Dark Matter in a twisted bottle!

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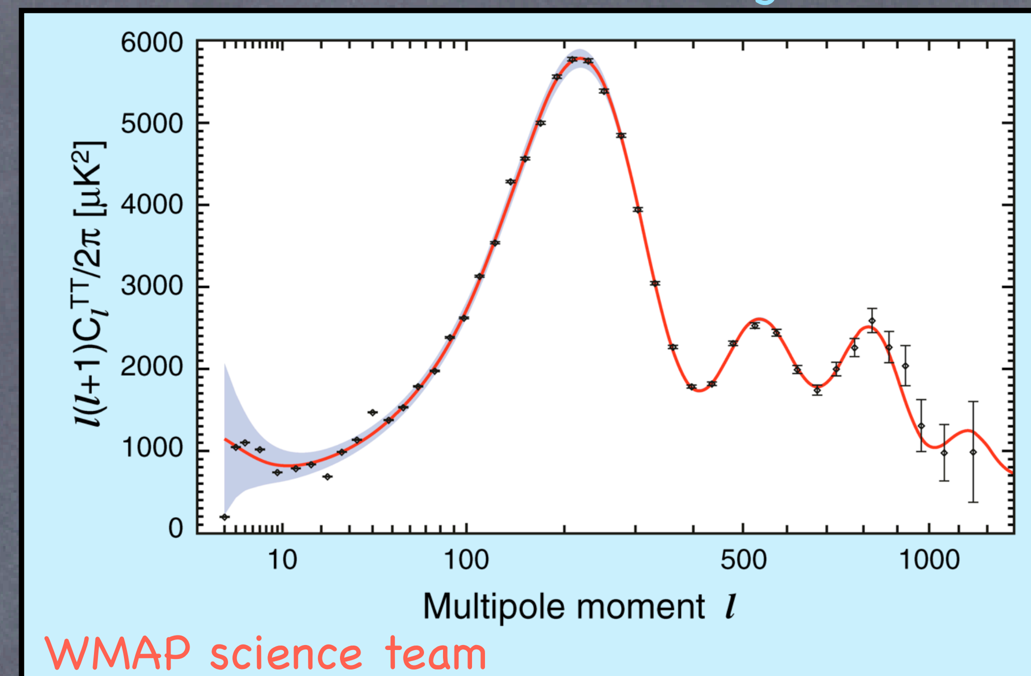
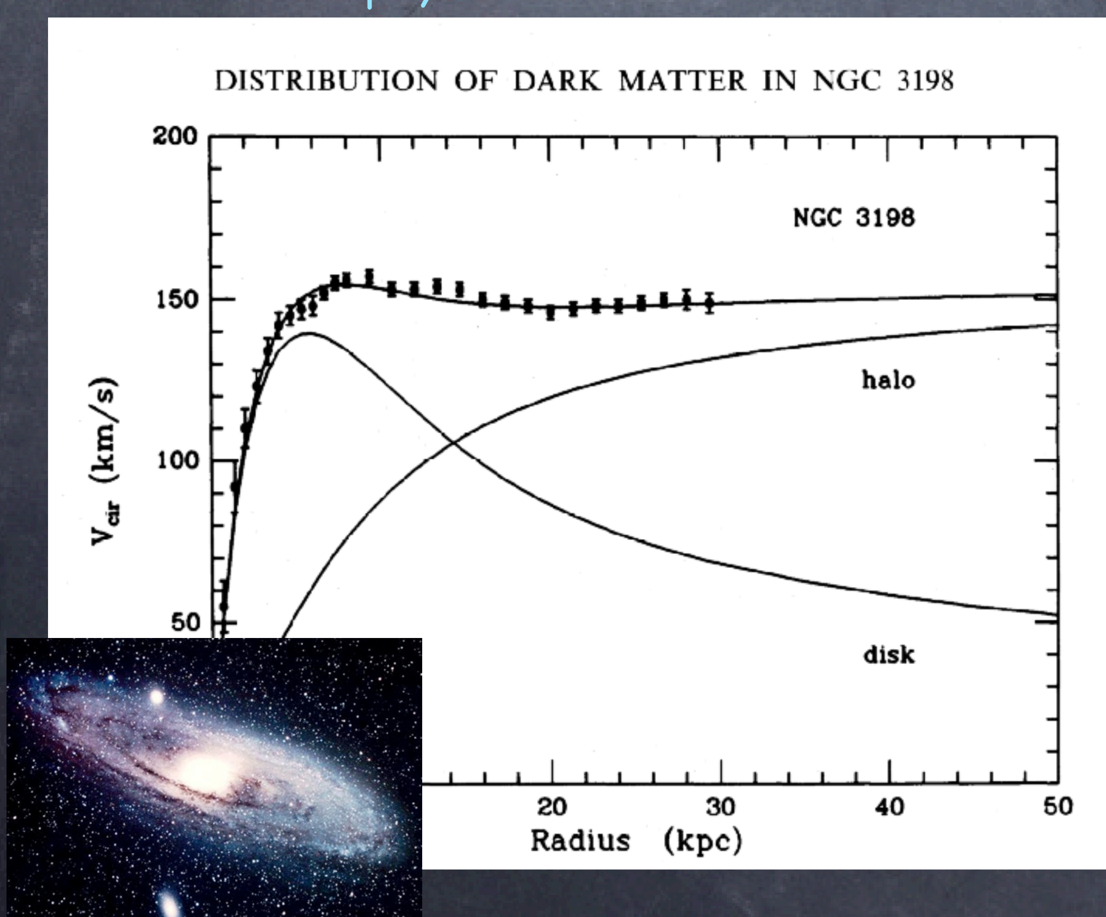
Why do we need Dark Matter?

Observations both in Astrophysics
and Cosmology suggest
the presence of "Dark" Matter,
not explained in the Standard Model!

Cosmic Microwave Background:



Astrophysical measurements:

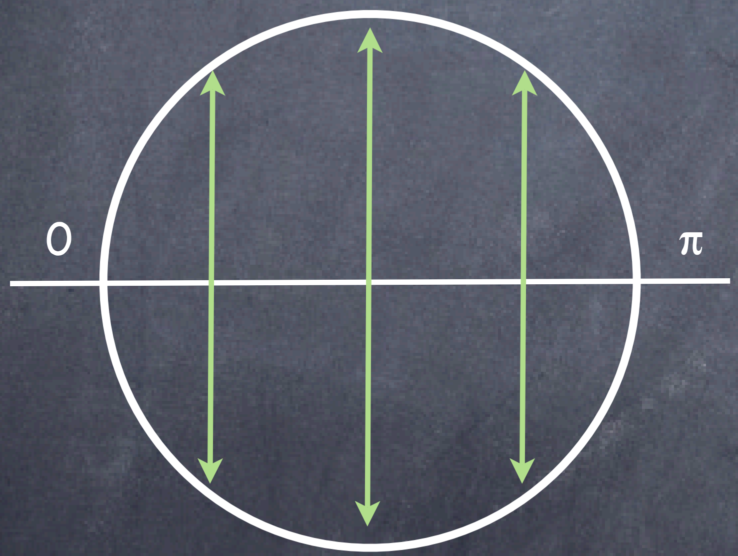


- The Universe contains 4.6% of baryons, and 23.3% of unknown matter.
- The flat rotation curves of spiral galaxies can be explained by the presence of extra non-luminous matter.

Extra dimensions are a versatile tool:

Can a parity arise ``naturally" from extra dimensions?

- Symmetries of the compact space ARE parities for the Kaluza-Klein modes!
- The physics is in the wave functions: for instance



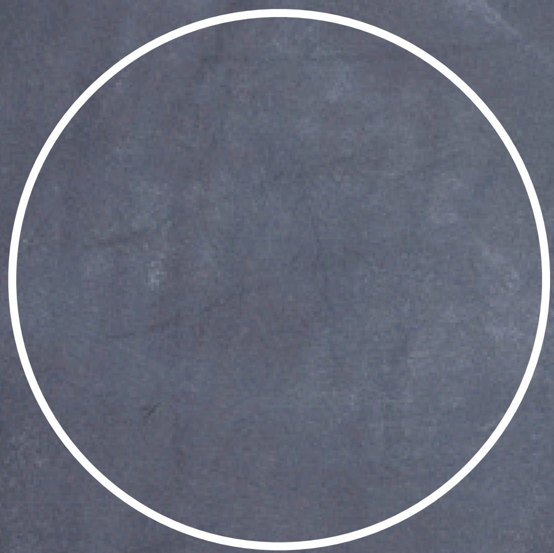
$$x_5 \to -x_5 = 2\pi - x_5$$

$$\begin{cases} \cos(kx_5) \to \cos k(2\pi - x_5) = \cos(kx_5) \\ \sin(kx_5) \to \sin k(2\pi - x_5) = -\sin(kx_5) \end{cases}$$

Is this enough?

DM and XD, a troubled couple?

The typical situation is:



Let's consider the simplest case:
one compact extra dimension!

A circle.

$$x_5 \leftrightarrow x_5 + 2\pi$$

DM and XD, a troubled couple?

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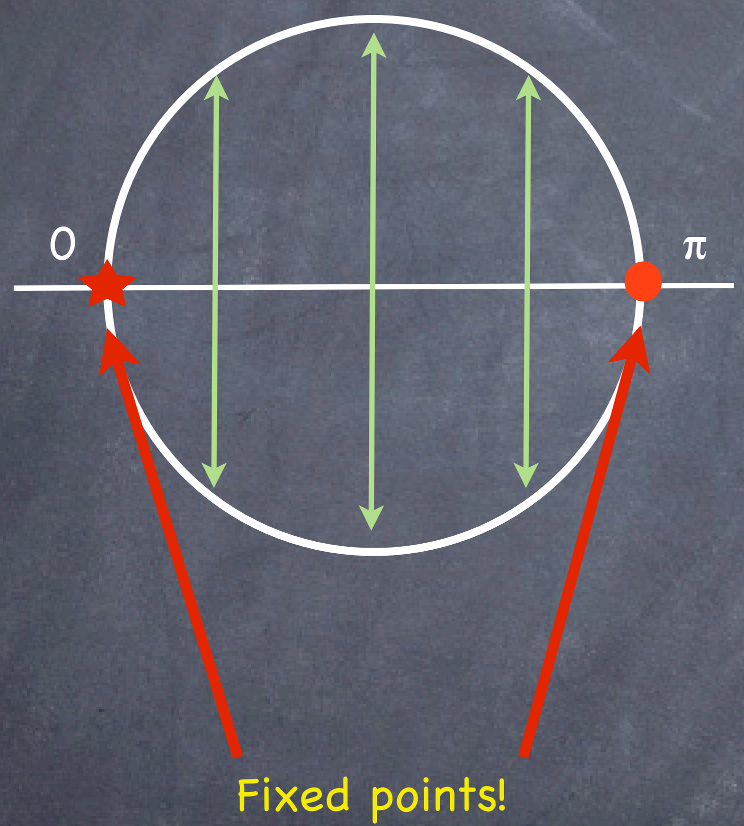

We impose an "orbifold":
identify points related by a symmetry

$$x_5 \to -x_5 = 2\pi - x_5$$

Each field has a fixed parity, and
KK modes of different parity are removed!

$$\phi(x_5) = \pm\phi(-x_5)$$

Required by chirality!!!

KK parity is not natural!

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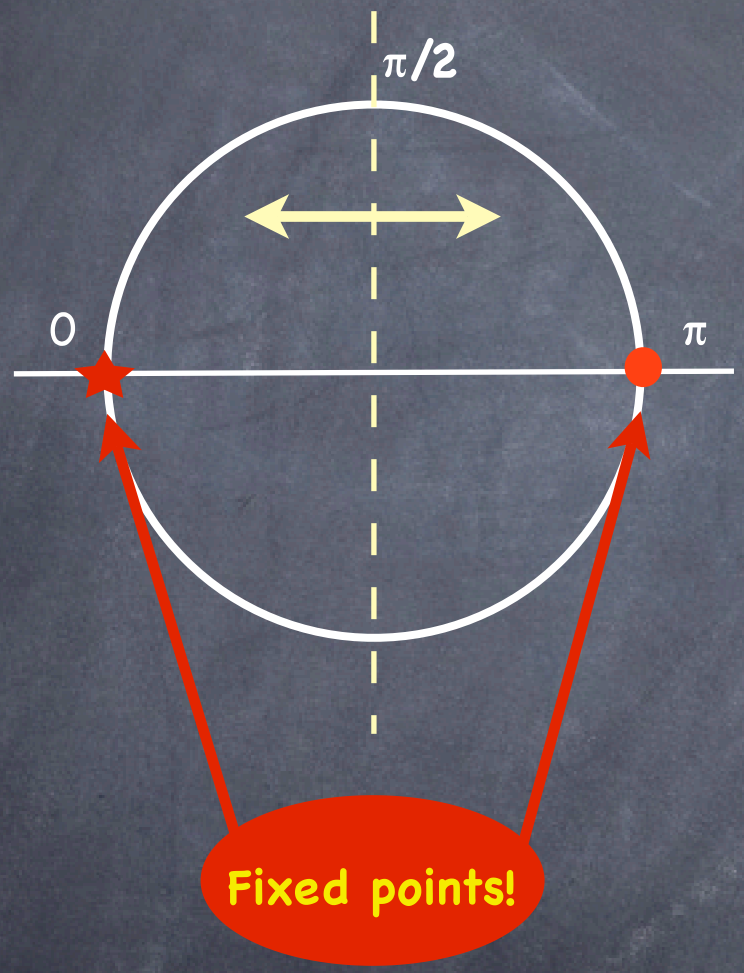


The half-circle is symmetric under:

$$x_5 \to \pi - x_5$$

Is it? NO!
The two fixed points are different!

We need to impose a symmetry on the fixed points to have a DM candidate!!!

In this example, the parity is added ad-hoc, it has nothing to do with the extraD!!

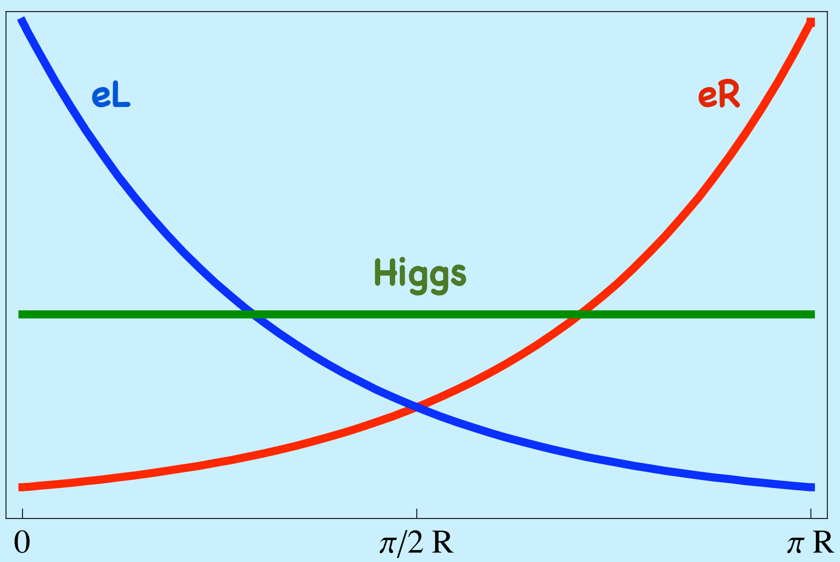
KK parity is not natural!

The typical situation is:

er:

nt!

In Gauge-Higgs models (Hosotani mechanism)
fermion localisation is essential!



Bulk fermion masses break
the KK parity!

Already pointed out by
Barbieri, Contino, Creminelli, Rattazzi, Scrucca
hep-th/0203039

it has nothing to do with the extraD!!

Do orbifolds exist without fixed points and with chiral fermions?

G.C., A.Deandrea, J.Llodra-Perez 0907.4993

- There is none in 5D...
- In 6D there are 17 orbifolds (characterised by the discrete symmetry groups of the flat plane)...
- only ONE has chirality and no fixed points/lines! Unique candidate!

Requiring an exact parity
and chirality is rather restrictive!

The flat real projective plane

$$\mathbf{pgg} = \langle r, g | r^2 = (g^2 r)^2 = \mathbf{1} \rangle$$

G.C., A.Deandrea, J.Llodra-Perez 0907.4993

$$r : \begin{cases} x_5 \sim -x_5 \\ x_6 \sim -x_6 \end{cases} \qquad g : \begin{cases} x_5 \sim x_5 + \pi R_5 \\ x_6 \sim -x_6 + \pi R_6 \end{cases}$$

Translations defined as:

$$\begin{aligned} t_5 &= g^2 \\ t_6 &= (gr)^2 \end{aligned}$$

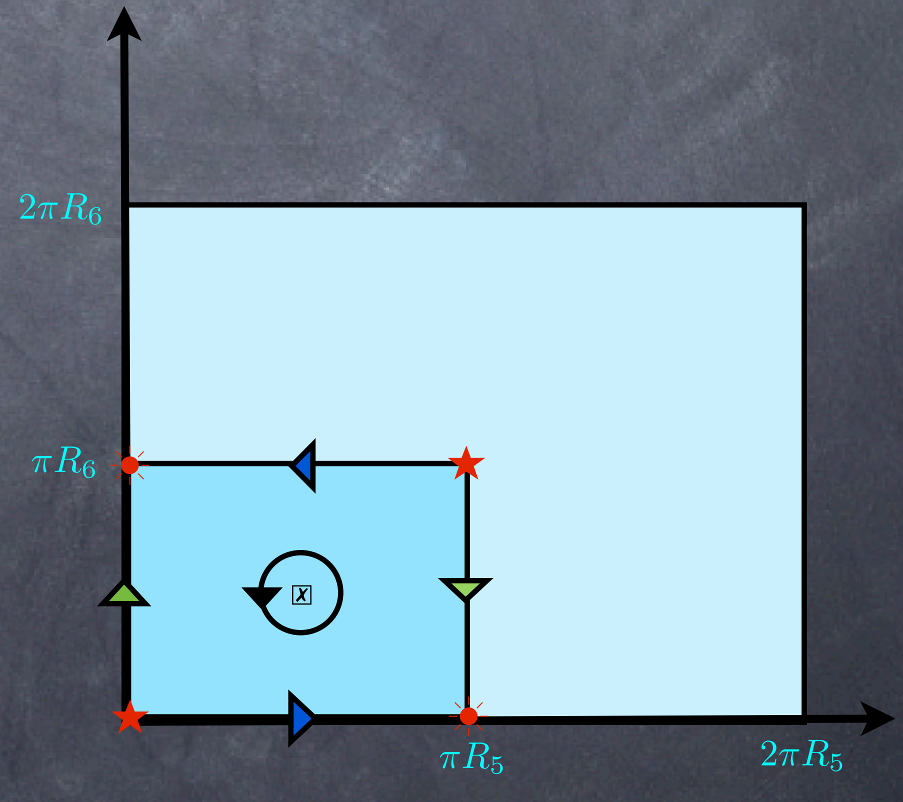
Two singular points:

$$(0, \pi) \sim (\pi, 0)$$

$$(0, 0) \sim (\pi, \pi)$$

KK parity is an exact symmetry of the space!

$$p_{KK} : \begin{cases} x_5 \sim x_5 + \pi \\ x_6 \sim x_6 + \pi \end{cases}$$



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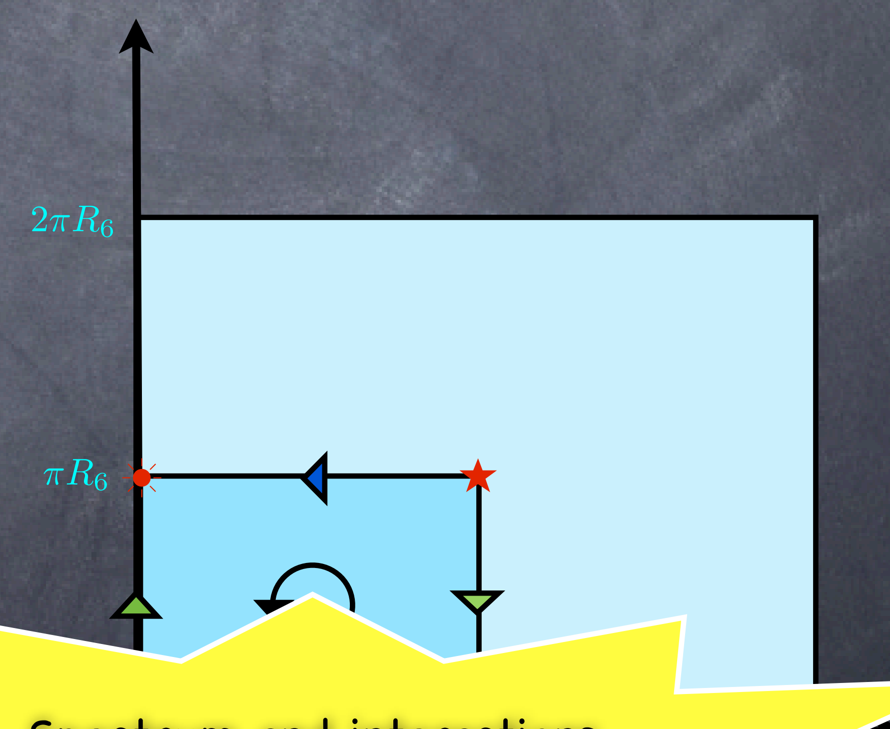

KK parity is an exact symmetry of the space!

$$p_{KK} : \begin{cases} x_5 \sim x_5 + \pi \\ x_6 \sim x_6 + \pi \end{cases}$$

Spectrum and interactions determined by these symmetries!

Spectrum of the SM

	+	−	+	+	−
$p_{KK} = (-1)^{k+l}$	(0,0) m = 0	(1,0) & (0,1) m = 1	(1,1) m = 1.41	(2,0) & (0,2) m = 2	(2,1) & (1,2) m = 2.24
Gauge bosons G, A, Z, W	✓		✓	✓	✓
Gauge scalars G, A, Z, W		✓	✓		✓
Higgs boson(s)	✓		✓	✓	✓
Fermions	✓	✓	✓ (x2)	✓	✓ (x2)

DM candidate here!

Spectrum of the SM

$p_{KK} = (-1)^{k+l}$	+ (0,0) m = 0	− (1,0) & (0,1) m = 1	+ (1,1) m = 1.41	+ (2,0) & (0,2) m = 2	− (2,1) & (1,2) m = 2.24
Gauge bosons G, A, Z, W	✓		✓	✓	✓
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Higgs boson(s)	✓		✓	✓	✓
Fermions	✓	✓	✓ (x2)	✓	✓ (x2)

One-loop corrections are crucial to determine spectrum and decays!

G.C., A.Deandrea, J.Llodra-Perez 1104.3800

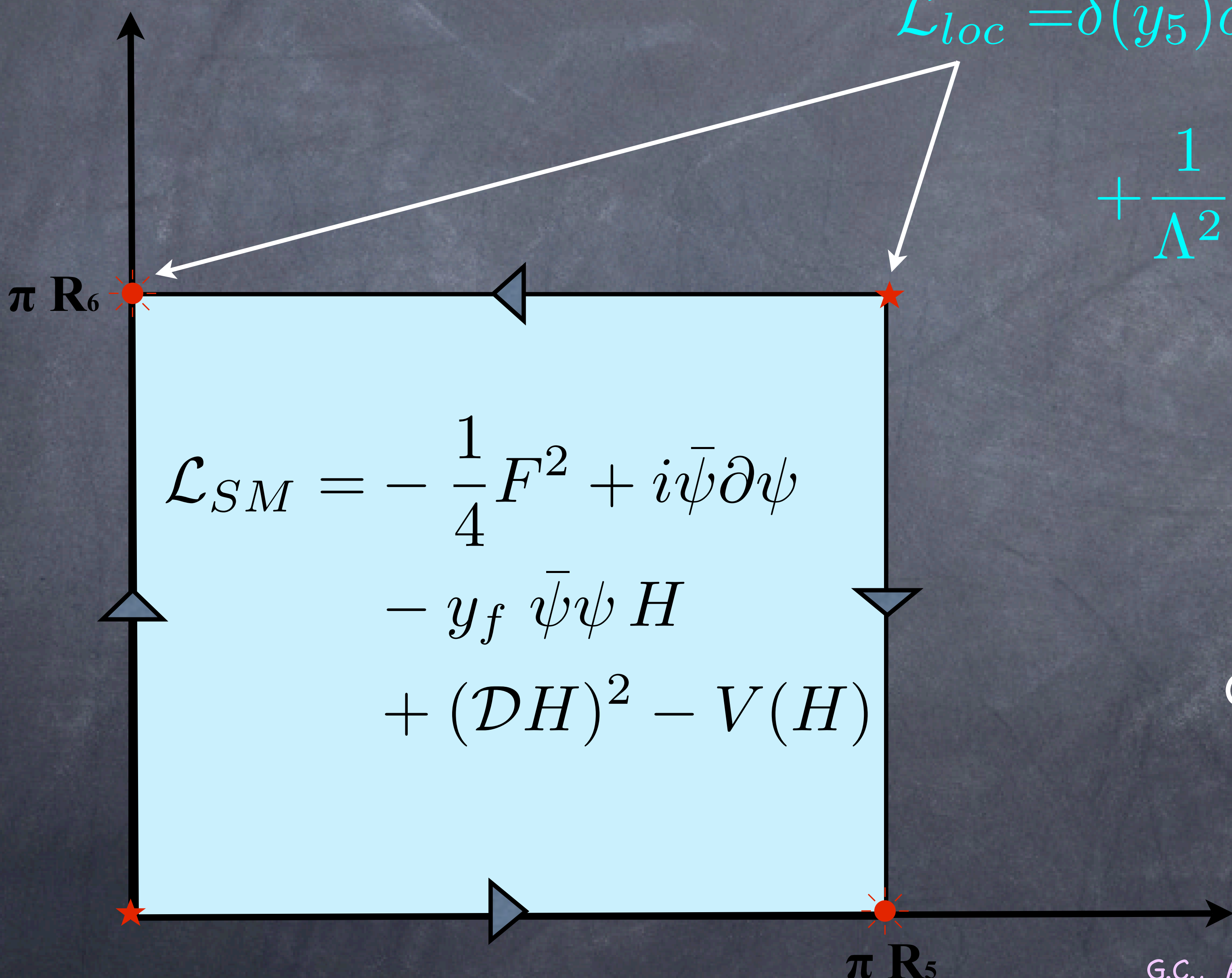
G.C., B.Kubik 1209.6556

Spectrum of the SM

Bulk: KK number conserving!

Localised: KK number violating!

$$\mathcal{L}_{loc} = \delta(y_5)\delta(y_6)\left\{ -m_{loc}^2 H^2 + \right.$$
$$\left. + \frac{1}{\Lambda^2}\left(-\frac{1}{4}F^2 + \dots \right) \right\}$$



$$\mathcal{L}_{SM} = -\frac{1}{4}F^2 + i\bar{\psi}\partial\psi$$
$$- y_f\, \bar{\psi}\psi\, H$$
$$+ (\mathcal{D}H)^2 - V(H)$$

Higher order operators!

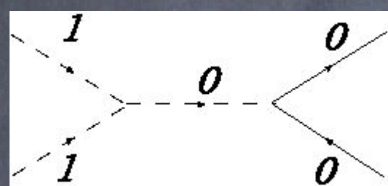
Counter-terms for 1-loop log divergences!

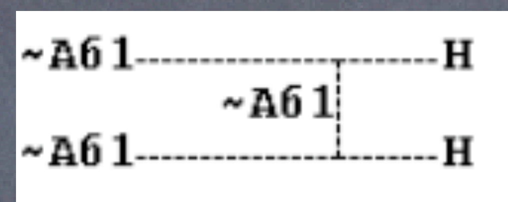
G.C., A.Deandrea, J.Llodra-Perez 1104.3800

WMAP bounds!

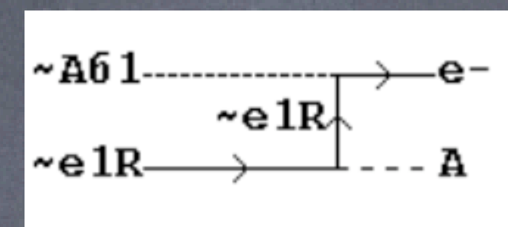
A.Arbey, G.C., A.Deandrea, B.Kubik 1210.0384

There are several equally relevant contributions:

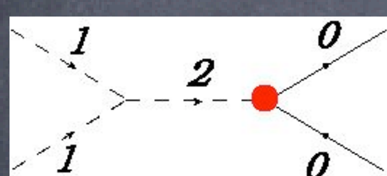


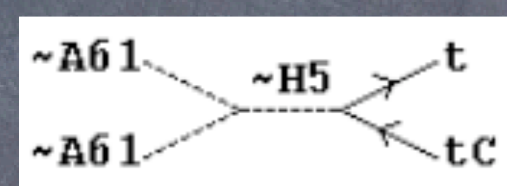


Annihilation

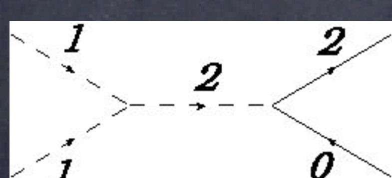


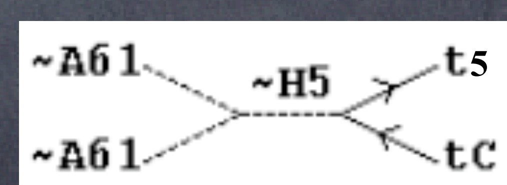
Co-annihilation
(small mass splitting)





Resonant annihilation
(s-channel level 2 states!)

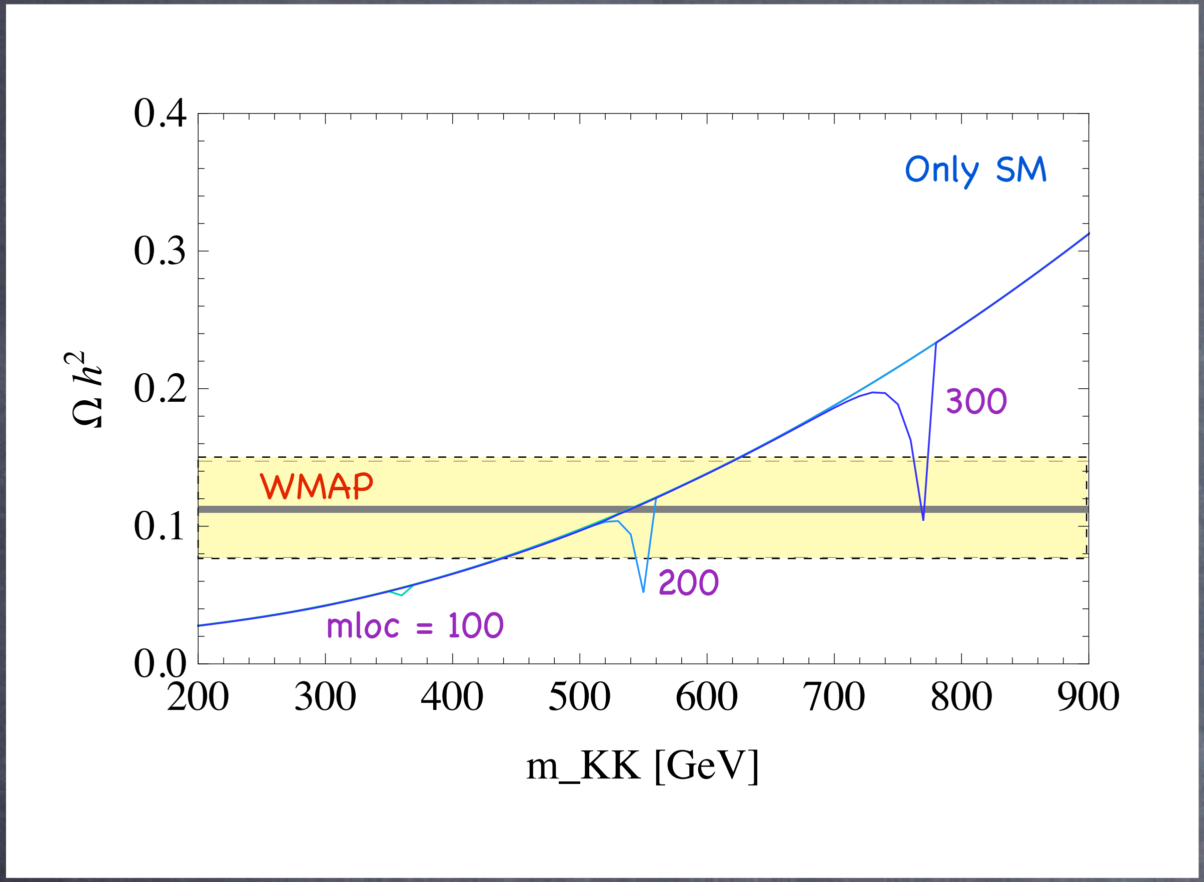


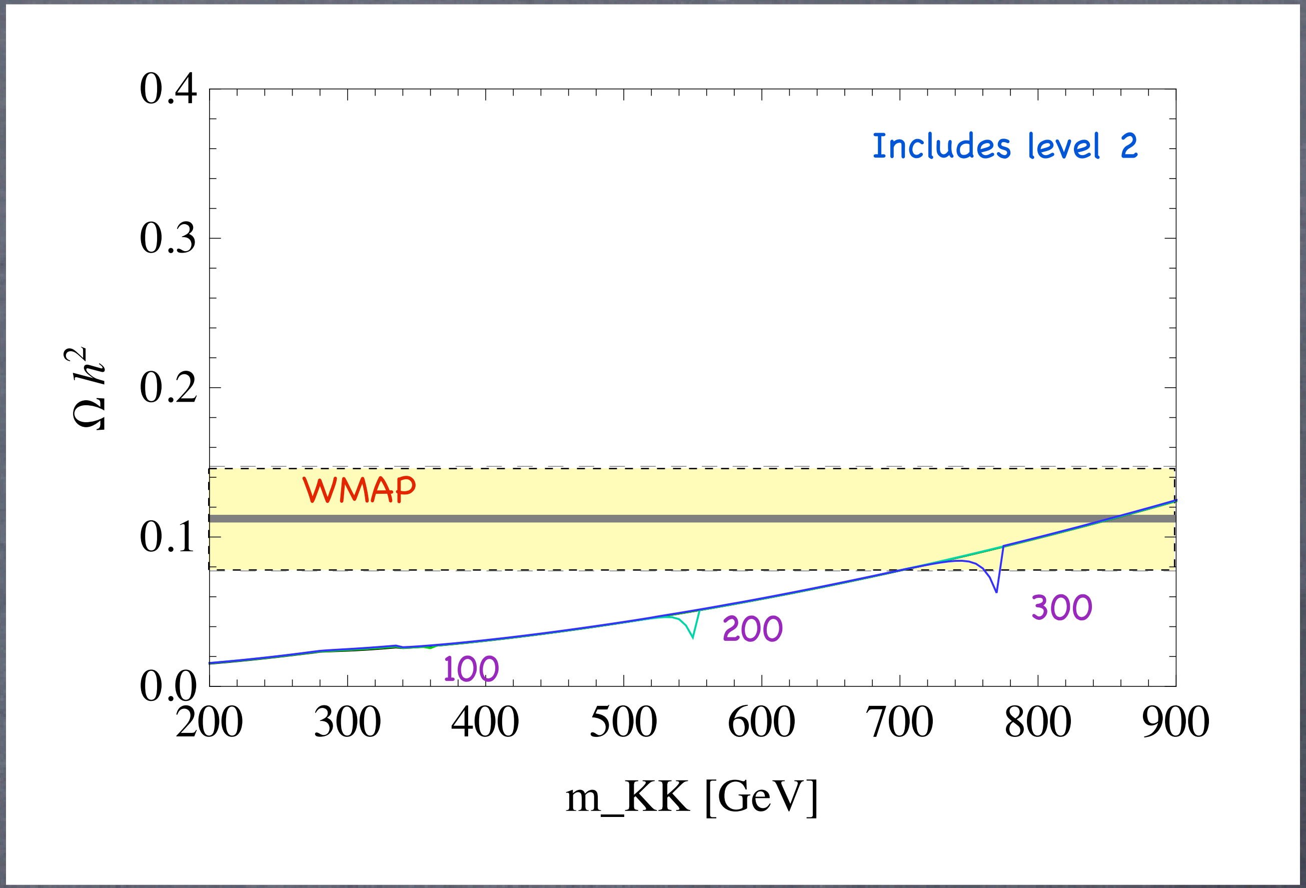


G.Belanger, M.Kakizaki, A.Phukov 1012.2577

Level 2 annihilation
(level 2 decaying into SM pair!)

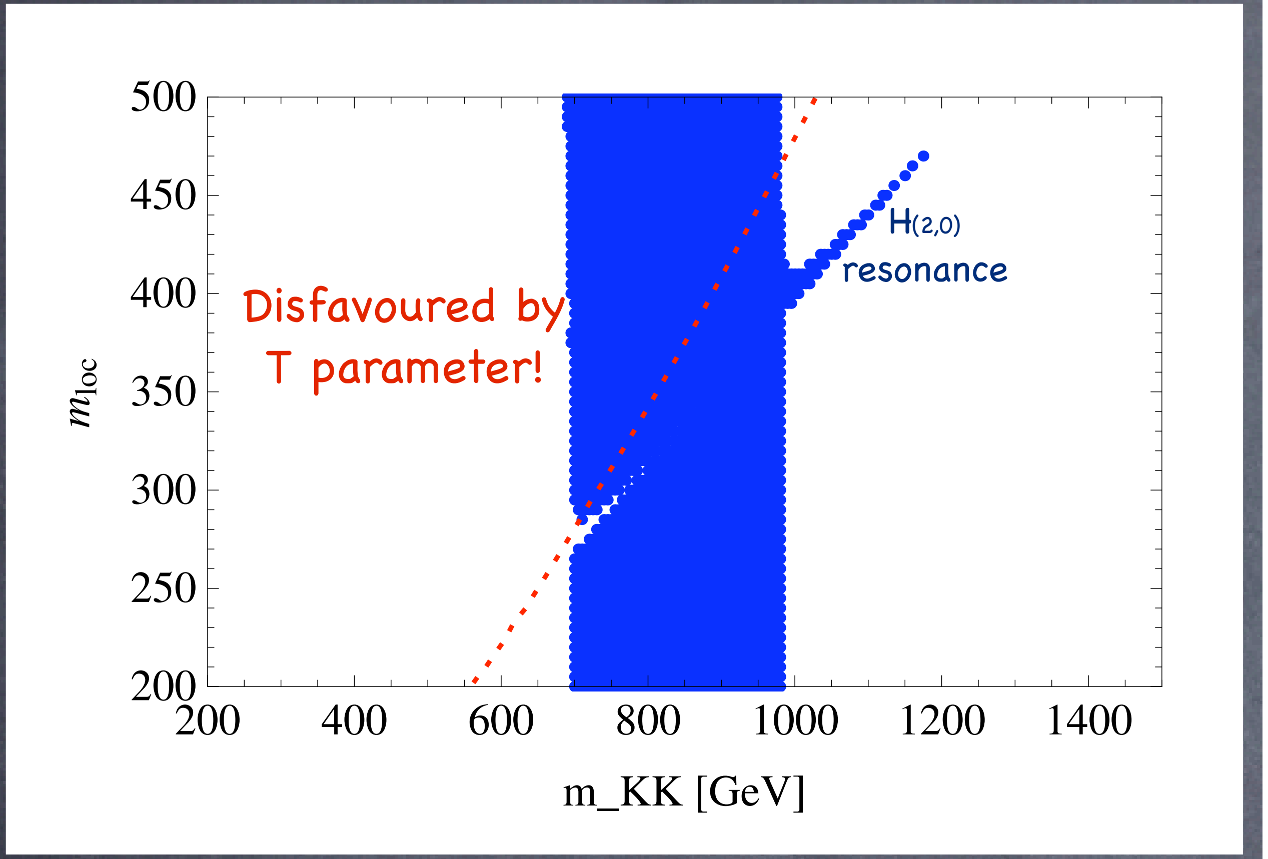
WMAP bounds!

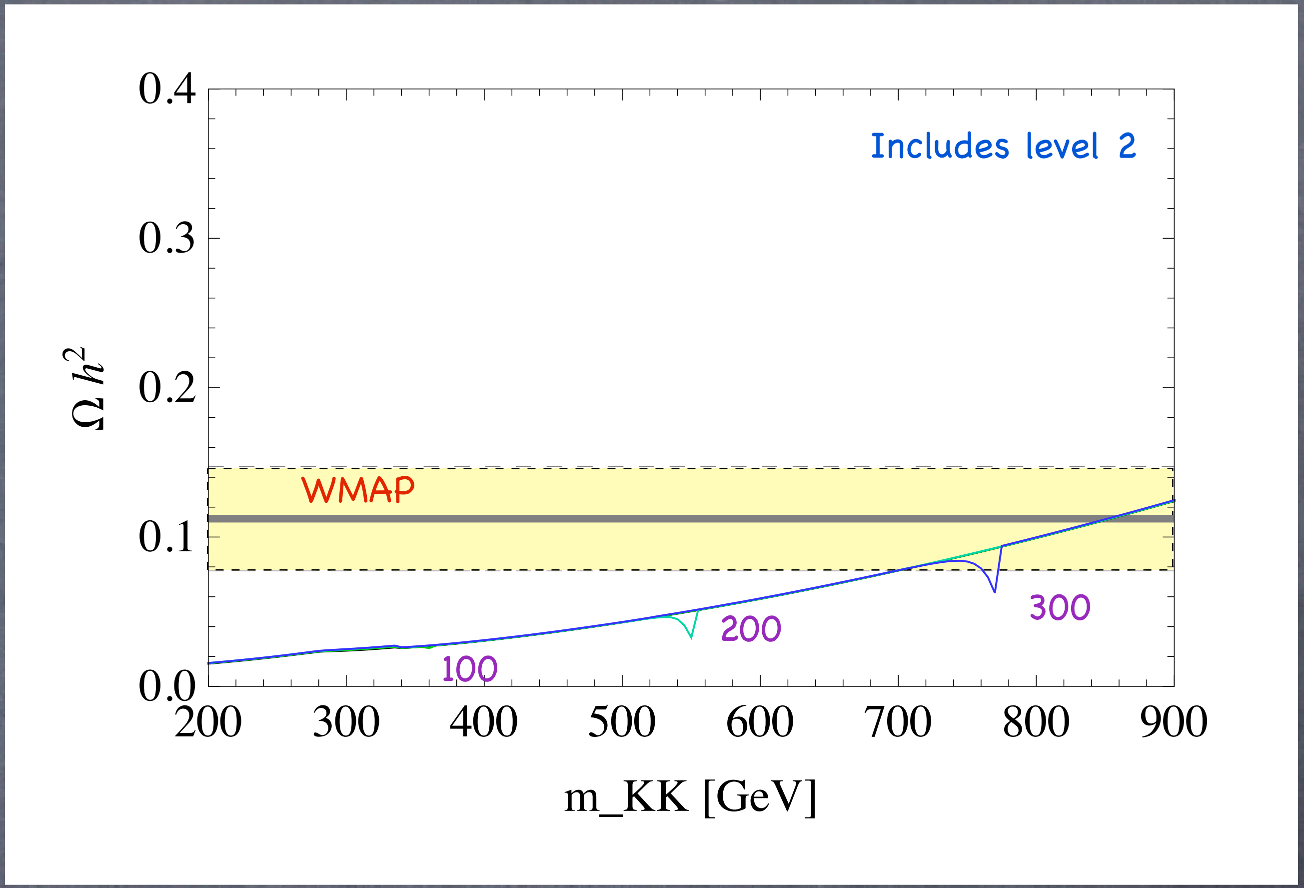




- Annihilation into level-2 ⇒ increased cross-sections ⇒ higher mKK
- mloc controls $H_{(2,0)}$ resonance!
- $H_{(2,0)}$ opens resonant funnel!

WMAP bounds!



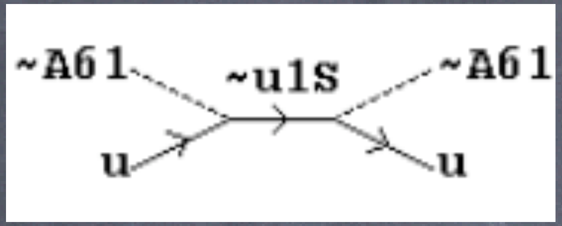


- Annihilation into level-2 ⇒ increased cross-sections ⇒ higher mKK
- mloc controls $H_{(2,0)}$ resonance!
- $H_{(2,0)}$ opens resonant funnel up to 1200!

WMAP preferred range:

700 < mKK < 1000

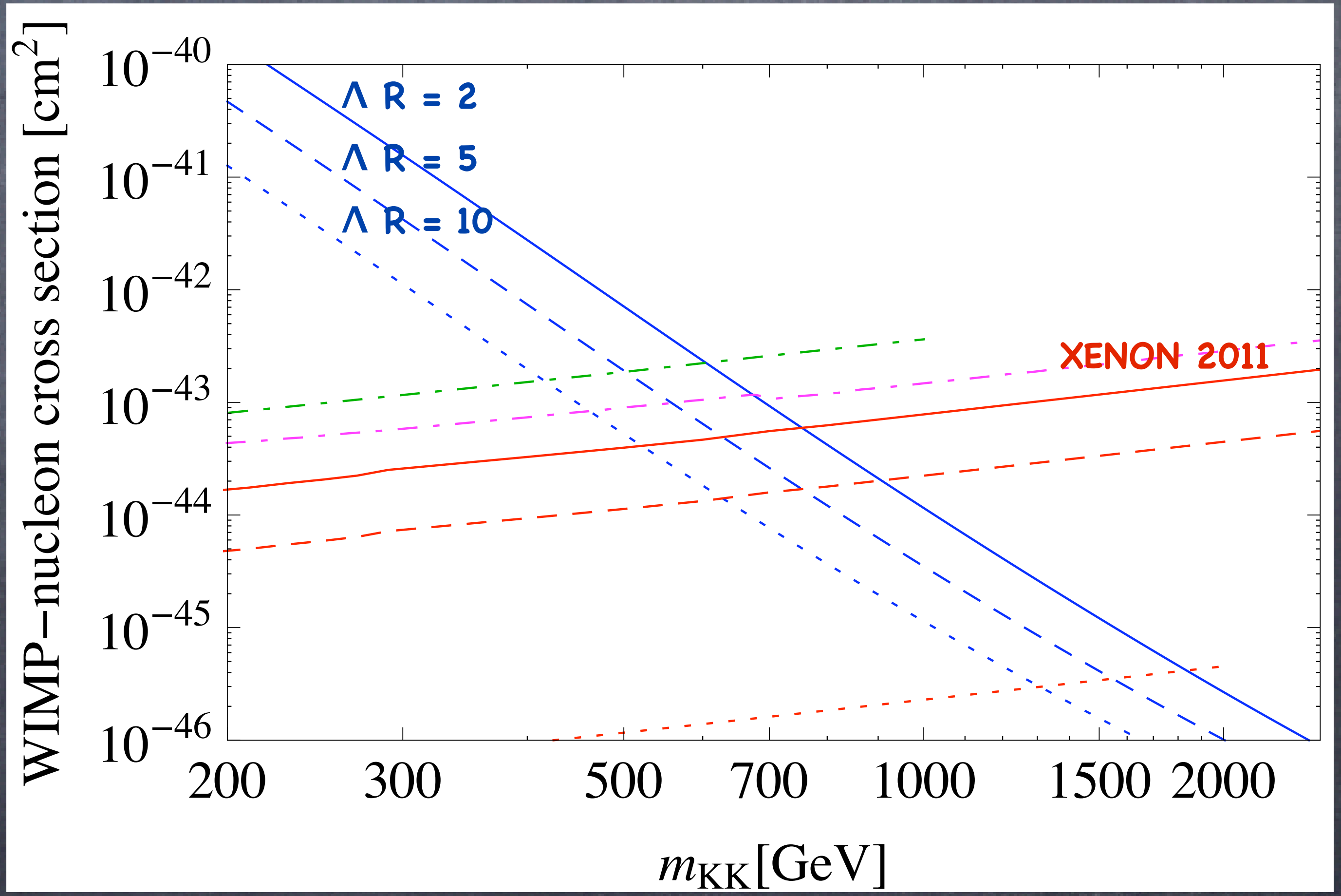
Direct detection bounds



Relevant processes:
crucial the loop corrections
to level-1 masses!

- The Spin-Independent cross section is enhanced by the small splittings!

Bound sensitive to
cut-off Λ
via log-div. loops!



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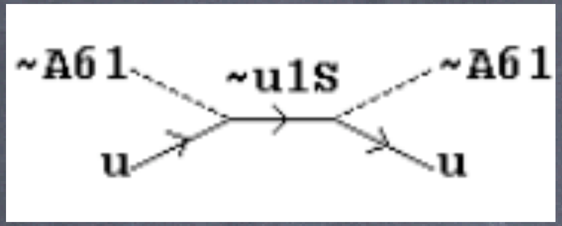

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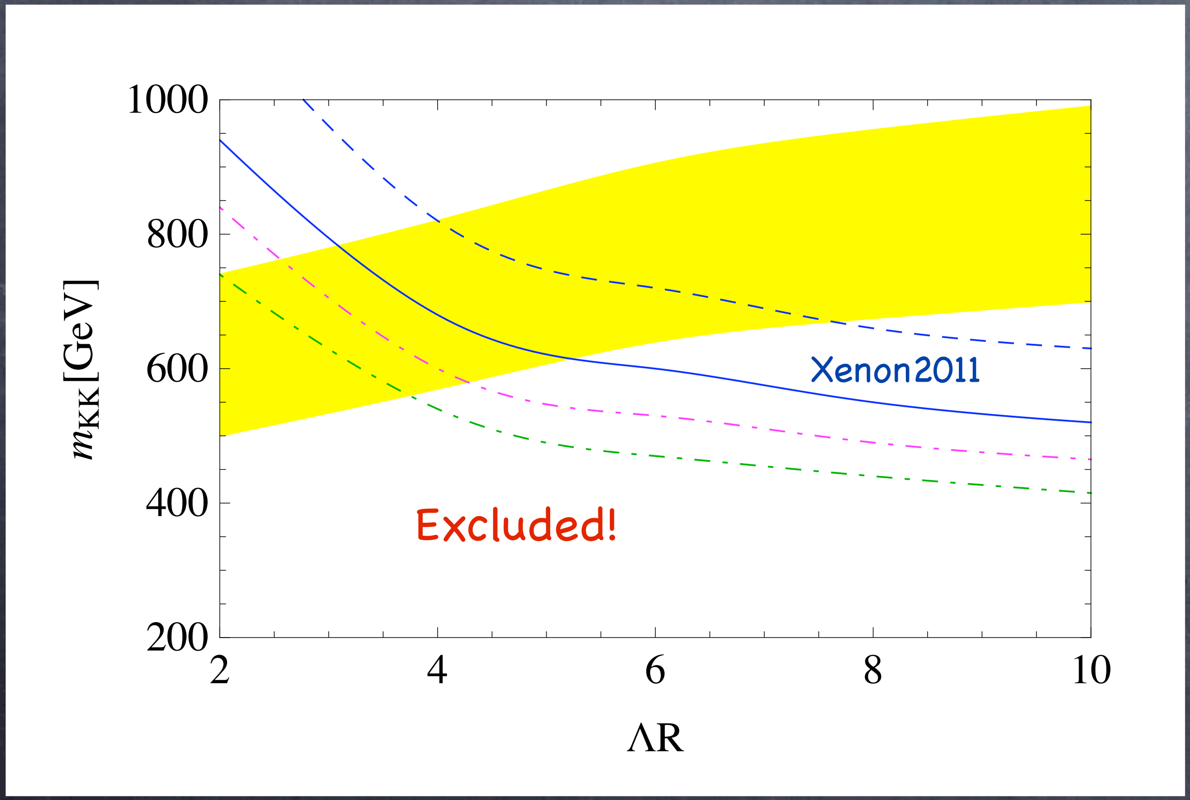
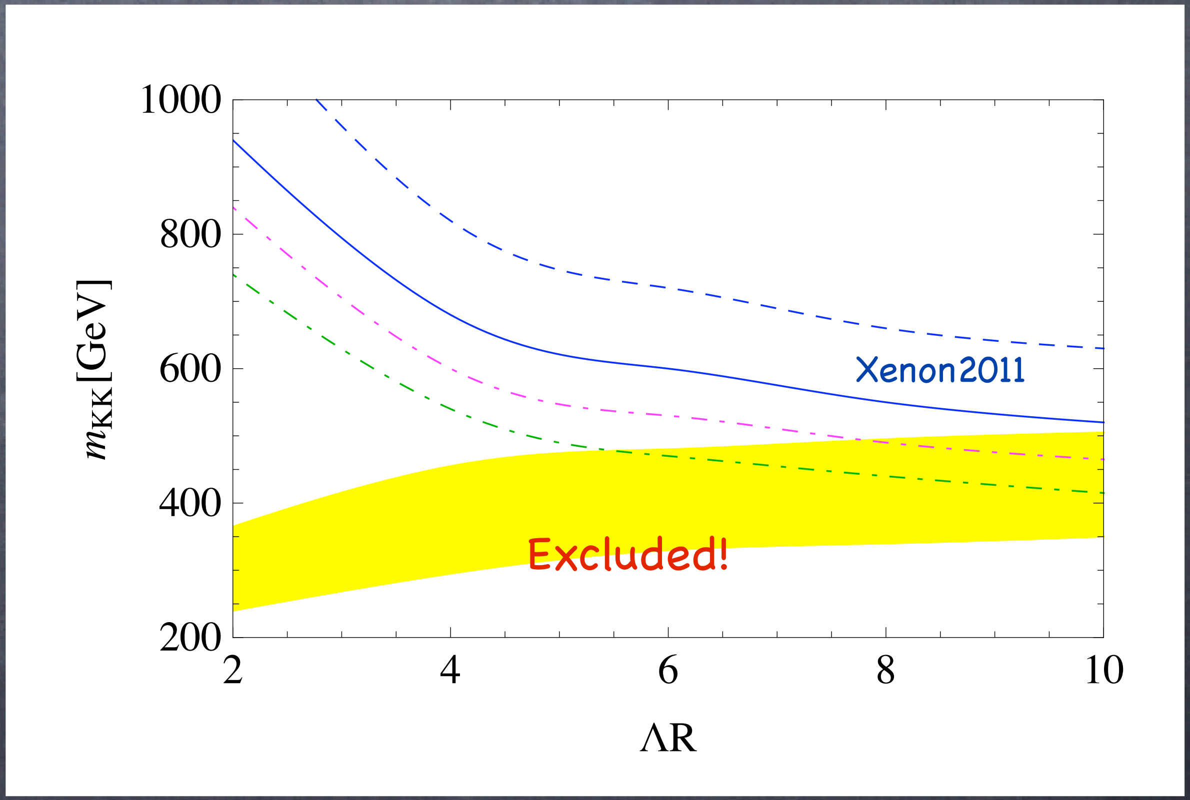


$R_5 > R_6$



$R_5 = R_6$

LHC signatures without MET:

tiers (2,0) and (0,2)

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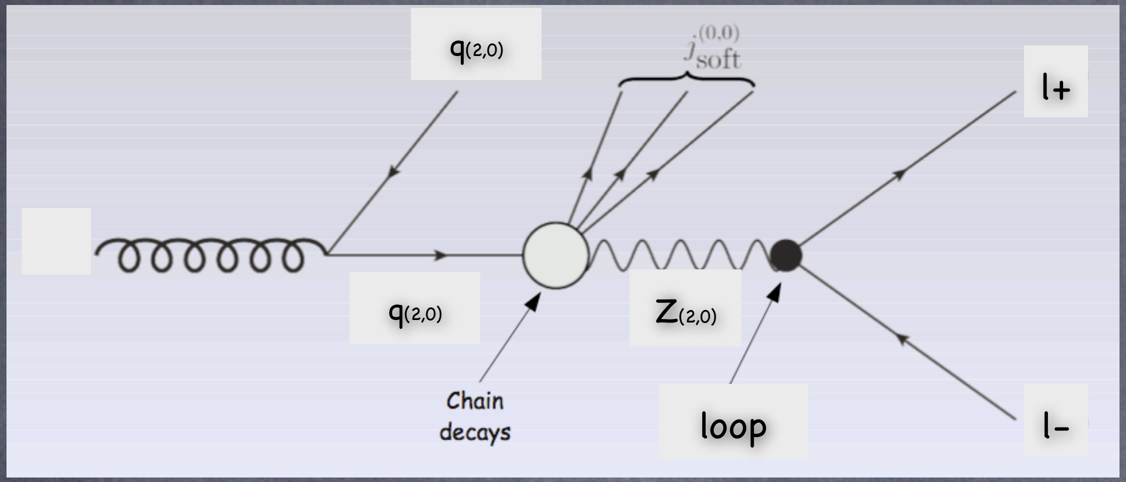
- Cleanest channels are di-lepton (Z′) and single lepton + MET (W′):

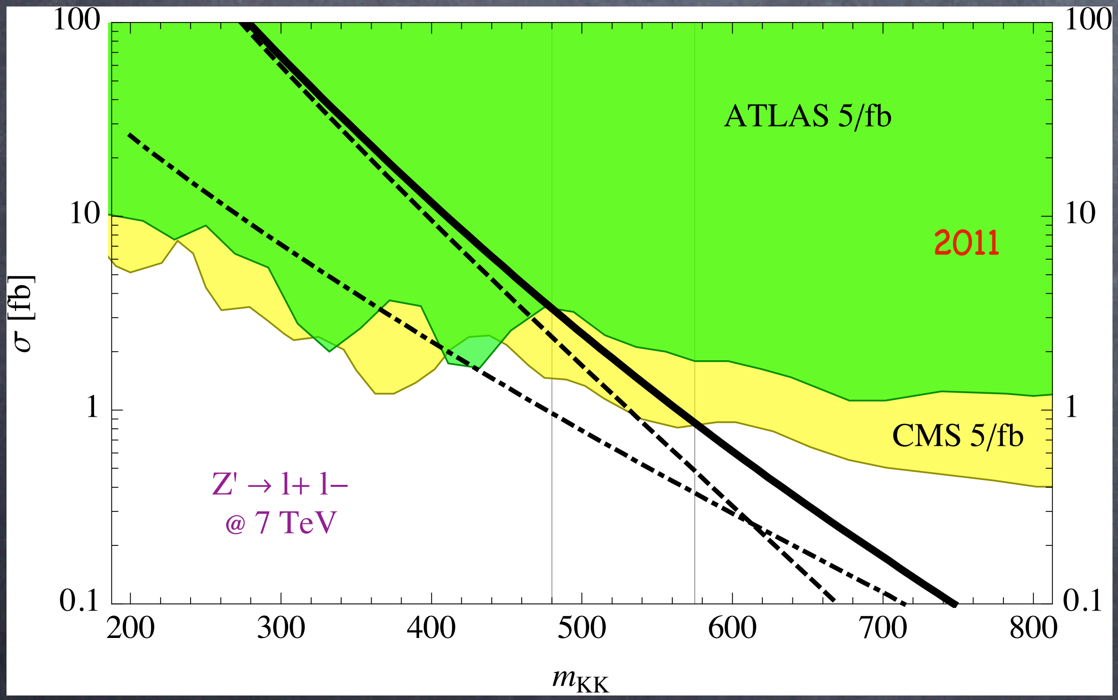


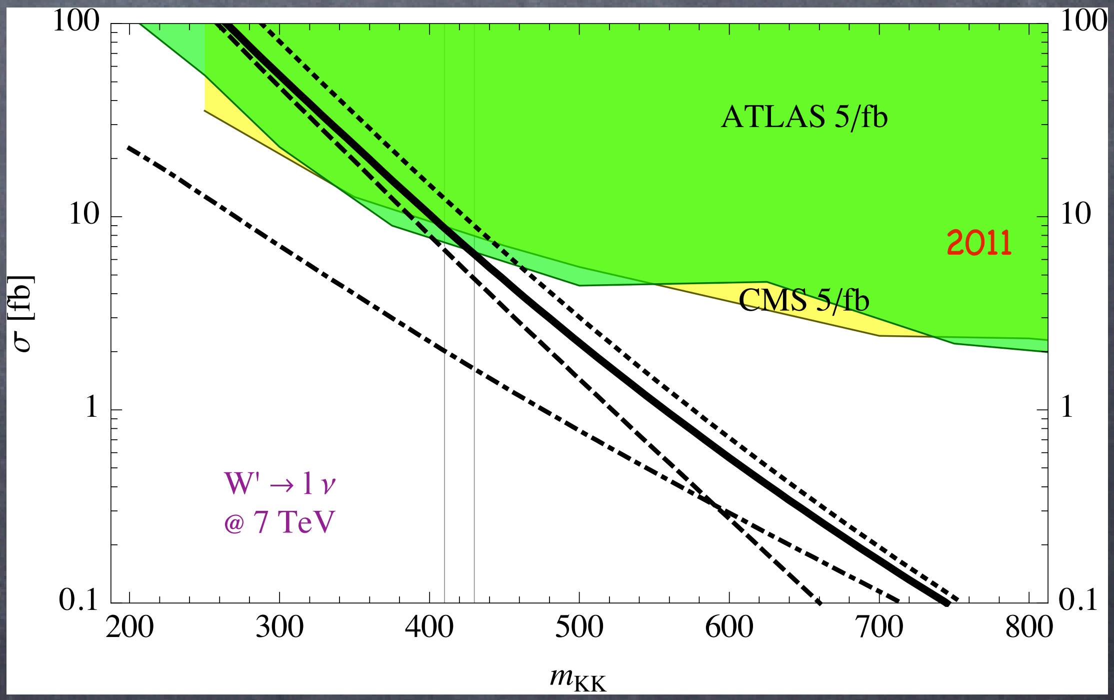
$Z_{(2,0)}$, $A_{(2,0)}$ -> l l

BR: 0.2% !!

$W_{(2,0)}$ -> l ν

2011 Data only!





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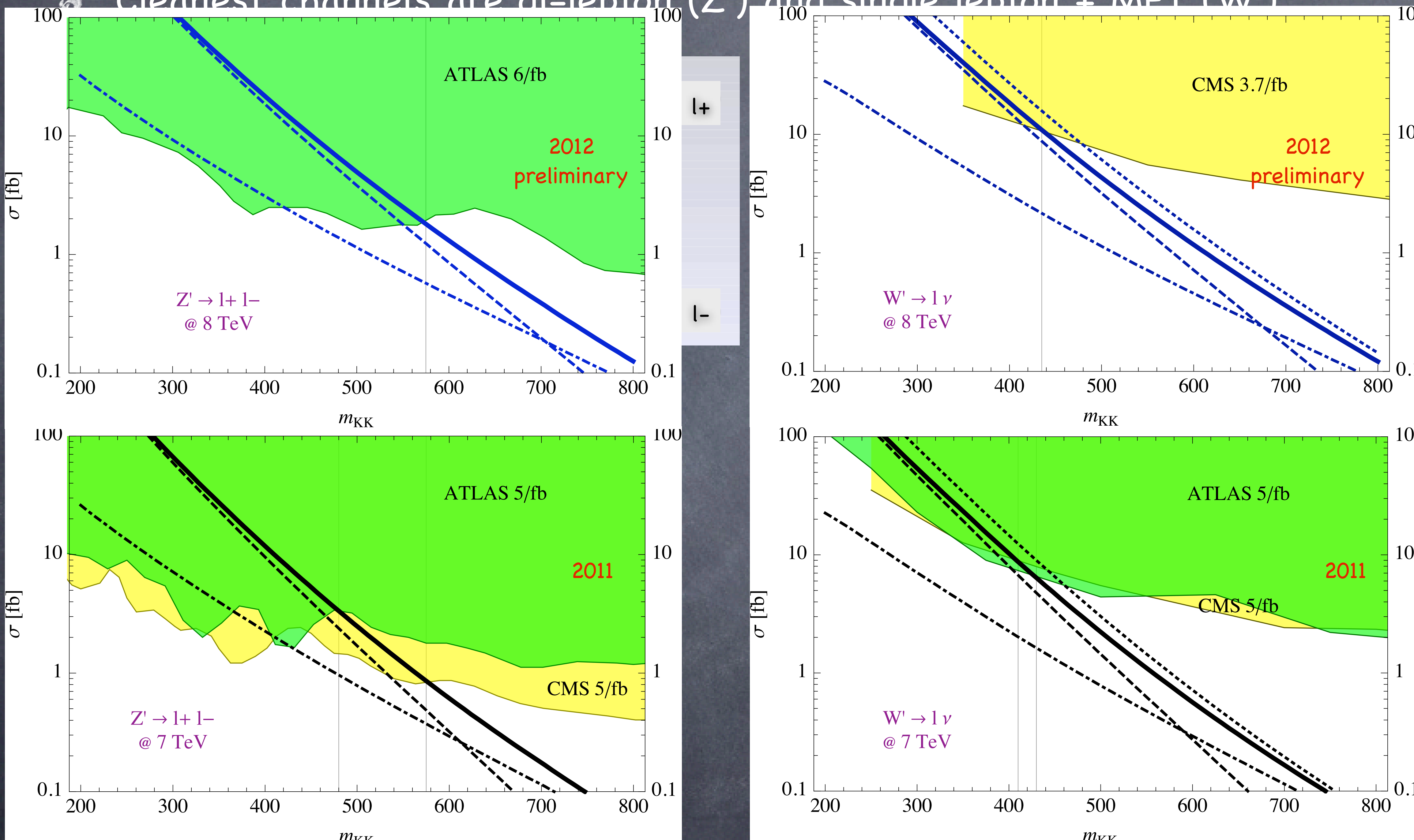


$R_5 > R_6$

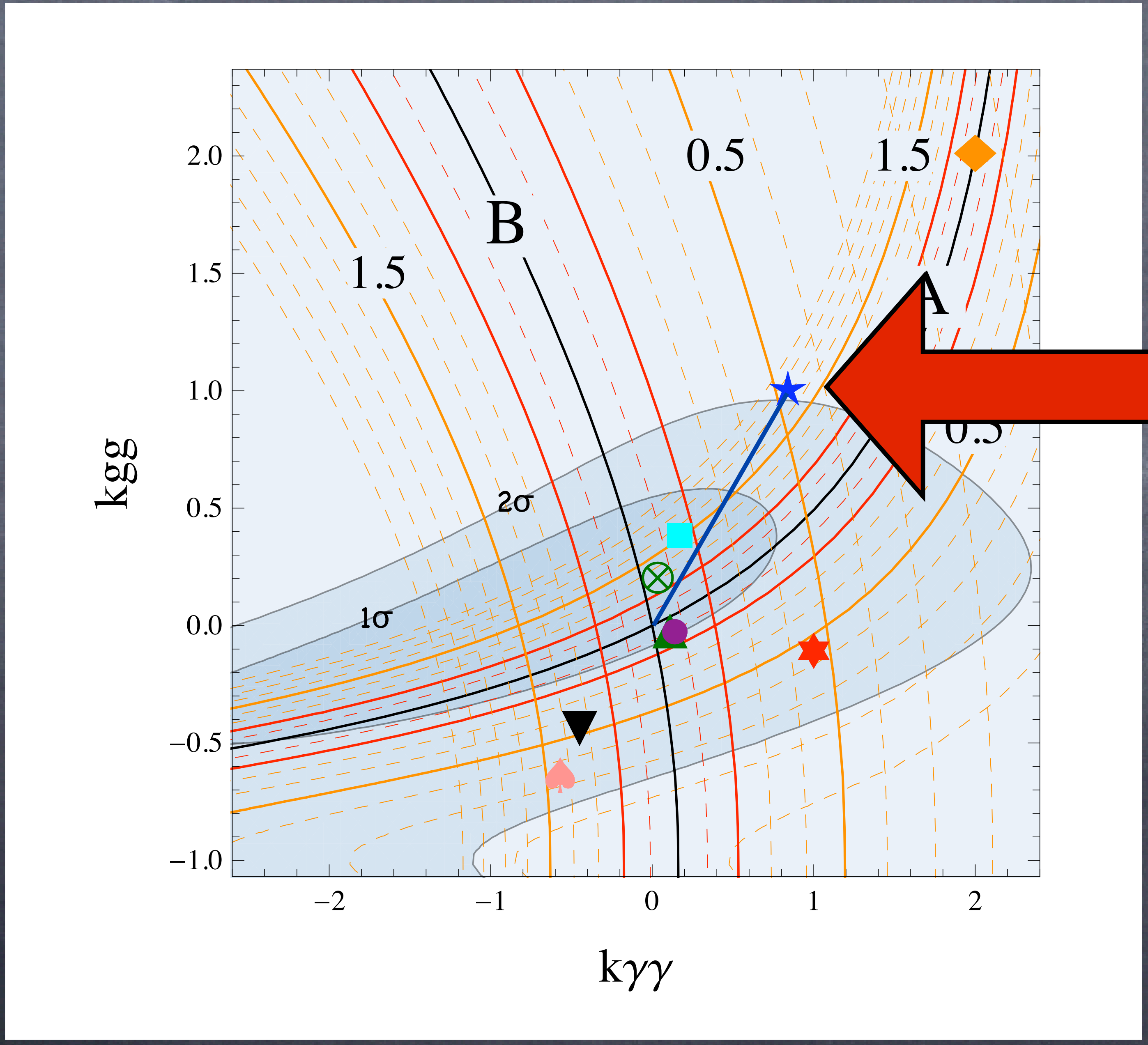
LHC: the Higgs discovery!

G.C., A.Deandrea, J.Llodra-Perez 0901.0927
G.C., A.Deandrea, G.Drieu La Rochelle, J.B.Flament 1210.8120

- The KK resonances of W and top contribute to H→gg and H →γγ loops!

ATLAS data

- H →γγ
- H →ZZ



mKK = 600 GeV

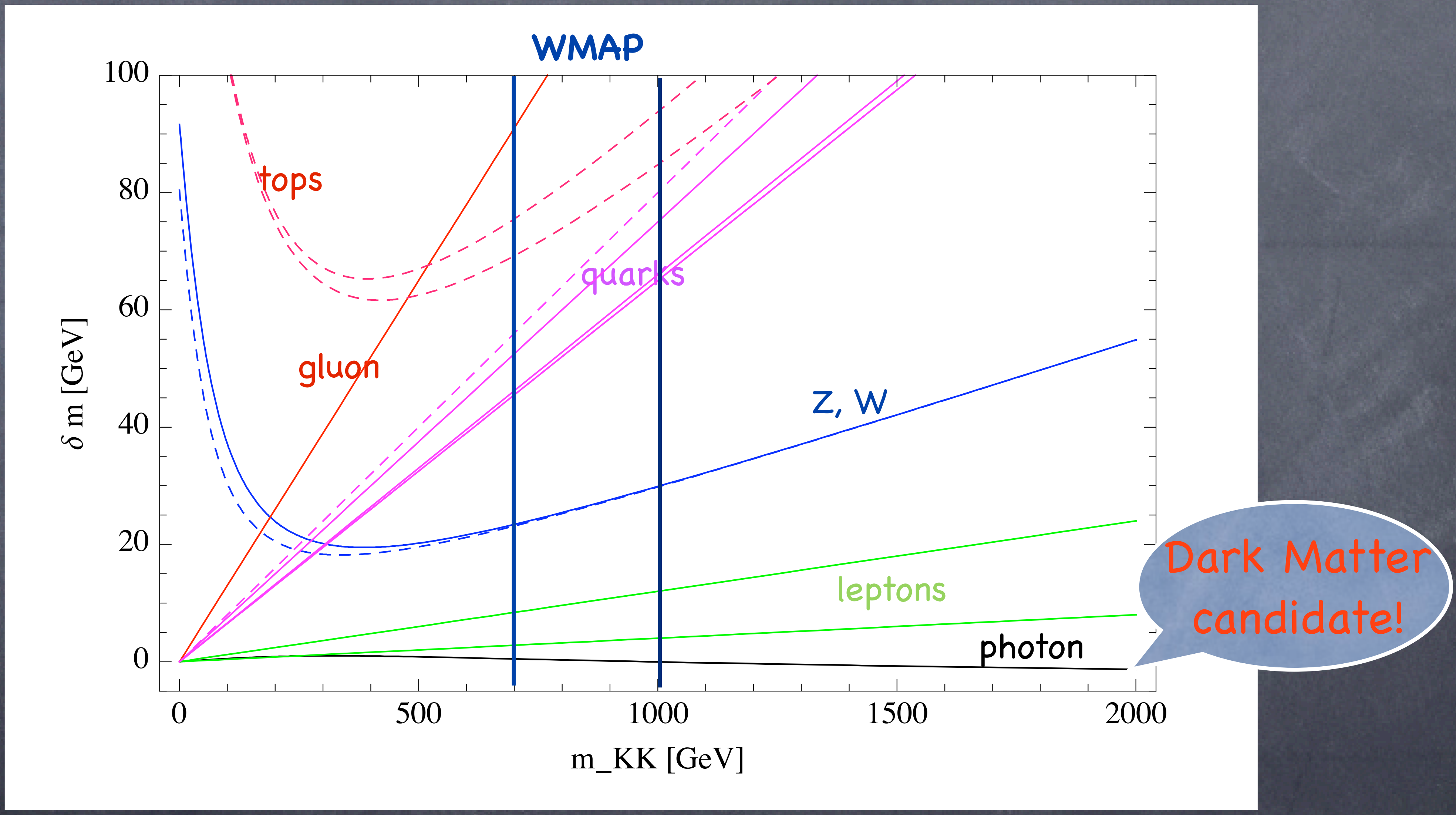
k_{gg}, $k_{\gamma\gamma} \approx 1/mKK^2$

Conclusions and outlook

- Exact KK parity is a very selective requirement on XDs: RPP in 6D flat!
- SM on the RPP: rich but challenging pheno (small mass splitting!)
- Case $R_5 = R_6$ excluded by Direct Searches.
- Case $R_5 > R_6$ preferred range 700 < mKK < 1000 GeV.
- LHC bounds @ mKK > 600 GeV level (leptonic Z' and W')
- Others: signatures with MET (+ jets) from (1,0) and (1,2); 4 tops from (1,1); etc.

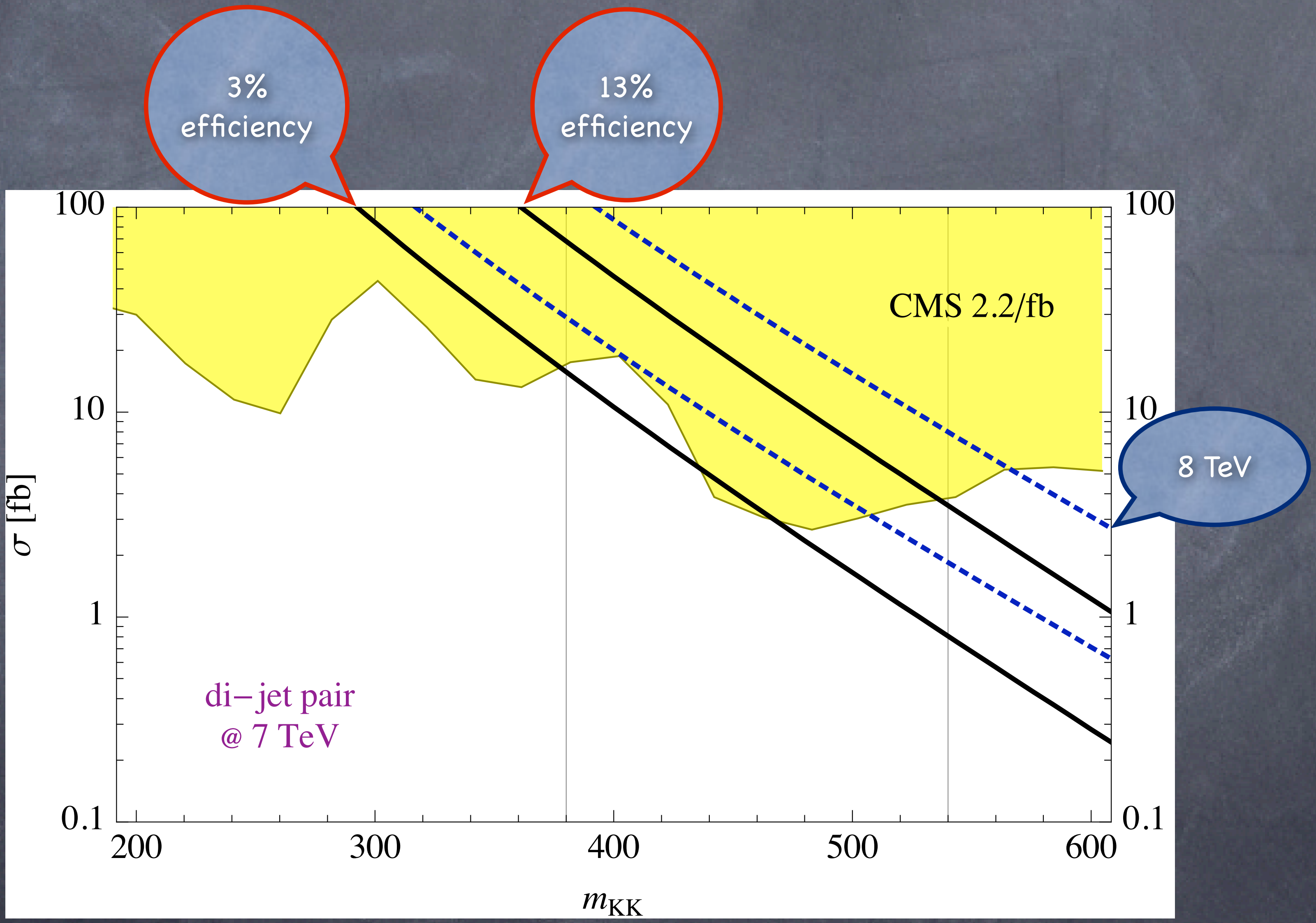
For the levels (1,0) and (0,1):

$$m = m_{KK} + \delta m$$



Other LHC bounds

Pair of di-jet resonances



$R_5 > R_6$