DP production in e^+ beam dump experiments via resonant e^+e^- annihilation

Cristian David Ruiz Carvajal

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XIX FRASCATI SPRING SCHOOL
"BRUNO TOUSCHEK"
IN NUCLEAR SUBNUCLEAR AND ASTROPARTICLE PHYSICS

COLCIENCIAS COLOMBIA

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

UNIVERSIDAD DE ANTIOQUIA 1803

Outline

- ✔ Beam dump experiments:
  - ✱ Production modes for DP searches
- ✔ Proposal:
  - ✱ Production via resonant $e^+e^- \to A'$
  - ✱ Peculiarities and advantages
- ✔ A specific goal:
  - ✱ Testing the ^{8}Be anomaly for the 17MeV DP
- ✔ Results and conclusions

Fixed target experiments for DP searches

1) e^- beams fixed target experiments

*Electron scattering off nuclei: A' bremsstrahlung

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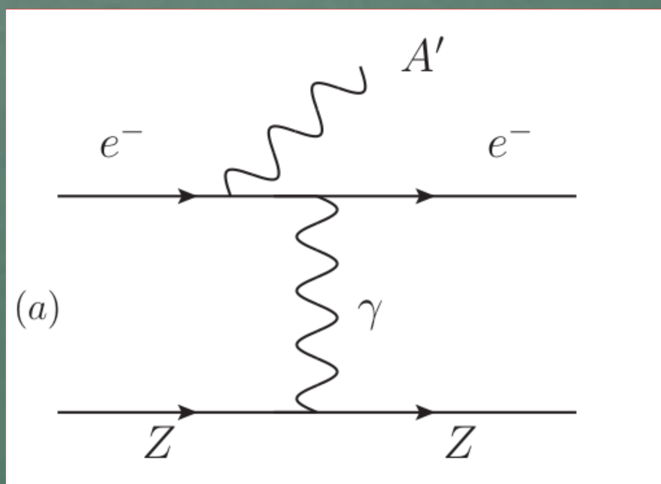

$O(\alpha^3)$ process

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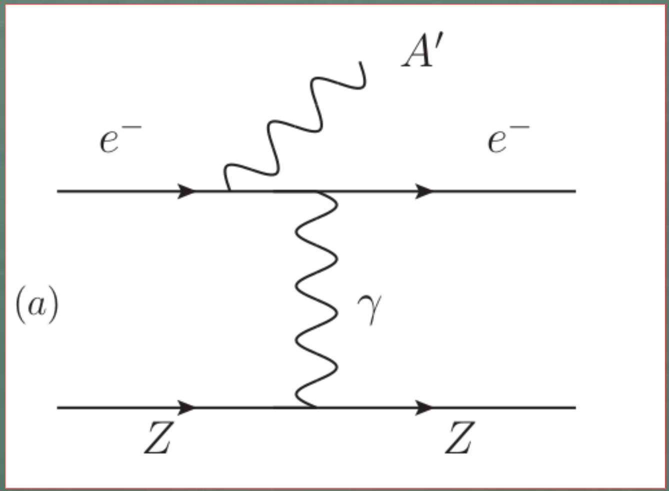

$O(\alpha^3)$ process

Some Experimental searches:

APEX, HPS, DarkLight (JLab) A1, MAGIX (Mainz), NA64 (CERN), (SLAC), (Cornell)...

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*Positron-electron 2-body annihilation $e^+e^- \rightarrow A'\gamma$ (analogous of $e^+e^- \rightarrow \gamma\gamma$)

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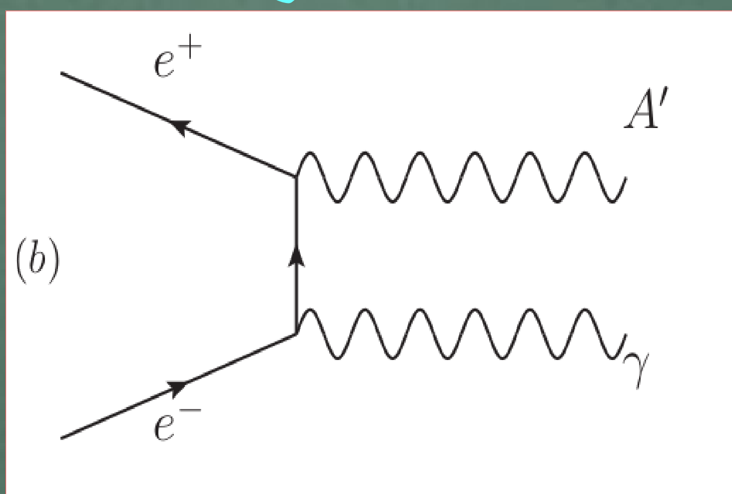

$O(\alpha^2)$ process

Some positron beam experiments (proposed):

VEPP3 (BINP), PADME (LNF), MMAPS (Cornell)

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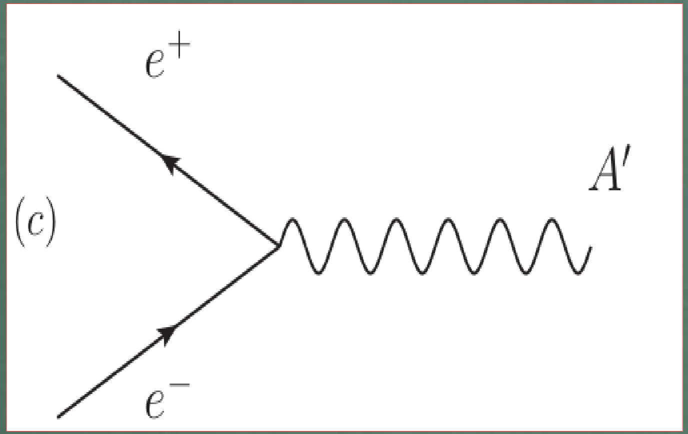

O(α) process

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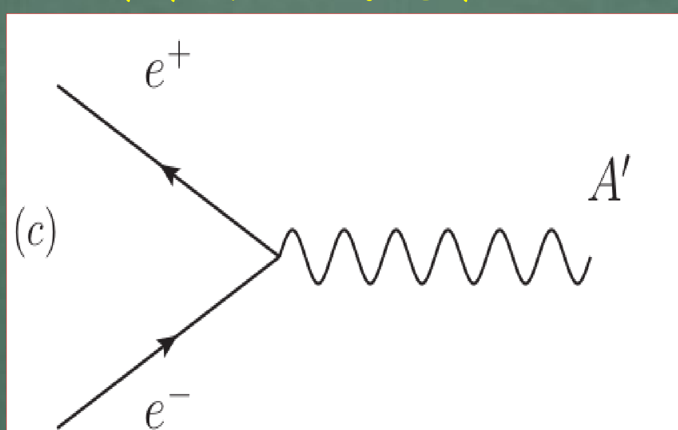
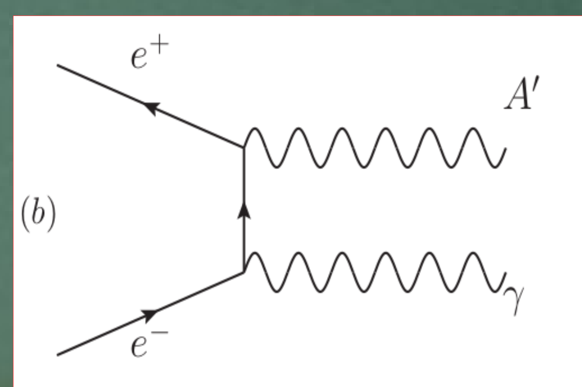
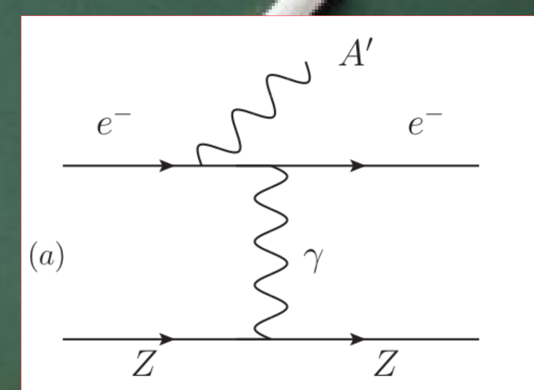


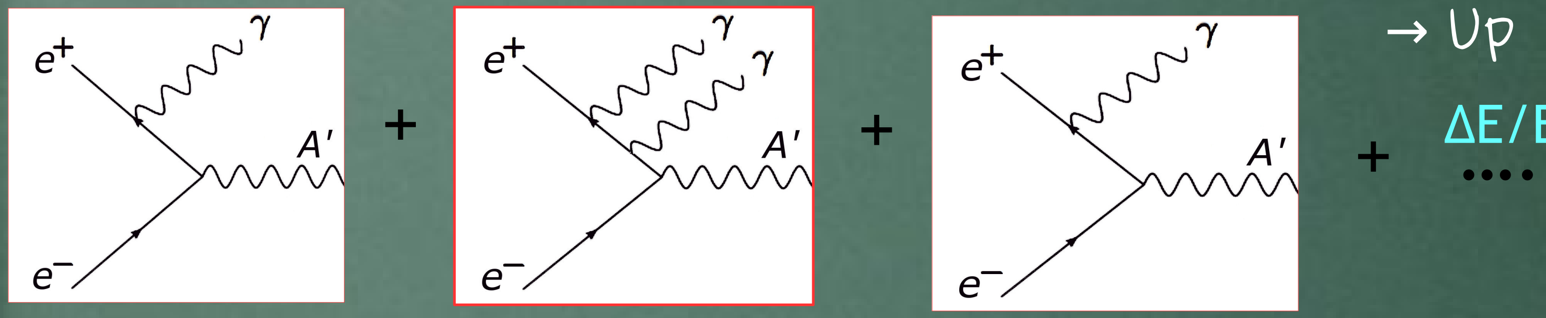
$O(\alpha)$ process





Peculiarities and advantages

**"Radiative return" helps enhancing the cross section by "widening" the resonance.



→ Up to energies

$\Delta E/E \sim 1\%$

→ The emission can radiatively enhance the resonance width, and thus the production rate.

Peculiarities and advantages

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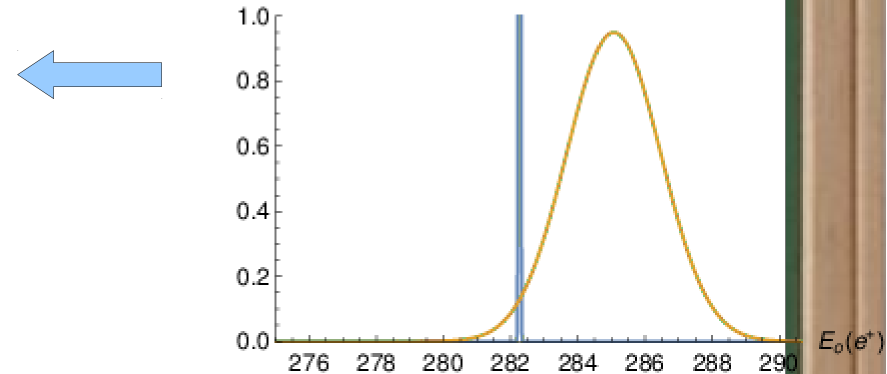

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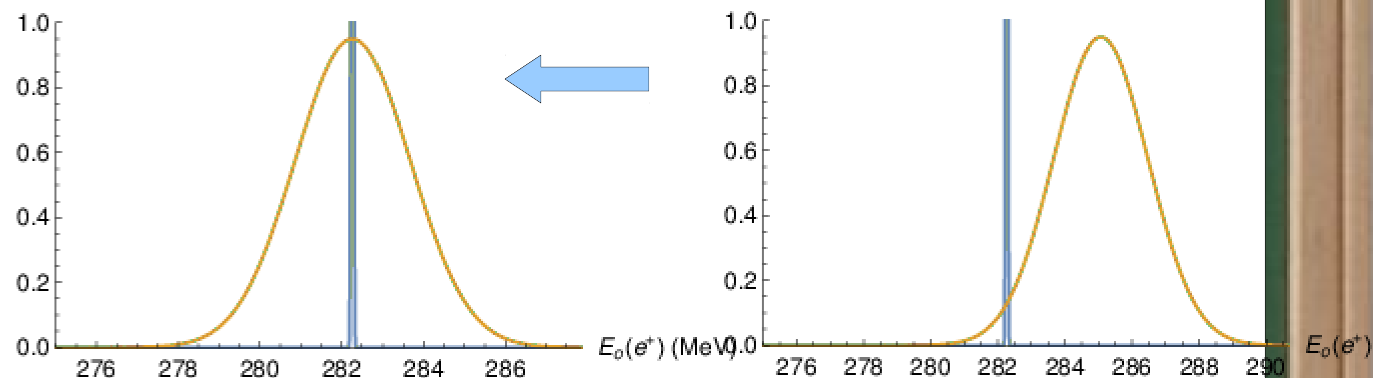

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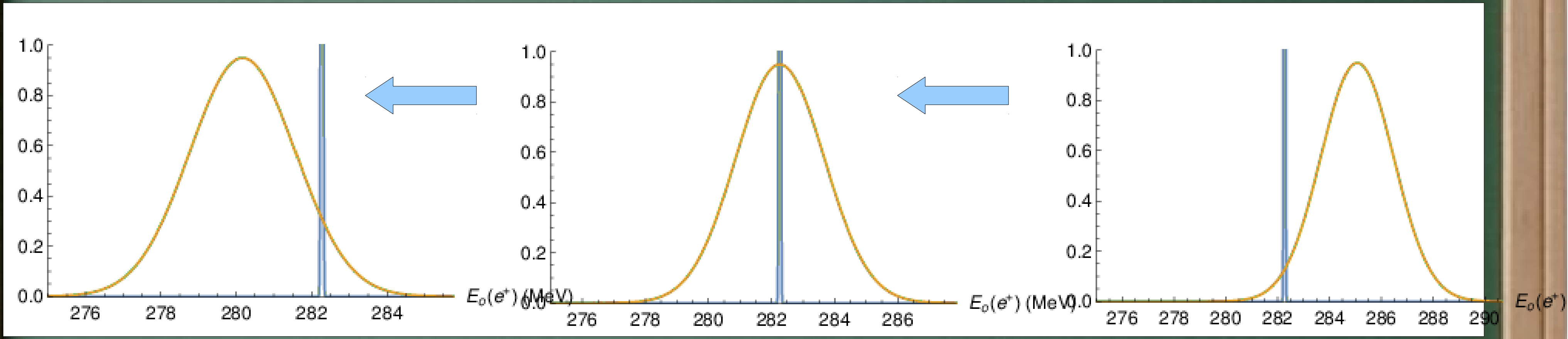

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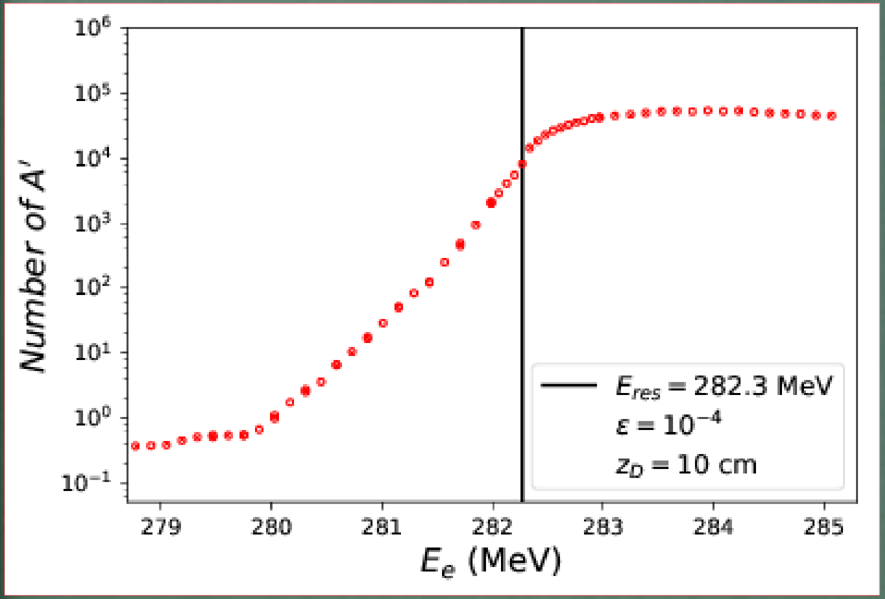

Number of DP outside the dump

→ $m_{A'} = 17$ MeV

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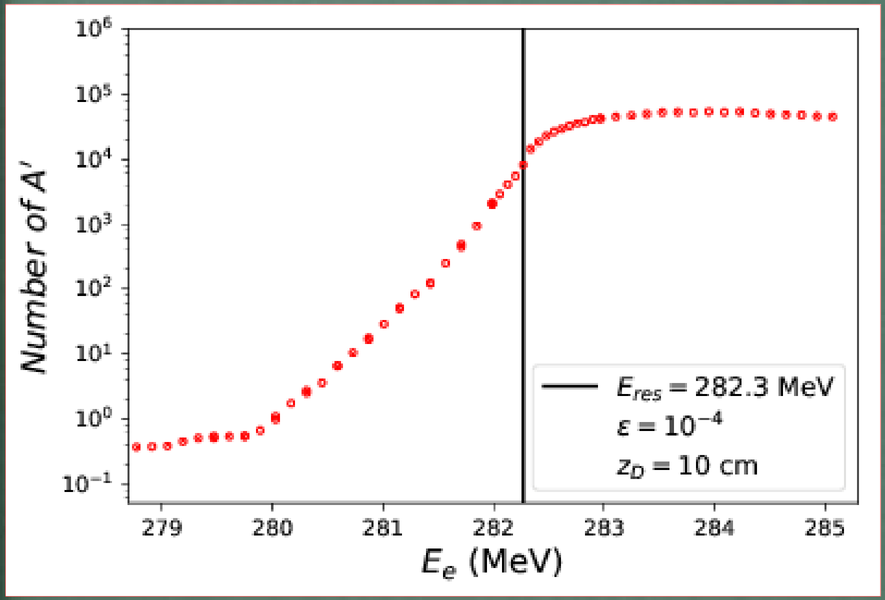


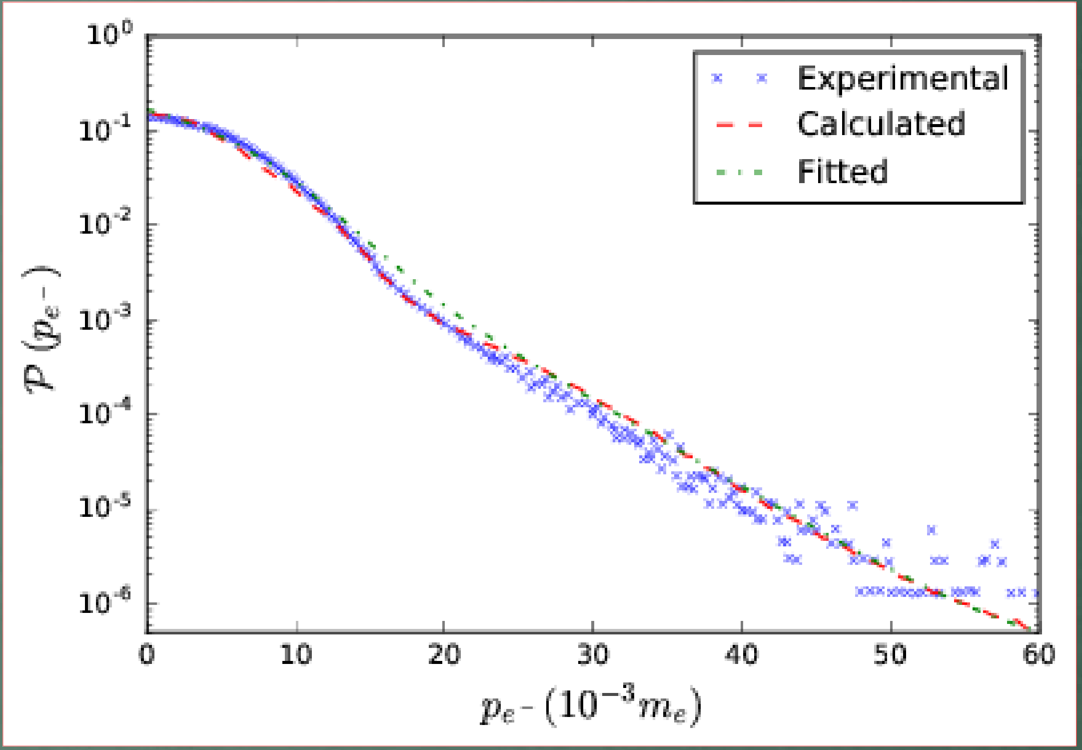
Number of DP outside the dump

→ mA' = 17 MeV

* Modifications of A' production rates from momentum distribution of target electrons (which are not at rest).

$P(p_{e^-})$ distribution

→ Measured in the Doppler broadening of the e+e− → γγ radiation.



e+ annihilation probability as a function of the target e− momentum (for tungsten).

Figure adapted from V. J. Ghosh et al. Phys. Rev. B(2000)

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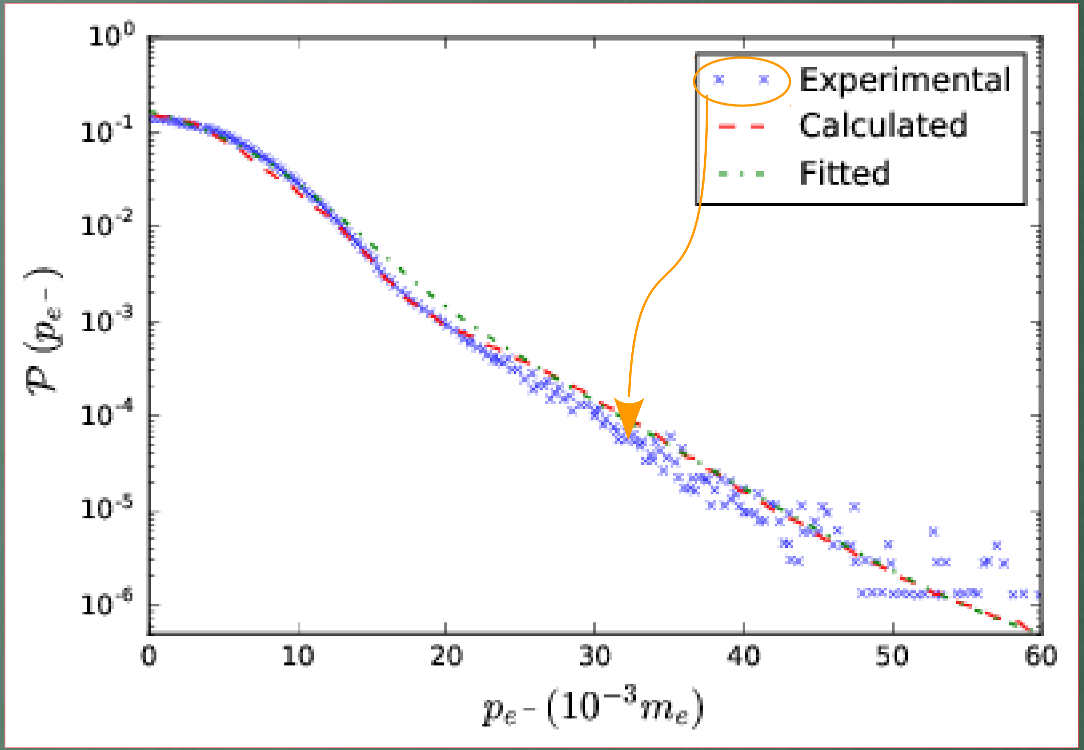

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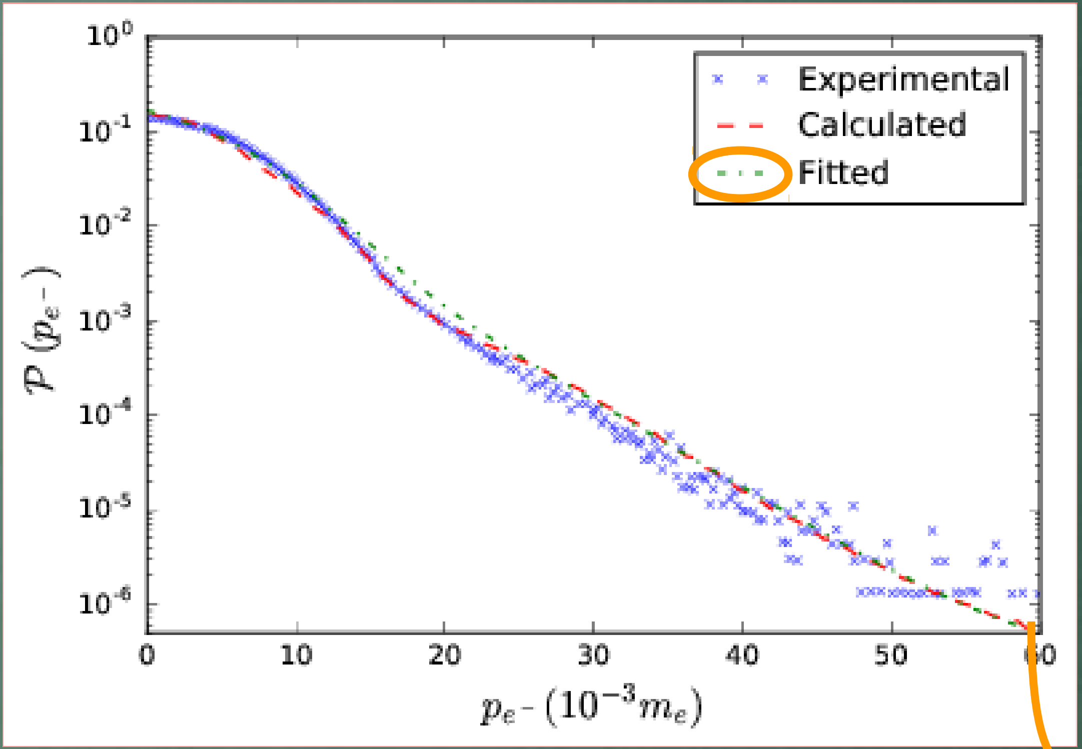

e+ annihilation probability as a function of the target e− momentum (for tungsten).

$$P(P_z) = \frac{1}{12}\left[1.015^{-p_z^2} + 1.112^{-2p_z} + 3\Theta(p_z - 50) \times 10^{1/p_z - 6}\right]$$

Effects of electrons velocities

To take into account the ve−, the Mandelstam variable s in the cross section is replaced by

$$s(v_e, \chi) = 2m_e \left[E_e \left(1 - \mathcal{P}(v_e) v_e \frac{1}{2} s_\chi c_\chi \right) + m_e \right]$$

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→ Probability distribution for the angle χ.

→ Projection of v_{e^-} along the direction of the incoming e^+.

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$\epsilon \Big/ N_{A'}^{\rm prod}$	$E_{\rm res}\ (v_e=0)$	$E_{\rm res}$	$E_{\rm res}+2\sigma_b$
1.0×10^{-3}	7.69×10^{11}	1.51×10^{11}	4.72×10^{11}
5.0×10^{-4}	1.81×10^{11}	3.79×10^{10}	1.17×10^{11}
1.0×10^{-4}	7.25×10^{9}	1.49×10^{9}	4.73×10^{9}

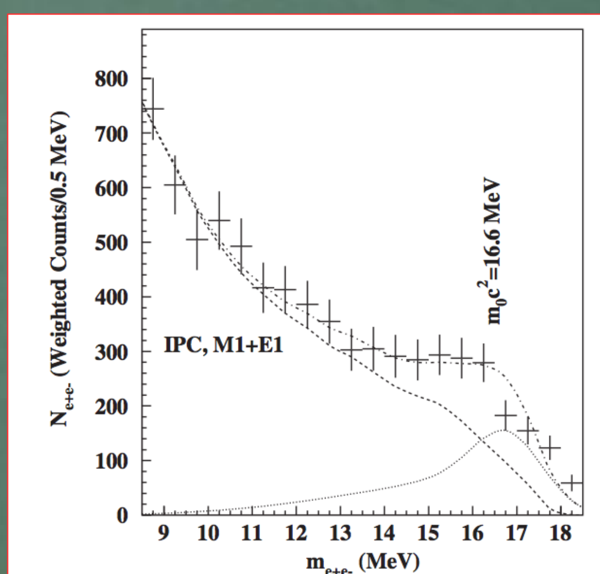
mA' =17 MeV

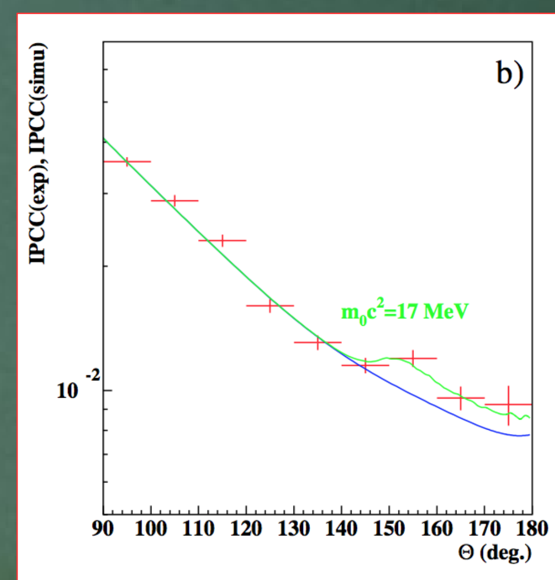
The Atomki anomaly in ^{8}Be nuclear decays

A bump in the opening angle and invariant mass distributions of e+e− pairs produced in the decays of an excited $^{8}Be^{*}$ nucleus.

→ A high statistical significance (6.8 σ)

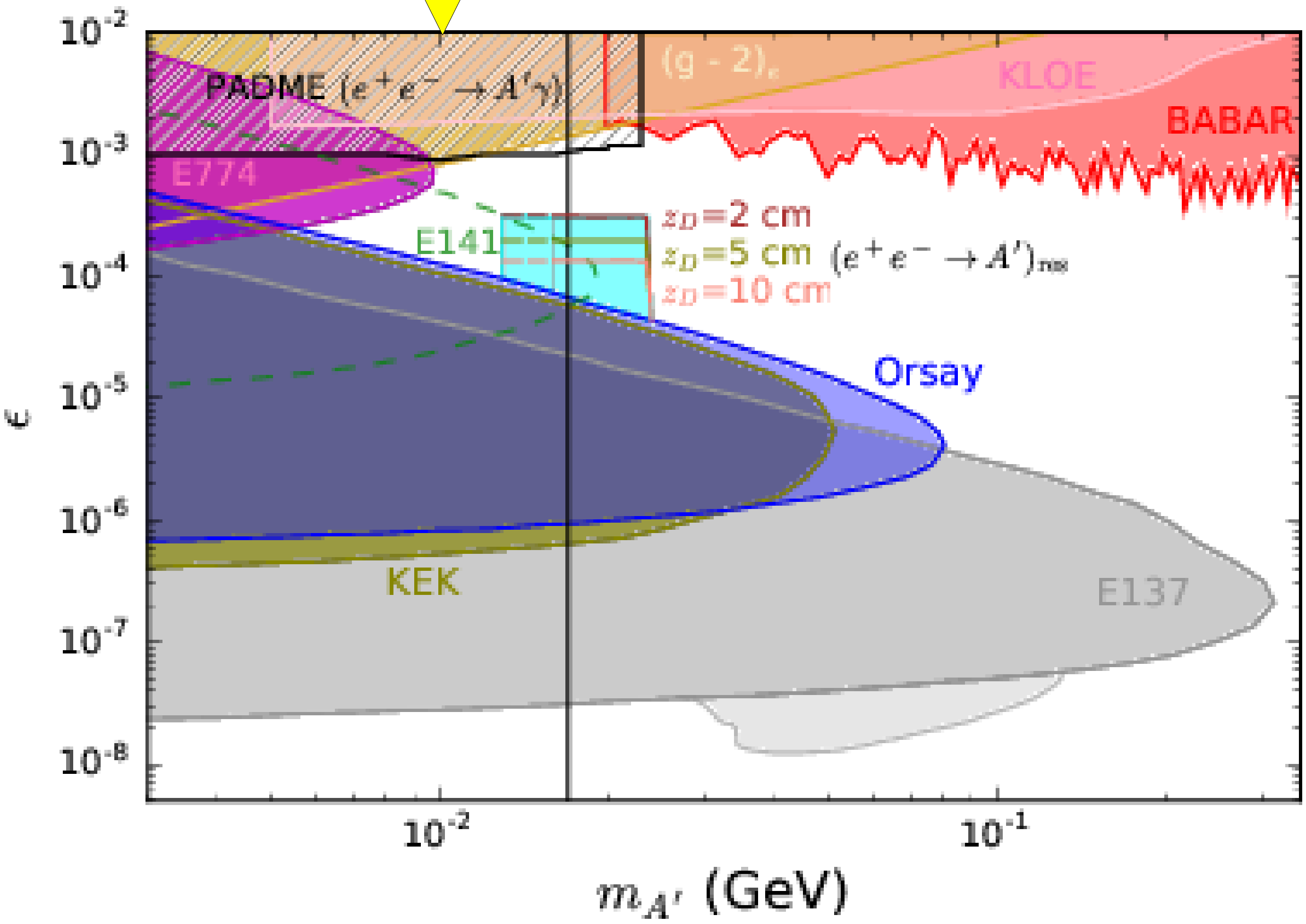
→ The shape of the excess is consistent with that expected if a new particle with mass $m_{A'} = 17.0 \pm 0.2(stat) \pm 0.5(sys)$ MeV is produced in the $^{8}Be^{*}$ decay.





A. Krasznahorkay et al. PRL117,071803,2016

Results



DP parameter space

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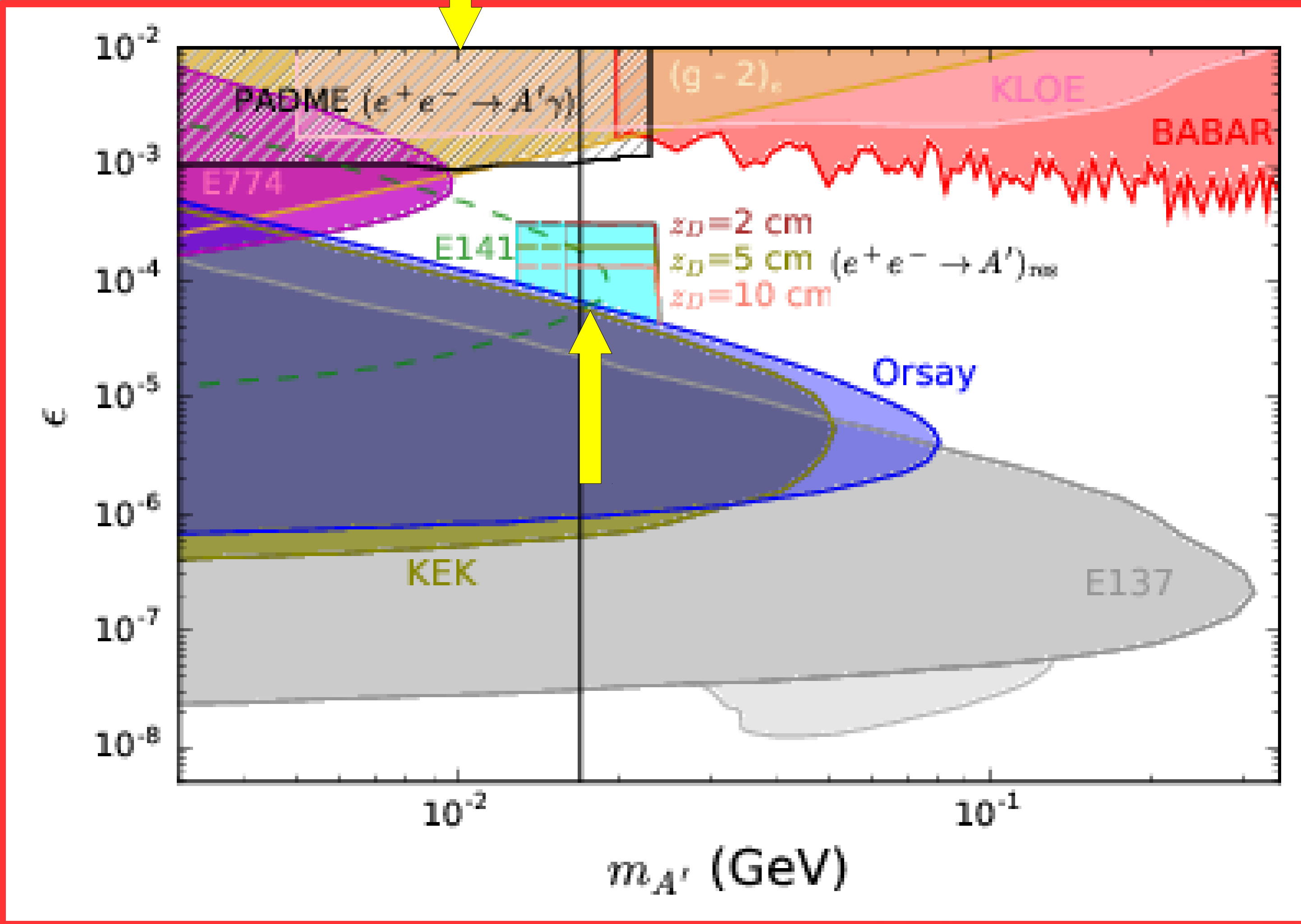

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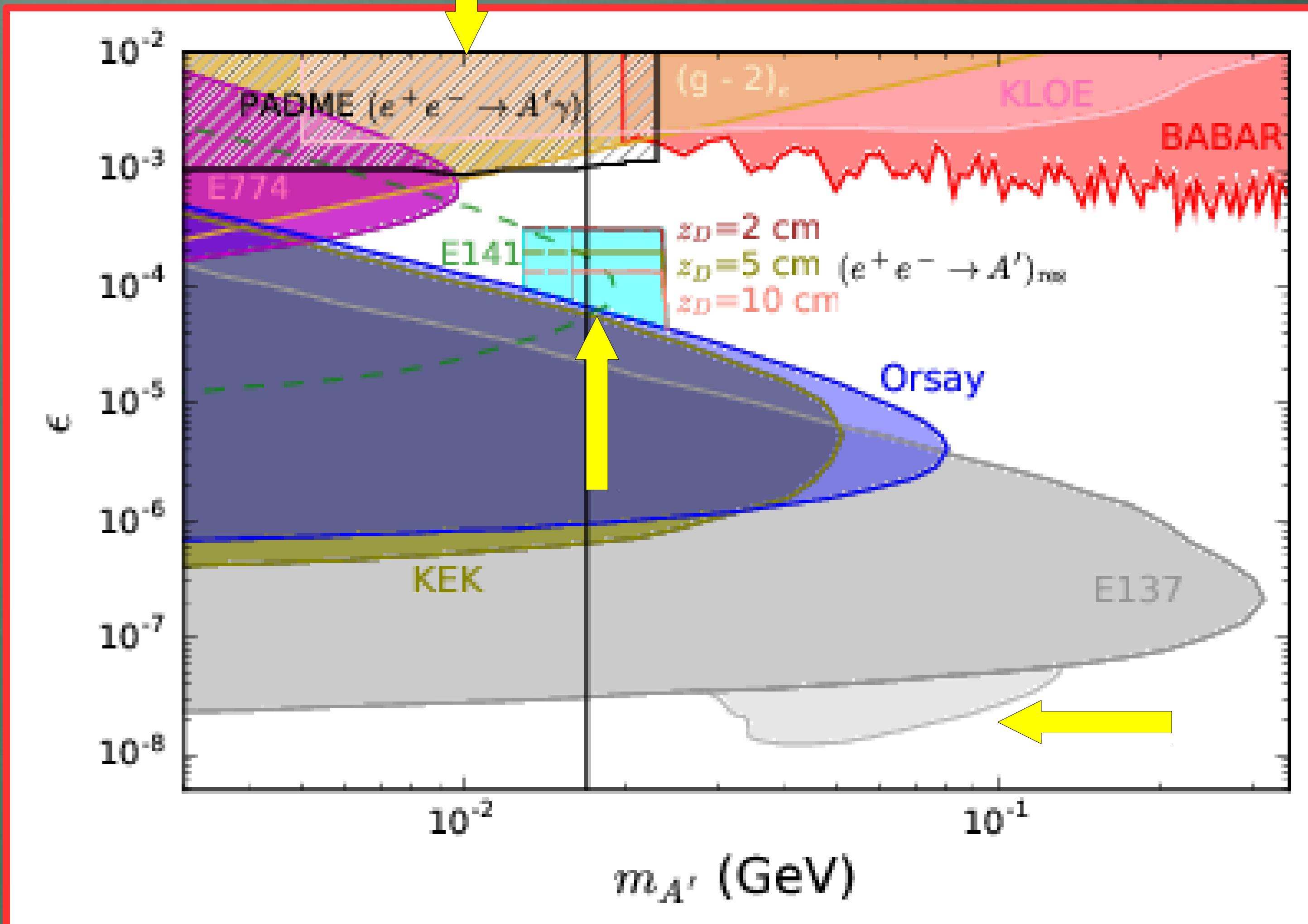

DP parameter space

Conclusions

A new way to search DP, coupled to e+e− pairs, via resonant production in e+e− annihilation is suggested as an alternative method to test new physics at high-intensity accelerators.

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A new way to search DP, coupled to e+e− pairs, via resonant production in e+e− annihilation is suggested as an alternative method to test new physics at high-intensity accelerators.

With this alternative is possible cover the center of mass energy needed to produce, via resonant e+e− annihilation, the $m_{A'} = 17$ MeV DP invoked to explain the anomaly ^{8}Be.

Thank you !

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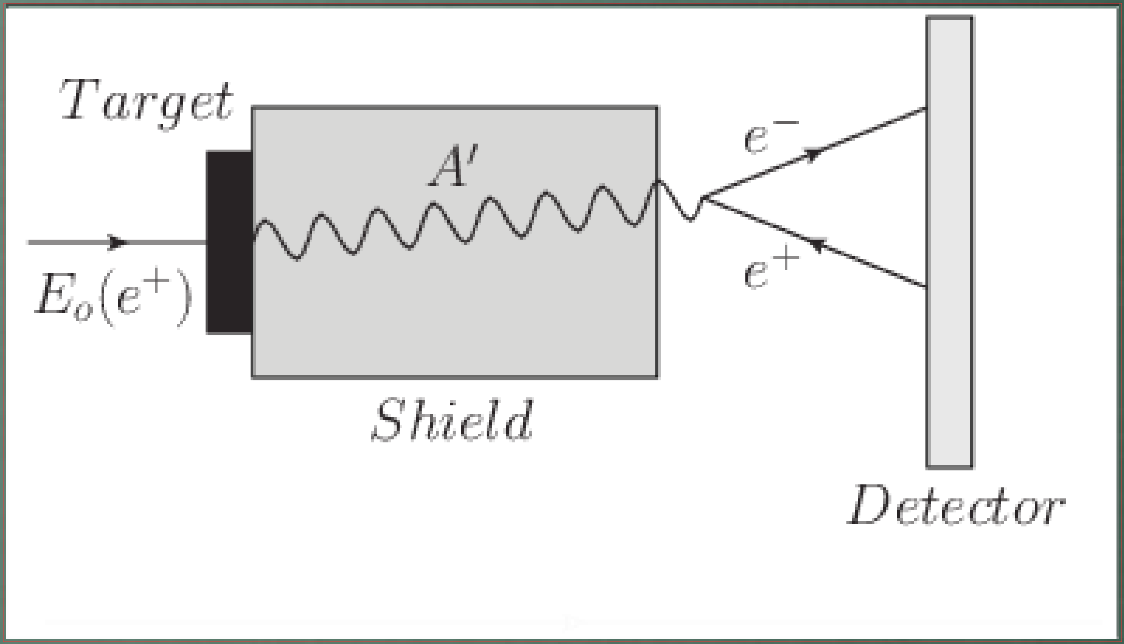
Sketch of the setup of a positron beam dump experiment



Comparing A' production modes

Production mode	E_{beam} (MeV)	T [integration]	A' produced
Bremsstrahalung (e^-)	550	0.5	4.1×10^7
Annihilation (e^+)	550	0.5	8.7×10^8
Resonant (e^+)	E_{res}=282 MeV	[0 - 0.5]	7.2×10^9
Resonant (e^+)	$E_{res} + 2\sigma_{beam}$	[0 - 0.5]	12.2×10^9

Momentum distribution of electrons in tungsten

Electron shell	n_{nl}	$Z_{\rm eff}$ [21]	$\langle v_{nl} \rangle$
1s	2	72.57	0.53
2s	2	54.67	0.40
2p	6	69.57	0.51
3s	2	51.87	0.38
3p	6	52.62	0.38
4s	2	40.56	0.30
3d	10	60.45	0.44
4p	6	39.55	0.29
5s	2	23.54	0.17
4d	10	37.17	0.27
5p	6	21.33	0.16
6s	2	9.85	0.07
4f	14	34.71	0.25
5d	4	16.74	0.12

Table I. Tungsten electron structure, effective nuclear charge $Z_{\rm eff}$ (taken from [21]) and average electron velocity for each electron subshell. In the second column n_{nl} is the number of electrons in each subshell.

The average velocities for each subshell are estimated via the virial theorem.
This gives an indication of the relevance of including the target electrons momentum.

Comparing with carbon

Electron shell	n_{ln}	$Z_{\rm eff}$ [21]	$\langle v_{nl} \rangle$
1s	2	5.67	0.04
2s	2	3.22	0.02
2p	2	3.14	0.02

Table II. Carbonium electron structure, effective nuclear charges $Z_{\rm eff}$ [21] and average electron velocity for each electron subshell. In the second column n_{nl} is the number of electrons in each subshell.