PAUL SCHERRER INSTITUT

Building Detector Modules for the (S)CMS Pixel Barrel Detector

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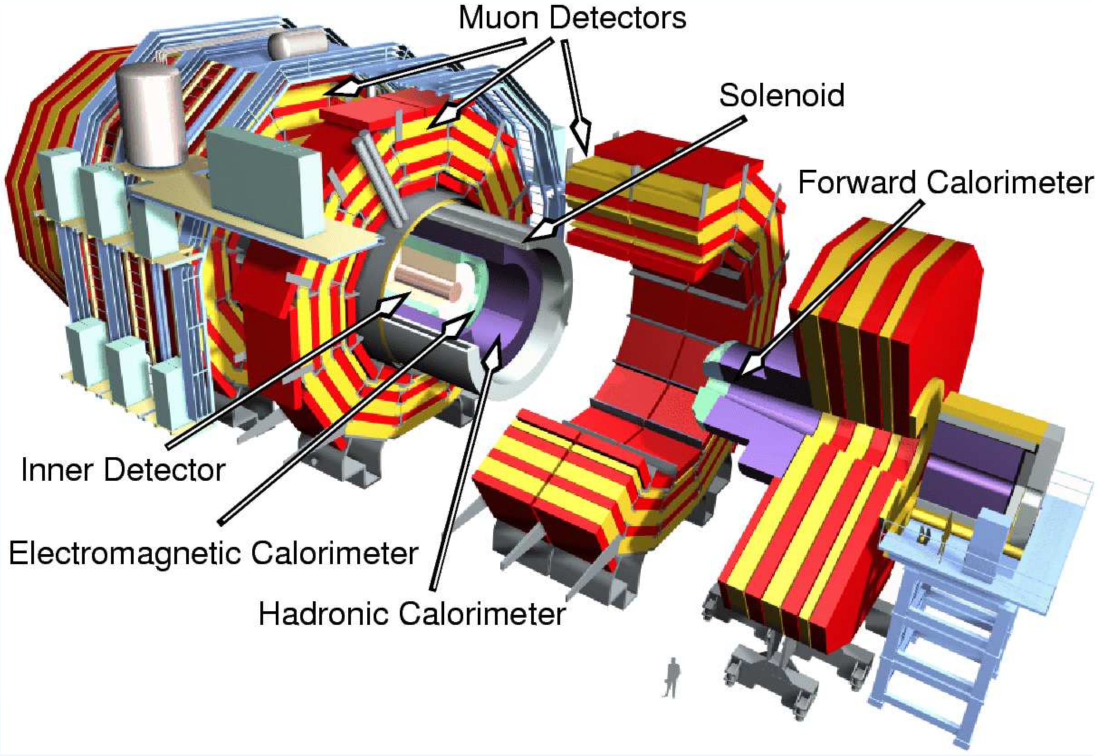
Outline:

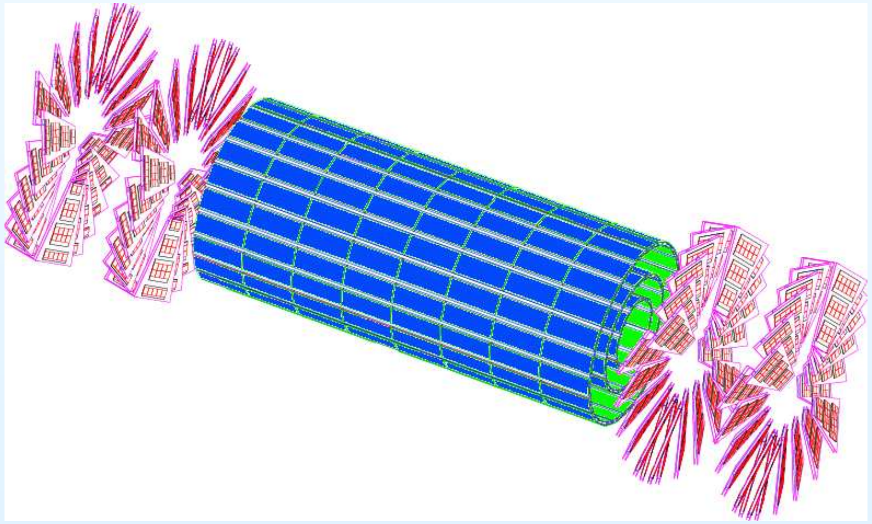
- barrel module production for LHC
- SLHC pixel barrel upgrade plans

The CMS Experiment

Si - Strip Tracker:

- 20 cm < r < 110 cm
- 200 m^2
- 10 barrell layers + 2x9 discs
- > 15k modules / ~10 Mch

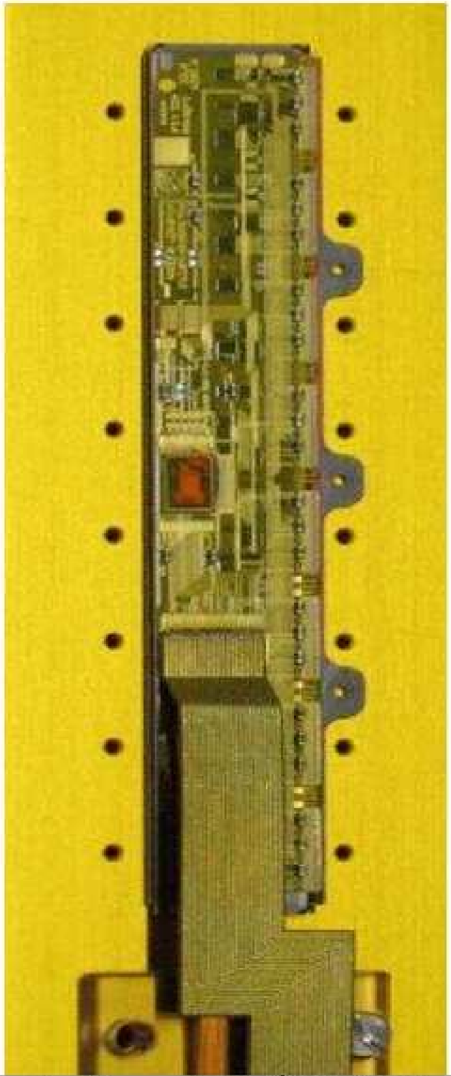




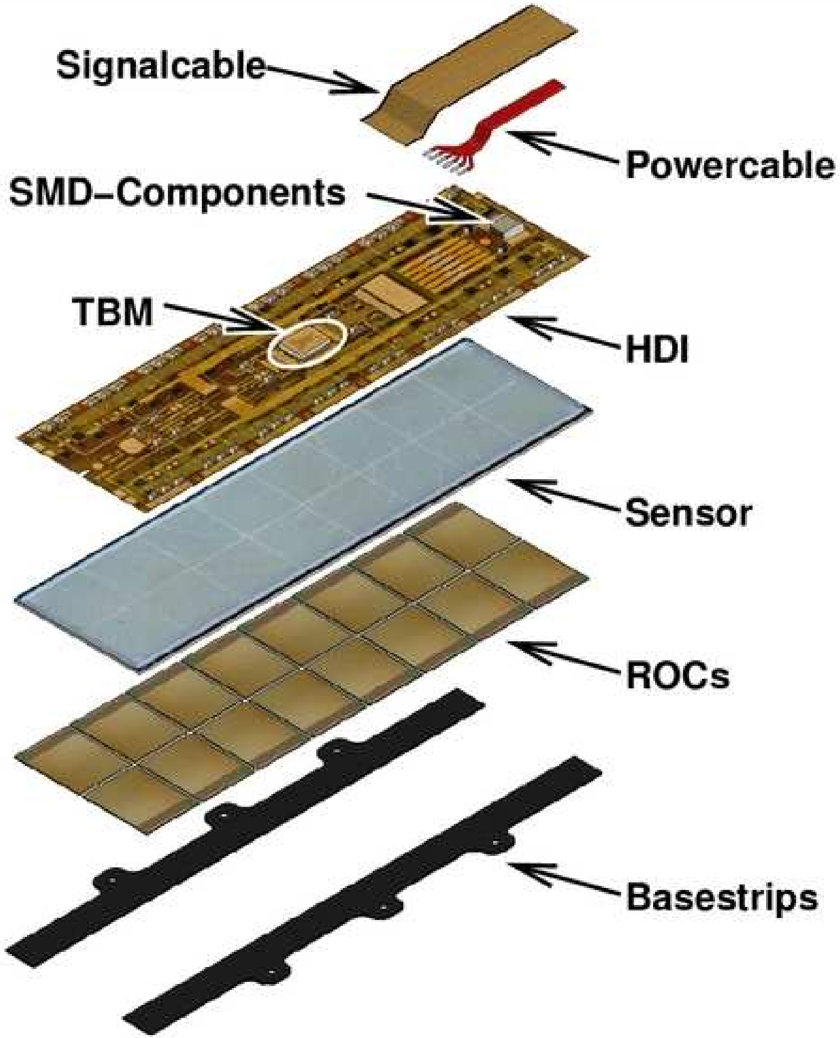
Pixel Tracker:

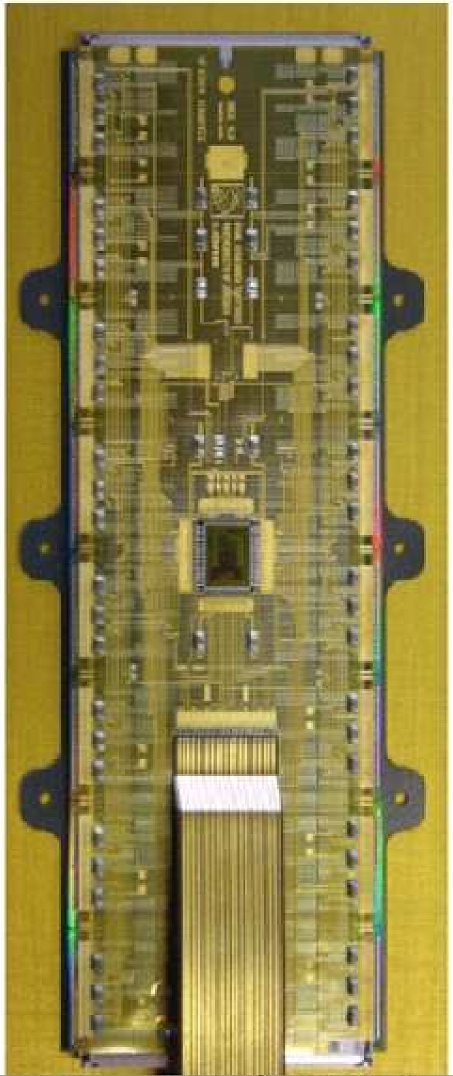
- ~ 1 m^2
- 3 barel layer + 2x2 discs
- ~ 1k modules / 16k ROCs /~ 66 Mch

Barrel Modules



half–module ≙ 8 ROCs





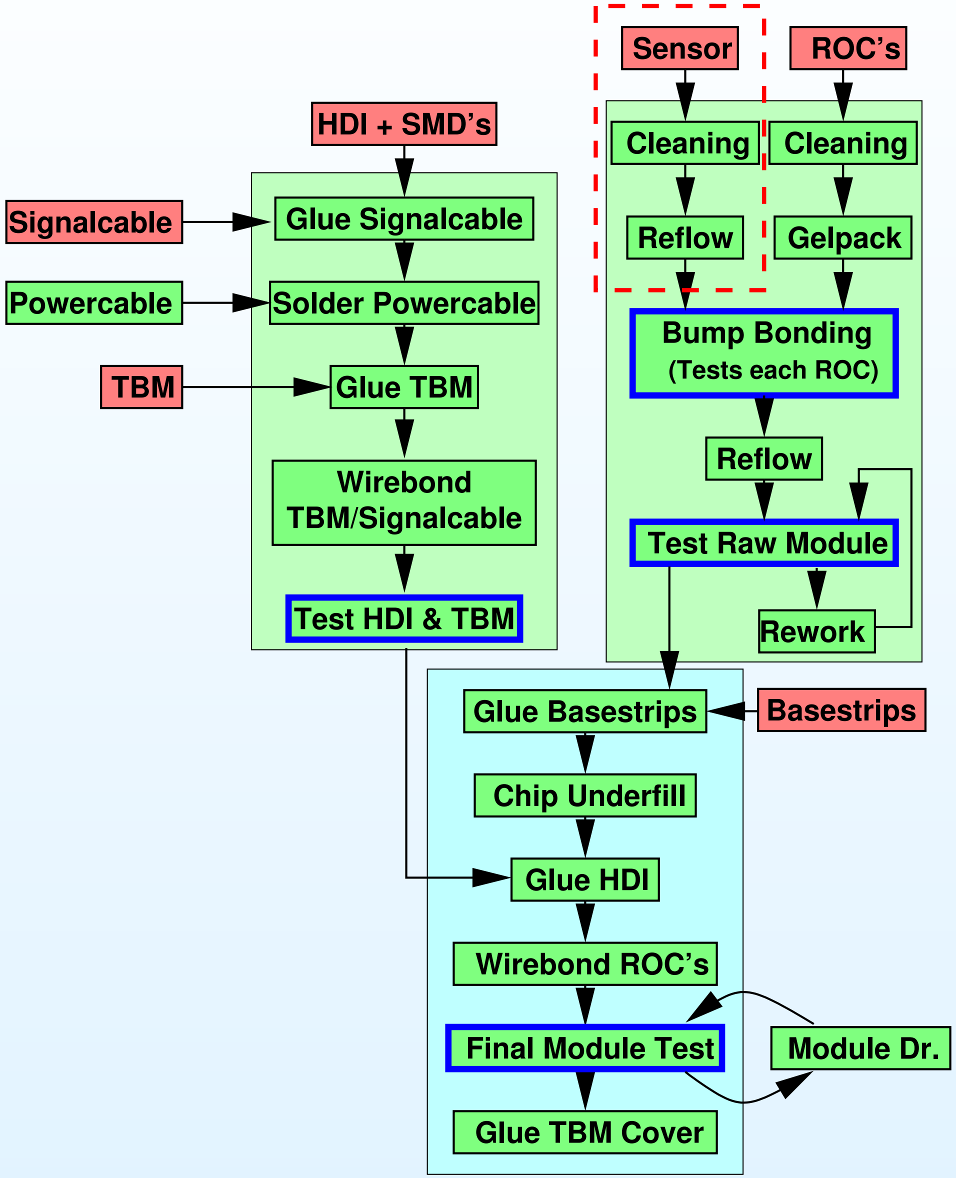
full–module ≙ 16 ROCs

production goal: 678 full modules + 2x48 half modules

Pixel Module Production at PSI

Three branches:

- HDI-assembly
- Bumpbonding
- Module-assembly



High Density Interconnect (HDI)

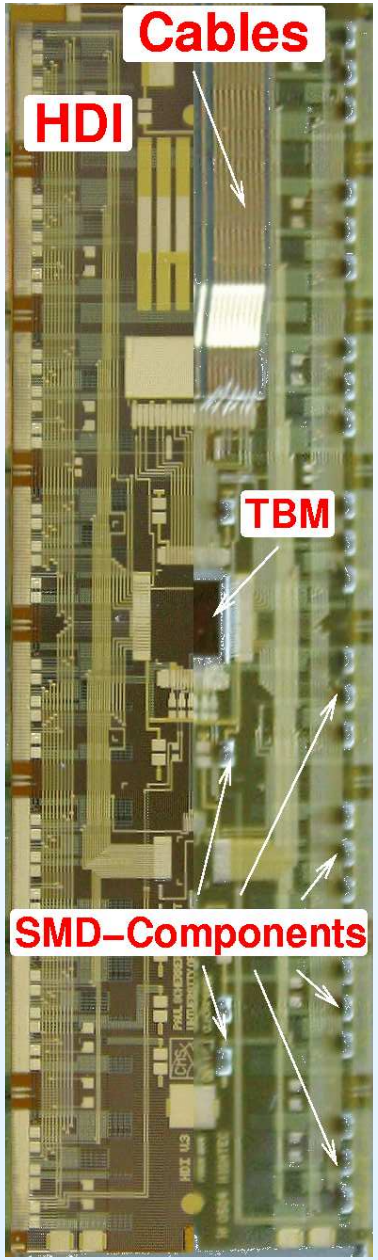
flexible low mass PCB:

- three layers of 6 micron thick traces
- equiped with rad hard SMD components & TokenBitManager-chip (TBM)

tasks:

- distributes controll signals and power to ROC's and TBM
- transfers readout data from ROC's
- transmitts token signal to all chips

PCB pre-tested by vendor but not error free...

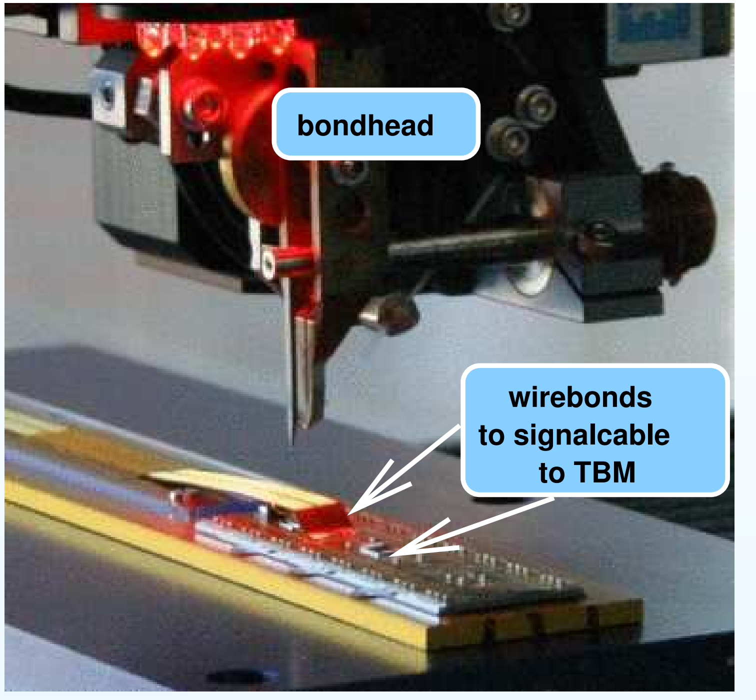


HDI-Assembly - Components

assembled components:

- HDI (incl. SMD components)
- TBM
- Signalcable
- Powercable (prod. @ PSI)

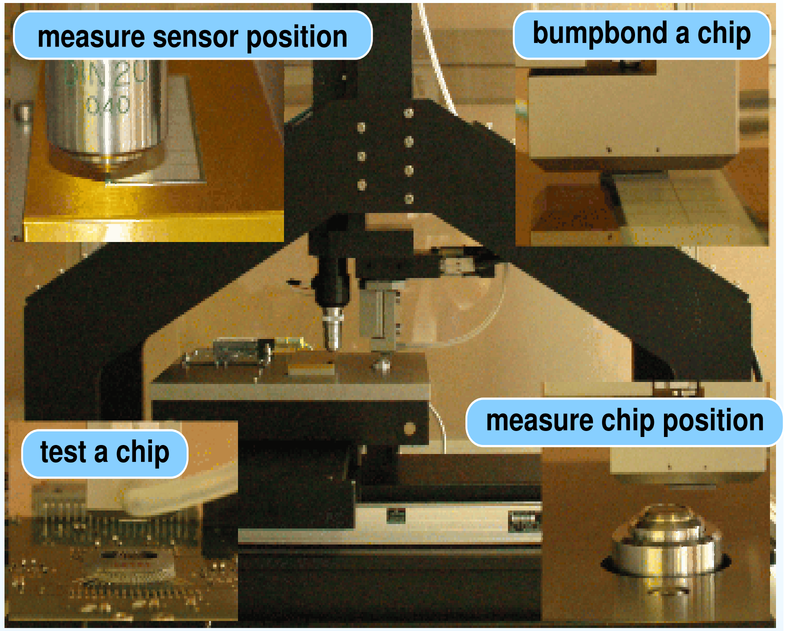
> 1000 HDIs & powercables done...

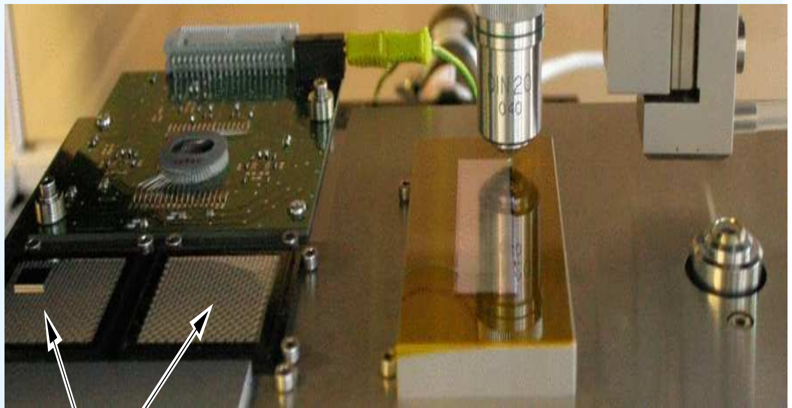


module/HDI diagnostics station at PSI

Bumpbonding at PSI

- indium bumpbonding developed at PSI
- fotolithographics & indium evaporation done at PSI
- bumpbonding machine:
  - fully automated
  - ~3/4 hour per module
  - (5 min operator time)
- chips tested just before bumping
- redundant:
  2nd machine in place (SLS)





after bumping, raw modules are reflowed & tested before assembly

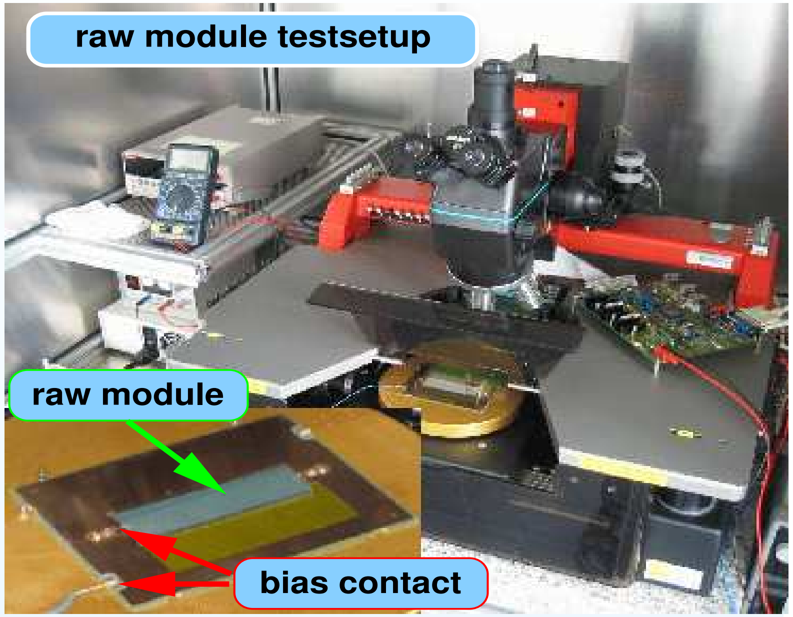
Raw Module: Test & Rework

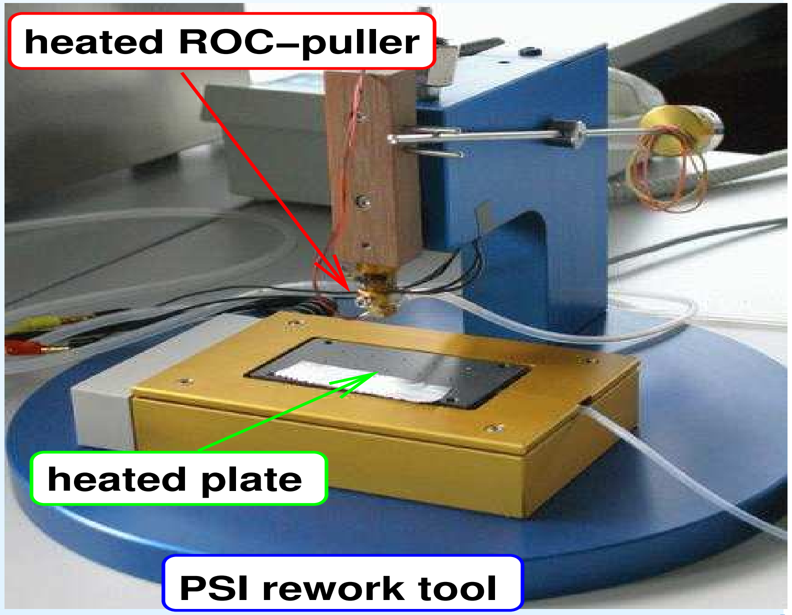
raw module test:

- IV-curve
- ROC functionality
- bump - yield

Rework station:

- up to 3 times if needed
- successfull in 80% !!!





'Handmade' Modules

assembly with hand operated jigs:

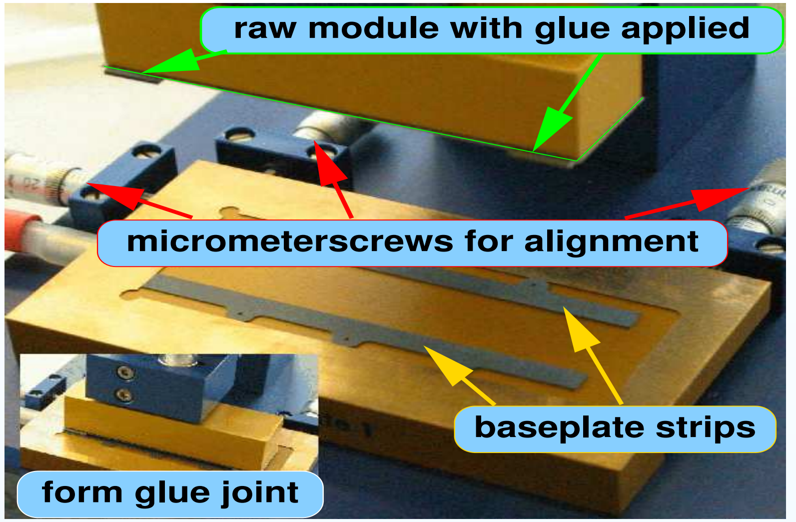
- 3 glueing steps
  - glue basestrips to raw module
  - underfill sensor with glue
  - glue HDI to complete assembly

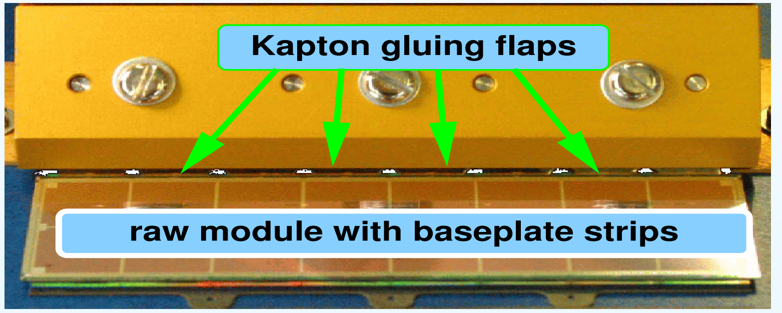
- glue is 'stamped' on parts

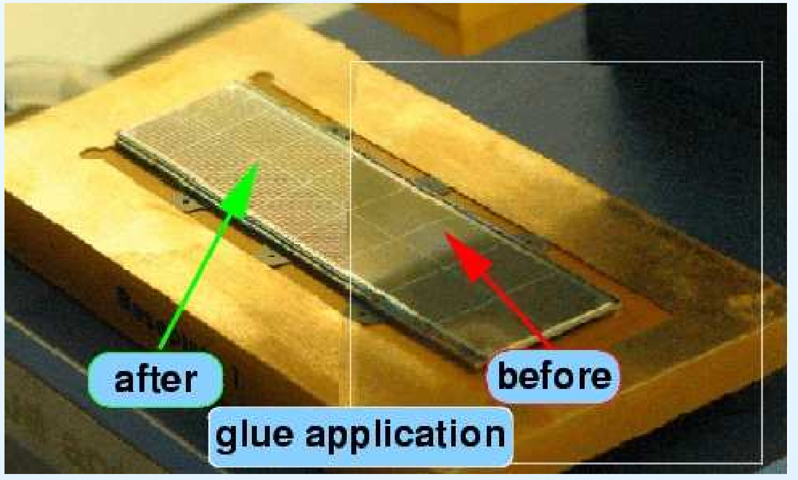
  ⇒easy & accurate!

total production capacity:

- 6 modules/day



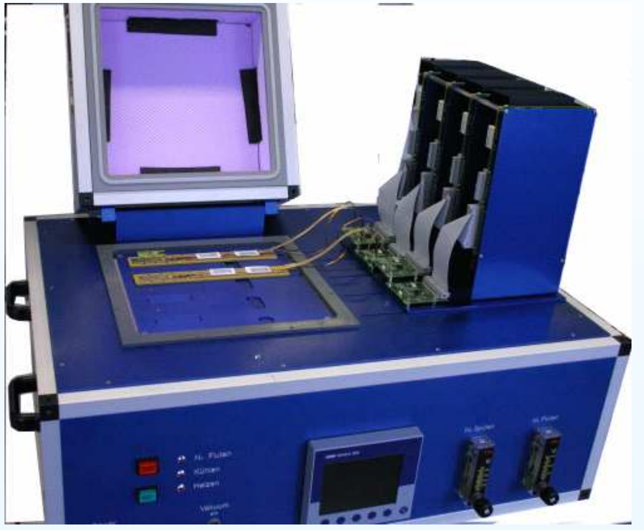


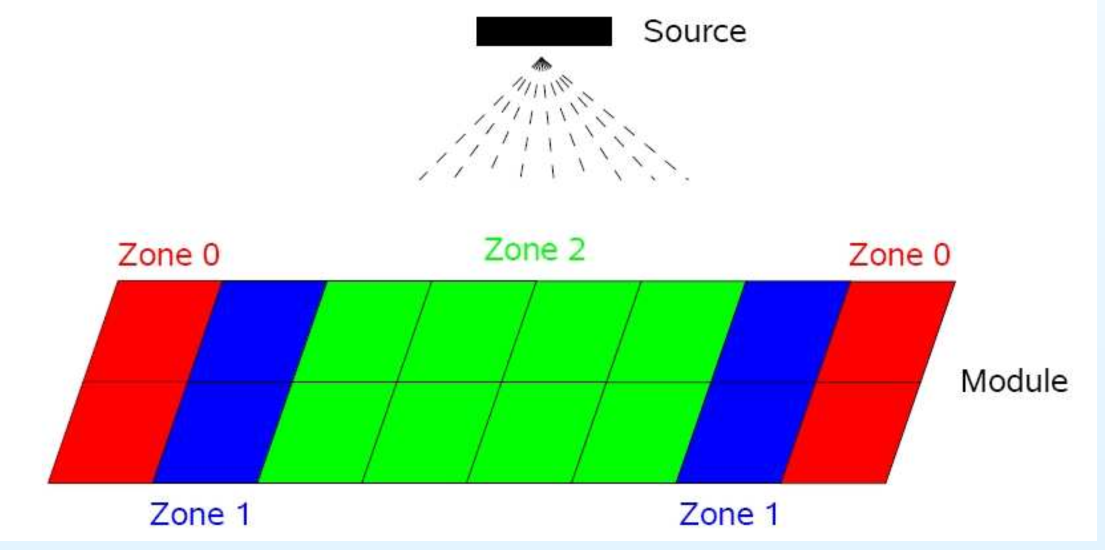


Module Qualification

final testing:

- electrical tests
- thermocycling (10x)
- extract configuration values @ -10 °C





- x-ray - test:
  - gain
  - pedestal

Production Result

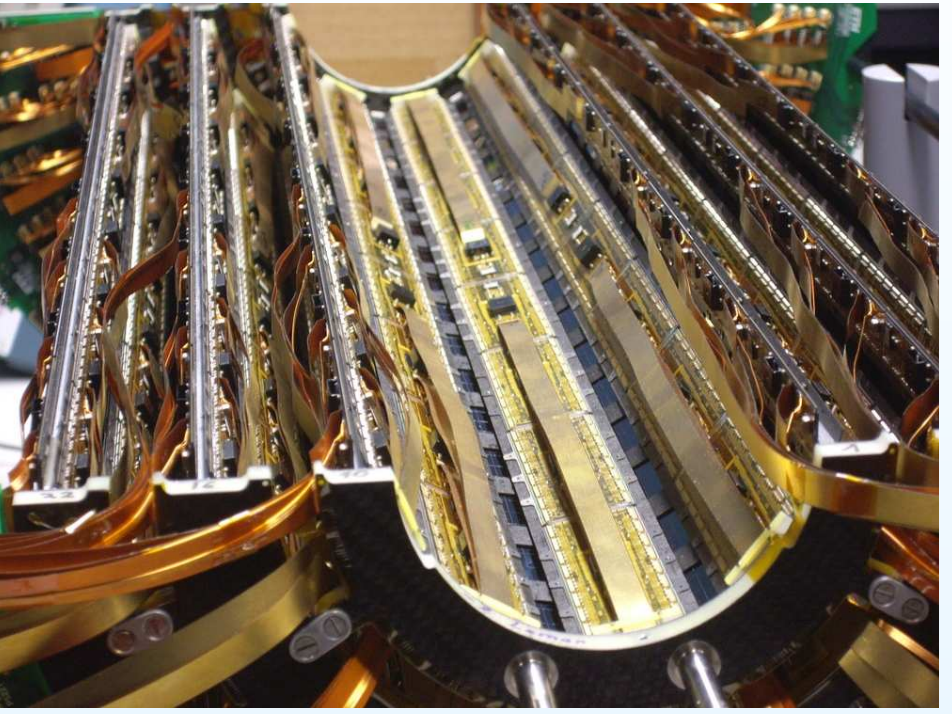
- bumped:
  950 full / 150 half
- good:
  710 full / 110 half
- used:
  678 full / 96 half
- yield:
  full 74 % / half 71 %

most modules lost due:

- bad sensors (raw test)
- bad HDI's (final test)
- accidents (both)

distribution of bad modules after raw/final test ~50/50

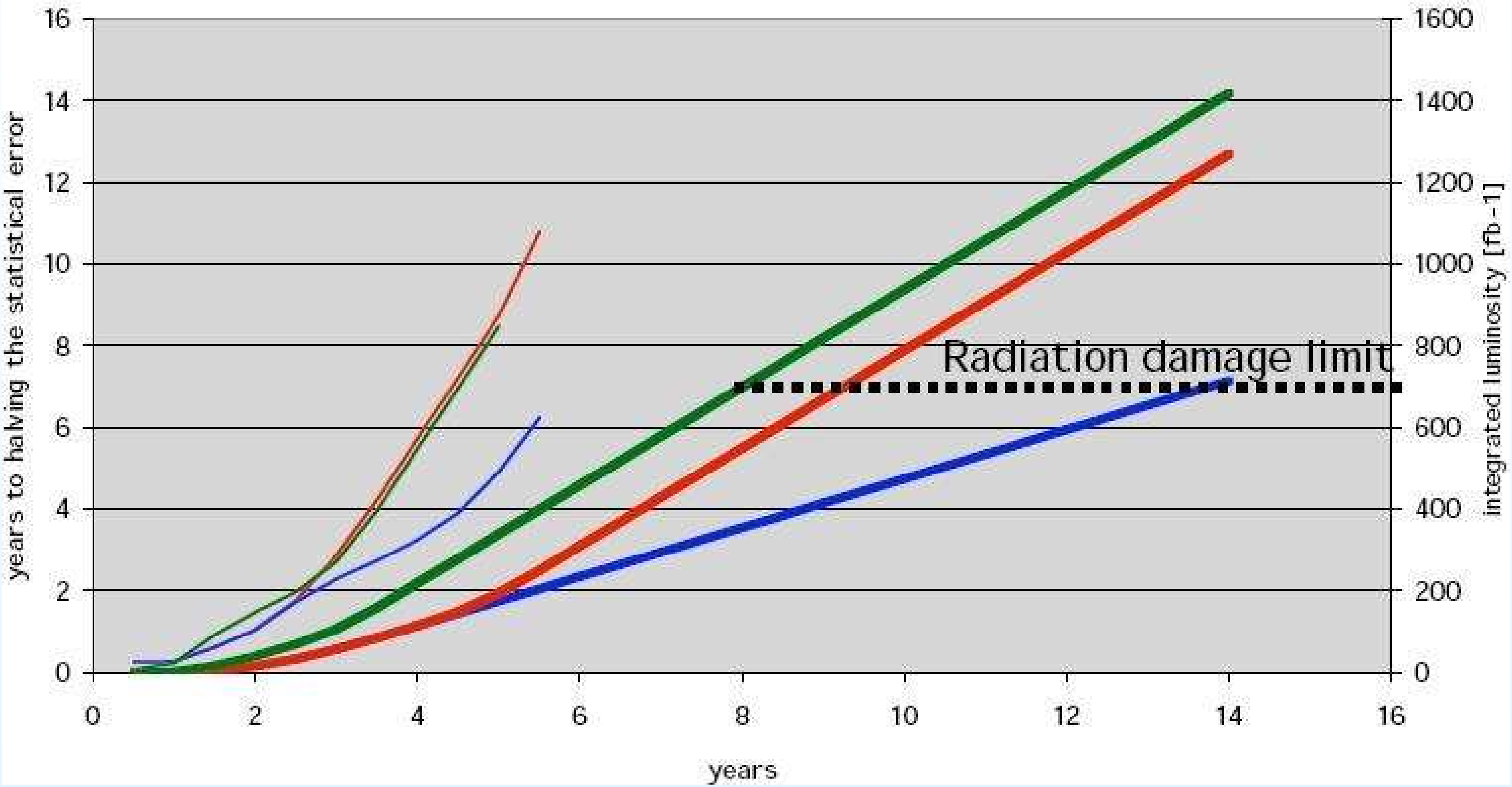
The Final Detector

- module losses in integration:
  - handling ~1%
  - reject due to system effects ~1%

detector integrated and waiting for comissioning with final hardware

From LHC to SLHC



SLHC ~ 2018

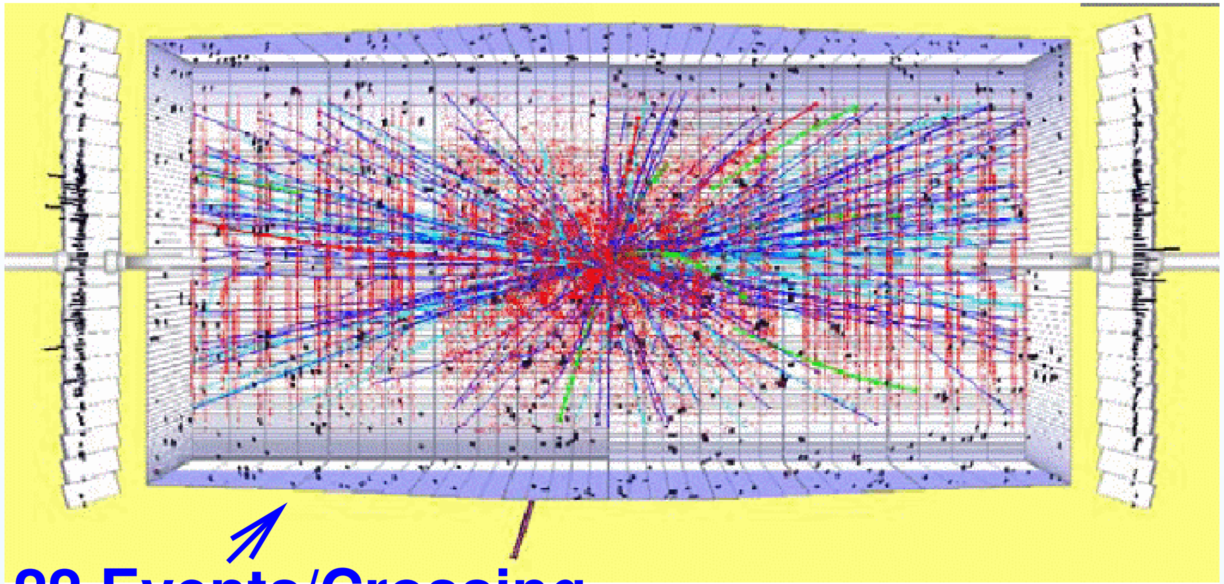
Luminosity:

- @peak: ~ $10^{35}cm^{-2}s^{-1}$
- integrated: ~6000 fb^{-1}
  → dose 10xLHC !

BX all 50ns

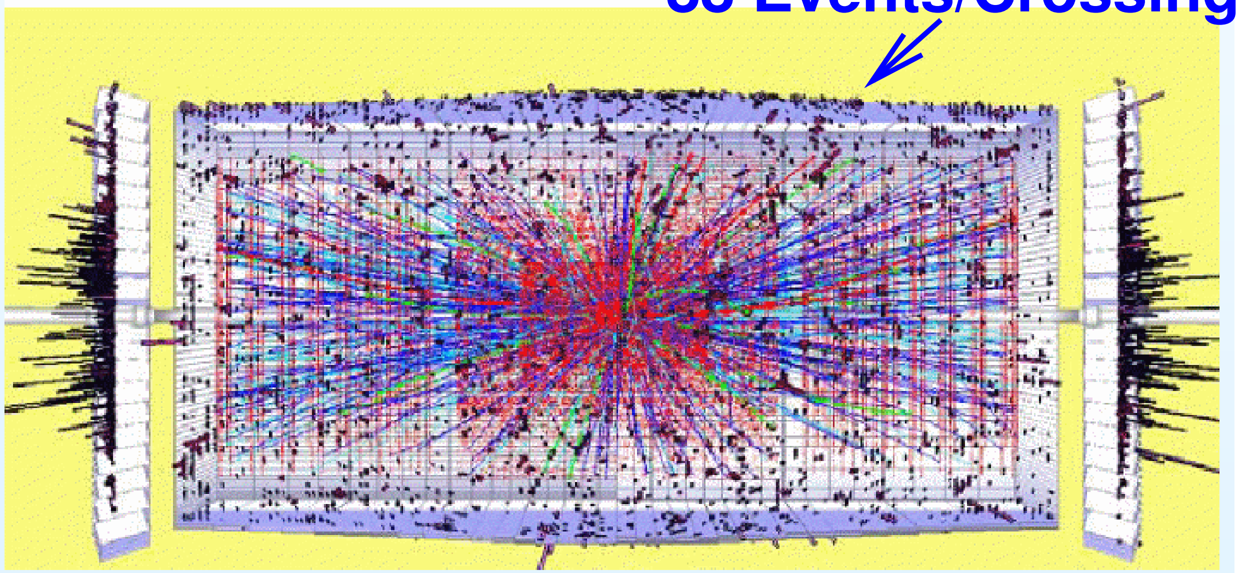
- ~400 (!) collisions / event
  → occupancy = 20xLHC

+ trigger latency doubled...



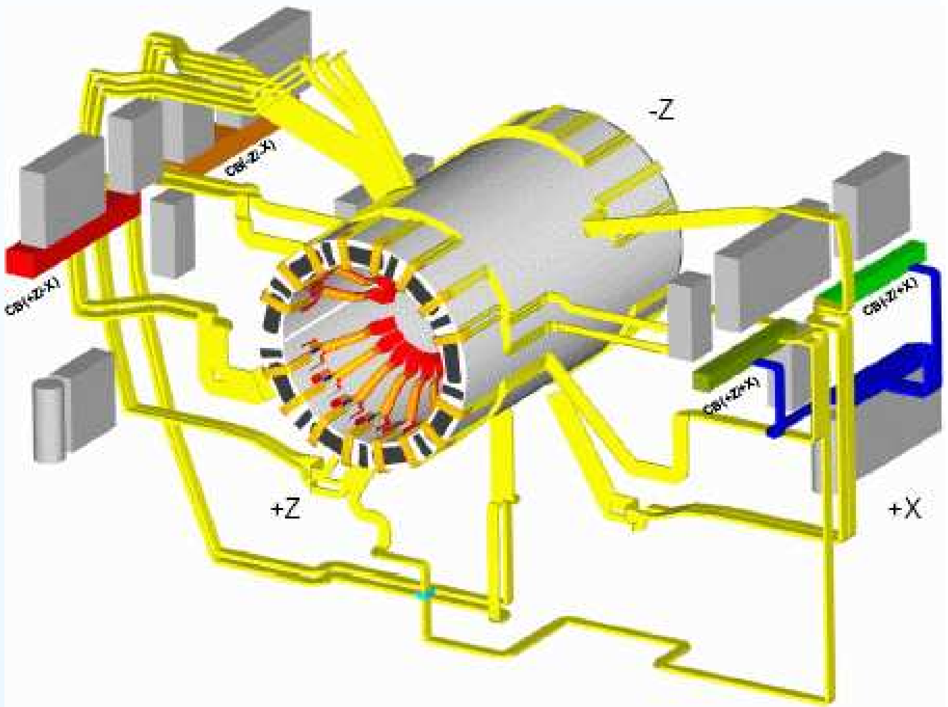
22 Events/Crossing

88 Events/Crossing



...now imagine 400 Events/Crossing...

New SCMS Tracker



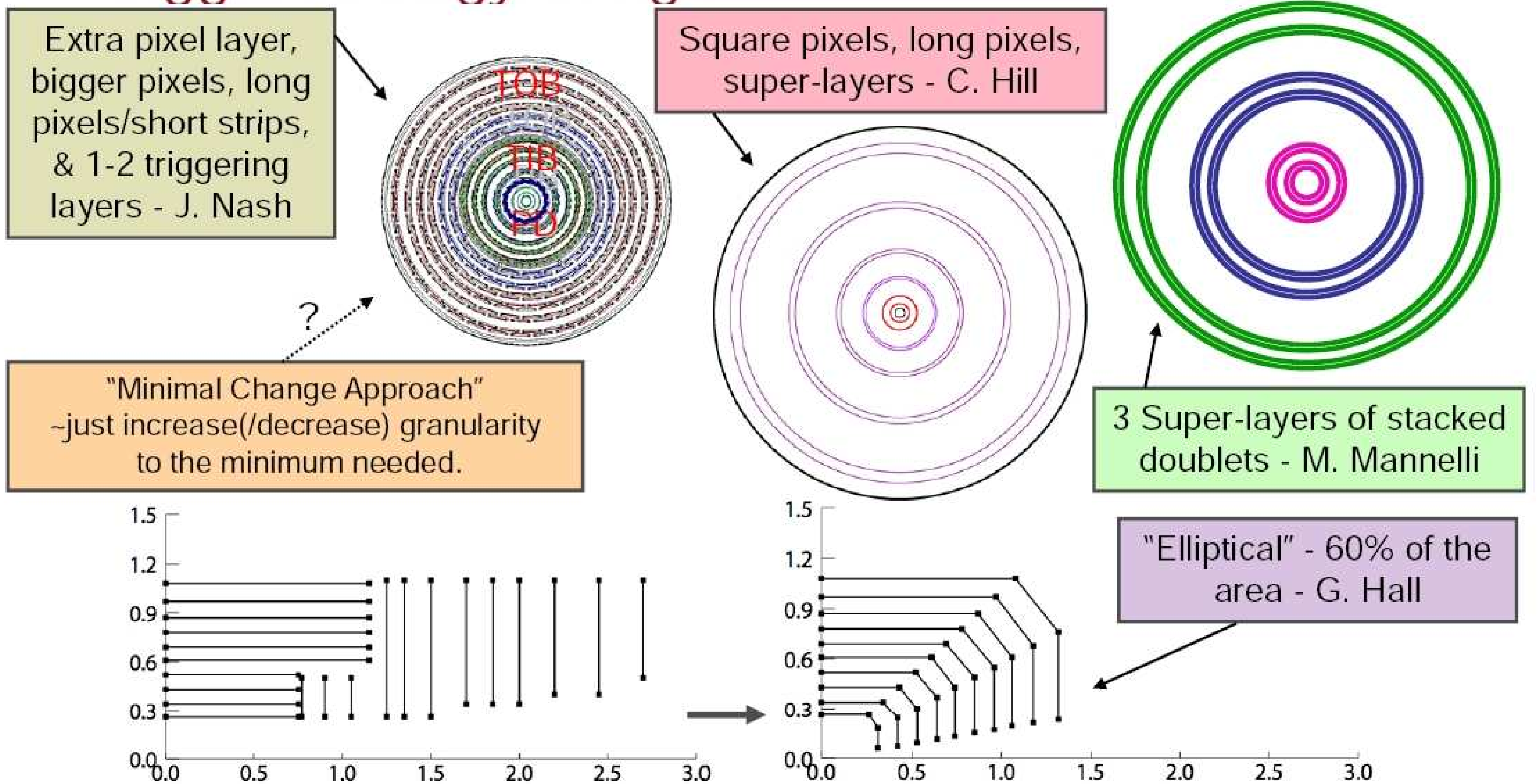
- same performance as current one
  - data volume handling
  - powering sheme
  - very radhard sensors
  - triggering tracker
  - reduced material (!)

several constraints:

- replaces current tracker
  ⇒envelope stays the same
- tracker services 'burried' in cable trenches
  ⇒use existing fibers, cabling & pipework from PP1 out

No Strawman for 2018 yet...

- No single strawman tracking system or tracking trigger strategy/design



...but there is a 'Phase 1' before...

SLHC Phase 1 ~ 2013

- machine changes to allow for 2xLHC luminosity by 2013
- done in a normal shutdown

consequences for CMS:

- most subdetectors need minimum changes, if any.
- only pixel system has to be replaced (rad damage)

2013 quite soon $\rightarrow$ 'simple' but effective upgrade is planned:

- compatible with existing services & infrastructure
- no change in module count, number or radii of the layers
  $\rightarrow$minimal disturbance to physics output
- testfield for 'general' tracker upgrade in 2018

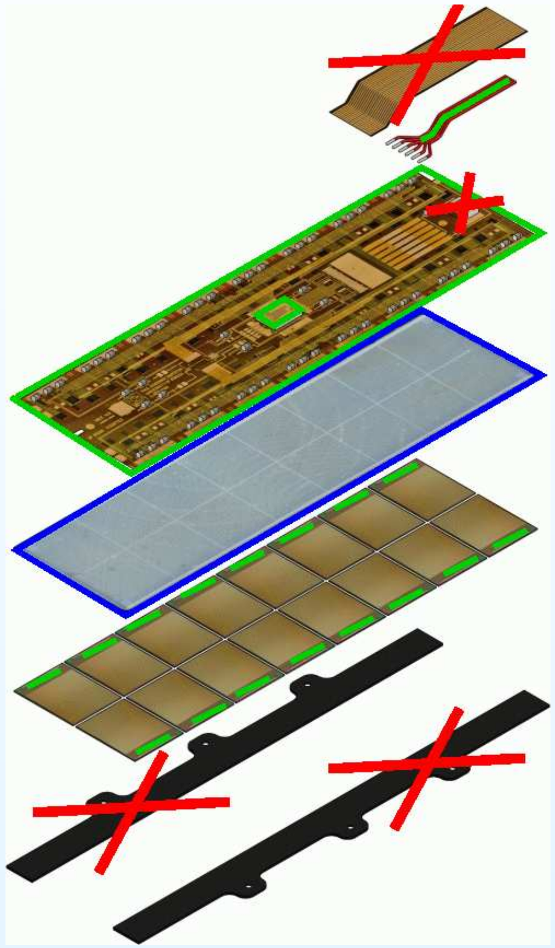
Pixel Barrel Plans for 'Phase-1' - I

mechanical upgrade:

- replace fluorcarbon cooling with CO_2
  $\rightarrow$smaller diameter pipes
- combine with lightweight structure

trimm fat @ modules:

- fewer/thinner cables
  $\rightarrow$ less connectors
- no HV-capacitor
- no basestrips



Pixel Barrel Plans for 'Phase-1' - II

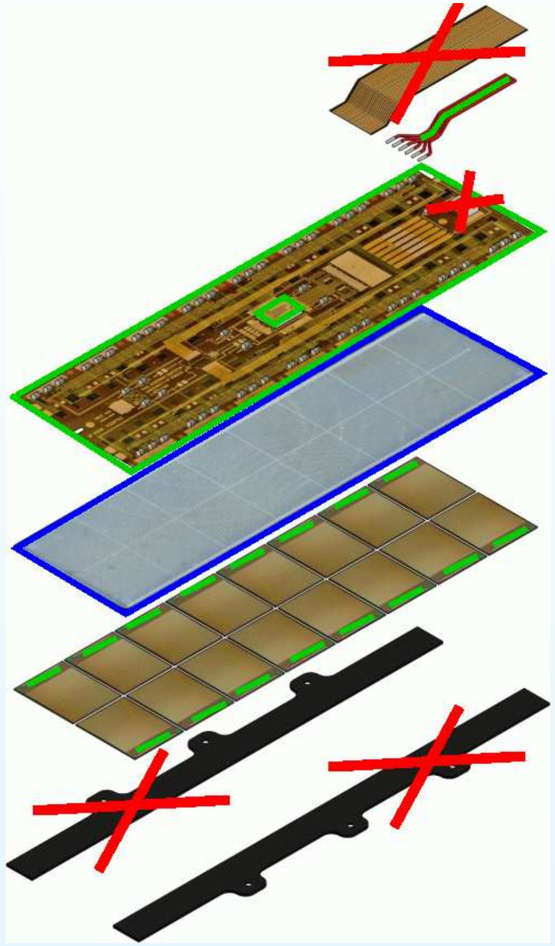
modified ROC:

- enlarge buffers
  $\rightarrow$ reduced inefficiency
- digitisation on chip
  $\rightarrow$ digital output

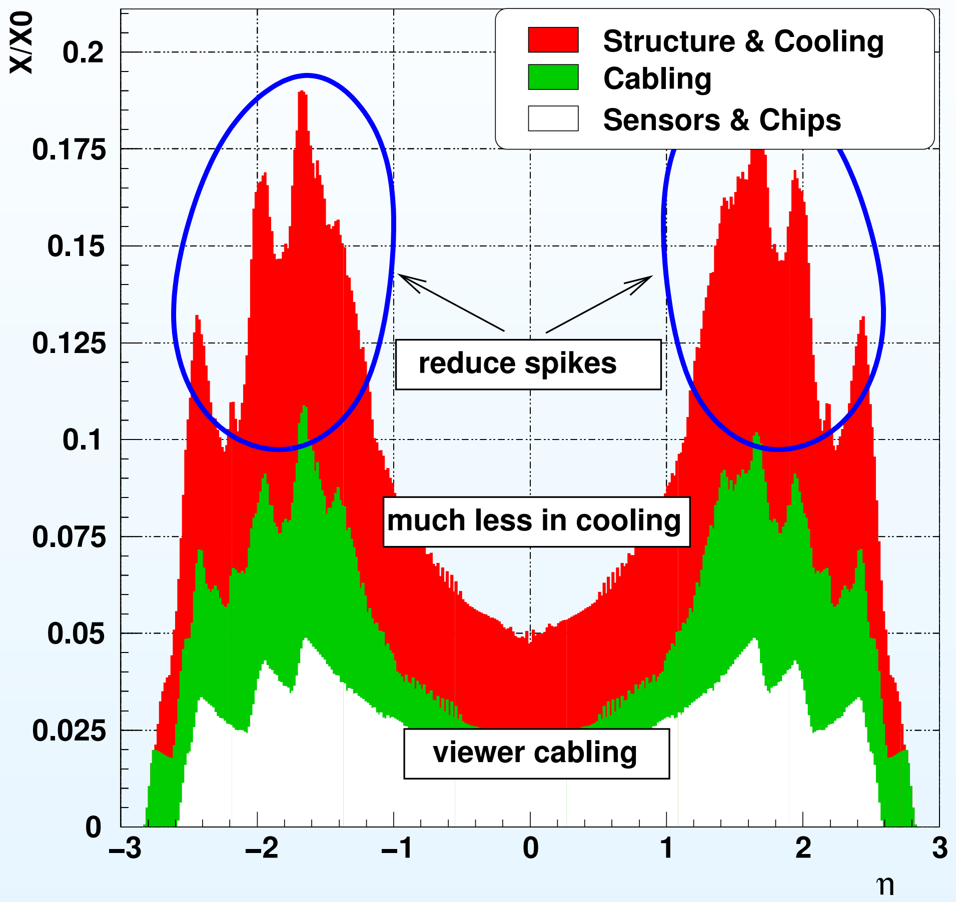
new module controller/flex hybrid:

- parallel readout of all chips & buffer events
  $\rightarrow$ reduced deadtime
- fast digital transmission protocoll

...perhaps one side processed sensors...



Pixel Barrel Plans for 'Phase-1' - Outcome



reduction potential:

- structure, cooling & cabling ~ 50%
- extra reduction in spikes:
  - half of connectors
  - no cooling manyfolds
- overall ~33%

phase I SCMS pixel tracker could have three layers for the material of two...

Backup Slides

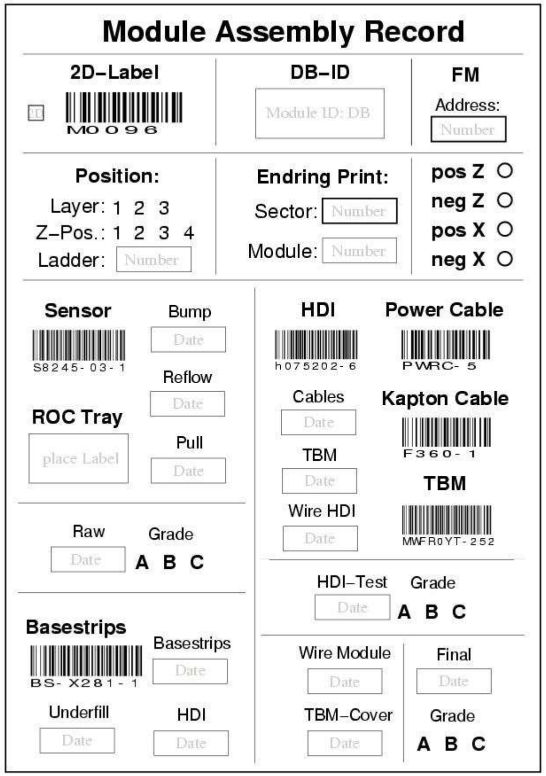
Record Keeping

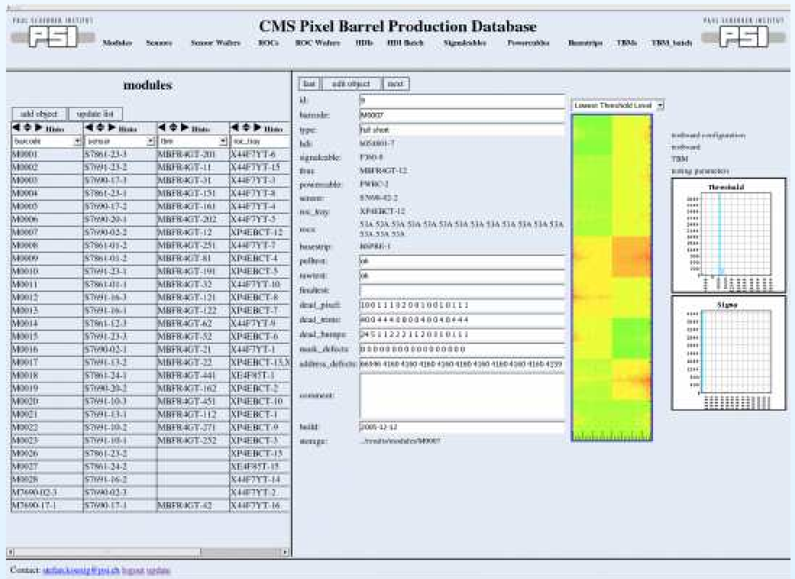
paper records:

- one record for HDI & module each
- paper labels for set of 16 ROCs

PixelDB @ PSI:

- contains all measurements
- backtraceabillity:
  - module to components
- defines mounting position
- web - Interface



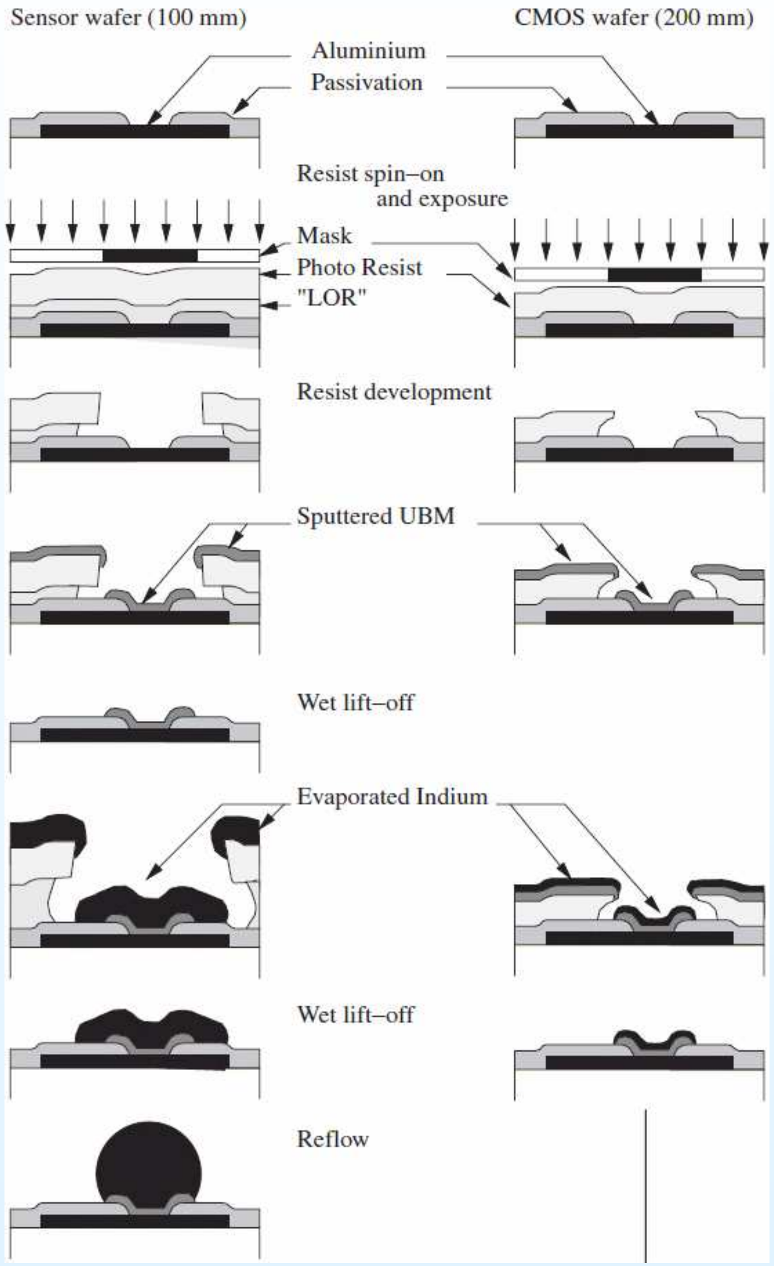


Bumpbonding - Processing

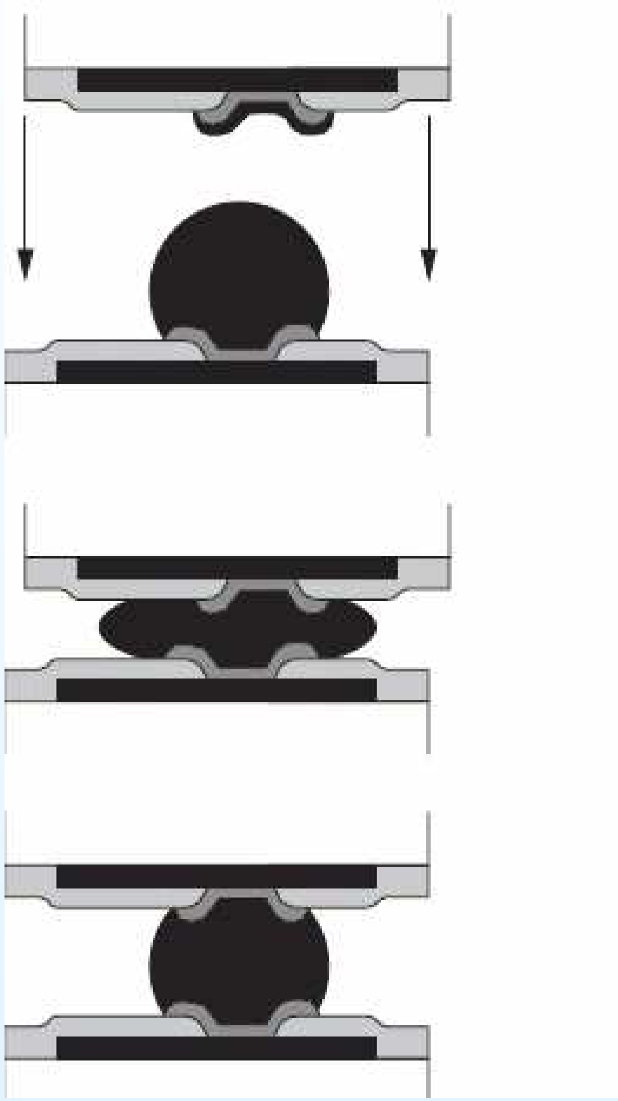
- add UnderBumpMetal*
  - sputter
- add bump material*
- (thinning of CMOS)

*step requires (several) photolithographic steps

- reflow
  - heat
  - special athmosphere



Bumpbonding - Flip - Chip

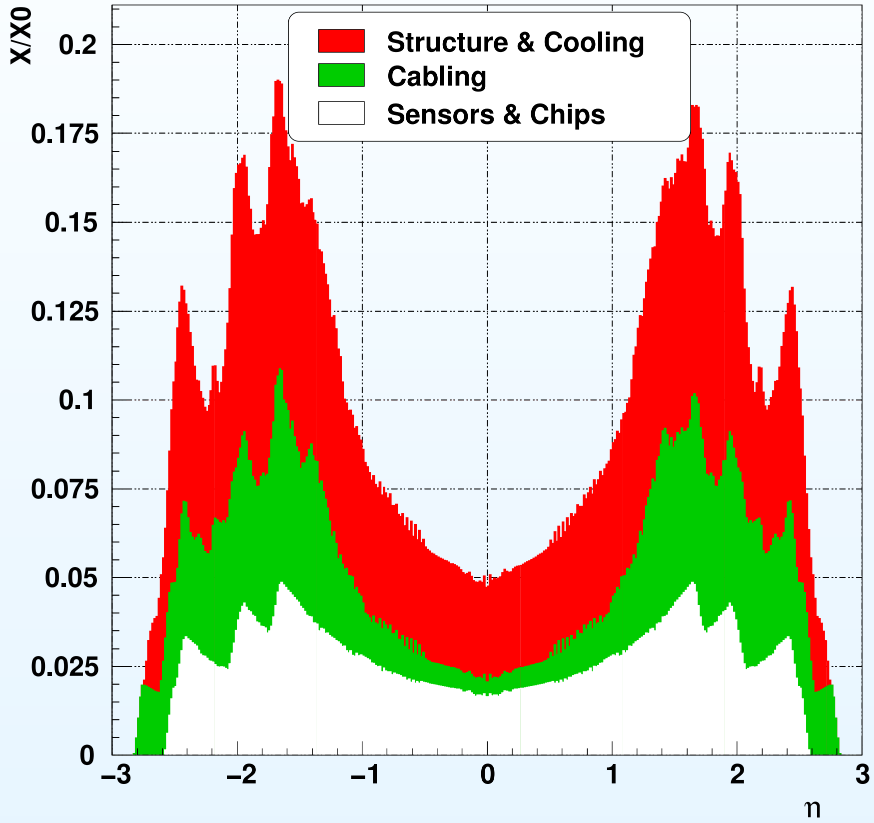


CMS Pixel Indium process

- flip-chip
  - pressure
  - (heat)
- 2. reflow

Current Pixel Barrel - Mean Values

more detailed look at present pixel barrel:



- MB rising steeply with eta
- active material ~1/3 only!
- cooling & structure ~1/2 !
- all the rest mostly cables ~1/6

SLHC Tracker Performance

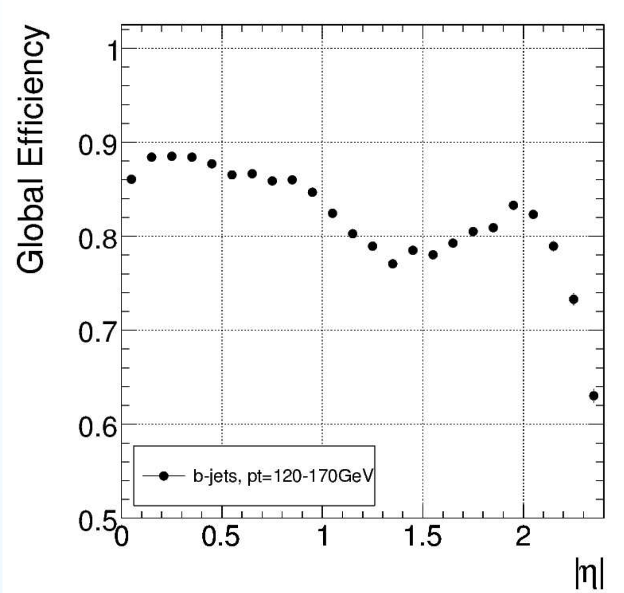
expected performance of CMS tracker:

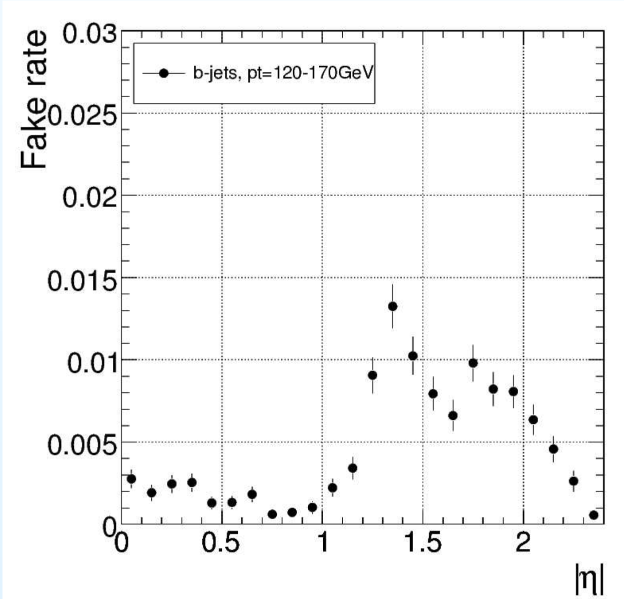
- trackfinding efficiency >98% for muons
- but pions suffer from material

(wish ?) for SLHC:

- same or better performance
  (in denser environment)
- add trigger capability !

⇒much lighter design !!!

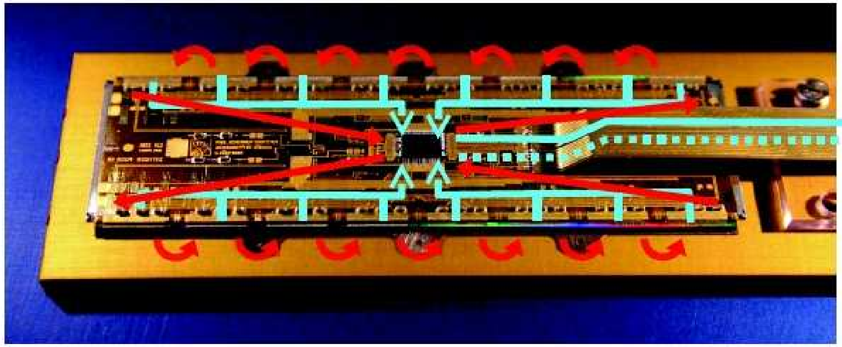




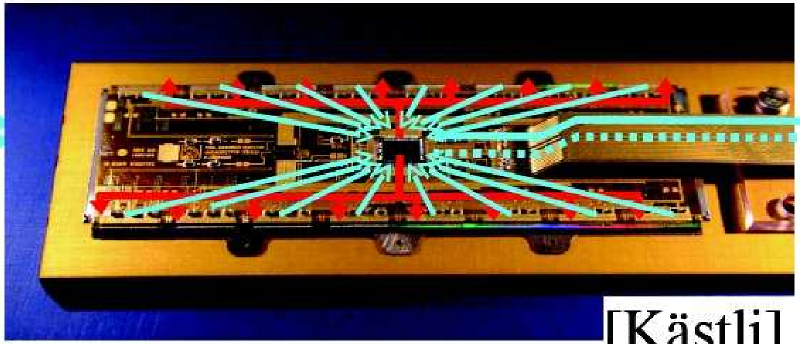
Evolutionary upgrade

- Innermost pixel layer has to be replaced 2yrs @ $10^{34}cm^{-2}s^{-1}$
- Increase of L is probably steady ("phase 0")
- Improve rate capability of present pixel modules
  - increasing buffer size
  - redesigning TBM for parallel ROC readout
- New module would be fully compatible with present system
- Allows operation up to L= $3\times10^{34}cm^{-2}s^{-1}$ (8cm @ $10^{35}cm^{-2}s^{-1}$)
- Longer trigger latency will require further actions

Present TBM Read Out Scheme



Future TBM Read Out Scheme

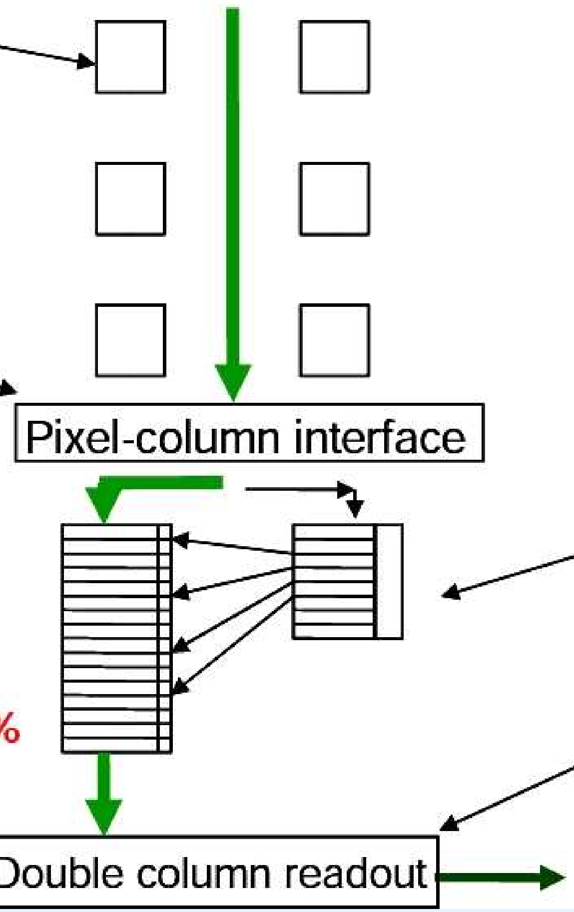


[Kästli]

Data Loss Mechanismns

Pixel busy:
0.04% / 0.08% / 0.21%
pixel insensitive until hit transferred to data buffer (column drain mechanism)

Double column busy:
0.004% / 0.02% / 0.25%
Column drain transfers hits from pixel to data buffer. Maximum 3 pending column drains requests accepted



Data Buffer full:
0.07% / 0.08% / 0.17%

- LHC: 10^{34} cm^{-2}s^{-1} 11cm/7cm/4cm layer total data loss at 100kHz L1:
  - 0.8%
  - 1.2%
  - 3.8%

Timestamp Buffer full:
0 / 0.001% / 0.17%

Readout and double column reset:
0.7% / 1% / 3.0%
for 100kHz L1 trigger rate