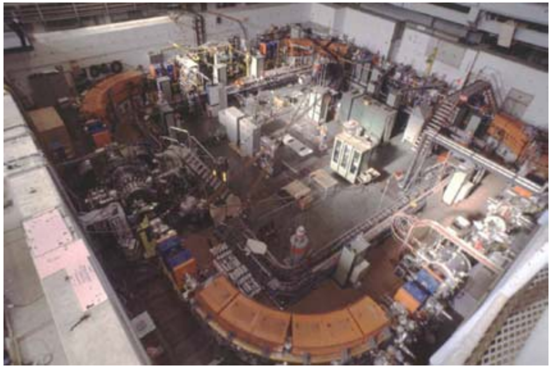
Nuclear and Particle Physics with FLAIR –

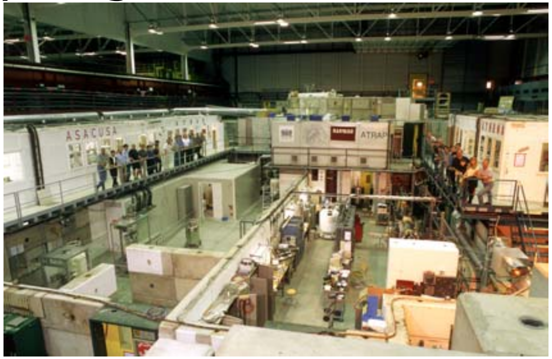
Facility for Low-energy Antiproton and Ion Research at FAIR

Dieter Grzonka , Forschungszentrum Jülich
for the FLAIR community

Low-energy Antiproton Facilities

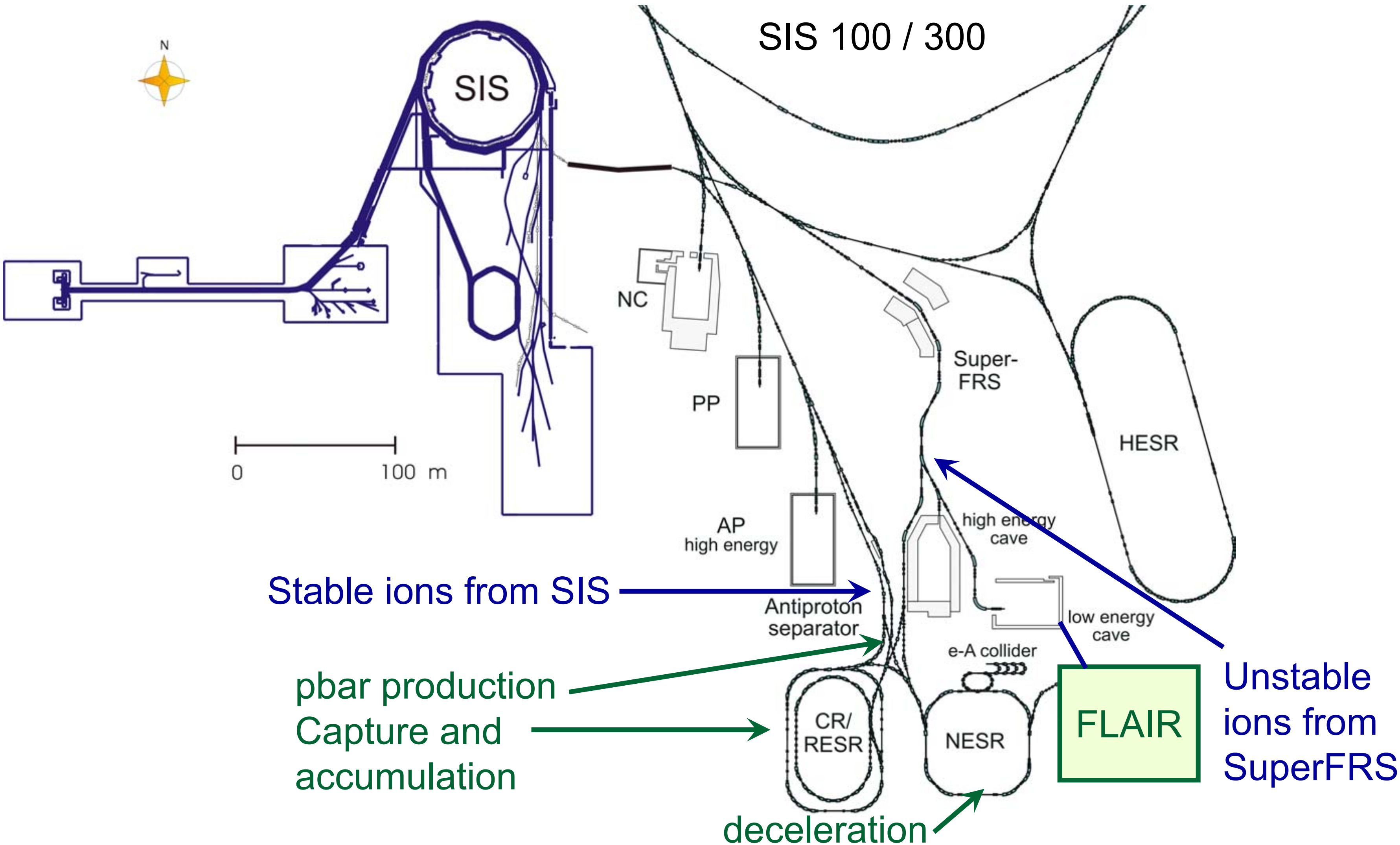


- *LEAR @ CERN*
  - 1982 – 1996
  - Fast and slow extraction
  - 105 MeV/c (5.6 MeV)
  - Up to 10^6 pbar/second DC, 10^9 pbar/shot
  - Trap (q/m), antiprotonic helium, protonium, nuclear radii, dE/dx (Barkas effect), ionization, 1st antihydrogen



- *AD @ CERN*
  - In operation since 2000
  - Only fast extraction
  - 100 MeV/c (5.3 MeV)
  - $3x10^7$ pbar / 85 ns
  - Cold antihydrogen, antiprotonic helium, dE/dx, ionization
- *Limitation*
  - 5 MeV is still to high for efficient stopping of antiprotons

FLAIR @ FAIR


SIS 100 / 300
N
SIS
0
100 m
NC
PP
AP
high energy
Antiproton
separator
Super-
FRS
HESR
high energy
cave
low energy
cave
e-A collider
CR/
RESR
NESR
FLAIR
Stable ions from SIS
pbar production
Capture and
accumulation
deceleration
Unstable
ions from
SuperFRS

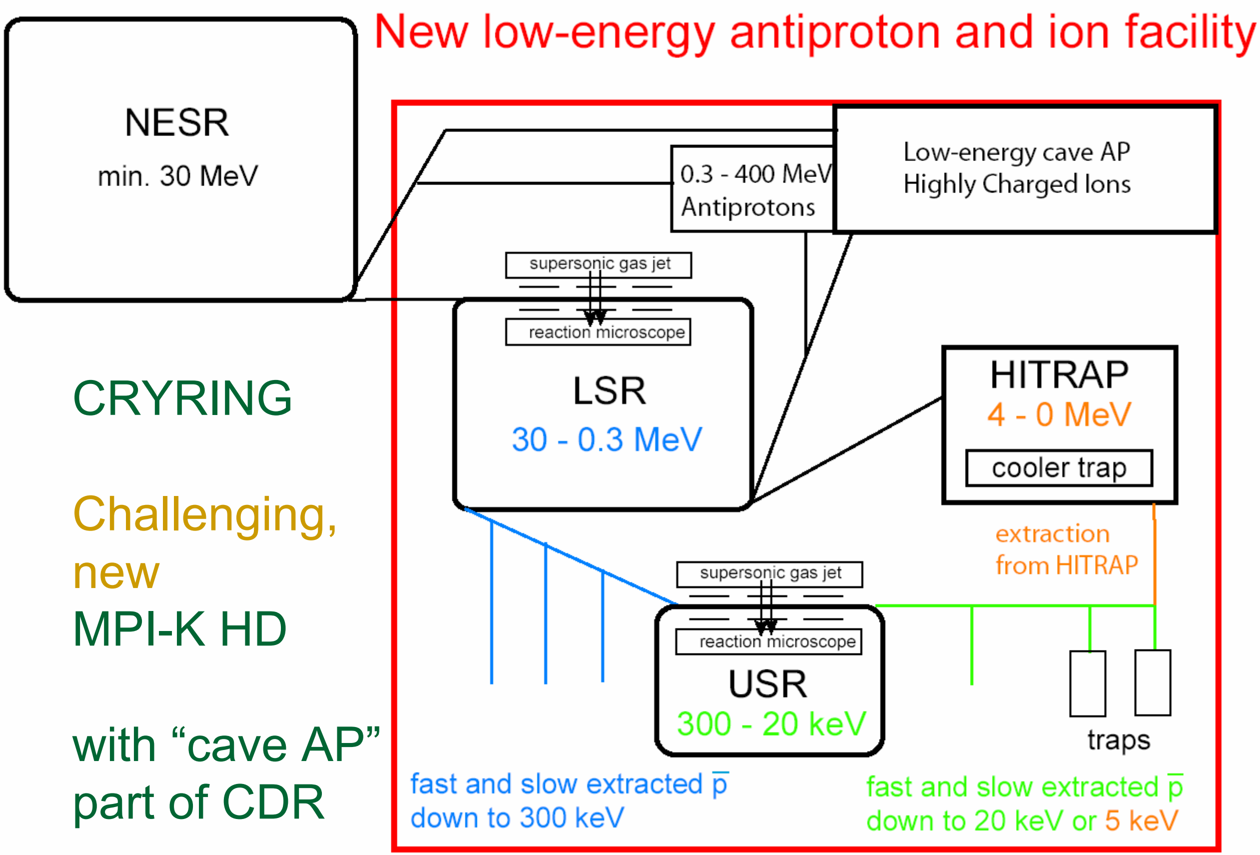
FLAIR – A Facility for Low-energy Antiproton and Ion Research @ FAIR

- *NESR*
  - Pbar & Ions
    30 – 400 MeV
- *LSR*
  - Standard ring
  - Min. 300 keV
- *USR*
  - Electrostatic
  - Min. 20 keV
- *HITRAP*
  - pbar and ions
  - Stopped & ext-
    tracted @ 5 ke\

CRYRING

Challenging,
new
MPI-K HD

with “cave AP”
part of CDR



Factor 100 more pbar trapped or stopped in gas targets than now

FLAIR Physics Topics with Antiprotons

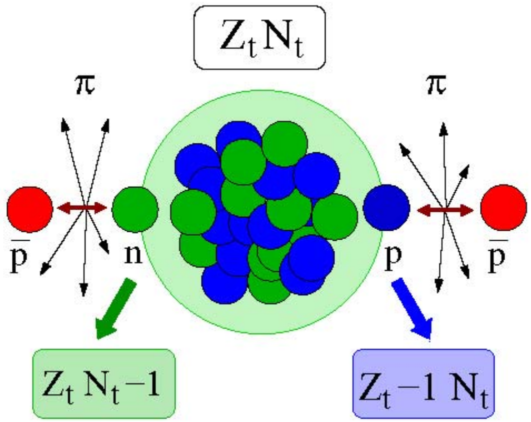
- *Spectroscopy for tests of CPT and QED*
  - Antiprotonic atoms (pbar-He, pbar-p), antihydrogen
- *Atomic collisions*
  - Sub-femtosecond correlated dynamics: ionization, energy loss, antimatter-matter collisions
- *Antiprotons as hadronic probes*
  - X-rays of light antiprotonic atoms: low-energy QCD
  - X-rays of neutron-rich nuclei: nuclear structure (halo)
  - Antineutron interaction
  - Strangeness –2 production
- *Medical applications: tumor therapy*

Features of FLAIR

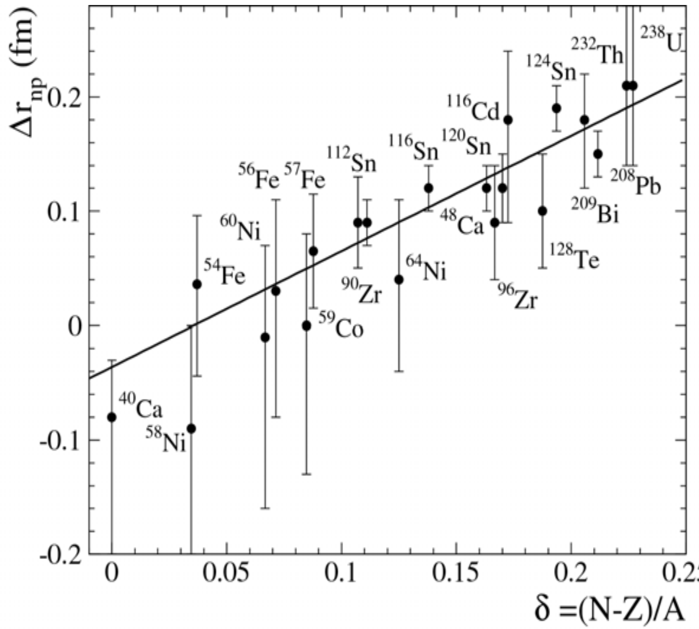
- Low-energy, high-brilliance beams for effective stopping
- High effective collision rates with USR: fully kinematic measurements
- Continuous beams: only possible @ FLAIR
- availability of radio-active ions offers synergies
- High energies, high intensities, slow extraction

Nuclear Periphery with $\bar{p}$ Atoms (DC)

determination of the **halo factor** (f_{halo})



PS209 @ LEAR

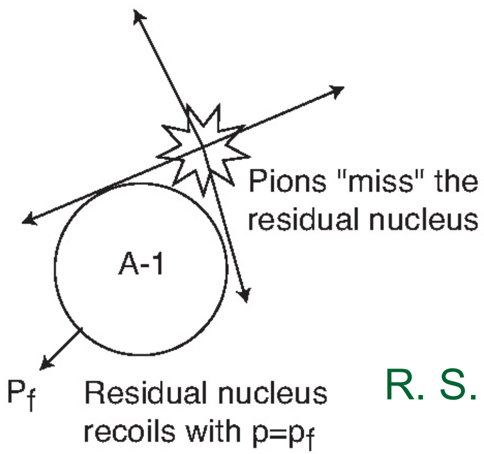


- *Exotic atom formation -> cascade ->*
  - Annihilation with outermost nucleons (<r>+ 2 fm)
- *Measurement of neutron halo parameters*
  - Radiochemical method, X-rays + model calculations
- *Neutron diffuseness increases with neutron excess*
- *Extension to unstable nuclei interesting*

A. Trzcinska,
J. Jastrzebski et al.
PRL 87 (082501)
2001

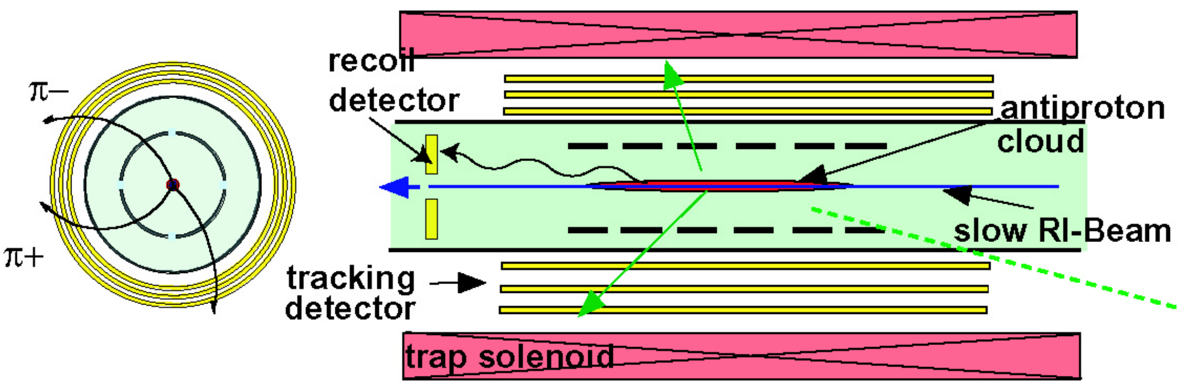
$\bar{p}$-RI in Traps for Nuclear Structure Study

- *$\bar{p}$ annihilates with outer-most nucleon*



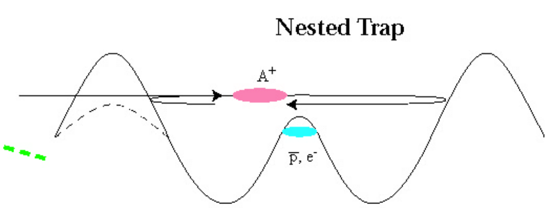
R. S. Hayano (Tokyo)

- *Momentum distribution of recoil nuclei*
  - Wave function of outer-most nucleon
- *Charged pion multiplicity*
  - Distinguish annihilation on p and n
  - Halo factors



M. Wada, Y. Yamazaki (Tokyo)

Nested Penning trap



Antineutron production and precision cross section measurements at low momentum

$\bar{p}p \rightarrow \bar{n}n$

(OBELIX / LEAR)

anomaly in the elastic cross section

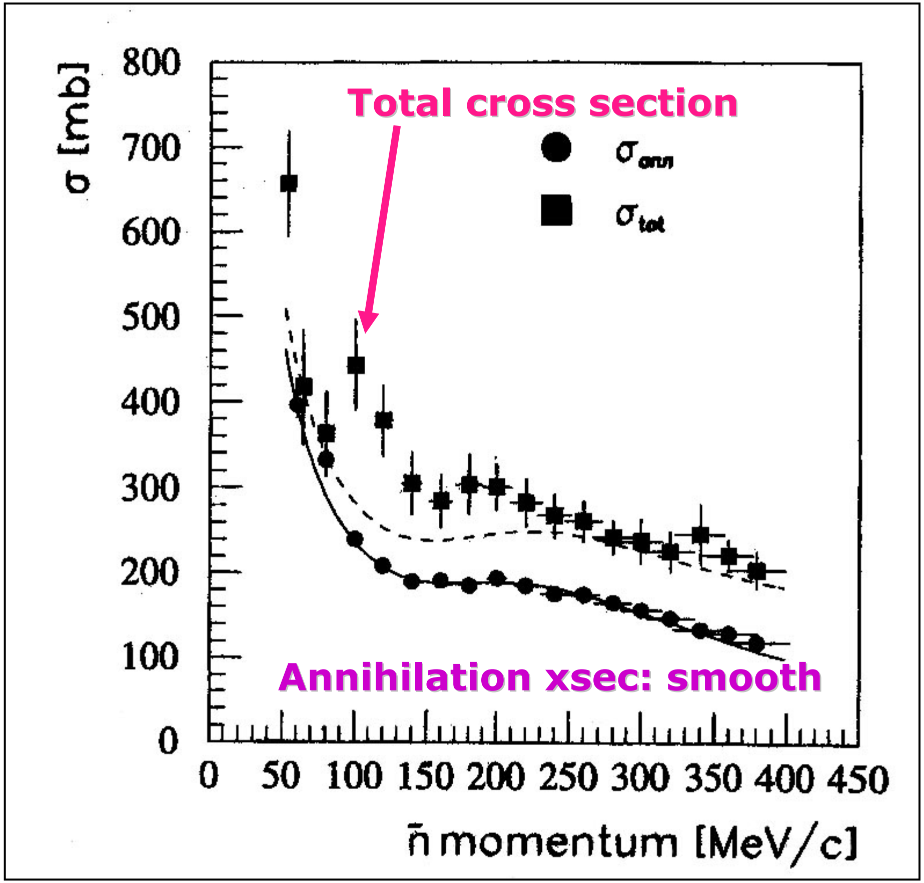
charge exchange cross section data inconsistent at low momentum

isospin dependence of $\bar{N}N$ annihilation

Total vs annihilation $\bar{n}p$ cross sections

A dip-bump effect is observed in $\sigma(\bar{n}p)_{TOT}$ at 65-80 MeV/c

- Regular and smooth trend of $\sigma(\bar{n}p)_{ANN}$ in the same momentum region
- Impossible to find a set of parameters able to describe correctly at the same time both σ_T and σ_{ann}
  - Bad fits of σ_T with ER expansions, of different kinds
- The elastic cross section is most likely responsible for the unexpected irregular trend of σ_T



Due to a $\bar{N}N$ bound state close to threshold?

I=0 vs I=1 interactions

- *From the ratio between $\sigma_T(\bar{p}p)$ and $\sigma_T(\bar{n}p)$ one can deduce the contribution to annihilation of the I=0 and I=1 sources of the $\bar{N}N$ interaction:*

$$R = \frac{\sigma_T(\bar{p}p)}{\sigma_T(\bar{n}p)} = \frac{\sigma_T(I=0) + \sigma_T(I=1)}{2\sigma_T(I=1)}$$

- Strong dominance of the I=0 component at low momentum:
  - $\sigma_T(I=0)/\sigma_T(I=1)$:
    - (2.5±0.4) @ 70 MeV/c
    - (1.1±0.1) @ 300 MeV/c
  - Effect explained as a manifestation of the coherence of meson exchanges in the central and tensor terms of the $\bar{N}N$ medium range force (Dover et al.)
- For σ_{ann} the same rule is valid: $\sigma_{ann}(\bar{n}p) < \sigma_{ann}(\bar{p}p)$
  - $\sigma_{ann}(I=0)/\sigma_{ann}(I=1)$:
    - (2.4± 0.4) @ 70 MeV/c
- σ(I=1) always lower than σ(I=0) BUT 1.5 @ ~ 700 MeV/c!

Production of S = -2 baryonic states

Study of baryon-baryon interaction
→ understanding of the strong interaction

NN extensive data base
detailed information

YN poor data base
caculations rely on flavour SU(3) symmetry

ΞN studies limited to H-dibaryon search (H : [uu dd ss])

Ξ – Production data: $K^- p \rightarrow \Xi K (\pi)$ properties of Ξ^0 and Ξ^-

Heavy ion collisions → multistrange yields
(AGS, SPS, RHIC) (QGP)

$\Sigma A \rightarrow \Xi(*) X$ spectrum of Ξ
WA89, CERN excited states

$\gamma p \rightarrow K^+K^+ \Xi^{-(0)} (\pi^-)$
CLAS , JLAB

Studies on H-particle search

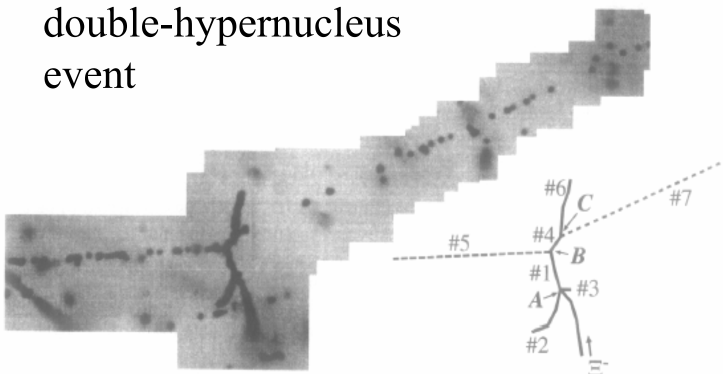
table taken from:
T. Sakai, K. Shimizu, K. Yazaki
Prog.Theo.Phys.Suppl. 137 (2000) 121

most effective Ξ production
via ($K^- K^+$) double strangeness exchange

ΛΛ-hypernuclei production

KEK E373: 1.66 GeV/c K^- → emulsion

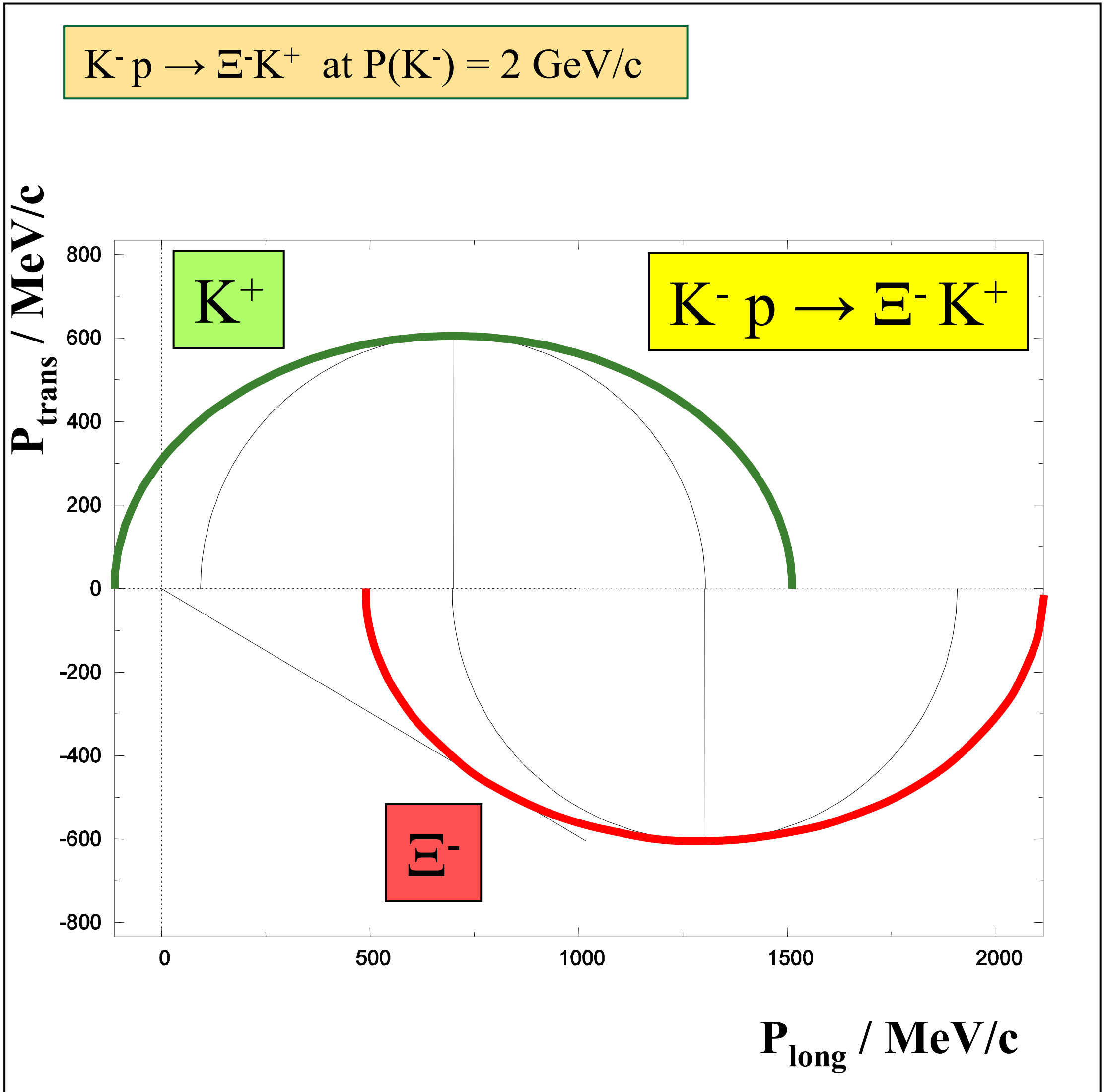
double-hypernucleus event



AGS E885: 2 GeV K^- : $K^- p \to \Xi^- K^+$
$\Xi^- \, {}^{12}C \to {}^{12}_{\Lambda\Lambda}B \; n$
scintillating fibre array

Collaboration	reaction process (production/decay)	sensitive mass range
BNL E703 [77)]	$p+p\to K^+ + K^+ + X$	$M_H = 2.0 \sim 2.5$ GeV
BNL E810 [86),87),104)]	Si + Pb collision / $H\to\Sigma^- p, \Lambda p\pi^-$	
BNL E813 [88)-92),103),104),106)]	$K^- + p\to K^+ + \Xi^-$, $(\Xi^- d)_{atom}\to H+n$	$-15 < B_H < 80$ MeV
BNL E830 [105)]	$K^- + {}^3He\to K^+ + H + n$	
BNL E836 [90)-93),103),104),106)]	$K^- + {}^3He\to K^+ + H + n$ $K^- + {}^6Li\to K^+ + H + X$	$B_H = 50 \sim 380$ MeV
BNL E864 [104),105)]	Au + Pb collision	
BNL E885 [92),94),95),104)]	$K^- + (p)\to K^+ + \Xi^-$, $(\Xi^- A)_{atom}\to H + X$ $K^- + A\to K^+ + X + H$	
BNL E886 [95),104)]	Au + Pt collision	
BNL E888 [97)-99),104),106)]	$p + A\to H + X$ / $H\to\Lambda n$ or $\Sigma^0 n$, $H + A\to\Lambda+\Lambda+A$	$M_H < 2150$ MeV
BNL E896 [100),104),105)]	Au + Au collision / $H\to\Sigma^- p\to n\pi^- p$, $H\to\Lambda p\pi^-\to p\pi^- p\pi^-$, $H\to\Lambda n\to p\pi^- n$	
BNL E910 [101)]	$p + A$ / $H\to\Lambda p\pi^-$, $H\to\Sigma^- p$	
BNL STAR [125),102)]	Au + Au collision	
KEK E176 [107)-109),115)]	$K^- + (pp)\to K^+ + H$ $K^- + p\to K^+ + \Xi^-$, $\Xi^- + (p)\to H$	
KEK E224 [110)-115)]	$K^- + (pp)\to K^+ + H$ $K^- + (p)\to K^+ + \Xi^-$, $\Xi^- + (p)\to H$	
KEK E248 [116)]	$p+p\to K^+ + K^+ + X$	
Fermilab E791 [119)]	$H\to p+\pi^- + \Lambda$, $\Lambda\to p+\pi^-$, $H\to\Lambda+\Lambda\to p+\pi^- + p+\pi^-$	
Fermilab KTeV Collab. [120)]	$p + A$ / $H\to p+\pi^- + \Lambda$	$M_H = 2194$ ~ 2231 MeV
Shahbazian et al. [79)-83)]	$p + {}^{12}C\to H(H^+) + X$ / $H\to\Sigma^- + p$, $\Sigma^-\to\pi^- n$ $H^+\to p+\pi^0+\Lambda$, $\Lambda\to p+\pi^-$ $H^+\to p+\Lambda$, $\Lambda\to p+\pi^-$	
Alekseev et al. [84)]	$n + A\to H + X$ / $H\to p\pi^-\Lambda$, $\Lambda\to p\pi^-$	
DIANA Collab. [117),118)]	$\bar p + Xe\to K^+ H X$, $K^+ K^+ H X$ / $H\to\Sigma^- + p$	
Condo et al. [78)]	$\bar p + A\to H + X$ / $H\to\Sigma^- + p$	
Ejiri et al. [85)]	$d\to H+\beta+\nu$, ${}^{10}Be\to{}^8Be + H$, ${}^{72}Ge\to{}^{70}Ge + H + \gamma$, ${}^{127}I\to{}^{125}I + H + \gamma$, ${}^{127}I\to{}^{125}Te + H + \beta^+ + \nu$	$M_H < 1875.1$ MeV
CERN NA49 [121)]	Pb + Pb collision / $H\to\Sigma^- p, \Lambda p\pi$	
CERN WA89 [122)]	$\Sigma^- + A\to X + H$ / $H\to\Lambda\Lambda, N\Xi$, $H\to\Lambda p\pi^-, \Sigma^- p, \Sigma^0 n, \Lambda n$	
CERN WA97 [123)]	Pb + Pb collision	
CERN ALICE [125)]	Pb + Pb collision	
CERN OPAL [124)]	Z^0 decay	

K^-K^+ double strangeness exchange using a K^- beam



→ Ξ^- ‘beam‘ $\tau(\Xi^-) = 1.6\ 10^{-10}$

$P_{lab}(\Xi^-) > 500$ MeV/c

stopped Ξ^- $(P_{lab}(\Xi^-) = 0)$

interact with targetnuclei

⇩

produce stopped Ξ^-

with $P_{lab}(\Xi^-) = 0$

→ not possible !

double strangeness exchange using $\bar{p}$ p annihilation

$(s, \bar{s})$

↑

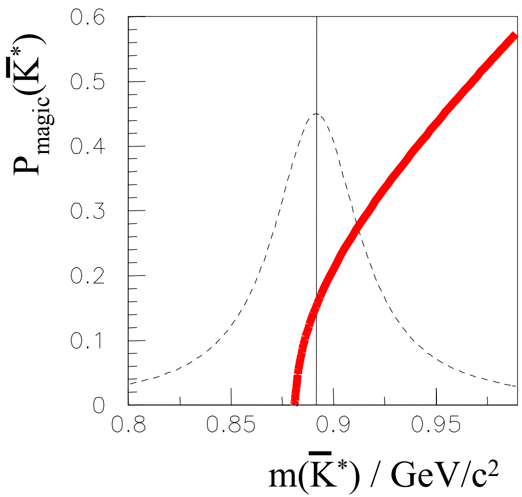
	annihilation channel	branching ratio	kaon momentum
$K^- = \bar{u}\, s$	$\bar{p}\, p \rightarrow K^+ K^-$	$1 \cdot 10^{-3}$	$P(K^-) = 780$ MeV/c
$\bar{K}^0 = \bar{d}\, s$	$\bar{p}\, p \rightarrow K^0 \bar{K}^0$	$3 \cdot 10^{-3}$	$P(\bar{K}^0) = 780$ MeV/c
$K^{*-} = \bar{u}\, s$	$\bar{p}\, p \rightarrow K^{*+} K^{*-}$	$1.5 \cdot 10^{-3}$	$P(K^{*-}) = 290$ MeV/c
$\bar{K}^{*0} = \bar{d}\, s$	$\bar{p}\, p \rightarrow K^{*0} \bar{K}^{*0}$	$3 \cdot 10^{-3}$	$P(\bar{K}^{*0}) = 290$ MeV/c
	$\bar{p}\, p \rightarrow K \bar{K}^*$	$1 \cdot 10^{-3}$	$P(\bar{K}^*) = 620$ MeV/c

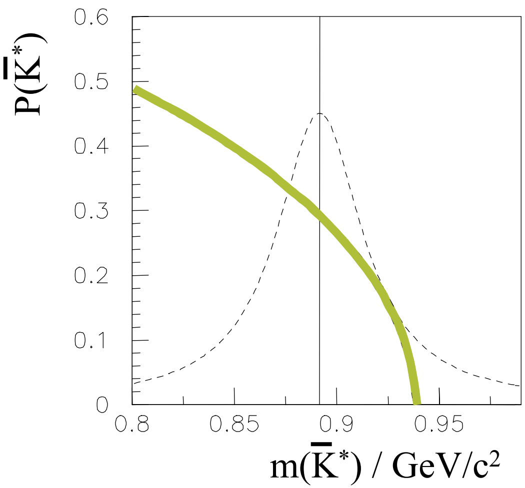
$\bar{K}^* N \rightarrow \Xi K$

$P(\bar{K}^*) = P_{magic}$

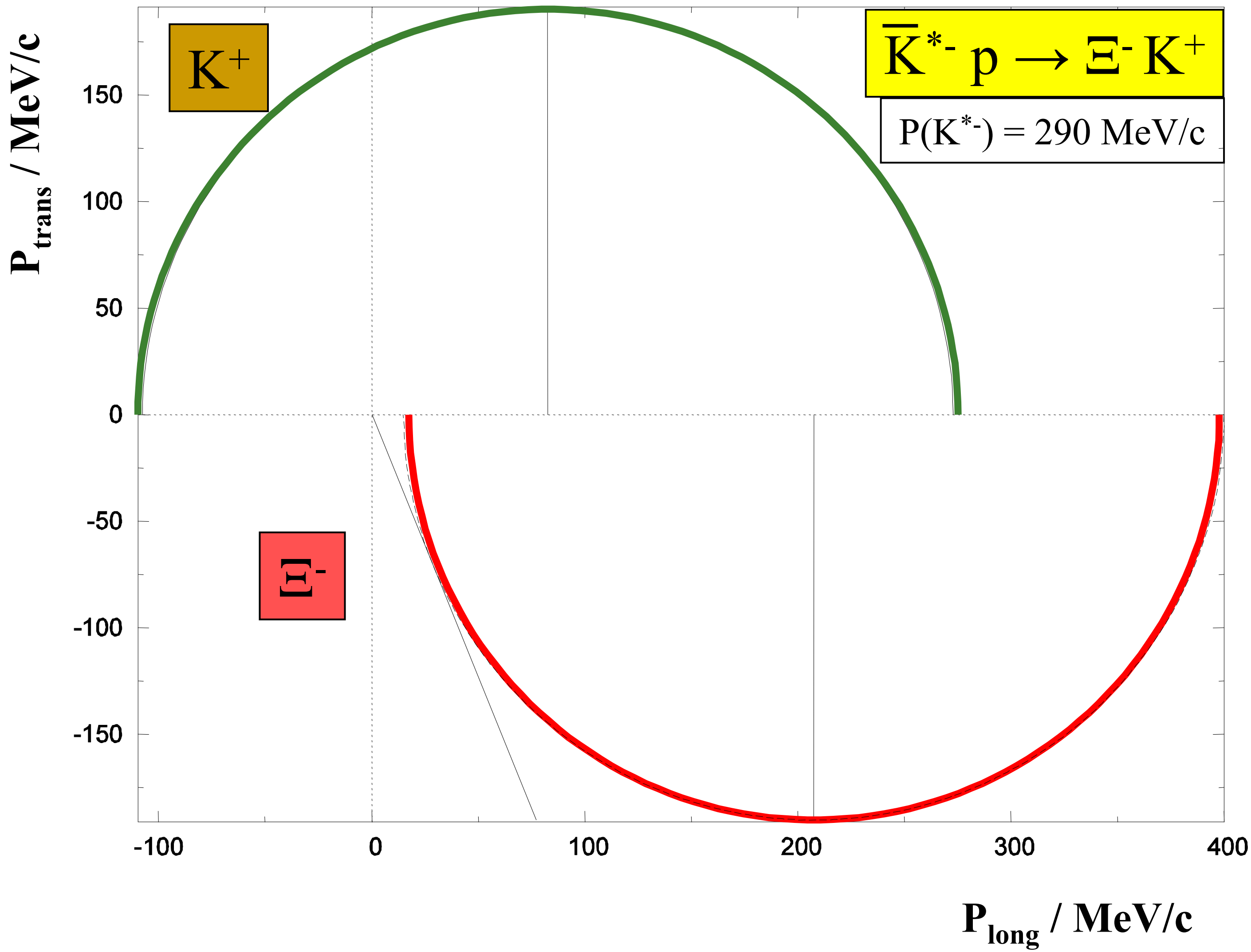
↓

$P(\Xi)_{lab} = 0$





Kinematics of $(\bar{K}^*,K)$ double strangeness exchange

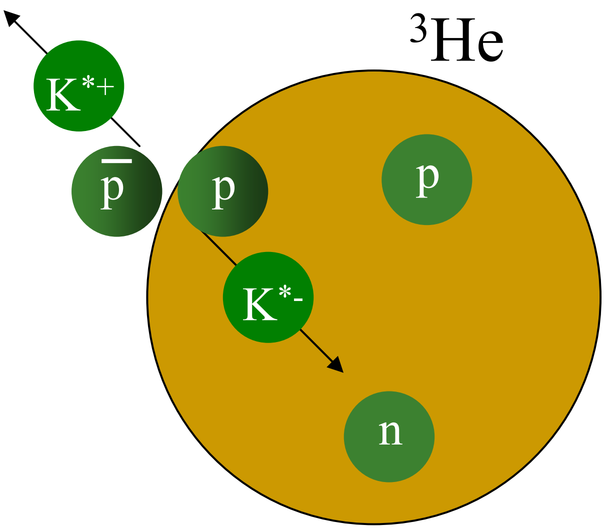


Production of S = -2 baryonic states

via $(\bar{K}^{*}, K)$ using stopped $\bar{p}$ e.g. :

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

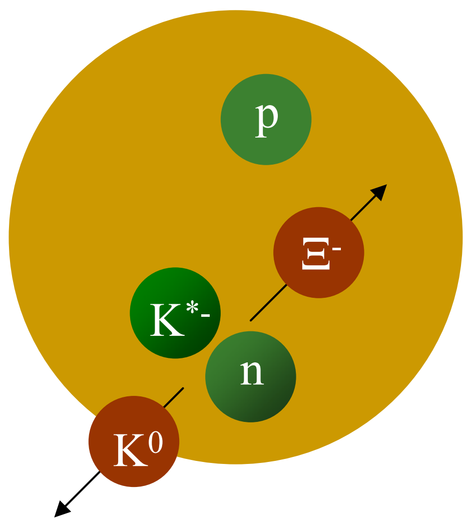
large $\bar{p}$ stop rate on a ^{3}He target



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

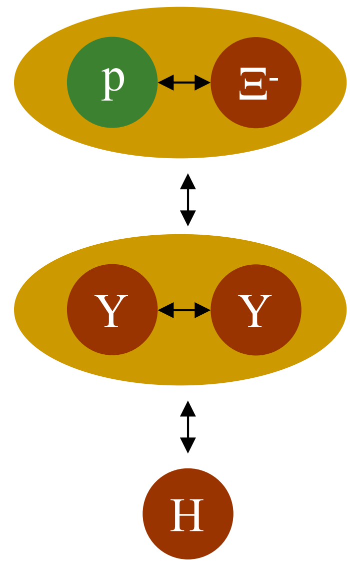
very low recoil on Ξ^{-}

(recoil free kinematics)



S= - 2 states

low relative energy



Production of S = -2 baryonic states

Ξ^- production

primary reaction
(step 1 + step 2)

multiplicity of charged particles

$\bar{p}\, d \rightarrow \Xi^- K_s^0 K^{*+}$ — 2

$K^{*+} \rightarrow K_s^0 \pi^+$

delayed decays

$K_s^0 \rightarrow \pi^+ \pi^-$

$K_s^0 \rightarrow \pi^+ \pi^-$ ($c\tau = 2.7$ cm)

$\Xi^- \rightarrow \Lambda \pi^-$ ($c\tau = 4.9$ cm)

$\Lambda \rightarrow p \pi^-$ ($c\tau = 7.9$ cm)

final state — 8

→ reaction trigger = multiplicity increase

geometry → event reconstruction

Ξ^- p interaction

$\bar{p}\, {}^3He \rightarrow p\, \Xi^- K_s^0 K^{*+}$

$\bar{p}\, {}^3He \rightarrow \Lambda\Lambda K_s^0 K^{*+}$

$\Lambda \rightarrow p \pi^-$

$\Lambda \rightarrow p \pi^-$

$\bar{p}\, {}^3He \rightarrow H K_s^0 K^{*+}$

$H \rightarrow \Sigma^- p\ ,\ \Sigma^0 n$
$\Lambda n\ ,\ p \pi^- \Lambda$

Production of S = -2 baryonic states

detector

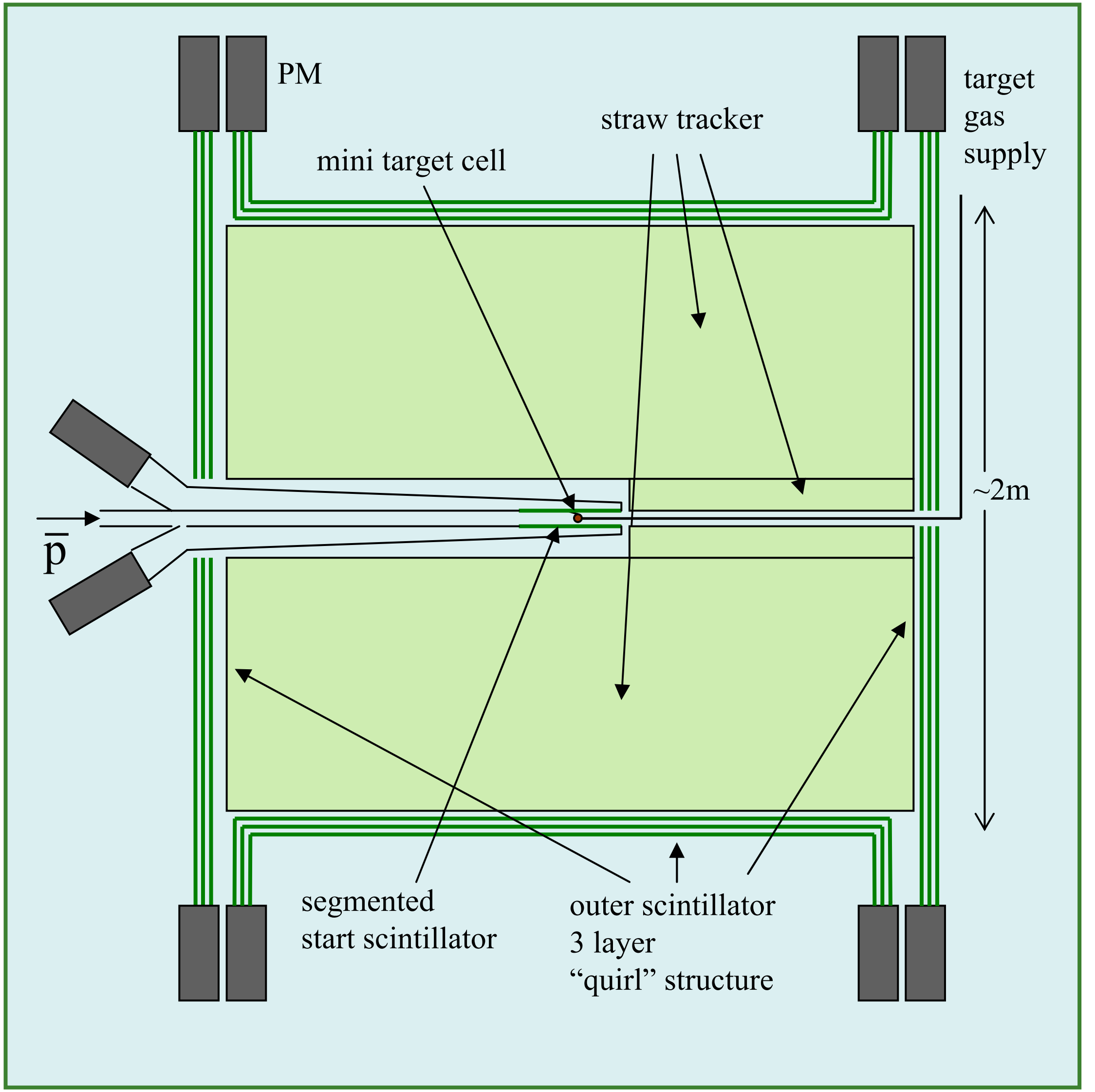
plastic scintillator layer

1. close to the target
2. ~1m distance

→ multiplicity trigger
timing

3-d tracking detector
straw tubes
in different directions

→ tracks of
charged particles
decay vertices

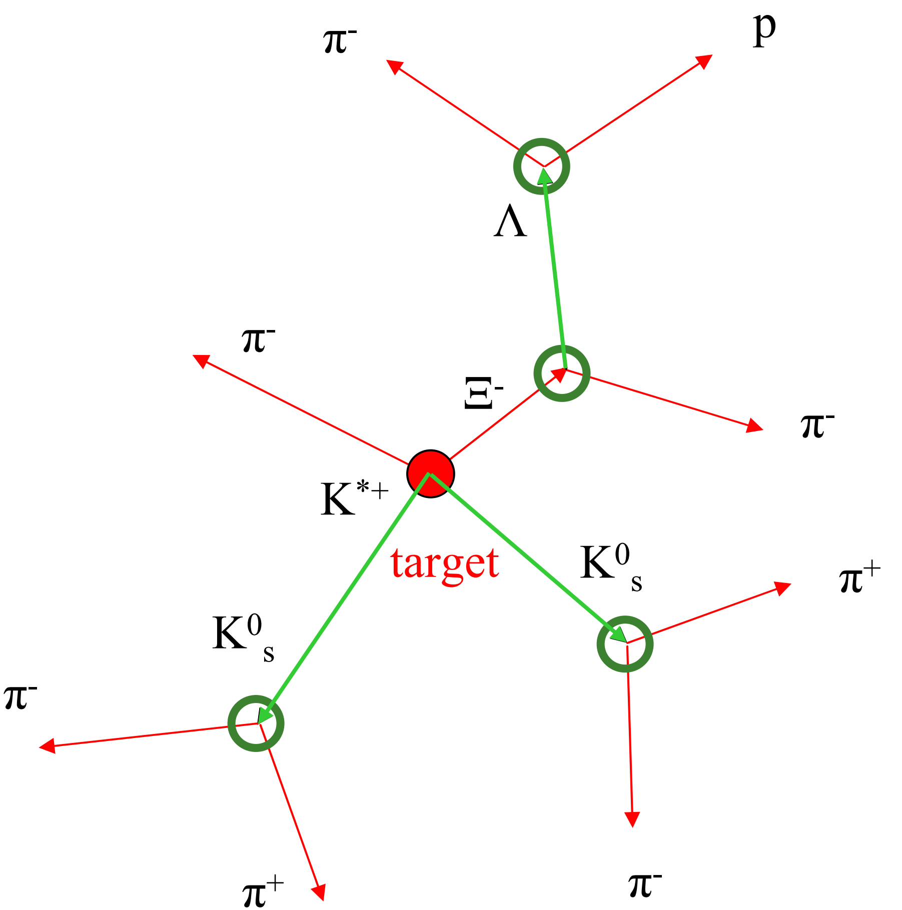


Production of S = -2 baryonic states

Event reconstruction

$\bar{p}\, d \rightarrow \Xi^- K_s^0 K^{*+}$

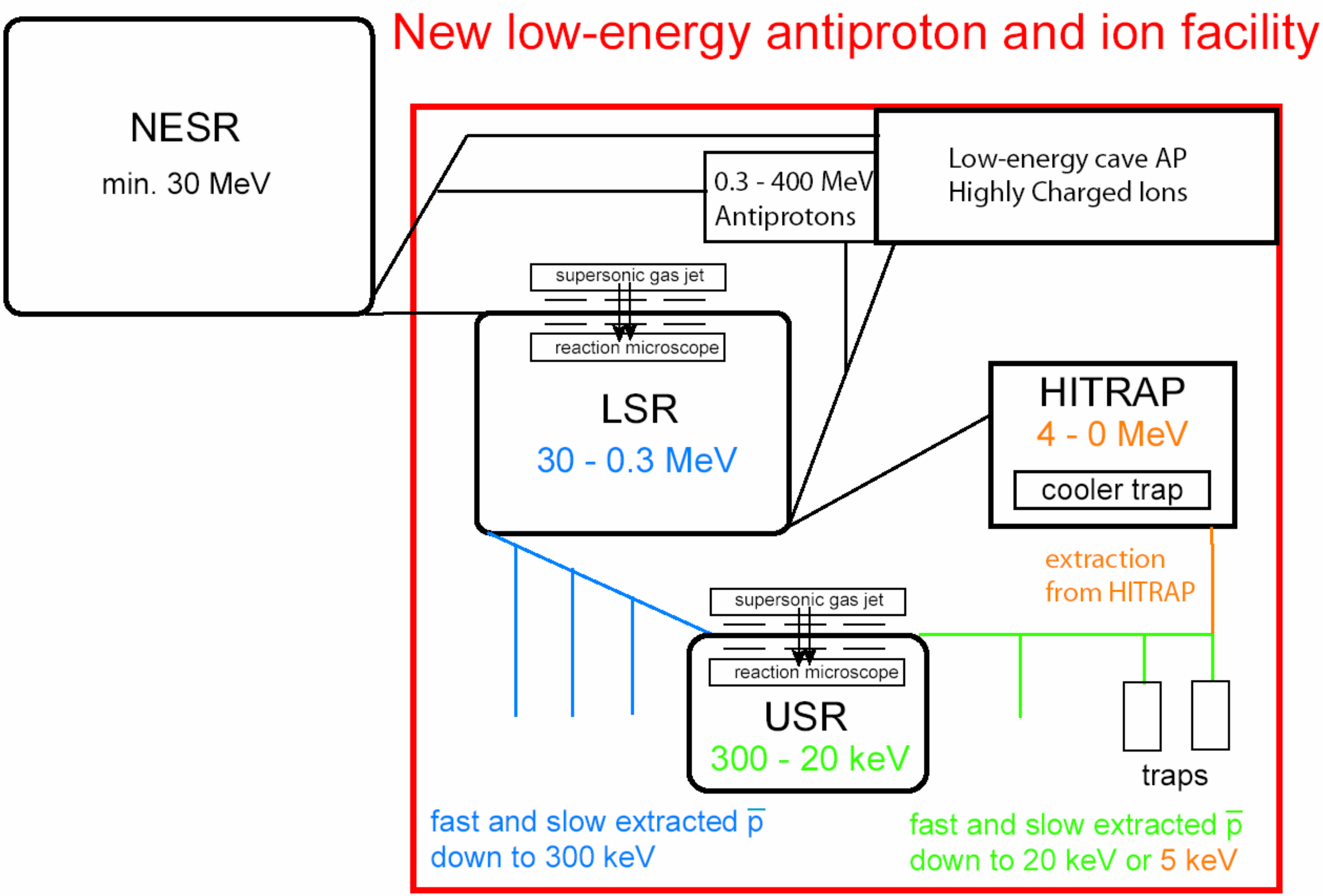
- $K^{*+} \rightarrow K_s^0 \pi^+$, $K_s^0 \rightarrow \pi^+ \pi^-$
- $K_s^0 \rightarrow \pi^+ \pi^-$
- $\Xi^- \rightarrow \Lambda \pi^-$, $\Lambda \rightarrow p\, \pi^-$



geometry

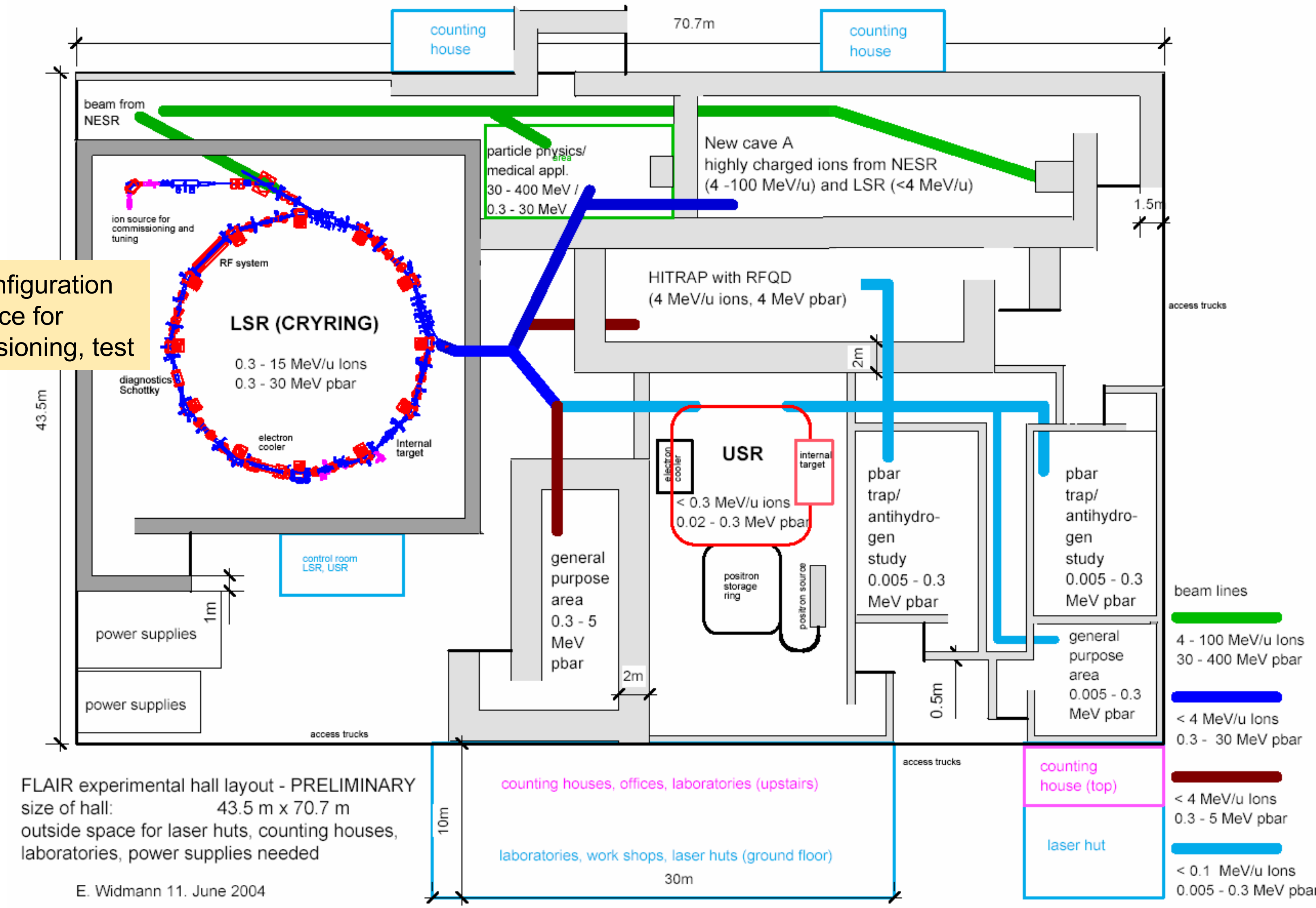
→ kinematical complete event reconstruction

FLAIR – A Facility for Low-energy Antiproton and Ion Research @ FAIR



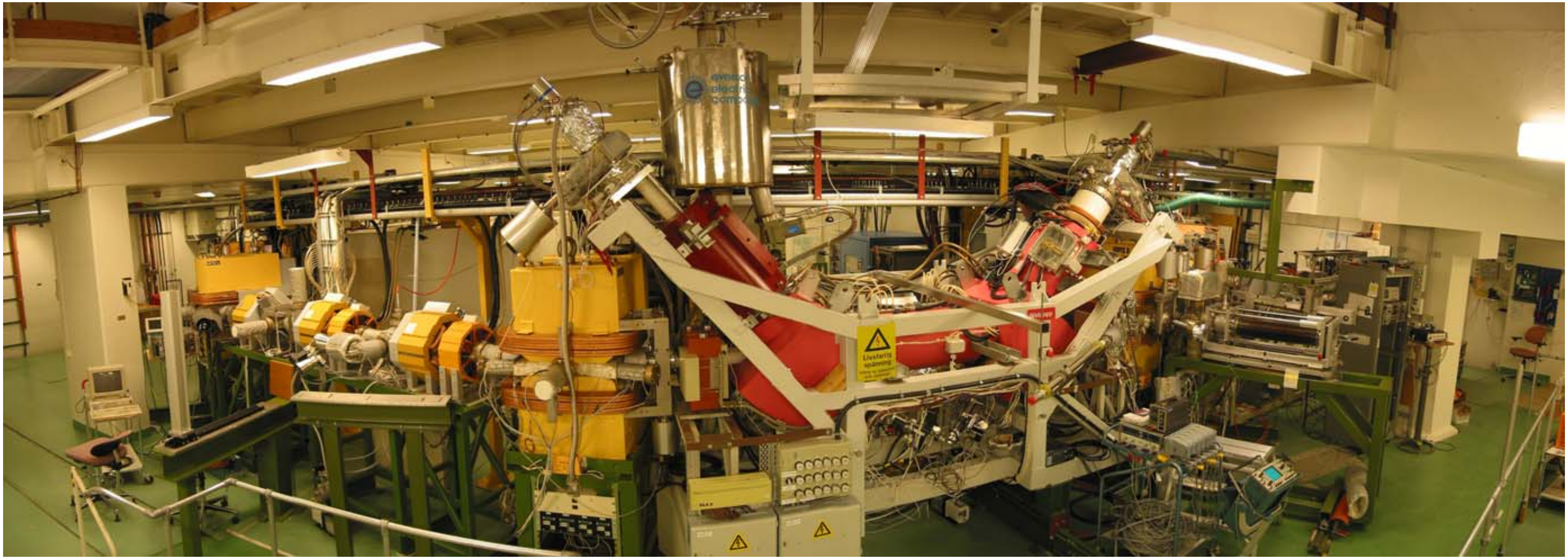
Layout of FLAIR Hall

New configuration
ion source for
commissioning, test

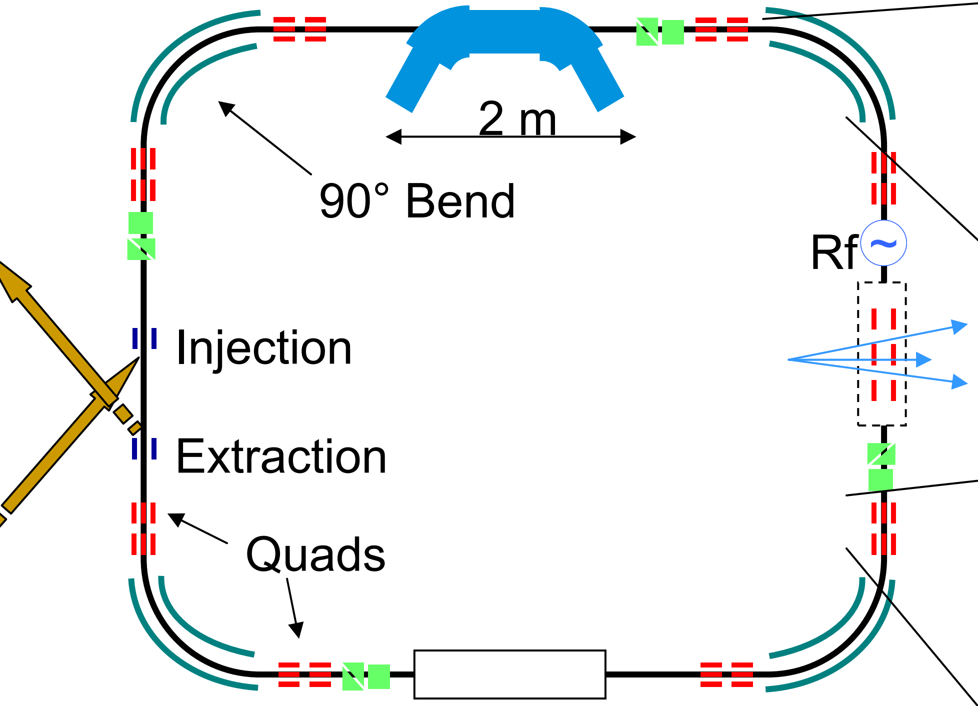


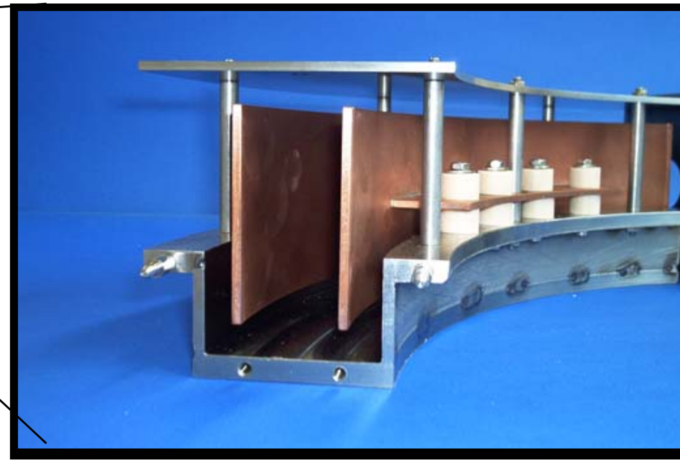
CRYRING and FLAIR

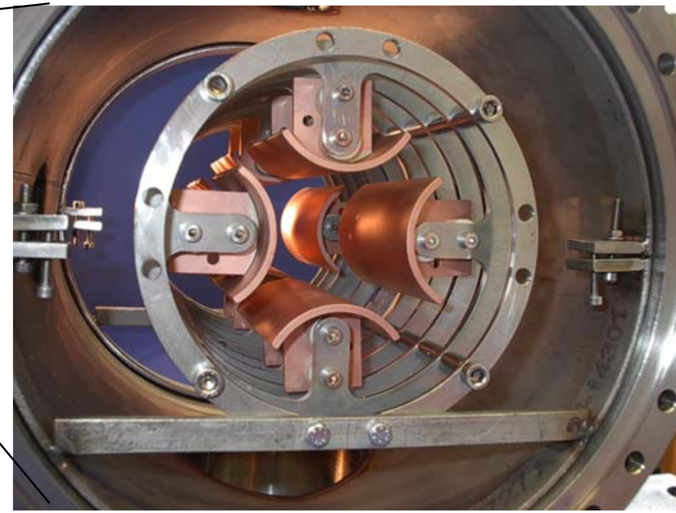
- *Storage ring at Manne Siegbahn Lab, Stockholm*
- *Is to stop operation within ~2 years*
- *Perfect fit for FLAIR LSR:*
  - Energy range, electron cooling, internal target, low-energy injection from ion source for commissioning



USR: Ultra-low Energy Storage Ring for Antiprotons (under development at MPI-K Heidelberg)







E_{min} / E_{max}	*20 / 300 keV*
Dimensions	*8 m x 8 m*
Voltages	*< ± 20 kV*
number of pbars at 20 keV	*$1 \cdot 10^7$*

Timeline and milestones

- *2004/5: technical report*
  - Design for modifications of CRYRING
  - layout of hall and beam lines
- *End 2005: agreement with Swedish funding agencies on contribution of CRYRING to FAIR needed*
- *End 2008: feasibility tests for USR finished, start of construction*
- *2009: finish implementation of modifications of CRYRING*
- *2010: Hall finished*
  move of CRYRING to FAIR
  Installation of USR
  Installation of experiments
- *2011 – 2012: commissioning and start of operation*

FLAIR Community

- *Austria (Vienna IMEP, TU)*
- *Canada (York)*
- *Denmark (Aarhus U, ISA)*
- *France (P. & M. Curie, Paris)*
- *Germany (GSI, Dresden, Frankfurt, Freiburg, München, Giessen, Heidelberg, Jülich, Mainz, Tübingen)*
- *Hungary (Budapest, Debrezen U, ATOMKI)*
- *Italy (Bologna, Firenze, Genova, Torino)*
- *Japan (Tokyo, Saitama (RIKEN))*
- *Netherlands (Amsterdam U, FOM)*
- *Poland (Warsaw U, Soltan Inst.)*
- *Russia (Moscow, St. Petersburg)*
- *Sweden (Stockholm U, Manne Siegbahn Laboratory)*
- *United Kingdom (Swansea)*
- *USA (Albuquerque, Harvard, pbar Medical, Texas A&M)*

47 institutions, 14 countries