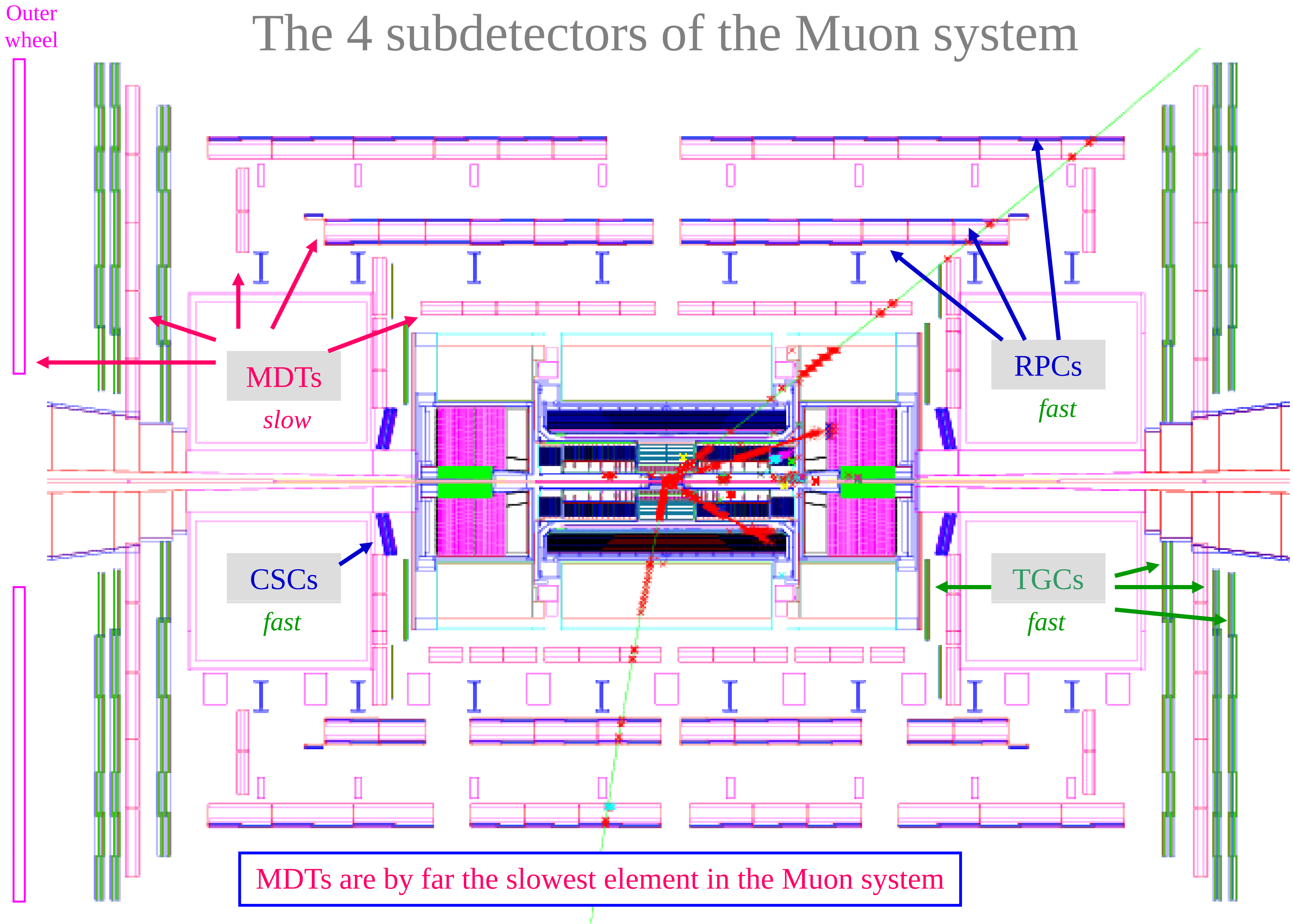
Overview

- The 4 subdetectors of the Muon system at SLHC
  - special problems of the MDT because of long drift time
    - reduced resolution because of space charge
    - efficiency because of BG hits
    - large data volume because of BG hits
  - high rate tests at the GIF facility
- Background levels at the SLHC
  - expected count rates in the MDT
- Options to solve the MDT bandwidth problem
  - Better detector ?
  - Better electronics ?
  - Better use of available information (Selective Readout) ?
- Rad-tol problems of electronics and services

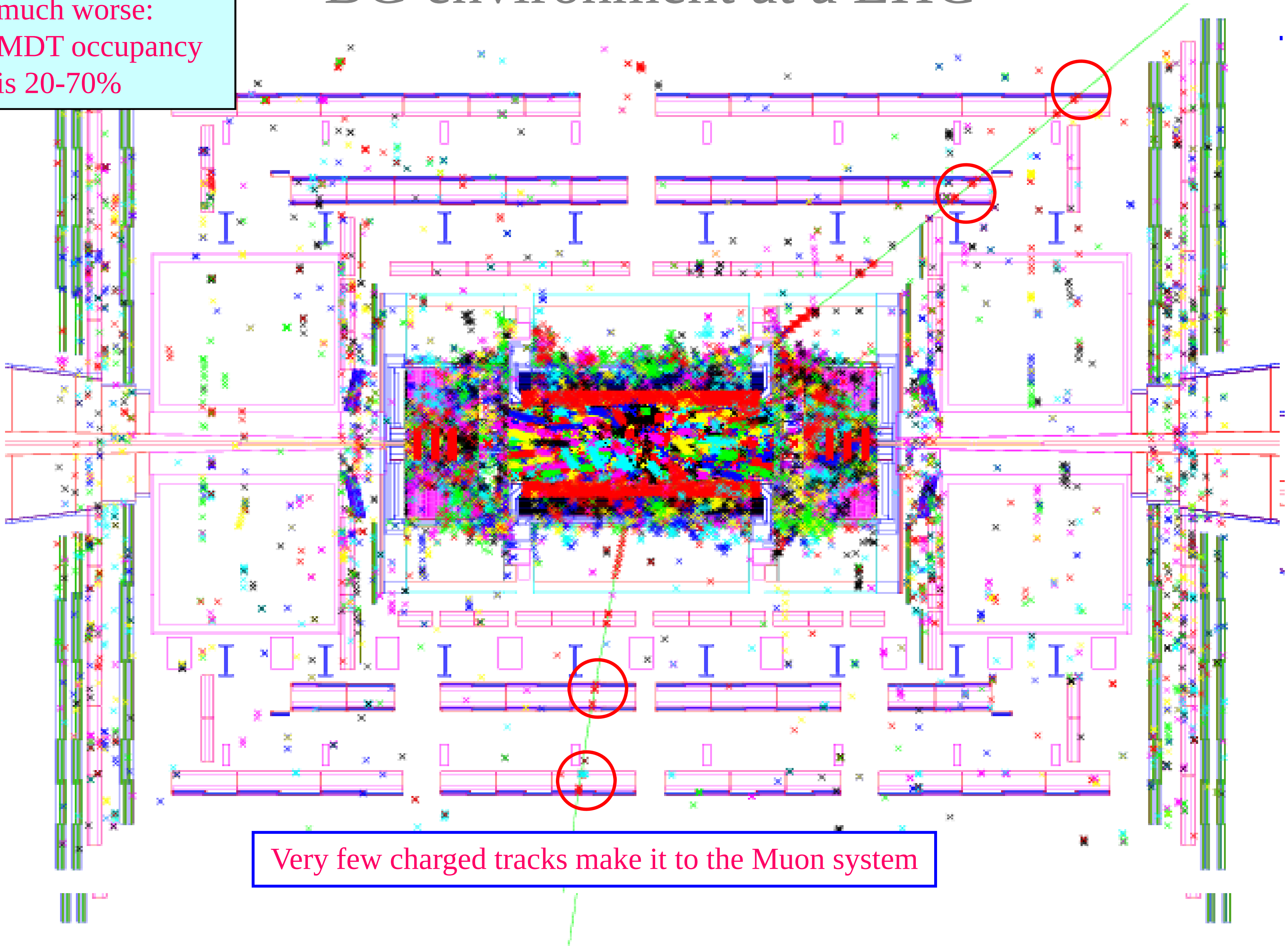
The 4 subdetectors of the Muon system



MDTs are by far the slowest element in the Muon system

BG environment at a LHC

SLHC situation much worse: MDT occupancy is 20-70%



Very few charged tracks make it to the Muon system

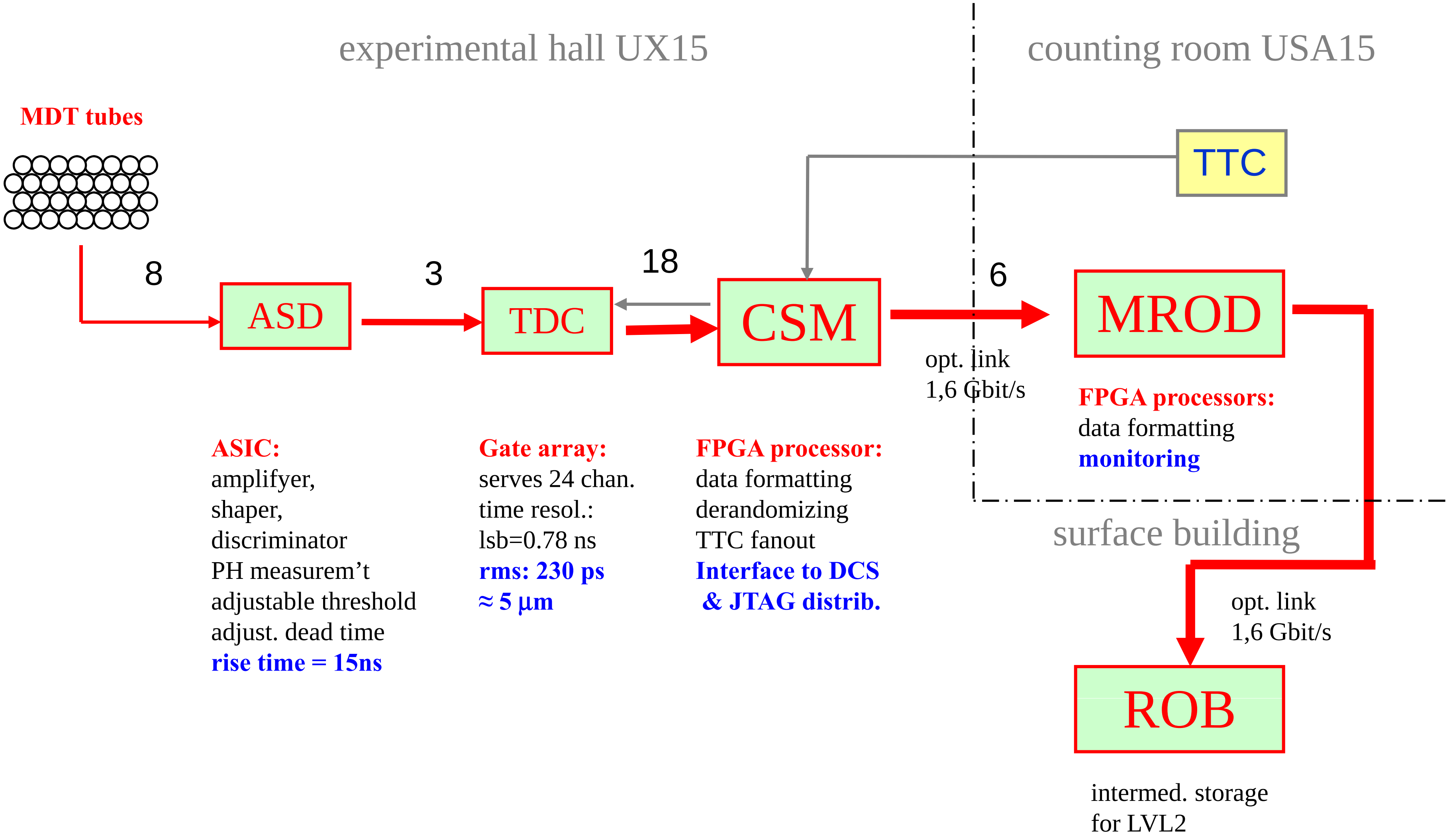
Problems of the Muon-system with higher BG

- MDTs are most exposed to accumulation of BG hits because of long drift time (30 BC) → R&D starting
  (MDT were not designed for operation at large BG)
- test at high BG done at GIF facility to test spacial resolution & efficiency → next slides
- problem: the required readout BW may exceed link capacity

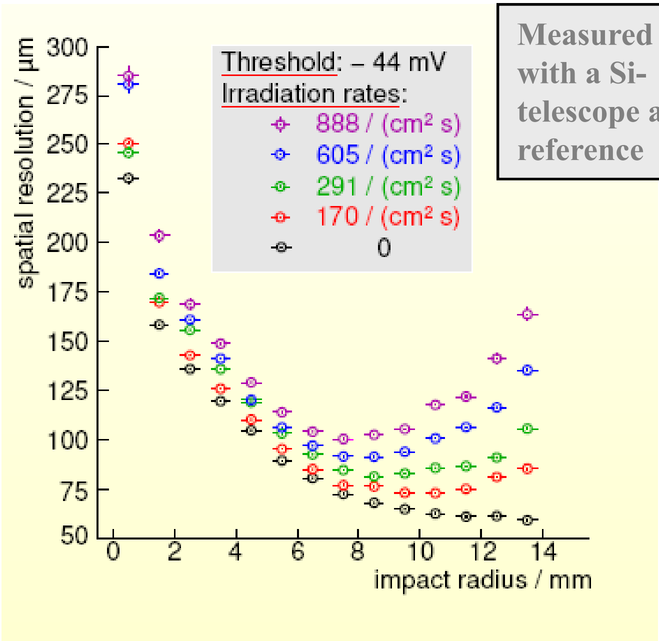
- CSCs most exposed w.r.t. local rate → R&D starting
- TGC-forward very exposed, probably needs new technology
  → R&D starting
- RPCs are probably OK, as Barrel region is relatively cool

- I will concentrate in this talk on the problems of the MDT system

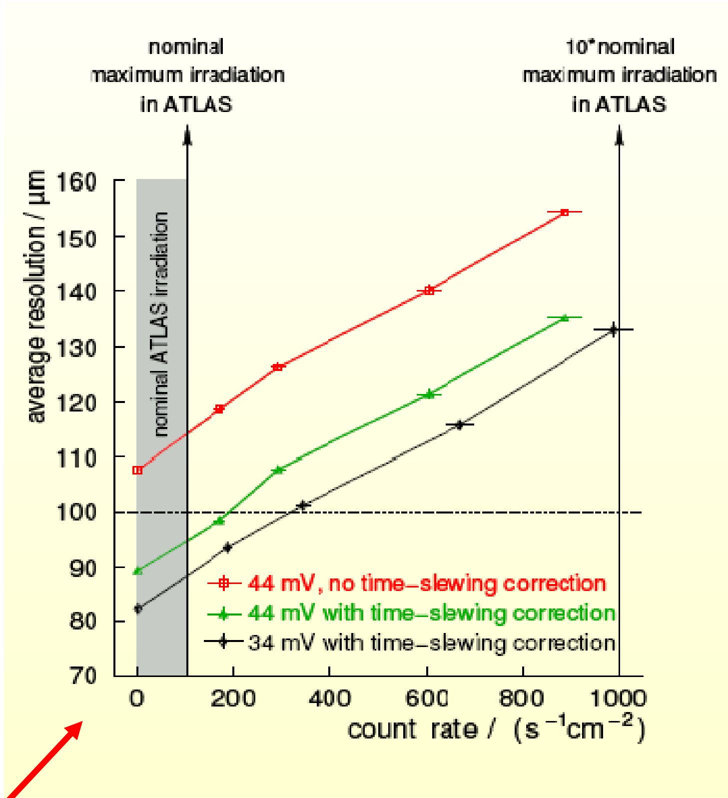
The MDT R/O scheme



Testbeam results of full MDT readout chain

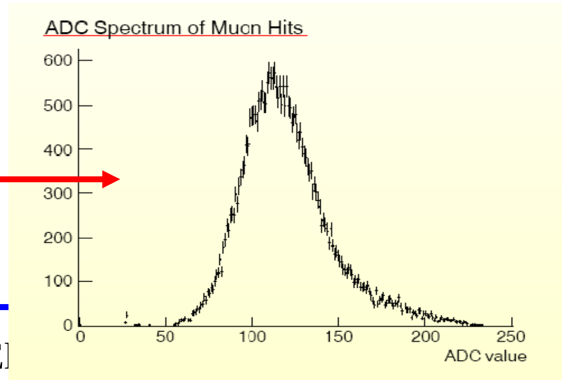


Measured with a Si-telescope as reference



Spatial resol. of MDT tubes as a function of impact radius and background irrad. in the GIF:

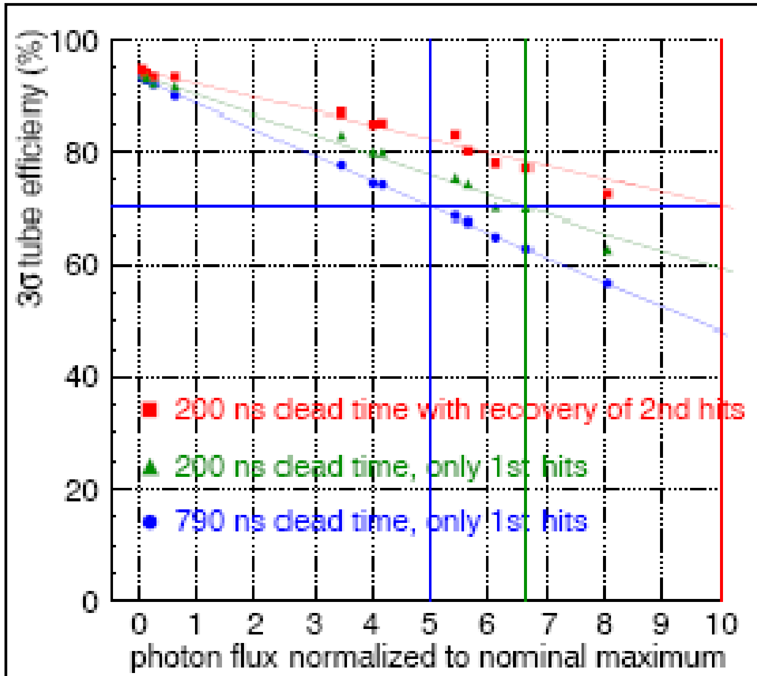
- dependence on r due to non-linear r-t relation, as expected
- dependence on background rate due to space charge
- slewing correction gives significant improvement
- performance is mainly limited by physical effects



Measured at the CERN-GIF facility by O. Kortner et al.

Other considerations about max. data rate

- reducing the deadtime of the ASD 750→200 ns improves efficiency at high hit rates substantially (O.Kortner er al.)
- increases data volume by a factor 2-3 !



Eff. vs. γ – flux (GIF 2003, O. Kortner et al.)

Is the MDT readout ready for SLHC?

Lessons from the GIF test:

- position resolution degrades *moderately* at high BG rates
- efficiency degradation is a serious problem and calls for shorter dead time → increases data volume by about 2

Test not meaningful for rate capability, as tests were done at only ~ 1 kHz trigger rate

- → Evaluate BG rates at LHC and SLHC
- → Analyze BW-limitations in the MDT readout chain

Calculations for LHC by Rad. Task Force

(M. Shupe et al.)

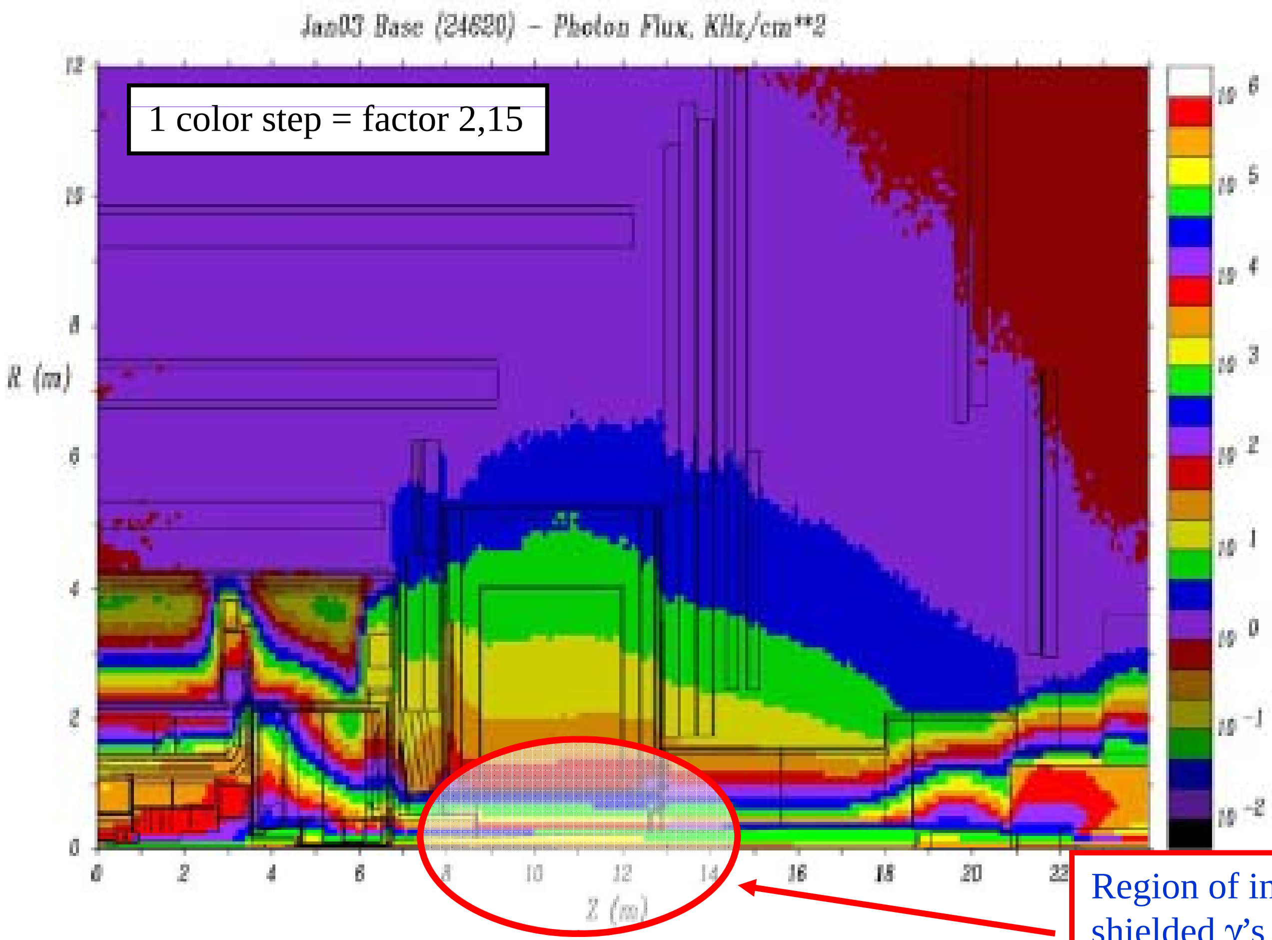


Figure 5.13 Photon flux in a full Atlas quadrant (GCALOR – Ja

Author’s conclusion: the EC (air core) toroid is essentially transparent to γ’s.

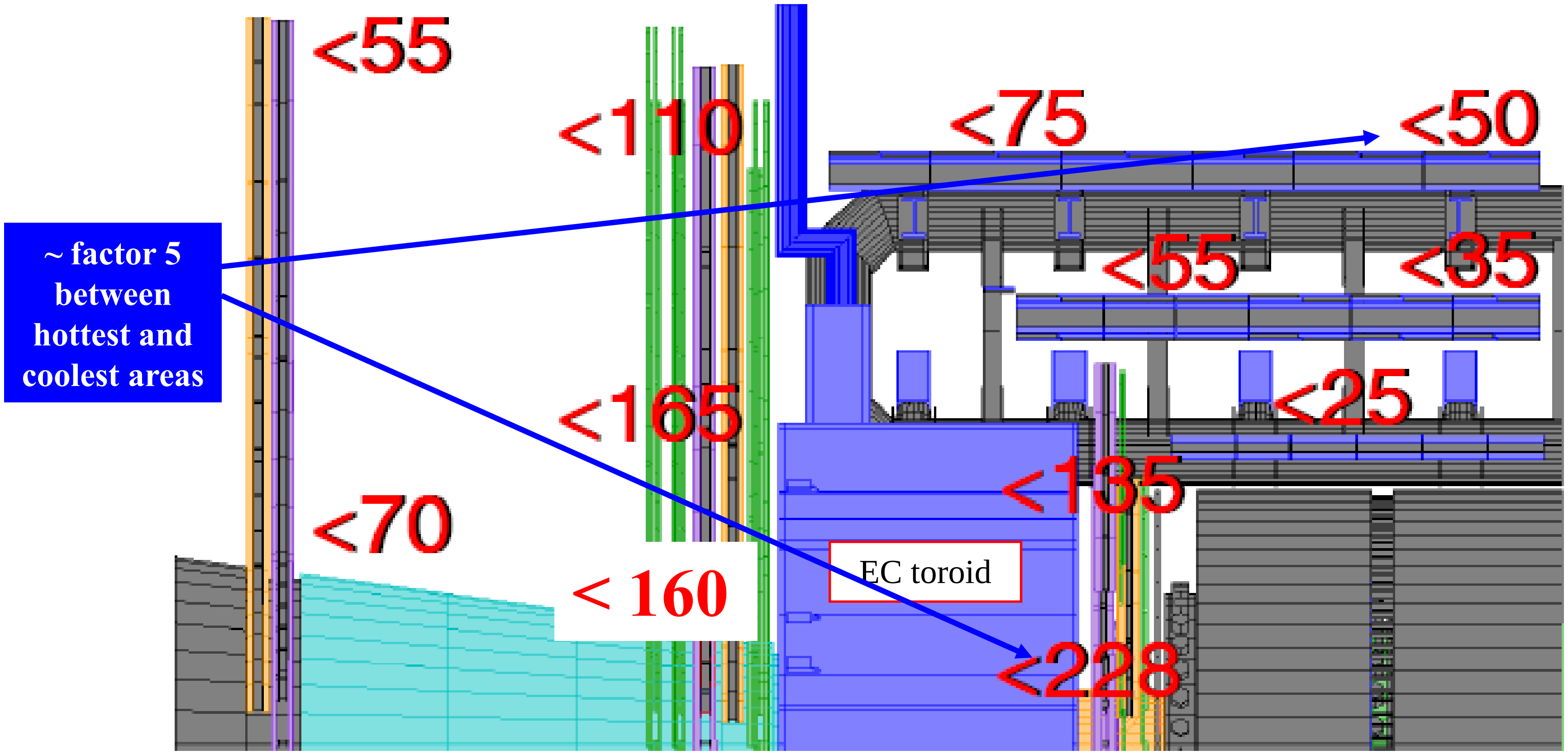
→Space between beam-pipe and inner radius of the EC toroid is already optimised for shielding (W instead of Cu brings little gain)

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

Region of insufficiently shielded γ’s which dissipate freely into the hall according to $1/r^2$

Calculated count rates per tube

Results for 5 * nominal LHC from radiation task force, 2003)



(Numbers include a safety factor of 5.)

Translating tube hit rates into total r/o BW per MDT

Example of the „hottest“ chamber (Small Wheel) in the MDT system with 230 kHz at 5 x nominal LHC:

- for each LVL1 trigger the hits are collected during 1,2 μs: at 230 kHz hit rate/tube this gives 0,28 recorded hits per LVL1 (= 27% ocupancy). This is the highest in any chamber at 5 x LHC.
- → 28k recorded hits/s at the nominal 100kHz LVL1 rate
- a MDT with 300 tubes thus records 8.3 M hit/s
- Each hit is represented by a 32 bit word + 10% overhead, so 290 Mbit/s are sent to the DAQ by this chamber
- the Gbit link has a useable BW of about 1,2 Gbit/s, so the 290 Mbit/s correspond to a saturation of the link of about 24%, which is OK

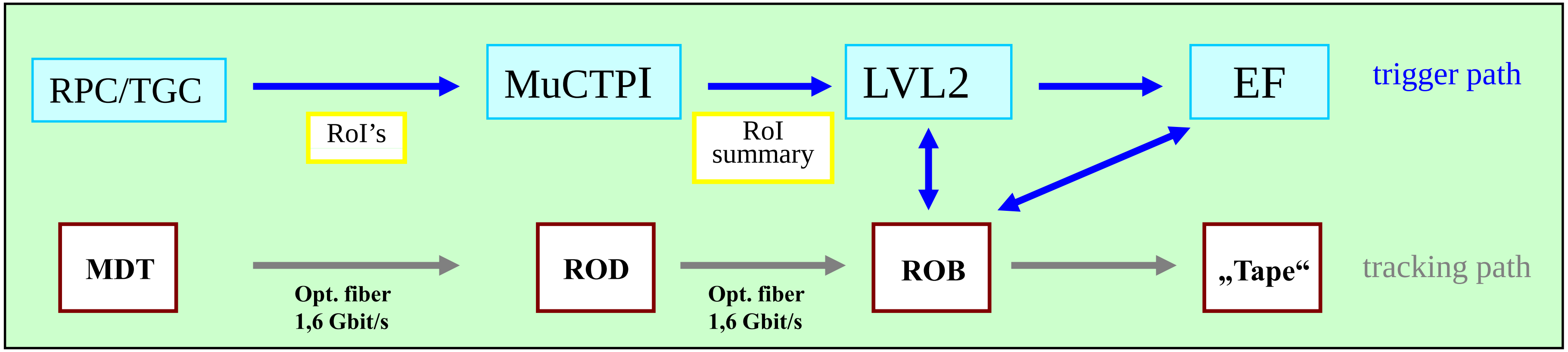
Summary of expected Hit and Bit rates for MDTs

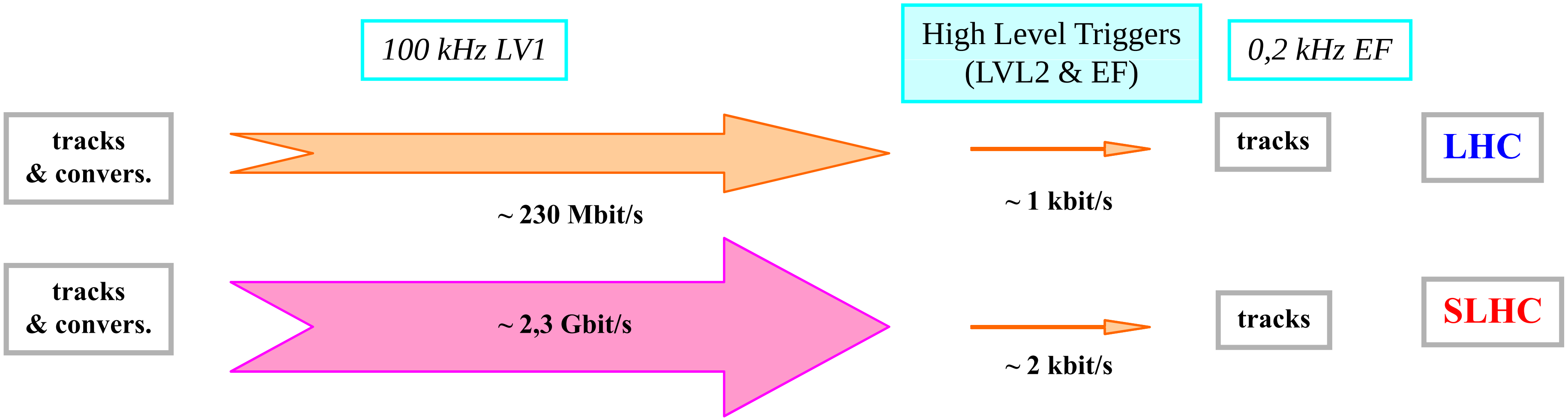
hit-rates per tube in kHz	LHC		SLHC = 10 x LHC	
MDT region	nom.	safty f. 5	nom.	safty f. 5
cool (Barrel, EO)	15	75	150	750
medium (mid BW, outer SW)	33	165	330	1650
hot (inner BW/SW)	46	230	460	2300
hit rate per chamber in MHz				
cool (Barrel, EO)	0,5	2,7	5,4	27,0
medium (mid BW, outer SW)	1,2	5,9	11,9	59,4
hot (inner BW/SW)	1,7	8,3	16,6	82,8
Data rate per ch. in Mbit/sec				
cool (Barrel, EO)	19	95	190	950
medium (mid BW, outer SW)	42	209	418	2091
hot (inner BW/SW)	58	291	583	2915
saturation of BW				
cool (Barrel, EO)	1,6%	7,9%	15,8%	79,2%
medium (mid BW, outer SW)	3,5%	17,4%	34,8%	174,2%
hot (inner BW/SW)	4,9%	24,3%	48,6%	242,9%

- tubes/chamb.: 300
- sensitive time: 1,2 µsec
- LVL1 rate 100 kHz
- avg. # bits/hit: 32 + 10%
- useful BW: 1,2 Gbit/s

→ Bandwidth of present MDT readout system is not sufficient for SLHC, even not at a safety factor < 5

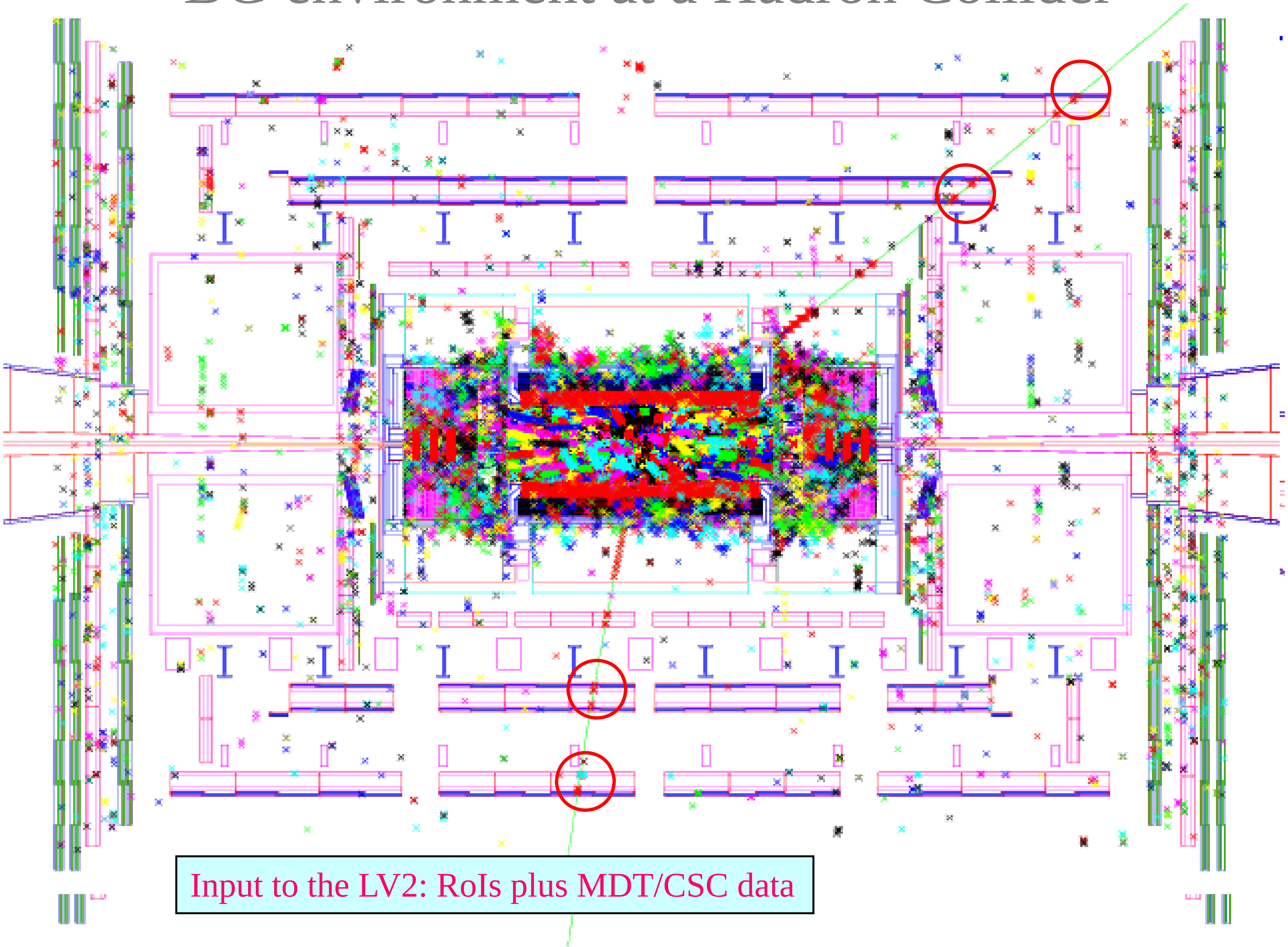
MDT data volume & bandwidth per chamber





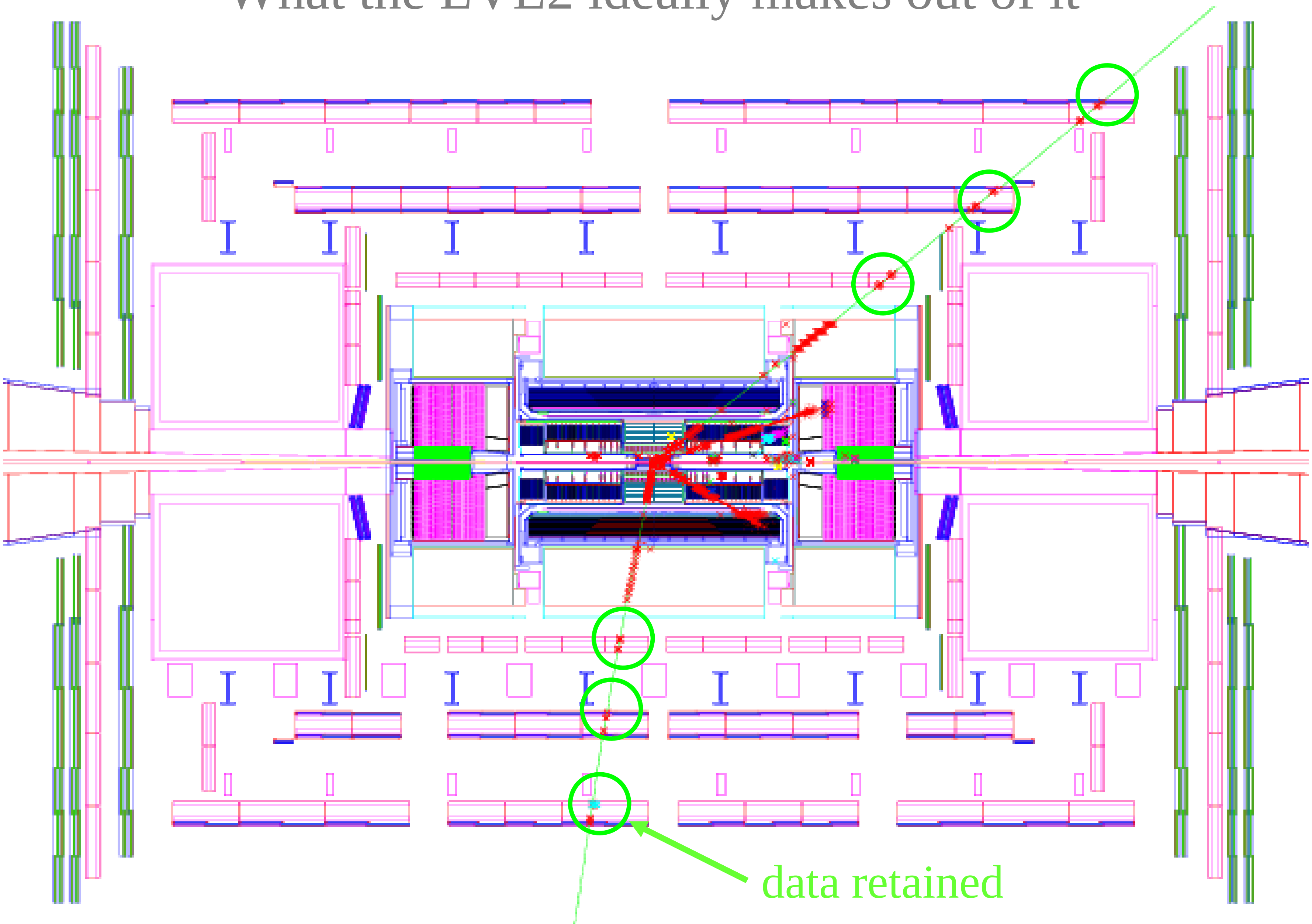
→ Unlike the ID, the Muon detector contains very few tracks per event (avg. ~ 1,5)
→ Most of the conversions are removed in LVL2 and in the Event Filter (EF), using the RoI information delivered by the trigger system.

BG environment at a Hadron Collider



Input to the LV2: RoIs plus MDT/CSC data

What the LVL2 ideally makes out of it



Options to solve the BW problem

Option 1: new MDTs from smaller tubes

If tube diameter was e.g. 50% of the present value:

- 50% of the background rate
- ~ 20% of the drift time (non-lin. r-t relation)

} → 10% data vol.

- can put more tubes along the track → improved pattern recognition
- → this is the ideal solution

BUT:

- more electronics channels, new mech. & electr. services → R&D, manpower, time, money
- this affects about 15-20% of the MDT EC chambers: not a small project

> The existing MDT chambers were not built with extremely high rates in mind.
> The diameter of 30 mm was selected mainly for cost reasons.

Option 2: increase BW of the entire R/O by about a factor 5 (brute force)

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

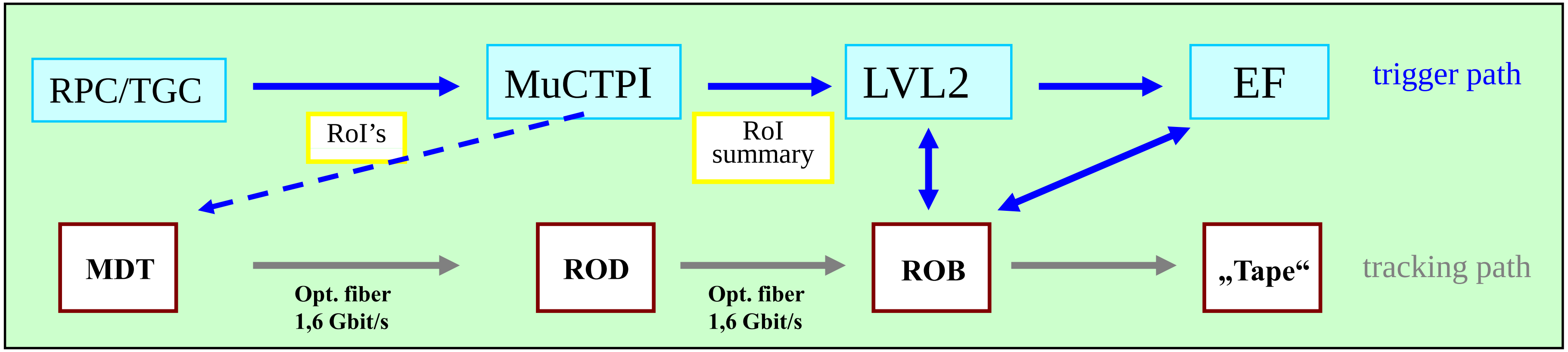
→ can be done, but not 'elegant'; requires big changes also for the off-detector elx; cost is hard to evaluate

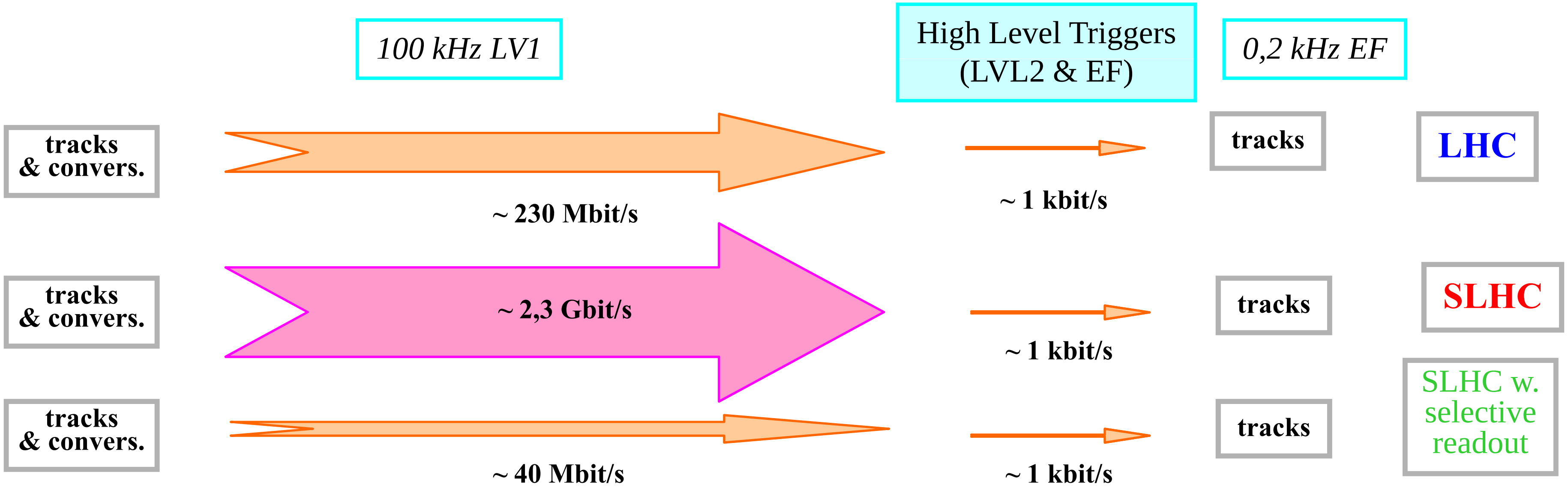
→ Why transfer 100% of the data, if only ~1% will be used?

Option 3: selective readout of MDTs

- unlike e.g. the ID, the muon detector is very poor in tracks
- even at full LHC luminosity there are only about 1,5 muon tracks retained in any given event (i.e. 1,5 RoI sent to the LVL1).
  - → only about < 10 chambers have "useful tracks" = tracks above ~ 6 GeV, while about 1190 chambers have only BG hits
  - this fact is "known" early in the event, because no RoI is assigned to an empty chamber
  - the MuCTPI collects the RoI info and forwards it to the LVL2
  - the LVL2 rejects/confirms the muon trigger solely on the basis of the RoIs & never looks at chambers without RoI.
    Only data corresponding to a RoI are later written to tape
- a generous readout scheme reading the MDTs in the RoI plus adjacent ones would still reduce the data volume by a factor > 10
- Once the data volume reduced, optical links, MRODs, ROBs and LVL2 could remain unchanged
- only ON-chamber elx, TDC and CSM would need modification

MDT data volume & bandwidth per chamber





→ Use RoI information to reduce data volume at the source → reduce required BW

RoI info provided by the Muon trigger system

Example: Format of the input data to the MuCTPI (Endcap part of the TGC)

X	X	BCID			Pt 1	Pt 2	O2	RoI 2	O1	RoI 1
31	30	29 28 27	26	25	24 23 22	21 20 19	18	17 16 15 14 13 12 11 10	9	8 7 6 5 4 3 2 1

- from the RoI the location and coarse momentum of the track can be derived
  - location: sector and subsector (RoI 1, RoI 2)
  - momentum: which of the 6 p_T-thresholds was passed (Pt 1, Pt 2)
  - there are flags for tracks passing close to sector boundaries (O1, O2)
- → the RoI unambiguously points to the chambers transversed by the track
- idea is to omit readout of those MDTs, to which no RoI is pointing
- this leads to a reduction of the data volume by a factor 50-100
  → opt. link, MROD and ROB see only a small data flow and will be less busy than at LHC

The fine granularity of the trigger sectors allows a 2-dim localization of the track candidate at the LVL2 level (example: TGC)

A trigger sector in the EndCap-part of the TGCs

6 x 8 = 48 per side

In addition there are 3 x 8 = 24 trigger sector in the FrontEnd-part of the TGCs

In total: 72 tr. sect. per side and 144 in the whole system.

Position information down to the subsector level is passed to the MuCTPI

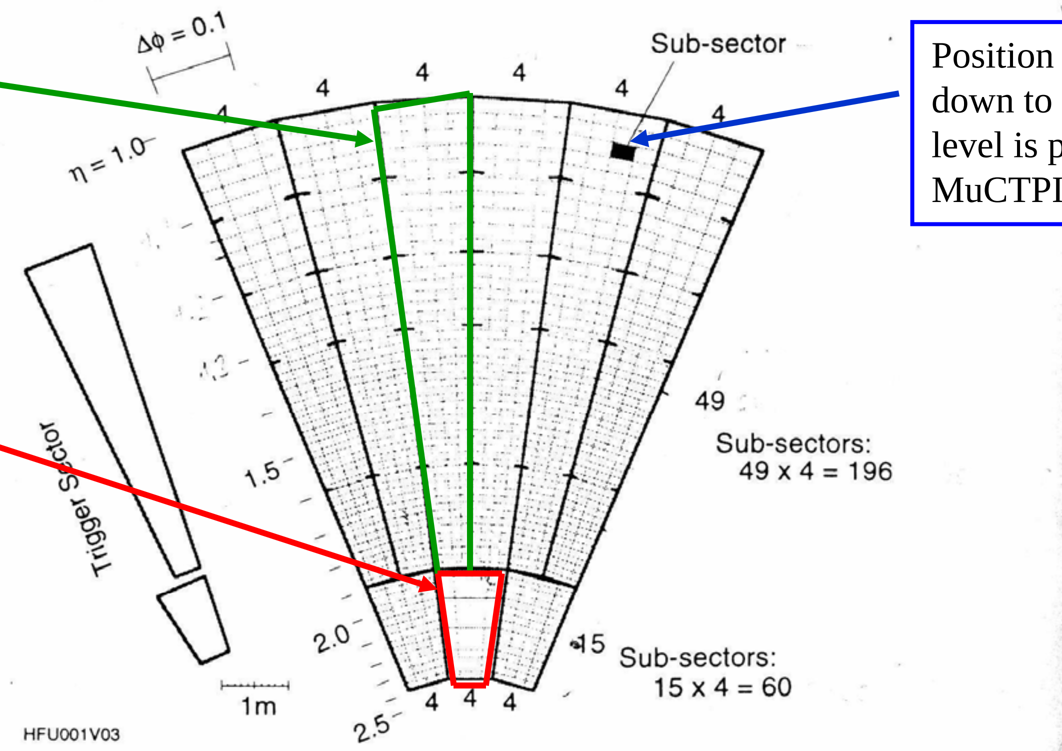


Figure 12-6 TGC level-1 trigger segmentation for an octant. One octant wheel is divided into six End-Cap sectors and three Forward sectors. Bold lines in the figure indicate individual trigger sectors. They are further subdivided into trigger subsectors.

The RPCs in the barrel are segmented in a similar, less fine grained way.

Data flow from trigger ch‘s to MUCTPI & CTP

The MuCTPI sends a short list of the RoIs to the CTP, which decides on LVL1.

On a LVL1 the MuCTPI sends a long list of RoIs to the LVL2, which looks at the MDT hits in the RoI.

Spying on this list the relevant MDTs can quickly be activated for readout.

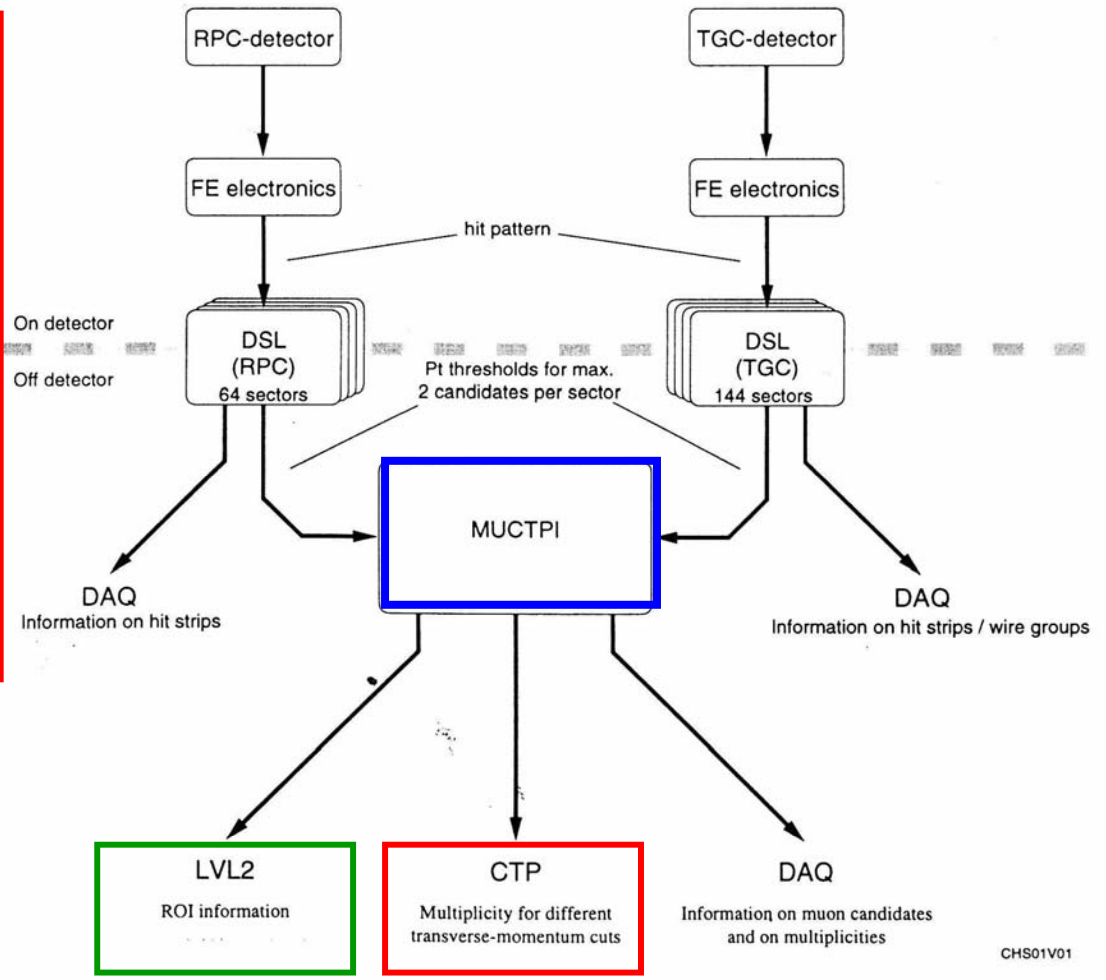
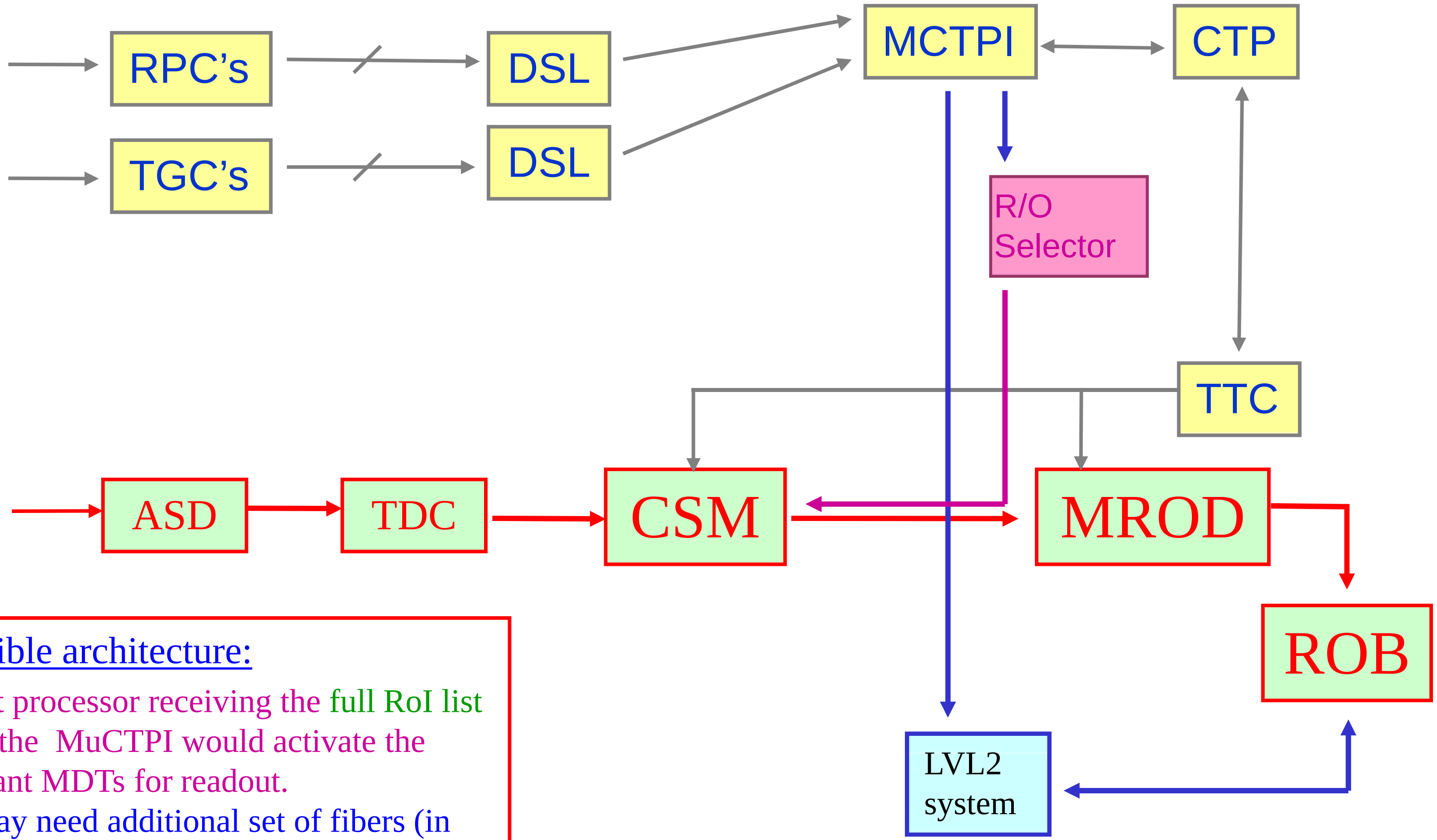


Figure 13-1 Data flow in the muon-trigger system.

A possible scheme for selective MDT readout



<u>Possible architecture:</u>

A fast processor receiving the full RoI list from the MuCTPI would activate the relevant MDTs for readout.

→ May need additional set of fibers (in the GBT system it could be done over the TTC fiber)

Option 3: selective readout of CSMs

Summary on selective readout

(possible problems, requiring more study)

- boundary effects: as the field is not strictly toroidal, tracks may migrate to a chamber in an adjacent sector, which has no RoI. In this case a part of the track may be lost (Φ-migration of track)
  - solved by the MUCTPI inside an octant, but not among octants
  - make use of boundary flag in RoI word
  - simulation needed to look for possible track loss
- there is some latency for the LVL2: on reception of the RoI list, the LVL2 must wait until selected data arrive in the ROBs
- these studies being successful, selective readout seems the way to go (cost, labour, scope of total modifications)

Work to be done

- Need working group between TDAQ and MDT people to define:
  - simulation studies
  - interface lines, data transfer, timing
  - prototype development
- MDT people to define specs for new TDC (needed independently of selective R/O)
  - increased storage capacity
  - technology
  - common development with other groups?
- MDT people to think about CSM upgrade
  - new FPGA ?
  - interface to optical link (GBT ?)

Rad-tol issues

Muon system exposure to increased rad. levels at SLHC

- Electronics on the MDT frontend
  - most components only certified up to LHC levels., e.g.
    - VIRTEX-II FPGA → is VIRTEX-IV more rad-tol ?
    - Toshiba gate-array (TDC) → new design as a monolythic
    - ELMB → replace by GBT branch ?
- → Similar problems for other subdetectors
- All power supplies of the Muon system are in UX15 (*about 1000 units)*
  - exact limit of tolerance not known, needs more testing
  - perhaps only exchange critical components, like
    - power MOSFETs?
    - CMOS processors?
- Rad-tol is common problem of SLHC. The best would be
  - a common approach among experiments and subdetectors
  - a strong involvement of ESS for techn. expertise and coordination

Summary

At SLHC background rates part of the MDTs need upgrade:

- decrease tube diameter or — R&D
- increased R/O bandwidth or — R&D
- use selective R/O based on trigger chamber info — R&D

- improve rad-tol of HV/LV power supplies — R&D

- 3 Expressions of Interest submitted to the ATLAS Upgrade Committee — R&D

Spares

Total neutron and photon flux

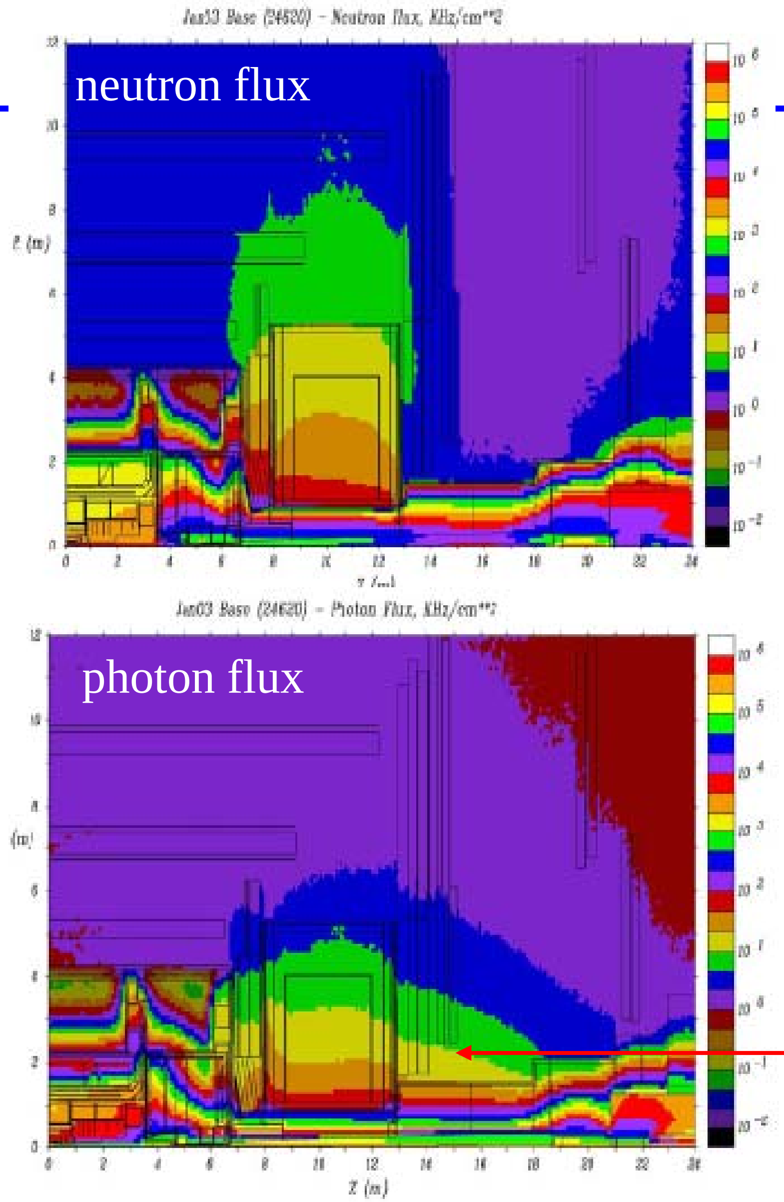
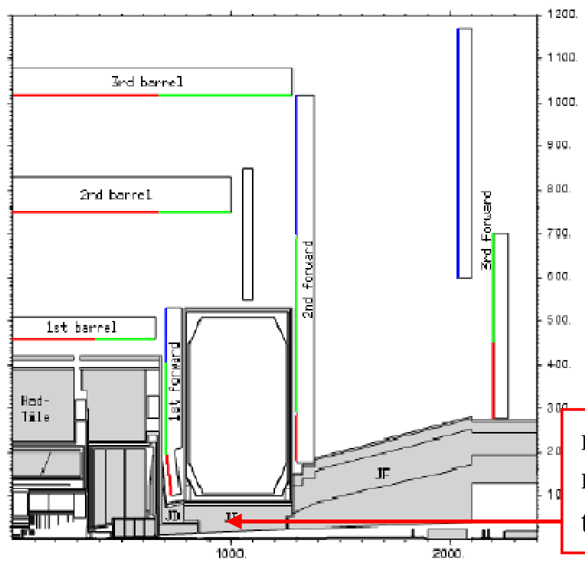


Figure 5.13 Photon flux in a full Atlas quadrant (GCALOR – Jan03).

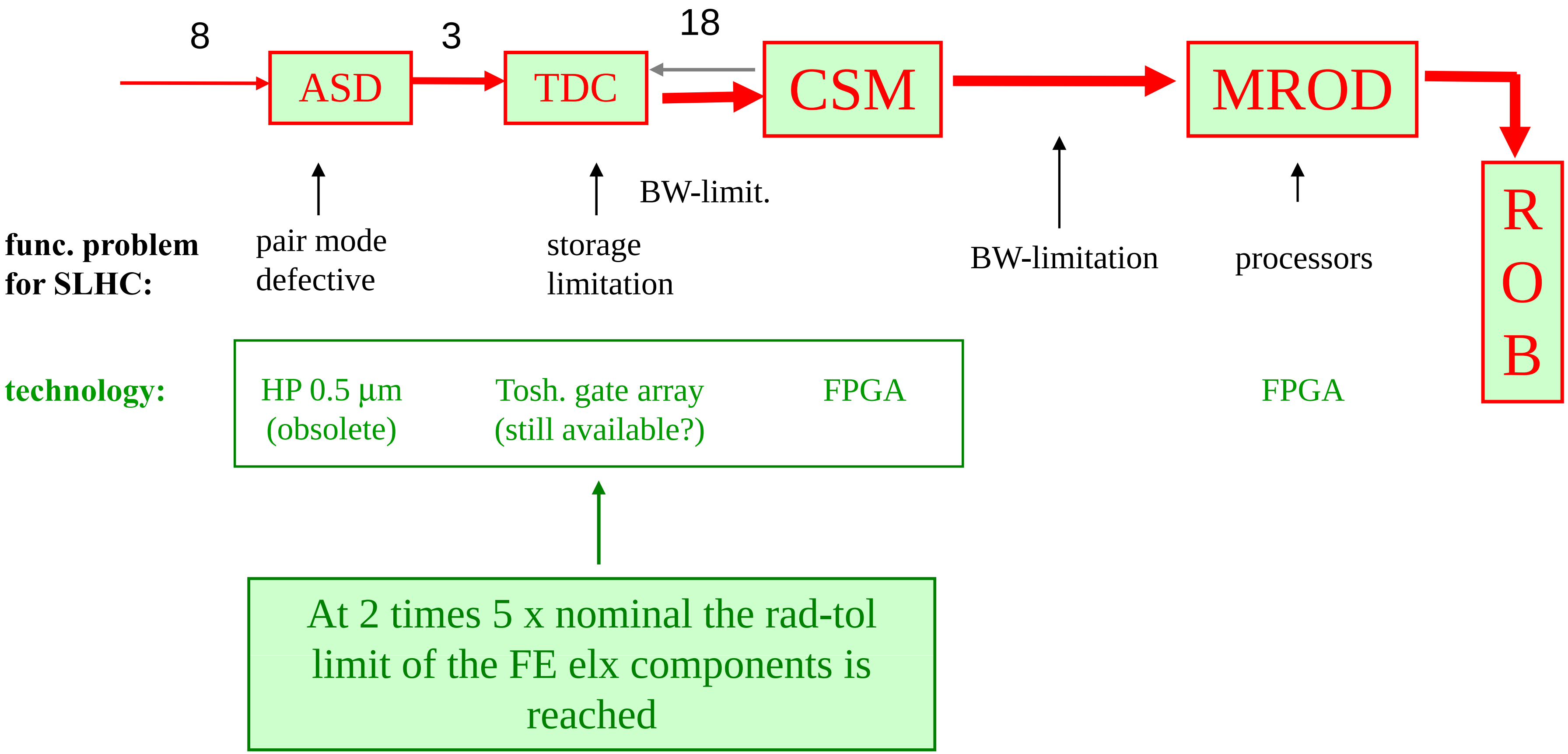


region of main n/γ leakage into the EC

Figure 4.18 The Atlas geometry in the FLUKA AV16 configuration, similar to "Aug01" GCALOR layout with previous JF concept: the picture represents a simple slice at a fixed phi angle. Horizontal axis gives Z in cm and the vertical axis R in cm. The old muon chambers positions have been kept for backward compatibility with earlier estimates.

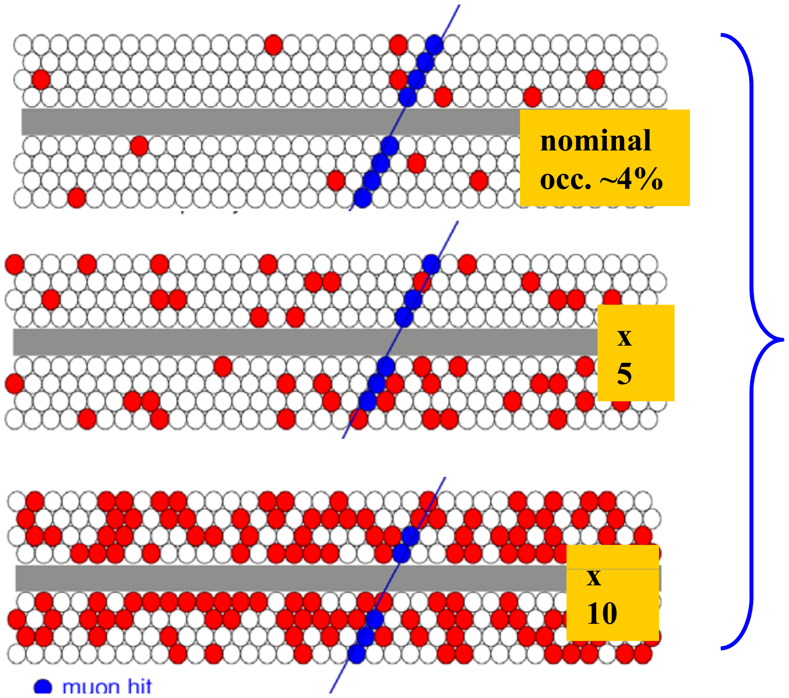
in the region of the BW-tip the γ -distribution does not correspond to the n-distribution → 'prompt' γ's from hadron showers created in the beampipe and shield are dominating NOT γ's from conversions of thermal n's

Limitations of MDT elx at high hit rates

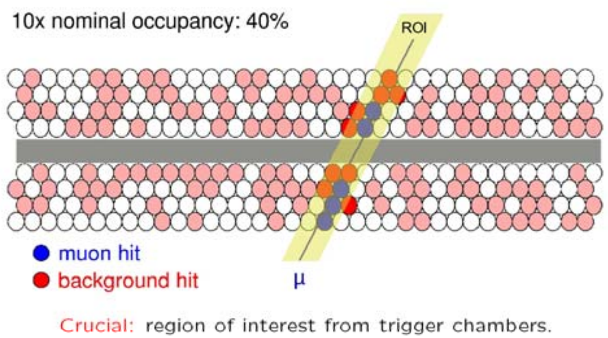


Track finding with LVL2

Typical hit Patterns in a MDT (O. Kortner)



In each of these 3 cases the LVL2 needs the guidance from a RoI



Option 3: selective readout of CSMs (2)

Strategy of the standard muon trigger (bird's eye view)

- each track of each BC is recognized by the trigger chambers and the η,ϕ co-ordinates sent to the MCTPI, specifying trigger threshold and trigger sector (μ-candidate → RoI)
- on the basis of the muon and calorimeter RoIs the LVL1 decision is taken
- after a LVL1 the RoI info is sent from the MUCTPI to the LVL2 processor
- The LVL2 looks for muon tracks, guided (only) by the RoIs sent from the MUCTPI (→ an exception to this is B and J/Ψ physics at low luminosity)
- The LVL2 constructs roads and determines a precise momentum of the track using the drift time info from the MDTs → rejecting low momentum fakes, fake double tracks, tracks with kinks, non-isolated tracks etc.

→ It may be sufficient to **only** transfer data from **those MDTs** which lay in the relevant trigger sectors (+ neighbouring sectors, if track is close to a sector boundary)

Trigger rates and thresholds at LHC and SLHC

The average rate of triggered muons is very low

If muons with p_T > 6 GeV were uncorrelated, the probability to find a second μ in a triggered event was about 23kHz / 40MHz = ~ 0.05 % at stage I.

→a triggered μ leads to a multiplicity of 1,0005 μ's.

In stage III the μ multiplicity of a p_T > 30 GeV trigger would be = ~ 1,05. (However, there are other sources of μ's).

→ The trigger community estimates the avg. μ-multiplicity at stage II to be ~ 1.5

→ About 5-10 MDT chambers out of the 1200 have relevant data

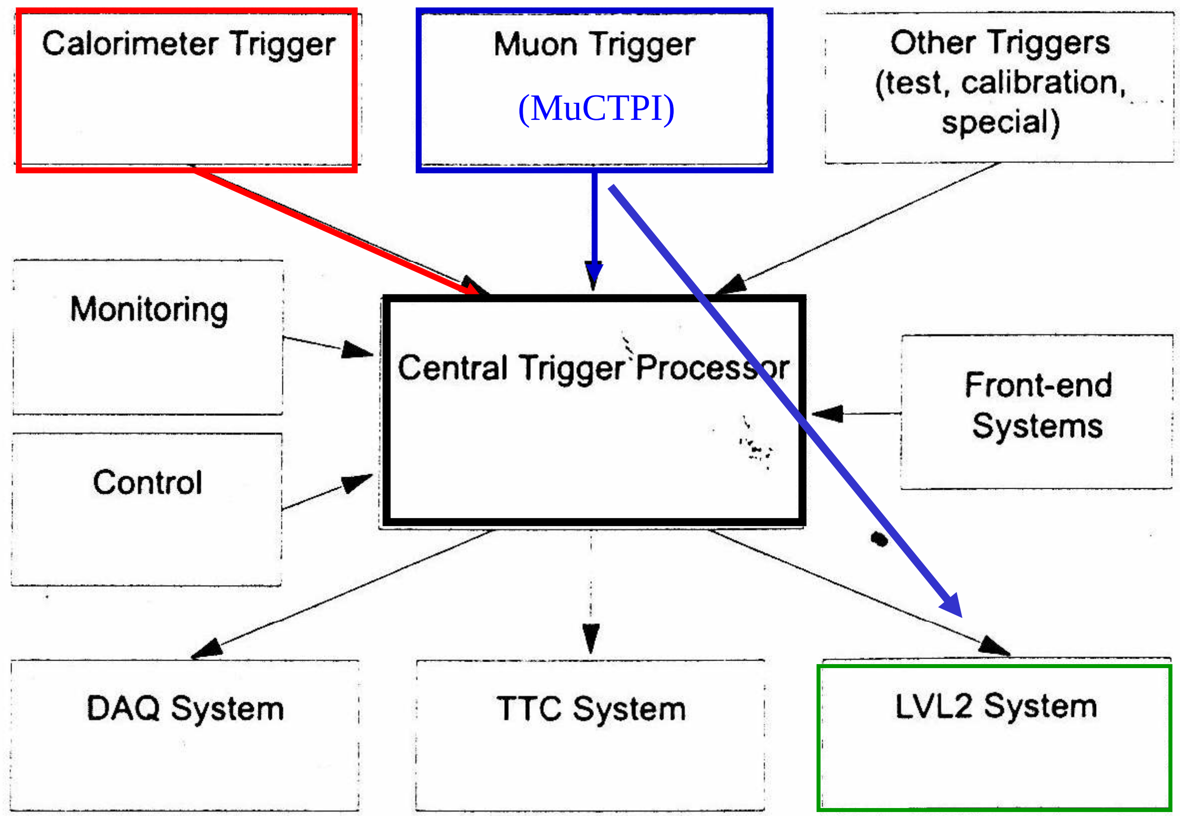
	I		II		III	
			LHC, high lumi		SLHC	
			2009 - 2015		2016 - 2025 ?	
			10^{34}		10^{35}	
		…Hz]	thresh.	rate [kHz]	thresh.	rate [kHz]
			p_T > 20 GeV	**4**	**p_T > 30 GeV**	**25**
			p_T > 6 GeV	**1**	**p_T > 20 GeV**	**few**
			E_T > 30 GeV	**22**	**E_T > 55 GeV**	**20 *)**
Pair of isolated EM clusters	**E_T > 15 GeV**	**2**	**E_T > 20 GeV**	**5**	**E_T > 30 GeV**	**5**
Single jet	E_T > 180 GeV	0.2	E_T > 290 GeV	0.2	E_T > 350 GeV	1
jet + missing E_T	50 + 50	0.4	100 + 100	0.5	150 + 80	1 - 2
		36		**32**		**52**
	(TDR, 1998)		(TDR, 1998)		(A. Lankford, 2005)	

Main source of μ's

*) added degradation from pile-up …t included

Different physics at the 3 luminosity stages: e.g. J/Ψ→ μμ only possible at stage I

The role of the MuCTPI in the ATLAS trigger system



Context diagram for the CTP.

The MuCTPI

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

- only 1 or 2 octants out of 16 are active in any given μ-trigger

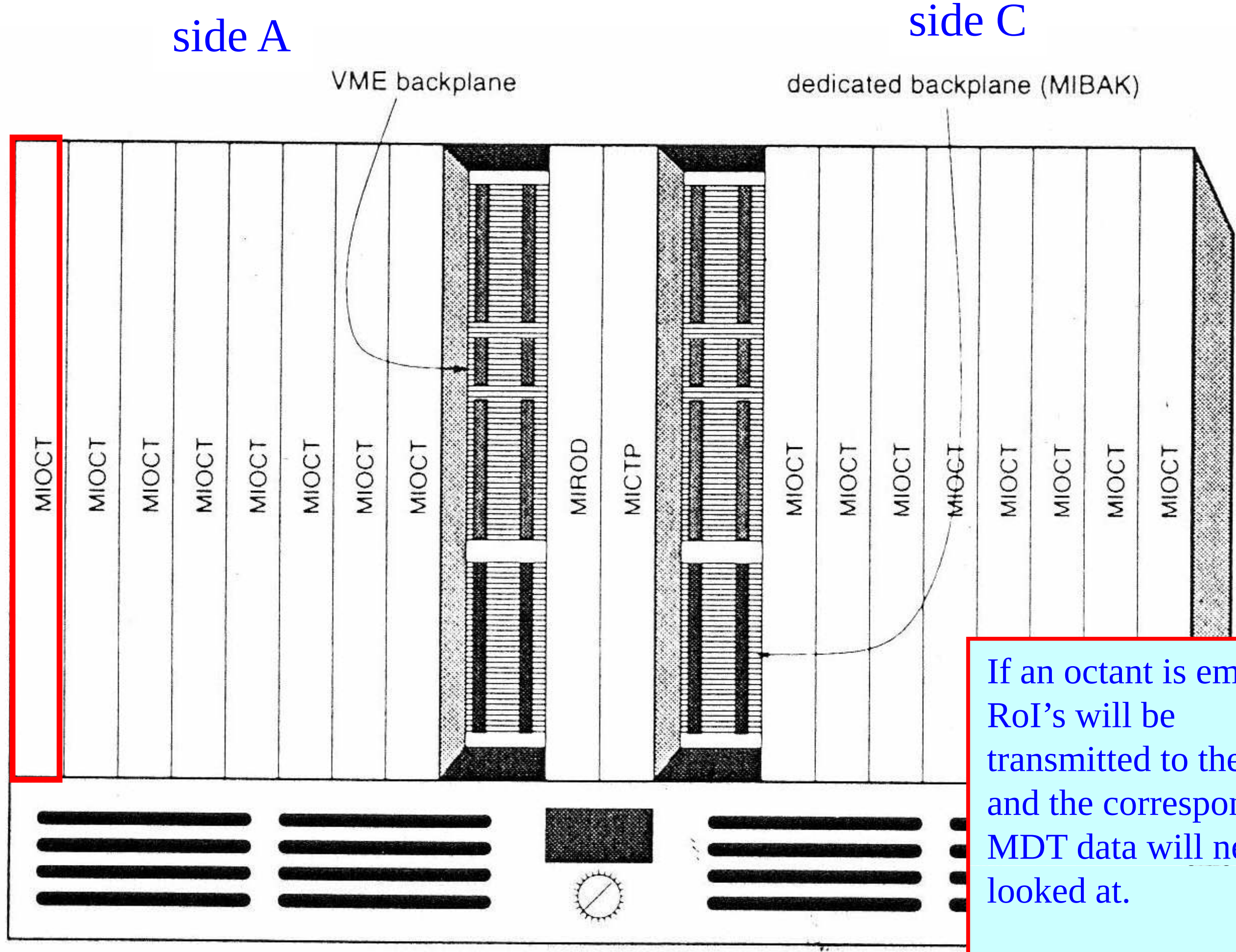
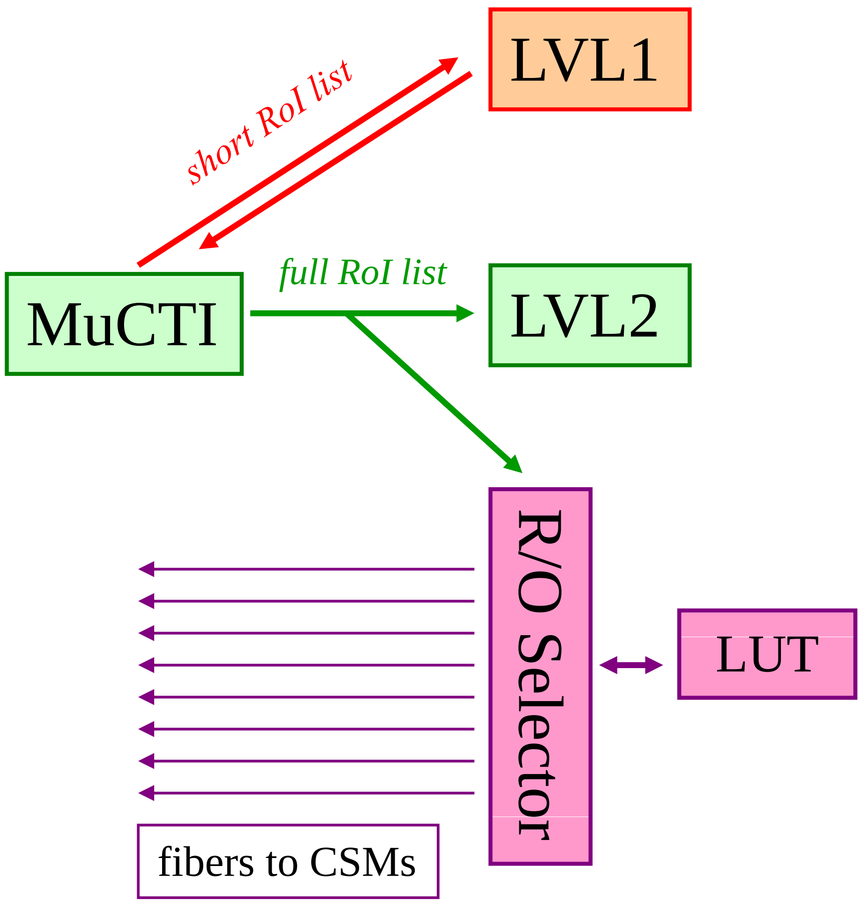


Figure 13-3 The layout of the MUCTPI crate.

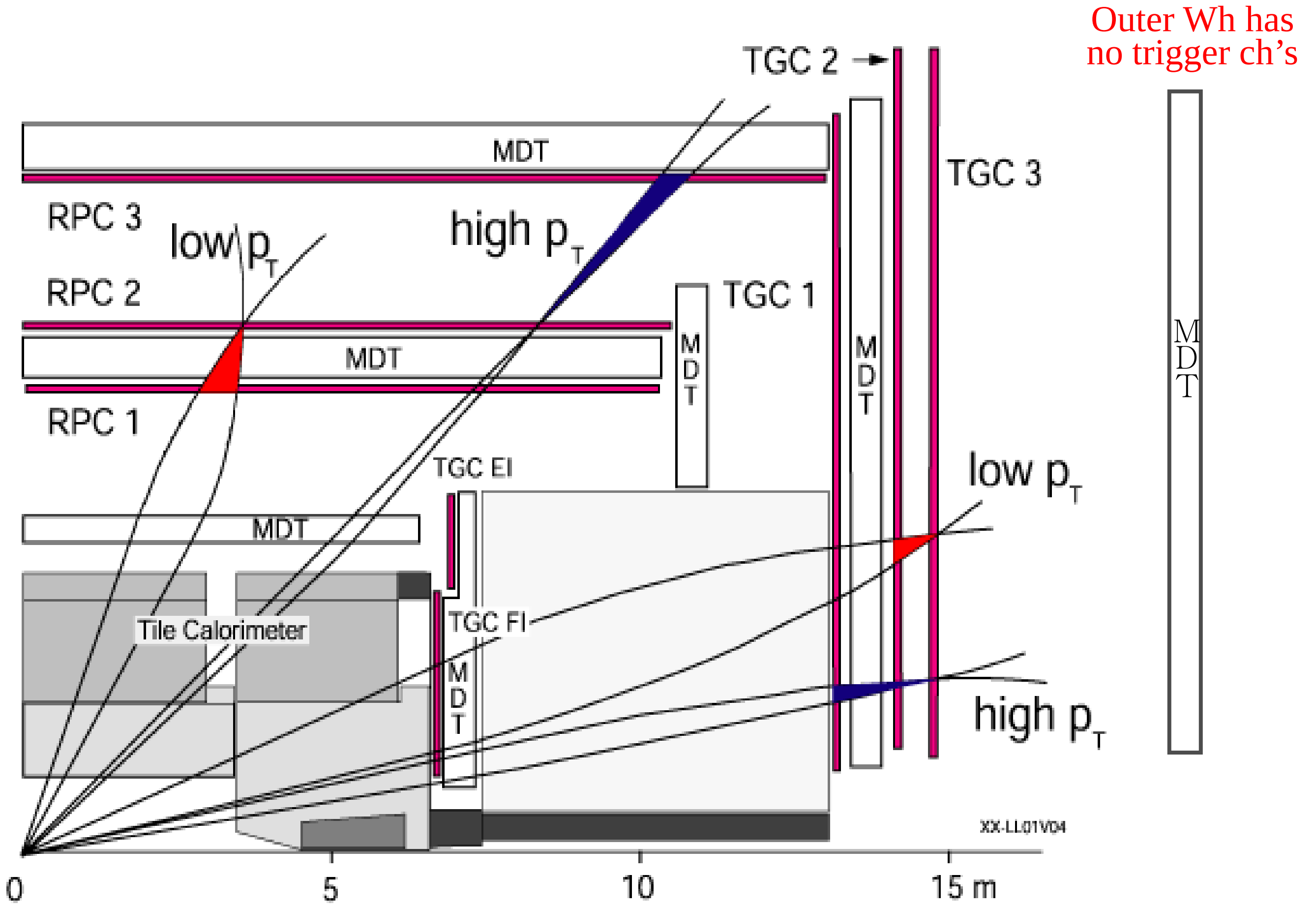
If an octant is empty, no RoI's will be transmitted to the LVL2 and the corresponding MDT data will never be looked at.

Possible R/O architecture



- trigger info to LVL2 contains subsector and p_T info
- can be decoded to select groups of CSMs which require readout

Option 3: is it safe enough?



There may be some losses:

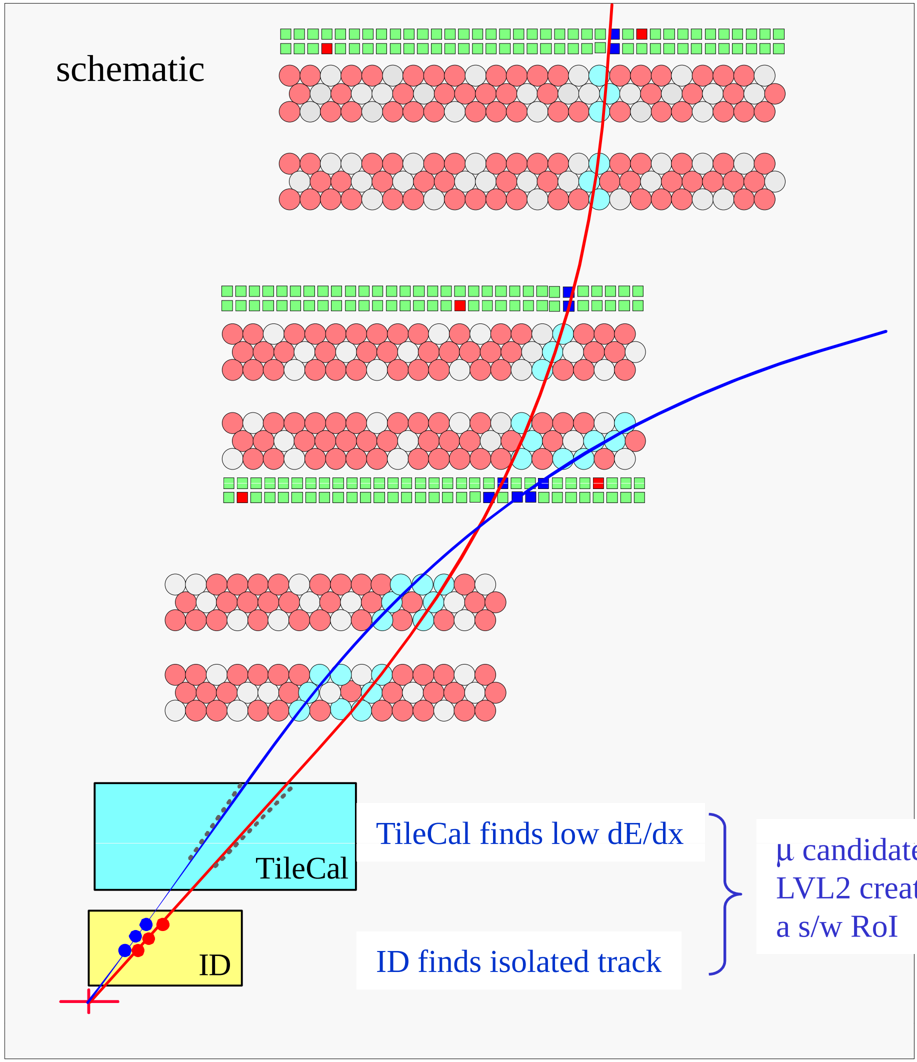
-in the region of feet, coils and struts

-in the RPC/TGC transition region

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

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

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, reduction not possible. No selective R/O.

Summary of rates discussion

- Beryllium beampipe in EC toroid region leads to a substantial BG reduction.- Beyond this no additional BG reduction can be expected realistically.
  - Tungsten JT: little additional gain, high costs
  - Iron core toroids replacing the air core toroids: reduces BG by a factor 10, but will degrade p_T resolution and cost ~ 30-50 MCHF… ! (not a good idea)
  - moving the quadrupoles closer to the IR will cut into the JF shield → more BG expected. This is not yet simulated in detail (M. Shupe et al.).
- MDT readout may already be at the limit in some regions at LHC if the 200 ns dead time is used
- MDT upgrade for high rates should be pursued