Upgrade of the ATLAS Level-1 Muon trigger for Phase II

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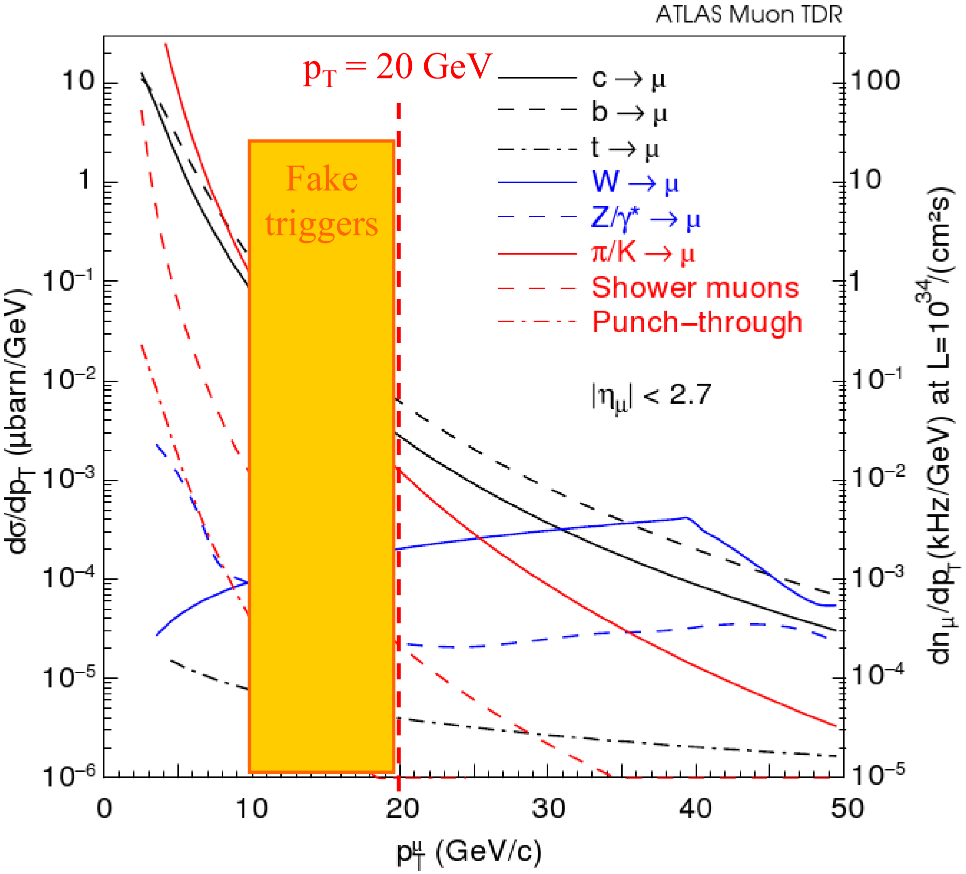
Thanks to T. Kawamoto, O. Sasaki, G. Mikenberg, N. Lupu

Why is the present L1-trigger of the ATLAS muon spectrometer inadequate for luminosities $> 10^{34}\ cm^{-2}\ s^{-1}$?

Physics reasons for high p_T trigger problem



a) The interesting physics is mainly at p_T above ~ 20 GeV (see e.g. W,Z cross section in the diagram)

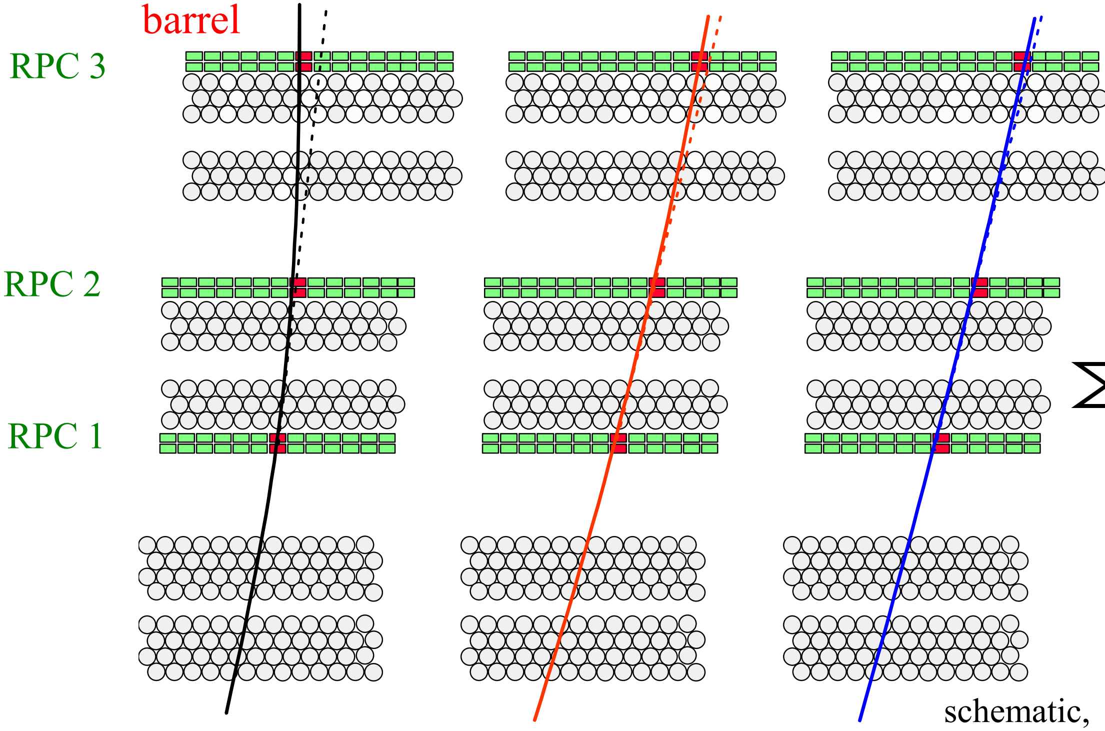
b) The slope of the inclusive p_T spectrum is very steep → threshold definition of the L1 trigger must be sharp to avoid high triggers rates from low p_T muons

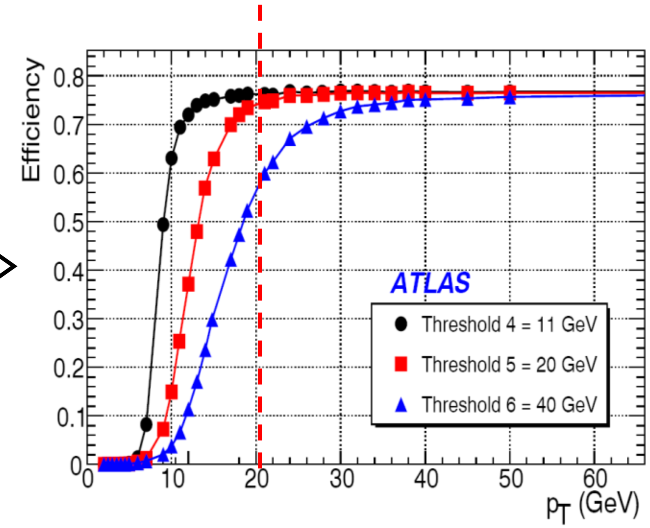
fake L1 triggers
p_T >10 GeV: ~400 nb

regular L1 triggers
p_T >20 GeV: ~47 nb

Detector reasons for high p_T trigger problem

Example: Muon barrel





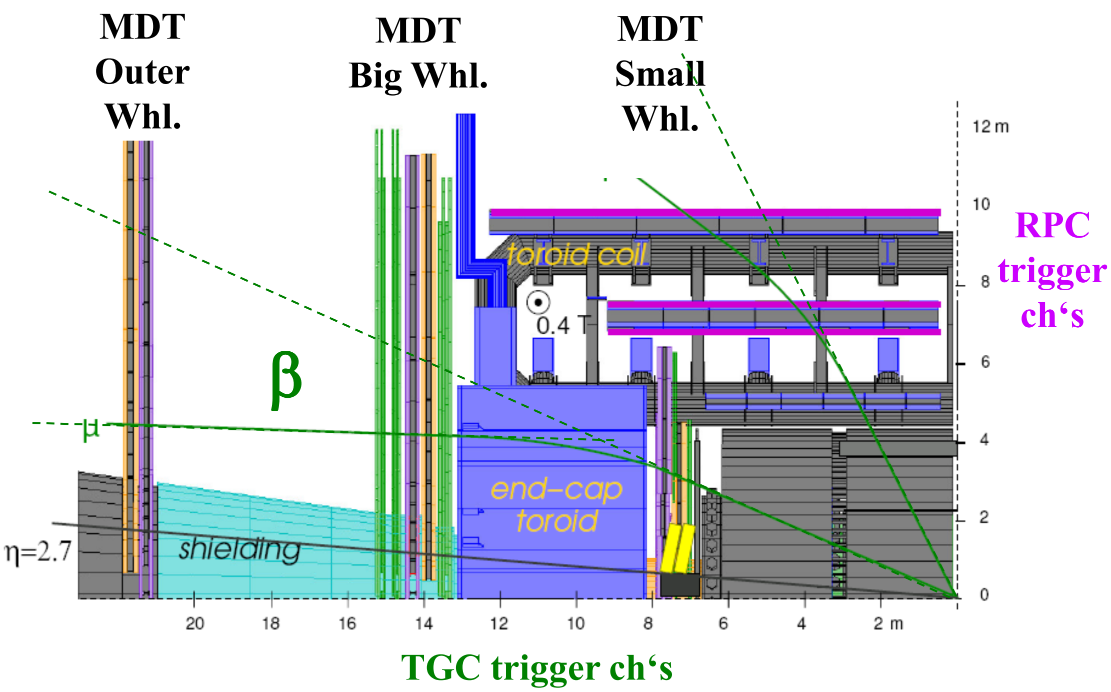
← RPC strip width ~30mm

→ The sagitta in the barrel is ~ 24 mm for p_T = 20 GeV

→ The present L1-trigger system has insufficient spatial resolution to identify muons above 10 GeV

	p_T = 10 GeV	p_T = 20 GeV	p_T = 40 GeV
$\sigma_\mu > p_T$:	734 nb	47 nb	3 nb
actual trig. rate	110 kHz	24 kHz	11 kHz

Detector reasons for high p_T trigger problem (cont.)



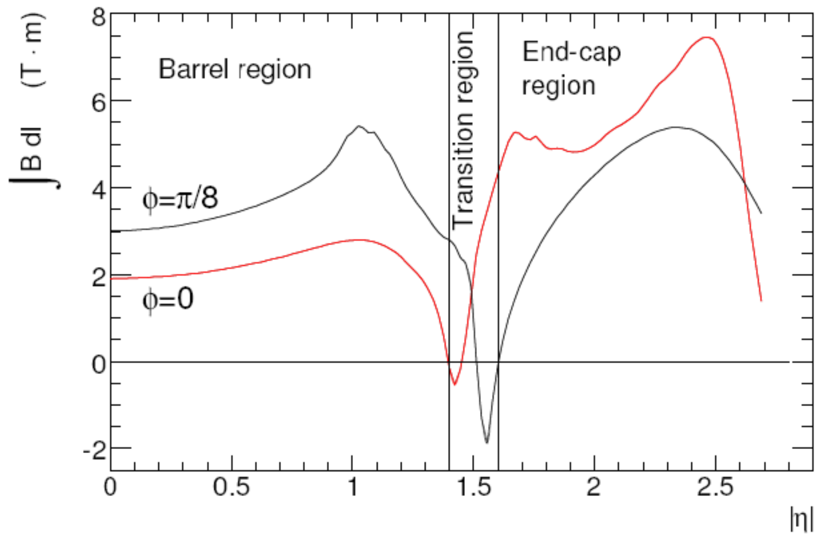
Present trigger relies on tracks coming from the IP vertex:

- vertex smearing at the IP limits the p_T resolution
- vertex smearing will increase from 50 mm to ~ 150 mm at SLHC !

Particular difficulties in the End-cap:

- High rate of tracks, increasing with η
- Particles emerging from the EC toroid may fake high-p_T trigger
- Background rates form converted γ's is much higher than in the barrel

Detector reasons for high p_T trigger problem (cont.)



ATLAS muon spectrometer integrated B strength vs. |η|

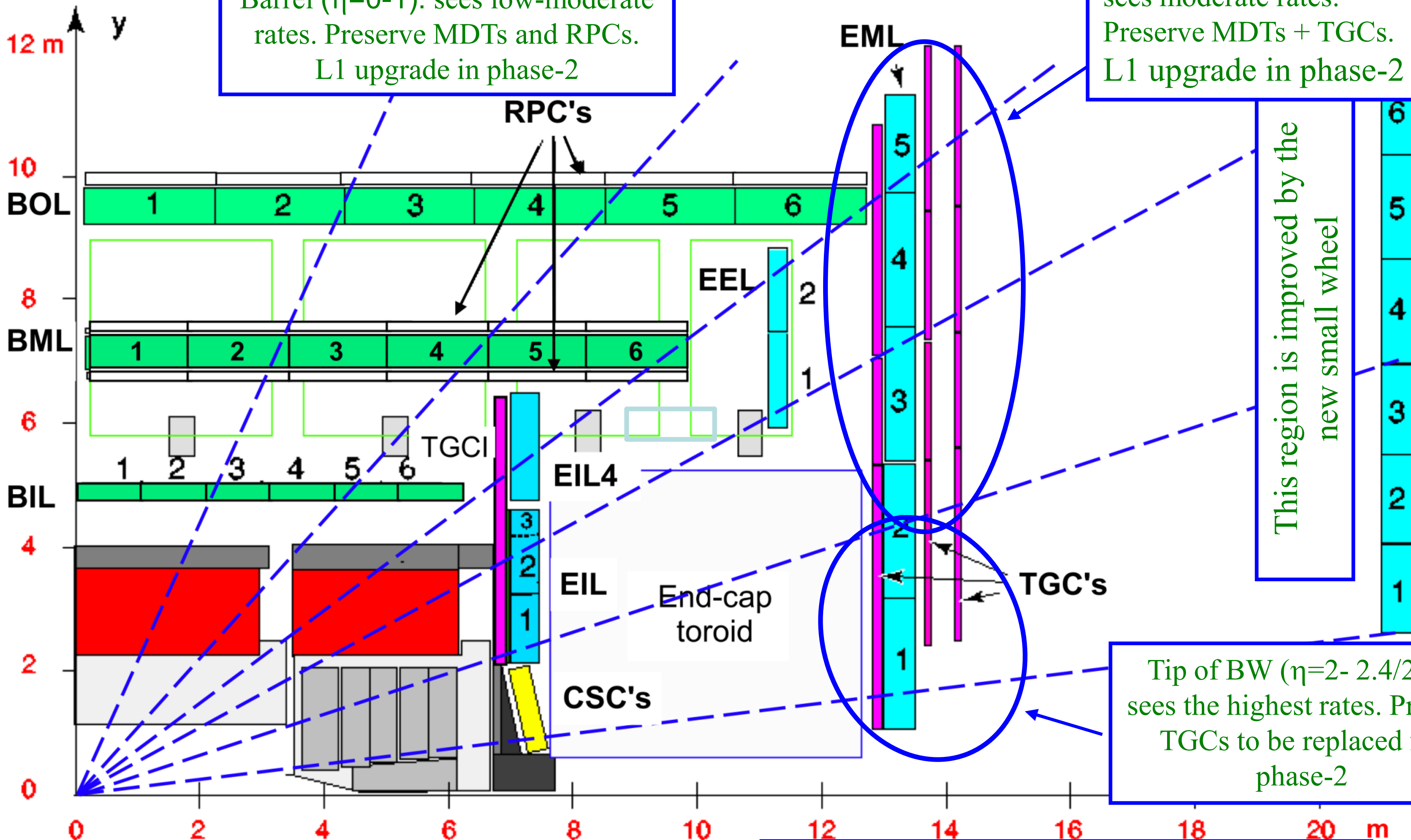
Difficulties to measure p_T over the full η-range:

- B field not homogeneous vs. η
- Region around η = 1,5 has ∫Bdl ~ 0! (This region can be masked off in L1).
- We measure momentum p but want to select p_T → requires much higher pos. resol. in the endcap than in the barrel → ($p = p_T / \sin(\theta)$)

Overview of L1 muon upgrade, phase-1& phase-2

Barrel (η=0-1): sees low-moderate rates. Preserve MDTs and RPCs. L1 upgrade in phase-2

Outer part of BW (η=1- 2): sees moderate rates. Preserve MDTs + TGCs. L1 upgrade in phase-2



Tip of BW (η=2- 2.4/2.6): sees the highest rates. Present TGCs to be replaced for phase-2

T.Kawamoto

Track angle before EC toroid needed → build new Sm. Whl.

Track angle behind EC toroid at EM existing TGC trigger : pT determination

Technical limitations of the present L1-trigger

- The transverse momentum resolution of the trigger chambers in barrel and end-cap was designed to just match the allowed L1 muon rate of ~ 20 kHz (out of the total 100 kHz). Was the result of an optimisation of many parameters, including channel count and cost.

- Barrel: RPCs have 30 mm wide pick-up strips → $\sigma \sim 10$ mm in the bending direction. Insufficient for $p_T > 20$ GeV.

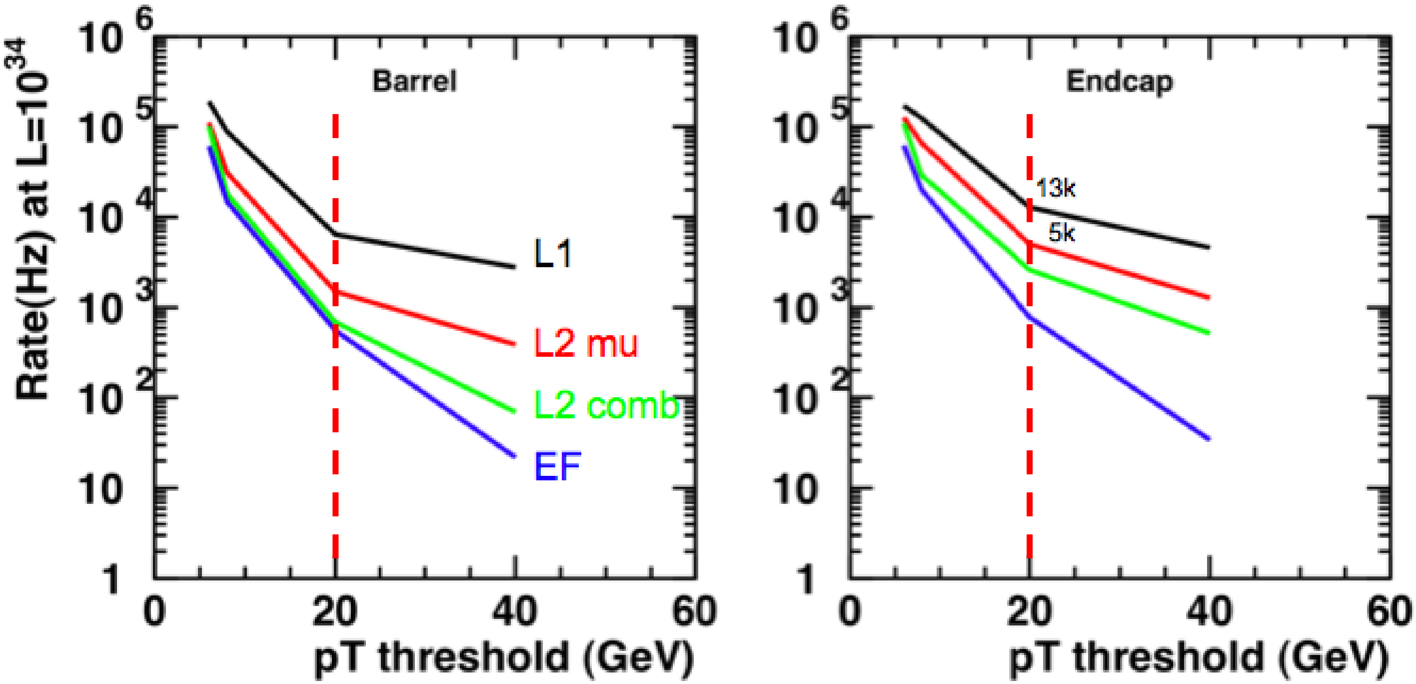
- End-cap:
  - TGC wires are spaced 1,8 mm, but are grouped by 6 – 31 wires along η, corresponding to a spatial resol. of 10.8 – 55.8 mm.
  - Typical angular resolution is ~ 3 mrad. We need : 1 mrad!
  - No tracking information from the Small Wheel (in front of the EC toroid) goes presently into L1. No selection of tracks from IP vertex (only a flag per sector may be used to avoid curling tracks emerging from the toroid).
- Historical reason: no notion/dream of lumi-upgrade beyond 10^{34} cm^{-2}s^{-1} back in 1995!

L1 sharpening: L2 selectivity sets the scale!

L2 is using the full resol. of the MDT to test the p_T of the track → rejects ~90% of muon L1
→ L1 upgrade can't do better than L2!

Max. rate reduction Barrel:
1/ 4.3 @ thresh. p_T = 20 GeV

Max. rate reduction Endcap:
1/ 2.6 @ thresh. p_T = 20 GeV



T. Kawamoto, Small Wheel Upgrade (http://indico.cern.ch/conferenceDisplay.py?confId=119122, 14.01.2011)

Q: how to get better L1-selectivity for phase-1?

Detailed discussion of phase-1 options given in the presentation by Osamu Sasaki

- Sharpen the L1 in the end-cap by determining the slope of the track in front of the toroid ($\eta = 1 - 2{,}7$)
  - The track must point to the IP vertex. → This discards muons from π,K decays and other background sources. Also corrects for the effects of multiple scattering.
  - All proposed L1 upgrade concepts for phase-1 require an extension of the current L1 latency of 2,5 µs to up to 3,2 µs.
  - Upgrade concepts for phase-1 must interface with phase-2 upgrade
  - For phase-2 we assume a L1 latency of 6,4 µs
- Build new Small Wheel with new technology (see O.Sasaki's talk), e.g.:
  - Trigger: new precision TGCs OR new thin Gap RPCs
  - Precision chambers: Small tube MDTs OR MicroMegas OR ….

Q: how to get better selectivity for phase-2?

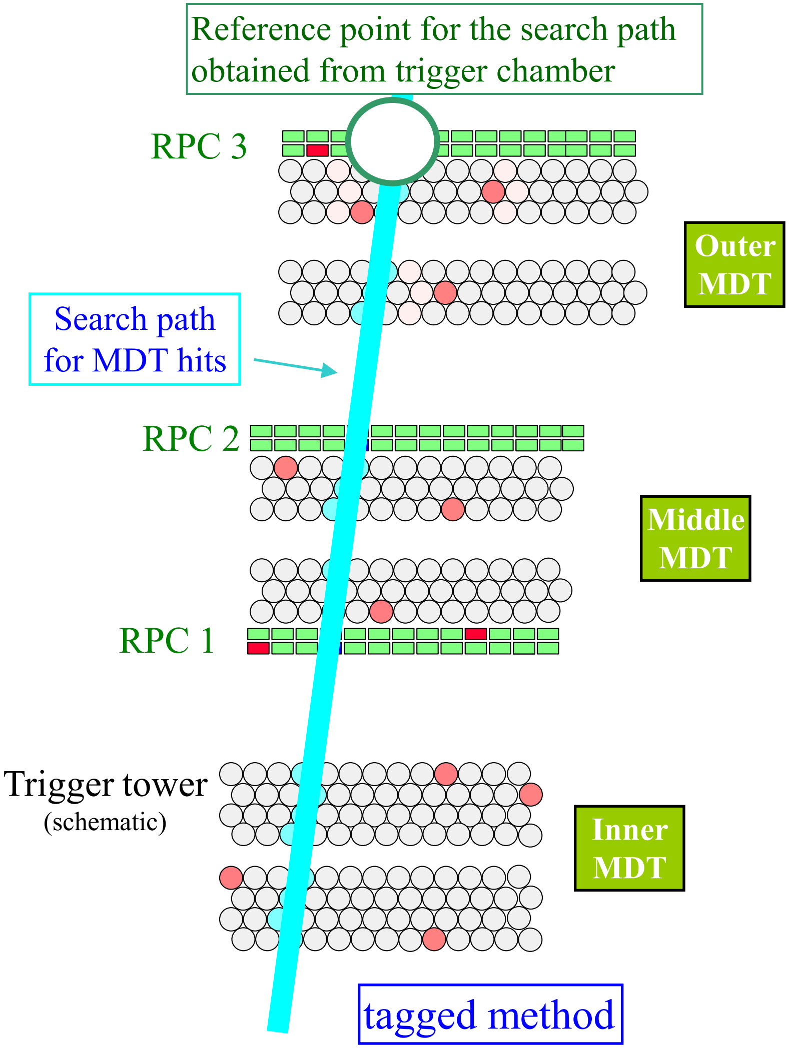
- Aim: improve L1 trigger sharpness over the full η-range
- Save time and cost: get the maximum out of the existing h/w.
  - Use the high accuracy track position measurement in the MDT for L1 sharpening
  - However:
  - Present MDT readout is serial and asychronous with BX (asynchroneous = time of availibility of data has no correlation with time of particle passage)
    → not suited for fast L1 decisions
    → need a concept for fast MDT readout

Include MDT info in L1: design concepts

- Concept for fast MDT readout :
  - Reduce drift time clock to BX frequency (40 MHz). Now: 16 * BX freq.
    (25 ns LSB error on drift time corresponds to 0,5 mm pos. error = 0,15 mm RMS!
    → good enough)
  - Parallel R/O of drift tubes by individual scalers (one scaler per tube) → data available at the same time
  - Synchronicity of R/O with BX: fixed time correlation with particle passage → yields absolute drift time! → Gives a constraint for d.t. of adjacent tubes.
- 2 options for fast readout:
  - Use information from the trigger chambers to define RoI („tagged method“):
    - only act when high-p_T trigger candidate („L0“) was found by trigger ch‘s → much reduced rate of data transfer
    - use „RoI“ defined by trigger ch‘s to selectively read the confined region, where the candidate track crosses the MDT → save data volume to be transferred → ignore hits from γ-conversions outside RoI!
    - requires about 2 μs extra latency, i.e. 4,5 μs total L1 latency → not suited for phase-1
  - Stand alone track finding in MDT chambers („un-tagged method“):
    - transfer the complete hit pattern of the MDT tubes to USA15 for each BX and look for track candidates in the hit pattern.

MDT precision coordinates for the L1-trigger („tagged method“)

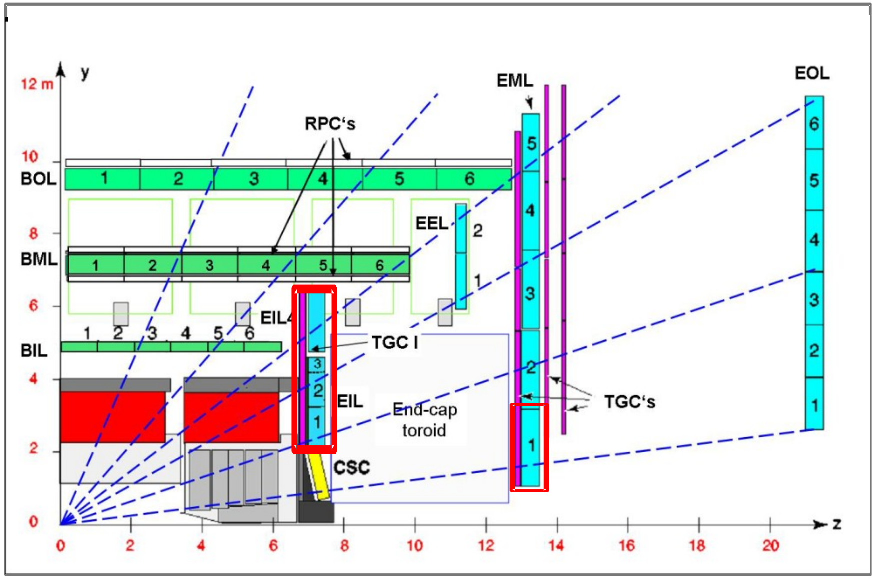
- Use the high-p_T tag („L0“) produced by the trigger chambers to
  - define a search road in the MDT (RoI). (Similar strategy as in the Level-2)
- Required hardware:
  - trigger chambers to supply coordinates of RoI for each high-p_T candidate („L0“)
  - interface between trigger and precision chambers at the frontend to transmit RoI
- PRO:
  - small rates: readout activity only for high-p_T candidates („L0“). ~ 100 Hz in a trigger tower.
  - small data volumina to be transferred
  - Immunity to the background hit rates. Most of the conversion background is outside the RoI!
- CON:
  - can‘t be done in 3,2 µs latency, not suited for phase-1
  - processing at the frontend (need rad-tol FPGAs)



Properties of the L1 trigger in the Muon barrel

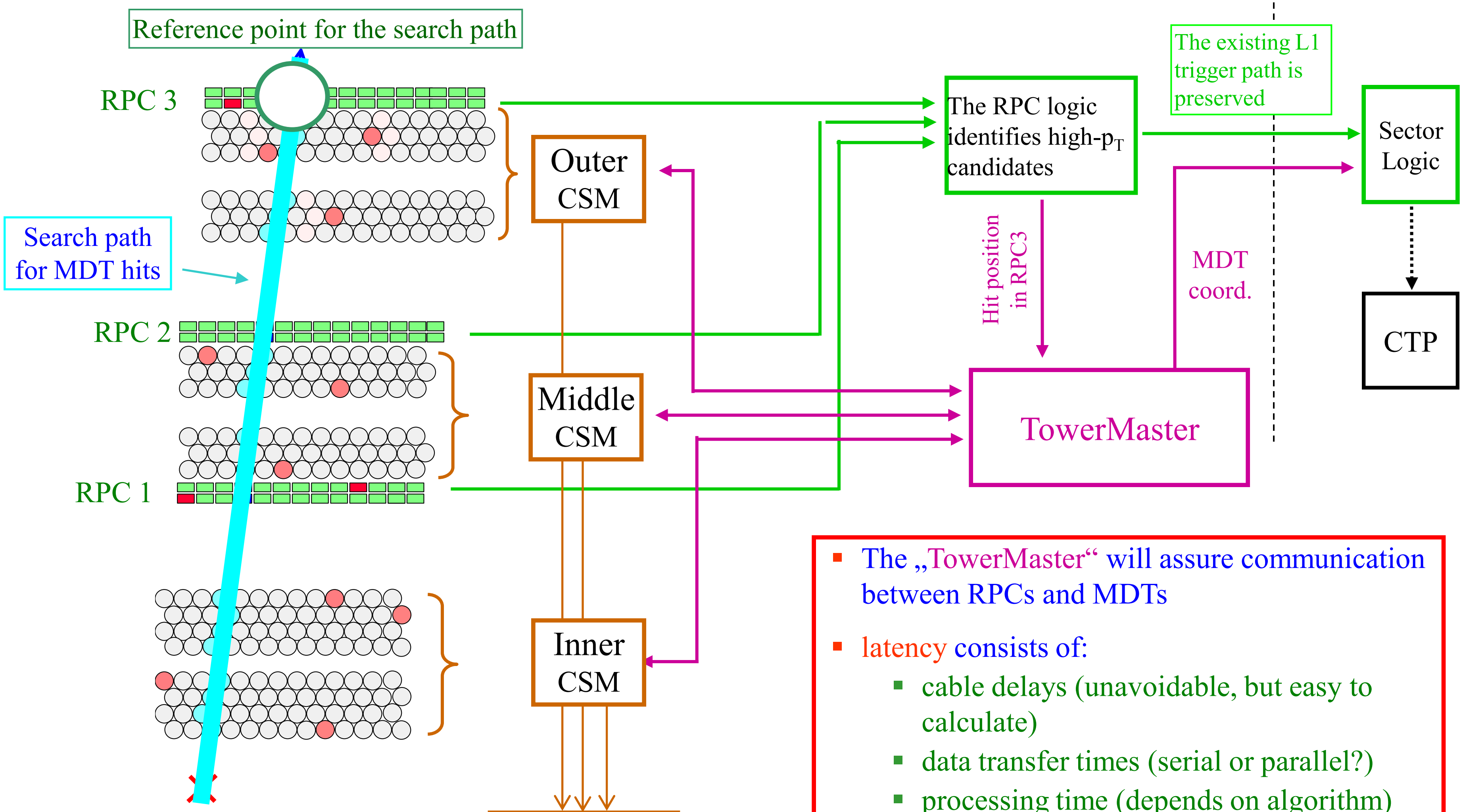
There are a couple of things which help you!

- The trigger produced by the RPC is organized inside trigger towers: MDTs matching RPCs. There are about 200 trigger towers in the barrel (16 x 6 x 2).
- High p_T tracks, being 'nearly' straight, mostly travel inside one and the same tower
- The RPCs predict the location of the straight track with 1-tube-width precision! → defines search road for MDT hits



- The high-p_T RPC trigger is very selective and immune w.r.t. accidentals, even at sLHC
- The high-p_T trigger rate in any given tower is very low ~ 100 Hz, even at sLHC
- So: use the RPC trigger as a "seed", don't try "a stand alone" trigger with the MDT (my philosophy)

Technical realisation: Implement communication between trigger- and precision chambers inside a trigger tower

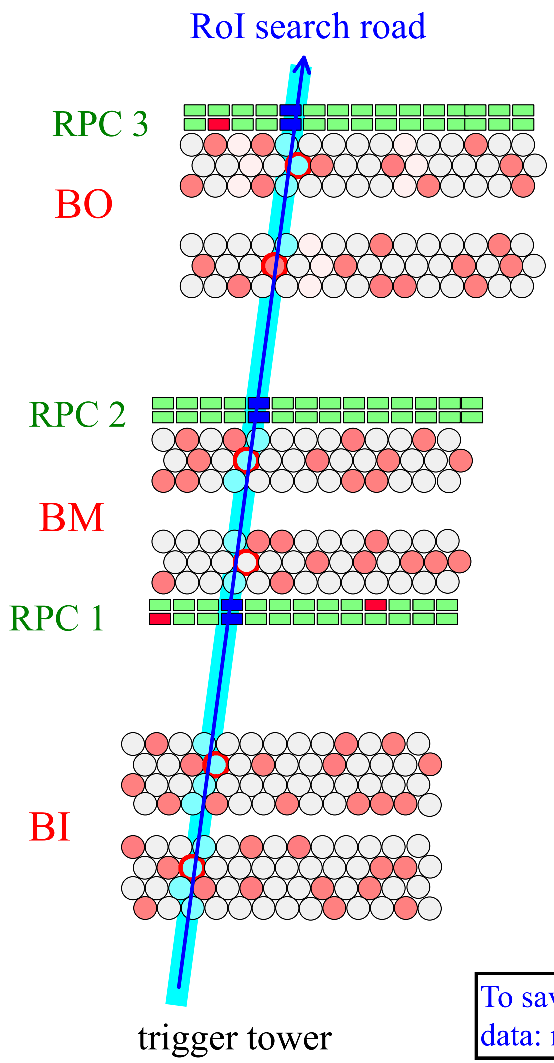


Trigger tower (schematic)

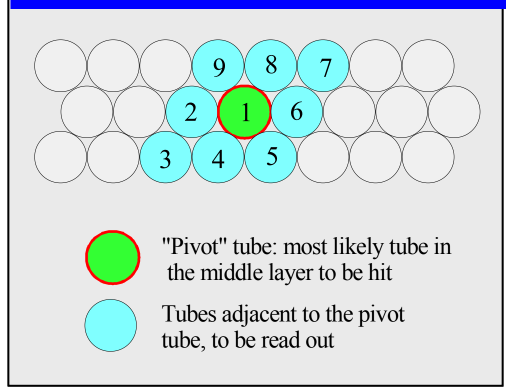
- The „TowerMaster“ will assure communication between RPCs and MDTs
- latency consists of:
  - cable delays (unavoidable, but easy to calculate)
  - data transfer times (serial or parallel?)
  - processing time (depends on algorithm)

A tentative recipe for tube readout

(don't look at the drift times, just read a fixed set of tubes)



The scalers (drift times) of a fixed pattern of tubes around the pivot tube are read out



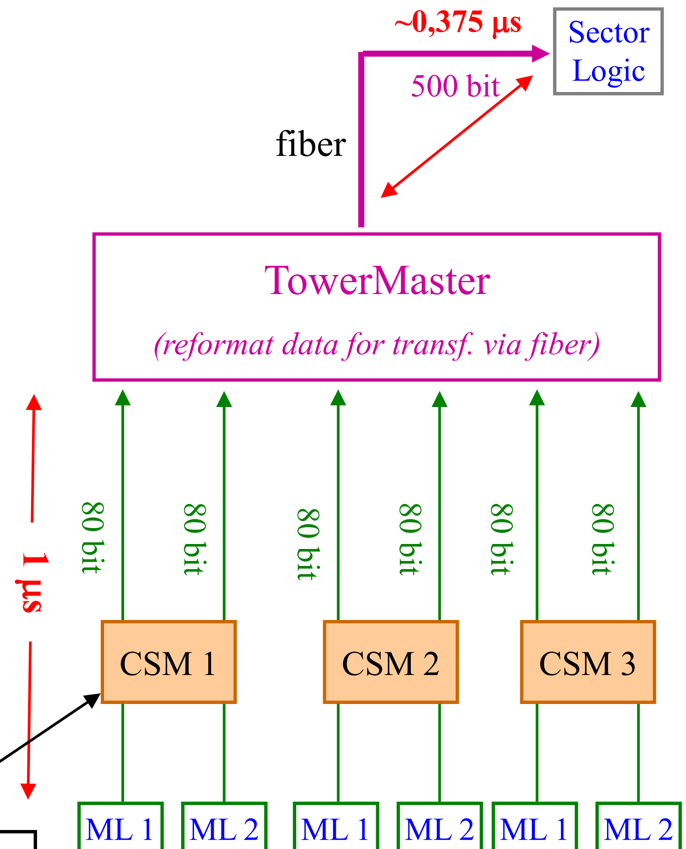
Use of a fixed readout format:

1 bit/tube for hit/no hit	=	9
9 x drift time (7 bits)	=	63
header, parity bit	~	1
		80 bit

At a rate of 12,5 ns/bit the transfer to the CSM takes 1µs

To save time, the CSMs are transparent to the mezz data: no formatting, no intermediate storage

6 x 80 + BX-id + ovhd = 500 bit
At a rate of 0,8 ns/bit the trf. to the SL takes ~375 ns (excl. travel time)



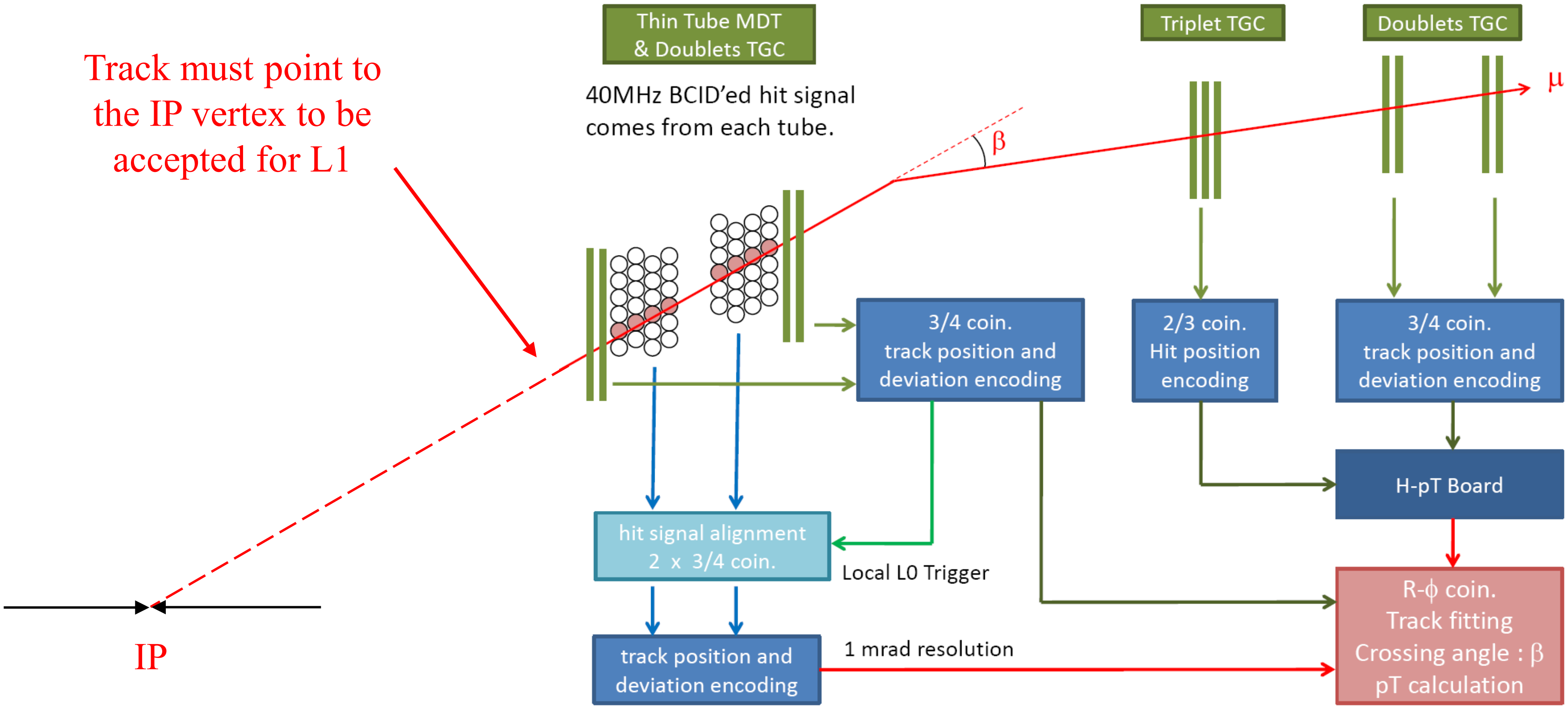
MDT precision coordinates for the L1-trigger („un-tagged method“)

- In the EC region of the detector high-p_T tracks coming from the IP will impinge under well-defined angles onto the MDT.
  - Look for all patterns of drift times in the MDT, matching this projection angle
  - The resolution of the drift time is 25 ns LSB = 0,15 mm RMS
  - Combine with TGC L1-trigger the sector logic (USA15)
- PRO:
  - No need for frontend communication
  - Latency comes down to 2,6 μs if faster precision chambers are used (e.g. Small Tube MDTs with only 200 ns drift time.)
  - Processing done in the radiation-safe USA15 (only parallel-to-serial conversion and fiber drivers at the frontend).
- CON:
  - Large bandwidth requirements, as the MDT hit pattern is transferred to USA15 for each BX → large number of fibers (e.g. 1 per mezzanine card)
  - Angle of incoming track must be known → most useful in the Small Wheel

See O. Sasaki, MDT based L1 (http://indico.cern.ch/conferenceDisplay.py?confId=105234, 29.09.2010)

Schematics of the un-tagged method

Track must point to the IP vertex to be accepted for L1

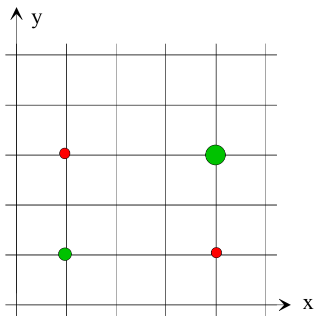


The detailed timing analysis yields an extra latency of 0,1 μs! → good for phase-1

See O. Sasaki, MDT based L1 (http://indico.cern.ch/conferenceDisplay.py?confId=105234,

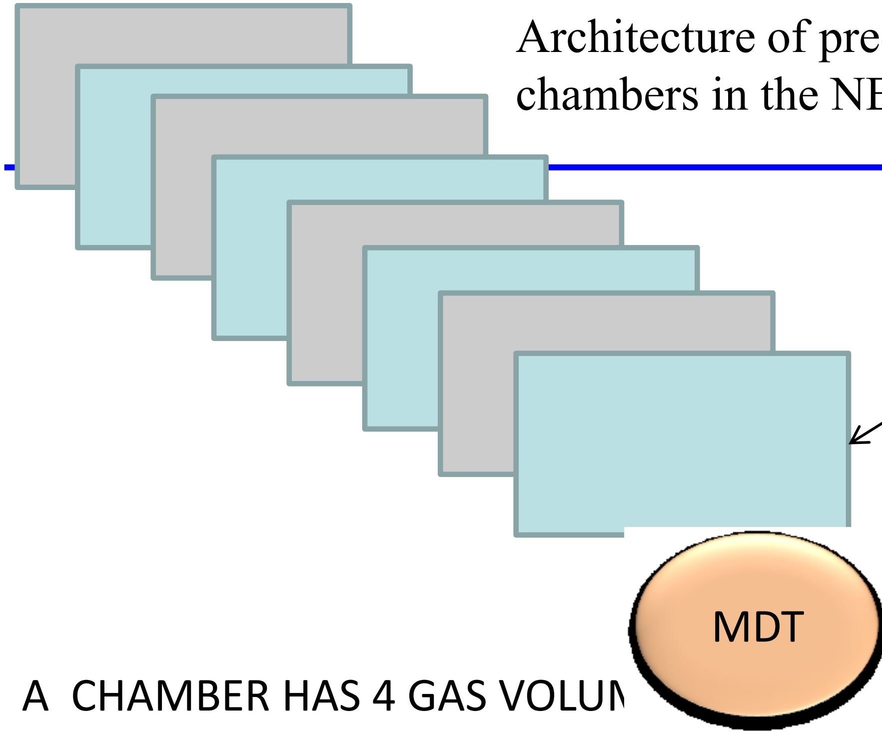
Proposal of Precision TGC for the NEW Small Wheel and for the innermost part of the Big Wheel

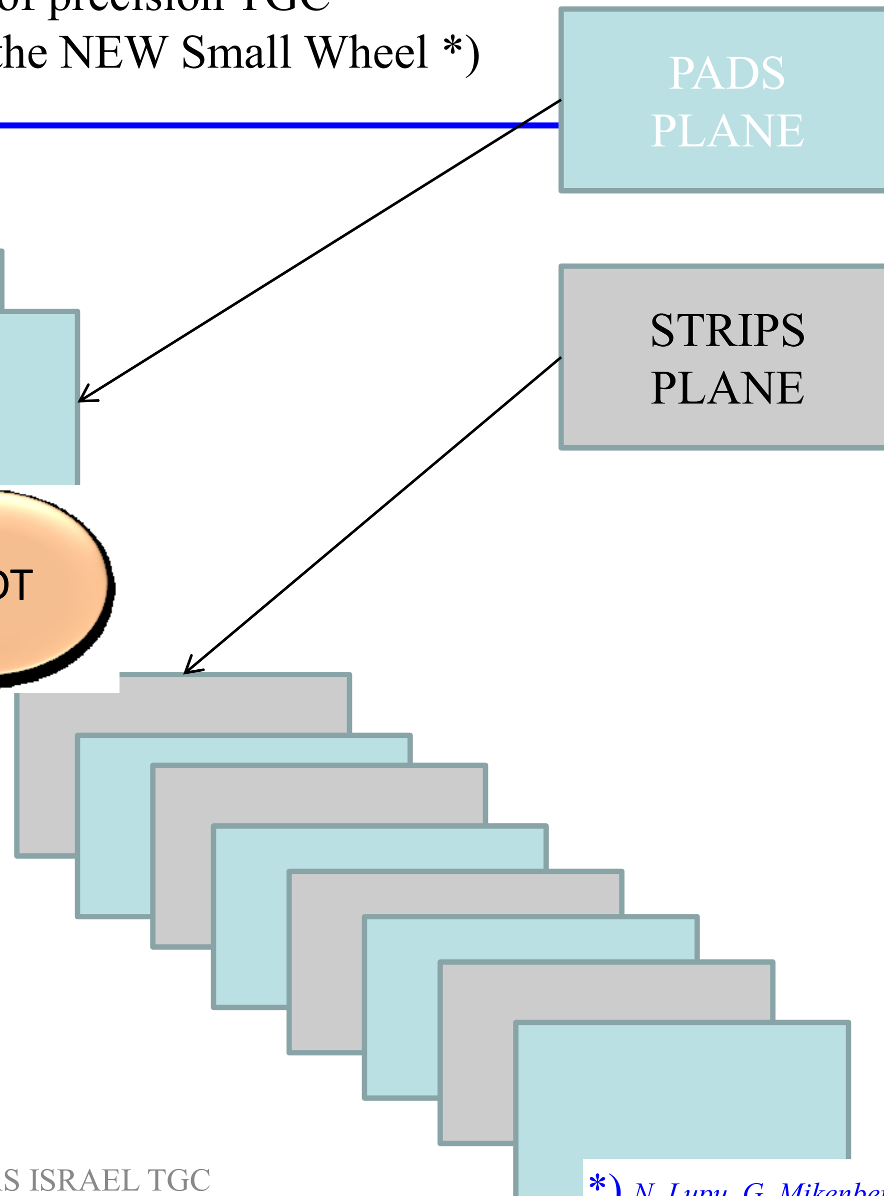
- Many details described in O. Sasaki's talk w.r.t. the use in the Small Wheel
- This technology is also relevant in phase-2 for regions of high track density
- Preformance aim: better spatial resolution and higher rate performance
  - Strips along η-coordinate with e.g. 3,4 mm spacing and charge interpolation (using time-over-threshold) can obtain spatial resolution of 70 µm per layer and 0,14 mrad angular resolution (lever arm = 350 mm) *)
- PRO:
  - Excellent position resolution
  - Excellent time resolution 95% in 1 BX → high immunity to conversion background
  - High rate capability due to low-resistive cathode coating was demonstrated
  - Cathode layers with pads can be used to resolve ambiguities →
- CON:
  - Resources needed for production of new chambers AND new electronics → can't be done for the large areas of the Big Wheel



*) *see G. Mikenberg , L. Nachman „TGC test beam results" (http://indico.cern.ch/conferenceDisplay.py?confId=62717 , 15 July 2009*

Architecture of precision TGC chambers in the NEW Small Wheel *)





A CHAMBER HAS 4 GAS VOLUN
IN A SANDWICH.

EACH GAS VOLUME HAS WIRES, STRIPS , PADS ON SEPARATE PLANES.

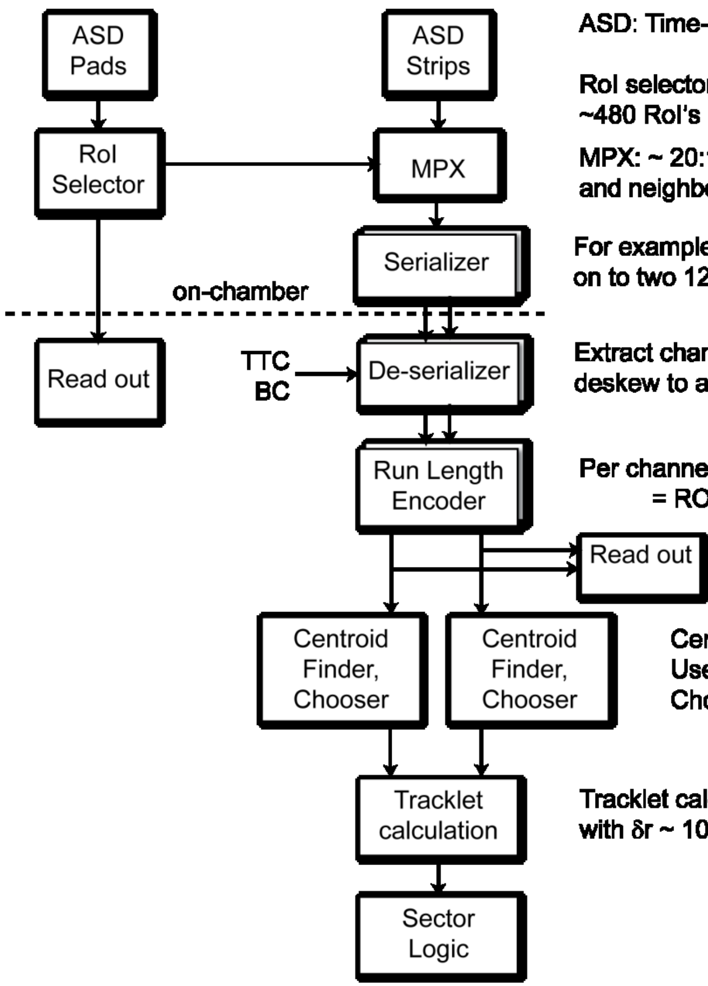
TWO CHAMBERS ARE MOUNTED AT THE SAME R AND PHI of the SMALL WHEEL.

ATLAS ISRAEL TGC

*) *N. Lupu, G. Mikenberg*

Readout scheme of the TGC L1 trigger in the new Small Wheel

sTGC precision strip trigger logic



ASD: Time-over-threshold output up to ~ 60nsec

RoI selector: 2 x 3-out-of-4 coincidence in tower of pads
~480 RoI's per chamber

MPX: ~ 20:1 selects 16 strips crossing the RoI (per chamber) and neighbours

For example, serialize 1 nsec samples of 4x16 channels, round robin on to two 12-fiber bundles, each fiber at 5.3Gb/s = 64Gb/sec

Extract channels, per channel serial-to-parallel deskew to align with BC clock

Per channel encoding to start time, time-over-threshold
= ROI-ID, BCID, offset in BC, TOT

Readout: Level-1 pipeline
Also for each block below

Centroid finder in each layer, in each 4-layer super-layer:
Uses 4-5 strips. Result is r, with $\delta r \sim 100\mu m$
Choose and average best centroids

Tracklet calculation: result is position, angle (r,α),
with $\delta r \sim 100\mu m$, $\delta\alpha \sim 1mrad$

The timing analysis yields an extra latency of < 0,25 µs! → OK for phase-1

ATLAS ISRAEL TGC

Scenarion for phase-2 *(my personal guess)*

NB: Phase-1 was already discussed by O. Sasaki → must smoothly interface to the phase-2 upgrade, to avoid extra work.

- Barrel scenario (η = 0 -1): gain factor > 10 in spatial resolution:
  - use tagged method, capitalizing on latency > 6,4 µs and RoI provided by RPCs.
  - Requires new elx for RPCs and MDTs + interface between both.
- End-cap:
  - (a) region in front of EC toroid (η = 1 – 2,7): need 1 mrad angular resolution:
    - Tagged or un-tagged method OR standalone TGC trigger, depending on available latency, see above. Technology in CSC region: still under discussion.
    - → Un-tagged MDT and standalone TGC trigger can operate with 3,2 µs latency.
  - (b) region behind EC toroid (h = 1 – 2,7): need 1 mrad angular resolution:
    - High η-region (η> 1,9 –2,7): New high resolution TGCs?
New MDTs for the inner part of the Big Wheel?
    - Low η-region (η<1-1,9): existing MDTs and TGCs maintained. Possibility to use tagged method? Simulation needed to show immunity against γ-conversion background.

Pointing accuracy of MDTs and TGCs in the Big Wheel

$\sigma_{track\ angle} = \text{sqrt}(2) * \sigma_{pos.} / \text{lev. arm}$

Some numbers:
(do not contain degradation from backgrounds)

	Location	pos. err./ modul	lever arm	track slope err.
		mm	mm	mrad
MDT	Big Wheel alone	0.1	252	**0.56**
	Big Wh. - Out. Whl.	0.1	7480	**0.02**
TGC	Big Wheel, high h	2.2	1700	**1.8**
	Big Wheel, low h	11.4	1700	**9.5**

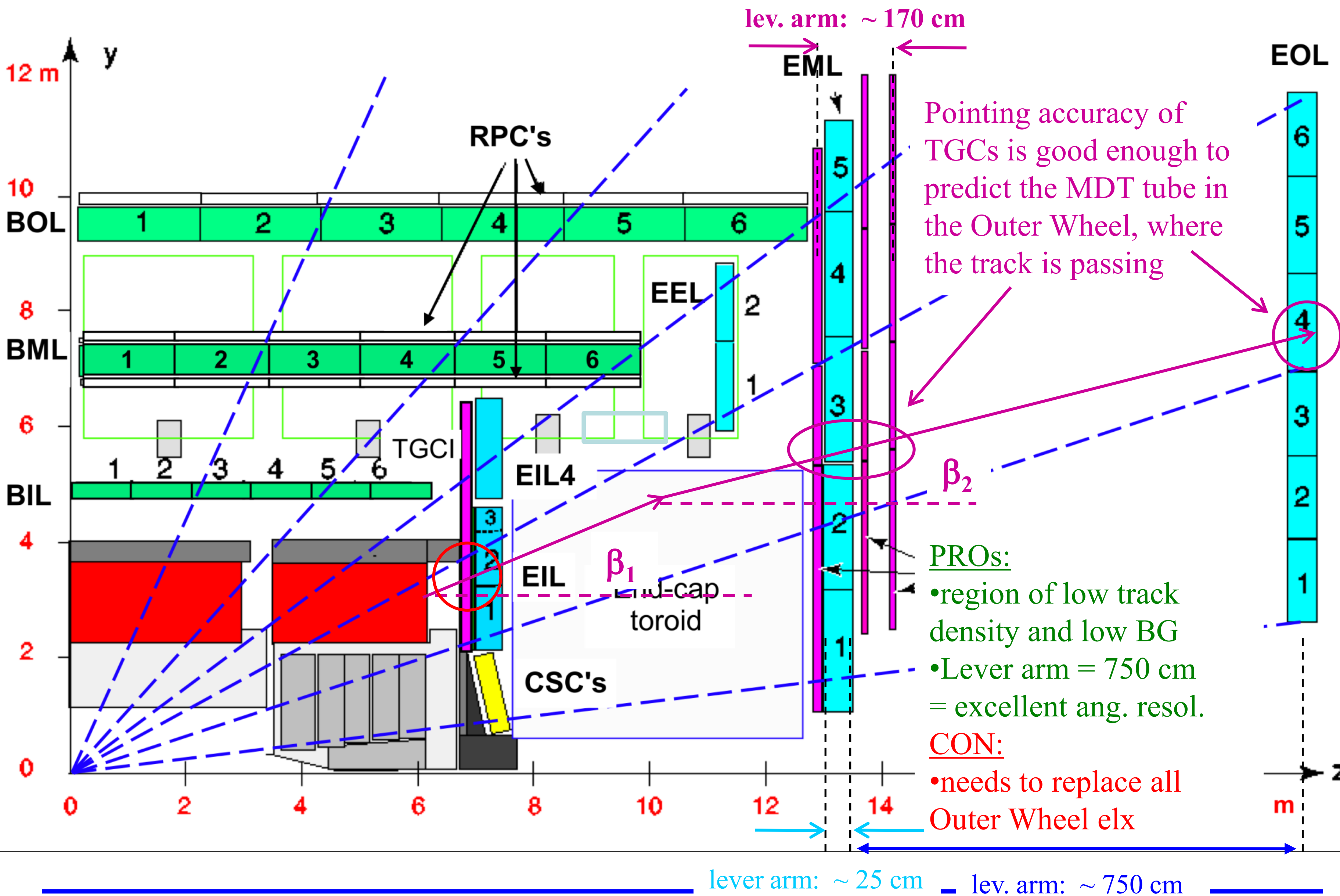
- MDTs are < 1 mrad because of good position resolution
- standard TGCs are > 1 mrad due to coarse wire grouping
- → MDT may be used to sharpen L1 trigger in the Big Wheel
- → MDTs in the Outer Wheel with RoI from the TGCs is even better!

→ The TGCs in the Big Wheel point to the MDT in the Outer Wheel with an accuracy of $9.5\ 10^{-3} * 7480 = 70$ mm (along η) = 3 tube diameters. → perfect RoI for tagged L1-trigger sharpening!

PROs:
•region of low track density and low BG
•Lever arm = 750 cm = excellent ang. resol.

CON:
•needs to replace all Outer Wheel elx

Some brainstorming: why not use the Outer Wheel for phase-2



Overview of Upgrade options for phase-2

detector region			location in z (mm)	η-range	trigger chambers	precision chambers	candidate methods of L1-trigger upgrade	modification of electronics	
Barrel			0 - 6900	0 - 1.05	keep	keep	tagged	new	phase-2
End-cap	Small Wheel	MDT region	7200-7600	1 - 2	new	new	tagged, untagged or high resol. TGC	new	phase-1
		CSC region	7115	2.0 - 2.7	new	new		new	
	Big Wheel	TGC "end-cap"	13800-14300	1 - 1.9	keep	keep	tagged	new	phase-2
		TGC "forward"	13800-14300	1.9 - 2.7	new	depends on background rate (??)	tagged or TGC stand alone	new	
	Outer Wheel		21300	1.3 - 2.7	------	keep	tagged	new	

Summary

- We are currently in an intense brainstorming for phase-1 and phase-2
  - Phase-1 decisions are more urgent, but should not preclude important options for phase-2
  - Relevant time scale of phase-1 has soon to be known (2016? 2018?)
  - Latency of 3,2 μs for phase-1 needs to become a firm commitment (basis for important muon design decisions for phase-1).
- open Q‘s for phase-1:
  - Trigger chamber technology in the Small Wheel (precision TGCs?)
  - Precision chamber technology in the Small Wheel (Small Tube MDTs, Micromegas, μ–pixels?)
  - Method for L1-trigger upgrade (non-tagged, precision TGCs)
  - Interface to L1-trigger in the Big Wheel in phase-2 (t.b. defined)
- open Q‘s for phase-2:
  - Concept for barrel upgrade (→ Q of accessibility of MDT elx in the Inner layer)
  - Trigger chamber technology in the „forward“ Big Wheel (precision TGCs?)
  - Method for L1-trigger upgrade in the „endcap“ region of the Big Wheel (η = 1-1.9)
- Muon procedure for decisions
  - TDR for Small Wheel upgrade by autumn 2011