Physics with High Energy Anti-Protons at FAIR

Inti Lehmann

Uppsala University

A Brief History

- 1930's: nucleus: protons + neutrons
  => nucleons
- 1950's - 60's: nucleons not elementary
  => hadron zoo
- 1960 ff: Quark model + QCD
  - Gell-Man: Nobel Price 1969
  - Friedman, Kendall, Taylor: Nobel Price 1990
  - Gross, David, Wilczek: Nobel Price 2004

everything understood???

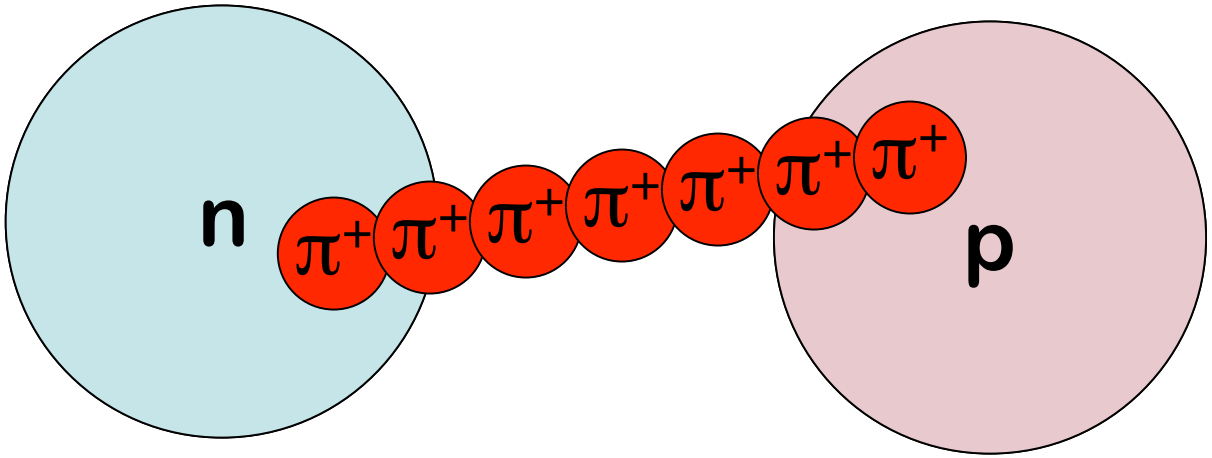
Some Open Questions

- Perturbative QCD is powerful at high energies but not applicable for hadronic matter!
- Only few % of the nucleon masses can be explained by the current quark masses!
- Why are only 2 and 3 quark states established?
  - 4,5-quark states, Hybrids, Glueballs should exist!
  - Hints on Pentaquarks and Glueballs...
- Particles found (PDG) outnumber the possible states in the multiplets!

A Short Introduction to Strong Interaction:

e.g. proton-neutron interaction

Yukava's prediction

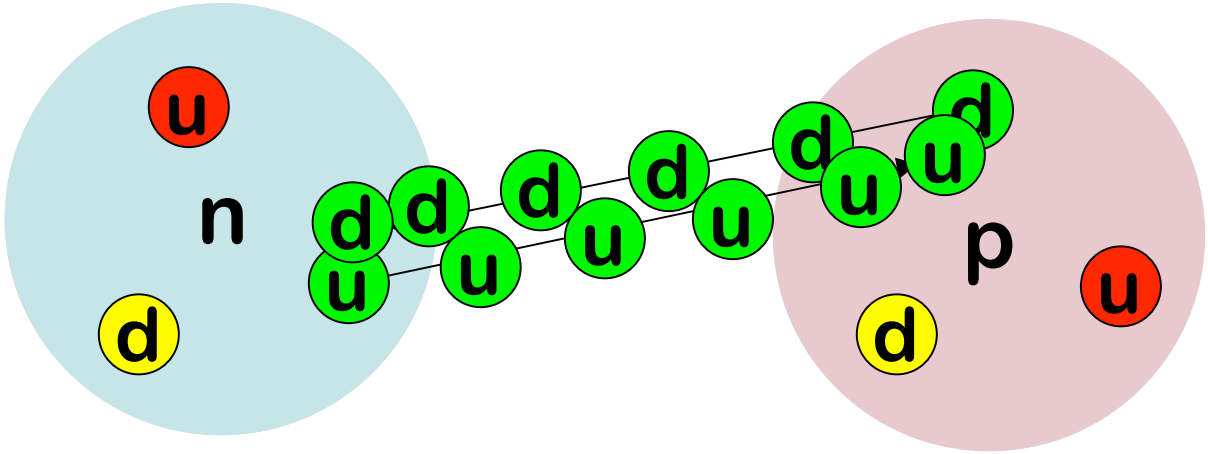


massive exchange particle $m_\pi \approx 100\text{MeV}$

A Short Introduction to Strong Interaction:

e.g. proton-neutron interaction

quark picture



very light quarks $m_q \approx$ 2-9MeV
are confined by colour charge
mass: quark-gluon condensate

A Little Comparison

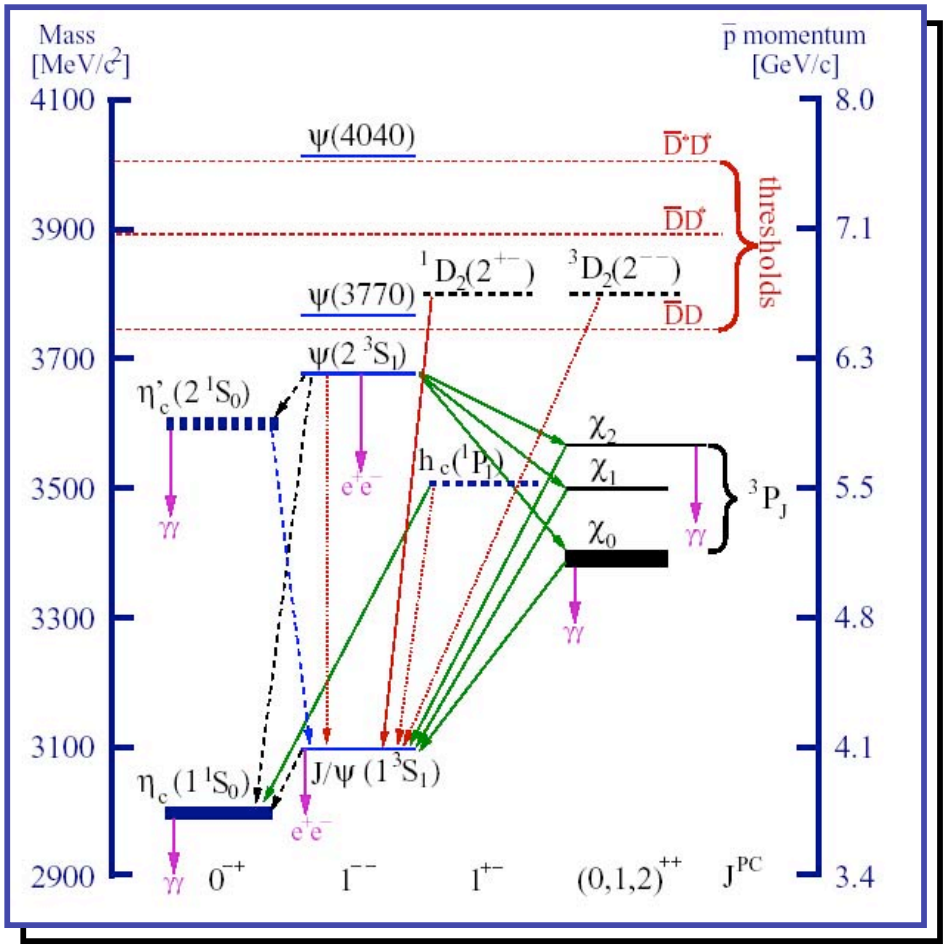
interaction	el-magn	strong
charge	positive, negative	3 colours, 3 anti-colours
exchange boson	1 photon (neutral)	8 gluons (charged)
coupling constant	$\alpha = 1/137$	$\alpha_s = 0.1 - 1$
theory	QED	QCD

Some PANDA Issues

- charmonium spectroscopy
- gluonic excitations (hybrids, glueballs)
- in medium mass modifications
- γ-ray spectroscopy of hypernuclei

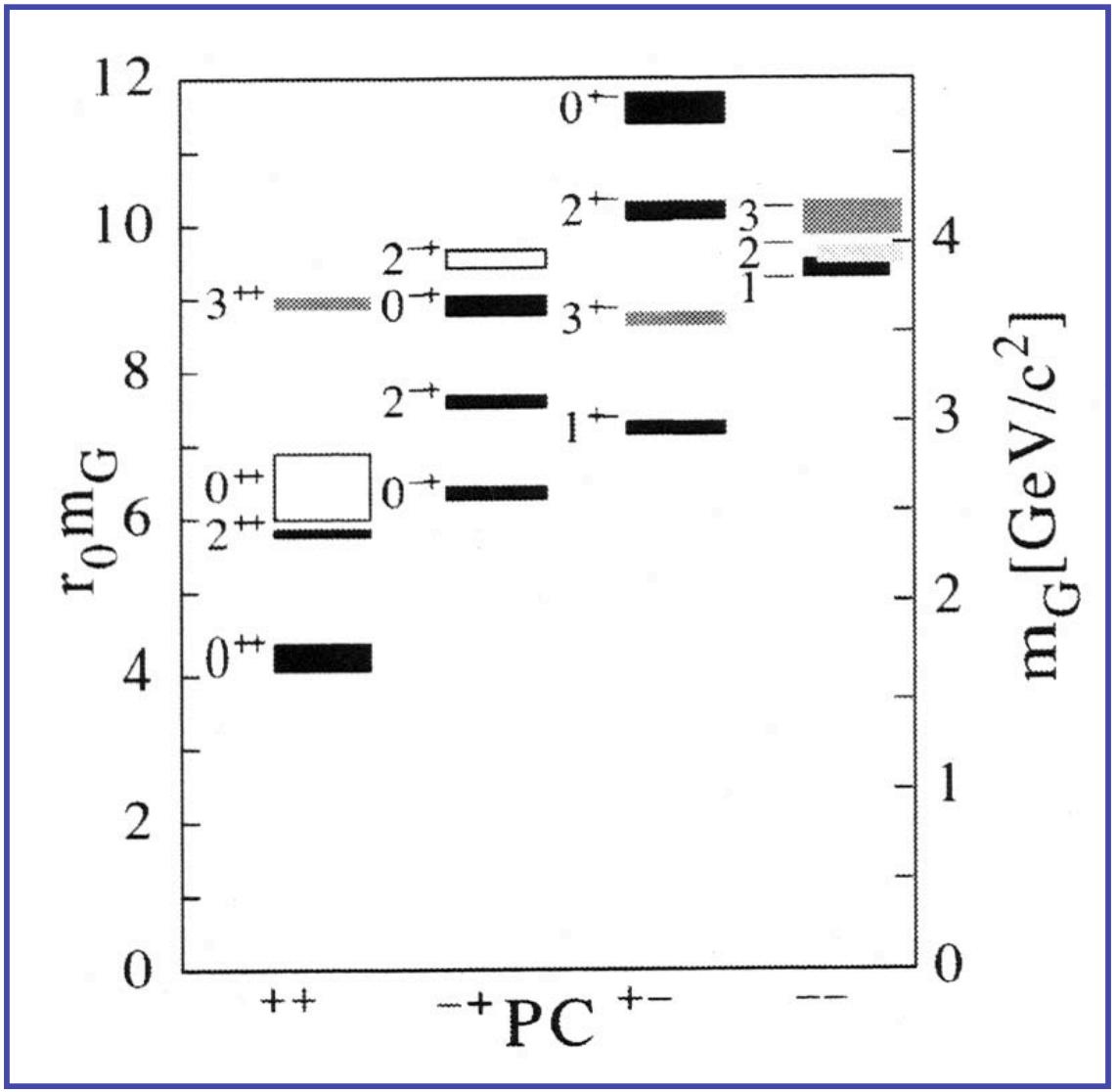
Charmonium Spectroscopy

- transition between massless and heavy quark limit!
- narrow states!
- precision measurements on D-states!



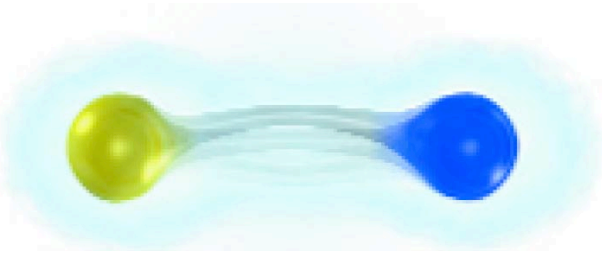
Gluonic Excitations

- **glueballs**: gluonic states without valence quarks



Gluonic Excitations

- glueballs: gluonic states without valence quark contribution

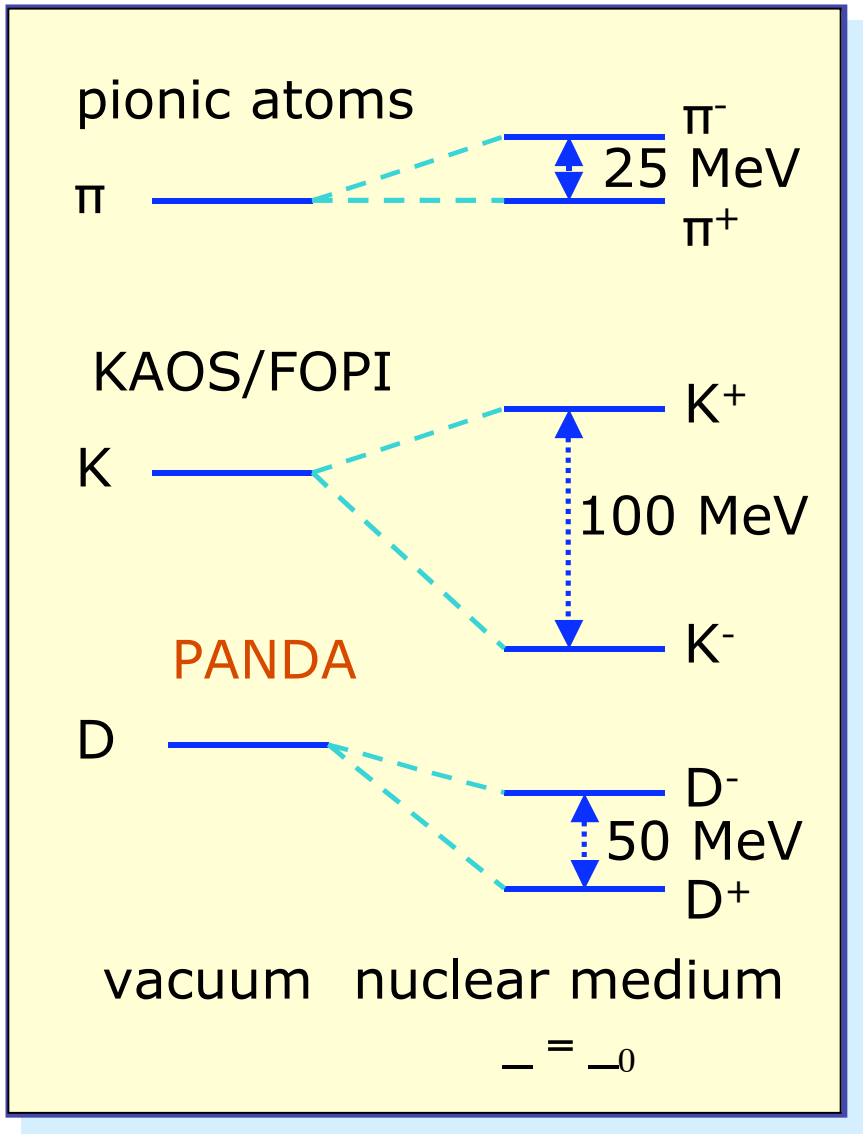


- hybrids: “ordinary” quark states containing excited glue

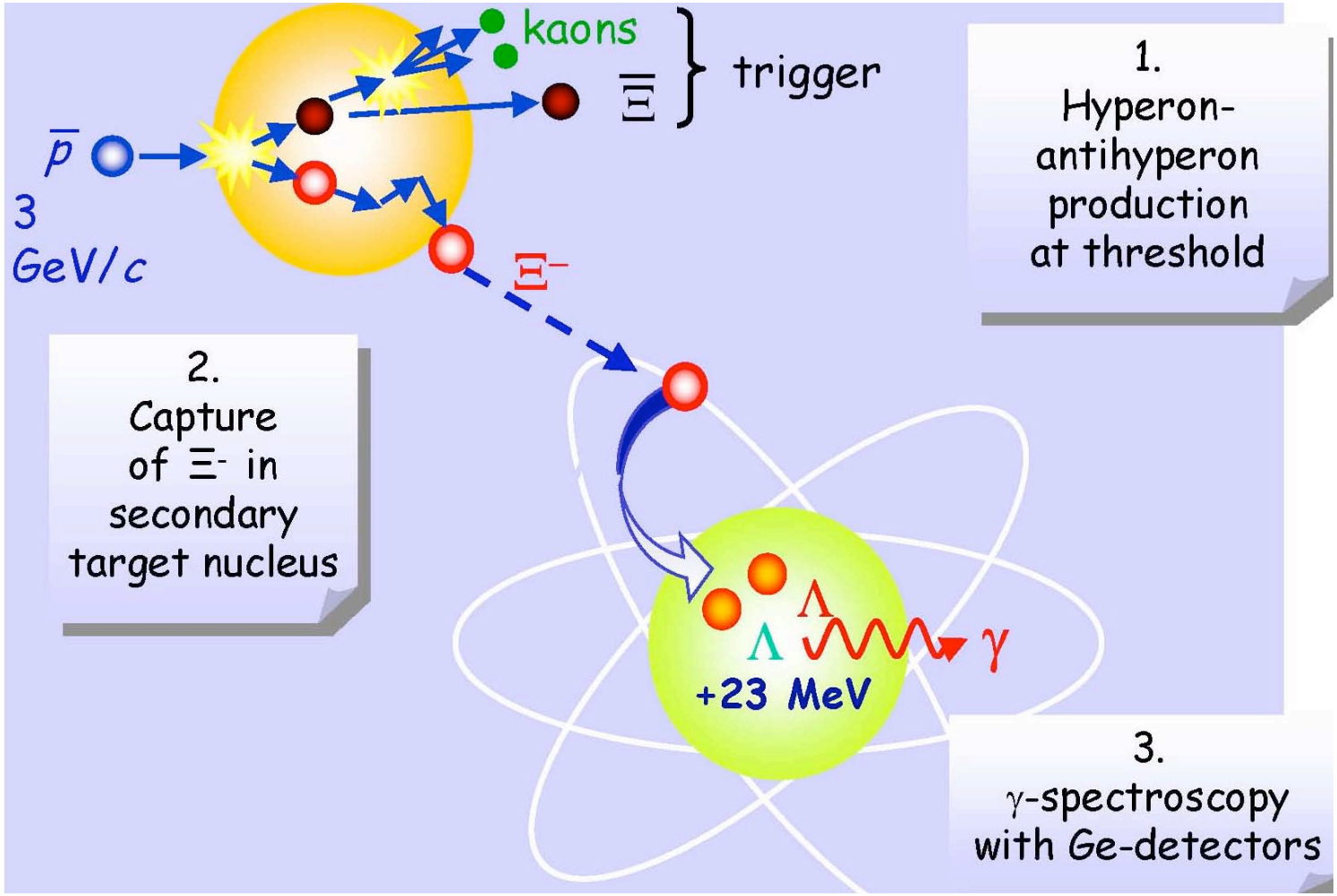
In-Medium Mass Modifications

- **HADES, CBM:**
  ρ, ω, ϕ **studies**

- **PANDA: extension to the charm sector**

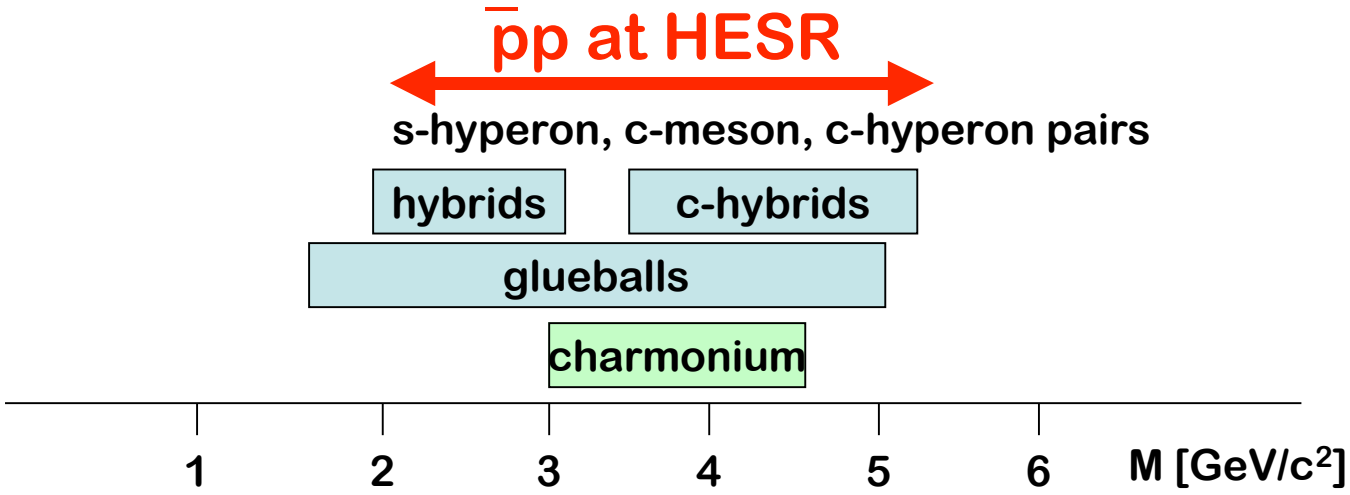


Spectroscopy of Single and Double Hypernuclei

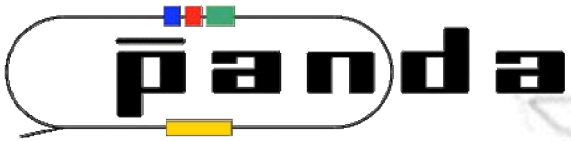


What is Experimentally Needed?

- **gluon-rich environment!**
  - ⇒ proton-antiproton anihilations
- **all quantum numbers!**
  - ⇒ production exp. i.e. large acc. detector
- **precise resonance scan!**
  - ⇒ high precision hadron beam (cooled)
- **high statistics samples!**
  - ⇒ high luminosity and prod. cross section
- **energies where gluon degrees of freedom become relevant!**



- 1999: Planning of a Charm-Glue Factory at GSI!



int. 4π detector

HESR

5×10^{11} anti-protons

p = 1.5 - 15 GeV/c

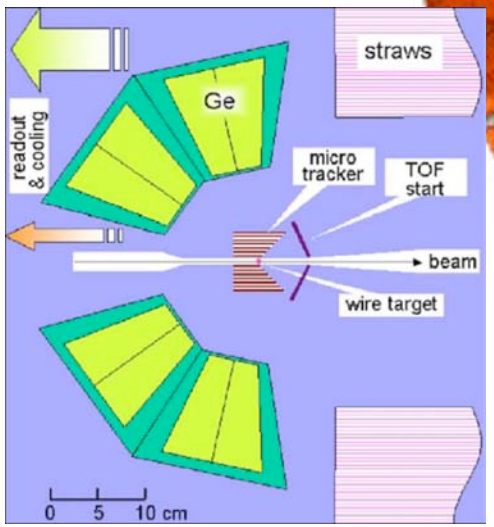
$L = 2 \times 10^{32} / (cm^2\ s)$

An International Accelerator Facility for Research with Ions and Antiprotons

FAIR

- 2003: Positive evaluation and commitment to FAIR by the German Government!
- 2004: Approval of LoI!
- Jan 2005: Technical Proposal!

Activities at ISS PANDA Detector



electro-magnetic calorimeter

drift chambers

target

forward system

muon counter

straws/TPC

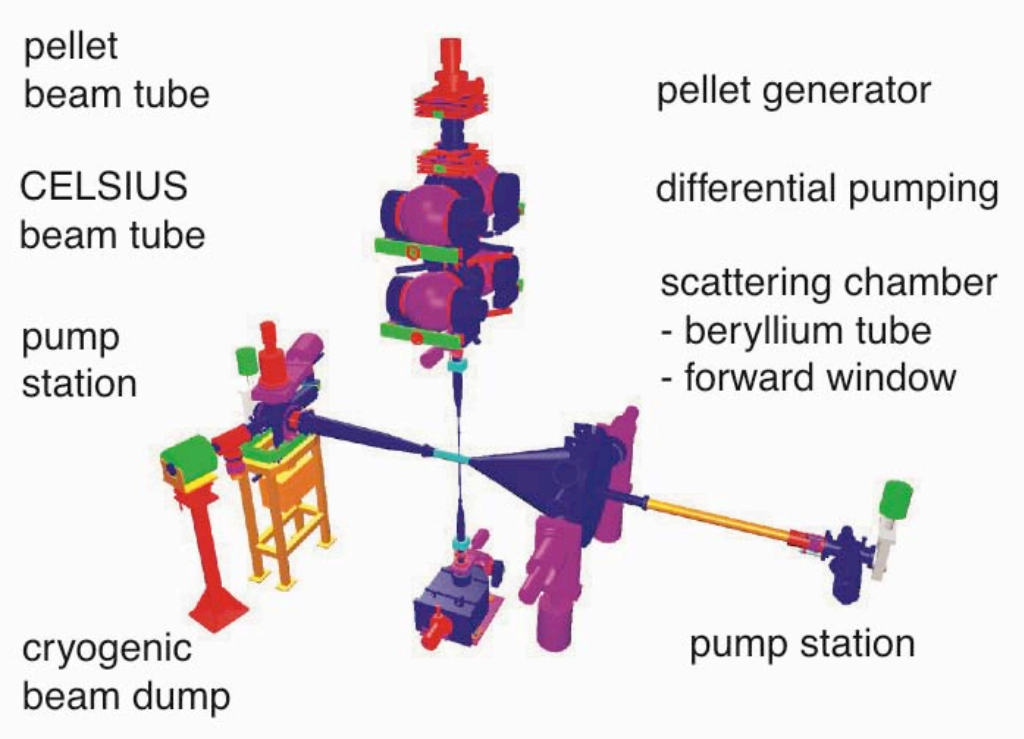
micro-vertex detector

Cerenkov

Pellet Target

delivers required target density
in conjunction with low gas load

WASA target



- **in operation for data taking since 2000!**
- **density as required for PANDA!**
- **divergence and frequency are to be improved by factors of 2-4!**
- **vacuum situation is studied at the PTS!**

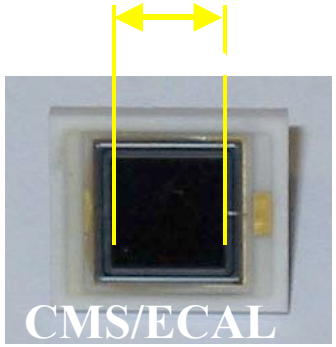
Pellet Target

Pellet Test Station (PTS)

- independent system!
- improved but parts interchangeable!
- flexible design and full access!
- simulating PANDA vacuum-wise!

Electro-Magnetic Calorimeter

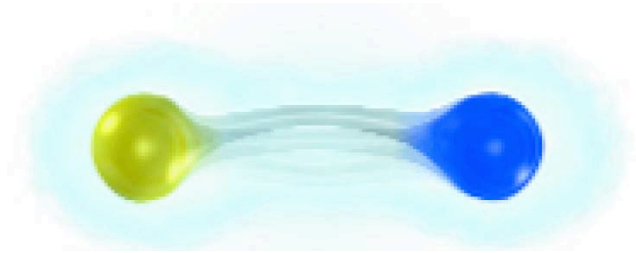
- test experiments at KVI and MAMI
  - crystal type
  - photo sensors
  - size, shape, position
  - radiation hardness

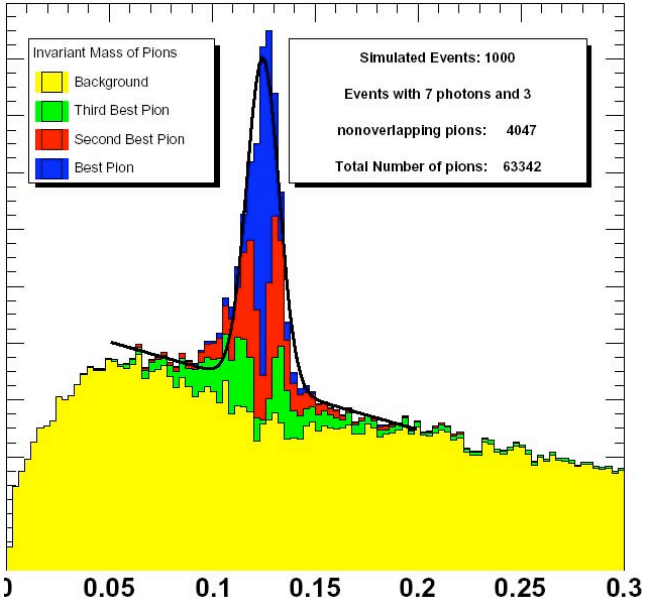


- joint efforts Uppsala-Stockholm
  - energy and timing resolutions
  - radiation hardness to neutron flux

Simulation of Benchmark Channels
e.g. charmonium hybrid

$$p\bar{p} \rightarrow H_c\,\eta$$
$$\hookrightarrow \gamma\gamma$$
$$\hookrightarrow \chi_c\,\pi^0\pi^0$$
$$\hookrightarrow \gamma\gamma\gamma\gamma$$
$$\hookrightarrow J/\psi\,\gamma$$
$$\hookrightarrow l^+\,l^-$$





$$\Rightarrow p\bar{p} \rightarrow l^+\,l^-\,7\gamma$$

$\Rightarrow$ **design of the EMC!**

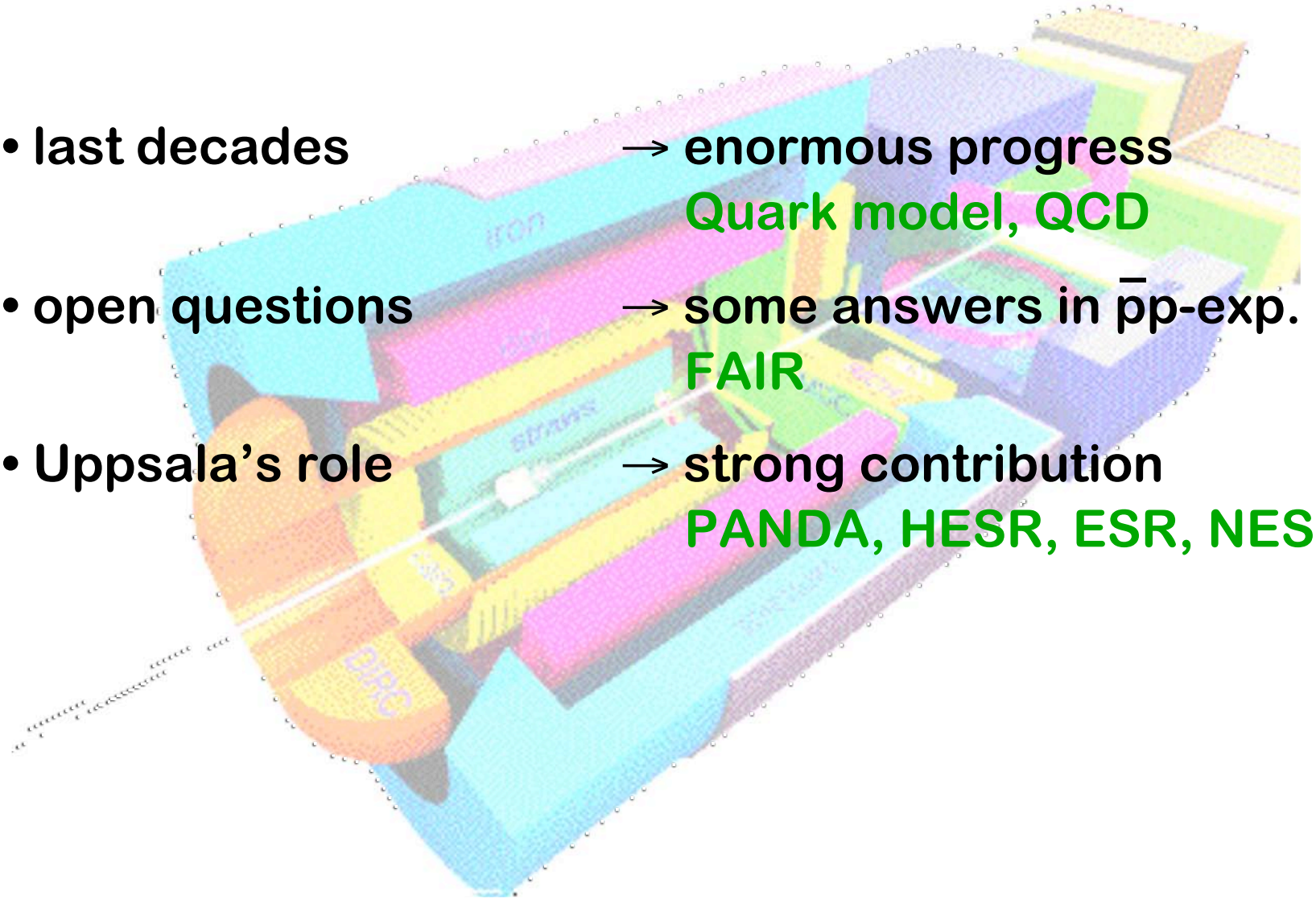
E-Cooler for HESR

TSL: Dag Reistad…

CELSIUS
300 keV

HESR proposal
10 MeV

Summary



- last decades → enormous progress
  Quark model, QCD
- open questions → some answers in $\bar{p}p$-exp.
  FAIR
- Uppsala's role → strong contribution
  PANDA, HESR, ESR, NESR

Gräftåvallen, January 4-9th, 2005

Programme dedicated to the physics at the future FAIR facility

- nuclear astrophysics
- heavy-ion physics
- hadron physics

Claus Rolfs (Bochum): "Nukleosynthesis-Key-Questions" and "Plasma effects in metals"

Hans Fynby (Aarhus): Helium burning in stars

Emma Olsson (Uppsala): Neutron star cooling

Fred Harris (Hawaii): Results from the BES electron-positron collider experiment

Bingsong Zou (Beijing): Exotic hadron-hadron s-wave interaction

Alex Dzierba (Indiana): GlueX at CEBAF

Eberhard Widman (Tokyo/Vienna): Low-energy antiproton physics

Dieter Roehrich (Bergen): What have we learned from heavy-ion experiments?

Joakim Nystrand (Bergen): Overview of RHIC experiments

Ana Marin* (GSI): Results from recent CERN heavy-ion experiments

Colin Wilkin* (University College): What have we learned from medium-energy hadron experiments?

preliminary

please register at: www5.tsl.uu.se/panda/gra15

scientific contributions welcome!