First Observation of a New Narrow D_s^+ Meson at 2632 MeV/c^2

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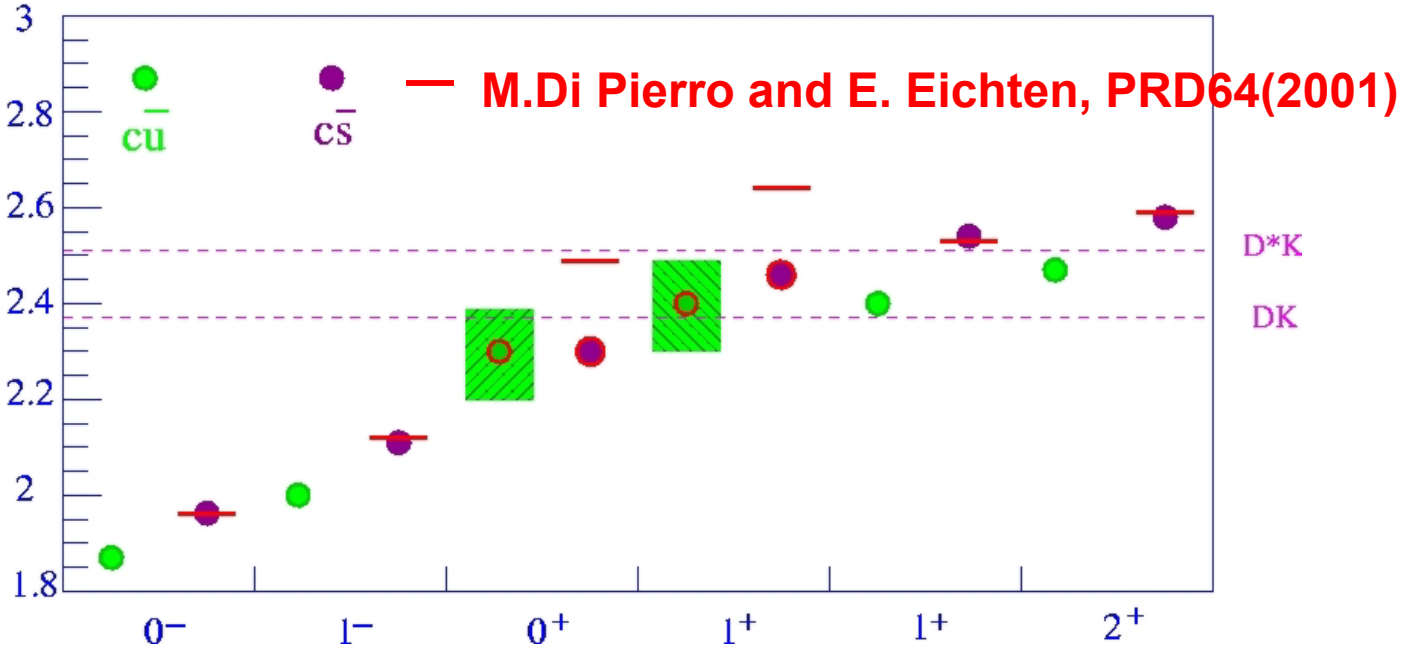
(*for the SELEX collaboration*)

Outline

- Heavy-Light Meson Spectroscopy
- Reminder about SELEX(E781)
  - Features:
    - PID
    - Precision tracking
    - Photon detection
- New state: observation in two decay modes
- Conclusions

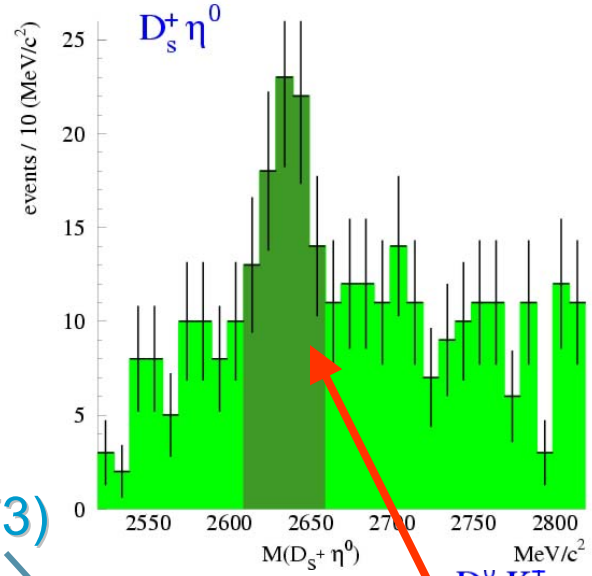
Heavy-light spectroscopy



- Model predicts mass and widths – works well for $D(c\bar{d})$, but not for all $D_s(c\bar{s})$
- 2003 – e+e- found Ds(2317), Ds(2463) – below threshold, inconsistent with model
- Higher states – expected above $D^{(*)}K$ threshold – therefore broad and hard to observe

But …

Today's new STORY: Another massive Ds state



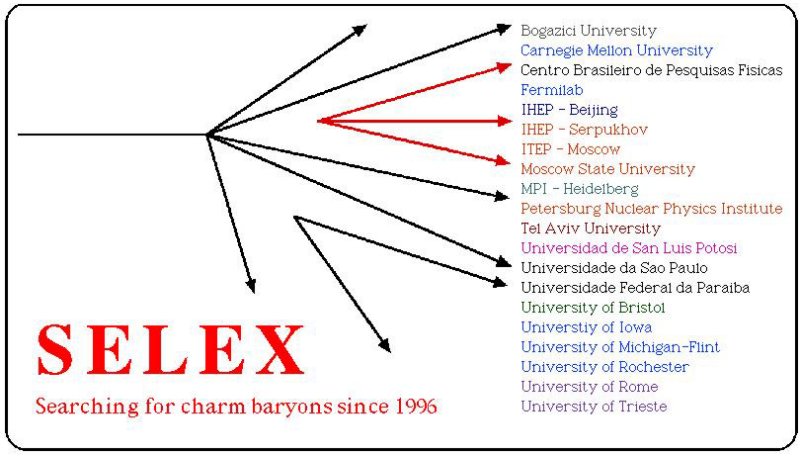
$D_{sJ}^+(2573)$

NEW state
$D_{sJ}^+(2632)$

We see a new particle decaying in two modes :

$D_{sJ}^+(2632) \Rightarrow D_s\eta$
$\Rightarrow D^0K$

SELEX(E781) Experiment collaboration



SEgmented LargE X_F ($x_F > 0.1$) Experiment

- SELEX(E781) is a multi-stage charged particle spectrometer with high acceptance for forward production and decays
- 1996-1997 Fixed Target Run at Fermilab (PC4) with 600 GeV/c Σ^-, π^-
- 125 participants from 20 institution in 11 countries

SELEX collaboration

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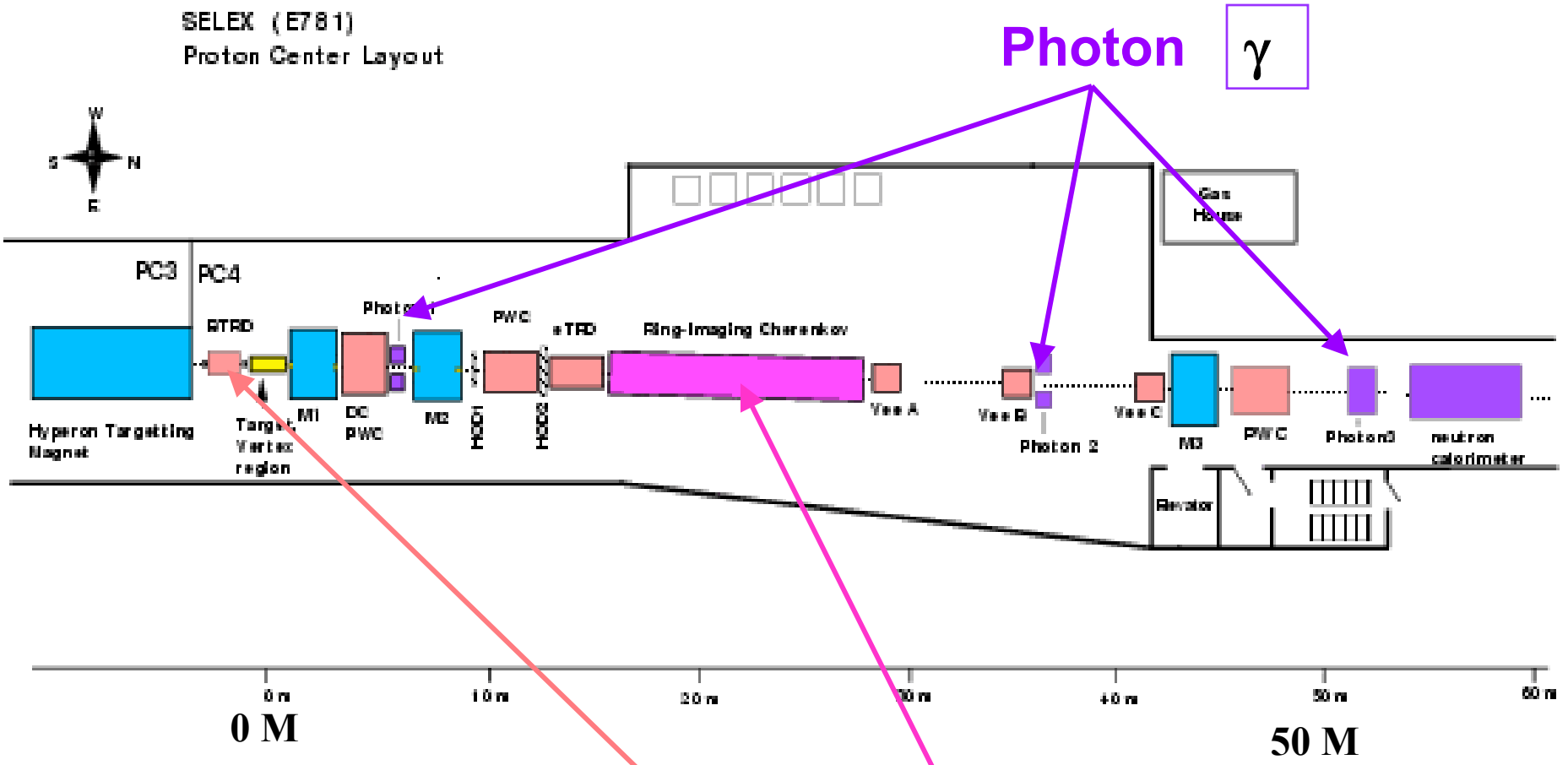
SELEX(E781) Experiment (PID)



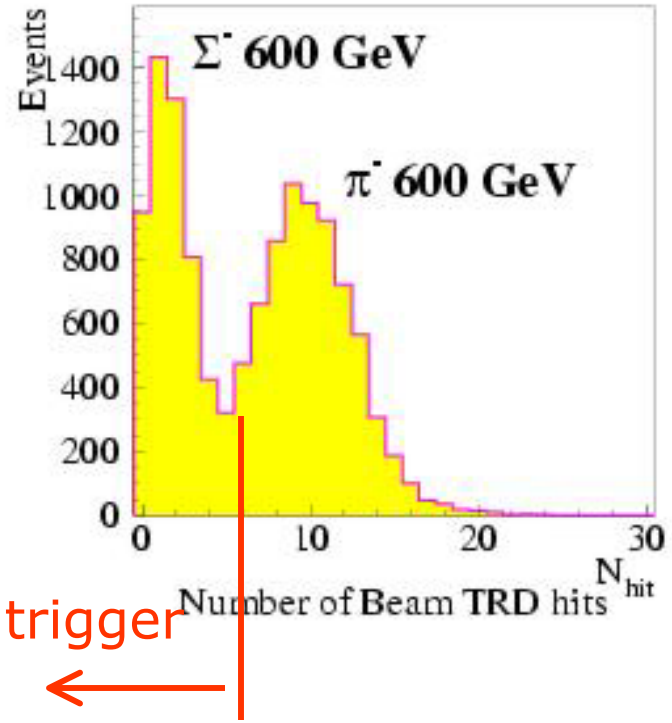
Particle ID : Beam TRD, RICH

Σ^-/π^- $\pi/K/p$

Charged Particle ID

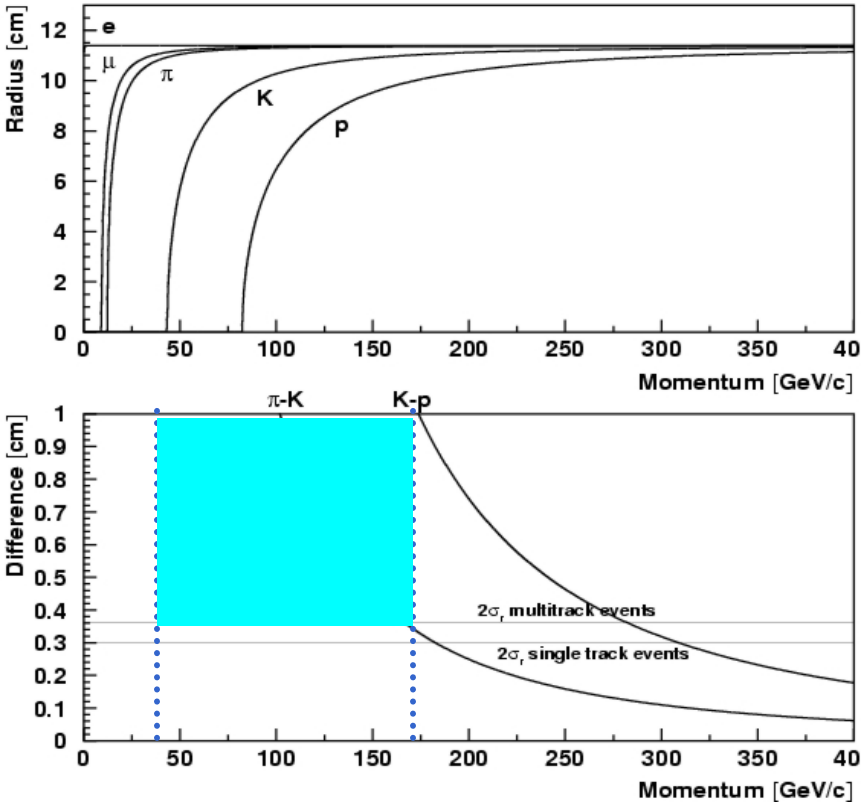
Beam TRD

Σ^- and π^- at 600 GeV/c



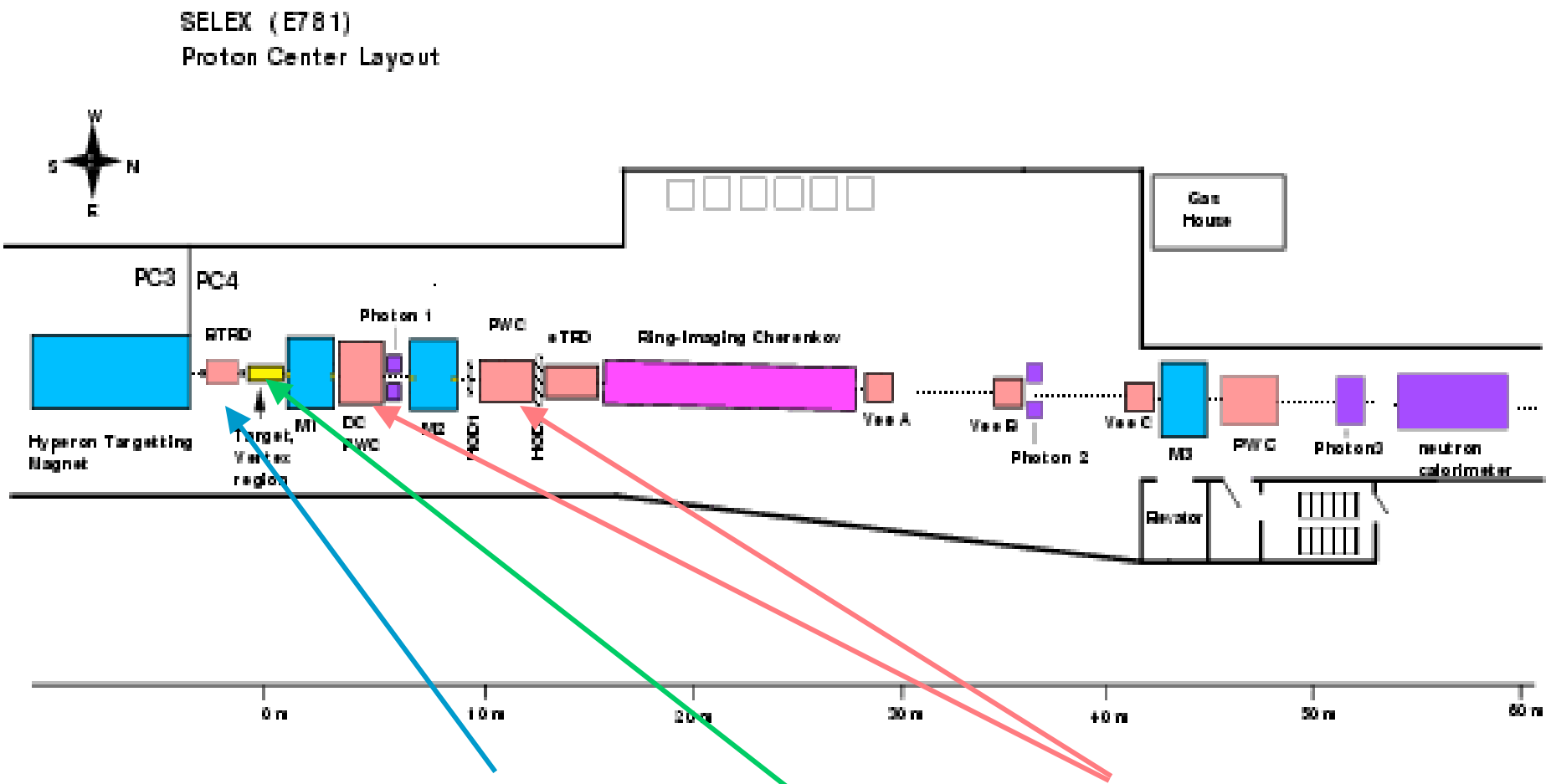
Only Σ^- trigger in this analysis

RICH



≥2σ K/(p,π) separation
46 to 165 GeV/c

SELEX(E781) Tracking



Precision Tracking

Beam Silicon Detectors

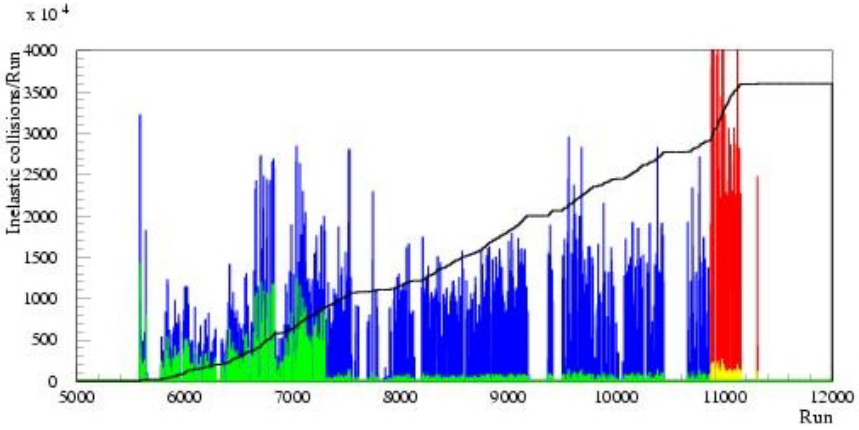
PWC Spectrometer Planes

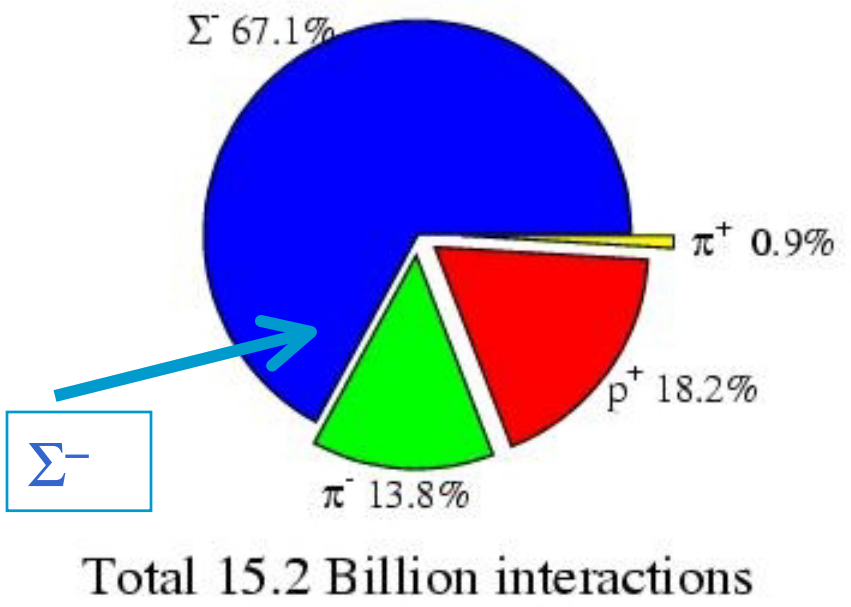
Vertex Silicon Detectors

Charm Trigger and SELEX dataset

- Hardware Trigger
  - ✓2 positive tracks in M2(p>15 GeV/C)
  - ✓4 charged track in the forward region
  - ✓30% triggered interactions
- Software trigger
  - ✓Evidence for the secondary vertex
  - ✓Reconstructing primary vertex using high momentum tracks (p>15 GeV/C)
  - ✓Data size reduced by factor of 8
  - ✓50% charm efficiency

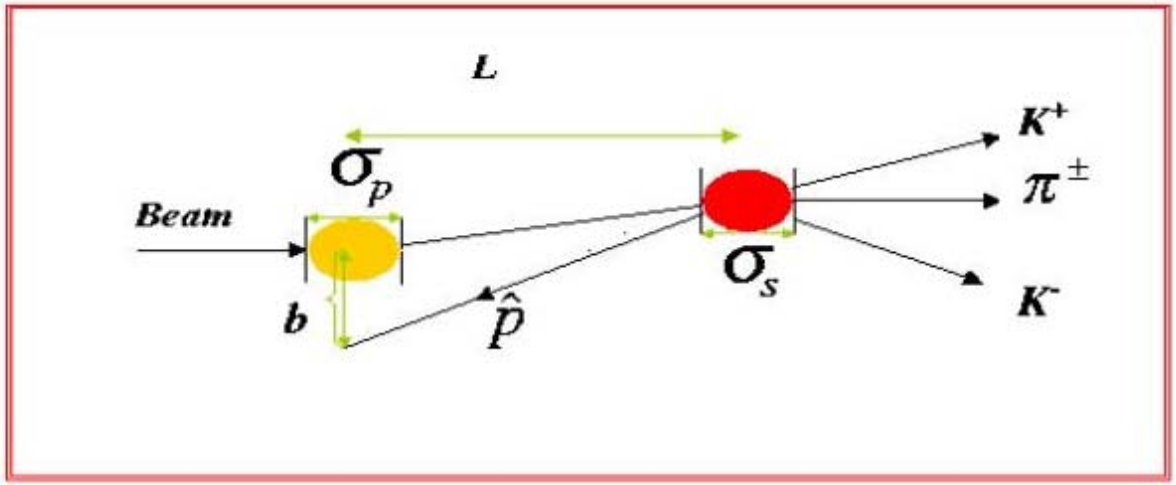
SELEX dataset





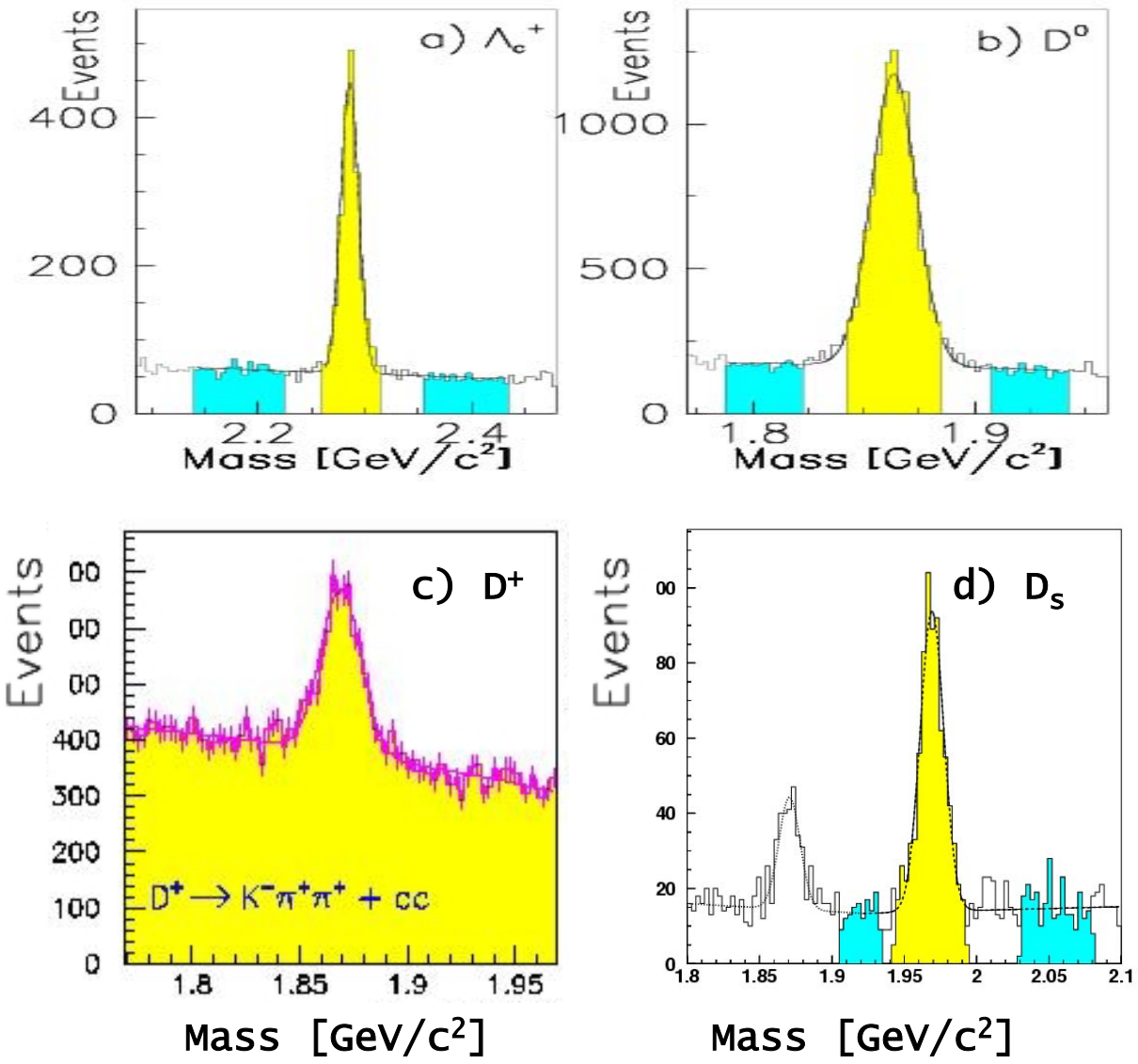
Total 15.2 Billion interactions

Charm selection



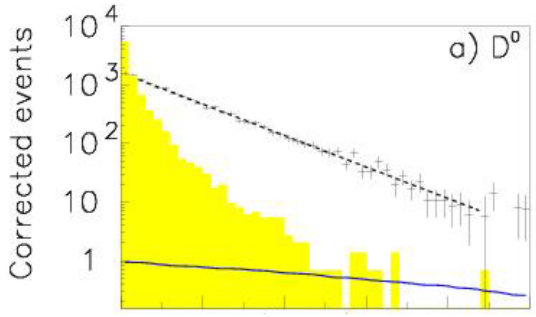
- ✓Decay vector separation significance L/σ
- ✓Charm vector momentum points back to primary vertex: cut on (b/ σ_b) (point back cut)
- ✓Decay vertex lies outside target material

SELEX single charm states

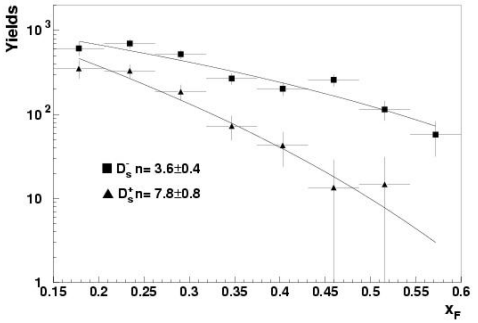


This analysis uses D^0 and D_s data

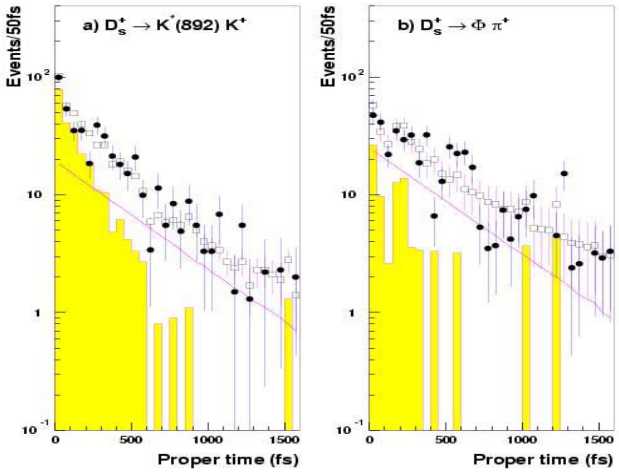
D^0, D_s Datasets already used in publications



D^0 lifetime



D_s Production



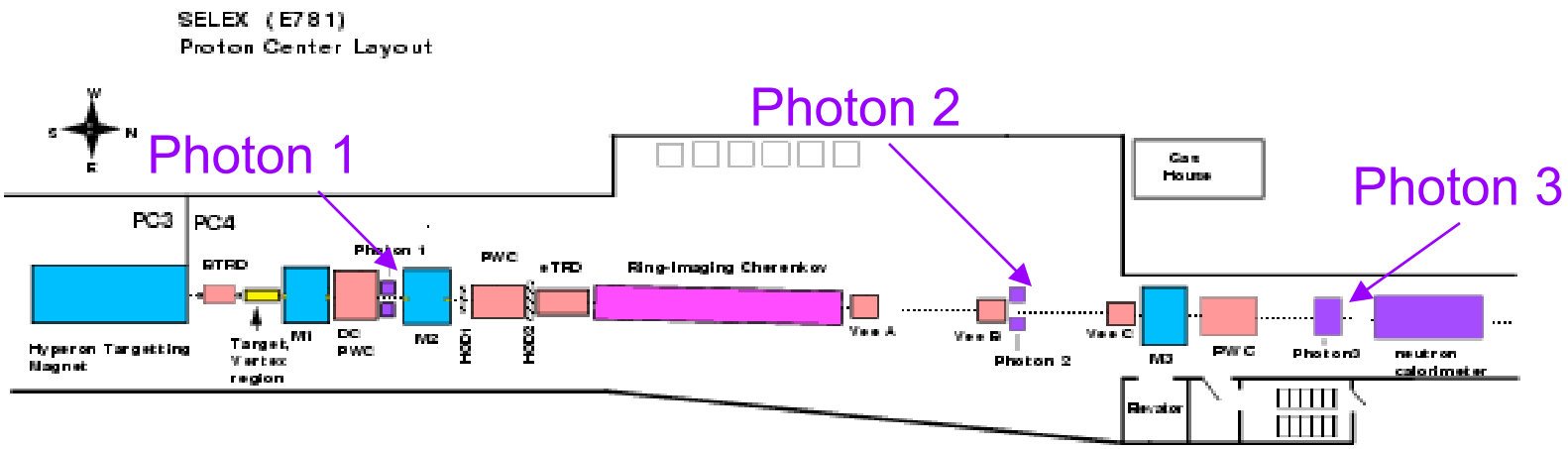
D_s lifetime

Precision measurements of the Lambda$_c^+$ and D^0 lifetimes Phys. Rev. Lett. 86, 5243 (2001).

Measurement of the D_s lifetime Physics Letters B 523 (2001) 22-28

Production Asymmetry of D_s from 600 GeV/c Sigma$^-$ and pi$^-$ beam Physics Letters B 558 (2003) 34-40.

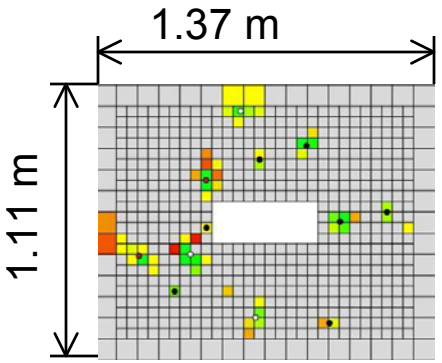
SELEX(E781) Photon Detectors



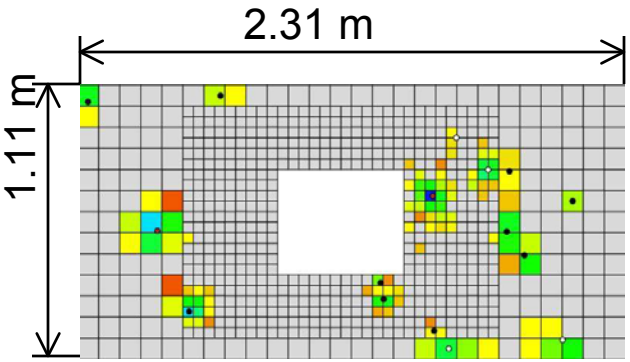
Each Spectrometer includes Lead-Glass Photon Calorimeter

2π coverage in c.m. of primary interaction

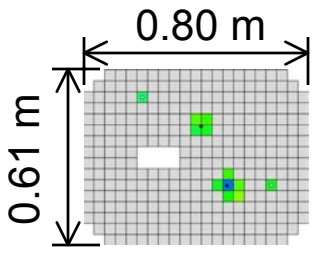
1GeV < Eγ < 10GeV ***2GeV < Eγ < 40GeV*** ***4GeV < Eγ < 80GeV***



630 Channels



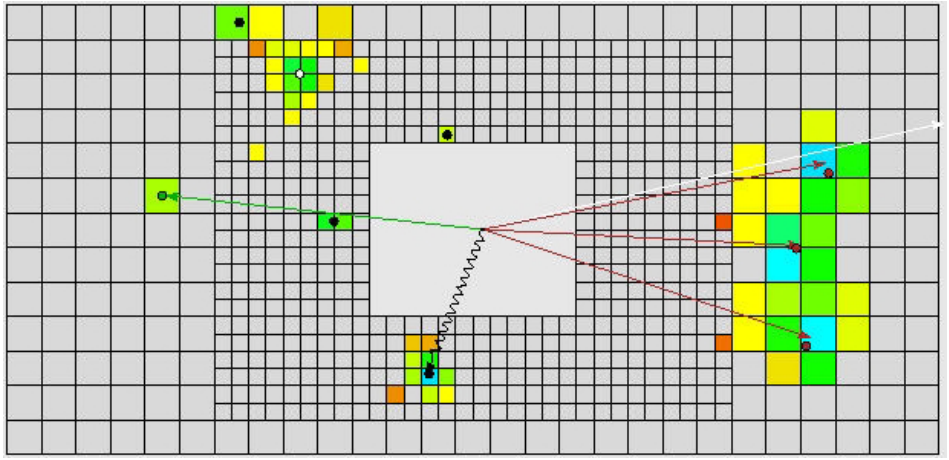
726 Channels



316 Channels

Photon reconstruction

- ✓ find Energy Clusters ($E_{clust} > 500$ MeV)
- ✓ make χ^2 test of single photon hypothesis
- ✓ if not single gamma, test for overlapping photons
- ✓ if clusters fails photon overlapping test reject as neutral hadron
- ✓ test for matching with the charged tracks



- **brown are any other charged particles**
- **green are MIP, possible μ**
- **white is neutral particles which have big χ^2 to be γ-s**
- **black is photon candidate**

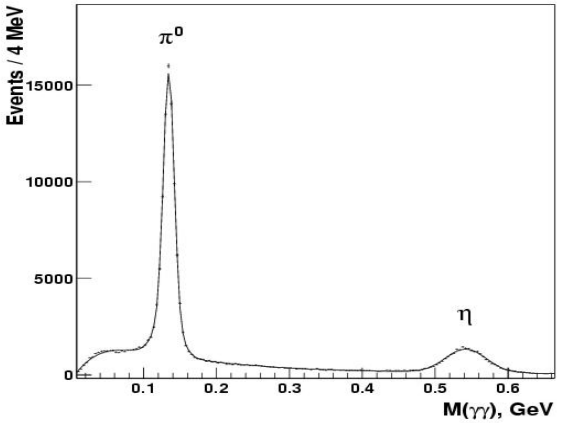
Calibration of the Photon Calorimeters

- Initial calibration used Laser system
- Electron beam calibration
- π^0 constrained fitting calibration
  - Exclusive trigger - look for final states with 3-5 charged track (low charged and photon multiplicity)

  The lead-glass electromagnetic calorimeter for the SELEX experiment, **FERMILAB-TM-2252**
- Refining of π^0 constrained fitting calibration using charm trigger data

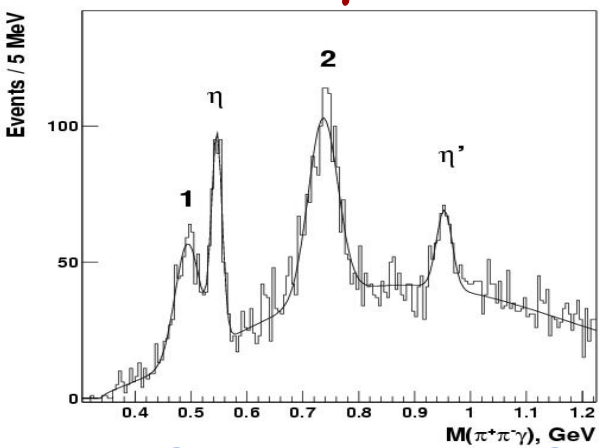
Effective mass distribution in Exclusive trigger

$\gamma\gamma$



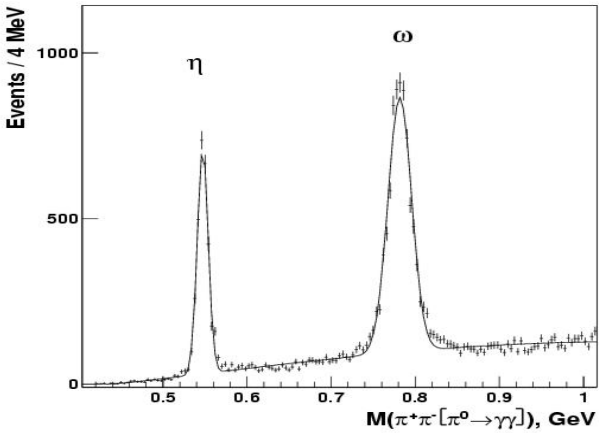
Eγ> 2 GeV, Nγ = 2, Eγγ >10GeV

$\pi^-\pi^+\gamma$



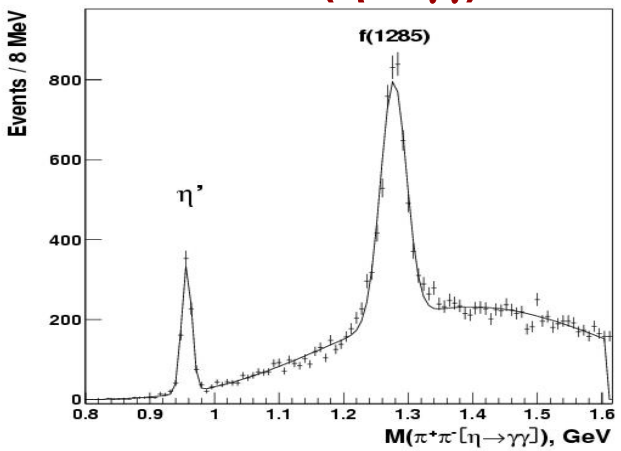
Eγ> 2 GeV Nγ = 2 Eγγ >10GeV

$\pi^-\pi^+(\pi^0\rightarrow\gamma\gamma)$



Eγ> 2 GeV Nγ = 2 Eγγ >10GeV

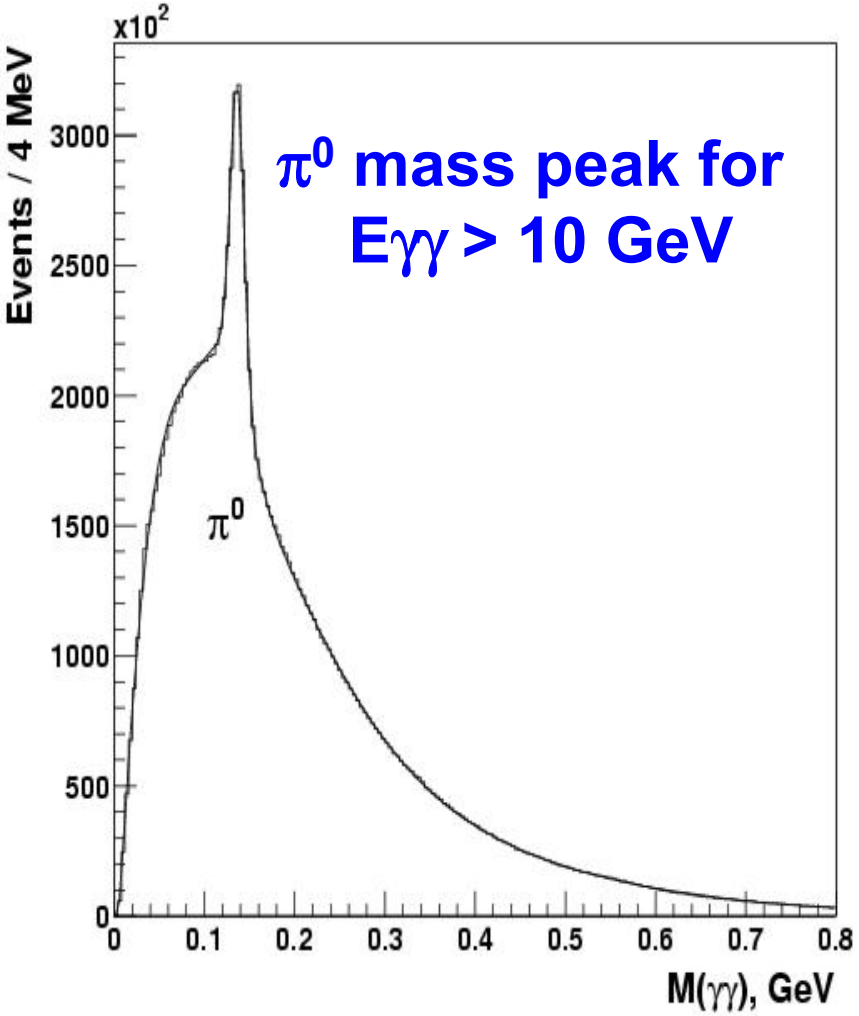
$\pi^-\pi^+(\eta\rightarrow\gamma\gamma)$



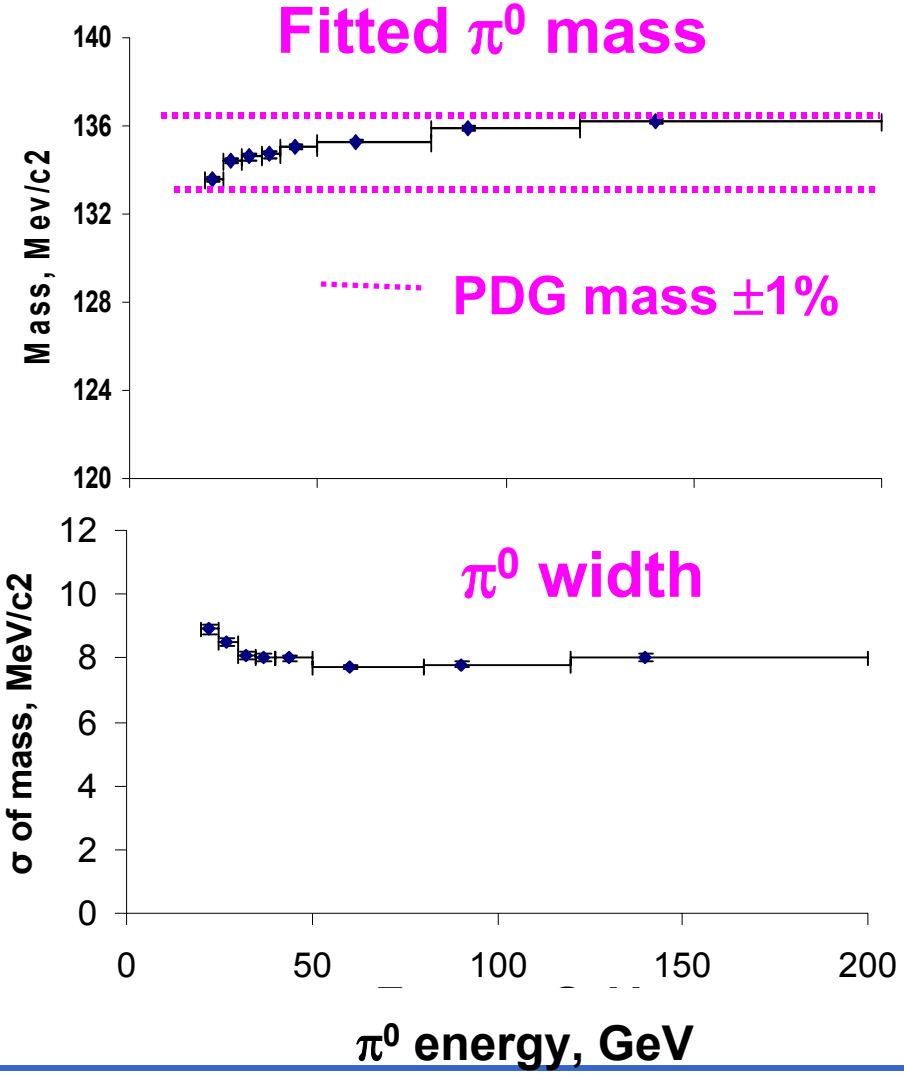
Eγ> 2 GeV Nγ = 2 Eγγ >10GeV

CHARM trigger $<n_{ch}> = 10$, $<n_{\gamma}> = 8$

Photon cuts: Eγ >2 GeV, Nγ ≤10

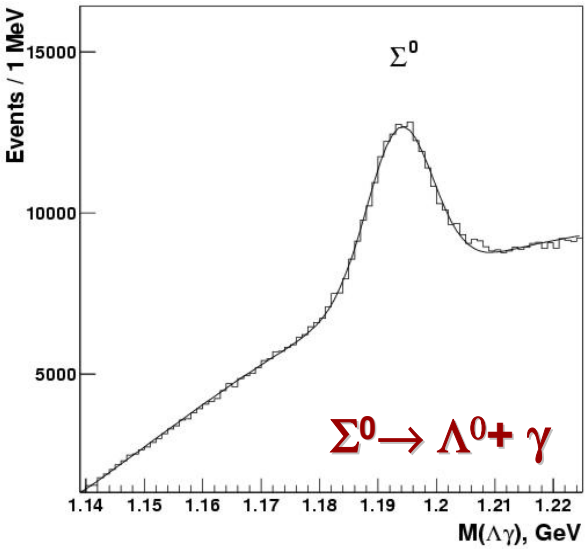


π^0 mass peak for Eγγ > 10 GeV



Single Photon States

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

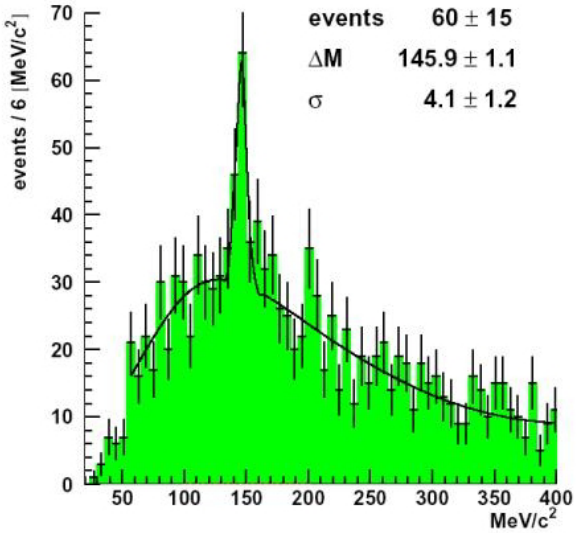


$\Delta M_{PDG}(\Sigma^0) = 76.96 \pm 0.025$

(obs) $= 78.1 \pm 0.6$

Photon energy scale agrees better than 2% for this decay

Study Ds (2112) $\rightarrow$ Ds+ γ

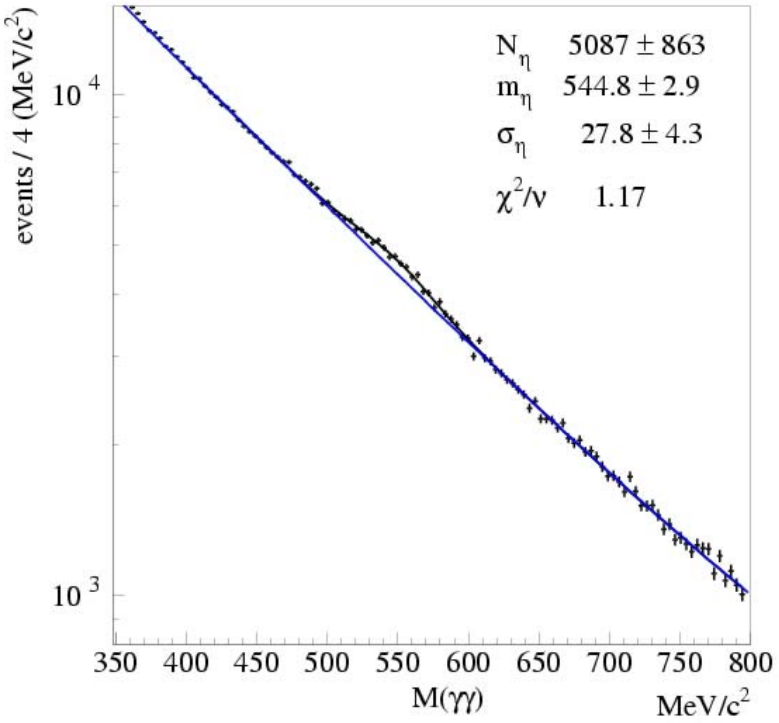


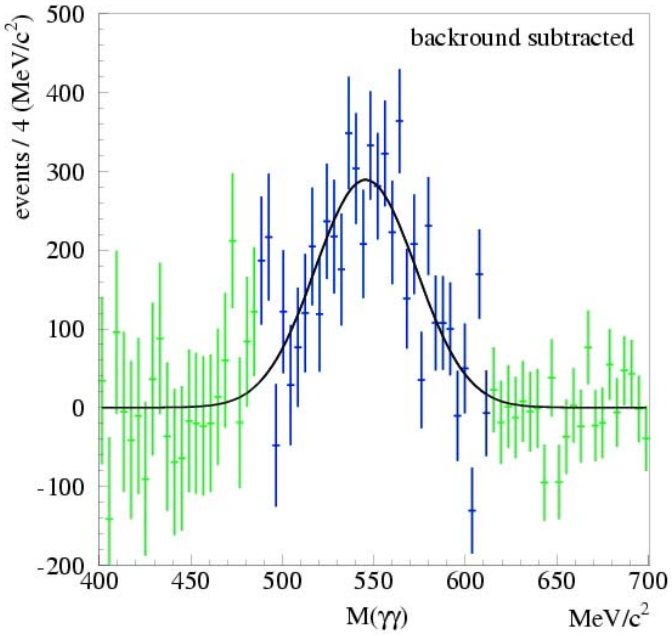
$\Delta M_{PDG} = 143.8 \pm 0.4$

Fitted with Gaussian width taken from Monte-Carlo we have good agreement

We understand well response of detector and will use Monte-Carlo resolution in fits

η signal in CHARM trigger





- Eγ >2 GeV, Eγγ > 10GeV, Nγ < 10

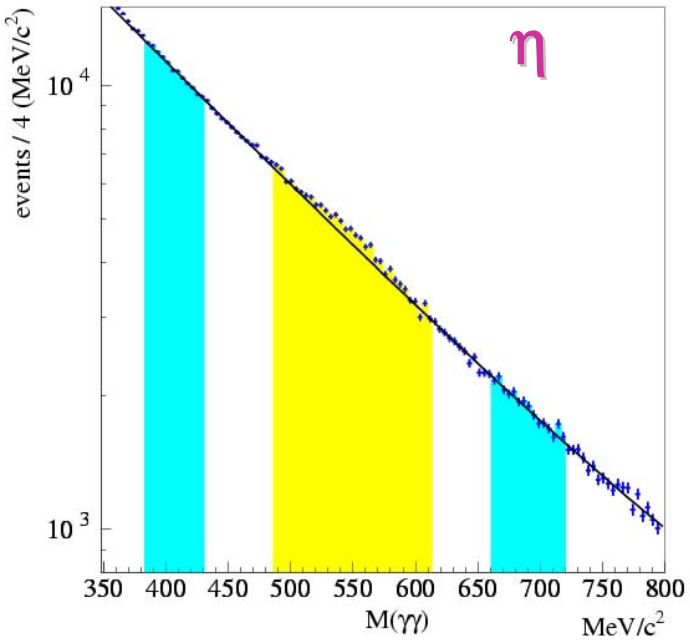
Fitted value M(γγ) = 544.8 ± 2.9
Fitted width (γγ) = 27.8 ± 4.3
M-C width (γγ) = 30.2 ± 1.2

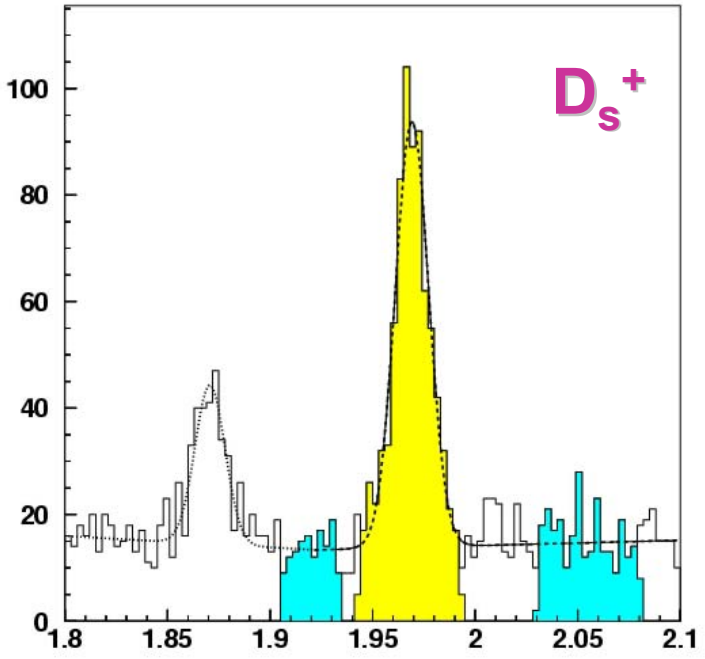
Fit to exp + Gaussian + constant

η mass agree within 1σ of PDG value

MC represents response very well

η and D_s selection



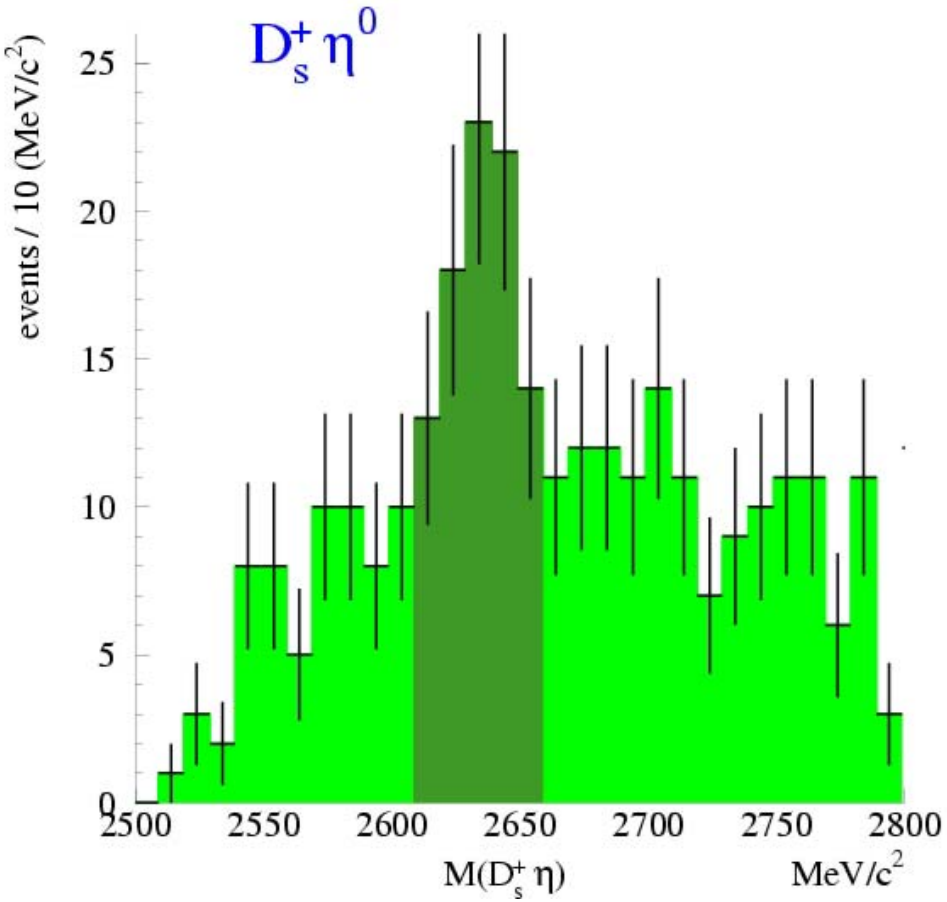


- Eγ >2 GeV
- Eγγ > 15GeV
- η mass region equal $M_{PDG}(\eta) \pm 2\sigma$

487.5 MeV ≤ M(γγ) ≤ 607.5 MeV

- L/σ > 8, pvtx <8
- 1943 MeV ≤ M(KKπ) ≤ 1993 MeV

New charm-strange meson



✓We combined our clean sample of Ds with η candidates

η constrained to PDG $\vec{p}_\eta$ =[$M_{PDG}(\eta)$, $\vec{p}$]

✓Reject events with Nη > 5 candidates

<Nη>= 0.2

Clear peak at a mass near 2635 MeV/c² seen

$\Delta M + M_{PDG}(D_s) = M(KK\pi\eta) - M(KK\pi) + M_{PDG}(D_s)$

Sideband studies

We studied:

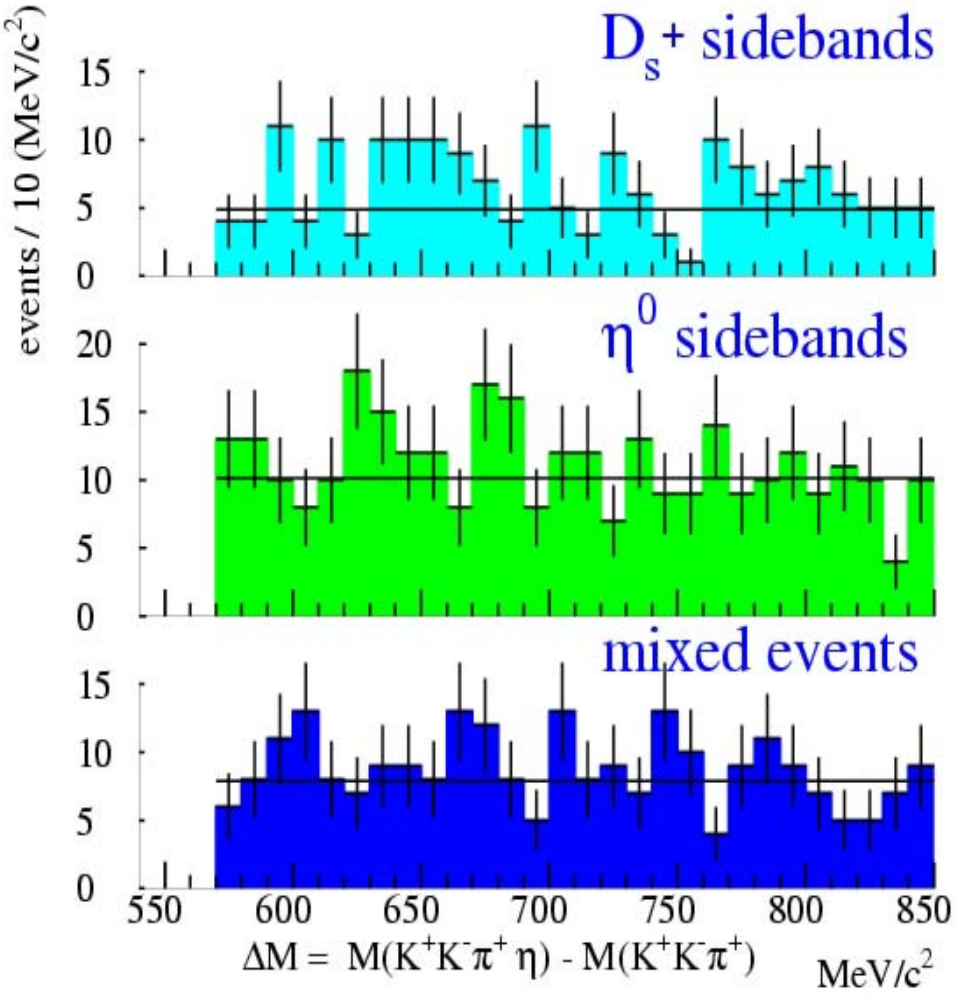
Ds sidebands + real η

η sidebands + real Ds

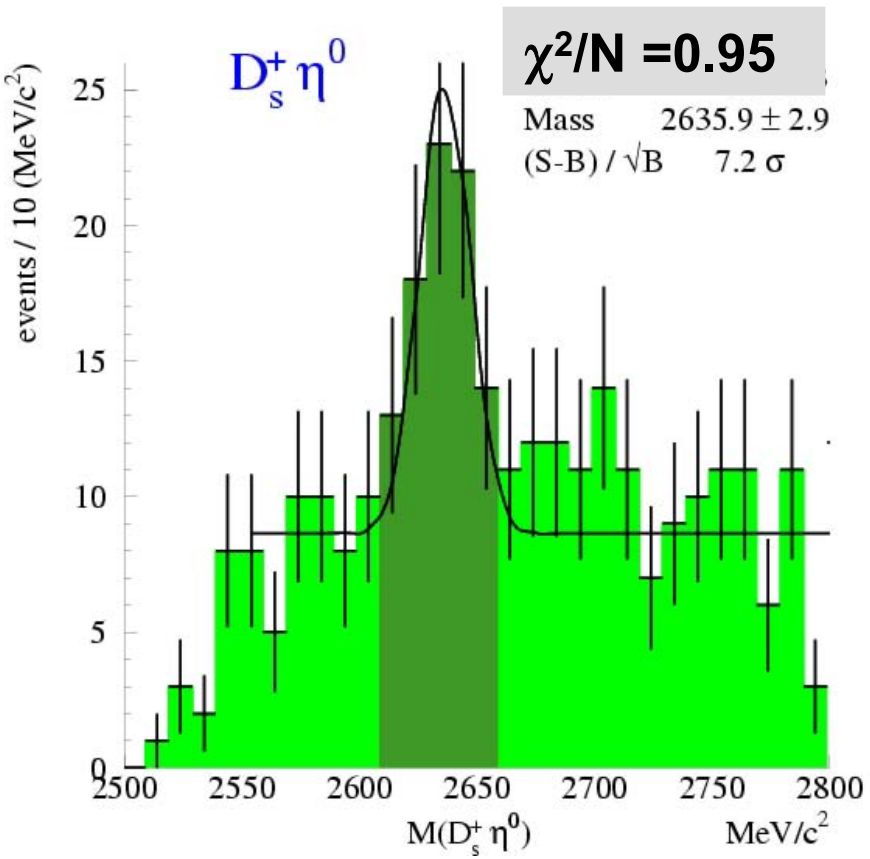
Event mixed technique:

η from previous event + real Ds

- No structure seen in any type of background !
- Constant background fits all distribution



Fit to D_{sJ} mass



- ✓M-C simulation gives resolution of 10.7 MeV
- ✓Sideband studies show that background is flat
- ✓Fit with fixed width Gaussian and constant background
- ✓χ^2 for fit is good

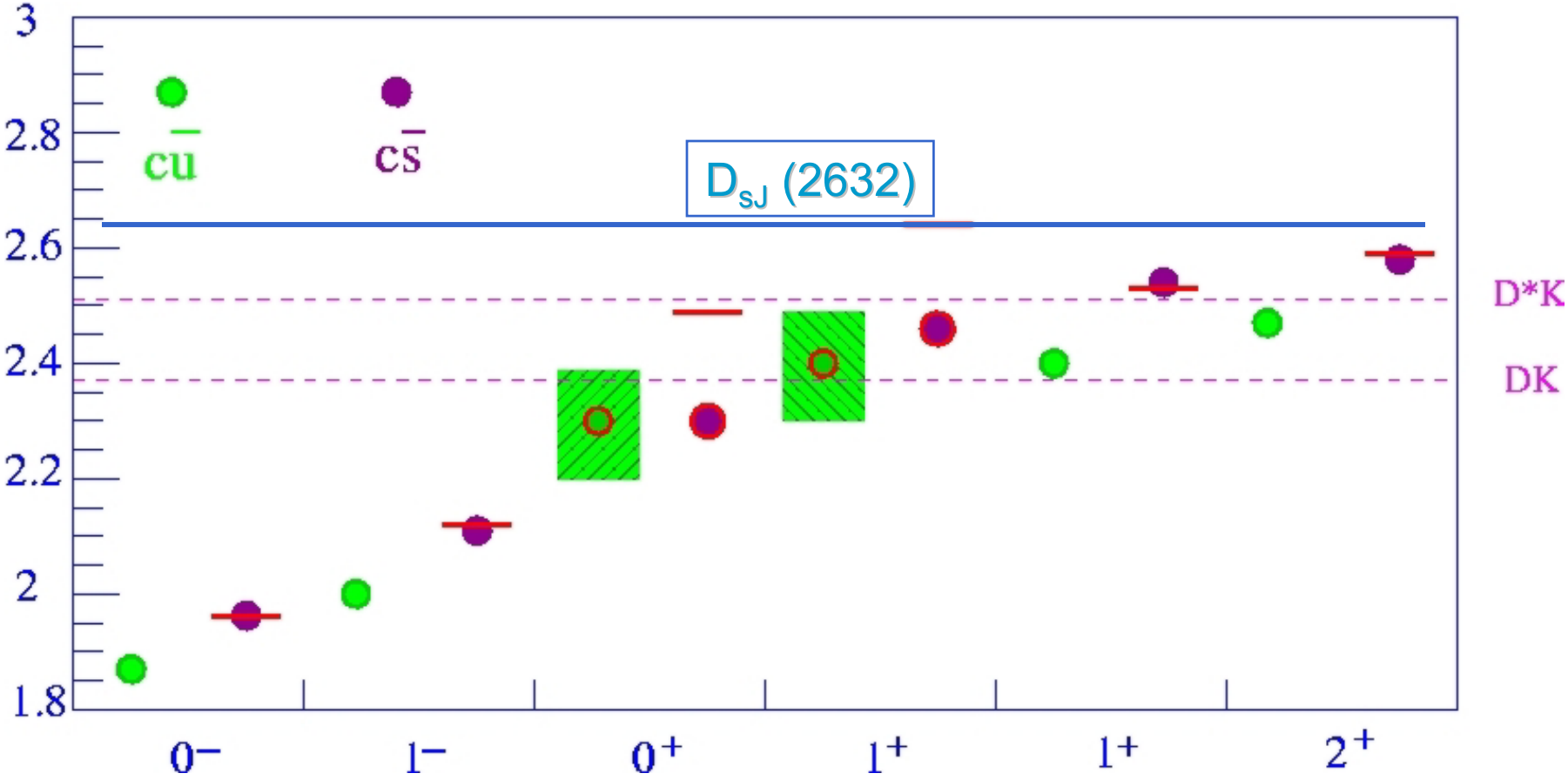
Count S = 101 B = 51

(S-B)/√B = 7.2σ

Fit events: 45 ± 9.3

Mass 2635.9 ± 2.9 MeV/c²

Heavy-light spectroscopy now



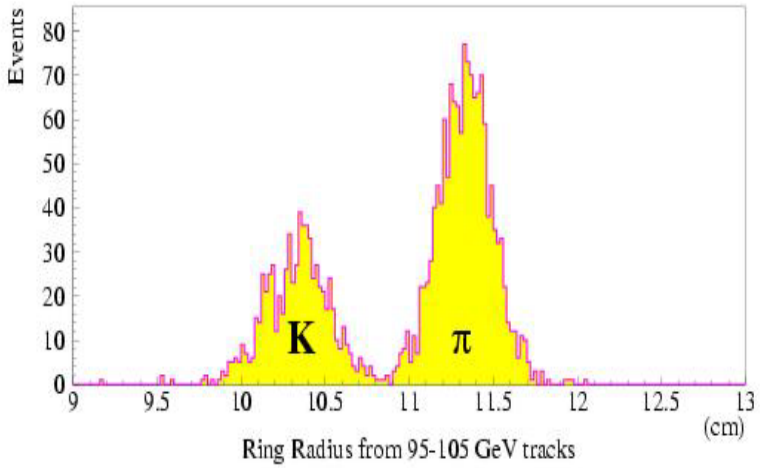
New state lies above $D^{(0)}$ K threshold

We looked for Ds(2632) $\overset{?}{\Rightarrow} D^0K$

K Purity Study

Adding bachelor K to D^0 requires strong K/π and K/p separation

K/π separation at 100 GeV

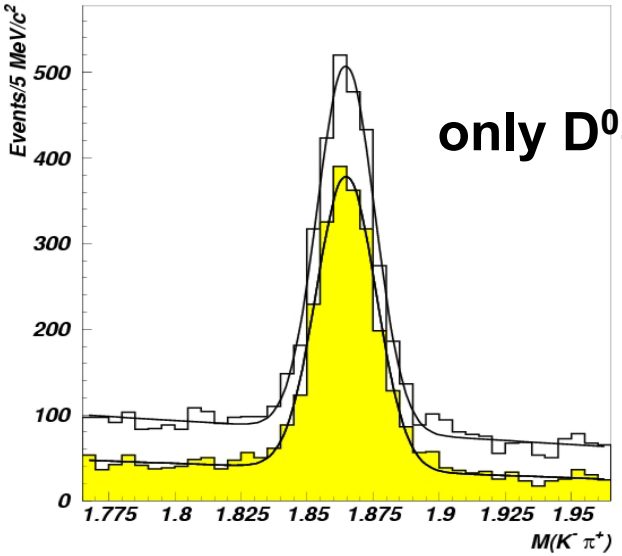


- To avoid K/p ambiguity we require K make light p> 45 GeV/c^2
- Prob(K) / Prob(other) > 10

Keep 83% of signal

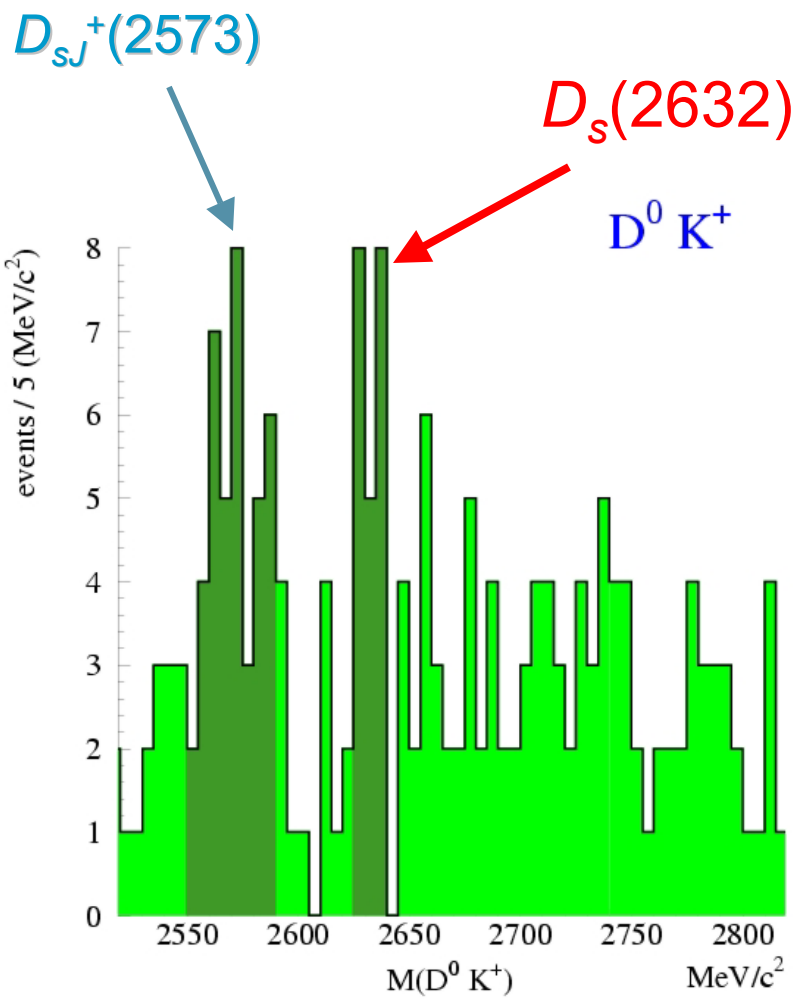
Keep 44% background

Check effect on K from D^0 sample



- Open histo $D^0 \to K\pi$ with standard RICH cut and P(K) > 45 GeV/c^2
- Shaded histo – same date with tight K

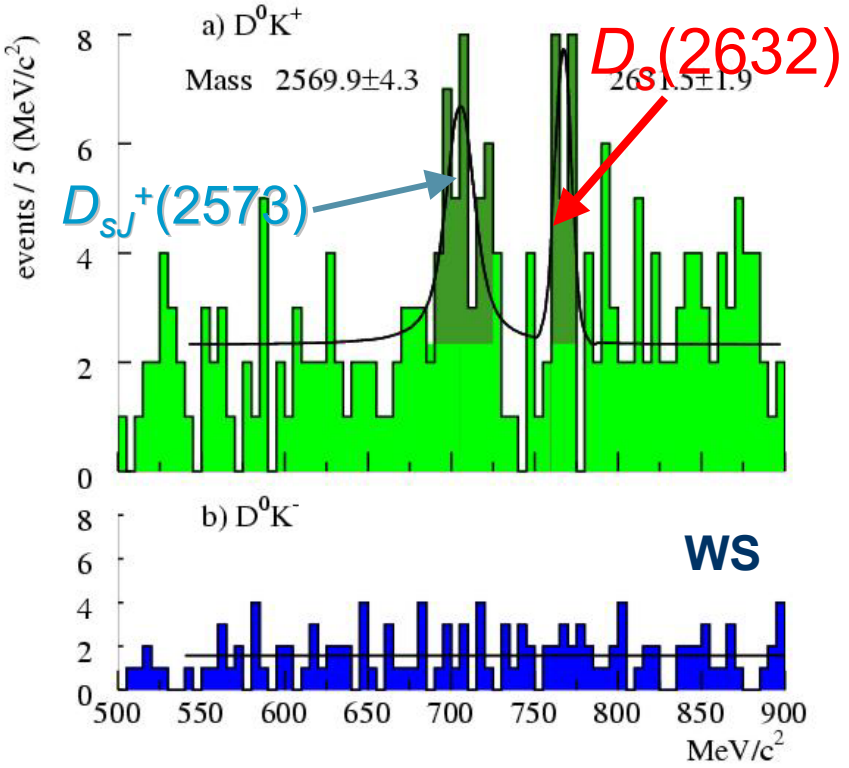
Observation D_s (2632) → D^0+ K



We see known D_{sJ}^+(2573)

We see new bump at same mass as the **Ds** η state

Fitting D_s (2632) → D^0+ K



DsJ(2573) PDG	2573.5 ± 1.7 MeV/c²	15^{+5}_{-4} MeV/c²
DsJ(2573) SELEX	2569.9 ± 4.3 MeV/c²	14^{+9}_{-6} MeV/c²

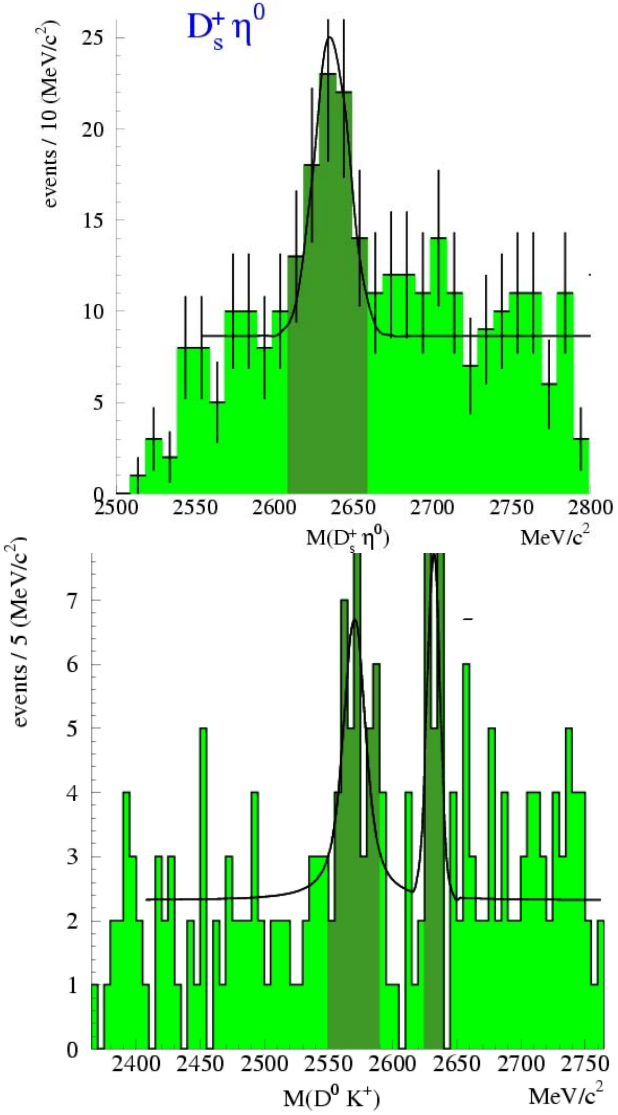
- Wrong sign background constant
- Fix resolution from simulation (4.9 MeV)
- Fit with BW convolved with Gaussian + constant background

New state is very narrow !

✓Consistent with resolution

✓A 90% CL upper limit Γ<17MeV/c²

Ds (2632) summary



State	**Ds (2632) → Dsη**	**Ds(2632) → D^0K**
mass	2635.9 ± 2.9	2631.5 ± 1.9
Sign.	7.2 σ	5.3 σ
Events	45 ± 9.3	14 ± 4.5
χ^2/n_d	**0.95**	**0.77**

Average Ds (2632) mass
2632.6 ± 1.6 MeV/c²

Γ<17MeV/c² @ 90% CL(D^0K)

$D_{sJ}(2632)$ Branching Ratios

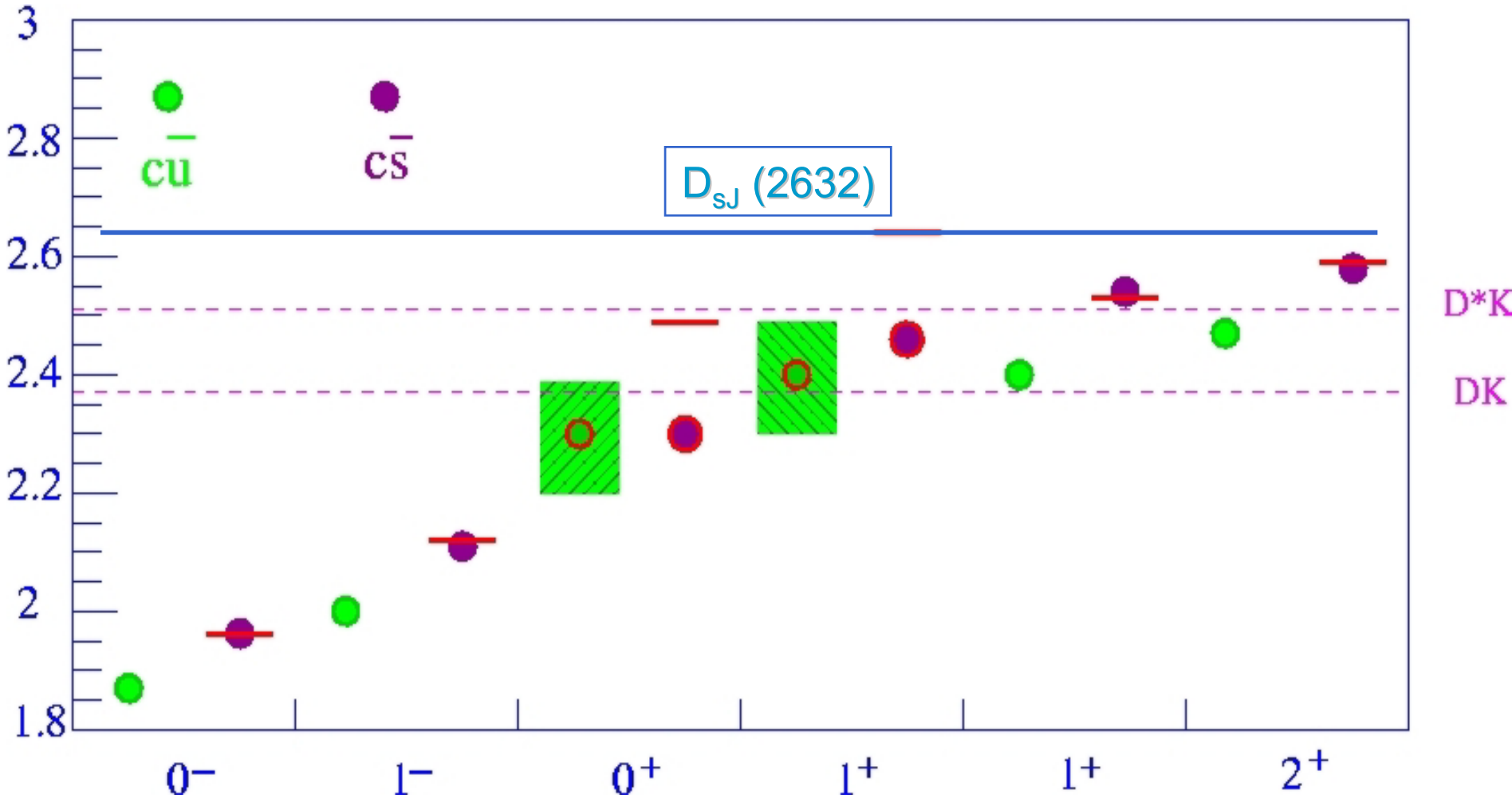
- Most models say that D^0 K coupling should be much bigger than $D_s\eta$
- Phase space favors D^0 K mode by 2.3x

- Acceptances given a detected D(s) meson are comparable

- We see 3x as many $D_s\eta$ decays as D^0 K

SURPRISE: $\Gamma(D^0 K)/\Gamma(D_s h) = 0.16 +/- 0.06$

Heavy-light spectroscopy now



HELP WANTED!

- Confirmation of the $D_{sJ}(2632)$ is required!

- If this is an orbital excitation, then HQET assures us that there will be a partner decaying in the same way to a D^* within 40 MeV/c^2 . (experimental help needed)
- The dominate of the $D_s\eta$ decay mode is surprisingly. Might this be a hybrid state (csg) ? (theoretical and experimental help needed)

Conclusions

- We combined our clean sample of D_s mesons with photon pairs made η candidates

  We observed a clear peak of 50 ± 10 events with a significance of 7.2 σ at a mass difference 667.4 ± 2.9 MeV/c^2 above ground state

- We combined our clean sample of D^0 mesons with pure K

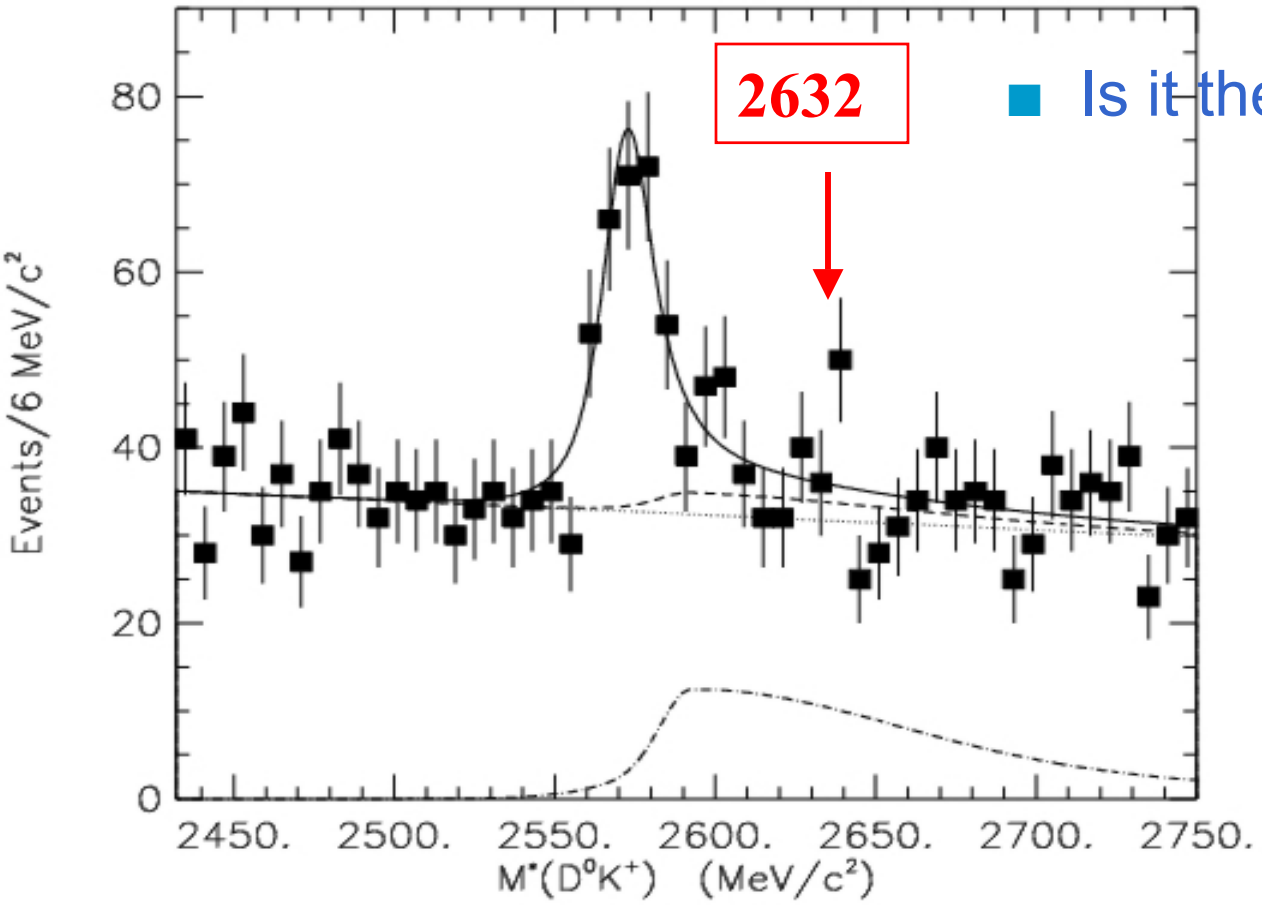
  We observed a clear peak of 14 ± 4.5 events with a significance of 5.3 σ at a mass difference 767.0 ± 1.9 MeV/c^2 above ground state

- Clear evidence for a new state DsJ(2632) !
- Combined of the mass is 2632.6 ± 1.6 MeV/c^2
- A 90% CL upper limit for the width of this state from $D^0K^+ < \mathbf{17}$ MeV/c^2

We await news from our experimental colleagues !

EMPTY SLIDE

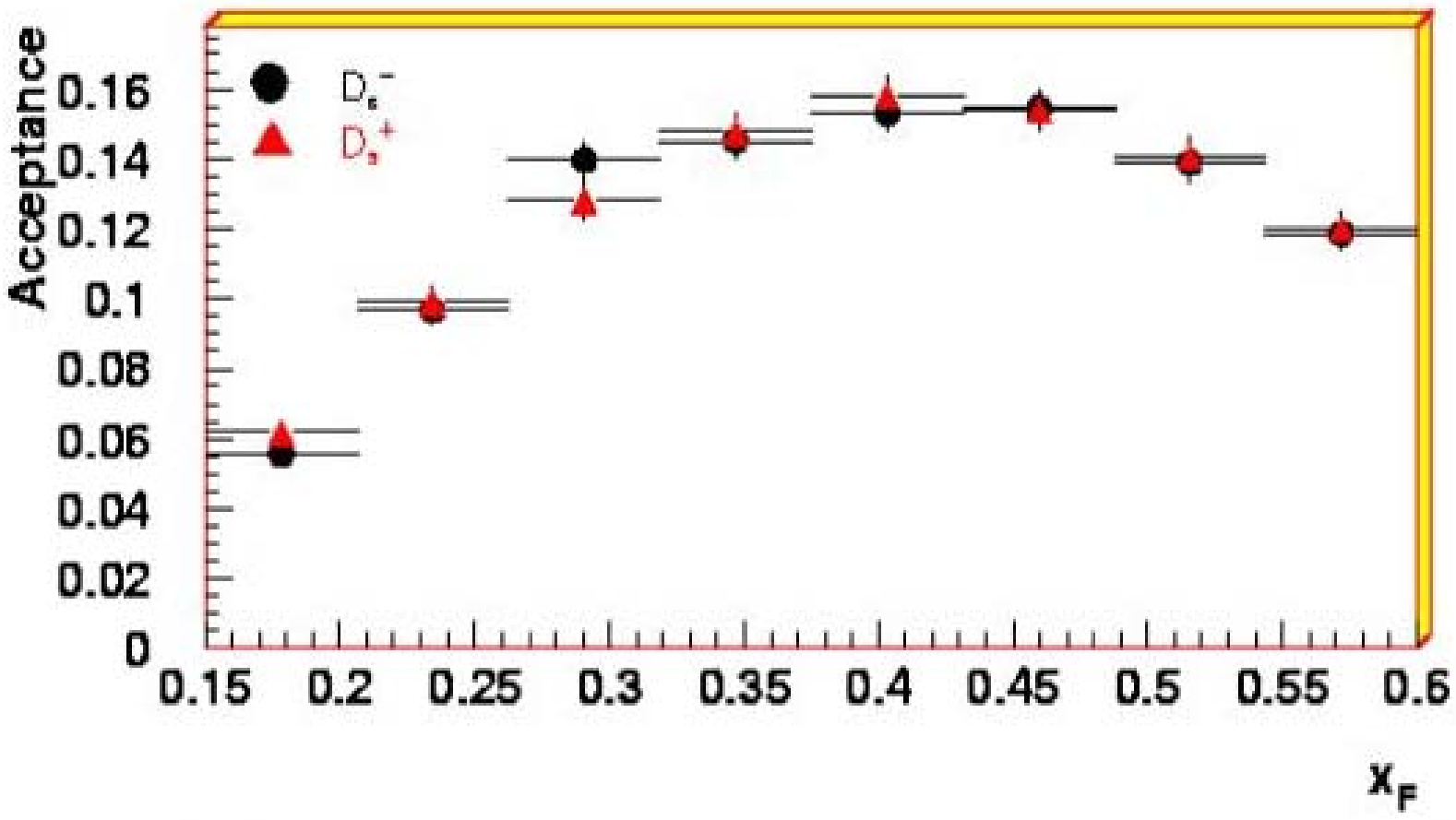
Something interesting: CLEO results on $D_s(2573)$



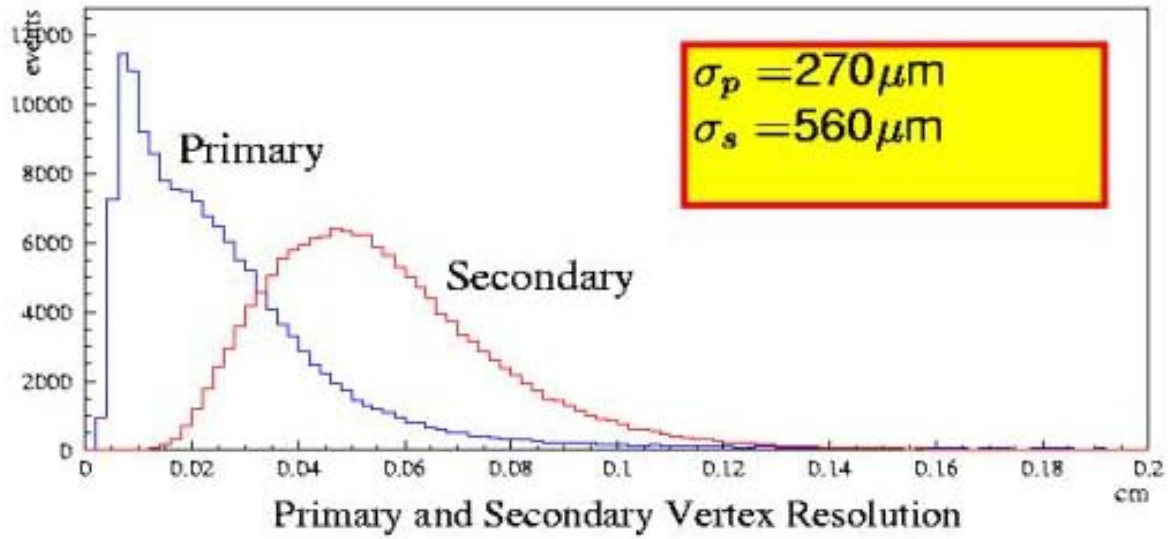
- Is it the same signal ?

Y.Kubota et al. (CLEO) PRL 72(1994)

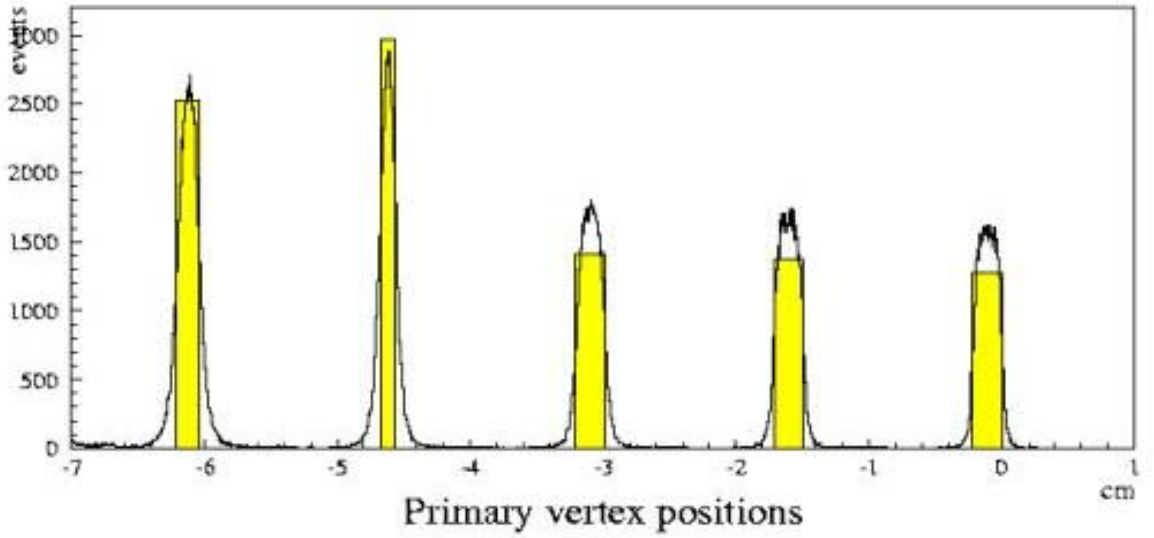
D_s acceptance as a function of x_f



Interaction and decay vertex resolution

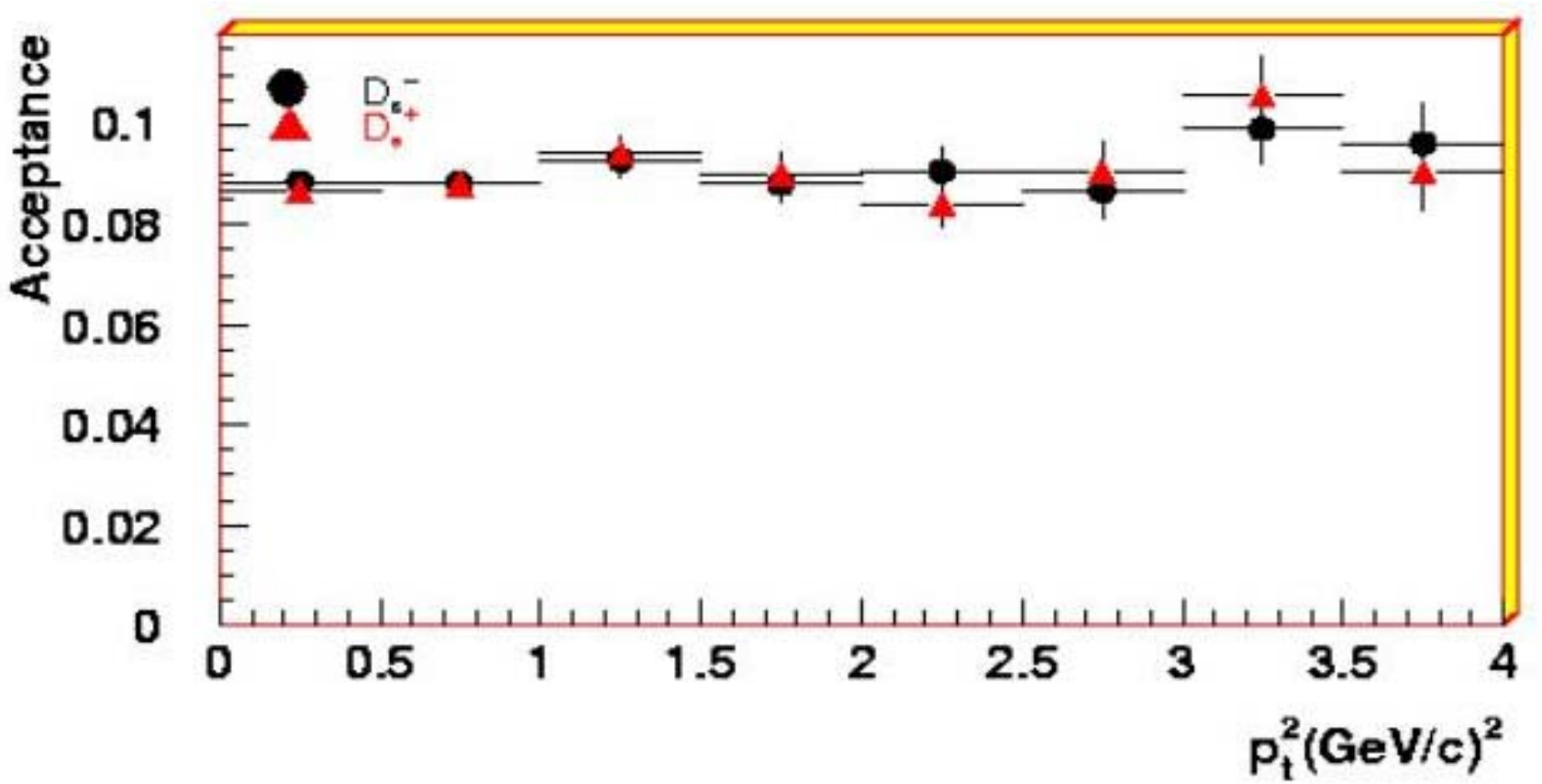


Primary and Secondary Vertex Resolution

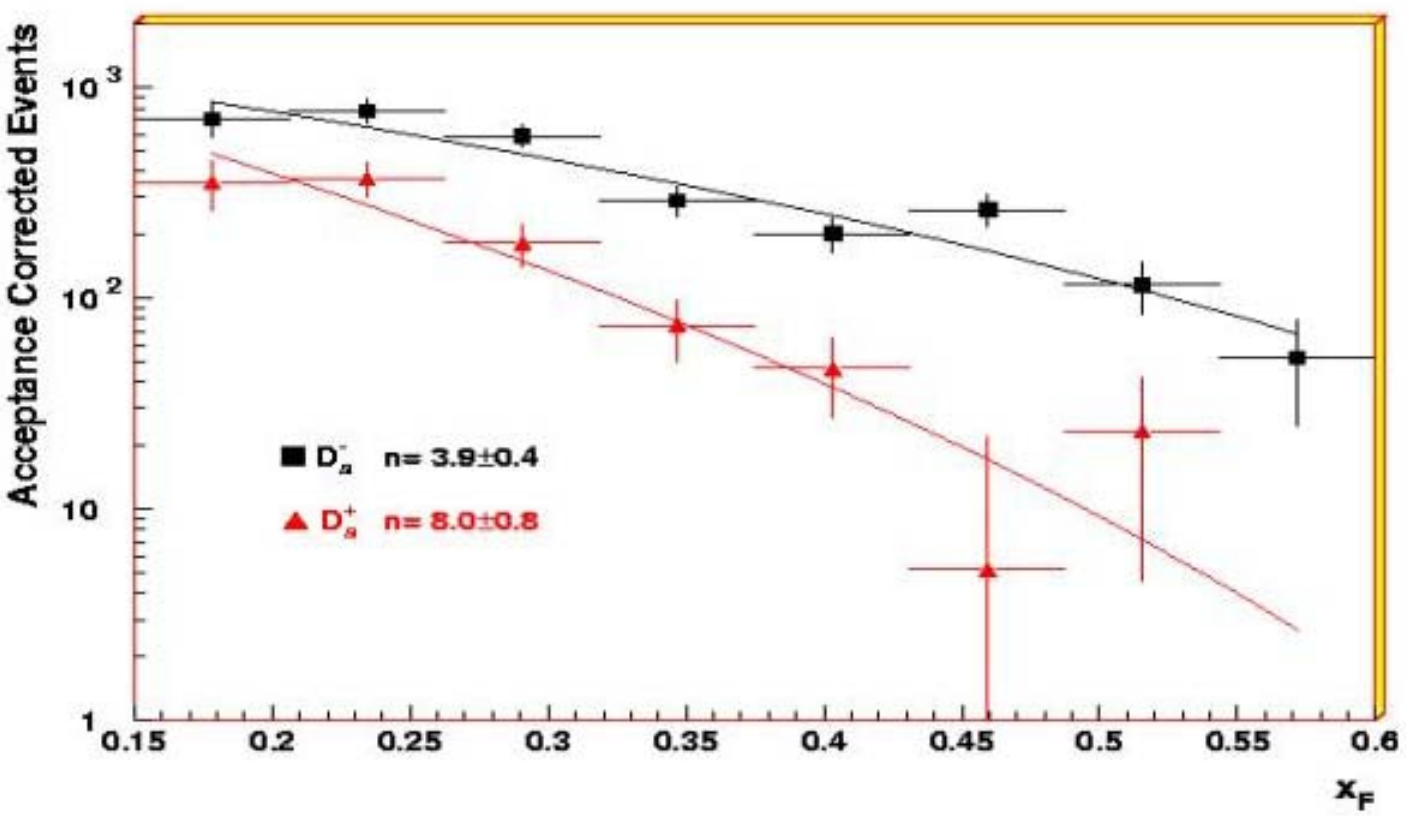


Primary vertex positions

D_s acceptance as a function of p_t

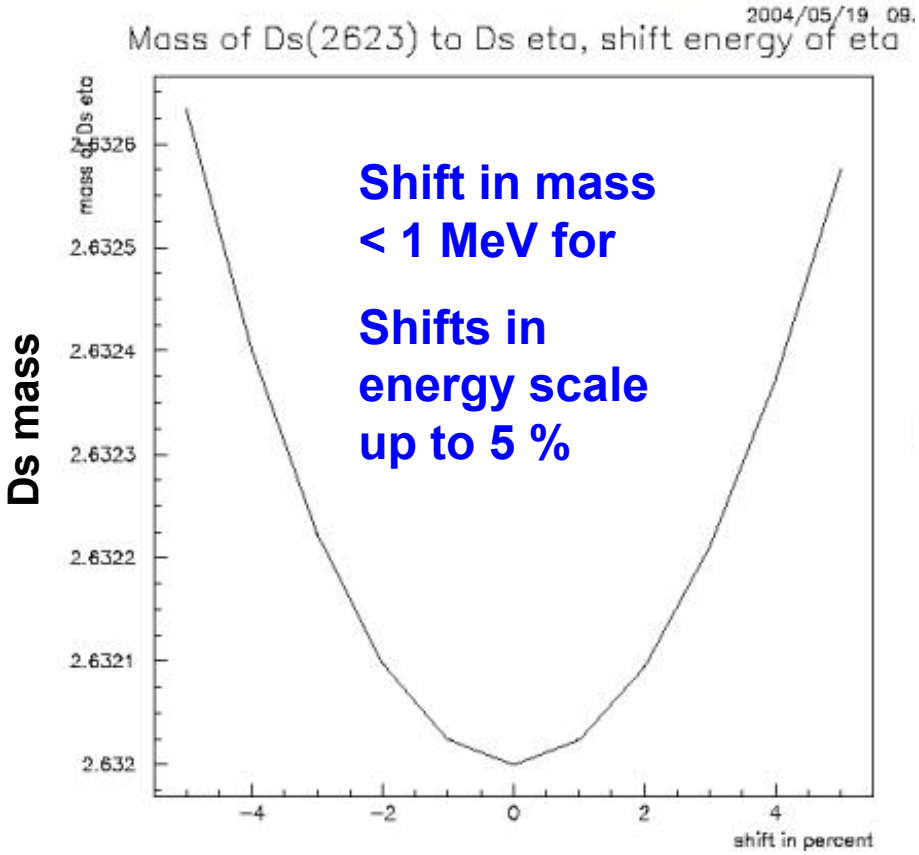


Ds x_f distribution in Sigma beam



Stability of calibration

- All $\gamma\gamma$ candidates kinematically constrained to PDG value.
- We studied our stability to calibration
- We proved that we independent for photon energy scale up to 5%



Shift of the energy scale in %