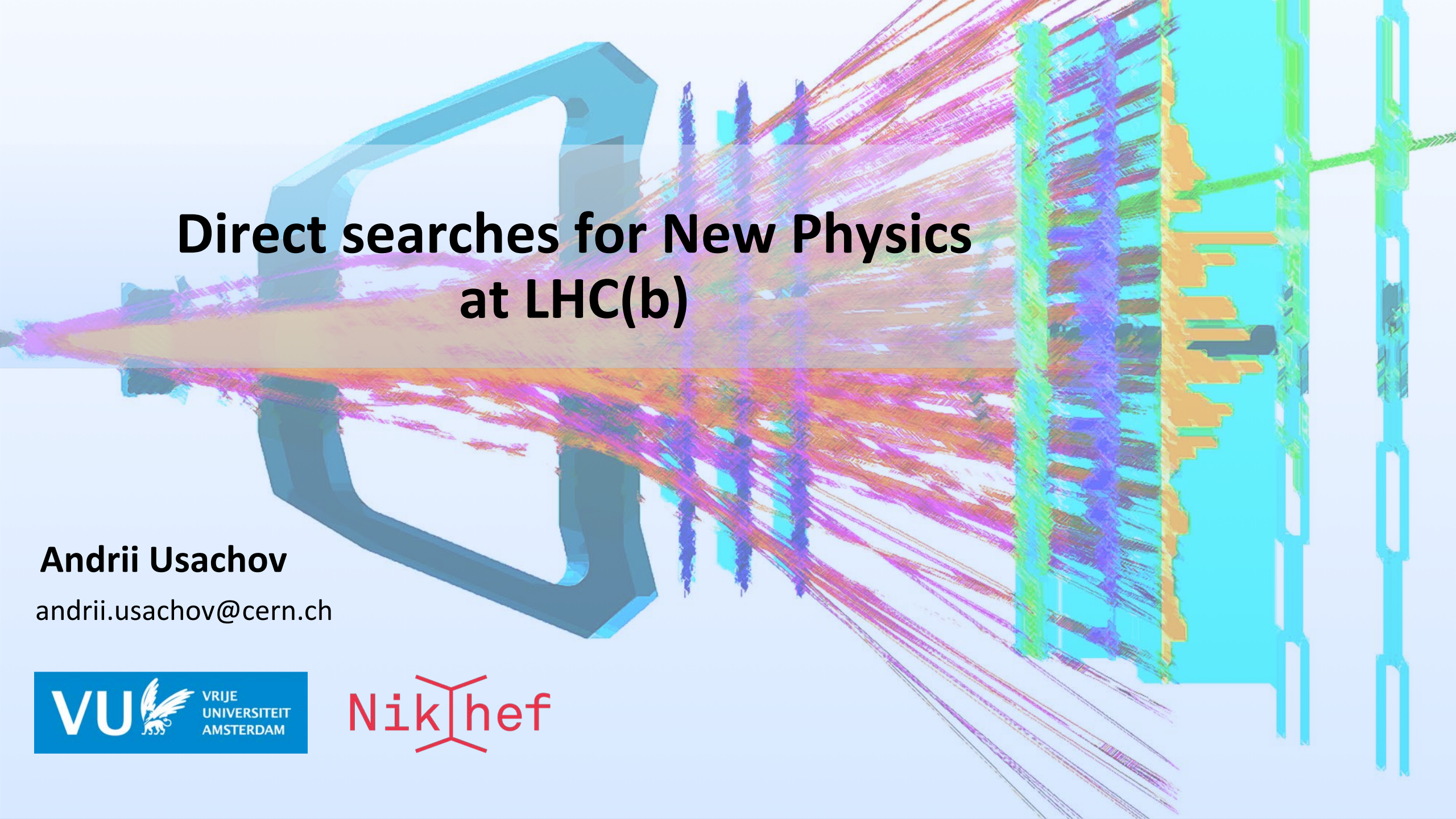
Direct searches for New Physics at LHC(b)



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Nikhef

FEW WORDS ABOUT ME

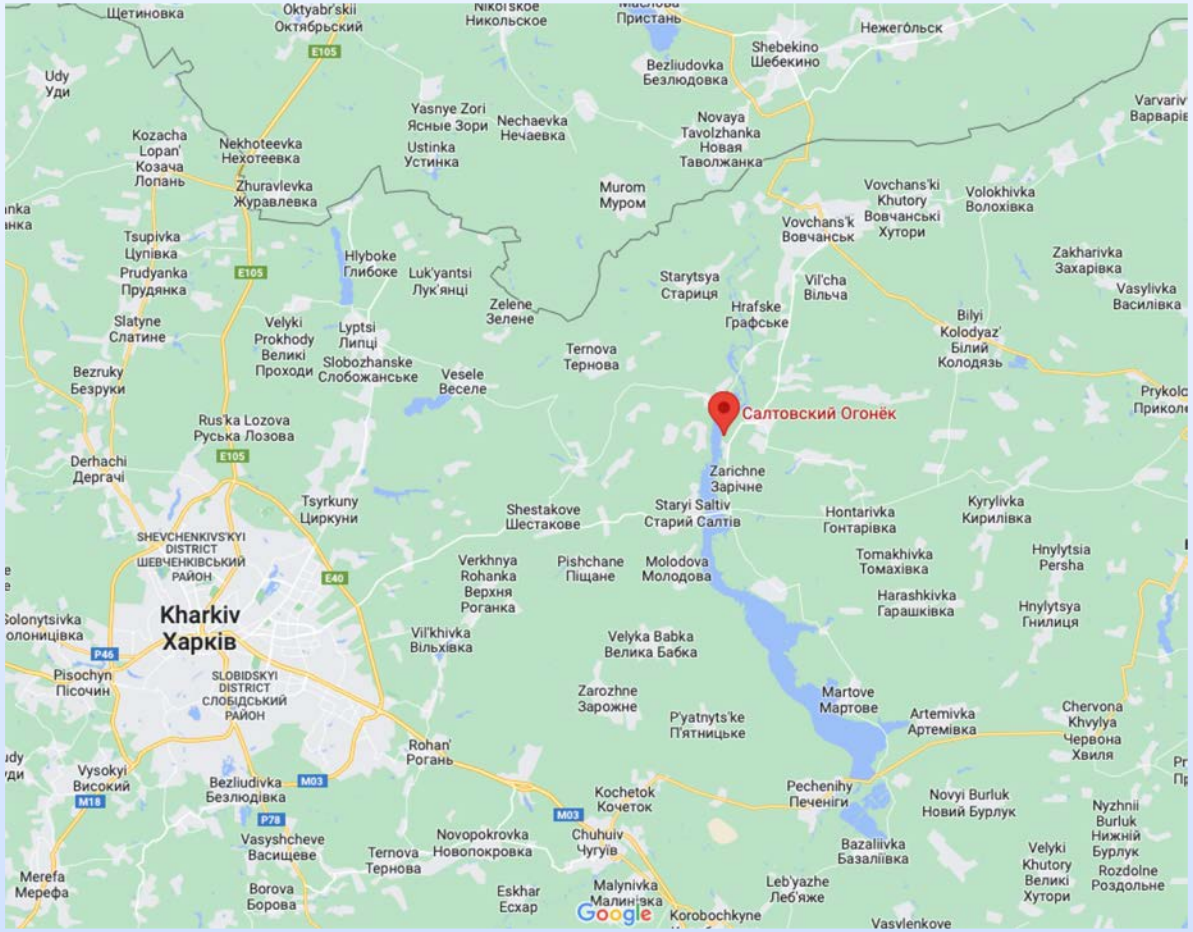
- 2015 – Master in particle physics, Nuclear Physics dep., Kyiv U.
- 2016 – Master, NPAC, Paris-Saclay U.
- 2019 – PhD in particle physics, Paris-Saclay U.

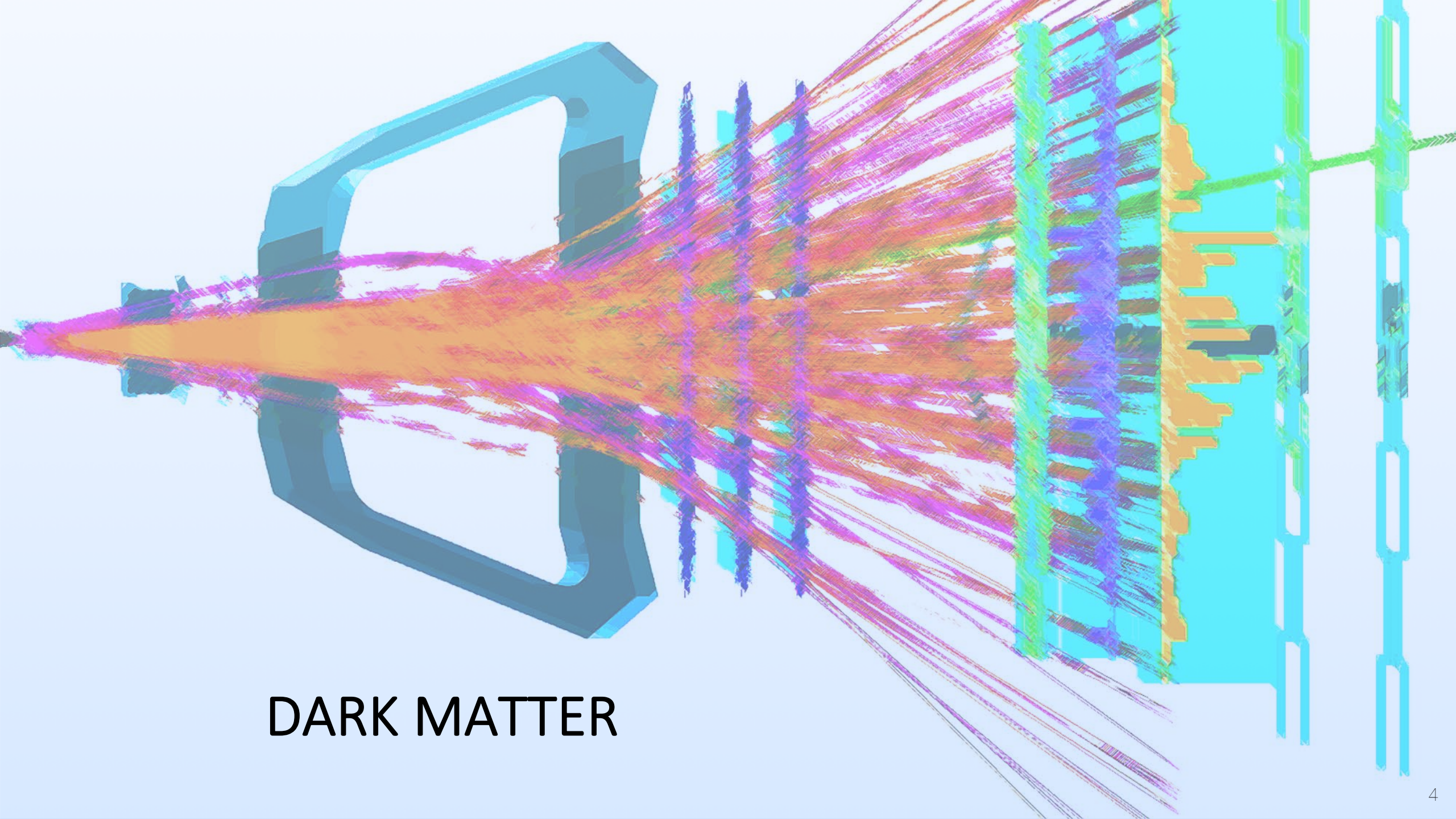
  study of quarkonium production at LHCb experiment
- 2019-2022 – Postdoc, Nikhef, Amsterdam

  track reconstruction at LHCb, new physics searches
- From 2022 – VENI scholar, VU and Nikhef, Amsterdam

  search for light dark matter at LHCb

HOW IT STARTED

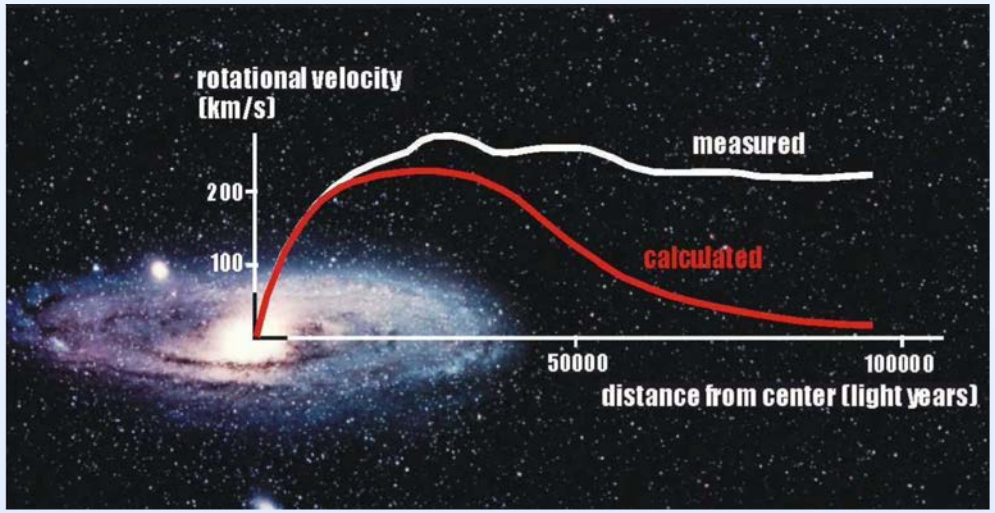




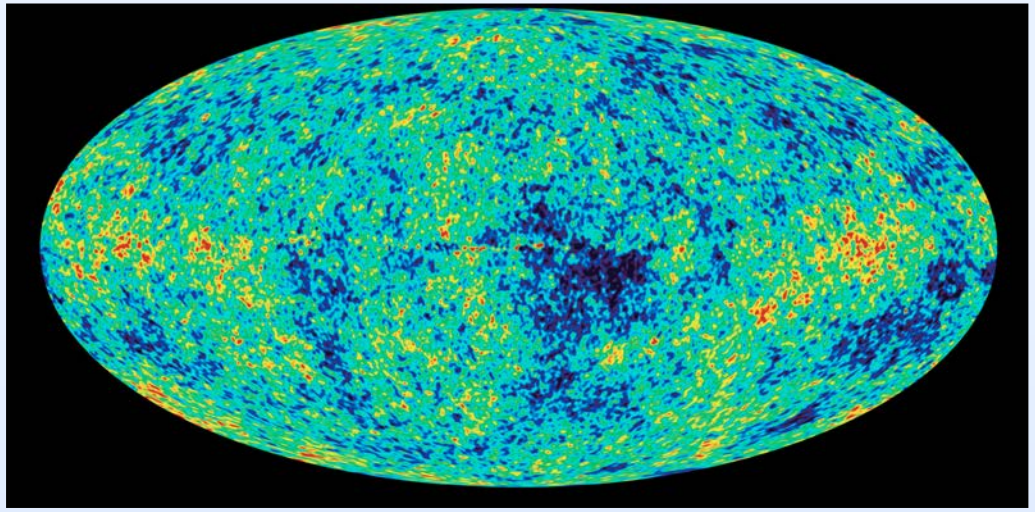
DARK MATTER

DARK MATTER: OBSERVATIONS

Galaxy rotation



Snapshot of early Universe: CMB

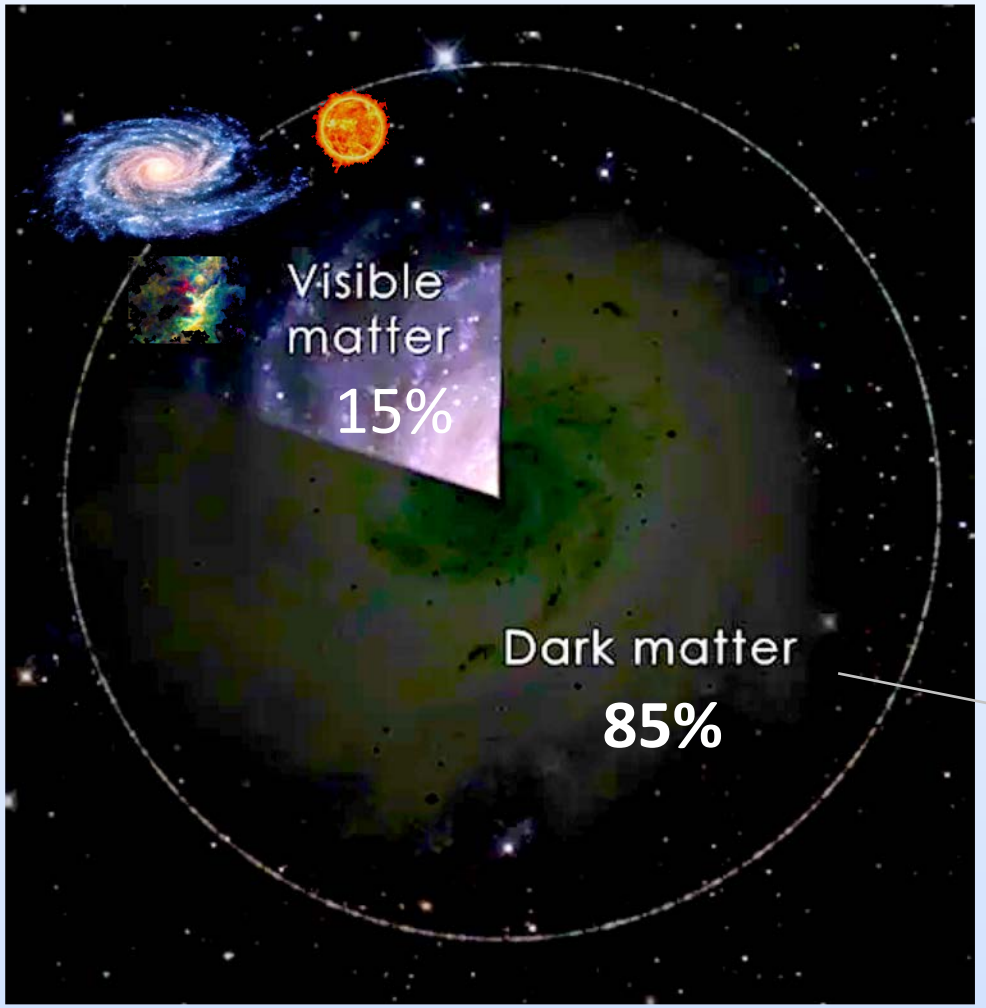


Galaxy clusters: high DM density

Dwarf galaxies formation

To be continued via gravitation waves studies

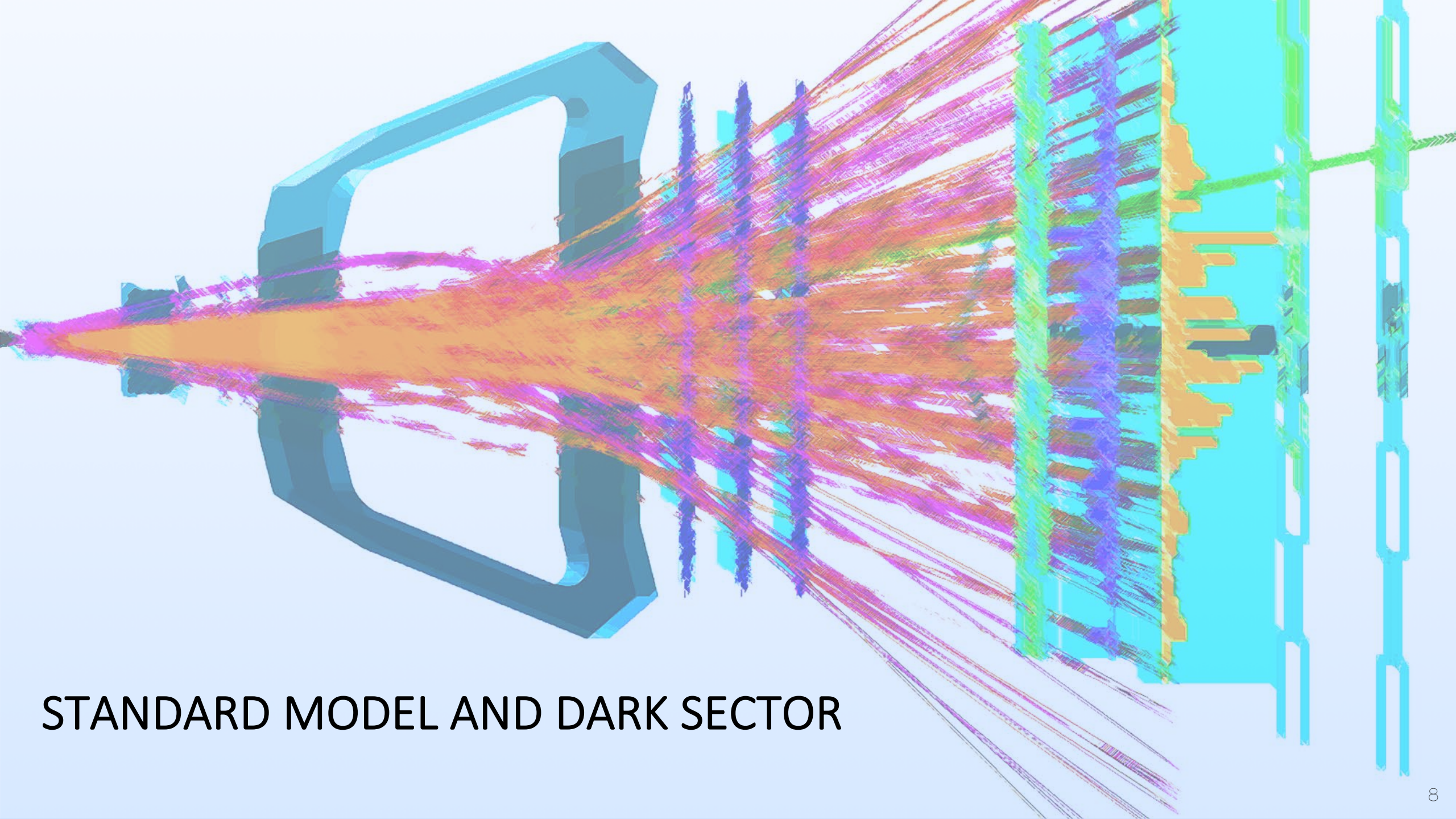
MATTER IN UNIVERSE AS FOR NOW



- abundant
- invisible, i.e. does not interact much
- cold
- what is it?
  - **most likely made of new type of subatomic particles**

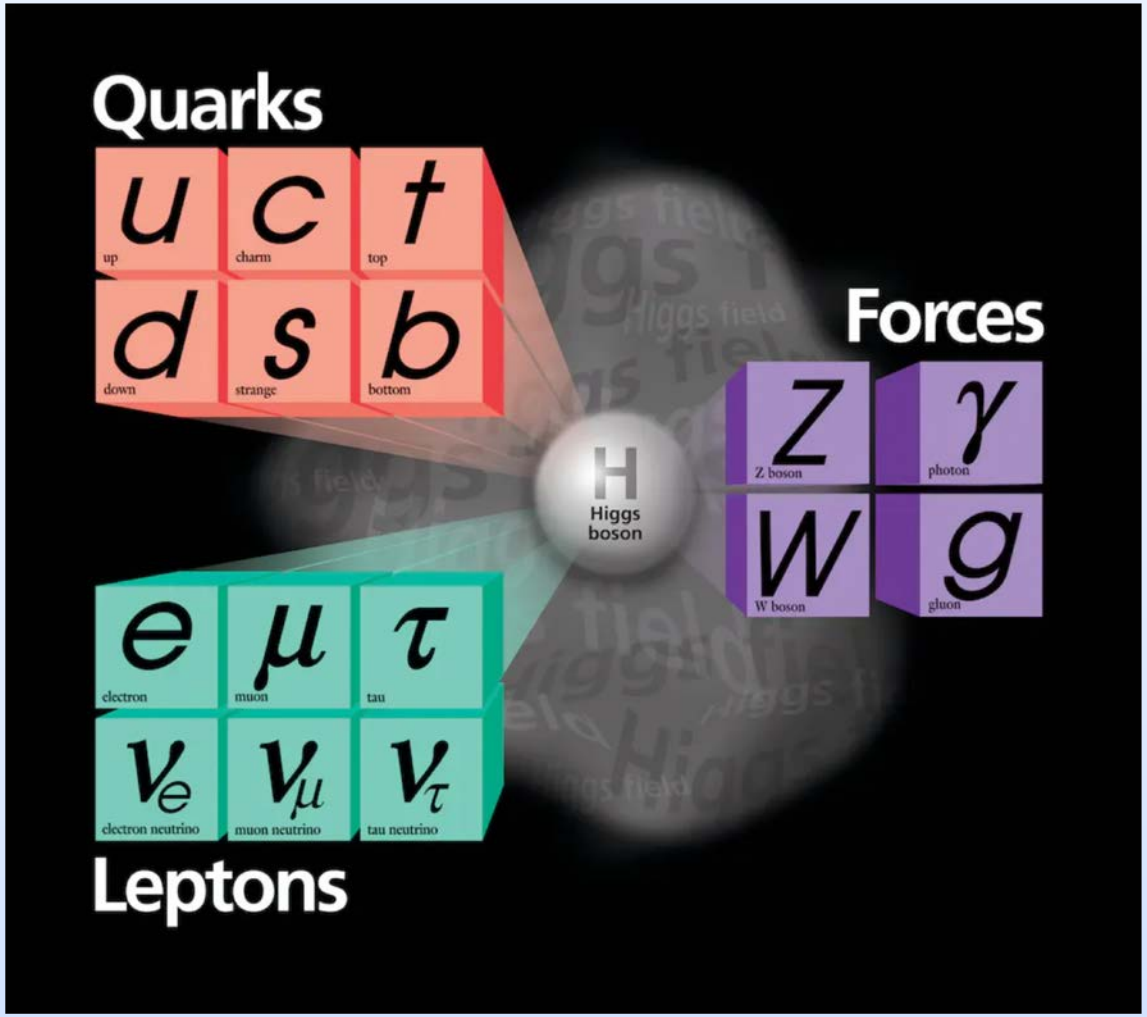
CANDIDATES

No shortage of ideas

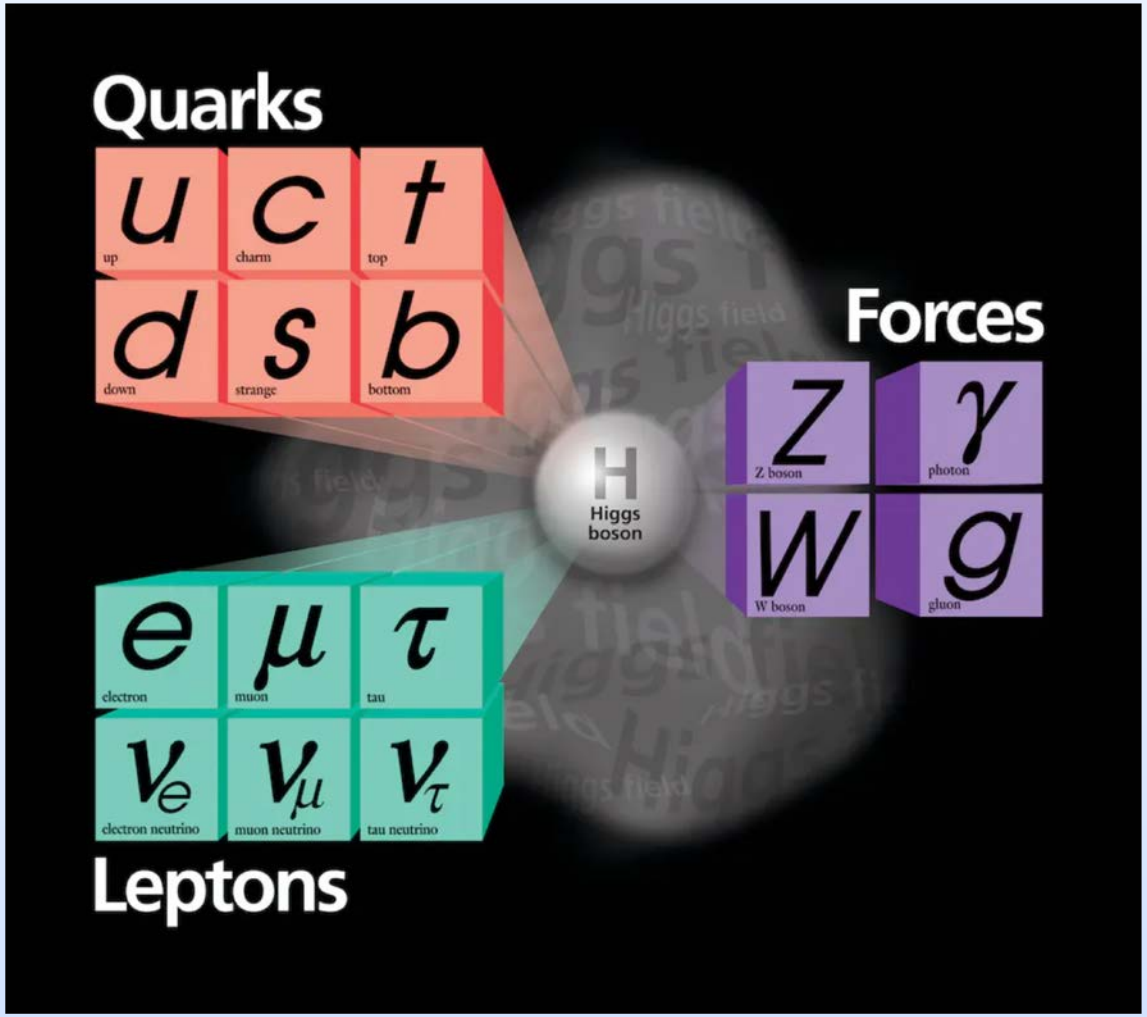


STANDARD MODEL AND DARK SECTOR

STANDARD MODEL OF ELEMENTARY PARTICLES



STANDARD MODEL OF ELEMENTARY PARTICLES



Big questions:

- Neutrino mass
- Baryogenesis
- Strong CP problem
- Hierarchy problem
- **Dark Matter**

=> dark sector particles ?

DARK SECTOR

- New force and new carrier
- Possibly entire family of dark particles

- Very weak coupling to SM particles
- Accessible via portal (mediator) at large energies,

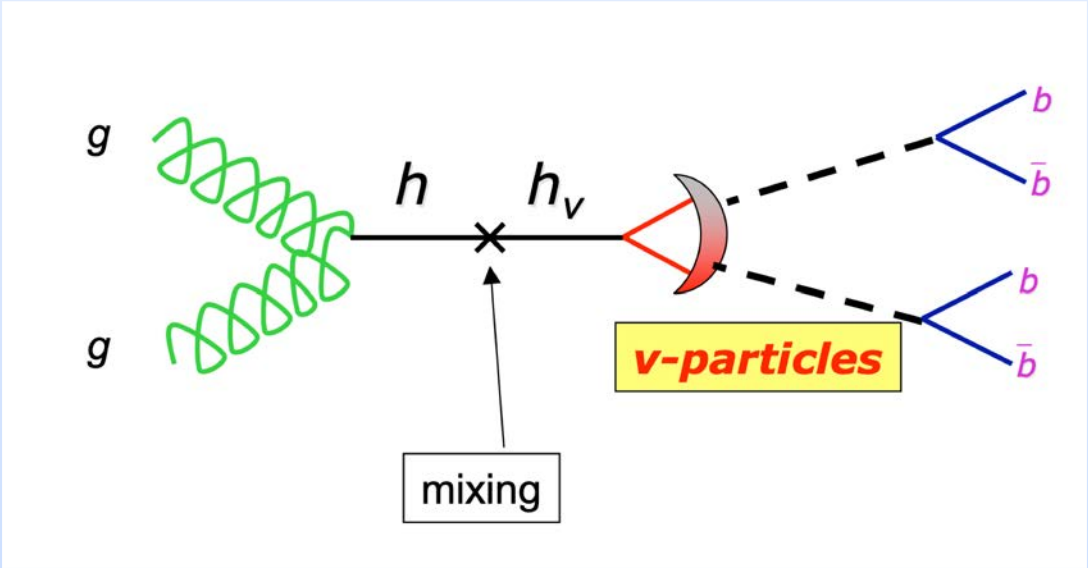
  e.g:

  - dark Higgs

  - dark photon

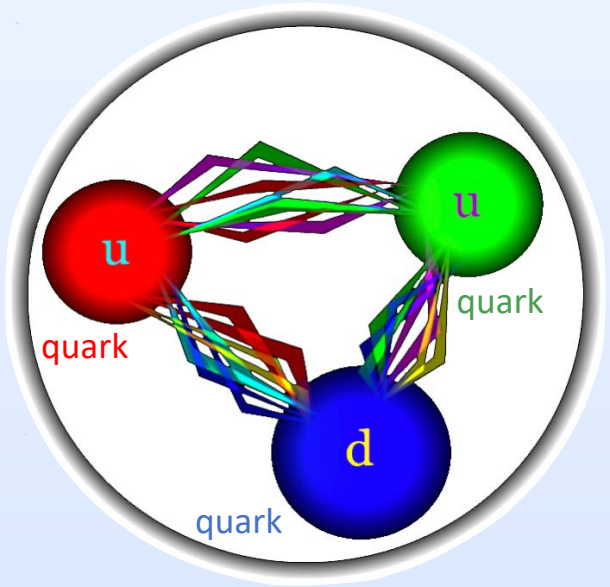
  - axion

  - …



EXAMPLE: DARK HADRONS

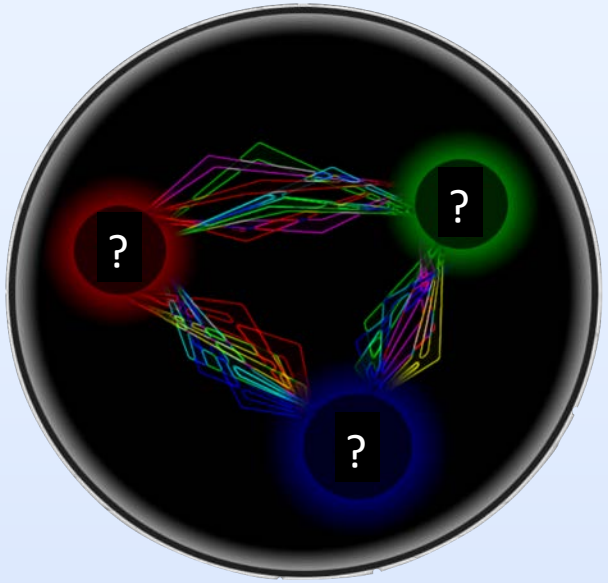
Ordinary matter



stable *hadron*: proton

other *hadrons* decay

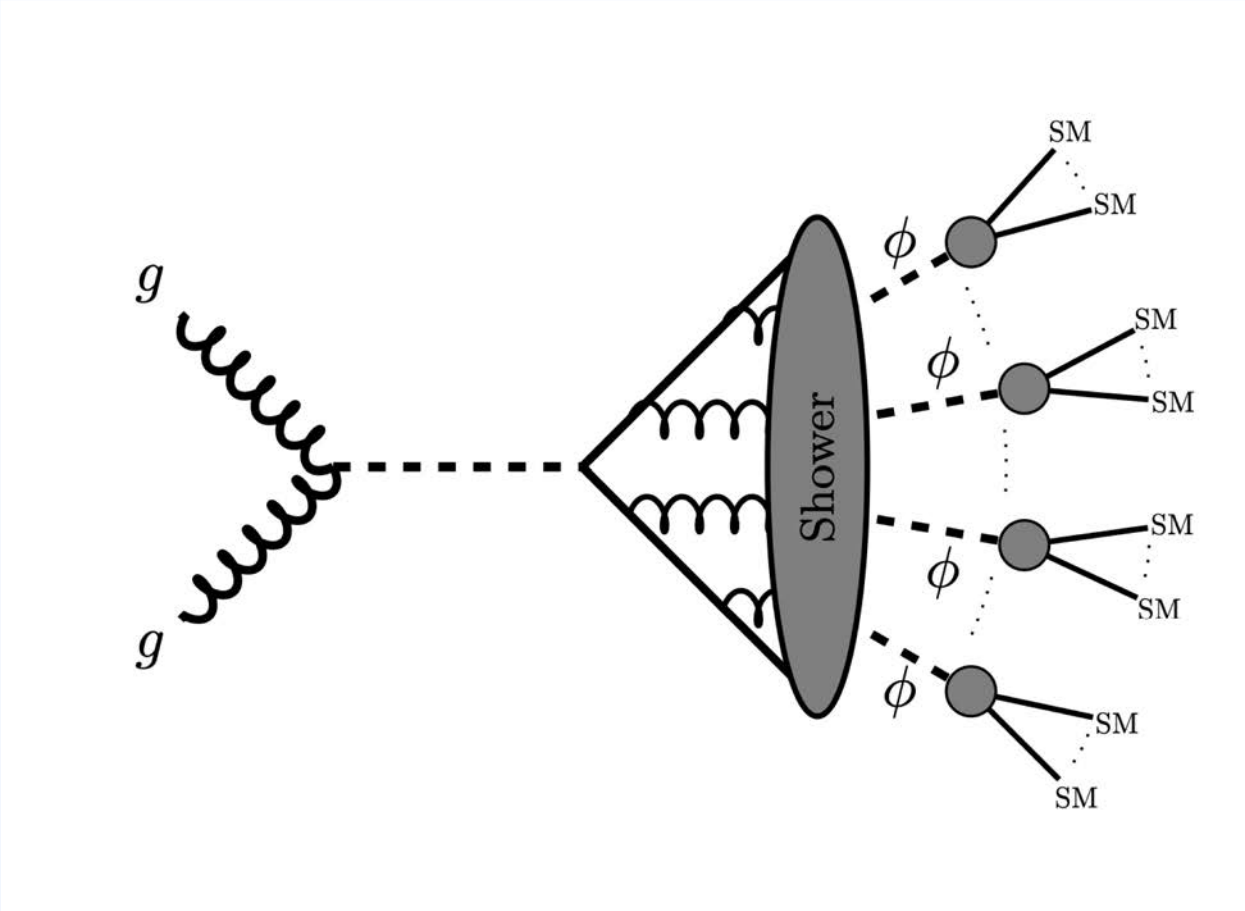
Dark matter



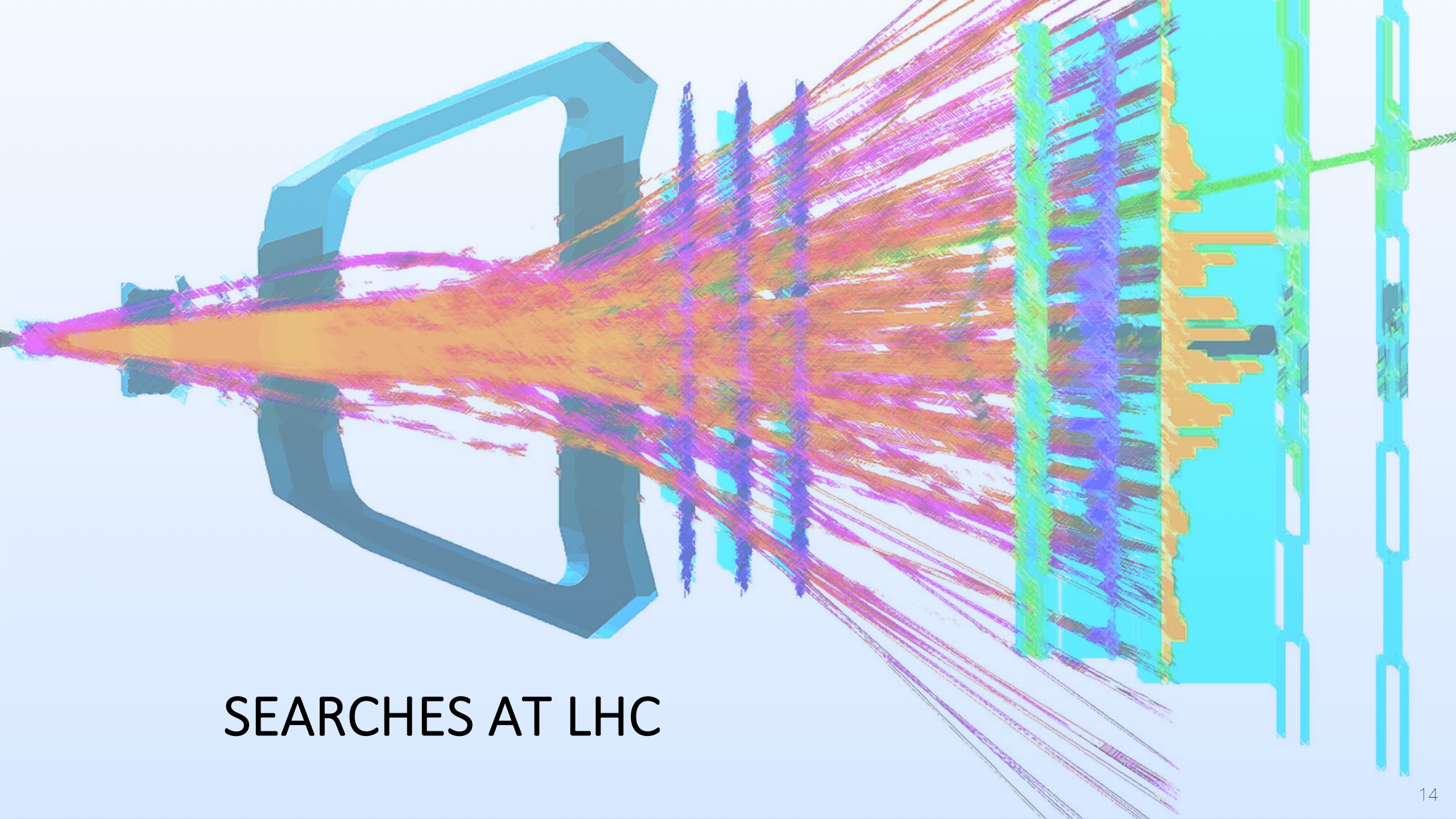
stable *dark hadron ?*

other *dark hadrons*
may decay to ordinary matter
→ detectable

EXAMPLE: DARK HADRONS

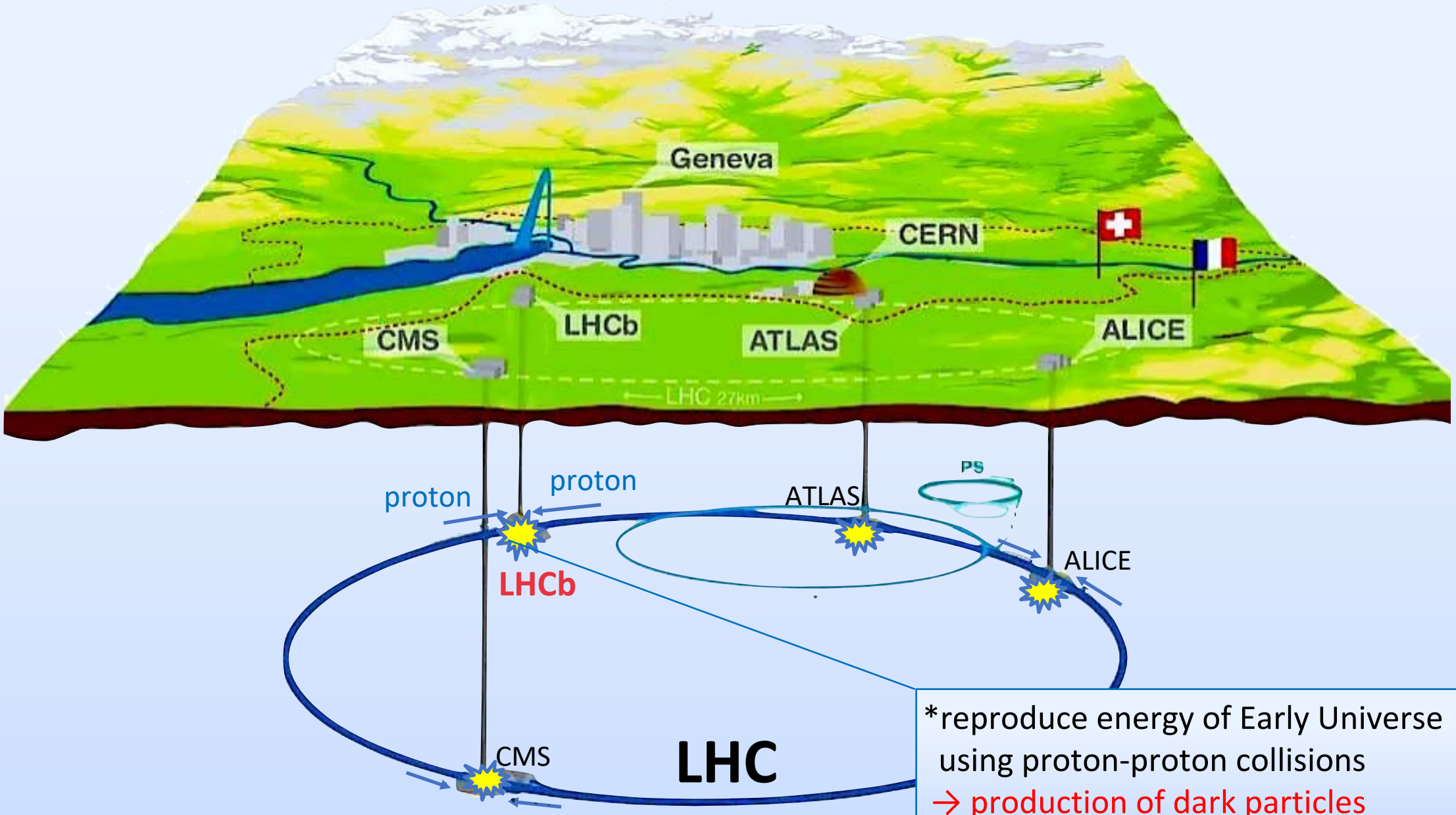


- QCD-like interaction
  - not necessarily SU(3) !
  - arbitrary number of flavours and colors
- Abundant production – good chance to detect
- Dark hadrons might be **long-lived**
- Higgs is a possible mediator



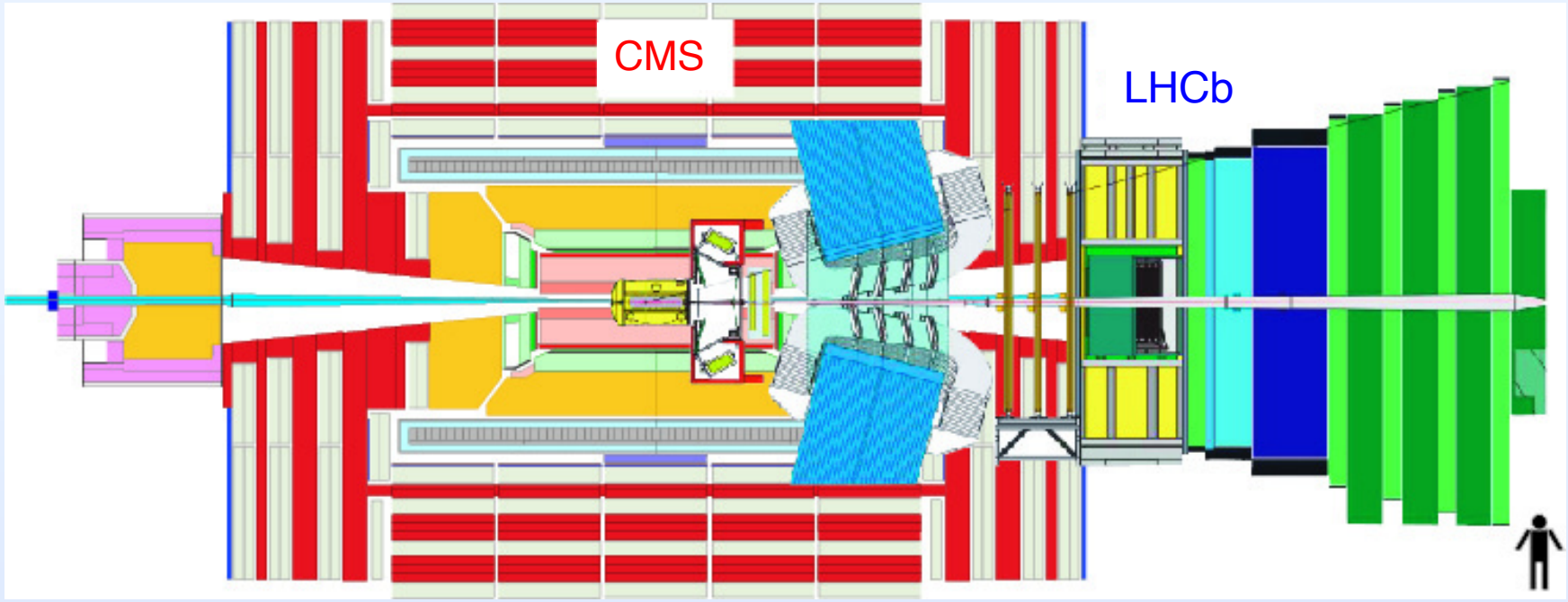
SEARCHES AT LHC

LARGE HADRON COLLIDER



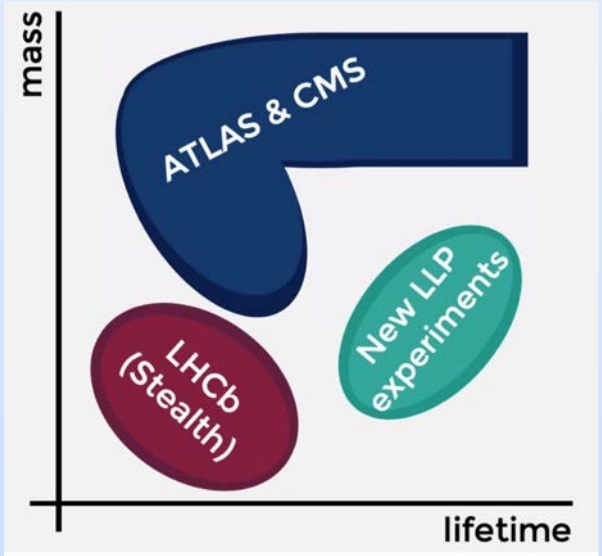
*reproduce energy of Early Universe using proton-proton collisions
→ production of dark particles

WHAT DO EXPERIMENTS OFFER?



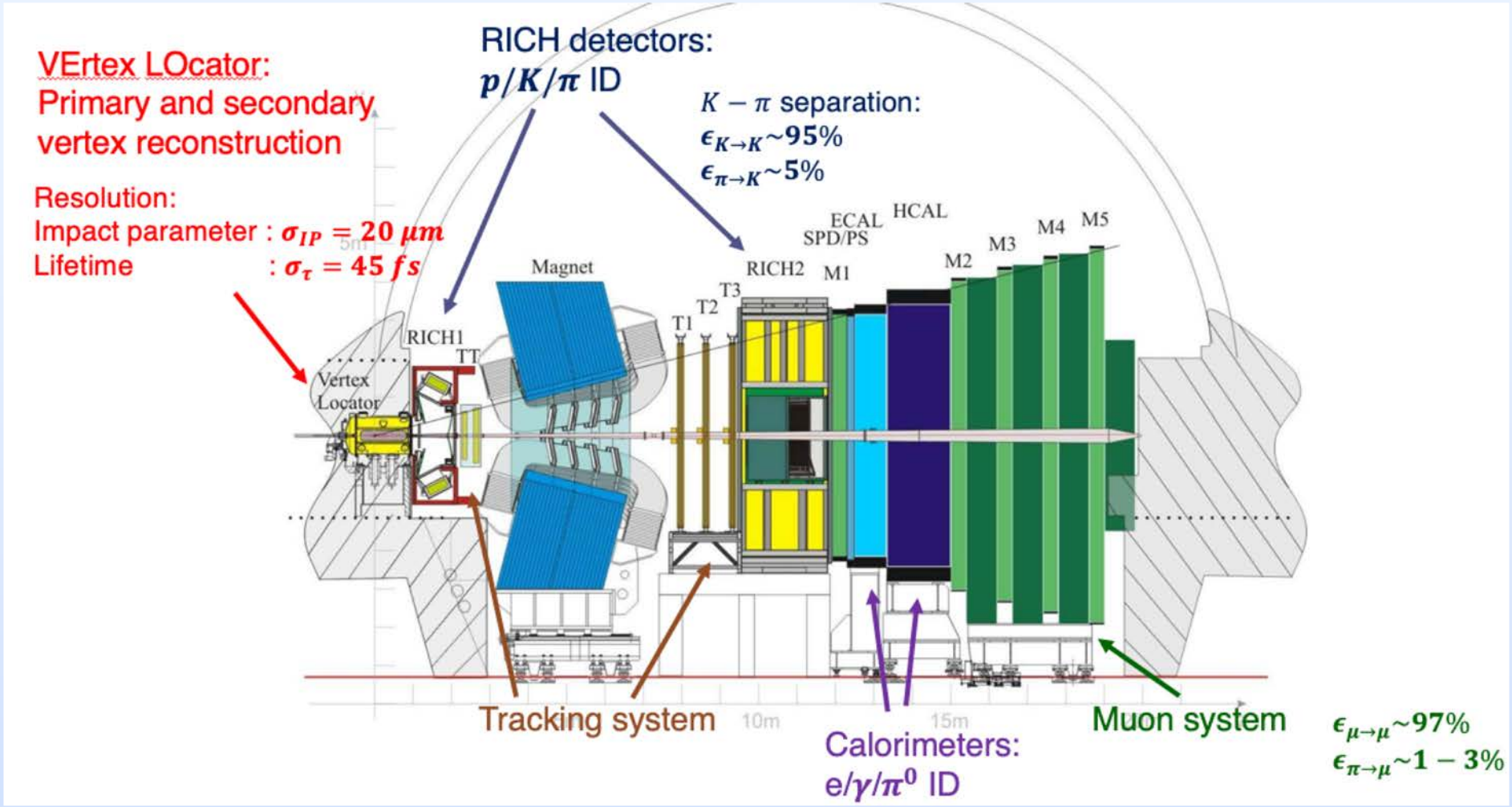
not to scale

- High mass searches at ATLAS and CMS
  - e.g. searches for new bosons
- Access to lower masses at LHCb
  - also complementary coverage in pt and eta
- LHC as gamma-gamma collider using PbPb collisions at ALICE
- *New LLP experiments such as FASER, SND, Codex-b*

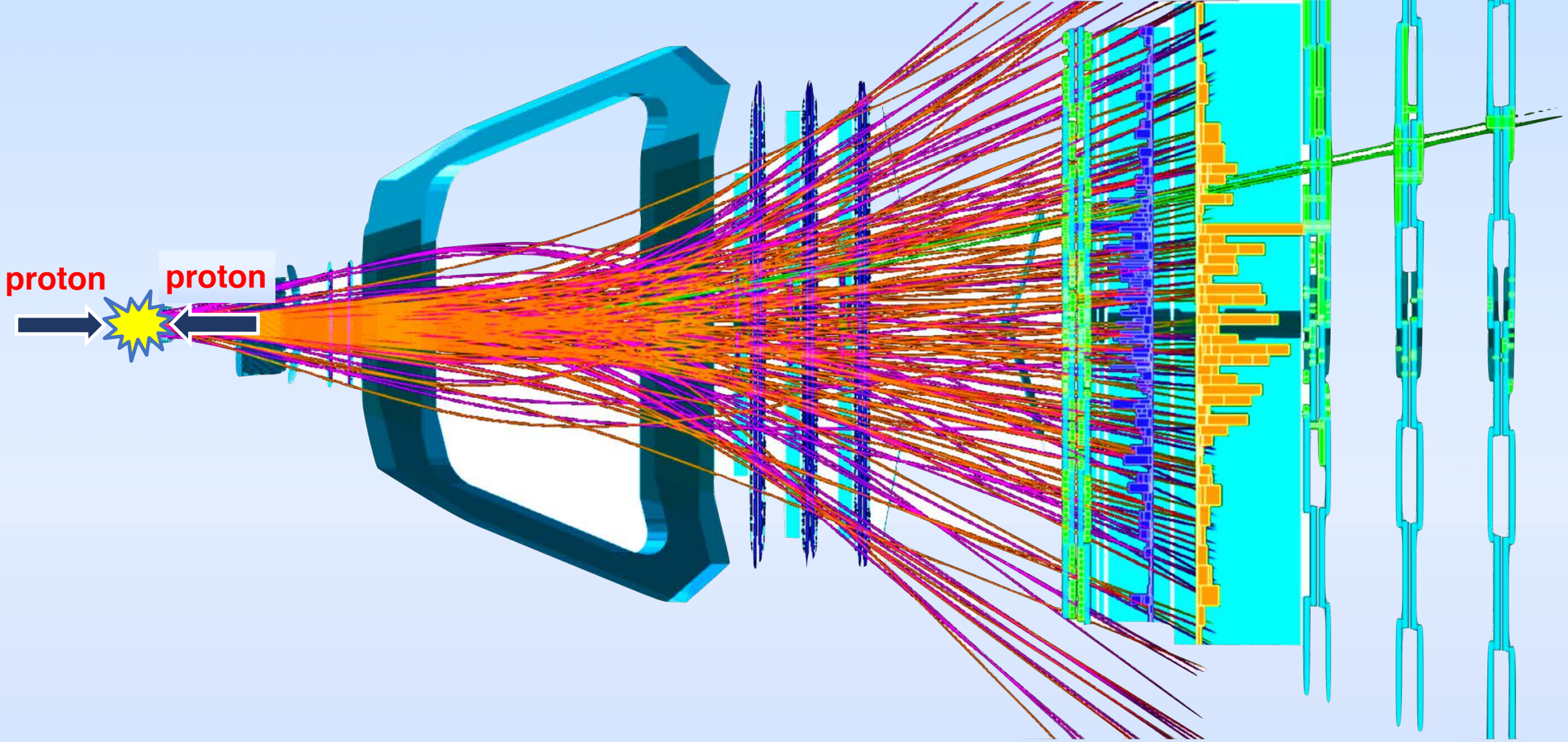


LHCB DETECTOR

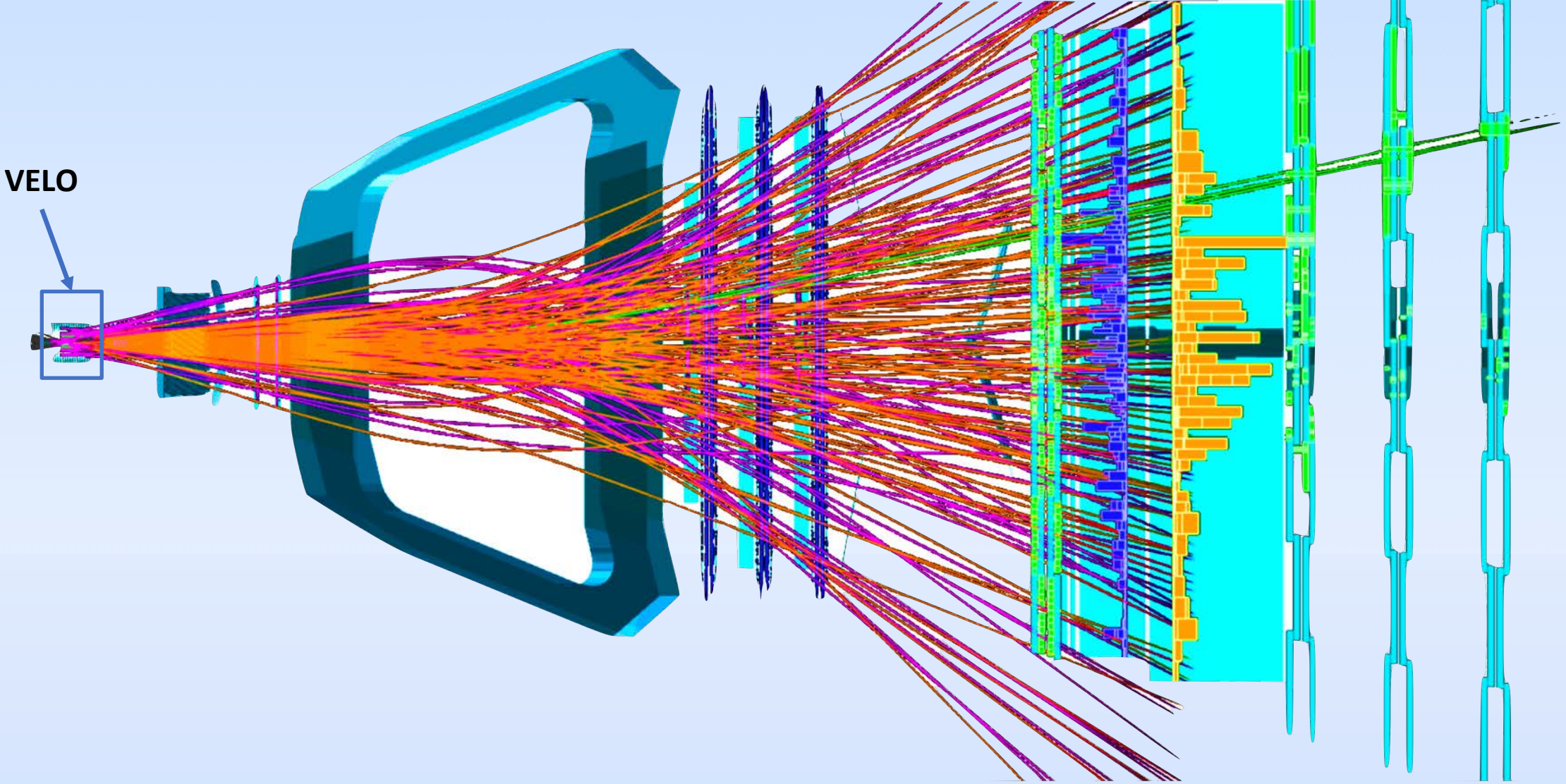
- Single-arm spectrometer designed for beauty and charm physics in forward region



- Precise vertex reconstruction with VELO
- Powerful charged hadrons ID by RICH detectors

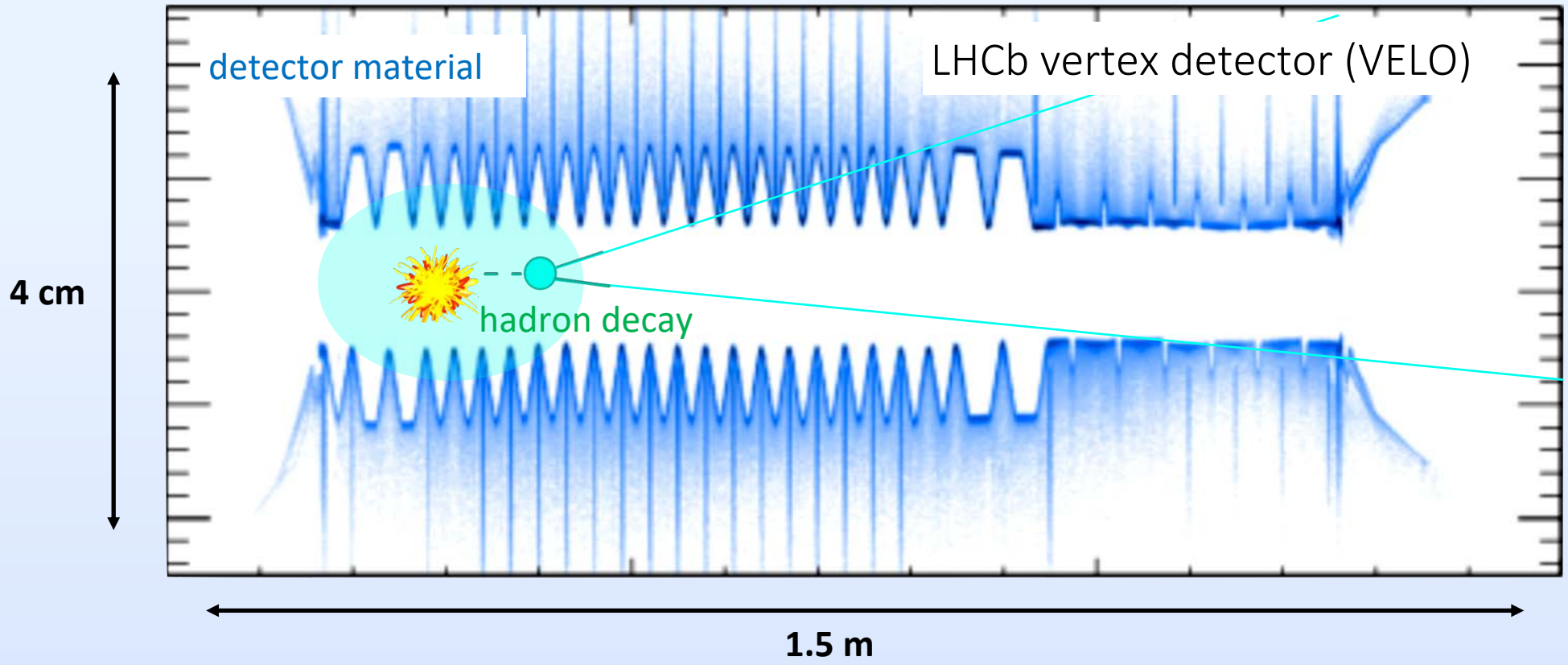


SEARCHES AT LHCB



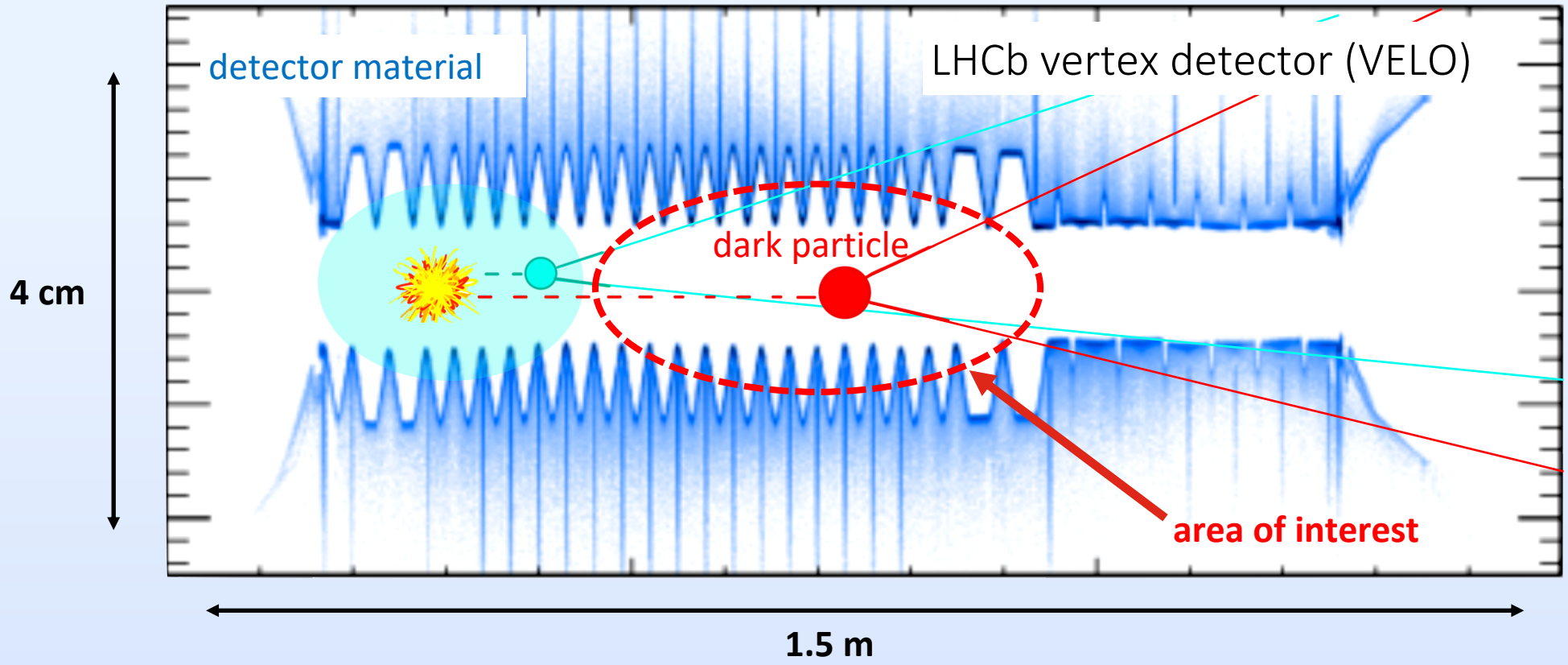
SEARCHES AT LHCB

SEARCH FOR DARK PARTICLES AT LHCB



- LHCb is the best in hadron studies: more than 50 discoveries

SEARCH FOR DARK PARTICLES AT LHCB

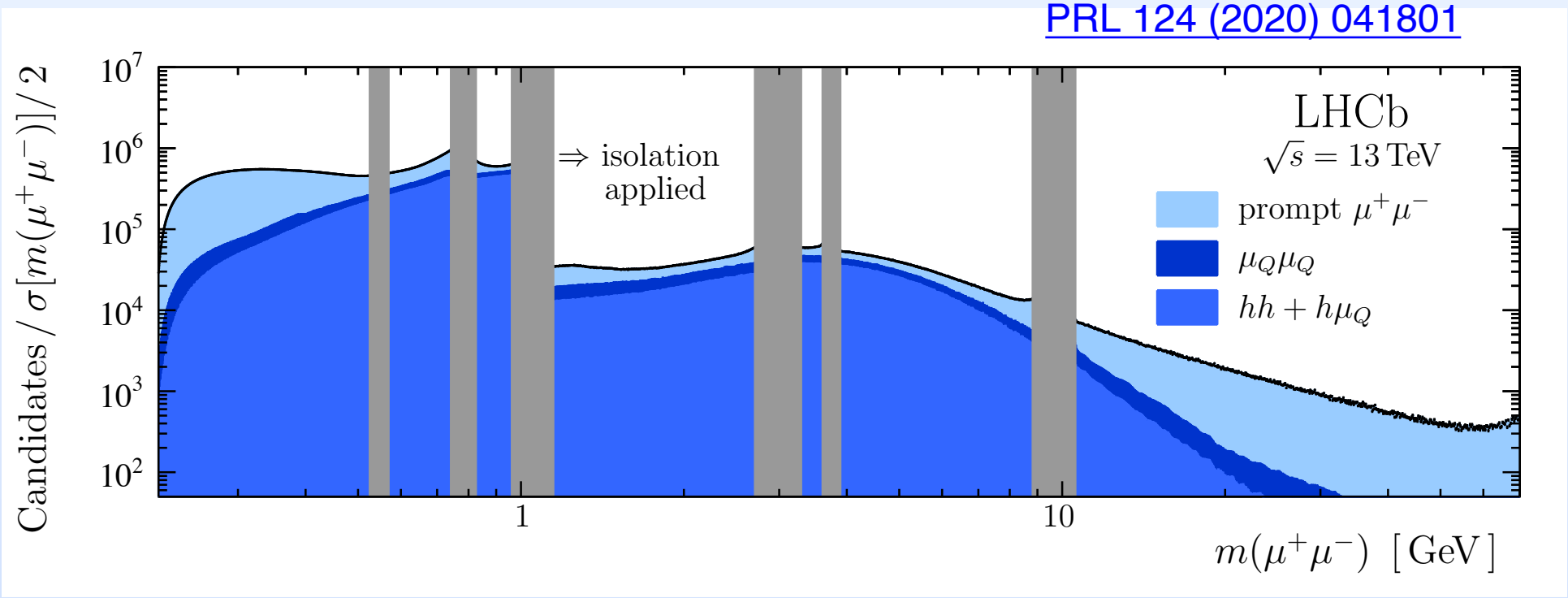


- Dark particle: just like a search for *hadron that flies long distance*

SEARCH FOR DARK PHOTONS

- Light dark photon can appear in a mixing with off-shell photon
  - large fraction in forward region, low p_T
- Normalized to off-shell photons
  - No need for efficiencies (for prompt search)

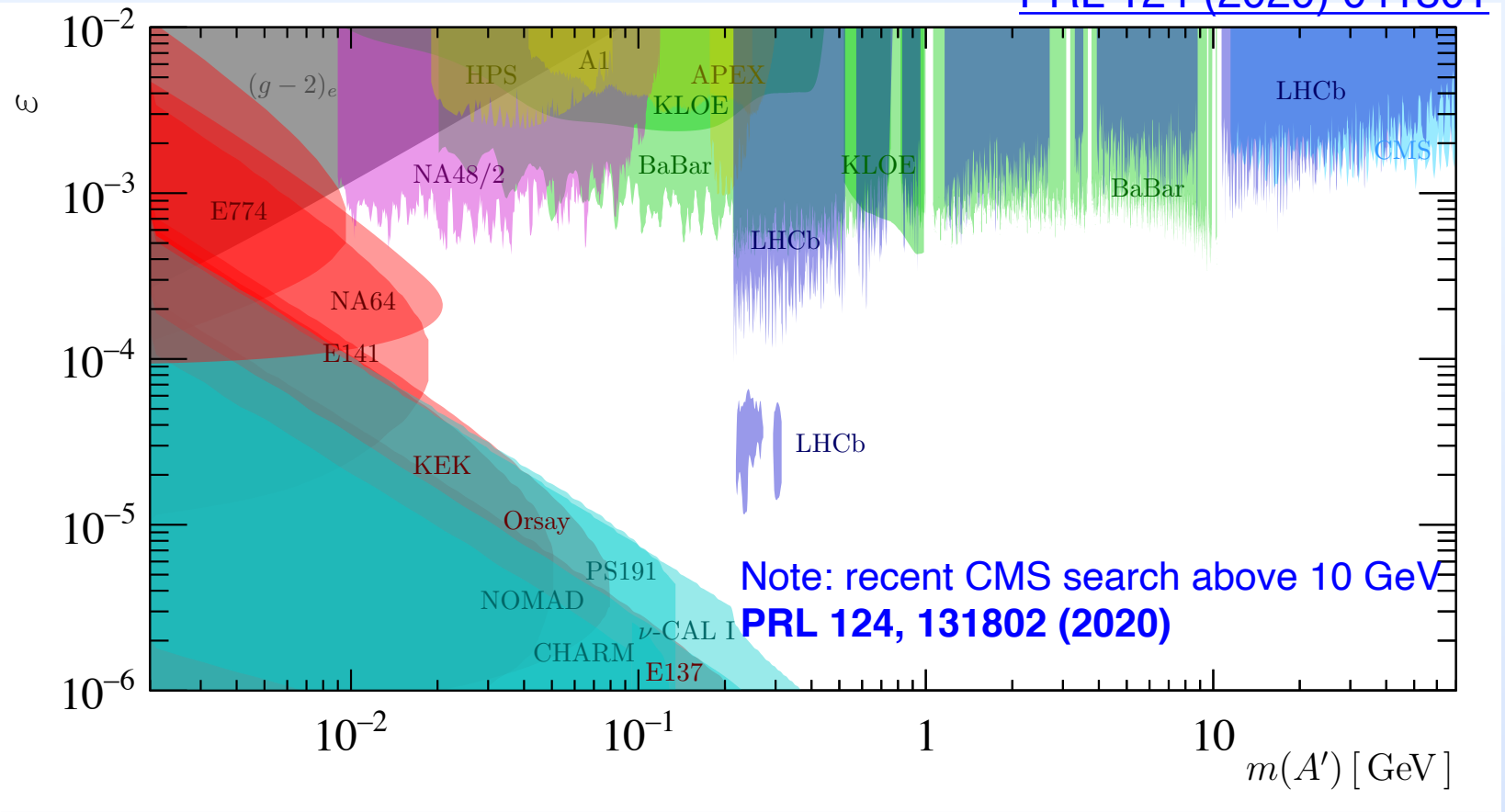
PRL 124 (2020) 041801



- Bump hunt analysis in ***di-muon spectrum***
- Regions of SM resonances removed
- Search for **both prompt and displaced** signatures

SEARCH FOR DARK PHOTONS

PRL 124 (2020) 041801

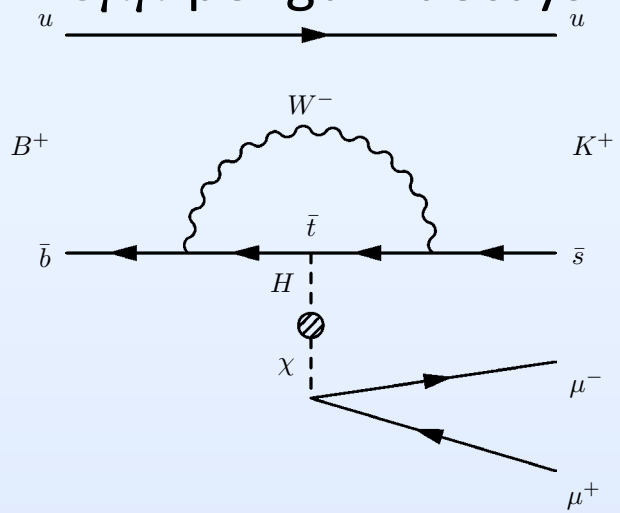


- World's best upper limits for inv. mass range of ~200-700 MeV (prompt)
- First displaced search not from beam-dump experiments
  - *explored invariant mass range: 214-350 MeV*
- *Can be extended with di-electron search at very low masses in $D^* \to Dee$ PRD92 (2015) 115017*

SEARCH FOR LIGHT BOSON IN $b \to s\mu\mu$ DECAYS

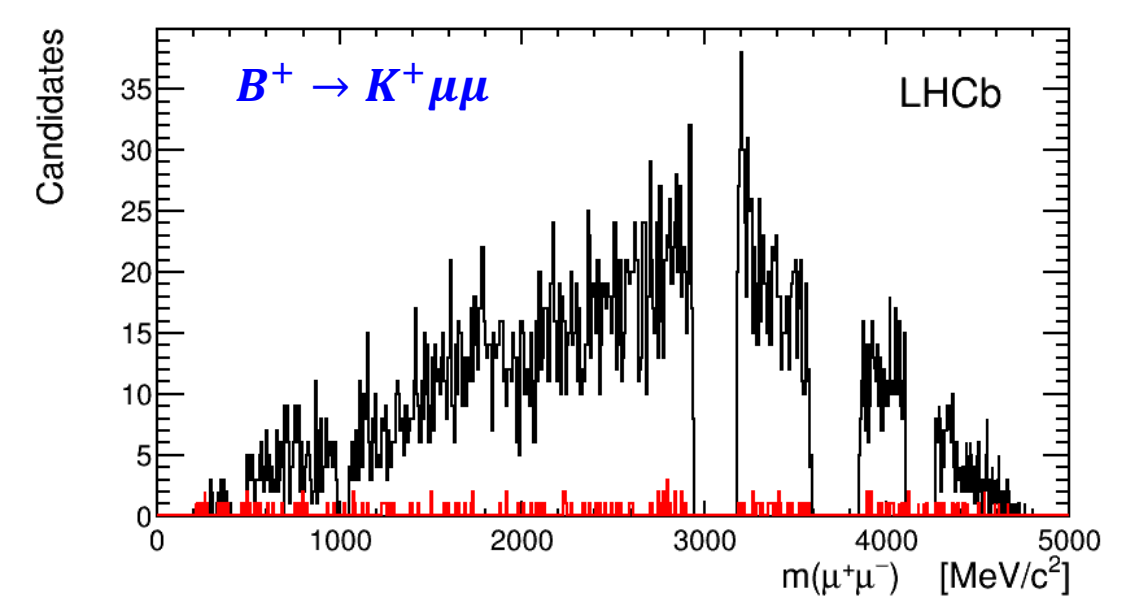
- Light boson can contribute to $b \to s\mu\mu$ penguin decays

PRL 115 (2015)161802
PRD 95 (2017) 071101



- LHCb has world's largest sample of $b \to s\mu\mu$ decays

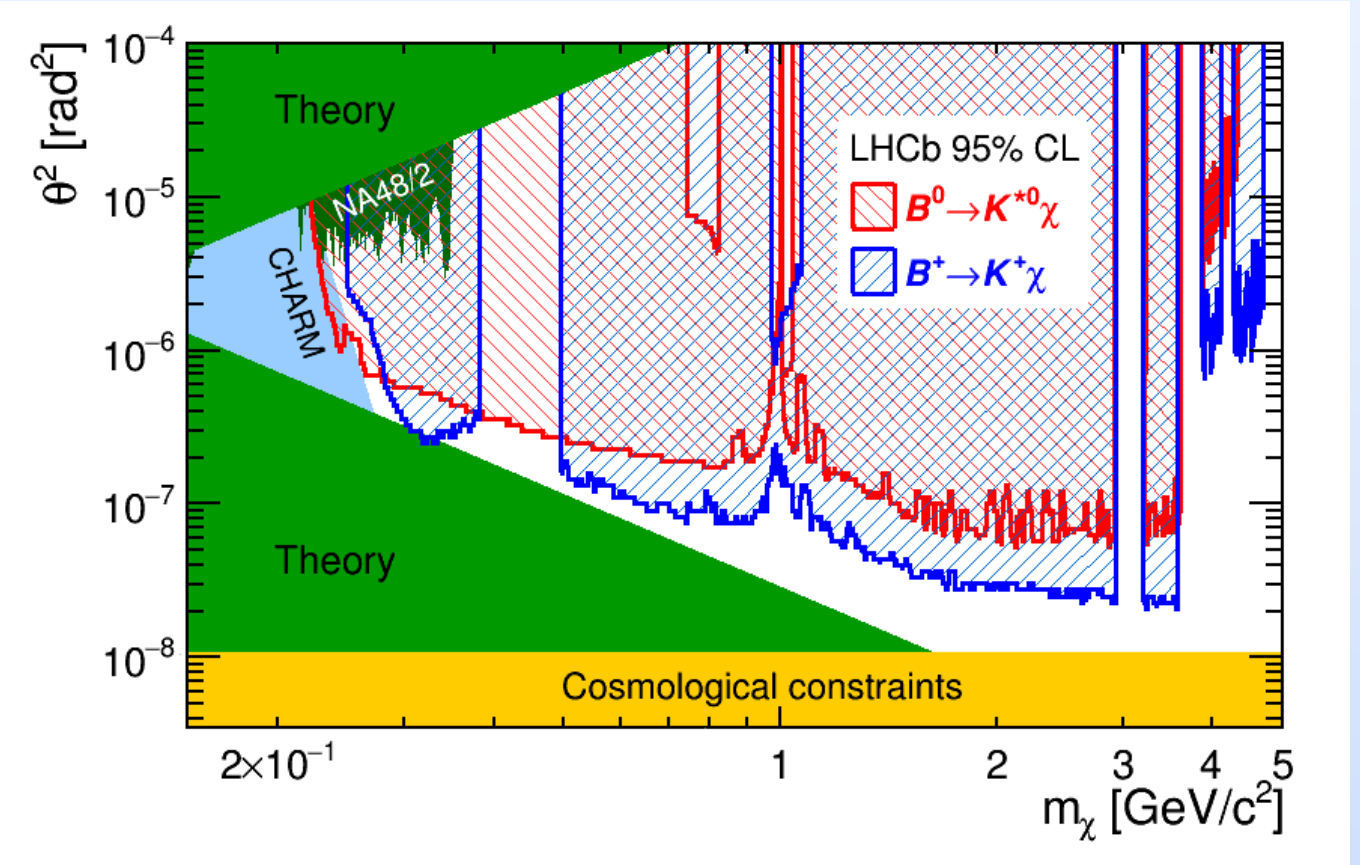
- Study of di-muon spectrum



SEARCH FOR LIGHT BOSON IN $b \to s\mu\mu$ DECAYS

PRL 115 (2015)161802
PRD 95 (2017) 071101

- Search for a narrow di-muon peak
- Displacement of muon pair is considered
- Upper limits on mixing with SM Higgs

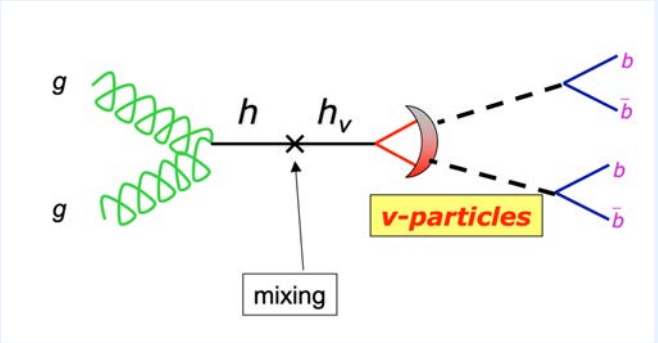


- **World's best upper limits below $2m_\tau$**

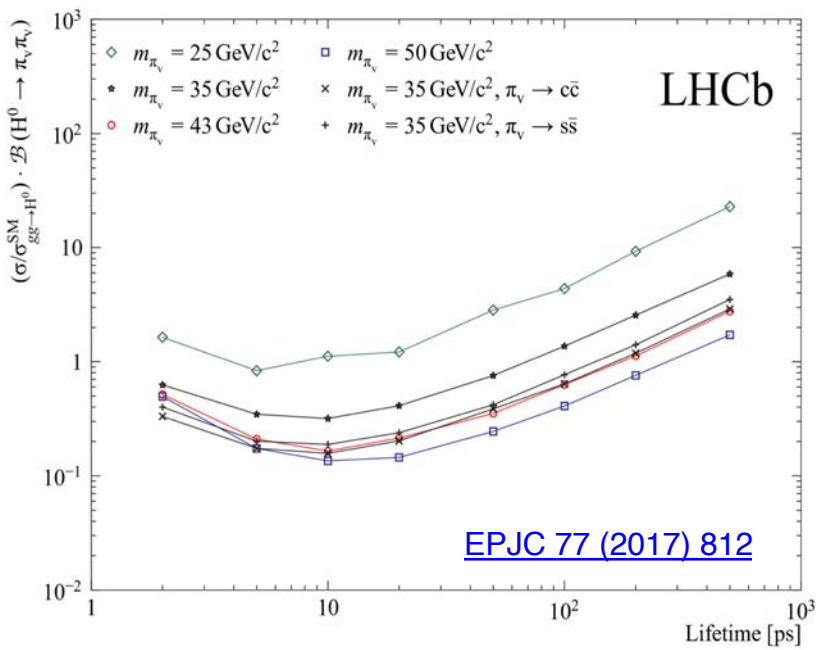
SEARCH FOR DARK HADRONS DECAYING TO JETS

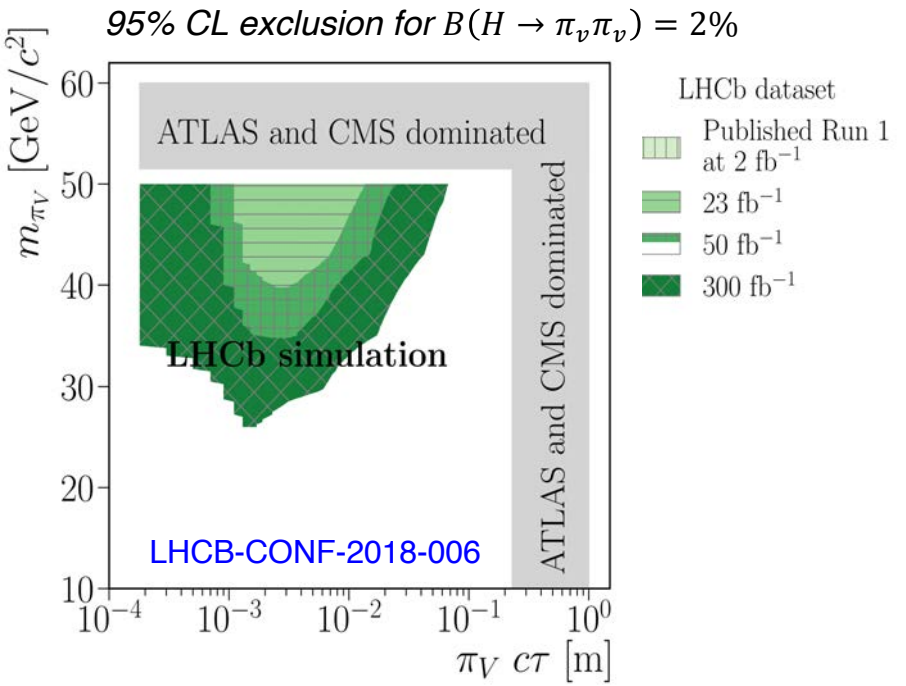
Signature: single displaced vertex with two (b-) jets

Model: Hidden Valley dark hadrons through Higgs portal



- Invariant mass range explored: 25-50 GeV
- No excess found, upper limit for lifetimes range 2-500 ps
- Complementary limits to ATLAS and CMS



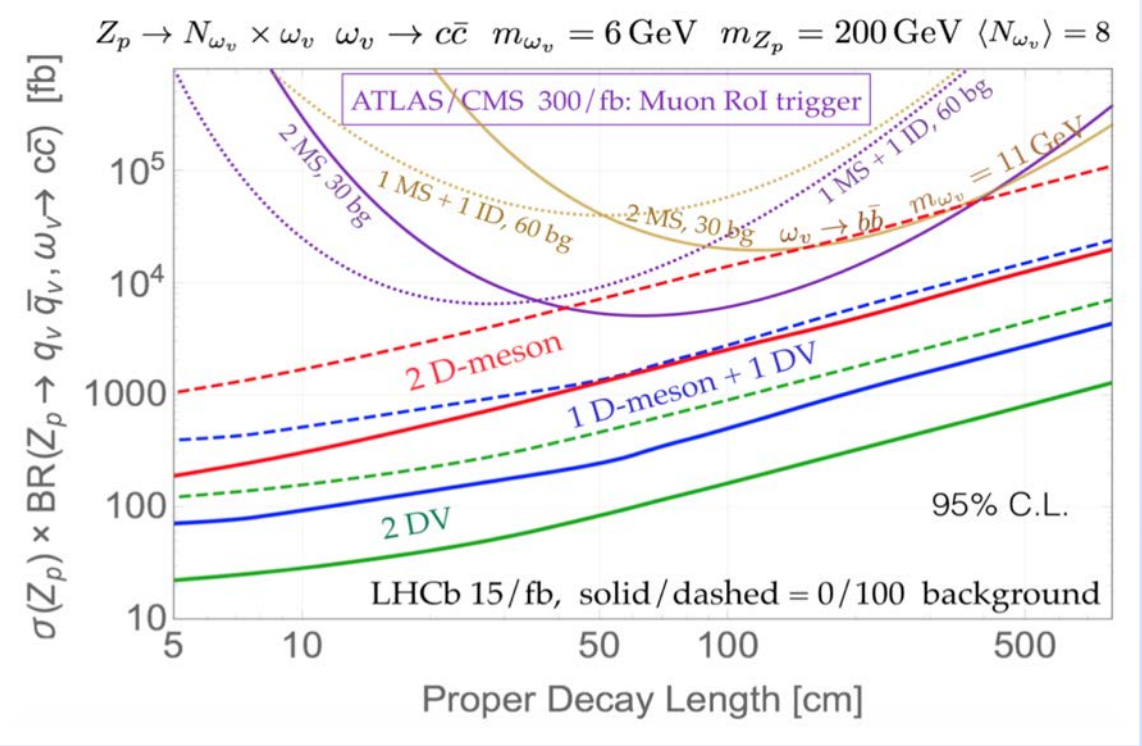


- Can be pushed to lower masses in Run 3 using jet substructure

LHCB-CONF-2018-006

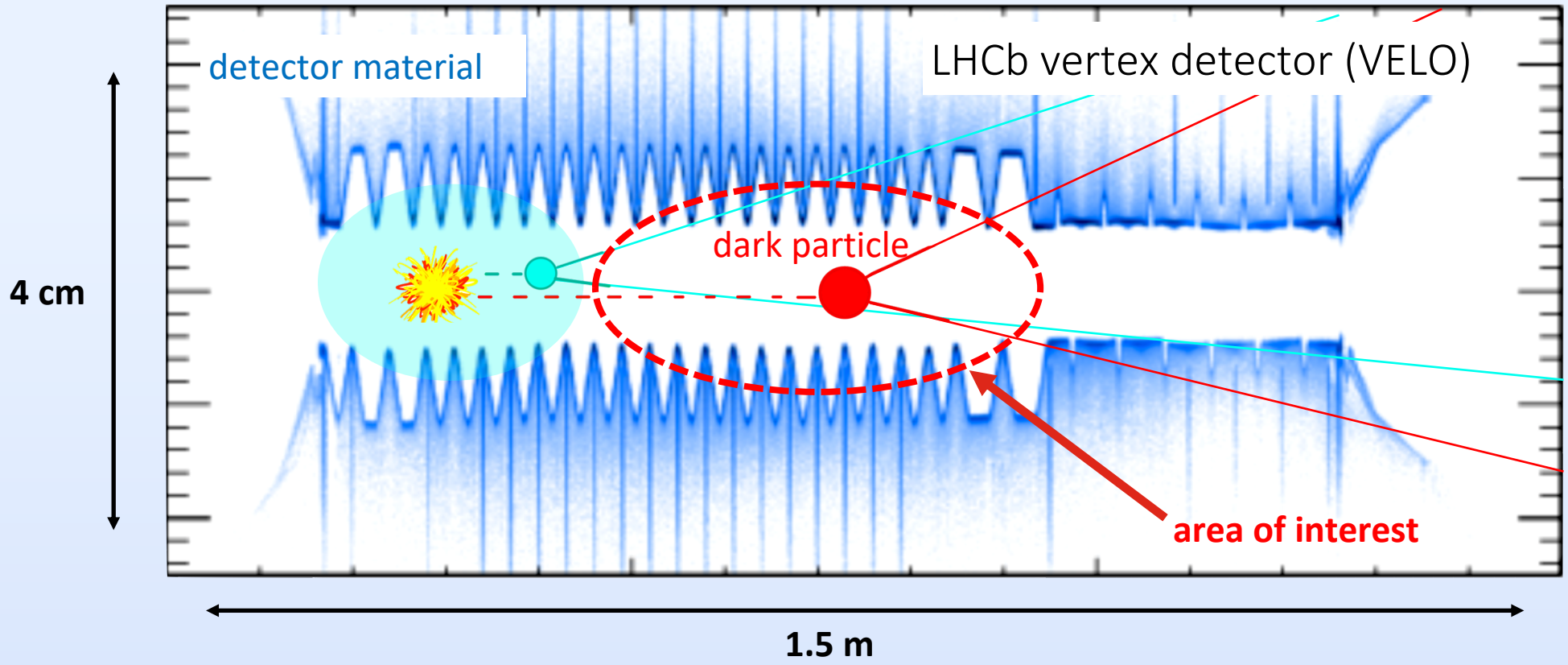
ONGOING: DARK HADRONS DECAYING LIGHT HADRONS

- Access to low masses O(GeV)
- Trigger on displaced vertices
- LHCb: use charged hadron ID from RICH in trigger
- Complicated mixture of heavy flavor background
- Several searches suggested:
  - Model-independent search for $H \to SS, S \to K^+K^-$ *projections*: JHEP 01 (2020) 115
  - Dark hadrons via decays to *D*-mesons / displaced vertices *projections*: PRD 97 (2018) 9, 095033



credit: Y. Tsai

SEARCH FOR DARK PARTICLES AT LHCB



- Dark particle: just like a search for *hadron that flies long distance*

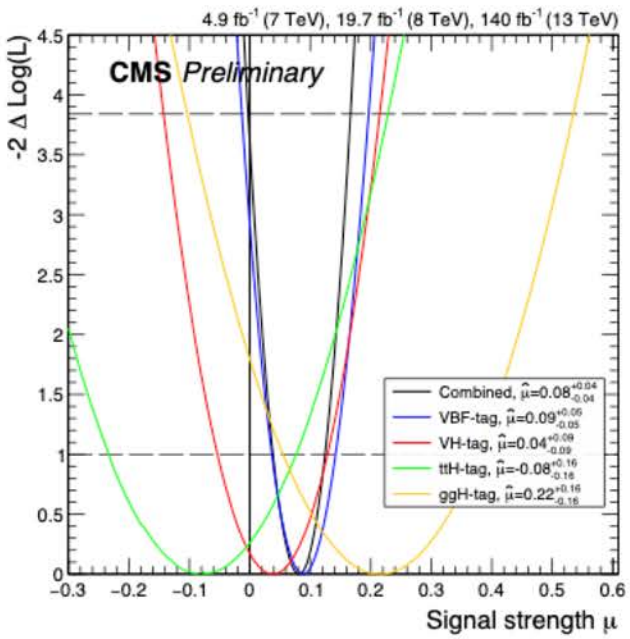
challenge: suppress noise from ordinary hadrons

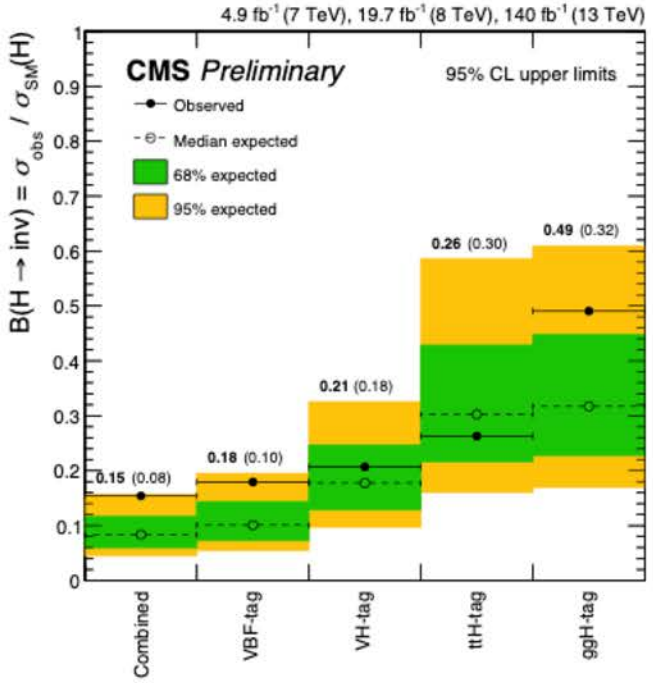
→ room for novel machine learning techniques
→ collaboration with theorists: simulation tool for LHCb
→ decay finding algorithm in area of interest – to be used in GPU trigger

RIGHT FROM THE OVEN: HIGGS CONSTRAINTS

- Upper limit on Higgs decays to invisible particles
- Very small BR expected in the Standard Model, O(0.1%)

CMS: HIG-21-007





Channels grouped by production mode

- Measurement dominated by VBF
- Other channels improve VBF-standalone by about 20%

Analysis	95% C.L. upper limit observed (expected)
Combination	$\mathcal{B}$(H→inv.) < 15% (8%)

Strongest expected exclusion limit to date from direct searches

Higgs Hunting, Orsay

INSTEAD OF CONSLUSIONS

- Dark Matter signatures can be discovered at LHC experiments if we are lucky :)

- Very rich program of New Physics searches at LHC
  - diverse signatures
  - mentioned only small part of it

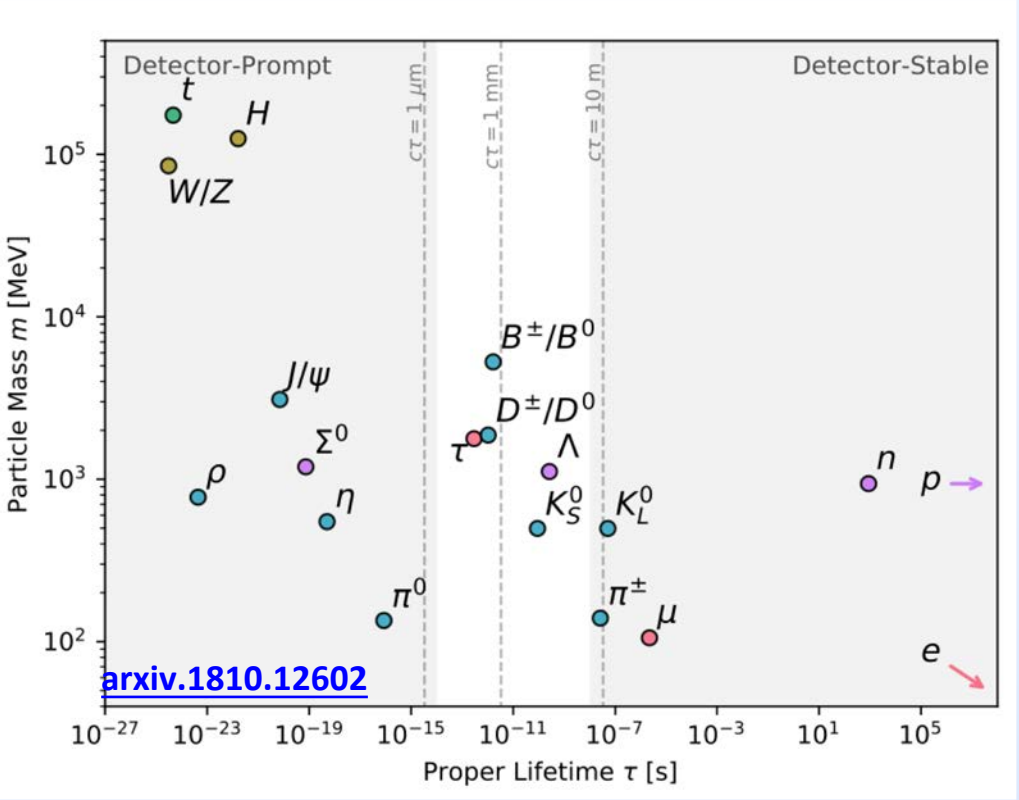
- Much more searches suggested by theorists

- High mass searches carried by ATLAS and CMS

- LHCb extends the searches to lower mass regions
  - especially in the case hadron signatures

- Hopes to discover

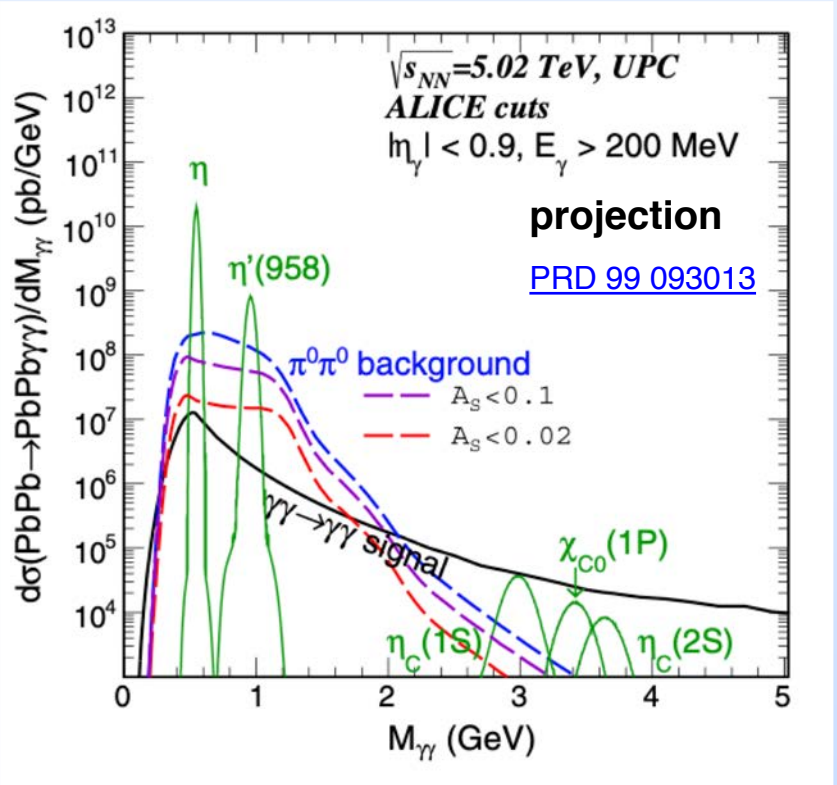
LONG-LIVED PARTICLES



- Long-lived particle (LLP) – neutral or charged object decaying at *macroscopic* and *reconstructible* distance from IP
- Several LLPs in SM
- This talk: **focus on searches for BSM LLPs** *with an LHCb bias*
  - diverse signatures
  - challenge for trigger and reconstruction

SEARCHES IN HEAVY ION COLLISIONS

- Use LHC as $\gamma\gamma$ collider
- All experiments can contribute
- Possible search for ALPs below 5 GeV – ALICE, LHCb
- Direct low-P_T photons or $\gamma \rightarrow e^+e^-$conversions PRD 99 093013
- Background from $\pi^0\pi^0$ and SM mesons



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