



# Physics with PANDA at FAIR

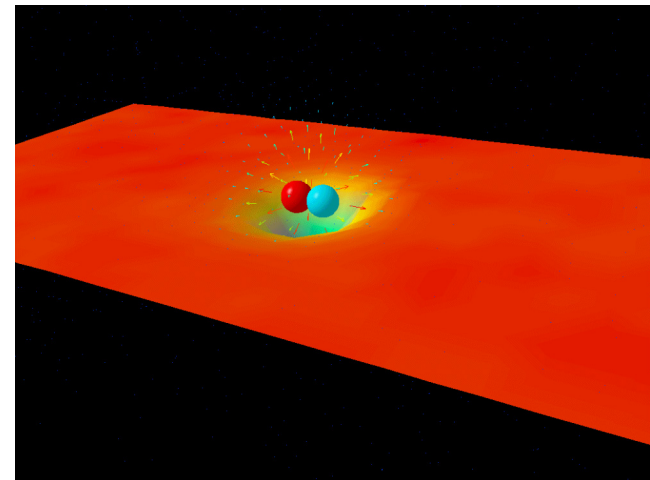
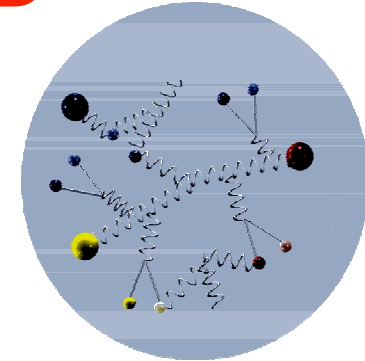
**Inti Lehmann**

**University of Glasgow**

**Tbilisi, Sept. 5th, 2006**

# Some Open Questions in Non-Perturbative QCD

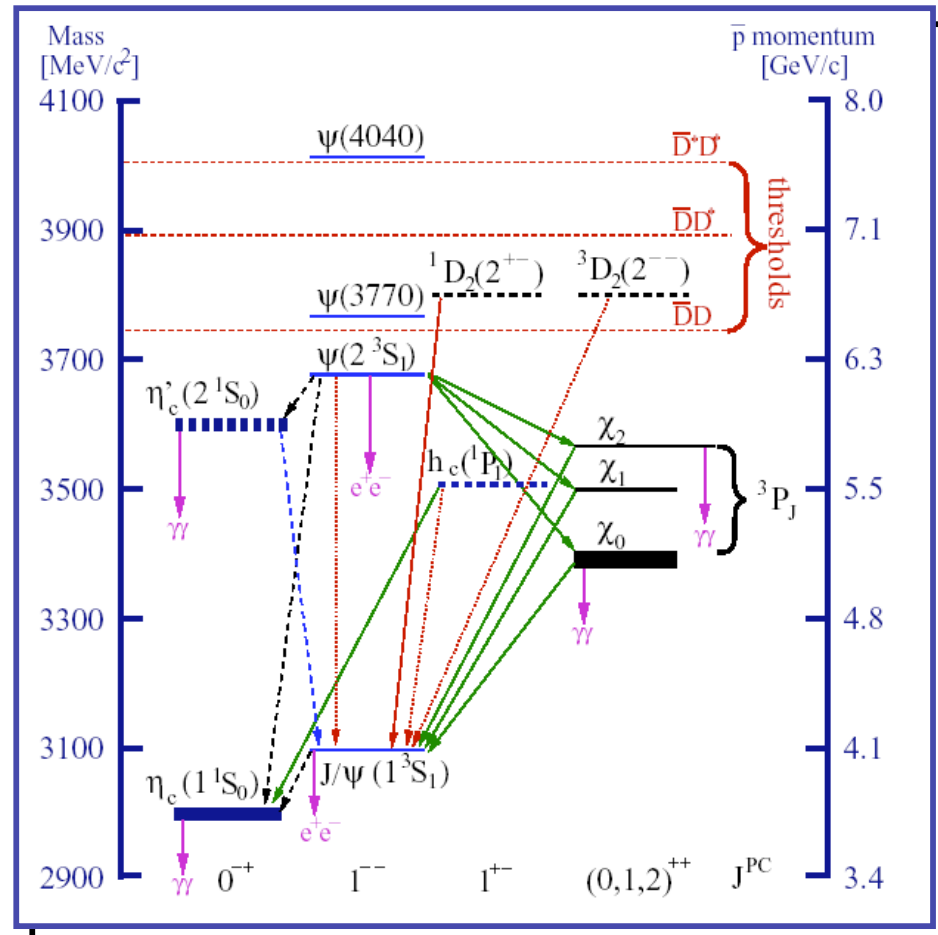
- generation of hadron masses
- strong interaction at large distances
- spin puzzle
- multi-quark systems



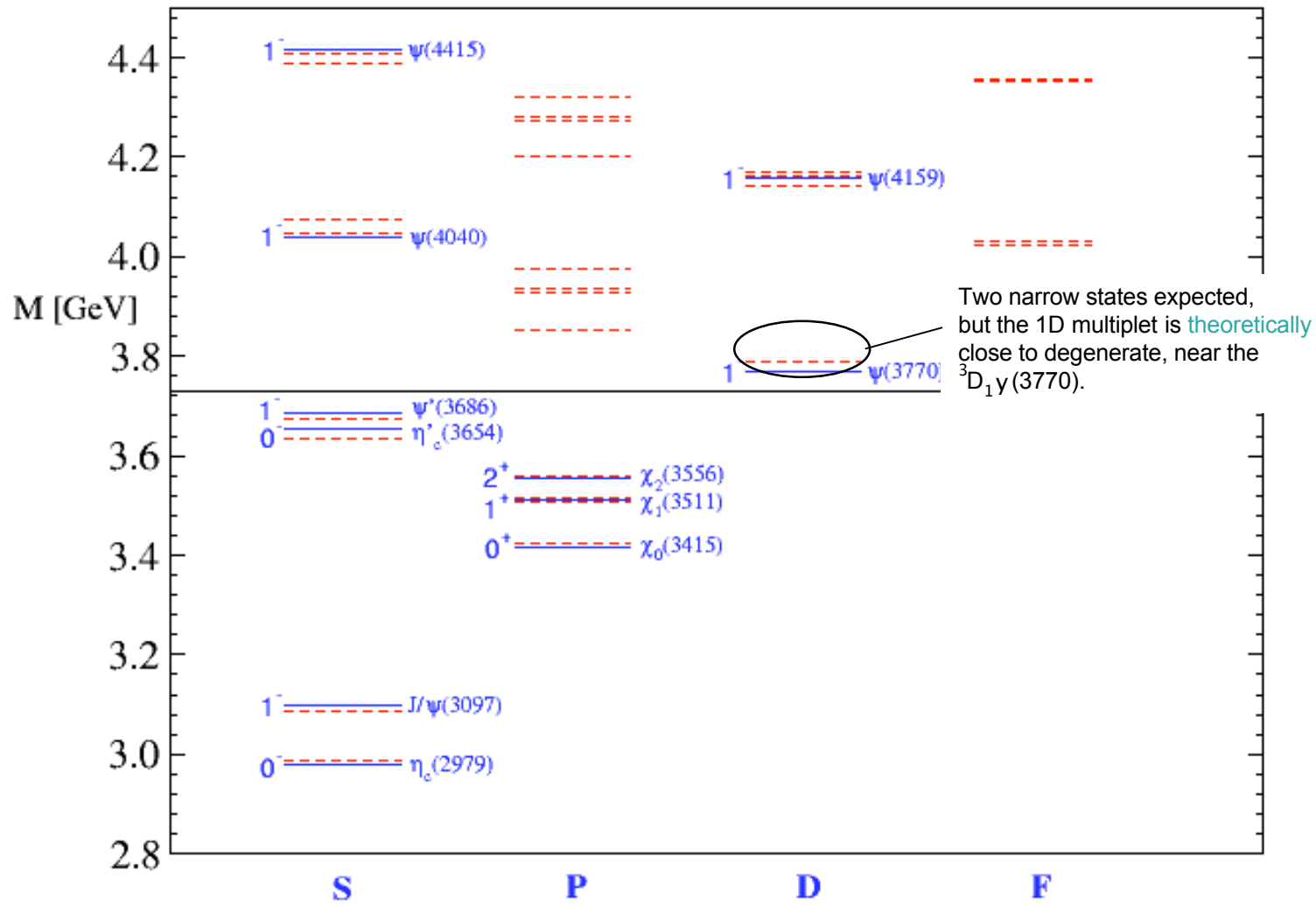
(flux tube animation by D. Leinweber et al.)

# Charmonium Spectroscopy

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

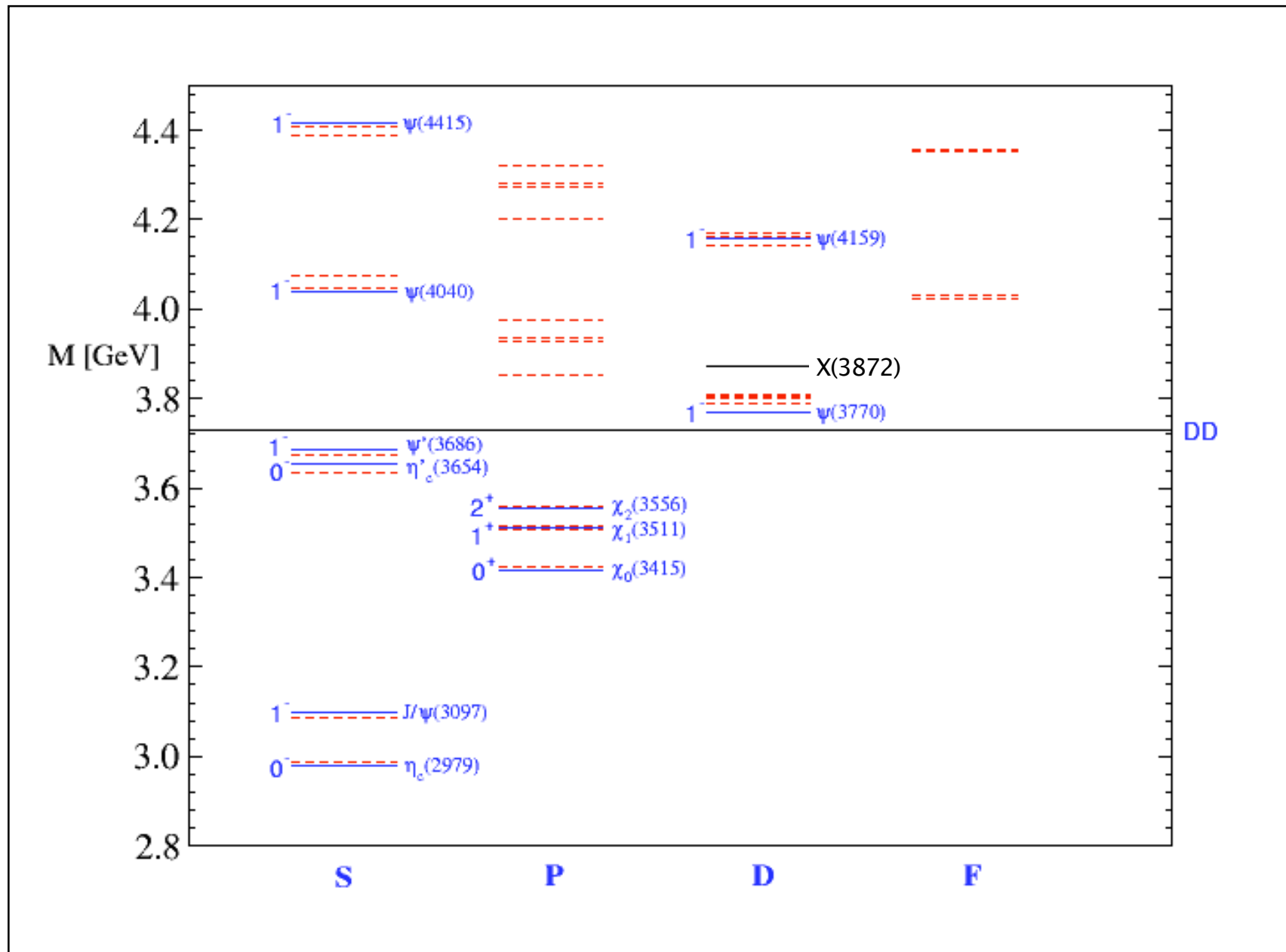


# Model Predictions in Charmonium

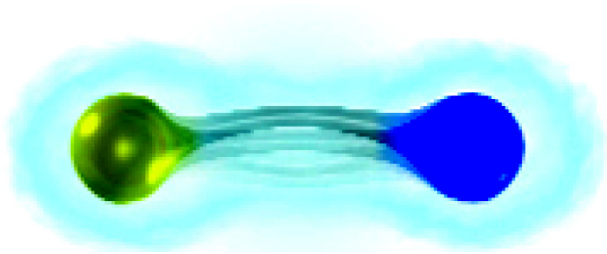


• T.Barnes, S. Godfrey, E.S. Svanson; hep-ph/0505002 (2005)

# Who ordered that?



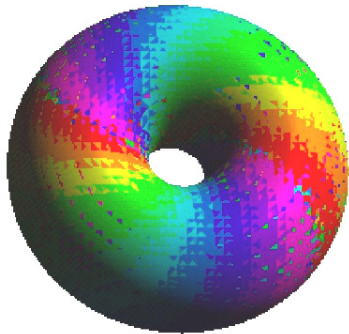
# Gluonic Excitations



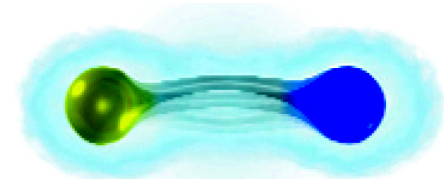
- **hybrids**: “ordinary” quark states containing excited glue



- **glueballs**: gluonic states without valence quark contribution



# Hybrids



- **light quark hybrids:**

- exp. candidates:  $\pi_1(1400)$ ,  $\pi_1(1600)$ , ...
- problem: mixing

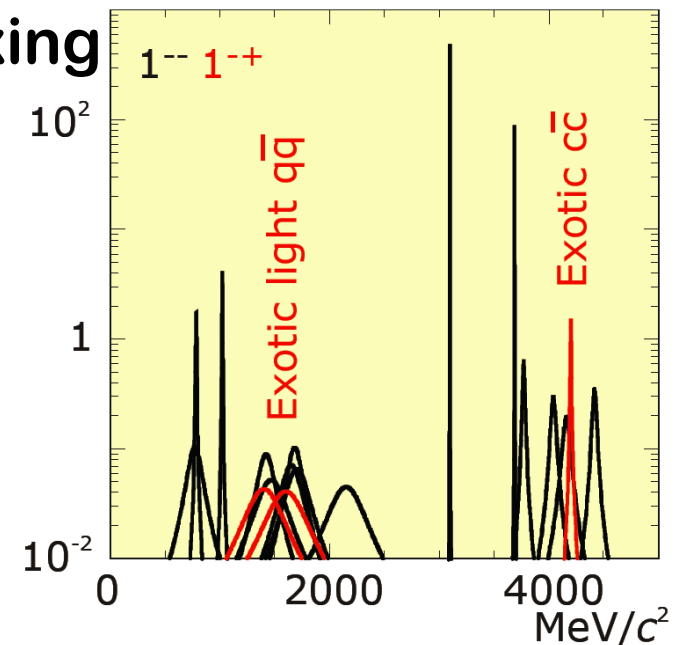
- **charmed hybrids:**

- prediction:  $m = 3.9 - 4.5 \text{ GeV}/c^2$ , narrow
- lowest state:  $1^{-+}$  exotic  $\Rightarrow$  no mixing

$$\begin{aligned} \text{decay: } 1^{-+} &\rightarrow \chi_c + (\pi\pi)_{l=0} \\ &\quad \downarrow \\ &\quad J/\psi + \gamma \\ &\quad \quad \downarrow \\ &\quad \quad e^+e^- \end{aligned}$$

(C. Michael, hep-lat/0207017)

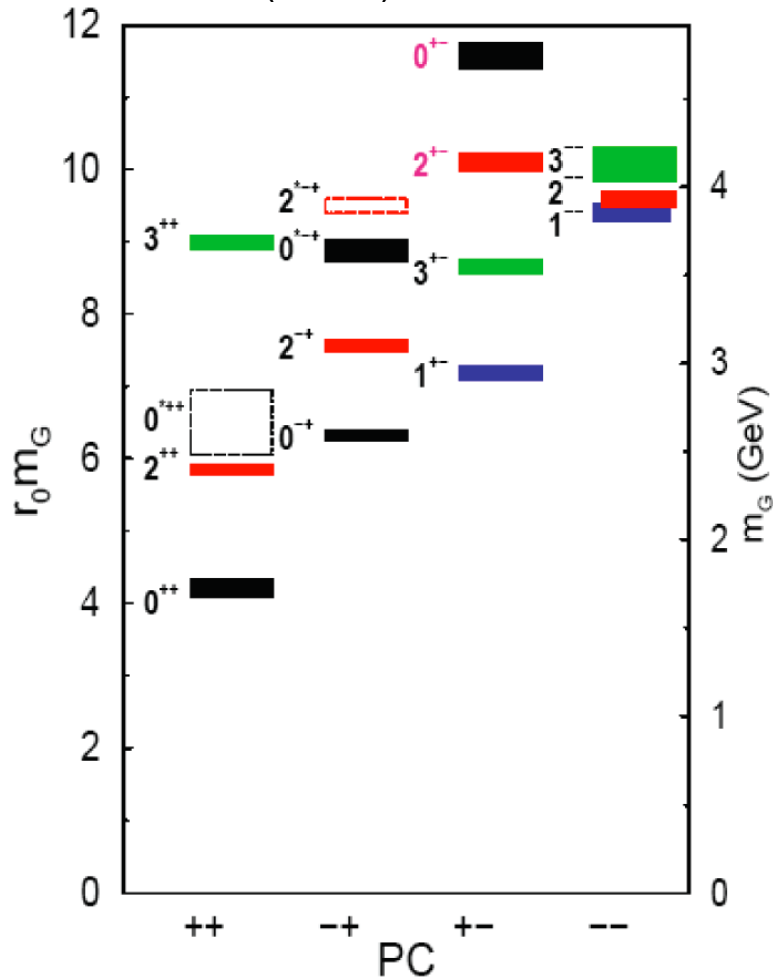
- also  $0^{-+}$ ,  $0^{+-}$  and  $2^{+-}$  do not mix



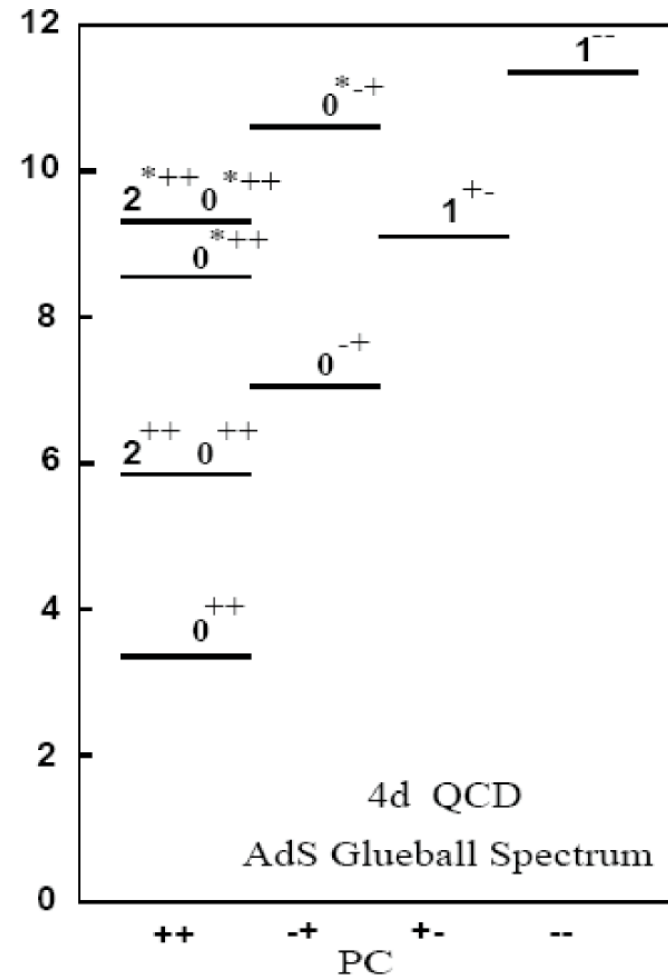


# Glueball Predictions

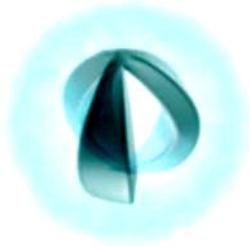
Lattice QCD calculations by  
Morningstar and Peardon;  
PRD60 (1999) 034 509



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

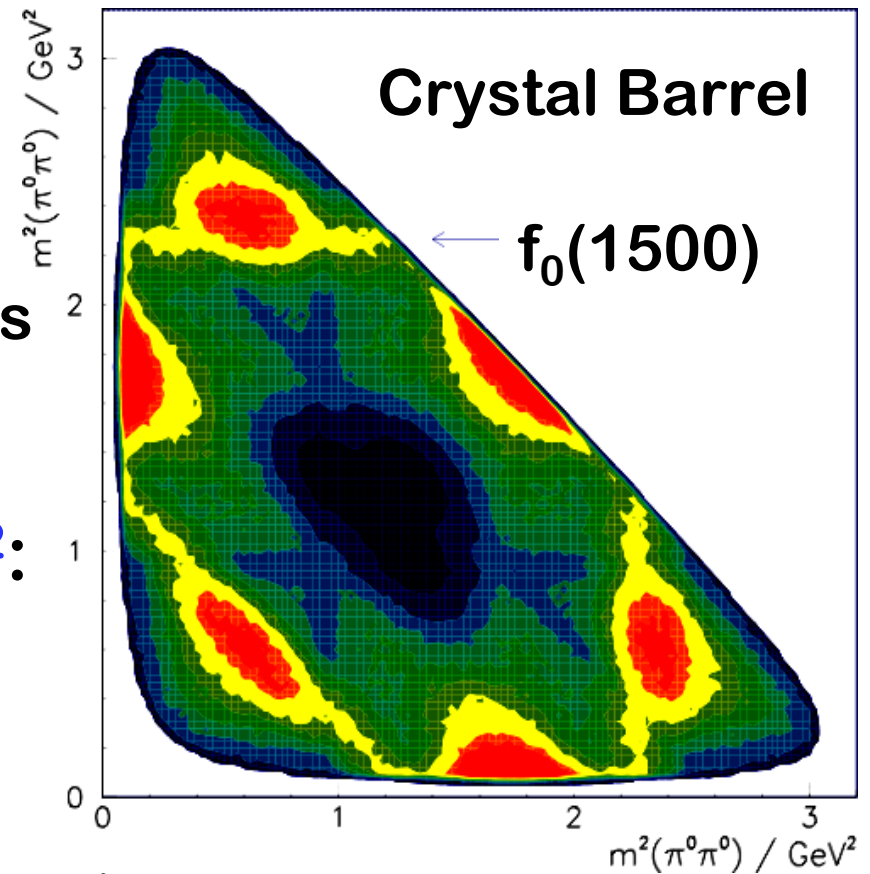






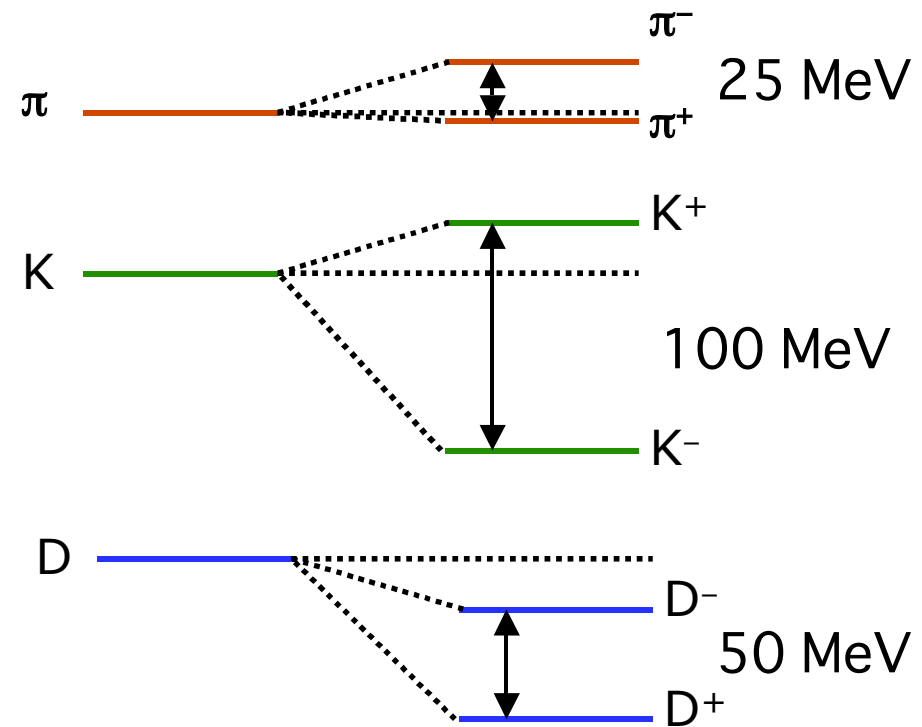
# Glueballs

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



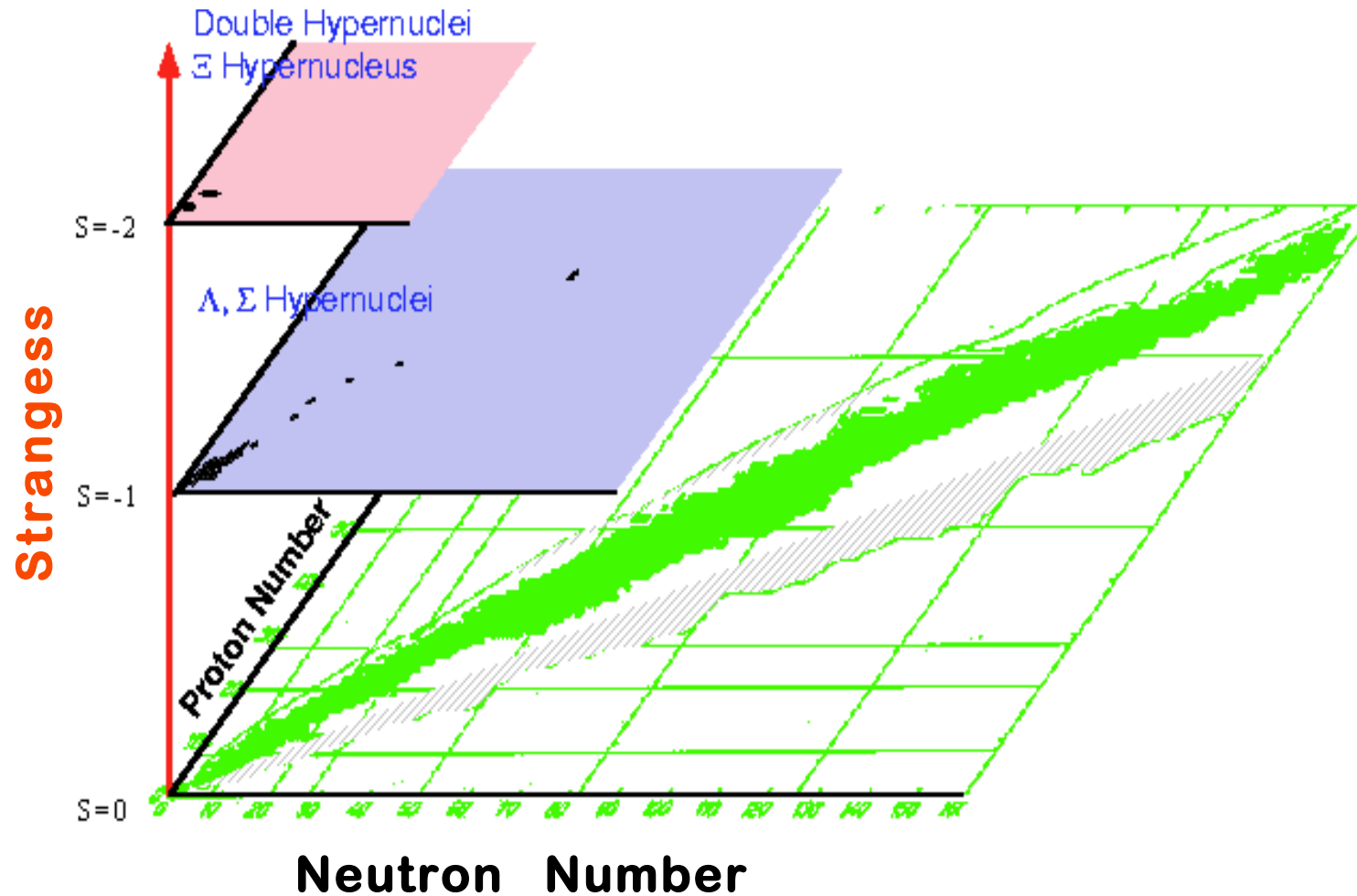
# In-Medium Mass Modifications

- **HADES, CBM:**  
 $\rho$ ,  $\omega$ ,  $\phi$  studies
- **PANDA:** extension  
to the charm sector



A. Hayashigaki, PLB 487 (2000) 96

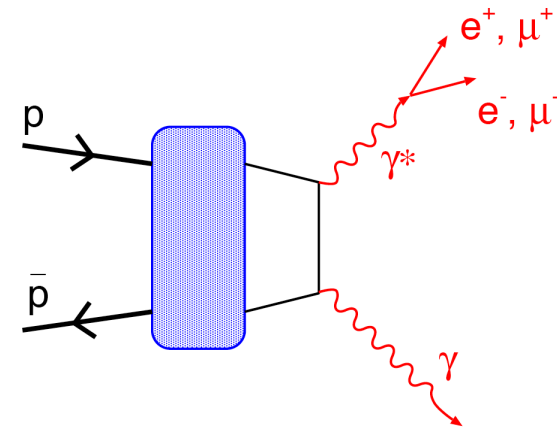
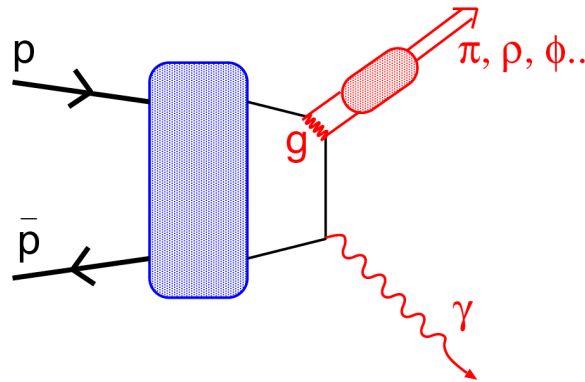
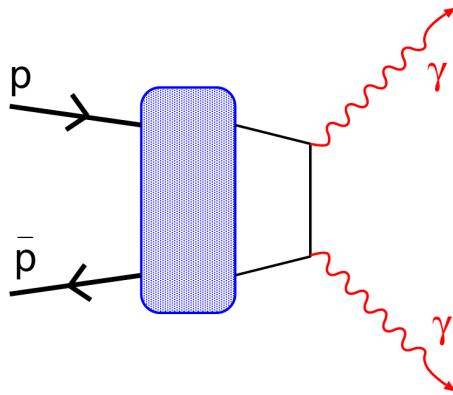
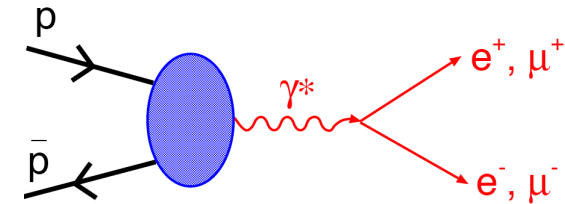
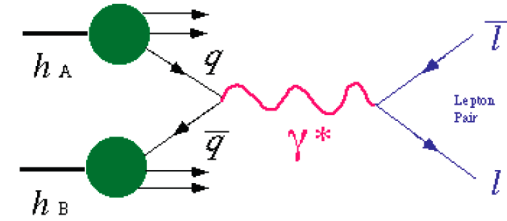
# Extension of the Nuclear Chart



- Do we understand the YN interaction?

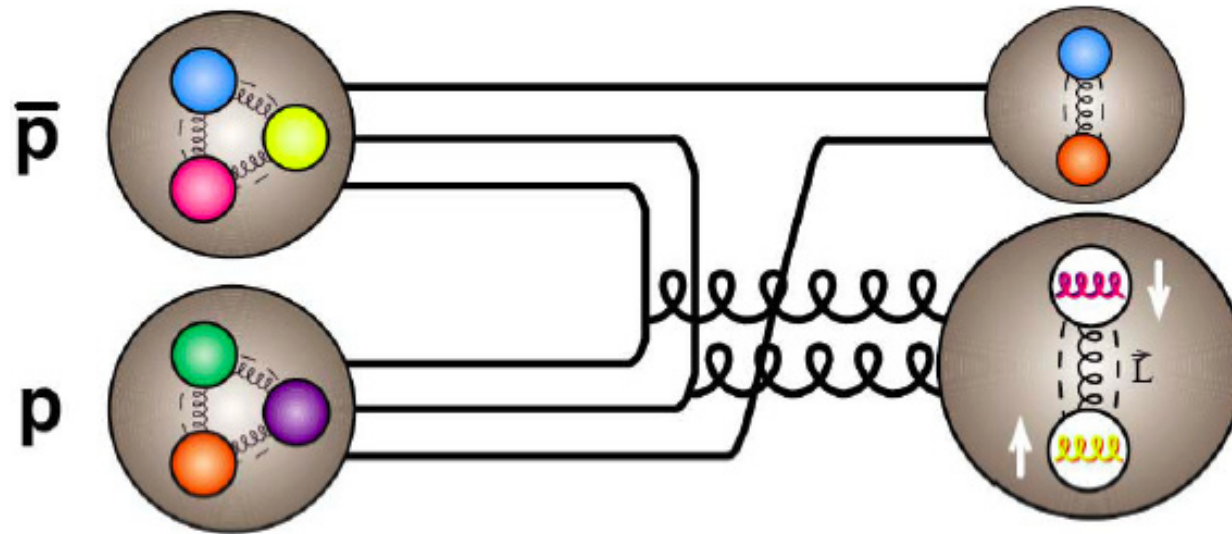
# Other Topics

- Drell-Yan processes
- Time-like form factors
- Hard exclusive processes



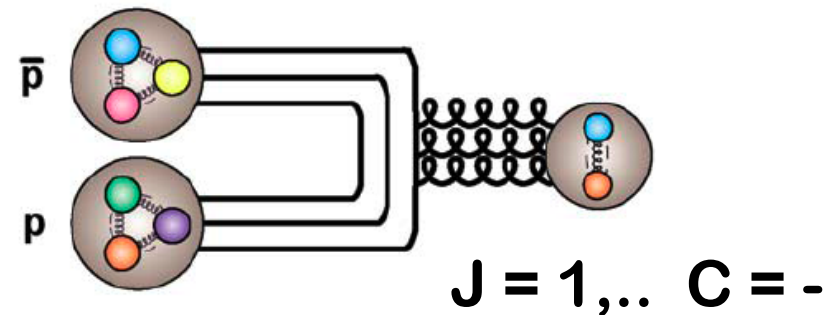
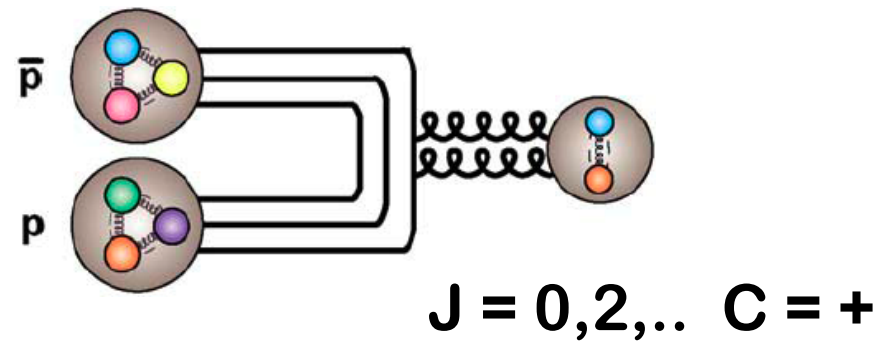
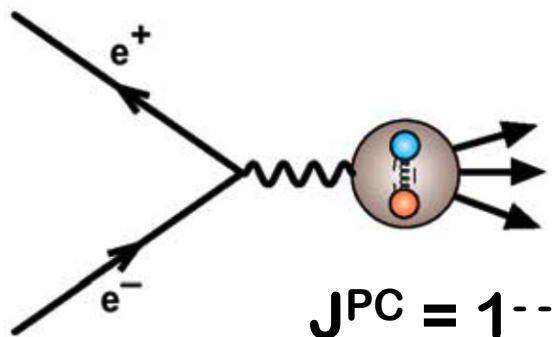
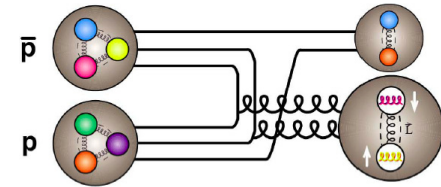
# What is Experimentally Needed?

- **gluon-rich environment**  
⇒ proton-antiproton annihilations



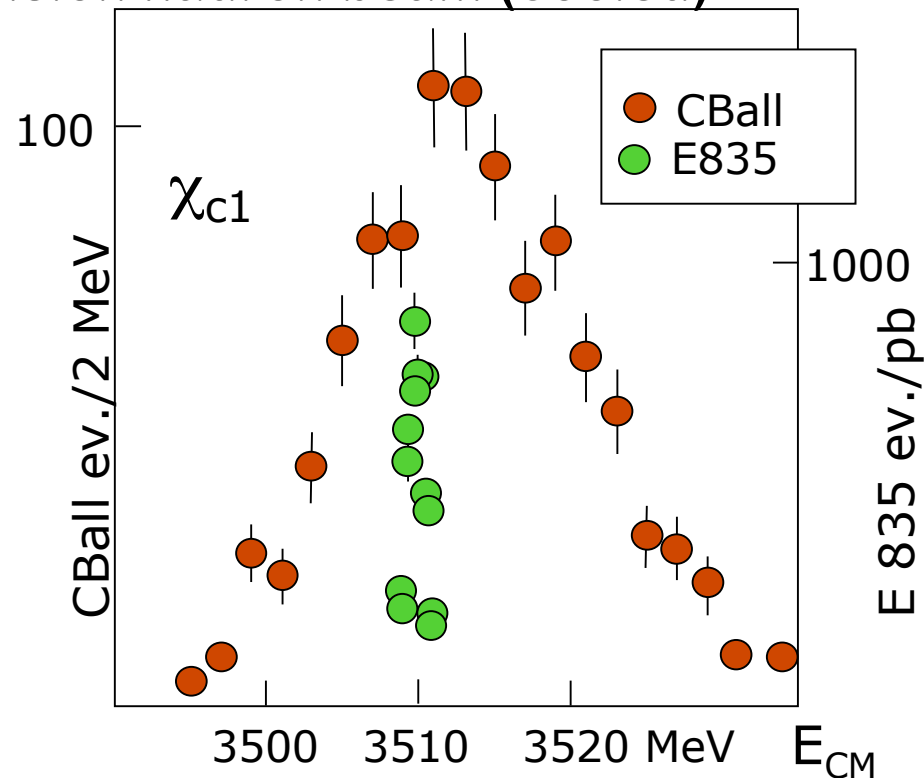
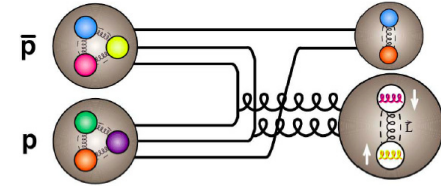
# What is Experimentally Needed?

- **gluon-rich environment**  
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- **all quantum numbers**  
 ⇒ formation exp. i.e. large acc. detector, fixed target



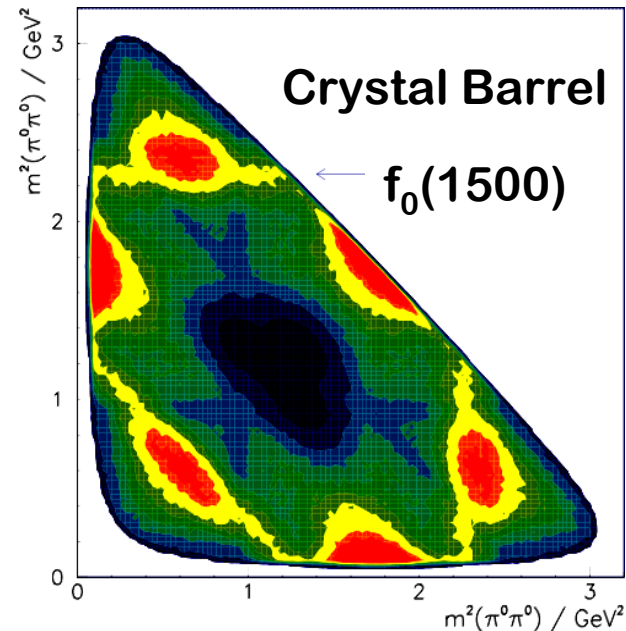
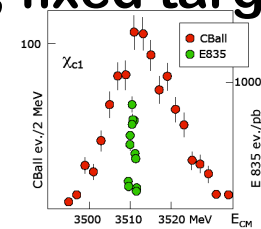
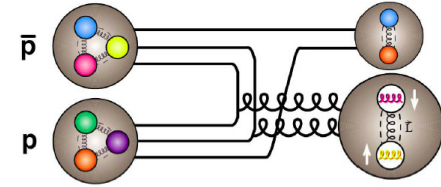
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- **precise resonance scan**  
⇒ high precision hadron beam (cooled)



# What is Experimentally Needed?

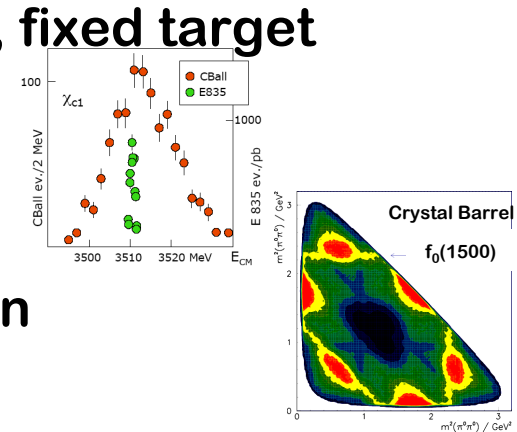
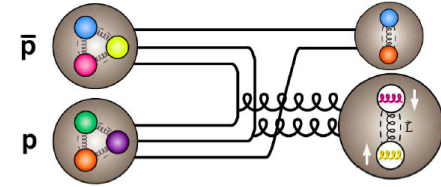
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- **high statistics samples**  
⇒ high luminosity and prod. cross section





# What is Experimentally Needed?

- **gluon-rich environment**  
⇒ proton-antiproton annihilations
- **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  $p_{\bar{p}} = 1.5 - 15 \text{ GeV}/c$



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

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

hybrids

c-hybrids

glueballs

charmonium

1

2

3

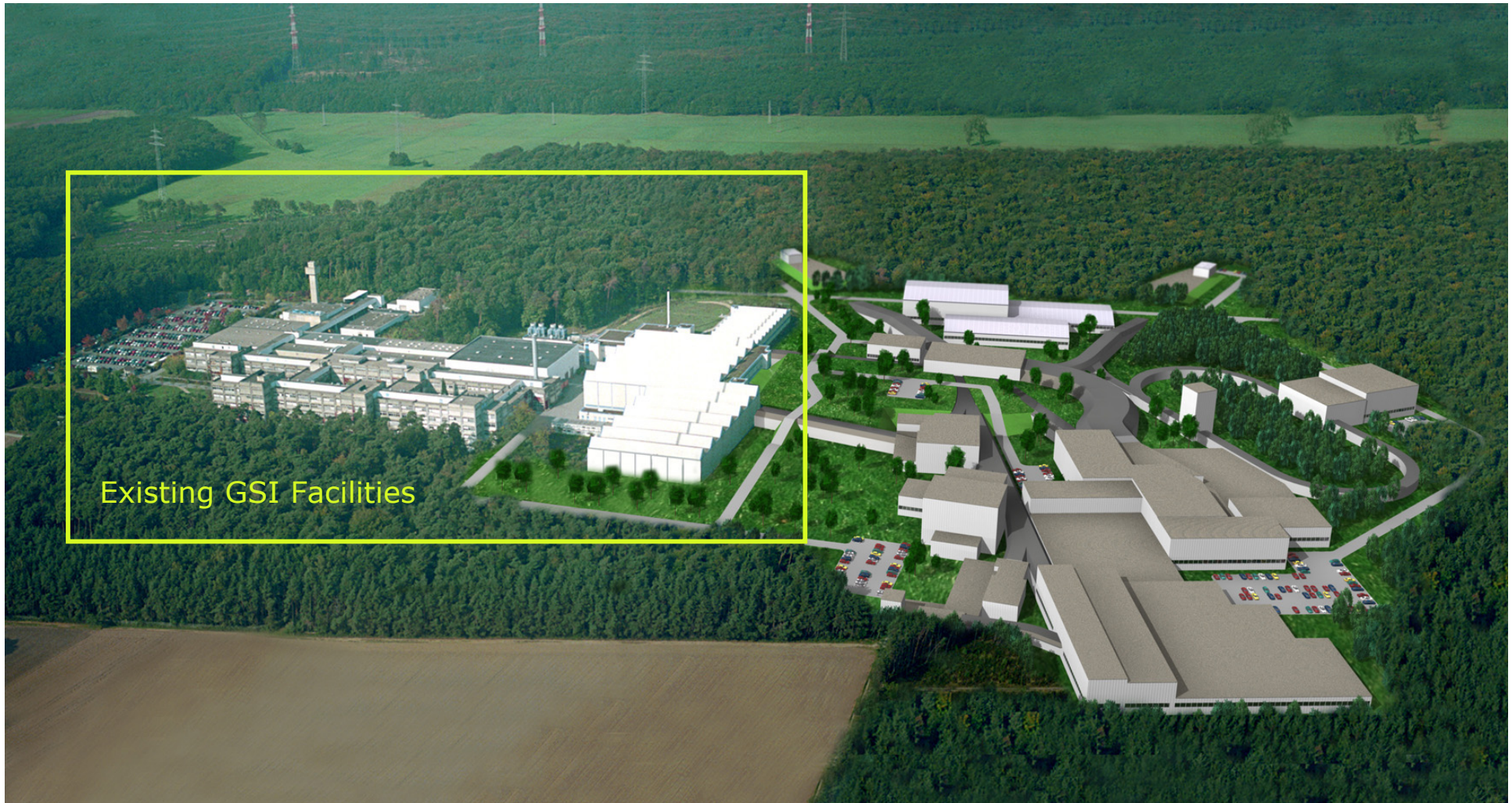
4

5

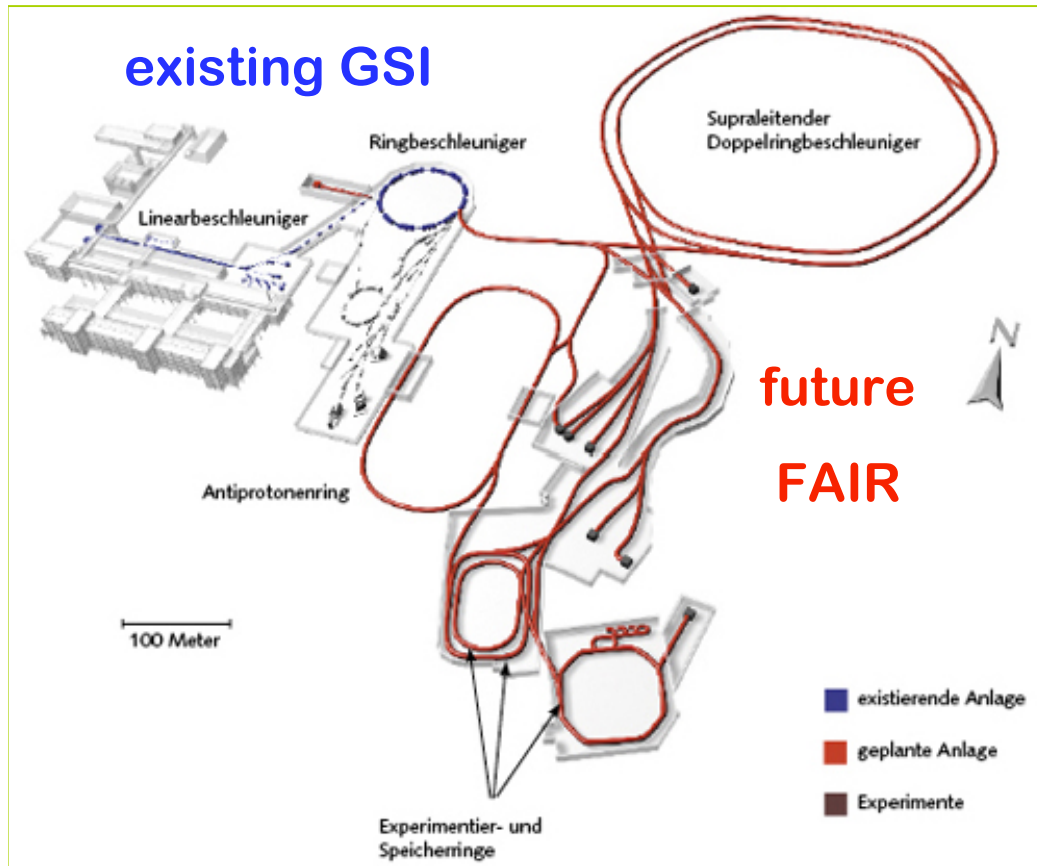
6

M [GeV/c<sup>2</sup>]

# FAIR: Facility for Antiproton and Ion Research



# FAIR: Probing the Intensity Frontier with Secondary Beams



## Primary Beams

- $10^{12}/s$ ; 1.5 GeV/u;  $^{238}\text{U}^{28+}$
- $10^{10}/s$   $^{238}\text{U}^{73+}$  up to 35 GeV/u
- $3 \times 10^{13}/s$  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

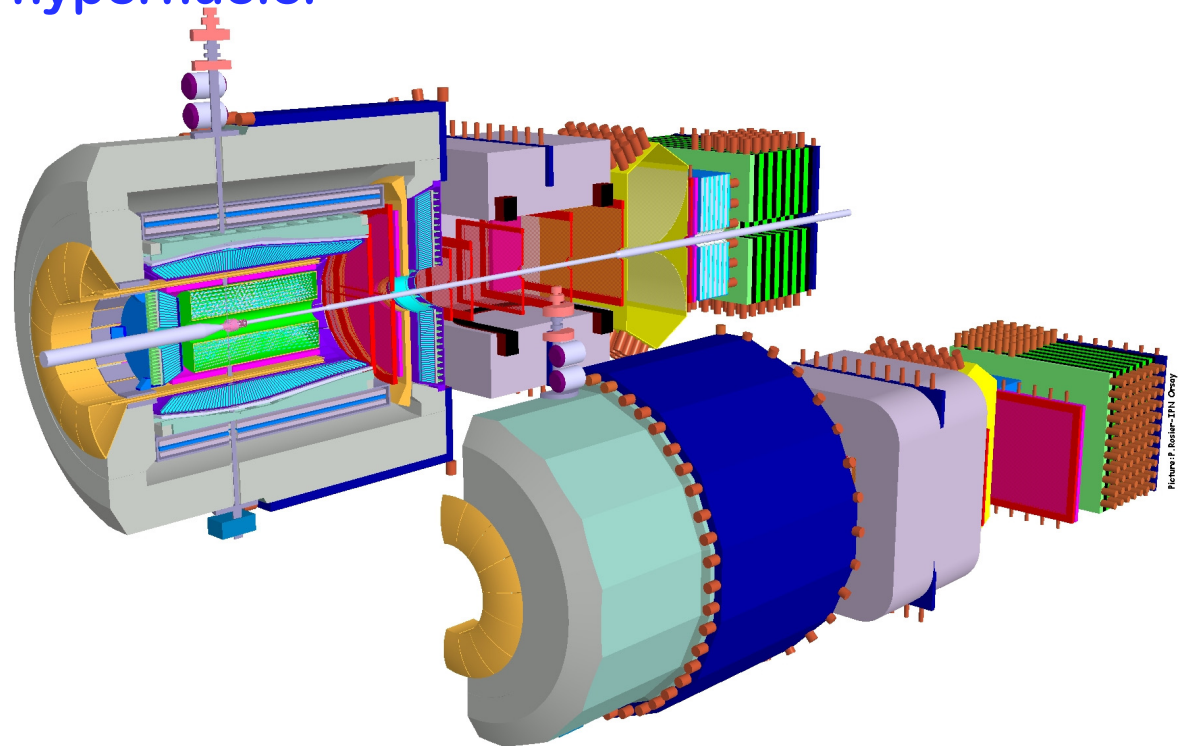
## Technical Challenges

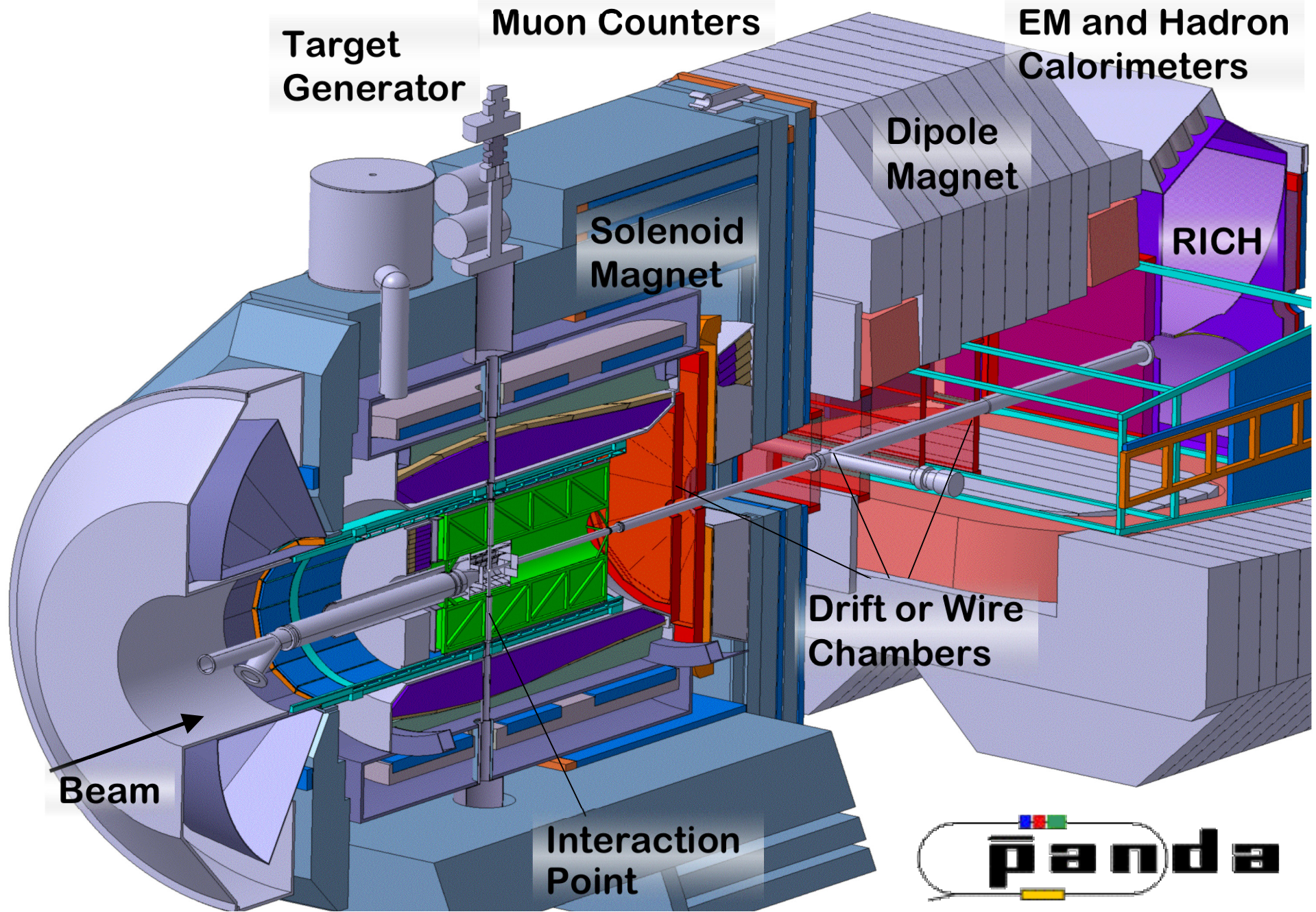
- cooled beams, rapid cycling superconducting magnets, etc.

# Antiproton Anihilations at Darmstadt

## PANDA

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





Disk DIRC

Coil

Pellets or  
Clusters

EMC

Barrel  
DIRC

Straws or TPC

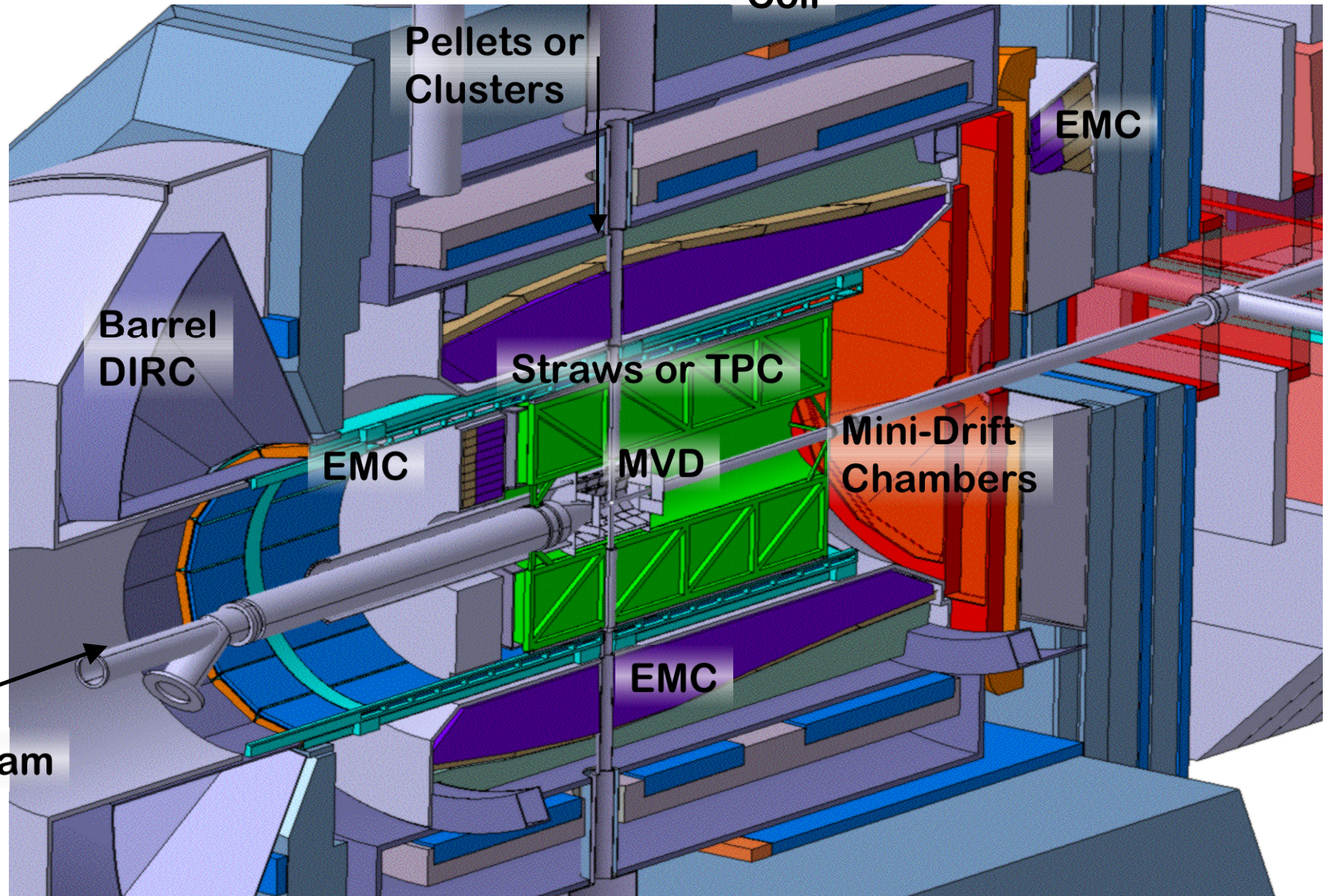
EMC

MVD

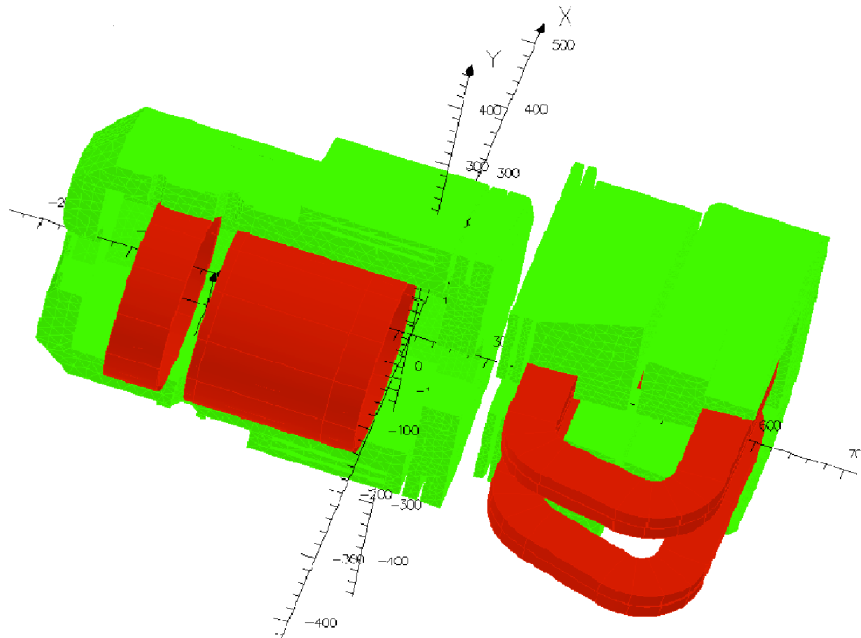
Mini-Drift  
Chambers

EMC

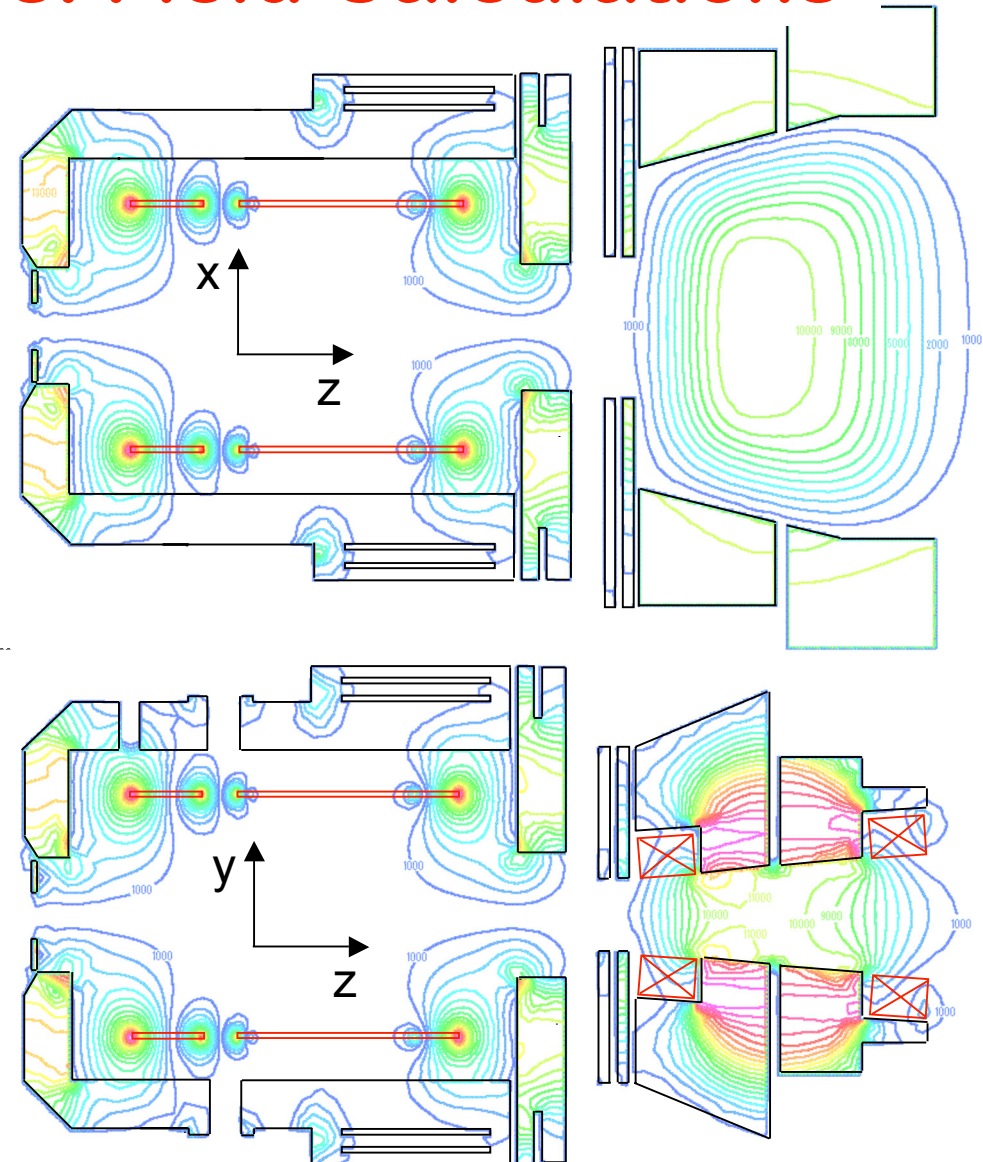
Beam



# Glasgow Activities: Field Calculations

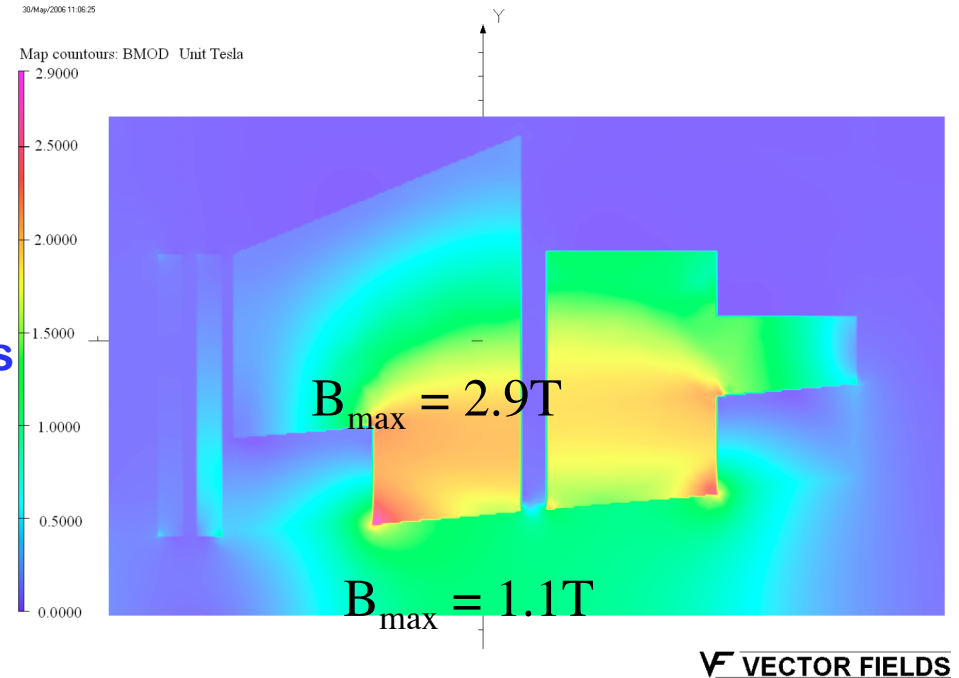


- **Clamping:**
  - field decoupling
  - homogeneity
  - space for muon counters



# Glaskow Activities: Orbit Errors

- Field alignment difficult
- Uncertainties of the magnet fields
- 3D Tosca magnetic field calculations



- **Small misalignment of the solenoid ( $0.2^\circ = 3.5\text{mrad}$ ):**
  - trajectory shift up to 23mm
  - beam-momentum dependent
- **Saturation effects in the dipole:**
  - small trajectory shift  $\sim 0.4\text{mm}$



# Glasgow Activities: PANDA GRID



powered by **AliEn**

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User: Nobody

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  - Mailing list



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# Glasgow Activities: PANDA GRID



|   | Site    | Installation | Firewall | Configuration | SE | CM | CE | Keys | FTD | Packages |
|---|---------|--------------|----------|---------------|----|----|----|------|-----|----------|
| 1 | Glasgow | OK           | OK       | OK            | OK | OK | OK | OK   | OK  | OK       |
| 2 | GSI     | OK           | OK       | OK            | OK | OK | OK | OK   | OK  | OK       |
| 3 | Crakow  | OK           | OK       | OK            | OK | OK | OK | OK   | OK  | OK       |
| 4 | Vienna  | OK           | OK       | OK            | OK | OK | OK | OK   | OK  | OK       |
| 5 | Juelich | OK           | OK       | OK            | OK | OK | OK | OK   | OK  |          |
| 6 | Torino  | OK           | OK       | OK            | OK | OK | OK | OK   | OK  | OK       |
| 7 | KVI     | OK           | OK       | OK            | OK | OK | OK | OK   | OK  | OK       |

File transfer tests are performed for all pair combinations.

| From/To | KVI | Torino | Juelich* | Vienna | Crakow | GSI | Glasgow |
|---------|-----|--------|----------|--------|--------|-----|---------|
| Glasgow | OK  | OK     |          | OK     | OK     | OK  |         |
| GSI     | OK  | OK     |          | OK     | OK     |     | OK      |
| Crakow  | OK  | OK     |          | OK     |        | OK  | OK      |
| Vienna  | OK  | OK     |          |        | OK     | OK  | OK      |
| Juelich | OK  | OK     |          | OK     | OK     | OK  | OK      |
| Torino  | OK  |        |          | OK     | OK     | OK  | OK      |
| KVI     |     | OK     |          | OK     | OK     | OK  | OK      |

Juelich has to remove the erroneous line "127.0.0.2:ip683:ip:ip-juelich:de:ip683" from its /etc/hosts

job submission and execution:

| Destination | KVI | Torino | Juelich | Vienna | Crakow | GSI | Glasgow |
|-------------|-----|--------|---------|--------|--------|-----|---------|
| Jobs        | OK  | OK     | OK      | OK     | OK     | OK  | OK      |

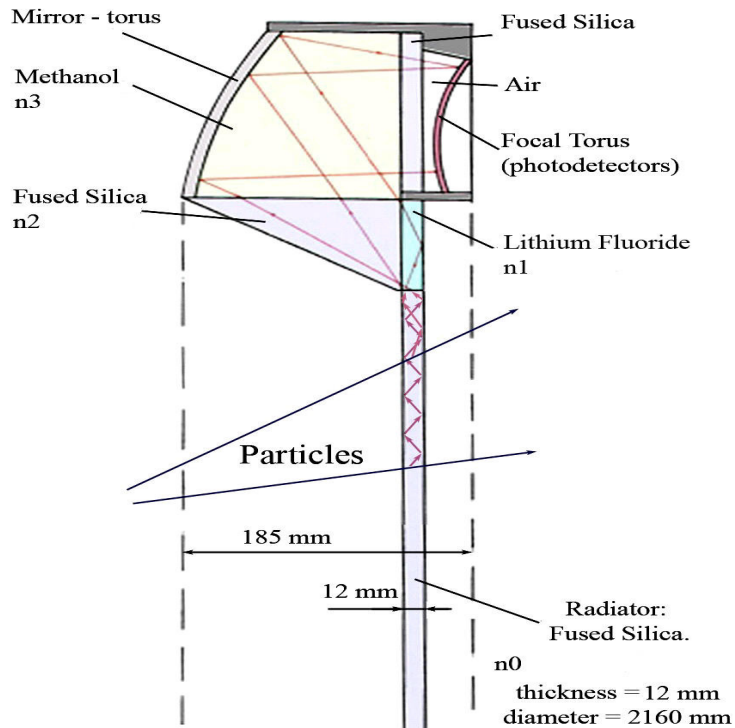
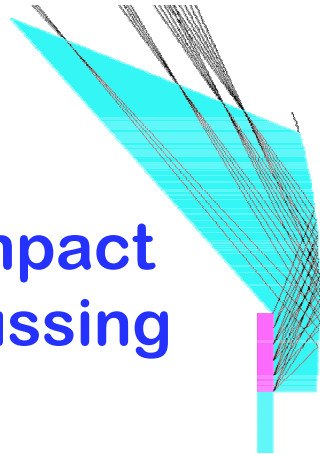
To do list:

1. Add batch queues behind the front end machines where available
2. Install CBM package and try it out
3. Add new sites

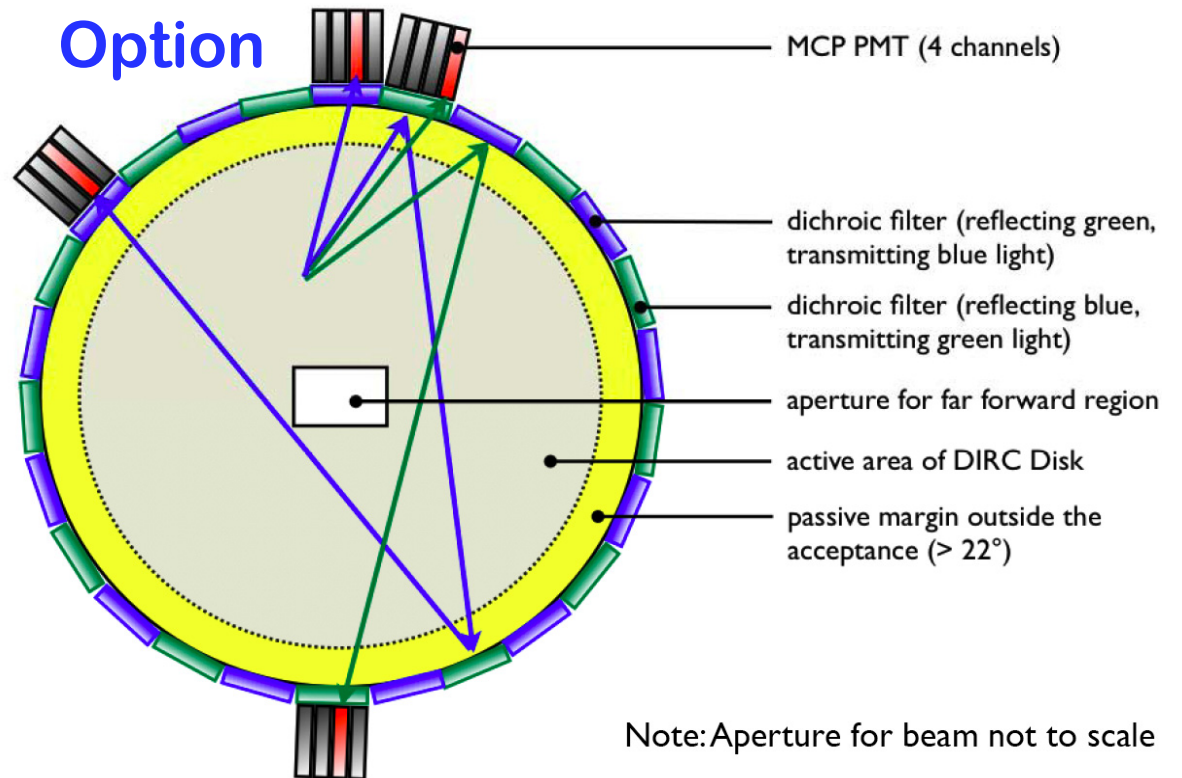
| Site      | kernel release           | arch    | gcc    | batch  | CBM | cpus  |
|-----------|--------------------------|---------|--------|--------|-----|-------|
| Glasgow   | 2.4.20-27.9smp           | i686    | 3.2.2  | ALIEN  | src | 20    |
|           | 2.6.9-11.ELsmp           | x86_64  | 3.4.3  | TORQUE | src | 2x30  |
|           | 2.4.21-27.ELsmp          | x86_64  | 3.2.3  | TORQUE |     | 2x120 |
| GSI       | 2.4.26-gsi               | unknown | 2.95.4 | LSF    | bin | 2x100 |
| Crakow    | 2.4.21-27.0.2.EL         | i686    | 3.2.3  | FORK   |     |       |
| Vienna    | 2.4.21-37.EL.cern        | i686    | 3.2.3  | FORK   |     |       |
| Juelich   | 2.6.11.4-21.11-smp       | i686    | 3.3.5  | FORK   |     |       |
| Torino    | 2.4.21-32.0.1.EL.cernsmp | i686    | 3.2.3  | FORK   | src |       |
| KVI       | 2.6.9-1.667smp           | i686    | 3.4.2  | FORK   | src |       |
| Bucharest | 2.4.21-37.EL.cernsmp     | i686    | 3.2.3  | FORK   | bin |       |

# Glaskow Activities: Cherenkov Disc DIRC

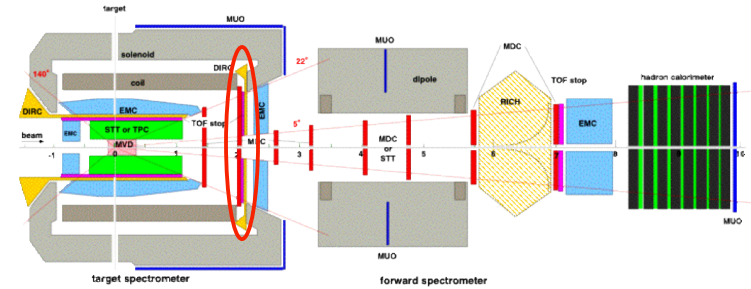
Compact focussing



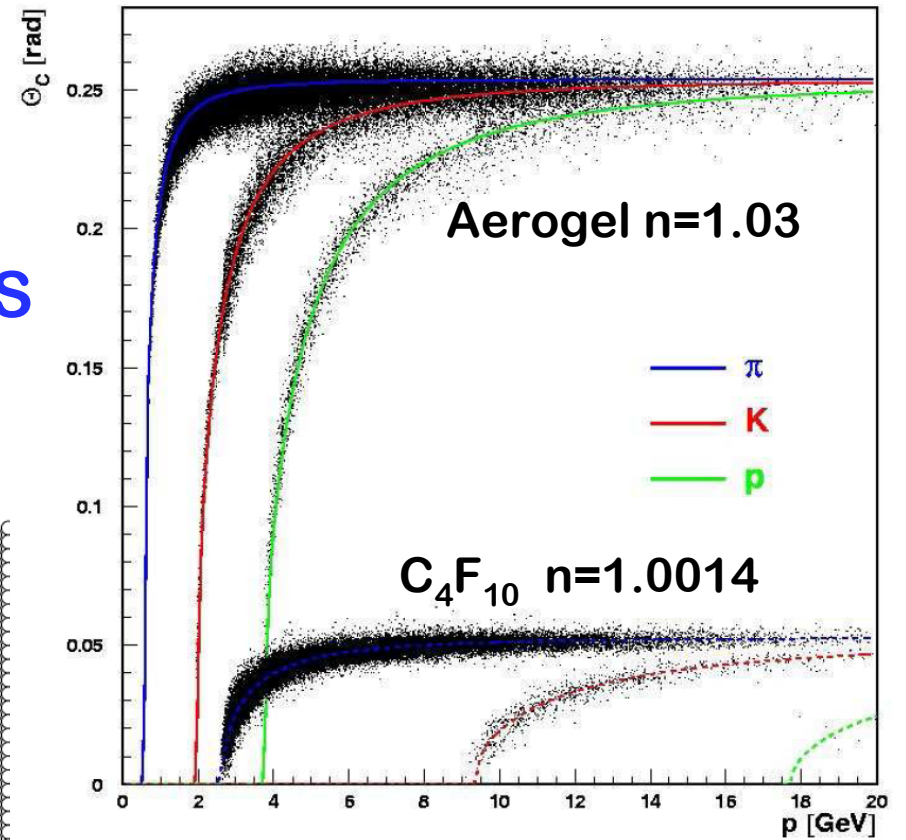
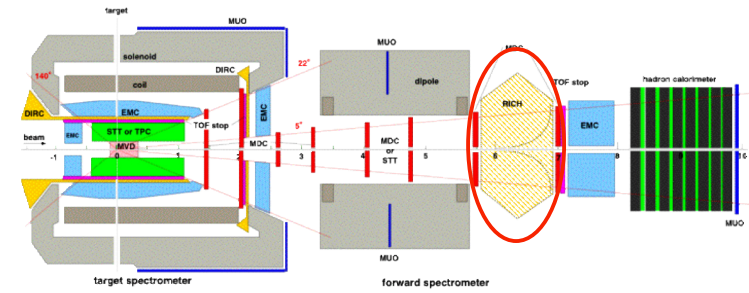
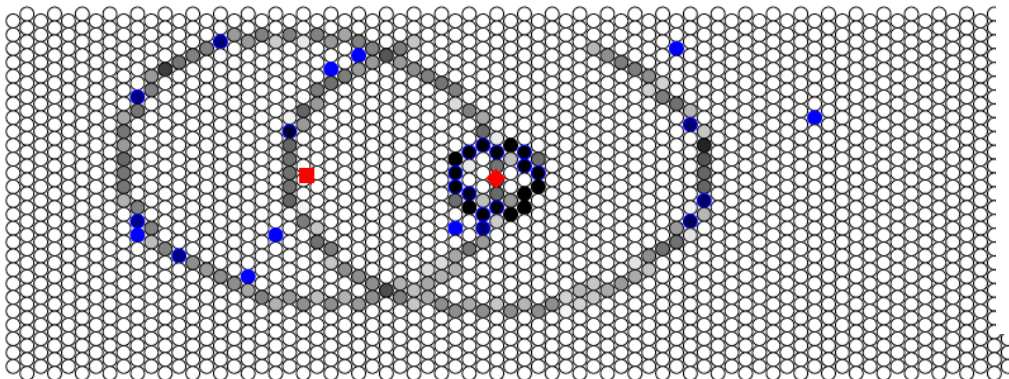
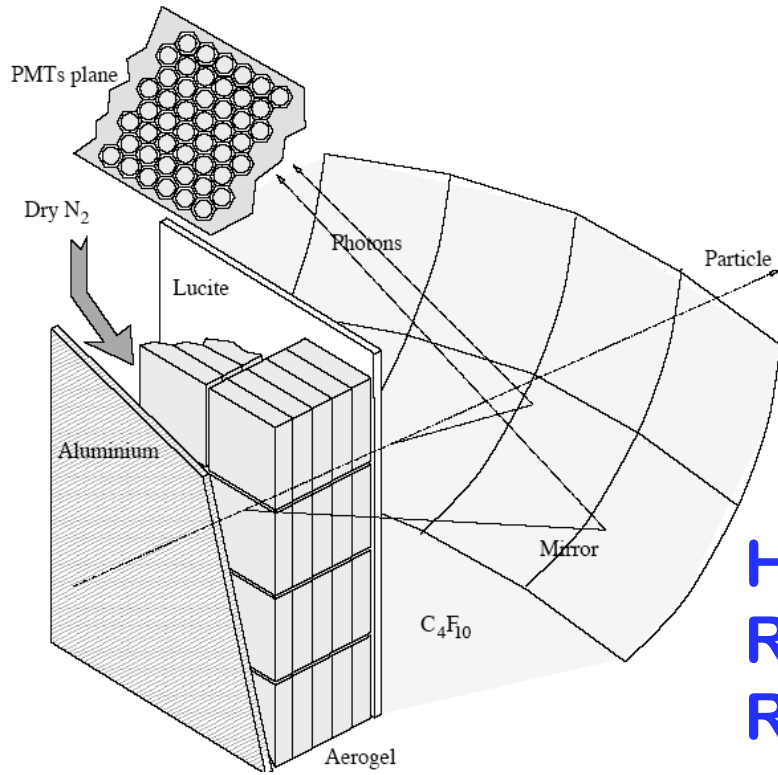
Chrom.  
TOP  
Option



Note: Aperture for beam not to scale

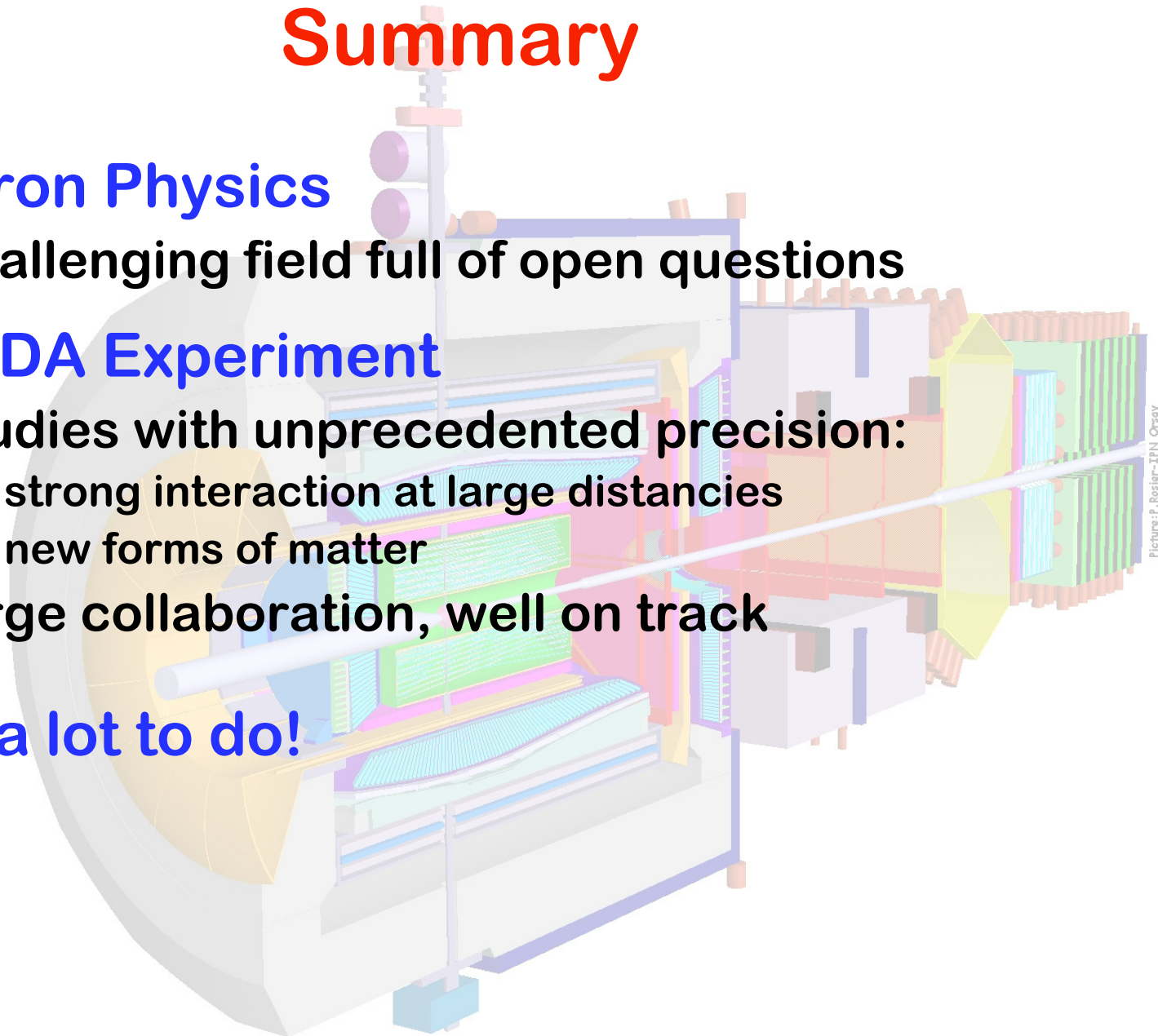


# Glaskow Activities: Cherenkov RICH



# Summary

- **Hadron Physics**
  - challenging field full of open questions
- **PANDA Experiment**
  - studies with unprecedented precision:
    - strong interaction at large distances
    - new forms of matter
  - large collaboration, well on track
- **Still a lot to do!**





# 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