P348:
Search for new physics in missing-energy events

S.N. Gninenko
(INR, Moscow)

SHIP Collaboration Meeting
CERN, 08.10.2015.
Proposed in December 2013
Approved for tests April 2014
Currently
~ 30 members
UP, Patras (Greece)
DESY (Germany)
IHEP Protvino (Russia)
INR Moscow (Russia)
JINR Dubna (Russia)
LPI Moscow (Russia)
TPU Tomsk (Russia)
ETH Zurich (Suisse)
KAIST Daijeon (S.Korea)
UTFSM Valparaiso (Chile)
One of main goals: search for $A' \rightarrow \text{inv}$

Okun, Holdom’86 ..

- extra (broken) $U'(1)$, new massive boson $A'$ (dark photon)
- $\Delta L = \varepsilon F_{\mu\nu}A'_{\mu\nu}$ - kinetic $\gamma$-$A'$ mixing, $\varepsilon$ - strength of coupling
- $A'$ could be light: e.g. $M_{A'} \sim \varepsilon^{1/2} M_Z$
- new phenomena: $\gamma$-$A'$ oscillations, LSW effect, $A'$ decays, possible contributions to $g$-2
- $A'$ decay modes: $e^+e^-$, $\mu^+\mu^-$, hadrons,.. or $A' \rightarrow$ invisible if $M_{A'} > M_{DM}$ and $\alpha_{DM} >> \varepsilon$

Large literature, many new theoretical and experimental results
Direct Search for $A' \rightarrow$ invisible decay

Signature:
- $e^-$, 100 GeV in,
- $e$-$m$ shower in ECAL $< \sim 50$ GeV
- no activity in the Veto+ HCAL

S.G., PRD(2014)
A\` production in a thick Pb target

- GEANT4 + A\` emission in e-m shower (M. Kirsanov, D. Kirpichnikov)
- eZ→e Z A\` cross section, Bjorken’09
  $10^{-4} < \varepsilon < 10^{-5}$
- very rare events: $\sigma_{A\`}/\sigma_{\gamma} < 10^{-12}-10^{-9}$

$\varepsilon \sim 10^{-1}$, $M_{A\`}=100$ MeV

Full simulations

Energy deposition ECAL

---

S.N. Gninenko(INR) - SHIP CM - Search for new physics at P348

E, GeV
### Summary of background sources for $A' \rightarrow$ invisible

<table>
<thead>
<tr>
<th>Source</th>
<th>Expected level</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beam contamination</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$-\pi, p, \mu$ reactions and punchthroughs,...</td>
<td>$&lt; 10^{-13}-10^{-12}$</td>
<td>Impurity $&lt; 1%$</td>
</tr>
<tr>
<td>- e- low energy tail due to brems., $\pi, \mu$ decays in flight,..</td>
<td>$&lt; 10^{-12}$</td>
<td>SR photon tag</td>
</tr>
<tr>
<td><strong>Detector</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECAL+HCAL energy resolution, hermeticity: holes, dead materials, cracks...</td>
<td>$&lt; 10^{-13}$</td>
<td>Full upstream coverage</td>
</tr>
<tr>
<td><strong>Physical</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- hadron electroproduction, e.g. $eA \rightarrow neA^*$, $n$ punchthrough;</td>
<td>$&lt; 10^{-13}$</td>
<td>$\sim 10$ mb $\times$ nonherm. WI $\sigma$ estimated. textbook process, first observation?</td>
</tr>
<tr>
<td>- WI process: $e Z \rightarrow e Z \nu \nu$</td>
<td>$&lt; 10^{-13}$</td>
<td></td>
</tr>
</tbody>
</table>
Expected limits vs $N_{e^-}$
The P348 detector

S.N. Gninenko(INR) - SHIP CM - Search for new physics at P348
The P348 detector

S.N. Gninenko(INR) - SHIP CM - Search for new physics at P348
BGO, Micromegas, straw, hodoscopes

Micromegas

BGO SR array

Strow tubes

S.N. Gninenko(INR) - SHIP CM - Search for new physics at P348
First look and first problems.

Hcal energy VS Ecal energy

Raw data, no cuts

<table>
<thead>
<tr>
<th>hHCvsEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean x</td>
</tr>
<tr>
<td>Mean y</td>
</tr>
<tr>
<td>RMS x</td>
</tr>
<tr>
<td>RMS y</td>
</tr>
</tbody>
</table>

S.N. Gninenko(INR) - SHIP CM - Search for new physics at P348
SR tagging of 100 GeV e-

No synchrotron tagging

Hcal energy VS Ecal energy (4x4), cell(2,2)

Energy deposited in Sync_Sciint

With synchrotron tagging

Hcal energy VS Ecal energy (4x4), cell(2,2)

SR in BGO: simulations

S.N. Gninenko(INR) - SHIP CM - Search for new physics at P348
A `Signal in the HCAL vs ECAL plane

No selections

Single hodoscope plane (1 mm) + SR tag

No background events for $\sim 4 \times 10^7$ e-

Further background suppression with Tracker

S.N. Gninenko(INR) - SHIP CM - Search for new physics at P348
No background events are expected with MM tracker for $> 10^{11}$ e-
## Physics prospects for P348

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Physics</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. eZ -&gt; eZ +..</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>◊ A` -&gt; e+e-</td>
<td>Dark photons, Hidden sectors, (g-2)_{μ}</td>
<td>10^{-4} &lt; ε &lt; 10^{-5}</td>
</tr>
<tr>
<td>◊ A` -&gt; invisible</td>
<td>new particles, milliQ, charge quantization</td>
<td>M_{A`} \sim \text{sub-GeV}</td>
</tr>
<tr>
<td>◊ alps</td>
<td></td>
<td>e`/e &lt; 10^{-5}-10^{-7}</td>
</tr>
<tr>
<td>◊ mQ</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2. μZ -&gt; μZ+...</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>◊ Z_{μ} -&gt; νν, μ+μ-</td>
<td>(g-2)<em>{μ}, gauged L</em>{μ}-L_{τ}, L-phobic boson Z_{μ}, LFV</td>
<td>α_{μ} &lt; 10^{-11}-10^{-9}</td>
</tr>
<tr>
<td>◊ μ-&gt;τ</td>
<td></td>
<td>&lt; 10^{-9}-10^{-8}/μ</td>
</tr>
<tr>
<td><strong>3. π(K)p -&gt; M^{0} n</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>◊ K_{L} -&gt; invisible</td>
<td>Bell-Steinberger Unitarity, CP, CPT , NHL, 2HDM,</td>
<td>\sim 10^{-5}</td>
</tr>
<tr>
<td>◊ K_{S} -&gt; invisible</td>
<td></td>
<td>Br &lt; 10^{-8}</td>
</tr>
<tr>
<td>◊ π^{0}, η, η` -&gt; invisible</td>
<td></td>
<td>&lt; 10^{-8}-10^{-7}</td>
</tr>
<tr>
<td><strong>4. pA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>◊ leptophobic X +h</td>
<td>\sim \text{GeV DM}</td>
<td>&lt;10^{-7}-10^{-8} /p</td>
</tr>
</tbody>
</table>
(g-2)_{\mu} and new leptophobic Z` from L_{\mu}-L_{\tau}

strong motivation for a sensitive search for Z` in a near future experiment by using (unique) muon beam at CERN.
Rare kaon decays with “missing energy”

William J. Marciano and Zohreh Parsa

and $K_L \rightarrow \nu \bar{\nu}$ (if neutrinos have mass). Those decays would be interesting to explore, but their detection looks essentially impossible. New ingenious experimental ideas are required.

$\pi, K+p \rightarrow M^0+ n; M^0 \rightarrow \text{invisible}$

$M^0=\pi^0, \eta, \eta', K_L, K_S$

$\text{Br}(K_L \rightarrow \text{invisible}) < 10^{-8}$
Summary

Searching for missing-energy events in an active beam dump is a sensitive probe of new physics developed by P348.

The simulations and recent test beam results show that after a small modification the detector is ready for data taking.

The experiment is complementary to NA62, KLOE, and planned SHIP.

These 2 weeks of beam tests would be impossible without support from CERN Vice-DG S. Bertolucci, and people including H. Wilkens, A. Fabich, H. Fischer, I. Konorov, V. Frolov, D.-L. Lazic, M. Jeckel, J. Novy who helped us in many ways, the CERN LCD group and the SPS crew.

THANK YOU!