Search for dark photon
and for exotic hadronic matter

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55 Cracow School of Theoretical Physics
Zakopane, June 27, 2015
Search for dark photon and for exotic hadronic matter

- dark photon
- mesic-nuclei
- discovery of dibaryon
Princess Elisabeth of Bohemia writes on 10.vi.1643:

„…I don’t see how the idea that you used to have about weight can guide us to the idea we need in order to judge how the (nonextended and immaterial) soul can move the body”

Descartes writes on 28.vi.1643:

„…I ought to have made clear that although one may wish to think of the soul as material (…), that wouldn’t stop one from realizing that the soul is separable from the body. I think that those cover everything that you asked me to do in your letter.”
CHANDRA SATELLITE

Particle physics four centuries later: How the "non-SM dark matter" can move the "SM matter".

chandra.harvard.edu
\[ \gamma^* \rightarrow \text{U} \]

\[ \pi \rightarrow \gamma \rightarrow \text{U} \rightarrow e^- e^+ \]

\[ \approx \ldots \varepsilon^2 \ldots \]
WASA-at-COSY

$10^9 \eta$ and $10^{11} \pi^0$

mesons on discs
WASA

A WARSHIP built for the war with Poland which sank in 1628 in the middle of Stockholm harbour after sailing barely 1300 meters
WASA-at-COSY

\[ \text{pp} \rightarrow \text{pp } \eta \]

\[ \text{pd} \rightarrow ^3\text{He } \eta \]
DAΦNE $e^+e^-$ collider Frascati (Rome)

- $e^+e^- \rightarrow \phi \quad \sqrt{s} \sim m_\phi = 1019.4$ MeV

**BR’s for selected $\phi$ decays**

<table>
<thead>
<tr>
<th>Decay</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+K^-$</td>
<td>49.1%</td>
</tr>
<tr>
<td>$K_SK_L$</td>
<td>34.1%</td>
</tr>
<tr>
<td>$\rho\pi^+\pi^-\pi^0$</td>
<td>15.5%</td>
</tr>
<tr>
<td>$\eta\gamma$</td>
<td>1.3%</td>
</tr>
<tr>
<td>$\eta'\gamma$</td>
<td>0.006%</td>
</tr>
</tbody>
</table>

KLOE Detector

KLOE completed data taking in 2005 with 2.5 fb$^{-1}$ corresponding to $\sim 8 \times 10^9 \phi$, $\sim 10^8 \eta$ and $\sim 5 \times 10^5 \eta'$.
KLOE

KLOng Experiment

Drift chamber
Gas: 90% He + 10% C

\[ \delta p / p < 0.4\% \quad (\theta > 45^\circ) \]

\[ \sigma_{xy} \approx 150 \mu m; \quad \sigma_z \approx 2 mm \]

EM calorimeter
lead/scintillating fibers
98% solid angle coverage

\[ \sigma E / E = 5.7\% / \sqrt{E (GeV)} \]
\[ \sigma_t = 55 ps / \sqrt{E (GeV)} \oplus 100 ps \]

PID capabilities

Magnetic field
0.52 Tesla

7 m

6 m
WASA-at-COSY

$10^9 \eta$ and $10^{11} \pi^0$

KLOE
completed data taking with 2.5 fb$^{-1}$

$\sim 8 \cdot 10^9 \phi$, $\sim 10^8 \eta$, $\sim 5 \cdot 10^5 \eta'$
\[ \gamma^* + U \rightarrow \pi^+ + \pi^- \]

\[ \text{\(\sim \ldots \varepsilon^2 \ldots\)} \]
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Kenta Itahashi, RIKEN
From talk at Symposium in Cracow 2013
THE ETA-MESIC NUCLEUS

η meson bound with nucleus via STRONG INTERACTION

G. A, Sokol et al., arXiv:nucl-ex/0106005

Talk by Wojciech Krzemień at this conference...

COSY, J-PARC, MAMI, GSI, LPI/JINR
THE ETA-MESIC NUCLEUS

$\eta$ meson bound with nucleus via STRONG INTERACTION
pd $\rightarrow ^3\text{He} \; \pi \; \eta$
• \( dp \to ^3\text{He}\eta \)

\[ \eta - ^3\text{He} \]


**MAMI:**
THE ETA-MESIC NUCLEUS

η meson bound with nucleus via STRONG INTERACTION

COSY, J-PARC, MAMI, GSI, LPI/JINR
WASA at COSY

- Cold head
- Liquid jet nozzle
- Droplet chamber
- Vacuum injection
- Skimmer
- Ion beam
- Pellet dump

EM Calorimeter

Thin Plastic Scintillators

Range Hodoscope

TOF Detector

He H₂

400 mbar

20 mbar

1·10⁻³

1·10⁻⁶
\[
\begin{align*}
\text{d} + \text{d} & \rightarrow ({}^4\text{He}-\text{n})_{\text{bound}} \rightarrow {}^3\text{He} + \text{p} + \pi^- \\
\text{d} + \text{d} & \rightarrow {}^3\text{He} + \text{p} + \pi^-
\end{align*}
\]

Upper limit of about 25 nb
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MATTER

Meson

Baryon

1947 Powell in Cracow
1950 Powell <-- Nobel Prize
~1960 Quark Model
MATTER

Meson

Baryon

Tetraquark

Pentaquark

Dibaryon

Z(4430)

Belle 2008; LHCb 2014
Double pionic fusion - a new resonance?

Cross section for $pn \rightarrow d\pi^0\pi^0$

Double pionic fusion - a new resonance

Cross section for $pn \rightarrow d\pi^0\pi^0$

$\Gamma_{d^*} = 70 \text{ MeV} \ll \Gamma_{\Delta\Delta} = 240 \text{ MeV}$

$\Gamma \sim 70 \text{ MeV}$


$pn \rightarrow \Delta\Delta \rightarrow d\pi^0\pi^0$ ; $pn \rightarrow NN^* \rightarrow d\pi^0\pi^0$

$pn \rightarrow \textbf{dibaryon} \rightarrow \Delta\Delta \rightarrow d\pi^0\pi^0$
Double pionic fusion - a new resonance?

Cross section for \( pn \to d\pi^0\pi^0 \)

\[
\sigma(\Theta) = \sum_{l=0}^{J} D_{2l} P_{2l}(\Theta)
\]


\( I = 0; \ J^P = 3^+ \)

Double pionic fusion - a new resonance

Cross section for $\text{pn} \rightarrow d\pi^0\pi^0$

$\Gamma_{d^*} = 70 \text{ MeV} \ll \Gamma_{\Delta\Delta} = 240 \text{ MeV}$

$\sqrt{s}$ [GeV]

$\Gamma \sim 70 \text{ MeV}$


$I = 0; \; J^P = 3^+$

The decay modes of the dibaryon

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<tr>
<th>Channel</th>
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| \( d \, \pi^0\pi^0 \) | P. Adlarson et. al. Phys. Rev. Lett. 106 (2011) 242302  
| \( d \, \pi^+\pi^- \) | P. Adlarson et. al Phys. Lett. B721 (2013) 229-236 |
| \( d \, \pi^+\pi^0 \) | P. Adlarson et. al Phys. Lett. B721 (2013) 229-236 |
| \( pp\pi^0\pi^- \) | P. Adlarson et. al Phys. Rev. C 88 (2013) 055208 |
| \( np\pi^0\pi^0 \) | P. Adlarson et al., Phys. Lett. B743 (2015) 325-332 |
| \( ^3\text{He} \, \pi\pi \) | P. Adlarson et al., Phys. Rev. C91 (2015) 015201 |
| \( ^4\text{He} \, \pi\pi \) | P. Adlarson et. al. Phys. Rev. C86 (2012) 032201 |
|               | .....                                              |
\[
\sigma[pn \to d\pi^+\pi^-] = \frac{1}{2} \sigma[pp \to d\pi^+\pi^0] + 2\sigma[pn \to d\pi^0\pi^0]
\]

\[I=1\]

\[I=0\]
The decay modes of the dibaryon

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| .... |
$A_y$ energy dependence at $83^\circ_{cm}$

\[ \Theta_n = 83 \text{ deg} \]

\[ \vec{n}p \rightarrow d^* \rightarrow pn \]

Deuteron to Deltaron

\[ I(J^p) = 0(1^+) \quad \text{Threshold} \quad I(J^p) = 0(3^+) \]

Deuteron

\[ 2.2 \text{ MeV} \]

\[ \Delta \Delta \]

\[ d^* \]

\[ 80 \text{ MeV} \]

M. Bashkanov, Jagiellonian Symposium, 2015
Deltaron vs Hexaquark

$\Delta L = 0$

$0.9 \text{ fm}$

$0.9 \text{ fm}$

$1.2 \text{ fm}$

$L = 2$

Approximately 5% of $\Delta \Delta$ configuration

Approximately 33%

Approximately 66%

F. Huang et al, arXiv:1408.0458

M. Bashkanov, Jagiellonian Symposium, 2015
MATTER

Meson

Baryon

Tetraquark

Dibaryon

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discovery of dibaryons
THANK YOU FOR YOUR ATTENTION