A new LHC device for the LHC: implementation aspects/options/cost estimates

- Detector
- Readout chain
- Gas target
- organization

This is a brain dump

the detector

New Device for LHC

NB: it will measure beam **shapes** → must be able to measure accurately absolute value of β function at the device position!

Specifications:

- provide measurement of emittance
  - stat accuracy of <5% in 5 min for 10^{11} p
  - syst uncertainty <5% (dominated by understanding of vtx resolution ?)
  - for $1.5 < \varepsilon_n/\mathrm{um} < 4$ and $0.45 < E/\mathrm{TeV} < 7$
  - bunch by bunch (max bunches per measurement to be defined?)
- should not affect beam operation

By-products:

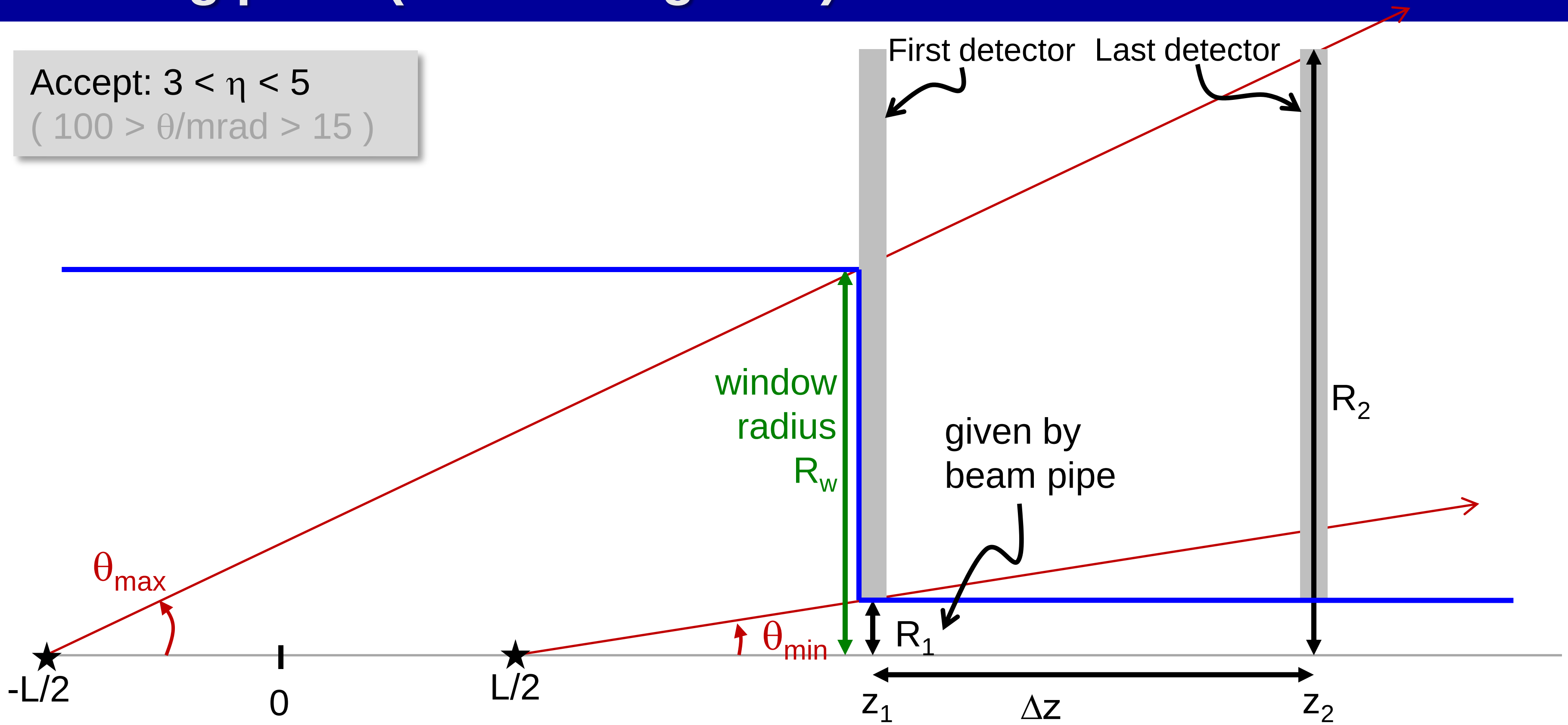
- measurement of ghost charge (crucial for lumi calib)
  see A. Alici et al. (BCNWG note4), CERN-ATS-Note-2012-029 PERF
- measurement of relative bunch charges (to be normed by DCCT)
  see G. Anders et al. (BCNWG note3), CERN-ATS-Note-2012-028 PERF

Possible add-on: (not in baseline discussed here)

- timing detector with < ~100ps resolution, would provide longitudinal profile as well

Starting point (educated guess)

Accept: $3 < \eta < 5$
($100 > \theta$/mrad > 15)



Z range to be covered by acceptance Take: L = 1m

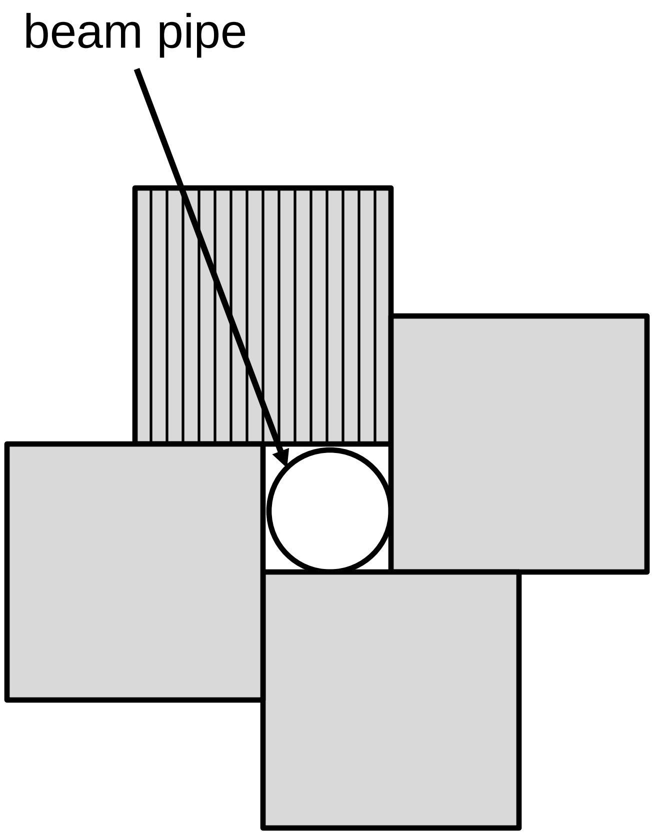
$z_1 = L/2 + R_1 / \tan(\theta_{min})$
$R_w = (z_1 + L/2) \tan(\theta_{max})$
$R_2 = (z_2 + L/2) \tan(\theta_{max})$

Take: R_1 = 15, 20, 25 mm

(VELO: R_1 = 8mm, L = ~0.5-1m)

- small R_1 implies small (compact) detector (probably silicon)
- larger R_1 implies larger detector (probably SciFi)

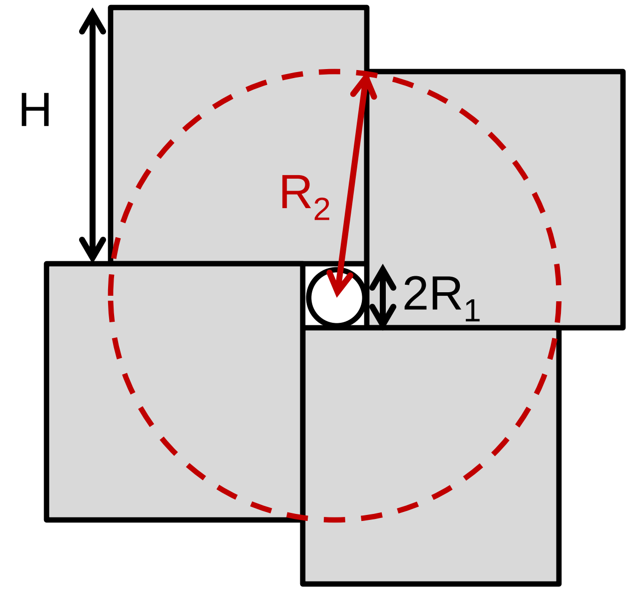
Simplest solution with straight segmented detectors



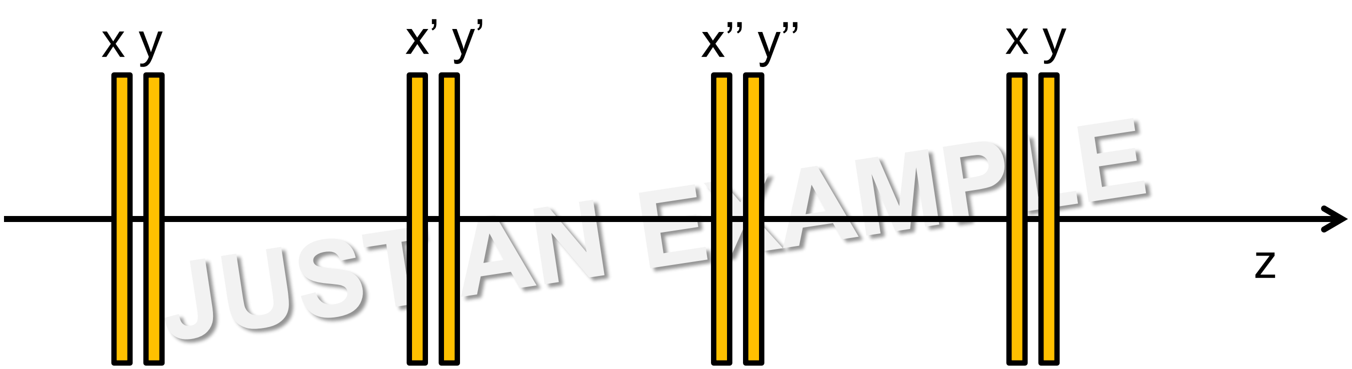
all tracks within radius R_2 are accepted

$R_2^2 = R_1^2 + (H-R_1)^2$

+ some bonus outside, in the corners...



«minimum» number of planes (4)



Comments to geometry

We must find the place with the smallest ratio R_{pipe}/σ_{beam}

- Want small aperture, but large beams!! :-)
- Option not considered here: movable device (in vacuum)
  - complexity (and cost) increases substantially, but allows to come closer

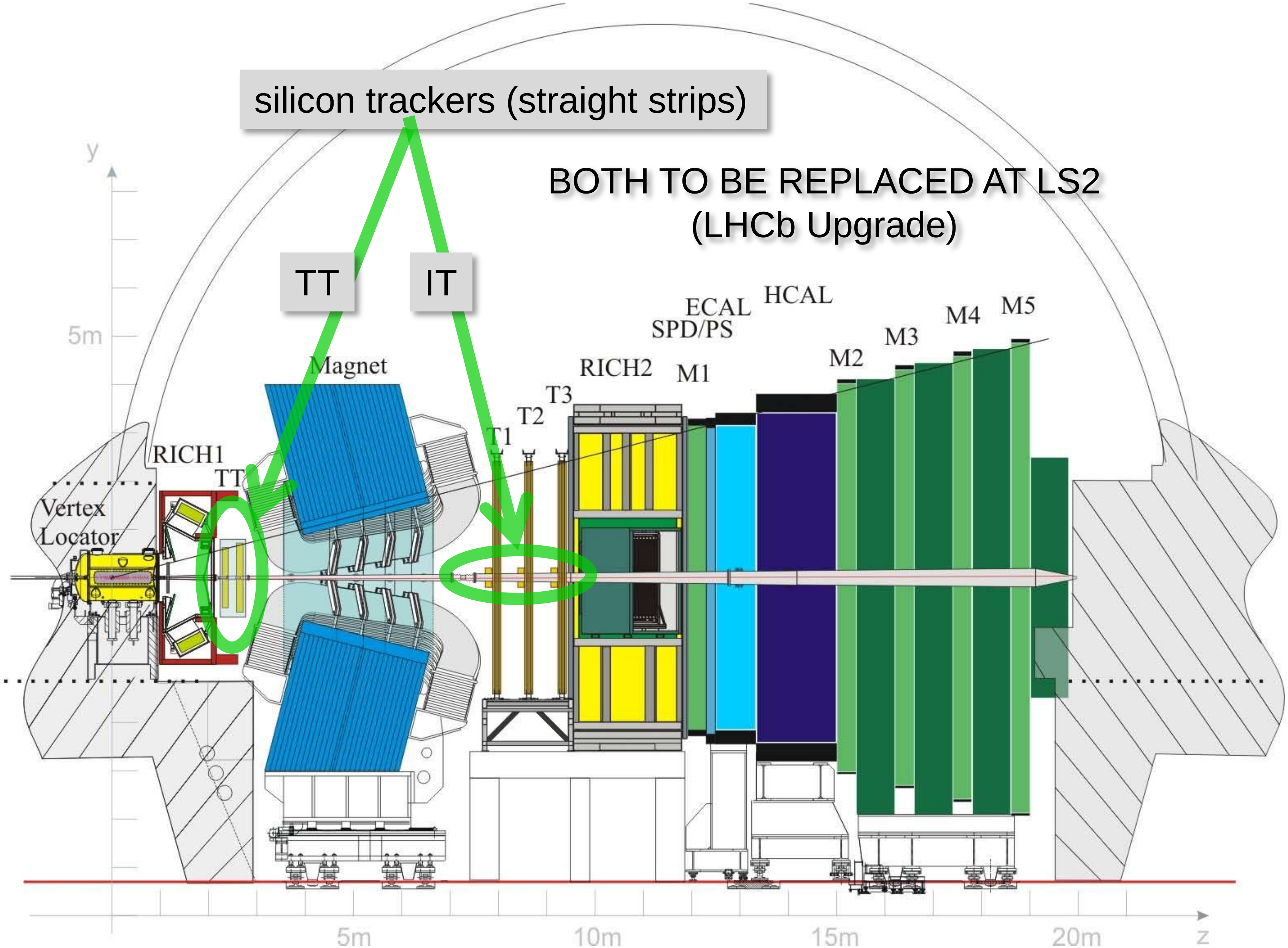
What is the smallest possible radius ? (even if smaller beam size)

- Drives whether we should use silicon or SciFi

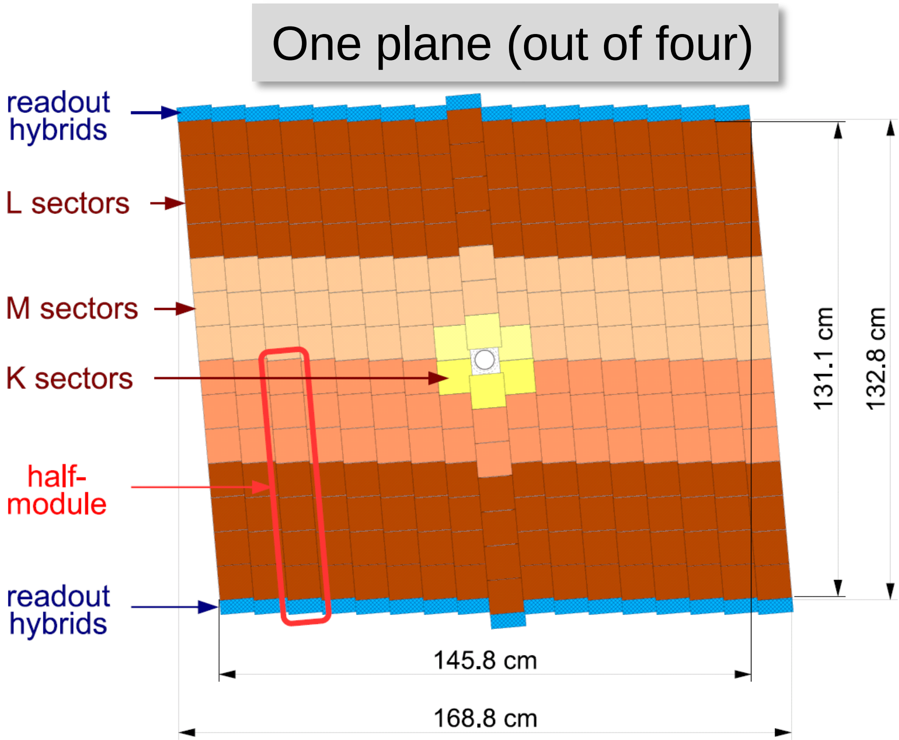
Performance/cost optimization to be done

- Inclined detectors, stereo angle, ...
- Saw tooth beam pipe ?
- Put ring1 device such that no bkg to ring2 device (and vice versa)
- Can we live with 4 planes (xyx'y') using vertex-constrained tracking ?
- etc...

recycle from LHCb ?



LHCb TT in more details



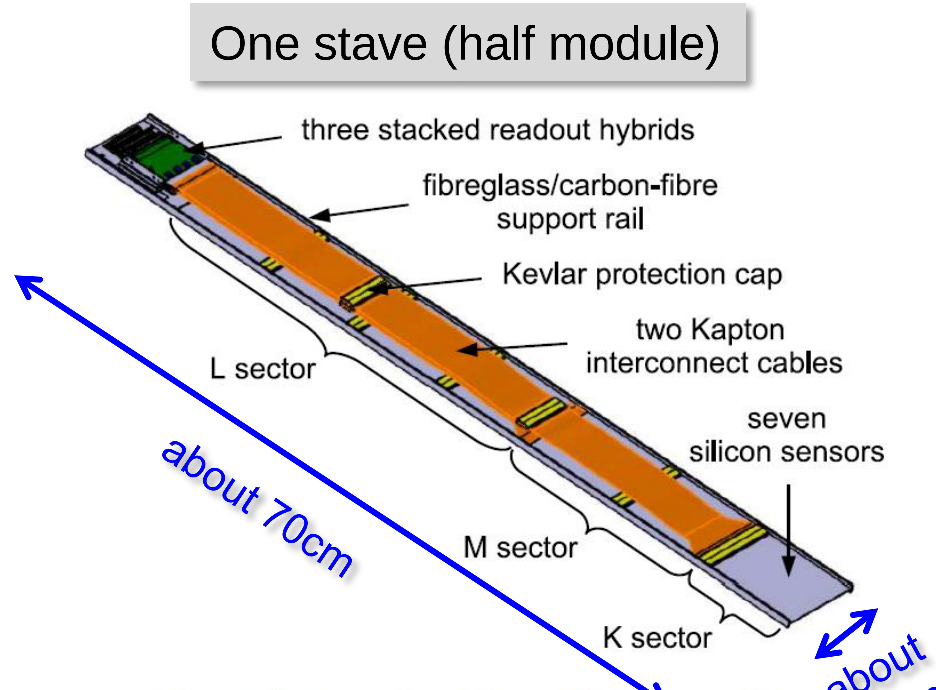


Figure 5.20: View of a 4-2-1 type TT detector module.

Sensor	thickness	pitch	dim (mm^2)
	500 um	183um	96.4x94.4

- 34 staves/plane x 4 planes = 136 staves
- Cooled to about 0 ^{o}C
- Issue: sensors are glued on the stave (7 by 7)

LHCb IT in more details

One plane (out of twelve)

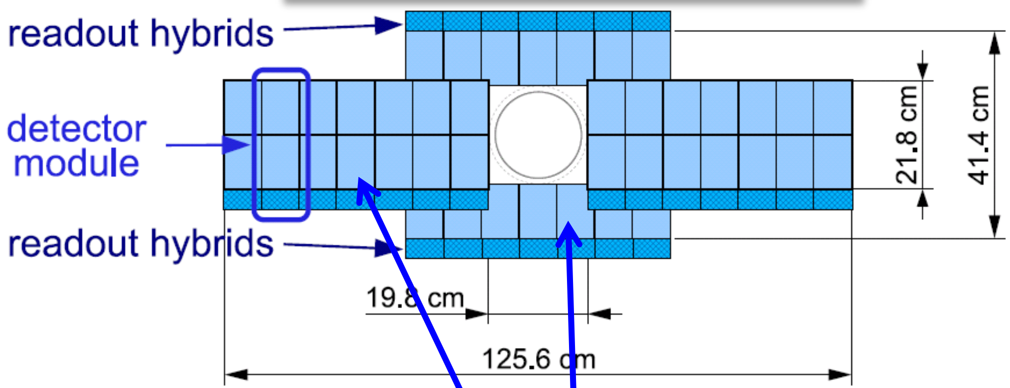
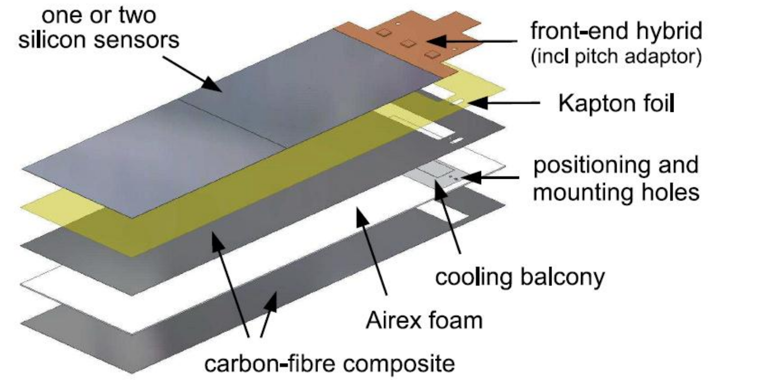


Figure 5.24: Layout of an *x* detection layer in the second IT station.

One module

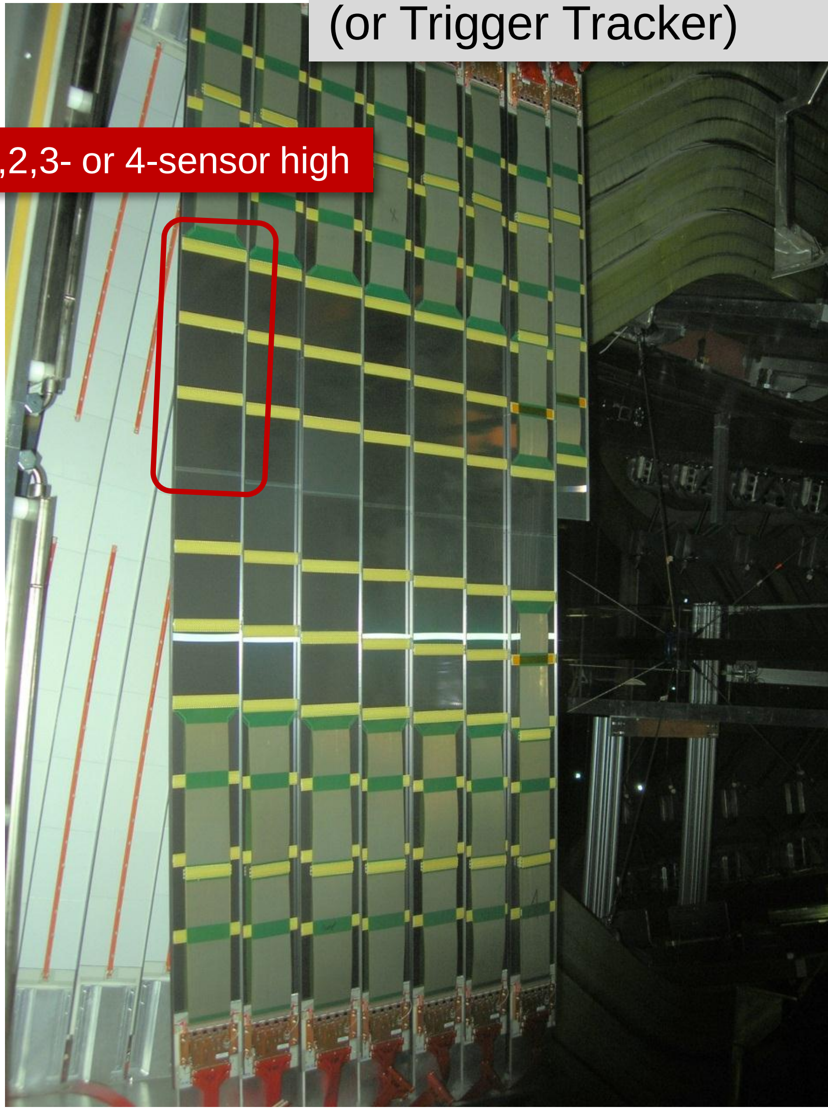


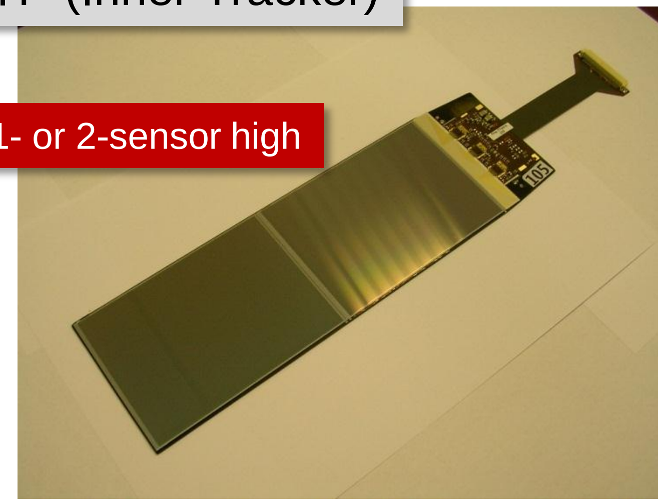
5.25: Exploded view of a two-sensor IT module. One-sensor modules are similar except that the support plate is shorter and carries only one sensor.

module type	thickness	pitch	dim (mm^2)
one-sensor modules (osm)	320 um	198um	76x110
two-sensor modules (tsm)	410 um	198 um	76x110

- 14 osm/plane x 12 planes = 168 osm
- 14 tsm/plane x 12 planes = 168 tsm
- Cooled to about 0 ^{o}C

Silicon modules in LHCb





- Both working well
- Apart perhaps from central part of TT, the detector modules will have little radiation damage, *but will be activated* (lightly radioactive material)

Scintillating Fiber modules in LHCb ?

- No SciFi detector in LHCb currently, but...
- Important R&D effort ongoing to consider SciFi for upgrade
  - would replace central part of Outer Tracker and the Inner Tracker
- Already some short modules available as a spare for the IT boxes
  - ~11cm long fibers
- More modules being fabricated for Upgrade R&D, with several lengths (22cm, 80cm, 250cm)
- Groups: EPFL, Dortmund, Heidelberg, CERN, ...

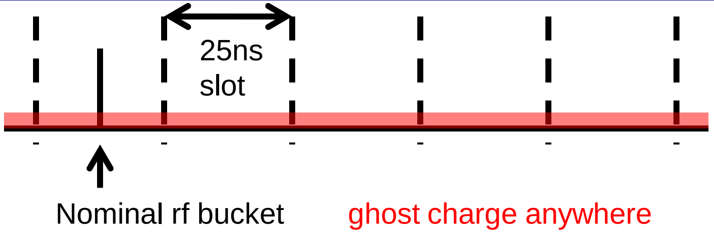
Movable vs not movable

Movable detector device:

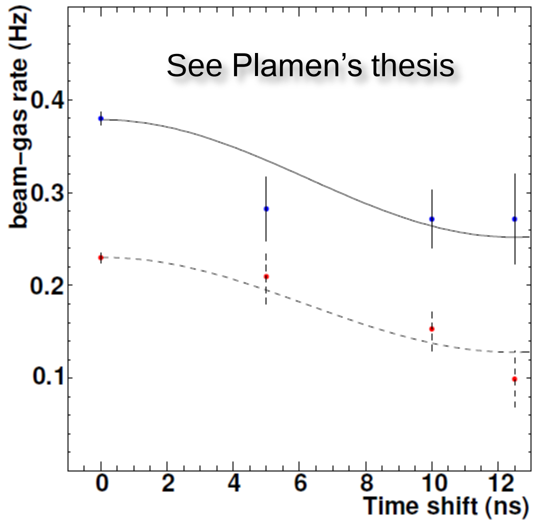
- can come closer to beam
  - improves resolution, compactifies the detector
- increases complexity of detector
  - mechanics, vacuum, protection, etc...
- Issues:
  - only movable in StableBeams ?
  - difficult to access detector (repair, maintenance)

My personal bias: «if it can be done with a fixed detector, don’t make it movable…»

Possible add-on to be considered/studied



- Currently, in LHCb: 25ns integration time, 40MHz synchronous
  - OK for nominal RF buckets
  - But for ghost charge, had to check detection efficiency vs time



Fast timing detectors

- See e.g. AFP: based on cerenkov radiation, quartz rods with MCP-PMT can reach ~ 20ps

- Would allow measuring the longitudinal profile
  - satellites, bunch lengths, ...
  - Scintillators with ~ 0.3 ns are sufficient for satellite measurements, but we need < ~100 ps for proper bunch length measurement

readout chain

IT/TT FE electronics

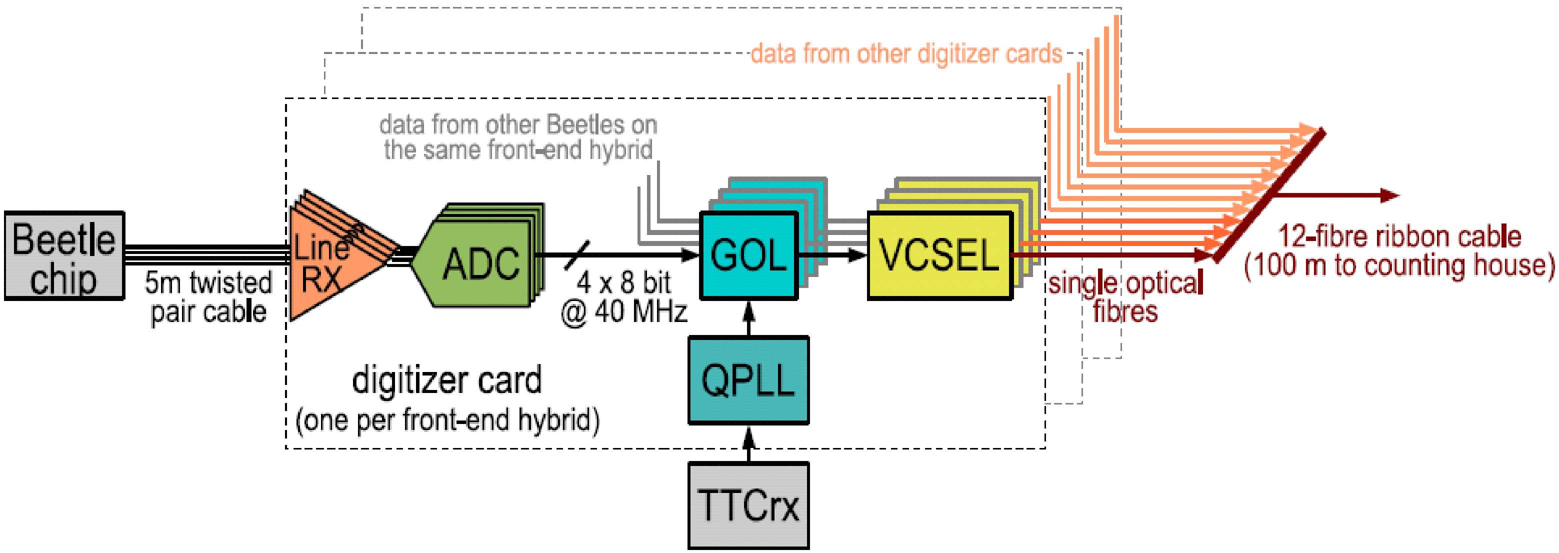
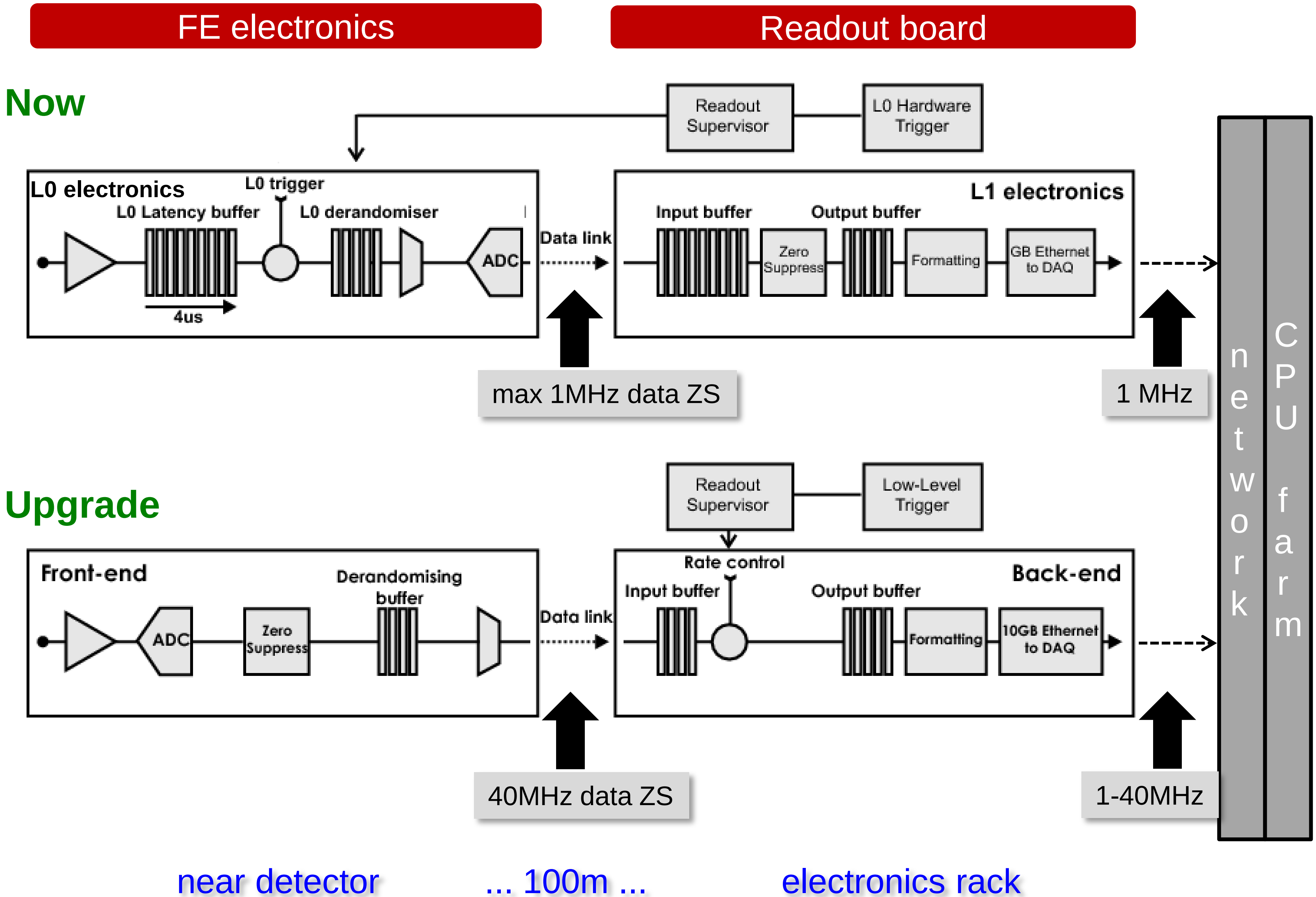


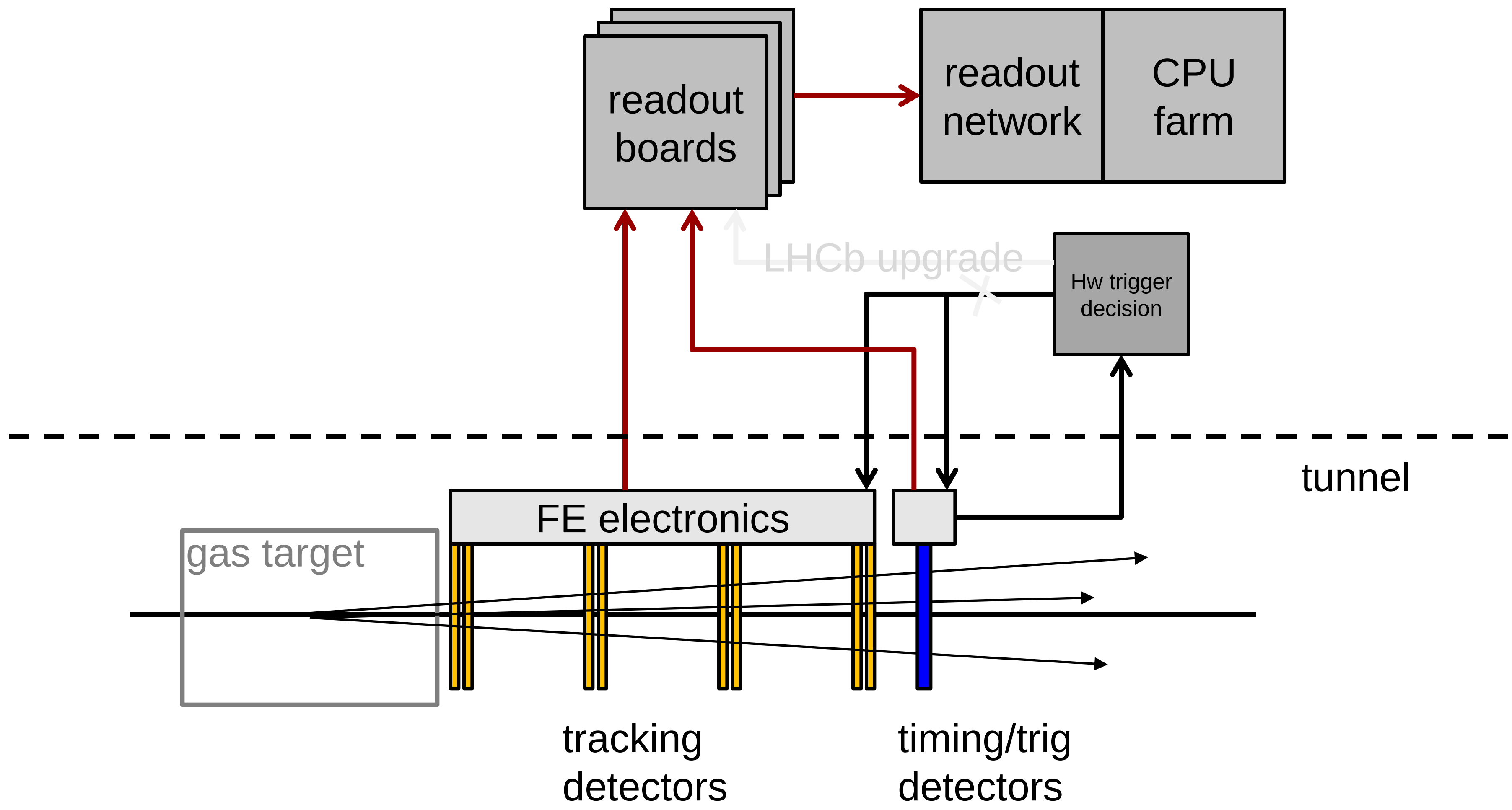
Figure 5.29: Functional block for the processing of the data from one Beetle chip. This functional block is repeated four times on a TT digitizer card and three times on an IT digitizer card.

In principle, all these beautiful electronics are to be «scrapped» at LS2...

LHCb readout chain (IT and TT)



At the LHC, a simple view...



Data rate (to be refined at a later stage…)

- Assumption:
  - zero-suppressed IT-like detector (3072 channels per Tell1 board)
  - 20 tracks per primary vertex per plane (conservative)
  - Each hit is a double-strip cluster encoded in 12 bits (channel address) + 3 bits for interstrip distance

- Data size per vertex (one ring):

15 bits/clus x 20 clus/plane x 8 planes = 300 Bytes

+ noise!

- Data rate:

Raw (good) event rate ~ 280 kHz

300 Bytes x 100 Hz/bunch x 2800 bunches = 84 MB/s

+ bkg!
+ headers…

Say: ~ 100 MB/s ZS cluster data ~ few hundred TB/yr

(no trigger selection, no data reduction by online processing)

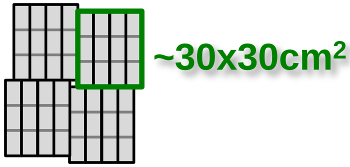
Detector cost estimate: Silicon «à la LHCb Upgrade»

Quick & dirty estimation

1 plane = 48 sensors

- ladder = 3 sensors bonded
- 3 chips per ladder
- 1 chip = 128 channels

2 rings 8 planes



Item	kCHF	Quantity	Remark
Sensors	~1100	768	2x8x(3x4x4) sensors
FE electronics	~400	768 / 256	Chips / Hybrids
Readout chain	~200	4 / 384 / 384	Tell40 / GBT links / fibers
HV/LV	~200		
Mech./cooling	~100		
TOTAL	**~2000**		

no spares taken into account
=> should add 10-15% cost

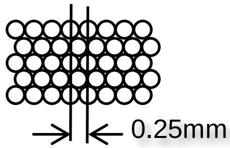
Detector cost estimate: SciFi «à la LHCb Upgrade»

Quick & dirty estimation

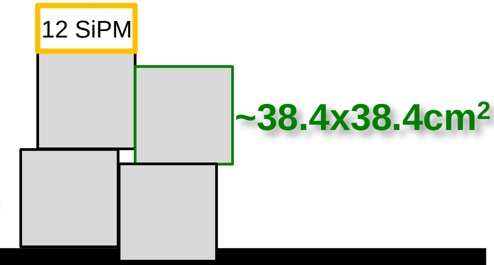
1 plane = 4x12x128 channels

(1 SiPM = 128 channels)

1 plane = 5-fiber layer, 0.25mm diameter



2 rings 8 planes



Item	kCHF	Quantity	Remark
Fiber	~20	47 km	2x8x(4x0.384mx5x12x128x0.25)
FE electronics	~1000	768 / 768	SiPM / Chips (+Hybrids)
Readout chain	~150	4 / 384 / 384	Tell40 / GBT links / fibers
HV/LV	~200		
Mech./cooling	~100		
TOTAL	**~1500**		

NB1: cost almost doesn't change with increasing size of detector
NB2: hard to get fiber diameter down...

no spares taken into account
=> should add 10-15% cost

gas target

The gas target

Requirements:

- must give sufficient beam-gas rate from the nominal gas z-range:

  R(nom. range) > ~100Hz/10^{11} p

  and sufficiently low bkg (from non-nominal z range)

  R(bkg) < R(nom. range)

  – Also: minimize «useless» radiation damage to detector
- largest possible track multiplicity per vertex
  – Xe better than Ne better than He ...

- must be able to operate continously (when beam in machine)
- no effect on beam operation
  – lifetime due to injected gas >100h
  – contamination of nearby section to be kept low
  – check SEY for gettered or cryosorbed gas species

Which gas ?

Inelastic cross section

$\sigma_{pA} \approx \sigma_{pp} \cdot A^{2/3}$

Charged pion multiplicities

$M_{pA} \approx M_{pp} \cdot (a+b \cdot A^{1/3})$

$a \approx 0.65$, $b \approx 0.3$

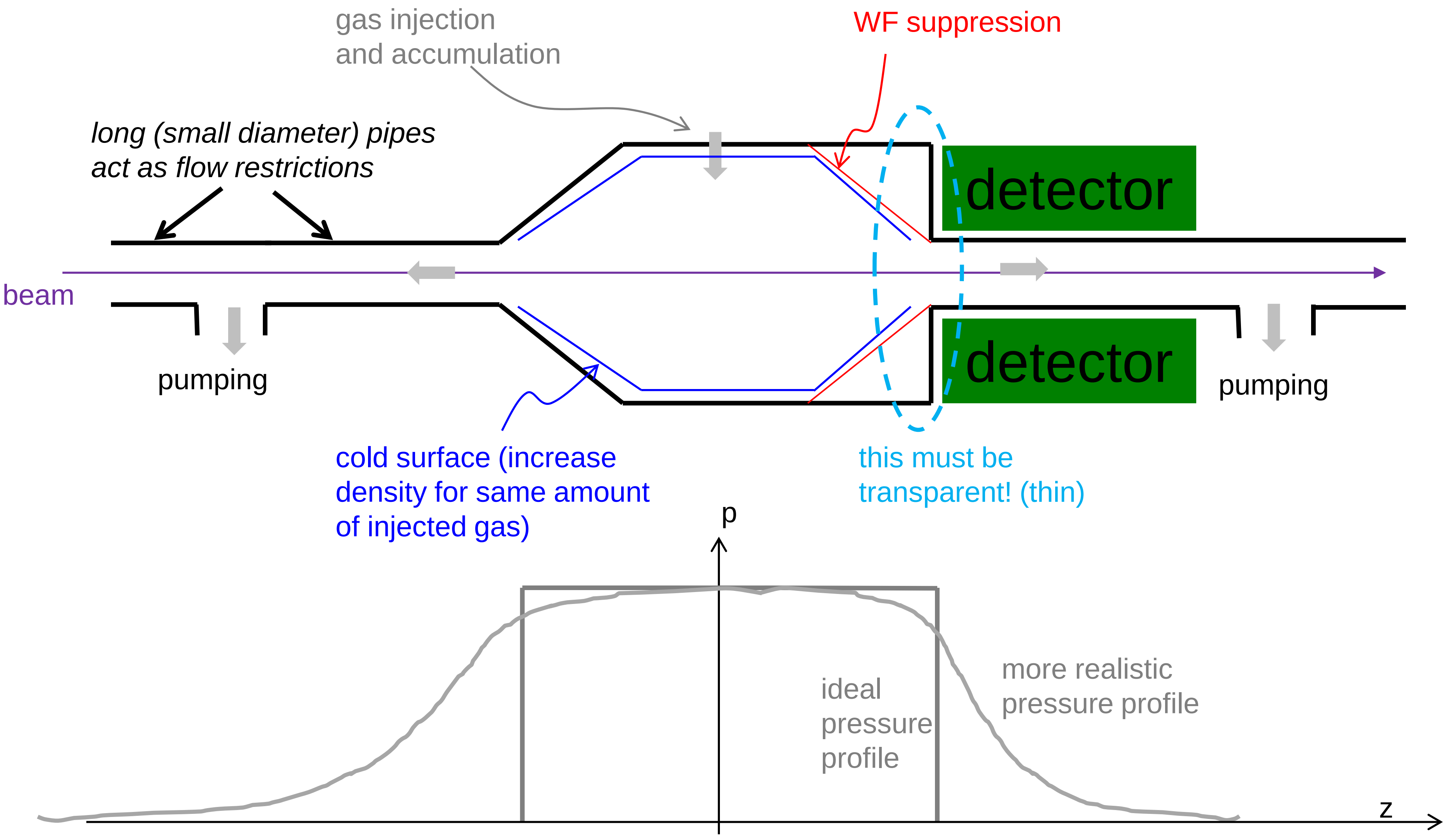
MG, DR, Z. Phys C65, 215-223 (1995)

Larger A → larger cross section and larger multiplicity per vertex

Getterable / non-getterable ? (or cryosorption ?)

- getterable: e.g. CO_2, N_2, O_2 ...
  - Very local pressure bump
  - Requires regenerating (changing ?) the NEG sporadically
- non-getterable: e.g. Ne, Xe, …
  - Longer pressure bump, requires differential pumping around the target
  - Some contamination of nearby cryo section surfaces ?

Gas target (sketch!!)



Reminder: contrary to VELO/LHCb, here gas injection must be continuous (with beam)... Consider impact on machine!

organization

Three (parallel) activities

- «Off-the-trunk» device: (immediate)
  - install asap in LHC (LS1 or winter stop thereafter)
  - proof of principle, gain experience
  - only one LHC ring ?
- Full-blown solution for LHC: (mid-term)
  - enough detectors (redundancy, acceptance)
  - one device per per ring in LS2
  - buy new or recycle LHCb ?
- Further applications: (long-term)
  - SPS, PS, etc.

Next steps: tentative list

- Write down specifications of the new imaging device for LHC
  - detector
  - gas target
- Find best place in LHC (smallest R_{pipe}/σ_{beam})
- Organization: who works on what ?
  - The device is mostly a beam diagnostics instrument → project **led by BE-BI**, *with strong support from* TE-VSC, BE-ABP, LHC-OP, LHC-MP and PH

Detector
- Mechanics
- Sensors
- FE electronics
- RO board
- Ctrl electronics
- Ctrl s/w
- Acq f/w
- Reconstr s/w
- Monitoring s/w
- ...

Gas Target
- Vacuum sys
- Gas injection
- Cryo cooling
- Impedance
- Ctrl s/w
- Monitoring s/w
- ...

We need a (generic) name for such a device !!

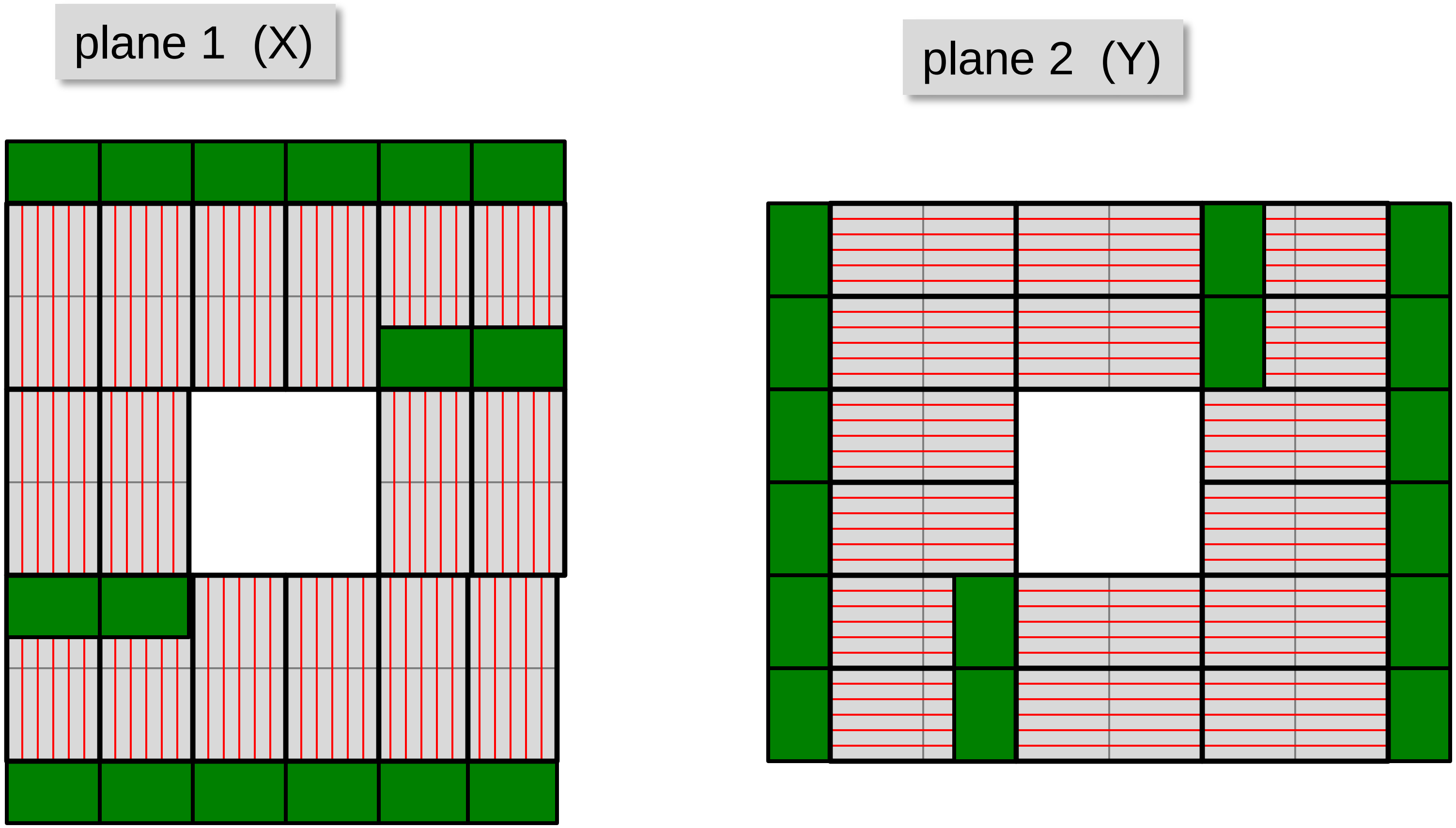
Device *Detector* *Beam* *Gas* *Interaction* *Imaging* *Vertex* *Shape* *Locator* *Accelerator* *Reconstructor* *Analyzer*

BGI	alas, already in use...
BSID	Beam Shape Imaging Detector (Device)
VIDET	Vertex Imaging DETector videt = latin for «it sees»
AVID	Accelerator Vertex Imaging Detector
VID	Vertex Imaging Detector (Device)
APID	Accelerator Particle? Imaging Detector
VELO	VErtex LOcator
BAGI	Beam Analyzer with Gas Interactions
???	
???	
???	
???	

Make your own suggestion!!

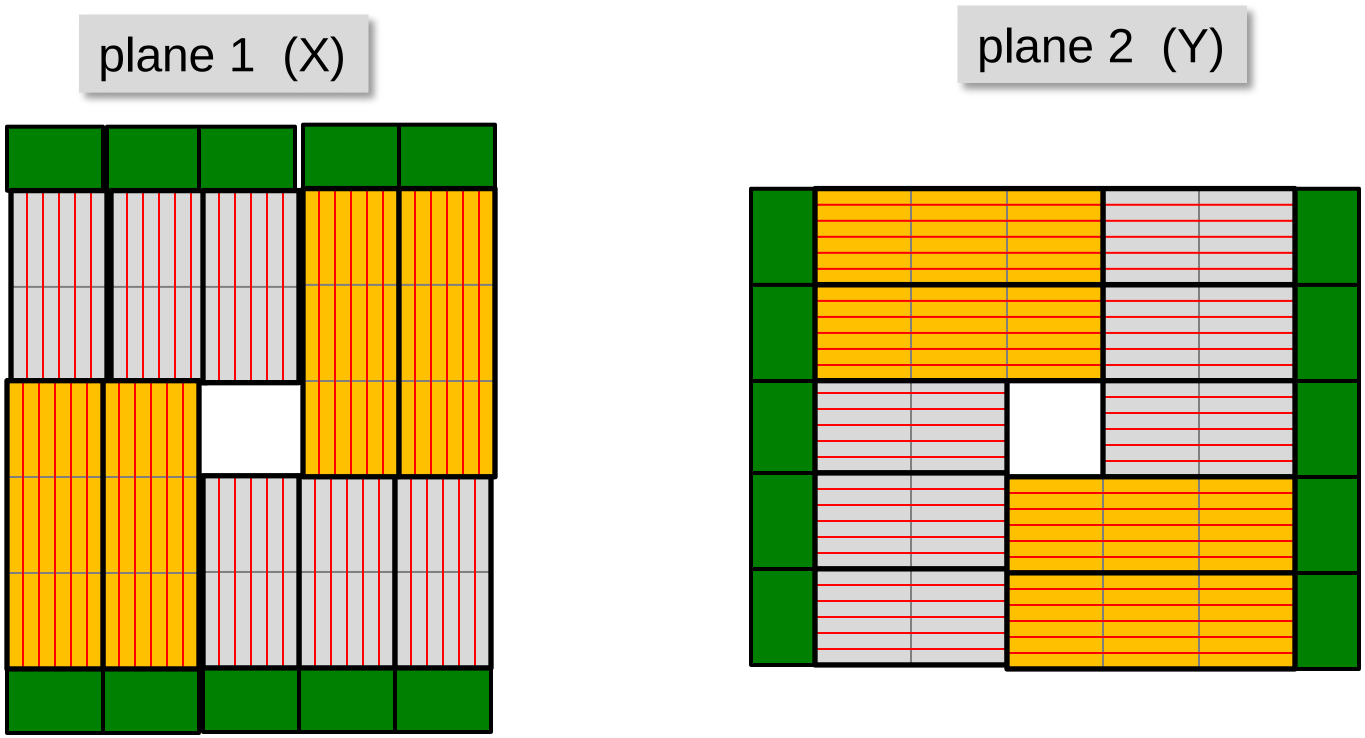
backup

Option 2 for the detector arrangement (one XY plane)

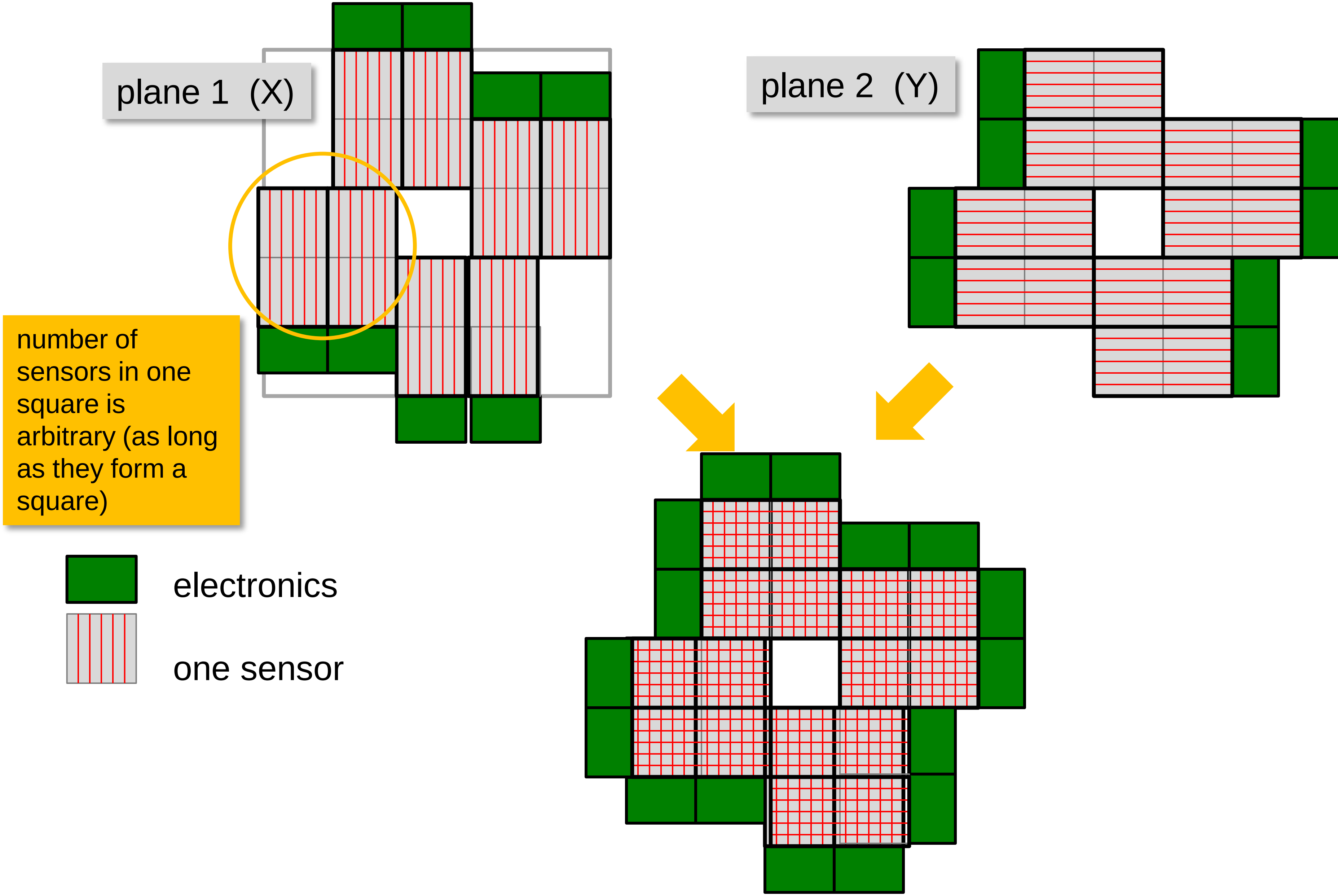


Option 3 for the detector arrangement (one XY plane)

Two modules types (two lengths)



Option1 for the detector arrangement (one XY plane)



LHCb electronics architecture

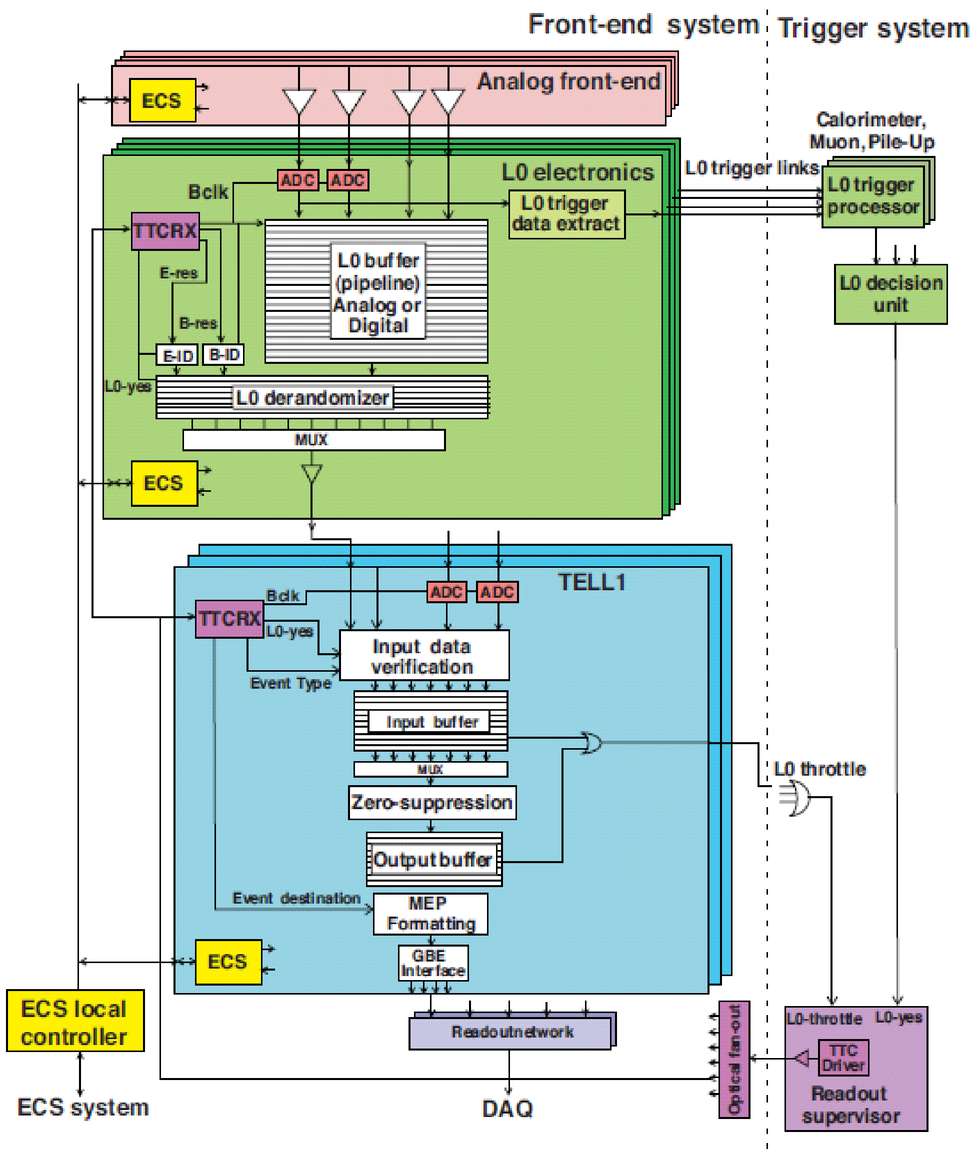


Figure 2.2: General front-end electronics architecture and data flow in the DAQ interface.