Upgrade of the Readout Electronics of the ATLAS MDT Detector for SLHC

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Description of the ***ATLAS Muon Drift Tube Electronics*** in:

http://www.iop.org/EJ/article/1748-0221/3/09/P09001/jinst8_09_p09001.pdf

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Overview

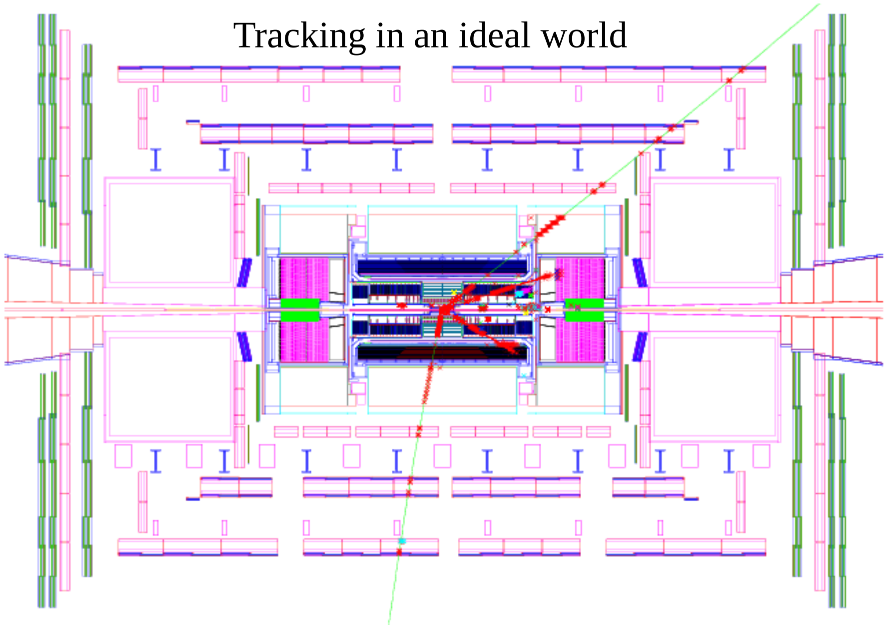
The SLHC recipe for better physics:

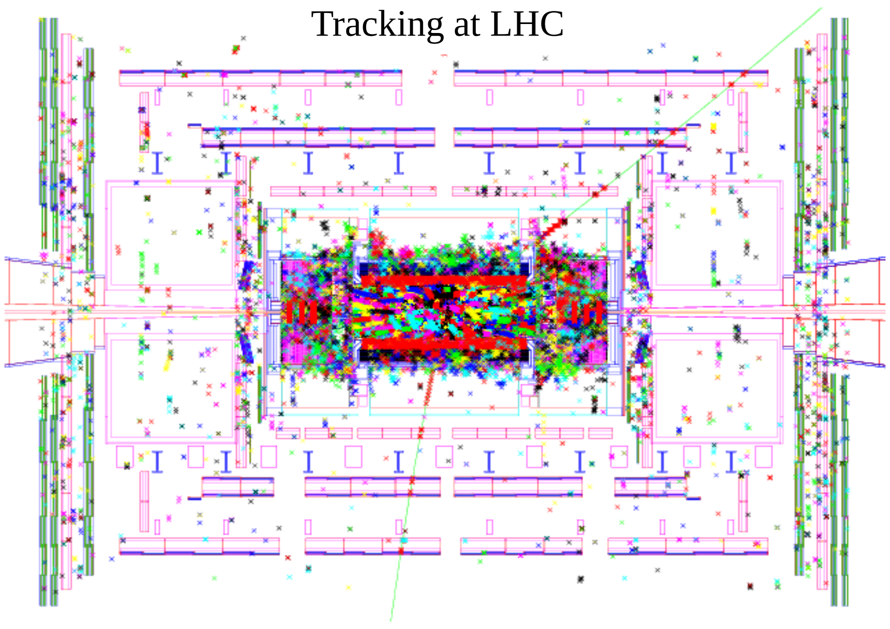
→ gain in statistics — task of the machine

→ don't lose in data quality — task of the detector

- SLHC: Challenges for the Detector
- Performance of the MDT detector in high γ-background; expectations for SLHC
- Need new Detector or New Electronics? Both?
- Need a Hybrid Solution depending on BG in the hall?
  - Hot regions: new chamber types?
  - Cool regions: new electronics and/or readout strategies sufficient?
- Summary

Data Quality: Tracking vs. Background in the MDT



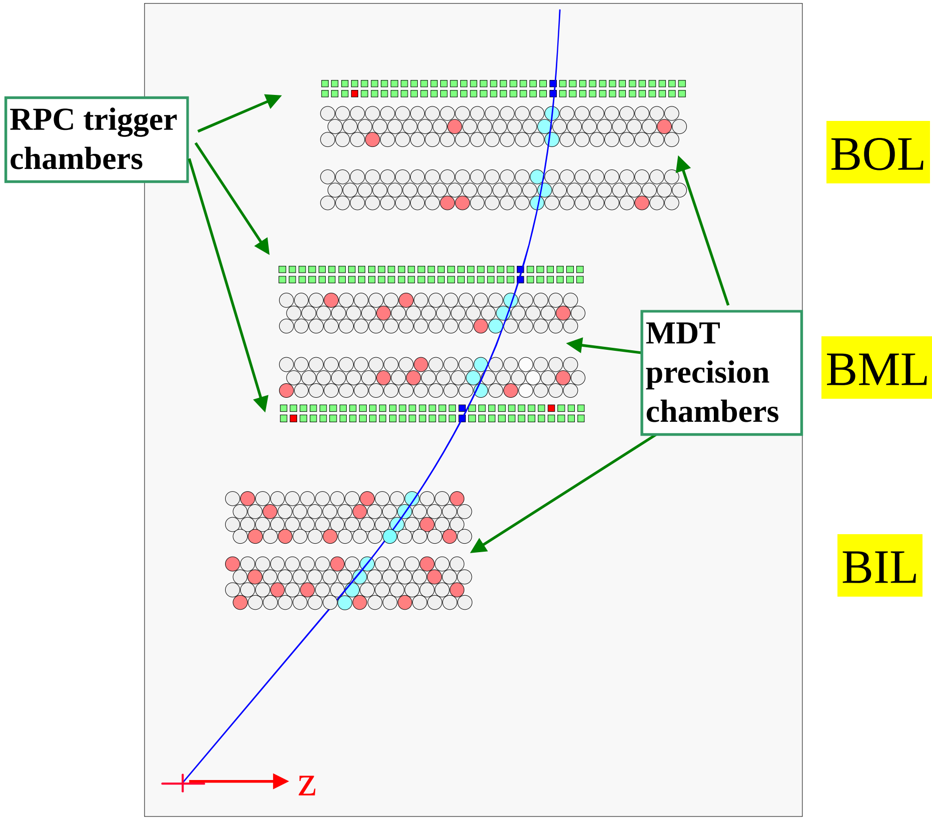


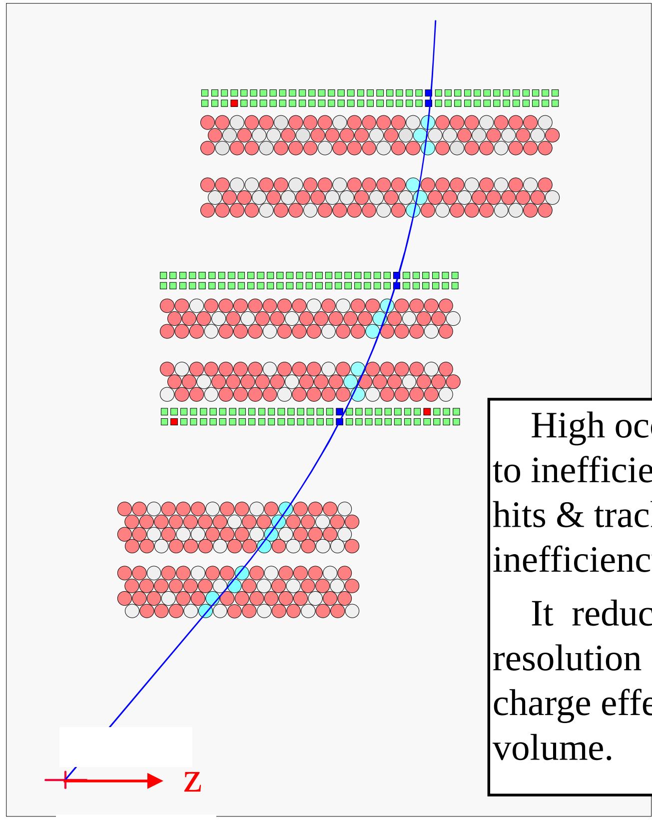
There are 72 MDTs shown in the barrel with about 24000 tubes.

About 20% of the MDT tubes have a BG hit at full LHC luminosity.

Tracking in a MDT tower

Hit patterns in a MDT tower (barrel) at low and high background rates





High occupancy leads to inefficiency of track hits & tracking inefficiency.

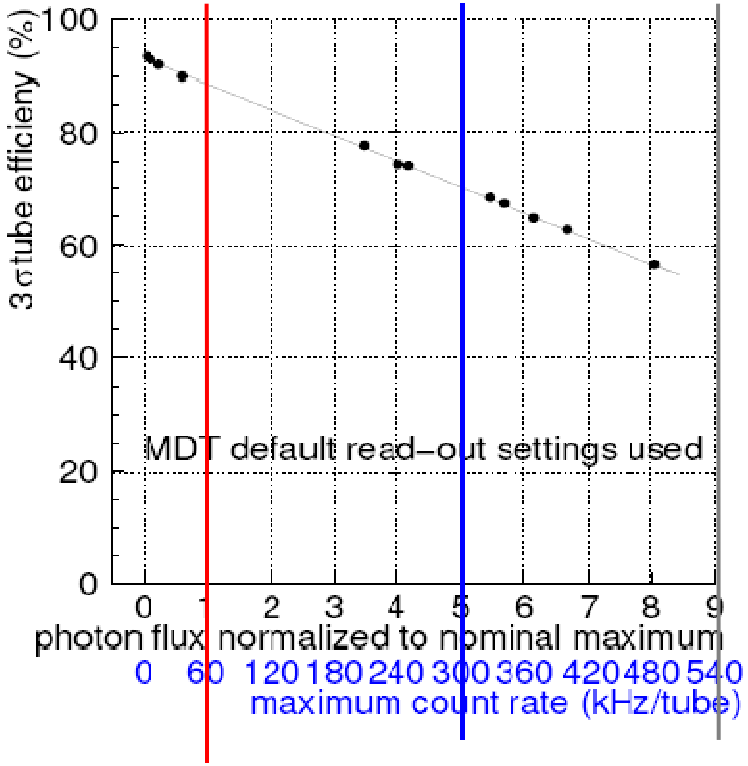
It reduces spatial resolution due to space charge effects in the drift volume.

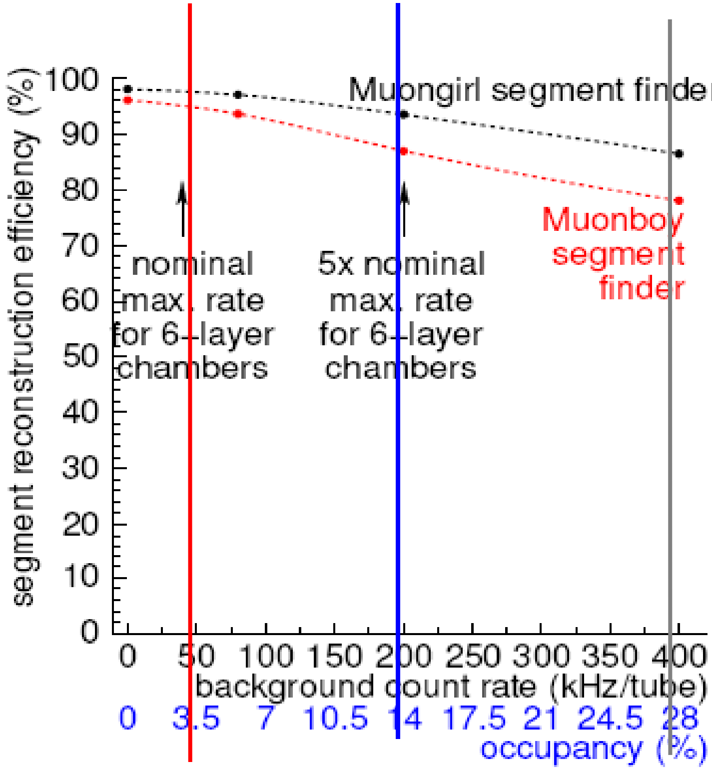
The Inner Barrel Layers have no trigger chambers. The track segment in the Inner Layer is extrapolated from the outer layers, based on the RoIs in the outer trigger chambers.

Track finding needs Region of Interest (RoI) information from the trigger chambers. Pattern recognition from tube hits only works at very low BG rates.

Data quality: Tube efficiency vs. occupancy

Degradation of tube efficiency most critical issue at high rates! → Leads to reduction of track segment reconstruction efficiency





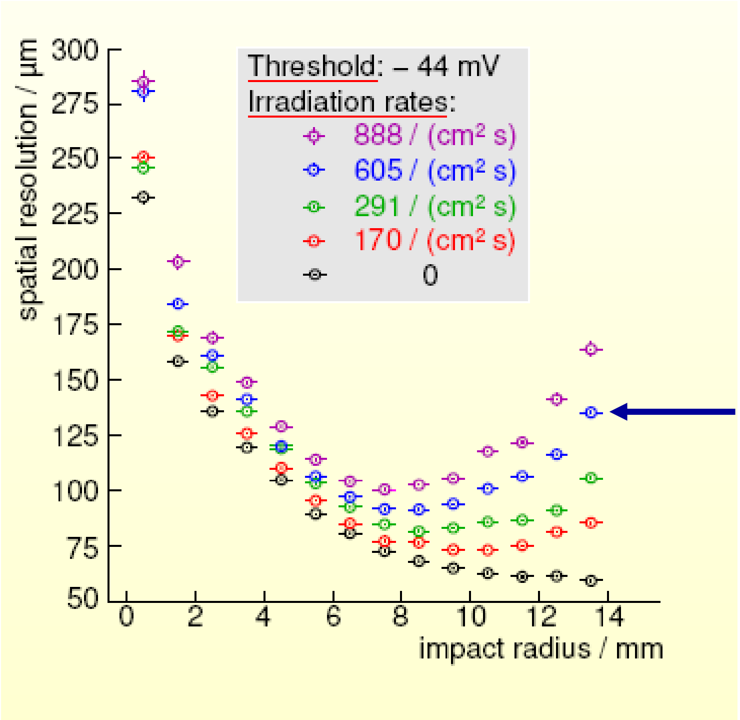
SLHC →

LHC as simulated: 90% eff. | 5 * LHC: 70% | 10 * LHC: 50%

LHC as simulated: 95% eff. | 5 * LHC: 90% | 10 * LHC: 82%

Main reason for inefficiency: signal duration due to large radius of tube

Data Quality: Spatial resolution vs. occupancy



Spatial resol. of MDT tubes as a function of impact radius and BG level

(measured at the GIF)

~ 5 * LHC nominal

- dependence on BG rate due to space charge from positive ions
- avg. resolution goes from ~ 80 µm → ~120 µm
- relevance of resolution reduction depends on physics channel (momentum spectrum)

Photon Flux in the ATLAS Hall

Radiation Task Force (2003)

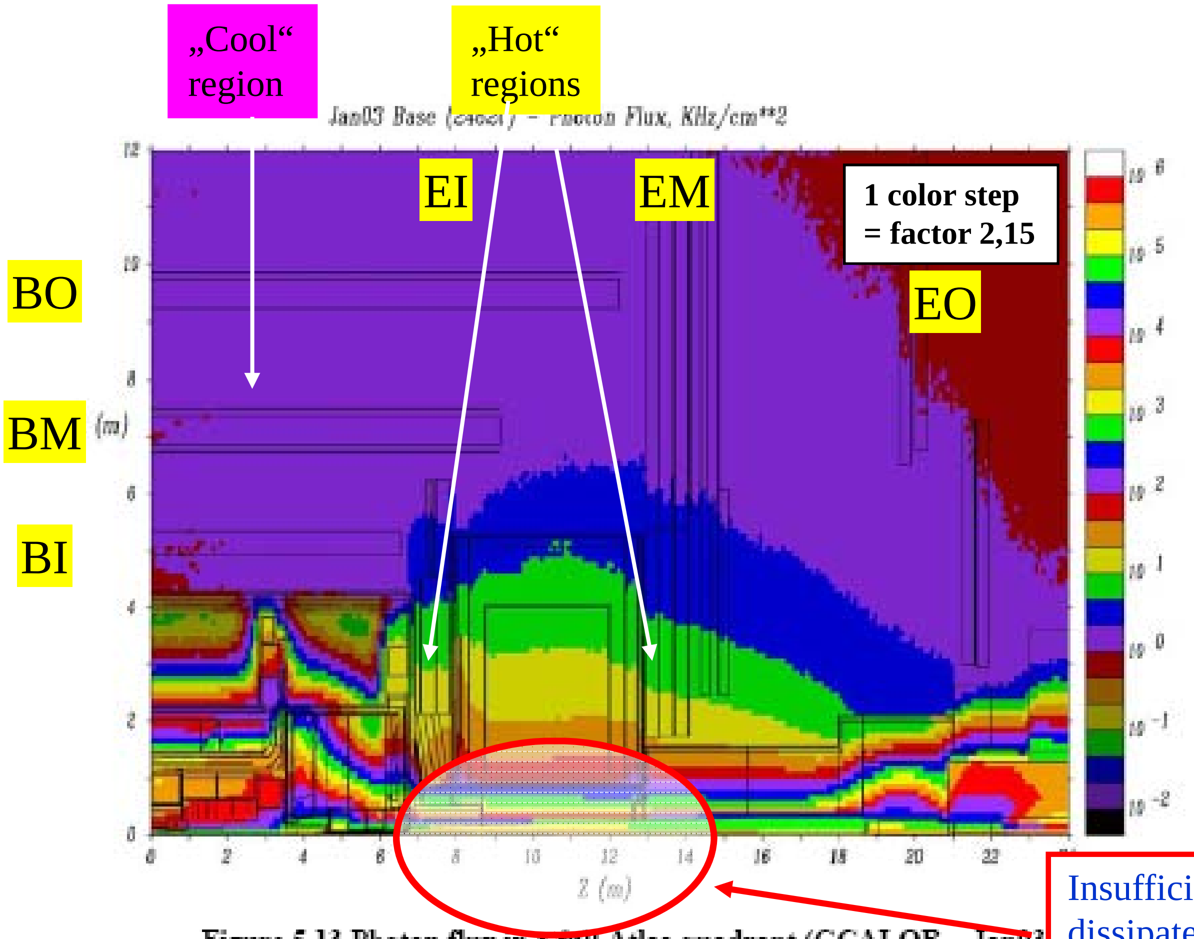


Figure 5.13 Photon flux in a full Atlas quadrant (GCALOR – Jan03

The EC toroid (air core) is nearly transparent to γ's.

→Space between beam-pipe and inner wall of the EC toroid is already optimised for shielding (W instead of Cu brings little gain)

→Be-pipe in this region would improve by factor 2-3 (cost 2 MCHF)

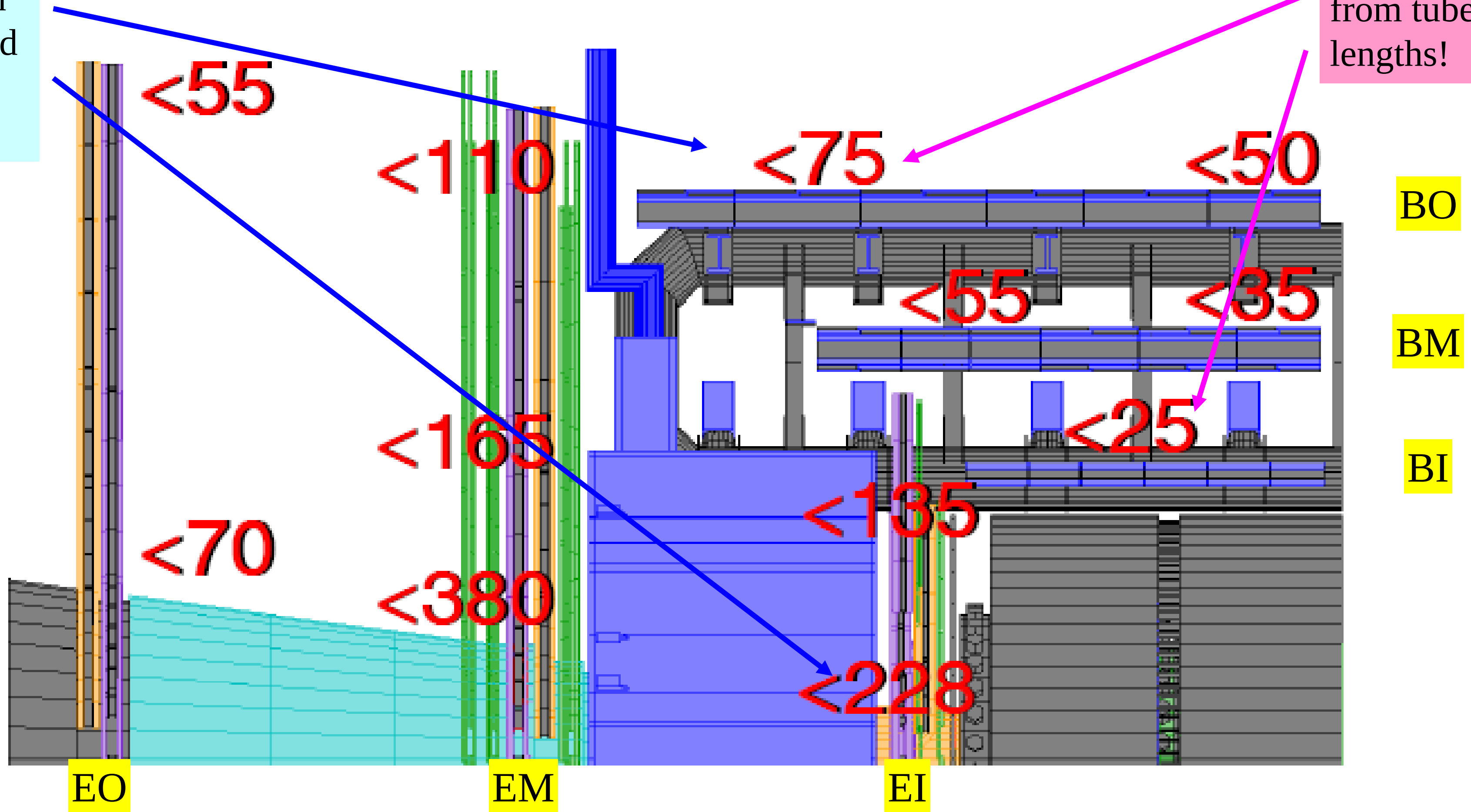
Insufficient shielding: γ's dissipate freely into the hall like $1/r^2$

Photon Flux translated into Count Rates per MDT tube (kHz)

(L = 10^{34} cm^{-2} s^{-1}; safety factor 5 included)

~ factor 3 between ‚hot‘ and ‚cool‘ regions

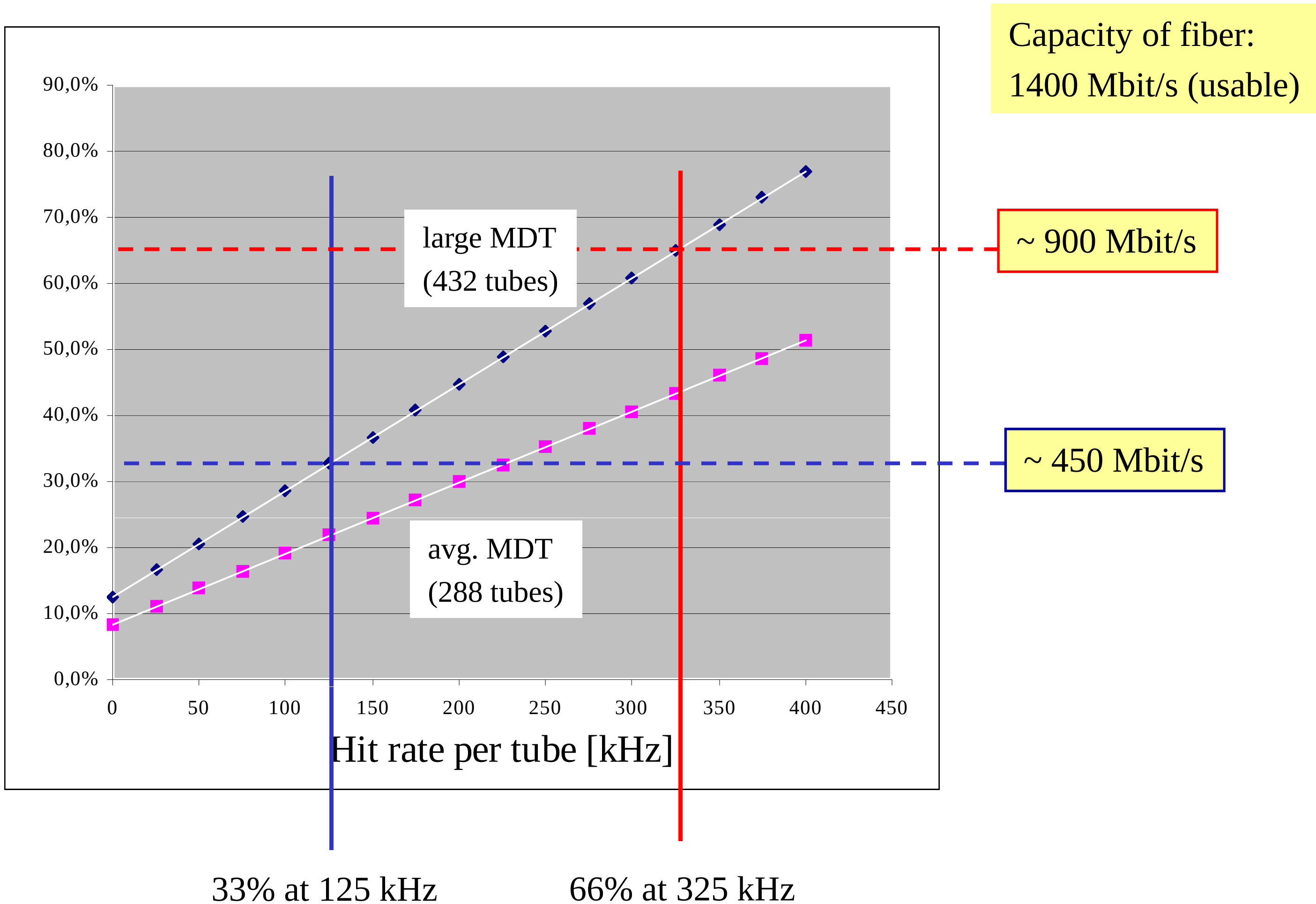
~ fact. 3 from tube lengths!



Large variations in count rates due to local photon flux and tube length

Optical link saturation for a MDT chamber

(@ 100 kHz LVL1 trigger rate)



Summary of expected MDT tube hit rates

Worst case assumption: SLHC BG = 10 * LHC BG and full safety factor 5

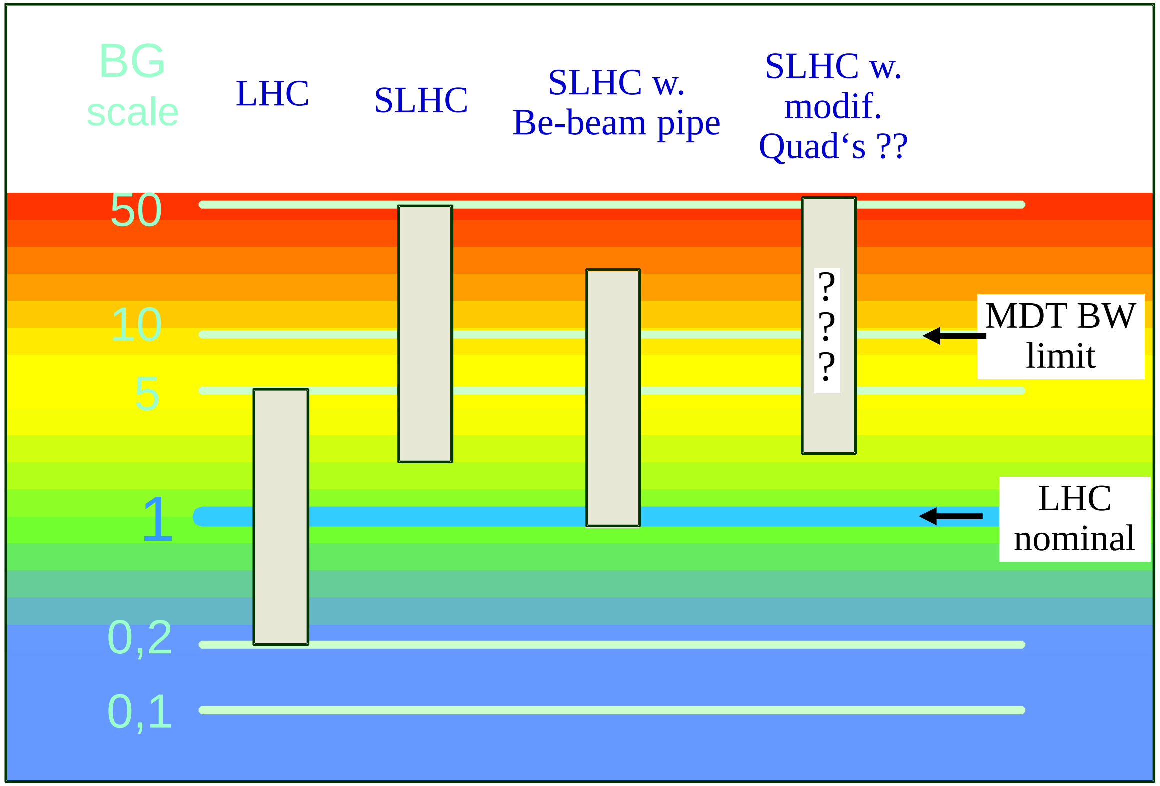
kHz/tube

MDT region	LHC nom.	LHC safty f. 5	SLHC = 10 * LHC nom.	SLHC = 10 * LHC safty f. 5
cool (BI, BM, BO; EO)	15	75	150	750
medium (mid EM, outer EI)	33	165	330	1650
hot (inner EI, EM)	72	236	720	2360

≤ 125	≤ 33 % available Readout BW
≤ 325	≤ 66 % available Readout BW
≥ 325	exceeding BW limit of Readout

"Worst case BG situation at SLHC" far beyond the BW capability of the links: requires upgrade of electronics in all 3 MDT regions

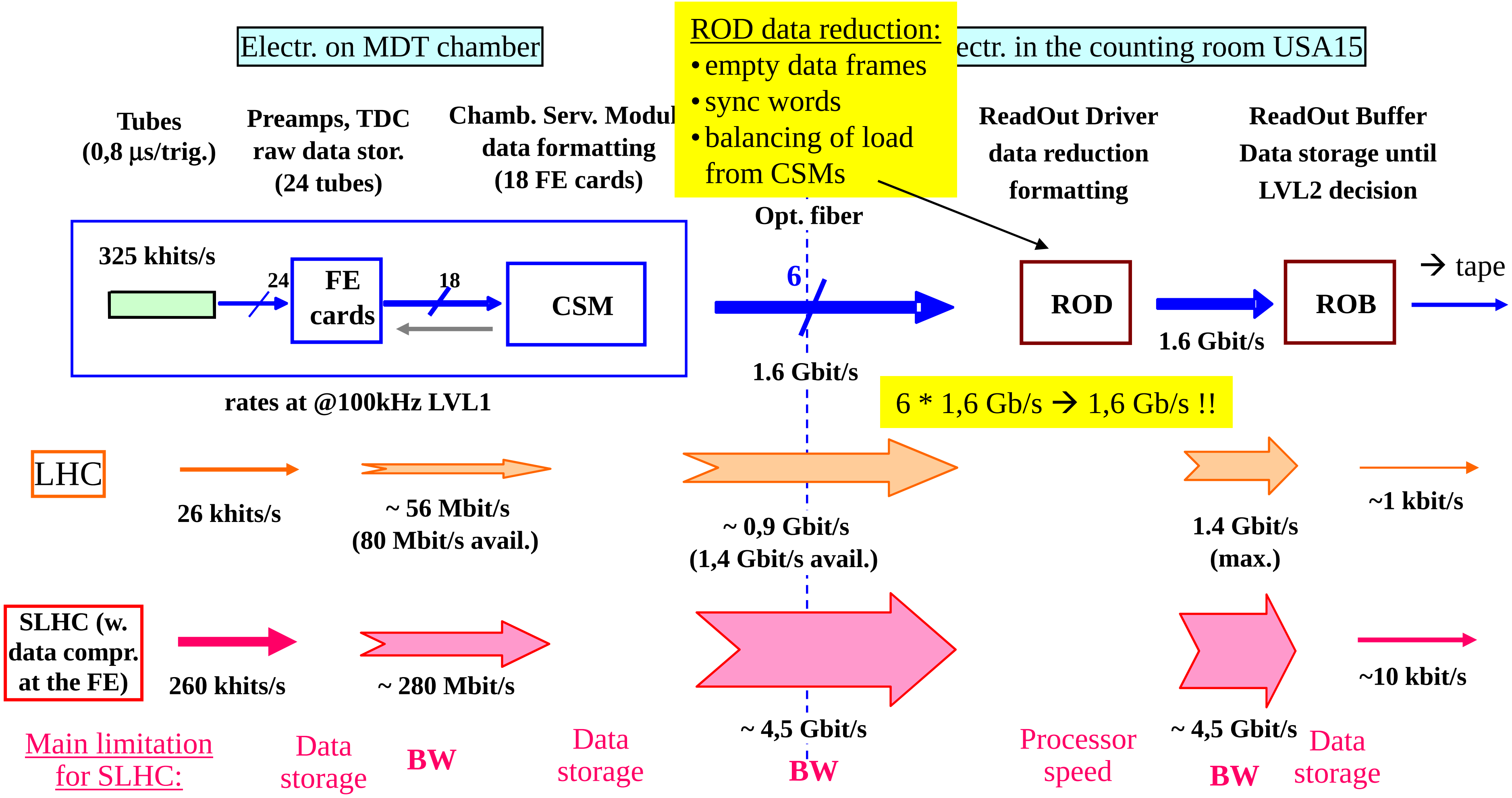
Uncertainty on LHC/SLHC background predictions



Due to uncertainties of SLHC BG predictions: need a flexible concept to match BG in the the different MDT regions…

… but hope to narrow the uncertainty in the coming months !

The MDT readout chain, schematic *(DCS not shown)*



Present MDT R/O architecture is tailored to the expected LHC BG rates
→Little margin for lumi-increase!

Options to solve the problems with occupancy, resolution, BW?

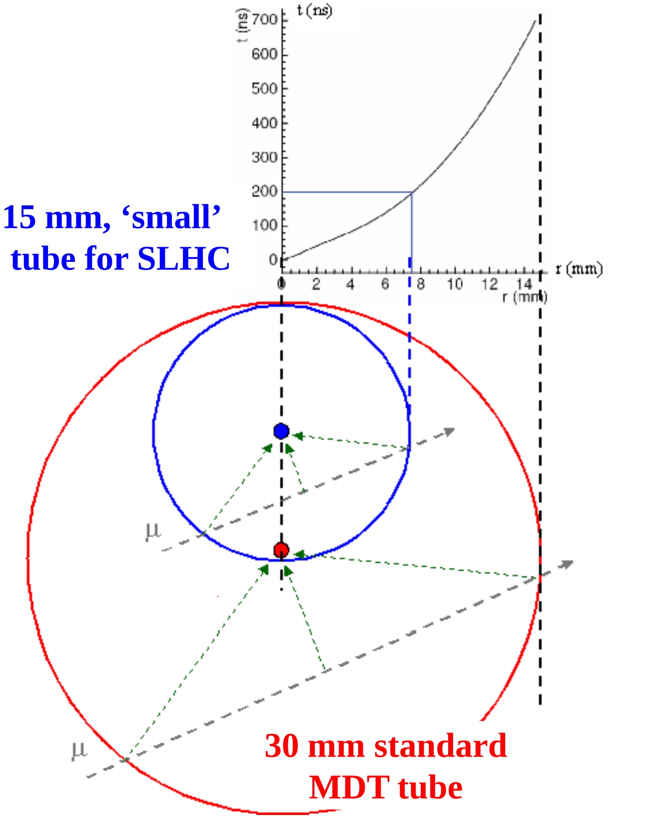
A) make better chambers ?
B) make better electronics ?

A) better chambers: new types for the 'hot' regions

- About 10-15% of the MDT chambers are in the "hot regions": i.e. ~180 MDTs from a total of 1200, corresponding to about 700 m^2 from a total of 5000 m^2
- The existing MDT chambers were not built with very high rates in mind. → The diameter of 30 mm was selected mainly for cost reasons (1992-1994).
- Why not try smaller tubes, e.g. with a diameter of 15 mm?

Small Tubes

non-lin. r-t relation is due to Ar/CO_2 gas



Small tubes have:

3.5 * shorter drift time window

2 * less conversions (less Al)

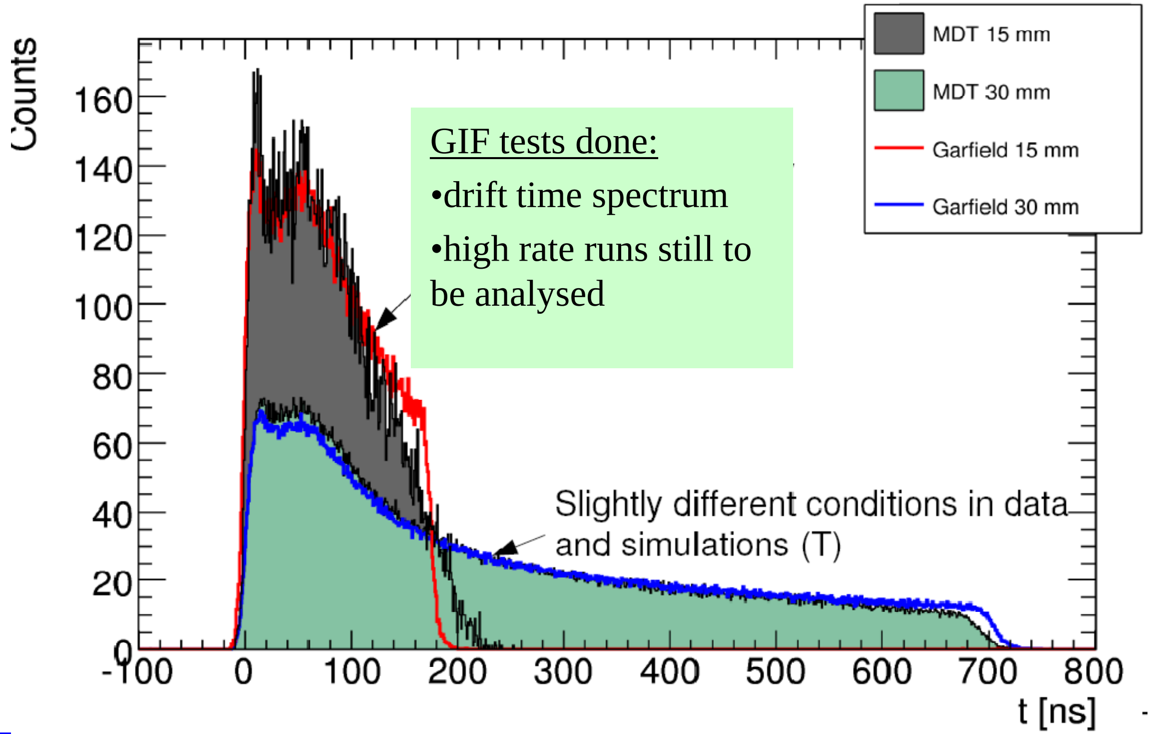
3.5 * shorter pulses

(→ less dead time → higher efficiency)

2 * less conversions (less Al)

8 * less space charge

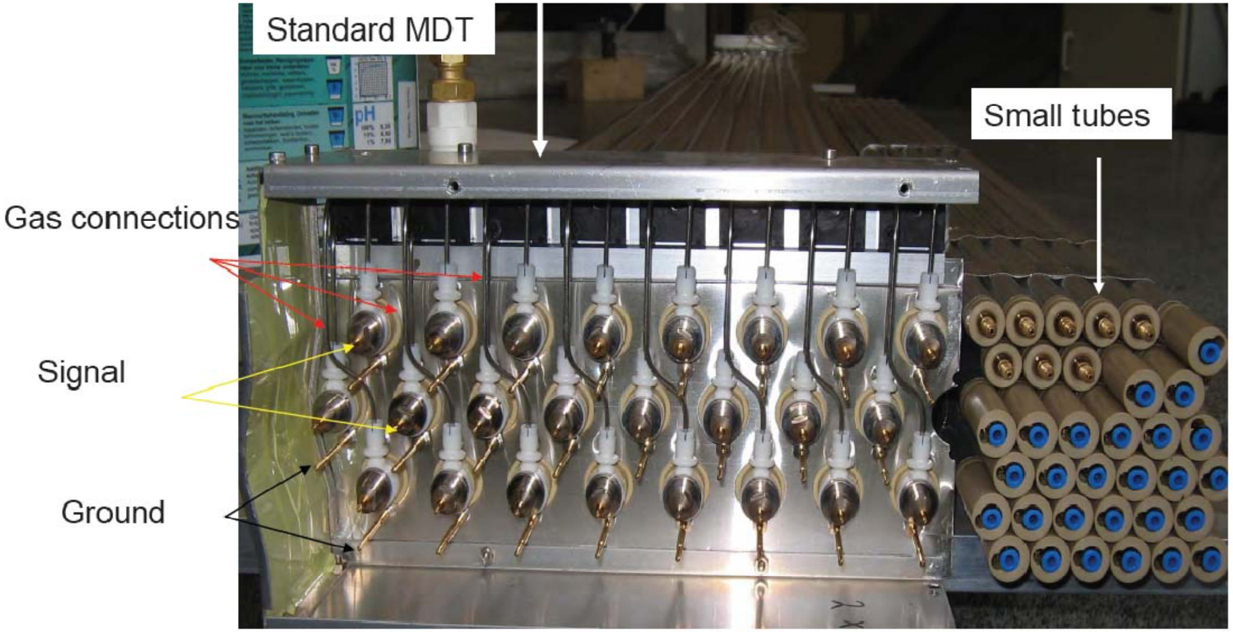
→ good candidate for SLHC



GIF tests done:

- drift time spectrum
- high rate runs still to be analysed

Challenges for the Small Tubes



One can put 6 small tube layers in the space of 3 large tube layers

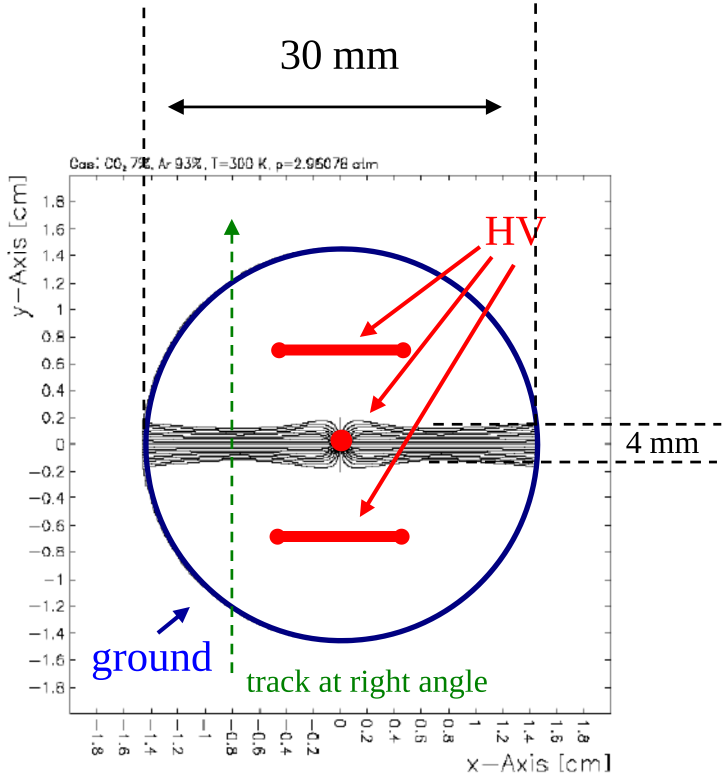
- → more robust pattern recognition
  BUT...
- more complicated services
- more electronics channels, more power

A) better chambers: Field Shaped Tubes

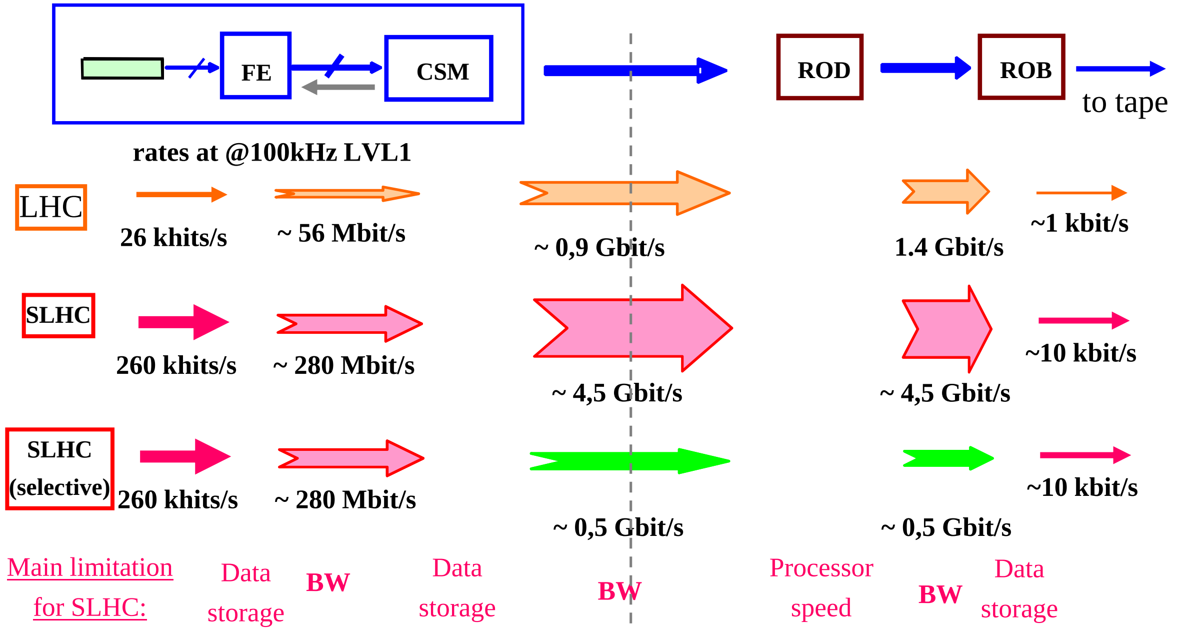
(J. Chapman et al., Univ. of Michigan)

Alternative way to obtain smaller drift cell: Field Shaped Tubes with 30 mm tube diameter

- pull electrons from unwanted regions to field plates, where no gas amplification takes place → less hits, less positive ions
- limit active drift field to a narrow slice ± 2 mm
- promising: this scheme CAN operate with 'large' tubes, so needs less electronics channels w.r.t. the Small Tubes
- BUT:
- track should pass at right angle to drift field for best resolution → need "clocking" of tubes
- Test of a demonstrator at the GIF in preparation for 2009



B) better electronics: increase BW of the entire R/O by about a factor 5 - 10



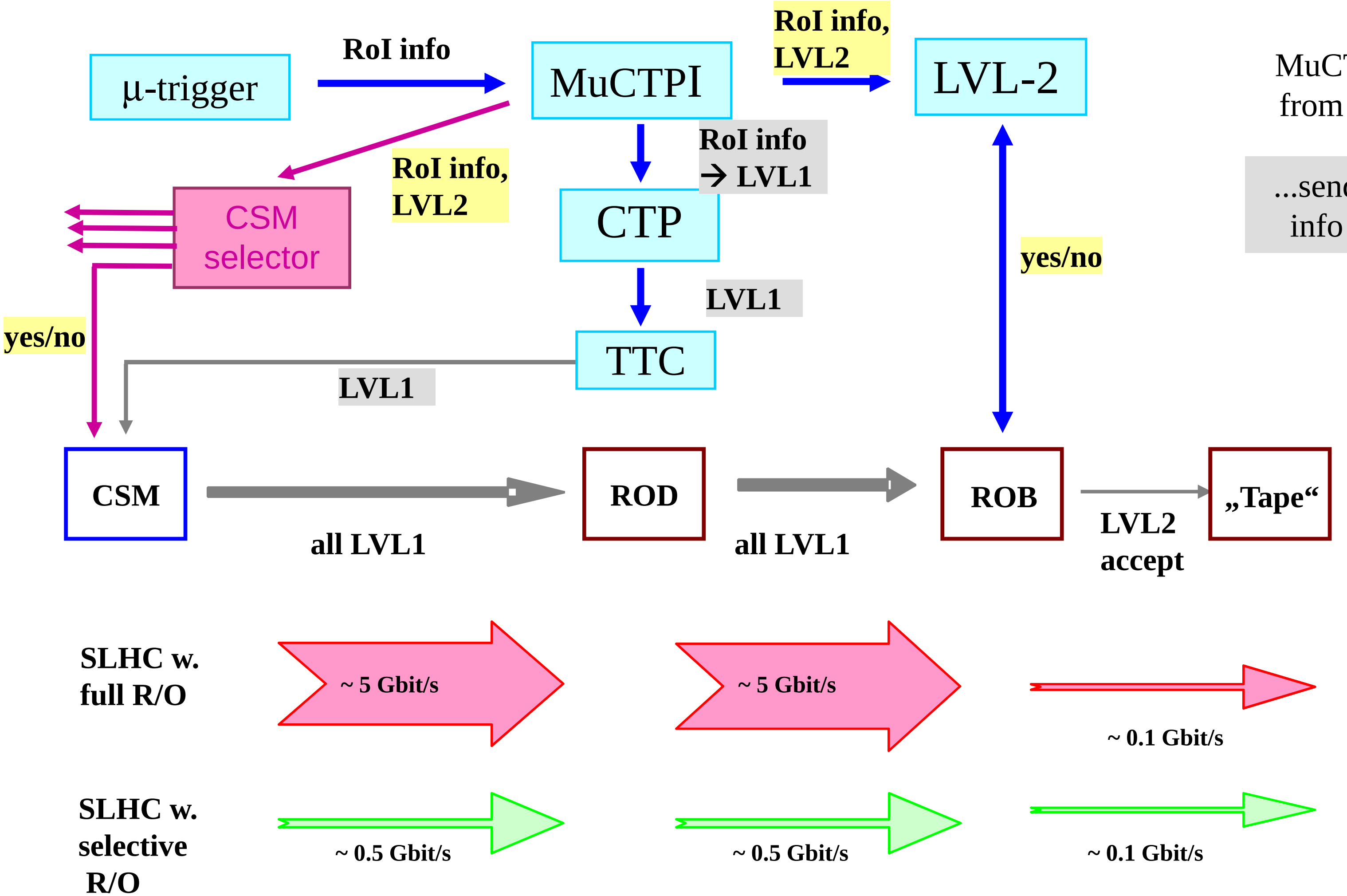
Why transfer data from chambers with only BG hits? There is no RoI pointing to them!

Reduction of data could be done <u>on the chamber</u>, using RoI info from trigger chambers

- new ASD with shorter shaping, shorter deadtime
- new TDC with more storage, faster processing, higher R/O bandwidth
- new CSM with more storage capacity, more processing power
- ~~need high BW optical links~~
- ~~need faster MRODs with more storage~~
- ~~need new ROBs with more storage, etc.~~
- ~~need more processing power & BW for the LVL2 system~~

How can the CSM "know", whether there was a RoI in his chamber?

A more complete scheme of the MDT readout chain



MuCTPI collects RoI info from all μ-trig. sources....

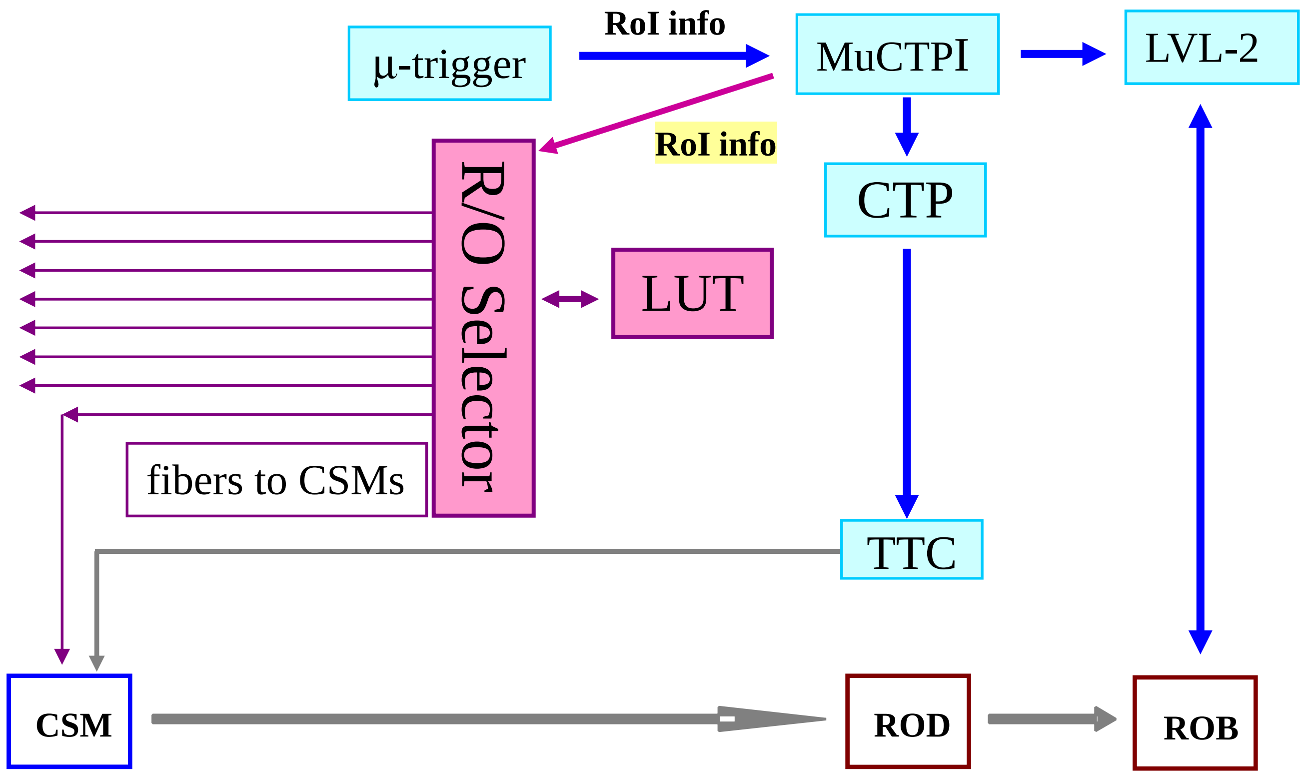
...sends „short list“ of RoI info to CTP for LVL1...

...and a detailed list to LVL2 for track ID.

This list points to regions in the MDT with fine granularity. Most MDTs are not flagged by a RoI, so don‘t need to be read out

MDTs without a RoI need not be read out → reduce data by factor 10 - 100

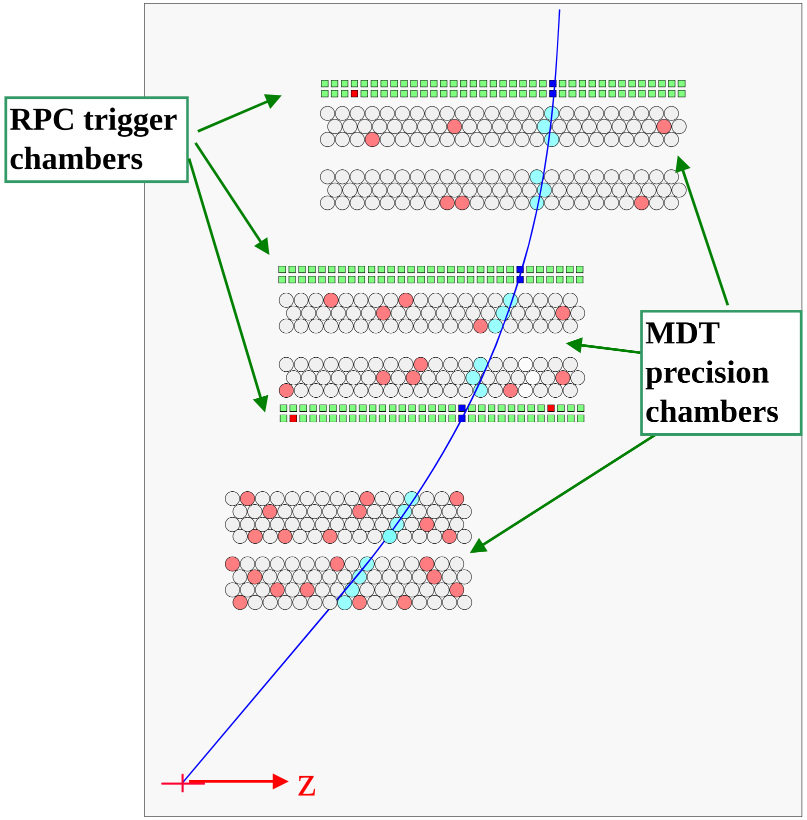
What the "ReadOut Selector " has to do



- The R/O Selector must be a programmable unit, which translates the RoI info into a list of CSMs to be read out (e.g. a tower). It sends a YES/NO info to each CSM via a fiber
- The total latency may be a few μ-sec, so the selected data arrive early enough for the LVL2 trigger to work on.
- The R/O Selector may go into a slot of the MuCTPI. The scheme could be tested in the present system, if the CSM is modified to receive the new fiber.

Tracking in a MDT tower

Hit patterns in a MDT tower (barrel)



With selective R/O, all chambers in a tower, belonging to a given RoI will be read out

Selective readout, cont.

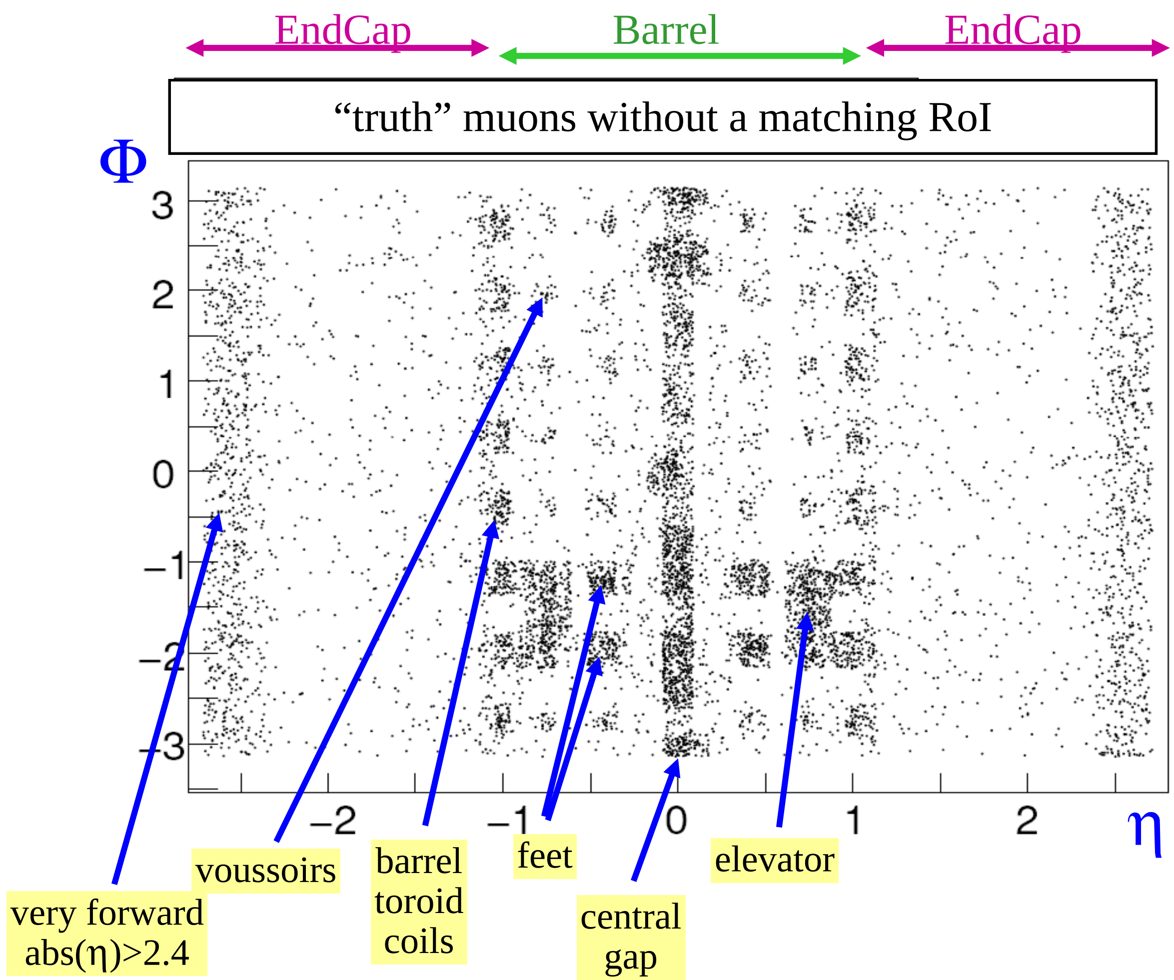
Could selective R/O lose tracks, which would have been found with the full R/O ?

Dead areas in the Muon detector, not generating a RoI

(simulation by S. Horvat)

For technical reasons, some regions of the μ-detector are not equipped with MDTs and trigger chambers. The simulation shows μ-tracks from H → 4 μ, which did not create a RoI.

(The event was „triggered“ by another μ-track at LVL1.)



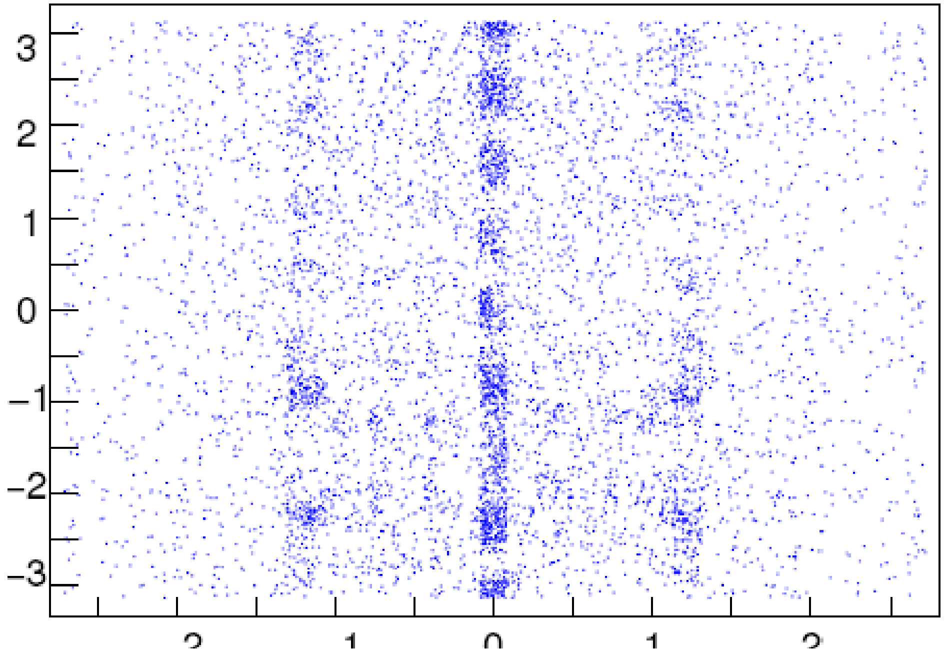
Areas in the Muon det. with MDTs, but no RPCs (trigger ch.)

In some regions there are MDTs, but no trigger chambers.
The simulation shows μ-tracks from H → 4 μ, which were generated in simulation, did not create a RoI, BUT were reconstructed in the off-line s/w.

→MDTs not matched by a trigger ch. must always be read out, because a track may still be re-constructable, however...

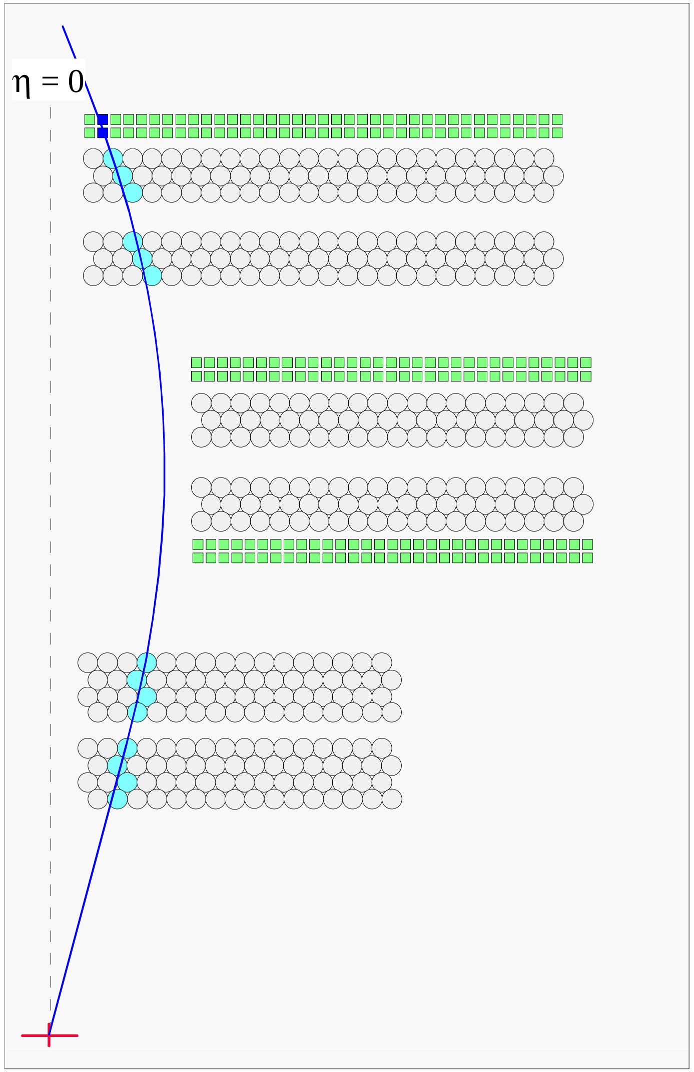
→this is only possible at low BG rates!!

"truth" muons without a matching RoI, which could be reconstructed



These tracks, pointing to MDTs w/o a trigger chamber, could be reconstructed, because there was no BG simulated and the MDTs were completely clean, so pattern recognition was possible w/o a RoI. At high luminosity this would not have been possible. Anyhow: chambers w/o trigger chamber will always have to be read out.

Untypical situation in the Central Gap



- Most chambers don't go up to the central plane (η = 0).
- Therefore this track only generated hits in the Inner and Outer Layer
- No RoI generated (event was "triggered" by a track in another tower)
- No BG-hits were part of the simulation
- Track was "reconstructed" via tube patter recognition which only works with very low BG

Summary of Selective Readout

- Selective R/O is entirely guided by the RoI information supplied by the trigger chambers
- It will not transmit track segments which did not receive a RoI and which might later be reconstructable in the offline from simple pattern recognition of hit tubes. However, this is only possible at low Luminosity (= low BG). For low luminosity mode Selective R/O is not proposed and not necessary.
- At the high BG rates of the SLHC track finding without RoI is impossible. Therefore, it is sufficient to limit data tranfer to those sets of chambers (e.g. towers) which are flagged by a RoI.
- In high BG environment Selective R/O is not prone to lose any usable data, however, it will provide a big saving in BW and storage required.

Summary on MDT Upgrade Options

At SLHC background rates the MDTs need upgrade:

Hot regions:

- use Small tubes ?
- use Field Shaped tubes ?
- MicroMegas ?
- ~ 150-180 MDTs will have to be re-built, covering ~ 600- 700 m^2

Cool regions:

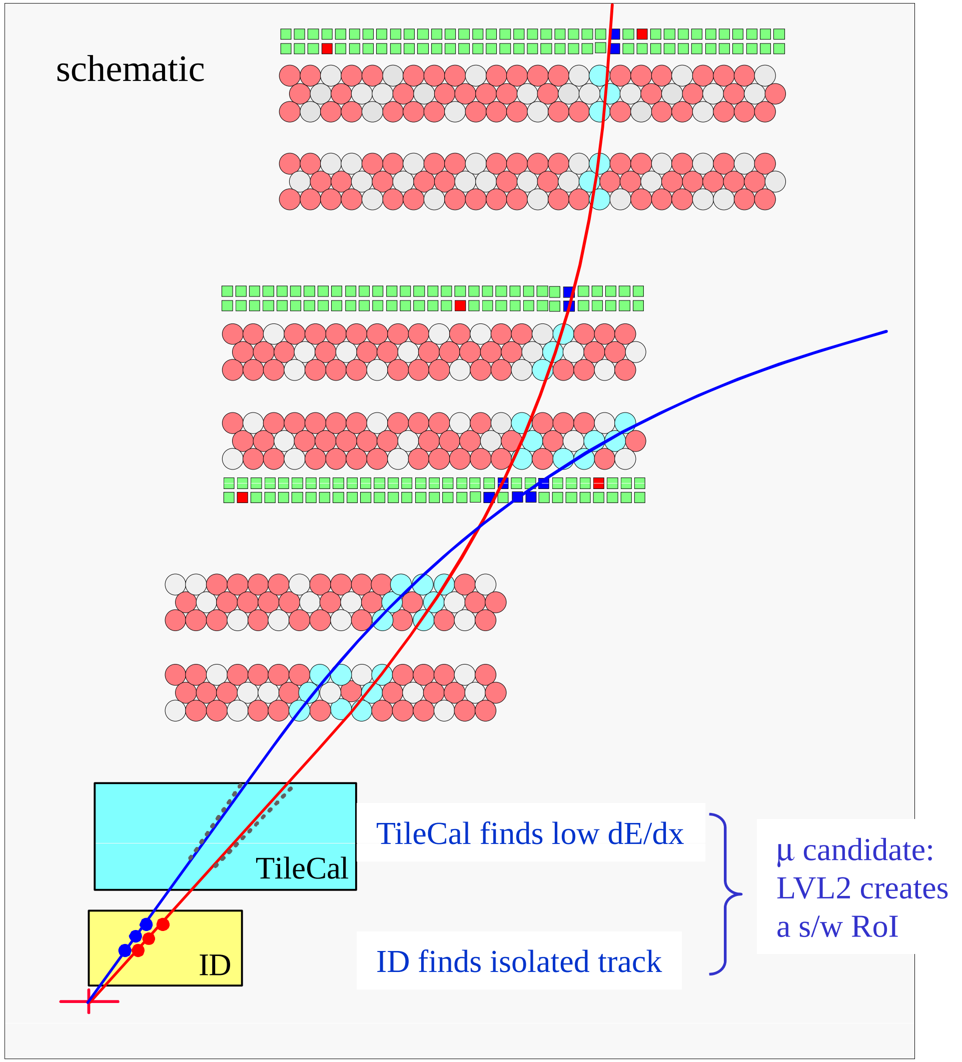
- Increased R/O bandwidth globally by factor 5-10 or
- Use selective R/O based on trigger chamber information

Everywhere in the MDT:

- FE electronics to be re-done (are there rad-tol FPGAs for SLHC ???)
- Ageing behaviour of tubes to be evaluated
- Improve rad-tol of HV/LV power supplies

Spares

Low p_T muons may be lost at η close to 1(transition region)



The convex track generates the LVL1 trigger (single μ > 6 GeV)

The concave track from (e.g. J/Ψ → μμ) may be lost because of p_T < 6 GeV (most frequent) or because of missing the BM layer AND the EC trigger (rare). Situation may be recuperated in LVL2 on the basis of ID & TileCal data (s/w RoI).

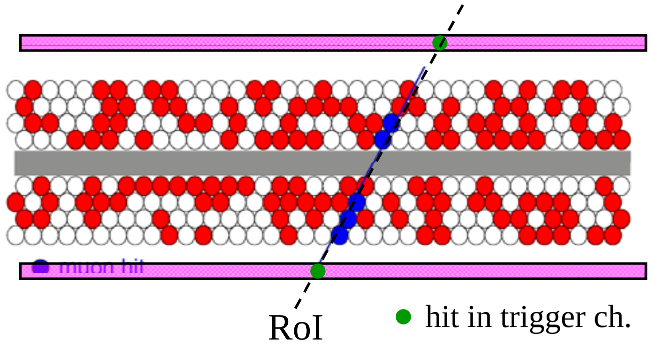
→ for low-lumi runs, data reduction via selective R/O not necessary

B) better electronics: Selective Readout of CSMs

Even at full LHC luminosity there are only about 1,5 muon tracks retained by the trigger in any given event (i.e. 1,5 RoI sent to the LVL1).

Read out only the MDTs with a RoI would reduce the data volume by a factor 10 – 100 (exception: MDTs without trigger chamber)

Optical links, MROD, ROB and LVL2 could remain unchanged



Most MDTs do not have a hit in the accompanying trigger chamber
→ no RoI → no track candidate

The MuCTPI

Octant:
processing all tr. sectors from $|\eta| = 0–2,4$
resolving e.g. double counting of tracks, boundary effects etc. for each BX

- formatting data to the CTP, ordered w.r.t. p_T
- on a LVL1all info is sent to the LVL2 system
- only 1 or 2 octants out of 16 are active in any given µ-trigger

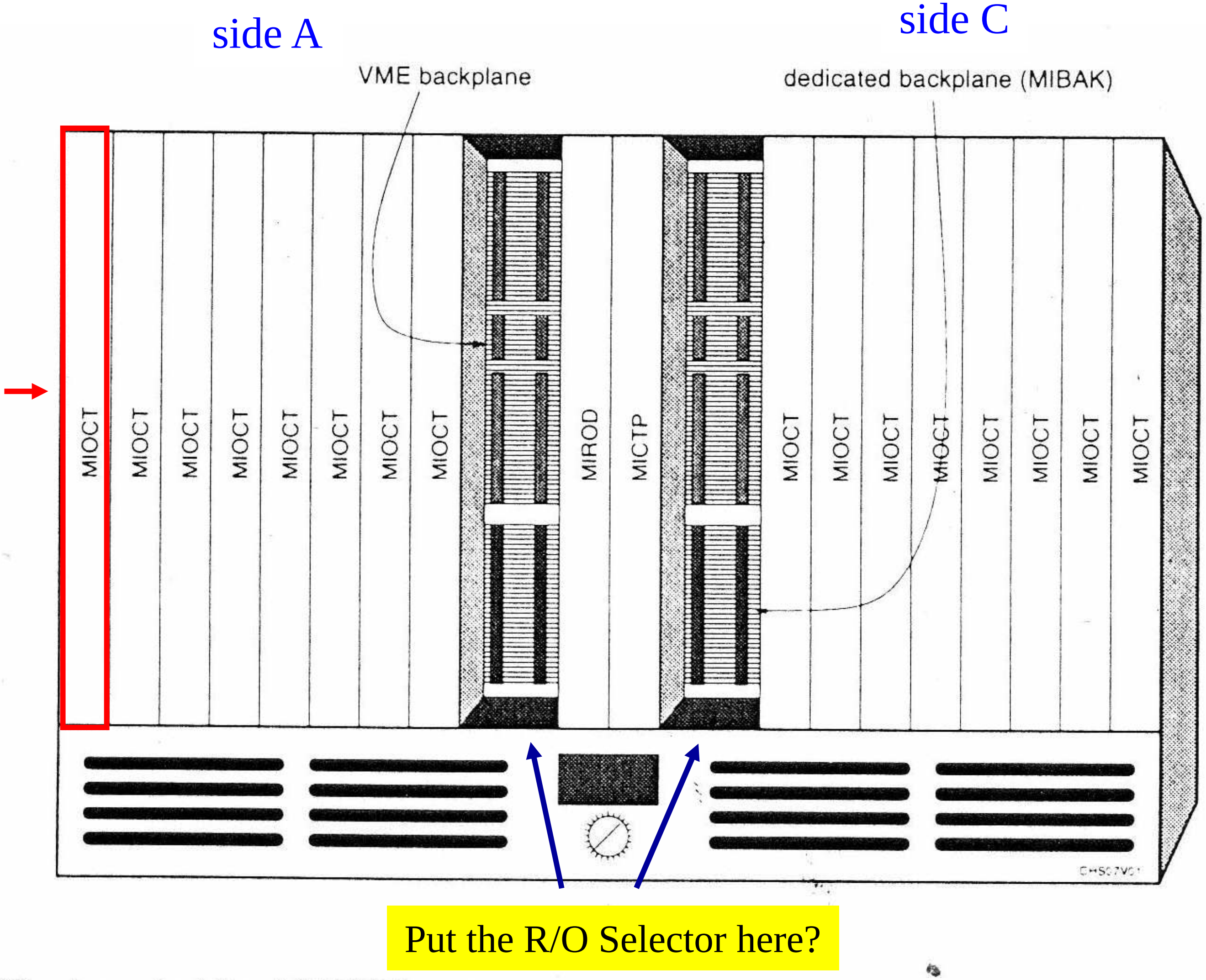
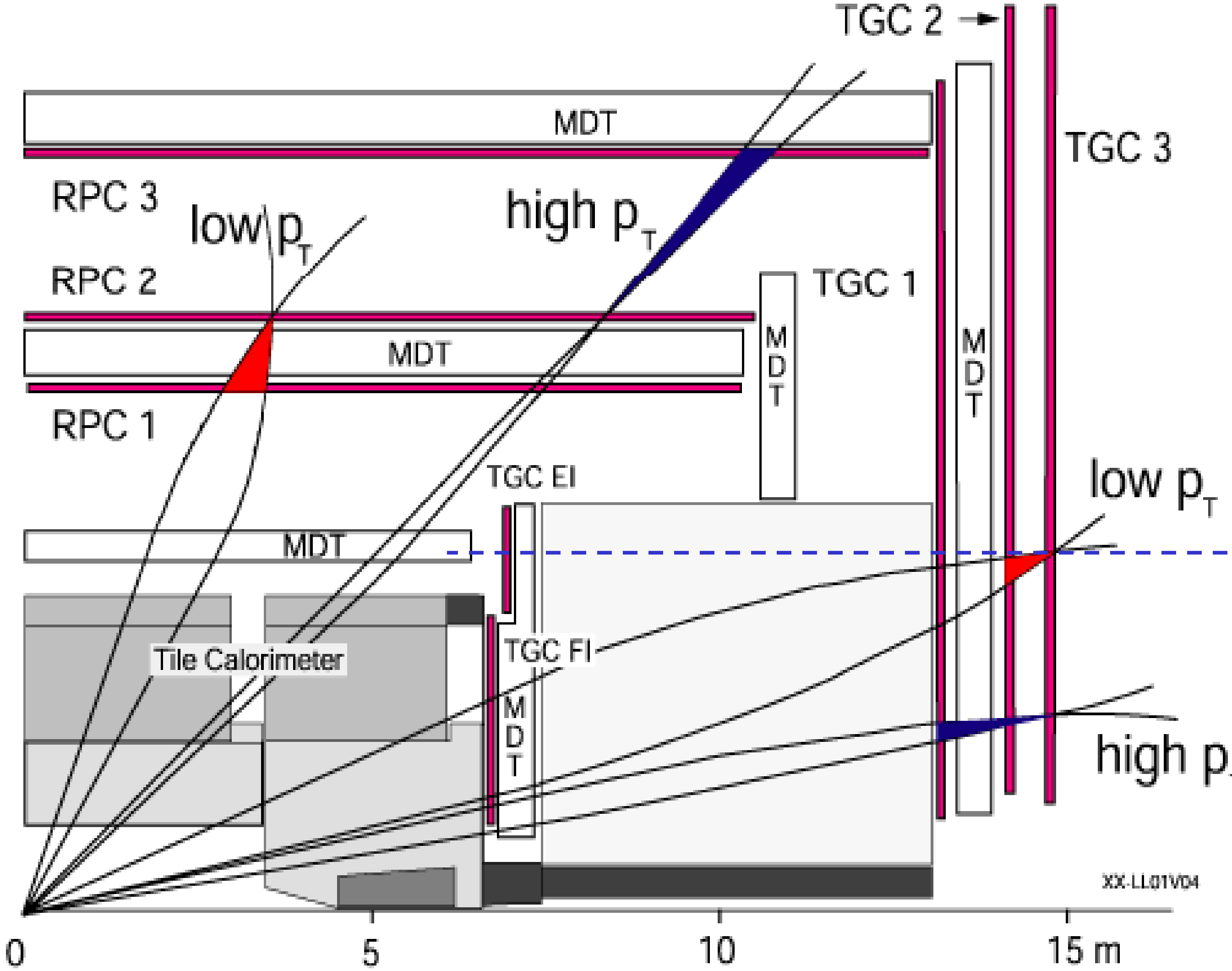


Figure 13-3 The layout of the MUCTPI crate.

Option 3: selective readout of CSMs



Enclosure of precision chambers by trigger chambers is quite tight.

There may be some losses:

-in the region of feet, coils and struts

-in the RPC/TGC transition region

-because of ϕ – components in the magnetic field (non-bending direction)

-for low p_T track close to $\eta = 1$