Evidence for new Nucleon resonance $N^*(1685)$: Review of available results and forthcoming experiments

Viacheslav Kuznetsov

PNPI, April 2013
In memoriam of Mitya Diakonov
Outline:
- Introduction. Two pictures of the nucleon;
- Some remark on the evidence/non-evidence for $\Theta^+$;
- "Neutron anomaly" in $\eta$ photoproduction on the neutron;
- Evidence for resonant structure at $W\sim1.685$ GeV in other reactions;
  - Partial Wave analyses;
  - Alternative explanations: Discussion of validity;
  - Properties of $N^*(1685)$;
- Current and future activities
  i) Photon facilities (GRAAL, CBELSA/TAPS, MaM1iC, BGO-OD);
  ii) High-resolution TOF detector for neutrons and charged particles;
  iii) Possible measurements at PNPI and EPECUR;
- Conclusions.
Gell Mann (1955-1964) - baryons are (qqq) systems, mesons are (q̅q)

<table>
<thead>
<tr>
<th>Quark Flavor</th>
<th>Charge (Q)</th>
<th>Baryon number</th>
<th>Strangeness (S)</th>
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<tbody>
<tr>
<td>u</td>
<td>+2/3</td>
<td>+1/3</td>
<td>0</td>
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<tr>
<td>d</td>
<td>−1/3</td>
<td>+1/3</td>
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<td>s</td>
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<td>u</td>
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<td>s</td>
<td>+1/3</td>
<td>−1/3</td>
<td>−1</td>
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</table>

\[ p = uu, \quad n = ud, \quad d = ud, \quad u = uu, \quad K^+ = s \bar{s} u, \quad K^- = s \bar{u} \]
Problem: the mass of the nucleon (3 quarks) is ~940 MeV, the mass of \( \pi^0 \) (2 quarks) is ~135 MeV. Solution: the quark masses inside baryons are dynamical - three effective (constituent) quarks with the masses ~ 200 – 350 MeV → **Constituent Quark Model.**
Higher-lying multiplies ([10,1/2-],[8,1/2-],[10,1/2-] etc) describe the spectrum of baryon resonances. In 70-90\textsuperscript{th} part of these resonances was found in experiment.

``...Quark model is the most successful tool for the classification and interpretation of hadrons spectrum.” (R.Jaffe)

Unresolved question: CQM also suggests the existence of qqqq~q (pentaquarks), qqqq~q q~q (septaquarks) etc. baryons.

Bag models [R.L. Jaffe ‘77, J. De Swart ‘80]

Jp =1/2- lightest pentaquark

Masses higher than 1700 MeV, width ~ hundreds MeV

Mass of the pentaquark is roughly $5 \ M +$(strangeness) ~ 1800 MeV

An additional q -anti-q pair is added as constituent

For decades experimentalists were searching for such pentaquarks, with no results. Why?
Problem of "Missing" Resonances

CQM predicts rich spectrum of baryons resonances.

Baryon Summary Table

<table>
<thead>
<tr>
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<tr>
<td>n</td>
<td>f</td>
<td>p</td>
<td>d</td>
<td>s</td>
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<tr>
<td>M(1440)</td>
<td>f1</td>
<td>p1</td>
<td>d2</td>
<td>s1</td>
<td>u1</td>
</tr>
<tr>
<td>M(1520)</td>
<td>p1</td>
<td>p1</td>
<td>d3</td>
<td>s1</td>
<td>u1</td>
</tr>
<tr>
<td>M(1550)</td>
<td>s1</td>
<td>p1</td>
<td>d3</td>
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<td>M(1650)</td>
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<td>p1</td>
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<td>p1</td>
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<td>M(1720)</td>
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<td>M(1750)</td>
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<td>p1</td>
<td>d3</td>
<td>s1</td>
<td>u1</td>
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<tr>
<td>M(1800)</td>
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<td>p1</td>
<td>d3</td>
<td>s1</td>
<td>u1</td>
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<tr>
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<td>d3</td>
<td>s1</td>
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<td>p1</td>
<td>d3</td>
<td>s1</td>
<td>u1</td>
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<td>p1</td>
<td>d3</td>
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<td>d3</td>
<td>s1</td>
<td>u1</td>
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<td>p1</td>
<td>d3</td>
<td>s1</td>
<td>u1</td>
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<td>p1</td>
<td>d3</td>
<td>s1</td>
<td>u1</td>
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<tr>
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<td>p1</td>
<td>d3</td>
<td>s1</td>
<td>u1</td>
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<tr>
<td>M(2250)</td>
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<td>d3</td>
<td>s1</td>
<td>u1</td>
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<td>M(2600)</td>
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<td>d3</td>
<td>s1</td>
<td>u1</td>
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<td>f1</td>
<td>p1</td>
<td>d3</td>
<td>s1</td>
<td>u1</td>
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Despite of the availability of modern precise polarized data, only a half of CQM-predicted resonances is now established in experiment, especially above 1.8 GeV.

Furthermore, some well-known resonances seem to disappear!
Chiral Soliton Model (χQM) - complementary description of the nucleon (baryons)

Baryons are excitations of the same object - soliton in the chiral field

D.Diakonov, V. Petrov, M.V.P., "Exotic Antidecuplet of baryons"
Further development

**Mean-Field Approach (MFA)**

Based on the papers

- D. Diakonov, "Baryons resonances in the mean-field approach and the simple explanation of Θ+ pentaquark", Arxiv:0812.3418
- D. Diakonov, "Prediction of New charmed and bottom exotics pentaquarks", Arxiv:1003.2157
- D. Diakonov, V. Petrov, and A. Vladimirov, "Baryon resonances at large $N_c$, or Quark Nuclear Physics", Arxiv:1207.3679
Baryons are multiquark systems stored in the mean field

Proton and Neutron

Charmed and Bottom baryons

Baryon Resonances

Pentaquarks - specific transitions
MFA predicts the same octet and decuplet of known baryons. It also predicts baryons resonances from the PDG Tables. Neither of resonances remain unaccounted for, and no additional resonances is predicted except only one $\Delta(3/2^+)$" (citation from D. Diakonov, V. Petrov, and A. Vladimirov, "Baryon resonances at large $N_c$, or Quark Nuclear Physics", Arxiv:1207.3679 )

Solution of the problem of "Missing Resonances"
As byproduct, this approach predicts the existence of long-lived narrow exotic states (pentaquarks)
Search for exotic states might critical!

Some remarks
on the evidence / non-evidence for $\Theta^+$
Some remarks on the recent (non)observation of $\Theta^+(1540)$

In 2002 - 2004 12 groups published the evidence for a narrow $S=+1$ baryon (plus ~12 preliminary results) which was attributed to the lightest member of the exotic antidecuplet $\Theta^+(1540)$.

In 2005 - 2007 there were generous negative reports on the search for this particle. Some groups (CLAS, COSY) did not confirm their previous positive results in high-statistics experiments.
**RECENT RESULTS**


LEPS (T. Nakano et al, nucl-ex/0812.1035)

SVD-2 (A. Aleev et al., Nucl-ex/0803.3313)

LEPSII (M. Niiyama et al., Nucl. Phys. A (in press))
Observation of anomaly near $W\sim 1.685$ GeV

M. Polyakov and A. Rathke
``On photoexcitation of baryon antidecuplet''

``...qualitative feature (of the second member of the antidecuplet, the P11) ...
  dominance of photoexcitation from the neutron target''.
``...antidecuplet ``friendly'' photoreactions...

$\gamma n \rightarrow K^+ \Lambda, \ \gamma n \rightarrow \eta n, \ \gamma n \rightarrow \gamma n$

In these channels the antidecuplet part of the nucleon resonances should be especially enhanced, whereas in the analogous channels with the proton target the anti-10 component is relatively suppressed....''
η Photoproduction off the neutron

\[ \gamma n \rightarrow \eta n \]
History: First results on $\gamma n \rightarrow \eta n$ from GRAAL

2002

Unexpected sharp rise of the ratio of the cross sections of the neutron and on the proton $\sigma_n/\sigma_p$ at $E_\gamma \approx 1$ GeV.

2004

Narrow bump at $W \approx 1.68$ GeV $\gamma n \rightarrow \eta n$ which is not seen in $\gamma p \rightarrow \eta p$.

Peak structure at $W \approx 1.68$ GeV, V. Kuznetsov et al., NSTAR2004, Grenoble, March 2004.

Sharp rise in the ratio of $\sigma_n/\sigma_p$.

V. Kuznetsov et al., NSTAR2002, Pittsburgh, October 2002.
Narrow bump-like structure at $W=1.68$ GeV in quasi-free $\eta$ photoproduction on the neutron at GRAAL


\[ \gamma + n \rightarrow \eta + n \]

Simulated signal of a narrow ($\Gamma=10$ MeV) resonance

The width of the peak in the quasi-free cross section is close to that expected due to Fermi motion of the target neutron. The width of the peak in $M(\eta,n)$ (40 MeV FWHM) is close to the instrumental resolution!
\[ \gamma n \rightarrow \eta n: \text{ Confirmation from other groups} \]

CBELSA/TAPS, J. Jeagle et al, PRL 100, 252002 (2008)


A2@Mainz, R. Wertmuller et al., Chin. Phys. C 33, 1345

CBELSA/TAPS, J. Jeagle et al, EPJA 47, 89 (2011)

Pronounced structure at \( W \sim 1.68 \) GeV which is not (or poorly) seen in the eta photoproduction on the proton
Quasi-free reactions: The nucleon bound in a deuteron target, is not at rest → Experimental cross section is smeared by Fermi motion

The width of the bump in the quasi-free cross section is close to that expected for a narrow resonance smeared by Fermi motion.

The invariant mass of the final-state $\eta$ and the neutron is not affected by Fermi motion. The width of the peaks in the invariant-mass spectra are close to the instrumental resolution (40 MeV at GRAAL and 60 MeV at CBELSA/TAPS).
Really narrow structure!
The effect of Fermi motion of the target neutron is reduced.

$\Gamma \leq 30$ MeV

$\Gamma \sim 25$ MeV
Do we see a new resonance?

- Ya.Azimov, V.Kuznetsov, M.Polyakov, and I.Strakovsky, EPJA 25, 325(2005);
- and others....

CBELSA/TAPS $\gamma n \rightarrow \eta n$

Graal $\gamma n \rightarrow \eta n$

New $N^*$?

LNS-Sendai $\gamma n \rightarrow \eta n$
INTERPRETATIONS OF THIS STRUCTURE AS NEW NARROW RESONANCE

• G. S. Yang, H. S. Kim, Arxiv:1204.5644

FIG. 2: The differential cross sections as functions of the total energy in the center of mass (CM) energy frame. We depict them in different targets [neutrons at left column and protons at right one], parities of \( N^\pi \) (positive at upper two panels and negative at lower two ones). The four curves in each panel indicate \( \mu_{N\pi N} = 0.0, 0.1, 0.2, 0.3 \mu_N \). The experimental data are taken from Ref. [20].
Photoproduction off the free proton

\[ \gamma p \rightarrow \eta p \]

If photoexcitation of any resonance occurs on the neutron, its signal should also be seen on the proton even if it suppressed by any reason.
\[ \gamma p \rightarrow \eta p \]
cross section

A structure near \( W = 1.68 \text{ GeV} \) is poorly seen in the eta photoproduction cross section on the free proton.

\[ \rightarrow N(1685) \text{ photoexcitation on the proton (if exists) is suppressed} \]

New high-resolution data from A2@MaMIC
arXiv:1007.0777 [nucl-ex]
Small dip structure at \( W \sim 1.67 \text{ GeV} \) at forward angles
Do we really see a narrow $N(1685)$ resonance?
Test with beam asymmetry data

If photoexcitation of any resonance occurs on the neutron, it should also occur on the proton, even being suppressed by any reasons.

The signal of a weakly photoexcited resonance may not be seen in the cross section on the proton because of the $S11(1535)$ dominance, but it should appear in polarization observables. On the contrary, interference of known resonances would not generate any structure on the proton.
Helicity amplitudes for pseudoscalar meson photoproduction \( \gamma N \rightarrow MN \) and the role of polarization observables

Photon polarization: \( \Sigma = (\sigma_\| - \sigma_\perp) / (\sigma_\| + \sigma_\perp) \)

Target polarization: \( T = (\sigma_\| - \sigma_\perp) / (\sigma_\| + \sigma_\perp) \)

Reaction plane: \( P = (\sigma_\| - \sigma_\perp) / (\sigma_\| + \sigma_\perp) \)

Helicity amplitudes:
\[
\sigma \sim |H_{\uparrow\uparrow}|^2 + |H_{\downarrow\downarrow}|^2 + |H_{\downarrow\uparrow}|^2 + |H_{\uparrow\downarrow}|^2
\]

\[
\Sigma \sim \text{Re}\{H_{\uparrow\uparrow}H^{\ast}_{\downarrow\downarrow} - H_{\downarrow\uparrow}H^{\ast}_{\uparrow\downarrow}\}
\]

\[
T \sim \text{Im}\{H_{\uparrow\downarrow}H^{\ast}_{\downarrow\uparrow} + H_{\downarrow\downarrow}H^{\ast}_{\uparrow\downarrow}\}
\]

\[
P \sim \text{Im}\{H_{\uparrow\uparrow}H^{\ast}_{\downarrow\downarrow} + H_{\downarrow\downarrow}H^{\ast}_{\uparrow\downarrow}\}
\]

Any weakly photoexcited \( N^* \) resonance may not be seen in the \( \eta \) cross section, but may appear in polarization observables through its interference with \( S11(1535) \).
GRAAL beam asymmetry for eta photoproduction on free proton with fine energy binning.

V. Kuznetsov, M.V.P., et al., hep-ex/0703003
V. Kuznetsov, M.V.P., JETP Lett., 88 (2008) 347

Well pronounced structure at $W=1.685$ GeV

Fit: smooth SAID multipoles
+ a narrow resonance

Blue - SAID only
Magenta - SAID + narrow P11(1688)
Green - SAID + narrow P13(1688)
Red - SAID + narrow D13(1688)

$M=1.685\pm10$ GeV, $\Gamma \leq 30$ MeV
Compilation of recent CBTAPS/ELSA ($\gamma n \rightarrow \eta n$) and A2@MaMiC ($\gamma p \rightarrow \eta p$) data (Logarithmic scale)

Beam asymmetry from GRAAL on the free proton: the structure at the same position as in the cross section.

- ‘peak’ in neutron cross section related to ‘dip’ in proton cross sections (？) only ‘dip’ reproduced by MAID!
Bonn-Gatchina PWA of new MAMI data
``Search for Narrow Nucleon Resonance in γp→ηp.”
A. V. Anisovich, E. Klempt, V. Kuznetsov, V. A. Nikonov, M. V. Polyakov,

Standard PWA shows a systematic deviation from the data in the mass interval of 1650-1750 MeV.

The description of the data can be improved significantly assuming the existence of a narrow resonance at about 1700 MeV, the width 30-40 MeV, and with small photo-coupling to the proton.
Compton scattering and $\pi^0$ photoproduction on the neutron (GRAAL)

$\gamma n \rightarrow \gamma n$  $\gamma n \rightarrow \pi^0 n$

V. Kuznetsov et al., PRC 83, 022201, 2011

Compton scattering: Peak structure at 1.685 GeV

$\gamma n \rightarrow \pi^0 n$: Flat cross section at 800 - 1300 MeV
Preliminary EPECUR data

$\pi^{-} p \rightarrow \pi^{-} p$

I. Alexeev et al., Arxiv 1204.6433

and Anatoly Gridnev, Private Communication

Green lines are from SAID. Red lines are calculations by A. Gridnev with two narrow resonances (M1 = 1.685 GeV and M2 = 1.72 GeV).

Well pronounced structure at W~1.685 GeV!
Additional structure at W~1.72 GeV?
... given our present knowledge of the $\Theta^+$, the state commonly known as the N(1710) is not the appropriate candidate to be a member of the antidecuplet. Instead we suggest candidates with nearby masses, N(1680) (more promising) and/or N(1730) (less promising, but not excluded). Our analysis suggests that the appropriate state should be rather narrow and very inelastic…


**ALTERNATIVE INTERPRETATIONS**

Interference of $S_{11}(1650)$ and $P_{11}(1710)$.

V. Shklyar, H. Lenske, U. Mosel, PLB650 (2007) 172 (Giessen group)

Interference effects of $S_{11}(1535)$ and $S_{11}(1650)$.

A. Anisovich et al. EPJA 41, 13 (2009), hep-ph/0809.3340 (Bonn-Gatchina group); X.-H. Zong and Q. Zhao, Arxiv:1106.2892

Intermediate sub-threshold meson-nucleon state


Fits of CBTAPS/ELSA $\gamma n \rightarrow n n$ data ONLY!

04/27/13

→ To be discussed
The structure in calculations seem to be wider than that experimental observations from GRAAL and CBTAPS-ELSA despite the latter are dominated by instrumental resolutions!
- The explanation of the bump in the $\gamma n \rightarrow \eta n$ cross section in terms of the interference of well-known resonances seem to be challenged
- by the narrow width of the structure,
- by the observation of the structures in the $\gamma p \rightarrow \eta p$ data;
- by the observation in Compton scattering on the neutron, elastic pion scattering, and no evidence in $\pi^0$ photoproduction. These reactions
  i) receive the contribution of resonances different from $\eta$ photoproduction;
  ii) If the structure is generated, it should be seen in all these reactions.
Question:
-Could the same effect occur in Compton scattering and do not occur in pion photoproduction?
Maxim Polyakov, Private Communication.

Explanation of the peak in $\gamma n \rightarrow \eta n$ due to cusp effect (Doring, Nakayama) implies very strong violation of flavour SU(3) symmetry as well as very strong violation of chiral symmetry.

Publication in Preparation.
At present, the only explanation that accommodates all experimental findings is the existence of a narrow N(1685) resonance.
Properties of tentative \( N(1685) \)
- \( M = 1685 \pm 10 \text{ MeV} \)
- \( \Gamma \leq 30 \text{ MeV} \)
- Isospin \( \frac{1}{2} \)
- \( S = 0 \)
- Strong photoexcitation on the neutron and suppressed (~100 times) photoexcitation on the proton

The existence of a resonance with such properties was not predicted by the conventional CQM!

Expected properties of the second member of the \( \chi\text{QM} \) antidecuplet [10,1/2-]

- \( M = 1650 - 1690 \text{ MeV} \)
- \( \Gamma \leq 30 \text{ MeV} \)
- Isospin \( \frac{1}{2} \)
- \( S = 0 \)
- Strong photoexcitation on the neutron and suppressed (~100 times) photoexcitation on the proton
- Quantum numbers P11
Further tasks:
- To determine quantum numbers;
- To determine the width.

New measurements at photon facilities (GRAAL, CBTAPS/ELSA, MaMiC, BGO-OD);
Detectors

**GRAAL**

**CBELSA/TAPS**

**TAPS**

**MaMiC**

**BGO-OD**
The detectors are similar.
Specific features:

- **GRAAL** - highly polarized (up to 98%) beam up to 1.5 GeV, detection of neutrons:
- **CBELSA/TAPS** - bremsstrahlung beam up to 3 GeV, polarized target;
- **MaMiC** - bremsstrahlung beam up to 1.5 GeV, polarized target, high-resolution tagger;
- **BGO-OD** (not yet in operation) - bremsstrahlung beam up to 3 GeV, high-resolution detection of charged particles due to magnetic spectrometer;
Expected results:
- High-precision single-polarization data;
- Search for N*(1685) in "production" reactions like $\gamma N \rightarrow \pi N^* (1685) \rightarrow \pi \eta N$;
- Double-polarization data

**double polarization obs. for $\gamma n \rightarrow n\eta$ (very preliminary)**

- MAMI: data taken for $T$ and $F$ (transversely pol. target, circularly pol. beam)
- ELSA: data taken for $E$ (longitudinally pol. target, circularly pol. beam)

- very preliminary results for helicity components $\sigma_{1/2}, \sigma_{3/2}$: enhancement in neutron cross section only in $\sigma_{1/2}$ component, if related to nucleon resonances $S_{11}, P_{11}$-states
- more statistics needed; also data for $2\pi^0, \eta'$ available
GRAAL - unique facility to measure beam asymmetry $\Sigma$

A lot of data have been collected, checked, calibrated and .... not yet analyzed. These data are now available at PNPI.

Their analysis is set in progress in collaboration with the former GRAAL collaborators (University of Catania, Rome, Torino) and Ruhr University of Bochum (Maxim Polyakov).

First Preliminary results on beam asymmetry for Compton scattering on the proton
Personal remark on BGO-OD

Possibility to measure
\[ \gamma n \rightarrow K^- \Theta^+ \rightarrow K^- K^+ n \]

A relevant proposal could be discussed…
New Time-of-Flight detector for neutrons and charged particles

One problem for all the mentioned detectors is poor resolution for neutrons. The only detectors that provides the reconstruction of neutron momentum is the ``Russian Wall” at GRAAL (TOF resolution ~ 300 ps).

Possibly the forward walls at BGO-OD will provide the same option.
GRAAL forward lead-scintillator wall (``Russian Wall")

V.Kouznetsoy et al., NIM A 487 (2002) 396.

An assembly of 16 modules. Each module is a sandwich of four 3000x40 mm$^2$ bars with 3 mm thick lead plates between them. A 25 mm thick steel plate at the front of the module acts as a main converter and as a module support.
Time-of-Flight Resolution of scintillator counters

\[
\sigma_t = \sqrt{\frac{\sigma_{sci}^2 + \sigma_{pmt}^2 + \sigma_{pl}^2}{N_{pe}}} + \sigma_{el}^2
\]

- Strongly depends on the length of scintillator bars and light guides
- Depends on the light attenuation and the light collections
- PM TTS ~ 0.4 ns
  Depends on the PM size
- The shorter and smaller scintillator bars, the better is the TOF resolution!
Test of prototype counters for the CLAS12 Central Time-of-Flight System using minimum-ionizing cosmic-ray muons

TOF resolution of a counter made of BC-408 66x3x3 cm³ scintillator bar and fine-mesh Hamamatsu R7761-70 PM for minimum-ionizing particles

\[ \sigma_{\text{TOF}} \approx 33 - 37 \text{ ps} (!) \]
Detector Design

Four separate layers each made of 16 counters covering altogether an active area of 80x80 cm. Veto counter at the front.
Single counter will be a 45x45x1000 mm³ scintillator bar viewed by two FEU-36 PMs

Anode pulse rise time $\sim 3$ ns

Expected TOF resolutions:
$\sim 50$ ps for MIP particles,
50 - 150 ps for neutron
(depending on the threshold)

All components for one layer are available in LMP.
Measurement of TOF resolution
Cosmic-ray tracking
Basic Idea.

Cosmic ray tracking

- We make use of three counters equipped with six identical PMTs. The counters are aligned horizontally and are stacked parallel at equal distance each from the other. The times of scintillations caused by a cosmic-ray muon crossing all three counters (top, middle, and bottom respectively), are defined as:

\[
\begin{align*}
  t_{\text{top}} &= (t_{\text{top}1} + t_{\text{top}2}) / 2 + C_1 \\
  t_{\text{middle}} &= (t_{\text{mid}1} + t_{\text{mid}2}) / 2 + C_2 \\
  t_{\text{bottom}} &= (t_{\text{bot}1} + t_{\text{bot}2}) / 2 + C_3
\end{align*}
\]

- Where \( t_{\text{top}1} \ldots t_{\text{bot}2} \) are the corresponding TDCs readout values, \( C_1 \ldots C_6 \) are the calibration constants. The muon loses a small part of its energy/momentum inside the counters. Its velocity remains nearly constant. Therefore

\[
\tau = t_{\text{middle}} - (t_{\text{top}} + t_{\text{bottom}}) / 2 = (t_3 + t_4) / 2 - (t_1 + t_2) / 2 - (t_5 + t_6) / 4 = C
\]

- However, since \( t_1 \ldots t_6 \) are smeared by the PMT resolutions, \( \tau \) is distributed around some constant value \( C \). Using the variance of \( \tau \), one may deduce the average PMT resolution

\[
\sigma_{\text{PMT}} = \frac{\sqrt{3} \Var(\tau)}{\sqrt{3}/2}
\]

- In practice, the PMT resolution is derived from the Gaussian fit of the peak in the measured spectrum of \( \tau \).
Beam Test at PNPI: Basic Idea and Experimental Setup (developed previously in Korea)

The counter is irradiated by well-collimated (point-like) beam.
Measured PM times are defined by the following relations

\[ t_1 = \text{TOF} + \frac{x}{v} + \text{Const} \quad \text{and} \quad t_2 = \text{TOF} + \frac{(L-x)}{v} + \text{Const}; \]

Where TOF is time-of-flight of protons from a certain point (target), \( x \) is a hit position along the counter axis, \( L \) is the counter length, \( v \) is the efficient speed of light propagation inside the counter, Constants originate from cable and electronic delays.

\[ \text{TOF} = \frac{(t_1 + t_2)}{2} + \text{Const}; \quad \frac{x}{v} = \frac{(t_1 - t_2)}{2} + \text{Const}; \]

\[ \text{TOF resolution } \sigma_{\text{TOF}} = \sigma\left(\frac{(t_1 + t_2)}{2}\right) = \sqrt{\sigma_{t_1}^2 + \sigma_{t_2}^2}/2; \]

Variation of \((t_1-t_2)/2\)

\[ \sigma\left(\frac{(t_1-t_2)}{2}\right) \approx \sigma_{\text{TOF}} + \Delta x/v \]

where \( \Delta x \) is the size of the beam spot.

For a point-like beam \((\Delta x \approx 0)\)

\[ \sigma\left(\frac{(t_1-t_2)}{2}\right) \approx \sigma_{\text{TOF}} \]
Possible experiments at LMP beam line

- Simultaneous measurements of pion scattering on the proton and on the neutron bound in a deuteron target

\[ \pi^- p \rightarrow \pi^- p \quad \pi^- n \rightarrow \pi^- n \]

- Study of \( \pi^- p \rightarrow \pi^- X \) at low energies \( \sim 200 \text{ MeV/c} \)

The goal is to verify the observation of narrow resonances with masses below Delta (1.004, 1044, and 1.094 GeV)

EPECUR (if repaired)

- $\pi^- p \rightarrow \eta n$ at the energies around $\sim 1020$ MeV/c
  
  Signal and properties of $N^*(1685)$

- $\pi^- p \rightarrow K^- K^+ n$ (to be investigated in detail)
  
  Search for $\Theta^+$
Byproducts

Potential participation in development/construction of new neutron detectors.

High-resolution neutron polarimeter for HallA@JLAB is now under discussion

→ possible collaboration with University of Catania and INFN Sezione di Catania.
Thank you for your attention!
Yield of $\gamma N \rightarrow \eta N$: Data and MC

Quasi-free neutron

Quasi-free proton

Soft cuts

Tight cuts
$\sim 4.6 \sigma$
Comments on O.Bartalini et al. (by the GRAAL Collaboration (?) \``Measurement of eta photoproduction on the proton from threshold to 1500 MeV\'', Nucl-ex:0707.1385.

Data analysis has been performed by A.Lleres, LPSC Grenoble.

Authors claimed no evidence for a narrow N(1670) state in beam asymmetry and cross section data for eta photoproduction on the proton.
Comparison of O. Bartalini et al. (black circles) with the old GRAAL publication V. Kuznetsov, πN News Letters, 16, 160(2002) (open circles) (angular dependences)

Despite the triple increase of statistics, new data are less accurate at forward angles! The reason is that events in which one of the photons from $\eta \rightarrow 2\gamma$ decay is detected in the forward wall, are excluded from data analysis.

$\gamma p \rightarrow n \gamma$ Yield for different types of events
Comparison of O.Bartalini et al. (open circles) and our results (black circles). Main difference is at 103/116 deg.

The same dip structure at 103 deg!

Comparison with preliminary results done by A.Lleres (A.Lleres, private communication (E-mail from Feb 5, 2007)).
What does mean quasi-free cross section?

To fit experimental data, the cross section calculated for the free neutron, is then smeared by Fermi motion using the deuteron wave function.

This formula is from A. Anisovich et al., Hep-ph/0809.3340

\[
\frac{d^2\sigma_{qf}(W, \theta_{cm})}{d\Theta} \propto \int d|\vec{p}_N||\vec{p}_N|^2 f^2(\vec{p}_N) \frac{d\cos(\theta_N)d\phi_N}{4\pi} \frac{d\sigma_{\text{free}}}{d\Theta}(W^*, \theta^*_{cm})d\Phi
\]

Is this formula applicable for experimental data?
The width and the position of the peak in the γn→ηn cross section are affected by the cut on the neutron missing mass!
Calculation of cross sections (Published in Acta Physica Polonica)

Blue - SAID only
Magenta - SAID + P11
Green - SAID + P13
Red - SAID + D13

P13 would generate a small dip structure at forward angles.