Parallel Session E:
Low Energy Spin Physics with Lepton, Photon and Hadron Probes

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(Helmholtz Institute Mainz, Institute for Nuclear Physics, PRISMA cluster of excellence JG-University Mainz)

FERRARA - ITALY
10-14 SEPTEMBER, 2018
Strong force
Hydrogen Atom, (g-2)-factor, QED
How do Hadrons arise from QCD?

- Fundamental differences relative to QED
  - Self-interaction: highly nonlinear
  - Interaction increases at large distance: Confinement
  - Interaction decreases at small distance: Asymptotic freedom

QED

\[ e \quad e \]

QCD

\[ q \quad g \quad q \]
How do Hadrons arise from QCD?
„Lamb Shift in QCD“
QCD-Renormalisation à la QED

- origin of nucleon mass
- quark and gluon condensates
- structure of the nucleon -> Form Factor
Impact of Strong Interaction Investigations

- Hadron Structure
- Fundament. Symmetries
- Strongly Coupled Systems
- Hyper-Nuclei
- Quark Gluon Plasma
- Laboratory for fundamental symmetries
- Laboratory for astrophysics
- Hadronic structure as input to high energy frontier: Physics beyond the Standard Model
- Hadronic structure as input to precision frontier: Physics beyond The Standard Model
- Laboratory for fundamental Symmetries: Physics beyond The Standard Model
- Matter-Antimatter asymmetry
- Industrial, medical Applications
- Propagation of cosmic radiation
Impact of Strong Interaction Investigations

Hadronic structure as input to
high energy frontier: Physics beyond
the Standard Model

At low energy

Hadronic structure
as input to
precision frontier: Physics beyond
The Standard Model

Fundament. Symmetries

Nuclei

Strongly Coupled Systems

Hyper-Nuclei

Quark
Gluon
Plasma

Matter-Antimatter
asymmetry

Industrial, medical
Applications

Laboratory for fundamental
symmetries

Implications for astrophysics

Propagation of
cosmic radiation

Laboratory for fundamental
Symmetries: Physics beyond
The Standard Model
Higher Order QED/electro-weak Processes involving non-perturbative Objects

- Razvan-Daniel Bucoveanu: QED radiative corrections for PV electron scattering
- Misha Gorshteyn: Reduced hadronic uncertainty in $V_{ud}$ and CKM unitarity
- Boxing Gou: Transverse Single Spin Asymmetries, two photon exchange amplitude

Nonperturbative Observables at low energy:

- Eugene Chudakov: Measurement of the $J/\Psi$ photoproduction cross section close to threshold, LHCb Pentaquark
- Isabella Garzia: Baryon electromagnetic from factors at BES-III
- Paolo Pedroni: Extracting the scalar dynamical polarizabilities from real Compton scattering data
- S. Dymov: Measurement of the analyzing powers in pd elastic and pn quasi-elastic scattering at small angles at ANKE-COSY
- Kiyoshi Tanida: Prospects for the spin structure study of hyperons using heavy quark decays at Belle II
Higher Order QED/electro-weak Processes involving non-perturbative Objects
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- Boxing Gou: Transverse Single Spin Asymmetry from \( 2\) photon exchange amplitude

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QED radiative corrections for the P2 experiment

Spin 2018

Razvan-Daniel Bucoveanu

PRISMA Cluster of Excellence,
Institut für Physik,
Johannes Gutenberg-Universität Mainz

September 10, 2018
$\sin^2 \theta_W$ is scale dependent

$$
\sin^2 \hat{\theta}_W(Q)_{\overline{\text{MS}}} = \kappa(Q)_{\overline{\text{MS}}} \sin^2 \theta_W(M_Z)_{\overline{\text{MS}}}
$$

\[ 
\begin{array}{c}
\text{measurements} \\
\text{proposed}
\end{array}
\]

$\rightarrow$ The future P2 experiment at low momentum transfer will complement other high-precision determinations and may thus help to resolve differences between previous measurements, or find interesting new effects.
Shift in momentum transfer due to photon radiation

\[ Q^2 = -(l_1 - l_2)^2 \Rightarrow Q'^2 = -(l_1 - l_2 - k)^2 \]

\( Q'^2 \) can be on average much smaller than \( Q^2 \).

The average shift in momentum transfer squared due to hard-photon bremsstrahlung can be defined as

\[ \langle \Delta Q^2 \rangle = \frac{1}{\sigma} \int \frac{d^4 \sigma^{1\gamma}}{dE'd\theta_i dE_\gamma d\theta_\gamma} dE'd\theta_i dE_\gamma d\theta_\gamma \Delta Q^2, \]

with

\[ \Delta Q^2 = Q'^2 - Q^2, \]

\[ \sigma = \sigma^{1\gamma \text{loop}}_{E_\gamma < \Delta} + \sigma^{1\gamma}_{E_\gamma > \Delta}. \]
QED virtual corrections

$O(\alpha)$

$O(\alpha^2)$

$2$ + 2-loop

photon emitted from on-shell line
$\mathcal{O}(\alpha^2)$ QED corrections to the asymmetry \textbf{(P2 kinematics)}

\begin{align*}
\begin{array}{c}
E = 155 \text{ MeV} \\
E'_{\text{min}} = 45 \text{ MeV} \\
\theta_l = 35^\circ
\end{array}
\end{align*}

The shift in $Q^2$ is a kinematical effect included in $1\gamma$ radiation $\rightarrow$ very small $\mathcal{O}(\alpha^2)$ corrections to the asymmetry.
Reduced hadronic uncertainty in $V_{ud}$ and CKM unitarity

Misha Gorshteyn
Universität Mainz

Collaborators:
Chien-Yeh Seng (U. Shanghai -> U. Bonn)
Hiren Patel (U. Mass. -> UC Santa Cruz)
Michael Ramsey-Musolf (U. Mass.)

Reduced hadronic uncertainty in $V_{ud}$ and CKM unitarity

Misha Gorchtein  Universität Mainz

Motivation:
CKM unitarity - stringent test of SM&BSM

$$|V_{ud}|^2 + |V_{ud}'|^2 + |V_{ud}|^2 = 0.9994 \pm 0.0005$$

$V_{ud}$ is the main contributor to the unitarity test

$V_{ud}$ from $0^+ - 0^+$ nuclear decays:

$$|V_{ud}^{0^+ - 0^+}| = 0.97420 \pm 0.00010 \text{Exp} \pm 0.00018 \text{Rad. Corr.}$$

Exp.: Hardy, Towner (2017)

Goal: Reduce uncertainty in RC

Uncertainty - due to hadronic structure effects in $\gamma W$-box diagram

Lower blob:

$$\int dx e^{iqx} \langle p | T[J^\mu_{em}(x)J_W(0)] | n \rangle = \frac{i e^{\mu\nu\alpha\beta} p_\alpha q_\beta}{2(pq)} T_3^{(0)}(\nu, Q^2) + \ldots$$

Forward Compton amplitude $T_3^{(0)}$ - axial, isovector $W \times$ isoscalar $\gamma$

New method: obtain $T_3$ from a dispersion relation

$T_3$ - analytic function in the complex $\nu$-plane
Discontinuity along the real axis - on-shell hadronic states:
poles (single particle) + cuts (continuum)
related to an inclusive structure function

$$\text{Disc} T_3^{\gamma W}(\nu, Q^2) = 4\pi i F_3^{\gamma W}(\nu, Q^2)$$
New representation: an integral over first Nachtmann moment of $F_3^{W(0)}$

\[
\Delta V^A_{\gamma W} = \frac{3\alpha}{2\pi} \int_0^\infty \frac{dQ^2}{Q^2} M_3^{(0)}(1, Q^2) \frac{M_W^2}{M_W^2 + Q^2}
\]

Nachtmann moment:

\[
M_3^{(0)}(1, Q^2) = \frac{4}{3} \int_0^1 dx \frac{1 + 2\sqrt{1 + \frac{4M^2x^2}{Q^2}}}{(1 + \sqrt{1 + \frac{4M^2x^2}{Q^2}})^2} F_3^{W(0)}(x, Q^2)
\]

\[
x = \frac{Q^2}{2M\nu} = \frac{Q^2}{W^2 - M^2 + Q^2}
\]

Physics input:
account for leading contributions on the $W^2-Q^2$ diagram

\[
F_3^{(0)} = F_{\text{Born}} + \begin{cases} F_{\text{pQCD}}, & Q^2 \gtrsim 2 \text{ GeV}^2 \\ F_{\pi N} + F_{\text{res}} + F_{\text{R}}, & Q^2 \lesssim 2 \text{ GeV}^2 \end{cases}
\]

Relate to neutrino data by isospin symmetry

Fit $M_3$ data from $\nu$ scattering

Isospin rotate to obtain the integrand for $\Delta V^A_{\gamma W}$

New evaluation of RC; new extraction of $V_{ud}$

Old result: Marciano, Sirlin 2006

\[
|V_{ud}^{0+}0^+| = 0.97420(10^{\text{Exp}})(18^{\text{RC}})
\]

New result: arXiv: 1807.10197

\[
|V_{ud}^{0+}0^+| = 0.97366(10^{\text{Exp}})(10^{\text{RC}})
\]

Tension with CKM unitarity (4σ)

\[
|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9983(4)
\]

Possible explanations:
- Nuclear effects in $V_{ud}$ wrong?
- $V_{us}$ wrong?
- New Physics?
Transverse Single Spin Asymmetries in Electron Scattering on Hydrogen Targets

Boxing Gou

11.09.2018

Spin 2018, Ferrara
Two-photon exchange

\[ R(e^+p/e^-p) \Rightarrow Re(\tilde{F}_{1,2,3}) \]

Single Spin Asymmetry (SSA) \[ \Rightarrow Im(\tilde{F}_{1-5}) \]

\[ \mathcal{M}_{ep \rightarrow ep} = q_e q_p \mathcal{M}_y + q_e^2 q_p^2 \mathcal{M}_{2y} \]

\[ |\mathcal{M}_{ep \rightarrow ep}|^2 = q_e^2 q_p^2 \mathcal{M}_y + q_e^3 q_p^3 \mathcal{M}_y \mathcal{M}_{2y} \]

\[ \sigma_{e^-p} = \alpha^2 \mathcal{M}_y^2 - \alpha^3 \mathcal{M}_y Re(\mathcal{M}_{2y}) + \ldots \]

\[ \sigma_{e^+p} = \alpha^2 \mathcal{M}_y^2 + \alpha^3 \mathcal{M}_y Re(\mathcal{M}_{2y}) + \ldots \]

\[ \frac{\sigma_{e^+p}}{\sigma_{e^-p}} \approx 1 + 2\alpha \frac{Re(\mathcal{M}_{2y})}{\mathcal{M}_y} \]

Azimuthal asymmetry

\[ A_{exp} = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = A_\perp \frac{\vec{s} \cdot \vec{p}}{|\vec{s}||\vec{p}|} = -A_\perp \cos \varphi \]

\[ A_\perp \propto \frac{Im(\mathcal{M}_y^* \mathcal{M}_{2y})}{|\mathcal{M}_y|^2} \approx \alpha \cdot \frac{m_e}{B} \sim 10^{-5} - 10^{-6} \]


- VEPP-3@Novosibirsk
- CLAS@JLab
- OLYMPUS@DESY
- SAMPLE@MIT-Bates
- HAPPEX, G0, Q_{weak} @JLab
- A4@MAMI
• A systematic two-photon exchange program has been carried out at MAMI-A4.
• New results at forward angle are obtained at 5 energies from 300 MeV to 1.5 GeV.
Prospects for the spin structure study of hyperons using heavy quark decays at Belle II

Kiyoshi Tanida
(Advanced Science Research Center, Japan Atomic Energy Agency)

SPIN2018@Ferrara
Sep. 11, 2018
Λ(1405) case

- 3 quark (uds) vs 5 quark?
- Bound state of $\bar{K}N$?
- Double-pole structure?

Mysterious & interesting!

We can distinguish these cases
- If 3 quark state, $P \sim +0.3$
- If 5 quark state (or $\bar{K}N$ bound state), $P \sim 0$
- If there are two poles, $P$ may change with mass
Lattice calculation on $\Lambda(1405)$

$\Lambda(1405)$ spin is not carried by s-quark?

Measurement of the $J/\psi$ photoproduction cross section close to threshold

E.Chudakov$^1$

$^1$JLab, for GlueX collaboration

Presented at
23-rd International Spin Spin Symposium
SPIN2018, Ferrara, 10-14 Spetember 2018
Measurement of the $J/\psi$ photoproduction cross section close to threshold

*E. Chudakov (JLab) for the GlueX Collaboration*

**Measured:** $\sigma(E_\gamma)$ for $\gamma + p \rightarrow J/\psi + p$ at $8.22 < E_\gamma < 12$ GeV

1-st measurement in this energy range

**Motivation:** Production dynamics, Search for the LHCb Pentaquark

**LHCb Pentaquark $P_c \rightarrow J/\psi \ p$**

LHCb PRL, 115, 072001 (2015)

![Graph showing data points and theoretical predictions for $P_c$ decay]

**Predictions for $\gamma p \rightarrow P_c \rightarrow J/\psi \ p$**

*Graphical representation of $t$-channel and $s$-channel diagrams*

$M. Volo$oshin et al PRD 92, 031502 (2015)

$Q. Wang$ et al PRD 92, 034022 (2015)

$M. Karliner$ et al PL 752, 329 (2016)


$\sigma_{\gamma p \rightarrow J/\psi p}(E_{\text{peak}}) \propto \text{BR}(P_c \rightarrow J/\psi p)^2$
Measurement of the $J/\psi$ photoproduction

JLAB, Hall D Experiment GlueX

$\approx 70\%$ of 2016+2017 data sample

Preliminary results for $\gamma p \rightarrow J/\psi p$:
- $\sigma(E_\gamma)$ measured close to threshold
- The data are $\sim 3\sigma (\text{stat})$ below a model-predicted yield for $P_c(4450)^{5/2}^+, \text{BR}(J/\psi p) = 0.7%$
Baryon Electromagnetic Form Factor at BESIII

Isabella Garzia, INFN and University of Ferrara
On behalf of the BESIII Collaboration

September 10-14, 2018
FERRARA, ITALY
Proton Form Factors at BESIII

Three different approaches:
- Energy scan
- ISR-tagged analysis (Preliminary results)
- ISR-untagged analysis (Preliminary results)

Consistent results with BaBar (PRD88,072009; PRD87,092005)
- Competitive uncertainties
\[ \Lambda \text{ and } \Lambda_c \text{ Form Factors at BESIII} \]

- \( \Lambda : \text{PRD97, 032013(2018)} \)
  - \( e^+e^- \rightarrow \Lambda\Lambda \bar{\Lambda}, \Lambda \rightarrow p\pi^-, \Lambda\bar{\Lambda} \rightarrow p\pi^+ \) (\( \Lambda\bar{\Lambda} \rightarrow n\pi^0, \Lambda \rightarrow X \)) @ 2.2324, 2.4, 2.8 and 3.08 GeV
  - \( \Lambda_c \) @ 4 c.m. energies: 4.5745, 4.5800, 4.5900, 4.5995 GeV
  - No Coulomb effect for neutral baryons BUT unexpected rise at the threshold: it underlying a more complicated physics scenario

- \( \Lambda_c : \text{PRL120, 132001(2018)} \)

- \( \text{arXiv:1808.08917} \)

- \( J/\psi \rightarrow \Lambda\Lambda\bar{\Lambda}, \Lambda \rightarrow p\pi^-, \Lambda\bar{\Lambda} \rightarrow p\pi^+ \) and \( \Lambda\bar{\Lambda} \rightarrow n\pi^0 \)

From polarization measurement:
- \( \Delta \phi = (42.4 \pm 0.6 \pm 0.5)^\circ \)
- \( \alpha_- = 0.750 \pm 0.09 \pm 0.04 : 5\sigma \) deviation from the PDG value
Extracting the scalar dynamical polarizabilities from real Compton scattering data

Paolo Pedroni
INFN-Sezione di Pavia, Italy

In collaboration with B. Pasquini and S. Sconfietti - University and INFN - Pavia
Extracting the scalar dynamical polarizabilities from real Compton scattering data - 2 page summary

Expansion of the RCS Hamiltonian in incident photon energy ($\omega$)
6 constant parameters (static polarizabilities) connected to the internal nucleon structure
In the PWA framework dynamical polarizabiliites dependent on $\omega$ can be defined

For the 2 spin-independent polarizabilities $\alpha_{E1}$ $\beta_{M1}$ the connection between static and dynamic case can be written as

$$\alpha_{E1} = \lim_{\omega \to 0} \alpha_{E1-DYN}(\omega) ; \beta_{M1} = \lim_{\omega \to 0} \beta_{M1-DYN}(\omega)$$

In the Dispersion Relation framework and with a Low energy expansion ($\omega < 140$ MeV)

$$\alpha_{E1-DYN}^{DR}(\omega) = f_{\alpha}(\alpha_{E1}, \beta_{M1}, \alpha_{E1,\nu}, \beta_{M1,\nu}) + g_{\alpha}(\gamma_{i}) + h_{\alpha}(\text{any other term})$$

$$\beta_{M1-DYN}^{DR}(\omega) = f_{\beta}(\alpha_{E1}, \beta_{M1}, \alpha_{E1,\nu}, \beta_{M1,\nu}) + g_{\beta}(\gamma_{i}) + h_{\beta}(\text{any other term})$$

(up to $\omega^5$)

2 new additional parameters to be fitted
Calculated using measured values
Evaluated with DRs
Poor quality of the data set for the proton: only 150 points for $\omega < 140$ MeV; large statistic-and systematical- errors; possible inconsistencies between subsets.

Due to this poor quality the standard gradient fitting method can not converge (too low sensitivity to the parameters to be fitted)

A new fitting method: Combination of **SIMPLEX** method and **BOOTSTRAP** technique

(purely geometrical search) (Monte Carlo)

$\Rightarrow$ inclusions of systematic errors in the fit procedure

<table>
<thead>
<tr>
<th></th>
<th>150 points</th>
<th>55 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_{E_1}$ ($10^{-4} fm^3$)</td>
<td>13.3 ± 0.8</td>
<td>11.6 ± 1.1</td>
</tr>
<tr>
<td>$\alpha_{E_1,\nu}$ ($10^{-4} fm^3$)</td>
<td>-8.8 ± 2.5</td>
<td>-3.2 ± 3.1</td>
</tr>
<tr>
<td>$\beta_{M_1}$ ($10^{-4} fm^3$)</td>
<td>0.4 ± 0.9</td>
<td>2.2 ± 1.1</td>
</tr>
<tr>
<td>$\beta_{M_1,\nu}$ ($10^{-4} fm^3$)</td>
<td>10.8 ± 2.8</td>
<td>5.1 ± 3.7</td>
</tr>
</tbody>
</table>

Very low sensitivity of the data to $\alpha_{E_1,\nu}$

Measurement of the analyzing powers in pd elastic and pn quasi-elastic scattering at small angles at ANKE-COSY

S. Dymov
(Ferrara University, Italy, JINR, Dubna, Russia)

11 September 2018 SPIN 2018, Ferrara
Experiment: ANKE at COSY

Polarized proton beam: $T_p = 0.8, 1.6, 1.8, 2.0, 2.2, 2.4$ GeV,

Beam polarization: Py~$50\%$, spin flipped every cycle (5 min)

$D_2$ cluster jet target: $d = 5 \cdot 10^{14}$ cm$^2$

Polarimetry: EDDA detector

Forward detector (FD):
fast proton @ 0-15$^\circ$

Silicon Tracking Telescope (STT):
low energy proton (spectator)
($5^\circ < \Theta_{cm} < 30^\circ$)

Triggers:
- Self-triggering STT L2
- FD*STT coincidence

Ideal for small angle elastic scattering studies

S.Dymov
Measurement of the analyzing powers in pd elastic and pn quasi-elastic scattering at small angles
Analyzing power in pn quasi-free elastic (3): Results at 1600 and 2200 MeV

SAID SP07:

Based on data < 1.5 GeV, fails at $T_p = 1.6$-2.4 GeV

SAID AD14:

Includes WASA data at ~1.1 GeV (Adlarson, PRL 112, 202301 (2014))
Expected to work only up to 1.5 GeV,
But fits ANKE data at 1.6 GeV

$A_y^p$ decreasing with energy same as in pd-elastic
• Low energy spin physics with electromagnetic and hadronic probes
• Very active field, done at low and high energy accelerator facilities
• Strong interaction theory at low energy: substantial progress

• Strong interaction: input, impact and overlap on high precision observables for beyond standard model physics

• Thanks to all speakers for providing slides in advance