SMARTHEP

REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY

ESR9: Real-time analysis for Dark Photons search in LHCb

Yearly Meeting 2023,

01/12/2023

Carlos Cocha

SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

MARIE CURIE ACTIONS

SMARTHEP
REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY

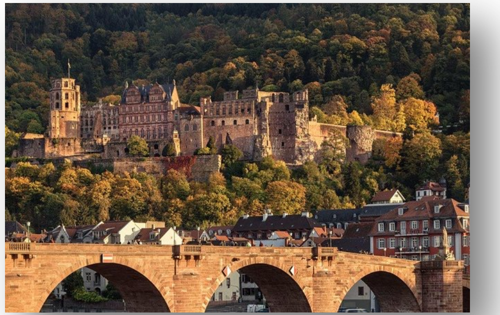
Outline

- ❑ About me
- ❑ Training activities
- ❑ Project
- ❑ Results

SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

About me

- I am Carlos, from Ecuador.
- Born in a small town called Ambato near Quito.
- I love the computing and Experimental Particle Physics.
- BSc in Ecuador (Yachay Tech university)
- Master in Italy (University of Padova)
- PhD at Heidelberg searching for dark photons.
- My major hobbies are:
  - ❖ Climbing (“cordillera de los Andes”)
  - ❖ Chess (chess.com user: carlos_cocha)
  - ❖ Football
  - ❖ Enjoying Germany (castles, sausages, bread, beer, bureaucracy ...)



Heidelberg

Ambato city and Chimborazo mountain (closest point to sun)

Quito, latitude 0°0′0″

SMARTHEP is funded by the European Union’s Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

SMARTHEP
REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY

Training activities

SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

MARIE CURIE ACTIONS

SMARTHEP REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY

Training activities

2022

- Oct 6 - Oct 7 Annual meeting of the German LHCb groups at Physikalisches Institut Heidelberg
- Oct 10 - Oct 13 49th Heidelberg Physics Graduate Days at Physikalisches Institut Heidelberg
- Nov 21 - Nov 25 SMARTHEP kick-off at the University of Manchester
- Nov 28 - Dec 2 LHCb Starterkit 2022 at CERN

2023

- Jan 09 - Jan 10 Mid-term check meeting with the Project Officer
- Jan 10 - Jan 13 SMARTHEP School on Collider Physics and Machine Learning at UniGe
- Mar 06 – Mar 07 First CHARM WG PhD days 2023
- Mar 15 – Mar 17 Flavour-Workshop Neckarzimmern
- April 11-14 50th Heidelberg Physics Graduate Days
- June 11 – June 17 1st HGSFP Summerschool 2023
- June 25 – June 28 Python software in HEP (PyHEP)
- Aug 20 – Sep 02 CERN School of Computing
- Oct 5 - Oct 6 Annual meeting of the German LHCb groups at Physikalisches Institut Heidelberg
- Oct 9 - Oct 13 51st Heidelberg Physics Graduate Days

SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

SMARTHEP
REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY

ESR9 Project

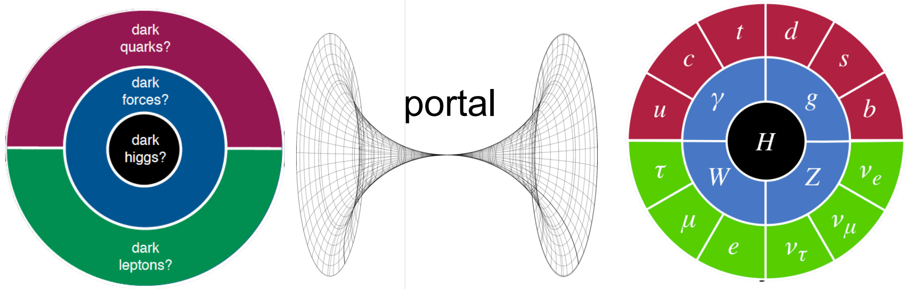
SMARTHEP is funded by the European Union’s Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

MARIE CURIE ACTIONS

ESR9 Project

Minimal Dark sector model

The nature of dark matter (~25% of matter) is still unknown.
What if dark matter can interact with SM matter via "portals"

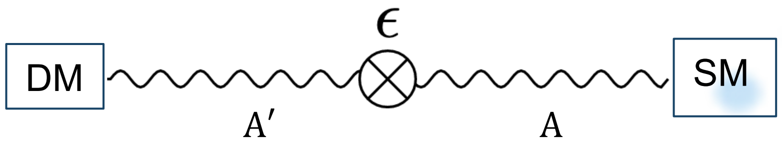


Dark photon portal

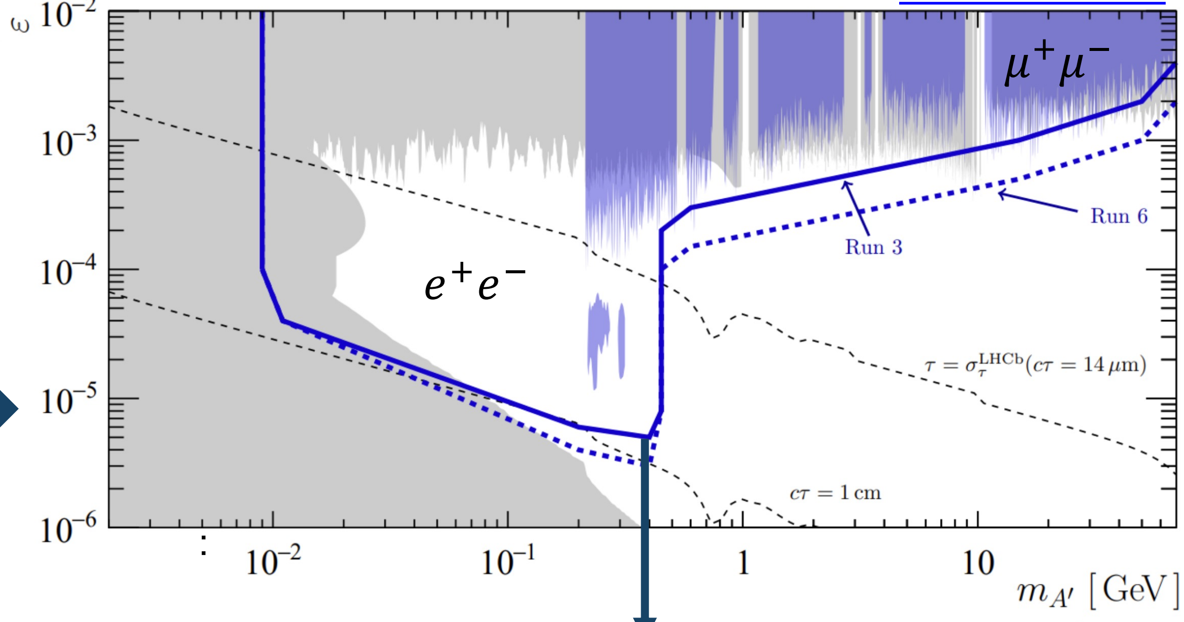
- Dark photon can kinetically mix with the SM photon
- Extend the SM by a new 'dark' gauge group $U(1)'$:

$$\mathcal{L} \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}\boldsymbol{m}^2_{\boldsymbol{A}'}A'_\mu A'^\mu + \boldsymbol{\epsilon} e A'_\mu J^\mu_{EM}$$

$\boldsymbol{m}_{\boldsymbol{A}'}$: dark photon mass $\boldsymbol{\epsilon}$: kinetic-mixing parameter



arXiv:2203.07048v1



Upgraded LHCb detector

- Very good trigger
- Good momentum and mass resolution
- Excellent vertex location resolution

SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

Dark photon search

Dark photon search

- Search driven by $\mathbf{A'}$ lifetime: $\tau_{A'} \propto (\epsilon^2 m_{A'})^{-1}$
  Displaced decay search: $\tau_{A'} > 1$ ps
  Prompt decay search: $\tau_{A'} < 1$ ps

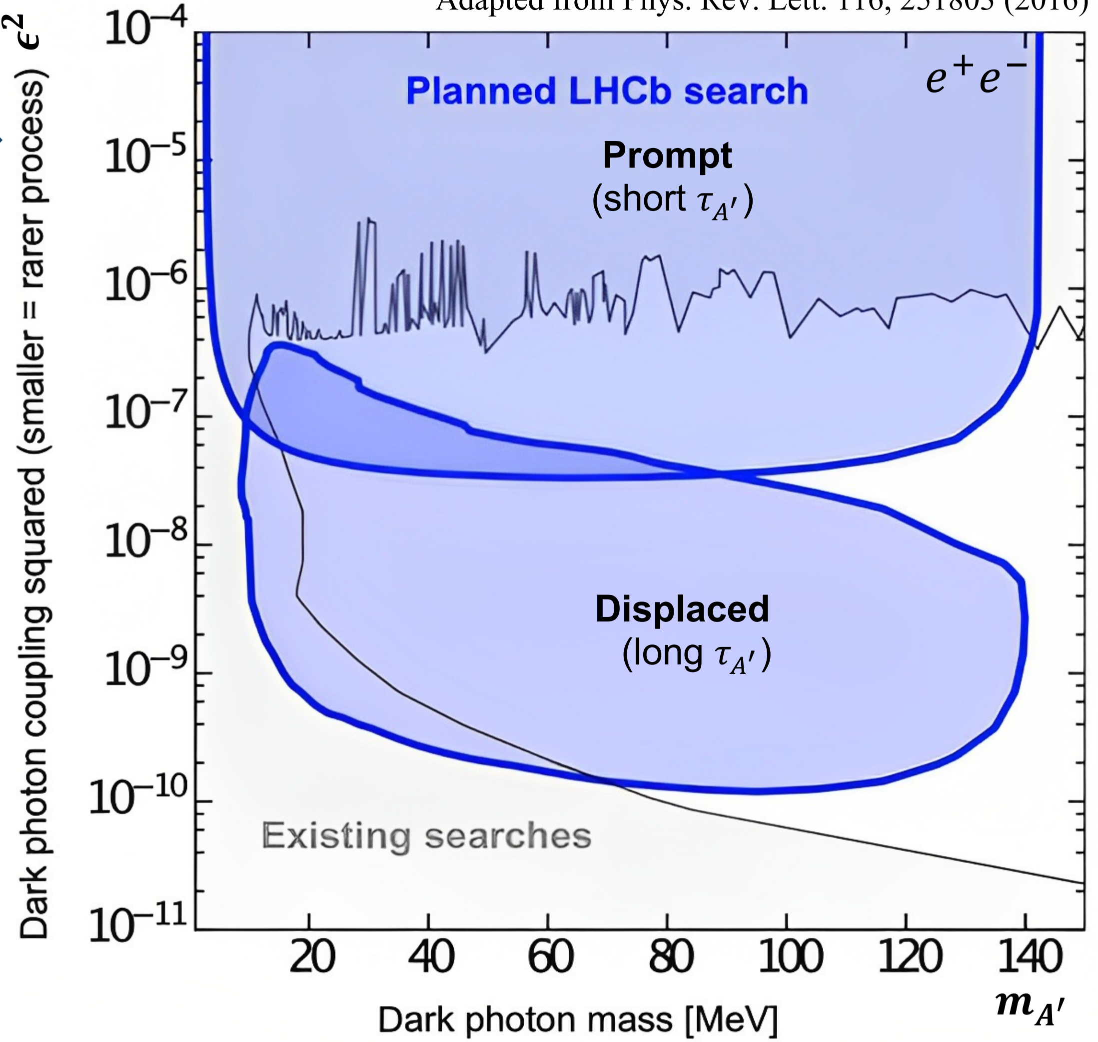
Where to search: Charm decays D^{*0}, D_s^{*+}

- Signal decays: $D^* \to D\, A' (\to e^+ e^-)$
- Search window: $\Delta m_D \approx 140$ MeV
- Production rate: $\mathcal{O}(10^{11})\ D^* \to D\gamma$ per fb^{-1}

- Expected BR:

$$\frac{\Gamma(D^{*0} \to D^0 \boldsymbol{A'})}{\Gamma(D^{*0} \to D^0 \gamma)} = \epsilon^2 \left(1 - \frac{m_{A'}^2}{\Delta m_D^2}\right)^{3/2}$$

Adapted from Phys. Rev. Lett. 116, 251803 (2016)

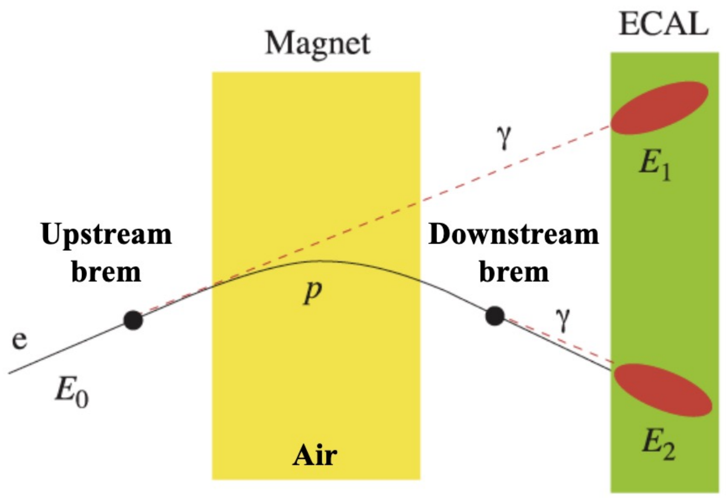


SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

Dark photon search

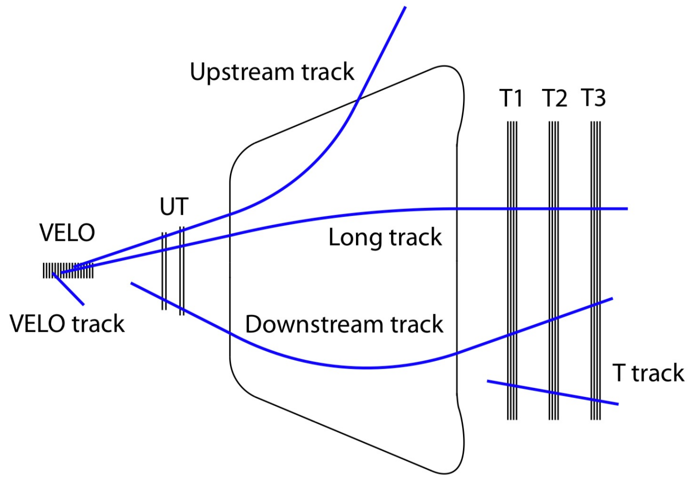
Why this measurement is difficult:

- ❑ Given the nature of the decay:
  - Electrons emitting bremsstrahlung radiation.
  - Super-**soft** (low momentum) electrons
  - Many soft electrons kicked out by the magnet.
  - Most decay chanels use **long** tracks (p > 1.5 GeV)



How such low momentum tracks can be reconstructed?

- ❑ Including **upstream** tracks:
  - Upstream electron identification thanks to RICH1
  - Use different combination of upstream (U) and long (L) electron tracks
  - HLT2 Upstream tracking is really difficult in the trigger



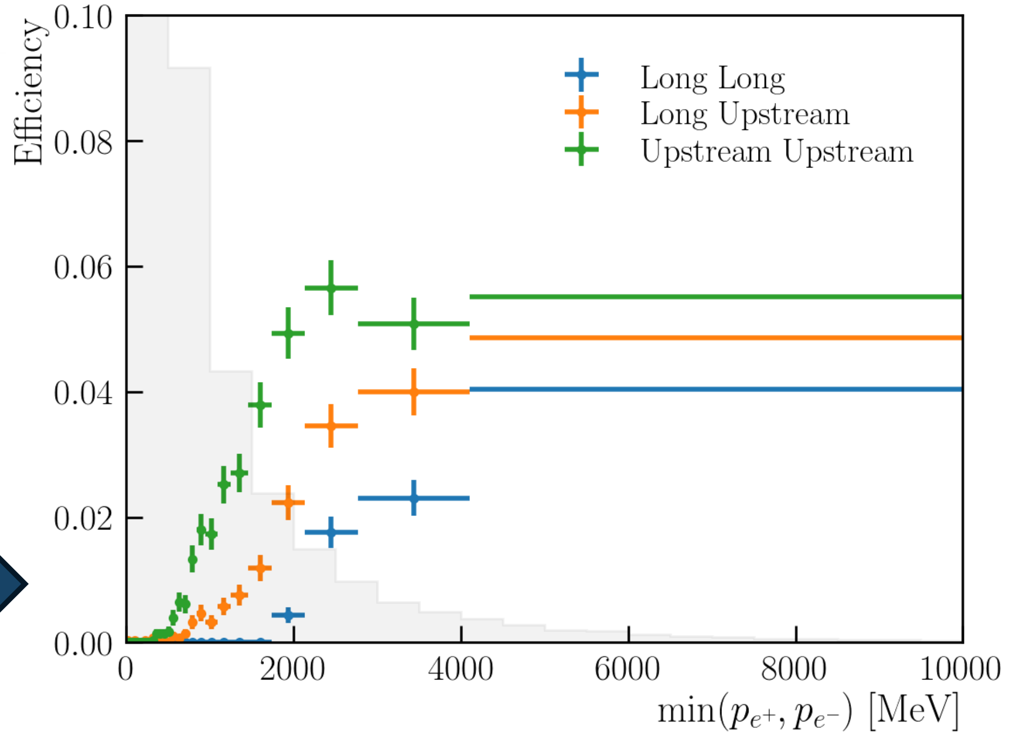
SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

HLT2 trigger lines

- **3 decay channels** including (LL-UL-UU) electron tracks

Line	ϵ_{ll} [%]	ϵ_{ul} [%]	ϵ_{uu} [%]
$D^{*0} \to D^0(\to K\pi)ee$	6.5	9.3	16.3
$D^{*0} \to D^0(\to K\pi\pi\pi)ee$	-	-	-
$D_s^{*+} \to D_s^+(\to KK\pi)ee$	-	-	-

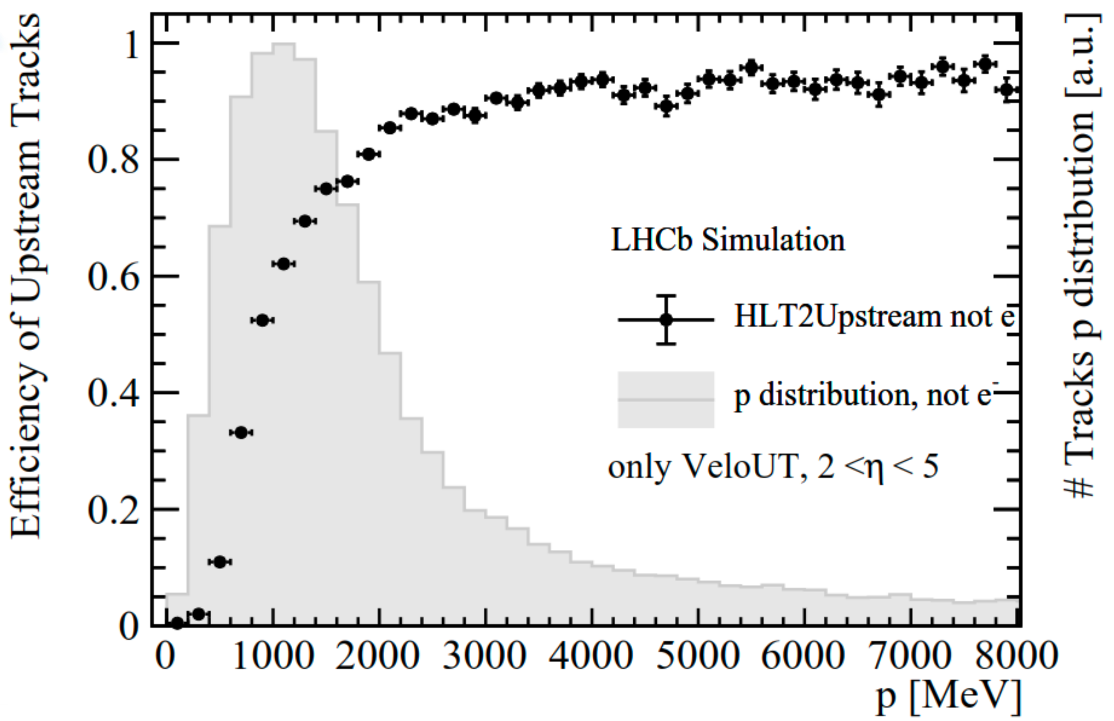
- **9** HLT2 trigger lines.
- Optimized upstream reconstruction [!2589]:
  - **5x more efficiency** when including upstream tracks
  - Reconstructed **very low-momentum electrons**
- Still optimizing the upstream tracking reconstruction.



SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

HLT2 Upstream tracking reconstruction

- ❑ There is a relevant efficiency drop at low momentum (<1.2 GeV)
- ❑ Current optimization focusses on high momentum tracks.
- ❑ What needs to be tested:
  - ➢ Does the track model upstream algorithm (PrVeloUT) need to be (re)parametrized for low momentum tracks?
  - ➢ Where low momentum candidates are lost, e.g., after hit clustering?



SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

SMARTHEP
REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY

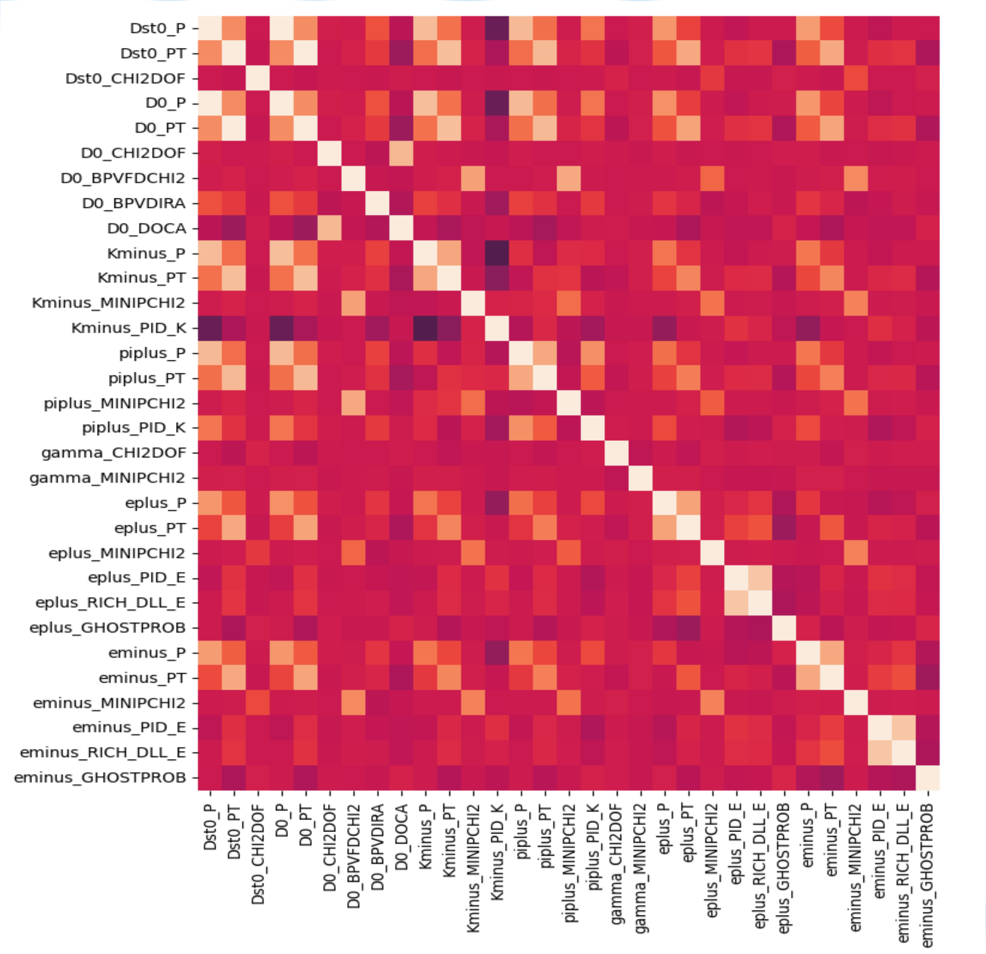
HLT2 lines optimization

- ❑ The optimization involves a **trade-off** (efficiency vs. rate)
- ❑ The lines are at the border of rate tolerance $\mathcal{O}(100\ \text{Hz})$
- ❑ How can it be optimized?

Idea:

- ❖ is it possible to implement a MVA at the trigger level similar to other MVA lines?

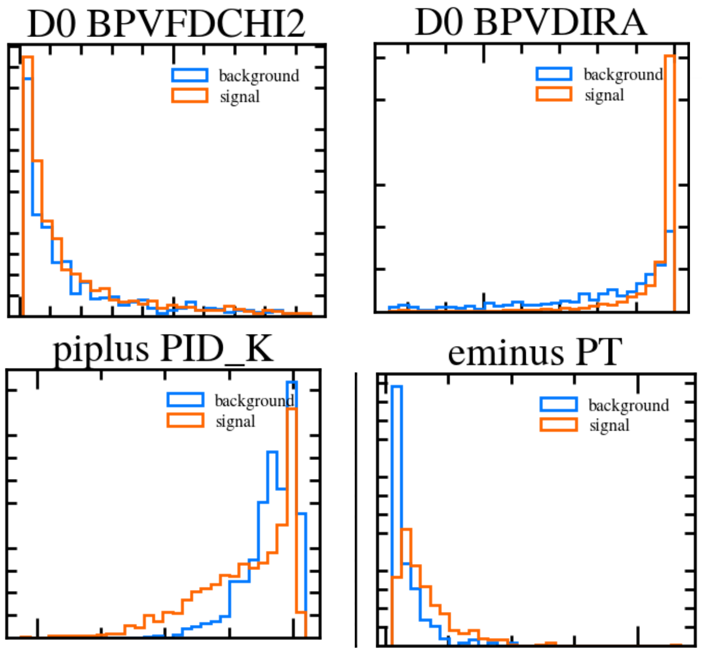
Methodology:
Untight trigger cuts
Train a BDT–based classifier with triggered events: • $\mathcal{O}(1000)$ signal events • $\mathcal{O}(1000)$ background events
Load the trained classifier in the trigger line
Optimize rates and efficiencies



SMARTHEP is funded by the European Union’s Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

HLT2 lines optimization

Triggered and loose selected data



BDT-based classifier
lr = 0.1
max_depth = 10
obj. function= logistic
Metric= AUC

	Rate [Hz]	Efficiency gain $\epsilon_{MVA}^{untight}/\epsilon_{trigger}^{current}$
LL	97	**~ 4**
UL	105	**~ 3**
UU	102	**~ 2**

- ❑ Good classification accucary and efficiency improvement at the same trigger rate.
- ❑ Main target is to implement an optimized real time classifier for dark photon selection in the trigger.

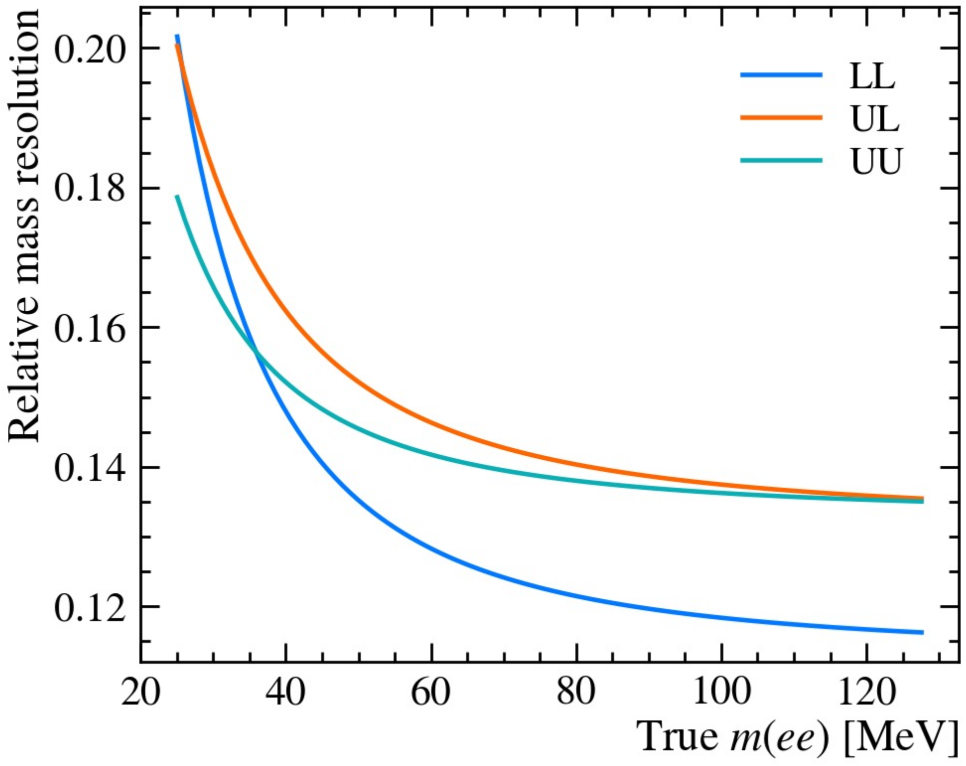
SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

Dark Photon Mass Resolution

- In the end, we will look for a dark photon peak in the dielectron mass spectra.

$$m(e_1e_2) \approx \sqrt{2E_1E_2(1-\cos\theta_{12})} \approx \theta_{12}\sqrt{2p_1p_2}$$

- How much sensitivity will be the detector?
  - Multiple scattering dominates the resolution.
  - Angular resolution worsens the resolution at low $m(ee)$.
  - Similar mass resolution in the three electron categories.



SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

Next steps

- ❑ Perform Run 2 and early Run 3 analysis
- ❑ End HLT2 lines optimization and MVA implementation
- ❑ Test if performance gains with low-p electrons can help in other analysis:
  - Flavour Tagging
  - LFV, e.g. in $\tau \to \mu\gamma$, using $\gamma \to e^+e^-$

	Efficiency $\epsilon_{trigger}^{current}$
LL	~ 4
UL	~ 3.7
UU	~ 3.8

- ❑ Start the secondments:
  - 3 months at Verizon Connect
  - 6 months at Milano Bicocca

SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

Summary

- Upstream tracking optimization showed a **5x improvement** in the trigger efficiency.
- At least another **x2 improvement** implementing a MVA classifier.
- Mass resolution of order of $\mathcal{O}(10\%)$ for LL-UL-UU categories.
- Excited and optimistic to see the performance in the upcoming 2024 run!

SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

SMARTHEP
REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY

THANKS

SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086