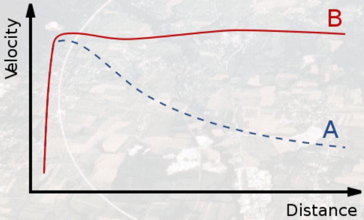
Search for New Physics in Z+MET channel at CMS

CMS-EXO-12-054

Michael Brodski on behalf of the CMS Collaboration

III. Physikalisches Institut A, RWTH Aachen University



SPONSORED BY THE Federal Ministry of Education and Research

III. Physikalisches Institut A

RWTH AACHEN UNIVERSITY

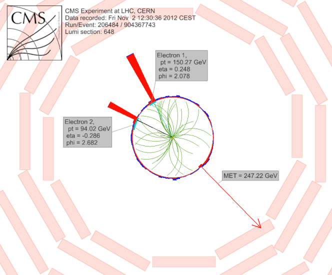
LHC ski 2016

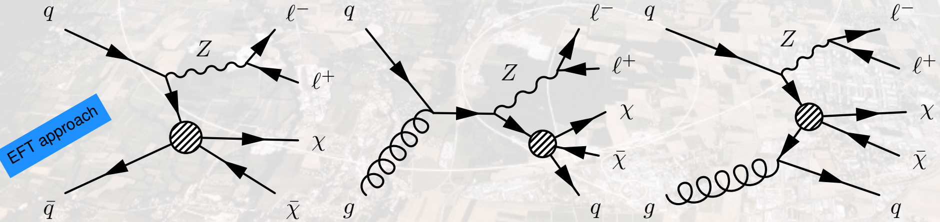
A first discussion of 13 TeV results

April 10-15, 2016, Obergurgl University Center, Tirol, Austria

Z boson decays into a lepton pair along undetectable particles

- clean dielectron signature in the ECAL
- clean dimuon lepton signature in the muon chambers
- kinematic cuts for best signal extraction, veto on b jets

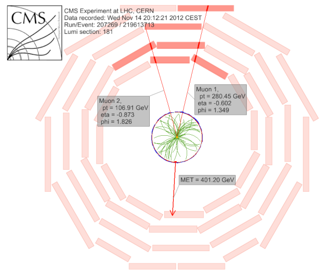


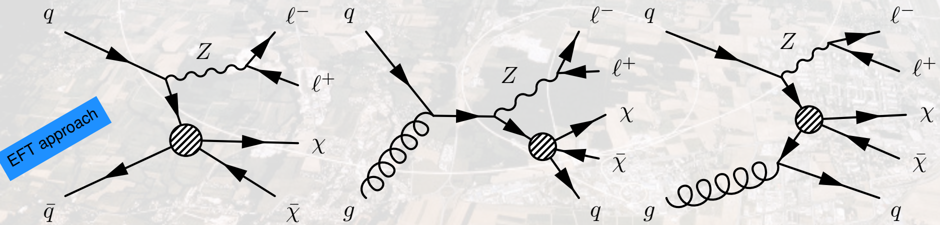


10.1103/PhysRevD.93.052011

Z boson decays into a lepton pair along undetectable particles

- clean dielectron signature in the ECAL
- clean dimuon lepton signature in the muon chambers
- kinematic cuts for best signal extraction, veto on b jets





10.1103/PhysRevD.93.052011

Lepton Selection

http://www.particlezoo.net/

- Exactly two leptons are required

Cuts

- $p_{T_l} > 20\,\mathrm{GeV}; 20\,\mathrm{GeV}$
- $|\eta| < 2.4(2.5)$

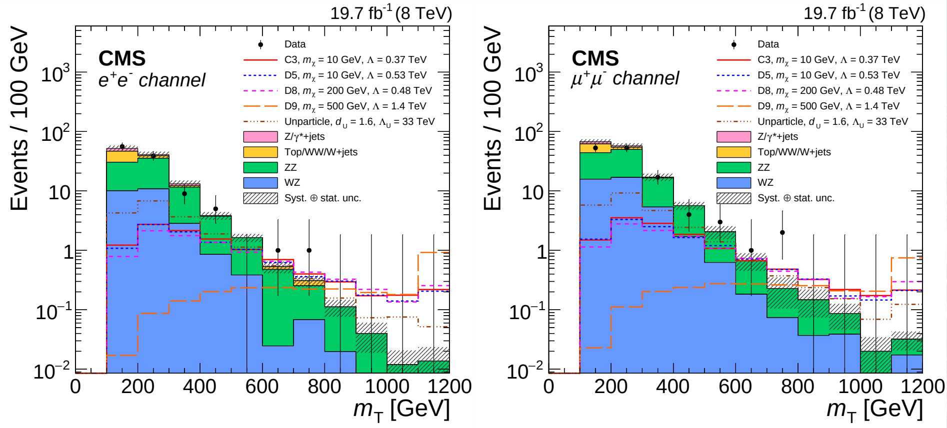
Object selection

- Isolation requirement
- Muon ID
- Electron ID

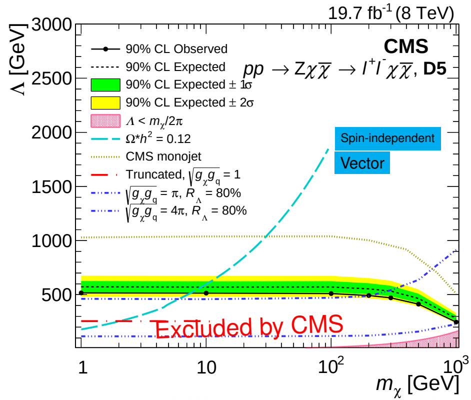
Event selection

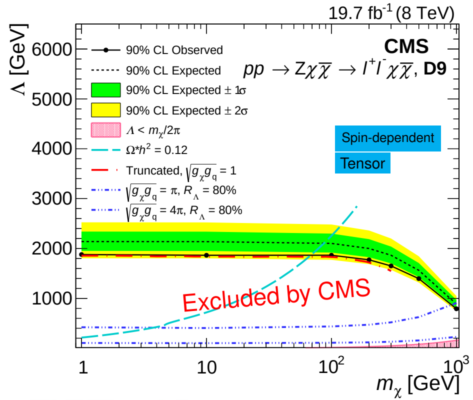
- $|M_Z - M_{ll}| < 10\,\mathrm{GeV}$
- Veto on any third lepton
- Veto on >1 jet with $p_T > 30\mathrm{GeV}$
- Cut on balance ll and MET
- Cut on angle ll and MET
- Veto on b-jets

Leading ZZ and WZ backgrounds estimated from Monte-Carlo. $\mathrm{W^+W^-}$, Top, Z backgrounds estimated from data.



Transverse mass calculated from the lepton pair and $E_{\mathrm{T}}^{\mathrm{miss}}$ agrees with the Standard Model prediction



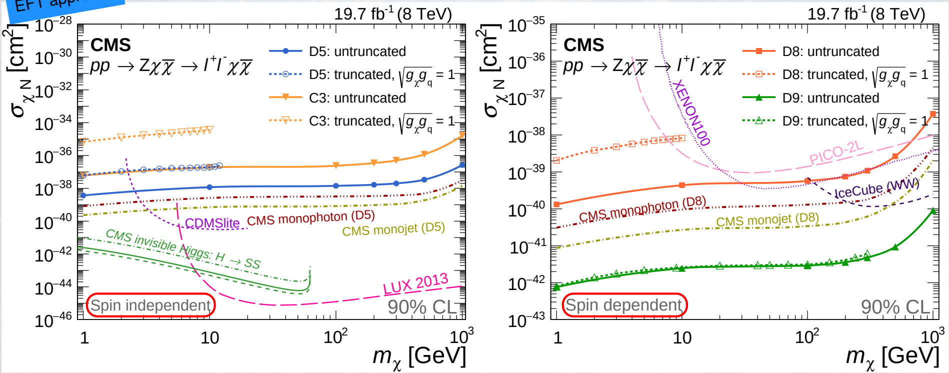


Limits on EFT parameter Λ calculated combined for both channels

$$\Lambda_{\text{obs}}^4 = \frac{\sigma_{\text{calc}} \cdot \Lambda_{\text{calc}}^4}{\sigma_{\text{obs}}}$$

Limits on the nucleon cross section set for four different coupling types

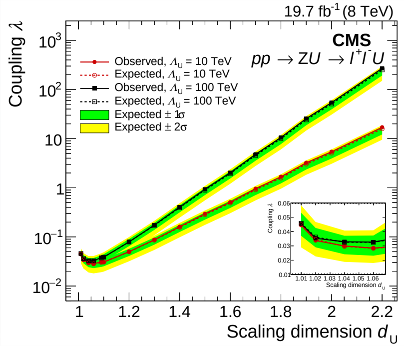
EFT approach

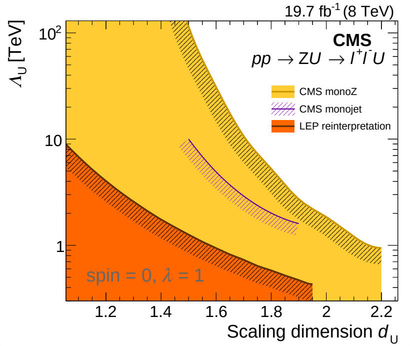


LUX stronger for higher masses with spin independent couplings

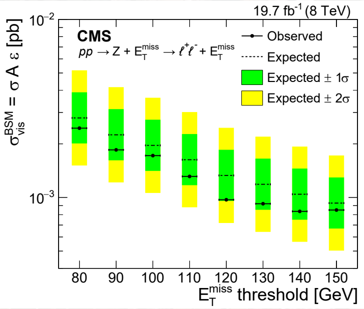
Very strong limits for tensor coupling

Expect to improve the truncated limits with the Simplified Model approach in Run II





Limits set for unparticle interpretation as well as for a model independent approach!



Summary and Outlook

- All-round Z+MET search for New Physics performed with Run 1 data – first of its kind for Dark Matter at CMS!
- Set strong limits for different New Physics scenarios
- Run 2 analysis in advanced progress (more (sophisticated) interpretations – Simplified Models, EWK Dark Matter, ADD)

CMS
Compact Muon Solenoid

CERN

SPONSORED BY THE
Federal Ministry of Education and Research

LHC ski 2016

A first discussion of 13 TeV results
April 10-15, 2016, Obergurgl University Center, Tirol, Austria

Summary and Outlook

- All-round Z+MET search for New Physics p rformed with Run 1 data – first of its kind for Dark Matter s
- Set strong limits for different Ne scenarios
- Run 2 analysis in advanc s (more (sophisticated) interpretations – Sim els, EWK Dark Matter, ADD)

No hints for New Physics

Compact Muon Soleno

CERN

SPONSORED BY THE

Federal Ministry of Education and Research

LHC ski 2016

A first discussion of 13 TeV results

April 10-15, 2016, Obergurgl University Center, Tirol, Austria

Summary and Outlook

- All-round Z+MET search for New Physics p rformed with Run 1 data – first of its kind for Dark Matter s
- Set strong limits for different Ne scenarios
- Run 2 analysis in advanc (more (sophisticated) interpretations – Sim DD)

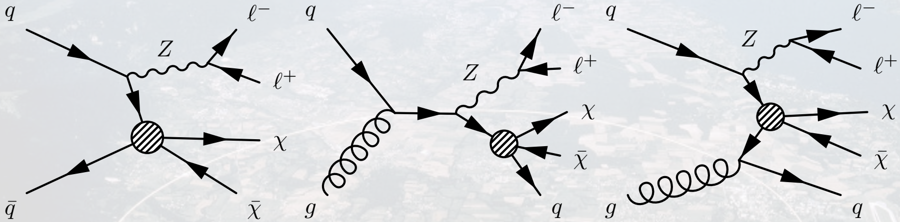
No hints for New Physics

LHC ski 2016

A first discussion of 13 TeV results
April 10-15, 2016, Obergurgl University Center, Tirol, Austria

BACKUP

Effective Field Theory



Vector coupling, Spin-independent (D5): $\frac{\bar{\chi}\gamma^{\mu}\chi\bar{q}\gamma_{\mu}q}{\Lambda^2}$

Axial-Vector coupling, Spin-dependent (D8): $\frac{\bar{\chi}\gamma^{\mu}\gamma^{5}\chi\bar{q}\gamma_{\mu}\gamma^{5}q}{\Lambda^2}$

Tensor coupling, Spin-dependent (D9): $\frac{\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q}{\Lambda^2}$

Vector coupling, Spin-independent (C3): $\frac{\chi^{\dagger}\overleftrightarrow{\partial}_{\mu}\chi\bar{q}\gamma^{\mu}q}{\Lambda^2}$

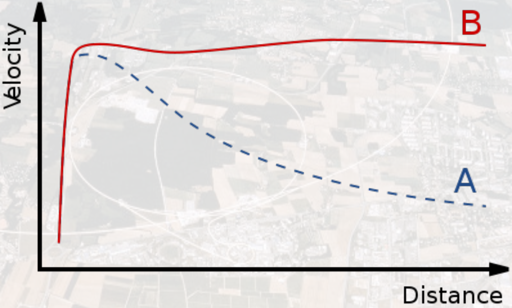
Very clean dilepton final state!

What is it?

- In the universe, there is more gravitation than can be explained by visible massive bodies
- The velocities of the stars in galaxies as a function of the distance to the center give us a hint that there is a lot more mass than we can see

Dark matter

- Not visible in the detector

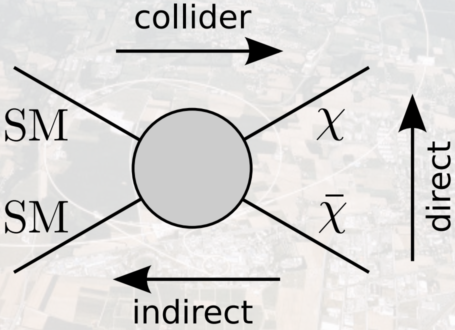


What is it?

- In the universe, there is more gravitation than can be explained by visible massive bodies
- The velocities of the stars in galaxies as a function of the distance to the center give us a hint that there is a lot more mass than we can see

Dark matter

- Not visible in the detector

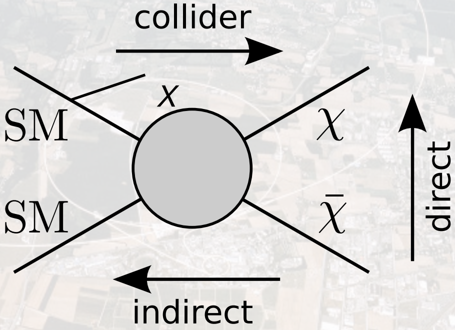


What is it?

- In the universe, there is more gravitation than can be explained by visible massive bodies
- The velocities of the stars in galaxies as a function of the distance to the center give us a hint that there is a lot more mass than we can see

Dark matter

- Not visible in the detector

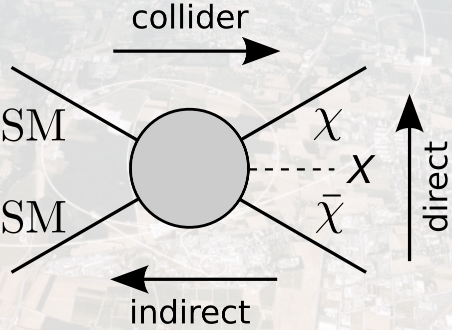


What is it?

- In the universe, there is more gravitation than can be explained by visible massive bodies
- The velocities of the stars in galaxies as a function of the distance to the center give us a hint that there is a lot more mass than we can see

Dark matter

- Not visible in the detector

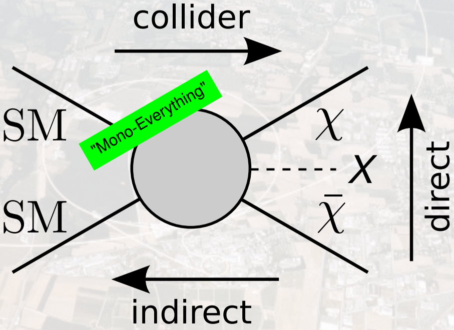


What is it?

- In the universe, there is more gravitation than can be explained by visible massive bodies
- The velocities of the stars in galaxies as a function of the distance to the center give us a hint that there is a lot more mass than we can see

Dark matter

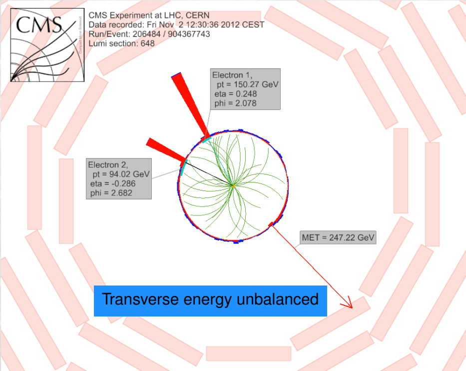
- Not visible in the detector



Assumptions about Dark Matter

Dark matter particle χ

- is a weakly interacting fermion (WIMP)
- has a mass between 1 GeV and up to 1 TeV
- is stable
- will not interact with the CMS detector $\rightarrow E_T^{miss}$



Interaction

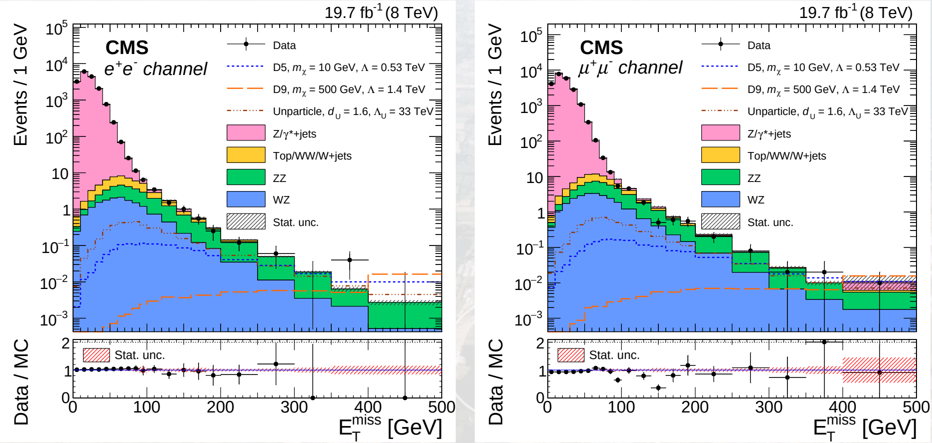
Historically divided in **spin independent** and **spin dependent** or scalar, vector etc. couplings

- Colloquial abbreviations used for different Dirac (D) fermionic couplings
- Complex scalar couplings (C) also considered

Selection

	Variable	Requirements
Preselection	p_T^ℓ	$>20\,\mathrm{GeV}$
	$\lvert m_{\ell\ell} - m_Z \rvert$	$<10\,\mathrm{GeV}$
	Jet counting	≤ 1 jets with $p_T^j > 30\,\mathrm{GeV}$
	$p_T^{\ell\ell}$	$>50\,\mathrm{GeV}$
	3rd-lepton veto	$p_T^{e,\mu} > 10\,\mathrm{GeV}$
	Top quark veto	veto on b jets and soft muon
Selection	$\lvert u_{\parallel} / p_T^{\ell\ell} \rvert$	<1
	$\Delta\phi_{\ell\ell, p_T^{miss}}$	> 2.7 rad
	$\lvert E_T^{miss} - p_T^{\ell\ell} \rvert / p_T^{\ell\ell}$	< 0.2
	E_T^{miss}	$>80\,\mathrm{GeV}$

Mono-Z



$E_{\mathrm{T}}^{\mathrm{miss}}$ at the preselection stage

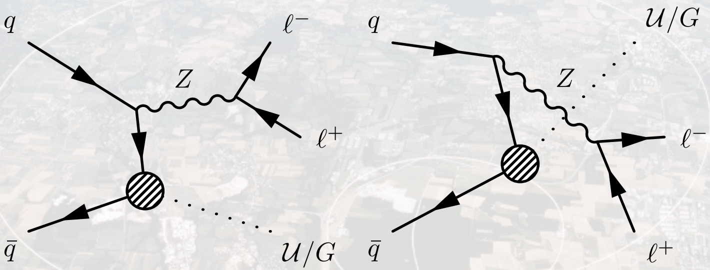
Mono-Z

Process	e^+e^-	$\mu^+\mu^-$
C3(10GeV)	$0.20 \pm 0.004 \pm 0.02$	$0.24 \pm 0.005 \pm 0.02$
D5(10GeV)	$0.79 \pm 0.02 \pm 0.09$	$0.97 \pm 0.02 \pm 0.09$
D8(200GeV)	$0.48 \pm 0.01 \pm 0.06$	$0.59 \pm 0.01 \pm 0.05$
D9(500GeV)	$10.24 \pm 0.12 \pm 1.59$	$10.80 \pm 0.13 \pm 0.98$
Unparticle(1.6)	$48.96 \pm 0.88 \pm 3.26$	$65.80 \pm 1.07 \pm 4.38$
$Z/\gamma^* \to \ell^+\ell^-$	$8.18 \pm 1.93 \pm 0.82$	$8.59 \pm 3.01 \pm 1.02$
$WZ \to 3\ell\nu$	$25.08 \pm 0.53 \pm 2.84$	$40.70 \pm 0.69 \pm 4.50$
$ZZ \to 2\ell 2\nu$	$58.81 \pm 0.65 \pm 10.30$	$78.68 \pm 0.79 \pm 13.83$
$\mathrm{Top}/W^+W^-/Z \to \tau^+\tau^-$	$18.74 \pm 3.39 \pm 3.27$	$22.92 \pm 2.29 \pm 3.44$
$W + \mathrm{jets}$	$1.84 \pm 0.64 \pm 0.27$	-
Total bkg.	$112.66 \pm 4.04 \pm 12.52$	$150.89 \pm 3.92 \pm 17.84$
Data	111	133

Mono-Z

Source	Background uncertainty(%)	Signal uncertainty(%)
PDF+α_S	5-6	8-20
Factorization/renormalization scale	7-8	5
Acceptance (ZZ)	14	-
Luminosity	2.6	2.6
Lepton trigger, reco & id, isolation	3	3
$Z/\gamma^* \to \ell^+\ell^-$ normalization	10-11	-
$t\bar{t}$, tW, WW normalization	15-17	-
$W+$jets normalization	15-23	-
MC statistics (Signal, ZZ, WZ)	1-2	1-2
Control region statistics ($Z/\gamma^* \to \ell^+\ell^-$)	25	-
Control region statistics ($t\bar{t}$, tW, WW)	18	-
Control region statistics ($W+$jets)	36	-
Pile up	0.5-1	0.1-0.7
b-jet tagging efficiency	0.4-1.4	0.6-1
Lepton momentum scale	0.4-0.5	0.1-1
Jet energy scale/resolution	5-7	3-5
Unclustered E_T^{miss} scale	1-2	1

- Unparticles might present themselves in the same final state $\Rightarrow$ interpret the search for Unparticle parameters!



$$\mathcal{L}_{\text{int}}^{\text{eff}} = C_{\mathcal{U}} \frac{\Lambda_{\mathcal{U}}^{d_{\mathcal{BZ}} - d_{\mathcal{U}}}}{M_{\mathcal{U}}^{k}} O_{\text{SM}} O_{\mathcal{U}} = \frac{\lambda}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}}} O_{\text{SM}} O_{\mathcal{U}},$$

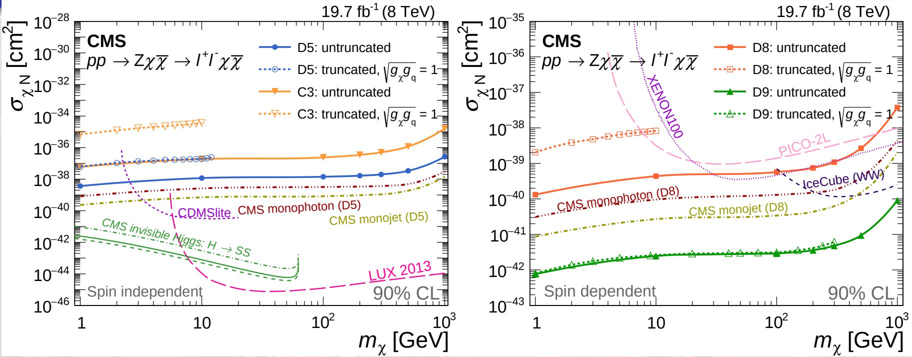
Truncation

EFT generally overestimates the signal prediction

1. Consider a tree-level simplified model from which follows: $\Lambda \sim \frac{M}{\sqrt{g_q g_\chi}}$
2. Introduce a momentum transfer Q_{tr} and demand
3. $Q_{\text{tr}} < M \sim \sqrt{g_q g_\chi}\Lambda$ whereby $\Lambda > \frac{m_\chi}{2\pi}$
4.
   1. Define
   $$R_\Lambda = \frac{\int_{p_T^{\min}}^{p_T^{\max}} \mathrm{d}p_T \int_{\eta^{\min}}^{\eta^{\max}} \mathrm{d}\eta \left.\frac{\mathrm{d}^2\sigma_{\text{eff}}}{\mathrm{d}p_T \mathrm{d}\eta}\right|_{Q_{\text{tr}} < \sqrt{g_q g_\chi}\Lambda}}{\int_{p_T^{\min}}^{p_T^{\max}} \mathrm{d}p_T \int_{\eta^{\min}}^{\eta^{\max}} \mathrm{d}\eta \frac{\mathrm{d}^2\sigma_{\text{eff}}}{\mathrm{d}p_T \mathrm{d}\eta}}$$
   and set it to a realistic value, e.g. 80%
   2. Manually remove events which do not satisfy $Q_{\text{tr}} > \sqrt{g_q g_\chi}\Lambda$

   for both options a choice of g_q and g_χ is necessary

Nucleon xsec – comparison



$$\sigma_0^{\mathrm{D8}} = \sum_q \frac{3\mu^2}{\pi\Lambda^4} \cdot \left(\Delta_q^N\right)^2$$

$$\sigma_0^{\mathrm{D5}} = \sum_q \frac{\mu^2}{\pi\Lambda^4} \cdot \left(f_q^N\right)^2$$

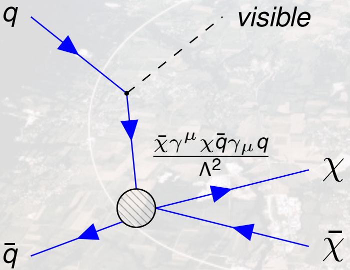
$$\sigma_0^{\mathrm{C3}} = \sum_q \frac{4\mu^2}{\pi\Lambda^4} \cdot \left(f_q^N\right)^2$$

where $\Lambda^4 = \Lambda_u^4 + \Lambda_d^4$ and μ stands for the reduced mass of the nucleon. Furthermore, Δ_q^N and f_q^N are characterising the nucleon structure (hereby, $f_u^p = f_d^n = 2$ and $f_d^p = f_u^n = 1$; $f = 0$ otherwise).
Δ is a spin dependent form factor with $\Delta_u^p = \Delta_d^n = 0.842 \pm 0.012$, $\Delta_d^p = \Delta_u^n = -0.427 \pm 0.013$ and $\Delta_s^p = \Delta_s^n = -0.085 \pm 0.018$ arxiv.1310.8327v2,arxiv.1310.8214v2

Two alternative Dark Matter models

Two possible interaction models for dark matter to the Standard Model

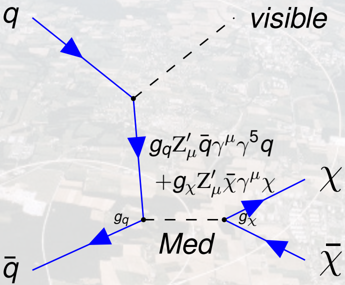
Model the interaction with an Effective Field Theory (EFT)



Allows for more model-independence

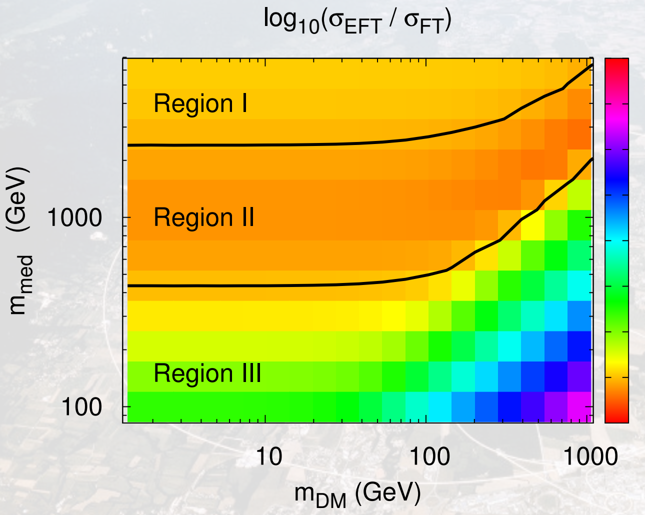
$\{m_\chi, \Lambda\}$

Assume a heavy mediator



Allows for more precise simulation

$\{g_q, g_\chi, m_\chi, M_{\text{med}}\}$



In Region I both theories **agree**

In Region II EFT **underestimates** the cross section

In Region III EFT **overestimates** the cross section

The difference betweet EFT and mediator models is studied

arxiv:1308.6799