Institute for Theoretical Particle Physics and Cosmology | RWTH AACHEN UNIVERSITY

CRC meeting KIT, March 2019

B3a: Dark sectors at the LHC

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The team

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Felix Kahlhoefer

Michael Krämer

Alexander Mück

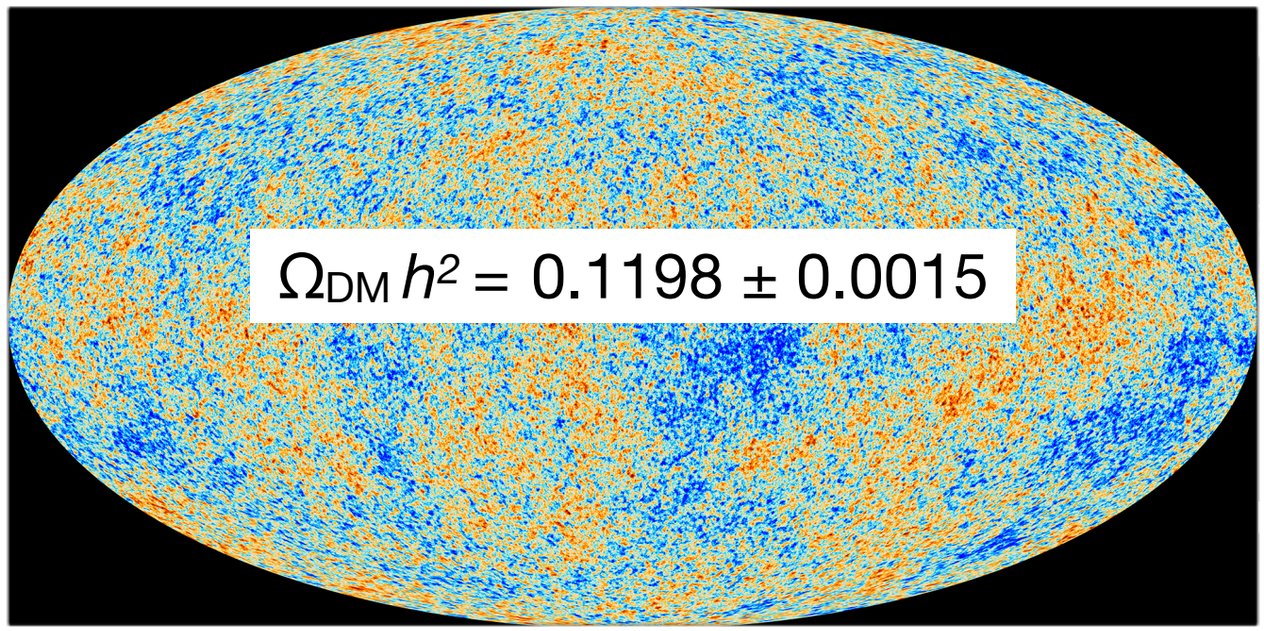
Tilman Plehn

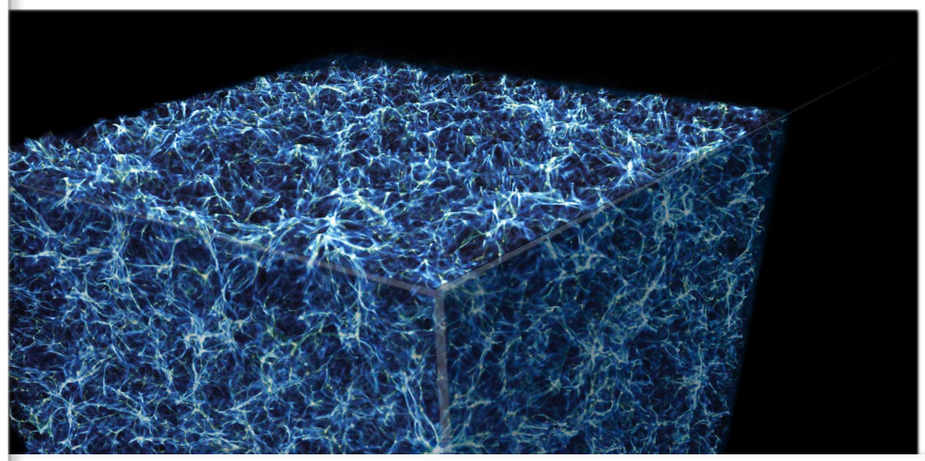
Peter Reimitz

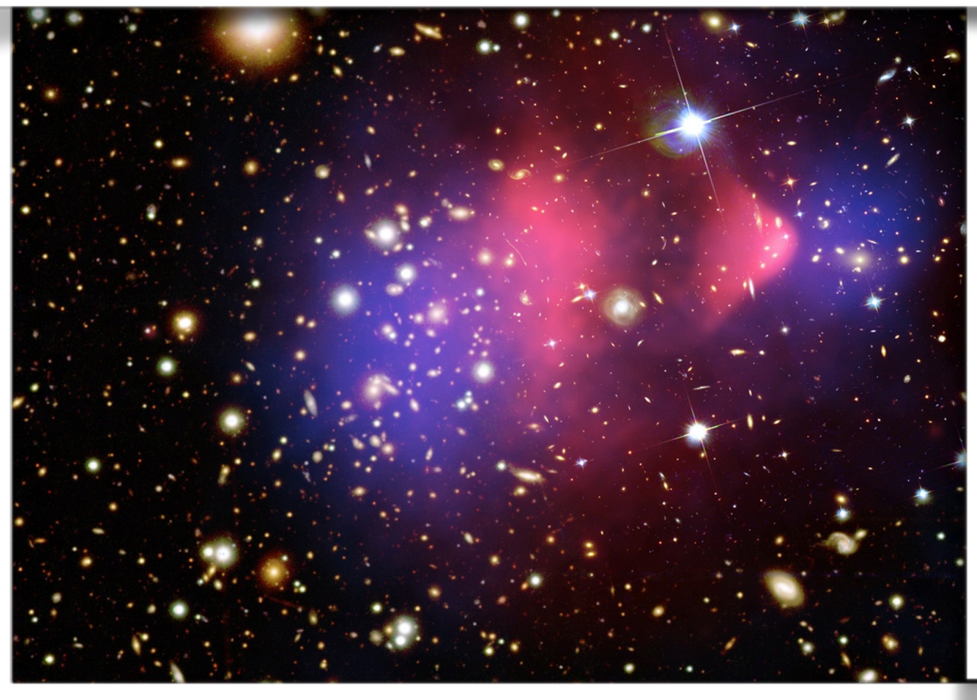
Patrick Tunney

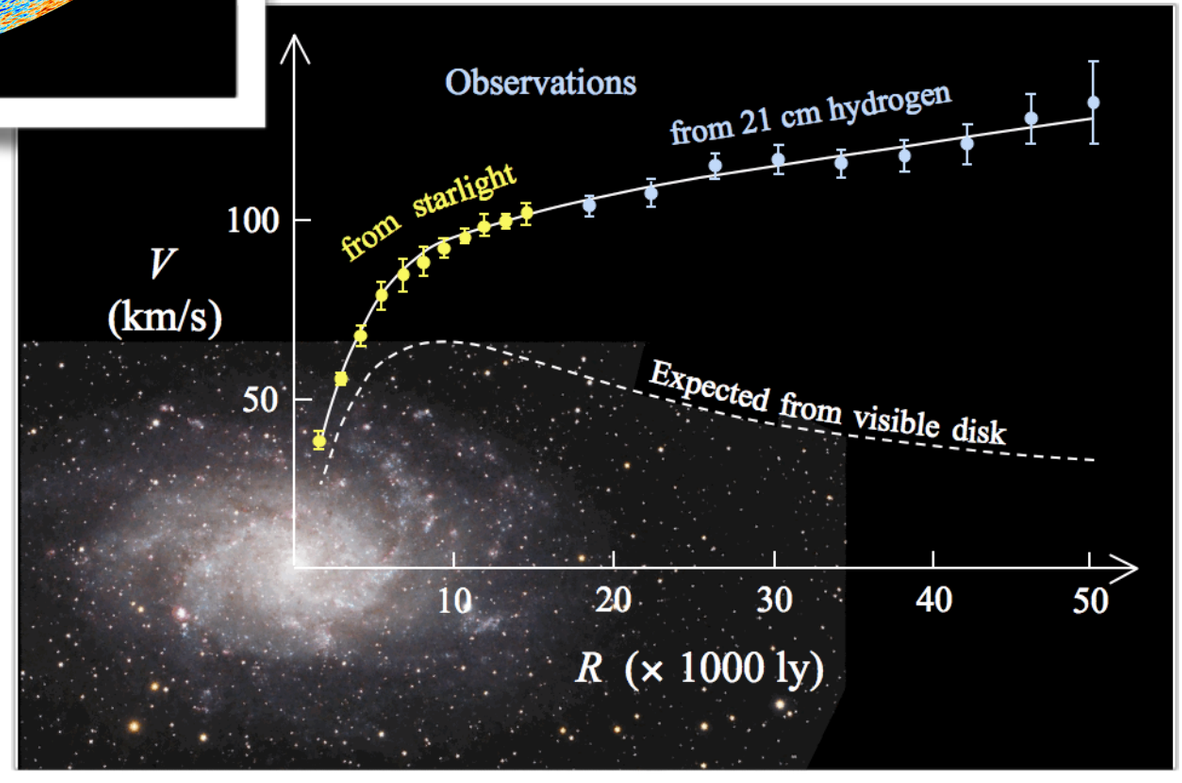
Susanne Westhoff

Dark matter

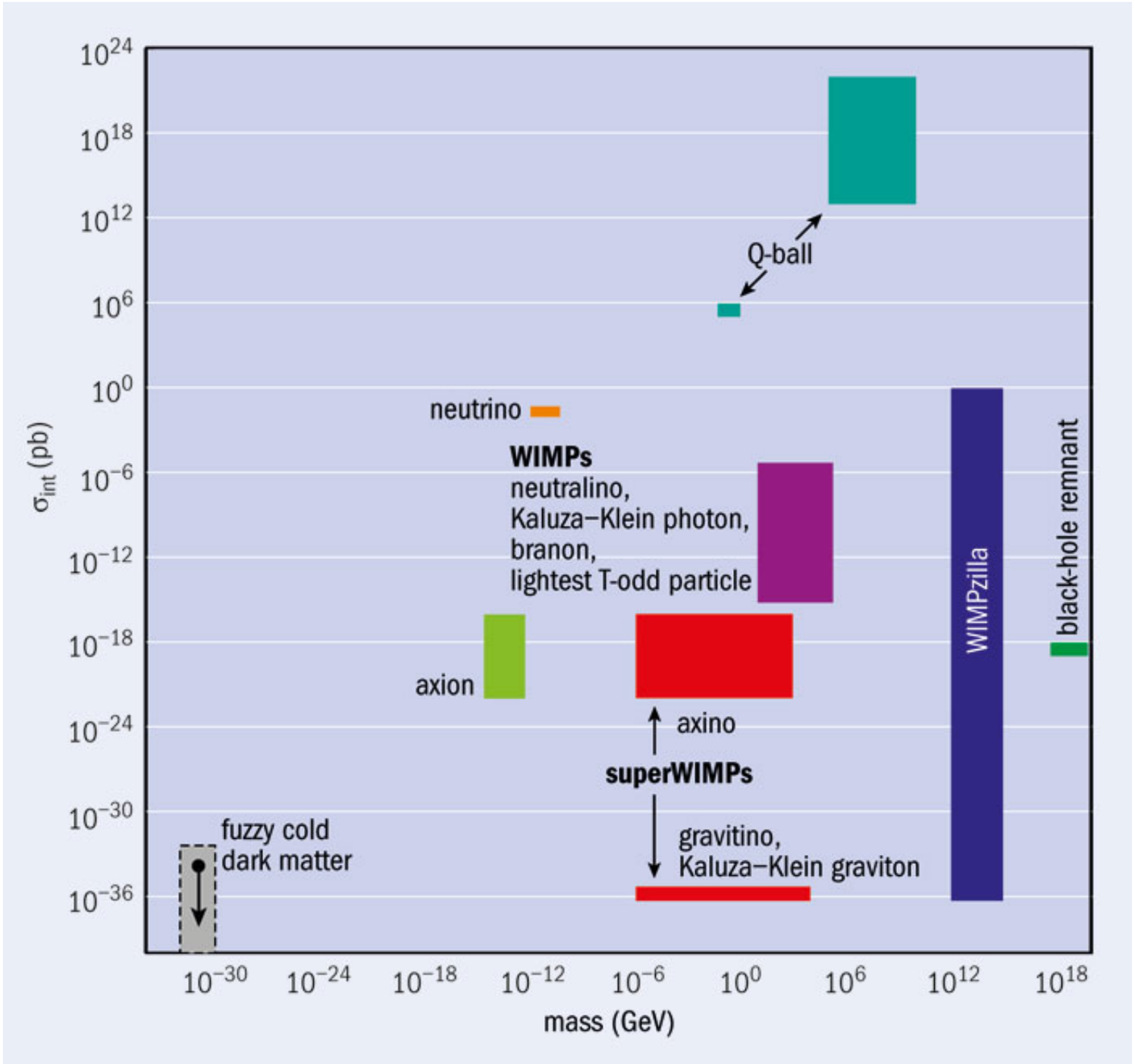

$\Omega_{DM}\, h^2 = 0.1198 \pm 0.0015$



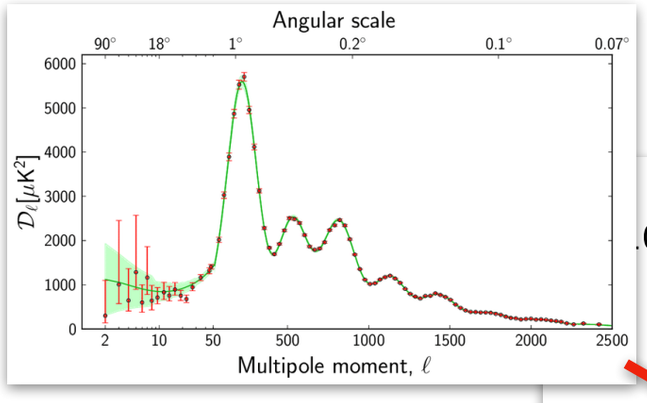


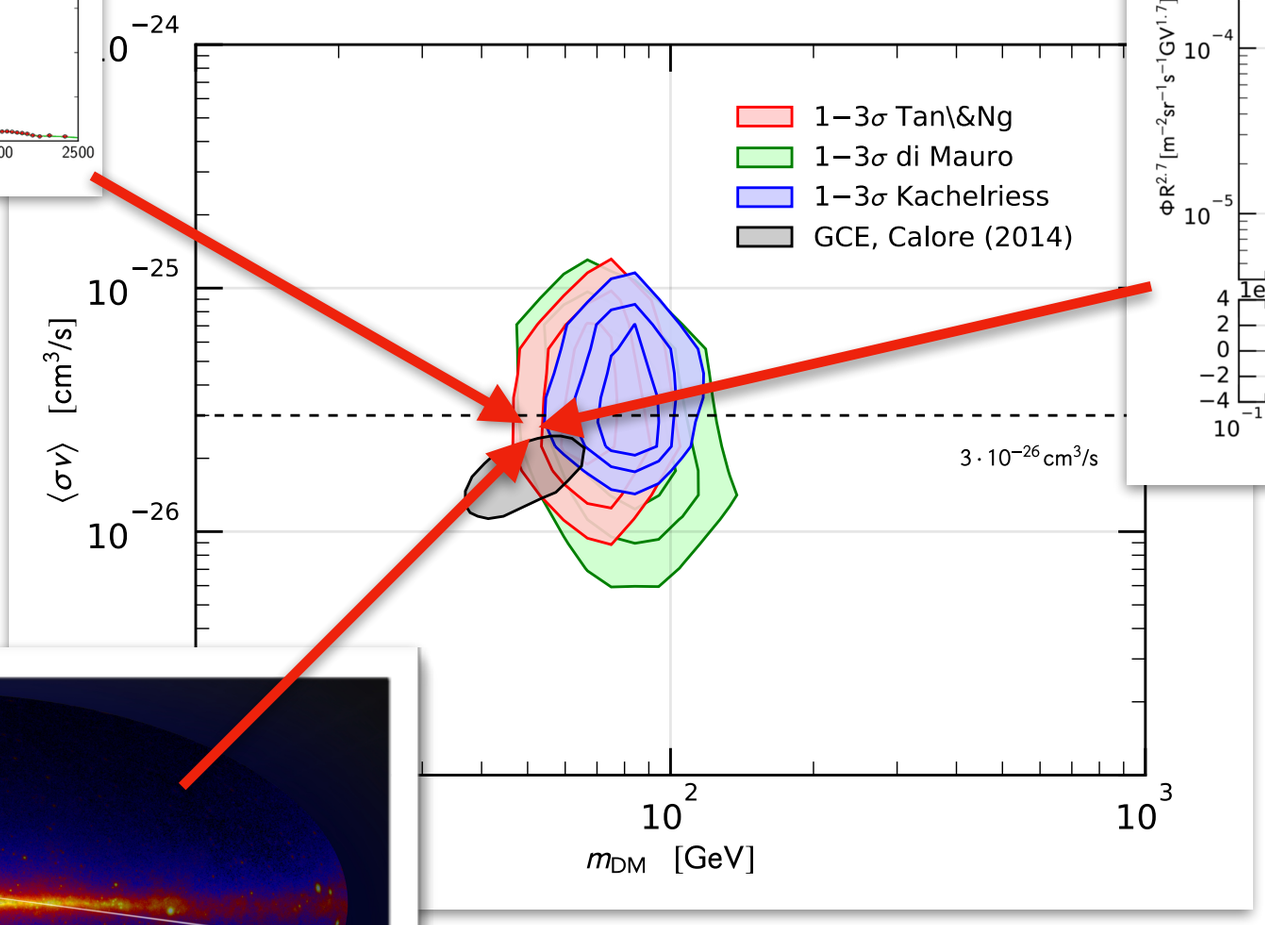

Observations
from 21 cm hydrogen
from starlight
100
50
V
(km/s)
Expected from visible disk
10
20
30
40
50
R (× 1000 ly)

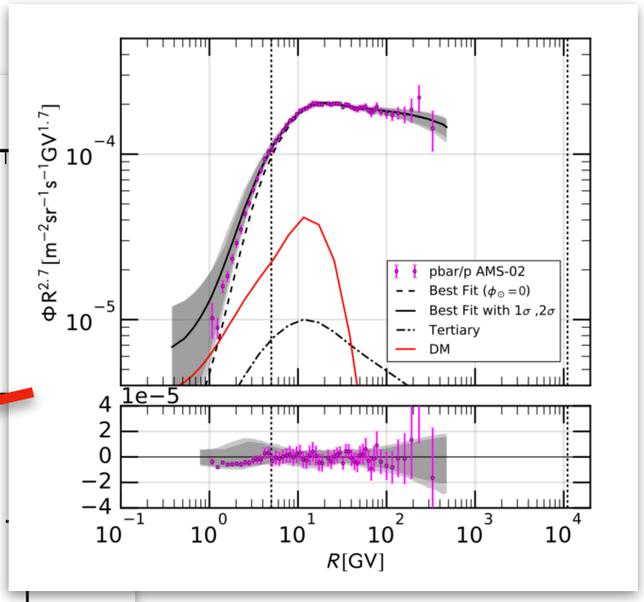
Dark matter

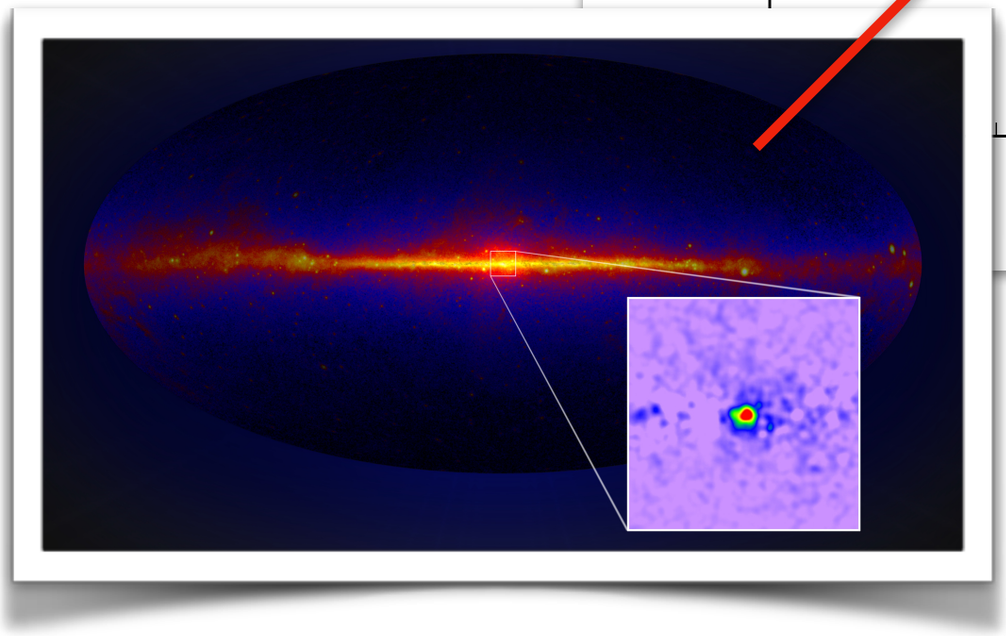

10^{24}
10^{18}
10^{12}
10^{6}
10^{0}
10^{-6}
10^{-12}
10^{-18}
10^{-24}
10^{-30}
10^{-36}
σ_{int} (pb)
Q-ball
neutrino
WIMPs
neutralino,
Kaluza–Klein photon,
branon,
lightest T-odd particle
axion
axino
superWIMPs
gravitino,
Kaluza–Klein graviton
fuzzy cold
dark matter
WIMPzilla
black-hole remnant
10^{-30} 10^{-24} 10^{-18} 10^{-12} 10^{-6} 10^{0} 10^{6} 10^{12} 10^{18}
mass (GeV)

Anomalies in astrophysics



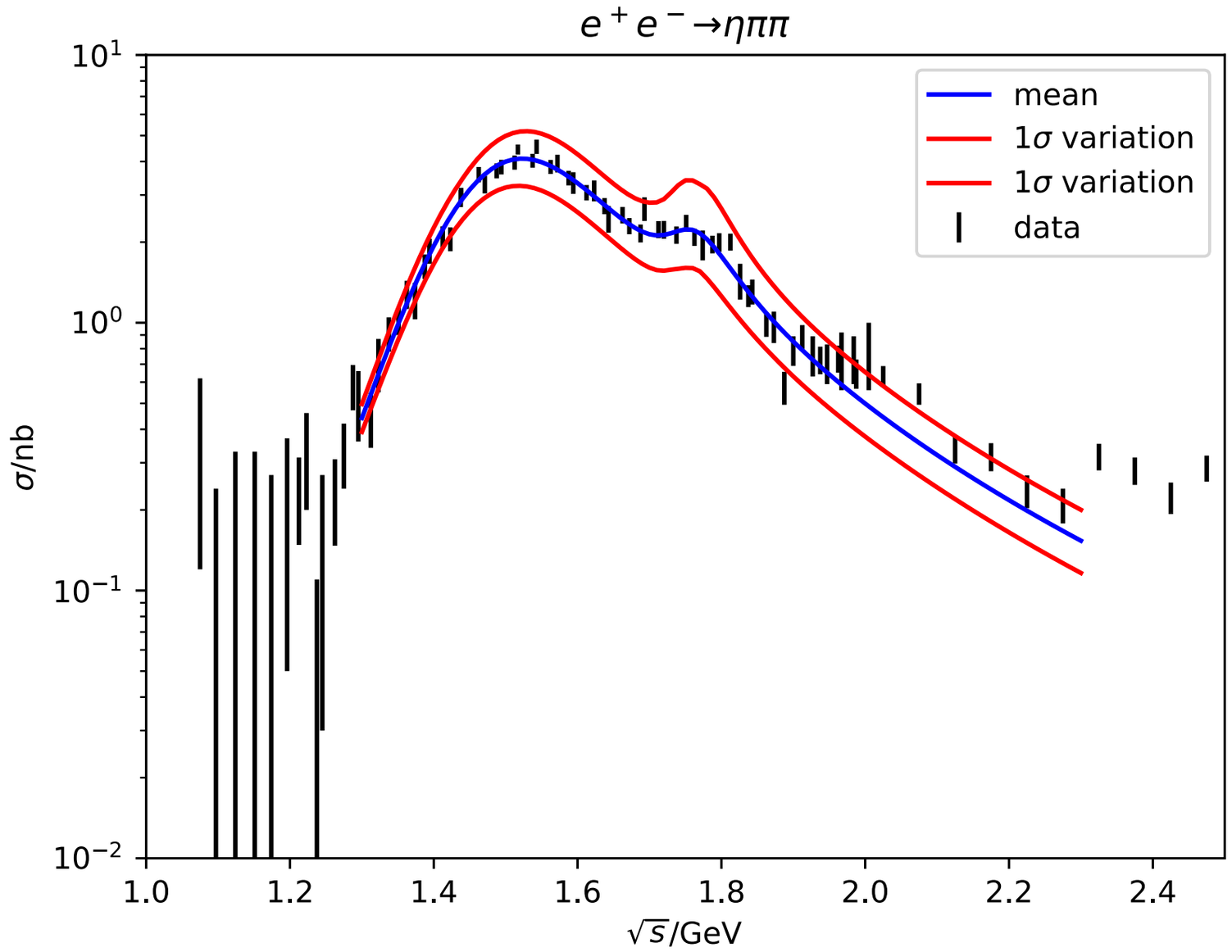






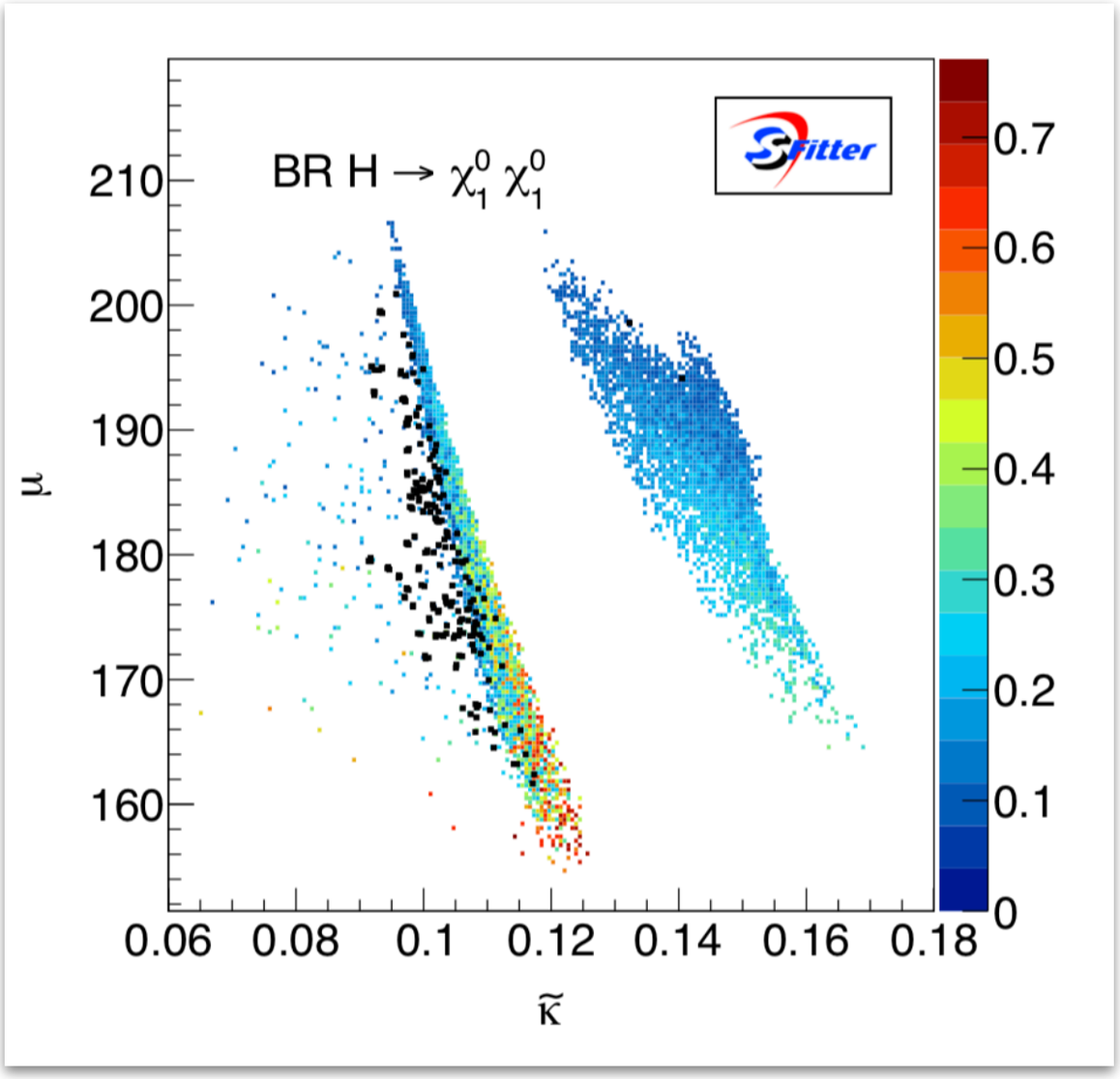
Cuoco, MK, Korsmeier, PRL 118 (2017) 191102

Anomalies in astrophysics: systematic uncertainties



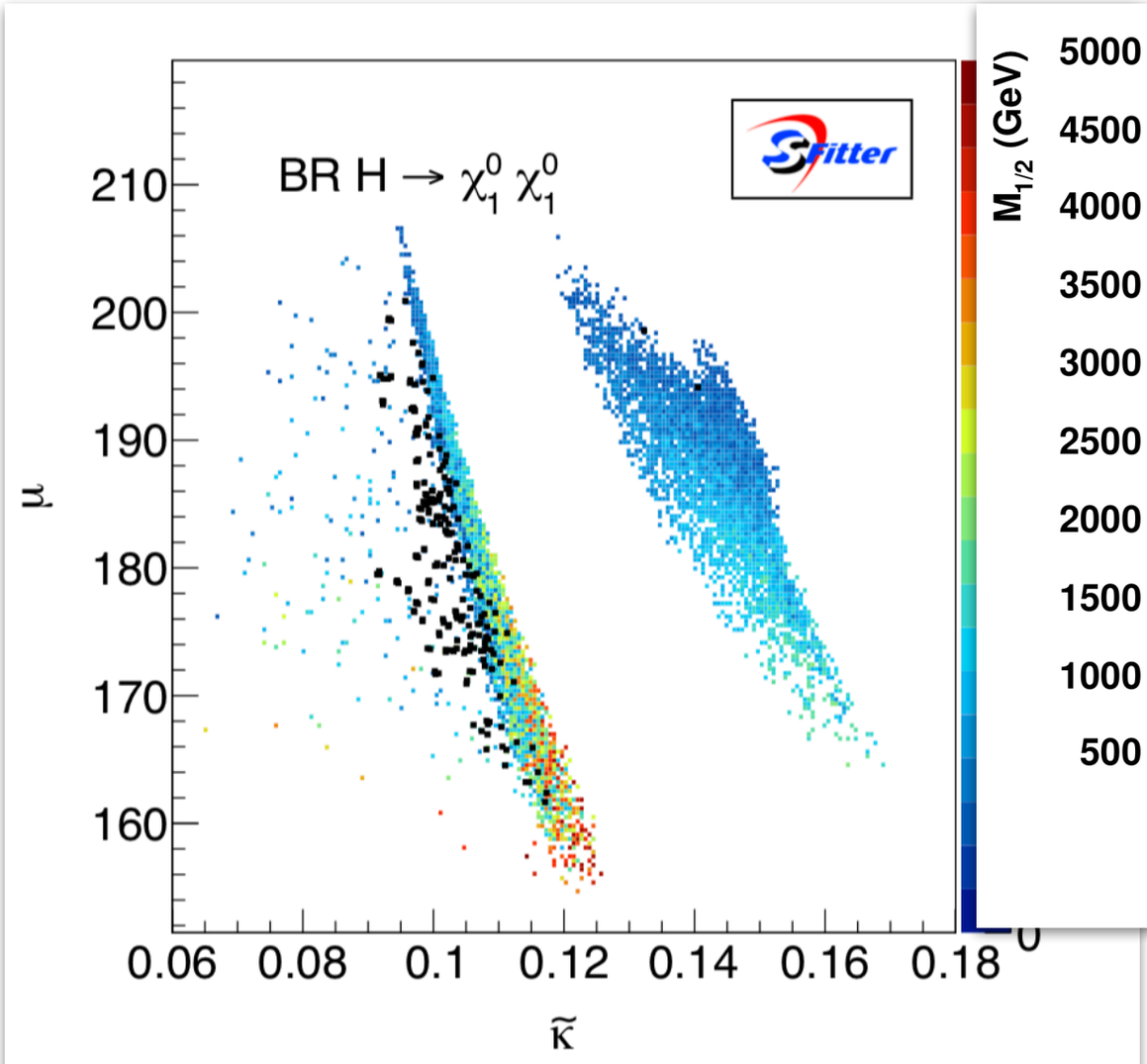
Reimitz, Plehn, Richardson + HERWIG, in prep.

Global analyses

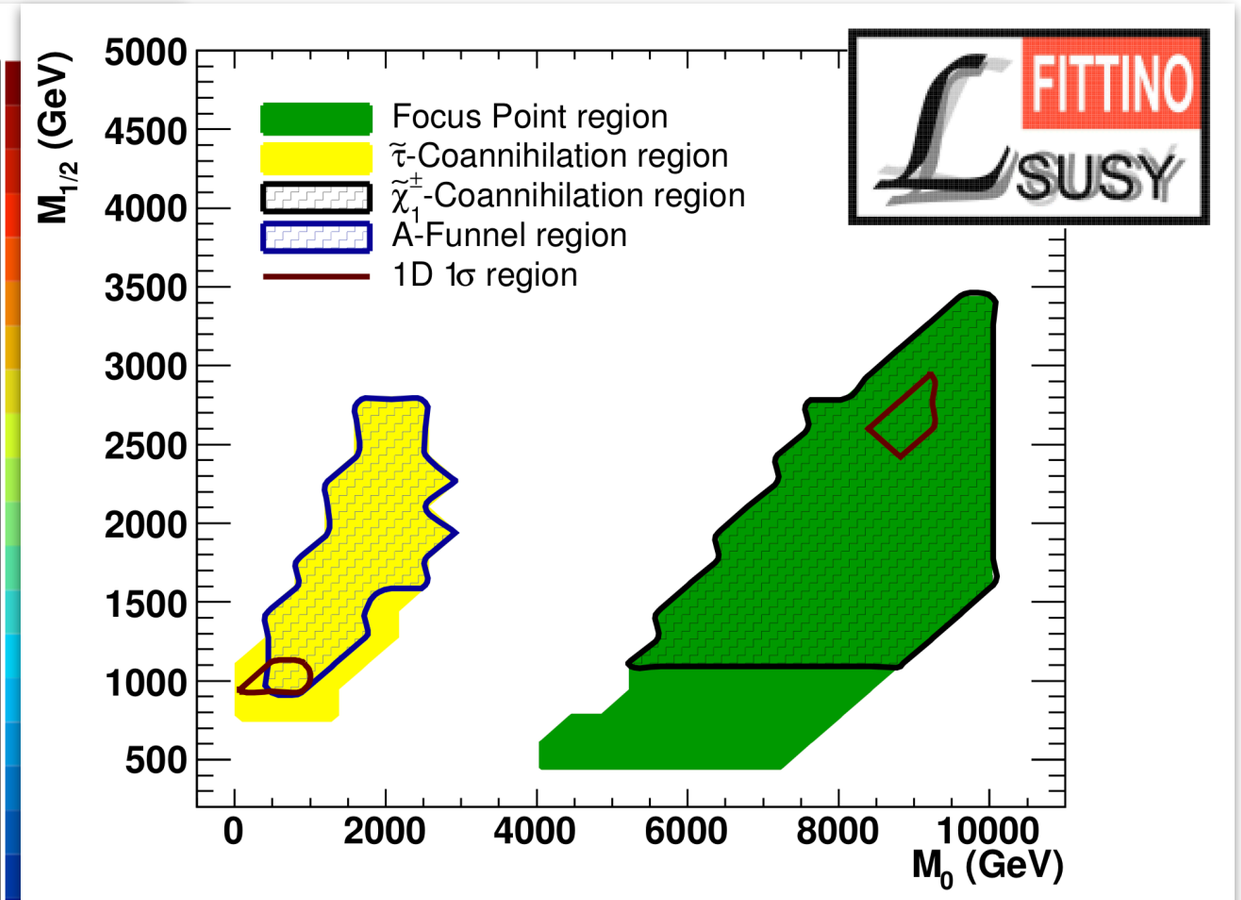


Butter, Plehn et al., PRD93 (2016) 015011

Global analyses

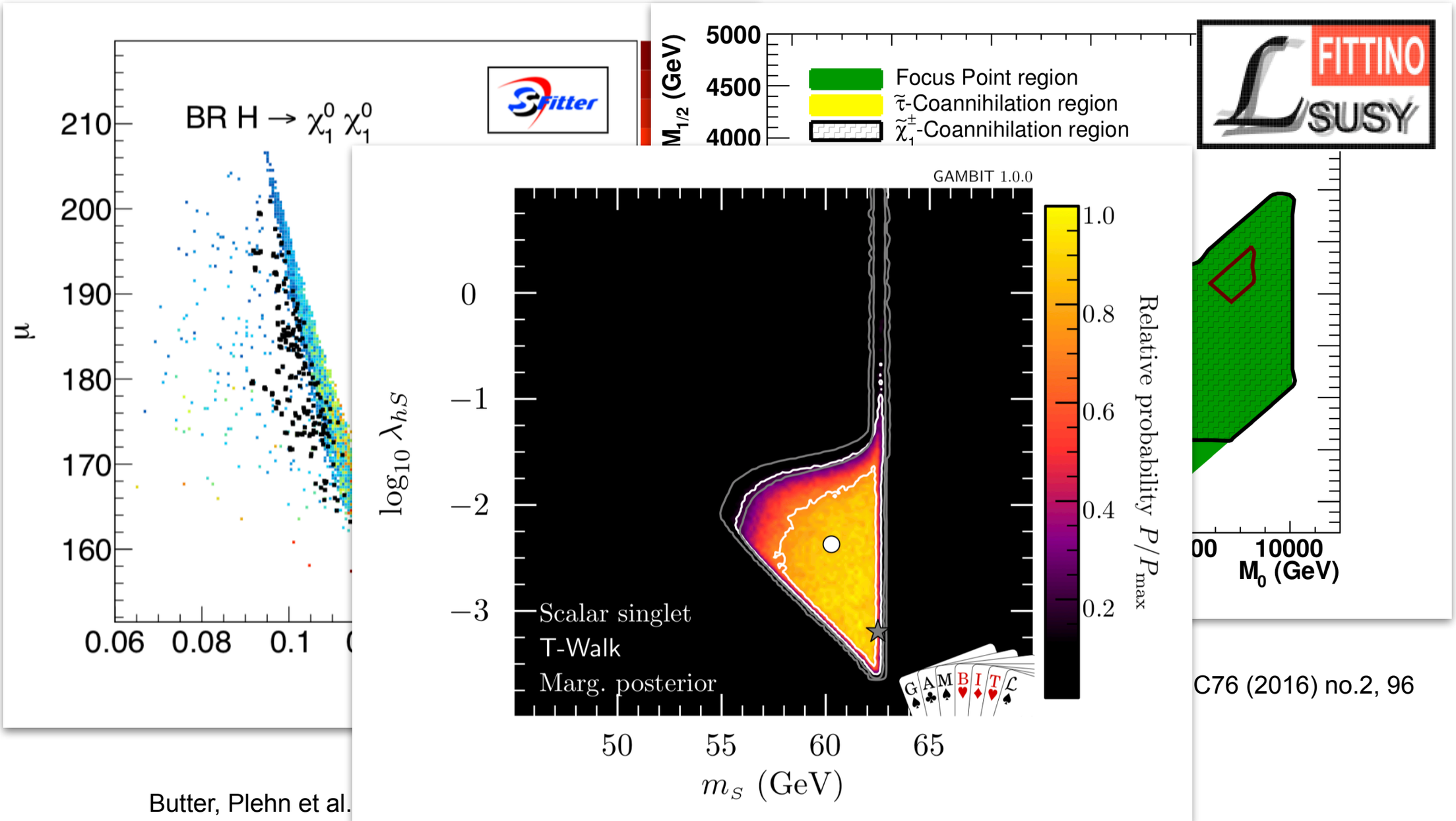


Butter, Plehn et al., PRD93 (2016) 015011



Bechtle, …, MK et al., Eur.Phys.J. C76 (2016) no.2, 96

Global analyses

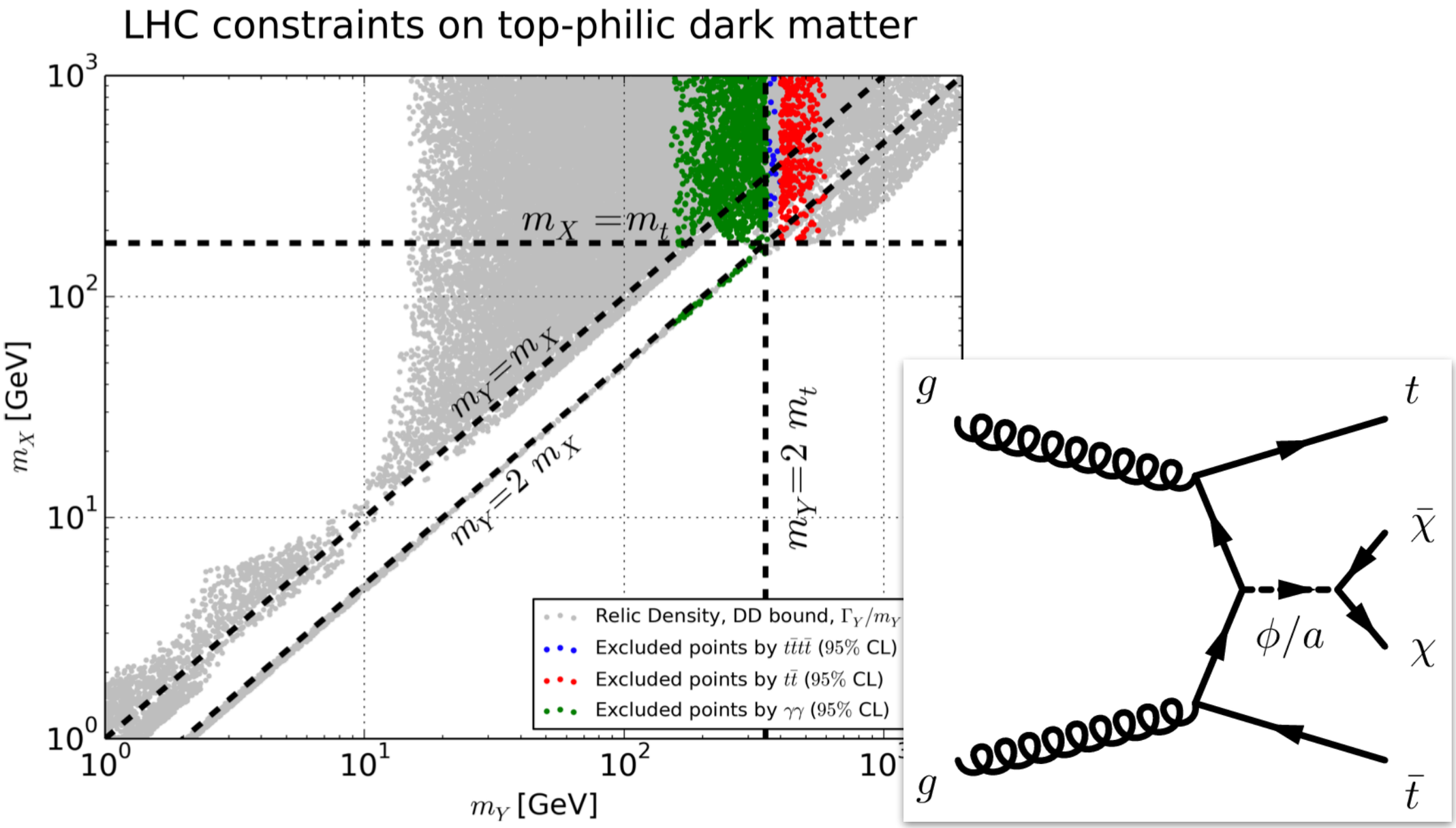


Butter, Plehn et al.

C76 (2016) no.2, 96

Athron, …, Kahlhoefer et al., Eur. Phys. J. C 77, 568 (2017)

From supersymmetry to simplified models



Arina, …, MK et al., JHEP 1611 (2016) 111

Dark matter simplified models

DMsimp: Simplified dark matter models

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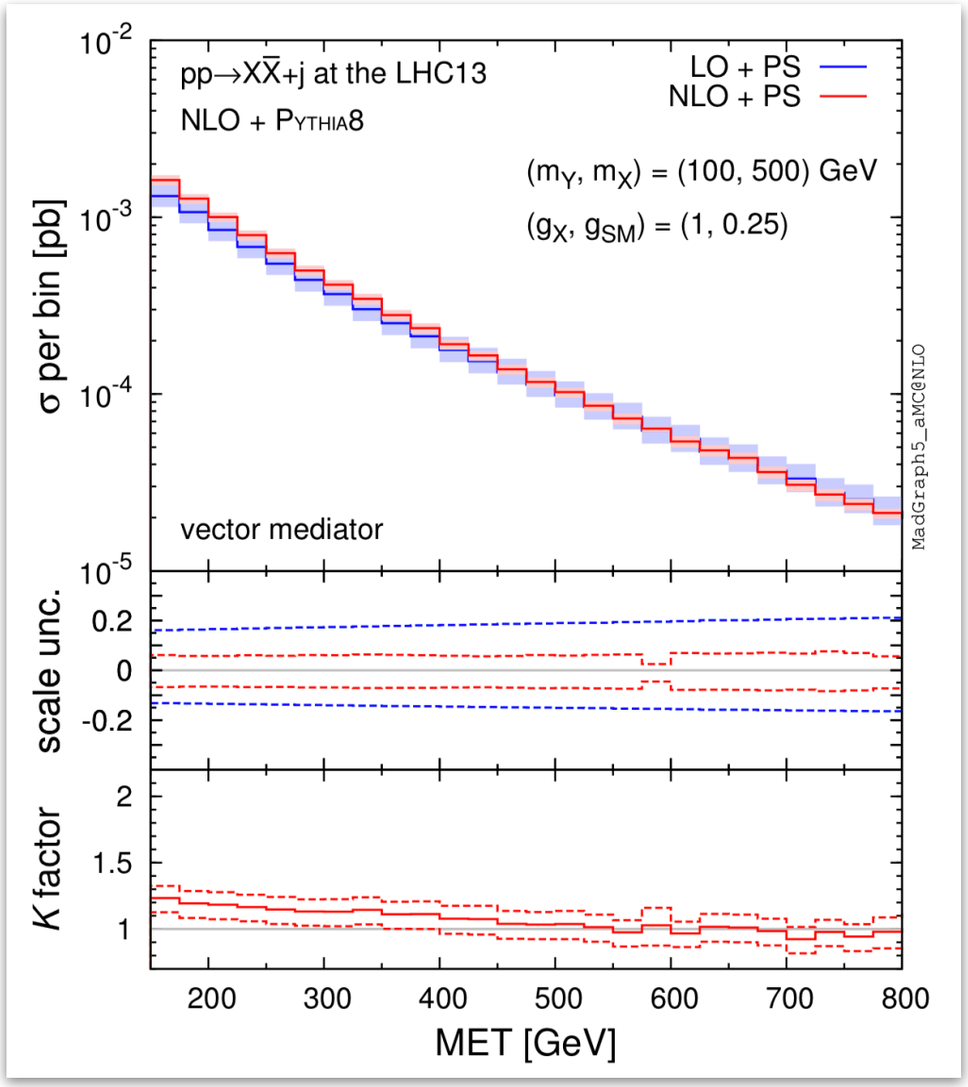
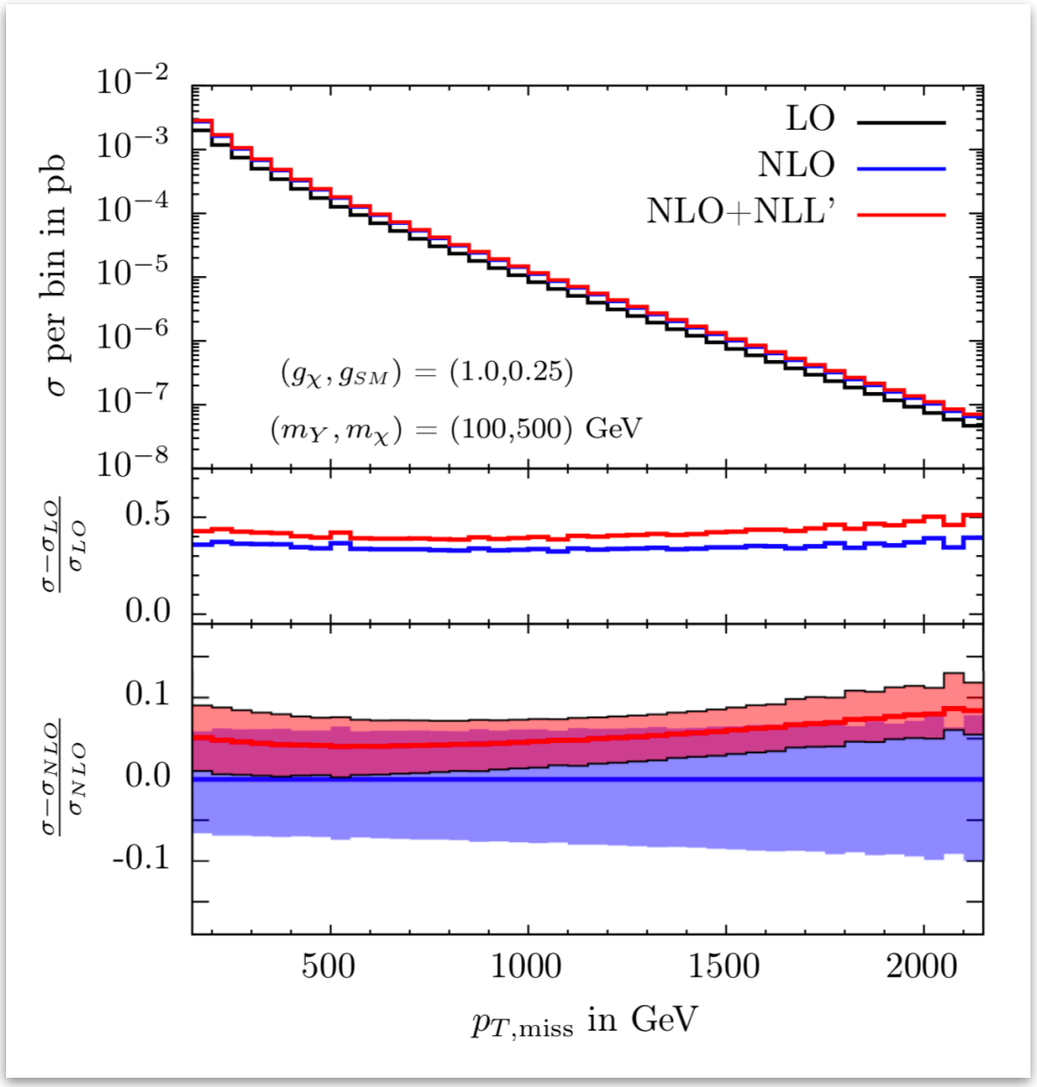
Dark matter simplified models

DMsimp: Simplified dark matter models

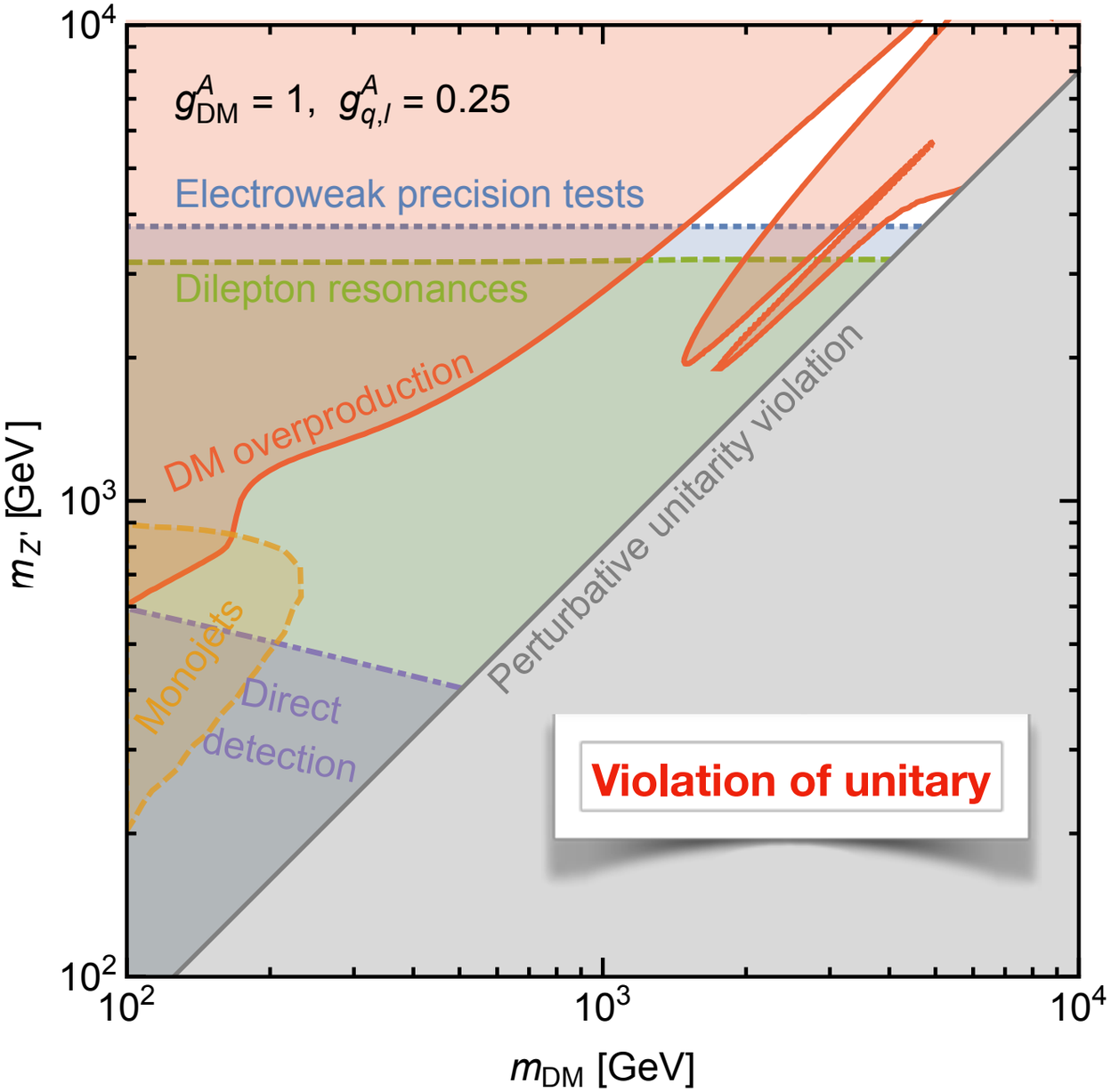


Backovic, MK et al., Eur.Phys.J. C75 (2015) 0, 482



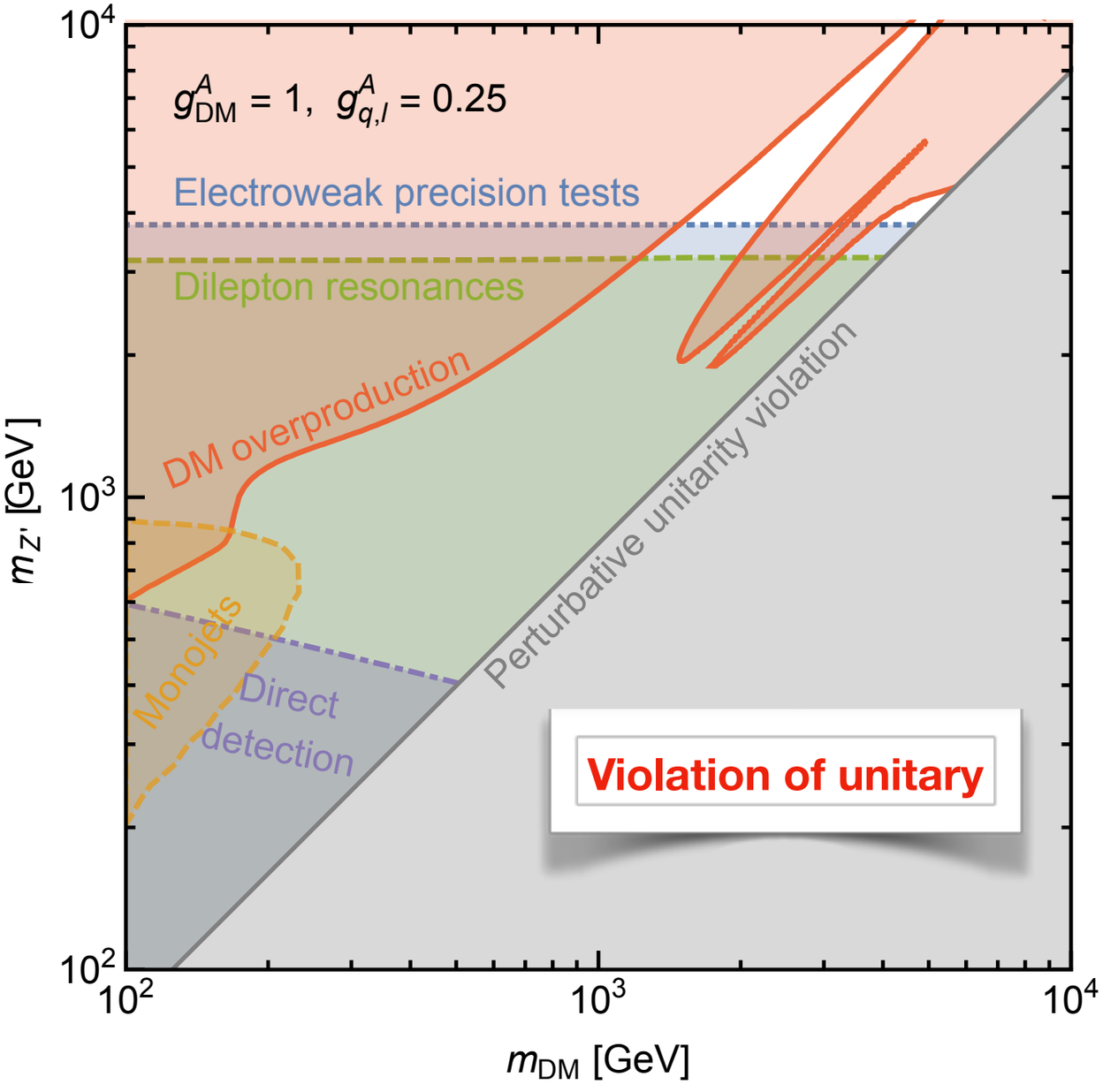
MK, Kulesza, Mück, Schürmann, arXiv:1903.06417, P3H-19-004

Simplified models may be theoretically inconsistent



Kahlhoefer, Schmidt-Hoberg, Schwetz, Vogl, JHEP 1602 (2016) 016

Simplified models may be theoretically inconsistent



Kahlhoefer, Schmidt-Hoberg, Schwetz, Vogl, JHEP 1602 (2016) 016

Consistent models have to be

- gauge invariant;
- unitary;
- free of gauge anomalies.


Need to extend simplified models → **dark sectors**

Need to extend simplified models → **dark sectors**

We will focus on three dark sector scenarios:

Weakly-Interacting Massive Particles (WIMPs),

Strongly-Interacting Massive Particles (SIMPs) and

Feebly-Interacting Massive Particles (FIMPs),

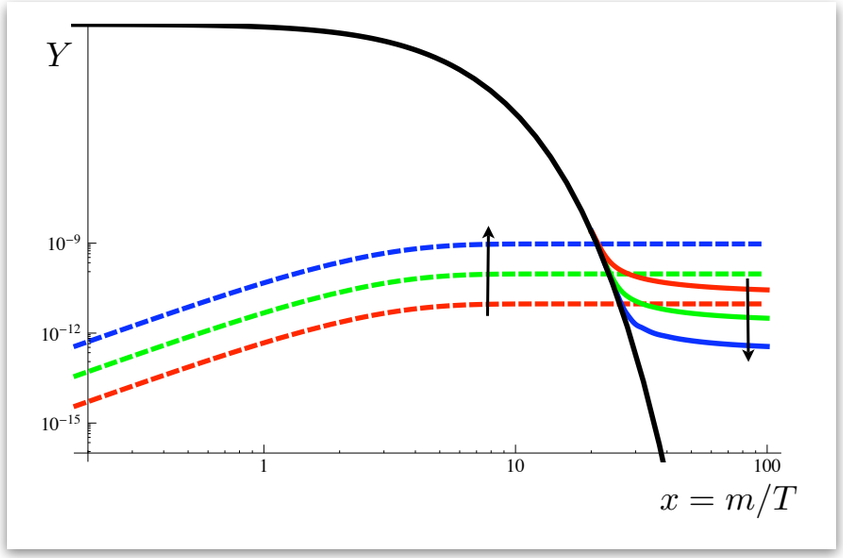
which exhibit features known from the weak, strong and electromagnetic interactions, respectively.

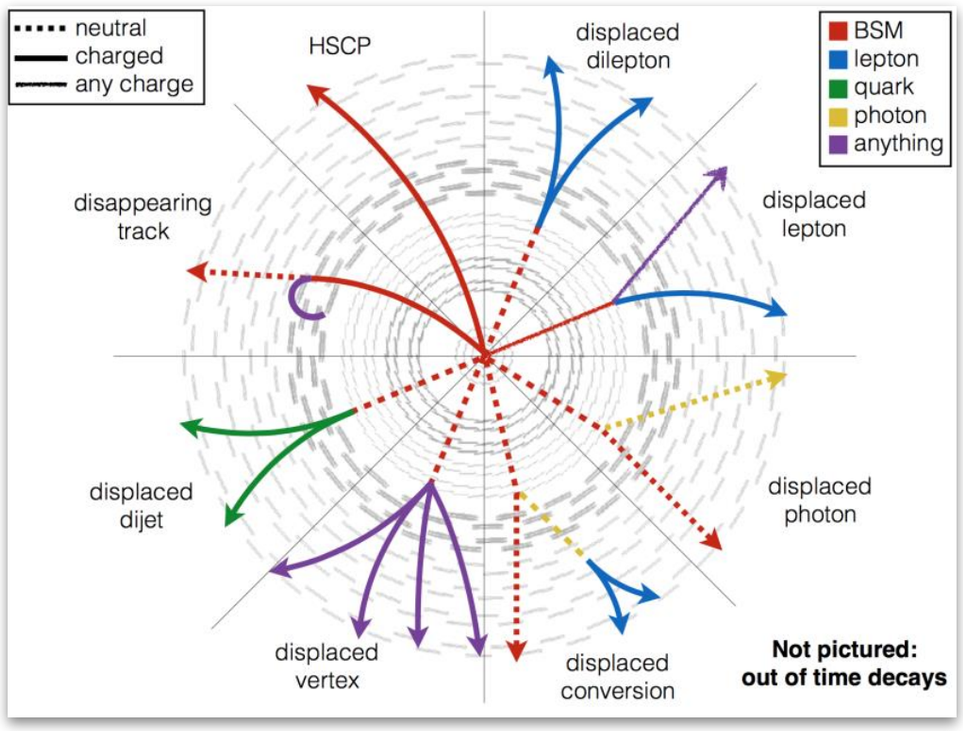
Novel LHC signatures for dark matter

Feebly interacting dark matter

Relic density through freeze-in

Hall, Jedamzik, March-Russell, West arXiv:0911.1120 [hep-ph]





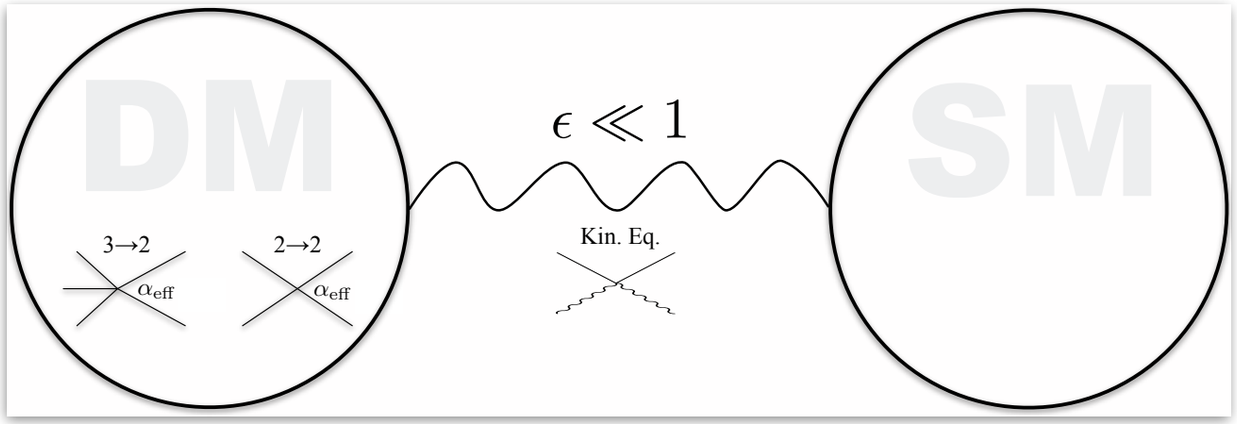
De Roeck

Search for long-lived particles and displaced decays

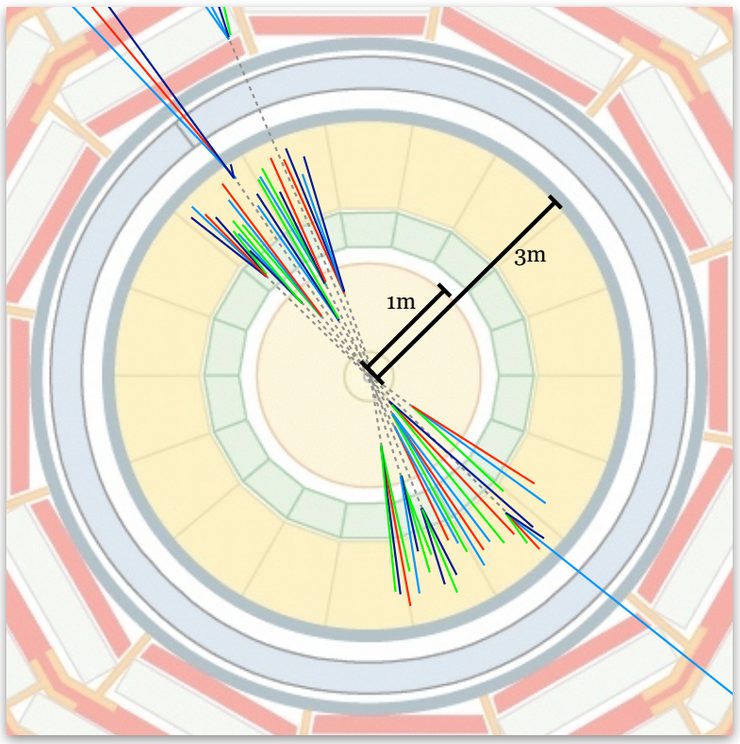
Novel LHC signatures for dark matter

Strongly interacting dark matter

Relic density set by dark sector



Hochberg, Kuflik, Volansky, Wacker, arXiv:1402.5143 [hep-ph]



Schwaller, Stolarski, Weiler, arXiv:1502.05409 [hep-ph]

Novel collider signatures, such as **semi-visible jets**, anomalous underlying events,…

Strongly interacting dark matter

$$\mathrm{SM} \otimes \mathrm{U}(1)_{\mathrm{mediator}} \otimes \mathrm{SU}(3)_{\mathrm{dark}}$$

Bernreuther, Kahlhoefer, MK, Tunney, in prep.

Strongly interacting dark matter

$$\mathrm{SM} \otimes \mathrm{U}(1)_{\mathrm{mediator}} \otimes \mathrm{SU}(3)_{\mathrm{dark}}$$

Particle content

$\boldsymbol{\pi}^{\pm}$, $\boldsymbol{\pi}^{0}$, $\boldsymbol{\rho}^{\pm}$, $\boldsymbol{\rho}^{0}$: dark mesons with mass of O(GeV)

Z': vector mediator with mass of O(100-1000 GeV)

Bernreuther, Kahlhoefer, MK, Tunney, in prep.

Strongly interacting dark matter

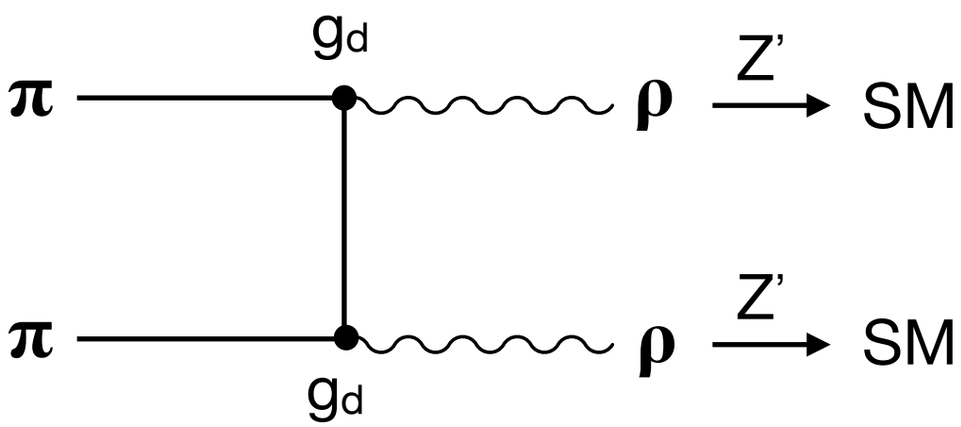
$SM \otimes U(1)_{mediator} \otimes SU(3)_{dark}$

Particle content

$\pi^{\pm}$, π^0, $\rho^{\pm}$, ρ^0: dark mesons with mass of *O*(GeV)

Z': vector mediator with mass of *O*(100-1000 GeV)

Relic density



If $\rho \rightarrow$ SM proceeds sufficiently fast,
Ω_{DM} is set by dark sector parameters:
g_d, m_π, m_ρ.

Bernreuther, Kahlhoefer, MK, Tunney, in prep.

Strongly interacting dark matter

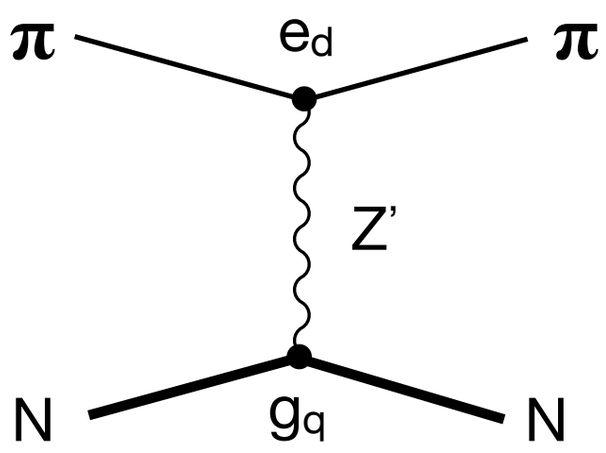
$$\mathrm{SM} \otimes \mathrm{U}(1)_{\mathrm{mediator}} \otimes \mathrm{SU}(3)_{\mathrm{dark}}$$

Particle content

$\boldsymbol{\pi}^{\pm}$, $\boldsymbol{\pi}^{0}$, $\boldsymbol{\rho}^{\pm}$, $\boldsymbol{\rho}^{0}$: dark mesons with mass of O(GeV)

Z': vector mediator with mass of O(100-1000 GeV)

Direct detection



$$\sigma^{\mathrm{SI}} \propto \frac{e_d^2\, g_q^2}{M_{Z'}^4}$$

Bernreuther, Kahlhoefer, MK, Tunney, in prep.

Strongly interacting dark matter

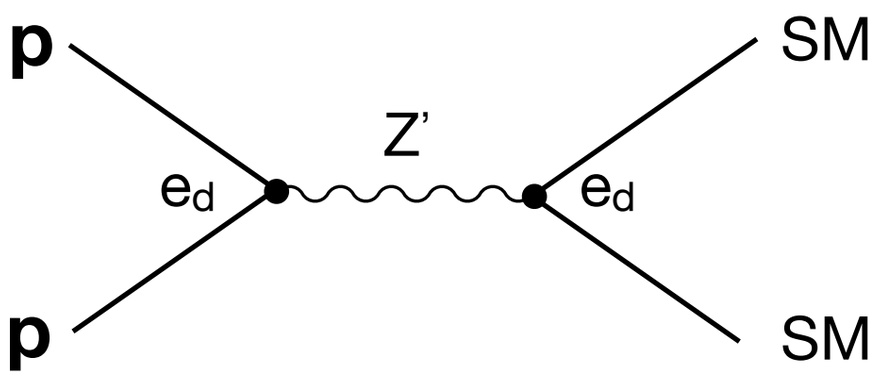
$$SM \otimes U(1)_{mediator} \otimes SU(3)_{dark}$$

Particle content

$\pi^{\pm}$, π^0, $\rho^{\pm}$, ρ^0: dark mesons with mass of O(GeV)

Z': vector mediator with mass of O(100-1000 GeV)

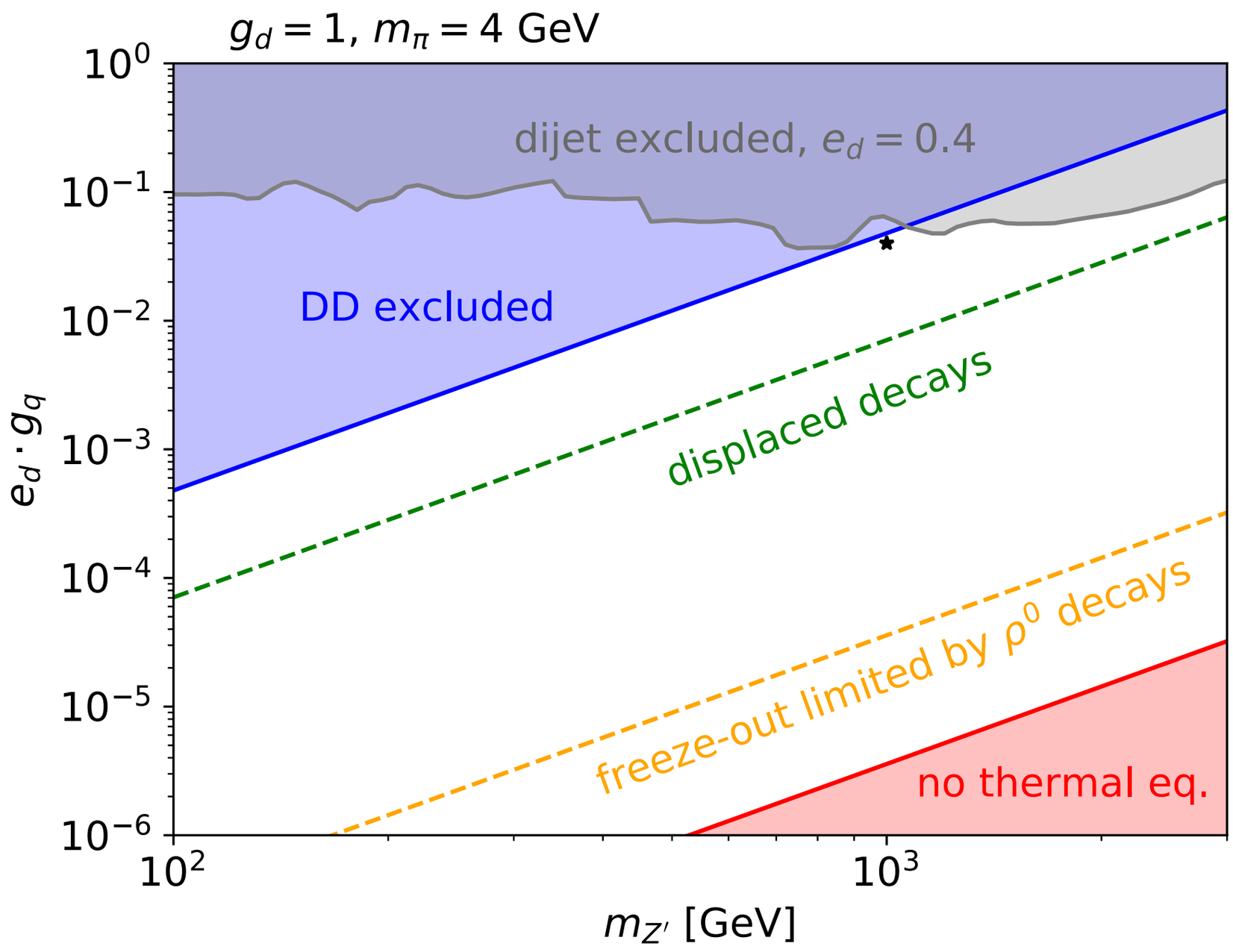
Dijet-resonance searches



Setting $e_d = 0.4$ reduces BR(Z' → SM) to less than 20% and thus the sensitivity of dijet-resonance searches.

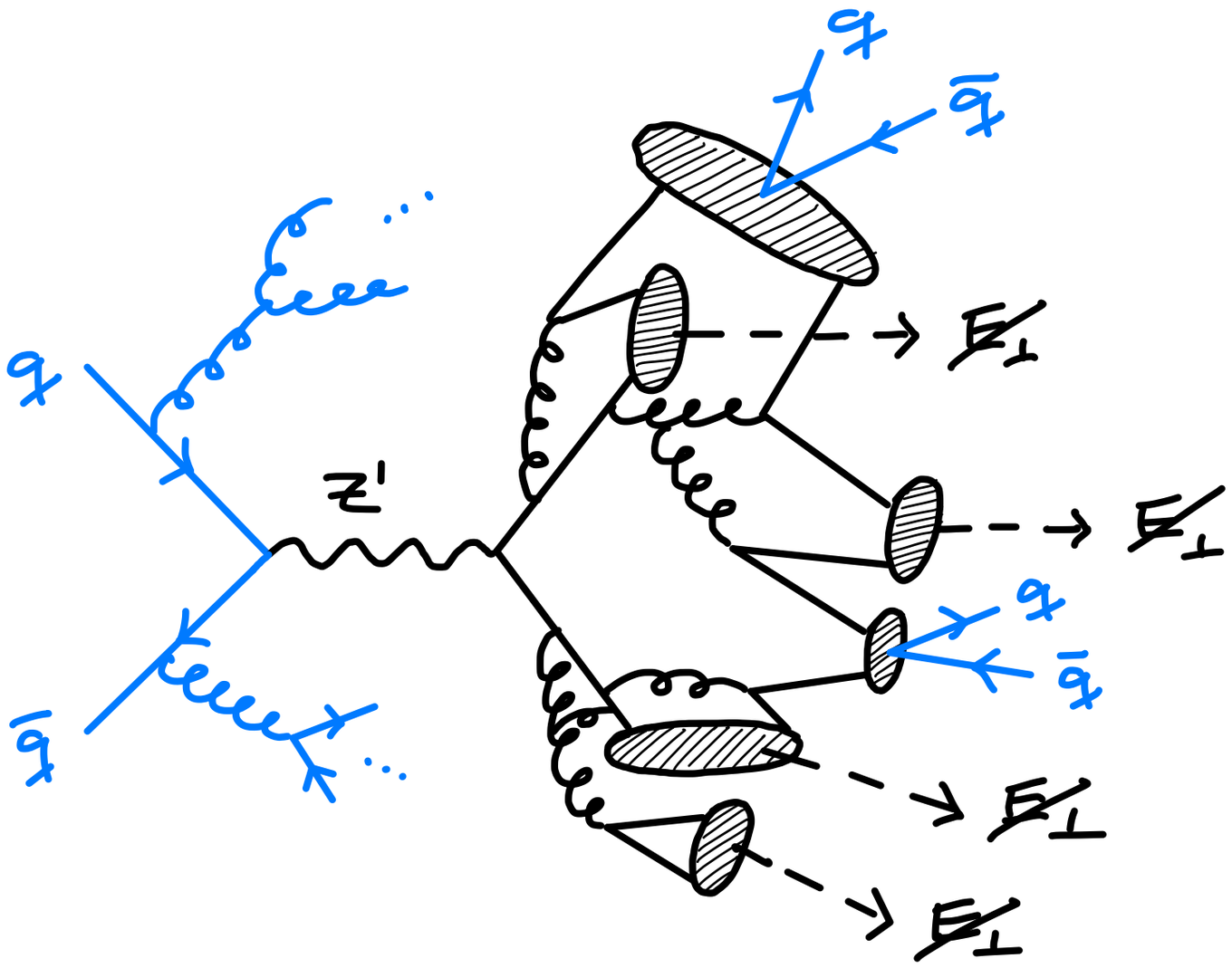
Bernreuther, Kahlhoefer, MK, Tunney, in prep.

Strongly interacting dark matter: LHC phenomenology



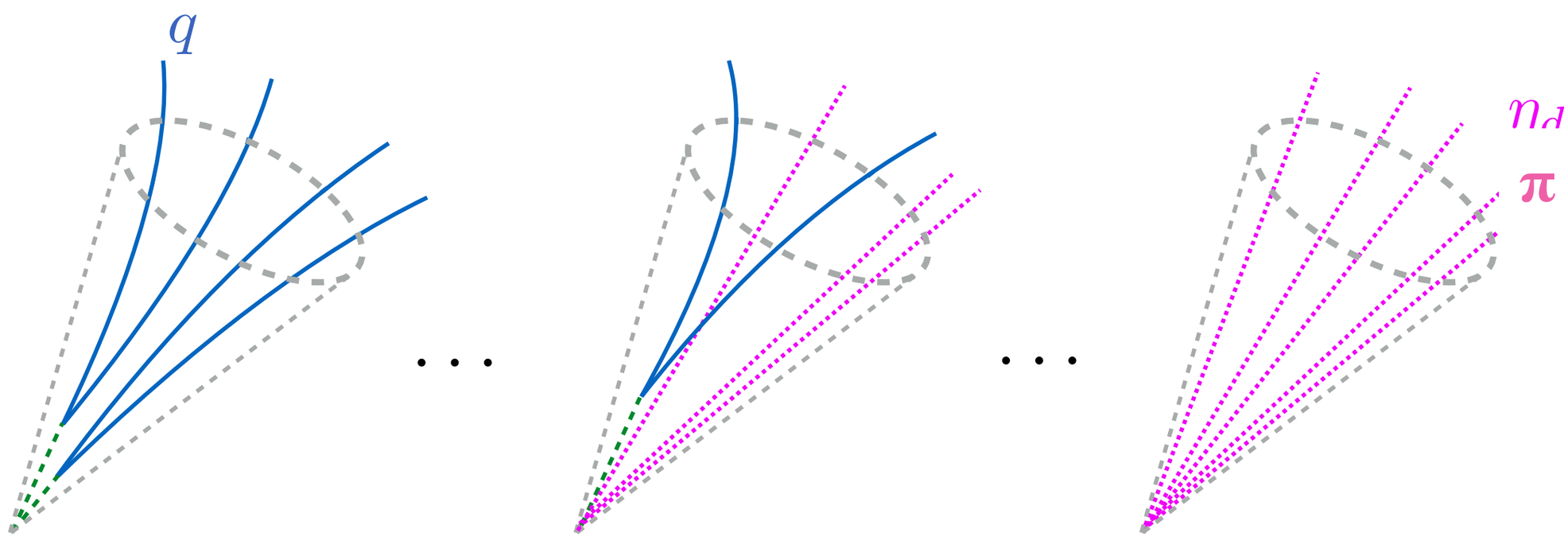
Bernreuther, Kahlhoefer, MK, Tunney, in prep.

Strongly interacting dark matter: LHC phenomenology



Signature as in “Hidden Valley” models (Strassler, Zurek)

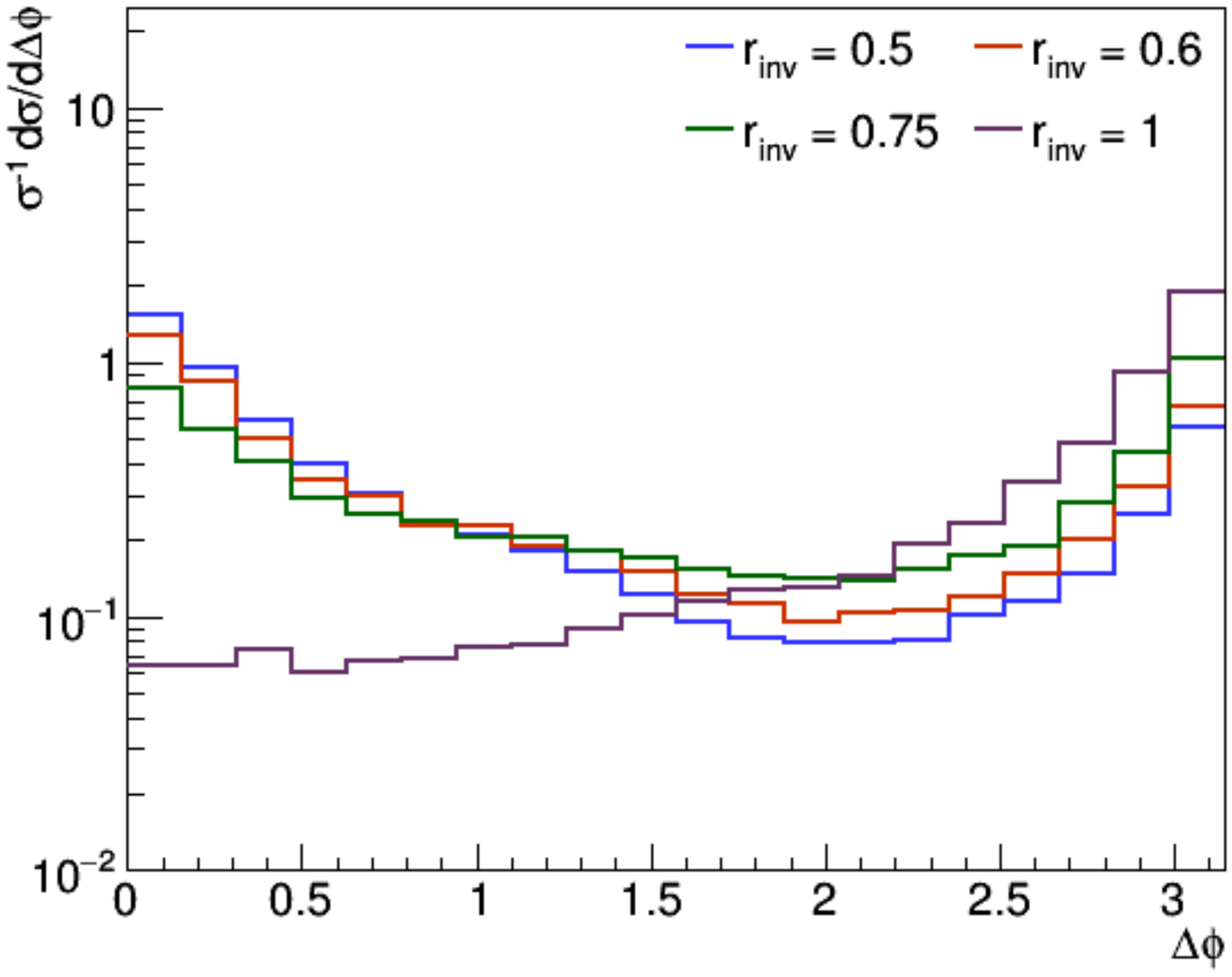
Strongly interacting dark matter: LHC phenomenology



$$r_{\rm inv} \equiv \left\langle \frac{\#\text{ of stable hadrons}}{\#\text{ of hadrons}} \right\rangle$$

Cohen, Lisanti, Lou, Mishra-Sharma, 1707.05326

Strongly interacting dark matter: LHC phenomenology



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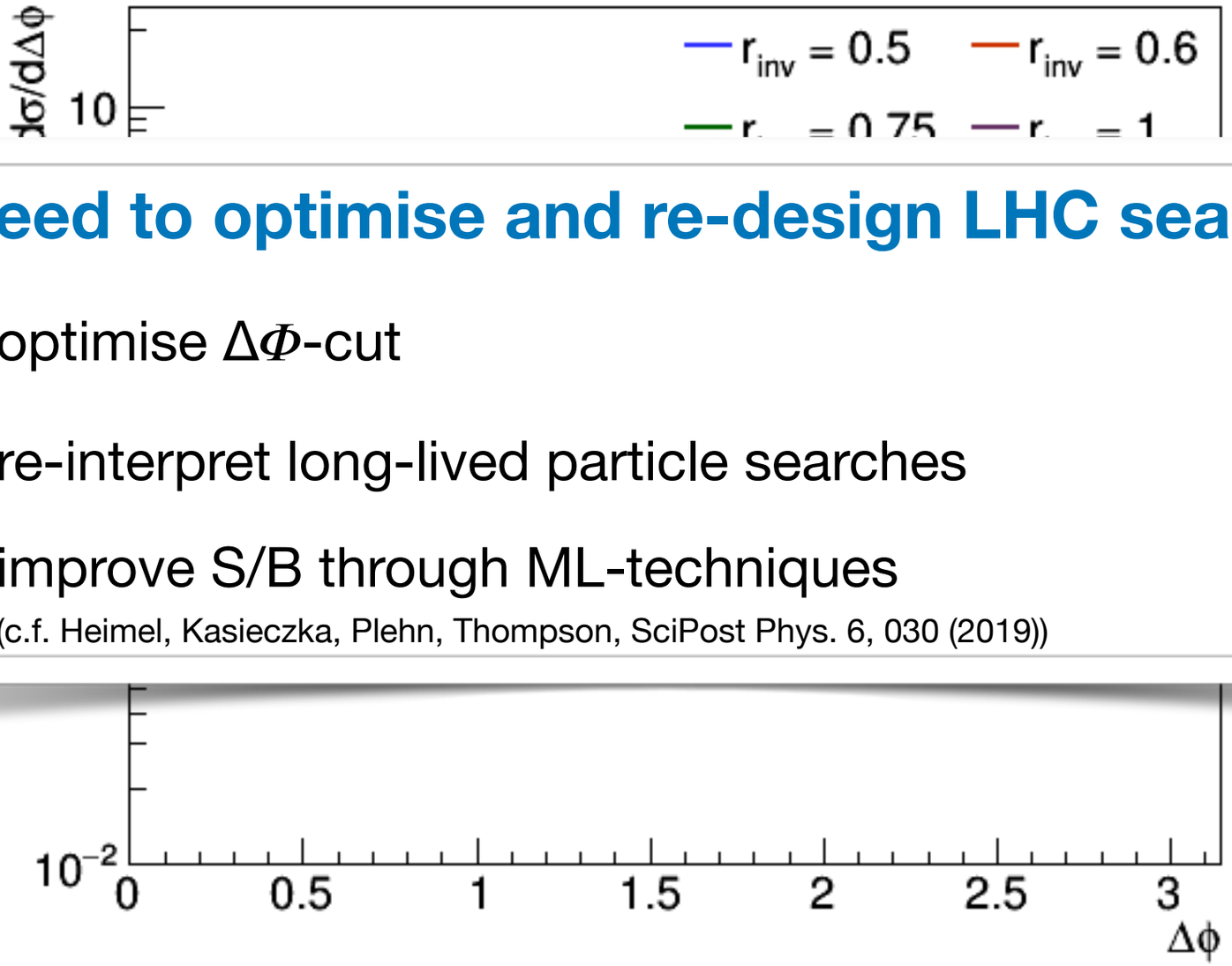


Need to optimise and re-design LHC searches

- optimise $\Delta\Phi$-cut
- re-interpret long-lived particle searches
- improve S/B through ML-techniques
  (c.f. Heimel, Kasieczka, Plehn, Thompson, SciPost Phys. 6, 030 (2019))

Bernreuther, Kahlhoefer, MK, Tunney, in prep.

Dark sectors lead to novel & subtle LHC signatures!

Dark sectors lead to novel & subtle LHC signatures!

We will focus on three dark sector scenarios:

Weakly-Interacting Massive Particles (WIMPs),

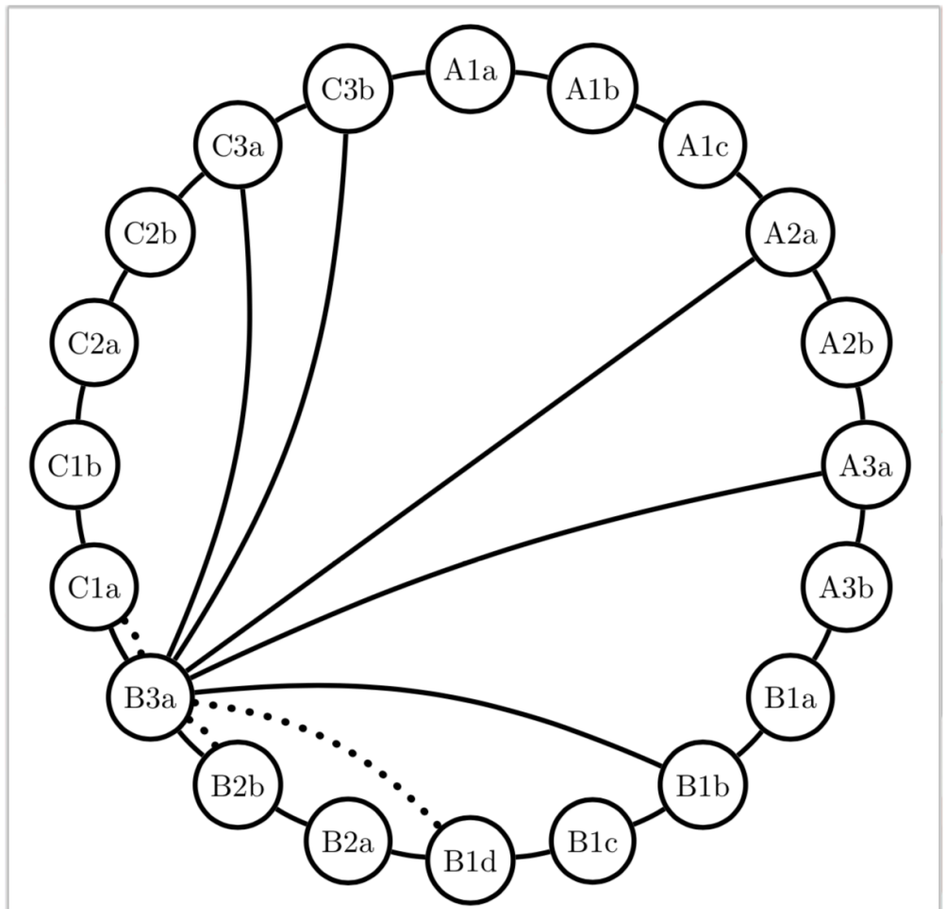
Strongly-Interacting Massive Particles (SIMPs) and

Feebly-Interacting Massive Particles (FIMPs),

and explore

models, phenomenology and interpretation.

Dark sectors lead to novel & subtle LHC signatures!



We benefit from

- accurate predictions for signal and SM background distributions (B1b, B1d)
- BSM searches in Higgs and top physics (A2a, A3a, B2b)
- BSM searches in flavour physics (C1a, C3a, C3b)

Thank you