

# Producing and detecting long-lived particles at different experiments at the LHC

*Chaochen Yuan*<sup>1,2</sup>, *Huaiqao Zhang*<sup>1,2</sup>, *Yue Zhao*<sup>3</sup>, *Guoming Chen*<sup>1</sup>

**1. Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, 100049, China**

**2. University of Chinese Academy of Sciences, Beijing, 100049, China**

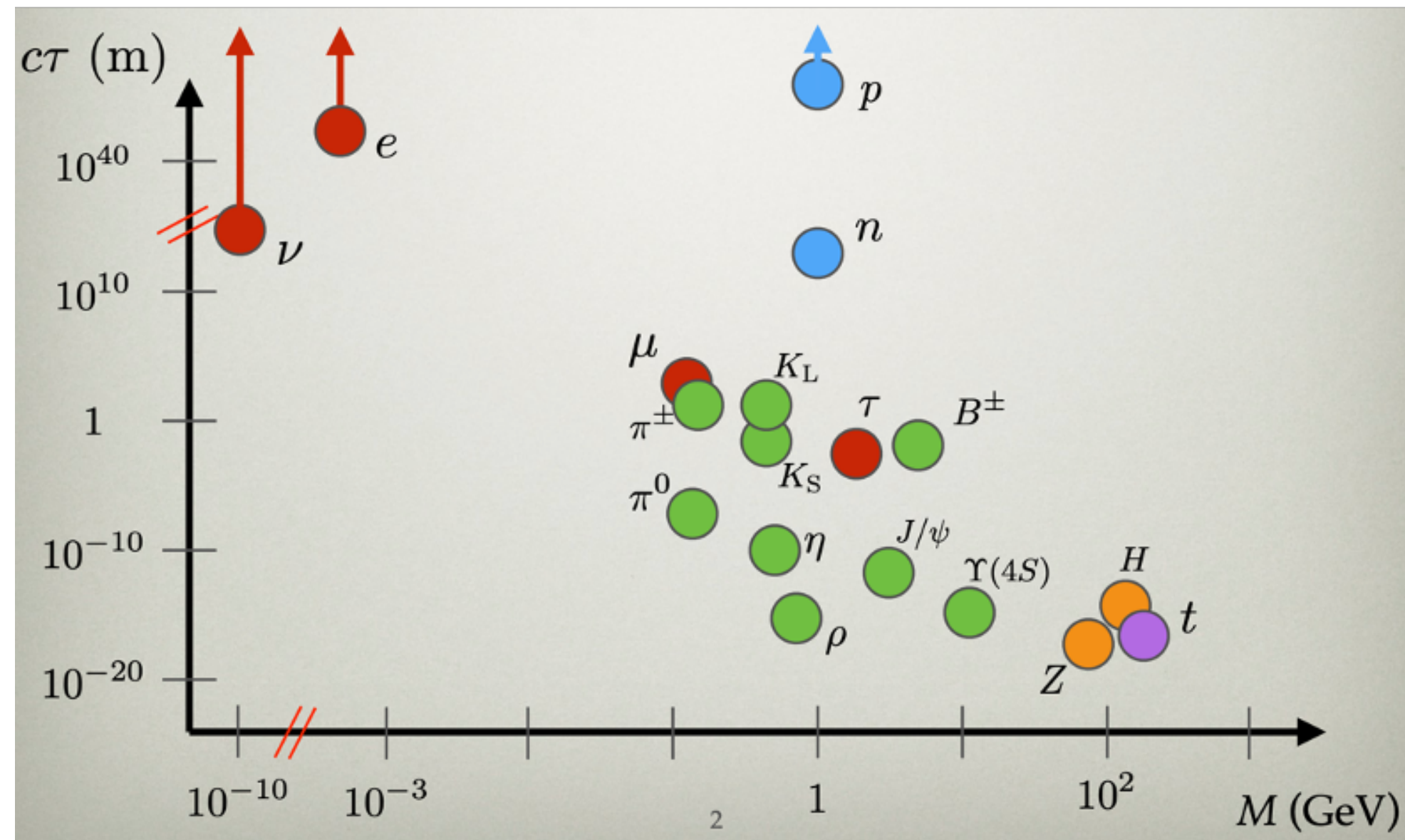
**3. Department of Physics and Astronomy, University of Utah, Salt Lake City, UT 84112, USA**

**doi:10.1007/JHEP02(2022)069**

# Outline

- Overview for long-lived particles
- Searching strategy
- Event selection
- Background
- Trigger
- Expected limit
- Summary

# Overview for long-lived particles



Long-lived particles generically exist in SM and many extensions of SM, SUSY, Hidden vector...

$$\frac{\hbar}{\tau} = \frac{f_\pi^2}{256\pi m_\pi} \left( \frac{g^2 m_\mu}{m_W^2 m_\pi} (m_\pi^2 - m_\mu^2) \right)^2$$

Annotations in the diagram:

- Small coupling constant (points to  $g^2$ )
- Large mediator mass (points to  $m_W^2$ )
- Helicity suppression (points to  $m_\pi^2 - m_\mu^2$ )
- Small mass splitting to decay product (points to  $m_\pi^2 - m_\mu^2$ )

set  $\pi$  for an example

**Why a particle is long-lived**

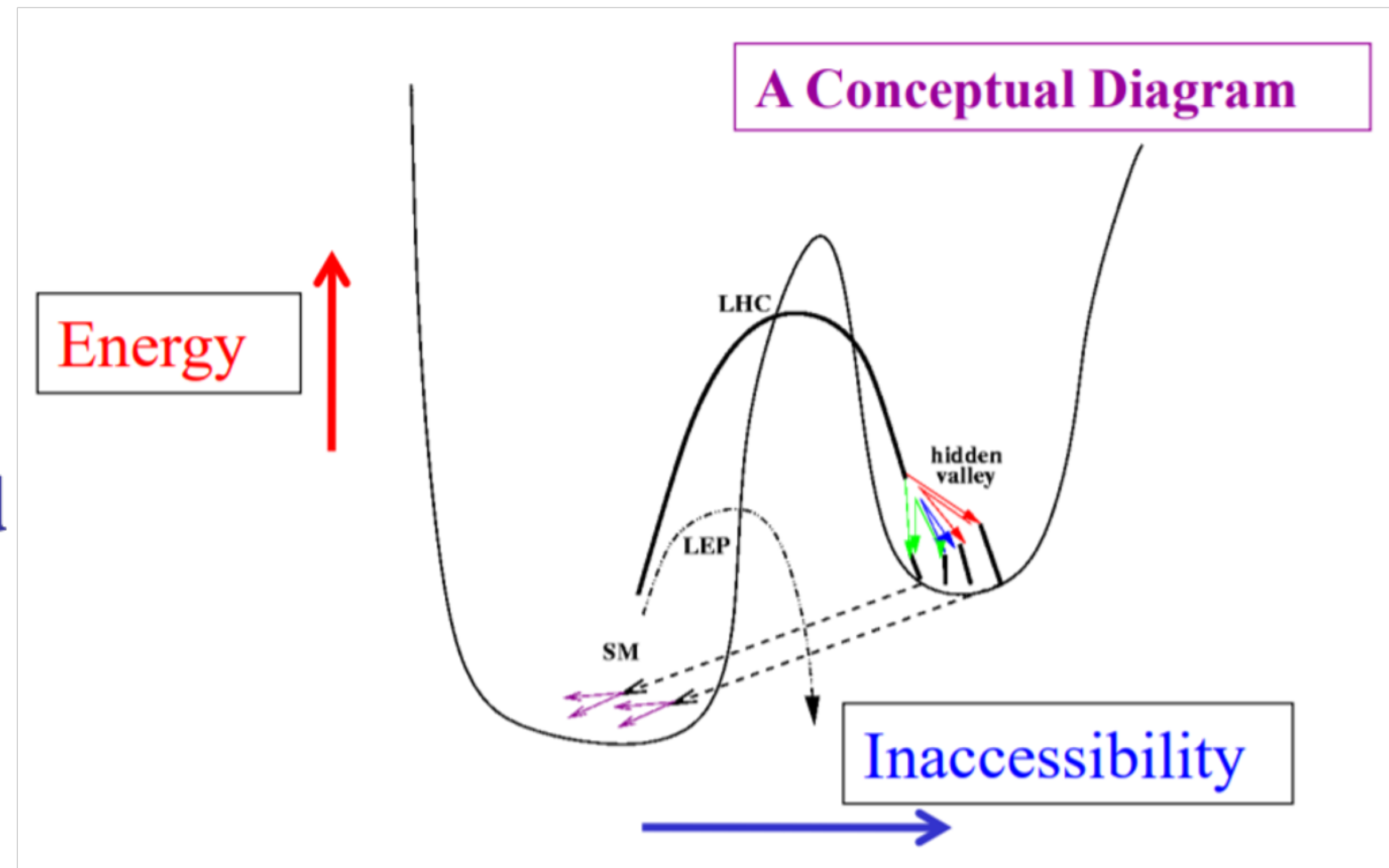
Discovery of BSM LLP indicate new hierarchies or old hierarchies in new places

# Overview for long-lived particles

## Non-Abelian Dark Sector

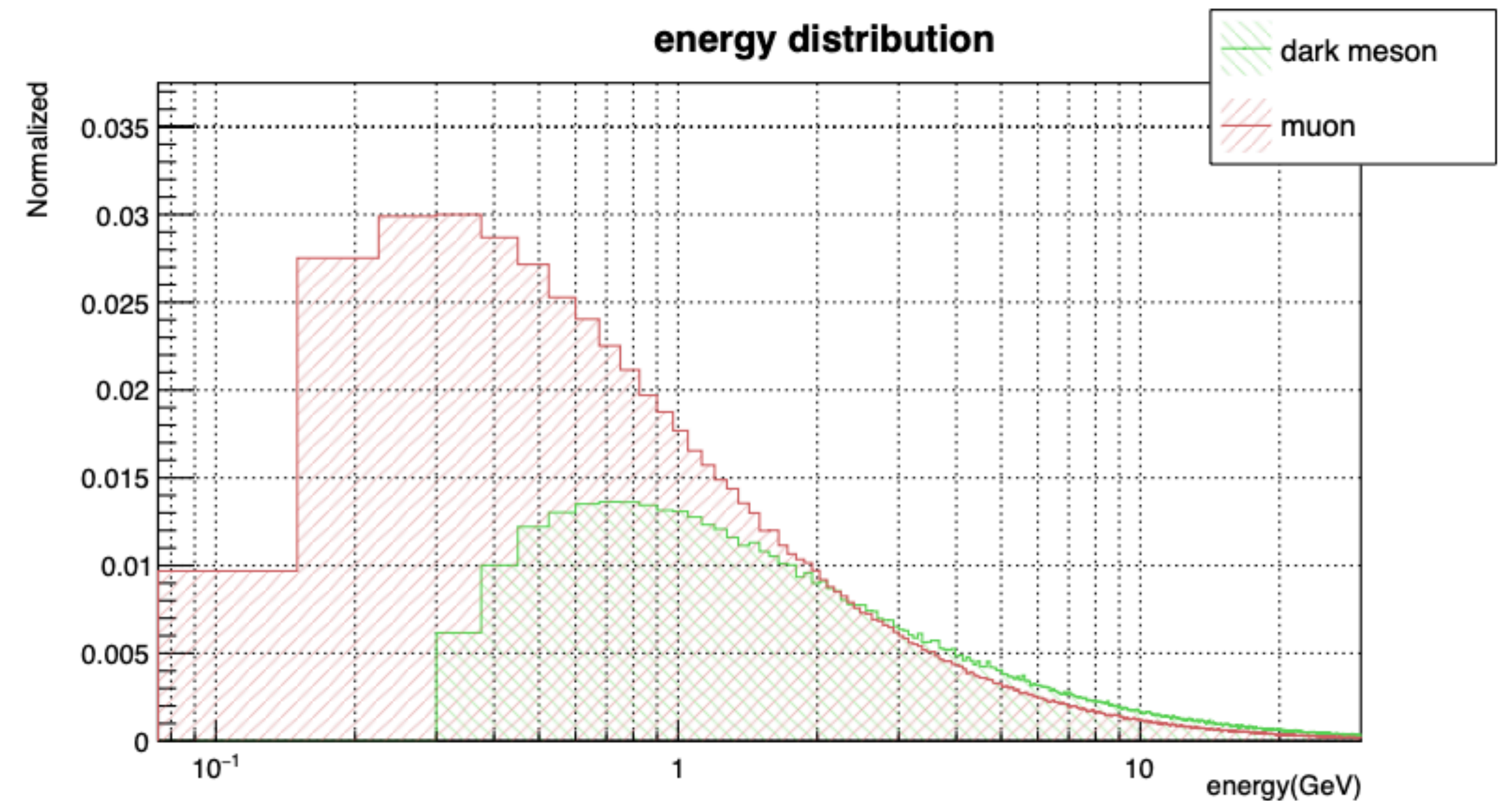
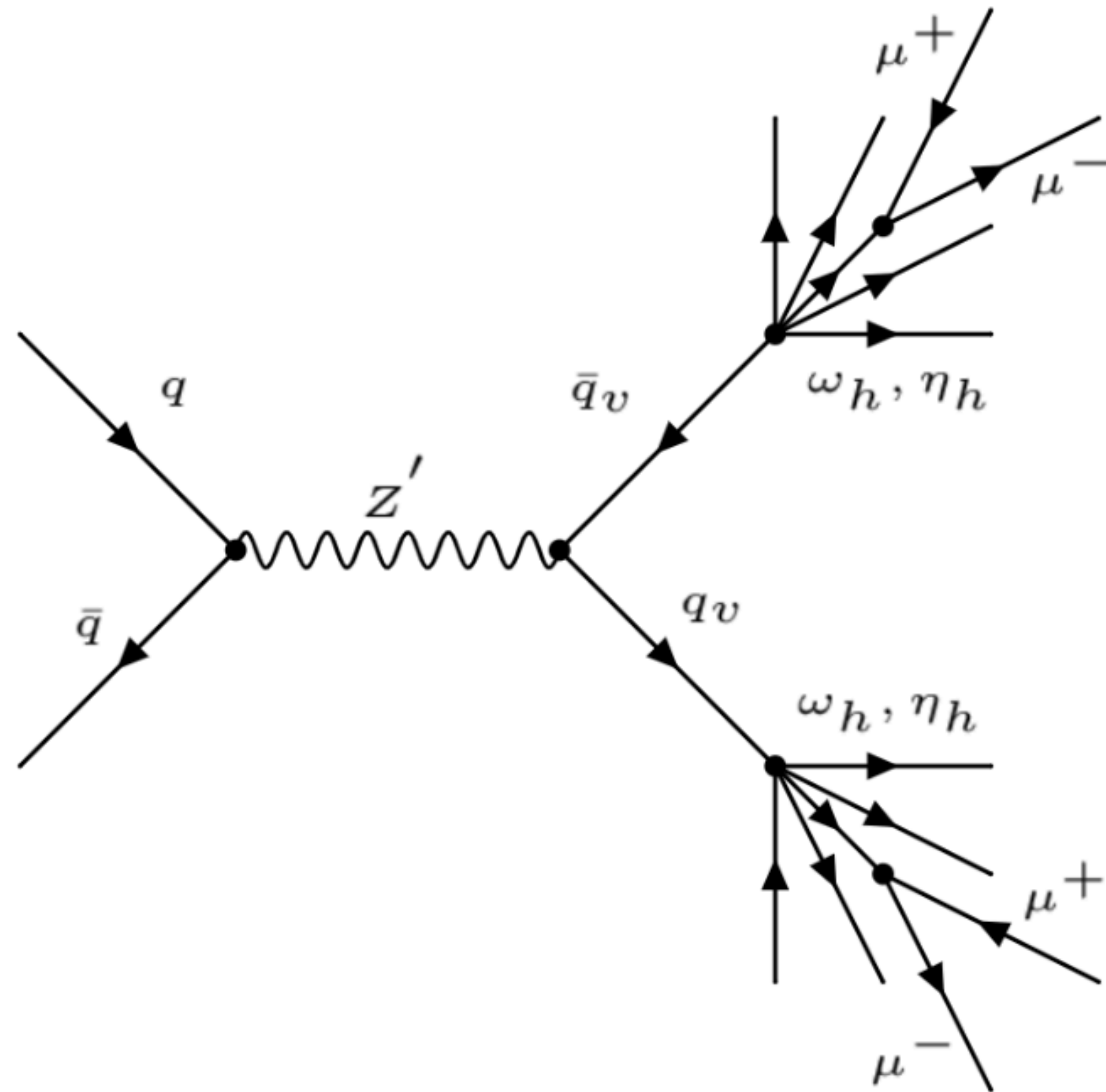
Dark sector remains largely unknown

Generically classified as **Hidden Valley Models**



# Overview for long-lived particles

## Non-Abelian Dark Sector



$Z'$  mass: 200GeV  
 HV meson: 0.3GeV  
 $\langle N \rangle \sim 40$

Showering and hadronization in the hidden sector distribute energy to many soft HV mesons

# Searching strategy

## current searching strategy

Search strategies roughly fall into two categories:

**New search/trigger strategies:**

LHCb with VELO/RICH,  
timing trigger

Forward Spectrometer

CMS High Granularity Calorimeter

**Adding new modules:**

FASER

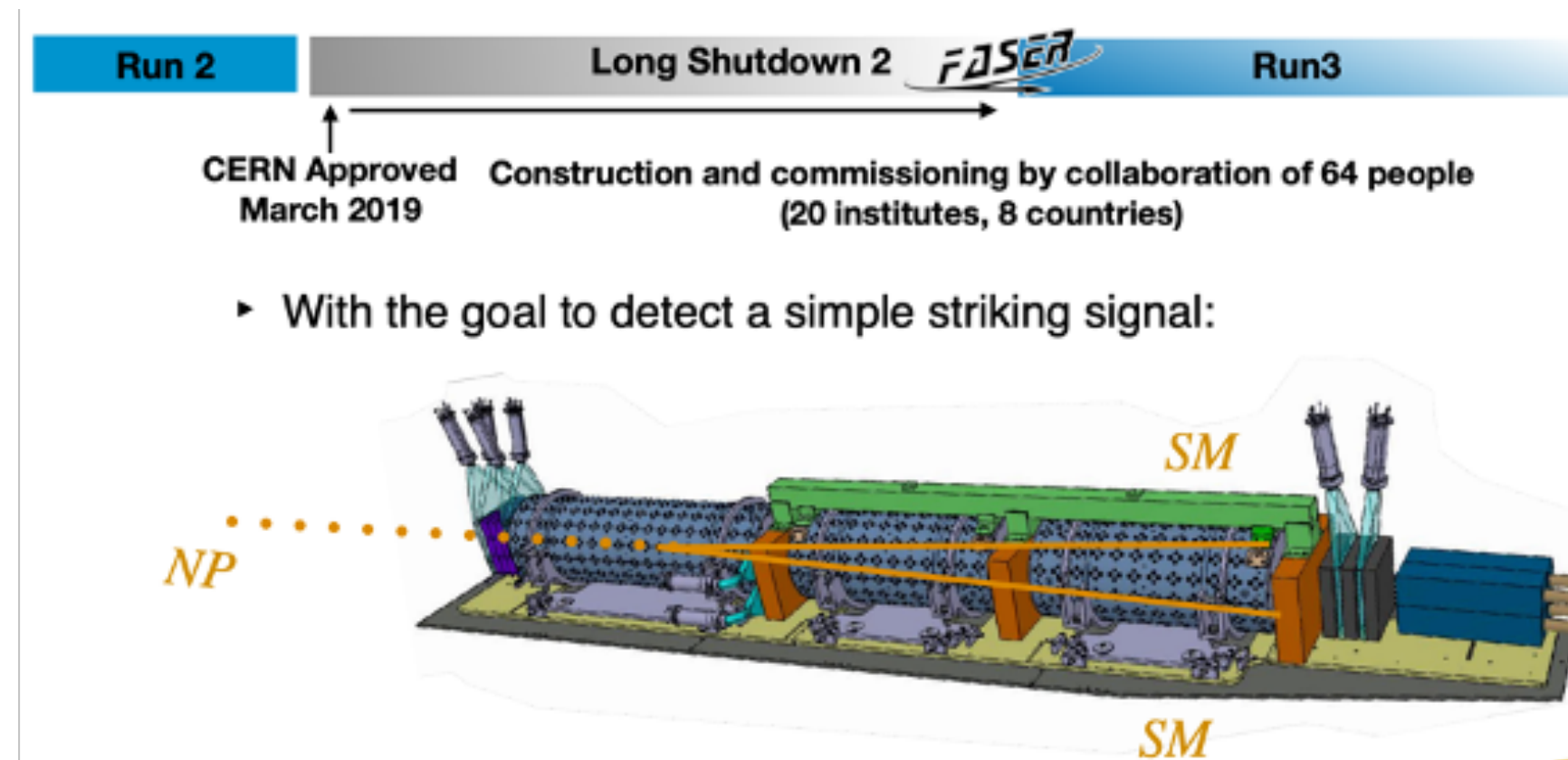
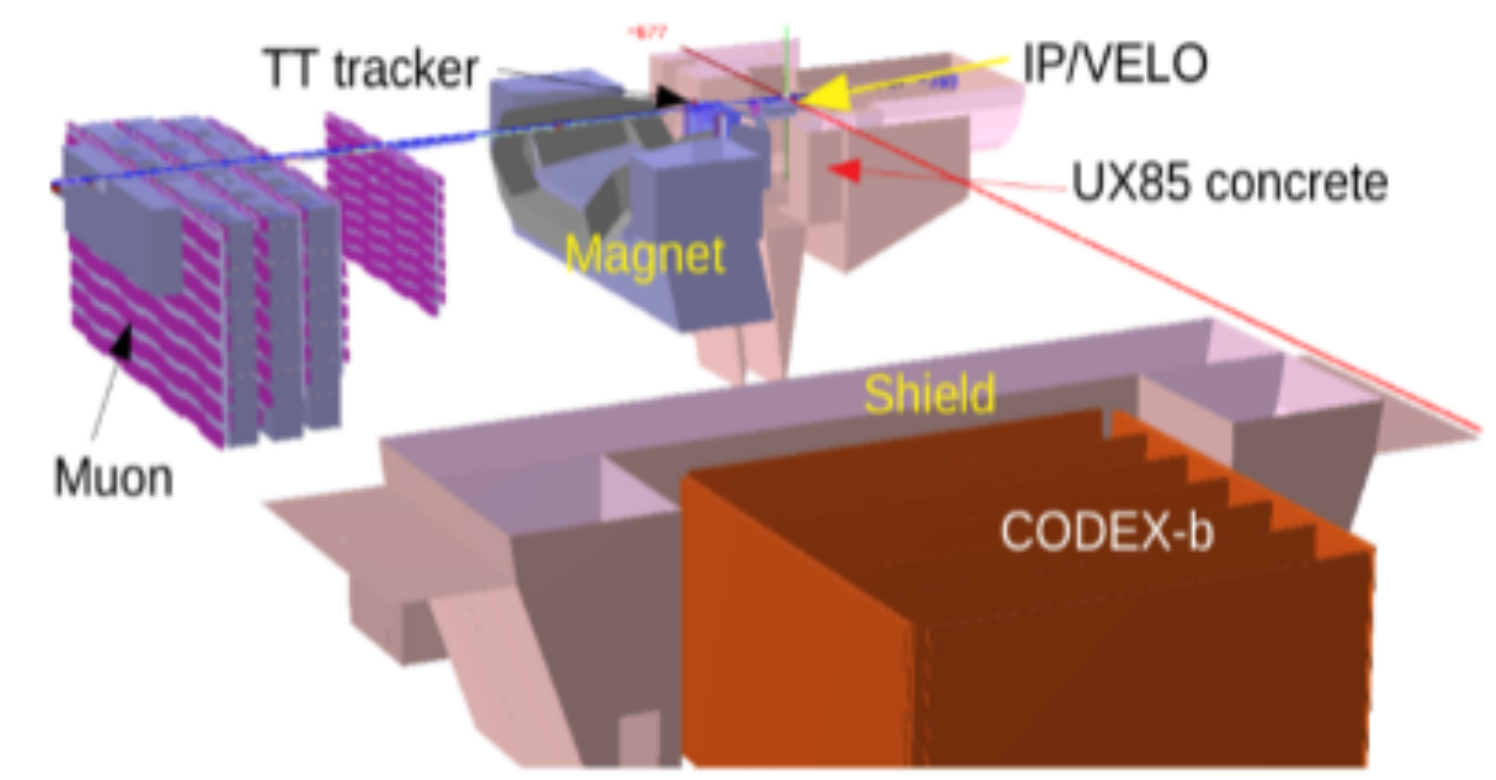
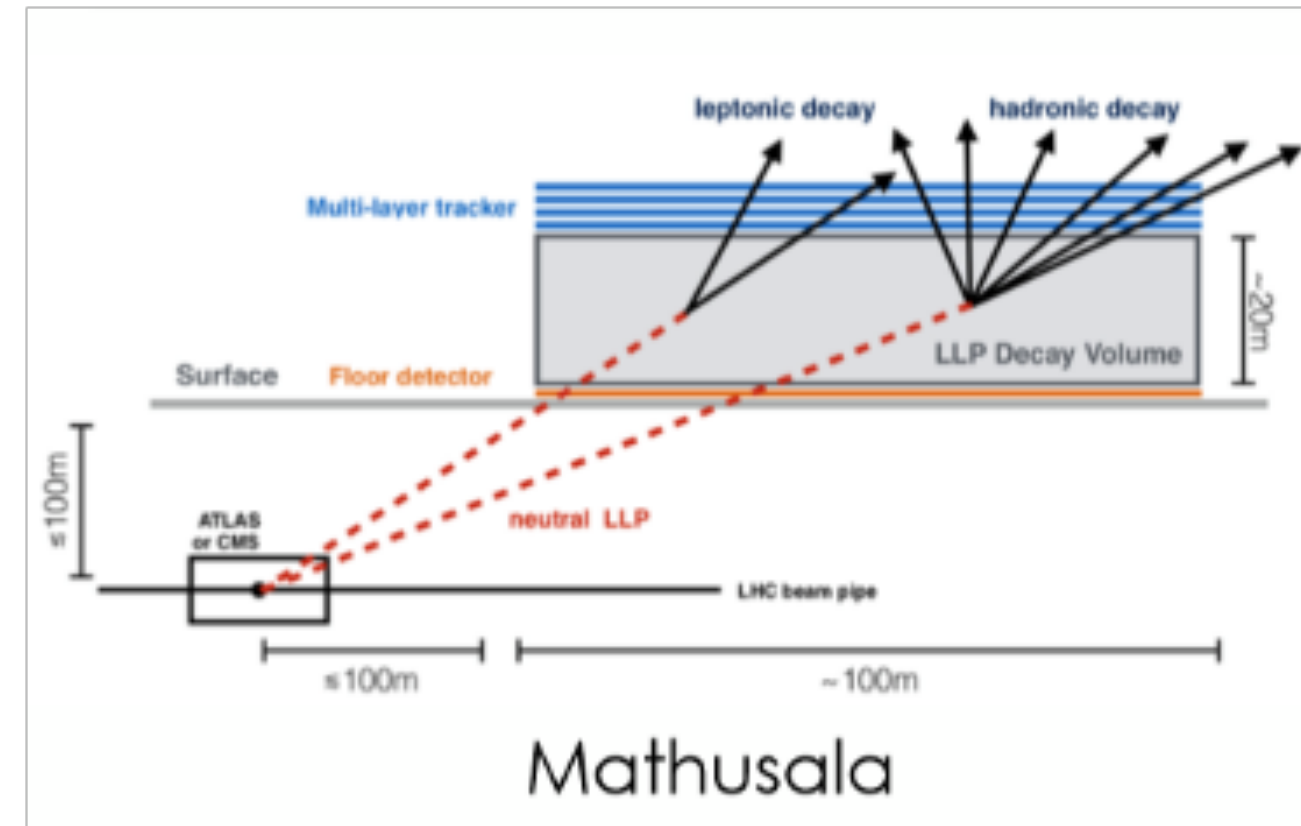
MATHUSELA

CODEX-b

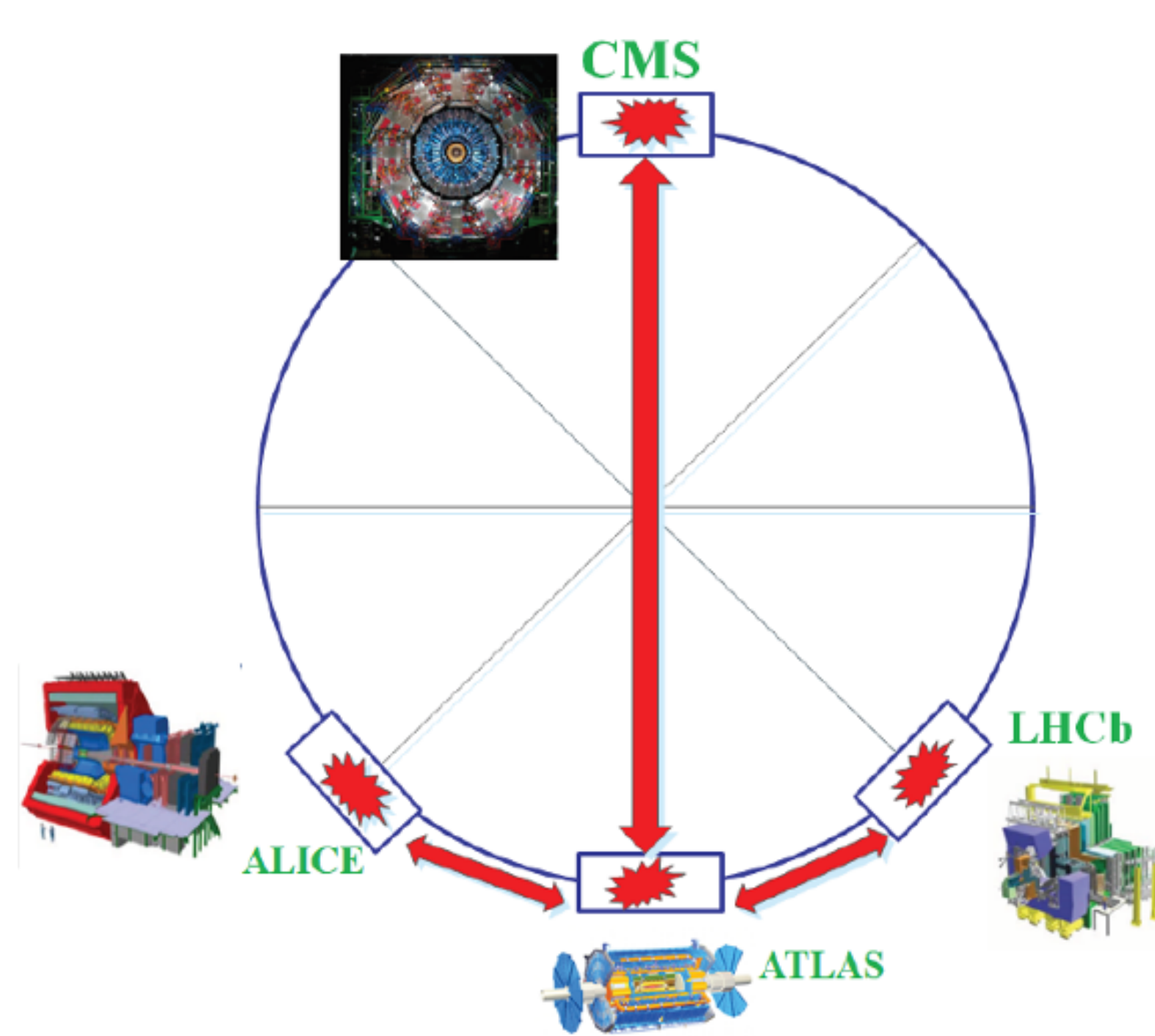
ANUBIS

MoEDAL with MAPP/MALL

MilliQan



# Searching strategy



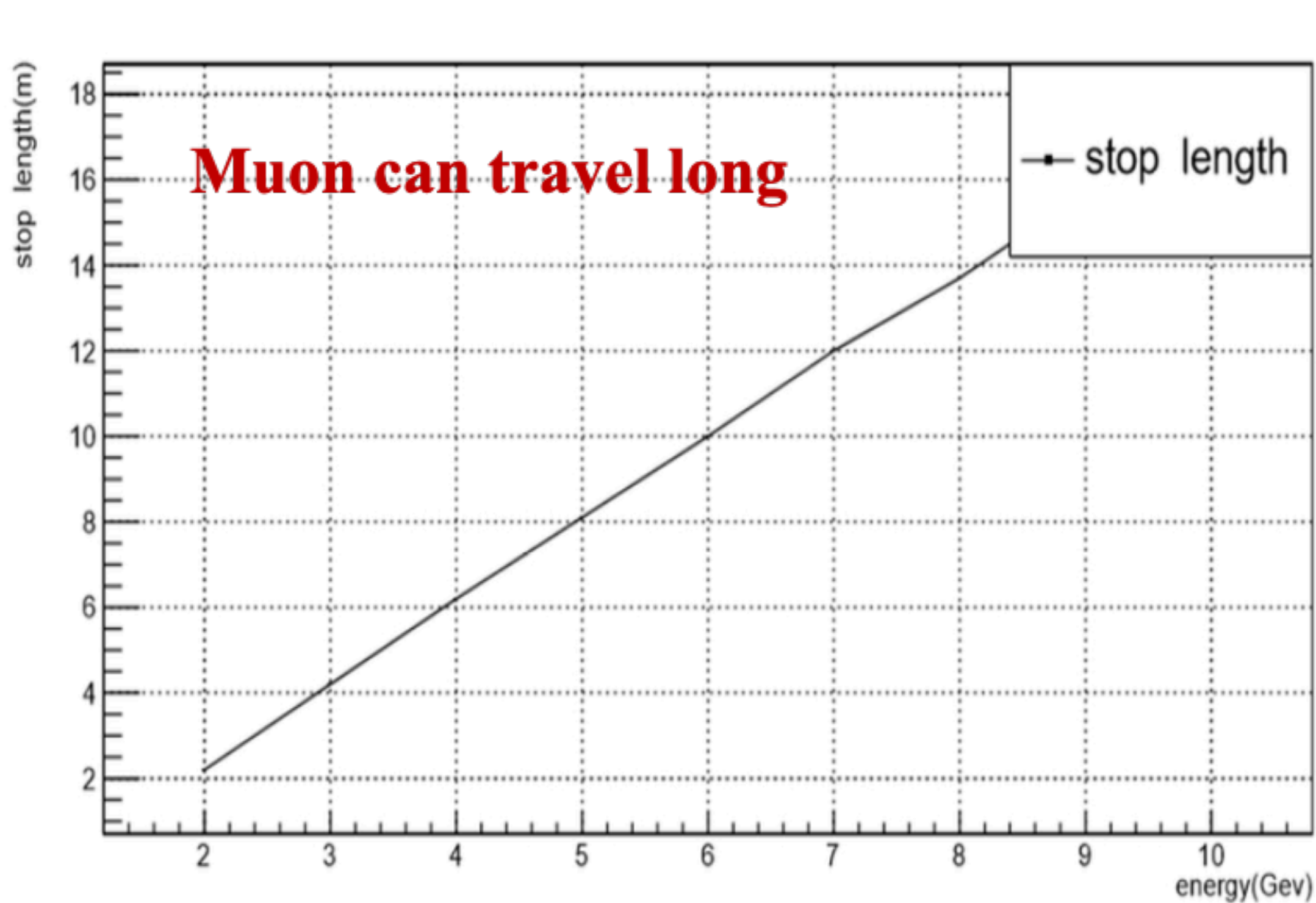
Produce	detect	distance(m)
LHCb/ALICE	ATLAS	3288
LHCb/ALICE	CMS	7940
CMS	ATLAS	8594
ALICE	LHCb	6077

Using existing facilities as far detector

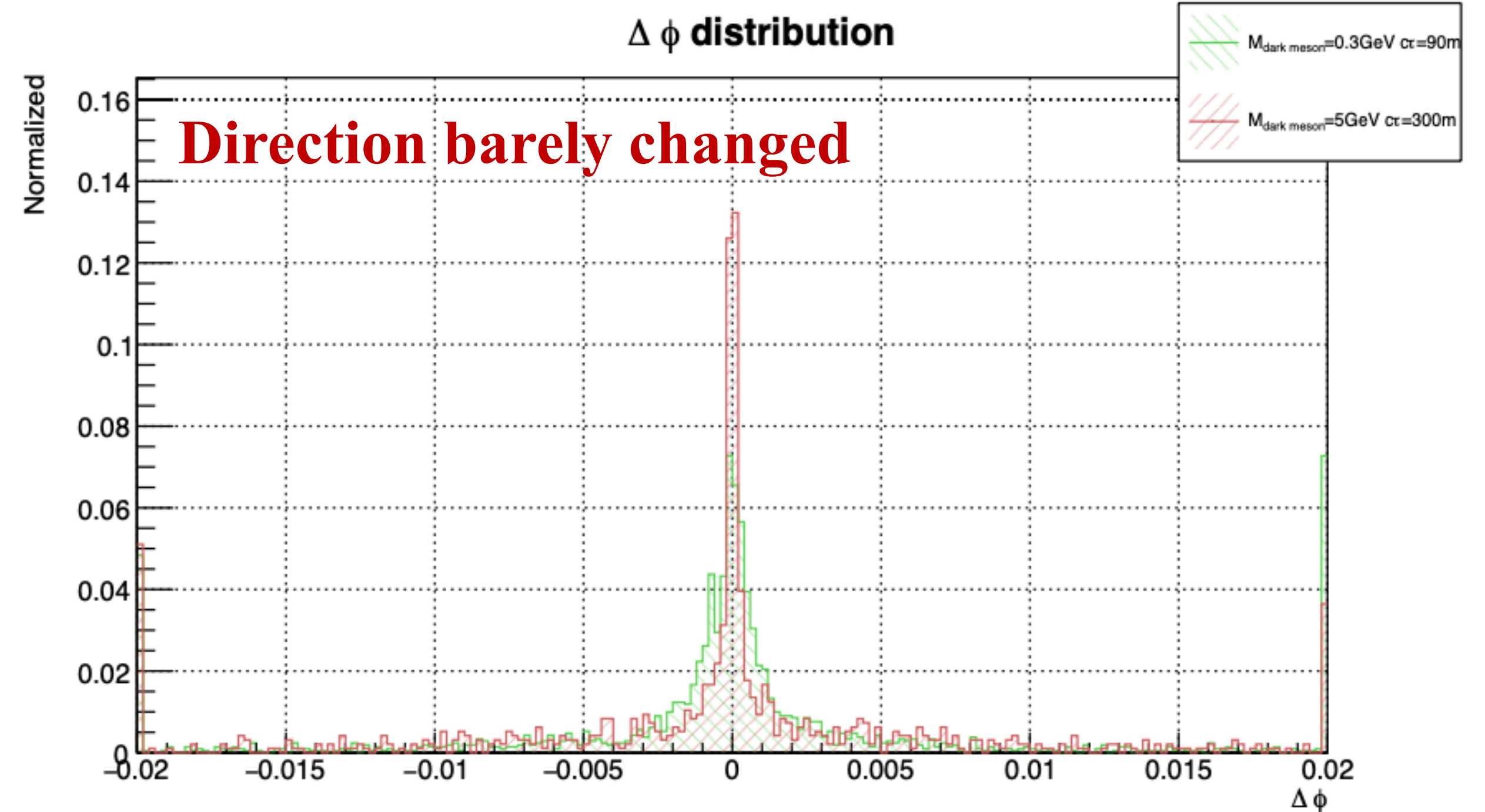
**Smallest distance**

# Searching strategy

Focus on muon channel



Muon can travel long distance in earth



Direction is barely changed during its propagation

# Searching strategy

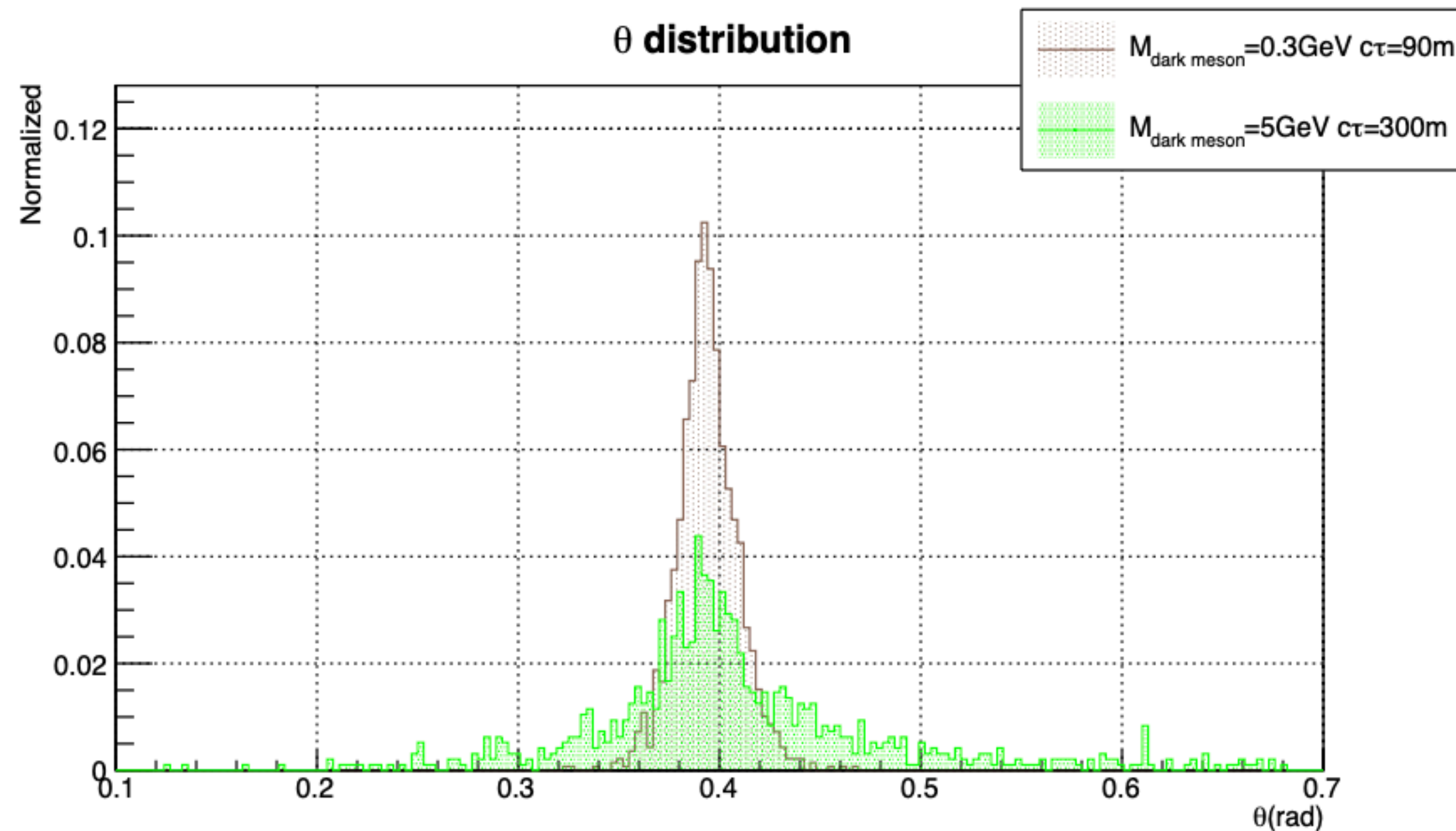
Idea combination

**LHCb and ALICE for production ATLAS for detection**

- **Smallest distance**
  - **Forward direction**
  - **Large muon chamber volume**
  - **Luminosity:**  
**LHCb is about 10 times lower than ATLAS pp luminosity**  
**ALICE is not clear**
- ATLAS has advantages**

Combine LHCb and ALICE we assume  $500\text{fb}^{-1}$  total luminosity

# Event selection



- Muons from LLP decay have a preferred incidence angle
- Muon  $pt > 1 \text{ GeV}$  to ensure multiple hit in muon chamber
- The timing sequence is reversed to that of a muon from ATLAS collisions
- Large displacement
- ...

The  $\theta$  distribution of incoming muons in the coordinate of the ATLAS detector.

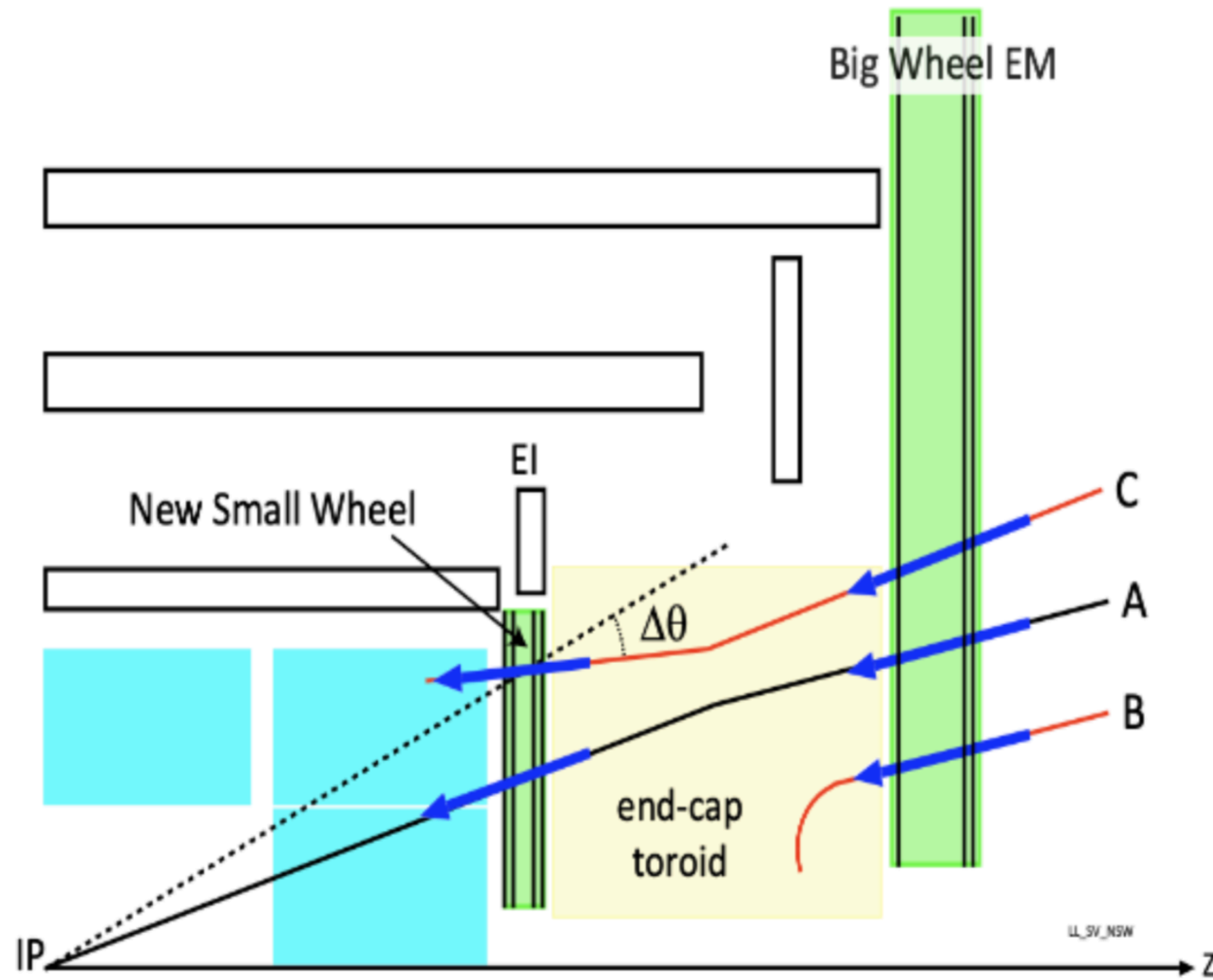
# Background

- **Cosmic muon**: can be removed using directional information( $\sim 36$  Km rocks)
- **Radioactive environment**: Can be removed by requiring muon  $p_t > 1$  GeV
- **High energy muons from LHCb/ALICE**: Expected number of events is  $\sim O(0.01)$  based on  $500 \text{ fb}^{-1}$
- **Neutrino conversion**: Expected number of events is  $\sim O(0.01)$  based on  $500 \text{ fb}^{-1}$
- **Background from ATLAS collision**:
  - A. Pointing back to production site(LHCb/ALICE)
  - B. Mostly have small impact parameter
  - C. Out-in track(inverse timing) coincides with in-out track

## Background Free!

# Trigger Endcaps

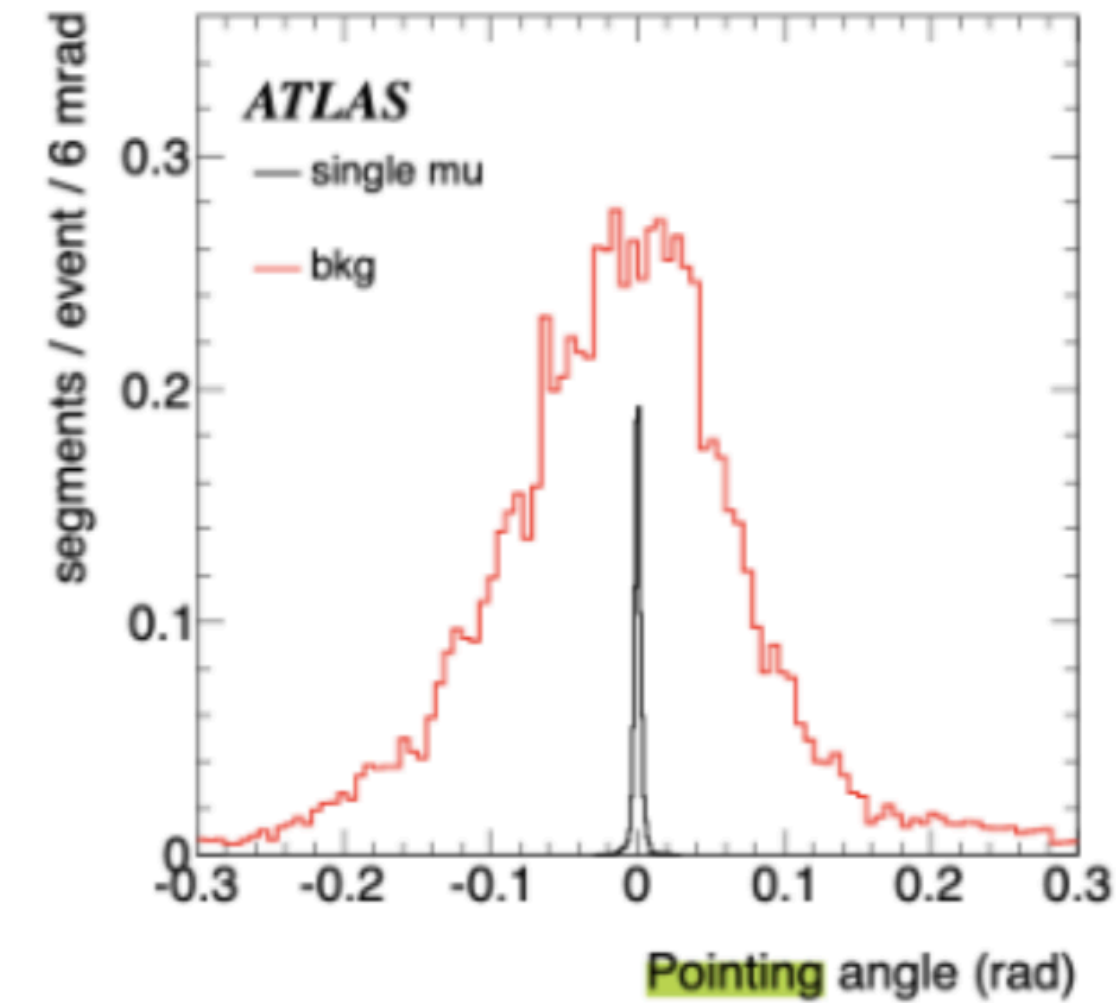
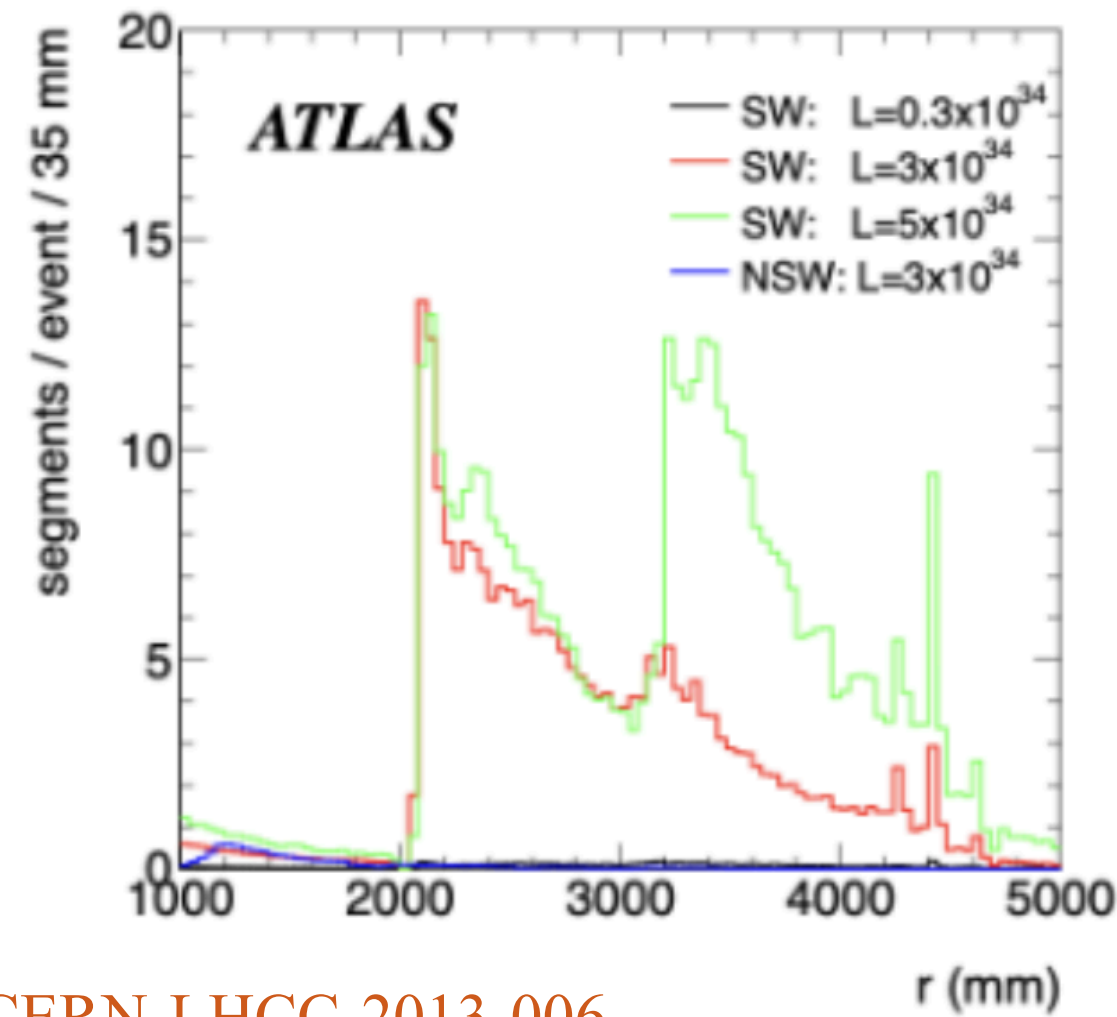
Similar for barrel(see backup)



From ATLAS NSW TDR, CERN-LHCC-2013-006

The pointing angle 1, is defined as the angle of the segment with respect to an ‘infinite momentum track’, i.e. a line from the interaction point of ATLAS detector to the segment’s radial position in the NSW.

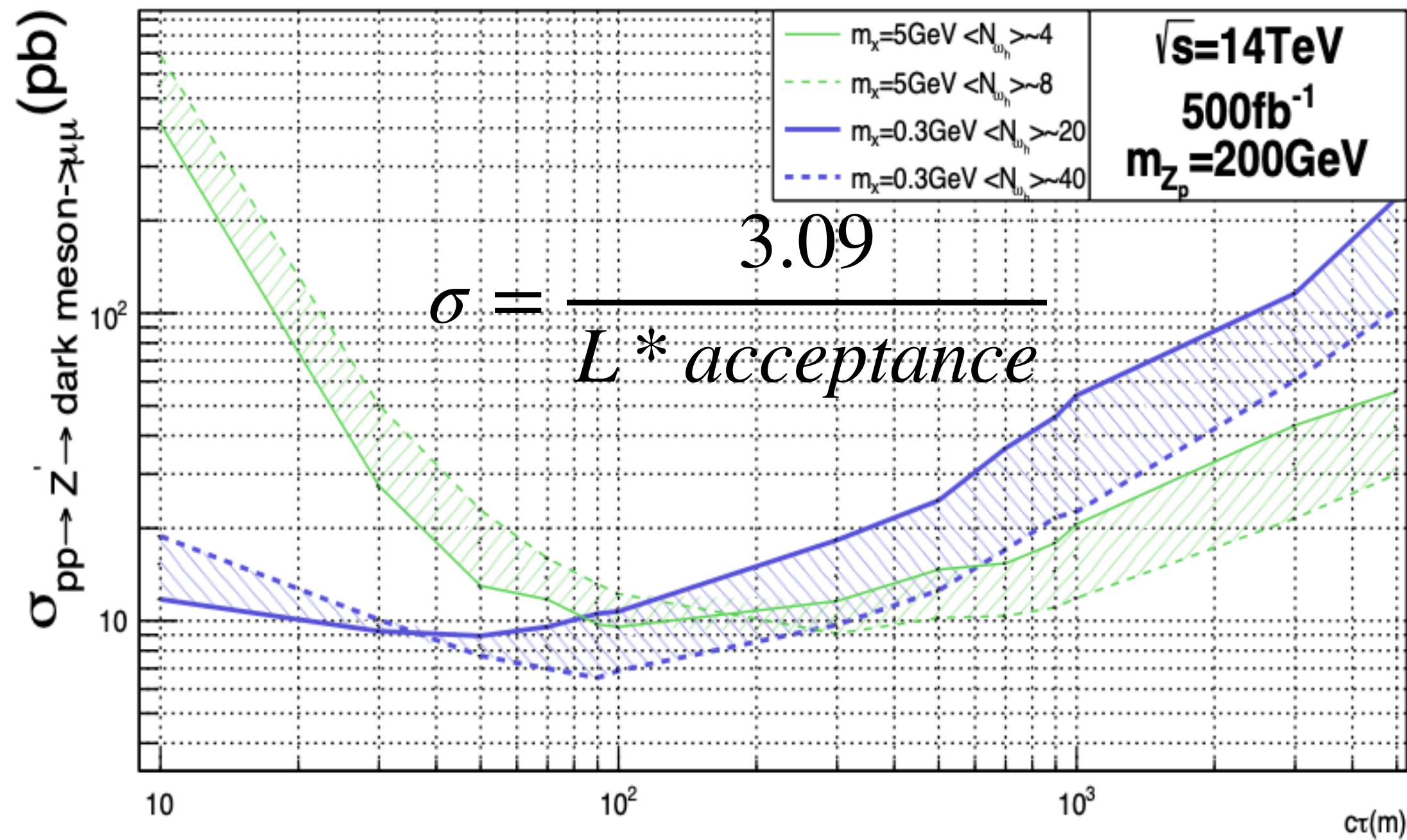
Pointing angle 2, as the angle of the segment in BW with respect to an ‘infinite momentum track’, i.e. a line from the interaction point of LHCb/ALICE



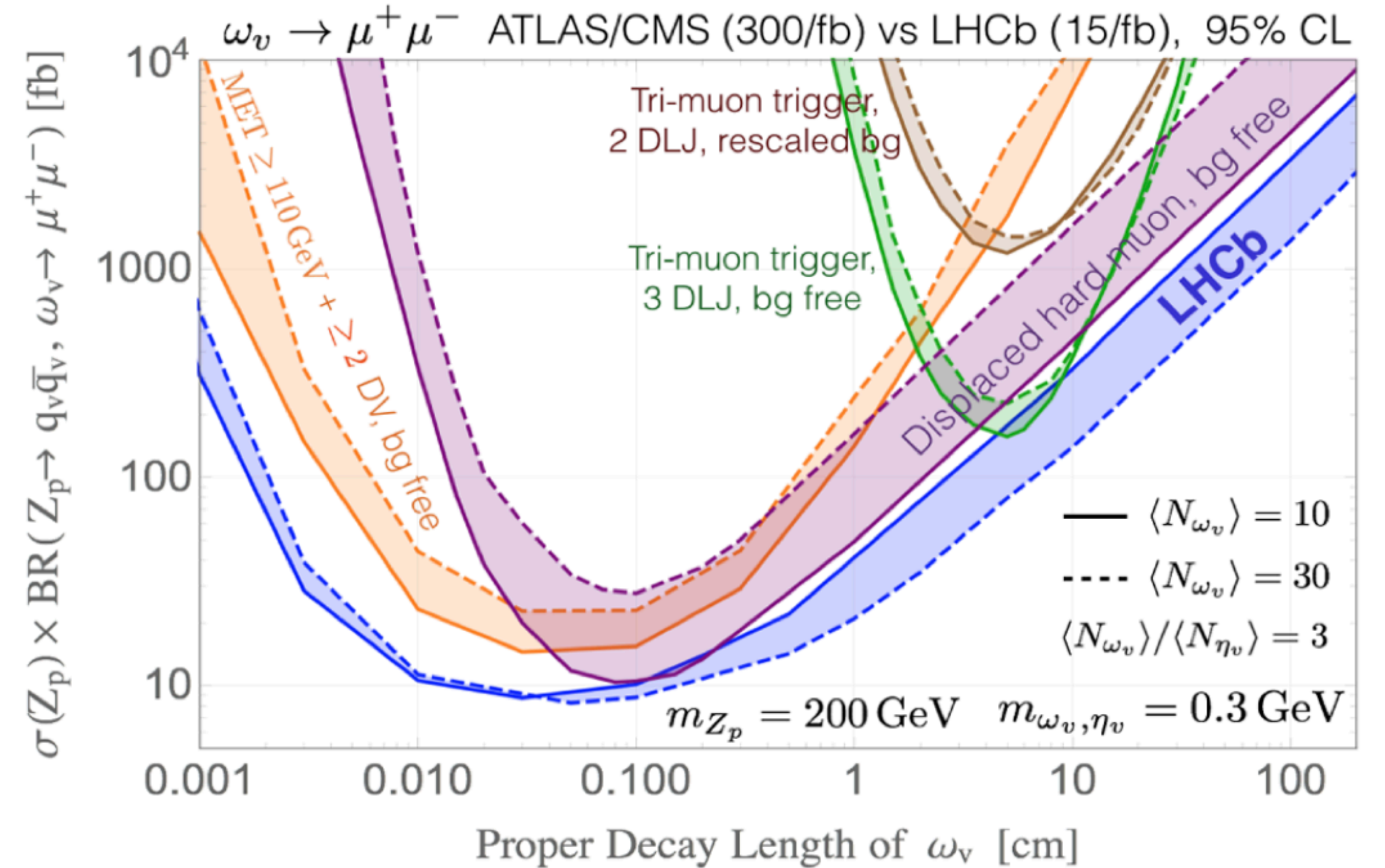
pointing angle2 ~0  
pointing angle1 >0.25

# Expected limit

Plot from PHYS. REV. D 97, 095033 (2018)



1GeV pt cut was applied



different lifetime range

# Summary

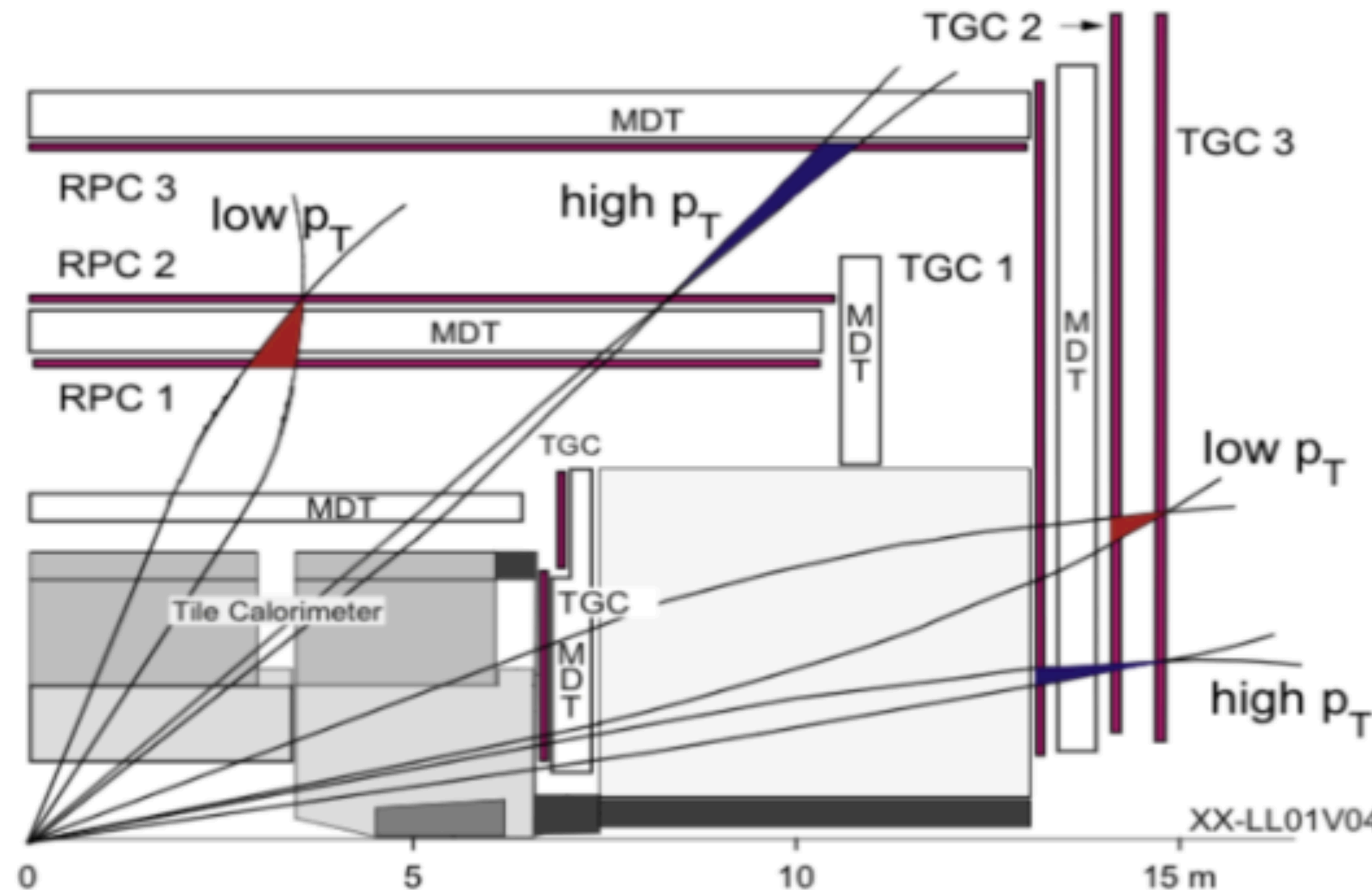
- We proposed a new LLP searching strategy with background free and low cost
- Sensitive to large lifetime range
- Can serve as an independent cross check
- Trying to implement to use CMS detector to detect

Thanks

# Backup

## trigger strategy for barrel

- For barrel we use same trigger strategy

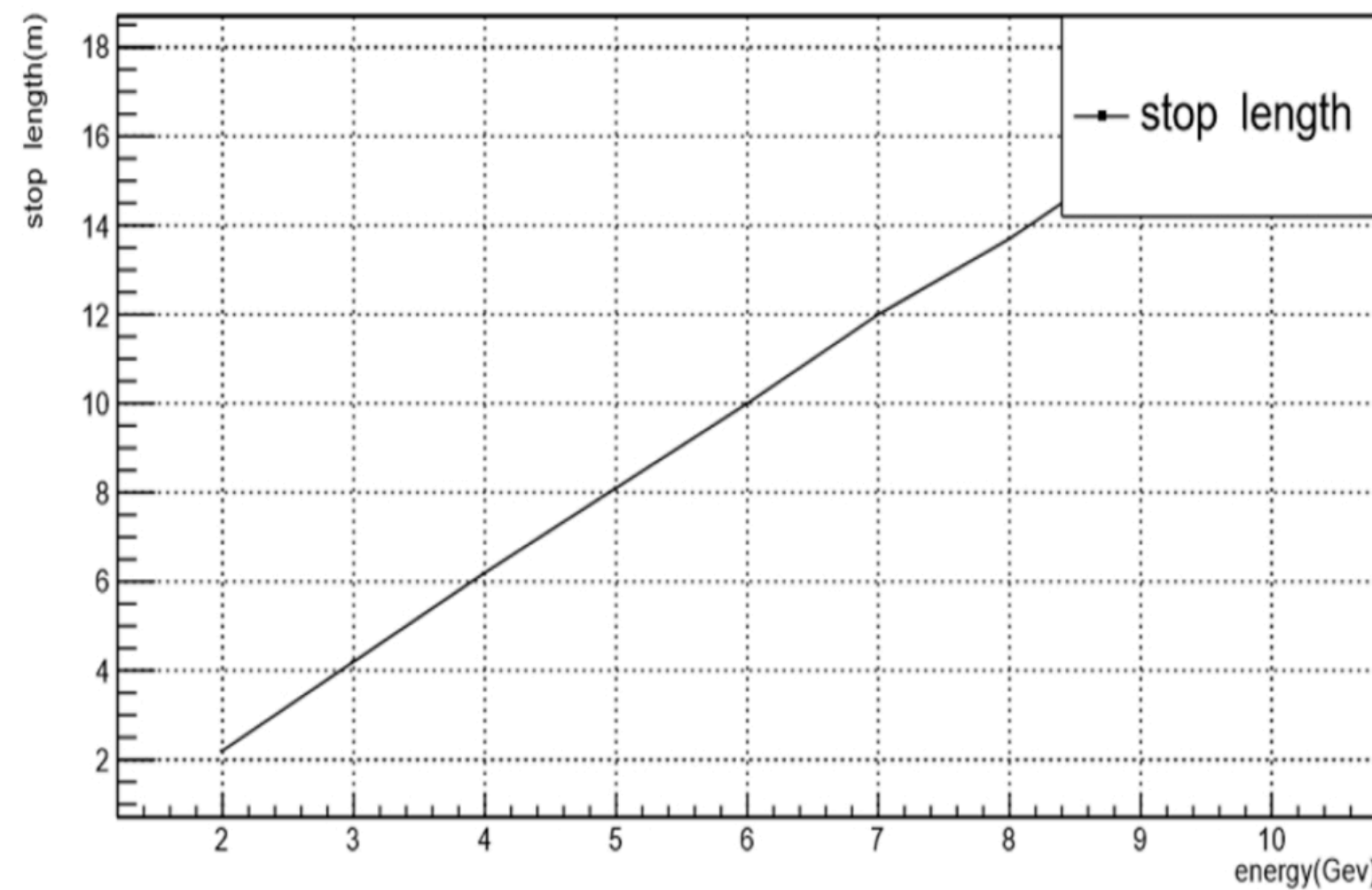


We define the pointing angle 1, as the angle of the track segment with respect to an infinite momentum track, which is a line from the ATLAS interaction point to the segments radial position in the RPC3 of ATLAS barrel muon chamber.

The pointing angle 2, is defined as the angle of the segment with respect to an infinite momentum track, i.e. a line from the interaction point of the LLP producing detector, such as LHCb, to the segments radial position also in RPC3. By setting cuts to  $\Delta\theta_1$  and  $\Delta\theta_2$ , we can select our signal and remove tracks come from ATLAS collisions

# Backup

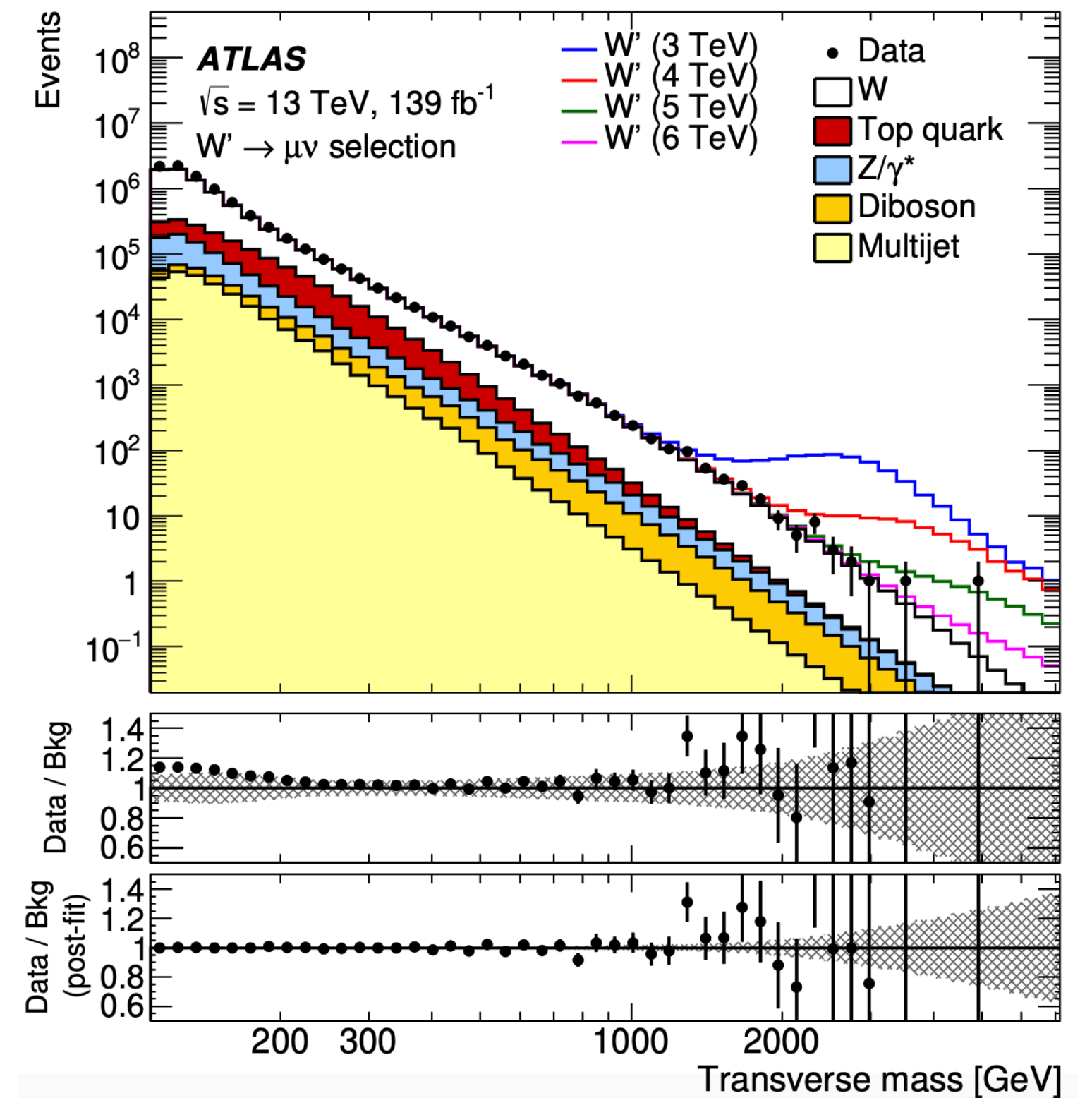
## High energy muon background



muon energy loss  $\sim 0.6 \text{ GeV/m}$   
if we take the density of earth is  $2.6 \text{ g/cm}^3$   
distance between LHCb and ATLAS is  $\sim 3300 \text{ m}$   
the muon need more than  $2 \text{ TeV}$  to travel from LHCb to ATLAS

These high energy muons are dominantly produced by W or Z boson decays in the leptonic channel

production cross section is around  $7 \text{ fb}$   
 $l=500 \text{ fb}^{-1}$   
geometric acceptance  $= 10^{-5}$   
expected events is at  $O(0.01)$



Plot from 10.1103/PhysRevD.100.052013

# Backup

## Neutrino conversion background

Plot from [https://indico.lip.pt/event/592/contributions/2941/attachments/2915/4467/Shalaev\\_Lisbon\\_08092021v5.pdf](https://indico.lip.pt/event/592/contributions/2941/attachments/2915/4467/Shalaev_Lisbon_08092021v5.pdf)

two sources of neutrinos:

hadron decay->mostly soft neutrinos, hard to convert to muons via charge current interaction

W/Z decay->take W decay as an example

Production cross section of W bosons is around 20 nb at 14 TeV

Luminosity of LHCb as  $500 \text{ fb}^{-1}$

Geometric acceptance  $\sim 10^{-5}$

So we can have  $\sim 10^5$  neutrinos from LHCb to ATLAS

Cross section of CC interaction for neutrino is around  $10^{-10} \text{ mb}$

Luminosity of this neutrino current can be considered as  $L_{eff} = N * \rho * l/M$

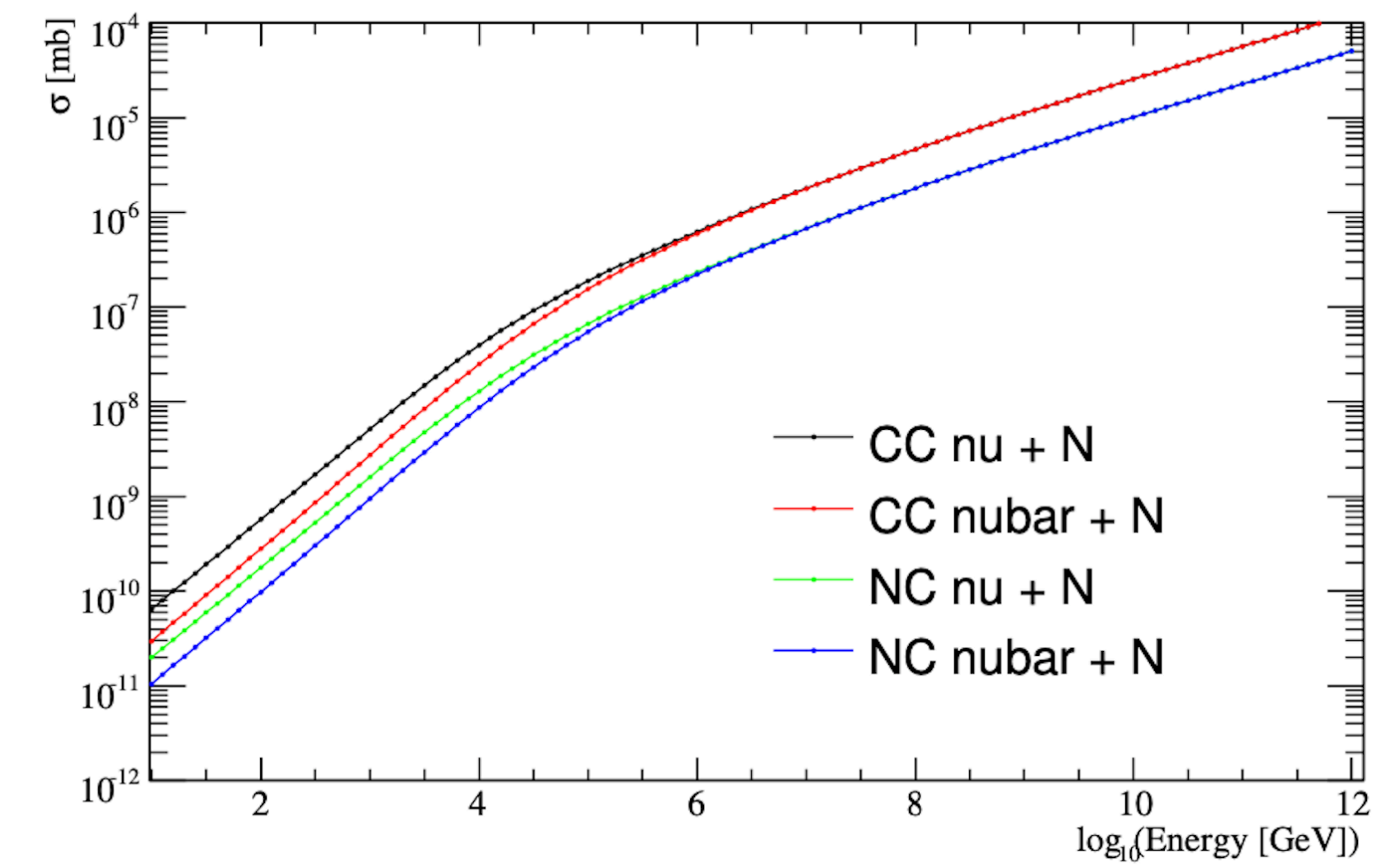
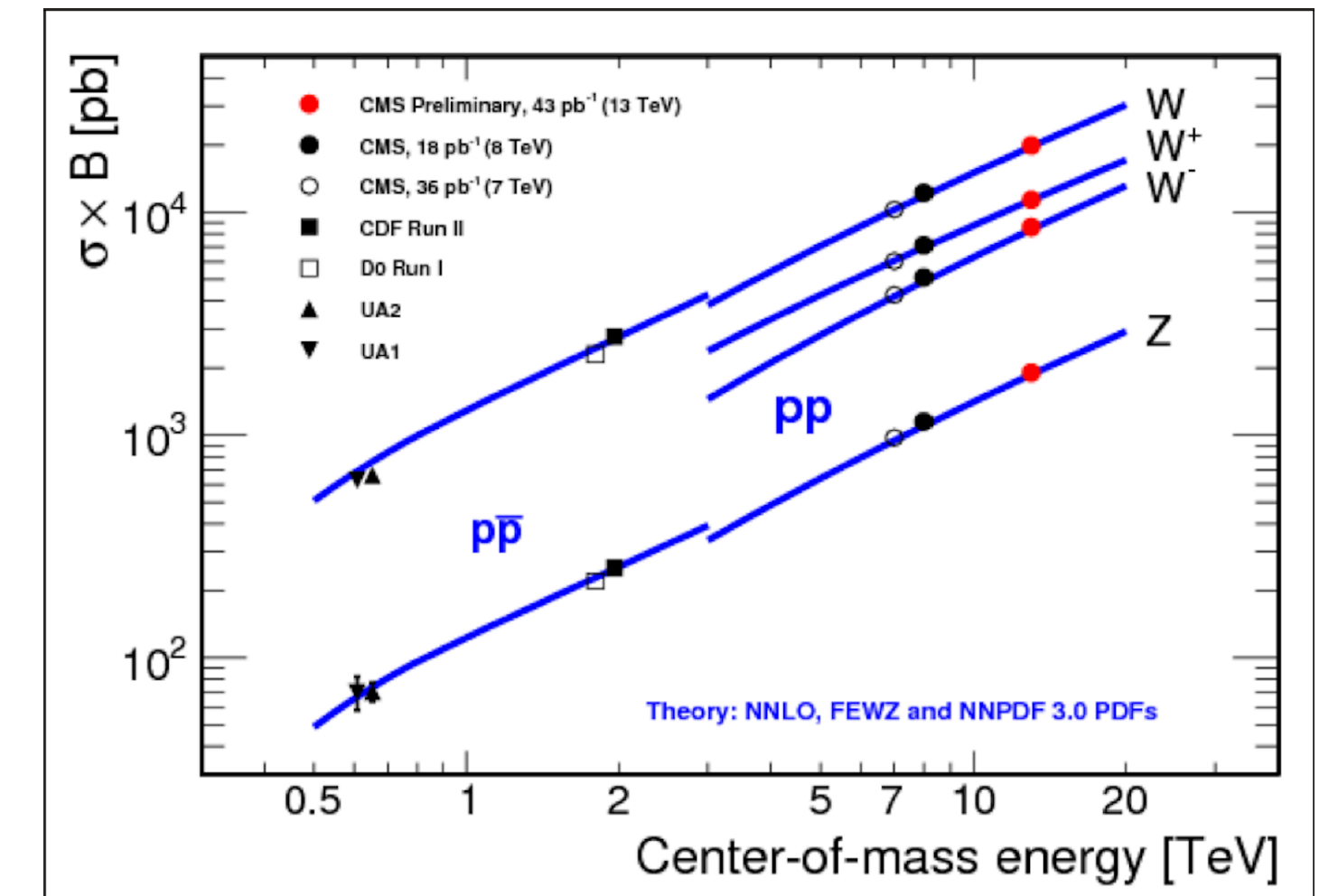
$N = \text{number of neutrino}$

$\rho = \text{density of earth}$

$l = \text{distance from LHCb to ATLAS}$

$M = \text{mass of proton}$

Expected events  $\sim O(0.01)$



# Backup

US ATLAS/ CMS, LHCb, ALICE assumed to be operational during LS.

	2015	2016	2017	2018	2019	2020	2021
<b>LHC</b>	13-14 TeV		14 TeV		LS2		14 TeV
	RUN 2						
<b>ATLAS &amp; CMS</b>	nominal luminosity $1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$			150 fb <sup>-1</sup>	LVL1 trigger, inner tracker		2 x nominal
<b>LHCb</b>	luminosity $4 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$			8 fb <sup>-1</sup>	40 MHz readout, new detectors, electronics		2 x lumi
<b>ALICE</b>	<i>PbPb collisions</i>			1 nb <sup>-1</sup>	TPC, inner tracker, r/o		
	2022	2023	2024	2025	2026	2027	2028
<b>LHC</b>	14 TeV		LS3		14 TeV		14 TeV
	RUN 3				RUN 4 HL-LHC		
<b>ATLAS &amp; CMS</b>	$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	300 fb <sup>-1</sup>	Tracker, calo., muon system		5-7 x nominal		
<b>LHCb</b>	$2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$		repair & maintenance		$2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$		
<b>ALICE</b>							
	2029	2030	2031	2032	2033	2034	2035
<b>LHC</b>	14 TeV	LS4	14 TeV		14 TeV	LS5	14 TeV
			RUN 5 HL-LHC				
<b>ATLAS &amp; CMS</b>	luminosity		$5 - 7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$				
<b>LHCb</b>	50 fb <sup>-1</sup>	additional dipole, new VELO, exploit full flavour potential of LHC		$1 - 2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$			
<b>ALICE</b>	10 nb <sup>-1</sup>						
	2036	2037					
<b>LHC</b>	14 TeV						
	RUN 6 HL-LHC						
<b>ATLAS &amp; CMS</b>	3000 fb <sup>-1</sup>						
<b>LHCb</b>	$\Rightarrow 300-500 \text{ fb}^{-1}$						