Trigger upgrade plans for LHCb

Jessica Prisciandaro
on behalf of the LHCb collaboration

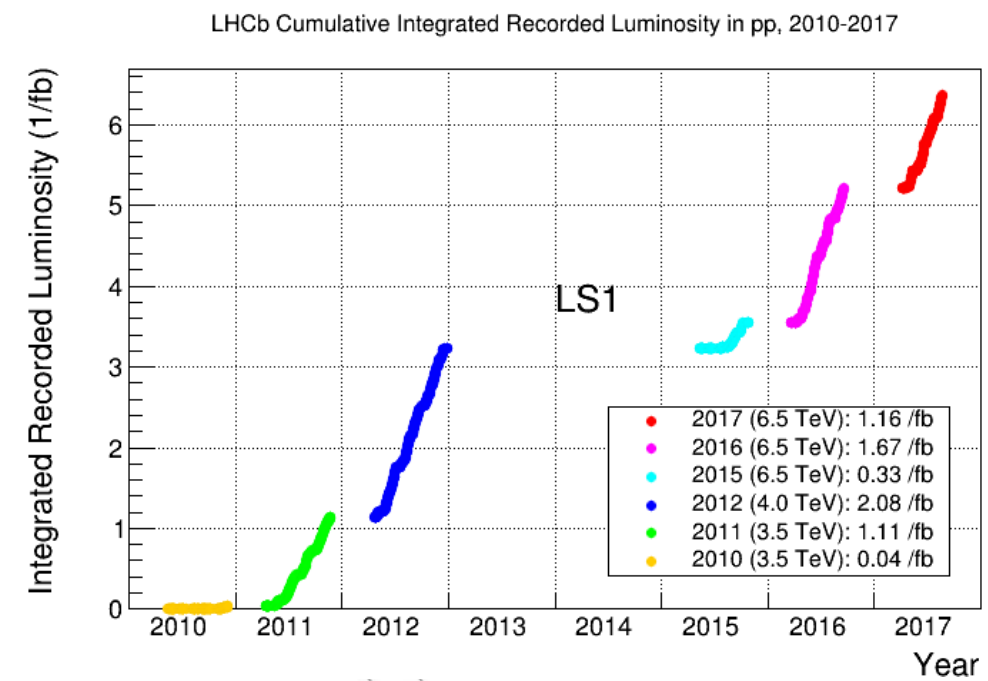
Searches for long-lived particles at the LHC
17-20 October 2017, Trieste

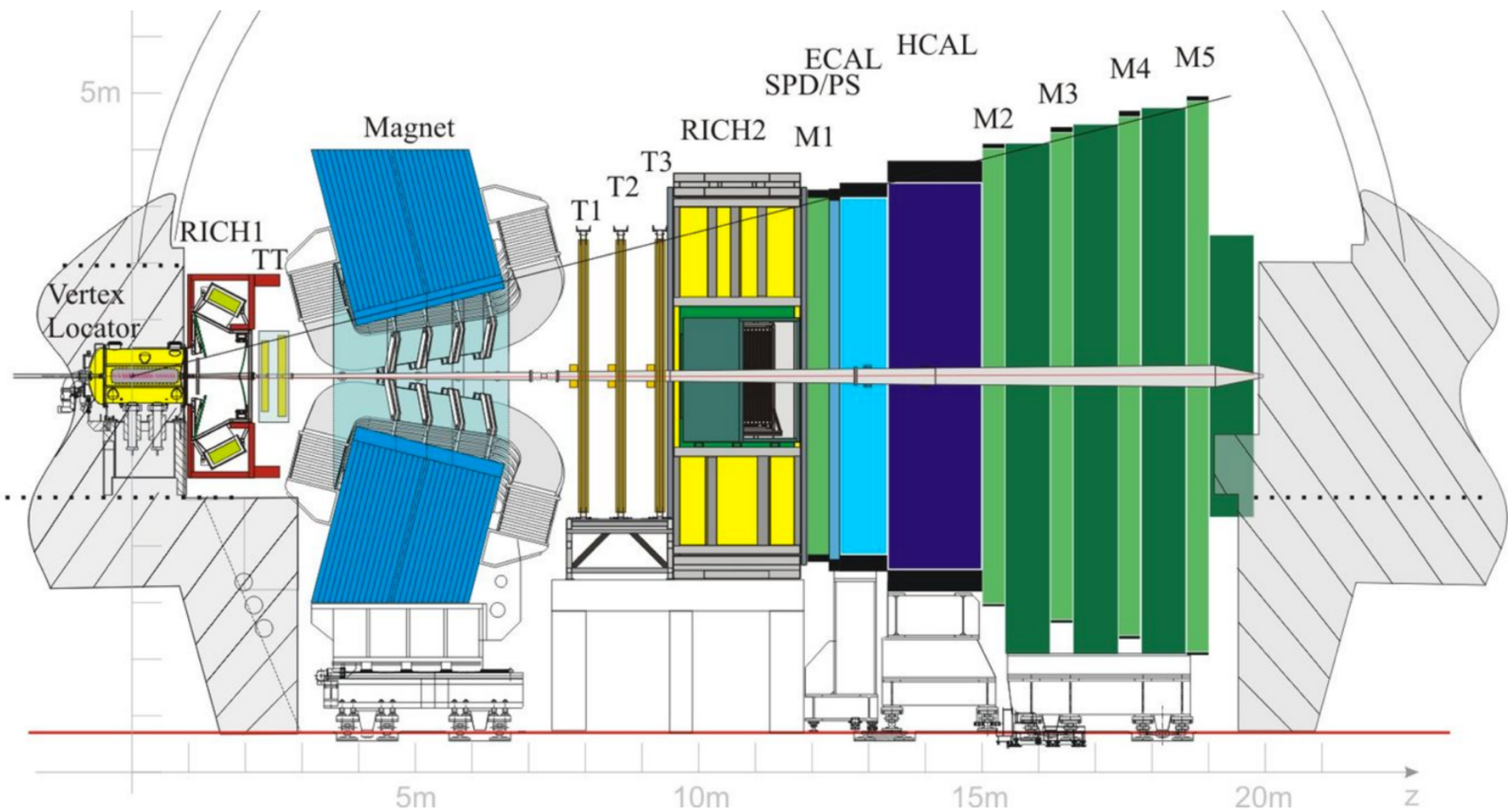
European Research Council
Established by the European Commission

USC
UNIVERSIDADE
DE SANTIAGO
DE COMPOSTELA

The LHCb detector

- Fully instrumented between $2 < \eta < 5$
- Momentum resolution between 0.5% (@5 GeV) and 1% (@200 GeV)
- Low instantaneous luminosity compared to ATLAS and CMS (4×10^{32} cm^{-2} s^{-1})





[Int. J. Mod. Phys. A 30, 1530022 (2015)]

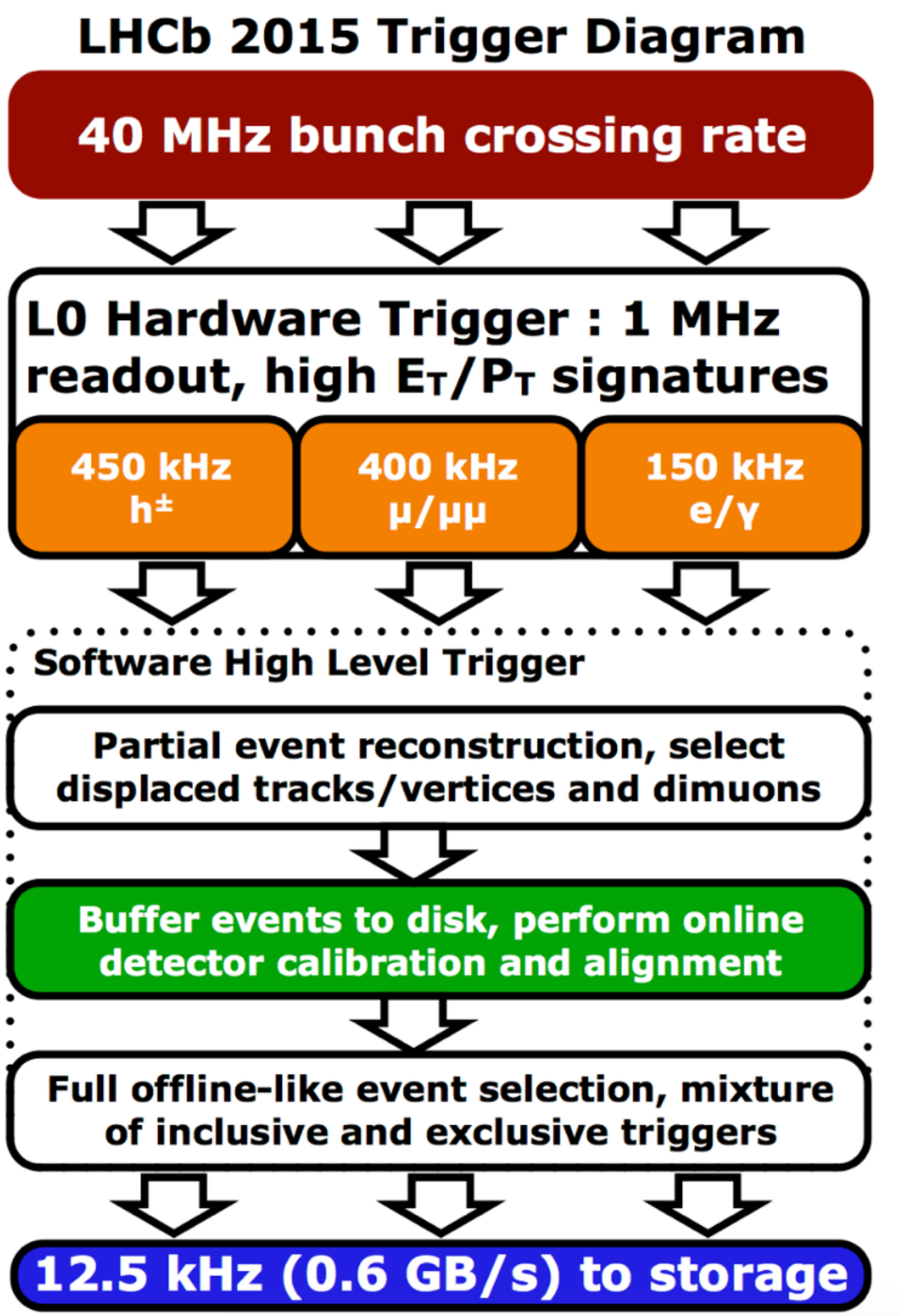
The LHC schedule

2019 2020	2021 2022 2023	2024 2025 2026	2027 2028 2029	2030 2031	2032 203+
	Run III		Run IV		Run V
LS2		LS3		LS4	
LHCb 40 MHz **UPGRADE**	$L = 2 x 10^{33}$	**LHCb Consolidation**	$L = 2 x 10^{33}$ $50\ fb^{-1}$	**LHCb Ph II UPGRADE ***	$L = 2 x 10^{34}$ $300\ fb^{-1}$
ATLAS **Phase I Upgr**	$L = 2 x 10^{34}$	**ATLAS** **Phase II UPGRADE**	**HL-LHC** $L = 5 x 10^{34}$	**ATLAS**	**HL-LHC** $L = 5 x 10^{34}$
CMS **Phase I Upgr**	$300\ fb^{-1}$	**CMS** **Phase II UPGRADE**		**CMS**	$3000\ fb^{-1}$
Belle II	$5\ ab^{-1}$ $L = 8 x 10^{35}$	$50\ ab^{-1}$			

- What we expect for Run III and Run IV:
  - Collect 50 fb^{-1} at 14 TeV
  - Higher luminosity: $2x10^{33}\ cm^{-2}\ s^{-1}$
  - More interactions per crossing

Detector and **trigger** have to be able to cope with the new conditions

The current LHCb trigger



HLT rate in CMS ~ 1kHz

- Hardware trigger (L0):
  - Based on calorimeter and muon chambers infos
  - Detector readout limited to 1MHz
  - Tight cuts, e.g. $p_T(\mu) > 1.4$ GeV, $E(e)>2.5$ GeV
- Software trigger (HLT):
  - HLT1:
    - Partial event reconstruction (tracking and PV)
    - Track reconstruction for $p_T > 0.5$GeV
    - Multivariate inclusive selection (based on IP, kinematic and muonID)
  - HLT2:
    - Full event reconstruction
    - Inclusive lines (selection of displaced vertices and hight p_T tracks)
    - Exclusive lines with reduced events informations for all the rest (>300 lines)

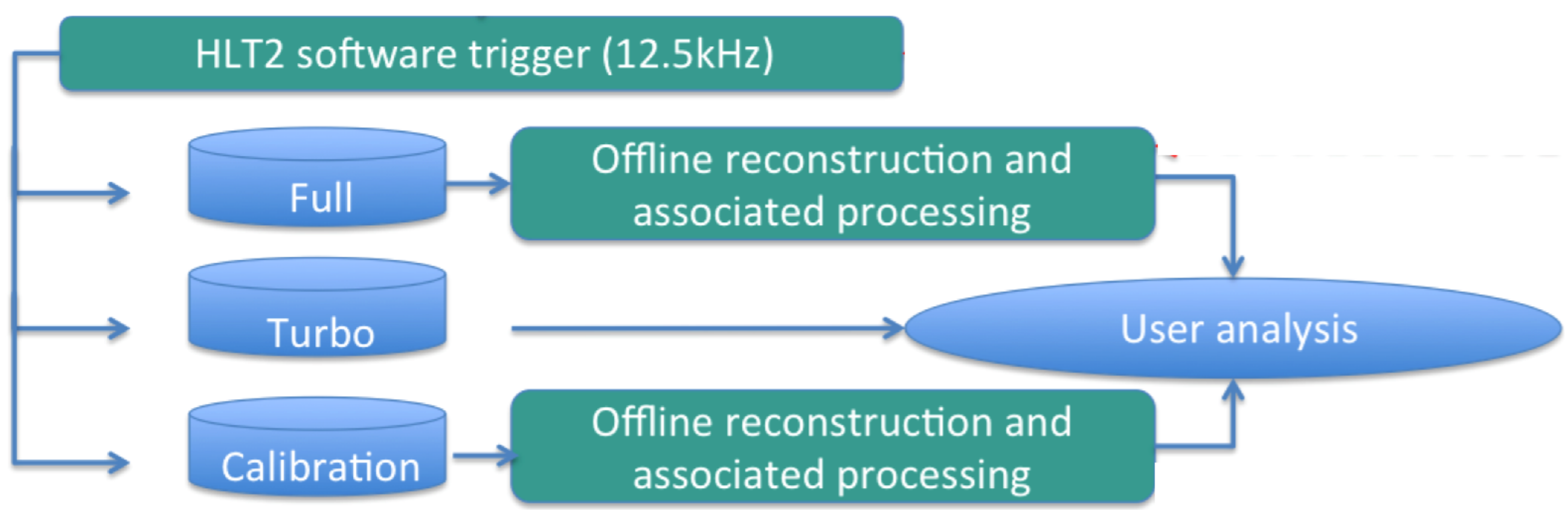
The LHCb trigger in Run II

Online and offline as close as possible:

- PID (and its calibration) performed at the trigger level
- Same calibration and detector alignment in trigger and offline
- Same reconstruction in the trigger and offline

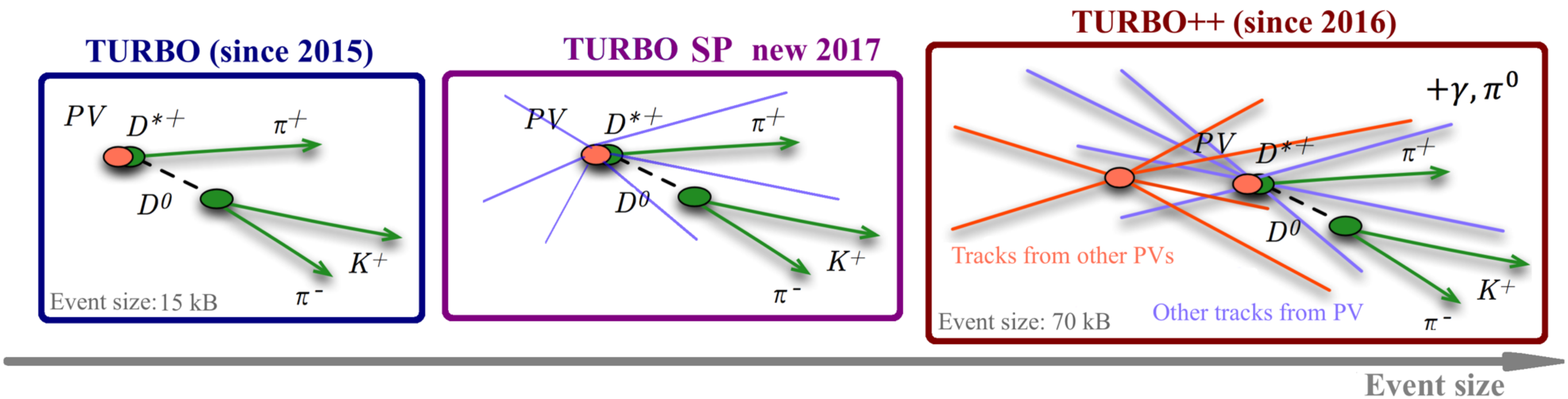
Possibility to perform analyses directly on the trigger output (Turbo stream):

- Candidates are saved directly after the trigger
- Only reconstructed objects saved
- Smaller events + more rate + fast data availability

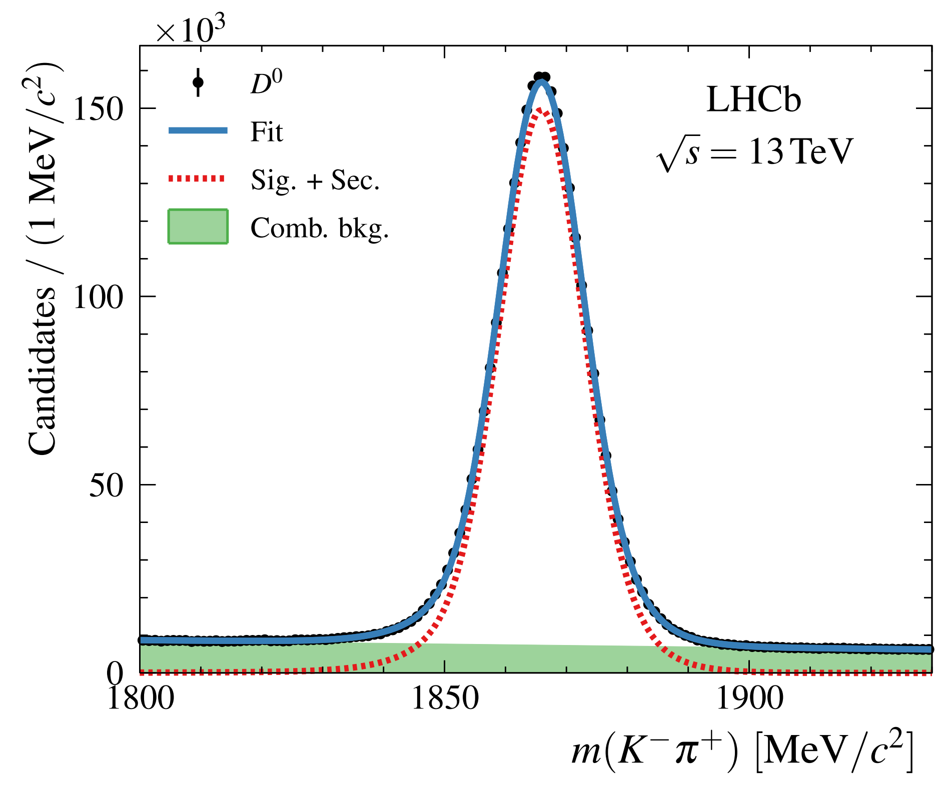


[LHCb-DP-2016-001]

Turbo stream in Run II

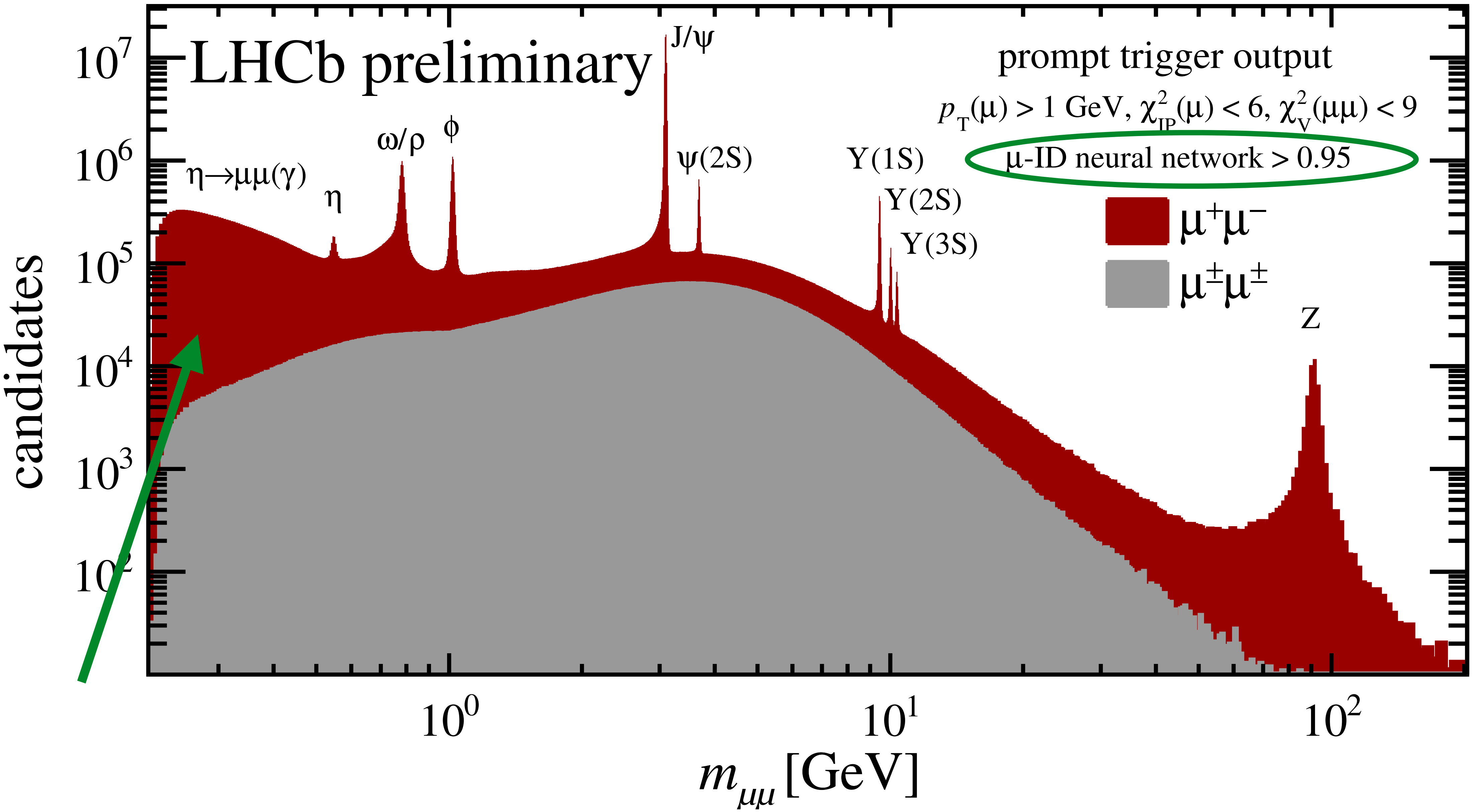


- Turbo:
  - only exclusive decays (and nothing else) saved
- Turbo++ :
  - Full event reconstruction can be persisted
  - Variables such as isolation, objects for jets reconstruction, can be saved
- Turbo SP:
  - New intermediate solution between Turbo and Turbo++
  - Trigger candidate + subset of reconstruction saved



[JHEP03(2016)159]

- Output from Turbo di-muon trigger in 2016
- No offline reconstruction



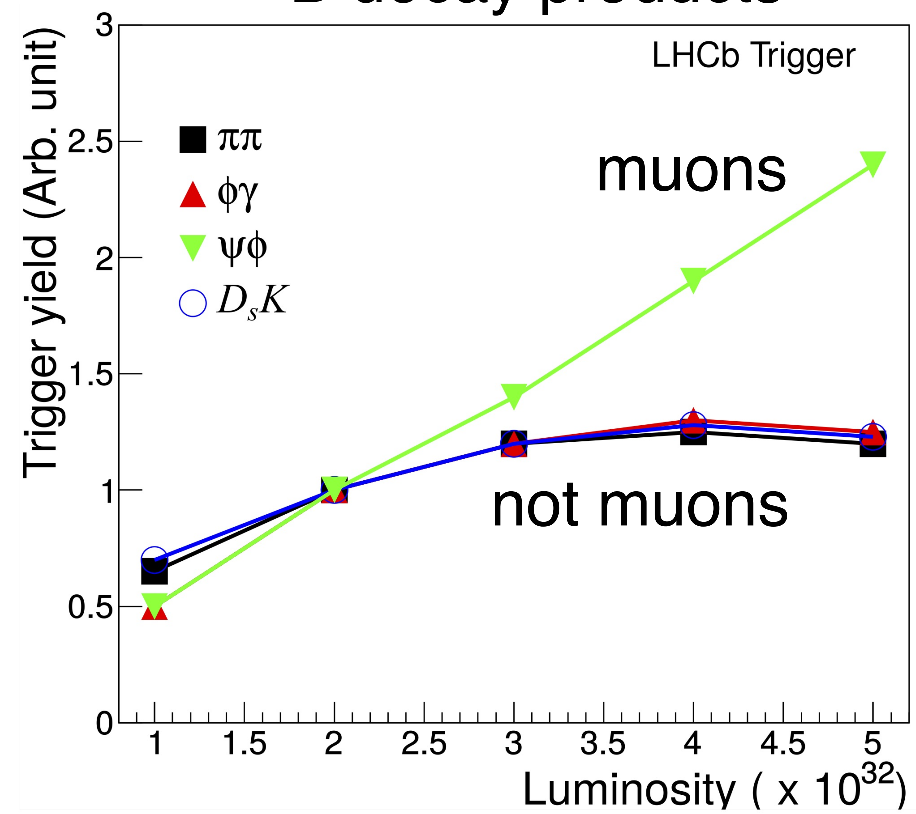
Turbo allows to collect more rate, especially at low masses!

Can we do better?

- L0 trigger has to reduce rate from 40 MHz to 1 MHz: limit on data exploitation
  - bottleneck for trigger on low p_T particles

- Increase in luminosity requires tighter thresholds:
  - loss in efficiency
  - some final states cannot benefit from the higher luminosity

B decay products

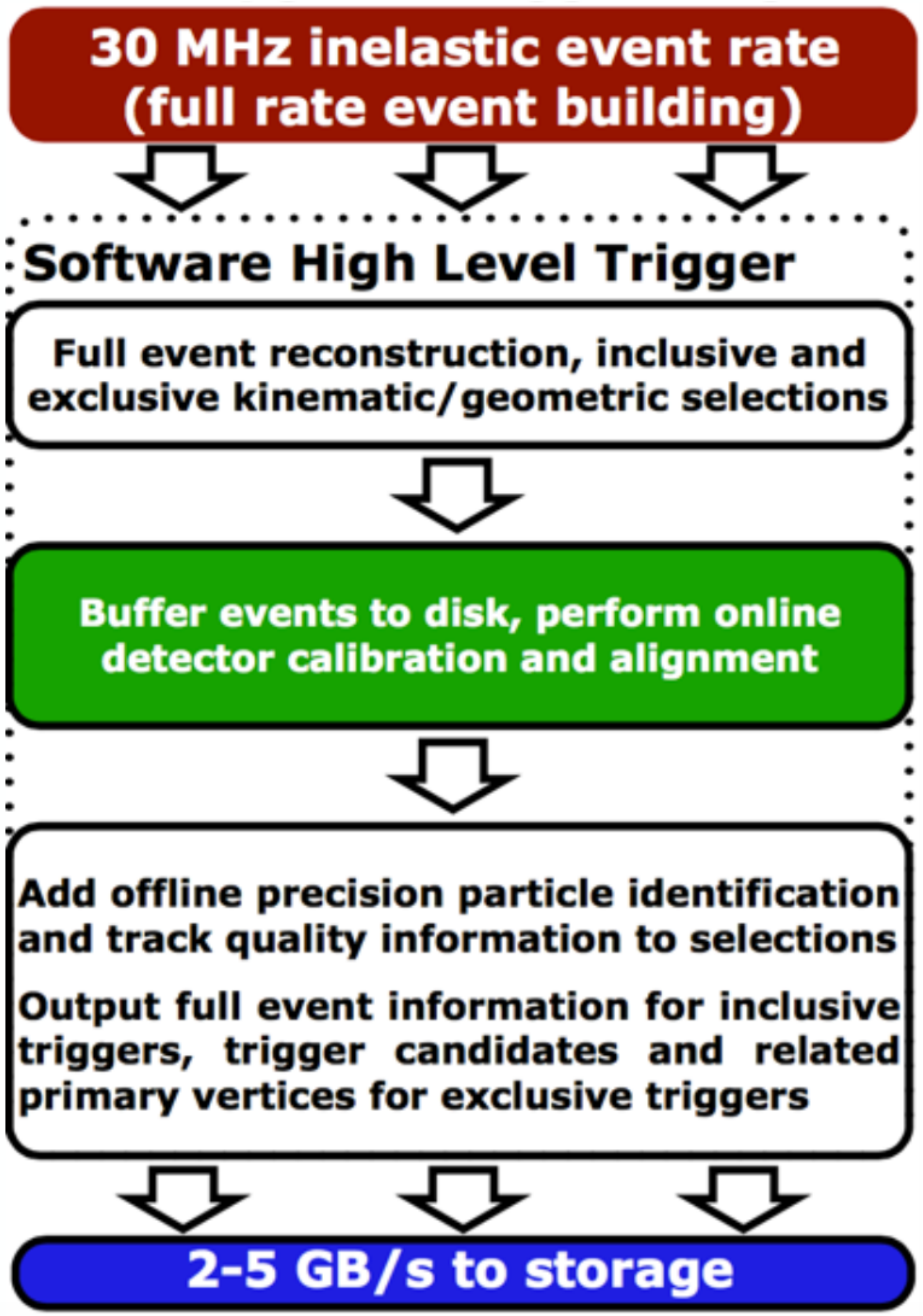


- Separating signal and background topologies is not enough:
  - signal classification is needed to stay within the processing bandwidth

Triggers today

Real-time data analysis tomorrow

The LHCb trigger in the Upgrade



LHCb trigger upgrade plan:

- Triggerless readout and full software trigger:
  -no L0 bottleneck
- No further offline processing:
  - Run II is a test-bed for the upgrade
  - Offline resource could be used for simulation and analysis

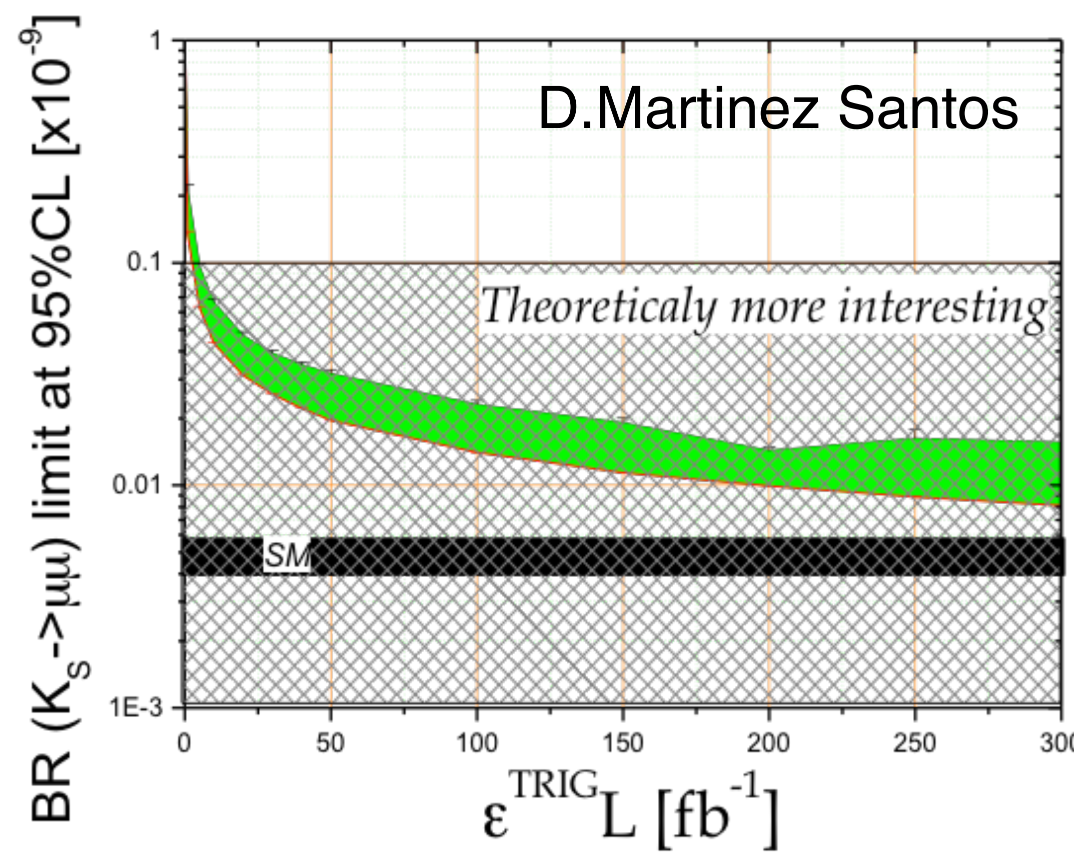
Impact on LLP searches

- Huge improvement expected in low p_T muon selections (L0 efficiency for low p_T muons is ~30%)

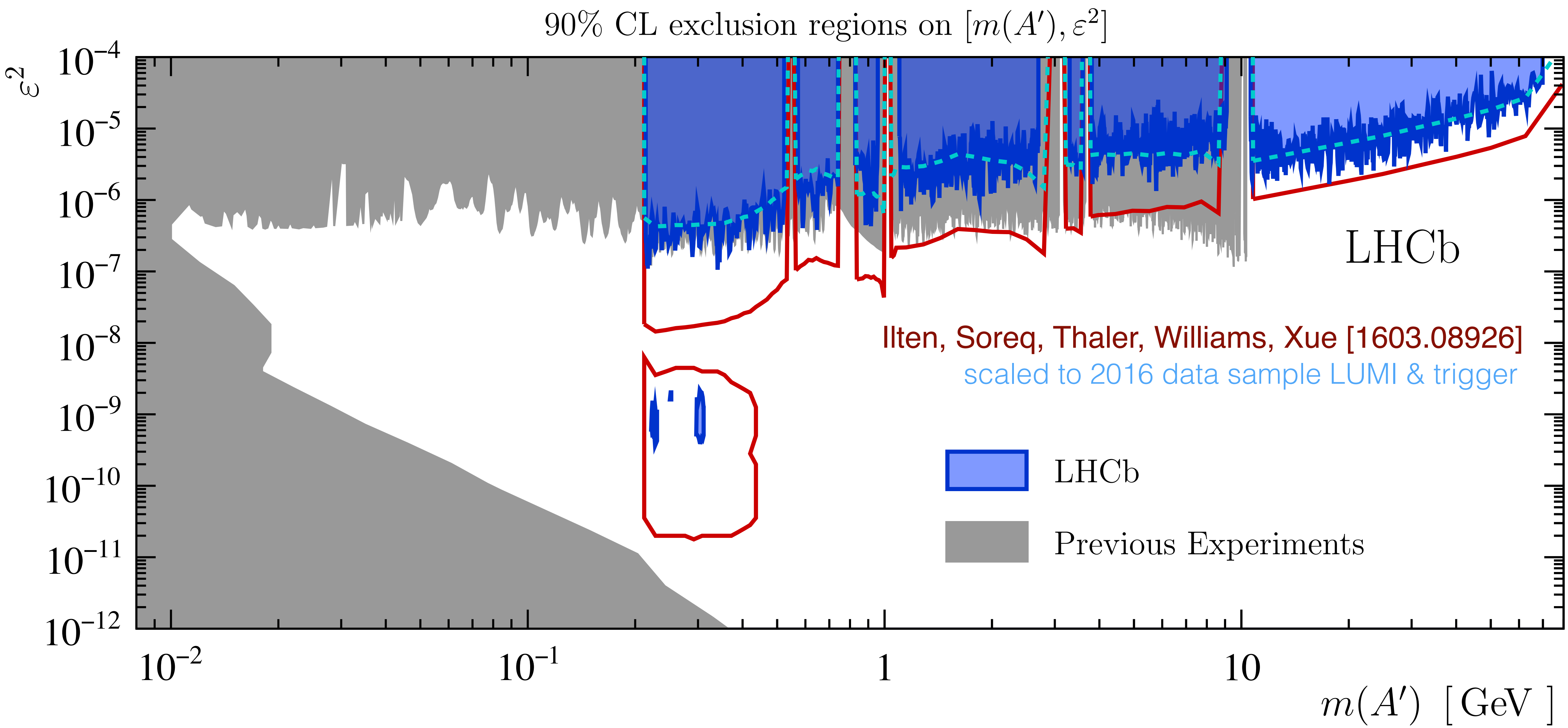
- Big step forward already for Run II:
  - reconstruction of muons down to 80MeV in p_T
  - dedicated trigger for low mass detached di-muons: efficiency on offline selected Ks decays between 10% and 20%
  - di-muon triggers which do not require pointing for cascading DM

- Even higher gain for low p_T electrons

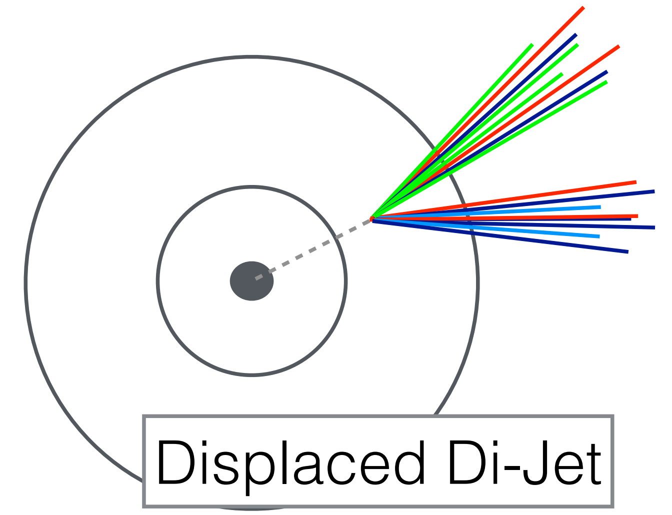
- Efforts to add dedicated electron trigger at the HLT1 level are foreseen

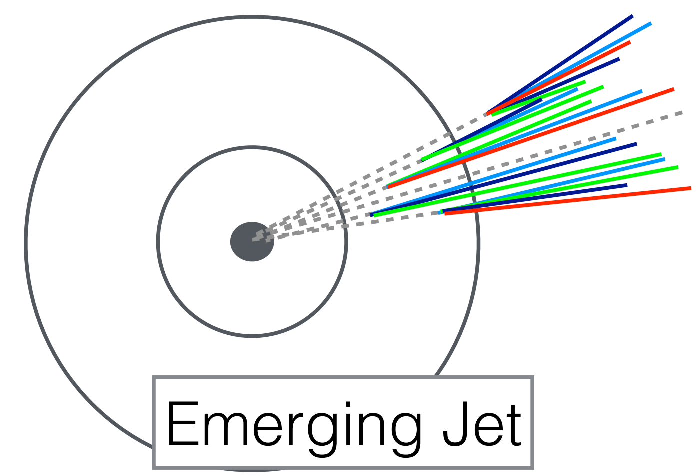


- BSM searches, including dark photons, will strongly benefit from a triggerless readout
- Huge improvements especially at low masses



Triggering on jets





- L0 has good efficiency for high-pt jets
  - removal of L0 will be beneficial for emerging jets, etc..

- High trigger efficiency for SV-tagged and muon-tagged jets at HLT1:
  - No need for dedicated lines

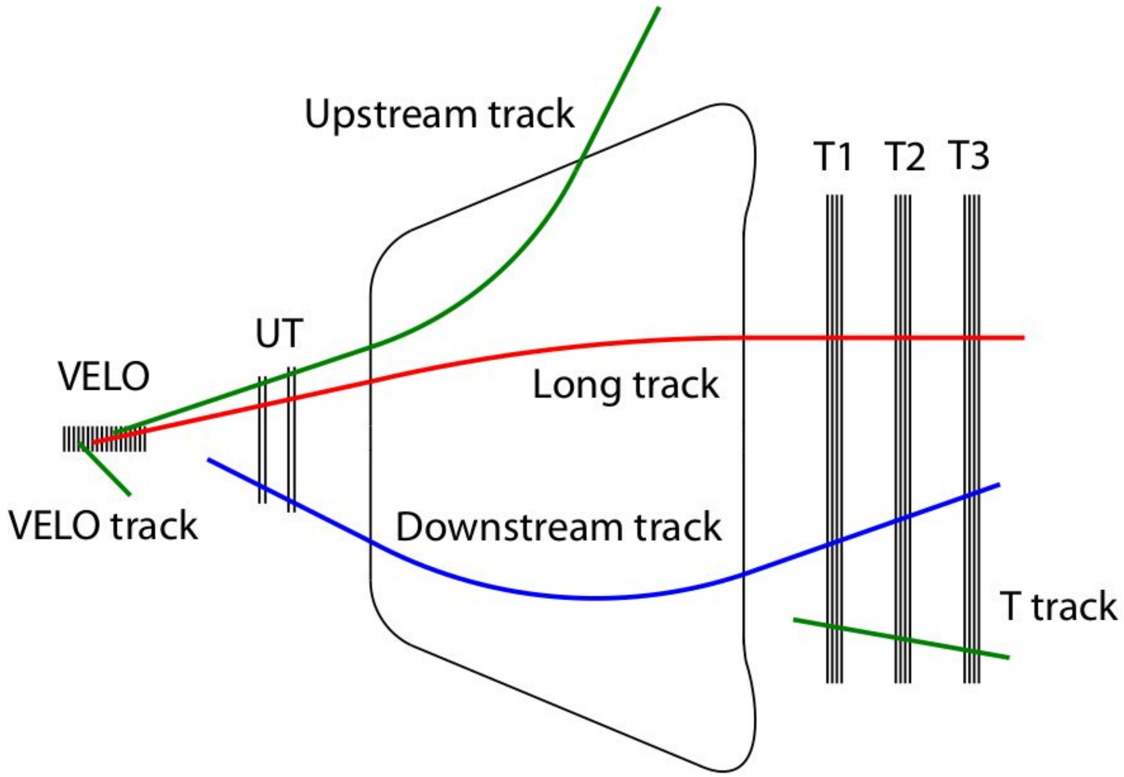
- From 2017 jet reconstruction performed in trigger (new Turbo lines):
  - very soft p_T requirements
  - dedicated exclusive di-jets and single-jet lines implemented in Turbo
  - no pointing to PV, fundamental requirement for LLP searches

Analyses with the current triggers ongoing, necessary to understand how to improve the trigger selection

Downstream tracking in trigger

- Downstream tracking at HLT2 level:
  - too much CPU time demanding for HLT1

- Low efficiency for decays with downstream tracks not triggered through other signatures at the earliest trigger stages



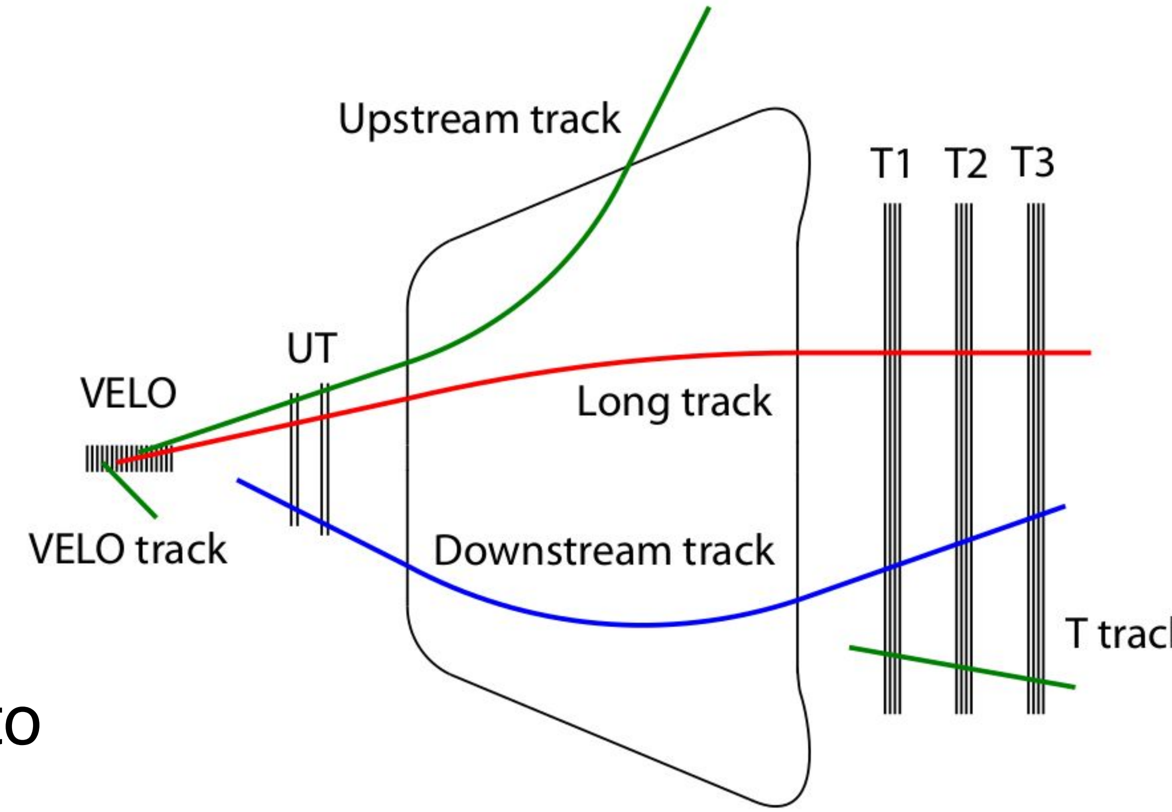
Wide physics program could benefit from dedicated triggers:

- Kaon physics. E.g.: 60% decay outside the Velo. Efficiency can be almost doubled by adding downstream
- Strange baryons
- Dark sector bosons
- Majorana neutrinos
- etc…

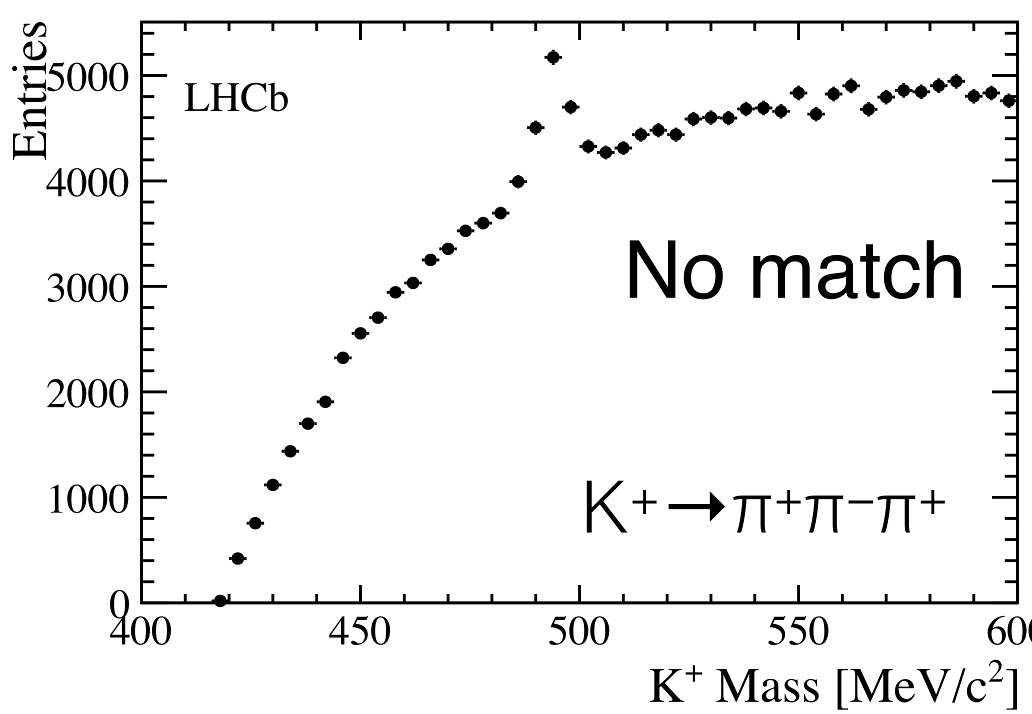
Options are being investigated: chambers inside the magnet, new downstream tracking unit that can be embedded in the DAQ architecture, …

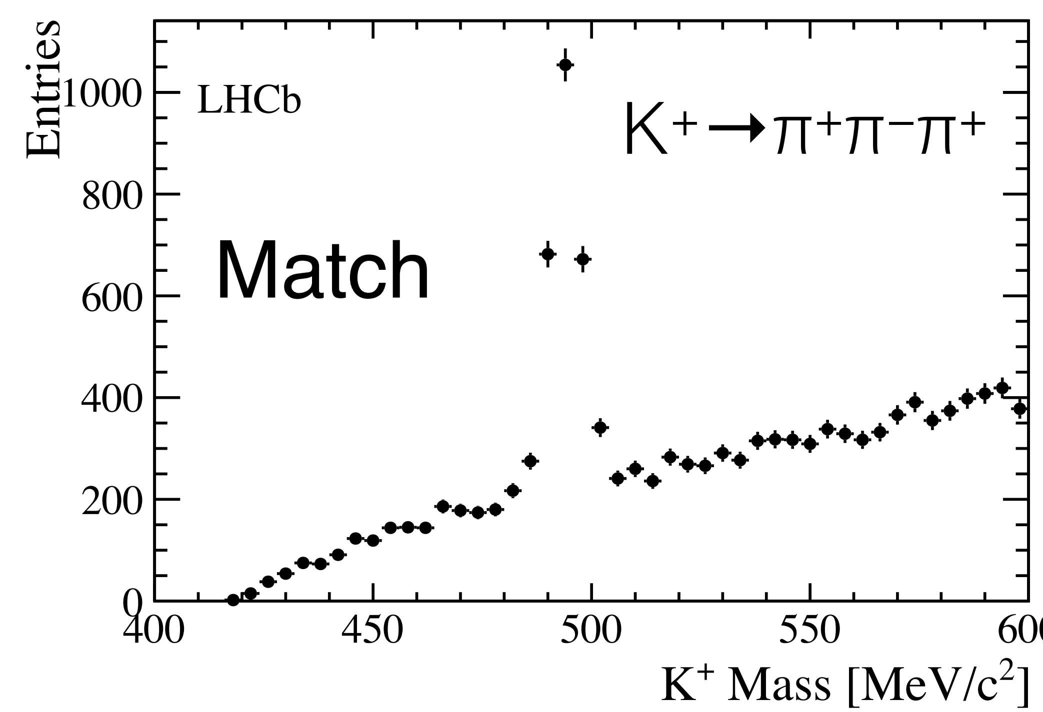
Downstream tracking in trigger

- Matching between downstream tracks and Velo segments of charged mother particles
- Study performed offline: high background rejection, no loose in efficiency
- Feasibility of implementation at trigger level to be studied



[LHCb-PUB-2017-005]





Conclusions

- 5x more instantaneous luminosity expected in Phase 1 Upgrade
- Trigger upgrade is needed to cope with the new conditions
  - triggerless readout
  - fully-software trigger with no further offline processing
  - signal classification at the trigger level
- L0 removal will strongly benefit low mass searches and electron modes
- Downstream reconstruction at HLT1 can improve efficiency for LLP searches

Thanks for the attention!