Muon System Upgrade

Phase-1b and beyond: Simulation studies

Beyond the LHCb Phase-1 Upgrade,
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On behalf of the muon group

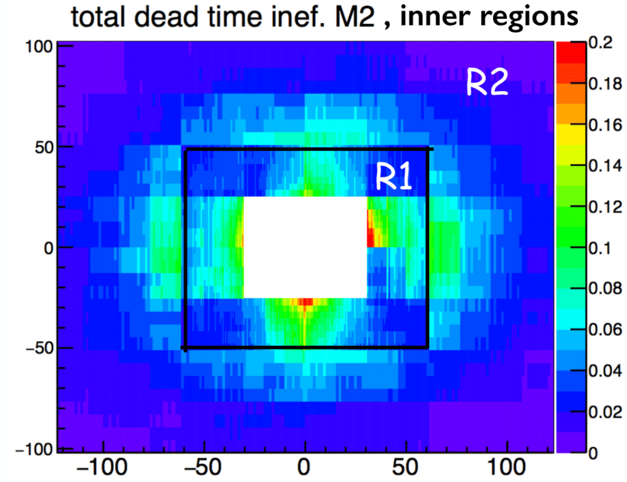
The muon system at 2E33 and beyond

- The muon system has performed exceptionally well in Run 1 and Run 2
  - Tracking inefficiencies from deadtime 1.0% in 2012, ~2.6% in 2015
- Increase in luminosity in Phase 1 and Phase 2 have consequences...
  - Large increase in dead time induced inefficiencies, both physical and logical channels
  - Increased pion misidentification
  - Increased ghost pads from accidental crossings in X-Y pads.

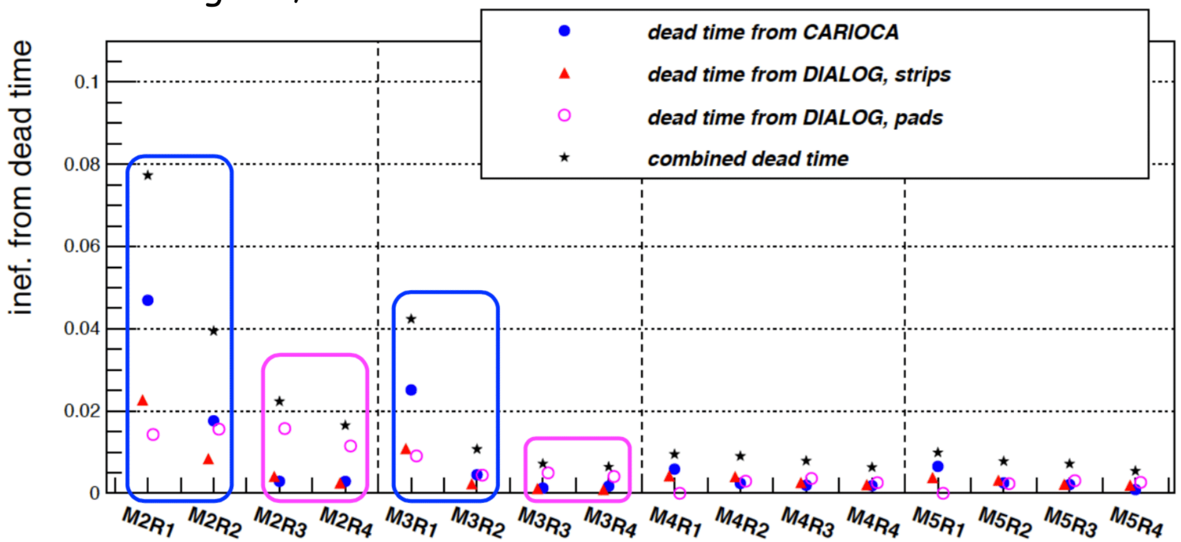
Deadtime induced inefficiency at $2*10^{33}$

Distribution of inefficiency is highly non uniform and concentrated in the inner regions;
Particularly important in M2, where the inefficiency value averaged on R1 is about 8%

Giacomo Graziani, https://indico.cern.ch/event/402710/contributions/955272/attachments/806817/1105644/deadtime9.pdf



All regions, M2-M5

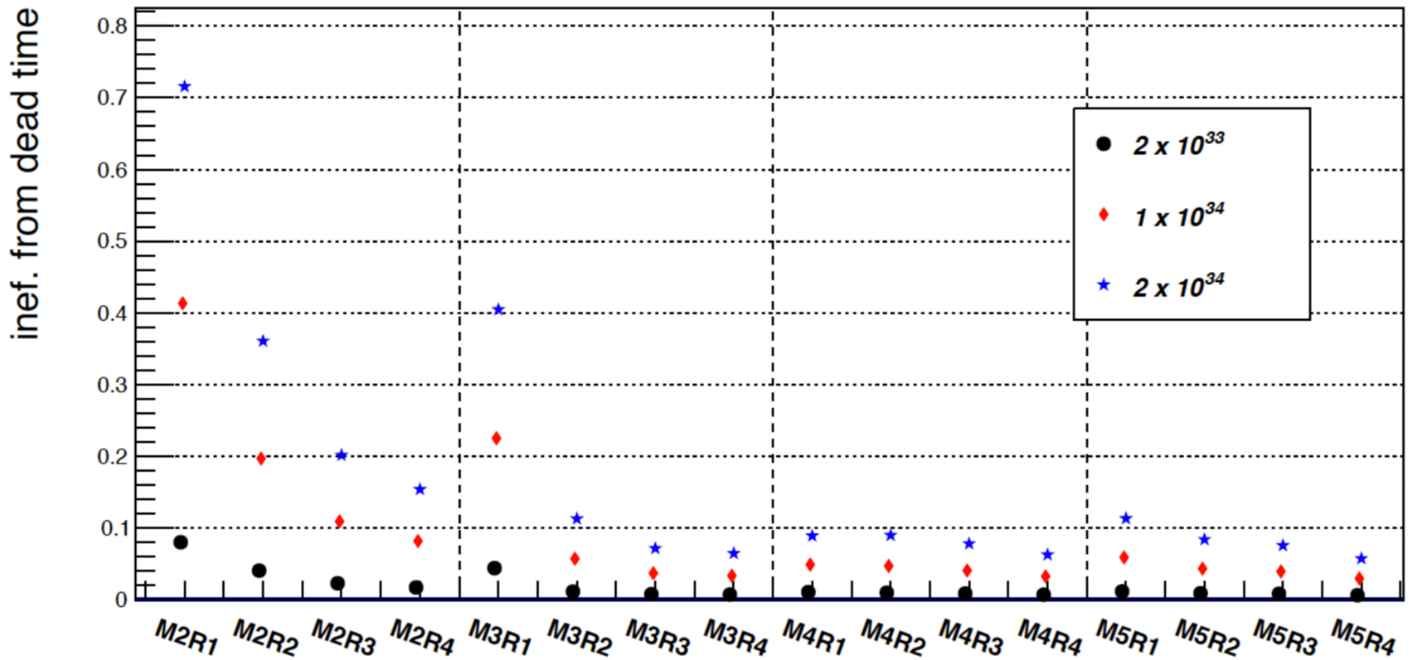


Mitigation strategy

1) In this projection **we're** assuming a conservative 30% rate reduction by the additional shielding in front of M2

2) In this projection **we're not considering still** the planned removal of IB boards which will reduce the DIALOG ineff in M2R2 (/2), in M2R3 (/24), and in M2R4 (/24).

Deadtime induced inefficiency at 10^{34}



Of course the projected inefficiency at 10^{34} and beyond becomes unsustainable

Deadtime induced loss on relevant physics channels

The above deadtime induced losses can be integrated with the phase space of relevant channels (given selection) with two or three muons to evaluate the total event loss for events passing isMuon

Phase I Phase II

	at least 1 muon in R1	at least 1 muon in R2 (*)	loss at $2*10^{33}$	loss at $1*10^{34}$
Bs->mumu	(23.3+-0.1)%	(36.2+-0.1)%	(9.1+-0.2)%	(38.3+-0.1)%
Bs->JpsiPhi	(25.0+-0.1)%	(39.1+-0.1)%	(9.3+-0.2)%	(39.2+-0.2)%
D0->mumu	(24.8+-0.2)%	(39.2+-0.3)%	(9.9+-0.7)%	(40.7+-0.5)%
Ks->mumu	(16.2+-0.3)%	(44.3+-0.4)%	(8.1+-1.0)%	(35.2+-0.7)%
tau->**3**mu	(27.2+-0.3)%	(42.5+-0.3)%	12.1+-0.8%	(47.5+-0.5)%

(*) and no muon in R1

(**) independent of lumi

Of course, the loss at 10^{34} is not acceptable

Reducing rates into muon system

- Dead time inefficiency can be mitigated by the introduction new high granularity pad chambers (see Giovanni's talk)

- However at 1E34 a maximum rate of several MHz is expected in the inner regions of M2 and M3 – rate reduction needed!

- Since HCAL will be no longer used in the trigger, can replace with ~1.7m of iron shielding

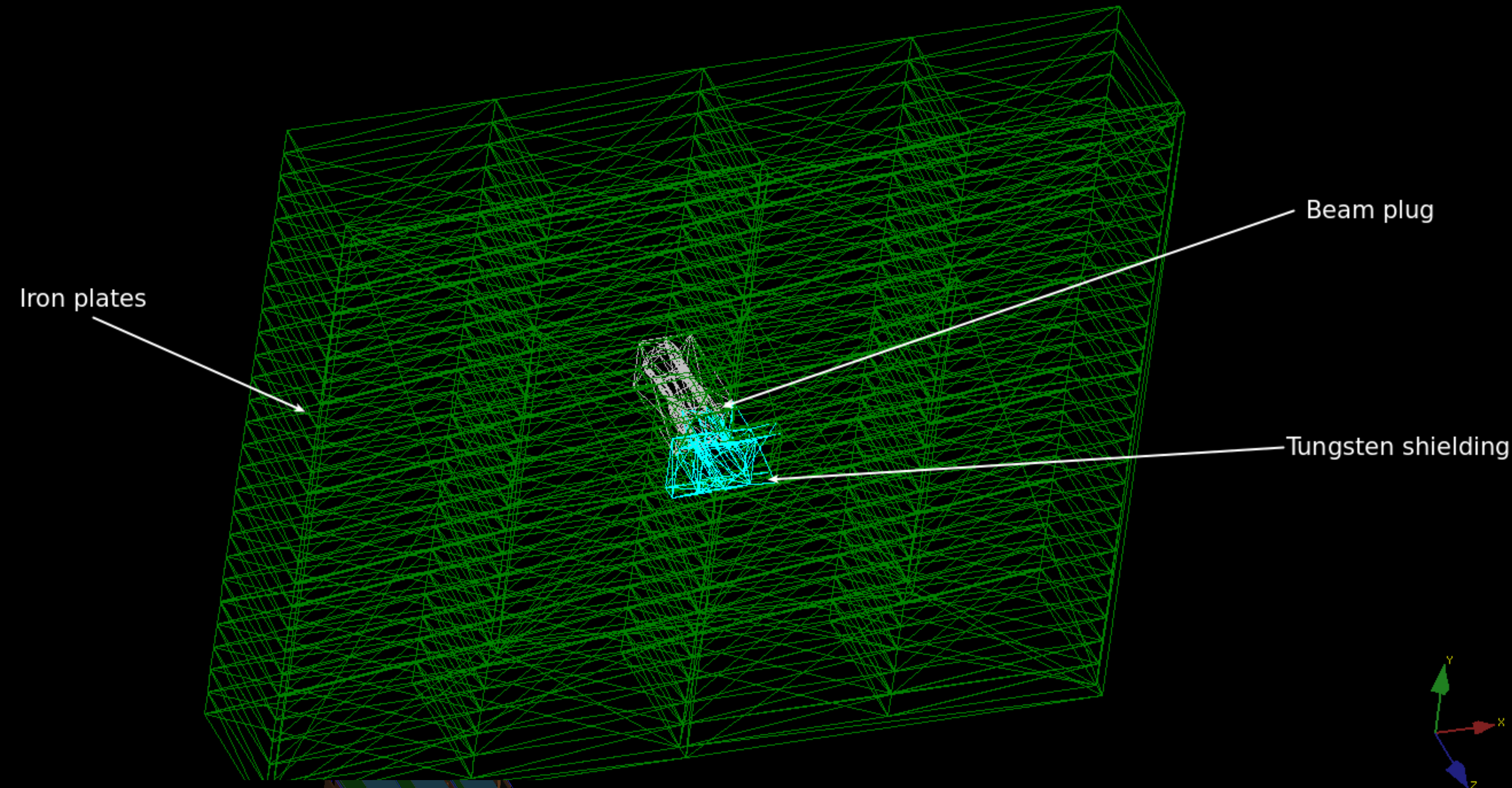
- HCAL provides 5.6 int. Lengths.
    - -> Replace HCAL with ~10 int. lengths (1.7m thick) of iron filter

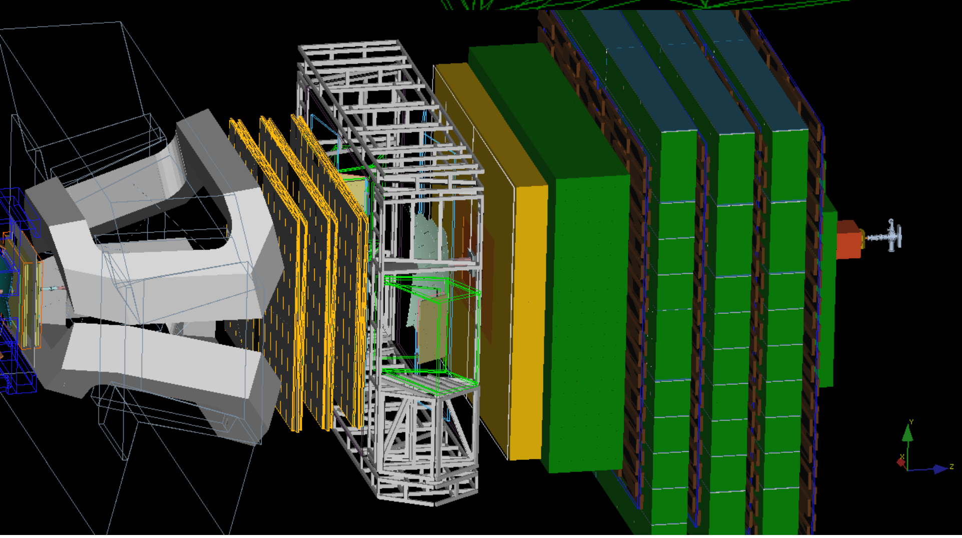
- Expected ~ 50% reduction from studies on data. Has needed to be assessed with full simulation

The iron wall simulation

- Start with something simple...
  - HCAL replaced in LHCb simulation (current upgrade configuration) with iron wall, with the same outer dimensions.
- What do we want to deduce?
  - Rate reduction into muon system – specifically M2R1/R2, M3R1/R2 – crucial for control of dead time inefficiencies

  - The effect on muonID (current and upgrade algs)
  - For rate reduction studies:
    - minimum bias
  - For (pion) muon (mis-)ID:
    - $D^* \rightarrow D0(K\pi)\pi$
    - $B0 \rightarrow J/\Psi(\mu\mu)K\pi$





Planned upgrade changes preserved:
(tungsten shielding, beam plugs under HCAL and M2, ...)

Iron wall specification:

Dimensions:	98.51% Iron
x: 8.403 m	0.5% Carbon
Y: 6.838 m	0.9% Manganese
z: 1.655 m	0.04% Phosphor

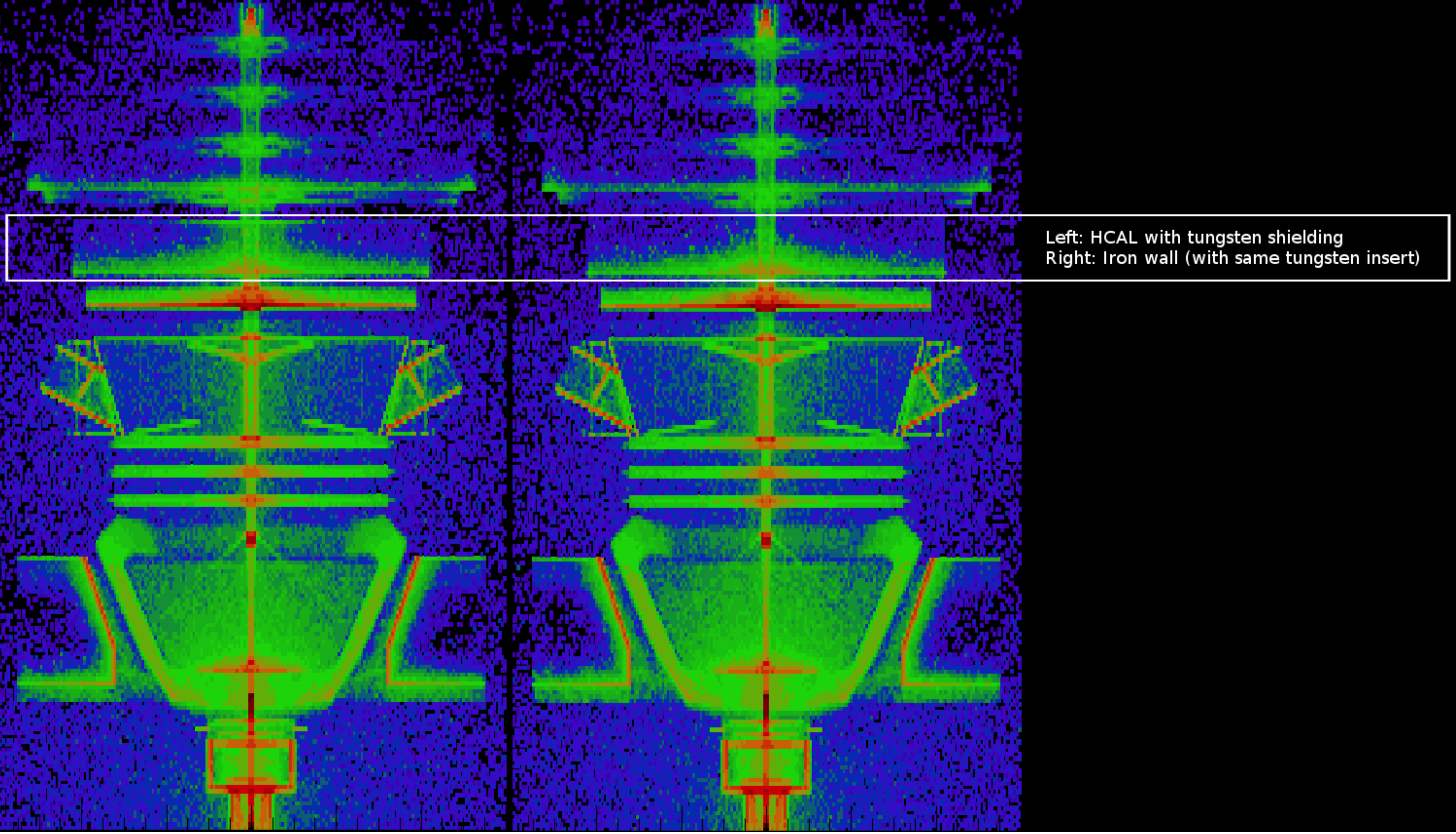
Occupancies in simulation at 2E34

Reduction rates for each overall region from average track multiplicities per cm^2s^-

M2R1	M2R2	M3R1	M3R2
46.2%	76.6%	5.9%	19.5%

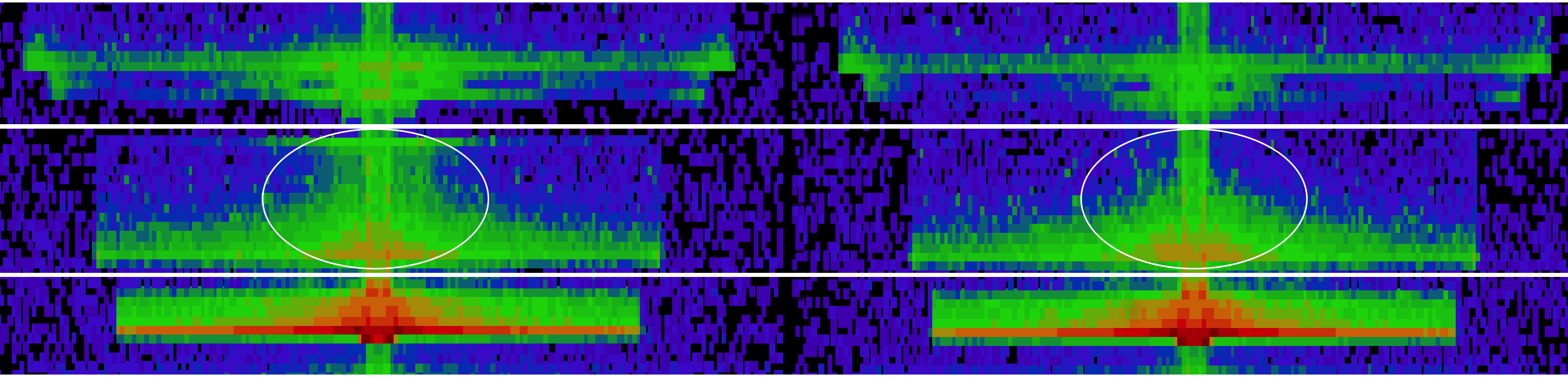
Simulation conditions

Gauss	v50r0
CondDB tag	sim-20140825-vc-mu100
Base DDDB tag	dddb-20150424
Event type	Min. bias
Luminosity	2E34
Bunch spacing	25ns



- Non-trivial interplay between particle momentum, path length through iron and angle from beampipe.
- Explains difference in reductions between regions.
- Needs to be understood in more detail
- Possibility of reconfiguring shape for better utilization of iron?

HCAL   WALL



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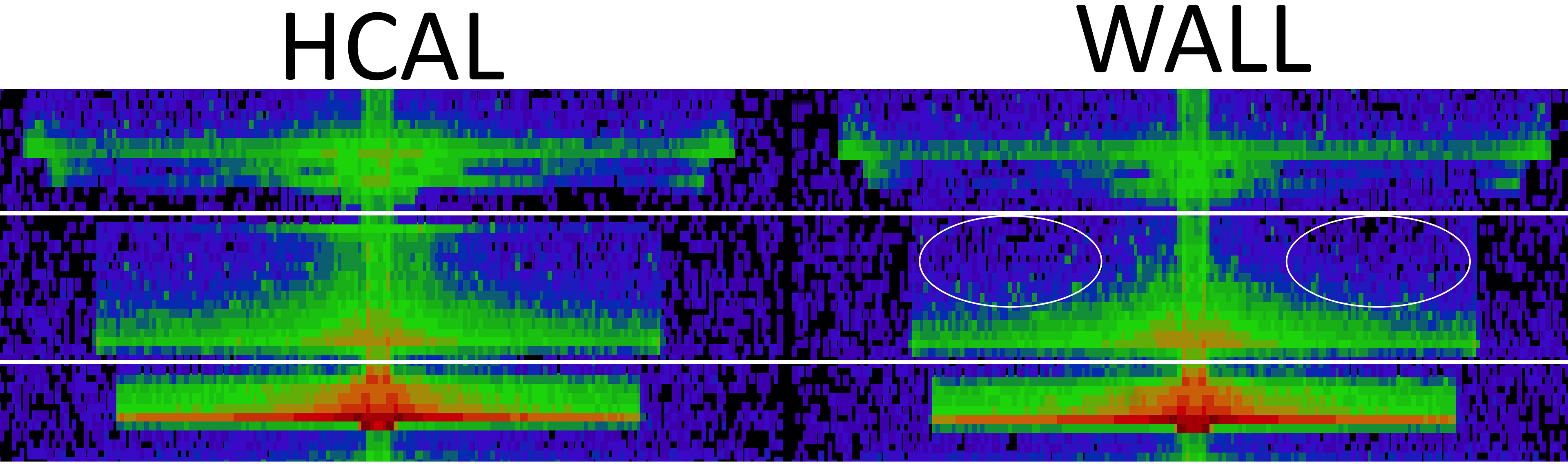

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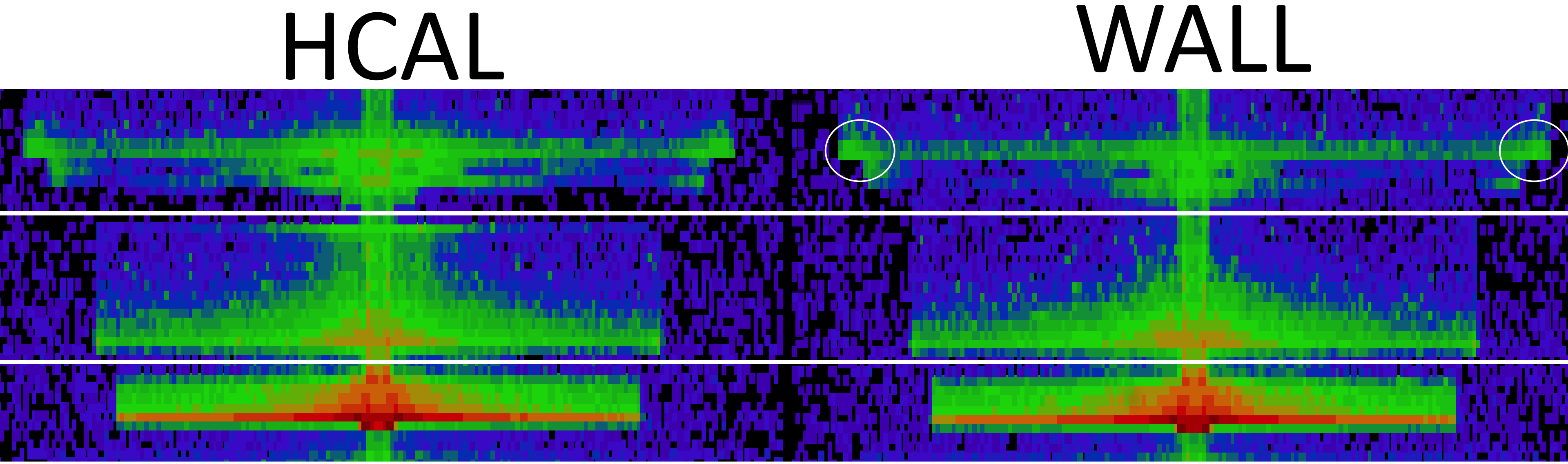

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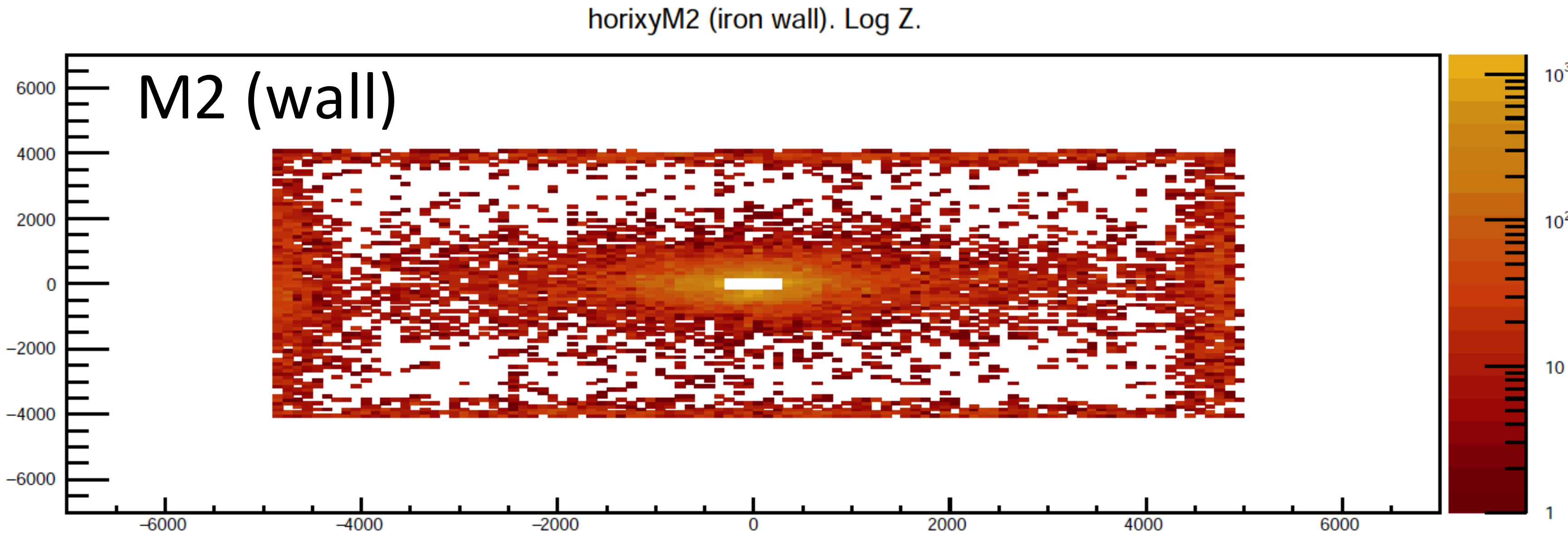
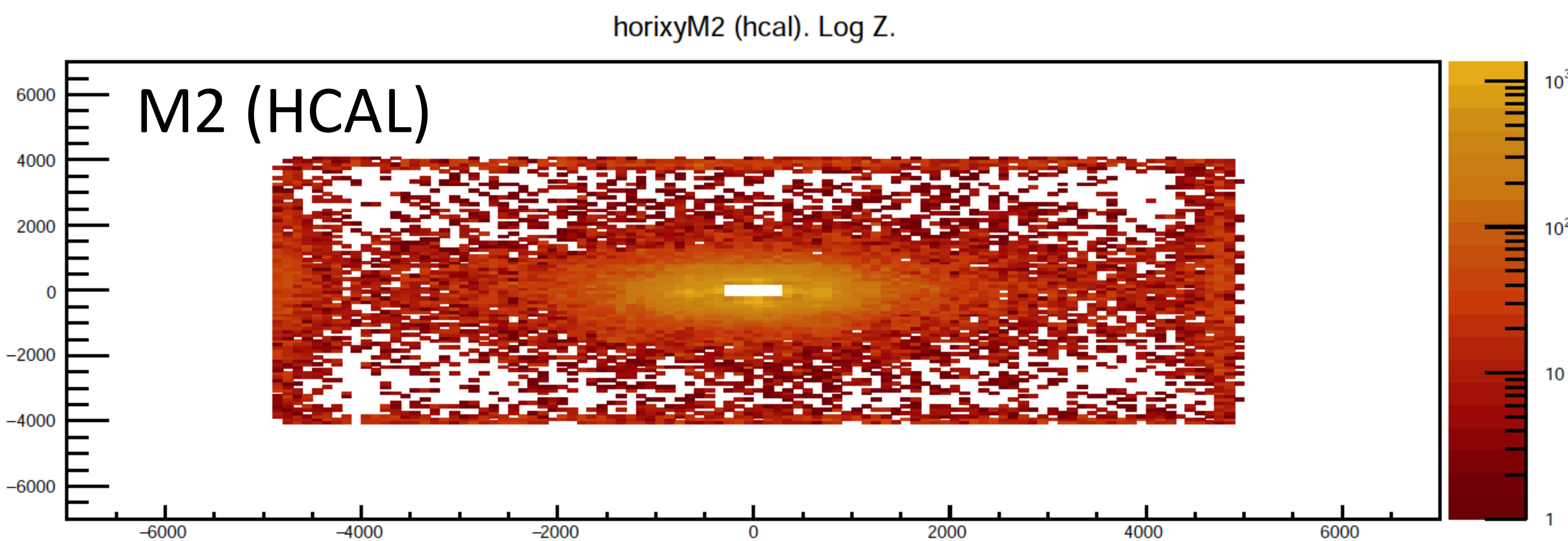
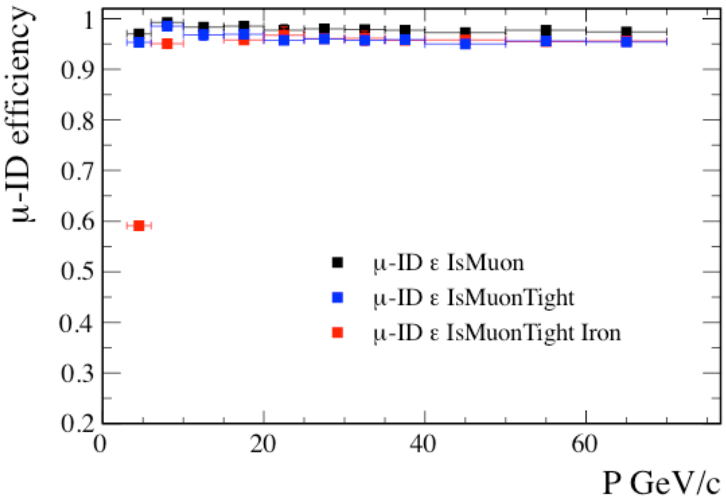

horixyM2 (iron wall). Log Z.
M2 (wall)
6000
4000
2000
0
−2000
−4000
−6000
−6000
−4000
−2000
0
2000
4000
6000
10^3
10^2
10
1


horixyM2 (hcal). Log Z.
M2 (HCAL)
6000
4000
2000
0
−2000
−4000
−6000
−6000
−4000
−2000
0
2000
4000
6000
10^3
10^2
10
1

effect on MuonID-ε

presented at TTFU 19/09/2016



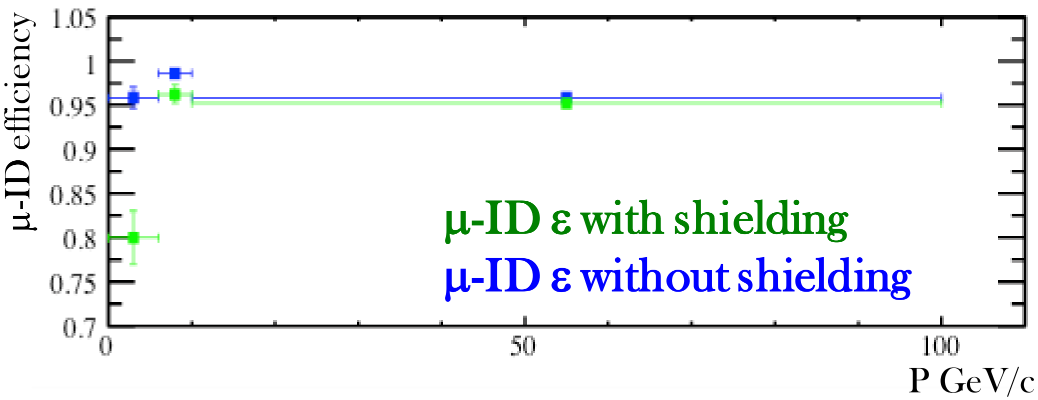
simple toy using data control sample of $J/\psi \rightarrow \mu^+\mu^-$

hit or miss procedure according to the probabilities to reach a muon station ➔ *substantial decrease for p < 6 GeV/c*

MC production of $B^0 \rightarrow J/\psi(\mu\mu)K\pi$ @ 4×10^{33} cm^{-2}s^{-1}

LHCb design at Upgrade phase 1 w/o shielding in place of HCAL

μs tracks identified as μs requiring **IsMuonThigt = 1**



	μ-ID ε
3<P<6 GeV	0.96 ± 0.01
6<P<10 GeV	0.986 ± 0.005
P>10 GeV	0.958 ± 0.003

	μ-ID ε with shielding
3<P<6 GeV	0.80 ± 0.03
6<P<10 GeV	0.96 ± 0.01
P>10 GeV	0.952 ± 0.004

effect on π-MisID

MC production of $D^* \rightarrow D^0(K\pi)\pi$ @ 4×10^{33} cm^{-2}s^{-1}

LHCb design at Upgrade phase 1 w/o shielding in place of HCAL

	π-MisID(IsMuon=1)	π-MisID(IsMuonTight=1)
3<P<6 GeV	0.36 ± 0.03	0.17 ± 0.02
6<P<10 GeV	0.25 ± 0.02	0.13 ± 0.02
P>10 GeV	0.043 ± 0.005	0.028 ± 0.004

	π-MisID(IsMuon=1)	π-MisID(IsMuonTight=1) with shielding
3<P<6 GeV	0.11 ± 0.02	0.05 ± 0.02
6<P<10 GeV	0.22 ± 0.02	0.13 ± 0.02
P>10 GeV	0.033 ± 0.005	0.024 ± 0.002

Large reduction in soft pion mis-ID

Iron-wall induced loss on relevant physics channels

The momentum-dependent inefficiency due to the iron wall can be integrated with the phase space of relevant channels (given selection) with two or three muons to evaluate the total event loss for events passing isMuon

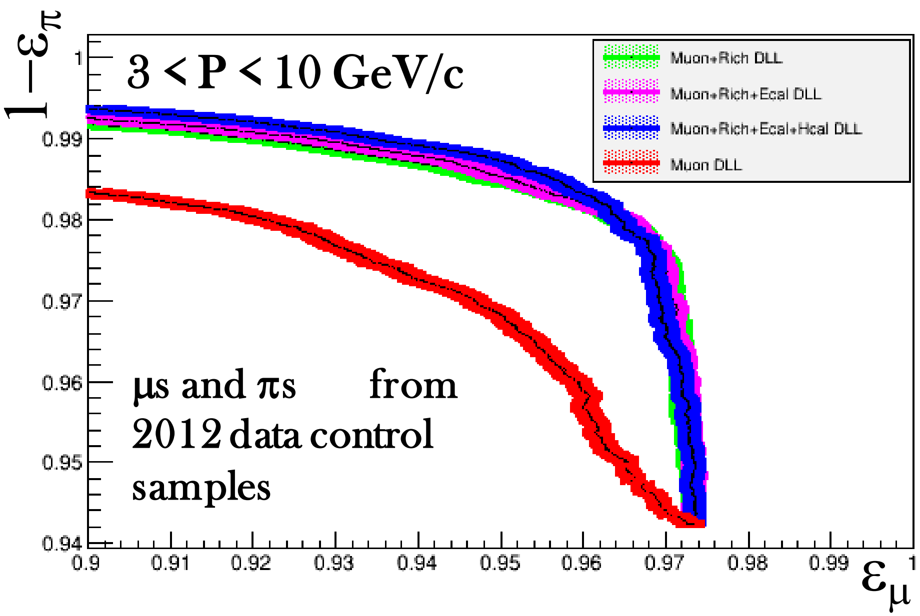
	at least 1 muon in R1	at least 1 muon in R2 (*)	loss due to iron wall
Bs->mumu	(23.3+-0.1)%	(36.2+-0.1)%	(1.8+-0.2)%
Bs->JpsiPhi	(25.0+-0.1)%	(39.1+-0.1)%	(3.2+-0.3)%
D0->mumu	(24.8+-0.2)%	(39.2+-0.3)%	(2.3+-0.8)%
Ks->mumu	(16.2+-0.3)%	(44.3+-0.4)%	**(11.4+-1.0)%**
tau->3mu	(27.2+-0.3)%	(42.5+-0.3)%	**(11.1+-0.8)%**

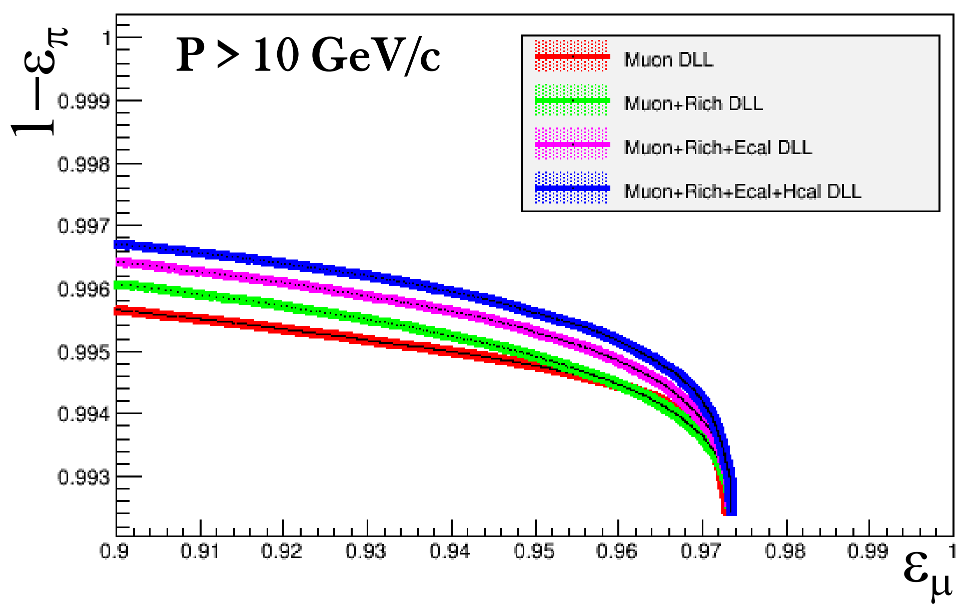
(*) and no muon in R1

- Most affected is Ks, which has a softer momentum spectrum, and tau which has 3 muons
- Losses are more important in the external regions (low momenta), where smaller rates are expected -> can profit from an optimization of the filter geometry

HCAL contribution to the combined PID

presented at TTFU 19/09/2016



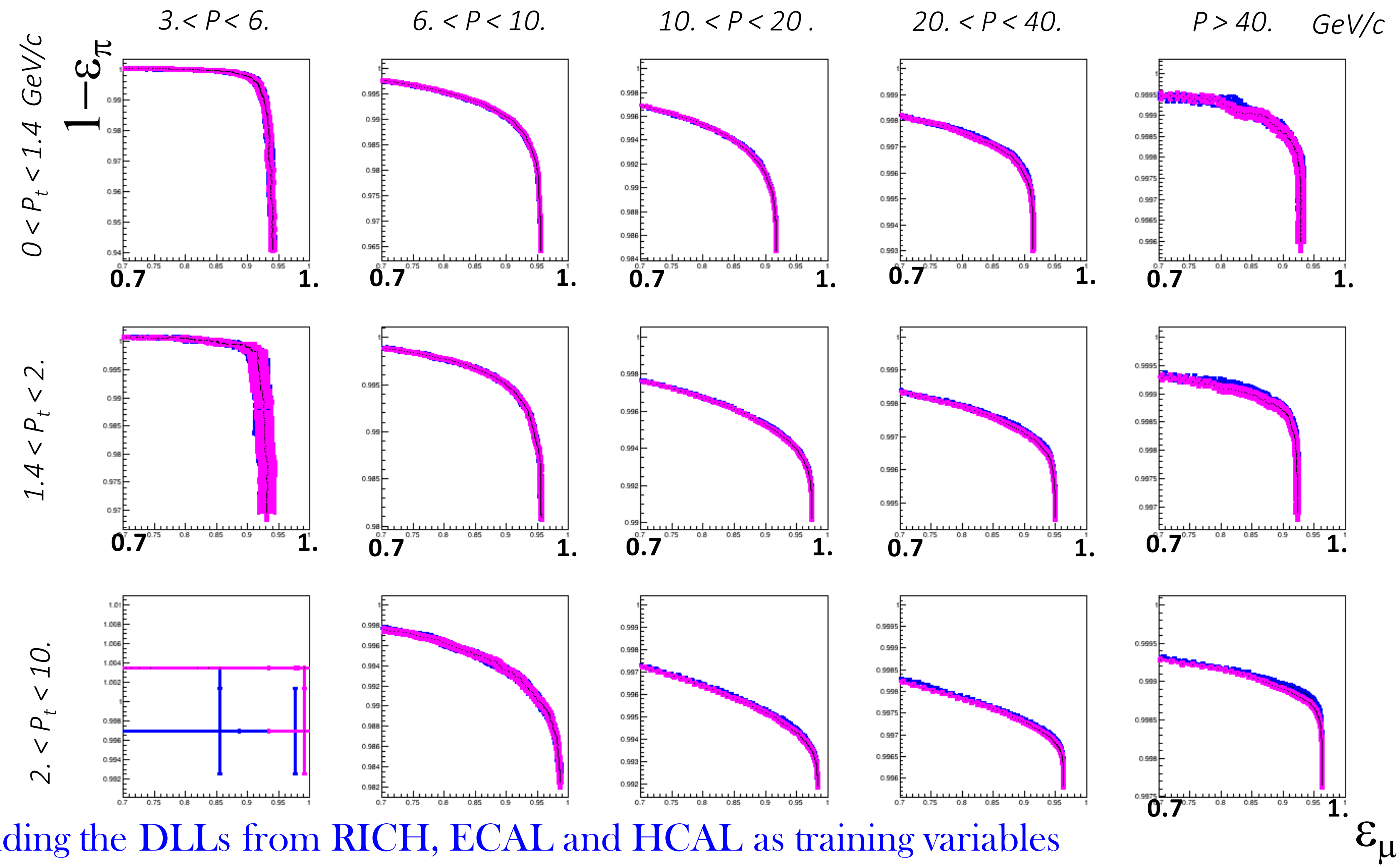


π_MisID ε_π evaluated at **$\varepsilon_\mu = 90\%$**

	3 < P < 10 GeV/c	P > 10 GeV/c
ε_π MUON	17.2×10^{-3}	4.4×10^{-3}
ε_π MUON+RICH	8.2×10^{-3}	4.0×10^{-3}
ε_π MUON+RICH+ECAL	7.4×10^{-3}	3.6×10^{-3}
ε_π MUON+RICH+ECAL+HCAL	6.4×10^{-3}	3.3×10^{-3}

HCAL contribution to the combined PID

how much do we will recover cutting on BDT ?



adding the DLLs from RICH, ECAL and HCAL as training variables

adding the DLLs from RICH and ECAL as training variables

ROCs curves are relative to isMuonTight

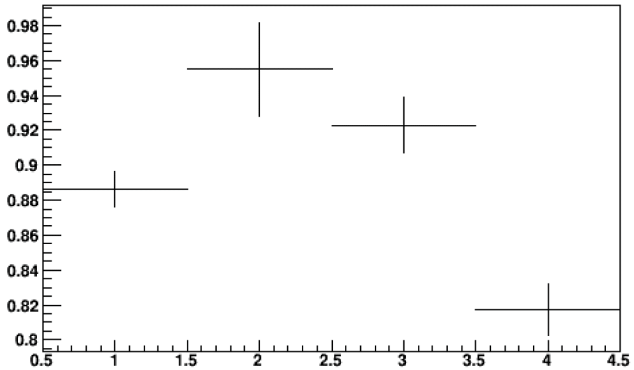
Conclusions

- Expected rate reduction from iron wall seen in the hottest regions
- Wall does not affect muon ID significantly w.r.t current ID strategy and improves pion mis-ID at low momentum
- Need to factor in low energy background to fully understand the rate reduction (extends far below energy cutoffs)
- Next steps:
  - Better understand spatial distribution of reduction – any hot spots to worry about?
  - More realistic filter geometry
  - Official productions for much larger samples for muon ID studies
  - Low energy productions and parametrization is crucial to fully understand affect on dead time.

Backup slides

Iron-wall induced loss on relevant physics channels

loss on Ks0->mumu splitter per region



1=all
2= mu+ or mu- in R1 (20%)
3= mu+ or mu- in R2, and not in R1 (39%)
4= mu+ and mu- in R3/R4 (41%)

The loss is larger in regions 3/4, where the momentum picture is softer; external regions are also less affected by rate problems, so that a better iron wall shaping could be imagined

Occupancies in simulation

Simulation conditions

Gauss	v50r0
CondDB tag	sim-20140825-vc-mu100
Base DDDB tag	dddb-20150424
Event type	Min. bias
Luminosity	4E33
Bunch spacing	25ns

Reduction rates for each overall region

M2R1	M2R2	M3R1	M3R2
51.2%	73.8%	4.5%	18.8%

Chamber	w/ wall	w/ hcal	Reduction (%)
C1	34826.7	65973.3	47.2
C2	40000	60320	33.7
C3	29546.7	58880	50.0
C4	25066.7	55893.3	55.2
C5	20000	47360	57.8
C6	24906.7	57013.3	56.3
C7	28373.3	48000	40.9
C8	28106.7	49333.3	43.0
C9	11626.7	29813.3	61.0
C10	10986.7	30773.3	64.3
C11	12000	30026.7	60.0
C12	10560	32053.3	67.1

Reduction rates per chamber in M2R1 from average track multiplicities per cm^2s^-1