Strangeness production with stopped antiprotons

J. Zmeskal / E. Widmann

Stefan Meyer Institute, Vienna

FLAIR Workshop, Heidelberg, 15.5.2014

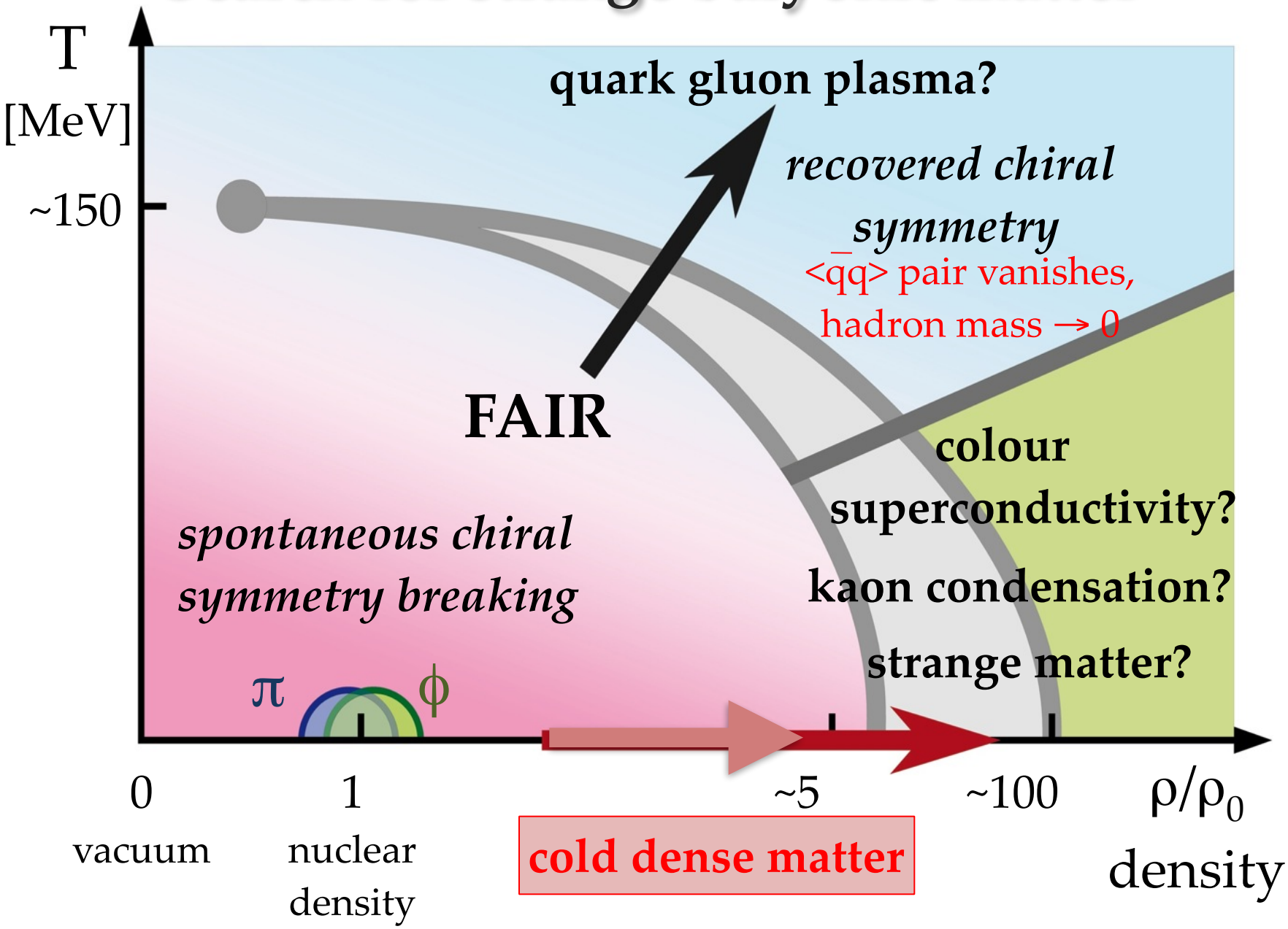
Introduction

- Search for (deeply) bound bound baryonic matter with strangeness, ongoing or planned at several facilities - *LNF, GSI, J-PARC and (FLAIR) FAIR*

- Strangeness production S=-2 with stopped antiprotons

- **pbar-4pi @ FAIR** high intensity low-energy antiproton beam and detector system to investigate strangeness production in antiproton annihilation

Search for strange baryonic matter



Motivation

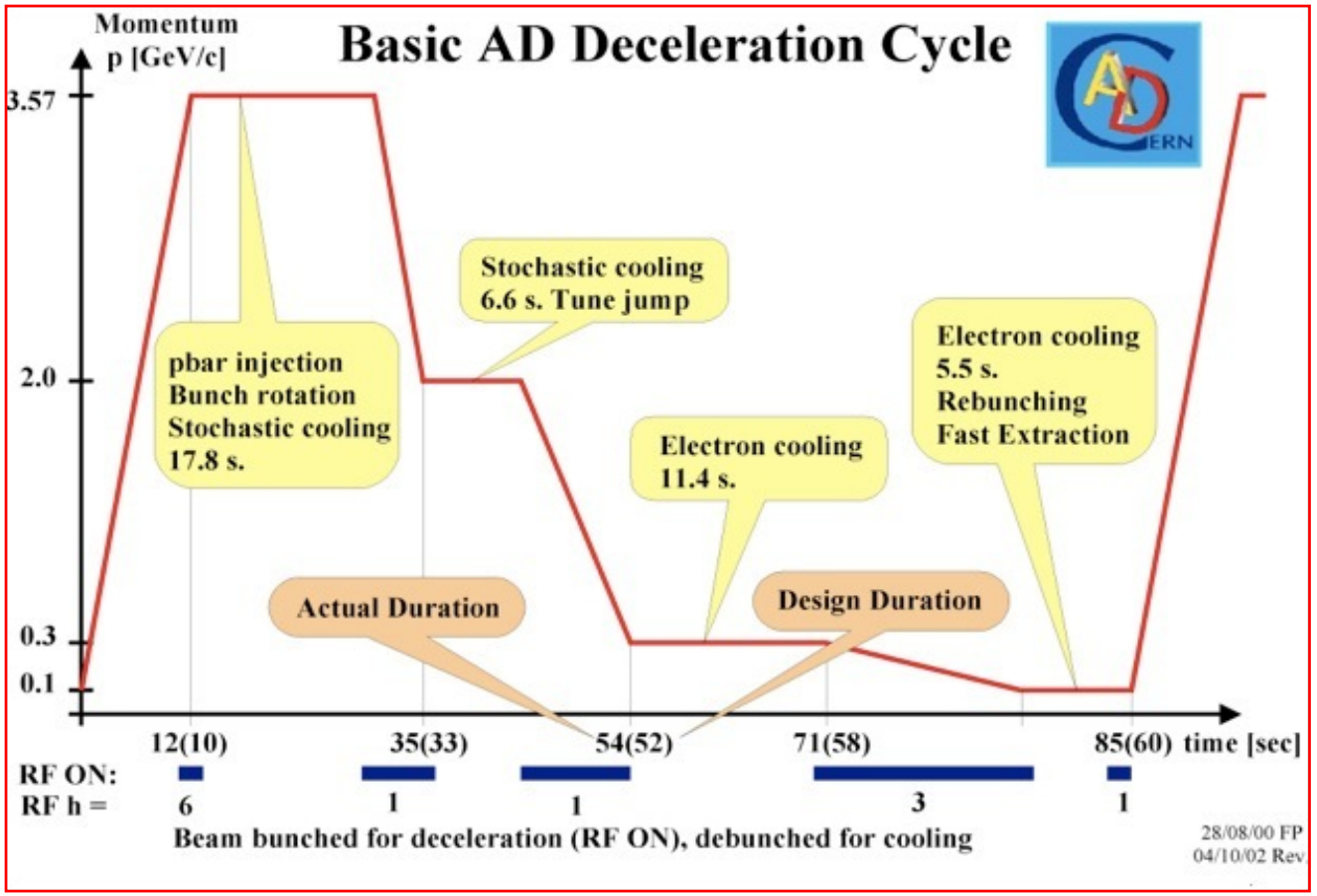
Methods to produce (dense) baryonic matter with strangeness

- stopped K^- reactions
- in-flight K^- reactions
- protons on proton (or light nuclei)
- heavy ion collisions
- strangeness production in antiproton annihilation

at CERN/AD & ELENA ?

No slow extraction foreseen, so space for large detector

AD since 2000, ELENA 2017~



- All-in-one machine:
  - Antiproton capture
  - deceleration & cooling
  - AD: 100 MeV/c (5.3 MeV)
  - ELENA: 100 keV

- Pulsed extraction
- 2-4 x 10^7 antiprotons per pulse of 100 ns length
- 1 pulse / 85–120 seconds

Search for double strangeness production in antiproton annihilation at J-PARC

Letter of Intent for J-PARC

Double Anti-kaon Production in Nuclei by Stopped Anti-proton Annihilation

dated on 17 / 06 / 2009

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Abstract

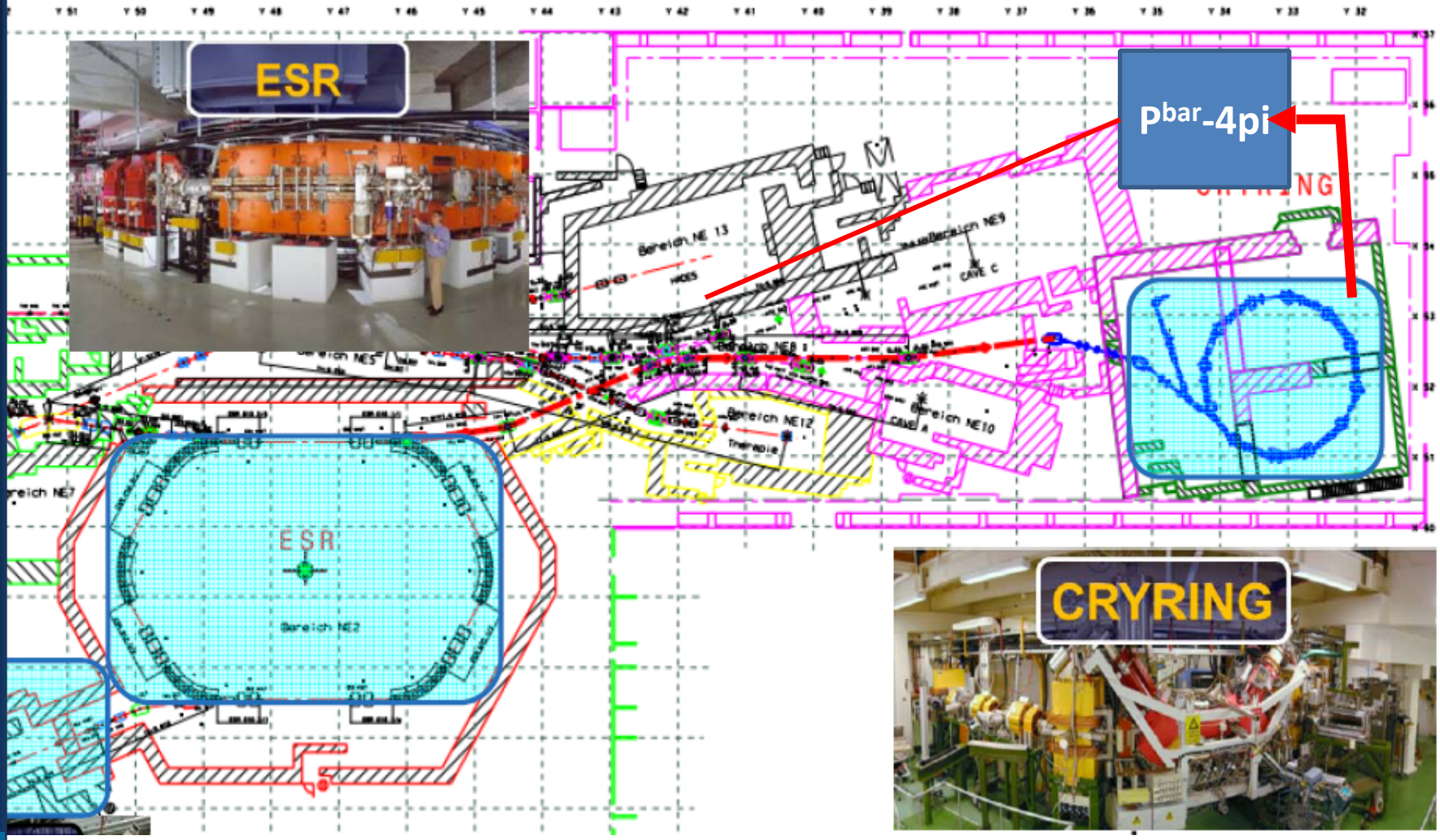
We propose to search for double strangeness production by $\bar{p}$ annihilation on helium nuclei at rest. The proposed experiment will provide significant information on double strangeness production and double strangeness cluster states.

- secondary beam produced at several 100 MeV/c
- maximum beam intensity needed
- large losses when stopping by degrader

GSI - FAIR


SIS100/300
p-LINAC
SIS18
UNILAC
ESR
HESR
CBM
Rare Isotope
Production Target
Super-FRS
PANDA
Antiprotons
Plasma Physics
Atomic Physics
Antiproton
Production Target
FLAIR
RESR/
CR
NESR
N

CRYRING and ESR a perfect match for low-energy antiprotons



Antiproton annihilation at FAIR

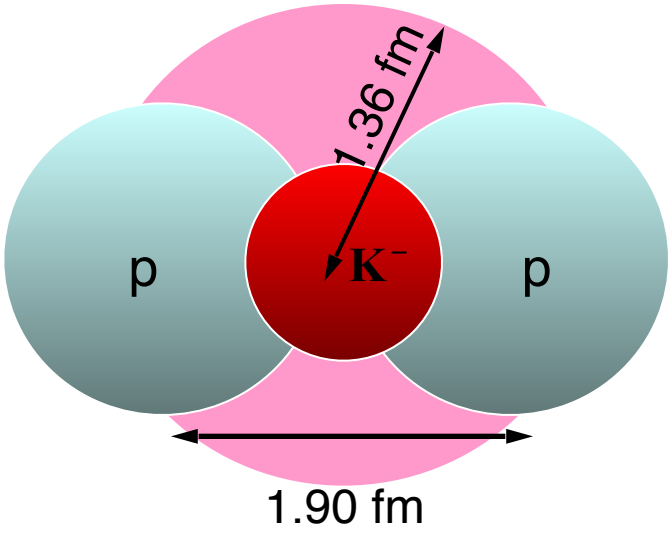
Experimental studies of double-strangeness production with a low-energy antiproton beam

at FAIR with FOPI

Search for dense baryonic matter with double-strangeness

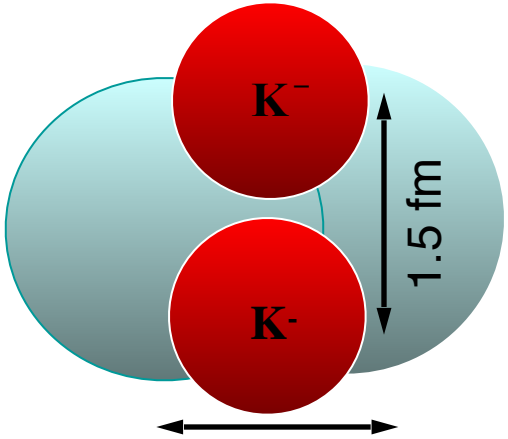
Antikaon bound nuclear cluster

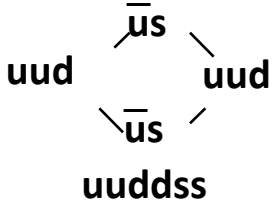
ppK⁻



Strange deuteron?

ppK⁻ K⁻





Jaffe's H* di-baryon?

Antiproton annihilation

OBELIX ('86~'96) [Nucl. Phys., **A797**, 109 (2007).]

- $\bar{p}^4$He annihilation
- stopped $\bar{p}$ @ CERN/LEAR
- gas target (^{4}He@NTP, H_2@3atm)
- **cylindrical spectrometer**
- spiral projection chamber, scintillator barrels, jet-drift chambers
- $2.4 \times 10^5 / 4.7 \times 10^4$ events of 4/5-prong in ^{4}He
- **p_{min} = 100/150/300MeV/c for π/K/p**

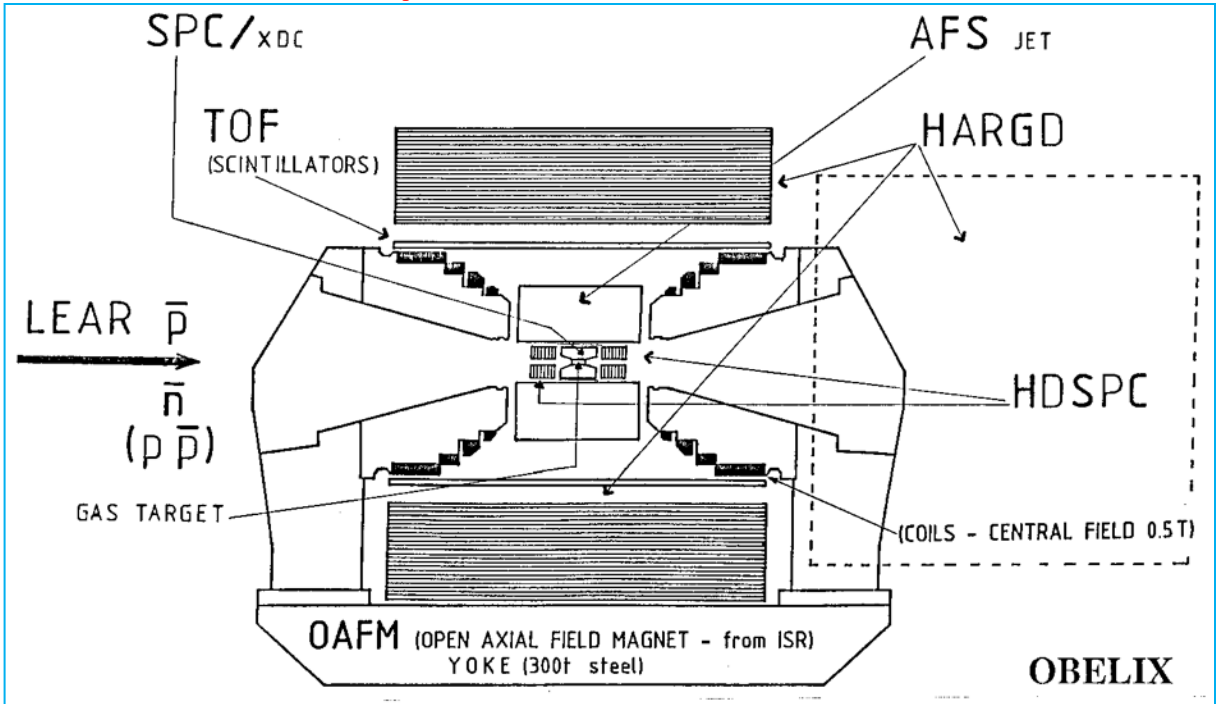


Fig. 1.1 OBELIX detector: schematic view

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Signal of bound states ?

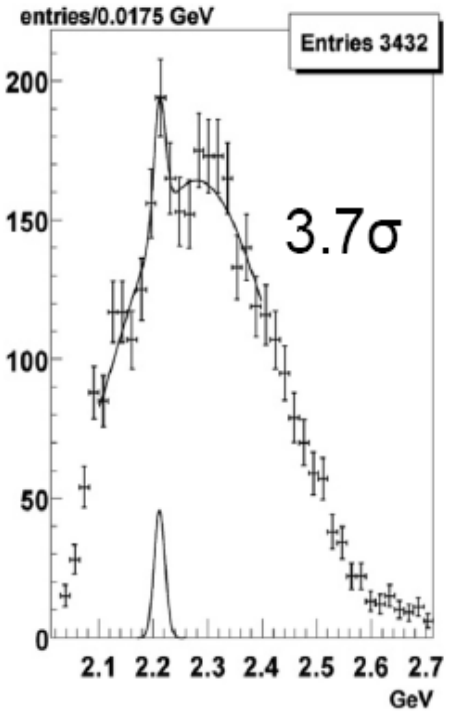
Antiproton annihilation

OBELIX data

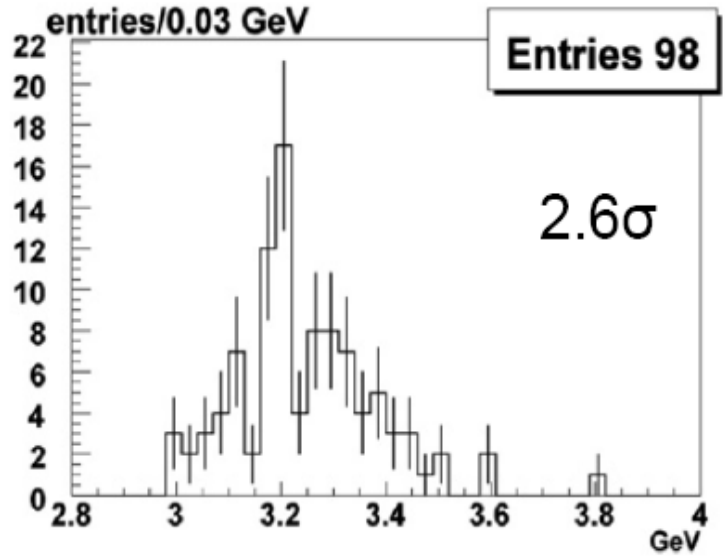
$$\bar{p} + {}^4He \rightarrow ppnK^- + K^0$$

$$ppnK^- + K^0 \rightarrow \Lambda^0 + d + K^0$$

Λp invariant mass



Λd invariant mass



G. Bendiscioli, et al., Nuclear Phys. A 789 (2007) 222

m = (2212.1±4.9) MeV
B.E. = −(160.9±4.9) MeV
Γ < (24.4±8.0) MeV $1.5 \cdot 10^{-4}$

m = (3190±15) MeV
B.E. = −(121±15) MeV
Γ < 60 MeV $0.4 \cdot 10^{-4}$

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OBELIX (CERN/LEAR) data for double strangeness production

S=−2 strangeness production in $\bar{p}^4He$ annihilations at rest

G. Bendiscioli, T. Bressani, *L. Lavezzi, A. Panzarasa and P. Salvini*

channel	events	yield (10^{-4})
$K^+K^+\Sigma^-\Sigma^-p_s$	34+/-8	0.17+/−0.04
$K^+K^+\Sigma^-\Sigma^+n\pi^-$	36+/−6	2.71+/−0.47
$K^+K^+\Sigma^-\Lambda n$	16+/−4	1.21+/−0.29
$K^+K^+K^-\Lambda nn$	4+/−2	0.28+/−0.14

Antiproton annihilation

ELSEVIER

14 October 1999

PHYSICS LETTERS B

Physics Letters B 464 (1999) 323–330

Double strangeness production in $\bar{p}Xe$ annihilation at low energy

DIANA Collaboration

V.V. Barmin [a], V.G. Barylov [a], V.S. Borisov [a], G.V. Davidenko [a], A.G. Dolgolenko [a], C. Guaraldo [b], V.A. Matveev [a], G.S. Mirosidi [a], K. Myklebost [c], M. Olsen [c], C. Petrascu [b,1], V.A. Shebanov [a], N.N. Shishov [a], A.A. Sibirtsev [d], L.I. Sokolov [a], B.S. Volkov [a], N.K. Zombkovskaya [a]

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33 double kaon events were found
yield ~ 10^{-4}

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Strangeness S=−2 production

Antiproton annihilation

We propose to use the antiproton annihilation reaction on light nuclei to produce and study double-strange nuclei in reactions such as:

$$\bar{p} + p \rightarrow K^- + K^- + K^+ + K^+$$

→ energetically forbidden at rest (−98 MeV)

$$\bar{p} + A \rightarrow K^+ + K^+ + [K^- K^- pp(A-3)]$$

→ bound state formation → E_B ~ 100 MeV

→ 2 K^+ indicate a strong binding of the K^- pair in the nucleus

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Search for antikaon bound systems

performing an "exclusive" measurement

formation process:

$$\bar{p} + {}^4He \rightarrow K^+ + K^0 + X \equiv [ppnK^-K^-]$$

$$\rightarrow K^+ / \pi^+ / \pi^-$$

decay processes:

$$[ppnK^-K^-] \rightarrow n + \Lambda + \Lambda$$

$$\rightarrow n + (p + \pi^-) + (p + \pi^-)$$

$$[ppnK^-K^-] \rightarrow p + \Lambda + \Sigma^-$$

$$\rightarrow n + (p + \pi^-) + (n + \pi^-)$$

$$\rightarrow p / \pi^+ / \pi^- / n$$

How to Measure?

Sakuma et al.
Hyp. Int. 213, 51 (2011).

we focus the reaction:

$$\bar{p} + {}^{3}He \rightarrow K^{+} + K^{0} + X \quad (X = K^{-}K^{-}pp)$$

(although $K^{-}K^{-}pp$ decay modes are not known at all,)

we assume the most energetic favored decay mode:

$$K^{-}K^{-}pp \rightarrow \Lambda + \Lambda$$

final state = $K^{+}K^{0}\Lambda\Lambda$

We can measure the $K^{-}K^{-}pp$ signal **exclusively** by detection of all particles, $K^{+}K^{0}\Lambda\Lambda$, using $K^{0} \rightarrow \pi^{+}\pi^{-}$ mode

wide-acceptance detector is important

Expected Kinematics

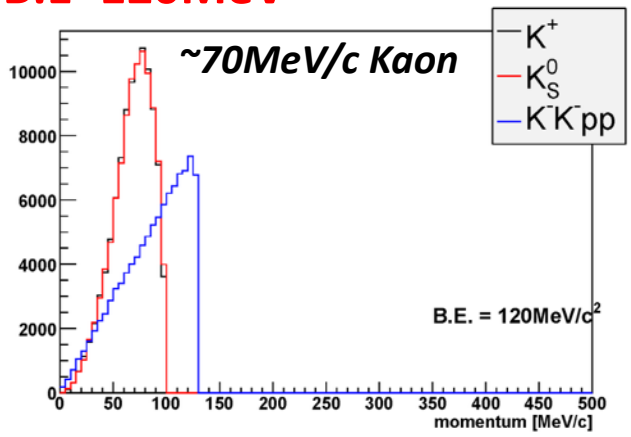
Sakuma et al.
Hyp. Int. 213, 51 (2011).

K^+K^0X momentum spectra

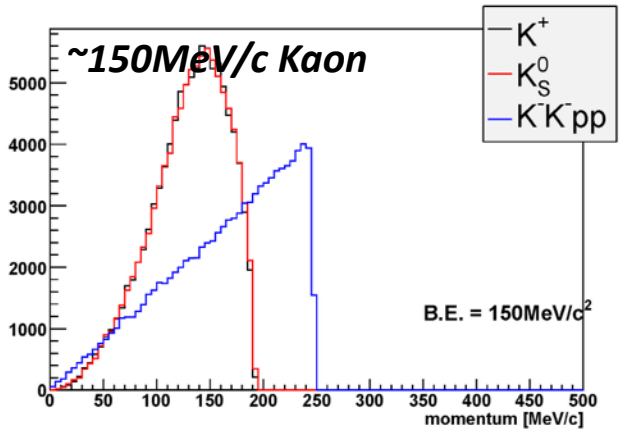
$$\bar{p} + {}^3He \rightarrow K^+ + K^0_S + K^- K^- pp$$

assumptions:
- ✓widths of K^-K^-pp = 0
- ✓isotropic decay

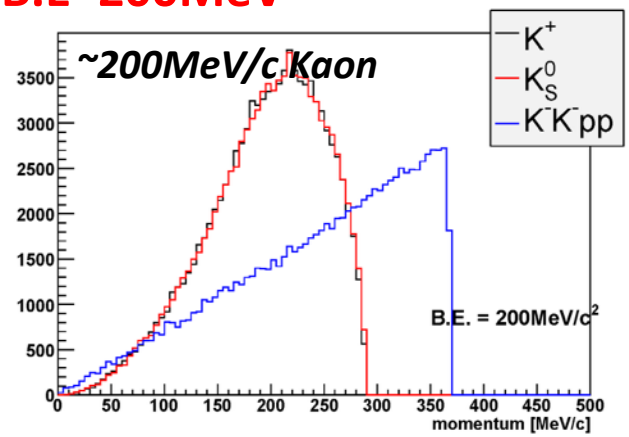
B.E=120MeV



B.E=150MeV



B.E=200MeV

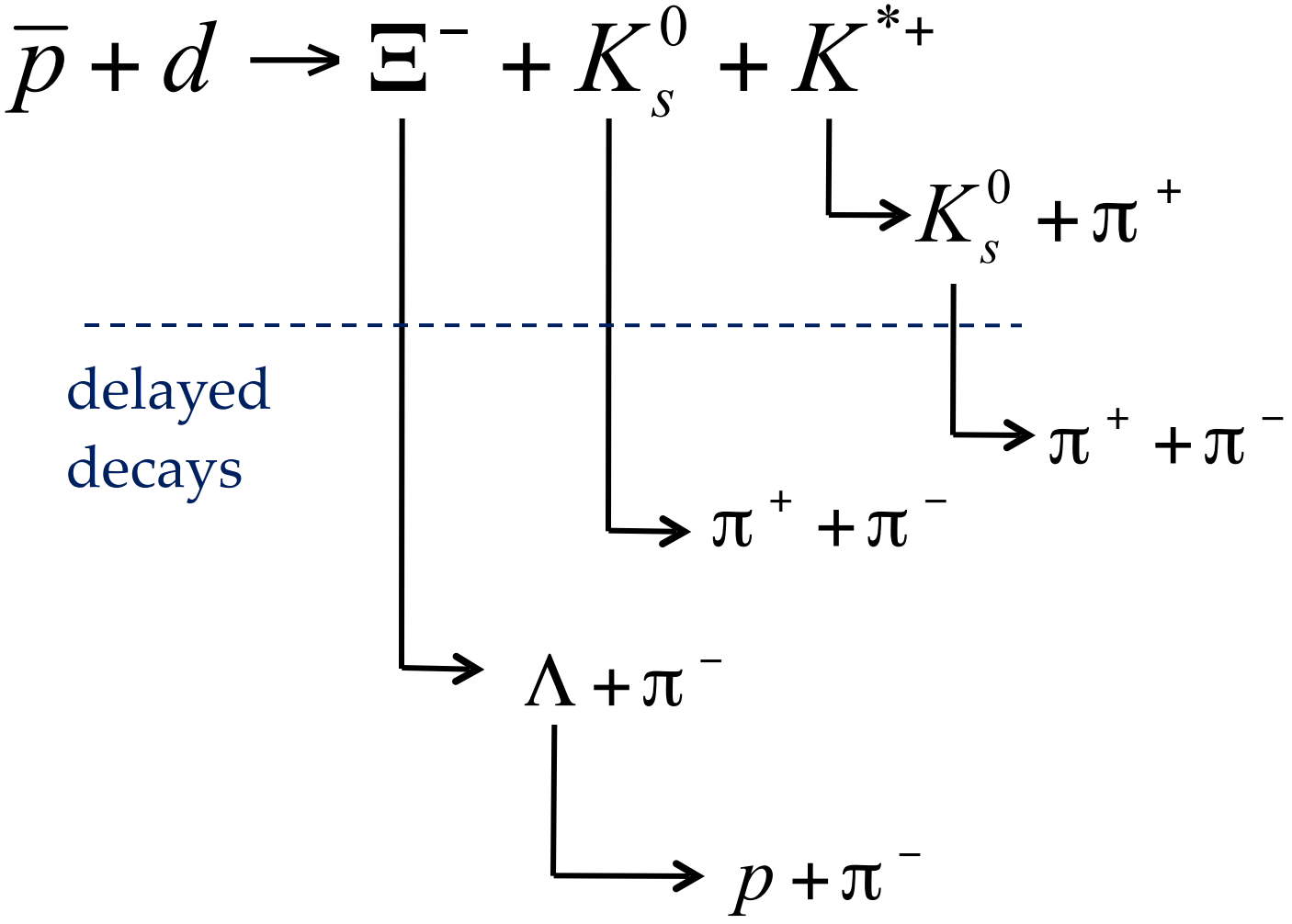


In the K^-K^-pp production channel, the kaons have very small momentum of up to 300MeV/c, even if B.E.=200MeV.

low mass detectors

~200MeV/c π from K^0_S, ~700MeV/c p from Λ, ~150MeV/c π^- from Λ

Production of S=–2: Ξ^-



Production of S=–2 baryonic states

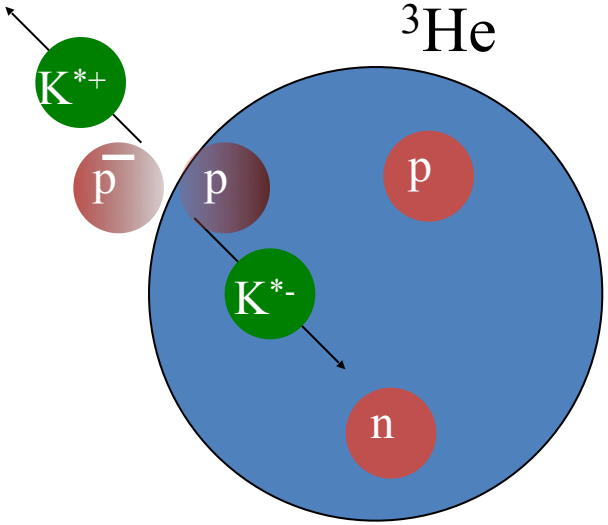
via $(\bar{K}^*, K)$ using stopped $\bar{p}$

K. Kilian, W. Oelert, D. Grzonka
Forschungszentrum Jülich

e.g. :

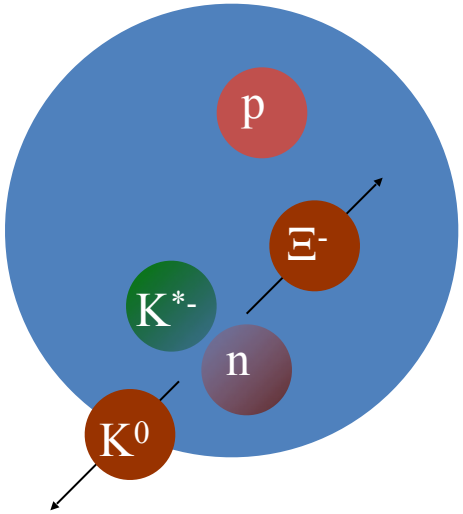
step 1 : $\bar{p}\ (p\ n\ p) \rightarrow K^{*-}\ K^{*+}$

large $\bar{p}$ stop rate on a ^{3}He target



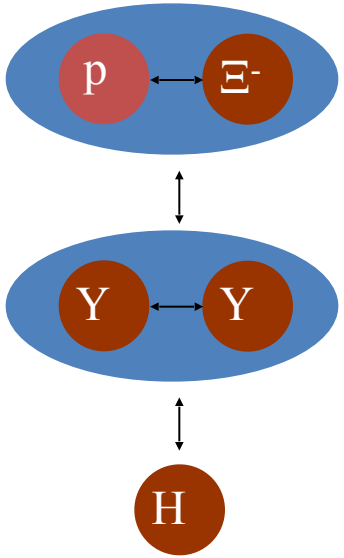
step 2 : $K^{*-}\ (n\ p) \rightarrow \Xi^-\ K^0$

very low recoil on Ξ^-
(recoil free kinematics)

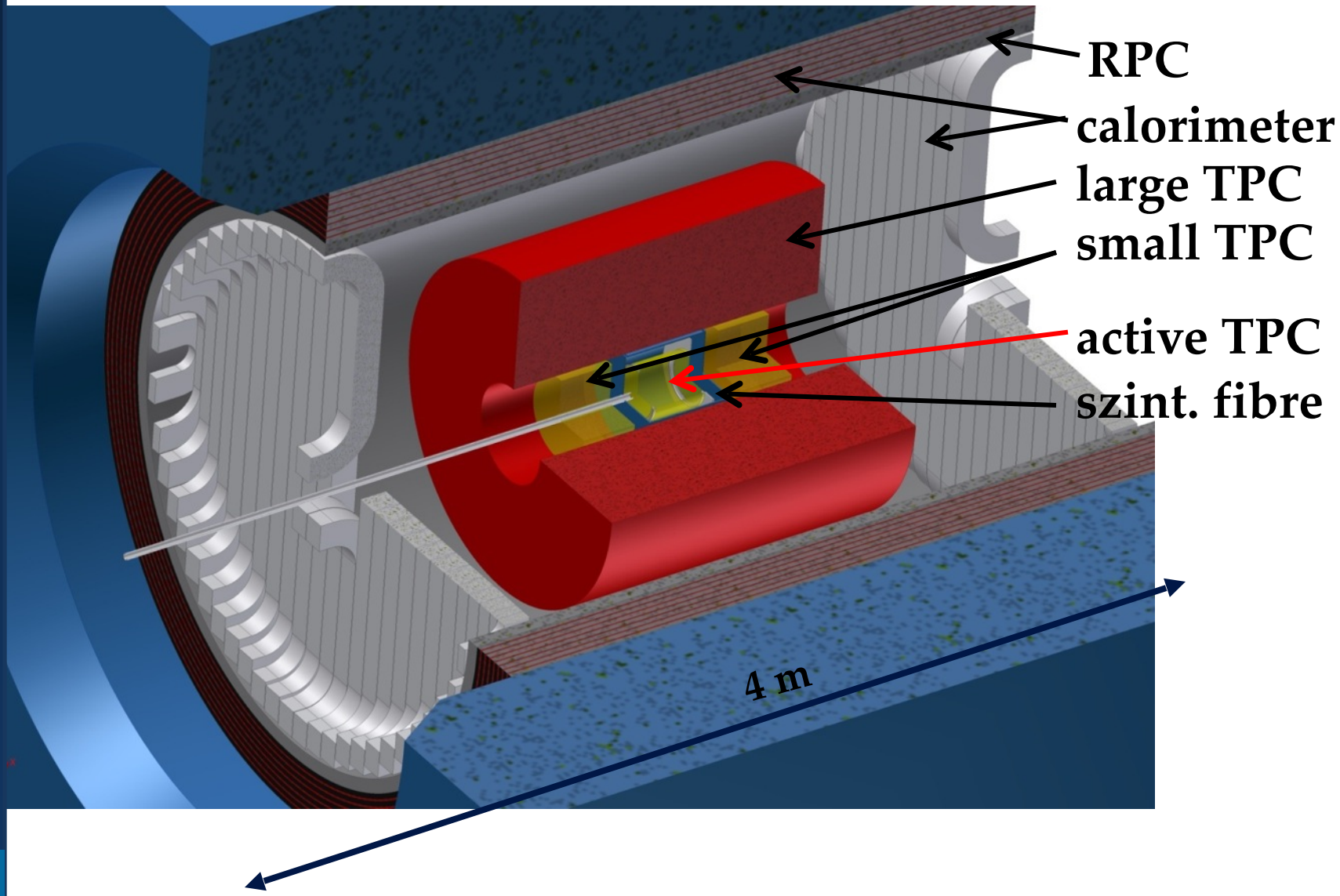


S= - 2 states

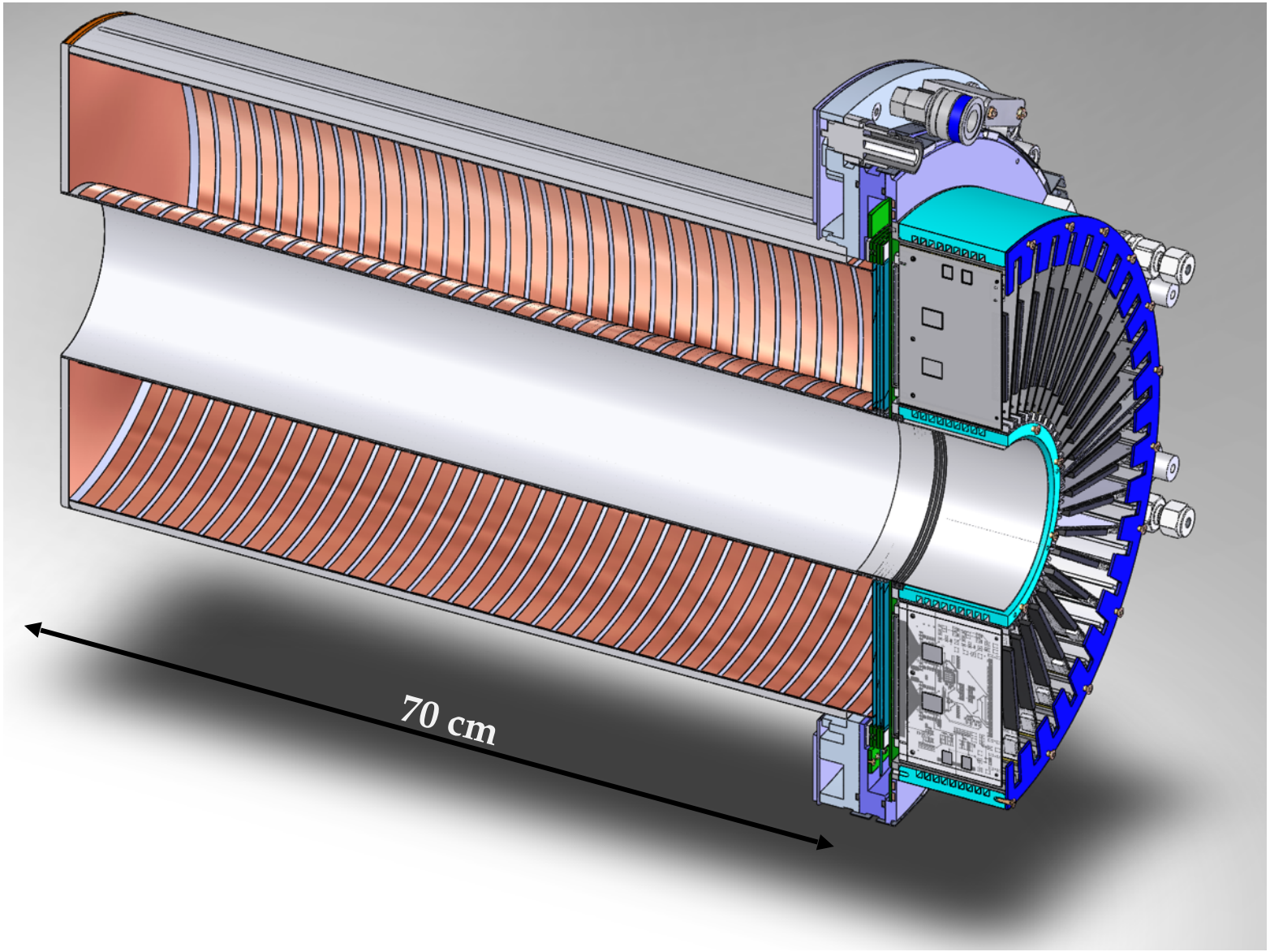
low relative energy



Unique 4π-detector system



TPC prototype for PANDA



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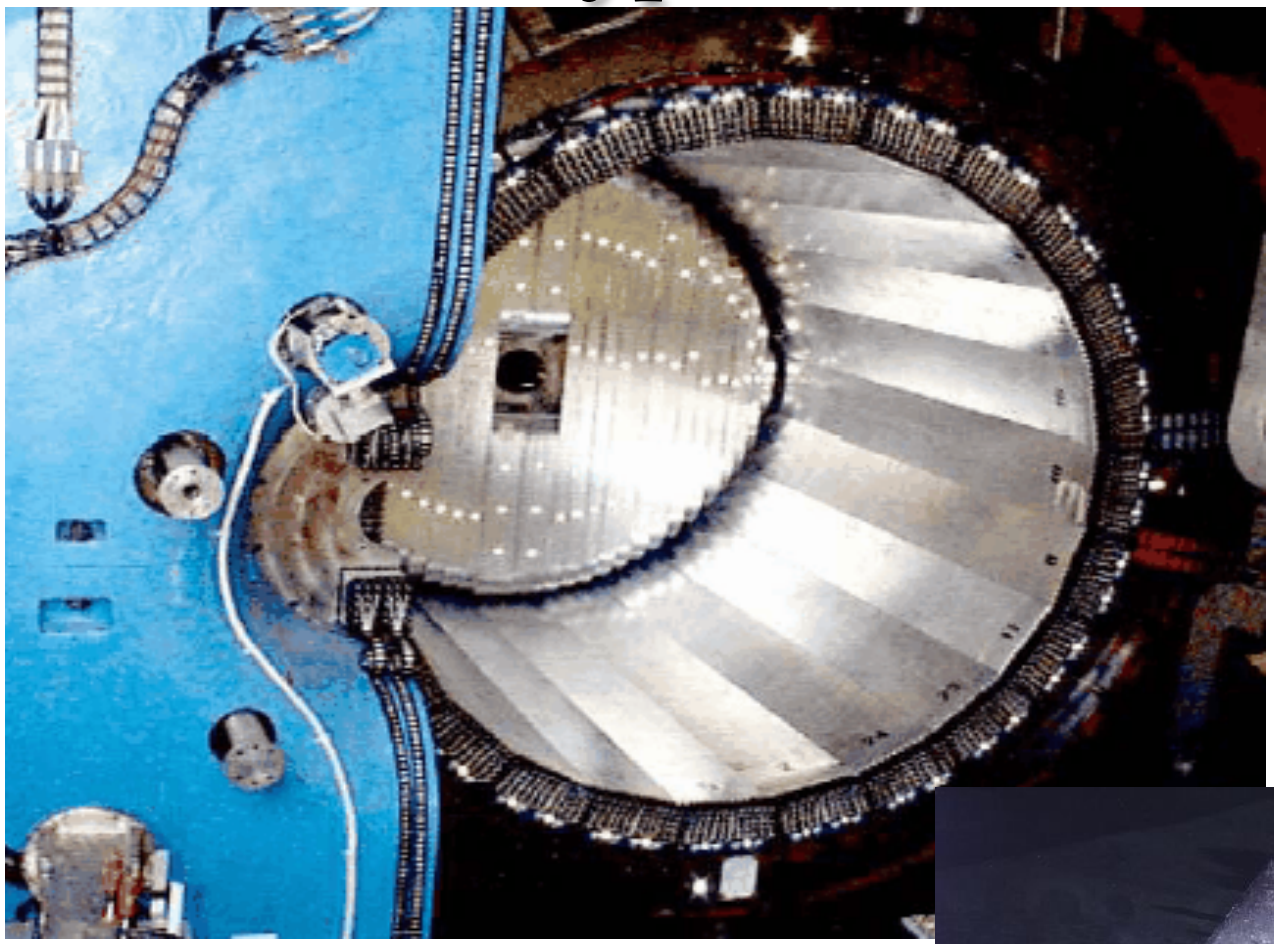
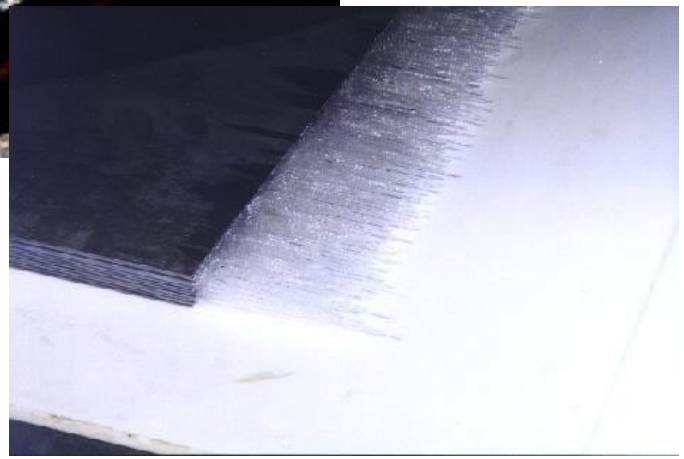
KLOE-type calorimeter





density ~ 5.0 g/cm^3
total length of fibres ~ 15000 km
read out by ~ 5000 mesh PM → SiPMs

CONCLUSIONS

- The CRYRING at FAIR could become a high-intensity source for low-energy, "slow"-extracted (single) antiprotons, to produce and study baryonic systems with strangeness S=–2.
- Necessary steps
  - define physics opportunities
  - form a collaboration
  - evaluate technical & financial needs
- *Satellite meeting to EXA2014 (Vienna)*
  - *Friday September 19th afternoon*