SMARTHEP

REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY

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

Yearly Meeting 2023,

28/11/2023

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

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Outline

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

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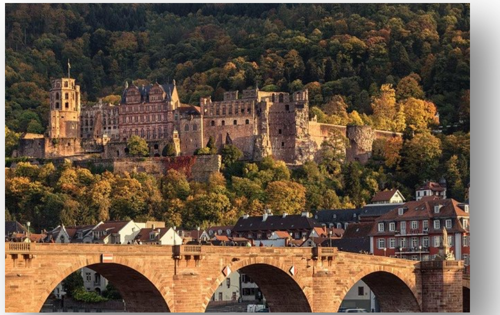
About me



Heidelberg

- I am 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 ...)

Ambato city and Chimborazo mountain (closest point to sun)

Quito, latitude 0°0′0″

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Training activities

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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

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ESR9 Project

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ESR9 Project

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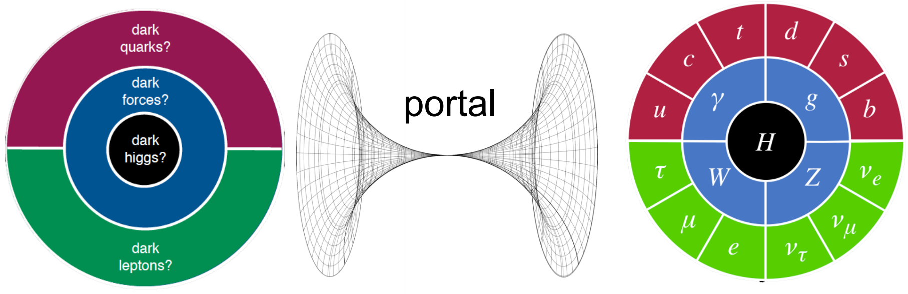
Minimal Dark sector model

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

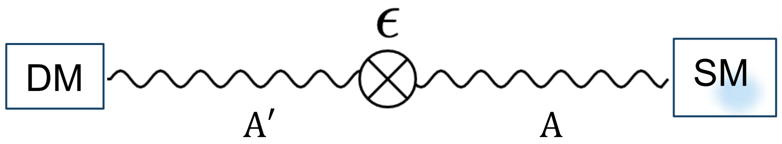


Dark photon portal

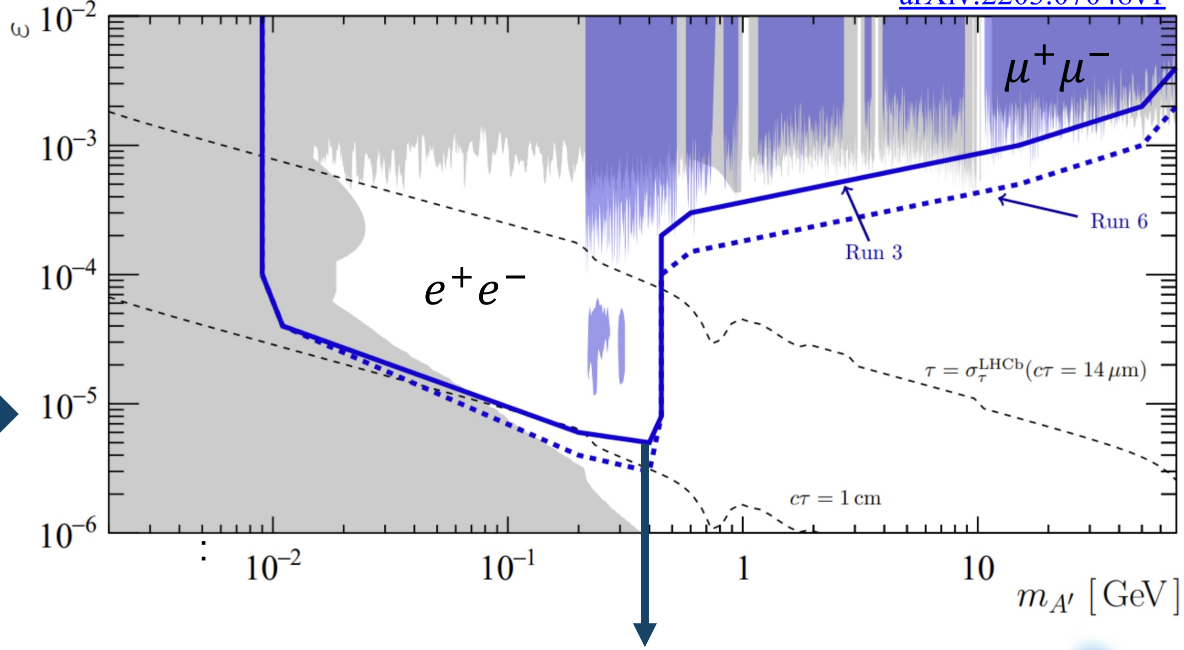
- Dark photon can kinetically mix with the SM photon
- Extend the SM by a new ‘dark’ gauge group $U(1)'$:

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

$\boldsymbol{m}_{\boldsymbol{A}'}$: 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

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Dark photon search

Dark photon search

- Search driven by A' lifetime: $\tau_{A'} \propto (\epsilon^2\, m_{A'})^{-1}$
  Displaced decay search: $\epsilon^2 \in [10^{-10}, 10^{-6}]$
  Prompt decay search: $\epsilon^2 \in [10^{-7}, 10^{-4}]$

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

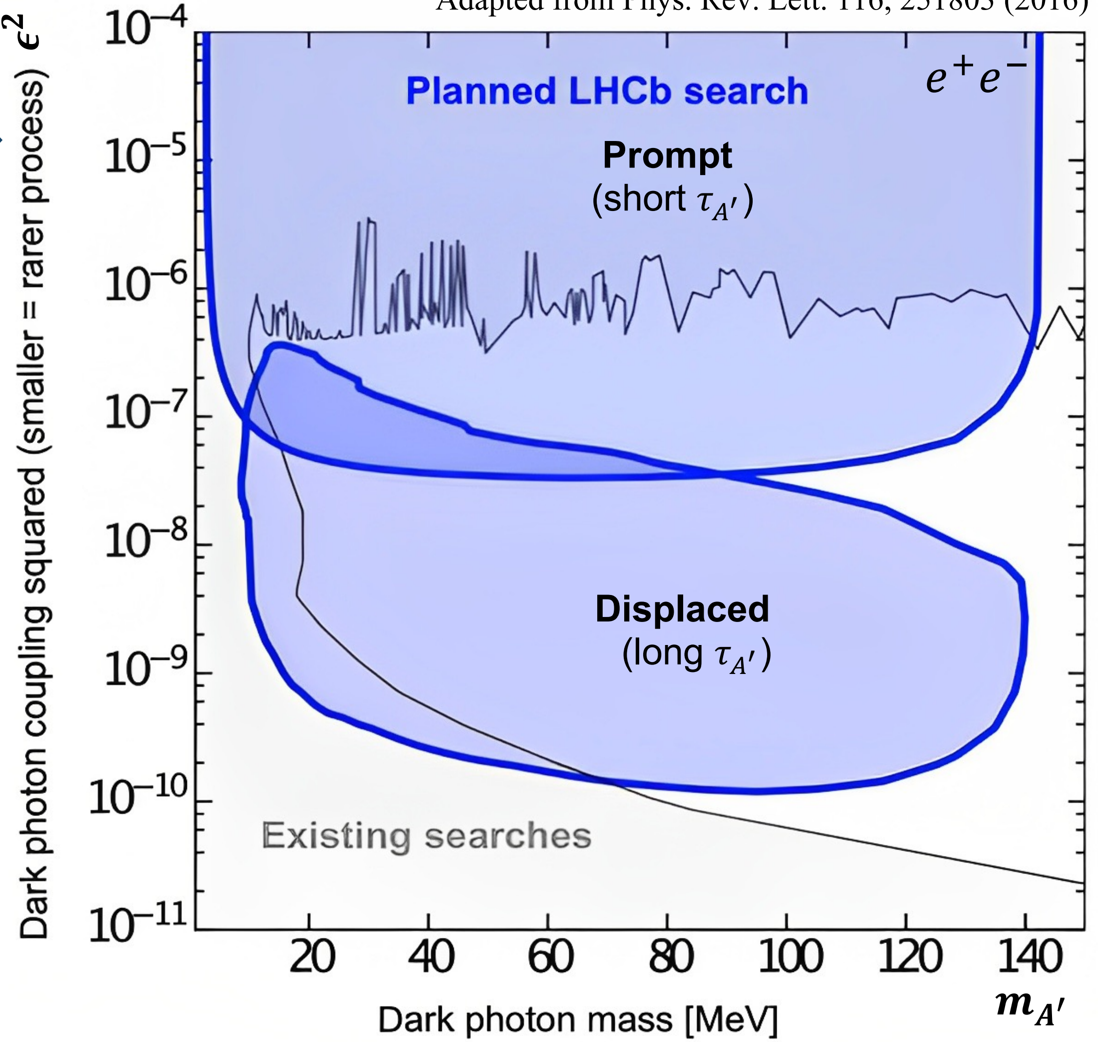
- Abundant charm production
- The displaced D decay vertex helps with the trigger
- Focus on very low mass regions
- Signal decays: $D^* \to D\, A'(\to e^+e^-)$
- Search window: $m_{A'} \in [2m_e, \Delta m_D]$, $\Delta m_D = 142$ MeV

- Irreducible Background: $D^{*0} \to D^0 e^+ e^-$
- Production rate: ~5 kHz

- Expected BR:

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

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



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Dark photon search

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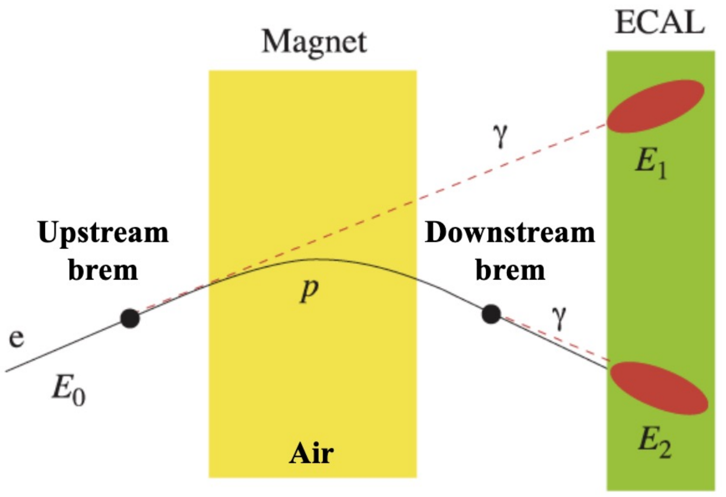
Why this measurenment is difficult:

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

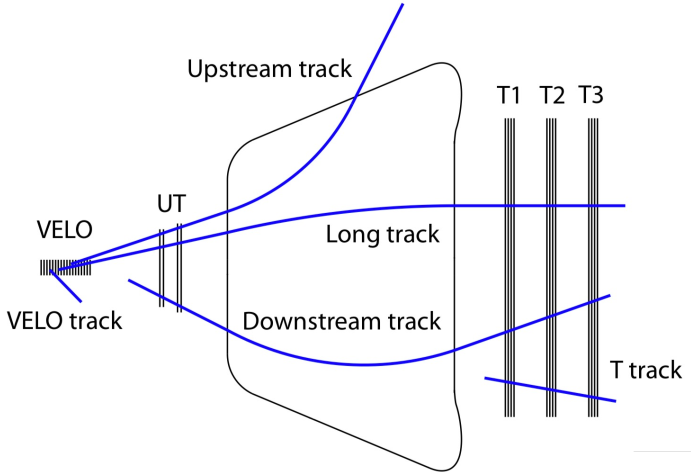


How can we reconstruct low momentum tracks?

- ❑ Including **upstream** tracks:
  - Upstream electron identification thanks to RICH1
  - Use different combination of upstream (U) and long (L) electron tracks

New "challenges":

- ❑ HLT2 Upstream tracking is really difficult in the trigger



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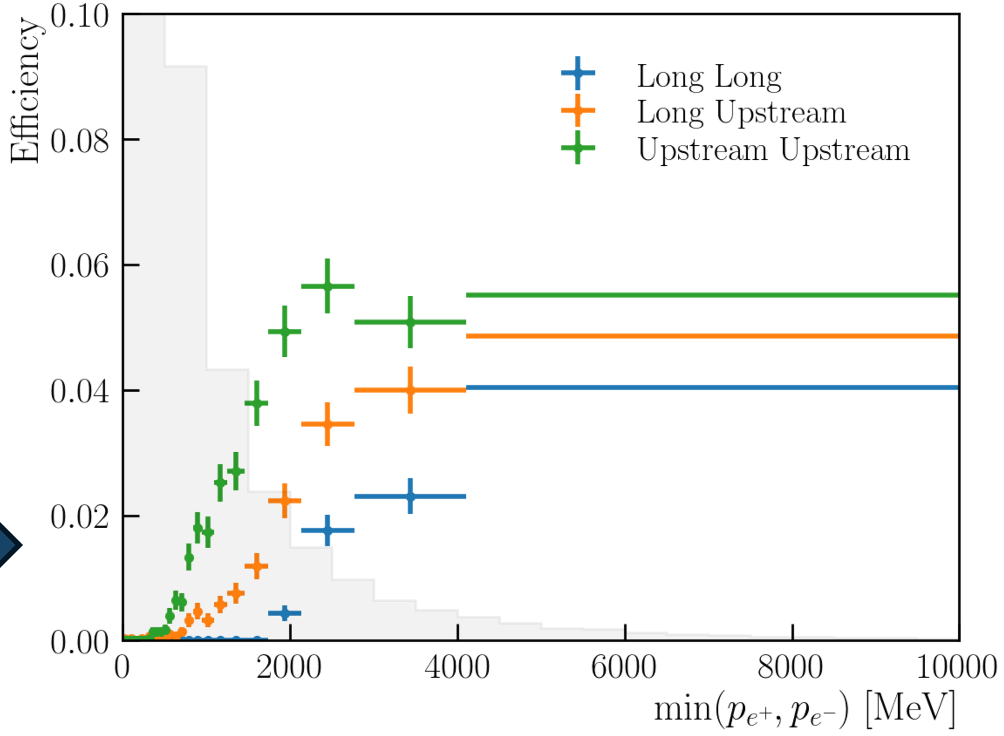
MARIE CURIE ACTIONS

HLT2 trigger lines

- **3 decay channels** including combinations of upstream and long electron tracks: LL-UL-UU

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.
- Upstream reconstruction efficiency was improved in collaboration with experts [!2589]:
  5x more efficiency when including upstream tracks
- **Very low-momentum electrons** are reconstructed
- Currently working in the upstream tracking reconstruction optimization.



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Upstream tracking optimization

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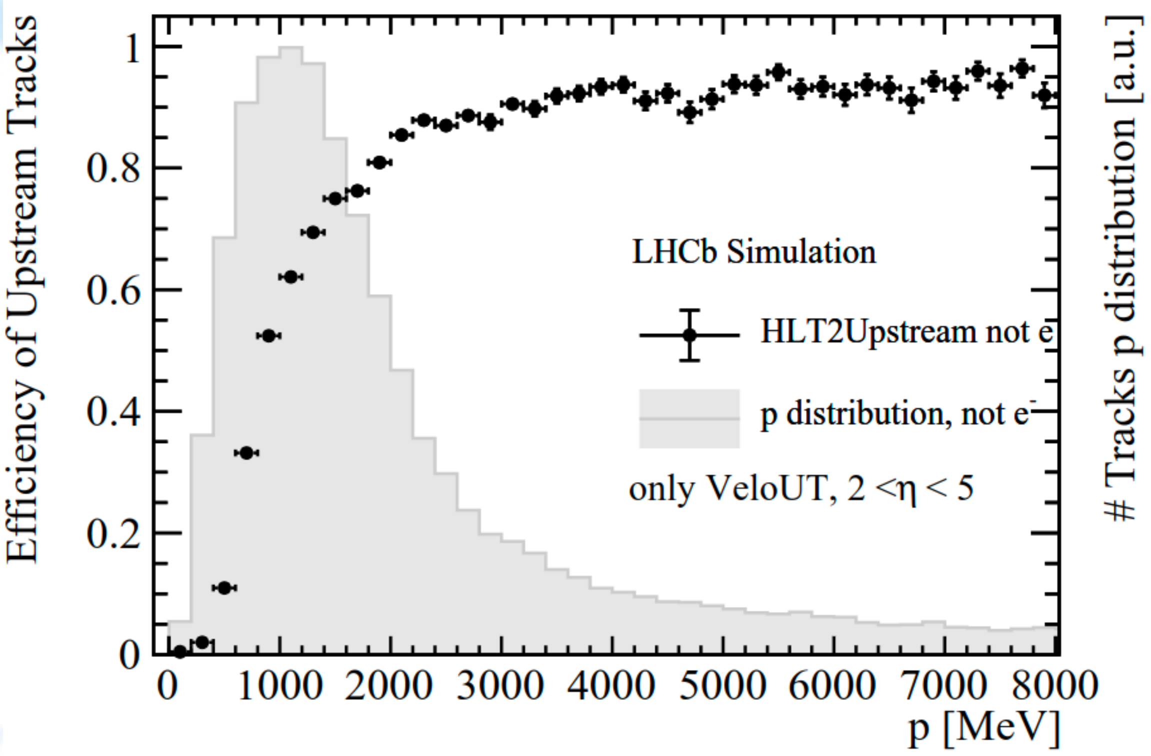
- ❑ There is a relevant efficiency drop at low momentum (<1.2 GeV)
- ❑ Current implementation focusses on high momentum tracks.

- ❑ 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. whether we find correct track candidates during clustering of the hits but loose them somewhere afterwards



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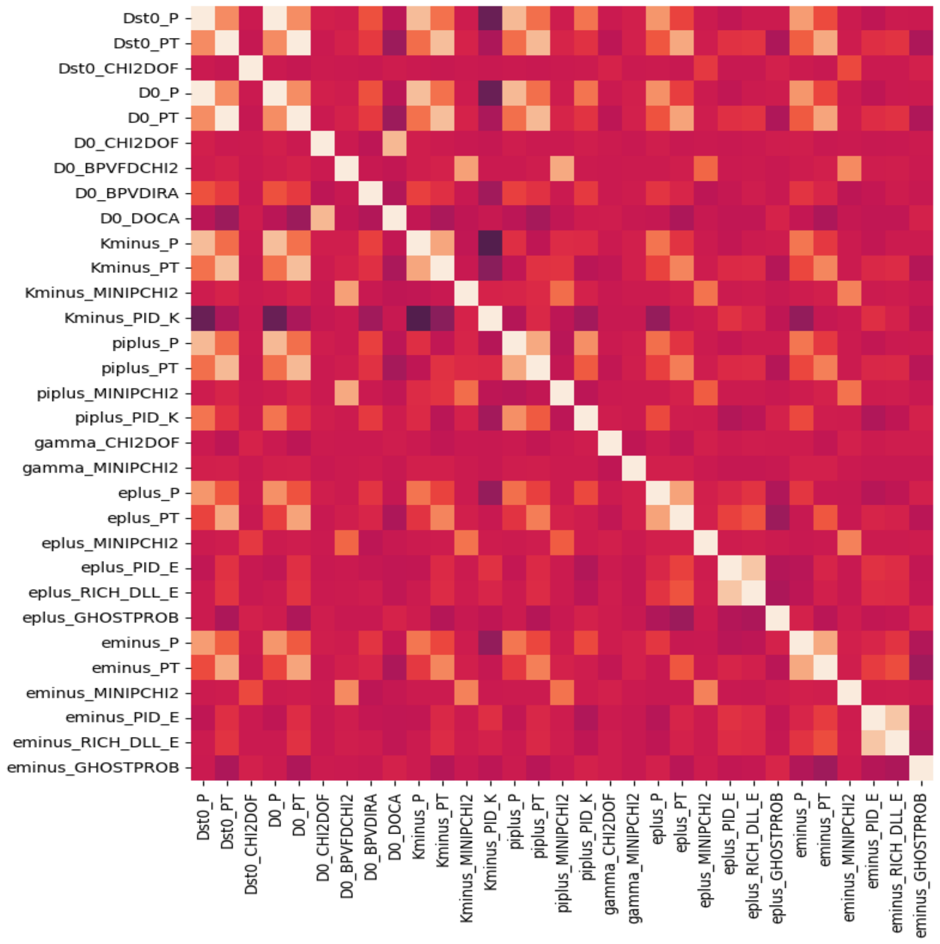
HLT2 lines optimization

- The HLT2 line optimization implies a **trade-off** between efficiency and rate.
- The lines are at the border of output rate tolerance $\mathcal{O}(100\ \text{Hz})$ where only triggered tracks and related primary vertices candidates are written to disk
- How can it be optimized without the rate exploding?
- **Idea:**
  - In line with the SMARTHEP network: is it possible to implement a real time MVA classifier 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



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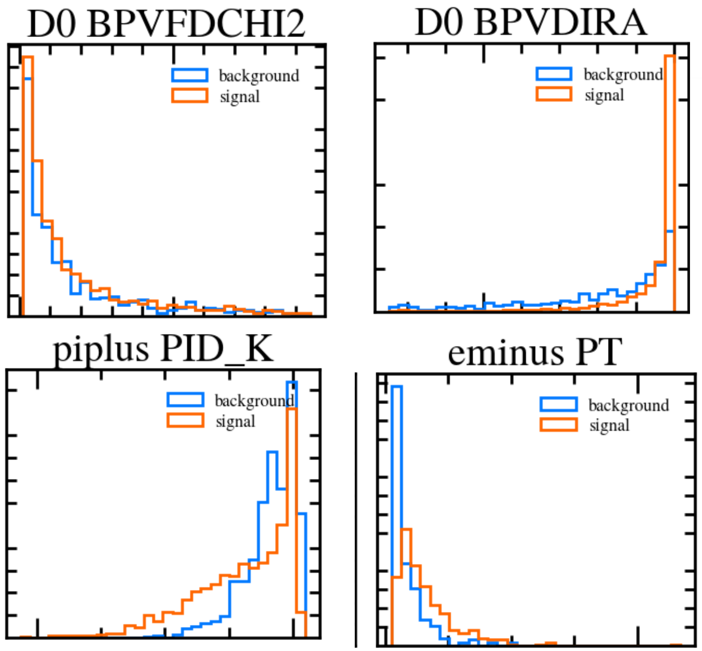
HLT2 lines optimization

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 have an optimized real time classifier for dark photon selection in the trigger.

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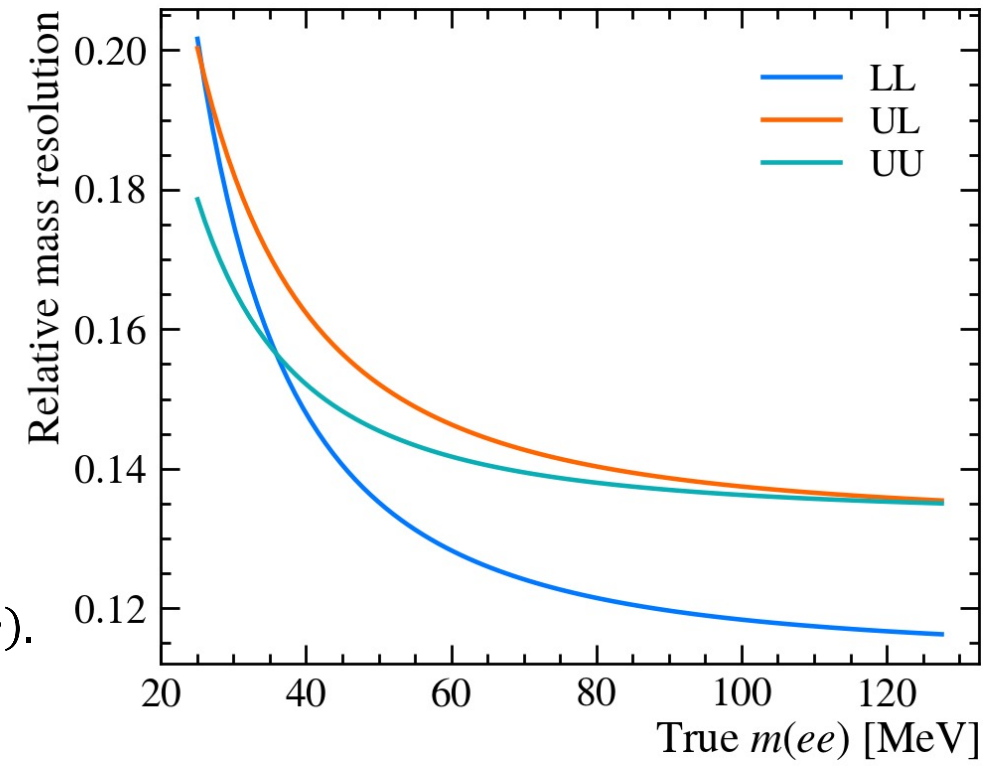
Dark Photon Mass Resolution

- 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 for this signature?
- The mass constrain in D^{*0} and D^0 improve the mass resolution
  - Multiple scattering dominates the resolution.
  - Angular resolution worsens the resolution at low $m(ee)$.
  - The mass resolution is almost the same in the three electron categories.



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Next steps

- ❑ Perform Run 2 and early Run 3 analysis
- ❑ End HLT2 lines optimization and MVA implementation before next data taking campaign
- ❑ 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

verizon connect

UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA

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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!

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THANKS

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