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The Physics Case for Axions, WIMPs, WISPs… …other weird stuff

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The participants of the Brainstorming&Calculationshop

†IPPP Durham

Remember Patras

Patras:

31°C
Sea-beach
Cloud free

Hamburg:

13°C
Elbstrand
sun free

Remember Patras

Patras:		Hamburg:
31°C-32°C		13°C-23°C
Sea-beach		Elbstrand
Cloud free	(nearly)	sun free

Have fun ☺ !

Hints for new Physics

Uglyness of old models

- The Standard Model has many free parameters: O(30)

- Naturalness problems. Finetuning.
  Examples:
  Higgs mass, θ-angle (strong CP-problem)

- Gravity separate, i.e. not unified.

- (Probably) Breaks down at a finite energy scale
  Landau poles etc.

Unexplained Stuff

- Dark Matter (25%)
  (astrophysical + cosmological observations)

- Dark Energy (70%)
  (astrophysical + cosmological observations)

- Mass Hierarchies
  (colliders, neutrino exp, etc)

- Small parameters (θ-angle, again)
  (neutron electric dipole measurements)

Contradictions (not proven)

- (g-2) deviations from SM prediction
- DAMA anomaly
- PVLAS anomaly

Hints for new Physics

Model Building

Bottom-up (pheno)

Fix problem
`here and now'

Top-down (theory)

Go back to drawing board
`Start from scratch'

The strong CP problem: Axions

- Introduce new Peccei-Quinn symmetry to solve naturalness problem

- Predict as a consequence a new particle: The Axion

(it's a Weakly Interacting Sub-eV Particle)

Dark matter candidate

Good `physics case'
for WISP experiments

The Hierarchy Problem: WIMPs

- Introduce new Super-symmetry to solve hierarchy problem

- Predict zillions of new particles among them WIMPs (Weakly Interacting Massive Particles)

Dark matter candidate

may explain (g-2)

Good `physics case' for WIMP experiment

The PVLAS anomaly: Many WISPs

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- Introduce new WISPs to explain PVLAS anomaly

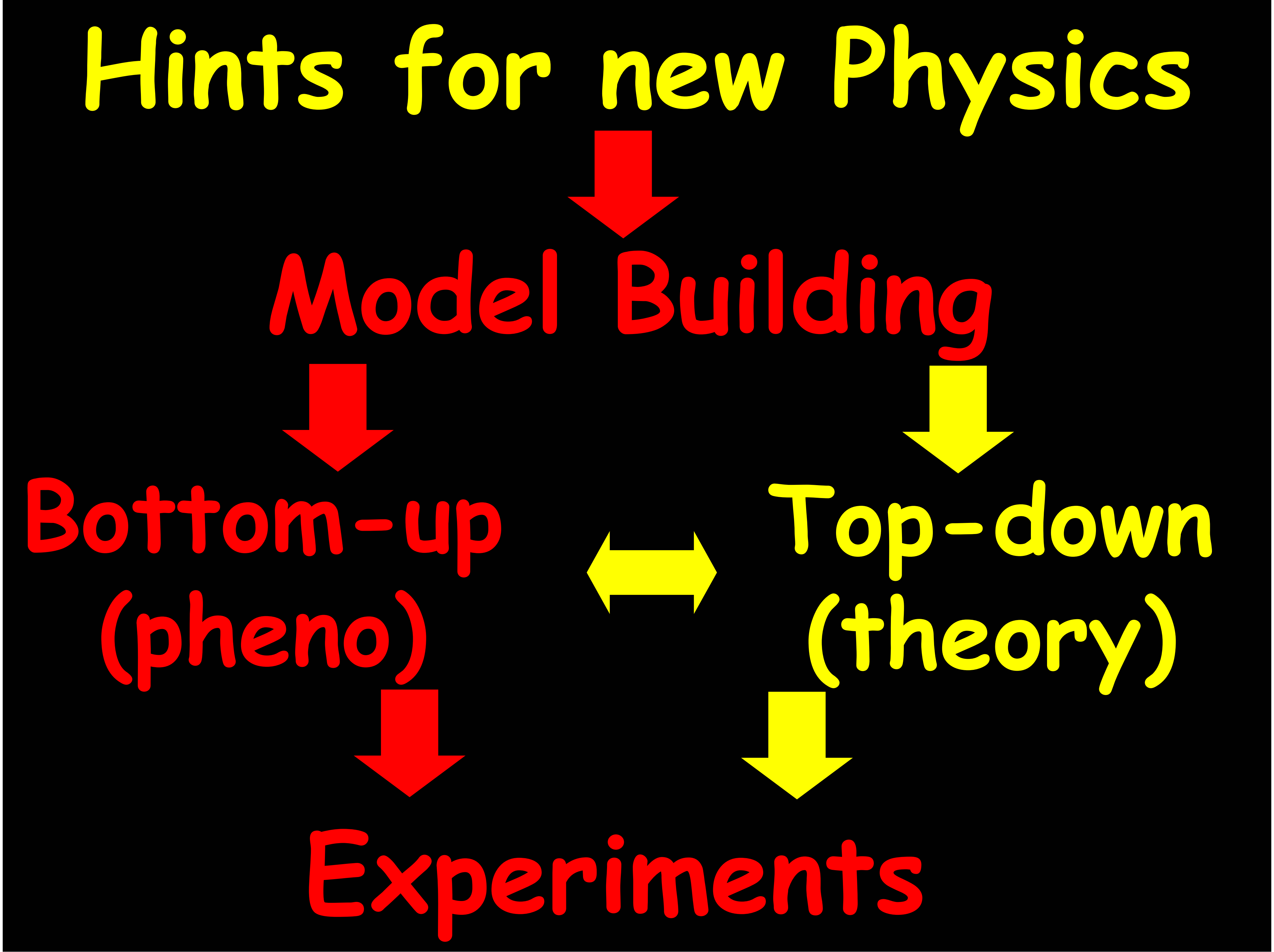
Improve Experiment
(anomaly vanishes)

Find loads of unexplored parameter space

Find that exps. are sensitive to ultrahigh energy scales $\sim 10^5$-10^{15} GeV

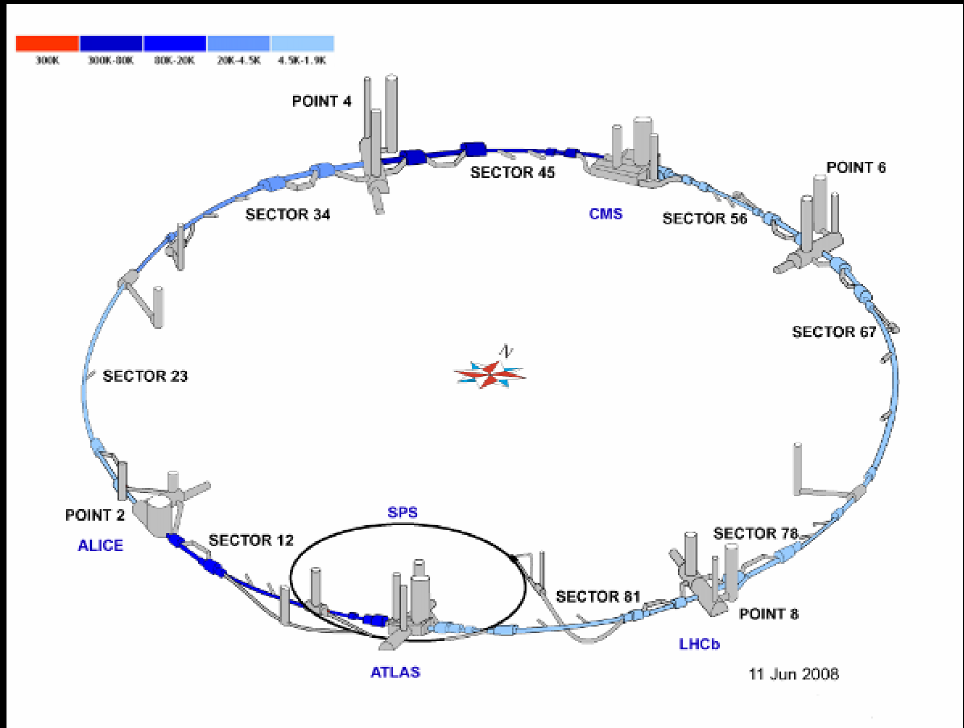
New ideas for experiments

Good `physics case'
for new and improved WISP experiment


Hints for new Physics
Model Building
Bottom-up (pheno)
Top-down (theory)
Experiments

Example experiment 0: LHC

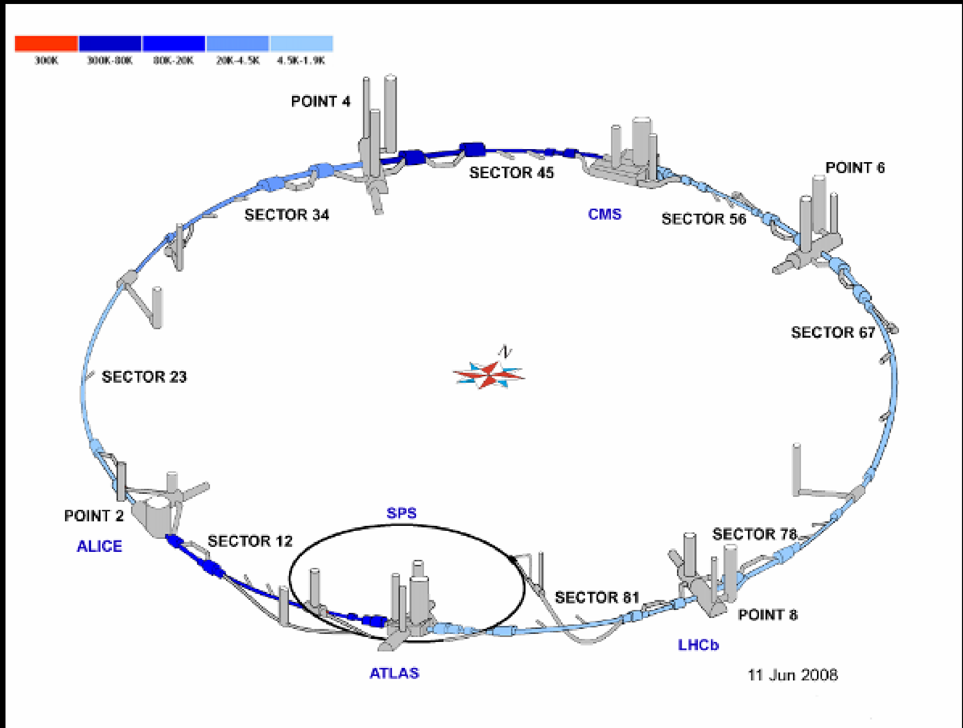
- The direct approach: MORE POWER



- Detects most things within energy range
- E.g. may find WIMPs

Example experiment 0: LHC

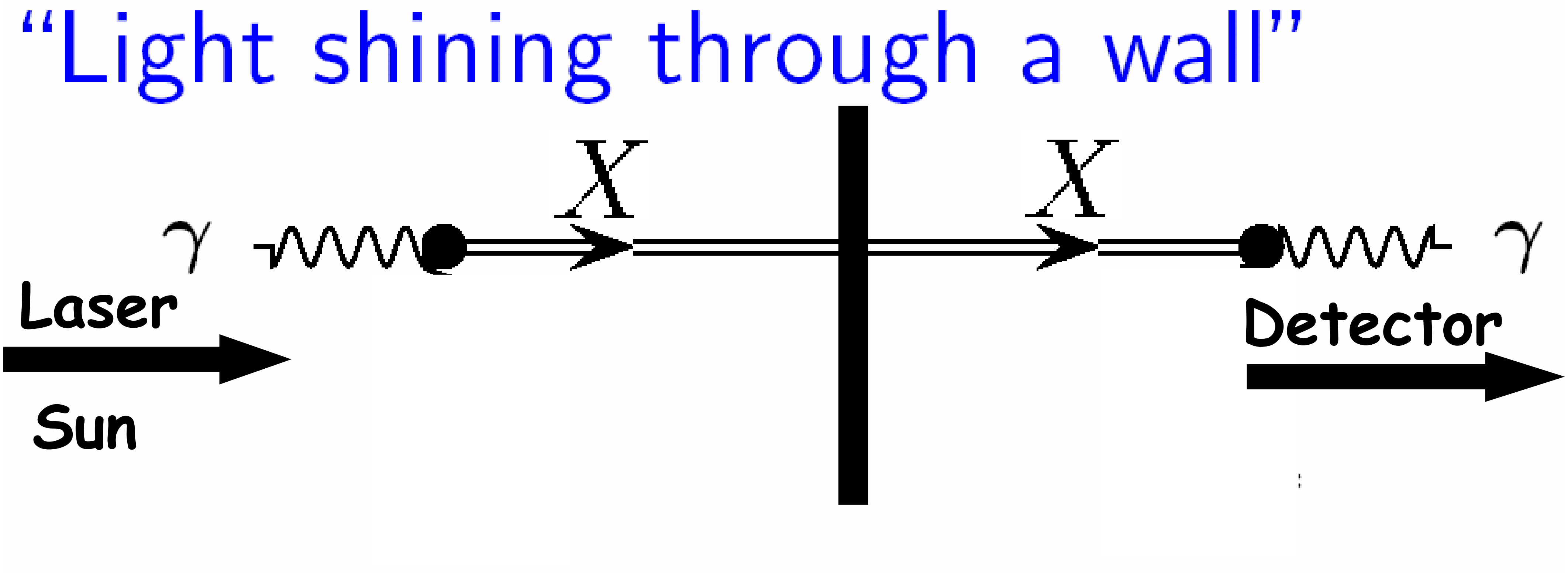
- The direct approach: MORE POWER



- Current maximal energy few TeV
- May miss very weakly interacting matter (Axions, WIMPs, WISPs…)
- Only indirect evidence for dark matter

Example experiment I: WISPs

- Laser is shone on an opaque wall
- One searches for photons `appearing' on the other side of the wall

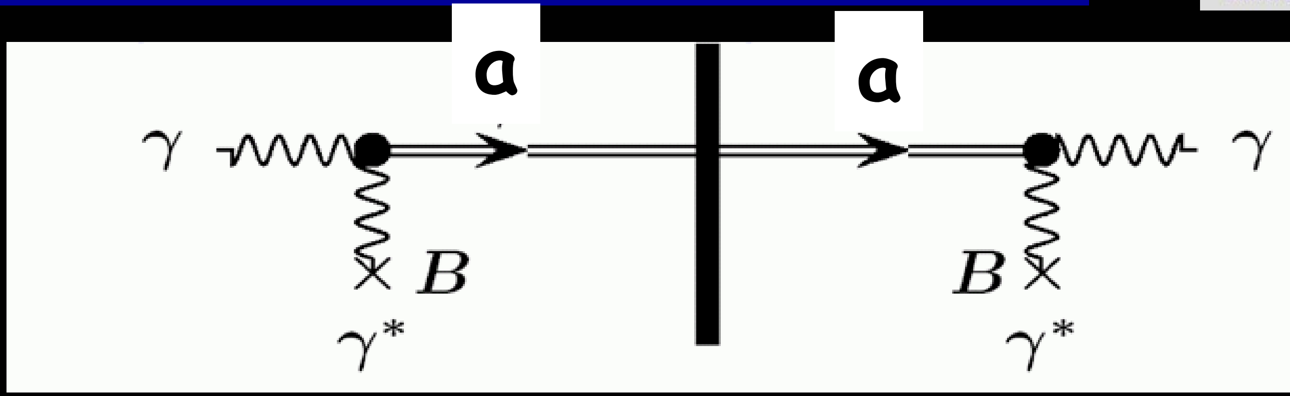


Light shining through walls experiments and helioscopes

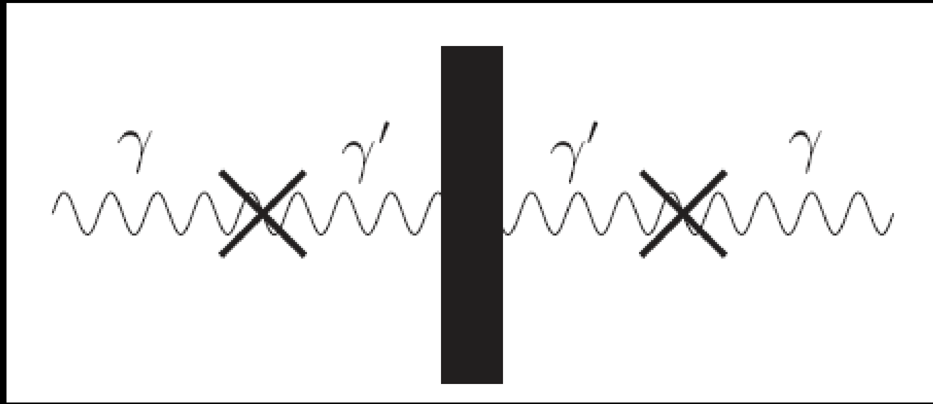
WISPs=Weakly interacting sub-eV particles

- Axions

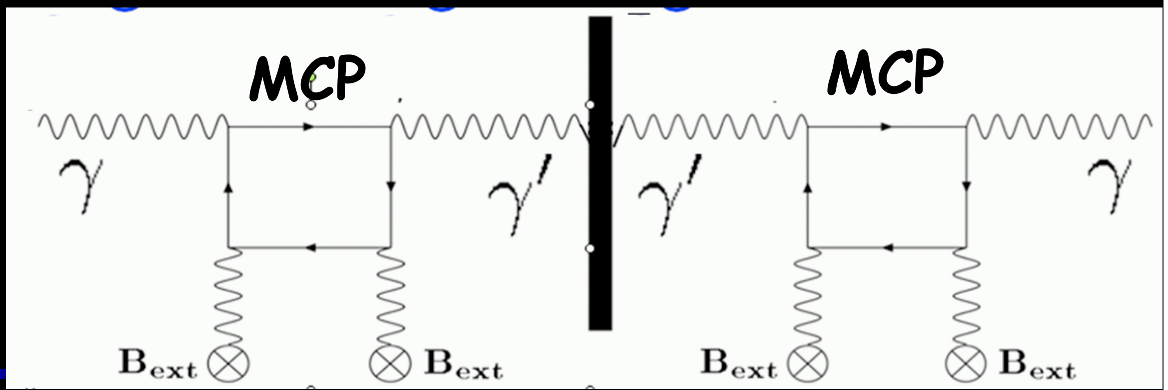
$$\frac{1}{M} a \tilde{F} F$$



- Massive hidden photons (without B-field) =analog ν-oscillations

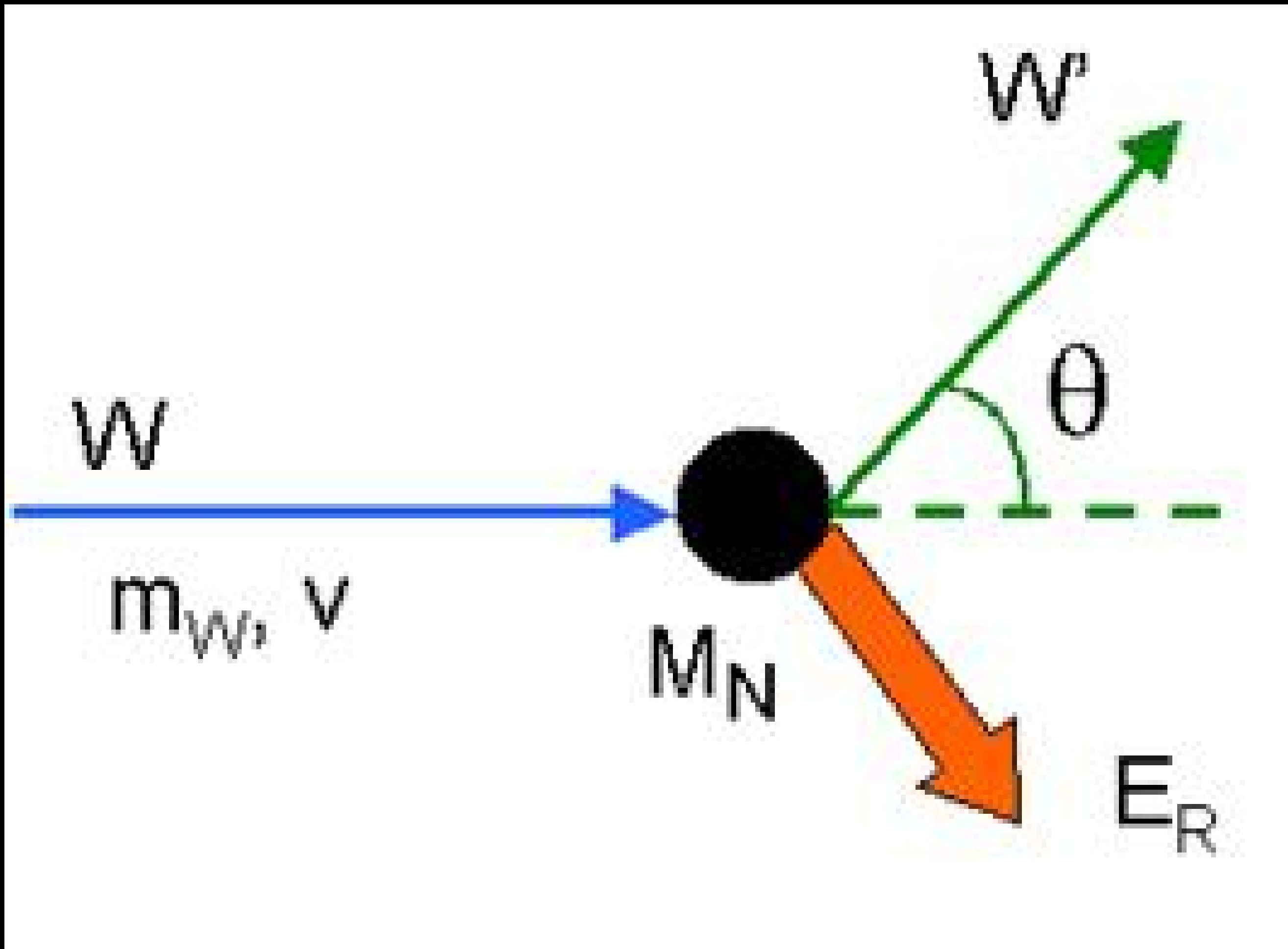


- Hidden photon + minicharged particle (MCP)



Example experiment II: WIMPs

- Dark Matter searches.
- Search for recoil of a WIMP on a nucleus



Hints for new Physics

Model Building

Bottom-up (pheno) ⟷ **Top-down (theory)**

String theory

- Attempt to unify SM with gravity
- New concept: strings instead of point particles

String theory likes SUSY

- Attempt to unify SM with gravity
- New concept: strings instead of point particles

Need SUSY for consistency

WIMPs etc.

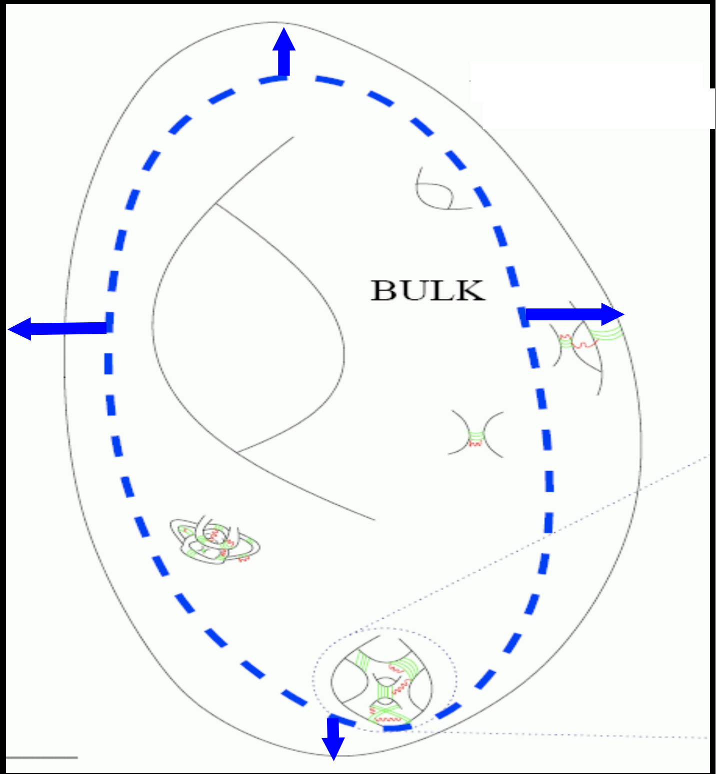
`Physics case' for WIMPs strengthened

String theory: Moduli, Axions, etc.

- String theory needs Extra Dimensions

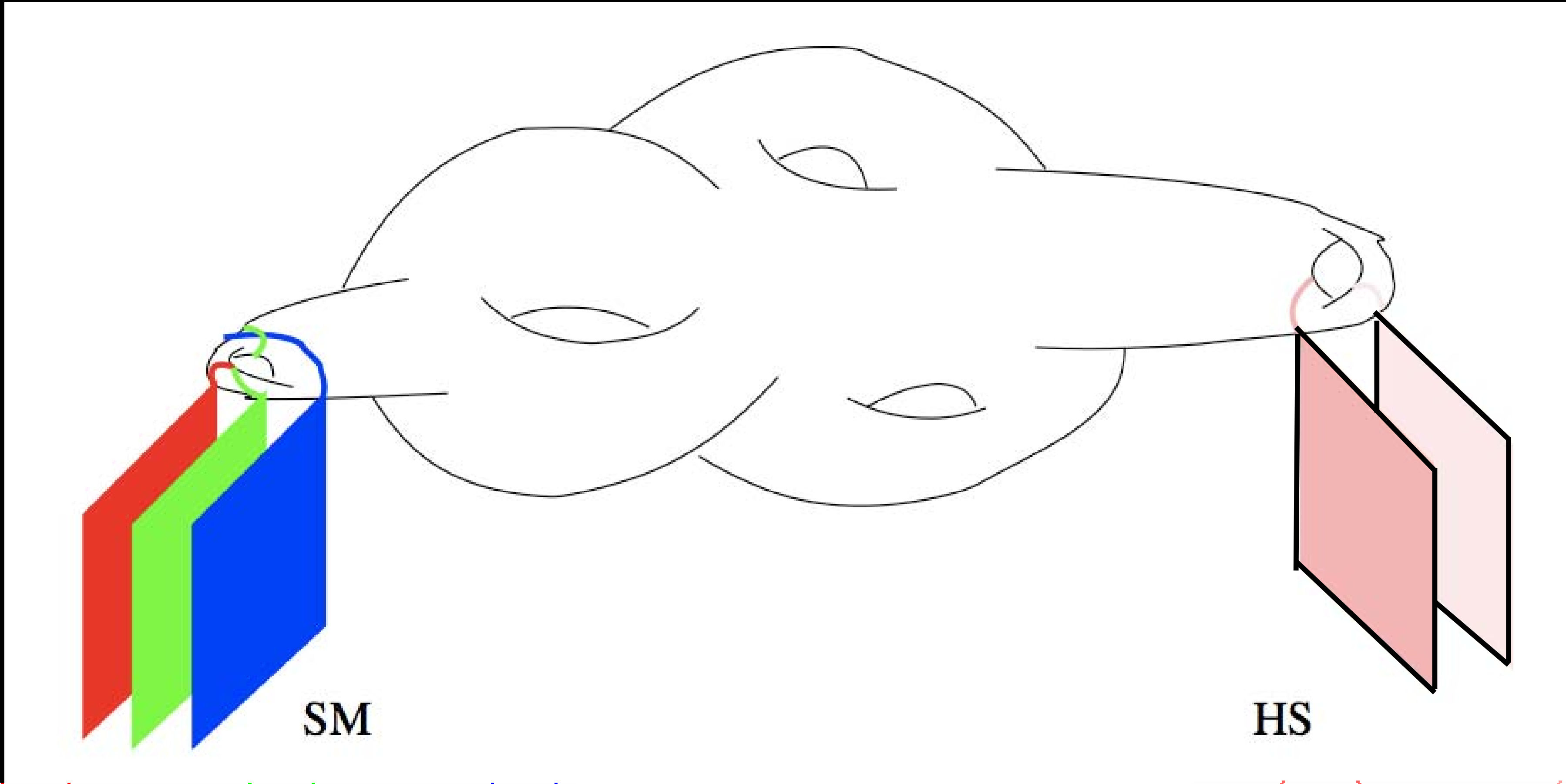
Must compactify

- Shape and size deformations correspond to fields:
  Moduli (WISPs) and Axions
  Connected to the fundamental scale, here string scale



`Physics case' for WISPs strengthened

String theory likes extra gauge groups

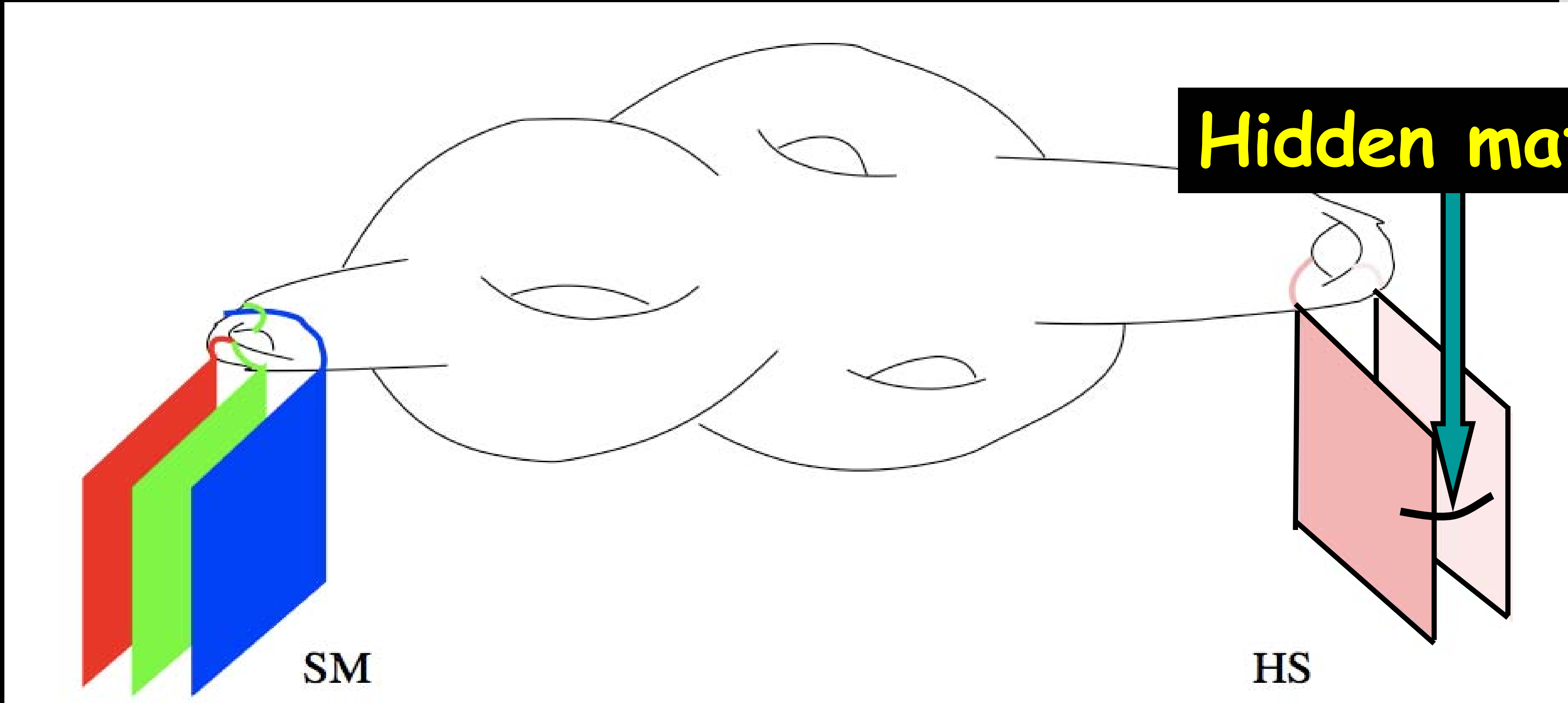


$U(A) \times U(B) \times U(C)$ $\qquad$ $U(A) \times U(B)$

Many extra U(1)s!

Candidates for WISPs

String theory likes extra matter



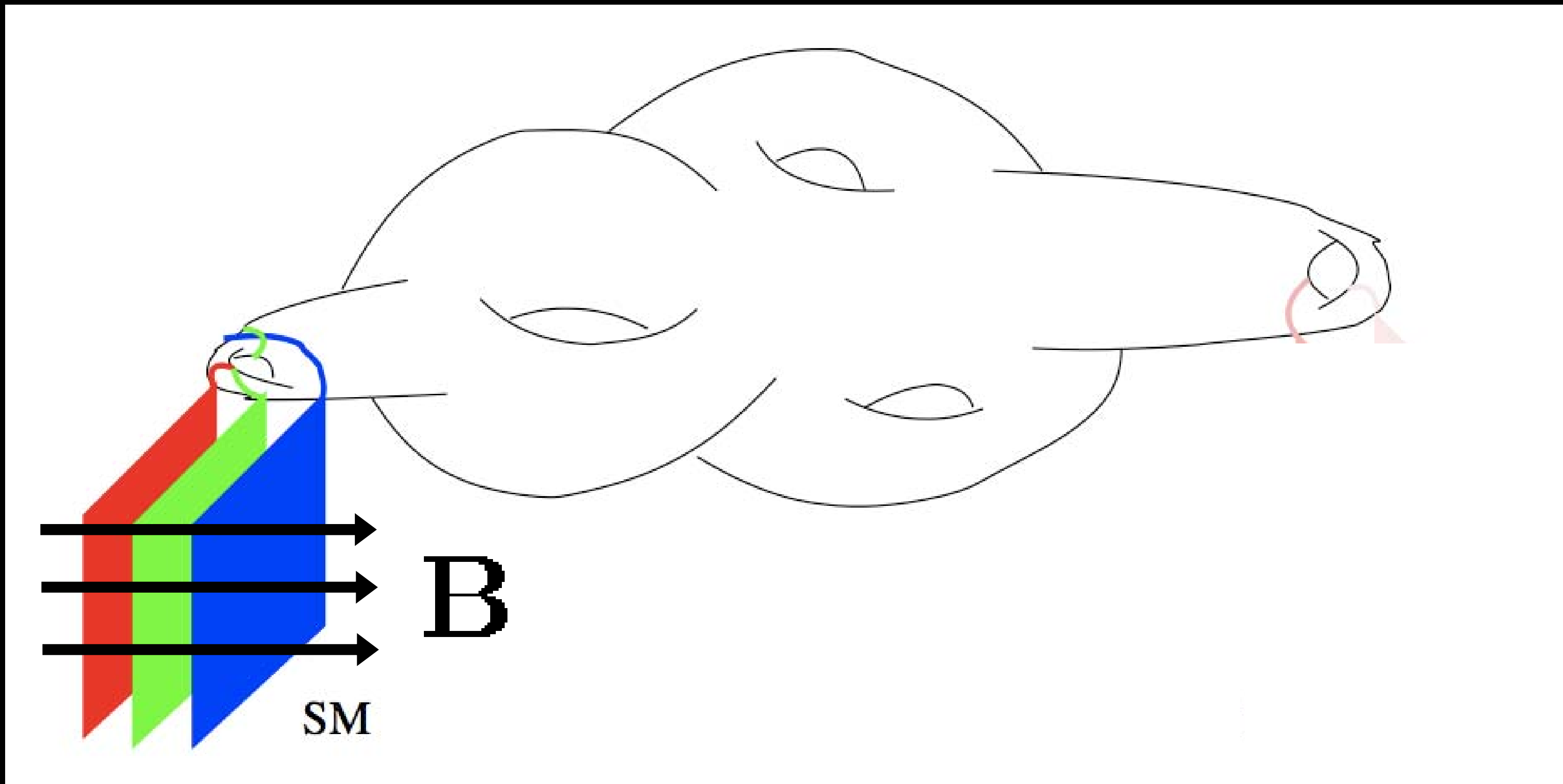
$U(A) \times U(B) \times U(C)$ $U(A) \times U(B)$

➡ Hidden sector matter

➡ May be light and WISPy
Or WIMPy and dark matter

String theory inspire weird stuff

- Some string theory models predict noncommutativity and other forms of Lorentz symmetry violation



Hints for new Physics

Model Building

Bottom-up (pheno)

Top-down (theory)

New, cool Experiments

Test Lorentz symmetry

- Lorentz symmetry breaking can leads to vacuum birefringence

➡ Ultra high Precision

➡ Test (nearly) Planck scale physics

Test CPT, Matter - Antimatter (a)symmetry

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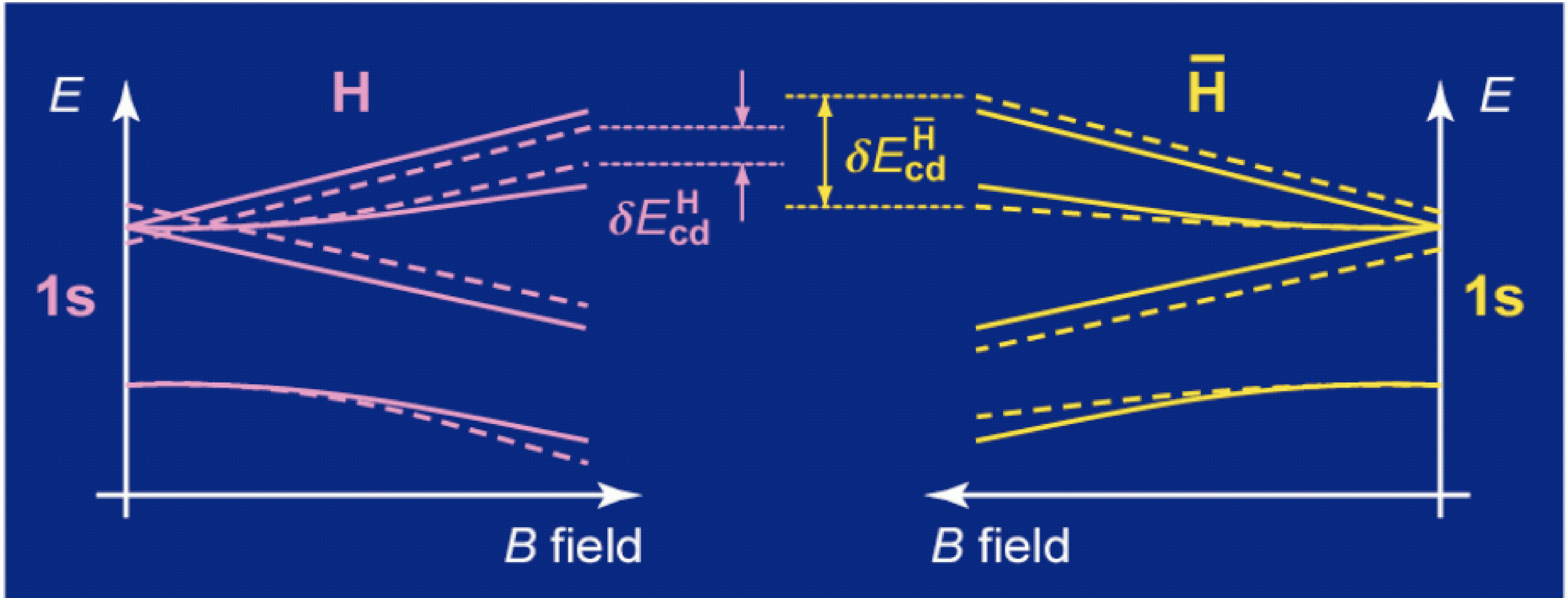
H / $\bar{H}$ spectroscopy: hyperfine Zeeman transitions



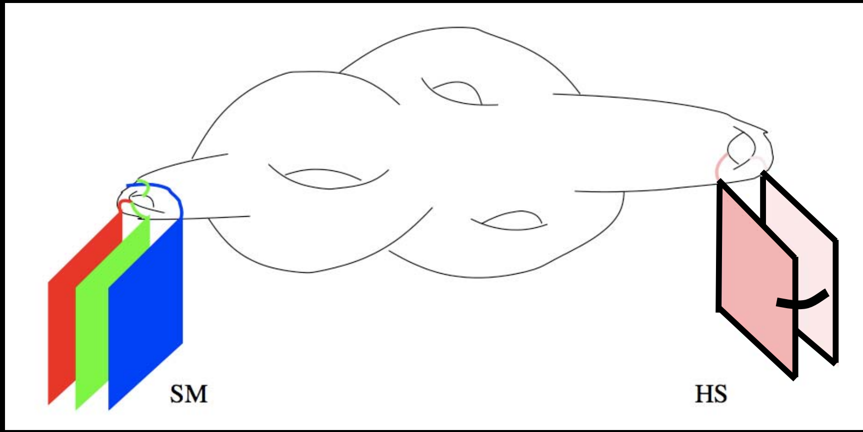
Ultra high Precision

Test very high energy scales.

Conclusions

Conclusions

- Good `Physics Case' for Axions, WIMPs and WISPs
  from bottom-up and top-down models
- Low energy experiments test energy scales much higher than accelerators
  ➡ Complementary!
- May provide information on hidden sectors and thereby into the underlying fundamental theory



- Surprises like Lorentz symmetry violation possible!

Details will follow soon…

White Paper:

The Physics case for...

The participants of the Brainstorming&Calculationshop


Stay tuned!
more soon @
will-o-WISP
wiki

Hints for new Physics

Model Building

Bottom-up (pheno) ⟷ Top-down (theory)

Experiments

Experiments

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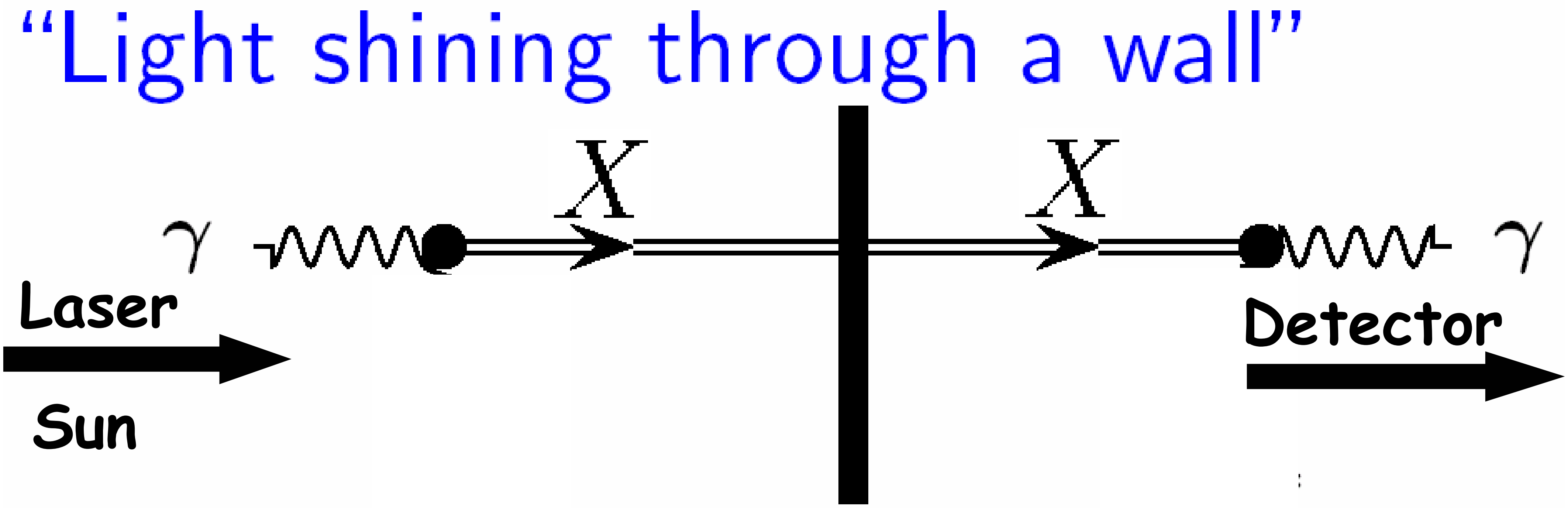

Light shining thorugh walls experiments and helioscopes

WISPS=Weakly interacting sub-eV particles

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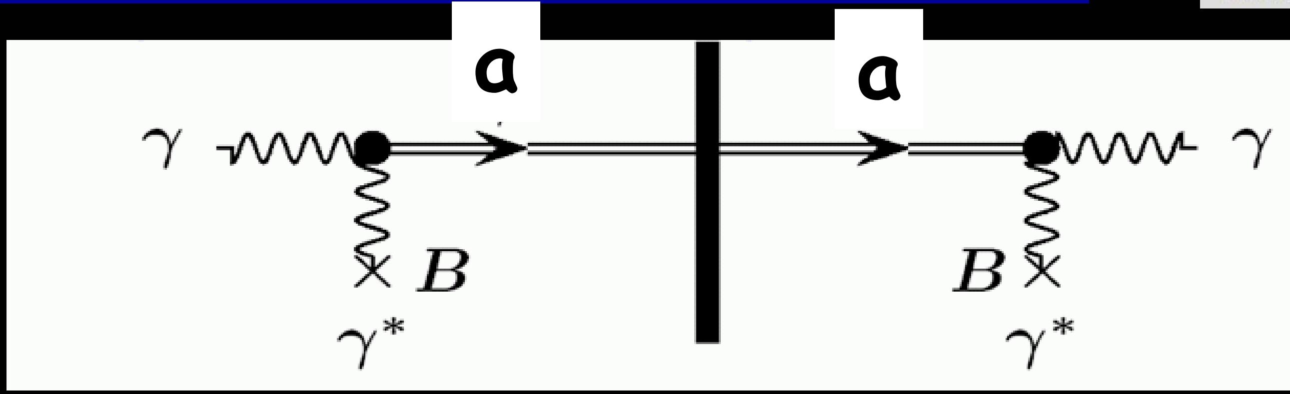

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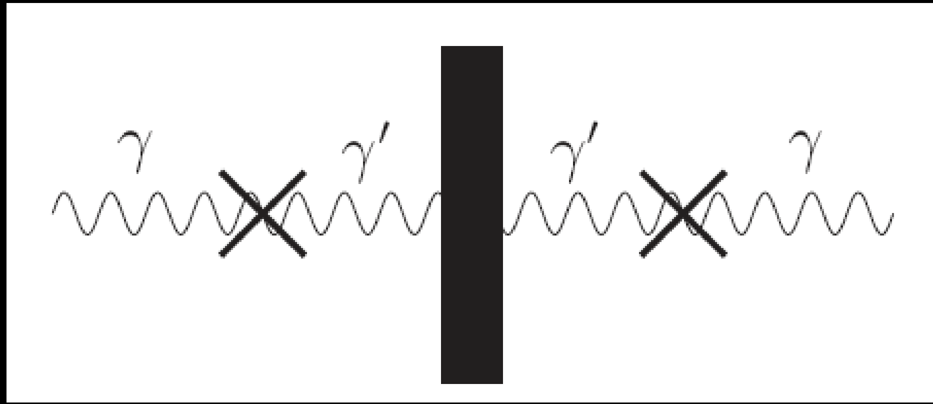

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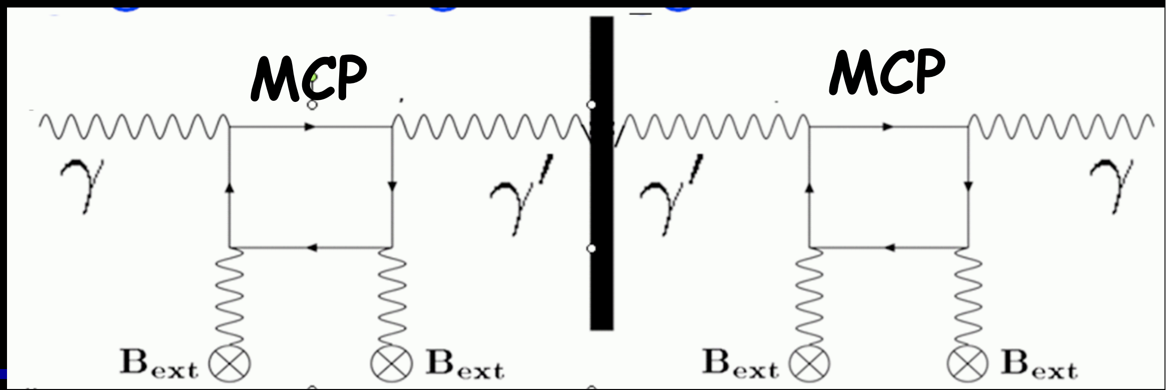

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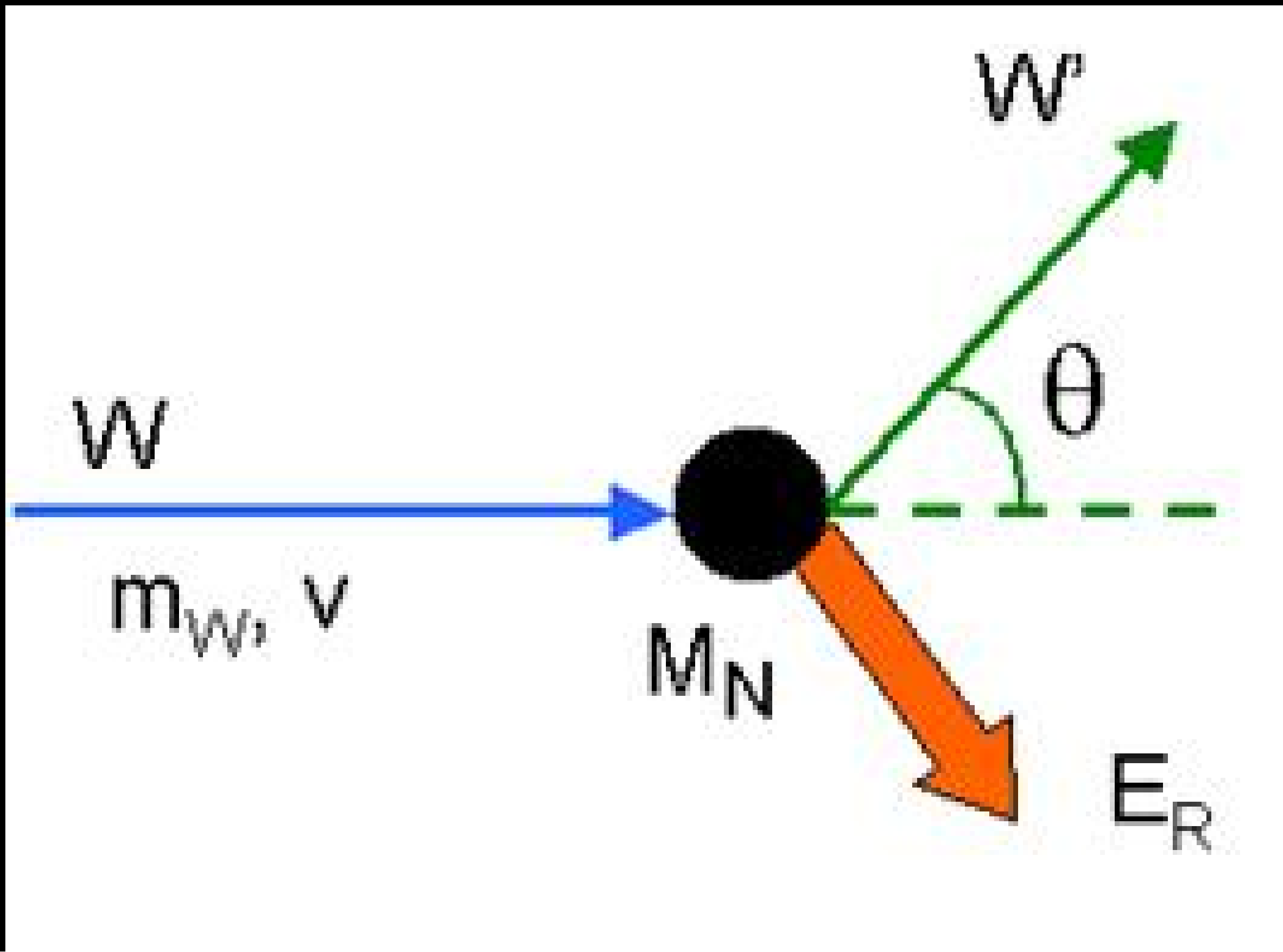

Evidence for new physics

WISPs: Axion example

- The strong CP problem


Stay tuned!
more soon @
will-o-WISP
wiki


Testing
string theory!

Kinetic Mixing - How to get Minicharges

- Two U(1)'s

$$\mathcal{L}_{\rm gauge} = -\frac{1}{4}F^{\mu\nu}_{\rm (A)}F_{{\rm (A)}\mu\nu} - \frac{1}{4}F^{\mu\nu}_{\rm (B)}F_{{\rm (B)}\mu\nu} + \frac{\epsilon}{2}F^{\mu\nu}_{\rm (A)}F_{{\rm (B)}\mu\nu},$$

„Our" U(1)

„Hidden" U(1)

Mixing

$$\begin{aligned} \text{''} &= \text{''}\, A^2 + B^2 - 2\epsilon AB, \\ &= A^2 + (B+\epsilon A)^2 + \mathcal{O}(\epsilon^2) \end{aligned}$$

Diagonalization: $B^\mu \longrightarrow B^\mu + \epsilon A^\mu$

Kinetic Mixing - How to get Minicharges

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- Two U(1)'s

$$\mathcal{L}_{\mathrm{gauge}} = -\frac{1}{4}F^{\mu\nu}_{(\mathrm{A})}F_{(\mathrm{A})\mu\nu} - \frac{1}{4}F^{\mu\nu}_{(\mathrm{B})}F_{(\mathrm{B})\mu\nu} + \frac{\epsilon}{2}F^{\mu\nu}_{(\mathrm{A})}F_{(\mathrm{B})\mu\nu},$$

„Our“ U(1) „Hidden“ U(1) Mixing

➡ Diagonalization: $B^{\mu} \to B^{\mu} + \epsilon A^{\mu}$

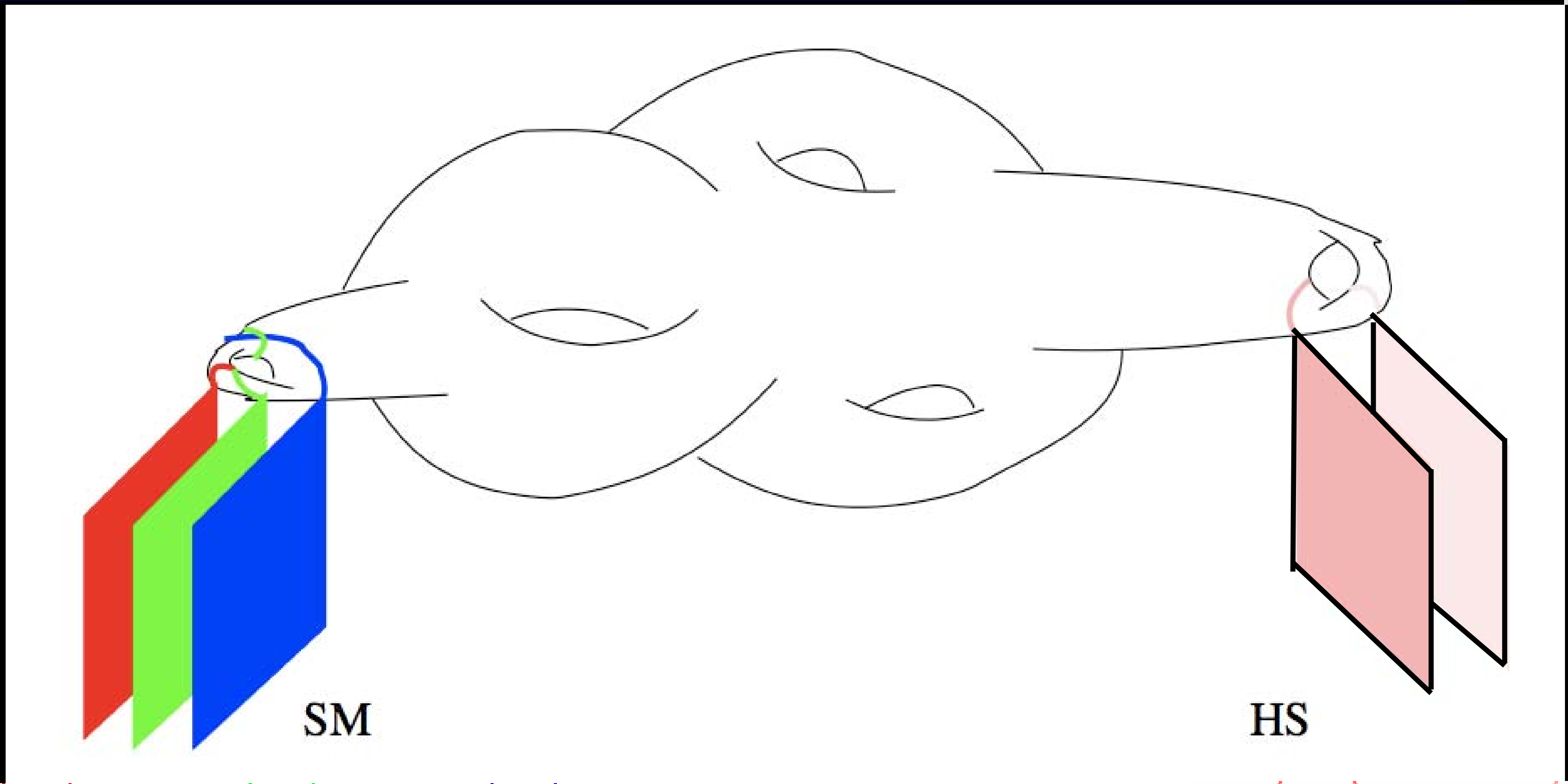
➡ $\bar{\mathrm{f}} B^{\mu} \mathrm{f} \to \bar{\mathrm{f}} B^{\mu} \mathrm{f} + \epsilon \bar{\mathrm{f}} A^{\mu} \mathrm{f}$

➡ f carries ϵ electric charge!

Necessary ingredients:

- Extra `hidden' U(1) gauge groups!
- Matter charged under hidden U(1)
- Kinetic mixing term!

Brane models



$U(A) \times U(B) \times U(C)$

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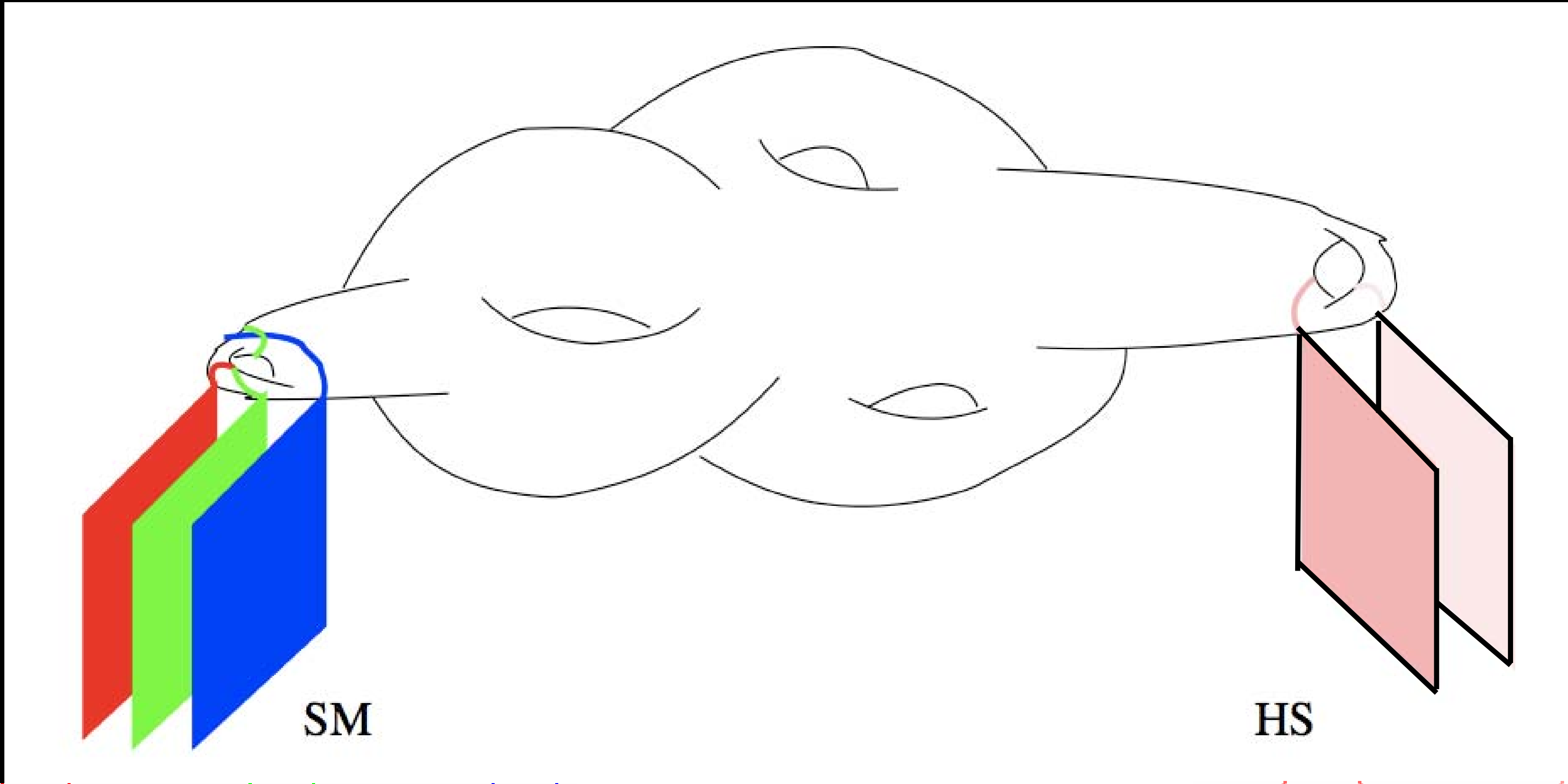
Brane models



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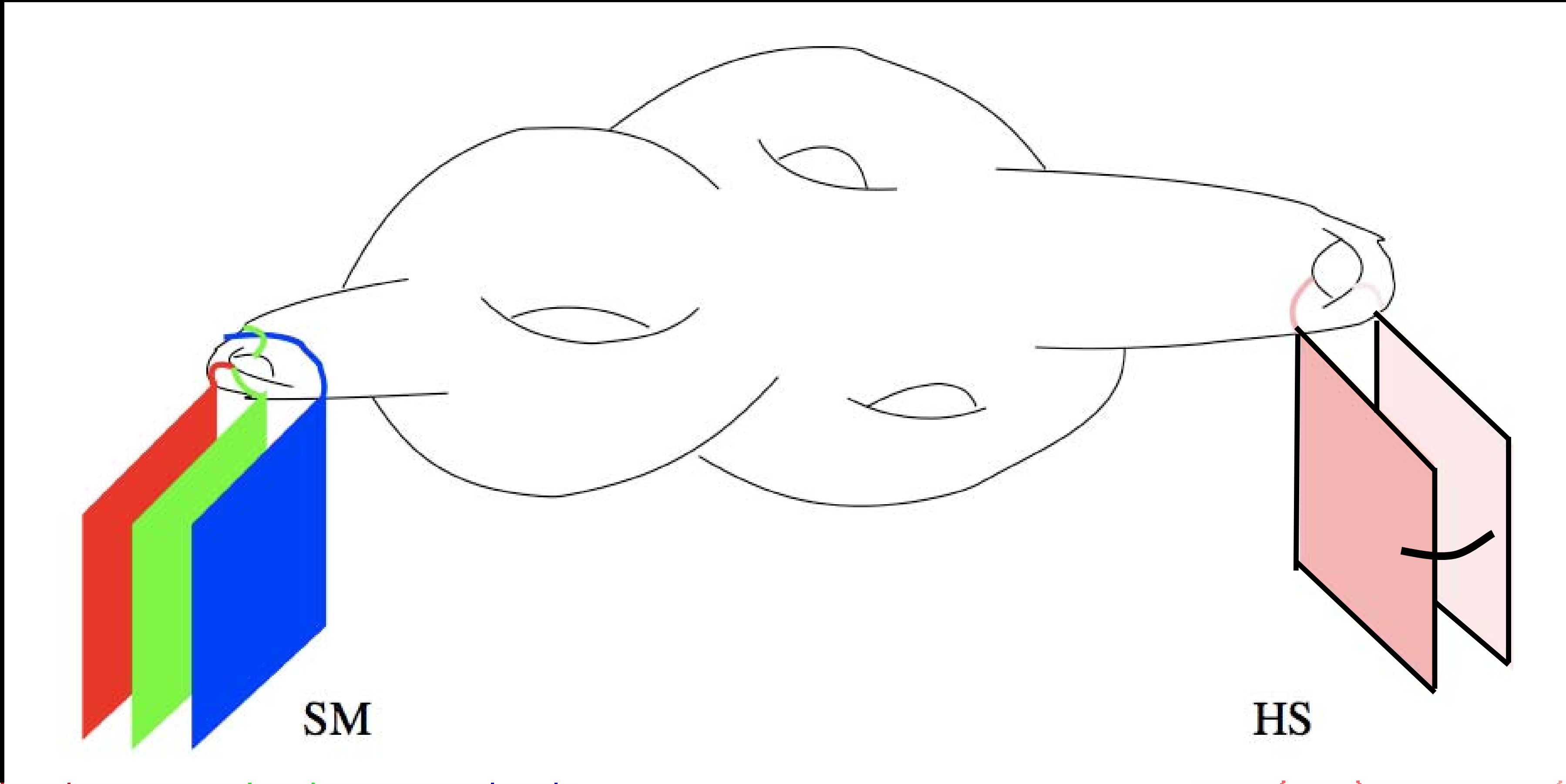
Brane models



$U(A) \times U(B) \times U(C)$

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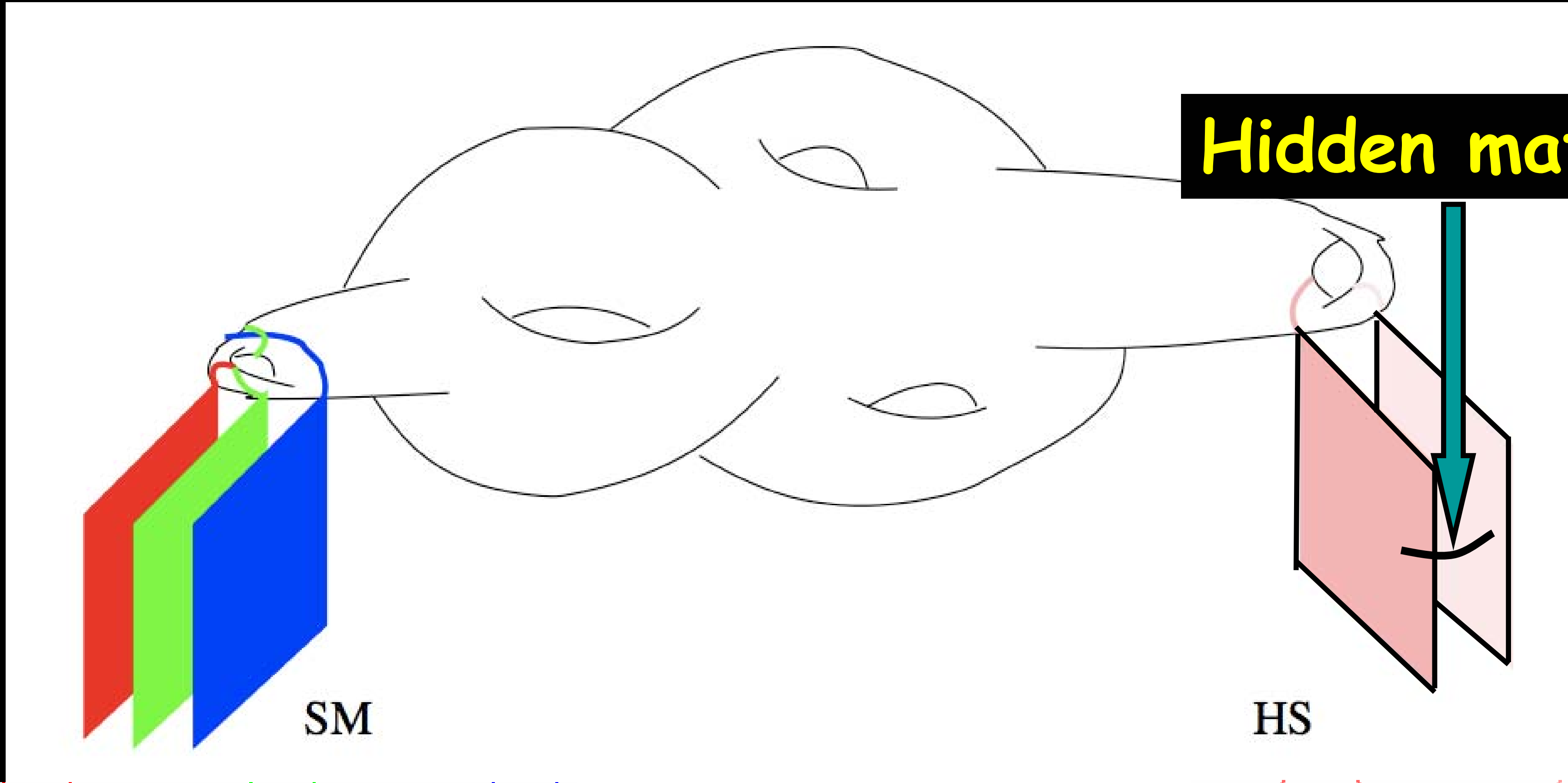
Brane models



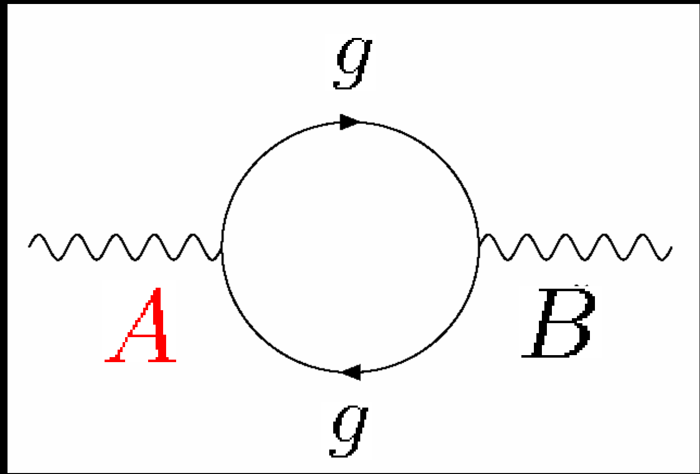
$U(A) \times U(B) \times U(C)$

$U(A) \times U(B)$

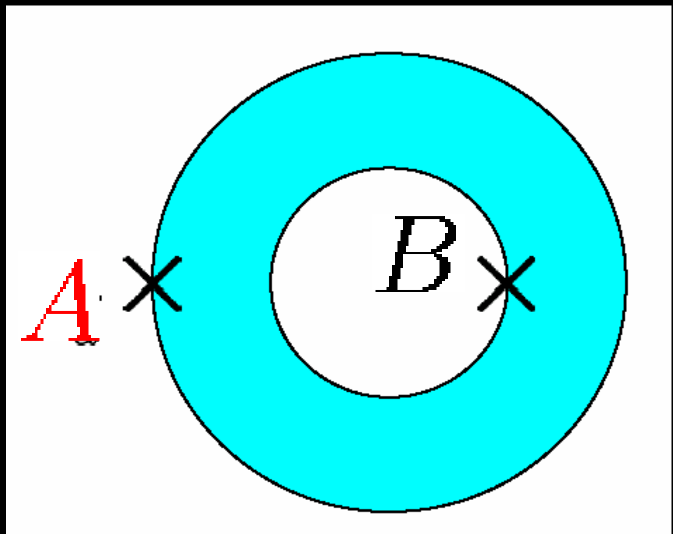
➡ Matter charged under hidden U(1)s

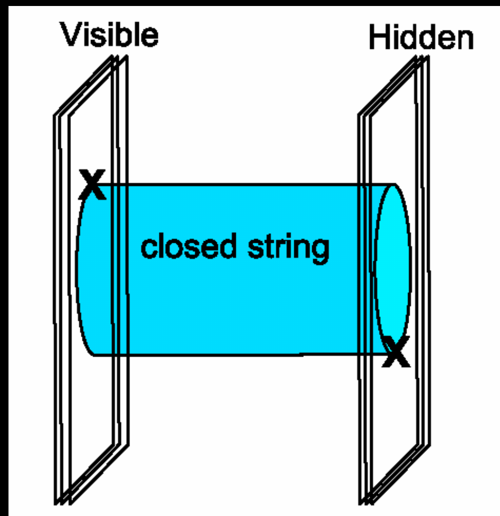
How to get Kinetic Mixing ...

- Field Theory:



- String Theory:





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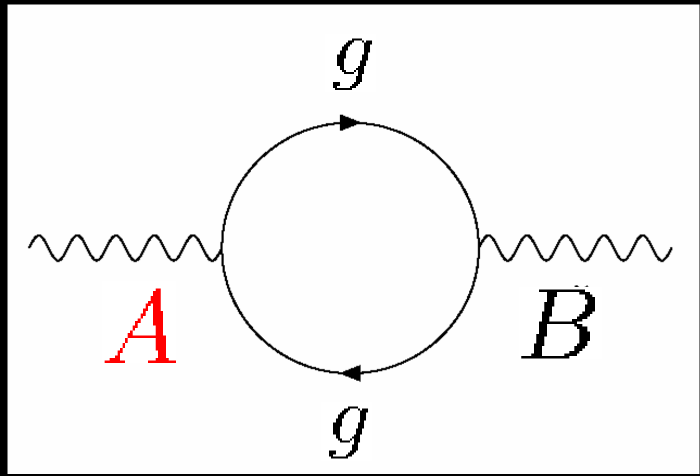

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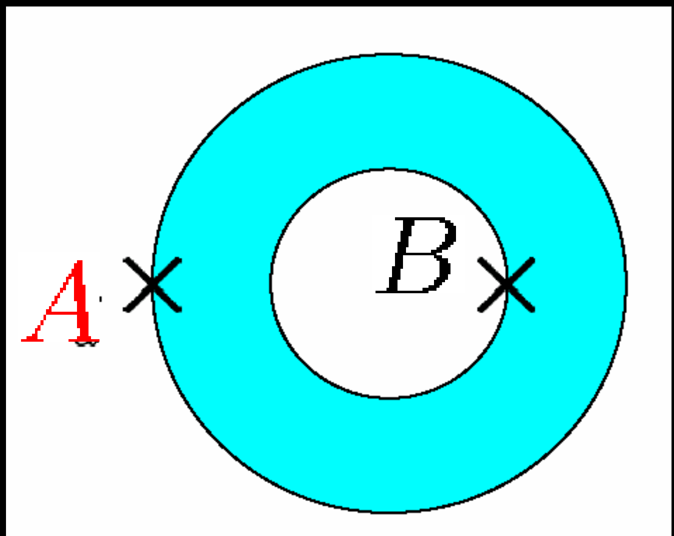
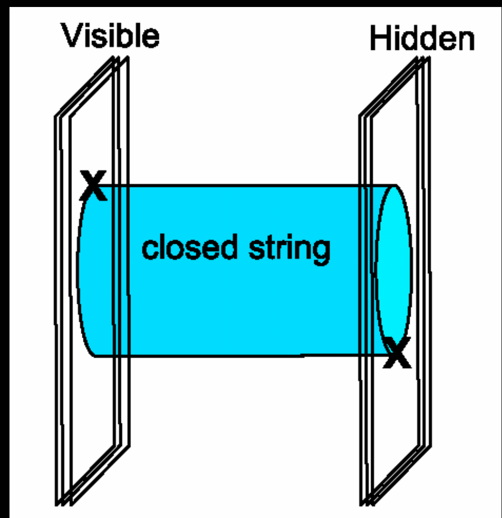
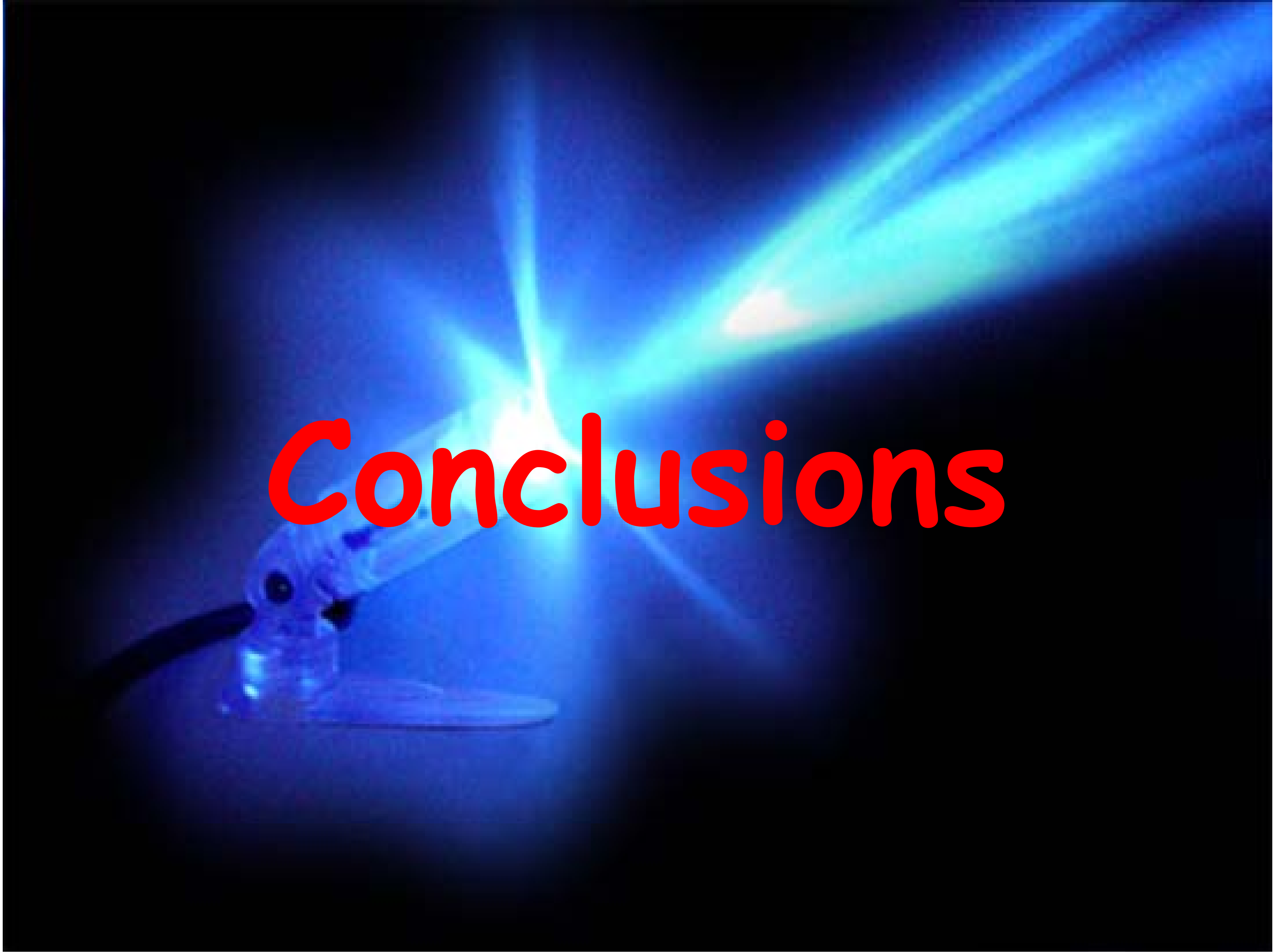




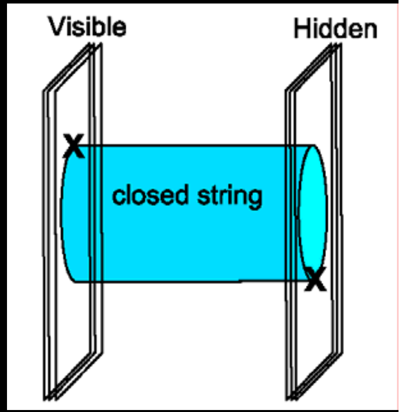
Typically we have kinetic mixing!

Conclusions

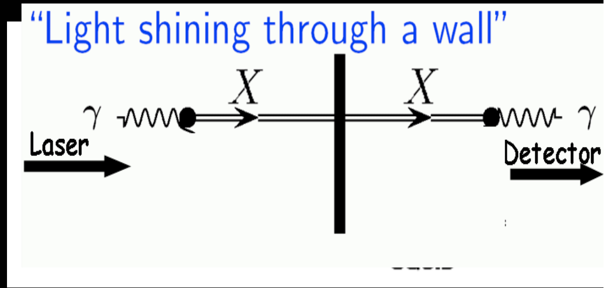


Searching new particles

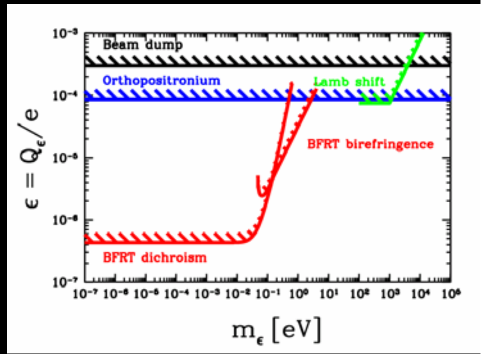
- Light particles coupled to photons are "expected" in Extensions of the Standard Model, e.g. string theory



- We can search for them using low energy experiments with photons!!



- Already existing experiments give interesting new constraints!



- Many more cool experiments possible!

Photons are a good probe of Fundamental physics complementary to accelerator experiments

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