K^-

Study of the $\Lambda(1405)$ going to $\Sigma^0\pi^0$ in AMADEUS

Dr. Kristian Piscicchia*

Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi
INFN, Laboratori Nazionali di Frascati

on behalf of the AMADEUS collaboration

Advanced studies in the low-energy QCD in the strangeness sector and possible implications in astrophysics

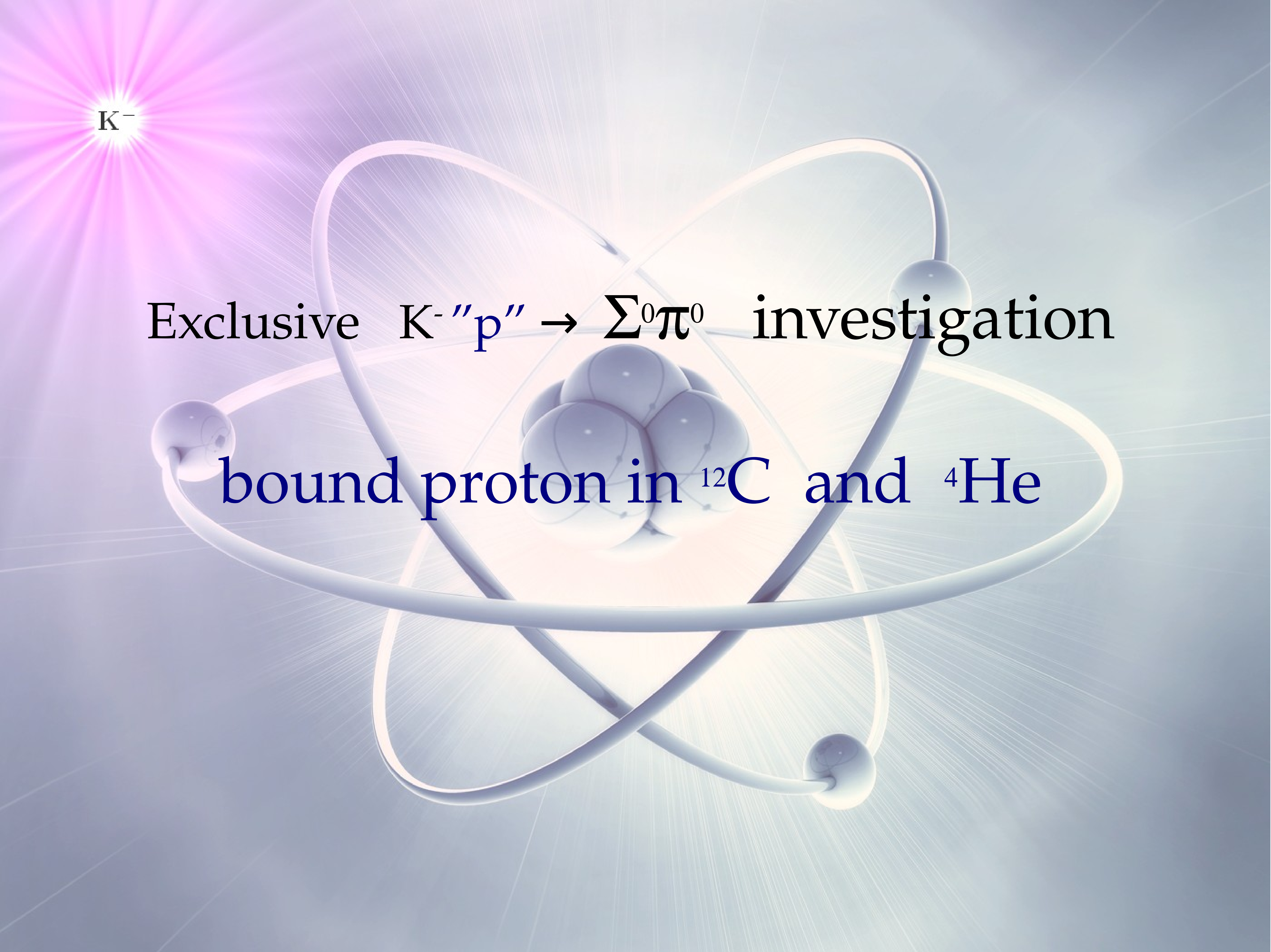
19-21 June 2013, LNF-INFN

Dedicated to the memory of Paul Kienle

*kristian.piscicchia@lnf.infn.it

Exclusive K^{-}"p" → $\Sigma^0\pi^0$ investigation

bound proton in ^{12}C and ^{4}He



Λ(1405) puzzle

Λ(1405): $(m, \Gamma) = (1405.1^{+1.3}_{-1.0}, 50 \pm 2)$ MeV, $I = 0$, $S = -1$, $J^p = 1/2^-$, Status: ****, strong decay into Σπ

K^-

Its nature is being a puzzle for decades: 1) *three quark state*: expected mass ~ 1700 MeV

2) *penta quark*: more unobserved excited baryons 3) *unstable $\bar{K}N$ bound state* in-medium modification of the Λ^* mass ? .. (Nucl. Phys. 13 (1987) 1361 / Phys. Rev. C 56 5 (1997) /arXiv:1211.6336v3 (2013))

(see Tucakovic's talk)

4) *two poles*: ($z_1 = 1424^{+7}_{-23} - i\,26^{+3}_{-14}$; $z_1 = 1381^{+18}_{-6} - i\,81^{+19}_{-8}$) MeV (Nucl. Phys. A881, 98 (2012))

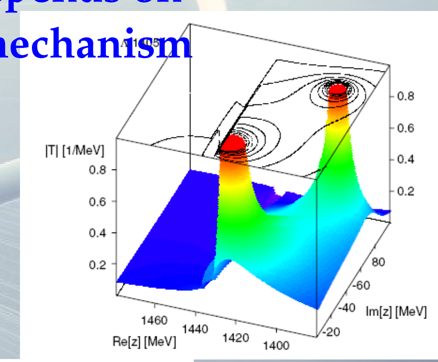
mainly coupled to $\bar{K}N$ mainly coupled to Σπ → line-shape depends on production mechanism

Line-shape also depends on the decay channel

$$\frac{d\sigma(\Sigma^-\pi^+)}{dM} \propto \frac{1}{3}|T^0|^2 + \frac{1}{2}|T^1|^2 + \frac{2}{\sqrt{6}}Re(T^0T^{1*})$$

$$\frac{d\sigma(\Sigma^0\pi^0)}{dM} \propto \frac{1}{3}|T^0|^2$$

$$\frac{d\sigma(\Sigma^+\pi^-)}{dM} \propto \frac{1}{3}|T^0|^2 + \frac{1}{2}|T^1|^2 - \frac{2}{\sqrt{6}}Re(T^0T^{1*})$$



Lower mass: 1385 MeV/c² HADES
(see L. Fabietti's talk)

5) One pole : Akaishi, Esmaili, Yamazaki model
Phys. Lett. B 686 (2010) 23-28

fit of $K^{-\,4}$He absorption at-rest data
(D. Riley et al. Phys. Rev. D11 (1975) 3065)

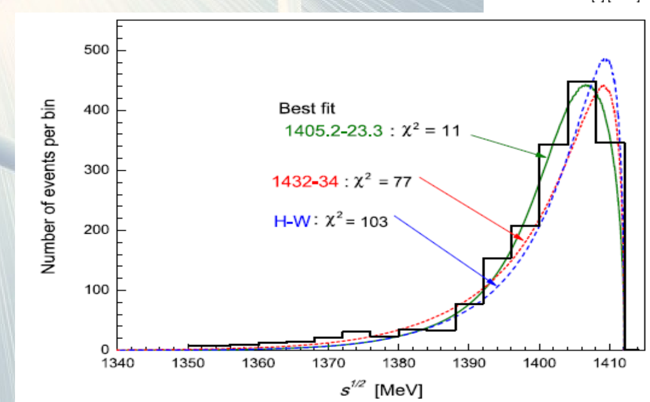


Fig. 6. Detailed differences in $M_{\Sigma\pi}$ spectra among the Hyodo–Weise prediction and the present model predictions.

Investigation of the $\Lambda(1405)$ produced in K^- nuclear absorption in light nuclei … why?

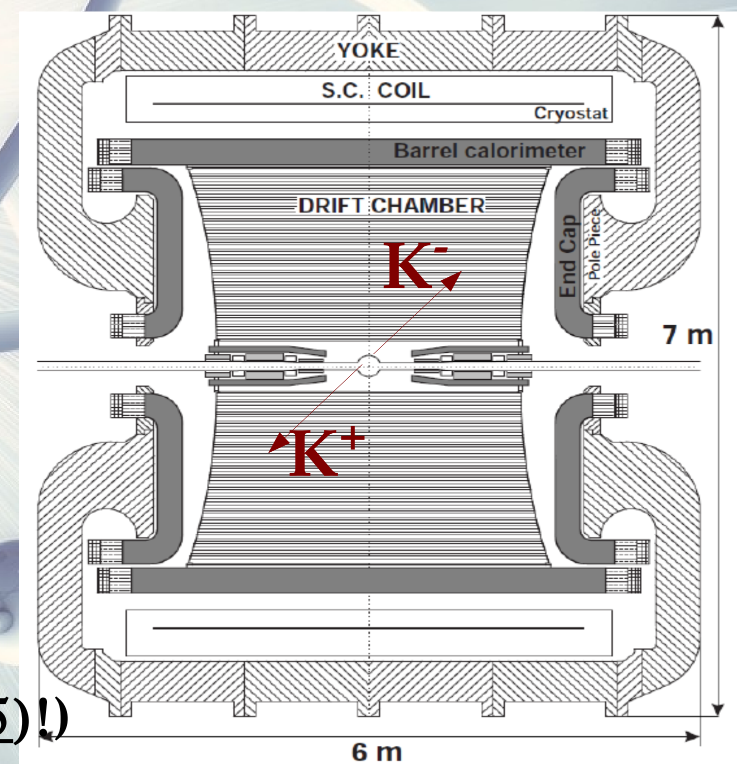
- Λ^* **production in K^-N reactions:** (only chance to observe a possible high mass pole, possibility to test in-medium modification of the Λ^* mass) …

Taking advantage of low (127 MeV/c) DAΦNE kaons we can investigate both

Stopped K^-N absorptions & low energy in-flight K^-N absorptions

"A study of $K^- \, ^4He \rightarrow (\Sigma^\pm\pi^\mp) + {}^3H$ using slow instead of stopping K^- would be very useful"

D. Riley, et al. Phys. Rev. D11 (1975) 3065



- **decay in $\Sigma^0\pi^0$:** (pure I=0 channel, free from $\Sigma(1385)$!)

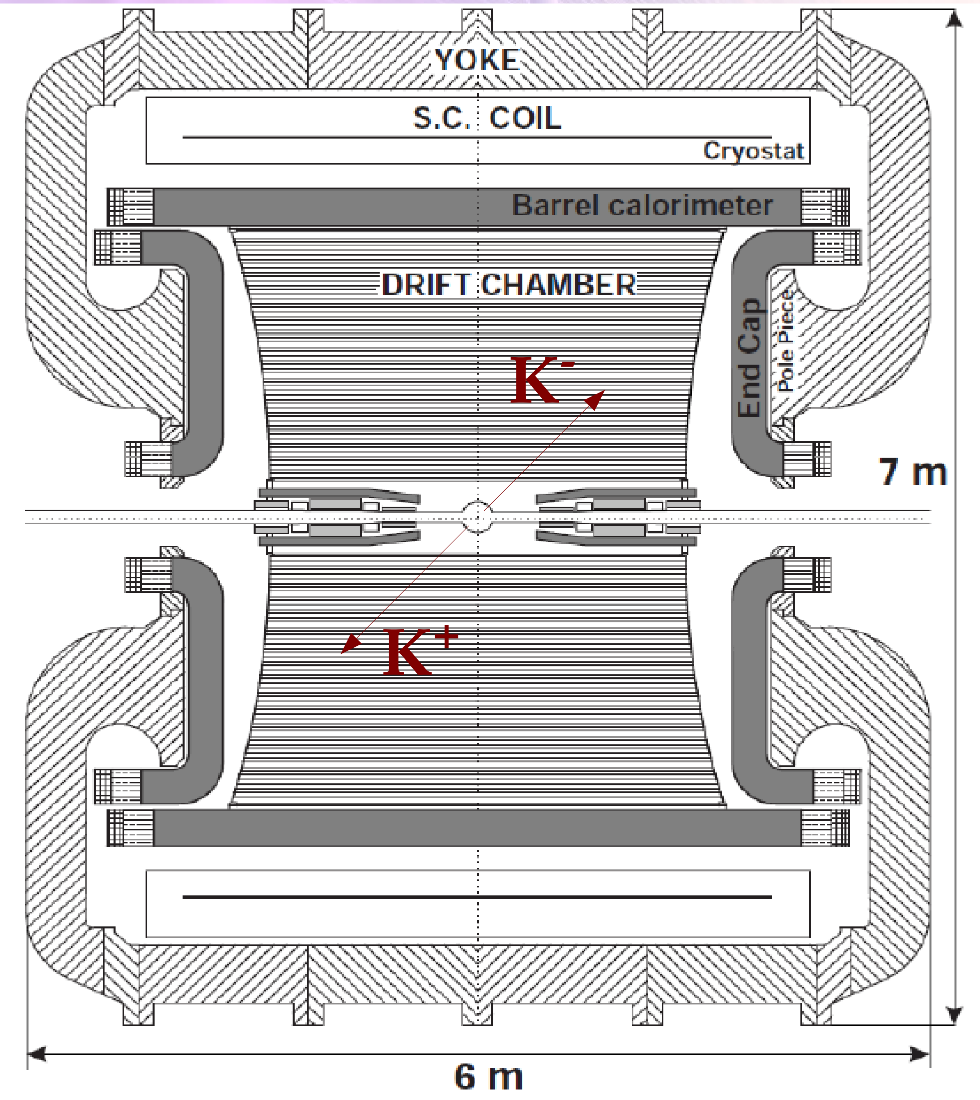
Possible thanks to the good performances of KLOE calorimeter!

Low-energy K^- hadronic interactions studies with KLOE, an idea of Prof. Paul Kienle

K^-

MC simulations show that :

- ~ 0.1 of K^- stopped in the DC gas (90% He, 10% C_4H_{10})
- ~2% of K^- stopped in the DC wall (mainly C with Al and H contamination).



Possibility to use KLOE materials as an active target

Advantage:
good resolution ..

$\sigma_{p\Lambda}$ = 0.49±0.01 MeV/c in DC gas

$\sigma_{m\gamma\gamma}$ = 18.3±0.6 MeV/c²

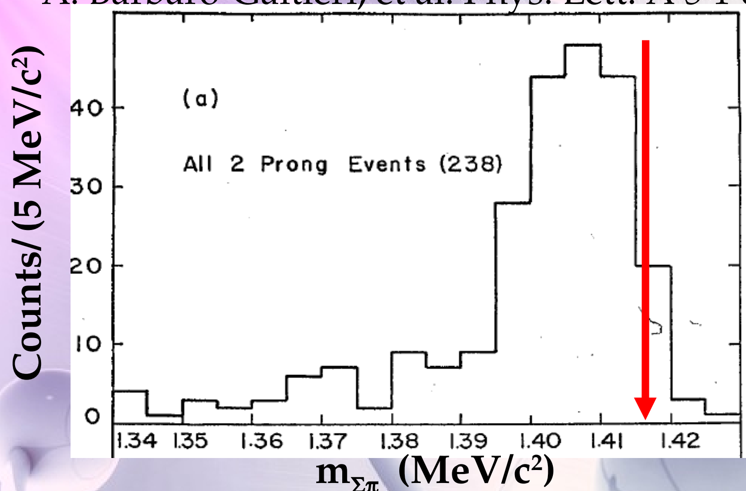
Disadvantage:
Non dedicated target → different nuclei contamination → complex interpretation ..
but → new features .. K^- in flight absorption.

Preceding studies

K⁻ nuclear absorption experiments .. long history .. BUT

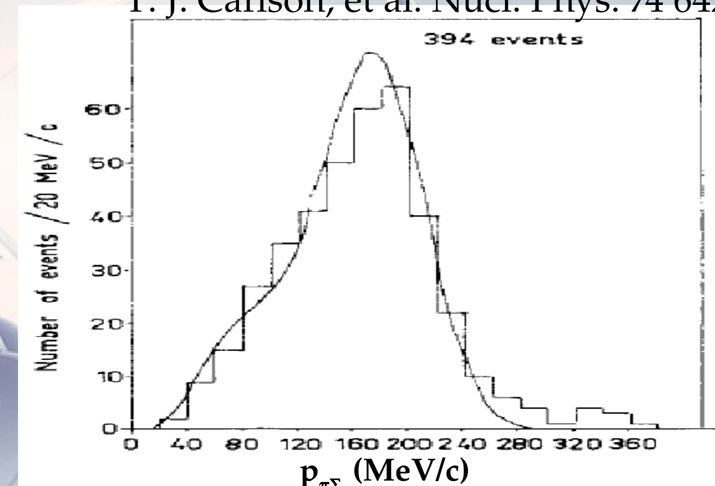
1) $m_{\pi\Sigma}$ spectra always cut at the at-rest limit

A. Barbaro-Galtieri, et al. Phys. Lett. A 5 1 63



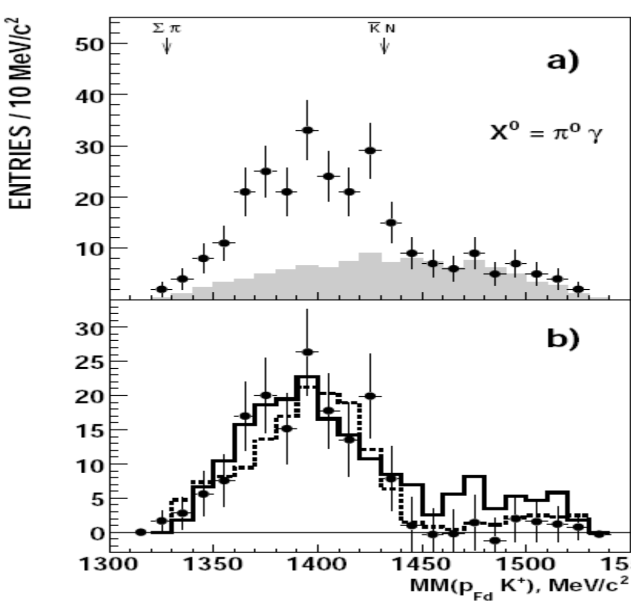
2) (Σ±π∓) spectra contain Σ(1385) contribution

P. J. Carlson, et al. Nucl. Phys. 74 642

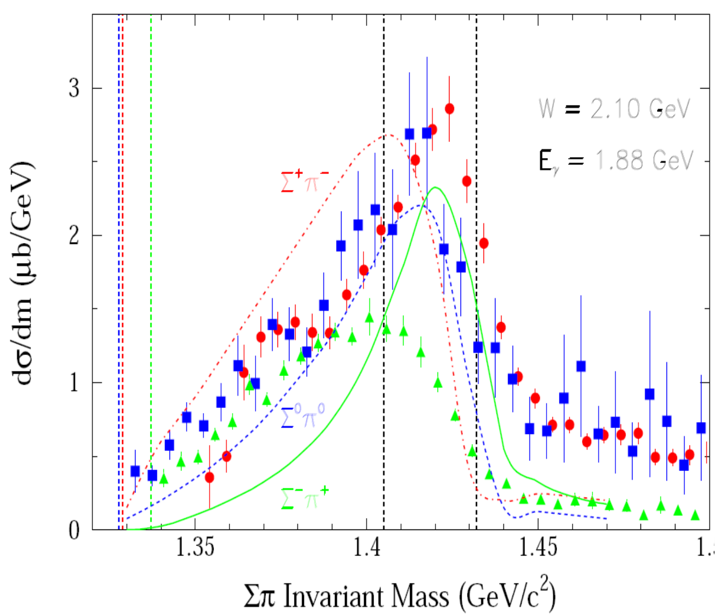


The $\Sigma^0\pi^0$ spectrum was only observed in 3 experiments … with different line-shapes !

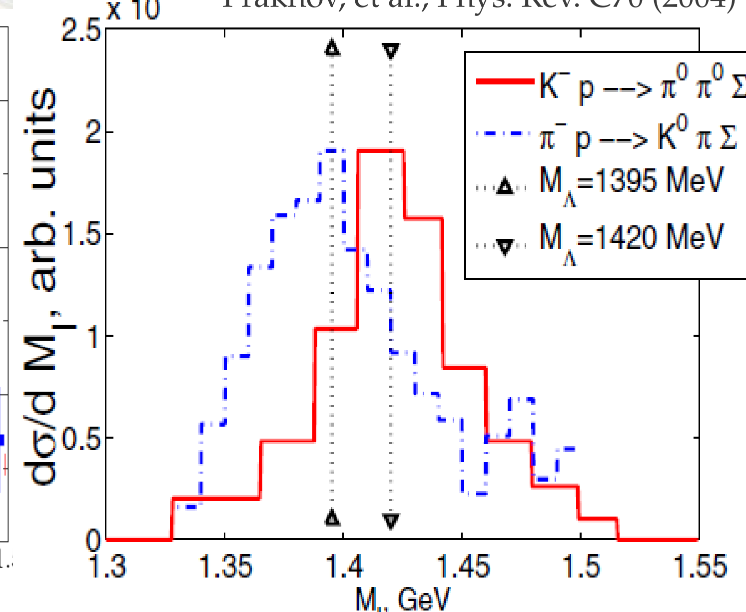
I. Zychor et al., Phys. Lett. B 660 (2008) 167



K. Moriya, et al., (Clas Collaboration) Phys. Rev. C 87, 035206 (2013)



Magas et al. PRL 95, 052301 (2005) 034605 S. Prakhov, et al., Phys. Rev. C70 (2004)



$\Sigma^0\pi^0$ analysis status

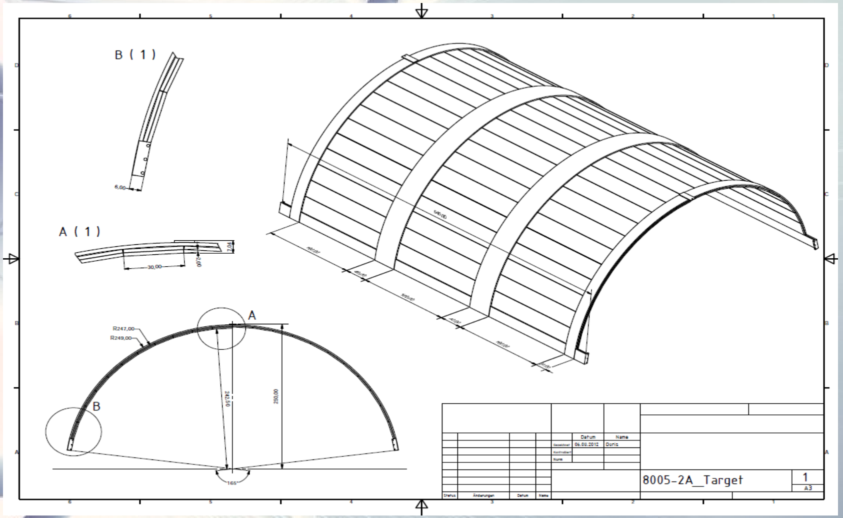
K^-

- **Analysis of the 2004-2005 KLOE data (~ 1 fb^{-1})**

- **Dedicated 2012 run with pure graphite Carbon target inside KLOE**

Advantages:

- **gain in statistics**
- **K^- absorptions occur in Carbon**
- **absorptions at-rest.**



- **MC simulation: 26% of K^- stopped in C, 2% of K^- stopped in Al hence aluminium contamination from 19% → 7% … H contamination absent!**

- **Thickness optimazied (based on MC simulations) to maximize the number of stopping K^- in the targed, minimizing the charged particles energy loss.**

(~90 pb^{-1}; analyzed 37 pb^{-1}, x1.5 statistics)

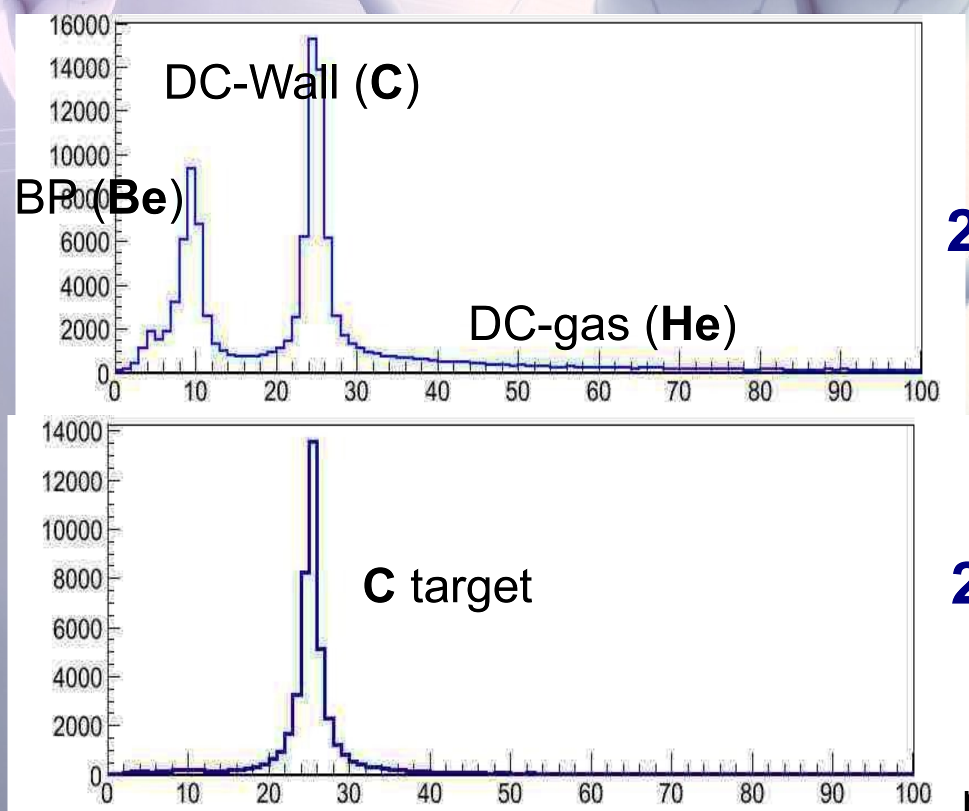
Characteristic data topology

K^-

Use of two different data samples:

- **KLOE data from 2004/2005**
- **Dedicated run with Carbon target**

Radial position of the K^- hadronic interaction inside KLOE:



2005 data

2012 with Carbon target

r(cm)

K^-

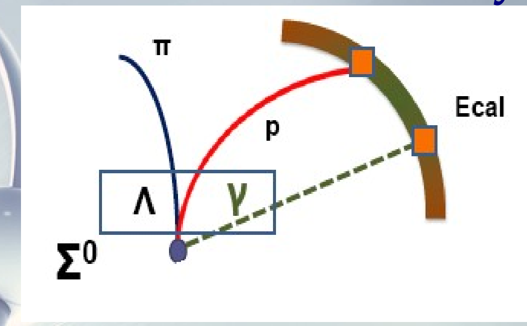
$$K^- \text{"p"} \rightarrow \Sigma^0\pi^0 \rightarrow (\Lambda(1116)\,\gamma_3)\,(\gamma_1\gamma_2) \rightarrow (p\pi^-)\,3\gamma$$

First step .. Λ(1116)

Λ(1116) the signature of K^- hadronic interaction

K^-

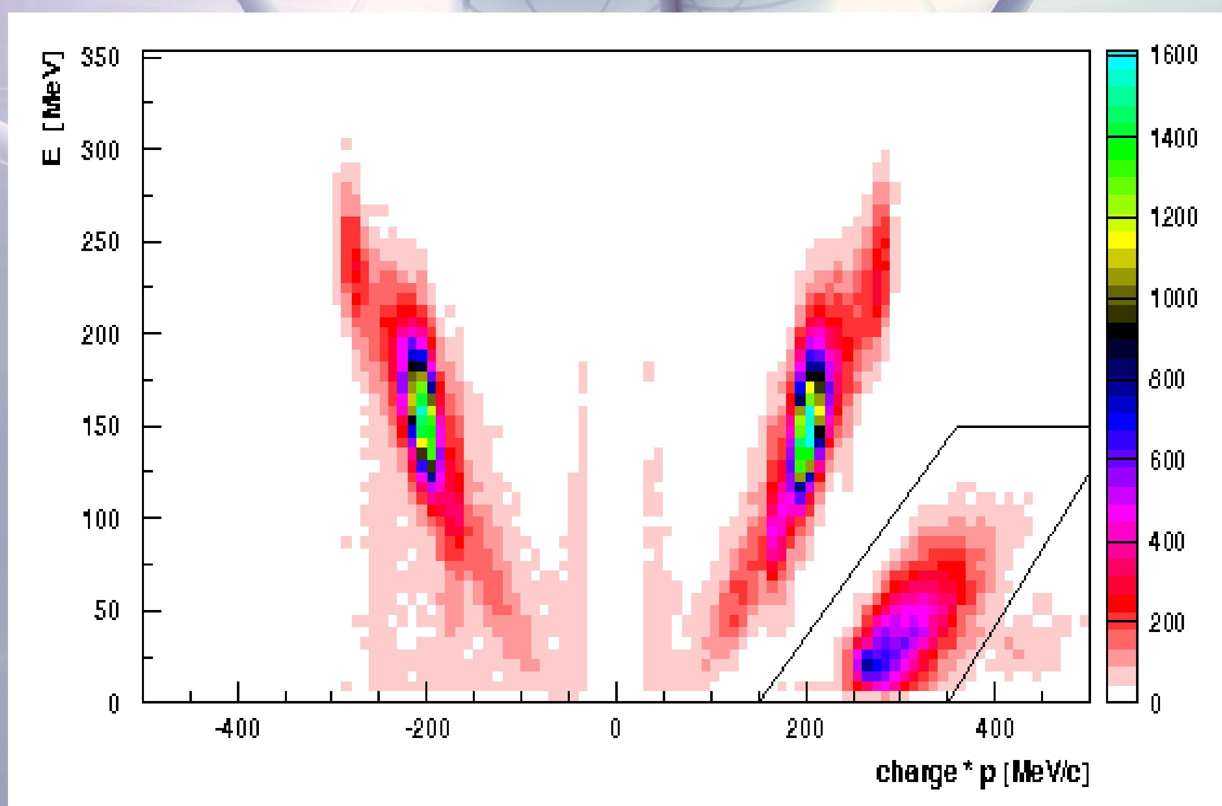
starting point of the performed analysis reconstruction of the Λ decay vertex: $\Lambda(1116) \to p\pi^-$ (BR ~ 64 %)



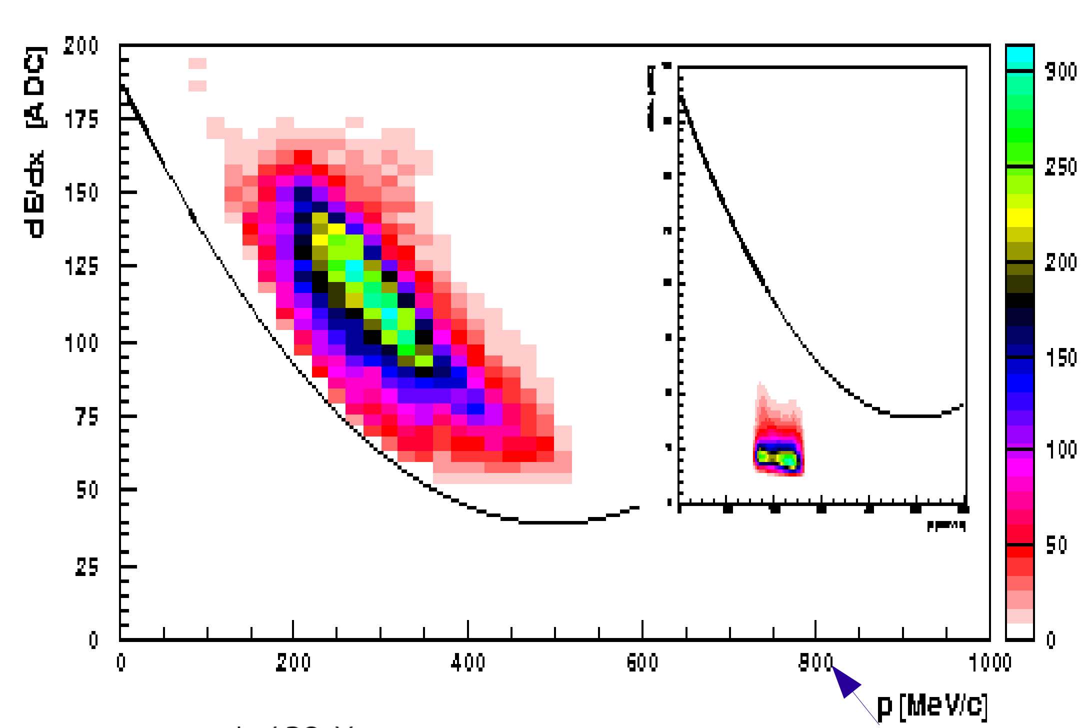
requests:

- **vertex with at least two opposite charged particles**
- **spatial position of vertex inside DC, or in DC entrance wall**
- **negative tracks with dE/dx < 95 ADC counts.**

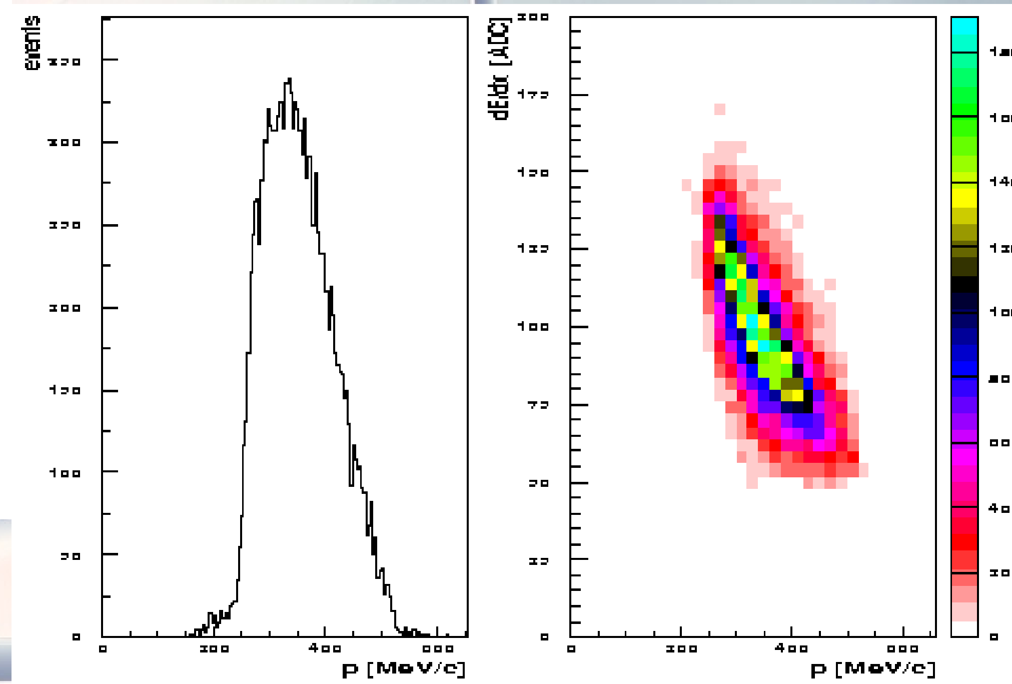
Positive tracks are requested to have an associated cluster in the calorimeter and the correct *E* - *p* relation. (KLOE Memo 330 September 2006)

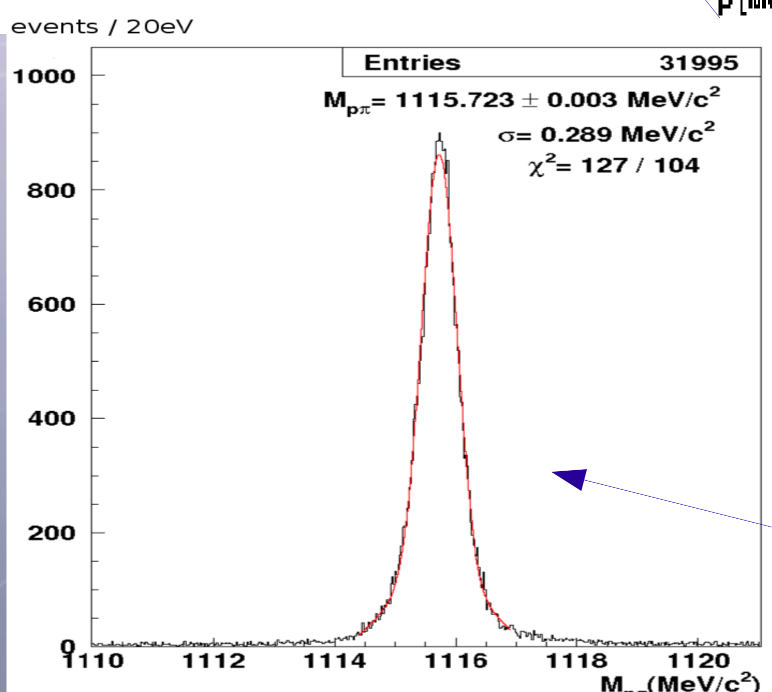


Λ(1116) the signature of K^- hadronic interaction



Correction for low momentum positive tracks (due to the kinetic energy threshold of the calorimeter ~ 20 MeV)





Clear separation with respect to pions (from K^+ two body decay)

Excellent fianal $p\pi^-$ invariant mass spectrum.

Photon clusters identification

K^-

K^- "p" $\rightarrow \Sigma^0\pi^0 \rightarrow (\Lambda(1116)\,\gamma_3)\,(\gamma_1\gamma_2) \rightarrow (p\pi^-)\,3\gamma$

1) 3 neutral clusters selection (E_{cl} > 20 MeV) not from K^+ decay ($K^+ \rightarrow \pi^+\pi^0$)

2) photon clusters selection: $\chi_t^2 = t^2/\sigma_t^2$ where $t = t_i - t_j$

time of flights in light speed hypothesis.

Selects three photon clusters in time from the Λ decay vertex r_Λ

3) photon clusters identification: γ_3 from $\pi^0 \rightarrow \gamma_1\gamma_2$ distinctioncay

$$\chi^2_{\pi\Sigma} = \frac{(m_{\pi^0} - m_{ij})^2}{\sigma^2_{ij}} + \frac{(m_{\Sigma^0} - m_{k\Lambda})^2}{\sigma^2_{k\Lambda}}$$

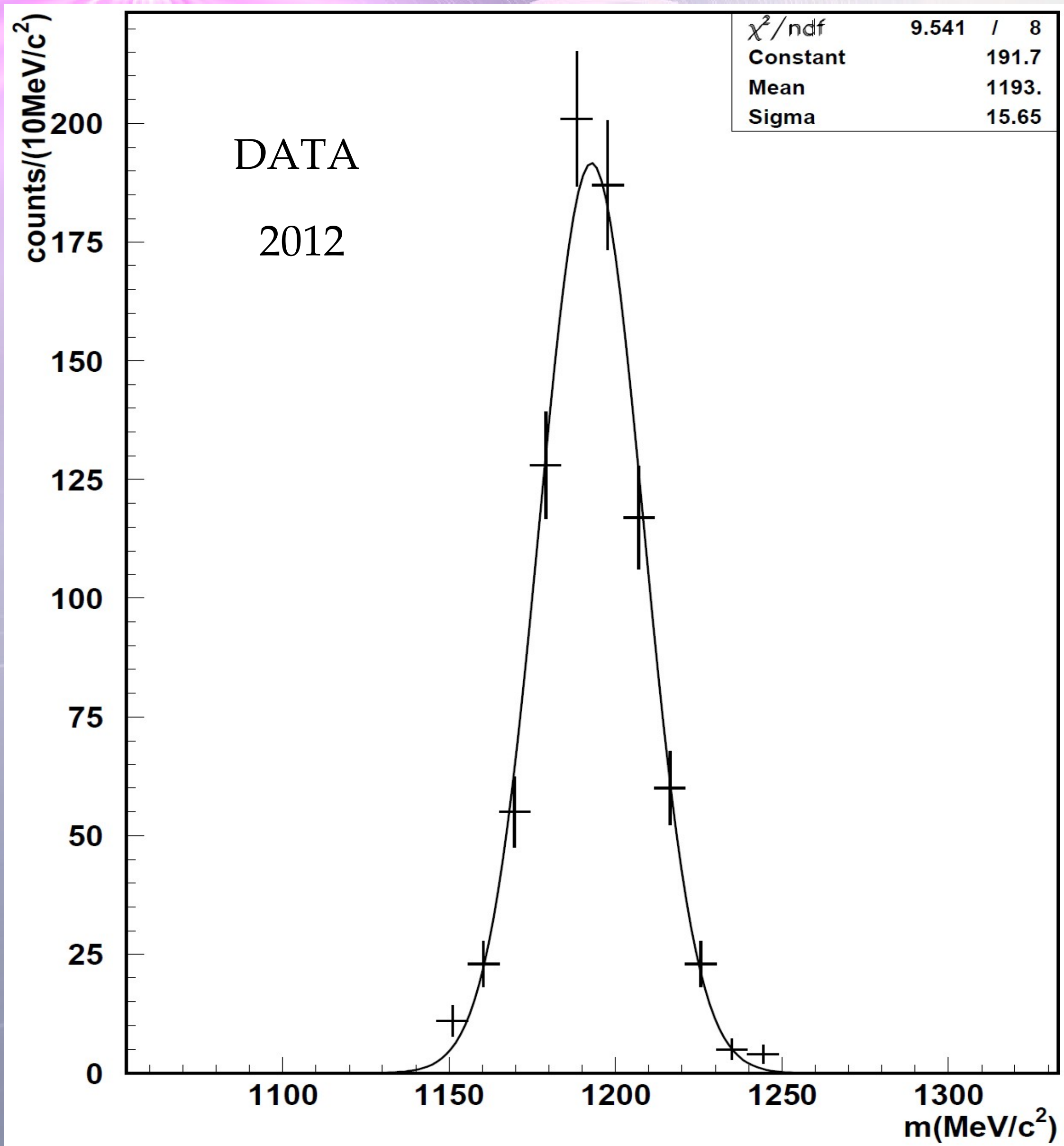
i,j and *k* represent one of the previously selected candidate photon cluster.

4) Cuts on χ_t^2 and $\chi_{\pi\Sigma}^2$ optimized on MC simulations & splitted clusters rejection

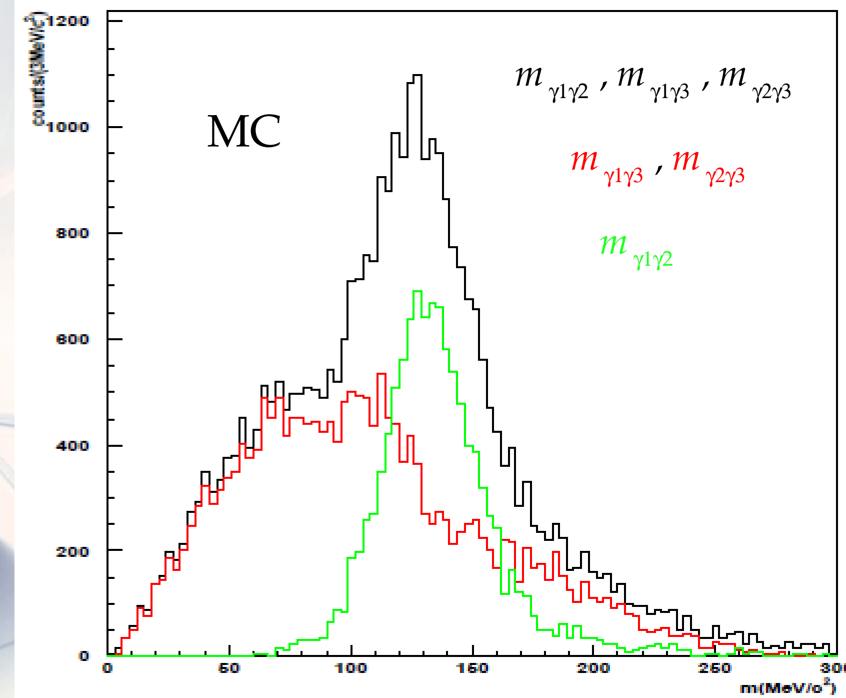
The algorithm has (from true MC information) an efficiency (98±1)% to identify photons and (78±2)% to select the correct triple of neutral clusters.

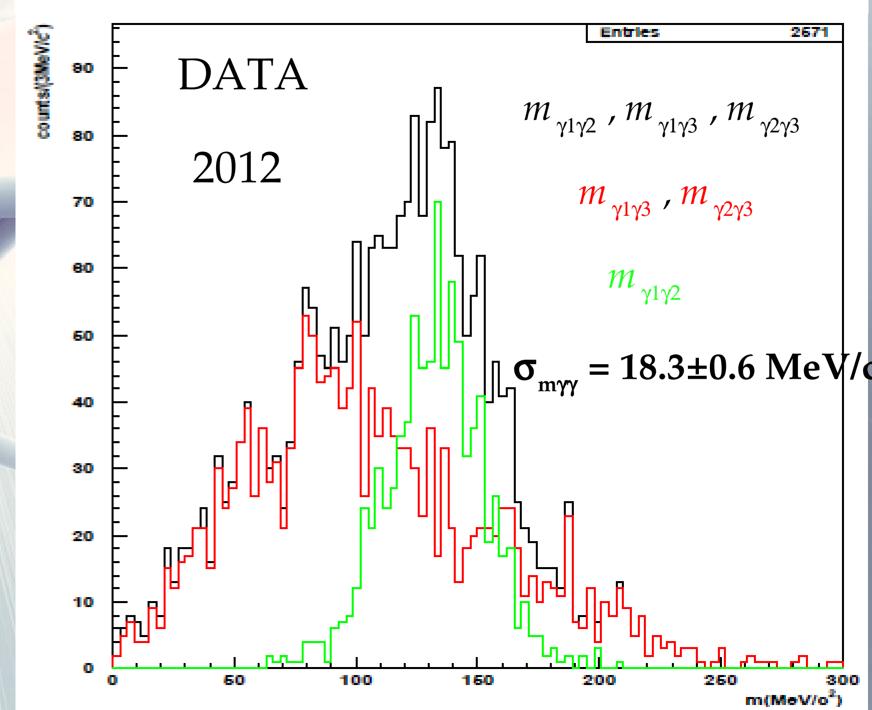
Photon clusters identification: Σ^0 invariant mass

K^-



$m_{\Lambda\gamma 3}$





$\Sigma^0 \pi^0$ mass & momentum

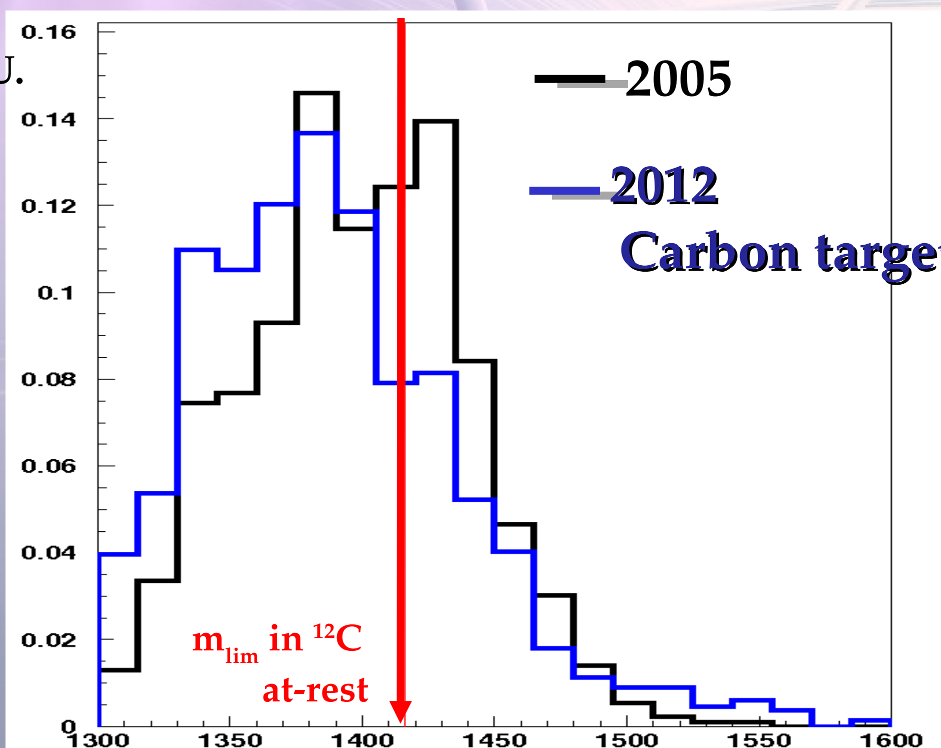
K^-

$\Lambda(1405)$ signal searched by K^- interaction with a bound proton in Carbon

$K^- p \rightarrow \Sigma^0 \pi^0$ detected via: $(\Lambda\gamma)(\gamma\gamma)$

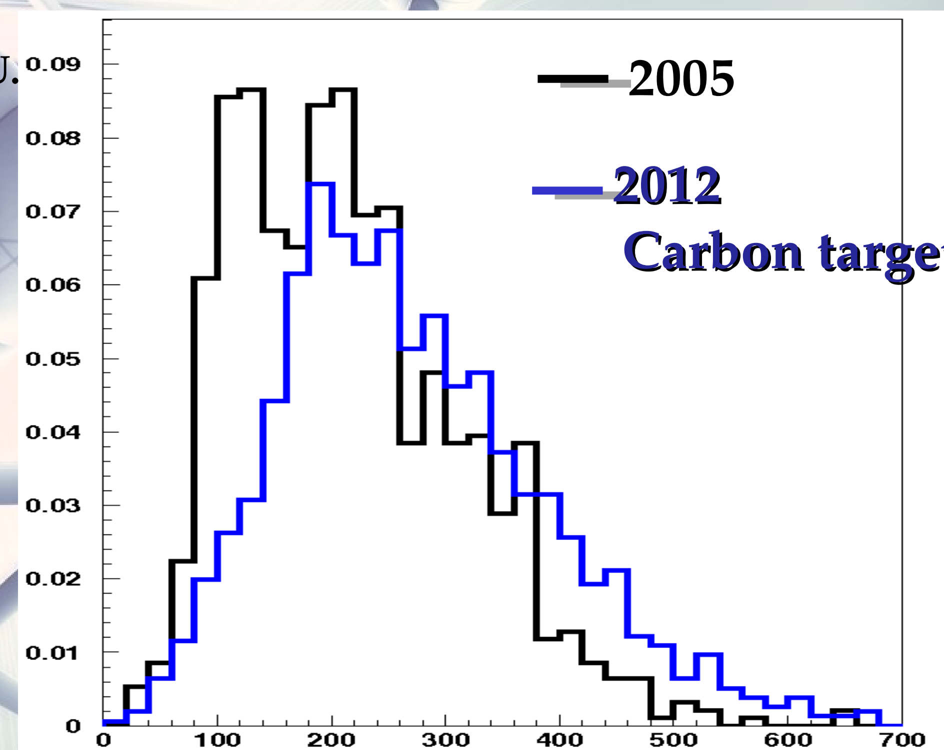
Strategy : K^- absorption in the DC entrance wall, mainly ^{12}C with H contamination (epoxy)

N. U.



$m_{\Sigma 0 \pi 0}$ (MeV/c²)

N. U.



$p_{\Sigma 0 \pi 0}$ (MeV/c²)

$m_{\pi 0 \Sigma 0}$ resolution $\sigma_m \approx 32$ MeV/c² ; **$p_{\pi 0 \Sigma 0}$ resolution:** $\sigma_p \approx 20$ MeV/c.

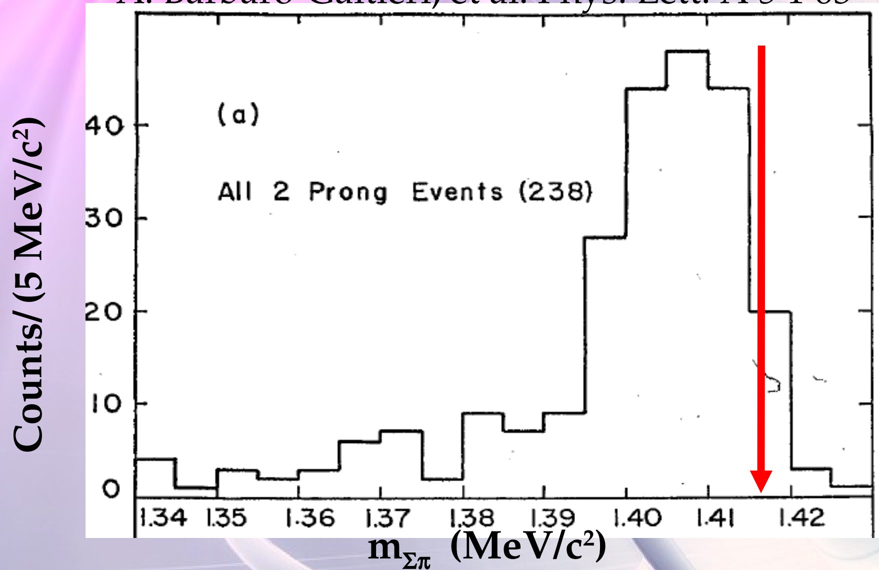
Comparison with K^- absorption in emulsion

K^- nuclear absorption experiments .. long history .. BUT

K^-

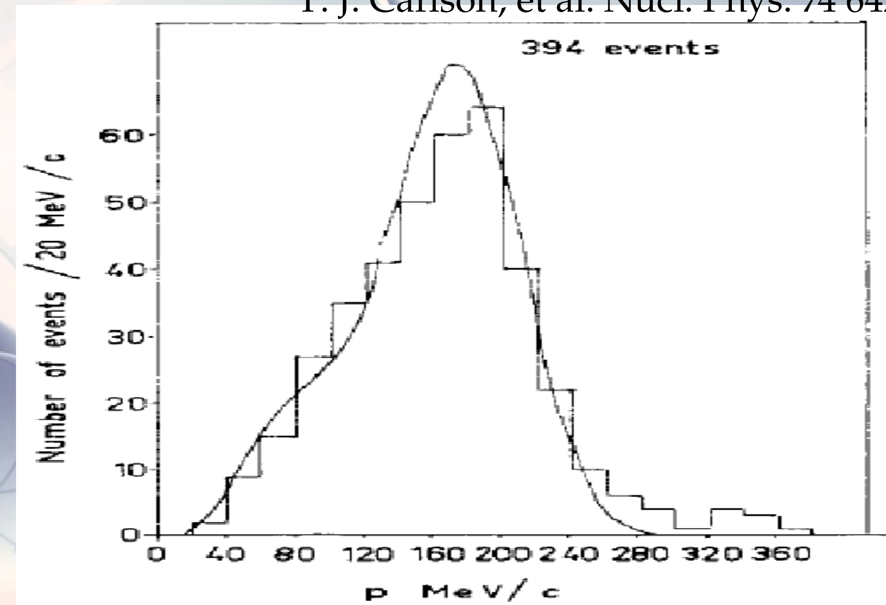
1) $m_{\pi\Sigma}$ spectra always cut at the at-rest limit

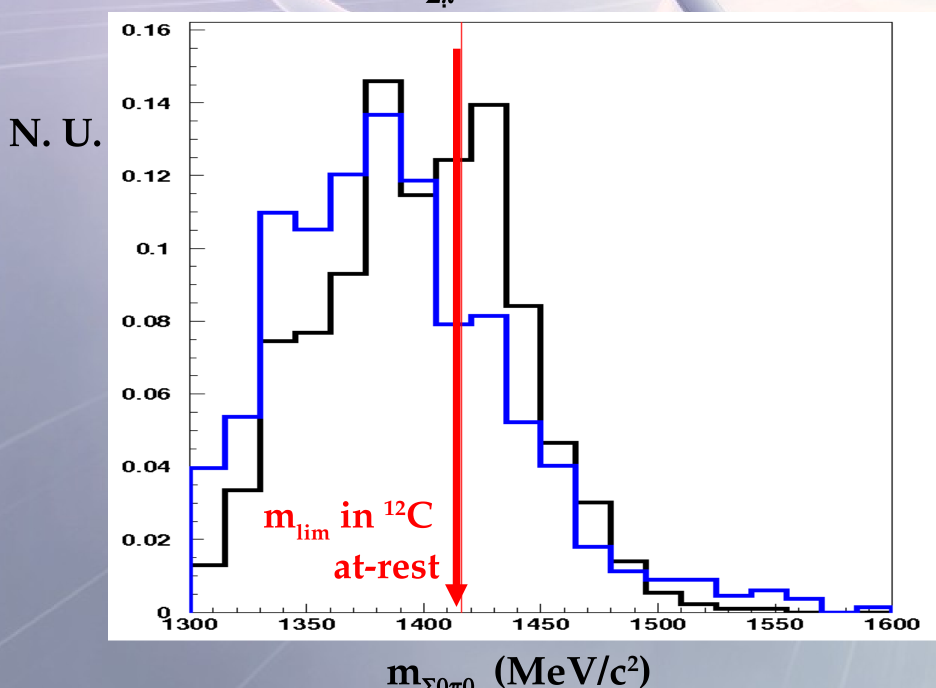
A. Barbaro-Galtieri, et al. Phys. Lett. A 5 1 63

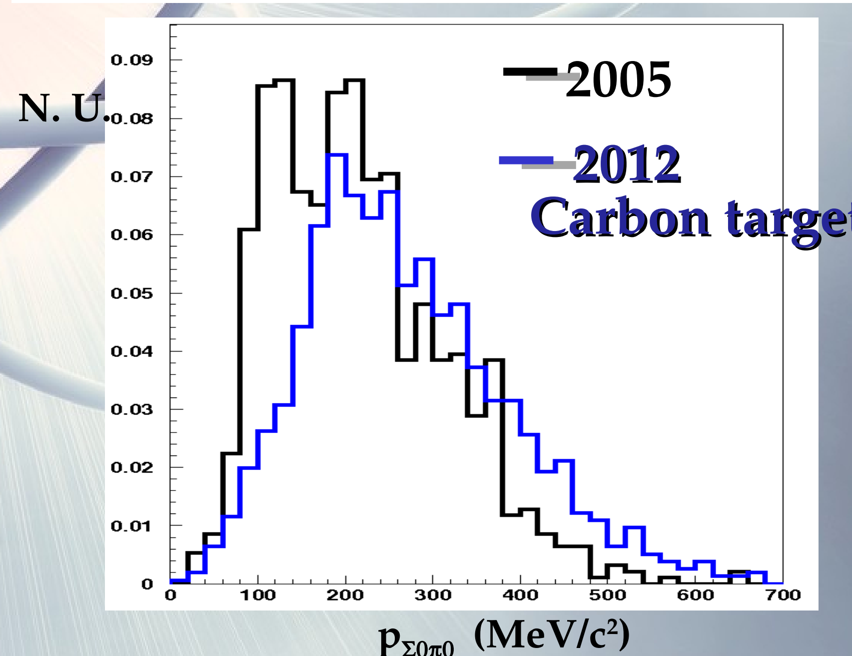


2) ($\Sigma\pm\pi\mp$) spectra suffer $\Sigma(1385)$ contamination

P. J. Carlson, et al. Nucl. Phys. 74 642



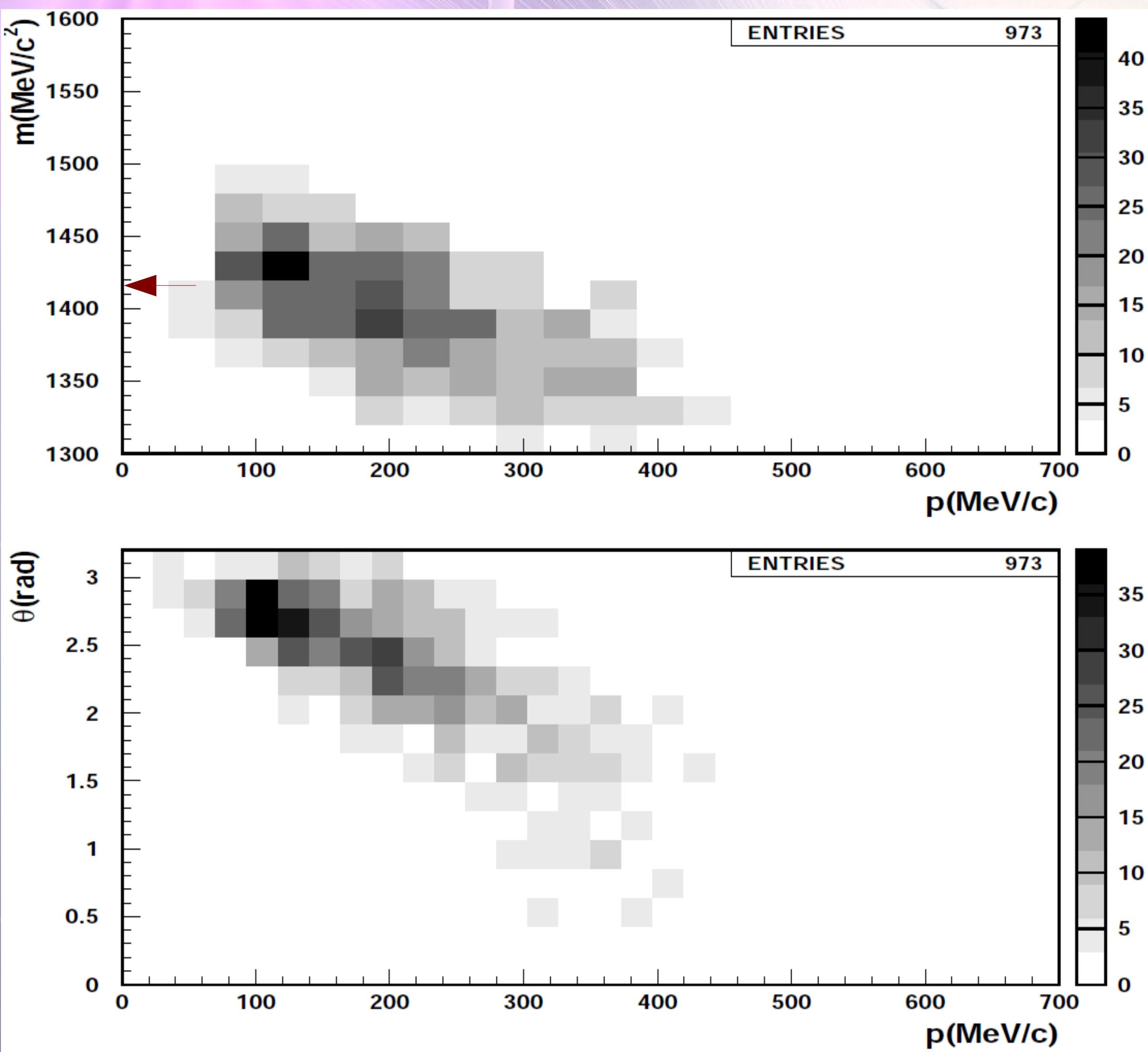




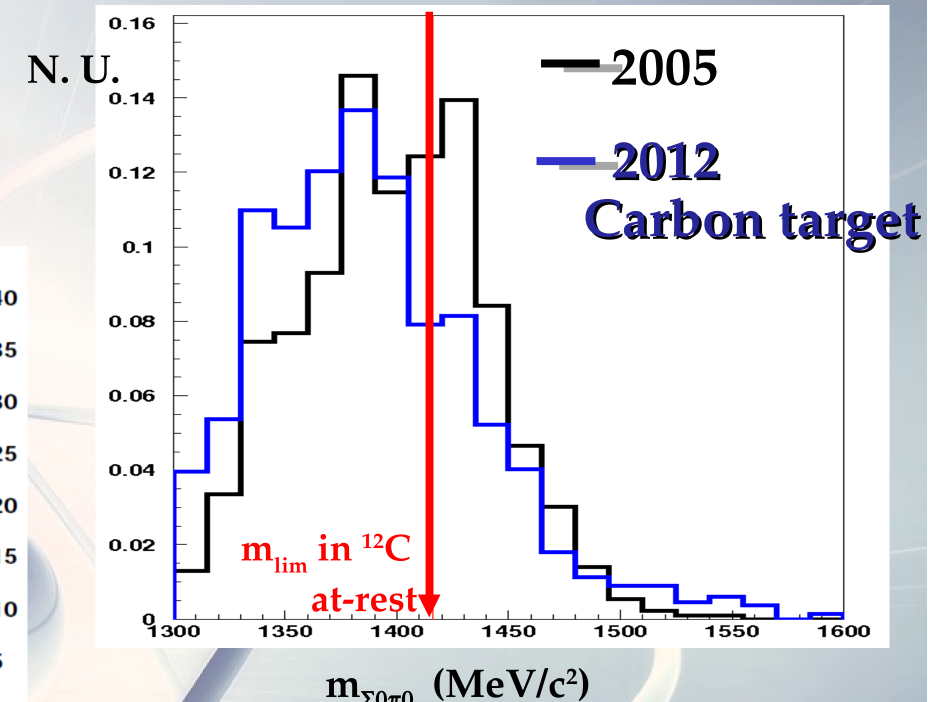
$\Sigma^0 \pi^0$ mass-momentum correlation

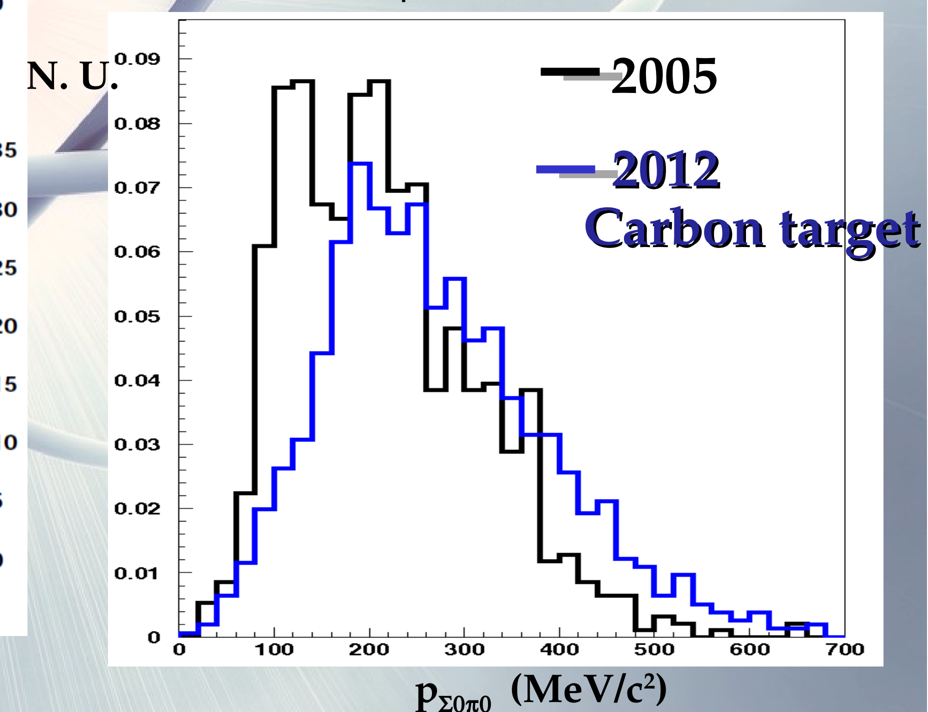
K^-

Mass momentum correlatation



Top $m_{\Sigma^0\pi^0}$ vs $p_{\Sigma^0\pi^0}$, bottom $\theta_{\Sigma^0\pi^0}$ vs $p_{\Sigma^0\pi^0}$.

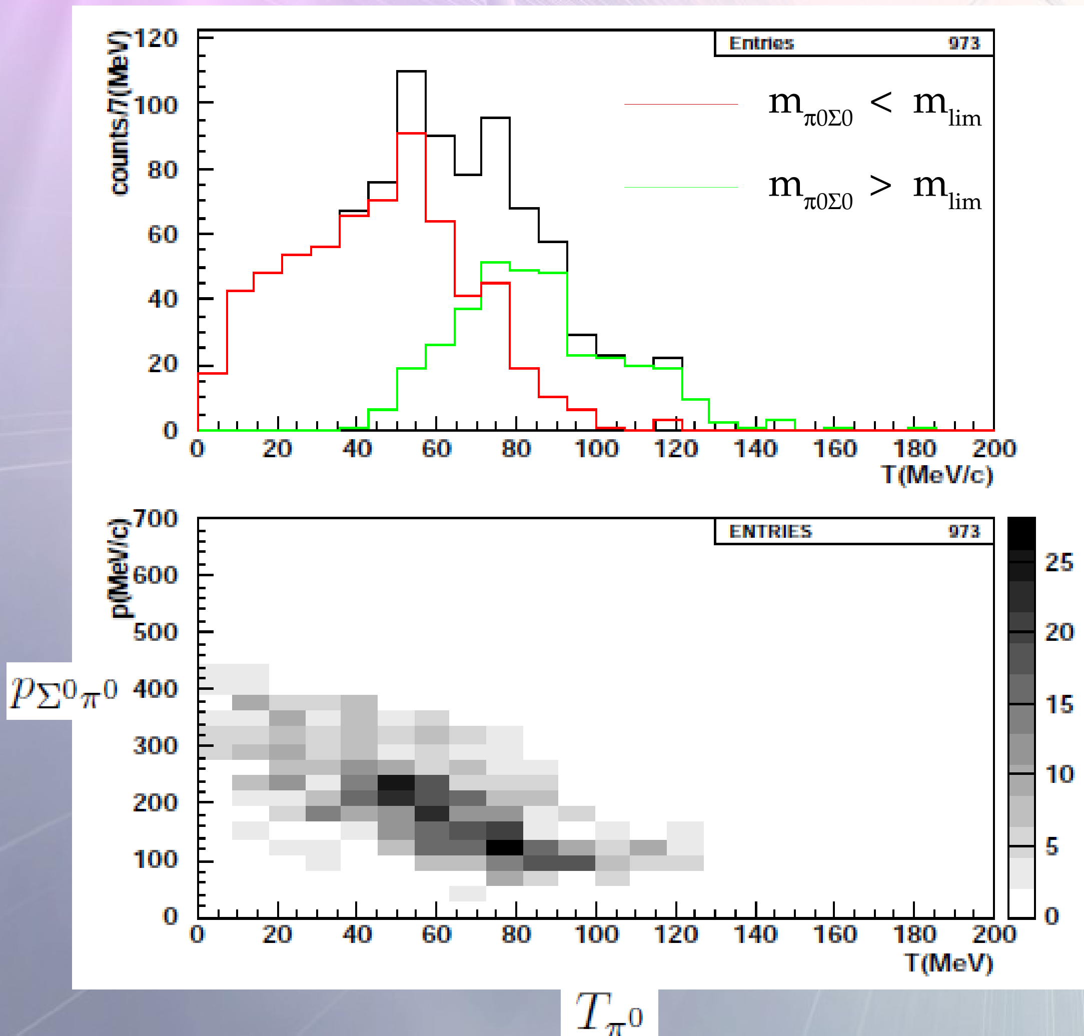


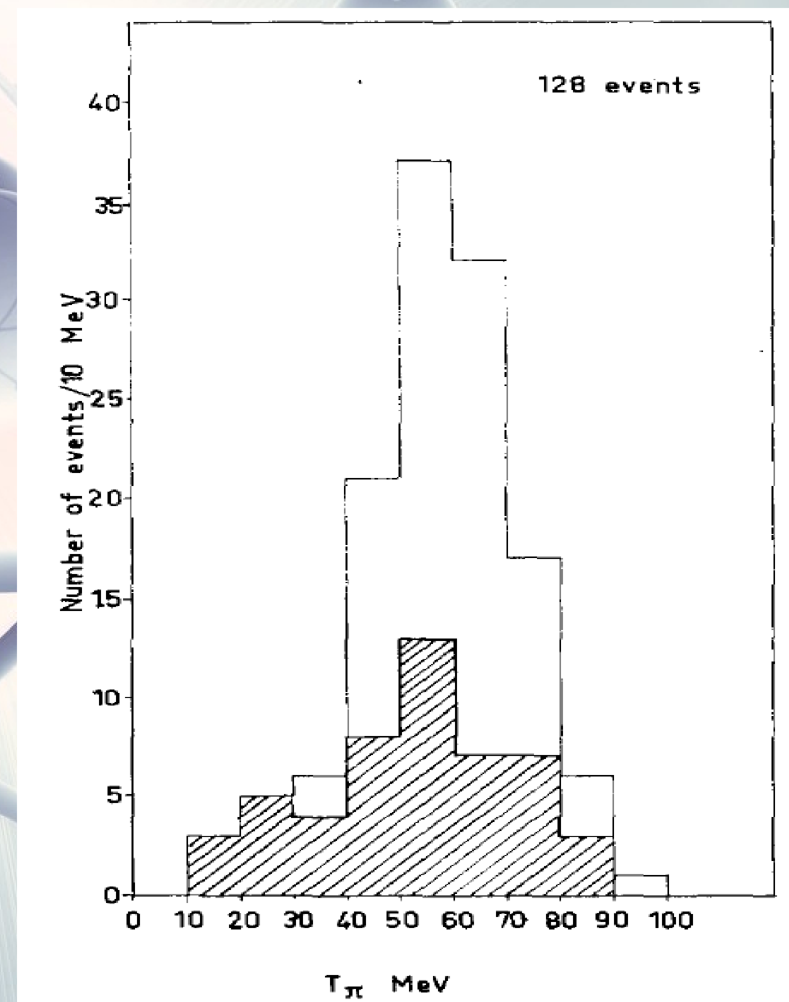


Comparison with K^- absorption in emulsion

K^-

Cut for $m_{\pi^0\Sigma^0} < m_{lim}$ .. lower T_{π^0} component (red) according with $T_{\pi\pm}$ from emulsion experiments (EVENTS AT-REST) correlated to the higher $p_{\pi^0\Sigma^0}$ component (190-200 MeV/c) ! ($\sigma_{T\pi^0}$ = 12.0 ± 0.2 MeV)





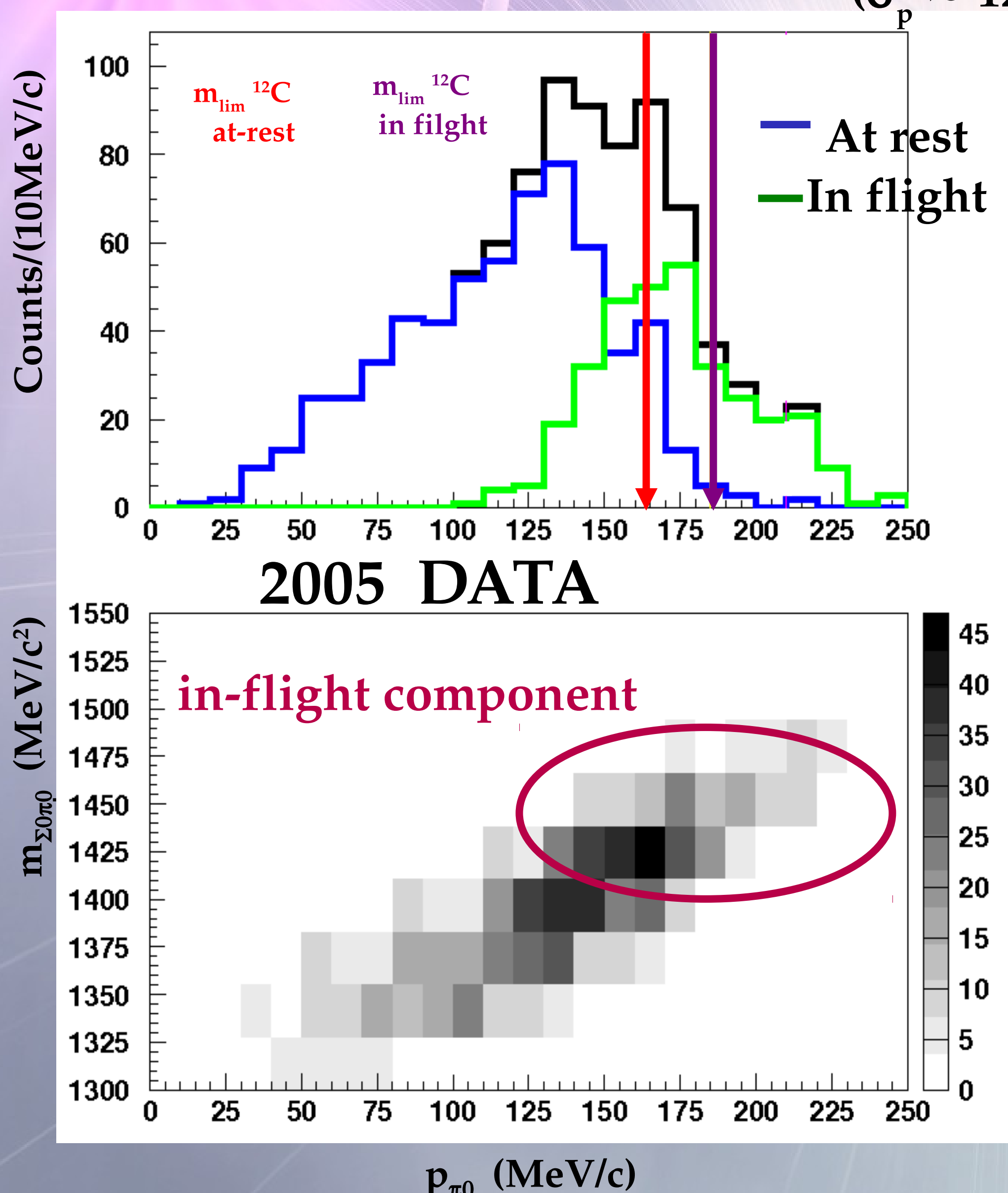
P. J. Carlson et al 1965.

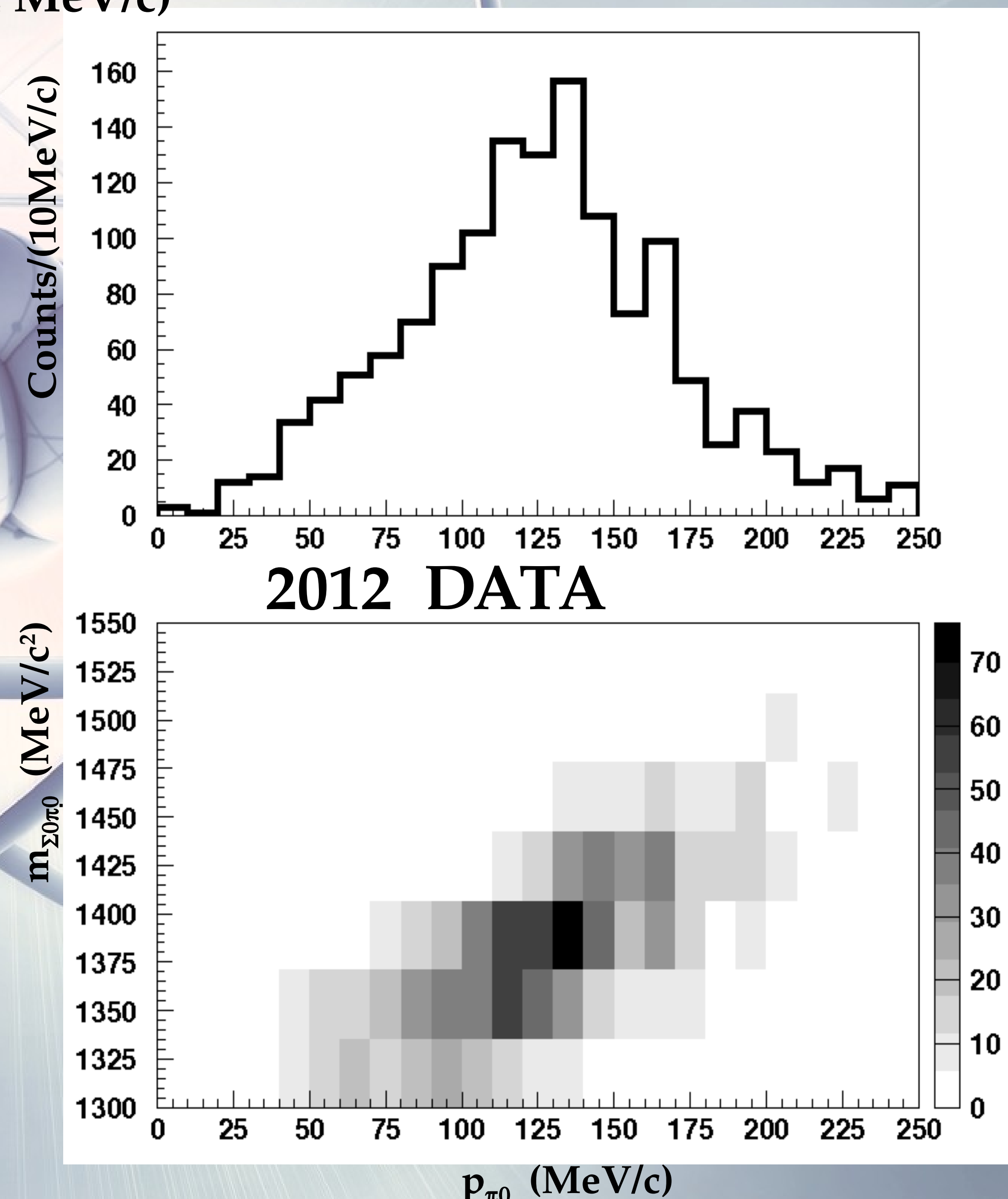
π^0 momentum distribution

in-flight component … FIRST EVIDENCE IN K^- ABSORPTION MASS SPECTROSCOPY

open a higher invariant mass region

($\sigma_p \approx 12$ MeV/c)





Study of the background

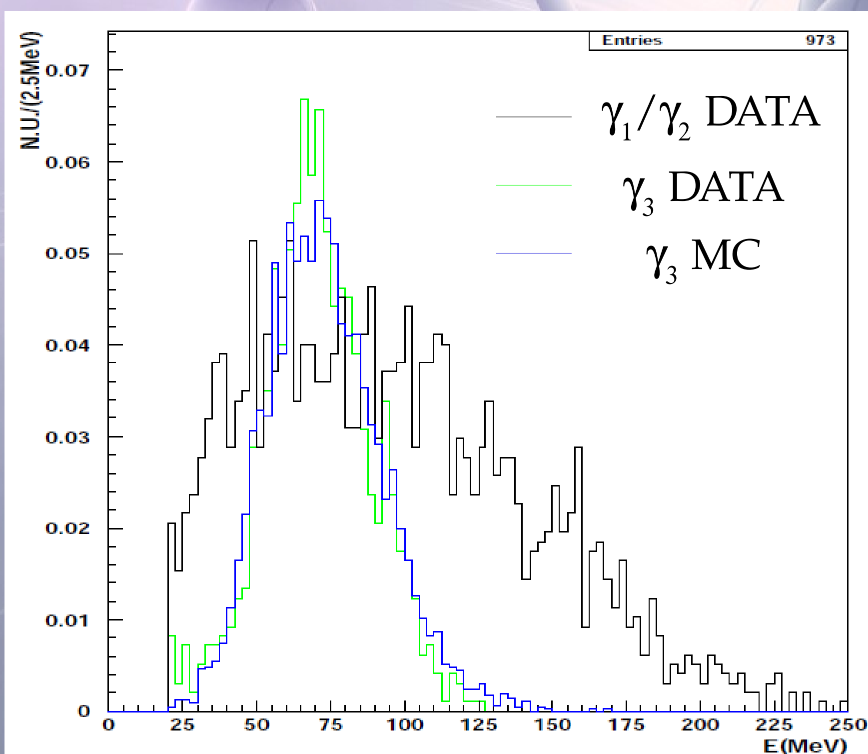
The main background sources for this channel are (example in ^{12}C):

- **$K^- \; ^{12}C \rightarrow \Sigma^0(1385) + {}^{11}B \rightarrow \Lambda\pi^0 + {}^{11}B$**

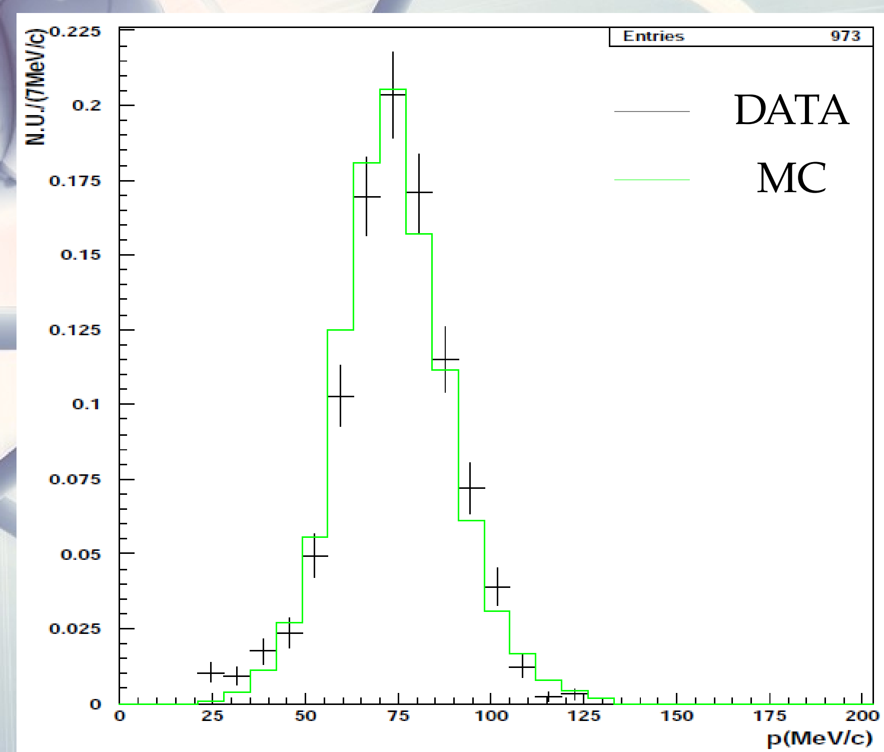
$\Sigma^0(1385)$ can not decay in $\Sigma^0 \pi^0$ for isospin conservation.

- **Internal conversion $K^- \; ^{12}C \rightarrow \Lambda(1405) + {}^{11}B \rightarrow \Sigma^0\pi^0 + {}^{11}B$, $\Sigma^0 N \rightarrow \Lambda N$ competes with the decay $\Sigma^0 \rightarrow \Lambda \gamma$.**

Both background sources were analized by different methods:



photons energy distribution



Λ momentum in the Σ^0 rest frame

Study of the background

K^-

The numbers of pure background $\Sigma(1385)$ and $\Sigma^0 N \rightarrow \Lambda N$ events passing the analysis cuts are normalized to pure signal $\Lambda(1405)$ events, then weighted to the BRs for $\Lambda\pi^0$ direct production (D), internal conversion (IC) and $\Sigma^0\pi^0$ production due to K^- interaction in ^{4}He and C respectively :

P. A. Katz et al., Phys.Rev. D1 (1970) 1267

C. Vander Velde-Wilquet et al., Nuovo Cimento 39 A, (1977) 538

The percentages of background events entering the final selected samples are:

$$\frac{n_{\Lambda\pi^0\,D}\mathrm{norm} + n_{\Lambda\pi^0\,IC}\mathrm{norm}}{n_{\Sigma^0\pi^0} + n_{\Lambda\pi^0\,D}\mathrm{norm} + n_{\Lambda\pi^0\,IC}\mathrm{norm}} = 0.03 \pm 0.01$$ in DC wall (0.03 ± 0.02 in DC gas)

Small ($\Lambda\pi^0$ + internal conversion) bkg → <u>no I=1 contamination</u>

$\Sigma^0\ \pi^0$ channel

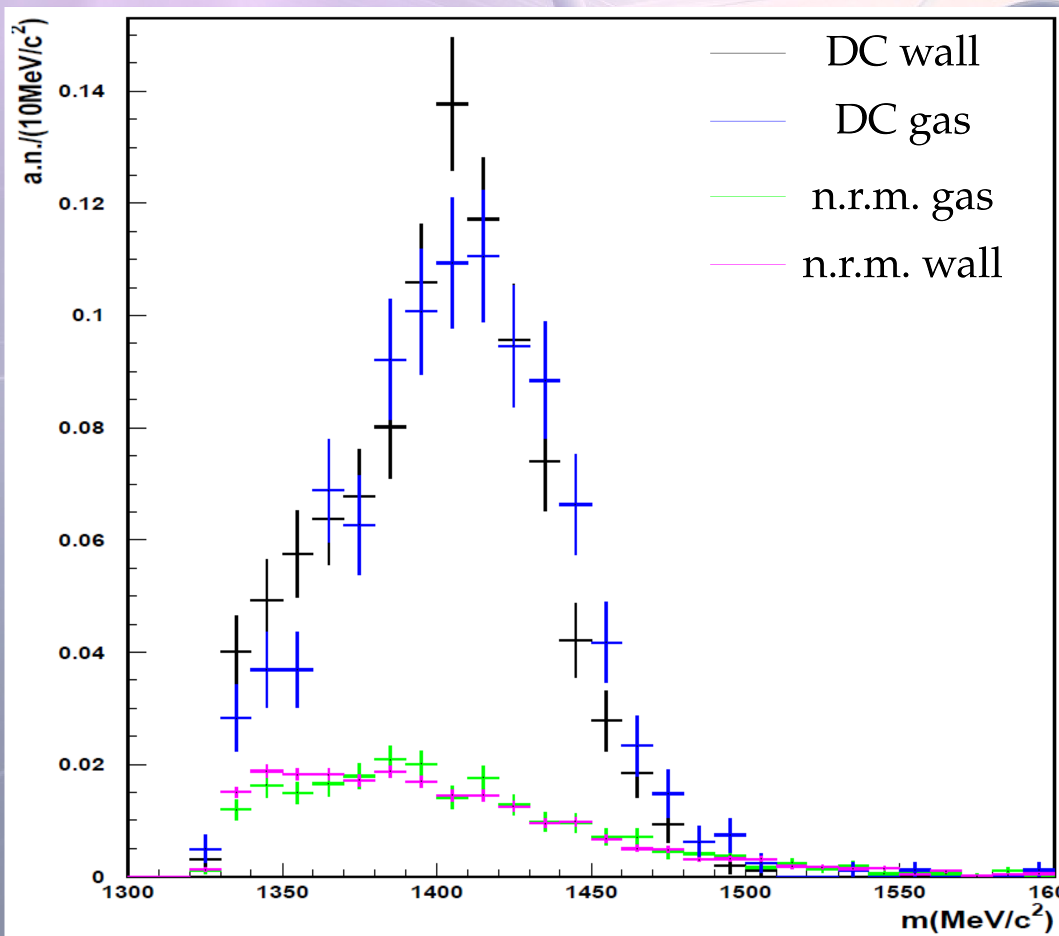
K^-

Invariant mass spectra with mass hypotesis on Σ^0 and π^0 ***non resonant misidentification background subtracted (left)***

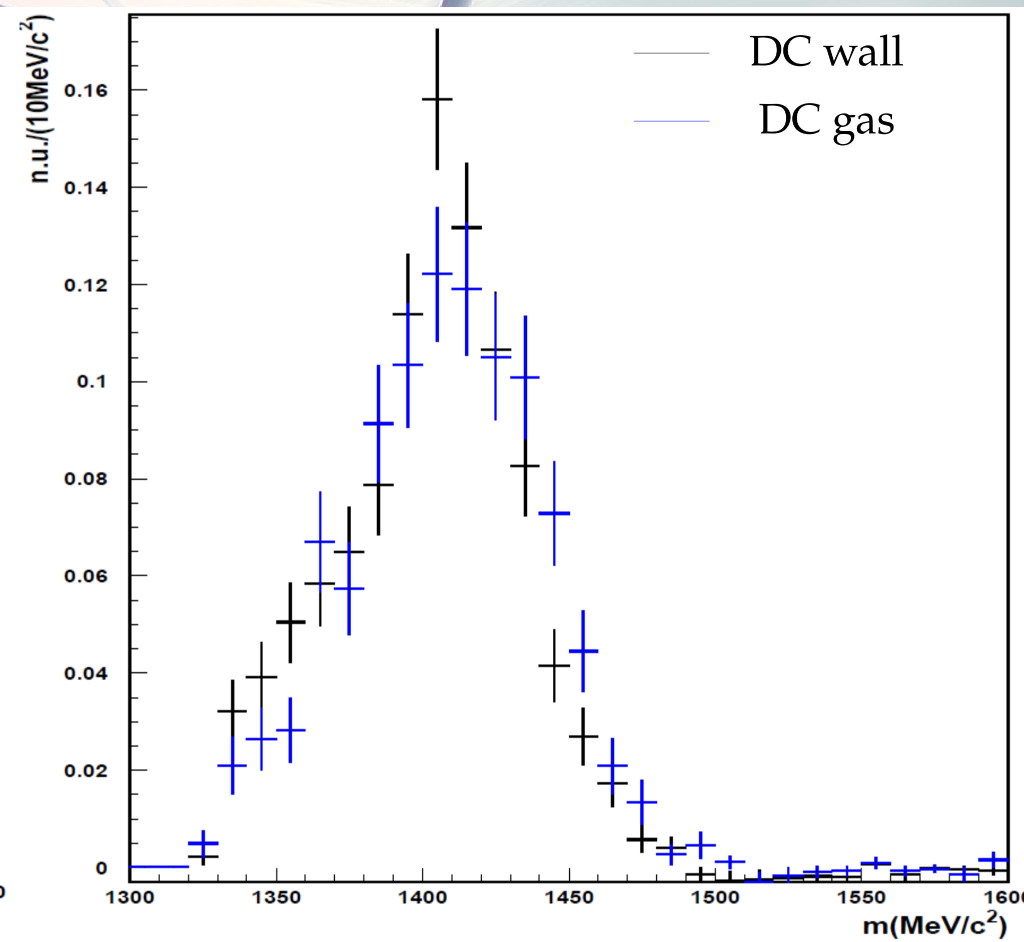
$\sigma_m \approx$ *17 MeV/c²* (DC wall) $\sigma_m \approx$ *15 MeV/c²* (DC gas)

Similar $\mathbf{m_{\pi0\Sigma0}}$ shapes due to the similar kinematical thresholds for ^{4}He and ^{12}C.

2005 DATA



$m_{\Sigma^0\pi^0}$ spectrum

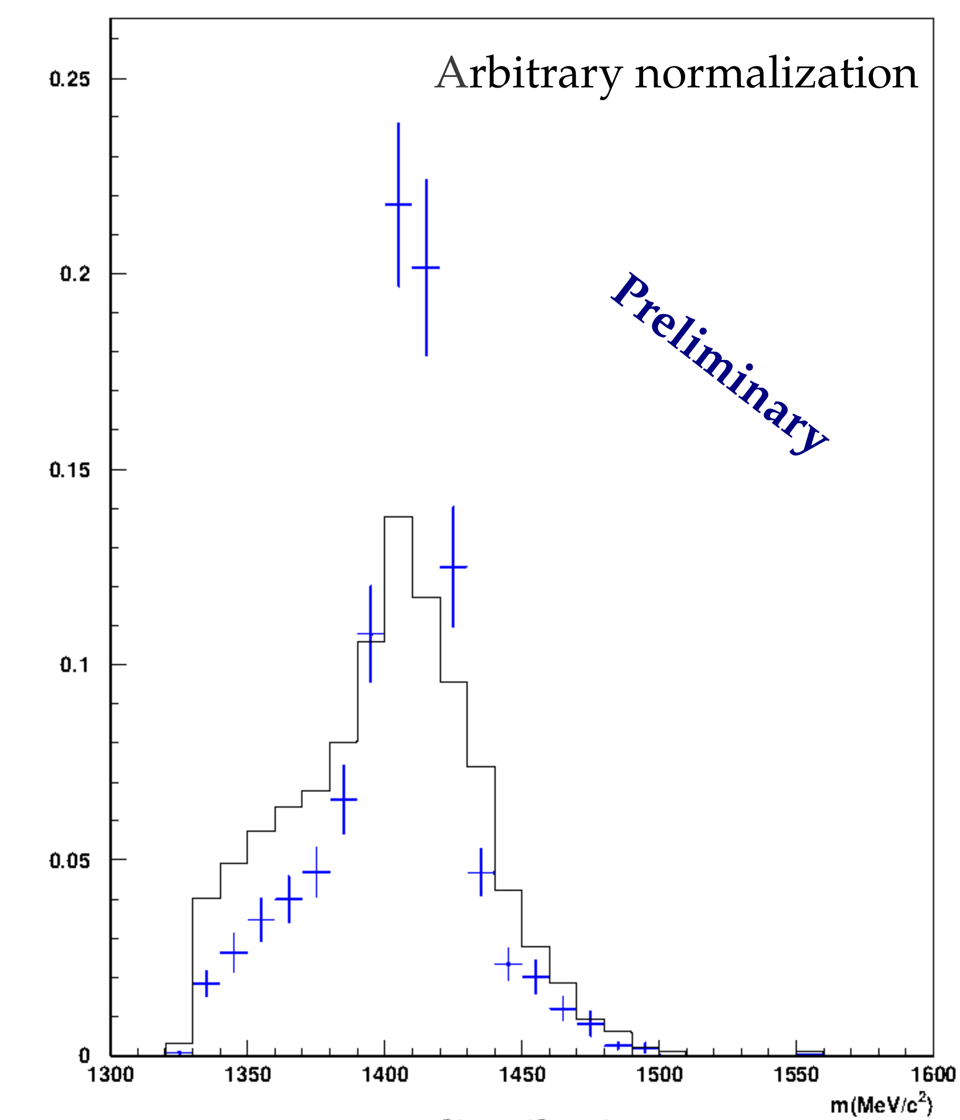


$m_{\Sigma^0\pi^0}$ spectrum

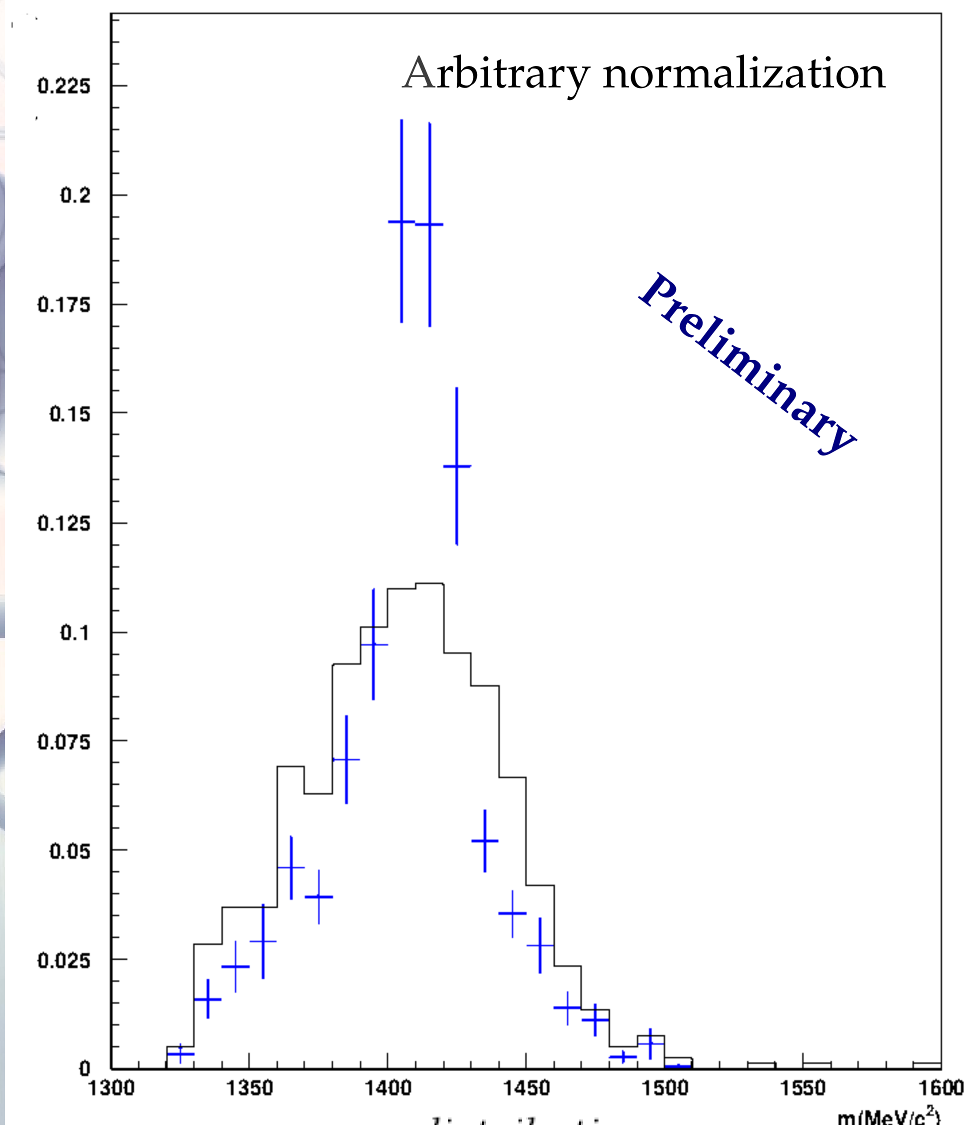
$\Sigma^0\ \pi^0$ channel

Acceptance corrected $m_{\pi0\Sigma0}$ spectra, DC wall (left) DC gas (right)

Acceptance function evaluated in 8 intervals of $p_{\pi0\Sigma0}$ (between 0 and 700 MeV/c) 8 intervals of $\theta_{\pi0\Sigma0}$ (between 0 and 3.15 rad) 30 intervals of $m_{\pi0\Sigma0}$ (between 1300 and 1600 MeV/c^2)



$m_{\Sigma^0\pi^0}$ *distribution*

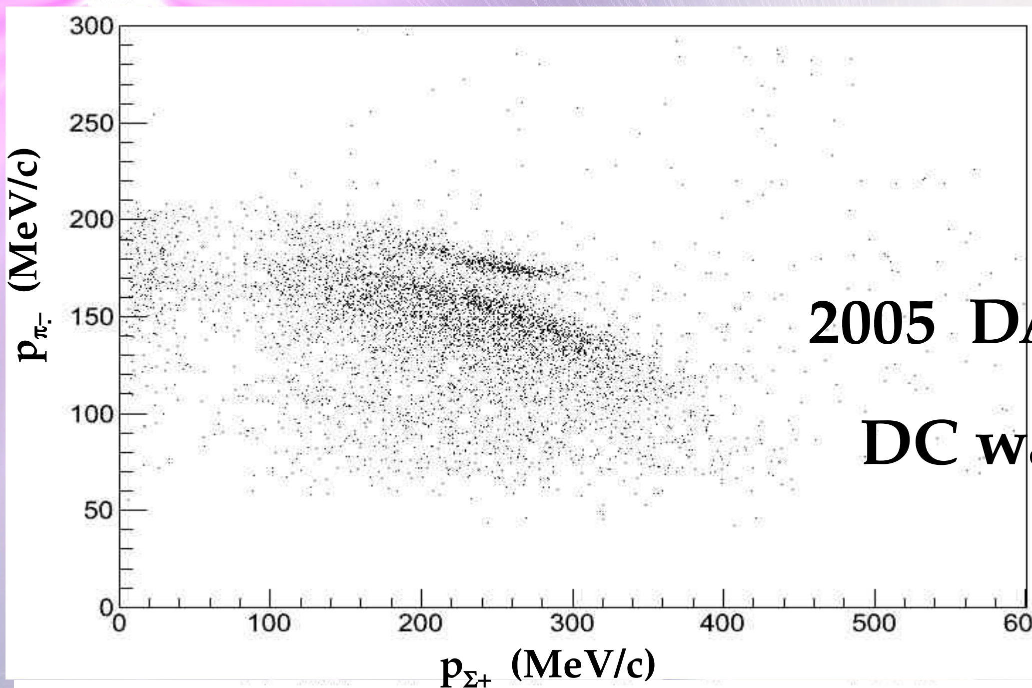


$m_{\Sigma^0\pi^0}$ *distribution*

$\Sigma^+ \pi^-$ channel … a new tool ! → see Scordo & Tucakovic talks

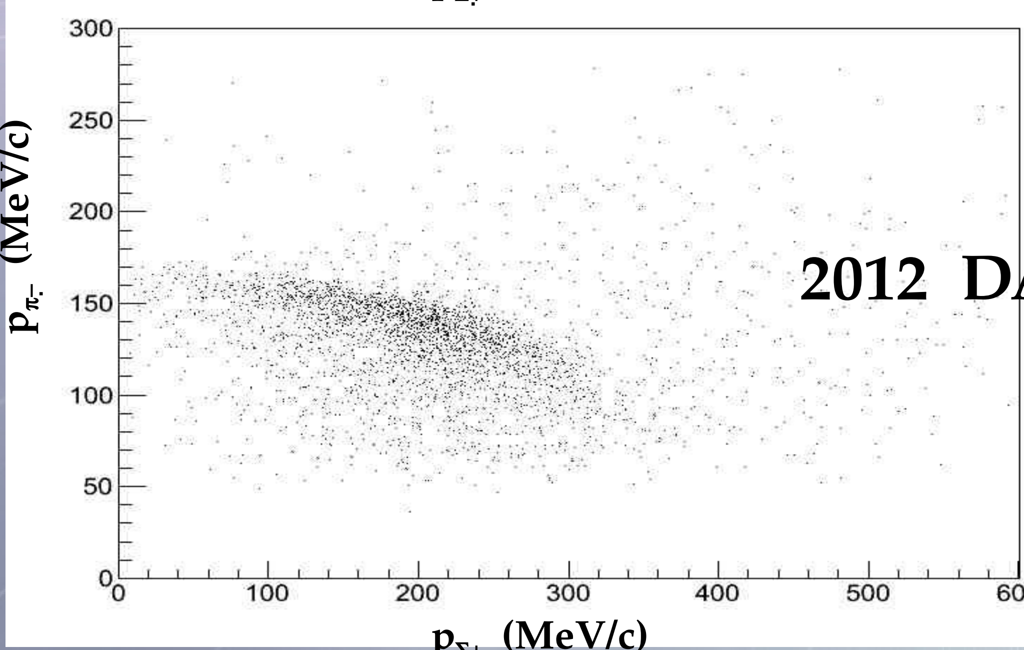
$K^- p \rightarrow \Sigma^+ \pi^-$ detected via: $(p\pi^0)\,\pi^-$

K^-



2005 DATA

DC wall



2012 DATA

BEFORE ...

K^-H interaction probability estimate based on K^- interaction in hydrocarbons mixture data (Lett. Nuovo Cimento, C 1099 (1972))

order of 1% !!!

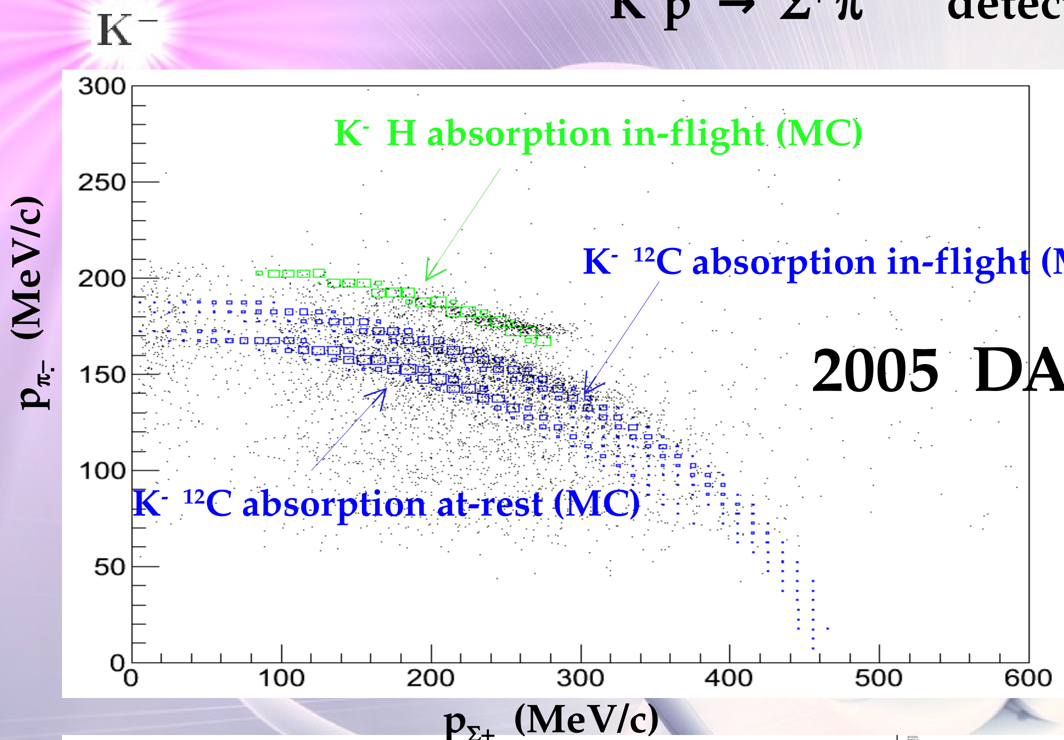
NOW

Thanks to the excellent p_{π^-} resolution

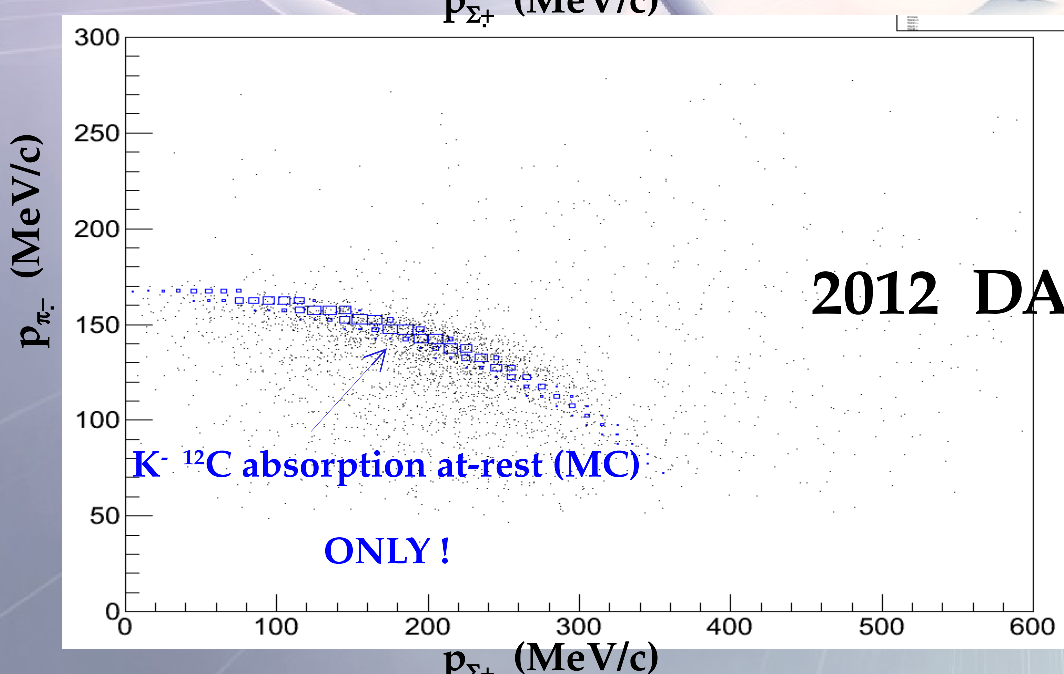
...

$\Sigma^+ \pi^-$ channel … a new tool ! → see Scordo & Tucakovic talks

$K^- p \rightarrow \Sigma^+ \pi^-$ detected via: $(p\pi^0)\,\pi^-$



2005 DATA



2012 DATA

Complete understanding of different nuclear targets in different KLOE materials

K^- H contribution ~ 10%

… in-flight components clearly evidenced by the excellent p_{π^-} resolution

Fit of $\Sigma^0\pi^0$ spectrum in C

K^-

8 component fit, simultaneously $m_{\Sigma0\pi0}$ & $p_{\Sigma0\pi0}$:

- Breit-Wigner resonant component K^- C at-rest/in-flight. $(M,\Gamma) = (1405 \div 1430\ ,\ 5 \div 52\ )$
- Non resonant $\Sigma^0\pi^0$ K^- H production at-rest/in-flight
- Non resonant $\Sigma^0\pi^0$ K^- C production at-rest/in-flight
- $\Lambda\pi^0$ background ($\Sigma(1385)$ + I.C.)
- non resonant misidentification (*n.r.m.*) background

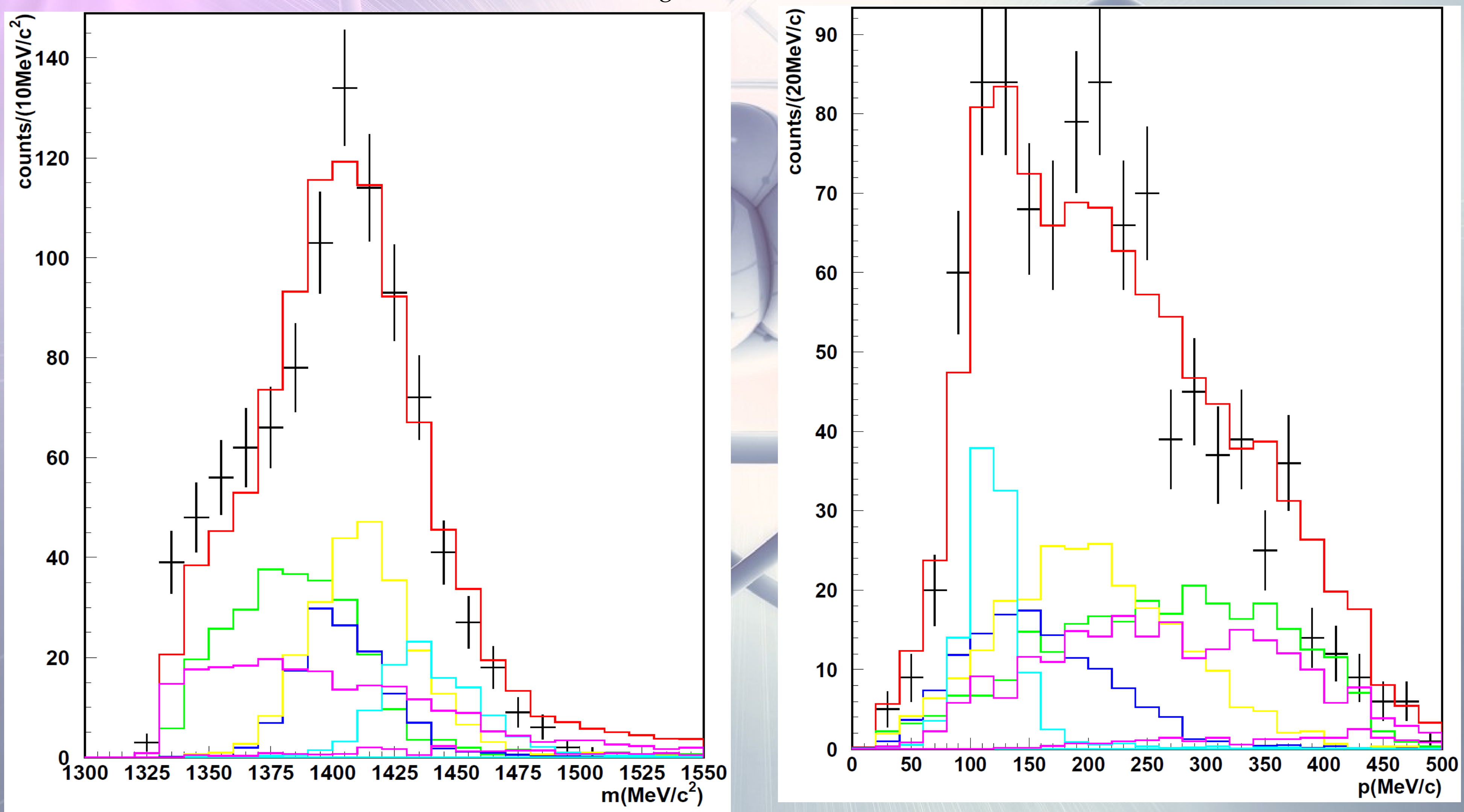
$K^-\ {}^{12}C \rightarrow \Sigma^0\pi^0 + {}^{11}B$ (Boron spectator, left in ground state)

secondary interactions not taken into account.

Fit of $\Sigma^0\pi^0$ spectrum in C

χ^2_{min} /ndf ~ 1.7 corresponding to $(M_{min}, \Gamma_{min}) = (1426, 52)$ MeV/c^2

- Global fit — Resonant component K^- C at-rest
- n. r. K^- C at-rest — n. r. K^- C in-flight — n. r. K^- H in-flight
- $\Lambda^0\pi^0$ background + n. r. m.



$m_{\Sigma0\pi0}$ $p_{\Sigma0\pi0}$

Concluding

- The $p_{\Sigma 0\pi 0}$ distribution shows a double component structure reflected in the $\theta_{\Sigma 0\pi 0}$ vs $p_{\Sigma 0\pi 0}$ and $m_{\Sigma 0\pi 0}$ vs $p_{\Sigma 0\pi 0}$ correlations. Such correlation is confirmed by the analysis of $p_{\pi 0}$ with similar behaviours in Helium and Carbon.
- The two components are interpreted as due to at-rest and in-flight absorptions of K^-, responsible for masses above the kinematical limit.
- Interepretation is confirmed by the analysis of K^- stop events in pure Carbon target installed in KLOE.

First in flight evidence in $m_{\Sigma\pi}$ from K^- - nuclear absorption!

To be finalized …

More refined (M,Γ) scan

Introduction of a Γ(E) dependece

Test possible intefrence between res. and non-res. production

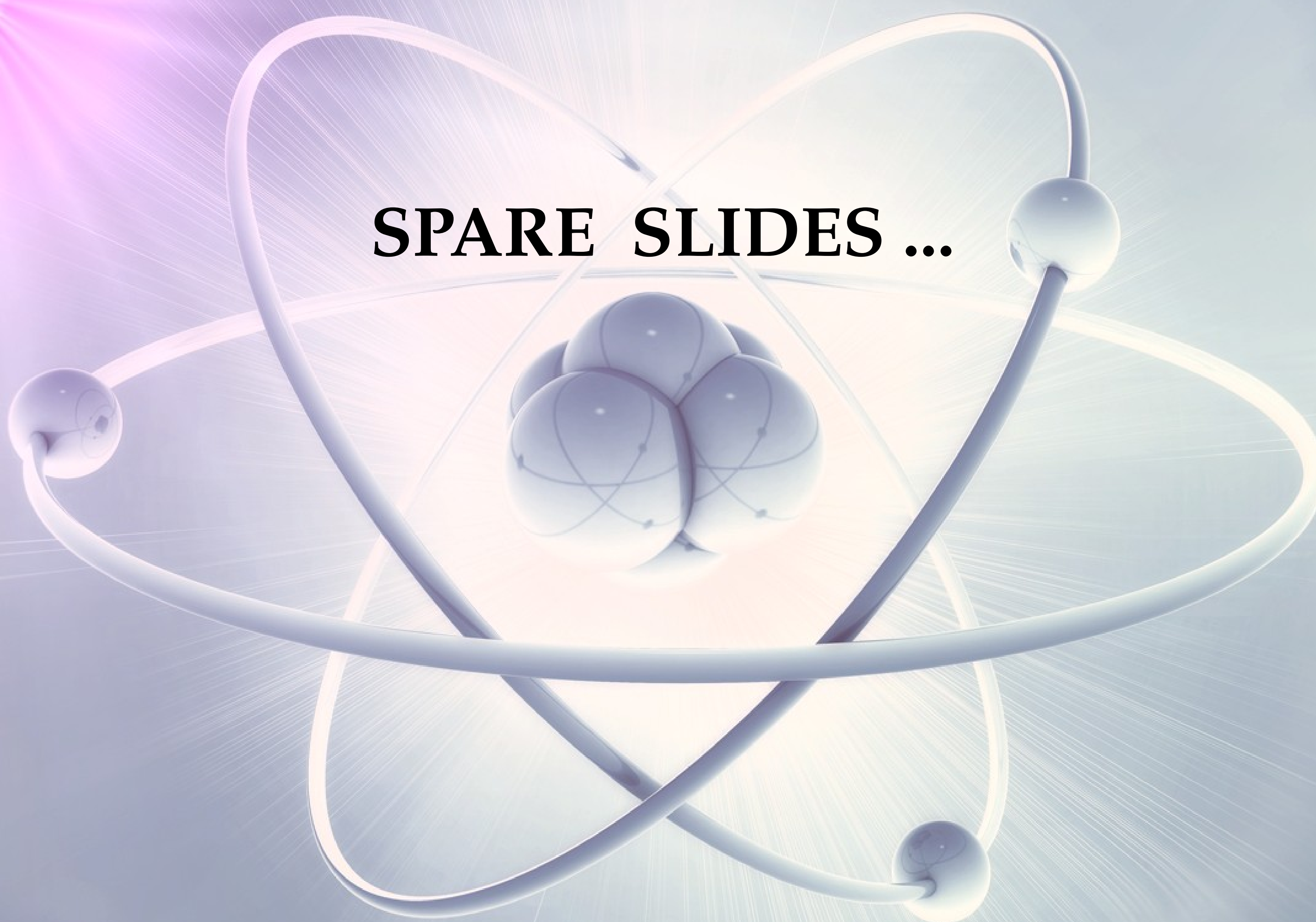
K^-

A very special tought for Prof. Paul Kienle, to whom this work is dedicated.

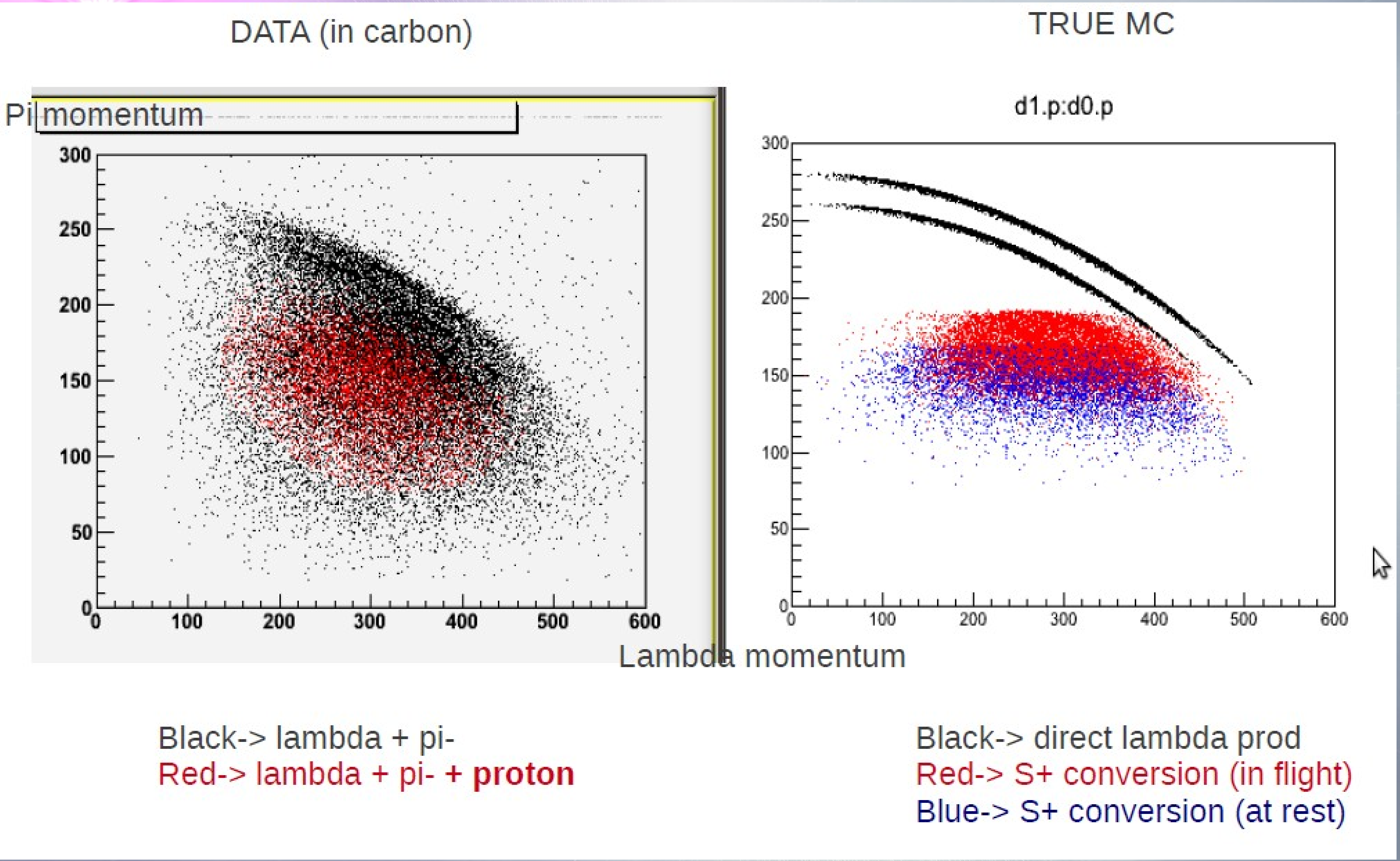
Thanks

K^-

SPARE SLIDES ...



Σ / Λ conversion in nuclear medium



The extra-p indicates nuclear fragmentation → Σ / Λ

K^- nuclear absorption

in the gas filling the DC volume

K^- nuclear absorption in gas

- KLOE DC gas mixture (90% He, 10% C_4H_{10})
  - ratio of absorptions in He and C:

$$\frac{N_{KHe}}{N_{KC}} = \frac{n_{He}\,\sigma_{KHe}\,BR_{KHe}(\Sigma^0\pi^0)}{n_C\,\sigma_{KC}\,BR_{KC}(\Sigma^0\pi^0)}$$

Nuovo Cimento 39 A, 538-547 (1977)

$$\frac{N_{KHe}}{N_{KC}} = 1.6 \pm 0.2$$

- K^-H interaction probability at rest estimated (based on K^- interaction in hydrocarbons mixture data)

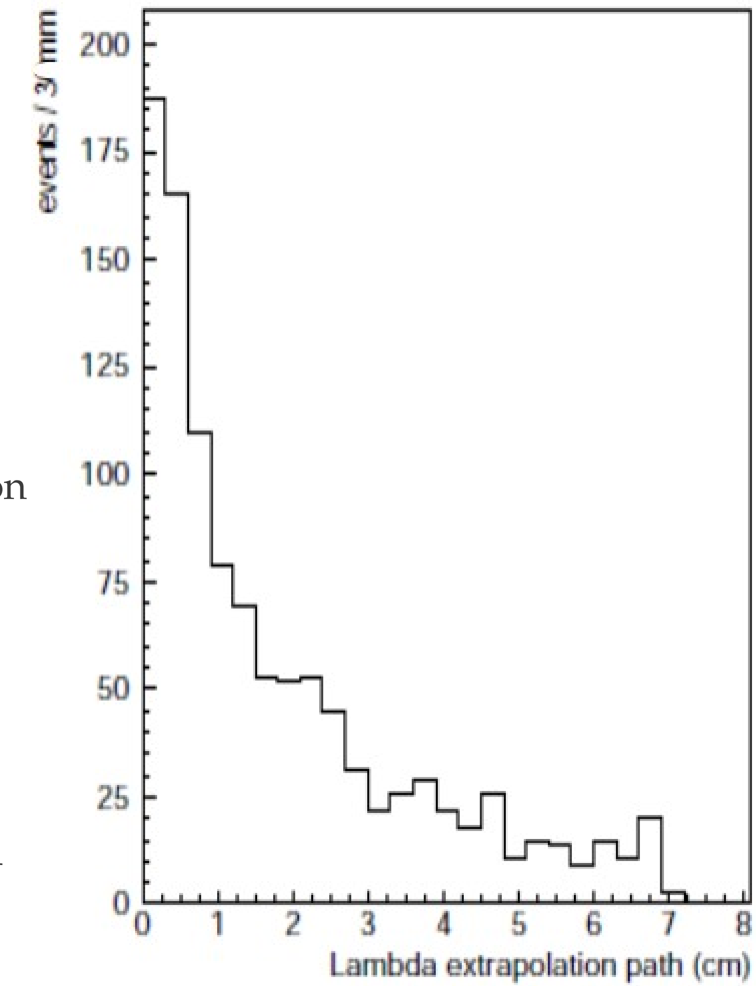
Lett. Nuovo Cimento, C, 1099 (1972)

$$\frac{N_{KHe}}{N_{KH}} = 570 \pm 71$$

- ρ_Λ limit set taking into account for Λ decay path and MC simulations

($\sigma_{\rho\Lambda} = 0.13 \pm 0.01$ cm): $\rho_\Lambda > 30$ cm

810 final selected $\Sigma^0\pi^0$ events.



$m_{\pi^0\Sigma^0}$ invariant mass distribution

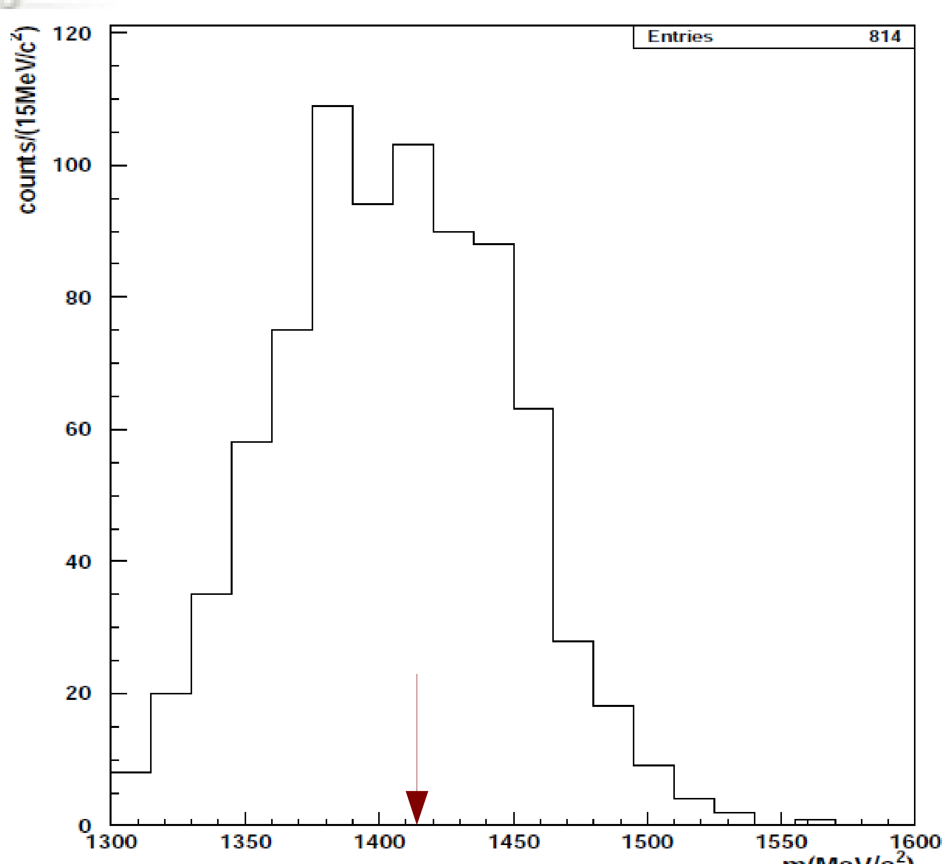
Invariant mass $m_{\pi 0\Sigma 0}$ (left) and momentum $p_{\pi 0\Sigma 0}$ (right) of the reconstructed π^0 - Σ^0 .

Two components in the $p_{\pi 0\Sigma 0}$ distribution LM ≈ 100 MeV/c , HM ≈ 200 MeV/c

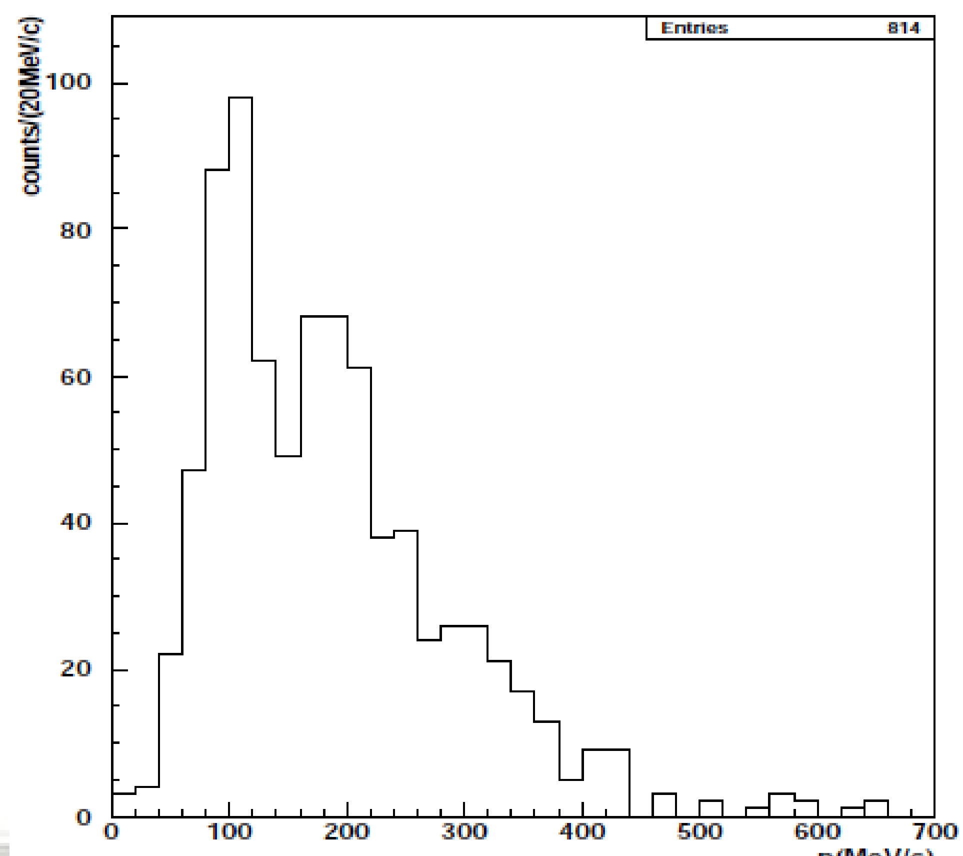
Invariant mass $\mathbf{m_{\pi 0\Sigma 0}}$ **resolution**: $\sigma_m \approx 30$ MeV/c², momentum $\mathbf{p_{\pi 0\Sigma 0}}$ **resolution**: $\sigma_p \approx 15$ MeV/c.

(true MC information, non resonant, quasi-free K^- C/K^- He, both at-rest/in-flight simulation)

Red arrow shows the kinematical limit for K^- He absorption at-rest.



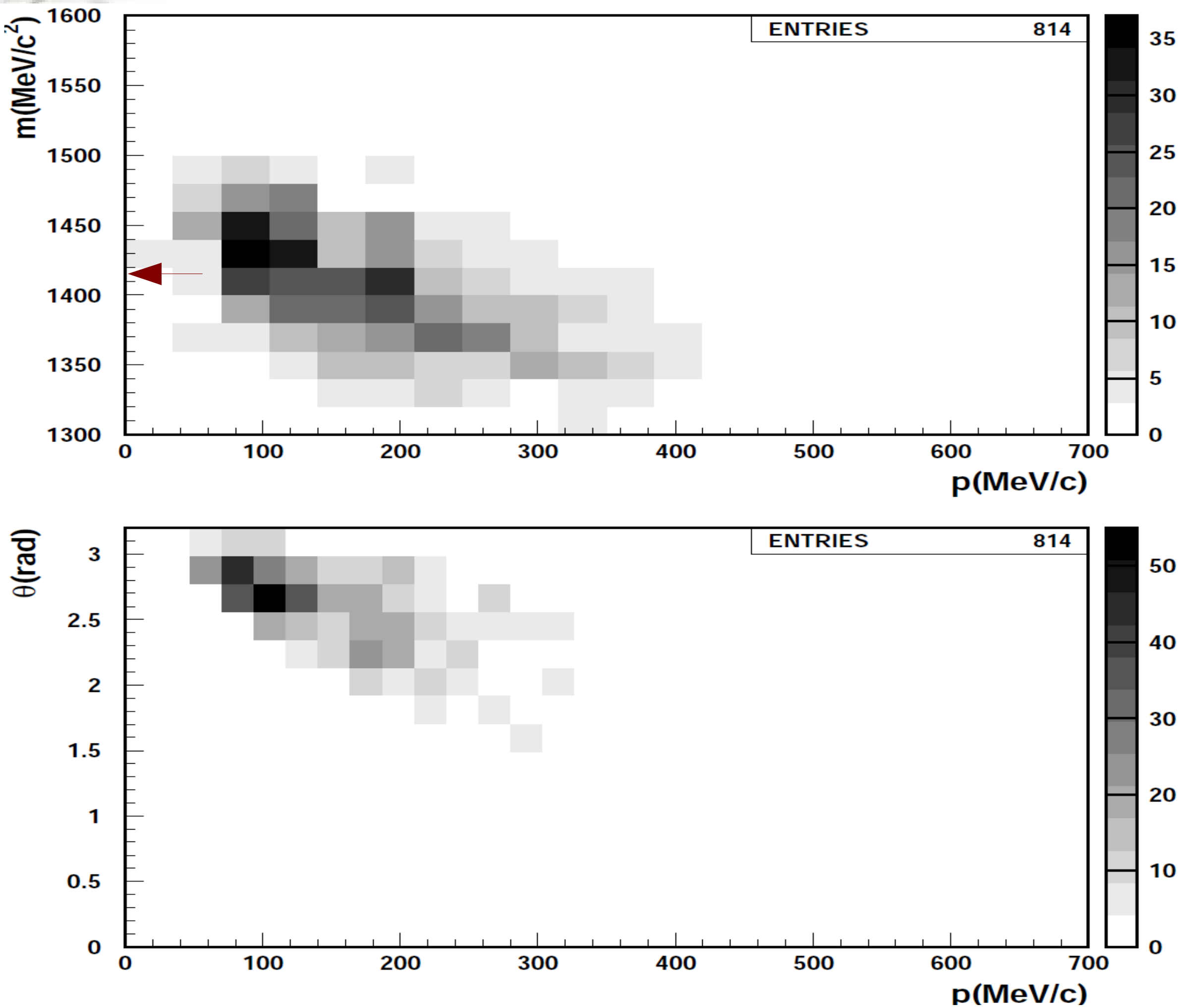
$m_{\Sigma^0\pi^0}$ *distribution*



$p_{\Sigma^0\pi^0}$ *distribution*

$\theta_{\pi^0\Sigma^0}$ vs $p_{\pi^0\Sigma^0}$ and $m_{\pi^0\Sigma 0}$ vs $p_{\pi^0\Sigma^0}$ correlation

Correlations of (bottom) the decay angle $\theta_{\pi 0\Sigma 0}$ (angle between π^0 - Σ^0 in the lab. frame) and (top) of $m_{\pi 0\Sigma 0}$ with the momentum $p_{\pi 0\Sigma 0}$. Red arrow corresponds to kinematical limit at-rest in He.



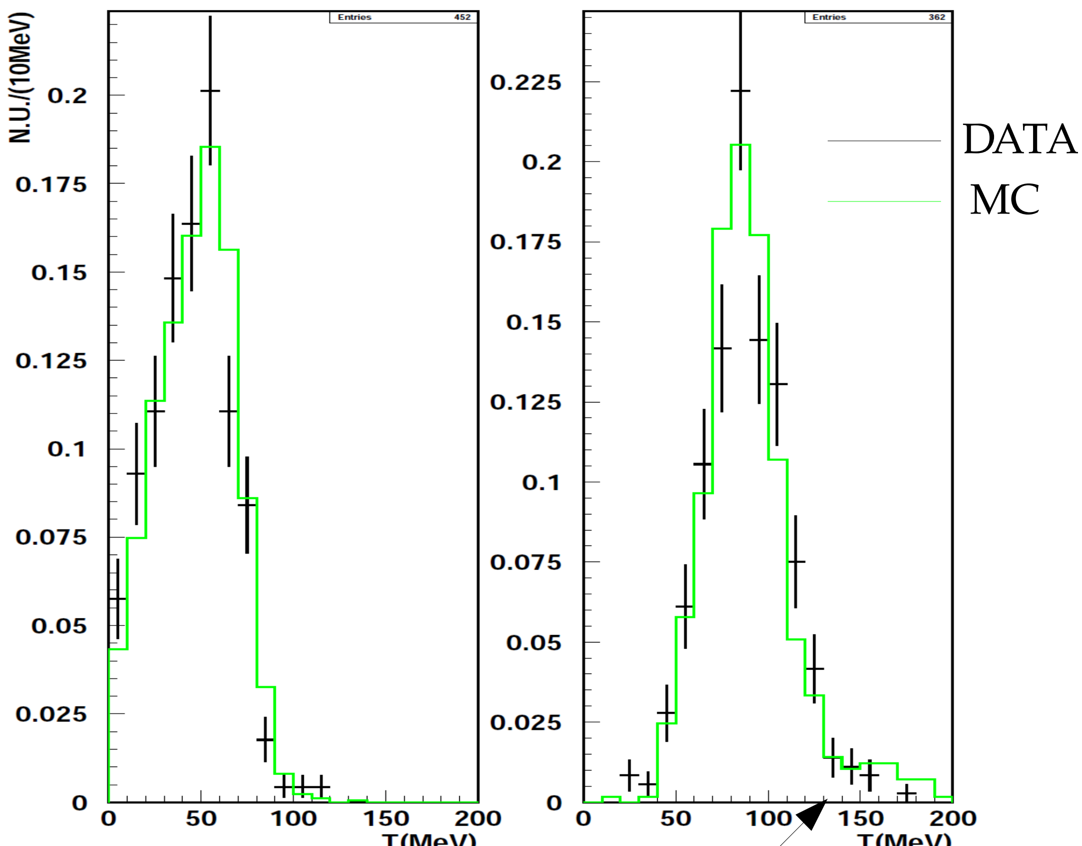
Top $m_{\Sigma^0\pi^0}$ vs $p_{\Sigma^0\pi^0}$, bottom $\theta_{\Sigma^0\pi^0}$ vs $p_{\Sigma^0\pi^0}$.

The LM component ($p_{\pi 0\Sigma 0}$ around 100 MeV/c) is correlated with masses above the k.l. at-rest and larger angles.

Comparison with K$^-$ absorption in bubble chamber

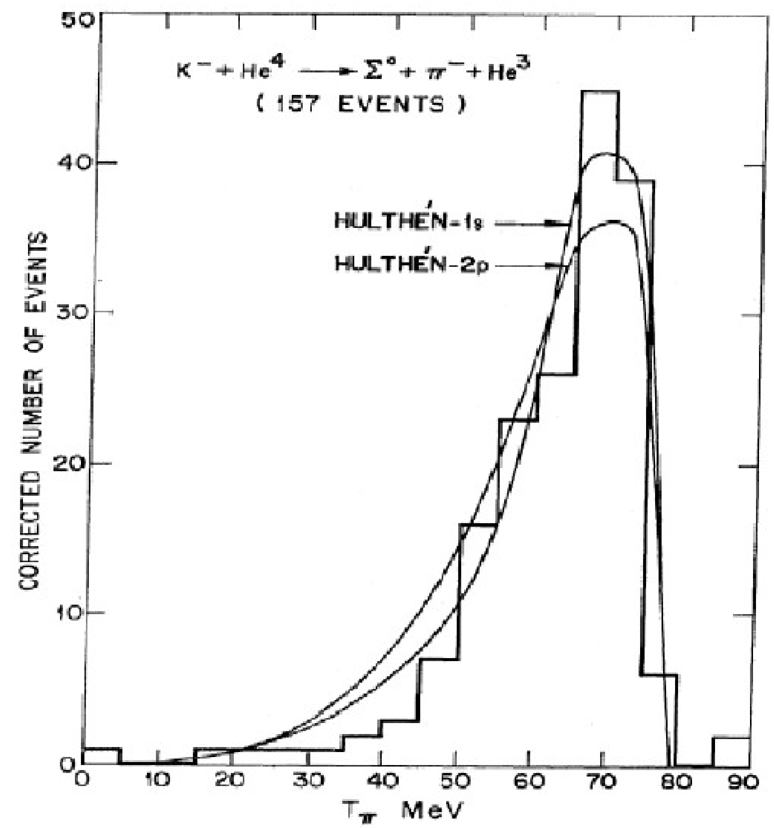
Cutting for $m_{\pi0\Sigma0} < m_{lim}$ (kinematical limit for absorption at-rest in He) a lower $T_{\pi0}$ component (left) emerge according with $T_{\pi-}$ from He bubble chamber experiments AT-REST correlated to the higher $p_{\pi0\Sigma0}$ component centered around 190-200 MeV/c ! (reasonable agreement with MC a.r. left / i.f right) (kinetic energy resolution $\sigma_{T\pi0}$ = 11.7 ± 0.2 MeV)

$n_{>mlim}/n_{<mlim}$ = 0.82± 0.06 only indicative due to C contribution.



T_{π^0}

no peak around 130 MeV
where direct $\Lambda\pi^0$
production is expected !



T_{π^-} Bunnel et al 1965.

Study of the background

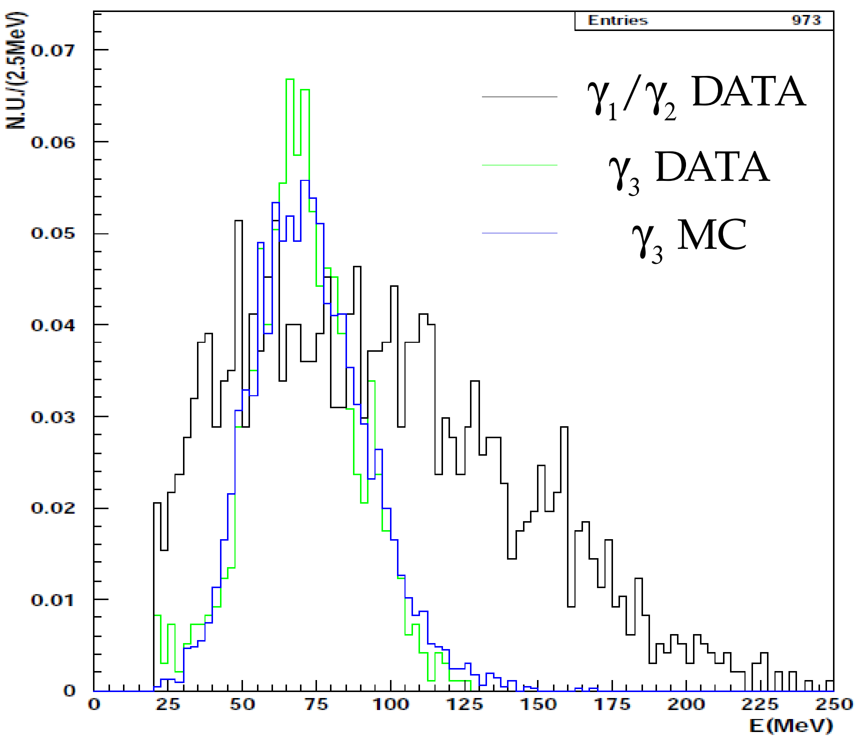
The main background sources for this channel are (example in ^{12}C):

- $K^- \; ^{12}C \rightarrow \Sigma^0(1385) + {}^{11}B \rightarrow \Lambda\pi^0 + {}^{11}B$

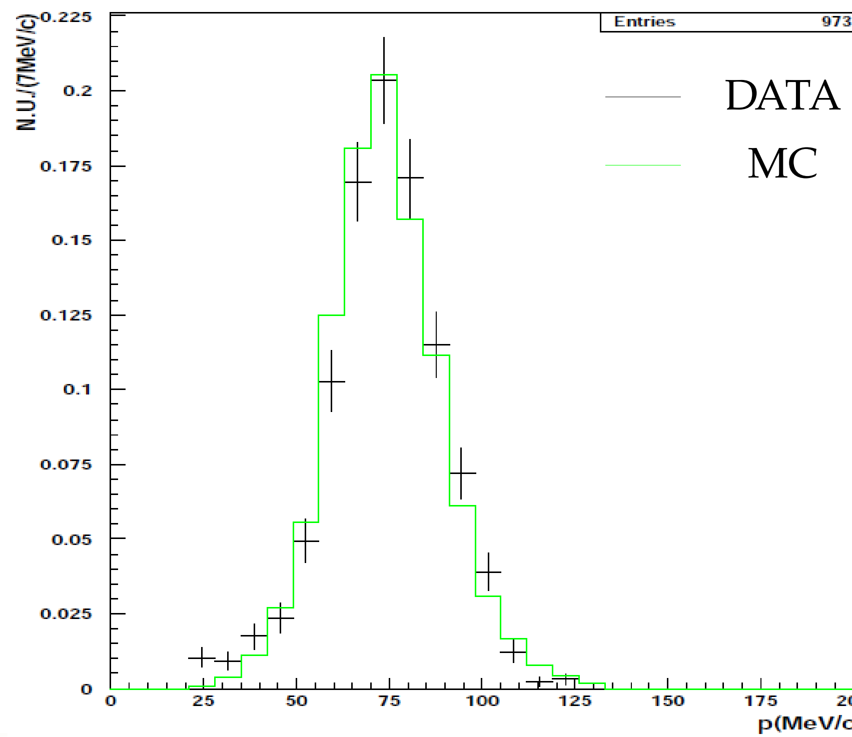
Σ^0(1385) can not decay in $\Sigma^0 \pi^0$ for isospin conservation.

- **Internal conversion** $K^- \; ^{12}C \rightarrow \Lambda(1405) + {}^{11}B \rightarrow \boldsymbol{\Sigma^0}\pi^0 + {}^{11}B$, $\Sigma^0 N \rightarrow \Lambda N$ competes with the decay $\Sigma^0 \rightarrow \Lambda \gamma$.

Both background sources were analized by different methods:



photons energy distribution



Λ momentum in the Σ^0 rest frame

Study of the background

The numbers of pure background $\Sigma(1385)$ and $\Sigma^0 N \to \Lambda N$ events passing the analysis cuts are normalized to pure signal $\Lambda(1405)$ events, then weighted to the BRs for $\Lambda\pi^0$ direct production (D), internal conversion (IC) and $\Sigma^0\pi^0$ production due to K^- interaction in ^{4}He and C respectively :

P. A. Katz et al., Phys.Rev. D1 (1970) 1267

C. Vander Velde-Wilquet et al., Nuovo Cimento 39 A, (1977) 538

The percentages of background events entering the final selected samples are:

$$\frac{n_{\Lambda\pi^0\,D}\,\mathrm{norm} + n_{\Lambda\pi^0\,IC}\,\mathrm{norm}}{n_{\Sigma^0\pi^0} + n_{\Lambda\pi^0\,D}\,\mathrm{norm} + n_{\Lambda\pi^0\,IC}\,\mathrm{norm}} = 0.03 \pm 0.01$$

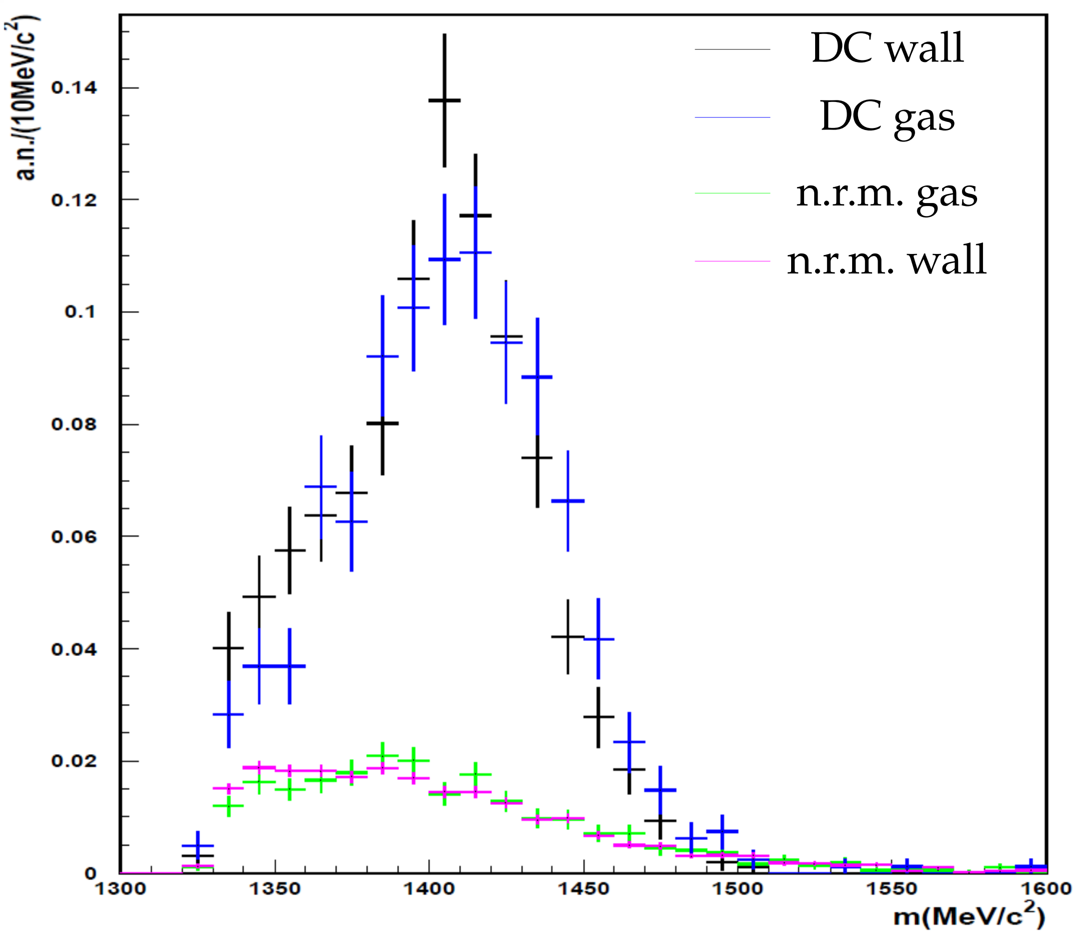
in DC wall (0.03 ± 0.02 in DC gas)

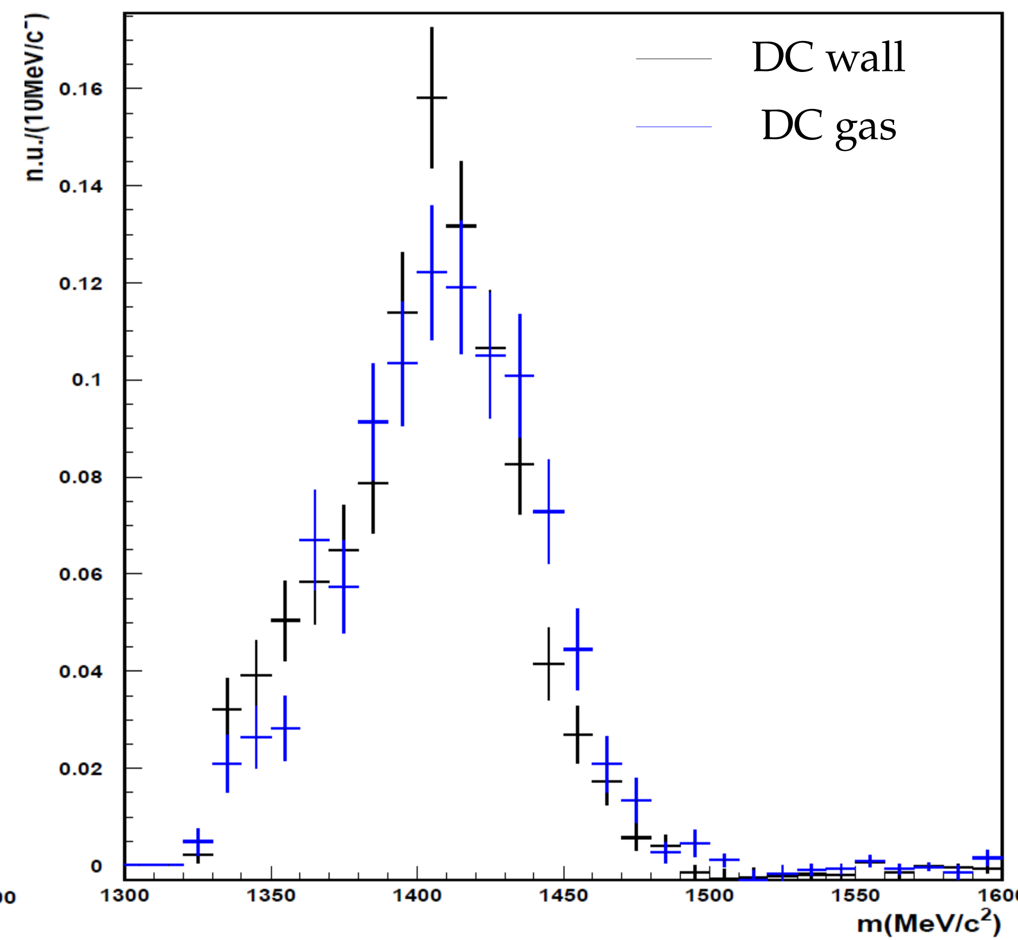
$m_{\pi^0\Sigma^0}$ spectrum with mass hypotesis

$m_{\pi0\Sigma0}$ spectra with mass hypotesis (M.H.) on Σ^0 and π^0 subtracted by *non resonant misidentification (n. r. m.)* (p = 0.22±0.01) the observed $m_{\pi0\Sigma0}$ and $p_{\pi0\Sigma0}$ are used as input for the MC generation of $\Sigma^0\,\pi^0$. Events in gas (blue), events in DC wall (black) normalized to 1.

$\sigma_m \approx 17$ MeV/c² (DC wall) $\sigma_m \approx 15$ MeV/c² (DC gas)

Similar $m_{\pi0\Sigma0}$ shapes due to the similar kinematical thresholds for ^{4}He and ^{12}C.





$m_{\Sigma^0\pi^0}$ *spectrum* $m_{\Sigma^0\pi^0}$ *spectrum*

Fit of $\Sigma^0\pi^0$ spectrum in C

A six component fit was performed:

- Resonant component K^- C at-rest/in-flight. (M,Γ) scan from 1381 MeV/c^2 to 1430 MeV/c^2, Breit-Wigner mass distribution
- direct $\Sigma^0\pi^0$ non resonant production at-rest/in-flight
- $\Lambda\pi^0$ background (Σ(1385) + I.C.)
- non resonant misidentification (*n.r.m.*) background

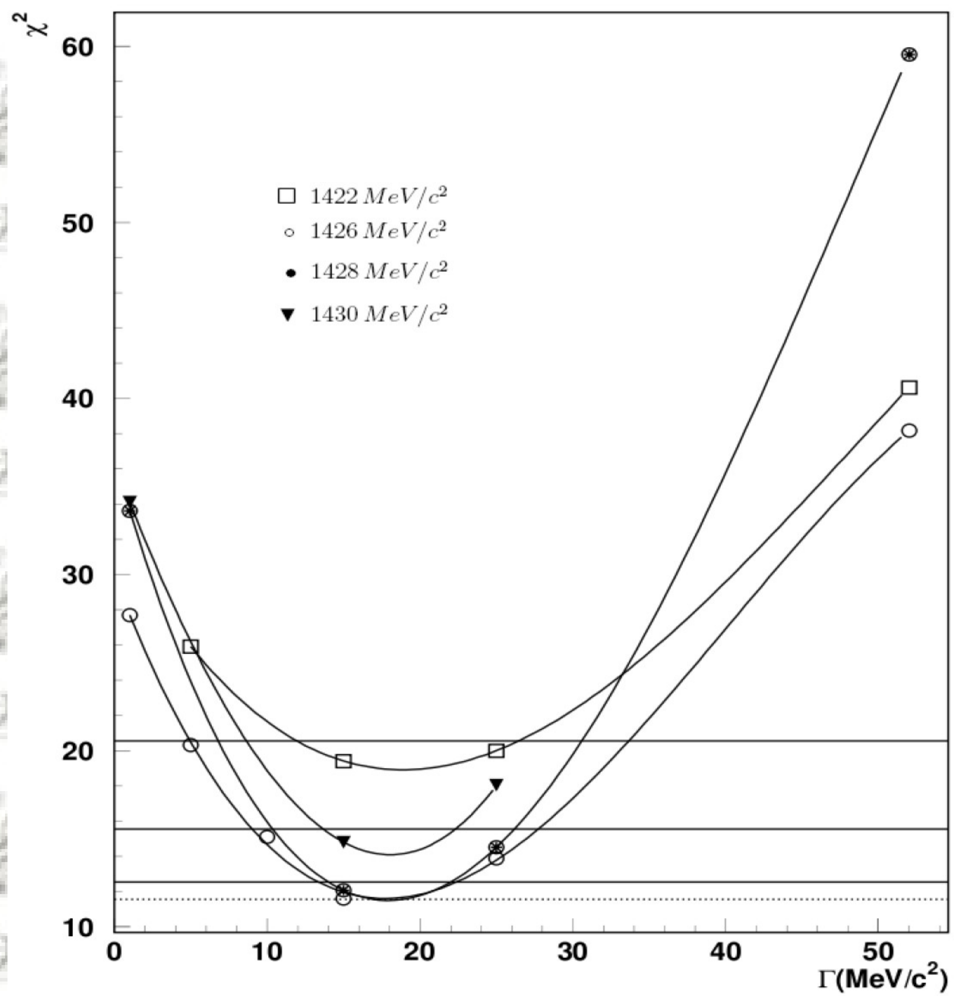
K^- C $\rightarrow \Sigma^0\pi^0 + {}^{11}B$ (boron considered as spectator) secondary interactions not taken into account. Then reconstructed in KLOE using standard KLOE MC (fits take into account for acceptance effects, energy loss..).

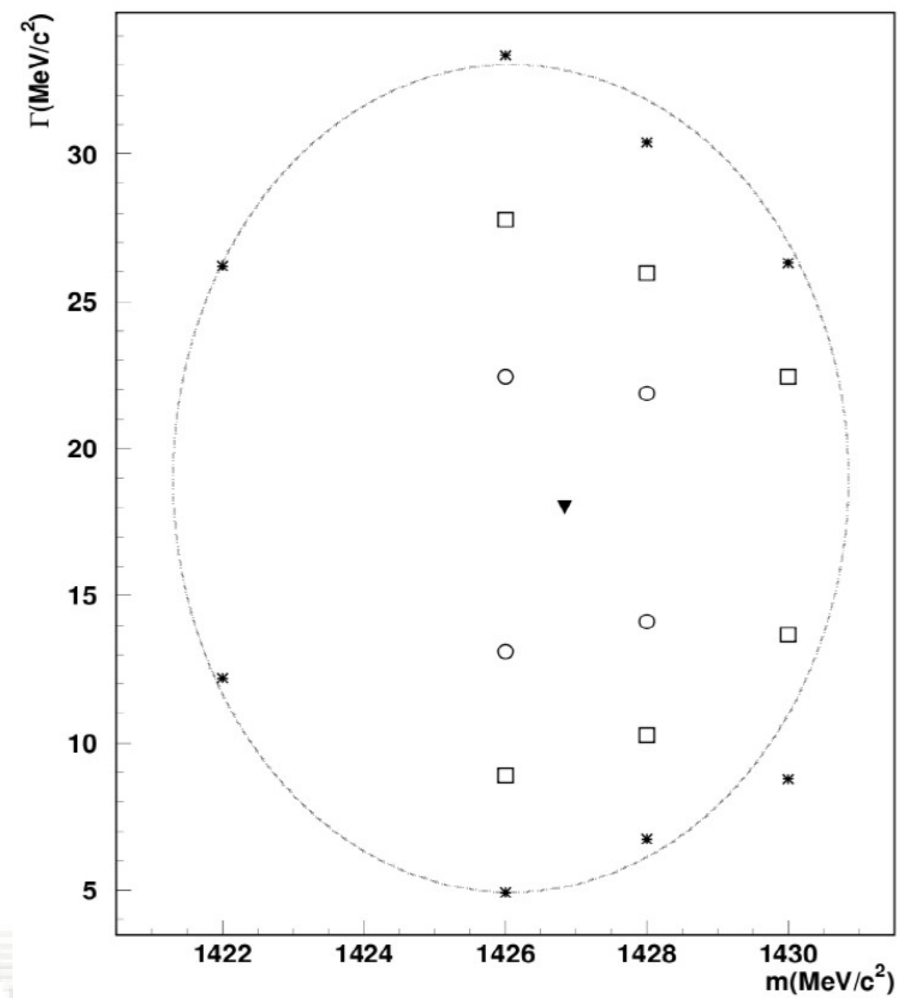
Fits performed with $m_{\Sigma 0}\, m_{\pi 0}$ hypothesis, employing the better resolution to distinguish the similar shapes of the components.

Fit of $\Sigma^0\pi^0$ spectrum in C

First scan global minimum χ^2_{min} /ndf ~ 1.2 → $(m_{min}, \Gamma_{min}) = (1427, 18) MeV/c^2$

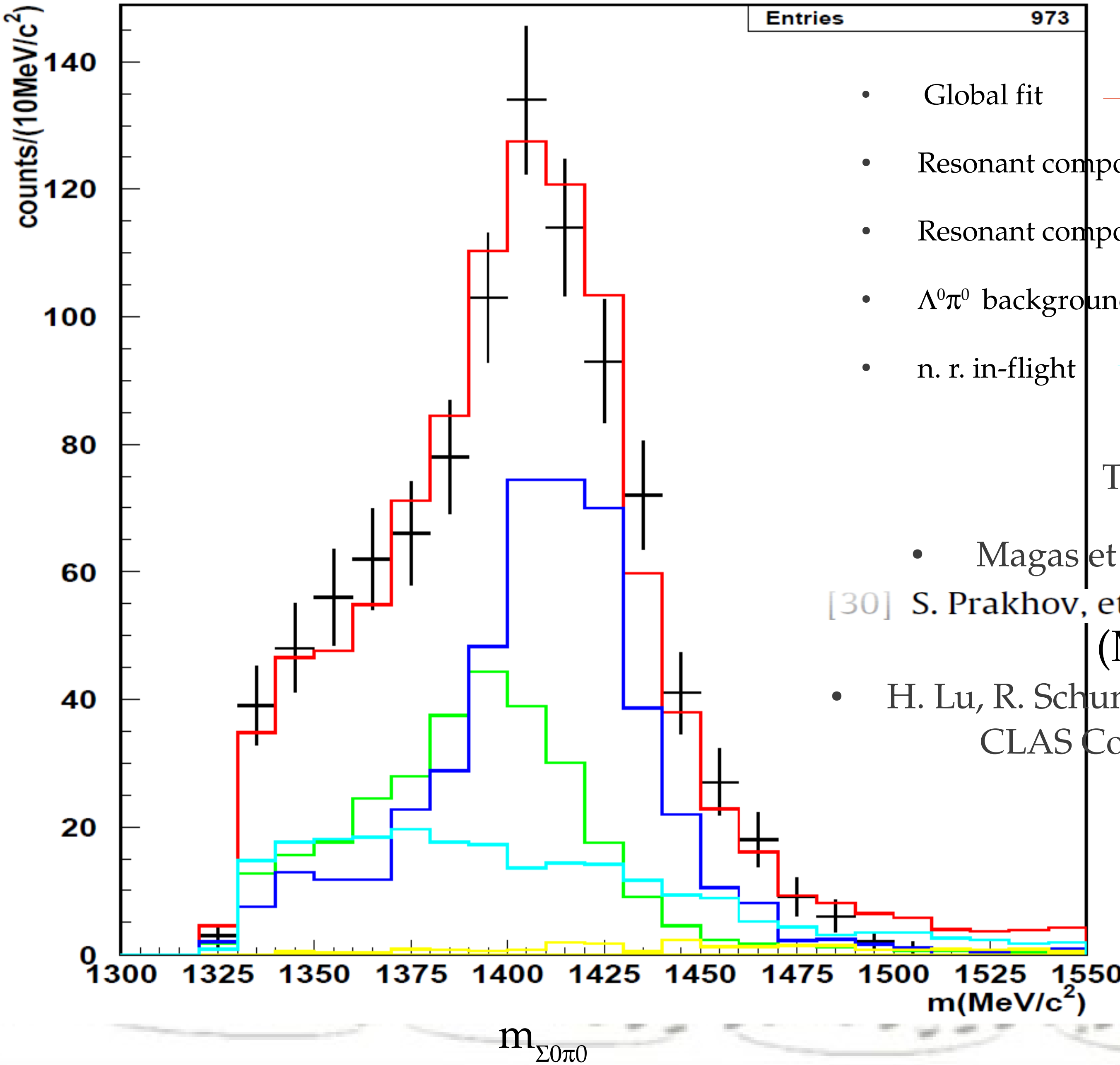
$(M_{min}, \Gamma_{min}) = (1427^{+4}_{-6}, 18^{+15}_{-13})$ MeV/c² cutting for $\chi^2 = \chi^2_{min} + 9$





Fit of $\Sigma^0\pi^0$ spectrum in C

χ^2_{min} /ndf ~ 1.2 corresponding to $(M_{min}, \Gamma_{min}) = (1427^{+4}_{-6}, 18^{+15}_{-13})$ MeV/c^2



To be compared with:

- Magas et al. PRL 95, 052301 (2005) **in $\Sigma^0\pi^0$**

[30] S. Prakhov, et al., Phys. Rev. C70 (2004) 034605.

$(M, \Gamma) = (1420,38)$ MeV/c^2

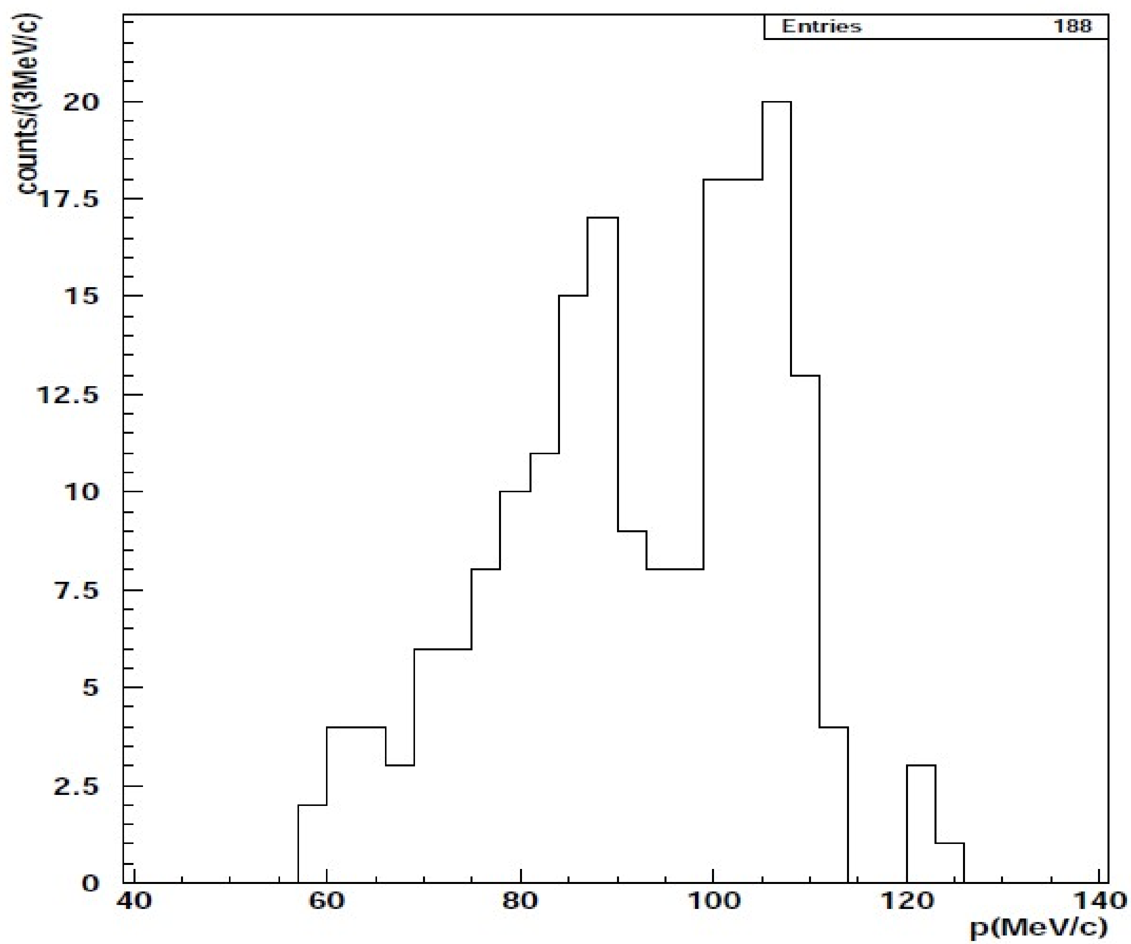
- H. Lu, R. Schumacher, B. Raue, M. Gabrielyan, and CLAS Collaboration, AIP Conf. Proc. 1432, (2012) 199. **in $\Sigma^+\pi^-$**

$(M,\Gamma) = (1422, 16)$ MeV/c^2

$(M,\Gamma) = (1393, 100)$ MeV/c^2

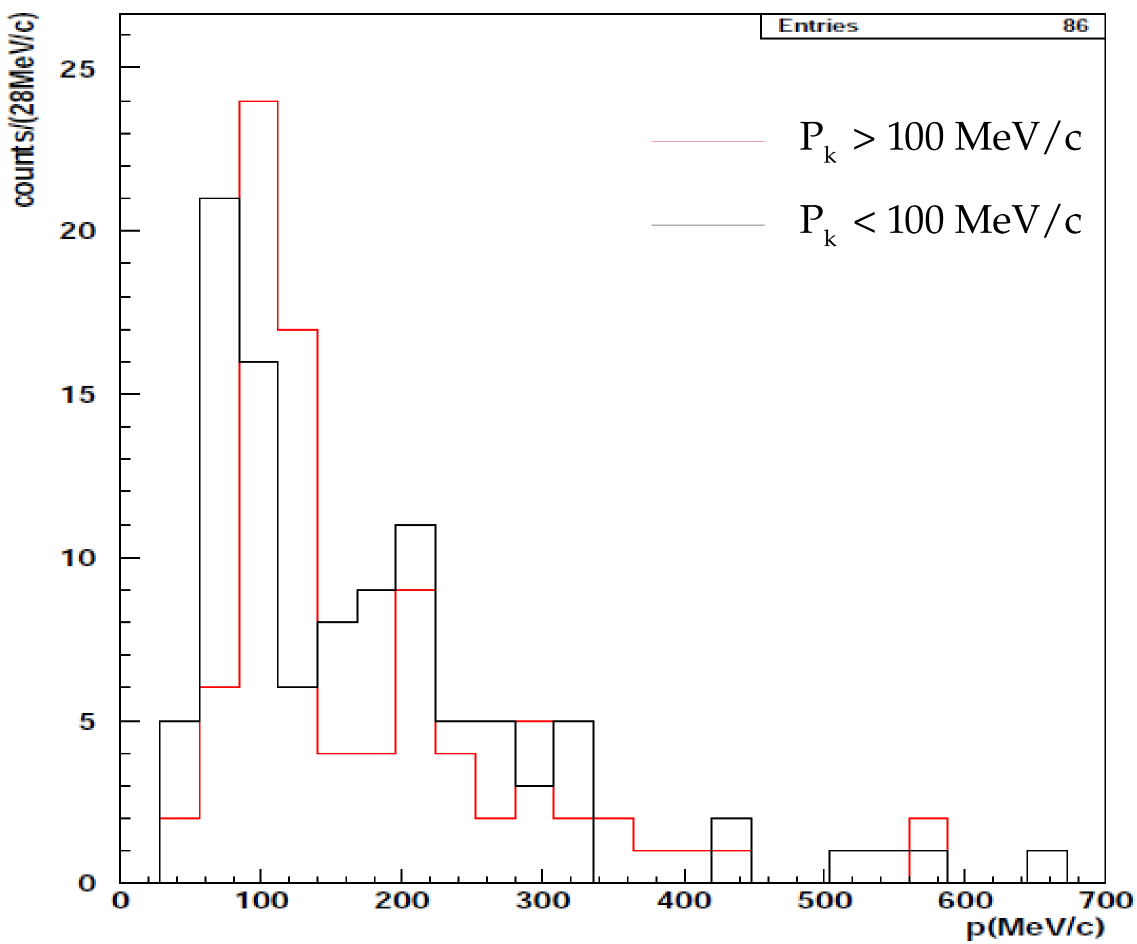
Kaons momentum distribution

Plot representing the $\boldsymbol{p}_k$ *distribution at the last point of the kaon track*



$p_{\pi^0\Sigma^0}$ spectrum for boost and anti-boost events

$p_{\Sigma^0\pi^0}$ distribution for lower (black) and higher (red) p_k values

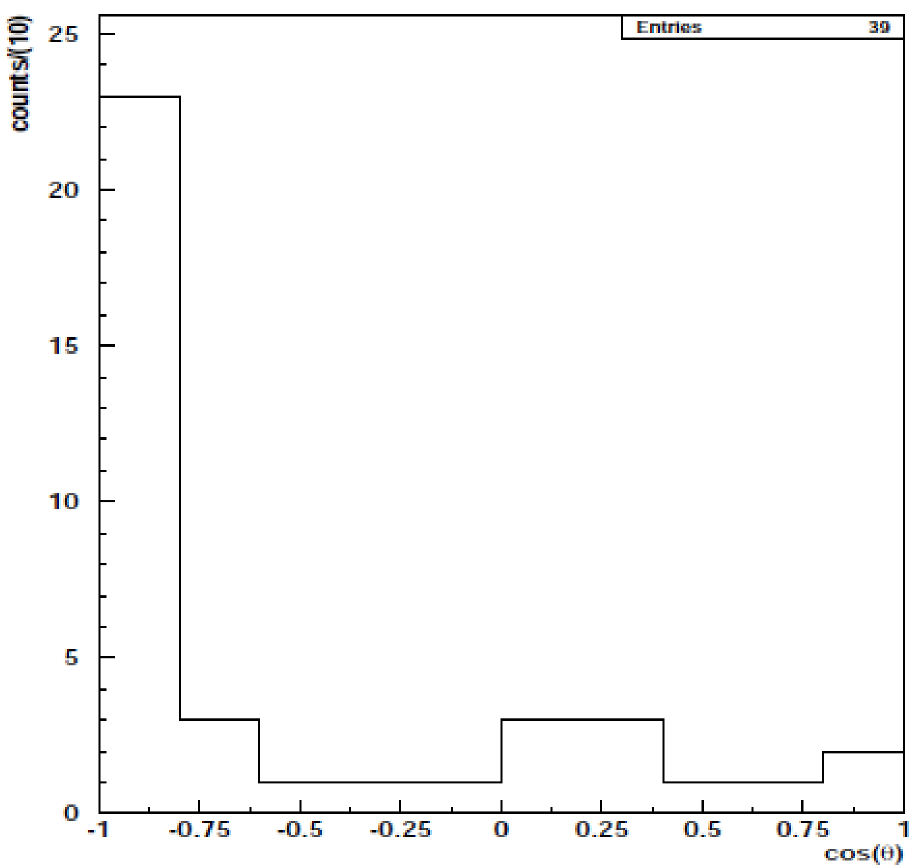


Search for extra-tracks from the hadronic interaction vertex

Positive tracks are searched by dE/dx vs p. Than the Λ path and charged track are extrapolated backwords for the primary interaction vertex. From the extrapolated $\mathbf{p}_{et}$ → $\cos(\theta_{\pi0\Sigma0,t})$

$$\cos(\theta_{\pi0\Sigma0,t}) = (\mathbf{p}_{\pi0\Sigma0} \cdot \mathbf{p}_{et}) / (|\mathbf{p}_{\pi0\Sigma0}|\ |\mathbf{p}_{et}|)$$

Back to back recoils correspond to $K^- He \rightarrow \Sigma^0\pi^0 + T$ events at-rest.



$cos(\theta_{\Sigma^0\pi^0,t})$

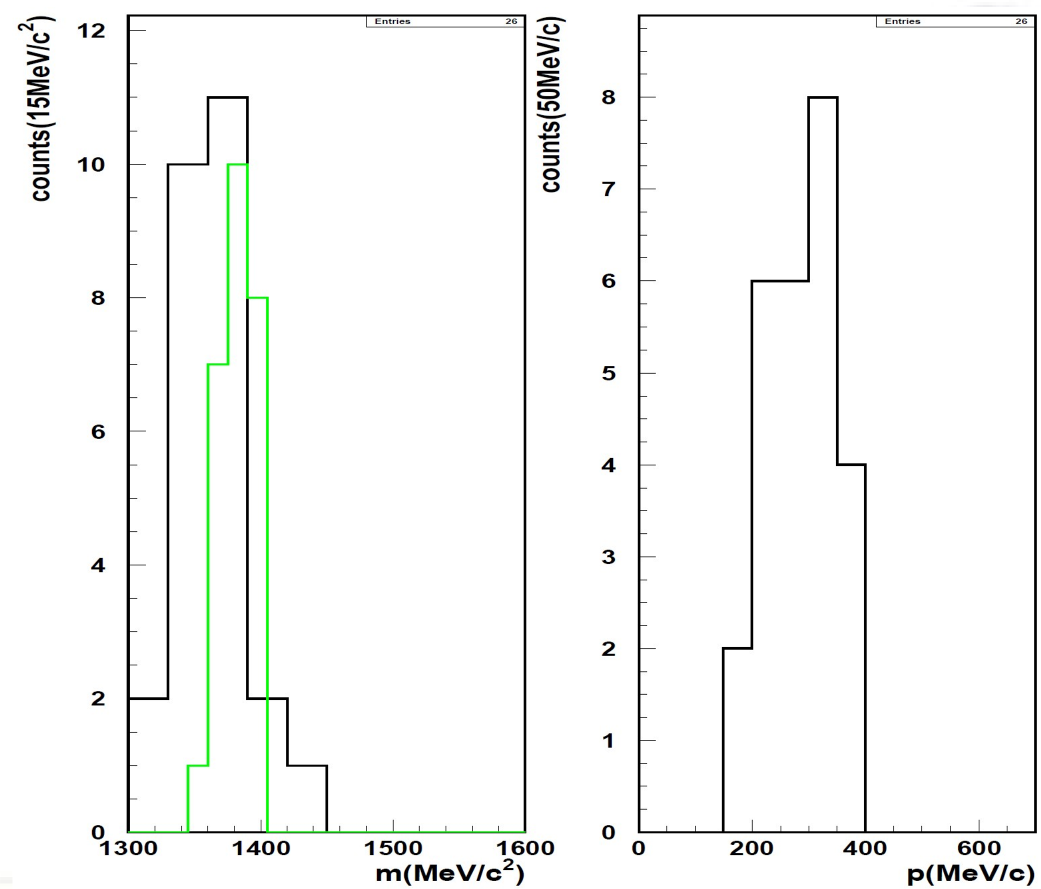
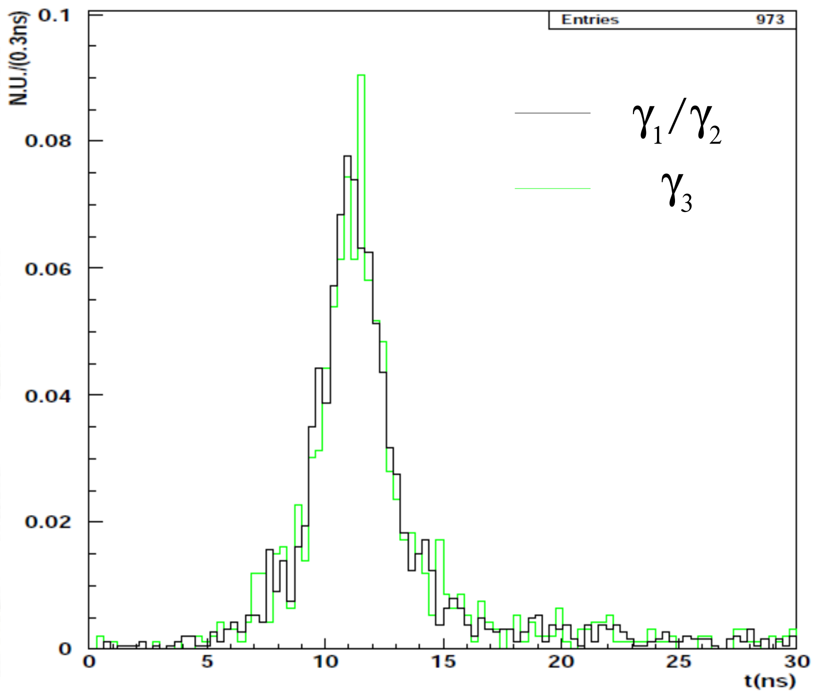
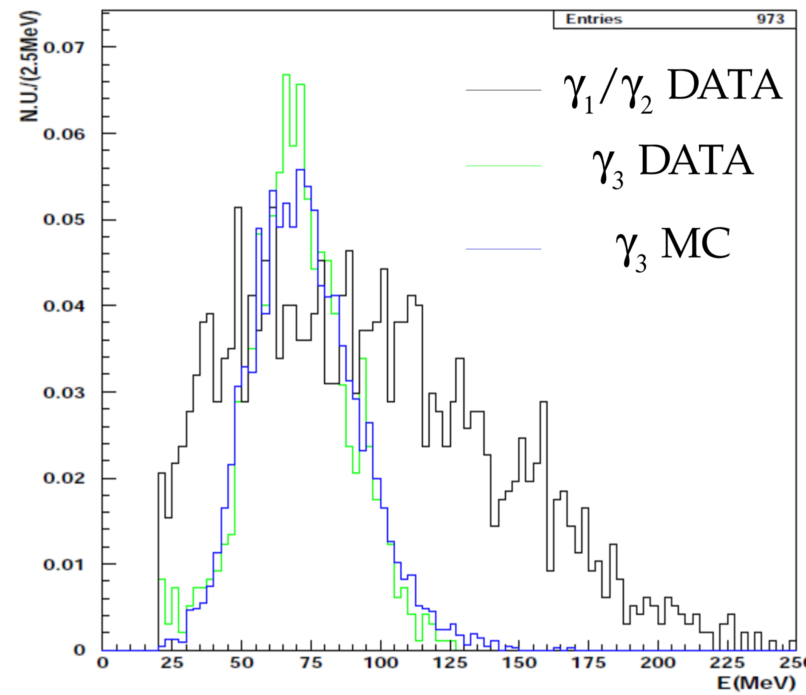


Figure 4.16: $m_{\Sigma^0\pi^0}$ *(left black) (binning: counts/(30MeV/c^2)), mm (left green) (binning: counts/(15MeV/c^2)),* $p_{\Sigma^0\pi^0}$ *(right black).*

Study of the background

In both cases γ_3 is not present, if a contamination is present, the neutral cluster which is associated to γ_3 by reconstruction should show differences.

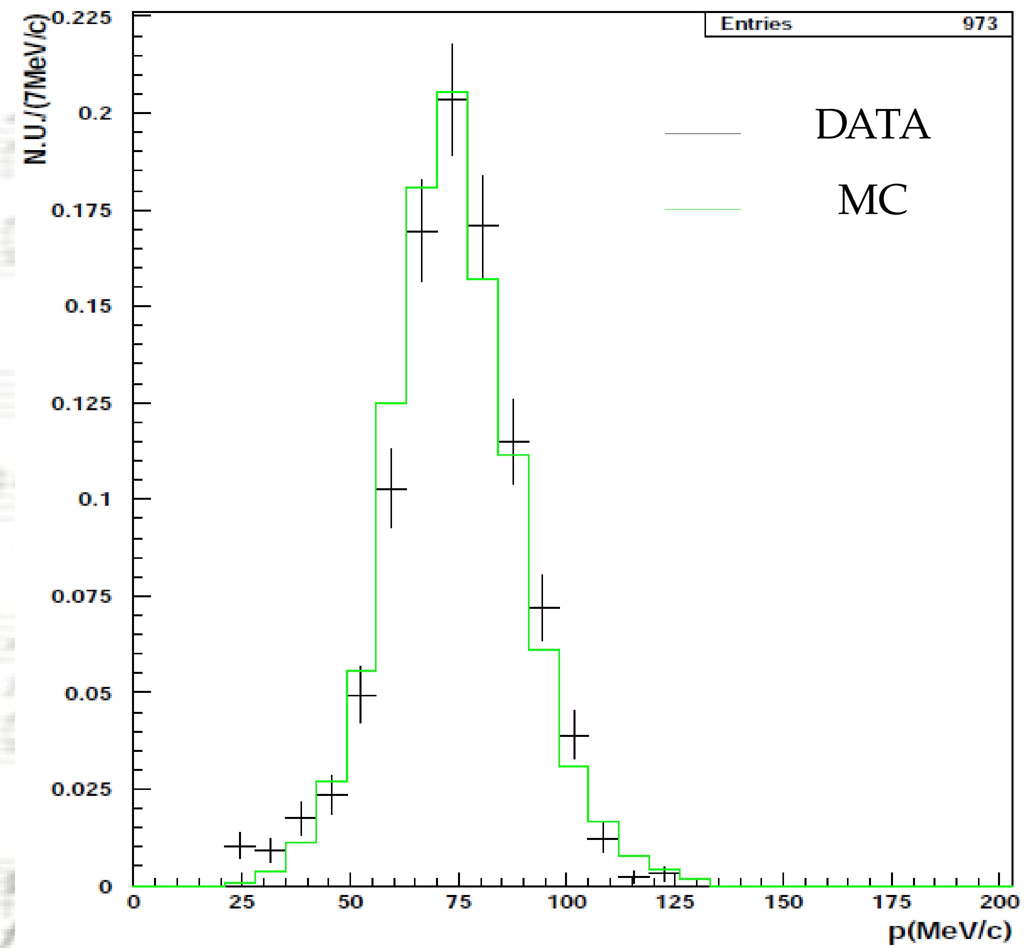




- Right: the energy distribution of γ_3 (green) is in perfect agreement with MC simulations of pure signal events (blue) (energy spectrum of $\gamma_1\gamma_2$ is shown in black).
- Left: the time distribution of γ_3 (green) is in agreement with the time distributions of the two photons coming from π^0 decay (black).

Study of the background

To test the possible contamination of $\Sigma(1385)$, we employed the great mass difference between $\Sigma(1385)$ and Σ^0 (1192 MeV) to distinguish such events. Indeed Σ^0 decays in its rest frame in $\Lambda\gamma$ with momentum of 74 MeV/c, while $\Sigma(1385)$ decays in its rest frame in $\Lambda\pi^0$ with momentum of 208 MeV/c.



$p_{\Lambda\gamma 3\,CM}$ *distribution*

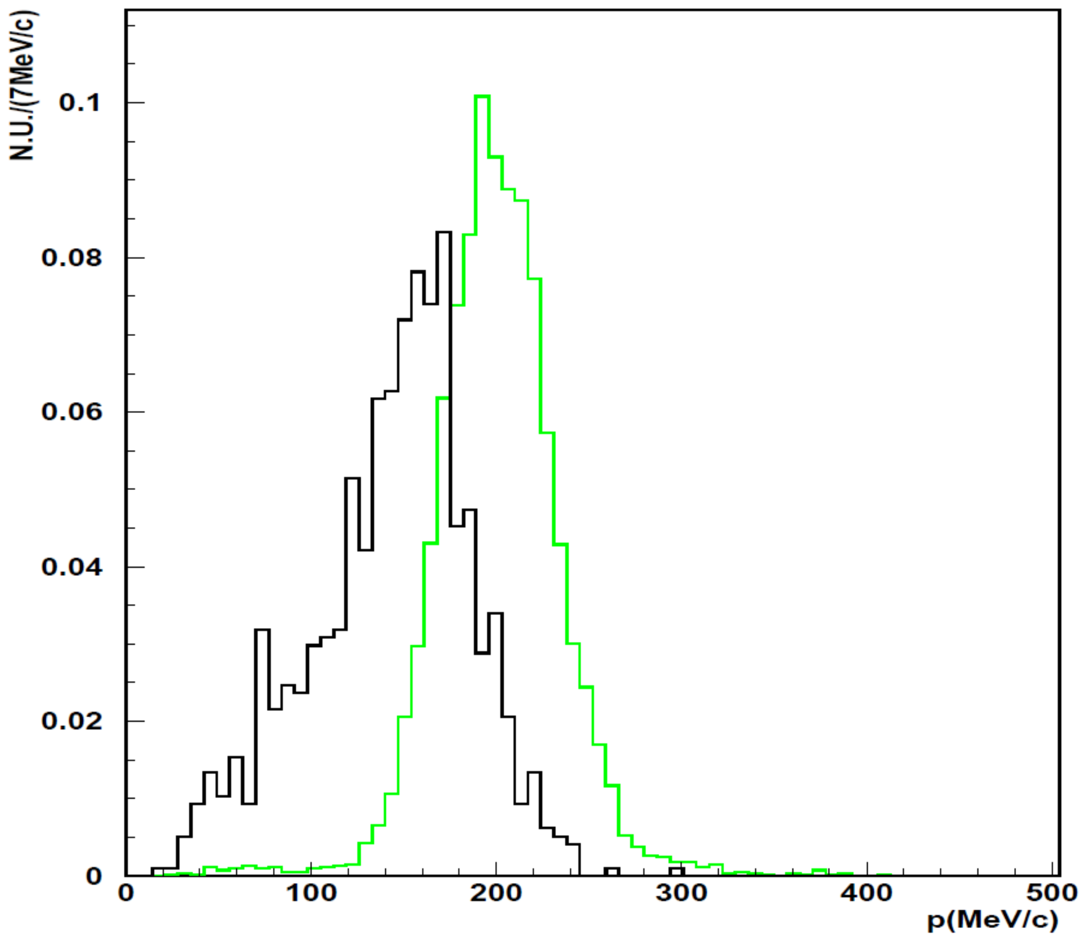
The **Λ momentum distribution** calculated **in the Σ^0 rest frame (black) agrees with pure signal MC** (green). A Gaussian fit to the green distribution gives a central value:

$$p_{\Lambda\gamma 3\,CM} = 74.5 \pm 0.5.$$

Study of the background

The Λ momentum was then transformed in the $\Lambda\pi^0$ rest frame (black distribution) and compared with $K^- \ {}^{12}C \rightarrow \Sigma^0(1385) + {}^{11}B \rightarrow \Lambda\pi^0 + {}^{11}B$

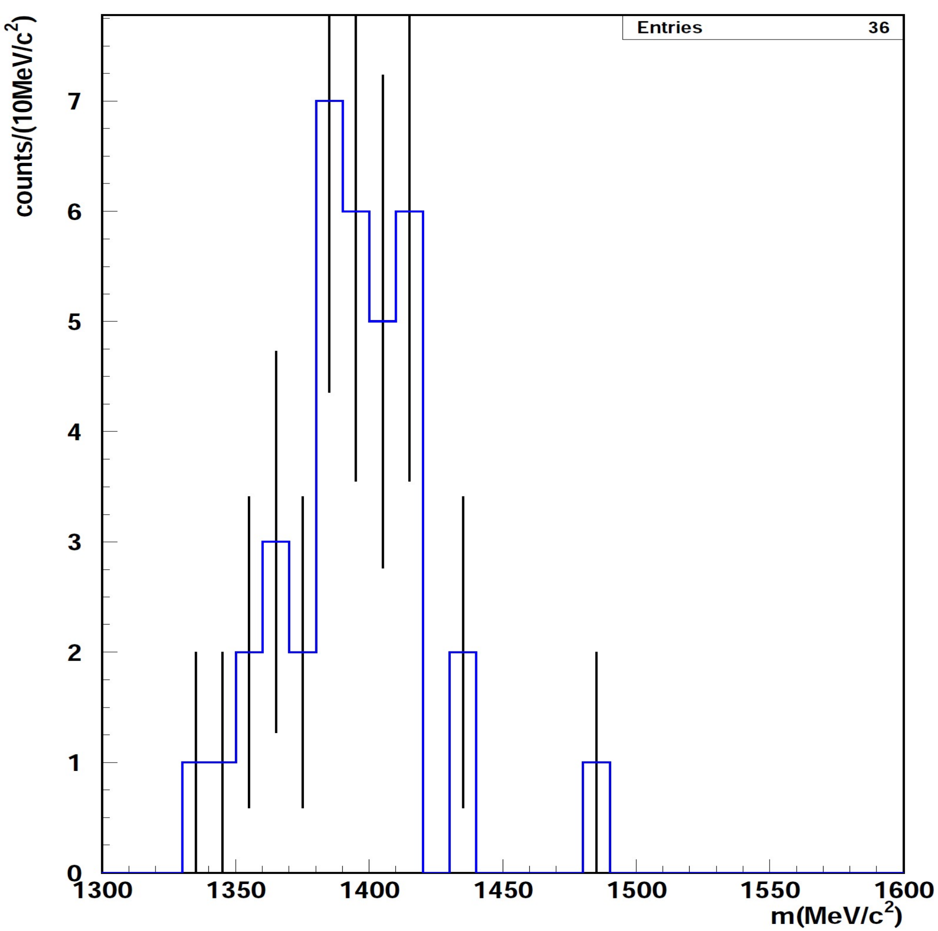
MC simulated events (green).



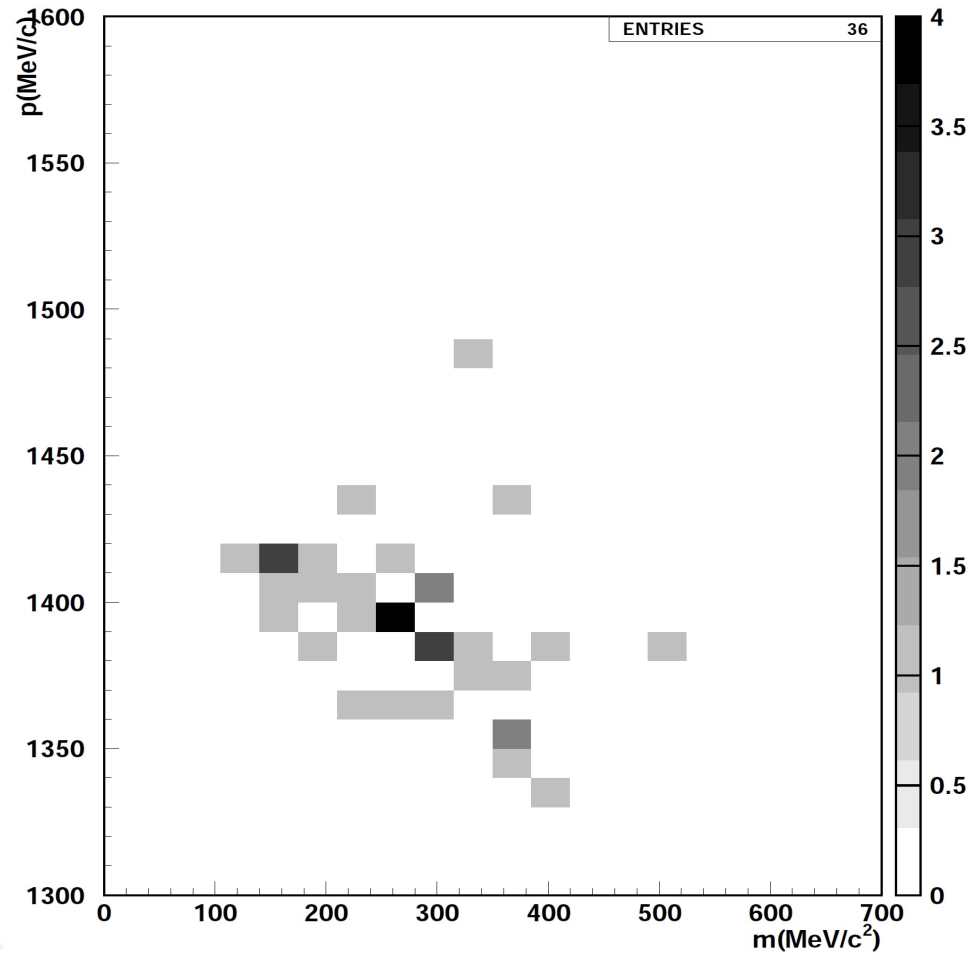
$p_{\Lambda\pi^0\,CM}$ distribution

Analysis of K- interactions in the beryllium beam sphere

K- interactions in the Beryllium-Alluminum sphere (r = 10 cm) surrounding the interaction point. Only **few events** surviving due to geometrical cut (r_{Λ} < 11.2 cm) to avoid absorptions in air. The invariant mass spectrum with MH is shown.



$m_{\pi 0 \Sigma 0}$ invariant mass

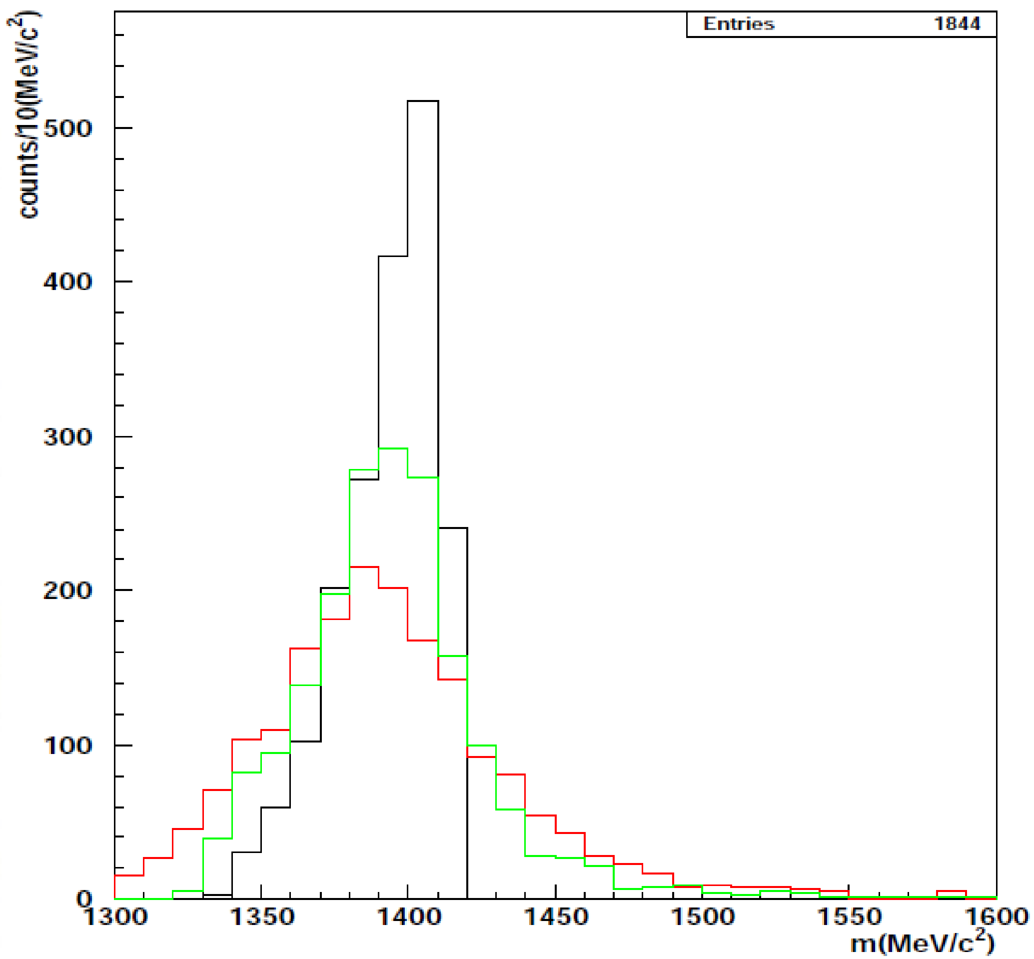


$m_{\pi 0 \Sigma 0}$ vs $p_{\pi 0 \Sigma 0}$

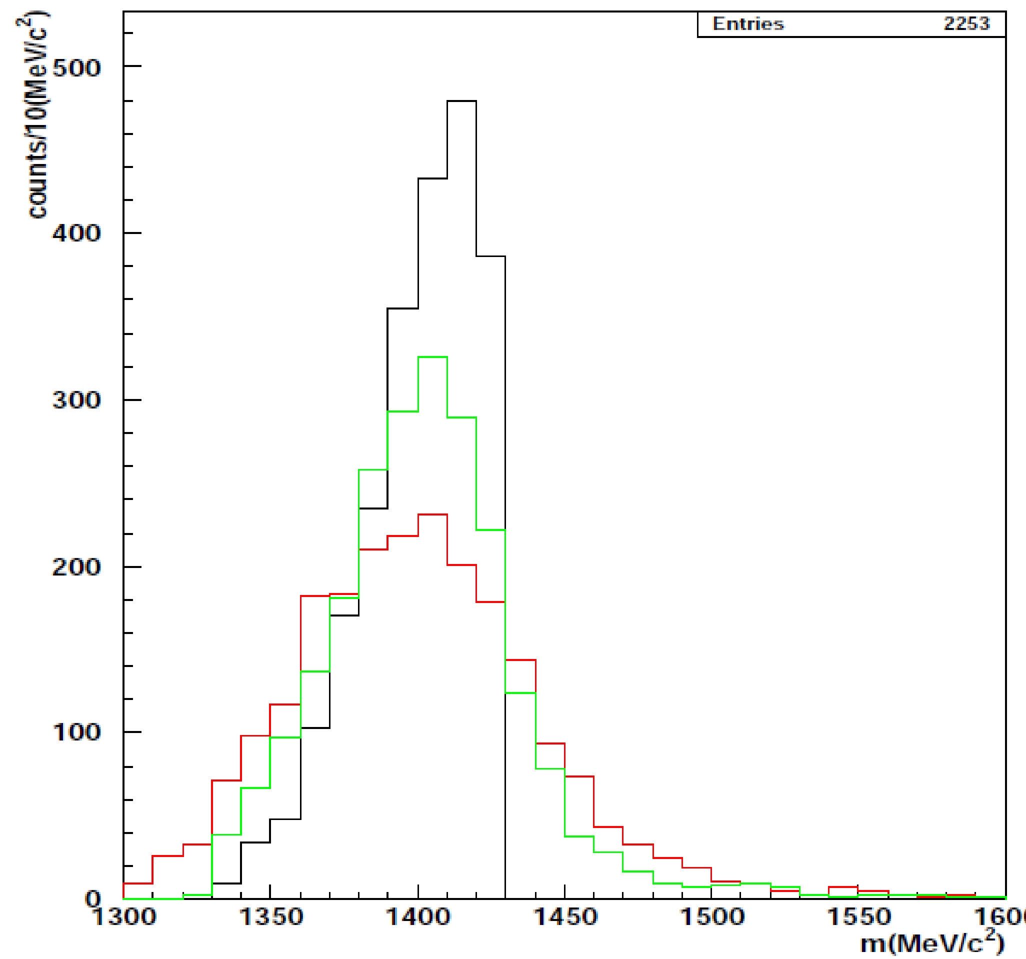
$m_{\pi^0\Sigma^0}$ spectrum

MC $m_{\pi0\Sigma0}$ spectrum for non-resonant, quasi-free $K^- C \rightarrow \Sigma^0\pi^0 + {}^{11}B$.

AT-REST left, IN-FLIGHT right. MC true black, reconstructed red, reconstructed with M.H. green.



$m_{\Sigma^0\pi^0}$ *spectrum*

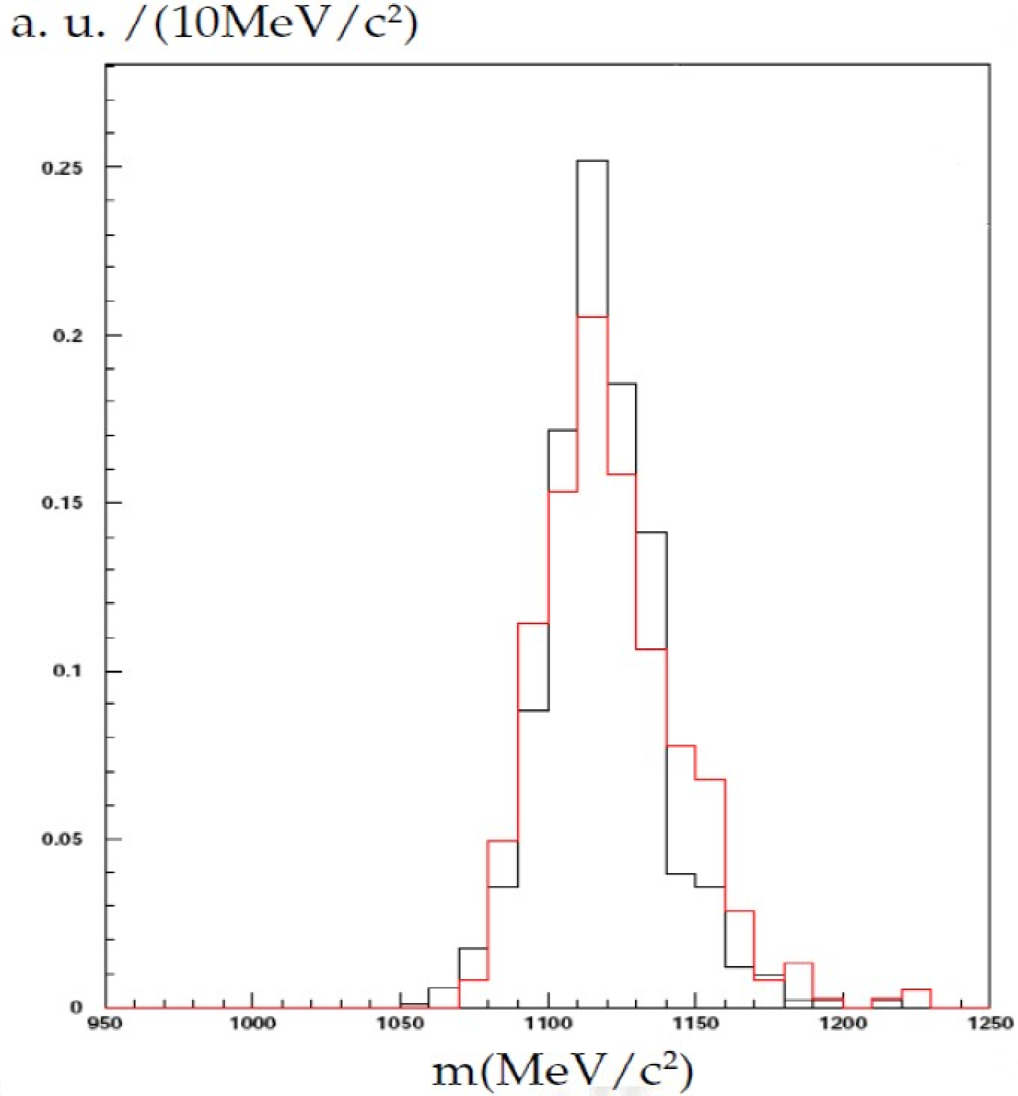


$m_{\Sigma^0\pi^0}$ *spectrum*

$m_{n\pi^0}$ spectrum

Investigated channels: K^-"p" $\rightarrow \Sigma^0\pi^0$ and K^-"p" $\rightarrow \Lambda\pi^0$

With: $\Sigma^0 \rightarrow \Lambda\gamma$ and $\Lambda \rightarrow n\,\pi^0$ decays



$m_{n\,\pi^0}$ invariant mass spectrum

K^- "p" → $\Sigma^+\pi^-$ channel

$K^- + p + {}^{11}B \to \Lambda^*(1405) + {}^{11}B \to \Sigma^+ + \pi^- + (5p+6n\ ?)$

$\quad + n$

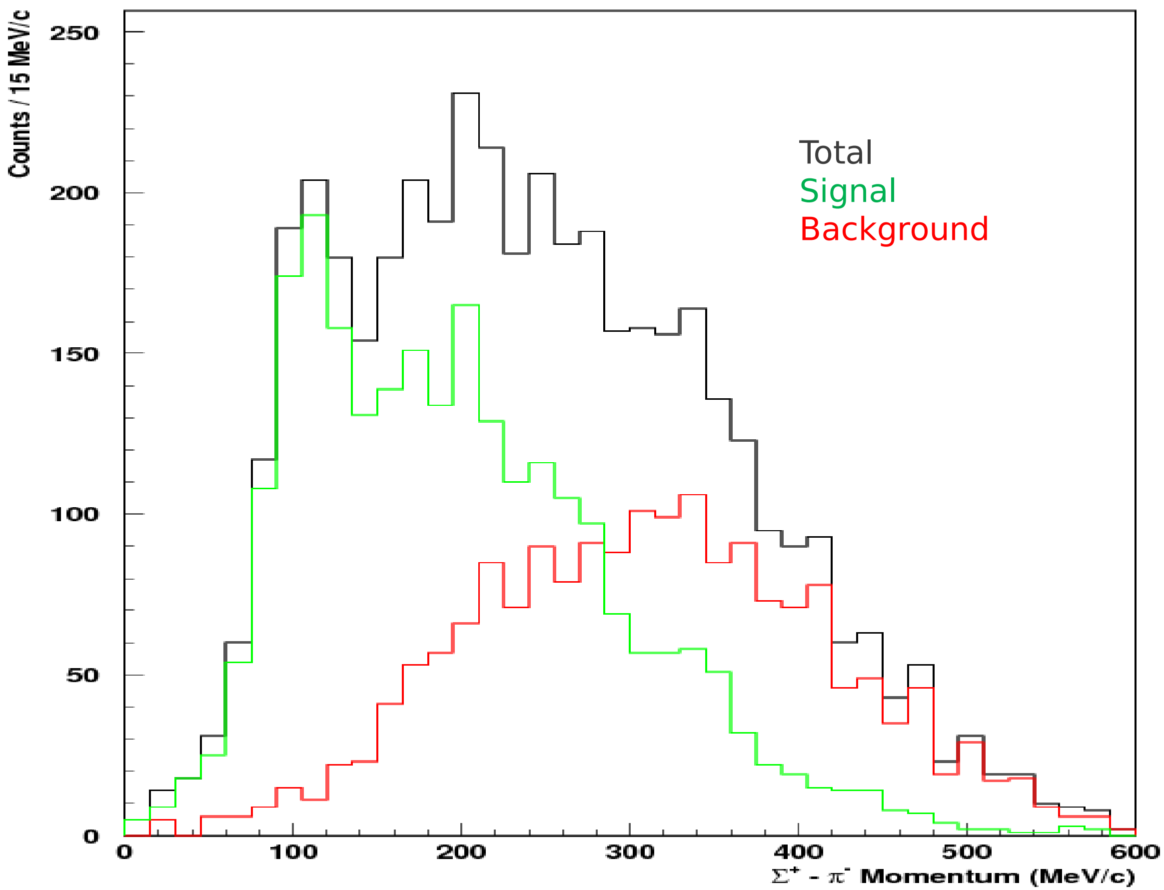
$n + \pi^0 + p \leftarrow \Lambda(1116) + p$

$\quad \pi^0 \to \gamma + \gamma$

Similar final states:

$K^- + p + {}^{11}B \to p + \pi^- + \gamma + \gamma + {}^{11}B$ (Signal)

$K^- + p + {}^{11}B \to p + \pi^- + \gamma + \gamma + (5p+6n\ ?)$ (BG)



First hint .. missing mass evidences nuclear fragmentation correlated to the possible internal conversion component