LHC tests and discovery reach of a 6D model with Lorentz dark matter

Aldo Deandrea, IPN Lyon

In collaboration with G.Cacciapaglia, B.Kubib, J.Llodra-Perez

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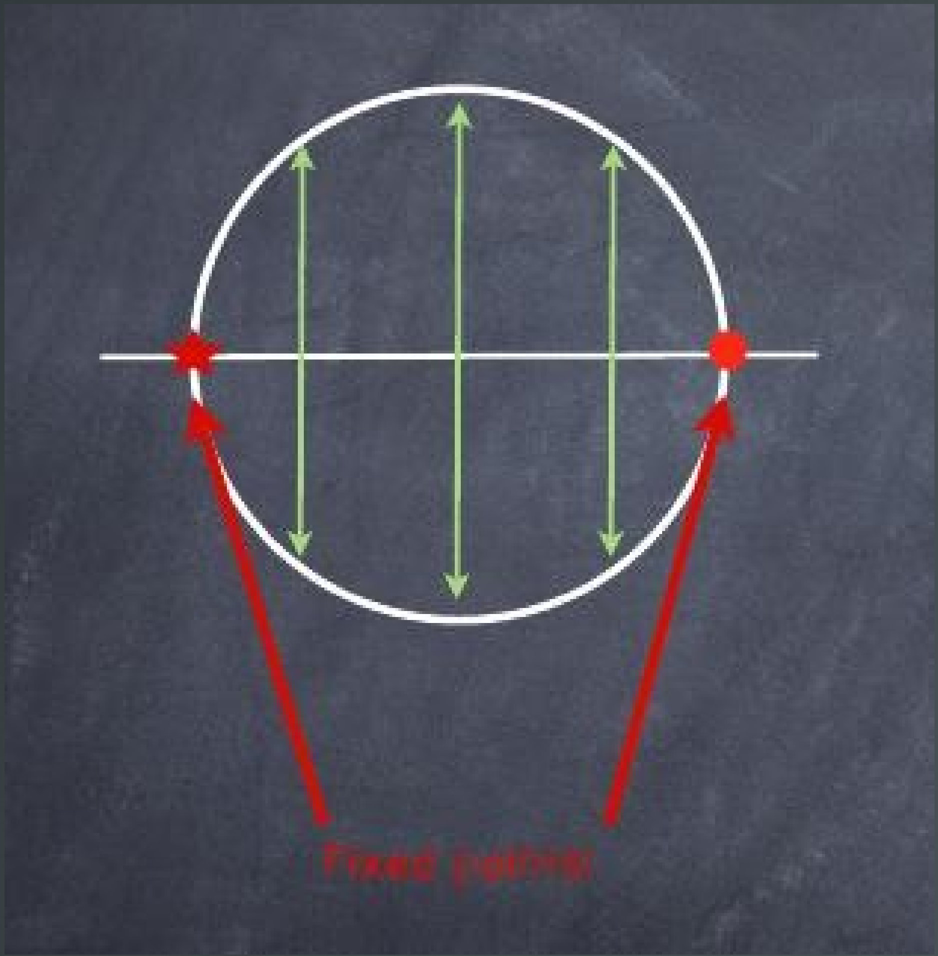
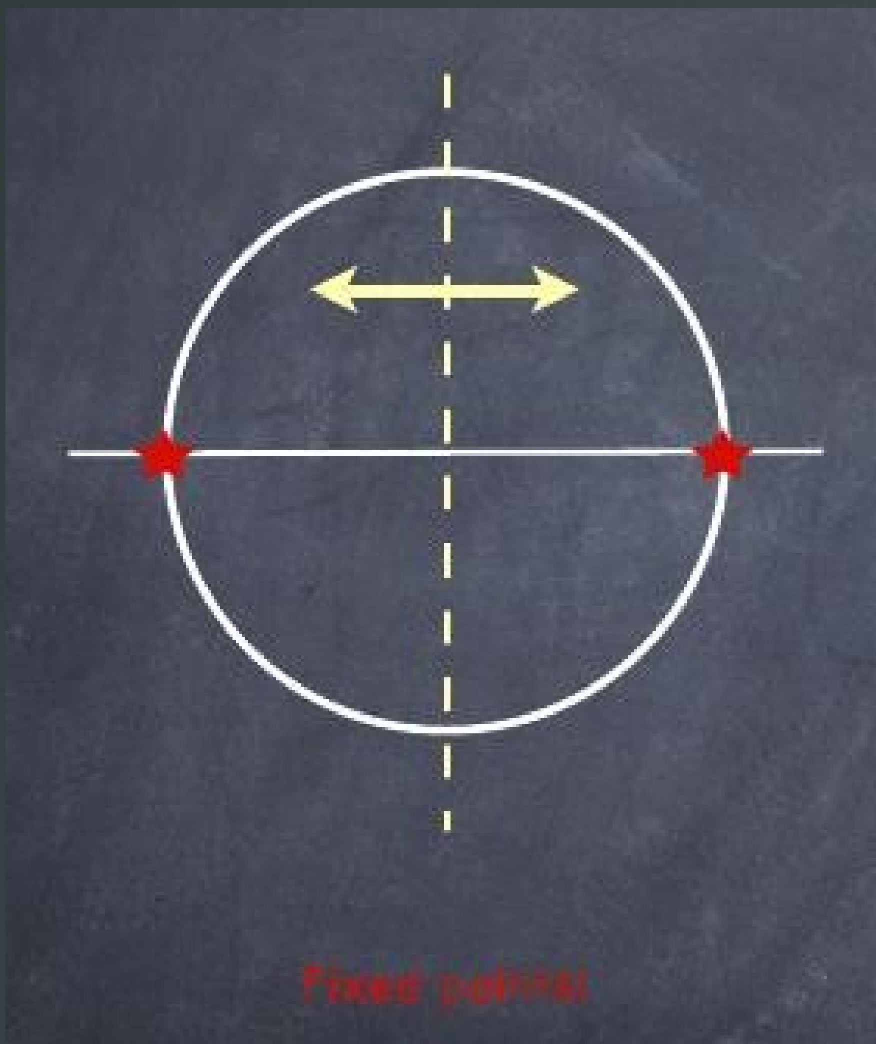
Extra dimensions and fermions



- Typical extra dimensional models require orbifolding to obtain 4-dim chiral fermion
- What about dark matter?

Extra dimensions and dark matter

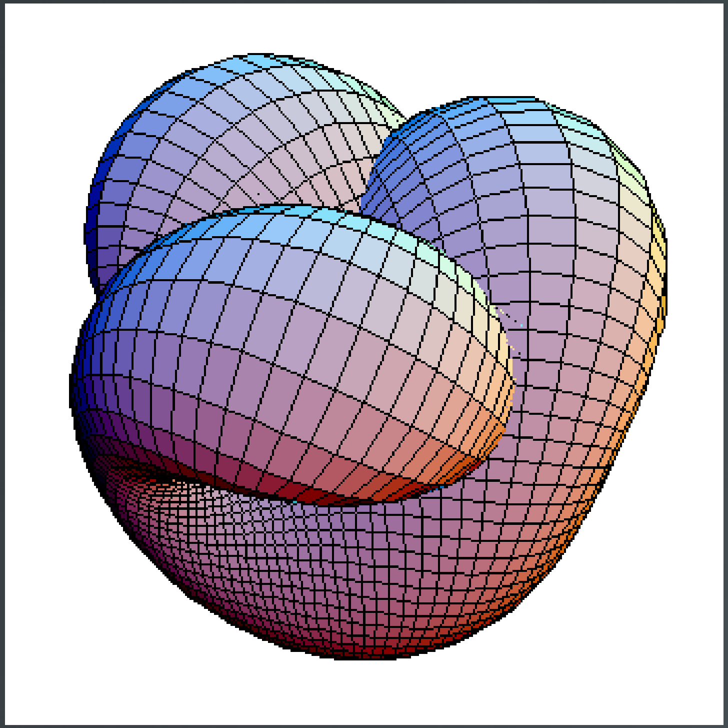


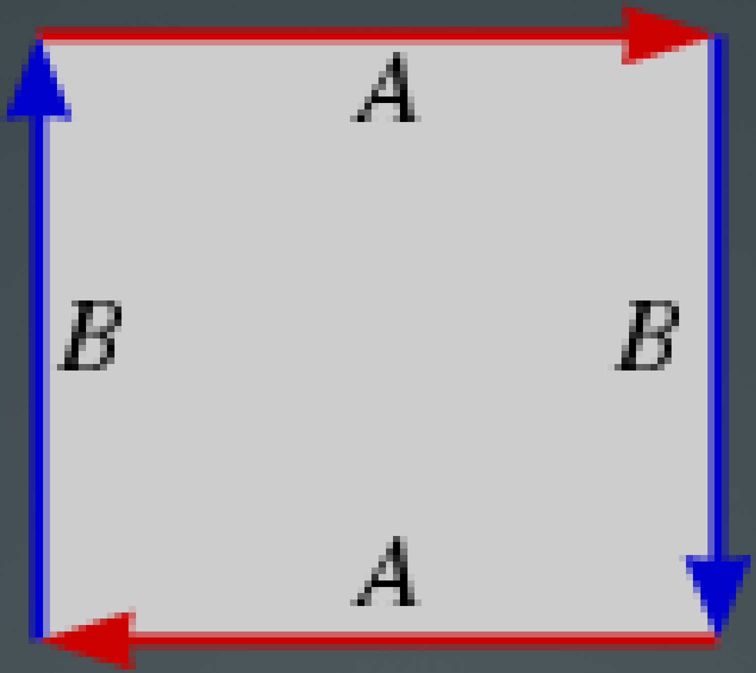
- KK parity is added ad-hoc to ensure dark matter is stable
- No fundamental (symmetry) reason for that

Orbifolds without fixed points

- One X-dim does not have candidates with chiral fermions and no fixed points
- 2 X-dim has the 17 wallpaper groups in the plane
  - Only 3 have no fixed points (Torus, Klein bottle and Real Projective Plane)
  - Only 1 has more over chiral fermions without further orbifolding (Real Projective Plane)

Real Projective Plane (geometry)





Symmetry group structure

$r : x_5 \rightarrow - x_5$

$\quad x_6 \rightarrow - x_6$

$g : x_5 \rightarrow x_5 + \pi R_5$

$\quad x_6 \rightarrow - x_6 + \pi R_6$

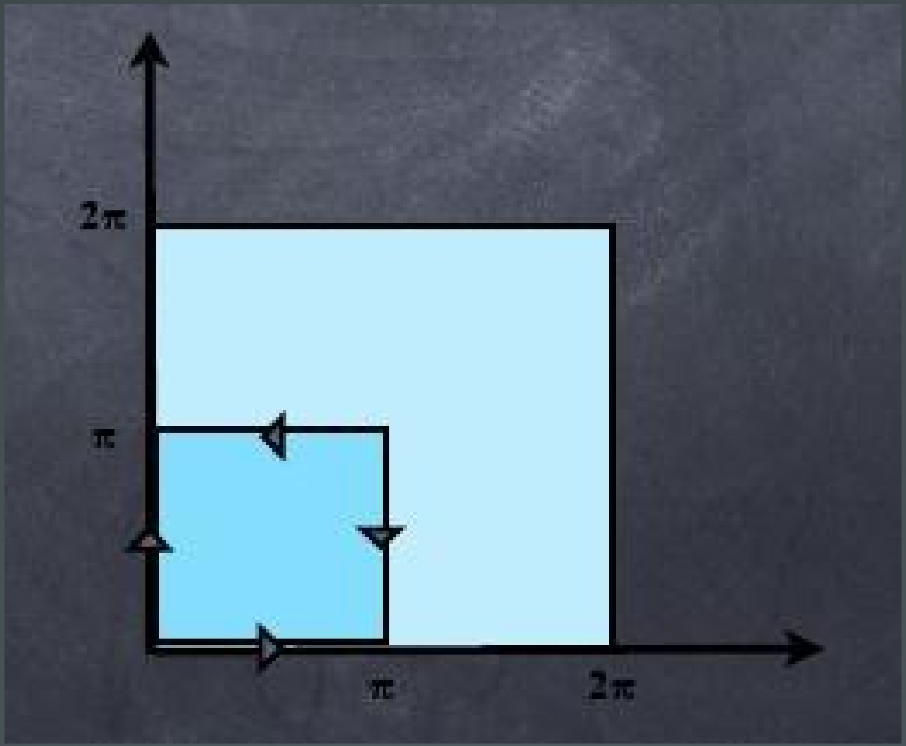
KK parity

$x_5 \rightarrow x_5 + \pi$

$x_6 \rightarrow x_6 + \pi$

Built in as an exact symmetry of the orbifold

$pgg = < r,g \mid r^2 = (g^2 r)^2 = 1 >$



Particles

$p_{KK} = (-1)^{k+l}$	(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)

Scalars

(k,l)	p_{KK}	$(++)$	$(+-)$	$(-+)$	$(--)$
$(0,0)$	$+$	$\frac{1}{2\pi}$			
$(0,2l)$	$+$	$\frac{1}{\sqrt{2}\pi}\cos 2lx_6$			$\frac{1}{\sqrt{2}\pi}\sin 2lx_6$
$(0,2l-1)$	$-$		$\frac{1}{\sqrt{2}\pi}\cos(2l-1)x_6$	$\frac{1}{\sqrt{2}\pi}\sin(2l-1)x_6$	
$(2k,0)$	$+$	$\frac{1}{\sqrt{2}\pi}\cos 2kx_5$		$\frac{1}{\sqrt{2}\pi}\sin 2kx_5$	
$(2k-1,0)$	$-$		$\frac{1}{\sqrt{2}\pi}\cos(2k-1)x_5$		$\frac{1}{\sqrt{2}\pi}\sin(2k-1)x_5$
$(k,l)_{\mathrm{k+l\ even}}$	$+$	$\frac{1}{\pi}\cos kx_5\cos lx_6$	$\frac{1}{\pi}\sin kx_5\sin lx_6$	$\frac{1}{\pi}\sin kx_5\cos lx_6$	$\frac{1}{\pi}\cos kx_5\sin lx_6$
$(k,l)_{\mathrm{k+l\ odd}}$	$-$	$\frac{1}{\pi}\sin kx_5\sin lx_6$	$\frac{1}{\pi}\cos kx_5\cos lx_6$	$\frac{1}{\pi}\cos kx_5\sin lx_6$	$\frac{1}{\pi}\sin kx_5\cos lx_6$

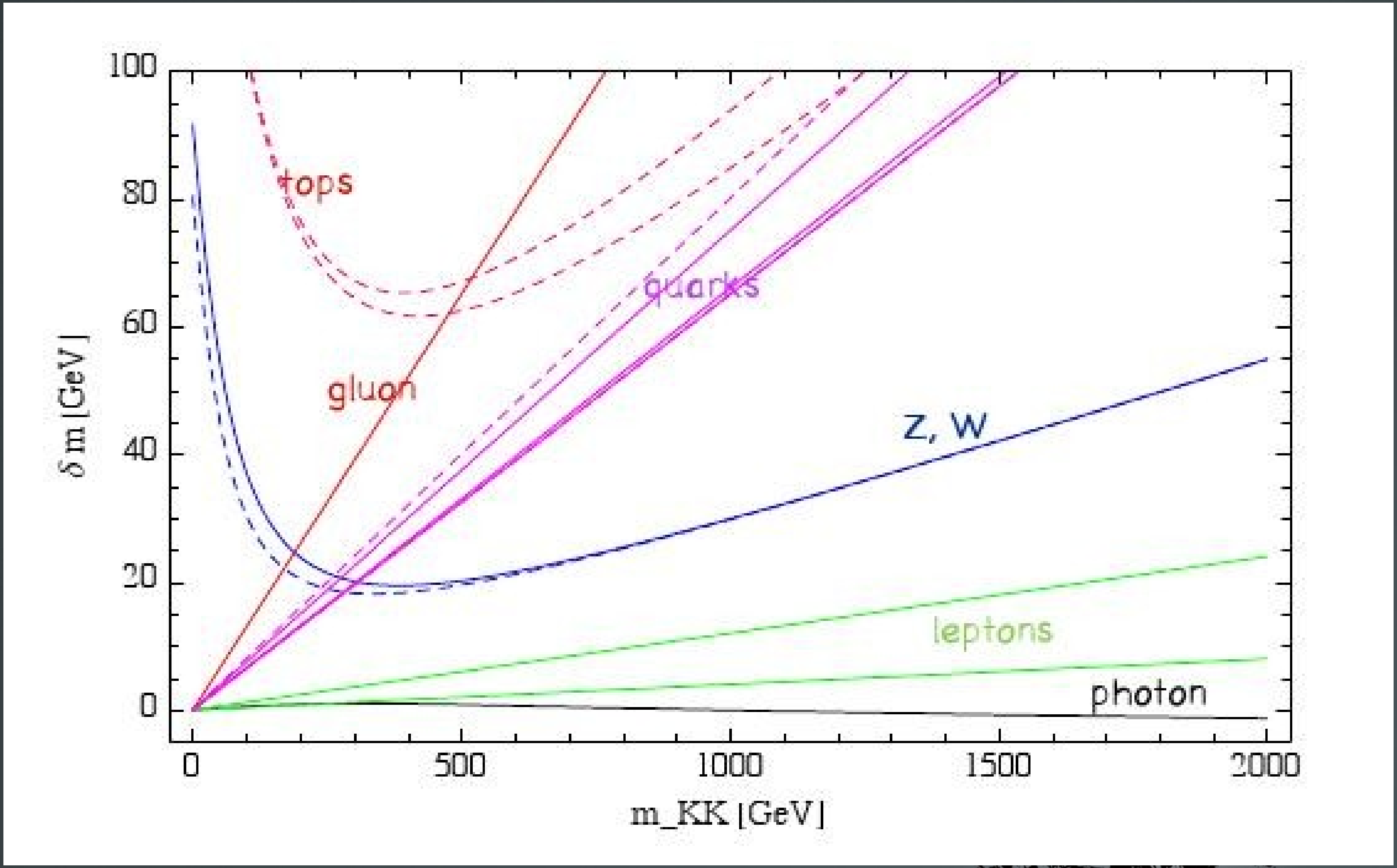
Gauge bosons

(k,l)	p_{KK}	$A_\mu^{(++)}$	$A_5^{(-+)}$	$A_6^{(--)}$
$(0,0)$	$+$	$\frac{1}{2\pi}$		
$(0,2l)$	$+$	$\frac{1}{\sqrt{2}\pi}\cos 2lx_6$		
$(0,2l-1)$	$-$		$\frac{1}{\sqrt{2}\pi}\sin(2l-1)x_6$	
$(2k,0)$	$+$	$\frac{1}{\sqrt{2}\pi}\cos 2kx_5$		
$(2k-1,0)$	$-$			$\frac{1}{\sqrt{2}\pi}\sin(2k-1)x_5$
$(k,l)_{\mathrm{k+l\ even}}$	$+$	$\frac{1}{\pi}\cos kx_5\cos lx_6$	$\frac{l}{\pi\sqrt{k^2+l^2}}\sin kx_5\cos lx_6$	$-\frac{k}{\pi\sqrt{k^2+l^2}}\cos kx_5\sin lx_6$
$(k,l)_{\mathrm{k+l\ odd}}$	$-$	$\frac{1}{\pi}\sin kx_5\sin lx_6$	$\frac{l}{\pi\sqrt{k^2+l^2}}\cos kx_5\sin lx_6$	$-\frac{k}{\pi\sqrt{k^2+l^2}}\sin kx_5\cos lx_6$

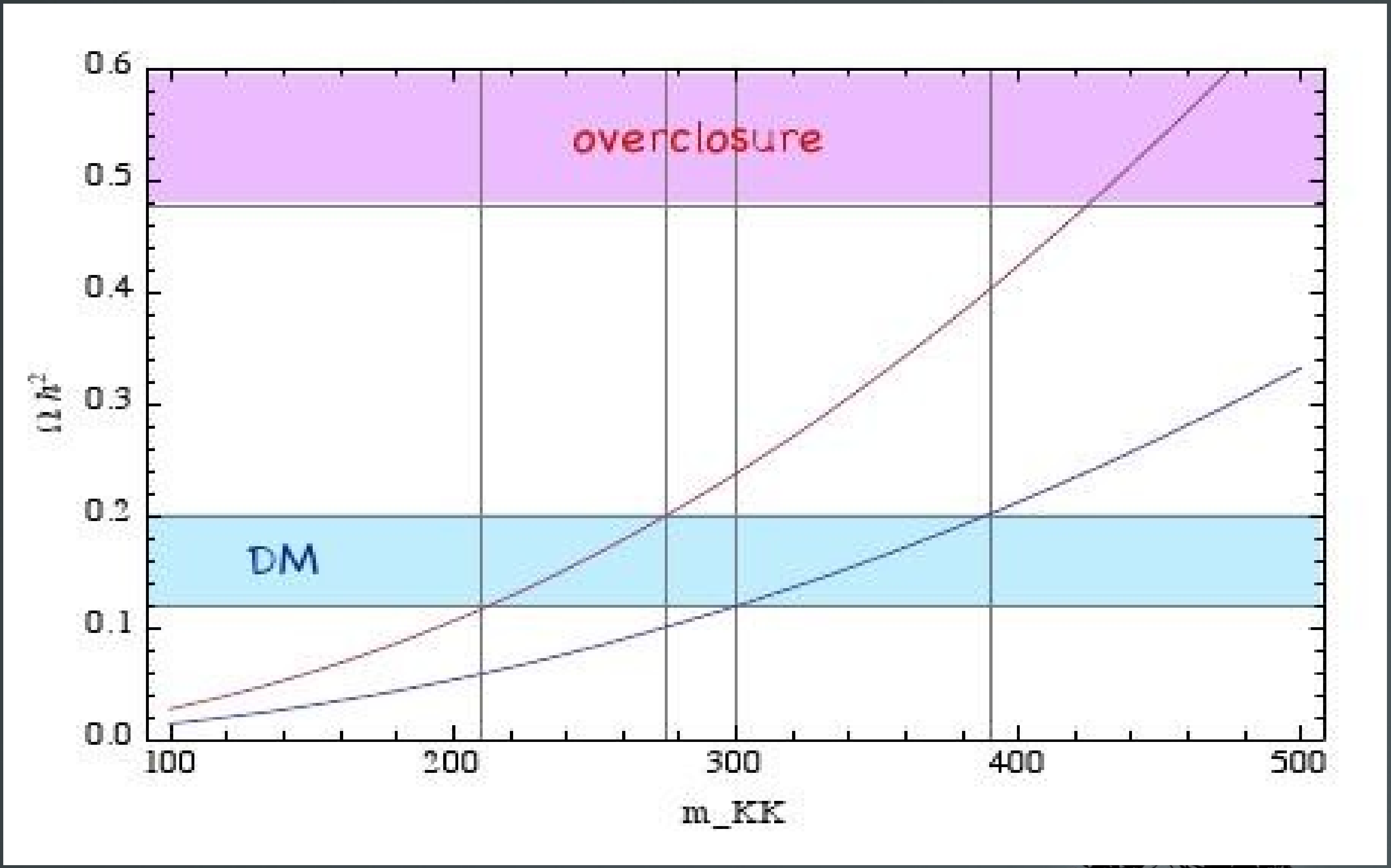
Masses

- KK mass of a (k,l) tier is $M_{(k,l)} = \sqrt{(k^2+l^2)}/R$
- Small correction from EW symmetry breaking should be added $M = \sqrt{(M_0^2 + M_{(kl)}^2)}$
- Therefore almost degenerate at tree level
- Loop contributions remove the degeneracy

Mass splittings



Dark Matter



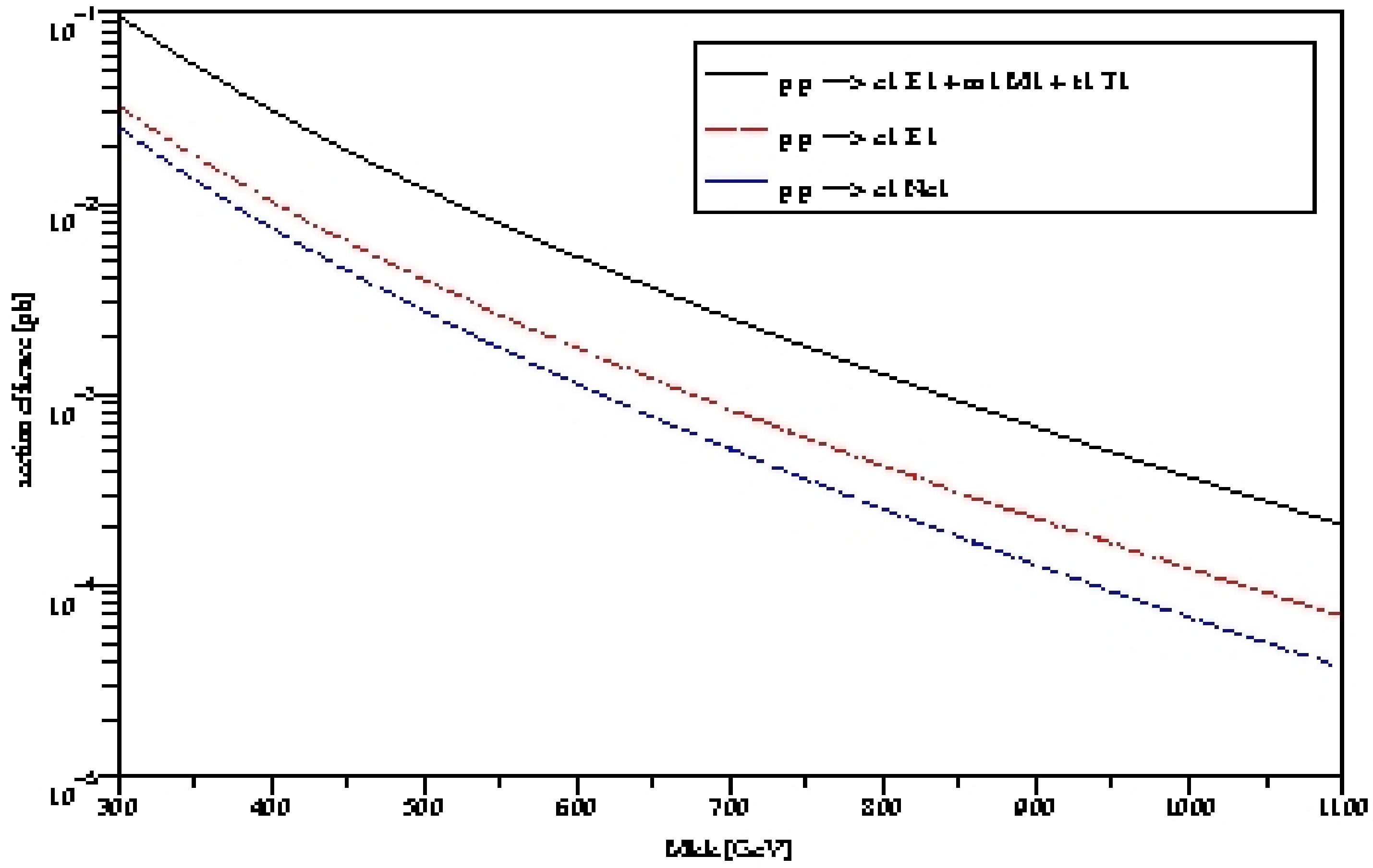
overclosure
DM
0.6
0.5
0.4
0.3
0.2
0.1
0.0
100
200
300
400
500
Ωh^2
m_KK

LHC discovery reach (preliminary)

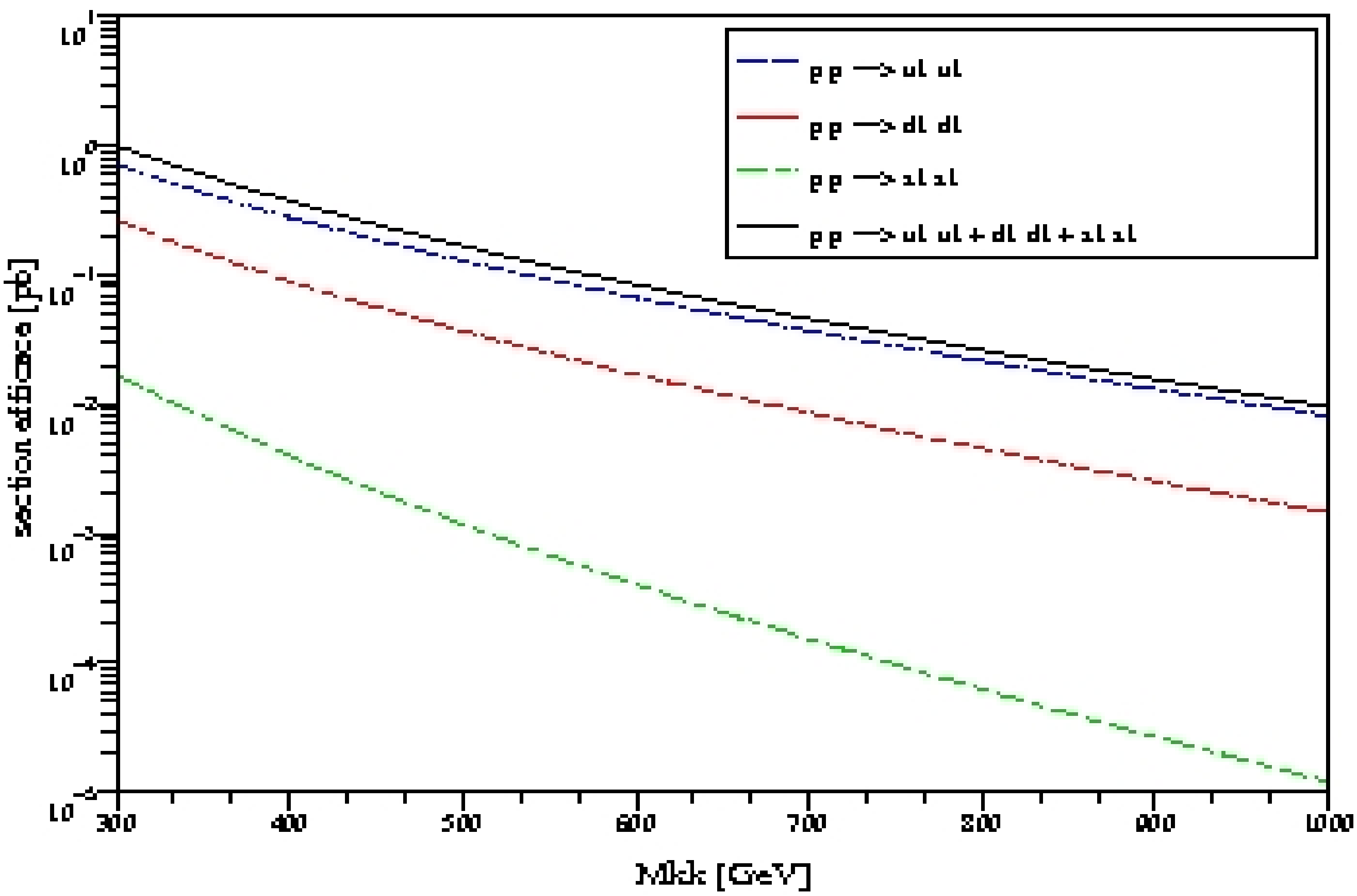
- Large production rates, but :
- (1,0) and (0,1) levels almost invisible (small splittings)
- (1,1) and (2,0) decay to SM particles
- (2,1) $\rightarrow$ (0,0) + (0,1) i.e. SM plus $\not{E}_T$

spectacular events with apparenly ”missing” charge conservation

pp → leptons

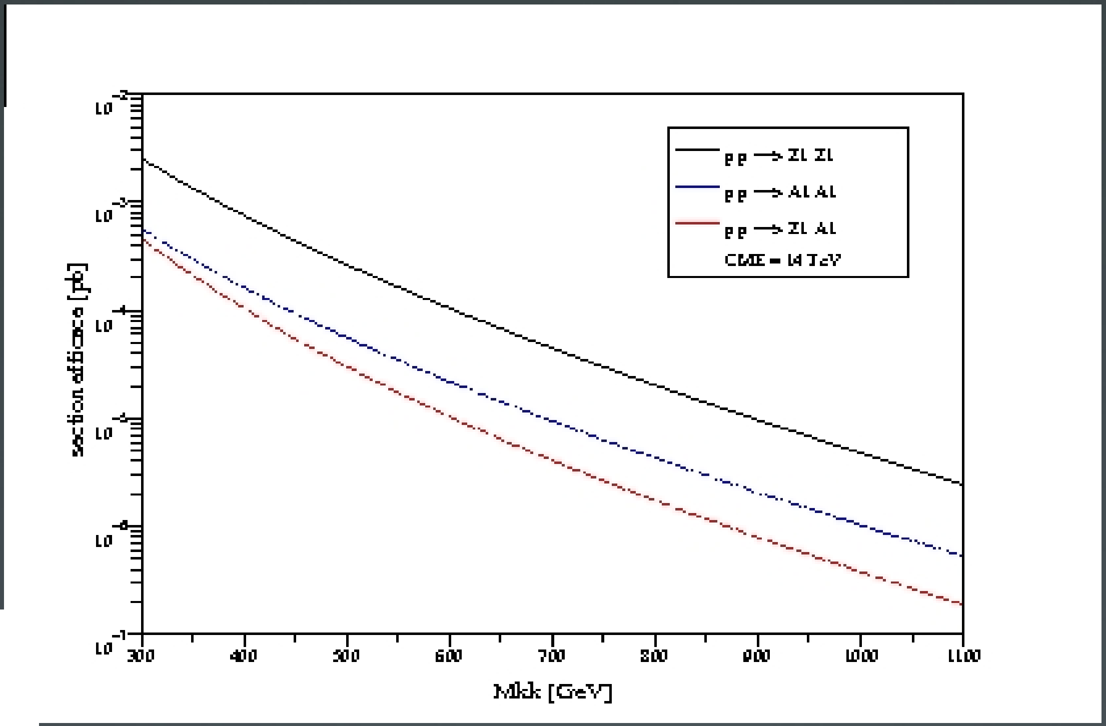


pp → quarks

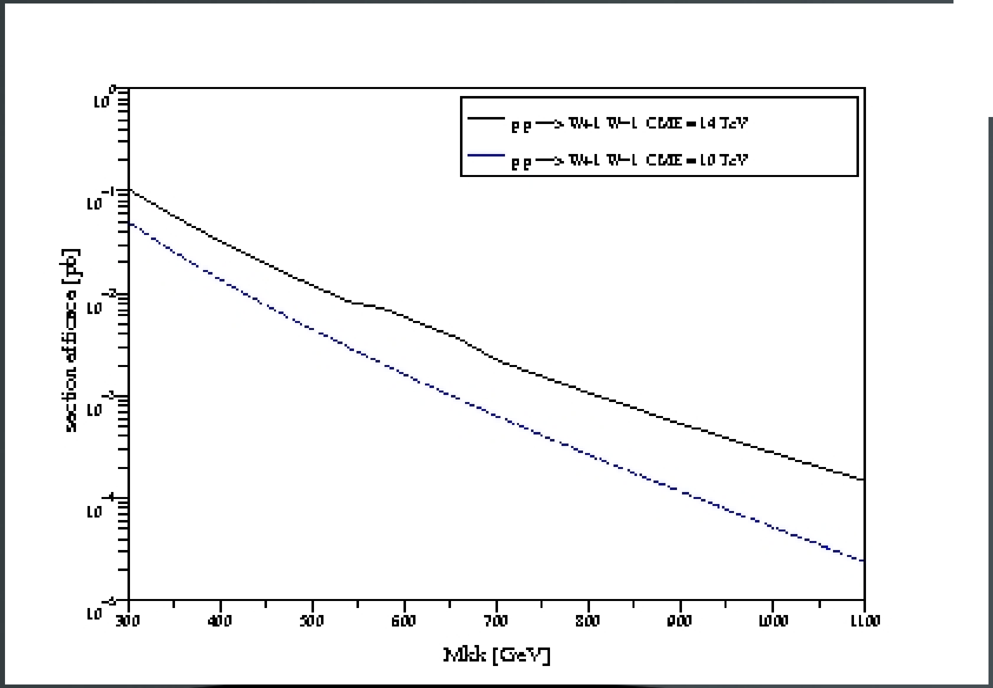


p p —> u1 u1
p p —> d1 d1
p p —> s1 s1
p p —> u1 u1 + d1 d1 + s1 s1
Section efficace [pb]
Mkk [GeV]
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
300
400
500
600
700
800
900
1000

pp → vectors



pp → ZL ZL
pp → AL AL
pp → ZL AL
CME = 14 TeV
section efficace [pb]
Mkk [GeV]



pp —> W+L W−L CME = 14 TeV
pp —> W+L W−L CME = 10 TeV
section efficace [pb]
Mkk [GeV]

Limit of 1 extra dimension

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Gauge scalars G, A, Z, W		✓	✓		✓
Higgs boson(s)	✓		✓	✓	✓
Fermions	✓	✓	✓ (x2)	✓	✓ (x2)

Conclusions

- No ad hoc parities! Stability of dark matter assured by a fundamental symmetry (remnant of 6D Lorentz invariance)
- Relic density suggests few hundred GeV new particles well in LHC range
- Preliminary FeynRules + CalcHep, MadGraph implementation
- 5D limit has quite different spectrum from usual 5D models (”geometrical” non-decoupling)