Could we run the upgraded muon system at 2E+34?

(… or it's just a dream?)

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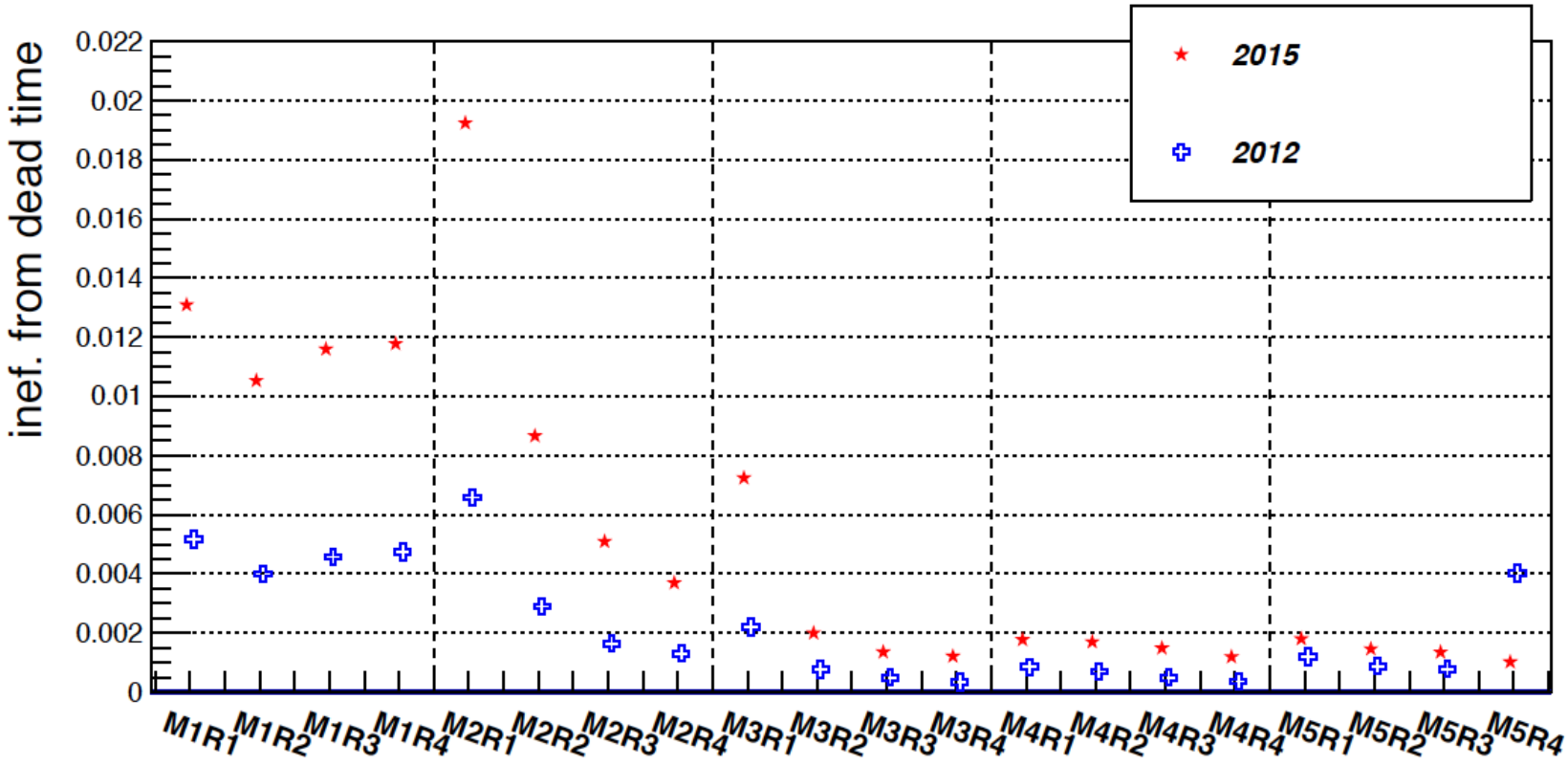
The Current Muon System

- The muon system has been designed to operate at the nominal LHC conditions (25ns, L=2E+32cm^{-2}s^{-1}, E_C=14 TeV)

- It has performed extremely well in Run1 (50ns, L=4E+32cm^{-2}s^{-1}, E_C= 8 TeV) and in Run2 (25ns, L~3E+32cm^{-2}s^{-1}, E_C= 13 TeV) running conditions

Inefficiencies: Run2 vs. Run1



Tracking ineff. from deadtime expected to be **2.6%** (1.0% in 2012)

G. Graziani, 25/6/2015

Rates at 2E+33

Rate extrapolations done originally using 2012 data for the PID TDR, taking into account

- 8→14TeV energy increase
- the additional spill-over due to 25ns bunch spacing
- the rate reduction in M2R1 by 26% due to additional shielding

Extrapolations verified with 2015 data (see G. Graziani 25/6/2015)

Region	Minimum	Average	Maximum
M2R1	162 ± 28	327 ± 60	590 ± 110
M2R2	15.0 ± 2.6	52 ± 8	97 ± 15
M2R3	0.90 ± 0.17	5.4 ± 0.9	13.4 ± 2.0
M2R4	0.12 ± 0.02	0.63 ± 0.10	2.6 ± 0.4
M3R1	39 ± 6	123 ± 18	216 ± 32
M3R2	3.3 ± 0.5	11.9 ± 1.7	29 ± 4
M3R3	0.17 ± 0.02	1.12 ± 0.16	2.9 ± 0.4
M3R4	0.017 ± 0.002	0.12 ± 0.02	0.63 ± 0.09
M4R1	17.5 ± 2.5	52 ± 8	86 ± 13
M4R2	1.58 ± 0.23	5.5 ± 0.8	12.6 ± 1.8
M4R3	0.096 ± 0.014	0.54 ± 0.08	1.37 ± 0.20
M4R4	0.007 ± 0.001	0.056 ± 0.008	0.31 ± 0.04
M5R1	19.7 ± 2.9	54 ± 8	91 ± 13
M5R2	1.58 ± 0.23	4.8 ± 0.7	10.8 ± 1.6
M5R3	0.29 ± 0.04	0.79 ± 0.11	1.69 ± 0.25
M5R4	0.23 ± 0.03	2.1 ± 0.3	9.0 ± 1.3

Rates at L=2E+33/cm^2/s, from PID Upgrade TDR

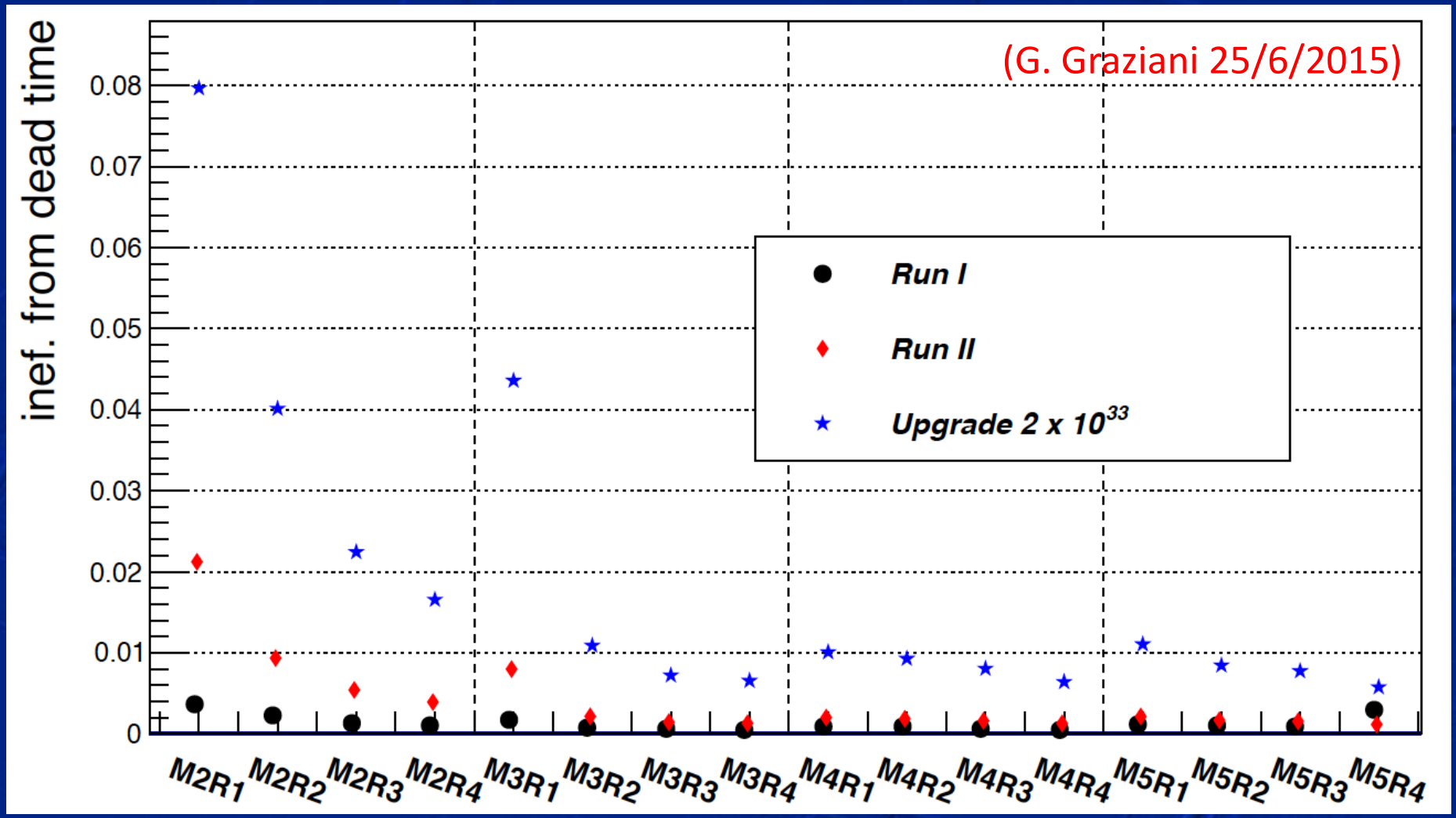
Consequences

- ➔ Efficiency reduction of muon station
  - Increased dead time of physical channels
  - Increased dead time of logical channels in regions where large ORs are performed to obtain large X or Y strips
- ➔ Larger pion misidentification
  - Increased accidentals
  - increased number of ghosts pads due to accidental crossings if many X,Y strips are ON

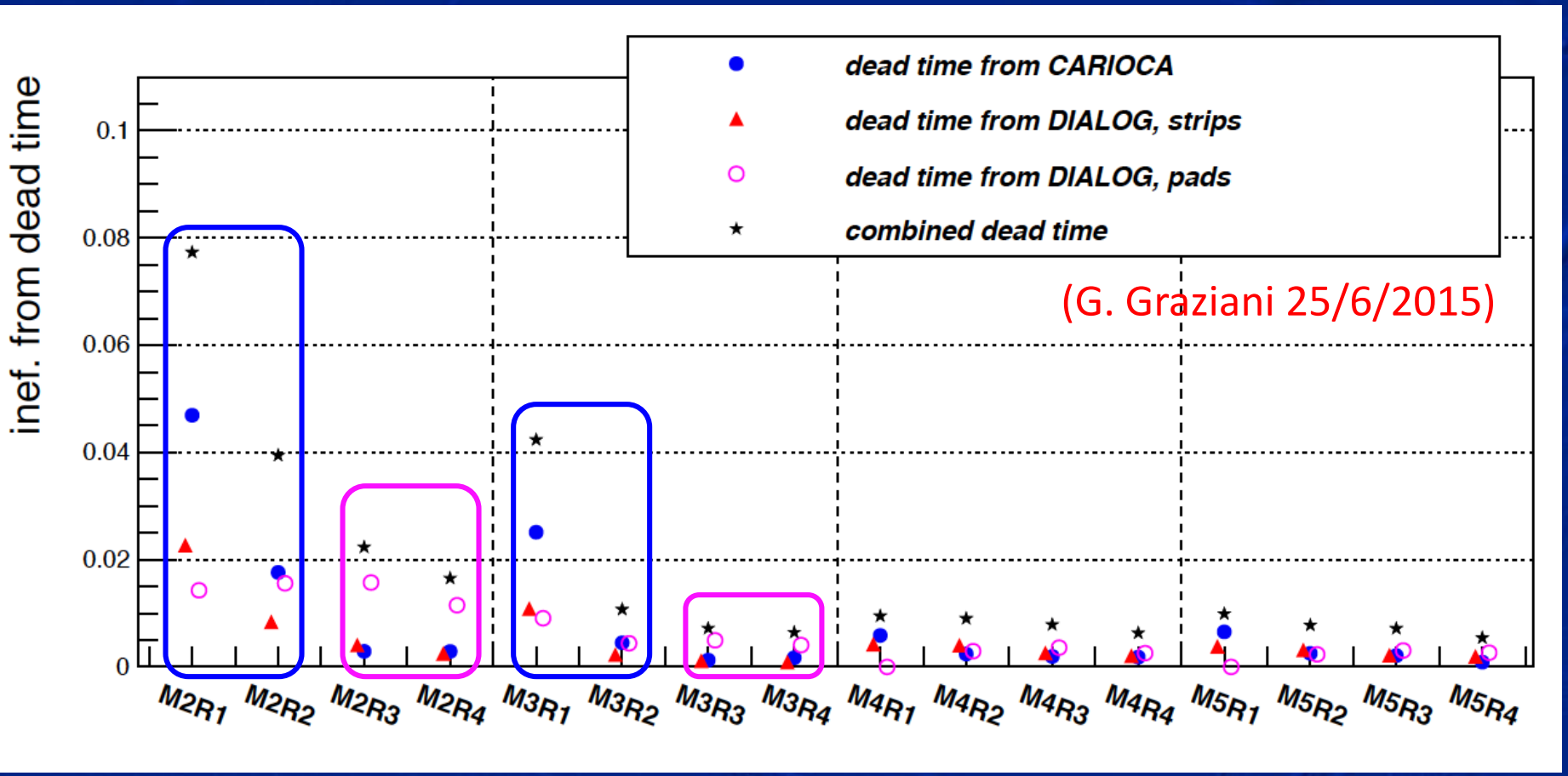
Critical points

- The current muon system is NOT built with pad-based detectors everywhere
- The muon system was designed to achieve the high-granularity required by L0mu, obtained by crossing X and Y strips to recover the XY pad information
- In every station the physical channel size is region dependent
- M2 and M3 are more granular than M4 and M5 because the increased multiple scattering will make a more precise position estimation useless
- All the above allowed to achieve an important reduction on readout channels, but this is a limit at higher luminosities
- To achieve a highly efficient L0mu - which uses 5/5 stations - the detectors uses 4 sensitive gaps in OR (and only 2 in M1)
- HV and thresholds are currently optimized for the efficiency
- The front-end ASIC (CARIOCA) dead-time is close to 75ns

DT induced-inefficiencies



Inefficiency breakout @2E+33



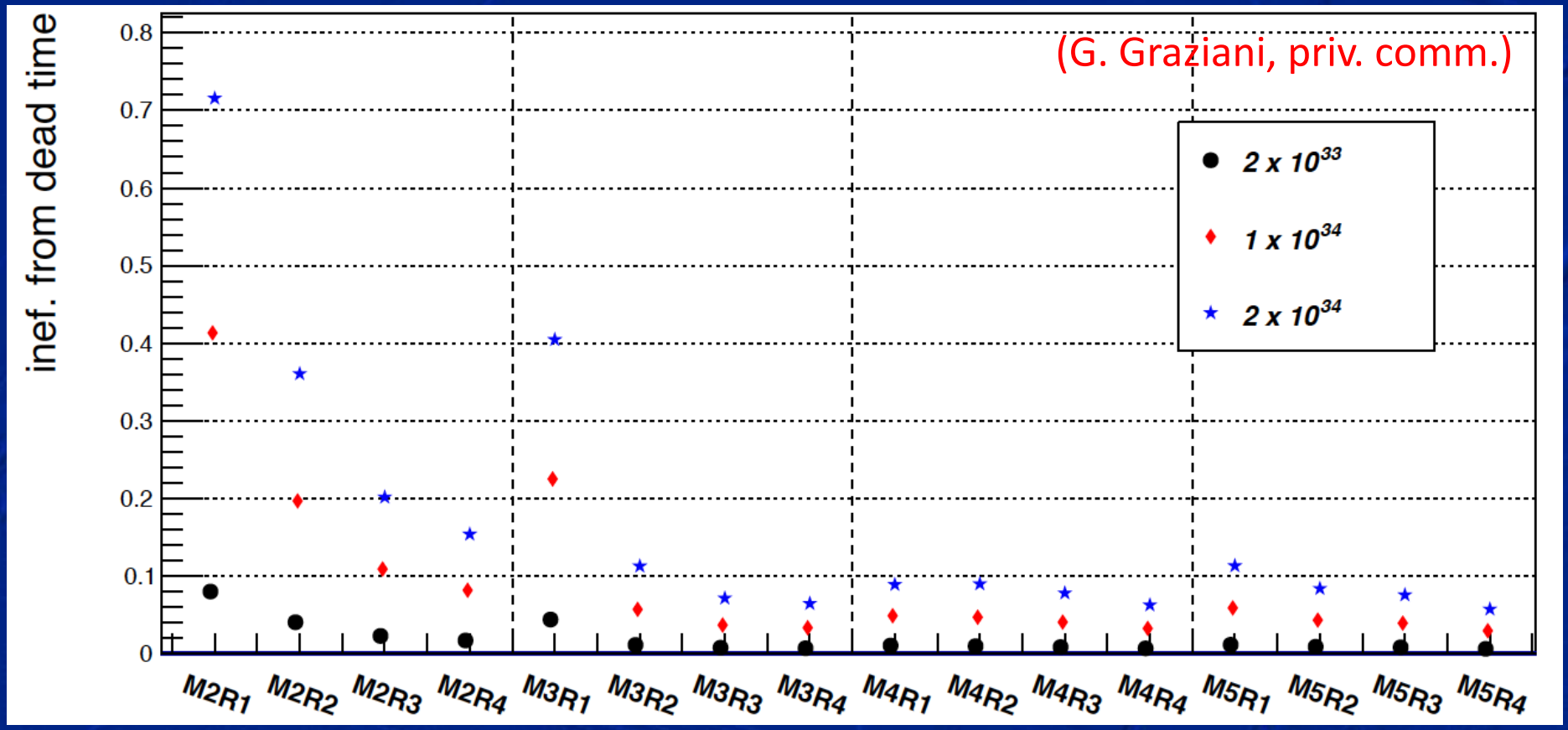
Corrective Actions for 2E+33

- To recover efficiency losses:
  - On the software side, we can soften the requirements for a "good" muon: there is no need anymore, in the upgrade, to have 1 hit/station (ongoing, see Patrizia's talk)
  - On the hardware side, it would be relatively easy to increase the number of readout channels by replacing IB (boards performing logical ORs) with nODE – no need to touch the detectors on the walls (optimization not yet concluded) + optimize detector configuration (2/4 gaps option + HV/THR optimization)
- To recover pion misidentification increase:
  - Develop better algorithms (ongoing, see Patrizia's talk)
- In addition, the new HCAL plug seems very effective, giving ~60% (not including low-energy background) rate reduction in M2R1 from preliminary simulations
- This is enough for 2E+33 $cm^{-2}s^{-1}$: we expect muonID performances similar to what we have now

What happens above 2E+33?

- Above 2E33 the upgraded muon system will soon reach its hardware limits - the increase in luminosity/occupancies will bring:
  - Occupancies will be extremely high in many regions:
    - Large DT ➔ large inefficiencies
    - Huge background ➔ fast deterioration of muonID
  - Very high currents on some HV channels, might need new HV power supplies and even new detectors with improved HV supply scheme
  - Some MWPC will easily exceed the 1 C/cm working limit, might require a detector replacement on a regular basis
  - Radiation damage of electronics to be assessed

DT induced-inefficiencies at 2E+34



(uncertainties as large as 50%)

A conservative solution for 2E+34

- Most of the problems seen are a consequence of the high rates on the muon stations, mainly due to the insufficient shielding provided by the calorimeters
- HCAL could be replaced with a full iron wall to reduce the rates to hopefully 50% on the muon stations (from 5.6 to ~10 nucl. int. lengths in front of M2)
- New detectors (with new higher-granularity front-end electronics) for inner regions M23R12 appear to be necessary to deal with rates exceeding few MHz/cm^2 per front-end channel
- Further increase the number of readout channels by removing IBs everywhere will help reducing DIALOG dead-time induced inefficiencies elsewhere

Conclusions

- The muon detector, upgraded for 2E+33 $cm^{-2}s^{-1}$, will not be able to operate at 2E+34 $cm^{-2}s^{-1}$
- Due to the very high rates on the muon stations, in particular in M2 and M3, a detector replacement in the innermost regions will be necessary
- A conservative solution (still to be checked carefully with simulations) could consist in the installation of a thick iron shielding in front of M2 to bring down the rates by ~50% on the muon stations. This implies the removal of HCAL
- Finally… in 2030 most of the muon system detectors and on-board electronics will be ~25 years old, exceeding their expected operating life
- Going to 2E+34 $cm^{-2}s^{-1}$ will be an extremely important effort

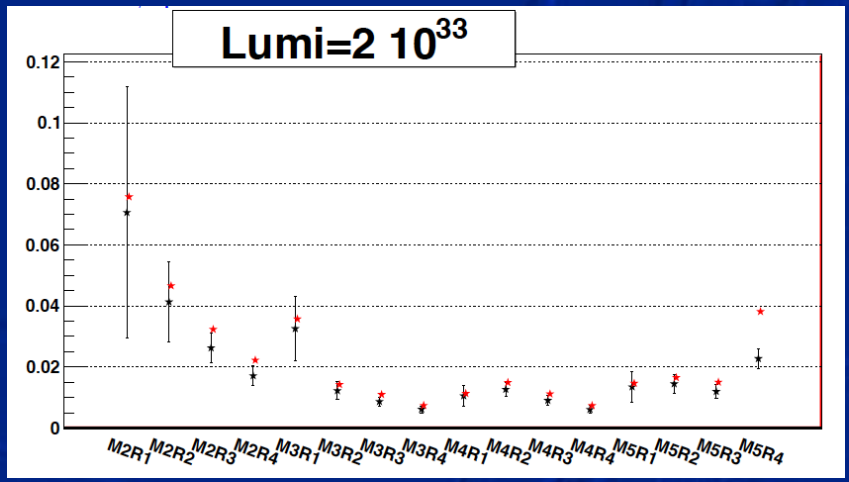
SPARE SLIDES

On muon efficiency

- Most problematic regions: M2R1, M2R2, M3R1, M2R3, M3R2, M2R4, M5R4
- Inefficiencies due to dead time can become quite large
- It is however less important to keep very high stations efficiency in upgrade conditions since there will be no L0mu trigger
- Some solutions have been proposed and require some testing which are in progress:
  - HV and threshold optimization
  - Switch OFF 2 of the 4 gaps to reduce uncorrelated rate in input to FEE channels (which creates dead time)

Region	Inefficiency at 2×10^{33} cm^{-2}s^{-1}
M2R1	7.1 ± 2.8 %
M2R2	4.1 ± 1.1 %
M2R3	2.6 ± 0.4 %
M2R4	1.7 ± 0.3 %
M3R1	3.3 ± 1.1 %
M3R2	1.2 ± 0.3 %
M3R3	0.9 ± 0.1 %
M3R4	0.6 ± 0.1 %
M4R1	1.1 ± 0.3 %
M4R2	1.3 ± 0.2 %
M4R3	0.9 ± 0.2 %
M4R4	0.6 ± 0.1 %
M5R1	1.3 ± 0.5 %
M5R2	1.4 ± 0.3 %
M5R3	1.2 ± 0.2 %
M5R4	2.3 ± 0.3 %

Inefficiencies at L=2E+33/cm^2/s, from PID Upgrade TDR



Updated inefficiencies with proper muon time distribution taken into account (March 2015)

Pion misidentification

- Misidentification MUST be kept to current levels, not to spoil the increase in statistics that we get with a higher luminosity
- Current muon ID algorithms have been optimized for
  - nominal luminosity
  - efficiency
- There are many handles to use to improve the performance of muon ID algorithms:
  - New FOI definitions
  - Use of crossed Hits
  - Include multiple scattering information
  - Use time information
  - …

Work in progress