Report on WG 1 - Hadron Physics

Ulrich Wiedner
Ruhr-Universität Bochum

NuPECC Town Meeting, Madrid, May 31, 2010
Members of the working group:

Long-range Plan

We have to communicate to:
Long-range Plan

We have to communicate to:

- our colleagues
- other physicists
- scientists
- general public
Long-range Plan

We have to communicate to:

- our colleagues
- other physicists
- scientists
- general public

👉 funding agencies
Long-range Plan

We have to communicate to:

- our colleagues
- other physicists
- scientists
- general public

... that we have an excellent scientific case and a **vision**. We have to show that this vision could be achieved by the envisaged long-term strategy.

Ulrich Wiedner / Madrid
Define Hadron Physics and its Hot Topics
Define Hadron Physics and its Hot Topics
Define Hadron Physics and its Hot Topics

Hadron Structure

Hadron Spectroscopy
Define Hadron Physics and its Hot Topics

- Hadron Structure
- Hadron Spectroscopy
- Hadronic Interactions
Define Hadron Physics and its Hot Topics

State-of-the-art

Future Physics Goals

Perspectives

Hadron Structure

Hadron Spectroscopy

Future Physics Goals

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Hadronic Interactions

Future Physics Goals

State-of-the-art

Perspectives
FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the “Standard Model.”

FERMIONS

<table>
<thead>
<tr>
<th>Flavor</th>
<th>Mass GeV/c^2</th>
<th>Electric Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>e^+</td>
<td>&lt;1x10^-8</td>
<td>0</td>
</tr>
<tr>
<td>e^-</td>
<td>0.000511</td>
<td>-1</td>
</tr>
<tr>
<td>muon+</td>
<td>&lt;0.00020</td>
<td>0</td>
</tr>
<tr>
<td>muon-</td>
<td>0.106</td>
<td>-1</td>
</tr>
<tr>
<td>tau+</td>
<td>&lt;0.020</td>
<td>0</td>
</tr>
<tr>
<td>tau-</td>
<td>1.777</td>
<td>-1</td>
</tr>
</tbody>
</table>

Spins are given in units of Planck's constant h. The energy of the electron is given in electron volts (eV), the mass of the electron is given in electron volts squared (eV^2), and the charge of the electron is given in electron charge units e.

Quarks

<table>
<thead>
<tr>
<th>Flavor</th>
<th>Mass GeV/c^2</th>
<th>Electric Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>u up</td>
<td>0.0034</td>
<td>2/3</td>
</tr>
<tr>
<td>d down</td>
<td>0.0068</td>
<td>-1/3</td>
</tr>
<tr>
<td>s strange</td>
<td>0.1</td>
<td>-1/3</td>
</tr>
<tr>
<td>c charm</td>
<td>1.3</td>
<td>2/3</td>
</tr>
<tr>
<td>t top</td>
<td>175.3</td>
<td>2/3</td>
</tr>
<tr>
<td>b bottom</td>
<td>4.3</td>
<td>-1/3</td>
</tr>
</tbody>
</table>

Each quark carries one of three types of electric charge: up, down, charm, strange, top, and bottom. The proton and neutron consist of quarks in the fundamental interactions.

BOSONS

<table>
<thead>
<tr>
<th>Name</th>
<th>Mass GeV/c^2</th>
<th>Electric Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>g</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>W^-</td>
<td>80.4</td>
<td>-1</td>
</tr>
<tr>
<td>Z^-</td>
<td>80.4</td>
<td>0</td>
</tr>
<tr>
<td>W^+</td>
<td>91.187</td>
<td>-1</td>
</tr>
</tbody>
</table>

Color Charge

Each quark carries one of three types of color charge: red, green, and blue. The proton and neutron consist of quarks in the fundamental interactions.

Residual Strong Interaction

The residual strong interaction is the force that holds protons and neutrons together in the nucleus. It is described by the Glashow-Weinberg-Salam (GWS) model, which is a subset of the Standard Model. The GWS model predicts the existence of the W and Z bosons, which mediate the strong force.

Properties of the Interactions

<table>
<thead>
<tr>
<th>Property</th>
<th>Gravitational</th>
<th>Weak</th>
<th>Electromagnetic</th>
<th>Strong</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acts on:</td>
<td>Mass, Energy</td>
<td>Flavor</td>
<td>Electric Charge</td>
<td>Color Charge</td>
</tr>
<tr>
<td>Particles experiencing:</td>
<td>All</td>
<td>Quarks, Leptons</td>
<td>Electrally charged Quarks, Gluons</td>
<td>Hadrons</td>
</tr>
<tr>
<td>Particles mediating:</td>
<td>Gravitational (not yet observed)</td>
<td>W^+ W^- Z^-</td>
<td>Gamma rays</td>
<td>Hadrons</td>
</tr>
<tr>
<td>Strength: relative to electron:</td>
<td>1x10^-17 m</td>
<td>10^-41</td>
<td>10^-41</td>
<td>10^-41</td>
</tr>
<tr>
<td>for two u quarks at:</td>
<td>5x10^-17 m</td>
<td>10^-41</td>
<td>10^-41</td>
<td>10^-41</td>
</tr>
<tr>
<td>for two protons in nucleus:</td>
<td>1x10^-17 m</td>
<td>10^-41</td>
<td>10^-41</td>
<td>10^-41</td>
</tr>
<tr>
<td>Matter and Antimatter</td>
<td>No</td>
<td>Not applicable to quarks</td>
<td>Not applicable to hadrons</td>
<td>Not applicable to hadrons</td>
</tr>
</tbody>
</table>

The Particle Adventure

Visit the award-winning website The Particle Adventure at http://ParticleAdventure.org

This chart has been made possible by the generous support of:

- U.S. Department of Energy
- U.S. National Science Foundation
- Lawrence Berkeley National Laboratory
- Stanford Linear Accelerator Center
- University of California: Berkeley, Institute of Physics and World Wide Web

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http://CPEPweb.org
The real world is not composed of fundamental particles.
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First level of complexity in the world: *hadron*
Structure within the Atom

Quark
Size $< 10^{-19}$ m

Nucleus
Size $= 10^{-14}$ m

Electron
Size $< 10^{-18}$ m

Neutron and Proton
Size $= 10^{-15}$ m

If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.
<table>
<thead>
<tr>
<th>Property</th>
<th>Interaction</th>
<th>Gravitational</th>
<th>Weak (Electroweak)</th>
<th>Electromagnetic</th>
<th>Strong</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acts on:</td>
<td></td>
<td>Mass - Energy</td>
<td>Flavor</td>
<td>Electric Charge</td>
<td>Color Charge</td>
<td>Hadrons</td>
</tr>
<tr>
<td>Particles experiencing:</td>
<td></td>
<td>All</td>
<td>Quarks, Leptons</td>
<td>Electrically</td>
<td>Quarks, Gluons</td>
<td>Mesons</td>
</tr>
<tr>
<td>Particles mediating:</td>
<td></td>
<td>Graviton</td>
<td>W⁺, W⁻, Z⁰</td>
<td>charged</td>
<td>Gluons</td>
<td></td>
</tr>
<tr>
<td>Strength relative to electromag:</td>
<td></td>
<td>10⁻¹⁸ m</td>
<td>0.8</td>
<td>1</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>for two u quarks at:</td>
<td></td>
<td>10⁻⁴¹</td>
<td>10⁻⁴</td>
<td>1</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>for two protons in nucleus</td>
<td></td>
<td>3 x 10⁻¹⁷ m</td>
<td>10⁻⁷</td>
<td>1</td>
<td>Not applicable to quarks</td>
<td>20</td>
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Basic underlying theory is known: QCD … but

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How to study hadrons?

• Observe them as existing particles
  
  γ / lepton beams are excellent probes (mostly of the nucleon)

• Build them together in a controlled manner

  ✦ e⁺e⁻ collider can produce vector mesons (other particles in decays)
  
  ✦ hadron beams have high production cross sections but little control (except for antiprotons)

The results from hadron physics will leads to an understanding of a (non-perturbative) interaction among the fundamental quarks.
Hadron Structure

Nucleus

$E_0 \approx 100 \text{ MeV}$
$q = 0.5 \text{ fm}^{-1}$
$\Delta r = 2 \text{ fm}$

$E_0 \approx 1 \text{ GeV}$
$q = 5 \text{ fm}^{-1}$
$\Delta r = 0.2 \text{ fm}$

$E_0 \approx 1 \text{ GeV}$
$q = 5 \text{ fm}^{-1}$
$\Delta r = 0.2 \text{ fm}$

$E_0 \approx 200 \text{ GeV}$
$q = 50 \text{ fm}^{-1}$
$\Delta r = 0.02 \text{ fm}$

Quark

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The Nucleon (as composed by fundamental particles)
Gluon polarization results from SMC, HERMES, and COMPASS, in comparison with theoretical fits.
Elastic scattering

... reveals transverse quark distribution in coordinate space
Deep inelastic scattering...

... reveals longitudinal quark distribution in momentum space
Common description:

Generalized Parton Distributions (GPDs)
X and Y mesons

\[ B \to K \pi^+\pi^- J/\psi \]

\[ M(\pi^+\pi^- J/\psi) - M(J/\psi) \]

\[ B \to K \omega J/\psi \]

\[ M(\omega J/\psi) \]

\[ B \to D D^* J/\psi \]

\[ M(DD^*) \]

\[ B \to D^* D^* J/\psi \]

\[ M(D^* D^*) \]

\[ B \to K \phi J/\psi \]

\[ M(\phi J/\psi) \]

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$\psi'$

$X(3872)$

Belle

$Y(4260)$

$Y(4008)$

Belle

$Y(3940)$

BaBar

$Y(4260)$

BaBar

$Y(4350)$

Belle

$Y(4350)$ & $Y(4660)$

Belle

e$^+$e$^-$

$\rightarrow$

$\gamma$

ISR

$\Lambda_{c} \bar{\Lambda}_{c}$

Belle

$Y(4630)$

Y(4140)

CDF

$Y(3940)$

BaBar

$X(3940)$

Belle

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$Z^+ (4430)$ - a new state of matter (tetraquark?) decaying into $\pi^+\psi'$

\[
M = (4.433 \pm 0.004 \text{ (stat)} \pm 0.001 \text{ (syst)}) \text{ GeV}
\]

\[
\Gamma = (0.044^{+0.017}_{-0.011} \text{ (stat)}^{+0.030}_{-0.011} \text{ (syst)}) \text{ GeV}
\]

\[
\mathcal{B}(B \to KZ(4430)) \times \mathcal{B}(Z \to \pi^+\psi') = (4.1 \pm 1.0 \text{ (stat)} \pm 1.3 \text{ (syst)}) \times 10^{-5}
\]
Like social elephants, quarks only exist in groups with other quarks and are never found alone. Composite particles made of quarks are called hadrons.

Although individual quarks have fractional electrical charges, they combine such that hadrons have a net integer electric charge. Another property of hadrons is that they have no net color charge even though the quarks themselves carry color charge (we will talk more about this later).

There are two classes of hadrons (try putting your mouse on the elephants):

**Baryons**

...are any hadron which is made of three quarks (qqq).

Because they are made of two up quarks and one down quark (uud), **protons** are baryons. So are **neutrons** (udd).

**Mesons**

...contain one quark (q) and one antiquark (\(\bar{q}\)).

One example of a meson is a pion (\(\pi^\pm\)), which is made of an up quark and a down antiquark. The antiparticle of a meson just has its quark and antiquark switched, so an antipion (\(\pi^\mp\)) is made up a down quark and an up antiquark.

Because a meson consists of a particle and an antiparticle, it is very unstable. The kaon (K-) meson lives much longer than most mesons, which is why it was called "strange" and gave this name to the strange quark, one of its components.

A weird thing about hadrons is that only a very very very small part of the mass of a hadron is due to the quarks in it.
Like social elephants, quarks only exist in groups with other quarks and are never found alone. Composite particles made of quarks are called hadrons. Although individual quarks have fractional electrical charges, they combine such that hadrons have a net integer electric charge. Another property of hadrons is that they have no net color charge even though the quarks themselves carry color charge (we will talk more about this later).

There are two classes of hadrons (try putting your mouse on the elephants):...are any hadron which is made of three quarks (qqq). Because they are made of two up quarks and one down quark (uud), protons are baryons. So are neutrons (udd). ...contain one quark (q) and one antiquark (\bar{q}). One example of a meson is a pion ($\pi^+$), which is made of an up quark and a down antiquark. The antiparticle of a meson just has its quark and antiquark switched, so an antipion ($\pi^-$) is made up a down quark and an up antiquark.

Because a meson consists of a particle and an antiparticle, it is very unstable. The kaon ($K^-$) meson lives much longer than most mesons, which is why it was called "strange" and gave this name to the strange quark, one of its components.

A weird thing about hadrons is that only a very very very small part of the mass of a hadron is due to the quarks in it.
Glueballs
Glueballs  $\rightarrow$  Creation of Mass
A few % of the proton mass is generated due to the **Higgs mechanism**.
Glueballs → Creation of Mass

A few % of the proton mass is generated due to the Higgs mechanism.

Most of the proton mass is created by the strong interaction.
Glueballs → Creation of Mass

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HOW ???????
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HOW ??????

We do not understand most of the baryonic mass of the Universe.
A few % of the proton mass is generated due to the Higgs mechanism.

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HOW ??????

We do not understand most of the baryonic mass of the Universe.

Glueballs gain their mass solely by the strong interaction and are
Glueballs → Creation of Mass

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HOW ???????

We do not understand most of the baryonic mass of the Universe.

Glueballs gain their mass solely by the strong interaction and are therefore an unique approach to the mass creation by the strong
A few % of the proton mass is generated due to the Higgs mechanism.

Most of the proton mass is created by the strong interaction.

HOW ?????

We do not understand most of the baryonic mass of the Universe.

Glueballs gain their mass solely by the strong interaction and are therefore an unique approach to the mass creation by the strong interaction.
Glueballs
Glueballs, closed fluxtubes and $\eta(1440)$
Ludvig Faddeev, Antti Niemi and Ulrich Wiedner
Phys.Rev.D70:114033, 2004
The glueball spectrum
Hadron Interactions
Experimental / theoretical results for the S-wave $\pi\pi$ scattering lengths

Precision: 2%!
Hypernuclear physics: a multicultural activity
Hypernuclei offer a bridge between traditional nuclear physics, hadron physics and astrophysics.

It helps to explore fundamental questions like:
- How do nucleons and nuclei form out of quarks?
- Can nuclear structure be derived \textit{quantitatively} from QCD?
- Properties of strange baryons in nuclei and structure of QCD vacuum?
- Can we constrain the interior of neutron stars?
Adding the third dimension to the nuclear chart
Adding the third dimension to the nuclear chart
Present limitations

- only single Λ-hypernuclei close to valley of stability
- only very few ΛΛ-hypernuclei events
- no information on antihyperons in nuclei
Present limitations

- only single $\Lambda$-hypernuclei close to valley of stability
- only very few $\Lambda\Lambda$-hypernuclei events
- no information on antihyperons in nuclei
Adding the third dimension to the nuclear chart

Increasing strangeness

Present limitations

- only single $\Lambda$-hypernuclei close to valley of stability
- only very few $\Lambda\Lambda$-hypernuclei events
- no information on antihyperons in nuclei

Ulrich Wiedner / Madrid
Present limitations

- only single Λ-hypernuclei close to valley of stability
- only very few ΛΛ-hypernuclei events
- no information on antihyperons in nuclei
Recommendations:

1) A speedy construction of the PANDA experiment at FAIR
\[ \mathcal{L} = 2 \cdot 10^{32} \text{cm}^{-2}\text{s}^{-1}; \]
\[ p_{\bar{p}} = 1.5 - 15 \text{GeV/c} \]
\[ \Delta p / p = 10^{-4} - 10^{-5} \]
Electromagnetic Processes: $\bar{p}p \rightarrow \gamma\gamma$

Handbag diagram separates a soft part described by GPDs from a hard $q\bar{q}$ annihilation process

Predicted rates*: several thousand / month or above

Exp. problem: Background channels like $\pi^0\gamma$ or $\pi^0\pi^0$ $5\times - 100\times$ stronger.

Related exclusive annihilation processes studies:

\[ p \rightarrow \pi, \rho, \varphi, \ldots \]

\[ \bar{p} \rightarrow \gamma \]

\[ p, q, \bar{p}, u, d \rightarrow e^+, e^- \]

\[ \gamma^* \rightarrow e^+, e^- \]

\[ \gamma \rightarrow p, p', q, q' \]

\[ \Rightarrow \text{check of factorization.} \]
Electromagnetic form factors of the proton

... can be extracted from the cross section:  $\bar{p} + p \rightarrow e^+ + e^-$

$$\frac{d\sigma}{d(\cos\theta^*)} = \frac{\pi\alpha^2\hbar^2c^2}{2xs}\left[|G_M|^2(1+\cos^2\theta^*) + \frac{4m_p^2}{s}|G_E|^2(1-\cos^2\theta^*)\right]$$

(first order QED prediction)

Data at high $Q^2$ test QCD predictions for the asymptotic behavior of the form factors and spacelike-timelike equality at corresponding $Q^2$. 

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PANDA will measure the form factors in the biggest $Q^2$ range for a single experiment up to values of $\sim 20 \text{ GeV}^2/c^4$ (beam time dependent).
Crystal Barrel \[ p\bar{p} \rightarrow \pi^0\pi^0\pi^0 \] Dalitz plot

700000 events = 6\times700000 \] entries
Production of $\chi_{1,2}$

\[ e^+e^- \rightarrow \psi' \]

\[ \chi_{1,2} \]

$\gamma (\gamma J/\psi)$

$\gamma (e^+e^-)$

Reconstruction of invariant mass:
detector resolution dependent
Production of $\chi_{1,2}$

$$e^+e^- \rightarrow \psi'$$

$\chi_{1,2}$

$\gamma (\gamma J/\psi)$

$\gamma\gamma (e^+e^-)$

Reconstruction of invariant mass:
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Reconstruction of invariant mass:
detector resolution dependent

\[ \gamma (\gamma J/\psi) \]

\[ \gamma (e^+e^-) \]

Formation of $\chi_{1,2}$

\[ \bar{p}p \rightarrow \chi_{1,2} \]

\[ \gamma J/\psi \]

\[ \gamma (e^+e^-) \]

Rate measurement (beam energy dependent):
detector resolution “independent”

\[ J = 0, 2, \ldots \]

\[ C = + \]

\[ J = 1 \]

\[ C = - \]
Production of $\chi_{1,2}$

$e^+e^- \rightarrow \psi'$

$\chi_{1,2}$

$\gamma (\gamma J/\psi)$

$\gamma (e^+e^-)$

Reconstruction of invariant mass:
detector resolution dependent

Formation of $\chi_{1,2}$

$\bar{p}p \rightarrow \chi_{1,2}$

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$\gamma (e^+e^-)$

Rate measurement (beam energy dependent):
detector resolution “independent”

$\sigma_m$ (beam) = 0.5 MeV

E 760 (Fermilab)
Production of $\chi_{1,2}$

$e^+e^- \rightarrow \psi'$

$\chi_{1,2}$

$\gamma (\gamma J/\psi)$

$\gamma (e^+e^-)$

Reconstruction of invariant mass:
detector resolution dependent

Formation of $\chi_{1,2}$

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$\gamma J/\psi$

$\gamma (e^+e^-)$

Rate measurement (beam energy dependent):
detector resolution “independent”

$\sigma_m (\text{beam}) = 0.5 \text{ MeV}$
Antiproton-Nucleus Interaction

\[ \bar{p} \rightarrow \psi + (A-1) \]

\[ \psi (c\bar{c}) \text{ decays into } D\bar{D} \]

D mesons interact with rest nucleus
\[ \psi(3770) \quad \text{quark – nucleus interaction} = d \text{ (or } \bar{d} \text{) – nucleus interaction}^* \]

\[ D^- = d\bar{c} \]

\[ D^+ = \bar{d}c \]

\[ \bar{D}^0 = u\bar{c} \]

\[ \psi(3770) \quad \text{quark – nucleus interaction} = u \text{ (or } \bar{u} \text{) – nucleus interaction}^* \]

\[ D_s^0 = u\bar{c} \]

\[ D_s = s\bar{c} \]

\[ \psi(4160) \quad \text{quark – nucleus interaction} = s \text{ (or } \bar{s} \text{) – nucleus interaction}^* \]

\[ D_s^+ = \bar{s}c \]

* ignoring c (or \( \bar{c} \)) – nucleus interaction
Production of Hypernuclei at PANDA
Production of Hypernuclei at PANDA

3 GeV/c

\(p\) beam

primary \(^{12}\text{C target}\)

Ulrich Wiedner / Madrid
Production of Hypernuclei at PANDA

3 GeV/c Kaons

+$28\text{MeV}$

Sandwich target
Si-strip + Be,B,C absorbers

$\bar{p}$ beam

primary $^{12}\text{C}$ target

Active secondary target

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Production of Hypernuclei at PANDA

3 GeV/c Kaons

Sandwich target
Si-strip + Be,B,C absorbers

$p$ beam

primary $^{12}$C target

Array of HPGe

$\bar{p}$ beam
PANDA Detector set-up for hypernuclei physics

- $\theta_{\text{lab}} < 45^\circ$: $\Xi$, $K^{-}$ trigger (PANDA)
- $\theta_{\text{lab}} = 45^\circ$-$90^\circ$: $\Xi$-capture, hypernucleus formation
- $\theta_{\text{lab}} > 90^\circ$: $\gamma$-detection Euroball at backward angles
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Recommendations:

1) A speedy construction of the PANDA experiment at FAIR

2) Complete and exploit currently operating facilities
Crystal Barrel Set Up at ELSA
**Polarization Observables**

\[ \frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta) \left( 1 - p_{\gamma}^{Lin} \Sigma \cdot \cos(2\phi) - p_{\gamma}^{Lin} p_{z} G \cdot \sin(2\phi) + p_{\gamma}^{Cir} p_{z} E \right) \]

- Linearly polarized photons \( \rightarrow \) beam asymmetry \( \Sigma \)
- Circularly polarized photons
- Longitud. polarized protons
- Linearly polarized photons
- Longitud. polarized protons \( \rightarrow \) double polarization asymmetry \( E \)
- Double polarization asymmetry \( G \)

**Crystal Barrel experiment at ELSA:** New preliminary results for \( G \) and \( E \)
Mainz Microtron MAMI: Electron Beam

Cascade of 3 Racetrack Microtrons
CW electron beam

**High Intensity** 140 μA
**High Resolution** <10^{-4}
**High Polarization** 80%
**High Reliability** 7000 h / year
Mainz Microtron MAMI: Electron Beam

Cascade of 3 Racetrack Microtrons
(MAMI, MAMI-A, MAMI-B)

MAMI B → MAMI C
Harmonic DoubleSided Microtron (HDSM)
0.885 GeV → 1.508 GeV
→ 1.604 GeV

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Mainz Microtron MAMI: Electron Beam

High resolution electron scattering experiments

3 spectrometers and KAOS

PbF2 Calorimeter (Parity viol.)

New
Mainz Microtron MAMI: Electron Beam

High intensity tagged photon beam

TAPS wall (BaF$_2$)  4$\pi$ - Detector Crystall Ball (NaI)  New Polarized frozen spin target (long. + transv.)
Upcoming Physics Program at MAMI

- Nucleon Formfactors
- Polarizabilities
- Baryon Spectroscopy (complete expt.s*)
- Hypernuclei*

- Measurement of $\sin^2\Theta_{\text{Weinberg}}$: electroweak precision test
- Hadronic light-by-light contribution to $(g-2)_\mu$*
- Search for light-mass Dark Matter (Dark sector)

*possible thanks to upgraded accelerator and/or instrumentation

Ulrich Wiedner / Madrid
DAFNE represents a unique opportunity to study in a complete way the kaon-nucleon/nuclei physics at low energy.
• SIDDHARTA Physics program will continue for next years
• LNF component ~ 16 researchers
The search for antikaon-mediated deeply bound nuclear states with AMADEUS

AMADEUS collaboration
116 scientists from 14 Countries and 34 Institutes
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EU funding in FP7- I3HP2: Network WP9 – LEANNIS
Strangeness physics with low energy antikaon-nucleon
COSY (COoler SYnchrotron)  FZ-Jülich

Running Program

- ANKE → Double Polarization
- TOF → Hyperons
  (PANDA Straw Tube Tracker)
- WASA → Fund. Symmetries
  (Pellet target, DISC-DIRC)
- PAX → Spin filtering
- Theory
COSY (COoler SYnchrotron)  FZ-Jülich

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\[ pd \rightarrow (pp)n \]
COSY (COoler SYnchrotron)  FZ-Jülich

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\[
\eta \rightarrow \pi^+ \pi^- e^+ e^- 
\]
COSY (COoler SYnchrotron)  FZ-Jülich

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COSY (COoler SYnchrotron)  FZ-Jülich

Accelerator Physics
- Absolute energy ($\delta \sqrt{s} < 50$ keV) Depol. Res.
- HESR stochastic cooling
- Barrier Bucket Cavity (→ thick targets)
- 2 MV Electron-Cooler
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Recommendations:

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2) Complete and exploit currently operating facilities

3) Continued support for theory
1) Lattice gauge theory calculations
1) Lattice gauge theory calculations

2) Effective field theories
Recommendations:

1) A speedy construction of the PANDA experiment at FAIR

2) Complete and exploit currently operating facilities

3) Continued support for theory

4) On the longer term: the upgrade of the HESR facility to a polarized proton-antiproton-collider or to a polarized electron-proton/ion collider
Polarized $\bar{p}$

**Accelerator Setup**

- **Antiproton Polarizer Ring (APR)**
- **Cooler Storage Ring (CSR)**
- **High Energy Synchrotron Ring (HESR)**

**Phase I:** Polarized Internal Target

**Phase II:** Asymmetric Antiproton-Proton Collider
idea: ENC@FAIR

- $L > 10^{32} \text{ 1/cm}^2\text{s}$
- $s^{1/2} > 10\text{GeV}$
- $(3.3\text{GeV} \, e^- \leftrightarrow 15\text{GeV} \, p)$
- polarised $e^-$ ($> 80\%$)
- $\leftrightarrow$
- polarised $p / d$ ($> 80\%$)
- (transversal + longitudinal)

using the PANDA detector

Common effort of
German Universities
(Bonn, Mainz, Dortmund)
plus collaboration with
Research Centres
FZJ, DESY, GSI, ...

Ulrich Wiedner / Madrid
Thank you for your attention!