Adiabatic and non adiabatic upgrades for LHCb

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Adiabatic upgrades (in LS3): to reach few 10^33 cm-2s-1

- Increase muon shielding
- New inner modules for ECAL
- Equipping magnet poles with tracking devices

Non-adiabatic upgrades (in LS4): to reach 10^34

- A new VELO
- A displaced IP, together with a new LHCb layout

1. Increase Muon shielding to reduce occupancy in inner Muon stations

Idea: current HCAL calorimeter offers a too small density

Replace HCAL with a full iron 1.6 m shielding
Drawback: big increase in p_min to cross enough Muon stations (affects tau→3mu, K*mumu final states)

Another possibility: replace HCAL with a magnetized active iron wall to re-measure p_track (a la CMS: outstanding low mu-misID).
Layout to be sorted out (not easy to fit a magnet – expert needed)

Status: nothing done

Could be a replica of OPERA spectrometer

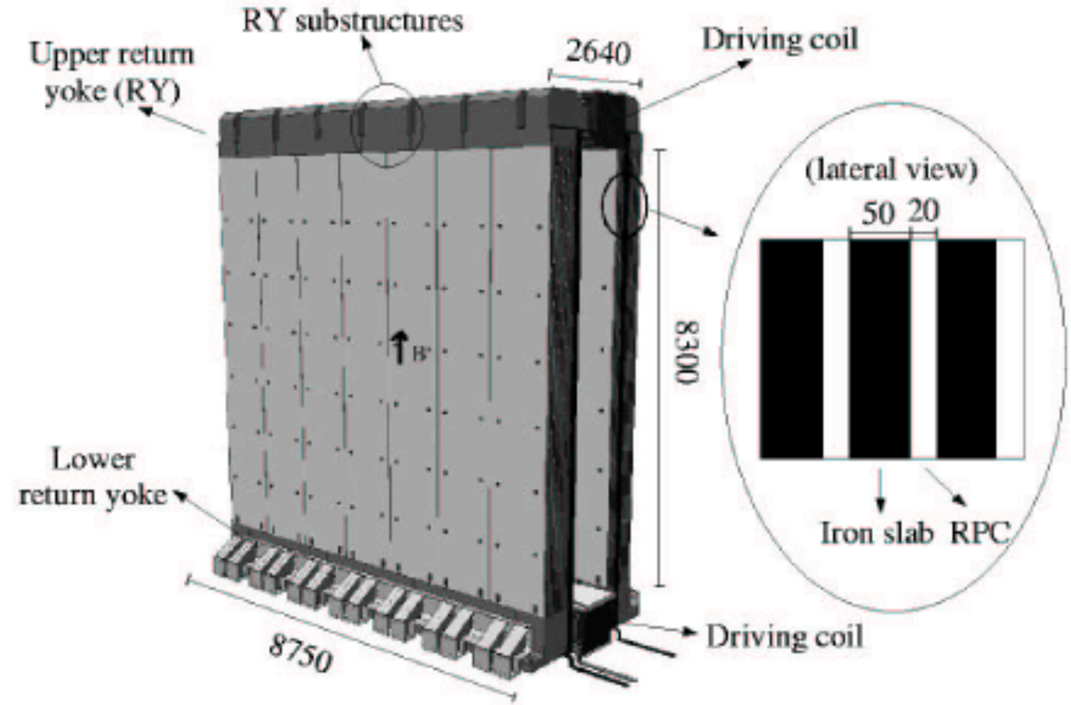
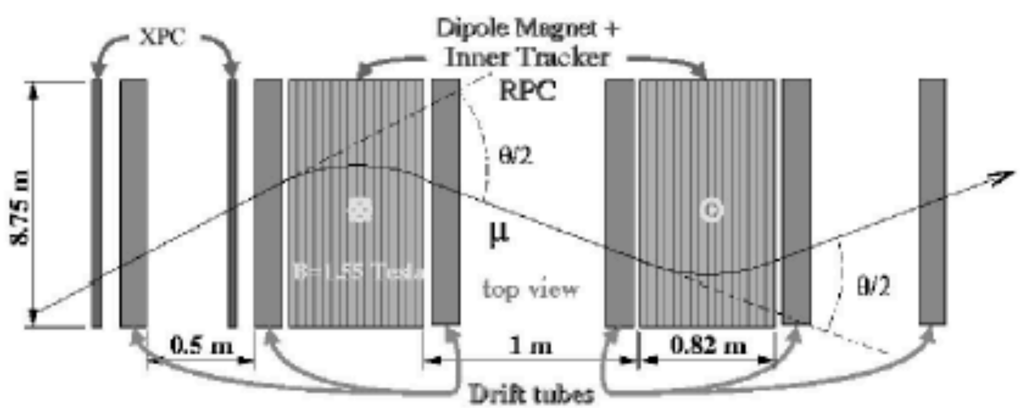


Fig. 2. 3D view of the OPERA magnet. Units are in mm.



2. Replace inner part of ECAL with high performance/high density ECAL elements

At 2 10^33 current ECAL granularity is too coarse for inner modules (definition of "inner" not clear)

Goals:
Recover granularity with small Moliere radius devices (PbWO from CMS ? Si/W sampling ?)

To be studied:
Area to be changed ?
Technology ? Timing ?

Status: so far, only a (not realistic) proposal by Syracuse to change ECAL with Si/W calorimeter (indico.cern.ch/event/373857/). New scheme under study in Syracuse/Orsay

Segmentation for >20x design

- Moliere radius (r_M) contains 90% of the shower currently is 3.5 cm. Other materials with smaller r_M are $PbWO_4$ 2.2 cm, W 0.9 cm.
- Possible to obtain γ position at mm level by having "thin" W layers alternating with Si
- Example: Calice proposal SiW, the thickness of the ECAL will be around 23 radiation lengths. Around 30 layers of silicon will be used, giving an energy resolution of about $0.16 / \sqrt{E}$. There is about 2400m^2 of silicon sensors. Segmentation at 1x1 mm^2 level.

+ ideas of inserting TOF readout (at ps level) to reconstruct origin of gammas

3. Equip pole magnets with tracking devices at low granularity

Goal:
Recover all soft tracks which do not enter in downstream station acceptance to increase tagging (e.g. soft pi from D*), measuring their momentum given TT and magnet poles coordinates

Area to be covered: a trapezoid of ~3 m2 per side (top/bottom not considered)

Status: studies made in Syracuse have shown a large increase in some samples. X-resolution needed ~1 cm
Occupancies to be understood

Displacing the IP: motivations and method

- Exploit HL-LHC potential running at 10**34 cm-2s-1 or more

- Move back the IP by 3.75 m to reduce occupancies in downstream detectors
  - no effect on VELO (a high performance vertex detector needed anyhow)
  - more space to handle and modify optics/electronics of RICH (and rates will be anyhow drastically reduced) far from magnetic field
  - less rate on UT
  - a smaller reduction (~x2) for Sci.Fi. & RICH2

However: reduction of acceptance due to fixed opening of the magnet. Two options:

- Larger dipole (very complex solution, +1 m in Y doable but not easy)
- A "small η" LHCb to recover occupancy before the dipole (**LHCb+**)

In this talk, a very preliminary and crude evaluation of acceptances for single tracks, a 2-body and a 4-body B decay mode

Decrease in occupancies (at fixed high η acceptance)

Acceptances NOW

High η ~4.9 (15 mrad) / low η 2.1 (250 mrad in Y), 1.9 (300 mrad in X)

At RICH1 (z~1 m) R(15 mrad)=1.5 cm
At UT (z~2.5 m) R(15 mrad)=3 cm
At T1 (z~8 m) R(15 mrad)=12 cm
At RICH2 (z~10 m) R(15 mrad)=15 cm

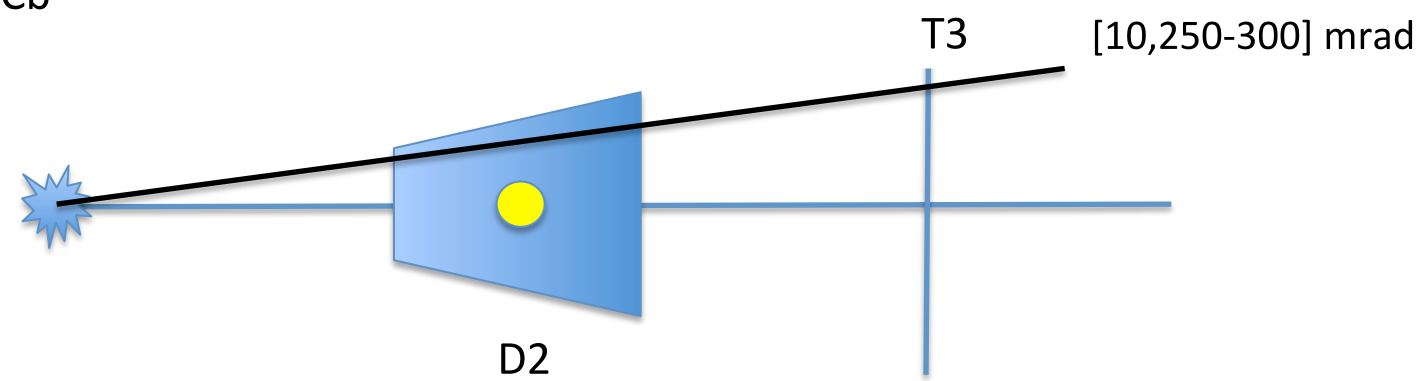
New z positions	R @ 15 mrad (Δz=-3.75m)	Decrease in occupancy
RICH1 4.75m	7.1 cm	÷ 22
UT 6.25m	9.4 cm	÷ 6
T1 11.75	17.6 cm	÷ 2.2
RICH2 13.75m	13.7	÷ 1.9

These numbers do not consider the effects of magnetic field(s) and of the fact that rates depend also on backgrounds around the beam pipe

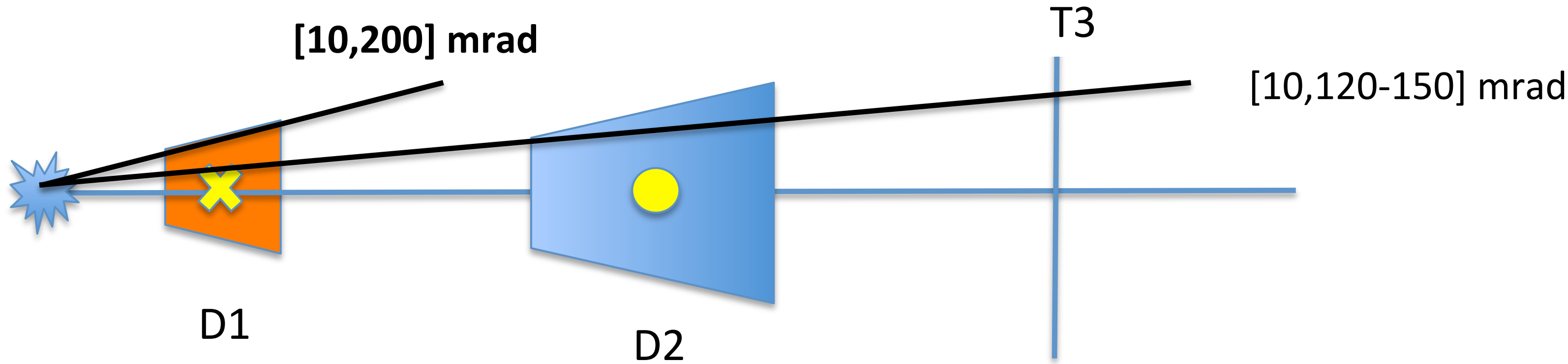
The sample: b-bbar (c-cbar) events generated from Pythia (14 GeV) + a very crude extrapolation of tracks through dipole(s) and detector acceptance for 2 cases

Simulated configurations:

"Standard LHCb"

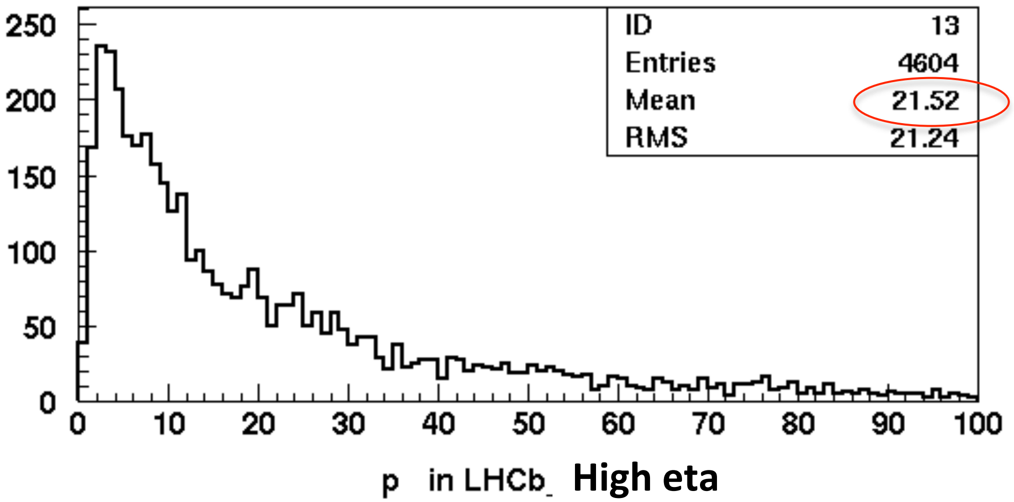


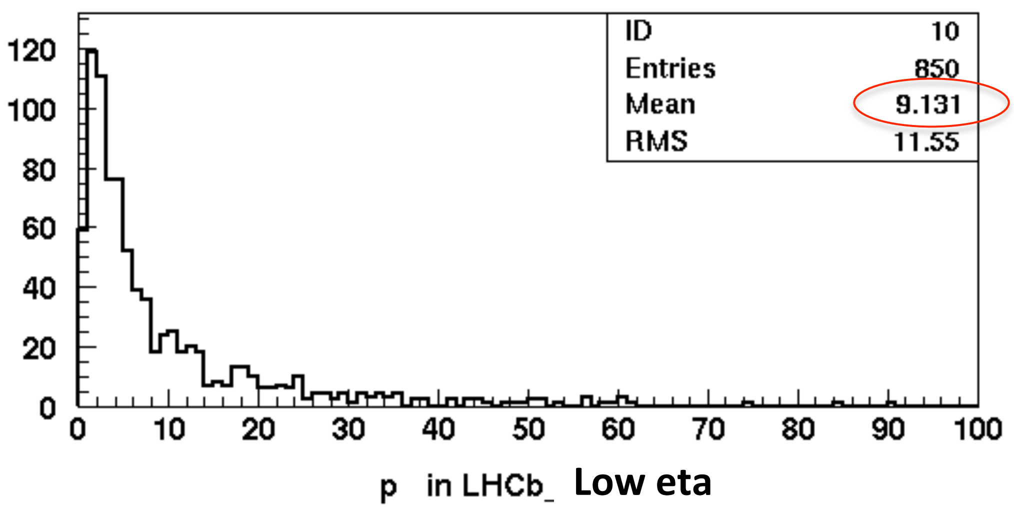
LHCb+="Standard LHCb" + displaced IP + a D1 dipole with opposite field

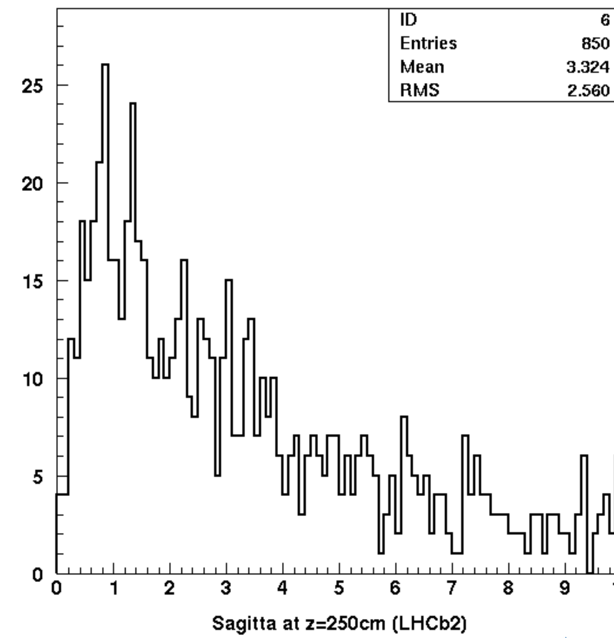


Acceptance efficiencies evaluated at the level of station T3

Practical question: how D1 should be done ? Which field ?
Low η particles are also the one with lower energy







Example: sagitta (cm) of tracks due to D1 in a hypothetical detector located at Z=250cm
Let's assume a dipole
B = 1 T, L = 1 m

Efficiencies on single tracks (from b decays – 3183 events)
Selection on tracks P>0.5 GeV ; $2<\eta<5$;
tracks must come from a **b** or from a **c from b** (6422 charged tracks)

LHCb standard **5903 tracks in T3 acceptance (reference)**

LHCb+ (B=0 Tm) 4592 tracks in T3 acceptance (= 78% of reference)

LHCb+ (B=1 Tm) 4604 tracks in T3 acceptance
+ 850 tracks recovered by D1 spectrometer (= 92%)

LHCb+ (B=2 Tm) 4427 tracks in T3 acceptance
\+ 791 tracks recovered by D1 spectrometer (= 88%)

Another Option: **IP+Larger magnet (+1m in Y opening)**
4946 tracks in T3 acceptance (= 84%)

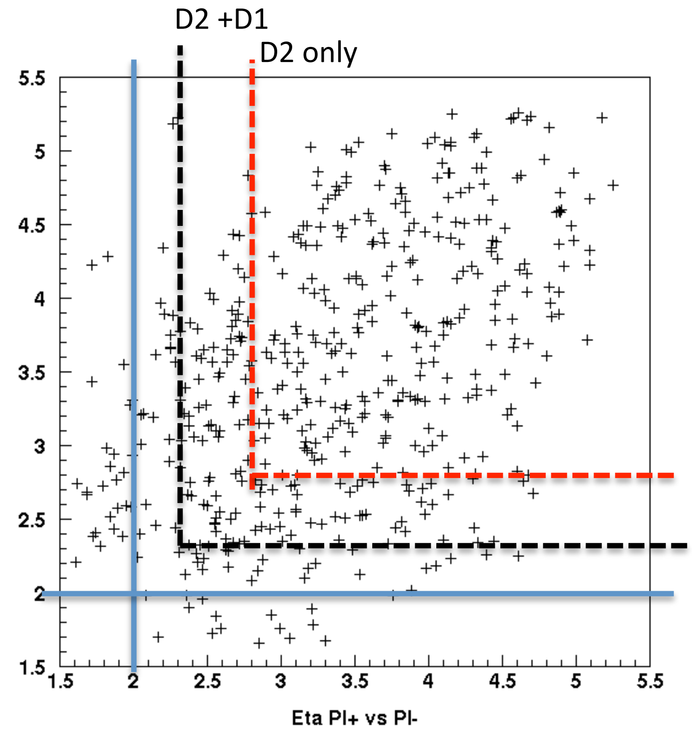
- A too high field in D1 does not seems useful (exact value to be optimized)
- 200 mrad "patch detectors" could bring efficiency to >90% (single track)
- A larger magnet gives results "in between"

- Same studies on a sample of B→$\pi^+\pi^-$ (3236 events – 4784 tracks from heavy flavour) - Selection on tracks P>0.5 GeV ; 2<eta<5 ;

LHCb standard (reference) 452 events with 2 tracks in T3 acceptance

LHCb+ (1 Tm)
10 events (2 tracks in D1)
+78 events (1 track in D1, 1 track in D2)
+339 events (2 tracks in D2) (tot = 94% of ref.)

This result is due to correlations in η of the two tracks (this may be less true for multi body)



- A more extreme case (toy study from Vava) B_S→$\phi\phi$ (4 tracks)

LHCb standard (reference) 993 events

LHCb+ (only D2 acceptance) 385 events
LHCb+ (D1+D2) 787 events (=79%)

Benefits of a displaced IP + a second spectrometer (**LHCb+**)

- The decrease in occupancy in downstream detectors could be faster than Z^2 as most of the background is coming from the beam pipe
- The D1 dipole could sweep low energy particles, reducing occupancy in downstream detectors
- A magnet just after the VELO is the beloved option of anyone interested in fast p_T trigger strategies
- A greater distance between IP and D2 would enhance Ks sample (or in general any other long lived particle)
- A double spectrometer would decrease a the number of ghosts
- Would a double spectrometer give also a better p resolution ? (to be studied)
- Detectors in LHCb+ could be built/inserted in steps, to gradually increase acceptance

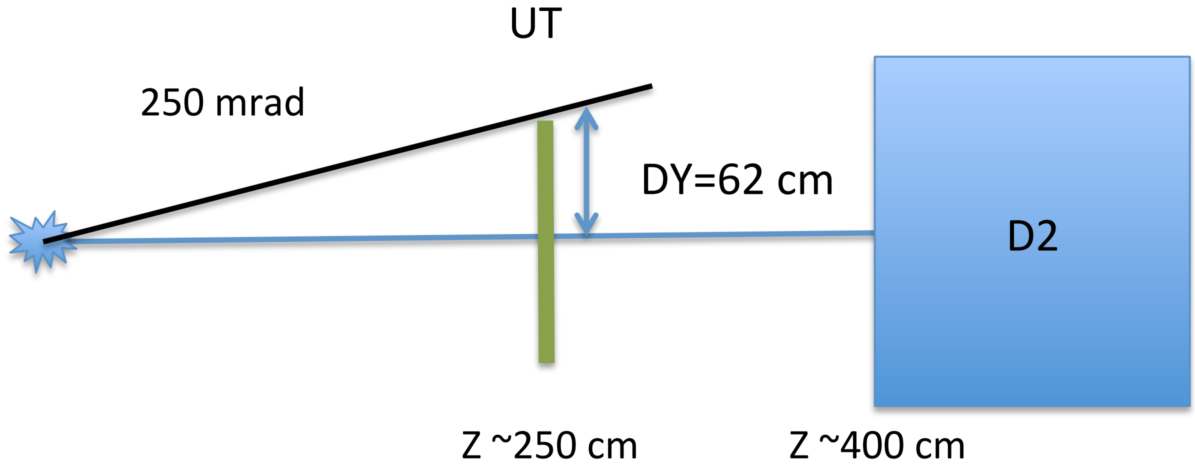
Headaches

- Asymmetry effects ? (maybe we can have runs with D1 and D2 alternate off)
- Two tracking systems ? (this happens already with IT/OT)
- Infrastructure constraints from experimental zone (pit, tunnel, machine cryo, etc…)

Other …. ?? (critics welcome)

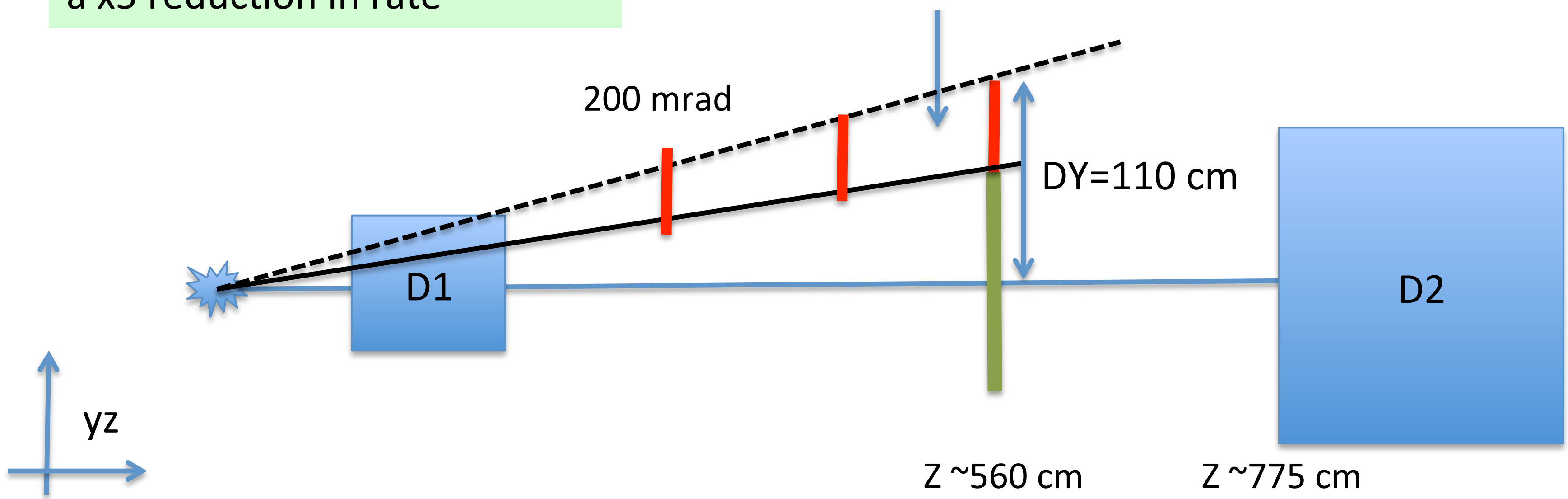
1. Thinking to a new LHCb layout (UT)

Now



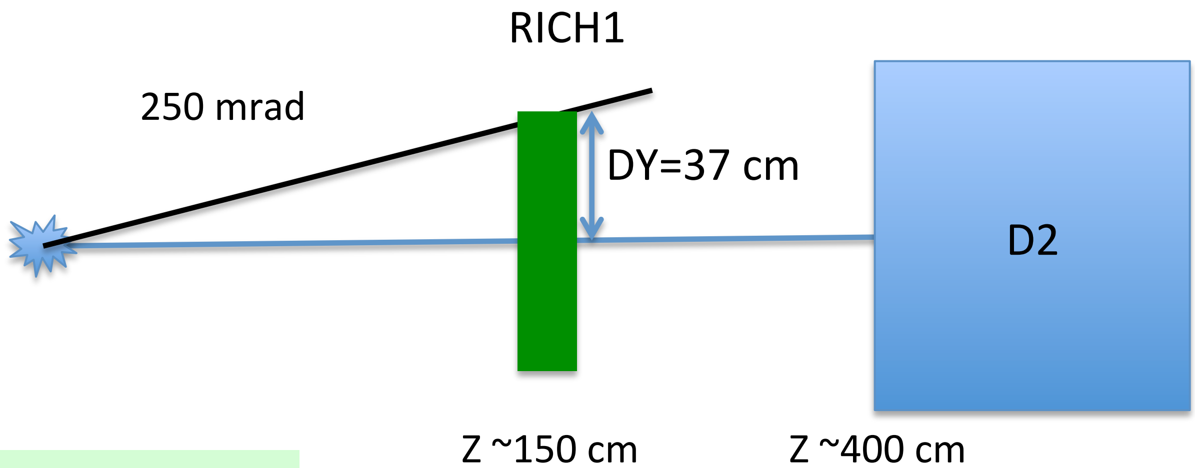
With displaced IP:
new Z position of UT to obtain a x5 reduction in rate

This sector has to be covered with relatively simple and small tracking devices (low occupancy)

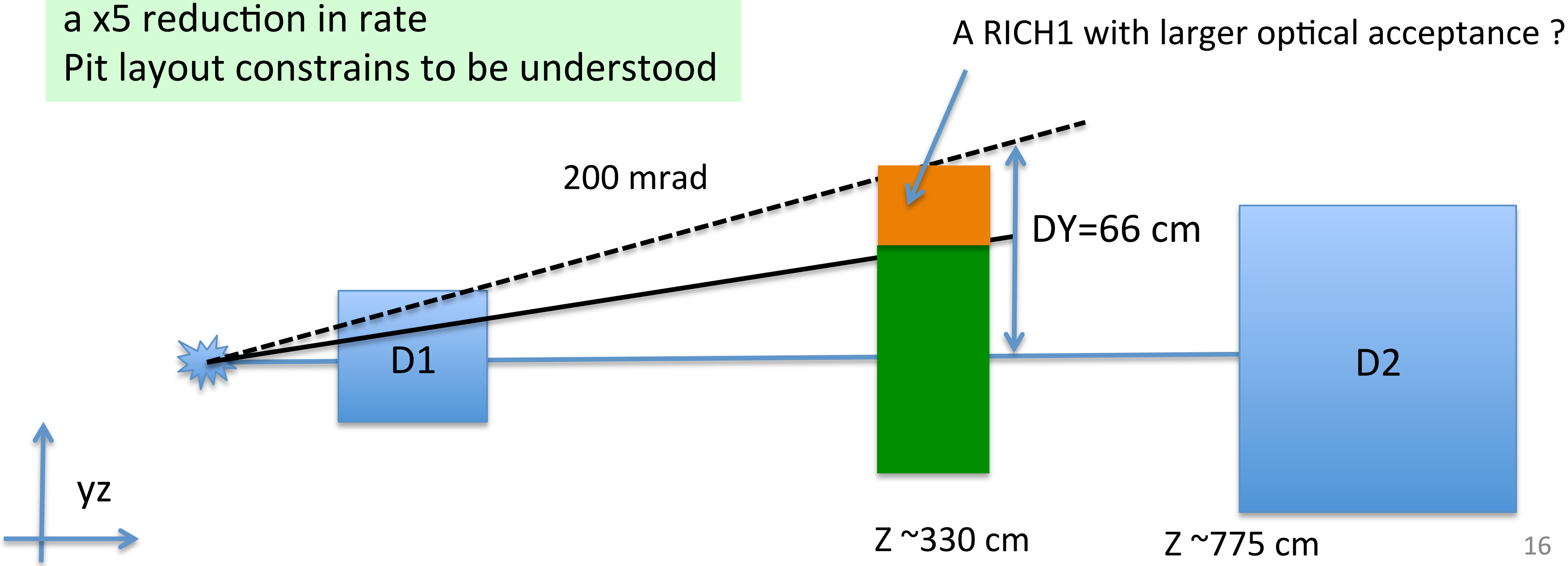


2. Thinking to a new LHCb layout (RICH1)

Now



With displaced IP:
new Z position of RICH1 to obtain
a x5 reduction in rate
Pit layout constrains to be understood



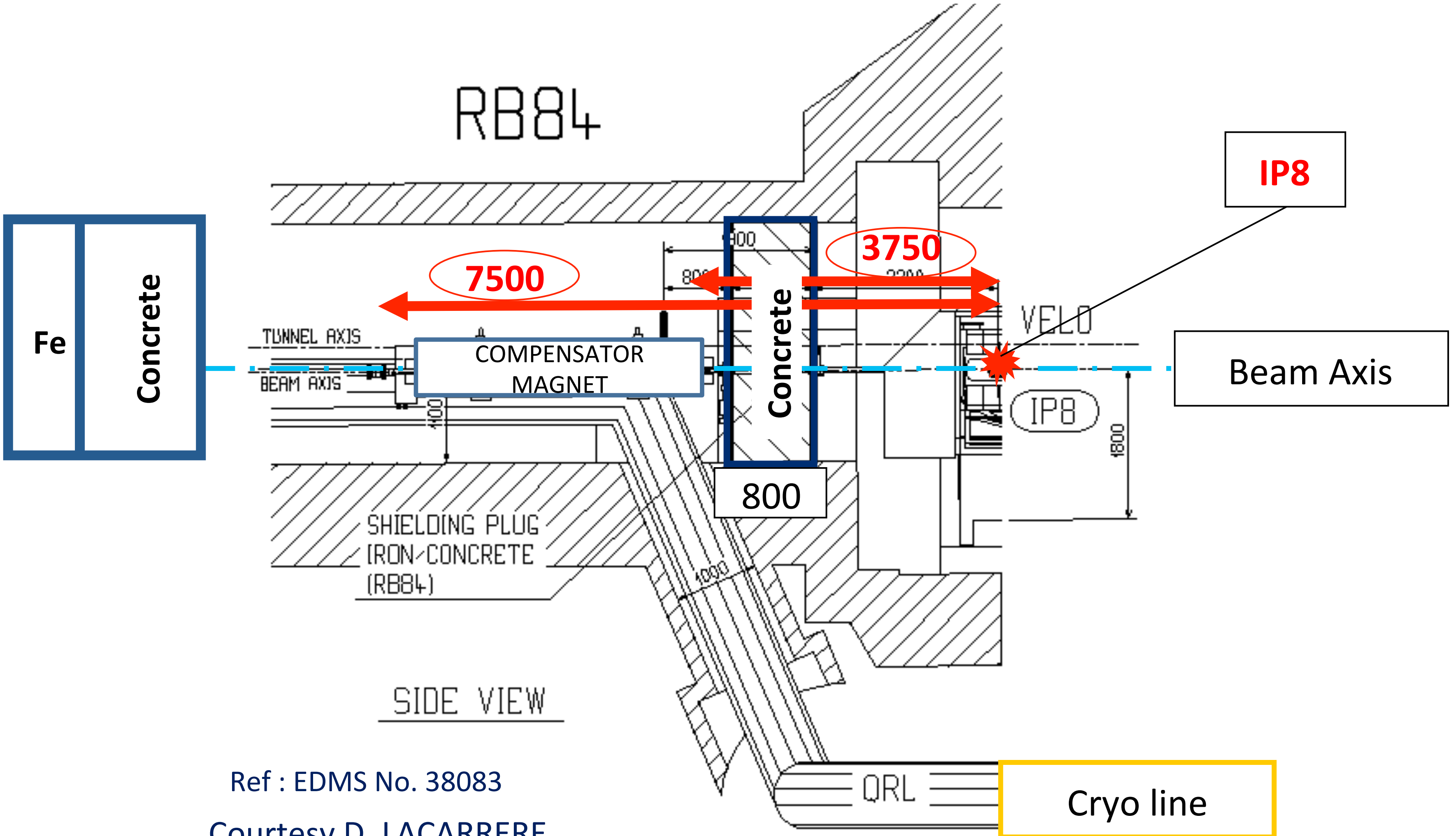
Conclusions

Adiabatic changes are doable during LS3 and do not impact (much) on current LHCb layout. They give the possibility to recover statistics or the degradation of some elements (e.g. ECAL) due to high occupancy
It is a good opportunity also for Italian groups to participate at moderate costs in a sort of “Phase 1.5 upgrade”

“Non adiabatic” changes are more oriented toward LS4. Among them, moving the IP is one of the possibilities to mitigate high occupancy using most of the systems in the present configuration and adding new (simpler) detectors in zones where occupancy is extremely low

A lot more (professional) simulations are needed to verify/confirm the above two statements

Layout LHCb Interaction Region
Side view



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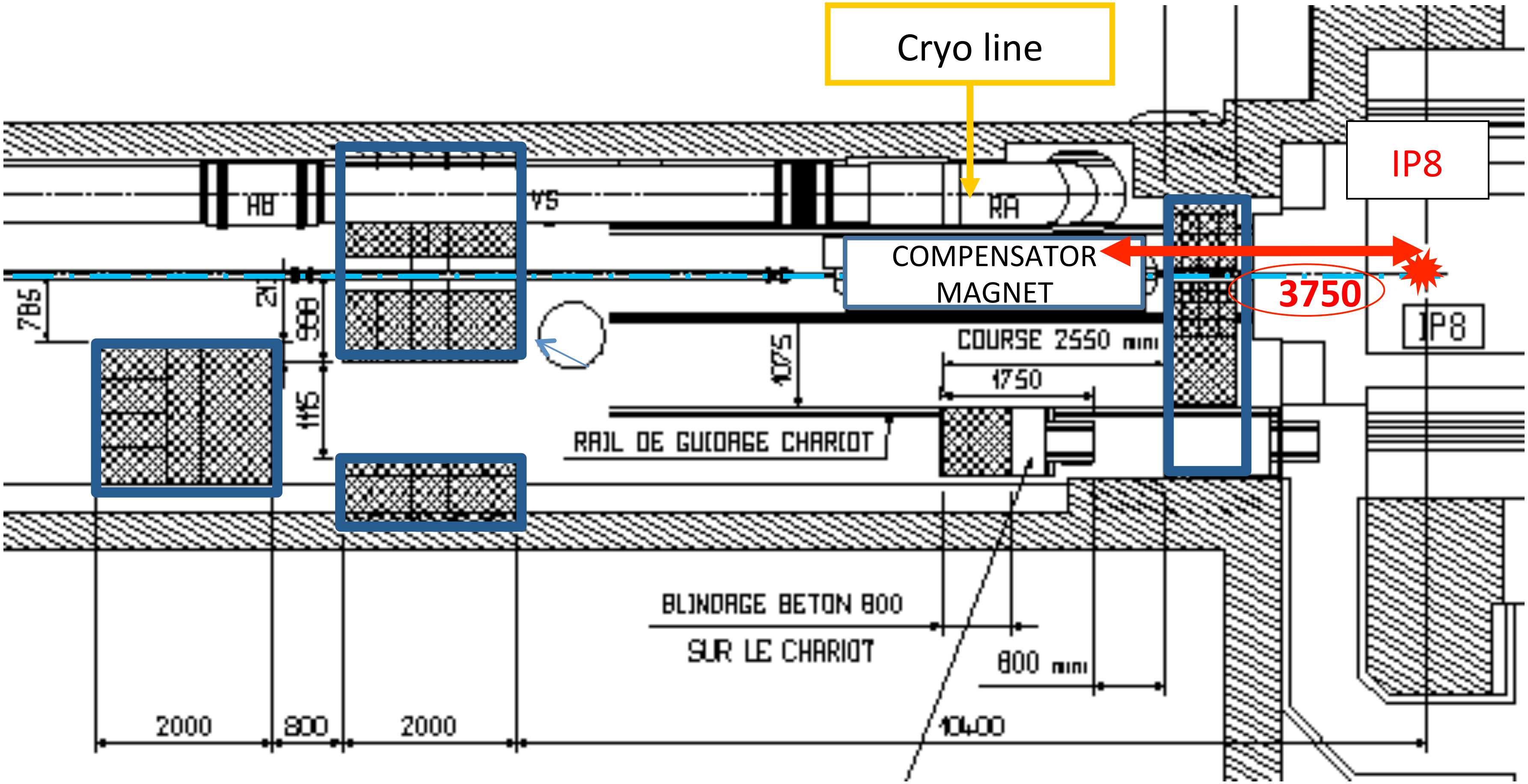
Courtesy D. LACARRERE

Layout LHCb Interaction Region
Top view



Courtesy D. LACARRERE

LHCb interaction region

- **Displacement of the IP by 3.75m:**
  - the **compensator magnet** would need to be moved upstream by several meters, which is feasible.
  - Modifications to the **cryo line** would be minor
  - Some modifications in the **RB84/tunnel area** would be needed to use the space effectively

- **Displacement of the IP by 7.5m:**
  - would require a major modification of the **cryo-line**.
  - The position of the **compensator** would be in conflict with the Shielding wall.
  - The **tunnel diameter** limits the effective use of the space
  - ➢ **Dis-favoured**

Courtesy D. LACARRERE