Outline

The Future GSI Facility

Physics opportunities

Antiproton physics

QCD qualitatively

Why antiprotons?

PANDA

HESR

Panda Detector

Panda Physics
2003: Decision by German Federal Government to construct the GSI Future Facility (25% International funding)

Now: Planning R&D
Formulation of goals
2009 first antiprotons
COLLABORATIONS ARE BEING FORMED

PANDA  Antiproton physics
       300 participants, 42 institutions, 13 countries

CBM    Compressed baryonic matter
       60 participants, 28 institutions, 14 countries

Super-FRS Radioactive Ions
       Continuation of FRS at GSI today

NUSTAR Nuclear Physics and Astrophysics

SPARC Atomic Physics

FLAIR Low energy Antiprotons and Heavy Ions
       new initiative from the low energy community

One Facility, Several experiments
Several Fields of Physics, Immense Opportunities ….
Do we try too much at once? The answer is no!

PARALLEL OPERATION of the multi-ring system

- Nuclear beam slow extraction SIS200
- Radioactive Ion beams slow extraction from the SIS100 (or SIS200)
- Antiprotons created, stored, re-accelerated
- Occasional Plasma Physics Beam

As if each experiment had a dedicated machine
PHYSICS OPPORTUNITIES

- Laser and Ions
- Radioactive Ion beams
- Proton Antiproton Annihilations
- Nucleus-nucleus Collisions
- Quark Matter Research
- Hadron Structure and Hadronic Matter Research
- Nuclear Structure and Astrophysics
- Dense Plasma Research
- Interdisciplinary Research with Ions Beams

- Matter: $10^{-1}$ m
- Crystal: $10^{-9}$ m
- Atom: $10^{-10}$ m
- Nucleus: $10^{-14}$ m
- Nucleon: $10^{-15}$ m

Quark-Gluon Plasma
PANDA – Antiproton Physics

- Quarks
- Quantum Chromo Dynamics
- Flux-tube
- Gluons
- Confinement
- Annihilations
- Hadronic mass generation
- Glueballs
- Hybrids
- Self-interaction
- Charm
- Charm Annihilations
Photons have no charge
they don’t see each other

Therefore QED has
a Coulomb like potential

Range is infinite with
a finite energy

Gluons have colour charge
they interact with each other

The larger the distance between
coloured objects the more
interaction can take place

Gluon interactions pull
the colour field
lines into a tube

**QED**

\[ V(r) = -\alpha \frac{\hbar c}{r} \]

**QCD**

\[ V(r) = -\frac{4}{3} \alpha_s \frac{\hbar c}{r} + K \cdot r \]

\( V(r) \to \infty \) for \( r \to \infty \)
To pull quarks apart a lot of energy needs to be pumped into the system. Eventually it’s advantageous to simply create another Quark-Antiquark Pair.

No free quarks have ever been observed. We call this **confinement**.

**Hadrons** = Quarks, Antiquarks and gluons interacting strongly.
**Small distances**
Single gluon exchange
! Coloumb-like potential
Asymptotic freedom
QCD very successful
! Perturbative QCD apply
Calculable like QED

**Larger distances**
Gluon Self interaction
? Confinement
? Formation of Hadrons
Hadronic Mass Generation

98% of the hadron mass and therefore most of the mass of the universe comes from the strong force somehow

There is no theory that can really explain how this all happens …
Simple quark model:
Valence quarks determine the properties of the hadron
Describes almost all known states since 25 years

BUT: we might just as well have particles of pure glue or with excited gluonic fields…..
(Or particles with four quarks and an antiquark)

Few glueballs or hybrids have been found…..
Light meson spectroscopy

Mixing occur when particles can decay into the same final state (quantum number conservation)

Many overlapping states → Mixing
What is what?
Difficult to compare theory and experiment….

Solution: Understand the complete light-quark meson spectrum experimentally and theoretically

\[
\text{same quantum numbers } J^{PC} = 0^{-+}
\]
We go somewhere where it is less crowded......

The charmonium spectrum is clean and well understood with few states.

Identification of additional states (hybrids) easier than in the light meson sector:

- Few states
- Narrow
- Understand potential well
- Perturbative methods (test QCD)
- Relativistic effects small (test QCD)
- Coupling constant \( \alpha_s \approx 0.3 \)
Charmonium Production in $\bar{p}p$

<table>
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<tr>
<th>$c\bar{c}$</th>
<th>$j^{PC}$</th>
<th>$M$ [MeV]</th>
<th>$\Gamma_{tot}$ [MeV]</th>
<th>Decay mode</th>
<th>$\sigma$(M)* [pb]</th>
<th>Events/ day**</th>
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<td>???</td>
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* For selected decay mode

** $L = 2 \times 10^{32}$ cm$^{-2}$s$^{-1}$, 50 % detection and accelerator efficiency
Integrated luminosity = 4 pb$^{-1}$/ day

*** 1% B.R. for this decay mode
What you can see depends on what you look for.....

Access to new particles
• Target and projectile identity (quantum number conservation, couplings)
• Energy scale

Proton-antiproton annihilations in flight directly access all nonexotic quantum numbers and
Exotics can be produced in association with other particles
Particles with spin-exotic quantum numbers have to come from production reactions.

Signal in production and not formation: Interesting!
Crystall Ball

**Production**: the energy resolution of the cross section depends on detector resolution

**Formation**: the energy resolution of the cross section depend on the beam momentum spread
Proton antiproton collisions are glue-rich

Hybrid candidate seen in $n\overline{p}$

$\pi_1(1400)$  Crystal Barrel, GAMS/CERN, VES/Serpukhov, E852/Brookhaven

$\pi_1(1600)$  Crystal Barrel, E852/Brookhaven

For proton antiproton reactions the production rate of hybrids is of the same order as normal mesons

Quark-antiquark pairs couple strongly to gluons

Incoherent intensity for an ordinary meson and a hybrid candidate from PWA on neutron-antiproton collisions (Crystal Barrel).
**Conclusions**

**Facility**: Many experiments – parallel operation

**QCD at small distances**: behaves like QED

**QCD at large distances**: flux-tube, confinement, hadronic mass generation -> not really understood

**Hadrons with excited gluonic fields**: should exist, but have been difficult to find due to overlap and mixing in the light meson sector

**Charm physics**: half-perturbative regime, fewer, narrow states

**Proton-antiproton collisions**: charm factory, all non-exotic quantum numbers accessible in formation

**Formation versus production**: resolution in formation depends on beam momentum spread

**Proton-antiproton collisions**: glue-rich