BTF at LNF and the dark photon paradigm

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Outline

- Motivation
- BTF @ LNF
- Idea
- Production

- Experimental setup
- Simulation & Reco
- Expected sensitivity
- Conclusions
**Motivation: New Physics**

- Standard Model is complete: 2012 LHC - Higgs boson
- Unknowns:
  - Matter-antimatter asymmetry
  - Dark matter
  - Dark Energy
- Still some places of discrepancies between theory and experiment
- The Standard Model is a low energy approximation of a more fundamental theory.

*But which theory?*
**Direct search experiment**

- DAMA/LIBRA results unexplained: 9.2 $\sigma$
- Used to be alone, now few other indications emerged
- Seem to be possible to build a consistent picture
- If the explanation is Dark Matter, it should be relative light: $\sim$10 GeV
Particle astrophysics

Antiparticles in the cosmic rays

- Positron excess: PAMELA, FERMI, AMS02
- No significant excess in antiprotons
  - Consistent with pure secondary production
- Leptofilic annihilation?
If Dark Matter is the explanation to the positron excess, then the mediator should be light ($< 2M_{\text{proton}}$)

- Coupling constant to DM could be arbitrary (even $O(1)$)
- The Lagrangian term can arise through
  - fermions being charged (mili) under this new gauge symmetry ($q_f \rightarrow 0$ for some flavours)
  - Kinetic mixing between ordinary photon and DM one
  - Using simply an effective description: $g' \cdot q'_e = \varepsilon$, $\alpha' = \alpha \cdot \varepsilon^2$
About $3 \sigma$ discrepancy between theory and experiment ($3.6 \sigma$, if taking into account only $e^+e^- \rightarrow$ hadrons)

\[ a_\mu^{\text{dark photon}} = \frac{\alpha}{2\pi} \varepsilon^2 F(m_\gamma / m_\mu), \tag{17} \]

where $F(x) = \int_0^1 2z(1-z)^2/[(1-z)^2 + x^2z] \, dz$. For values of $\varepsilon \sim 1-2 \cdot 10^{-3}$ and $m_\gamma \sim 10-100$ MeV, the dark photon, which was originally motivated by cosmology, can provide a viable solution to the muon $g-2$ discrepancy. Searches for the dark
**Heavy/Dark photon/boson**

- The most attractive explanation of the phenomena is the simplest one – with a single object
- If this is the U-boson, it should be sufficiently light – 10-100MeV
- Searches
  - Beam dump experiments
    - A'-strahlung production
    - Every observed event is signal
  - Fixed target
    - peaks in the e+e- invariant mass spectrum
  - Meson decays
    - Peaks in $M_{e^+e^-}$ or $M_{\mu^+\mu^-}$
Present limits

- There is no direct present limit in the $U \rightarrow \text{invisible decay}$ – from $a = \frac{g-2}{2}$
- The discrepancy is not in $g_\mu -2$ itself, it's in the consistency of $g_e$ & $g_\mu$
- Alternative inputs can be used to extract info from $g_e - \alpha$

Anomalous magnetic moment limits
- $\alpha_{\text{EM}}$ usually a determined from $g_\mu -2$
- Used further to constrain $g_\mu -2$
- Dark photon contribution:

$$\delta a = \frac{\alpha_{\text{EM}} \epsilon^2}{2\pi} \star f, \ f = \begin{cases} 1, \text{ for } m_l \gg M_U \\ 2m_l^2/(3M_U^2), \text{ for } m_l \ll M_U \end{cases}$$

$$|a_e^{\text{th}} - a_e^{\exp}| = (1.06 \pm 0.82) \times 10^{-12}$$

However this is based on a single measurement with drastically improved precision
U boson searches

- Searching a U-boson in a kinematically constraint event and using full reconstruction
- Basic process: positron on a fixed target
  \[ e^+ + e^- \rightarrow \gamma + U \]
  \[ \gamma + E_{\text{miss}} \quad (\text{invisible channel}) \]
  \[ \gamma + e^+e^- \quad (\text{visible channel}) \]
- Normalizing to the concurrent process - annihilation
  \[ \frac{\sigma(e^+e^\rightarrow \gamma U)}{\sigma(e^+e^\rightarrow \gamma \gamma)} = \frac{N(\gamma U)}{N(\gamma \gamma)} \times \frac{\text{Acc}(\gamma \gamma)}{\text{Acc}(\gamma U)} = \varepsilon^2 \times \delta \]
  - \( N(\gamma U), N(\gamma \gamma) \) - number of registered events
  - \( \text{Acc}(\gamma U), \text{Acc}(\gamma \gamma) \) - detection efficiency
  - \( \delta \) – cross section enhancement factor (see further)

Is it possible such a search to be conducted here at LNF?
Variable beam energy (from ~250 MeV to $E_{\text{MAX}}$)

Possibility for single particle beam

  However we need statistics...

Planned upgrades:

  Maximal beam energy (1GeV for e-)
  Beam intensity (up to $10^{10}$/bunch)
  Bursts per second
  Burst length (at least 40 ns)

The accessible region is limited by the maximal beam energy

  Around 22 MeV for 500 MeV $e^+$ beam
Heavy/Dark photon/boson

- After production, U boson may decay into $e^+e^-$

$$
\Gamma_U = \Gamma_{U \rightarrow e^+e^-} = \frac{1}{3} \alpha e^2 M_U \sqrt{1 - \frac{4me^2}{M_U^2}} \left( 1 + \frac{2me^2}{M_U^2} \right)
$$

Simple model implemented in CalcHEP, used for the further studies
U-boson production

For $\varepsilon = 10^{-3}$

$\delta = \delta(M_U, E_{\text{beam}})$

- Increasing of the cross section with the approach of the kinematics limit – resonant production of $U$
  - Speculation on the possibility to scan the region 10 MeV - 23 MeV by varying the beam energy?
Basic idea: U@BTF

- Electron is at rest
- Positron momentum is determined by the accelerator characteristics – 1% resolution
- Basic contribution to the missing mass resolution – reconstruction of the photon 4-momentum
  - Interaction point inside the target – beam transverse size is small, but the time stability is not sufficient
  - Cluster position in the calorimeter
  - Energy resolution of the calorimeter
Event reconstruction

- Clear 2 body correlation
- Background minimization
  - Best possible resolution on energy/angle measurement
  - Dominant process in e+/e- interactions with matter is bremsstrahlung
  - Photons vetoing
  - Minimize the interaction remnants + vetoing
Target

Active target for burst by burst beam profiling

Main interaction process of $e^+/e^-$ - bremsstrahlung

$\sigma_{\text{annih}}/\sigma_{\text{brems}}$ as a function of $Z$

- Target with minimal $Z$
- Target with minimal thickness to suppress number of secondary interactions, contributing to the beam position/momentum spread

CARBON
Missing mass resolution: target

- Toy studies on kinematics
- Target optimization to minimize the scattering of the beam inside while keeping the annihilation probability relatively high

$10^4 - 10^5$ positrons/burst, 50um target thickness
- 10 diamond strips of 2 mm x 50 mm with 25um thickness
  - Horizontal and vertical mounted on a vacuum flange
  - Readout with SiPM (Čerenkov light) or using it as a standard ionization chamber
- Information for beam position and intensity (normalization crosscheck)

- U boson may also be produced in a higher cross section
  - U-strahlung process: $e^+ + N \rightarrow e^+ + N + U$
  - Accessible if the experiment is sensitive to $U \rightarrow e^+e^-$

- 1MeV cut on bremsstrahlung $\gamma$
Production possibilities

- Benchmark BTF operation:
  - 1 year of continuous running
  - 60% efficiency (data taking)
  - 50 bursts/s
  - $10^4$ positrons/burst
  - Total of $\sim 10^{13}$ positrons on target
  - $> 100$ U bosons produced in $e^+e^- \rightarrow \gamma U$, for any $M_U$, assuming $\varepsilon \sim 10^{-3}$!
  - U bosons produced also in a higher cross section U-strahlung
    - Possibly accessible through $U \rightarrow e^+e^-$ decay reconstruction
- If exists and couples to electrons the U-boson can be produced in a very thin target at BTF, provided $\varepsilon \sim X*10^{-4}$ or higher

But can those events be detected by a suitable experimental setup?
Spare
Event reconstruction

- The resolution depends on the U-boson mass
- The photon energy is dependent on the photon angle (2 body kinematics)
• Possible simultaneous registration of both visible and invisible channel
• The magnetic field serves for both:
  – Deflecting the primary positron beam out of the ECAL acceptance
  – Measurement of the momenta of charged particles