Search for dark scalars at the colliders

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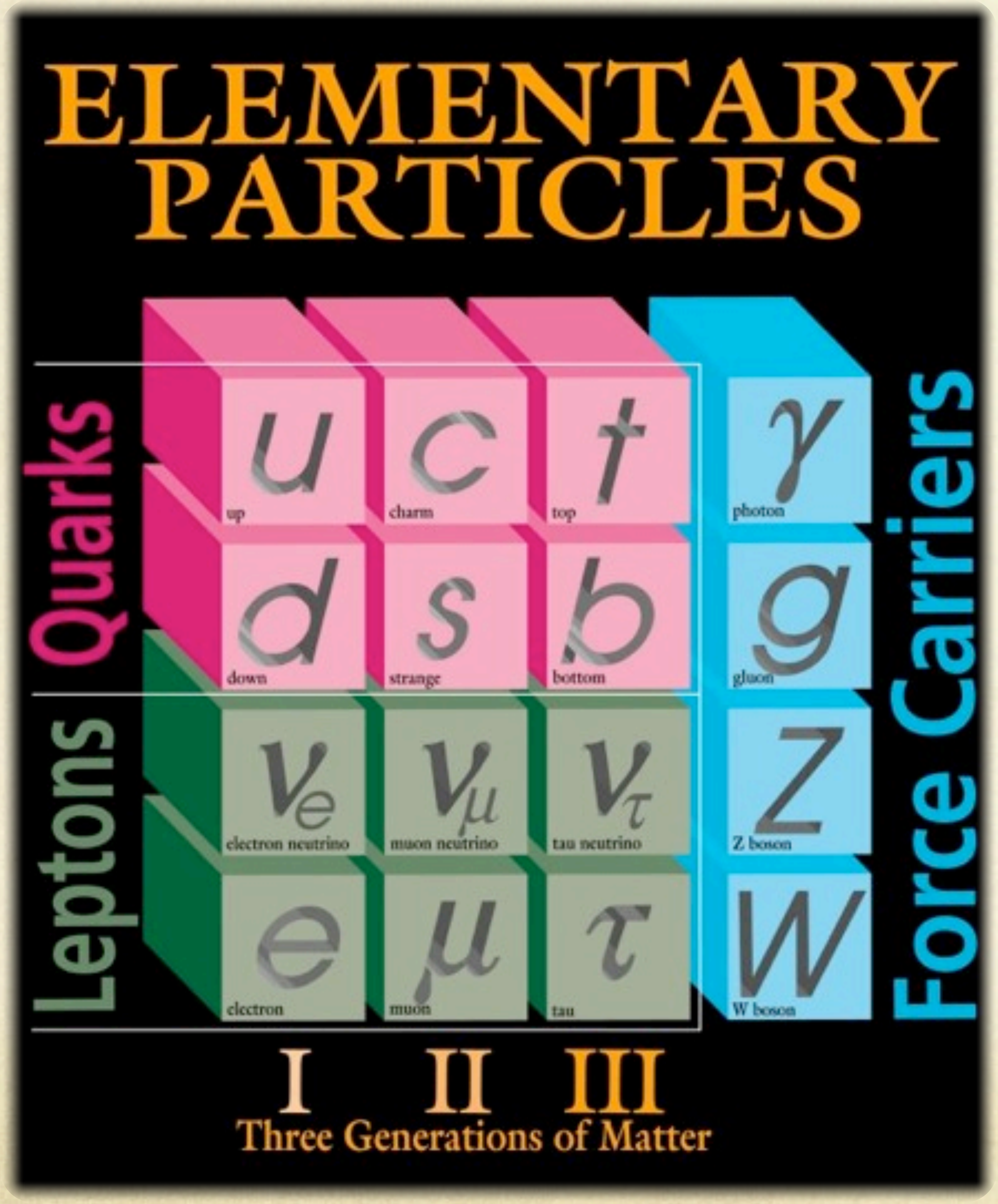
In collaboration with

Ernest Ma, G. Rajasekaran and Gabe Shaughnessy

Argonne NATIONAL LABORATORY THE UNIVERSITY OF CHICAGO

Standard Model of Particle Physics



SM is the most precise,
most predictive,
well tested theory.

Deficiencies

- Hierarchy problem
- Unification
- Flavor

New Physics beyond SM

New physics beyond SM

Supersymmetry

MSSM, NMSSM, nMSSM, uMSSM

R-violating

Extra Dimension

Flat (ADD, UED)

Warped (RS1)

Little Higgs

Simple Little Higgs

Little Higgs

Little Higgs with T-parity

Higgsless

Technicolor

Top quark condensate

Three-site

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Each item has hundreds of cousins.

New physics beyond SM

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MSSM, NMSS[illegible]MSSM, [illegible]MSSM

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Many others…

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New physics beyond SM

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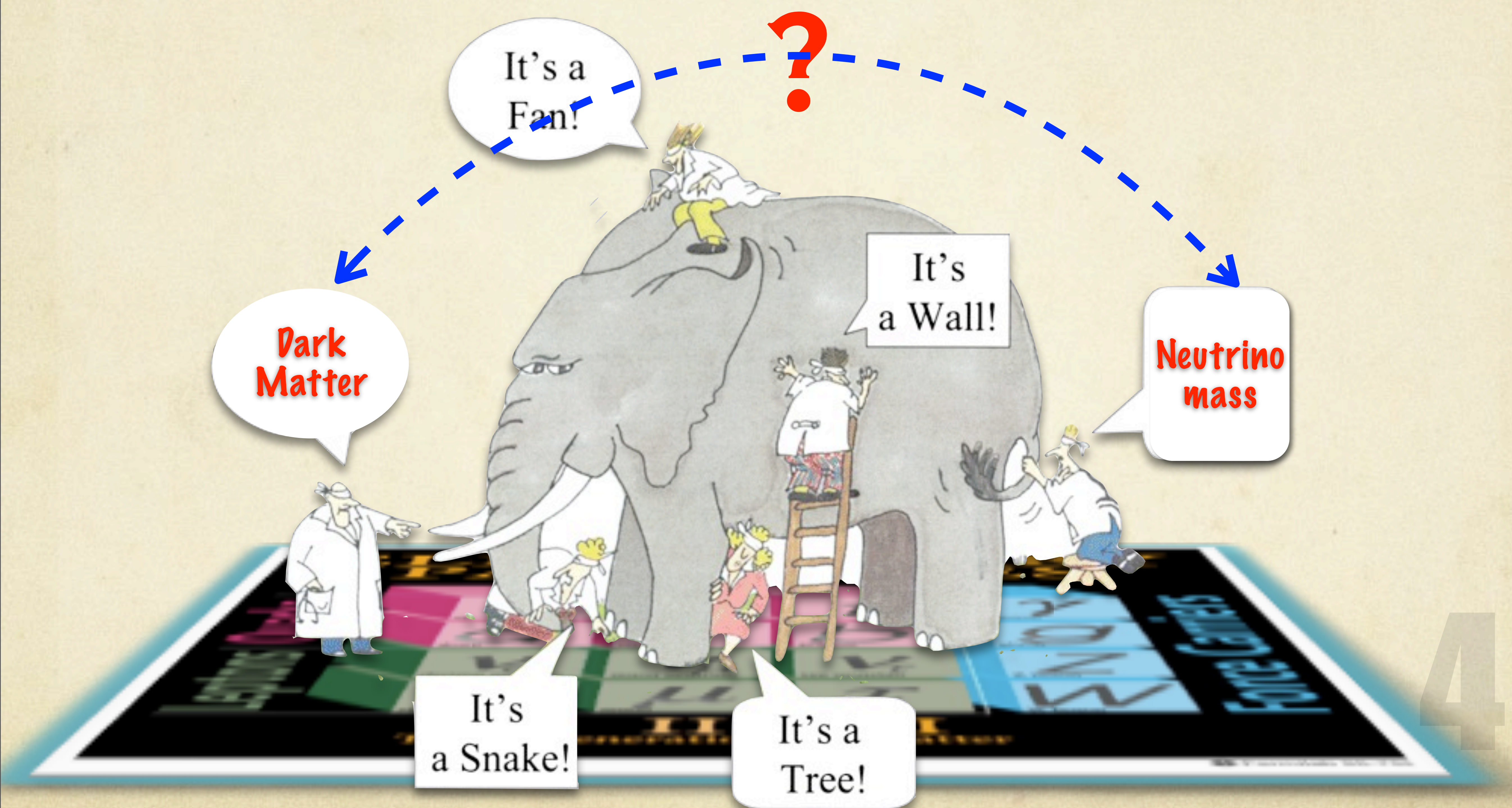
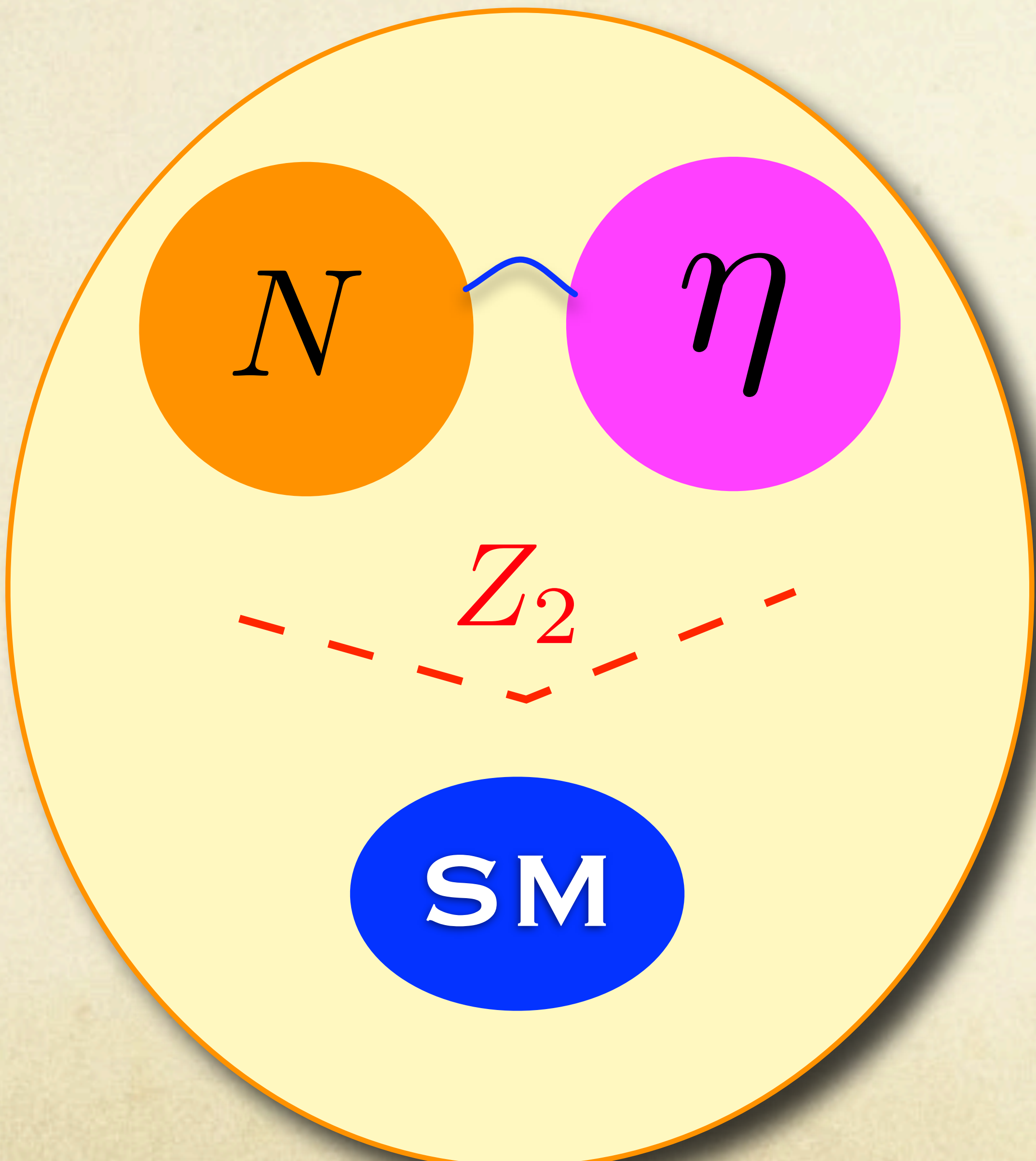


Dark scalar model (Inert Higgs model)

Ernest Ma, hep-ph/0601225
R. Barbieri, L.J. Hall, V.S. Rychkov, hep-ph/0603188



	$SU(2)_L$	$U(1)_Y$	Z_2
(ν_i, ℓ_i)	2	-1/2	+
ℓ_i^c	1	1	+
N_i	1	0	-
(ϕ^+, ϕ^0)	2	1/2	+
(η^+, η^0)	2	1/2	-

Neutrino mass: generic mechanisms

Weinberg (1979) :

Unique dimension-five operator for Majorana neutrino mass in the SM

$$\frac{f_{\alpha\beta}}{2\Lambda}(\nu_\alpha\phi^0 - \ell_\alpha\phi^+)(\nu_\beta\phi^0 - \ell_\beta\phi^+)$$

Ma (1998) :

Three tree-level realizations

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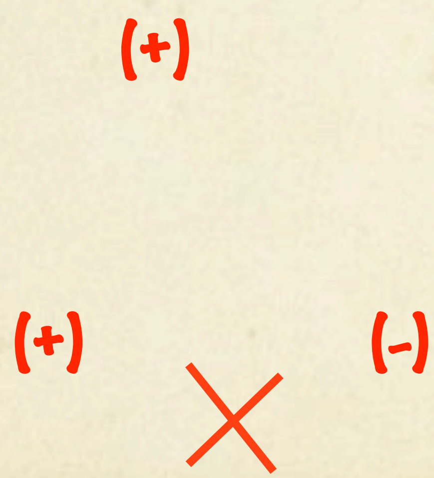
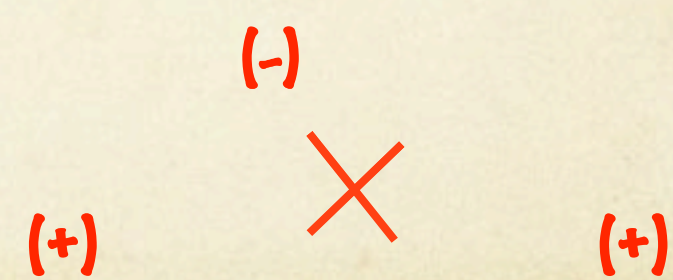
Ma (1998) :

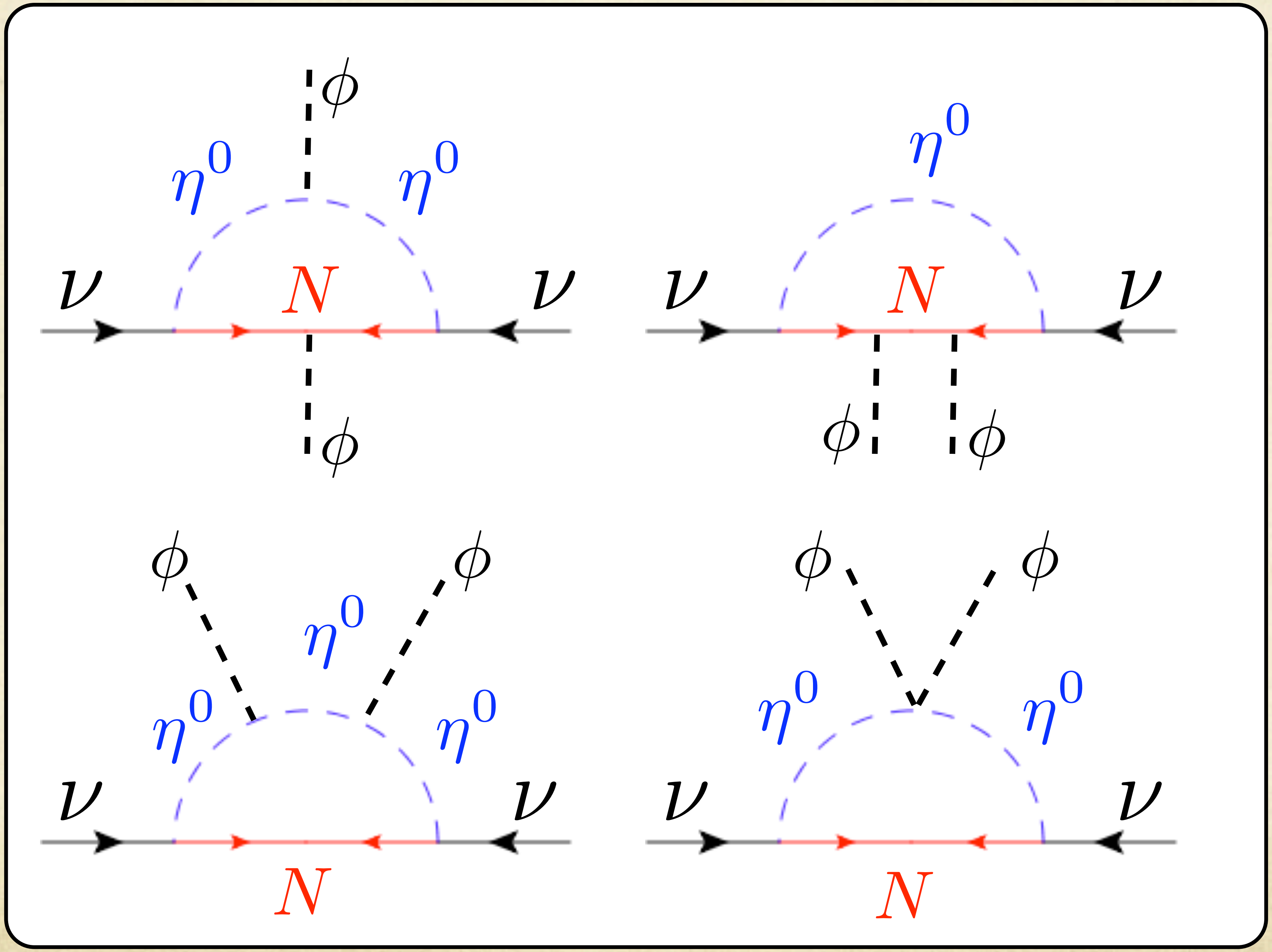
Three tree-level realizations do NOT work due to Z_2 symmetry: SM (+) DM (-)





Loop induced →

Neutrino mass (radiative seesaw)



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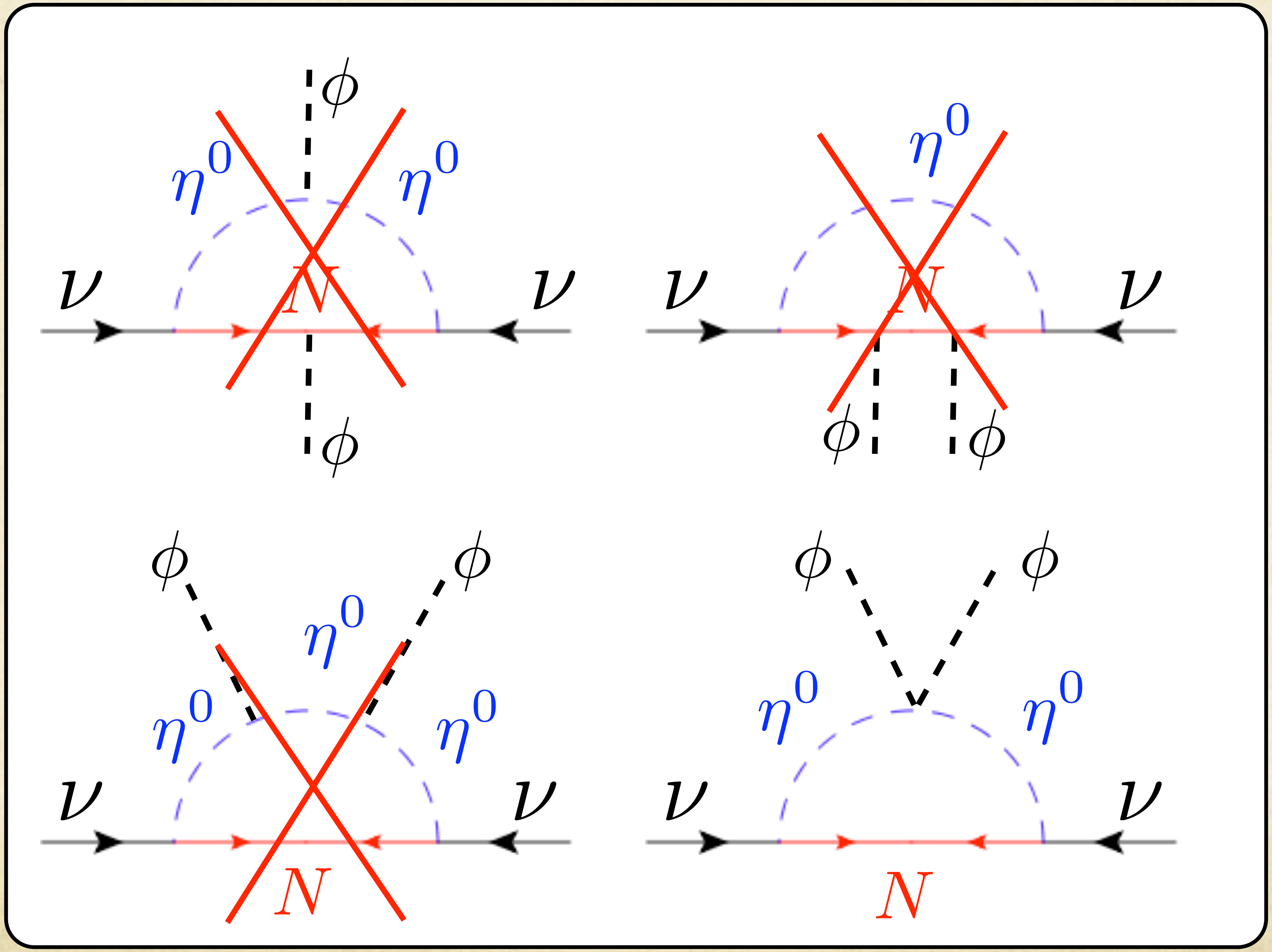

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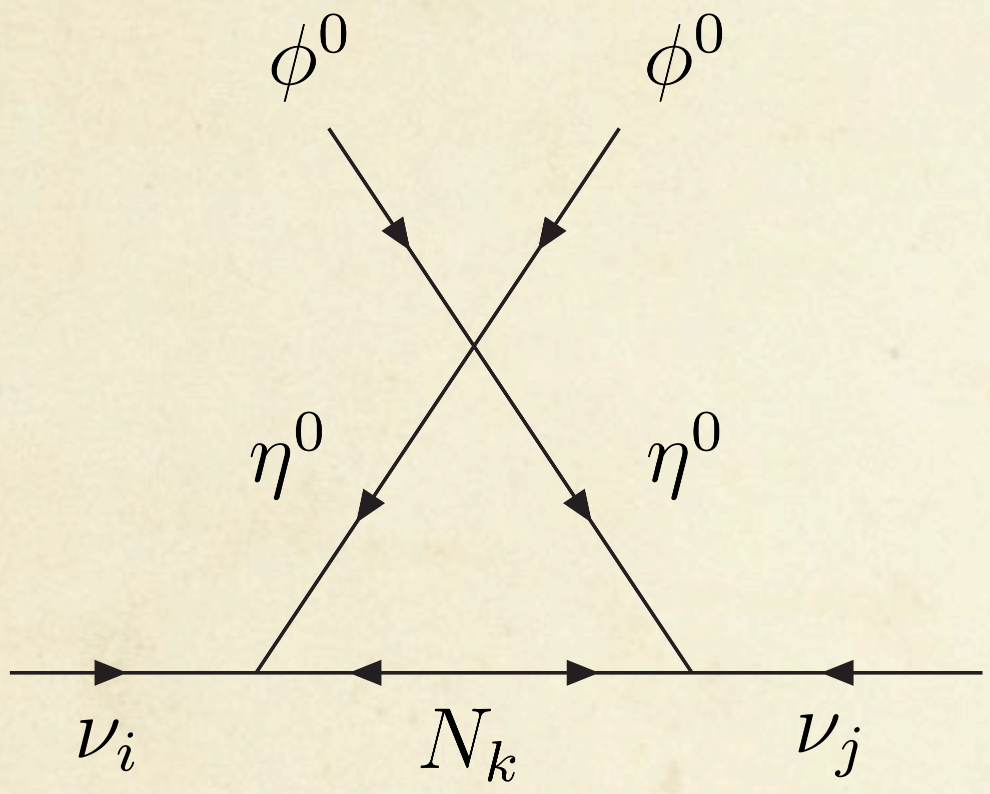


$$\mathcal{L} \supset h_{ij}\left(\nu_i \eta^0 - \ell_i \eta^+\right) N_j$$
$$+\frac{1}{2}\lambda_5\left(\Phi^\dagger \eta\right)^2 + \frac{1}{2} M_i N_i N_i$$
$$+H.c.$$

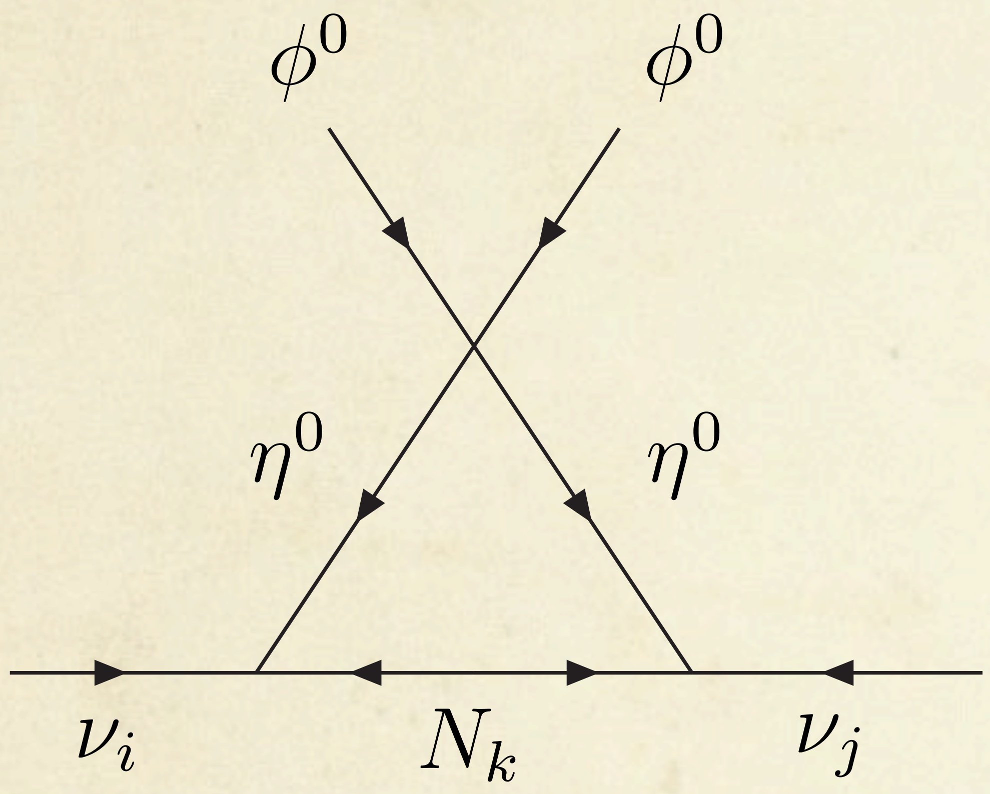
When $M_N > M_\eta$

$$m_\nu \sim \frac{\lambda_5 h^2}{16\pi^2}\frac{v^2}{M}$$

- ★ **See-saw scale** M ~ TeV
- ★ η **is dark matter**

8

Neutrino mass (radiative seesaw)



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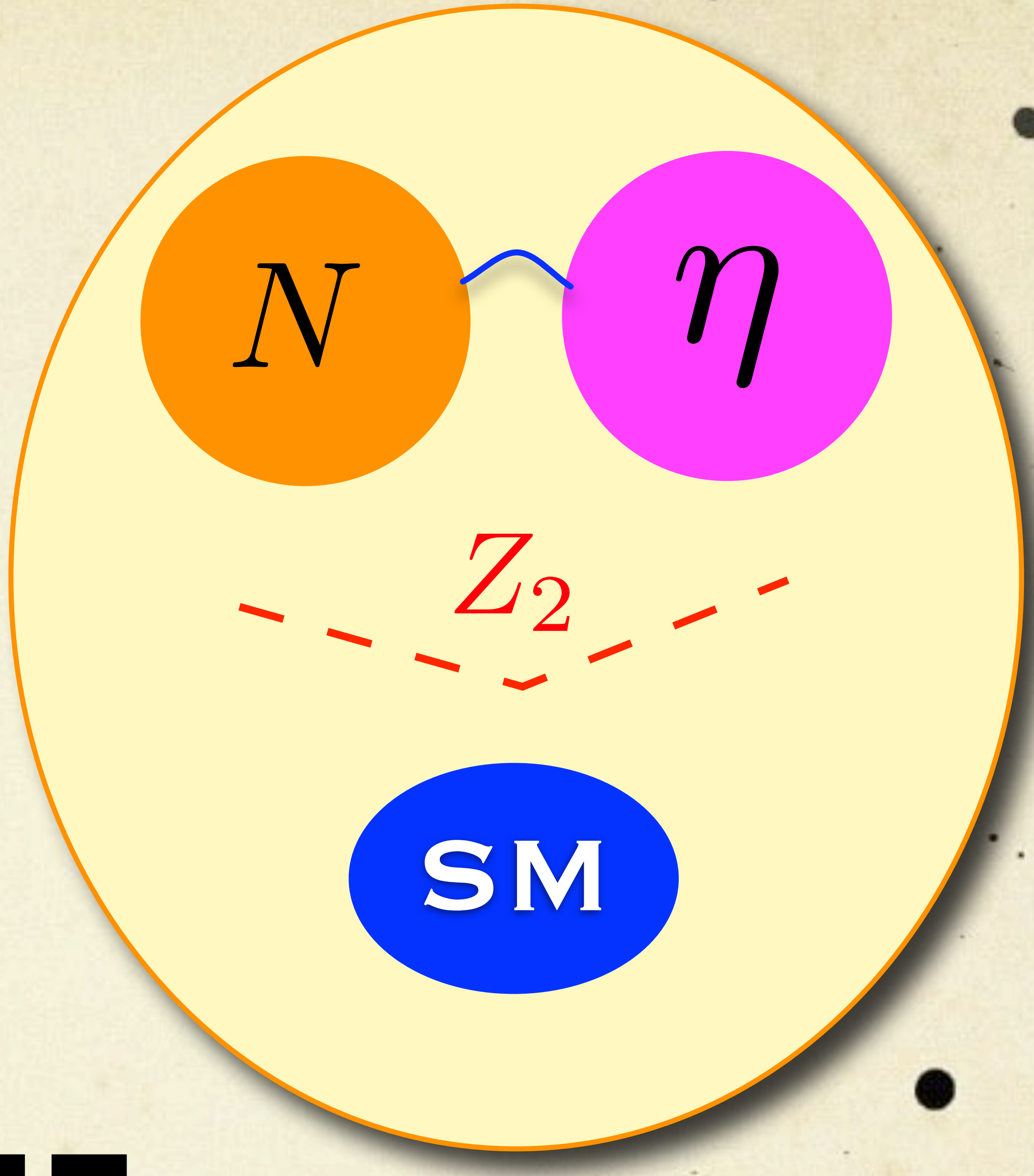
dark scalar (DS)

THE MODEL



The model: scalar potential

$$V = \mu_1^2 \Phi^\dagger \Phi + \mu_2^2 \eta^\dagger \eta + \frac{1}{2}\lambda_1 (\Phi^\dagger\Phi)^2 + \frac{1}{2}\lambda_2(\eta^\dagger\eta)^2 + \lambda_3(\Phi^\dagger\Phi)(\eta^\dagger\eta) + \lambda_4(\Phi^\dagger\eta)(\eta^\dagger\Phi) + \frac{1}{2}\lambda_5(\Phi^\dagger\eta)^2 + \frac{1}{2}\lambda_5^*(\eta^\dagger\Phi)^2$$

where $\Phi_{\rm SM} = (\phi^+, \phi^0)$ $\quad \eta = [H^+, (H^0 + iA^0)/\sqrt{2}]$

Z2 - even Z2 - odd

$$m^2(H^\pm) = \mu_2^2 + \lambda_3 v^2$$

$$m^2(H^0) = \mu_2^2 + (\lambda_3 + \lambda_4 + \lambda_5)v^2$$

$$m^2(A^0) = \mu_2^2 + (\lambda_3 + \lambda_4 - \lambda_5)v^2$$

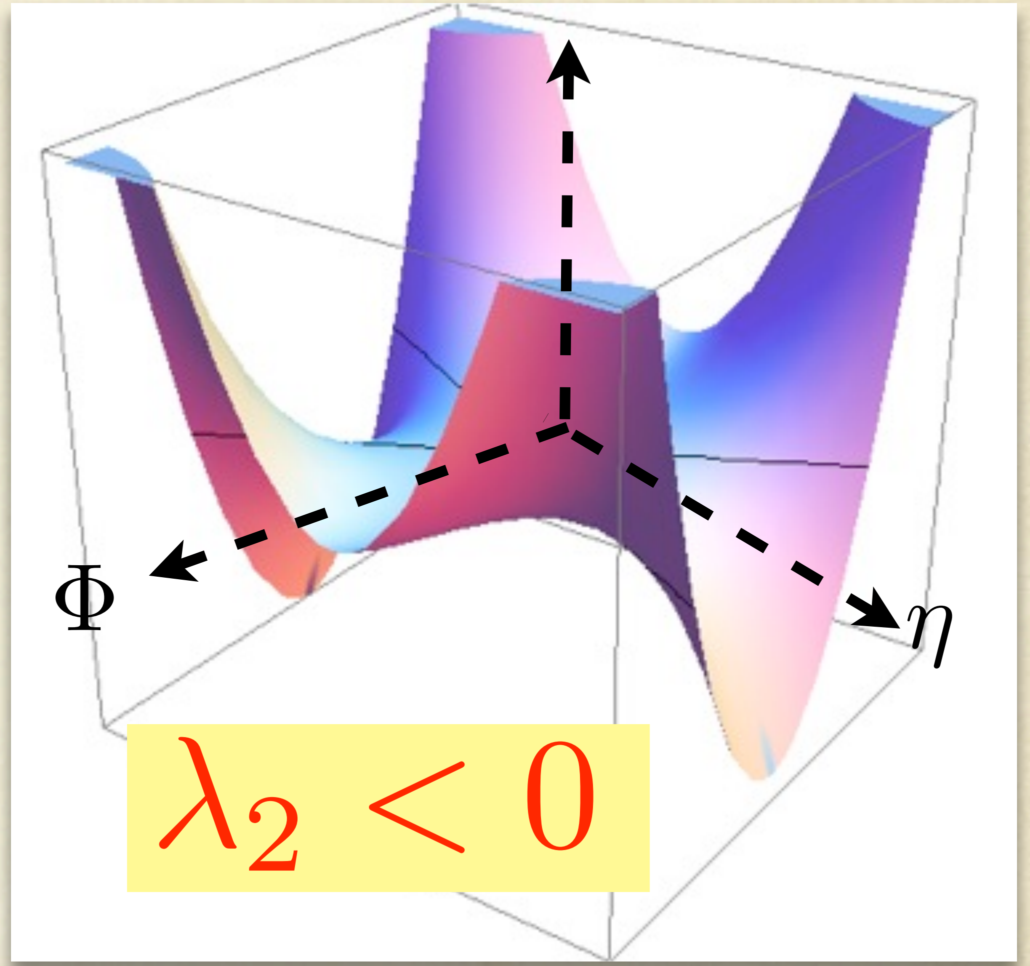
Mass split

The model: constraints

Vacuum stability:

$$\lambda_1 > 0 \qquad ; \qquad \lambda_2 > 0$$

$$\lambda_3, \lambda_3 + \lambda_4 - |\lambda_5| > -2\sqrt{\lambda_1 \lambda_2}$$



Perturbativity:

$|\lambda_i| > 4\pi$ Excluded

$1 < |\lambda_i| < 4\pi$ Tolerated

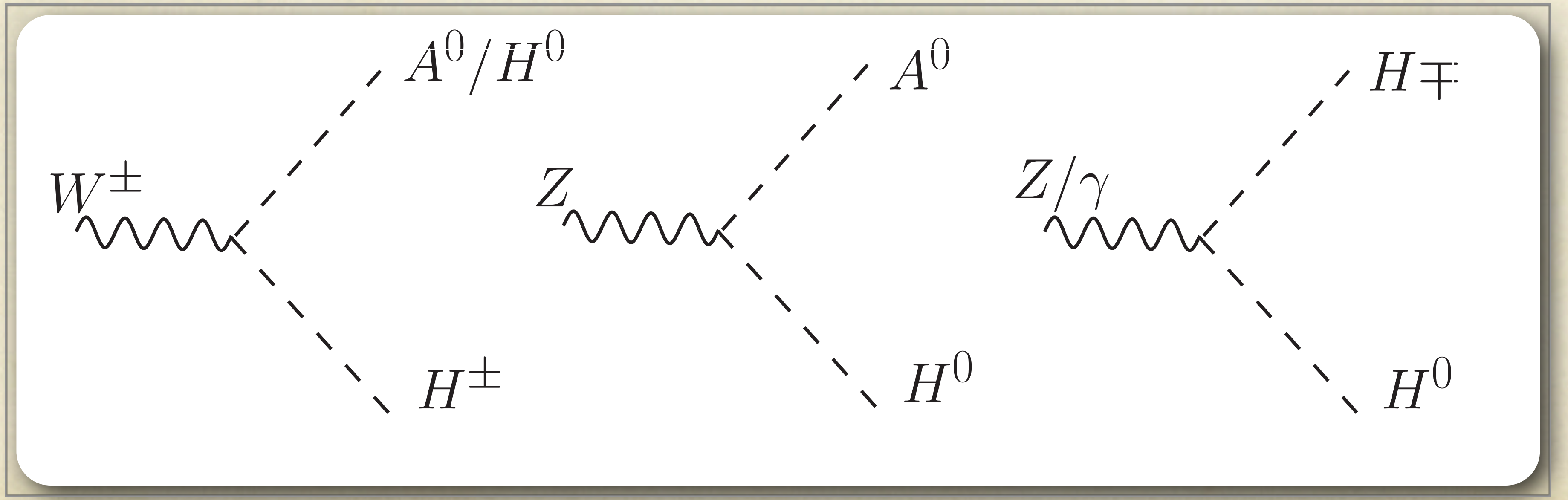
$$|\lambda_i| \leq 1$$

The model: gauge interaction

$$\frac{g}{2\cos\theta_W} Z_\mu (H^0 \partial^\mu A^0 - A^0 \partial^\mu H^0)$$

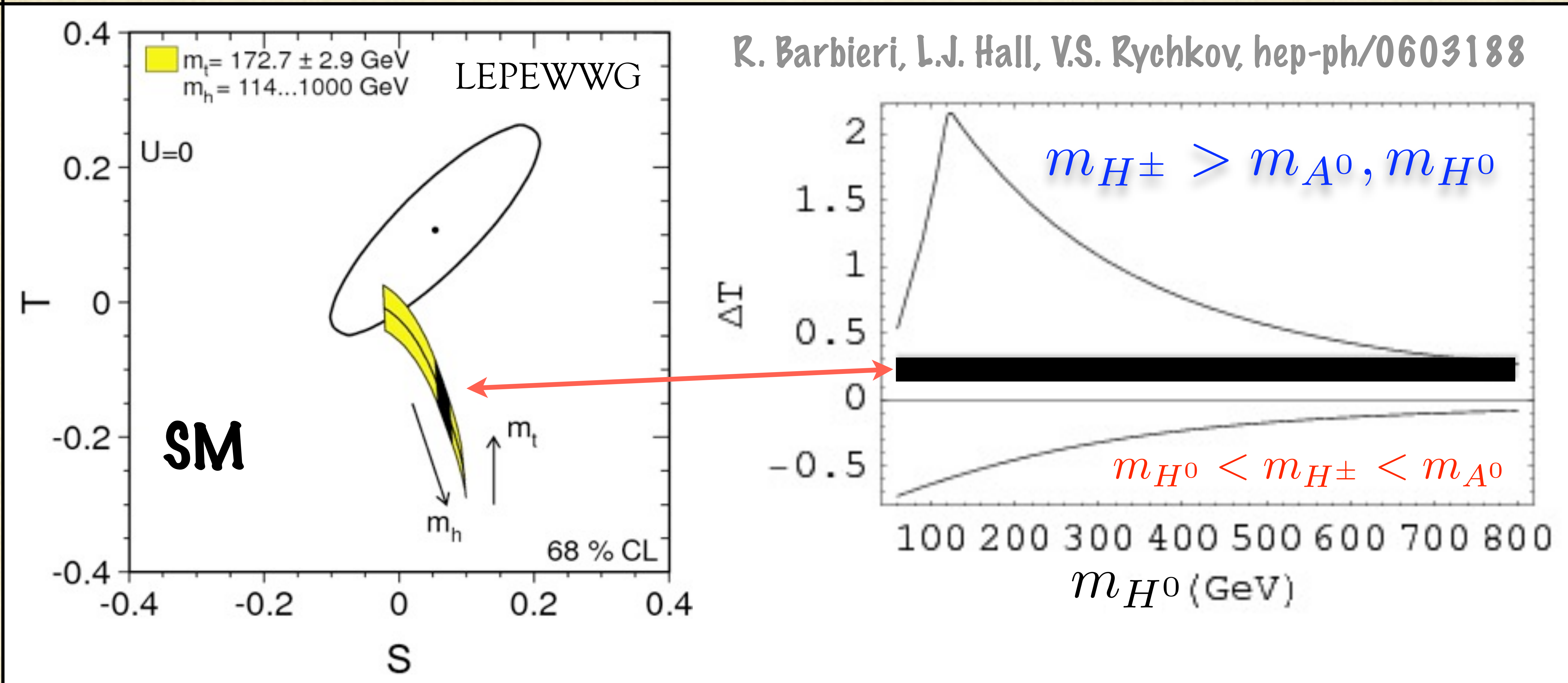
$$\frac{ig}{2} W_\mu^- (H^0 \partial^\mu H^+ - H^+ \partial^\mu H^0)$$

$$\frac{g}{2} W_\mu^- (A^0 \partial^\mu H^+ - H^+ \partial^\mu A^0)$$



Need to check their impact on the EW precision test

Electroweak precision test

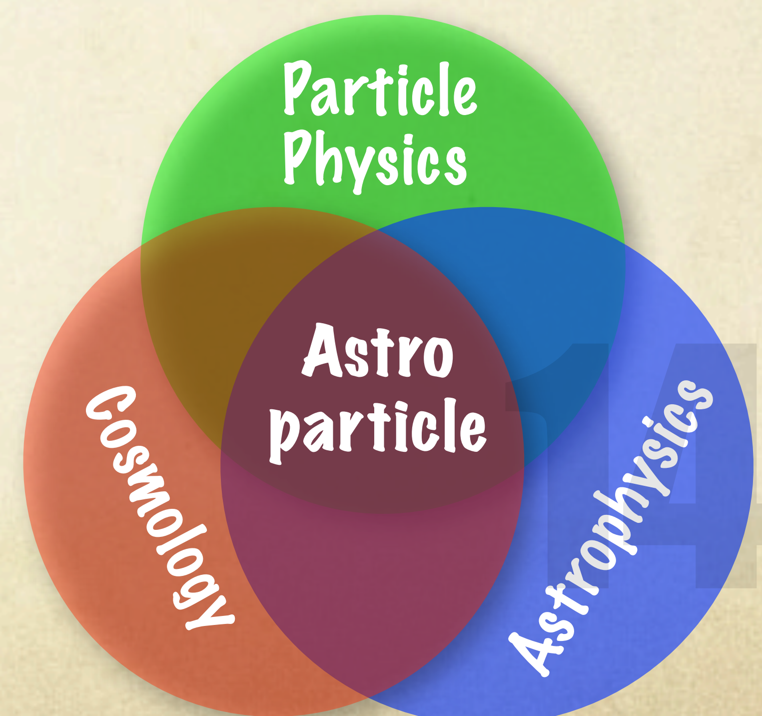


$$\Delta T_{\rm SM} \sim -\ln\left(\frac{m_h}{m_Z}\right)$$

$$\Delta T \approx \frac{1}{24\pi^2 \alpha v^2}(m_{H^\pm} - m_{A^0})(m_{H^\pm} - m_{H^0})$$

Cosmological Implications

Relic abundance, direct and indirect detection ...



Dark matter

What we know ...

What we don't know ...

Dark matter

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- Dark matter is material that gravitates but does not emit very much light.

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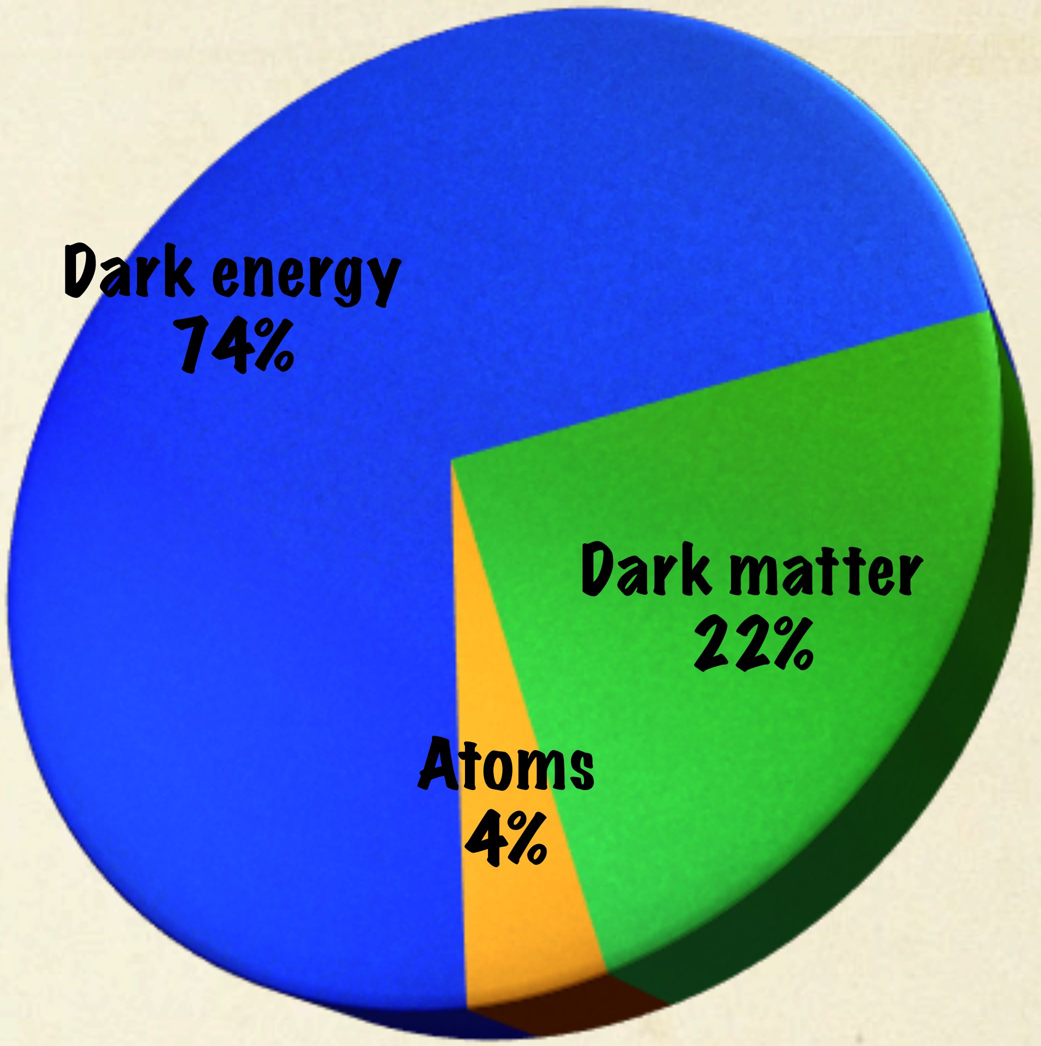

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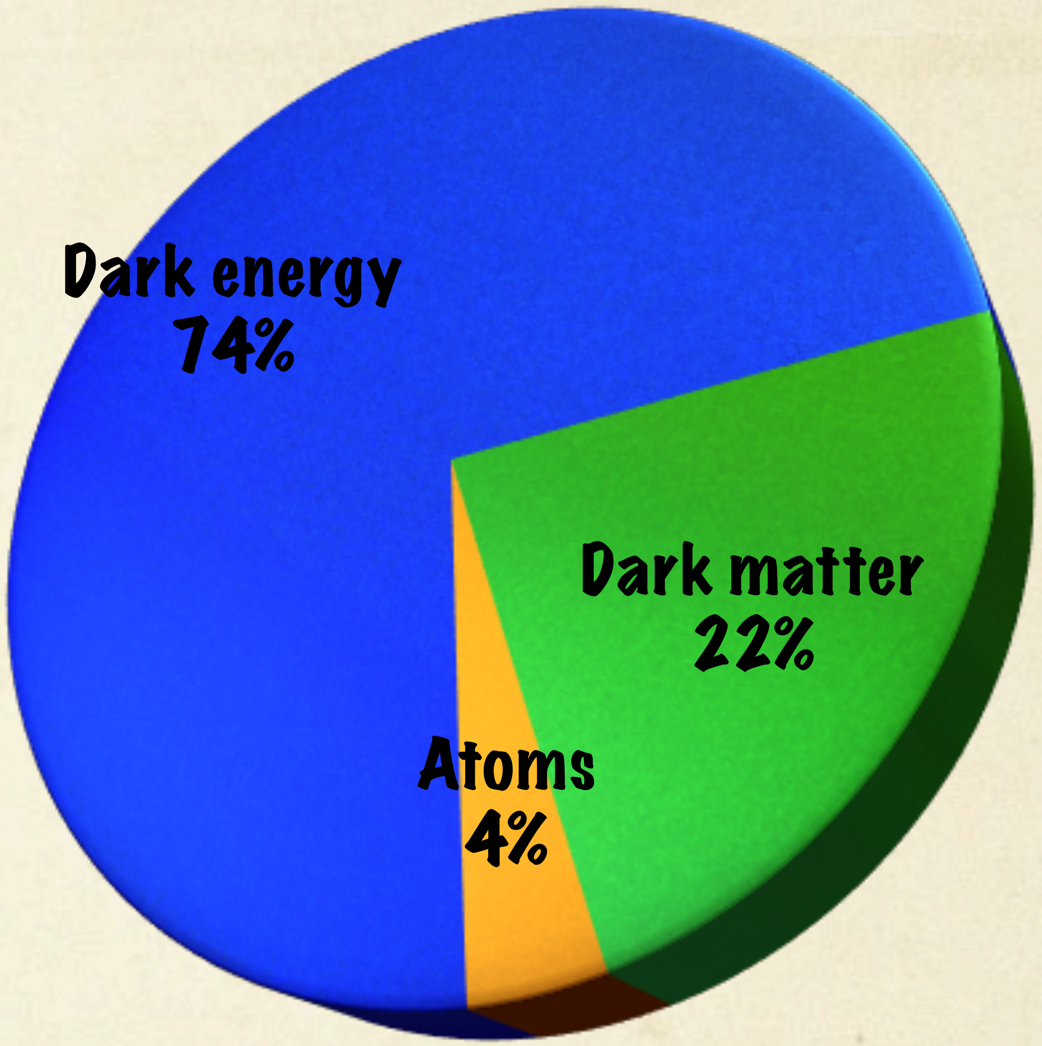
- Its mass and spin



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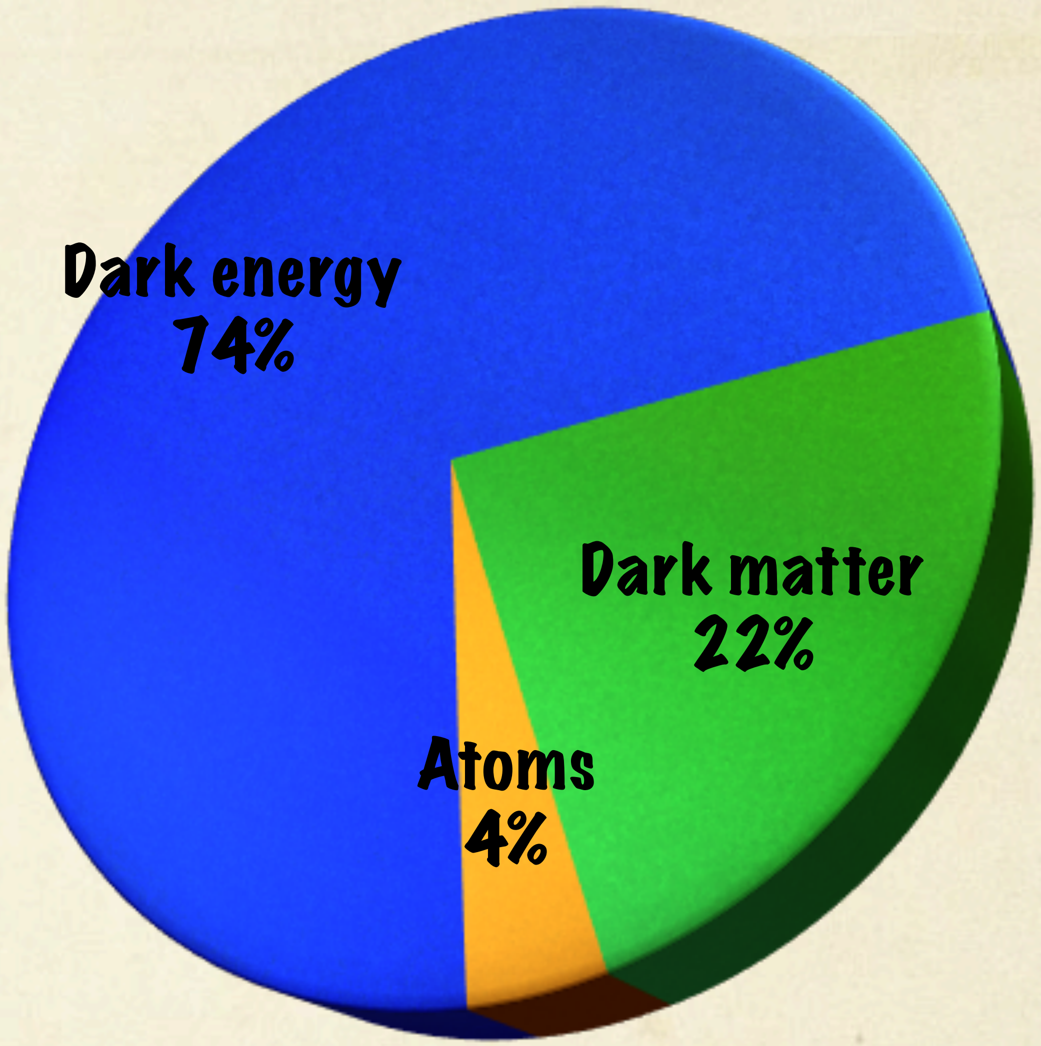
- Its mass and spin
- Its interacts with other particles



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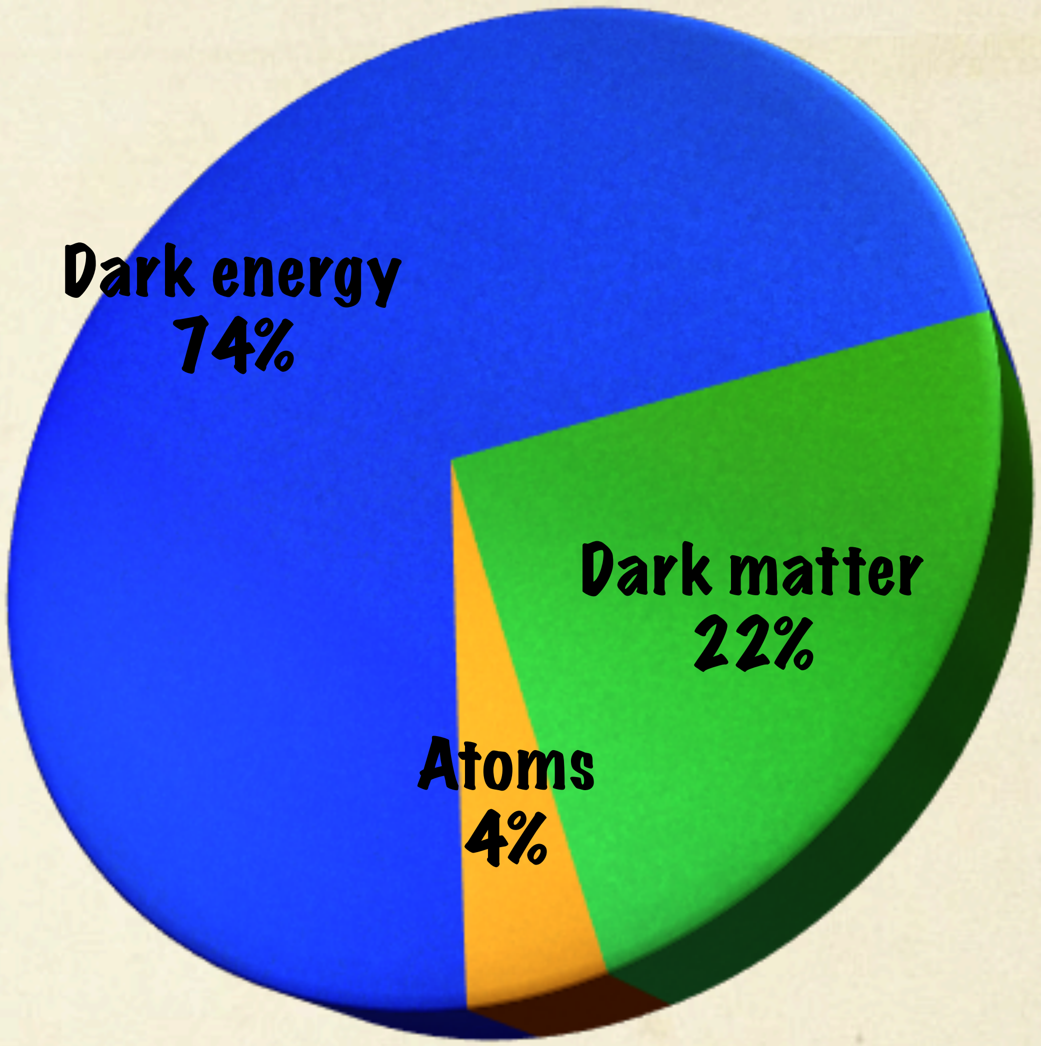

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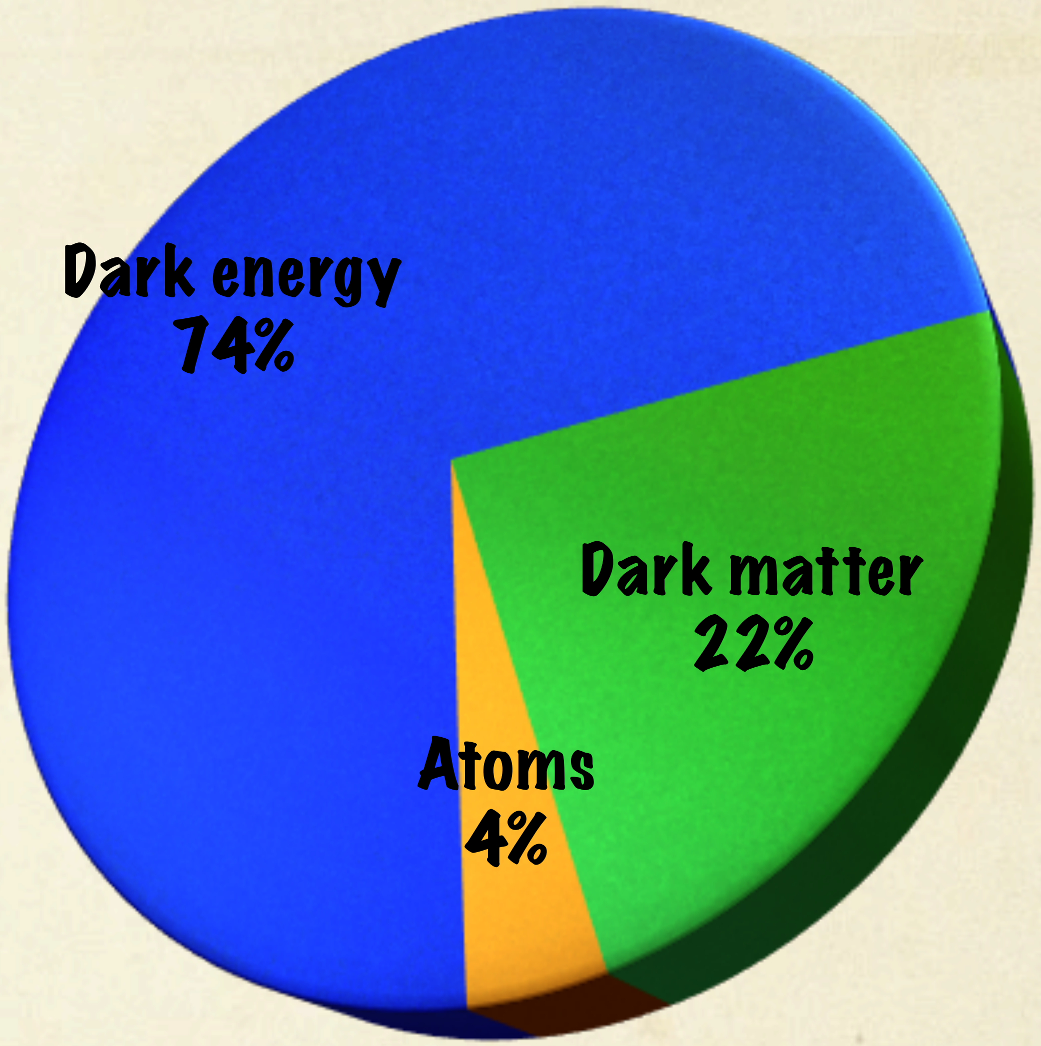

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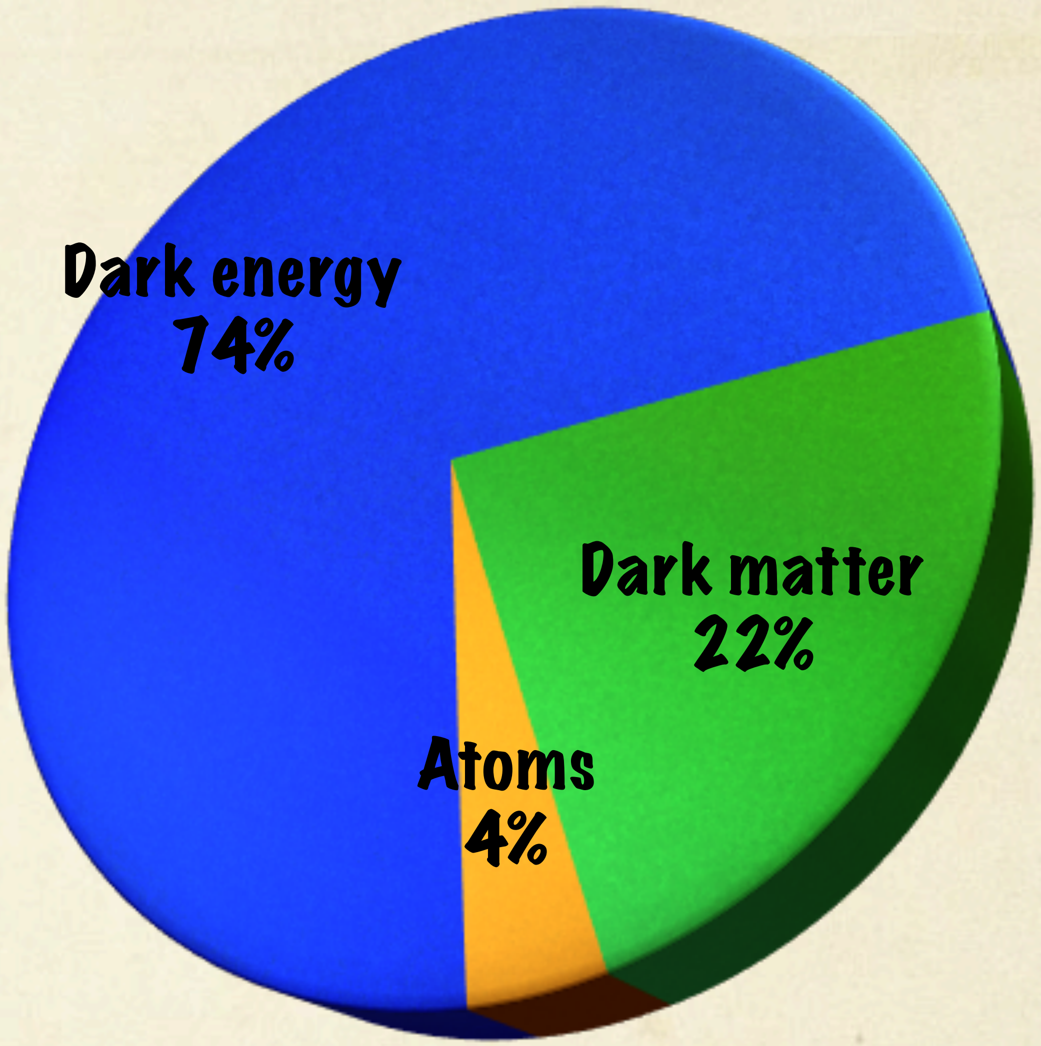

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- Its mass and spin
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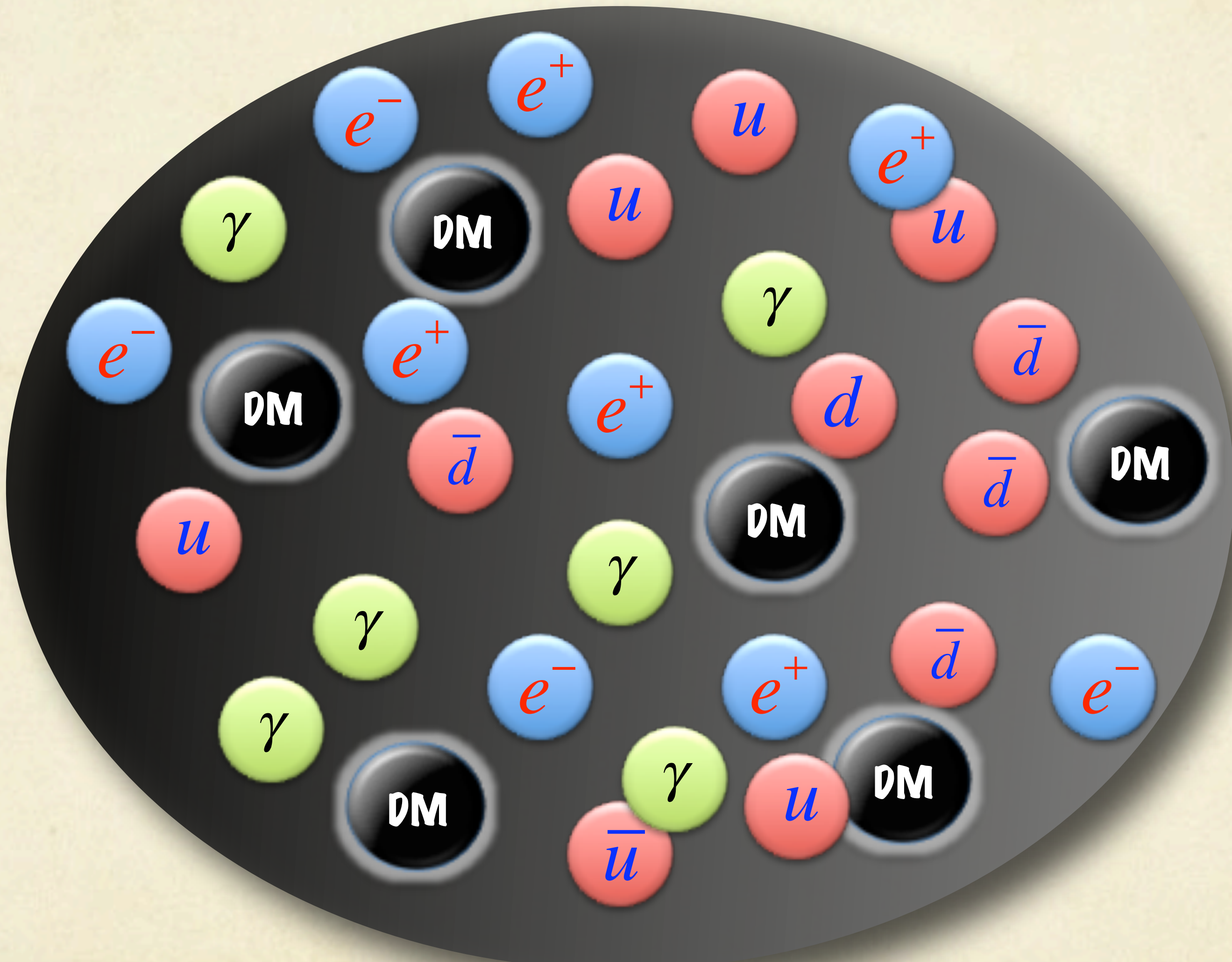
More exciting data in the near future!!!

How comes very few dark
matter remain today,
if it is absolutely stable ?

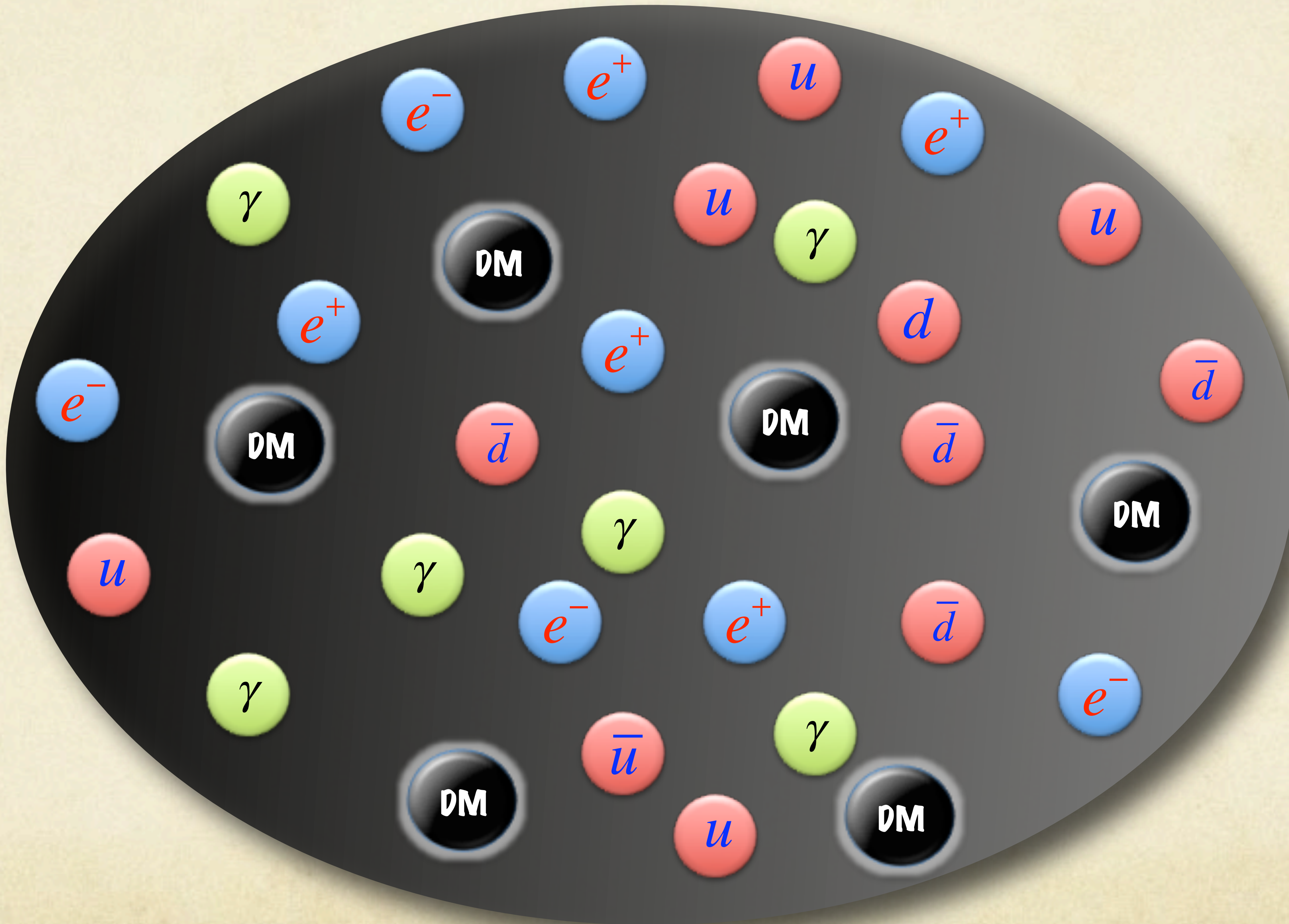
Stage 1: Universe in equilibrium



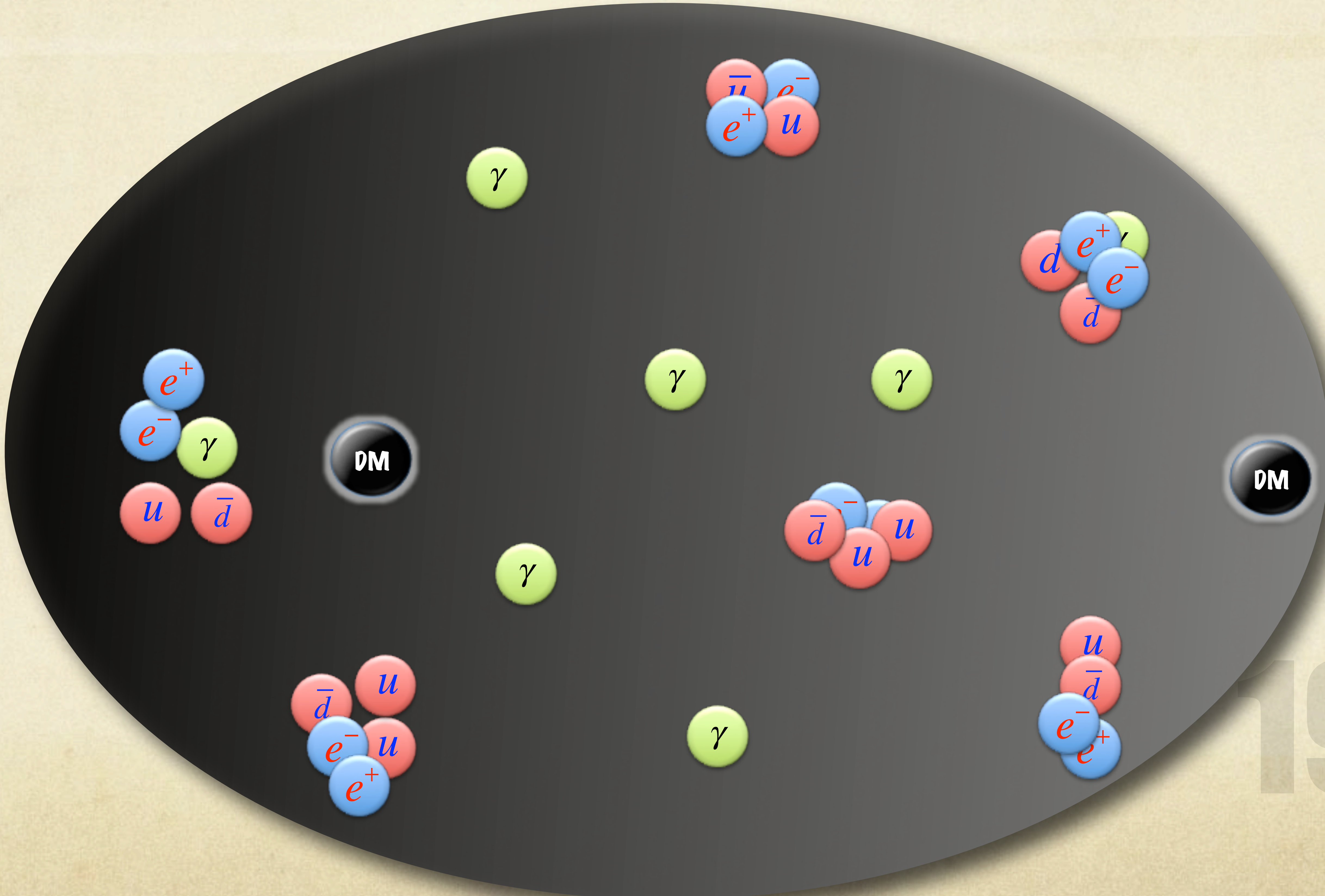
Stage 2: Universe in expansion

Universe cools down

DM becomes Non-relativistic



Stage 3: dark matter frozen out



Relic abundance

- Assume the new particle is initially in thermal equilibrium:

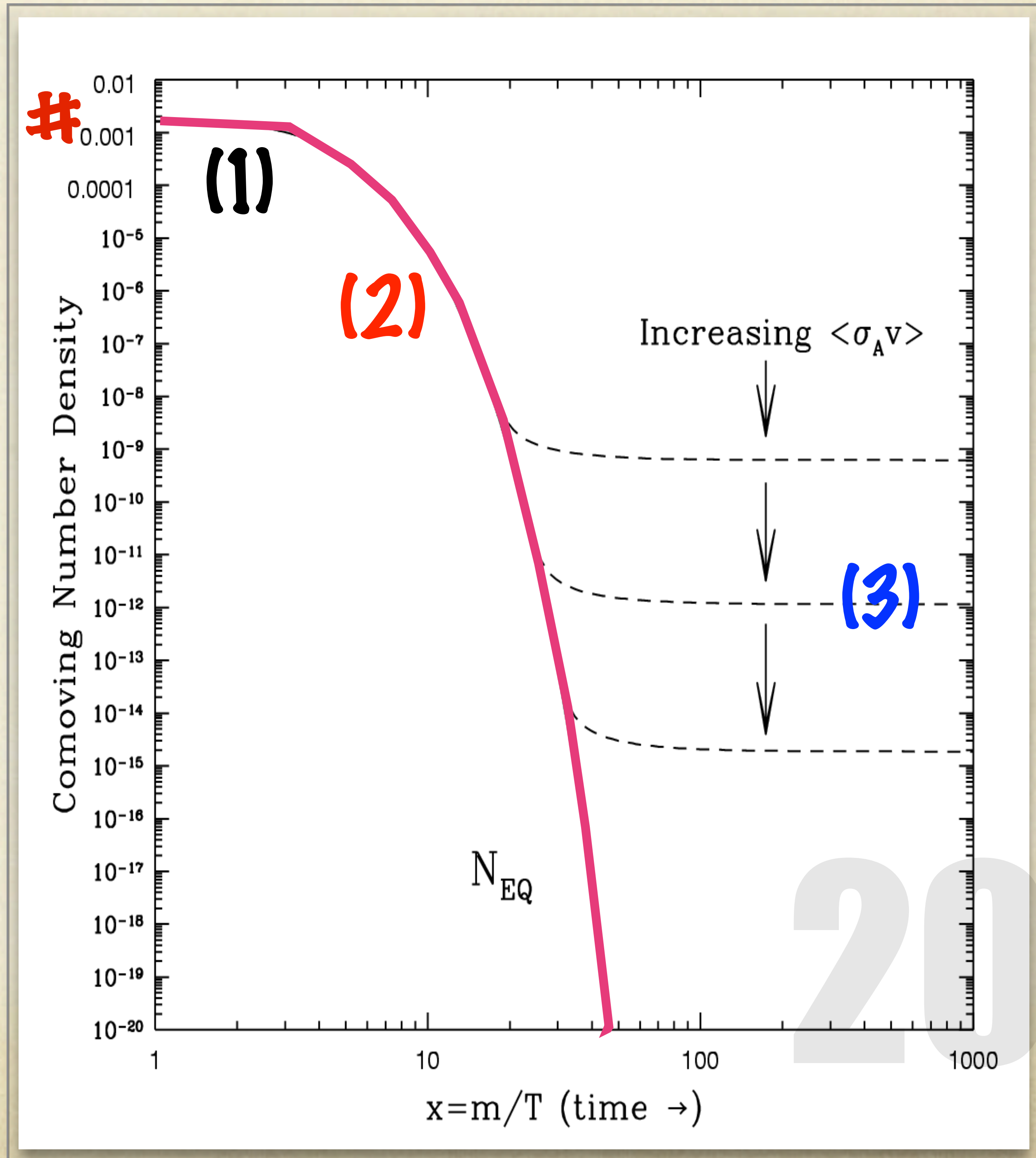
$$\chi\chi \leftrightarrow f f$$

- Universe cools down:

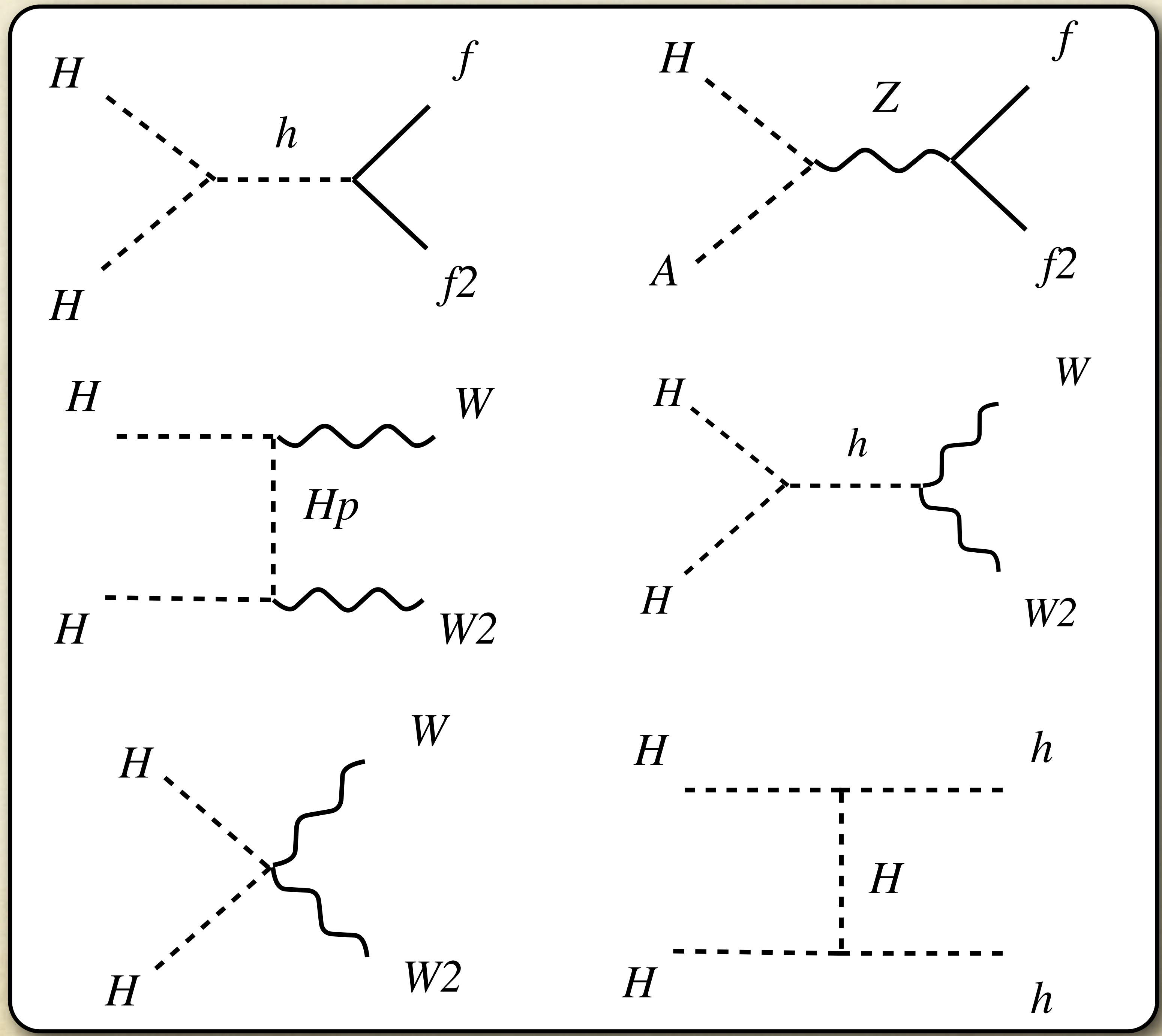
$$N = N_{EQ} \sim e^{-\frac{m}{T}}$$

- Dark matter freeze out:

$$N \sim \text{Constant}$$



DM annihilation channels



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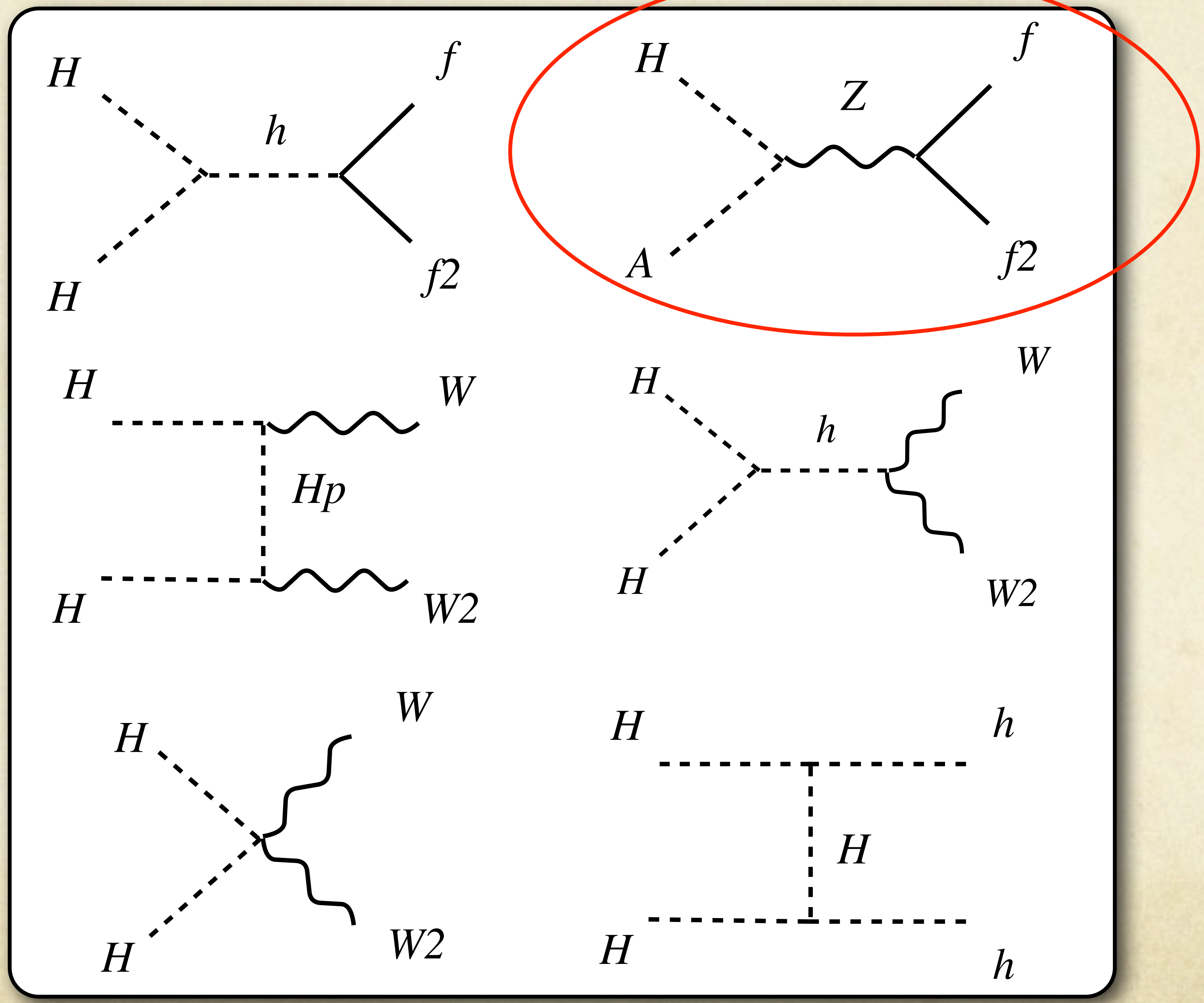


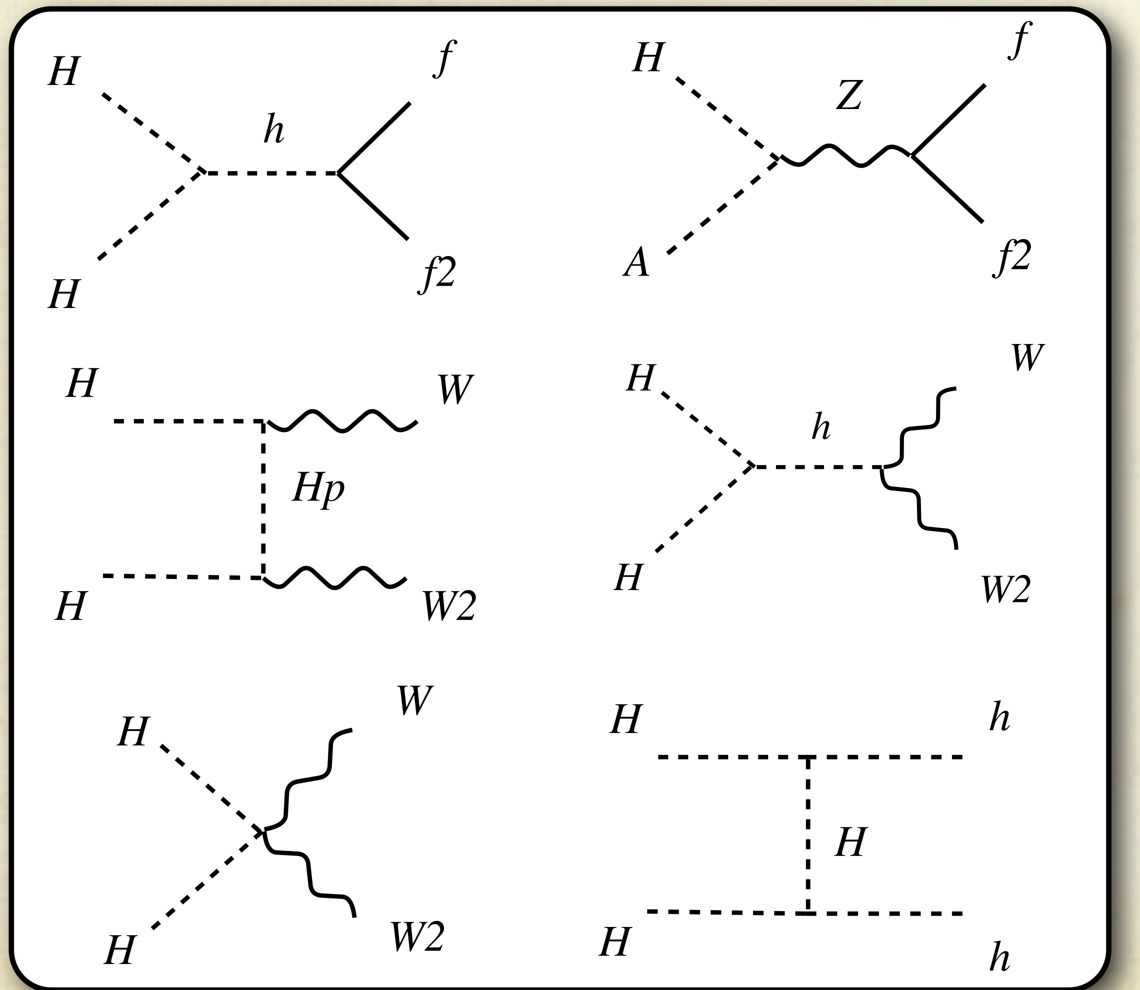
$m_A \approx m_H$

Co-annihilation

cao

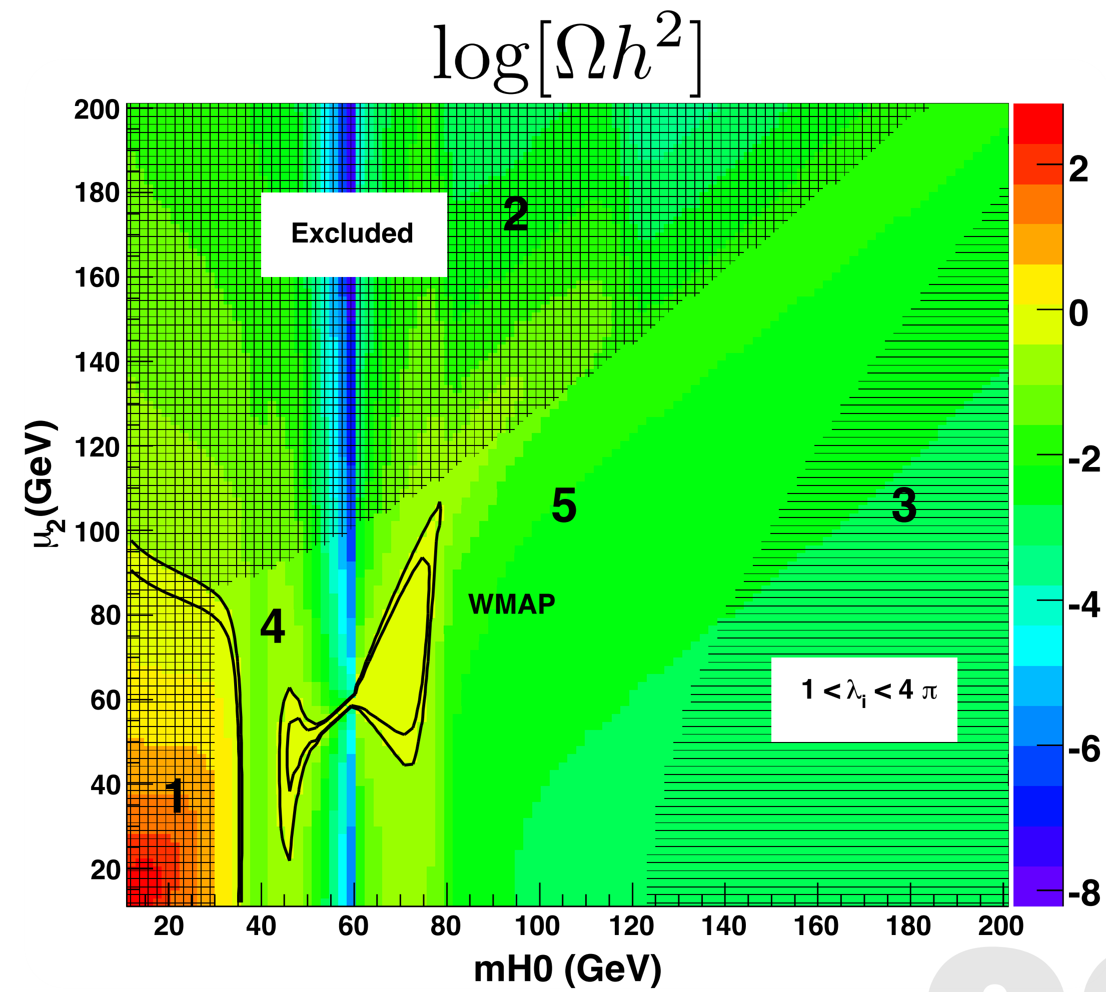
Relic abundance

$$\Omega_{\rm CDM} h^2 \sim \frac{0.1 \rm pb}{\langle \sigma v \rangle_{\rm ann}}$$



$$\rm WMAP : \Omega_{CDM} h^2 \sim 0.1$$

Laura Lopez Honorez, et al. hep-ph/0612275



$$m_h = 120 \rm GeV$$

$$m_{A^0} = m_{H^0} + 10 \rm GeV$$

$$m_{H^\pm} = m_{H^0} + 50 \rm GeV$$

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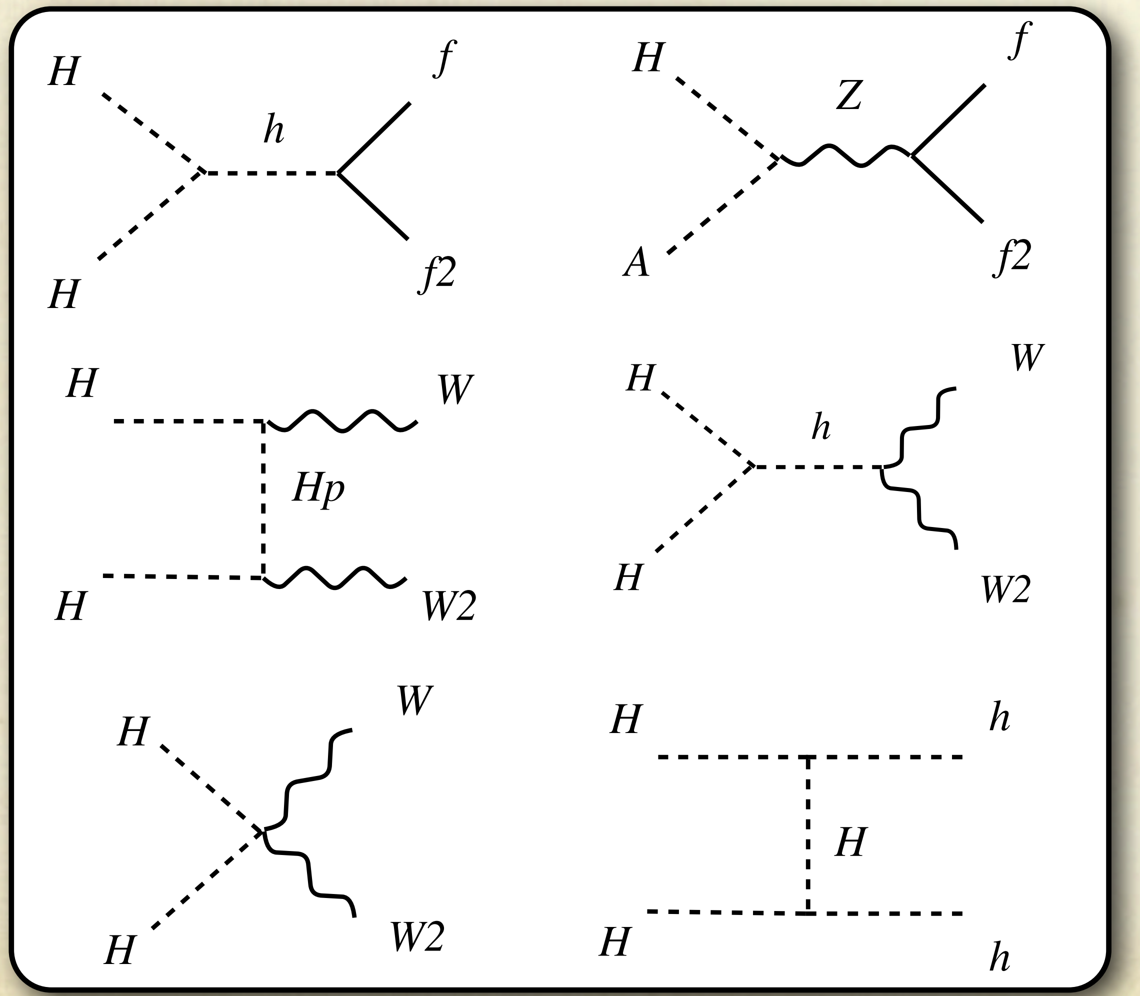

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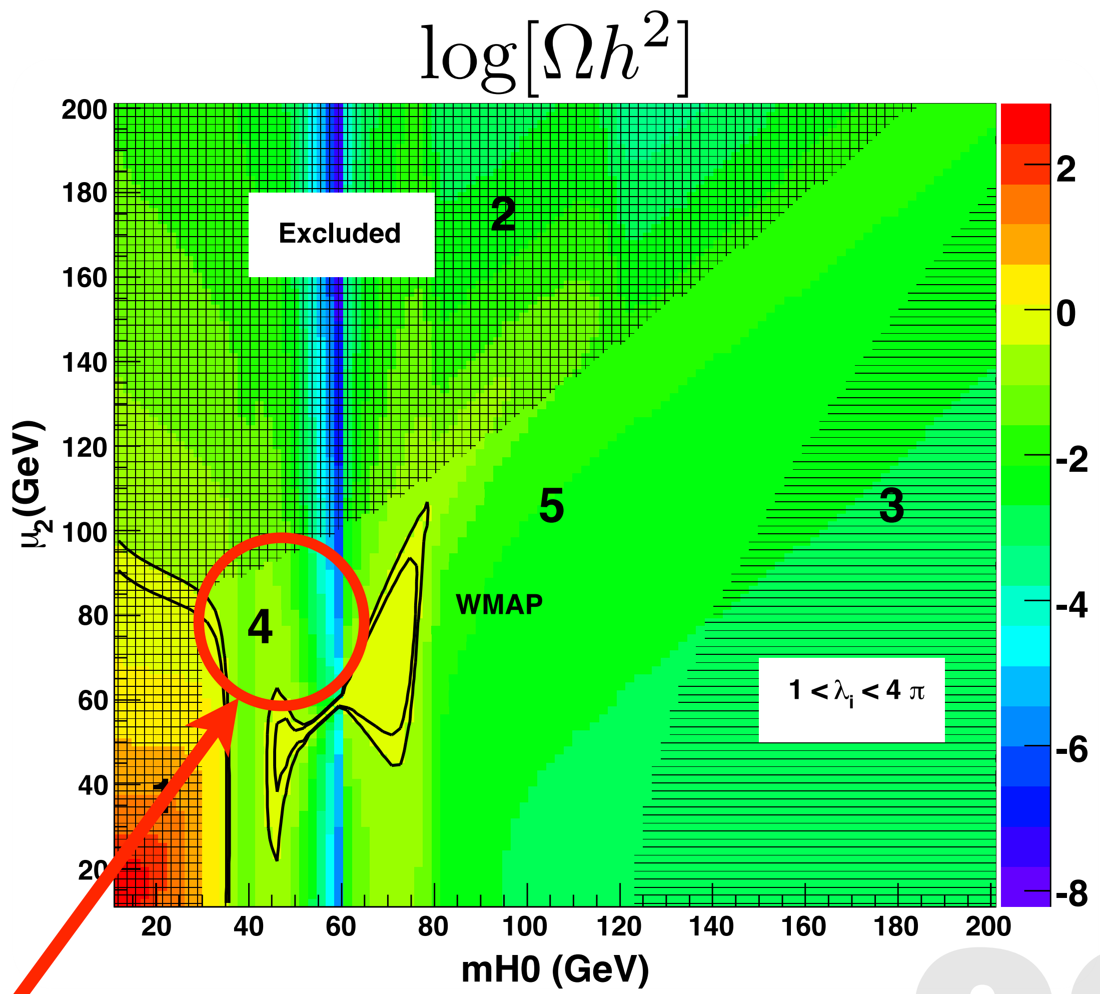

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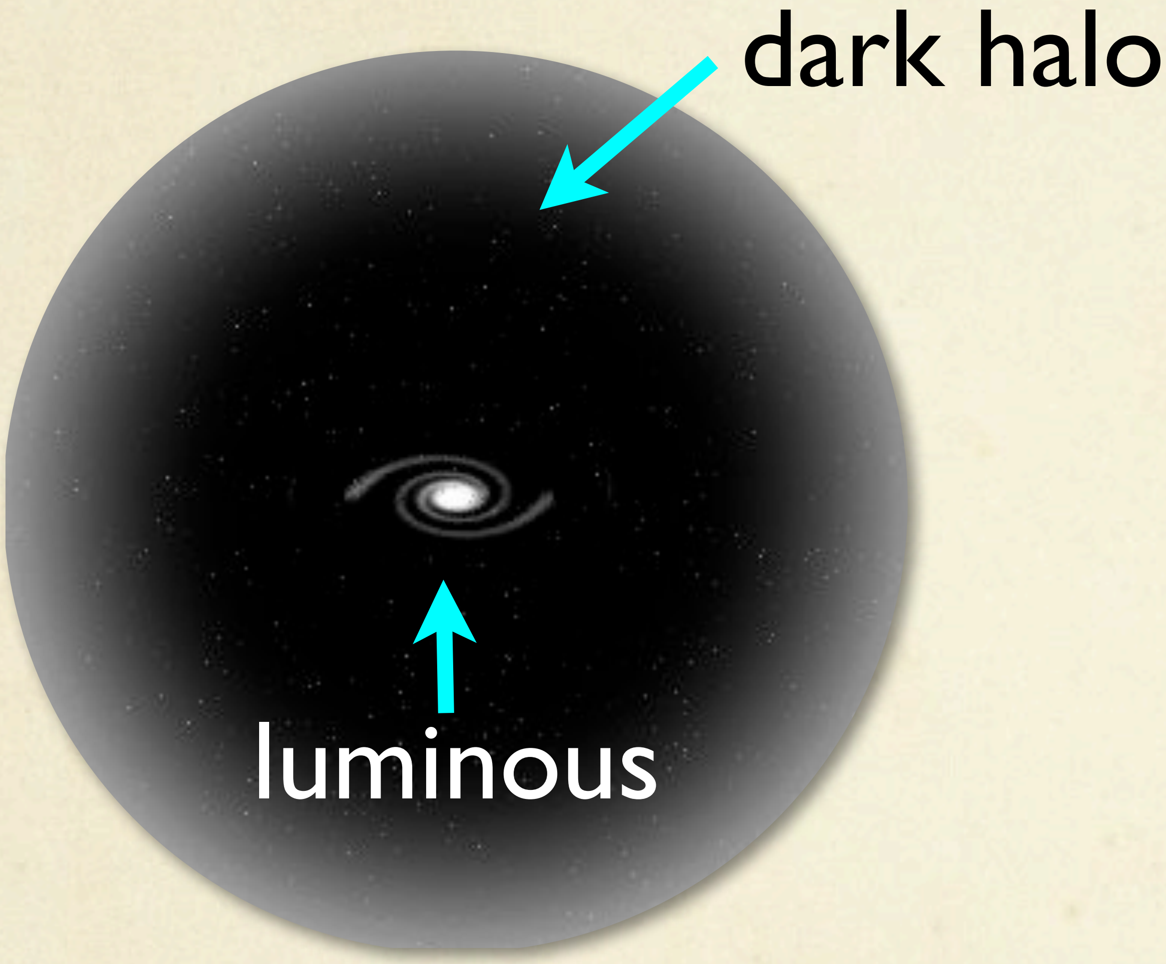
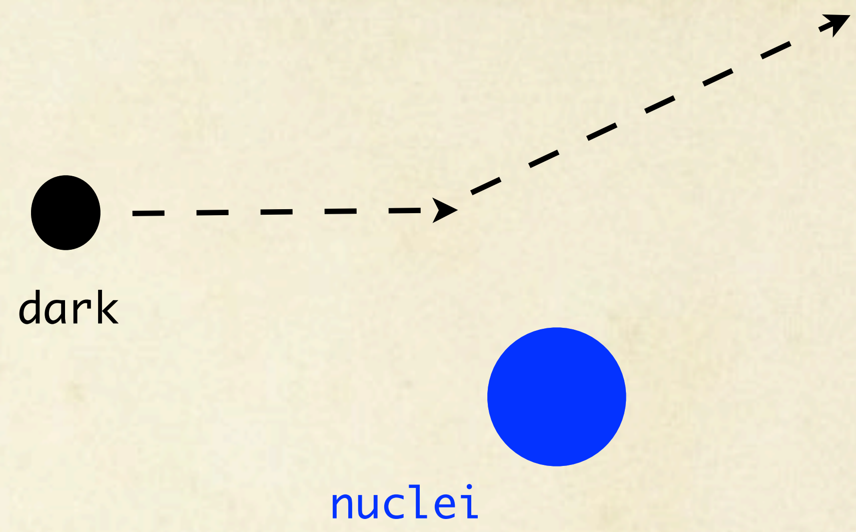
Constraint from DM direct detection





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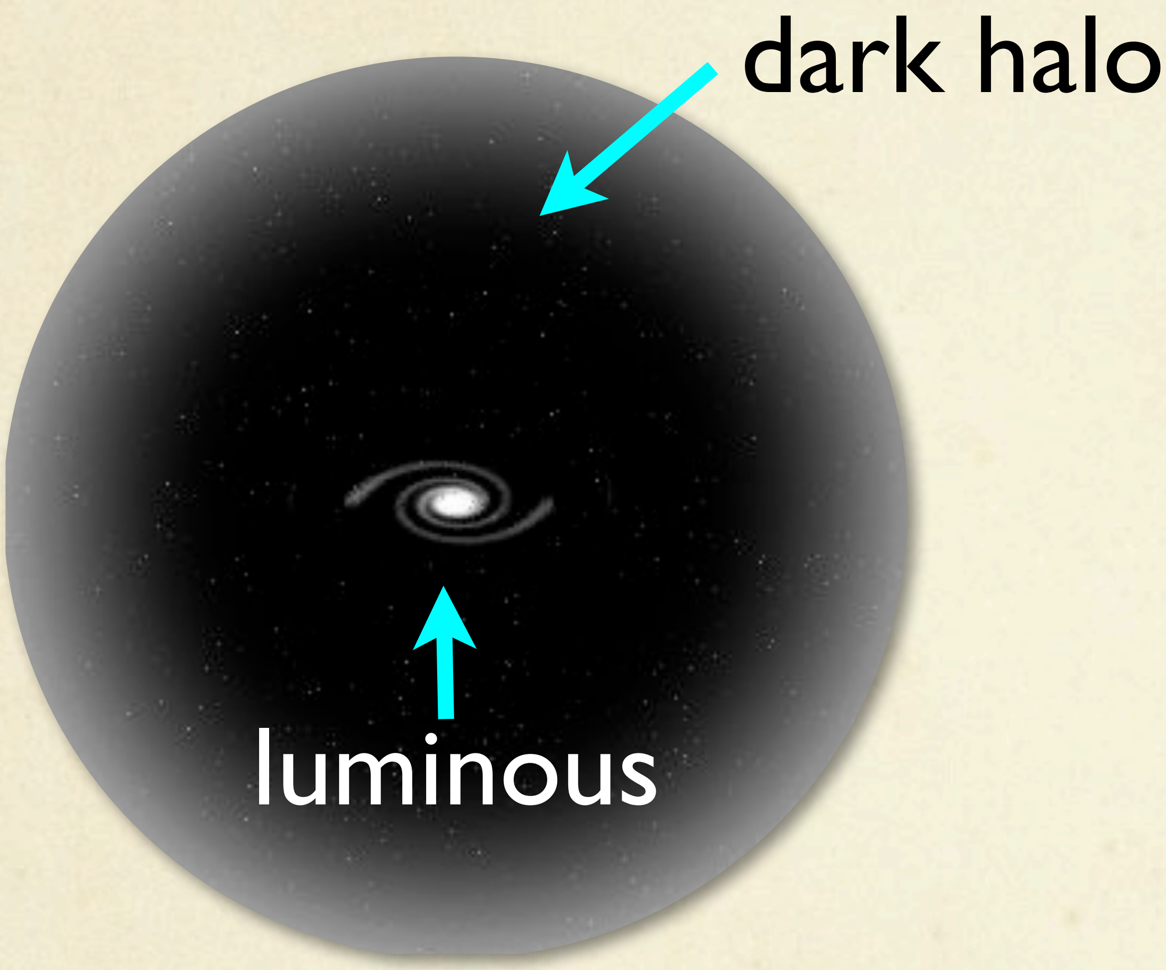

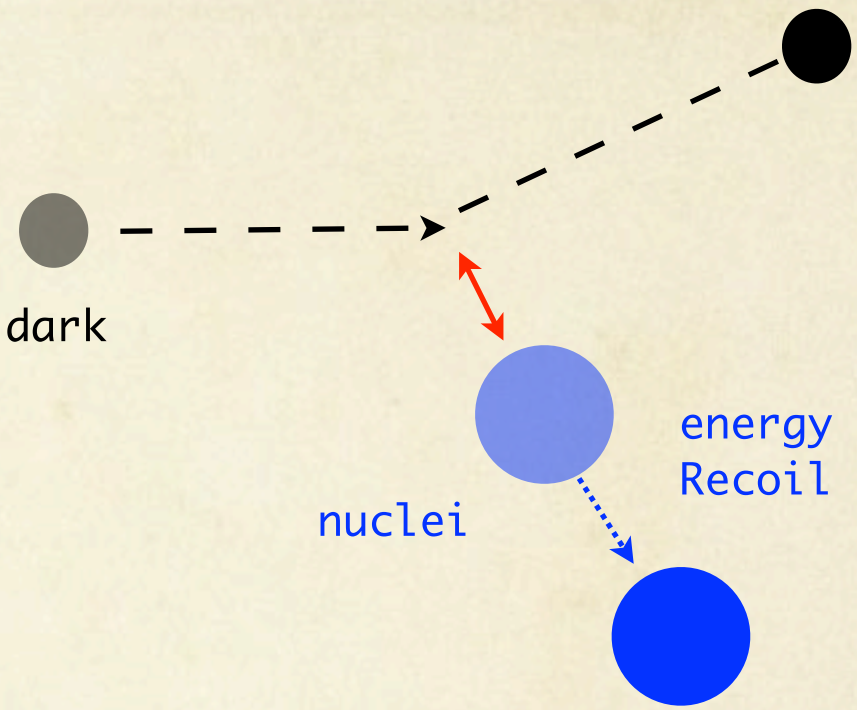

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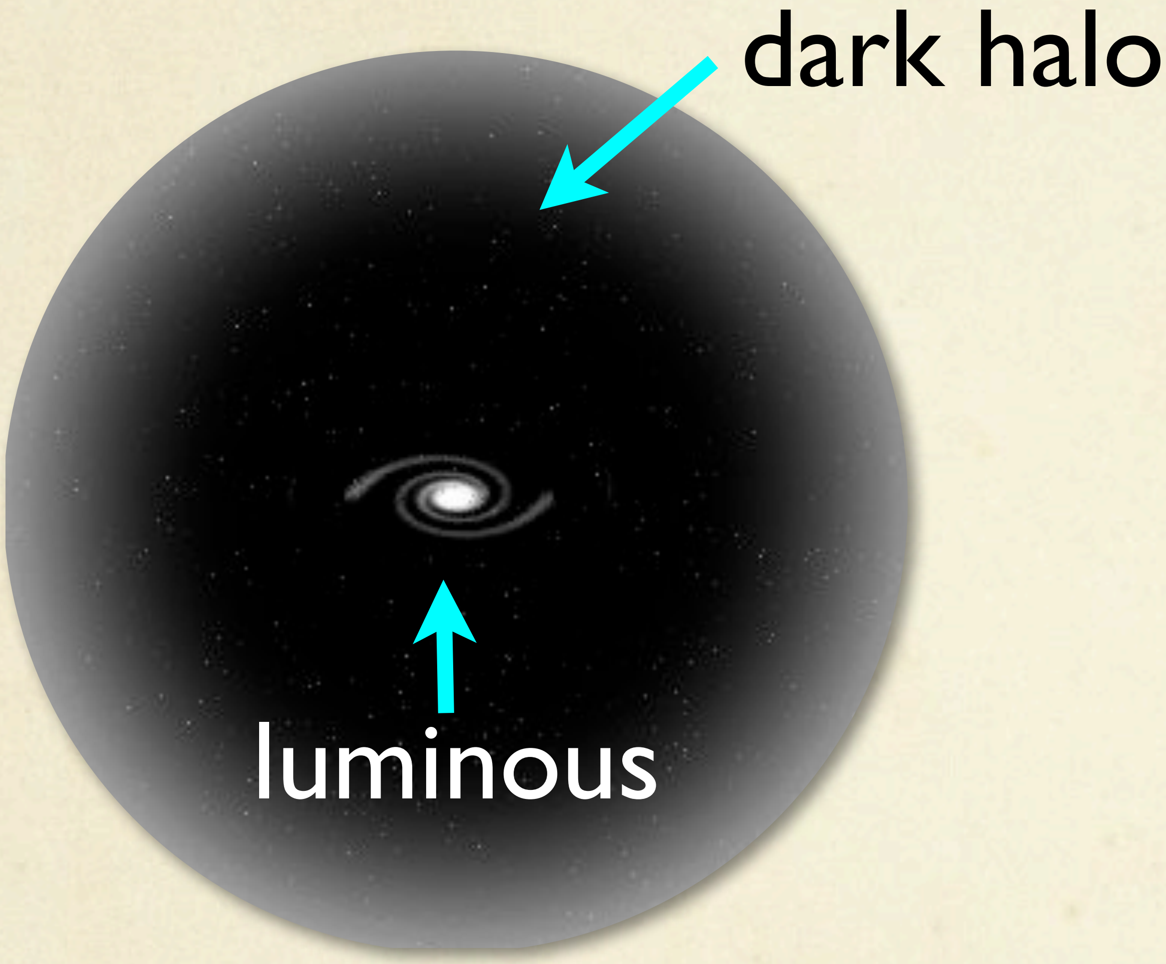

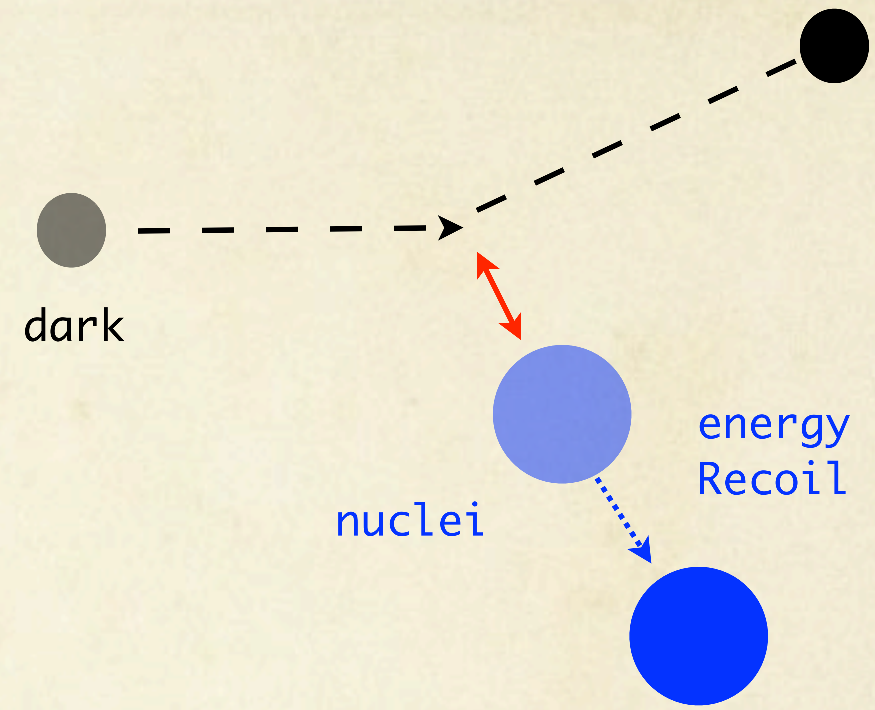

CDMS : $\sigma_{DN} < 10^{-7}\mathrm{pb}$

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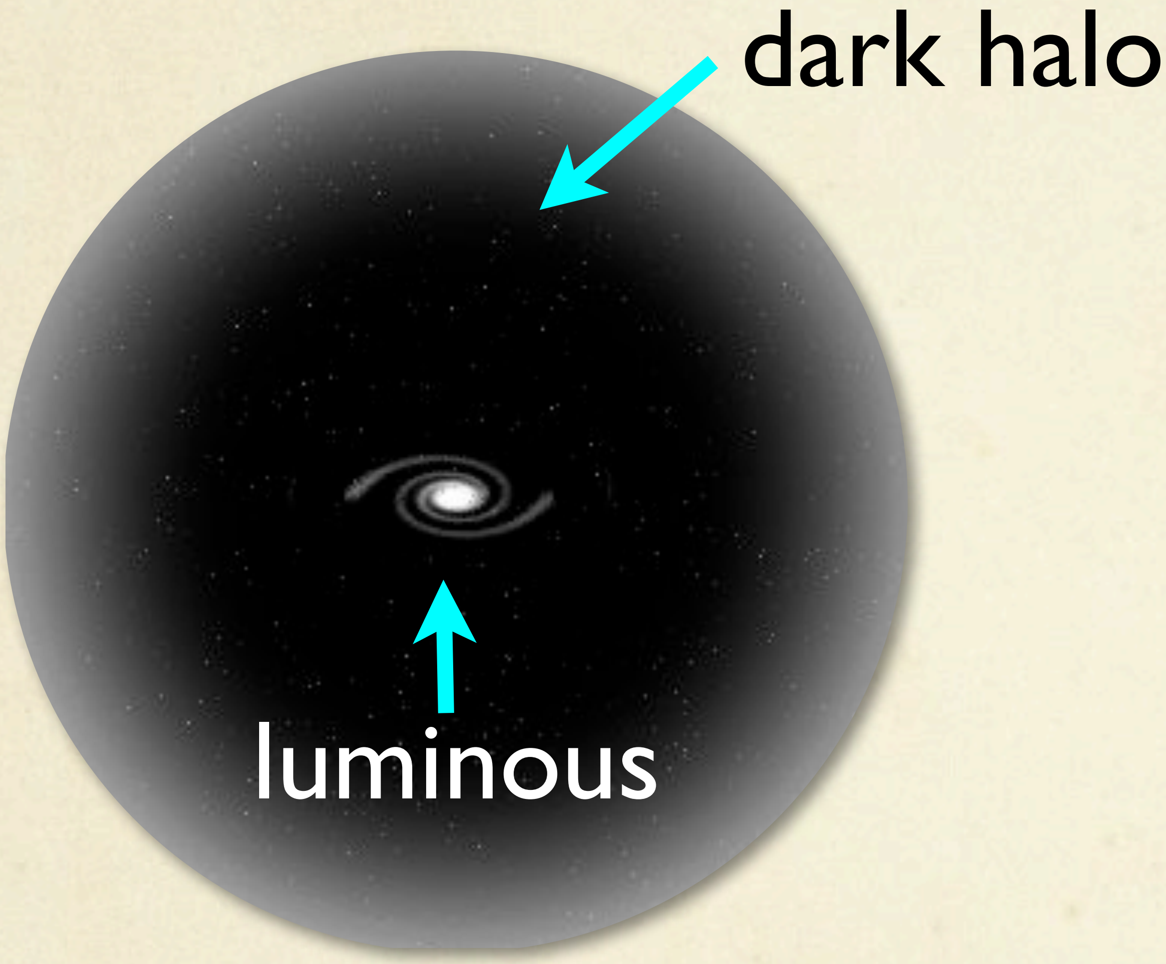

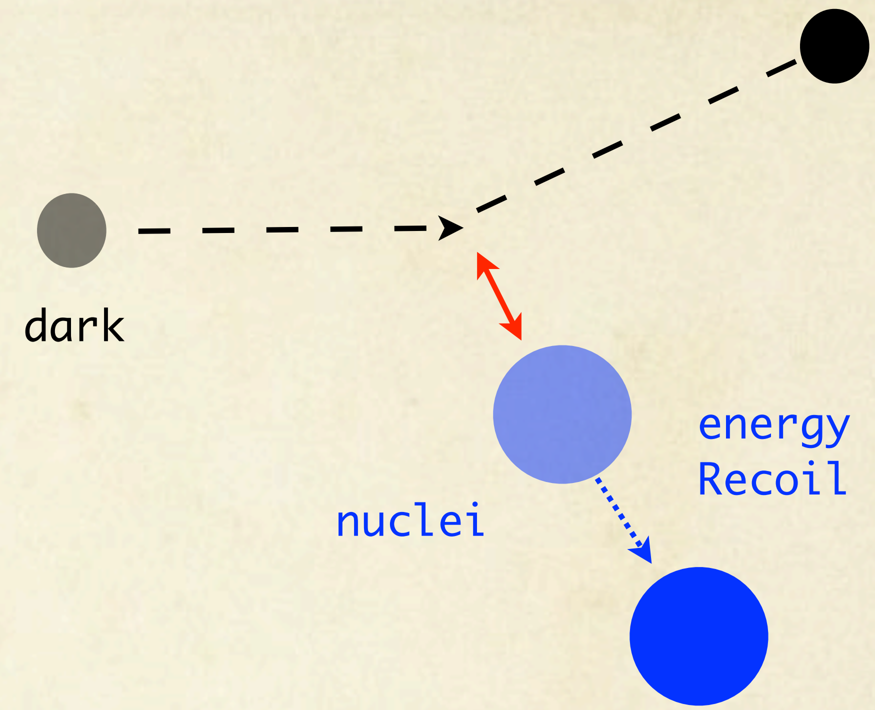

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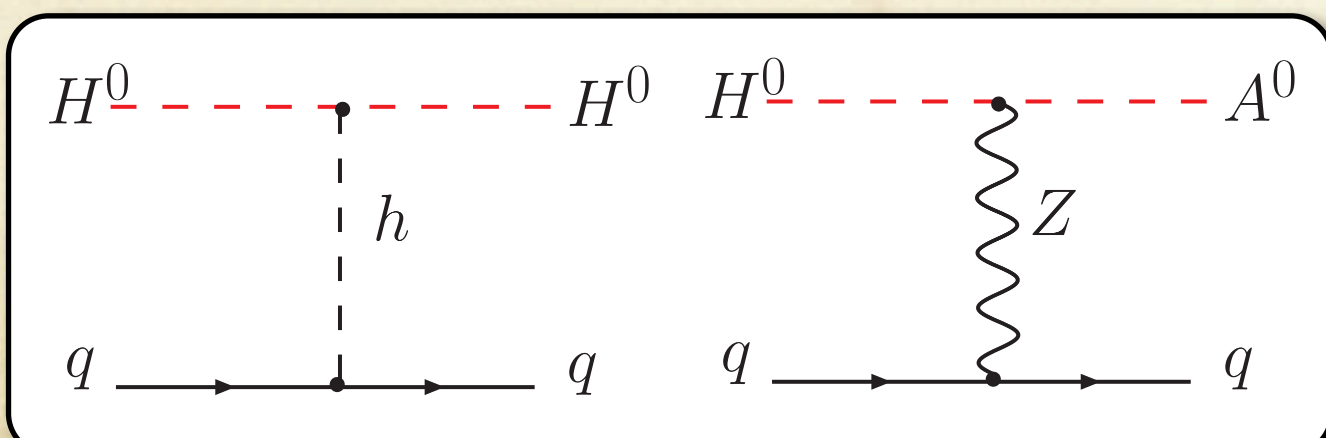

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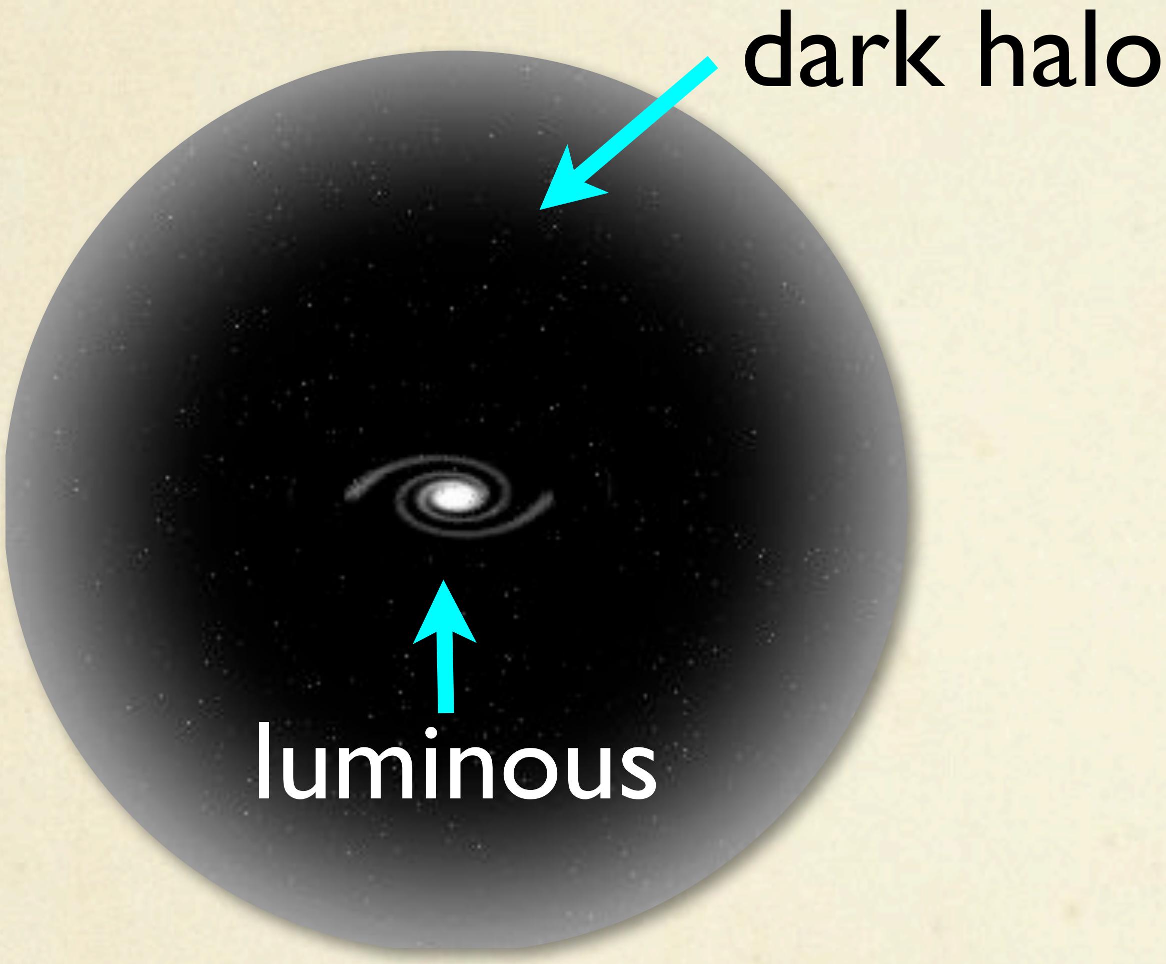

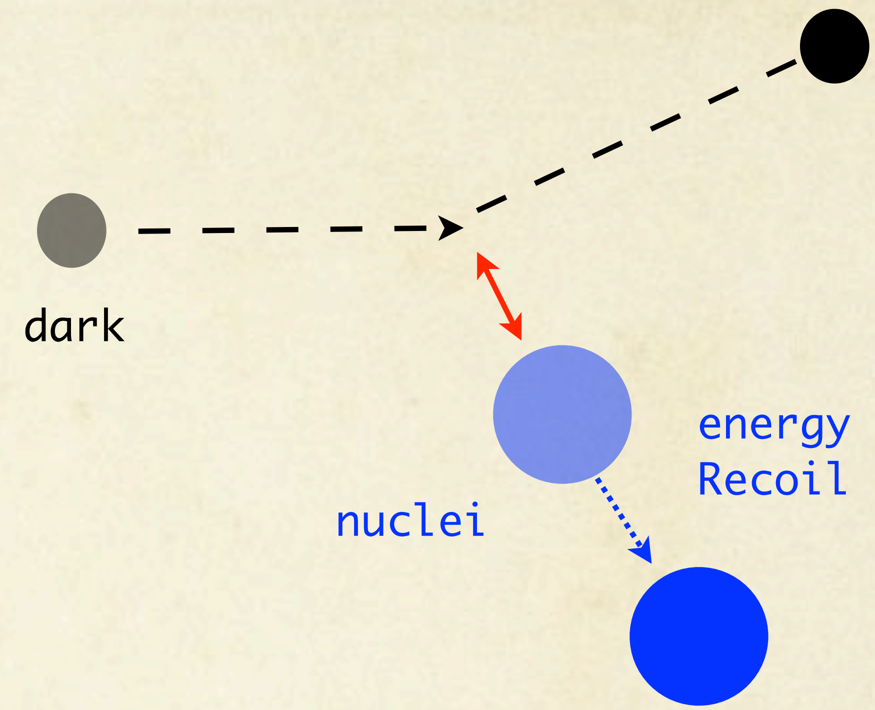

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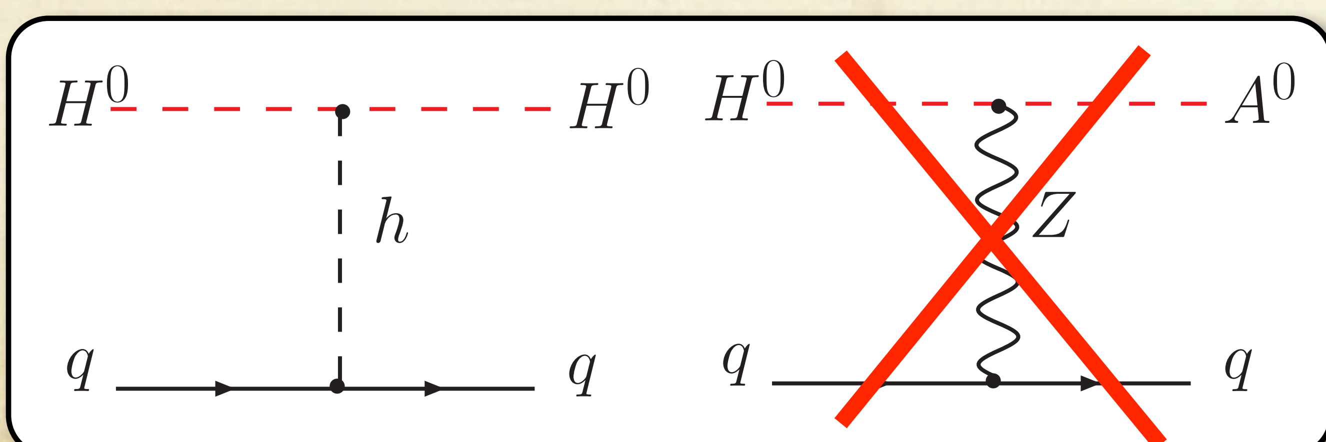

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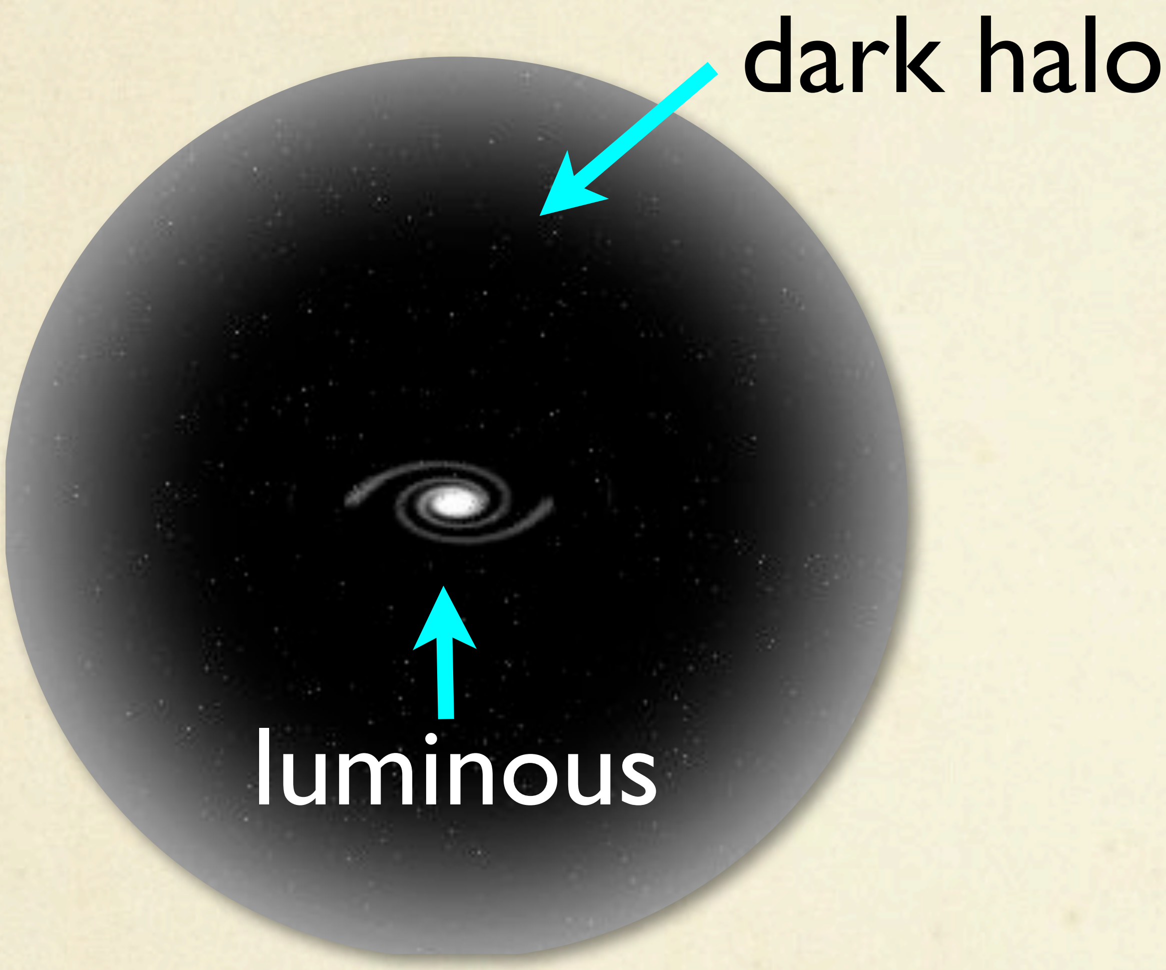

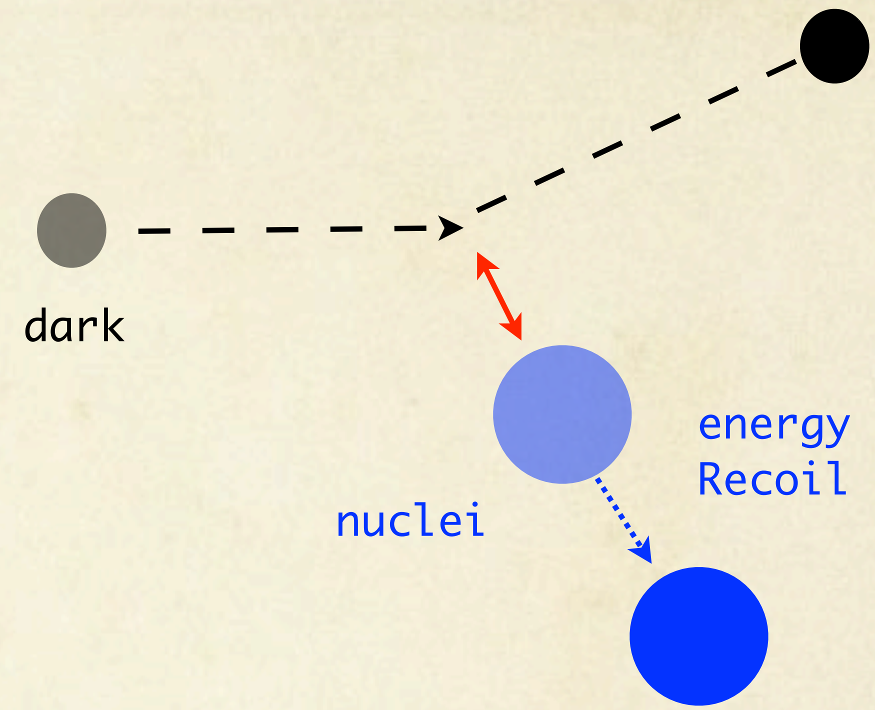

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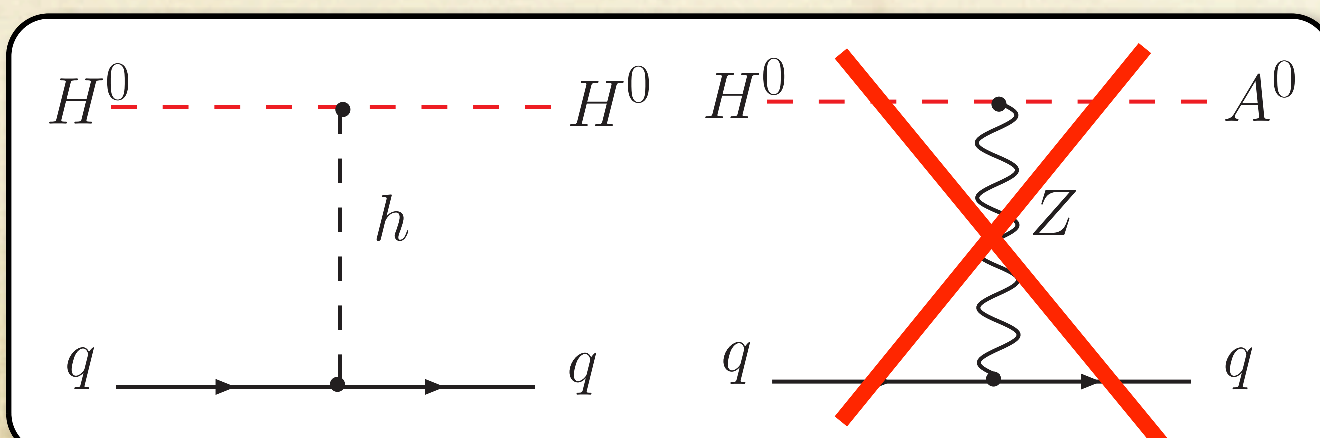
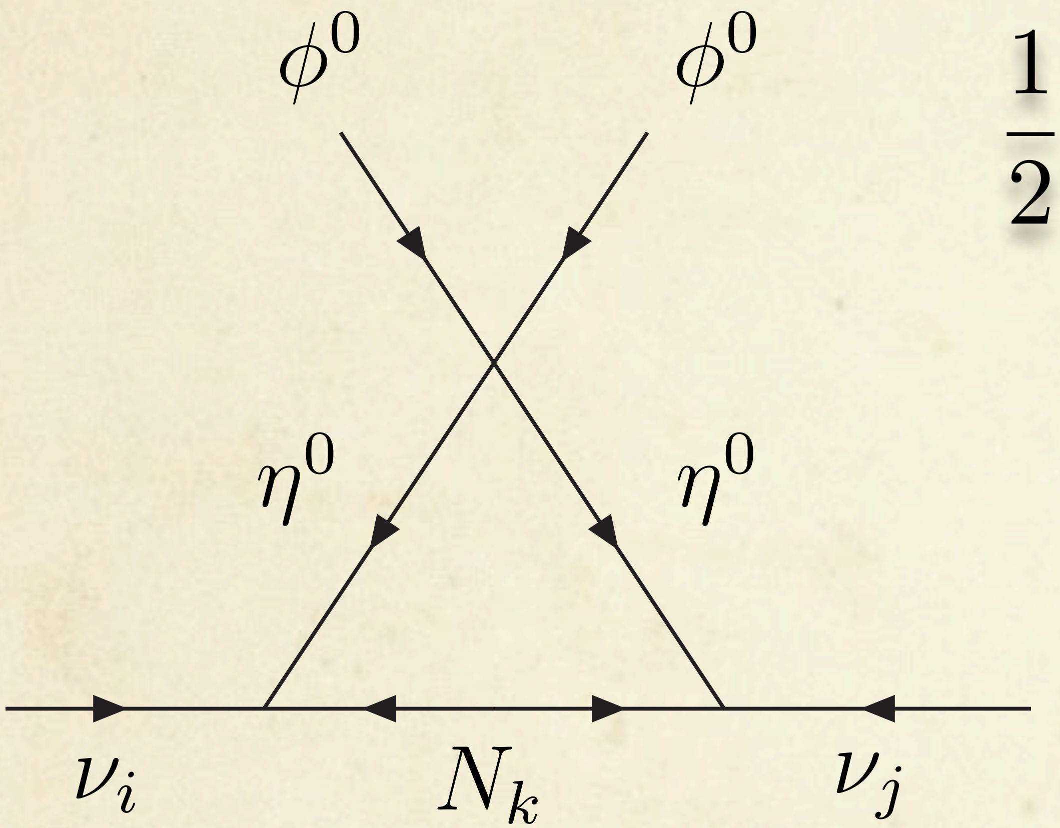


$$m_{A^0} > m_{H^0} + \text{MeV}$$

Neutrino mass



$$\frac{1}{2}\lambda_5\left(\Phi^\dagger\eta\right)^2 + h.c.$$

$$\left|\Phi^\dagger\eta\right|^2 \to \Re(\eta)^2 + \Im(\eta)^2$$

$$\left(\Phi^\dagger\eta\right)^2 \to \Re(\eta)^2 - \Im(\eta)^2$$

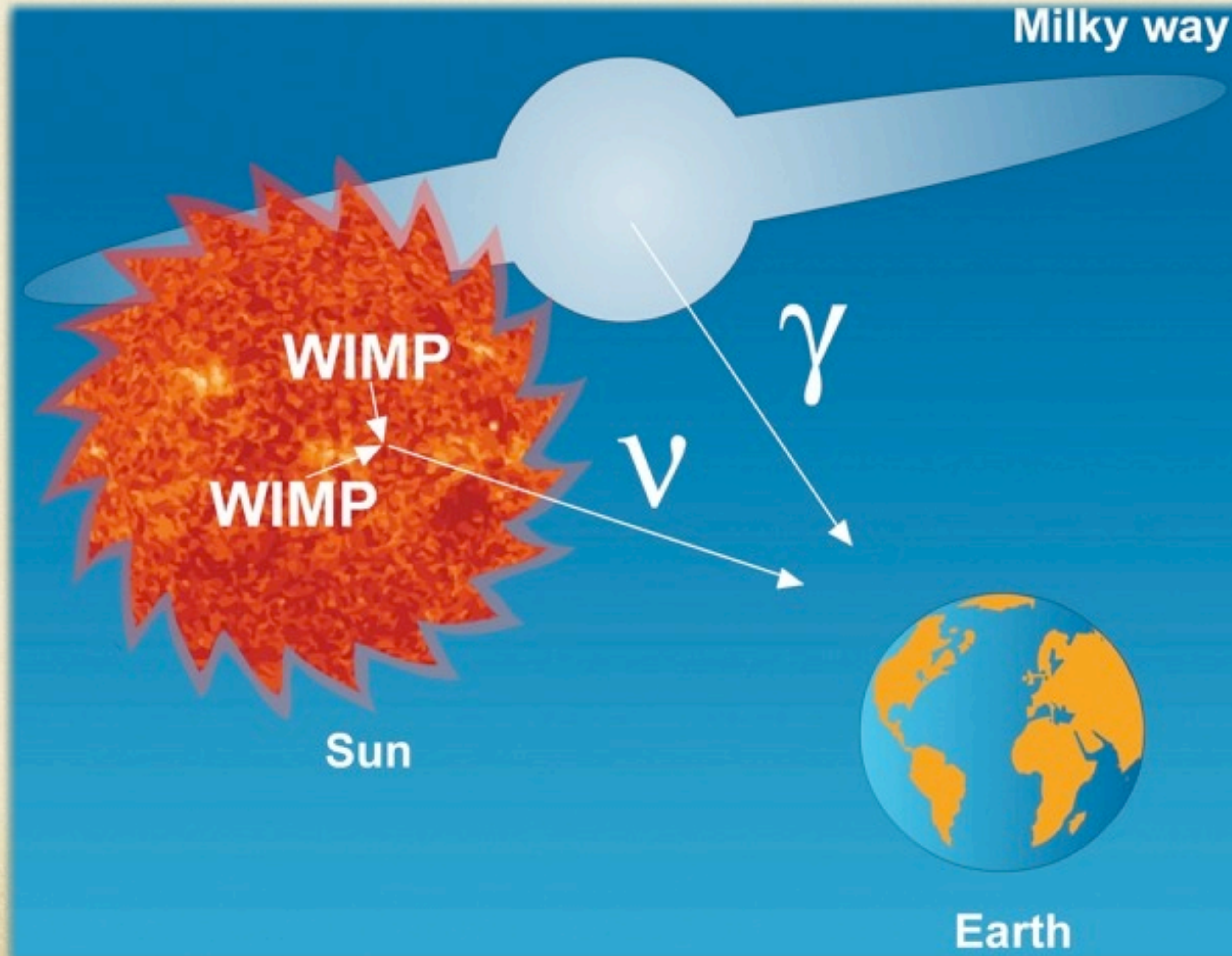
$$m_{H^0}^2 - m_{A^0}^2 = 2\lambda_5 v^2$$

Dark Matter

(1) Generate neutrino mass via the radiative see-saw mechanism

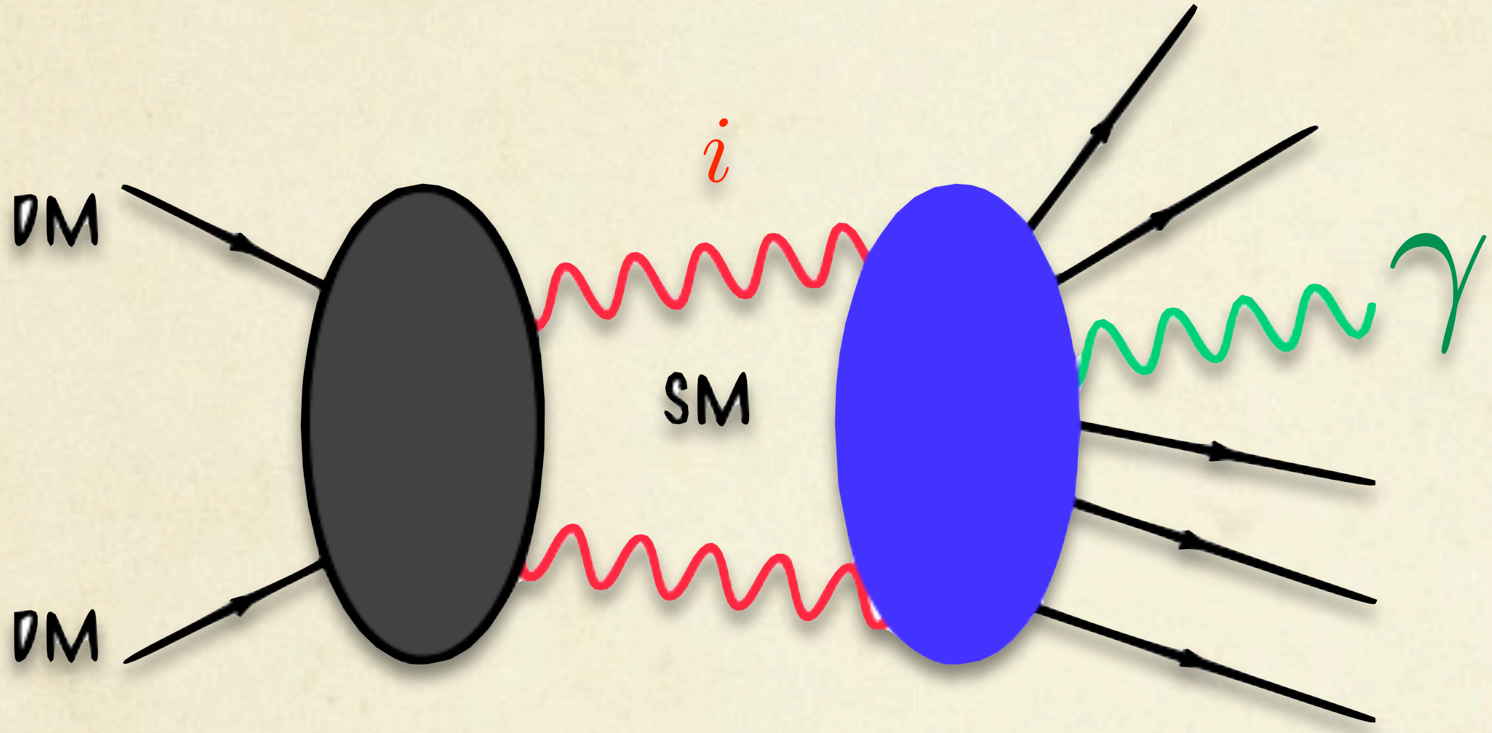
(2) Save the model from the dangerous dark matter direct detection

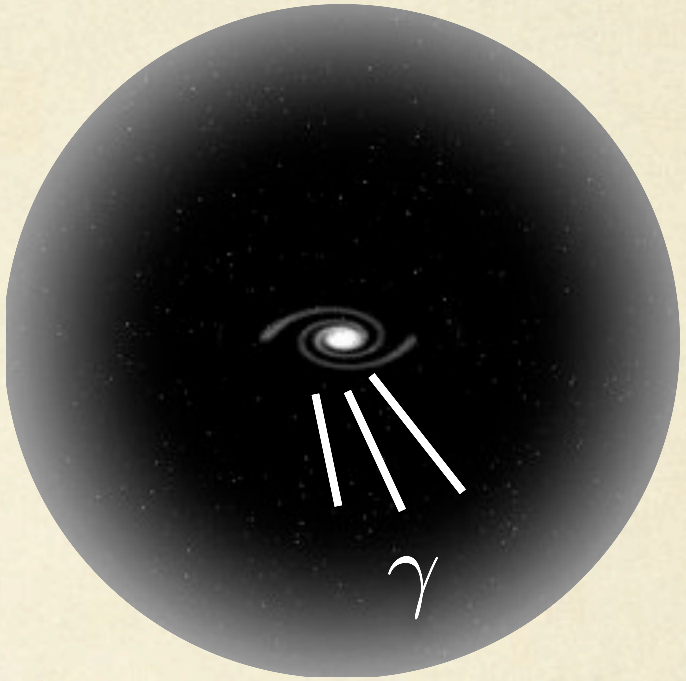
Indirect search of dark matter



Cosmic gamma-ray (indirect)

$\eta\eta \to WW, ZZ, \cdots$ in the Galactic halo

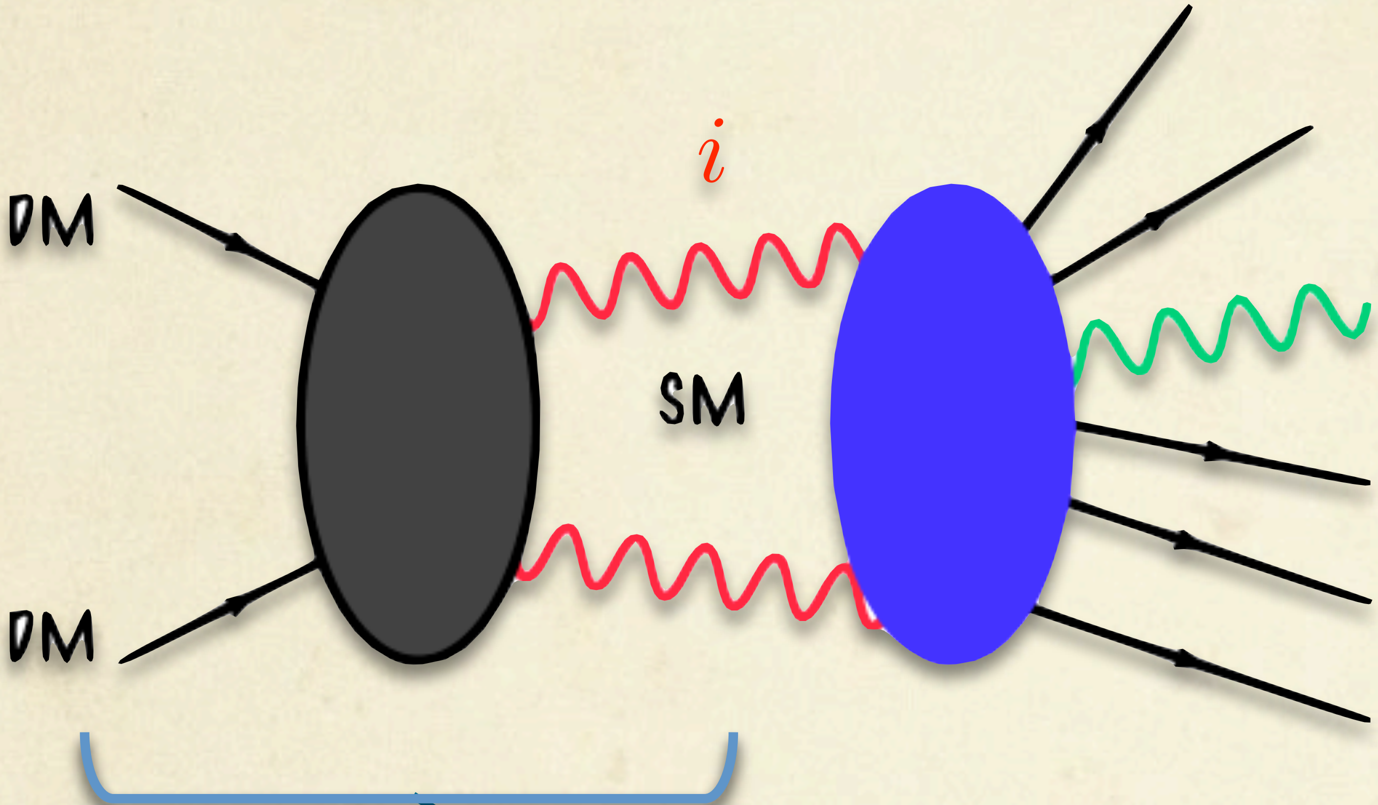


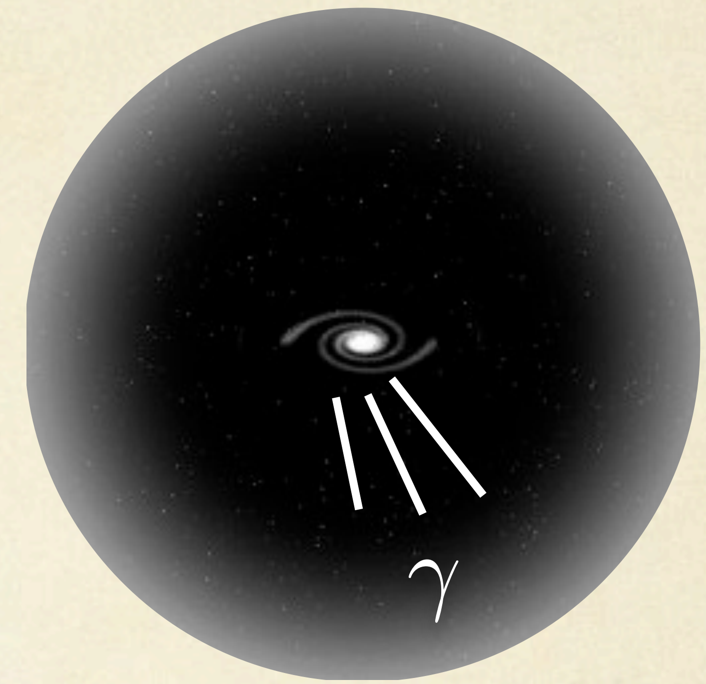


$$\frac{d\Phi}{d\Omega dE} = \sum_i \langle \sigma v \rangle_i \frac{dN_i}{dE} \frac{1}{4\pi m_{DM}^2} \int_{\mathrm{l.o.l}} \rho^2 dl$$

Cosmic gamma-ray (indirect)

$\eta\eta \to WW, ZZ, \cdots$ **in the Galactic halo**

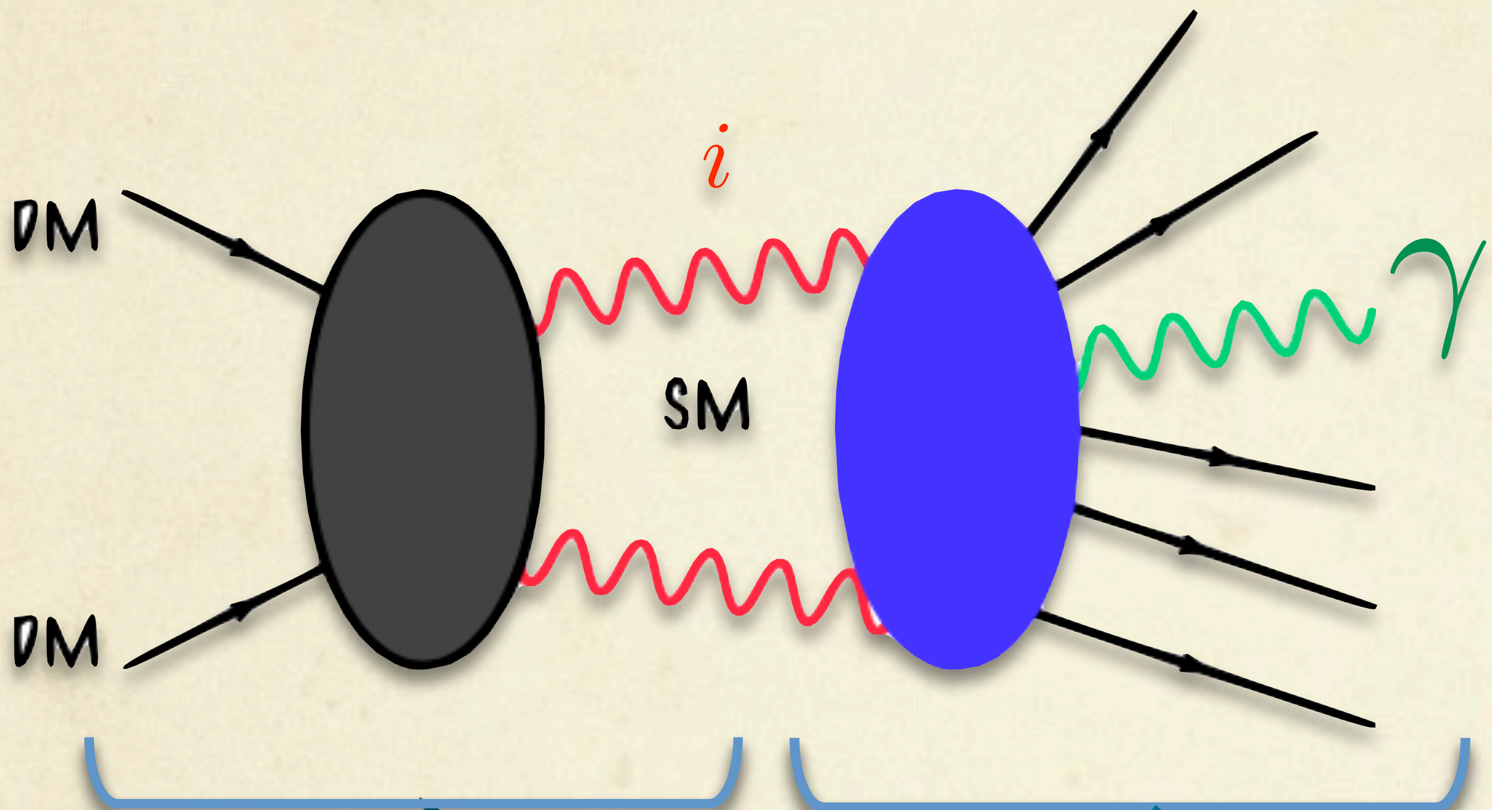


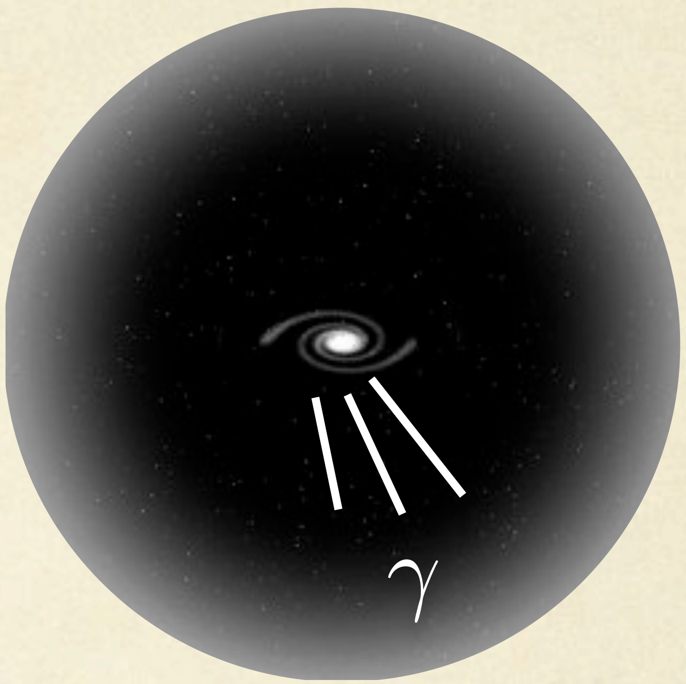


$$\frac{d\Phi}{d\Omega dE} = \sum_i \langle \sigma v \rangle_i \frac{dN_i}{dE} \frac{1}{4\pi m_{DM}^2} \int_{\mathrm{l.o.l}} \rho^2 dl$$

Cosmic gamma-ray (indirect)

$\eta\eta \to WW, ZZ, \cdots$ in the Galactic halo



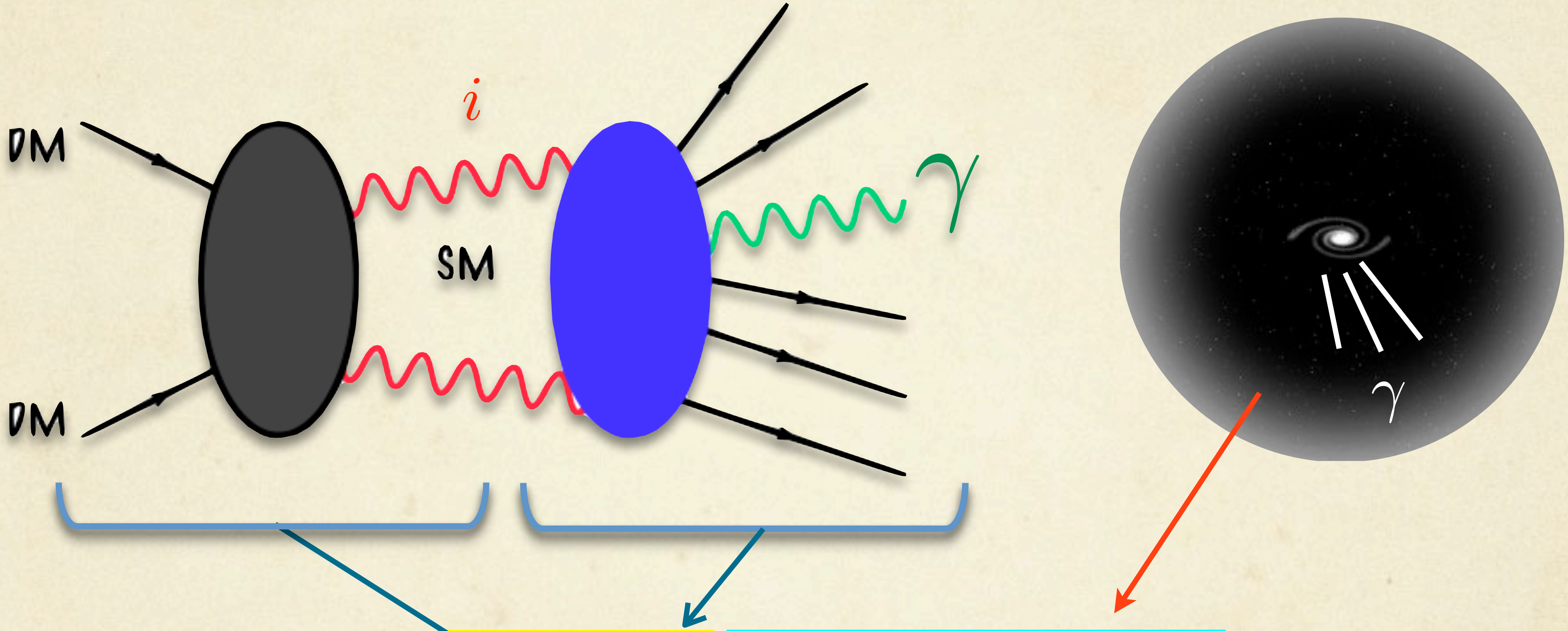


$$\frac{d\Phi}{d\Omega dE} = \sum_i \langle \sigma v \rangle_i \frac{dN_i}{dE} \frac{1}{4\pi m_{DM}^2} \int_{\mathrm{l.o.l}} \rho^2 dl$$

Particle Physics

Cosmic gamma-ray (indirect)

$\eta\eta \to WW, ZZ, \cdots$ in the Galactic halo

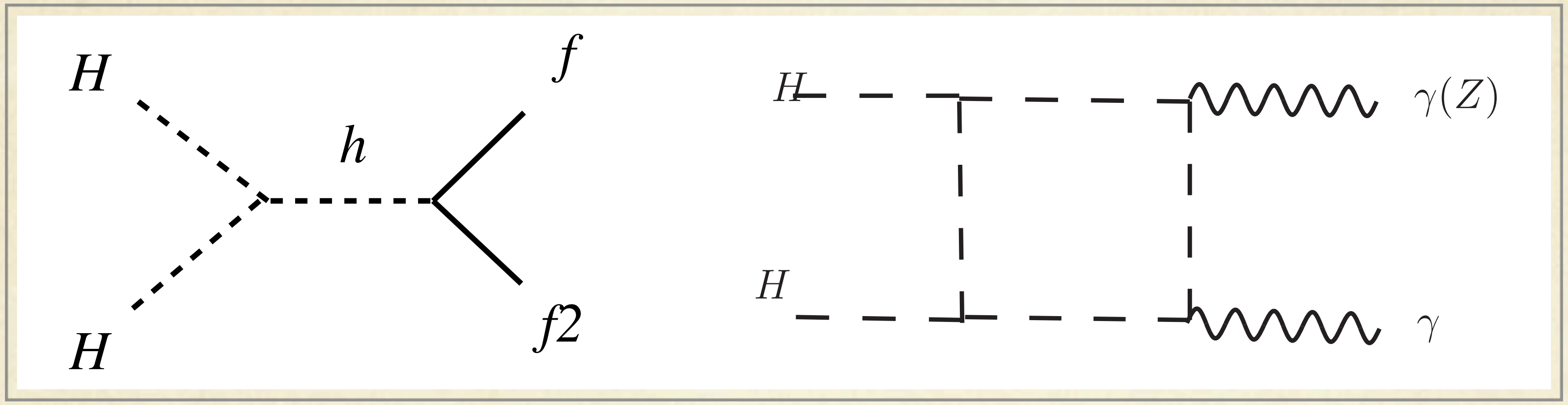


$$\frac{d\Phi}{d\Omega dE} = \sum_i \langle \sigma v \rangle_i \frac{dN_i}{dE} \frac{1}{4\pi m_{DM}^2} \int_{\text{l.o.l}} \rho^2 dl$$

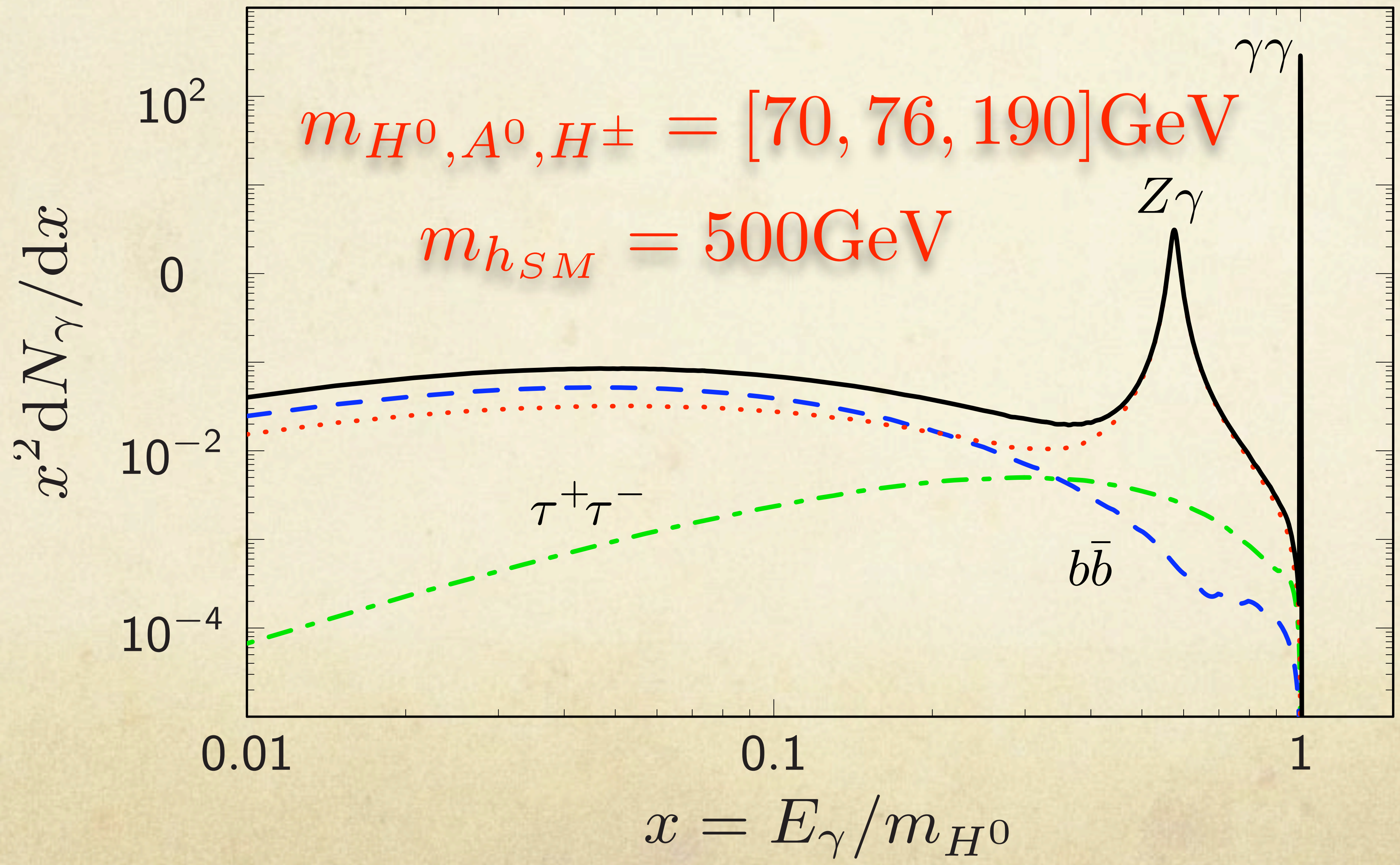
Particle Physics

Astrophysics

Spectacular line-shape in the DSM



M. Gustafsson, et al, hep-ph/0703512



$BR(\gamma\gamma) = 36\%$

$BR(Z\gamma) = 33\%$

$BR(b\bar{b}) = 26\%$

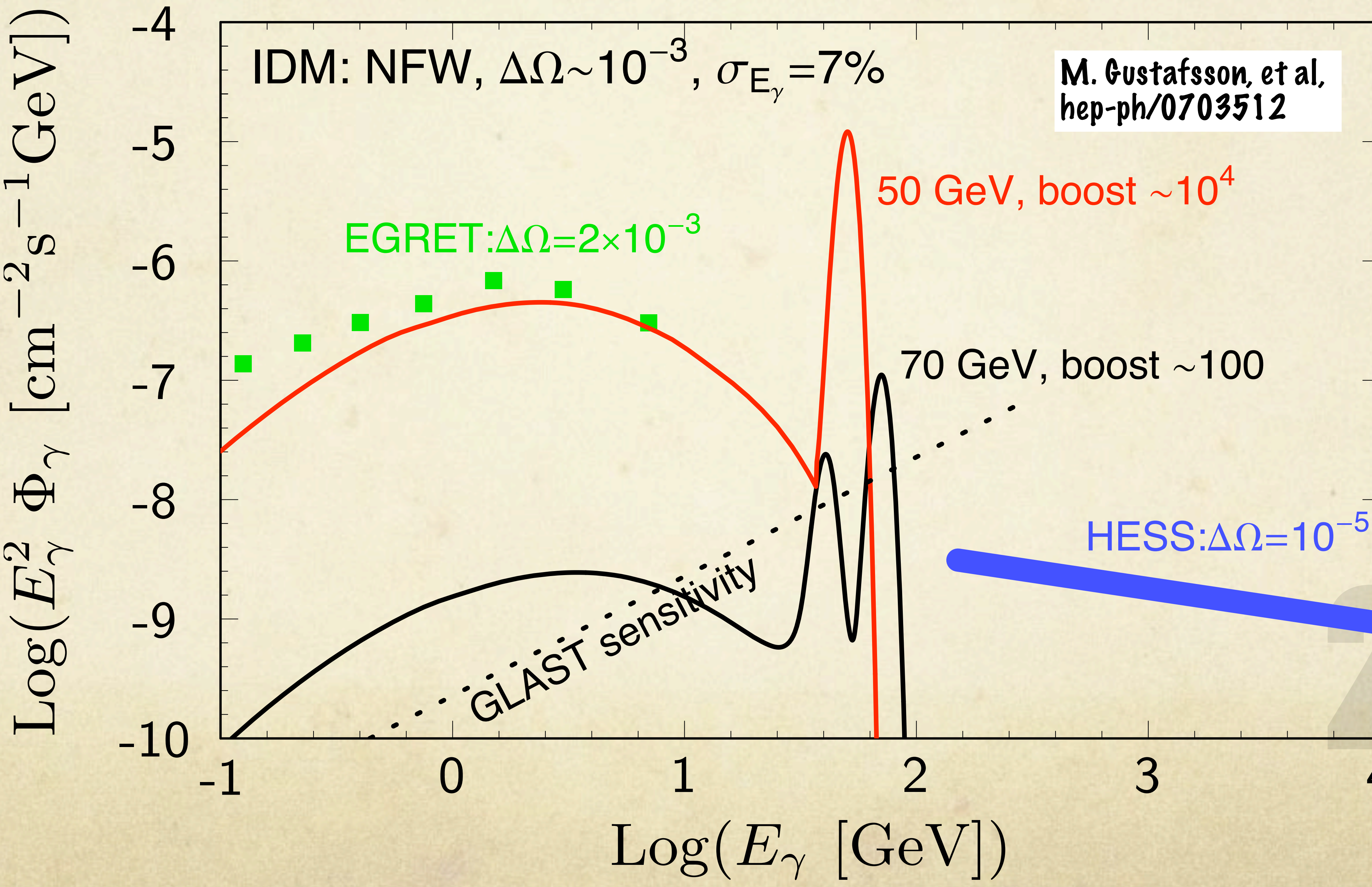
$BR(c\bar{c}) = 2\%$

$BR(\tau^+\tau^-) = 3\%$

cao

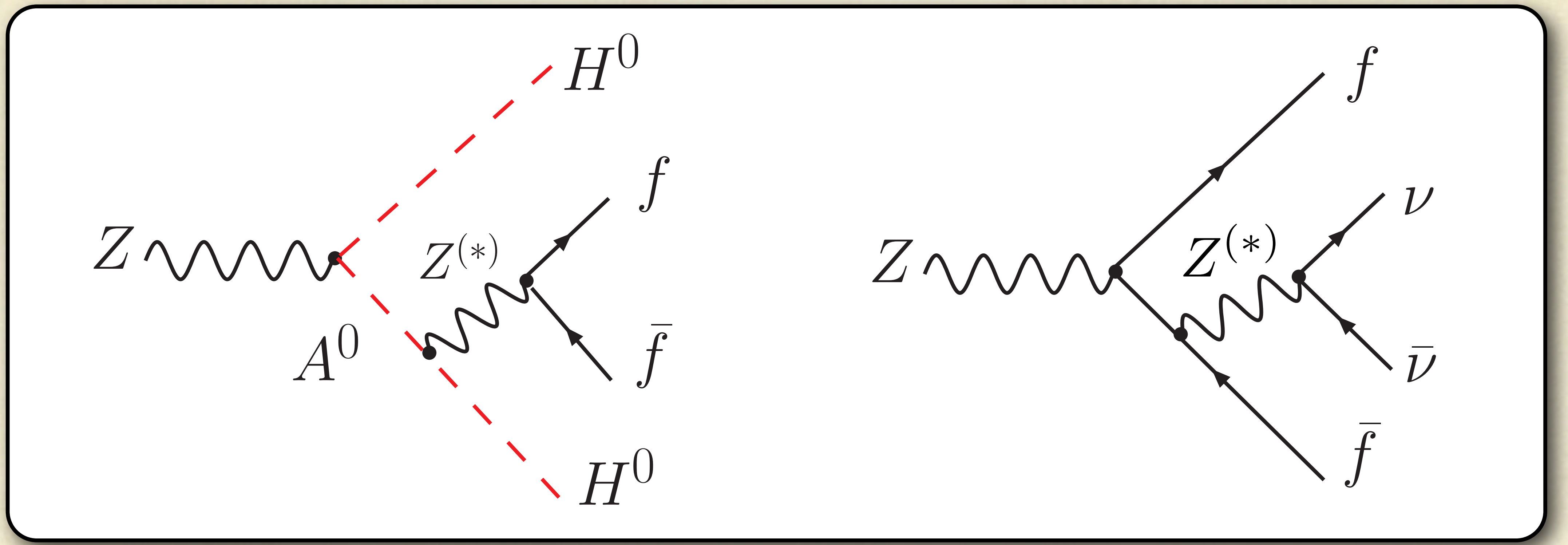
Spectacular line-shape in the DSM

$$\frac{d\Phi}{d\Omega dE} = \sum_i \langle \sigma v \rangle_i \frac{dN_i}{dE} \frac{1}{4\pi m_{DM}^2} \int_{\text{l.o.l}} \rho^2 dl$$

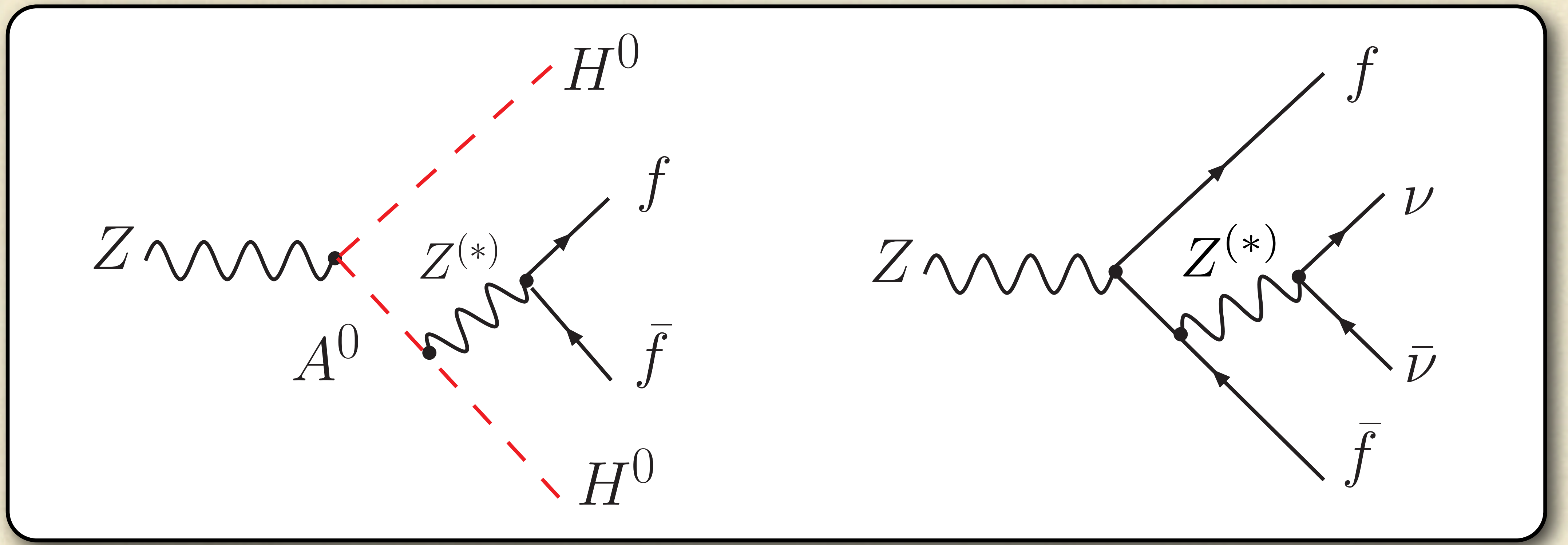


Collider Phenomenology

LEP Constraints (Z-pole)



LEP Constraints (Z-pole)

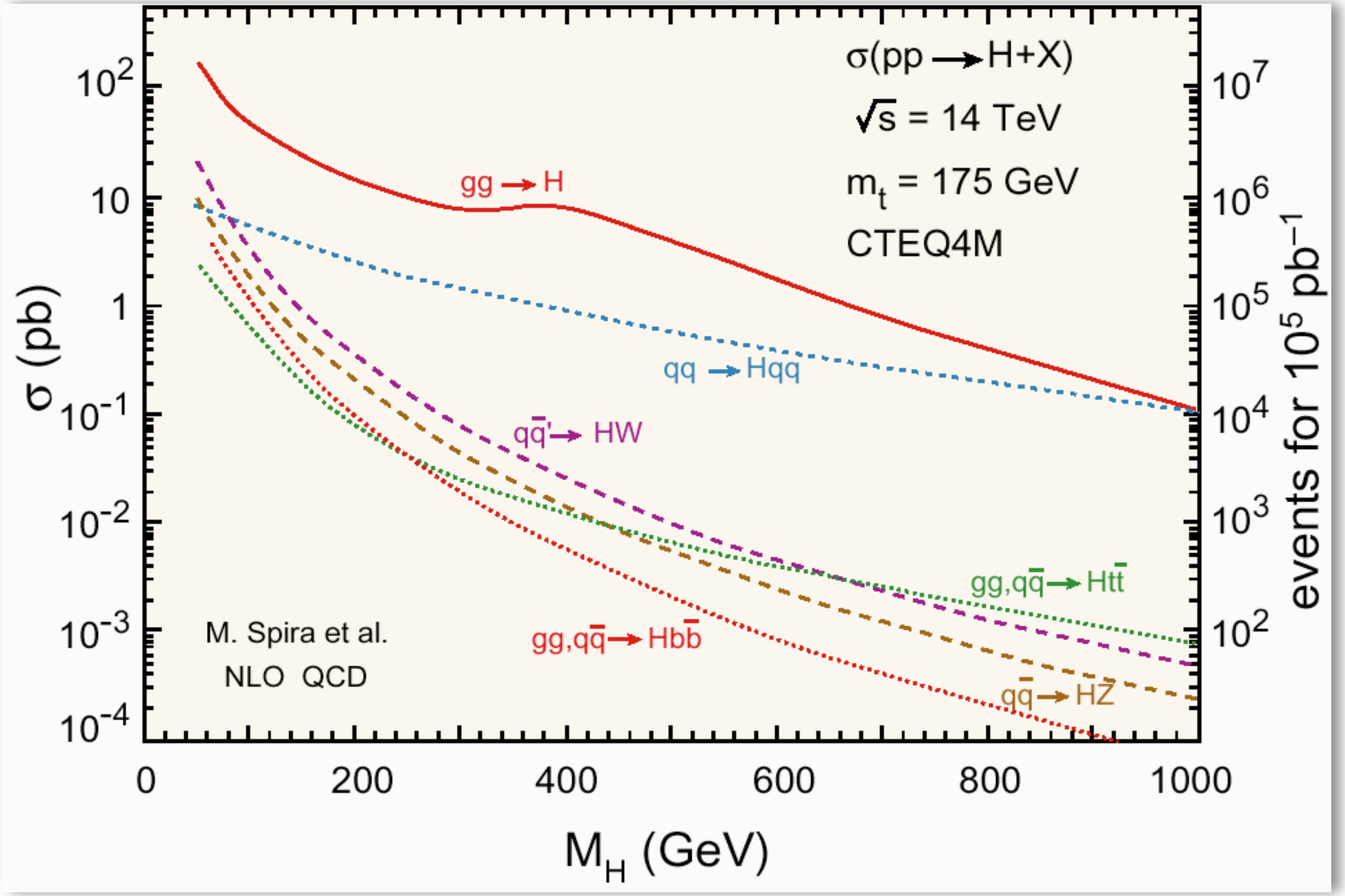


No new physics effects were found in the mode of **two charged leptons + Missing Energy** at the LEP-I

$$m_{A^0} + m_{H^0} > m_Z$$

Impact on the SM Higgs boson search

- SM Higgs boson production at the Large Hadron Collider



Impact on the SM Higgs boson search

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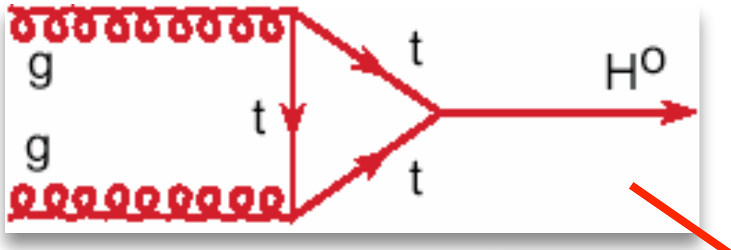
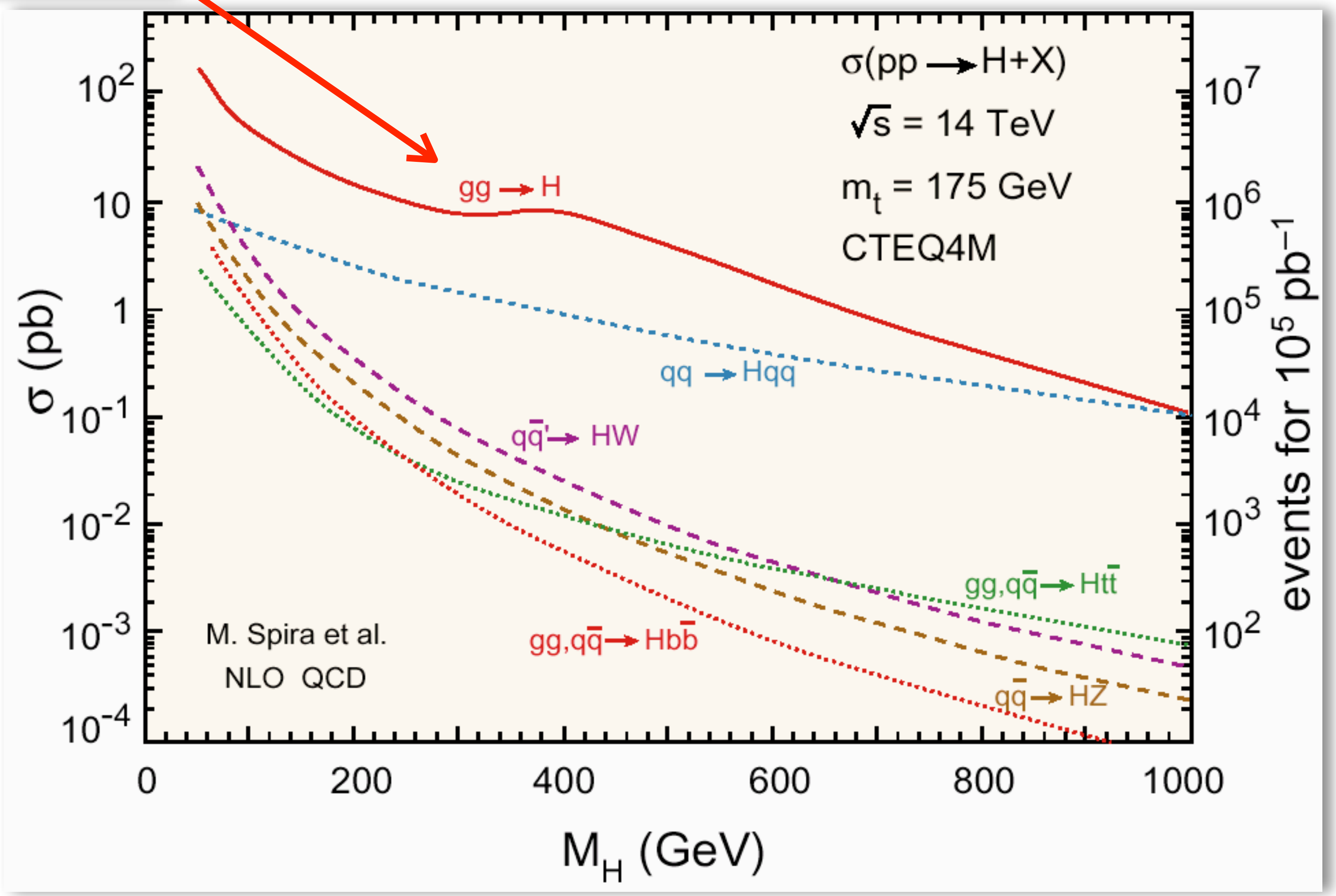


Gluon fusion



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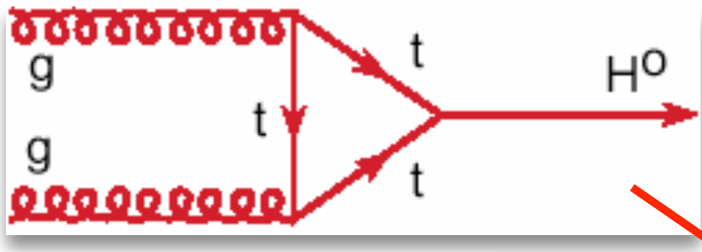
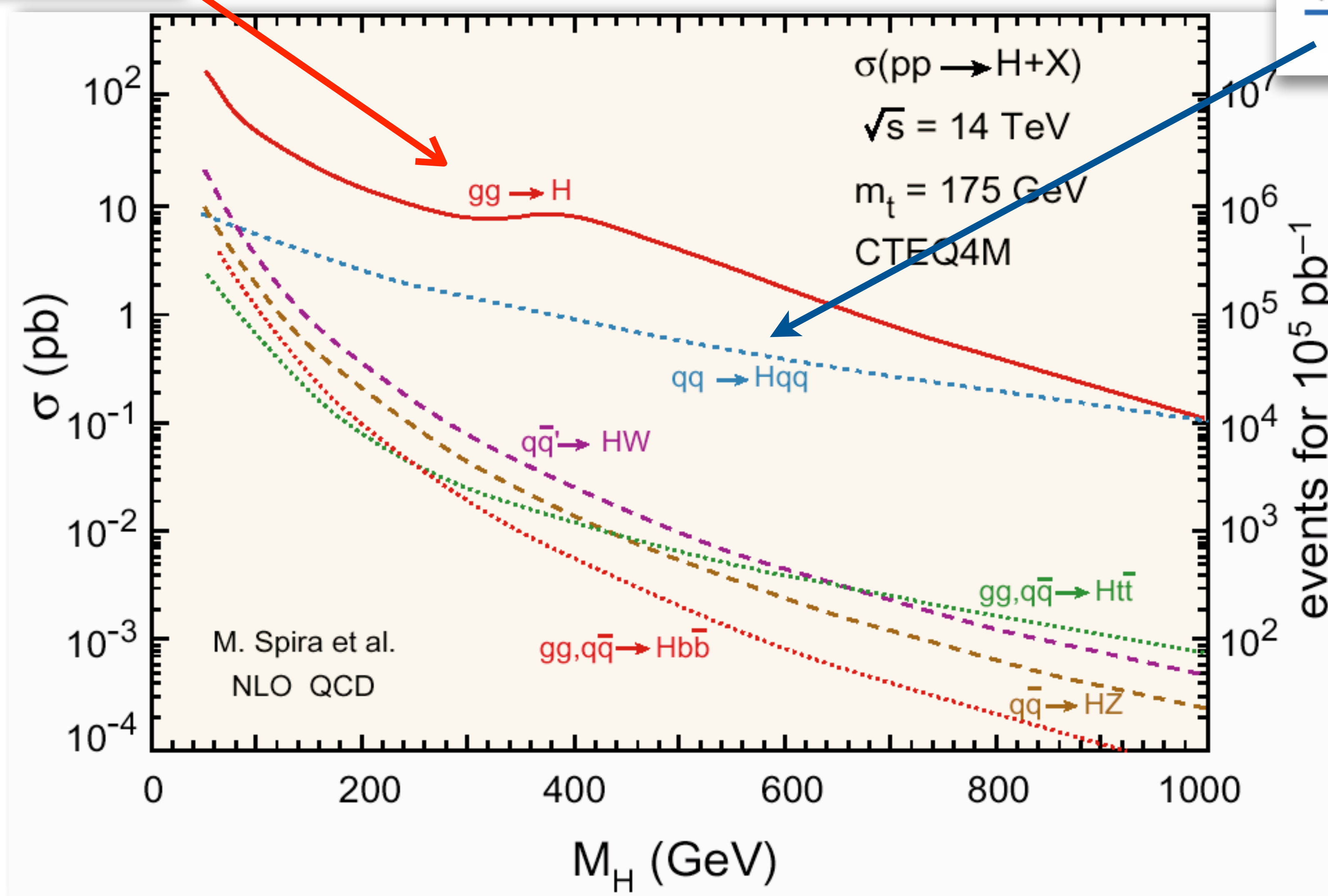
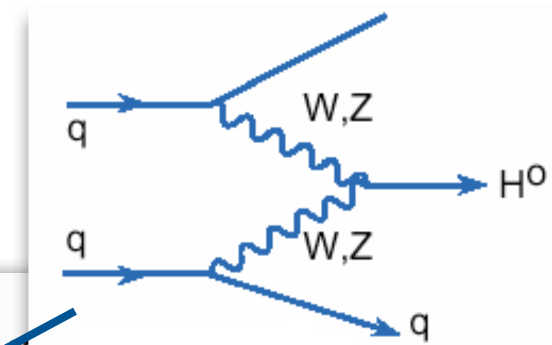


Gluon fusion

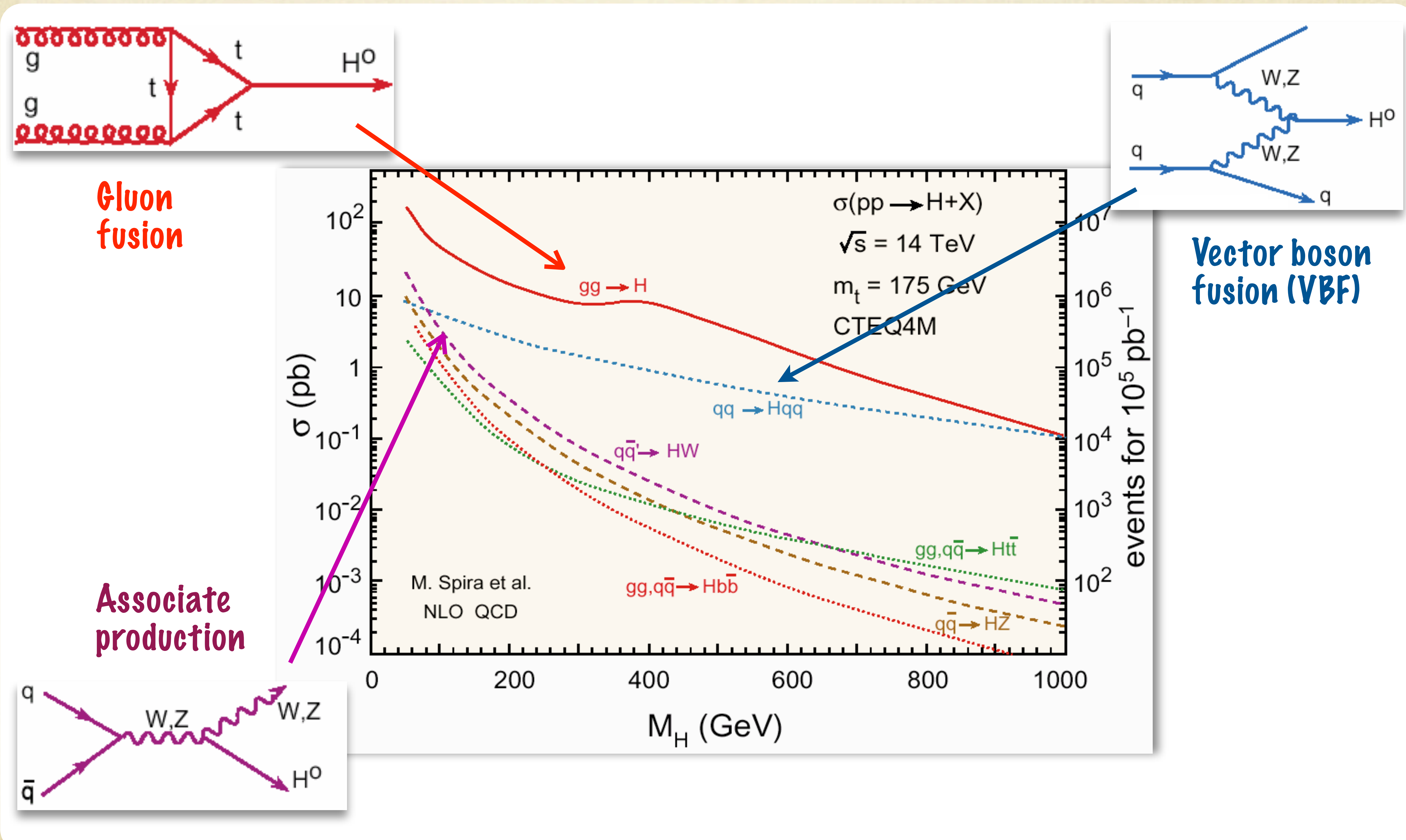




Vector boson fusion (VBF)

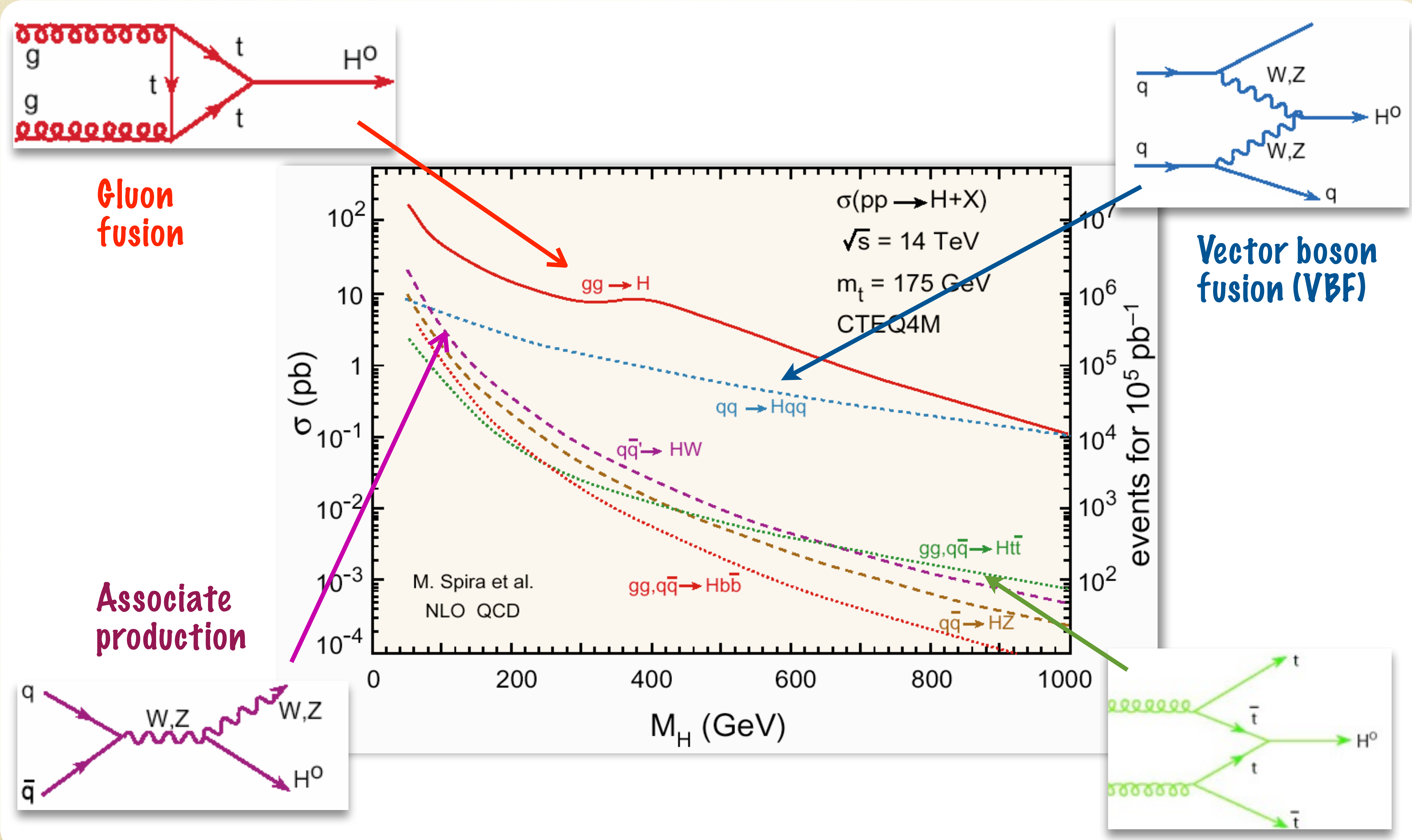
Impact on the SM Higgs boson search

- SM Higgs boson production at the Large Hadron Collider



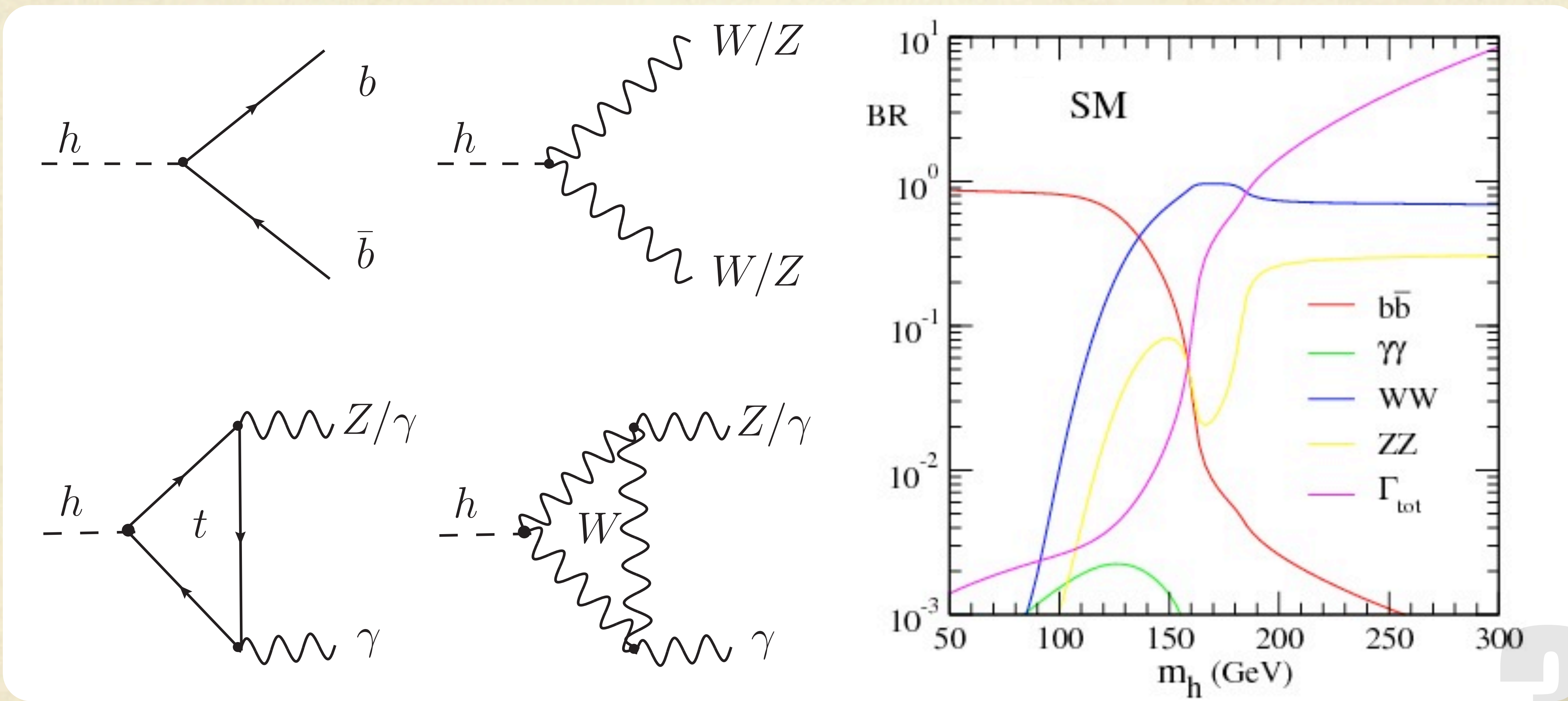
Impact on the SM Higgs boson search

- SM Higgs boson production at the Large Hadron Collider

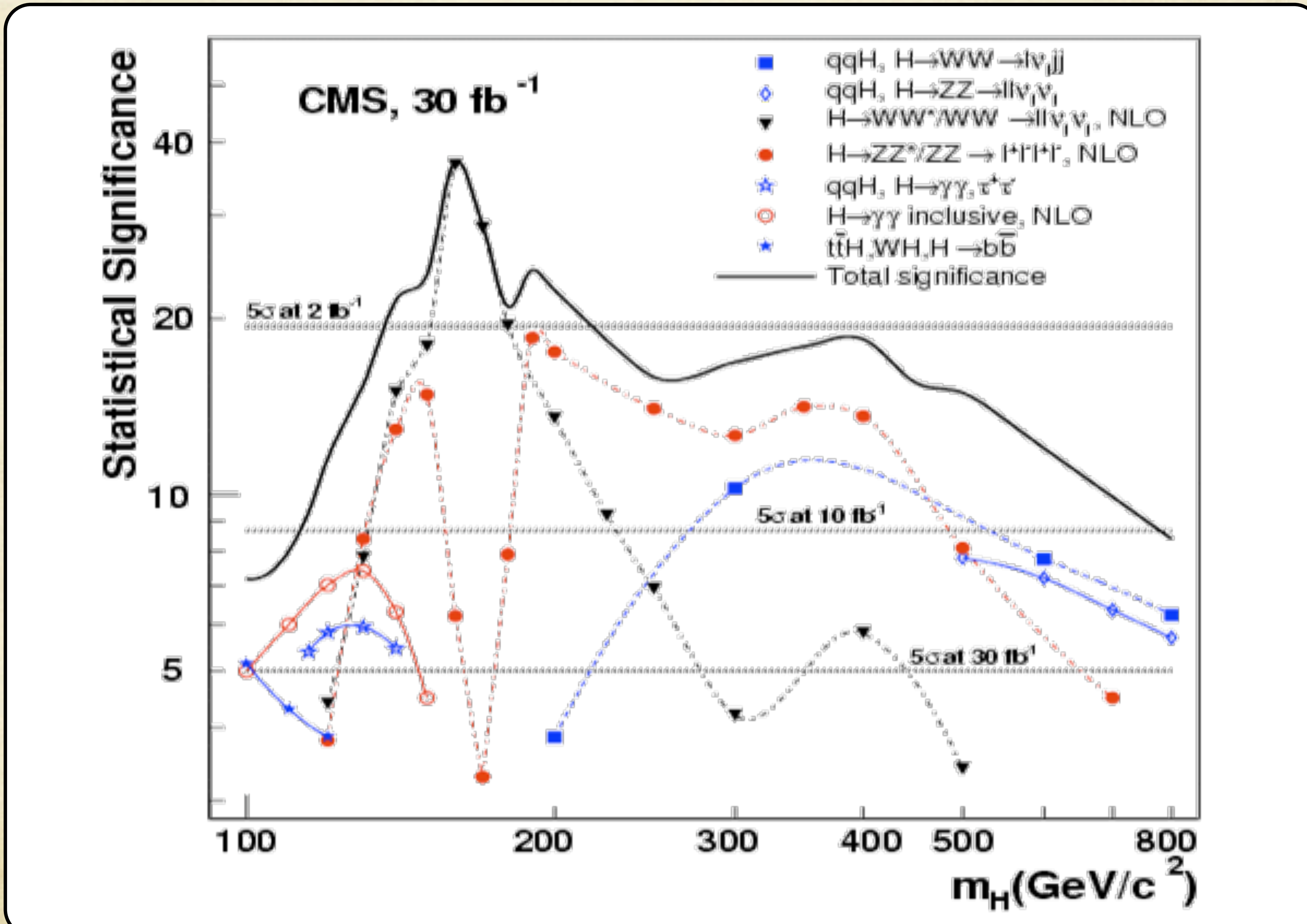


Impact on the SM Higgs boson search

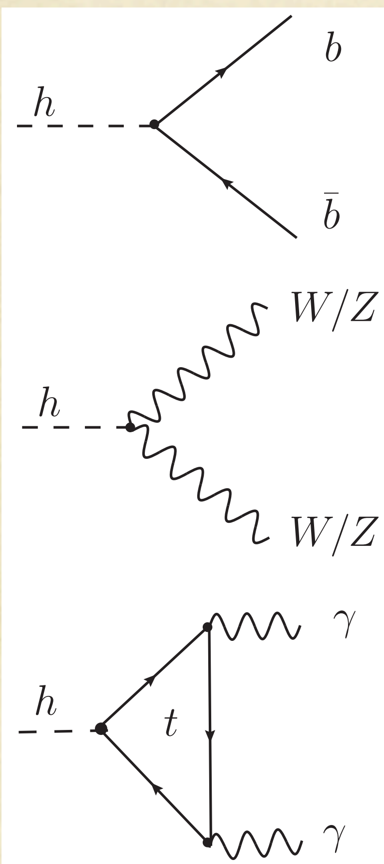
- Searching strategy of SM Higgs boson highly depends on how it decays



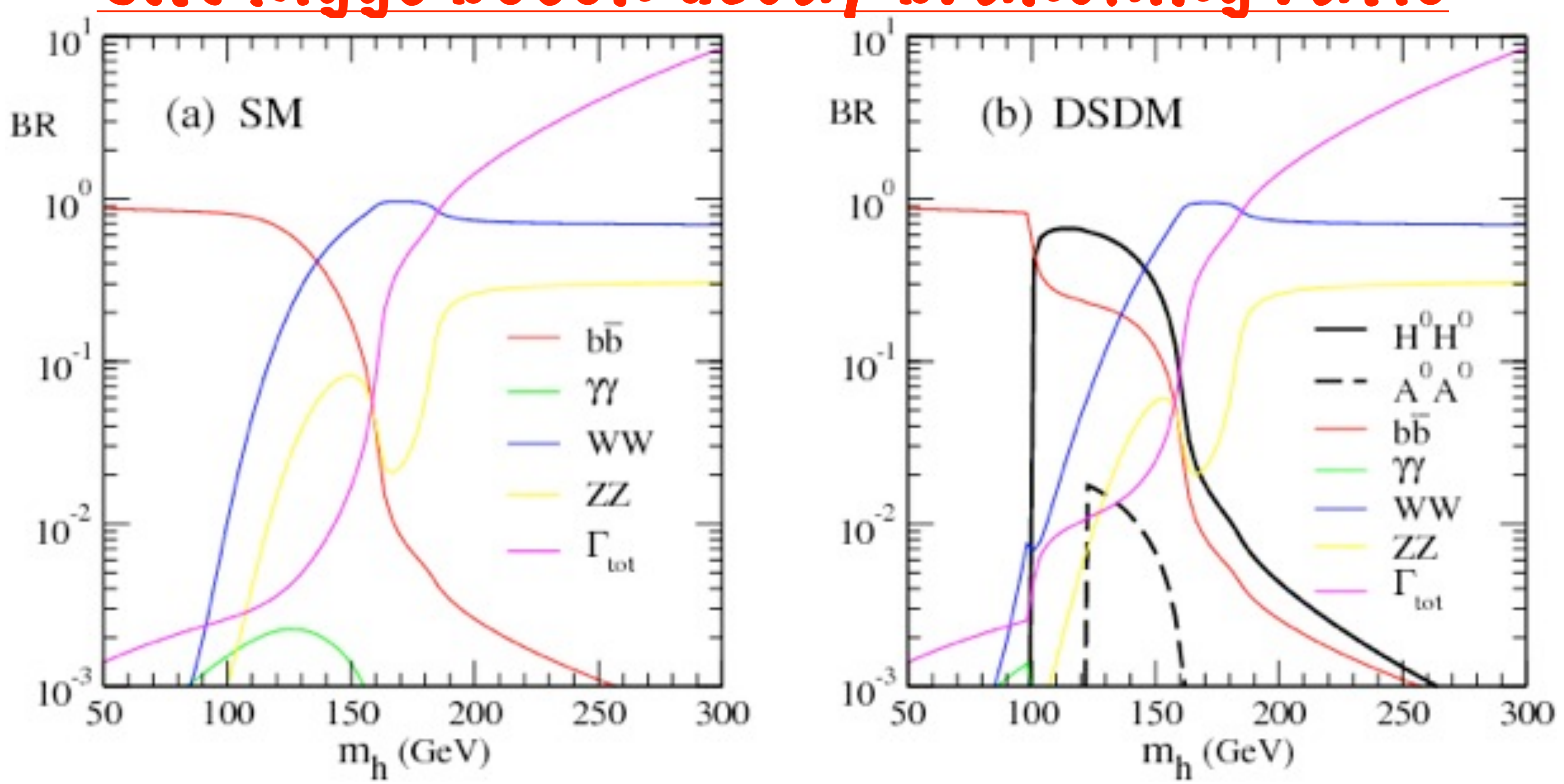
Discovery potential of SM Higgs boson @ LHC



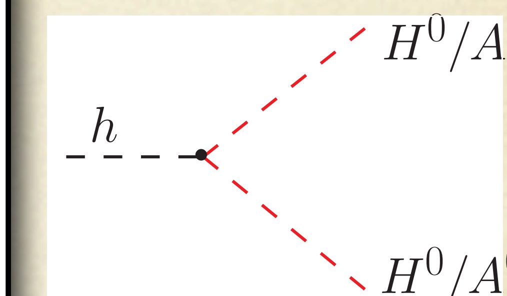
Impact on the SM Higgs boson search



SM Higgs boson decay branching ratio



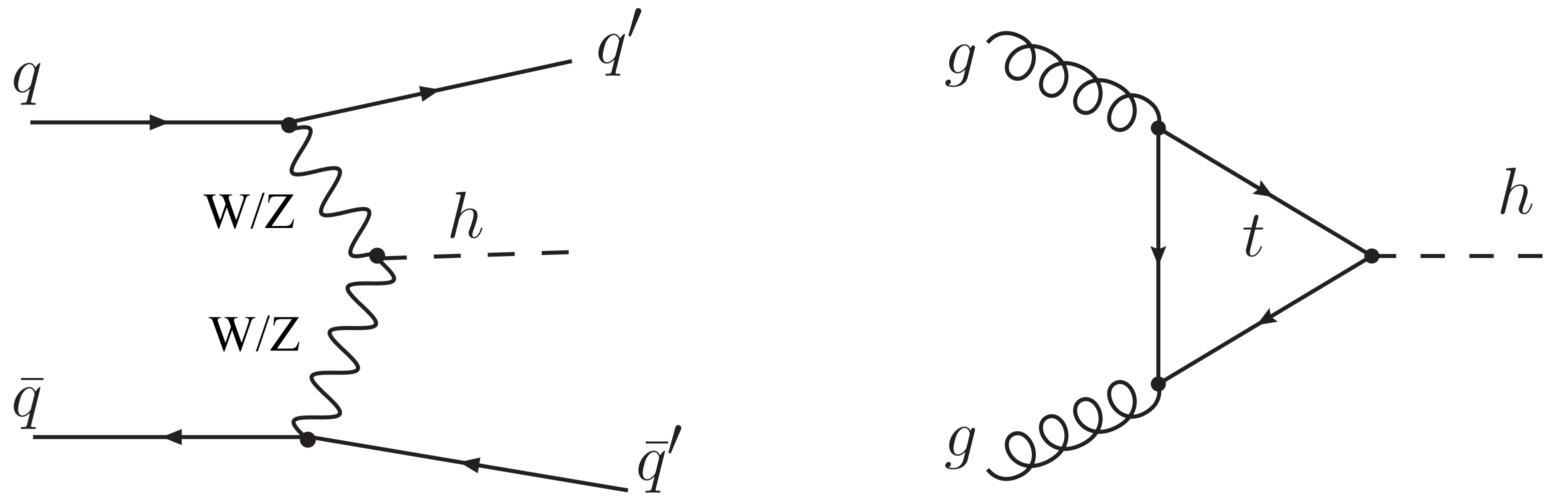
$m_{H^0} = 50\text{GeV}$ $m_{A^0} = 60\text{GeV}$ $m_{H^\pm} = 170\text{GeV}$

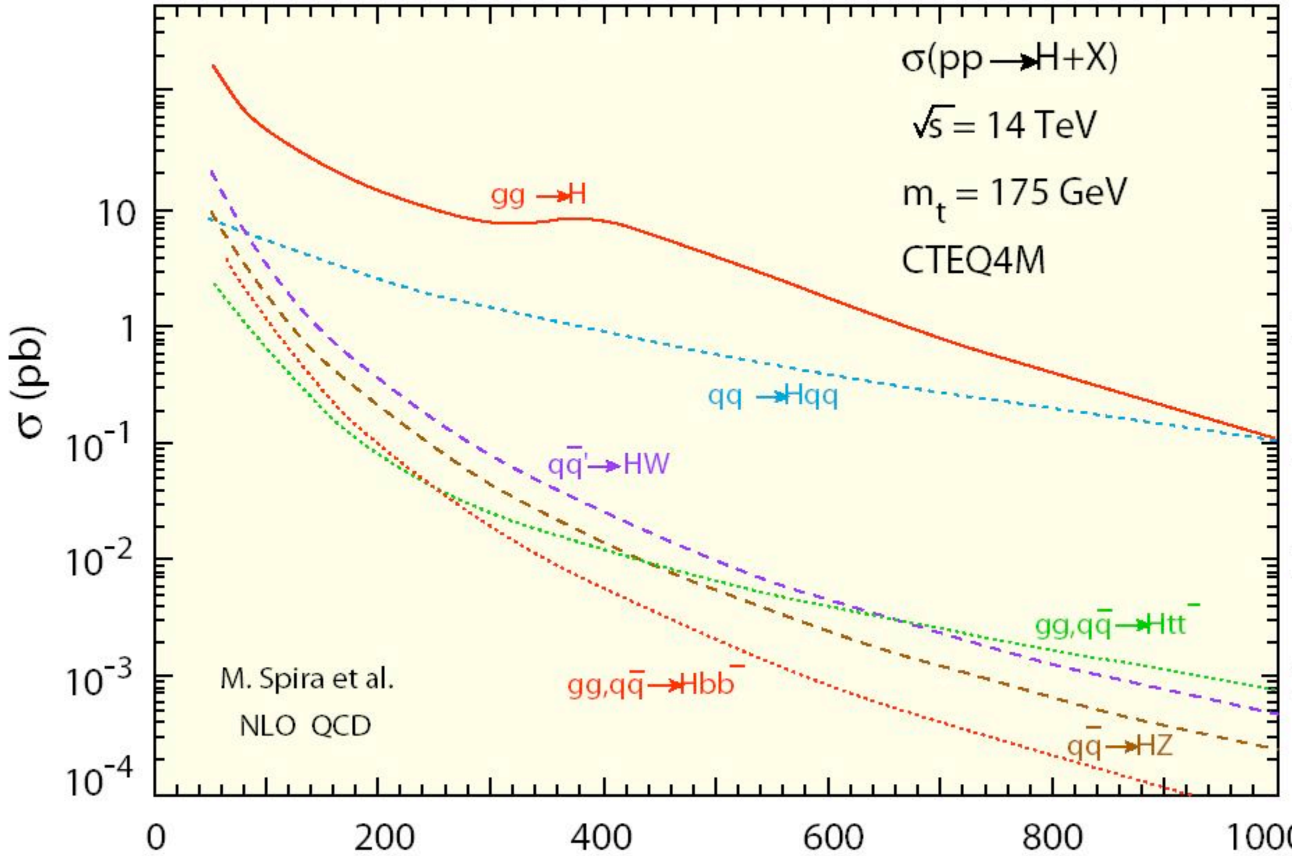


★ Usual decay modes of h are highly suppressed, ~60%, which makes the SM Higgs search more challenging.

★ Large BR($h \to H^0 H^0$) enables us to search DS in the VBF process

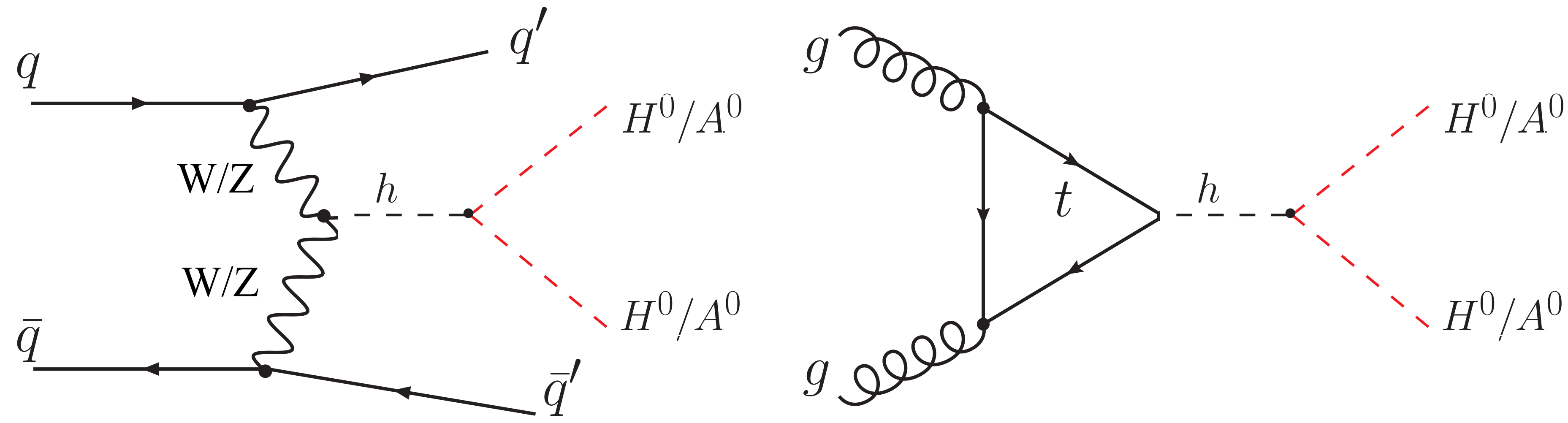
Searching dark scalars via the VBF process

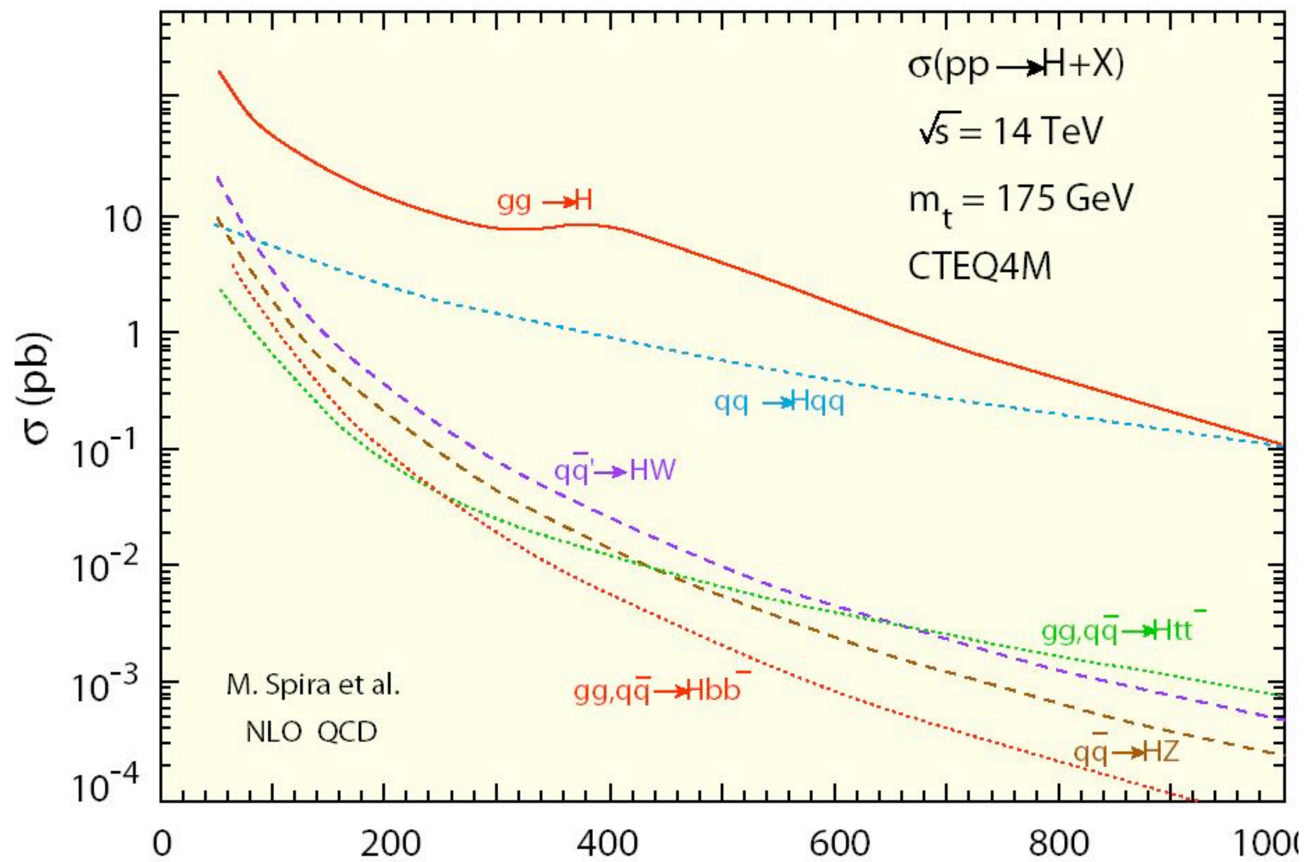




VBF: SECOND LARGEST CROSS SECTION

Searching dark scalars via the VBF process

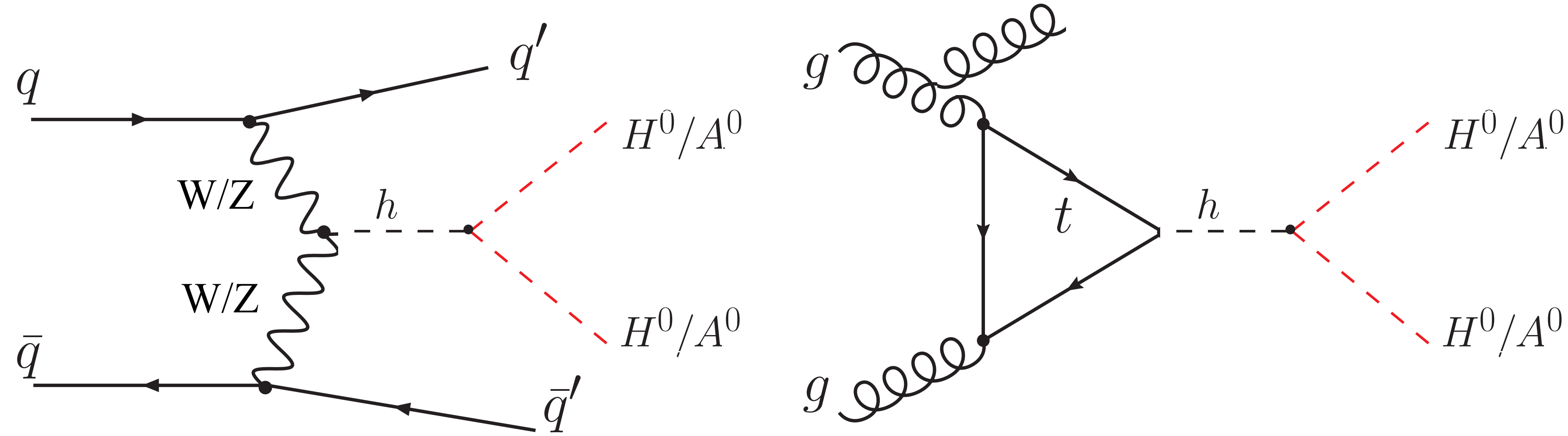


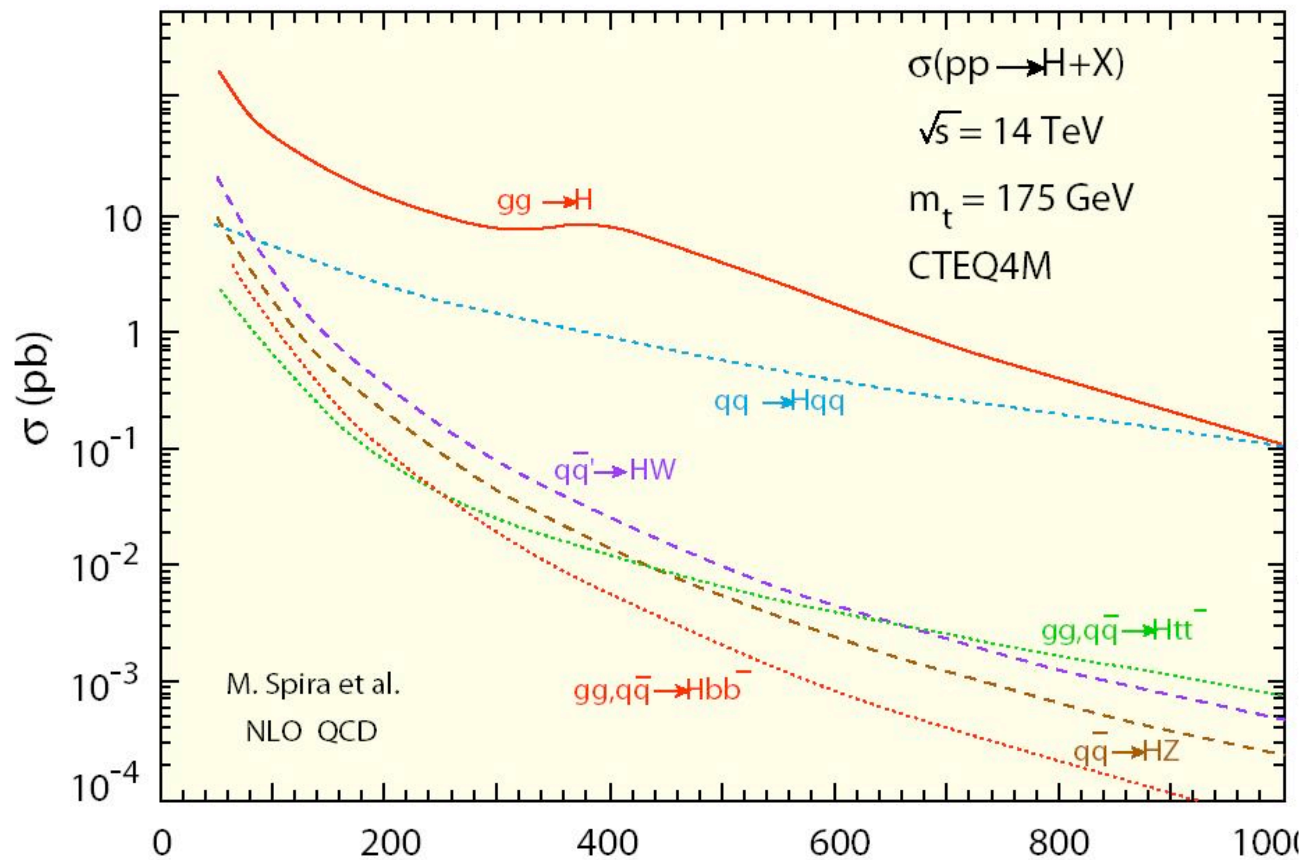


VBF:

SECOND LARGEST CROSS SECTION

Searching dark scalars via the VBF process

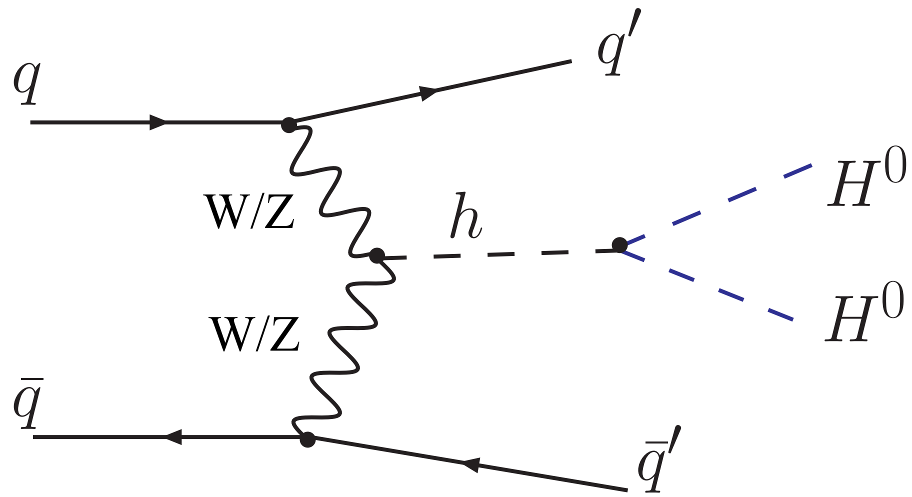




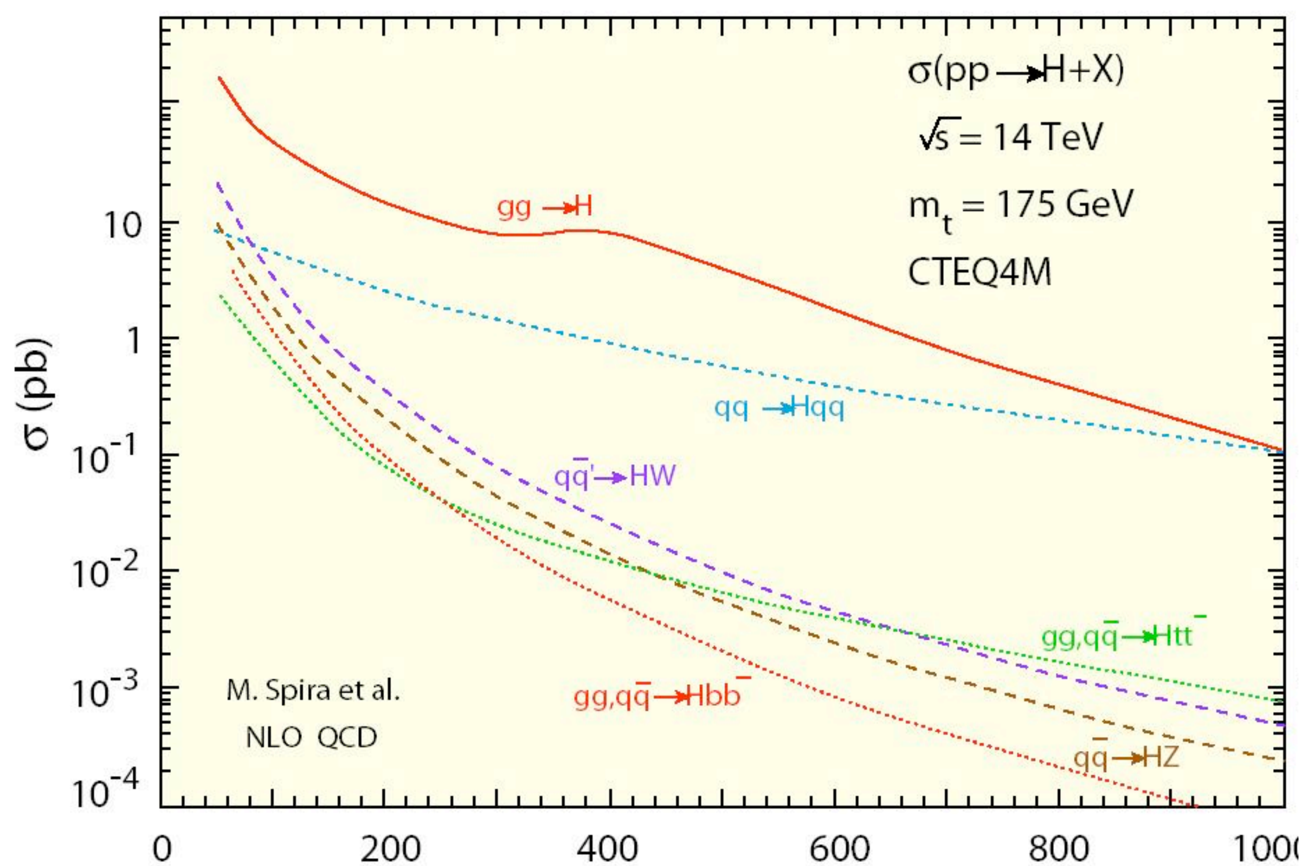
VBF: SECOND LARGEST CROSS SECTION

Searching dark scalars via the VBF process

O. Eboli and D. Zeppenfeld (2000)



2 JETS + MET



VBF: SECOND LARGEST CROSS SECTION

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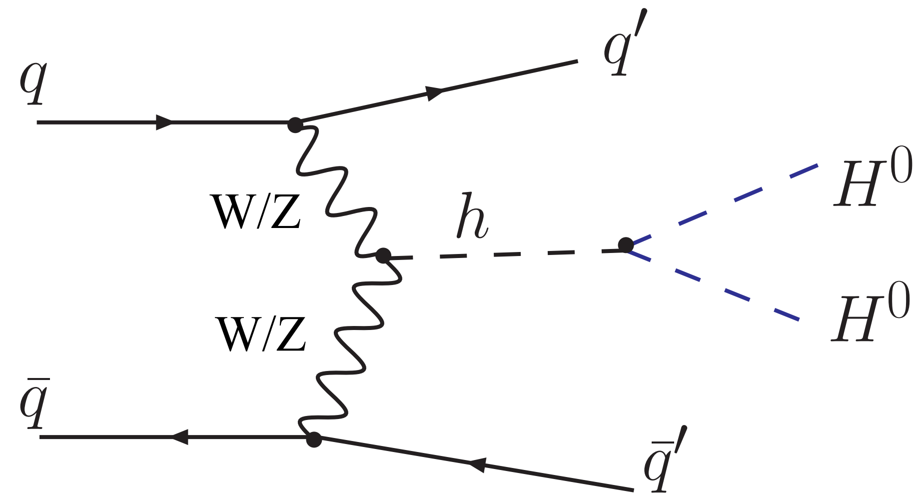
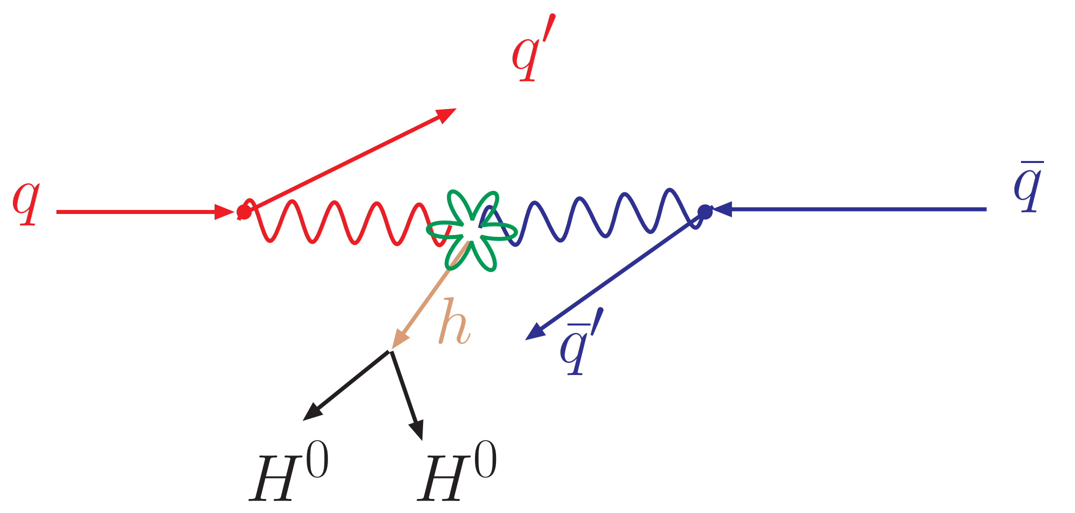
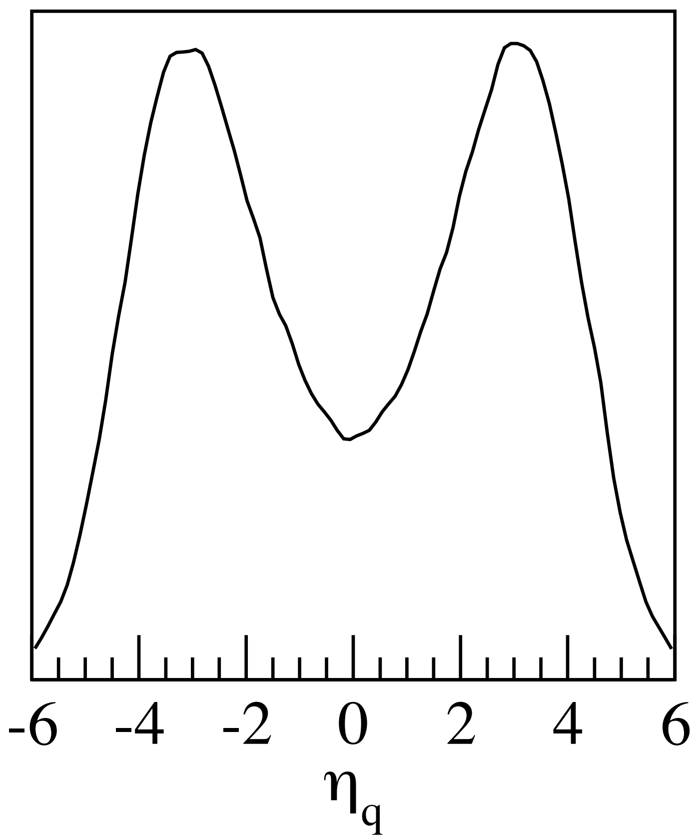


2 JETS + MET

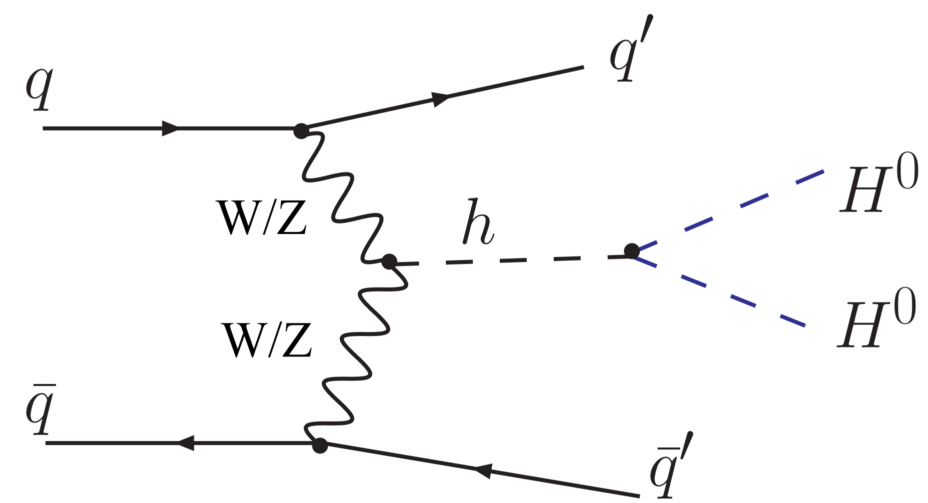
EFFECTIVE-W APPROXIMATAION





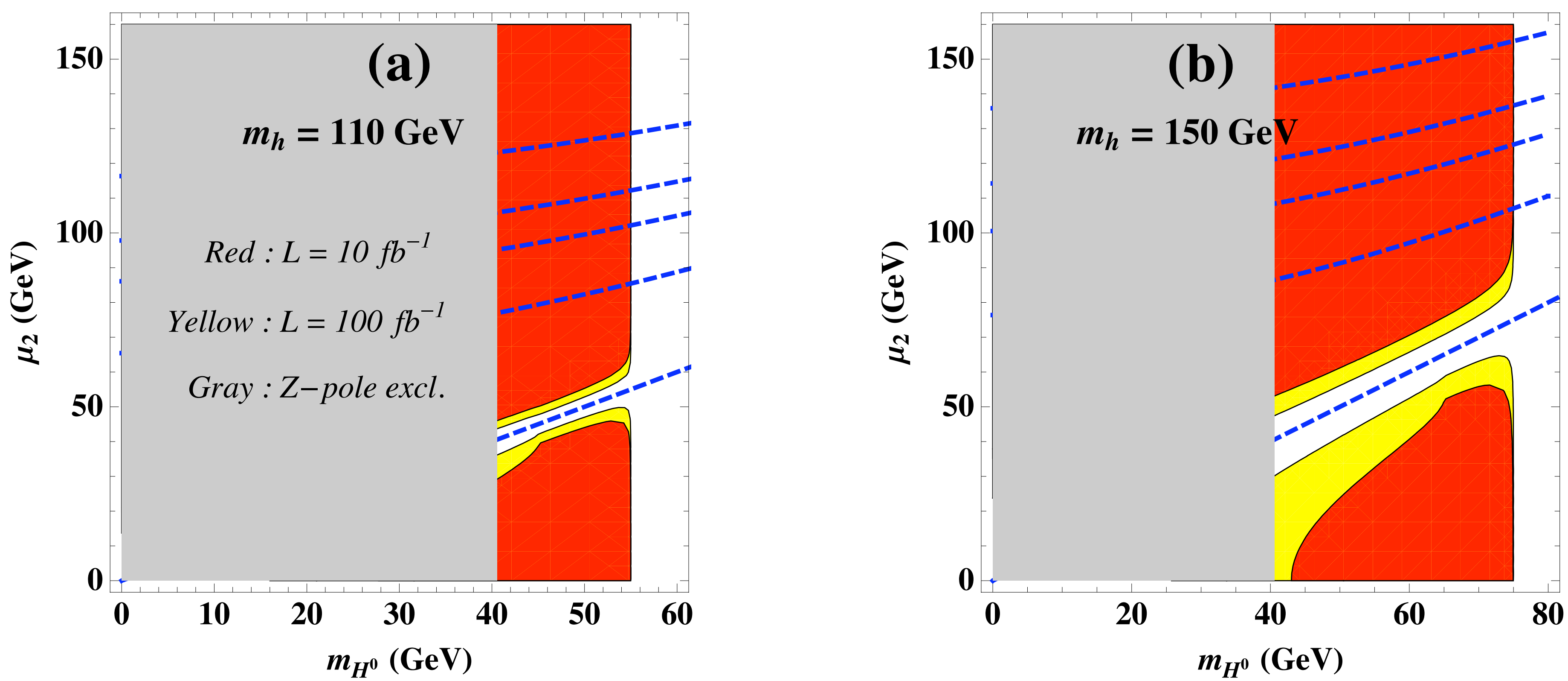
Searching dark scalars via the VBF process

O. Eboli and D. Zeppenfeld (2000)



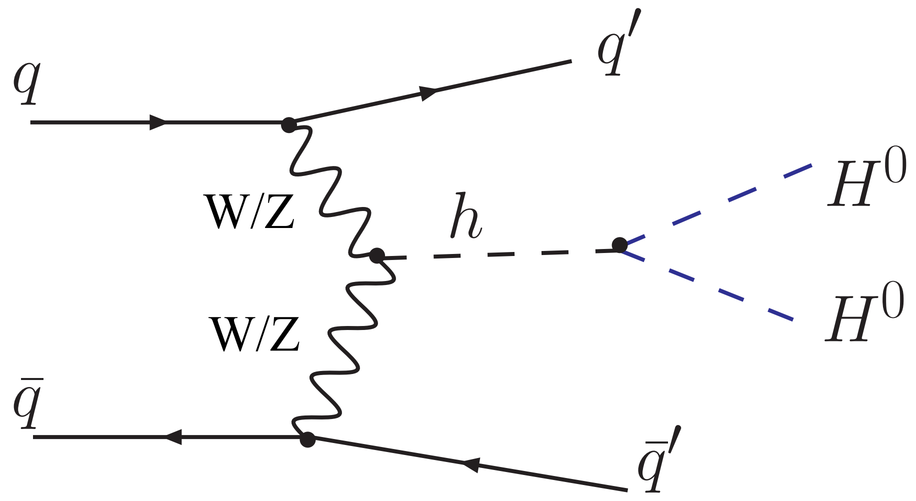
2 JETS + MET

5 SIGMA DISCOVERY CONTOUR AT THE LHC



Searching dark scalars via the VBF process

O. Eboli and D. Zeppenfeld (2000)



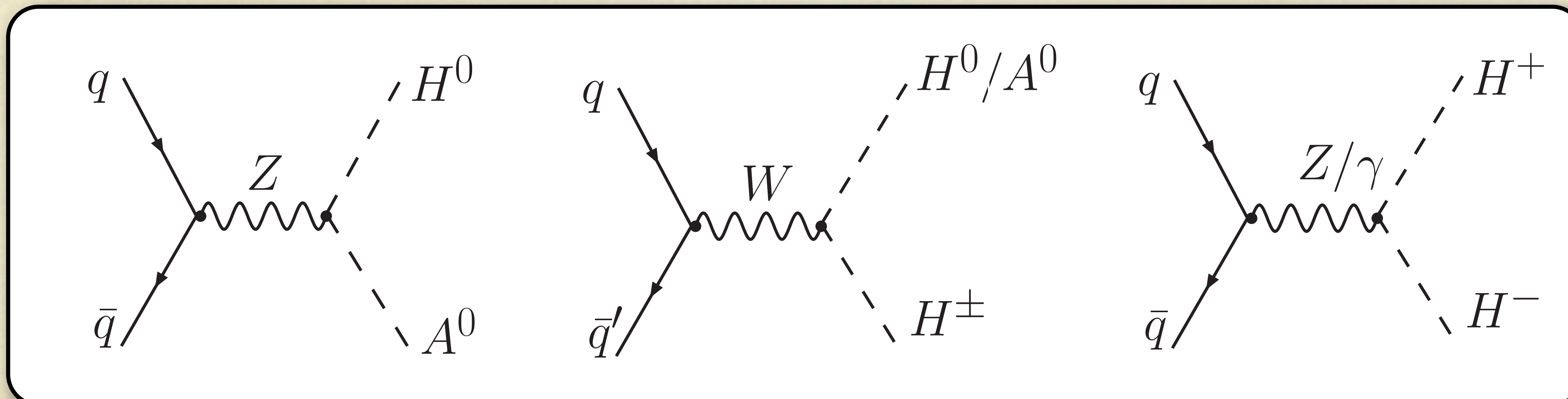
2 JETS + MET

BUT MANY OTHER NEW PHYSICS MODELS CAN RESULT IN THIS COLLIDER SIGNATURE.

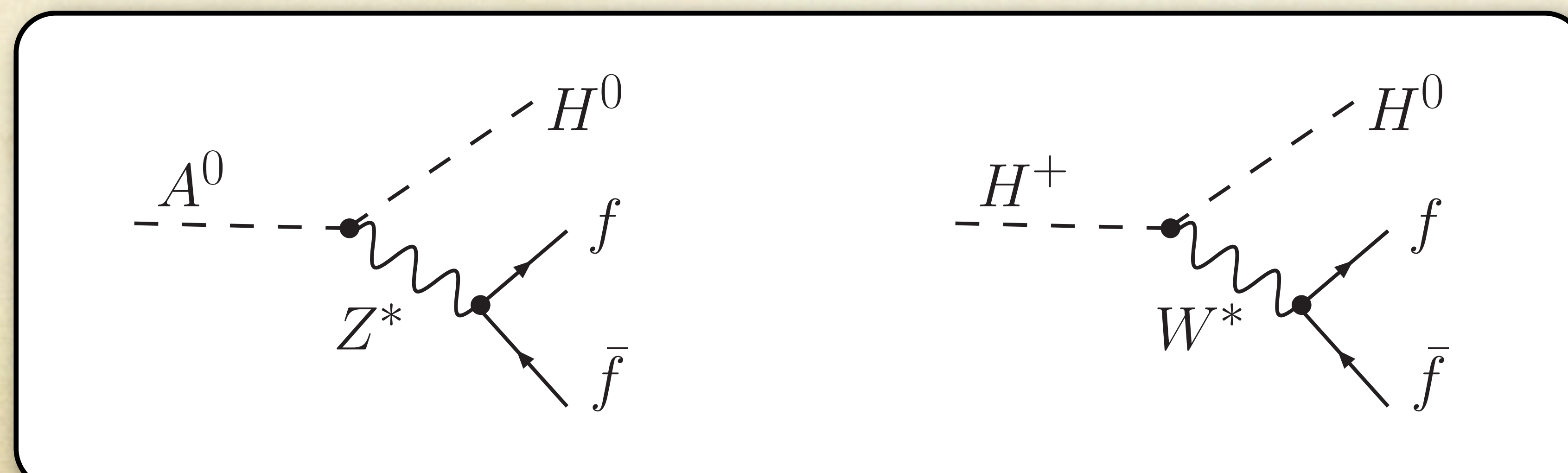
OTHER INDEPENDENT MEASUREMENTS ARE NEEDED TO CONFIRM THE DSDM.

Dark scalar production and decay

★ Production

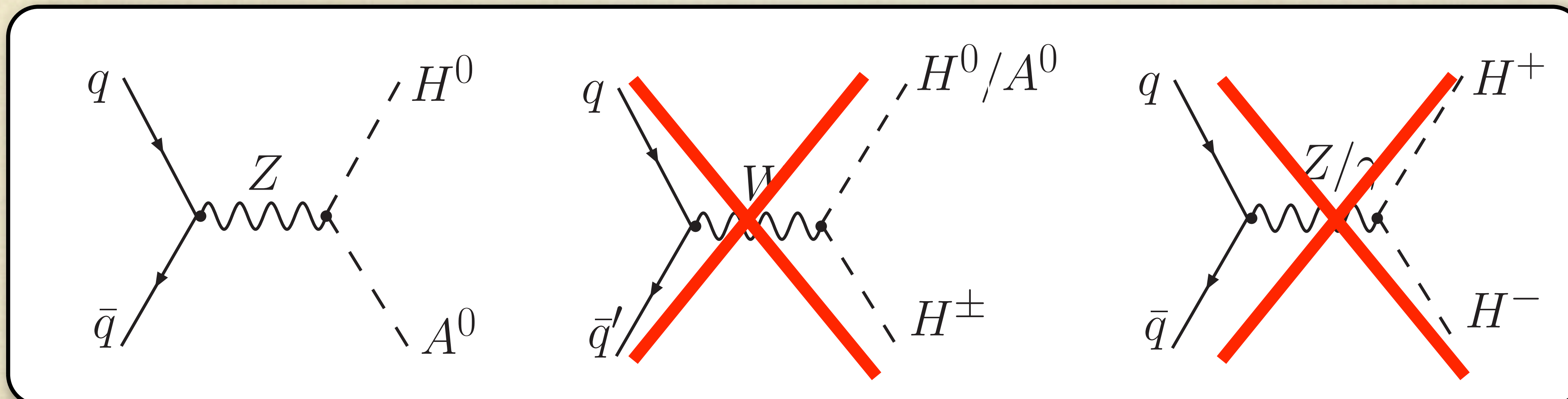


★ Decay



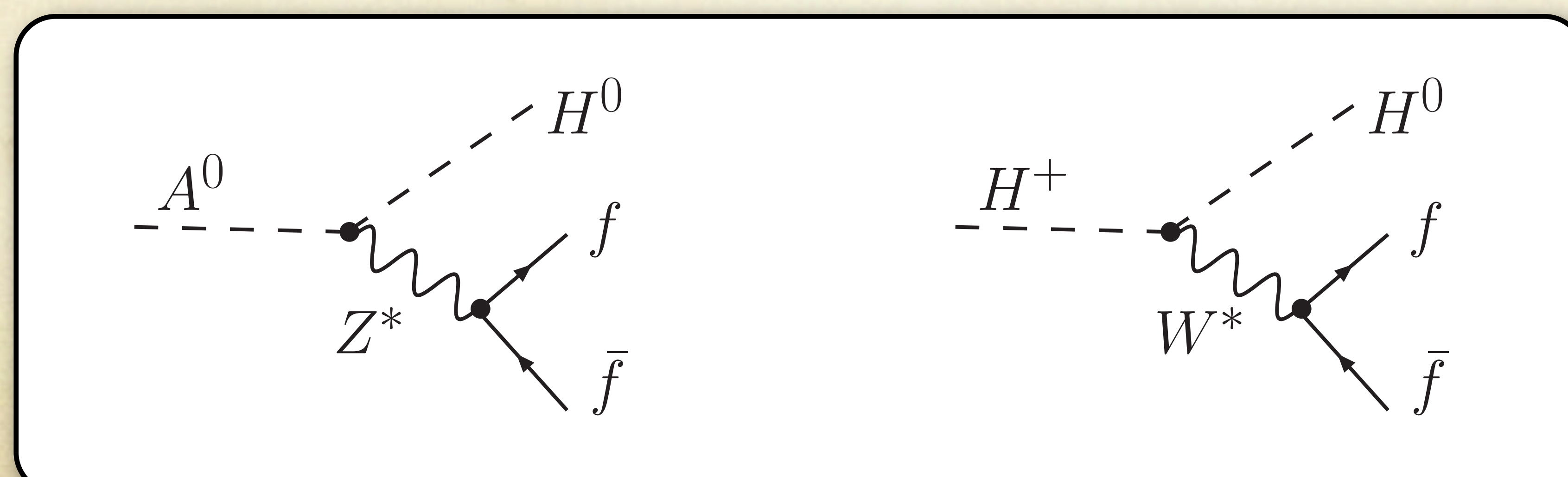
Dark scalar production and decay

★ Production

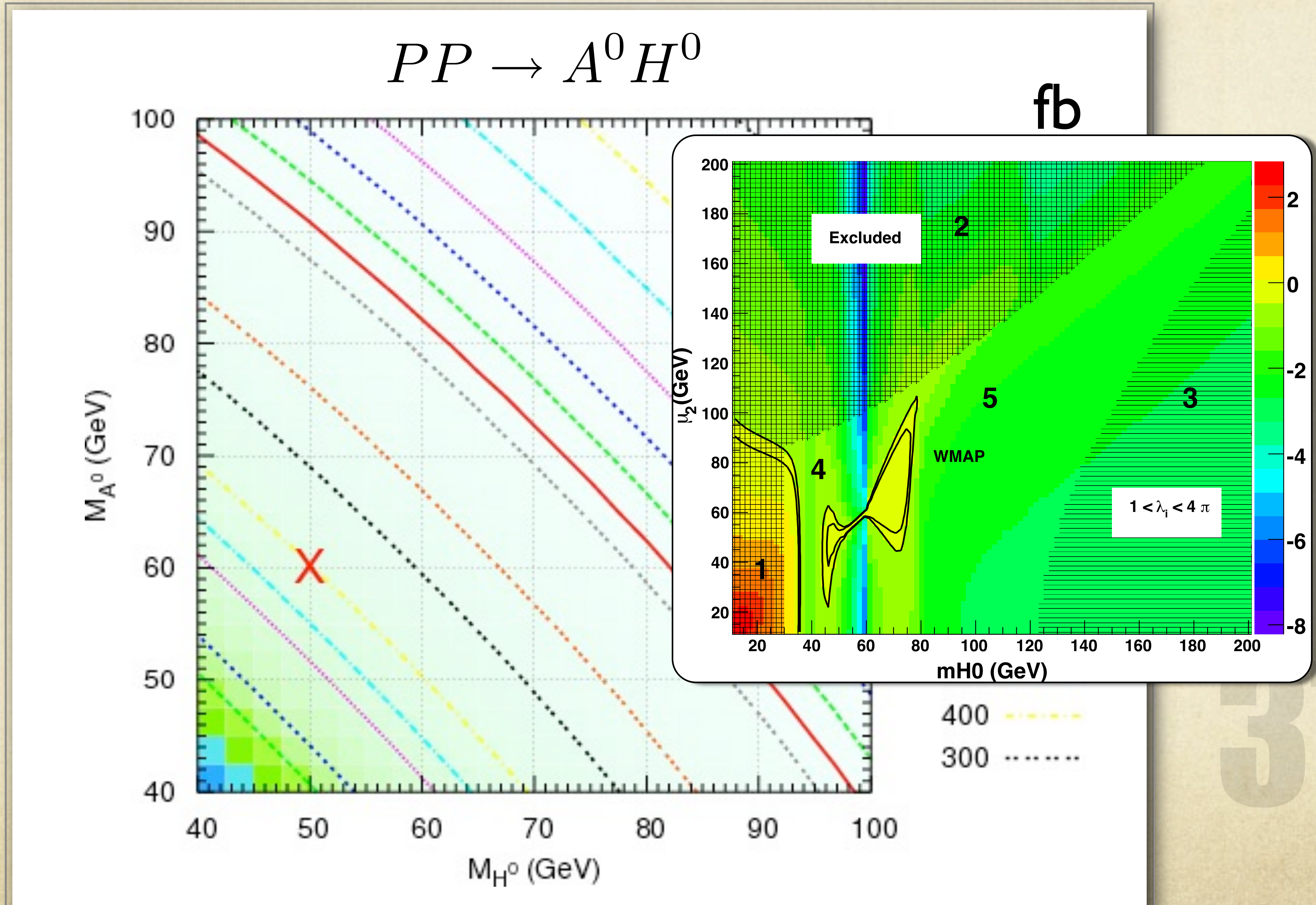


SM Backgrounds are too large

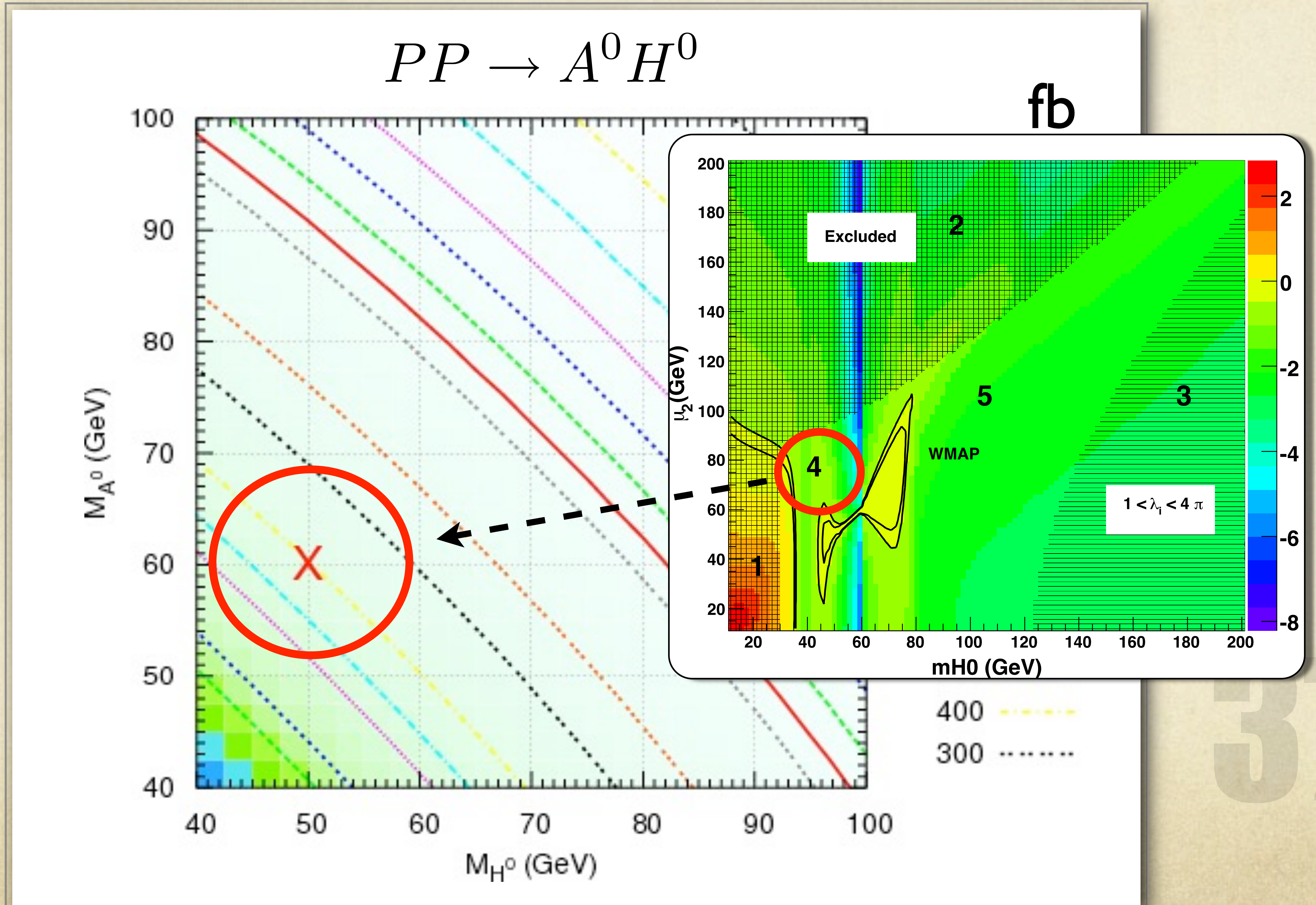
★ Decay



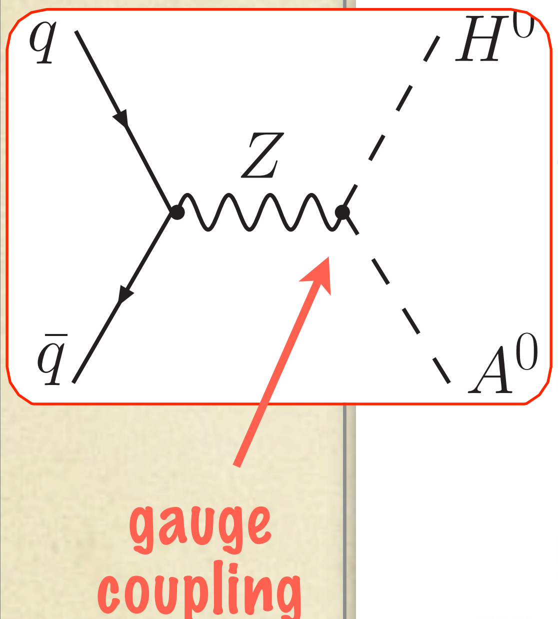
Cross section of dark scalar pair production

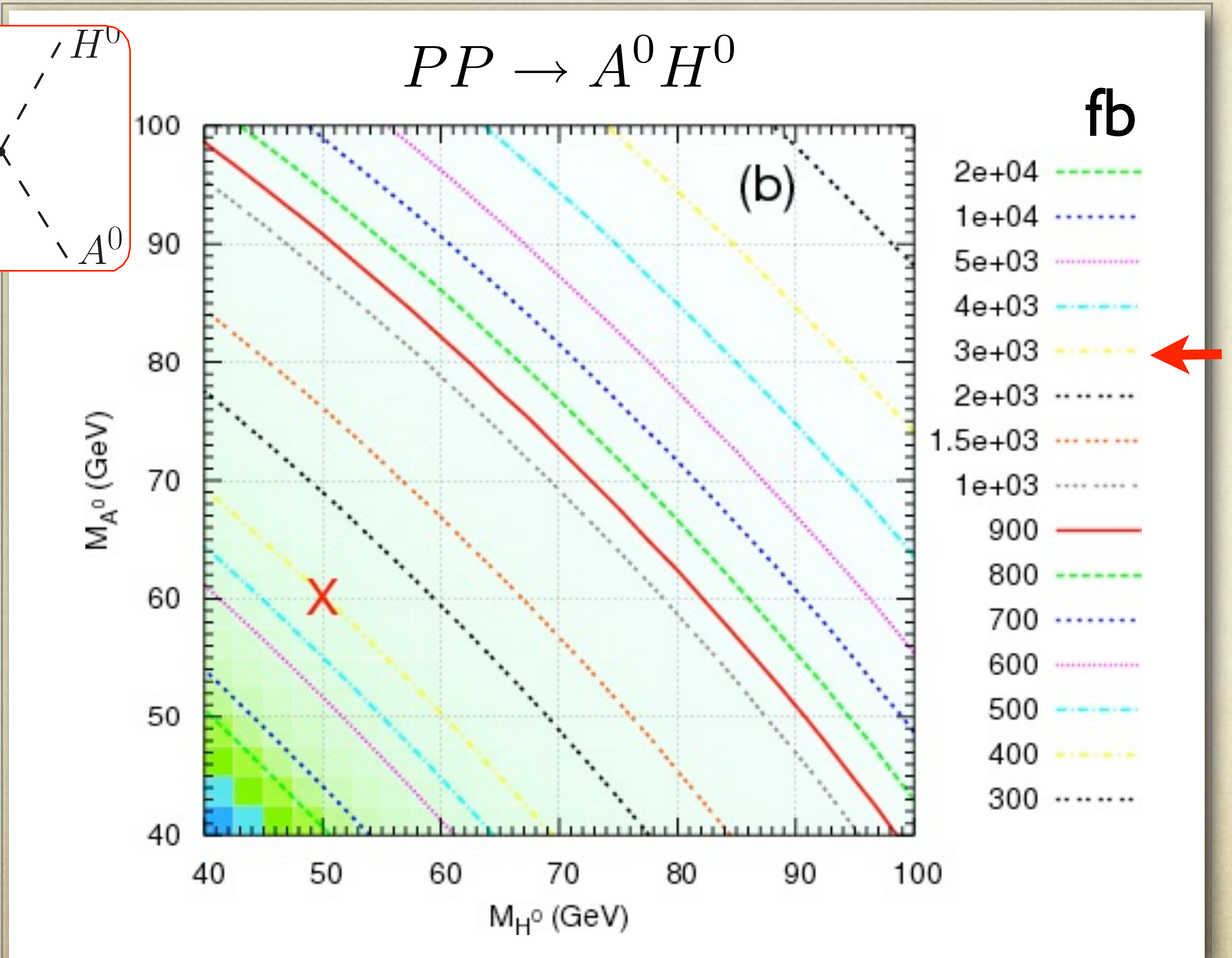


Cross section of dark scalar pair production

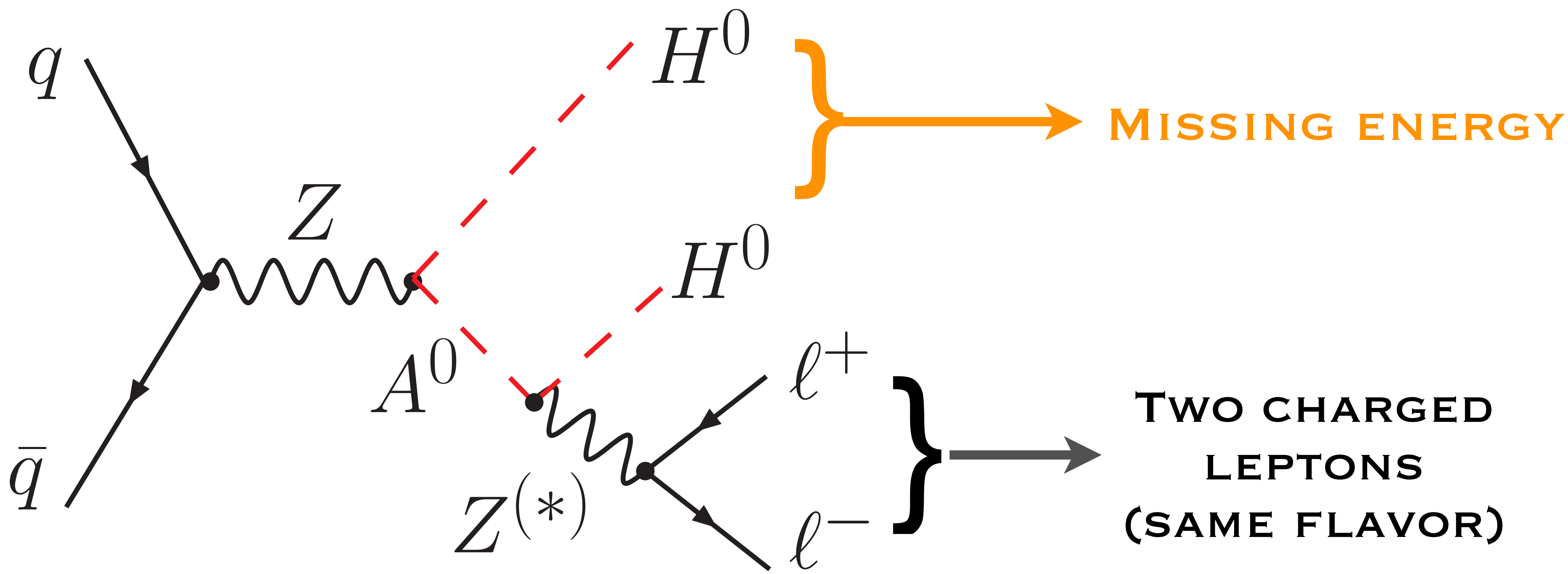


Cross section of dark scalar pair production





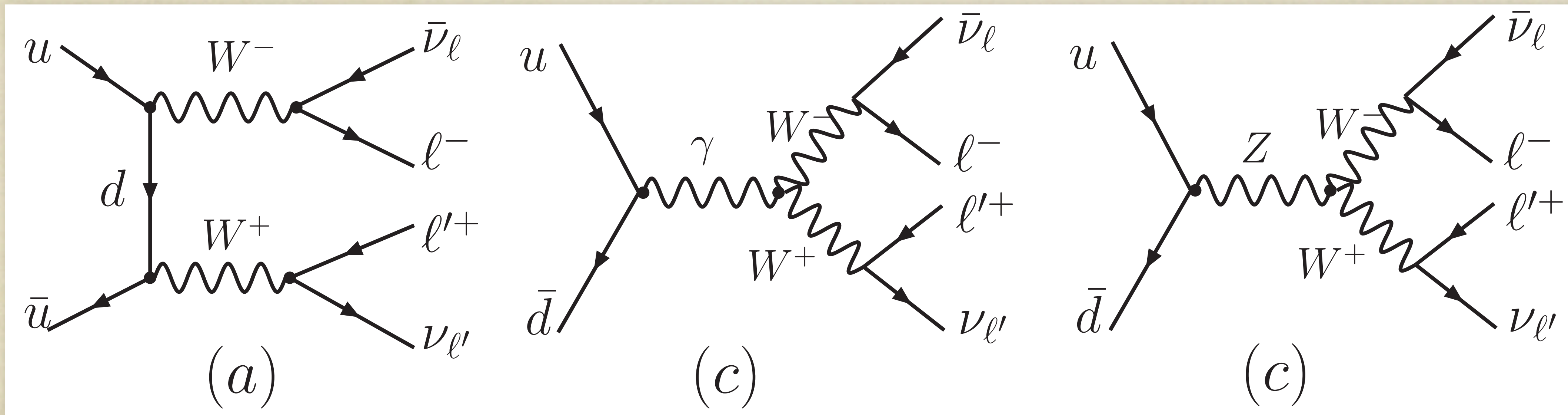
Collider signature



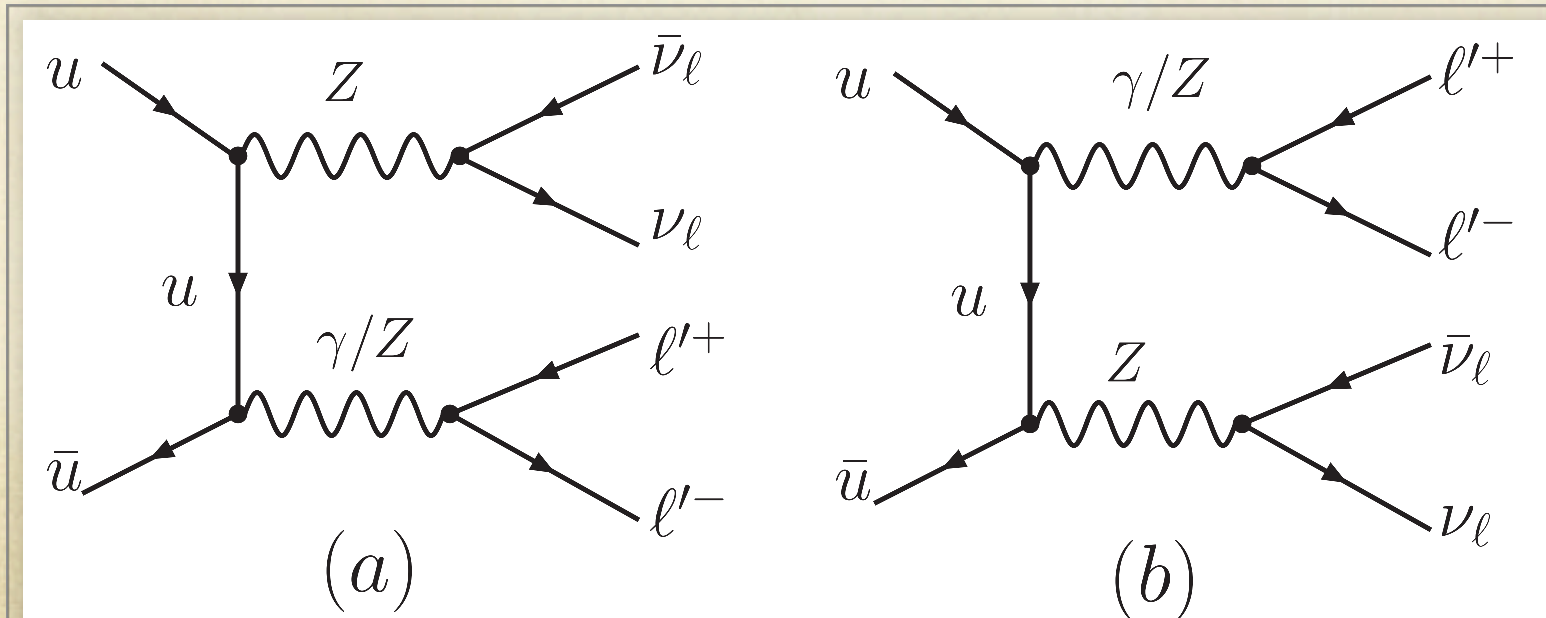
two charged leptons + MET

SM backgrounds (Intrinsic backgrounds)

- WW

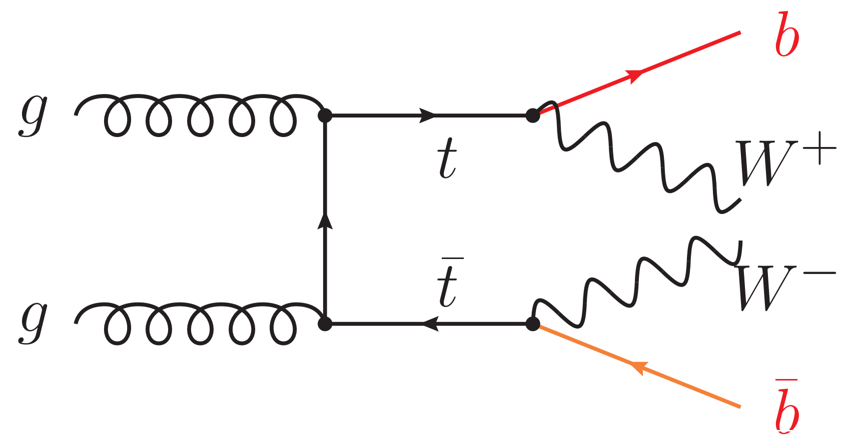


- ZZ



SM backgrounds (Reducible backgrounds)

Sample:



Good Jet veto efficiency (no need to worry)

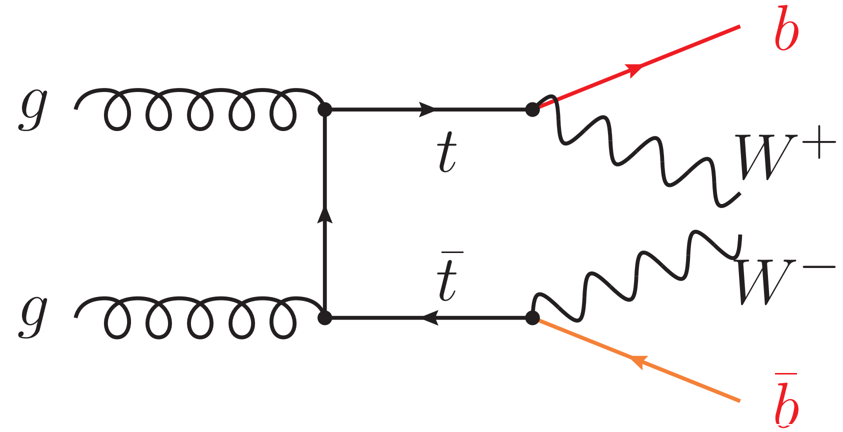
Detector

Proton

Proton

SM backgrounds (Reducible backgrounds)

Sample:



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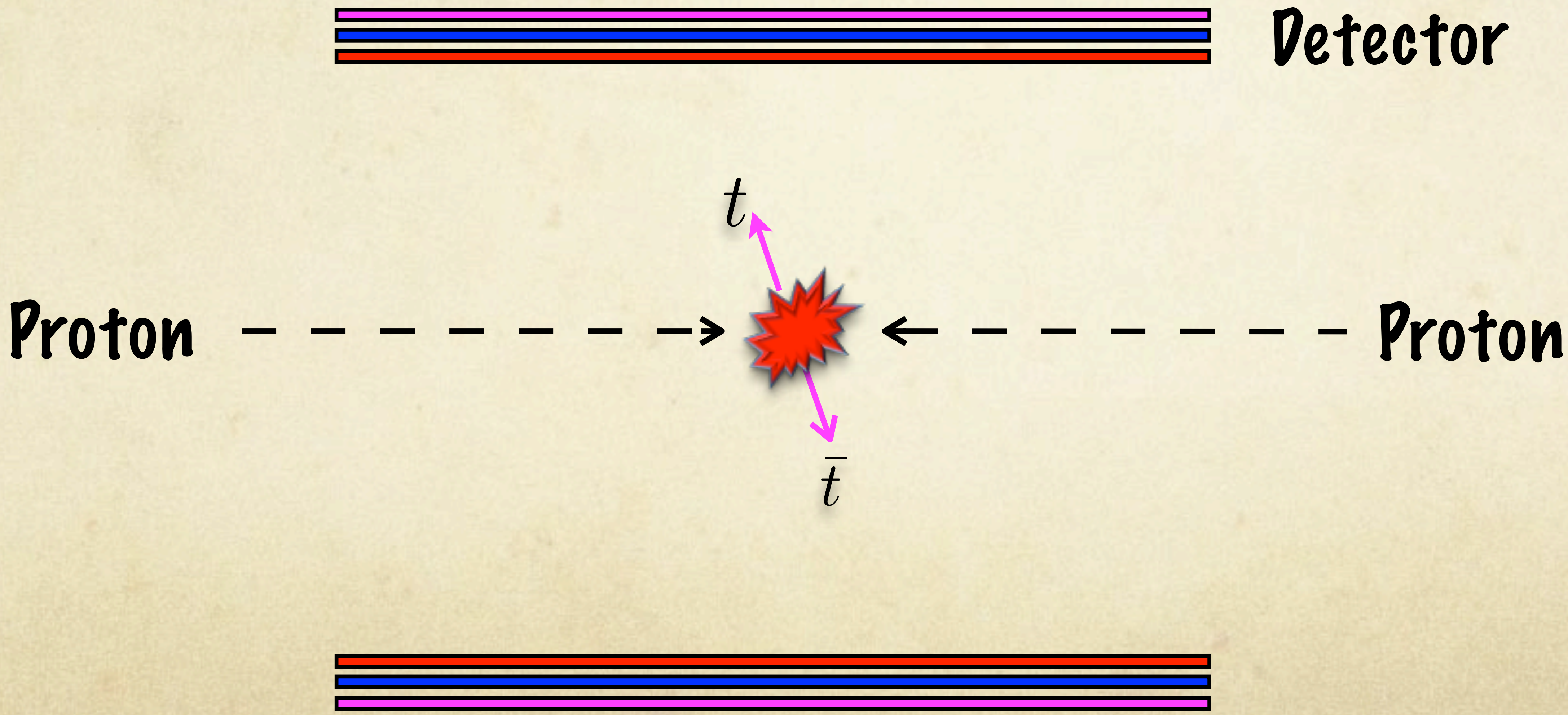
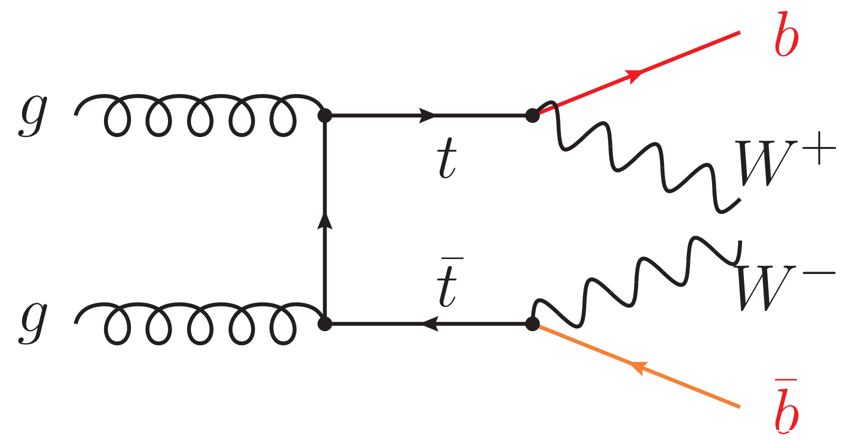
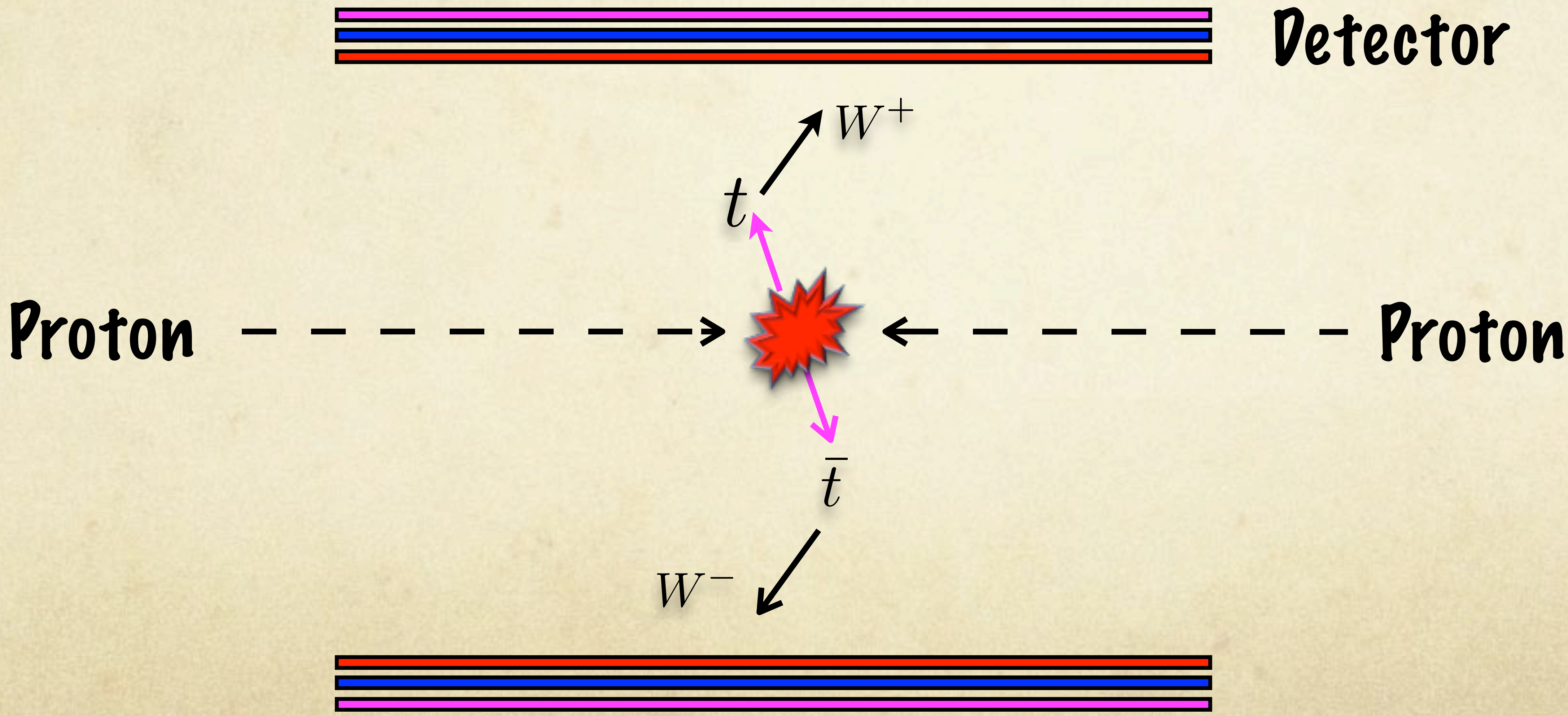


SM backgrounds (Reducible backgrounds)

Sample:

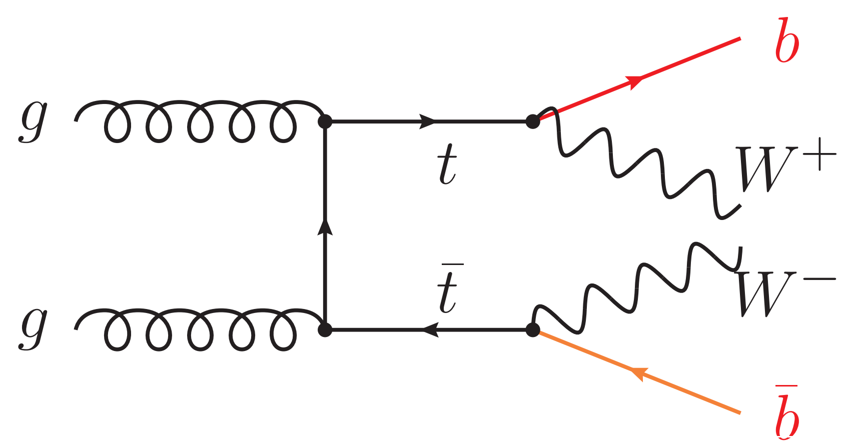


Good Jet veto efficiency
(no need to worry)



SM backgrounds (Reducible backgrounds)

Sample:



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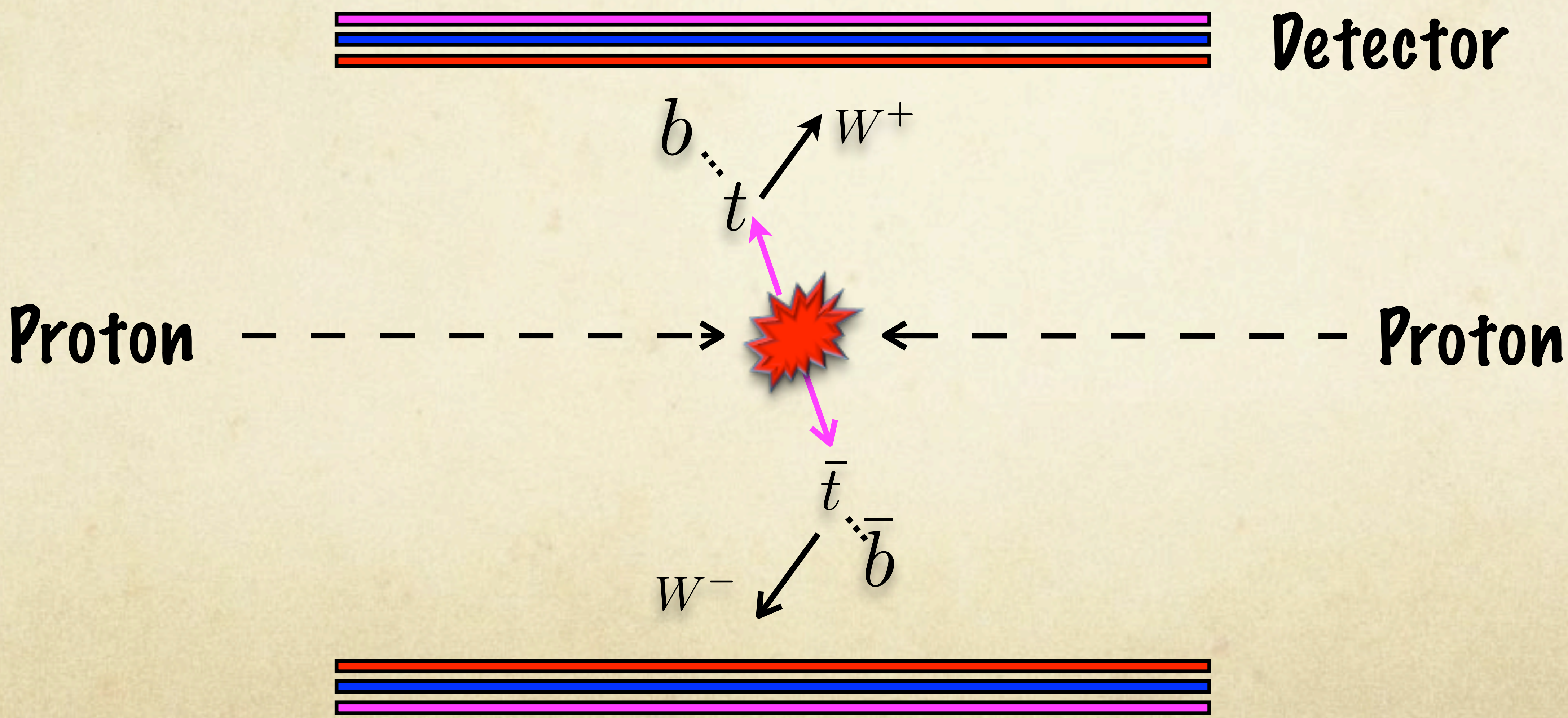
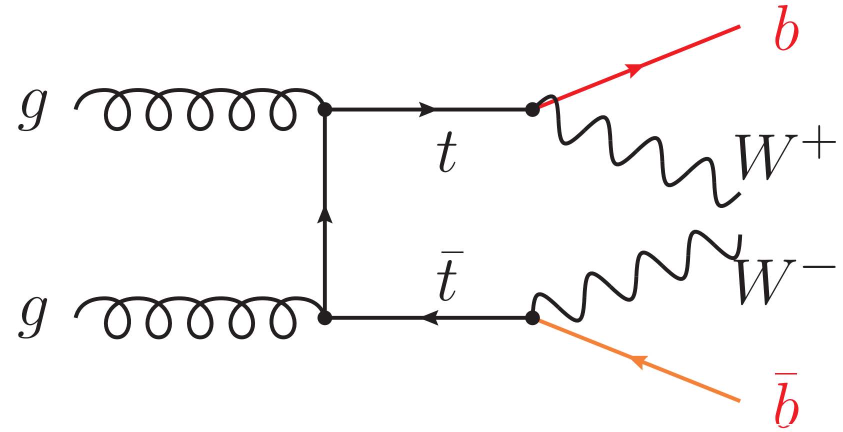


SM backgrounds (Reducible backgrounds)

Sample:



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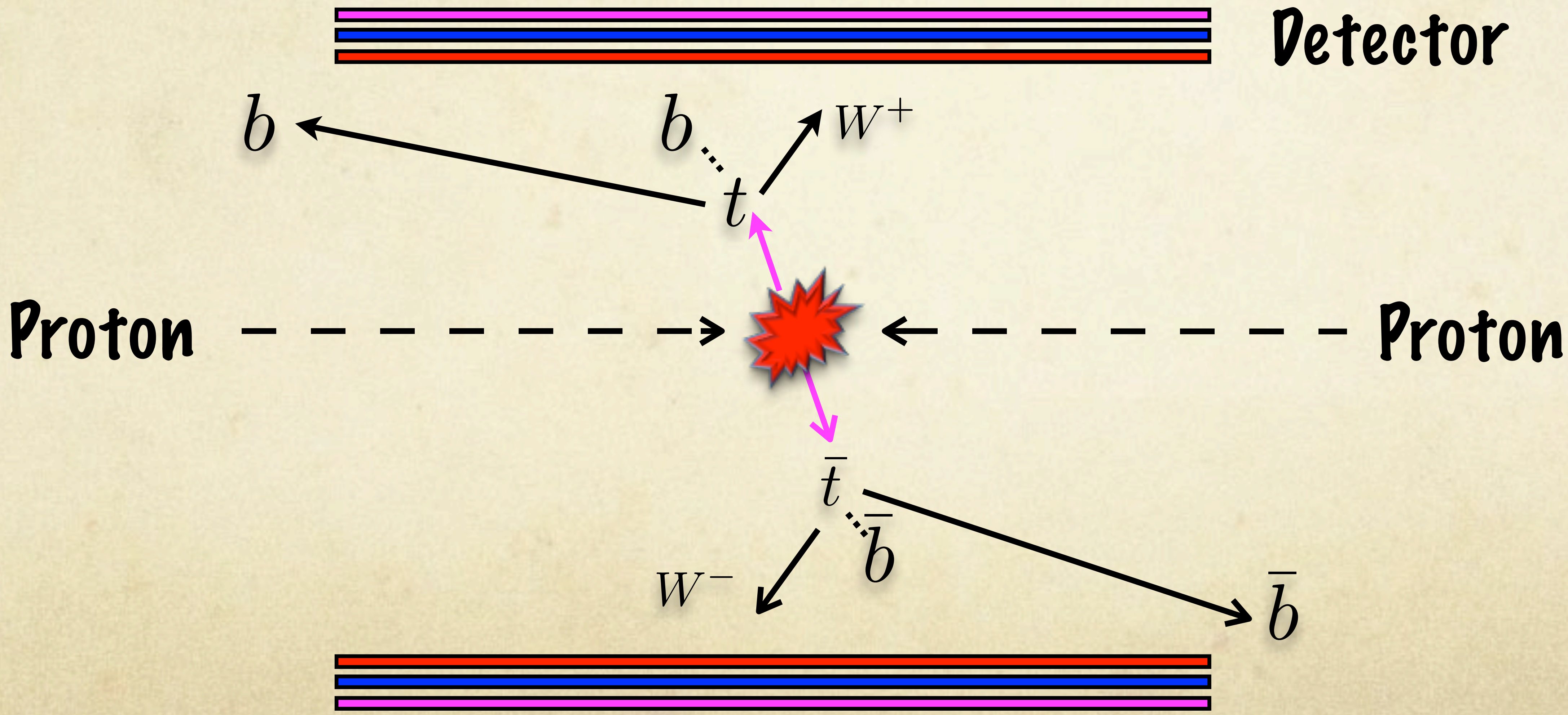
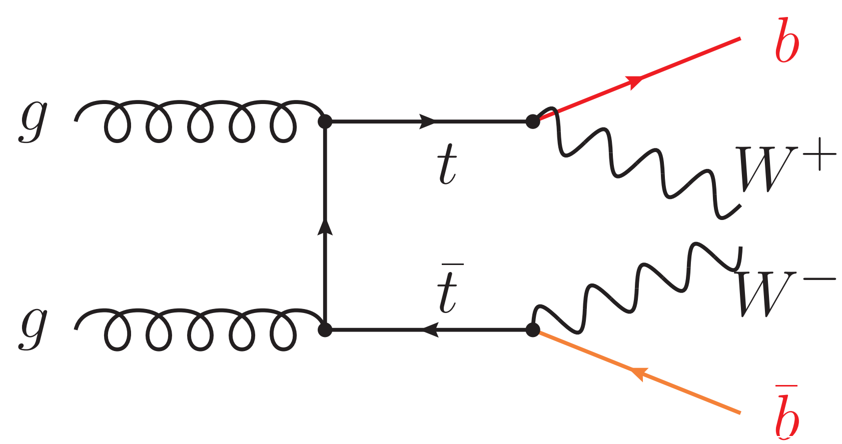


SM backgrounds (Reducible backgrounds)

Sample:



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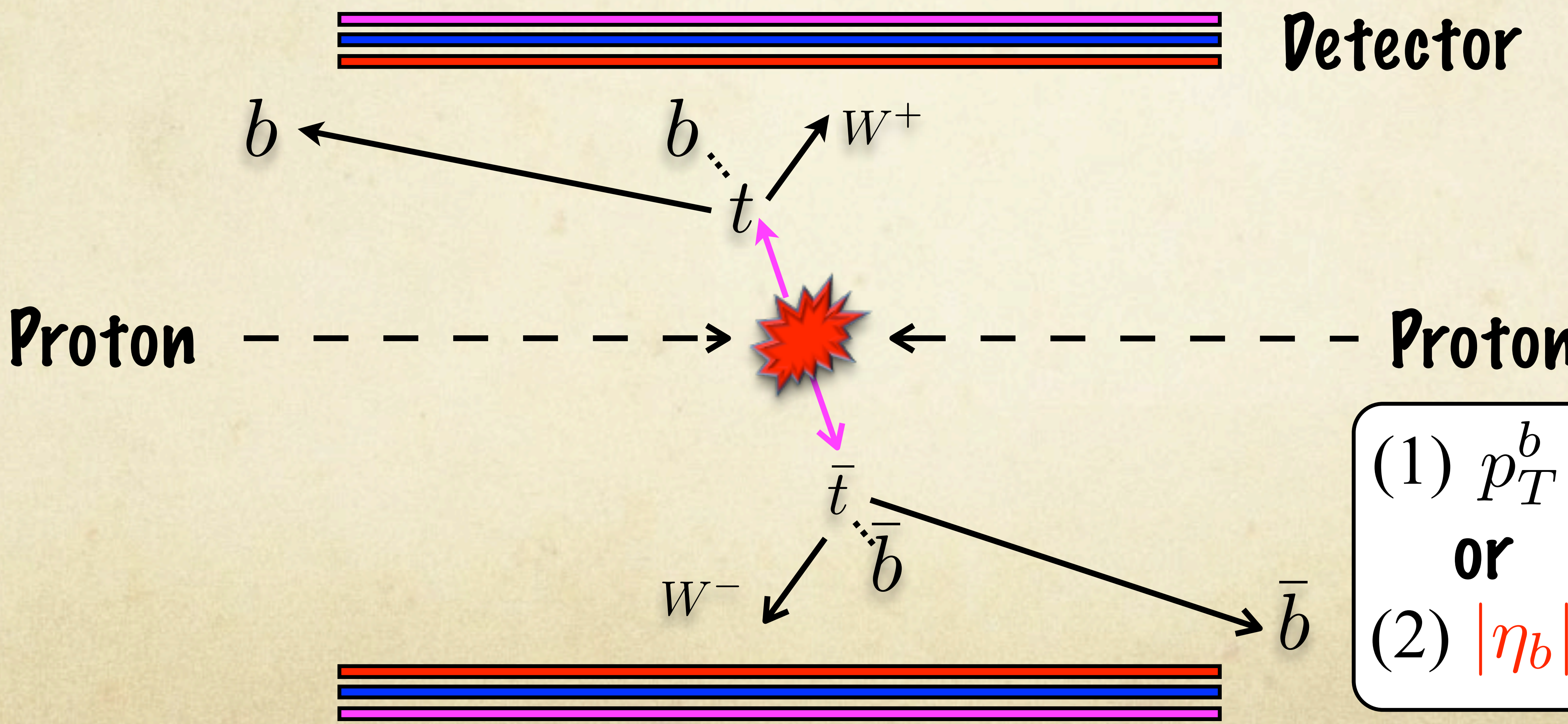
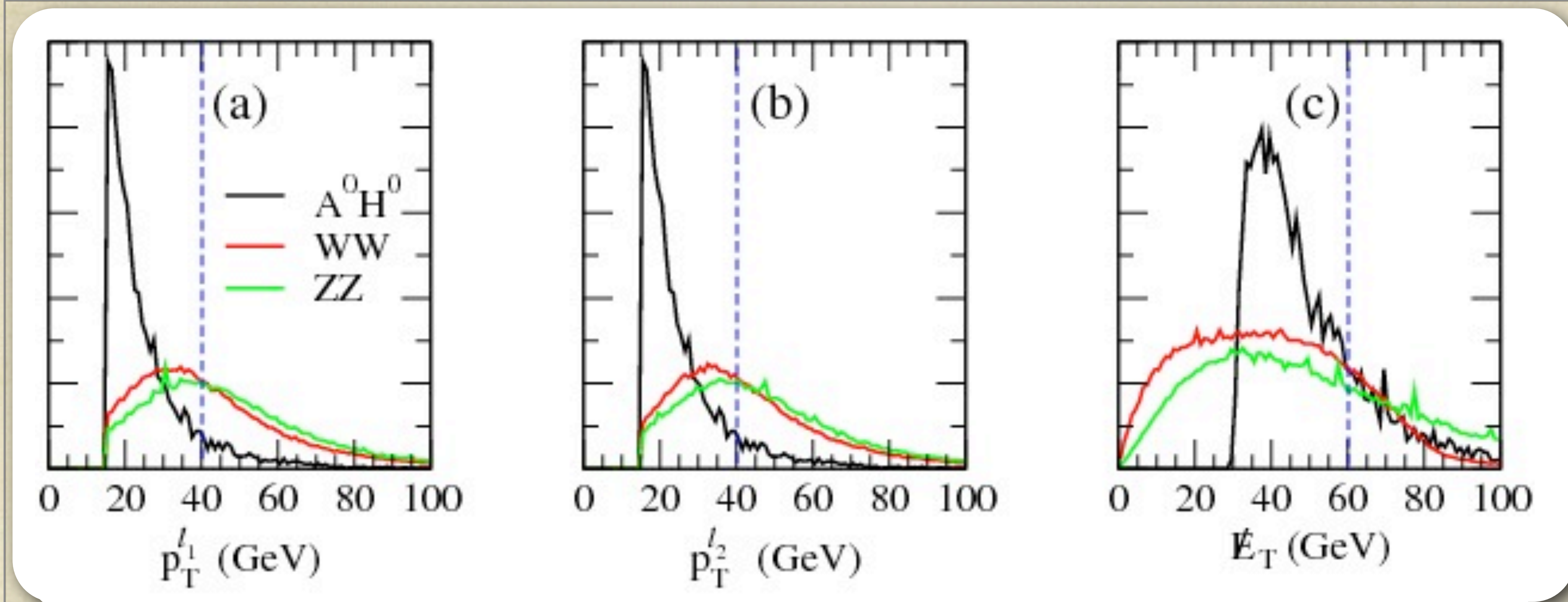


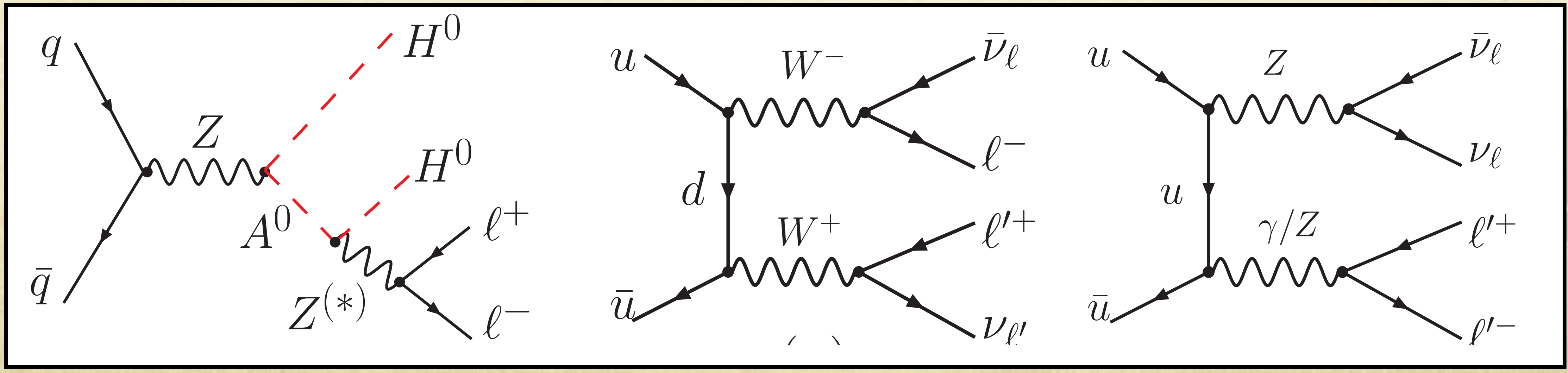
(1) $p_T^b < 10\text{GeV}$

or

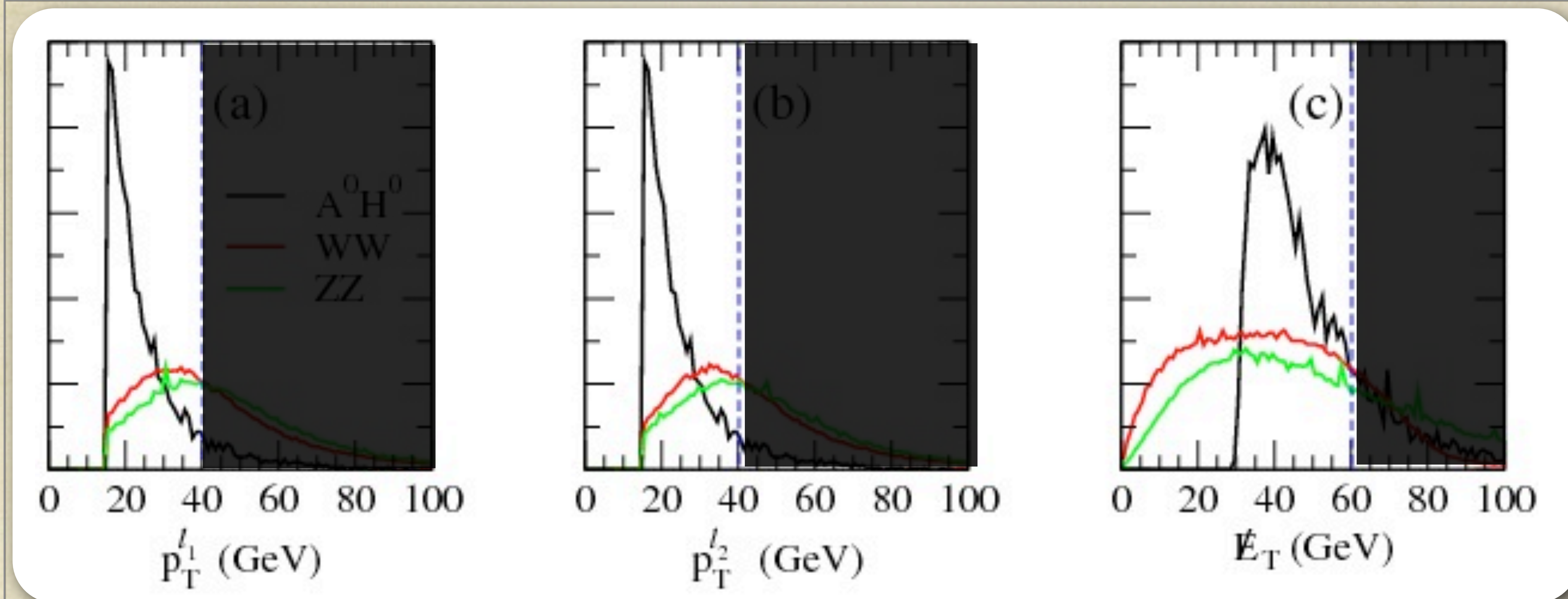
(2) $|\eta_b| > 3.0$

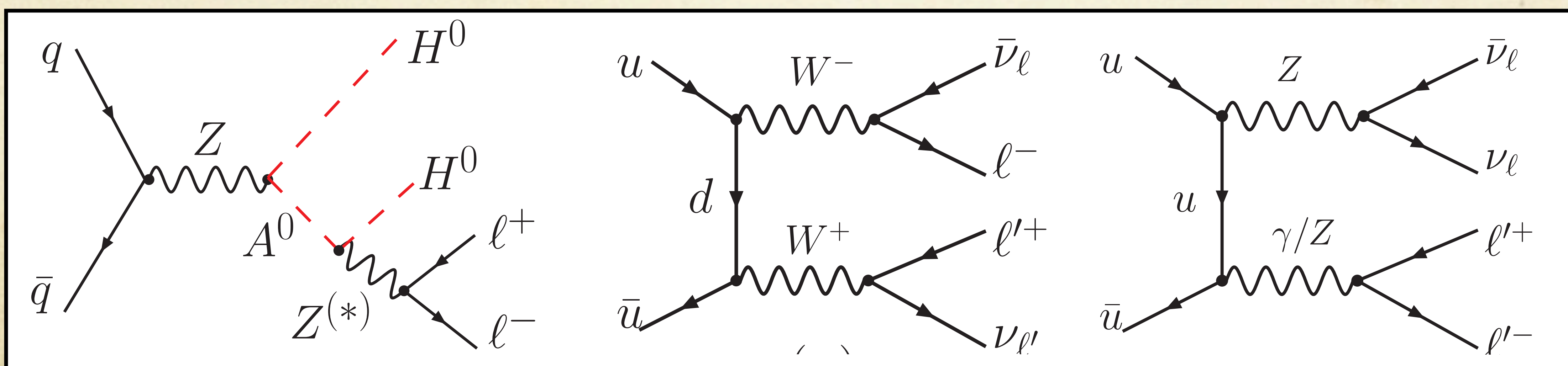
kinematical Distributions



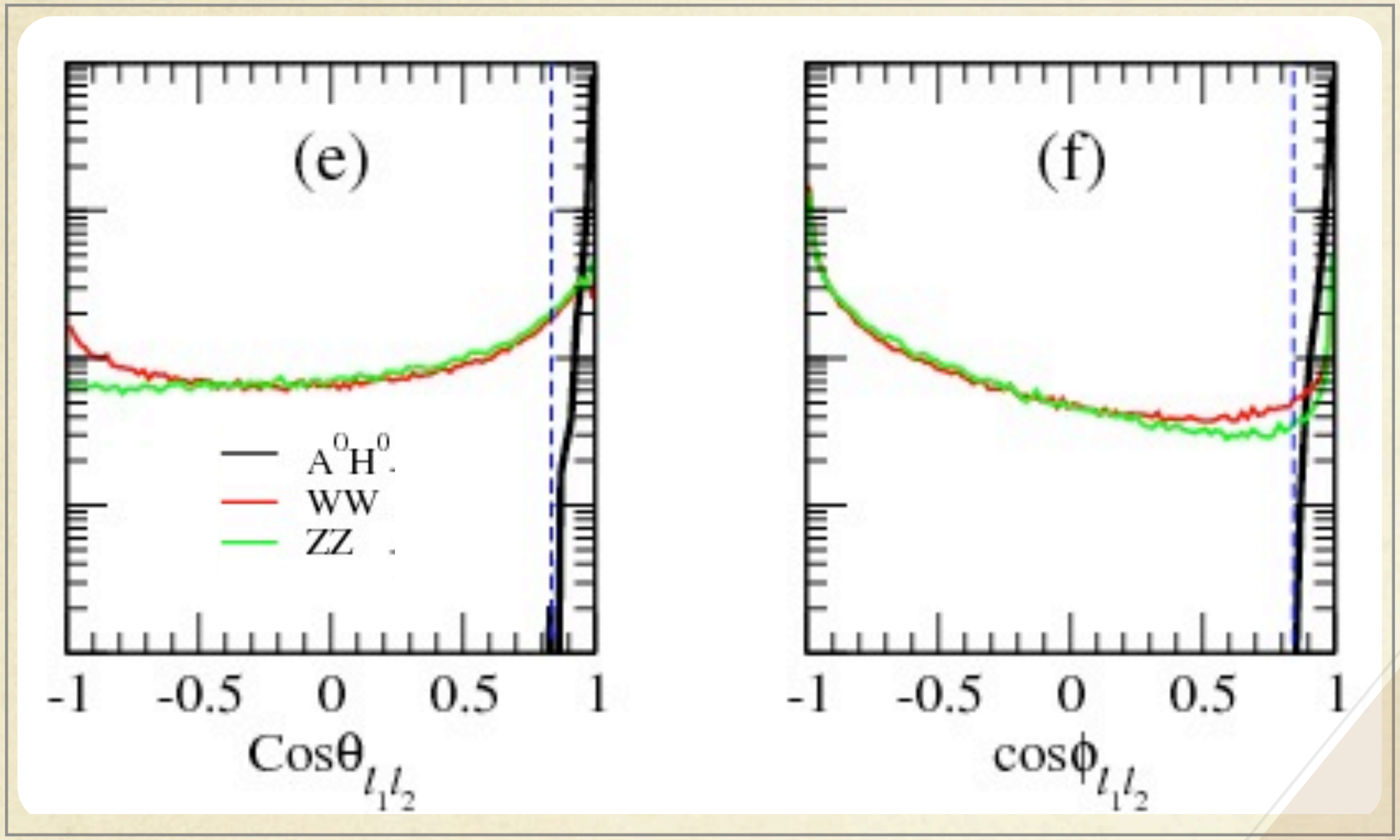


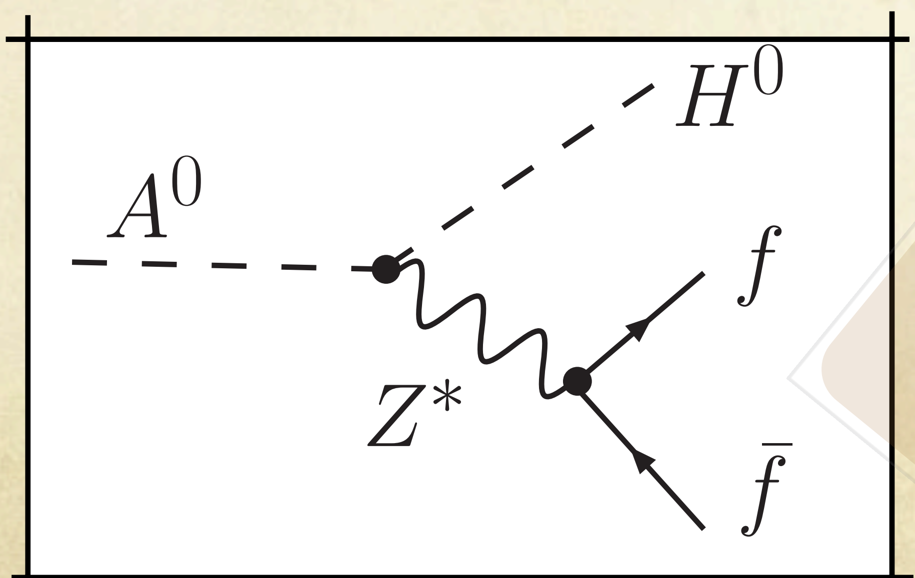
kinematical Distributions

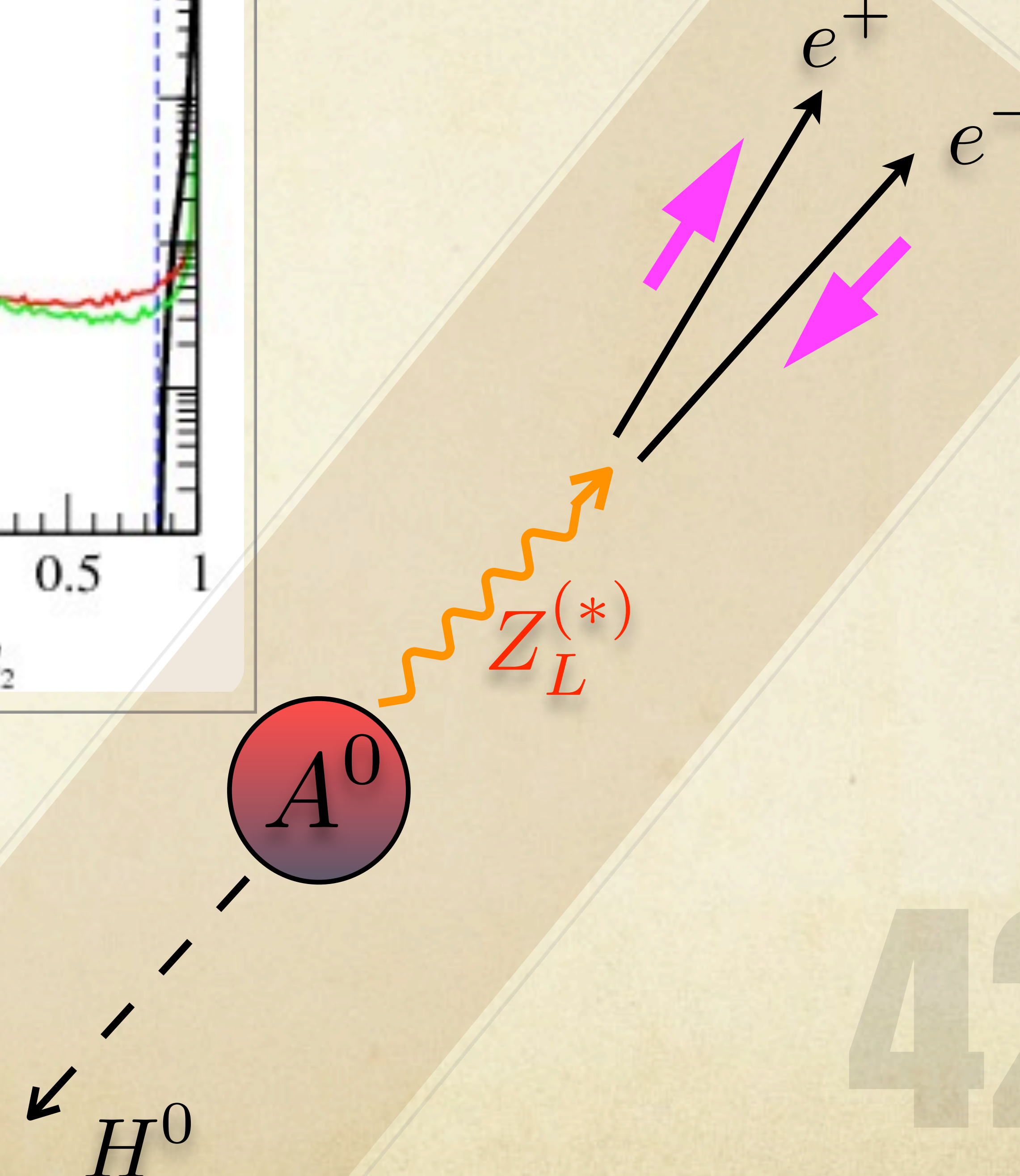




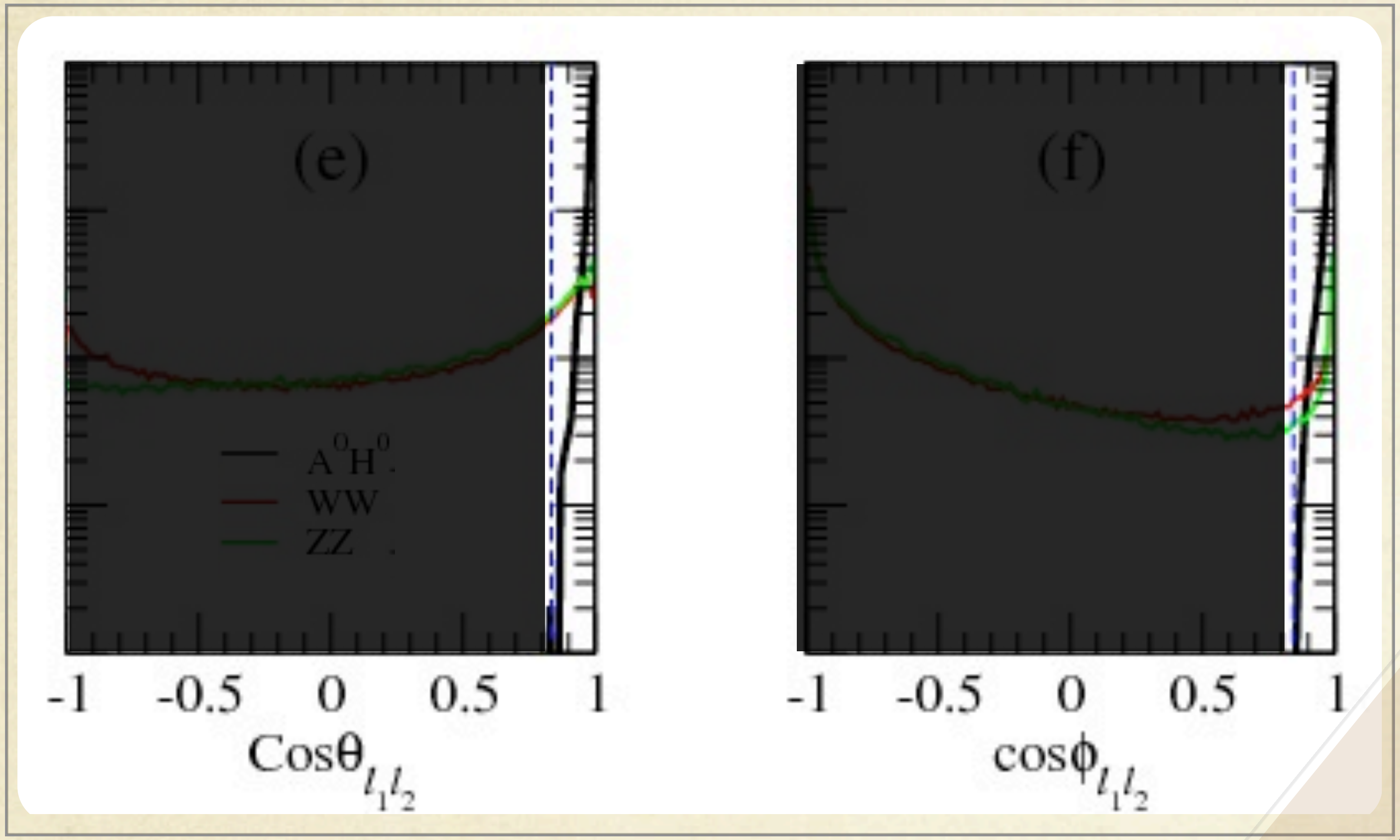
Kinematical Distributions

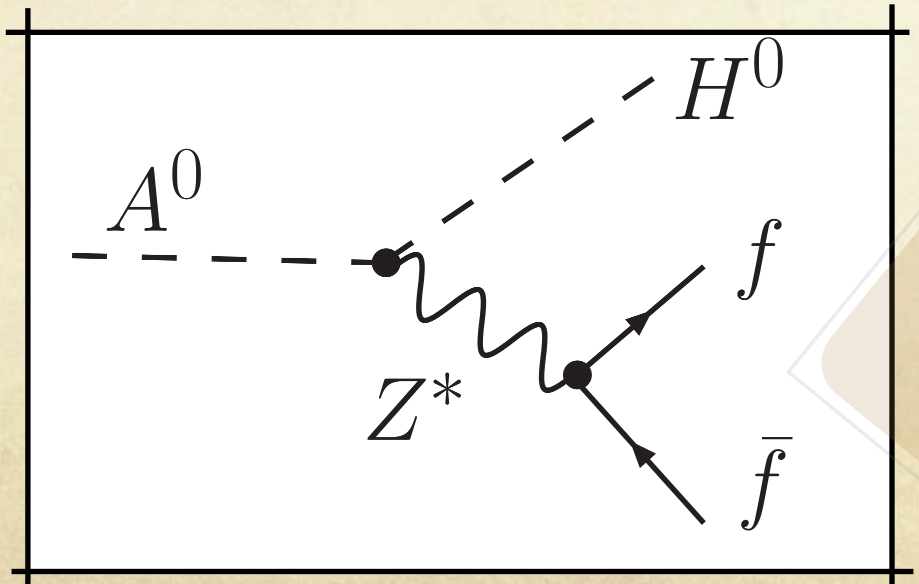


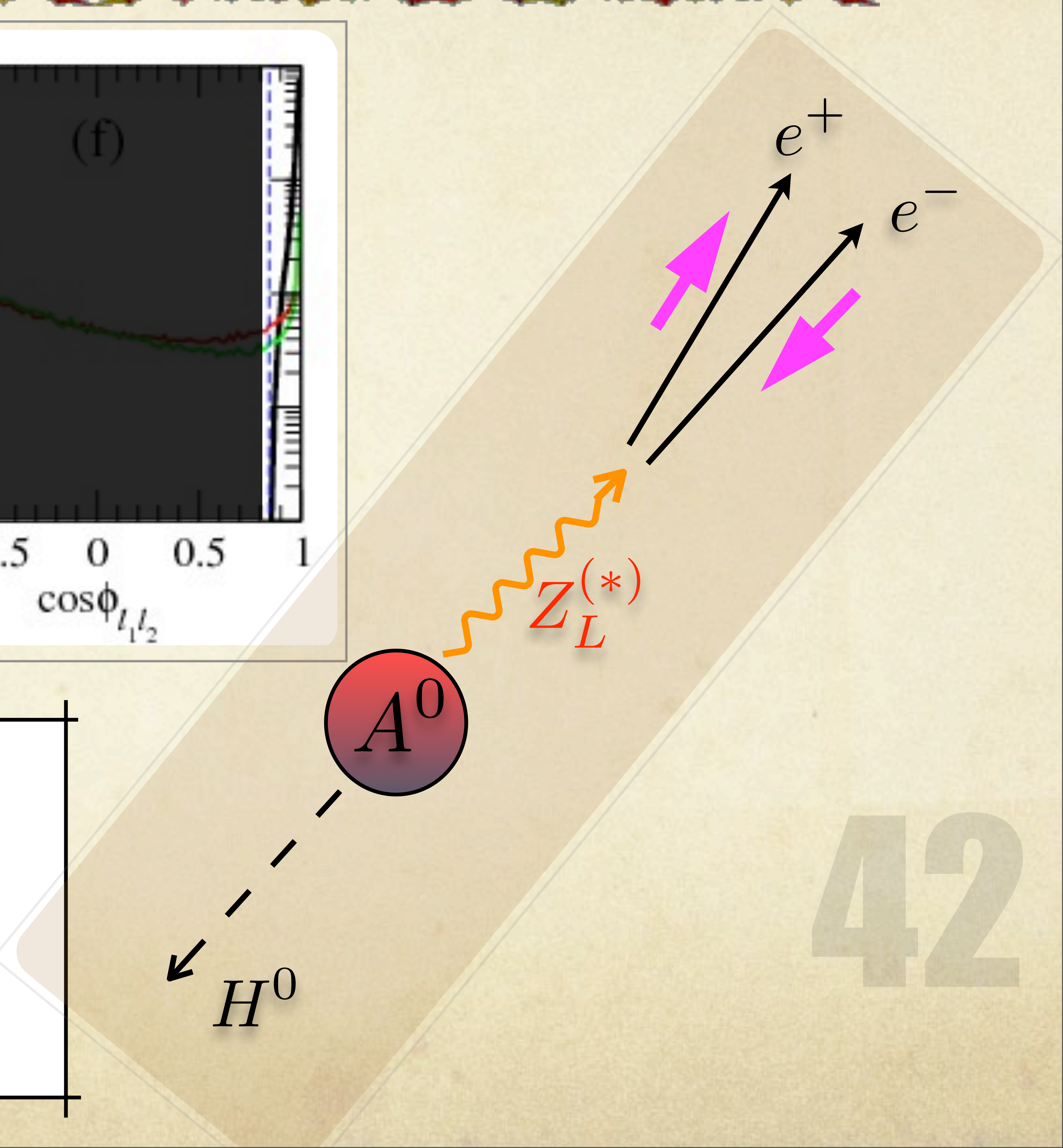




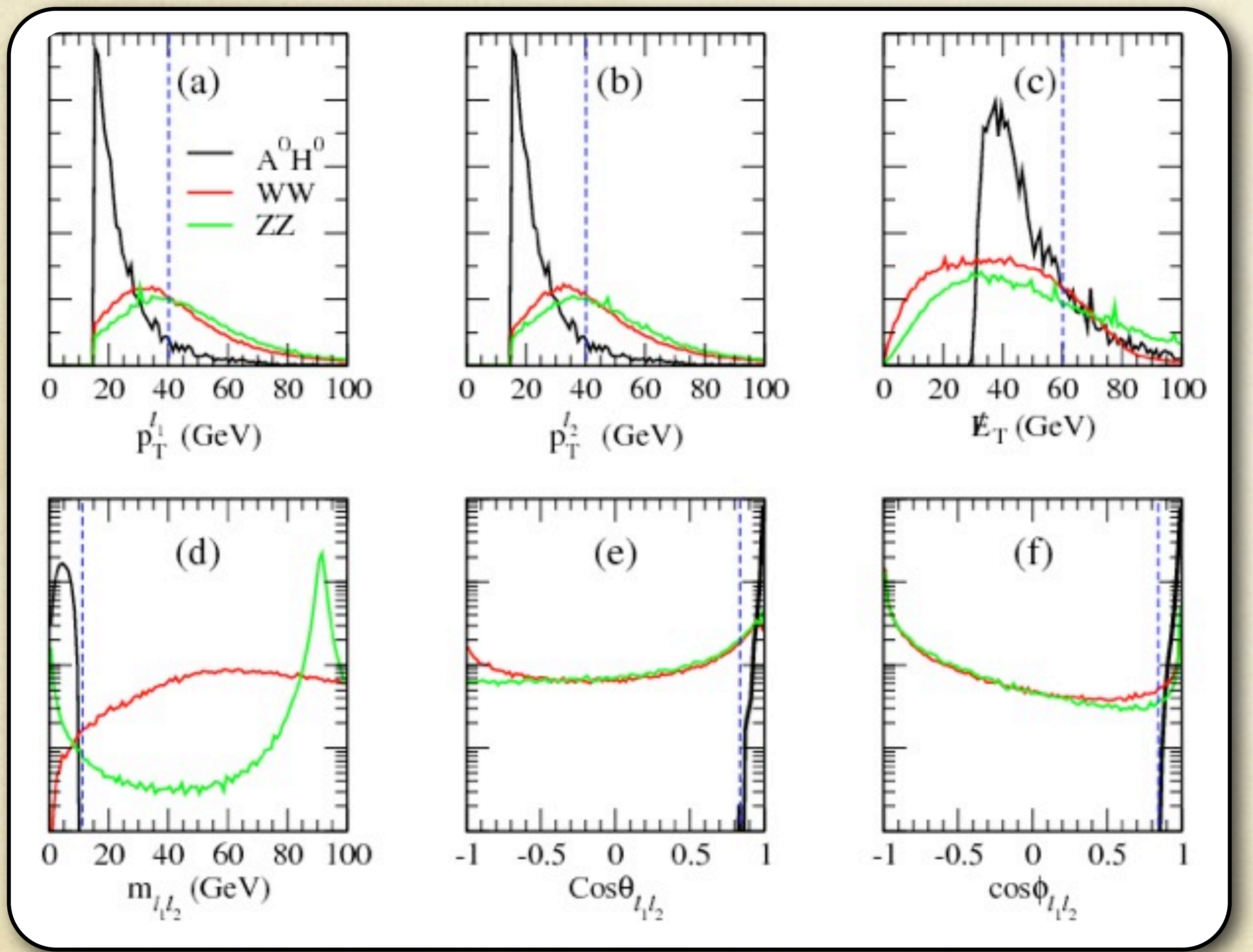
Kinematical Distributions







Kinematical Distributions



Basic

$$p_T(\ell) > 15\text{GeV}$$

$$|\eta(\ell)| < 3$$

Optimal

$$p_T(\ell) < 40\text{GeV}$$

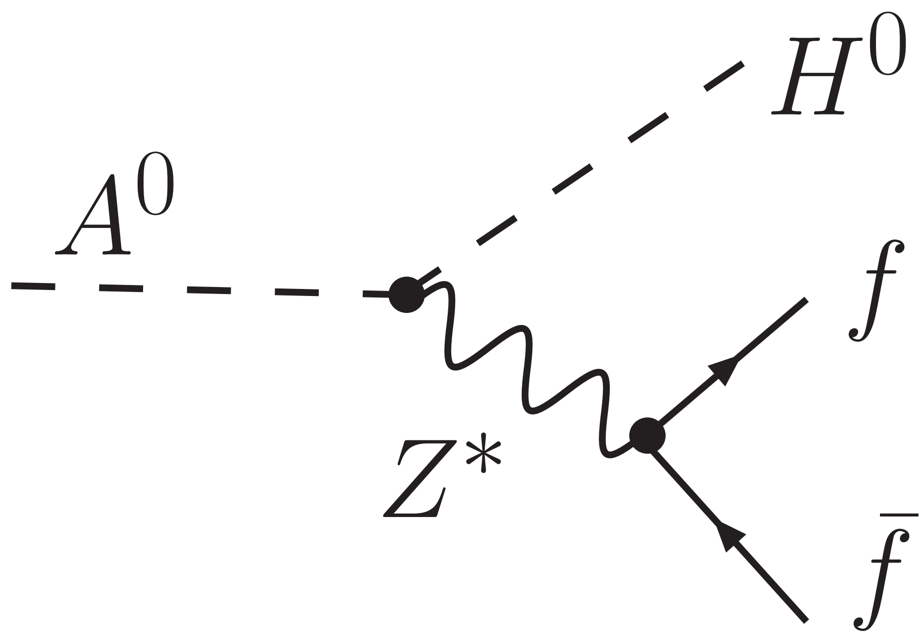
$$\not{E}_T < 60\text{GeV}$$

$$\cos\theta_{\ell\ell} \geq 0.9$$

$$\cos\phi_{\ell\ell} \geq 0.9$$

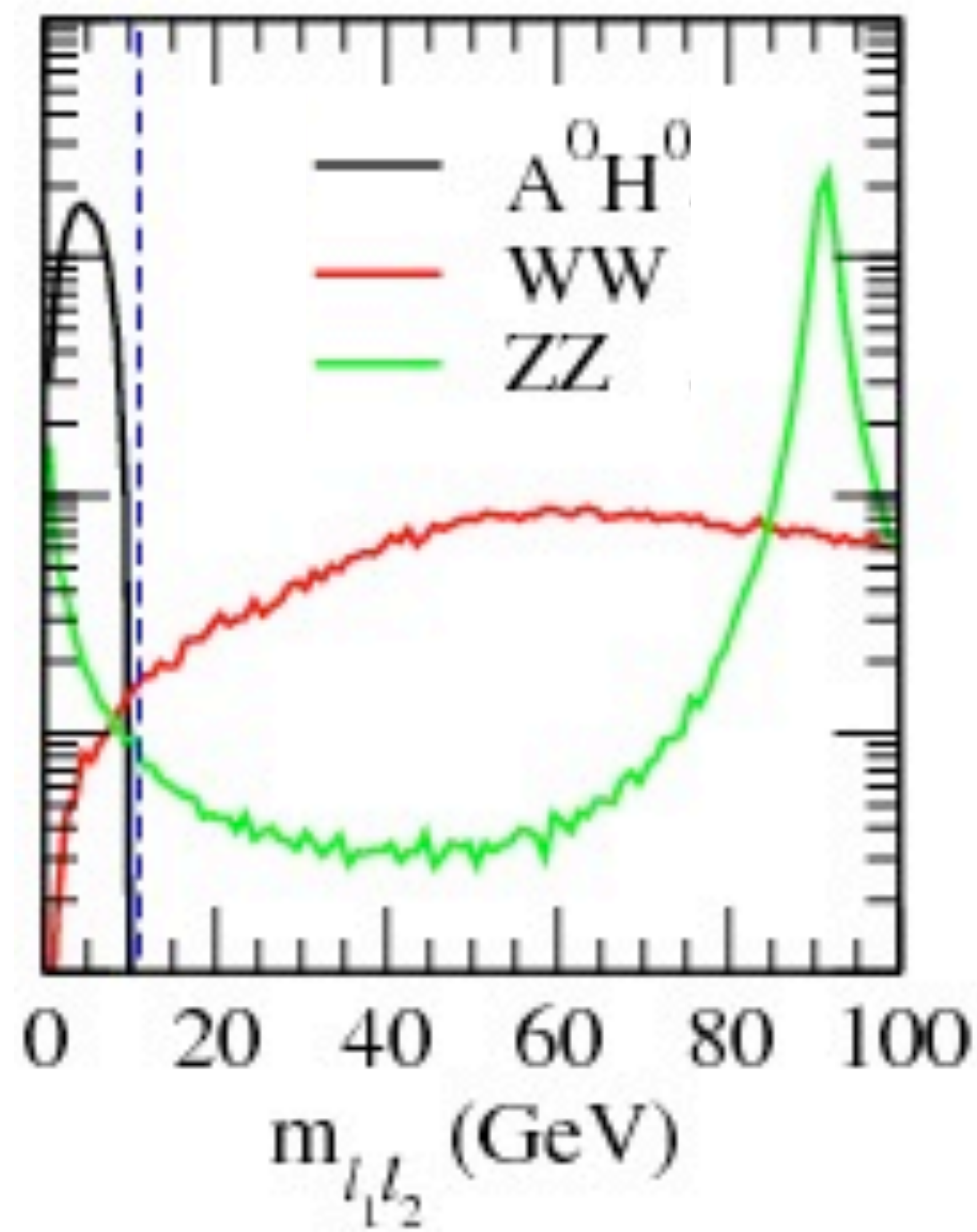
$$0 \leq m_{\ell\ell} \leq 10\text{GeV}$$

Kinematics Distributions



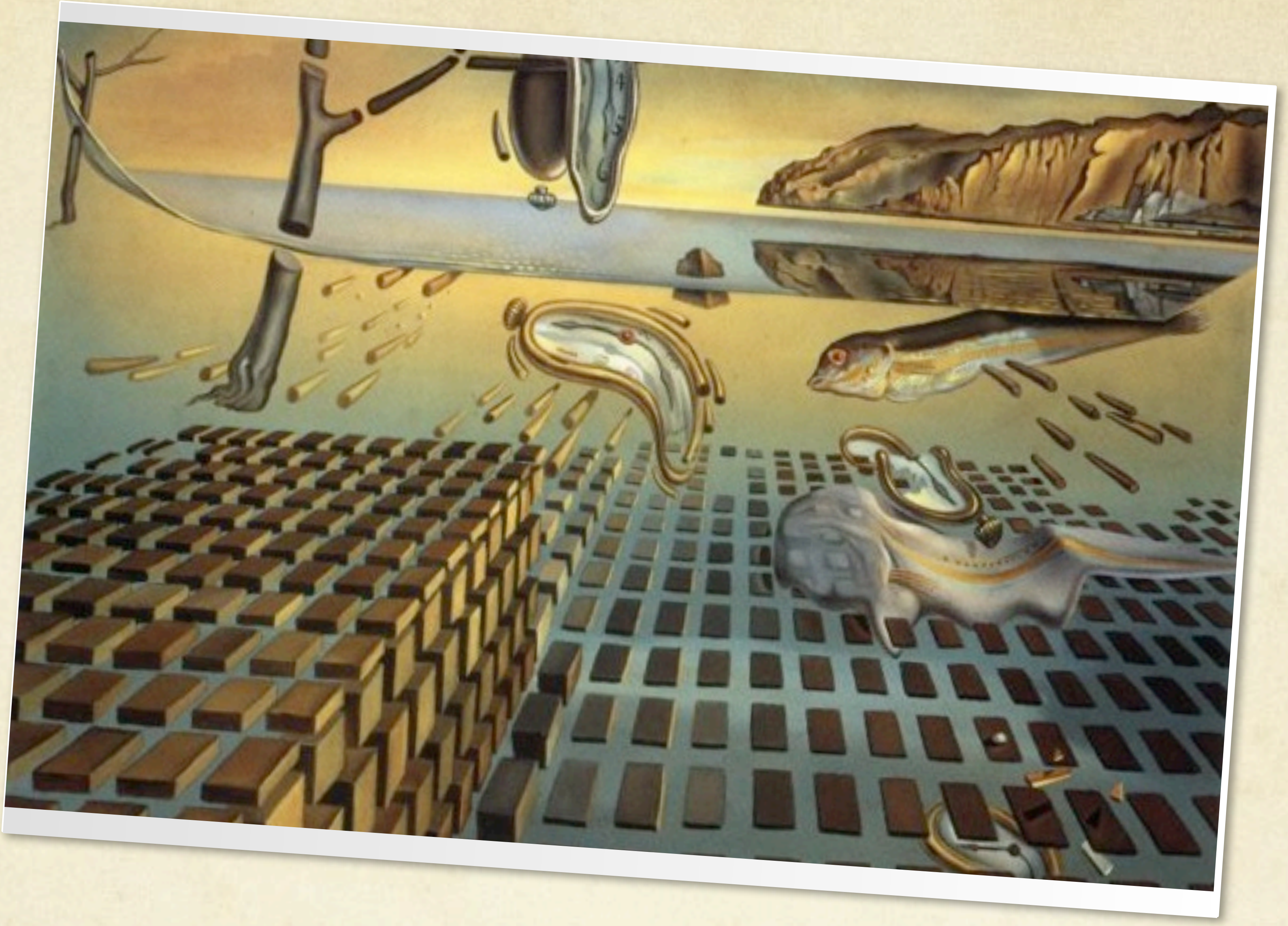
$$m_{\ell_1\ell_2} \leq m_{A^0} - m_{H^0}$$

Spectacular mass peak



Discovery potential at the LHC

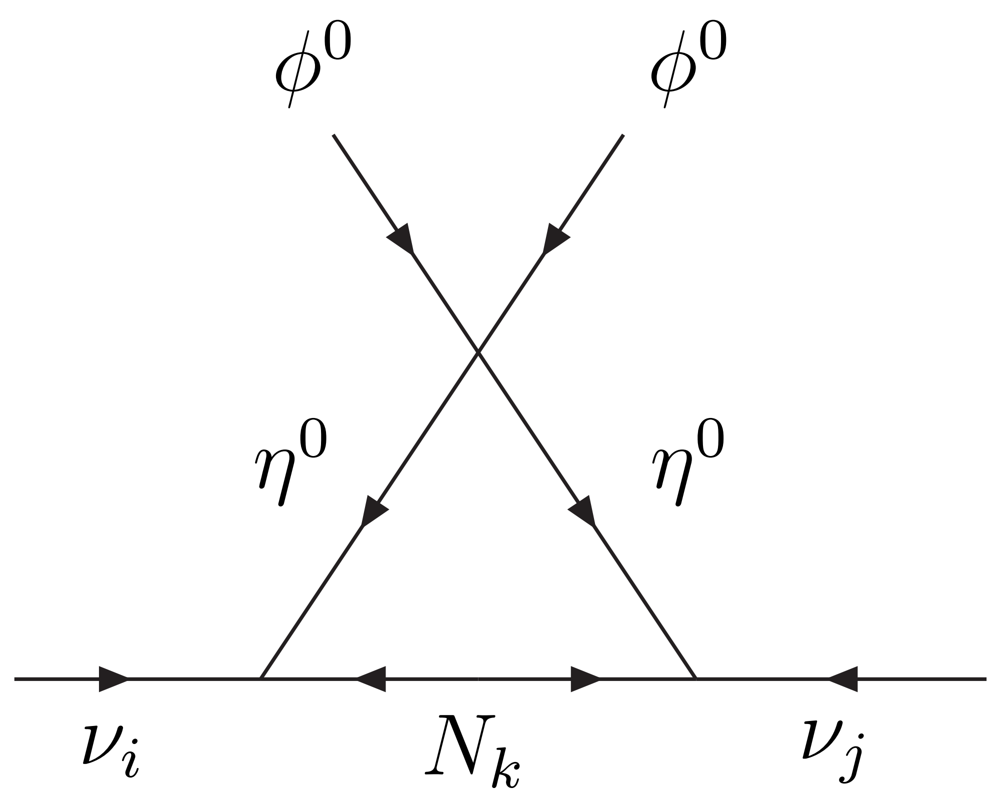
Signal $\mathcal{L} = 100\text{fb}^{-1}$			
$m_{H^0},\ m_{A^0}$	Basic	Optimal	$m_{\ell\ell} < 10\text{GeV}$
[50, 60]	117	37	37
$S/\sqrt{B}$	0.32	3.48	4.70
[50, 70]	433	56	50
$S/\sqrt{B}$	1.20	5.27	6.35
[50, 80]	680	38	26
$S/\sqrt{B}$	1.89	3.57	3.30
SM Backgrounds			
WW	1.1×10^5	110	62
ZZ	2.1×10^4	3	0

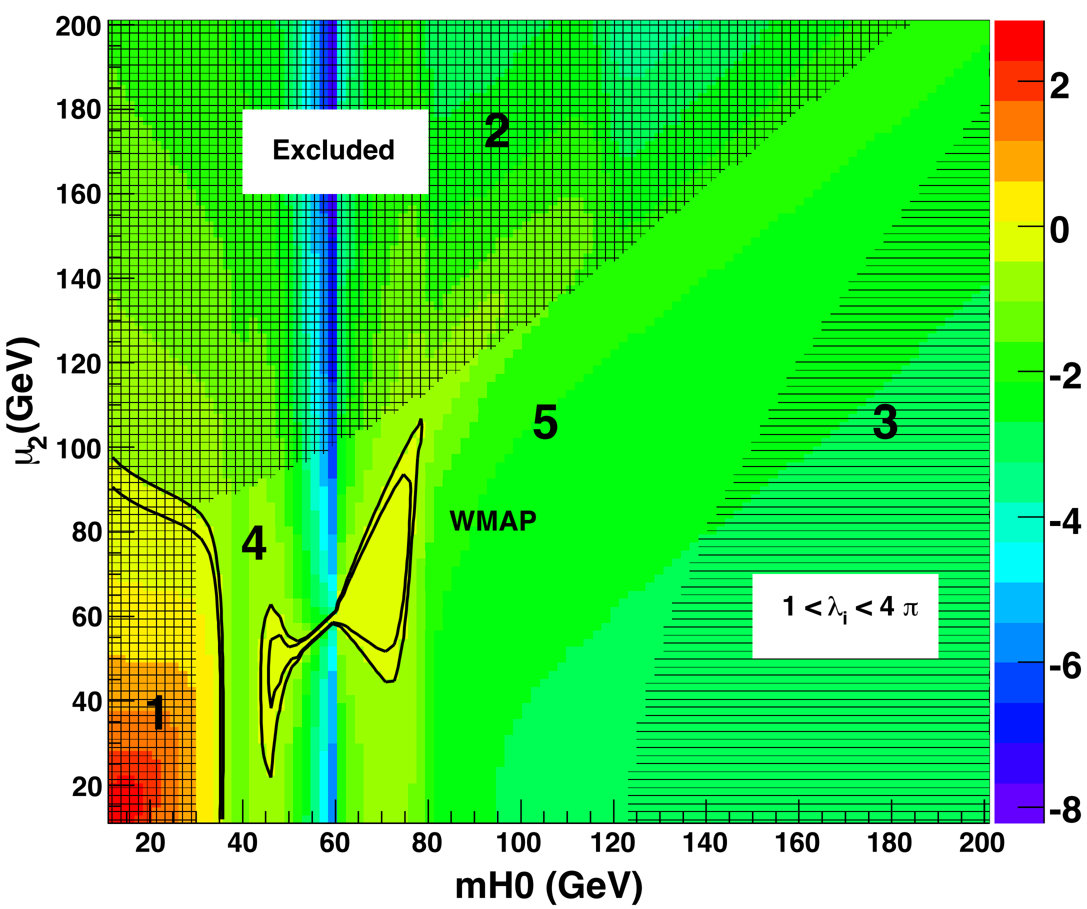


Summary and outlook

Summary

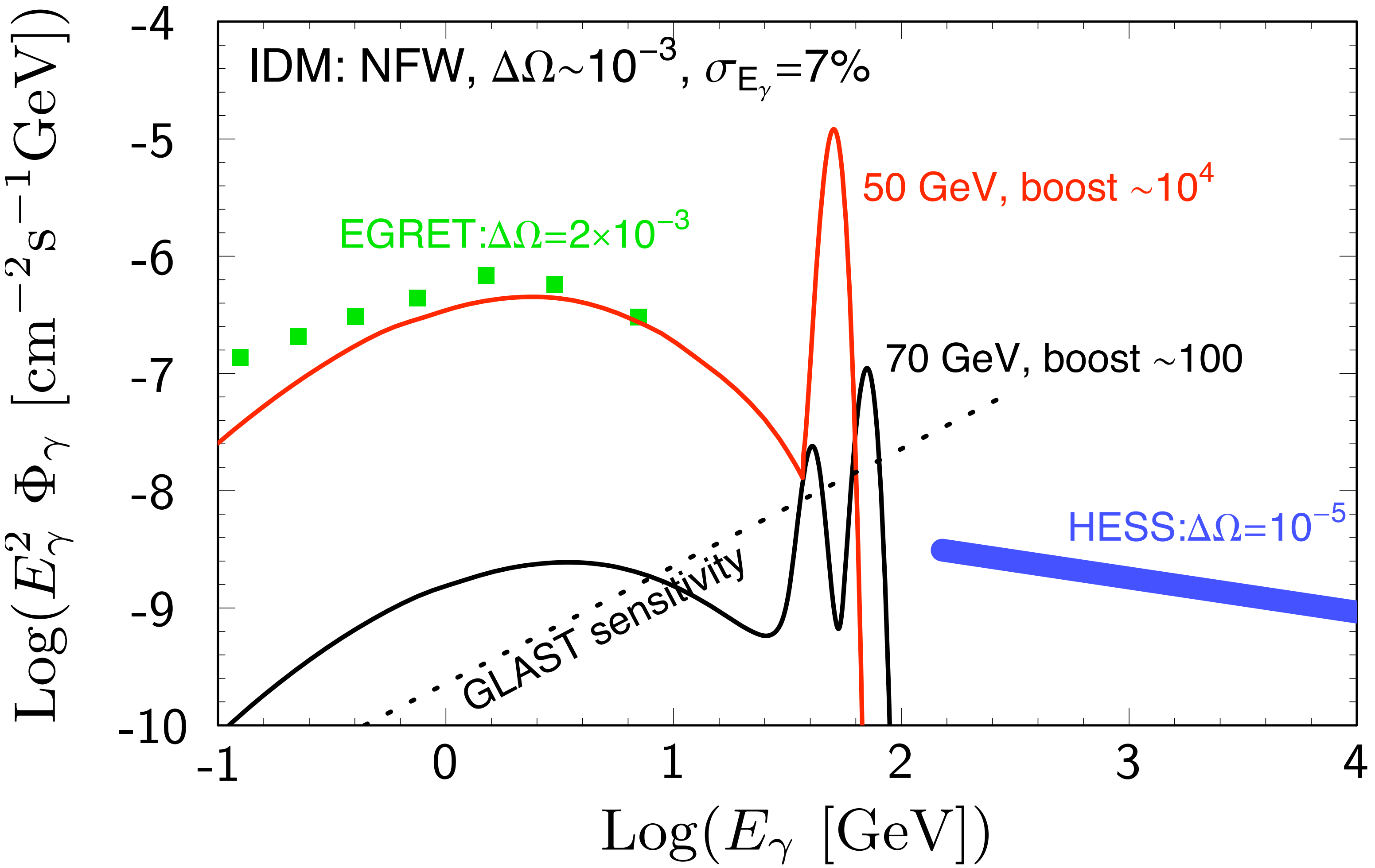
- Dark scalar model provides an interesting solution of both neutrino mass and the dark matter.





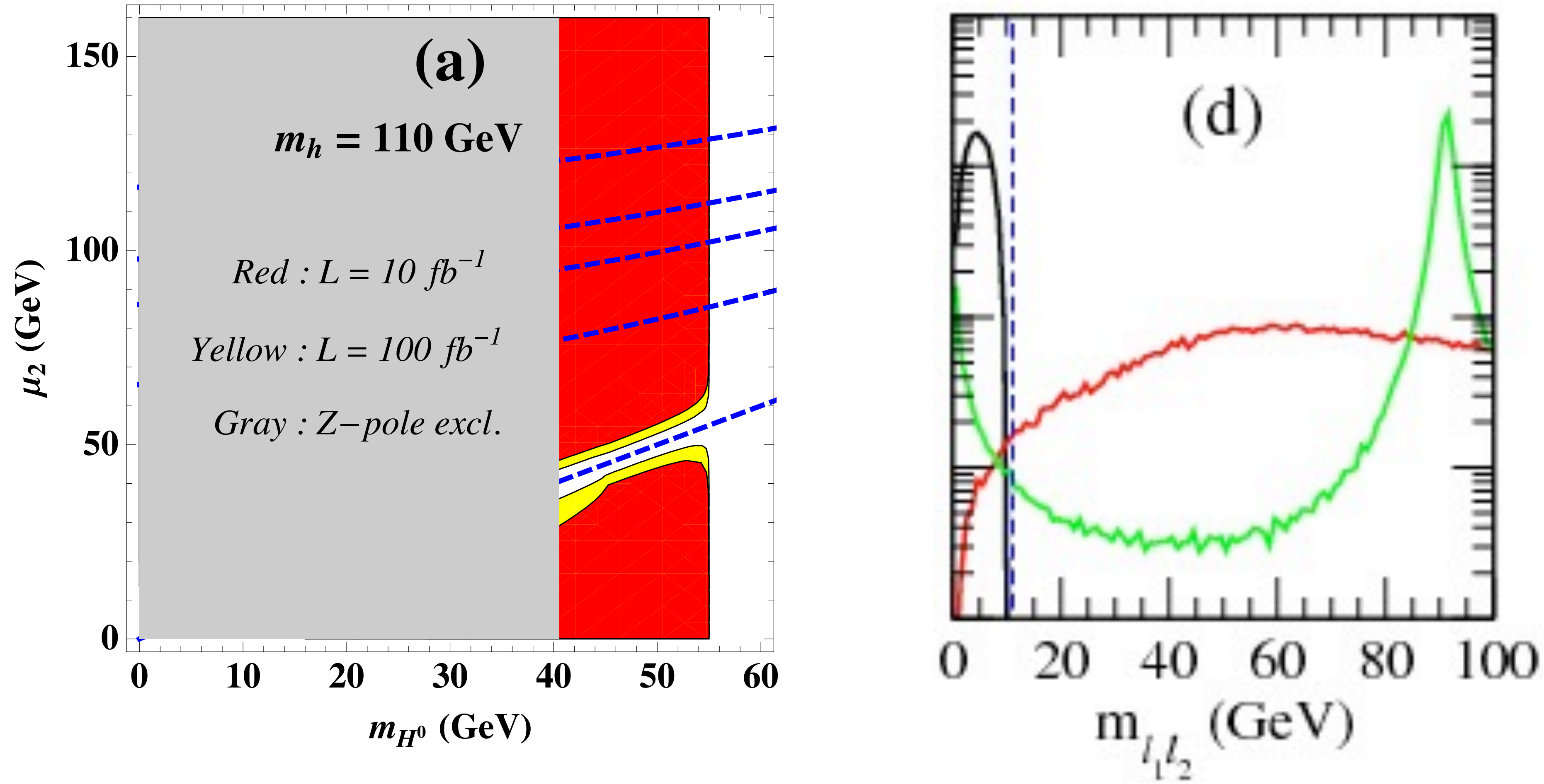
Summary

- A significant line-shape of the cosmic gamma-ray can be observed at the GLAST/FERMI soon.



Summary

- It is very promising to observe the dark scalars at the LHC.



BACKUP SLIDES

Outlook

- Comparison between Cosmology and Collider data is crucial to check the DSM.

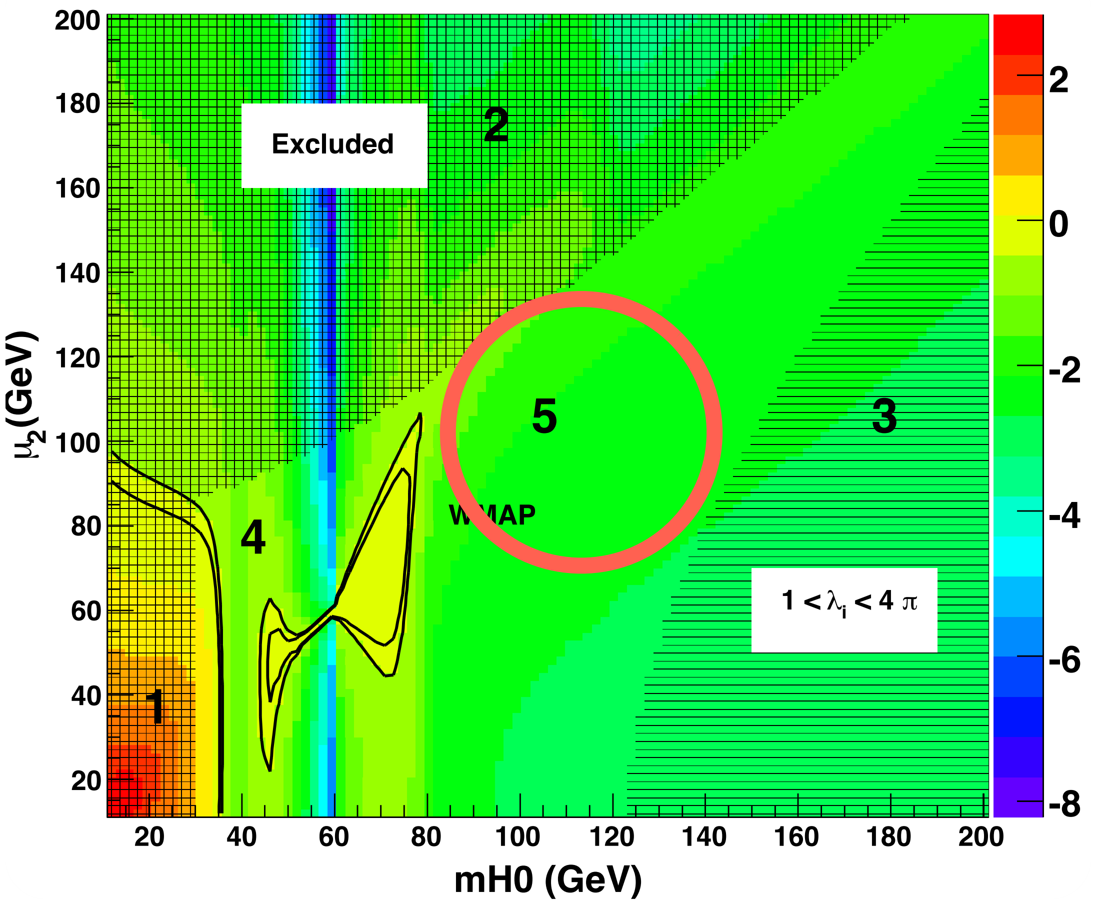
Region 5 (less relic abundance)

Two or more co-existing DMs

$$\sum_i \Omega_i h^2 = 0.11$$

- Large cross section of dark matter production

- Linear collider ???



Lepto-Philic Dark Matter Model and Positron Excess

Work in progress

To whom do not suffer enough from my previous talk

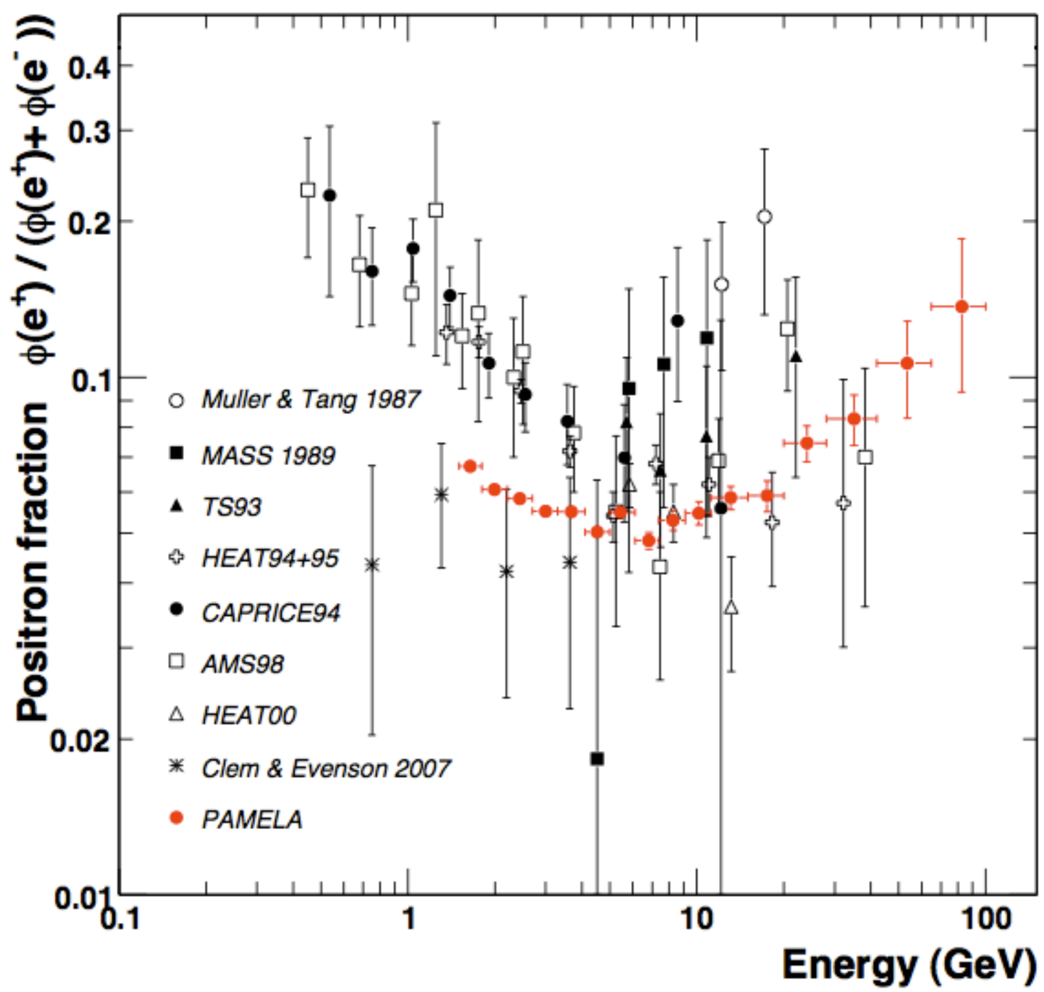
PAMELA Data (positrons)

Observation of an anomalous positron abundance in the cosmic radiation

O. Adriani,[1,2] G. C. Barbarino,[3,4] G. A. Bazilevskaya,[5] R. Bellotti,[6,7] M. Boezio,[8] E. A. Bogomolov,[9] L. Bonechi,[1,2] M. Bongi,[2] V. Bonvicini,[8] S. Bottai,[2] A. Bruno,[6,7] F. Cafagna,[7] D. Campana,[4] P. Carlson,[10] M. Casolino,[11] G. Castellini,[12] M. P. De Pascale,[11,13] G. De Rosa,[4] N. De Simone,[11,13] V. Di Felice,[11,13] A. M. Galper,[14] L. Grishantseva,[14] P.

arxiv:0810.4995

Data features an abrupt rise in positron fraction



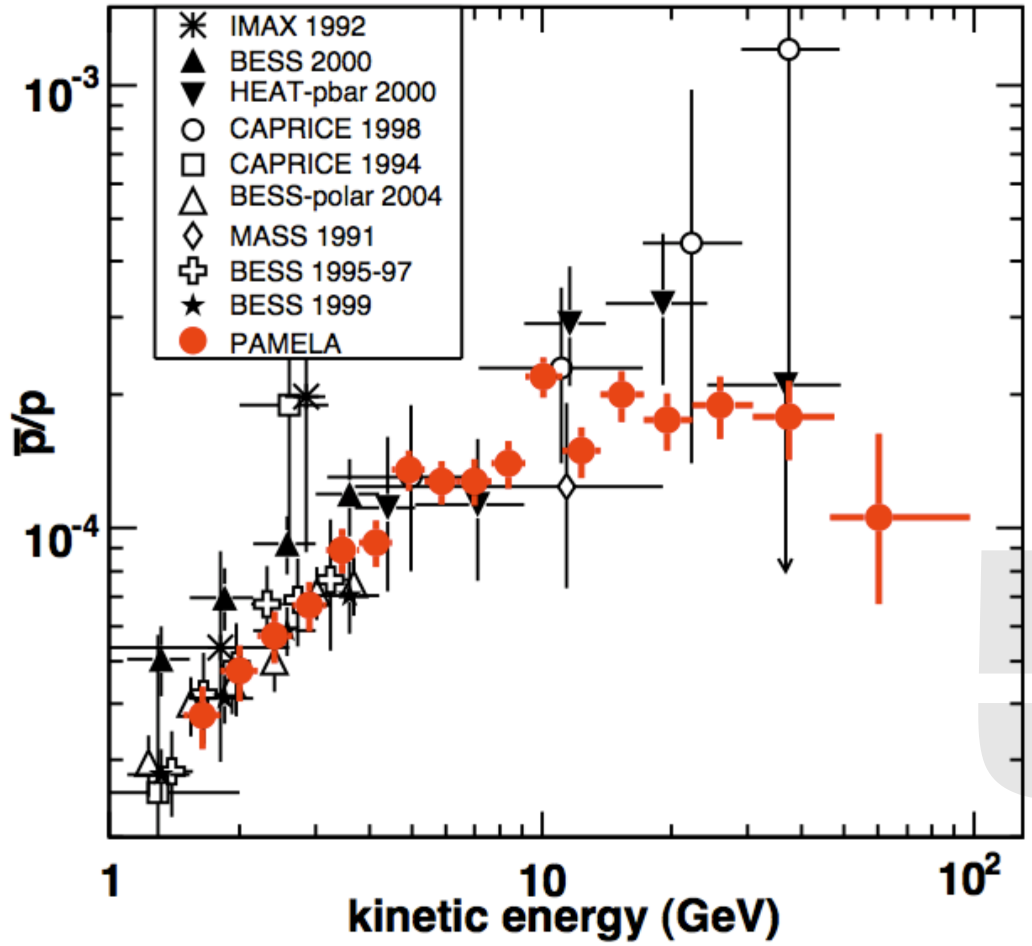
PAMELA Data (antiprotons)

A new measurement of the antiproton-to-proton flux ratio up to 100 GeV in the cosmic radiation

arxiv:0810.4994

O. Adriani,[1,2] G. C. Barbarino,[3,4] G. A. Bazilevskaya,[5] R. Bellotti,[6,7] M. Boezio,[8] E. A. Bogomolov,[9] L. Bonechi,[1,2] M. Bongi,[2] V. Bonvicini,[8] S. Bottai,[2] A. Bruno,[6,7] F. Cafagna,[7] D. Campana,[4] P. Carlson,[10] M. Casolino,[11] G. Castellini,[12] M. P. De Pascale,[11,13] G. De

No significant excess seen above expectation



Lessons we learned ...

(1) Dark Matter is lepton favored,

i.e. DMs cannot annihilate into quarks,

or, quark modes are highly suppressed.

(2) Dark Matter should be heavier

than $\sim 100\mathrm{GeV}$.

Model independent study

Barger, Keung, Marfatia, Shaughnessy, arxiv:0809.0162

- Perform Markov Chain Monte Carlo to scan parameters:
  - M_{DM}
  - Fraction of annihilation to modes:

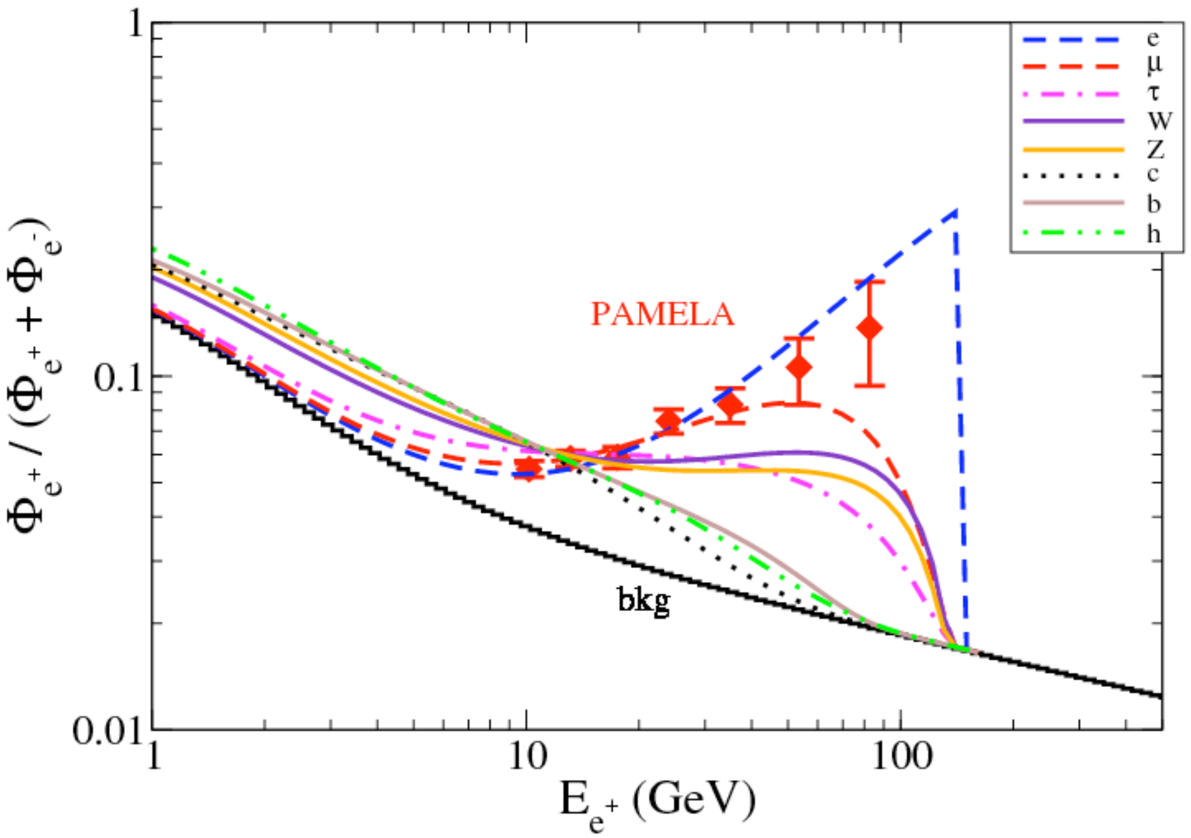
    $$e^+e^-, \mu^+\mu^-, \tau^+\tau^-, c\bar{c}, b\bar{b}, t\bar{t}, W^+W^-, ZZ, hh$$
  - Vary positron boost factor to minimize χ^2
- MCMC scan optimally scans over parameter space
  - Bayesian approach that optimally scans parameter space
  - More efficient with large number of parameters
  - Chain based on collection of points chosen by relative likelihood

Model independent study

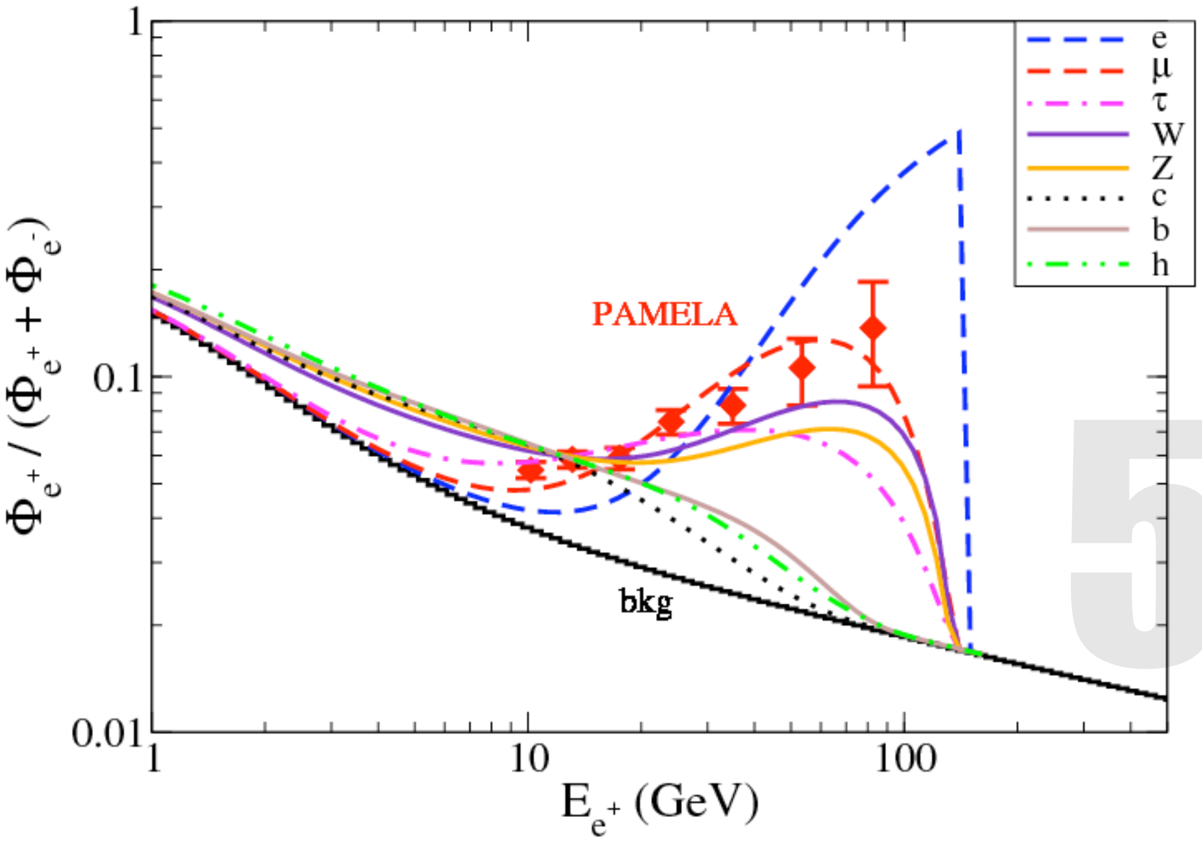
Barger, Keung, Marfatia, Shaughnessy, arxiv:0809.0162

- For 150 GeV DM mass,
  - Good fit: annihilation to lepton
  - In the middle: W/Z boson depending on propagation model
  - Bad fit: annihilation to quarks / Higgs boson

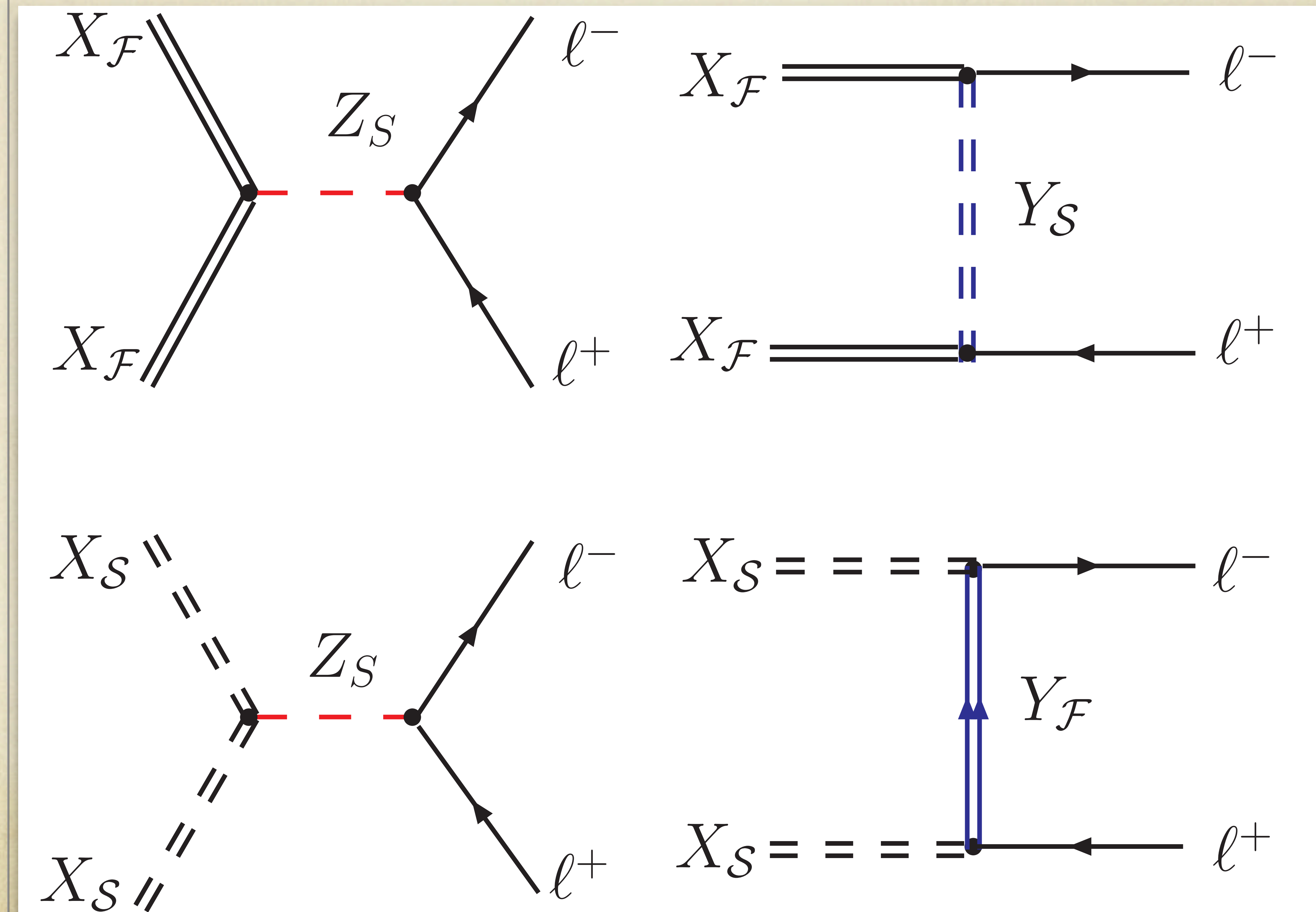
Med



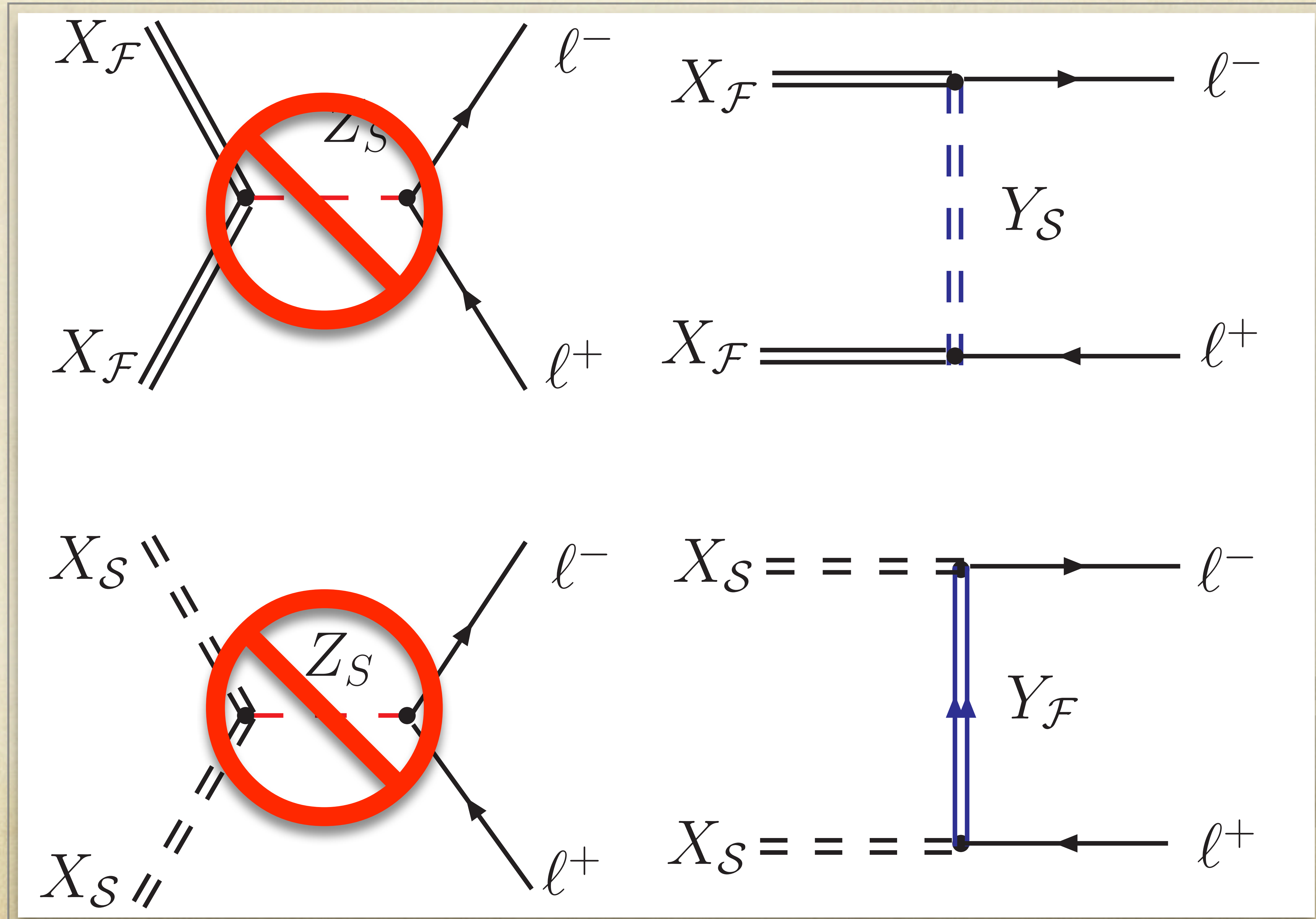
Min



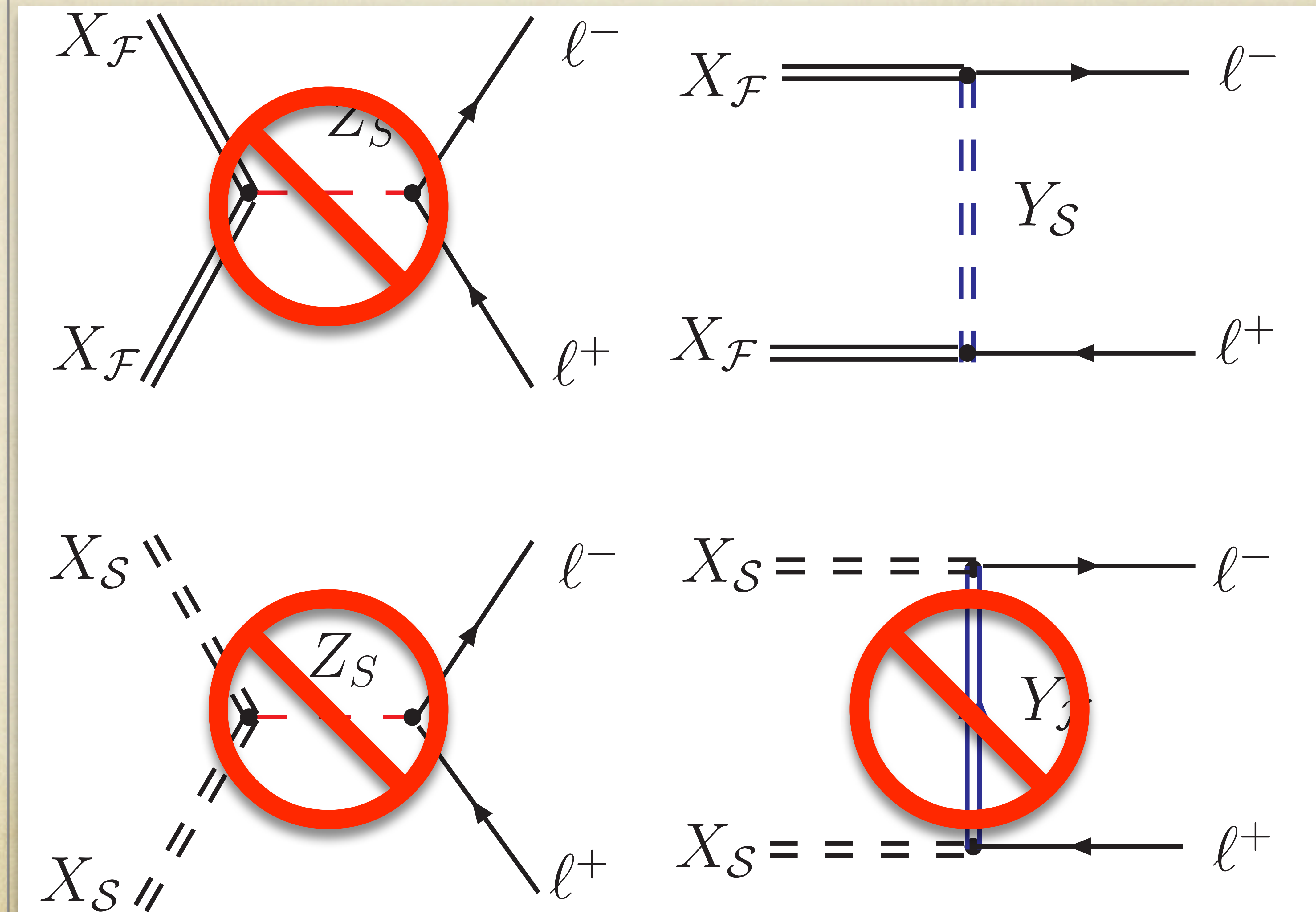
Lepto-philic Dark Matter Model



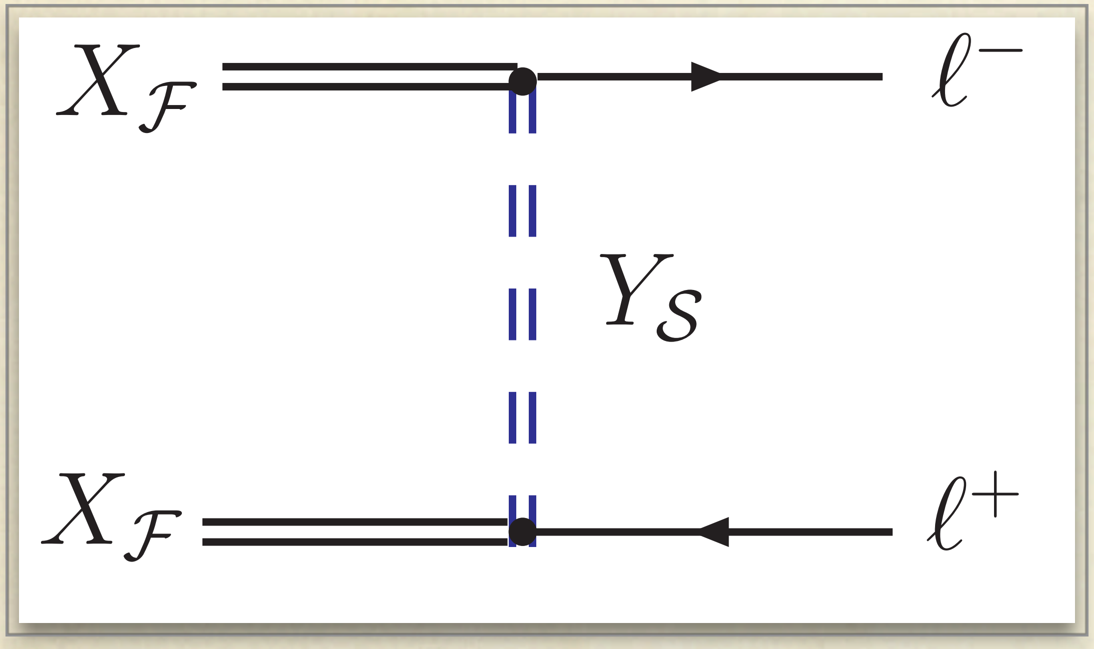
Lepto-philic Dark Matter Model



Lepto-philic Dark Matter Model



Lepto-philic Dark Matter Model



$$(\nu\eta^0 - \ell\eta^+)\chi + h.c.$$

$$\mathcal{F} = \chi \quad \mathcal{S} = \eta$$

(1) Lepton number conservation

Majorana $L_{\mathcal{F}} = 0, L_{\mathcal{S}} = 1$

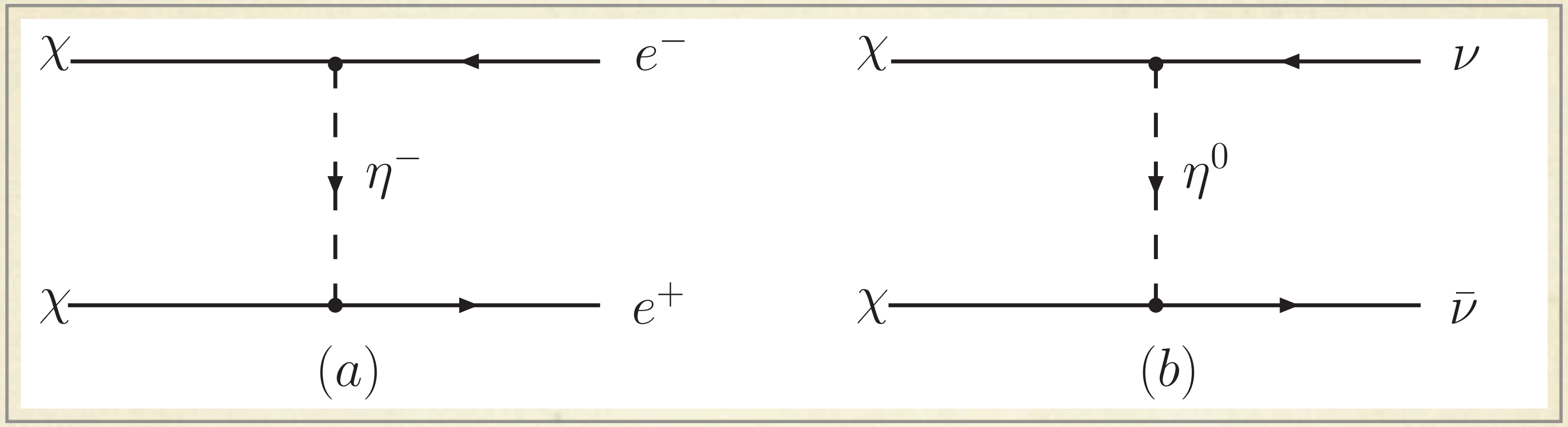
Dirac $L_{\mathcal{F}} = 2, L_{\mathcal{S}} = 1$

$$R = (-)^{L+2S}$$

(2) Additional Z2 symmetry

Dirac $L_{\mathcal{F}} = 1, L_{\mathcal{S}} = 0$

DM annihilation in the LDM



$$\langle \sigma v \rangle \approx a + b v^2 + \cdots$$

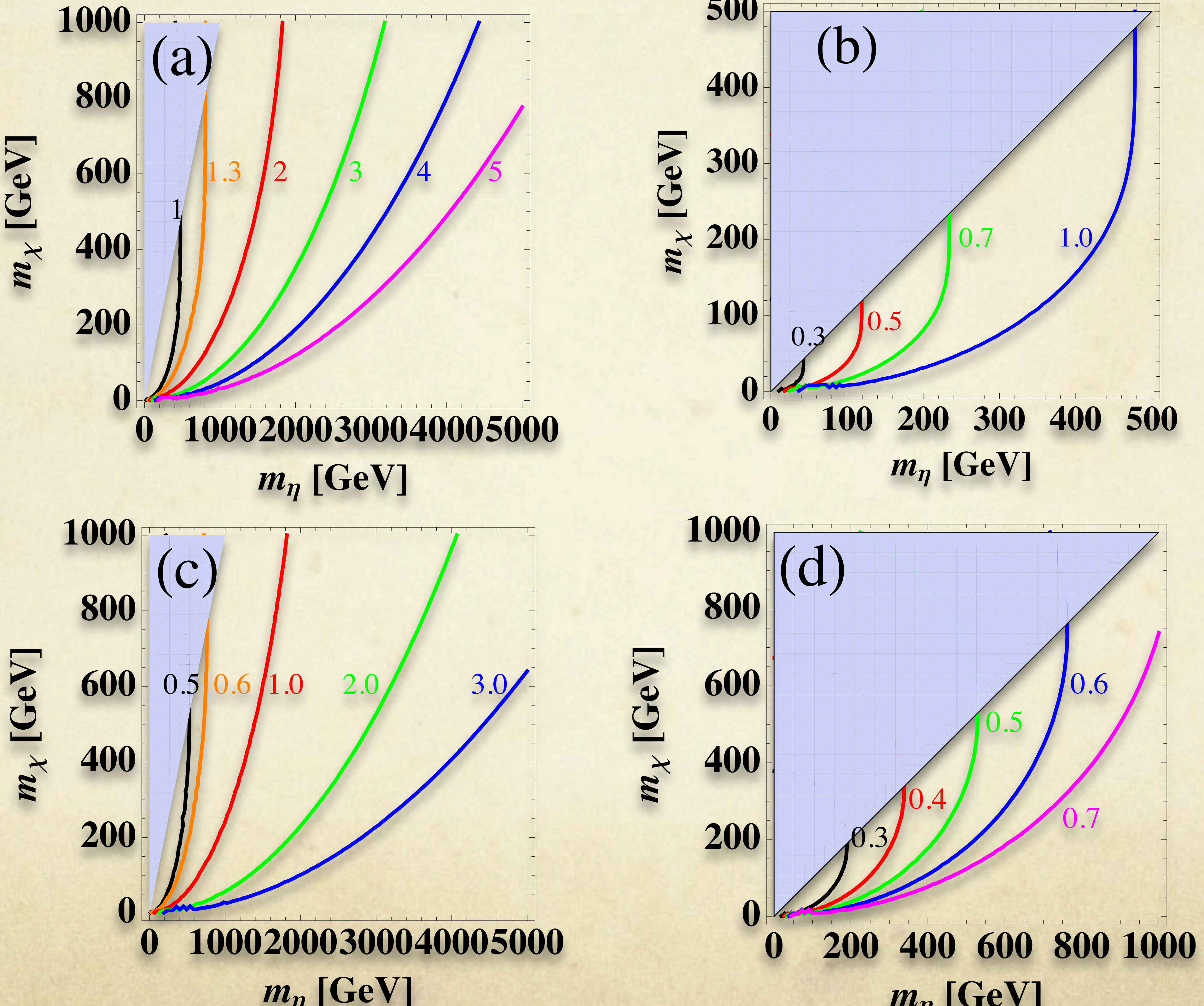
Majorana DM: (p-wave suppression)

$$a = 0, \qquad b = \frac{r_k^2 \left(1 - 2r_k + 2r_k^2\right)}{48\pi m_\chi^2}$$

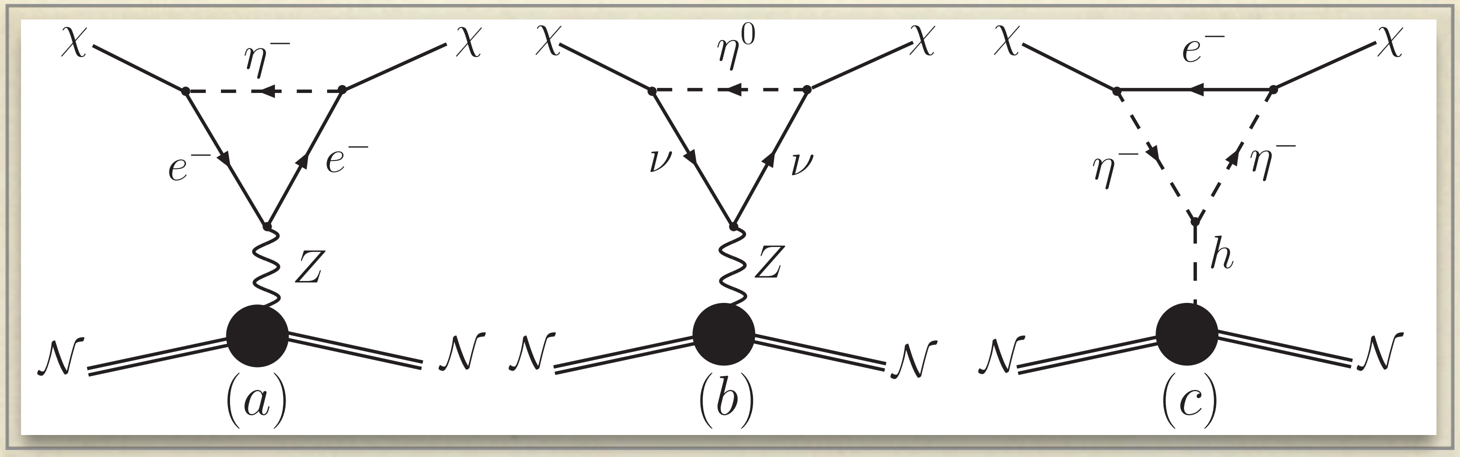
Dirac DM:

$$a = \frac{\lambda_k^4 r_k^2}{32\pi m_\chi^2}, \qquad b = \frac{\lambda_k^4 r_k^2 \left(11 - 40 r_k + 24 r_k^2\right)}{768\pi m_\chi^2}$$

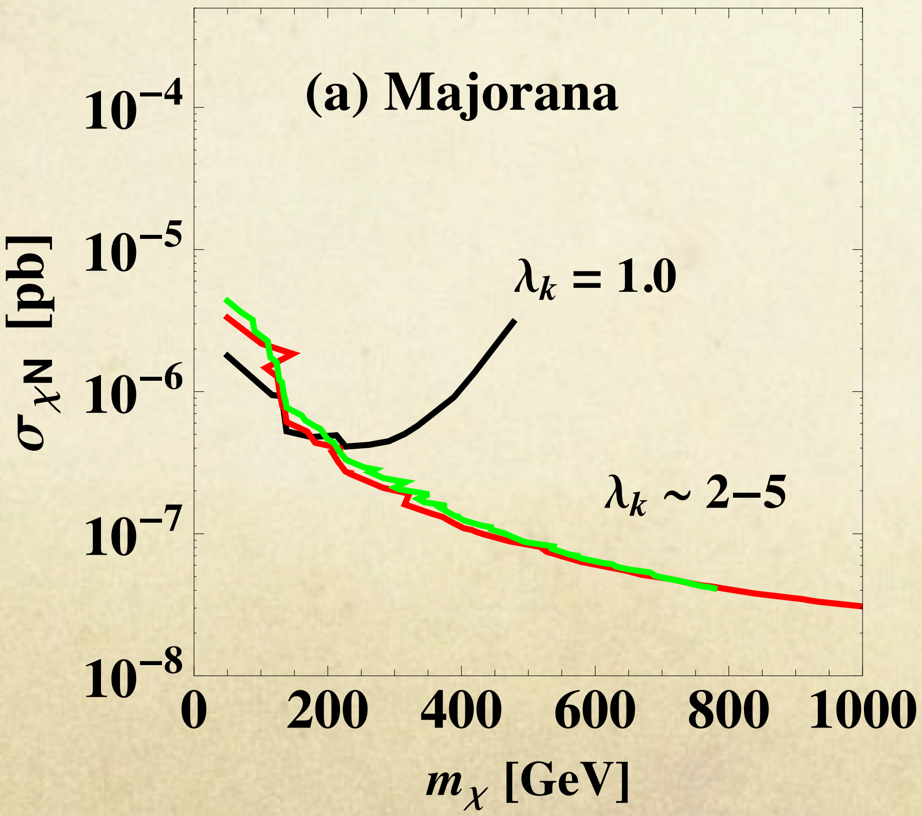
DM annihilation in the LDM

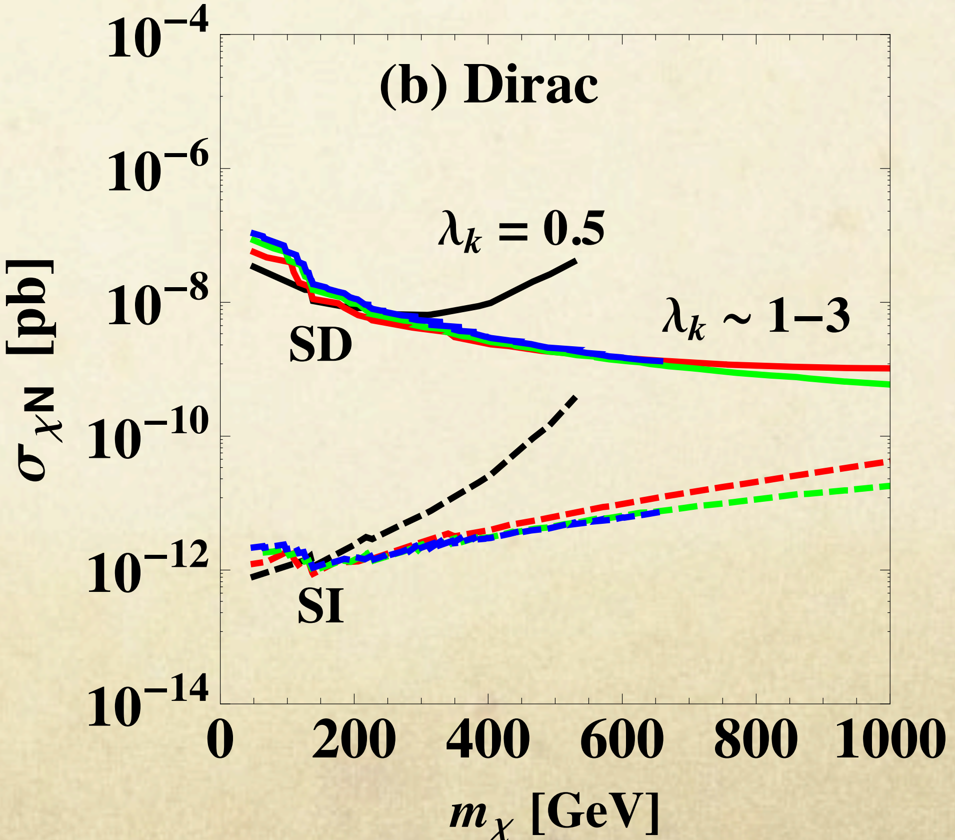


Direct detection

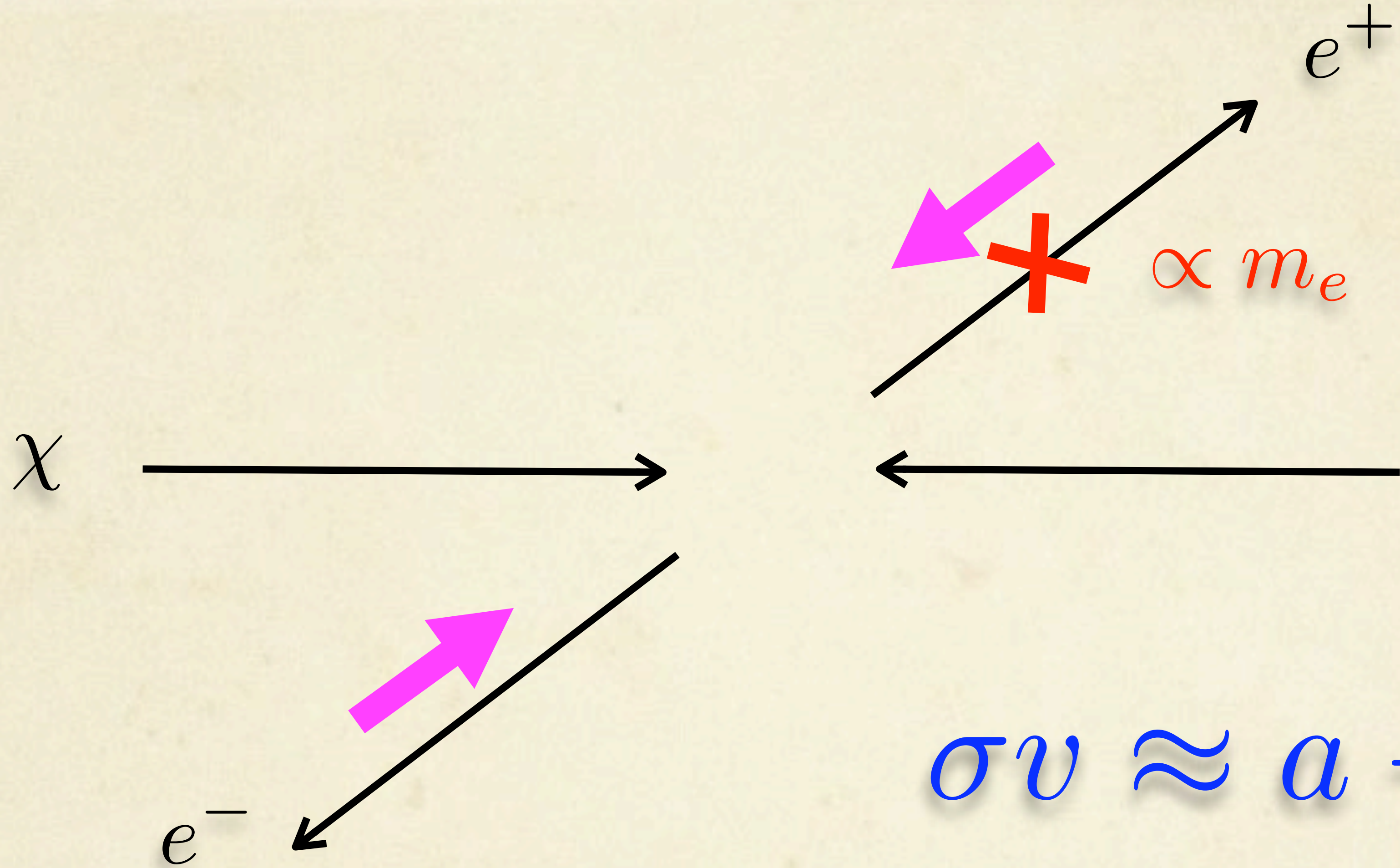


$$\mathcal{L}_{\chi\mathcal{N}} = \frac{\mathcal{G}_V}{m_Z^2}\chi\gamma^\mu\chi\bar{q}\gamma_\mu q + \frac{\mathcal{G}_A}{m_Z^2}\chi\gamma^\mu\gamma_5\chi\bar{q}\gamma_\mu\gamma_5 q$$





Majorana DM suffers from p-wave suppression

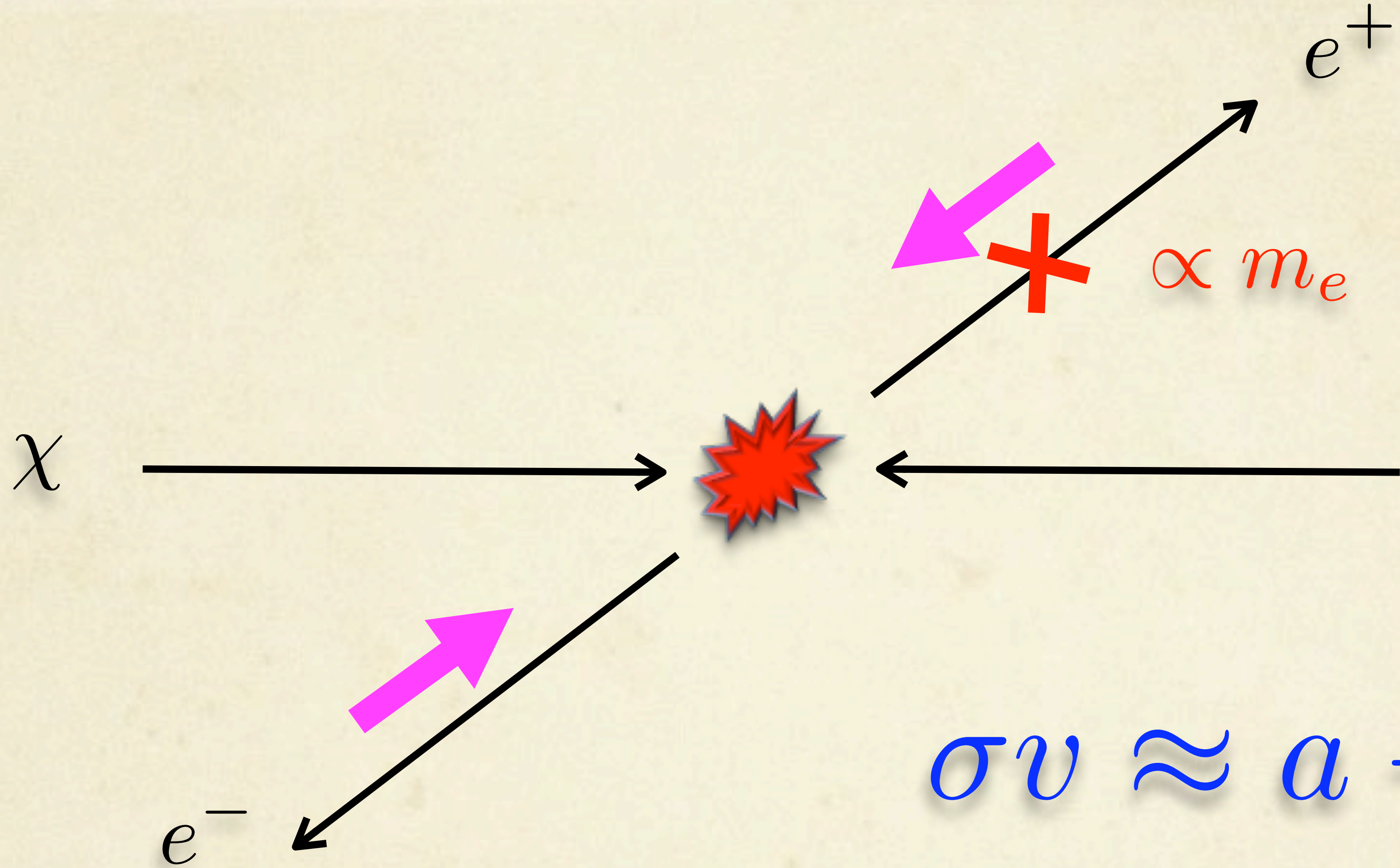


$$\sigma v \approx a + b v^2$$

(1) The s-wave amplitude highly suppressed by the tiny electron mass.

(2) The p-wave amplitude highly suppressed by the small relative velocity.

Majorana DM suffers from p-wave suppression

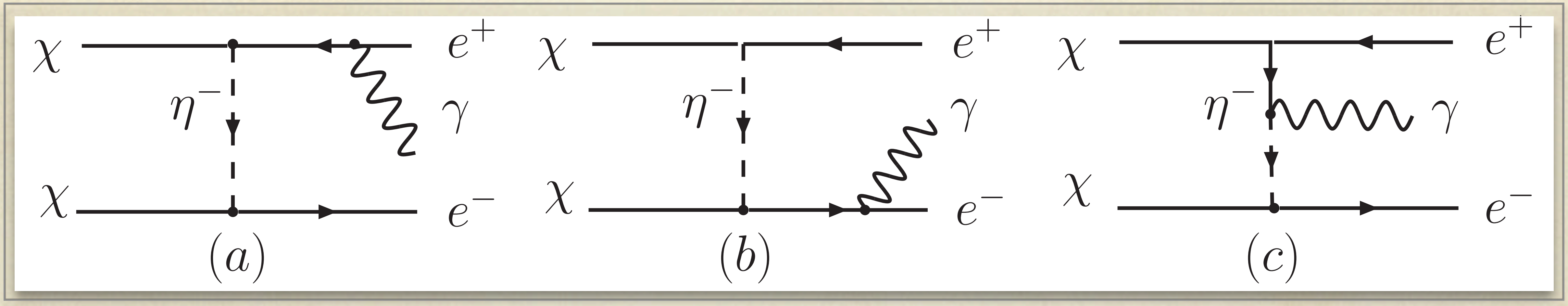


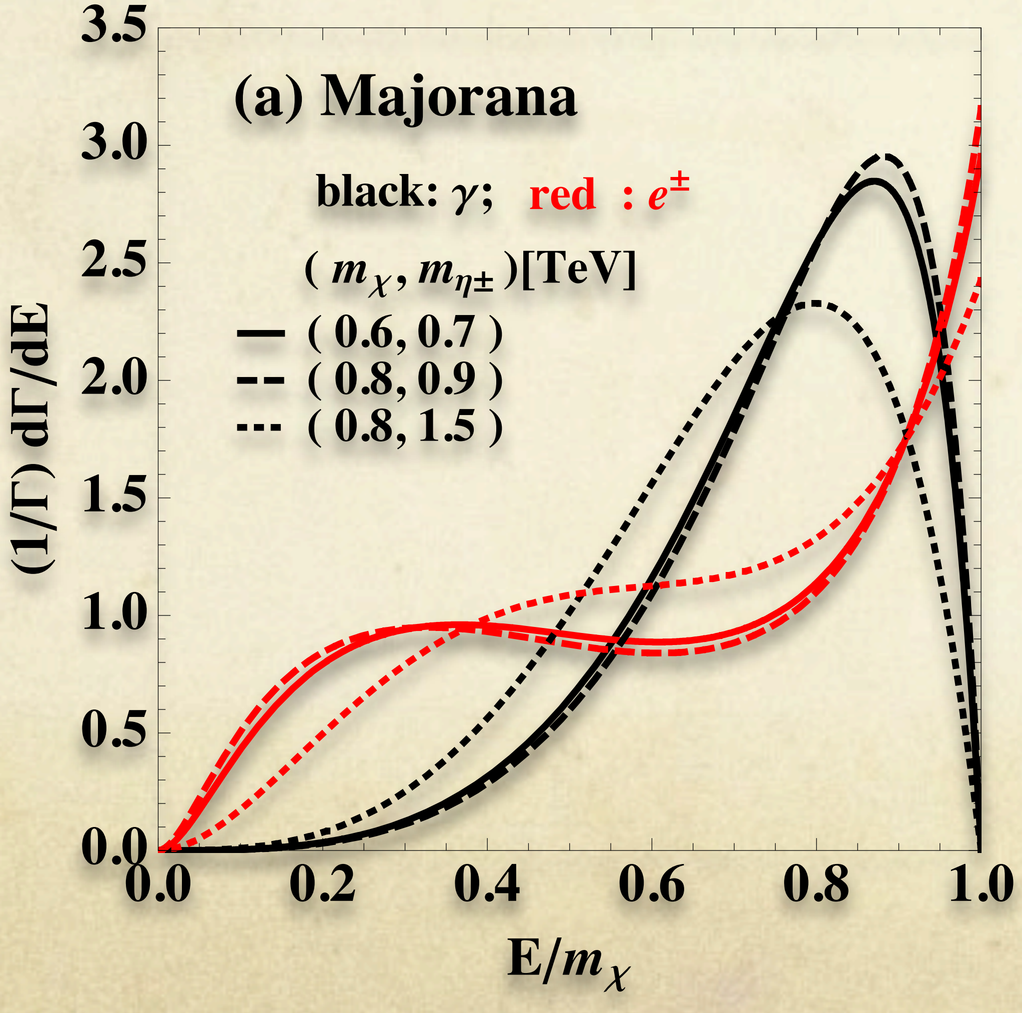
$$\sigma v \approx a + b v^2$$

(1) The s-wave amplitude highly suppressed by the tiny electron mass.

(2) The p-wave amplitude highly suppressed by the small relative velocity.

Positron and photon spectrum

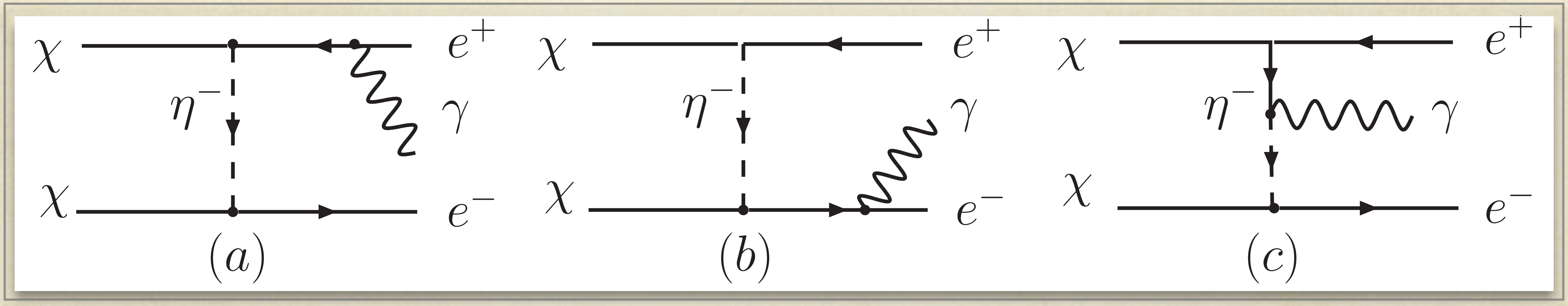


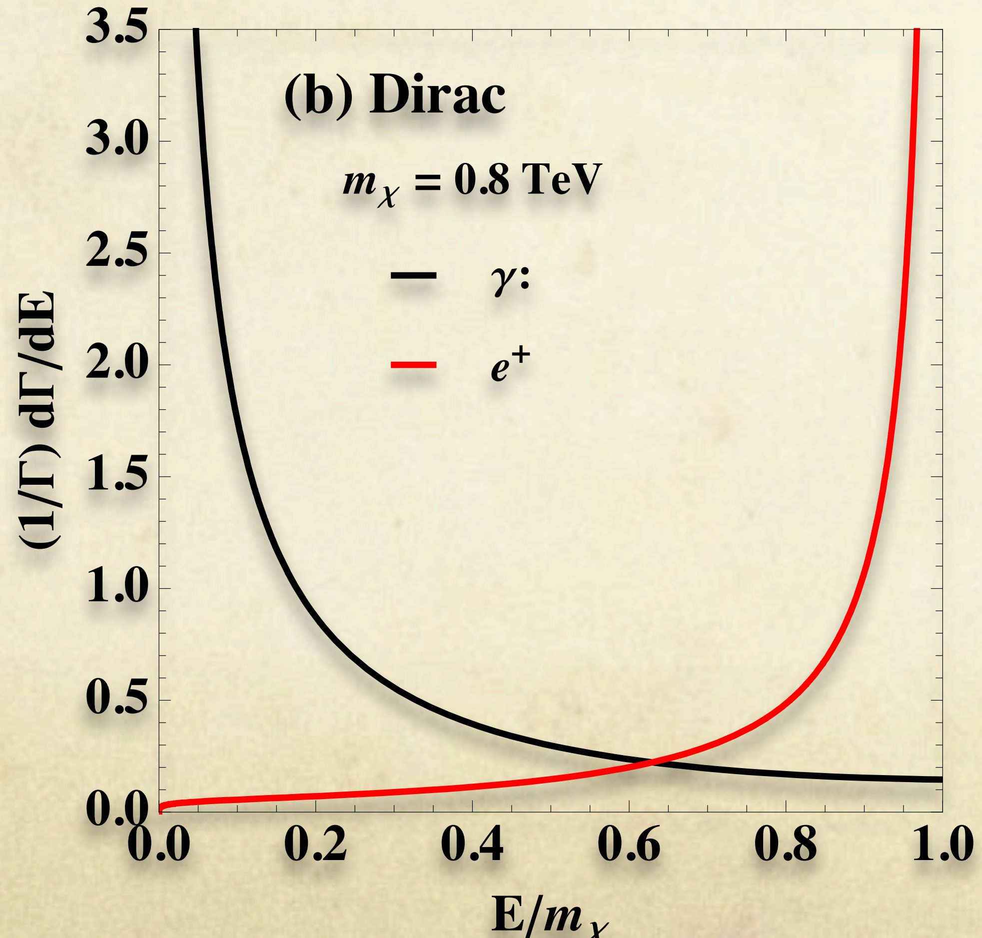


(1) Relatively soft positron

(2) Hard photon
Gamma-Ray detection

Positron and photon spectrum





(1) Hard positron

(2) Soft photon

Soft and collinear enhancement

Positron propagation through Halo

- Positron spectra at source propagates to Earth via diffusion-loss equation

$$\frac{\partial f}{\partial t} - K_0 E^\delta \nabla^2 - \frac{\partial}{\partial E}\left(\frac{f E^2}{\tau_E}\right) = \frac{1}{2}\frac{\rho^2}{M_{DM}^2} f_{inj} \qquad f = \frac{dN_{e^+}}{dE}$$

  – Positron flux at Earth

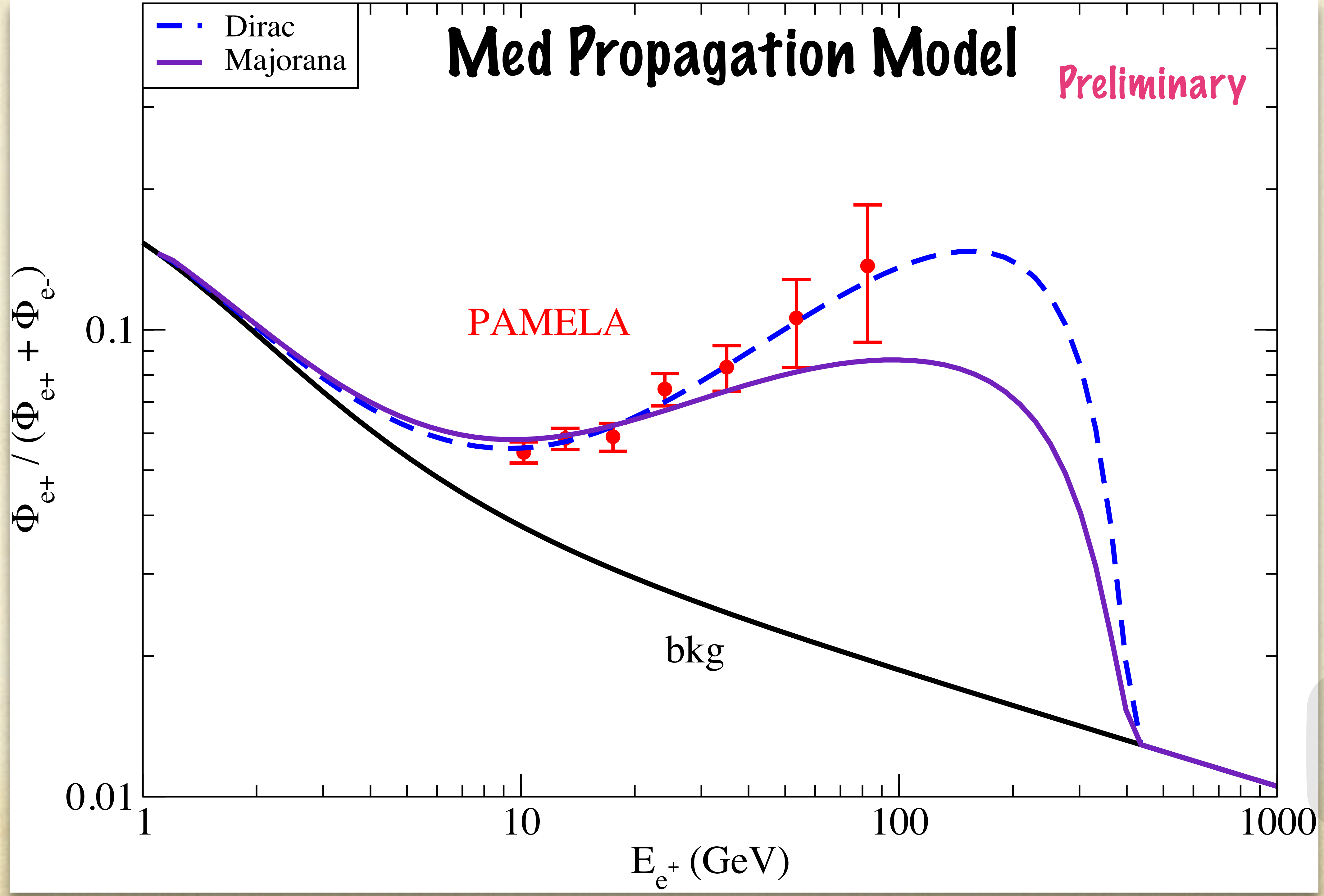
Cirelli, Franceshini, Stumia

$$\Phi_{e^+}(E, \vec{r}_\odot) = B \frac{v_{e^+}}{4\pi b(E)} \frac{1}{2}\left(\frac{\rho_\odot}{M_{\rm DM}}\right)^2 \int_E^{M_{\rm DM}} dE' \; f_{\rm inj}(E') \cdot I\left(\lambda_D(E, E')\right)$$

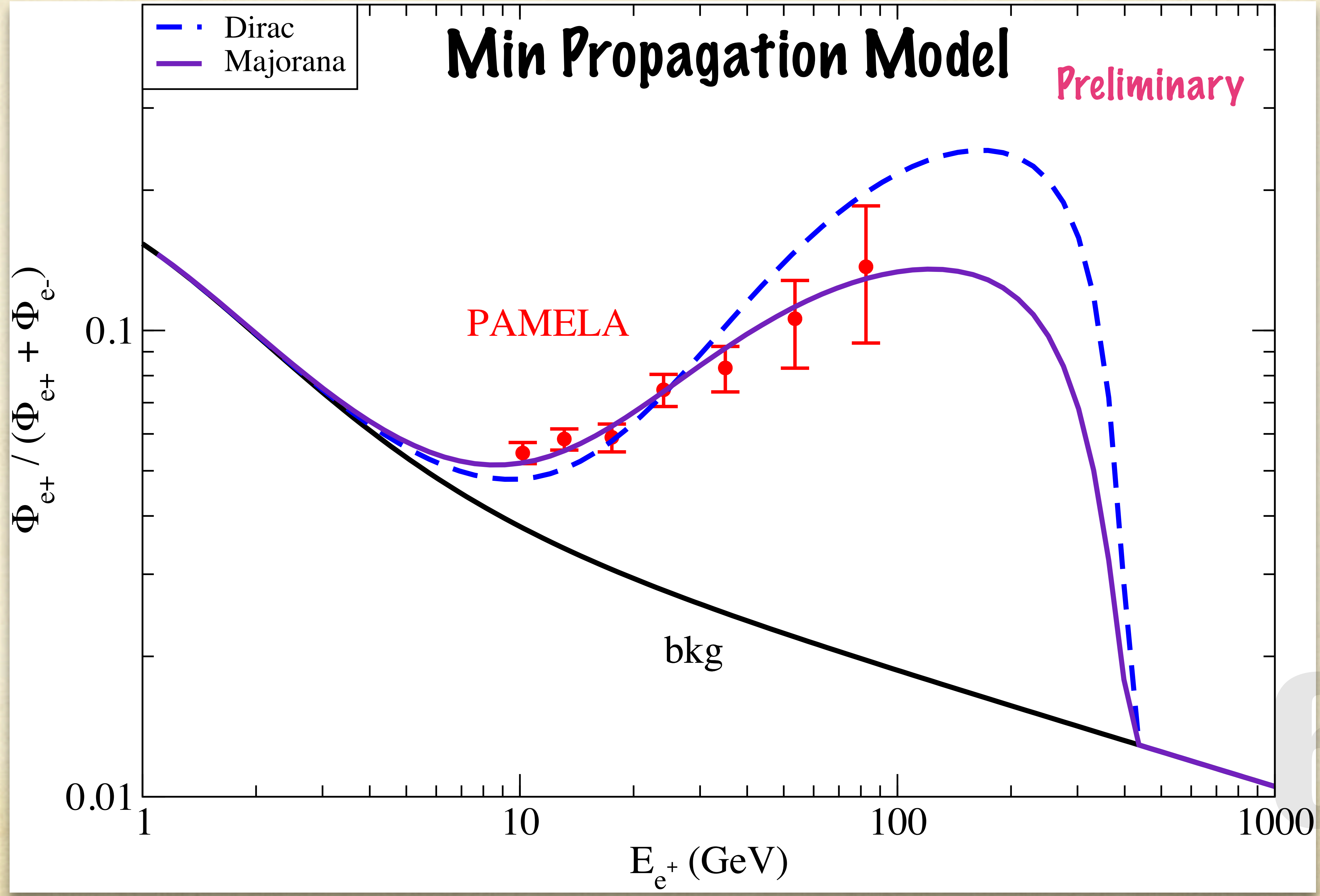
- Halo function $I(\lambda_D)$ describes propagation through galaxy and depends on Halo model and propagation parameters:

Model	δ	K_0 in kpc^2/Myr	L in kpc
min (M2)	0.55	0.00595	1
med	0.70	0.0112	4
max (M1)	0.46	0.0765	15

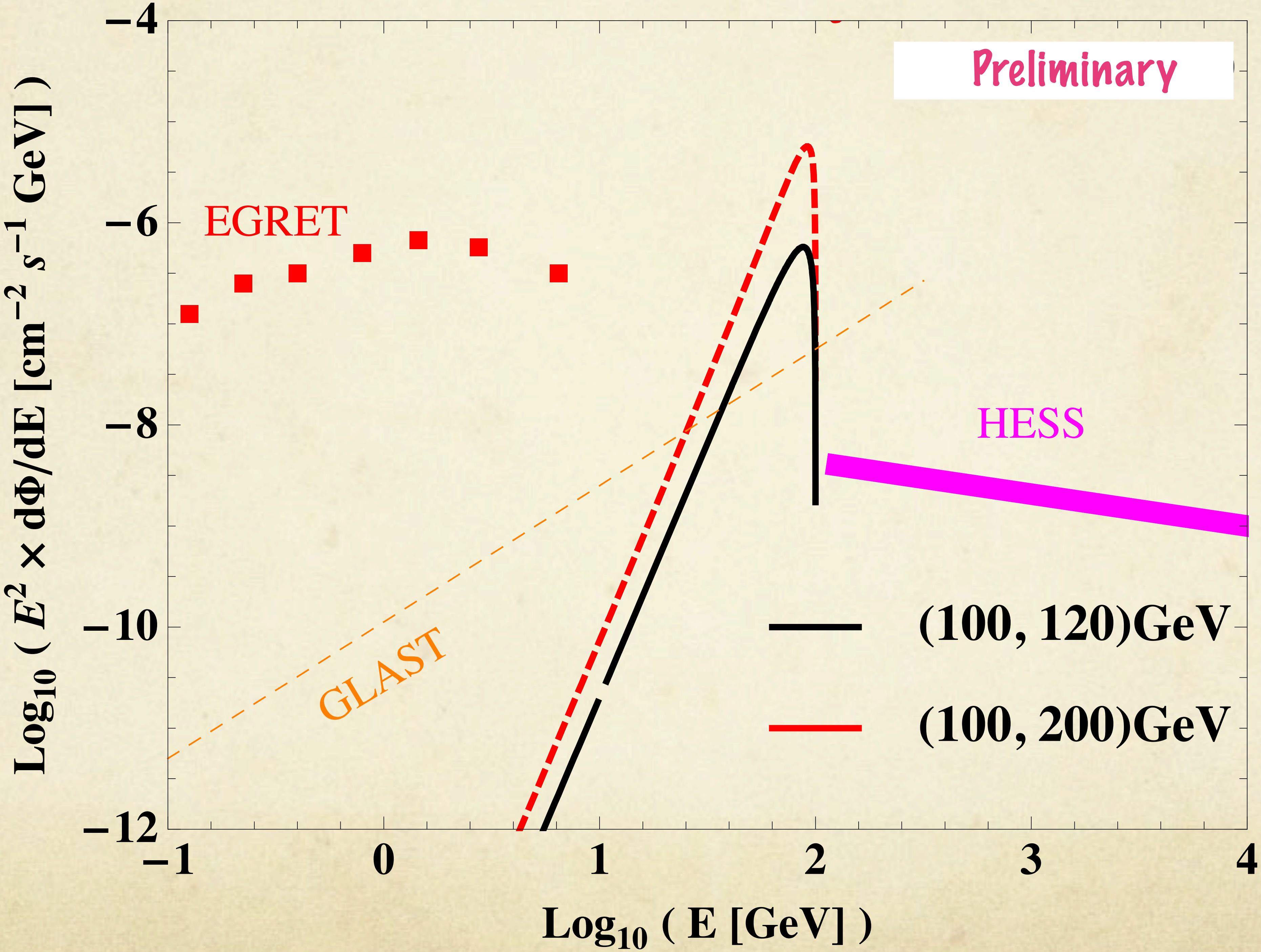
Positron and PAMELA data



Positron and PAMELA data



Gamma-Ray from Majorana Dark matter annihilation



Connection, why ?

PAMELA data