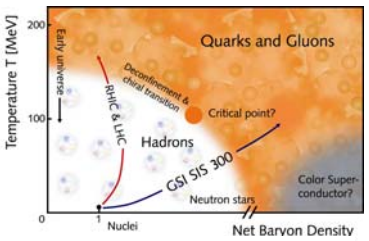
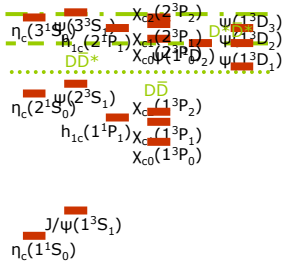
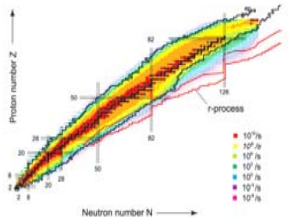
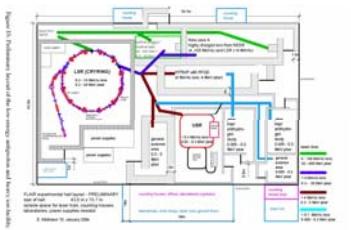


# Hadron Physics @ FAIR

Klaus Peters

*KPIII/HPI, GSI Darmstadt*
*IKF, JWGU Frankfurt*

Project X Workshop "Physics"

Nov 16, 2007

# Nov. 7, FAIR Start-Event – last week




Offical Start Signed
By 12 Partners

Volume in Phase A
940 M€

16 Countries

# Where is Darmstadt ?



# FAIR @ GSI




Existing GSI
FAIR
CDR 2001
FTBR 2006
Construction Start 2007
Ground Breaking 2008
First Experiments 2012
Fully Completed 2015
Budget € 1.1

# Structure of Matter



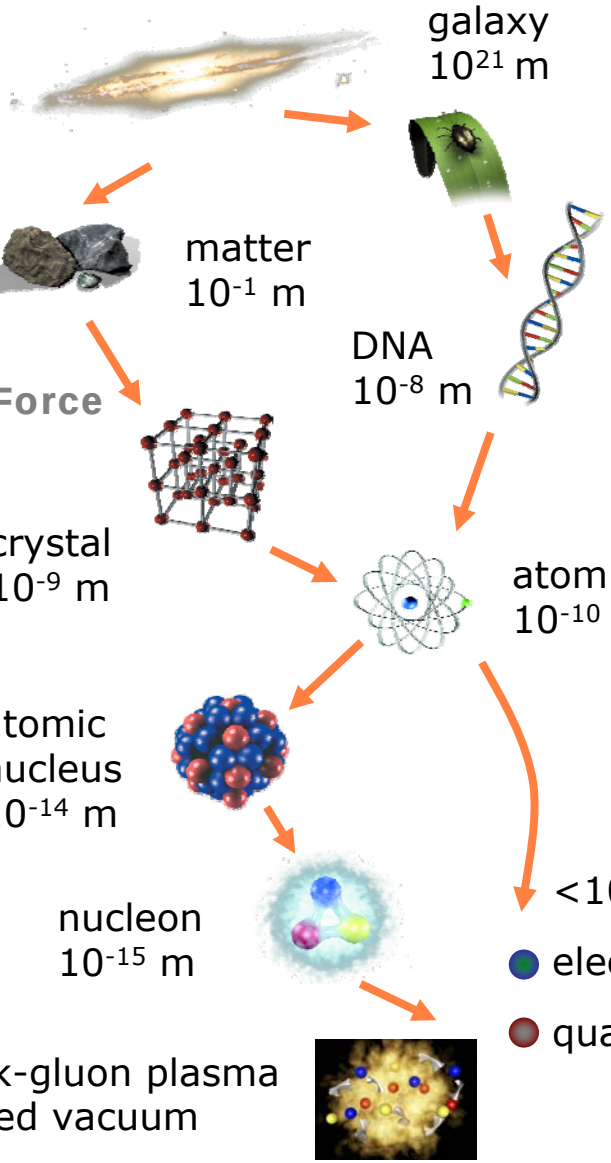
**Gravitational Force**
**General Relativity**

**Electromagnetic Force**
**QED**

**Electroweak Force**

**Weak Force**
**Standard Model**

**Strong Force**
**QCD**




## Research with Beams of Hadrons and Ions

Ion-Matter Interactions
Dense Plasmas

HI Beams → 12 TW/g

Ultra High EM Fields
Nuclei at the Extremes

RIBs → 1.5 – 2 GeV/u

Quark Gluon Structure of Hadrons

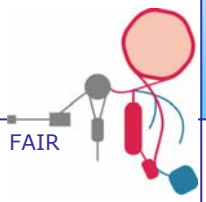
Antiprotons 0-15 GeV

Quark Matter

Relativ. HI → 35 GeV/u

# Mission Statement





- Strong and weak interaction critically determine the structure of matter at the microscopic level

Goal: Comprehensive and quantitative understanding

- Many-body aspects play an important role at all levels of the hierarchical structure of matter

Goal: Investigate many-body effects at all scales

# Five Areas of Research at FAIR



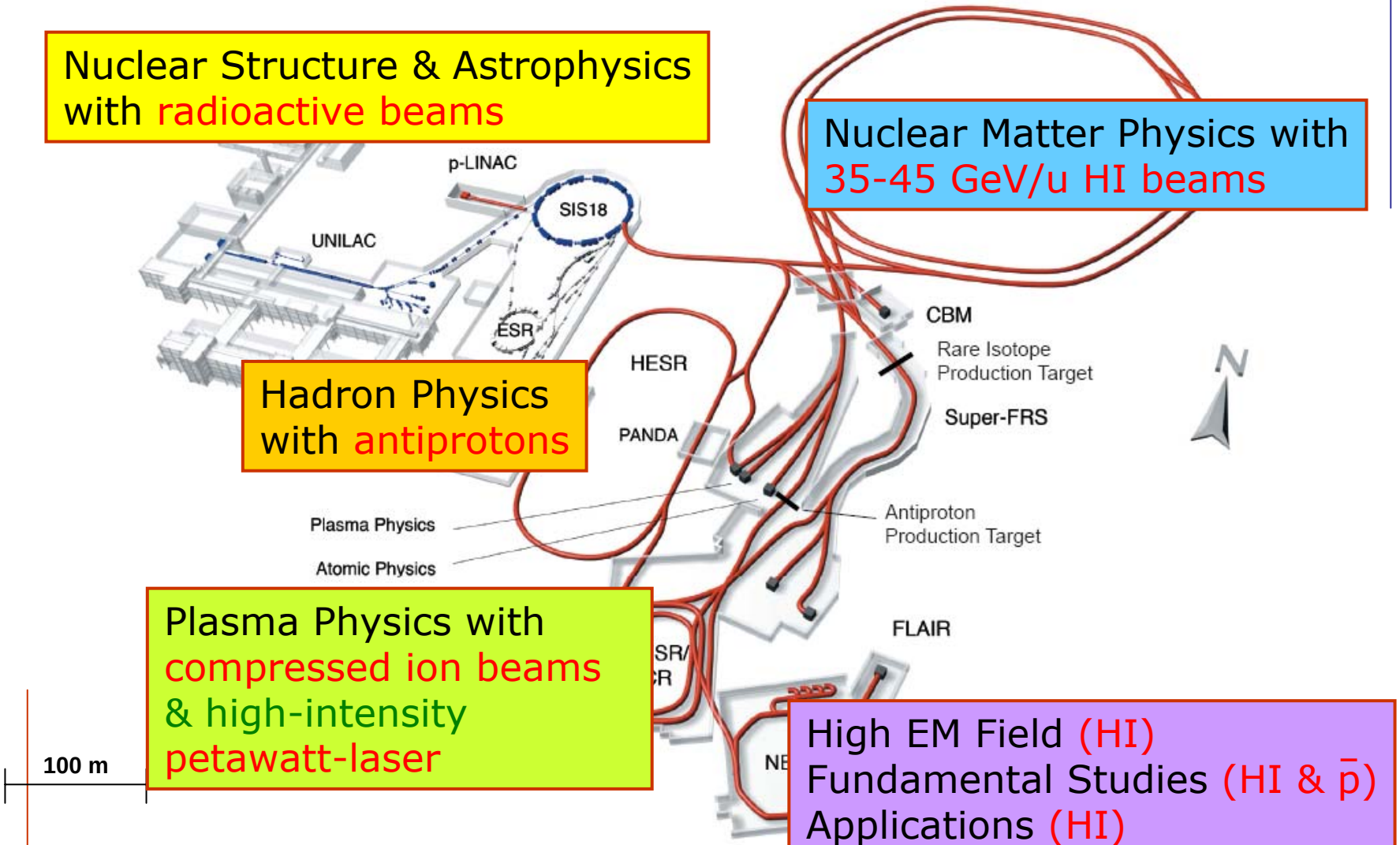
Nuclear Structure & Astrophysics with radioactive beams

Nuclear Matter Physics with 35-45 GeV/u HI beams

Hadron Physics with antiprotons

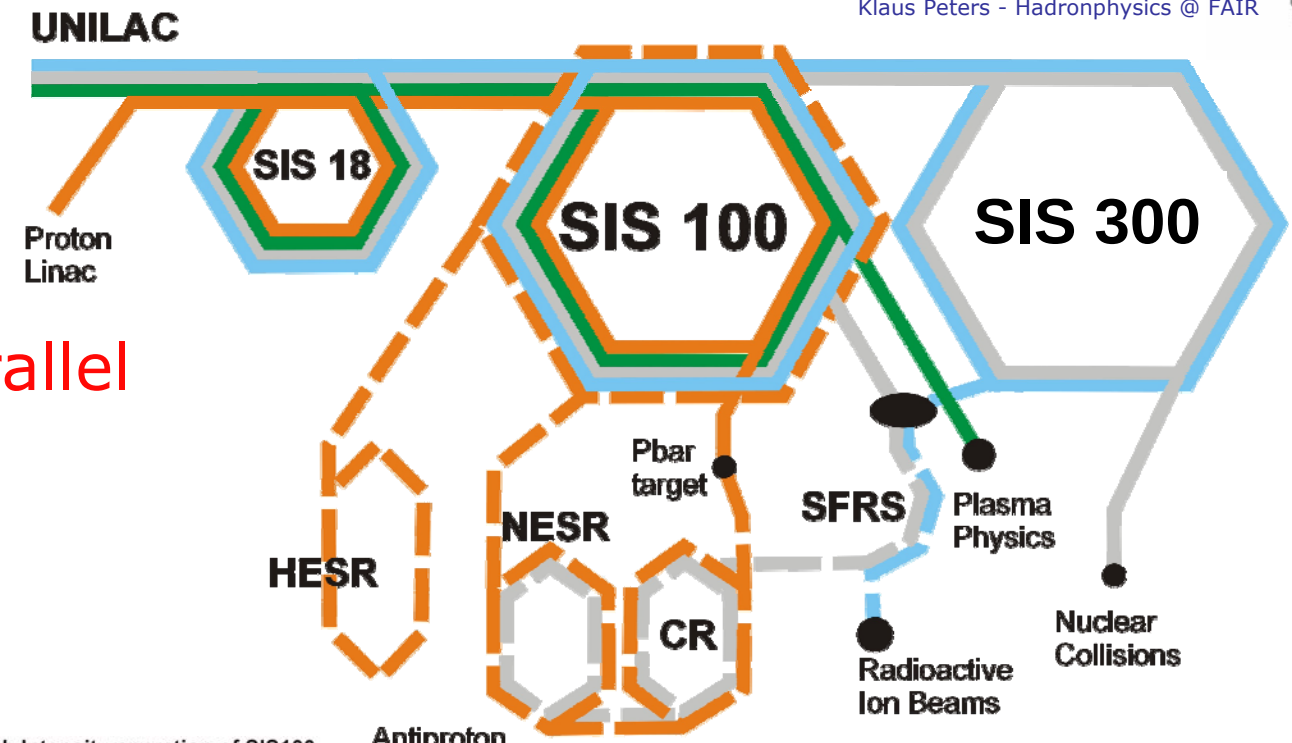
Plasma Physics with compressed ion beams & high-intensity petawatt-laser

High EM Field (HI)
Fundamental Studies (HI & $\bar{p}$)
Applications (HI)



# Accelerator Chain

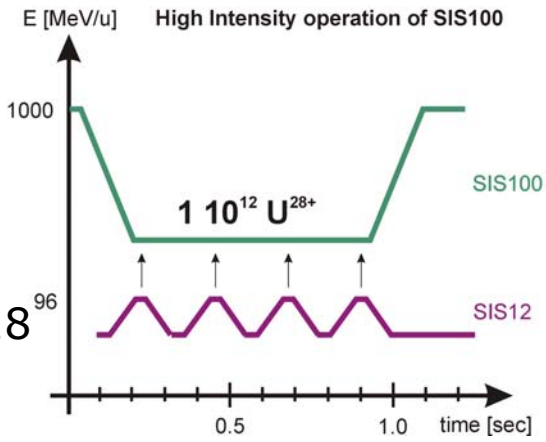




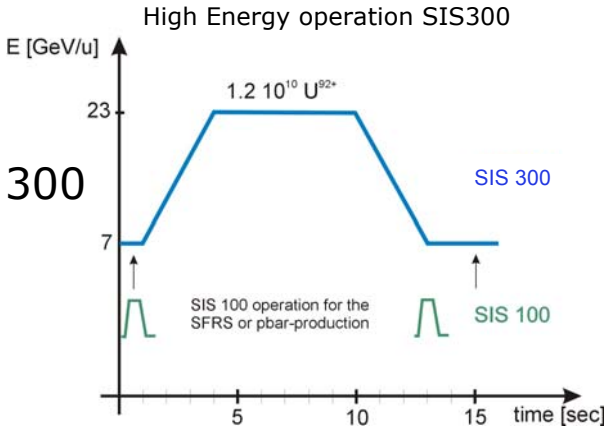

Highly Parallel Operation

SIS 100

SIS 12/18

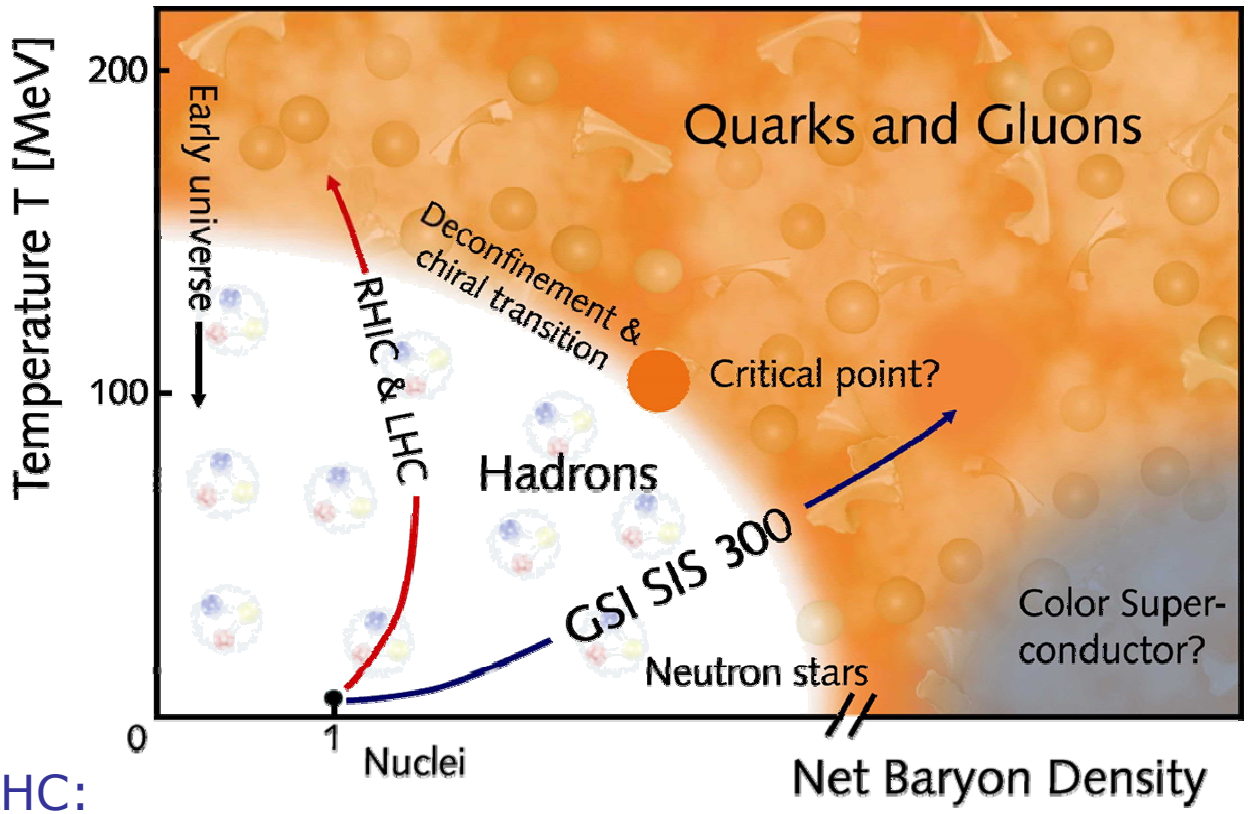



SIS 300



# Phase diagram of strongly interacting matter

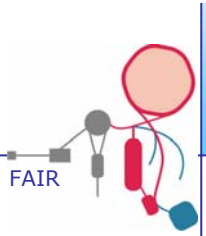





- SPS, RHIC, LHC:
  high temperature, low baryon density
- SIS300:
  moderate temperature, high baryon density

# CBM Experiment - Objectives



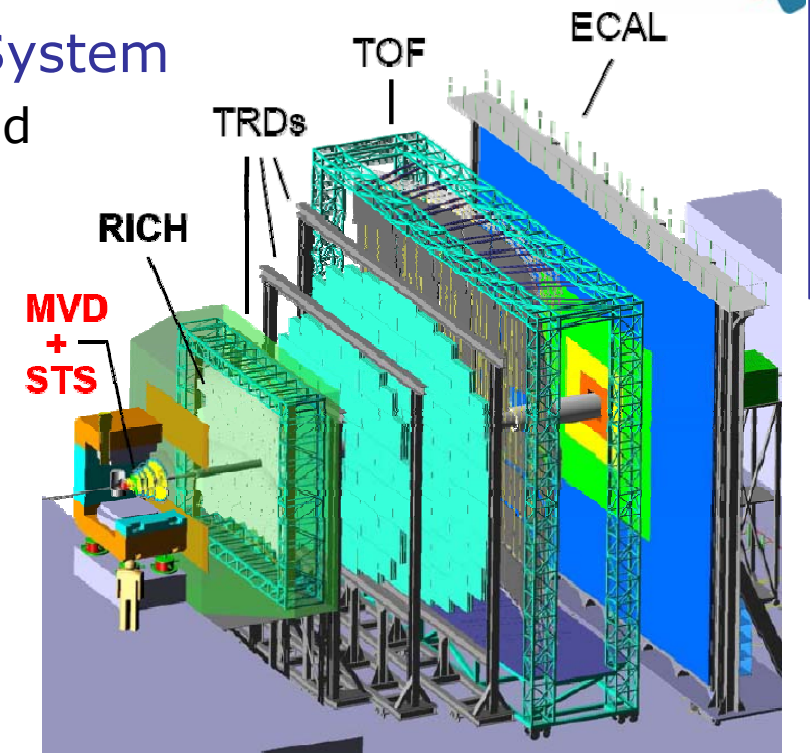


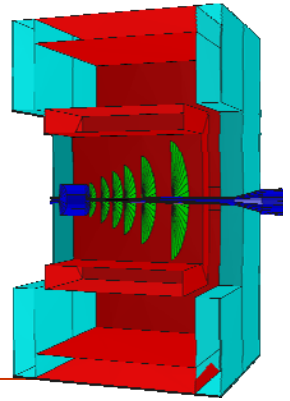
- **In-medium modifications of hadrons**
  onset of chiral symmetry restoration at high $\rho_B$
  measure: $\rho$, $\omega$, $\phi$ → $e^+e^-$ and open charm (D mesons)
- **Strangeness in matter (strange matter?)**
  enhanced strangeness production ?
  measure: K, $\Lambda$, $\Sigma$, $\Xi$, $\Omega$
- **Indications for deconfinement at high $\rho_B$**
  anomalous charmonium suppression ?
  measure: J/$\psi$, D
- **Critical point**
  event-by-event fluctuations
- **Color superconductivity**
  precursor effects ?

# CBM @ FAIR



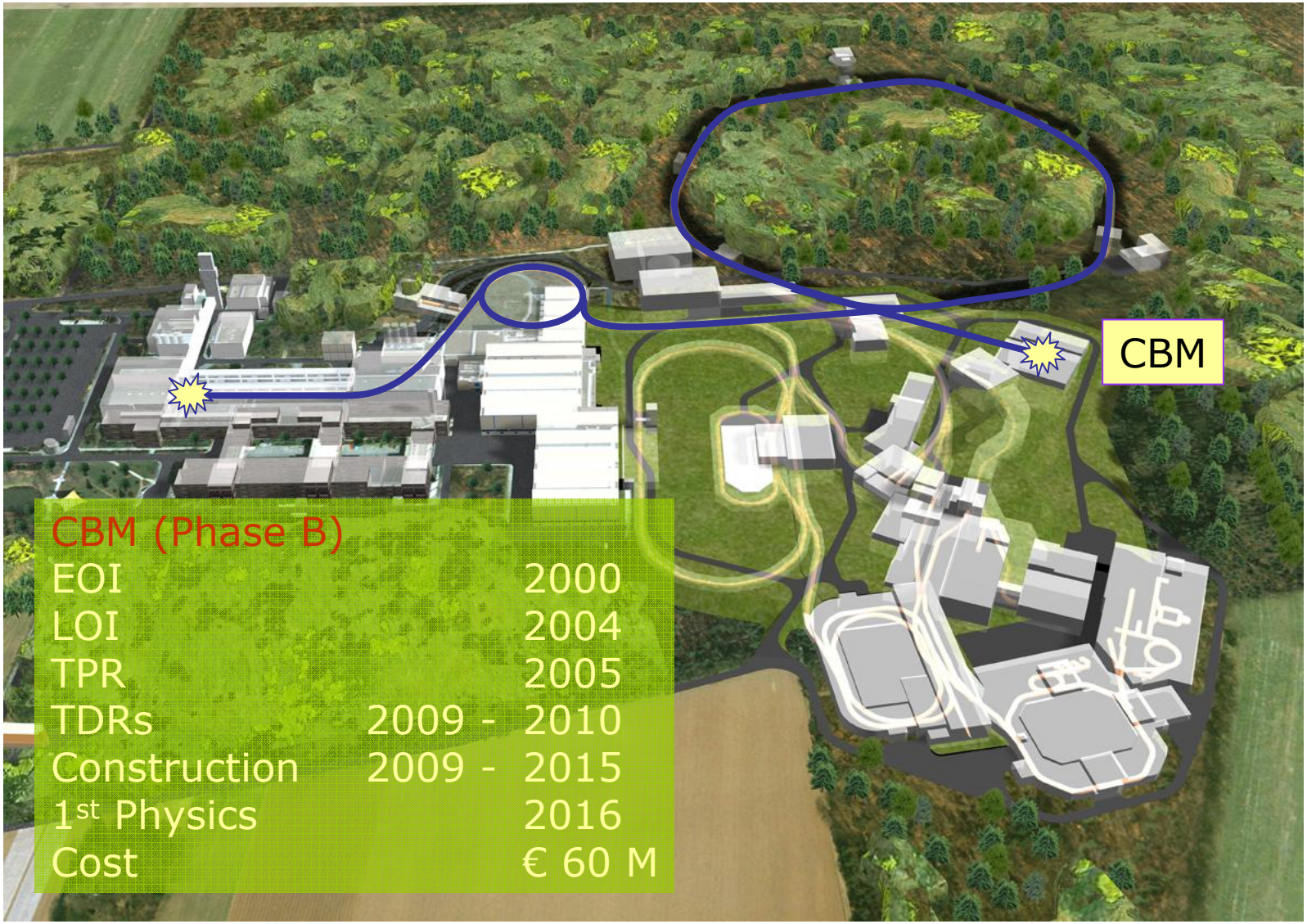
- Radiation hard Silicon Tracking System
  (pixel/strip) in a magnetic dipole field
- Electron detectors:
  RICH & TRD & ECAL:
  pion suppression better $10^4$
- Hadron identification:
  TOF-RPC
- Measurement of
  photons, π, η, and muons:
  electromagnetic calorimeter (ECAL)
- High speed data acquisition and trigger system



# QCD phases @ FAIR



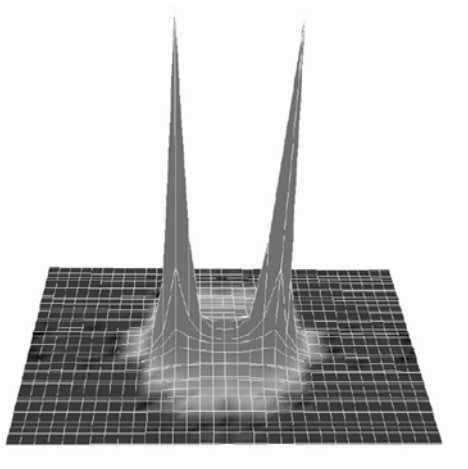


# The Fluxtube in a Meson

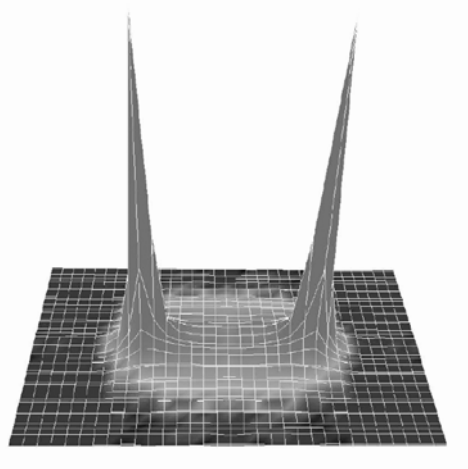


$[\bar{q}q]$ bound state

**strong interaction strength**

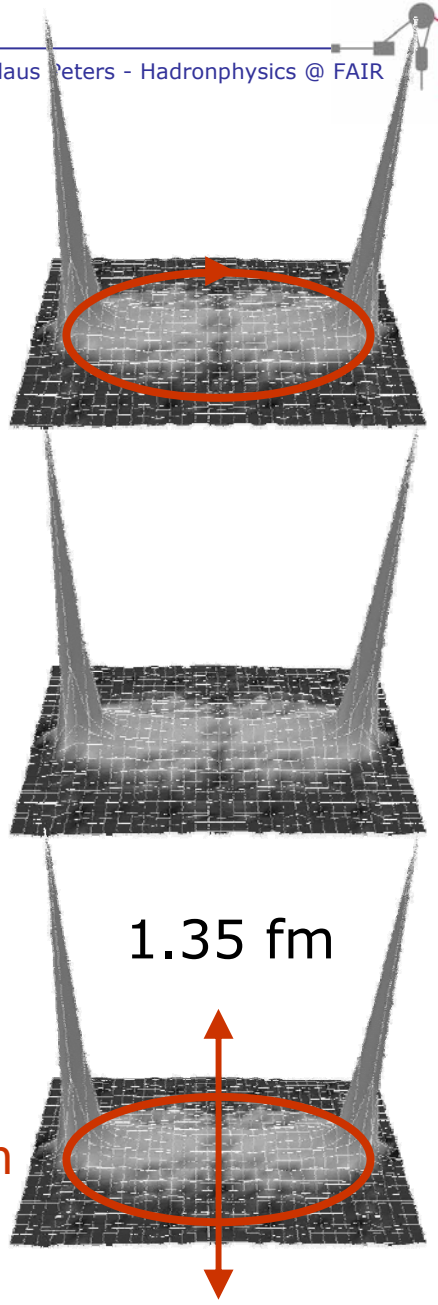


0.7 fm



1.0 fm

Rotation



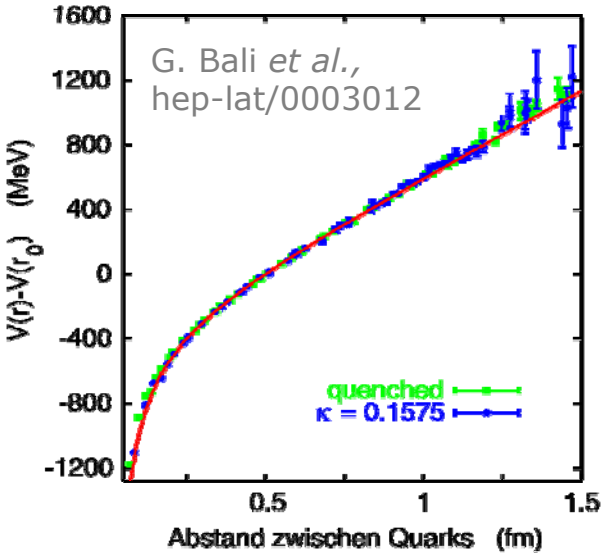
1.35 fm

Vibration

Lattice QCD calculations
G. Bali, hep-lat/9409005

# The Potential – A Guide





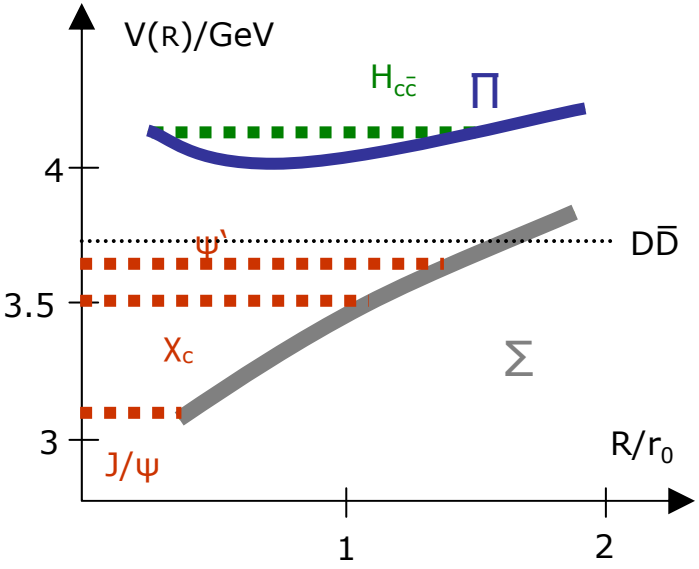

$$H_{SD} = V_{LS} + V_{SS} + V_T$$

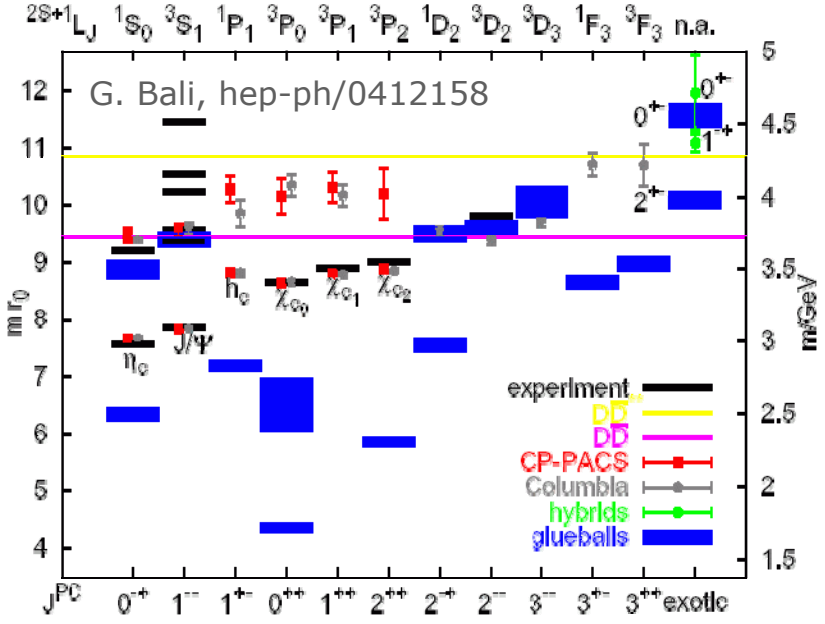
spin-orbit (fine structure)
$$V_{LS} = \frac{(\vec{L}\cdot\vec{S})}{2m_c^2 r}\left(3\frac{dV_V}{dr} - \frac{dV_S}{dr}\right)$$

spin-spin (hyperfine structure)
$$V_{SS} = \frac{2(\vec{S}_1\cdot\vec{S}_2)}{3m_c^2}\nabla^2 V_V(r)$$

tensor
$$V_T = \frac{2\left[3(\vec{S}\cdot\hat{r})(\vec{S}\cdot\hat{r}) - S^2\right]}{12m_c^2}\left(\frac{1}{r}\frac{dV_V}{dr} - \frac{d^2V_V}{dr^2}\right)$$

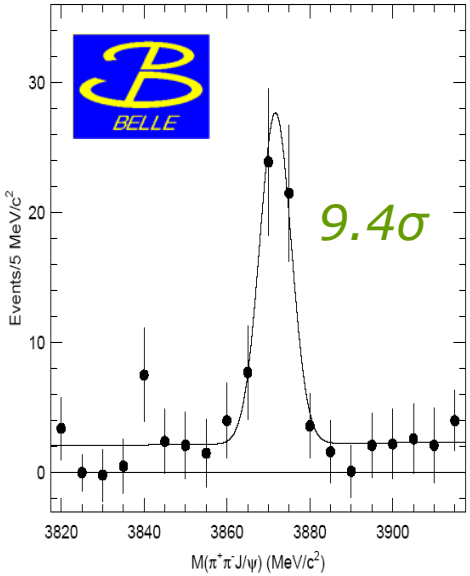
$V_S$ and $V_V$ are the scalar and vector components of the non-relativistic potential



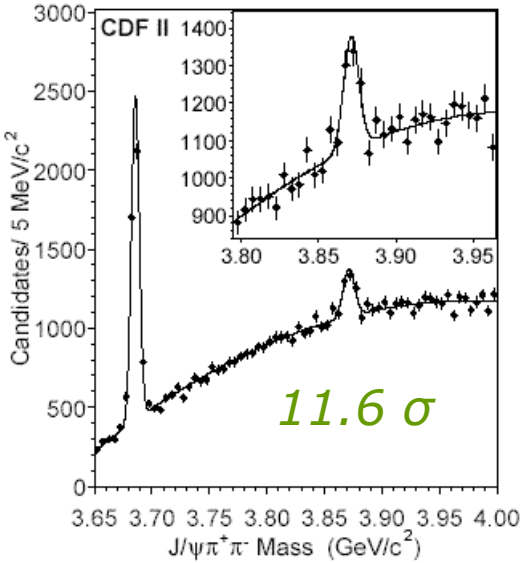
# X(3872) and Confirmation



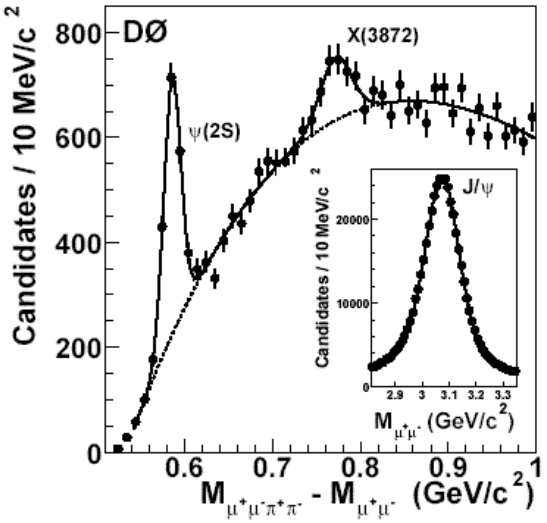


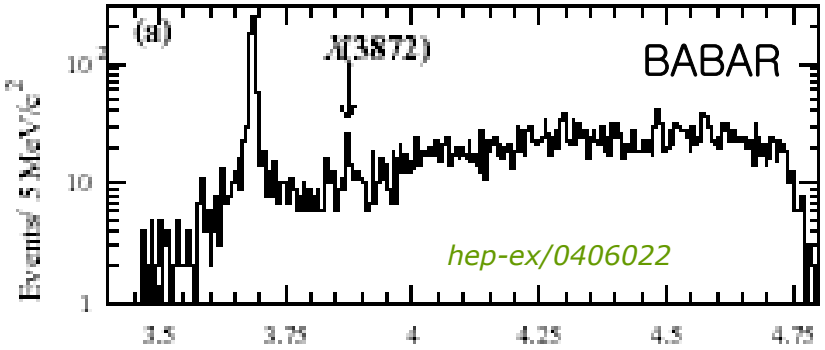

*Phys. Rev. Lett. 91(2003)262001*
*152 Mill. BB*

hep-ex/0312021




hep-ex/0405004




*hep-ex/0406022*

# Why Antiprotons for Heavy Flavour Spectroscopy



- high resolution spectroscopy with $\bar{p}$-beams in formation experiments:

  $\Delta E \approx \Delta E_{beam}$

  - $e^+e^-$ interactions:

    Only $1^{--}$ states are formed

    Other states only by secondary decays

    moderate mass resolution

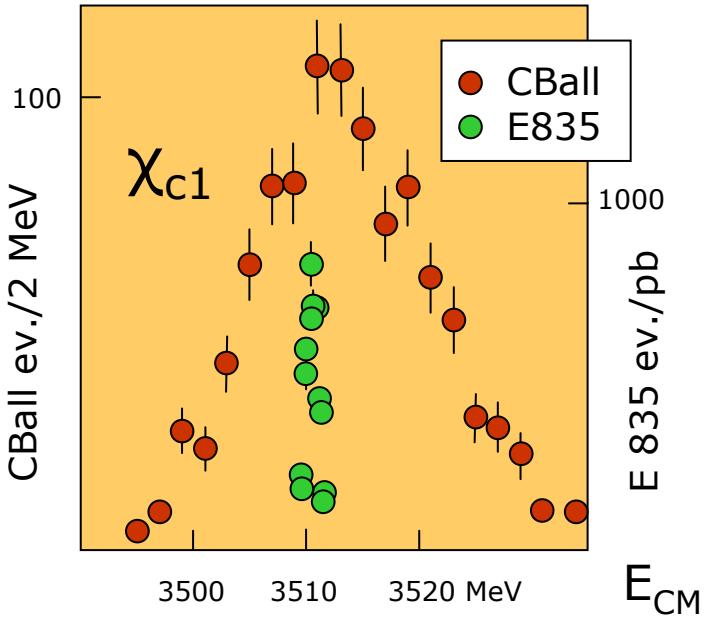
$$e^+e^- \rightarrow \psi' \rightarrow \gamma\chi_{c1,2} \rightarrow \gamma\gamma J/\psi \rightarrow \gamma\gamma e^+e^-$$

  - $p\bar{p}$ reactions:

    All states directly formed

    very good mass resolution

$$p\bar{p} \rightarrow \chi_{c1,2} \rightarrow \gamma J/\psi \rightarrow \gamma e^+e^-$$

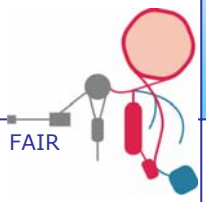



CBall, Edwards et al. PRL 48 (1982) 70

E835, Ambrogiani et al., PRD 62 (2000) 052002

# Why Antiprotons for Heavy Flavour Spectroscopy





- high resolution spectroscopy with $\bar{p}$-beams in formation experiments:
  ΔE ≈ ΔEbeam → Precision Frontier

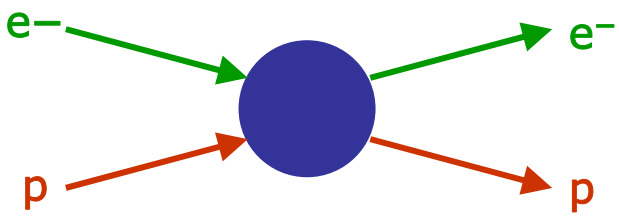
- high yield of gluonic and radial excitations in $p\bar{p}$
  glueballs, charmed hybrids → Discovery Potential

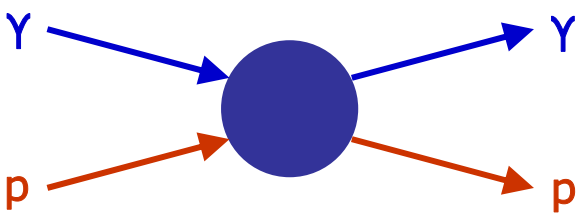
- event tagging by pair wise associated production,
  (particle, anti-particle) e.g. $pp \rightarrow D\bar{D}$

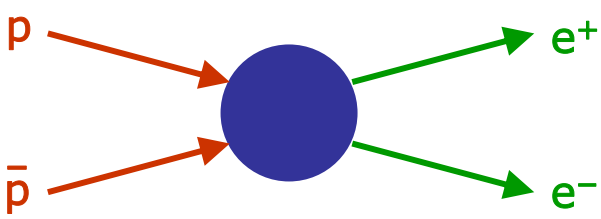
- large √s at low momentum transfer
  important for in-medium "implantation" of hadrons:
  study of in-medium effects of charmed states

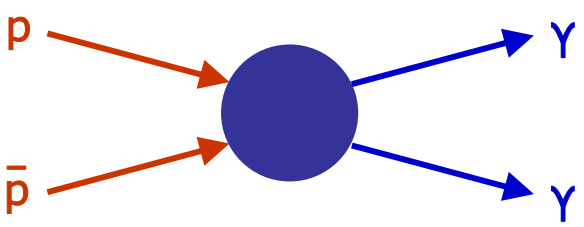
# Electromagnetic Reactions





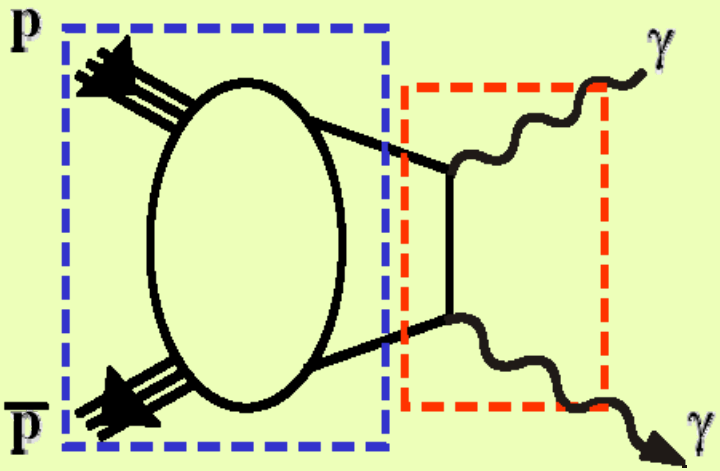



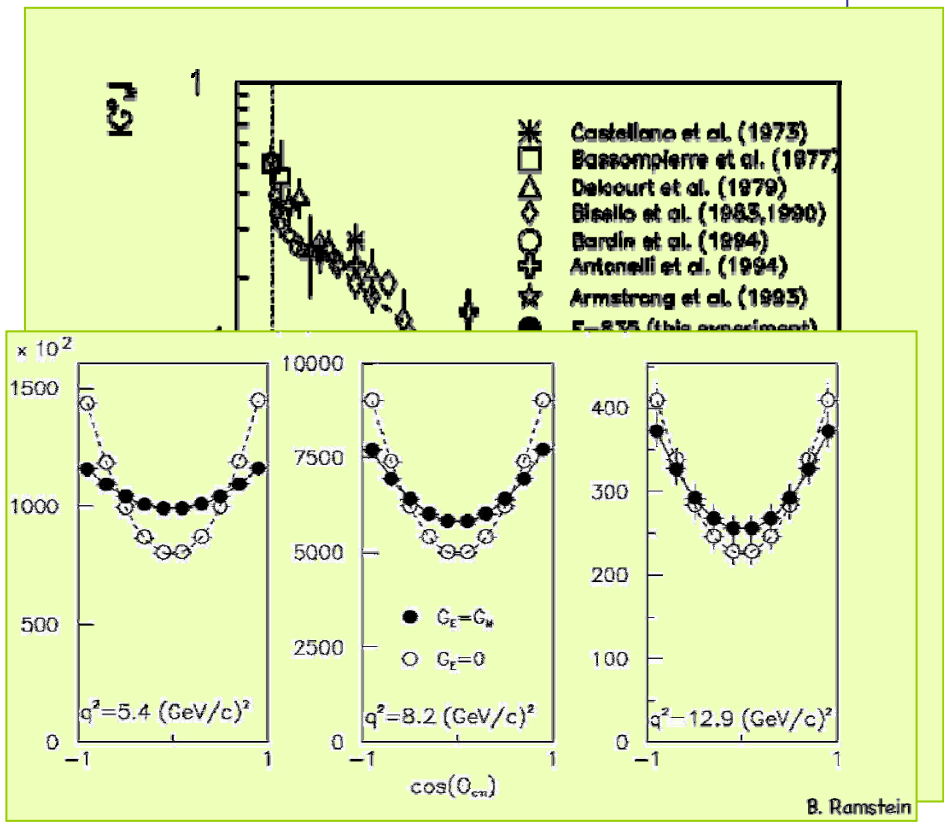



# Crossed-Channel Compton Scattering





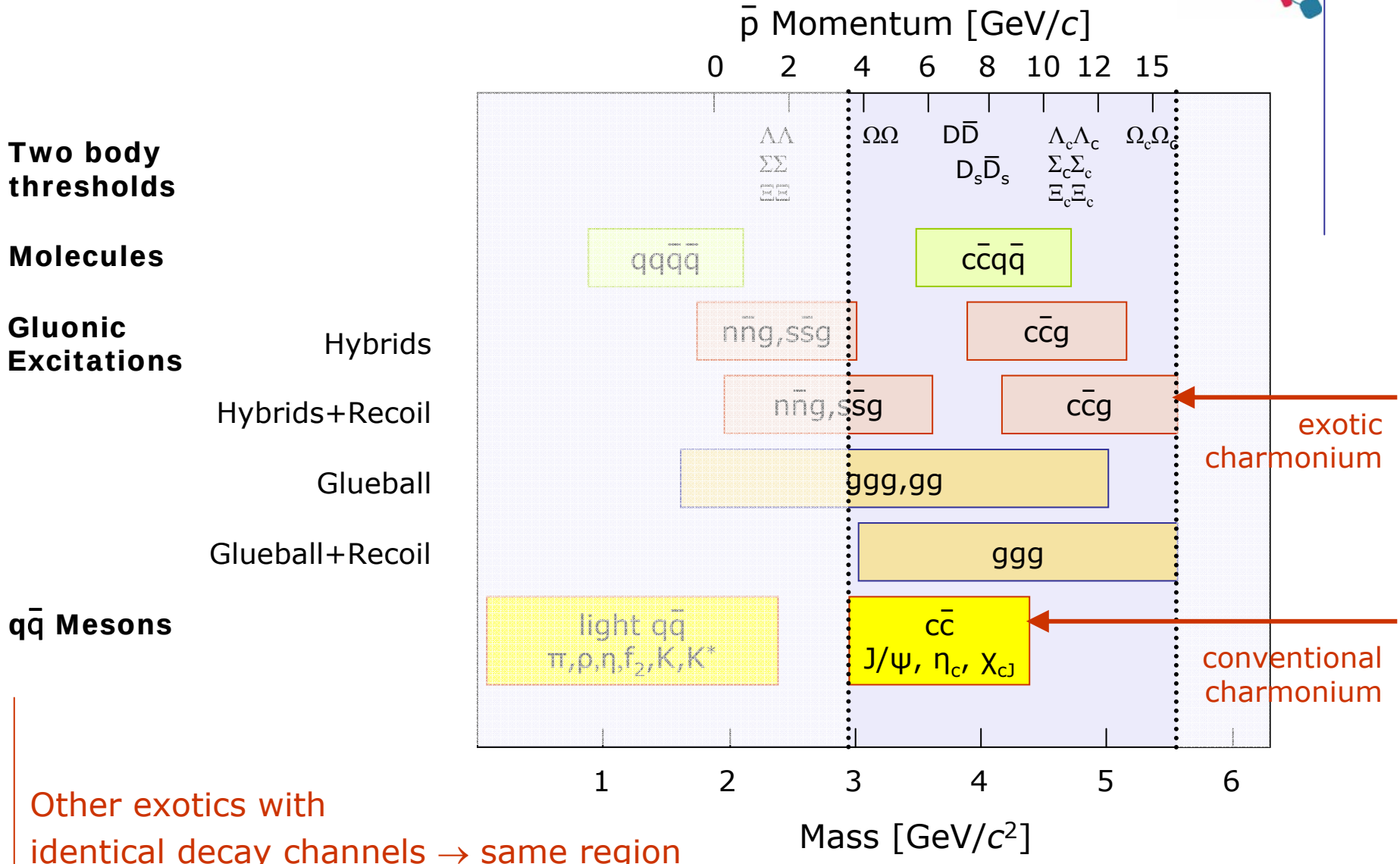

Cross section σ ≈ 2.5pb @ s ≈10 GeV$^2$
L = 2·10$^{32}$ cm-2 s-1→ 10$^3$ Events/Month




# Electromagnetic Formfactor of the Proton (time-like)

# Accessible Charmed Hadrons at $\bar{P}$ANDA





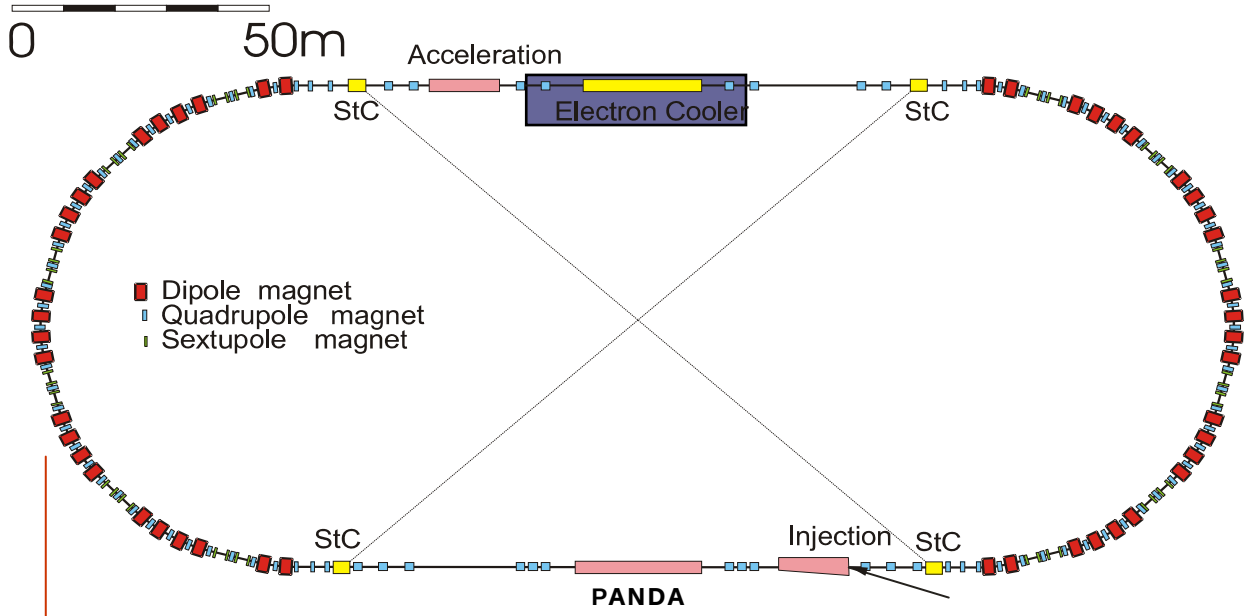

Other exotics with
identical decay channels → same region

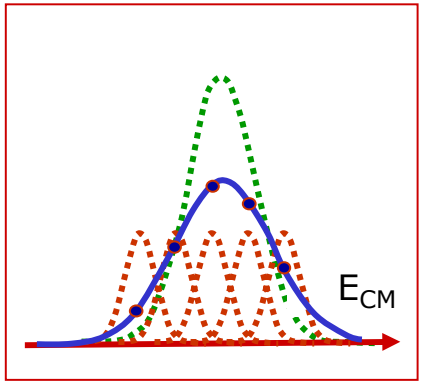
# HESR – Storage Ring for Antiprotons

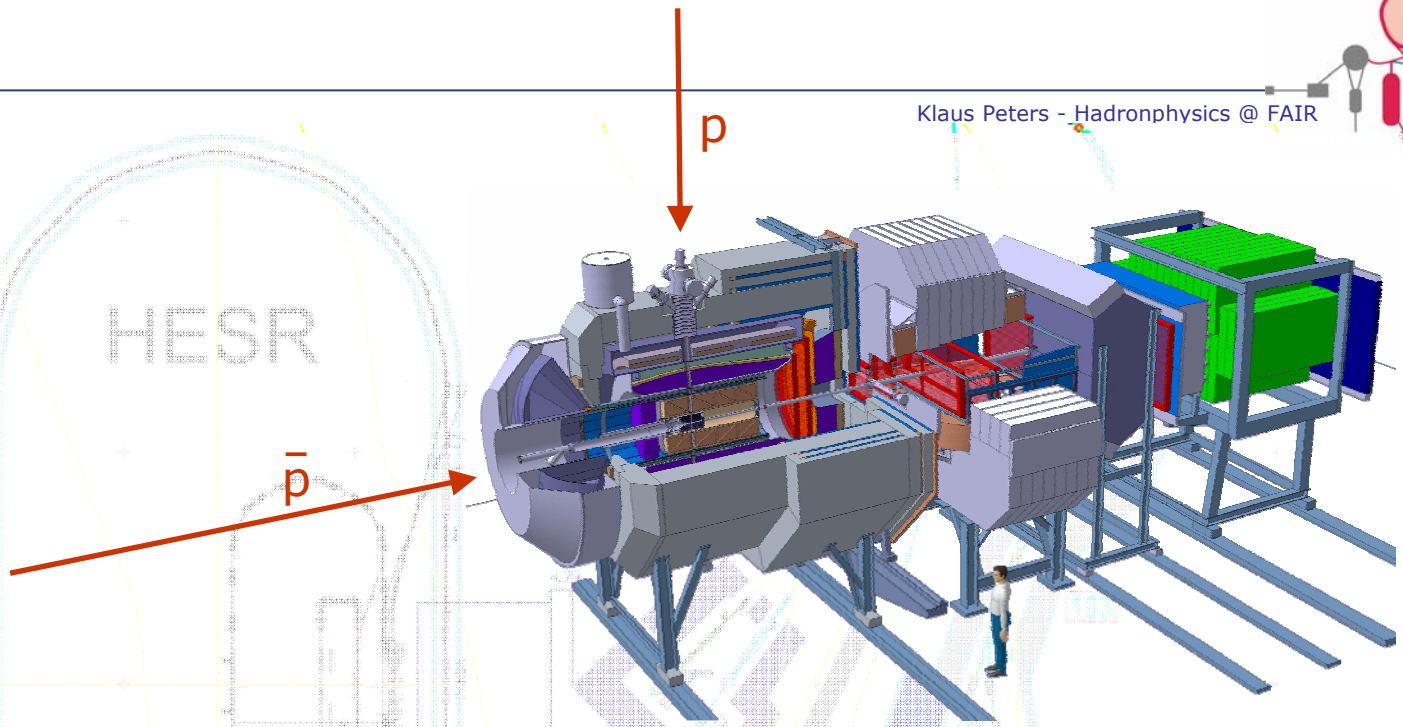


**Parameters of HESR**
- Injection of p at 3.7 GeV
- Slow synchrotron (1.5-14.5 GeV/c)
- Storage ring for internal target operation
- Luminosity up to L~ $2x10^{32}$ $cm^{-2}s^{-1}$
- Beam cooling (stochastic & electron)

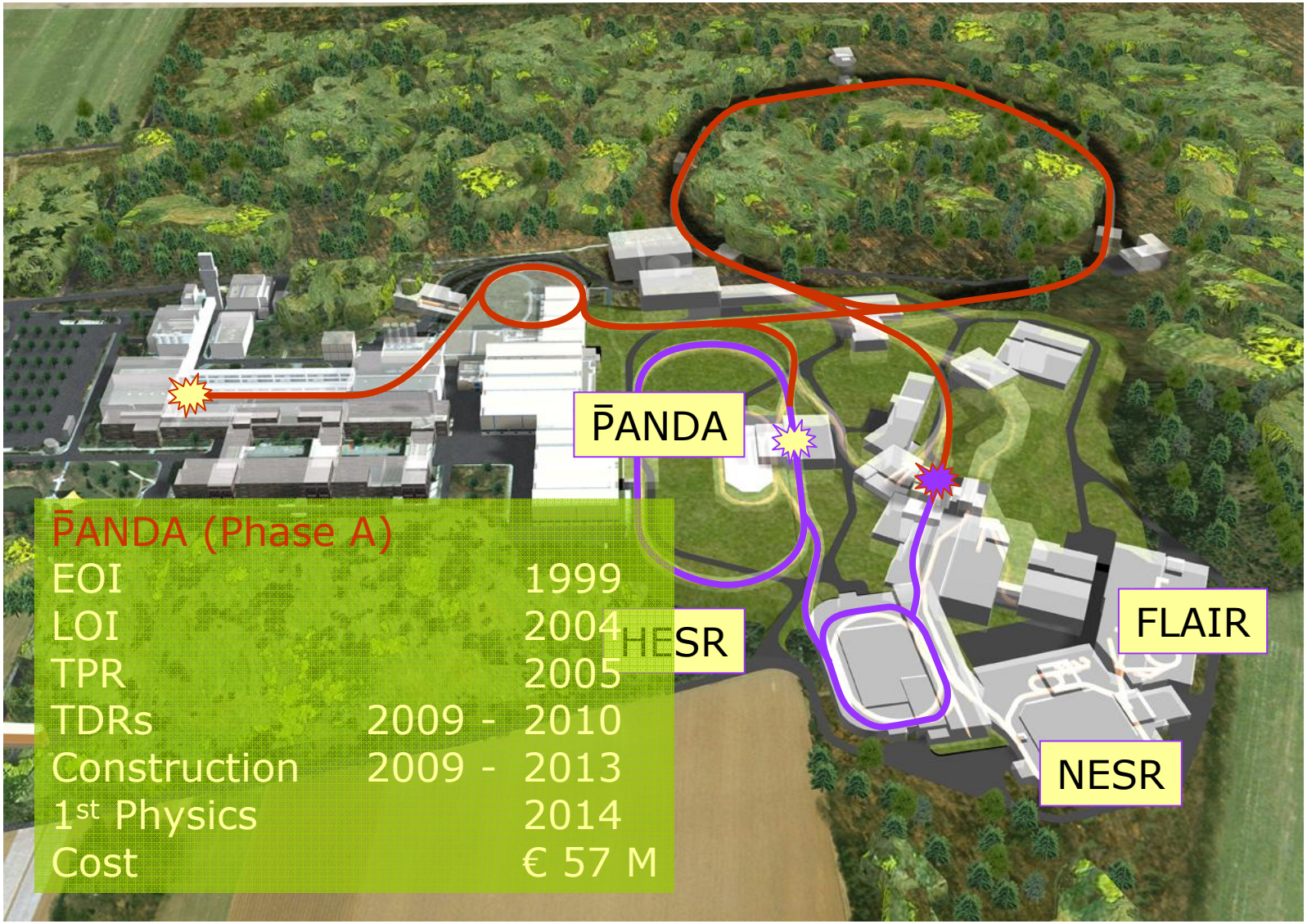
**Resonance scan**
- Energy resolution ~50 keV
- Tune $E_{CM}$ to probe resonance
- Get precise mass and width






- High luminosity mode
  Luminosity = 2 x $10^{32}$ $cm^{-2}s^{-1}$
  $\delta p/p \sim 10^{-4}$ (stochastic cooling)
- High resolution mode
  $\delta p/p \sim$ few $10^{-5}$ (+electron cooling)
  Luminosity > $10^{31}$ $cm^{-2}s^{-1}$
- Gas-Jet/Pellet/Wire Target


PANDA
HESR
FLAIR
NESR
PANDA (Phase A)
EOI 1999
LOI 2004
TPR 2005
TDRs 2009 - 2010
Construction 2009 - 2013
1st Physics 2014
Cost € 57 M

# First "cold" Anti-Hydrogen 2002 @ AD



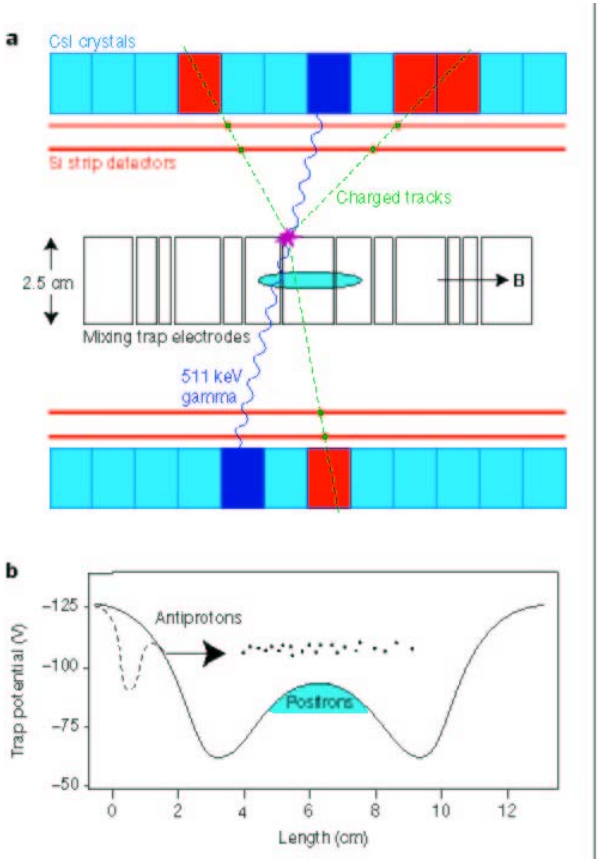
advance online publication

**Production and detection of cold antihydrogen atoms**

M. Amoretti*, C. Amsler†, G. Bonomi‡§, A. Bouchta‡, P. Bowe‖, C. Carraro*, C. L. Cesar¶, M. Charlton#, M. J. T. Collier#, M. Doser‡, V. Filippini☆, K. S. Fine‡, A. Fontana☆**, M. C. Fujiwara††, R. Funakoshi††, P. Genova☆**, J. S. Hangst‖, R. S. Hayano††, M. H. Holzscheiter‡, L. V. Jørgensen#, V. Lagomarsino*‡‡, R. Landua‡, D. Lindelöf†, E. Lodi Rizzini§☆, M. Macri*, N. Madsen†, G. Manuzio*‡‡, M. Marchesotti☆, P. Montagna☆**, H. Pruys†, C. Regenfus†, P. Riedler‡, J. Rochet†#, A. Rotondi☆**, G. Rouleau‡#, G. Testera*, A. Variola*, T. L. Watson# & D. P. van der Werf#

ATHENA Nature 419 (2002) 456

Nested Penning traps
catch energy: some keV




VOLUME 89, NUMBER 21 PHYSICAL REVIEW LETTERS 18 NOVEMBER 2002

**Background-Free Observation of Cold Antihydrogen with Field-Ionization Analysis of Its States**

G. Gabrielse,[1,*] N. S. Bowden,[1] P. Oxley,[1] A. Speck,[1] C. H. Storry,[1] J. N. Tan,[1] M. Wessels,[1] D. Grzonka,[2] W. Oelert,[2] G. Schepers,[2] T. Sefzick,[2] J. Walz,[3] H. Pittner,[4] T. W. Hänsch,[4,5] and E. A. Hessels[6]

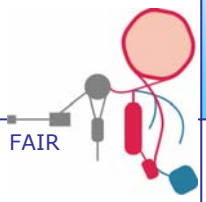
(ATRAP Collaboration)

[1]*Department of Physics, Harvard University, Cambridge, Massachusetts 02138*
[2]*IKP, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany*
[3]*CERN, 1211 Geneva 23, Switzerland*
[4]*Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany*
[5]*Ludwig-Maximilians-Universität München, Schellingstrasse 4/III, 80799 München, Germany*
[6]*York University, Department of Physics and Astronomy, Toronto, Ontario, Canada M3J 1P3*
(Received 11 October 2002; published 31 October 2002)

ATRAP

*Ultimate Resolution: neutral atom traps and laser cooling to milli-Kelvin temperatures - Long Term Project - FAIR*

# FLAIR Physics Overview (Antiprotons)





- **Spectroscopy as Test for CPT and QED**
  Antiprotonic atoms ($\bar{p}$-He, $\bar{p}$-p), anti-hydrogen

  High-brilliant Low energy beams

- **Gravitation of anti-matter**
  Trapped and laser-cooled anti-hydrogen

- **Atomic Collisions**
  Ionization, energy loss, anti-matter-matter

  USR

- **Antiprotons as hadronic Probes**
  X-rays of light $\bar{p}$-Atoms: Low energy QCD
  X-rays of neutron rich nuclei: nuclear structure (halo)
  Antineutron interaction
  Strangeness –2 production

  DC beam, rare ions

- **Medical application: Tumor therapy**

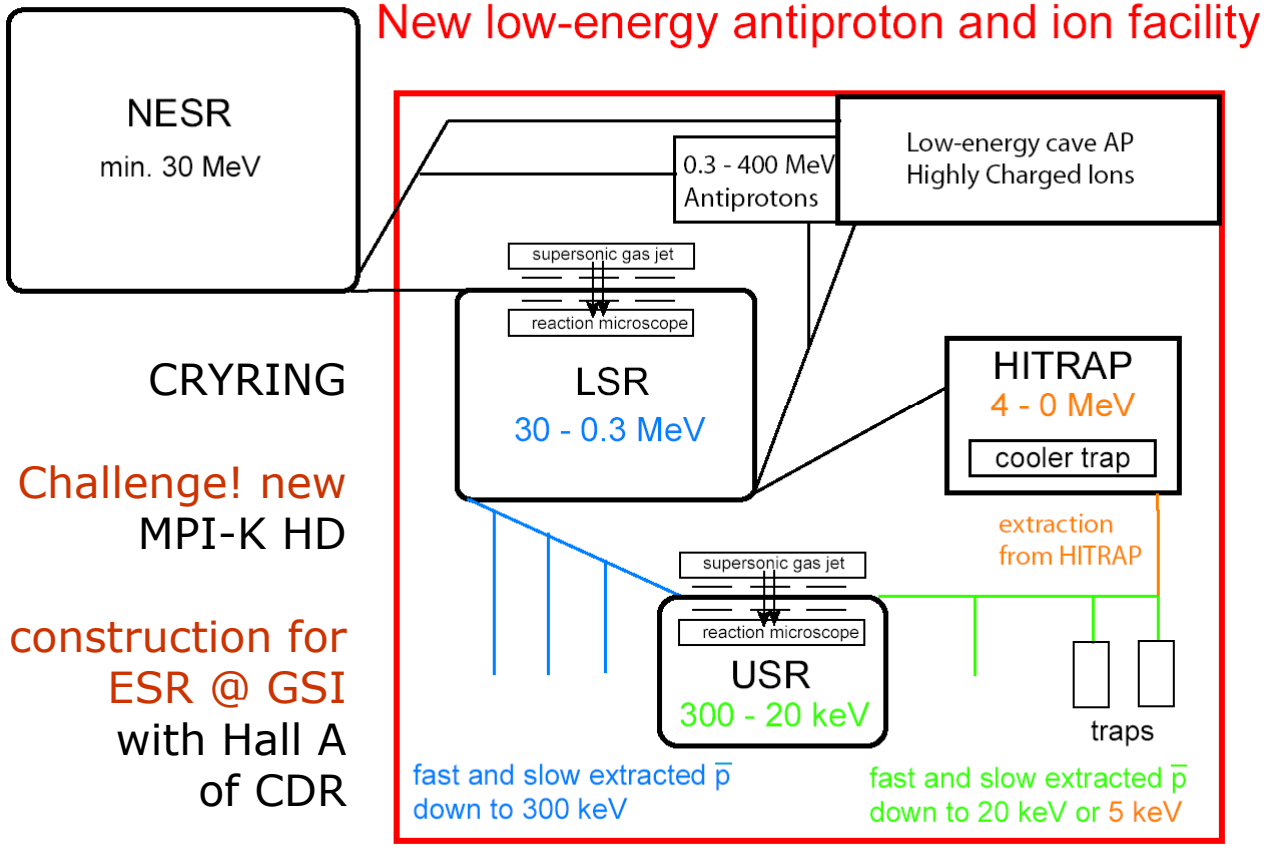
  Higher energies

# FLAIR – Facility for Low-energy Antiproton and Ion Research



- NESR
  $\bar{p}$ & Ions
  30 – 400 MeV
- LSR:
  Standard Ring
  < 300 keV
- USR
  Electrostatic
  < 20 keV
- HITRAP
  $\bar{p}$ & Ions
  stopped & extracted
  @ 5 keV

New low-energy antiproton and ion facility




Challenge! new
MPI-K HD

In construction for
ESR @ GSI
with Hall A
of CDR


FAIR Facility for Antiproton and Ion Research
Kick-Off Event
and
Symposium on the Physics at FAIR
7 - 8 November 2007
GSI, Darmstadt, Germany
Thank You
Advisory Committee
Horst Stöcker (Chair)
Ingo Augustin
Roland Garoby
Bill Gelletly
Hans Gutbrod
Zbigniew Majka
Thomas Stöhlker
Ulrich Wiedner
Local Organizing Committee
Ingo Augustin
Bruno Becker-de Mos
Hans Gutbrod
Alexander Kurz
Ingo Peter
Horst Stöcker
Registration deadline:
15 October 2007
Contact:
fair-event@gsi.de
phone: +49 6159 71 2916
fax: +49 6159 71 3916