Study of the Λ(1405) Resonance in Proton Induced Reactions

Eliane Epple

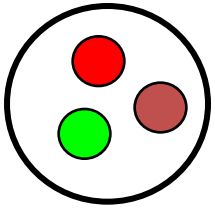
Mo, 12.10.09 Trento

- Introduction
- $\Sigma(1385)^+$ and kinematic refit
- Analysis of the Channel
  $\Lambda(1405) \rightarrow \Sigma^0 \pi^0$
- Analysis of the Channels
  $\Lambda(1405) \rightarrow \Sigma^{-/+} \pi^{+/-}$
- Outlook

Structure of the $\Lambda(1405)$

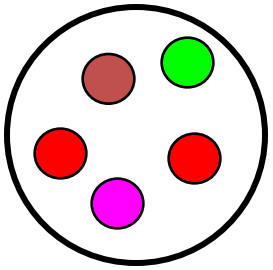
$m \approx 1406$ MeV/c²
$\Gamma \approx 50$ MeV/c²

(uds)



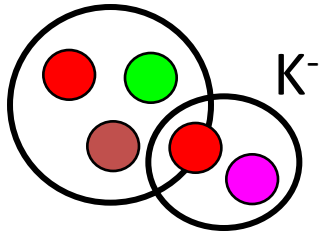
q^3 baryon ?

$(q^4\bar{q})$



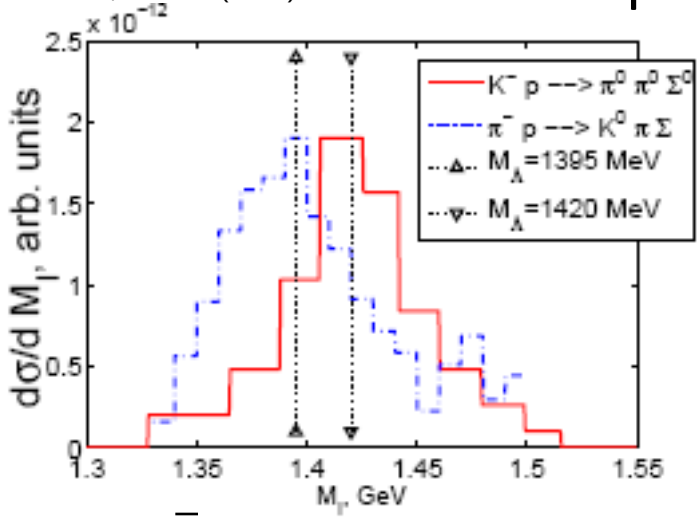
Pentaquark ?

N



Molecular state ?

V. K. Magas et al. Phys. Rev. Lett. 95, 052301 (2005)



— $\bar{K}N$-Amplitude dominant
···· $\pi\Sigma$-Amplitude dominant

S. Prakhov et al. Phys. Rev. C 70 (2004) 034605
A.W. Thomas et al., Nucl. Phys. B56 15 (1973)

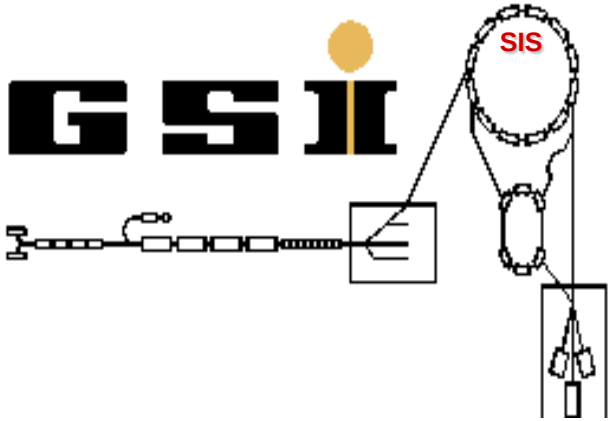
- $\Lambda(1405) \overset{?}{=} \bar{K}N + \pi\Sigma$
- $\bar{K}N$ potential strength
- Spectral function of the $\Lambda(1405)$ in the $\Sigma\pi$ decay channel in pp

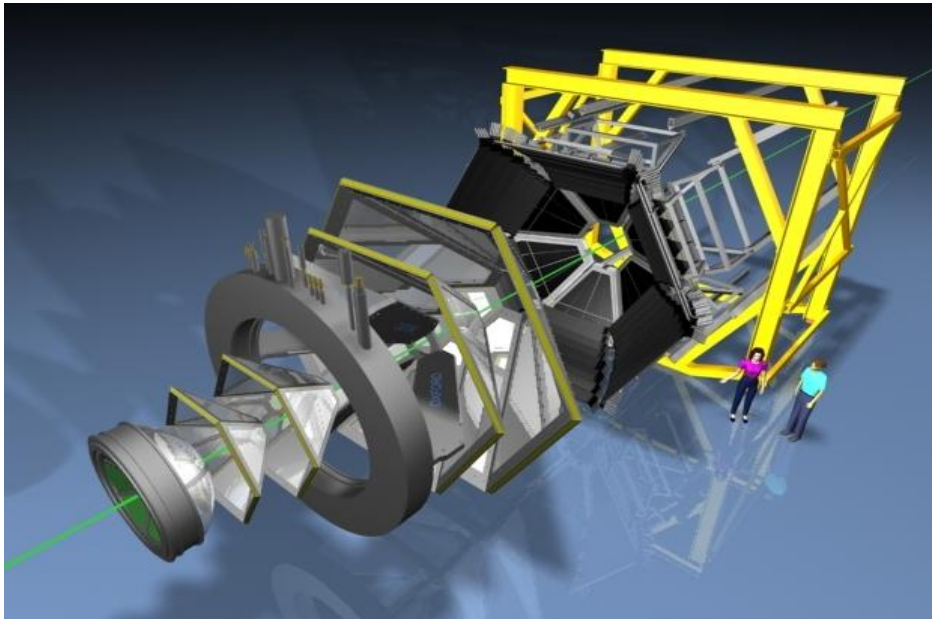
$\Lambda(1405) \rightarrow \Sigma^0\pi^0$
$\rightarrow \Sigma^{+/-}\pi^{-/+}$

Different ?

The HADES Spectrometer

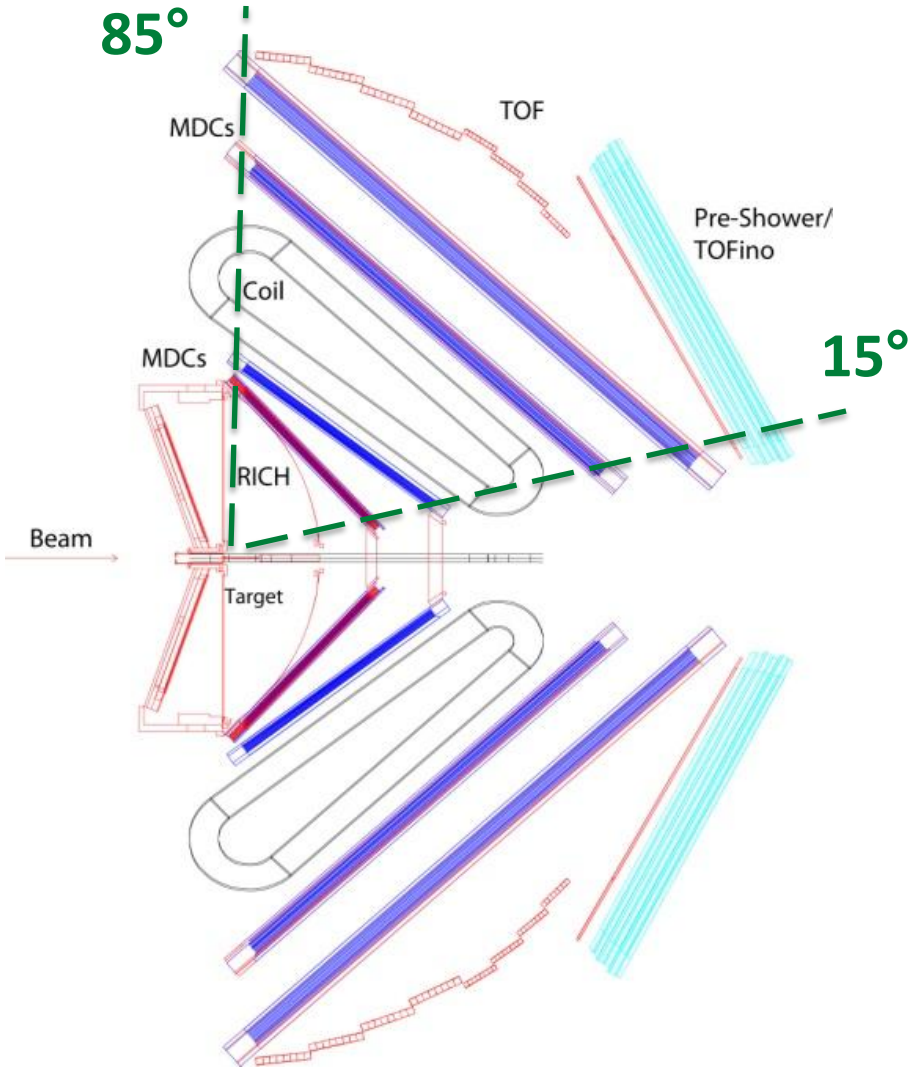
High **A**cceptance **D**ielectron **S**pectrometer





3 Weeks of p+p at E_{beam}= 3.5 GeV
a total Statistic of $1.2 \cdot 10^9$ Events

The HADES Spectrometer



- Proton beam + LH2 target
- Detector geometry
  - full azimuthal range covered, 6 sectors
  - Polar angle: $15^o<\theta<85^o$
- Tracking
  - Superconducting coils, toroidal field
  - 24 Mini Drift Chambers
- Particle identification (e,π,K,p)
  - RICH, MDC, TOF, TOFINO, Shower
- $\Delta p/p \sim 2\text{-}4\%$
- Trigger:
  - 1st Level: charged particle mult. (TOF/TOFINO)
  - 2nd Level: single electron trigger (RICH)

Designed for di-electron spectroscopy, also suited for hadronic channels

Hadron identification with HADES

Energy loss per distance travelled of swift charged particles traversing matter (dE/dx)

$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2\beta^2}{I\cdot(1-\beta^2)}\right) - \beta^2\right]$$

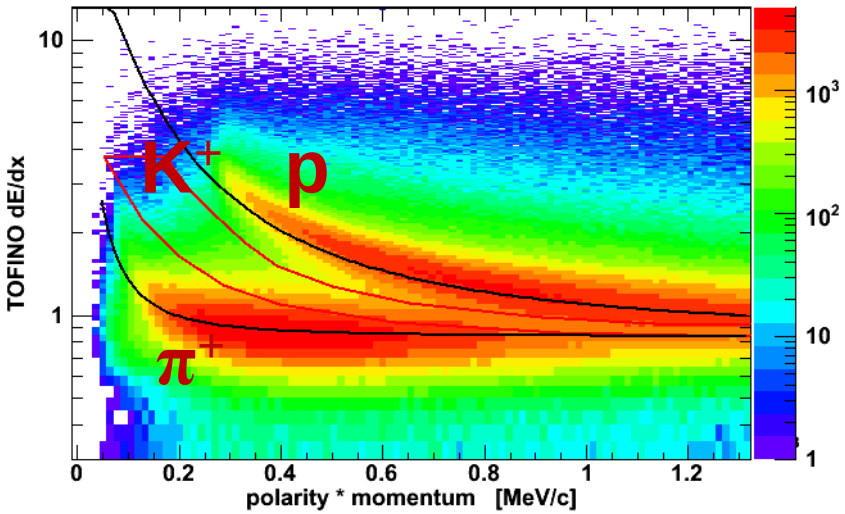
$\beta = v / c$

I mean excitation potential of the target

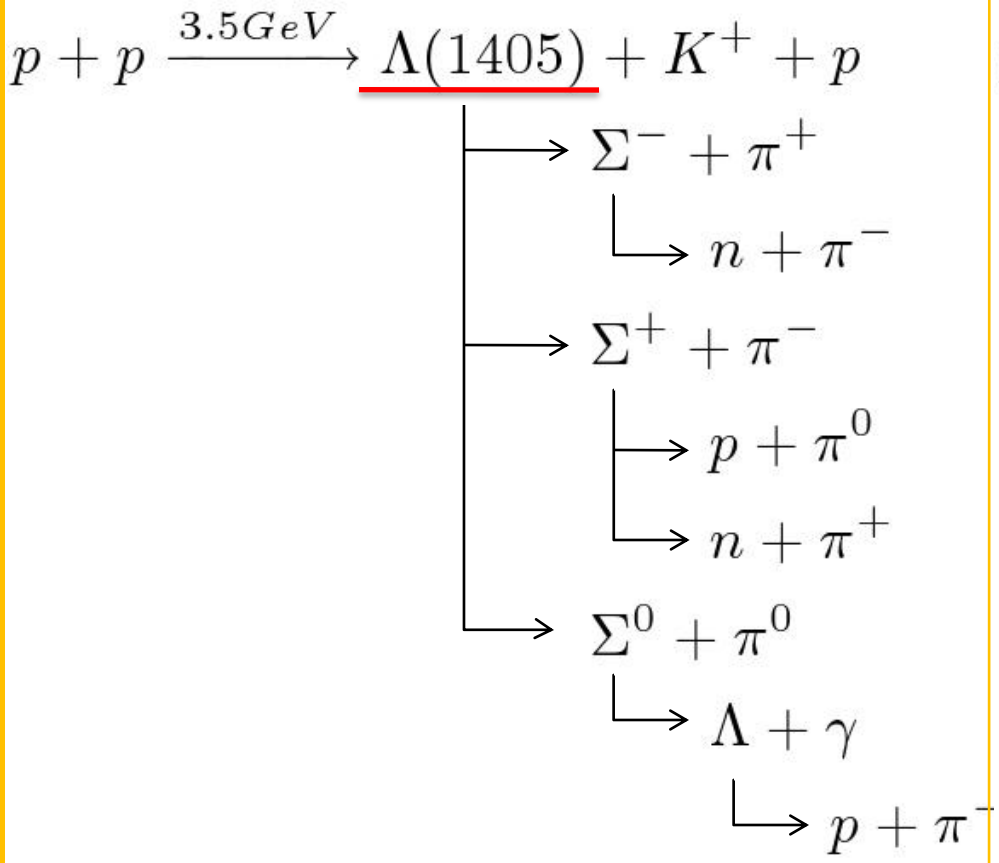
x distance travelled by the particle

n electron density of the target

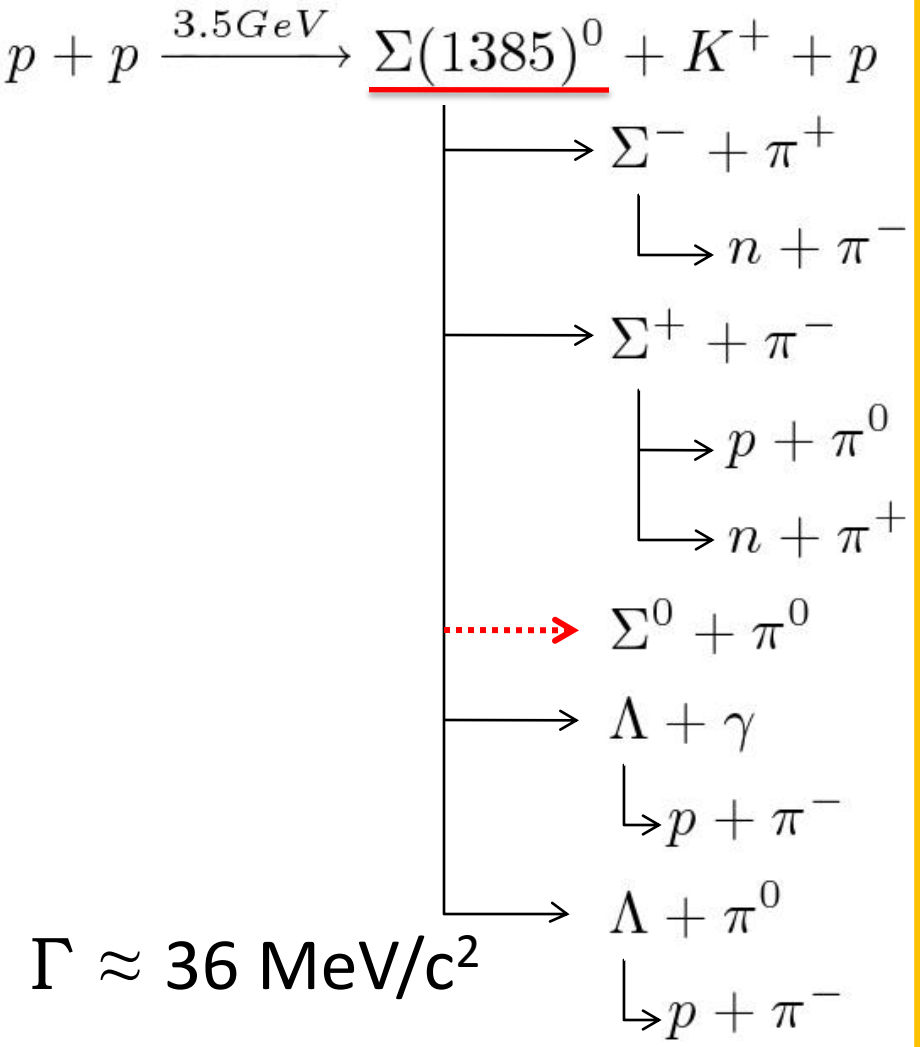
dE/dx and p are measured by the spectrometer



Decay channels of $\Lambda(1405)/\Sigma(1385)^0$



$\Gamma \approx 50$ MeV/c²



$\Gamma \approx 36$ MeV/c²

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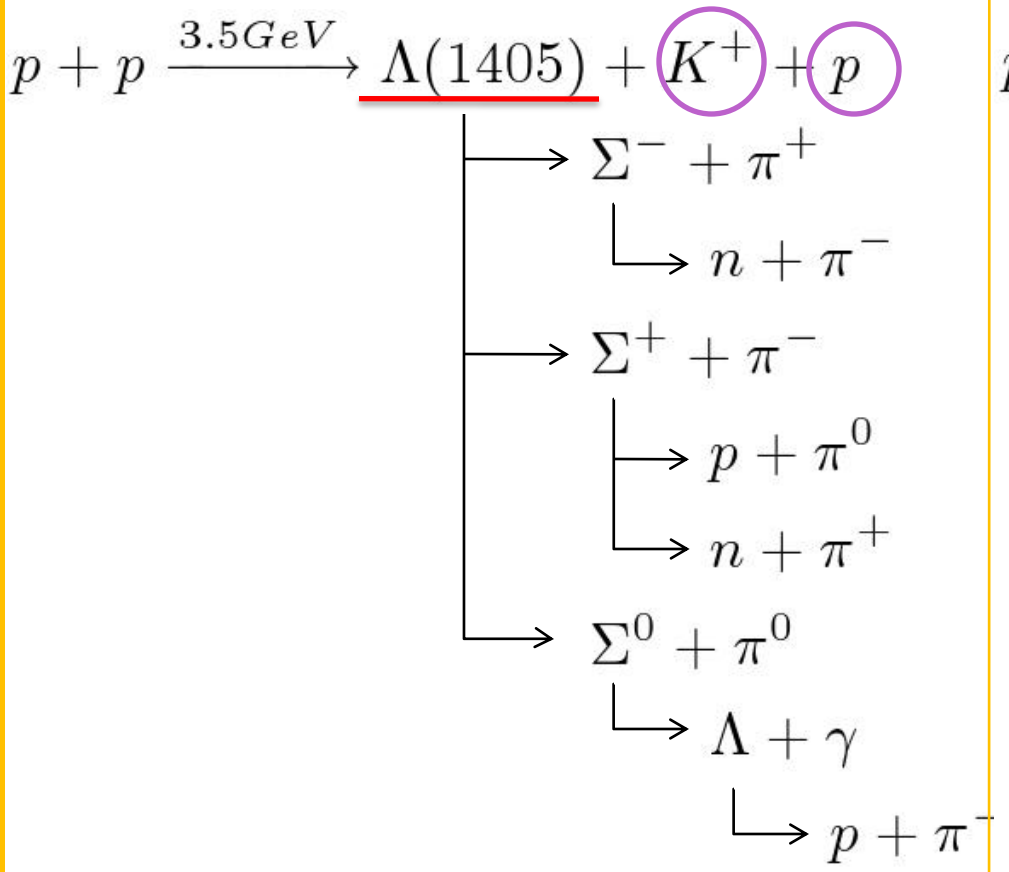

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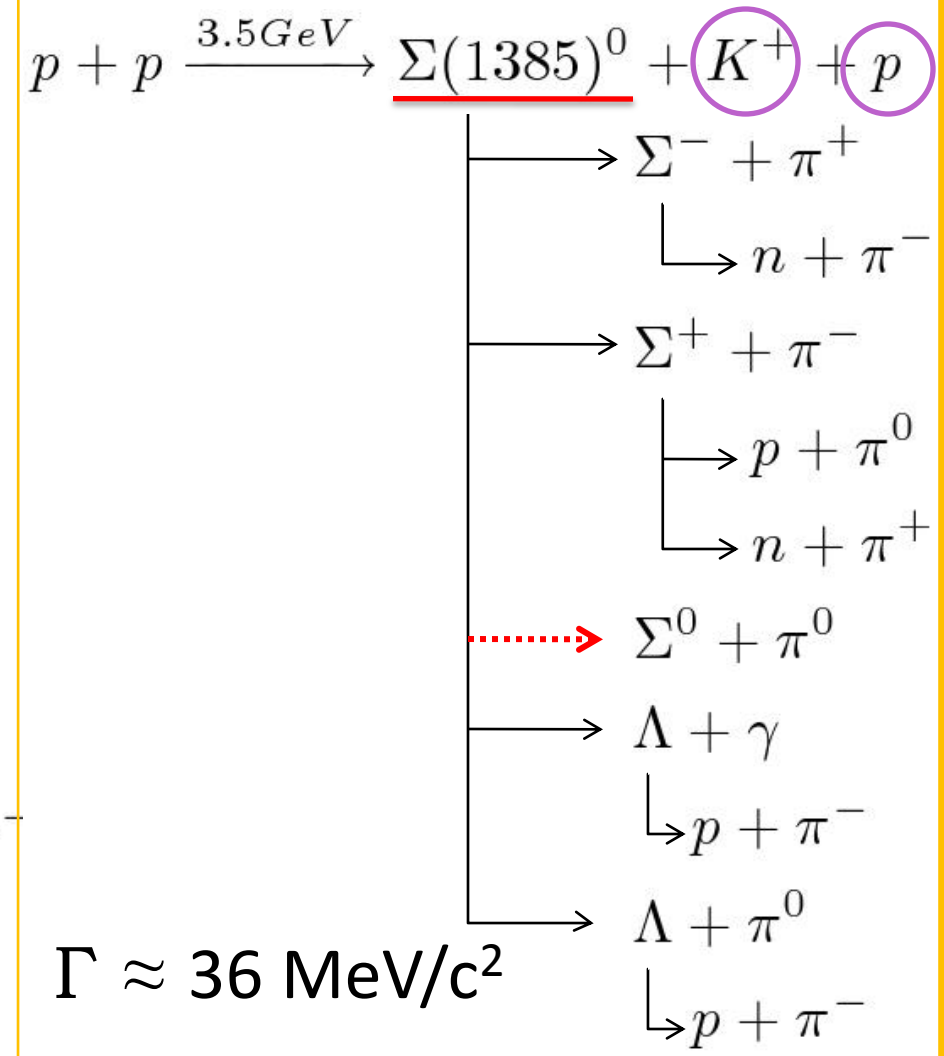

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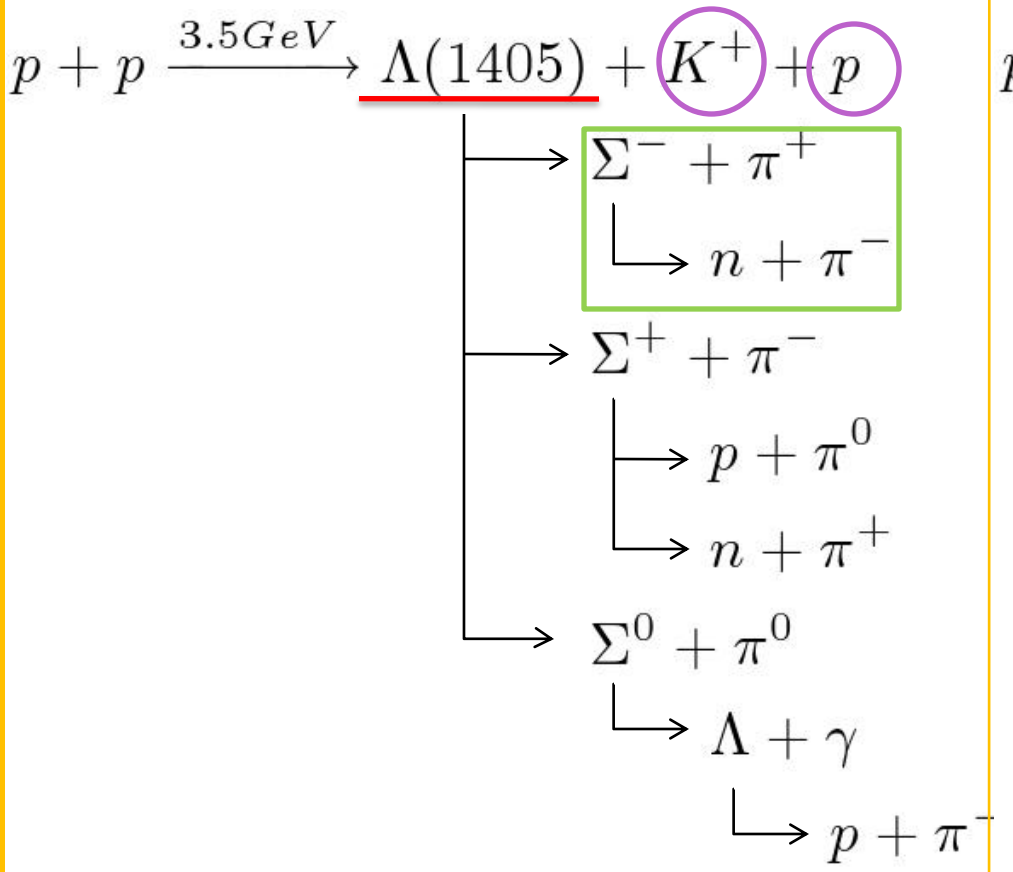

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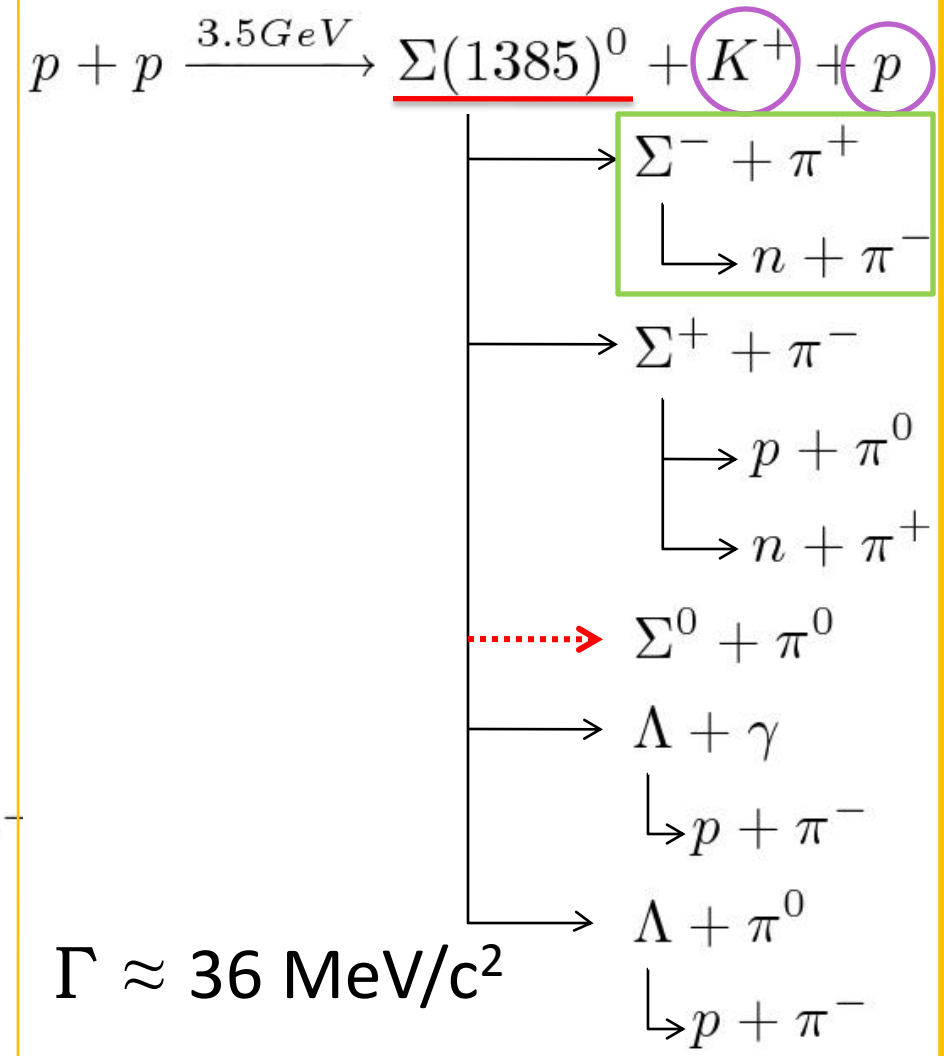

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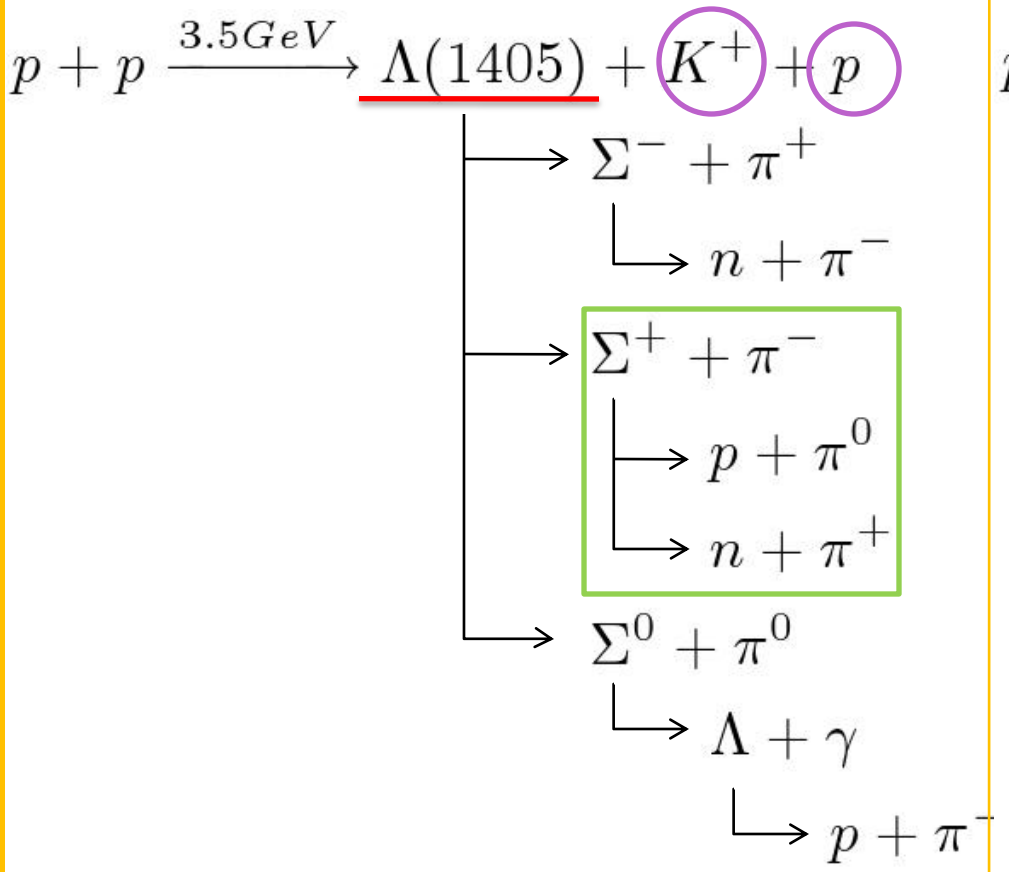

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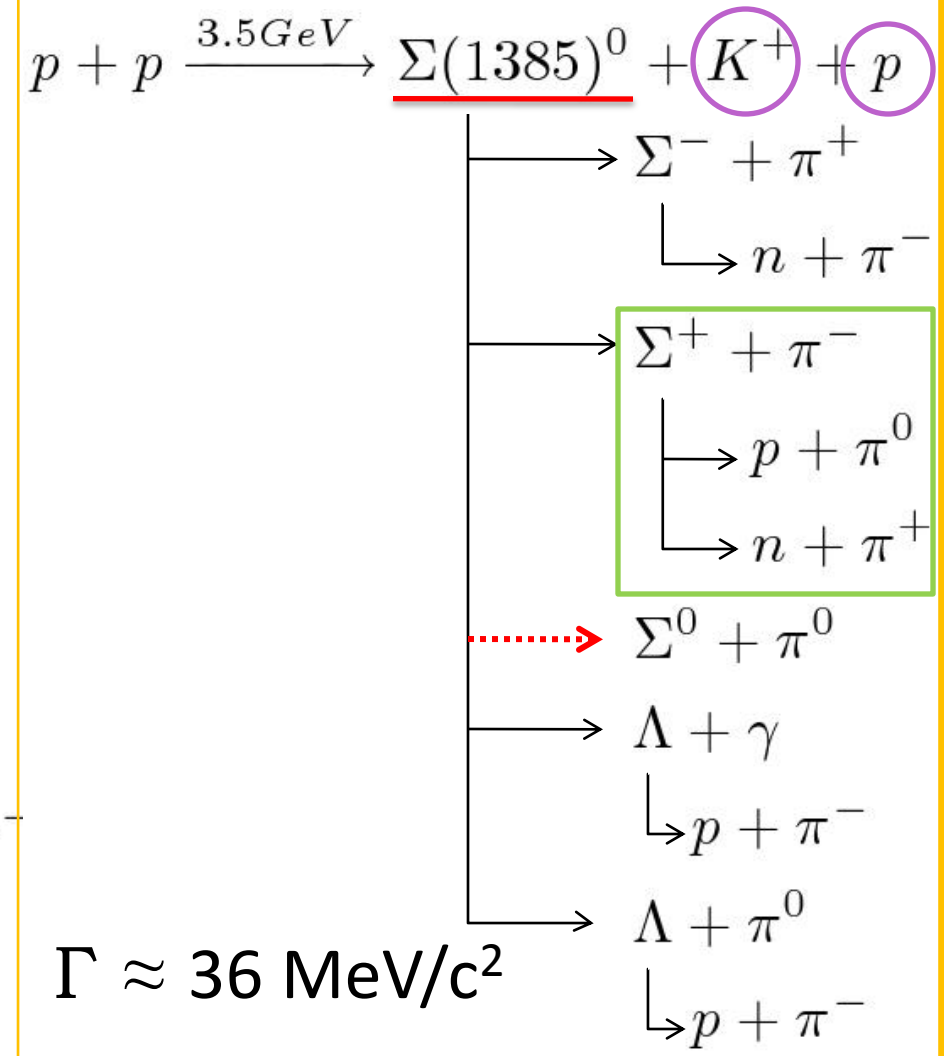

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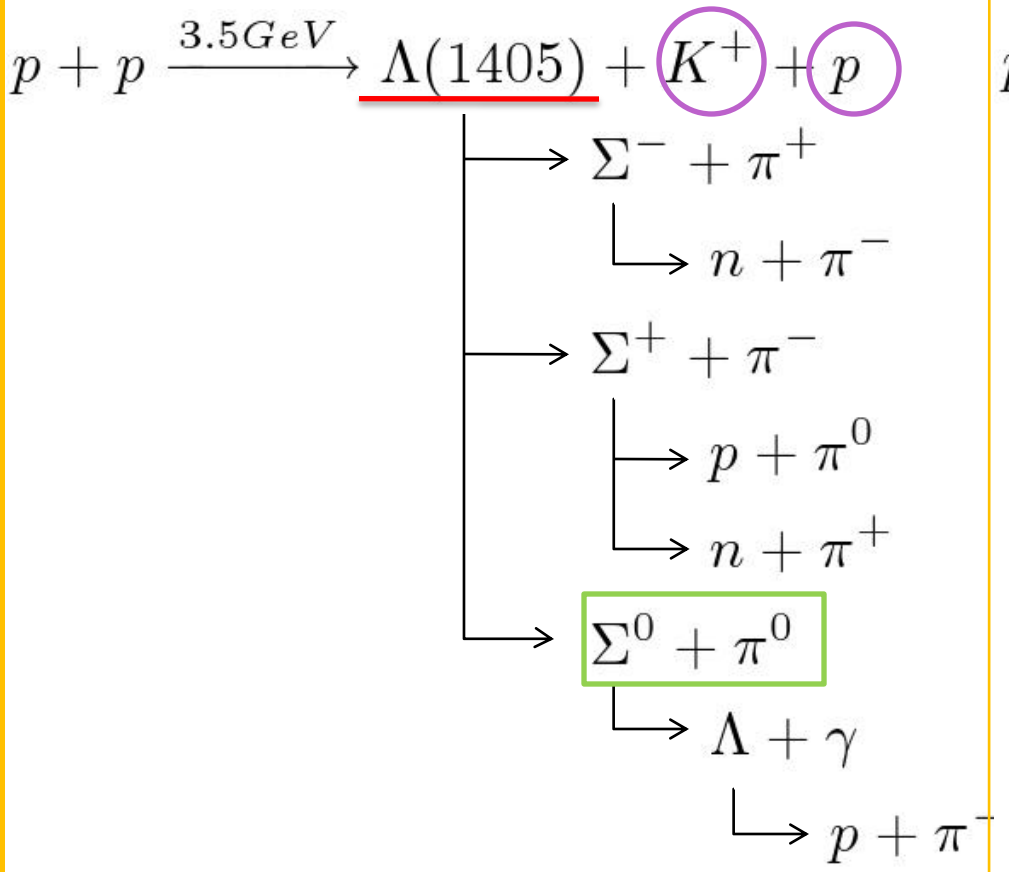

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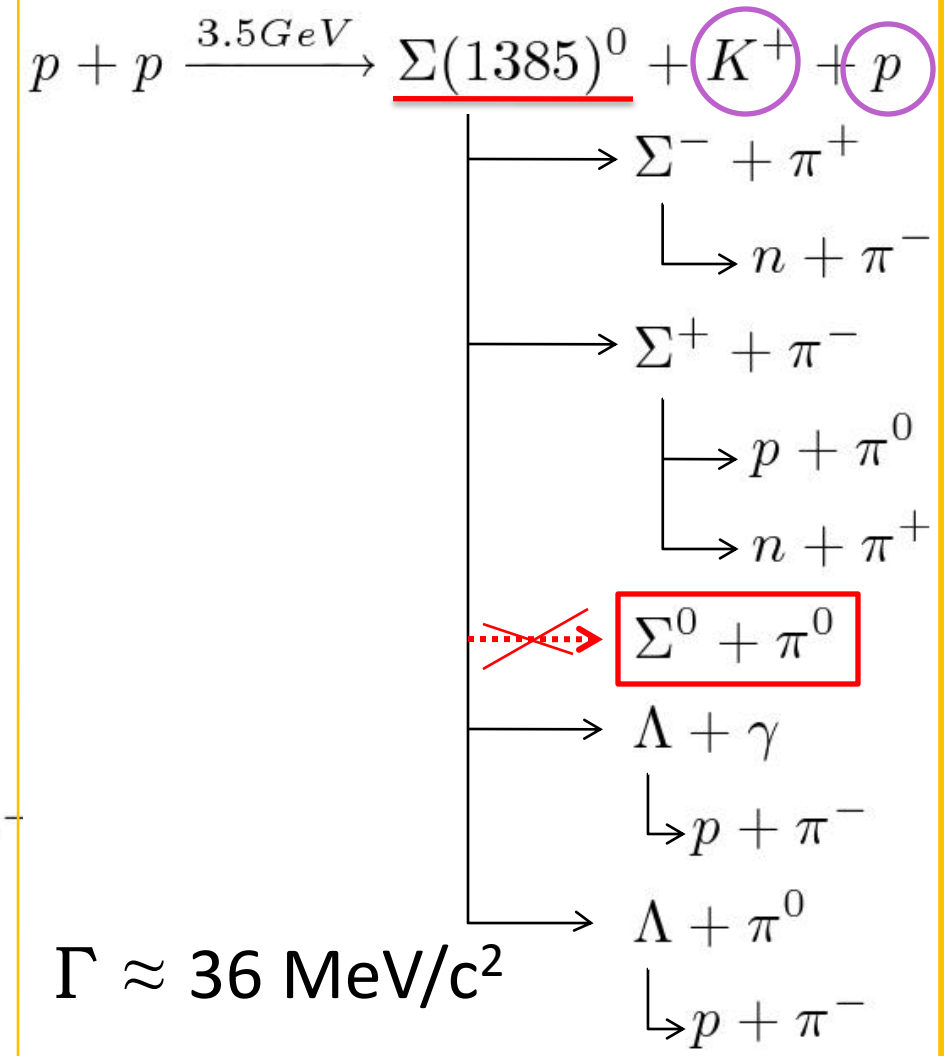

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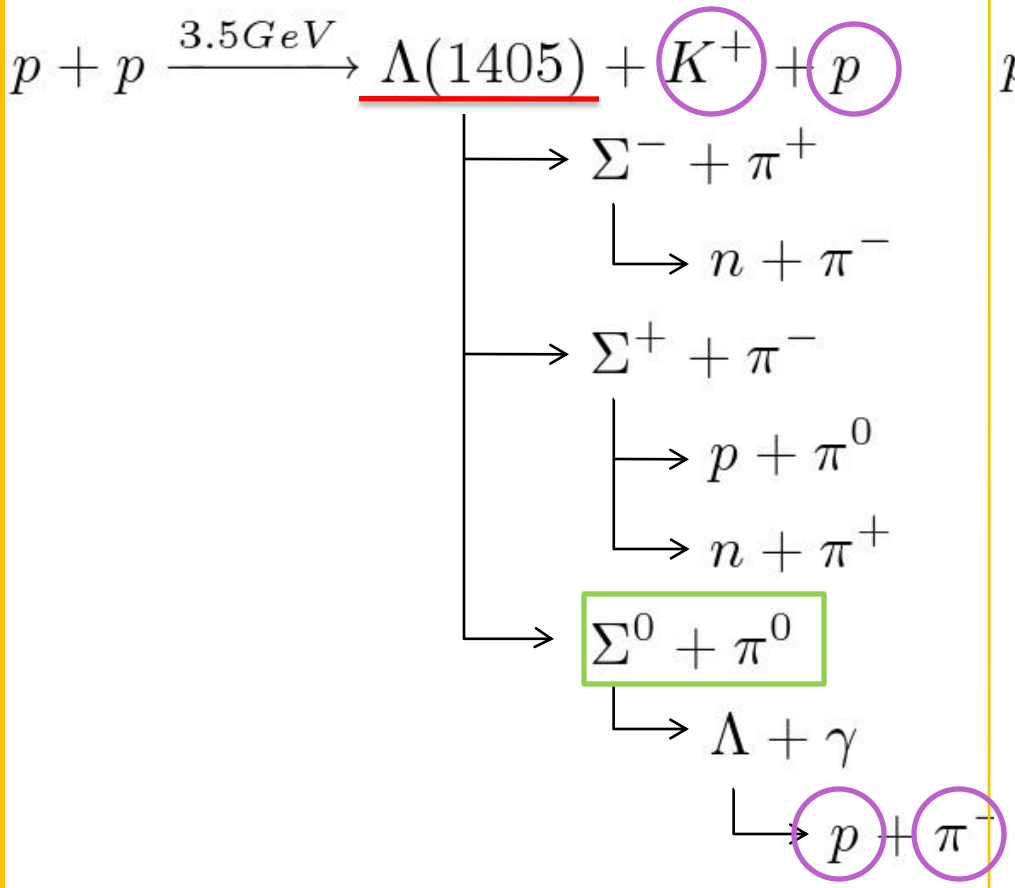

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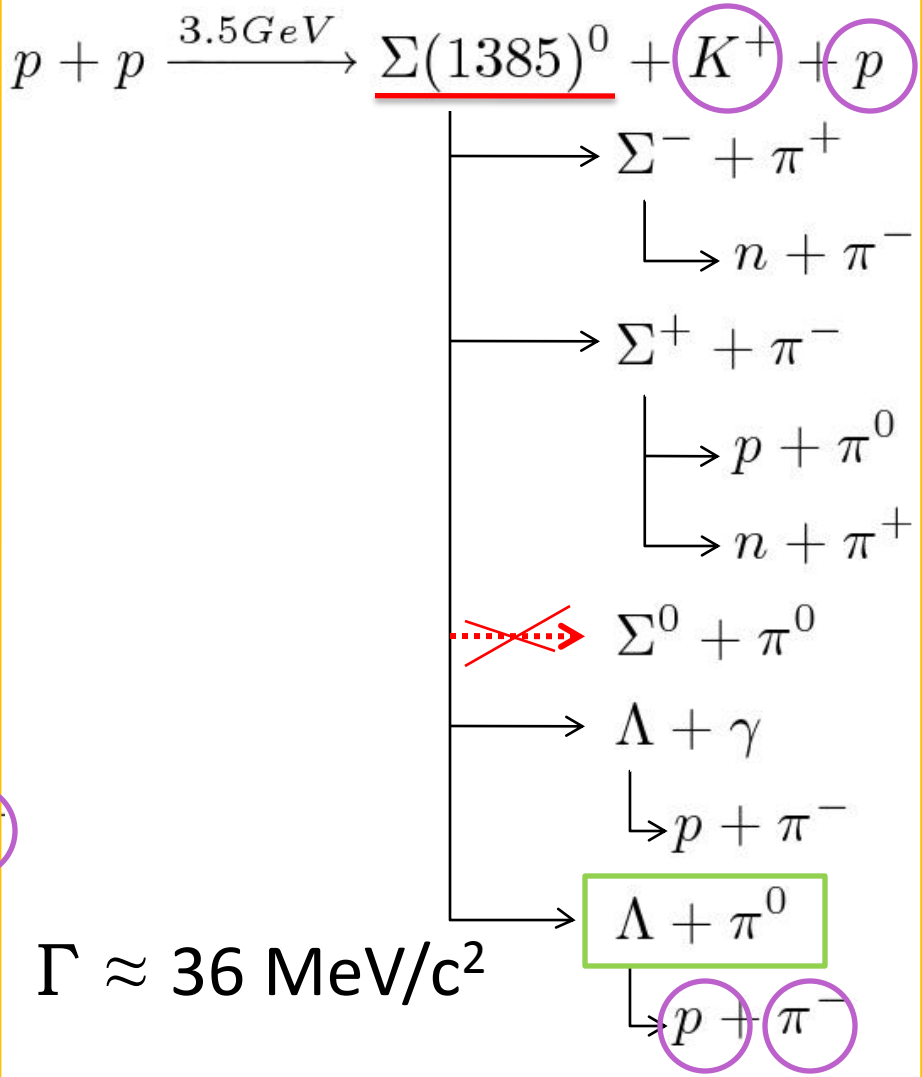

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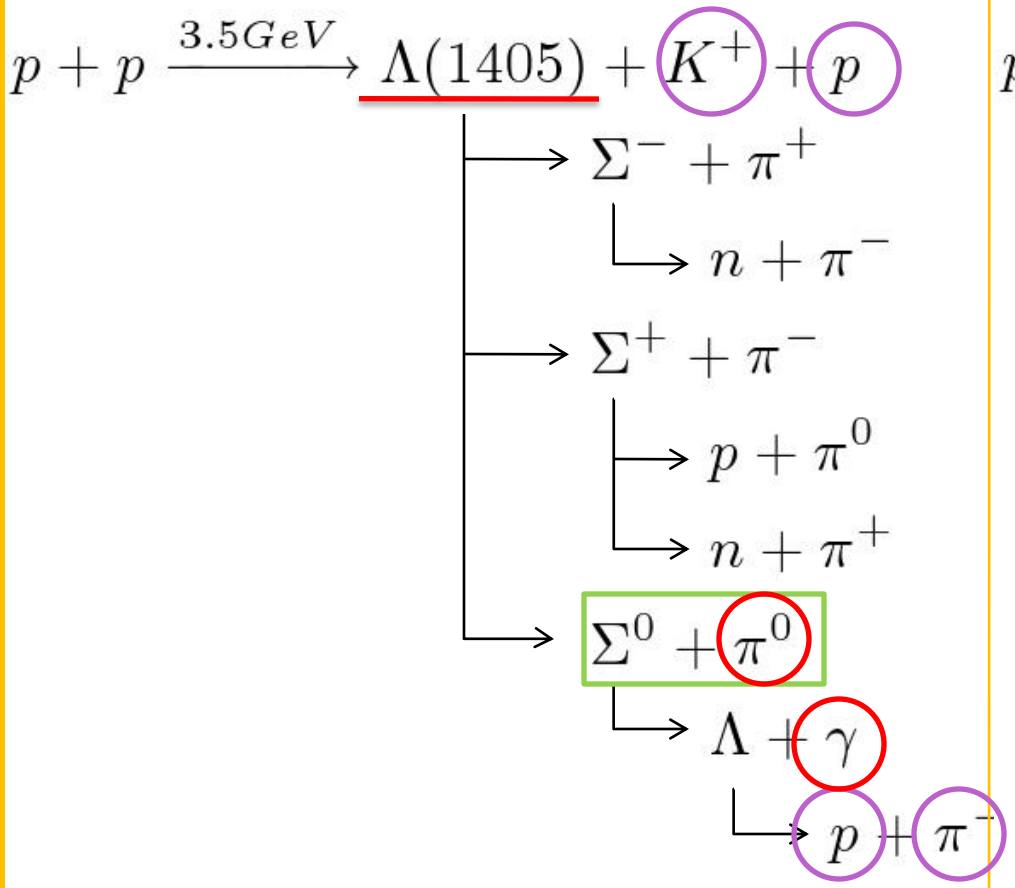

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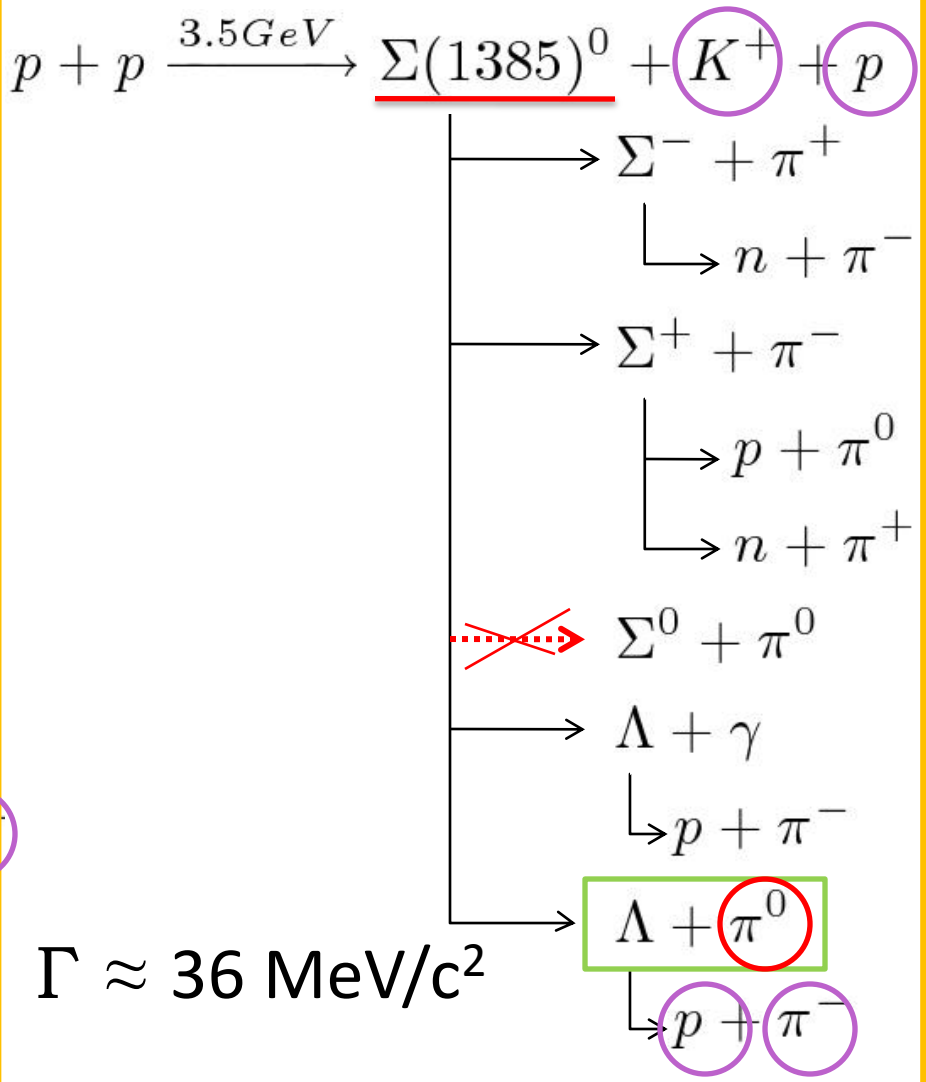


$\Gamma \approx 36$ MeV/c²

Expected $\Lambda(1405)$ yield

$\Lambda(1405)$ decay Channel	Events with p and K^+ in acceptance	Events with all 4 particles in acceptance	Expected $\Lambda(1405)$
$\Sigma^- + \pi^+$	5.7%	0.9%	2500
$\Sigma^+ + \pi^- \rightarrow p + \pi^0$	5.7%	0.33%	450
$\Sigma^+ + \pi^- \rightarrow n + \pi^+$	6 %	1.2%	1600
$\Sigma^0 + \pi^0$	4.3%	0.12%	400

E_{beam}= 3.5 GeV in p+p

$1.2 \cdot 10^9$ LVL1 Trigger Events

$\sigma_{\Lambda(1405)} \approx 10\ \mu b$

$\sigma_{pp} \approx 42\ mb$

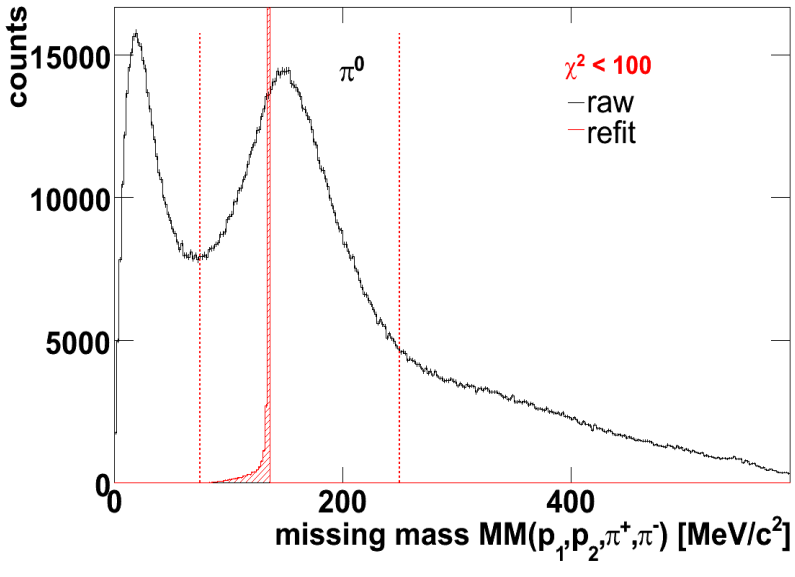
calculated by DST simulation of geometrical and trigger acceptance

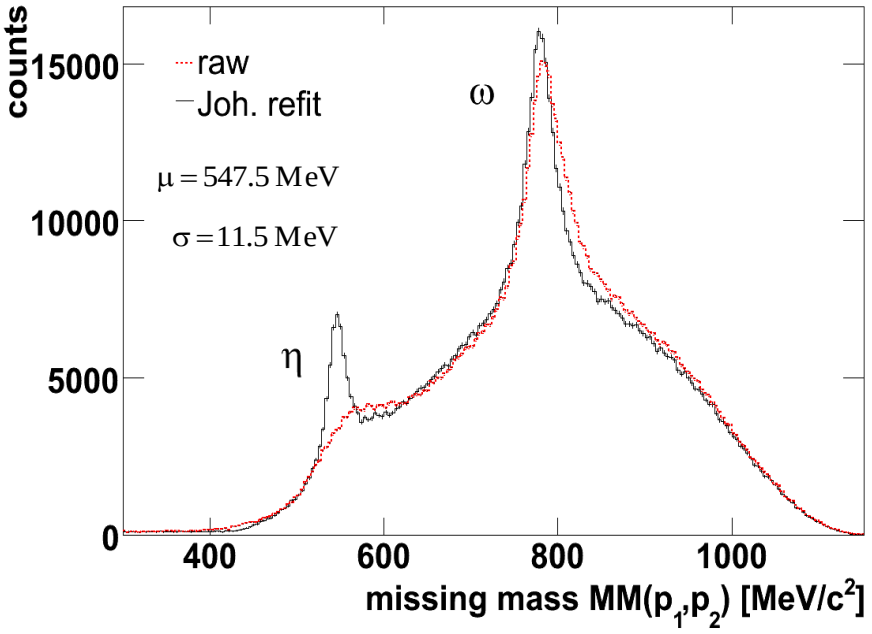
Reconstruction of the $\Sigma(1385)^+$

Kinematic refit

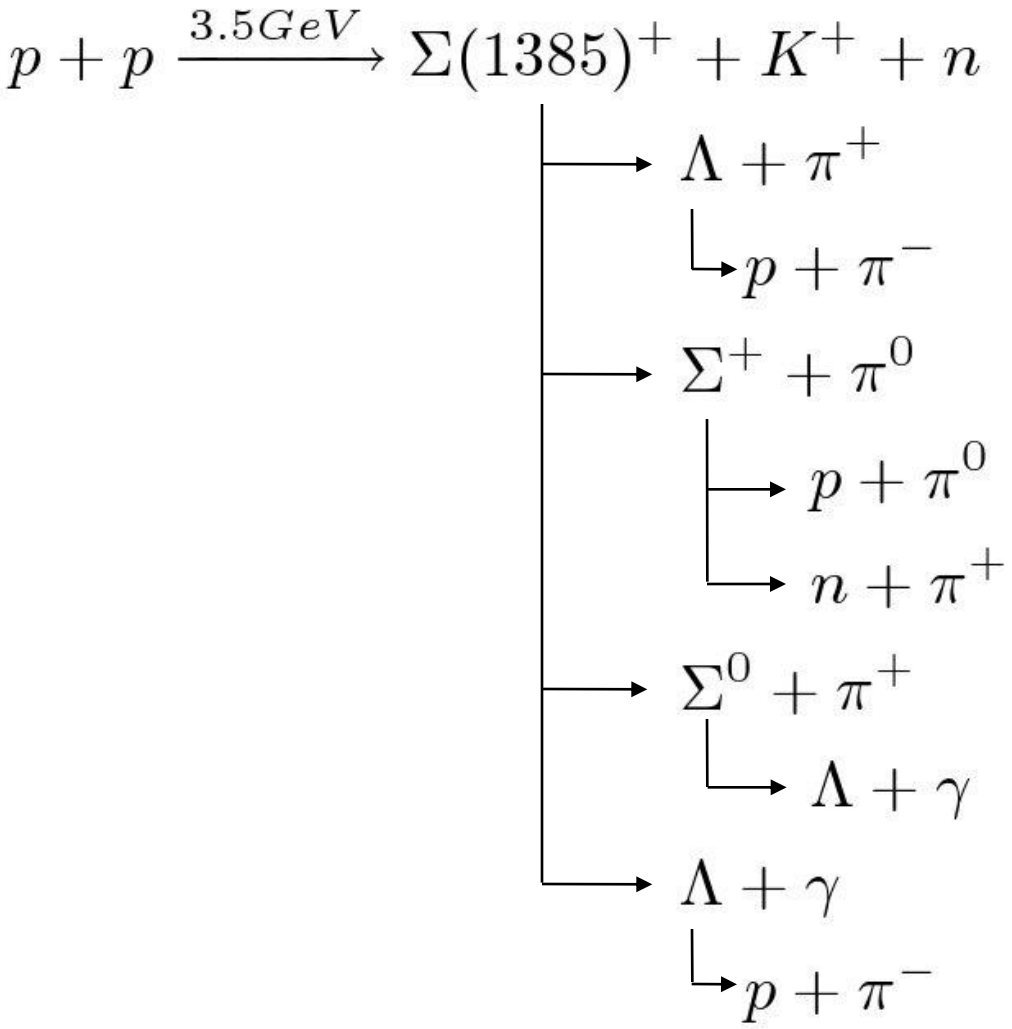
$$p + p(3.5GeV) \rightarrow \omega/\eta + p + p$$
$$\hookrightarrow \pi^+ + \pi^- + \pi^0$$

$$\Delta M^2(pp\pi^+\pi^-) - M^2(\pi^0) = 0$$





Decay channels of the $\Sigma(1385)^+$ Resonance



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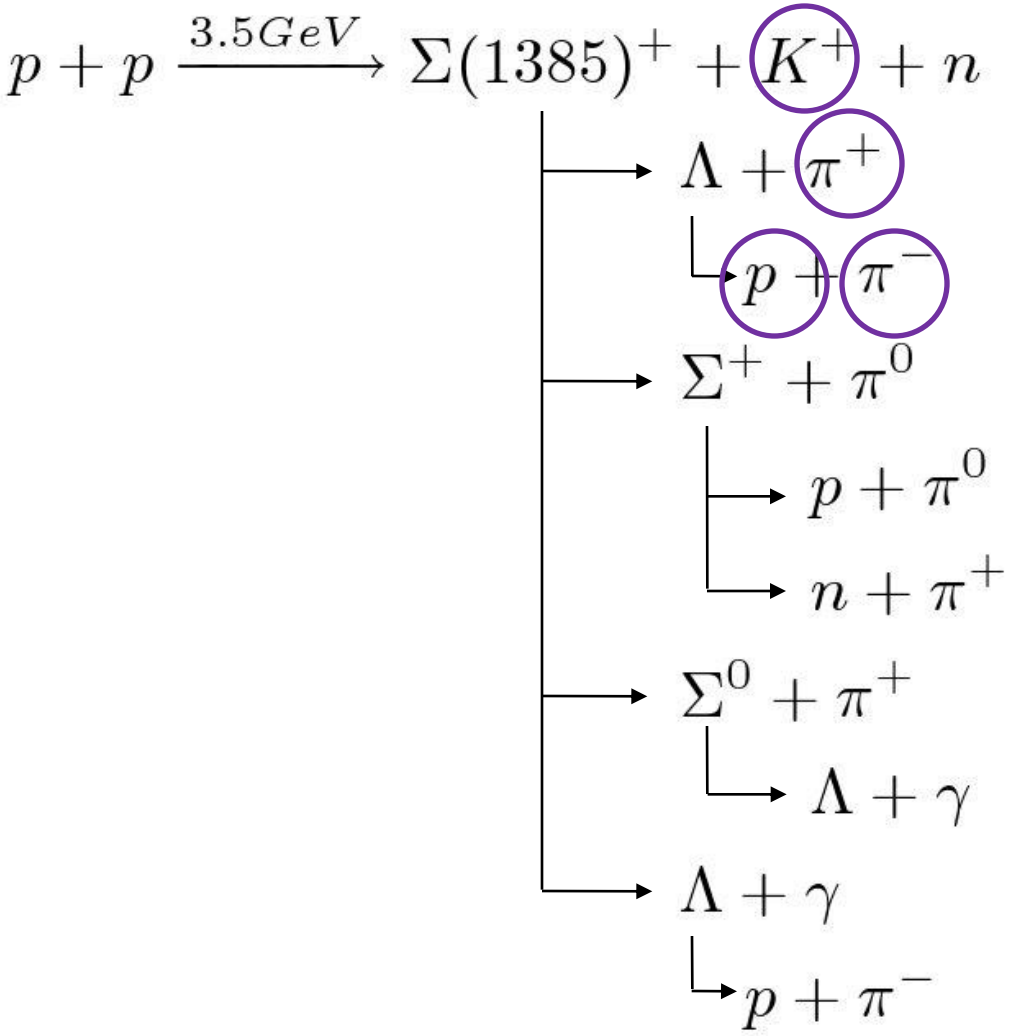

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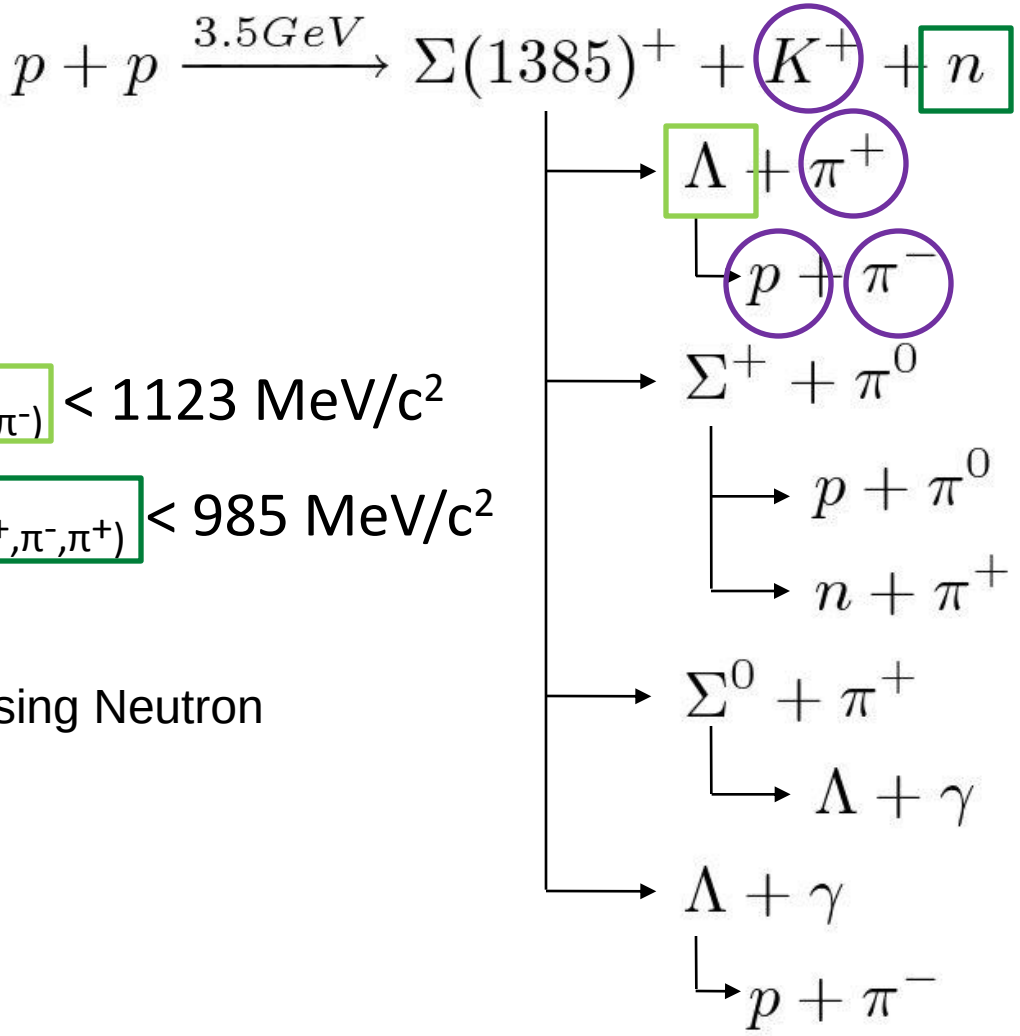


Constraints:

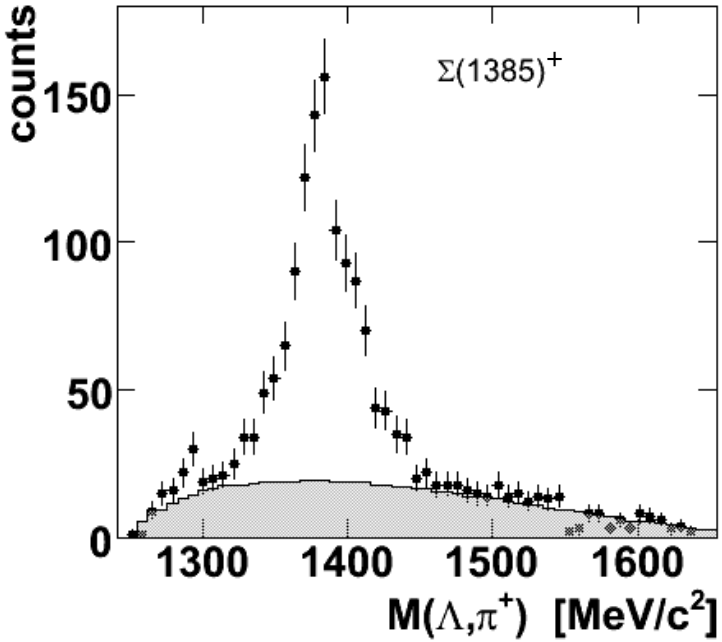
- 1103 MeV/c² < $M_{Inv\ (p\pi^-)}$ < 1123 MeV/c²
- 900 MeV/c² < $\Delta M_{(p,K^+,\pi^-,\pi^+)}$ < 985 MeV/c²

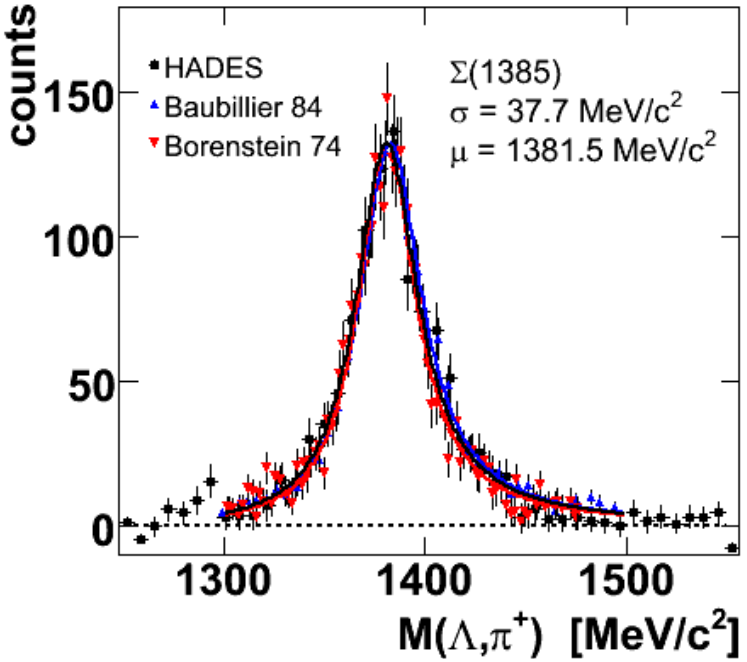
Kinematic Refit on missing Neutron

Reconstruction of $\Sigma(1385)^+$

Experiment

PDG Entries
- M. Baubillier et al., Z. Phy. C23 213 (1984)
- S.R. Borenstein et al., Phys. Rev. D 9 3006 (1974)





- Background fitted via phase space
- Agreement with other measured data

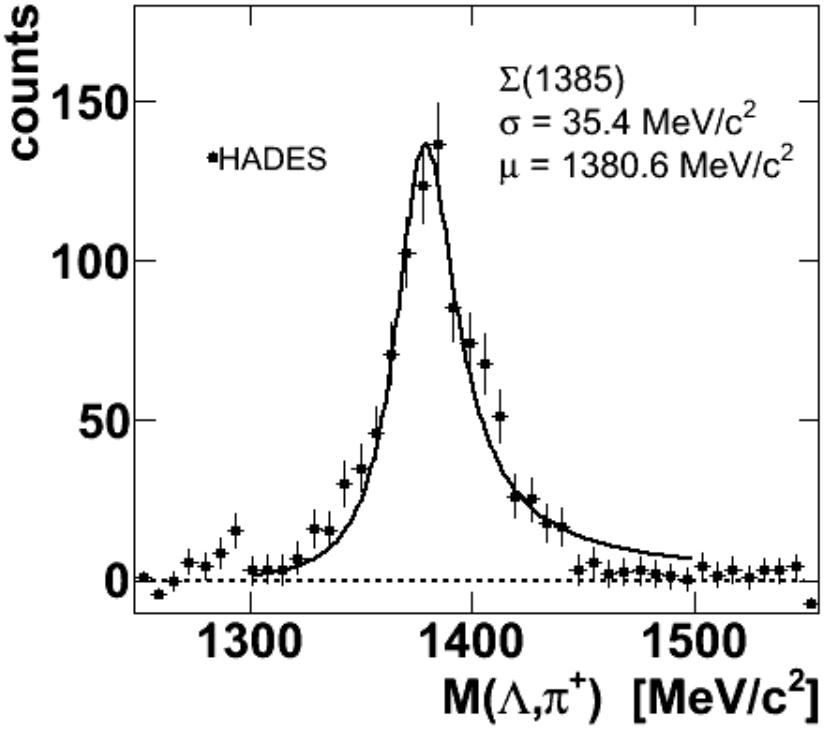
Evaluation of the cross-section is in preparation
Efficiency and Acceptance corrections missing

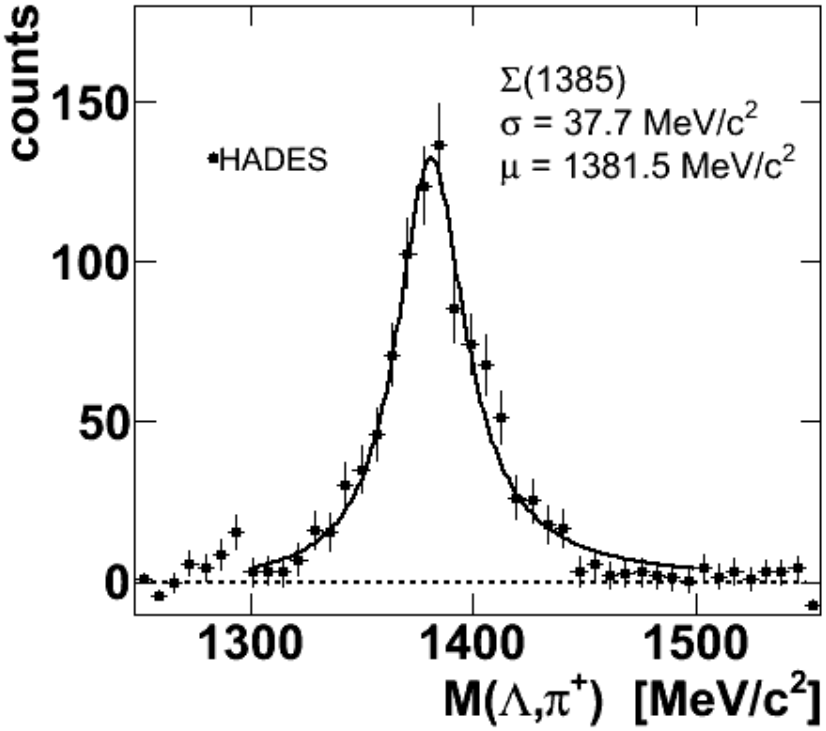
Decay channels of the $\Sigma(1385)^+$ Resonance

Σ(1385)⁺ fitted with P-wave

Preliminary

Σ(1385)⁺ fitted with S-wave

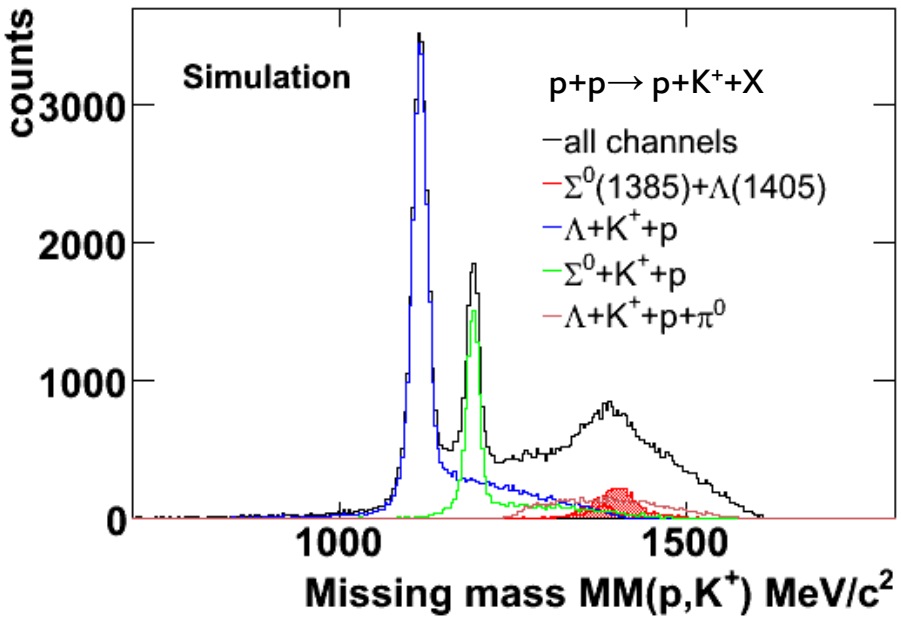


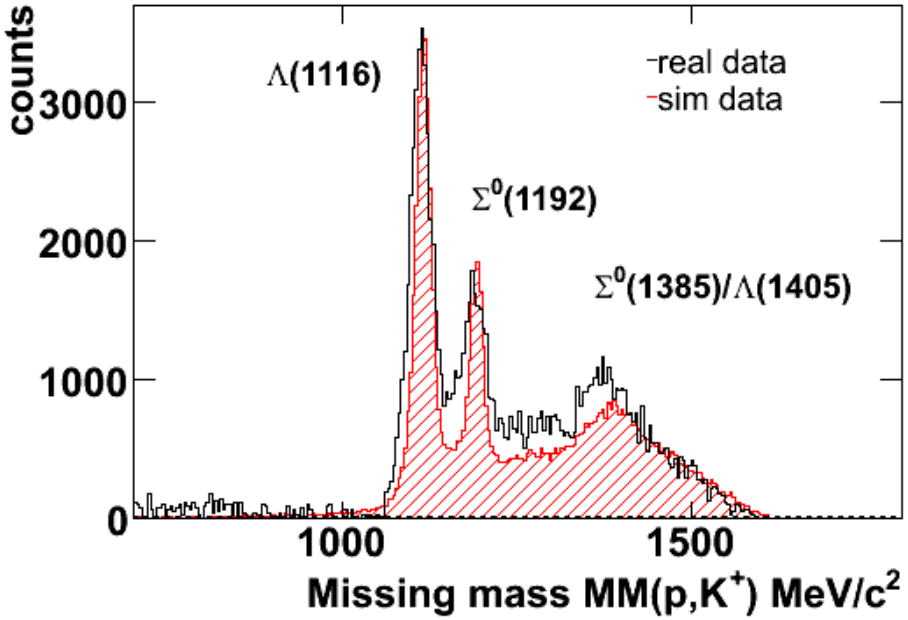


Analysis of the channel $\Lambda(1405) \rightarrow \Sigma^0 \pi^0$

Missing mass analysis

$$p + p \xrightarrow{3.5GeV} p + K^+ + X$$



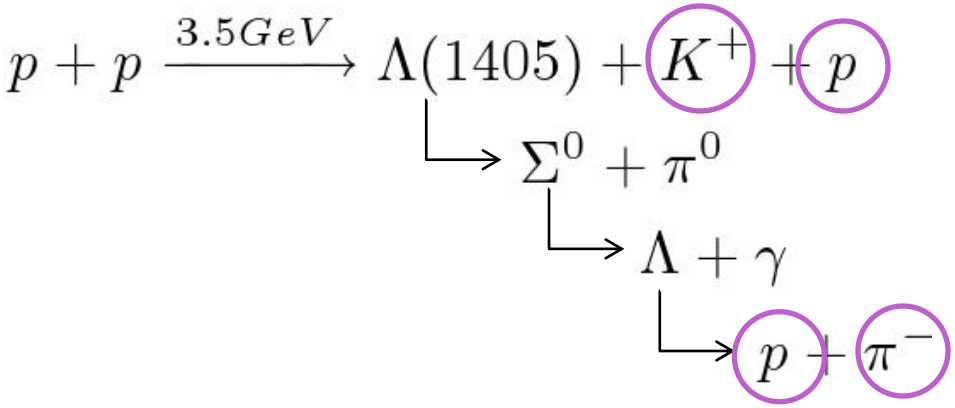


Landolt Börnstein tables Group I Volume 12

Event Generator **PLUTO** ⟶ GEANT⟶ Digitizer Analysis of simulated events with strangeness content

Pre selection of events

First select a interesting sub samle of all the measured data
in our case events with p_1, K^+, p_2, π^-



<u>On that sample the analysis will proceed</u>

- cuts on primary Vertex
- cuts on track quality
- cuts on Λ(1116) [mass and track cuts]
- cuts on the K^+ mass
- cuts on missing mass of all charged particles [> π^0]

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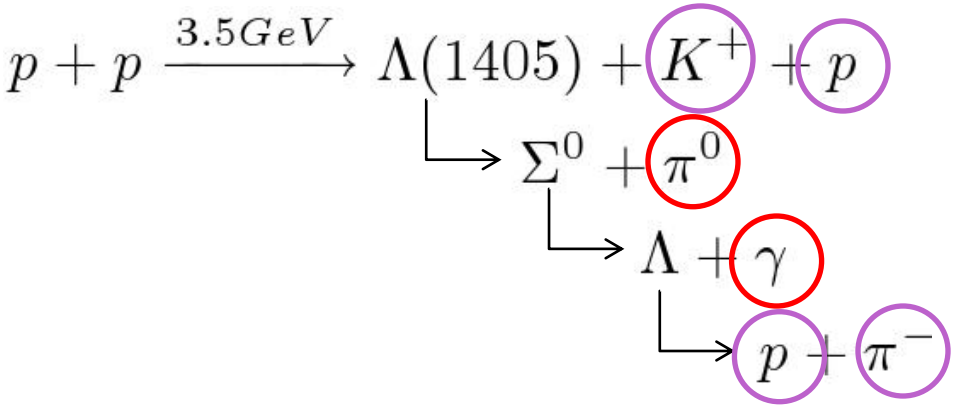

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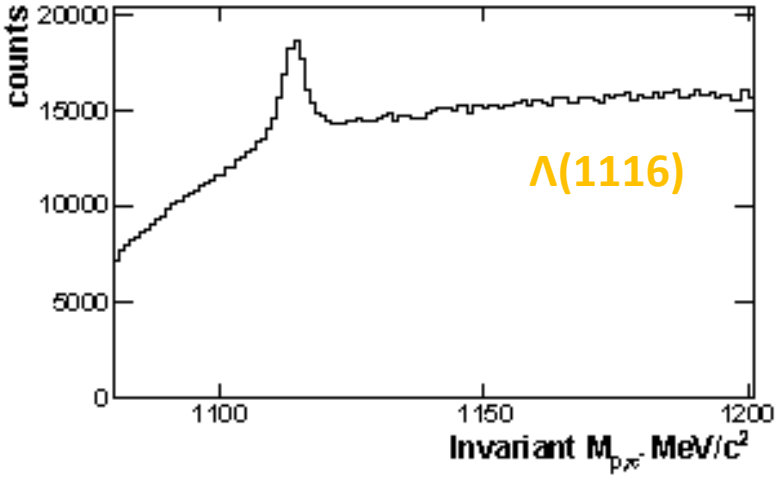
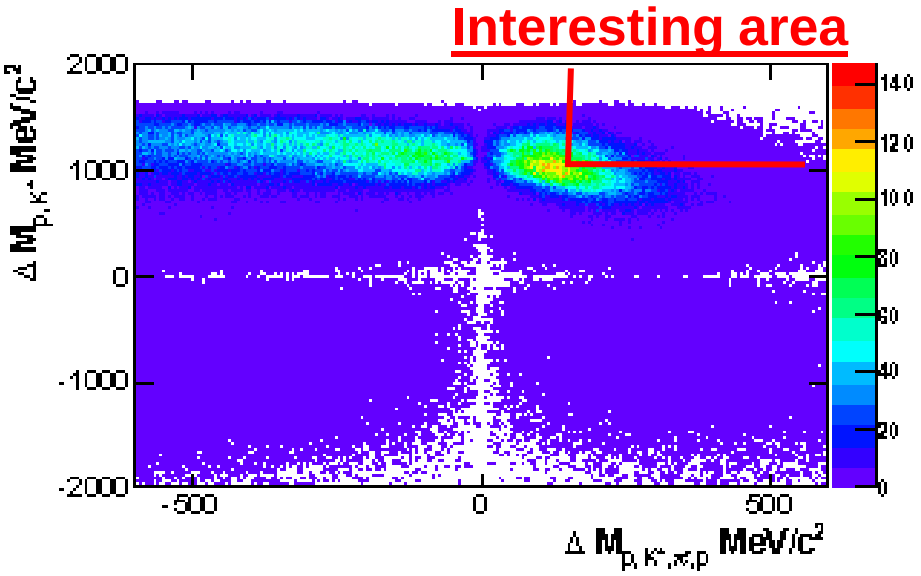
The analysis of the Λ(1405)

$$p + p \xrightarrow{3.5GeV} \Lambda(1405) + K^+ + p$$
$$\hookrightarrow \Sigma^0 + \pi^0$$
$$\hookrightarrow \Lambda + \gamma$$
$$\hookrightarrow p + \pi^-$$

All data in our preselected sample
NO cuts on K^+





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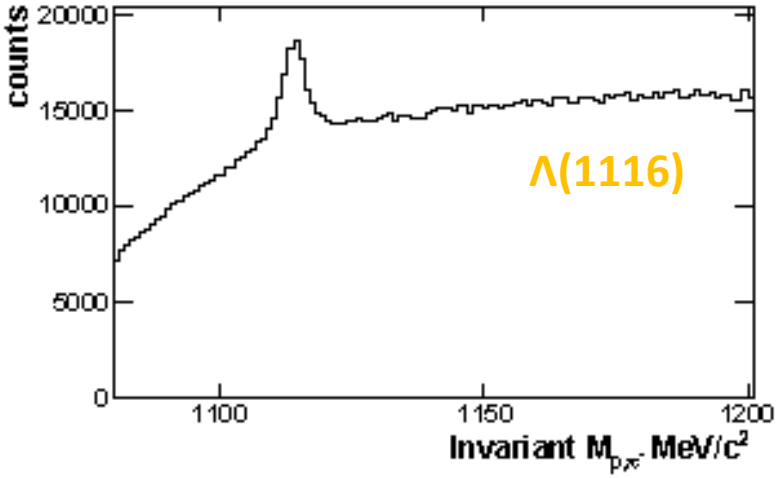
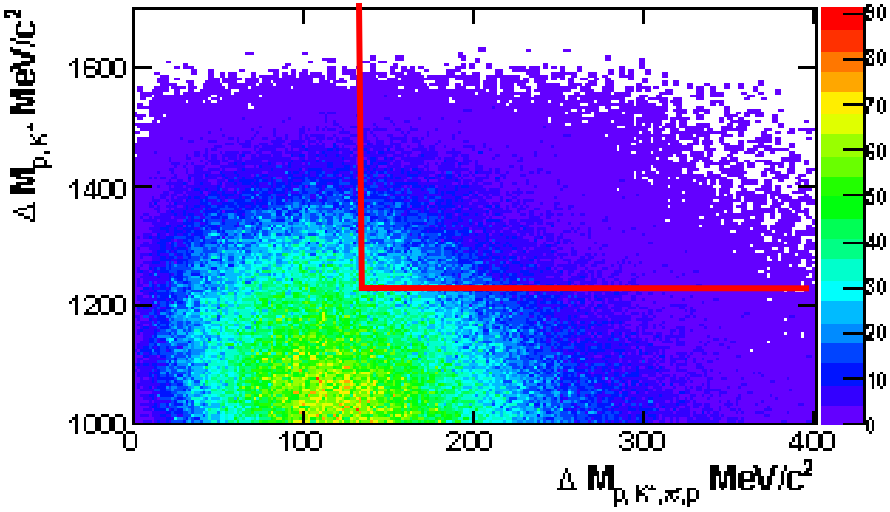


Interesting area



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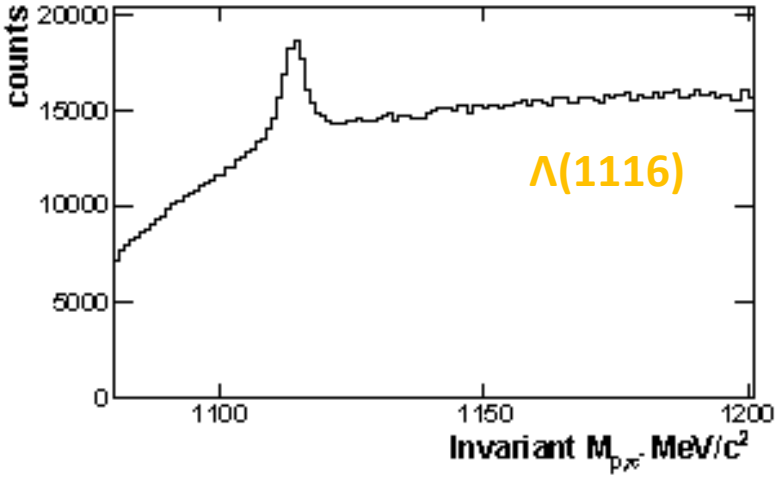

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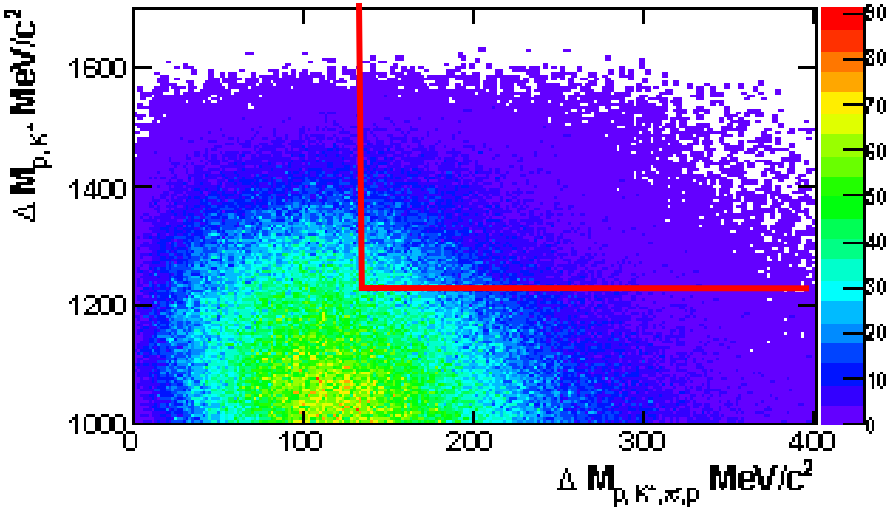
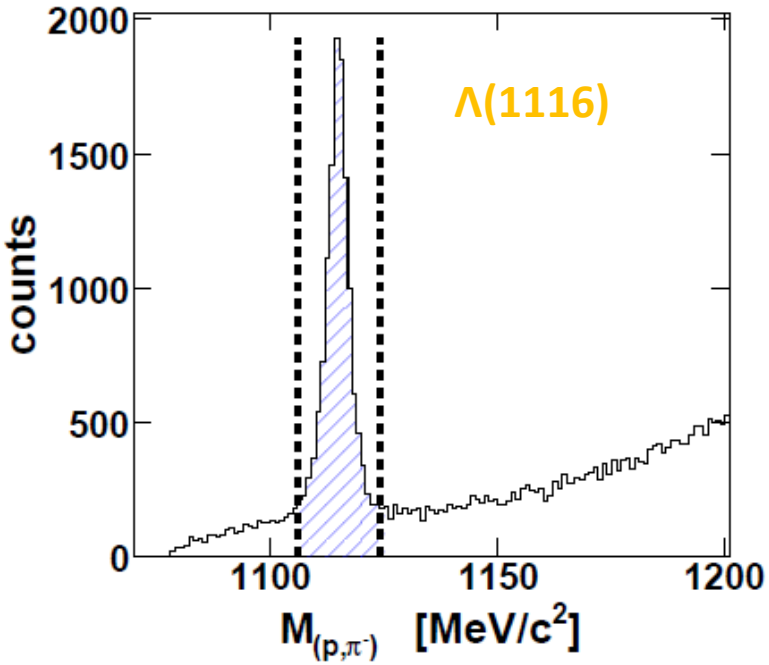


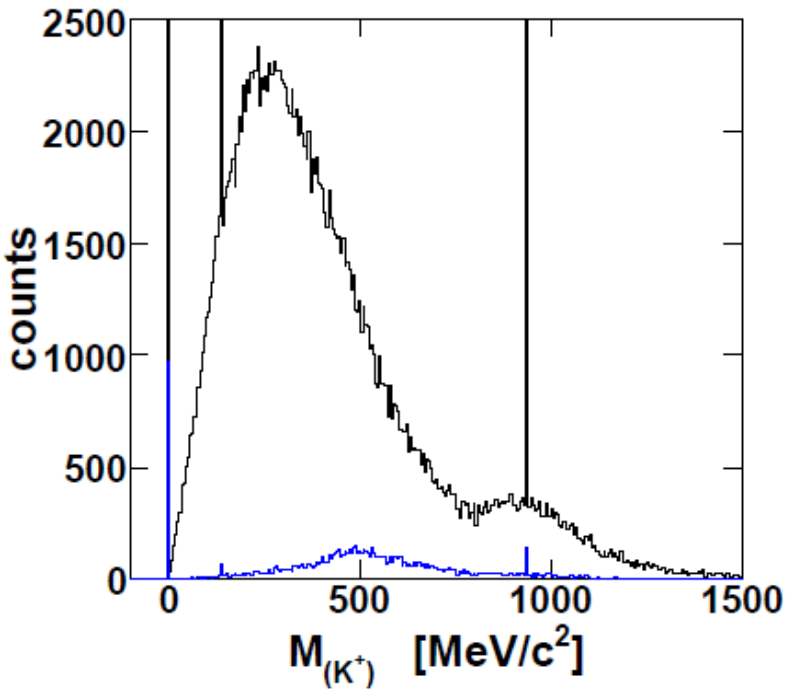
- cut on $\Delta M_{(pK^+)}$ > 1000 MeV/c^2
- cut on $\Delta M_{(p1,K^+,p2,\pi^-)}$ > - 75 MeV/c^2

The analysis of the Λ(1405)

$$p + p \xrightarrow{3.5GeV} \Lambda(1405) + K^+ + p$$
$$\hookrightarrow \Sigma^0 + \pi^0$$
$$\hookrightarrow \Lambda + \gamma$$
$$\hookrightarrow p + \pi^-$$

reduce background from the Λ(1116) signal to tune the Λ(1116) track cuts on these pure Λ's

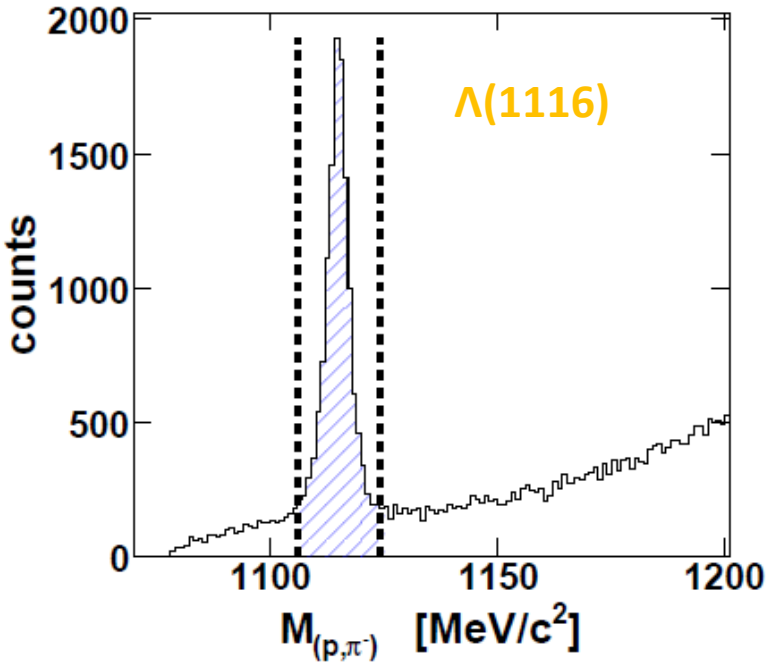


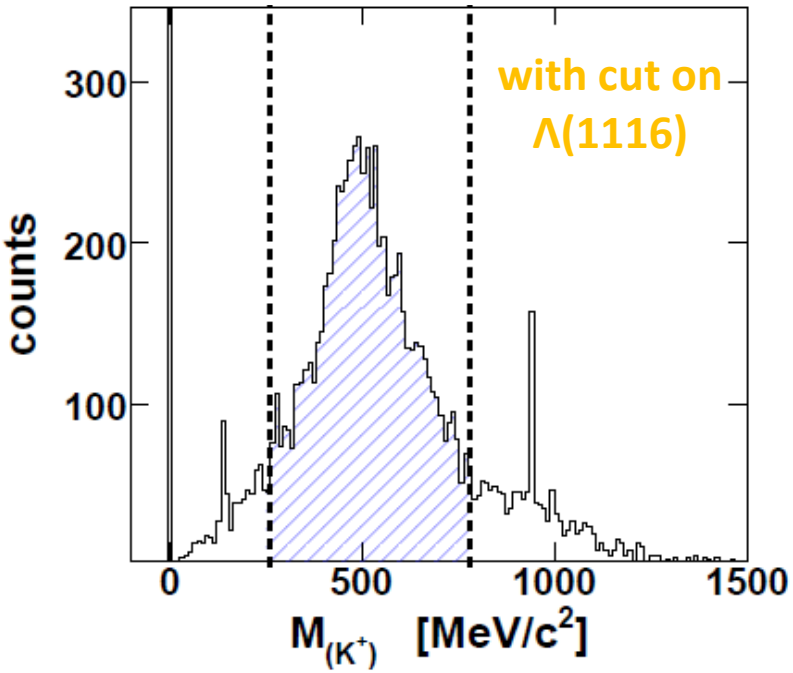


The analysis of the Λ(1405)

$$p + p \xrightarrow{3.5GeV} \Lambda(1405) + K^+ + p$$
$$\Lambda(1405) \hookrightarrow \Sigma^0 + \pi^0$$
$$\Sigma^0 \hookrightarrow \Lambda + \gamma$$
$$\Lambda \hookrightarrow p + \pi^-$$

reduce background from the Λ(1116) signal to tune the Λ(1116) track cuts on these pure Λ's



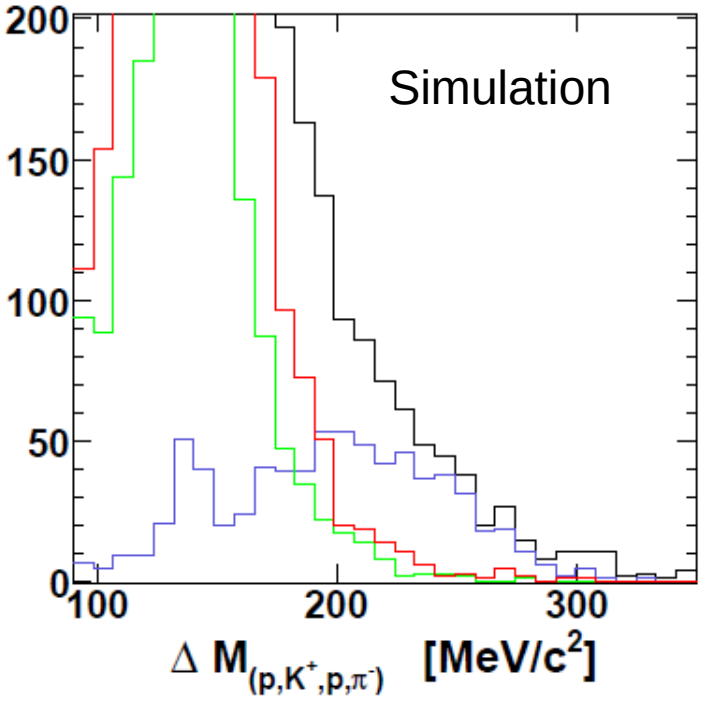


The analysis of the Λ(1405)

$$p + p \xrightarrow{3.5GeV} \Lambda(1405) + K^+ + p$$
$$\hookrightarrow \Sigma^0 + \pi^0$$
$$\hookrightarrow \Lambda + \gamma$$
$$\hookrightarrow p + \pi^-$$

- Λ(1116) track cuts
- cut on Λ(1116) mass
- cut on K^+ mass

→ Λ(1405) + K^+ + p
→ Σ(1385) + K^+ + p
→ Λ(1116) + π^0 + K^+ + p



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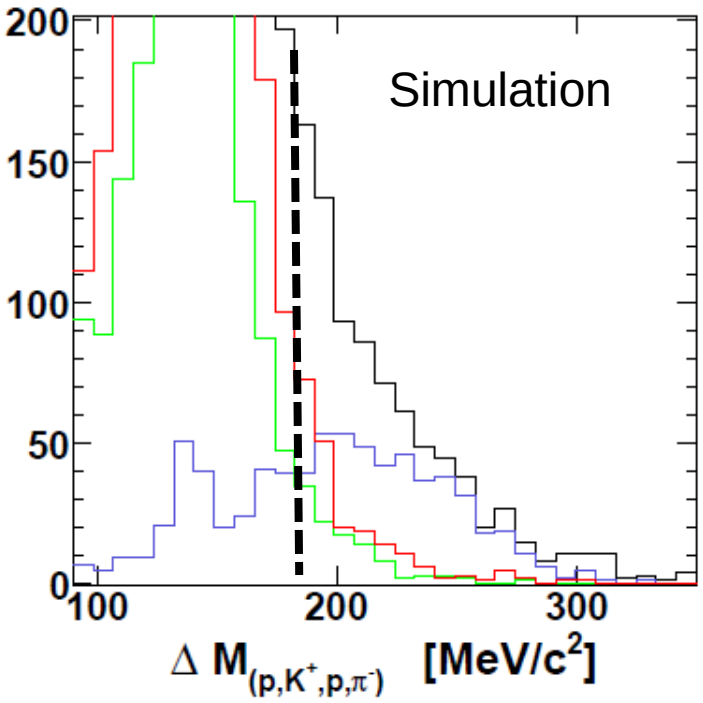
- Λ(1116) track cuts
- cut on Λ(1116) mass
- cut on K^+ mass

→ Λ(1405) + K^+ + p
→ Σ(1385) + K^+ + p
→ Λ(1116) + π^0 + K^+ + p

Cut on
$\Delta M(p,K,p,\pi^-) > 170$ MeV/c^2

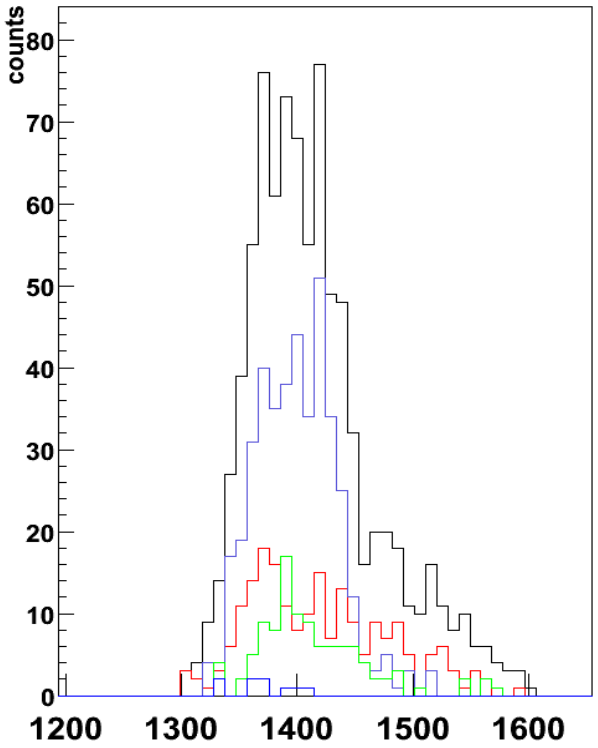


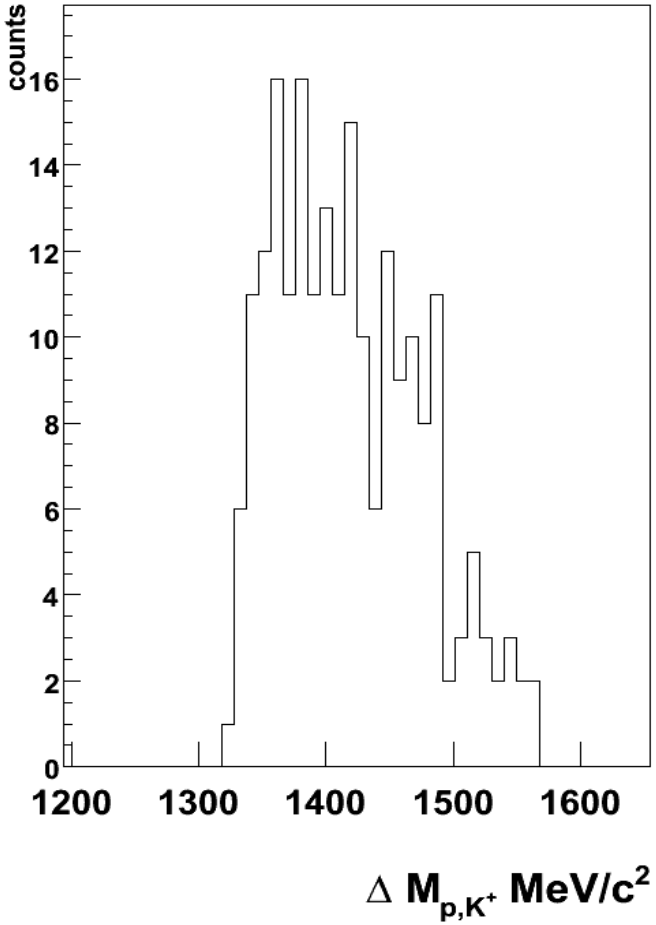
Comparison with Full-Scale Simulation

Simulation

Preliminary

Experiment





→ Λ(1405) + K^+ p

→ Σ(1385) + K^+ p 20 %

→ Λ(1116) + π^0 + K^+ + p 10 %

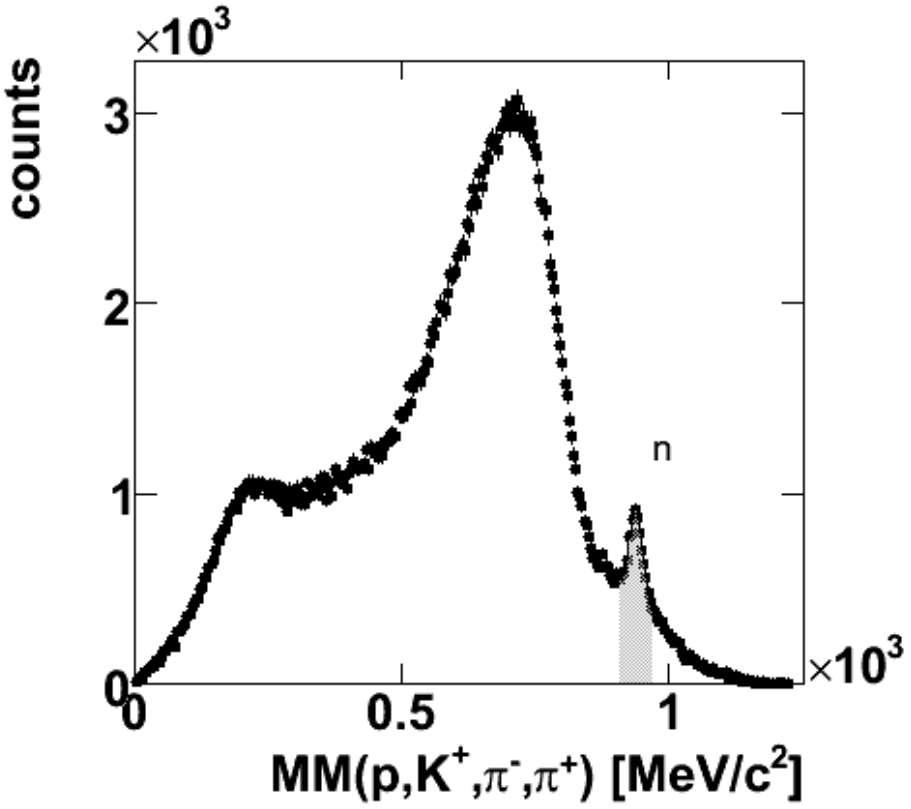
Analysis of the channel $\Lambda(1405) \rightarrow \Sigma^{+/-} \pi^{-/+}$

$\Lambda(1405) \rightarrow \Sigma^{+/-} + \pi^{-/+}$

Pre selection of p, K^+, π^-,π^+,
cut on the K^+ mass

$$p + p \rightarrow \Lambda(1405) + p + K^+$$
$$\hookrightarrow \Sigma^+ + \pi^-$$
$$\hookrightarrow n + \pi^+$$

$$p + p \rightarrow \Lambda(1405) + p + K^+$$
$$\hookrightarrow \Sigma^- + \pi^+$$
$$\hookrightarrow n + \pi^-$$



Σ^+ and Σ^-

After a kinematic refit with the neutron mass as a constraint

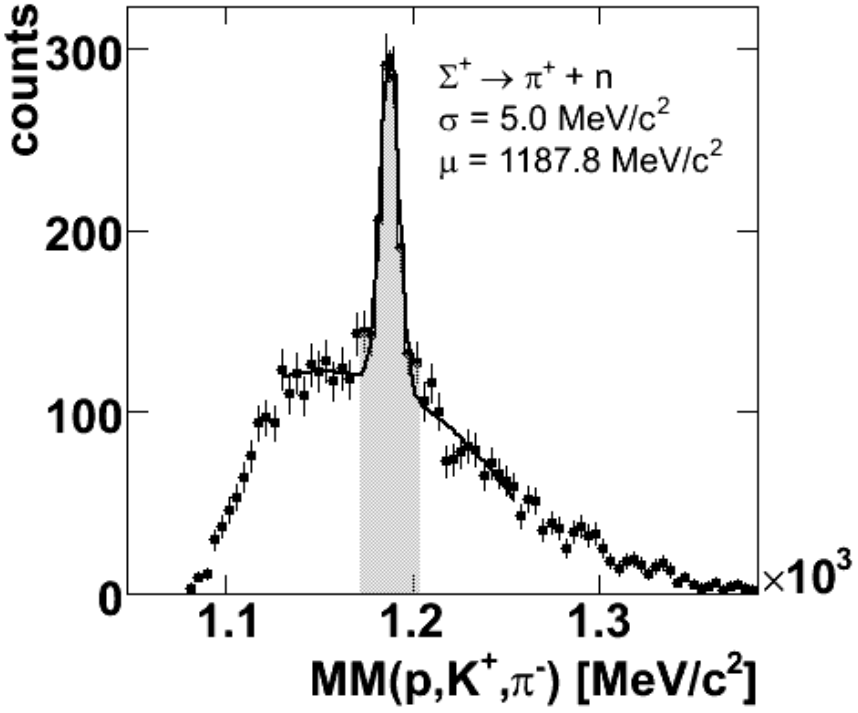
$p+p \rightarrow \Lambda(1405)/\Sigma(1385) + p + K^+$

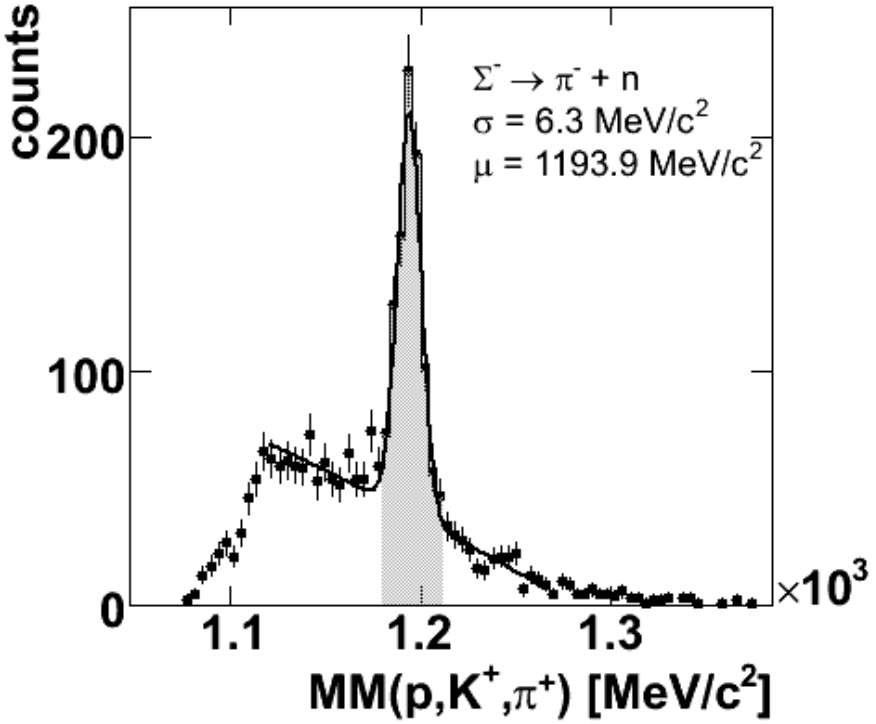
$\hookrightarrow \Sigma^{+/-} + \pi^{-/+}$

$\hookrightarrow n + \pi^{+/-}$

Preliminary

Experimental Data



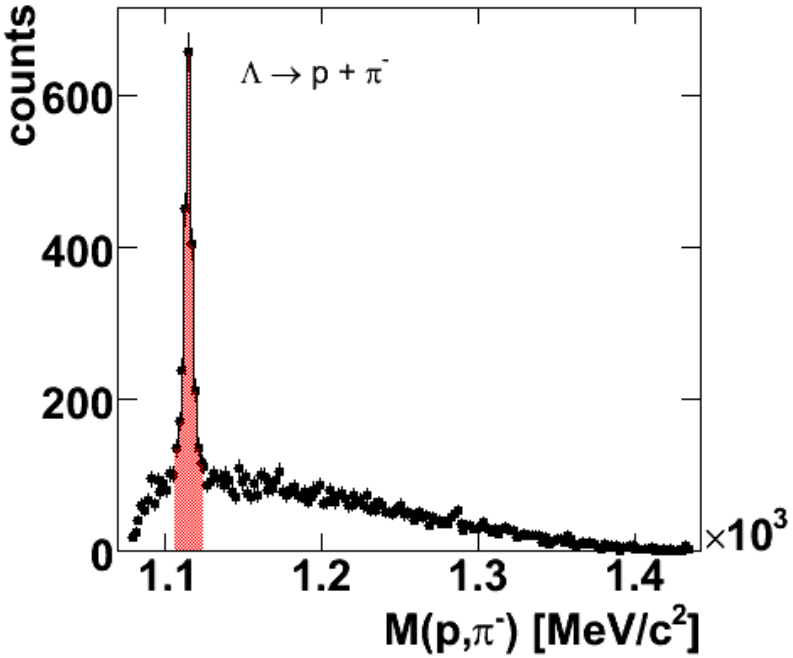


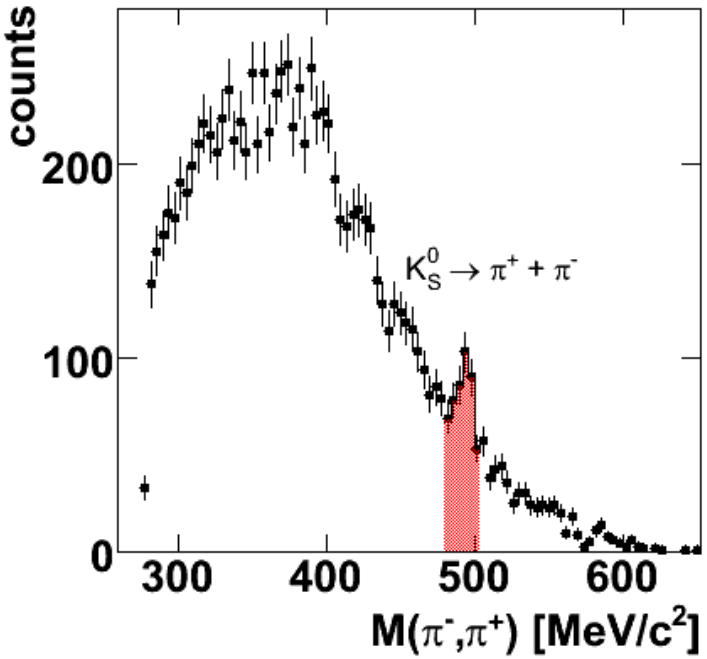
Reduction of Background

The same final products are also produced in other channels:

$$p + p \rightarrow \Lambda + n + K^+ + \pi^+$$
$$\Lambda \rightarrow p + \pi^-$$

$$p + p \rightarrow \overline{K}^0 + n + p + K^+$$
$$\overline{K}^0 \rightarrow \pi^+ + \pi^-$$

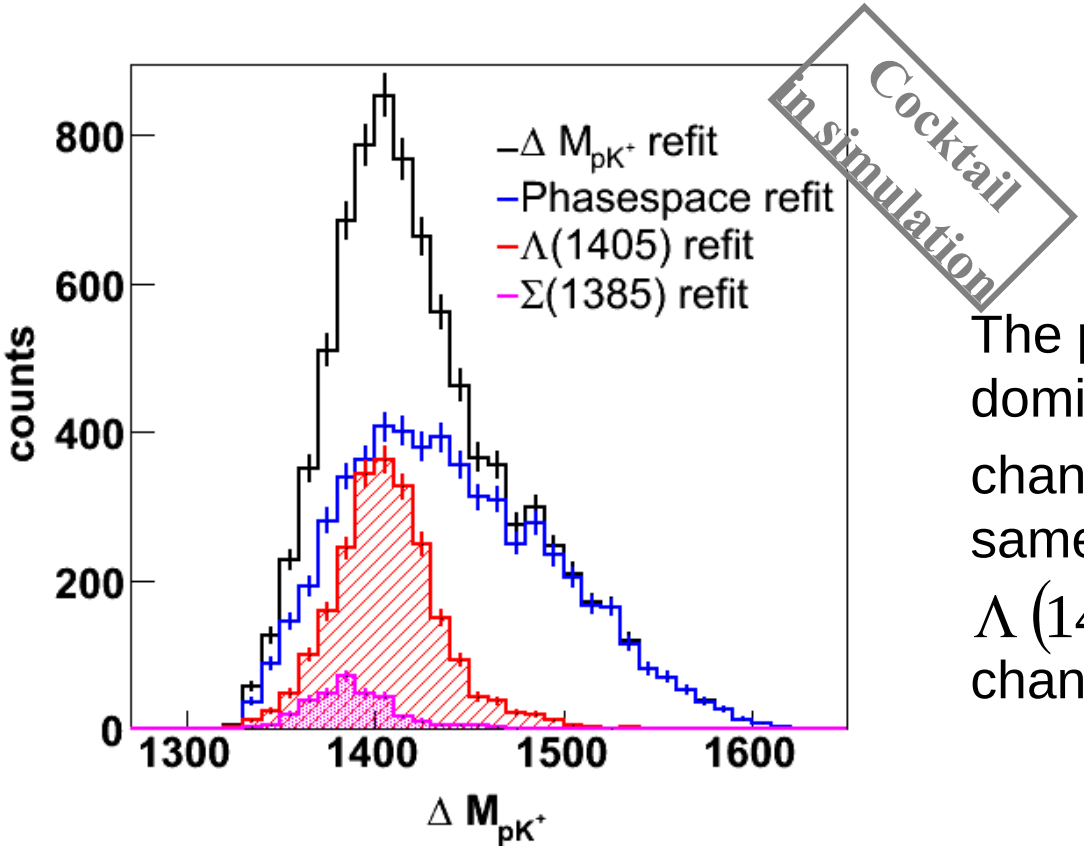




Simulation Results

What contributes to the obtained signal?

$$p + p \rightarrow \Lambda(1405)/\Sigma(1385) + p + K^+$$
$$\Sigma^{+/-} + \pi^{-/+}$$
$$n + \pi^{+/-}$$



The phase space is highly dominated by non resonant channels, which have the same decay products as the $\Lambda(1405)$ and $\Sigma(1385)$ channel.

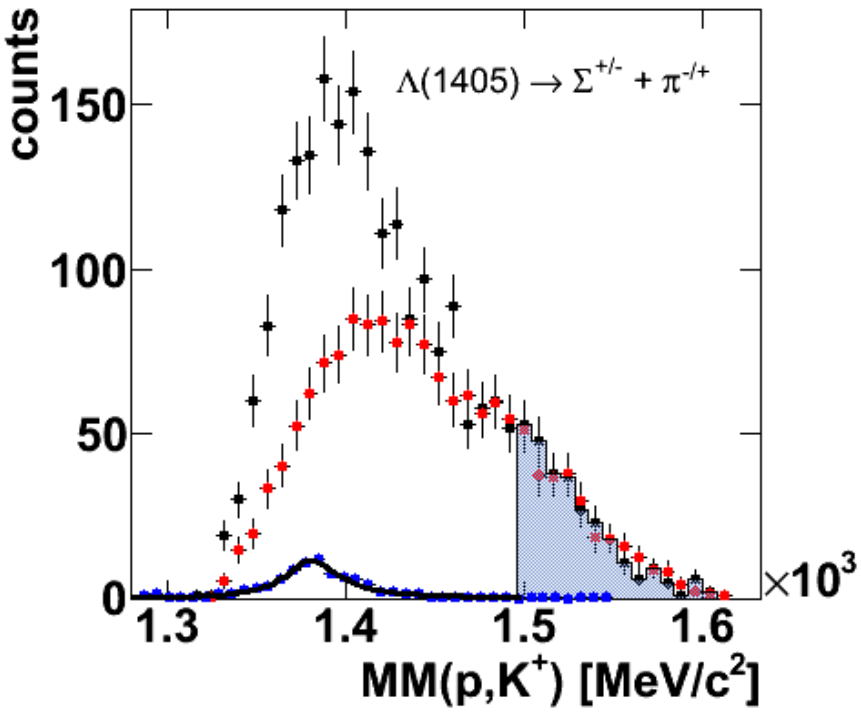
Results from the Experiment

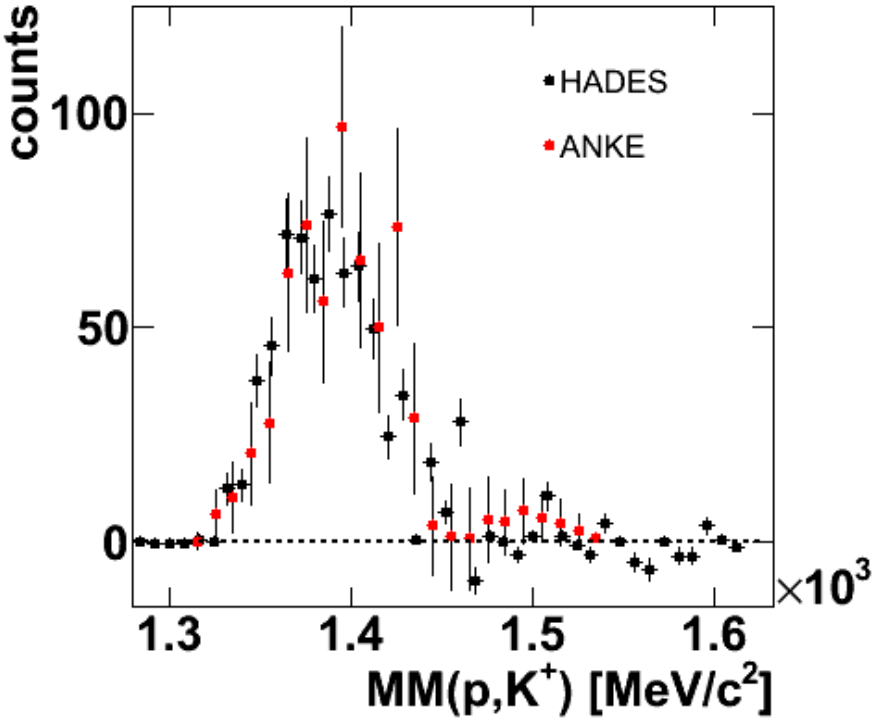
Background shape taken from Simulations and normalized to the data

$\Sigma(1385)^0$ contribution extracted from the reconstructed $\Sigma(1385)^+$

Very Preliminary !

I. Zychor et al., Phys. Lett. B660 (2008) 167-171.





Summary

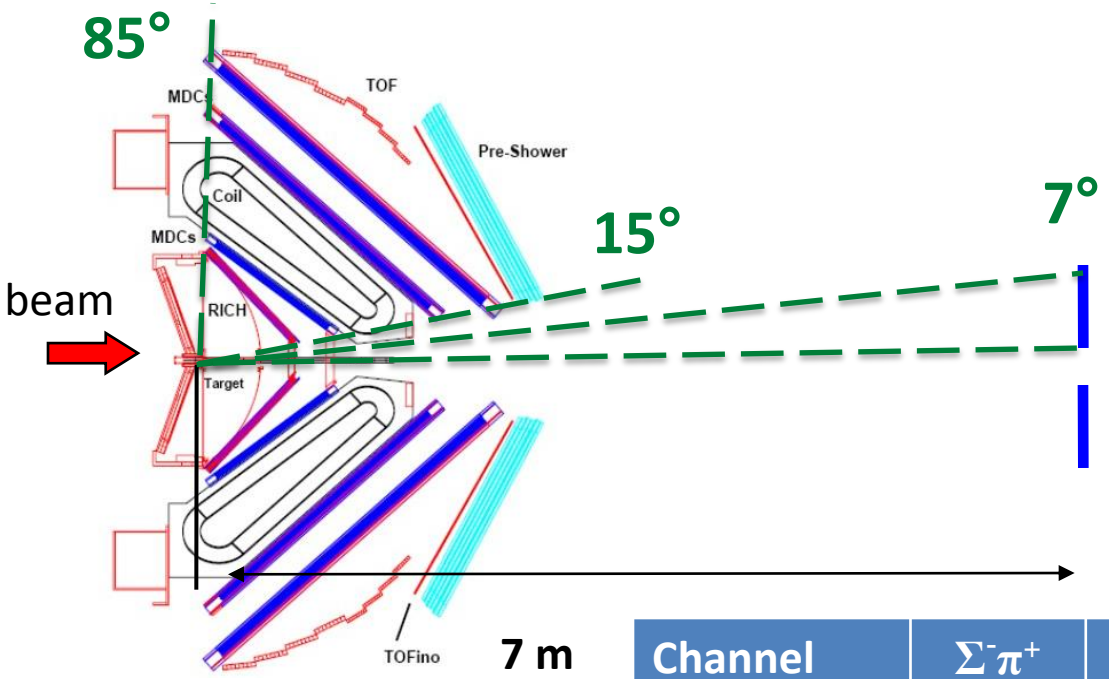
- The feasibility of the Measurement of $\Lambda(1405)$ with HADES has been shown
- The Statistics collected in the channel $\Lambda(1405) \rightarrow \Sigma^0\pi^0$ is not sufficient to study the line shape in details but provides a reference for the other decays
- New High Quality Data for the $\Sigma(1385)^+$ line shape
- Fit compatible with an s-wave description
- Kinematic Refit on the neutron applied to reconstruct the $\Lambda(1405) \rightarrow \Sigma^{+/-}\ \pi^{-/+}$ decay
- Preliminary results on the line shape are consistent with the recent ANKE result on the decay $\Lambda(1405) \rightarrow \Sigma^0\ \pi^0$
- Separate the two Decay Channels $\Lambda(1405) \rightarrow \Sigma^+\pi^-$ and $\Lambda(1405) \rightarrow \Sigma^-\ \pi^+$
- Look for kaonic cluster

HADES collaboration

G. Agakishiev[8], C. Agodi[1], A. Balanda[3,e], G. Bellia[1,a], D. Belver[15], A. Belyaev[6], A. Blanco[2], M. Böhmer[11], J. L. Boyard[13], P. Braun-Munzinger[4], P. Cabanelas[15], E. Castro[15], S. Chernenko[6], T. Christ[11], M. Destefanis[8], J. Díaz[16], F. Dohrmann[5], A. Dybczak[3], T. Eberl[11], E. Epple[11], L. Fabbietti[11], O. Fateev[6], P. Finocchiaro[1], P. Fonte[2,b], J. Friese[11], I. Fröhlich[7], T. Galatyuk[4], J. A. Garzón[15], R. Gernhäuser[11], C. Gilardi[8], M. Golubeva[10], D. González-Díaz[4], E. Grosse[5,c], F. Guber[10], M. Heilmann[7], T. Hennino[13], R. Holzmann[4], A. Ierusalimov[6], I. Iori[9,d], A. Ivashkin[10], M. Jurkovic[11], B. Kämpfer[5], K. Kanaki[5], T. Karavicheva[10], D. Kirschner[8], I. Koenig[4], W. Koenig[4], B. W. Kolb[4], R. Kotte[5], A. Kozuch[3,e], F. Krizek[14], R. Krücken[11], W. Kühn[8], A. Kugler[14], A. Kurepin[10], J. Lamas-Valverde[15], S. Lang[4], J. S. Lange[8],K. Lapidus[10], L. Lopes[2], M. Lorenz[4], L. Maier[11], A. Mangiarotti[2], J. Marín[15], J. Markert[7], V. Metag[8], B. Michalska[3], D. Mishra[8], E. Morinière[13], J. Mousa[12], C. Müntz[7], L. Naumann[5], R. Novotny[8], J. Otwinowski[3], Y. C. Pachmayer[7], M. Palka[4], Y. Parpottas[12], V. Pechenov[8], O. Pechenova[8], T. Pérez Cavalcanti[8], J. Pietraszko[4], W. Przygoda[3,e], B. Ramstein[13], A. Reshetin[10], M. Roy-Stephan[13], A. Rustamov[4], A. Sadovsky[10], B. Sailer[11], P. Salabura[3], A. Schmah[4], J. Siebenson, R. Simon[4], S. Spataro[8], B. Spruck[8], H. Ströbele[7], J. Stroth[7,4], C. Sturm[7], M. Sudol[4], A. Tarantola[7], K. Teilab[7], P. Tlusty[14], M. Traxler[4], R. Trebacz[3], H. Tsertos[12], I. Veretenkin[10], V. Wagner[14], H. Wen[8], M. Wisniowski[3], T. Wojcik[3], J. Wüstenfeld[5], S. Yurevich[4], Y. Zanevsky[6], P. Zumbruch[4]

Backup Slides

Take the FW into account



FW Momentum Resolution = 10%
→ Kinematic Refit is necessary
Systematic studies and calibration currently on-going

Channel	$\Sigma^-\pi^+$	$\Sigma^+\pi^-$ ↳ $p\pi^0$	$\Sigma^+\pi^-$ ↳ $n\pi^+$	$\Sigma^0\pi^0$
HADES acceptance	2500	450	1600	400
HADES + FW	3500	1300	2000	900

Take the FW into account

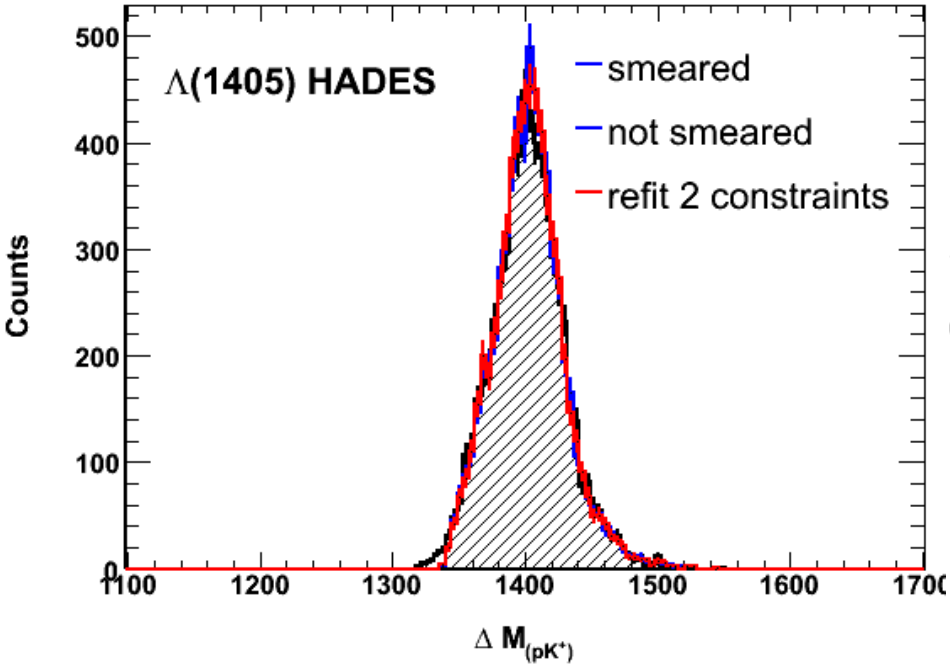
kinematic refit applied in the the reaction

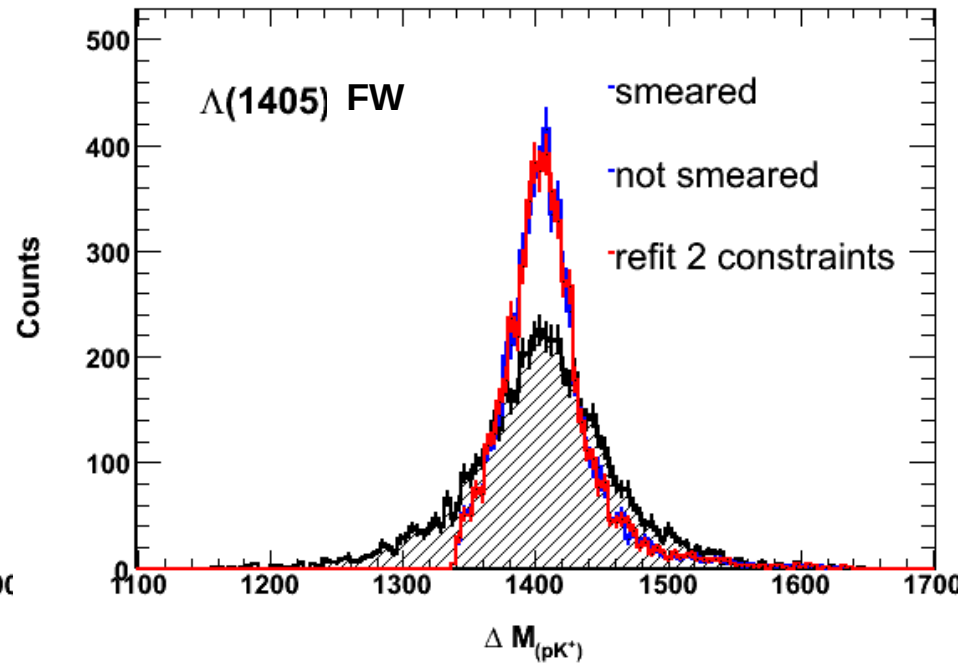
$$p + p \xrightarrow{3.5GeV} \Lambda(1405) + K^+ + p$$

in FW

$$\Sigma^- + \pi^+$$

$$n + \pi^-$$

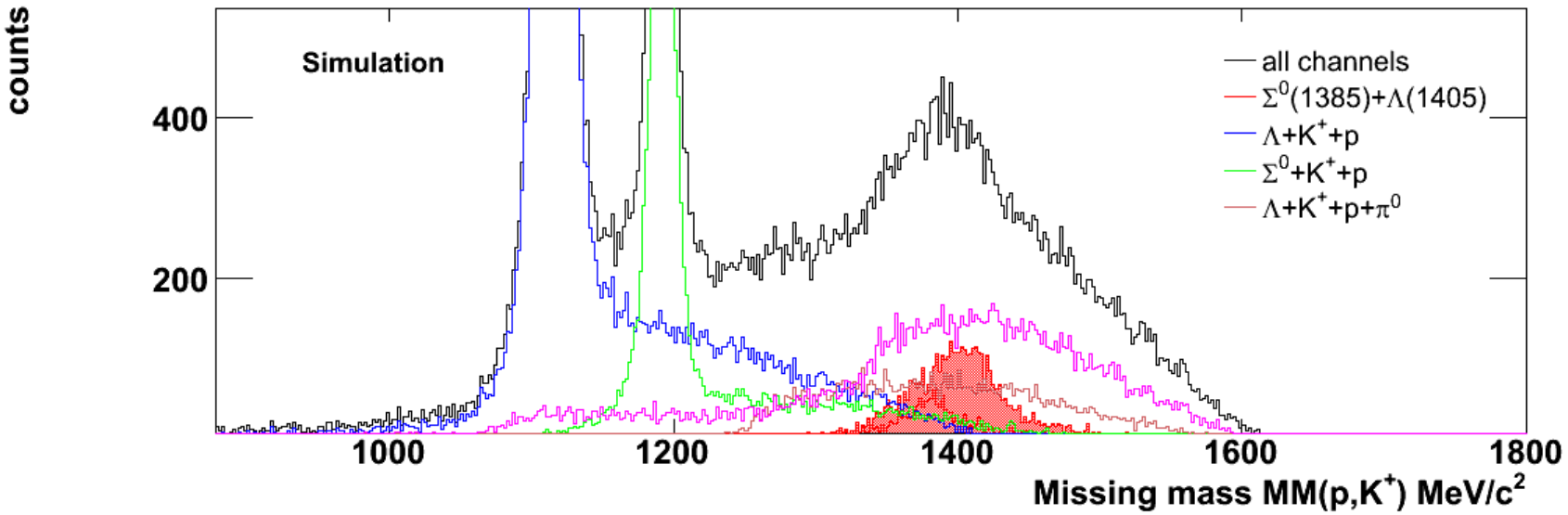




Channels for the background simulation

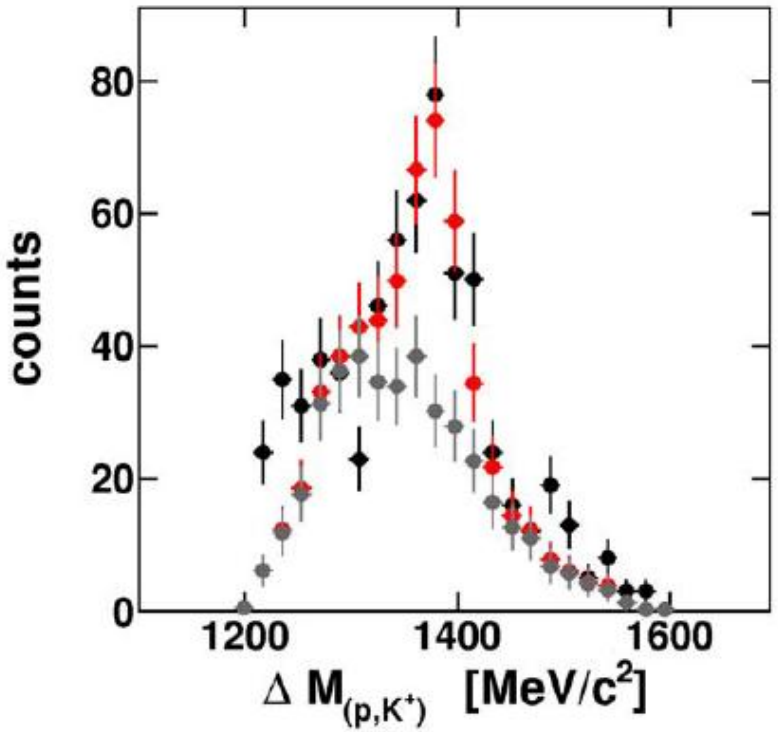
$$p + p \rightarrow \Lambda + p + K^+$$
$$p + p \rightarrow \Lambda(1405) + p + K^+$$
$$p + p \rightarrow \Sigma^+ + n + K^+$$
$$p + p \rightarrow p + p + K^+ + K^-$$
$$p + p \rightarrow \Lambda + n + \pi^+ + K^+$$
$$p + p \rightarrow \Sigma^0 + p + K^+$$
$$p + p \rightarrow \Lambda + p + \pi^0 + K^+$$
$$p + p \rightarrow \Sigma^- + p + \pi^+ + K^+$$
$$p + p \rightarrow \Sigma^+ + p + \pi^- + K^+$$
$$p + p \rightarrow \Sigma^+ + n + \pi^- + \pi^+ + K^+$$
$$p + p \rightarrow p + n + K^+ + K_S^{\ 0}$$
$$p + p \rightarrow \Sigma^+(1385) + n + K^+$$
$$p + p \rightarrow \Sigma^- + p + \pi^0 + \pi^+ + K^+$$
$$p + p \rightarrow \Sigma^+ + p + \pi^0 + \pi^- + K^+$$
$$p + p \rightarrow \Sigma^0 + p + \pi^- + \pi^+ + K^+$$
$$p + p \rightarrow \Lambda + p + \pi^0 + \pi^+ + \pi^- + K^+$$
$$p + p \rightarrow \Sigma^-(1385) + p + K^+$$
$$p + p \rightarrow \Lambda + n + \pi^+ + \pi^+ + \pi^- + K^+$$
$$p + p \rightarrow \Lambda + p + \pi^+ + \pi^- + K^+$$
$$p + p \rightarrow \Sigma^- + n + \pi^+ + \pi^+ + K^+$$
$$p + p \rightarrow p + p + \pi^- + K^+ + K_S^{\ 0}$$

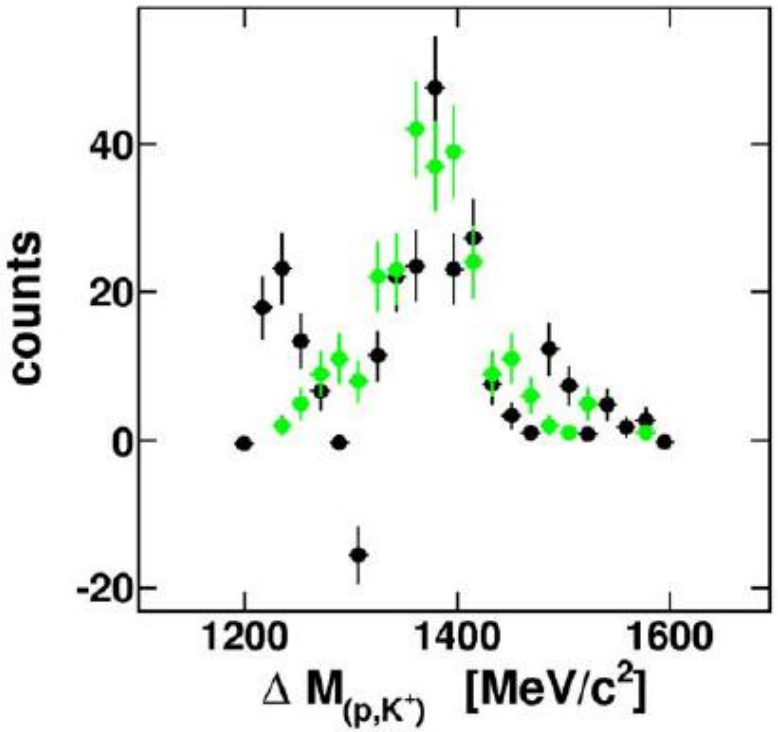
Missing mass analysis



- $\Sigma^+ + K^+ + n$
- $\Sigma(1385)^+ + K^+ + n$
- $\Sigma^+ + K^+ + n + \pi^+ + \pi^-$
- $\Sigma^+ + K^+ + p + \pi^0$
- $\Sigma^- + K^+ + p + \pi^+$
- $\Lambda + K^+ + \pi^+ + n$

All other channels


counts
80
60
40
20
0
1200
1400
1600
Δ M(p,K+) [MeV/c2]


counts
40
20
0
-20
1200
1400
1600
Δ M(p,K+) [MeV/c2]

Comparison with Full-Scale Simulation

Preliminary