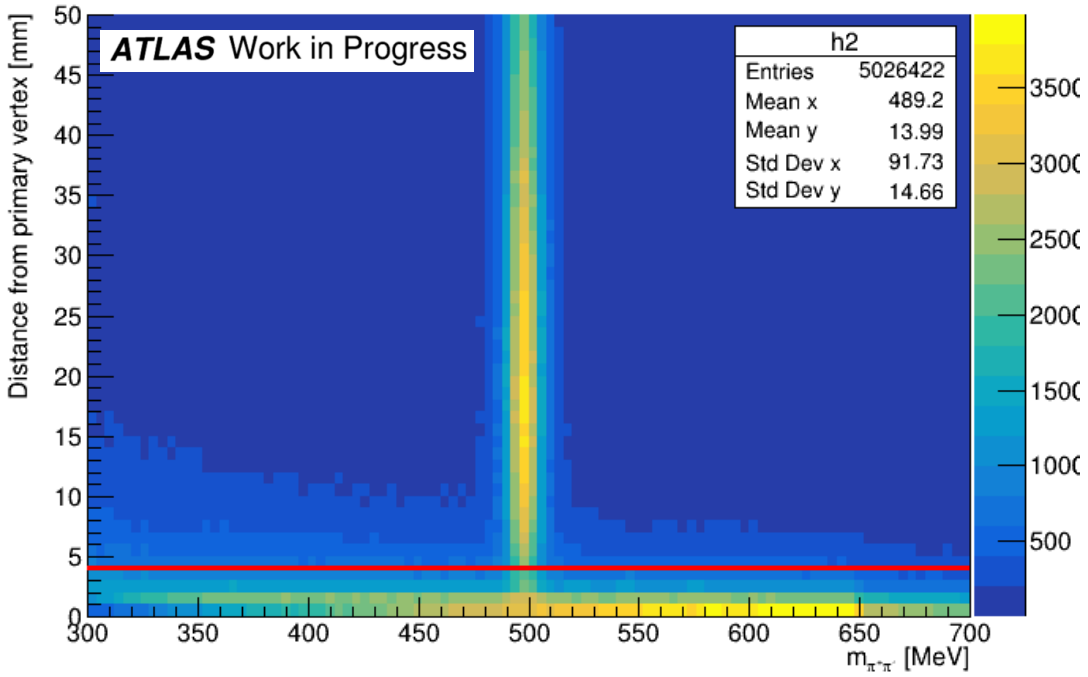
TO DO:

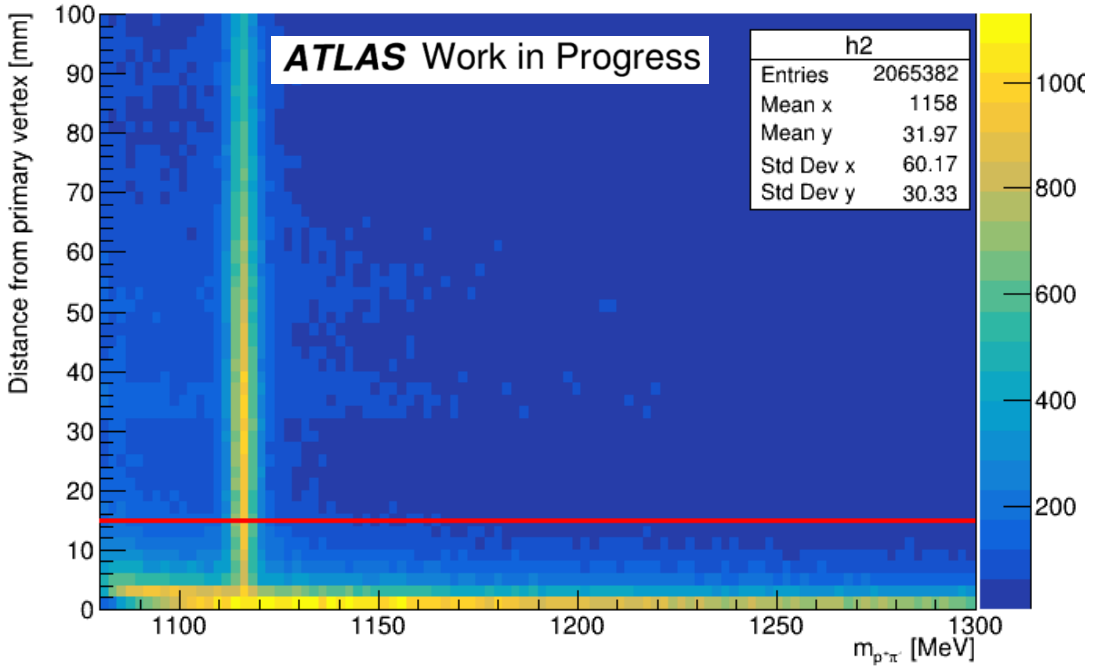
- Use 2016-18 datasets
- Better understanding of backgrounds
- Improve bump search method
- Extend search methods for $K_s^0 \Lambda^0$ and $\Lambda^0 \Lambda^0$ combinations.

THANK YOU

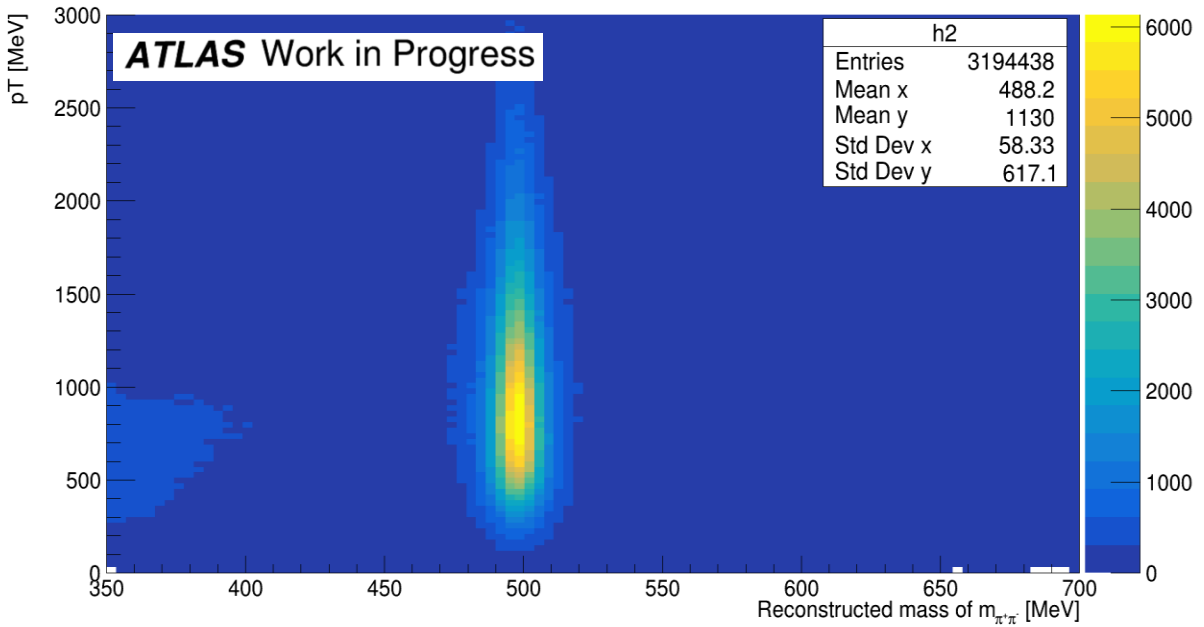
BACKUP

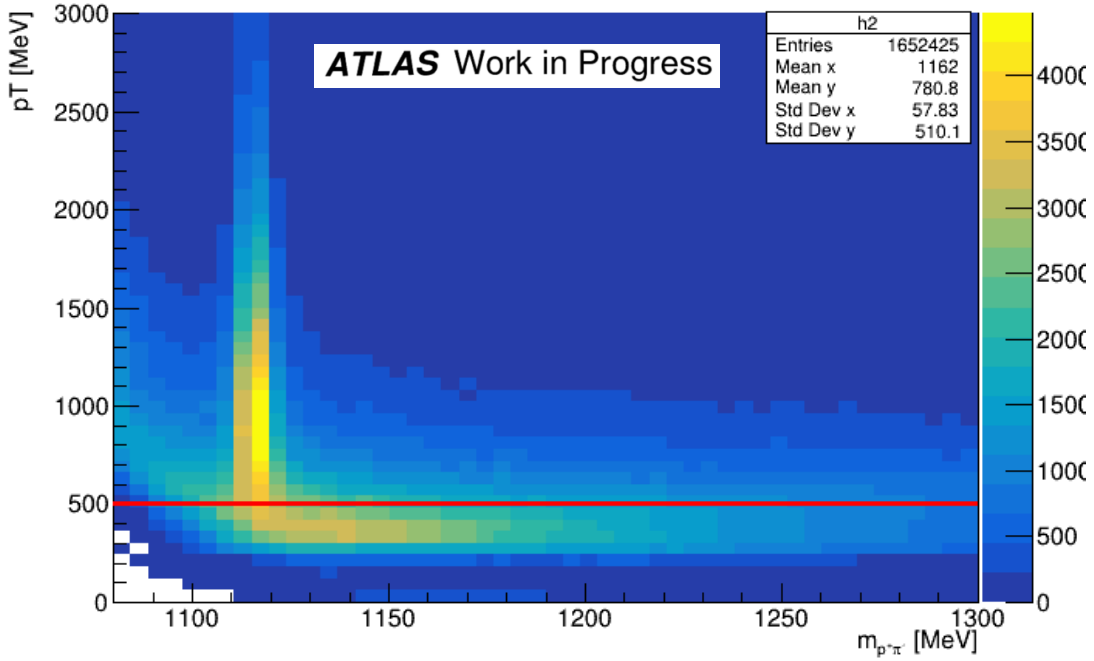
Cuts on distance travelled (d)



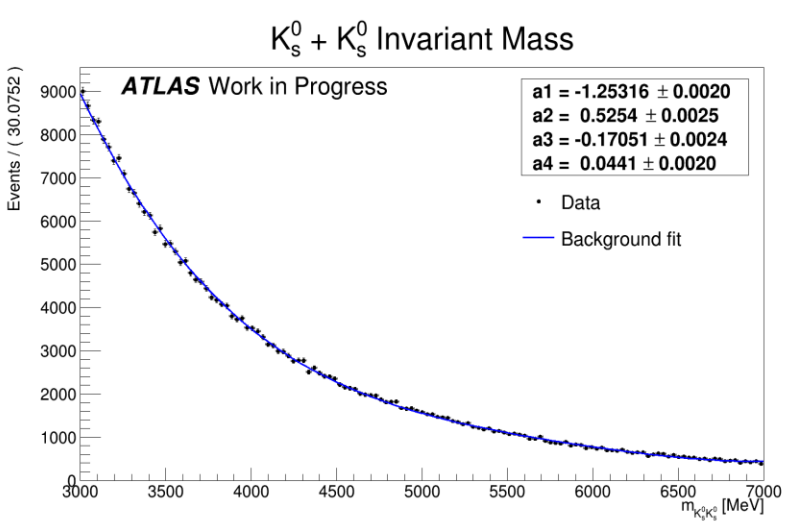


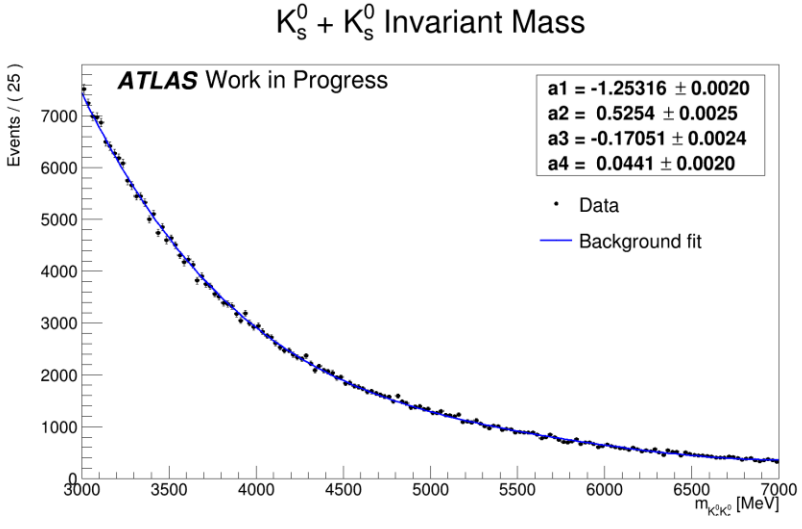
Cuts on transverse momentum

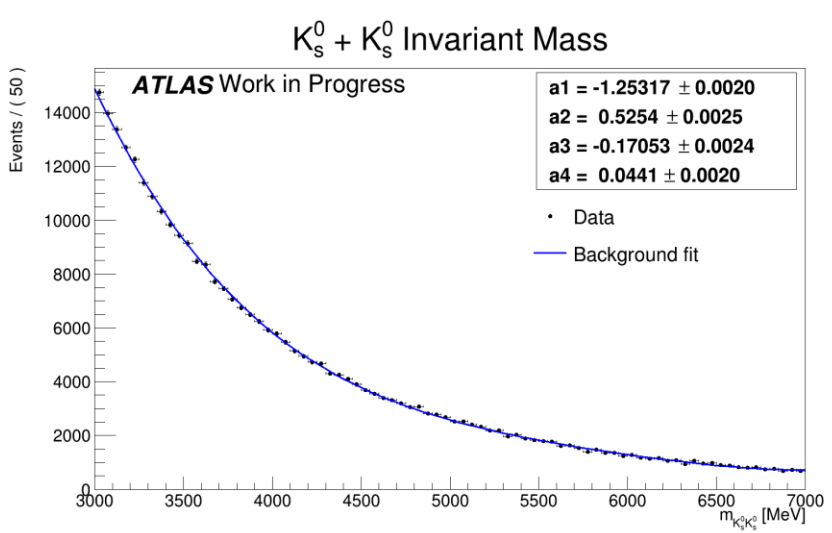


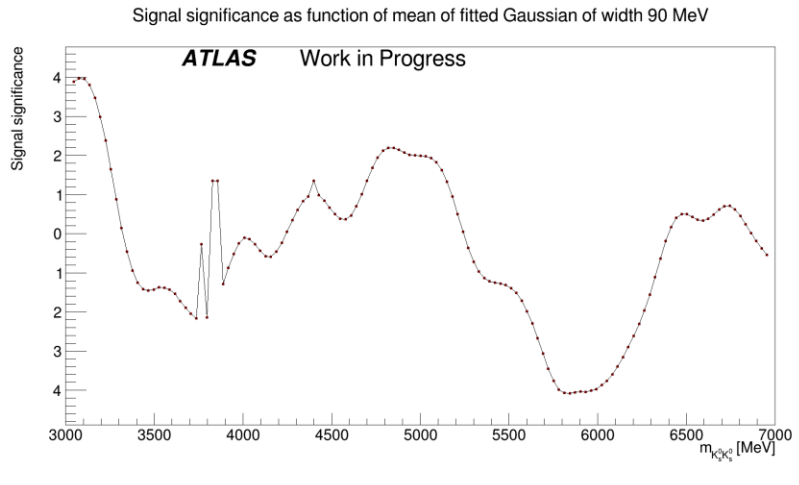


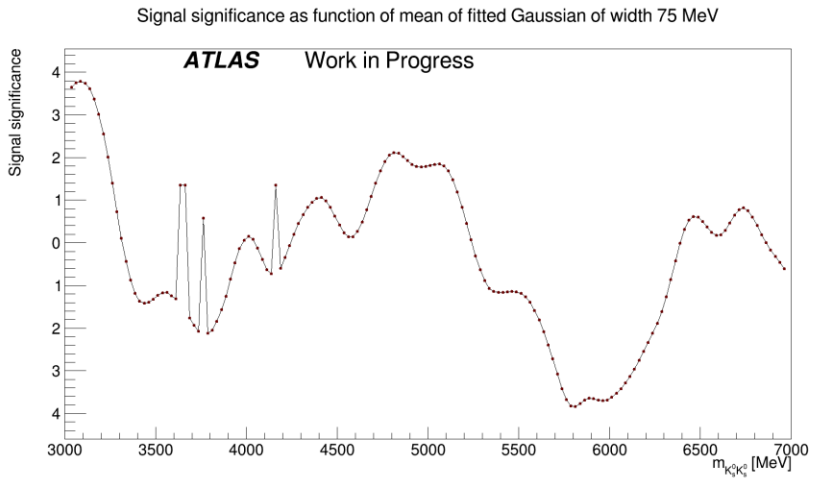
Significance studies (variable binning)

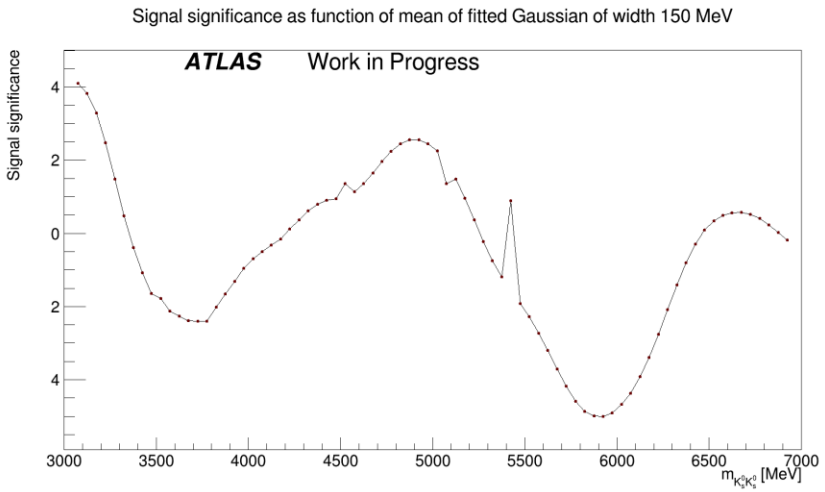












Bin width 30 MeV

Bin width 25 MeV

Bin width 50 MeV