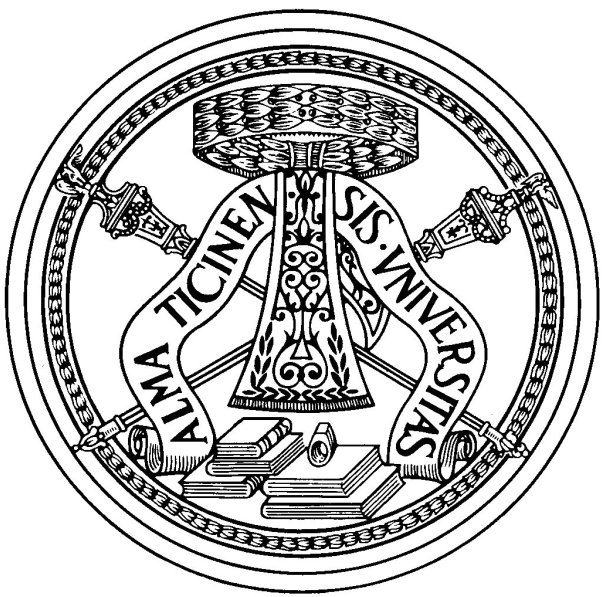
Looking for Dark Matter at Leptonic Colliders



Luca Barzè

University of Pavia
INFN

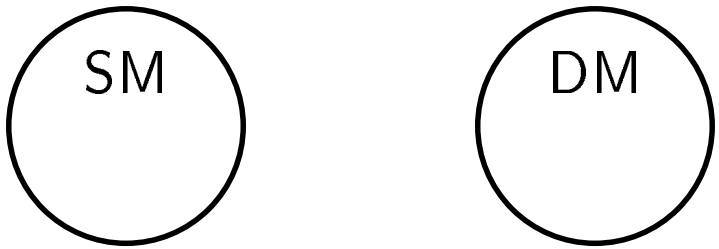
TOOLS 2010
1st July 2010

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

Outline

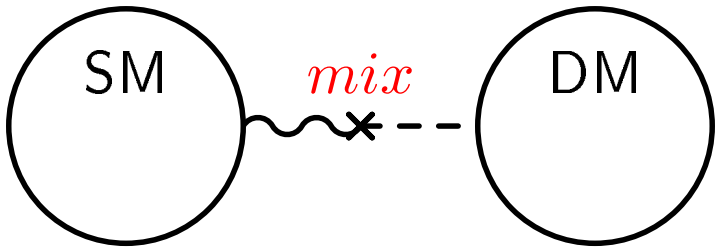
Axiom 1: Dark Matter exists

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



Axiom 1: Dark Matter exists and interacts with SM

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



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

A simple way

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

$$\mathcal{L}_{SM} = \mathcal{L}^F_{SM} + \mathcal{L}^B_{SM} + \mathcal{L}^H_{SM}$$

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

A simple way

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

$$\mathcal{L}_{SM} = \mathcal{L}^F_{SM} + \mathcal{L}^B_{SM} + \mathcal{L}^H_{SM}$$

$$\begin{aligned} \mathcal{L}_{DM} &= \mathcal{L}^F_{DM}(\chi) && \Rightarrow \quad M_\chi \sim \text{50 - 100 GeV from exp} \\ &+ \mathcal{L}^B_{DM}(U) && \Rightarrow \quad m_U \sim \text{?} \\ &+ \dots \end{aligned}$$

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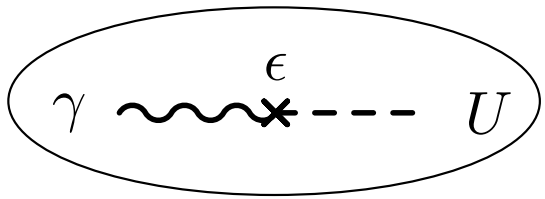
$$\mathcal{L}_{mix} = \frac{\epsilon_Y}{2} F^{DM\mu\nu} F^Y_{\mu\nu}, \qquad \epsilon \equiv \epsilon_Y c_W$$

SSB

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



Small effects at low energies.

Motivation

- Compatible with a number of theories;

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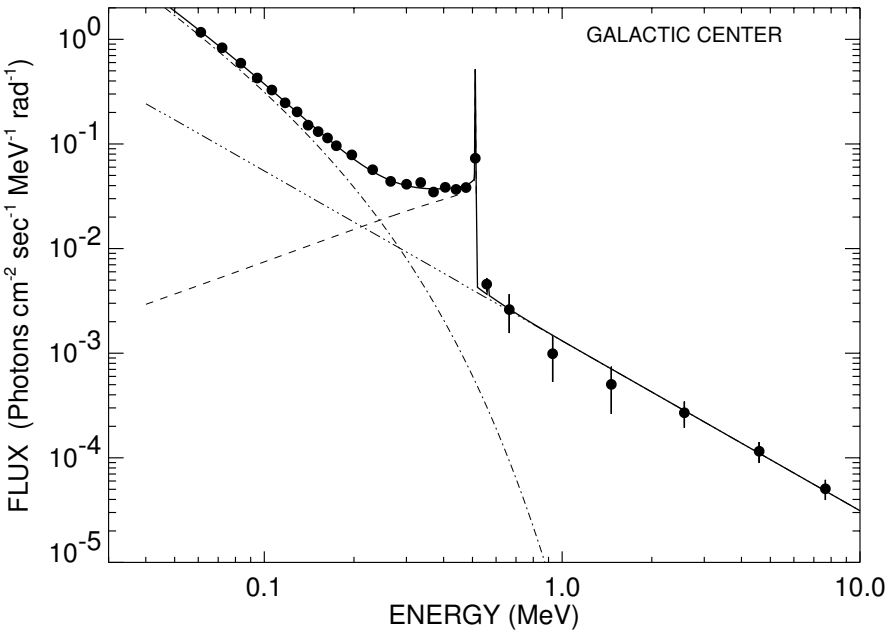
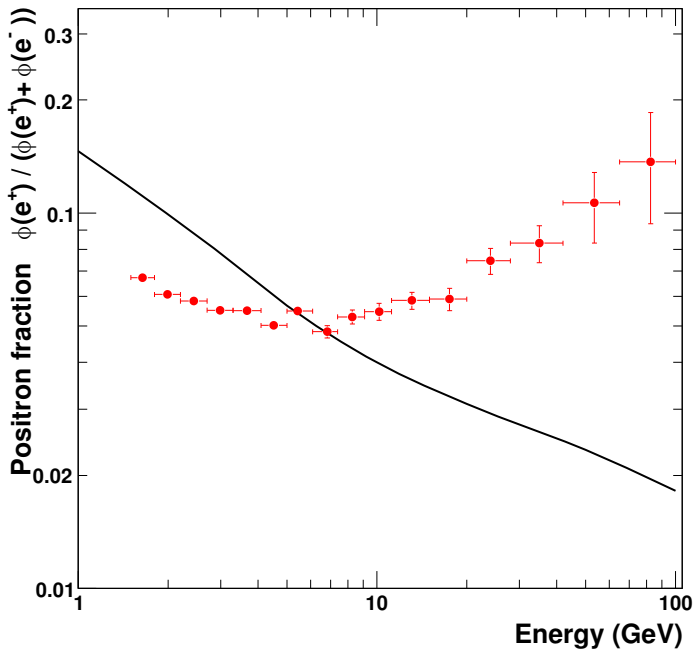
  - PAMELA, ATIC, EGRET, INTEGRAL, DAMA, FERMI ...



511 keV line by INTEGRAL



Excess of positrons - PAMELA

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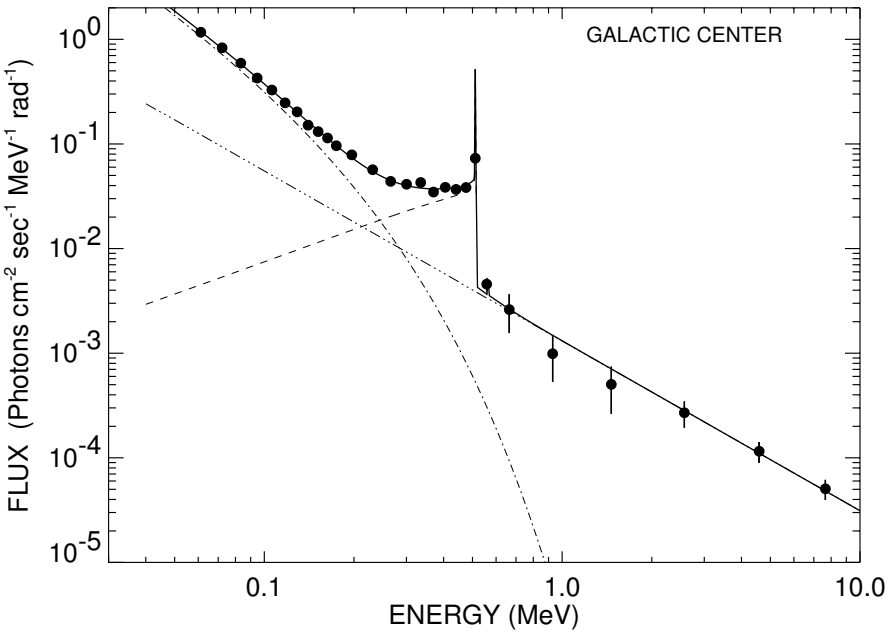

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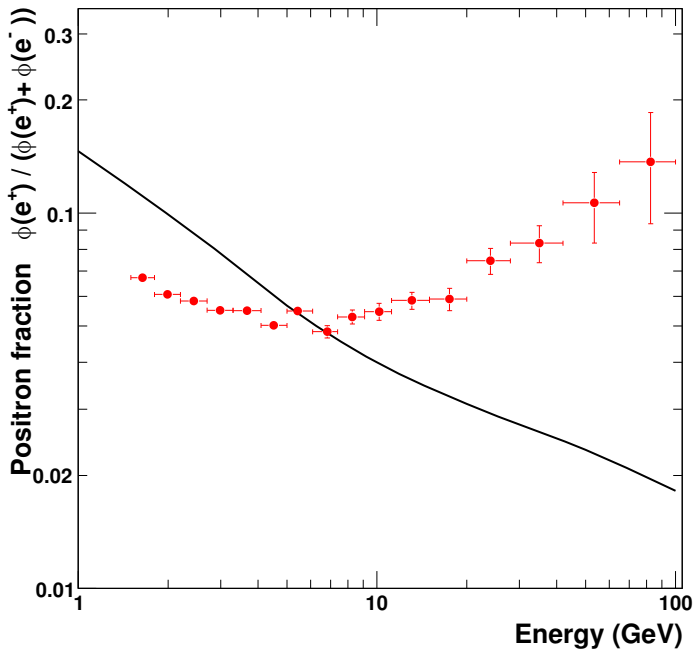
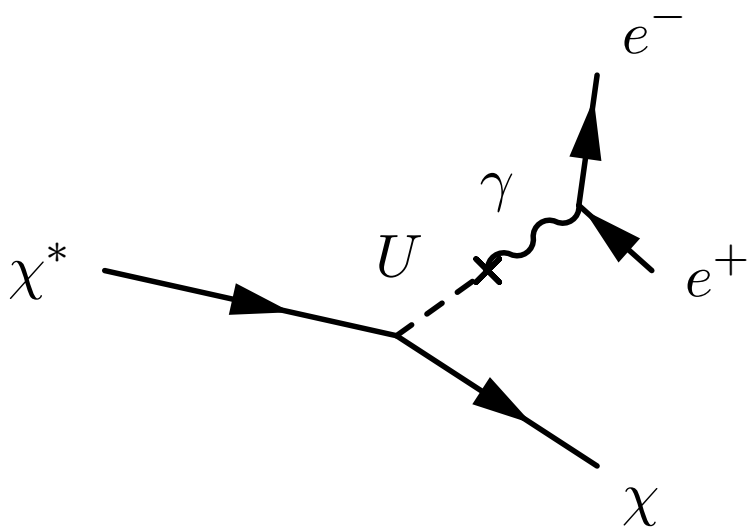
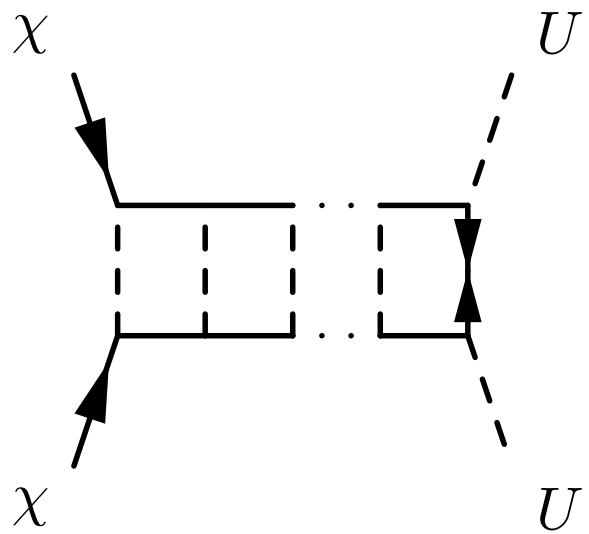


Excess of positrons - PAMELA

Axiom 2: Data due to DM

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





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

Flavour factories, an ideal enviroment

- Low energy $\sim$ GeV ($\sigma \propto E^{-2}$);
- high luminosity (up to ab^{-1} at BaBar/Belle);
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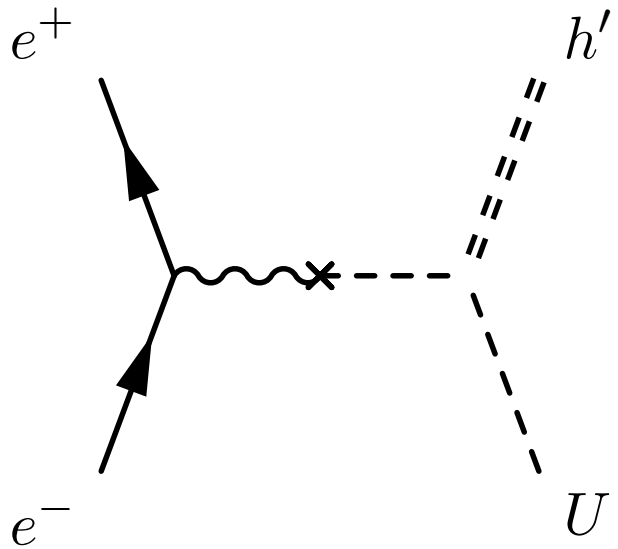

$l^+l^- + \not{E}_T$
$6l \rightarrow 4\epsilon + 2m_U \rightarrow$ tiny
model dependent

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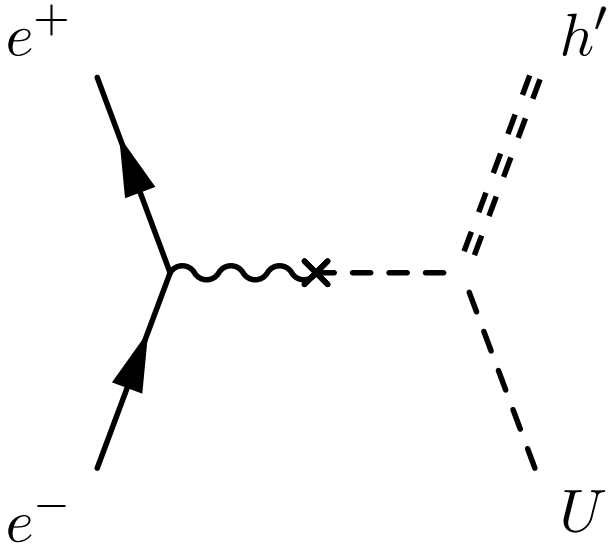

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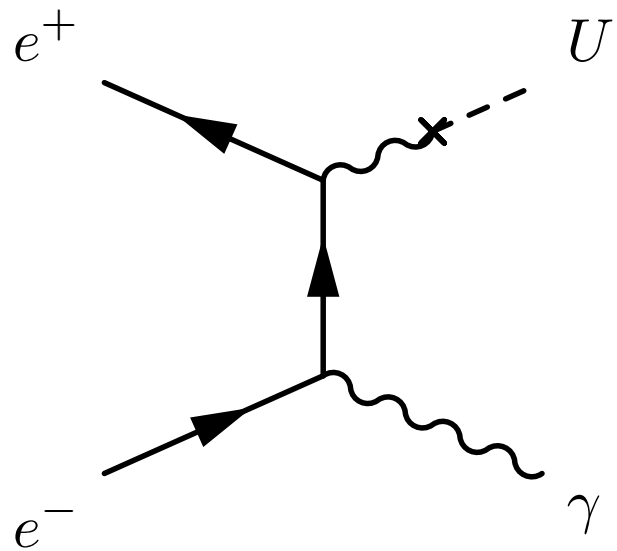
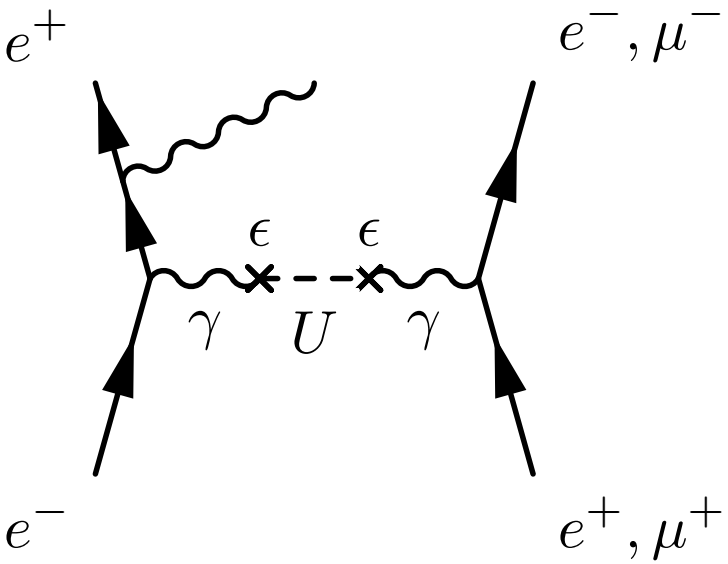


$l^+l^-\gamma$
model independent

A really difficult channel



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

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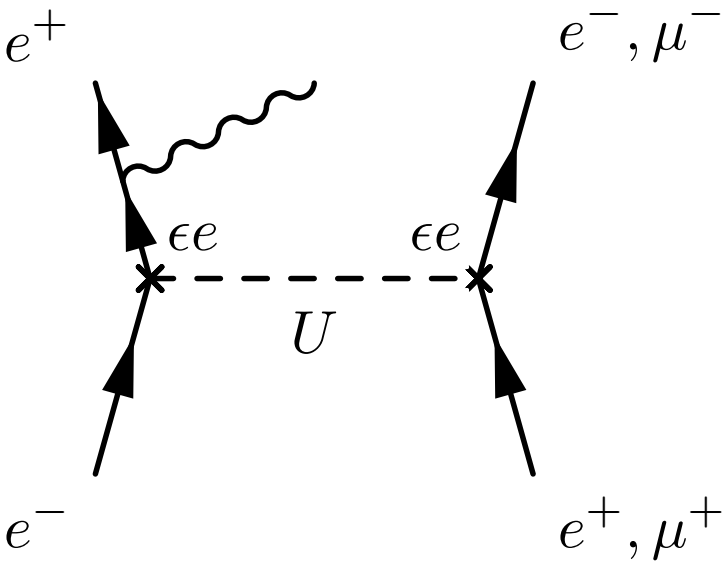

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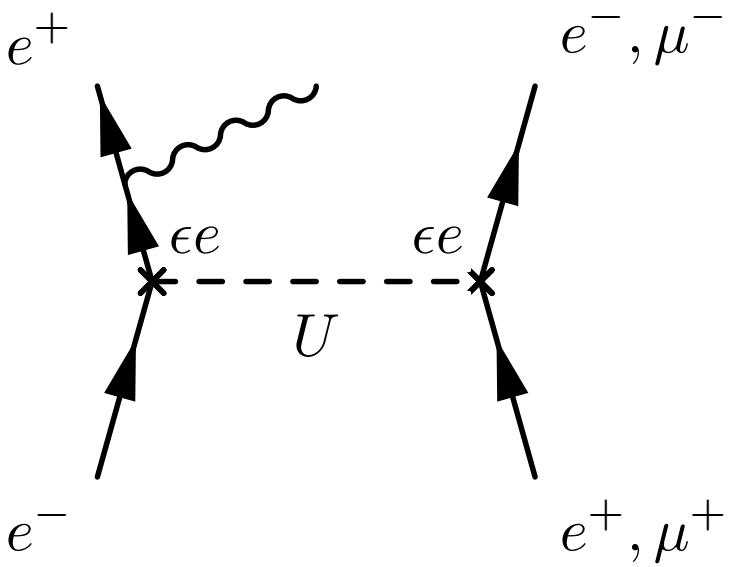
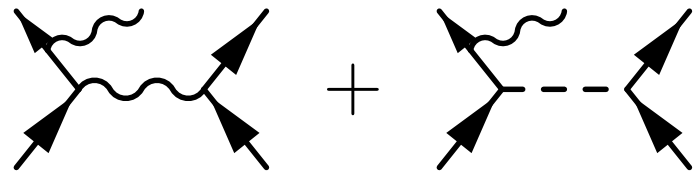


- Resonant channel:
  - particular signal shape $\neq$ BG;
- radiative return:
  - energy scan;

- 2nd order process,
- 2 ϵ:
  - 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

$$\Big| \quad + \quad + \cdots \text{ 14 terms for } e^{\pm}\text{, 6 for } \mu^{\pm} \Big|^2$$



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

BabaYaga

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

- Common used for measure flavour factories luminosity:
  - $(g-2)_\mu$, R, $\Delta\alpha_{had}$;
- theoretical error $\sim 1‰$ ($\mathcal{O}(\alpha^2)$) for first order processes.

`http://www.pv.infn.it/hepcomplex/babayaga.html`

A tool for Light Dark Matter at Leptonic Colliders

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

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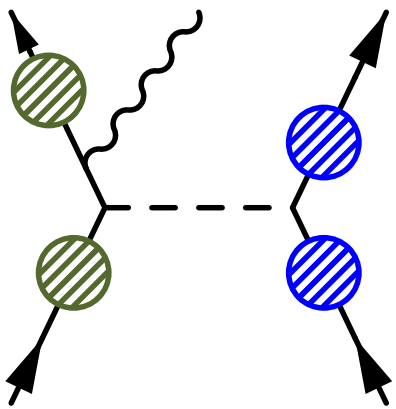
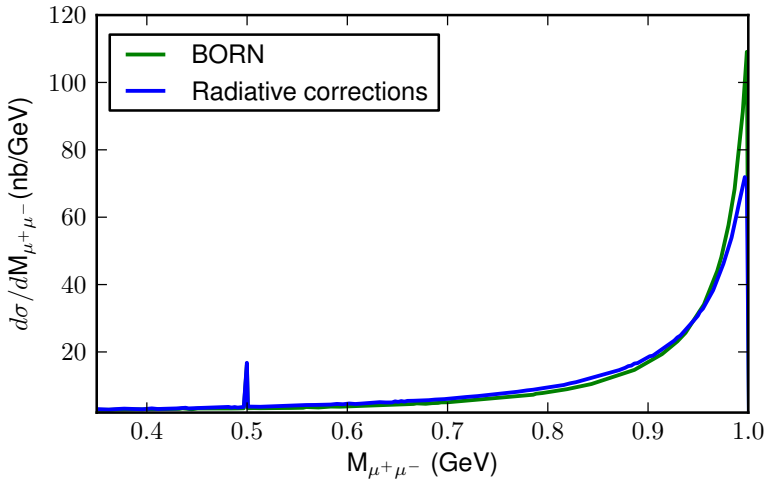
- exact three body kinematics;
- vacuum polarization $\to$ `HADR5N09` routine from Jegerlehner;
- radiative corrections $\to$ ~~structure functions of the electron;~~
  $\to$ not fully implemented
- theoretical error $\mathcal{O}(\alpha)$ (second order processes).





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
```

OUTPUT

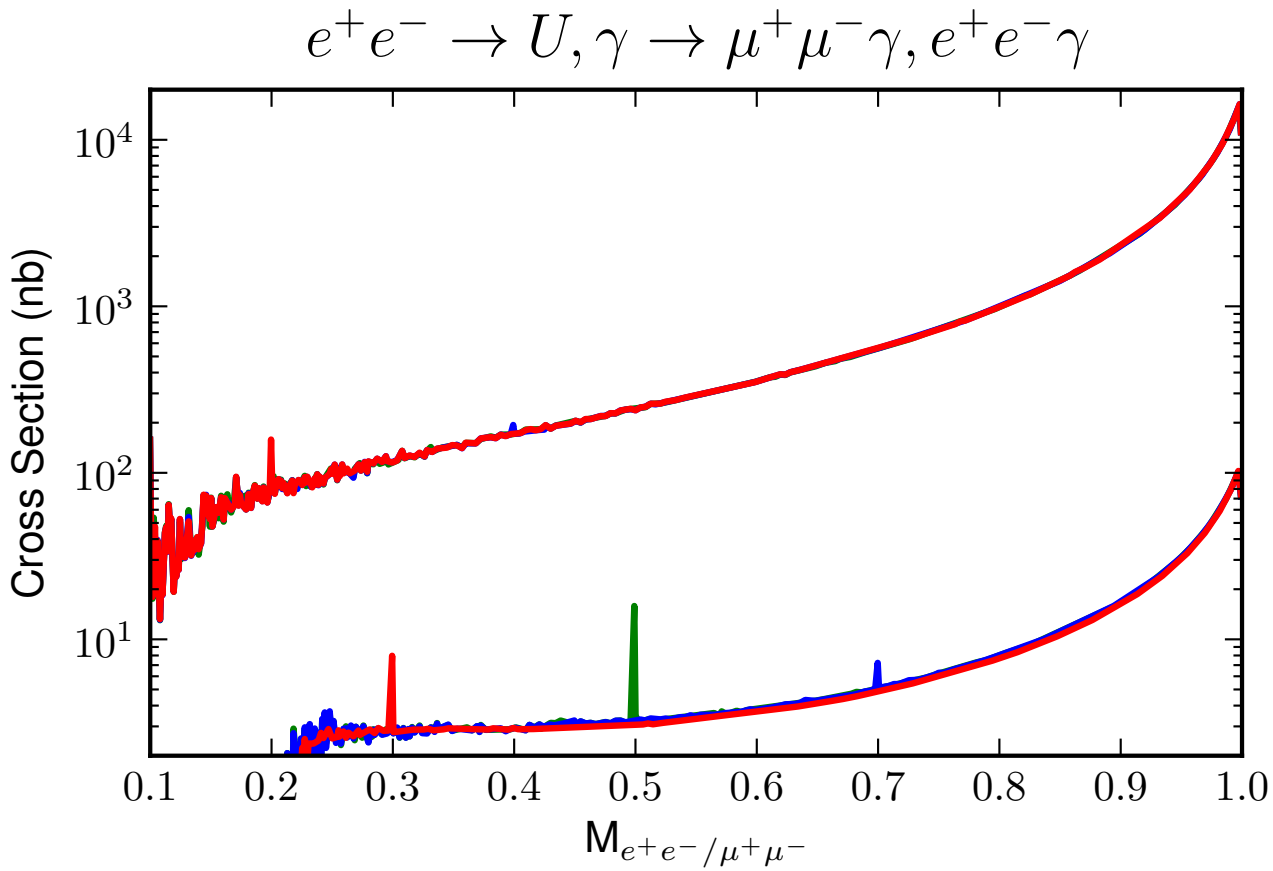
- Cross section;
- distributions of useful quantities;
- simulated events.

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 take into account; possible axial coupling constant (almost ruled out by data).

A possible signal

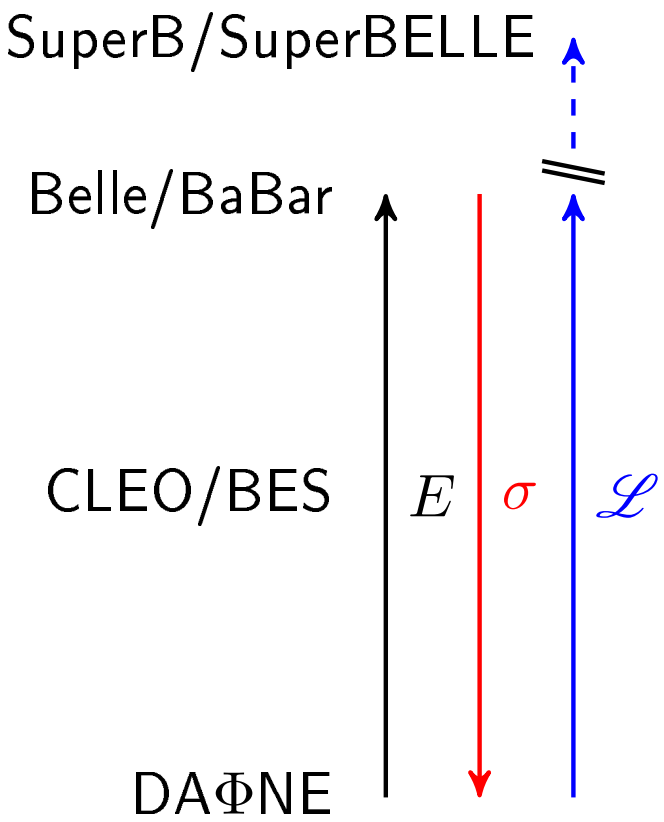


Final state invariant mass for different ϵ and m_U.

- Huge background on e^+e^-

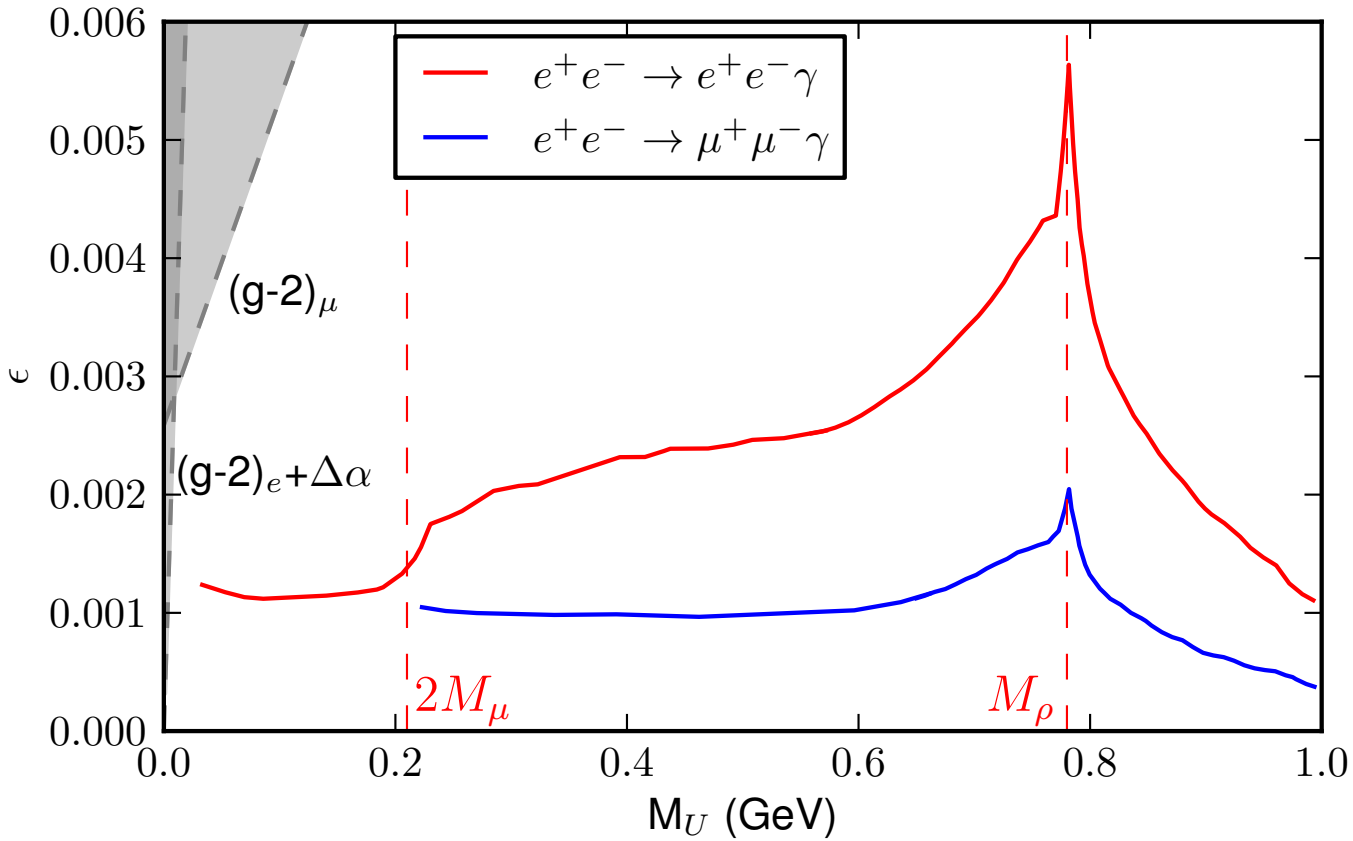
Statistical significance

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



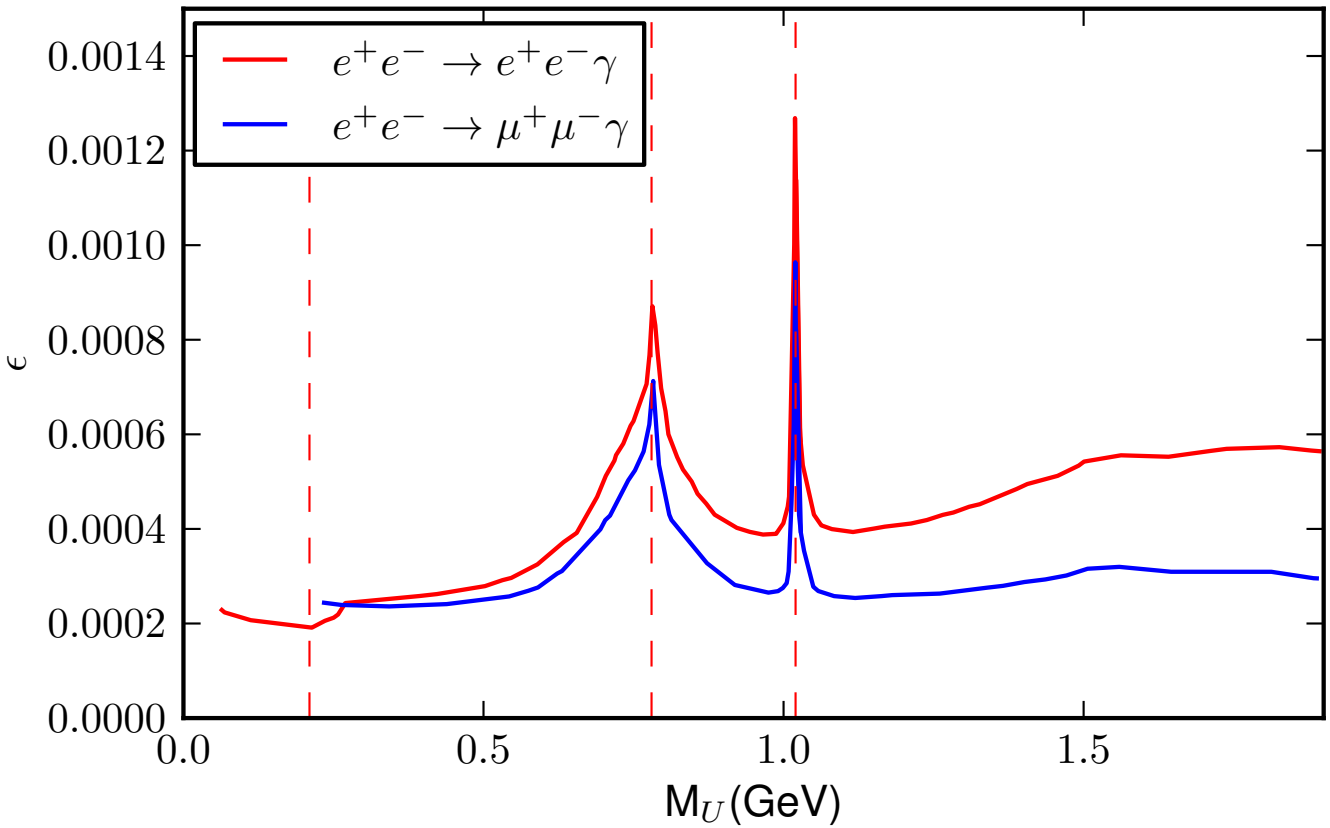
hep-ph[0904.1743] - Reece, Wang
Searching for the light dark gauge boson in GeV-scale experiments

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)

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 possibile signatures;
  - prepare accurate event generators.

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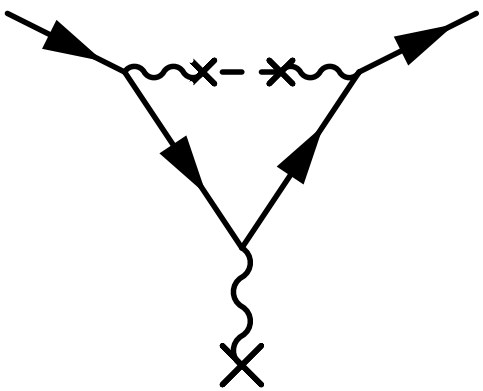
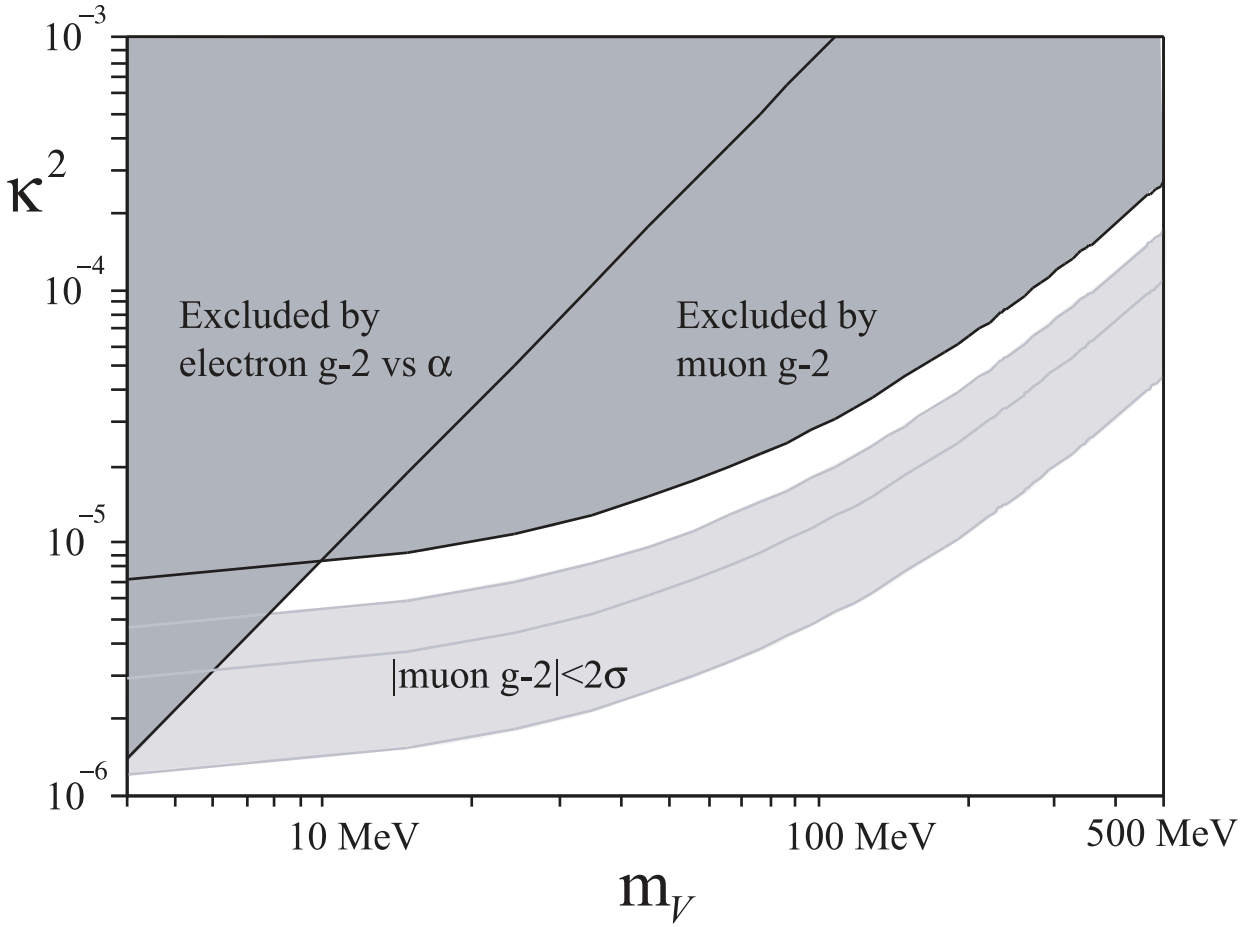
Other useful references

- 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
- Bohem, Fayet
  Scalar Dark Matter candidates
  hep-ph/0305261

THANK YOU!

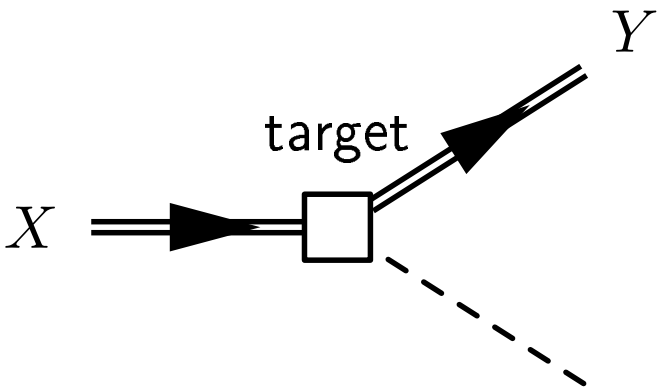
Predictions are testable: anomalous magnetic moment





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

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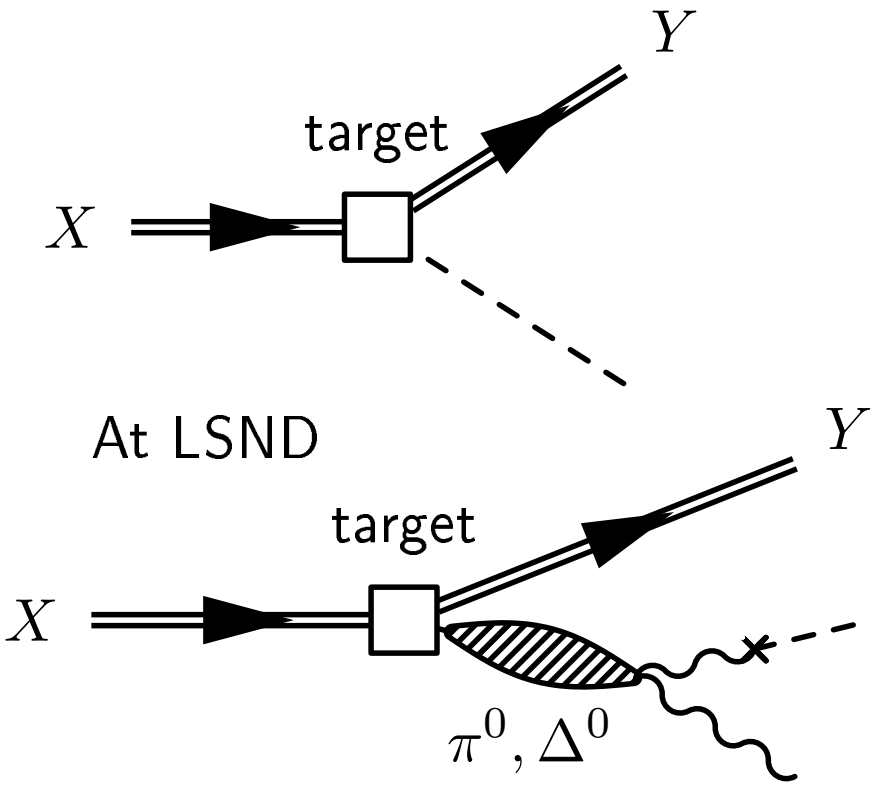

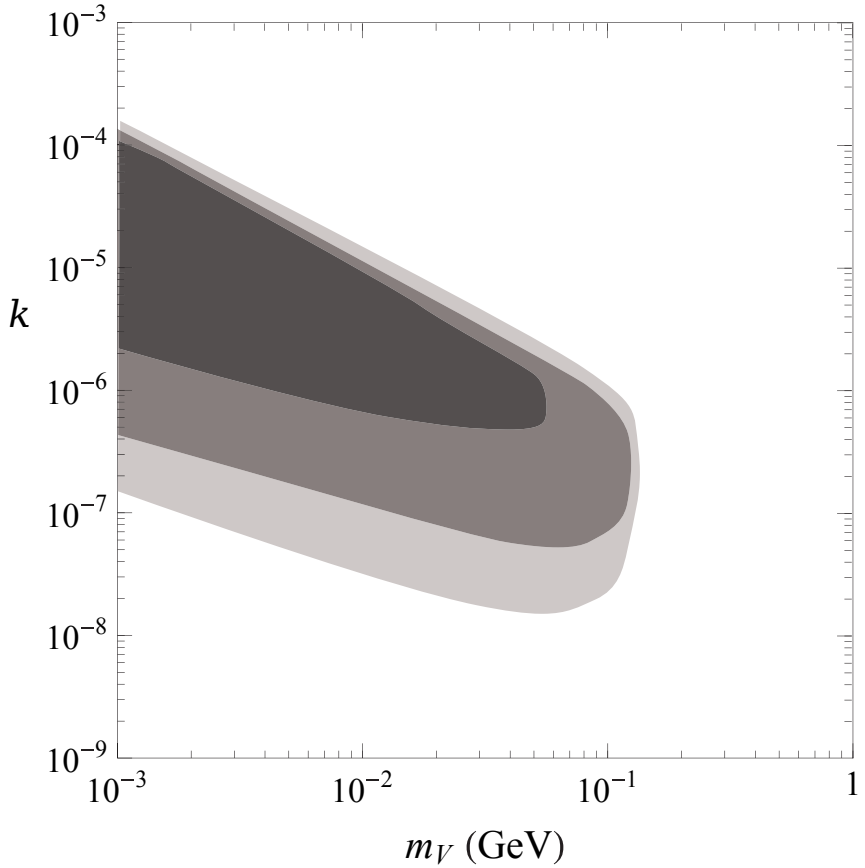

hep-ph[0906.5614] - Batell, Pospelov, Ritz
Exploring portals to a hidden sector through fixed targets

Hidden valley