THEORIES BEYOND THE STANDARD MODEL

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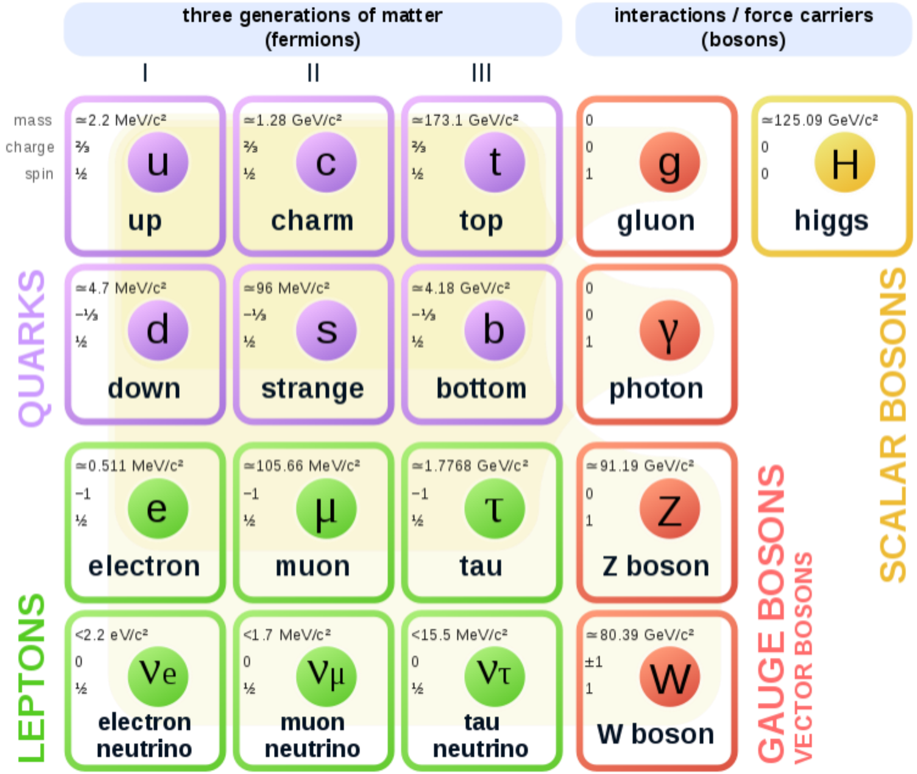
The STANDARD MODEL

The Standard Model (SM) describes three of the four fundamental interactions among the elementary particles. It includes **Fermions**, which constitute the matter and **Bosons** which are considered as force carriers.

INTERACTIONS

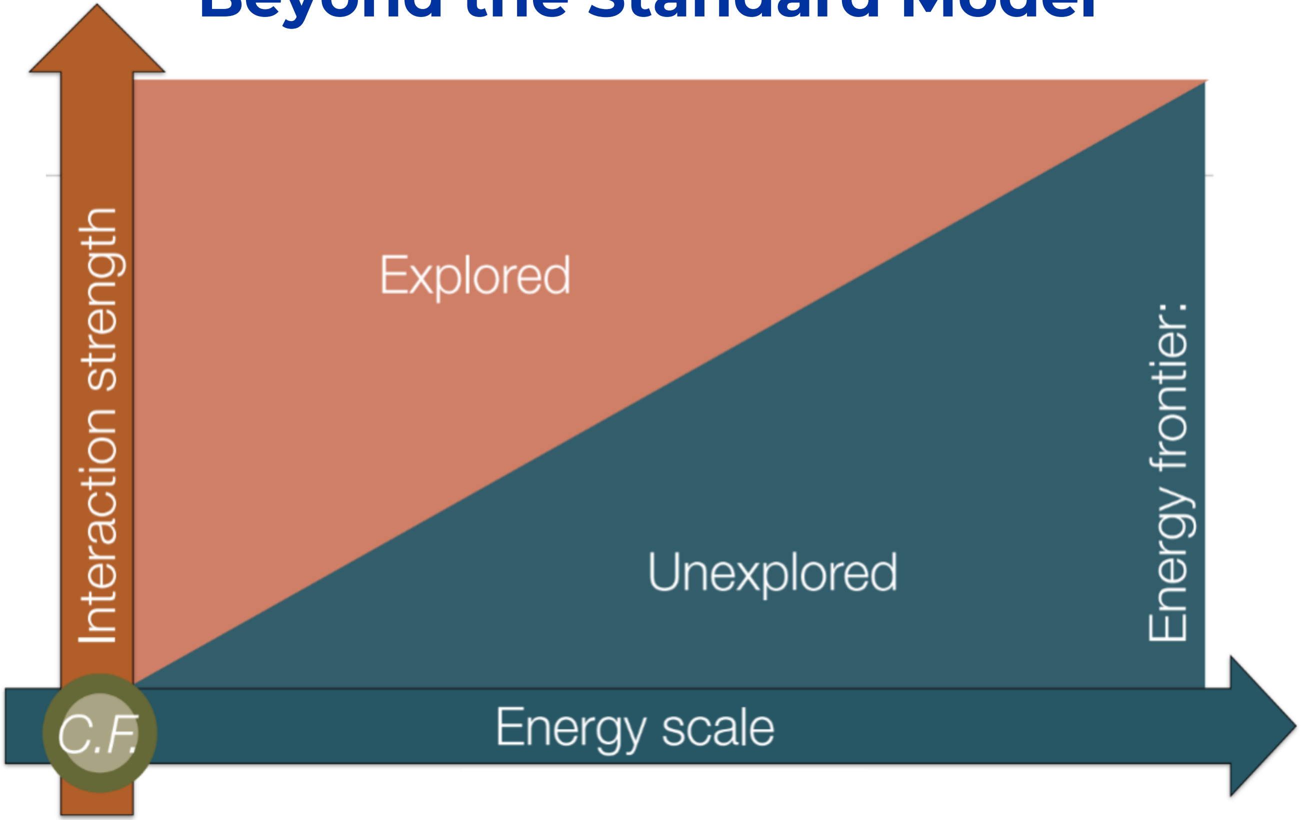
- ➔ **Strong** interaction
- ➔ **Electromagnetic** interaction
- ➔ **Weak** interaction
- ➔ *Gravitational* interaction



Some of the main limits of the **Standard Model**

1	GRAVITATION ISSUE	Gravitational interaction is not considered by the SM.
2	MASS OF NEUTRINOS	The SM does not incorporate mass in the **neutrinos** particles.
3	DARK MATTER EXISTENCE	**Dark matter** (DM) is not mentioned or explained by the SM.
4	MASS HIERARCHY PROBLEM	Each particle has a different mass which is not explained within the interaction with the **Higgs field**.
...	...	...

Beyond the Standard Model



Beyond the Standard Model

BSM

Energy frontier

- e.g.: **SUSY**
- e.g.: **Z'**

Interaction strength

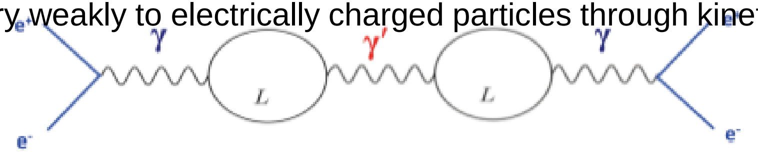
- e.g.: **Heavy Neutral Leptons**
- e.g.: **Dark photon**

Not-singlet extension
More than one particle is added to explain the BSM theory.

Singlet extension
Just one particle is added to explain the BSM theory.

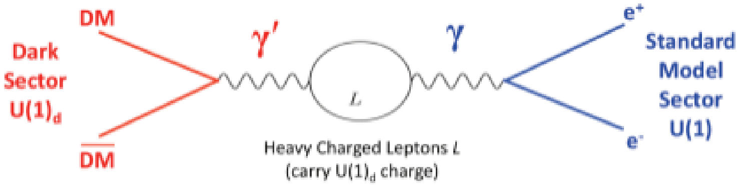
Dark Photons

- Dark Photons (DP) are thought to be **force-carrying particles**.
- Unlike massless photons, these dark-matter particles would have a **mass**.
- Individually, DP hardly interact with normal matter, but as waves, they would exert a very weak force.
- The DP can couple very weakly to electrically charged particles through kinetic mixing with the ordinary photon.



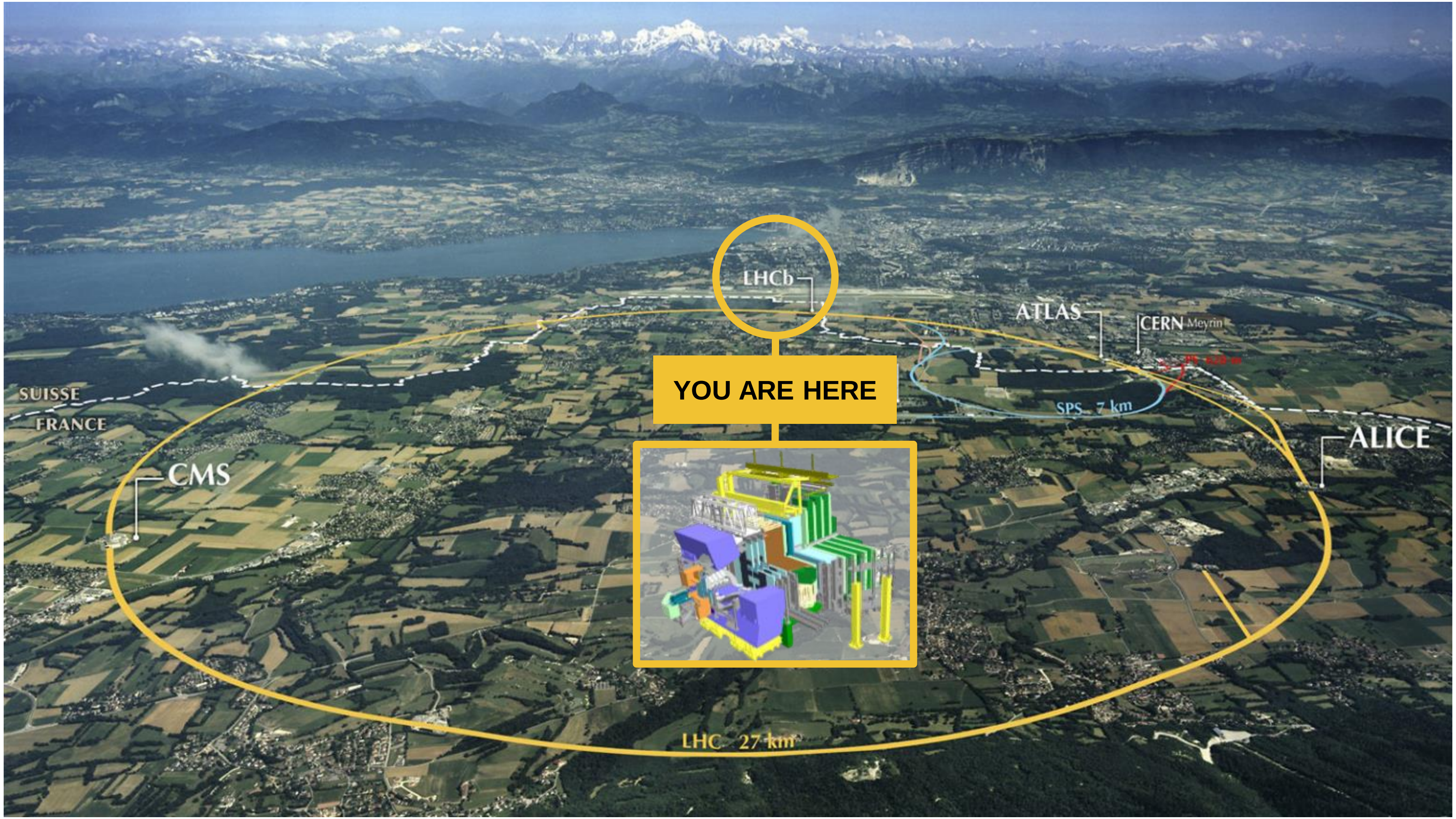
Kinetic mixing is a phenomenon in which DP can change back and forth into the regular photon.

DM particles annihilate via a DP into an e+e− pair



→ which could give rise to the positron excess presently seen in the spectrum of cosmic rays.

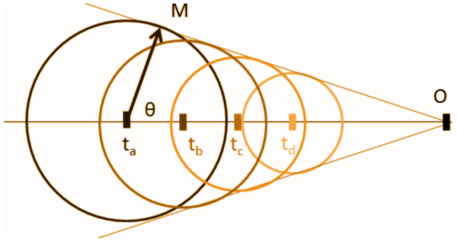
2 free parameters remain:
- mass of the DP, m_{γ}
- mixing parameter ϵ


LHCb
ATLAS
CERN Meyrin
YOU ARE HERE
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km

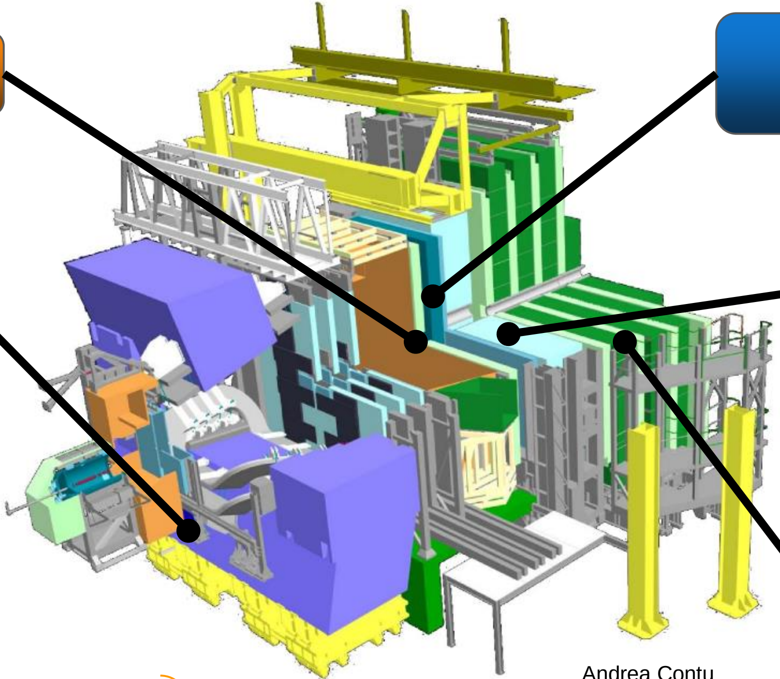
LHCb Experiment's sub-detectors

Both provide **K/π separation** between 2–100 GeV/c

When a particle crosses the radiator, with a very high velocity, it forms a light cone (*Cherenkov light cone*).

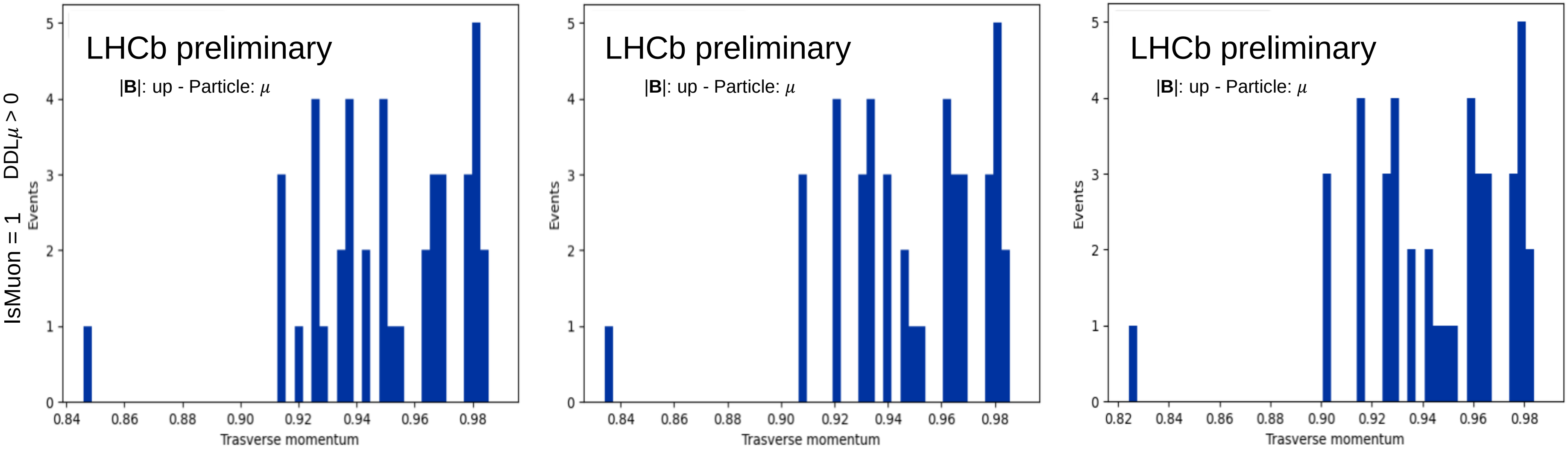


The **photosensitive surface** is designed to capture the particles' emission crossing the radiator. By measuring the angle, θ, of the Cherenkov cone, RICH detectors extract the particle velocity.



Andrea Contu

LHCb Data analysis



Year: 2016

Year: 2017

Year: 2018

- It is possible to use experimental data of LHCb to correct the efficiency of the PID using simulation correcting the systematic uncertainty.
- PID capability is a function year data taking.

Summary

1. **The SM is certainly incomplete.**
2. **Demonstrating dark photon's existence could be the key to discover deeper the unknown world of dark matter.**
3. **Particle physics is at crossroads. For the first time in particle physics we know that there are new particles, but we do not know yet where to find them.**
4. **It is even more important to focus on the synergy with cosmology and astrophysics.**
5. **Dark matter's nature hopefully may be uncovered in a couple of years.**

Backup

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5	CP SYMMETRY PROBLEM	The SM does not provide an explanation to the **imbalance** between matter and antimatter in the universe.

BSM

Not-singlet extension

Interaction strength

Energy

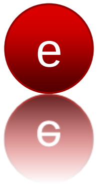
Heavy Neutral Leptons

SUSY

Backup

SUPERSYMMETRY

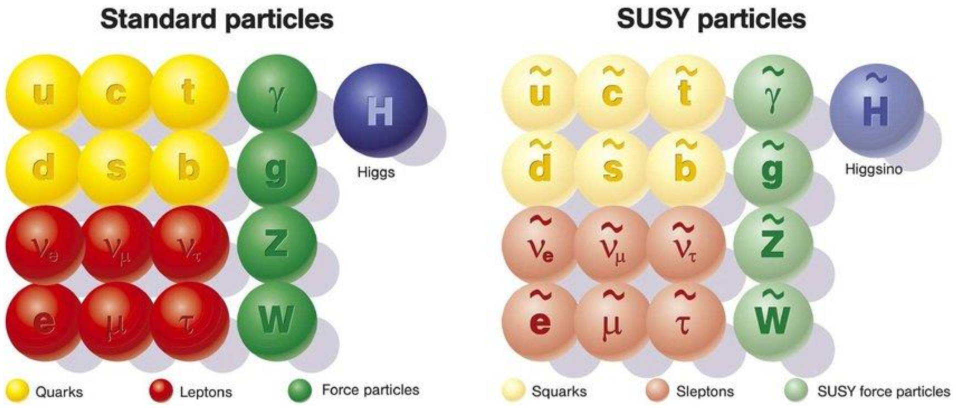
Each of the particles in the SM has a partner with a spin that differs by half of a unit



electron

selectron

These new particles would solve a major problem with the SM: fixing the **mass** of the **Higgs boson**.



If the theory is correct, supersymmetric particles should appear in collisions at the LHC

Backup

Why should dark photons exist?

There is a deviation between the measurement and the SM prediction of the anomalous magnetic moment of the muon. **Why?**

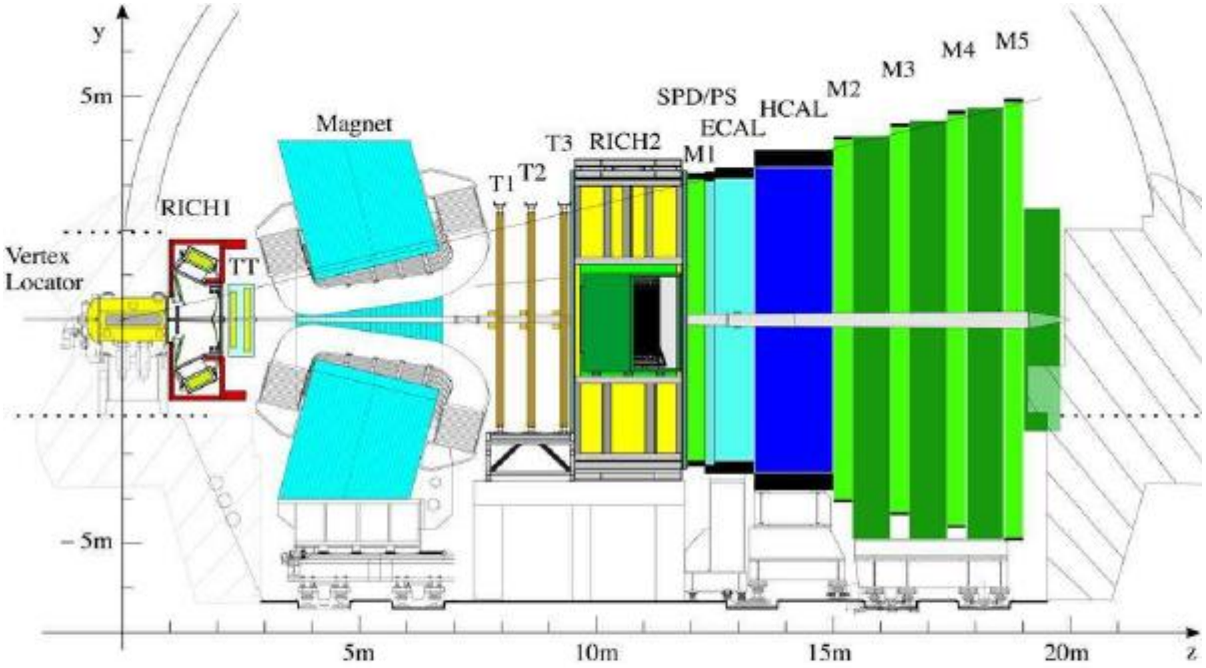
What causes the positron excess presently seen in the spectrum of cosmic rays**?**

Very recently, an anomaly was observed in a nuclear decay of Beryllium. **Could this be** a first hint for a 17 MeV Dark Photon signal**?**

Proving the dark photon's existence could answer to all of these questions...

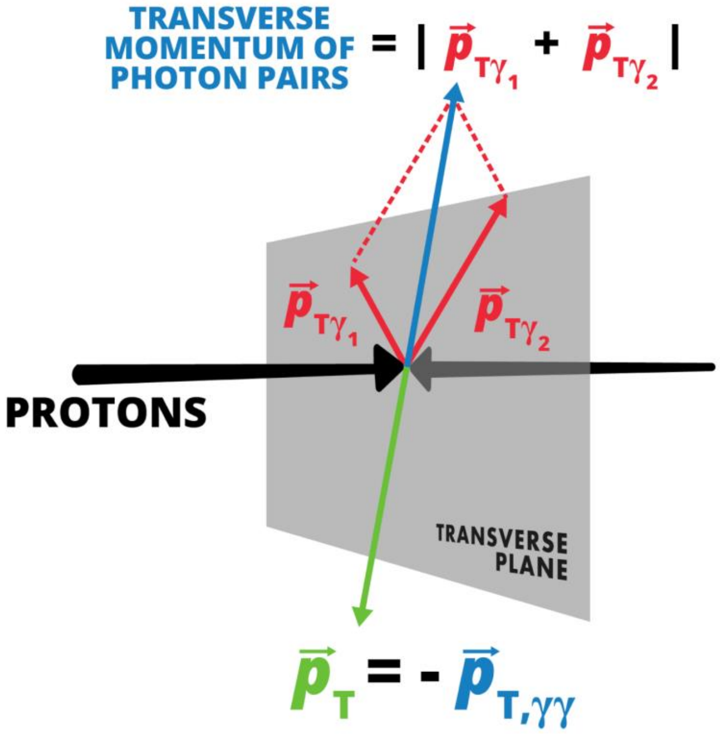
Backup

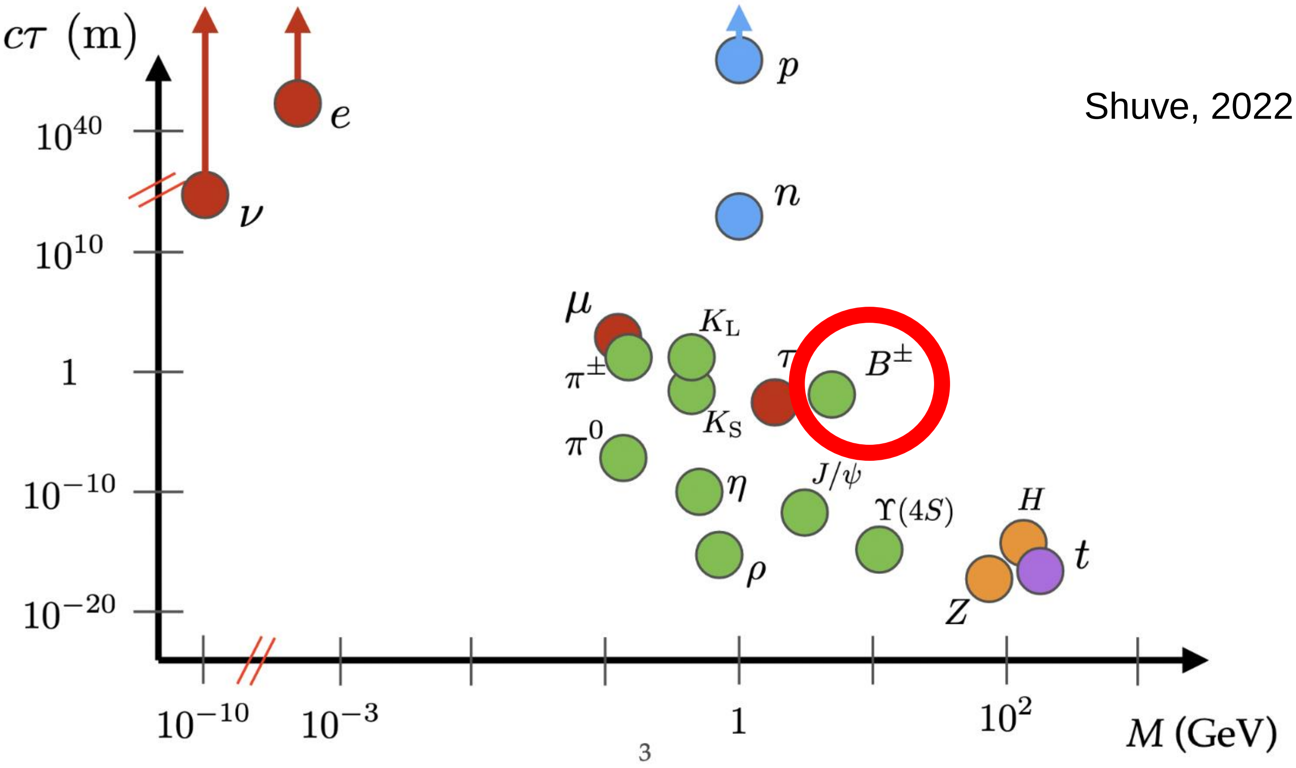
LHCb Experiment's sub-detectors



Backup

Transverse momentum





$c\tau$ (m)
10^{40}
10^{10}
1
10^{-10}
10^{-20}
10^{-10}
10^{-3}
1
10^{2}
M (GeV)
ν
e
p
n
μ
$\pi^{\pm}$
K_L
K_S
τ
$B^{\pm}$
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η
ρ
J/ψ
$\Upsilon(4S)$
H
t
Z
3

Shuve, 2022