# AMADEUS: analysis of the KLOE data


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LNF - INFN

40th LNF Scientific Committee
Thursday, June 24, 2010

# Summary

## Analysis of Kloe data

- Motivation
- Statistics and selection
- Analysis: $\Lambda p$ $\Lambda d$ $(\Sigma\pi)^0$
- First steps with MonteCarlo: acceptancy

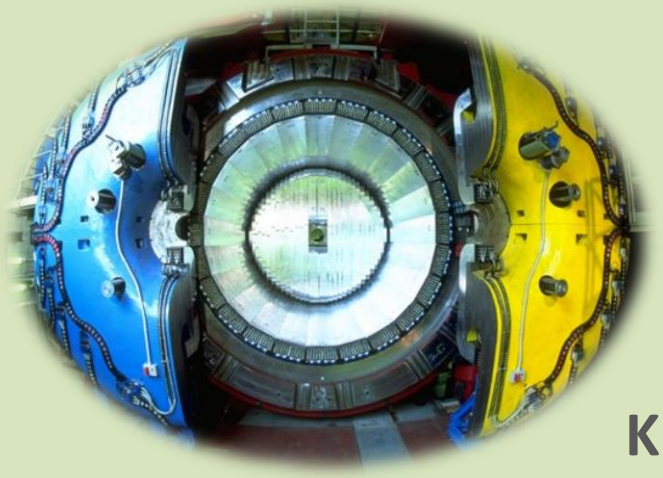
## a few words about AMADEUS

- Collaboration with KLOE2 run
- R&D tests

# Study of the hadronic interactions of $K^-$ in light nuclei at DAΦNE:

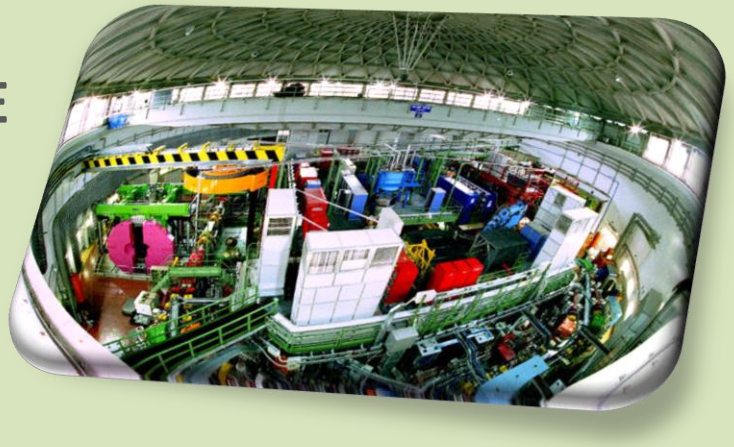
**KLOE**
$K^-$ hadronic interactions in the KLOE data

**AMADEUS**
**First dedicated full-acceptance study**



KLOE

DAΦNE



# Experimental programme
# AMADEUS (1) – stopped kaons

-- study of the (most) fundamental antikaon deeply bound nuclear systems,:

kaonic dibaryon states: $ppK^-$ and $(pnK^-)$
produced in a $^3He$ gas target, in formation and decay processes

kaonic 3-baryon states: $ppnK^-$ and $pnnK^-$
produced in a $^4He$ gas target, in formation and decay processes

--Measure heavier targets

--Hypernuclei?

# Experimental programme
# AMADEUS (2) – low energy kaons

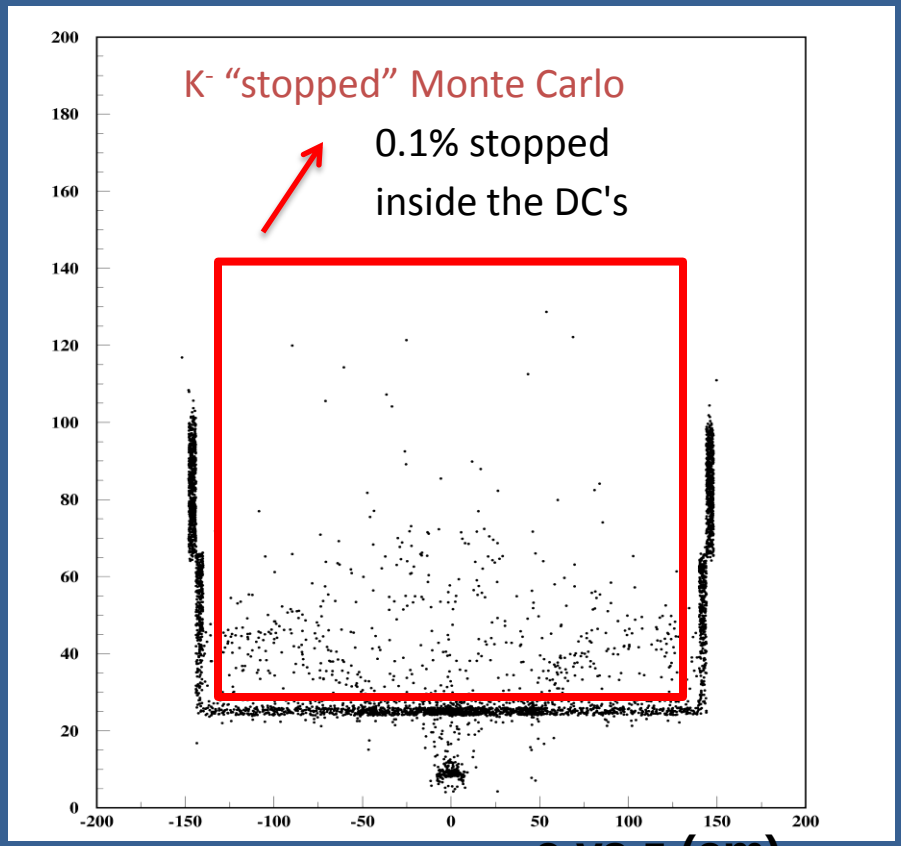
- Low-energy charged kaon cross sections and interactions on H, d, Helium(3 and 4), for K- momentum lower than 100 MeV/c (missing today);
- The K- nuclear interactions in Helium reactions (poorly known – based on one paper from 1970 …)
- Properties of L(1116) and charged S – for example decays in channels with neutrino -> astrophysics implications (cooling of compact stars)
- Resonance states as the elusive-in-nature but so important L(1405) or the S(1385) could be better understood with high statistics; their behaviour in the nuclear medium can be studied too.

# KLOE:

The implementation of the AMADEUS dedicated setup around the beam pipe will modify the topology of the events, stopping the K- in a target inner to the DC.

- The Drift Chambers of KLOE contain mailny **$^4$He** (90%)
- From analysis of KLOE data and Monte Carlo: **0.1 % of $K^-$ should stop in the DC volume**
- This would lead to hundreds of events with K- hadronic interactions at rest

"AMADEUS Step-0"




**KLOE Drift Chamber**

# Hadronic interactions of $K^-$ in KLOE

$$K^-_{stopped} + {}^4He \rightarrow n + n + (\underline{K^- pp}) \rightarrow \Lambda + p$$

$$K^-_{stopped} + {}^4He \rightarrow n + (\underline{K^- ppn}) \rightarrow \Lambda + d$$

- **Statistics:**

- Total amount of data analyzed up to an integrated luminosity of **~1,7 $fb^{-1}$** from KLOE data (K-charged group). **80% KLOE RUNS 2004/2005**

- **Kaons TAG system:** **CHARGED KAON**

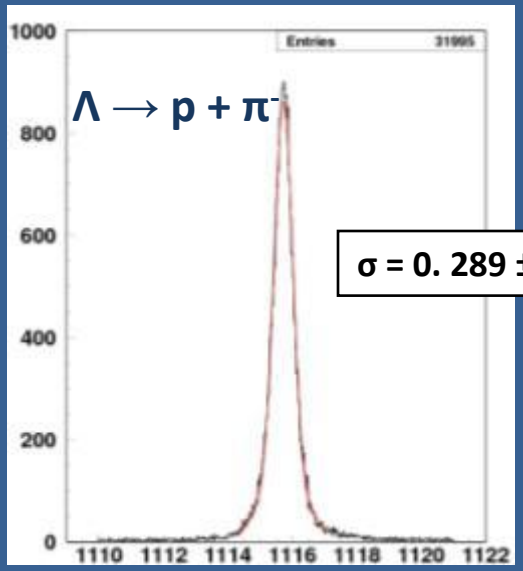
  **2-body decay** or by the **dE/dx** signature in the DC gas.

- **Data nalisis**

  Search for hadronic interactions with Λ(1115) as products:

  - **$\Lambda \rightarrow p + \pi^-$** (64% BR) vertex made by KLOE reconstruction
  - Construct a vertex with **Λ + an extra particle**

# **AMADEUS STEP-0:** The KLOE data analysis




$M_{inv}$ pπ (MeV)

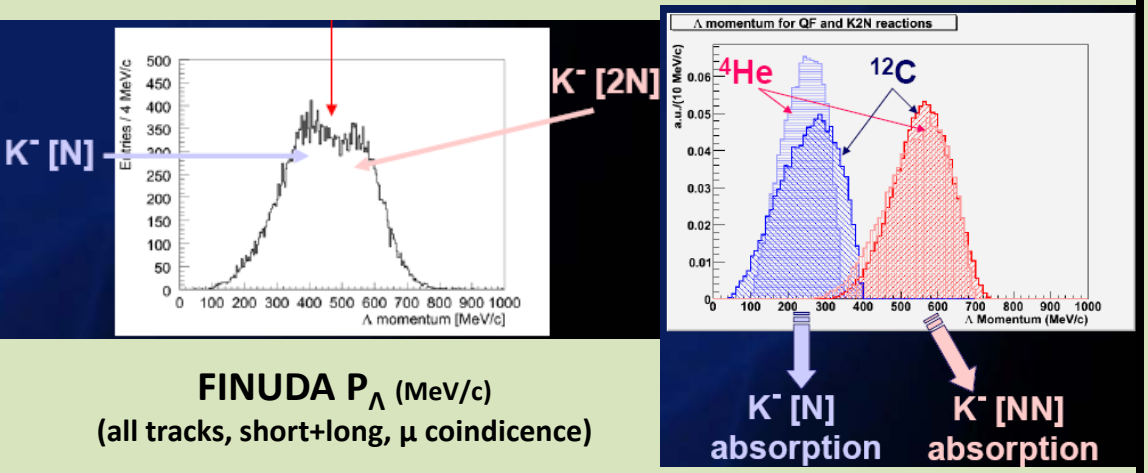
**KLOE: $M_{inv}$ = 1115,723 ± 0. 003 stat (MeV/$c^2$)**

PDG: $M_\Lambda$ = 1115,683 ± 0.006 stat ± 0.006 syst (MeV/$c^2$)

**σ = 0. 289 ± 0.003** MeV/$c^2$

# Lambda momentum

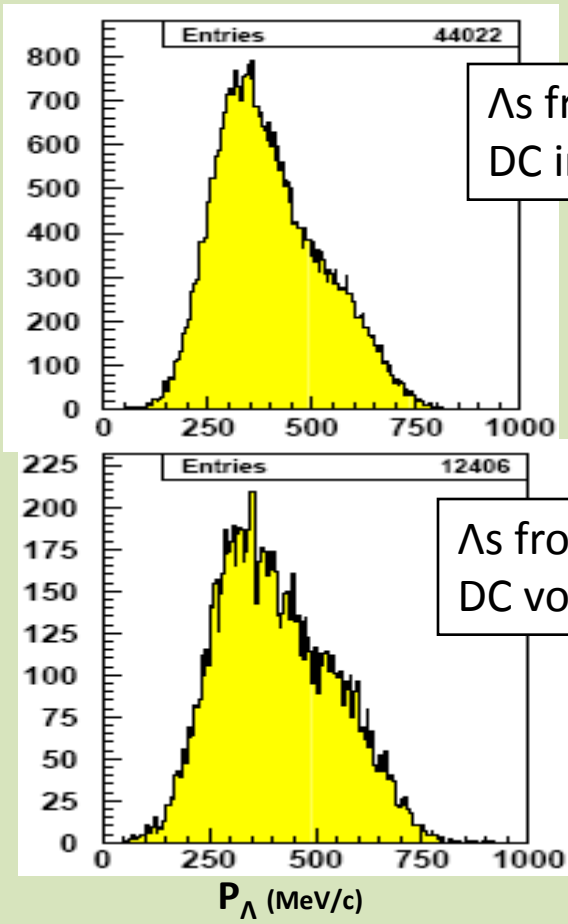
**Simulation: expected signals for inclusive Λ production in $^4$He and $^{12}$C**




**FINUDA $P_\Lambda$ (MeV/c)**
**(all tracks, short+long, μ coindicence)**

Thanks to S. Piano, A. Filippi

**KLOE:**




-Well defined double structure in both cases
-Similar momentum range
-Differences at lower momentum due to acceptancy
-**Perfectly compatible**

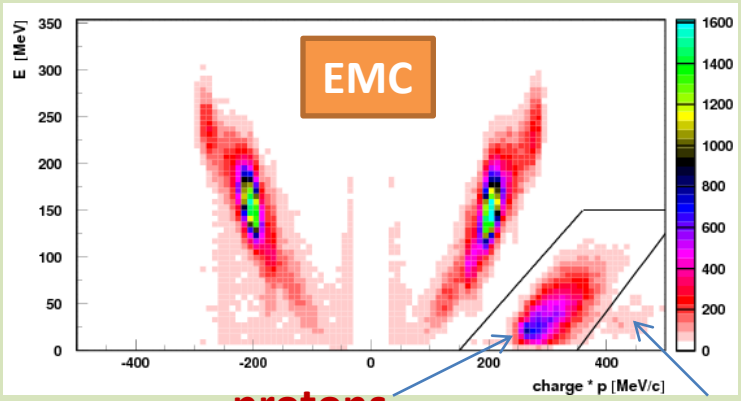
# Selection of protons and deuterons

PID

•Protons and deuterons are **firstly** selected from the spectrum of particles near to the Lambda vertex **by dE/dx**

$\Lambda + p$

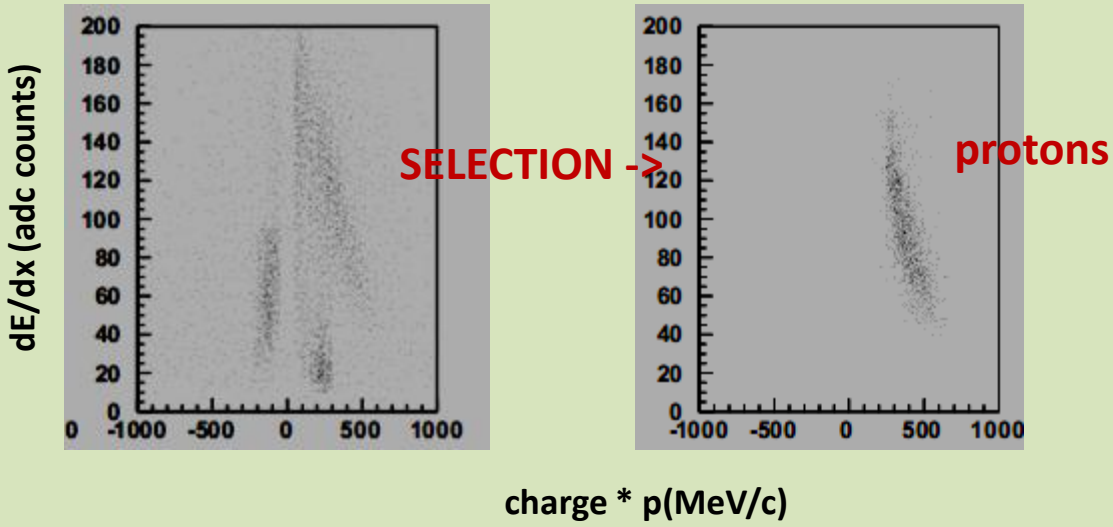
$\Lambda + d$



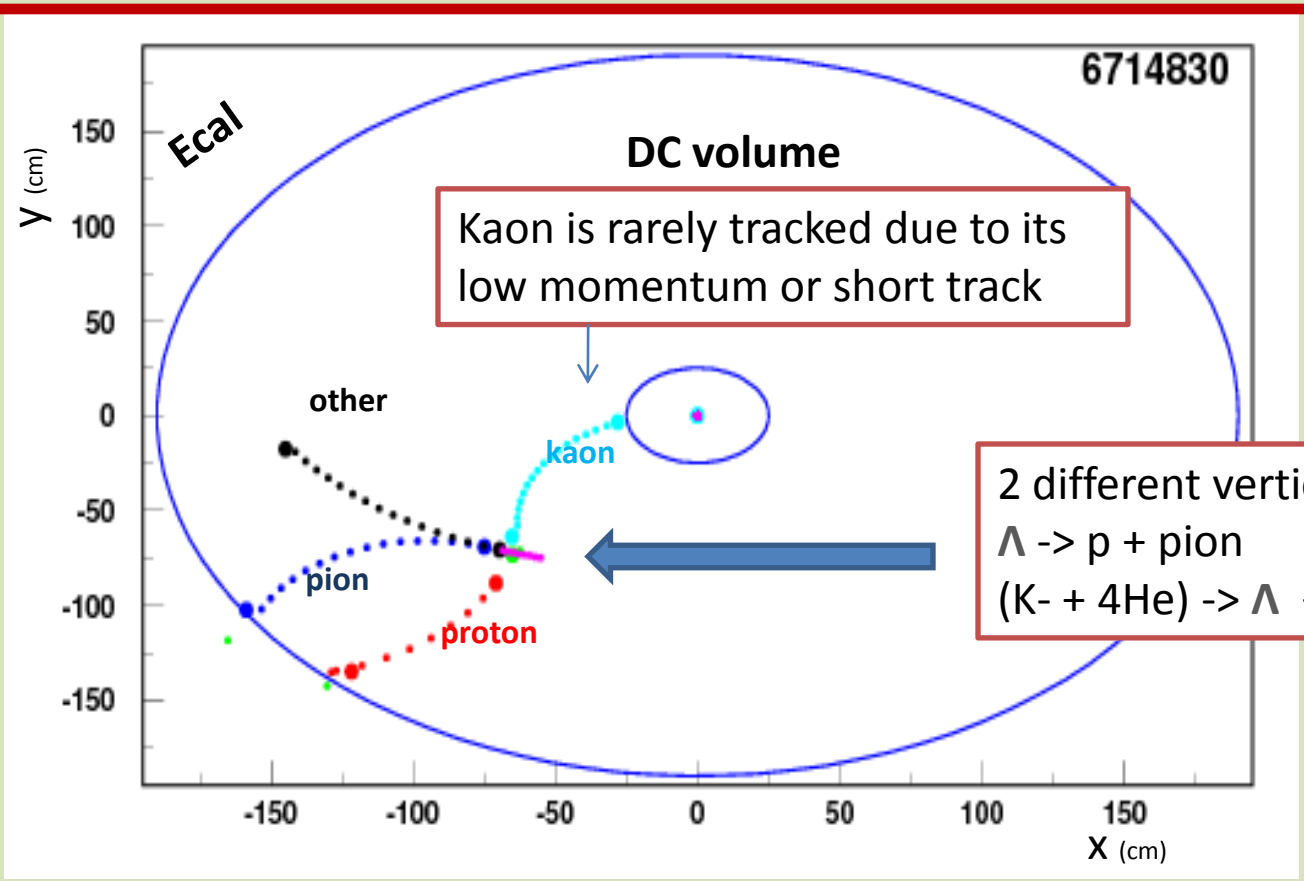

ENERGY RELEASE IN THE EMC

DC

DEDX IN THE WIRES OF THE DC



# Selection of events

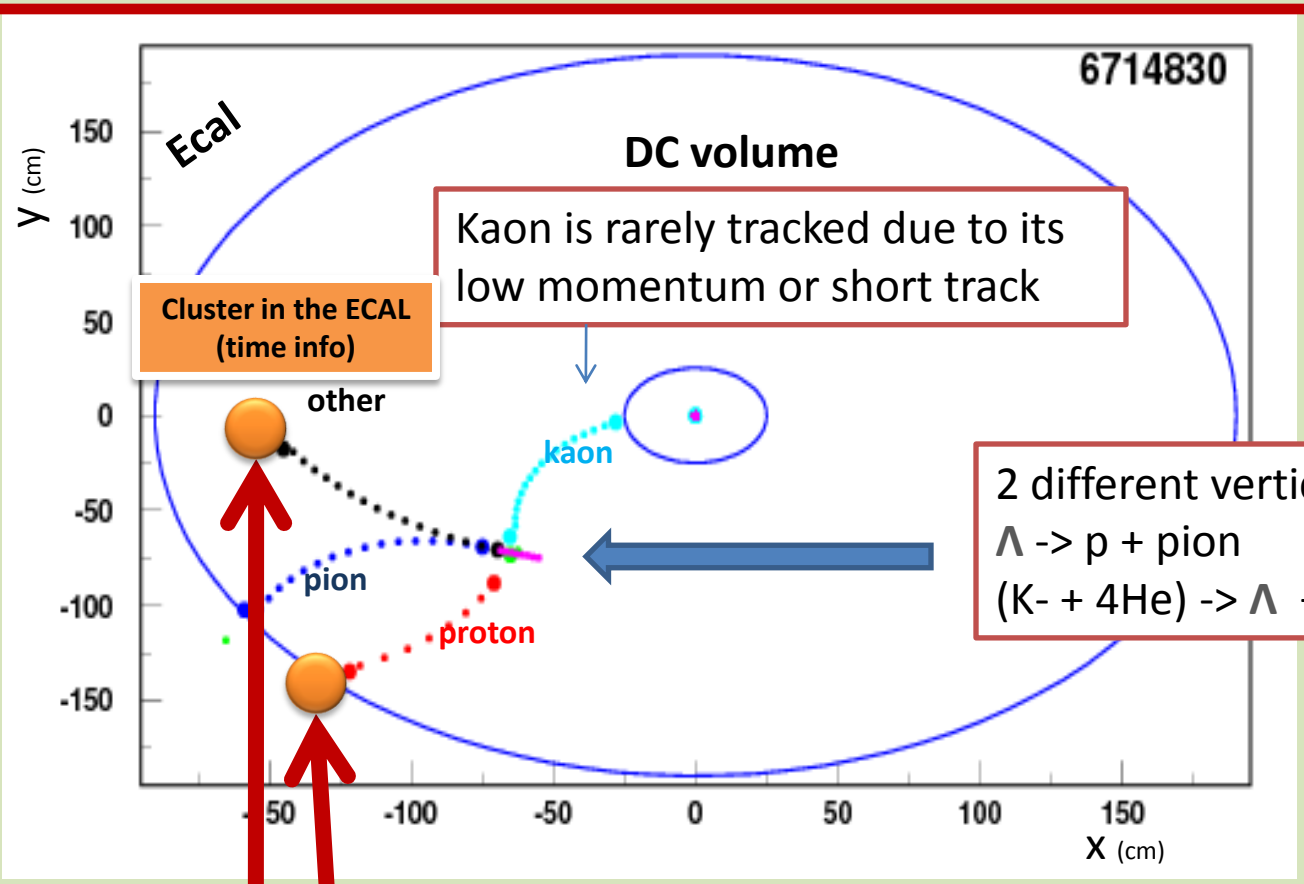



Λ + p

Λ + d

2 different vertices reconstrucion:
Λ -> p + pion
(K- + 4He) -> Λ + d

# Selection of events




Λ + p

Λ + d

2 different vertices reconstrucion:
Λ -> p + pion
(K- + 4He) -> Λ + d

**Proton from Λ**

**Deuteron /proton**

**Are required to have at least 1 cluster to reproduce the time of the event**

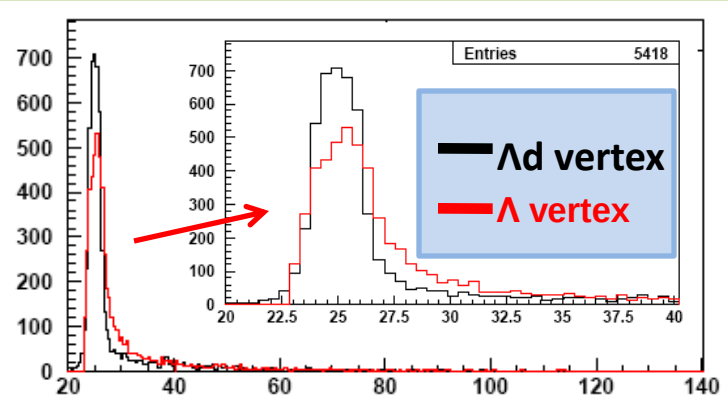
- **Calculate proton/deuteron mass by TOF**
- **Evaluate SIGMA0 background**

# Correlations: Lambda-d vertices

Improved Λd vertex reconstruction

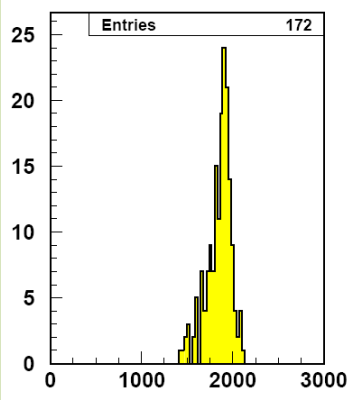
**Improved mass recognition (PID) of deuterons and protons**

**Improved selection of events in DC-gas**



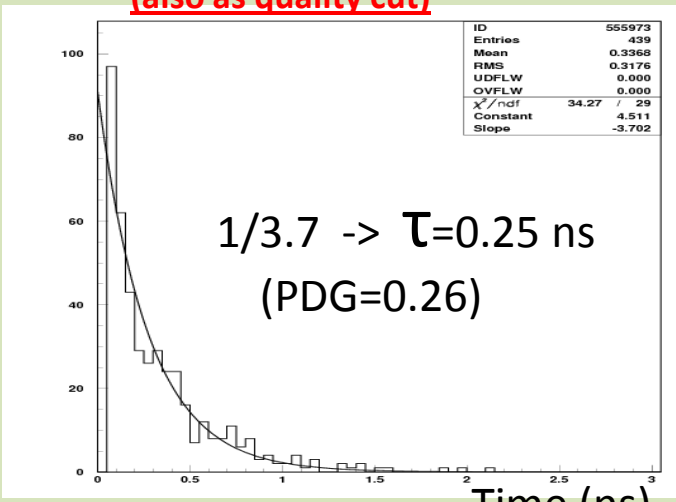

Vertex radial position (cm)

**• Proton/deuteron candidates are required to have an associated cluster in the EMC and its mass is measured by time of flight.**




$M_{deuteron}$ (MeV/$c^2$)

**LAMBDA LIFETIME**
**(also as quality cut)**

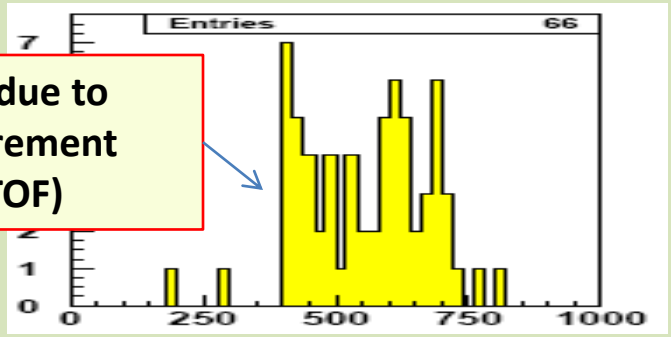



Time (ns)

# Selection of events

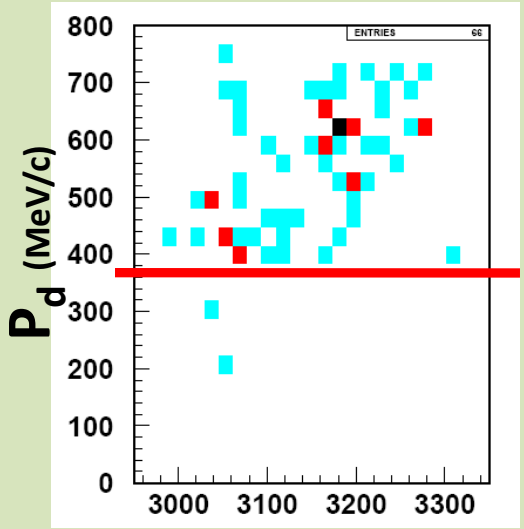
Λ + d

Previously...




**Sharp cut due to EMC requirement (mass by TOF)**

deuteron momentum vs. Minv

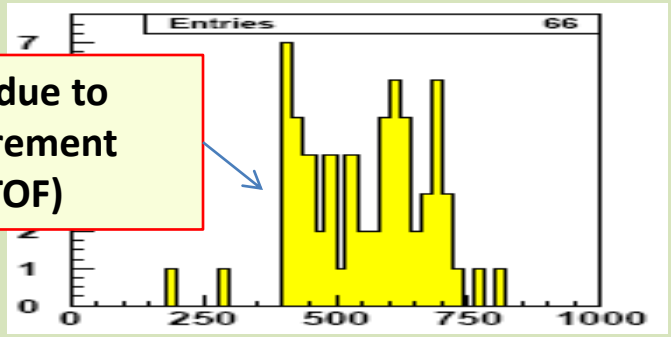



$M_{inv}$ Λd (MeV/$c^2$)

# Selection of events

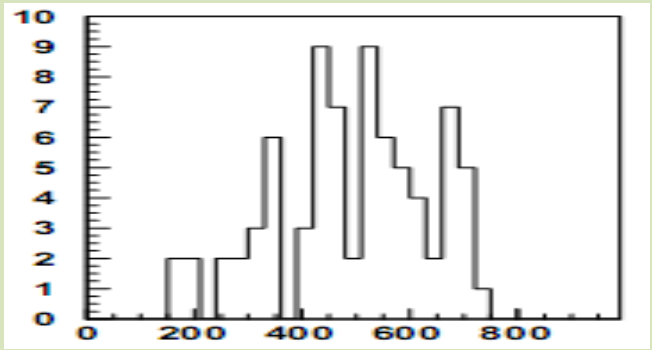
Λ + d

Previously...




Sharp cut due to EMC requirement (mass by TOF)

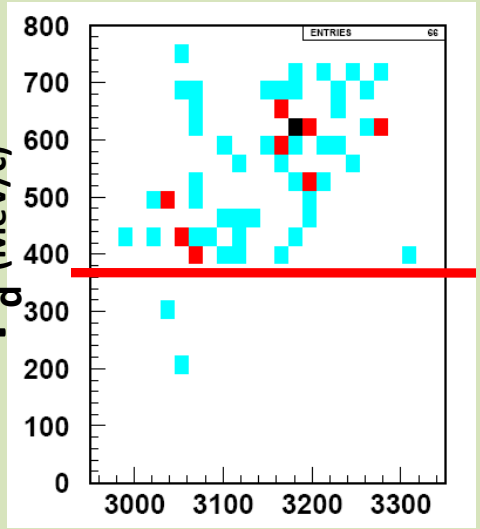
$P_d$ (MeV/c)




$P_d$ (MeV/c)

Efficency for tracks with P < 400 MeV improved **increased acceptancy**

deuteron momentum vs. Minv

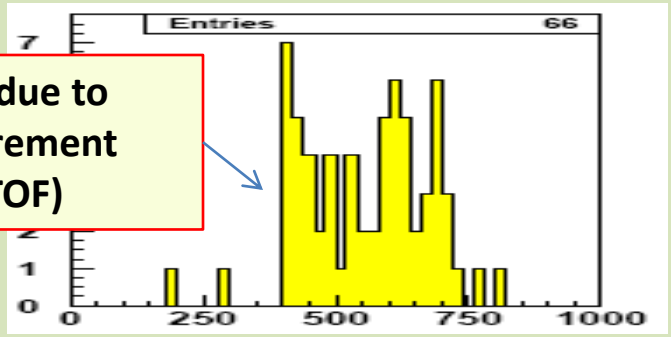



$M_{inv}$ Λd (MeV/$c^2$)

# Selection of events

Λ + d

Previously...

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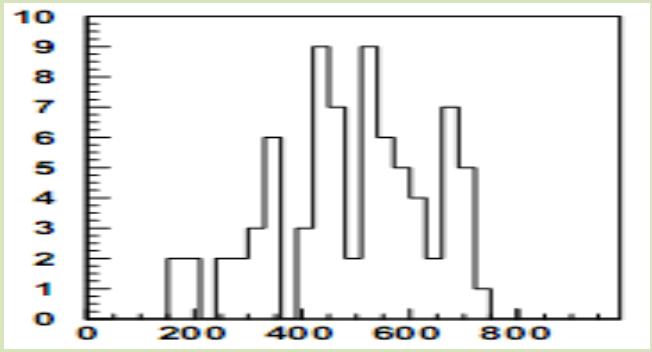
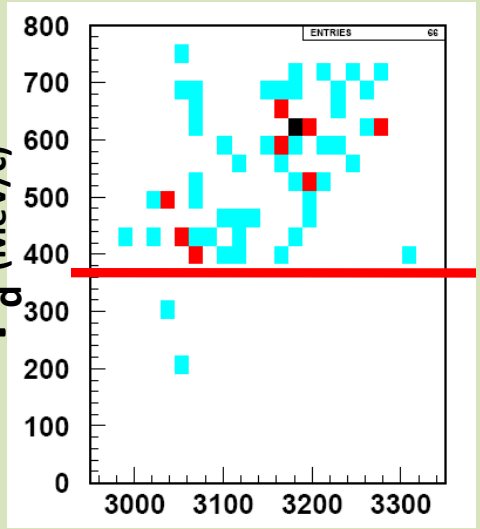
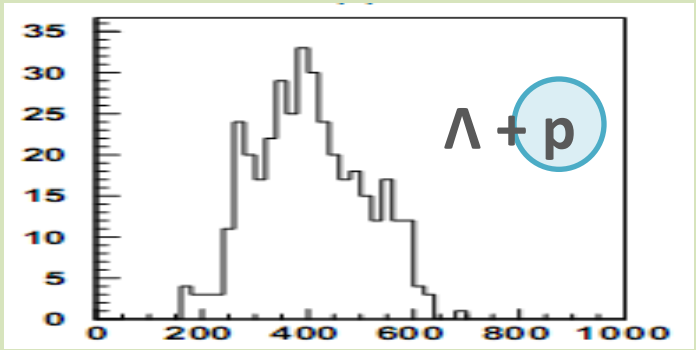



$P_d$ (MeV/c)

deuteron momentum vs. Minv




$M_{inv}$ Λd (MeV/$c^2$)

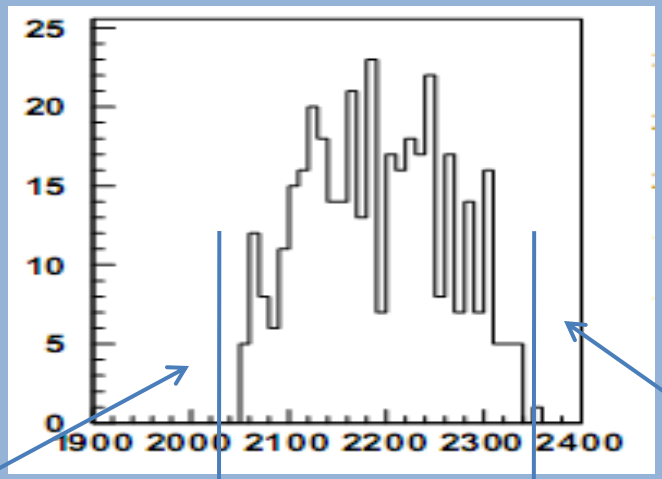



$P_p$ (MeV/c)

# Invariant mass

## Λ p analysis

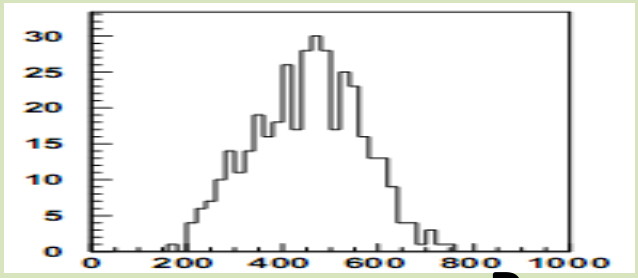
Total events in DC Volume 187



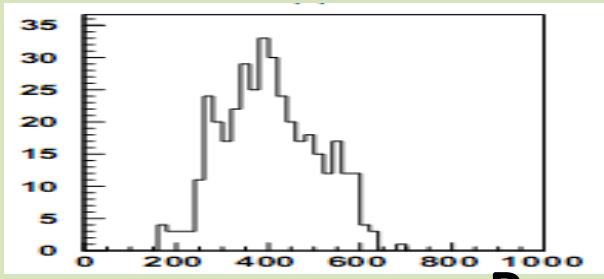

$2M_p+M_{\pi^-}$

$M_{inv}$ Λp (MeV/c²)

$2M_p+M_K$




$P_\Lambda$ (MeV/c)




$P_p$ (MeV/c)

# Invariant mass

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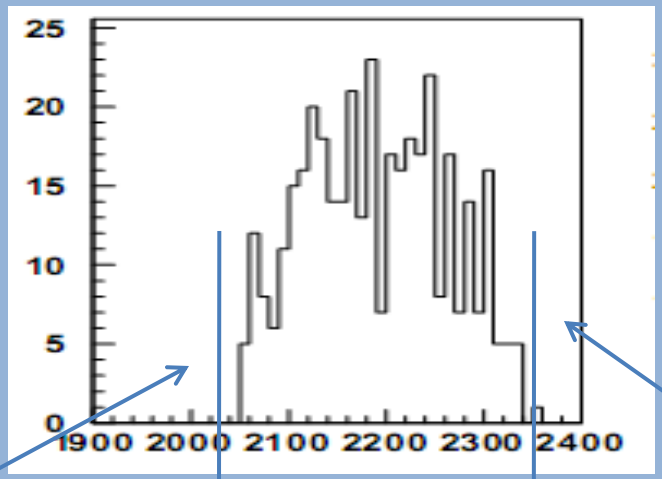
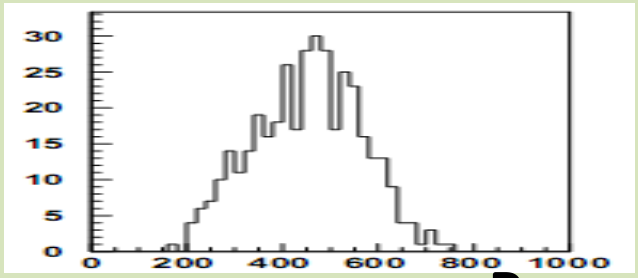
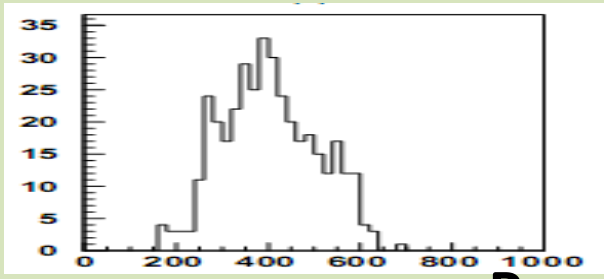
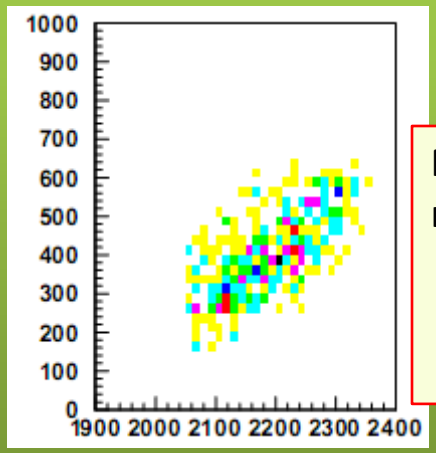


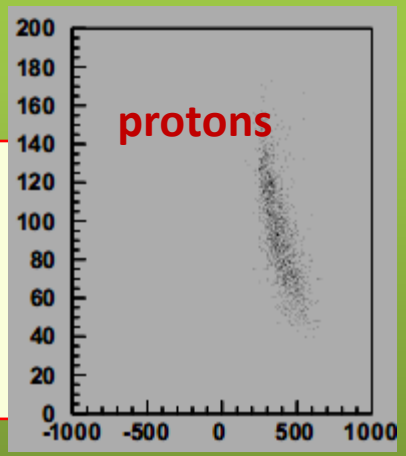




NO EMC-CLUSTER (mass by TOF) requirement for protons !!!!

Rely only on DEDX in the DC wires -->

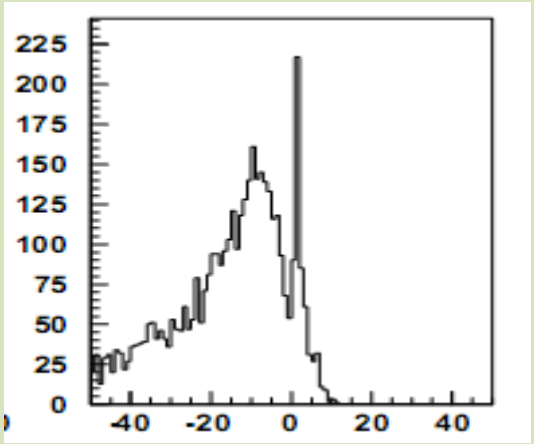


# $\Sigma^0$ Contamination in $\Lambda p$ events

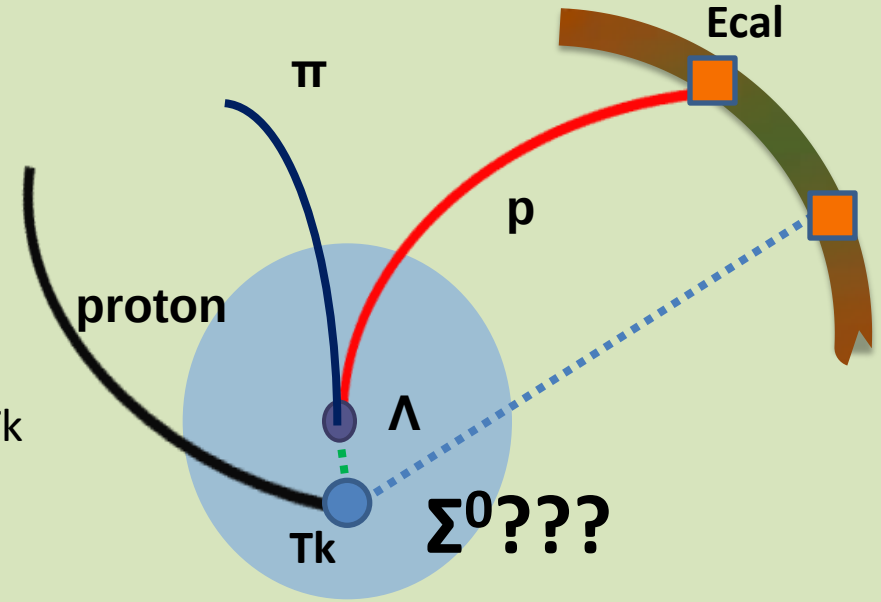
Use of the time information from the EMC

-With the extrapolation of the charged and neutral (lambda) tracks the time of the Interaction (Tk) is obtained

Time correlation between neutral clusters (not associated to any charged track) and Tk assuming a photon travelling:




**Tphoton -Tk (MeV/c)**



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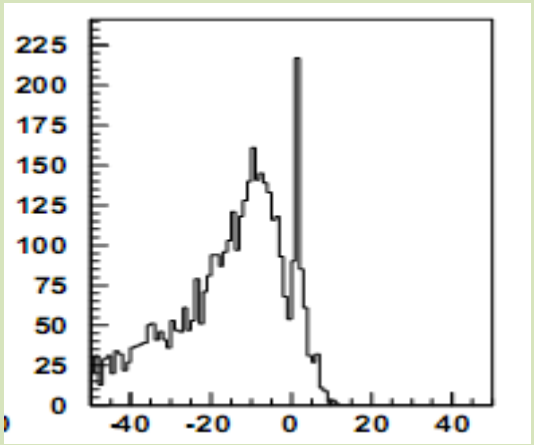


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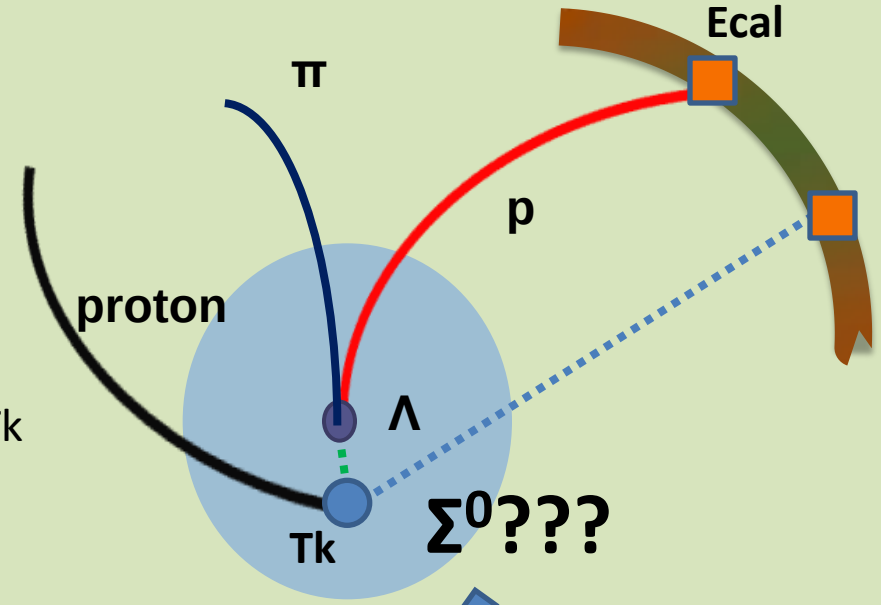
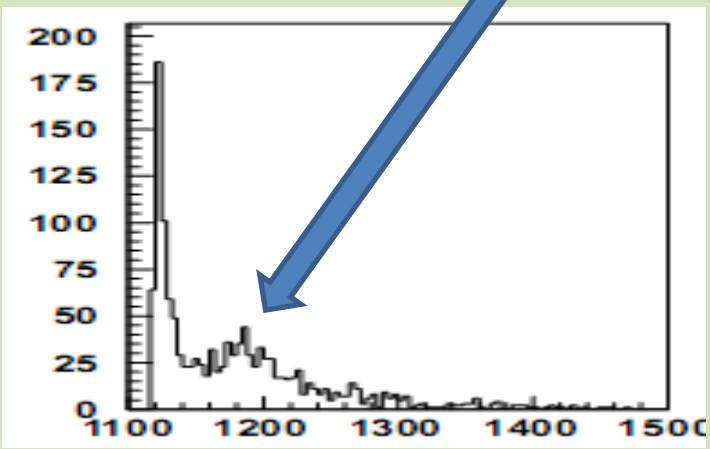


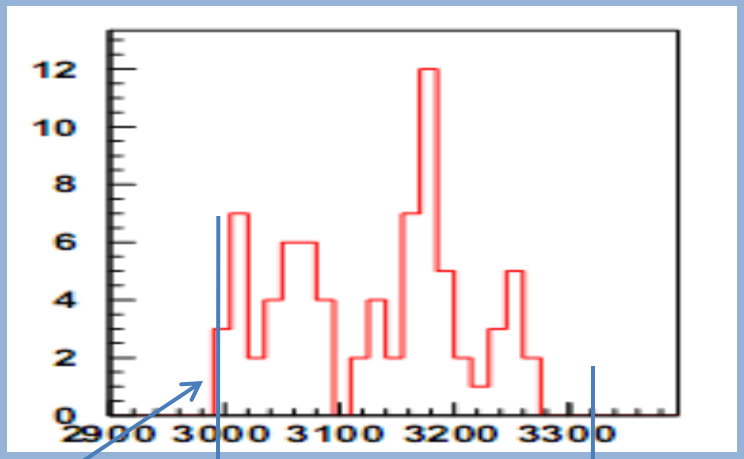




$M_{inv}\ \gamma\gamma$ (MeV/$c^2$)

# Invariant mass

**Λ d** analysis

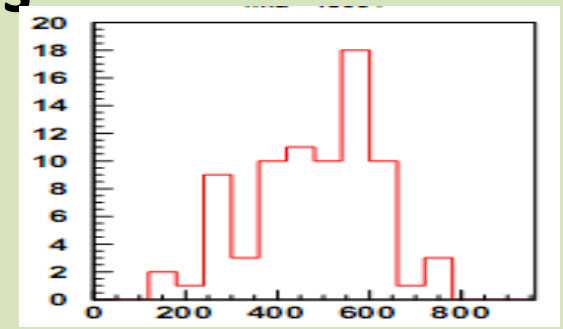
**Total events in DC Volume 79**



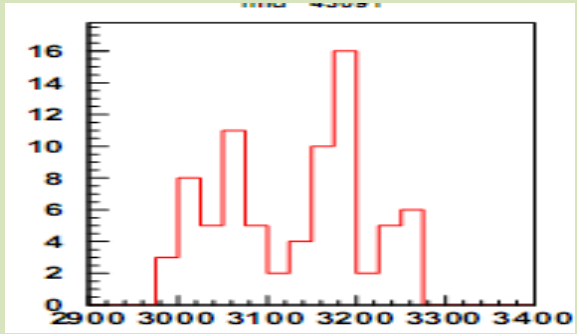

$M_d + M_p + M_{\pi^-}$

$M_{inv}$ **Λd** (MeV/$c^2$)

$M_d + M_p + M_K$




$P_\Lambda$ (MeV/c)

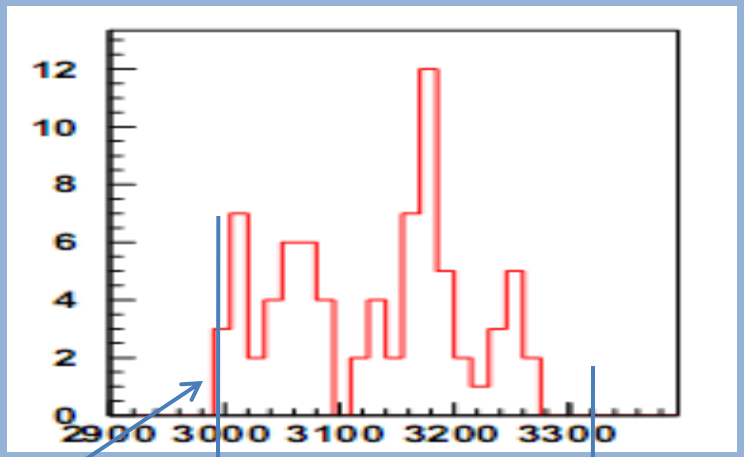



$P_d$ (MeV/c)

# Invariant mass

**Λ d analysis**

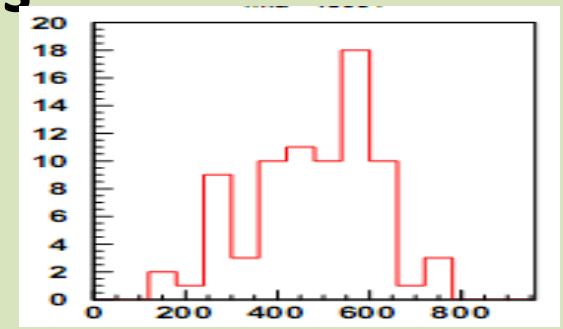
**Total events in DC Volume 79**



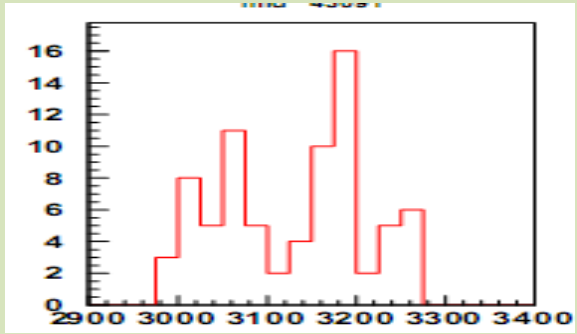

$M_d + M_p + M_{\pi^-}$

$M_{inv}$ Λd (MeV/c²)

$M_d + M_p + M_K$

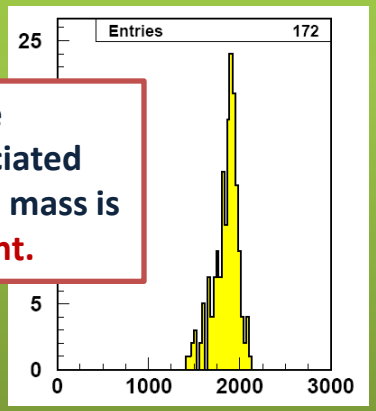



$P_\Lambda$ (MeV/c)



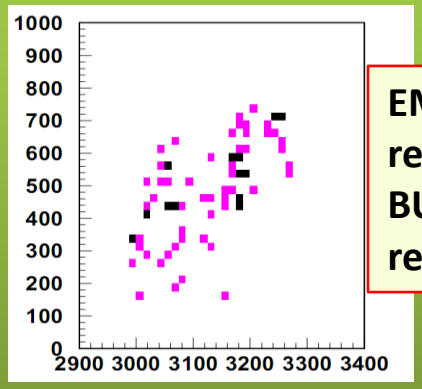

$P_d$ (MeV/c)

•Deuteron candidates are required to have an associated cluster in the EMC and its mass is measured by **time of flight.**




$M_{deuteron}$ (MeV/c²)

$P_d$ (MeV/c)



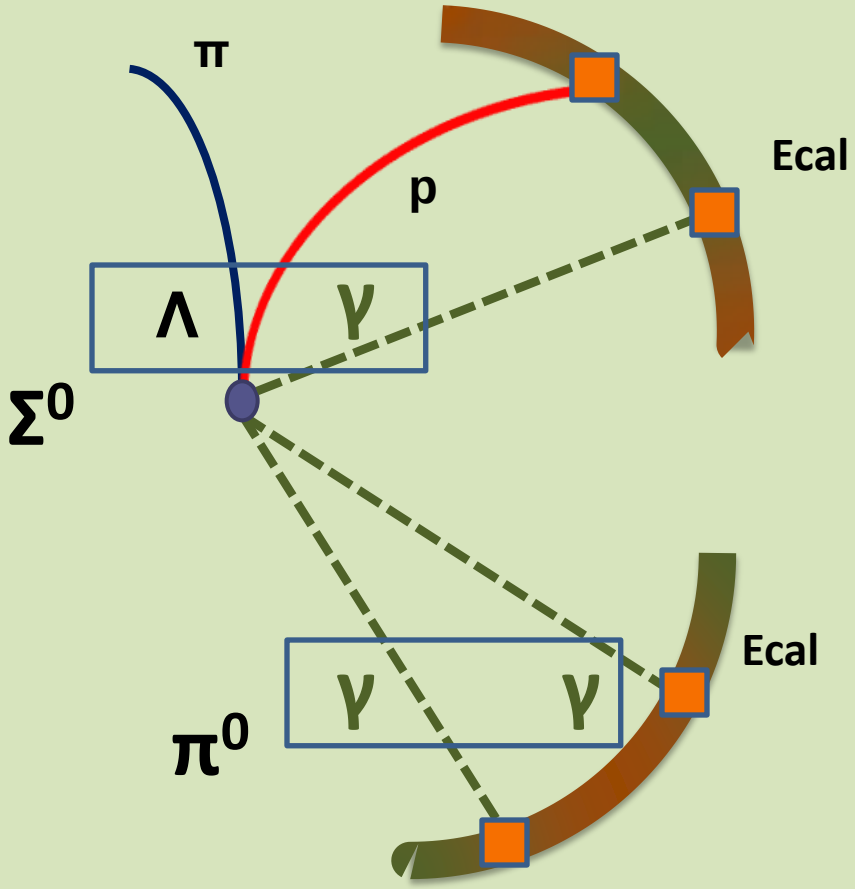

$M_{inv}$ Λd (MeV/c²)

**EMC-cluster ALWAYS required for deuterons BUT NOT sharp cut reducing acceptancy ☺**

# $(\Sigma\pi)^0$

**Λ(1405)/Λ(1420) search**

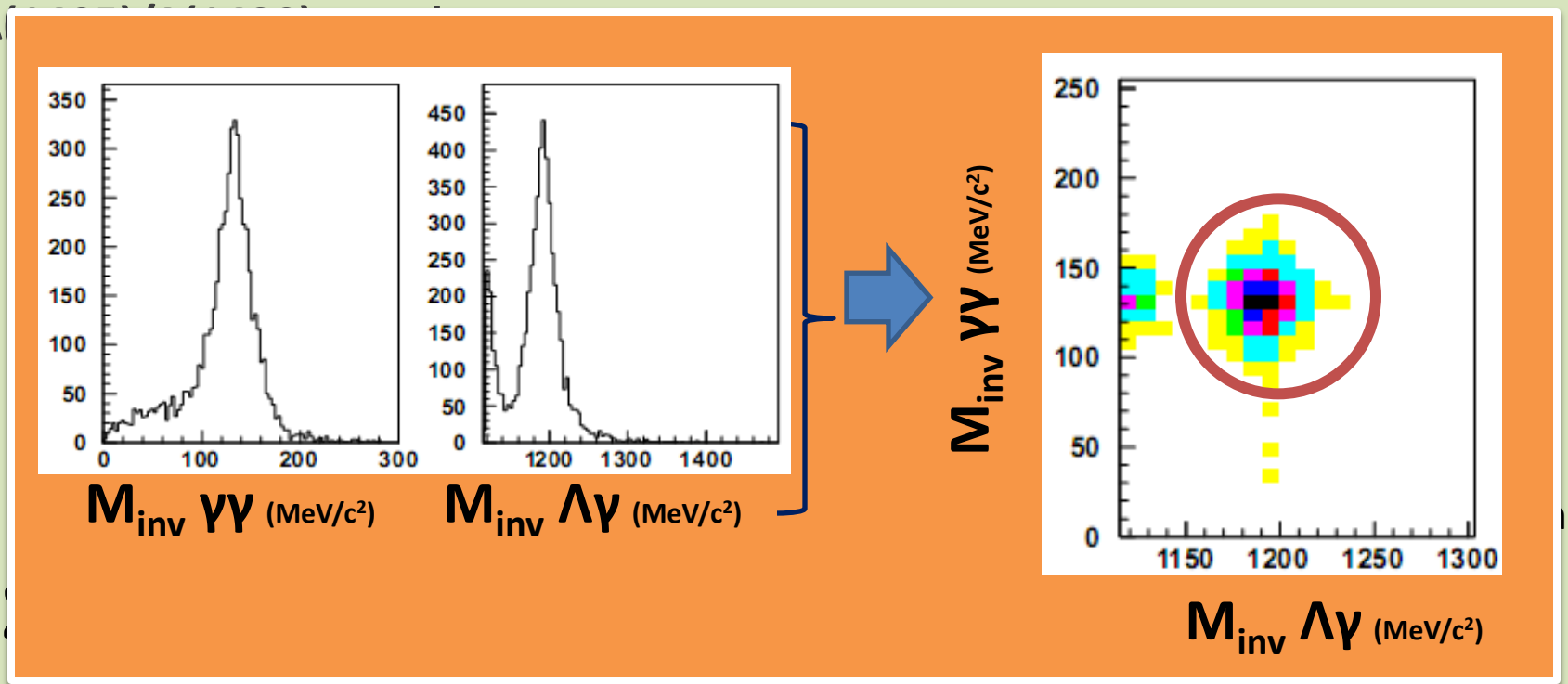
- **Strongly related with the deeply bound kaonic states prediction**
- **Lack of experimental data**

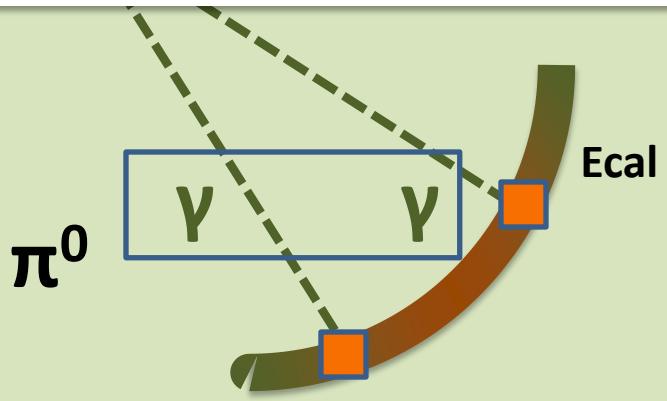



## Kinematic fit:

- $\chi^2$ computing:
  - -momentum of proton and pion
  - -Covariance matrix elements for every track
  - -time and positions plus resolutions for photons
- **Allows to reject background selecting the right combination of photons**
- Constraints: Δt for the arrival time of photons
- No mass assumption -> unbiased mass spectras

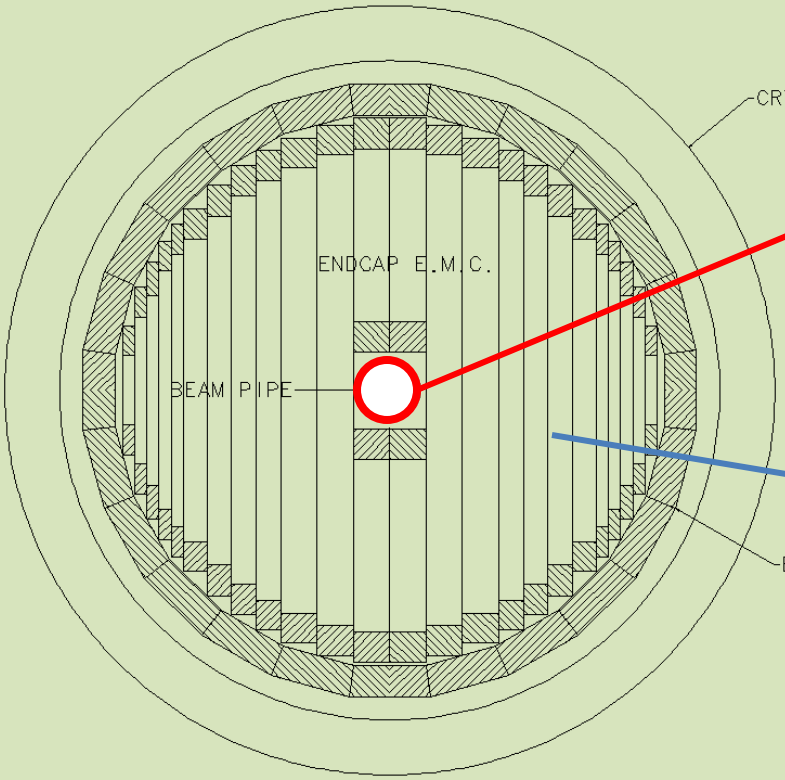
# $(\Sigma\pi)^0$

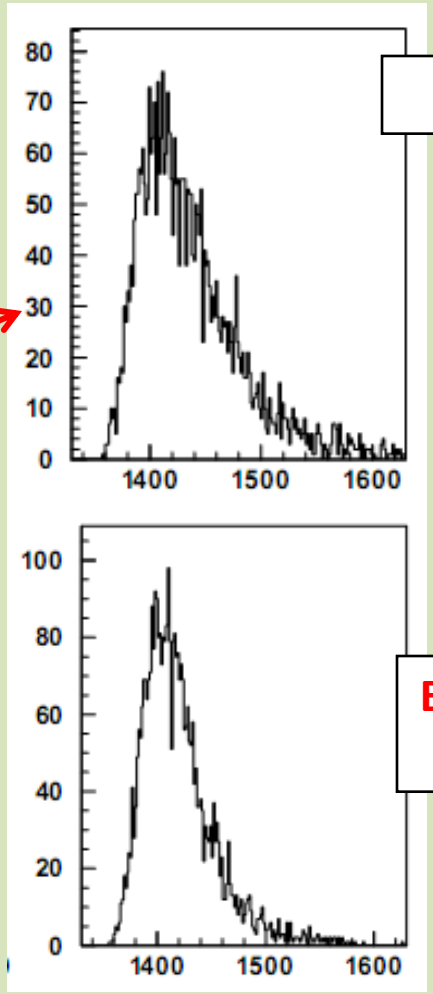



- Constraints: Δt for the arrival time of photons
- No mass assumption -> unbiased mass spectras

# $(\Sigma\pi)^0$




**DC wall**

**Events 3990**

**Events in the DC volume**

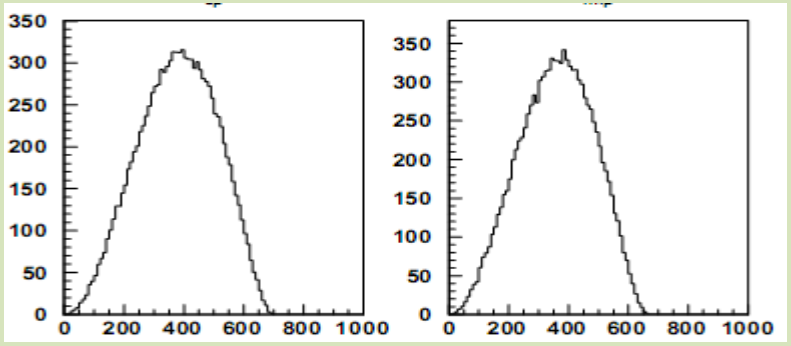
**Events 3379**

$M_{inv}\Sigma^0\pi^0$ (MeV/$c^2$)

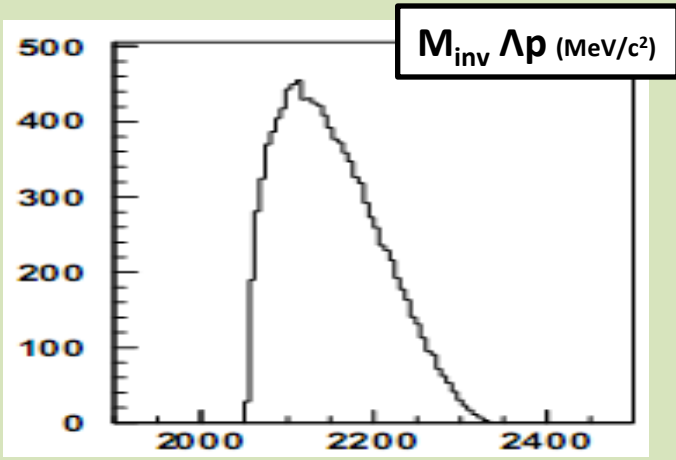
# KLOE Monte Carlo

- Use of the standard KLOE MC with hadronic interaction of stopped K-
- Evaluate background distributions (hadronic interaction, multi-nucleon absorption, etc) for the analises shown previously
- First output: **ACCEPTANCE CORRECTION** (evaluation)

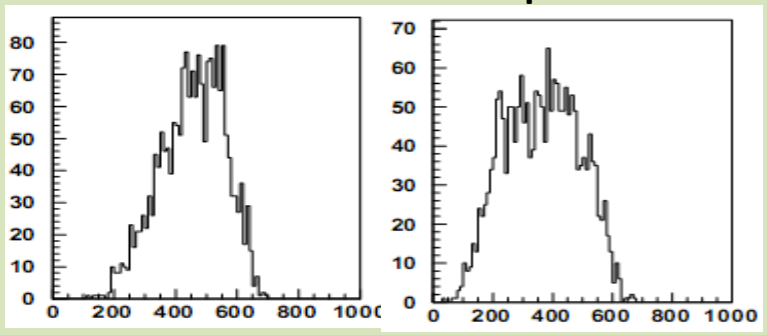
**K- + 4He → Λ p n n** (phase space)



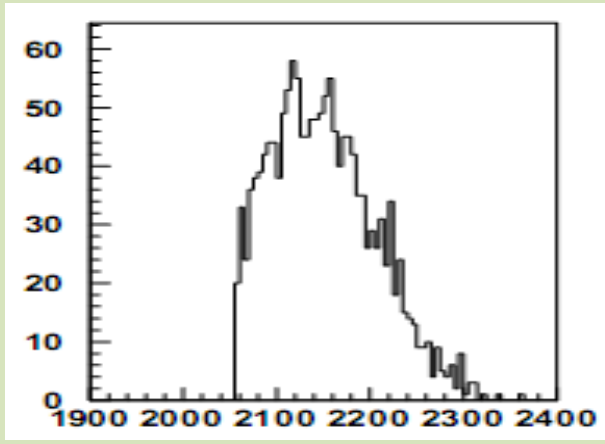
**True MC**




$P_\Lambda$ (MeV/c) $P_p$ (MeV/c)



**After reconstrucition and selection**



# KLOE Monte Carlo

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**$K^- + {}^4He \rightarrow \Lambda p n n$** (phase space)

# KLOE Monte Carlo

- Use of the standard KLOE MC with hadronic interaction of stopped K-
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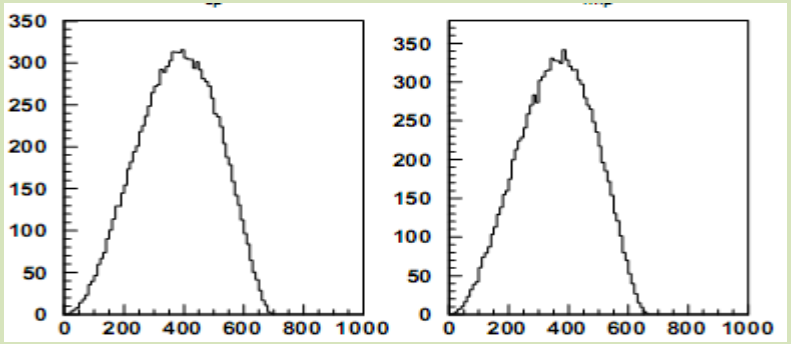
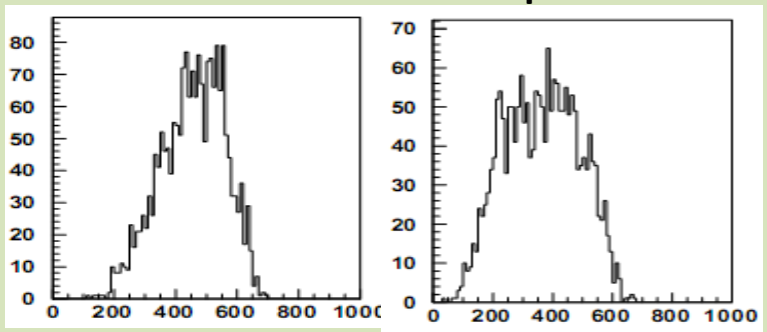
- First output: **ACCEPTANCE CORRECTION** (evaluation)

**K- + 4He → Λ p n n** (phase space)

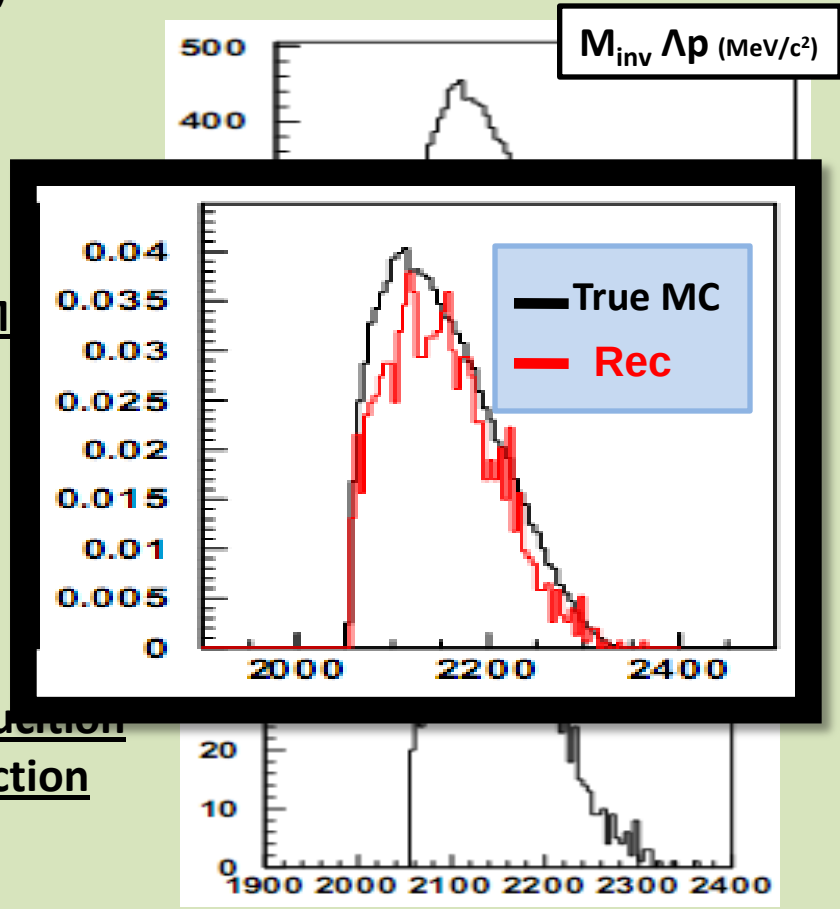



**$P_\Lambda$ (MeV/c)** **$P_p$ (MeV/c)**




**True M**

**After reconstruction and selection**



- We need....
  - Monte Carlo distributions (hadronic interaction, multi-nucleon absorption, etc)
  - More data...

Work in progress

## AMADEUS contributions in KLOE2:

1) Monitor - Shinji Okada

2) Slow Controls & run control - Alessandro d'Uffizi

3) Calorimetro - F. Sirghi & Kristian Piscicchia

4) Alberto Clozza: roll-in, mechanics, etc

5) DC TDC: Marco  Poli-Lener and Oton Vázquez Doce

6) DC HW: Oton Vázquez Doce

7) Gas DC: Marco Poli-Lener

8) DC calibration: Antonio Romero

9) Trigger: Alessandro Scordo and Alessandro Rizzo

10) Other participants: Massimiliano Bazzi, Diana Shirgi

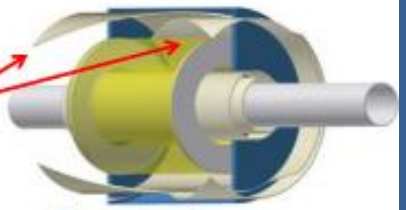
**ALL AVAILABLE TO DO SHIFTS AS WELL**

...a few words about AMADEUS R&D

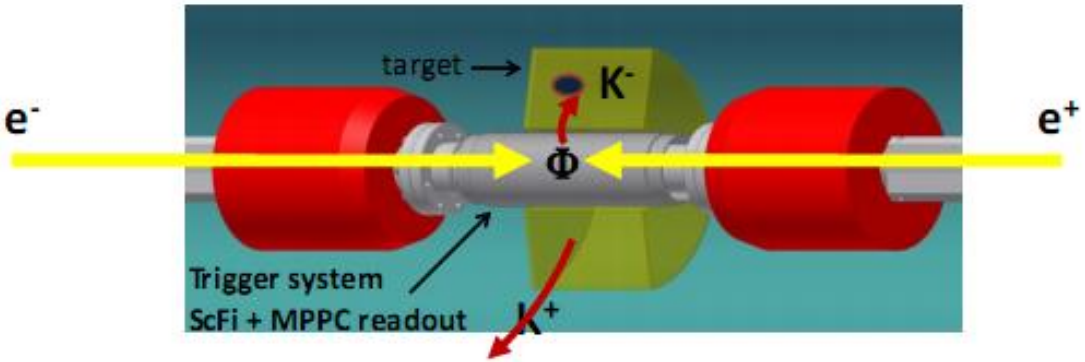
## AMADEUS setup: Trigger system

- **Cilindrical layer of scintillating fibers** surrounding the beam pipe to **trigger $K^+$ $K^-$ in opposite directions**
- Single or double layer

In this case possibility of perform tracking as well: X-Y measurement with high granularity layers



- Readout to be done by MPPC **(Multi Pixel Photon Counter)**



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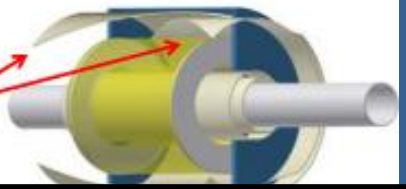
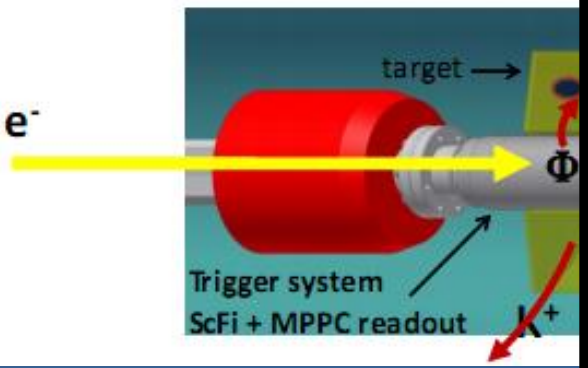
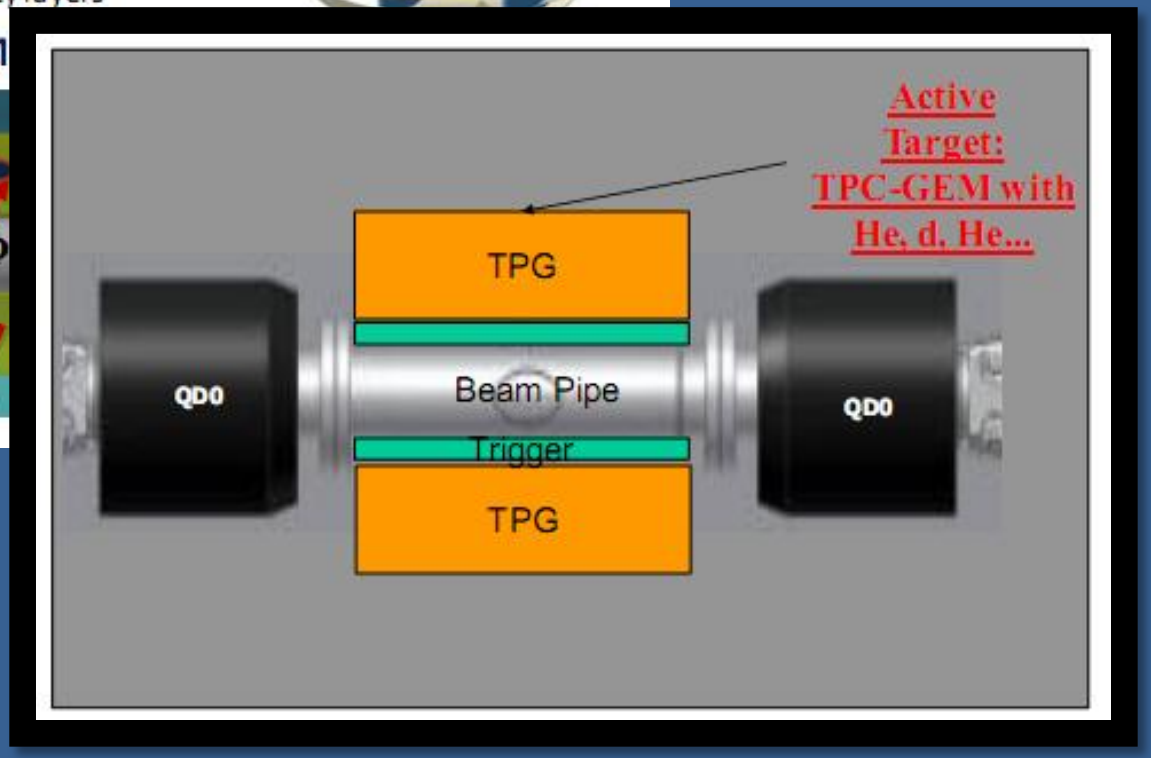


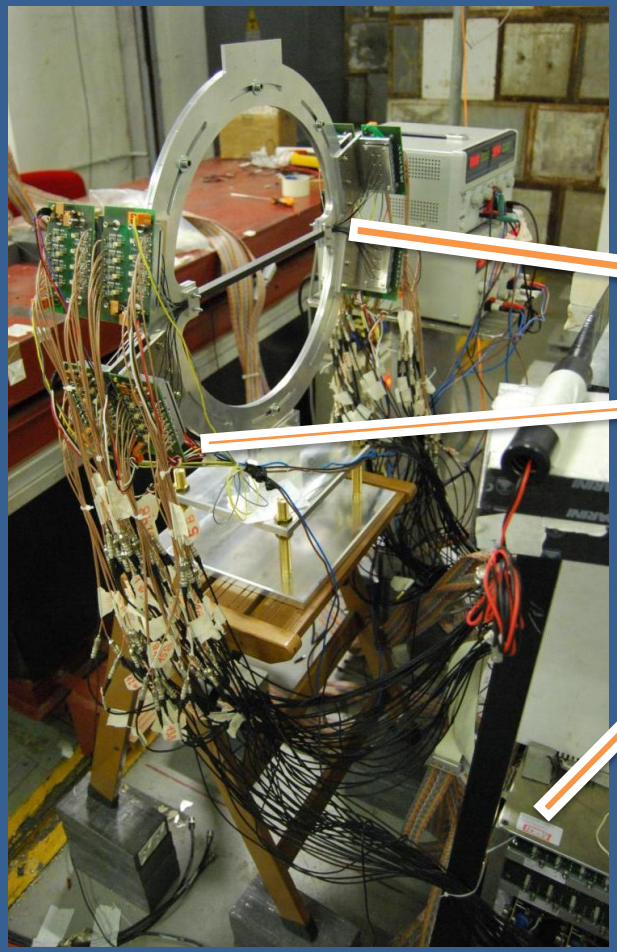
- Readout to be done by MPPC (M




**TPG**



## AMADEUS setup: Trigger system



**New TEST SETUP**

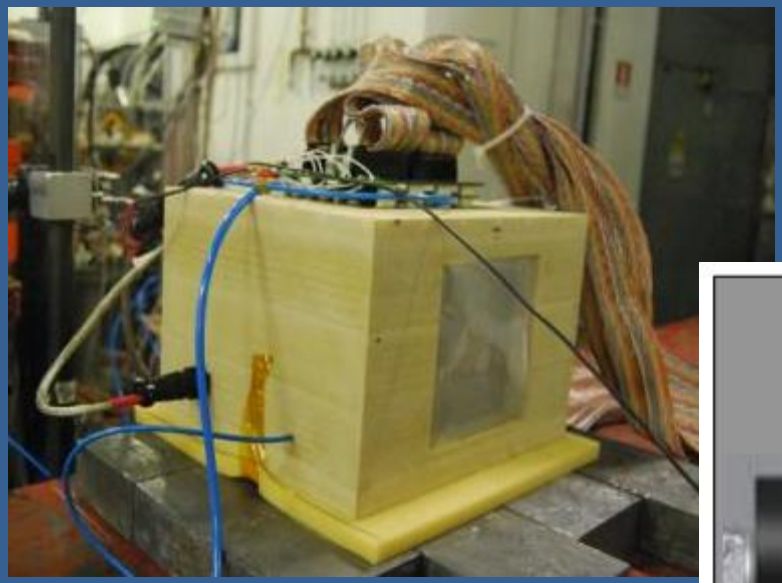
Last week test beam at
BTF in Frascati

2-rings of double layer 16 fibres

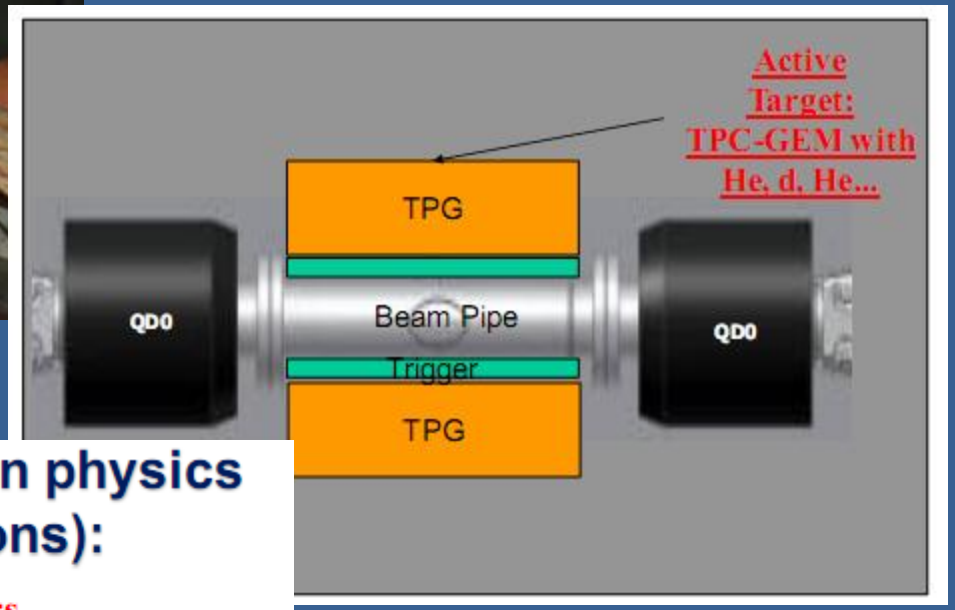
64 fast pre-amplifiers (64x)

2 boards of 32 constant fraction discriminator with zero jitter

## AMADEUS setup: TPG for inner tracking



**Prototype tested last week at BTF**




**AMADEUS for low-energy Kaon physics (scattering and interactions):**

Use of the today's equivalent of bubble chambers
(all previous scattering meas. were done like this):
an Active Target: TPC-GEM filled with with H, d, He..

**THANKS**