Production rates of hyperons and charmed baryons in e^+e^- collision at Belle

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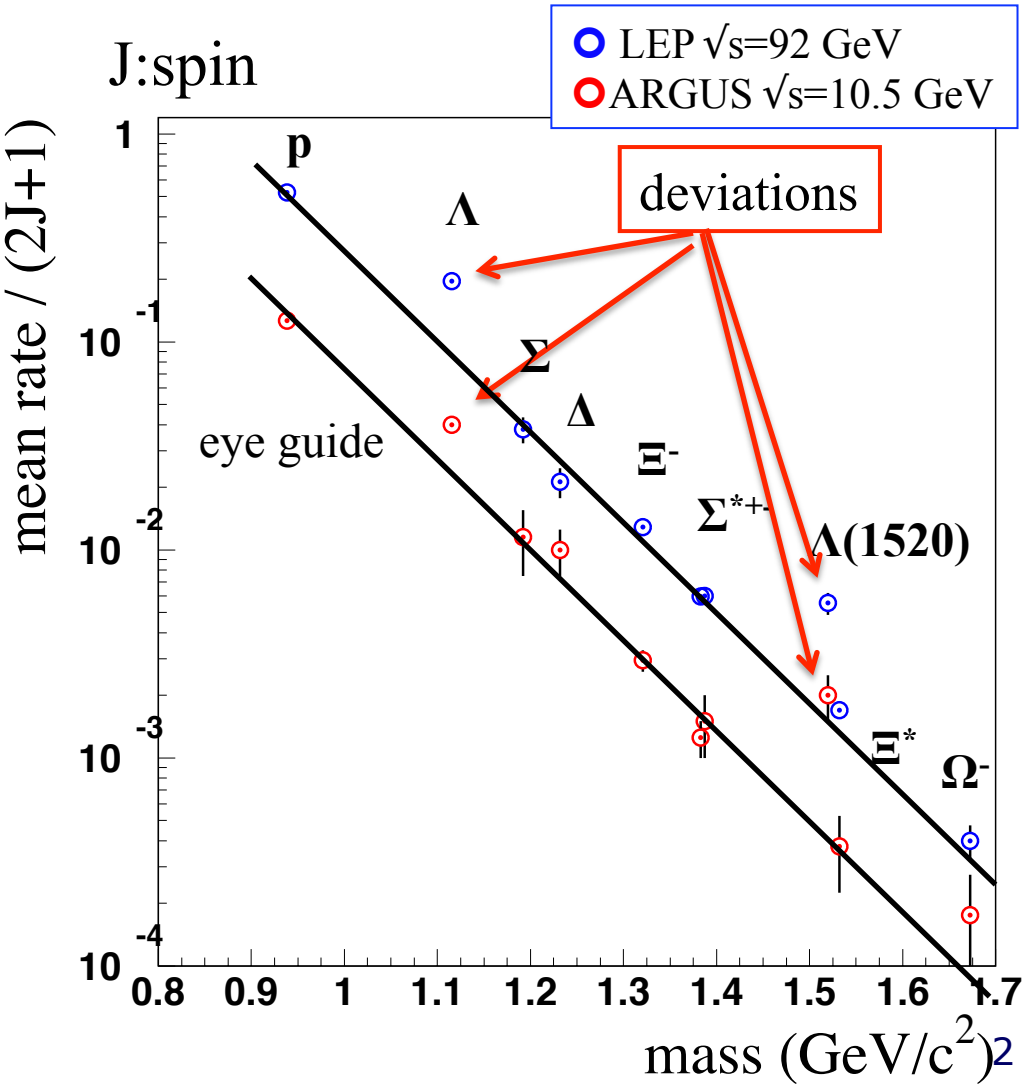
Baryon production rates in e^+e^- collision

- $e^+e^- \rightarrow \gamma^* \rightarrow q\bar{q} \rightarrow$ Jets
- $\frac{\sigma}{\sigma_{had}(2J+1)} \propto \exp(-\alpha m_{had})$
  - Relativistic-string model
    S.B. Chun & C.D. Buchanan
    PLB 308(1993)153
  - Thermodynamical model
    F. Becattini Z.Phys. C69 (1996) 485
- Higher rates for Λ and Λ(1520) in ARGUS and LEP.
  - Feed down is subtructed?
  - Large error in ARGUS results.
- J=0, light (ud) diquark in Λ?
  - R.L. Jaffe, Phys.Rept.409,1 (2005)

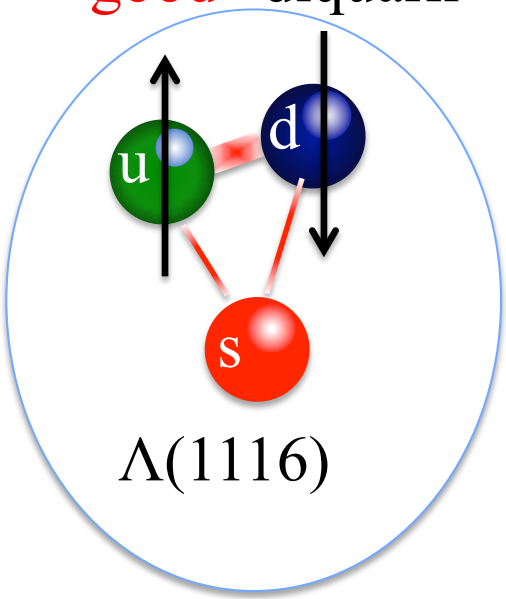


Diquark structure in hadrons

- Color magnetic interaction
  - Strong attraction in spin 0 flavor 0 channel
    - "Good" diquark
  - Structure of Λ, Σ hyperons

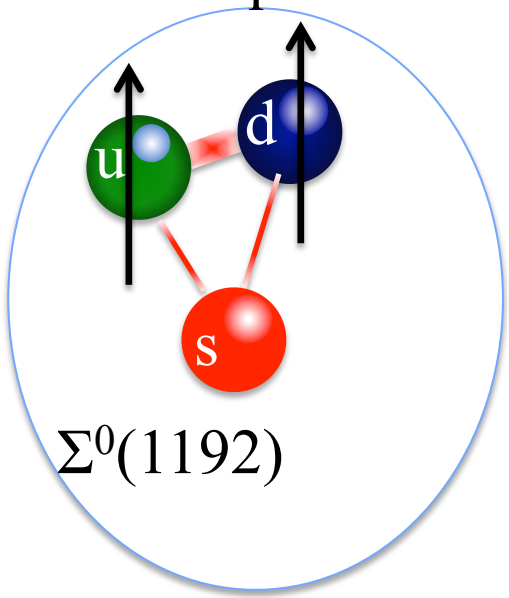
$$\frac{\alpha}{m_i m_j}\frac{\lambda^a(i)}{2}\frac{\lambda^a(j)}{2}\vec{\sigma}(i)\cdot\vec{\sigma}(j)$$

S=0 [ud]
"good" diquark



Λ(1116)

S=1 [ud]
"bad" diquark

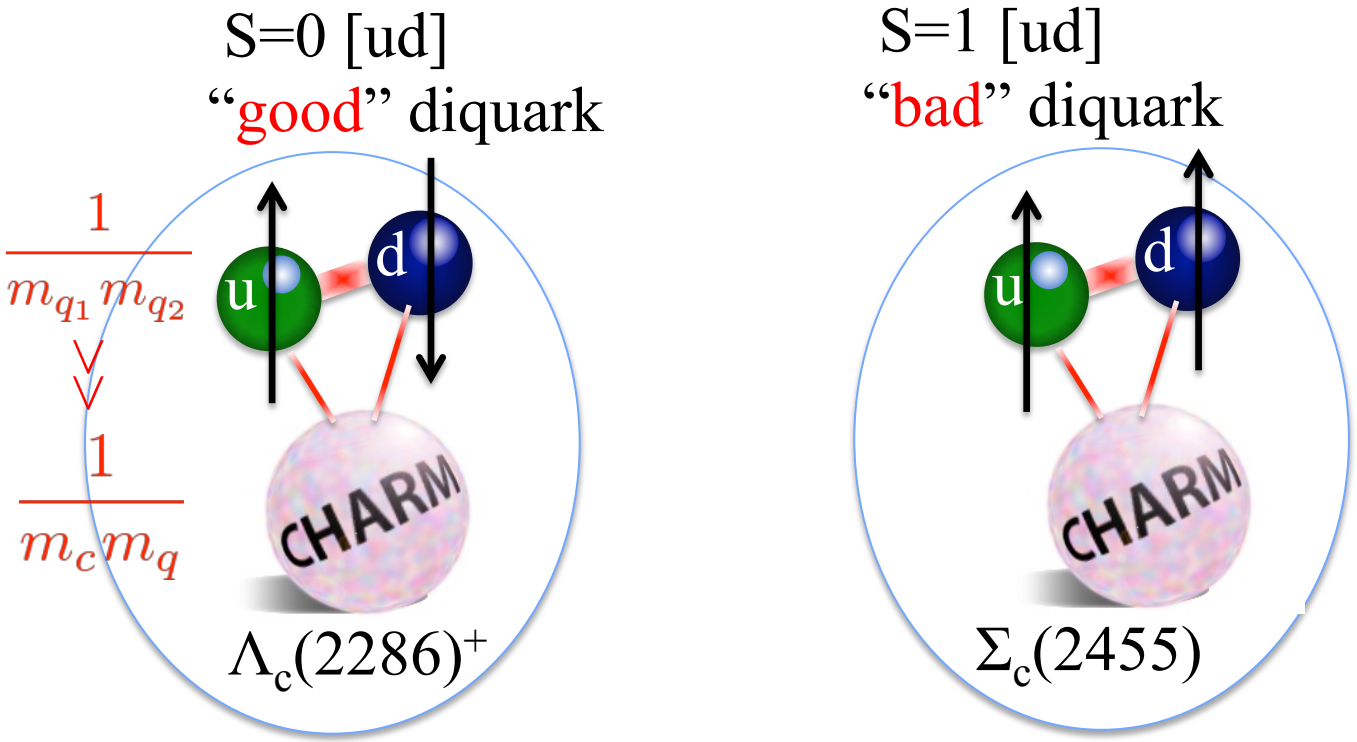


$\Sigma^0(1192)$

Diquark structure in hadrons

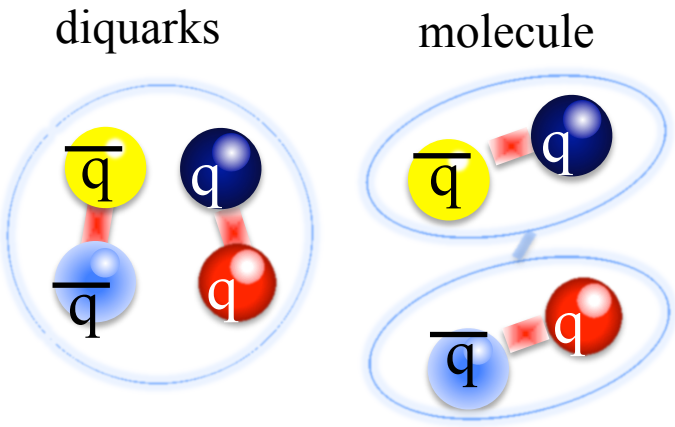
- Color magnetic interaction
  - Strong attraction in spin 0 flavor 0 channel
    - "Good" diquark
  - Structure of Λ_c, Σ_c

$$\frac{\alpha}{m_i m_j}\frac{\lambda^a(i)}{2}\frac{\lambda^a(j)}{2}\vec{\sigma}(i)\cdot\vec{\sigma}(j)$$

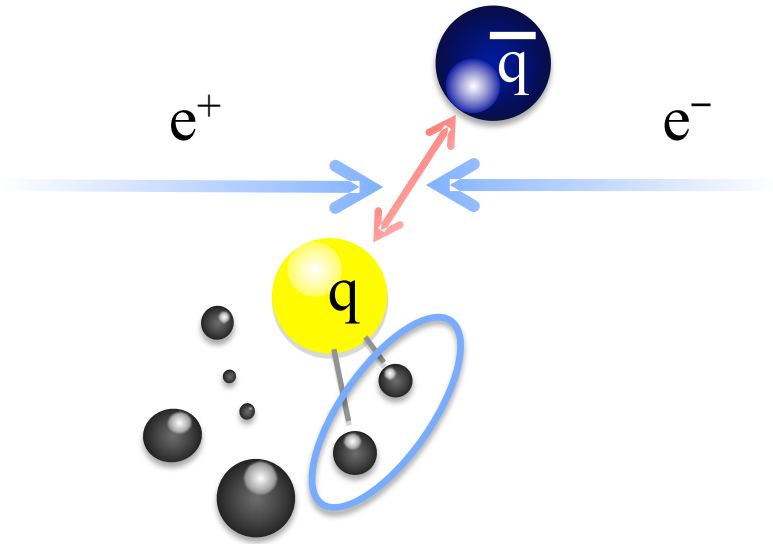


Motivation

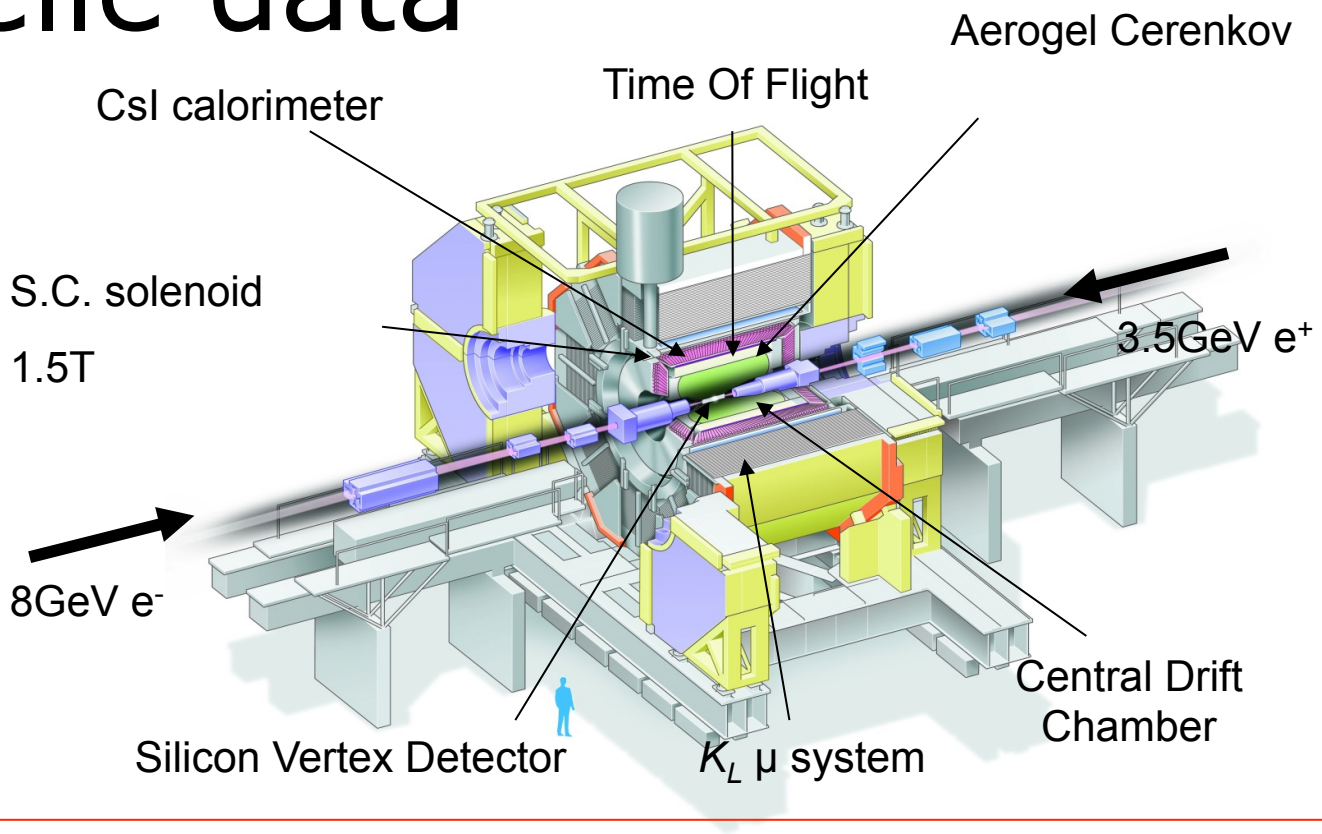
- Diquark correlation is highly important to understand exotic hadrons.
  - X(3872), $Z^+(4430)$, Z_b,
  - Multi-quark system? Hadron molecule?



- Check ARGUS measurements of hyperons with Belle data
  - Huge statistics,
  - Excellent PID power.
  - Subtract feed down contributions.
- First systematic measurements for charmed baryon production rates.



Belle data



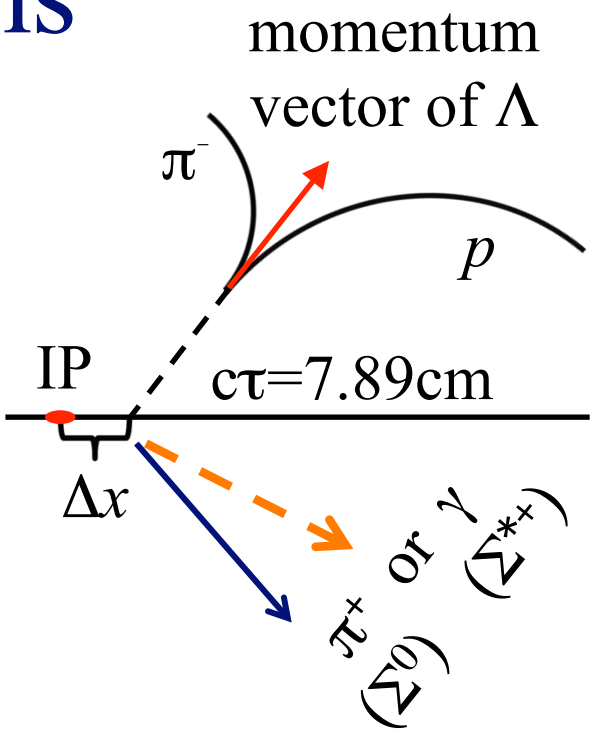
Integrated luminosity

: 562. fb^{-1} @ on $\Upsilon(4S)$ resonance data for charmed baryons ($\sqrt{s}$ =10.58 GeV)

: 79.3 fb^{-1} @ continuum data for hyperons and charmed baryons ($\sqrt{s}$ =10.52 GeV)

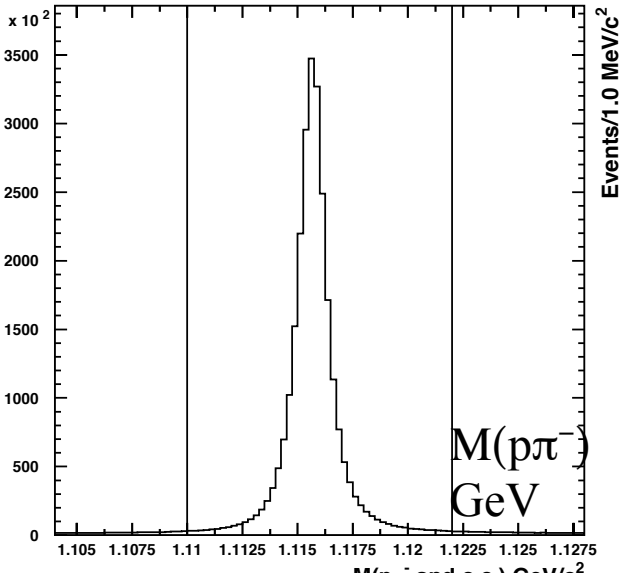
Λ, Σ^0, Σ^{*+} hyperons

- Reconstruct decay point and $\vec{p}$ of Λ.
- Check consistency of Λ and interaction point (IP).
- For Σ^0 or Σ^{*+} , we combine Λ with γ or π^{+}.

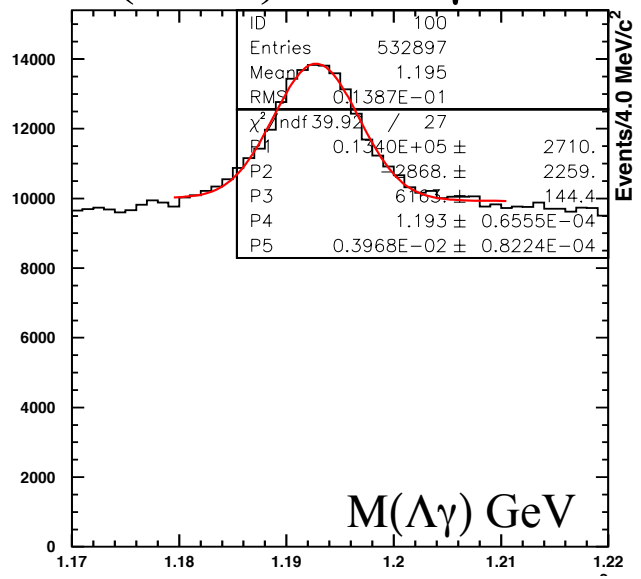


Continuum data

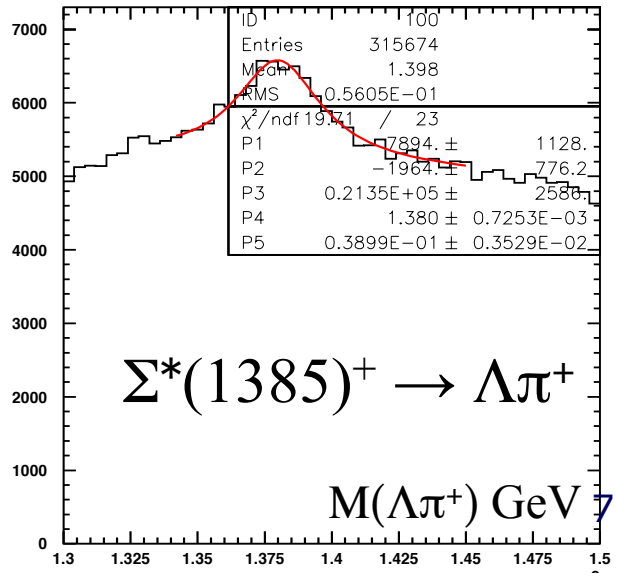
$\Lambda \rightarrow p\pi^-$



$\Sigma(1192)^0 \rightarrow \Lambda\gamma$



$\Sigma^*(1385)^+ \rightarrow \Lambda\pi^+$



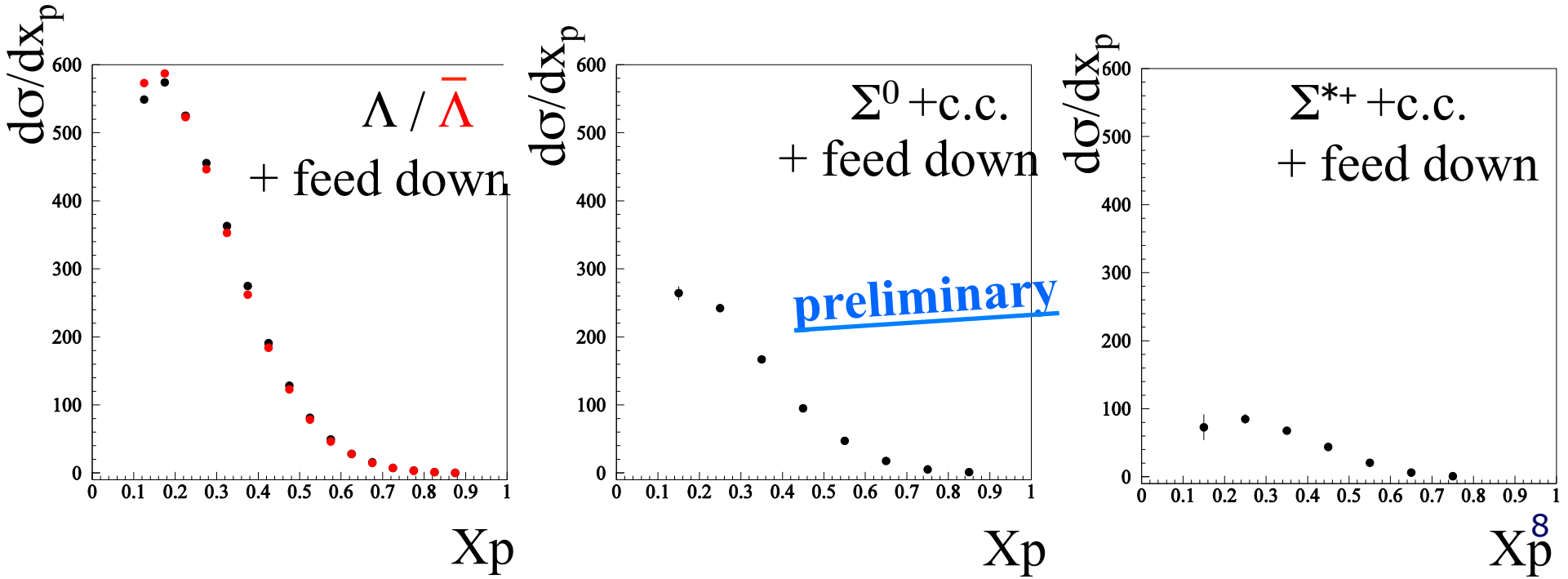
"Inclusive" cross sections vs. x_p

- "Inclusive" cross sections are obtained as a function of hadron scaled momentum (x_p).

$$x_p = p/\sqrt{s/4 - M^2}$$ (M, p : mass and CM momentum)

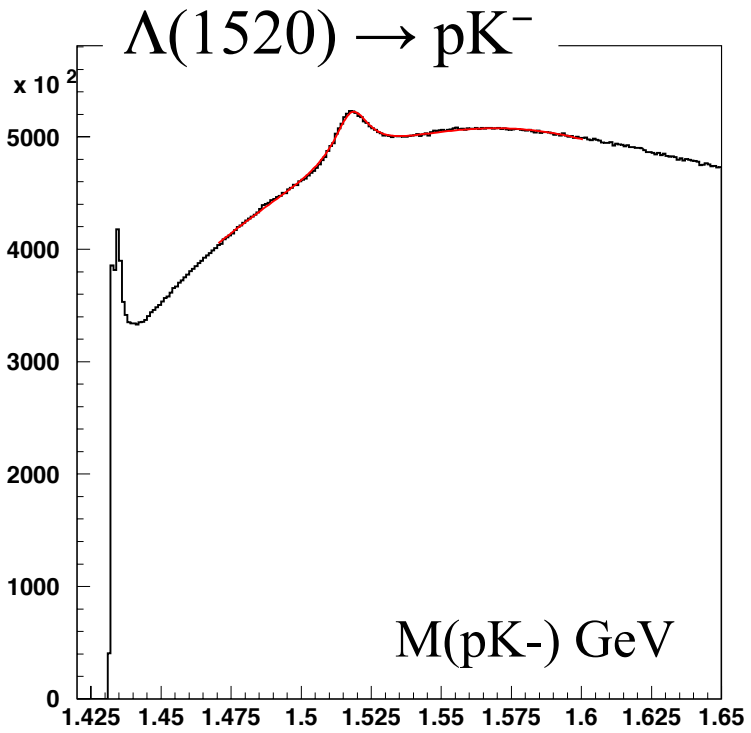
- Feed down contributions are subtracted later.

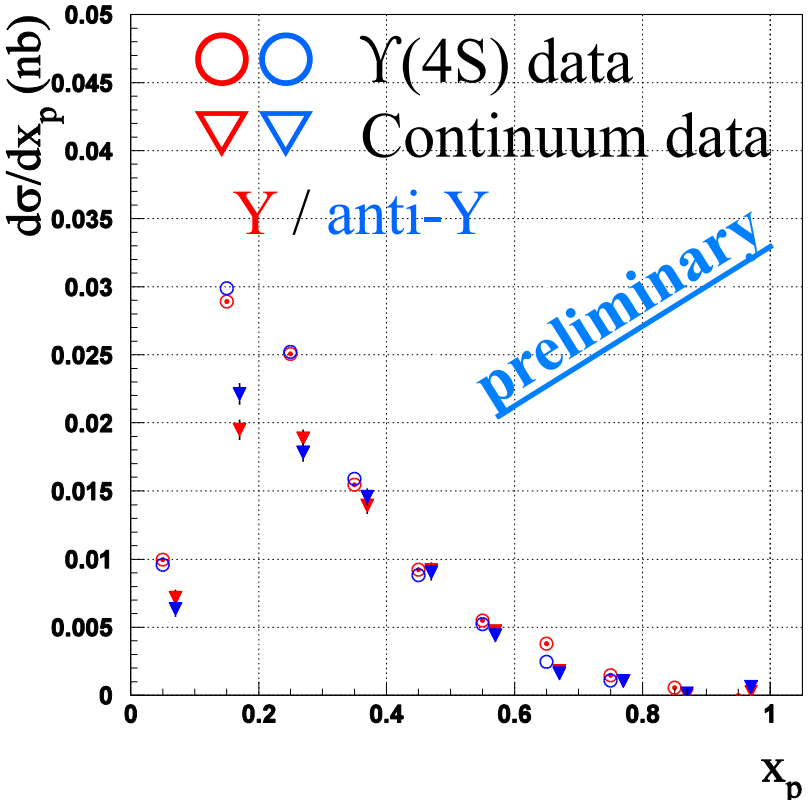
Continuum data



Λ(1520)

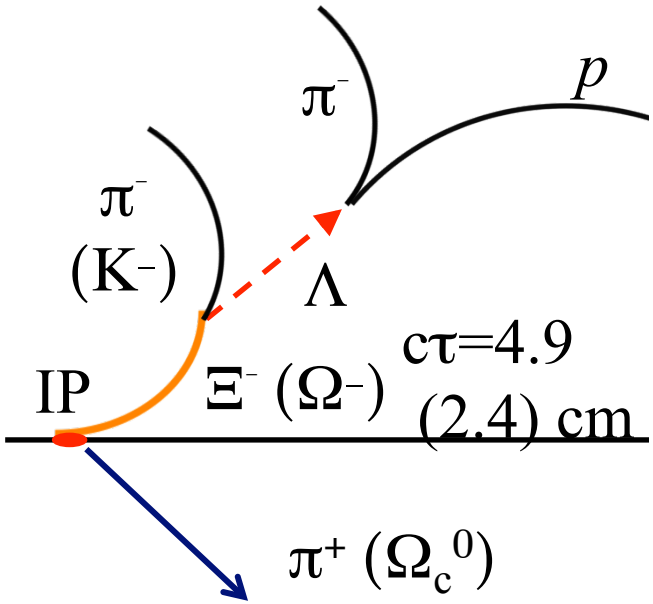
- Select p and K^- from IP.
- "Inclusive" cross section is obtained from continuum data.



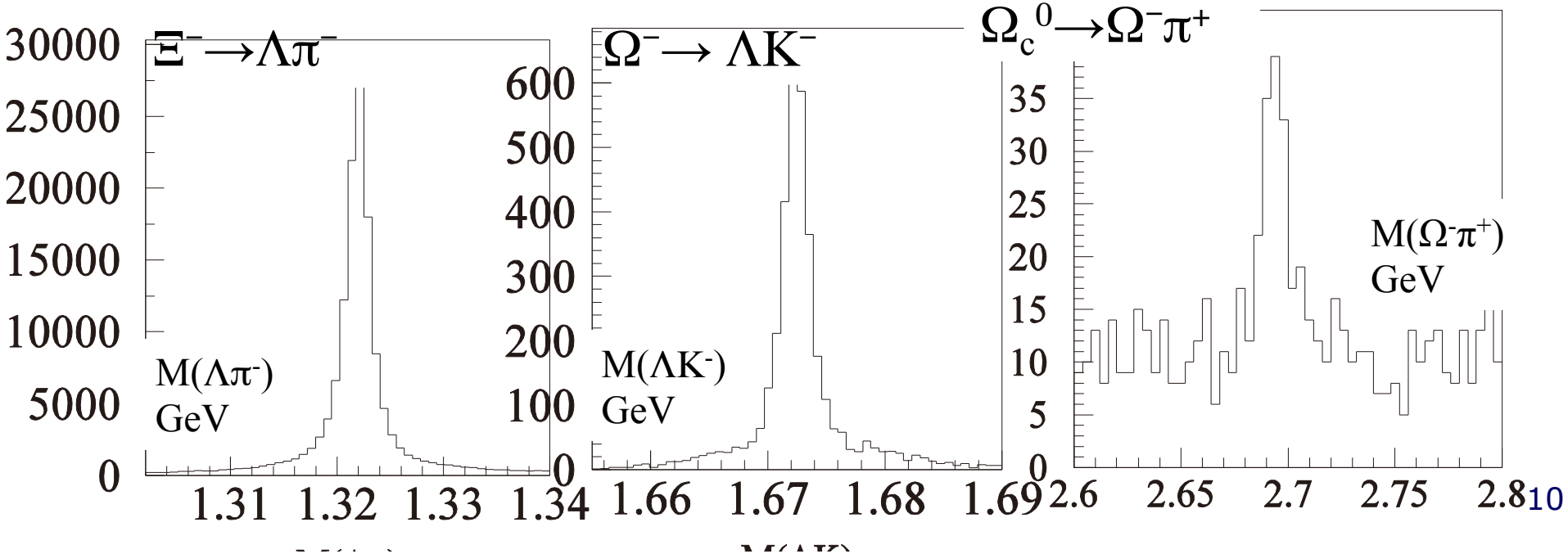


Ξ^-, Ω^-, Ω_c^0

- Reconstruct decay point and $\vec{p}$ of Λ.
- Λ is combined with π^- (K^-) and $\Xi^-(\Omega^-)$ is reconstructed.
- Check consistency of $\Xi^-(\Omega^-)$ and IP.
- For Ω_c^0, we combine Ω^- with π^+.

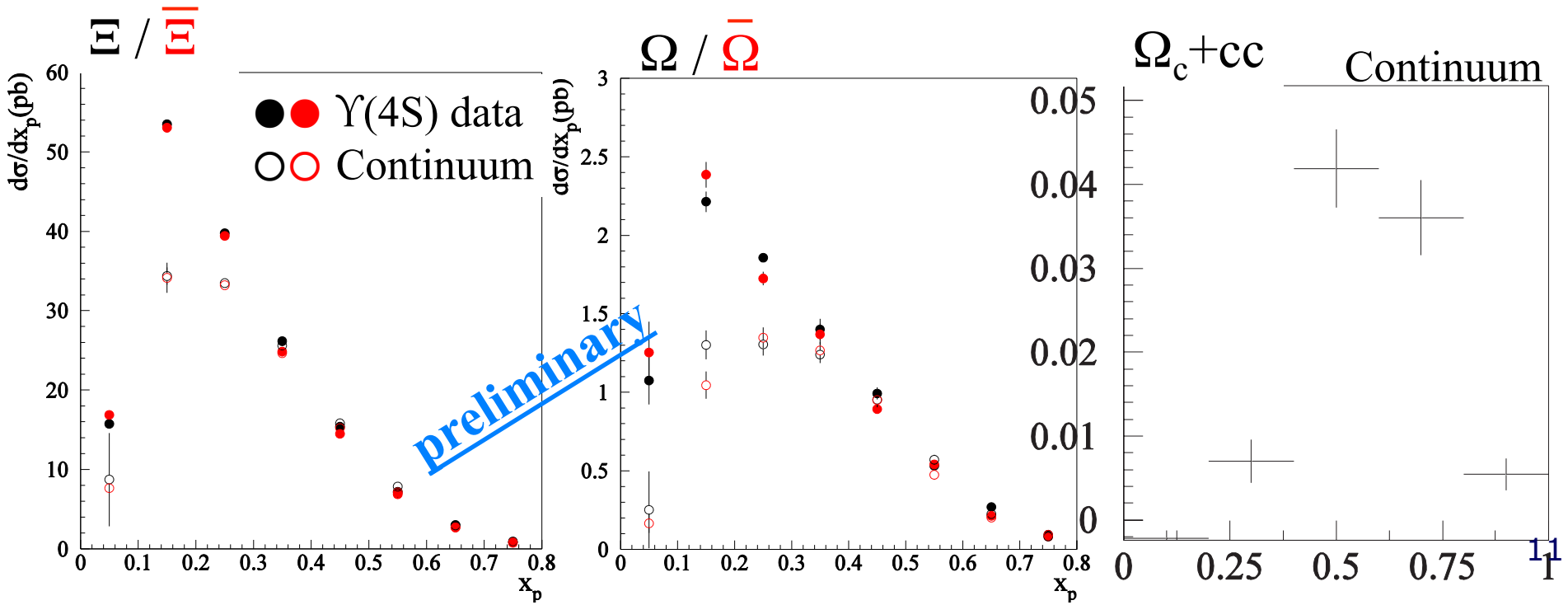


Continuum data



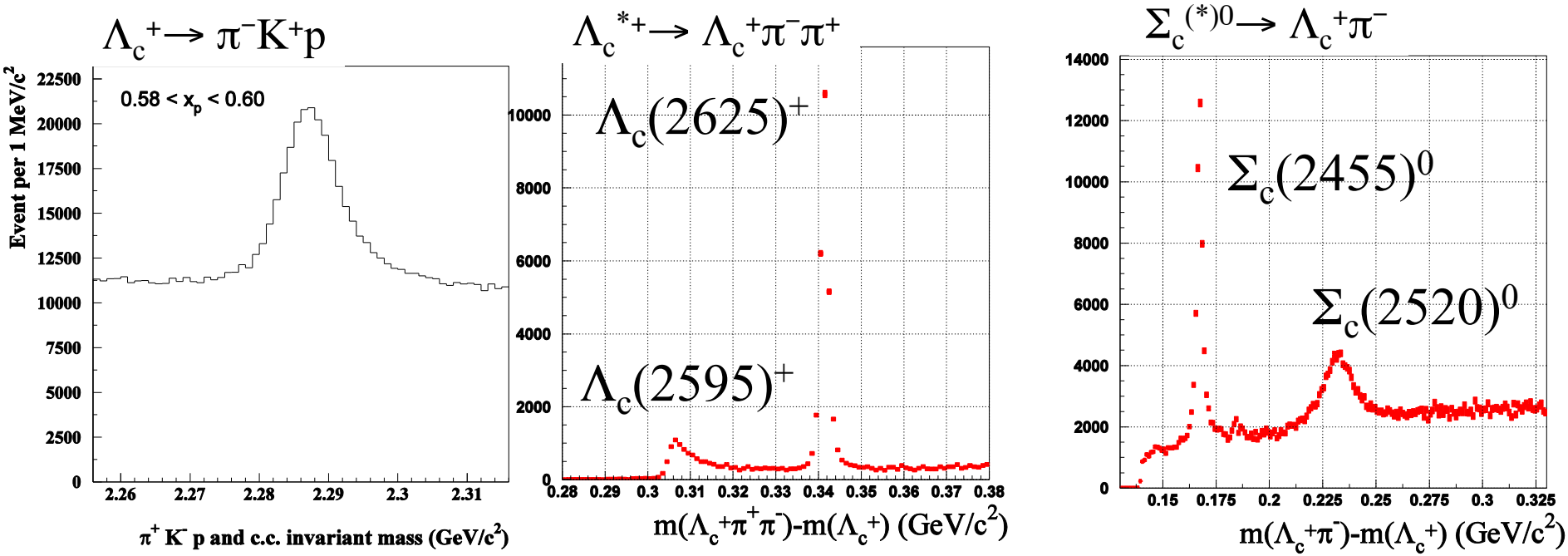
"inclusive" cross sections of Ξ and Ω

- Cross sections of hyperons are obtained from continuum data.



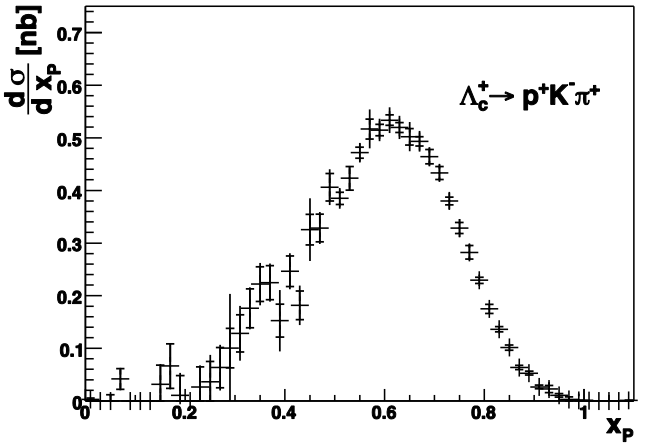
Λ_c^+, Λ_c^{*+}, Σ_c^0, and Σ_c^{*0}

- Reconstruct Λ_c^+ in invariant mass of π^+K^-p.
- Combine Λ_c^+ with π^- for $\Sigma_c^{(*)0}$ reconstruction.
- Combine Λ_c^+ with π^+ π^- for Λ_c^{*+} reconstruction.

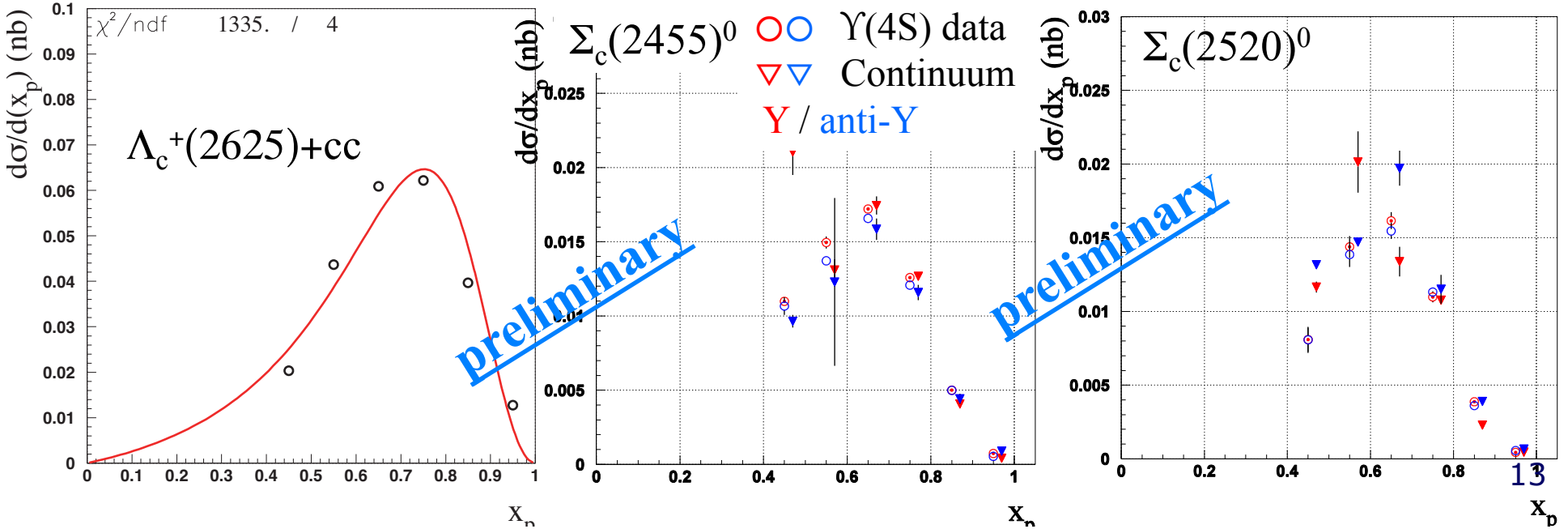


"Inclusive" cross sections

- Belle previous result of Λ_c^+ is used to normalize Λ_c^{*+}, $\Sigma_c^{(*)0}$ cross sections.
- Λ_c^{*+}, $\Sigma_c^{(*)0}$ are measured using $\Upsilon(4S)$ and continuum data in $x_p>0.4$ where B-decays don't contribute due to kinematics.
- Extrapolate to whole x_p range using Peterson model.



Belle, Phys. Rev. D **73** (2006) 032002.



Feed down subtraction

Λ

ARGUS : 257±28 pb Z.Phys C9,177

$\Lambda+\bar{\Lambda}: 373.9 \pm 0.5\ pb$	$\Lambda+\bar{\Lambda}$(incusive)
$-97.0 \pm 1.5\ pb$	$\Sigma^0 + c.c.$
$-86.6 \pm 6.3\ pb$	$\Sigma^* + c.c.$
$-51.2 \pm 1.2\ pb$	$\Xi^-, \Xi^0 + c.c.$
$-3.3 \pm 0.3 pb$	$\Lambda(1520)+\bar{\Lambda}(1520)$
$-23.6 \pm 31.2\ pb$	$\Lambda_c + c.c.$
$=112.2 \pm 31.8\ pb$	

Uncertainty on BR in PDG inclusive

$\Lambda_c \rightarrow \Lambda$ + anything BR: 35±11%

sum of all exclusive BR ($\Lambda_c \rightarrow \Lambda\pi$, $\Lambda\pi\pi$, $\Lambda l\nu$,...): 12.5±1.9%

One of three measurements of inclusive BR turned out to be unreliable.

The error will be improved much better.

$\Sigma(1385)^+$

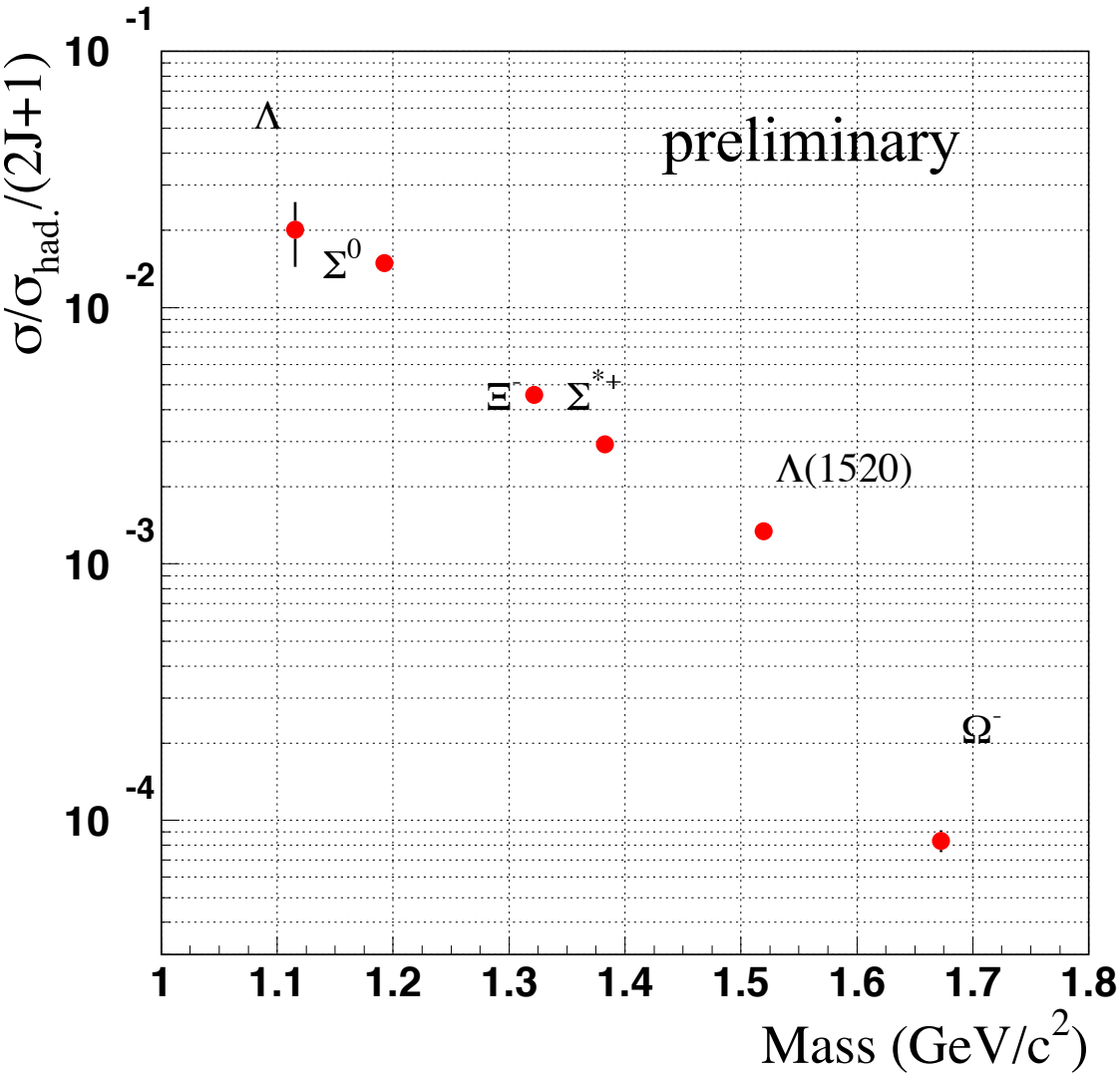
$33.2 \pm 2.4\ pb$	Σ^{*+} + c.c. (inclusive)
$-0.4 \pm 0.06\ pb$	$\Lambda(1520)$ + c.c.
$= 32.8 \pm 2.4$ pb	

Σ^0

$97.0 \pm 1.5\ pb$	$\Sigma^0+\bar{\Sigma}^0(inclusive)$
$-4.0 \pm 0.3\ pb$	$\Sigma^{*-}, \Sigma^{*+} + c.c.$
$-2.7 \pm 0.3 pb$	$\Lambda(1520) + c.c.$
$-7.2 \pm 3.9\ pb$	$\Lambda_c + c.c.$
$=83.1 \pm 4.2\ pb$	

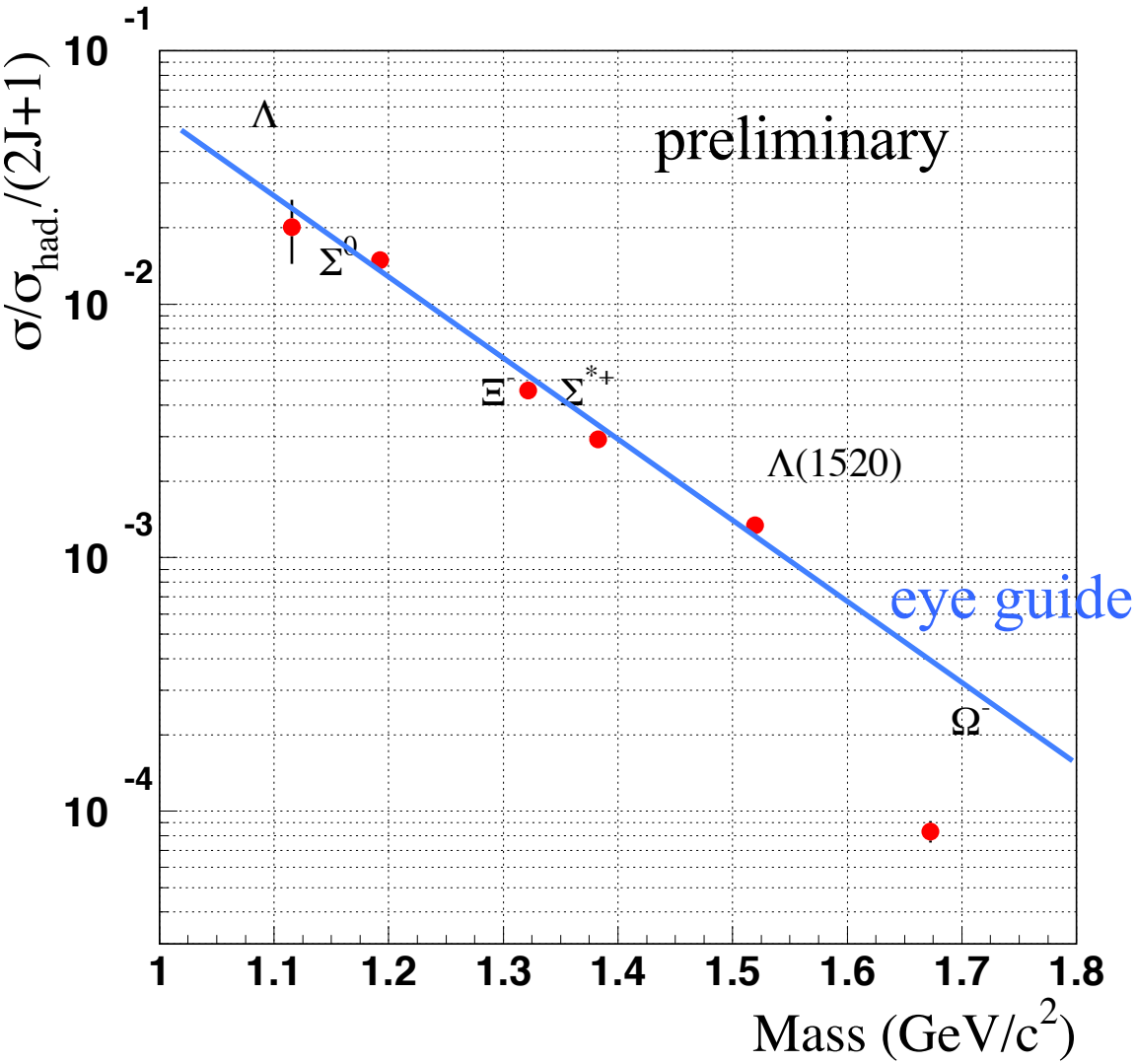
Results of hyperons

- Feed down from heavier states are subtracted.
  - 70% of inclusive Λ.
  - 14% of inclusive Σ.
  - 1.2% of inclusive Λ(1520).
  - $\Xi^{0*} \rightarrow \Xi^{-}\pi^{+}$ is included.
- $\sigma_{had} = 2.794$ nb.
- w/o radiative correction.
- Divided by spin multiplicity.



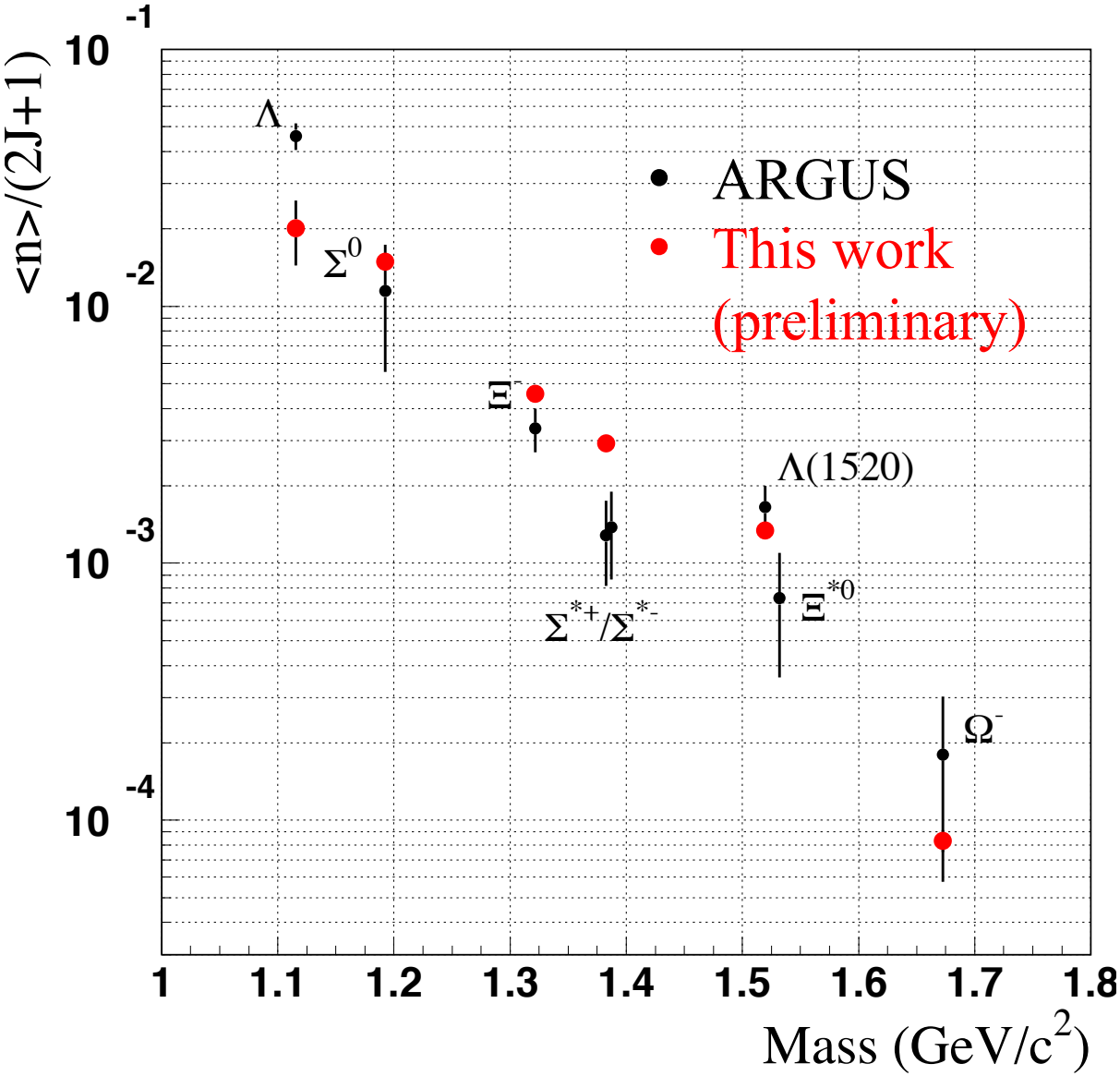
Results of hyperons

- S=-1 hyperons look lie on “one line”.
- Ω^- is suppressed
  - ss-bar suppression?



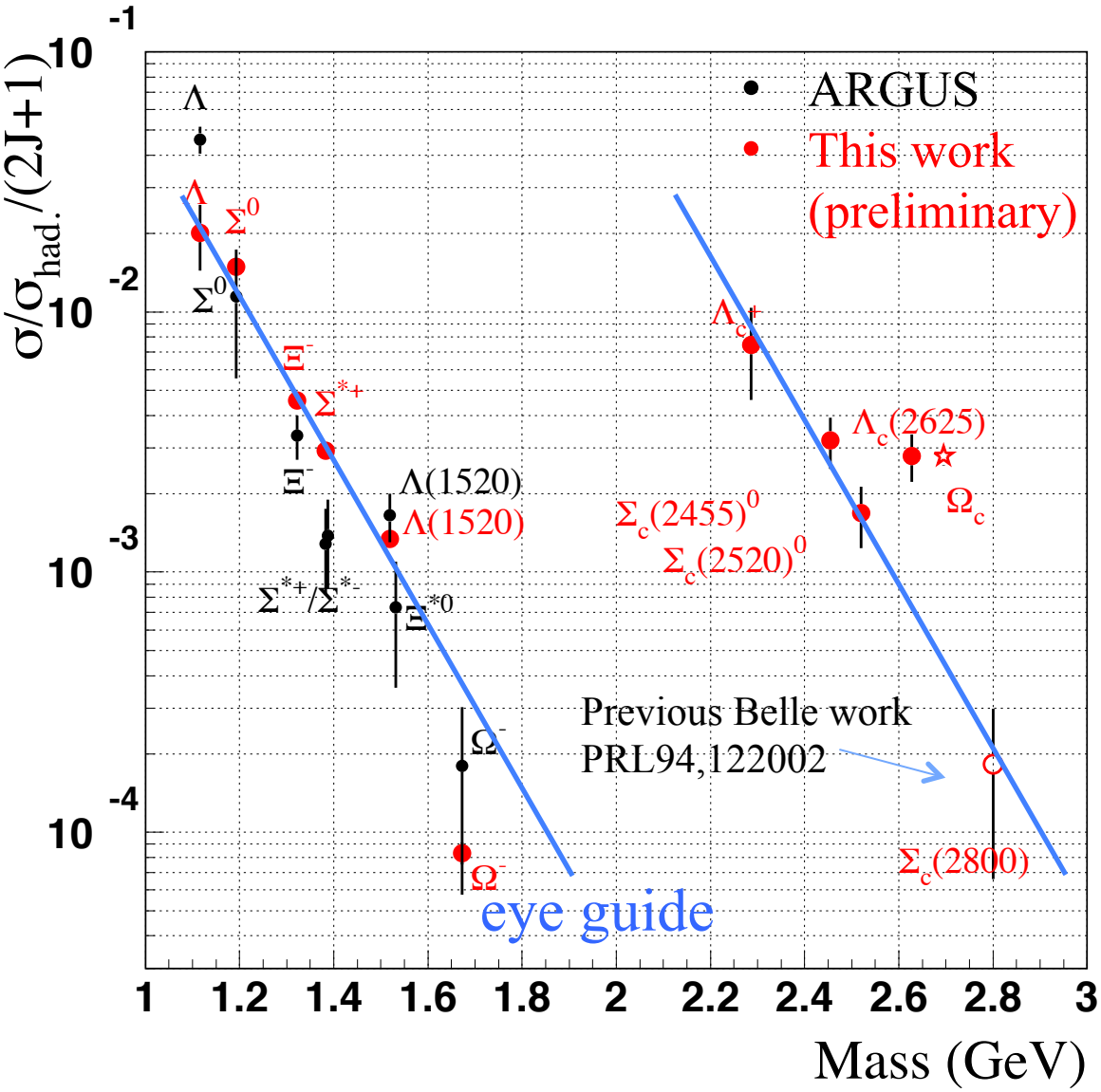
Comparison with ARGUS results

- Strong enhancement of Λ is not observed after the proper feed down subtraction.
- Results of other particles are obtained much higher precision than ARGUS results.



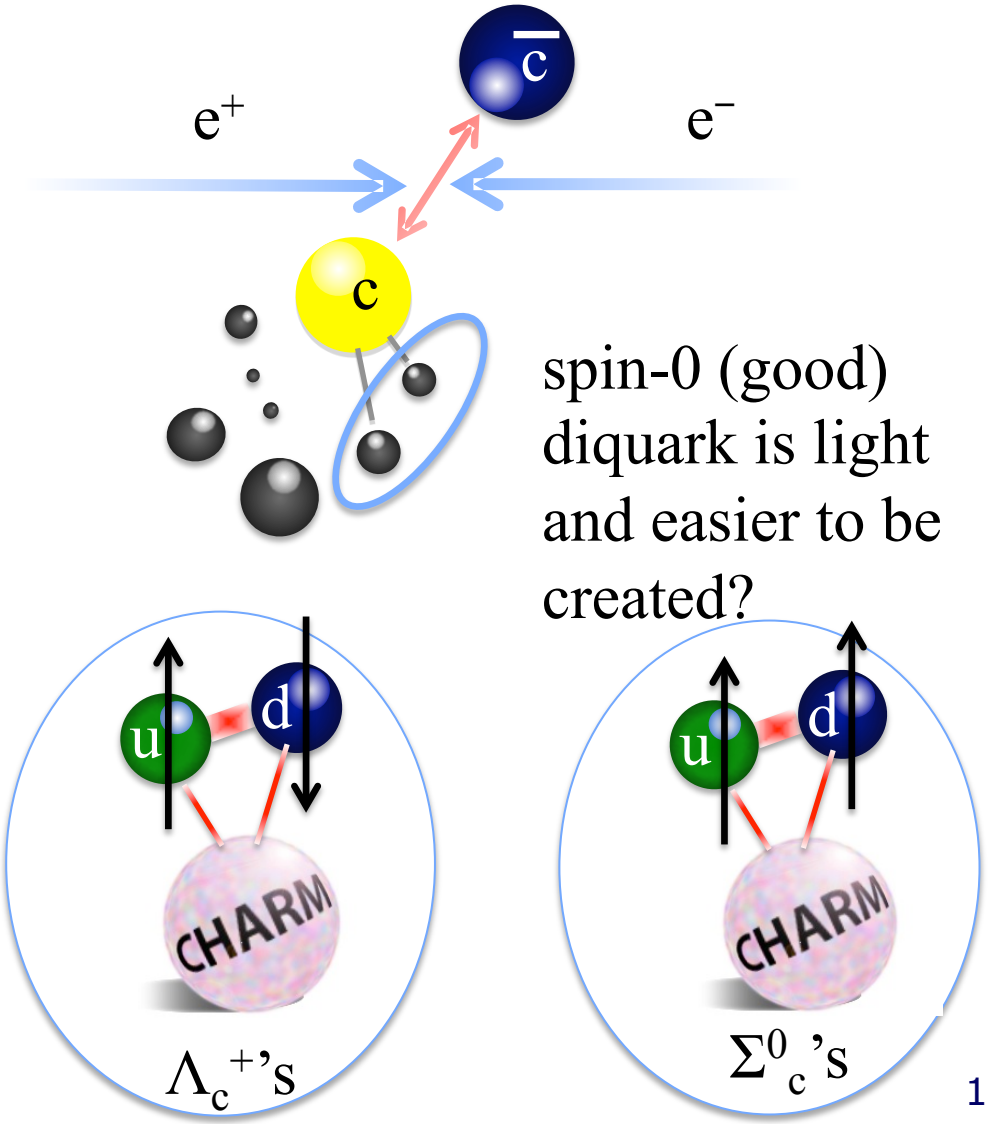
Results of charmed baryons

- Feed down from Σ_c, Σ_c^*, $\Lambda_c(2625)^+$ are subtracted.
  - 75% of inclusive Λ_c^+ .
  - ~10% of inclusive Σ_c^0.
  - Those from $\Lambda_c(2595)^+$ and $\Lambda_c(2765)^+$ are included.
- Ω_c
  - No measurement of BR.
  - A phenomenological calculation gives 0.24±0.12%.
  - Theoretical estimation is necessary.
- High production rate of $\Lambda_c(2625)^+$ is seen.



Discussion

- Higher rate of $\Lambda_c(2625)^+$ is observed.
  - For all Λ_c^+ members?
    - More "good diquark" component in all Λ_c^+'s than Σ_c^+'s?
    - Baryon production rate may be sensitive for diquark structure.
  - Only for $\Lambda_c(2625)^+$ ($J^P=3/2^-$)?
    - Special mechanism for this particle?
    - But not for ($J^P=3/2^-$) $\Lambda(2520)$ hyperon.
  - $\Lambda_c(2595)^+$, $\Lambda_c(2880)^+$ are in study.



Summary

- Production rates of hyperons and charmed baryons from e^+e^- collision near $\Upsilon(4S)$ energies using Belle data.
- Strong enhancement of Λ reported is not observed after the feed down subtraction.
  - Other hyperons are consistent with ARGUS results but much higher precision.
- The first systematic measurements of charmed baryon production rates.
- An enhancement of $\Lambda_c(2625)^+$ ($J^P=3/2^-$) is observed.
  - Only this state is favored? Or all Λ_c^+ members are favored?
  - Measurements of other Λ_c^+ members are on-going.
- Baryon production rates can be a good tool to investigate not only fragmentation but also internal structure of baryons.

Backup

Baryon production rate in e^+e^- collision

- $q\bar{q}$ creation
- hadronization (jet)
- $$\frac{\sigma}{\sigma_{had}(2J+1)} \propto \exp(-\alpha m_{had})$$
  - Mesons and baryons have different slope.
    - Slope : quark counting
  - Relativistic-string model

    S.B. Chun & C.D. Buchanan
    PLB 308(1993)153
  - Thermodynamical model

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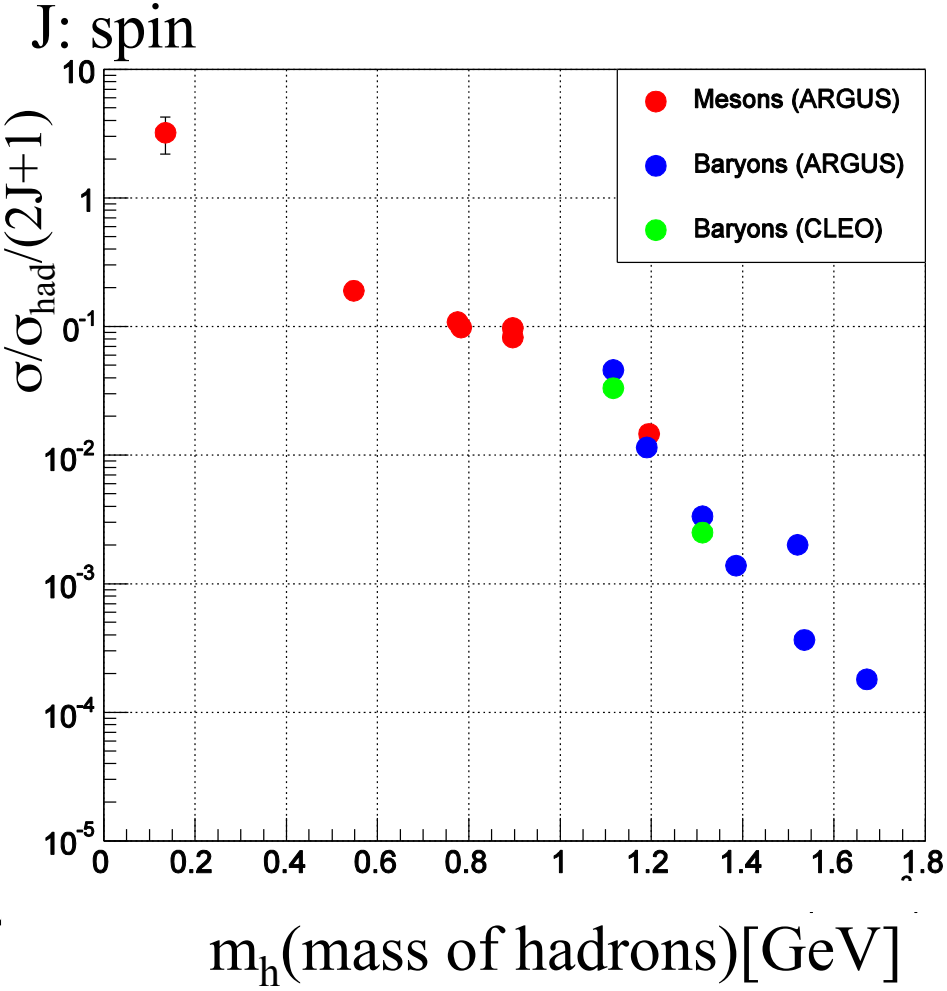

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$=83.1 \pm 4.2\ pb$	

direct Λ_c and Σ_c production

- Λ_c^+ + c.c. (direct)

  $= 189 \pm 66\ pb$ inclusive

  $- (17.9 \pm 6.0\ pb) \times 3$ $\Sigma_c^{0,+,++}(2455)$ + c.c.

  $- (18.8 \pm 6.4\ pb) \times 3$ $\Sigma_c^{0,+,++}(2520)$ + c.c.

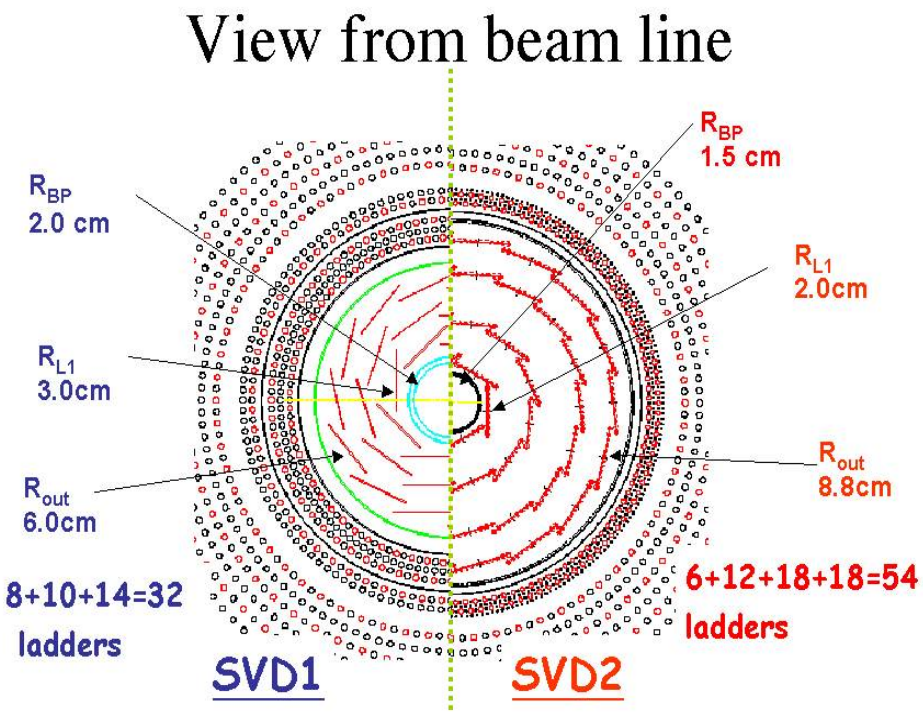
  $- (31.3 \pm 10\ pb)$ $\Lambda_c^+(2625)$ + c.c.

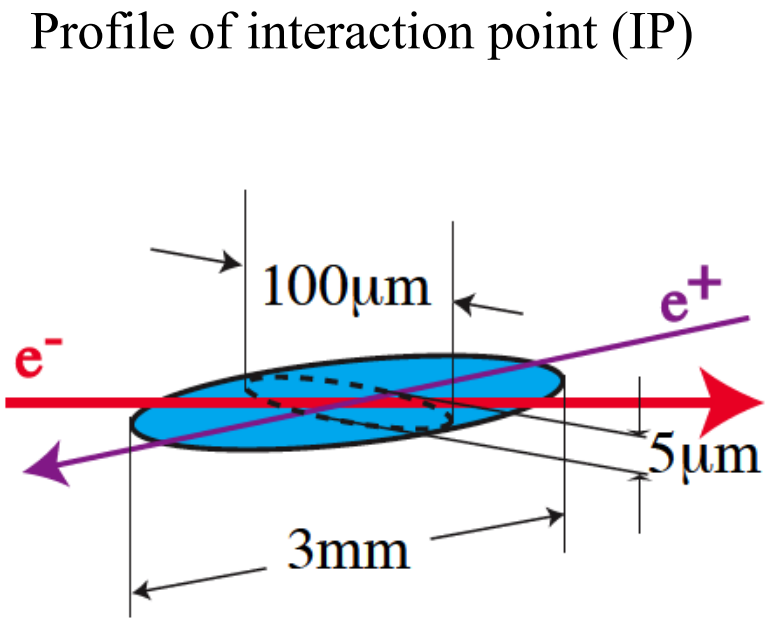
  $= 47.6 \pm 16.2\ pb$

$\Lambda_c(2595)$ and $\Lambda_c(2775)$ feed down are included.

- $\Sigma_c^0(2455)$ +c.c. (direct) $= 17.9 \pm 6.0\ pb$
- $\Sigma_c^0(2520)$ + c.c. (direct) $= 18.8 \pm 6.4\ pb$
- $\Lambda_c^+(2625)$ + c.c. (direct) $= 31.3 \pm 10\ pb$

Good vertex reconstruction





- SSD placed in 3cm/2cm from Interaction point (IP), and low materials.
- Resolution of reconstructed vertex for B →J/Psi Ks is about 80 μm.
- Good for hyperon (long life) reconstruction.