NRNU MEPhI
Particle physics department (N40)

Search for possibility of FSR suppression in specific dark matter models explaining cosmic positron data

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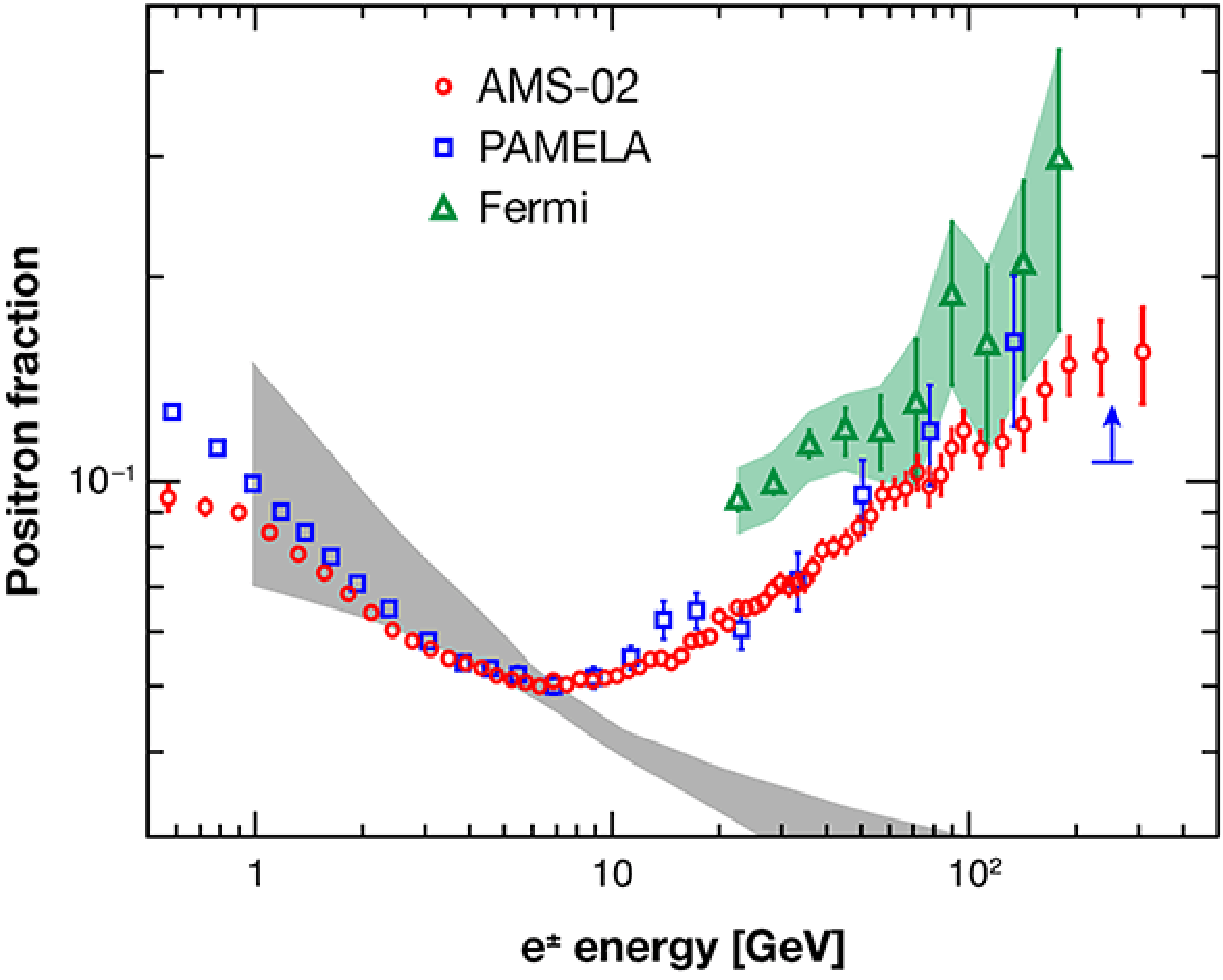
Cosmic antiparticle rays experiments

Pamela
Спутник: Ресурс ДК1
Since: 15 june 2006

АМС-02
Установлен на МКС
Since: 16 may 2011

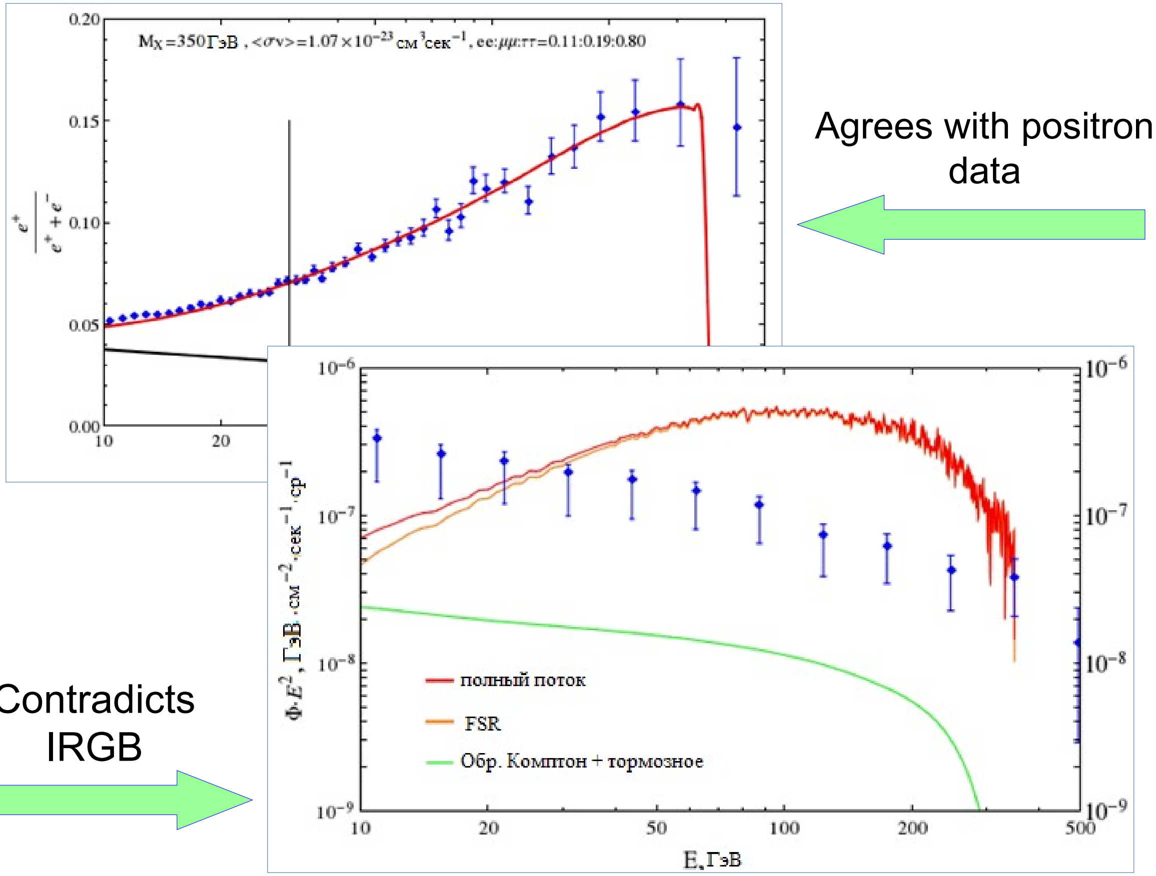
Fermi-LAT
Космический гамма телескоп
Since: 11 june 2008

Positron anomaly



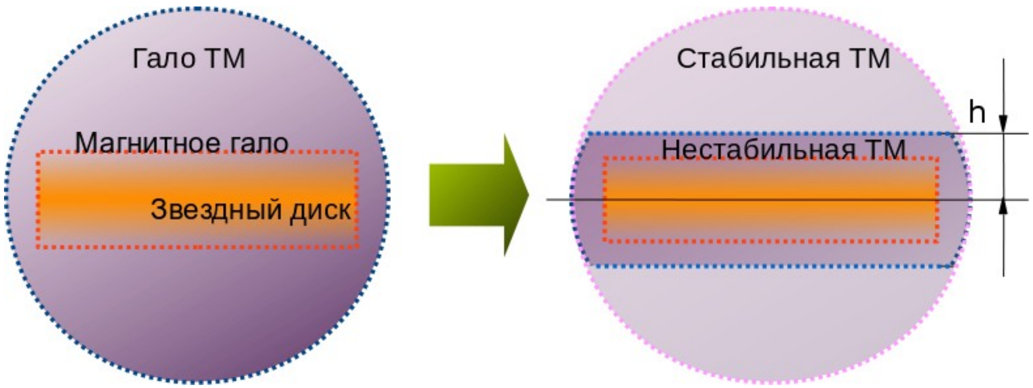
Tension with gamma data

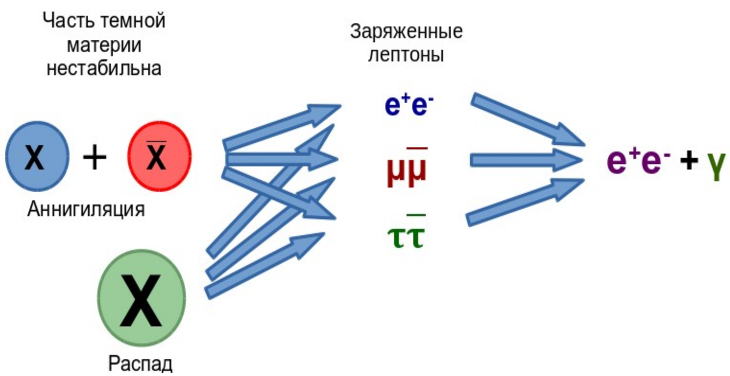
Agrees with positron data



Contradicts IRGB

Possible ways of gamma suppression



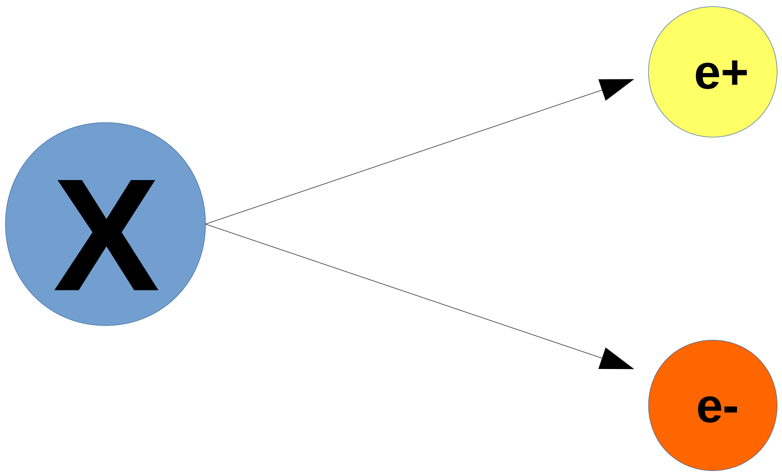


- Due to space DM distribution
- Physics of DM interaction
- ???

???

Possible DM interaction types

We consider two-lepton decays of unstable DM



DM particle X can be:

Scalar:

$$\mathscr{L}_{scalar} = X\overline{\psi}\psi$$

Pseudoscalar:

$$\mathscr{L}_{scalar\gamma^5} = X\overline{\psi}\gamma^5\psi$$

Vector:

$$\mathscr{L}_{vector} = \overline{\psi}\gamma^\mu\psi X_\mu$$

Axial vector:

$$\mathscr{L}_{vector\gamma^5} = \overline{\psi}\gamma^\mu\gamma^5\psi X_\mu$$

Parametrisation of interaction Lagrangian

The idea is to use different combinations of vector and pseudo-vector coupling, or scalar and pseudoscalar, to understand which coupling constants must be chosen in order to suppress a photon.

$$\mathscr{L}_{scalar} = X\overline{\psi}(a + b\gamma^5)\psi$$

$$\mathscr{L}_{vector} = \overline{\psi}\gamma^\mu(a + b\gamma^5)X_\mu\psi$$

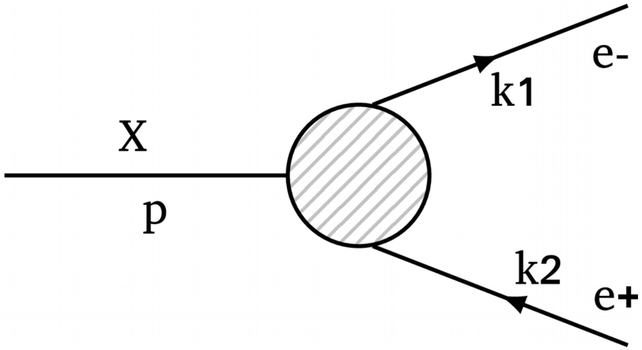
Then suppression of the photon will mean that:

$$\frac{\sigma(X \to e^+e^-\gamma)}{\sigma(X \to e^+e^-)} = min$$

Calculations for scalar DM particle

The calculations were made manually. For verification, the Wolfram Mathematica FeynCalc package was used.

Two-particle decay: X → e+ e-



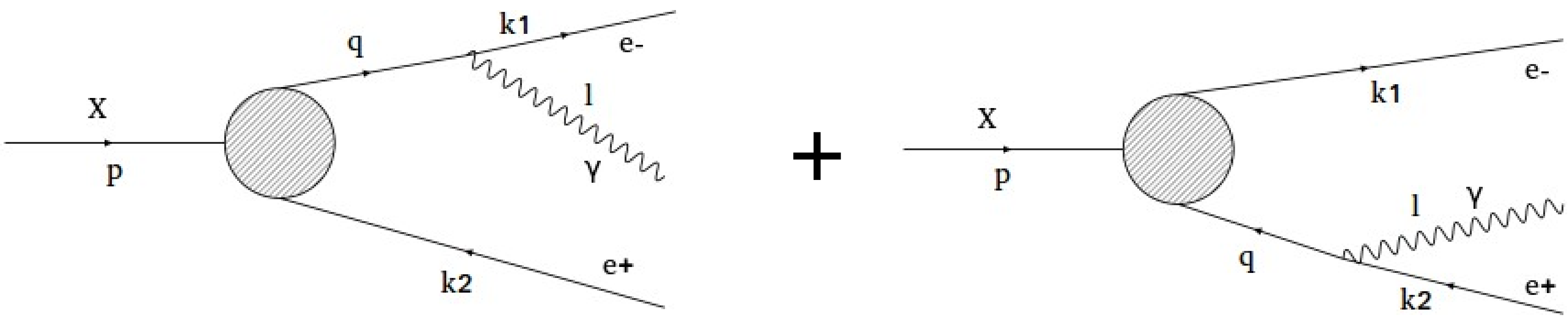
$$\mathscr{L}_{scalar} = X\overline{\psi}(a + b\gamma^5)\psi$$

$$\mathrm{M} = \overline{u}(a + b\gamma^5)v$$

$$|M|^2 = u_1(a + b\gamma^5)v_2\overline{v_2}(a - b\gamma^5)u_1 =$$
$$= Tr(\widehat{k_1}(a + b\gamma^5)\widehat{k_2}(a - b\gamma^5)) =$$
$$= (a^2 + b^2)Tr(\widehat{k_1}\widehat{k_2}) = 4(a^2 + b^2)(k_1 k_2)$$

Calculations for scalar DM particle

Three-particle decay: **X → e+ e- γ**



$$M = \frac{\overline{u_1}(a+b\gamma^5)(\widehat{k_2}+\widehat{l})\gamma^\mu\epsilon_\mu v_2}{(k_2+l)^2} + \frac{\overline{u_1}\gamma^\mu\epsilon_\mu(\widehat{k_1}+\widehat{l})(a+b\gamma^5)v_2}{(k_2+l)^2}$$

$$|M|^2 = 16(a^2+b^2)[\frac{(k_1 l)(k_2 l)}{(k_1+l)^4} - 2\frac{(k_1 k_2 + k_1 l)(k_1 k_2 + k_2 l)}{(k_1+l)^2(k_2+l)^2} + \frac{(k_1 l)(k_2 l)}{(k_2+l)^4}]$$

Calculations for vector DM particle

$$\mathscr{L}_{vector} = \overline{\psi}\gamma^{\mu}(a + b\gamma^5)X_{\mu}\psi$$

Two-particle decay: **X → e+ e-**

$$\mathrm{M} = \overline{u_1}\gamma^{\mu}(a + b\gamma^5)X_{\mu}v_2$$

$$|M|^2 = \frac{4(a^2 + b^2)(m^2(k_1 k_2) + 2(pk_1)(pk_2))}{m^2}$$

Three-particle decay: **X → e+ e- γ**

$$M = \frac{\overline{u_1}\gamma^{\mu}(a + b\gamma^5)X_{\mu}(\widehat{k_2} + \widehat{l})\gamma^{\nu}\epsilon_{\nu}v_2}{(k_2 + l)^2} + \frac{\overline{u_1}\gamma^{\nu}\epsilon_{\nu}(\widehat{k_1} + \widehat{l})\gamma^{\mu}(a + b\gamma^5)X_{\mu}v_2}{(k_2 + l)^2}$$

$$|M|^2 = 16(a^2 + b^2)[...]$$

Preliminary conclusion

The considered cases do not allow suppressing FSR.

That is we obtained that ratio $$\frac{\sigma(X \to e^+e^-\gamma)}{\sigma(X \to e^+e^-)}$$

does not depend on the parameters *a* and *b* in interaction Lagrangian

One of the possible solutions, which we elaborate now, may be connected with double charged DM particle decay to two positrons

Two-positron decay model:

Double charged DM particle decay to identical particles (positrons) can be described in one of the simple cases in the following way:

$$\mathscr{L}_C = X\overline{\psi^C}(a+b\gamma^5)\psi + X^*\overline{\psi}(a+b\gamma^5)\psi^C$$

The second term implies decay $X^* \rightarrow e^- e^-$
One can suppose a charge assymetry between X^{++} (X) and X^{--} (X^*)

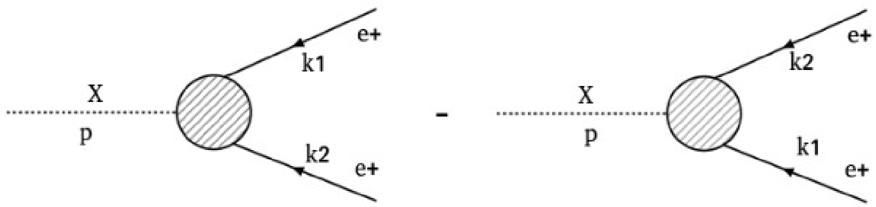
($X^{++}Y^{--}$) - DM candidate

Results for scalar DM particle

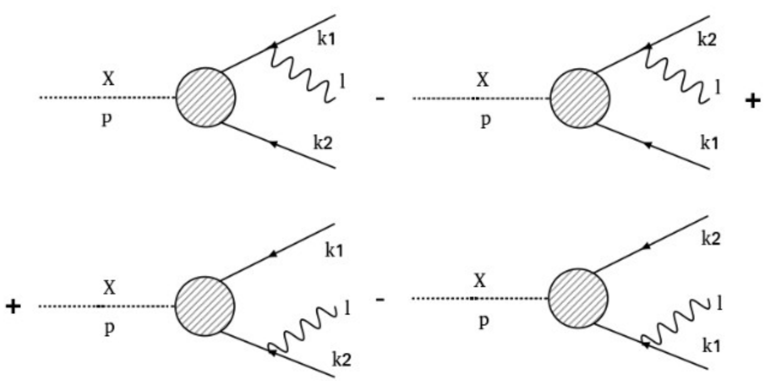
In this case we can consider only one term in interaction Lagrangian

$$\mathscr{L}_C = X\overline{\psi^C}(a + b\gamma^5)\psi$$

Two-particle decay diagram



Three-particle decay diagram:



Results for scalar DM particle

Two-particle decay:

$$M =< k_1 k_2 | X \overline{\Psi}^C (a + b\gamma^5) \Psi | p > - < k_1 k_2 | X \overline{\Psi}^C (a + b\gamma^5) \Psi | p > \; =$$

$$=< k_1 k_2 | X \Psi^T C^T \gamma^0 (a + b\gamma^5) \Psi | p > - < k_1 k_2 | X \Psi^T C^T \gamma^0 (a + b\gamma^5) \Psi | p > \; =$$

$$= v^T(k_1) C^T \gamma^0 (a + b\gamma^5) v(k_2) - v^T(k_2) C^T \gamma^0 (a + b\gamma^5) v(k_1)$$

Three-particle decay:

$$M = \frac{v^T(k_1) C \gamma^0 \gamma^\mu (\hat{k}_1 + \hat{l})(a + b\gamma^5) v(k_2) \epsilon_\mu(l)}{2(k_1 l)} -$$

$$- \frac{v^T(k_1) C \gamma^0 (a + b\gamma^5)(\hat{k}_2 + \hat{l}) \gamma^\mu v(k_2) \epsilon_\mu(l)}{2(k_2 l)} +$$

$$+ \frac{v^T(k_1) C \gamma^0 (a + b\gamma^5)(\hat{k}_2 + \hat{l}) \gamma^\mu v(k_2) \epsilon_\mu(l)}{2(k_2 l)} -$$

$$- \frac{v^T(k_1) C \gamma^0 \gamma^\mu (\hat{k}_1 + \hat{l})(a + b\gamma^5) v(k_2) \epsilon_\mu(l)}{2(k_1 l)} = 0$$

Results for vector particle decay

Interaction Lagrangian:

$$\mathscr{L}^C_{vector} = \overline{\psi^C}\gamma^\mu(a+b\gamma^5)X_\mu\psi$$

Matrix element of two-particle decay:

$$M = < k_1 k_2|\overline{\Psi}^C\gamma^\mu(a+b\gamma^5)\Psi X_\mu|p > - < k_1 k_2|\overline{\Psi}^C\gamma^\mu(a+b\gamma^5)\Psi X_\mu|p > =$$

$$= v^T(k_1)\gamma^2\gamma^0\gamma^\mu(a+b\gamma^5)v(k_2)X_\mu(p) + v^T(k_1)\gamma^2\gamma^0(a+b\gamma^5)\gamma^\mu v(k_2)X_\mu(p)$$

Matrix element of three-particle decay:

$$M = v^T(k_1)C\gamma^0\gamma^\nu(\hat{k_1}+\hat{l})\gamma^\mu(a+b\gamma^5)v(k_2)X_\mu(p)A_\nu(l) +$$

$$+ v^T(k_1)C\gamma^0(a+b\gamma^5)\gamma^\mu(\hat{k_2}+\hat{l})\gamma^\nu v(k_2)X_\mu(p)A_\nu(l) +$$

$$+ v^T(k_1)C\gamma^0\gamma^\mu(a+b\gamma^5)(\hat{k_2}+\hat{l})\gamma^\nu v(k_2)X_\mu(p)A_\nu(l) +$$

$$+ v^T(k_1)C\gamma^0\gamma^\nu(\hat{k_1}+\hat{l})(a+b\gamma^5)\gamma^\mu v(k_2)X_\mu(p)A_\nu(l)$$

Results for vector particle decay

Two-particle decay:

$$|M|^2 = 16a^2 \frac{m^2(k_1k_2) + 2(k_1k_2)^2}{m^2}$$

Three-particle decay:

$$|M|^2 = \frac{16(a^2 + b^2)}{m^2} F(k_1, k_2, l, m)$$

The ratio of decay widths:

$$\frac{\Gamma(X \to e^+e^-\gamma)}{\Gamma(X \to e^+e^-)} = G(a, b) = 1 + \frac{b^2}{a^2} \to 0$$ at b → ia

Conclusion

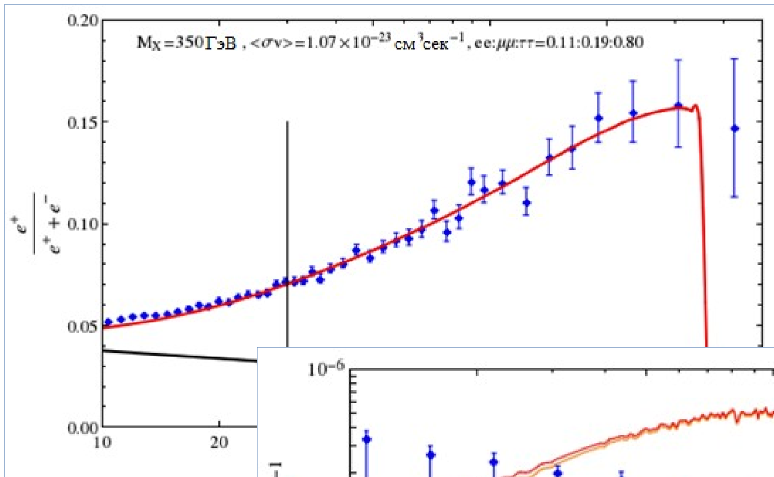
We considered possibility to suppress final state photons yield in DM particle decays.
In the considered $e^+ e^-$ modes, we did not find such a possibility.

We suggest a new DM model with double charged DM particle which perhaps has such suppression due to Pauli exclusion principle.

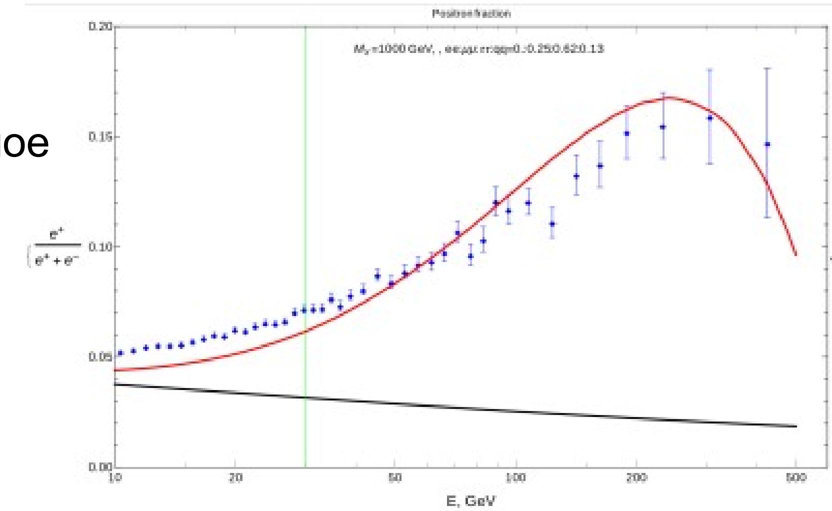
We plan to investigate this possibility

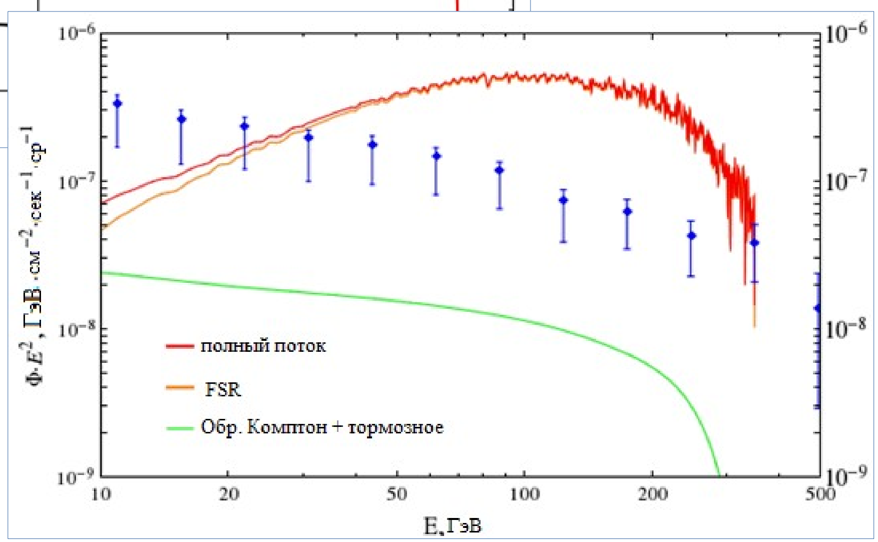
Backup

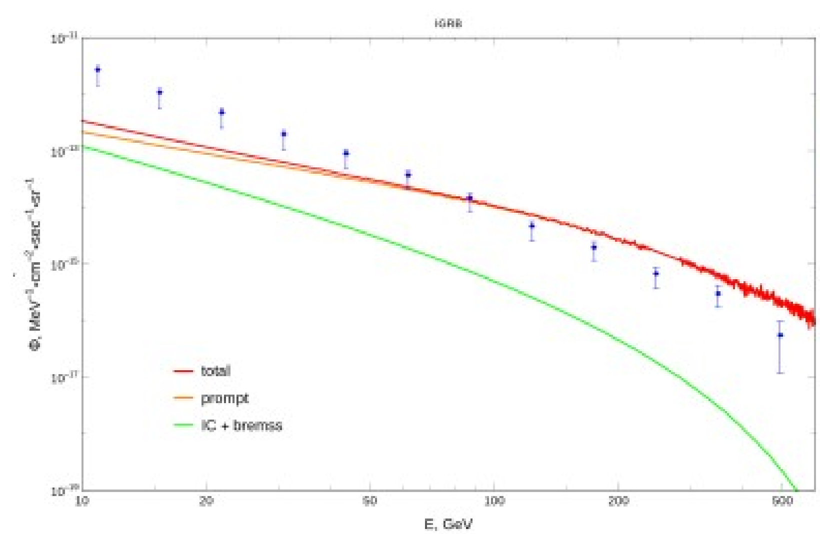
Проблема с гамма



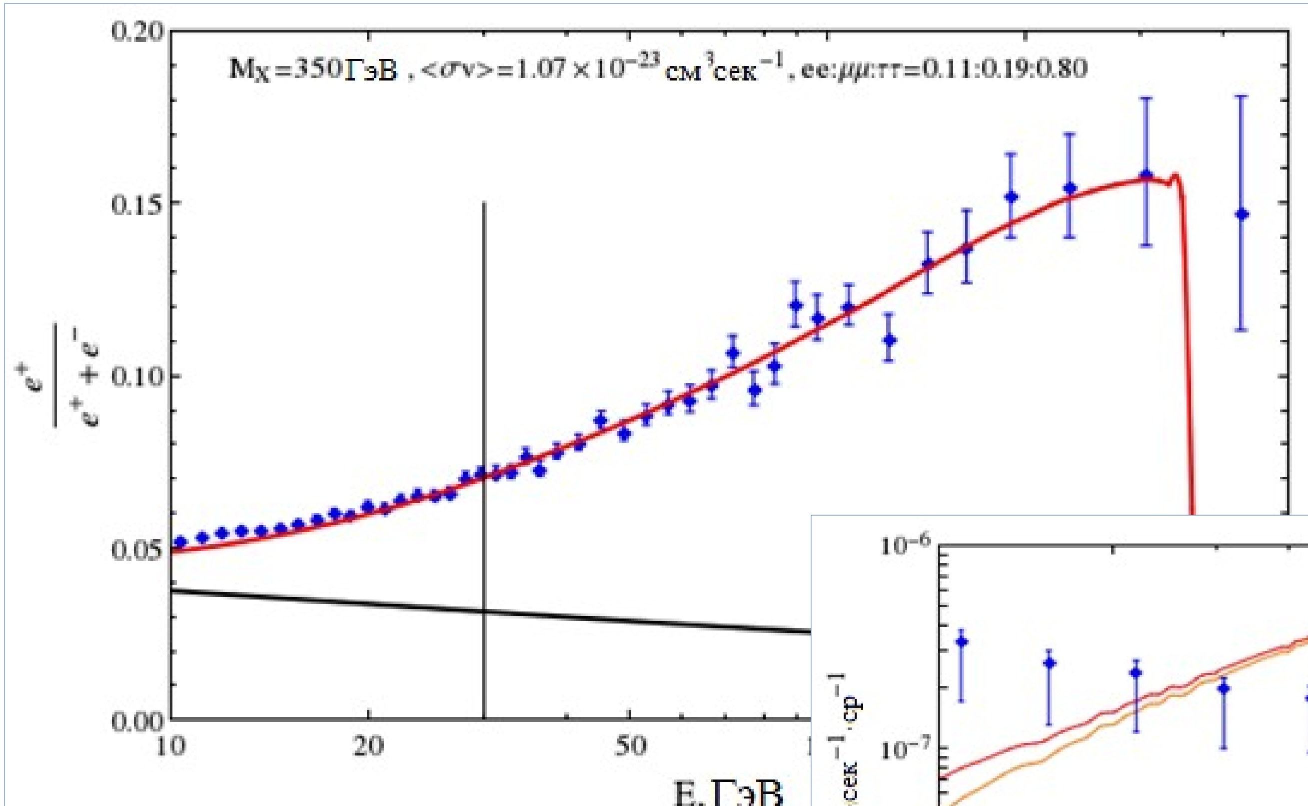
Удовлетворительное описание доли позитронов





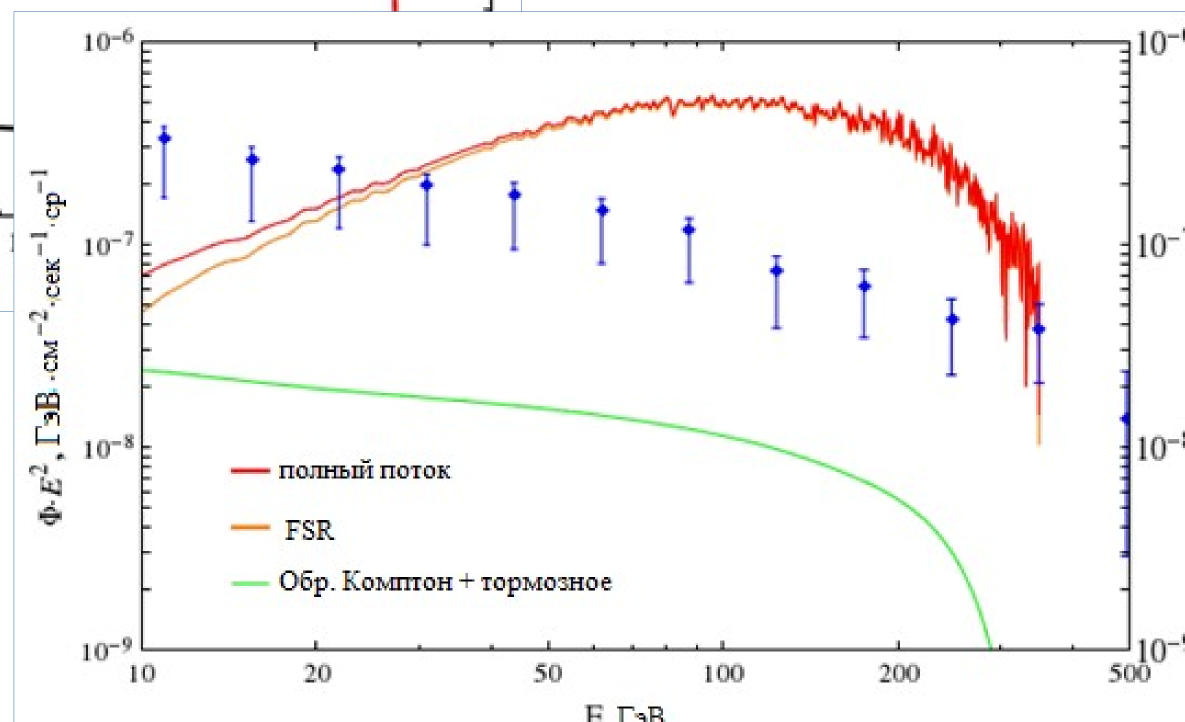


Модель ТМ в гало



Удовлетворительное описание доли позитронов

Сильное противоречие (превышение) в IGRB



Трёхчастичный распад в FeynCalc для скалярного X

```
$LoadTARCER = $LoadPhi = False;
Needs["FeynCalc`"];
SP[k1, k1] = SP[k2, k2] = m^2;
SP[l, l] = 0;
SP[p, p] = M^2;

Ma = PD[k2 + l, m] * SpinorUBar[k1, m].(f + h * GA[5]).(GS[k2 + l] + m).GA[a].SpinorV[k2, m] +
  PD[k1 + l, m] * SpinorUBar[k1, m].GA[a].(GS[k1 + l] + m).(f + h * GA[5]).SpinorV[k2, m]
MaC = ComplexConjugate[Ma] /. {a → b, b → d}
Ma2 = FermionSpinSum[Ma * MaC] * (-MT[a, b]) /. m → 0 // Contract;
res = Ma2 /. DiracTrace → Tr /. m → 0  /. E1 → M - E2 - E3 // Simplify
```

$$\frac{\bar{u}(\mathrm{k1},m).\bar{\gamma}^{a}.(\bar{\gamma}\cdot(\overline{\mathrm{k1}}+\bar{l})+m).(h\bar{\gamma}^{5}+f).(v(\mathrm{k2},m))}{(\mathrm{k1}+l)^2-m^2}+\frac{\bar{u}(\mathrm{k1},m).(h\bar{\gamma}^{5}+f).(\bar{\gamma}\cdot(\overline{\mathrm{k2}}+\bar{l})+m).\bar{\gamma}^{a}.(v(\mathrm{k2},m))}{(\mathrm{k2}+l)^2-m^2}$$

$$\frac{(\varphi(-\overline{\mathrm{k2}},m)).(f-h\bar{\gamma}^{5}).(\bar{\gamma}\cdot(\overline{\mathrm{k1}}+\bar{l})+m).\bar{\gamma}^{b}.(\varphi(\overline{\mathrm{k1}},m))}{(\mathrm{k1}+l)^2-m^2}+\frac{(\varphi(-\overline{\mathrm{k2}},m)).\bar{\gamma}^{b}.(\bar{\gamma}\cdot(\overline{\mathrm{k2}}+\bar{l})+m).(f-h\bar{\gamma}^{5}).(\varphi(\overline{\mathrm{k1}},m))}{(\mathrm{k2}+l)^2-m^2}$$

$$16\left(f^2+h^2\right)\left({\frac{1}{(\mathrm{k1}+l)^2}}^{2}(\overline{\mathrm{k1}}\cdot\bar{l})(\overline{\mathrm{k2}}\cdot\bar{l})-2\frac{1}{(\mathrm{k1}+l)^2}\,\frac{1}{(\mathrm{k2}+l)^2}(\overline{\mathrm{k1}}\cdot\overline{\mathrm{k2}}+\overline{\mathrm{k1}}\cdot\bar{l})(\overline{\mathrm{k1}}\cdot\overline{\mathrm{k2}}+\overline{\mathrm{k2}}\cdot\bar{l})+{\frac{1}{(\mathrm{k2}+l)^2}}^{2}(\overline{\mathrm{k1}}\cdot\bar{l})(\overline{\mathrm{k2}}\cdot\bar{l})\right)$$

Двухчастичный распад в FeynCalc для векторного X

```
Needs["FeynCalc`"];
SP[k1, k1] = SP[k2, k2] = m^2;
SP[l, l] = 0;
SP[p, p] = M^2;

Ma = SpinorUBar[k1, m].GA[a].(f + h*GA[5]).SpinorV[k2, m]
MaC = ComplexConjugate[Ma] /. {a → b}
Ma2 = FermionSpinSum[Ma*MaC] * (-MT[a, b] + (FV[p, a]*FV[p, b]) / M^2) /. m → 0 // Contract;
res = Ma2 /. DiracTrace → Tr /. m → 0  /. E1 → M - E2 - E3 // Simplify
```

$$\overline{u}(\text{k1}, m).\gamma^{a}.\left(h\,\gamma^{5}+f\right).(\text{v}(\text{k2}, m))$$

$$(\varphi(-\overline{\text{k2}}, m)).\left(f-h\,\gamma^{5}\right).\gamma^{b}.(\varphi(\overline{\text{k1}}, m))$$

$$\frac{4\left(f^{2}+h^{2}\right)\left(M^{2}\left(\overline{\text{k1}}\cdot\overline{\text{k2}}\right)+2\left(\overline{\text{k1}}\cdot\overline{p}\right)\left(\overline{\text{k2}}\cdot\overline{p}\right)\right)}{M^{2}}$$

Трёхчастичный распад в FeynCalc для векторного X

```
$LoadTARCER = $LoadPhi = False;
Needs["FeynCalc`"];
SP[k1, k1] = SP[k2, k2] = m^2;
SP[l, l] = 0;
SP[p, p] = M^2;

Ma = PD[k2 + l, m] * SpinorUBar[k1, m].GA[a].(f + h * GA[5]).(GS[k2 + l] + m).GA[b].SpinorV[k2, m] +
  PD[k1 + l, m] * SpinorUBar[k1, m].GA[b].(GS[k1 + l] + m).GA[a].(f + h * GA[5]).SpinorV[k2, m]
MaC = ComplexConjugate[Ma] /. {a → c, b → d}
Ma2 = FermionSpinSum[Ma * MaC] * (-MT[b, d]) * (-MT[a, c] + FV[p, a] * FV[p, c] / M^2) /. m → 0 // Contract;
res = Ma2 /. DiracTrace → Tr /. m → 0 /. Ɛ1 → M - Ɛ2 - Ɛ3 // FullSimplify
```

$$\frac{\overline{u}(\mathrm{k1}, m).\gamma^b.(\gamma\cdot(\overline{\mathrm{k1}}+\overline{l})+m).\gamma^a.(h\gamma^5+f).(\mathrm{v}(\mathrm{k2}, m))}{(\mathrm{k1}+l)^2-m^2}+\frac{\overline{u}(\mathrm{k1}, m).\gamma^a.(h\gamma^5+f).(\gamma\cdot(\overline{\mathrm{k2}}+\overline{l})+m).\gamma^b.(\mathrm{v}(\mathrm{k2}, m))}{(\mathrm{k2}+l)^2-m^2}$$

$$\frac{(\varphi(-\overline{\mathrm{k2}}, m)).(f-h\gamma^5).\gamma^c.(\gamma\cdot(\overline{\mathrm{k1}}+\overline{l})+m).\gamma^d.(\varphi(\overline{\mathrm{k1}}, m))}{(\mathrm{k1}+l)^2-m^2}+\frac{(\varphi(-\overline{\mathrm{k2}}, m)).\gamma^d.(\gamma\cdot(\overline{\mathrm{k2}}+\overline{l})+m).(f-h\gamma^5).\gamma^c.(\varphi(\overline{\mathrm{k1}}, m))}{(\mathrm{k2}+l)^2-m^2}$$

$$\frac{1}{M^2}16\left(f^2+h^2\right)\Bigg(-2\frac{1}{(\mathrm{k1}+l)^2}\frac{1}{(\mathrm{k2}+l)^2}\Big(M^2(\overline{\mathrm{k1}}\cdot\overline{\mathrm{k2}})^2+(\overline{\mathrm{k1}}\cdot\overline{\mathrm{k2}})\big(M^2(\overline{\mathrm{k1}}\cdot\overline{l}+\overline{\mathrm{k2}}\cdot\overline{l})+(\overline{l}\cdot\overline{p})(\overline{\mathrm{k1}}\cdot\overline{p}+\overline{\mathrm{k2}}\cdot\overline{p})+2(\overline{\mathrm{k1}}\cdot\overline{p})(\overline{\mathrm{k2}}\cdot\overline{p})\big)-(\overline{\mathrm{k1}}\cdot\overline{p}-\overline{\mathrm{k2}}\cdot\overline{p})\big((\overline{\mathrm{k1}}\cdot\overline{p})(\overline{\mathrm{k2}}\cdot\overline{l})-(\overline{\mathrm{k1}}\cdot\overline{l})(\overline{\mathrm{k2}}\cdot\overline{p})\big)\Big)+$$

$$\frac{1}{(\mathrm{k1}+l)^2}^2(\overline{\mathrm{k1}}\cdot\overline{l})\big(M^2(\overline{\mathrm{k2}}\cdot\overline{l})+2(\overline{\mathrm{k2}}\cdot\overline{p})(\overline{l}\cdot\overline{p})\big)+\frac{1}{(\mathrm{k2}+l)^2}^2(\overline{\mathrm{k2}}\cdot\overline{l})\big(M^2(\overline{\mathrm{k1}}\cdot\overline{l})+2(\overline{\mathrm{k1}}\cdot\overline{p})(\overline{l}\cdot\overline{p})\big)\Bigg)$$

COMPOSITE DARK MATTER FROM STABLE CHARGED CONSTITUENTS

COMPOSITE DARK MATTER FROM STABLE CHARGED CONSTITUENTS

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Heavy stable charged particles can exist, hidden from us in bound atomlike states. Models with new stable charged leptons and quarks give rise to realistic composite dark matter scenarios. Significant or even dominant component of O-helium (atomlike system of He4 nucleus and heavy -2 charged particle) is inevitable feature of such scenarios. Possible O-helium explanation for the positron excess in the galactic bulge and for the controversy between the positive results of DAMA and negative results of other experiments is proposed.

Ссылка: https://arxiv.org/abs/0806.3581

Матричные элементы в теории с зарядово-сопряжённым спинором

$$M =< k_1 k_2 | X \overline{\Psi}^C (a + b\gamma^5) \Psi | p > - < k_1 k_2 | X \overline{\Psi}^C (a + b\gamma^5) \Psi | p > \; =$$

$$=< k_1 k_2 | X \Psi^T C^T \gamma^0 (a + b\gamma^5) \Psi | p > - < k_1 k_2 | X \Psi^T C^T \gamma^0 (a + b\gamma^5) \Psi | p > \; =$$

$$= v^T(k_1) C^T \gamma^0 (a + b\gamma^5) v(k_2) - v^T(k_2) C^T \gamma^0 (a + b\gamma^5) v(k_1)$$

$$M =< k_1 k_2 l | X \overline{\Psi}_a^C (a + b\gamma^5)_{ab} \Psi_b \overline{\Psi}_c \gamma^\mu_{cd} \Psi_d A_\mu | p > -$$

$$- < k_1 k_2 l | X \overline{\Psi}_a^C (a + b\gamma^5)_{ab} \Psi_b \overline{\Psi}_c \gamma^\mu_{cd} \Psi_d A_\mu | p > +$$

$$+ < k_1 k_2 l | X \overline{\Psi}_a^C (a + b\gamma^5)_{ab} \Psi_b \overline{\Psi}_c \gamma^\mu_{cd} \Psi A_\mu | p > -$$

$$- < k_1 k_2 l | X \overline{\Psi}_a^C (a + b\gamma^5)_{ab} \Psi_b \overline{\Psi}_c \gamma^\mu_{cd} \Psi_d A_\mu | p > \; =$$

$$= v_d^T(k_1) \gamma^{\mu\, T}_{dc} (\hat{k}_1 + \hat{l})^T_{ck} C^T_{kn} \gamma^T_{na} (a + b\gamma^5)_{ab} v_b(k_2) \epsilon_\mu(l) -$$

$$- v_d^T(k_2) \gamma^{\mu\, T}_{dc} (\hat{k}_2 + \hat{l})^T_{ck} C^T_{kn} \gamma^T_{na} (a + b\gamma^5)_{ab} v_b(k_1) \epsilon_\mu(l) +$$

$$+ v_k^T(k_2) C^T_{kn} \gamma^0_{na} (a + b\gamma^5)_{ab} (\hat{k}_2 + \hat{l})_{bc} \gamma^\mu_{cd} v_d(k_1) \epsilon_\mu(l) -$$

$$- v_k^T(k_1) C^T_{kn} \gamma^0_{na} (a + b\gamma^5)_{ab} (\hat{k}_1 + \hat{l})_{bc} \gamma^\mu_{cd} v_d(k_2) \epsilon_\mu(l)$$