

# First Observation of the $D_{sJ}(2632)$

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## OUTLINE

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*for the SELEX Collaboration*

- Motivation for Search
- $\eta$  characteristics in SELEX
- $D_s \eta$  and  $D^0 K^+$  Peaks
- Production Characteristics
- Conclusions

# SELEX Collaboration

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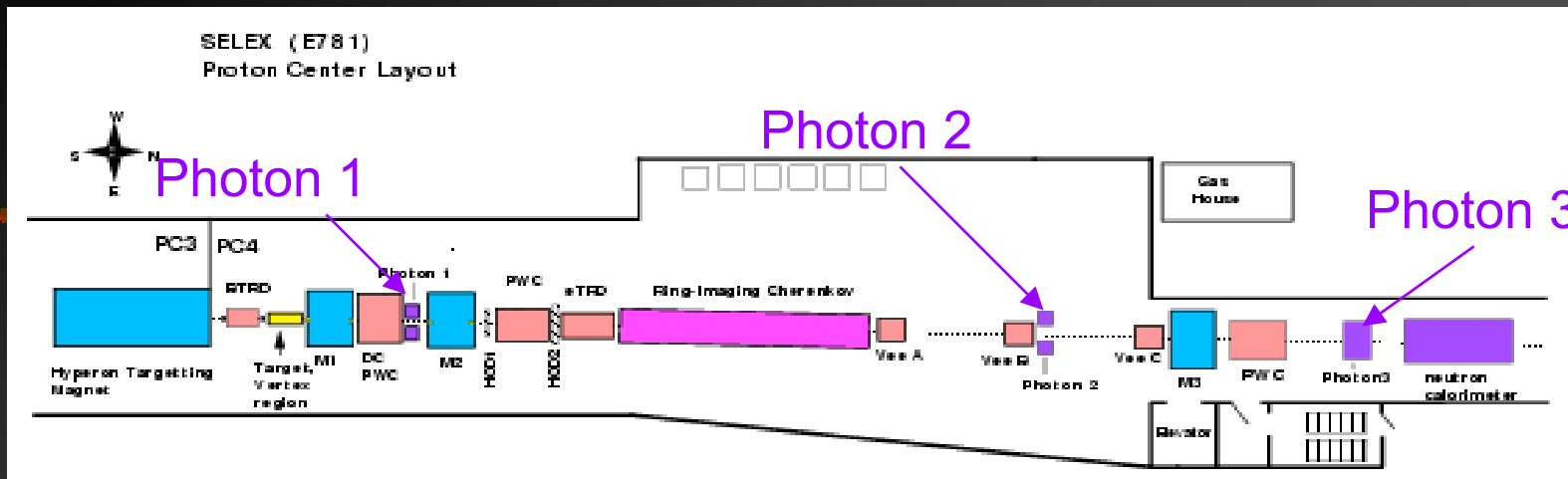
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# The SELEX Experiment

- Report of unusual  $D_{sJ}(2317)$  and  $D_{sJ}(2460)$  states prompted search for additional narrow  $D_s +$  pseudoscalar channels in the vicinity of the next generation of orbitally-excited states near 2600 in SELEX, the Fermilab charm hadroproduction expt.
- SELEX has good photon detection to go along with precision vertexing and superb RICH particle ID
- The 600 GeV  $\Sigma^-$  beam produced clean  $D_s$  sample ( $S/B > 5/1$ ), but with large production asymmetry favoring s-quark state.
- Check photon energy scale on  $\pi^0, \Sigma^0$  decays. Good to  $< 2\%$  over full photon energy range (2 – 150 GeV)

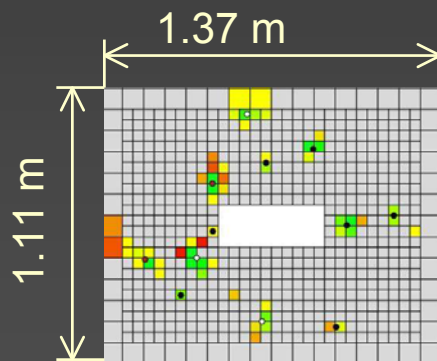
# SELEX(E781) Photon Detectors



Each Spectrometer includes Lead-Glass Photon Calorimeter

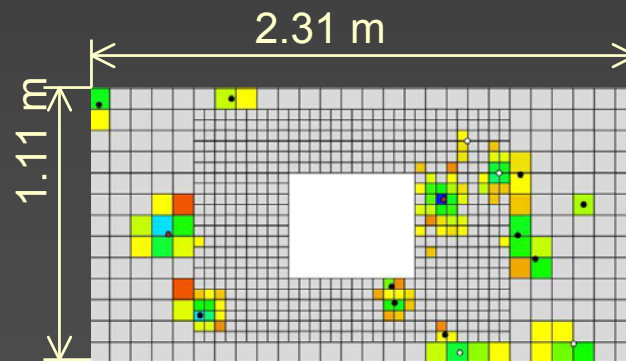
$2\pi$  coverage in c.m. of primary interaction

$1\text{GeV} < E_\gamma < 10\text{GeV}$



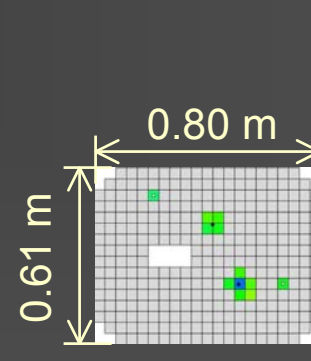
630 Channels

$2\text{GeV} < E_\gamma < 40\text{GeV}$



726 Channels

$4\text{GeV} < E_\gamma < 80\text{GeV}$



316 Channels

# $\eta$ signal in CHARM trigger

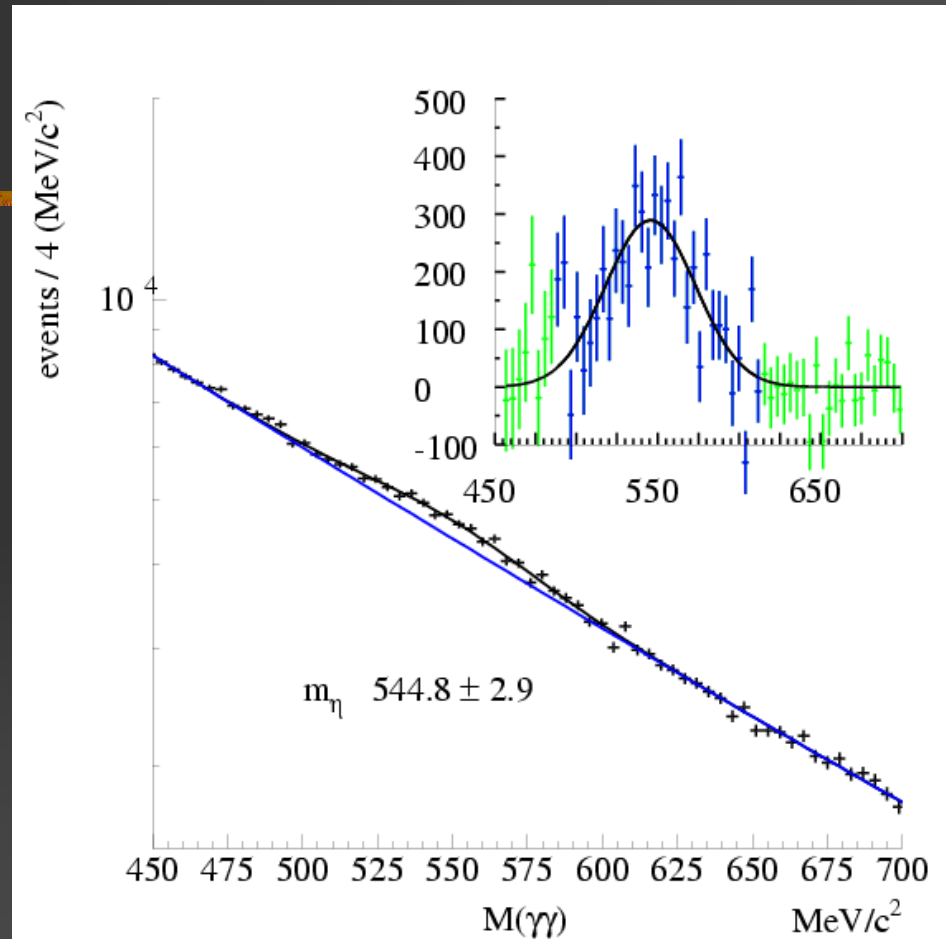
(0.1% of total data)

- ✓  $E_\gamma > 2 \text{ GeV}$ ,  $E_{\gamma\gamma} > 15 \text{ GeV}$
- ✓ Good fit to: exp + Gaussian + constant

Fit $M(\eta)$	$544.8 \pm 2.9$
PDG $M(\eta)$	$547.3 \pm 0.12$
Fit resolution	$27.8 \pm 4.3$
MC resolution	$30.2 \pm 1.2$

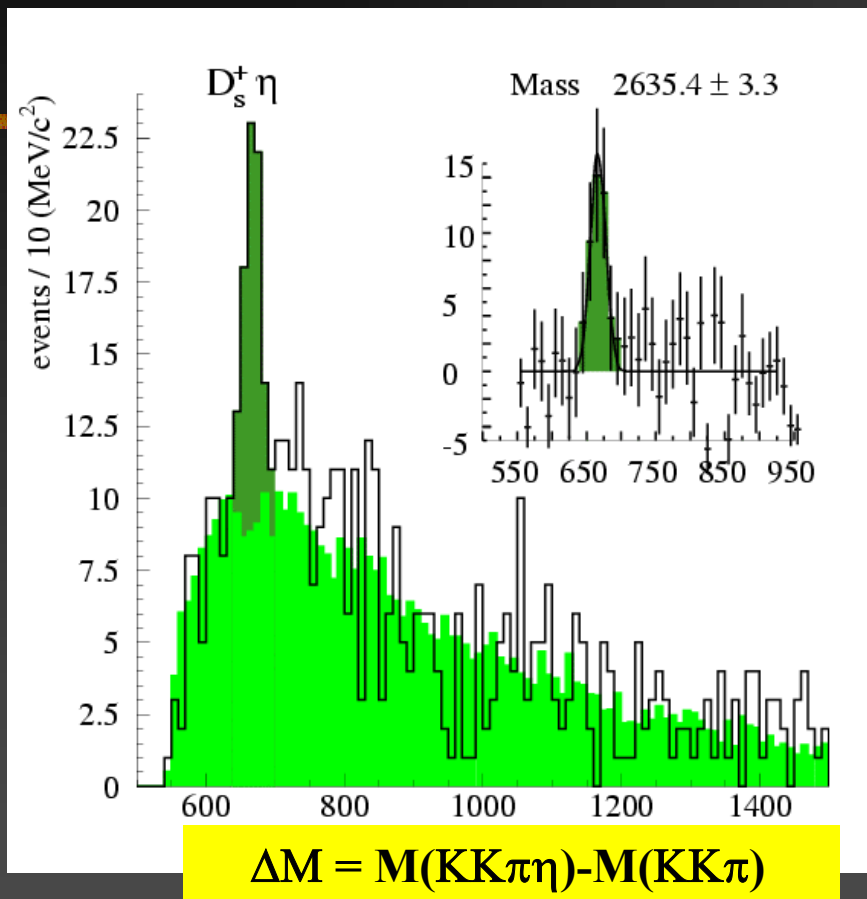
$\eta$  mass agrees with PDG value  $\Rightarrow$   
energy scale is under control.

MC represents resolution well.



$\eta$  yield/interaction: 0.05

# New charm-strange meson



✓ Combine  $D_s$  events with  $\eta$  candidates

$\eta$  mass constrained  $\mathbf{p}_\eta = [M_{\text{PDG}}(\eta), \vec{p}]$

✓ Reject events with  $N_\eta > 5$  candidates (loss: 18/544)

✓ Bkgnd: mix  $\eta$  from 25 other events per  $D_s$ ; weight by 0.04

✓ Inset:  $43.4 \pm 9.1$  signal events for fixed-width Gaussian fit to subtracted data. Probability 31%

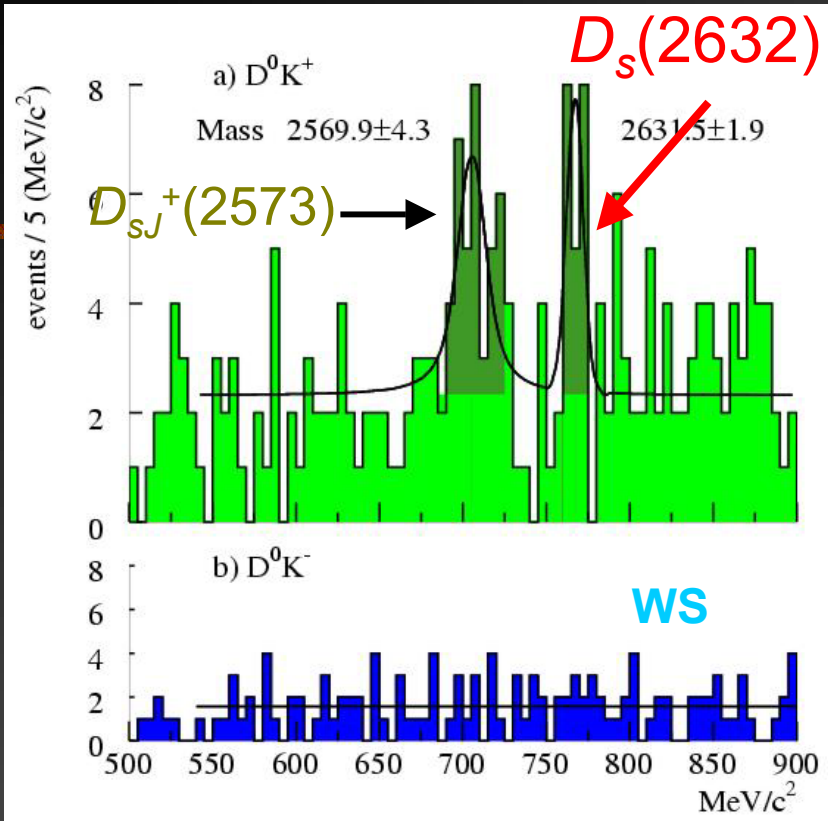
6.2  $\sigma$  peak at 2635.4 MeV/c<sup>2</sup>

Poisson fluctuation prob  $< 6 \times 10^{-6}$

Signal band,  $\eta$  yield/interaction with  $D_s$ : 0.18

Remove signal:  $\eta$  yield:  $0.12 \pm 0.05$

# Look For $D_s(2632) \rightarrow D^0 K^+$



- ✓ Well-identified  $D^0, K^+$
- ✓  $D^0 \rightarrow K^- \pi^+$  only (S/N 4/1)
- ✓  $\text{Prob}(K^+) > 10 \text{ Prob}(\text{any other})$
- ✓ Wrong sign background constant
- ✓ Fit with 2 [ BW convolved with Gaussian ] + constant background
- ✓ Fix resolution from MC (4.9 MeV)
- $14 \pm 4.5$  evts at  $2631.5 \pm 1.9 \text{ MeV}/c^2$
- Poisson excess probability =  $1 \times 10^{-4}$
- New state is narrow (resolution only)
- ✓ A 90% CL upper limit  $\Gamma < 17 \text{ MeV}/c^2$
- Above threshold! Why so narrow?***

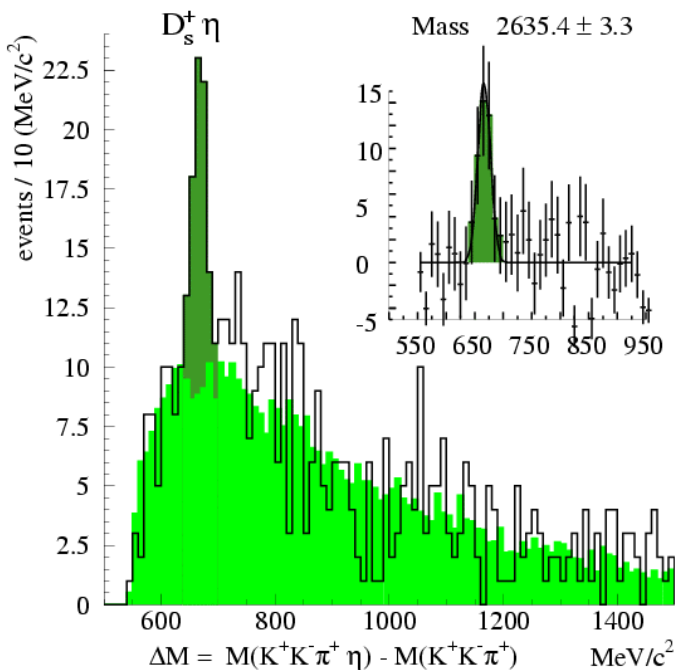
$D_{sJ}(2573)$	$2573.5 \pm 1.7$	$15^{+5}_{-4}$
PDG	MeV/ $c^2$	MeV/ $c^2$
$D_{sJ}(2573)$	$2569.9 \pm 4.3$	$14^{+9}_{-6}$
SELEX	MeV/ $c^2$	MeV/ $c^2$

# $D_{sJ}(2632)$ Branching Ratios

- Most models say that  $D^0 K^+$  coupling should be much bigger than  $D_s^+ \eta$  for  $c\bar{s}$  state
- Phase space favors  $D^0 K^+$  mode by x 1.5
- We see 3x as many  $D_s^+ \eta$  decays as  $D^0 K^+$

SURPRISE:  $\Gamma(D^0 K^+)/\Gamma(D_s^+ \eta) = 0.14 \pm 0.06$

# D<sub>s</sub> (2632) summary



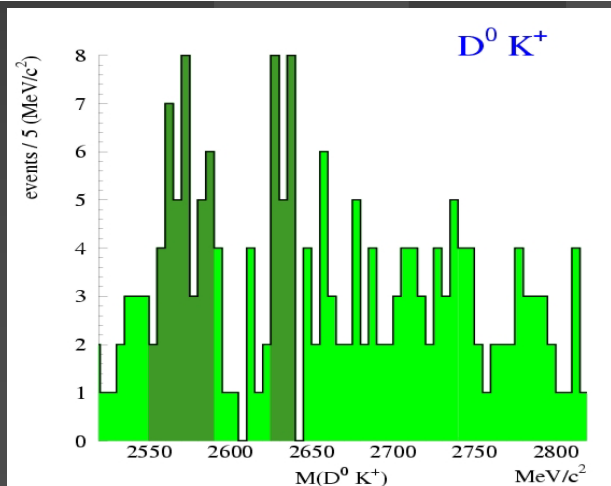
State	D <sub>s</sub> (2632) → D <sub>s</sub> η	D <sub>s</sub> (2632) → D <sup>0</sup> K
mass	$2635.4 \pm 3.3$	$2631.5 \pm 1.9$
Sign.	$6.2 \sigma$	$5.3 \sigma$
Events	$43.4 \pm 9.1$	$14 \pm 4.5$
$\chi^2 / n_d$	1.10	0.77

✓ Average D<sub>sJ</sub>(2632) mass  $2632.5 \pm 1.7$  MeV/c<sup>2</sup>

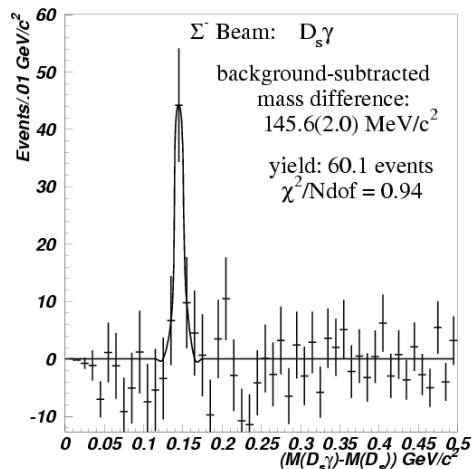
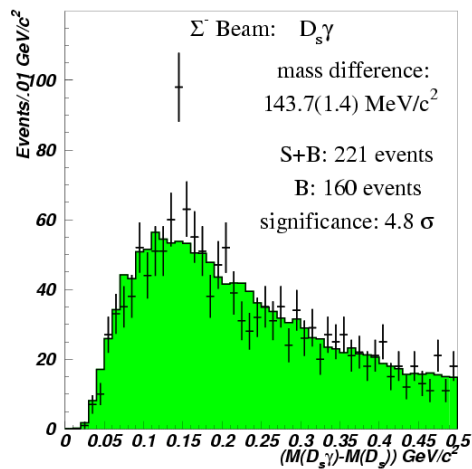
✓  $\Gamma < 17$  MeV/c<sup>2</sup> @ 90% CL(D<sup>0</sup>K<sup>+</sup>)

✓  $\Gamma(D^0K^+) / \Gamma(D_s + \eta) = 0.14 \pm 0.06$

And it's not seen in e<sup>+</sup> e<sup>-</sup> production at CLEO (PIC04) or BaBar (ICHEP04)!



# Look at $D_s(2112)$



Treat Same Way as  $D_s\eta$

- Mix 25 photon events with each  $D_s$  to get uncorrelated background shape
- Renormalize and subtract: fit signal

Good representation of subtracted data by single Gaussian with no extra terms.

- $\chi^2$  of fit is 0.94/dof.
- Yield:  $60.1 \pm 14.9$  evts.
- Again, combinatoric bkg suffices.

# $D_{sJ}(2112)$ Production at CLEO, SELEX

CLEO:  $D_s^*(2112)/D_s = 0.59 \pm 0.03 \pm 0.01$

SELEX:  $D_s^*(2112)/D_s = 0.24 \pm 0.06$

These numbers are different!

Correct SELEX  $D_s$  yield for new signal contribution (55%):

SELEX:  $D_s^*(2112)/D_s \rightarrow 0.53 \pm 0.13$

New SELEX signal is NOT related to  $D_s^*(2112)$  production.

Different production mechanism ( large SELEX  $D^-/D^+$  ratio!)

Is this new state not just  $\bar{c}s$ ?

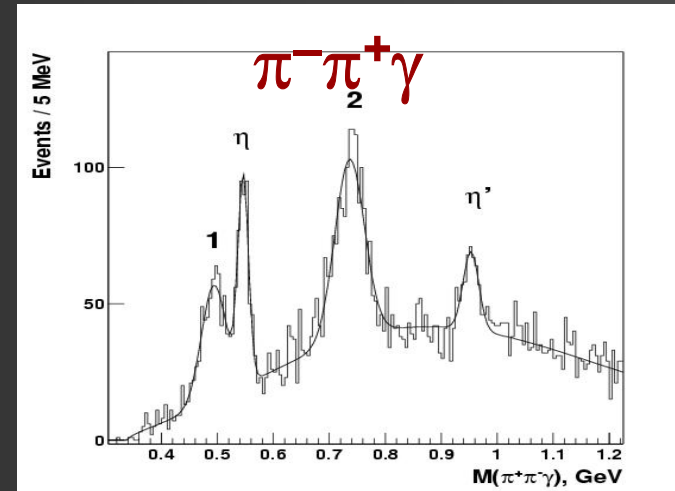
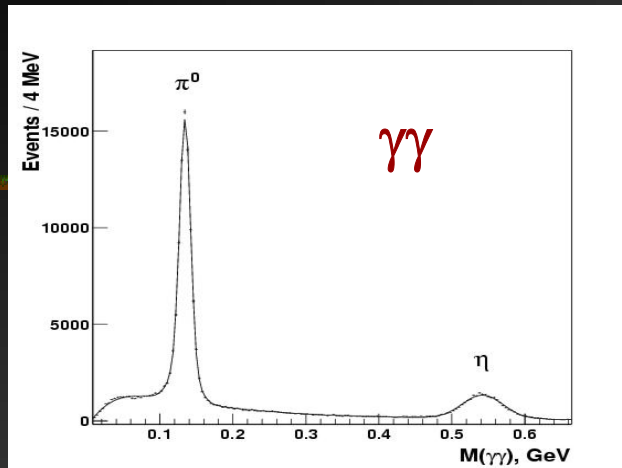
# Conclusions

- SELEX reports a new narrow  $D_{sJ}$  candidate at  $2632 \text{ MeV}/c^2$ , decaying into  $D_s^+ \eta$  and  $D^0 K^+$ :  $\Gamma(D^0 K^+)/\Gamma(D_s^+ \eta) = 0.14 \pm 0.06$ .
- These decays are not seen in careful searches at B factories
- SELEX evidence favors production mechanism with large asymmetry from  $\Sigma^-$  beam. No such effect in  $e^+ e^- D_s$  data.
- Combination of unusual production and unusual decay mode raise questions about whether this state can be  $\overline{cs}$ . For example, tetraquark models can account for both production and decay
- Finding the state in hadroproduction and not in  $e^+ e^-$  suggests unusual quantum numbers.

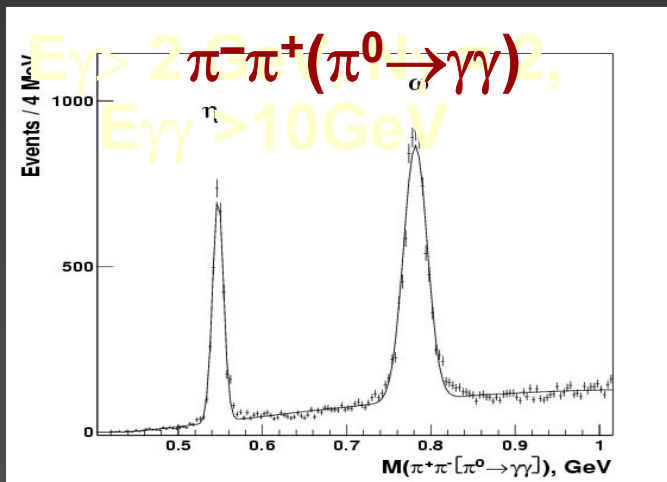
# Backup Slides



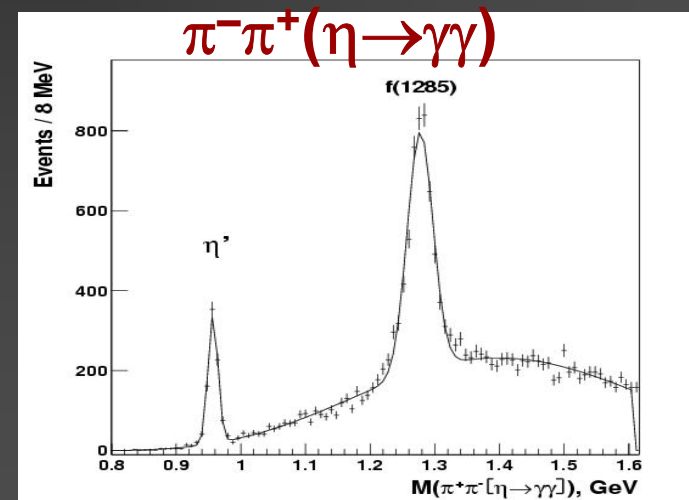
# Mass distributions - Exclusive trig ( $N_{ch}$ 3-5)



$E_\gamma > 2 \text{ GeV } N_\gamma = 2$   
 $E_{\gamma\gamma} > 10 \text{ GeV}$



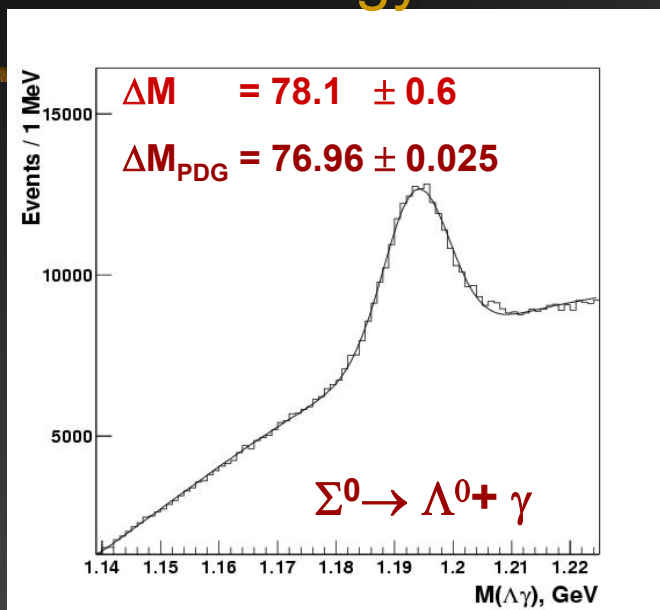
$E_\gamma > 2 \text{ GeV } N_\gamma = 2$   
 $E_{\gamma\gamma} > 10 \text{ GeV}$



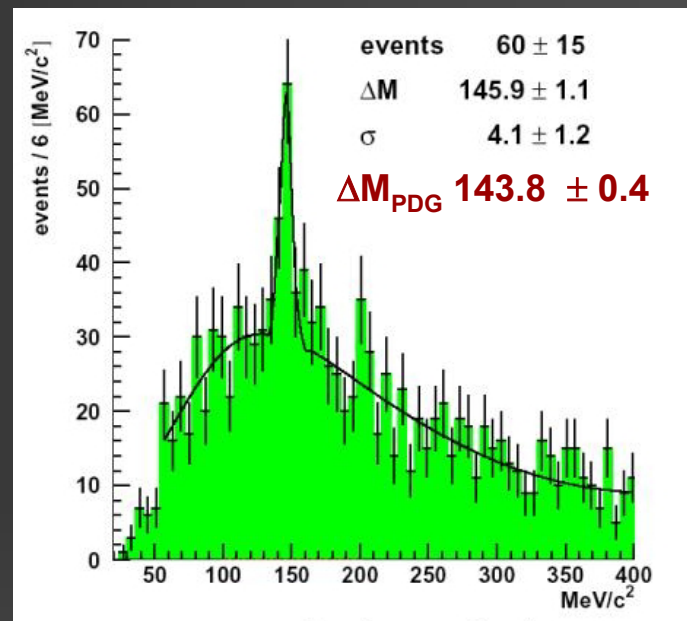
$E_\gamma > 2 \text{ GeV } N_\gamma = 2$   
 $E_{\gamma\gamma} > 10 \text{ GeV}$

# Single Photon States

Use  $\Sigma^0 \rightarrow \Lambda^0 + \gamma$  to test energy scale



Study  $D_s(2112) \rightarrow D_s + \gamma$



✓ Photon energy scale agrees better than 2% for this decay

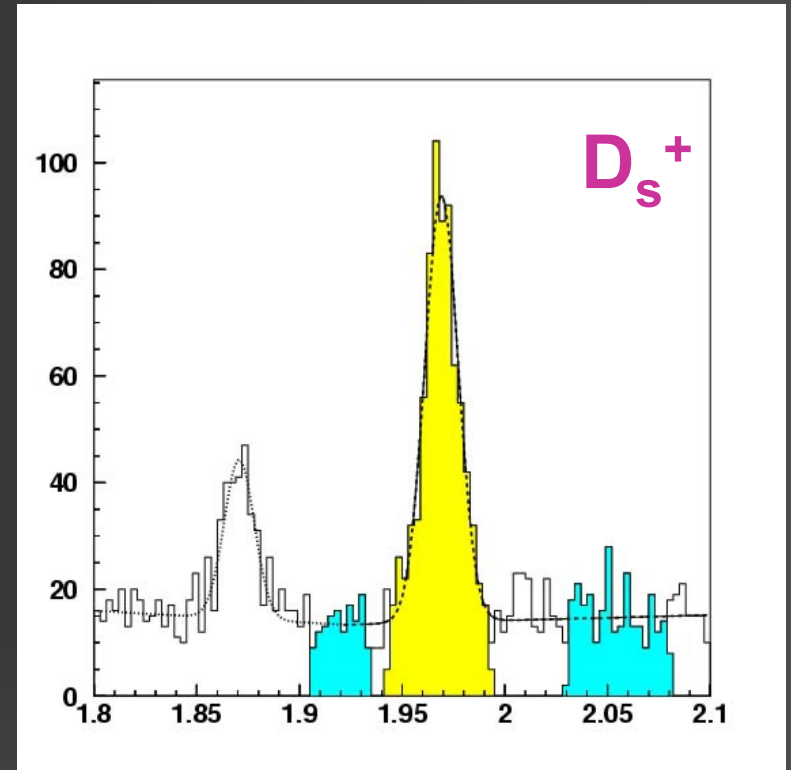
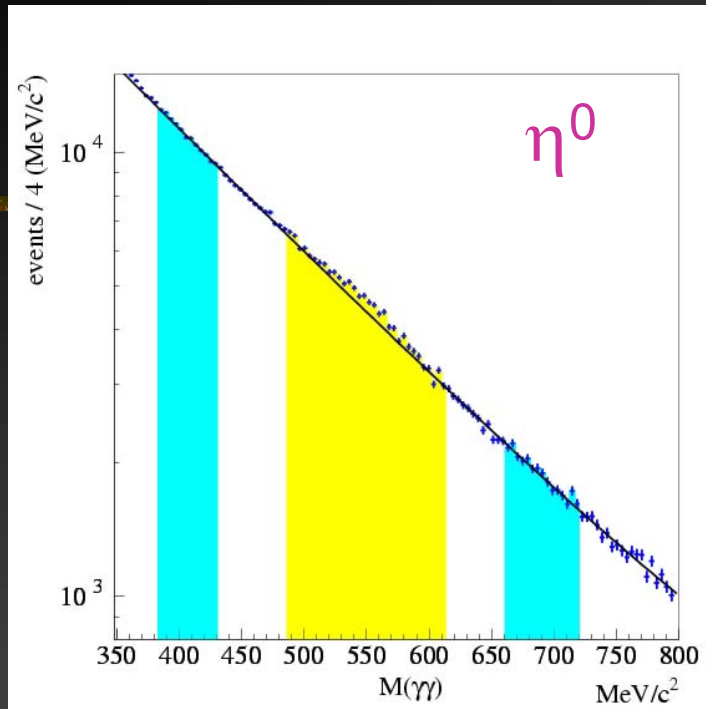
✓ We understand detector response

✓ will use Monte-Carlo resolution in fits

✓ Fitted with Gaussian width taken from Monte-Carlo

✓ Good agreement

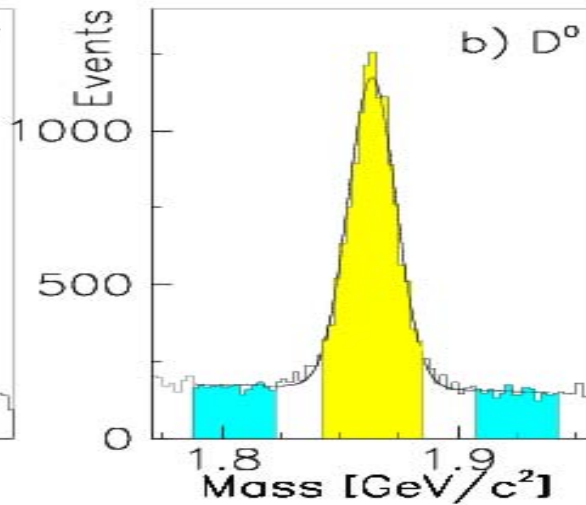
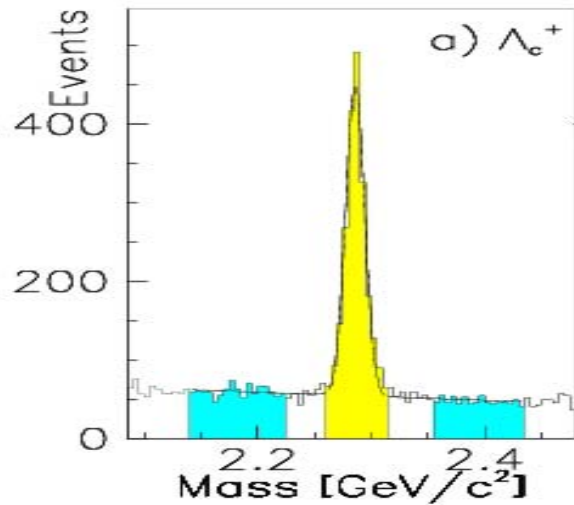
# $\eta$ and $D_s$ selection



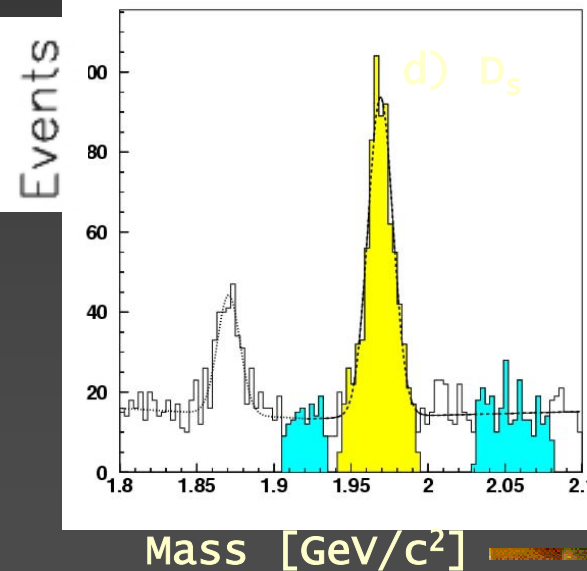
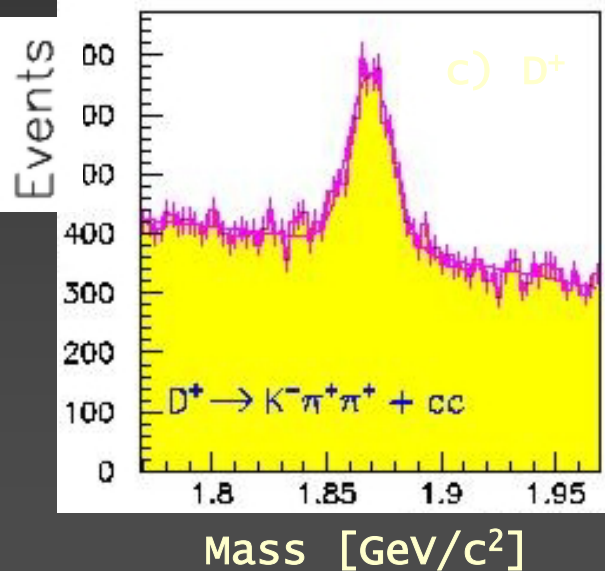
$M(KK\pi)$   $\text{GeV}/c^2$

- ✓  $E_\gamma > 2 \text{ GeV}$ ,  $E_{\gamma\gamma} > 15 \text{ GeV}$
- ✓  $\eta$  mass region:  $M_{\text{PDG}}(\eta) \pm 60 \text{ MeV}$
- ✓ 5M  $\eta$  in 150M candidates  
S/N  $\sim 1/30$
- ✓ 0.15  $\eta$  candidates /event
- ✓  $L/\sigma > 8$ ,  $p_{\text{vtx}} < 8$
- ✓  $|M(KK\pi) - 1968.5| < 25 \text{ MeV}$
- ✓  $\sim 1.2 \text{ h candidate} / D_s \text{ candidate}$

# SELEX single charm states

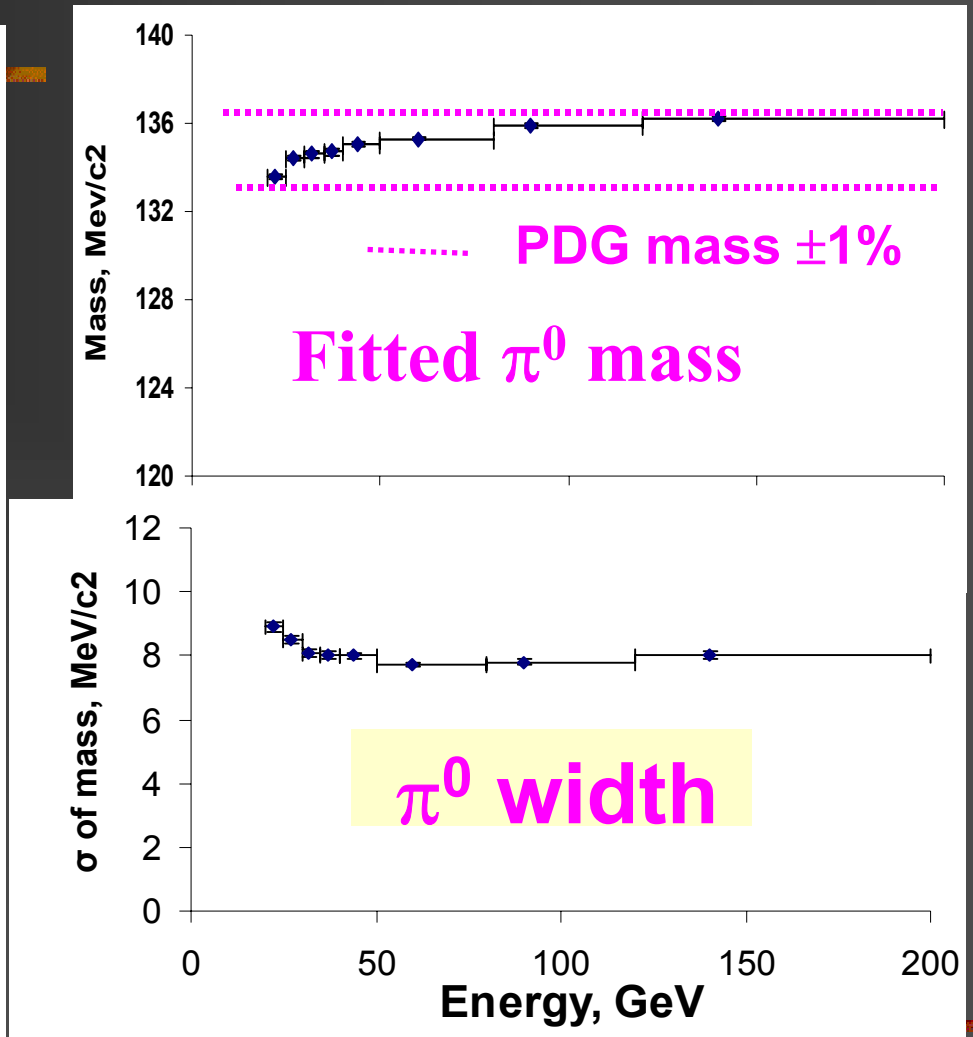
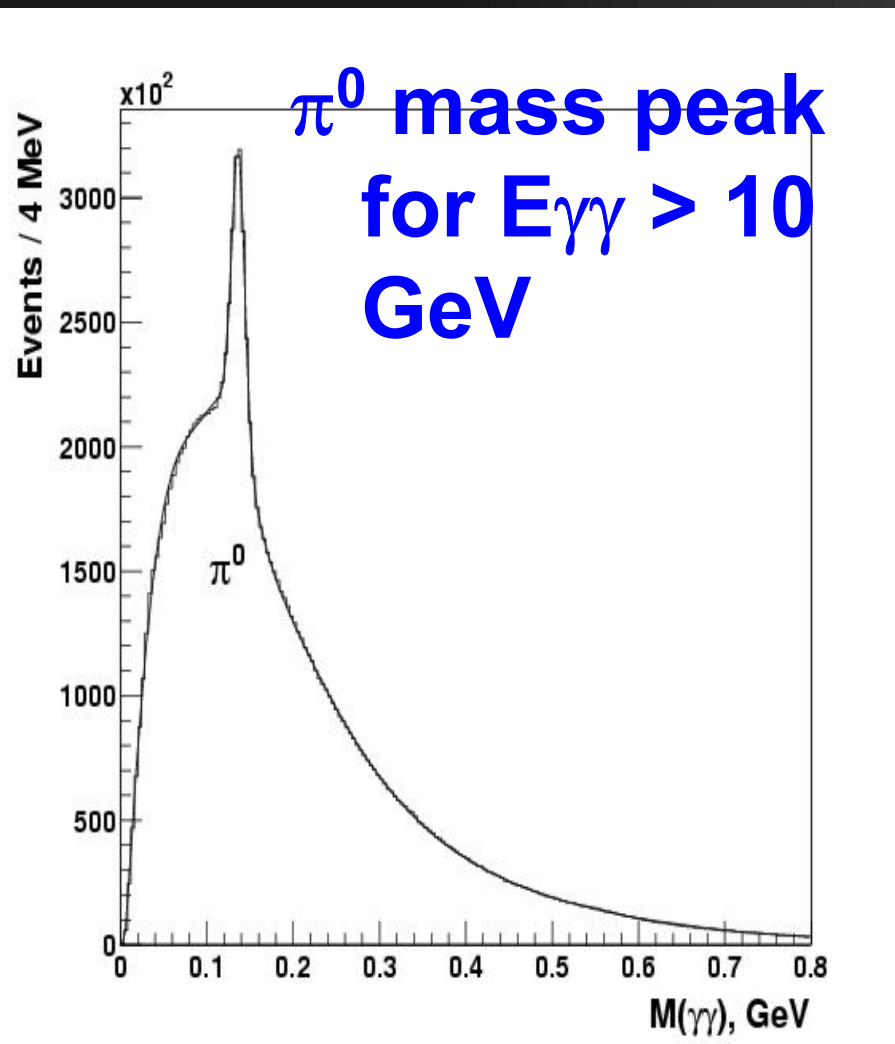


This analysis uses  $D^0$  and  $D_s$  data

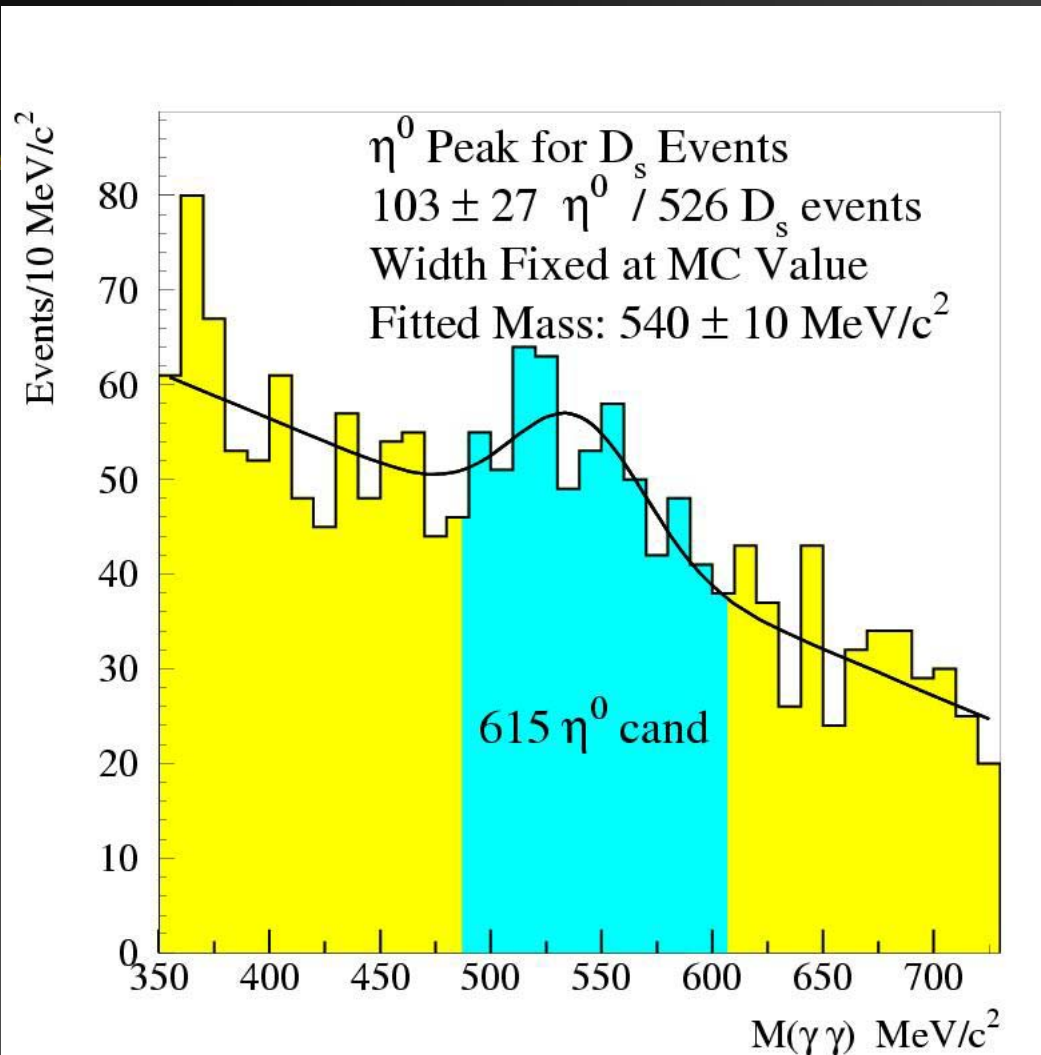


# CHARM trigger $\langle n_{ch} \rangle = 10$ , $\langle n_{\gamma} \rangle = 8$

Photon cuts:  $E_{\gamma} > 2$  GeV,  $N_{\gamma} \leq 10$



# Check $\eta$ in events with $D_s^+$ candidates



$\eta$ candidates / event	$N(\eta)$ candidates	$N(D_s)$ events
0	0	205
1	158	158
2	174	87
3	117	39
4	76	19
5	90	18
6	30	5
7	7	1
8	48	6
9	0	0
10	40	4
11	22	2
sum	762	544
$\langle N(\eta) \rangle / D_s$	615	526
		1.17

Subtract signal  $\eta$ s:  $\eta/\text{evt}$  is  $0.12 \pm 0.05$  compared to  $0.05 \pm 0.009$  for all evts.  
 (Dis)agree at  $1.4\sigma$  level