The Hadron Physics Programme at FAIR

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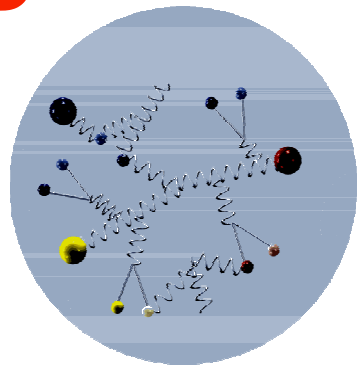
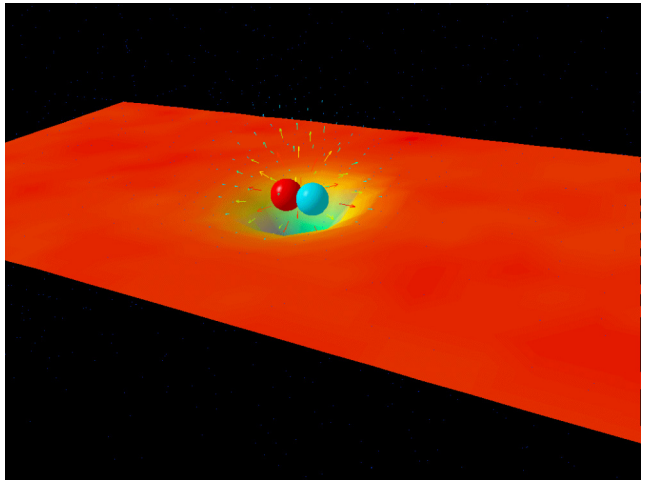
Lanzhou, Jan. 14th, 2005

Some Open Questions in Non-Perturbative QCD

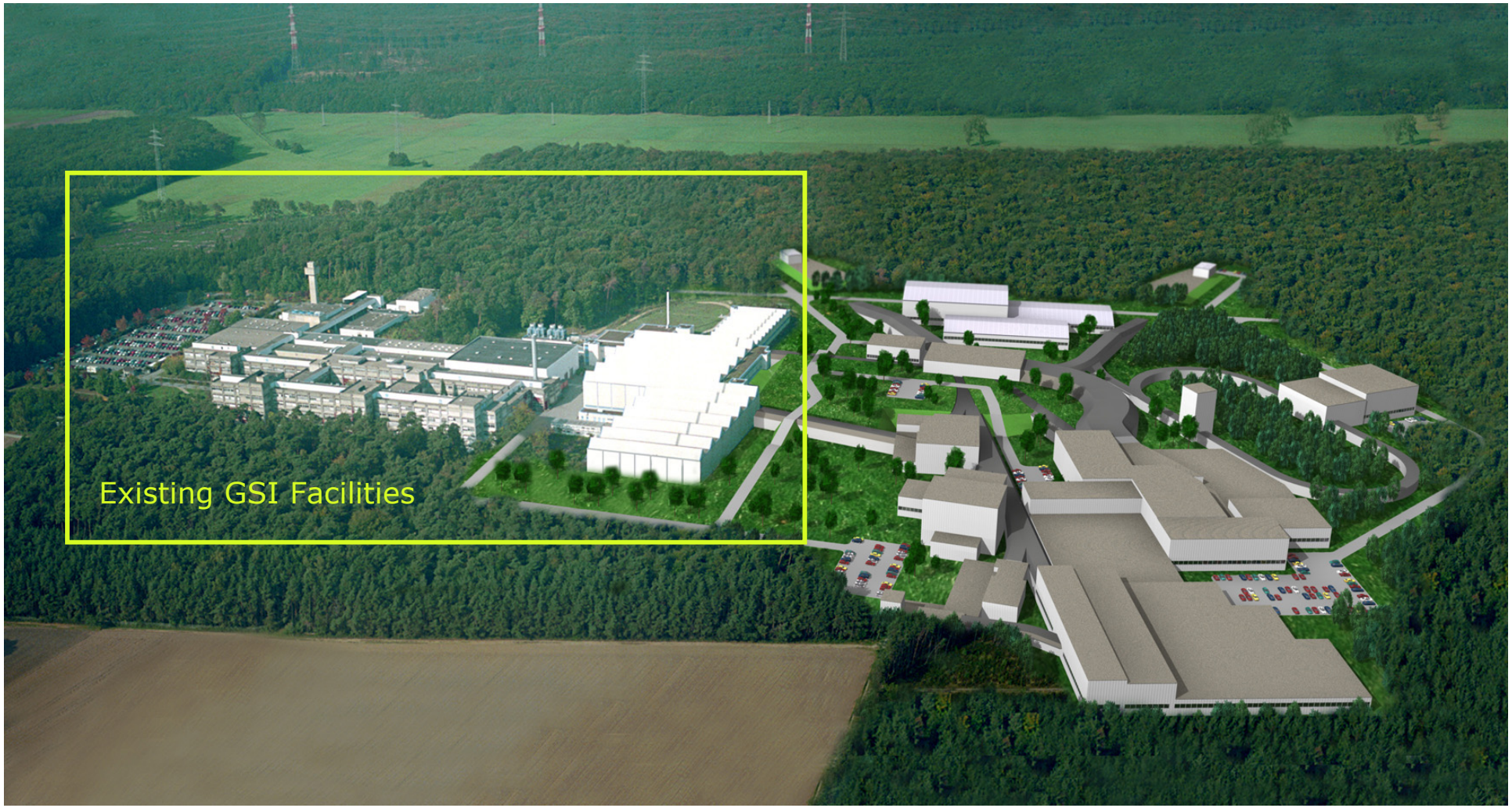
- generation of hadron masses
- strong interaction at large distances
- spin puzzle
- multi-quark systems





(flux tube animation by D. Leinweber et al.)

FAIR: Facility for Antiproton and Ion Research



FAIR: Probing the Intensity Frontier with Secondary Beams

Primary Beams

- 10^{12}/s; 1.5 GeV/u; $^{238}U^{28+}$
- 10^{10}/s $^{238}U^{73+}$ up to 35 GeV/u
- 3x10^{13}/s 30 GeV protons

Secondary Beams

- broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 higher in intensity than presently
- antiprotons 3 - 30 GeV

Storage and Cooler Rings

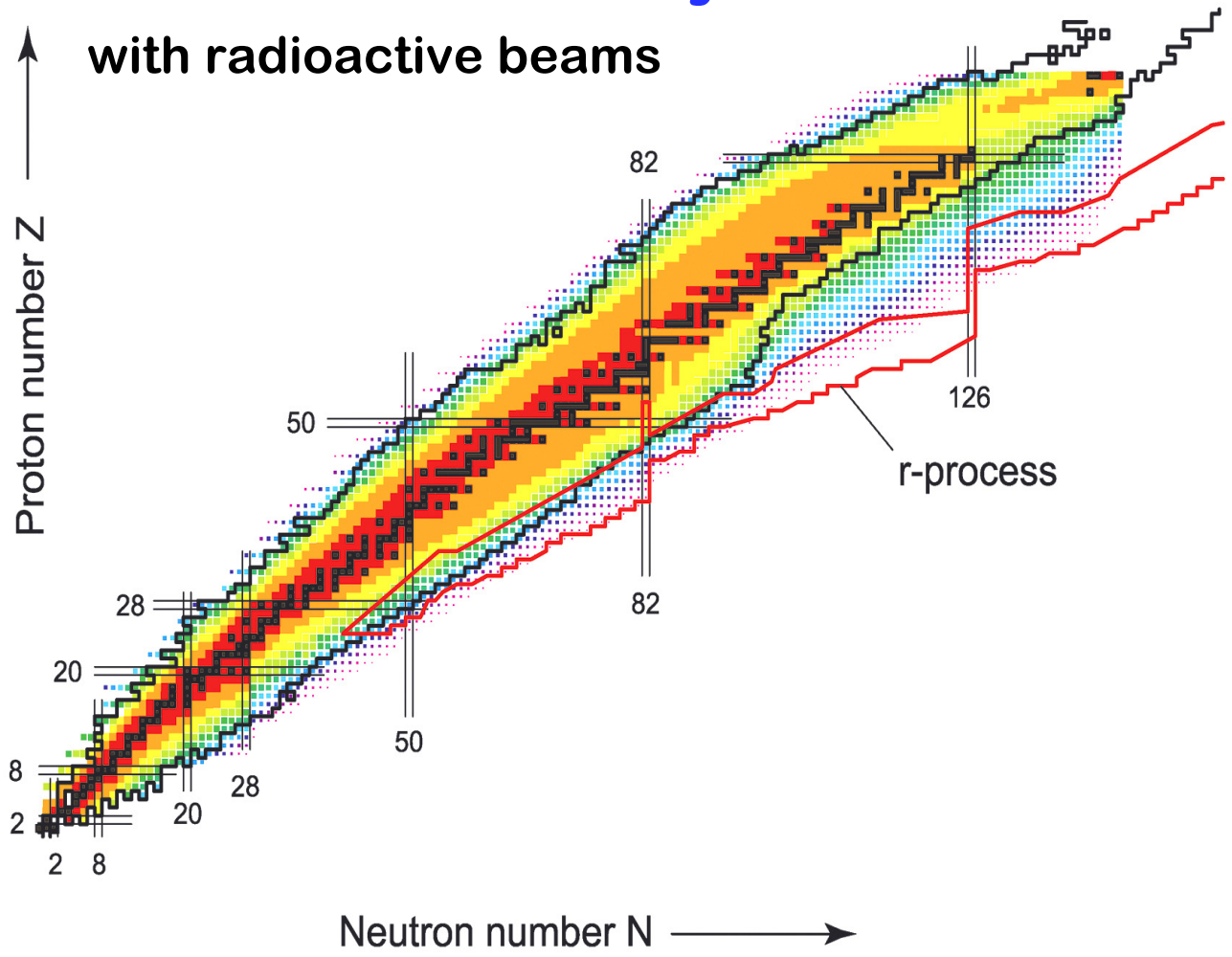
- radioactive beams
- 10^{11} antiprotons 1 - 15 GeV/c, stored and cooled

Technical Challenges

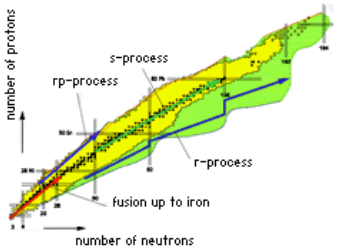
- cooled beams, rapid cycling superconducting magnets, etc.

Research at FAIR

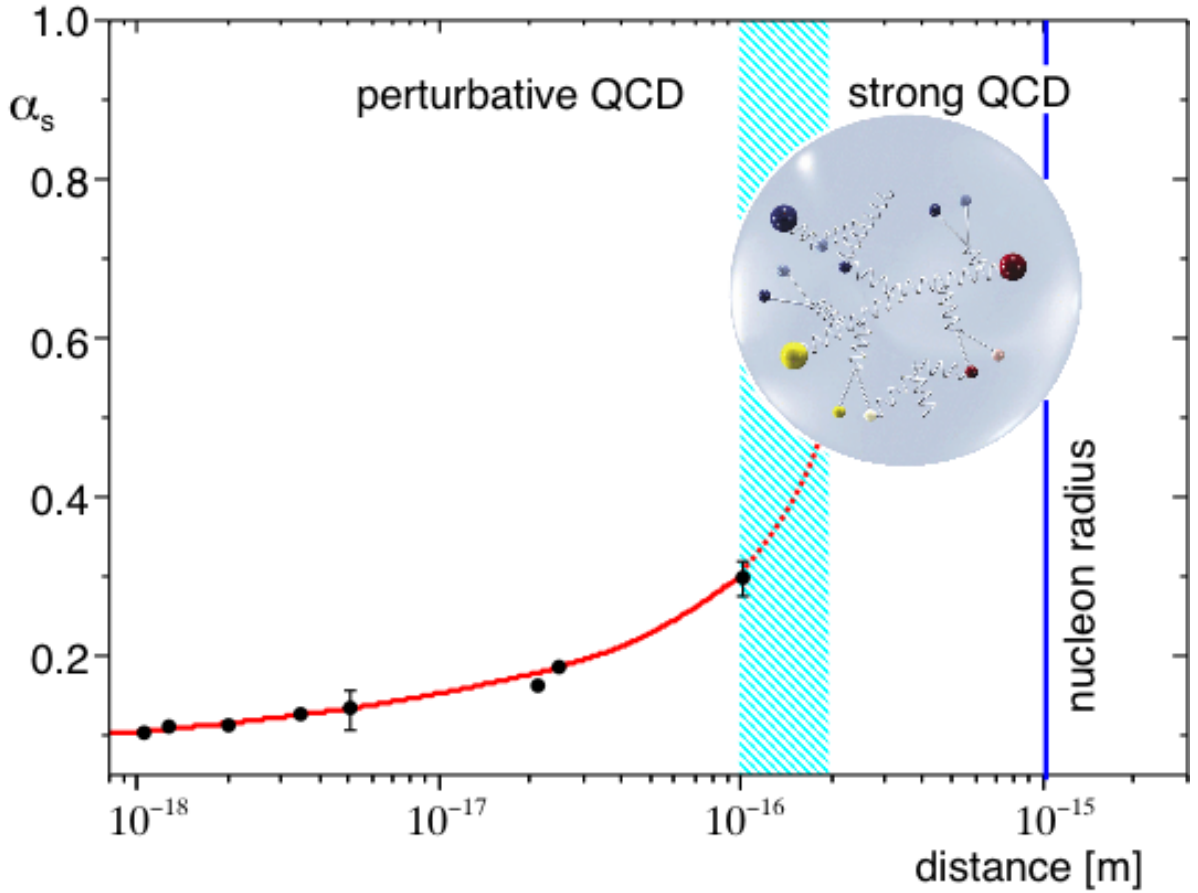
- **Nuclear Structure Physics**



Research at FAIR

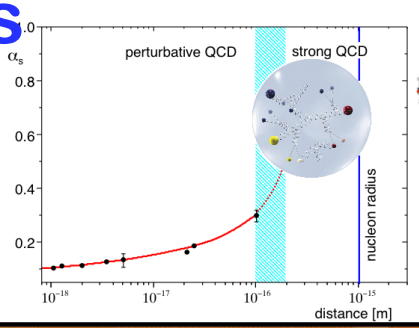


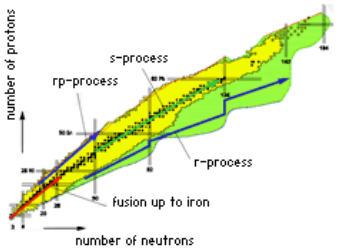
- Nuclear Structure Physics
- Physics with Antiprotons



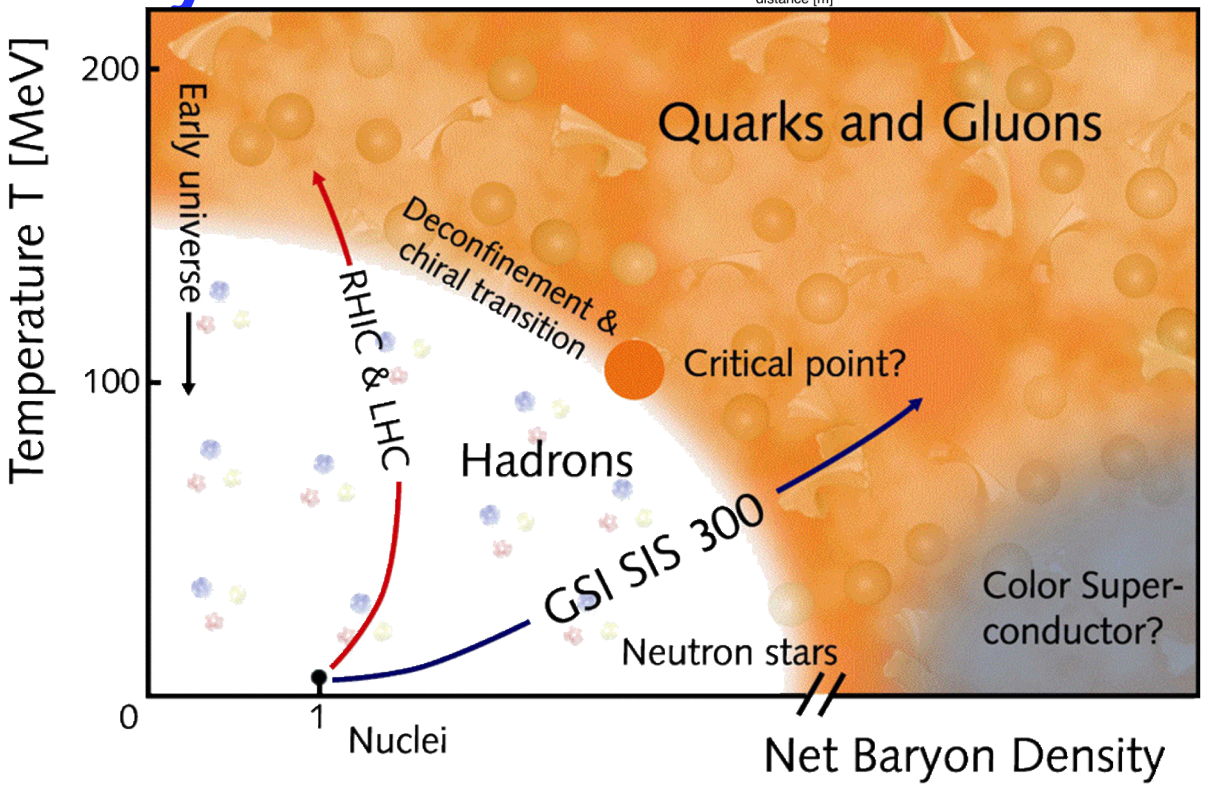
Research at FAIR

- **Nuclear Structure Physics**
- **Physics with Antiprotons**
- **Nuclear Matter Physics**





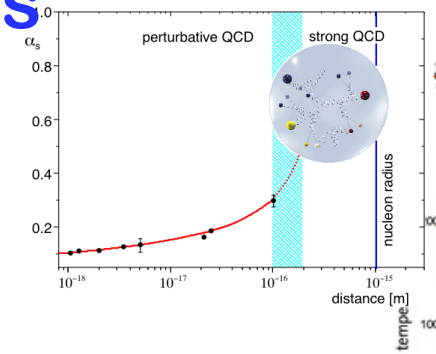
with 35-45 GeV/u heavy ion beams

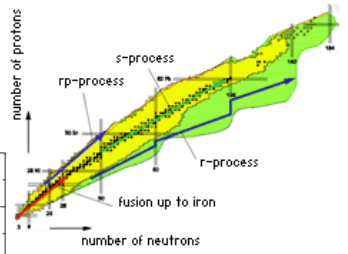


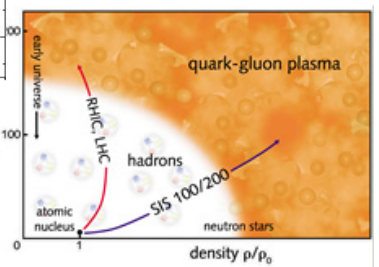
Research at FAIR

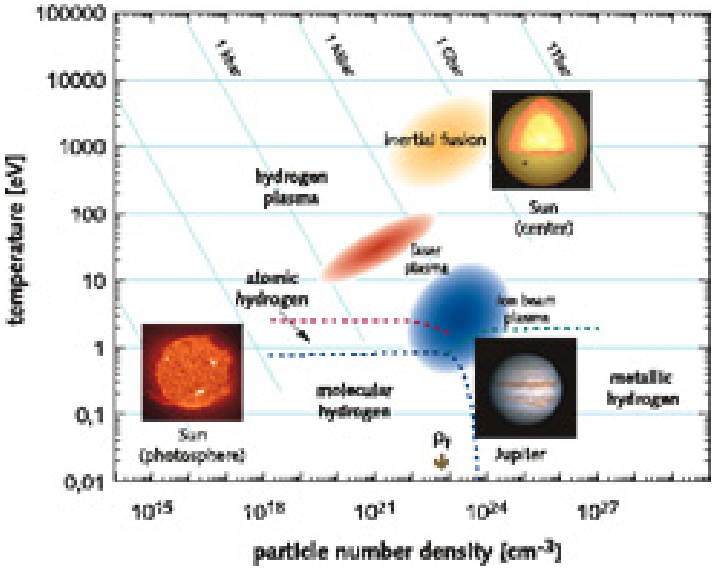
- Nuclear Structure Physics
- Physics with Antiprotons
- Nuclear Matter Physics
- Plasma Physics

  - with high intensity pulsed heavy ion beams
  - and petawatt lasers



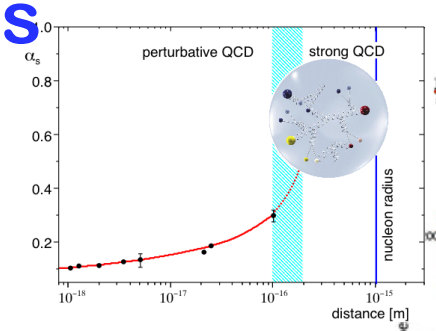


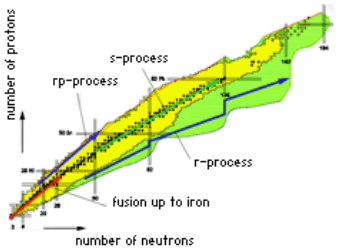


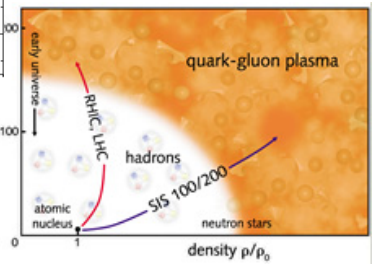


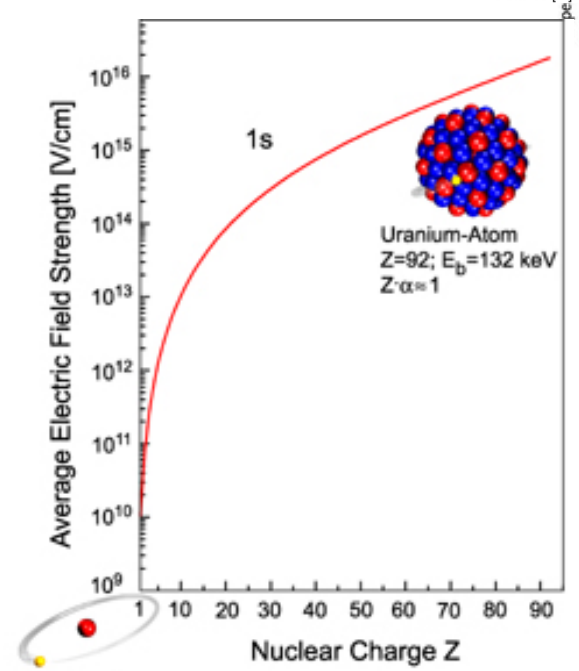
Research at FAIR

- Nuclear Structure Physics
- Physics with Antiprotons
- Nuclear Matter Physics
- Plasma Physics
- Atomic Physics
  - with highly charged ions
  - and very slow antiprotons



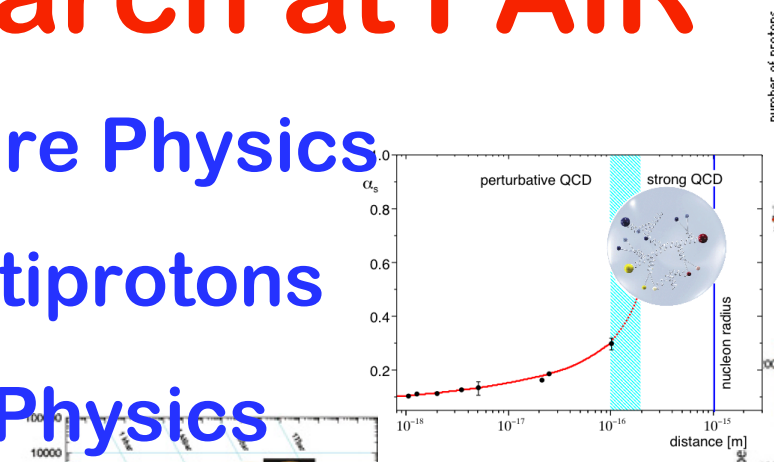


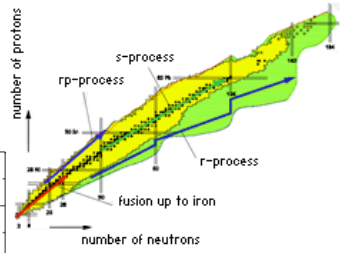


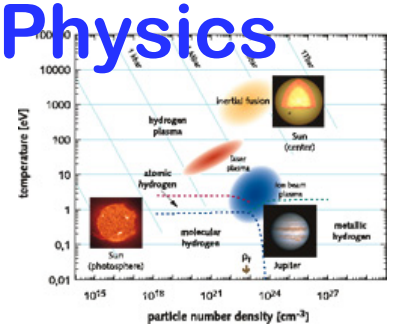


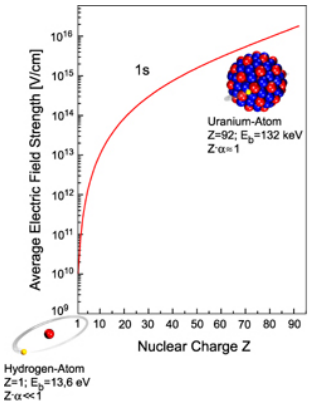
Research at FAIR

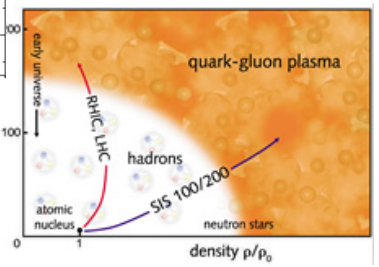
- Nuclear Structure Physics
- Physics with Antiprotons
- Nuclear Matter Physics
- Plasma Physics
- Atomic Physics
- Applied Science





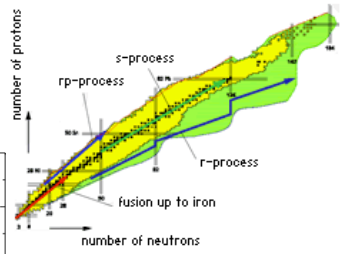


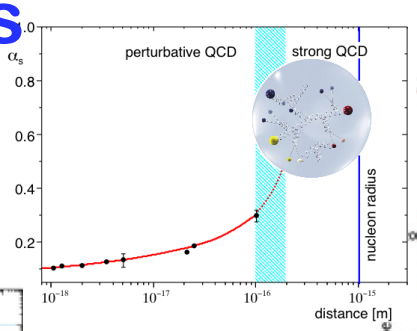


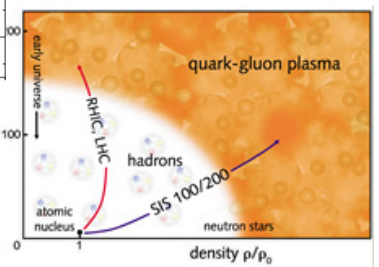


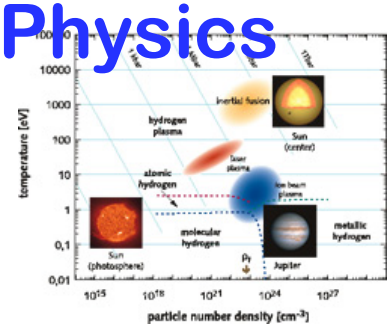
Research at FAIR

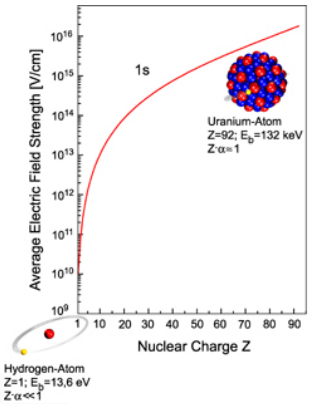
- Nuclear Structure Physics
- Physics with Antiprotons
- Nuclear Matter Physics
- Plasma Physics
- Atomic Physics
- Applied Science
- Accelerator Physics

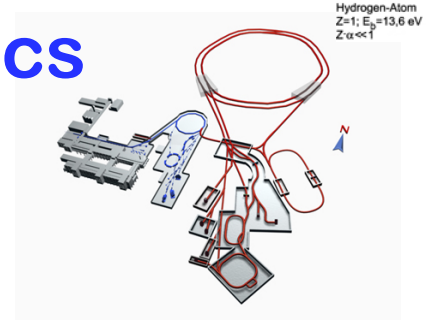












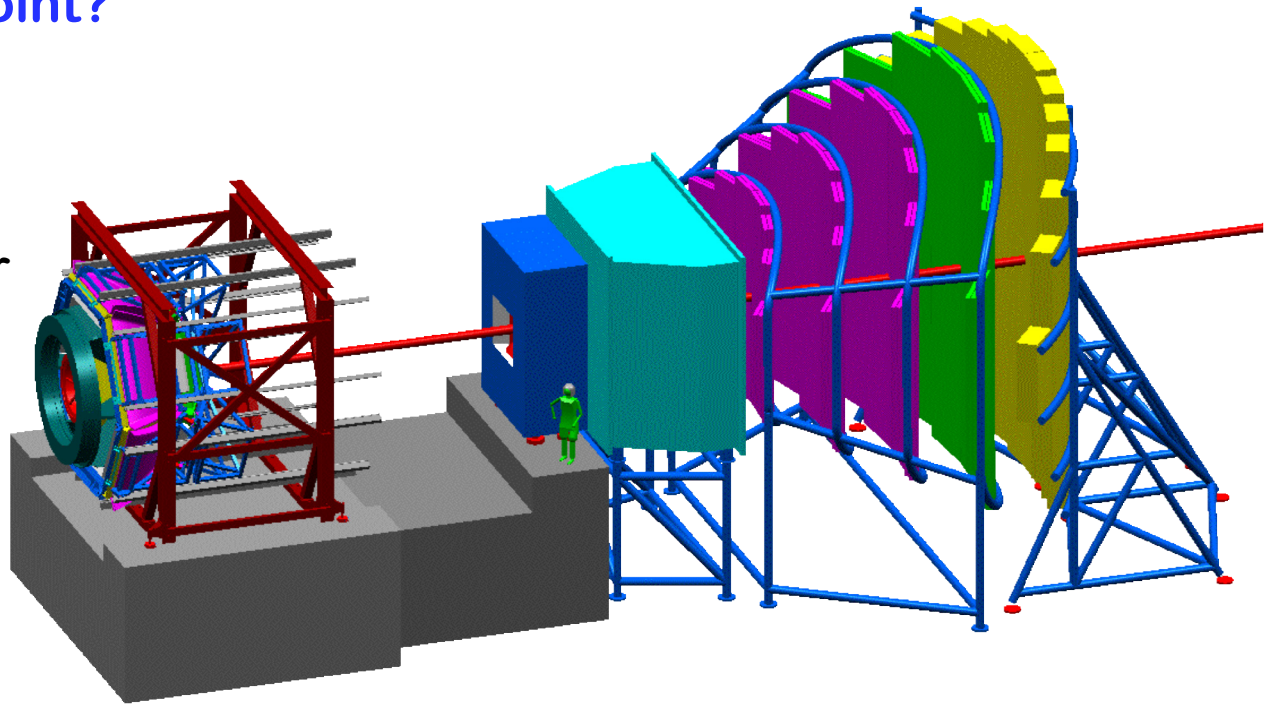
Hadron Physics at FAIR

- Compressed Baryonic Matter (CBM)
- Polarized Antiprotons (PAX)
- „High Energy“ Antiprotons (PANDA)
- Stopped Antiprotons (FLAIR)

Compressed Baryonic Matter CBM

- deconfinement phase transition at high baryon densities
- chiral symmetry restoration in superdense baryonic matter
- nuclear equation of state
- critical endpoint?

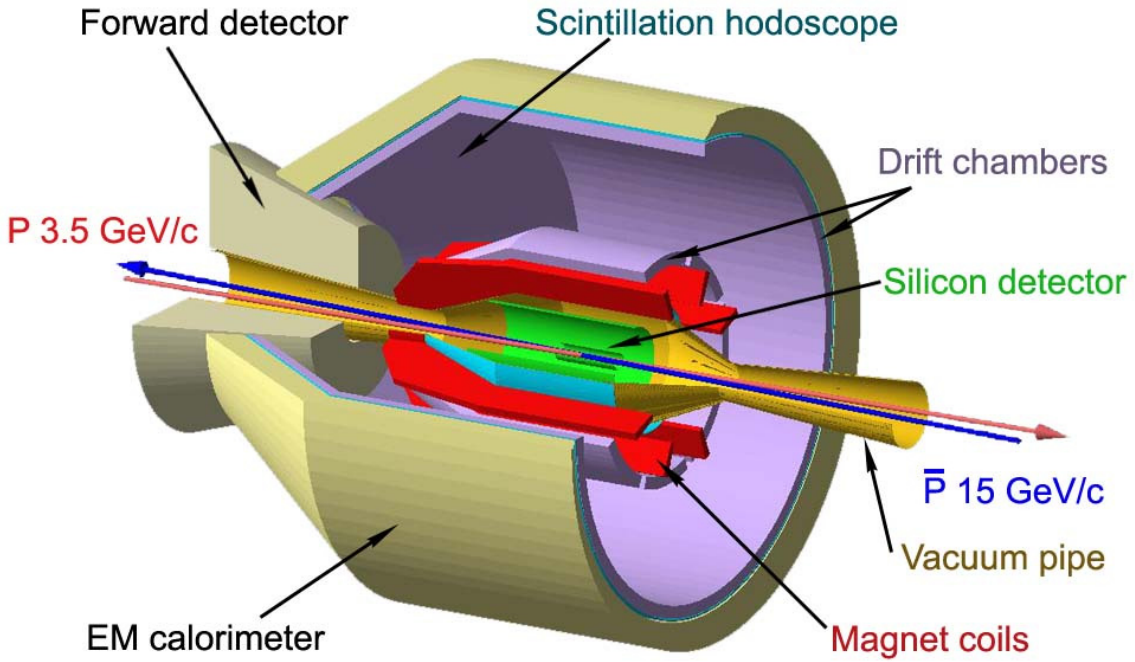
High count rates are challenging for the detector



Polarized Antiproton Experiment PAX

- transversity measurements
- Drell-Yan production
- time-like proton form factors

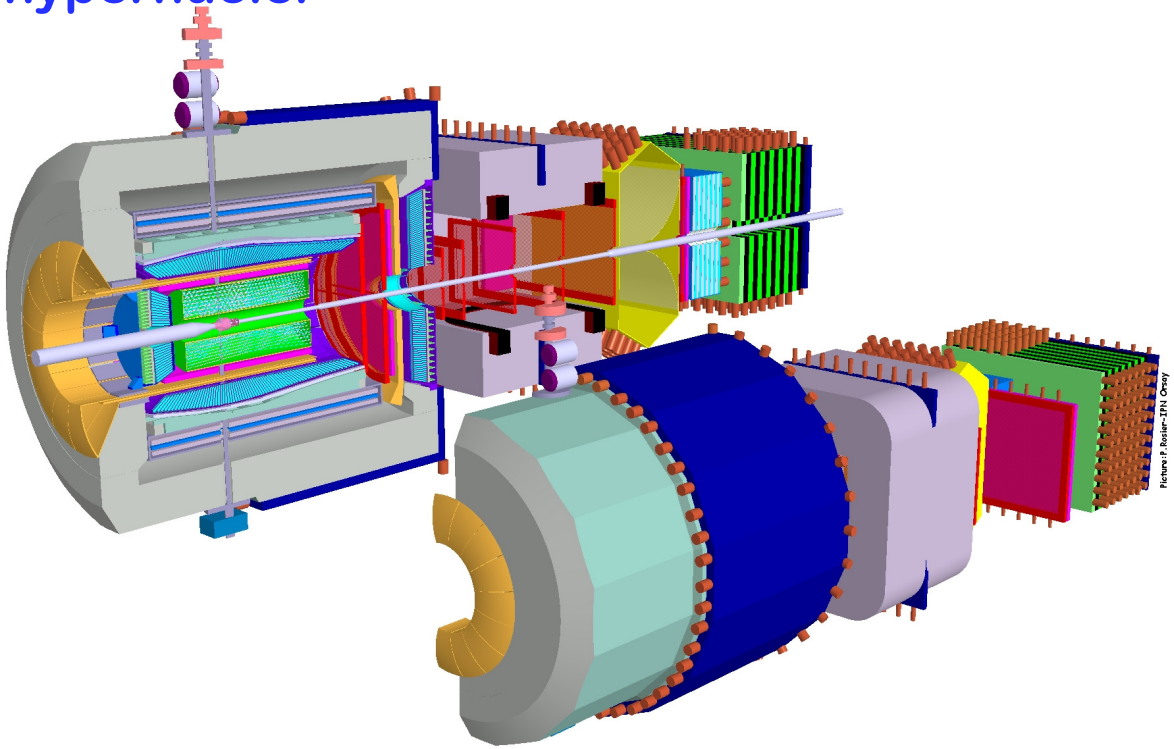
Requires COSY-like antiproton polarizer ring and asymmetric proton-antiproton collisions -> staging



PAX Detector

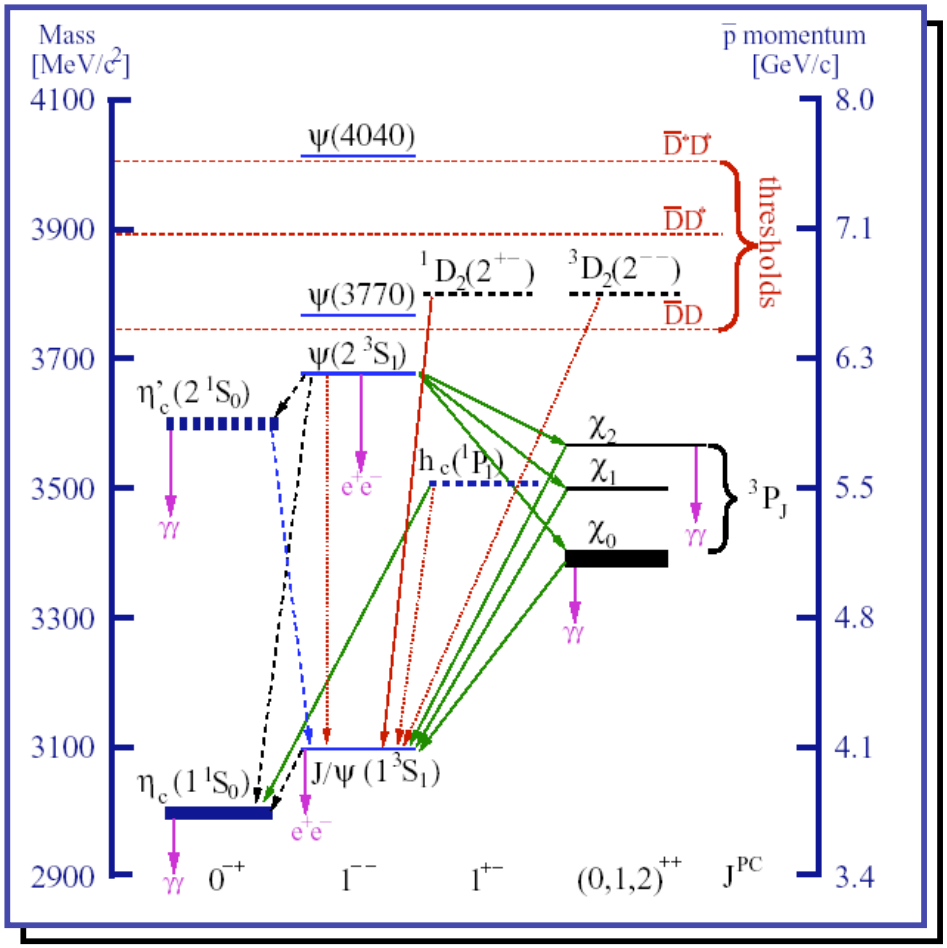
Antiproton Anihilations at Darmstadt
PANDA

- charmonium spectroscopy
- gluonic excitations (hybrids, glueballs)
- open and hidden charm in nuclei
- γ-ray spectroscopy of hypernuclei
- J/ψ-N scattering
- inverted DVCS
- ...

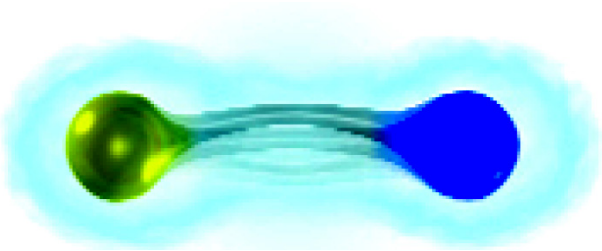


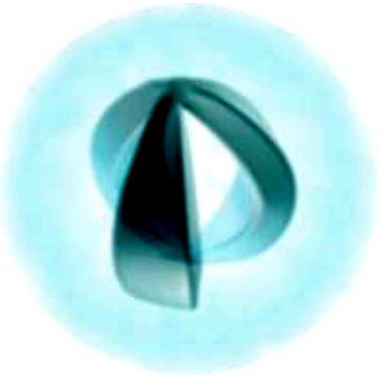
Charmonium Spectroscopy

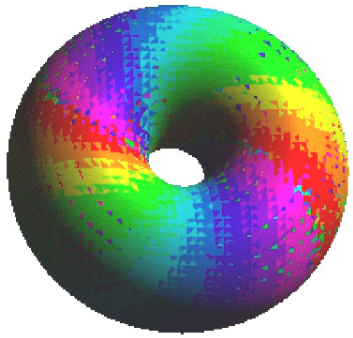
- positronium of QCD
- narrow states
- transition between massless and heavy quark limit
- well understood!??



Gluonic Excitations



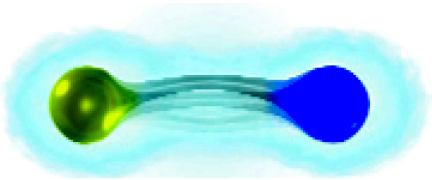




- hybrids: “ordinary” quark states containing excited glue

- glueballs: gluonic states without valence quark contribution

Hybrids



- **light quark hybrids**:
  - exp. candidates: $\pi_1(1400)$, $\pi_1(1600)$, ...
  - problem: mixing
- **charmed hybrids**:
  - prediction: m = 3.9 - 4.5 GeV/c^2, narrow
  - lowest state: 1^{-+} exotic => no mixing

decay: $1^{-+} \rightarrow \chi_c + (\pi\pi)_{l=0}$

$\hookrightarrow J/\psi + \gamma$

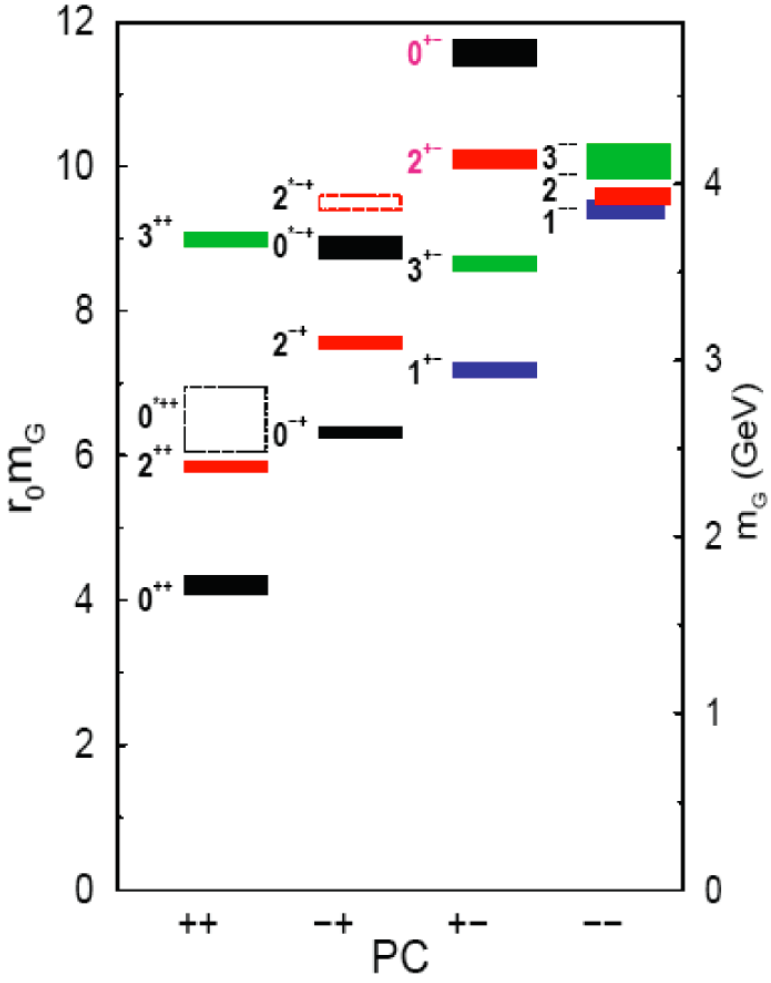
$\hookrightarrow e^+e^-$

(C. Michael, hep-lat/0207017)

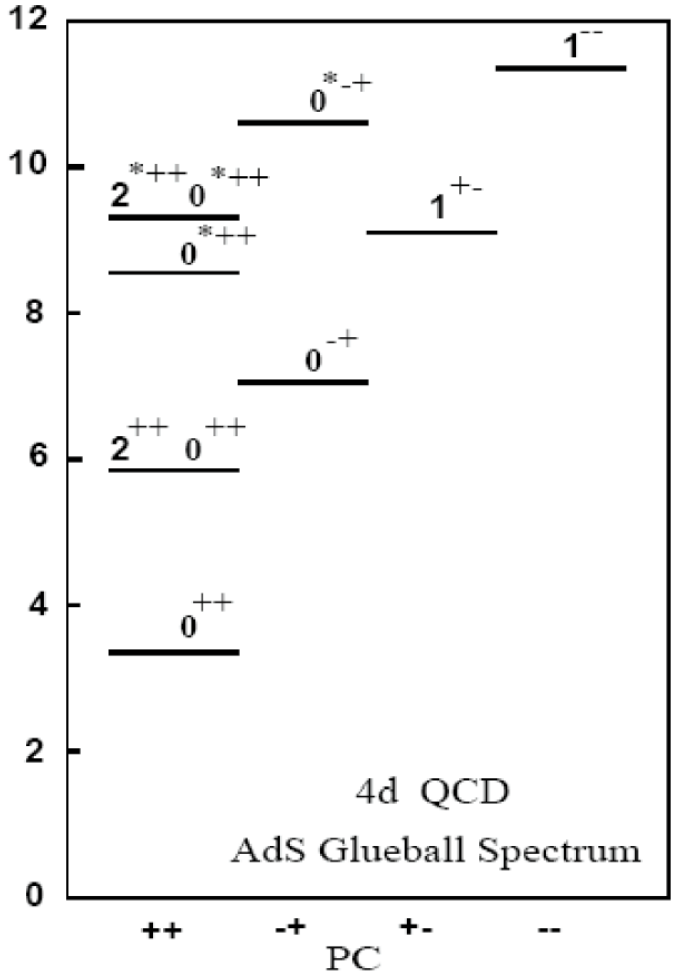
  - also 0^{--}, 0^{+-} and 2^{+-} do not mix

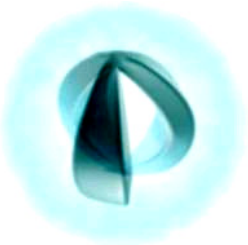
Glueball Predictions

Lattice QCD calculations by Morningstar and Peardon; PRD60 (1999) 034 509



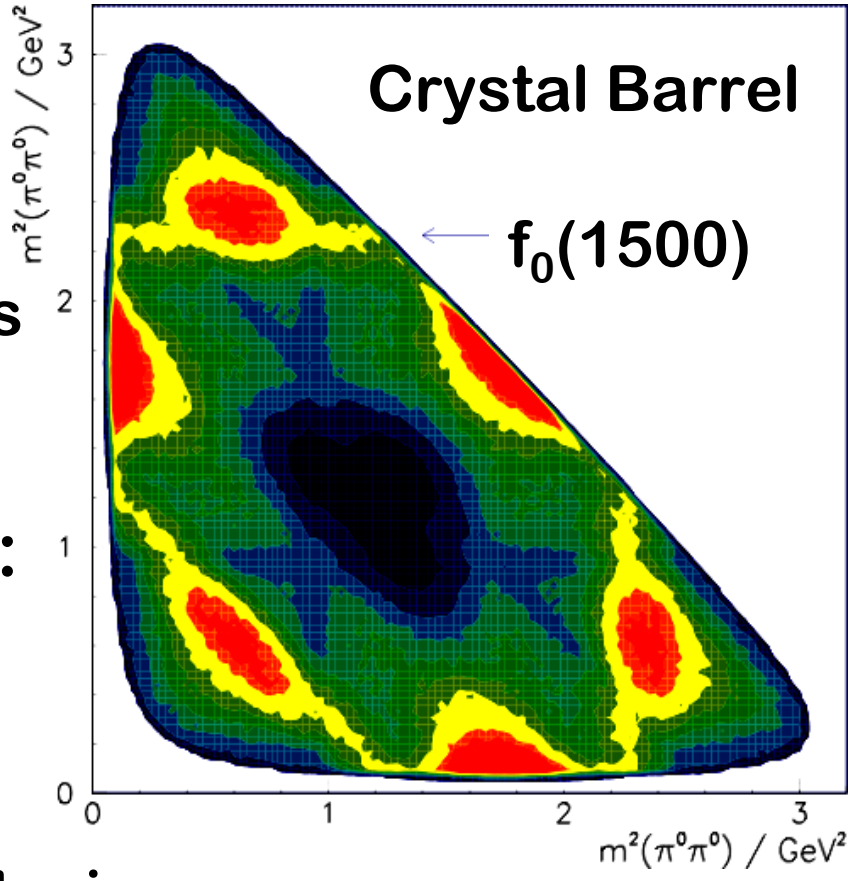
Flux tube calc. by Brower, Mathur and Tan. Nucl. Phys. B587 (2000)249





Glueballs

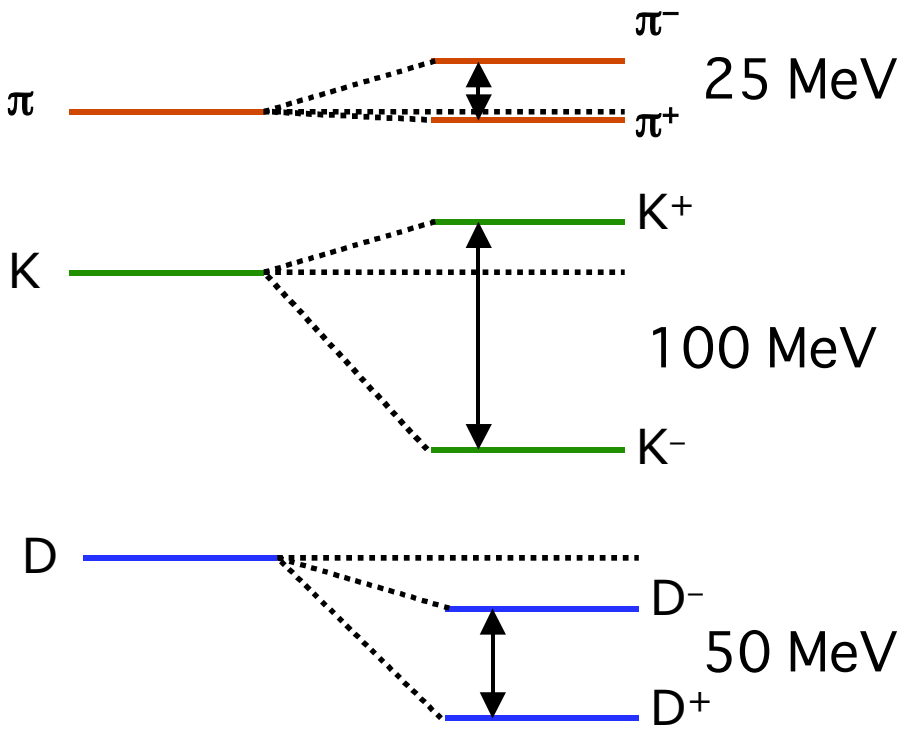
- **light glueballs**:
  - exp. candidate: $f_0(1500)$
  - well established
  - ordinary quantum numbers
  - problem: mixing,
- **glueballs above 3 GeV/c²**:
  - few mesonic states
  - less mixing
  - smaller width
  - exotic states: 2^{+-}, 0^{+-} do not mix



In-Medium Mass Modifications

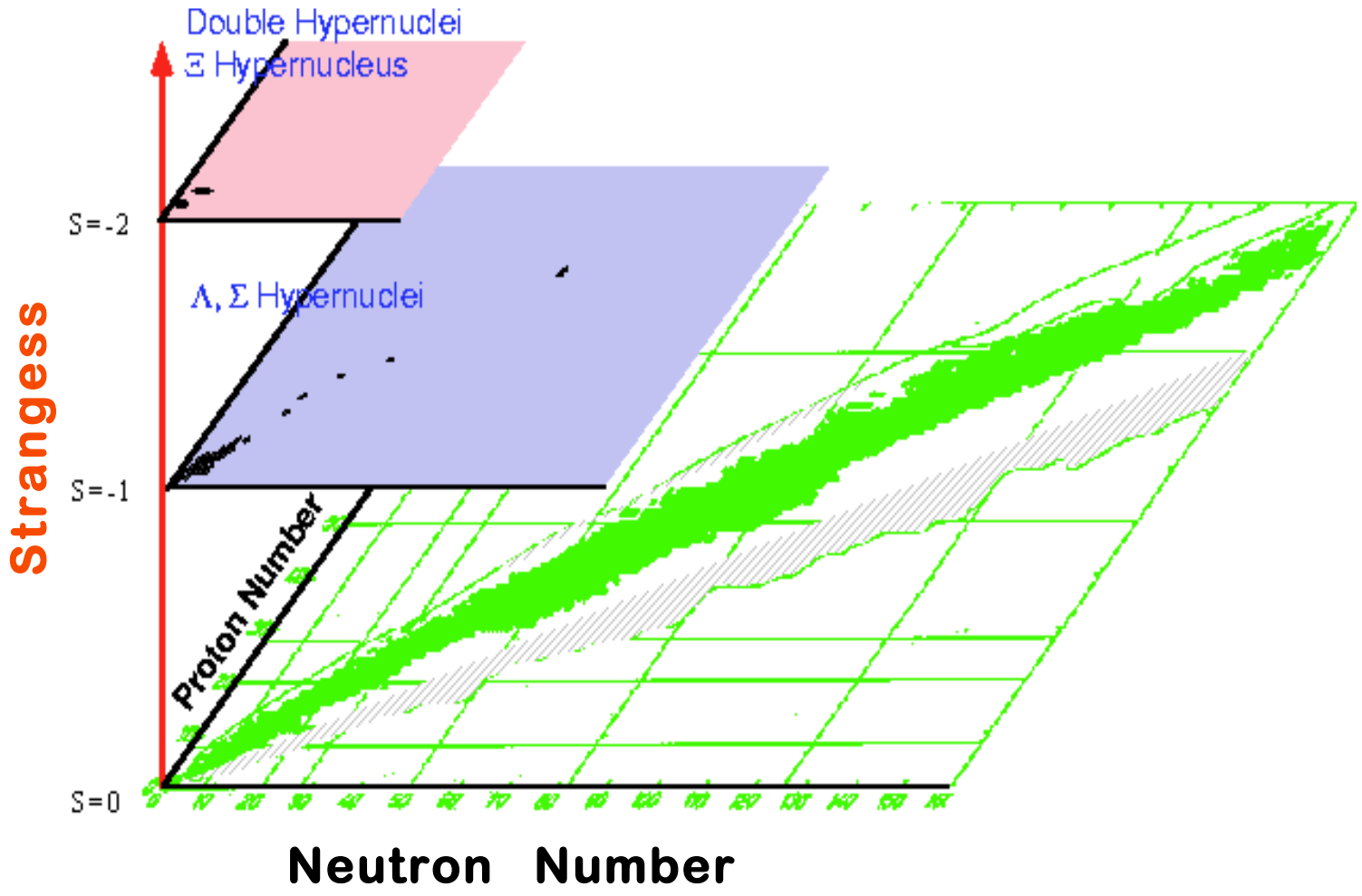
- **HADES, CBM:**
  ρ, ω, ϕ **studies**

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



A. Hayashigaki, PLB 487 (2000) 96

Extension of the Nuclear Chart

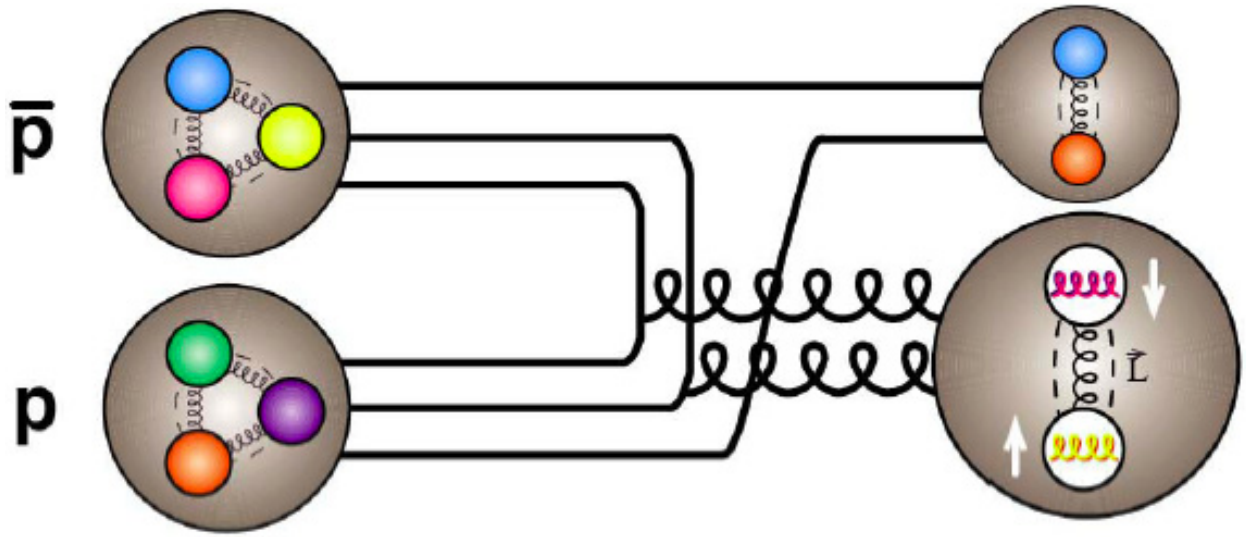


- Do we understand the YN interaction?

What is Experimentally Needed?

- **gluon-rich environment**

  ⇒ **proton-antiproton anihilations**



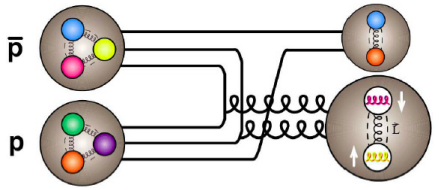
What is Experimentally Needed?

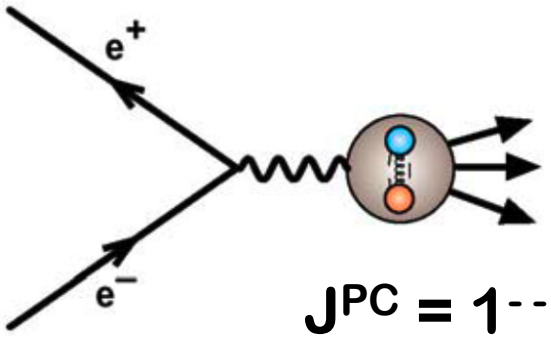
- **gluon-rich environment**

  ⇒ proton-antiproton anihilations

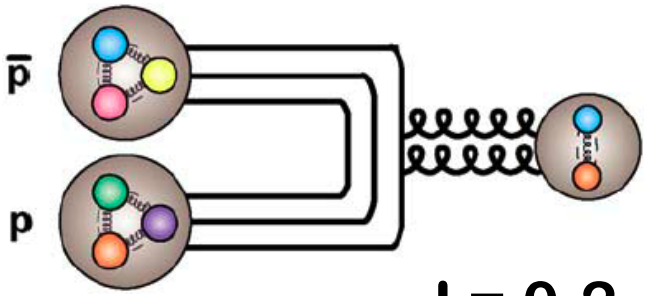
- **all quantum numbers**

  ⇒ formation exp. i.e. large acc. detector, fixed target

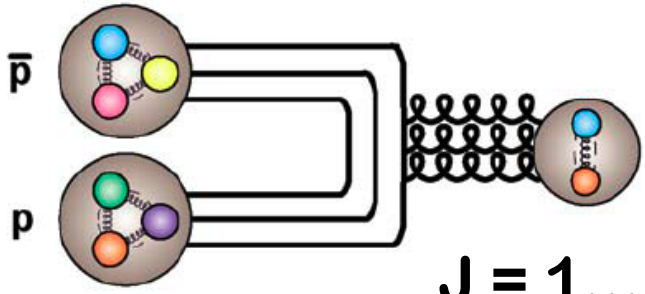




$J^{PC} = 1^{--}$

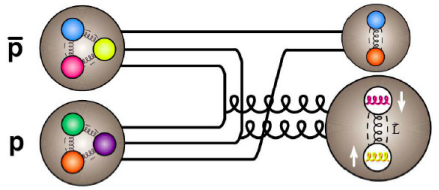


J = 0,2,.. C = +

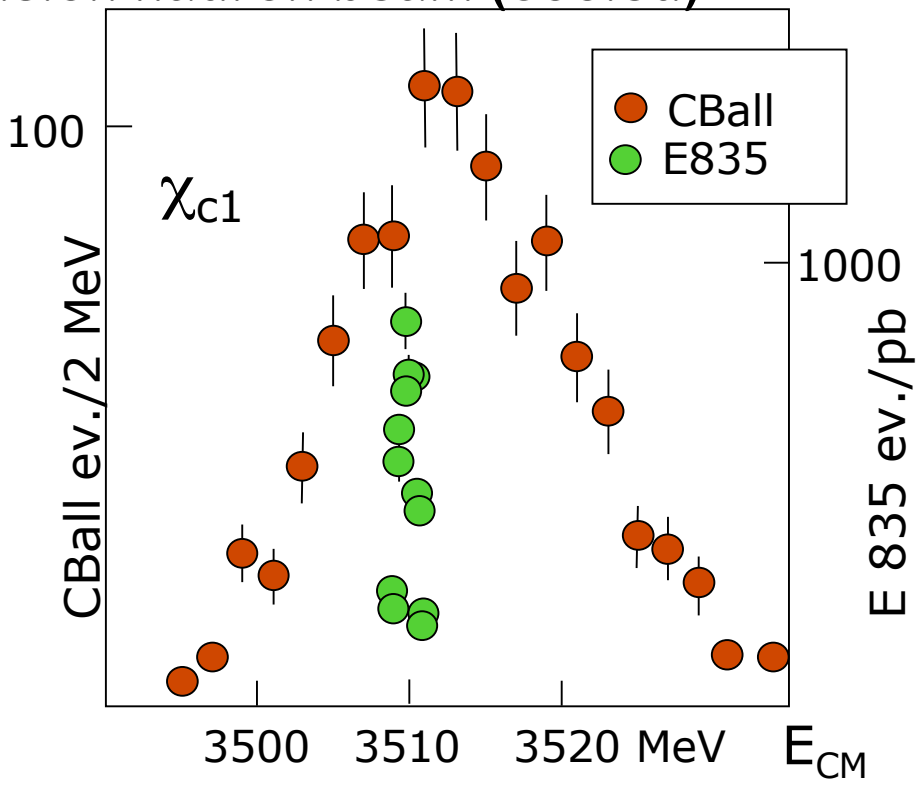


J = 1,.. C = -

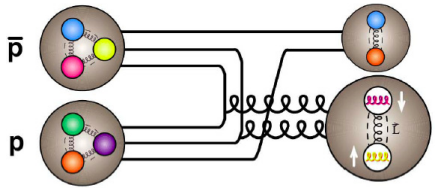
What is Experimentally Needed?



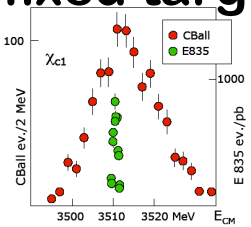
- **gluon-rich environment**
  ⇒ proton-antiproton anihilations
- **all quantum numbers**
  ⇒ formation exp. i.e. large acc. detector, fixed target
- **precise resonance scan**
  ⇒ high precision hadron beam (cooled)

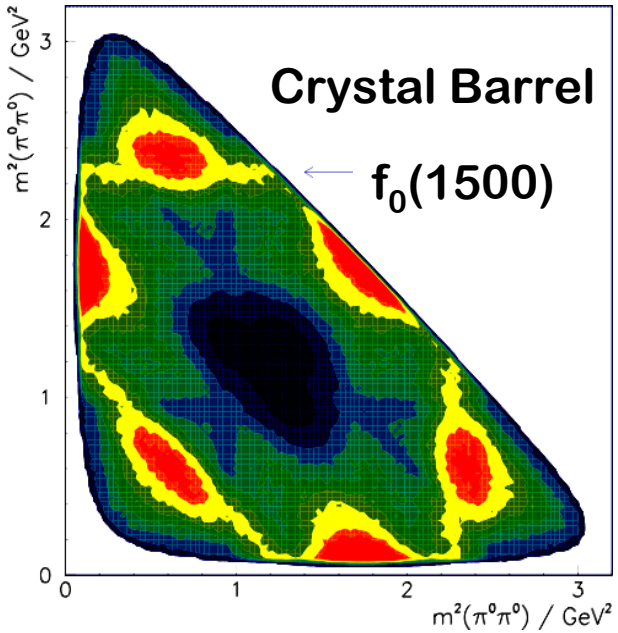


What is Experimentally Needed?

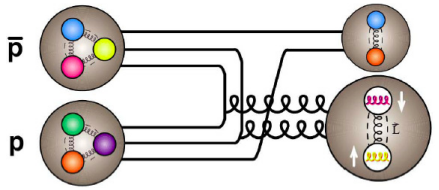


- **gluon-rich environment**
  ⇒ proton-antiproton anihilations
- **all quantum numbers**
  ⇒ formation exp. i.e. large acc. detector, fixed target
- **precise resonance scan**
  ⇒ high precision hadron beam (cooled)
- **high statistics samples**
  ⇒ high luminosity and prod. cross section

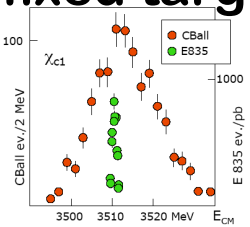


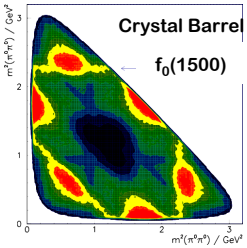


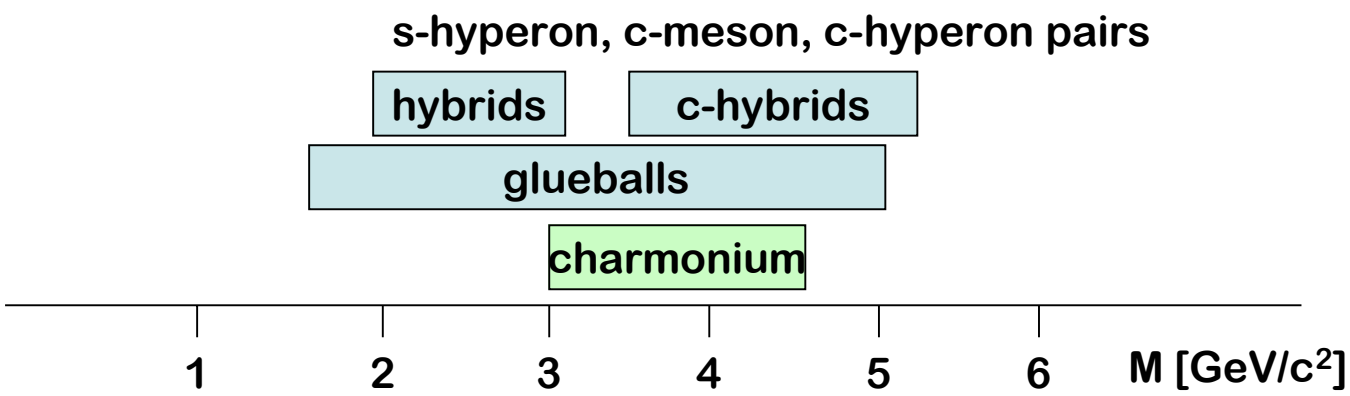
What is Experimentally Needed?

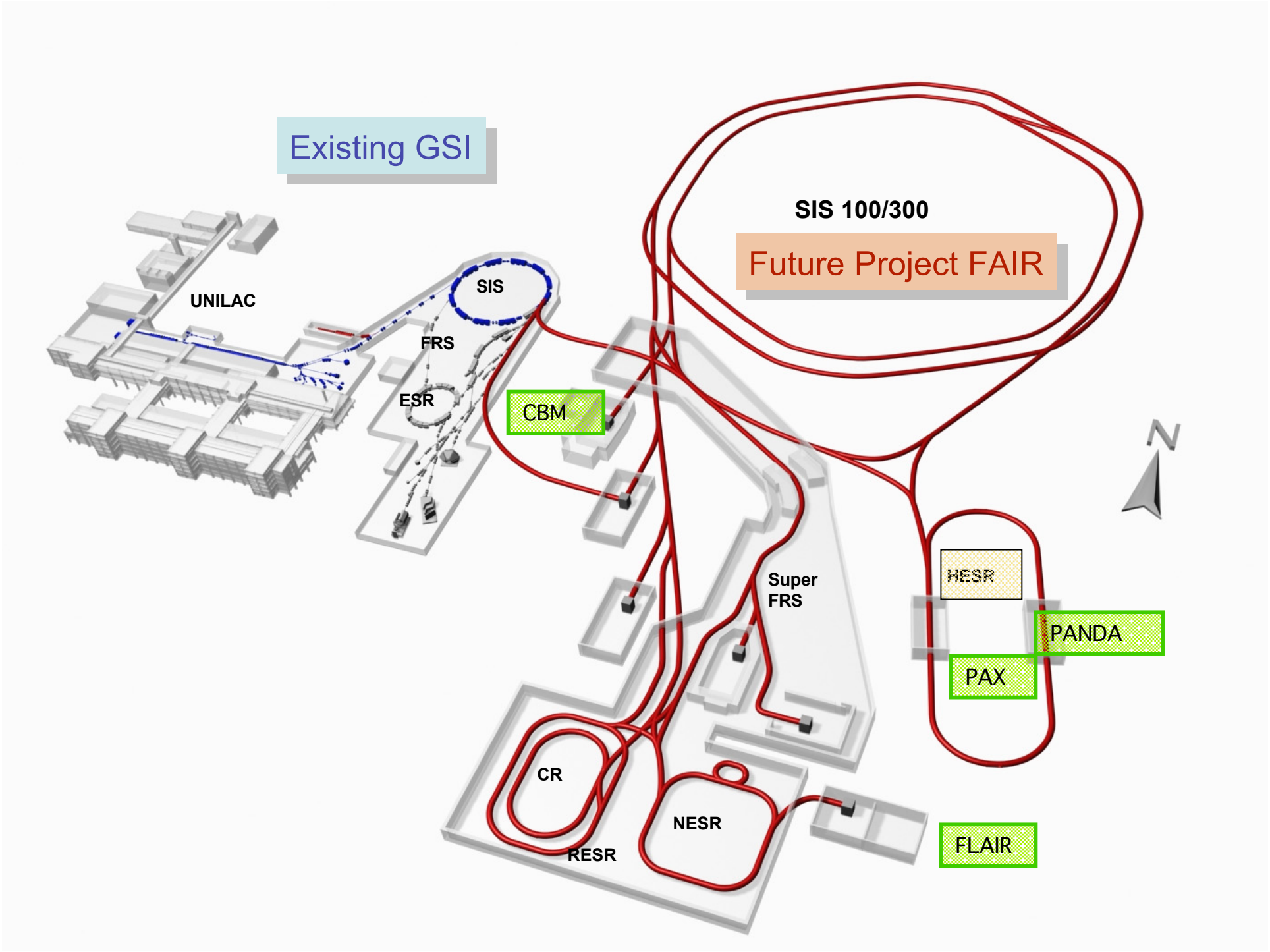


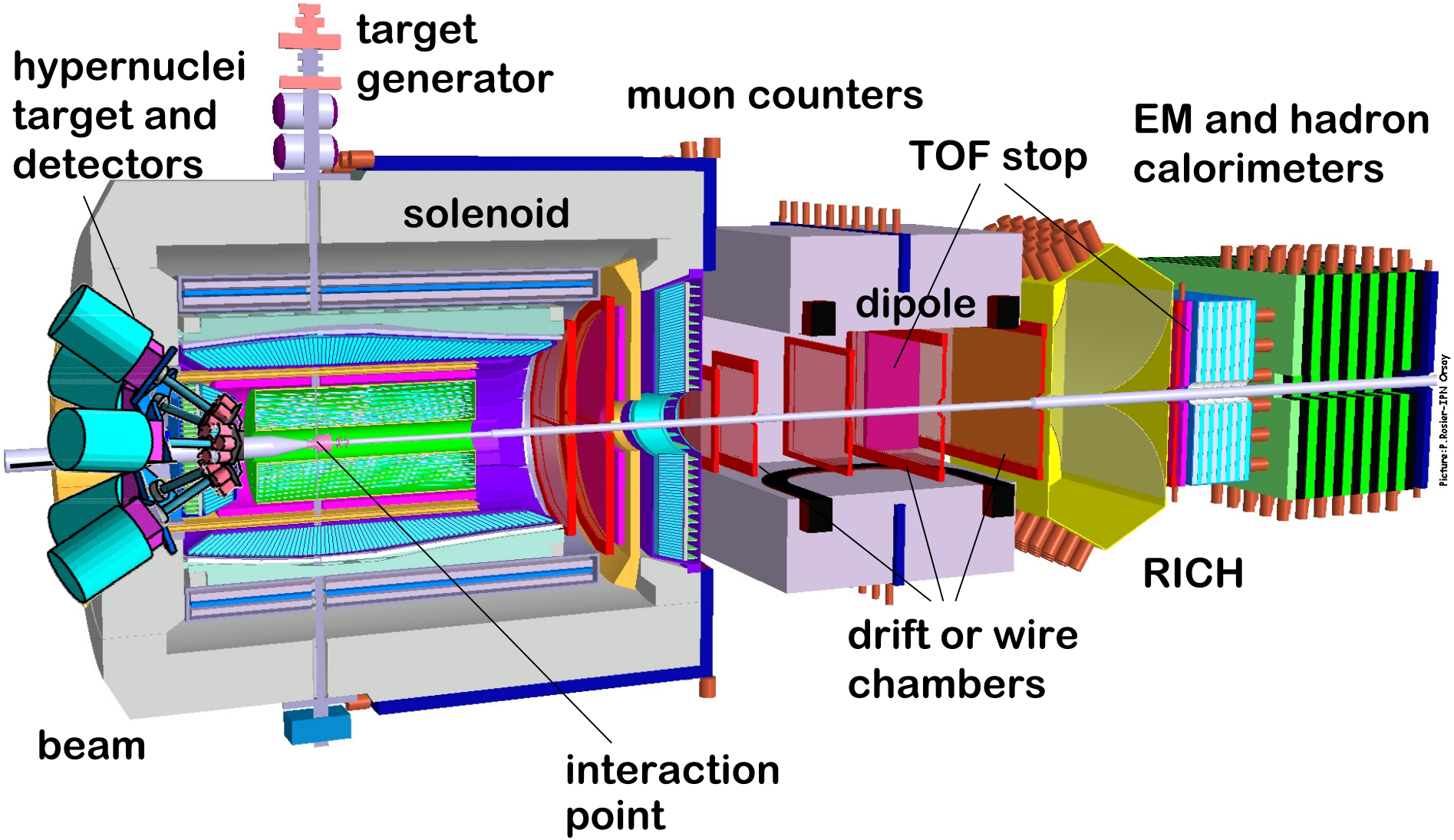
- **gluon-rich environment**
  - ⇒ proton-antiproton anihilations
- **all quantum numbers**
  - ⇒ formation exp. i.e. large acc. detector, fixed target
- **precise resonance scan**
  - ⇒ high precision hadron beam (cooled)
- **high statistics samples**
  - ⇒ high luminosity and prod. cross section
- **physics topics**
  - ⇒ energy range $p_{\bar{p}}$ = 1.5 - 15 GeV/c

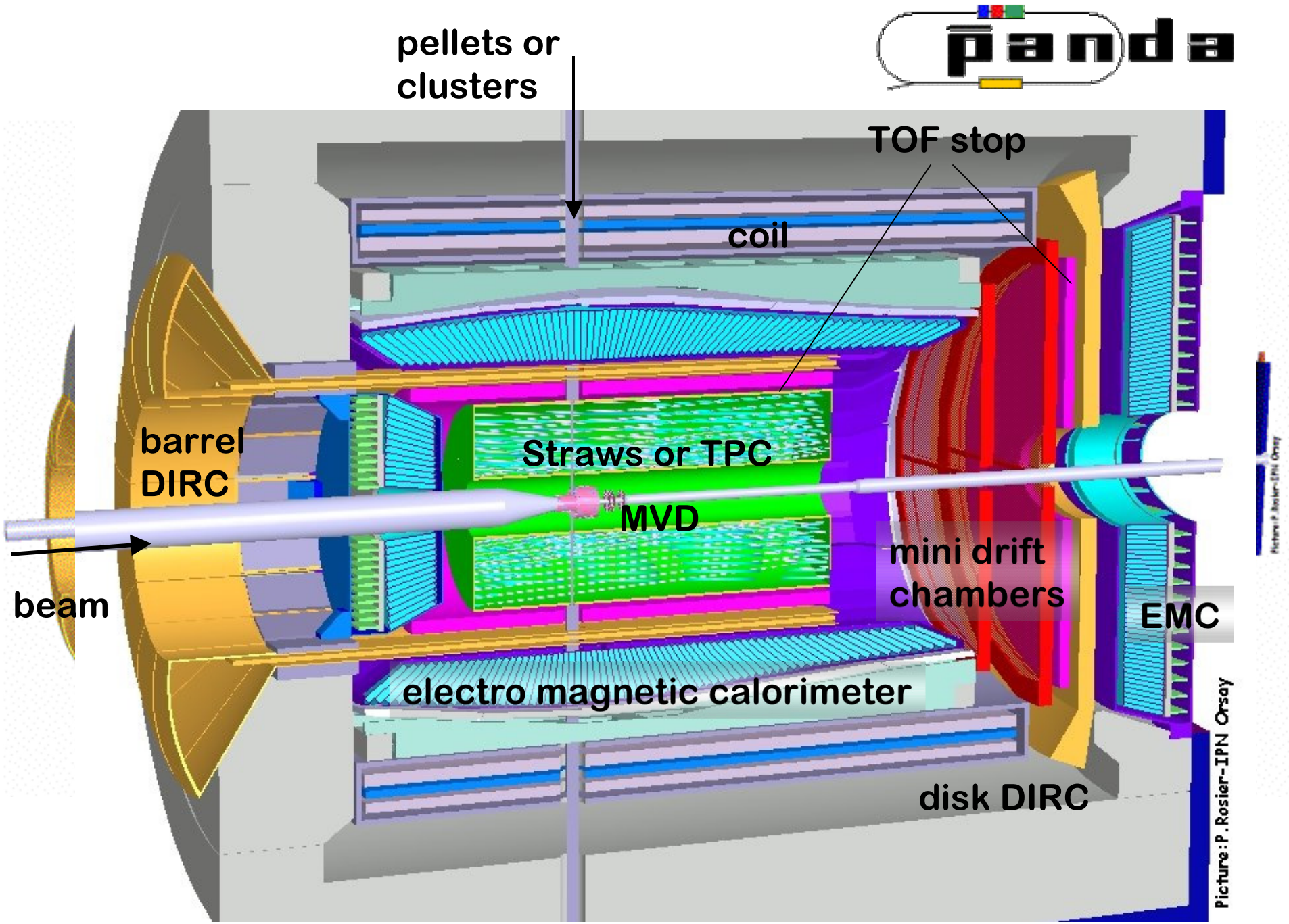







Existing GSI
SIS 100/300
Future Project FAIR
UNILAC
SIS
FRS
ESR
CBM
Super
FRS
HESR
PANDA
PAX
CR
NESR
RESR
FLAIR
N


panda
hypernuclei target and detectors
target generator
muon counters
TOF stop
EM and hadron calorimeters
solenoid
dipole
RICH
drift or wire chambers
beam
interaction point
12 m
Picture: P. Rosier - IPN Orsay


pellets or clusters
TOF stop
coil
barrel DIRC
Straws or TPC
MVD
beam
mini drift chambers
EMC
electro magnetic calorimeter
disk DIRC
Picture: P. Rosier-IPN Orsay

R&D at Uppsala University

- simulation of meson hybrid and glueball production
  - ISV, Uppsala
- e-cooler for the HESR
  - TSL, Uppsala -> Dag Reistad
- pellet target development, design and construction
  - TSL and ISV, Uppsala
- electromagnetic calorimeter (EMC)
  - ISV, Uppsala
  - Fysikum Stockholm University

Simulation of Benchmark Channels

e.g. charmonium hybrid

$$p\bar{p} \rightarrow \Psi_g\, \eta \qquad J^{PC} = 1^{-+}$$

$$\hookrightarrow \gamma\gamma$$

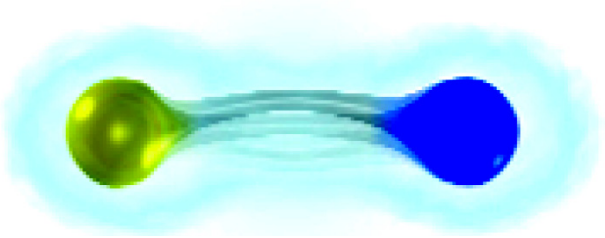
$$\hookrightarrow \chi_c \left(\pi^0\pi^0\right)_s$$

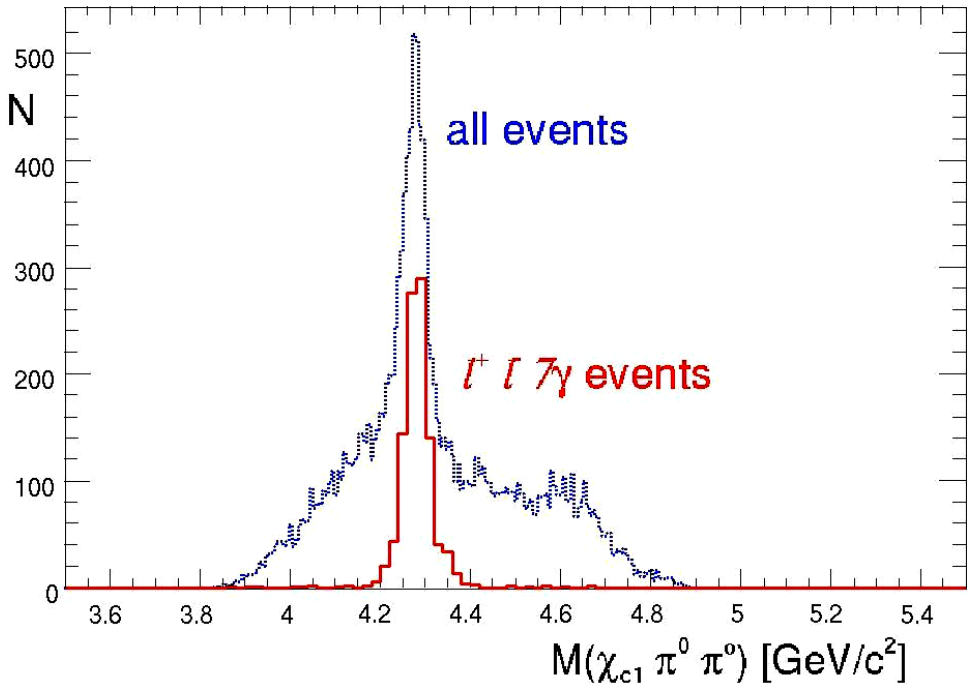
$$\hookrightarrow \gamma\gamma\gamma\gamma$$

$$\hookrightarrow J/\psi\, \gamma$$

$$\hookrightarrow l^+ l^-$$

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

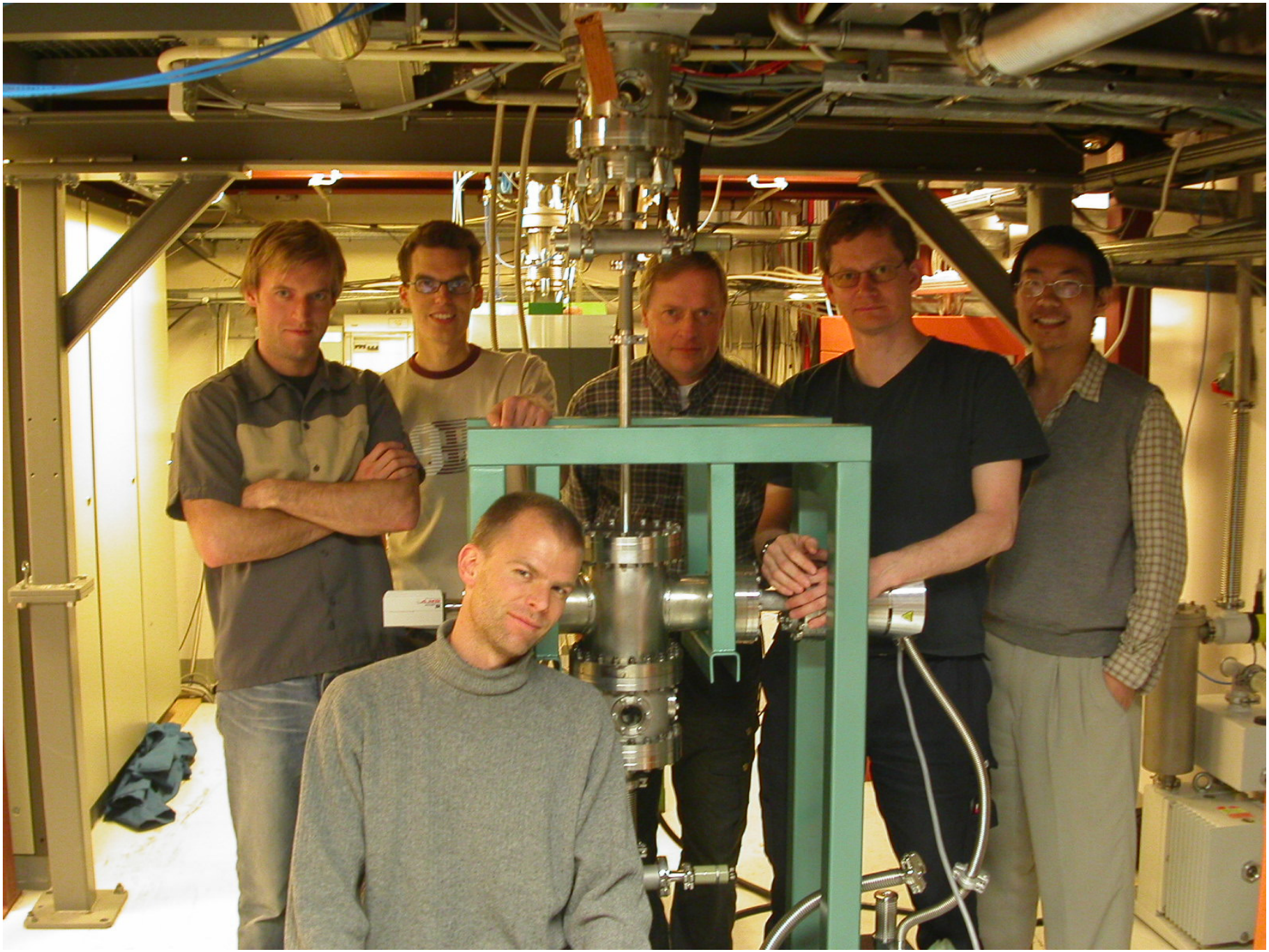


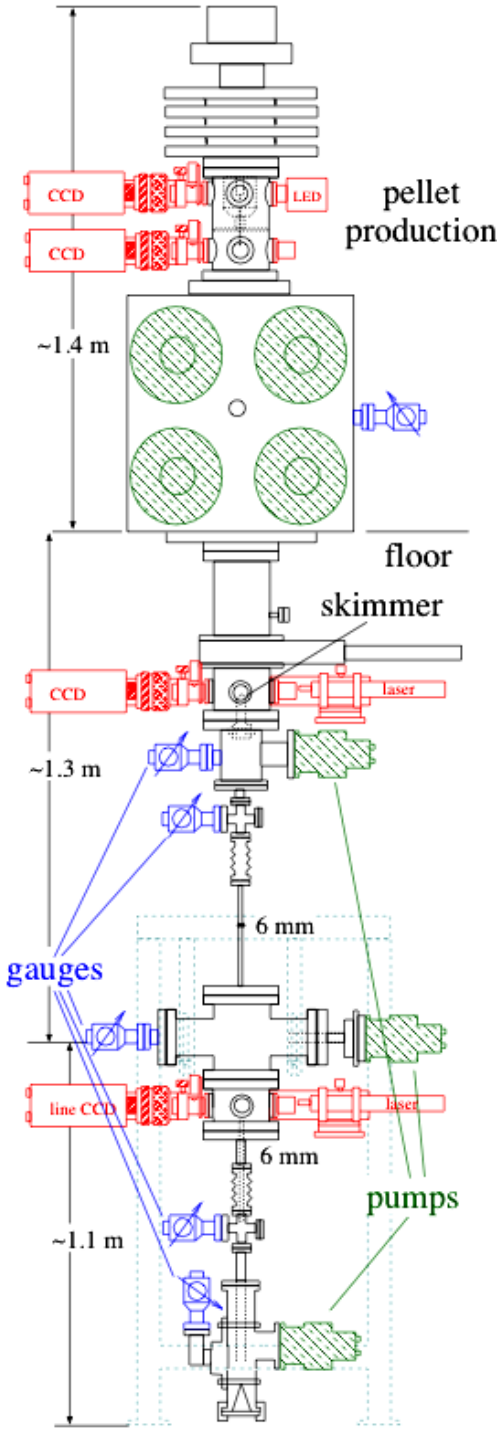


- **Reconstruction of Ψ_g**
  - 12% efficiency feasible
  - split off reconstruction?

Pellet Target

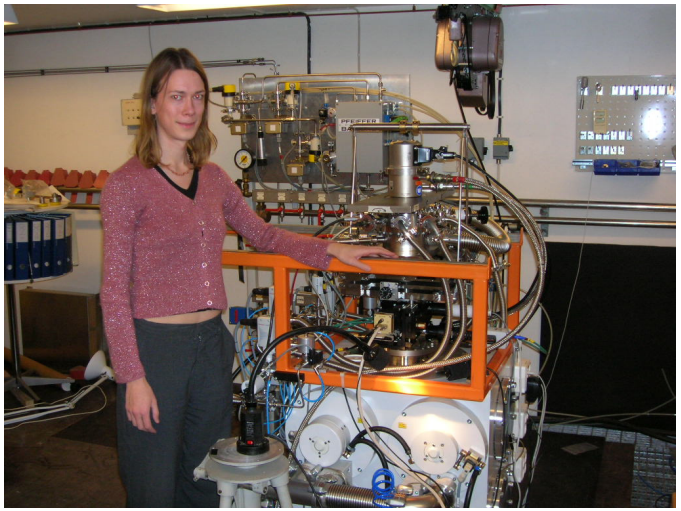
- pellet targets - solution for internal targets with
  - space for detectors around the interaction point
  - low out-gassing
  - high luminosities
  - vertex definition
  - but: beam size has to be matched (or larger)
- achievements at Uppsala:
  - dedicated test stand
  - R&D on all components started
  - vacuum compatibility shown for PANDA
  - first pellets tracked with a CCD camera
- use at COSY, CSR, and

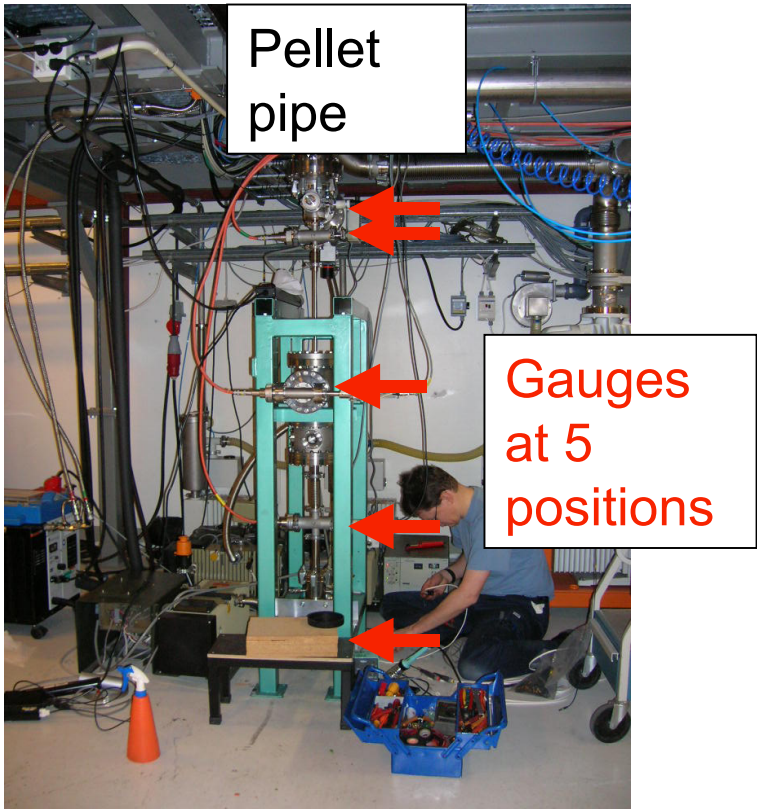




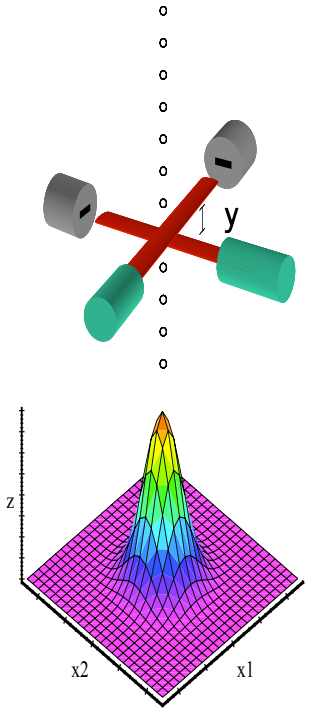
Status 2006

- independent system
- PANDA like
- 5x vacuum measurement
- CCD monitors
- pellet counter
- observation of individual pellets using a line-scan camera

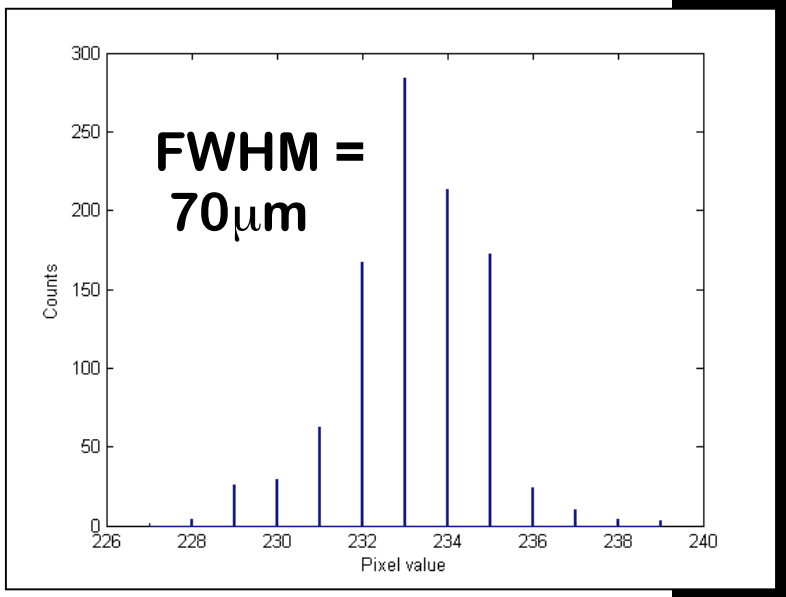




The Pellet Tracking System



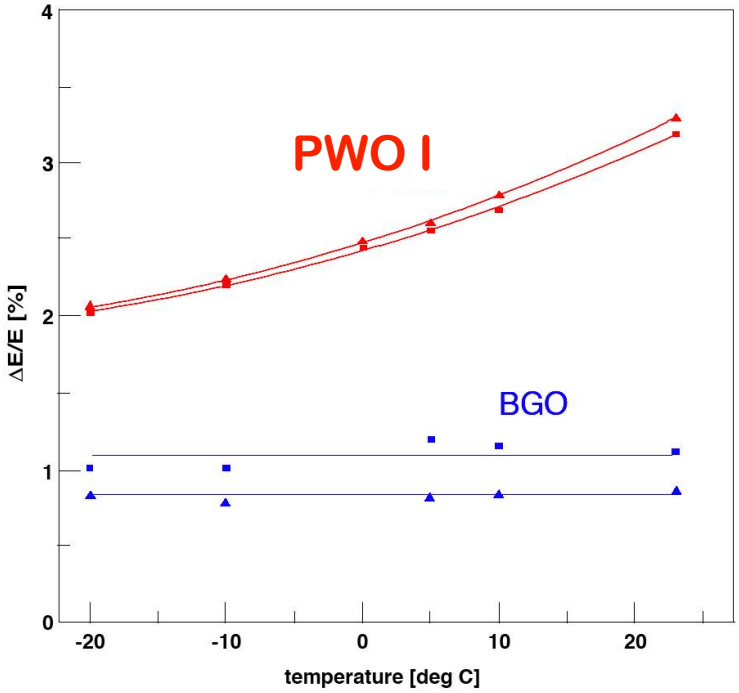
98 kHz, 512 pixel line-scan camera

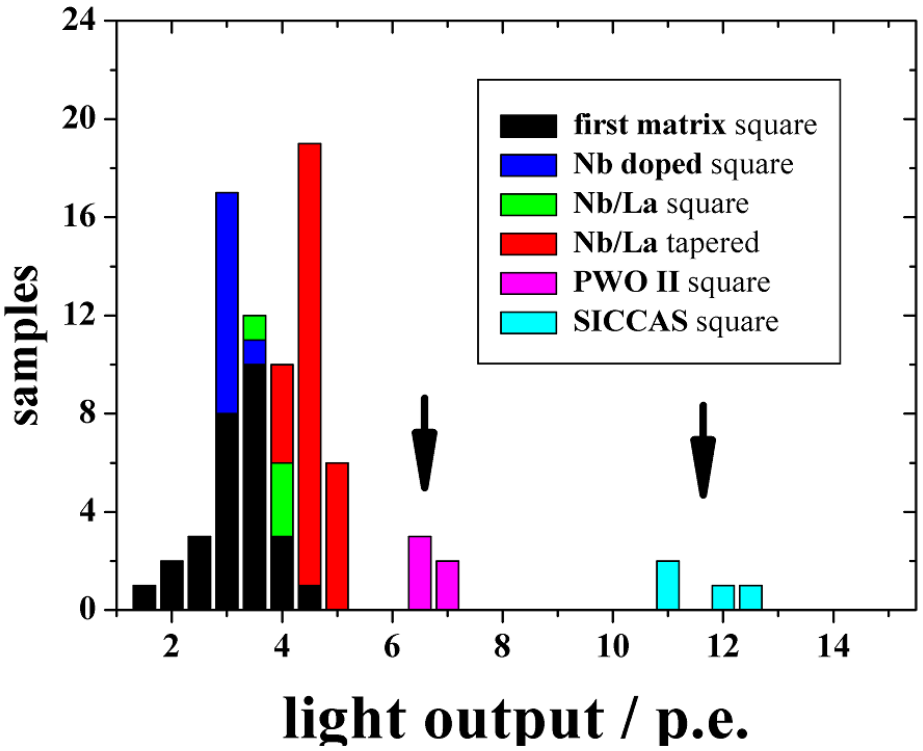


Electro-Magnetic Calorimeter

scintillator material

- **scintillator material**
  - PWO II, III, BGO





Electro-Magnetic Calorimeter

light yield dependence on position

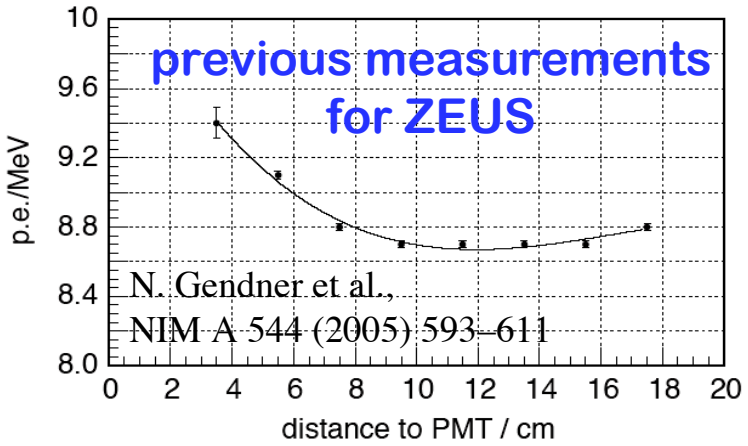
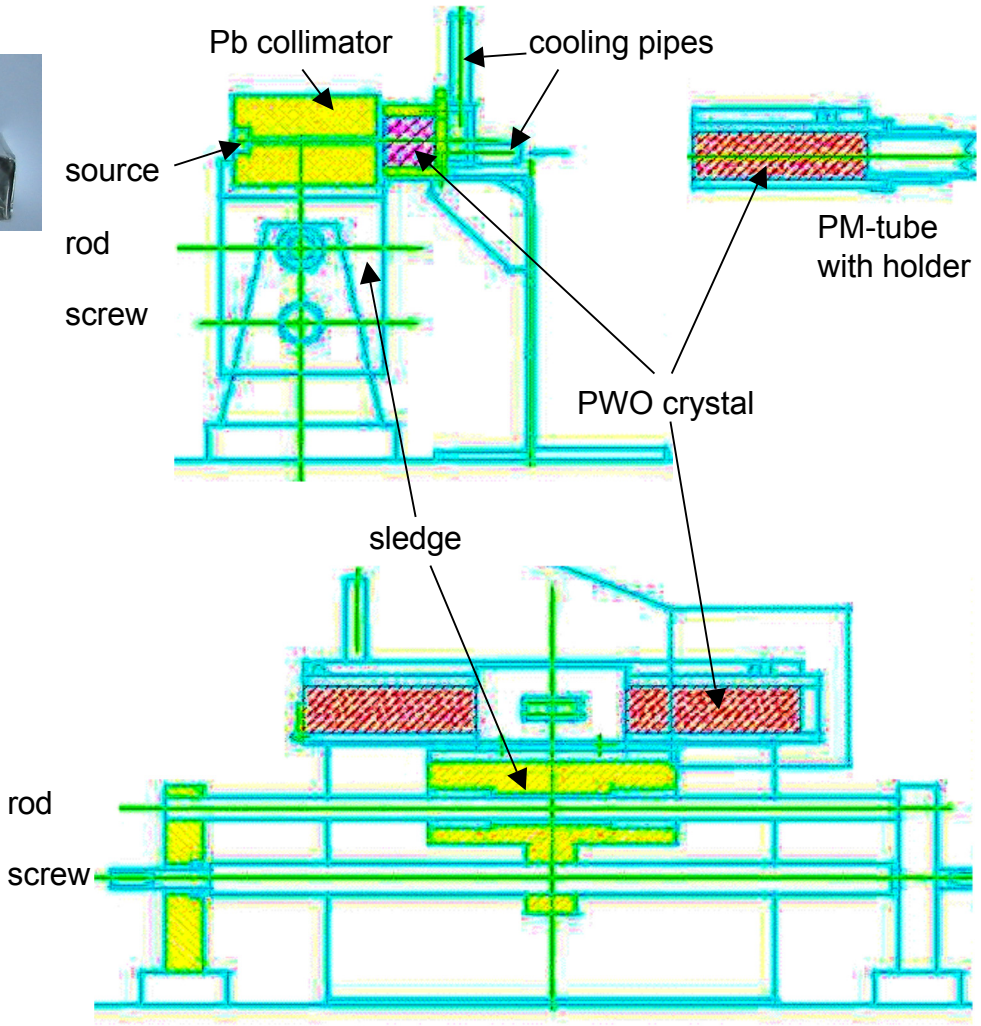


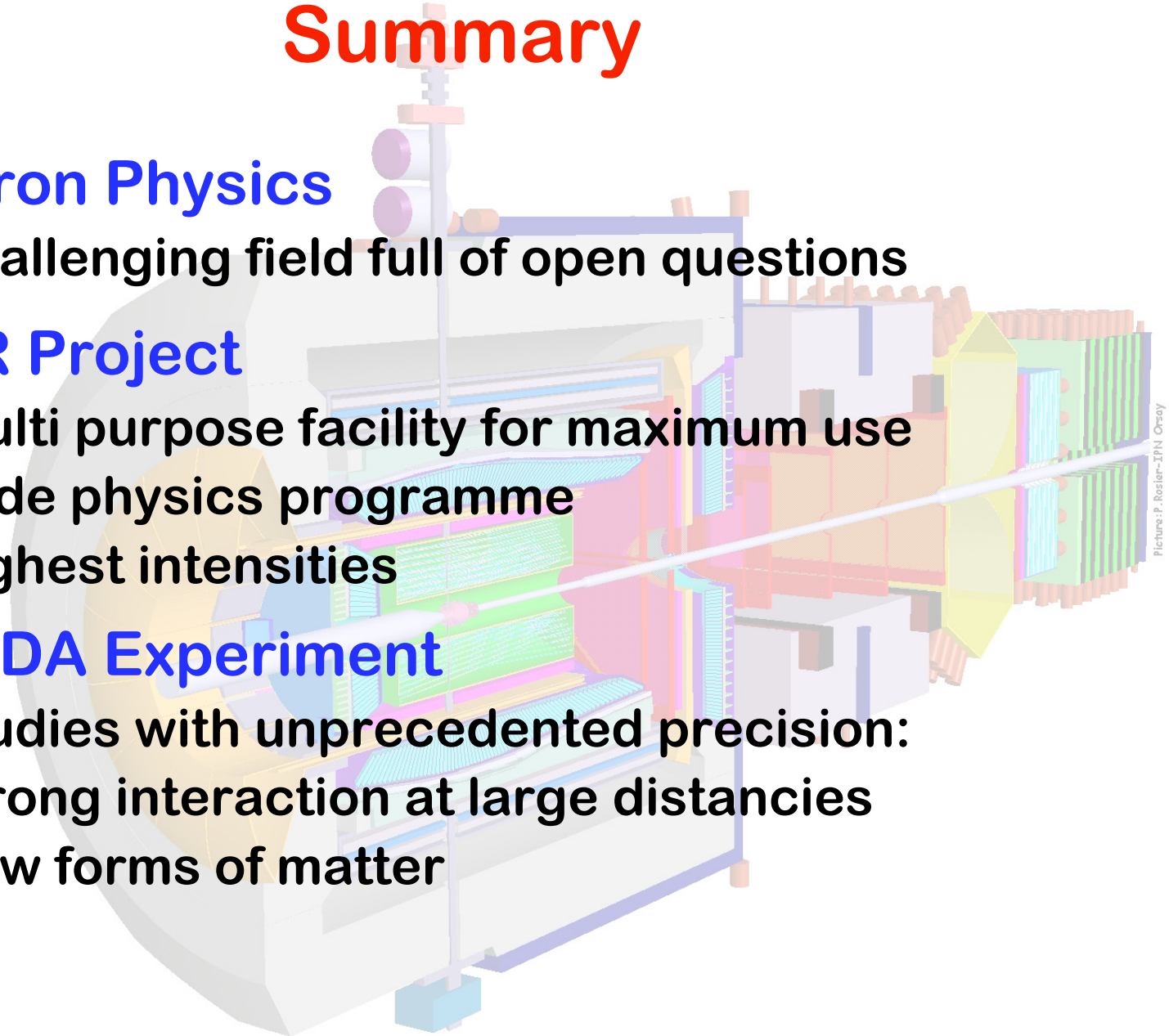
Fig. 3. The light yield of crystal 388 as a function of the distance from the exciting ^{60}Co source to the PMT.

set up build in Stockholm



Summary

- **Hadron Physics**
  - challenging field full of open questions
- **FAIR Project**
  - multi purpose facility for maximum use
  - wide physics programme
  - highest intensities
- **PANDA Experiment**
  - studies with unprecedented precision:
  - strong interaction at large distancies
  - new forms of matter



PANDA Collaboration

Universität Basel, IHEP Beijing, Ruhr-Universität Bochum, Universität Bonn, Università di Brescia + INFN, Università di Catania, University of Silesia, University Cracow, GSI Darmstadt, TU Dresden, JINR Dubna, JINR Dubna, University Edinburgh, Universität Erlangen, Northwestern University, INFN Sezione di Ferrara, Universität Frankfurt, LNF-INFN Frascati, INFN Sezione di Genova,Università di Genova, Universität Gießen, University of Glasgow, KVI Groningen, Institute of Physics Helsinki, FZ Jülich - IKP I, FZ Jülich - IKP II, IMP Lanzhou, Universität Mainz, Università di Milano, TU München, Universität Münster, BINP Novosibirsk, IPN Orsay, Università di Pavia, PNPI Gatchina St. Petersburg, IHEP Protvino, Stockholm University , Università di Torino, Università de Piemonte, Università di Trieste + INFN, Universität Tübingen, Uppsala Universitet, TSL Uppsala, Universidad de Valencia, Stefan Meyer Institut für subatomare Physik, Vienna, SINS Warschau

15 countries – 47 institutes – 370 scientists