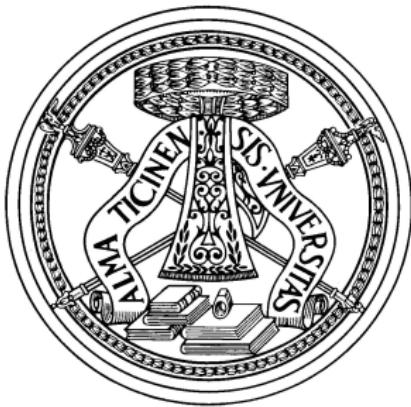


U boson at e^+e^- Colliders - [1007.4984]



Luca Barzè

University of Pavia
INFN

LC10

2nd December 2010

with Balossini, Bignamini, Carloni
Calame, Montagna, Nicrosini, Piccinini

Outline

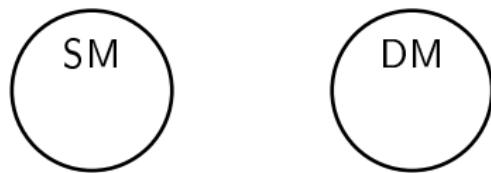
Description of the Model

Description of the Generator

Results

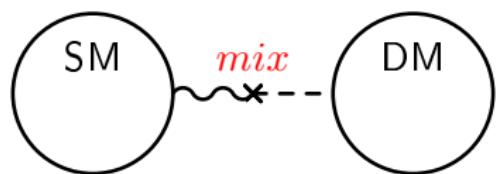
Axiom 1: Dark Matter exists

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{DM}$$



Axiom 1: Dark Matter exists and interacts with SM

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{DM} + \mathcal{L}_{mix}$$



$$\mathcal{L}_{mix} = \sum_{ij} k_{ij} \Theta_{SM}^i \Theta_{DM}^j$$

A simple way

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

$$\mathcal{L}_{SM} = \mathcal{L}_{SM}^F + \mathcal{L}_{SM}^B + \mathcal{L}_{SM}^H$$

$$\mathcal{L}_{DM} = ?$$

A simple way

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_{DM} \otimes \dots$$

$$\mathcal{L}_{SM} = \mathcal{L}_{SM}^F + \mathcal{L}_{SM}^B + \mathcal{L}_{SM}^H$$

$$\begin{aligned} \mathcal{L}_{DM} &= \mathcal{L}_{DM}^F(\chi) & \Rightarrow M_\chi \sim 50 - 100 \text{ GeV (WIMP)} \\ &+ \mathcal{L}_{DM}^B(U) & \Rightarrow m_U \sim ? \\ &+ \dots \end{aligned}$$

A simple way

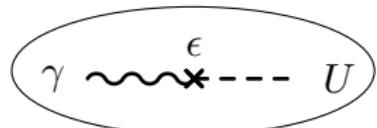
$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_{DM} \otimes \dots$$

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$$\mathcal{L}_{mix} = \frac{\epsilon_Y}{2} F^{DM\mu\nu} F_{\mu\nu}^Y, \quad \epsilon \equiv \epsilon_Y c_W$$

$$\mathcal{L}_{mix} = \frac{\epsilon}{2} F^{DM\mu\nu} F_{\mu\nu}^{EM}$$



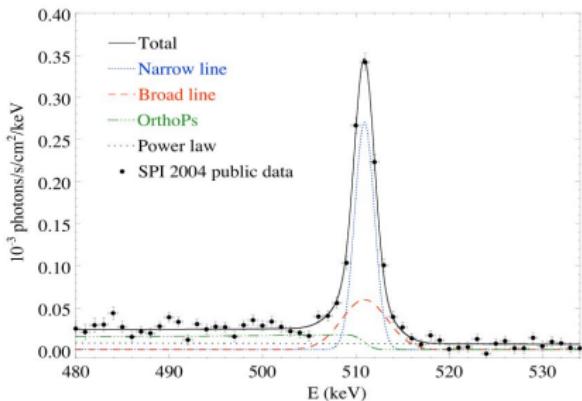
Small effects at low energies.

Motivation

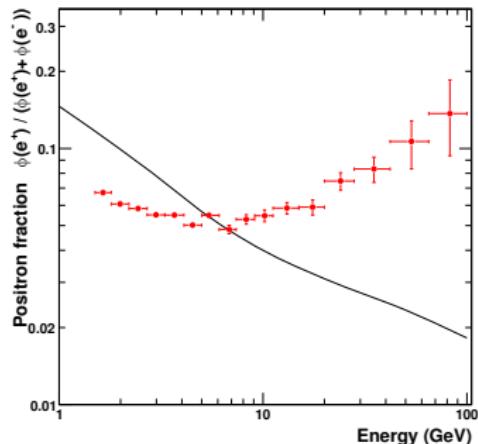
- Compatible with a number of theories;

Motivation

- Compatible with a number of theories;
- it would be possible to explain some experimental data:
 - PAMELA, ATIC, EGRET, INTEGRAL, DAMA, FERMI ...



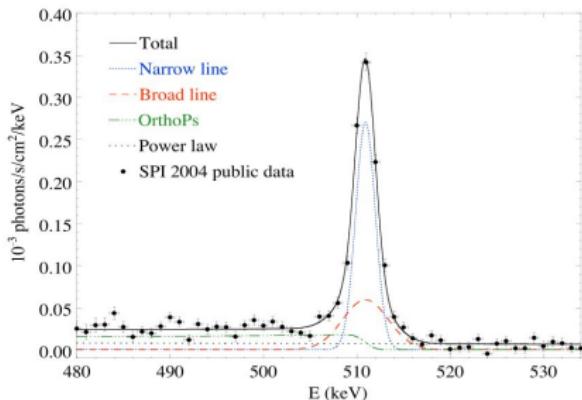
511 keV line by INTEGRAL



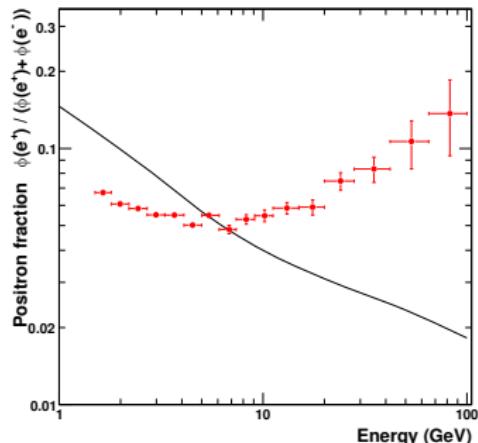
Excess of positrons - PAMELA

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511 keV line by INTEGRAL



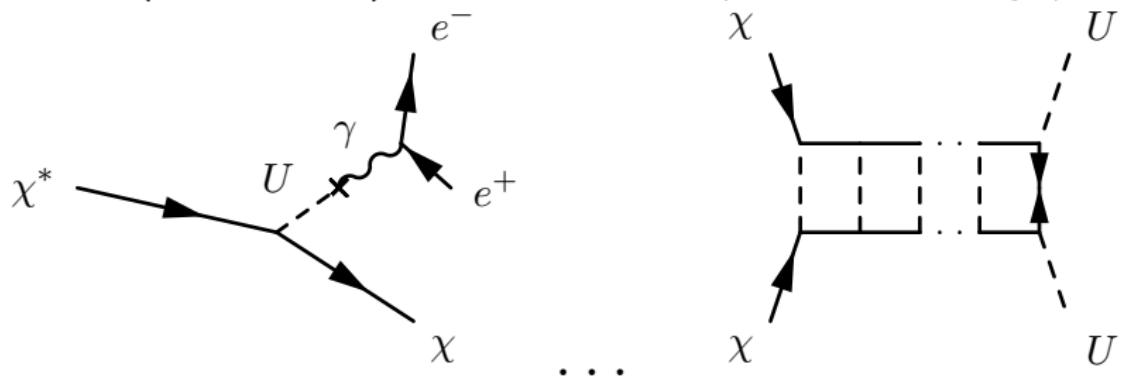
Excess of positrons - PAMELA

Astrophysical sources → difficulties

Axiom 2: Data due to DM

An excess of e^+ without \bar{p}

WIMPS ($m \geq 10$ GeV) annihilation would produce too many γ



No \bar{p} excess $\rightarrow U$ must be light (\sim MeV - GeV) $\Rightarrow \epsilon \lesssim 10^{-2,-3}$
 $M_{\chi^*} - M_\chi \sim 100$ keV \Rightarrow DAMA/CoGeNT signals

*hep-ph[0810.0713] - Arkani-Hamed, Finkbeiner, Slatyer, Weiner
A Theory of Dark matter*

From Particle Physics . . .

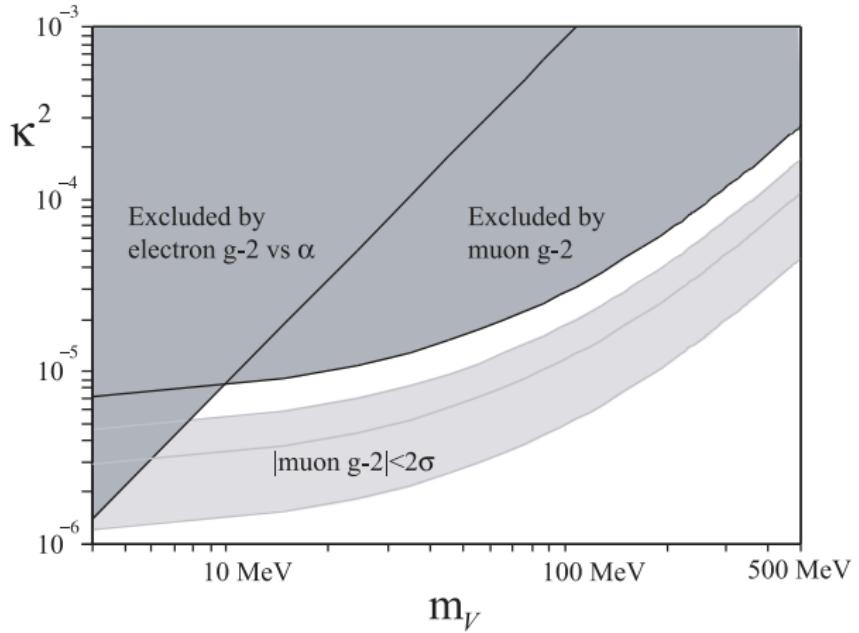
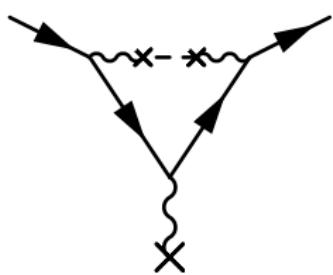
- No observations in Z decays at LEP;
- strong suppression of the couplings with ν ;
- compatibility with existent data (e and μ g-2, beam dump);

. . . From Astrophysics

- Annihilation rates \gg weak interactions;
- constraints from γ -rays and radio fluxes.
- constraint from the low energy positron component of Cosmic Rays.

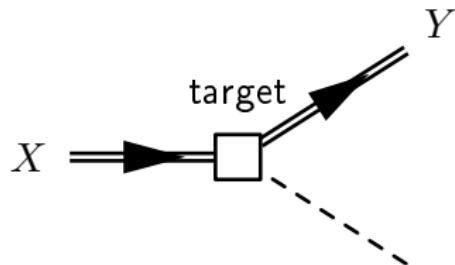
There is quite a wide window not excluded by any obvious laboratory measurement or astrophysical argument, while the INTEGRAL (PAMELA) observation could be easily (not so easily) accounted for

Predictions are testable: anomalous magnetic moment



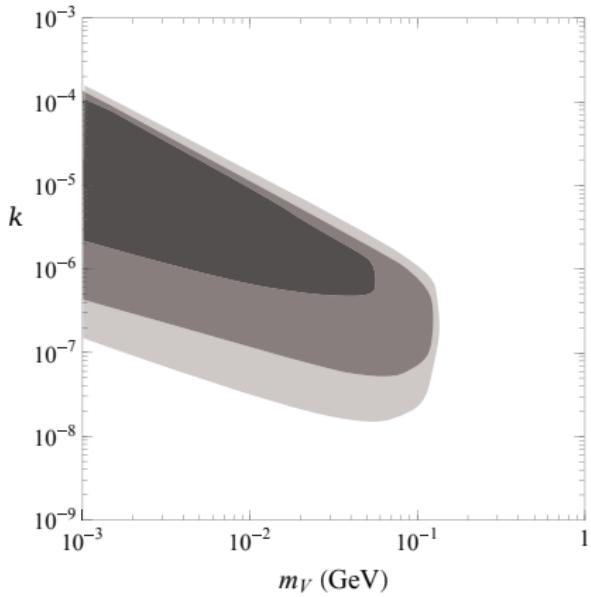
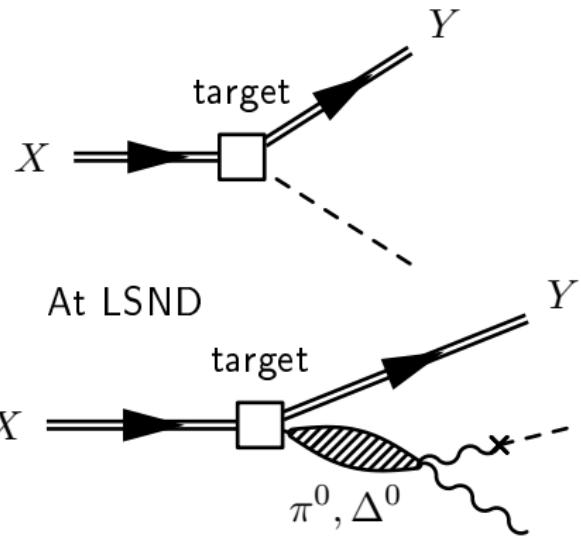
*hep-ph[0811.1030] - Pospelov
Secluded U(1) below the weak scale*

Predictions are testable: beam dump



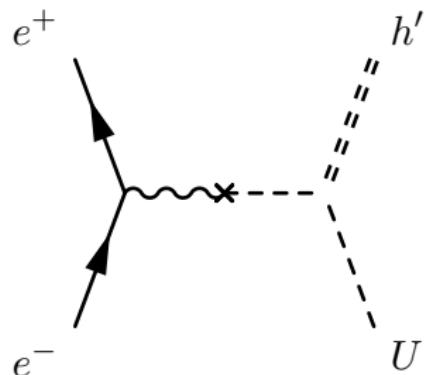
*hep-ph[0906.5614] - Batell, Pospelov, Ritz
Exploring portals to a hidden sector through fixed targets*

Predictions are testable: beam dump

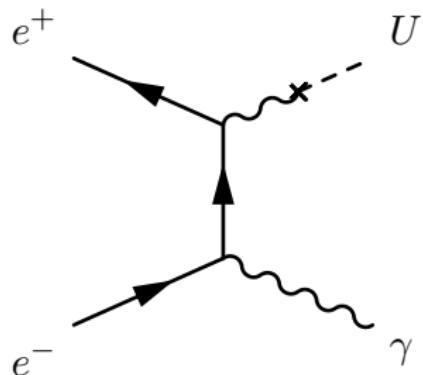


*hep-ph[0906.5614] - Batell, Pospelov, Ritz
Exploring portals to a hidden sector through fixed targets*

Possible discovery channels

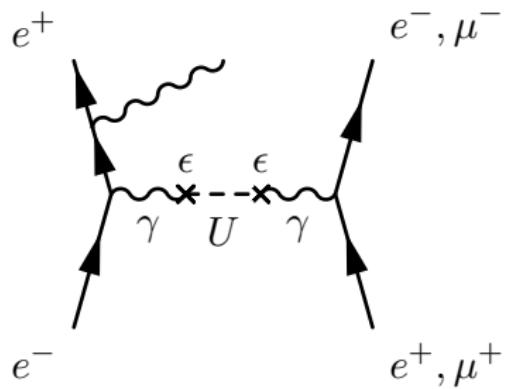


$l^+l^- + \cancel{E}_T$
 $6l \rightarrow 4\epsilon + 2m_U \rightarrow$ tiny
model dependent



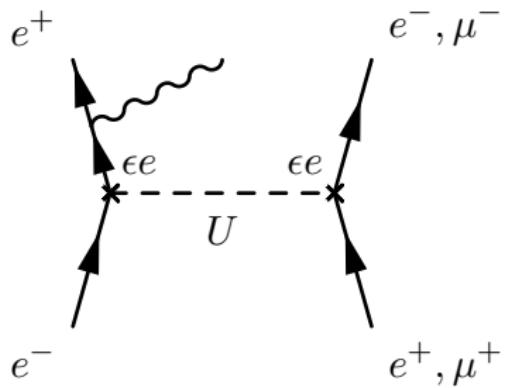
$l^+l^- \gamma$
model independent

A really difficult channel



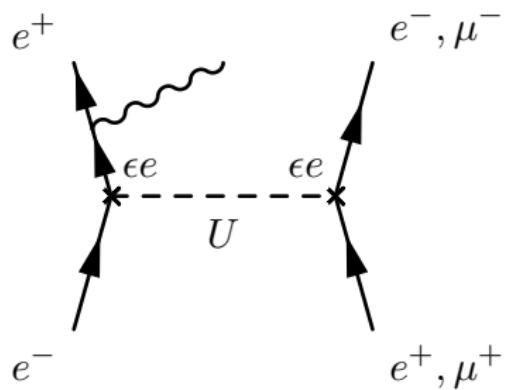
- Resonant channel:
 - particular signal shape \neq BG;
- radiative return:
 - energy scan;

A really difficult channel



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A really difficult channel



- Resonant channel:
 - particular signal shape \neq BG;
- radiative return:
 - energy scan;

- 2nd order process,
- $2\ \epsilon$:
 - really small signal! ($\sigma_U \sim 10^{-7} \sigma_{BG}$)
($\sigma_Z(1\text{ GeV}) \sim 10^{-3} \sigma_{BG}$)
- An accurate estimate of the background is mandatory.

Necessity of a very accurate event generator

$$| \text{Feynman diagram} + \text{Feynman diagram} + \dots |^2$$

14 terms for e^\pm , 6 for μ^\pm

ALPHA

BabaYaga

- Exact tree level calculation;
- very well tested generator.

hep-ph[0607181] - Balossini, Carloni Calame, Montagna, Nicrosini, Piccinini
Matching perturbative and Parton Shower corrections to Bhabha process at flavour factories

hep-ph[9507237v1] - Caravaglios, M. Moretti
An algorithm to compute Born scattering amplitudes without Feynman graphs

A MCEG for $e^+e^- \rightarrow e^+e^-, \mu^+\mu^-, \gamma\gamma$ processes at flavour factories.

- Common used for measure flavour factories luminosity:
 - $(g - 2)_\mu$, R , $\Delta\alpha_{had}$;
- theoretical error $\sim 10\%$ ($\mathcal{O}(\alpha^2)$) for first order processes.

<http://www.pv.infn.it/hepcosplex/babayaga.html>

A tool for Light Dark Matter at Leptonic Colliders

- Exact tree level calculation for the process $e^+e^- \rightarrow U, Z, \gamma \rightarrow l^+l^-\gamma$;
- exact three body kinematics;
- vacuum polarization \rightarrow HADR5N09 or HMNT;
- radiative corrections \rightarrow structure functions of the electron;
- theoretical error $\mathcal{O}(\alpha)$ (second order processes).

BabaYaga interface

INPUT

```
[ type "run" to start generation,  
"legenda" for help or "quit" to quit ]  
[ fs      ] final state = ee  
[ ecms    ] CoM energy     =   1.020  GeV  
[ thmin   ] min. angle     =   20.000 deg  
[ thmax   ] max. angle     =  160.000 deg  
[ zmax    ] acollinearity  =   10.000 deg  
[ emin    ] min. energy    =   0.408  GeV  
[ nev     ] 10000000. events will be generated  
[ path    ] files saved in test-run/  
[ ntuple   ] ntuple creation no  
[ menu2   ] the second menu is on  
[ menud   ] the dark matter menu is on
```

Second Menu (inner parameters):

```
[ arun    ] alpha running is on  
[ mode    ] requested evts. are weighted  
[ eps     ] soft photon cutoff = 0.0005  
[ ord     ] corrections at exp order  
[ model   ] model for corrections is matched  
[ seed    ] seed for RANLUX 700253512  
[ nphot   ] max. number of photons mode is -1  
[ nwrite  ] file(s) dumped every 1000000 events  
[ nsearch ] events for maximum searching 5000000  
[ verbose ] verbose mode (for debugging) 0  
[ sdmax   ] starting "sdifmax" 0.100E-17
```

16 of 23

OUTPUT

- Cross section;
- distributions of useful quantities;
- simulated events.

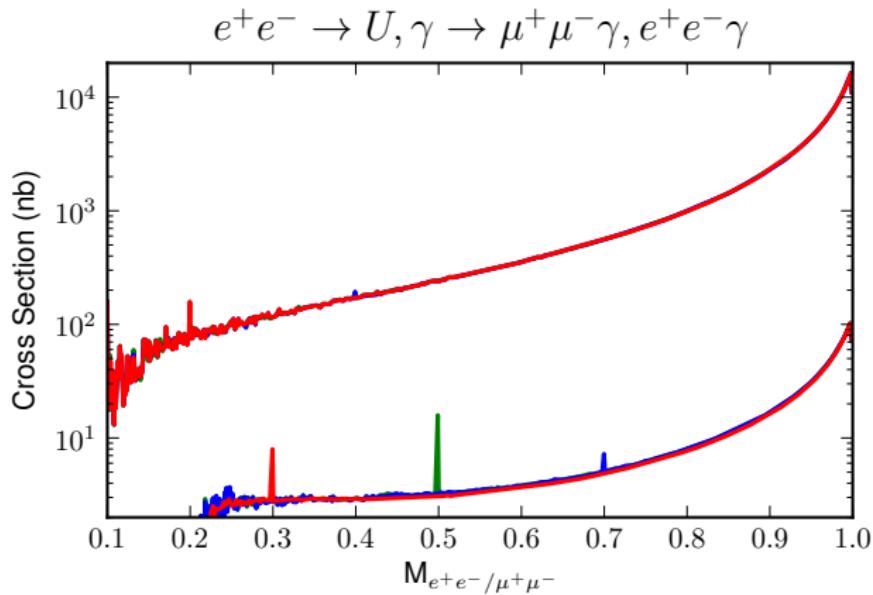
DM interface

Dark matter Menu:

```
[ darkmod ] The U channel is off
[ massU   ] U mass   =   0.400  GeV
[ gammaU  ] U width  = -1.000  GeV
[ k       ] vect g   =   0.001
[ gaxU   ] axial g  =   0.000
[ egmin   ] photon min energy =   0.020
[ thgmin  ] photon min angle  = 20.000
[ thgmax  ] photon max angle  = 160.000
[ massmin ] min invariant mass=   0.000
[ massmax ] max invariant mass=   1.020
```

if $\Gamma < 0$ only decays into SM particles are taken into account;
possible axial coupling constant (almost ruled out by data).

A possible signal



Final state invariant mass for different ϵ and m_U .

- Huge background on e^+e^-

Statistical significance

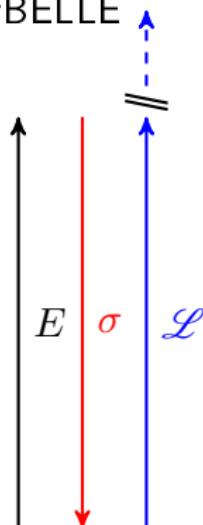
$$\frac{\#S}{\sqrt{\#B}} = \frac{\mathcal{L}(\sigma_{SM+U} - \sigma_{SM})}{\sqrt{\mathcal{L}\sigma_{SM}}} \equiv \sqrt{\mathcal{L}} \frac{\sigma_S}{\sqrt{\sigma_{SM}}} > 5 \text{ for discovery}$$

SuperB/SuperBELLE

Belle/BaBar

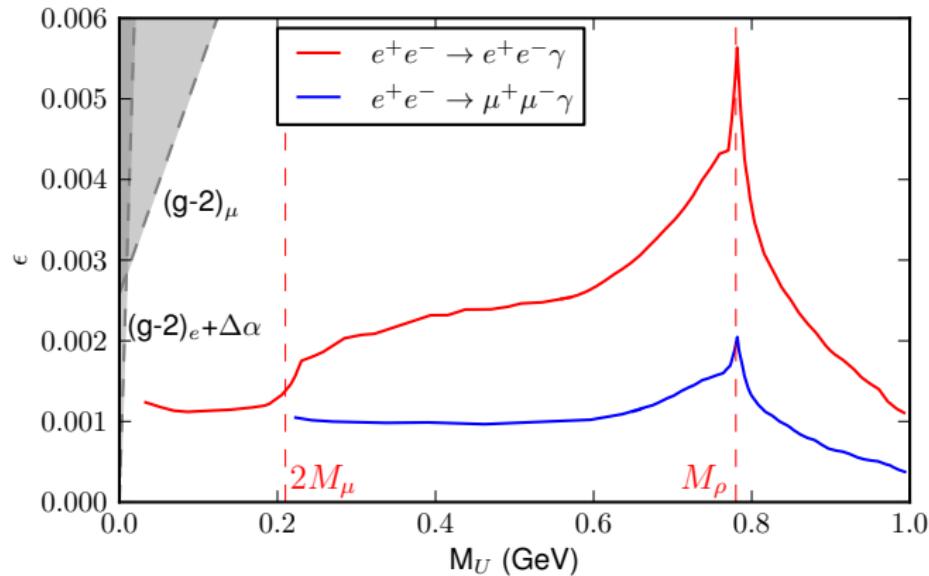
CLEO/BES

DAΦNE



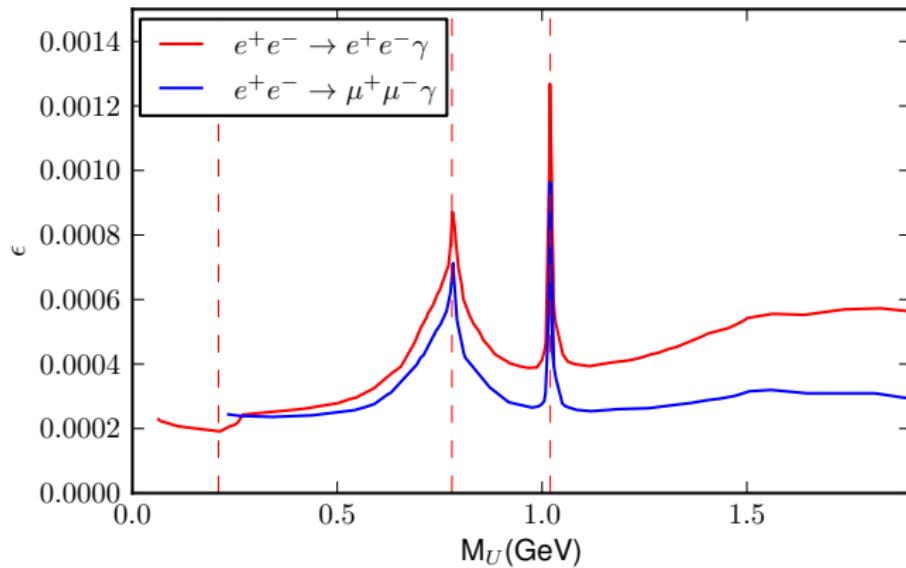
*hep-ph[0904.1743] - Reece, Wang
Searching for the light dark gauge boson in
GeV-scale experiments*

Simulation's results



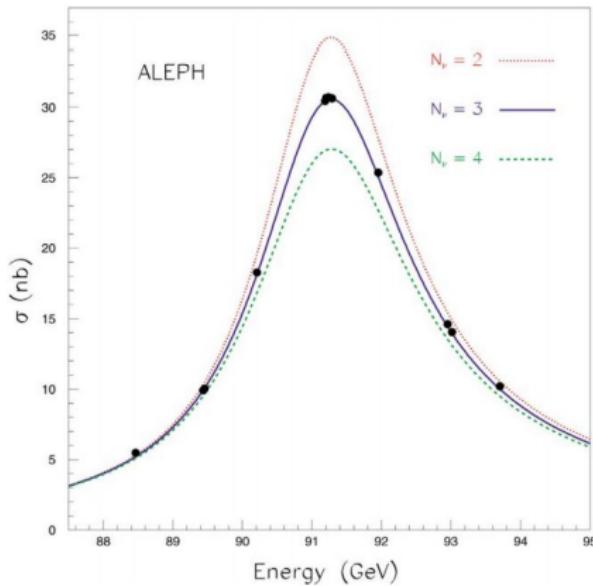
5 σ reach at KLOE+KLOE2 (5 fb^{-1} - 1.02 GeV)

Simulation's results



5 σ reach at Possible SuperB (100 ab^{-1} - 10.56 GeV)

Linear Collider - GigaZ



Accurate study of Z properties

TODO

Addition of the complete weak corrections

A lot of work to do!

- Experimental:
 - analyze existing data;
 - produce new data (flavour factories, beam dump);
- model builders:
 - explain the experimental data;
 - explain ALL the data at the same time;
- phenomenologists:
 - describe other possible signatures;
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Other useful references

- ▶ Pospelov, Ritz

Resonant scattering and recombination of pseudo-degenerate WIMPS
[hep-ph/0803.2251](#)

- ▶ Zhu

U-boson at BESIII
[hep-ph/0701001](#)

- ▶ Bjorken, Essig, Schuster, Toro

New Fixed-Target Experiments to Search for Dark Gauge Forces
[hep-ph/0906.0580](#)

- ▶ Bohm, Fayet

Scalar Dark Matter candidates
[hep-ph/0305261](#)

THANK YOU!