Recent Results from FOCUS

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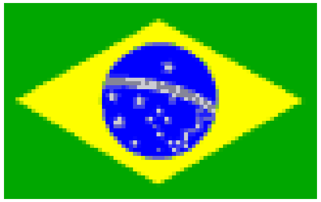
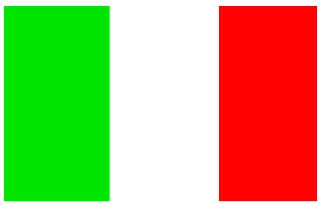
Outline

- Results on semileptonic decays
  - Non-parametric form-factors from $D^+ \to K^* \mu^+ \nu$
  - Measurement of $D^+ \to \rho^0 \mu^+ \nu$
- Results from pentaquark searches
  - Search for $\Theta^+ \to p K_s$

The FOCUS Collaboration



Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro
Pontifícia Universidade Católica, Rio de Janeiro



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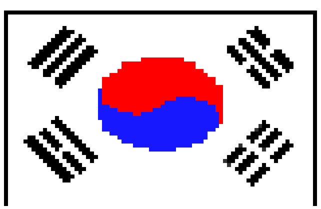
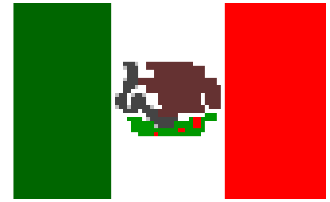
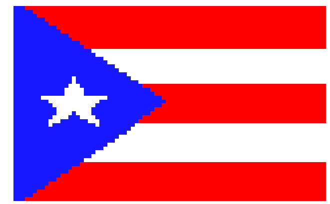


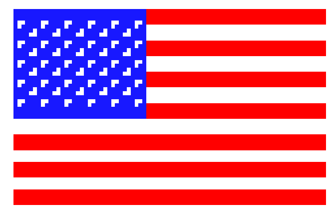
Korea University, Seoul
Kyungpook National University, Taegu



CINVESTAV, México City
Universidad Autónoma de Puebla, Puebla
University of Guanajuato, Guanajuato



University of Puerto Rico, Mayaguez



University of California, Davis
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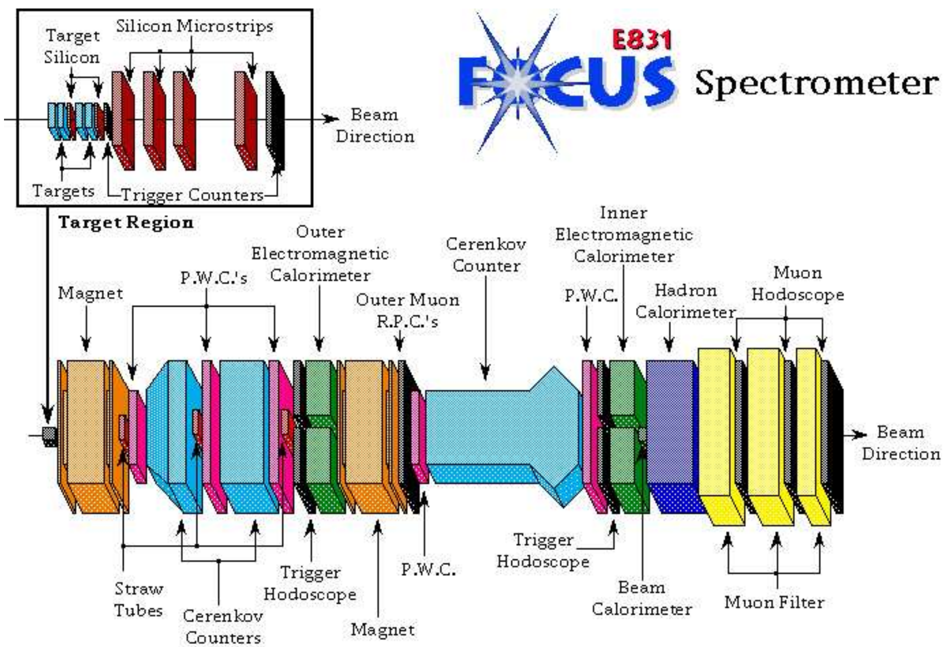
University of North Carolina, Ashville
University of South Carolina, Columbia
University of Tennessee, Knoxville
Vanderbilt University, Nashville
University of Wisconsin, Madison

FOCUS Experiment and Data Set

- FOCUS took data in the Fermilab fixed-target run of 96/97
- $e^{\pm}$ at $\sim$ 300 GeV bremsstrahlung on lead target to create photon beam
- Photons interact in segmented 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
- 6 billion events on tape
- over 1 million charm decays fully reconstructed

Recent Semileptonic Results

Motivation

- SL decays provide an excellent environment for the study of hadronic currents since
  - proceed only through spectator diagrams
  - Hadronic and Leptonic currents are factorizable
- The decay rates can be computed from Feynman diagrams using CKM matrix elements:
  - The hadronic complications are contained in the form factors (FF)
  - FF can be calculated through LQCD, HQET or quark models.
- Charm SL decays provide a high quality lattice calibration
  - crucial in reducing systematic errors in the Unitarity Triangle
  - techniques validated by charm decays can be applied to beauty decays

$D^+ \to K^- \pi^+ \mu^+ \nu$ Decay

- Strongly dominated by $\overline{K}^*(892)$ resonance
- ... but a small scalar component (NR) is needed
- decay amplitude described in terms of helicity basis form-factors
  essentially $H_\pm(q^2), H_0(q^2), h_0(q^2)$

FOCUS has published:

- Evidence for S-wave contribution PLB 535, 43 (2002)
- $\Gamma(D^+ \to \overline{K}^{*0} \mu^+ \nu)/\Gamma(D^+ \to K^- \pi^+ \pi^+)$ PLB 541, 243 (2002)
- Measurement of FF ratios PLB 544, 89 (2002)

- $K\pi$ Lineshape fit and $\overline{K}^*(892)$ mass and width PLB 621, 72 (2005)
- Non-parametric approach to FF in $D^+ \to \overline{K}^{*0} \mu^+ \nu$ PLB 633, 183 (2006)

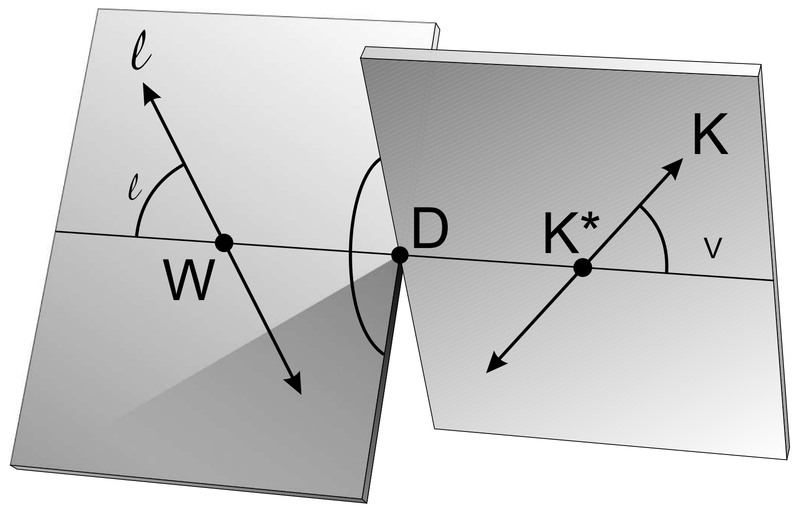
⋆ Spin-0 D meson to 4-Body final state
⟶ 5 independent variables:

$$d\Gamma = |\mathcal{M}|^2\,\phi_{PS}\,dm_{K\pi}\,dq^2\,d\cos\theta_V\,d\cos\theta_l\,d\chi$$

⋆ Scalar and vector amplitudes contributing to $\mathcal{M}$: dropping terms $\propto m_l^2$

$$\mathcal{M}_1 = (1+\cos\theta_\ell)\sin\theta_{\mathrm{v}} e^{i\chi} H_+(q^2) - (1-\cos\theta_\ell)\sin\theta_{\mathrm{v}} e^{-i\chi} H_-(q^2) - 2\sin\theta_\ell\cos\theta_{\mathrm{v}} H_0(q^2)$$

$$\mathcal{M}_0 = 2\sin\theta_\ell\, H_0^s(q^2)$$



⋆ FF assumed to have a q^2 dependence given by pole dominance

$$FF(q^2) = \frac{FF(0)}{1-q^2/m^2_{\mathrm{pole}}}$$

excellent description in $D \to P\mu\nu$ decays
FOCUS **PLB 607, 233 (2005)**

$K\pi$ Lineshape Fit

$$\frac{d\Gamma}{dm_{K\pi}} = \int \epsilon |\mathcal{M}_0 \mathcal{S} + \mathcal{M}_1 \mathcal{V}|^2 \phi_{PS} d\Omega$$

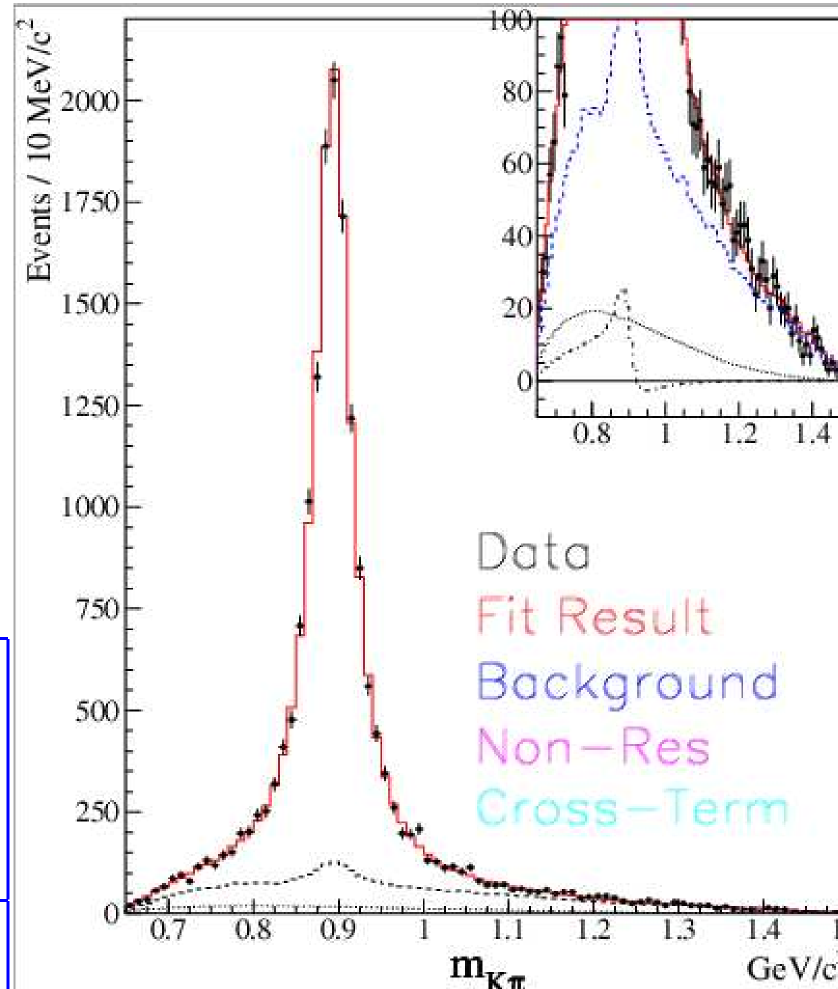
$$= F_{00}|\mathcal{S}|^2 + F_{11}|\mathcal{V}|^2 + 2F_{01}\mathcal{R}(\mathcal{V}\mathcal{S}^*)$$

- Fit Procedure:

- Unbinned Maximum Likelihood
- Includes PDf for Signal and Background
- Fit parameters:
  $\overline{K}^*(892)^0$ mass and width
  r_0 from Blatt-Weisskopf factor
  magnitudes for scalar, $\overline{K}^*(1680)^0$, $\overline{K}^*_0(1430)^0$

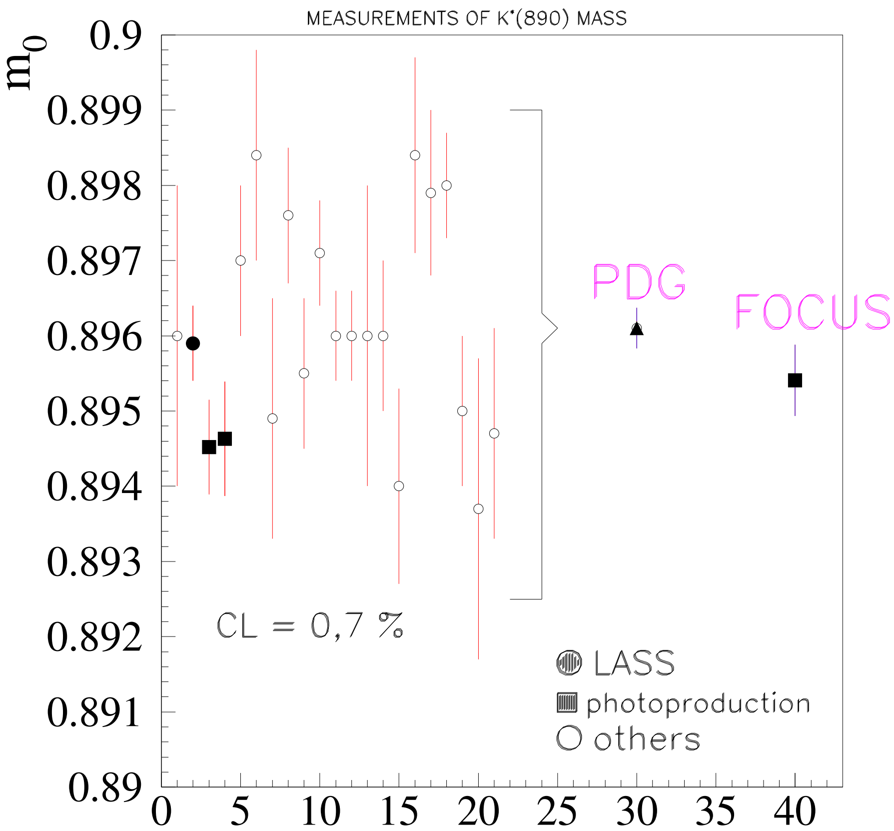
$m_{\overline{K}^*(892)^0}$ (MeV)	$895.41 \pm 0.32^{+0.35}_{-0.43}$
$\Gamma_{\overline{K}^*(892)^0}$ (MeV)	$47.79 \pm 0.86^{+1.32}_{-1.06}$
f_S	$5.30 \pm 0.74^{+0.99}_{-0.96}\%$
r_0 (Gev^{-1})	$3.96 \pm 0.54^{+1.31}_{-0.90}$
$f_{\overline{K}^*(1680)}$	$< 4.0\%$ 90% CL
$f_{\overline{K}^*_0(1430)}$	$< 0.64\%$ 90% CL

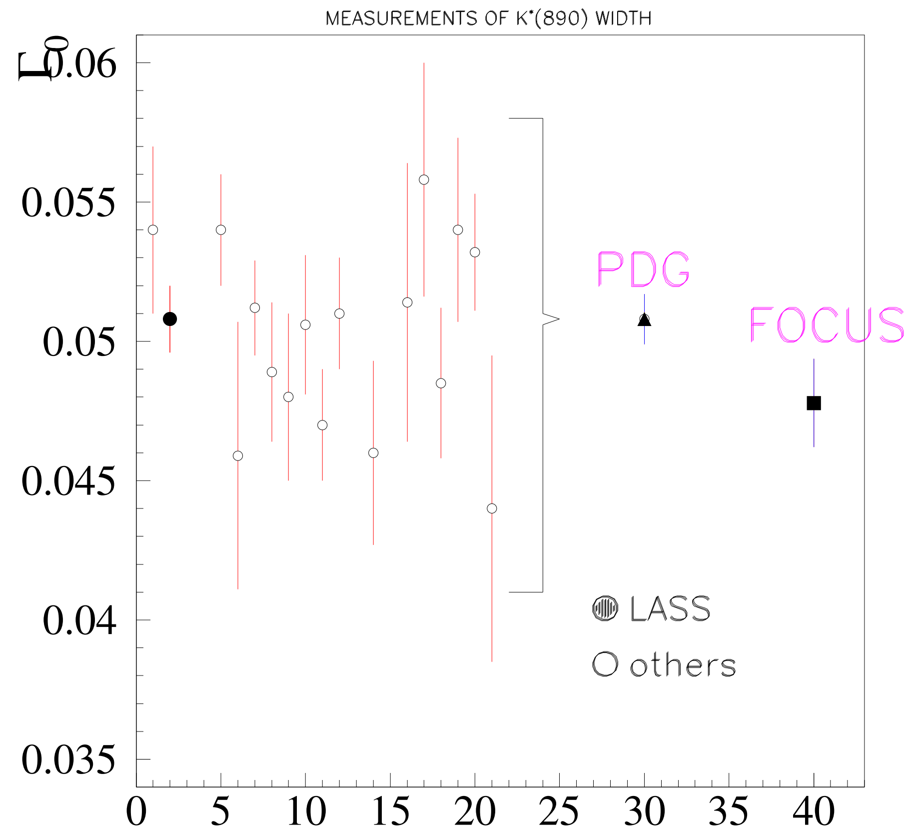
18K events



χ^2/N_{dof} = 0.93
CL=66 %

$\overline{K}^*(892)^0$ Mass and Width





PDG dominated by LASS

Compared to PDG, measurements from FOCUS are:
$\sim 1\,\sigma$ below for mass
$\sim 2\,\sigma$ below for width

$D^+ \to \overline{K}^{*0}\mu^+\nu$ Form Factors

Non-Parametric Approach

$$\int |A|^2 d\chi = \frac{q^2 - m_\ell^2}{8} \left\{ \begin{array}{l} ((1+\cos\theta_\ell)\sin\theta_{\mathrm{v}})^2 \, |H_+(q^2)|^2 |\mathrm{BW}|^2 \\ +((1-\cos\theta_\ell)\sin\theta_{\mathrm{v}})^2 \, |H_-(q^2)|^2 |\mathrm{BW}|^2 \\ +(2\sin\theta_\ell\cos\theta_{\mathrm{v}})^2 \, |H_0(q^2)|^2 |\mathrm{BW}|^2 \\ +8\sin^2\theta_\ell\cos\theta_{\mathrm{v}} \, H_0(q^2) h_o(q^2) \mathrm{Re}\{A e^{-i\delta} \mathrm{BW}\} \end{array} \right\}$$

Obs: For simplicity, terms proportional to m_ℓ^2/q^2 were omitted above, which include also an explicit dependence on $H_t(q^2)$ form factor. They are included in the analysis though.

$$H_\pm(q^2) = (M_D + m_{K\pi})A_1(q^2) \mp 2\frac{M_D K}{M_D + m_{K\pi}} V(q^2),$$

$$H_0(q^2) = \frac{1}{2m_{K\pi}\sqrt{q^2}} \left[(M_D^2 - m_{K\pi}^2 - q^2)(M_D + m_{K\pi})A_1(q^2) - 4\frac{M_D^2 K^2}{M_D + m_{K\pi}} A_2(q^2) \right]$$

Each of the above terms contributes with a specific signature when looking at $\{\cos\theta_{\mathrm{v}}, \cos\theta_\ell\}$

⇓

Projection Weighting Technique

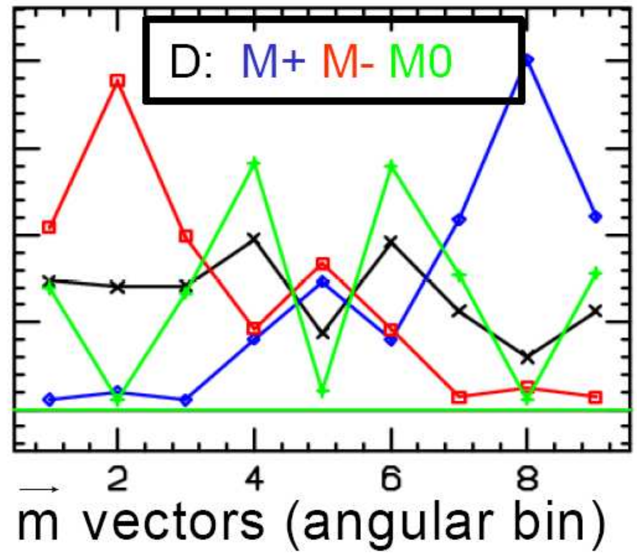
Projection Weighting Technique

- For a given q^2 bin "i" for data

Look at 25 $\cos\theta_v \times \cos\theta_\ell$ angular bins : $\vec{D}_i$

- $\{\vec{m}_\alpha\} = (\vec{m}_+, \vec{m}_-, \vec{m}_0)$: number of events present in the angular bins when each term (H_+, H_-, H_0) is turned on

$$\vec{D}_i = f_+(q_i^2)\vec{m}_+ + f_-(q_i^2)\vec{m}_- + f_0(q_i^2)\vec{m}_0$$



$$\begin{pmatrix} \vec{m}_+ \cdot \vec{D}_i \\ \vec{m}_- \cdot \vec{D}_i \\ \vec{m}_0 \cdot \vec{D}_i \end{pmatrix} = \begin{pmatrix} \vec{m}_+ \cdot \vec{m}_+ & \vec{m}_+ \cdot \vec{m}_- & \vec{m}_+ \cdot \vec{m}_0 \\ \vec{m}_- \cdot \vec{m}_+ & \vec{m}_- \cdot \vec{m}_- & \vec{m}_- \cdot \vec{m}_0 \\ \vec{m}_0 \cdot \vec{m}_+ & \vec{m}_0 \cdot \vec{m}_- & \vec{m}_0 \cdot \vec{m}_0 \end{pmatrix} \begin{pmatrix} f_+(q_i^2) \\ f_-(q_i^2) \\ f_0(q_i^2) \end{pmatrix}$$

$$f_+(q_i^2) = {}^i\vec{P}_+ \cdot \vec{D}_i \,,\; f_-(q_i^2) = {}^i\vec{P}_- \cdot \vec{D}_i \,,\; f_0(q_i^2) = {}^i\vec{P}_0 \cdot \vec{D}_i$$

$$\begin{pmatrix} {}^i\vec{P}_+ \\ {}^i\vec{P}_- \\ {}^i\vec{P}_0 \end{pmatrix} = \begin{pmatrix} \vec{m}_+ \cdot \vec{m}_+ & \vec{m}_+ \cdot \vec{m}_- & \vec{m}_+ \cdot \vec{m}_0 \\ \vec{m}_- \cdot \vec{m}_+ & \vec{m}_- \cdot \vec{m}_- & \vec{m}_- \cdot \vec{m}_0 \\ \vec{m}_0 \cdot \vec{m}_+ & \vec{m}_0 \cdot \vec{m}_- & \vec{m}_0 \cdot \vec{m}_0 \end{pmatrix}^{-1} \begin{pmatrix} \vec{m}_+ \\ \vec{m}_- \\ \vec{m}_0 \end{pmatrix}$$

$\Downarrow$

projection weights

Projection Weighting Technique

$$f_i^+ = {}^i\vec{P}_+ \cdot \vec{D}_i = \frac{(H_+(q_i^2))^2}{(\tilde{H}_i^+)^2}\, {}^i\vec{P}_+ \cdot \vec{M}_i$$

$$\Rightarrow (H_+(q_i^2))^2 = \left[\frac{({}^i\tilde{H}_+)^2}{{}^i\vec{P}_+ \cdot \vec{M}_i}\;\; {}^i\vec{P}_+\right] \cdot \vec{D}_i \equiv {}^i\rho_+ \cdot \vec{D}_i$$

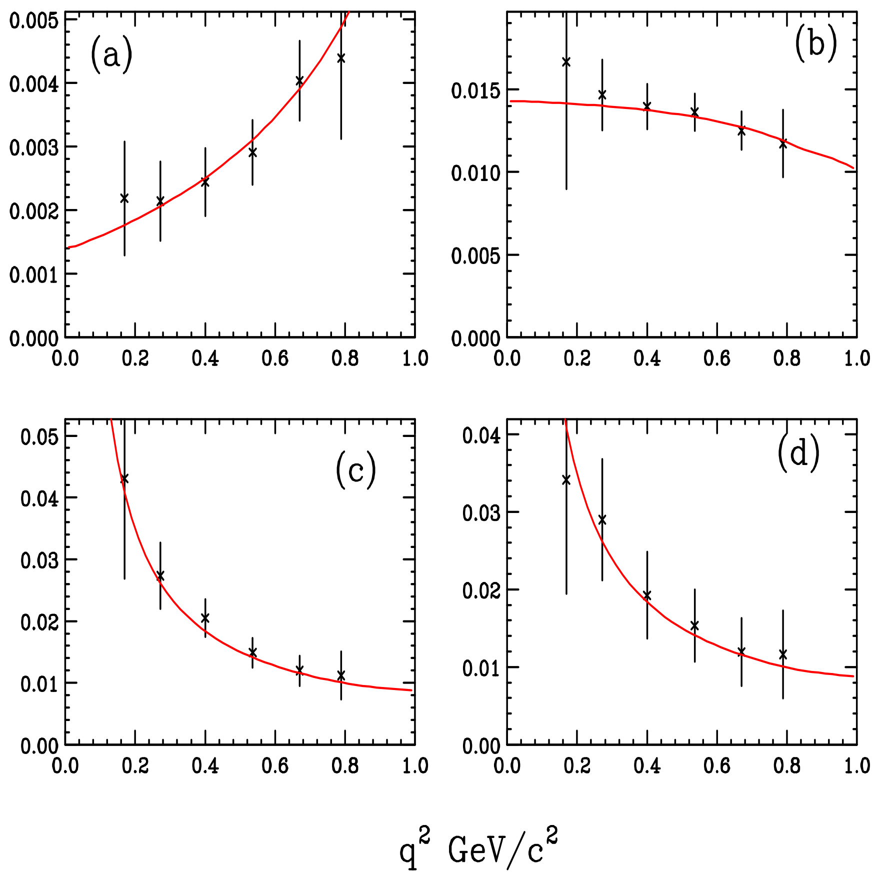
- $\vec{M}_i$: bin populations from MC, generated with a trial set

$$\tilde{H}_+^2(q^2),\ \tilde{H}_-^2(q^2),\ \tilde{H}_0^2(q^2)$$

- from projection weights ${}^i\vec{P}_+$ and projection-weighted MC distributions $({}^i\vec{P}_+ \cdot \vec{M}_i) \Rightarrow$ weight vector ${}^i\vec{\rho}_+$
- $H_+^2(q^2), H_-^2(q^2), H_0^2(q^2)$ obtained from the projection histograms

$${}^i\vec{\rho}_+ \cdot \vec{D}_i$$
$${}^i\vec{\rho}_- \cdot \vec{D}_i$$
$${}^i\vec{\rho}_0 \cdot \vec{D}_i$$

Results for MC



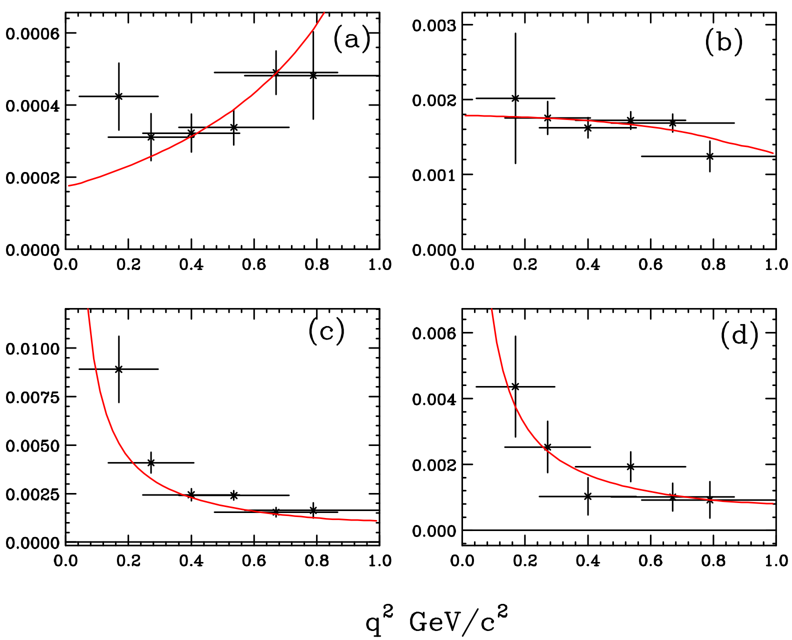
(a) $H_+^2(q^2)$
(b) $H_-^2(q^2)$
(c) $H_0^2(q^2)$
(d) $h_0(q^2) \times H_0^2(q^2)$

- abscissa: average generated q^2 for each of the 6 evenly spaced measured q^2
- input FF from our previous analysis including S-wave term **PLB 544, 89 (2002)**
- MC with 9 times our data sample
- error bars inflated $3\times$
- very good agreement between input and output FF

Results for Data

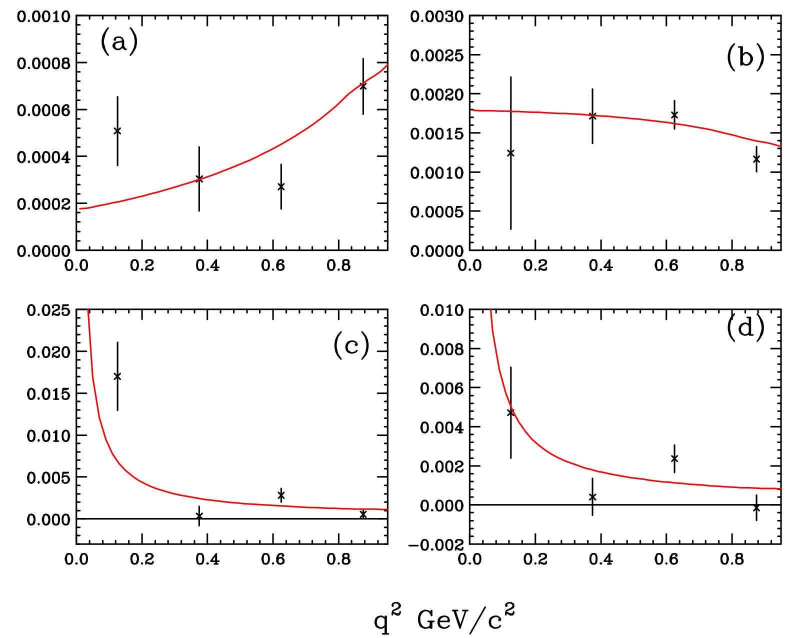
Unconvolved Analysis:

- abscissa: average generated q^2 for each of the 6 evenly spaced measured q^2 - as determined from MC
- horizontal error bars: r.m.s. q^2 resolution



Deconvolved Analysis:

- sum of $\vec{P}_+$ weights in a reconstructed q^2 bin depend on H_+^2 from all 6 true q^2 bins
- a deconvolution weighting technique is applied
- can use only 4 q^2 bins due to our level of resolution
- same features as unconvolved results on a coarser scale



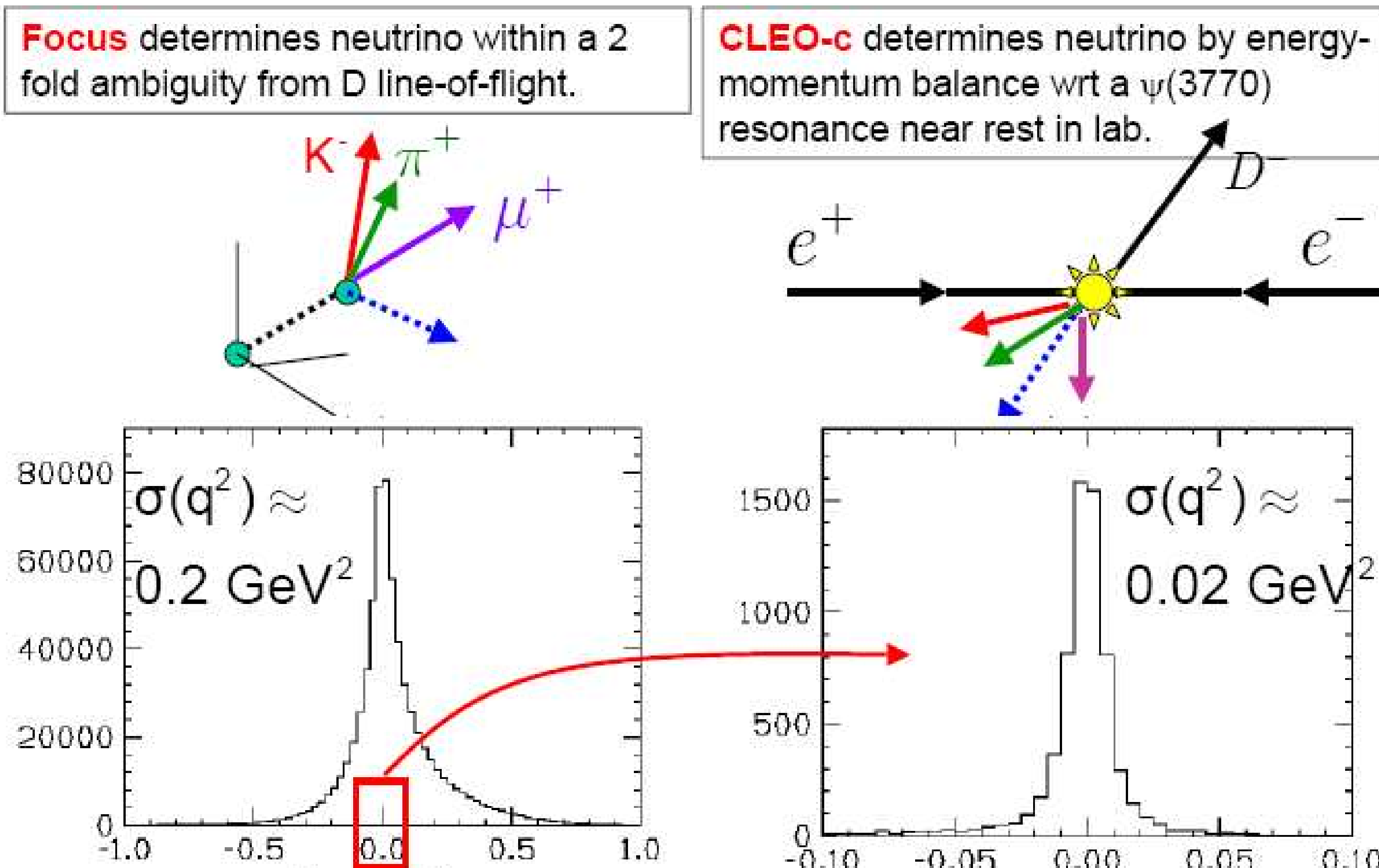
Comparison with Cleo-c

Cleo-c has just submitted the same analysis for the electron mode,

$$D^+ \to K^*(892)^0 e^+ \nu$$

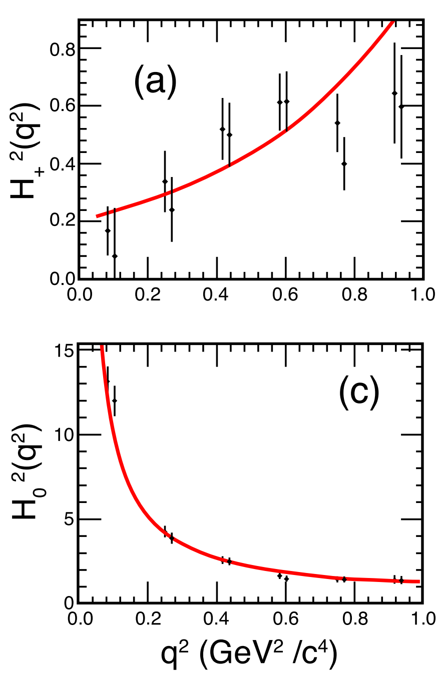
hep-ex/0606010

q² Resolution

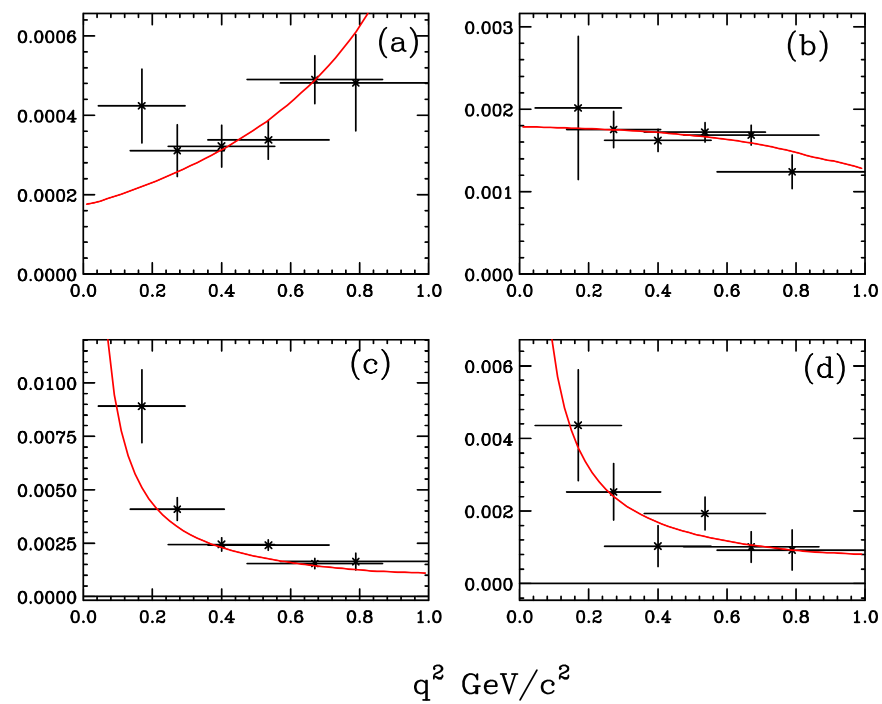


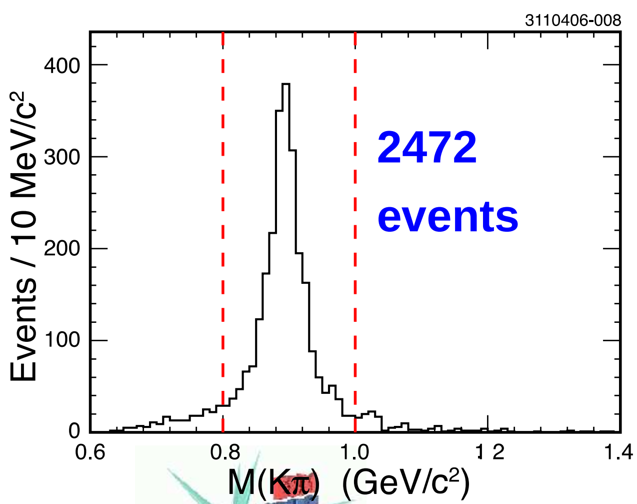
Comparison with Cleo-c: Form-Factors

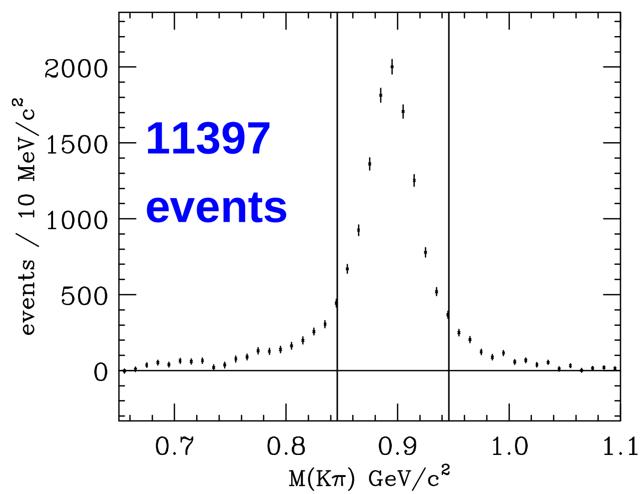
CLEO-c



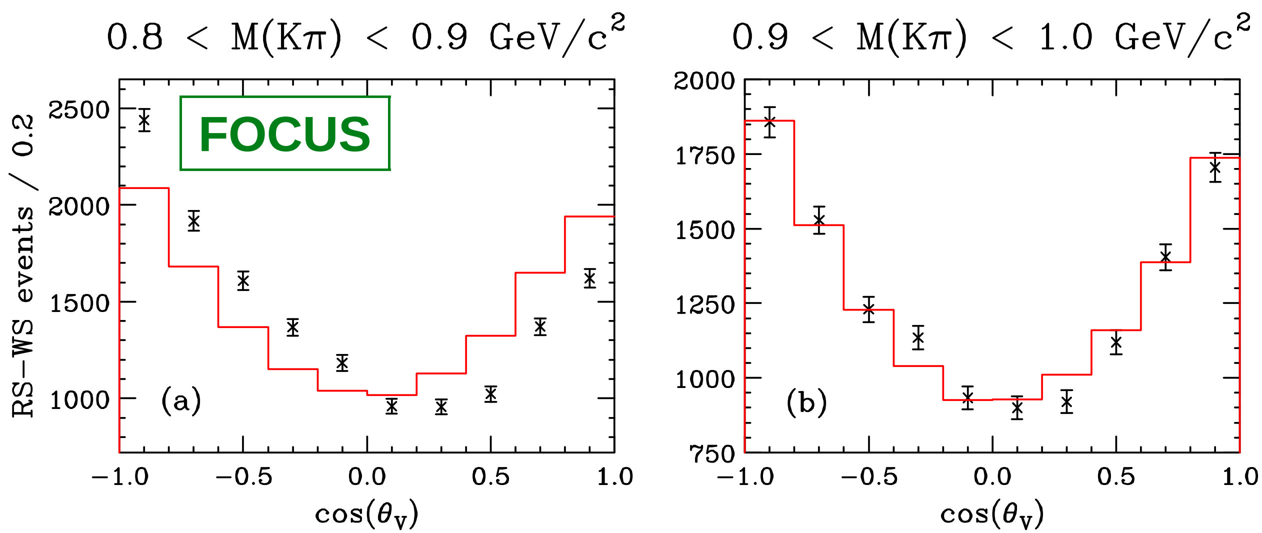
FOCUS

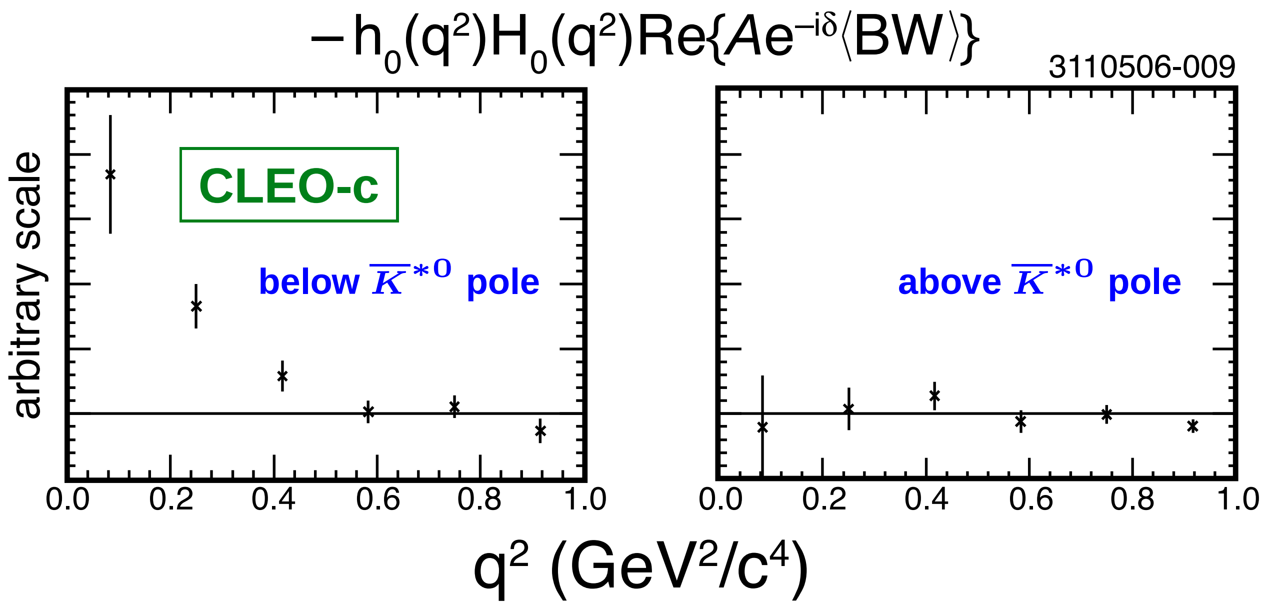






Comparison with Cleo-c: S-wave interference





$D^+ \longrightarrow \rho^0\mu^+\nu$ BR measurement

- Present PDG world average:

$$\frac{\Gamma(D^+ \to \rho^0\mu^+\nu)}{\Gamma(D^+ \to \bar{K}^*(892)^0\mu^+\nu)} = 0.061 \pm 0.014$$

- Previous measurements (E653, E687, E791) with large statistical errors
- most theoretical predictions differ by at least 2σ from the PDG value
  - calculations based on Quark Model, LQCD, Sum Rules, ...
  - values range from 0.020 –0.045

Event Selection and Contributions to $\pi\pi$ Mass Spectrum

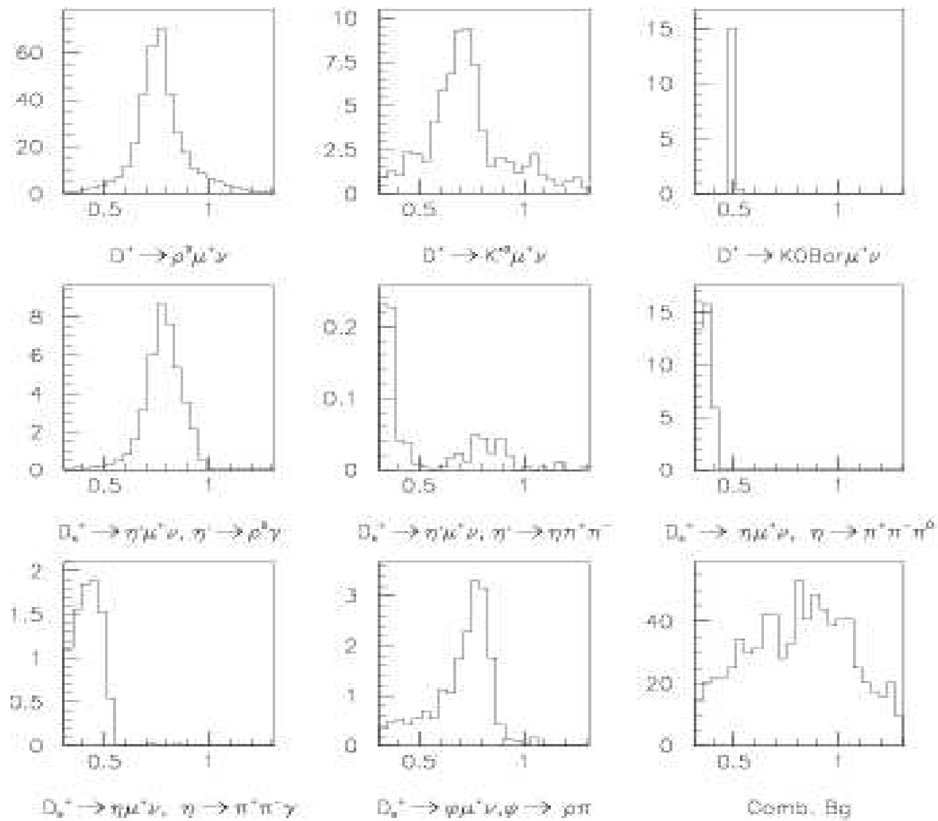
Invariant Mass (GeV)	Particle ID	Vertex
$1.0 < M(\pi\pi\mu) < 1.8$ $M(\pi^-\pi^+\mu^+) - M(\pi^-\mu^+) > 0.2$	$\mathrm{CL}_{imu} > 1\%$ π_{odd} pionicity> 0 π_{same} pionicity> 5	$\mathrm{CL}_{sec} > 5\%$, $\mathrm{ISO2} < 1\%$ $\mathrm{CL}_{pri} > 1\%$, inside target $L/\sigma > 15$, $\mathrm{OoT} > 1\sigma$

⋆ Charm semimuonic with 2 pions

- $D^+ \to \rho^0\mu^+\nu$
- $D^+ \to K^-\pi^+\mu^+\nu$ (K/π misid)
- $D^+ \to \bar{K}^0\mu^+\nu$
- $D_s^+ \to \eta'(\rho^0\gamma)\mu^+\nu$
- $D_s^+ \to \eta'(\pi^+\pi^-\eta)\mu^+\nu$
- $D_s^+ \to \eta'(\pi^+\pi^-\gamma)\mu^+\nu$
- $D_s^+ \to \phi(\rho\pi)\mu^+\nu$

⋆ Muon mis-id

⋆ Combinatoric Background



Fit Technique

Binned maximum-likelihood fit of $\pi^+\pi^-$ invariant mass

$$\mathcal{L} = \prod_{i=1}^{\#\text{bins}} \frac{n_i^{s_i} e^{-n_i}}{s_i!} \times \text{penalty}$$

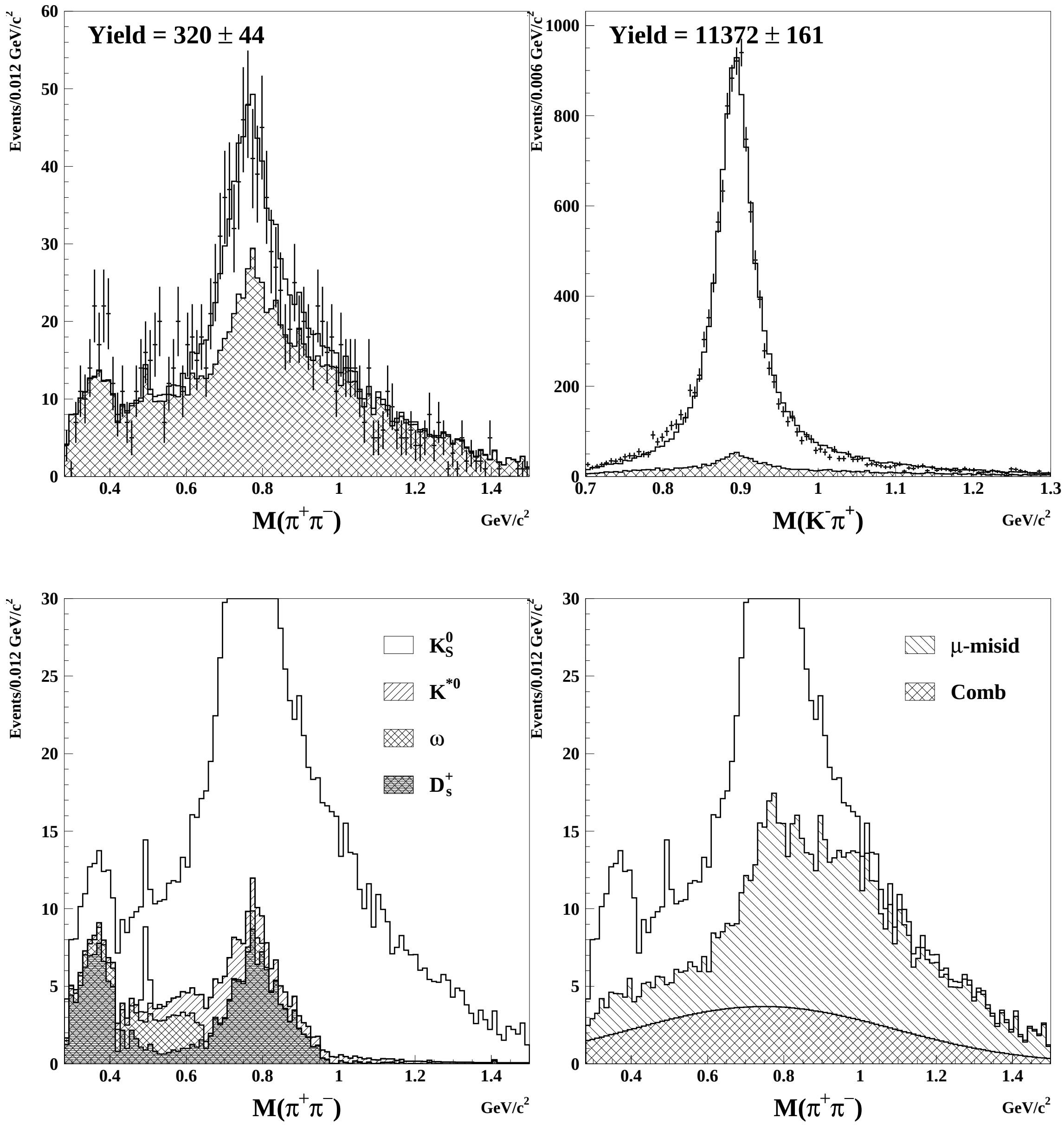
s_i = number of events in bin i for data histogram
n_i = number of events in bin i for fit histogram :

$$\begin{aligned} n_i \; = \; & Y_{\rho^0\mu^+\nu} S_{\rho^0\mu^+\nu} \\ & + \text{ECY}_{K^-\pi^+\mu^+\nu}\epsilon(K\pi\mu\mu \to \rho\mu\nu) S_{K^-\pi^+\mu^+\nu} \\ & + Y_{K_s^0\mu^+\nu} S_{K_s^0\mu^+\nu} + Y_{\omega\mu^+\nu} S_{\omega\mu^+\nu} + Y_{D_s^+} S_{D_s^+} \\ & + Y_C S_C + Y_M S_M \end{aligned}$$

- Binned, normalizes shapes S_x from MC
- Yields Y_x are fit parameters
- $D^+ \to K^-\pi^+\mu^+\nu$ is fixed
- penalty factor: loose constraint on $Y_{\omega\mu^+\nu}$

Fit Results

Decay Mode	Total Yield
$D^+ \to \rho^0 \mu^+ \nu$	320±44
$D^+ \to K^- \pi^+ \mu^+ \nu$	68
$D^+ \to K^0_S \mu^+ \nu$	7±6
D^+_s modes total	179±40
$D^+ \to \omega \mu^+ \nu$	51±22
Muon Mis-Id	550±44
Combinatoric	233±50



Result for $\frac{\mathrm{BR}(\mathrm{D}^+ \to \rho^0 \mu^+ \nu)}{\mathrm{BR}(\mathrm{D}^+ \to \overline{\mathrm{K}}^{*0} \mu^+ \nu)}$

★ The ratio of branching ratios is defined:

$$\frac{\mathrm{BR}(D^+ \to \rho^0 \mu^+ \nu)}{\mathrm{BR}(D^+ \to \overline{K}^{*0} \mu^+ \nu)} = \frac{Y_{\rho\mu\nu}/\epsilon_{\rho\mu\nu}}{Y_{K\pi\mu\nu}/\epsilon_{K\pi\mu\nu}} \times \frac{\mathrm{BR}(D^+ \to K^- \pi^+ \mu^+ \nu)}{\mathrm{BR}(D^+ \to K^* \mu^+ \nu)} \times \mathrm{BR}(\overline{K}^{*0} \to K^- \pi^+)$$

★ With 320 ± 44 $D^+ \to \rho^0 \mu^+ \nu$ events and 11372 ± 161 $D^+ \to K^- \pi^+ \mu^+ \nu$ events, we find

$$\frac{\mathrm{BR}(\mathrm{D}^+ \to \rho^0 \mu^+ \nu)}{\mathrm{BR}(\mathrm{D}^+ \to \overline{\mathrm{K}}^{*0} \mu^+ \nu)} = 0.041 \pm 0.006 \text{ (stat.)} \pm 0.004 \text{ (syst.)}$$

which gives:

$$\Gamma(D^+ \to \rho^0 \mu^+ \nu) = (0.22 \pm 0.03 \pm 0.02 \pm 0.01) \times 10^{10}\ \mathrm{s}^{-1}$$

Comparisons

This Result: 0.041±0.007

Experiment	$\frac{BR(\rho\mu\nu)}{BR(\overline{K}^{*0}\mu\nu)}$	$\frac{BR(\rho e\nu)}{BR(\overline{K}^{*0}e\nu)}$
E653 (1993)	$0.044^{+0.034}_{-0.029}$	
E687 (1997)	0.079±0.023	
E791 (1997)	0.051±0.017	0.045±0.017
CLEO (2005)		0.038±0.008

Authors	$\frac{BR(D^+ \to \rho^0 \ell^+ \nu)}{BR(D^+ \to \overline{K}^{*0} \ell^+ \nu)}$
APE (LQCD) 1995	0.043± 0.018
Jaus (QM) 1996	0.030
ISGW2 (QM) 1995	0.023
Yang–Hwang (SR) 1997	0.018± 0.005
O'Donnell–Turan (LF) 1997	0.025
Ligeti–Stewart–Wise 1998	0.044
Melikhov–Stech (QM) 2000	0.035
Wang–Wu–Zhong (LC) 2003	0.035±0.011
Fajfer–Kamenik 2005	0.045

Other Interesting Comparisons ...

X	Semileptonic $D^+ \to X\mu\nu$	Hadronic $D^+ \to X\pi^+$
$\rho(770)$	$\sim$ 100%	$\sim$ 30%
scalar $\pi\pi$	not seen	$\sim$ 60%
$K^*(892)$	95%	15%
scalar $K\pi^+$	5%	80–90%

Pentaquarks ...

⋆ Jan(2003) – March (2004) $\Longrightarrow$ 10 independent pentaquark observations at a mass $\sim$ 1540 GeV: $\Theta^{+}(uudd\bar{s})$

$$\Theta^{+} \rightarrow nK^{+}$$
$$\Theta^{+} \rightarrow pK^{0}_{S}$$

⋆ Results have also appeared for doubly-strange pentaquark and charm pentaquark

... but

⋆ Higher statistics and higher energy experiments have failed to find supporting evidence

⋆ **FOCUS** has published recently on the search for a charm pentaquark, failing to find evidence for it **PLB 622,229 (2005)**

Search for $\Theta^{+}(uudd\bar{s}) \longrightarrow pK_S^0$

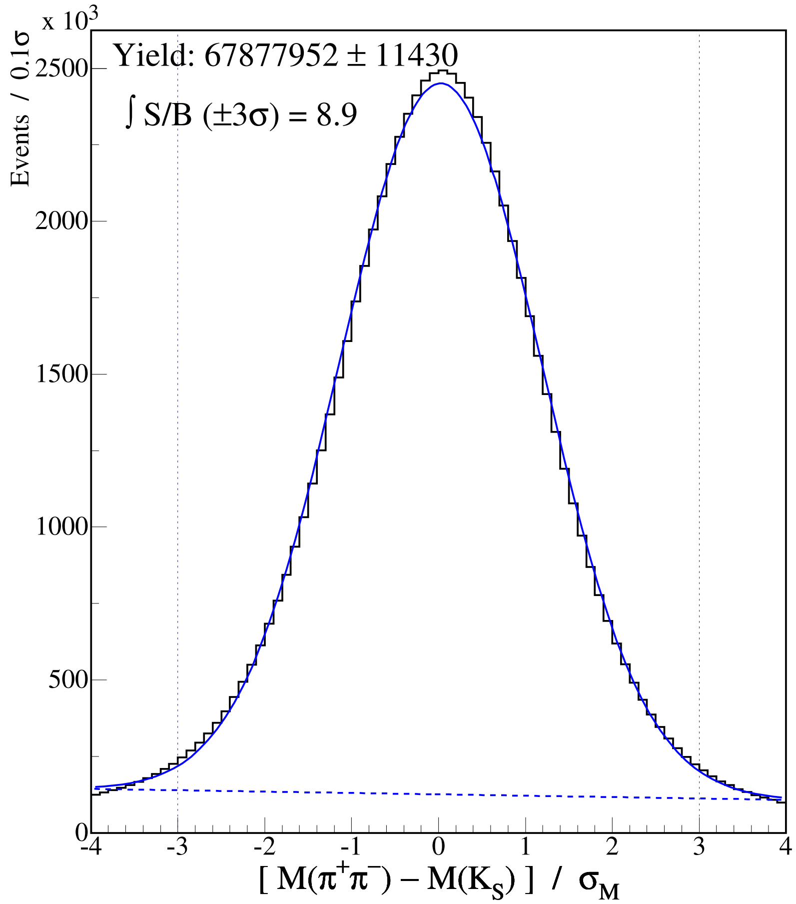
final results just released

hep-ex/0606014

- Search for $\Theta(1540)^{+} \rightarrow pK_S^0$ and compare to $K^*(892)^{+} \rightarrow K_S^0\pi^{+}$ and $\Sigma(1385)^{\pm} \rightarrow \Lambda^0\pi^{\pm}$ **similar decay topology**
- Reconstruct $K_S^0 \rightarrow \pi^{+}\pi^{-}$ and $\Lambda^0 \rightarrow p\pi^{-}$ **called vees**
- Use Čerenkov ID on fast track to separate K_S^0 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_S^0 or Λ^0 candidate within 3.0σ of nominal mass
- Very stringent Čerenkov ID cut applied to proton in pK_S^0 (misid $\sim$0)

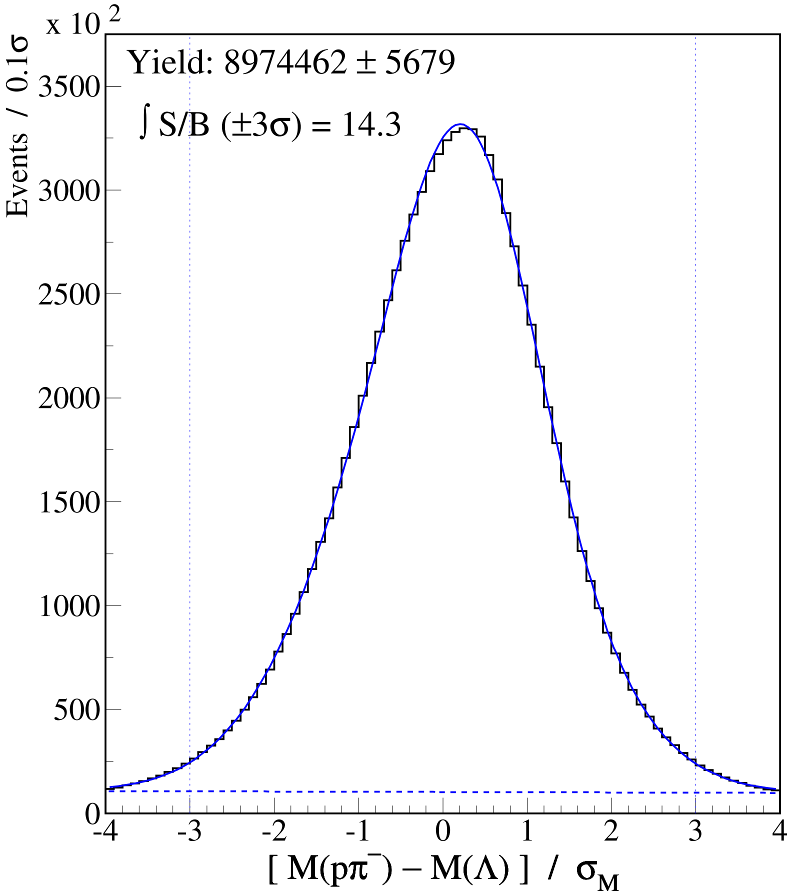
Vee Samples

$K^0_S \to \pi^+\pi^-$



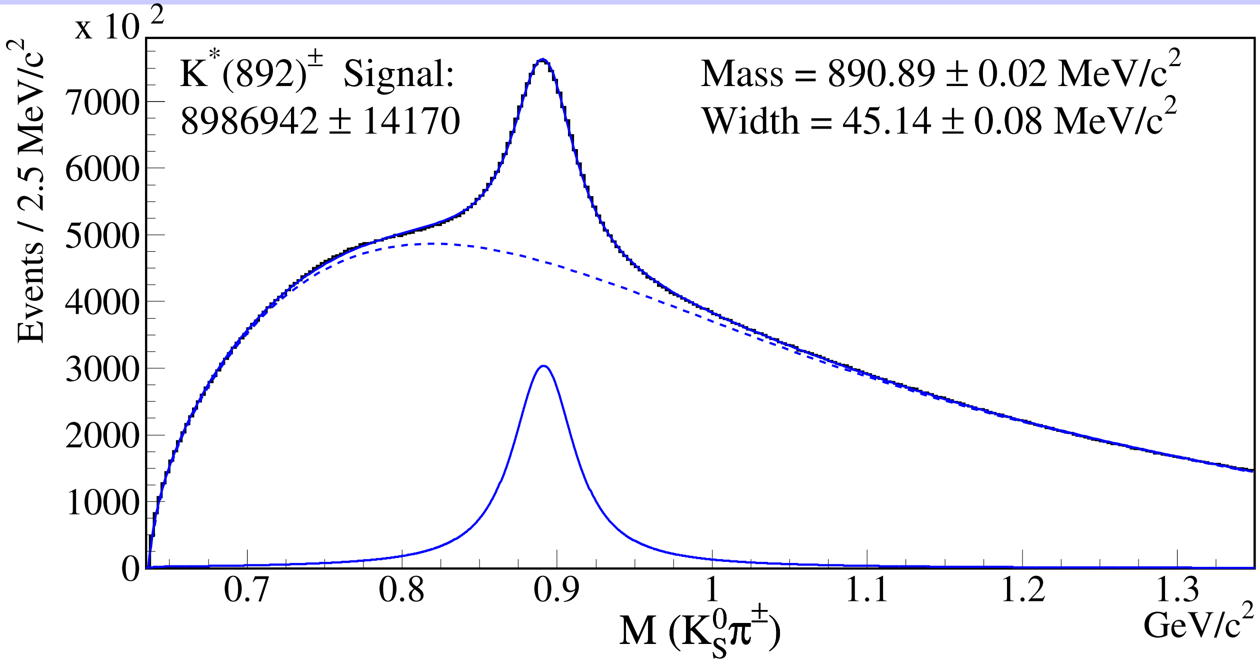
~ 68 million events

$\Lambda^0 \to p\pi^-$

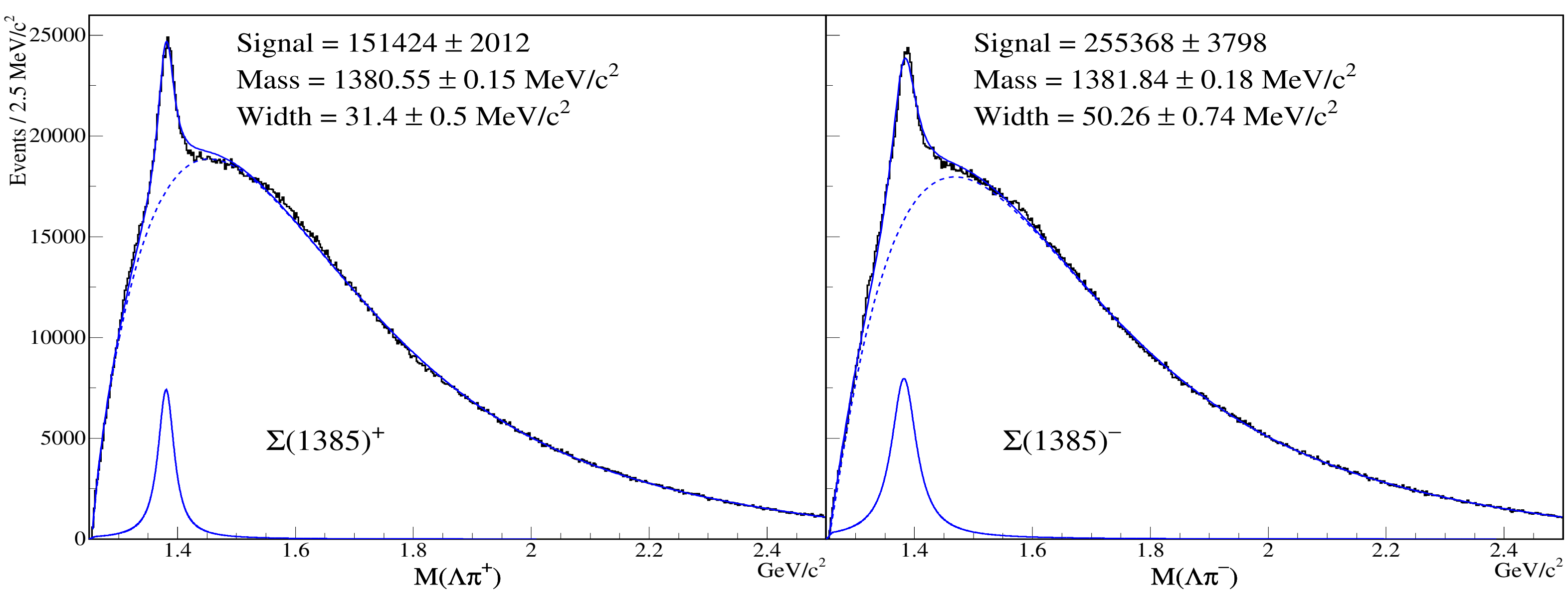


~ 9 million events

$K^*(892)^+$ and $\Sigma^*(1385)^\pm$ Fits

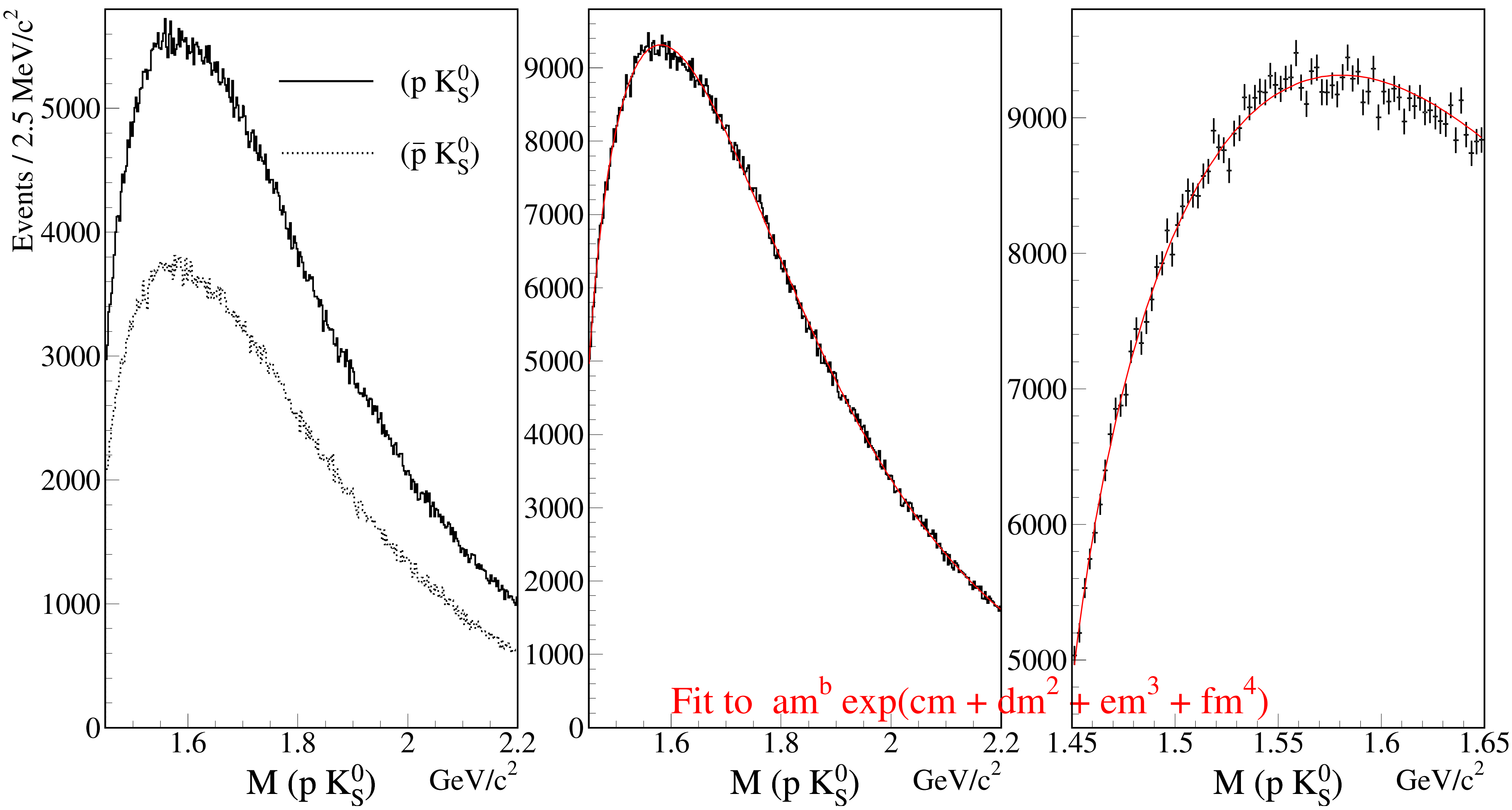


9 million events

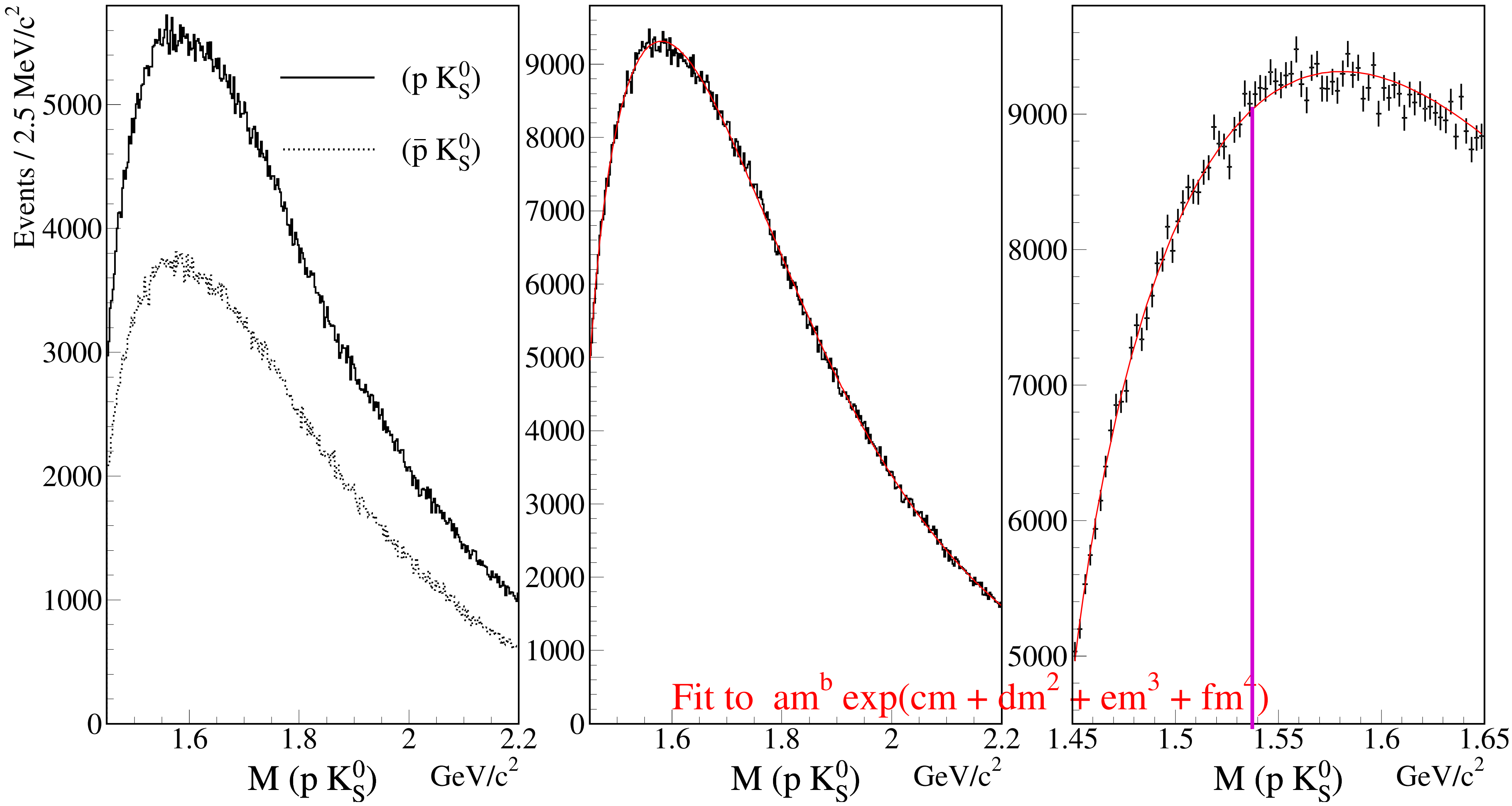


0.4 million events

pK_S^0 Invariant Mass



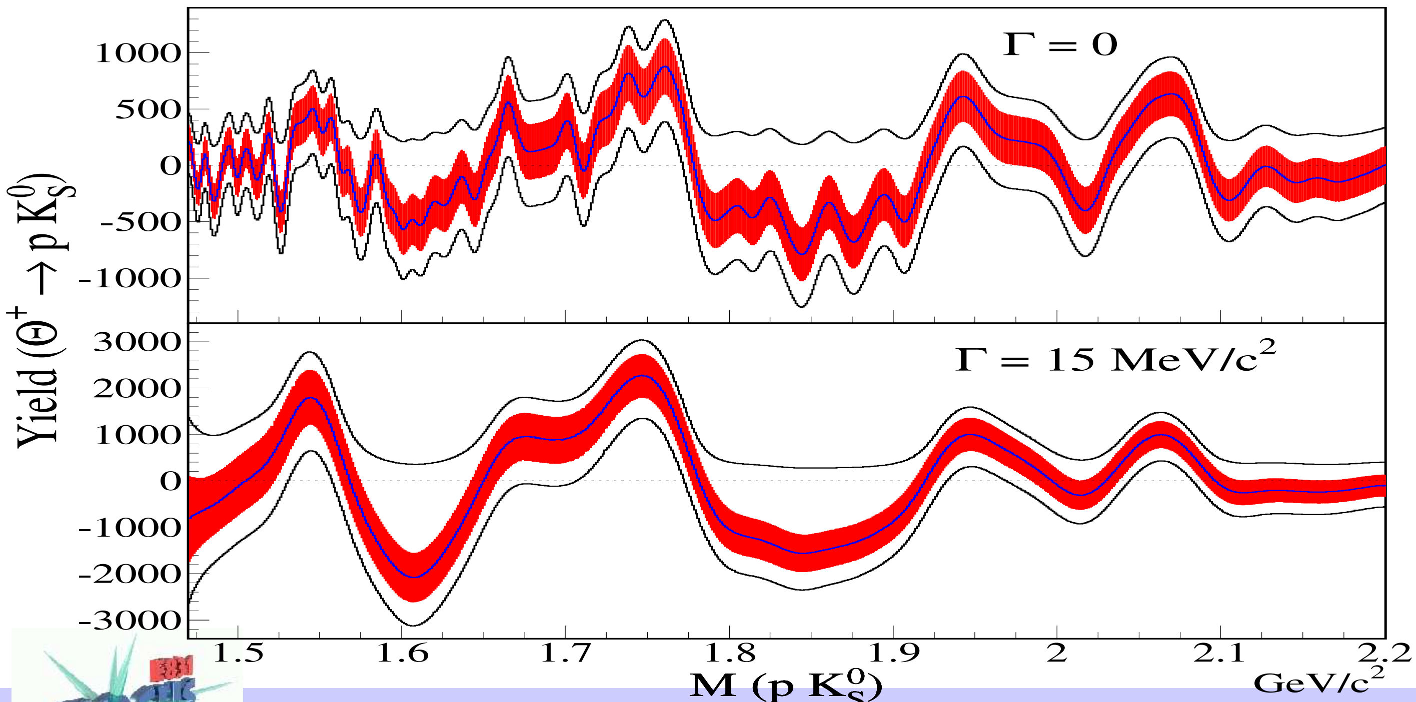
pK_S^0 Invariant Mass



No evidence for a pentaquark near 1540 MeV or at any mass less than 2200 MeV is observed

Limit on $\Theta^+ \to pK^0_S$ yield

- Fits to models with Γ=0 and Γ =15 MeV, convoluted with experimental resolution
- Fit for signal in 1 MeV steps from 1470 to 2200 MeV
  - Red region corresponds to $\pm 1\sigma$ errors from $\Delta \log \mathcal{L}$=0.5
  - Lower limit is 95% CL from $\Delta \log \mathcal{L}$=1.92
  - Upper limit is 95% CL from integrating $\mathcal{L}$ above 0
- Of the 1462 fits, none of them finds a yield greater than 5σ
- no effect $> 3\sigma$ is found in the expected region of 1520–1555 MeV



Converting to Production

- Ratio $\Theta(1540)^+$ production to $K^*(892)^+$ & $\Sigma^*(1385)^\pm$ production

$$\frac{\sigma(\Theta^+)\cdot \mathrm{BR}(\Theta^+ \rightarrow pK^0_S)}{\sigma(K^*(892)^+)} \text{ and } \frac{\sigma(\Theta^+)\cdot \mathrm{BR}(\Theta^+ \rightarrow pK^0_S)}{\sigma(\Sigma^*(1385)^\pm)}$$

- Need ratio of acceptance+efficiency — from MC

$$\frac{\sigma(\Theta^+)\cdot \mathrm{BR}(\Theta^+ \rightarrow pK^0_S)}{\sigma(K^*(892)^+)} = \frac{\mathrm{Y}(\Theta^+)\cdot \mathrm{BR}(\Theta^+ \rightarrow pK^0_S)\cdot \epsilon_{K^*(892)^+}}{\epsilon_{\Theta^+ \rightarrow pK^0_S}\cdot \mathrm{Y}(K^*(892)^+)}$$

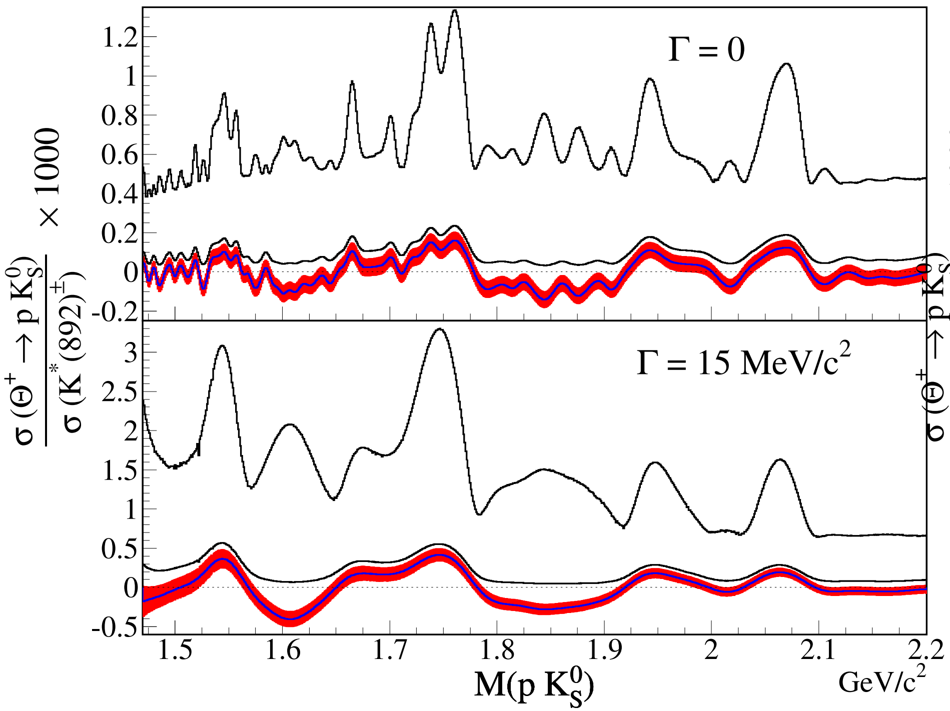
$$\frac{\sigma(\Theta^+)\cdot \mathrm{BR}(\Theta^+ \rightarrow pK^0_S)}{\sigma(\Sigma^*(1385)^\pm)} = \frac{\mathrm{Y}(\Theta^+)\cdot \mathrm{BR}(\Theta^+ \rightarrow pK^0_S)\cdot \epsilon_{\Sigma^*(1385)^\pm}}{\epsilon_{\Theta^+ \rightarrow pK^0_S}\cdot \mathrm{Y}(\Sigma^*(1385)^\pm)}$$

- Assume reasonable production model: $\Theta(1540)^+$ produced like $\Sigma(1385)^+$ and $\Xi^*(1530)^0$
- Use PYTHIA event generator to model production and FOCUS simulation to account for acceptance and efficiency
- Also need to account for branching ratios

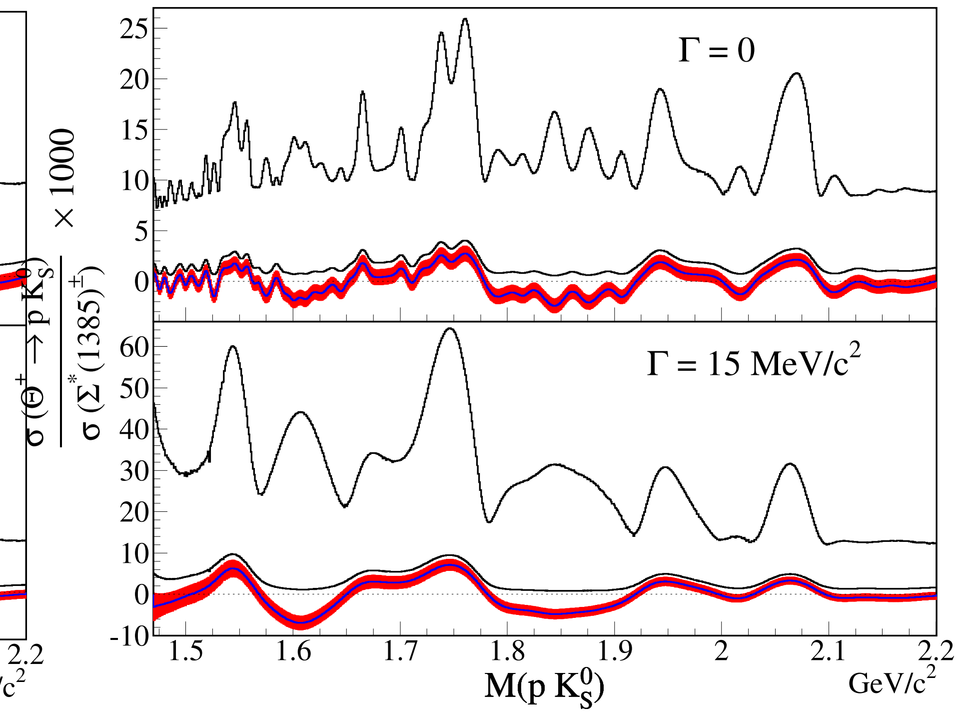
Decay	B.R.	Decay	B.R.
$K^*(892)^+ \rightarrow \overline{K}^0\pi^+$	66.6%	$\Lambda^0 \rightarrow p\pi^-$	63.9%
$K^0_S \rightarrow \pi^+\pi^-$	68.6%	$\Sigma(1385)^\pm \rightarrow \Lambda^0\pi^\pm$	88.0%
$\overline{K}^0 \rightarrow K^0_S$	50.0%	$\Theta(1540)^+ \rightarrow p\overline{K}^0$	50.0%

Relative Cross Sections

$$\frac{\sigma(\Theta^+)\cdot \mathrm{BR}(\Theta^+ \to p K_S^0)}{\sigma(K^*(892)^+)}$$



$$\frac{\sigma(\Theta^+)\cdot \mathrm{BR}(\Theta^+ \to p K_S^0)}{\sigma(\Sigma^*(1385)^+) + \sigma(\Sigma^*(1385)^-)}$$

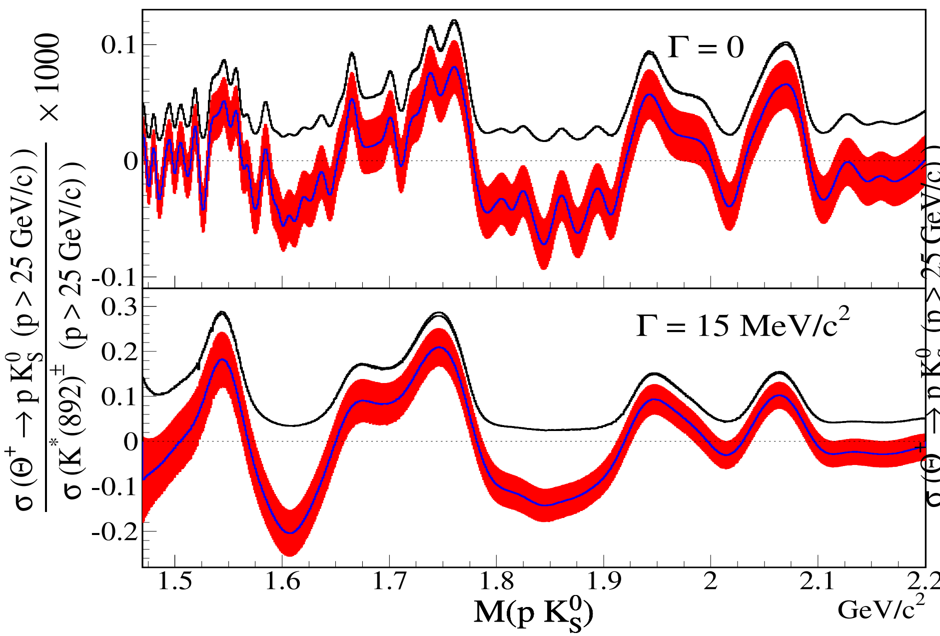


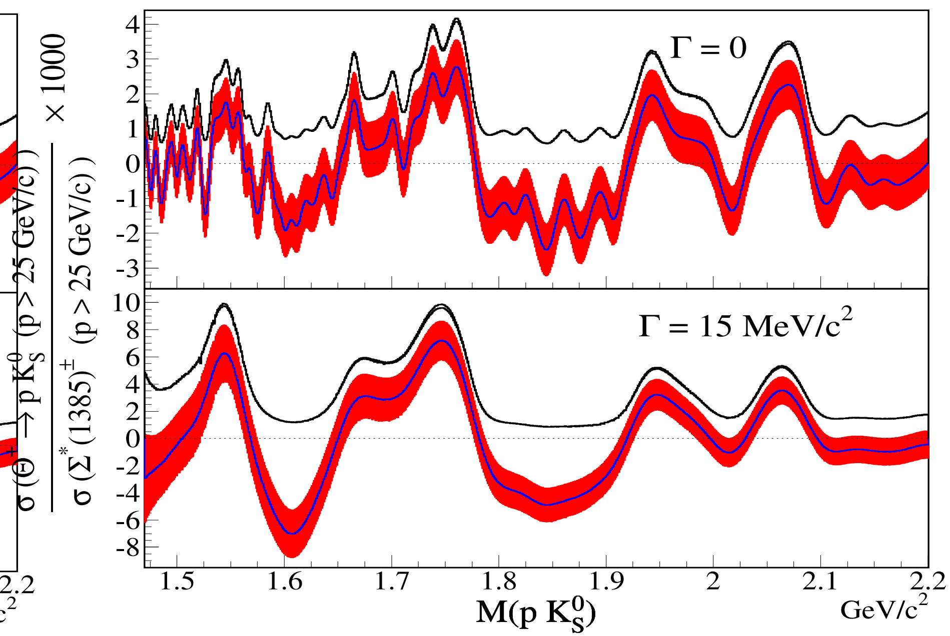
- Shaded curve is statistical uncertainty with central value in middle
- Top curve shows 95% CL upper limit including systematic uncertainties
- Middle curve is 95% CL upper limit with statistical uncertainties only

Relative Cross Sections

For $p > 25$ GeV : region of good FOCUS acceptance
$\longrightarrow$ reduces systematics dramatically

$$\frac{\sigma(\Theta^+)\cdot BR(\Theta^+\rightarrow pK_S^0)}{\sigma(K^*(892)^+)} \qquad \frac{\sigma(\Theta^+)\cdot BR(\Theta^+\rightarrow pK_S^0)}{\sigma(\Sigma^*(1385)^+)+\sigma(\Sigma^*(1385)^-)}$$





Pentaquark Search Summary

- FOCUS fails to find any evidence for a pentaquark decaying to pK_S^0 over a mass range extending to 2.2 GeV
- We set 95% CL upper limits on the yield of 1300 (Γ=0) and 3000 events (Γ=15 MeV)
- We set 95% CL upper limits on the relative cross section wrt to $K^*(892)^+ \to K_S^0\pi^+$ and $\Sigma(1385)^\pm \to \Lambda^0\pi^\pm$
- Over entire mass range, we find

Cross Section Ratio	95% CL Upper Limit Γ = 0	95% CL Upper Limit Γ = 15 MeV
$\frac{\sigma(\Theta^+)\cdot BR(\Theta^+\to pK_S^0)}{\sigma(K^*(892)^+)}$	0.0013	0.0032
	0.00012	0.00029
$\frac{\sigma(\Theta^+)\cdot BR(\Theta^+\to pK_S^0)}{\sigma(\Sigma^*(1385)^+)+\sigma(\Sigma^*(1385)^-)}$	0.025	0.062
	0.0042	0.0099

blue : $p > 25$ GeV

Pentaquark Search Summary

- Very few observing experiments report results for $K^*(892)^+ \to K^0_S \pi^+$ and $\Sigma(1385)^\pm \to \Lambda^0 \pi^\pm$ yields
- Comparing FOCUS to those:

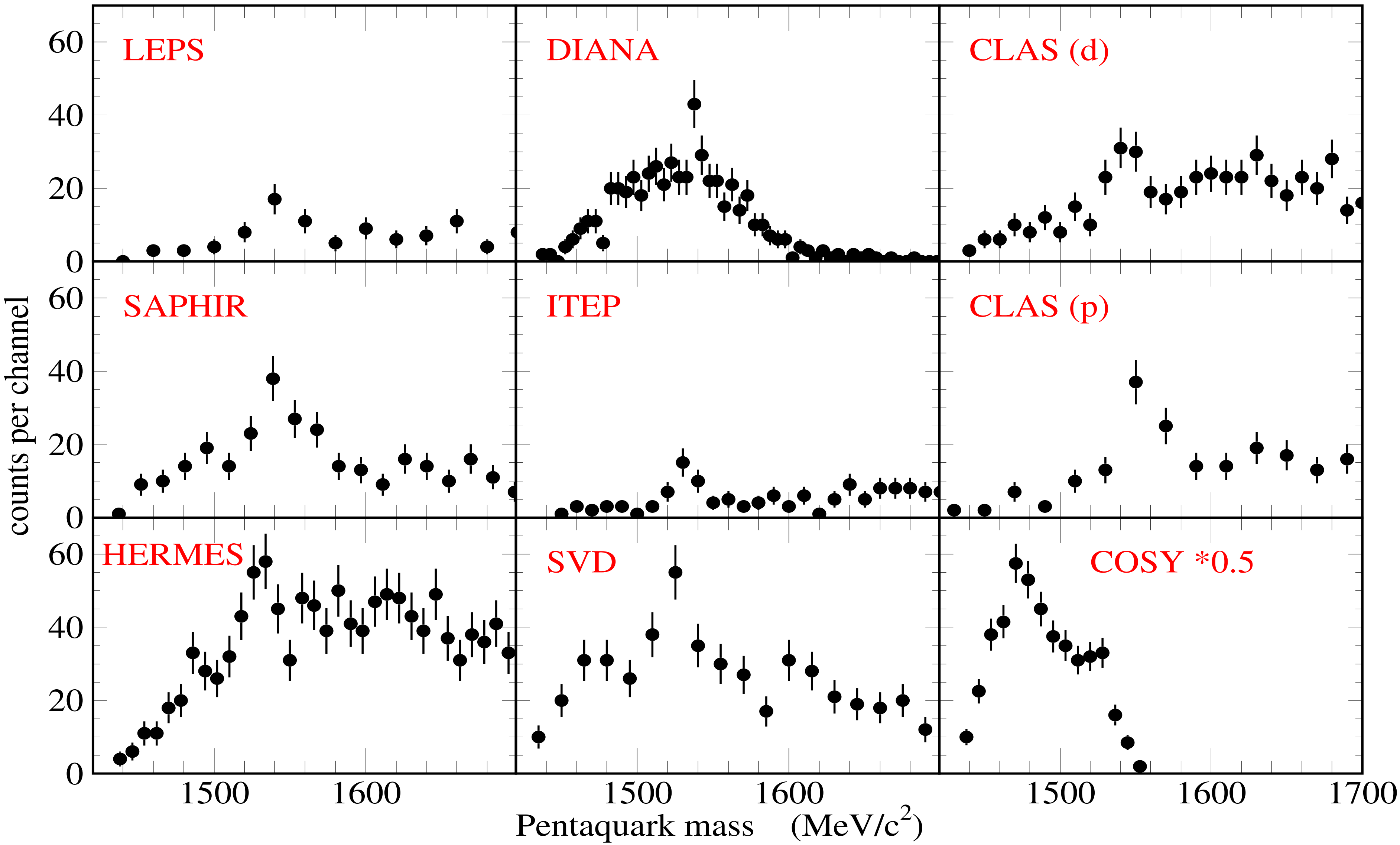
	$K^*(892)^+ \to K^0_S \pi^+$ Yield	$\Sigma(1385)^\pm \to \Lambda^0 \pi^\pm$ Yield
CLAS	$\sim$ 1000	
SVD	$\sim$ 125	$\sim$ 100
FOCUS	9 million	0.4 million

- Differences in production between experiments with observing results and a high energy experiment as FOCUS prevent any definite conclusions

EXTRAS ....

Is this a convincing case?

Plots with errors and without fits (courtesy Pochodzall – hep-ex/0406077):



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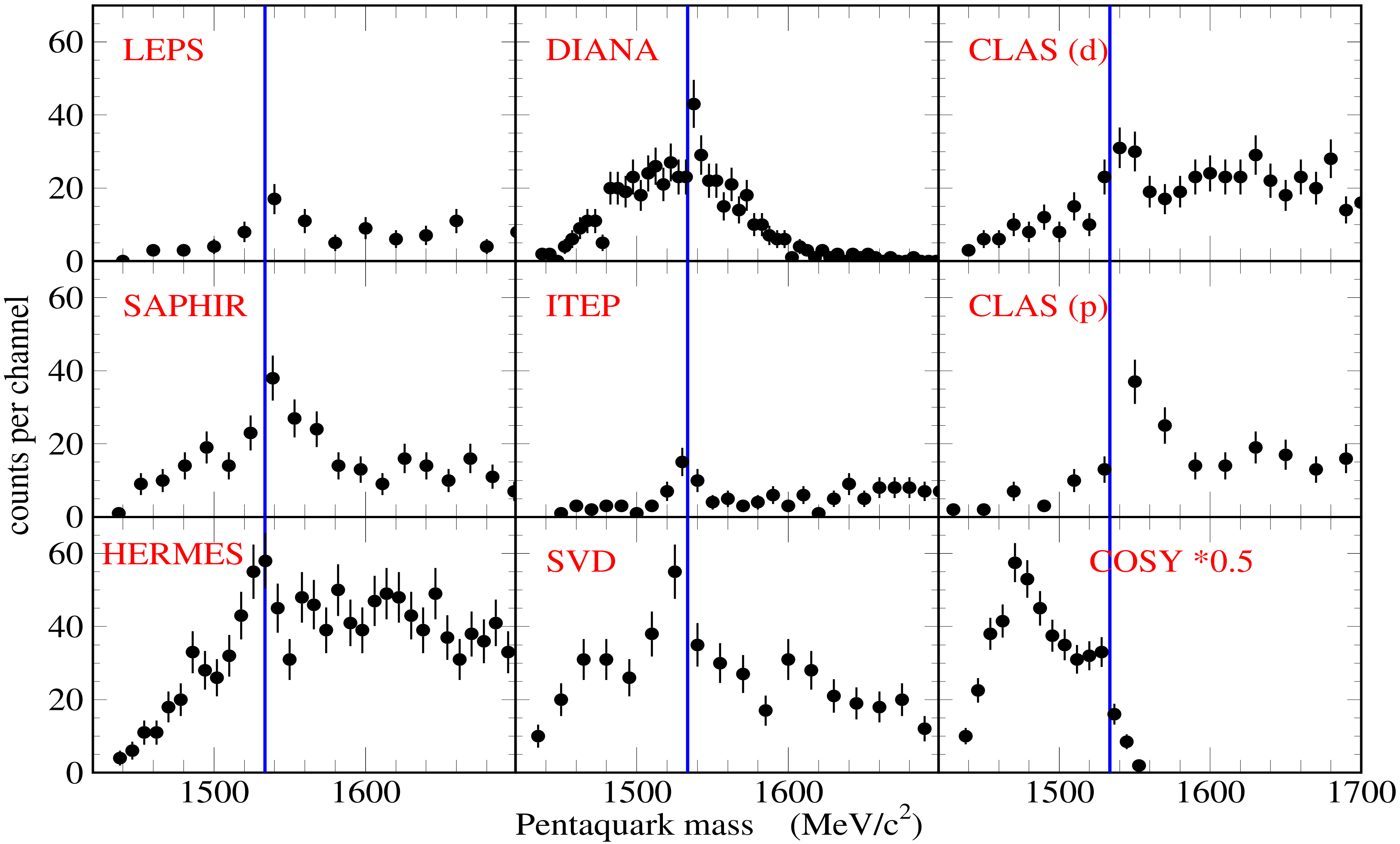
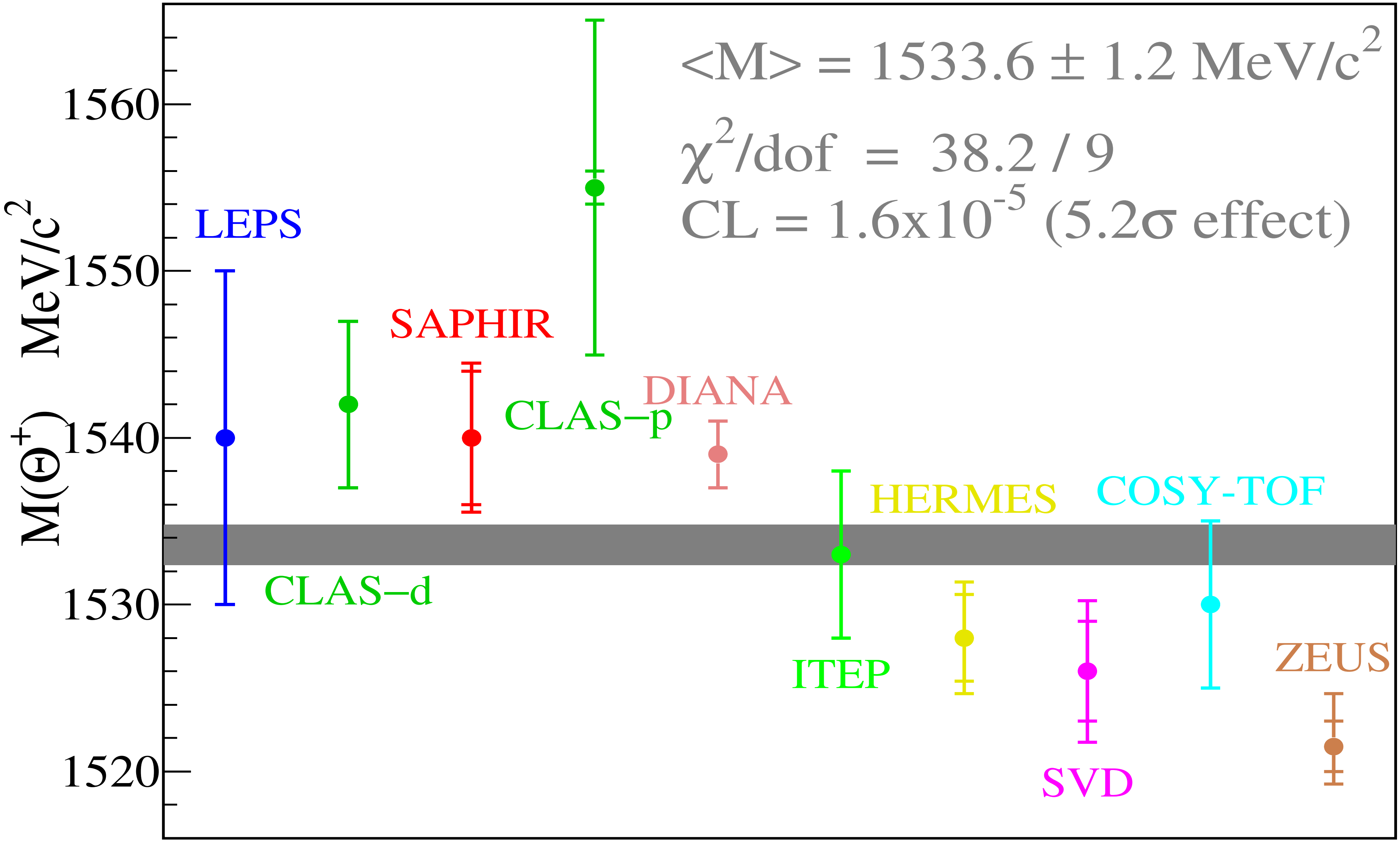


Summary of Θ^+ mass measurements

Lack of agreement on mass does not build confidence:



Summary of Θ^+ observations

- 10 observations, all at the $\sim 4\,\sigma$ level
- The measured masses disagree at the $5\,\sigma$ level (CL = 10^{-5})
- All observed widths are consistent with resolution (1–20 MeV/c^2)
- Most results from γN but also νN and pN production
- Choice of cuts often not well motivated
- Evolution of signal versus cuts rarely given
- Finally, there exist many theories on how these peaks may be artifacts

Experiment	Yield $\Theta(1540)^+$	σ_{M_Θ} MeV/c^2	Yield $\Lambda(1520)^0$	Yield/10^3 K^0_S	Yield/10^3 K^{*+}	Yield/10^3 $\Sigma(1385)^\pm$
LEPS γn	19 ± 3	18	25			
DIANA K^+Xe	29	3.3		25		
CLAS γd	43	12	212			
SAPHIR γp	63 ± 13	12	630			
Asratyan νN	26 ± 6	8.5		6		
CLAS γp	41 ± 10	12			1.4	
HERMES ed	59 ± 16	6	710	1		
SVD pN	50	3			0.3	0.2
COSY-TOF pp	$\sim$60	10		1		
ZEUS ep	221 ± 48	2	$\sim$2000	867		
FOCUS γN	< 695	2.8		65000	8300	238
ALEPH e^+e^-	< 140	4	2874	1200	100	
BABAR e^+e^-	$\lesssim 500$	2	40000			
BELLE e^+e^-	< 120	2	15519			
CDF $p\bar{p}$	< 154	2.6	8191	2300	52	
E690 pp	< 25	1.5	5000		15	
HERA-B pN	$\lesssim 30$	3.9	5600	4900		
HyperCP X^+N	< 406	11		80		
SPHINX pN	< 125	10	25000			2.5

Summary of $\Xi_{3/2}(1862)^{--}$ searches

Experiment	Yield $\Xi_{3/2}(1862)^{--}$	Yield $\Xi(1530)^0$	$\frac{\sigma\left(\Xi_{3/2}(1862)^{--}\right)\cdot \text{BR}}{\sigma\left(\Xi(1530)^0\right)}$
NA49 pp	~ 45	~ 150	$\sim 20.00\,\%$
FOCUS γN	< 114	59391 ± 536	$< 0.16\,\%$
ALEPH e^+e^-		322 ± 33	$< 8.00\,\%$
BABAR e^+e^-	$\lesssim 80$	~ 5000	$< 0.50\,\%$
CDF $p\bar{p}$	< 63	2182 ± 92	$< 4.00\,\%$
E690 pp	< 561	93728 ± 422	$< 0.40\,\%$
HERA-B pN		2300	$< 2.70\,\%$
HERMES ed	< 5	35 ± 11	$< 18.00\,\%$
WA89 $\Sigma^-,\pi^- N$		63000	$< 1.40\,\%$
ZEUS ep		192 ± 30	$< 19.00\,\%$

- FOCUS has the best limit on the ratio of $\Xi_{3/2}(1862)^{--}$ production relative to $\Xi(1530)^0$ production
- All results in serious disagreement with NA49 observation

Summary of charm pentaquark results

Experiment	$Y(\Theta_c)$	$Y(D^{*-})$	$Y(D^-)$	$\frac{\sigma(\Theta_c \to D^{*-})}{\sigma(D^{*-})}$	$\frac{\sigma(\Theta_c \to D^{-})}{\sigma(D^{-})}$
H1 ep	50.6 ± 11.2	~ 3500		$\sim 1\ \%$	
FOCUS γN	< 15	105000	137000	$< 0.04\ \%$	$< 0.04\ \%$
ALEPH e^+e^-		~ 4300	~ 5400	$< 0.31\ \%$	$< 1.80\ \%$
CDF $p\overline{p}$	< 27	537000			
ZEUS ep		~ 60000		$< 0.23\ \%$	

- FOCUS result is in serious disagreement with H1 observation for $\Theta_c \to D^{(*)-}p$
- ZEUS has identical production and similar experiment; claims H1 signal excluded at $9\ \sigma$