Particles unseen in FOCUS

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DPF 2004: Riverside, CA

The search list

What was searched for:

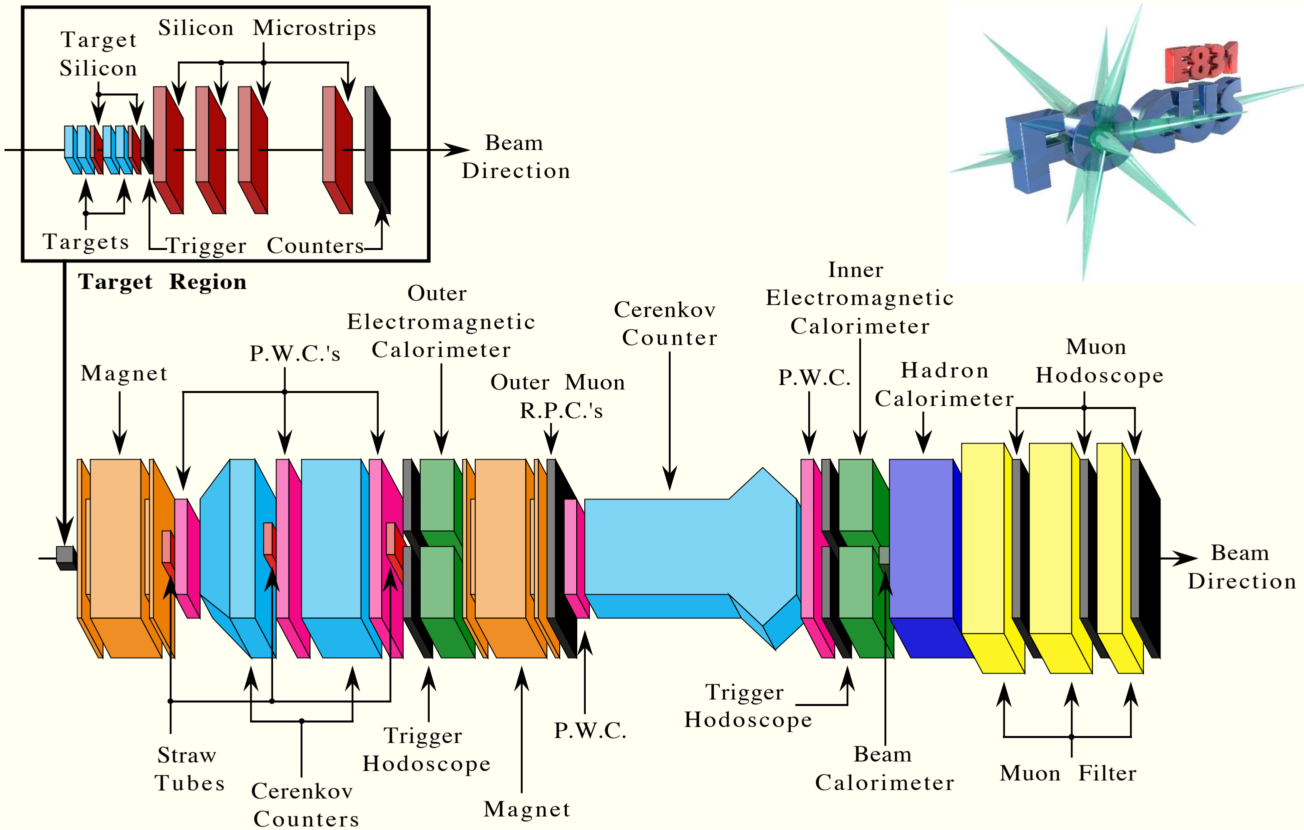
- $S = -1$ pentaquark $\Theta(1540)^+$ with quark content $uudd\bar{s}$
- $S = -2$ pentaquark $\phi(1860)^{--}$ with quark content $\bar{u}ddss$
- Charm pentaquark $\Theta_c(3100)^0$ with quark content $uudd\bar{c}$
- Double charm baryons Ξ_{cc} with quark content ccu and ccd

Please note the following:

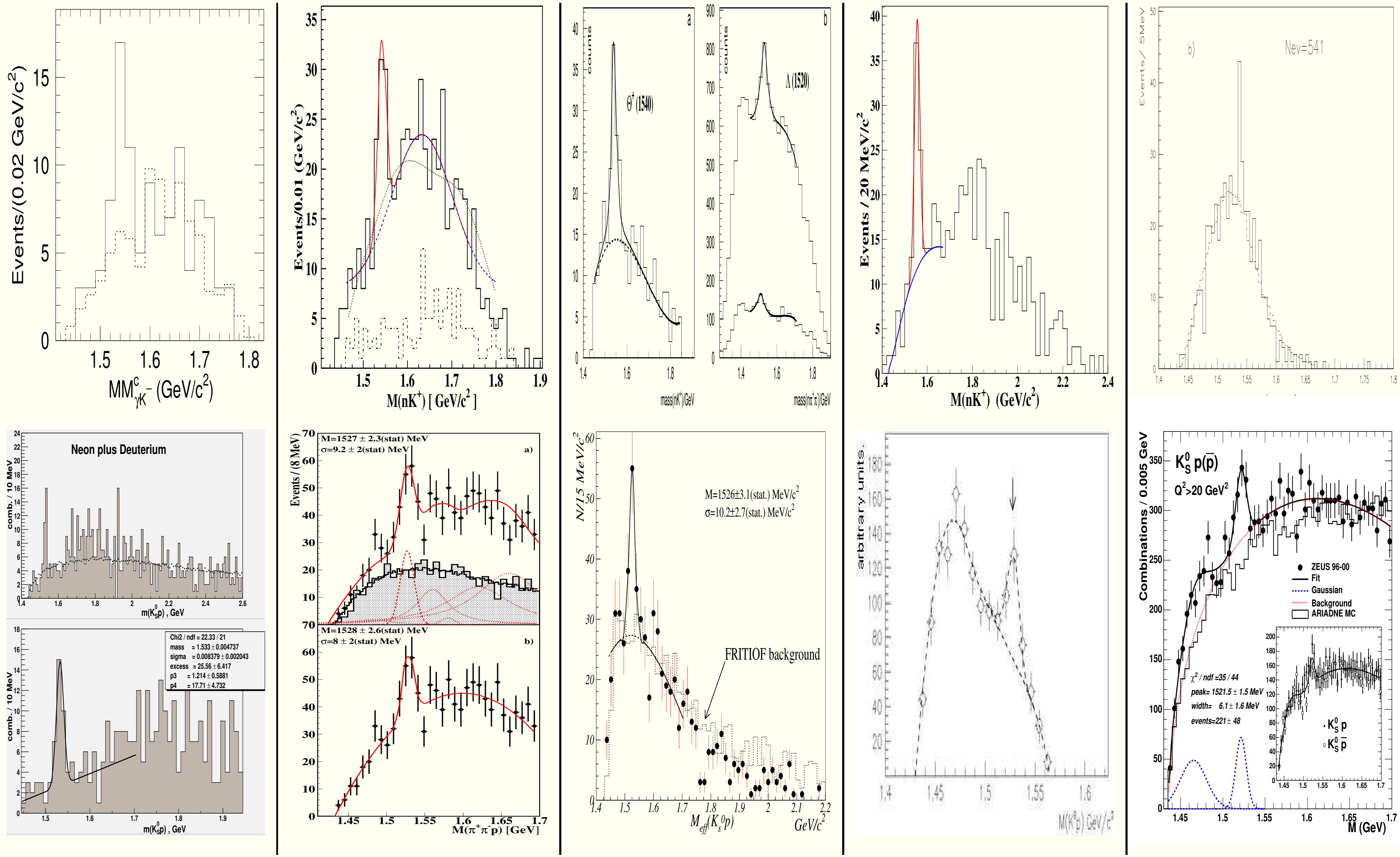
- All results are preliminary
- Charge conjugates are always implied

The FOCUS experiment

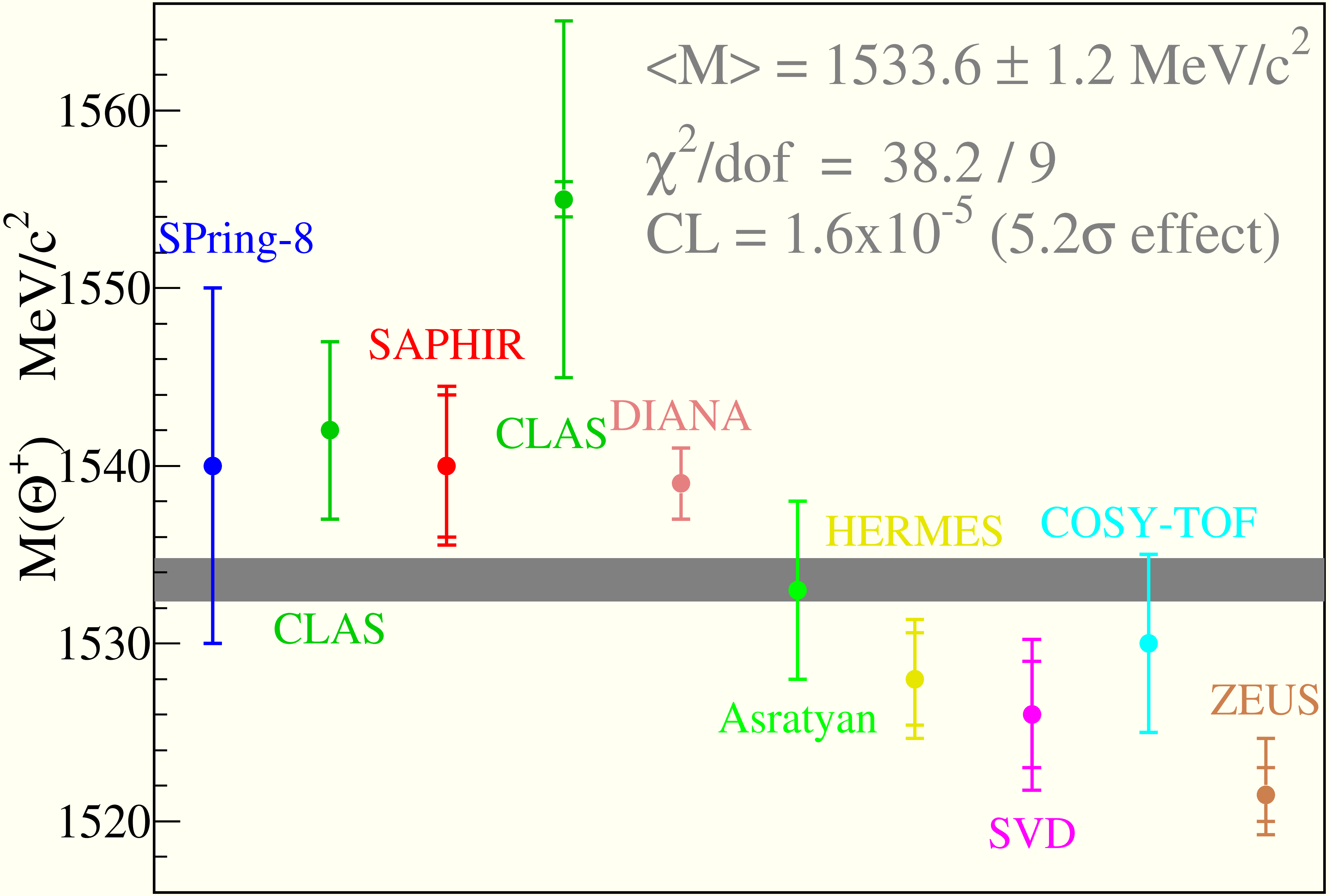
- FOCUS took data in the Fermilab fixed-target run of 1996-7
- $e^{\pm}$ at $\sim$300 GeV bremsstrahlung on lead target to create photon beam
- Photons interact in BeO targets
- Charged particles tracked and momentum analyzed with silicon strips, wire chambers, and two magnets
- Three multicell threshold Čerenkov counters for particle ID
- Trigger required $\sim$35 GeV of energy in the hadron calorimeter
- 7 billion hadronic events on tape



Evidence for $\Theta^+(uudd\bar{s})$



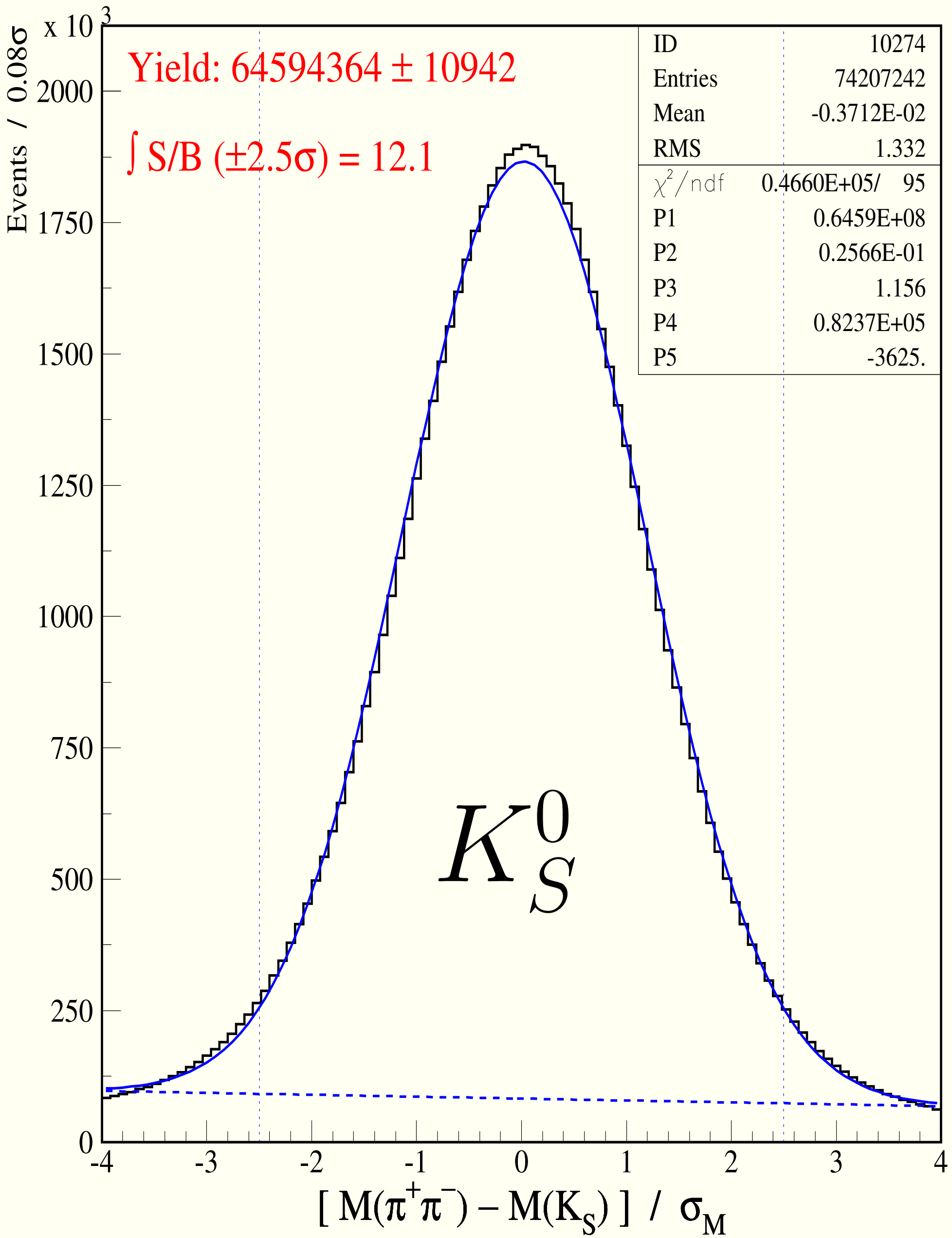
Summary of Θ^+ mass measurements

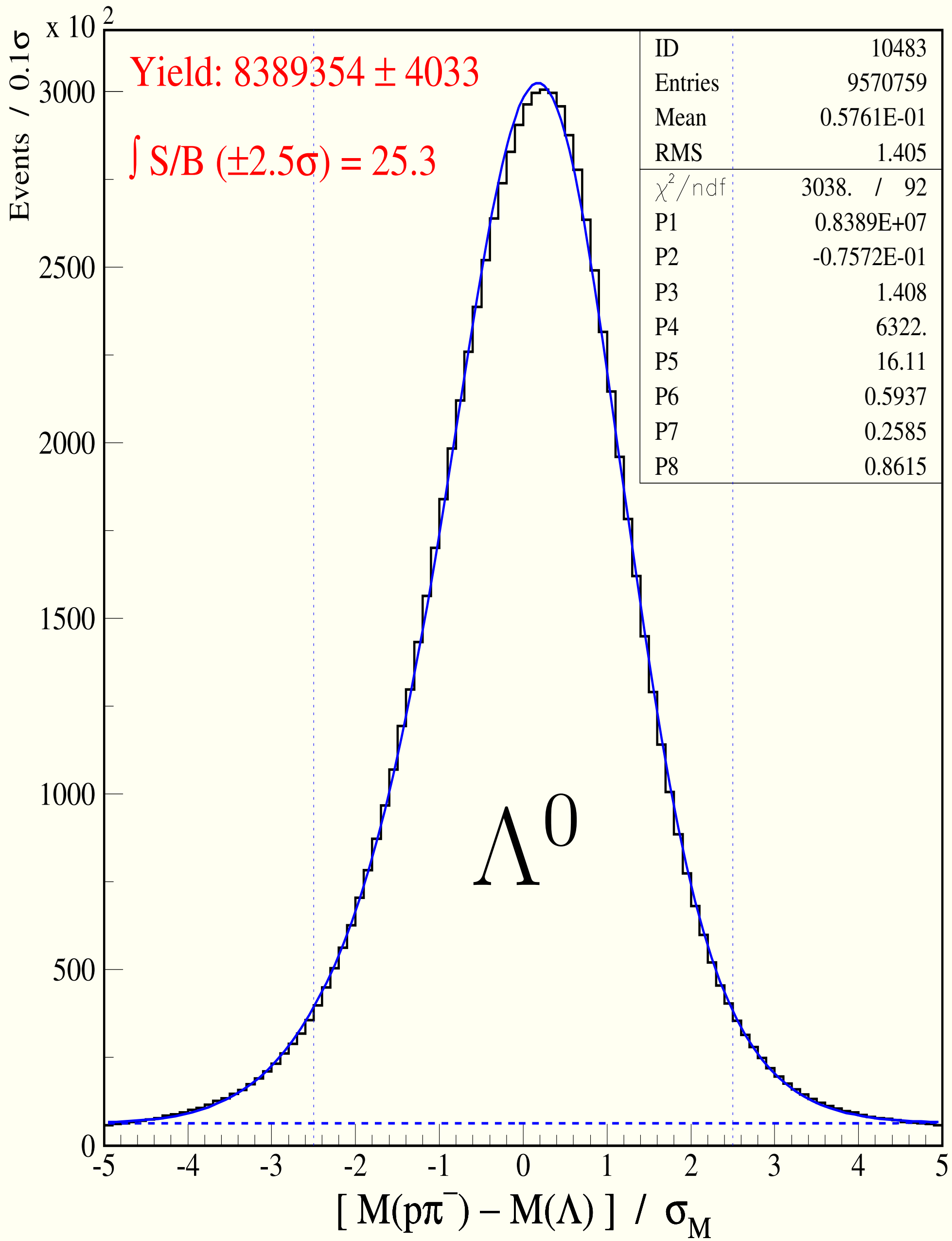


FOCUS analysis: $\Theta(1540)^+ \to pK^0_S$ search

- Search for $\Theta^+ \to pK^0_S$ and compare to $K^{*+}(892) \to K^0_S\pi^+$ and $\Sigma(1385)^\pm \to \Lambda^0\pi^\pm$ (similar topology)
- Reconstruct $K^0_S \to \pi^+\pi^-$ and $\Lambda^0 \to p\pi^-$
- Use Čerenkov ID on fast track to separate K^0_S and Λ^0
- Remaining good quality tracks must be consistent with one vertex (CL$>$1%) suppressing charm decays and reinteractions
- Various minor clean up cuts applied to vees and charged tracks
- Mass of K^0_S or Λ^0 candidate within 2.5σ of nominal mass
- Very stringent Čerenkov ID cut applied to proton in pK^0_S (misid $\sim$0)

Vee samples

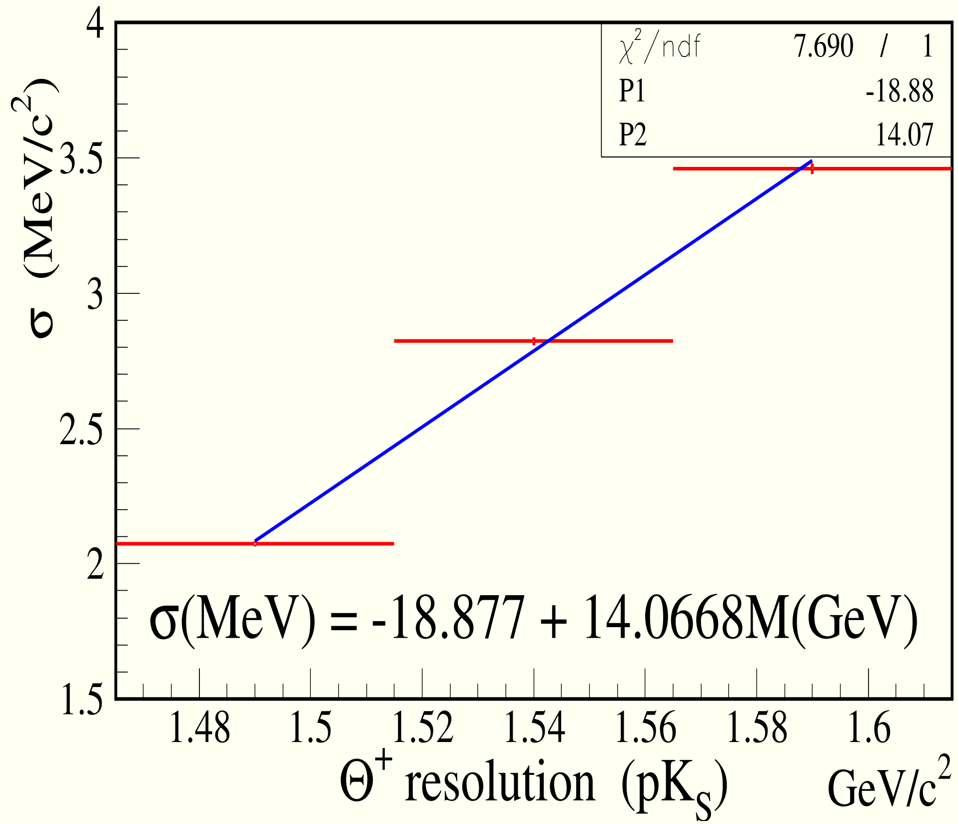

Yield: 64594364 ± 10942
∫ S/B (±2.5σ) = 12.1
ID 10274
Entries 74207242
Mean -0.3712E-02
RMS 1.332
χ²/ndf 0.4660E+05/ 95
P1 0.6459E+08
P2 0.2566E-01
P3 1.156
P4 0.8237E+05
P5 -3625.
K_S^0
Events / 0.08σ
x 10³
[M(π⁺π⁻) – M(K_S)] / σ_M


Yield: 8389354 ± 4033
∫ S/B (±2.5σ) = 25.3
ID 10483
Entries 9570759
Mean 0.5761E-01
RMS 1.405
χ²/ndf 3038. / 92
P1 0.8389E+07
P2 -0.7572E-01
P3 1.408
P4 6322.
P5 16.11
P6 0.5937
P7 0.2585
P8 0.8615
Λ^0
Events / 0.1σ
x 10²
[M(pπ⁻) – M(Λ)] / σ_M

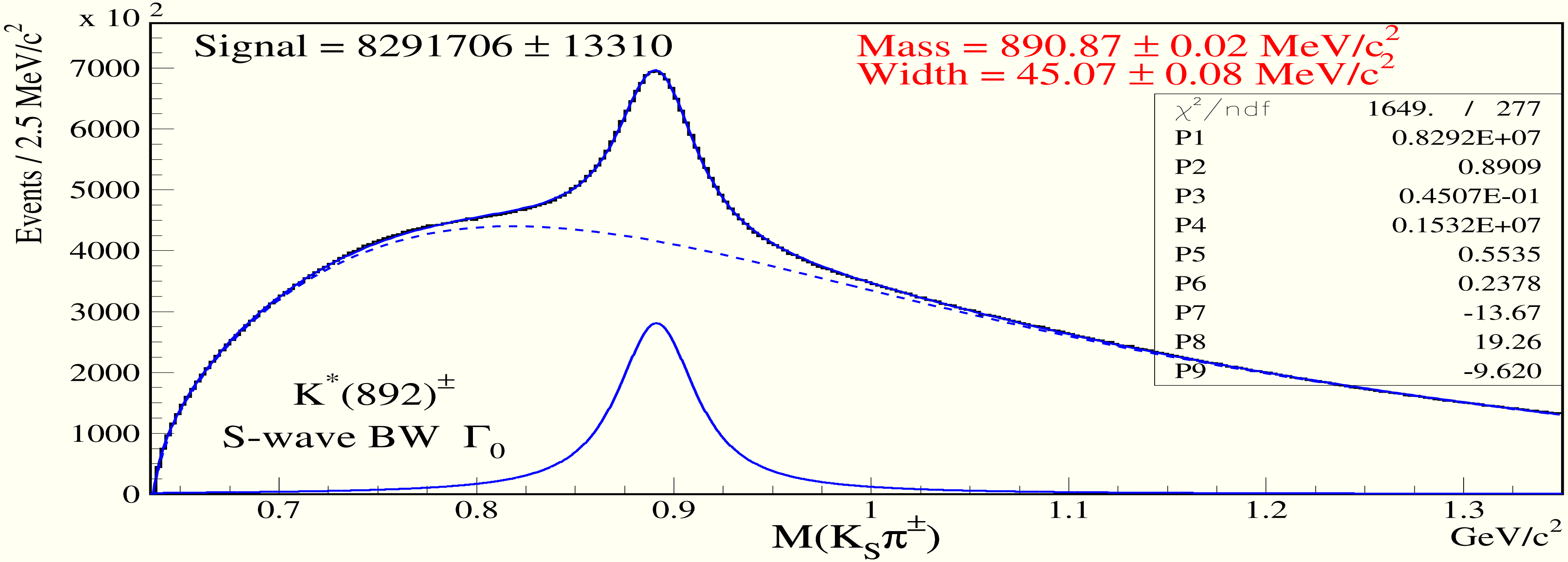
Fitting mass plots

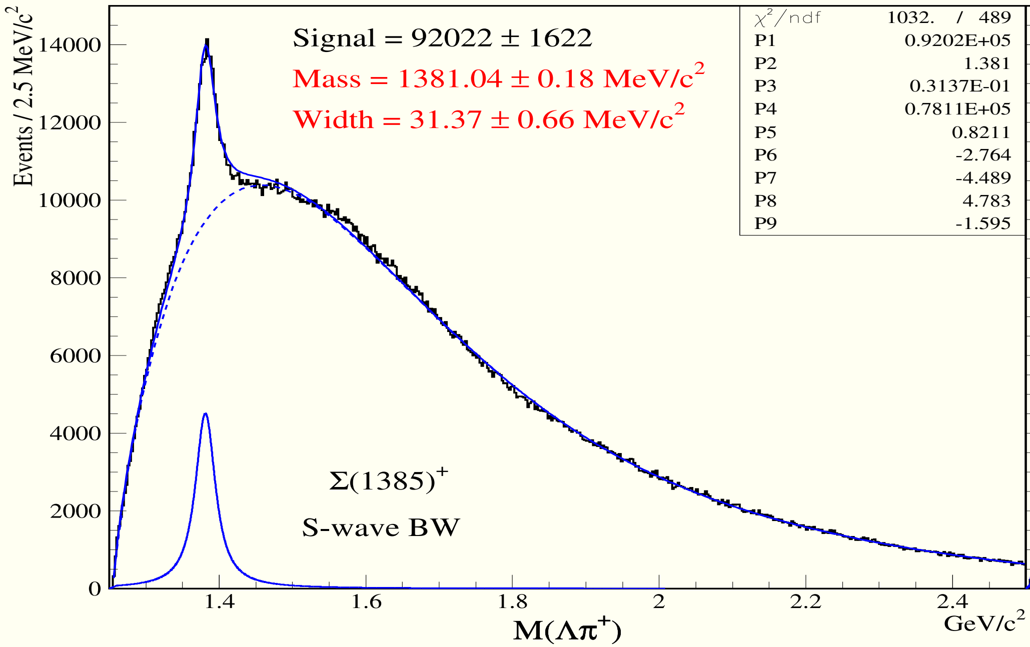
- Mass plots are fit with Breit-Wigner convoluted with the Gaussian resolution (from Monte Carlo)
- $K^*(892)$ and $\Sigma(1385)$ *should* be P-wave but best fit is simple S-wave Breit-Wigner with energy independent width
- Best (of tried) background shape is $aq^b \exp\left(cq + dq^2 + eq^3 + fq^4\right)$

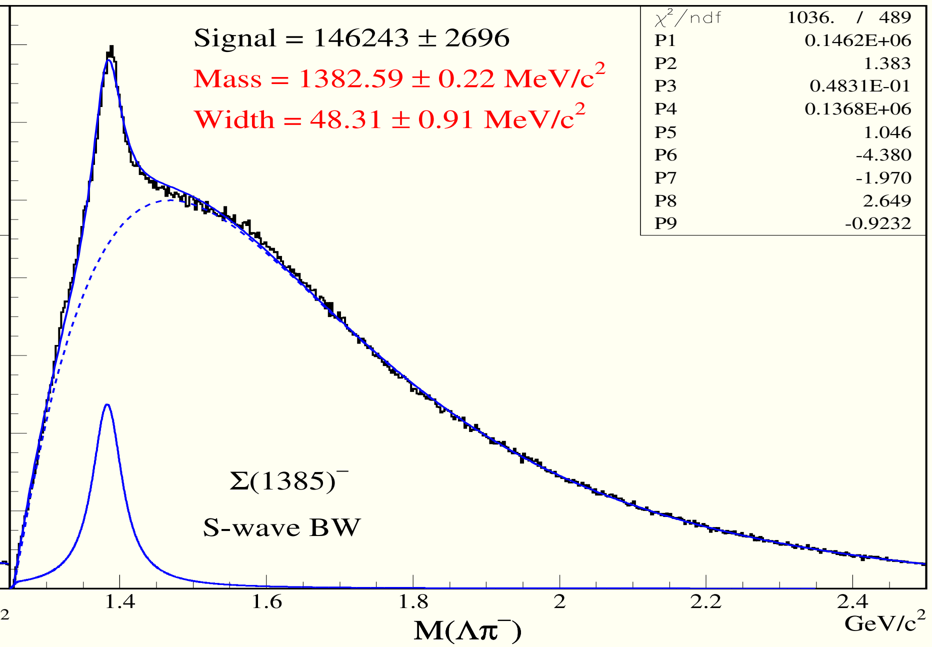
Decay Mode	Q (MeV)	Resolution (MeV/c^2)
$K^*(892)^+ \to K^0_S \pi^+$	254	4.9
$\Sigma(1385)^+ \to \Lambda\pi^+$	128	3.1
$\Sigma(1385)^- \to \Lambda\pi^-$	132	3.2
$\Theta(1490)^+ \to pK^0_S$	54	2.1
$\Theta(1540)^+ \to pK^0_S$	104	2.8
$\Theta(1590)^+ \to pK^0_S$	154	3.5



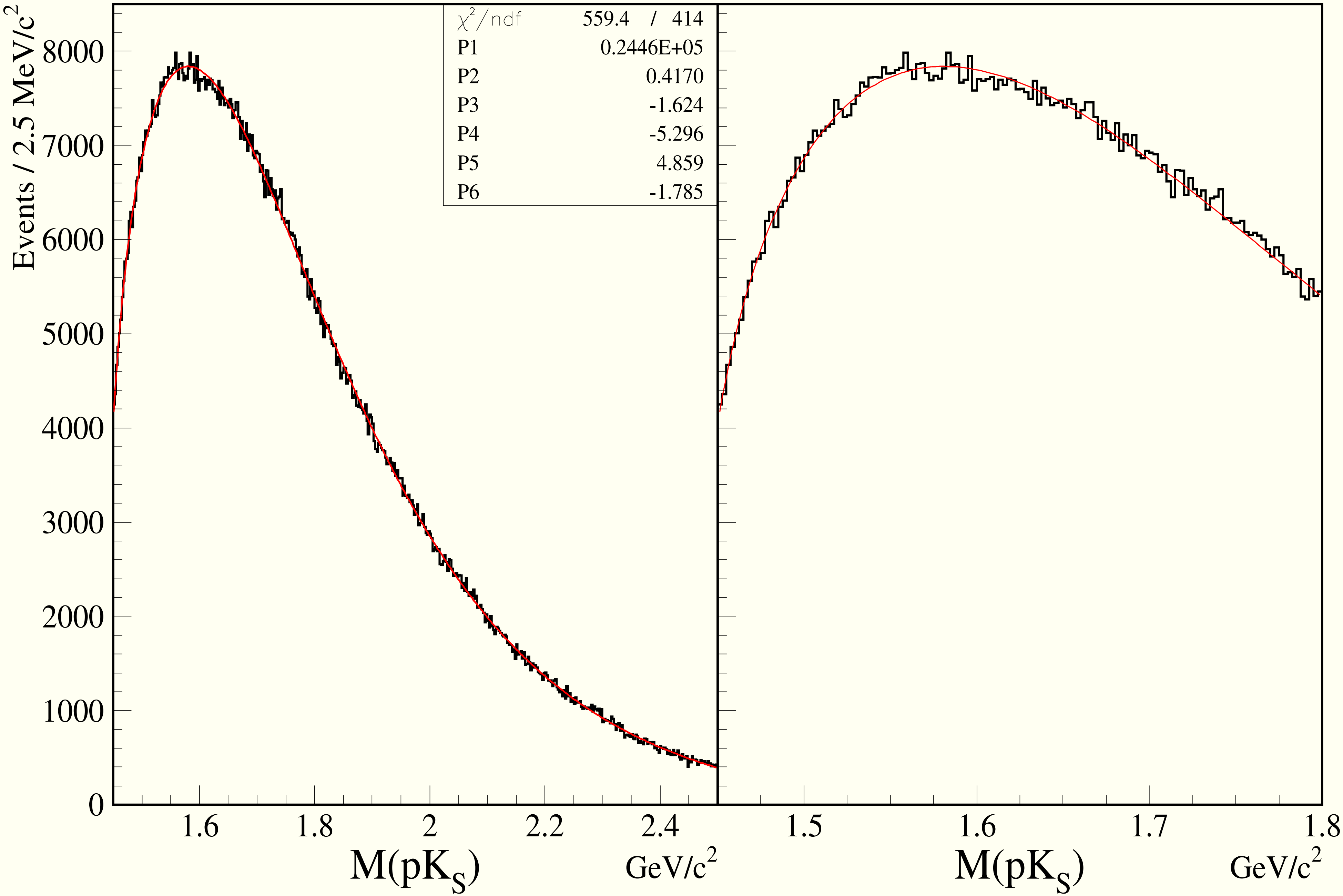
$K^*(892)^+ \to K^0_S\pi^+$ and $\Sigma(1385)^\pm \to \Lambda\pi^\pm$ signals



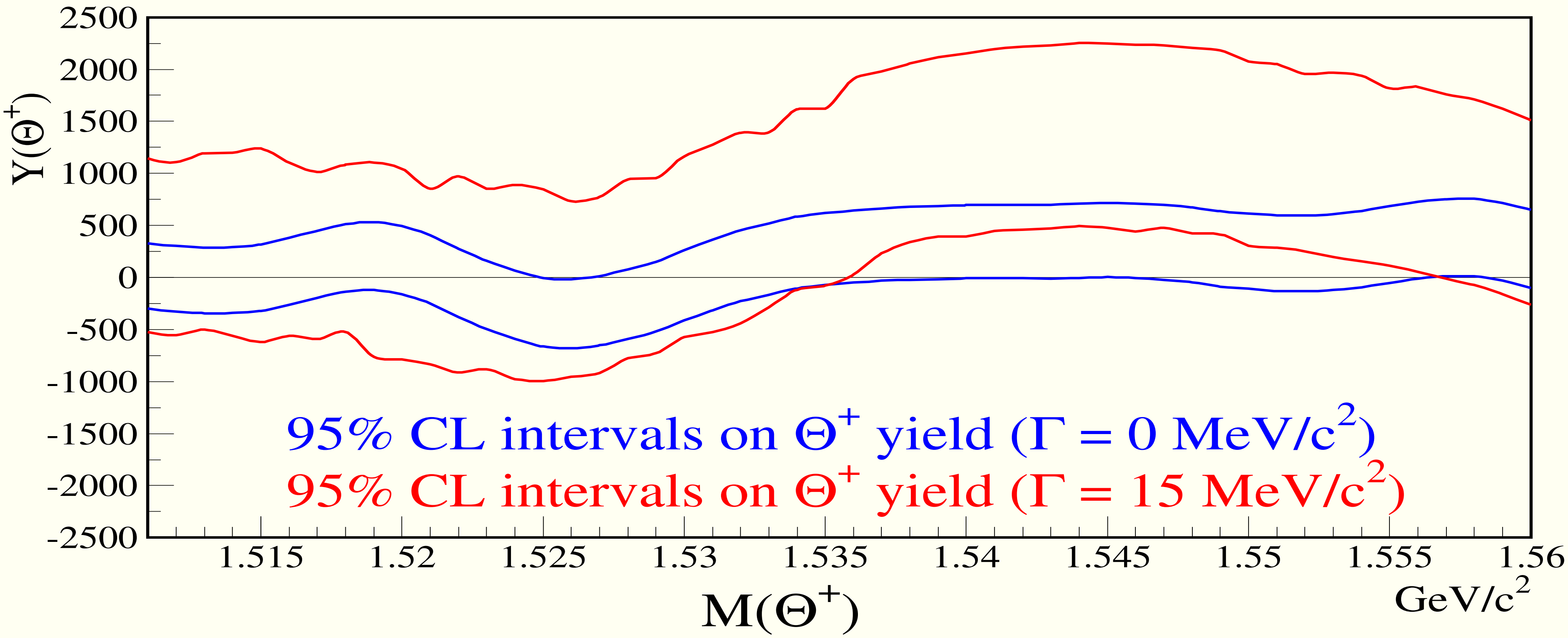




$\Theta^+ \to pK_S^0$ search



Limit on $\Theta^+ \to pK_S^0$ yield



- Fit for signal in 1 MeV/c^2 steps from 1511 to 1560 MeV/c^2
- Find where $-2\ln\mathcal{L}$ changes by 3.84 w.r.t minimum as yield is varied (allowing other variables to be continually minimized)

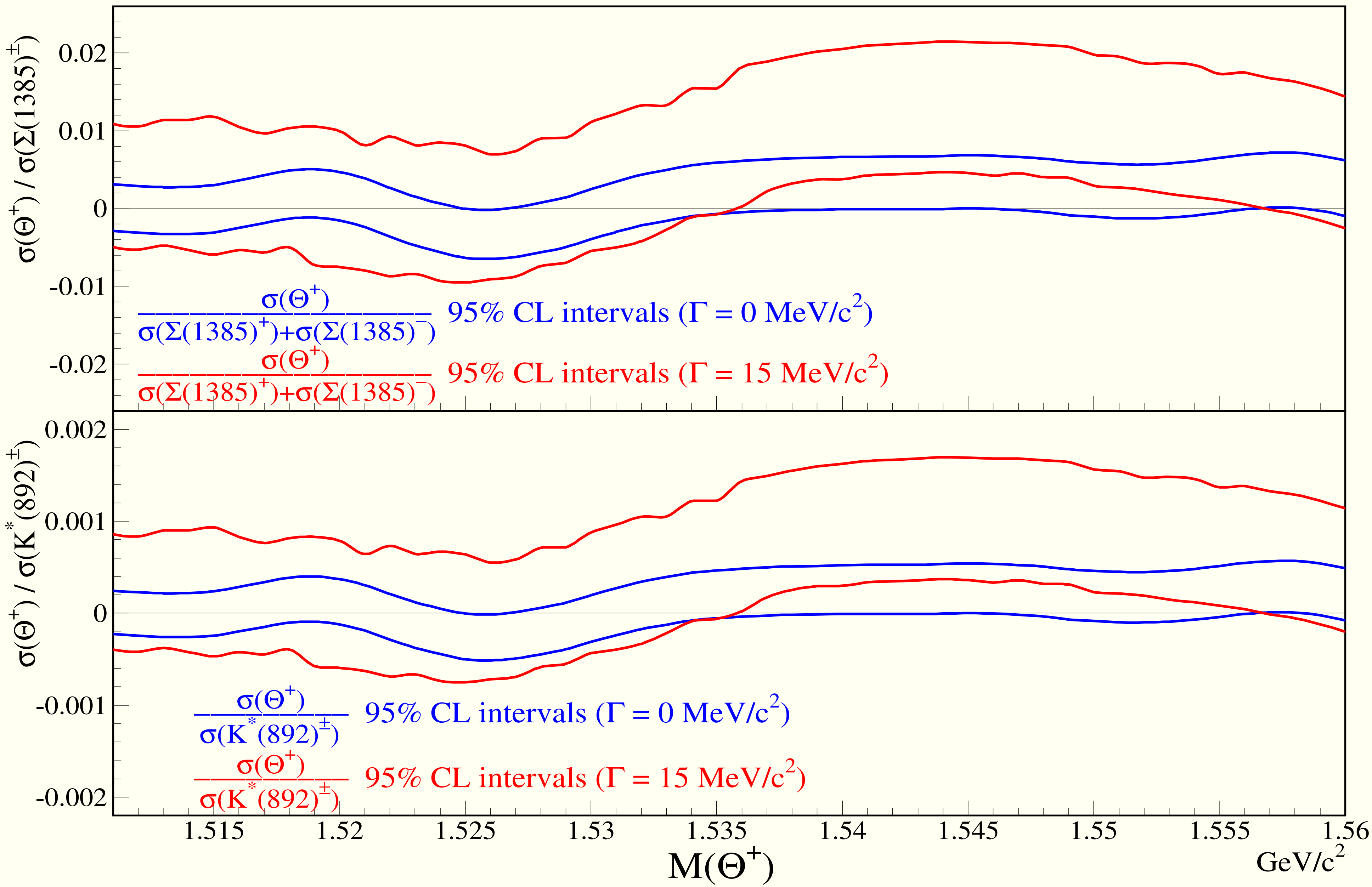
Corrected yields

Particle Decay	$<p>$ GeV/c	Acc $\times\epsilon$	B.R. correction	Reconstructed Yield/Limit	Corrected Yield/Limit
$K^*(892)^+ \to K^0_S\pi^+$	19	1.83%	$0.686\times0.5\times0.666$	8.3×10^6	2.0×10^9
$\Sigma(1385)^+ \to \Lambda\pi^+$	10	0.27%	0.639×0.88	9.2×10^4	6.1×10^7
$\Sigma(1385)^- \to \Lambda\pi^-$	10	0.27%	0.639×0.88	14.6×10^4	9.6×10^7
$\Theta(1540)^+ \to pK^0_S$					
$\Gamma = 0$ MeV/c^2	12	0.39%	$0.686\times0.5\times0.5$	<695	$<1.0\times10^6$
$\Gamma = 15$ MeV/c^2	12	0.39%	$0.686\times0.5\times0.5$	<2154	$<3.2\times10^6$

Decay	B.R.
$K^*(892)^+ \to \overline{K}^0\pi^+$	66.6%
$K^0_S \to \pi^+\pi^-$	68.6%
$\overline{K}^0 \to K^0_S$	50.0%
$\Lambda \to p\pi^-$	63.9%
$\Sigma(1385)^\pm \to \Lambda\pi^\pm$	88.0%
$\Theta(1540)^+ \to p\overline{K}^0$	50.0%

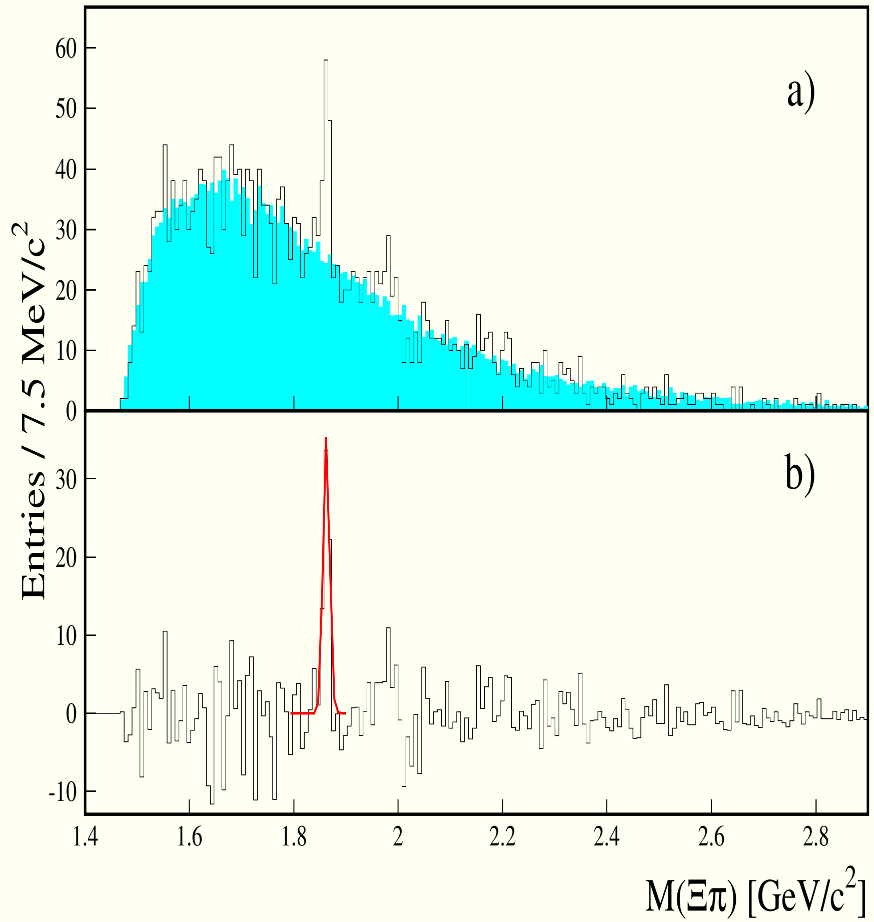
- Events generated by minimum bias PYTHIA γ–N interactions with bremsstrahlung photon spectrum
- $\Theta(1540)^+$ generated as $\Sigma(1385)^+$

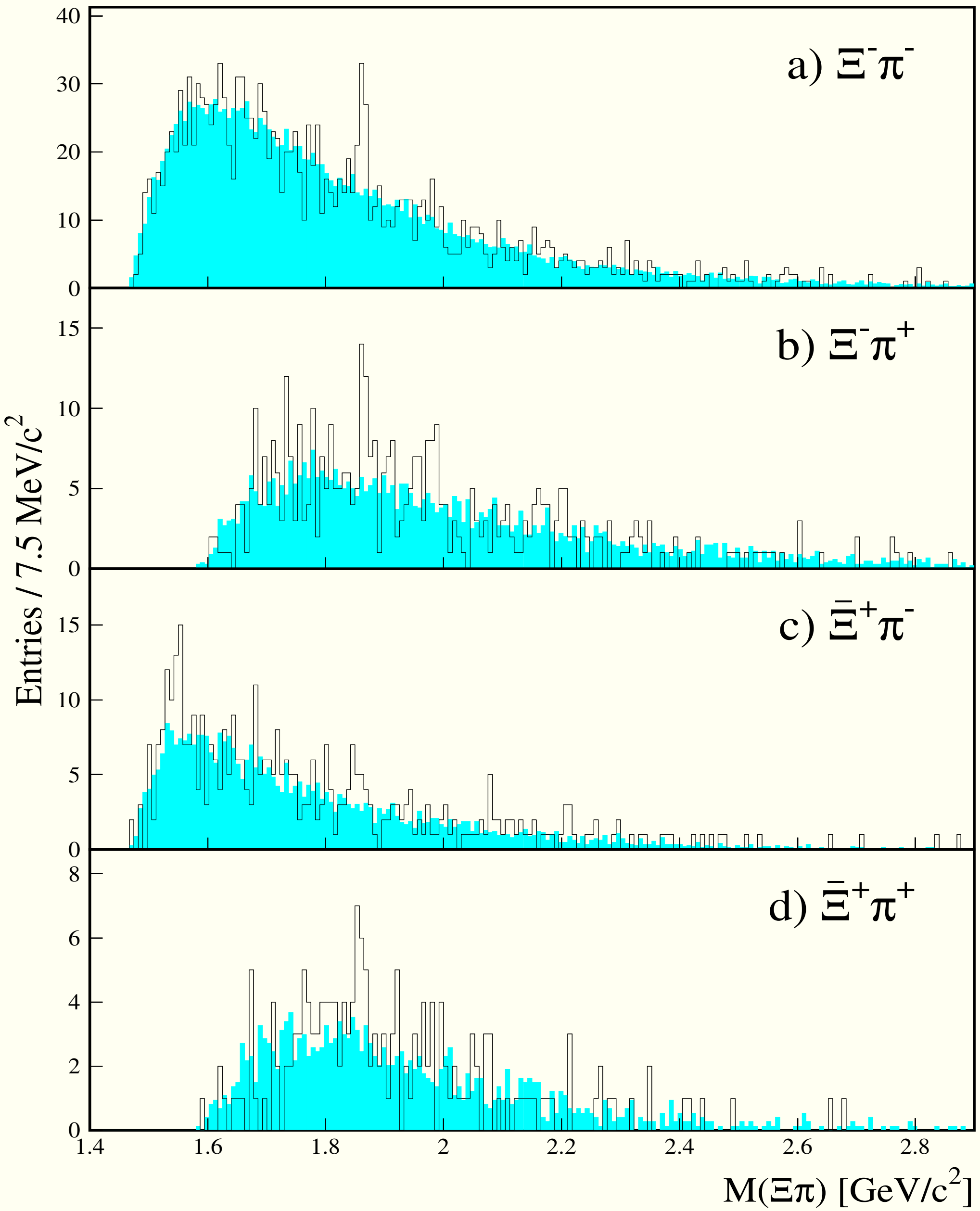
Limits on $\Theta(1540)^+$ production



$S = -2$ pentaquarks ($\phi(1860)^{--}$)

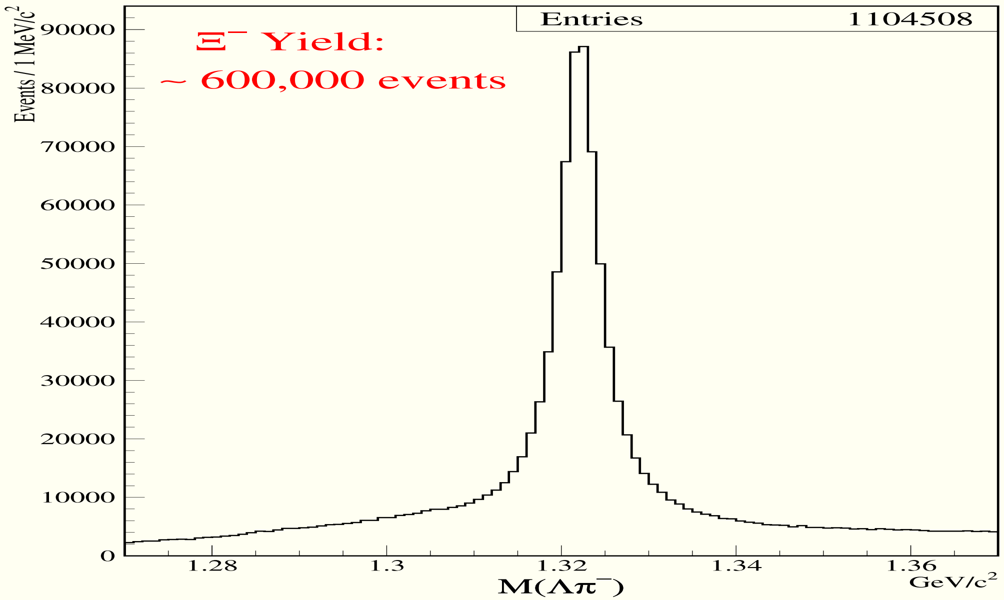
- NA49 evidence for $\phi(1860)^{--}(dds s\bar{u})$ and $\phi(1860)^0$ decaying $\Xi^-\pi^\pm$
- 158 GeV p on LH

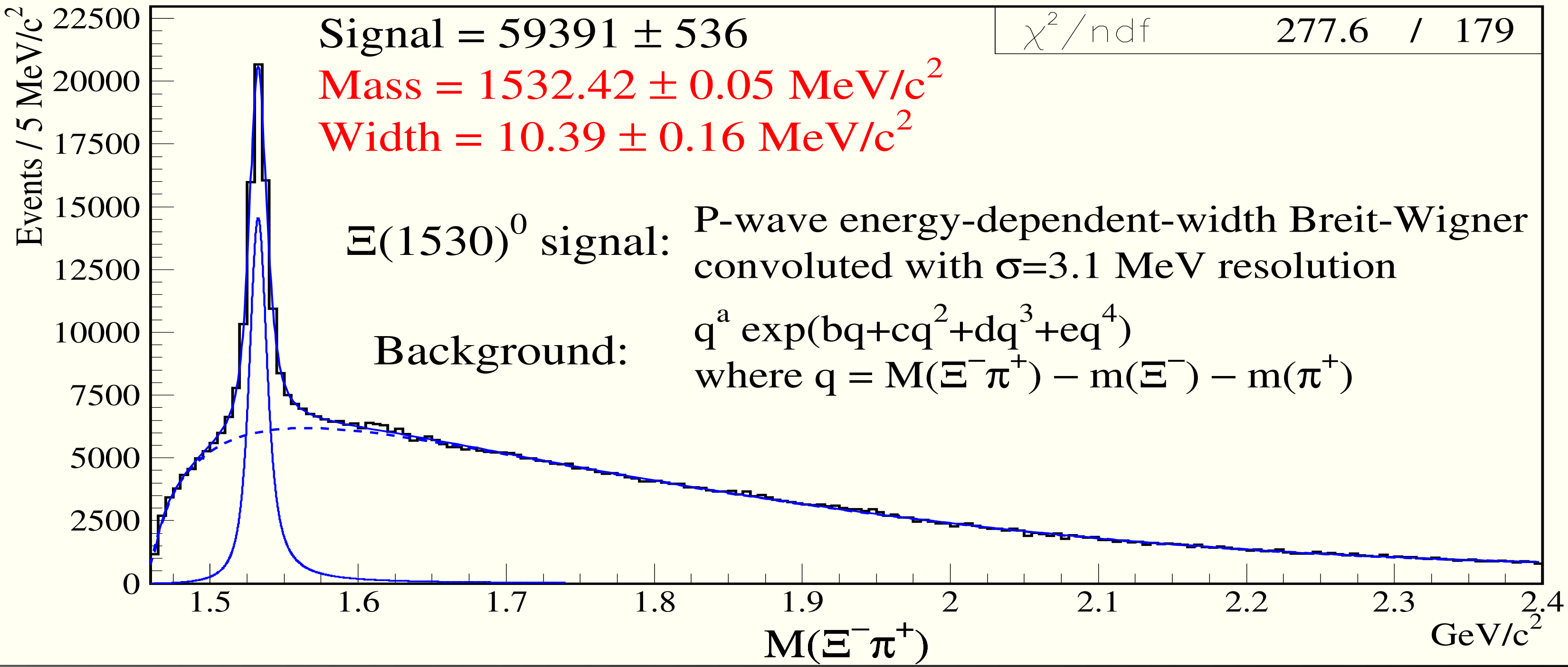




FOCUS analysis: $\phi(1860)^{--} \to \Xi^-\pi^-$ search

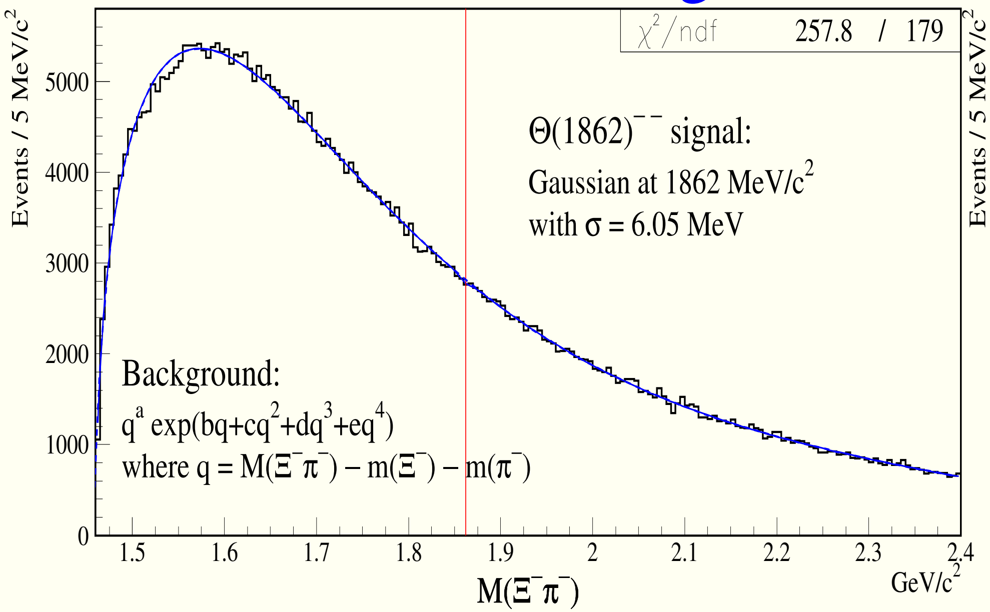
- $\sim$600,000 $\Xi^- \to \Lambda^0\pi^-$ sample
- Vertex Ξ^- with $\pi^\pm$ and find production vertex
- Require $< 4\sigma$ separation between vertices
- In $\Xi^-\pi^+$, observe $\sim$60,000 $\Xi(1530)^0$ candidates

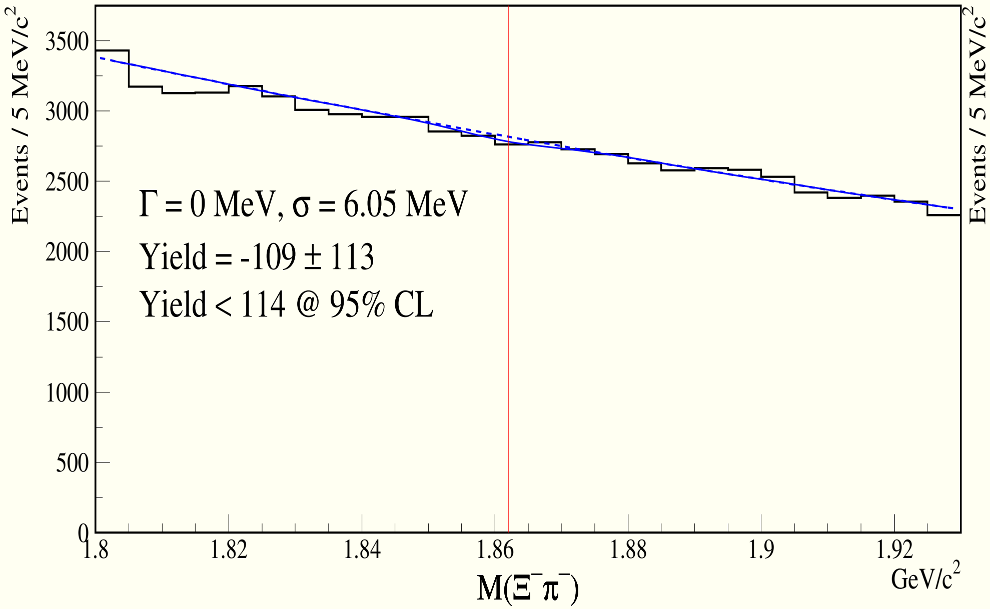




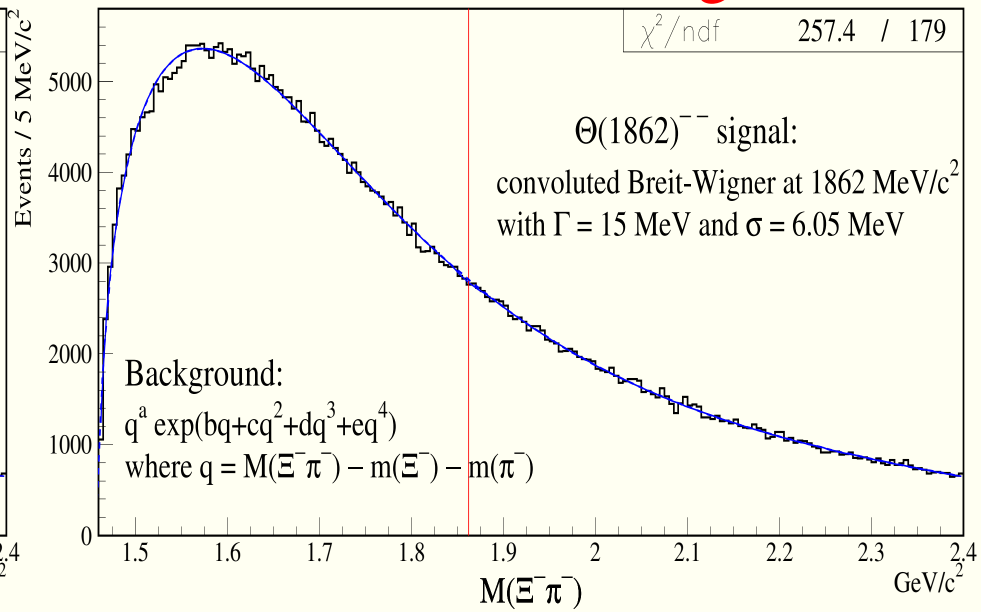
Results of FOCUS search for $\phi(1860)^{--}$

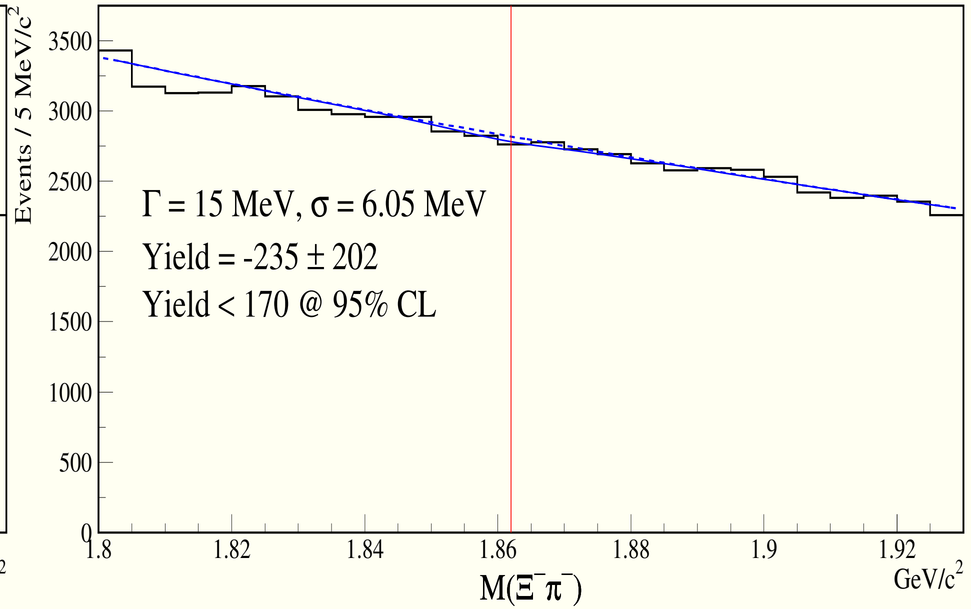
Fit to $\Gamma = 0\,\mathrm{MeV}$ signal





Fit to $\Gamma = 15\,\mathrm{MeV}$ signal





Limits on $\phi(1860)^{--}$ production

- Using PYTHIA, generate Monte Carlo samples of $\Xi(1530)^0$ and of $\phi(1860)^{--}$ (using $\Xi(1530)^0$)
- Average momentum is 15 GeV/c
- Efficiency ratio is $\frac{\epsilon(\phi(1860)^{--}\to\Xi^-\pi^-)}{\epsilon(\Xi(1530)^0\to\Xi^-\pi^+)} = 0.78$
- Thus, for a $\phi(1860)^{--}$ produced like $\Xi(1530)^0$ we obtain the limits:

$$\frac{\sigma(\phi(1860)) \times \mathbf{BR}(\phi(1860) \to \Xi^-\pi^-)}{\sigma(\Xi(1530))} < 0.25\,\%\ @\ 95\%\ \mathbf{CL\ for}\ \Gamma = 0\ \mathbf{MeV}$$

$$\frac{\sigma(\phi(1860)) \times \mathbf{BR}(\phi(1860) \to \Xi^-\pi^-)}{\sigma(\Xi(1530))} < 0.37\,\%\ @\ 95\%\ \mathbf{CL\ for}\ \Gamma = 15\ \mathbf{MeV}$$

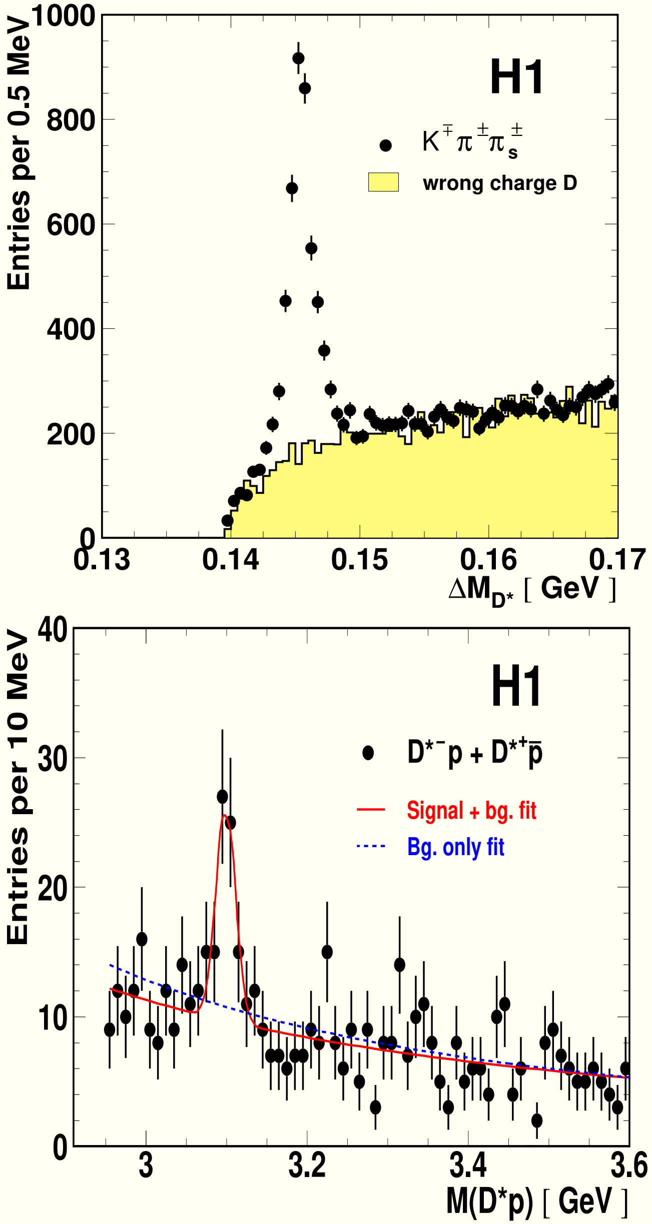
- Sharp contrast to NA49 which seems to be $\gtrsim 50\%$

Charm pentaquarks

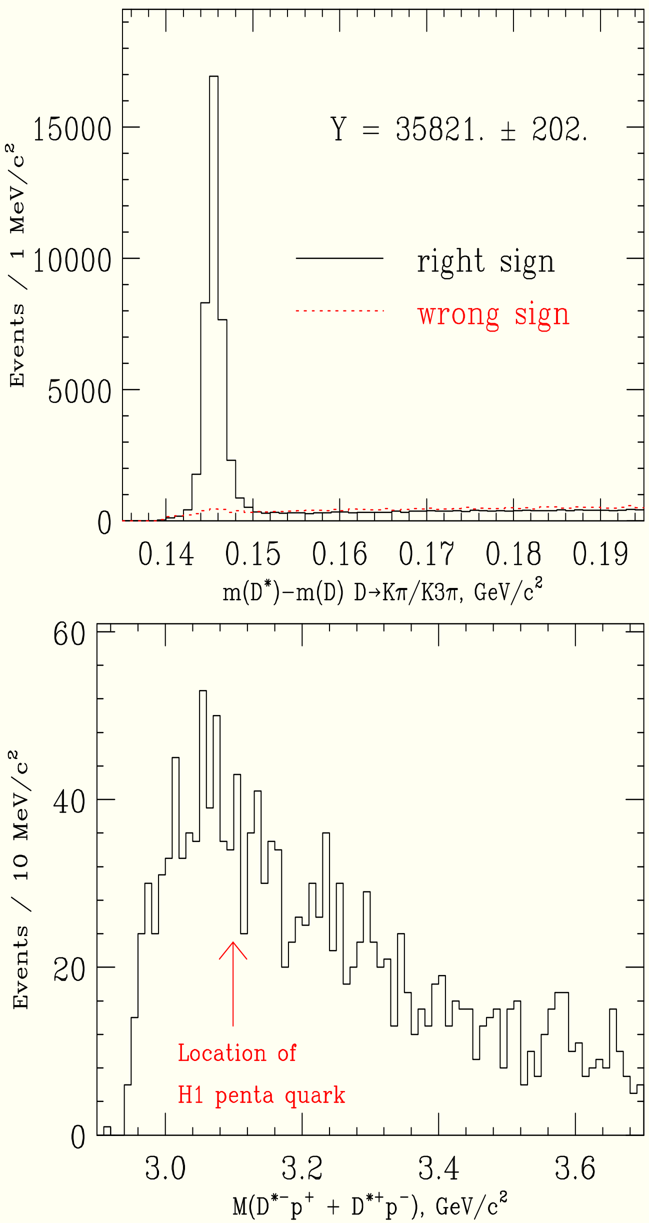
- H1 at HERA reported a $> 6\sigma$ significant particle at $3.099\,\mathrm{GeV}/c^2$ decaying to $D^{*-}p$
- Using a D^{*+} sample $10\times$ larger and much cleaner, FOCUS searched for this particle
- FOCUS also investigated D^+p decays
- Standard fixed-target charm selection criteria used for D^{*+} and D^+ reconstruction
- p candidate must originate from production vertex and be positively identified by Čerenkov system

FOCUS finds no charm pentaquarks

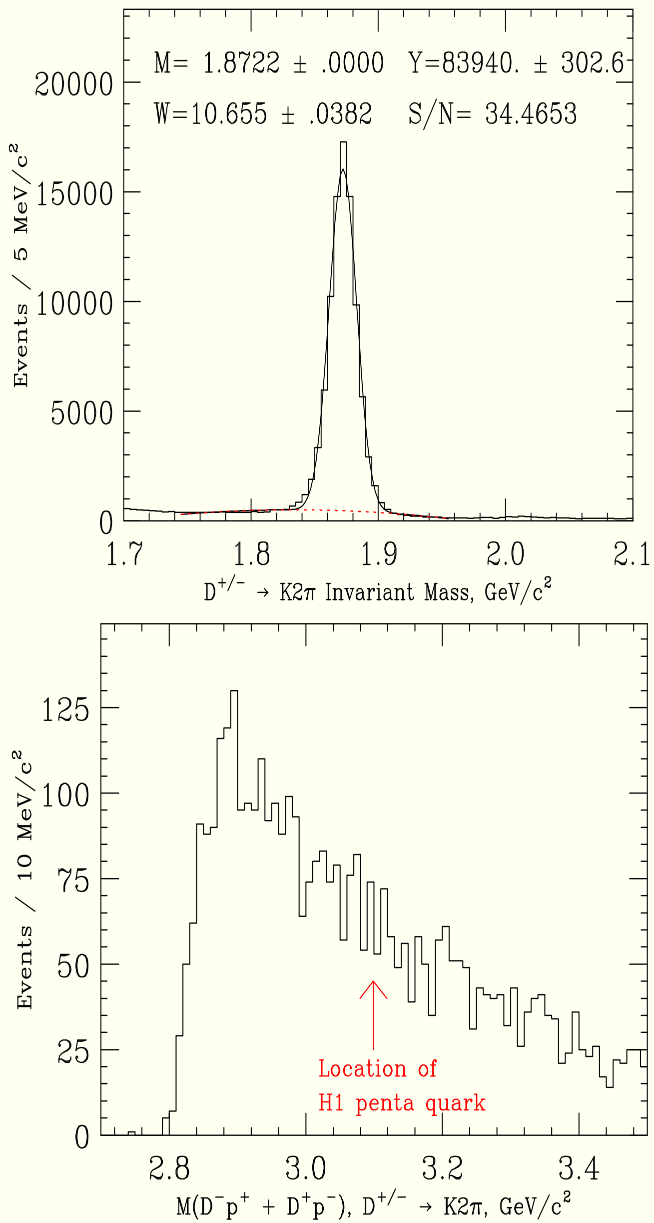
H1 $D^{*-}p$



FOCUS $D^{*-}p$



FOCUS D^+p



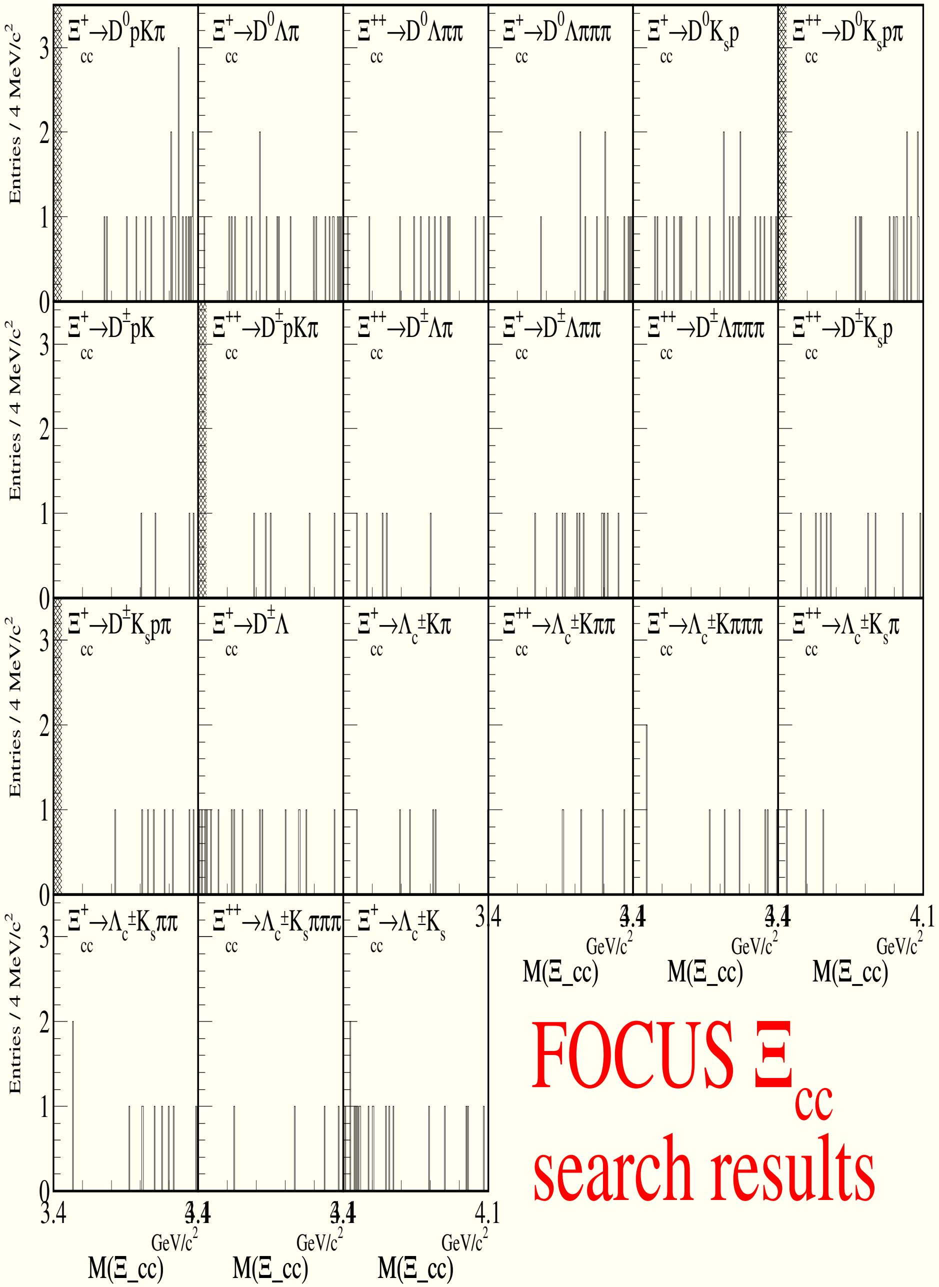
Double charm baryons

SELEX has reported various observations of double charm baryons. SELEX uses hadron beams and only reconstructs high x_F particles.

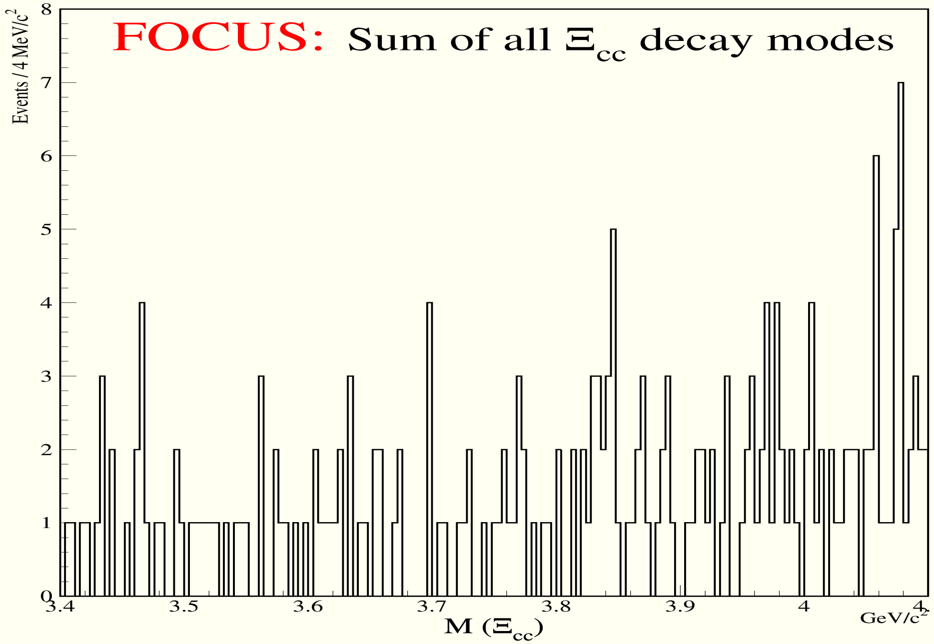
FOCUS analysis:

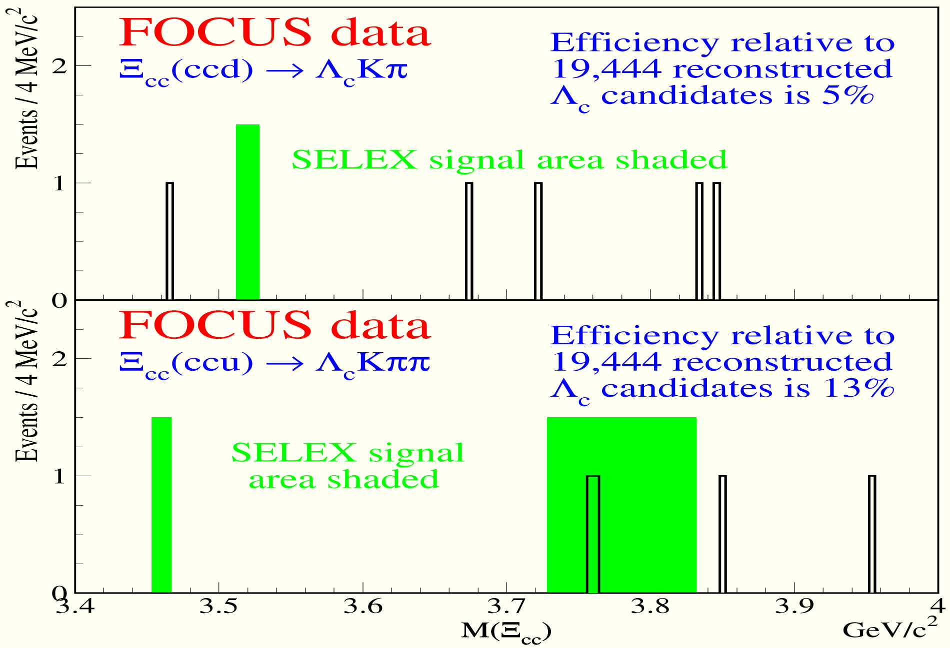
- Topology consists of three vertices
- Use candidate driven algorithm
- Reconstruct D^+, D^0, or Λ_c requiring a good vertex
- Add tracks to charm vector to search for Ξ_{cc} decay requiring a good vertex
- Use Ξ_{cc} vector to find production vertex
- Require separation between all vertices
- Use Čerenkov system to positively identify protons and kaons

FOCUS Ξ_{cc} search results



FOCUS Ξ_{cc} search results





Double charm baryon production compared

Decay Mode	$\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$		$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$	
Experiment	FOCUS	SELEX	FOCUS	SELEX
Ξ_{cc} Events	<2.21 @ 90%	15.8	<2.21 @ 90%	8
Reconstructed Λ_c	$19,444 \pm 262$	1650	$19,444 \pm 262$	1650
Relative Efficiency	5%	10%	13%	5%
Ξ_{cc}/Λ_c^+	<0.23% @ 90%	9.6%	<0.09% @ 90%	9.7%
$\frac{\text{SELEX}}{\text{FOCUS}}$ Rel $\frac{\Xi_{cc}}{\Lambda_c}$ Prod	>42 @ 90%		>111 @ 90%	

If the $\Lambda_c^+ K^- \pi^+$ ($\Lambda_c^+ K^- \pi^+ \pi^+$) signal is real, SELEX produces at least 42 (111) times more Ξ_{cc} baryons relative to Λ_c than FOCUS

Summary of the FOCUS searches

- No evidence for $\Theta(1540)^+ \rightarrow pK^0_S$ but reconstructs 8 million $K^*(892)^+ \rightarrow K^0_S\pi^+$ and 240,000 $\Sigma(1385)^\pm \rightarrow \Lambda^0\pi^\pm$ in similar decay modes
- No evidence for $\phi(1860)^{--} \rightarrow \Xi^-\pi^-$ but reconstructs 60,000 $\Xi(1530)^0 \rightarrow \Xi^-\pi^+$, approximately 1,000 times more than the observing experiment
- No evidence for a charm pentaquark decaying to $D^{*-}p$ or D^-p with a factor of 10 more D^{*+} decays than the observing experiment
- No evidence for double charm baryons with a factor of 10 more Λ_c decays than the observing experiment