The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

1942-45

Sixth International Conference on Perspectives in Hadronic Physics

12 - 16 May 2008

The FAIR project.

K. Peters
KPIII/HPI, GSI Darmstadt & IKF JWGU
Frankfurt
Germany

Hadron Physics @ FAIR

Klaus Peters *KPIII/HPI, GSI Darmstadt & IKF, JWGU Frankfurt*

Sixth International Conference on
Perspectives in Hadronic Physics

The Abdus Salam
International Centre for Theoretical Physics

May 16, 2008

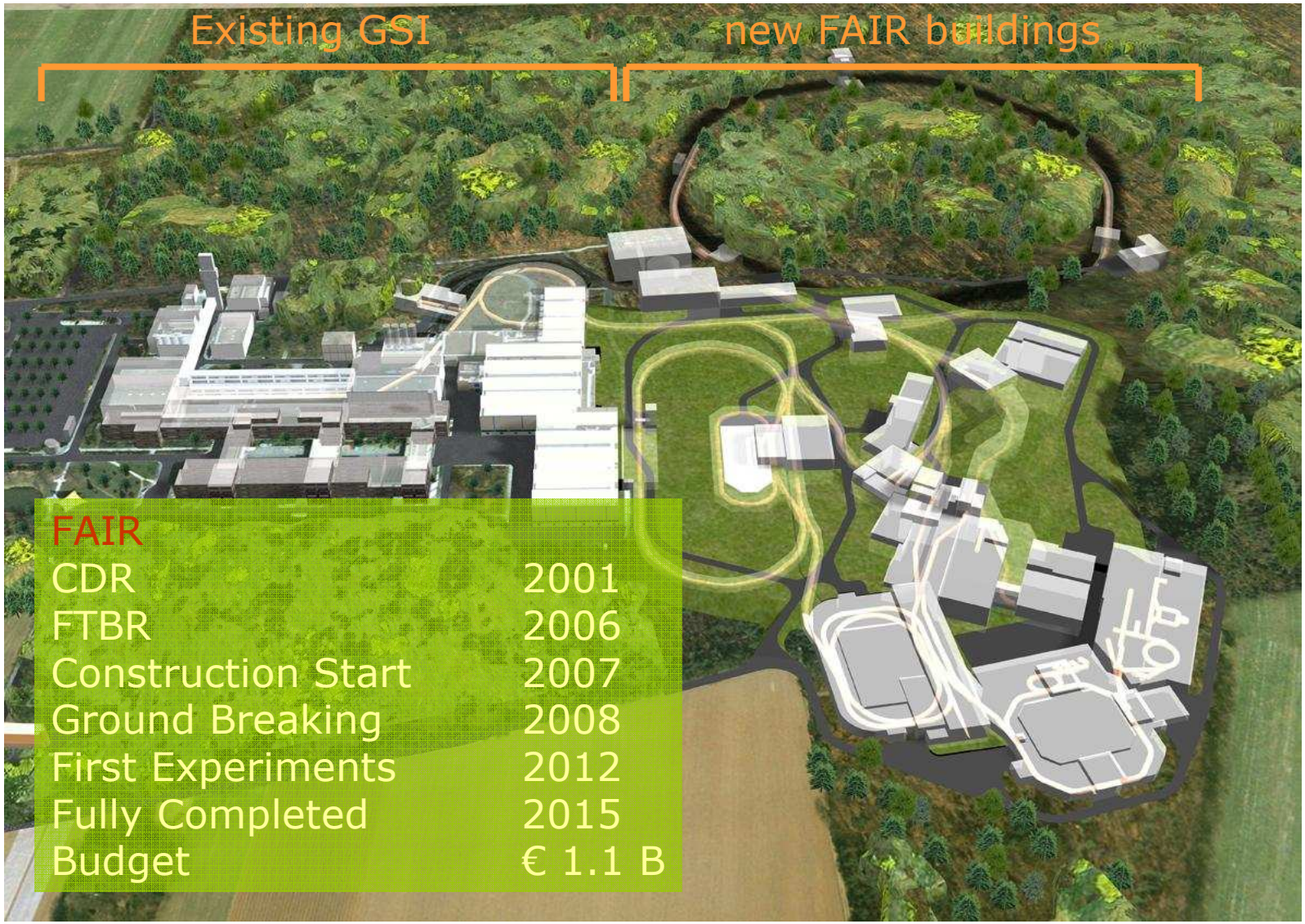
Nov. 7, FAIR Start-Event – last week

Offical Start Signed
By 12 Partners

Volume in Phase A
940 M€

16 Countries

FAIR @ GSI


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

Structure of Matter

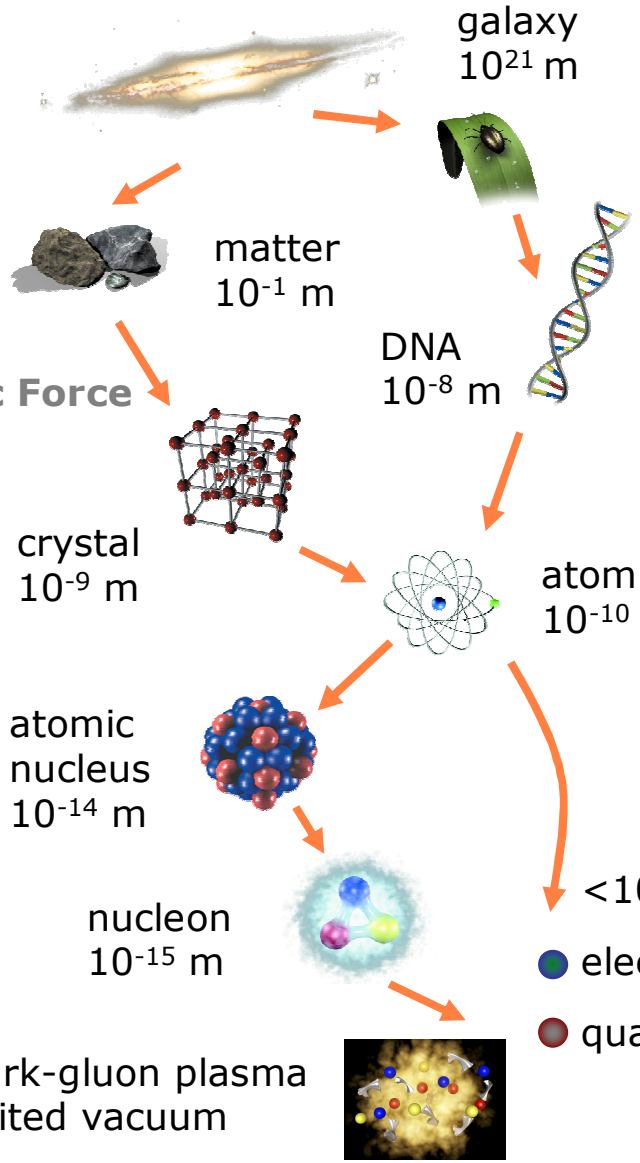
Gravitational Force
General Relativity

Electroweak Force

Electromagnetic Force
QED

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

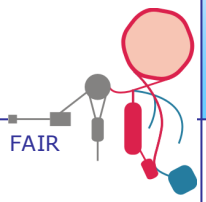
Quark Gluon Structure
of Hadrons

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

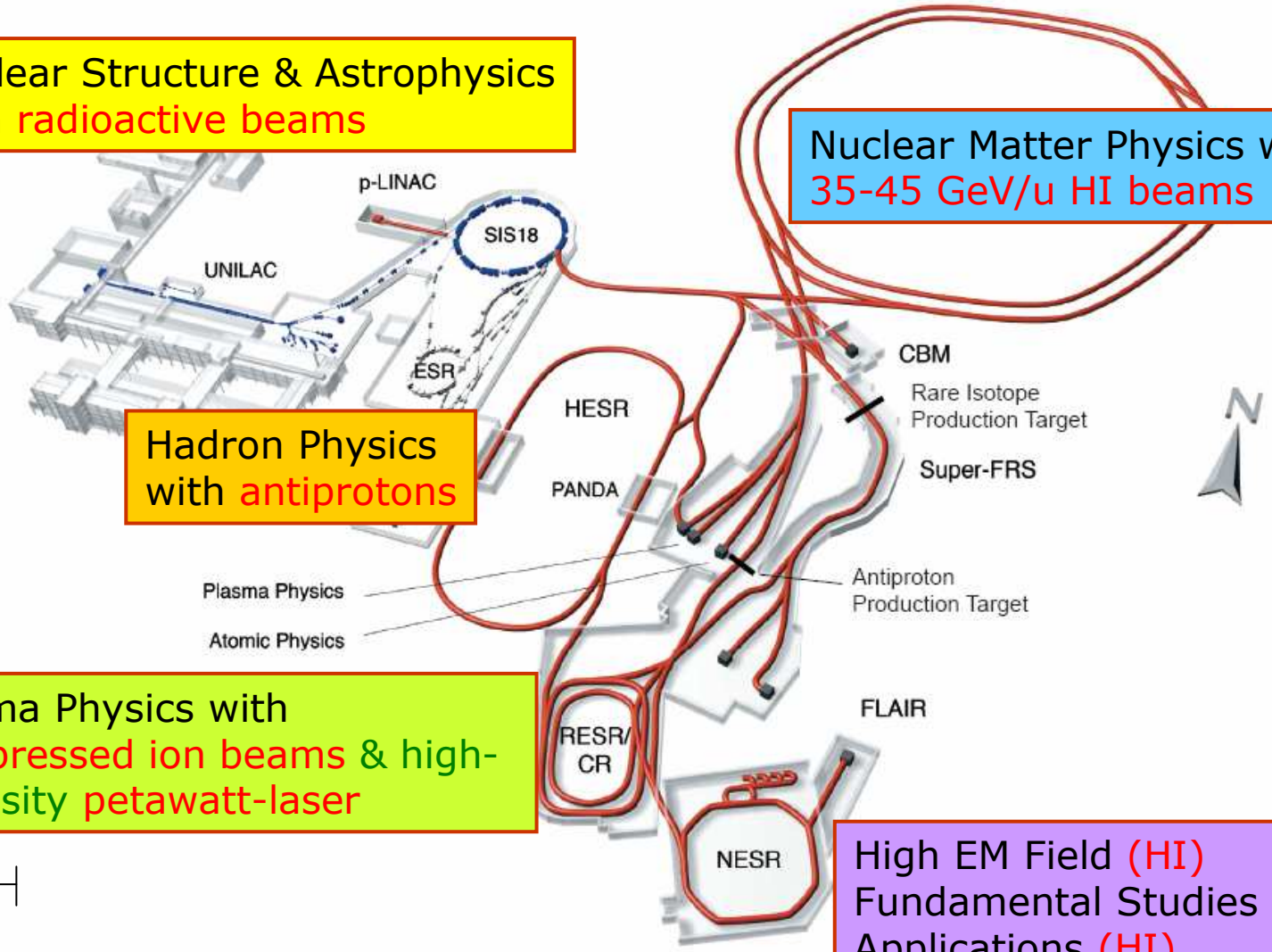
- Many-body aspects play an important role at all levels of the hierarchical structure of matter

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

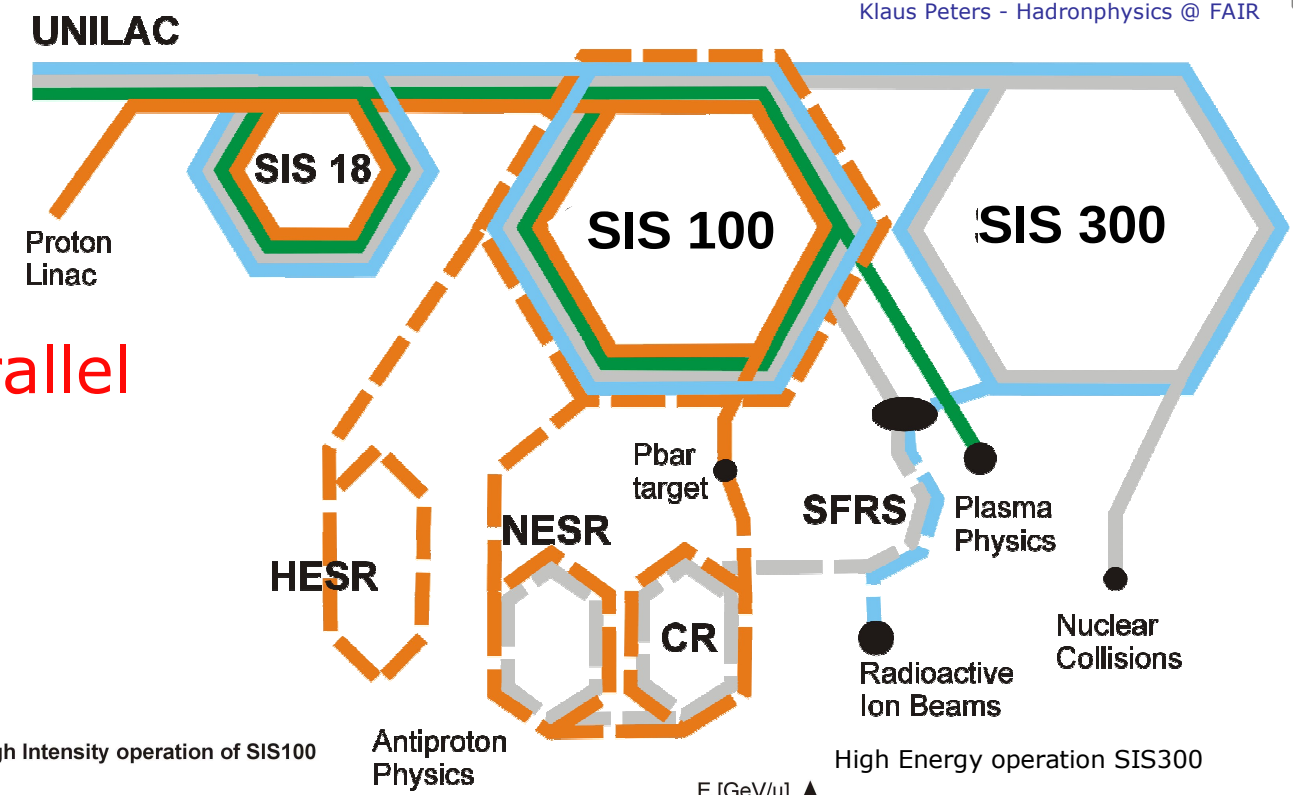


Hadron Physics with antiprotons

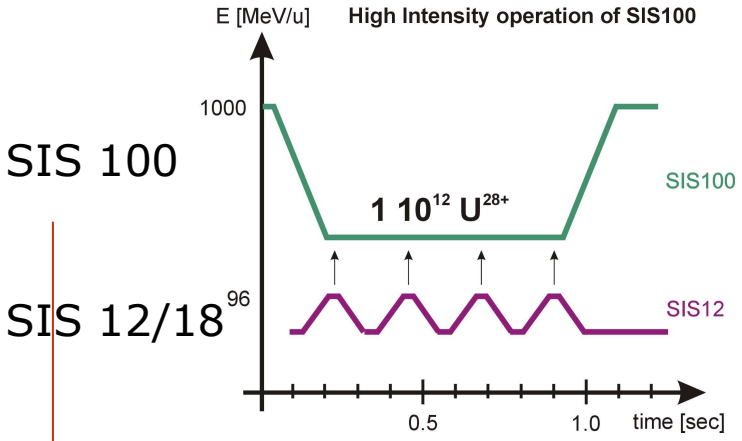
Plasma Physics with compressed ion beams & high-intensity petawatt-laser

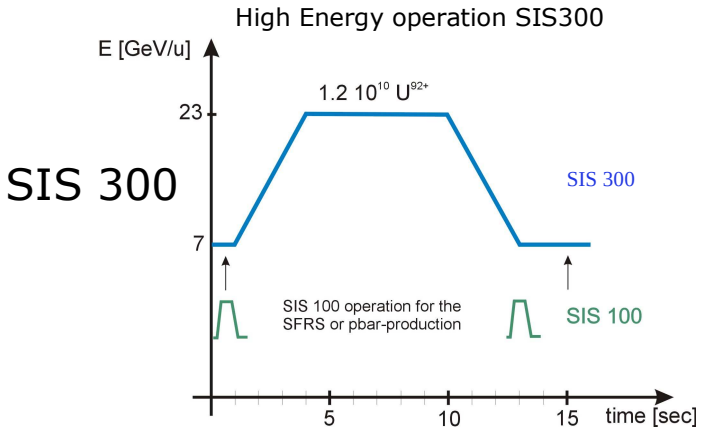
High EM Field (HI)
Fundamental Studies (HI & p)
Applications (HI)

Accelerator Chain

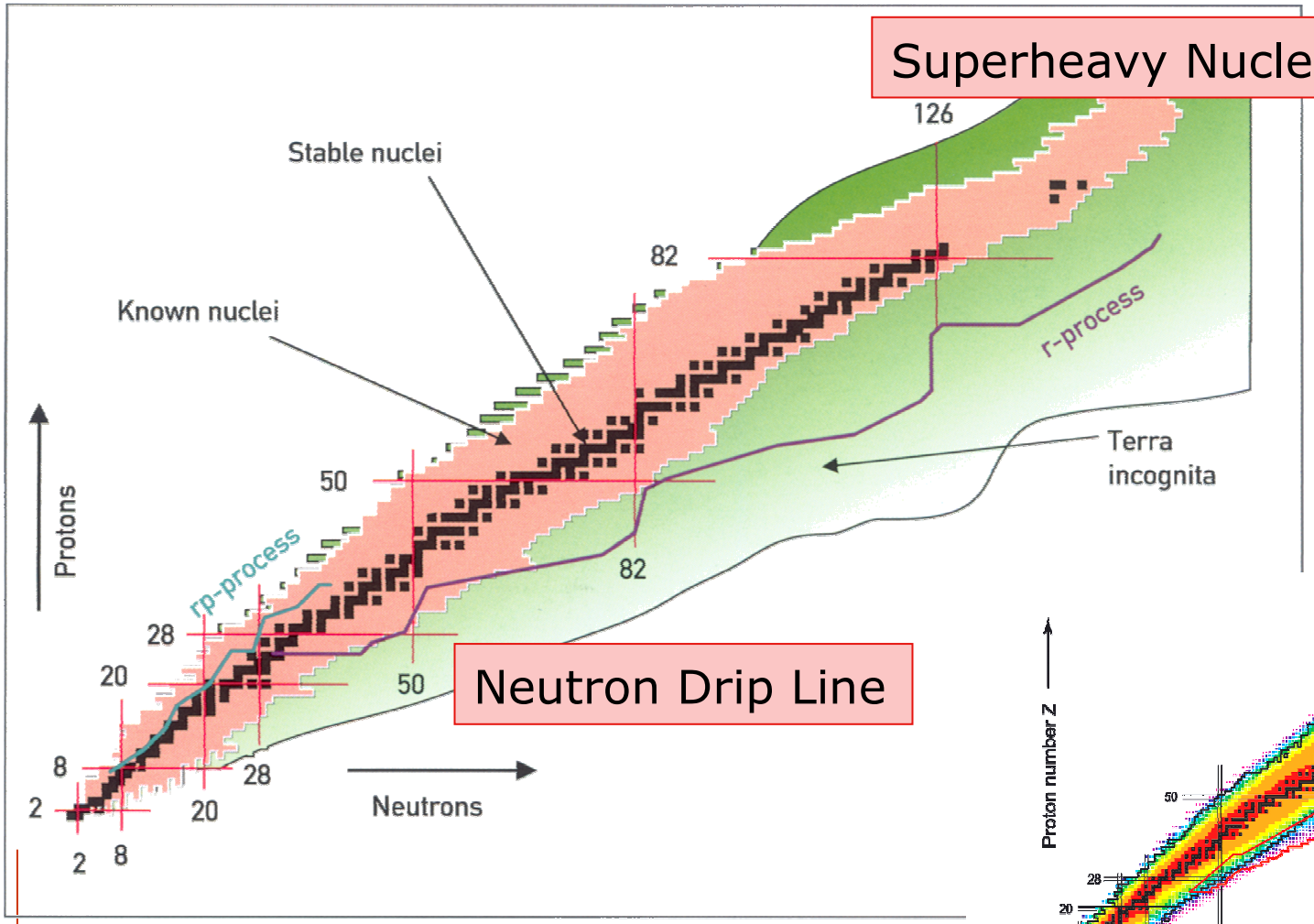


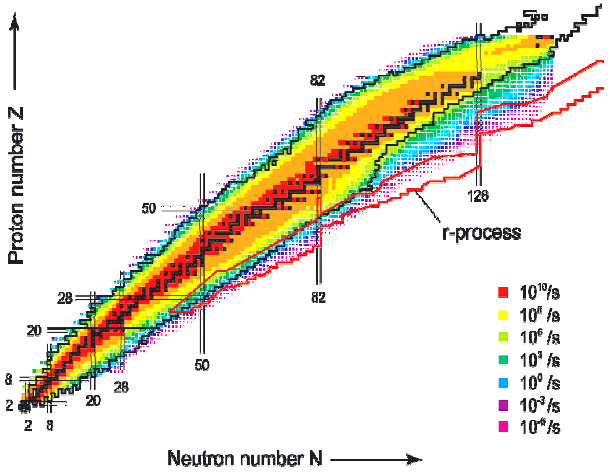
Highly Parallel Operation





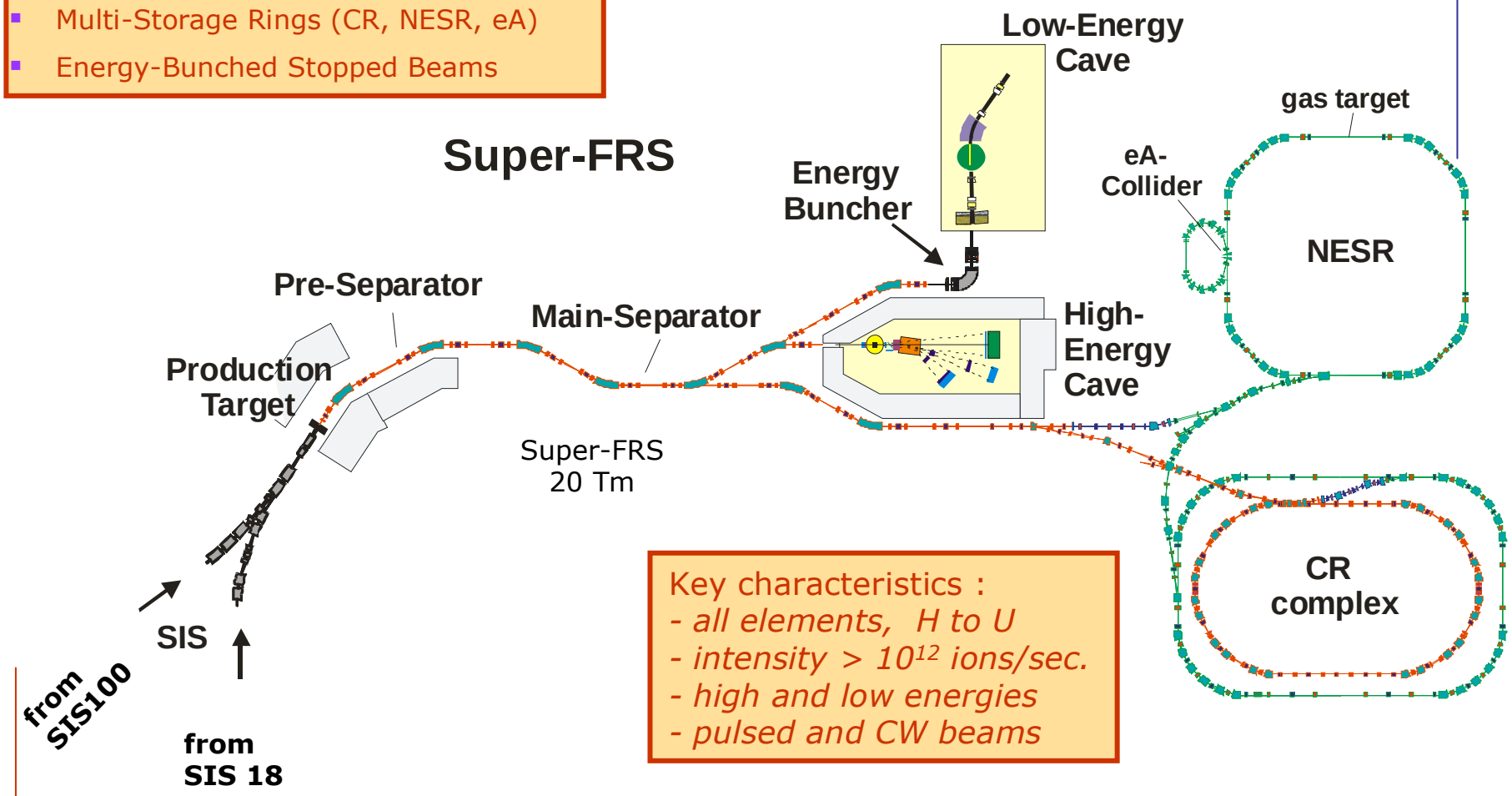
The Nuclear Landscape





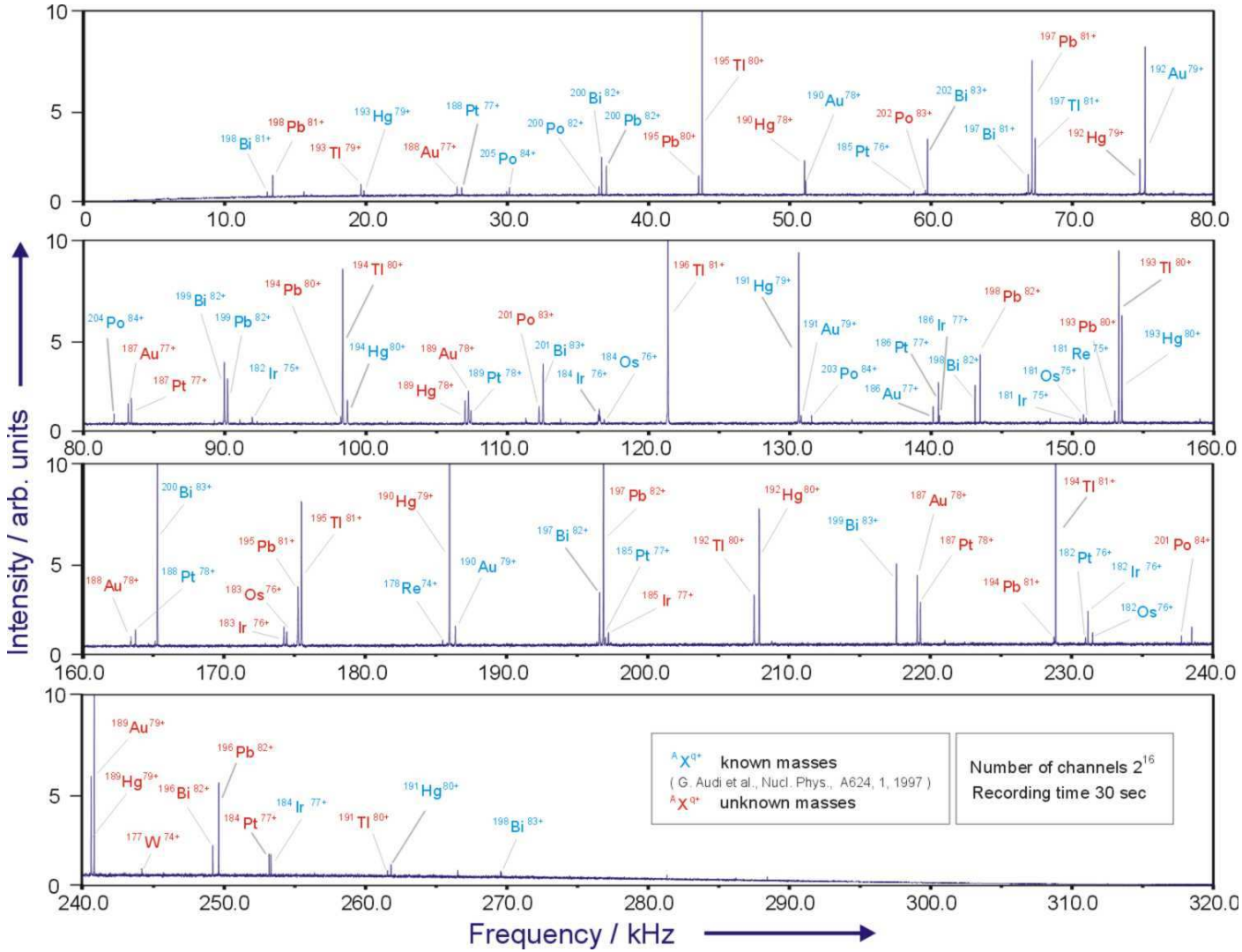
The In-Flight Rare-Isotope Beam Facility 0 - 1500 AMeV

- **Super**conducting **FR**agment **S**eparator
- High-Energy Reaction Setup
- Multi-Storage Rings (CR, NESR, eA)
- Energy-Bunched Stopped Beams

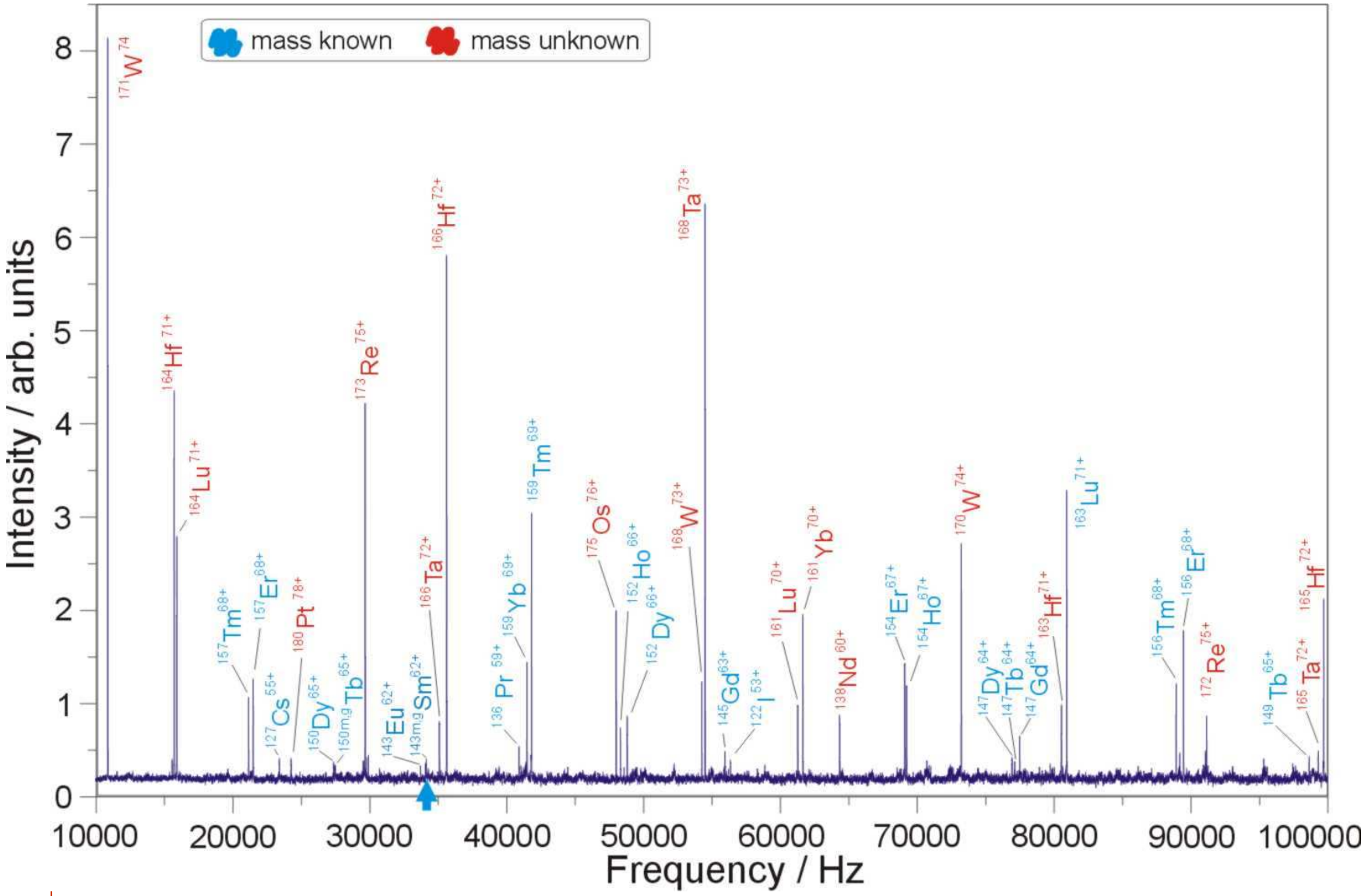


Key characteristics :
- *all elements, H to U*
- *intensity > 10^{12} ions/sec.*
- *high and low energies*
- *pulsed and CW beams*

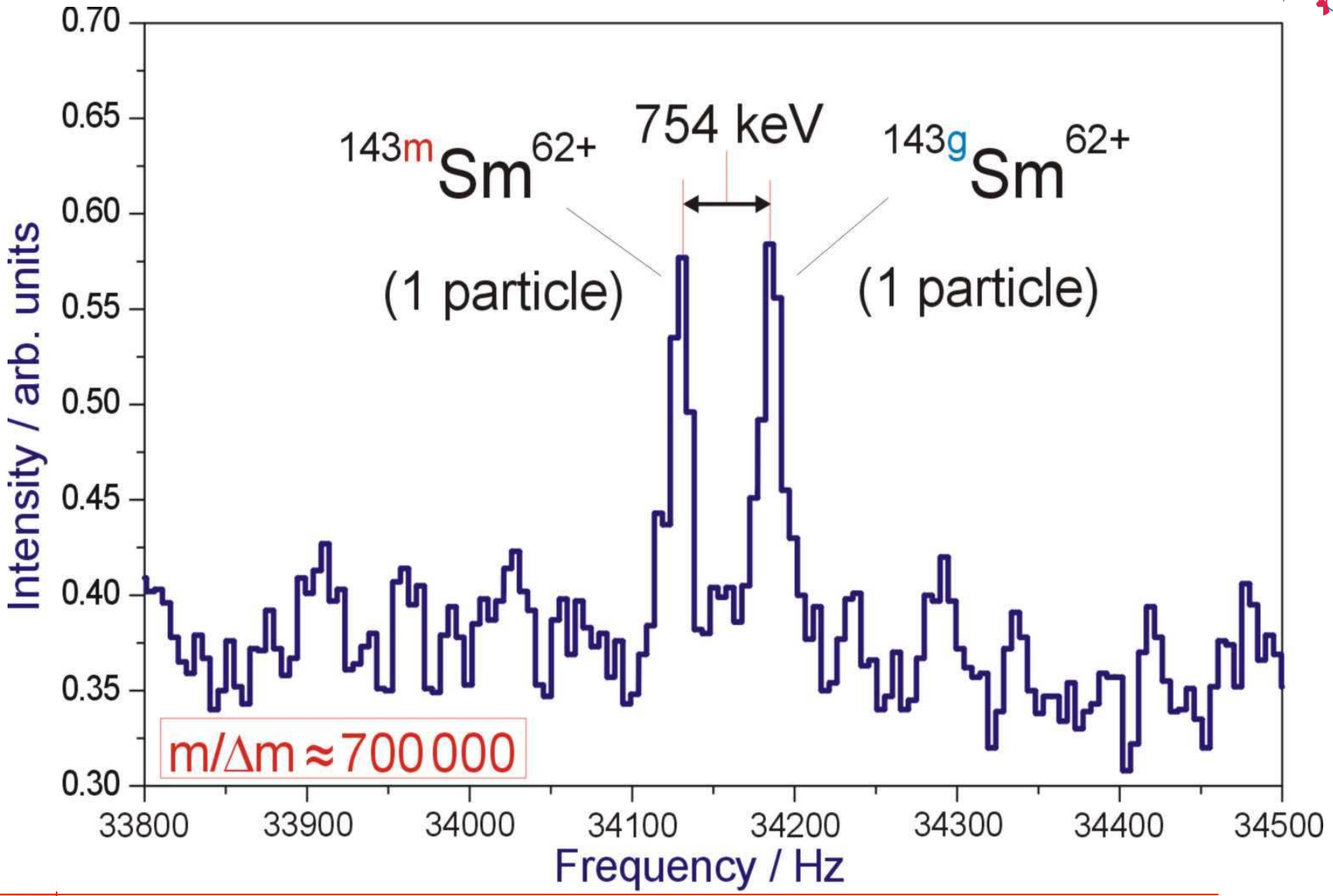
Schottky Frequency Spectrum



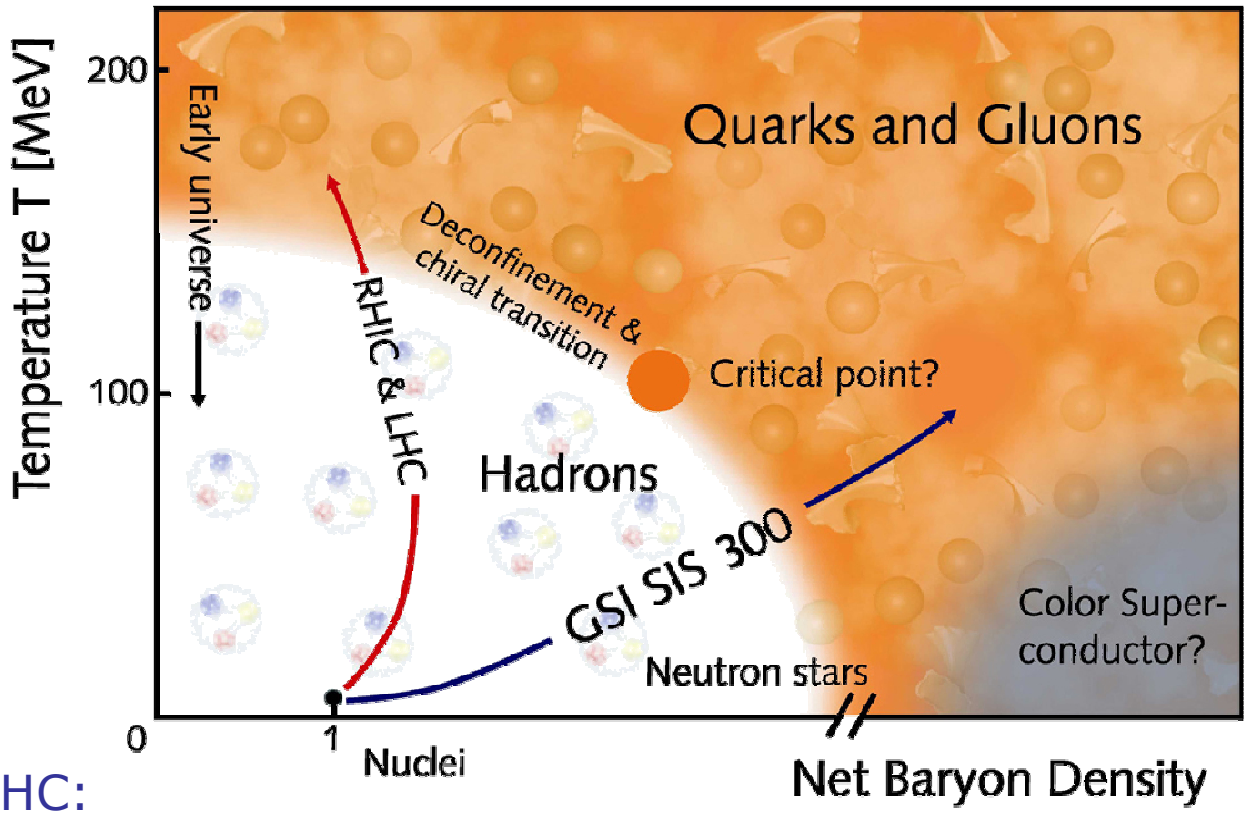
Schottky Frequency Spectrum



Schottky Frequency Spectrum

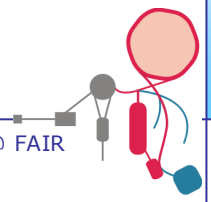


Phase diagram of strongly interacting matter



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

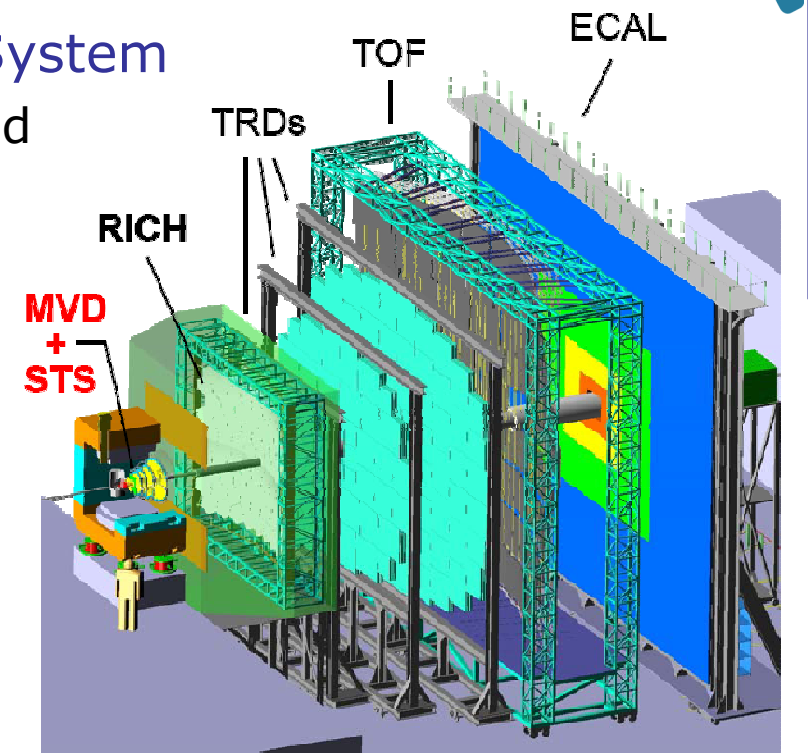
CBM Experiment - Objectives

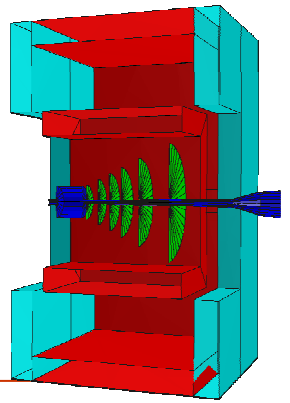


- **In-medium modifications of hadrons**
  onset of chiral symmetry restoration at high ρ_B
  measure: ρ, ω, ϕ → e^+e^- and open charm (D mesons)
- **Strangeness in matter (strange matter?)**
  enhanced strangeness production ?
  measure: K, Λ, Σ, Ξ, Ω
- **Indications for deconfinement at high ρ_B**
  anomalous charmonium suppression ?
  measure: J/ψ, D
- **Critical point**
  event-by-event fluctuations
- **Color superconductivity**
  precursor effects ?

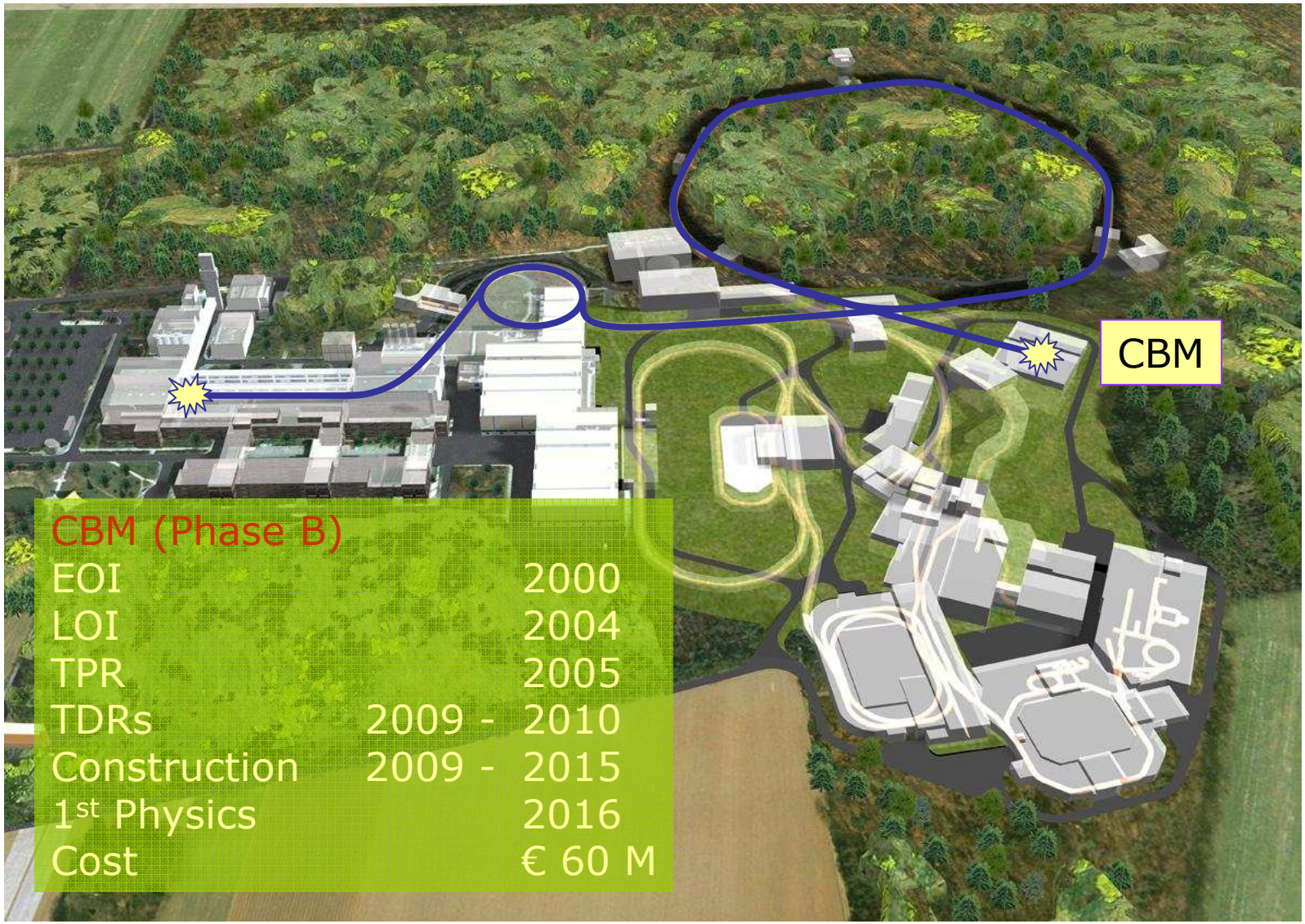
CBM @ FAIR

- 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





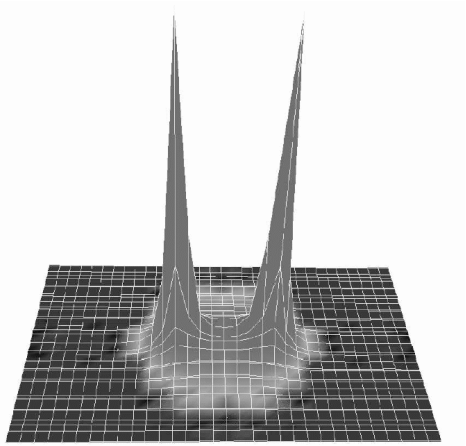
QCD phases @ FAIR



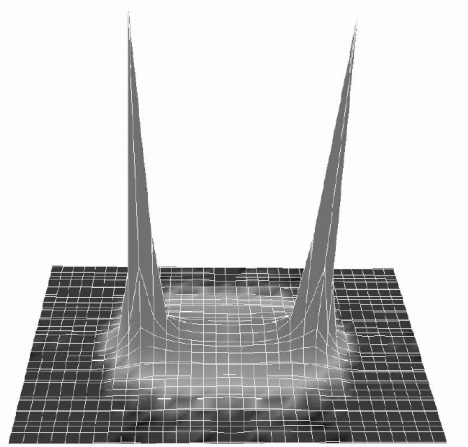
The Fluxtube in a Meson

[qq] bound state

strong interaction strength

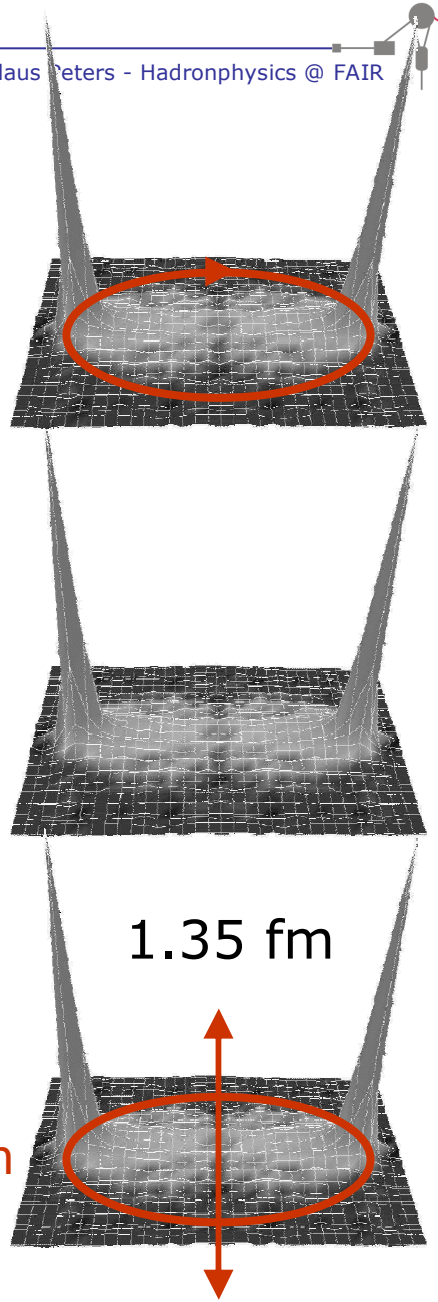


0.7 fm



1.0 fm

Rotation

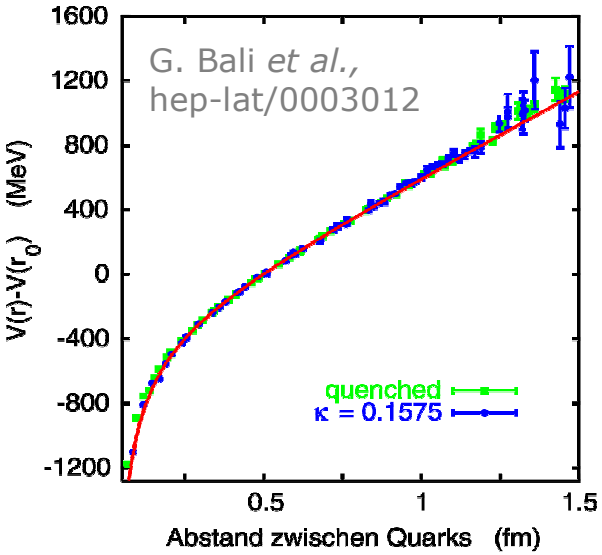


1.35 fm

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)

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

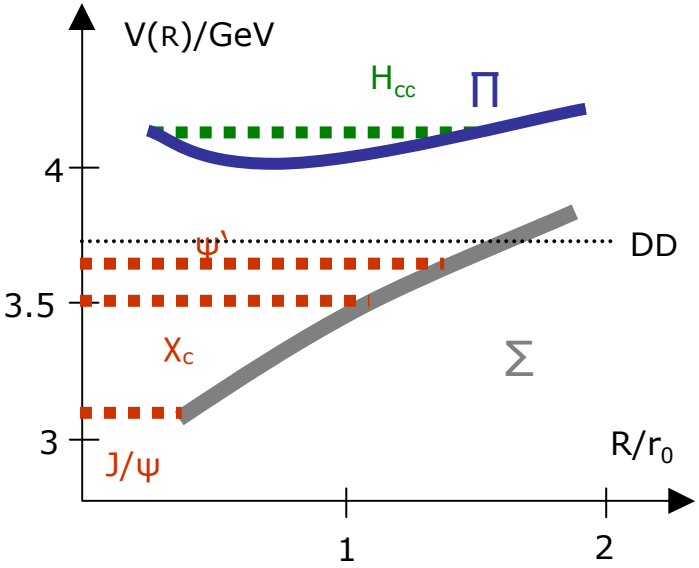
spin-spin (hyperfine structure)

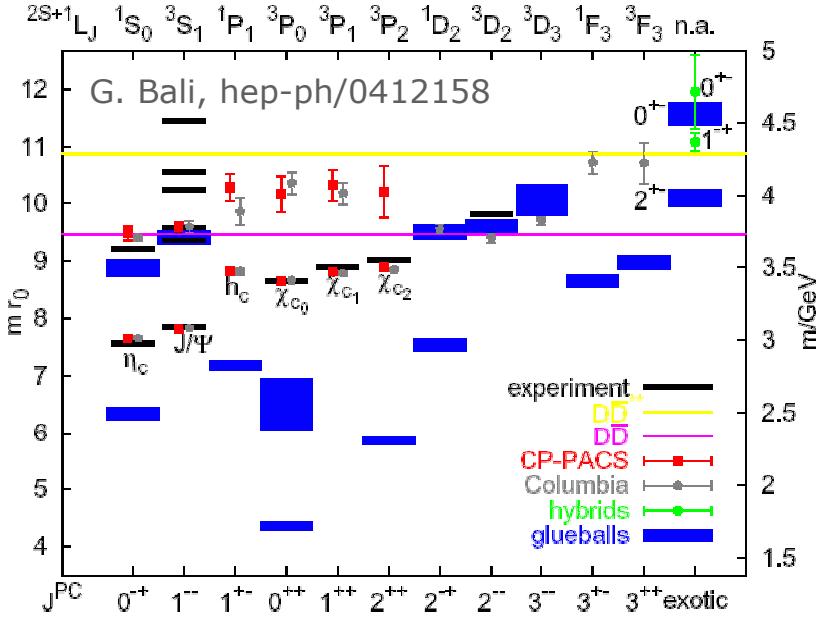
$$V_{SS} = \frac{2(\vec{S}_1\cdot\vec{S}_2)}{3m_c^2}\nabla^2 V_V(r)$$

tensor

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

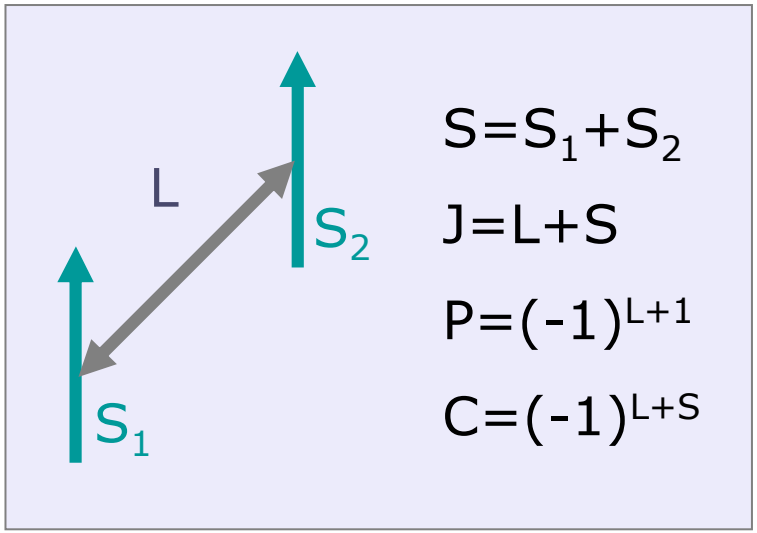
V_S and V_V are the scalar and vector components of the non-relativistic potential





Exotic Quantum Numbers with Simple Hybrids

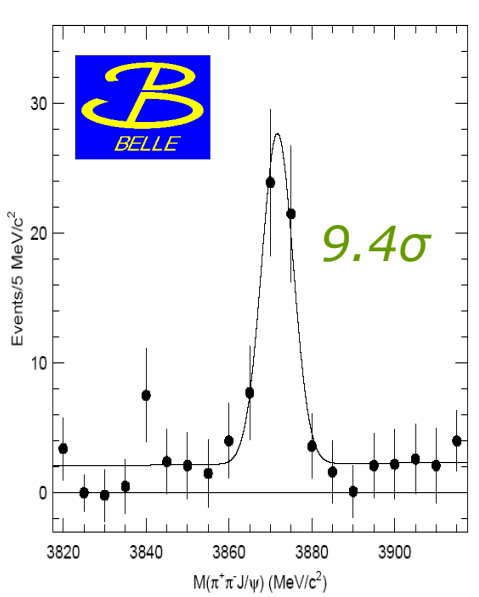
- S-Wave + Gluon $(q\bar{q})_8 g$ with $()_8$=colored
- $^1S_0 \uparrow\downarrow$ $^3S_1 \uparrow\uparrow$ combined with 1^+ or 1^- gluon



Gluon	1^- (TM)	1^+(TE)
$^1S_0$, 0^{-+}	1^{++}	1^{--}
$^3S_1$, 1^{--}	0^{+-}	0^{-+}
	1^{+-}	1^{-+}
	2^{+-}	2^{-+}

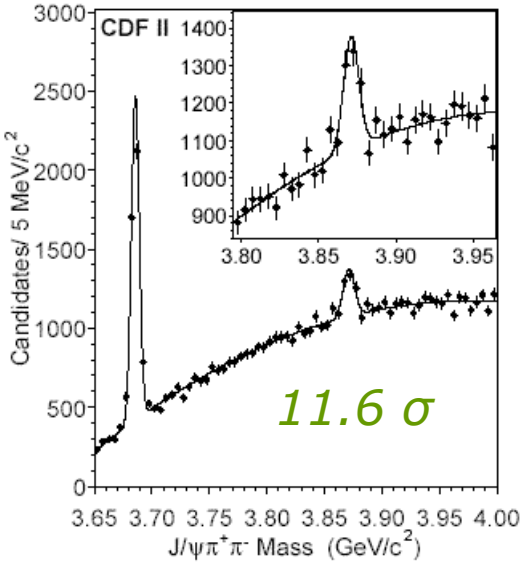
J^{PC} exotic
impossible for $q\bar{q}$

X(3872) and Confirmation



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

hep-ex/0312021



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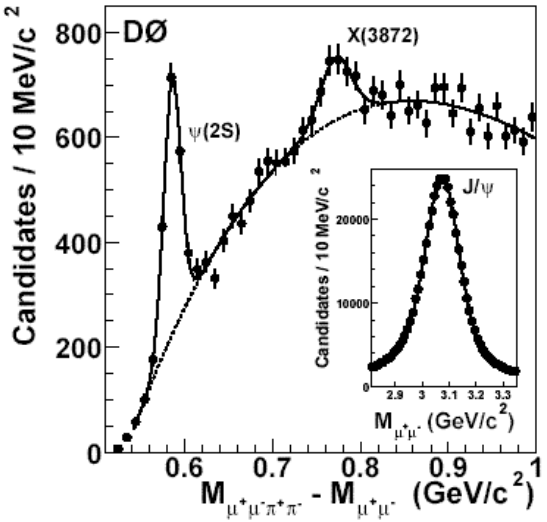
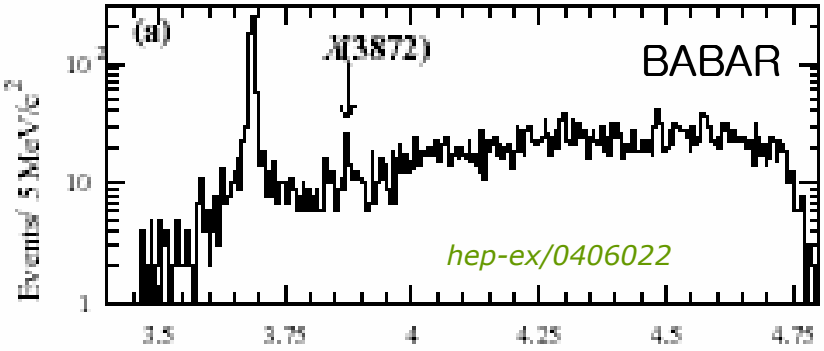




hep-ex/0406022

Recent Overview on D_{sJ},X,Y,Z et al. from E. Swanson

state	mass (MeV)	width (MeV)	production/decay mode	comments	ref
h_c	$3524.4 \pm 0.6 \pm 0.4$	–	$\psi(2S) \to \pi^0 h_c \to (\gamma\gamma)(\gamma\eta_c)$	$\approx$ CQM / tests spin dependence	CLEO[85]
η_c'	$3654 \pm 6 \pm 8$	< 55	$B \to K\eta_c' \to KK_SK\pi$	$\approx$ CQM / tests hyperfine splitting	Belle[88]
	$3642.9 \pm 3.1 \pm 1.5$	$6.3 \pm 12.4 \pm 4.0$	$e^+e^- \to \eta_c' J/\psi$		CLEO[91]
	$3630.8 \pm 3.4 \pm 1.0$	$17.0 \pm 8.0 \pm 2.5$	$\gamma\gamma \to \eta_c' \to K_SK\pi$		BaBar[92]
$X(3872)$	$3872.0 \pm 0.6 \pm 0.5$	< 2.3 95% C.L.	$B \to KX \to K\pi\pi J/\psi$	molecule, cusp, tetraquark	Belle[32]
	3873.4 ± 1.4	–	$B \to KX \to K\pi\pi J/\psi$		BaBar[35]
	–	–	$B \to X \to \pi\pi\pi J/\psi$		Belle[43]
	–	–	$B \to X \to \gamma J/\psi$		Belle[43]
	$3871.3 \pm 0.7 \pm 0.4$	–	$p\bar{p} \to X \to \pi\pi J/\psi$		CDF[33]
	$3871.8 \pm 3.1 \pm 3.0$	–	$p\bar{p} \to X \to \pi\pi J/\psi$		DØ[34]
	avg $= 3871.9 \pm 0.5$				
$X(3940)$	$3943 \pm 6 \pm 6$	< 52	$e^+e^- \to J/\psi X \to J/\psi D\bar{D}^*$	χ_{c1}', η_c'' / needs confirmation	Belle[94]
$Y(3940)$	$3943 \pm 11 \pm 13$	$87 \pm 22 \pm 26$	$B \to KY \to K\pi\pi\pi J/\psi$	needs confirmation	Belle[103]
$Z(3930)$	$3931 \pm 4 \pm 2$	$20 \pm 8 \pm 3$	$\gamma\gamma \to Z \to D\bar{D}$	χ_{c2}' / $\approx$ CQM	Belle[105]
$Y(4260)$	$4259 \pm 8 \pm 4$	$88 \pm 23 \pm 5$	$e^+e^- \to \gamma_{ISR}Y \to \gamma_{ISR}J/\psi\pi\pi$	hybrid?/ needs confirmation	BaBar[107]
$D_s(2317)$	$2317.3 \pm 0.4 \pm 0.8$	< 10	$e^+e^- \to D_s(2317) \to D_s\pi^0$	molecule, tetraquark, shifted $c\bar{s}$	BaBar[118]
	$2319.8 \pm 2.1 \pm 2.0$	≈ 0	$B \to \bar{D}D_s(2317) \to \bar{D}D_s\pi^0$		Belle[136]
	$2318.5 \pm 1.2 \pm 1.1$		$D_s(2317) \to D_s\pi^0$		CLEO[129]
$D_s(2460)$	$2463.6 \pm 1.7 \pm 1.2$	< 7 90% C.L.	$D_s(2460) \to D_s^*\pi^0$	molecule, tetraquark, shifted $c\bar{s}$	CLEO[129]
	$2458.0 \pm 1.0 \pm 1.0$	resolution	$D_s(2460) \to D_s\pi^0\gamma$		BaBar[131]
	$2459.2 \pm 1.6 \pm 2.0$	≈ 0	$B \to \bar{D}D_s(2460) \to \bar{D}D_s^*\pi^0$, $\bar{D}D_s\gamma$		Belle[136]
$D_s(2630)$	2632.6 ± 1.6	< 17 90% C.L.	$D_s \to D^0K^+$ and $D_s\eta$	artefact	SELEX[163]
B_c	$6285.7 \pm 5.3 \pm 1.2$	$0.474 \pm 0.07 \pm 0.33$ ps	$p\bar{p} \to B_c \to J/\psi\pi^\pm$	$\approx$ CQM	CDF[175]

Mass Differences in ψππ and $D\bar{D}\pi$

- X(3872) in (ψππ) K^+

  Belle m=3872±0.6±0.5

  Babar m=3871.3±0.6±0.1

- X(3872) in (ψππ) K_S

  Belle m=3871.8±1.1±0.6

  Babar m=3868.6±1.2±1.2

  Γ<2.3

about 3 MeV between final states

- X(3872) in $D\bar{D}\pi$ K

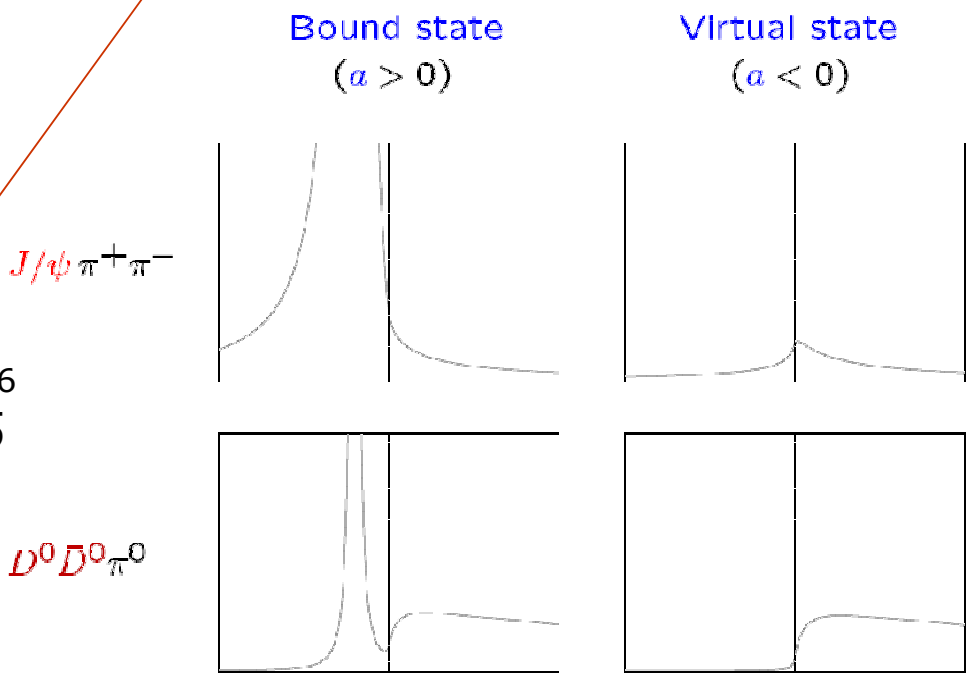
  Belle $m=3875.4\pm0.7^{+0.9}_{-1.6}$

  Babar $m=3875.1^{+0.7}_{-0.5}\pm0.5$

  $\Gamma=3.0^{+1.9}_{-1.4}\pm0.9$

m_{D0D0^*} =3871.8±0.3

m_{D+D-*} =3879.9±0.3



E. Braaten, only D^0D^{0*} threshold considered

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

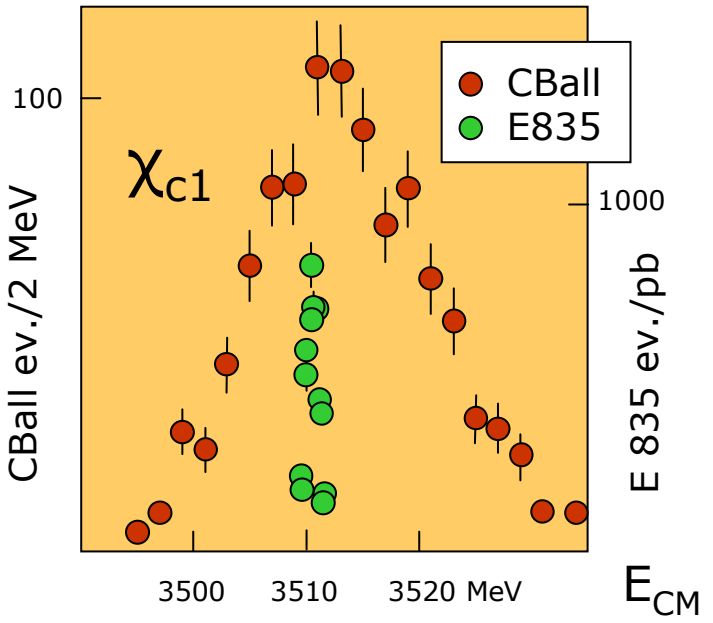
$$e^+e^- \rightarrow \psi' \rightarrow \gamma\chi_{c1,2} \rightarrow \gamma\gamma J/\psi \rightarrow \gamma\gamma e^+e^-$$

  - pp reactions:

    All states directly formed

    very good mass resolution

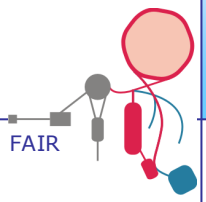
$$p\bar{p} \rightarrow \chi_{c1,2} \rightarrow \gamma J/\psi \rightarrow \gamma e^+e^-$$



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

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

Why Antiprotons for Heavy Flavour Spectroscopy



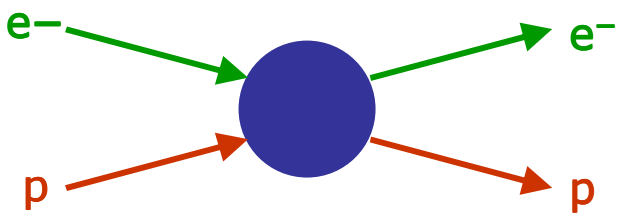
- high resolution spectroscopy with $\bar{p}$-beams in formation experiments:
  ΔE ≈ ΔEbeam → Precision Frontier

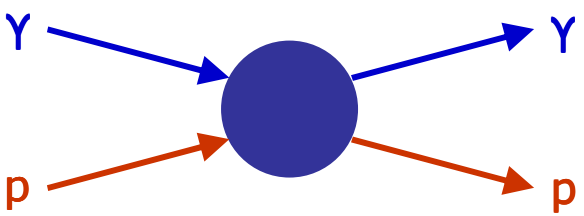
- high yield of gluonic and radial excitations in $p\bar{p}$
  glueballs, charmed hybrids → Discovery Potential

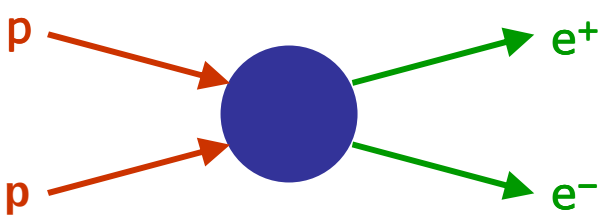
- event tagging by pair wise associated production,
  (particle, anti-particle) e.g. $pp \rightarrow D\bar{D}$

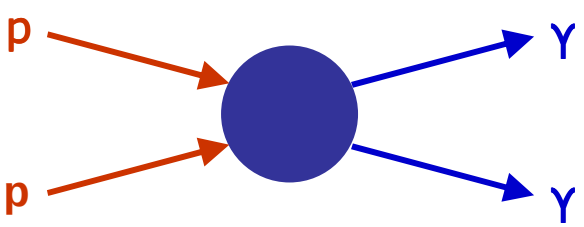
- large √s at low momentum transfer
  important for in-medium "implantation" of hadrons:
  study of in-medium effects of charmed states

Electromagnetic Reactions

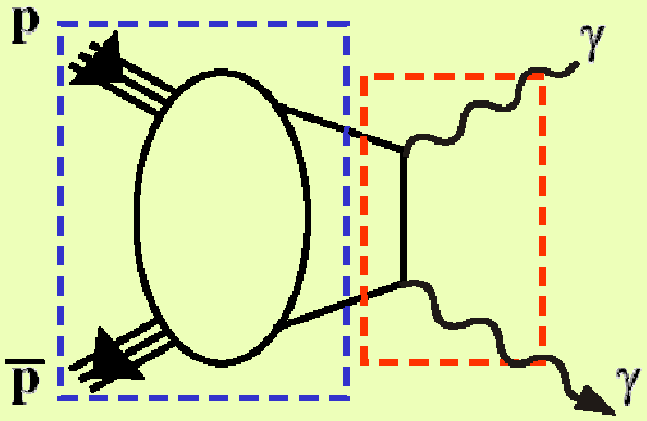




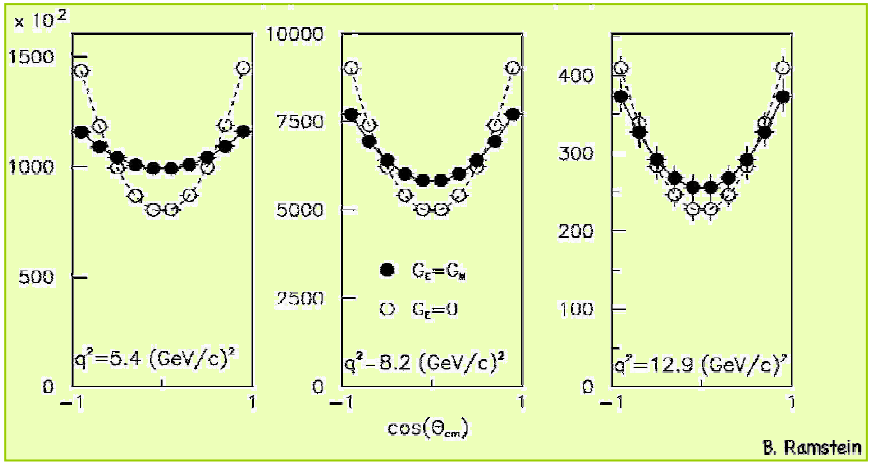


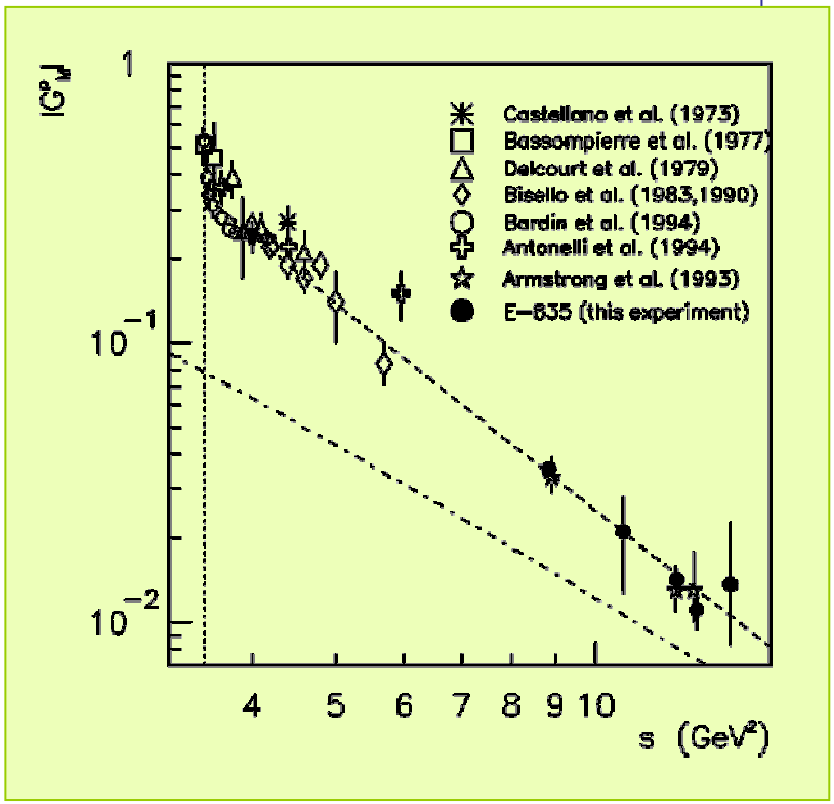


Crossed-Channel Compton Scattering



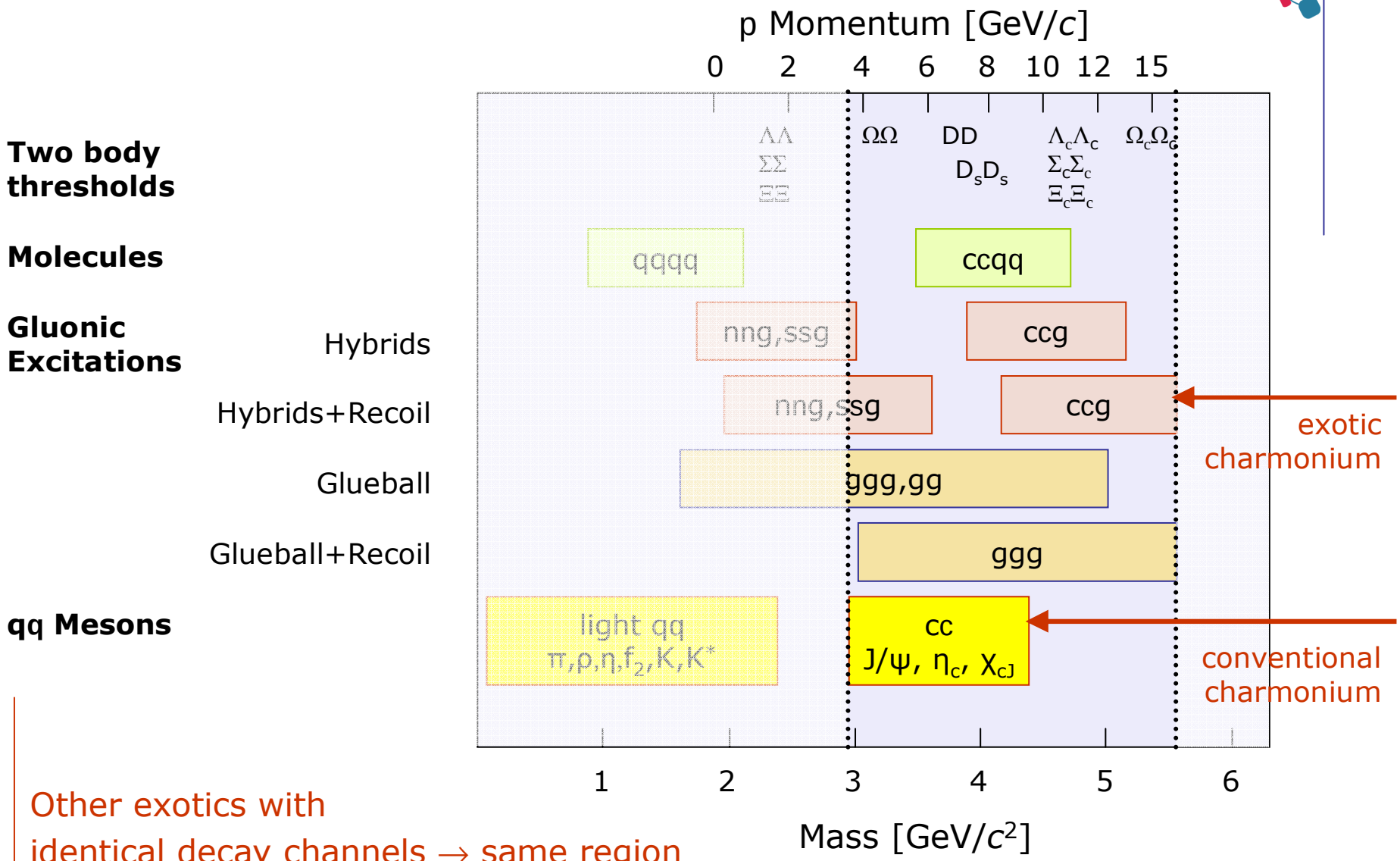
Cross section σ ≈ 2.5pb @ s ≈10 GeV^2
L = 2·10^{32} cm-2 s-1→ 10^3 Events/Month



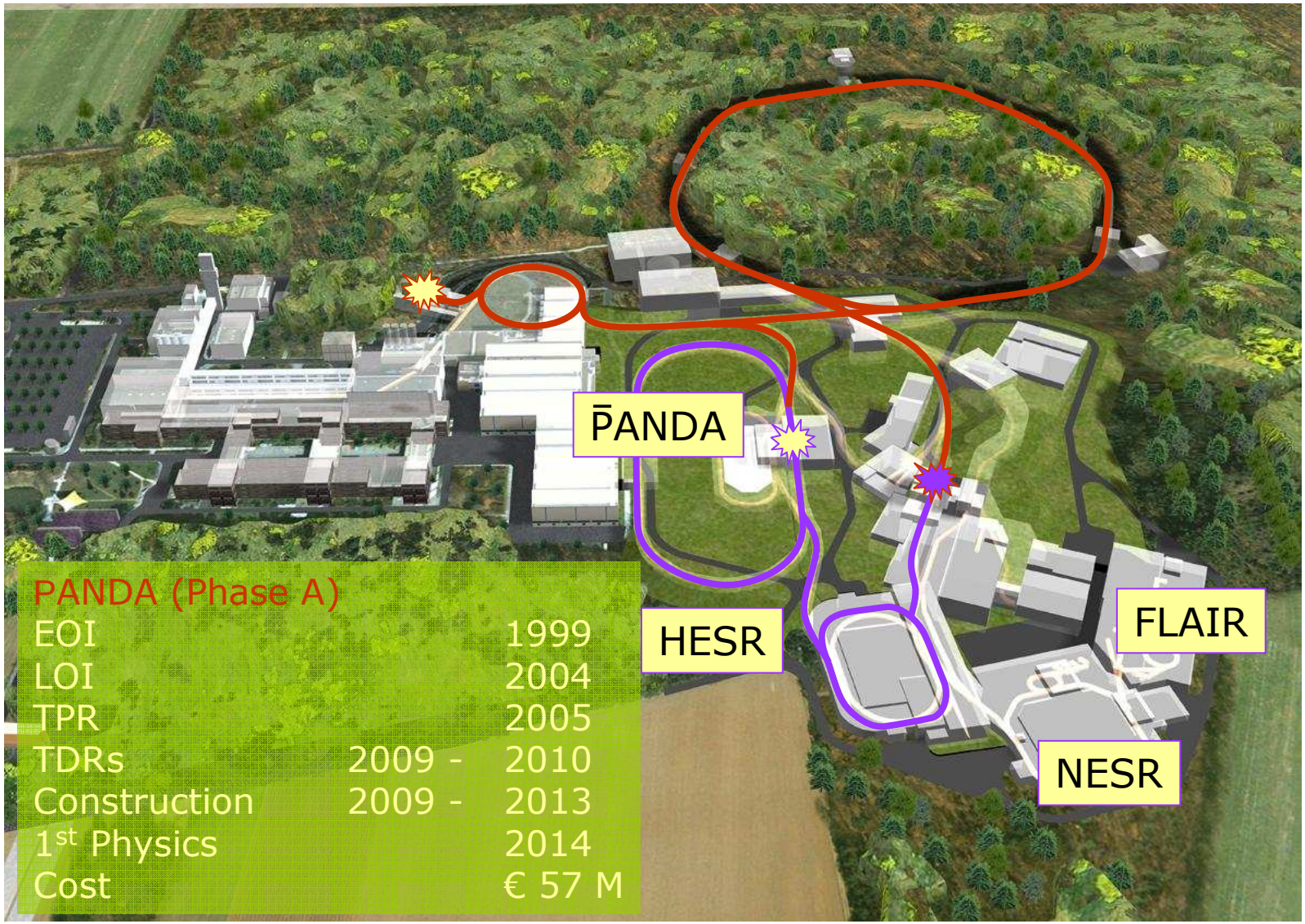


Electromagnetic Formfactor of the Proton (time-like)

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



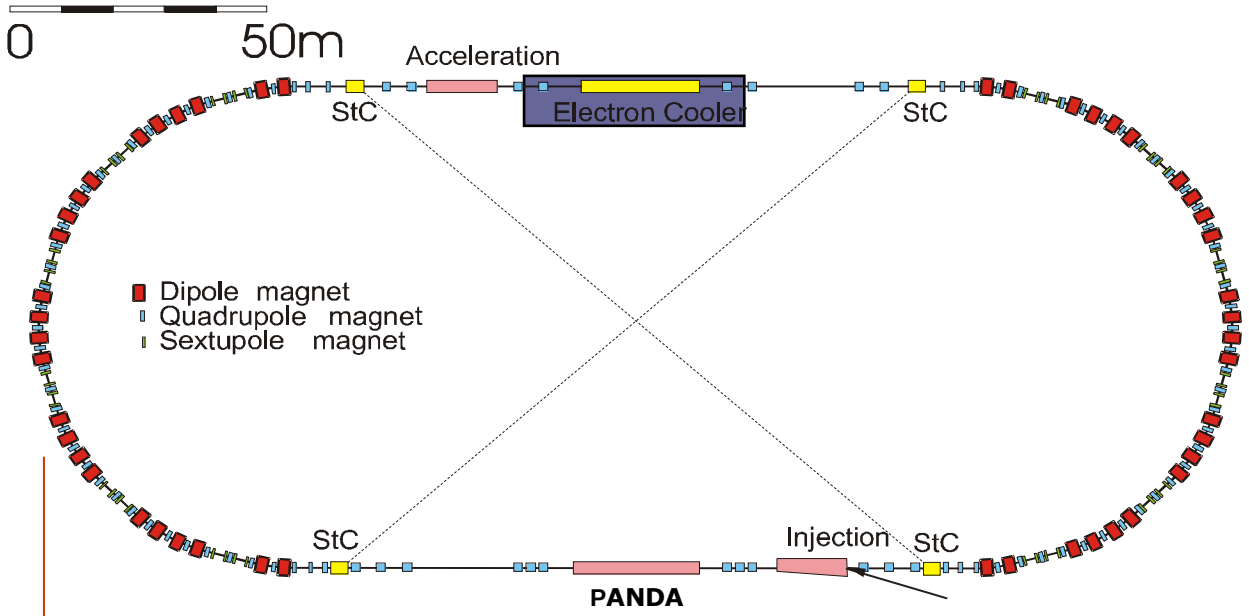
Other exotics with
identical decay channels → same region

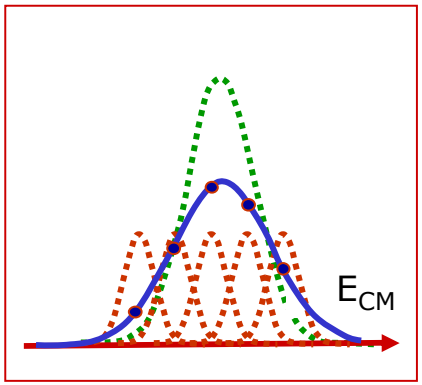

PANDA (Phase A)
EOI 1999
LOI 2004
TPR 2005
TDRs 2009 - 2010
Construction 2009 - 2013
1st Physics 2014
Cost € 57 M
P̄ANDA
HESR
FLAIR
NESR

HESR – Storage Ring for Antiprotons

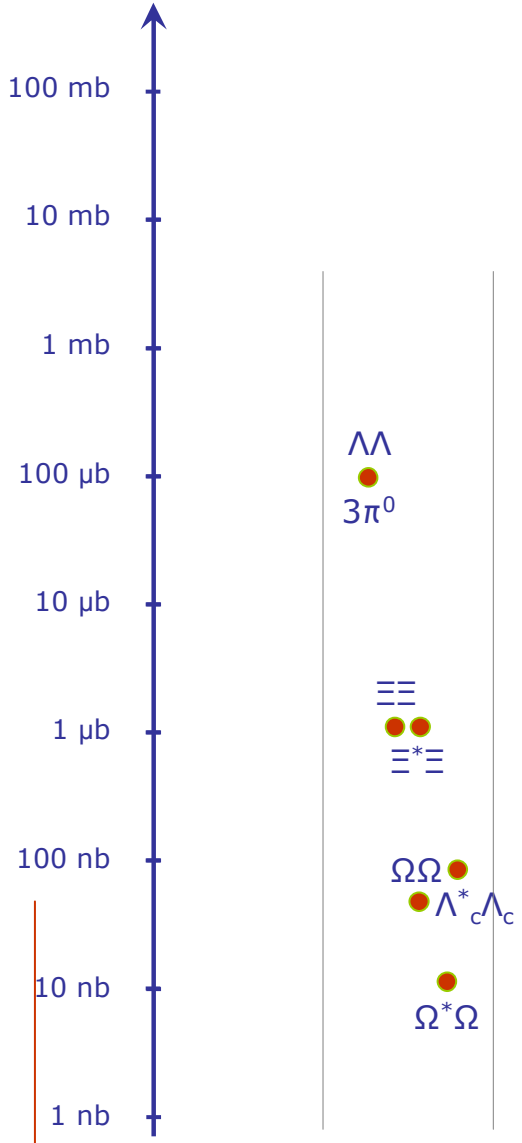
Parameters of HESR
- Injection of p at 3.7 GeV
- Slow synchrotron (1.5-14.5 GeV/c)
- Storage ring for internal target operation
- Luminosity up to L~ $2x10^{32}$ $cm^{-2}s^{-1}$
- Beam cooling (stochastic & electron)

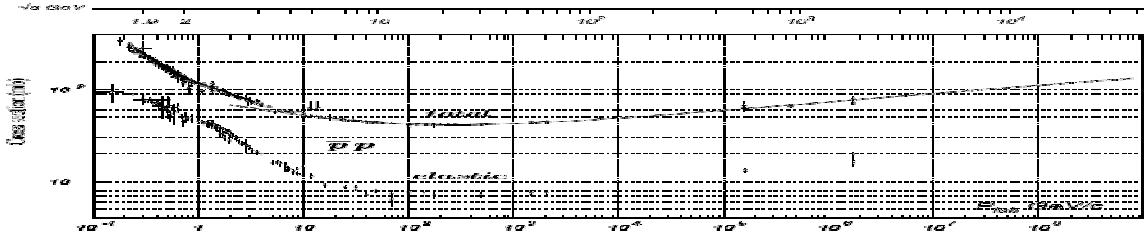
Resonance scan
- Energy resolution ~50 keV
- Tune E_{CM} to probe resonance
- Get precise mass and width





$\bar{p}p$ cross sections – exclusive final states

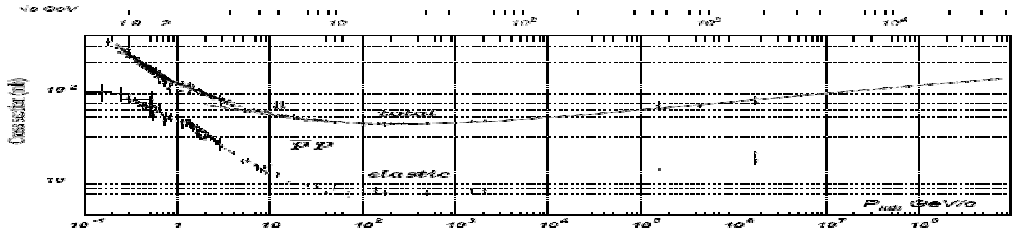




drop of cross section due to disconnected quark lines

s dependence $\sigma \sim s^{-X}$ for large phase space (e.g. $2\pi^0$ $\sigma \sim s^{-7.2}$ @ χ_{cJ})

$\bar{p}p$ cross sections – exclusive final states



100 mb
10 mb
1 mb
100 μb
10 μb
1 μb
100 nb
10 nb
1 nb

Glueballs

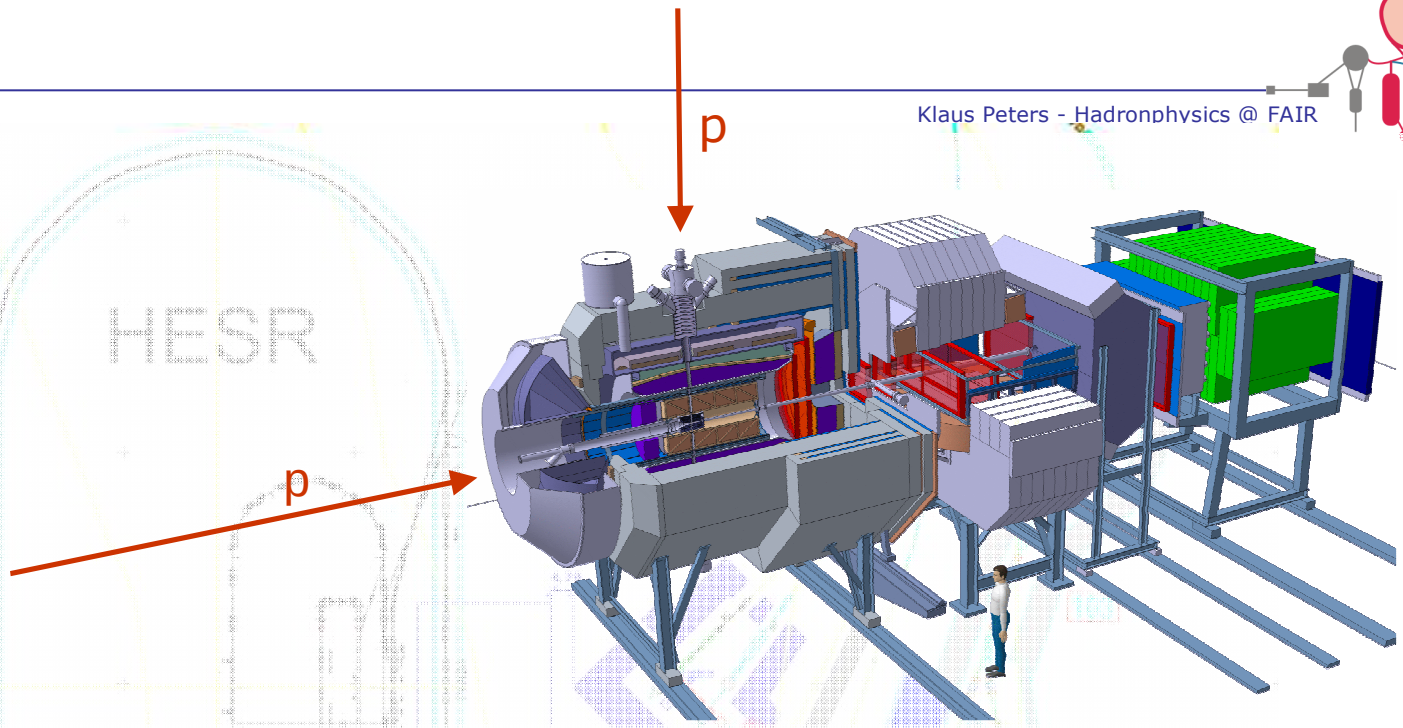
η_c
χ_{c2}
X(3872)
$\eta_c\pi^0$
χ_{c0}

Hybrids

Example X(3872)
peak ~50 nb (E. Braaten)
$D\bar{D}\pi/\psi\pi\pi$ ~10:1
→ $\psi\pi\pi$ 250 pb (ee and μμ)
→ $D\bar{D}\pi$ 500 pb (multiple channels)

includes eff. and BR

$L=2\cdot10^{31}$, duty $\varepsilon=0.5$
$\int(L*\varepsilon)$ = 0.86 pb^{-1}/d
→ 2 d/point
→ peak (~400 ev. $\psi\pi\pi$/~800 ev. $D\bar{D}\pi$)
x 20 points → 40 days



- 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

First "cold" Anti-Hydrogen 2002 @ AD

Nested Penning traps
catch energy: some keV

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#

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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)

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[5]*Ludwig-Maximilians-Universität München, Schellingstrasse 4/III, 80799 München, Germany*
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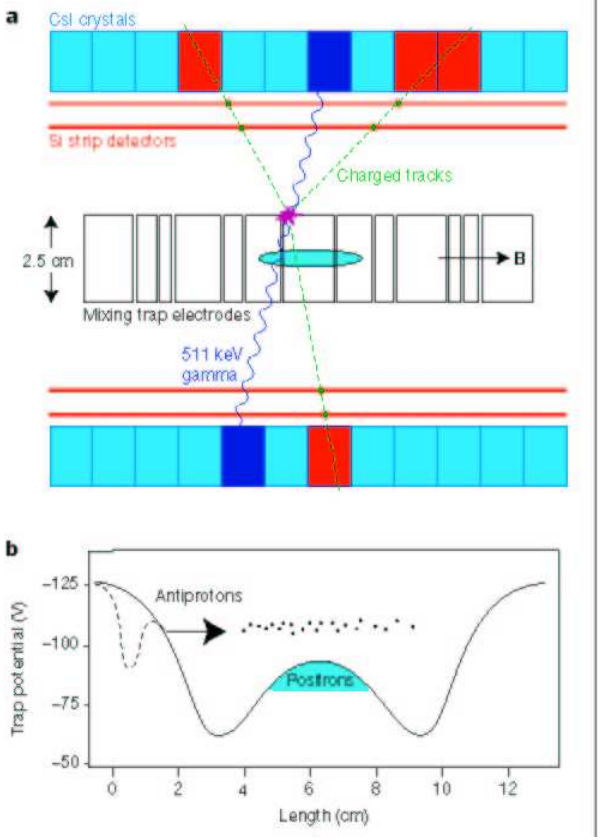
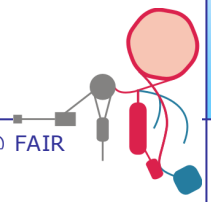
(Received 11 October 2002; published 31 October 2002)



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

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

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

- **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

- **Medical application: Tumor therapy**

High-brilliant Low energy beams

USR

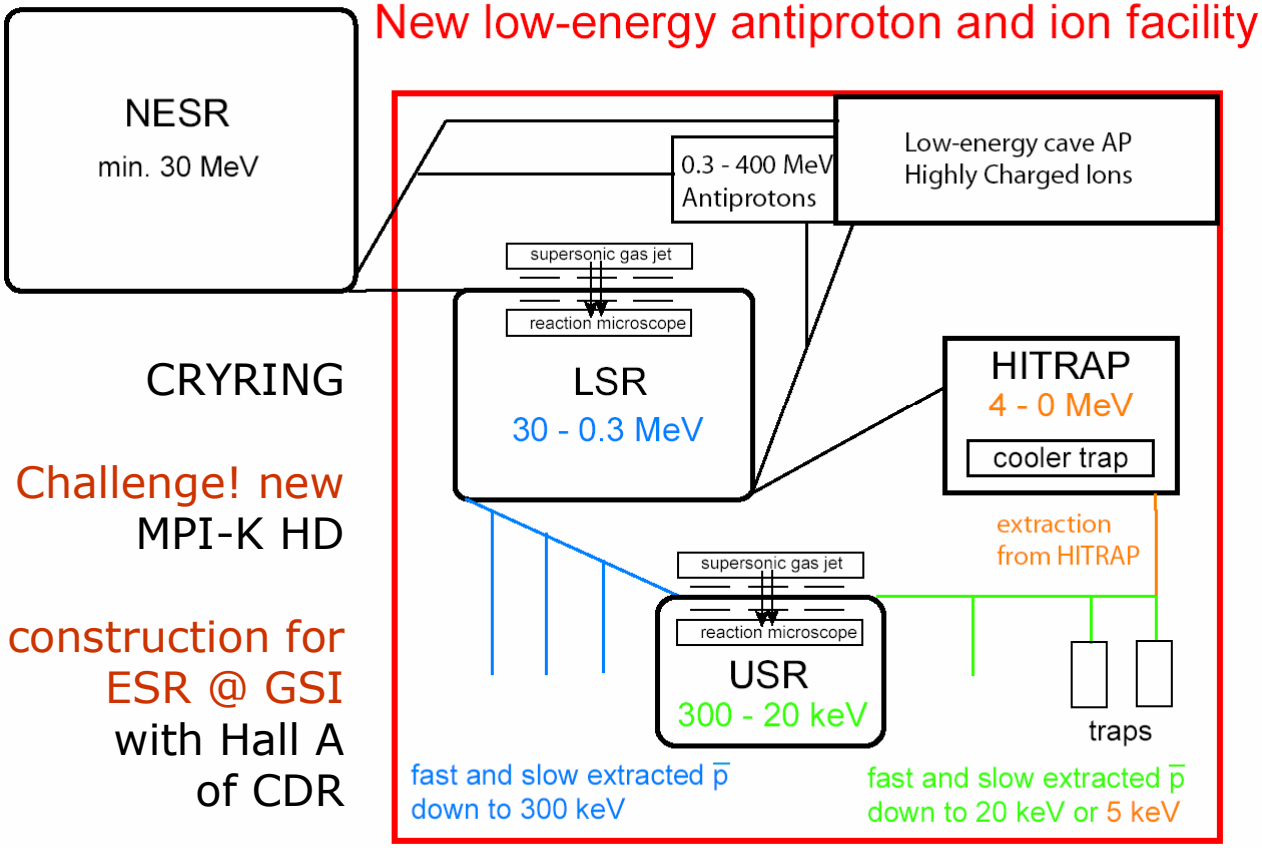
DC beam, rare ions

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



CRYRING

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:
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