



# Observation of $\Xi$ pentaquark states at NA49

**K. Kadija**

**for the NA49 Collaboration**

**Ruđer Bošković Institute, Zagreb, Croatia**



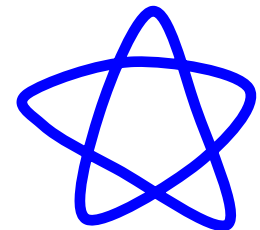
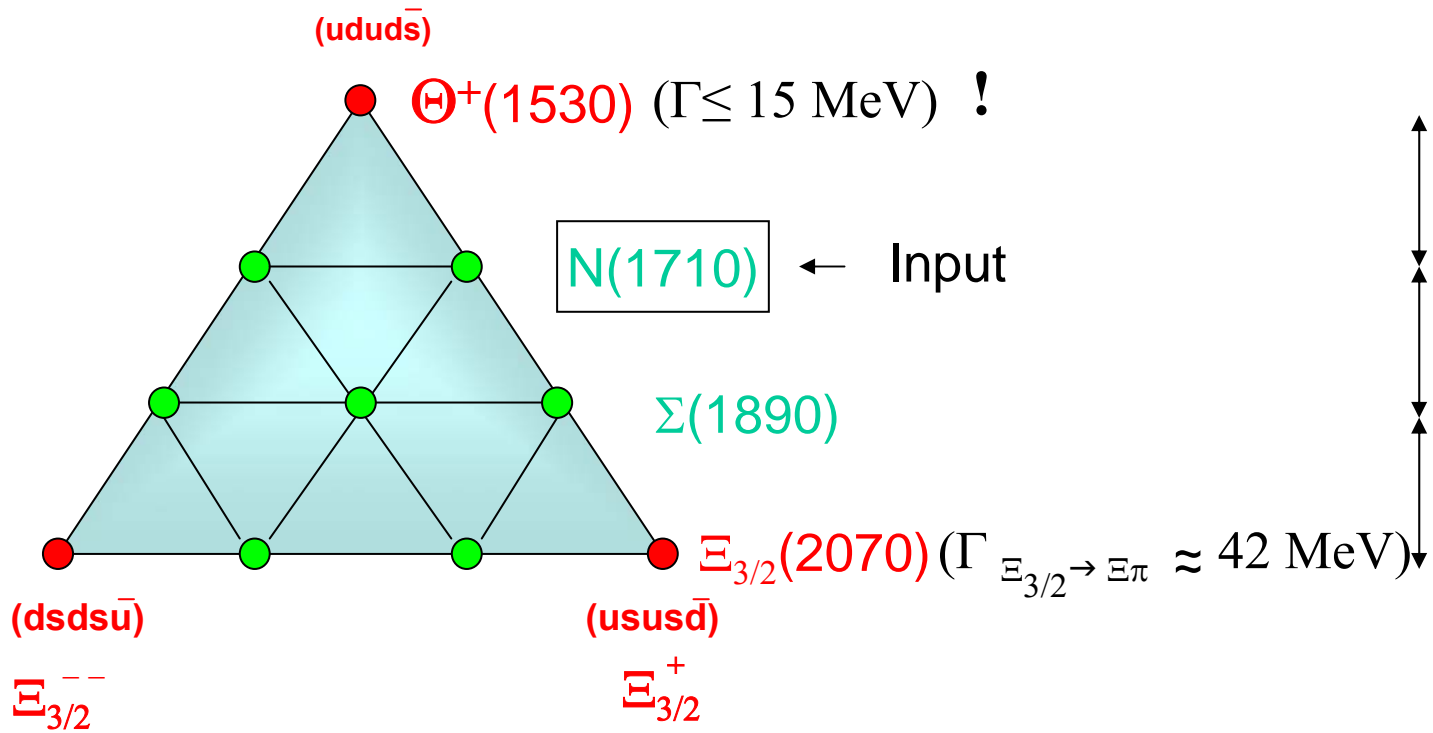
# Outline



- Pentaquark models
- NA49 experiment
- Analysis
- $\Xi^- \pi^{-(+)}$  and  $\bar{\Xi}^+ \pi^{+(-)}$  invariant mass spectra
- Preliminary  $\Xi(1530)^0 \pi$  spectra
- Conclusion

## Suggested anti-decuplet of baryons: $J^P=1/2^+$

D. Diakonov, V. Petrov, M. Polyakov, Z.Phys. A 359 (1997) 305

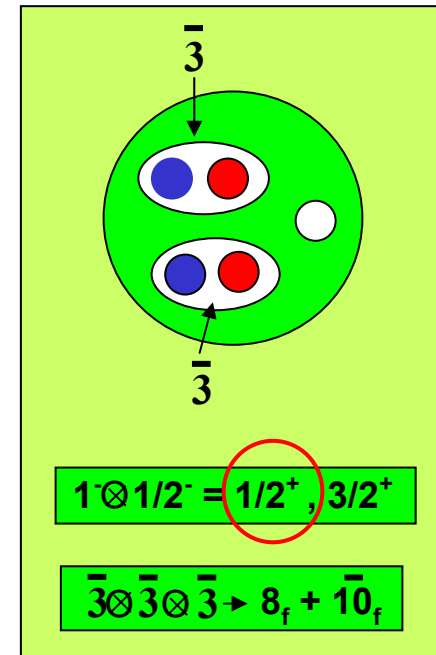
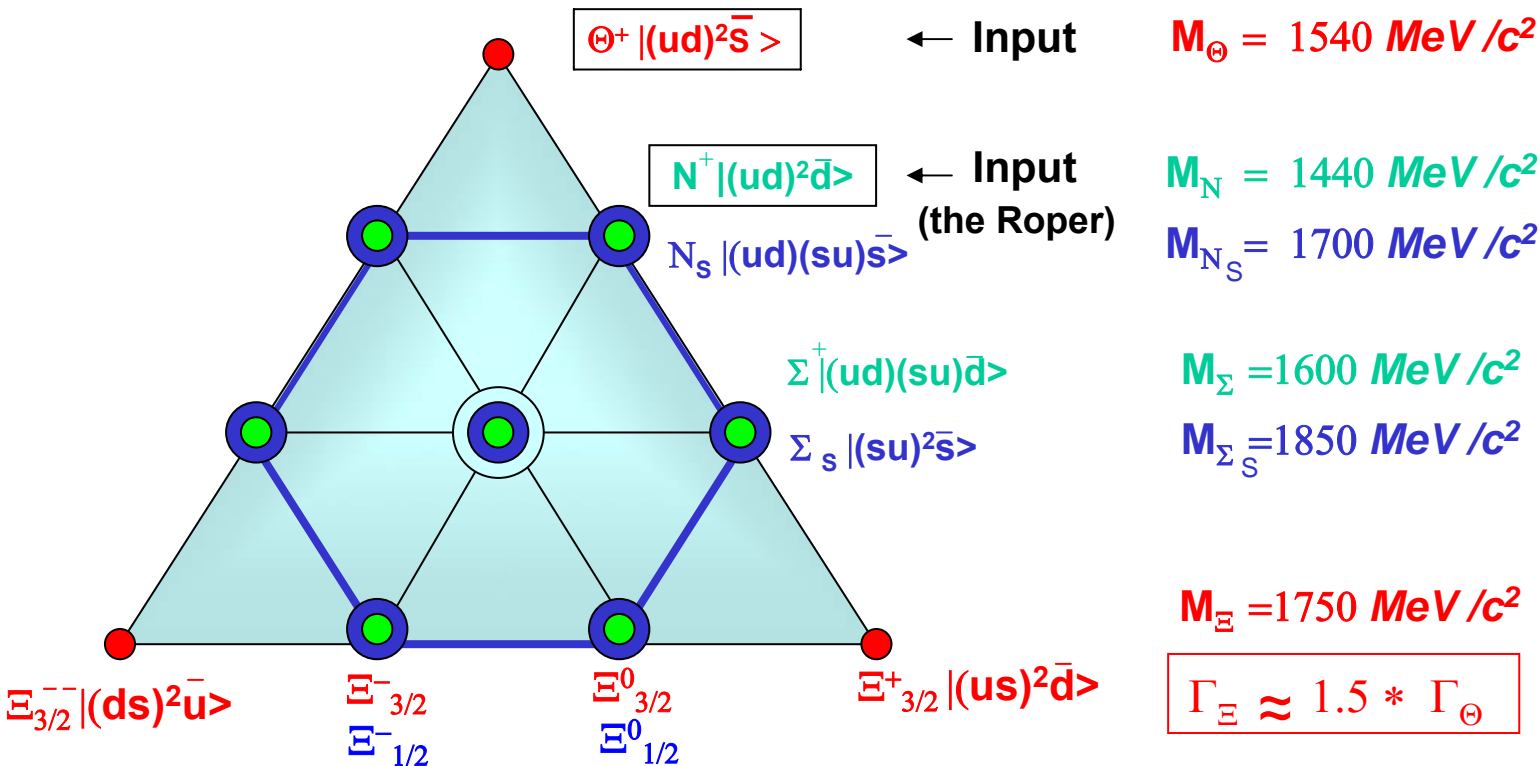


$\Delta m_{10} \approx 180 \text{ MeV}$

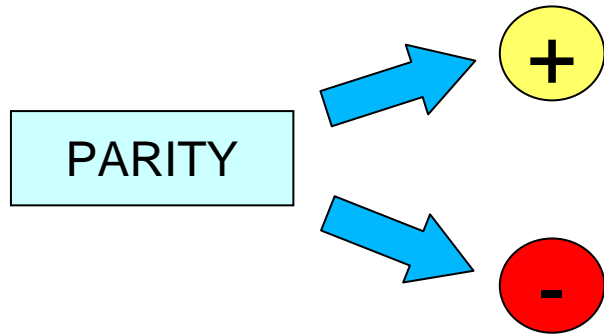
# Models: Correlated quarks

Suggested  $\bar{10}_f + 8_f$  of baryons:  $J^P=1/2^+$

R. Jaffe and F. Wilczek, arXiv:hep-ph/0307341

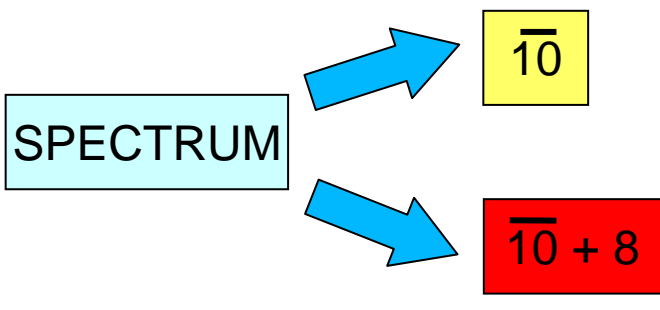


Note that the  $\Xi_{3/2}$  and  $\Xi_{1/2}$  have the same mass



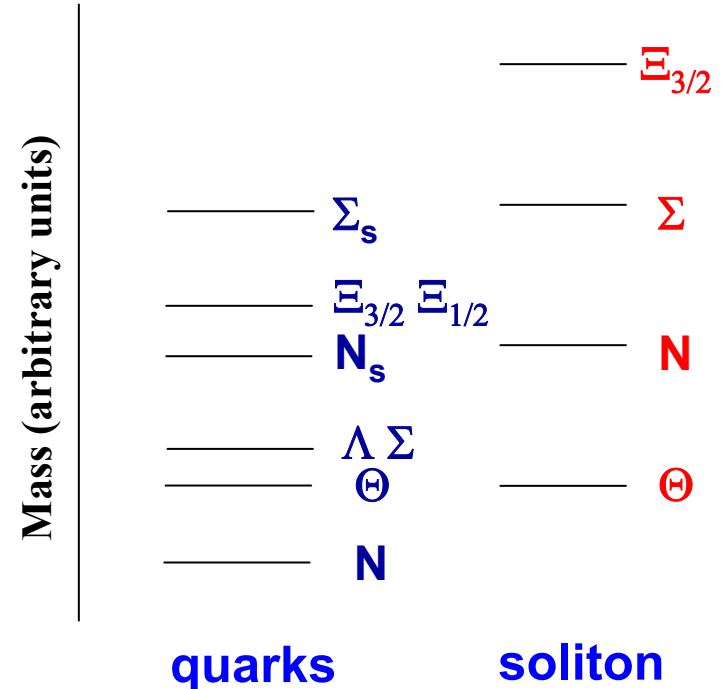
Chiral soliton model  
Correlated quarks

Uncorrelated quarks  
Lattice QCD

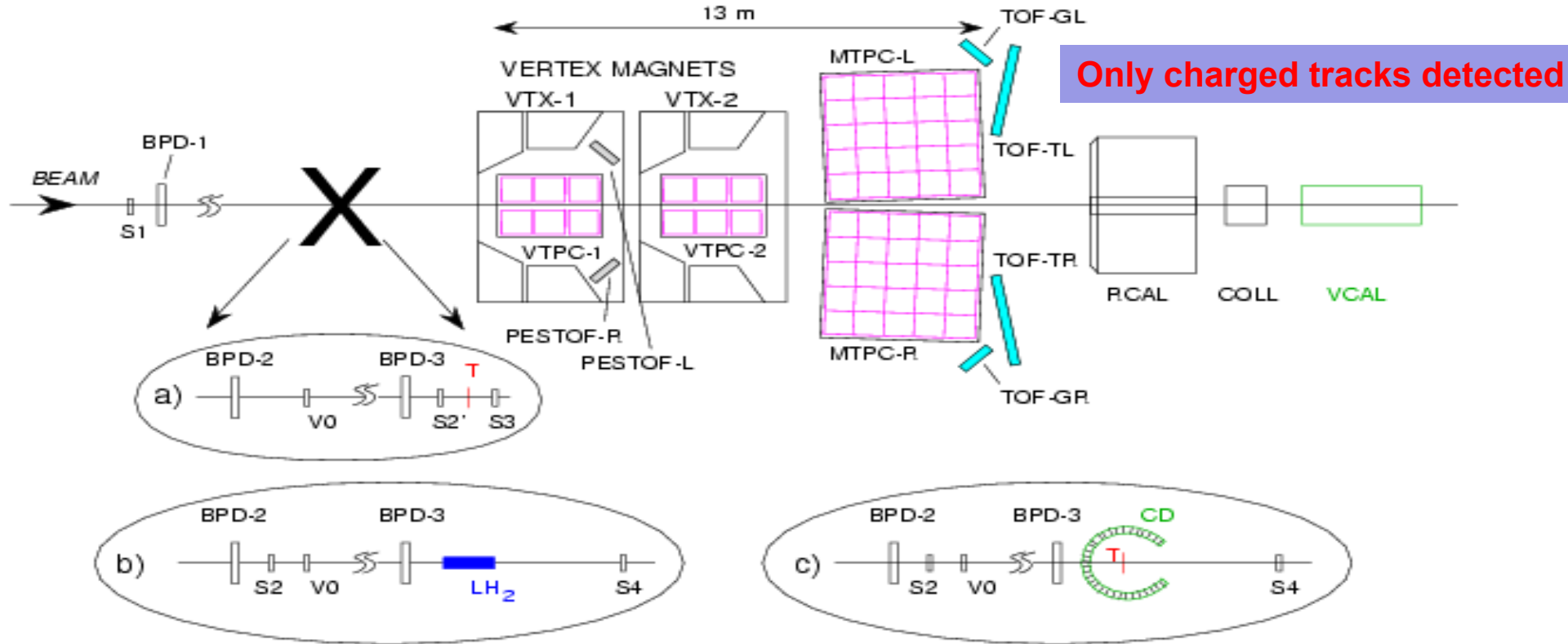


Chiral soliton model:  
Heavy exotic cascades ??

Quarks:  
Light exotic cascades



**More pentaquarks and their properties needed to determine correct model**



$$dp/p^2 = 7 \times (0.3) 10^{-4} (\text{GeV}/c)^{-1} \quad \text{VTPC-1 (VTPC-2+MTPC)}$$

3-6 %  $dE/dx$  resolution

$$\sigma_{\text{Trig}} = 28.1 \text{ mb}$$

p+p at  $\sqrt{s} = 17.2$  GeV

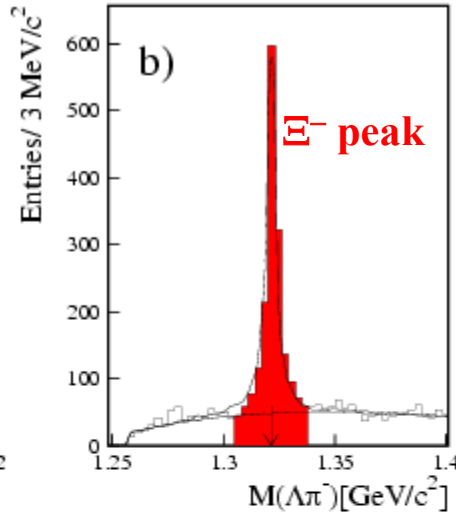
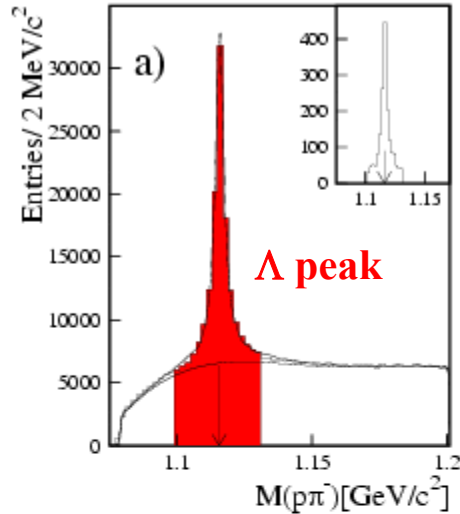
	Before vertex cut	After Vertex Cut
1999	1.2 M	0.66 M
2000	2.7 M	1.5 M
2002	2.9 M	1.6 M
Total	6.8 M	3.76 M

Main vertex cuts:

- 1.) fit converged
- 2.)  $x^2 + y^2 < 1 \text{ cm}^2$
- 3.)  $-590.5 \text{ cm} < z < -572.5 \text{ cm}$

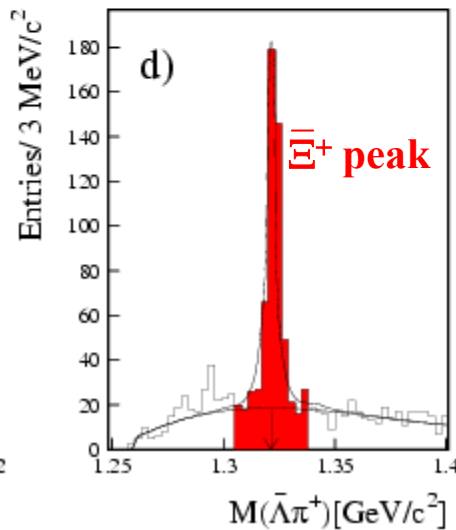
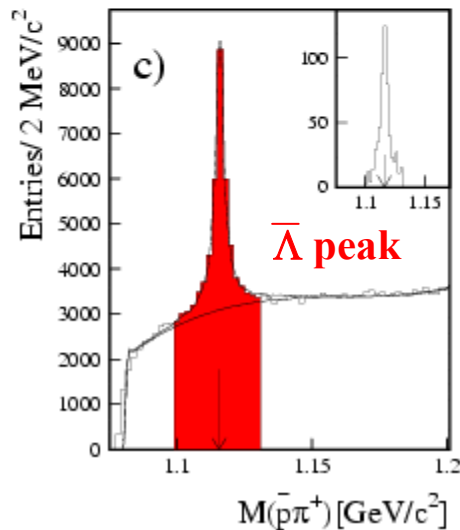
**i.e. within target**

# V0 and $\Xi$ Invariant Mass Spectra



1640 events

$$|M(\Lambda\pi) - 1.32131| < 0.015 \text{ GeV}$$

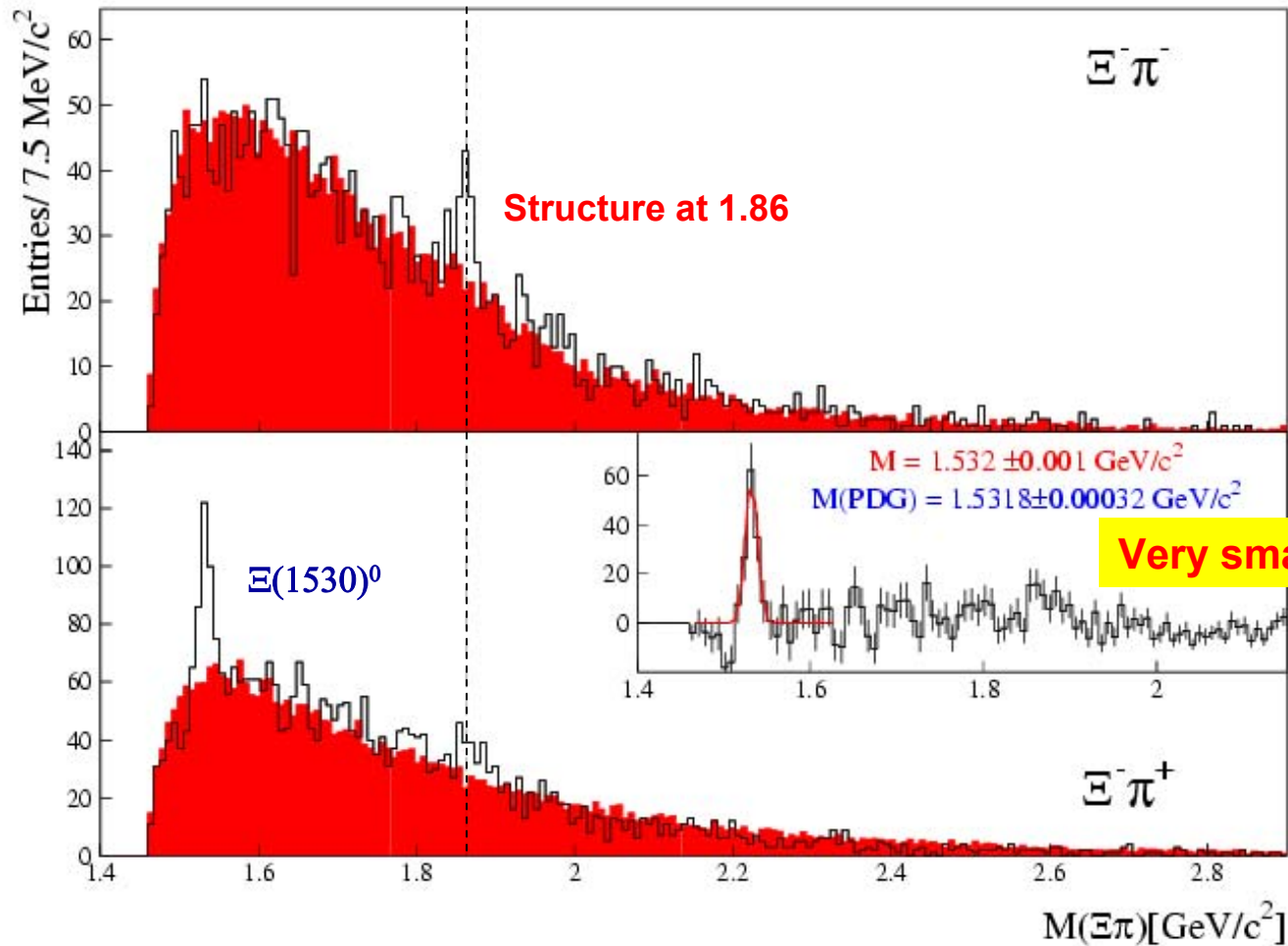


551 events



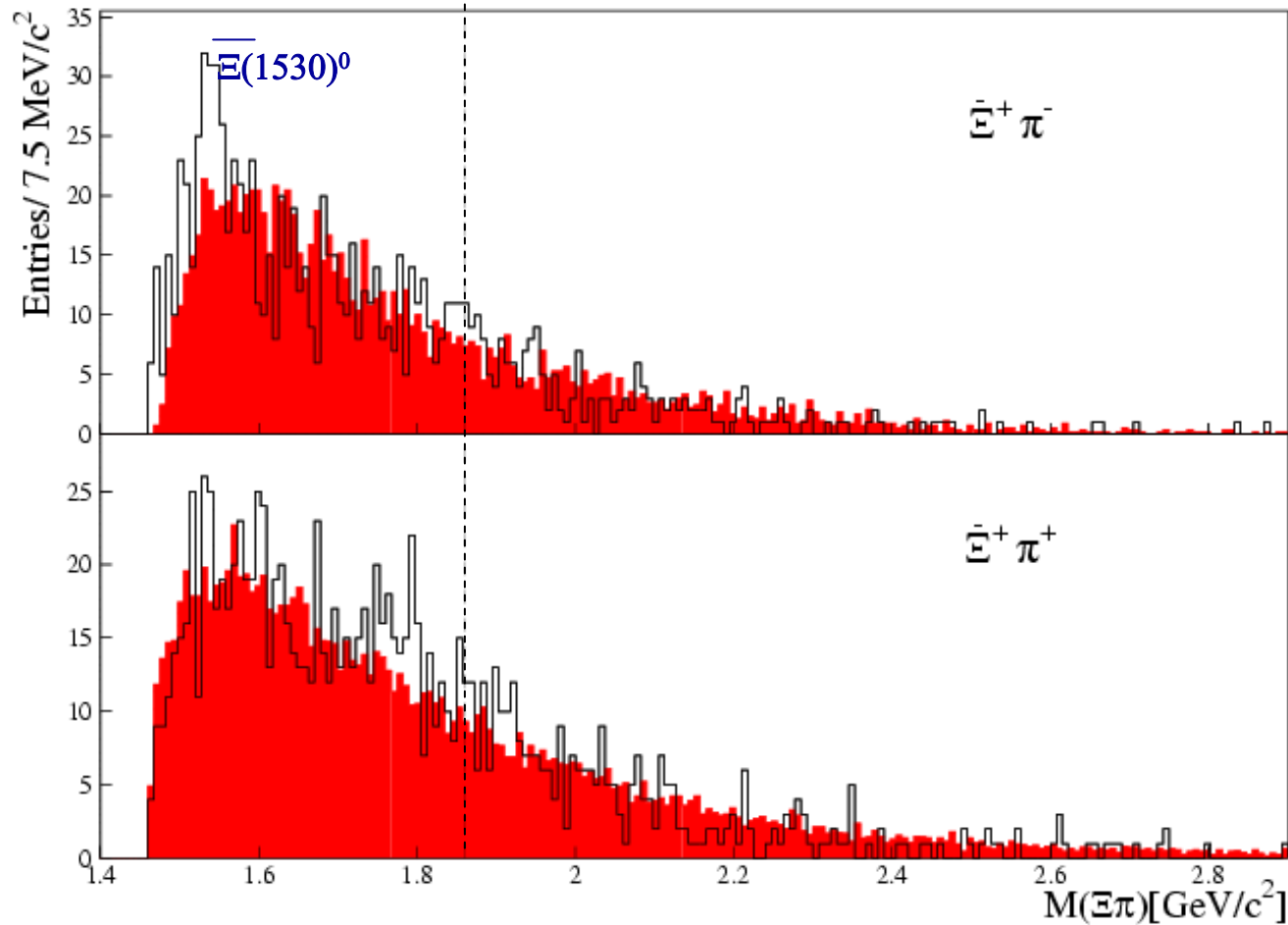
$$(\bar{E}^- \pi, \bar{E}^+ \pi)$$

- $|d_{bb}^\pi| < 1.5 \sigma$ ,  $d_{bb}$  .... distance to Bethe-Bloch curve
- position at main vertex ( $b_x, b_y$ ):
  - $|b_x| < 1.0 \text{ cm}$
  - $|b_y| < 0.5 \text{ cm}$
- # of point cut  $> 10$

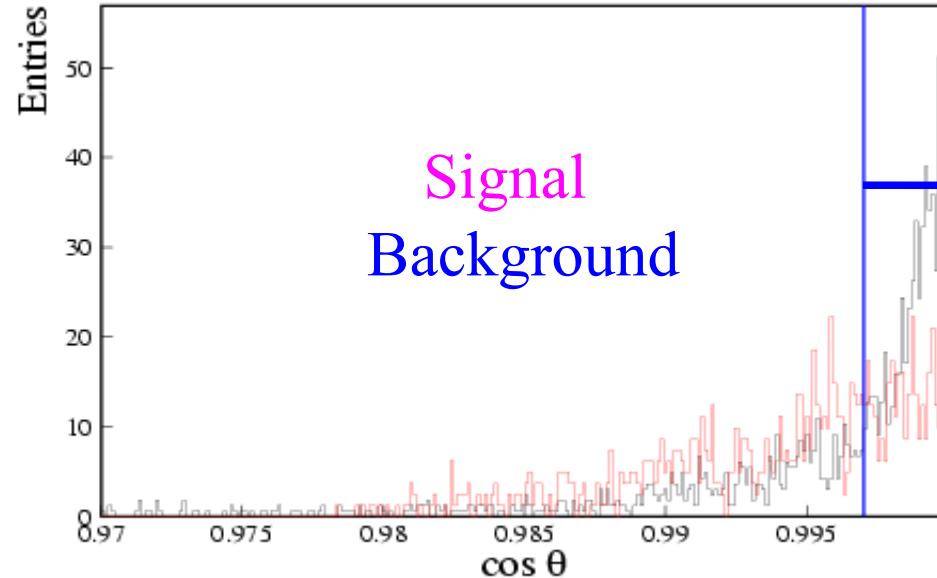
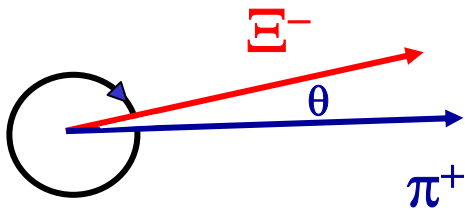


# $\Xi^+ \pi$ Invariant Mass Distribution

No clear structures at  $1.86 \text{ GeV}/c^2$



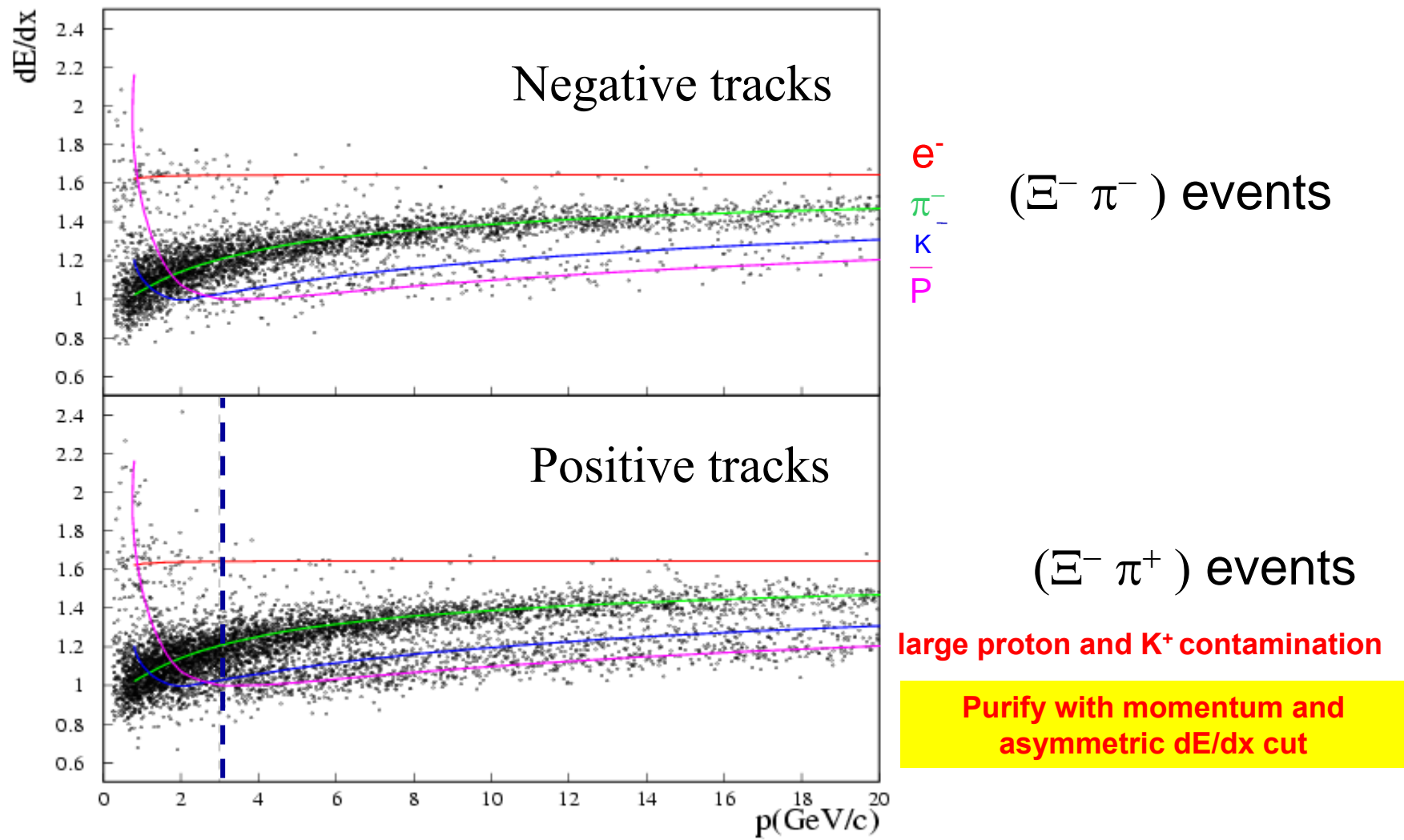
From the Monte Carlo simulation



$\theta > 4.5^\circ$

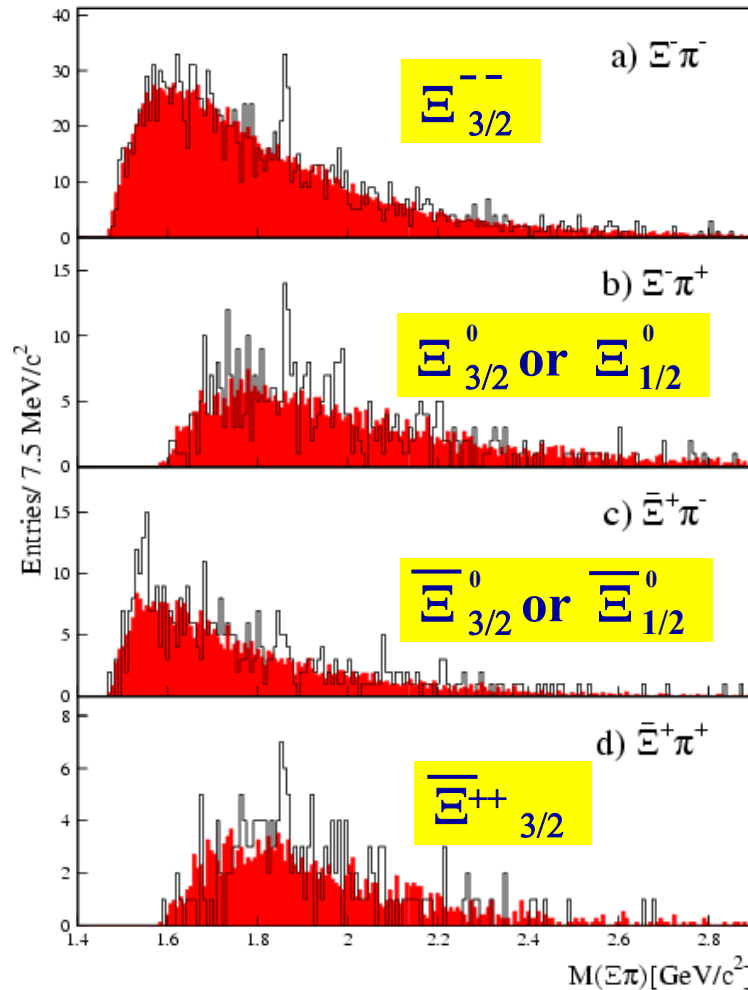
$\theta$ : lab. angle between  $E^-$  and  $\pi^+$

# Primary $\pi^+$ cuts: dE/dx and momentum



$$\cos(\theta) < 0.997 \quad (\theta > 4.5)$$

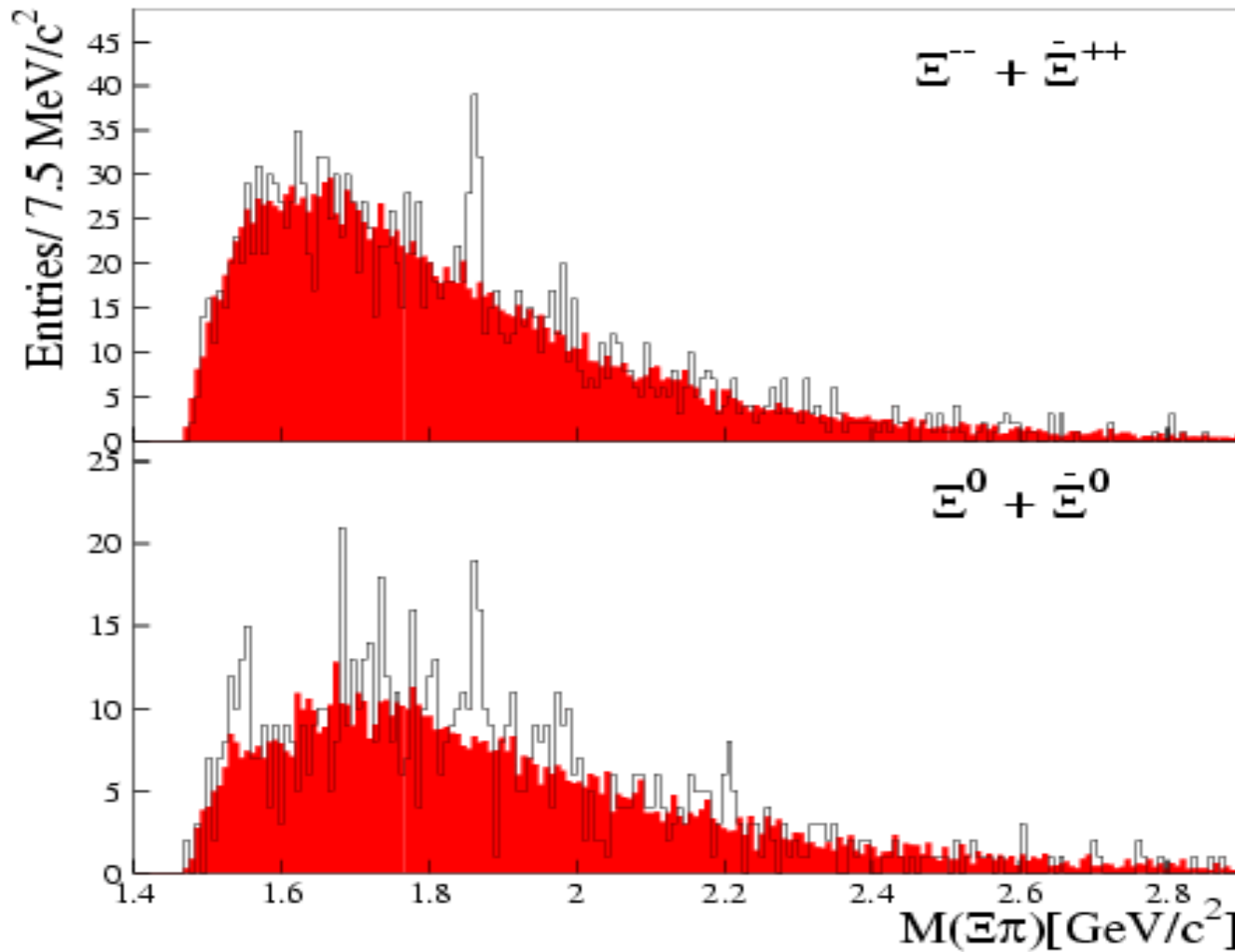
	$\Xi^-$	$\Xi^+$
$\pi^-$	$-1.5 \sigma < d_{bb}^\pi < 1.5 \sigma$	$-1.5 \sigma < d_{bb}^\pi < 1.5 \sigma$
$\pi^+$	$-0.5 \sigma < d_{bb}^\pi < 1.5 \sigma$ $p_\pi > 3 \text{ GeV}/c$	$-1.5 \sigma < d_{bb}^\pi < 1.5 \sigma$ $p_\pi > 3 \text{ GeV}/c$



C. Alt et al., hep-ex/0310014

Accepted by PRL

# Summed spectra



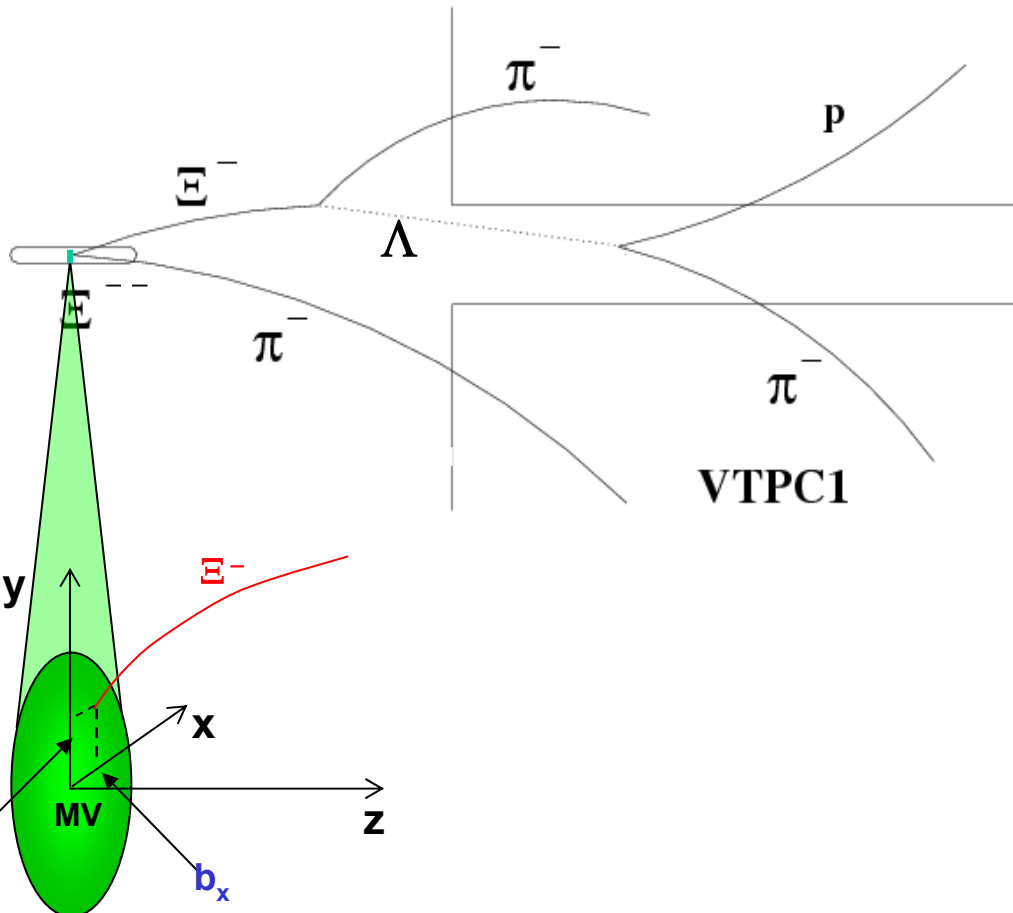


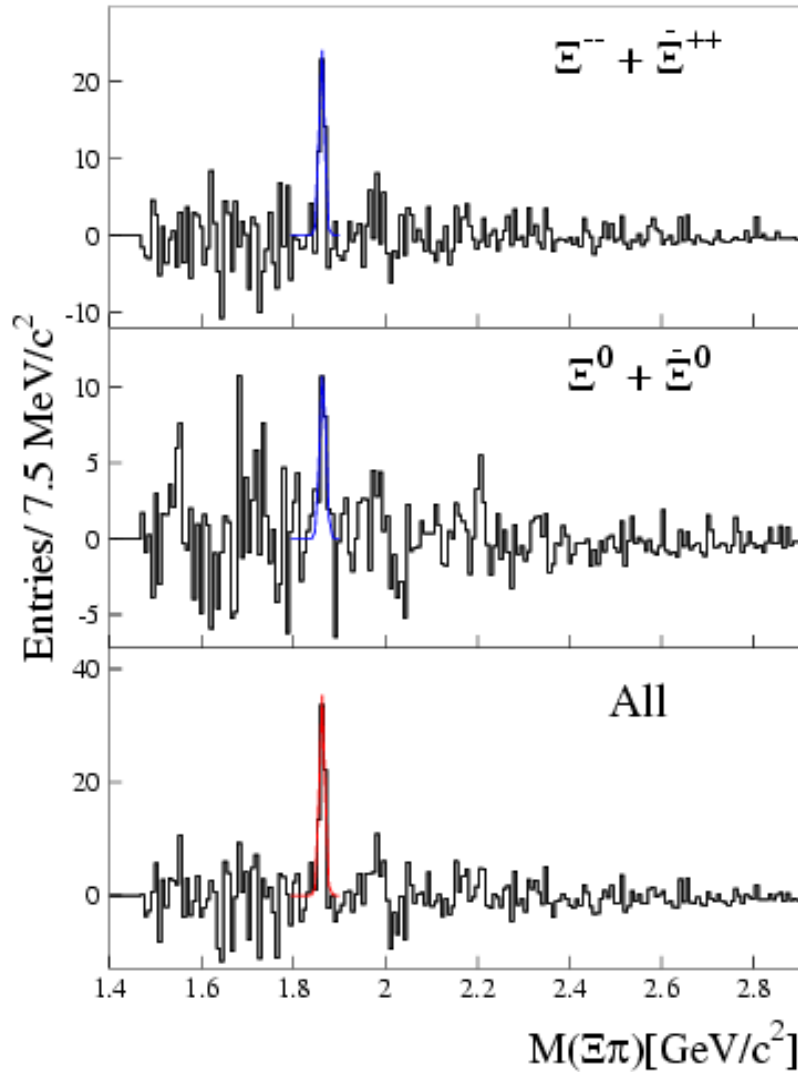
$$\Xi_{3/2}^- \longrightarrow \Xi^- \pi^- \quad (\Xi_{3/2}^{++} \longrightarrow \Xi^+ \pi^+)$$

$$\Xi_{3/2}^0 \longrightarrow \Xi^- \pi^+ \quad (\Xi_{3/2}^0 \longrightarrow \Xi^+ \pi^-) \quad \text{could also be the } \Xi_{1/2}$$

## $\Xi^-$ selection:

- Distance to Bethe- Bloch curve:  $|d_{bb}| < 3 \sigma$
- $|M(p\pi^-) - 1.115683| < 0.015 \text{ MeV}$
- $Z_{\Xi^-} - Z_{\text{main\_vtx}} > 12 \text{ cm}$
- $\Xi^-$  position at main vertex  $(b_x, b_y)$ :
  - $|b_x| < 2 \text{ cm}$
  - $|b_y| < 1 \text{ cm}$
- $\pi$  (from  $\Xi^-$  decay) position at main vertex
  - $|b_y| > 0.5 \text{ cm}$



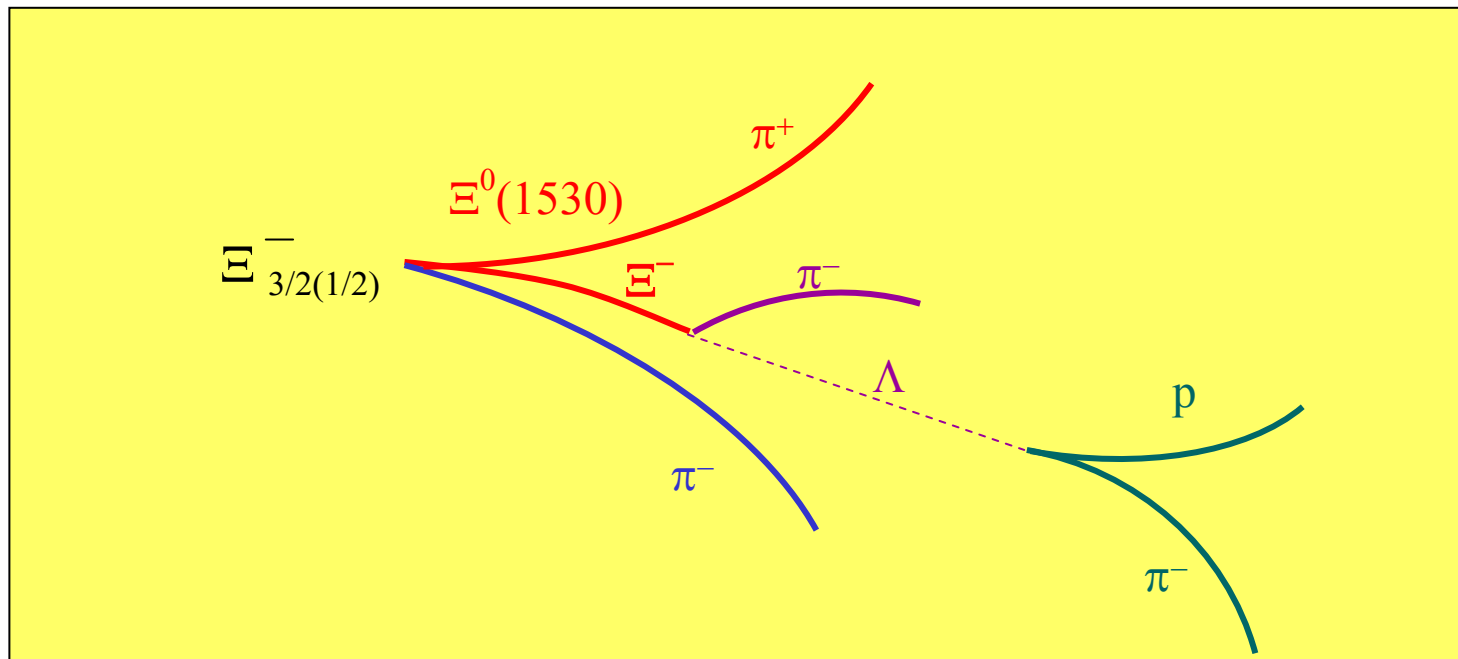
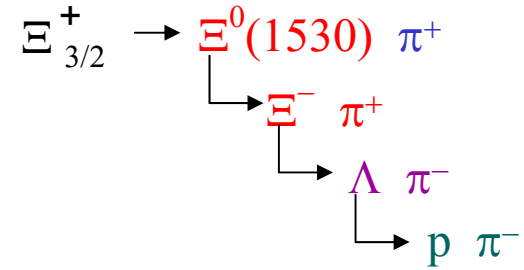
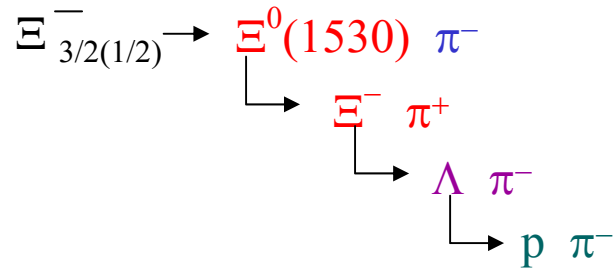


$$M = 1.862 \pm 0.002 \text{ GeV}/c^2$$

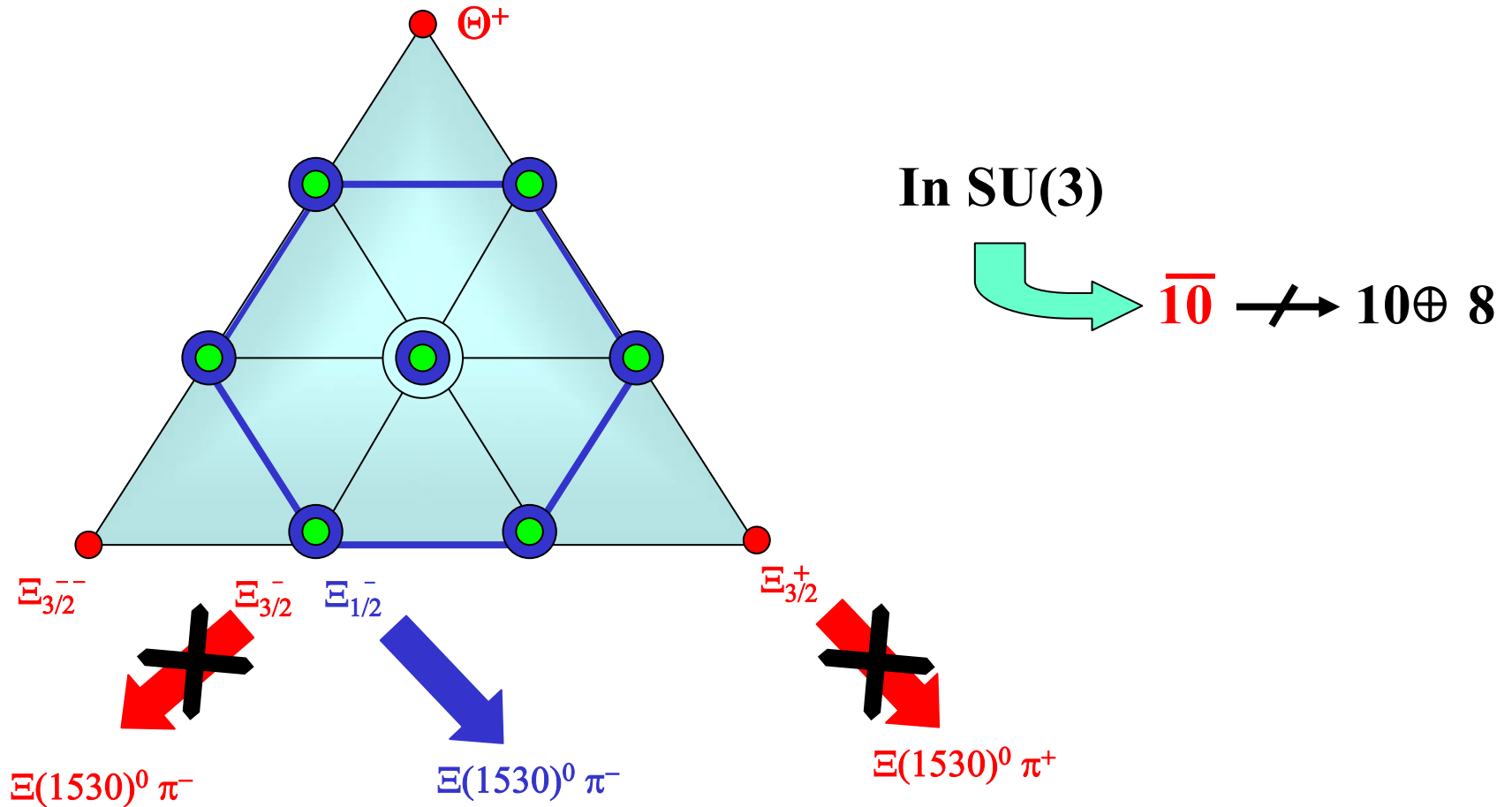
$$M = 1.864 \pm 0.005 \text{ GeV}/c^2$$

$$M = 1.862 \pm 0.002 \text{ GeV}/c^2$$

$$\Gamma \leq 18 \text{ MeV}/c^2$$

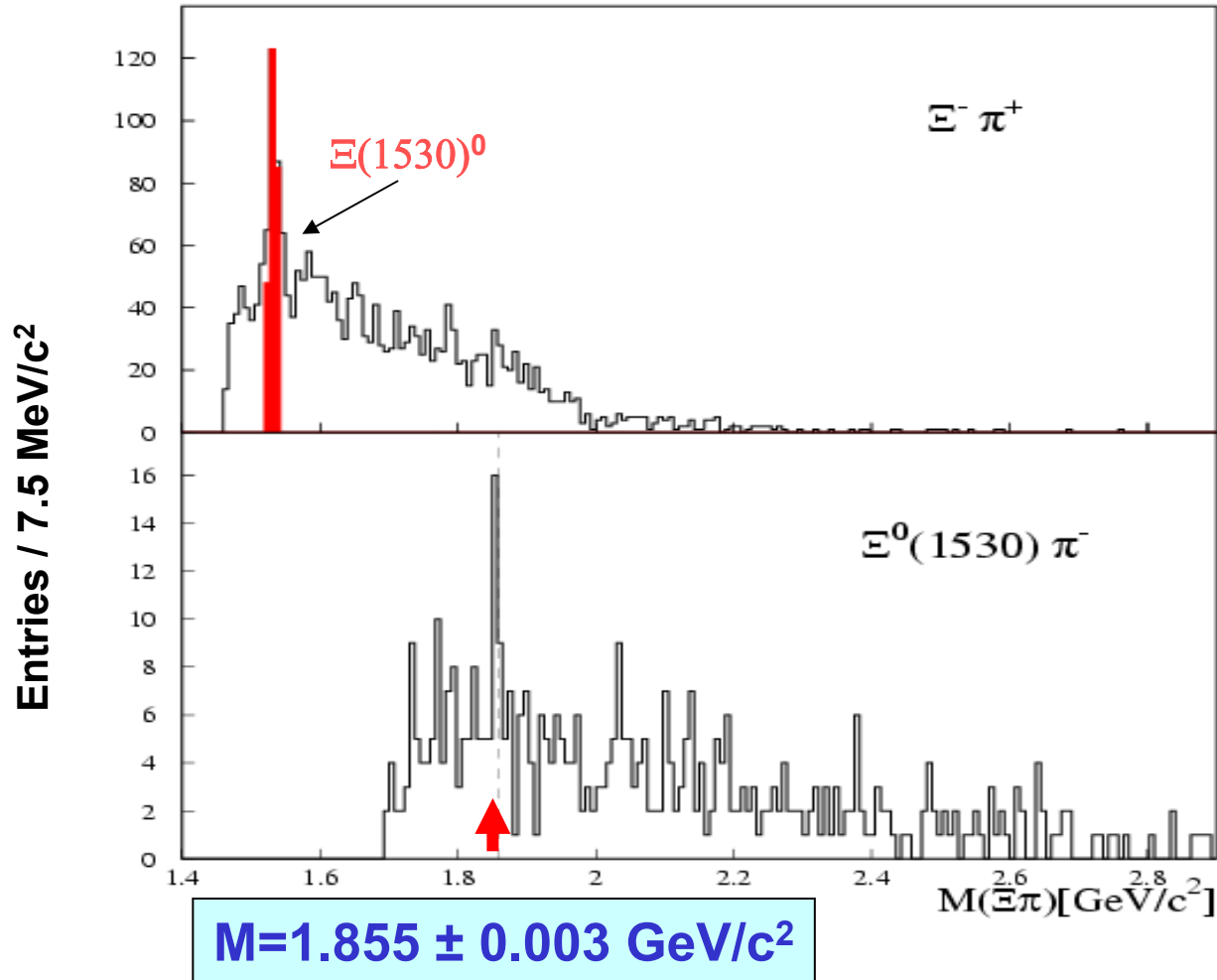



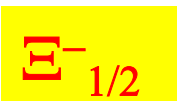


# What do we expect in $\Xi(1530)^0\pi$ ?



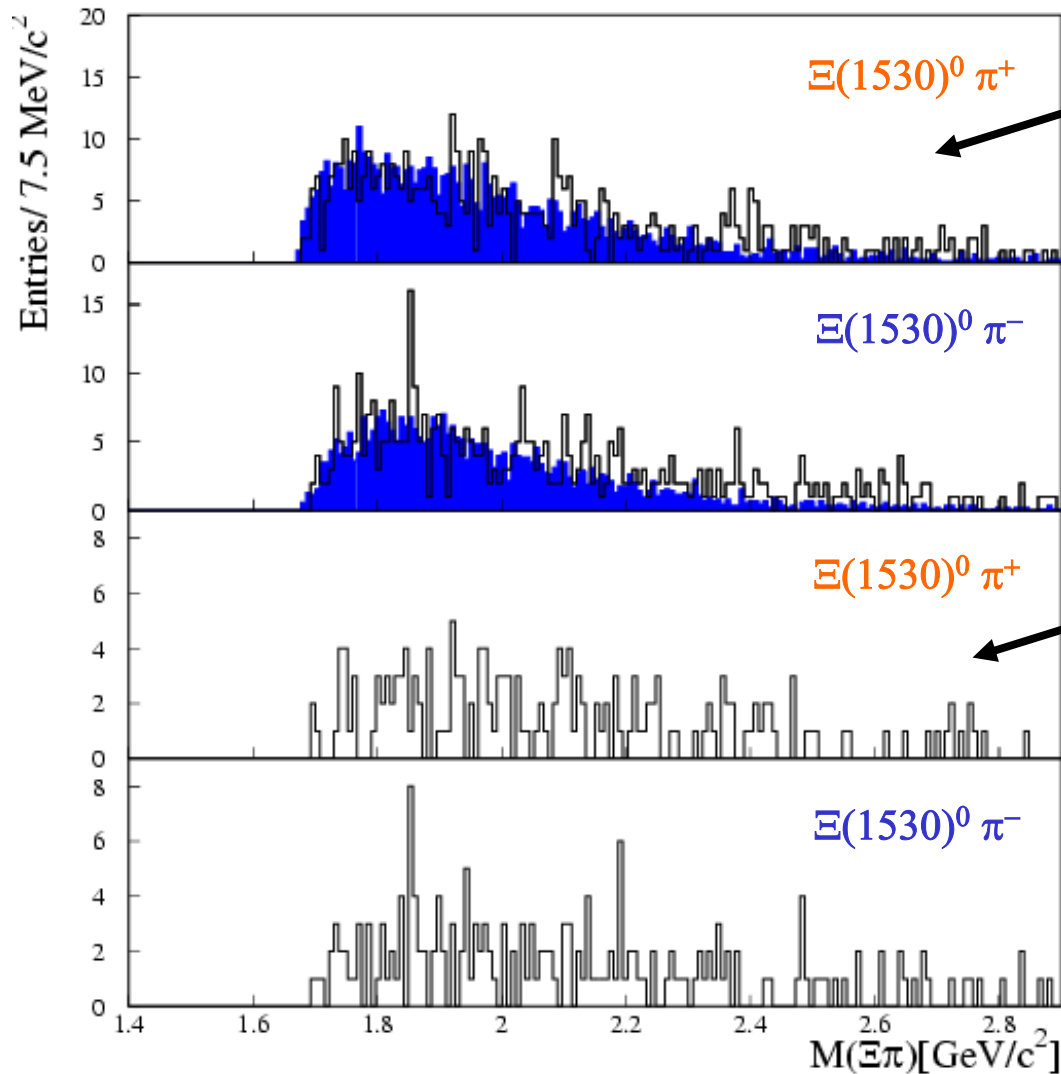
R. Jaffe and F. Wilczek, hep/ph/0312369

# $\Xi(1530)^0 \pi^-$ : PRELIMINARY



R. Jaffe and F. Wilczek



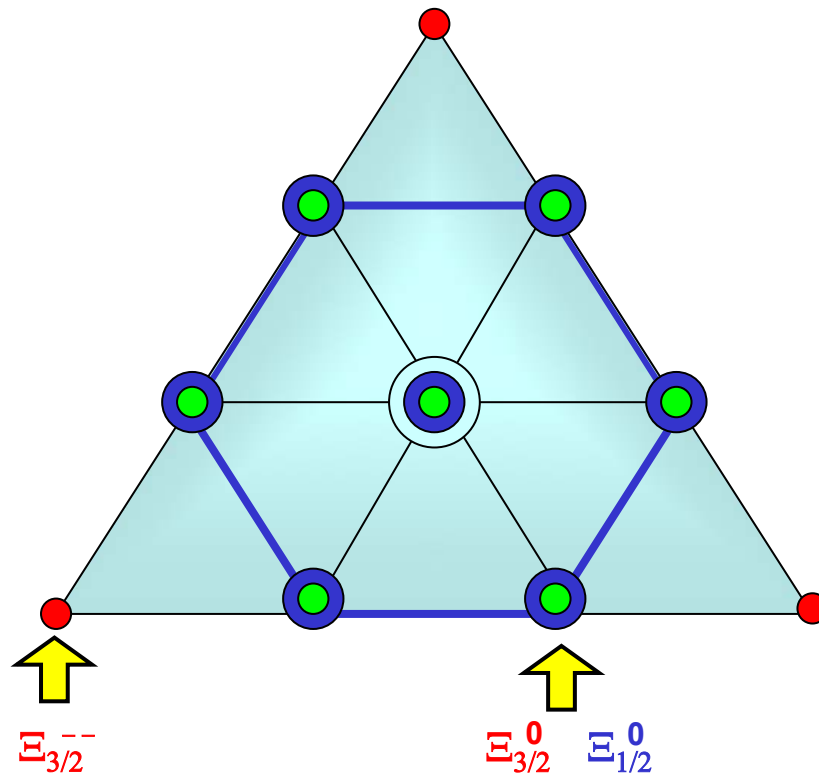
No evidence for  $\Xi_{3/2}^+$  to  $\Xi(1530)^0 \pi^+$  decay

No cuts

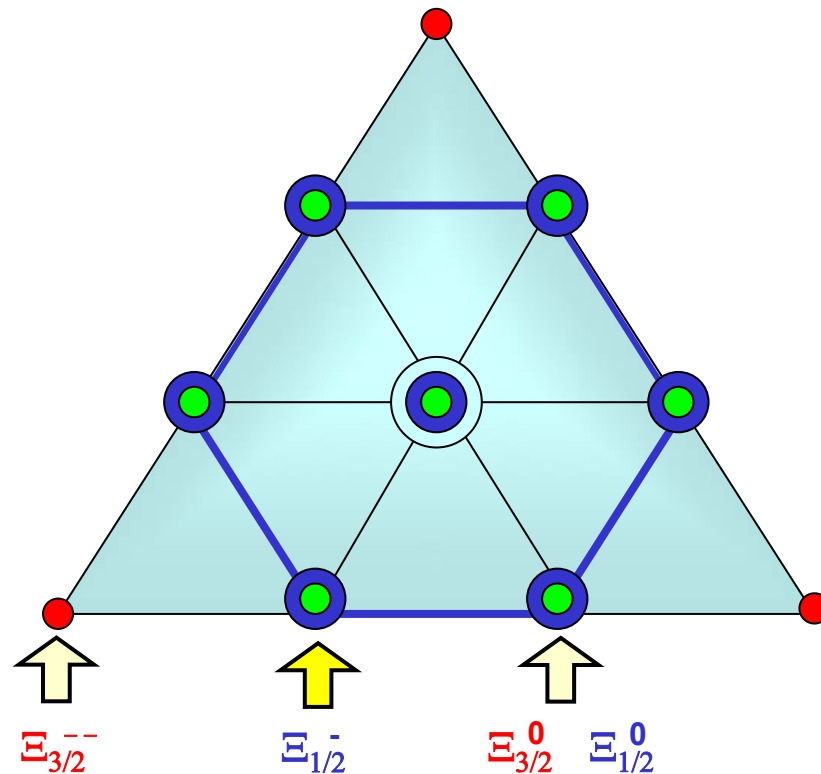
No evidence for  $\Xi_{3/2}^+$  to  $\Xi(1530)^0 \pi^+$  decay

$p_\pi > 3 \text{ GeV}/c$   
 +  
 $-0.5 \sigma < d_{bb}^\pi < 1.5 \sigma$

- Strong evidence for the existence of a narrow  $\Xi^- \pi^-$  resonance at  $M = 1.862 \pm 0.002 \text{ GeV}/c^2$  ( $\Gamma \leq 18 \text{ MeV}/c^2$ ) is observed
- At the same mass a peak is observed in the  $\Xi^- \pi^+$  spectrum
- The corresponding antibaryon spectra show enhancement at the same mass



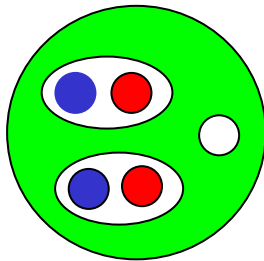
- There is preliminary evidence for existence of a narrow  $\Xi(1530)^0 \pi^-$  resonance at  $M = 1.855 \pm 0.003 \text{ GeV}/c^2$
- There is no indication for a  $\Xi(1530)^0 \pi^+$  resonance



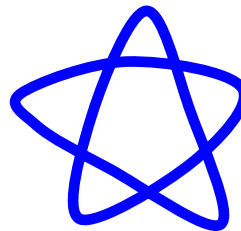


- Existence of the  $\Xi_{1/2}^-$  octet member supports the diquark model, and seems to contradict the standard soliton model
- There is a possibility to add an octet to the anti-decouplet in the soliton model, but there seems to be no reason to expect, as is observed, similar masses for the  $\Xi_{3/2}$  and  $\Xi_{1/2}$  states
- In the diquark model, the  $\Xi_{3/2}$  and  $\Xi_{1/2}$  naturally lie at the same mass

correlated quark



Soliton/Skyrme



## Open Questions

- Spin is unknown
- Parity is unknown
- Width ?
- Production mechanism?

## NA49

- Further improvement of experimental resolution
- Data sample increase by up to  $\sim 30\%$
- Search for  $\Sigma_s^{0(-)} \rightarrow \Xi^- K^+ (\Xi^- K^0_s)$

## NA49' Project

(Expression of Interest CERN-SPSC-2003-038)

### In particular :

- $(3-6) \cdot 10^7$  p+p events (new DAQ system)
- Neutral pions

C. Alt,<sup>9</sup> T. Anticic,<sup>20</sup> B. Baatar,<sup>8</sup> D. Barna,<sup>4</sup> J. Bartke,<sup>6</sup> M. Behler,<sup>13</sup> L. Betev,<sup>10,9</sup> H. Bialkowska,<sup>18</sup>  
A. Billmeier,<sup>9</sup> C. Blume,<sup>7,9</sup> B. Boimska,<sup>18</sup> M. Botje,<sup>1</sup> J. Bracinik,<sup>3</sup> R. Bramm,<sup>9</sup> R. Brun,<sup>10</sup> P. Bunčić,<sup>9,10</sup>  
V. Cerny,<sup>3</sup> P. Christakoglou,<sup>2</sup> O. Chvala,<sup>15</sup> J.G. Cramer,<sup>16</sup> P. Csató,<sup>4</sup> N. Darmanov,<sup>17</sup> A. Dimitrov,<sup>17</sup>  
P. Dinkelaker,<sup>9</sup> V. Eckardt,<sup>14</sup> G. Farantatos,<sup>2</sup> P. Filip,<sup>14</sup> D. Flierl,<sup>9</sup> Z. Fodor,<sup>4</sup> P. Foka,<sup>7</sup> P. Freund,<sup>14</sup>  
V. Friese,<sup>7,13</sup> J. Gál,<sup>4</sup> M. Gaździcki,<sup>9</sup> G. Georgopoulos,<sup>2</sup> E. Gladysz,<sup>6</sup> S. Hegyi,<sup>4</sup> C. Höhne,<sup>13</sup> K. Kadija,<sup>20</sup>  
A. Karev,<sup>14</sup> S. Kniese,<sup>9</sup> V.I. Kolesnikov,<sup>8</sup> T. Kollegger,<sup>9</sup> R. Korus,<sup>12</sup> M. Kowalski,<sup>6</sup> I. Kraus,<sup>7</sup> M. Kreps,<sup>3</sup>  
M. van Leeuwen,<sup>1</sup> P. Lévai,<sup>4</sup> L. Litov,<sup>17</sup> M. Makariev,<sup>17</sup> A.I. Malakhov,<sup>8</sup> C. Markert,<sup>7</sup> M. Mateev,<sup>17</sup>  
B.W. Mayes,<sup>11</sup> G.L. Melkumov,<sup>8</sup> C. Meurer,<sup>9</sup> A. Mischke,<sup>7</sup> M. Mitrovski,<sup>9</sup> J. Molnár,<sup>4</sup> St. Mrówczyński,<sup>12</sup>  
G. Pála,<sup>4</sup> A.D. Panagiotou,<sup>2</sup> D. Panayotov,<sup>17</sup> K. Perl,<sup>19</sup> A. Petridis,<sup>2</sup> M. Pikna,<sup>3</sup> L. Pinsky,<sup>11</sup> F. Pühlhofer,<sup>13</sup>  
J.G. Reid,<sup>16</sup> R. Renfordt,<sup>9</sup> W. Retyk,<sup>19</sup> C. Roland,<sup>5</sup> G. Roland,<sup>5</sup> M. Rybczyński,<sup>12</sup> A. Rybicki,<sup>6,10</sup> A. Sandoval,<sup>7</sup>  
H. Sann,<sup>7,\*</sup> N. Schmitz,<sup>14</sup> P. Seyboth,<sup>14</sup> F. Siklér,<sup>4</sup> B. Sitar,<sup>3</sup> E. Skrzypczak,<sup>19</sup> G. Stefanek,<sup>12</sup> R. Stock,<sup>9</sup>  
H. Ströbele,<sup>9</sup> T. Susa,<sup>20</sup> I. Szentpétery,<sup>4</sup> J. Sziklai,<sup>4</sup> T.A. Trainor,<sup>16</sup> D. Varga,<sup>4</sup> M. Vassiliou,<sup>2</sup> G.I. Veres,<sup>4,5</sup>  
G. Vesztergombi,<sup>4</sup> D. Vranić,<sup>7</sup> A. Wetzler,<sup>9</sup> Z. Włodarczyk,<sup>12</sup> I.K. Yoo,<sup>7</sup> J. Zaranek,<sup>9</sup> and J. Zimányi<sup>4</sup>

(NA49 Collaboration)

<sup>1</sup>NIKHEF, Amsterdam, Netherlands.

<sup>2</sup>Department of Physics, University of Athens, Athens, Greece.

<sup>3</sup>Comenius University, Bratislava, Slovakia.

<sup>4</sup>KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.

<sup>5</sup>MIT, Cambridge, MA, USA.

<sup>6</sup>Institute of Nuclear Physics, Cracow, Poland.

<sup>7</sup>Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany.

<sup>8</sup>Joint Institute for Nuclear Research, Dubna, Russia.

<sup>9</sup>Fachbereich Physik der Universität, Frankfurt, Germany.

<sup>10</sup>CERN, Geneva, Switzerland.

<sup>11</sup>University of Houston, Houston, TX, USA.

<sup>12</sup>Świętokrzyska Academy, Kielce, Poland.

<sup>13</sup>Fachbereich Physik der Universität, Marburg, Germany.

<sup>14</sup>Max-Planck-Institut für Physik, Munich, Germany.

<sup>15</sup>Institute of Particle and Nuclear Physics, Charles University, Prague, Czech Republic.

<sup>16</sup>Nuclear Physics Laboratory, University of Washington, Seattle, WA, USA.

<sup>17</sup>Atomic Physics Department, Sofia University St. Kliment Ohridski, Sofia, Bulgaria.

<sup>18</sup>Institute for Nuclear Studies, Warsaw, Poland.

<sup>19</sup>Institute for Experimental Physics, University of Warsaw, Warsaw, Poland.

<sup>20</sup>Rudjer Boskovic Institute, Zagreb, Croatia.

C. Alt,<sup>9</sup> T. Anticic,<sup>10</sup> H. Atar,<sup>13</sup> D. Barna,<sup>4</sup> J. Bartke,<sup>6</sup> M. Behler,<sup>13</sup> L. Betev,<sup>10,9</sup> H. Białkowska,<sup>18</sup>  
A. Billmeier,<sup>9</sup> C. Blume,<sup>7,9</sup> B. Boimska,<sup>18</sup> M. Botje,<sup>1</sup> J. Bracinik,<sup>3</sup> R. Bramm,<sup>9</sup> R. Brun,<sup>10</sup> P. Bunčić,<sup>9,10</sup>  
V. Cerny,<sup>3</sup> P. Christakoglou,<sup>2</sup> O. Chvala,<sup>15</sup> J.G. Cramer,<sup>16</sup> P. Csató,<sup>4</sup> N. Darmanov,<sup>17</sup> A. Dimitrov,<sup>17</sup>  
P. Dinkelaker,<sup>9</sup> V. Eckardt,<sup>14</sup> G. Farantatos,<sup>2</sup> P. Filip,<sup>14</sup> D. Flierl,<sup>9</sup> Z. Fodor,<sup>4</sup> P. Foka,<sup>7</sup> P. Freund,<sup>14</sup>  
V. Friese,<sup>7,13</sup> J. Gál,<sup>4</sup> M. Gaździcki,<sup>9</sup> G. Georgopoulos,<sup>2</sup> E. Gladysz,<sup>6</sup> S. Hegyi,<sup>4</sup> C. Höhne,<sup>3</sup> K. Kadija,<sup>9</sup>  
A. Karev,<sup>14</sup> S. Kniege,<sup>9</sup> V.I. Kolesnikov,<sup>8</sup> T. Kollegger,<sup>9</sup> R. Korus,<sup>12</sup> M. Kowalski,<sup>6</sup> I. Kraus,<sup>7</sup> M. Krieps,<sup>7</sup>  
M. van Leeuwen,<sup>1</sup> P. Lévai,<sup>4</sup> L. Litov,<sup>17</sup> M. Makariev,<sup>17</sup> A.I. Malakhov,<sup>8</sup> C. Markert,<sup>7</sup> M. Mateev,<sup>17</sup>  
B.W. Mayes,<sup>11</sup> G.L. Melkumov,<sup>8</sup> C. Meurer,<sup>9</sup> A. Mischke,<sup>7</sup> M. Mitrovski,<sup>9</sup> J. Molnár,<sup>4</sup> St. Mrówczyński,<sup>12</sup>  
G. Pála,<sup>4</sup> A.D. Panagiotou,<sup>2</sup> D. Panayotov,<sup>17</sup> K. Perl,<sup>19</sup> A. Petridis,<sup>2</sup> M. Pikna,<sup>3</sup> L. Pinsky,<sup>11</sup> F. Pühlhofer,<sup>13</sup>  
J.G. Reid,<sup>16</sup> R. Renfordt,<sup>9</sup> W. Retyk,<sup>19</sup> C. Roland,<sup>5</sup> G. Roland,<sup>5</sup> M. Rybczyński,<sup>12</sup> A. Rybicki,<sup>6,10</sup> A. Sandoval,<sup>7</sup>  
H. Sann,<sup>7</sup> N. Schmitz,<sup>14</sup> P. Seyboth,<sup>14</sup> F. Siklér,<sup>4</sup> B. Sitar,<sup>3</sup> E. Skrzypczak,<sup>19</sup> G. Stefanek,<sup>12</sup> R. Stock,<sup>9</sup>  
H. Ströbele,<sup>9</sup> T. Suga,<sup>19</sup> P. Szentpétery,<sup>4</sup> J. Sziklai,<sup>4</sup> T.A. Trainor,<sup>16</sup> D. Varga,<sup>4</sup> M. Vassiliou,<sup>2</sup> G.I. Veres,<sup>4,5</sup>  
G. Vesztegombi,<sup>4</sup> D. Vranić,<sup>7</sup> A. Wetzler,<sup>9</sup> Z. Włodarczyk,<sup>12</sup> I.K. Yoo,<sup>7</sup> J. Zaranek,<sup>9</sup> and J. Zimányi<sup>4</sup>

(NA49 Collaboration)

<sup>1</sup>NIKHEF, Amsterdam, Netherlands.

<sup>2</sup>Department of Physics, University of Athens, Athens, Greece.

<sup>3</sup>Comenius University, Bratislava, Slovakia.

<sup>4</sup>KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.

<sup>5</sup>MIT, Cambridge, MA, USA.

<sup>6</sup>Institute of Nuclear Physics, Cracow, Poland.

<sup>7</sup>Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany.

<sup>8</sup>Joint Institute for Nuclear Research, Dubna, Russia.

<sup>9</sup>Fachbereich Physik der Universität, Frankfurt, Germany.

<sup>10</sup>CERN, Geneva, Switzerland.

<sup>11</sup>University of Houston, Houston, TX, USA.

<sup>12</sup>Świętokrzyska Academy, Kielce, Poland.

<sup>13</sup>Fachbereich Physik der Universität, Marburg, Germany.

<sup>14</sup>Max-Planck-Institut für Physik, Munich, Germany.

<sup>15</sup>Institute of Particle and Nuclear Physics, Charles University, Prague, Czech Republic.

<sup>16</sup>Nuclear Physics Laboratory, University of Washington, Seattle, WA, USA.

<sup>17</sup>Atomic Physics Department, Sofia University St. Kliment Ohridski, Sofia, Bulgaria.

<sup>18</sup>Institute for Nuclear Studies, Warsaw, Poland.

<sup>19</sup>Institute for Experimental Physics, University of Warsaw, Warsaw, Poland.

**Ruder Bošković Institute, Zagreb, Croatia**