PANDA - Hadron Physics Utilising Proton-Antiproton Annihilations

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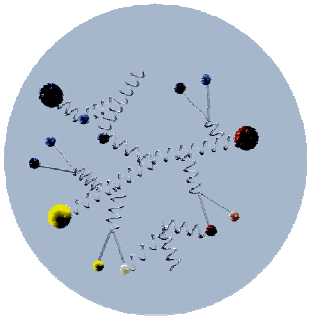
A Brief History

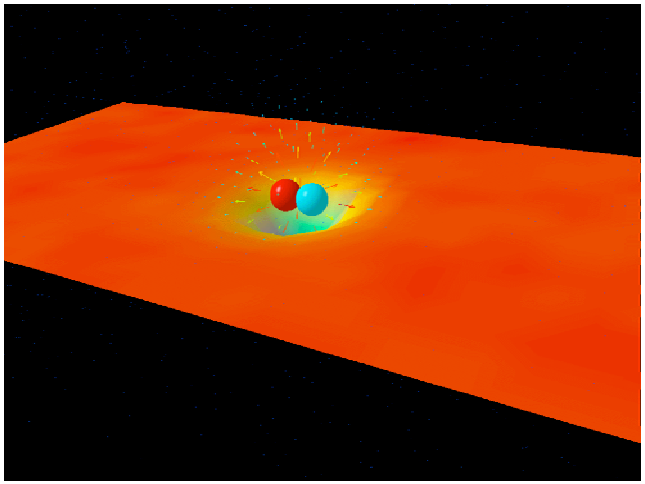
- 1930's: atoms (ατομον) in fact divisible
  => nucleons (p + n) and electrons
- 1950's - 60's: nucleons not elementary
  => "hadron zoo"
- 1960 ff: Quark model + QCD
  - Gell-Man: Nobel Price 1969
  - Friedman, Kendall, Taylor: Nobel Price 1990
  - Gross, David, Wilczek: Nobel Price 2004
- 2007 ff: Higgs ??

everything understood???

No!!!

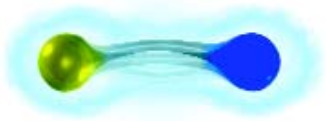
- Only few % of the hadronic mass can be explained by the Higgs Mechanism!
- How is the mass created?
- How does the long distance interaction look like?
- What is the role of partons?
- Do other than 2, 3 quark objects exist?
- Experimental surprises!





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

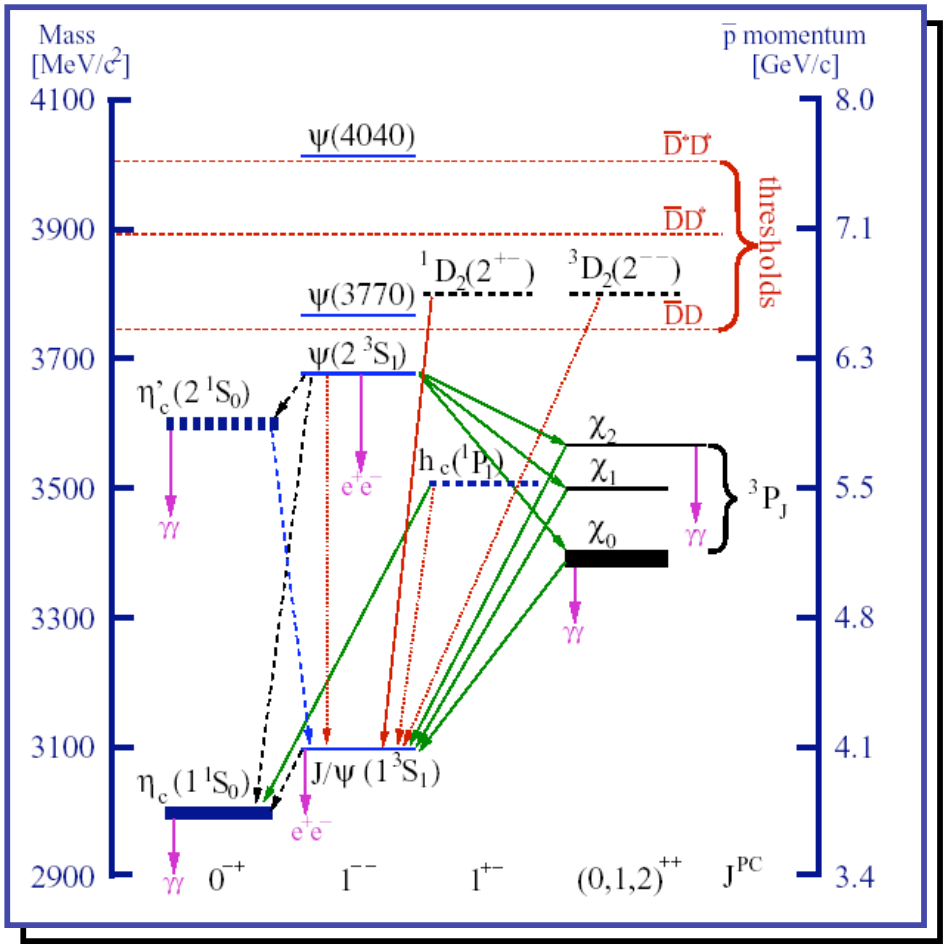
Some Places to Explore Non-Pertubative QCD



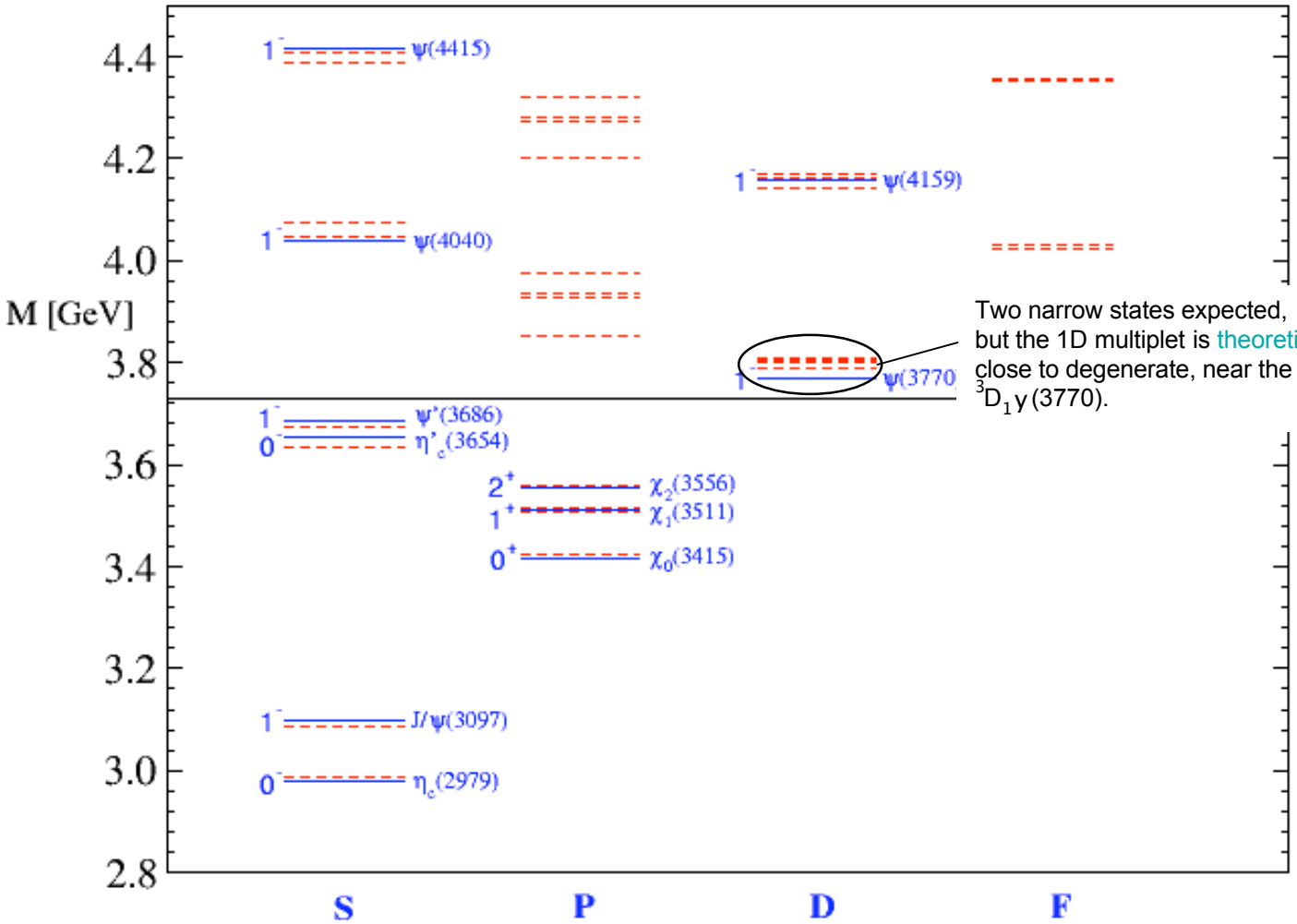
- charmonium spectroscopy
- gluonic excitations (hybrids, glueballs)
- open and hidden charm in nuclei
- γ-ray spectroscopy of hypernuclei

Charmonium Spectroscopy

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



Model Predictions in Charmonium

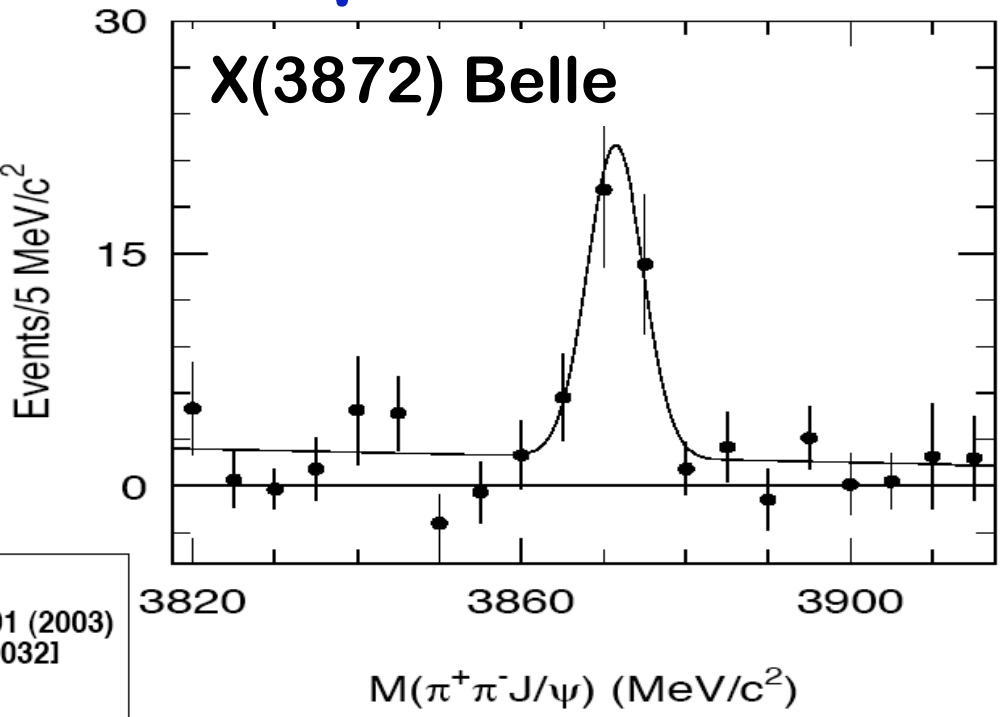


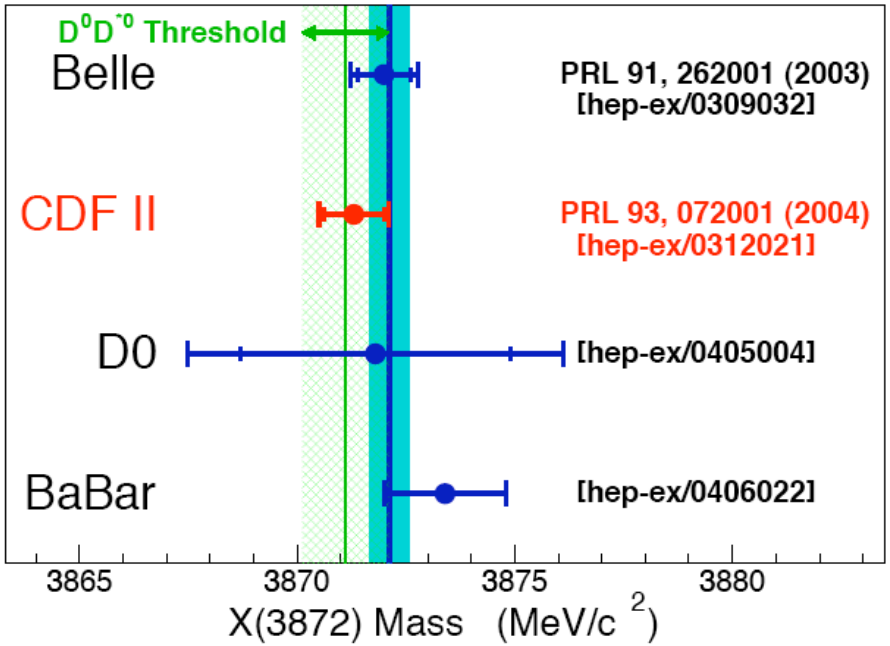
Two narrow states expected, but the 1D multiplet is theoretically close to degenerate, near the $^3D_1$ ψ(3770).

• T.Barnes, S. Godfrey, E.S. Svanson; hep-ph/0505002 (2005)

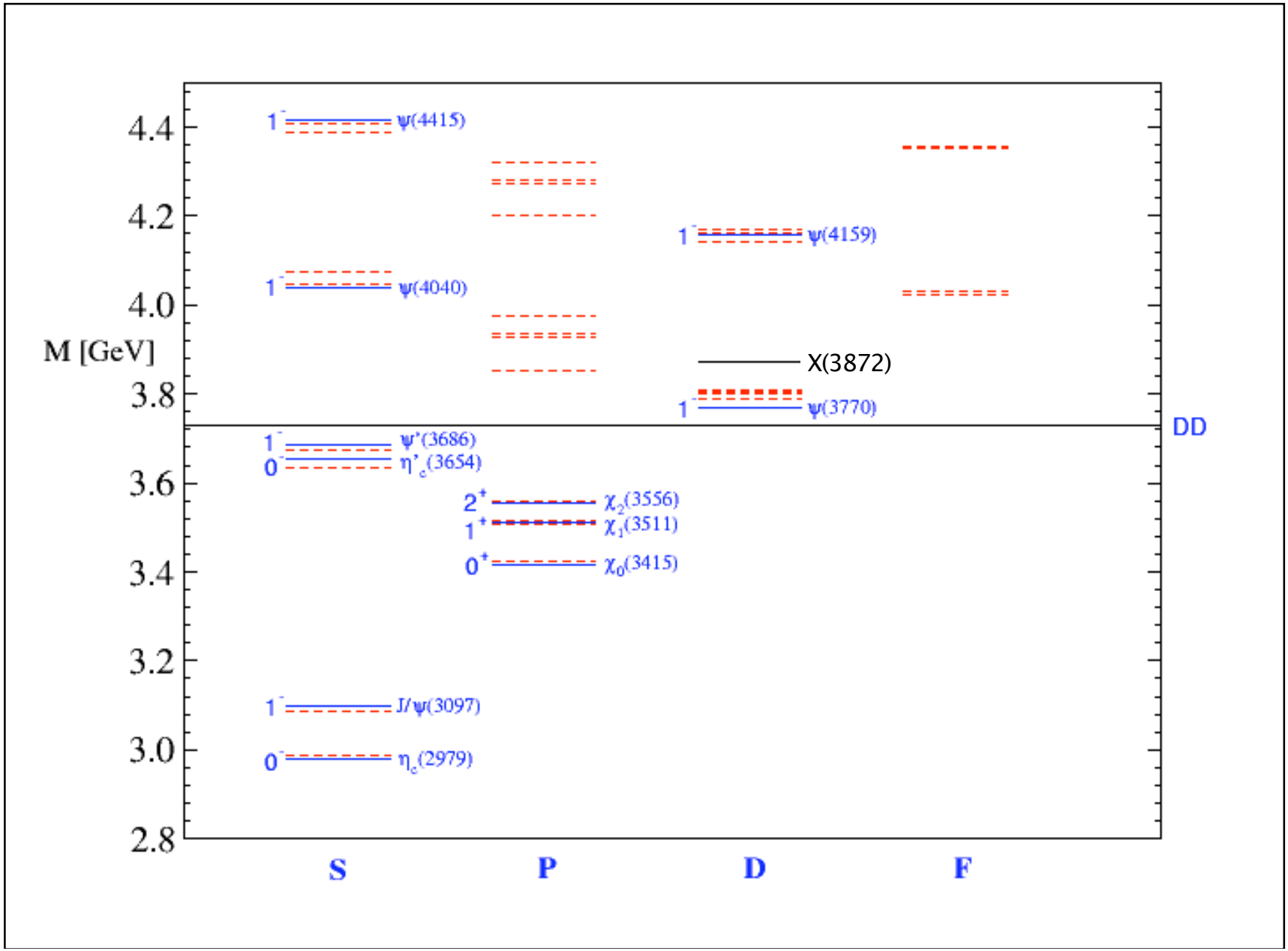
Experimental Surprise

- **First observation:**
  Belle 2003
- **Confirmation by:**
  CDF II, D0, BaBar





Who ordered that?



What is its nature?

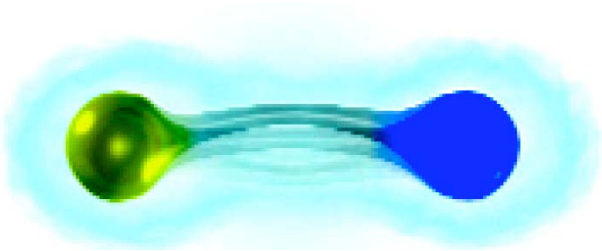
- **Evidence for $J^{PC} = 1^{++}$ is increasing.**
  - K. Abe et al. (Belle), hep-ex/0505038 (2005)

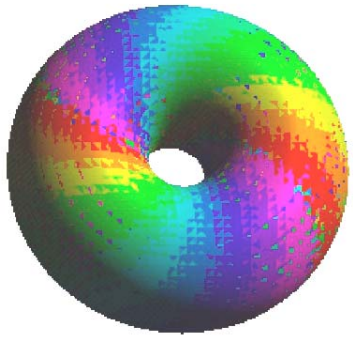
- **Is it a multiquark state, a $D^0\underline{D}^{*0}$ molecule, cusp, …?**

$$M(D^{o} + \underline{D}^{*o}) = (3871.5 \pm 0.5)\ \text{MeV}$$

- N.A.Tornqvist, PRL67, 556 (1991); hep-ph/0402237, PLB590, 209 (2004).
- F.E.Close and P.R.Page, hep-ph/0309253, PLB578, 119 (2004).
- C.Y.Wong, hep-ph/0311088. PRC69, 055202 (2004).
- E.Braaten and M.Kusunoki, hep-ph/0311147, PRD69, 074005 (2004).
- E.S.Swanson, hep-ph/0311229, PLB588, 189 (2004).
- D.V. Bugg, hep-ph/0406293, PLB598, 8-14 (2004)
- D.V. Bugg, hep-ph/0410168, PR71, 016006 (2005)
- Yu.S. Kalashnikova, hep-ph/0506270, (2005)
- E.Braaten, M.Kusunoki, hep-ph/0507163 (2005)

Gluonic Excitations

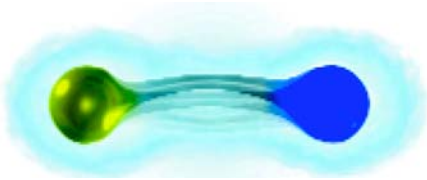




- hybrids: “ordinary” quark states containing excited glue

- 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, exp. Y(4260)?**
  - **lowest state: 1^{-+} exotic => no mixing**

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

$\hookrightarrow J/\psi + \gamma$

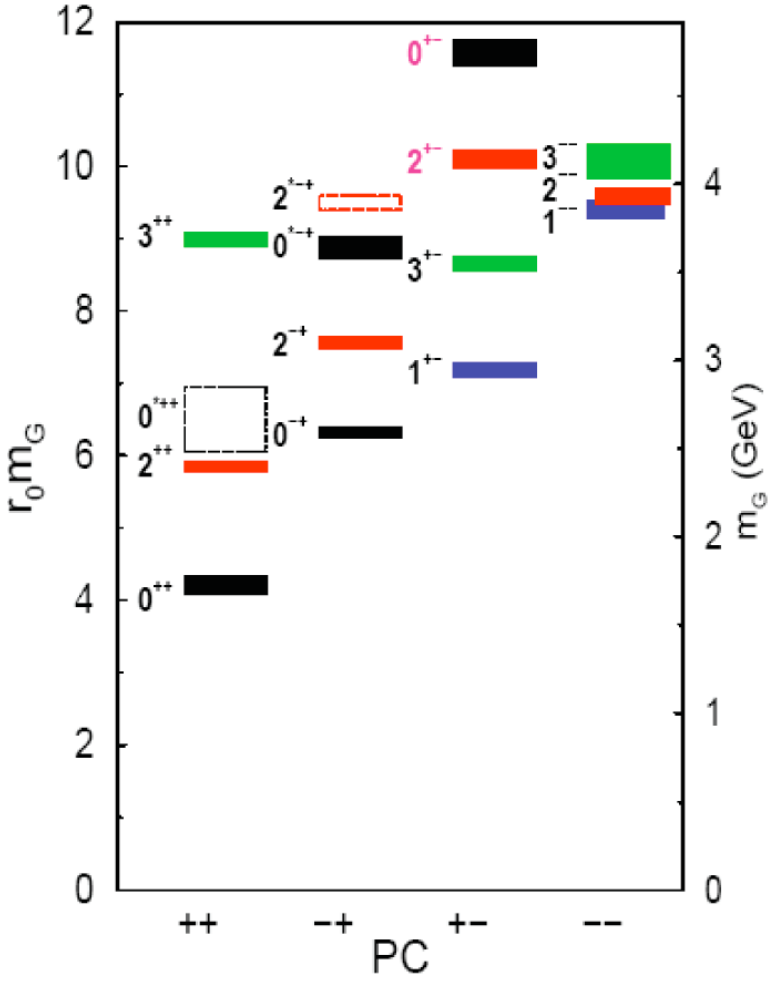
$\hookrightarrow e^+e^-$

(C. Michael, hep-lat/0207017)

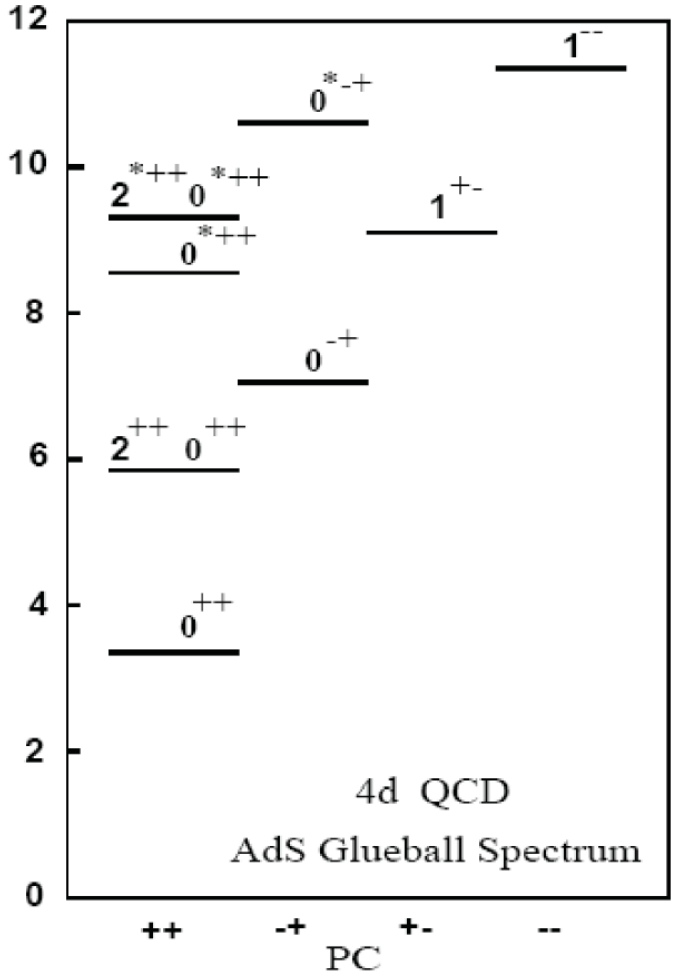
  - **also 0^{--}, 0^{+-} and 2^{+-} do not mix**

Glueball Predictions

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

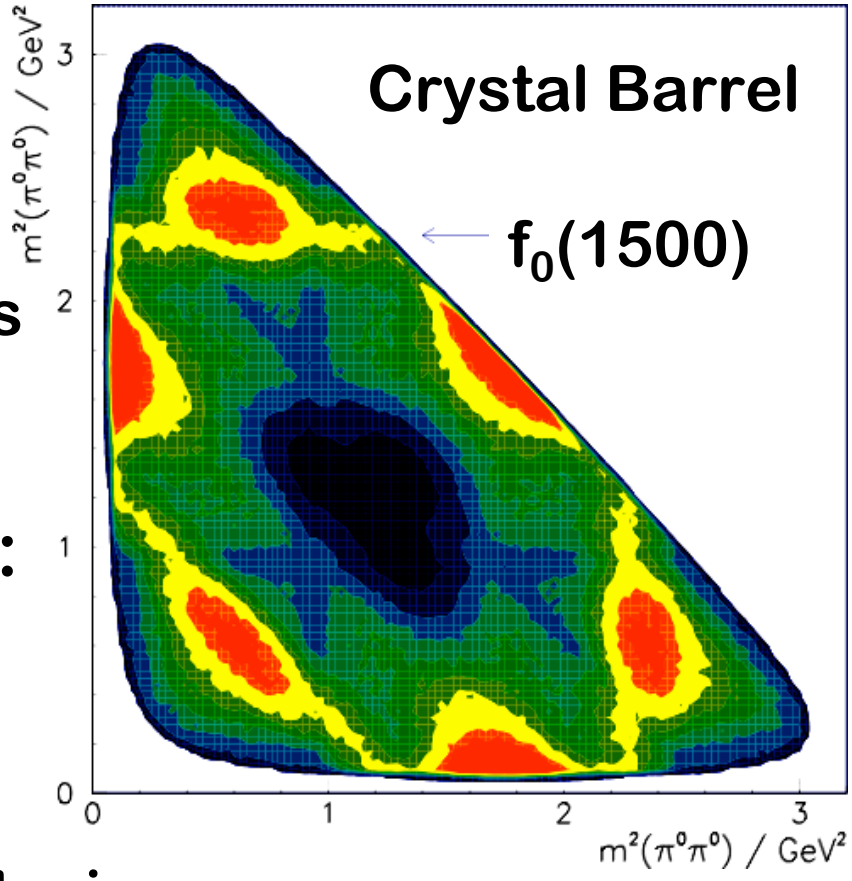


Flux tube calc. by Brower, Mathur and Tan. Nucl. Phys. B587 (2000)249



Glueballs

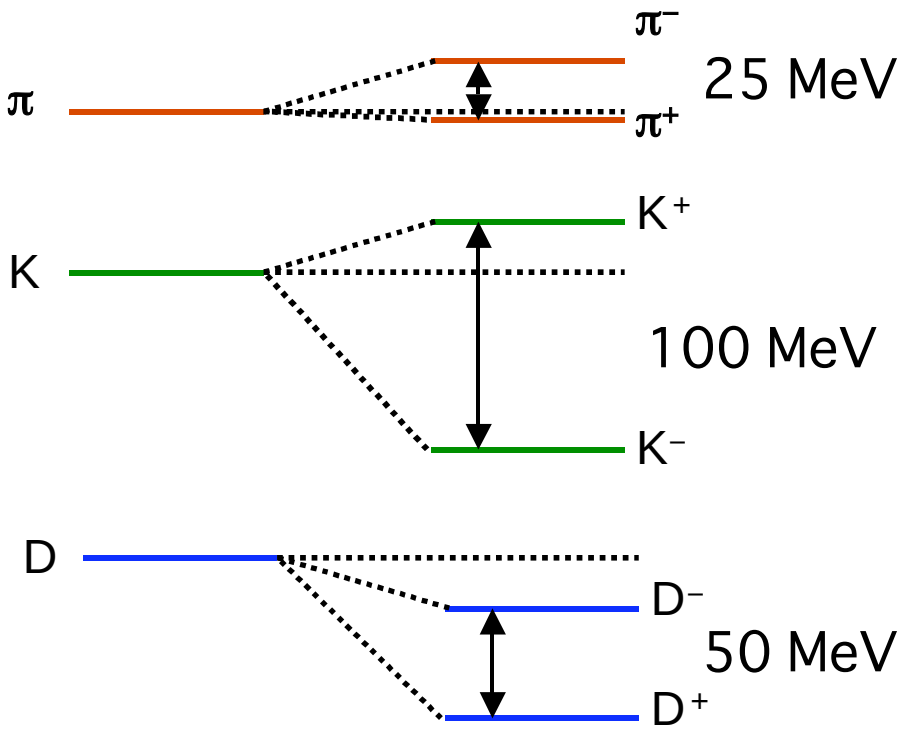
- **light glueballs**:
  - exp. candidate: $f_0(1500)$
  - well established
  - ordinary quantum numbers
  - problem: mixing,
- **glueballs above 3 GeV/c²**:
  - few mesonic states
  - less mixing
  - smaller width
  - exotic states: 2^{+-}, 0^{+-} do not mix



In-Medium Mass Modifications

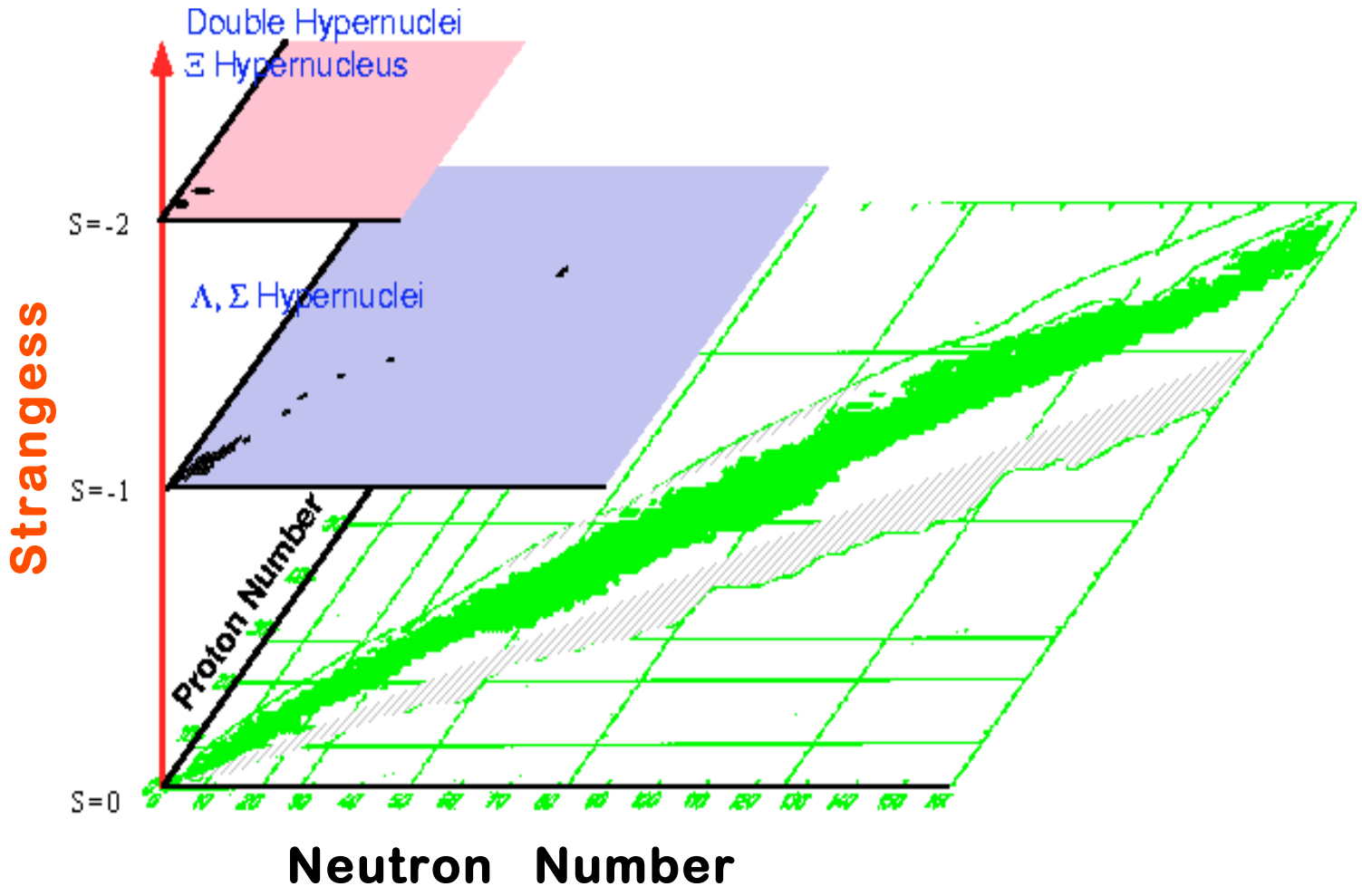
- **HADES, CBM**:
  ρ, ω, ϕ **studies**

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



A. Hayashigaki, PLB 487 (2000) 96

Extension of the Nuclear Chart

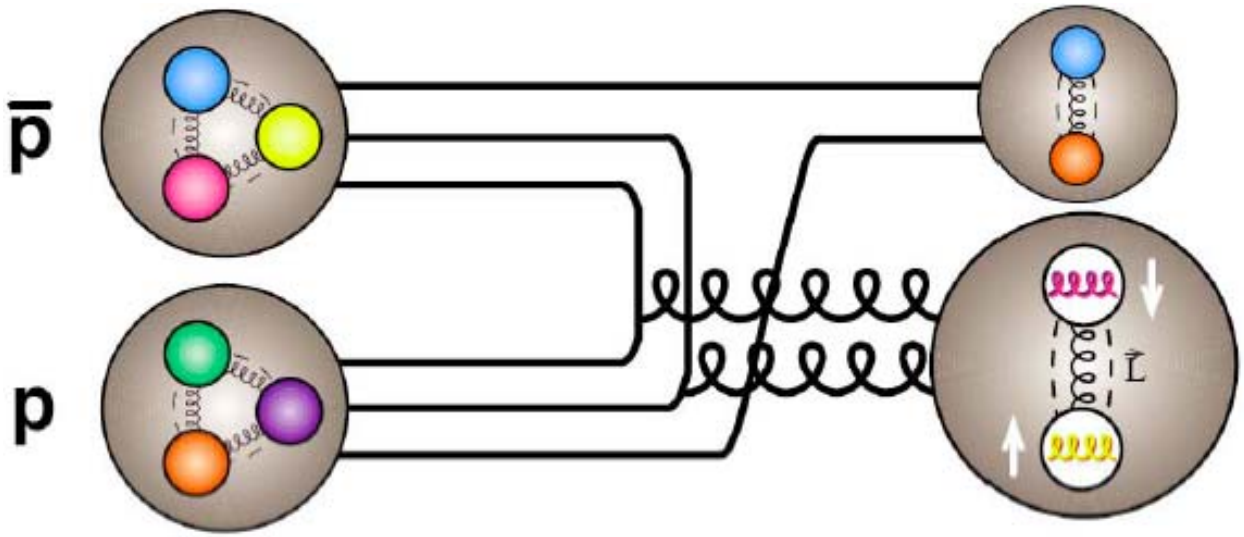


- **Do we understand the YN interaction?**

What is Experimentally Needed?

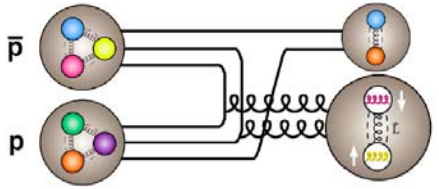
- **gluon-rich environment!**

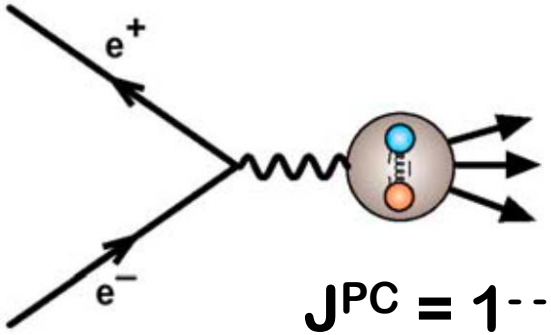
  ⇒ **proton-antiproton anihilations**



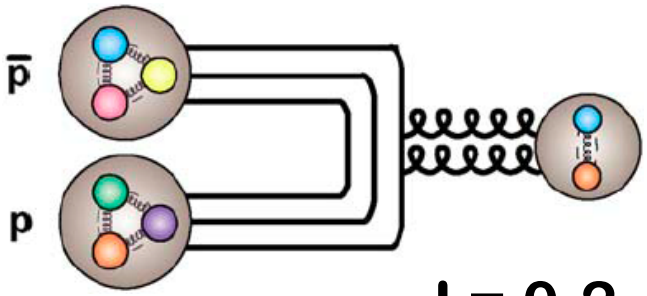
What is Experimentally Needed?

- **gluon-rich environment!**
  - ⇒ proton-antiproton anihilations
- **all quantum numbers!**
  - ⇒ production exp. i.e. large acc. detector, fixed target

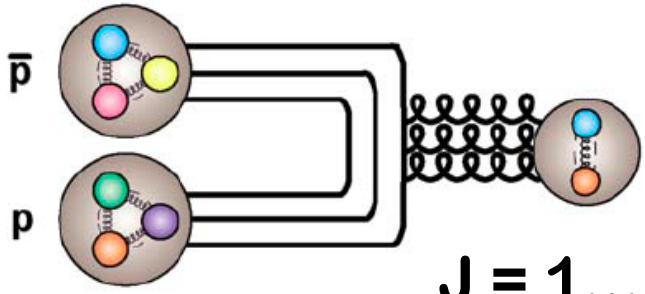




$J^{PC} = 1^{--}$

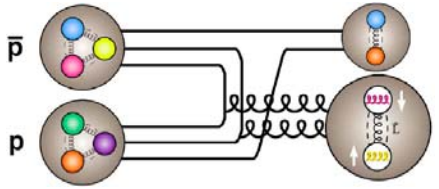


J = 0,2,.. C = +

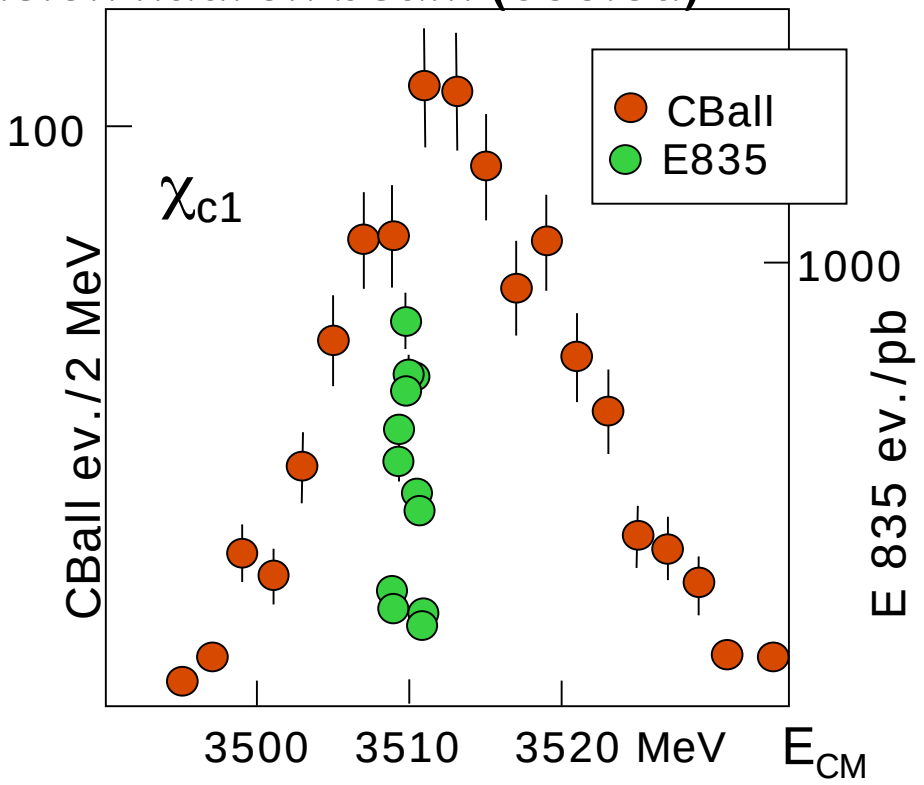


J = 1,.. C = -

What is Experimentally Needed?



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



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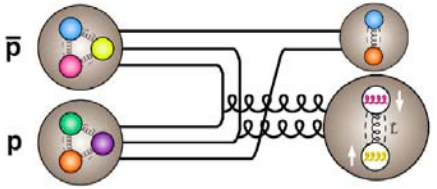
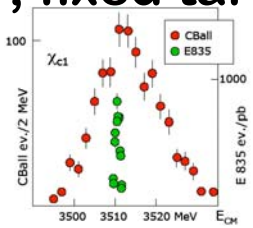
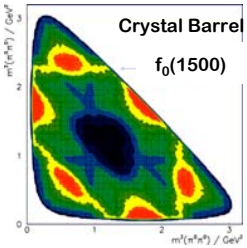
- **high statistics samples!**
  - ⇒ high luminosity and prod. cross section







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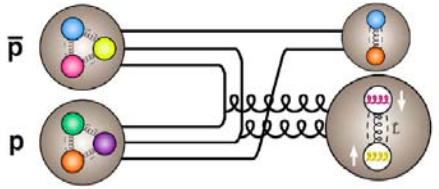
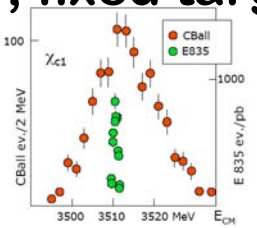
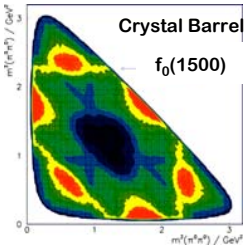


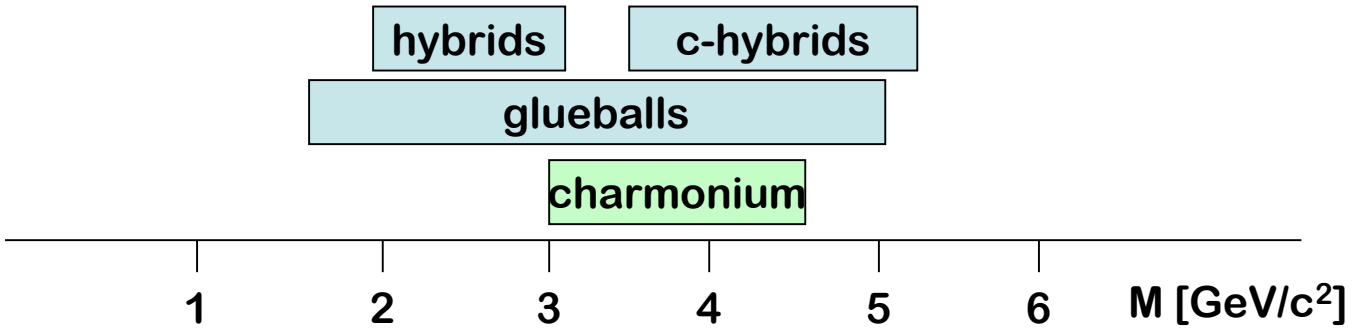
- **gluon-rich environment**!
  ⇒ proton-antiproton anihilations
- **all quantum numbers**!
  ⇒ production exp. i.e. large acc. detector, fixed target
- **precise resonance scan**!
  ⇒ high precision hadron beam (cooled)
- **high statistics samples**!
  ⇒ high luminosity and prod. cross section
- **relevant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





$p_{\bar{p}}$ = 1.5 - 15 GeV/c

s-hyperon, c-meson, c-hyperon pairs



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

int. 4π detector

HESR

10^{11} anti-protons

p = 1.5 - 15 GeV/c

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

FAIR

An International Accelerator Facility
for Research with Ions and Antiprotons

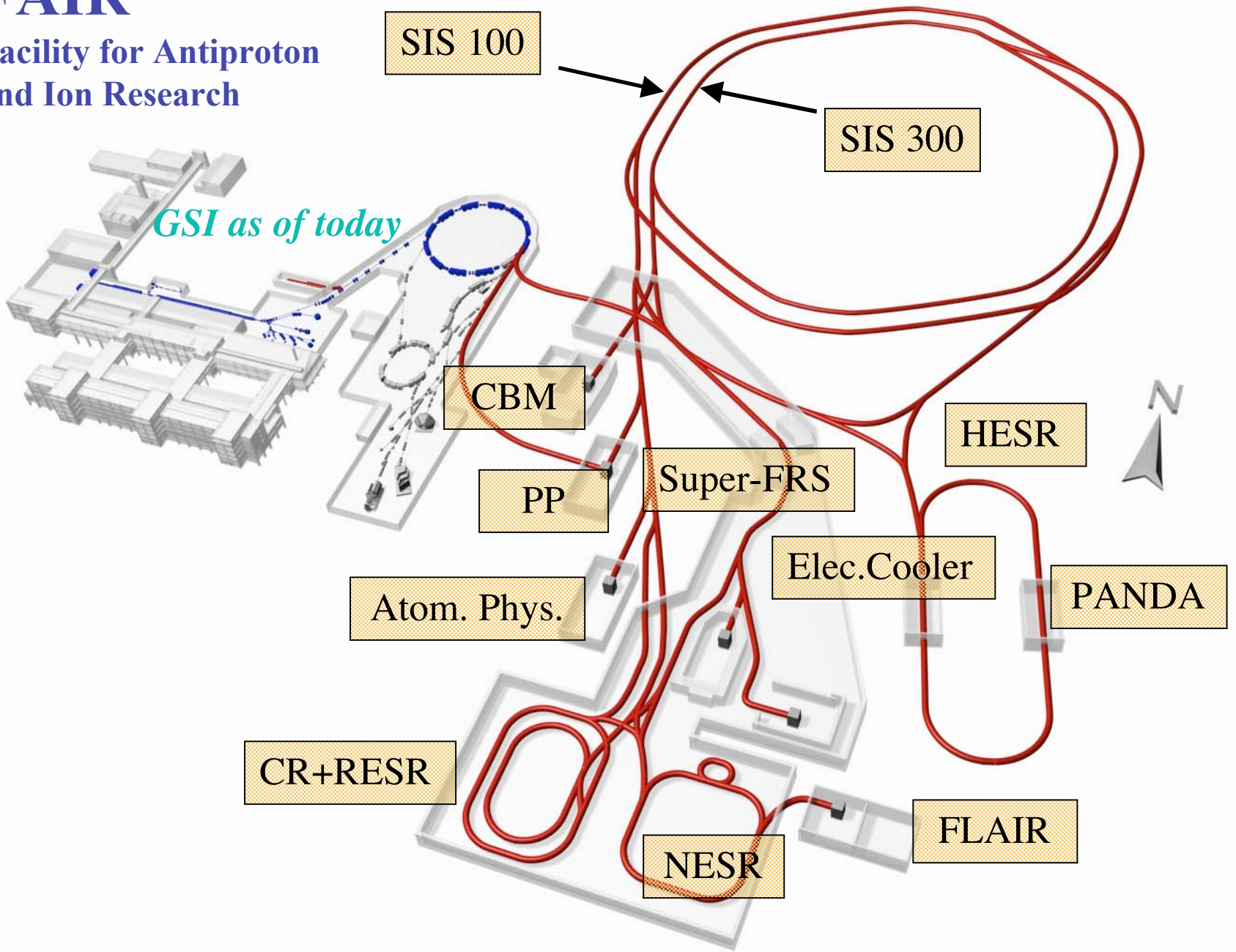
- 2003: Positive evaluation and commitment to FAIR by the German Government.

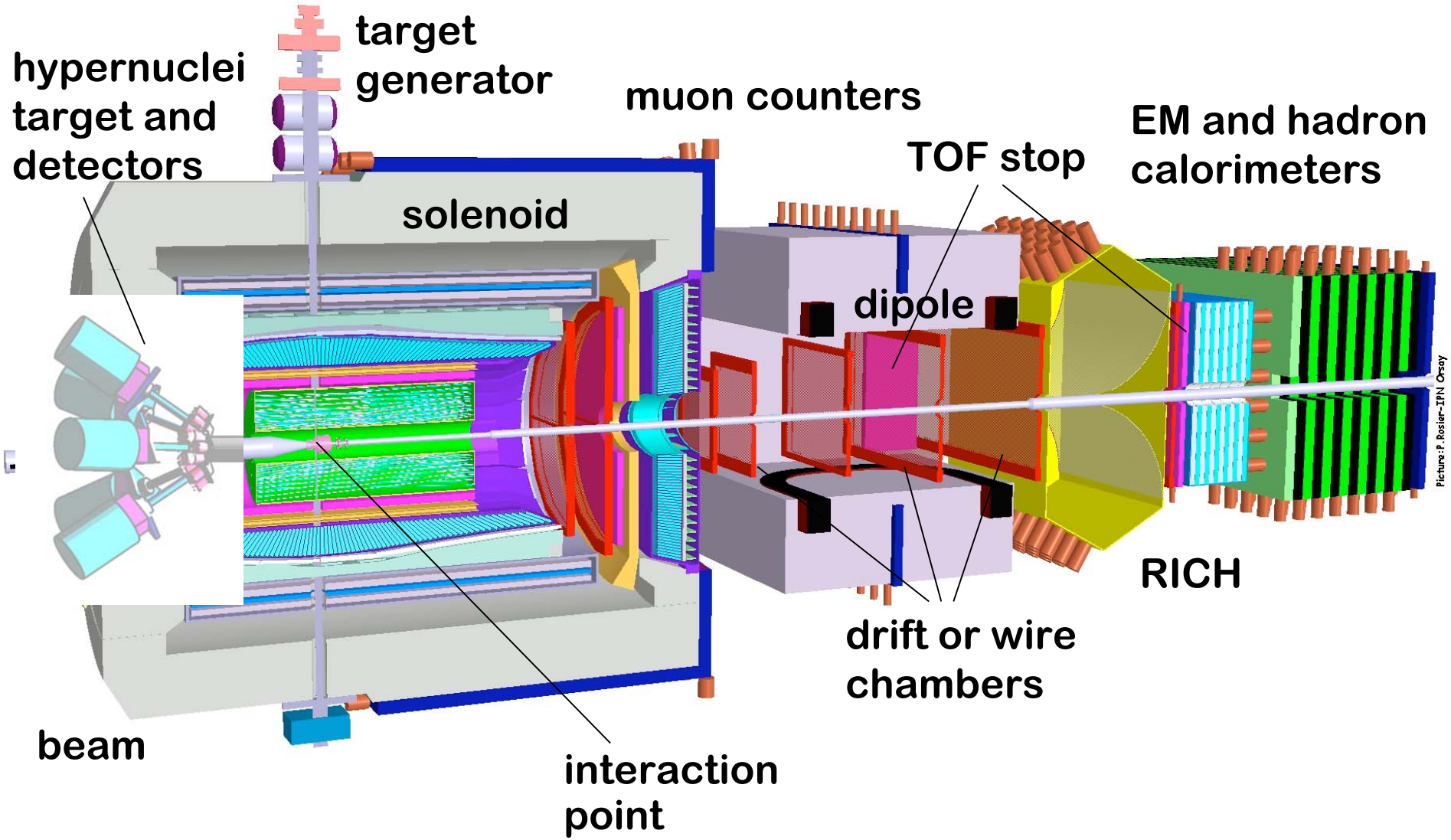
FAIR

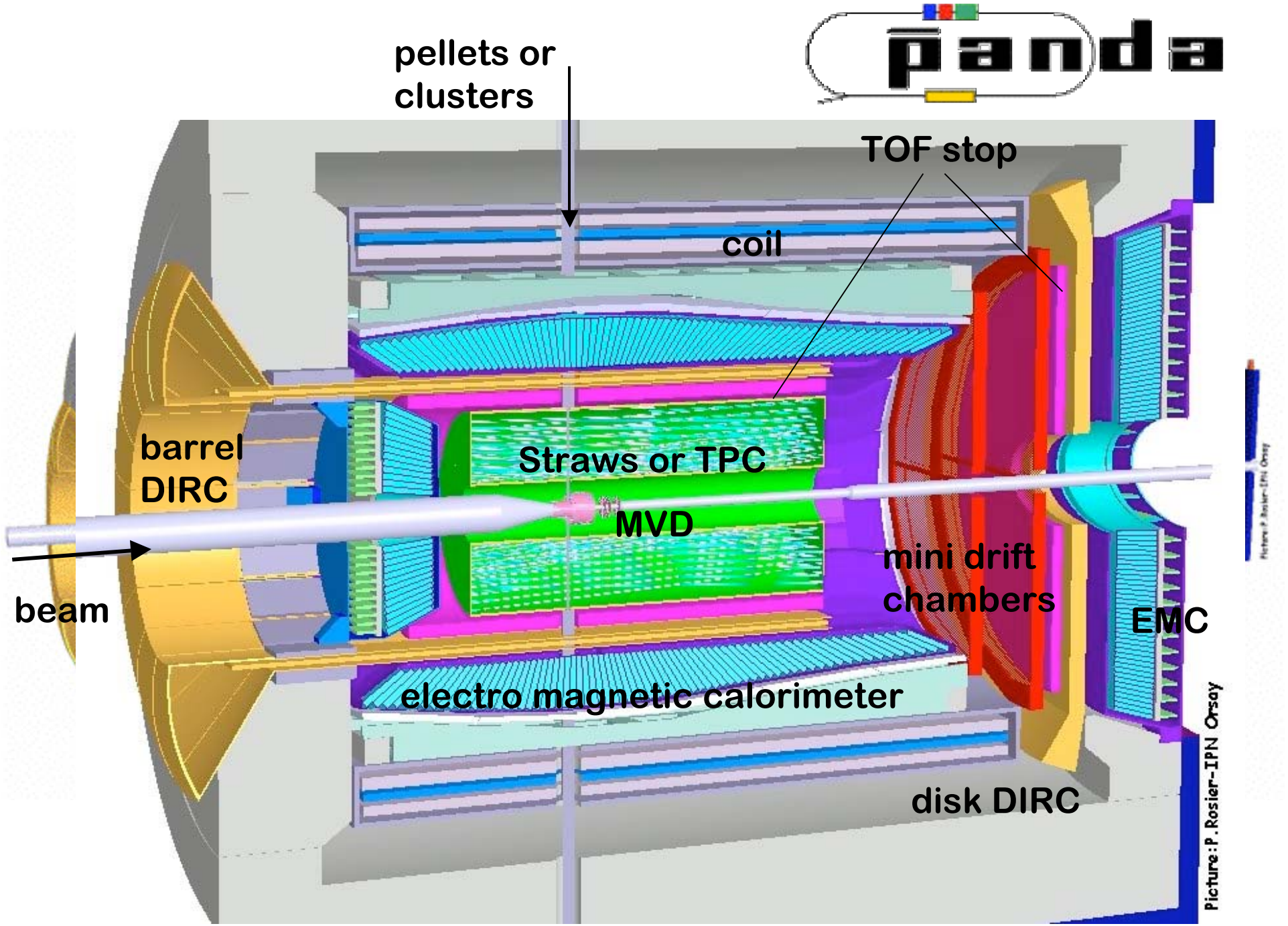
- 2004: Approval of LoI.
- Jan 2005: Technical Progress Report approved by QCD PAC!

FAIR

Facility for Antiproton and Ion Research




hypernuclei
target and
detectors
target
generator
muon counters
TOF stop
EM and hadron
calorimeters
solenoid
dipole
RICH
drift or wire
chambers
beam
interaction
point
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

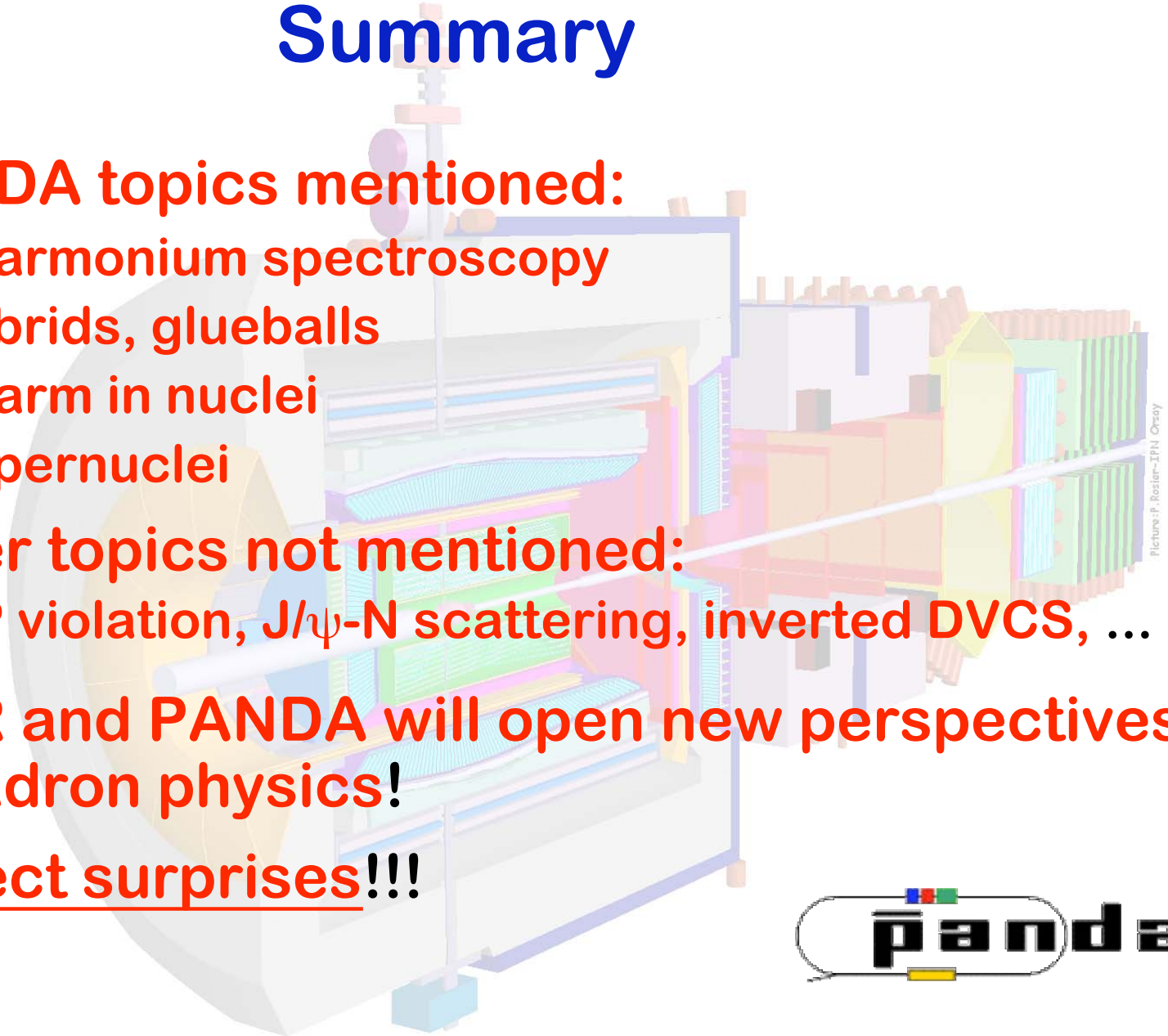
Status and Timeline

- **A lot of R&D work is going on:**
  - Excellent resolution achieved with PWO
  - Gas load of a pellet target can be pumped
  - A TPC prototype is being tested
  - .....

- **Technical Design Report:**
  for all parts in 2008
- **Installation and Commissioning: 2009 - 2011**
- **Start of Data Taking: 2012**

Summary

- PANDA topics mentioned:
  - charmonium spectroscopy
  - hybrids, glueballs
  - charm in nuclei
  - hypernuclei
- Other topics not mentioned:
  - CP violation, J/ψ-N scattering, inverted DVCS, ...
- FAIR and PANDA will open new perspectives in hadron physics!
- Expect surprises!!!



panda

PANDA Collaboration

- At present a group of **350 physicists** from 47 institutions of 15 countries

Austria – Belaruz – China – Finland – France – Germany – Italy – Poland – Romania – Russia – Spain – Sweden – Switzerland – U.K. – U.S.A.

Basel, Beijing, Bochum, Bonn, IFIN Bucharest, Catania, Cracow, Dresden, Edinburgh, Erlangen, Ferrara, Frankfurt, Genova, Giessen, Glasgow, GSI, Inst. of Physics Helsinki, FZ Jülich, JINR Dubna, Katowice, Lanzhou, LNF, Mainz, Milano, Minsk, TU München, Münster, Northwestern, BINP Novosibirsk, Pavia, Piemonte Orientale, IPN Orsay, IHEP Protvino, PNPI St. Petersburg, KTH Stockholm, Stockholm, Dep. A. Avogadro Torino, Dep. Fis. Sperimentale Torino, Torino Politecnico, Trieste, TSL Uppsala, Tübingen, Uppsala, Valencia, SINS Warsaw, TU Warsaw, AAS Wien

http://www.gsi.de/panda