AMADEUS status and perspectives

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On behalf of the AMADEUS Collaboration

47th Meeting of the LNF Scientific Committee
Laboratori Nazionali di Frascati
November 14, 2013

Antikaonic
Matter
At
DAΦNE: an
Experiment
Unraveling
Spectroscopy

→ *AMADEUS*

Unprecedented studies of the low-energy kaons interactions in nuclear matter

AMADEUS

Antikaon Matter At DAΦNE: Experiments with Unraveling Spectroscopy

AMADEUS collaboration
116 scientists from 14 Countries and 34 Institutes

LOI: lnf.infn.it/esperimenti/siddharta
and
LNF-07/24(IR) Report on lnf.infn.it web-page (Library)

AMADEUS started in 2005 and
was presented and discussed in all the LNF Scientific Committees

HadronPhysics I3 — Study of Strongly Interacting Matter

HadronPhysics2 — Study of Strongly Interacting Matter

AMADEUS present status

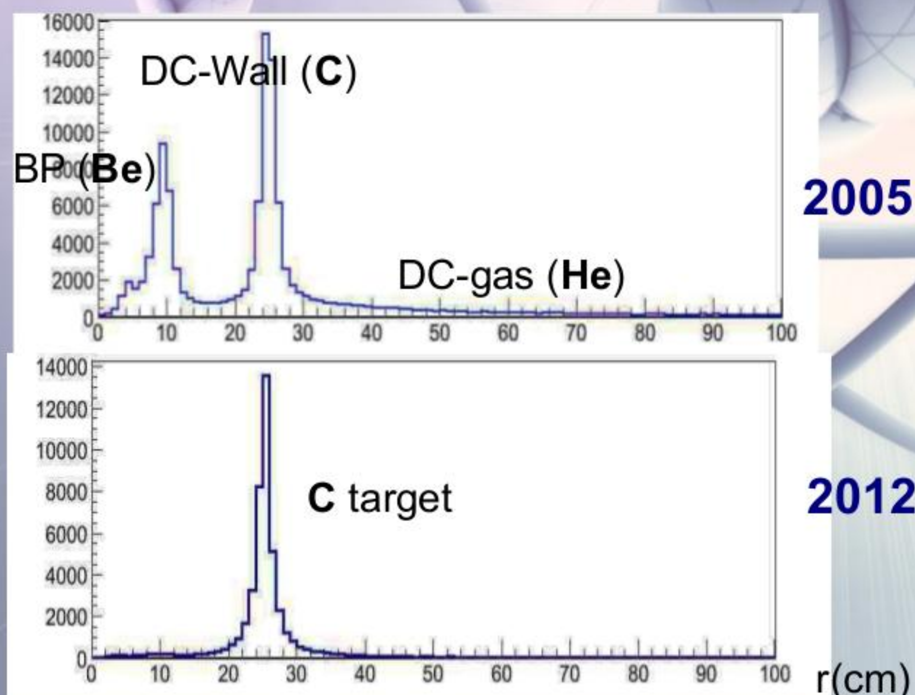
- Analyses of the 2002 – 2005 KLOE data
- Analyses of the dedicated 2012 data with pure carbon target
- R&D for dedicated setup(s)
- Studied channels resulting from the **low-energy K^- interactions** in nuclear matter:
  - Λp from 1NA or 2NA
  - Λd and Λt channels
  - $\Lambda(1405) \rightarrow \Sigma^0\pi^0$
  - $\Lambda(1405) \rightarrow \Sigma^+\pi^-$ ($\Sigma^-\pi^+$)
  - $\Sigma N \rightarrow \Lambda N$
  - study of $\Lambda\pi^-$
  - ……..others ongoing…..

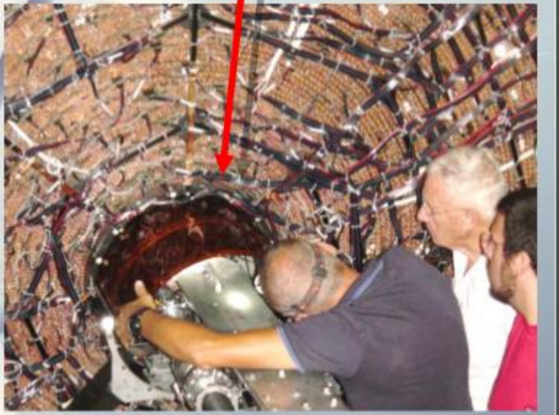
KLOE data on K^- nuclear absorption

Use of two different data samples:

- KLOE data from 2004/2005 (2.2 fb^{-1} total, 1.5fb^{-1} analyzed)
- Dedicated run in november/december 2012 with a Carbon target 4/6 *mm* thickness (~90 pb^{-1}; analyzed 37 pb^{-1}, x1.5 statistics)

Position of the K^- hadronic interaction inside KLOE:





(Slides from the talk of Kristian Piscicchia at ECT* Trento, Oct. 2013)

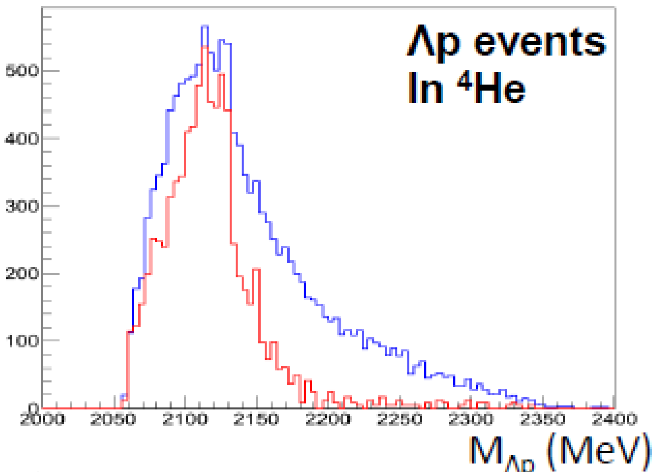
Λp analysis

-Competing processes:

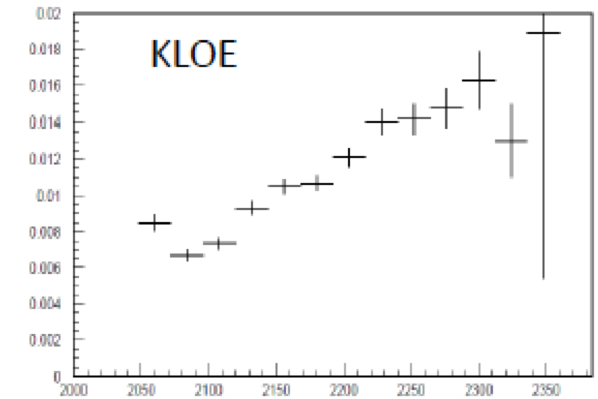
1NA: **$K^-N \rightarrow \Lambda\pi^-$** (N from residual nucleus)

2NA: **$K^-NN \rightarrow \Lambda N$** (pionless)

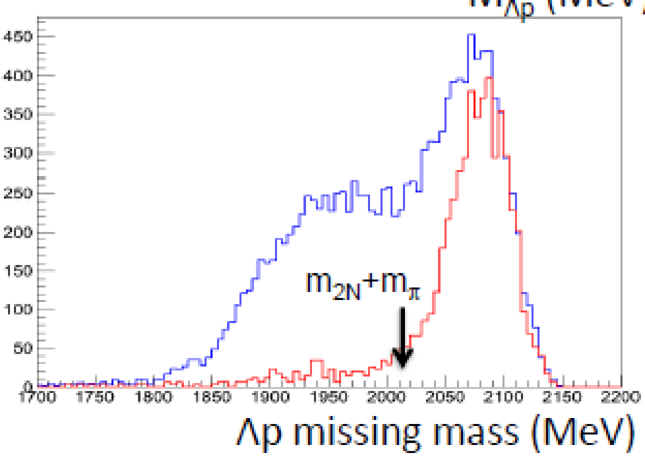
A perfect disentanglement between single and multi-nucleon absorption can be achieved thanks to the **nice acceptance:**



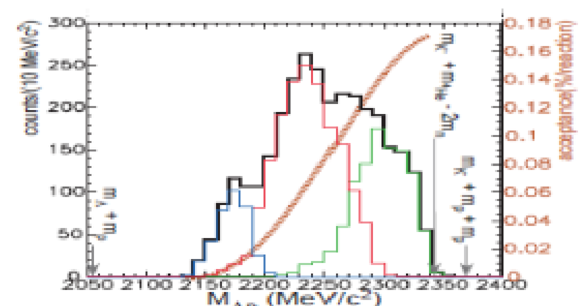
Λp all events
$\Lambda\pi^-$(p) events
(arbitrary normalization)



Acceptance in $M_{\Lambda p}$ (MeV)
(arbitrary normalization)



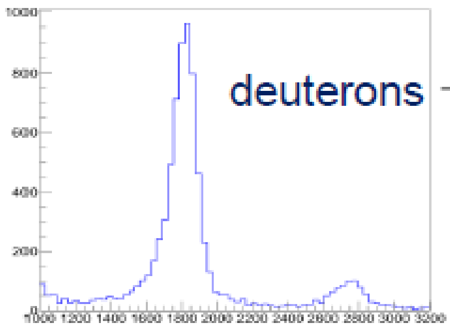
The Λp missing mass for the $\Lambda\pi^-$(p) events lies exactly In the 2N+π^- mass region



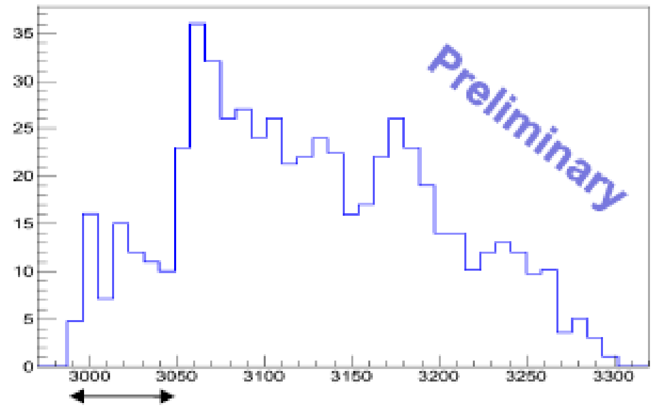
KEK-E549
Mod.Phys.Lett.A23, 2520 (2008)

Λd, Λt analyses

- Search for signal of bound states in the **Λd** channel. Candidate to be a **K^-ppn** cluster. Observed spectra from FINUDA and KEK again showing possible bound states in the in the high invariant mass region.



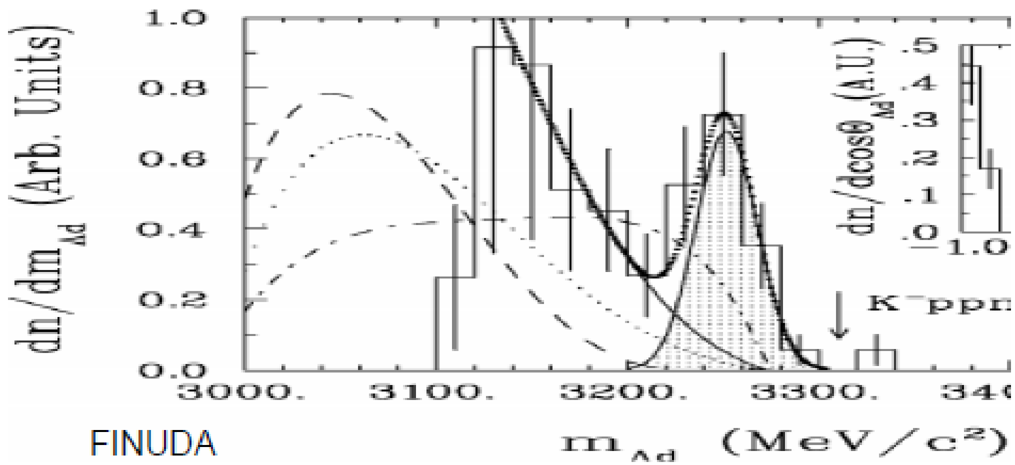
TOF Particle Mass (MeV)



low accept. region

$M_{\Lambda d}$ (MeV)

Λd events
In ^{4}He



FINUDA
Nucl.Phys.A835, 43 (2010)

$\Sigma^0 \pi^0$ channel

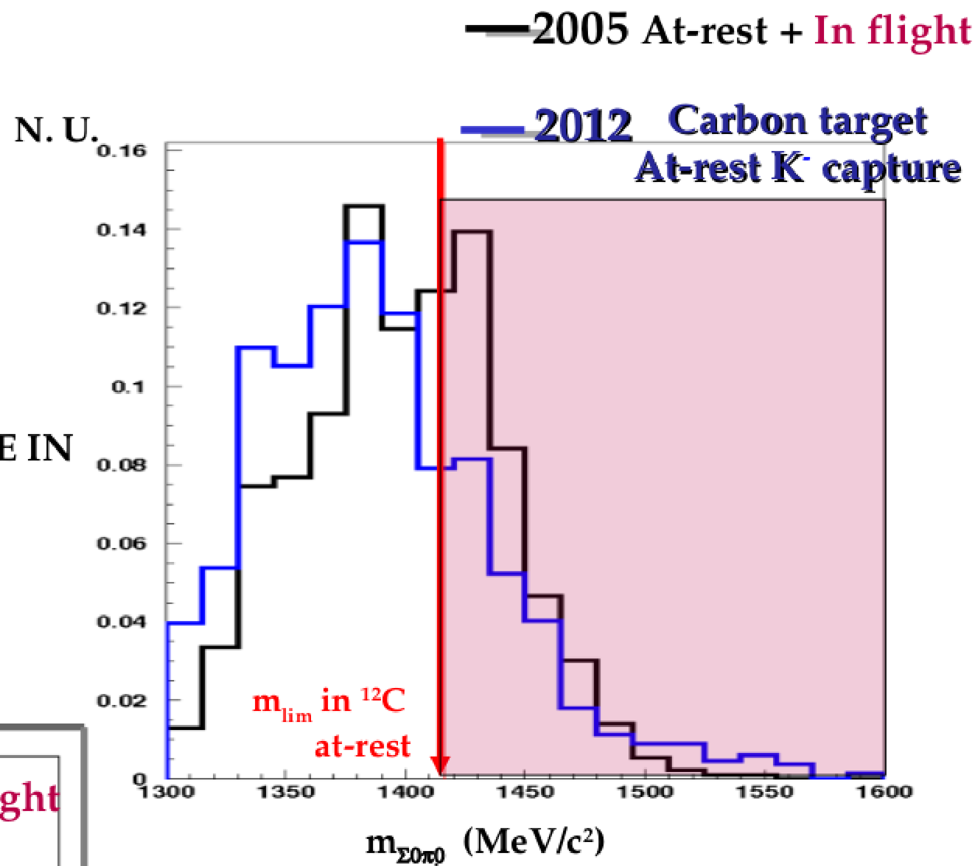
- Pure isospin I = 0

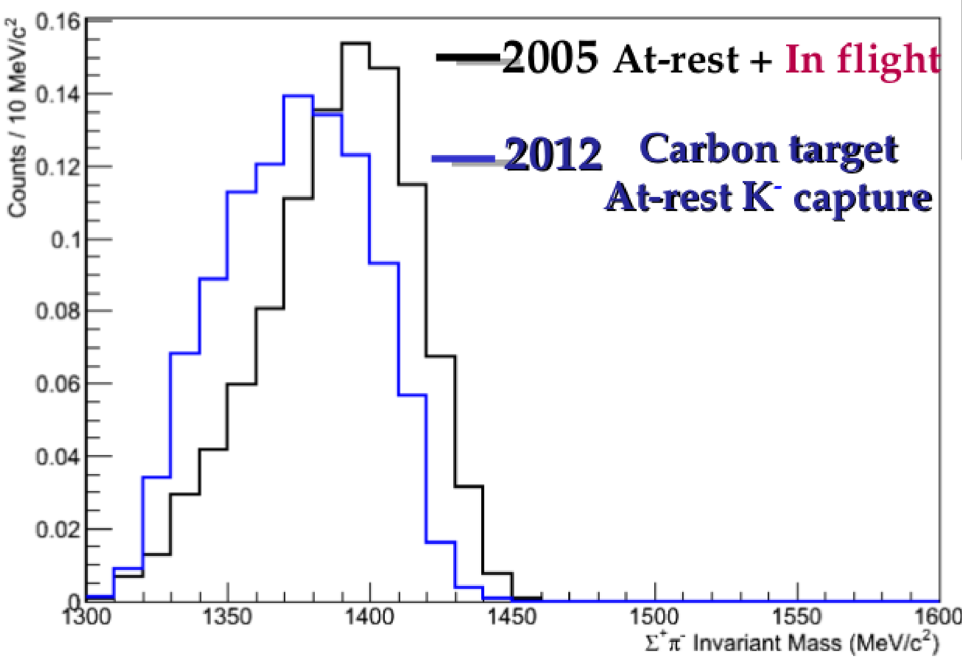
(I=1 contamination = (3±1) %)

- In-flight component … FIRST EVIDENCE IN

$\Sigma\pi$ MASS SPECTROSCOPY

open a higher invariant mass region





$\Sigma^+ \pi^-$ channel

- Excellent acceptance & resolution

hadronic background suppression (≈ 1%)

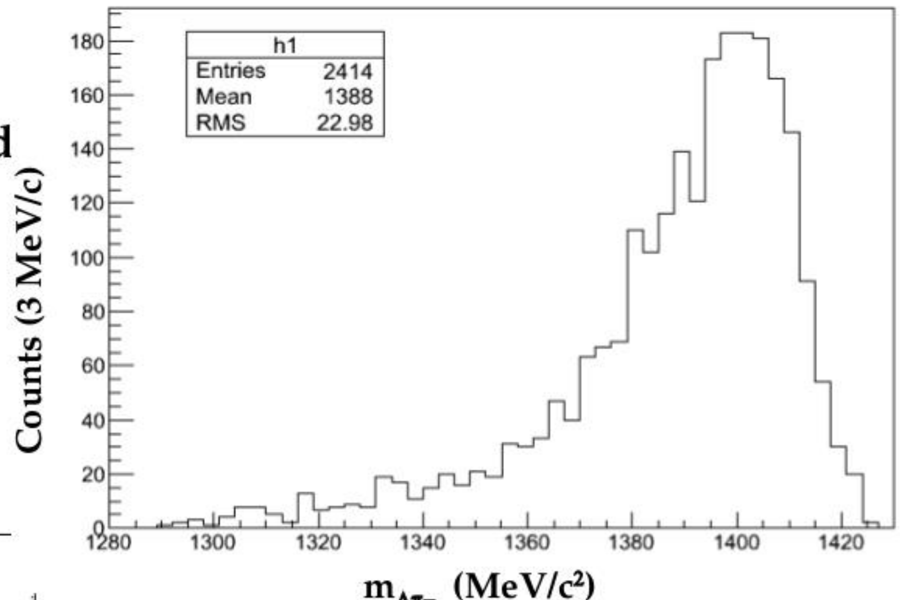
Next step: $\Sigma^+ \pi^-$ channel → in medium modification of Σ^* & Λ^* properties!

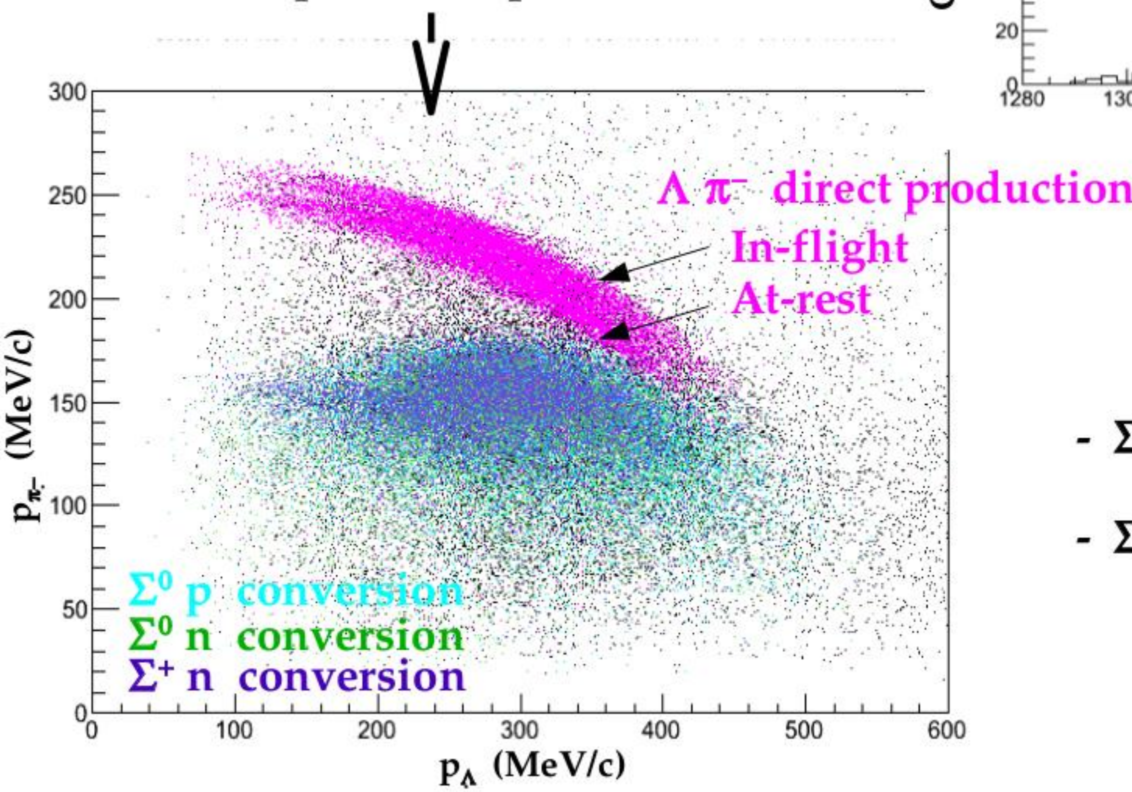
First measurement of the non-resonant $|f^{N\text{-}R}_{\Lambda\pi}|$ transition amplitude

- excellent mass resolution $\sigma_{m\Lambda\pi} \approx 1\ MeV/c^2$

- S-wave vs P-wave calculations performed by Prof. S. Wycech

- possibility to disentangle direct $\Lambda\pi^-$ production from internal conversion (Σ p/n $\rightarrow$ Λ p/n)





Next steps:

- $\Sigma^0\pi^-$ channel $\rightarrow$ $|f^{N\text{-}R}_{\Sigma\pi}|$ I=1

- $\Sigma^+\pi^- / \Sigma^+\pi^-$ $\rightarrow$ isospin interference term

First studies of the KLOE data have shown the excellent capability of the KLOE detector to perform AMADEUS physics

Experimental programme of AMADEUS

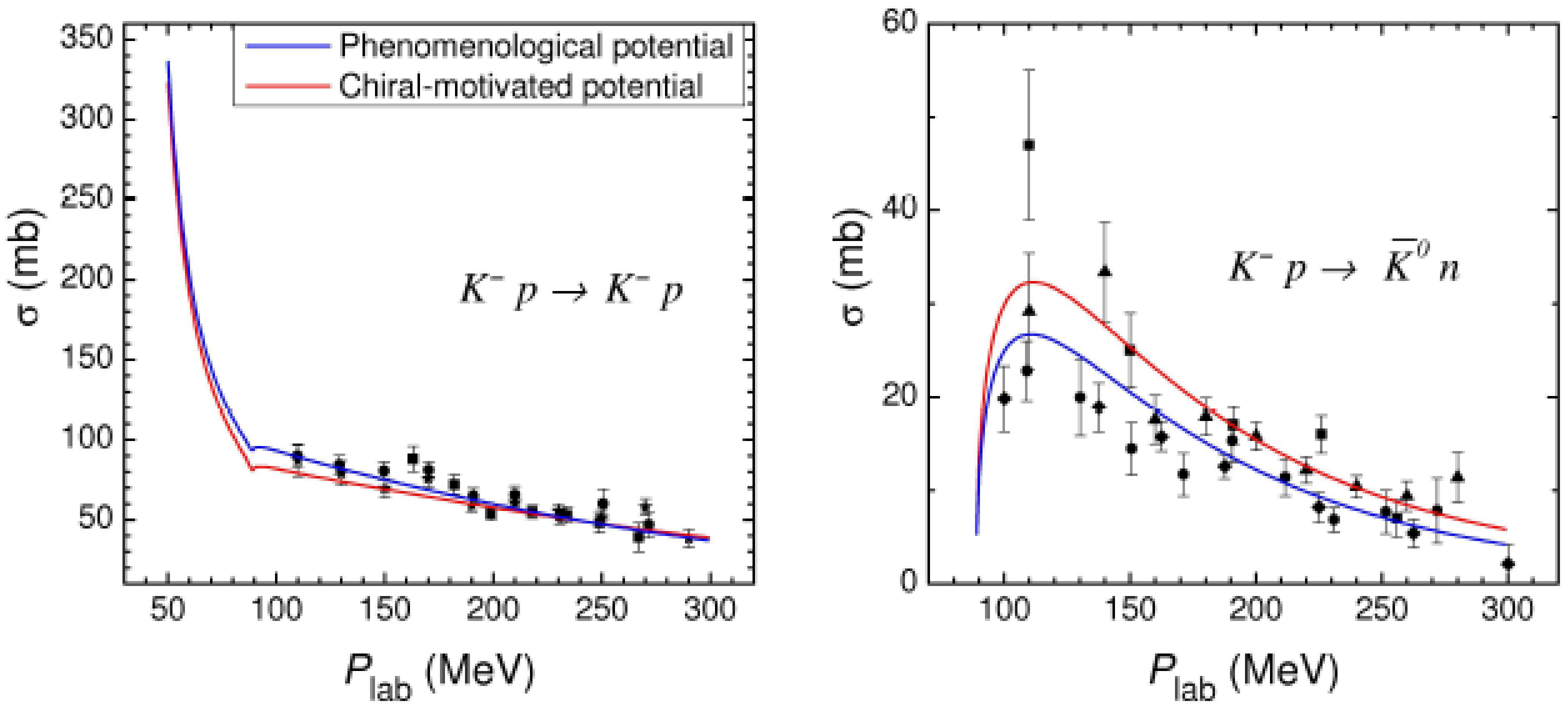
Unprecedented studies of the low-energy charged kaons interactions in nuclear matter: solid and gaseous targets (d, ^{3}He, ^{4}He) in order to obtain unique quality information about:

- Settle the nature of the controversial Λ(1405)
- Low-energy charged kaon scattering and cross sections for momenta lower than 100 MeV/c (missing today)
- Possible existence of kaonic nuclear clusters (deeply bound kaonic nuclear states)
- Interaction of K^- with one and two nucleons.
- Many other processes of interest in the low-energy QCD in strangeness sector -> **implications from particle and nuclear physics to astrophysics** (structure of neutron stars)

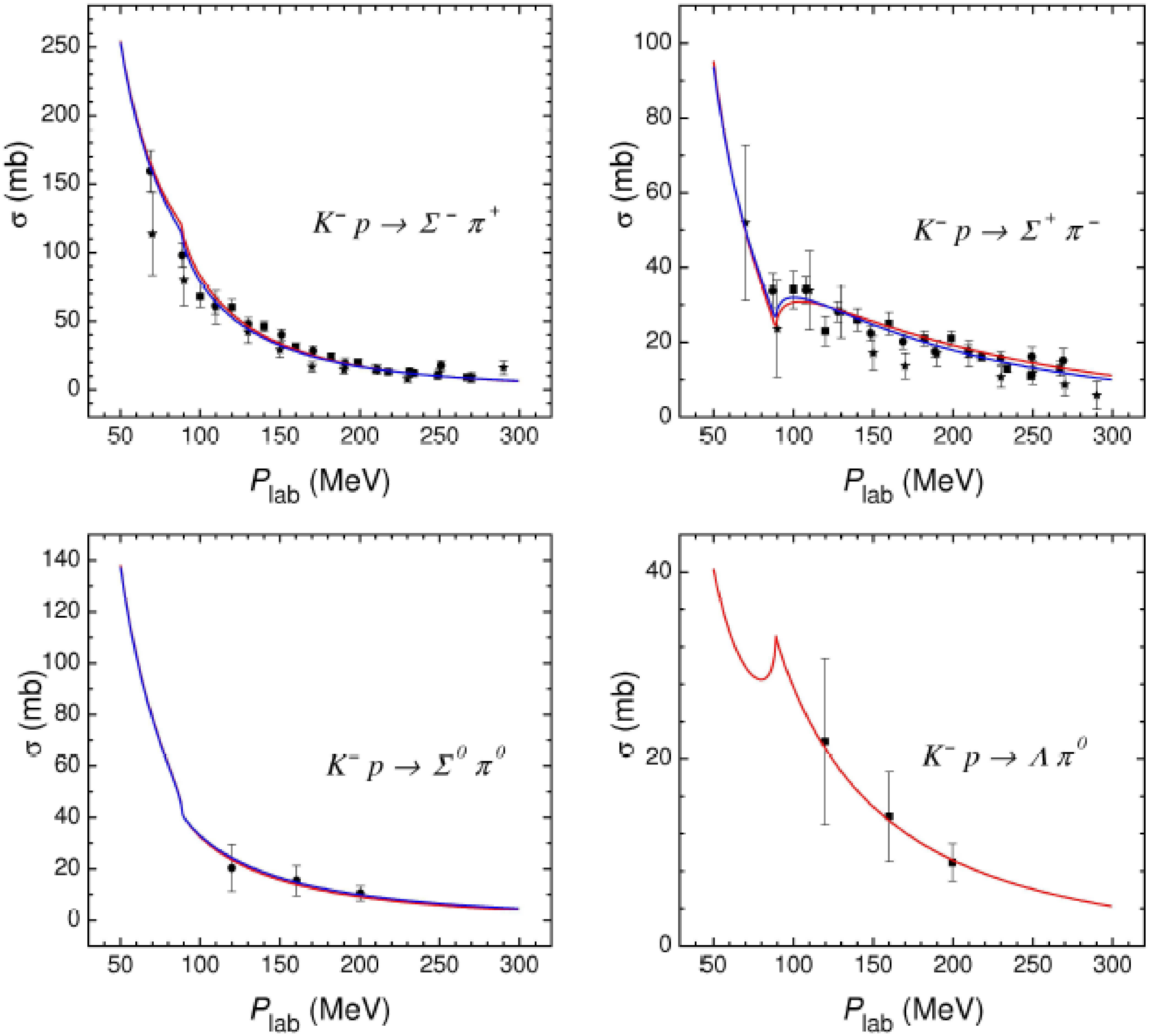
Experimental programme of AMADEUS
Scattering & Cross sections

Comparison with experimental data on $K^- p$ cross-sections

phenomenological and chiral-motivated potentials



Experimental programme of AMADEUS
Cross sections



(continuation)

K^-pp nuclear cluster

+ Kaonic nuclei

- Deeply bound state by strong interaction.
- Strong attraction of the I =0 $\bar{K}N$ interaction $(\bar{K}N^{I=0})$ plays an important role in kaonic nuclei.

SIDDHARTA

+ K^-pp bound state

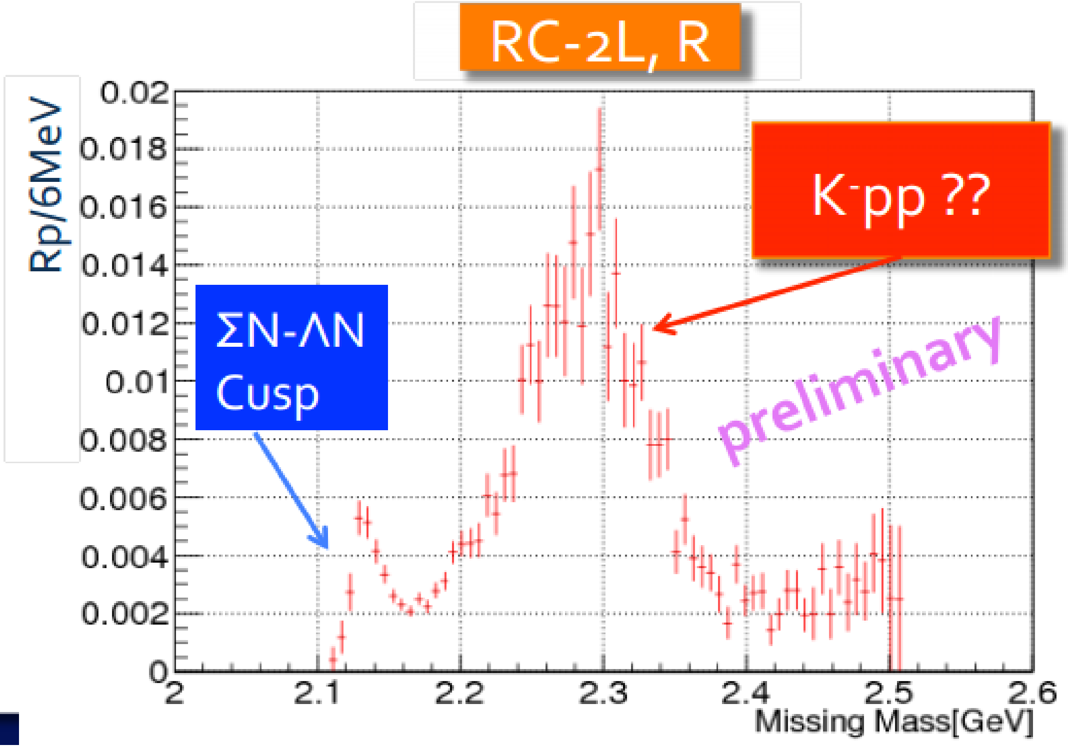
- The simplest kaonic nuclei.
- Theoretical prediction of B.E. and Γ depend on the $\bar{K}N$ interaction and the calculation method .

	Theoretical prediction	B.E (MeV)	Γ (MeV)
PRC76, 045201 (2002)	T. Yamazaki and Y. Akaishi	48	61
arXiv:0512037v2[nucl-th]	A. N. Ivanov, P. Kienle, J. Marton, E. Widman	118	58
PRC76, 044004 (2007)	N. V. Shevchenko, A. Gal, J. Mares, J. Revai	50~70	~100
PRC76, 035203 (2007)	Y. Ikeda and T. Sato	60~95	45~80
NPA804, 197 (2008)	A. Dote, T. Hyodo, W. Weise	20±3	40~70
PRC80, 045207 (2009)	S. Wycech and A. M. Green	56.5~78	39~60
PRL B712, 132-137 (2012)	Barnea et al.	15.7	41.2

K⁻pp – E27 (J-PARC), Hadron2013, Nara

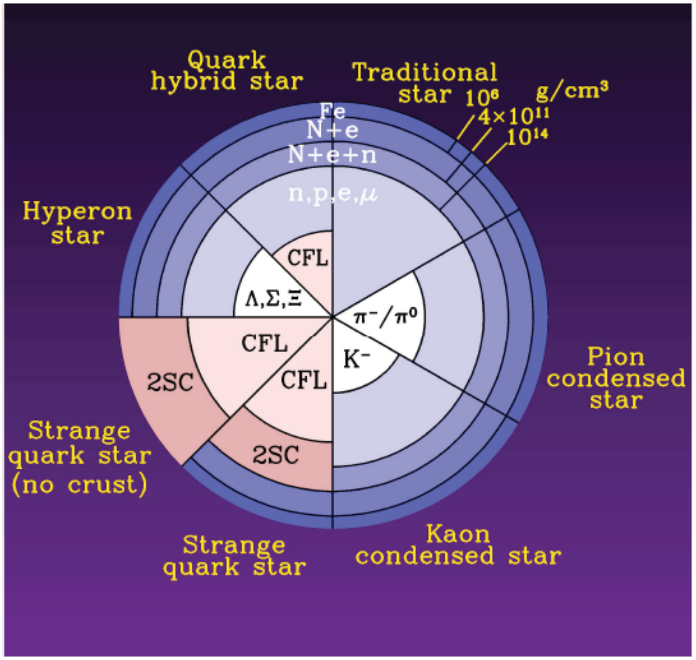
Proton Coincidence

- RC-2L, R are almost free from QF backgrounds.
- Excess due to ΣN-ΛN cusp is clearly observed around 2.13GeV.
- Broad Enhancement is observed around 2.3GeV.
  - There is a proton emitting source involving two nucleons (non quasi free) in high emission probability.
  - A broad resonance such as K^-pp is a candidate.



NEUTRON STARS and the EQUATION OF STATE of DENSE BARYONIC MATTER

J. Lattimer, M. Prakash: Astrophys. J. 550 (2001) 426

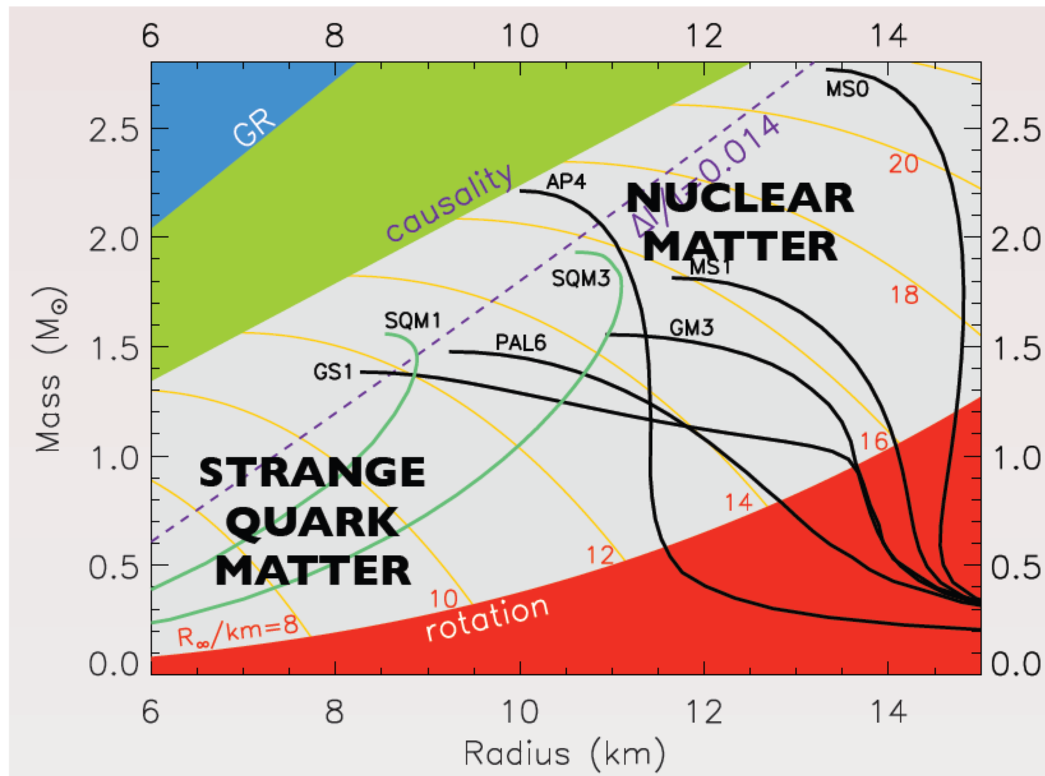


- Neutron Star Scenarios

$$\frac{dP}{dr} = -\frac{G}{c^2}\frac{(M + 4\pi P r^3)(\mathcal{E} + P)}{r(r - GM/c^2)}$$

$$\frac{dM}{dr} = 4\pi r^2 \frac{\mathcal{E}}{c^2}$$

- Mass-Radius Relation



New constraints from NEUTRON STARS

A two-solar-mass neutron star measured using Shapiro delay

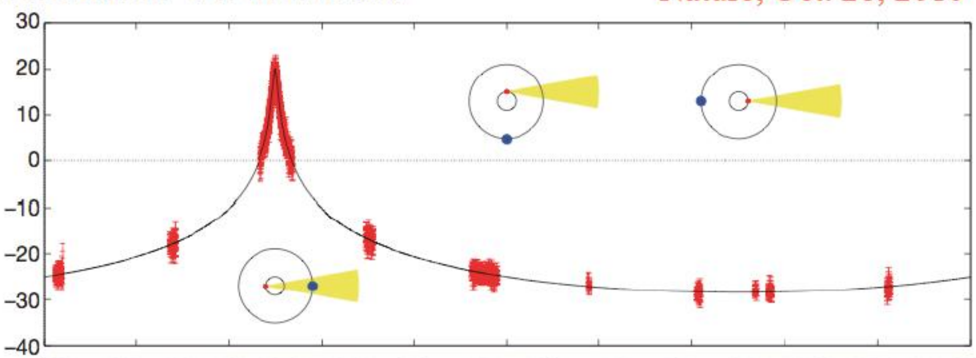
P. B. Demorest[1], T. Pennucci[2], S. M. Ransom[1], M. S. E. Roberts[3] & J. W. T. Hessels[4,5]

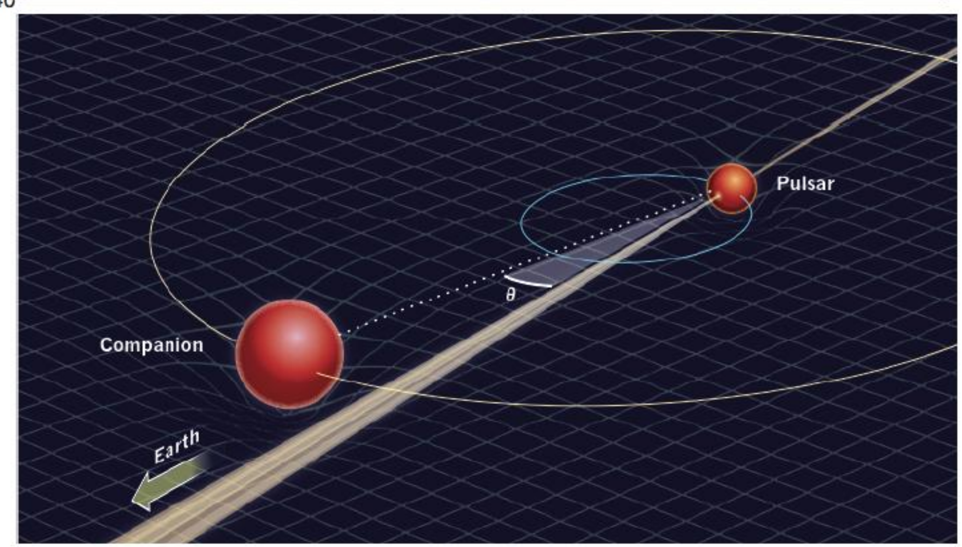
Nature, Oct. 28, 2010

direct measurement of neutron star mass from increase in travel time near companion

J1614-2230
most edge-on binary pulsar known (89.17°)
+ massive white dwarf companion (0.5 M_{sun})

heaviest neutron star with 1.97±0.04 M_{sun}





Experimental programme of AMADEUS &

EOS (Equation Of State) for Nuclear Matter

■ Outer core ($\rho < 2\rho_0$)

How EOS changes in n-rich matter?

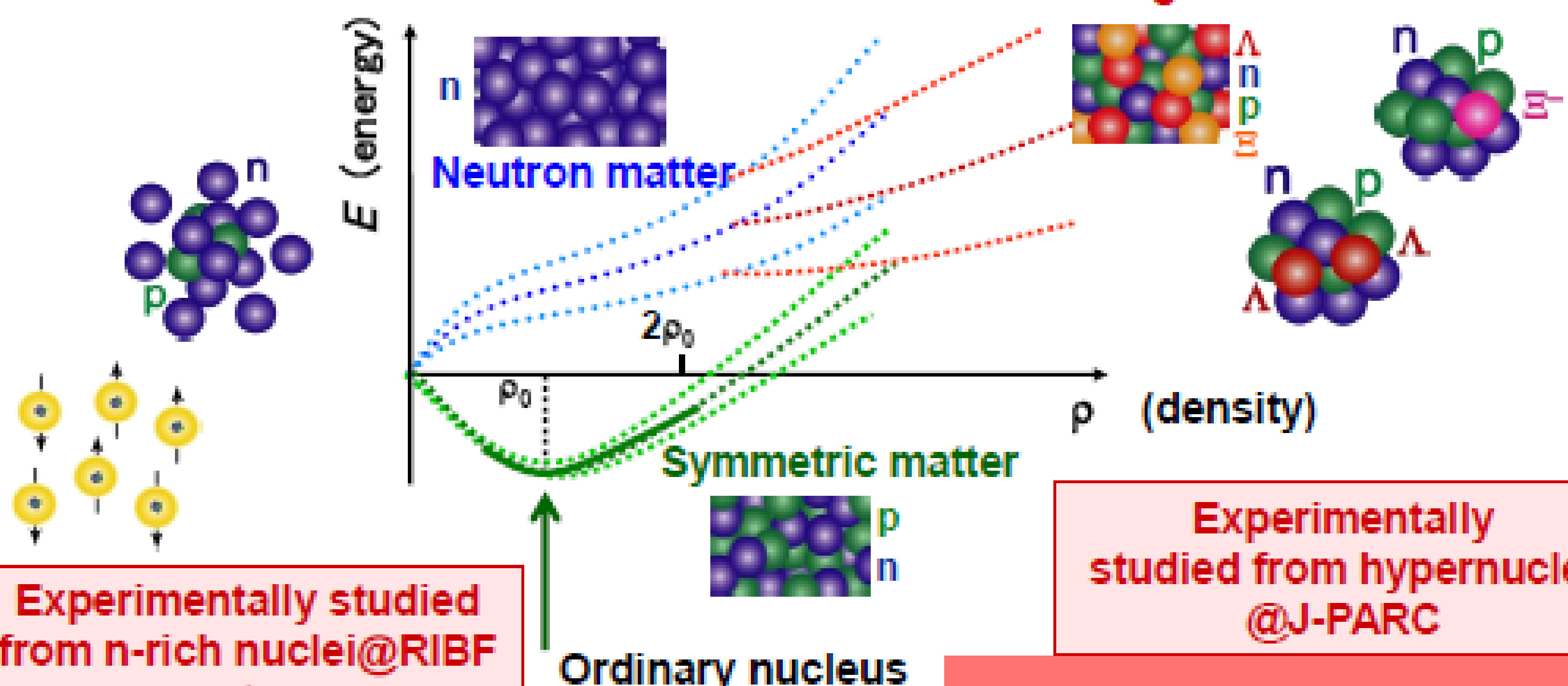
■ Inner core ($\rho > 2\rho_0$)

Hyperon really appear? Which and how much?

Density Fraction

$$E = F(\rho, (n_n, n_p, n_Y))$$

Strange hadronic matter



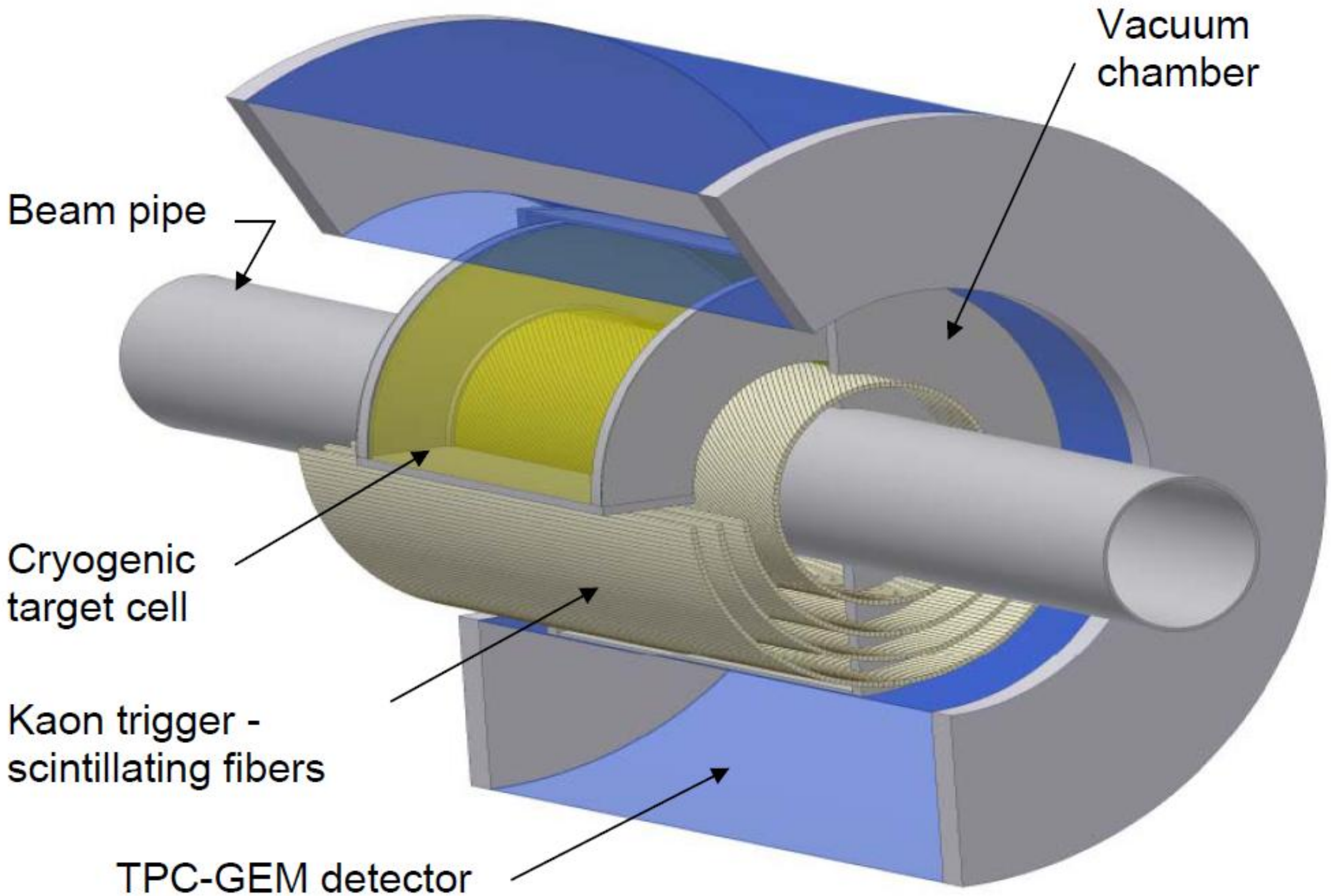
Experimentally studied from n-rich nuclei@RIBF
+
Ultra-cold Fermi gas

Experimentally studied from hypernuclei @J-PARC

Experiments at DAΦNE

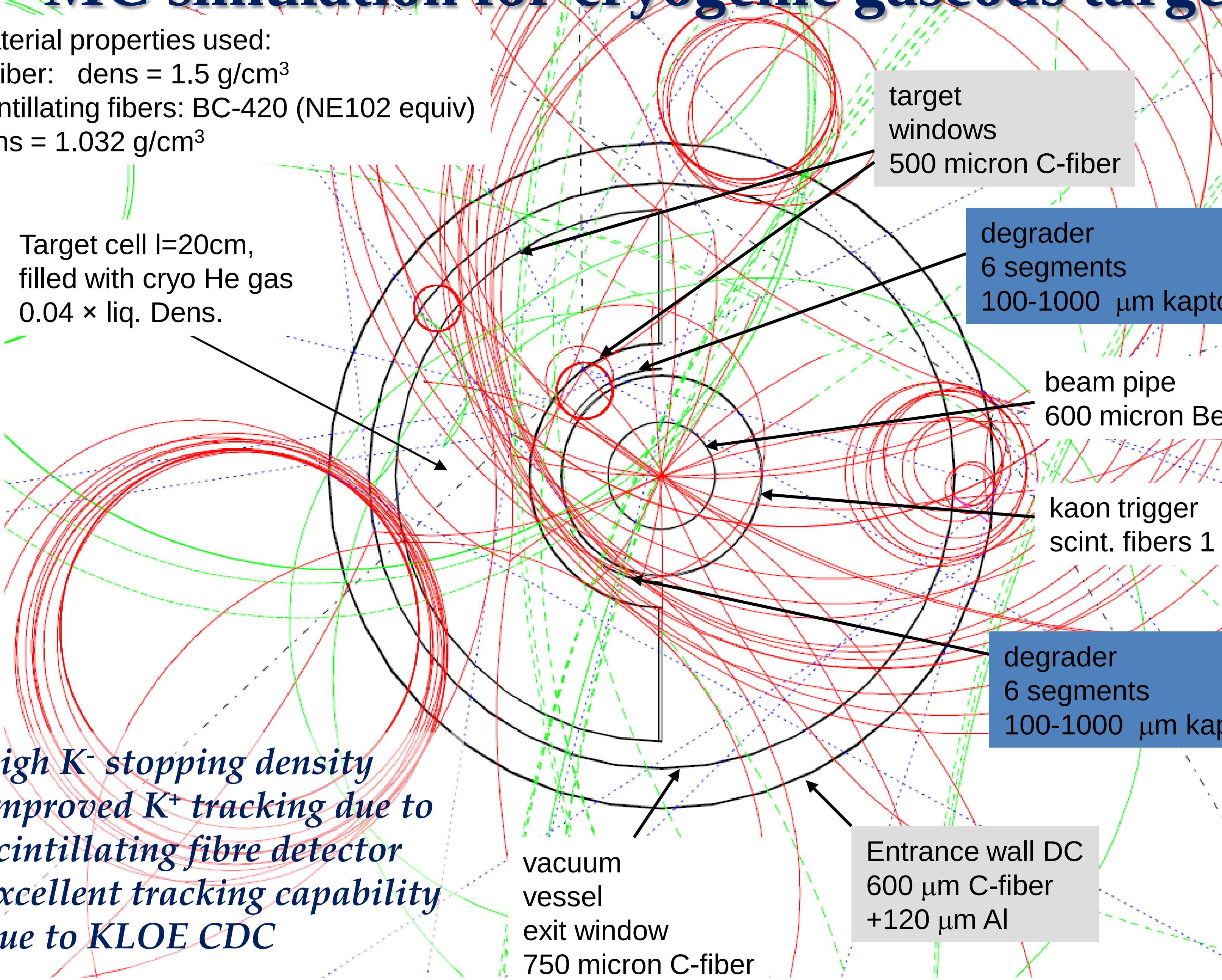
AMADEUS – cryogenic gaseous target

- **cryogenic gaseous target cell**
- **scintillating fibre detector**



MC simulation for cryogenic gaseous target

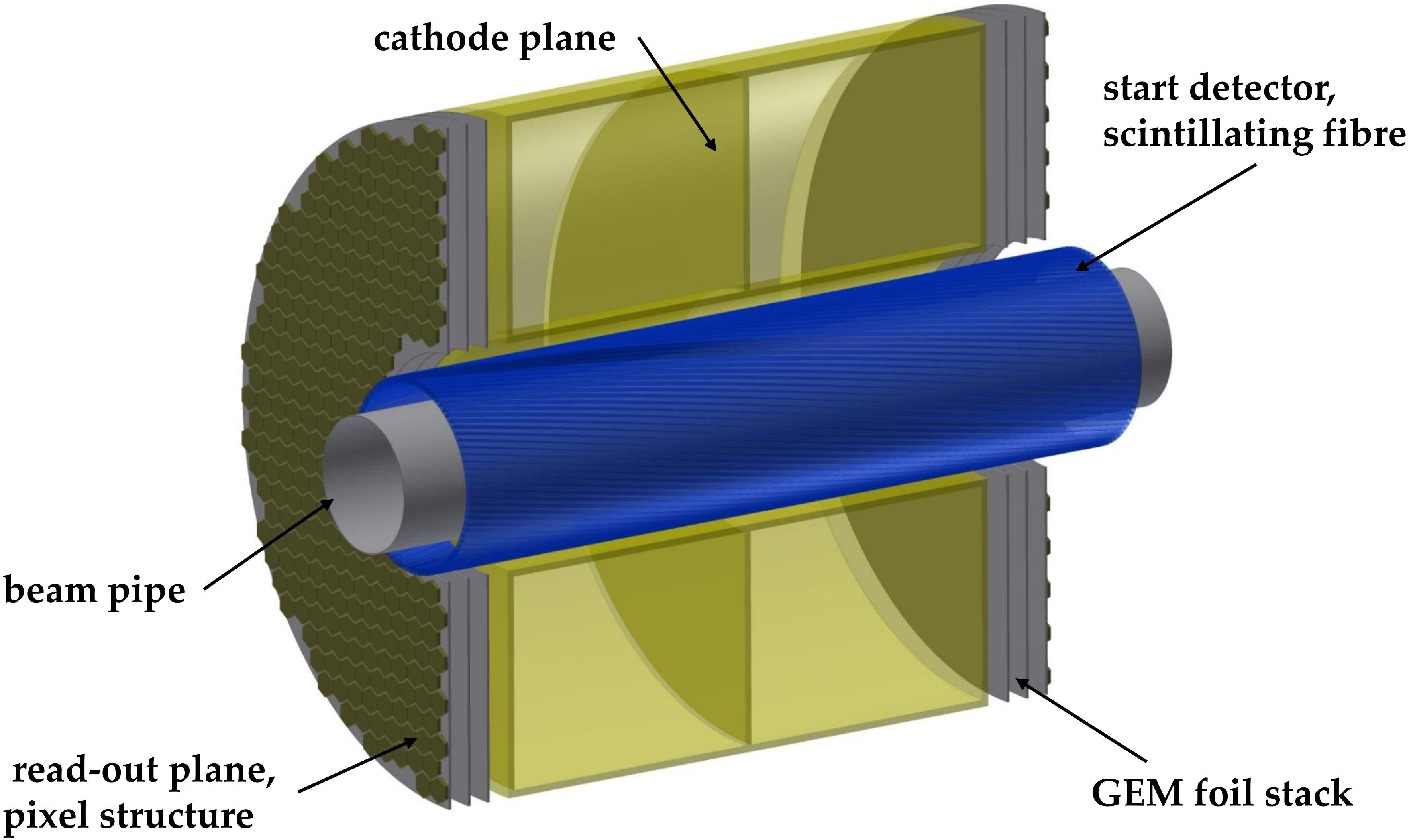
material properties used:
C-fiber: dens = 1.5 g/cm^3
scintillating fibers: BC-420 (NE102 equiv)
dens = 1.032 g/cm^3



- ***high K^- stopping density***
- ***improved K^+ tracking due to scintillating fibre detector***
- ***excellent tracking capability due to KLOE CDC***

AMADEUS – advanced setup

- **active target TPC filled with pure gas with GEM technology, with 2 read-out sides;** R&D work within EU-FP7 HadronPhysics3



Technical papers in 2013;

1) Performances of a GEM-based Time Projection Chamber prototype for the AMADEUS experiment e-Print: arXiv:1302:3054

2) Characterization of a scintillating fibers read by MPPC detectors trigger prototype for the AMADEUS, JINST 8 (2013) T05006;

Forming an international collaboration and going from LOI to TRD

- LNF– INFN, Poli. Milano, other INFN sections
- Stefan Meyer Institut für subatomare Physik
- Physikalisches Institut, Universität Heidelberg
- GSI Helmholtzzentrum, Darmstadt
- Physik Department, Technische Universität München
- RIKEN, Japan
- University of Kyoto, Japan
- IFIN-HH Bucharest, Romania
- Univ. Zagreb
- *others*

→ **granted beam time schedule**

Project funding

Potentil Funding Agencies in:

- Germany
- Austria
- Japan
- Romania
- Croatia
- Italy
- EU Horizon 2020

as well as possible EU projects within **Horizon2020**

need a granted beam time schedule!

Conclusions

Analyses of the KLOE data and of dedicated carbon-taregt run have shown the excellent capability of the KLOE detector to perform AMADEUS-like physics

- *dedicated beam time schedule for AMADEUS is necessary for:*
  - *forming an international collaboration*
  - *funding for detector upgrade and personnel*