Charmed baryons and HQ spectroscopy results from E831 FOCUS

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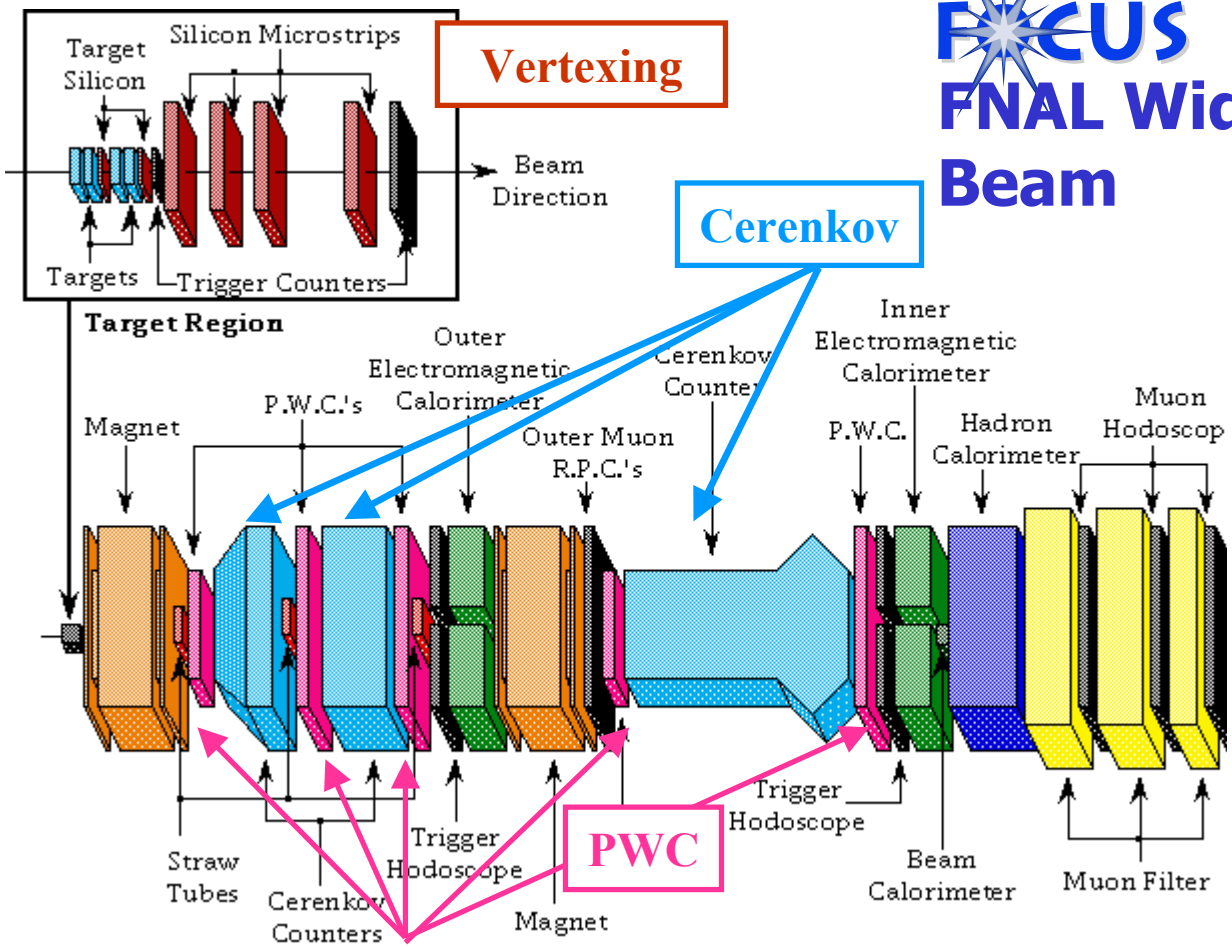
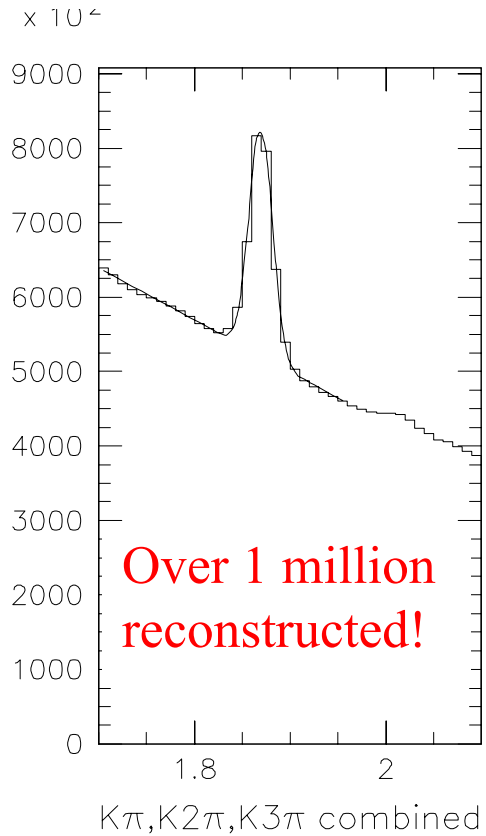
Outline

- Charm Baryon lifetimes
- Measurements of Λ_c^+ decay modes
- Double Charm Baryon search
- Conclusions

XXXI International Conference on High Energy Physics
July 24-31, Amsterdam

FOCUS Spectrometer at FNAL Wide Band Photon Beam





Successor to E687. Designed to study charm particles produced by ~180 GeV photons using a fixed target spectrometer with updated Vertexing, Cerenkov, EM Calorimeters, Hadron Calorimeter and Muon id capabilities.

Member groups from USA, Italy, Brazil, Mexico, Korea.

Charm Baryon Lifetimes

- The hadronic partial width has contributions from mechanisms other than spectator quark decay (W exchange, destr. and constr. PI)
- Not universal semileptonic decay widths for charm baryons

Qualitatively (neglecting mass difference and CS decays):

$$\Gamma(\Lambda_c^+) = \Gamma_{spec} + \Gamma_{exc} + \Gamma^-$$
$$\Gamma(\Xi_c^+) = \Gamma_{spec} + \Gamma^+ + \Gamma^-$$
$$\Gamma(\Xi_c^0) = \Gamma_{spec} + \Gamma_{exc} + \Gamma^+$$
$$\Gamma(\Omega_c^0) = \Gamma_{spec} + (10/3)\,\Gamma^+$$

Expected hierarchy:

$$\Gamma(\Xi_c^+) < \Gamma(\Lambda_c^+) < \Gamma(\Xi_c^0) \lessapprox \Gamma(\Omega_c^0)$$

Lifetimes study provides:

- Probe into the non-perturbative sector of heavy quark decay
- Test of various quark models and Heavy Quark Expansion methods
- Exp BR→ calculated decay rates

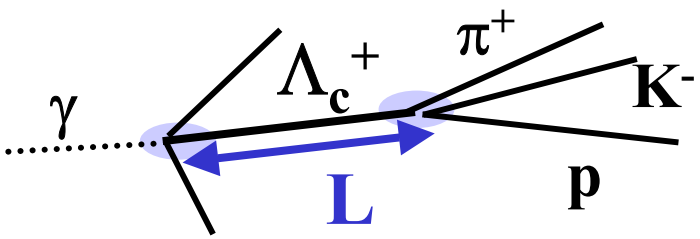
Needed τ of Ξ_c^+ ,Ξ_c^0 ,Ω_c^0 to 10% to quantify contributions

Improvement on the lifetimes understanding can be provide by:

- measurement of the semileptonic BR of charm baryons to probe HQE
- study of the exclusive modes of Λ_c^+ (in particular CS decays)

Lifetime measurement technique

•Vertex algorithm is driven by charm candidates (cut on $L > N\,\sigma_L$)



•The fit variable is the **reduced proper time $t' = (L - N\,\sigma_L)/\beta\gamma c$,** where N is the detachment cut → minimize acceptance corrections

•Proper time resolution: (σ ~40fs)
– No resolution convolution systematics/error inflation
–Systematic test of the method validity for short lived decays

Binned likelihood method

The expected number of events in each t' bin is:

$$\mu_i = (N_s - B)\frac{f(t'_i)\,\exp(-t'_i/\tau)}{\Sigma_i f(t'_i)\, e^{-t'_i/\tau}} + B\frac{b_i}{\Sigma_i b_i}$$

➢**Acceptance/efficiency/absorption f(t') correction by MC**

➢**b_i: background from the i^{th} t' bin of sidebands distributions**

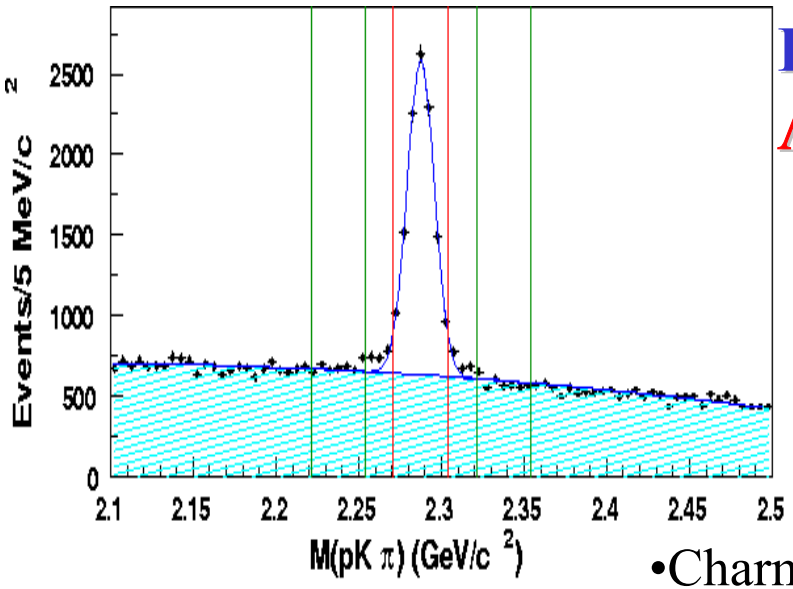
We maximize likelihood function:

$$\mathcal{L} = \left(\prod_i \frac{\mu_i^{-n_i} e^{-\mu_i}}{n_i!}\right) \times \left(\frac{(\alpha B)^{\Sigma_i b_i} e^{-\alpha B}}{(\Sigma_i b_i)!}\right)$$

Fit Parameters are τ , **B**

B-tie term.

Λ_c^+ lifetime measurement



High statistics measurement with a $\Lambda_c^+ \rightarrow pK^- \pi^+$ sample of 8034±122 events

A detailed study of systematics sources has been performed

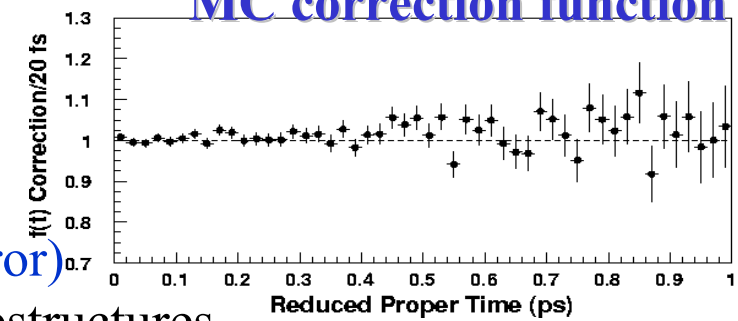
Absolute time scale

Background: Level and lifetime distribution

- Charm reflection backgrounds: no significant contribution
- Variation of sidebands location and size/ no B-tie term

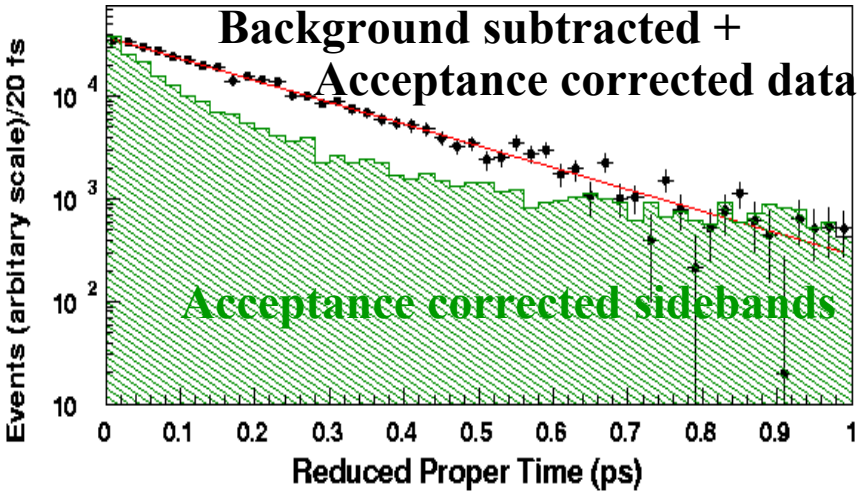
Uncertainty of f(t') correction:

MC correction function



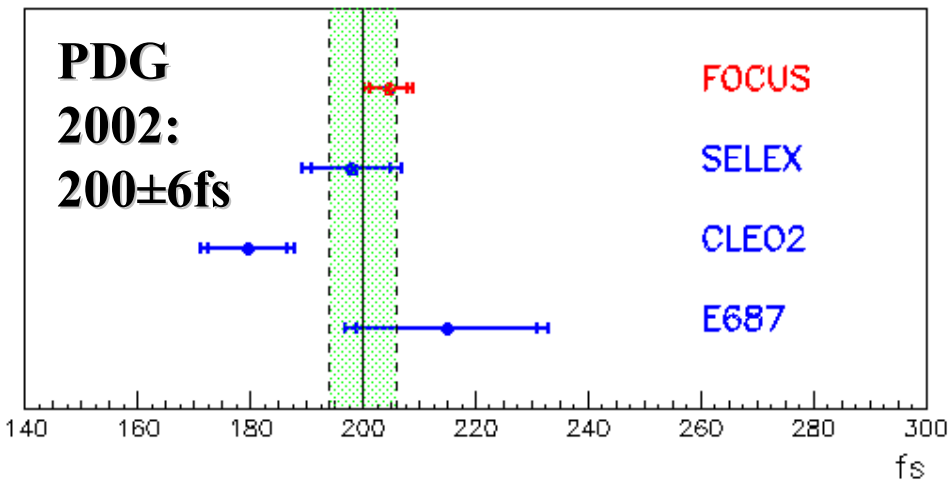
- Check MC simulation: momenta, primary vtx multiplicity, decay lengh, proper time resolutions
- Acceptance/efficiency corrections check using short-lived Ks (excellent agreement →upper limit error)
- Variation of production parameter and resonance substructures
- Proper time resolution comparing data-MC, bin size and fit range variations
- Absorption effects: cross sections variation, in-out target decays, different target

Λ_c^+ lifetime result



Syst. Source	σ_{sys}(%)
Time scale	0.11
Backgrounds	0.77
Acceptance	0.83
Production	0.38
Resolution	0.12
Absorption	0.23
Total	**1.23**

Comparison with other measurements



PRL, 88:161801,2002

$$\tau\left(\Lambda_c^+\right) = 204.6 \pm 3.4(\text{stat}) \pm 2.5(\text{sys})\ \text{fs}$$

Significant improvement on the τ (Λ_c^+) accuracy

Ξ_c^+ lifetime measurement

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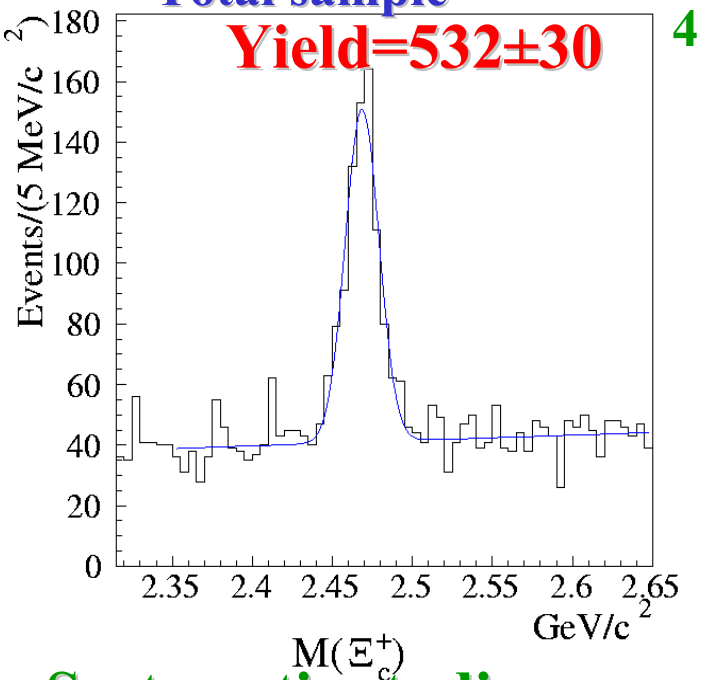
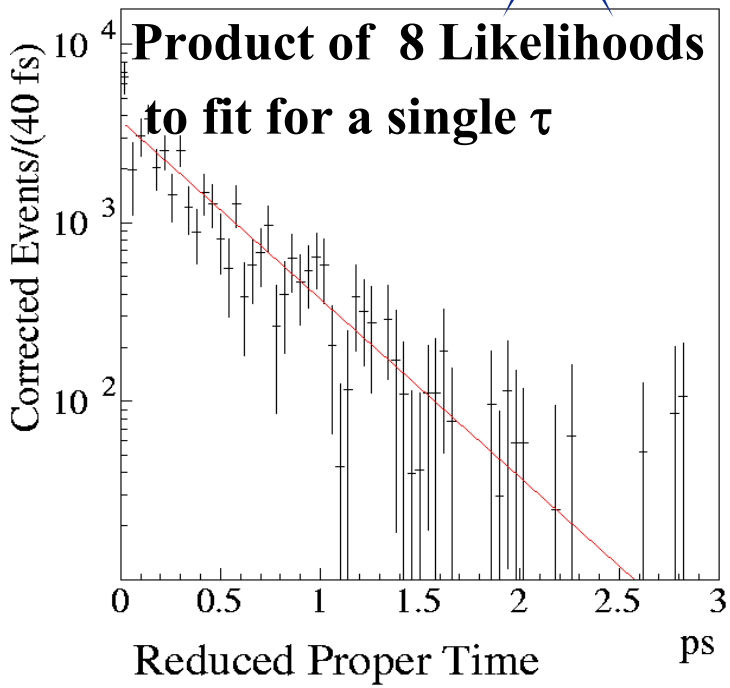
Total sample

Yield=532±30



4 decay modes in 8 different topologies:

1. $\Xi^- \pi^+ \pi^+$ (300 events)
2. $\Sigma^+ K^- \pi^+$ (130 events)
3. $p K^- \pi^+$ (45 events)
4. $\Lambda^0 K^- \pi^+ \pi^+$ (58 events)



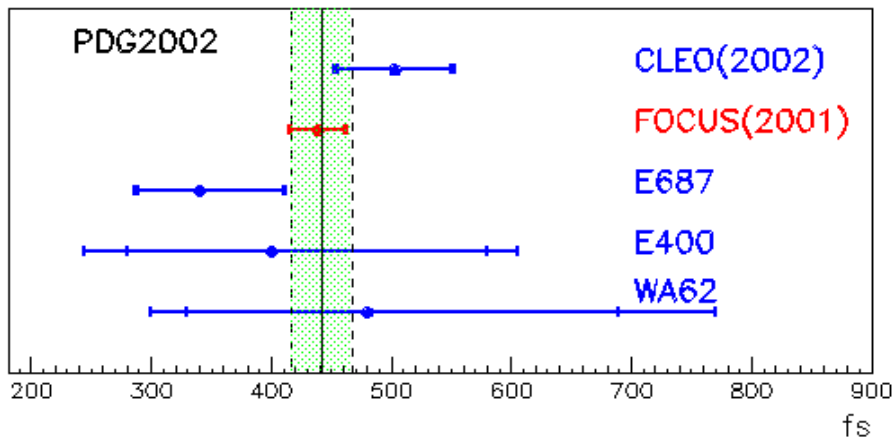
Systematic studies

- No contribution when split topologies/modes
- Main contribution from variation of the fit conditions (8fs)

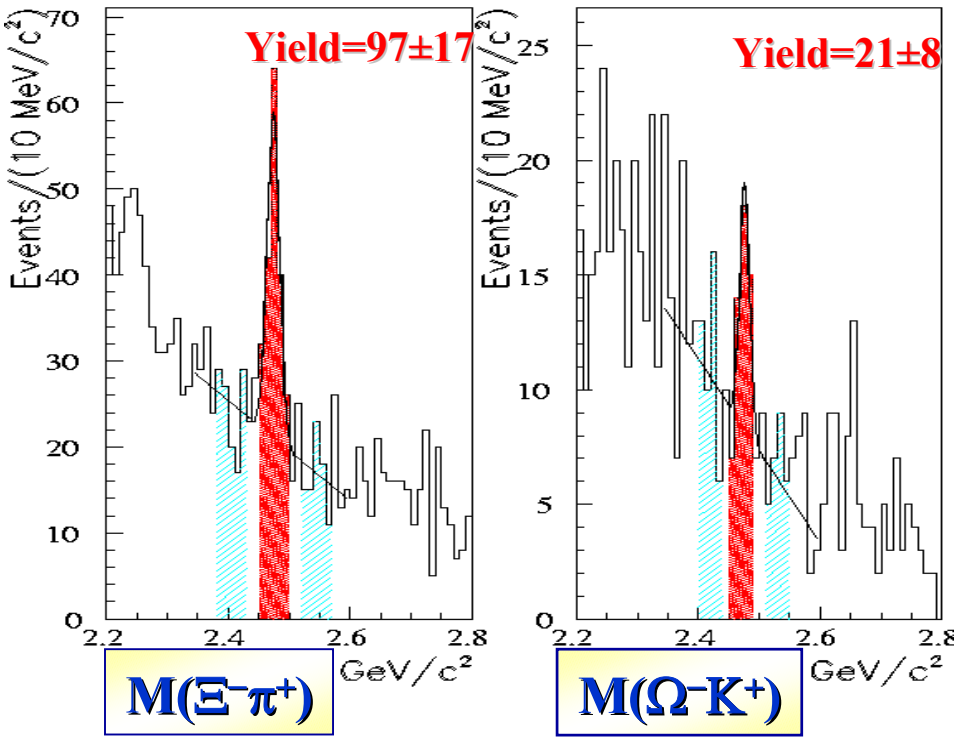
PLB, 523:53-59,2001

$$\tau\left(\Xi_c^+\right) = 439 \pm 22(\text{stat}) \pm 9(\text{sys})\ \text{fs}$$

FOCUS reduces the previous world average error by a factor of 3

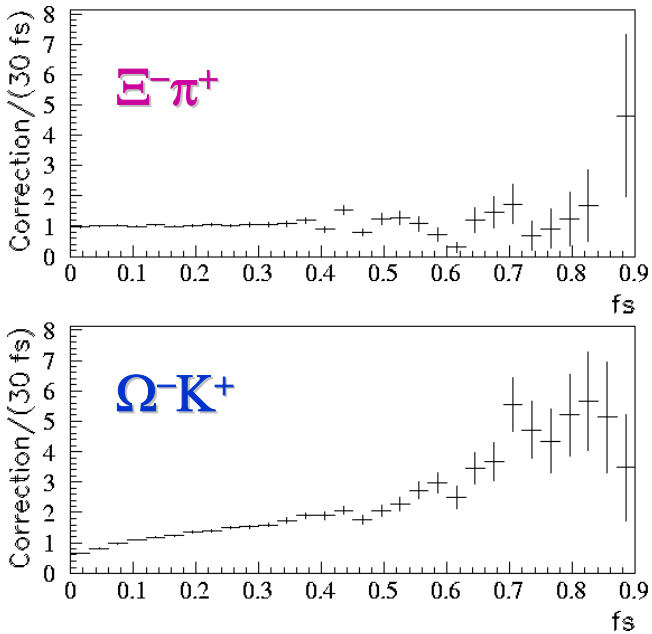


Ξ_c^0 lifetime measurement



Total sample: 110±17 events

MC correction functions

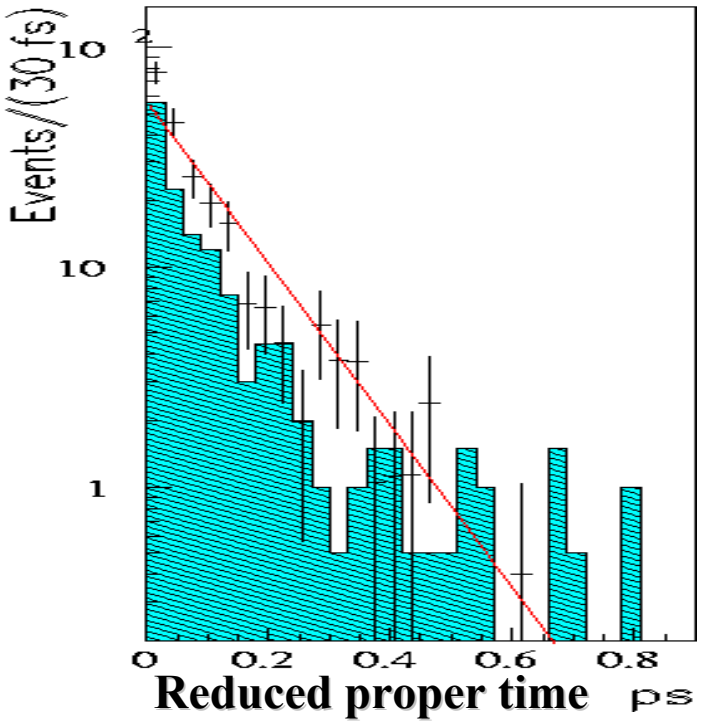


- **Binned Likelihood method**
- $\mathcal{L}(\Xi_c^0) = \mathcal{L}(\Xi^- \pi^+) \times \mathcal{L}(\Omega^- K^+)$
- **Systematic investigation of resolution effect**

($\sigma_t(\Xi^-\pi^+)$ =40 fs, $\sigma_t(\Omega^-K^+)$ =80fs comparable to τ)

  - **Variation of the fit method (*resolution convolution*)**
  - **Mini MC study with a wide range of input lifetimes**

Ξ_c^0 lifetime systematics and result

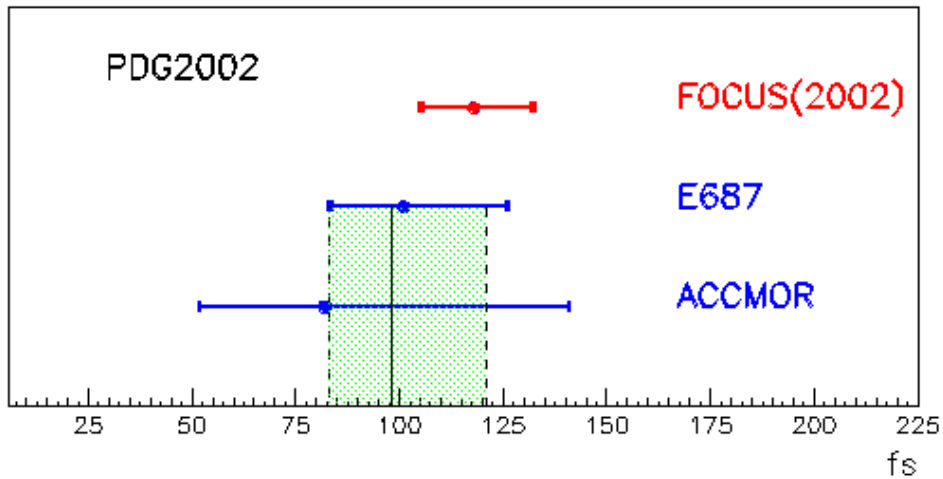


Syst. Source	σ_{sys}(fs)
Production	3
Fit	4
Method (miniMC)	2
Total	**5**

(Ref:hep-ex/0206069)

$$\tau\left(\Xi_c^0\right) = 118^{+14}_{-12}\left(\text{stat}\right) \pm 5(\text{sys})\ \text{fs}$$

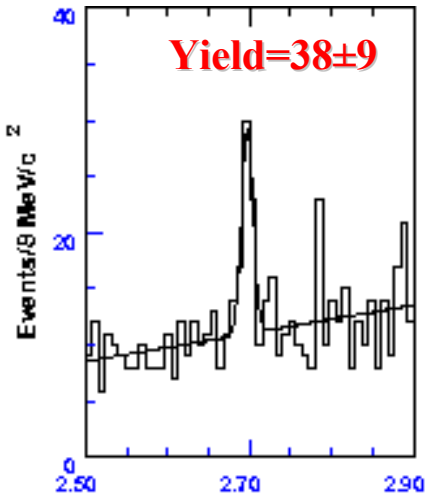
Comparison with other measurements



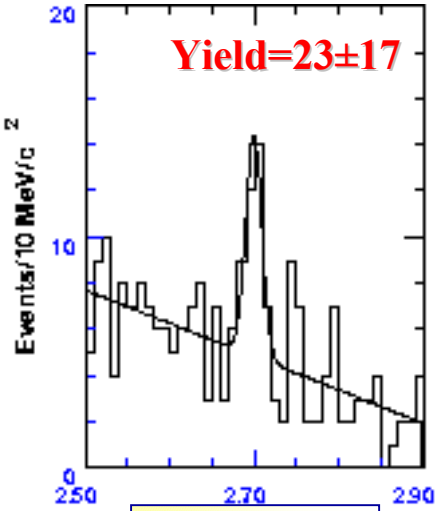
FOCUS reduces the percentage error on the $\tau(\Xi_c^0)$ from 20% to 10%

preliminary

Ω_c^0 samples



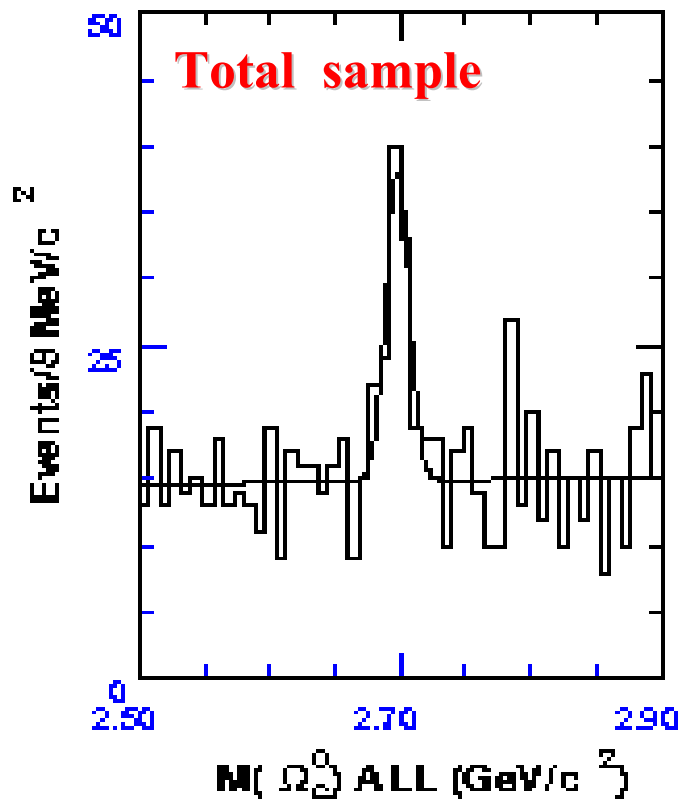
$M(\Xi^- K^- \pi^+ \pi^+)$



$M(\Omega^- \pi^+)$

Year	Expt.	Mass (MeV/c^2)	Mode(s)	Events
1985	WA62	2740.0 ± 20	$\Xi^- K^- \pi^+ \pi^+$	3
1992	ARGUS	$2719.0 \pm 7.0 \pm 2.5$	$\Omega^- \pi^- \pi^+ \pi^+$	11
1993	E687	$2705.9 \pm 3.3 \pm 2.0$	$\Omega^- \pi^+$	10
1994	E687	$2699.9 \pm 1.5 \pm 2.5$	$\Sigma^+ K^- K^- \pi^+$	42
2000	CLEO	$2694.6 \pm 2.6 \pm 1.9$	4 modes	40
2001	Belle	2697.3 ± 1.5	$\Omega^- \pi^+$	24

PDG 2002 $= 2697.5 \pm 2.6$ MeV/c^2



Yield=64±14

Mass=2697.5 ± 2.2 MeV/c^2

preliminary

Ω_c^0 lifetime measurement

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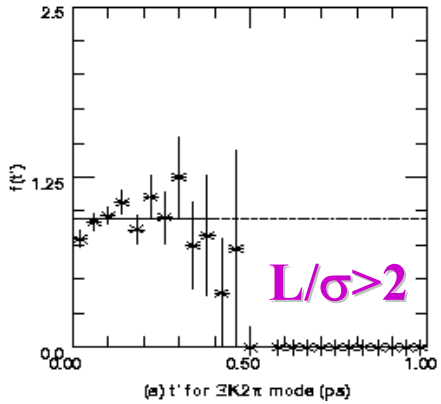
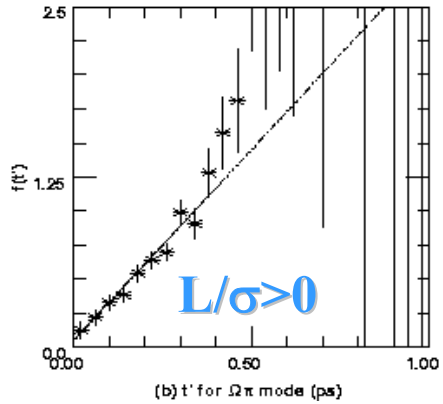
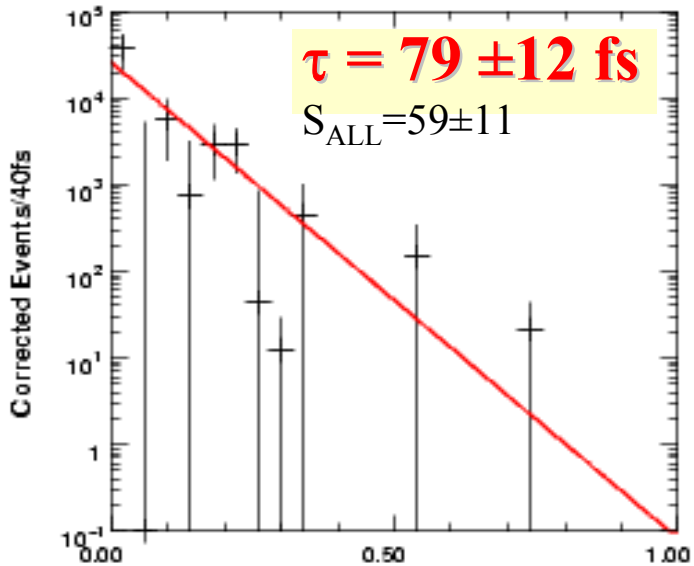
MC correction functions

$\mathcal{L}(\Omega_c^0) = \mathcal{L}(\Xi^- K^- \pi^+ \pi^+) \times \mathcal{L}(\Omega^- \pi^+)$

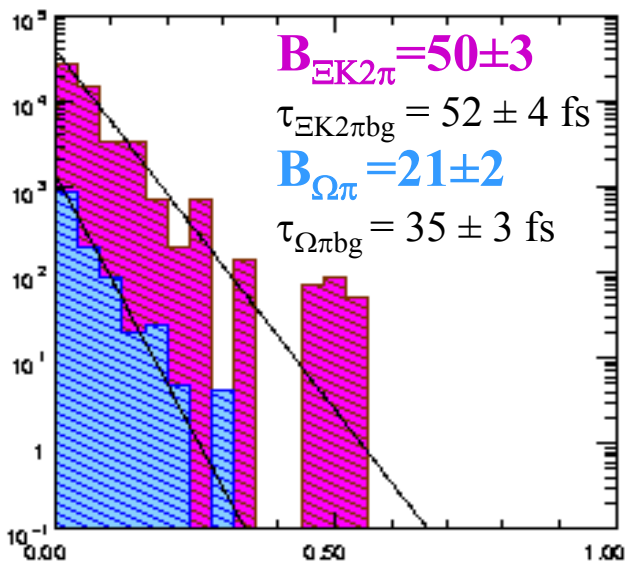
- Large corrections because of loose detachement cut
- 3 fit parameters: τ , $B_{\Xi K2\pi}$, $B_{\Omega\pi}$







t' for signal (ps)



t' for background (ps)

preliminary

Ω_c^0 lifetime systematics and result

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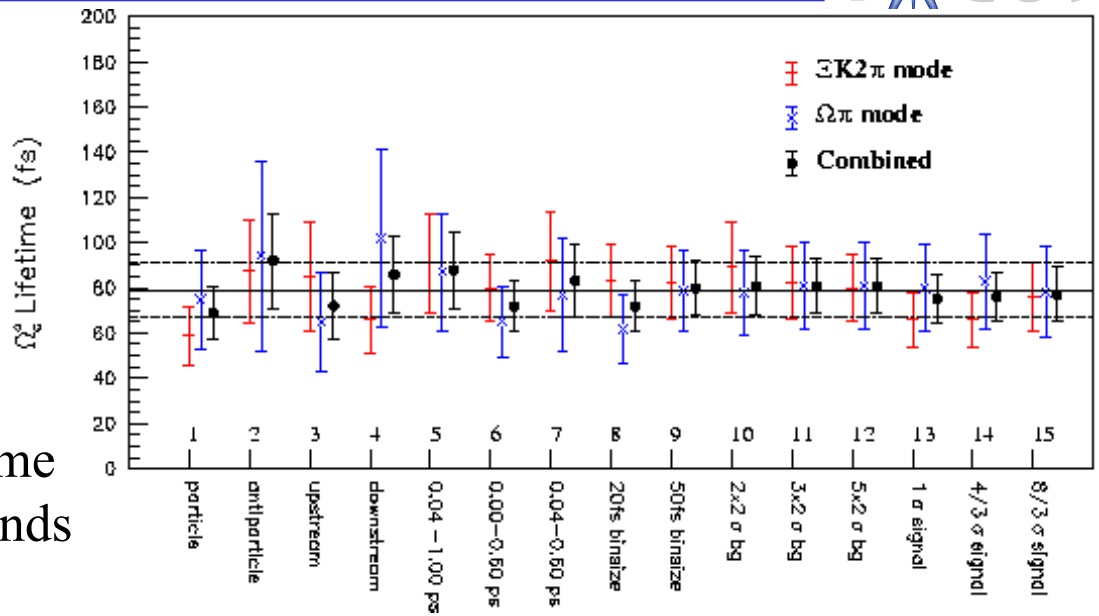
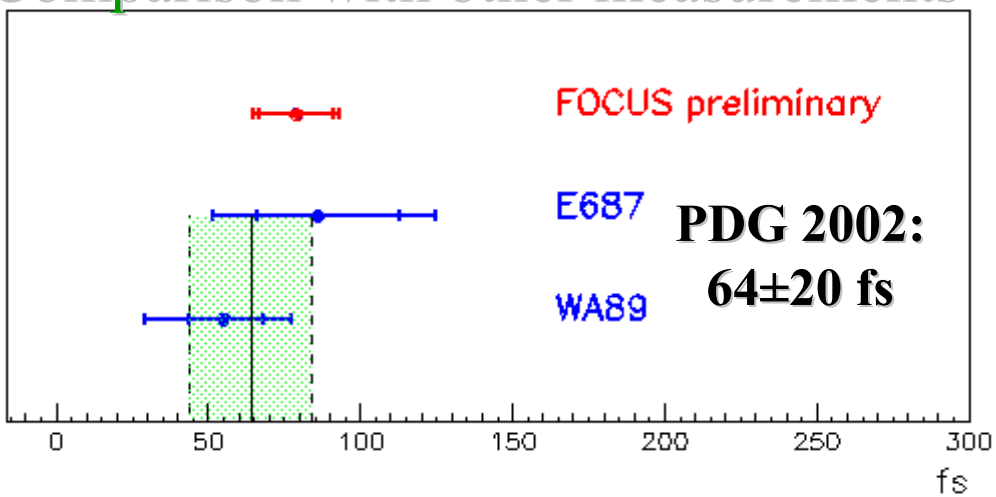
Systematic studies:

- No remarkable effects of production/absorption
- proper time resolution (bin size-fit range dependency)
- as for Ξ_c^0 , study effects due to resolution comparable to the lifetime
- Background studies: signal /sidebands region (location and widths)



Comparison with other measurements

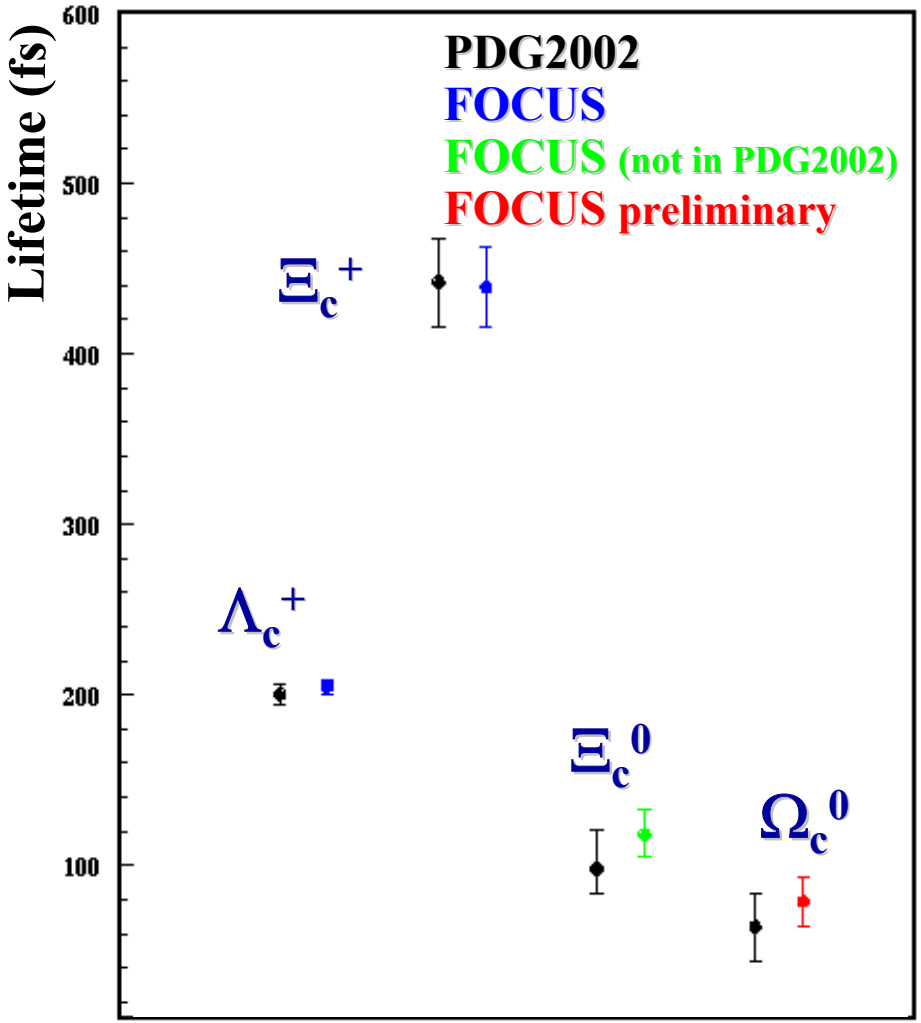


Preliminary FOCUS measurement:

$$\tau\left(\Omega_c^0\right) = 79 \pm 12(\text{stat}) \pm 9(\text{sys})\ \text{fs}$$

Accuracy improved by a factor of 2

Results for Charm Baryons Lifetimes



FOCUS significantly improved the accurancy of all charm baryons lifetimes.

From the FOCUS results:

$$\frac{\tau\left(\Xi_c^+\right)}{\tau\left(\Lambda_c^+\right)} = 2.15 \pm 0.13$$

(PDG 2002: 2.21 ± 0.15)

Theory predictions: 1.2-1.7

$$\frac{\tau\left(\Xi_c^0\right)}{\tau\left(\Omega_c^0\right)} = 1.5 \pm 0.3$$

Theory predictions: >~ 1

BR measurement of Λ_c^+ decays into states containing Σ

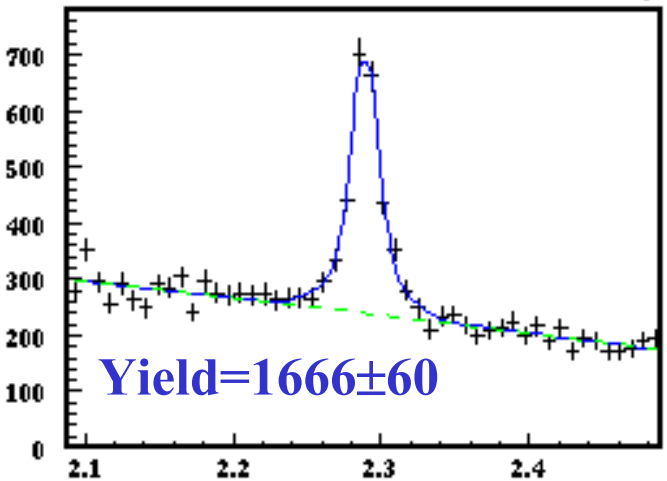
- Th: Complicated dynamics for charm baryon decays
  - investigation of the W-exchange contribution
  - inputs for Ξ_c^+ lifetime from CS modes
- Exp: low accuracy for many BR

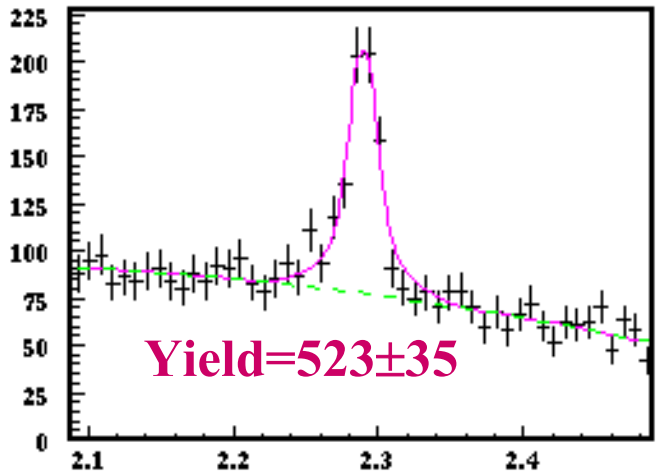
E831 FOCUS

- FOCUS reconstructs Σ candidates throught the modes:
- Our largest samples: $\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-$ and $\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+$

$\Sigma^+ \to p\pi^0 / n\pi^+$

$\Sigma^- \to n\pi^-$





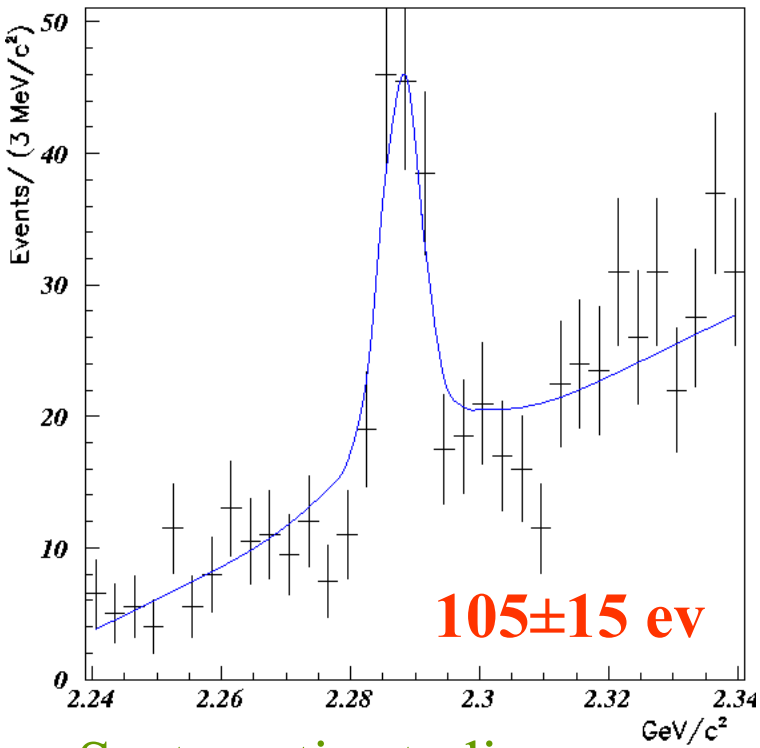
Unique previous measurement by E687:

$0.53 \pm 0.15 \pm 0.07$

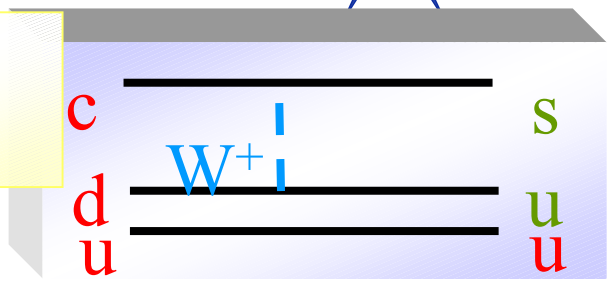
FOCUS preliminary: (stat error only)

$$\frac{\Gamma\left(\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+\right)}{\Gamma\left(\Lambda_c^+ \to \Sigma^+ \pi^- \pi^+\right)} = 0.422 \pm 0.033$$

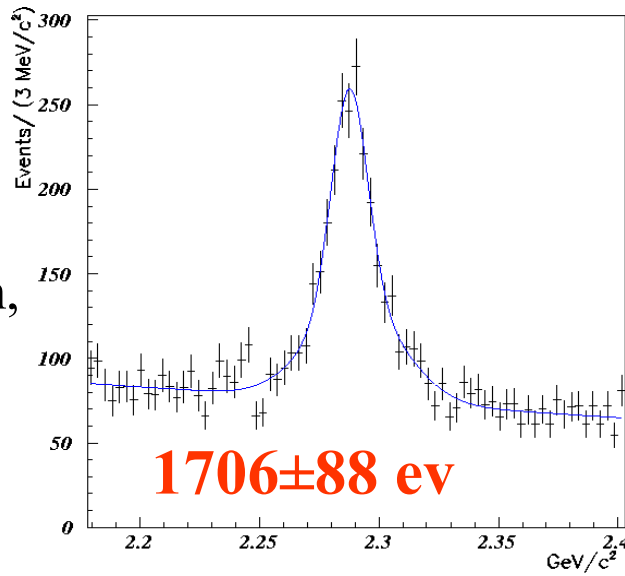
Study of the $\Lambda_c^+ \to \Sigma^+ K^+ K^-$ decay



W -exchange decay



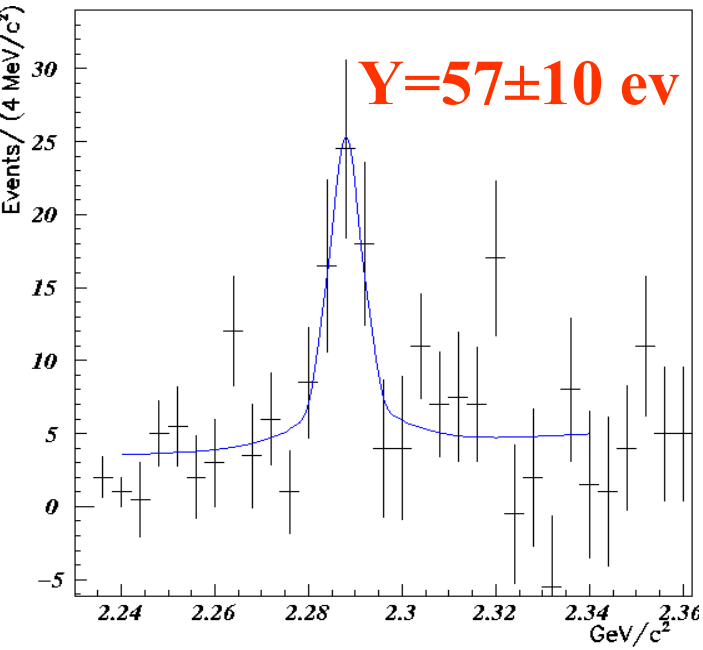
Systematic effects reduced by using the $\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-$ decay as normalization mode, with similar selections



Systematic studies:

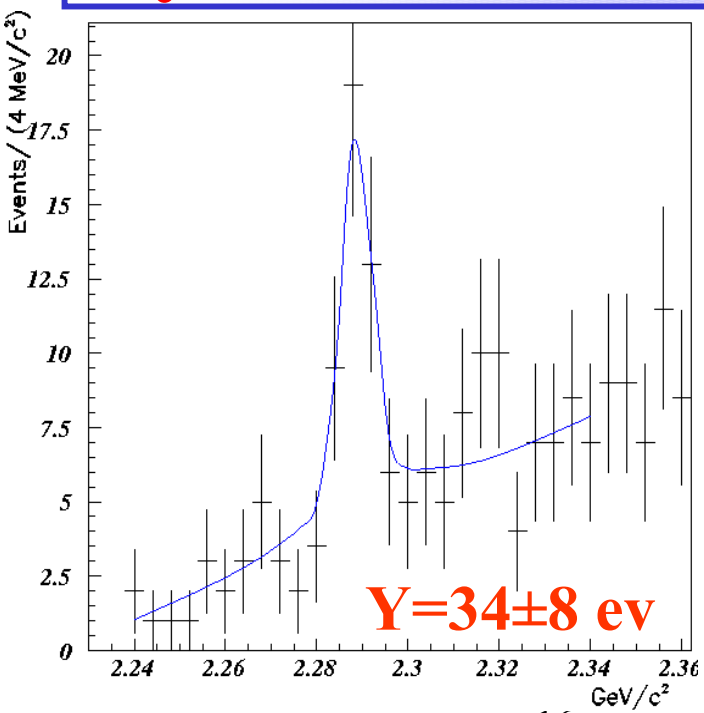
- Comparison of independent sub-samples: momentum, particle/antiparticle, run conditions, Σ modes
- Fit procedure varying: bin size, fitting range, signal shape (check two-fold ambiguity effect)

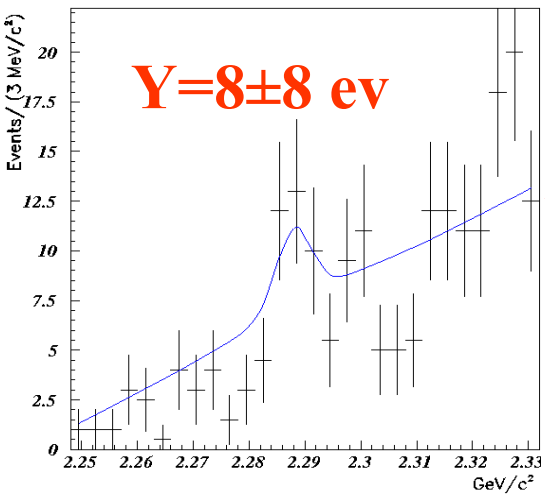
$\Lambda_c^+ \to \Sigma^+ \Phi$



- ✓Same selection as $\Sigma^+ K^+ K^-$, but lower L/σ
- ✓Cut on ϕ / Ξ^* signal regions
- ✓Suppression of non-resonant / other resonances contributions with SB subtraction/ resonances mass cut → detailed systematics investigation

$\Lambda_c^+ \to \Xi^{*0}(1690)K^+$





Non-resonant $\Sigma^+ K^+ K^-$ contribution

Results for $\Lambda_c^+ \to \Sigma^+ K^+ K^-$ decay

Almost all $\Sigma^+ K^+ K^-$ throught resonant modes

Upper limit @90%CL for the **non resonant** $\Lambda_c^+ \to \Sigma^+ K^+ K^-$ decay

(Ref:hep-ex/0206013) **comparison with other measurements**

	FOCUS	BELLE	CLEO
$\frac{\Gamma(\Lambda_c^+ \to \Sigma^+ K^+ K^-)}{\Gamma(\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-)}$	(7.1±1.1 ±1.1) %	(7.6±0.7 ±0.9) %	(9.5±1.7 ±1.9) %
$\frac{\Gamma(\Lambda_c^+ \to \Sigma^+ \phi)}{\Gamma(\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-)}$	(8.7±1.6 ±0.6) %	(8.5±1.2 ±1.2) %	(9.3±3.2 ±2.4) %
$\frac{\Gamma(\Lambda_c^+ \to \Xi^*(\Sigma^+ K^-) K^+)}{\Gamma(\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-)}$	(2.2±0.6 ±0.6) %	(2.3±0.5 ±0.5) %	-
$\frac{\Gamma(\Lambda_c^+ \to \Sigma^+ K^+ K^-)_{NR}}{\Gamma(\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-)}$	<2.8 % @ 90%CL	<1.8 % @ 90%CL	-

Λ_c^+ Cabibbo suppressed decays

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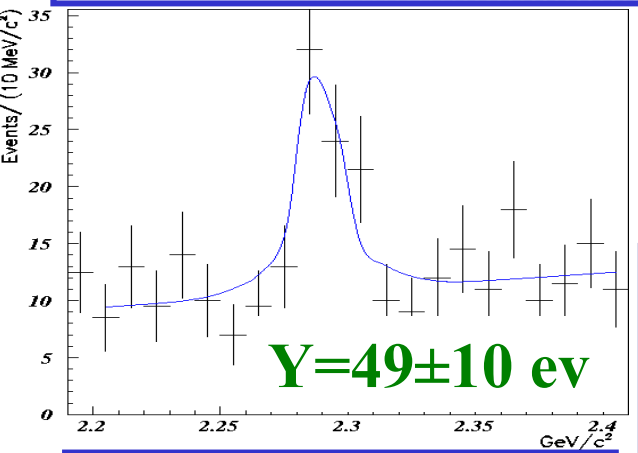
$\Lambda_c^+ \to \Sigma^+ K^{*0}(892)$

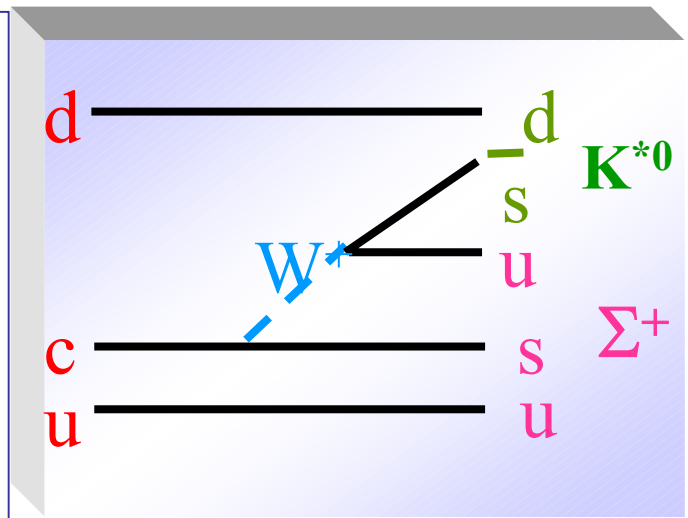


First measurement

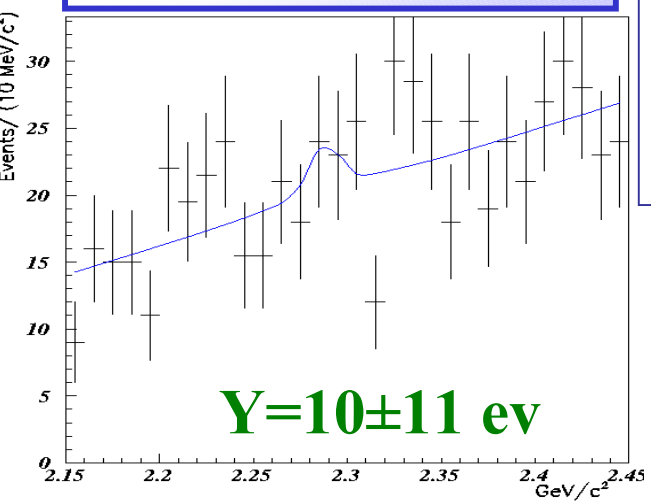
$$\frac{\Gamma(\Lambda_c^+ \to \Sigma^+ K^{*0})}{\Gamma(\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-)} = (7.8 \pm 1.8 \pm 1.3)\%$$

(Ref:hep-ex/0206013)

- ✓Most,if not all, of the $\Sigma^+K^+\pi^-$ via Σ^+K^{*0}
- ✓For the non-resonant 3-body decays quark pairs need to be created



$\Lambda_c^+ \to \Sigma^- K^+ \pi^+$



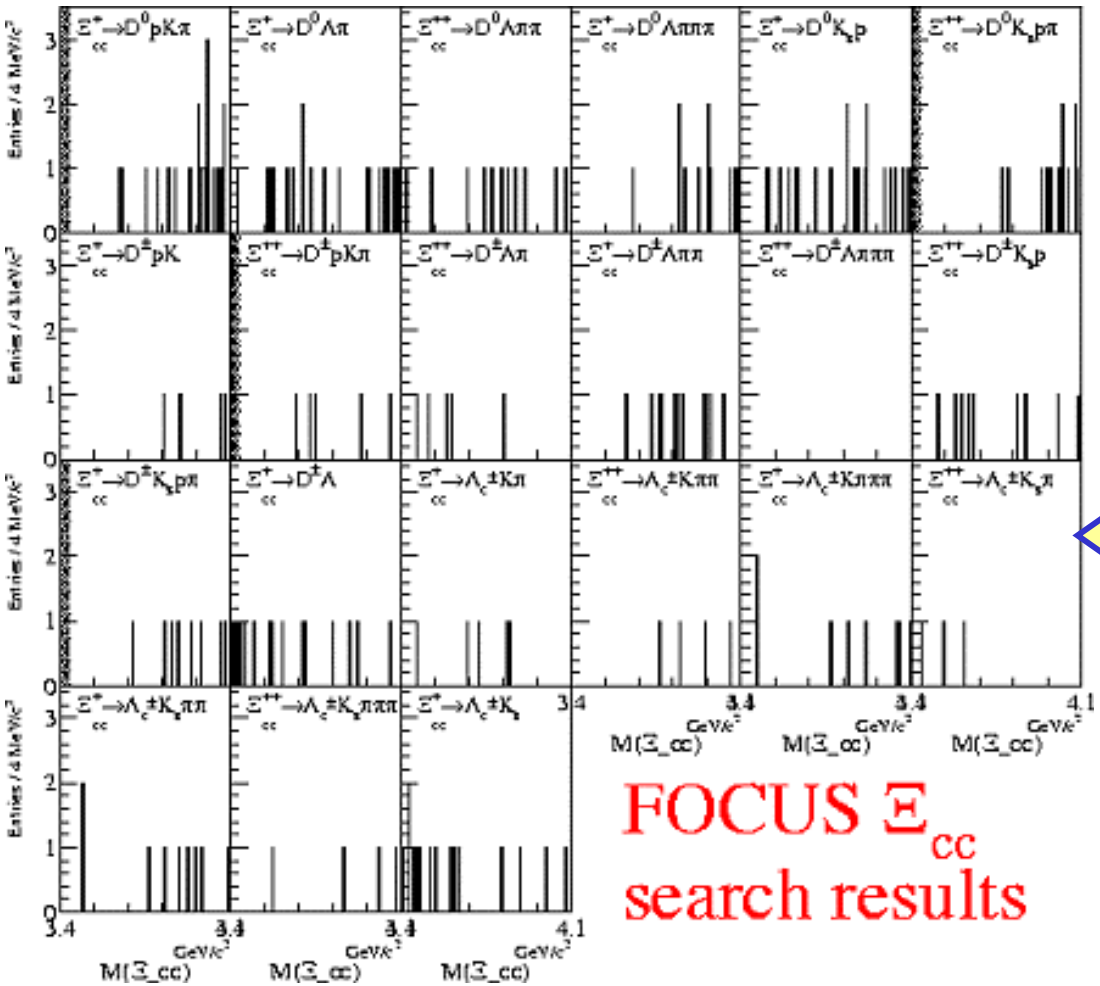
$$\frac{\Gamma(\Lambda_c^+ \to \Sigma^- K^+ \pi^+)}{\Gamma(\Lambda_c^+ \to \Sigma^+ K^{*0})} < 35\% \ @ \ 90\% \ CL$$

Double charm baryon search: Ξ^{+}_{cc} & Ξ^{++}_{cc}

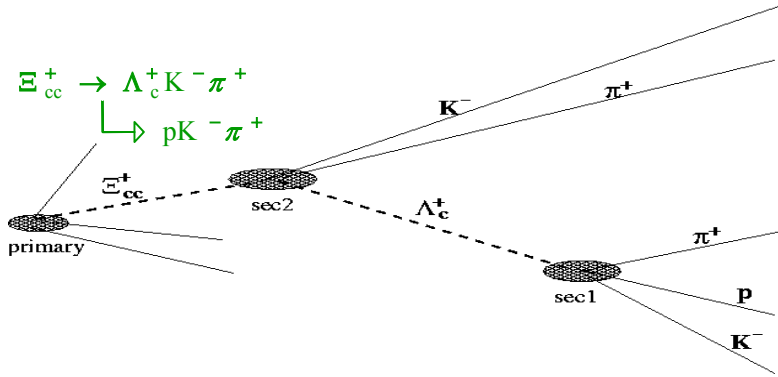
E831 FOCUS

An extensive search was conducted in 2000 using:

~20,000 $\Lambda^{+}_{c} \rightarrow pK\pi$ + ~1.2 million $D^{+,0}$ ($K\pi$, $K2\pi$, $K3\pi$)



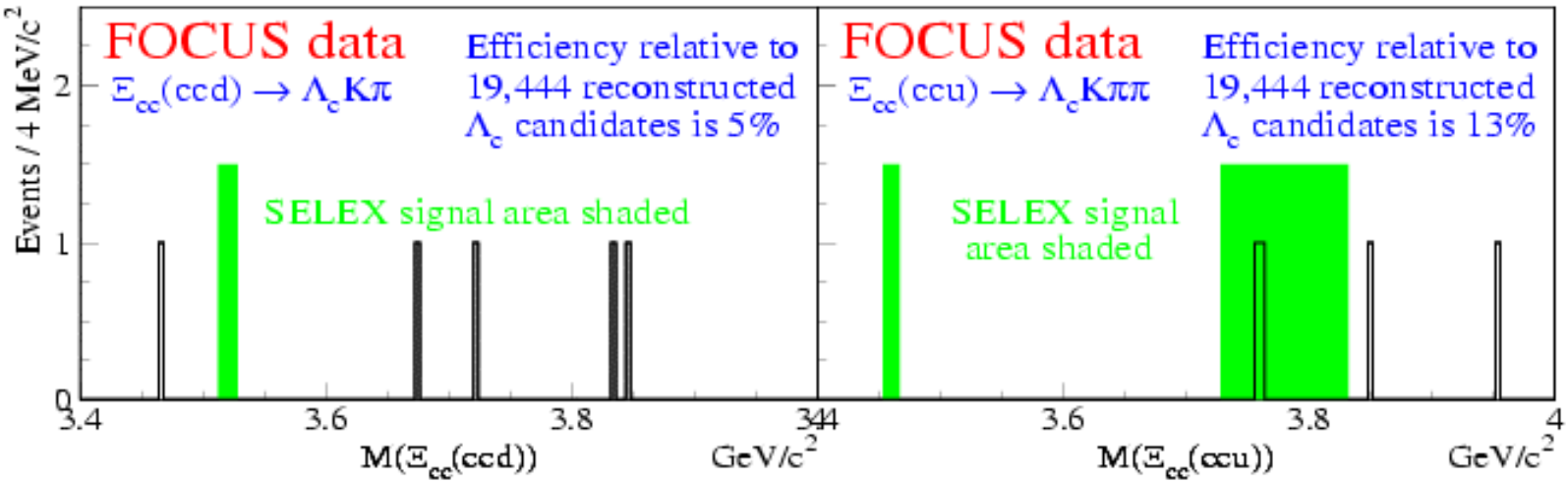
FOCUS Ξ_{cc} search results



14 $\Xi_{cc}(D^{0,\pm}X)$ and 7 $\Xi_{cc}(\Lambda^{+}_{c}X)$ decay modes searched

No evidence of Ξ_{cc}

FOCUS *data for* SELEX *decay modes*



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
Efficiency Relative to Λ_c	5%	10%	13%	5%
Ξ_{cc}/Λ_c^+	<0.23% @ 90%	9.6%	<0.09% @ 90%	9.7%
$\frac{\text{SELEX}}{\text{FOCUS}}$ Relative $\frac{\Xi_{cc}}{\Lambda_c}$ Prod	> 42 @ 90%		> 111 @ 90%	

FOCUS efficiencies assume Ξ_{cc}^+ (Ξ_{cc}^{++}) lifetime of 0.2 ps (1.0 ps), a mass of $3.6\,\text{GeV}/c^2$, and production characteristics of a $3.6\,\text{GeV}/c^2$ Ξ_c particle in PYTHIA

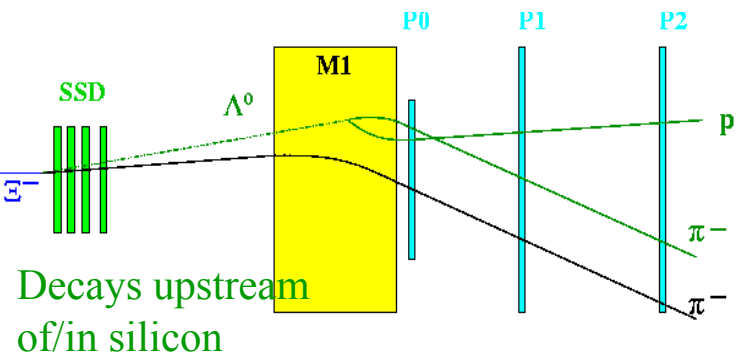
Conclusions

All charm baryon lifetimes measured with improved accuracy.
Published measurements for $\Lambda^+_c, \Xi^+_c, \Xi^0_c$
Preliminary results for Ω^0_c should be published by year end.

BR's. of Λ^+_c decays containing Σ's has been presented.
First measurement of the CS decay mode $\Sigma^+ K^*(892)$ and upper limit for the $\Sigma^- K^+ \pi^+$ mode.

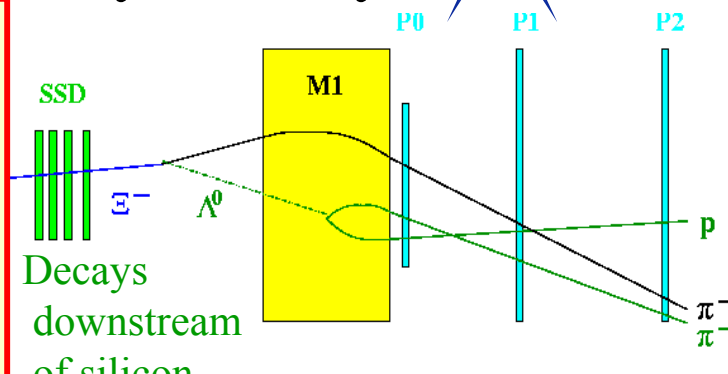
With ~20,000 Λ^+_c + ~1.2 million $D^{+,0}$, we found no evidence for production of Ξ^+_{cc} and Ξ^{++}_{cc} double charm baryons seen by SELEX

FOCUS developed several techniques to reconstruct hyperons for an extensive search of charm baryon decays.

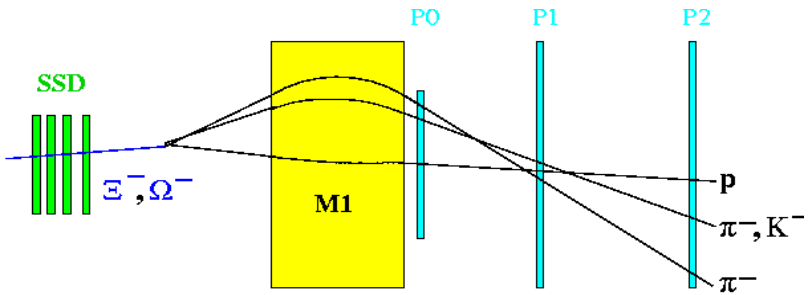


Decays upstream of/in silicon

$\Xi^- \to \Lambda^0\pi^-$
$\Omega^- \to \Lambda^0 K^-$
with $\Lambda^0 \to p\pi^-$
reconstructed over large regions of the spectrometer



Decays downstream of silicon



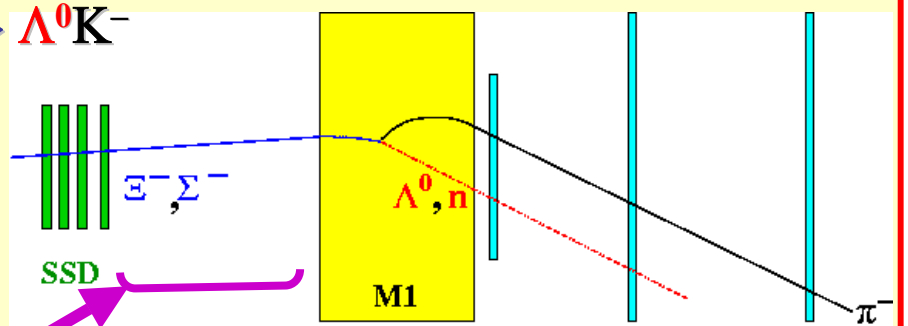
Three tracks vertex downstream of silicon to recover decays with Λ^0 decay vertex close to the Ξ^- or Ω^- one.

Reconstruction of $\Sigma^- \to n\pi^-$, $\Sigma^+ \to n\pi^+$, $\Sigma^+ \to p\pi^0$

Recover of the decays $\Xi^- \to \Lambda^0\pi^-$ or $\Omega^- \to \Lambda^0 K^-$ when Λ^0 unreconstructed.

- Link **SSD track** and **MPWC track**.
- The **neutral** particle is undetected.

(for Σ confirm n in HadCal)



- If decay vertex upstream of magnet, twofold ambiguity for the parent's momentum.