

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

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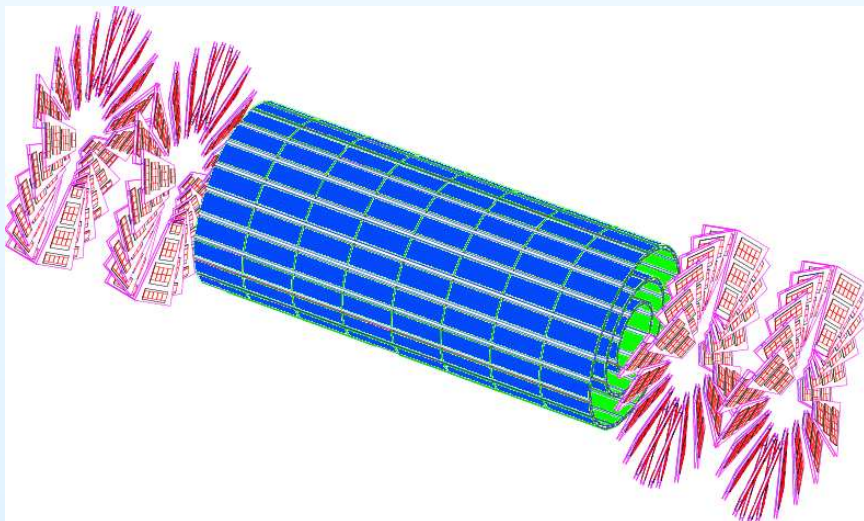
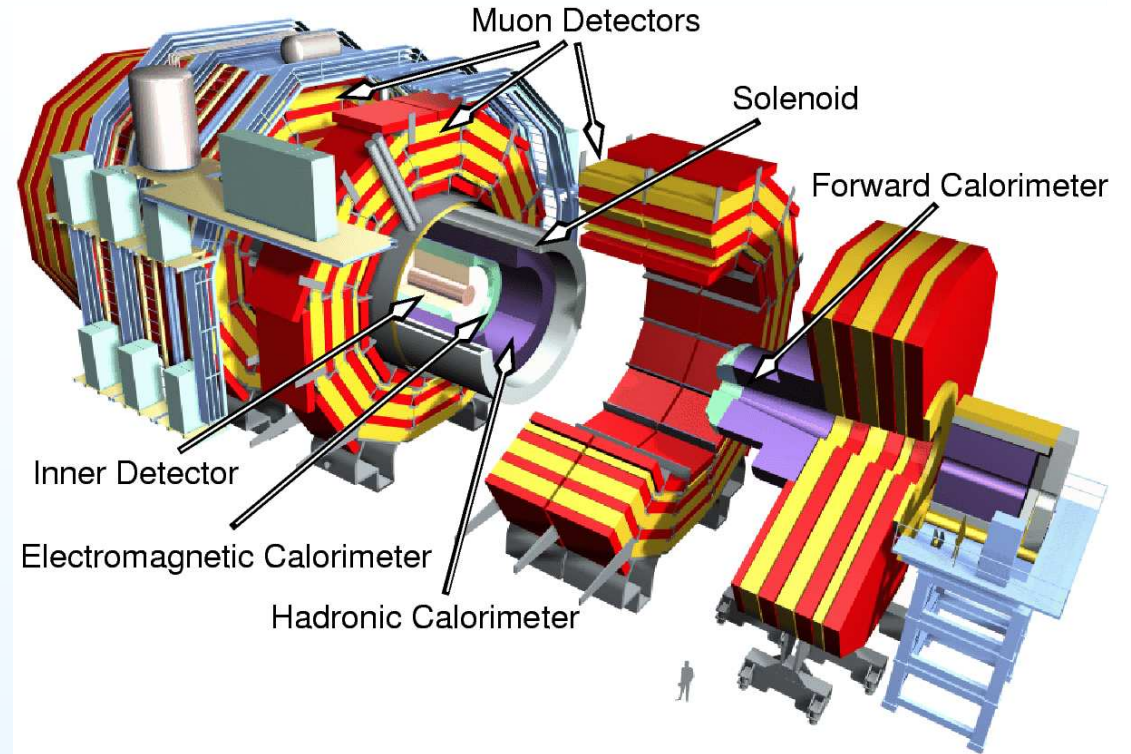
Outline:

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

The CMS Experiment

Si - Strip Tracker:

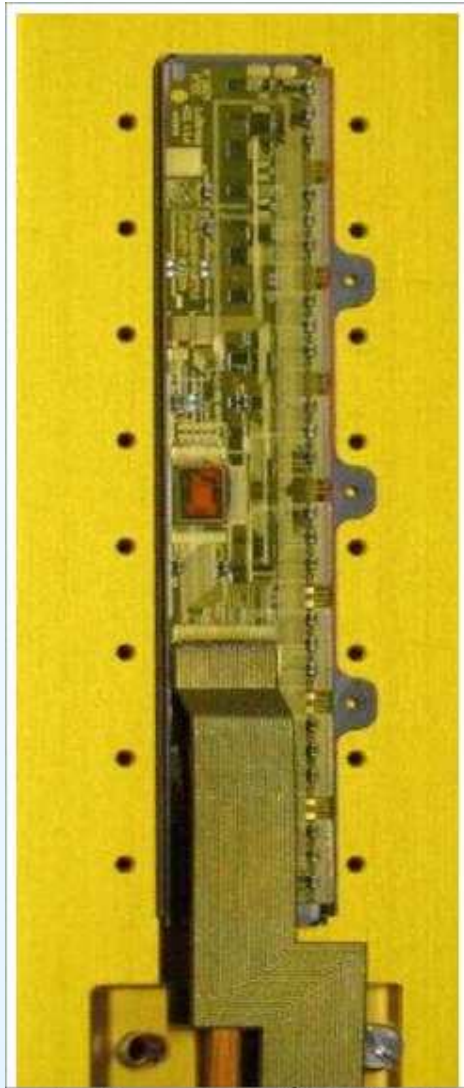
- $20 \text{ cm} < r < 110 \text{ cm}$
- 200 m^2
- 10 barrel layers + 2x9 discs
- $> 15\text{k}$ modules / $\sim 10 \text{ Mch}$



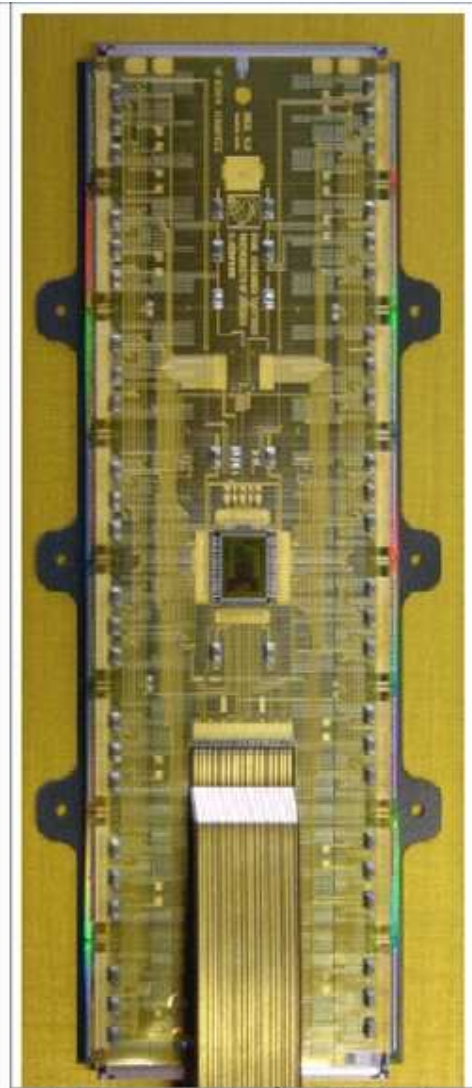
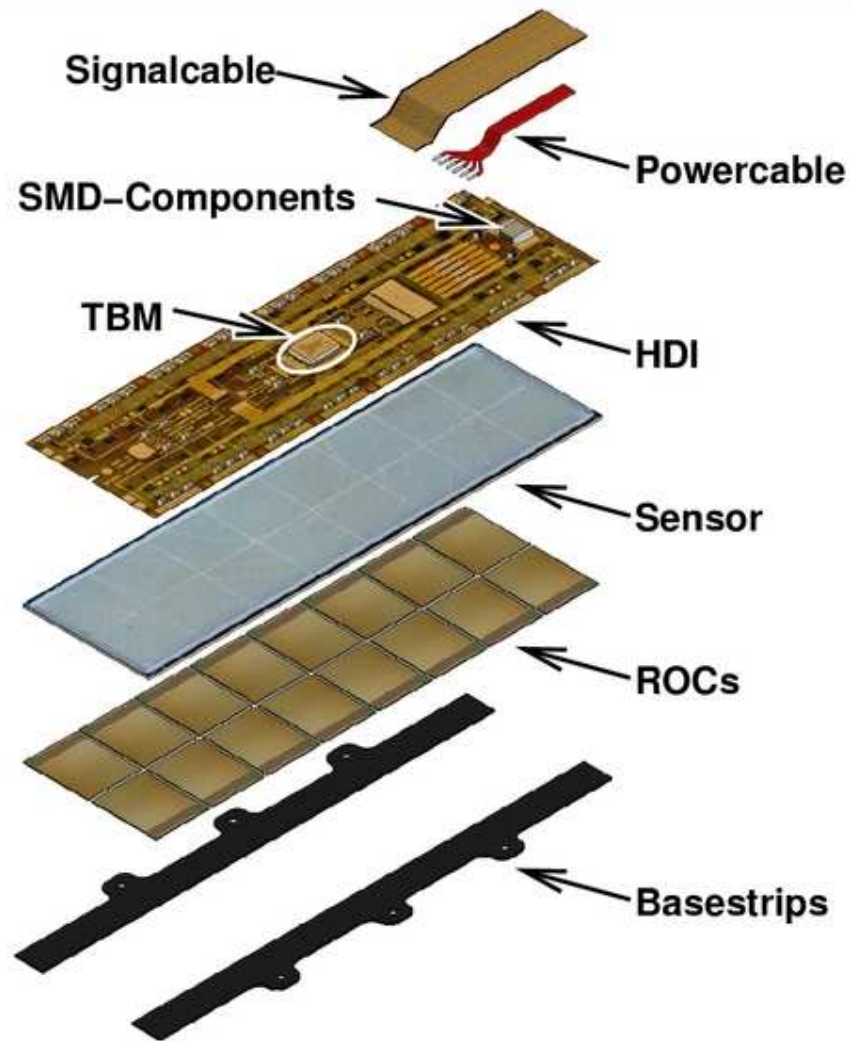
Pixel Tracker:

- $\sim 1 \text{ m}^2$
- 3 barrel layer + 2x2 discs
- $\sim 1\text{k}$ modules / 16k ROCs
/ $\sim 66 \text{ Mch}$

Barrel Modules



half-module $\hat{=}$ 8 ROCs



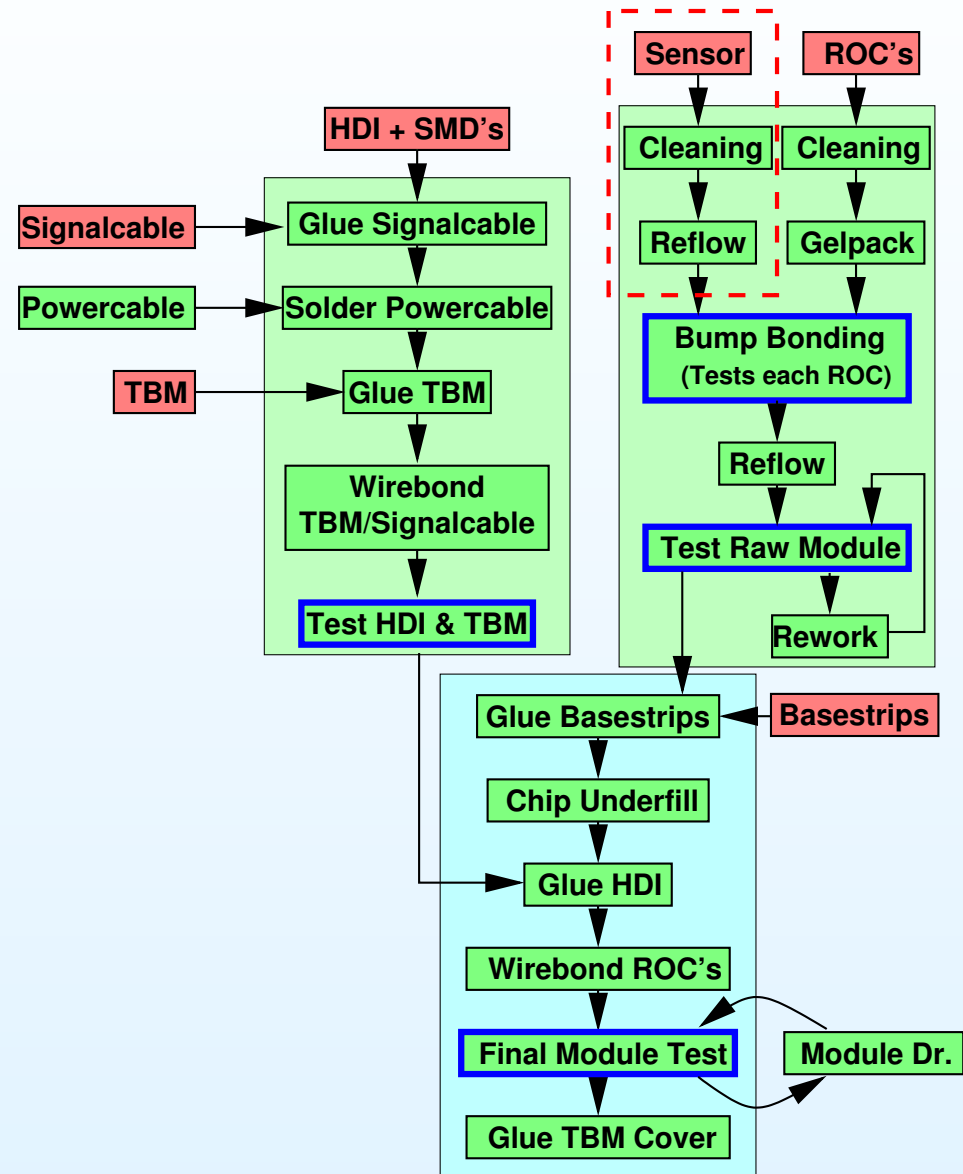
full-module $\hat{=}$ 16 ROCs

production goal: 678 full modules + 2x48 half modules

Pixel Module Production at PSI

Three branches:

- HDI-assembly
- Bumpbonding
- Module-assembly



High Density Interconnect (HDI)

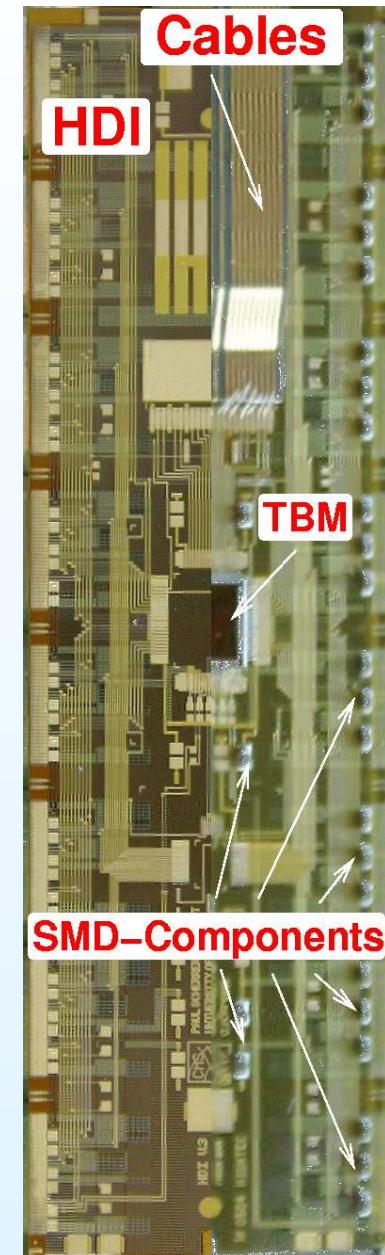
flexible low mass PCB:

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

tasks:

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

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

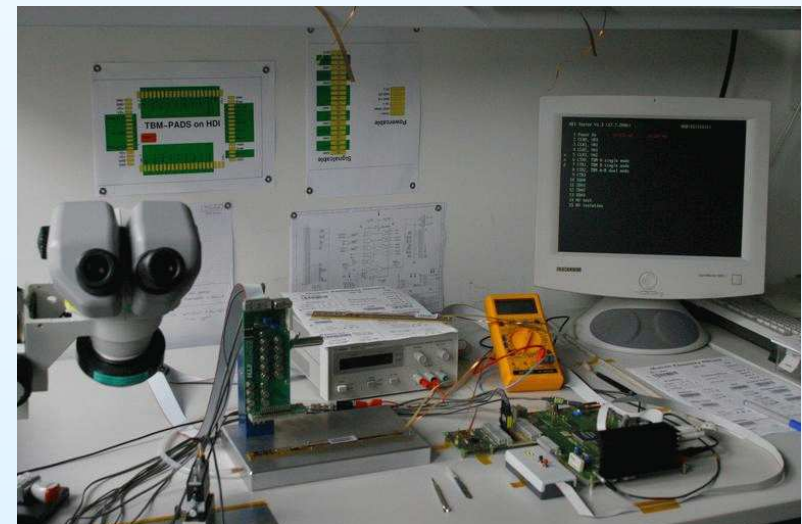
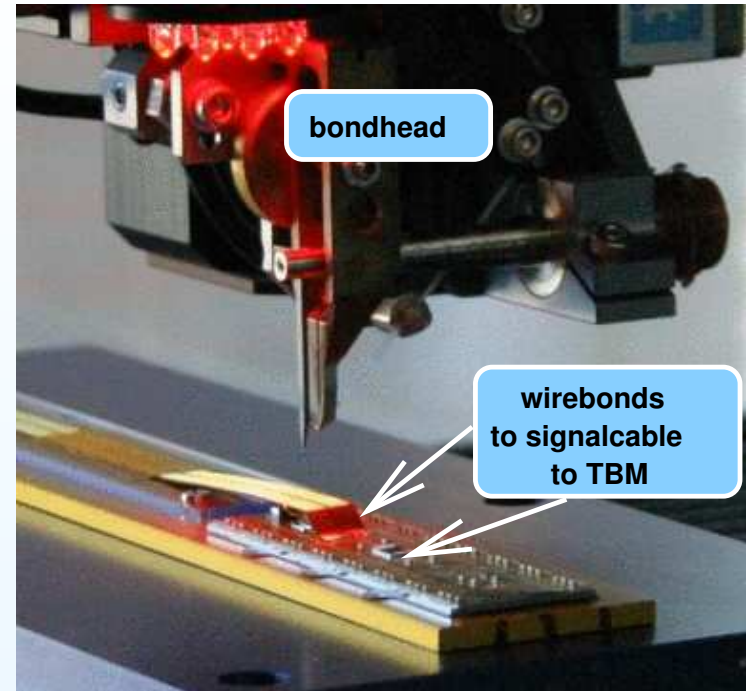


HDI-Assembly - Components

assembled components:

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

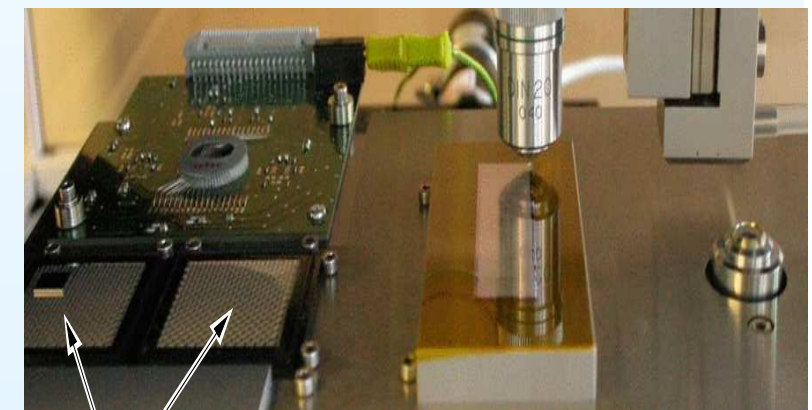
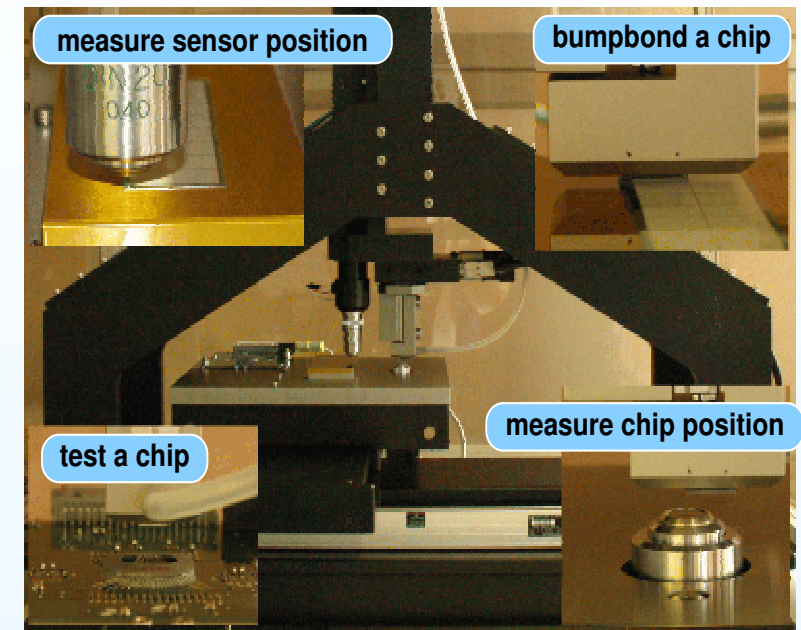
> 1000 HDIs & powercables done...



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)



Gelpacks with Rocs

after bumping, raw modules are reflowed & tested before assembly

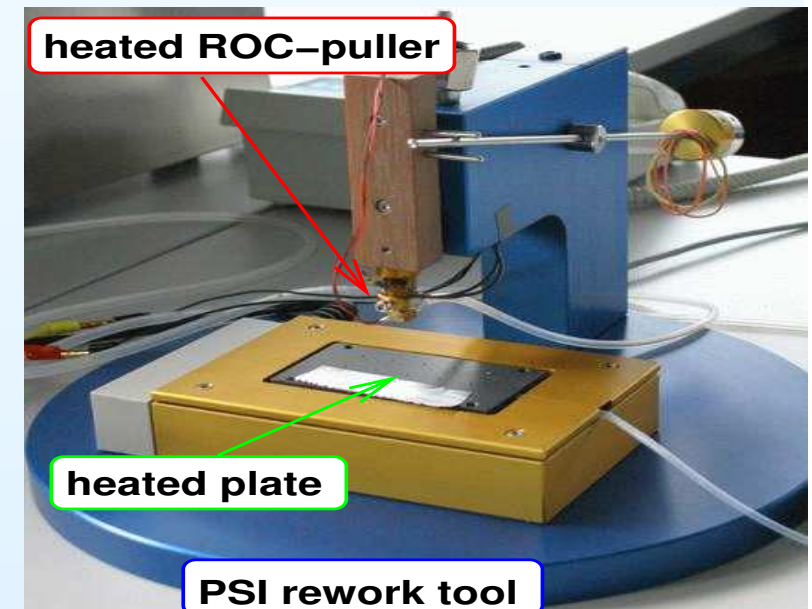
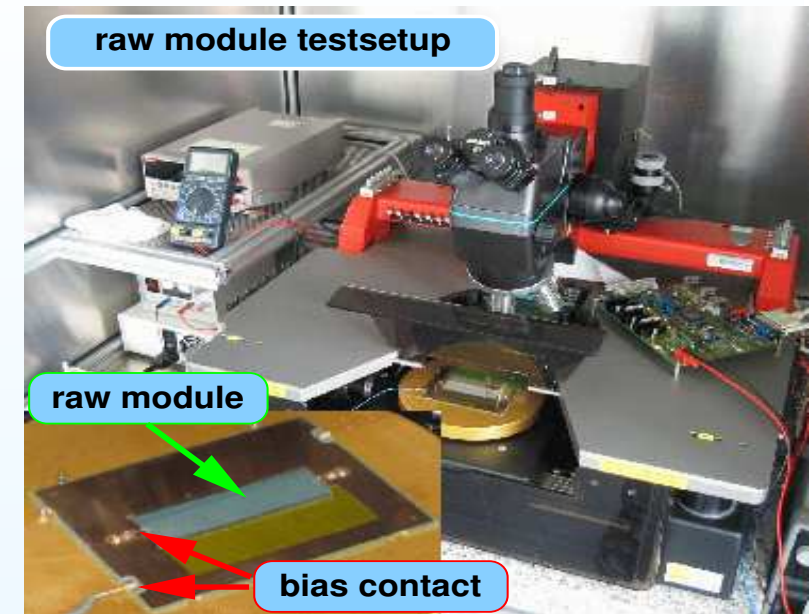
Raw Module: Test & Rework

raw module test:

- IV-curve
- ROC functionality
- bump - yield

Rework station:

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



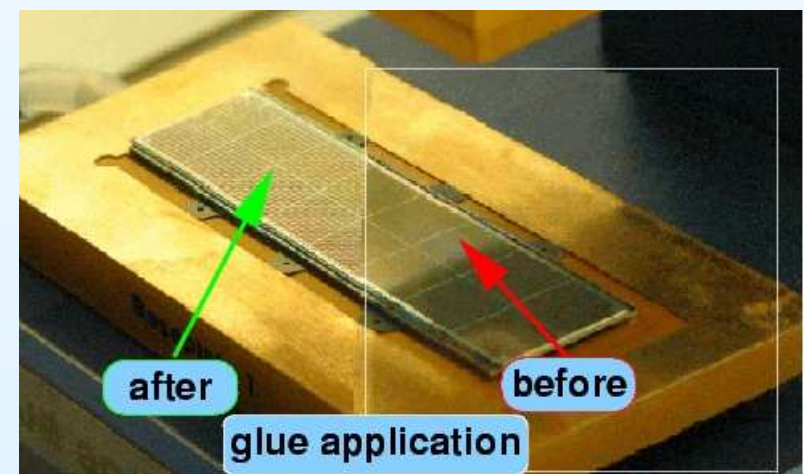
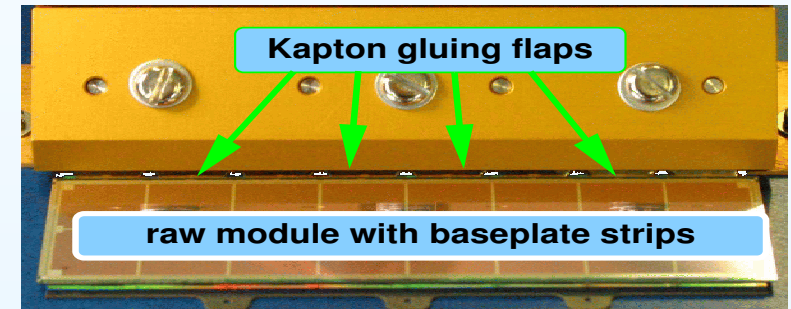
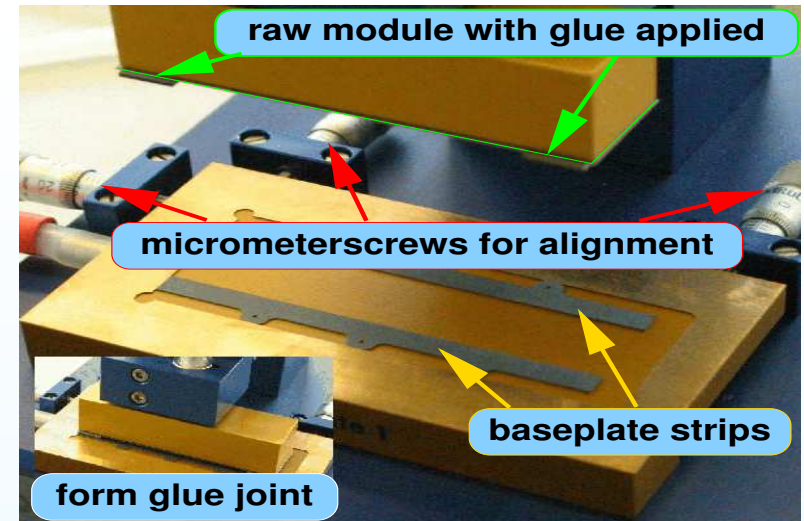
'Handmade' Modules

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:

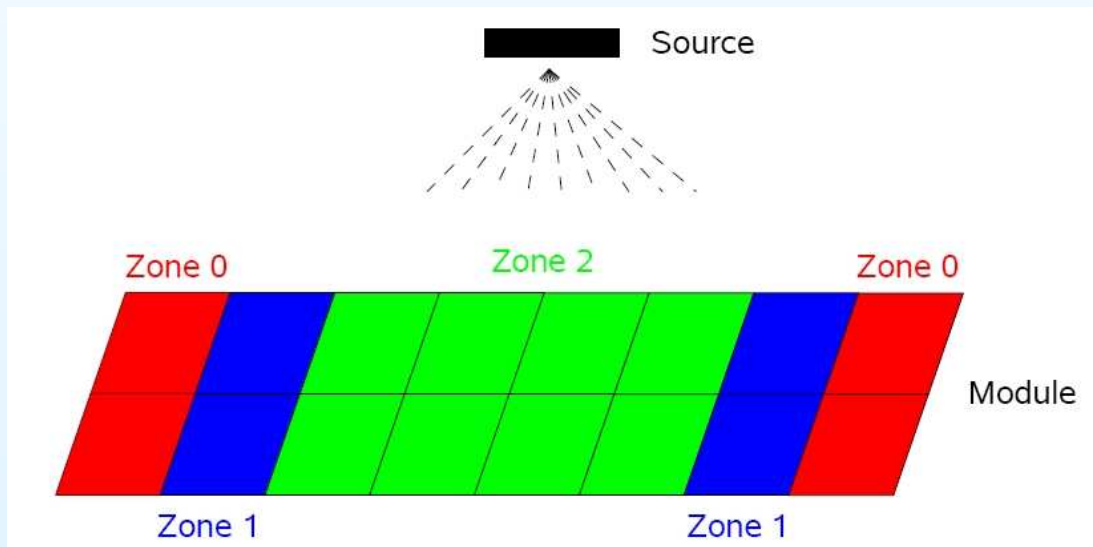
- 6 modules/day



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

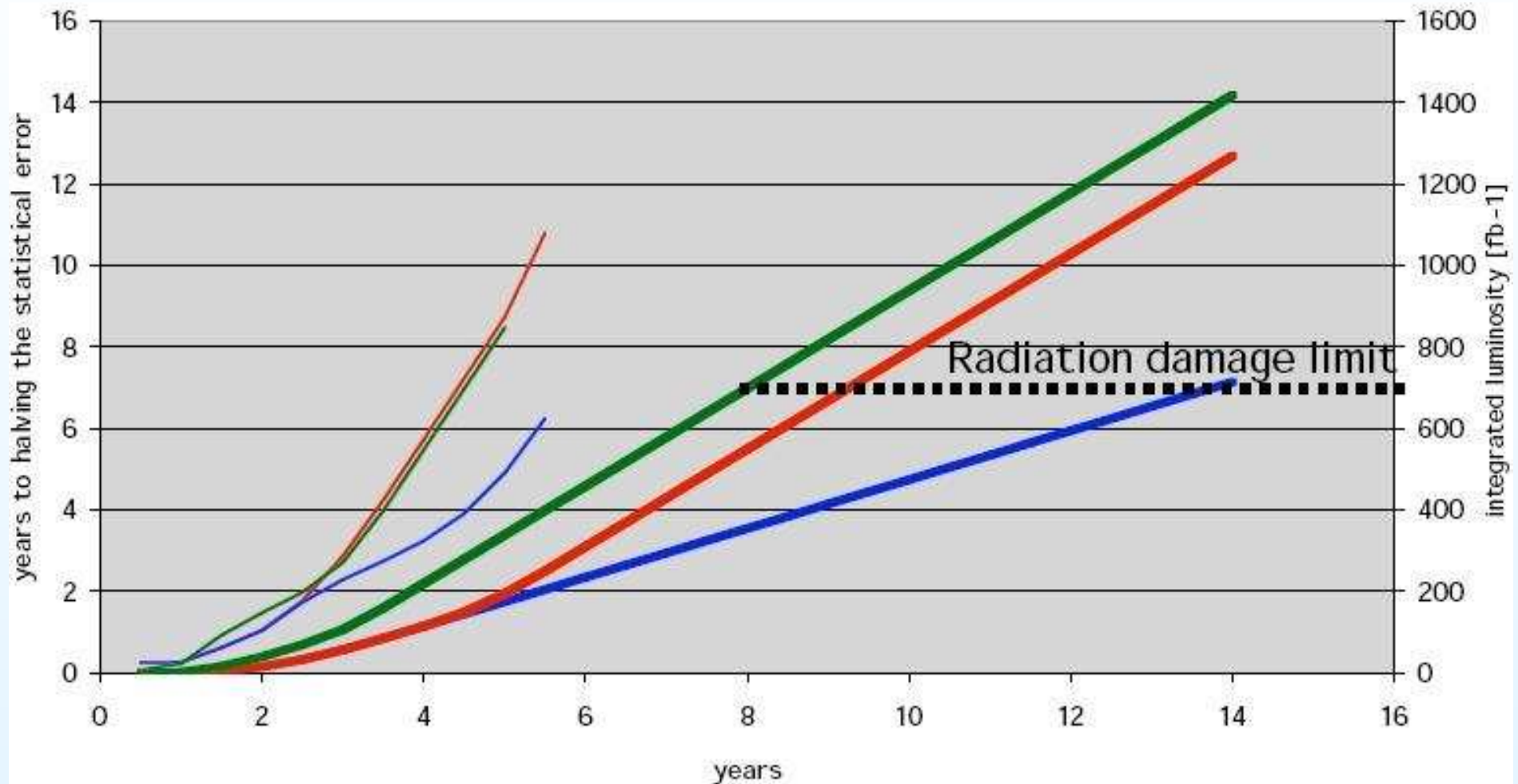
The Final Detector



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

detector integrated and waiting for commissioning with final hardware

From LHC to SLHC



SLHC ~ 2018

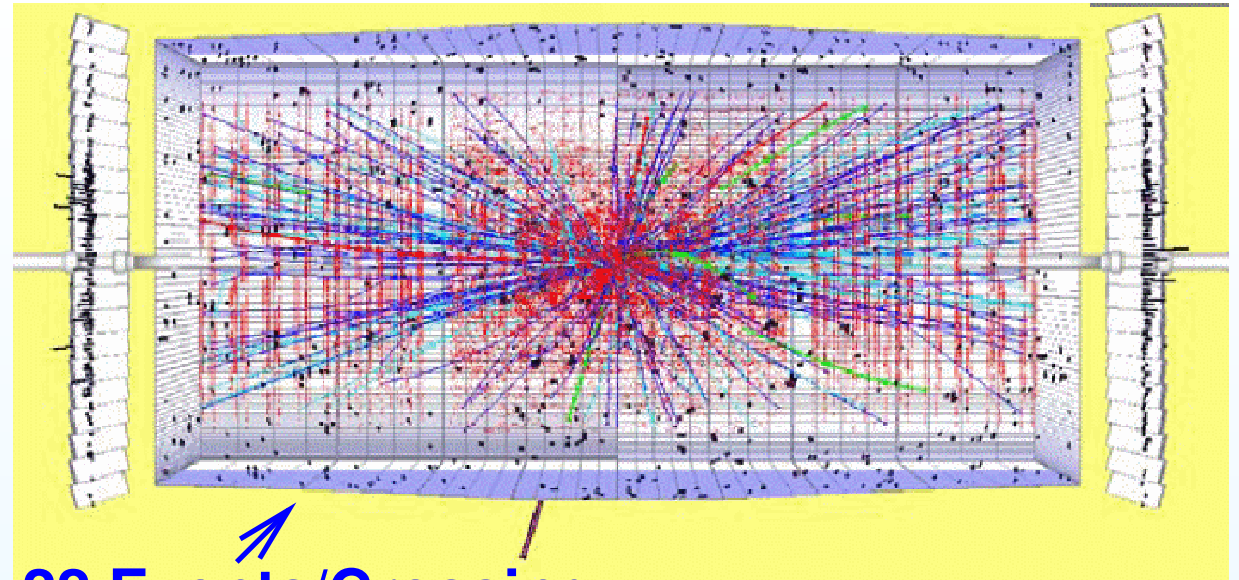
Luminosity:

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

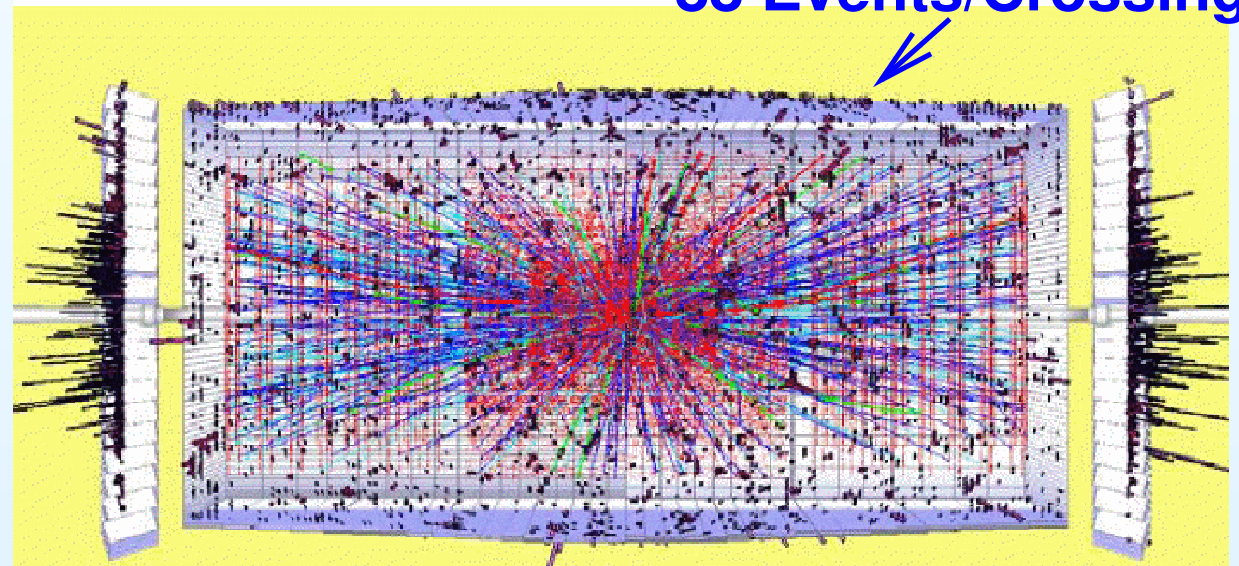
BX all 50ns

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

+ trigger latency doubled...



22 Events/Crossing

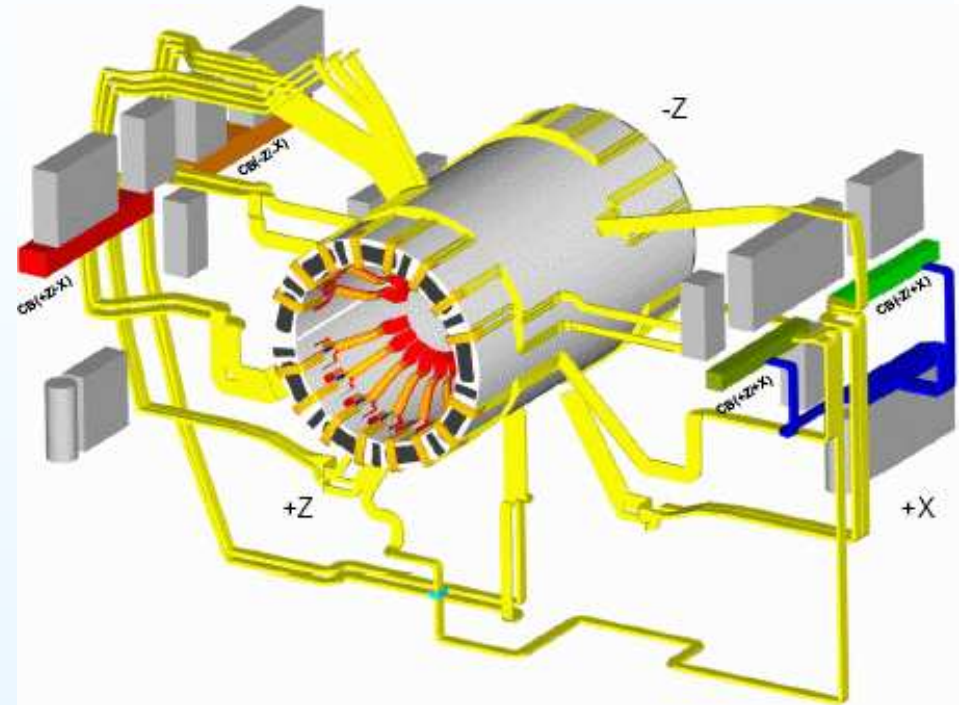


88 Events/Crossing

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

New SCMS Tracker

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

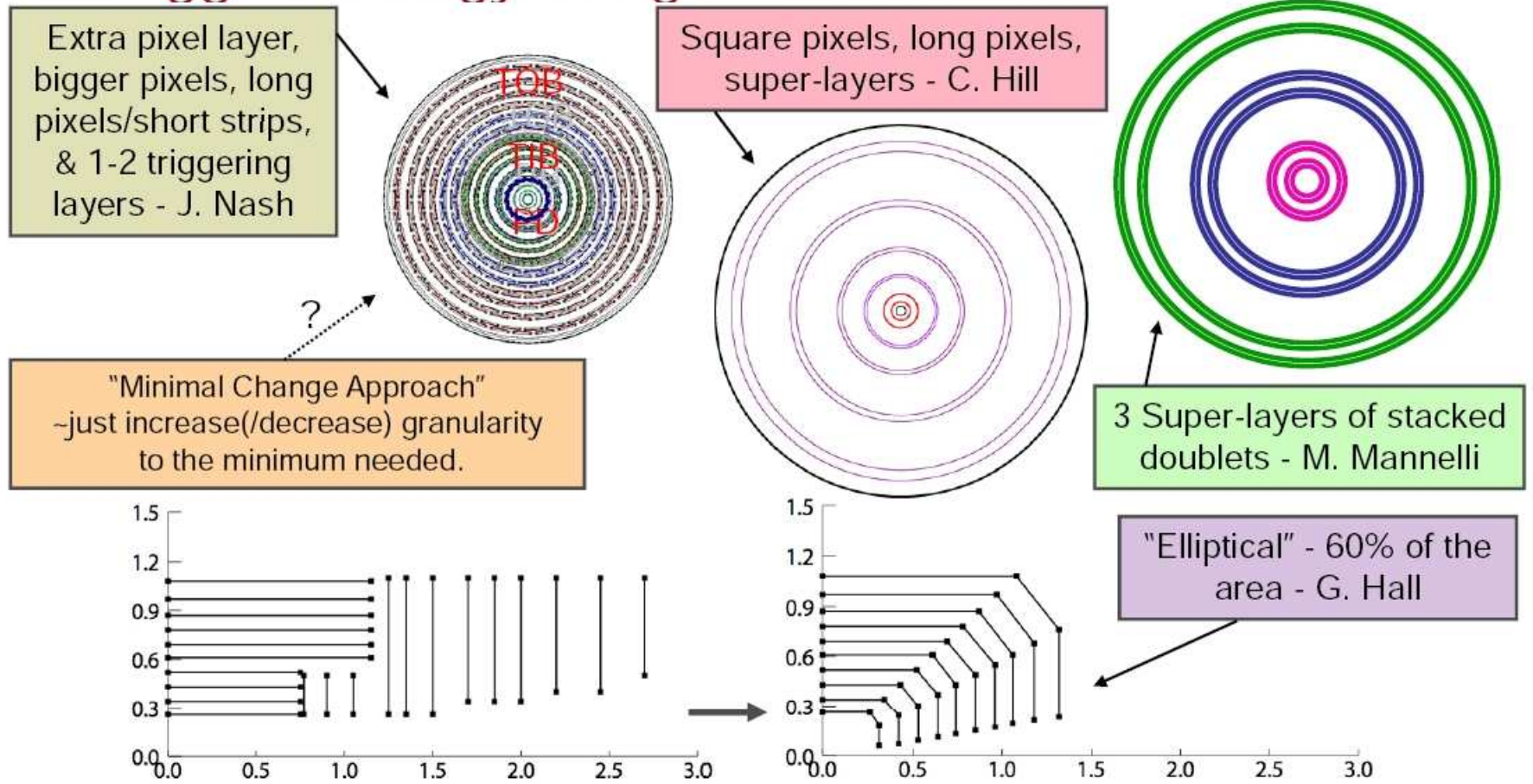


several constraints:

- replaces current tracker
⇒ envelope stays the same
- tracker services 'buried' 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 → 'simple' but effective upgrade is planned:

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

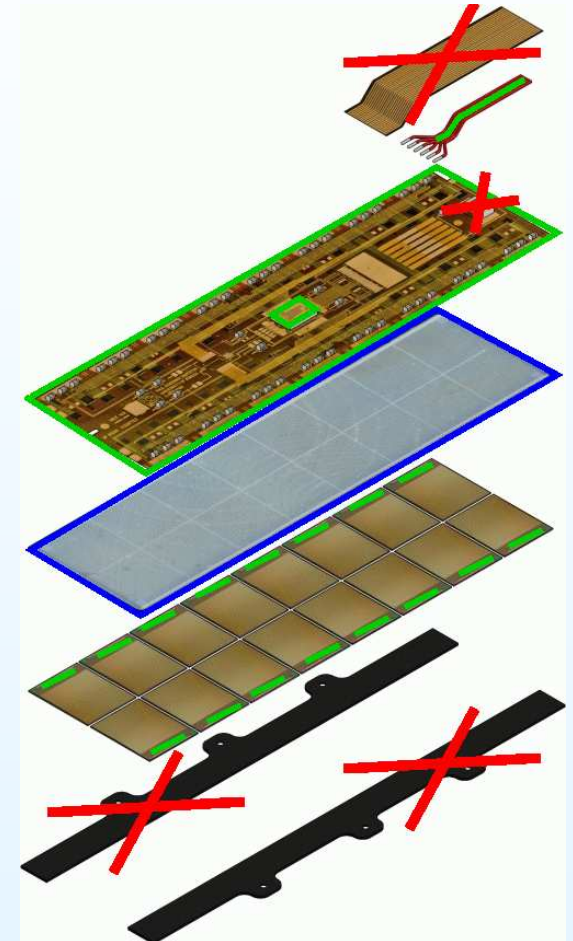
Pixel Barrel Plans for 'Phase-1' - I

mechanical upgrade:

- replace fluorocarbon cooling with CO₂
→ smaller diameter pipes
- combine with lightweight structure

trimm fat @ modules:

- fewer/thinner cables
→ less connectors
- no HV-capacitor
- no basestrips



Pixel Barrel Plans for 'Phase-1' - II

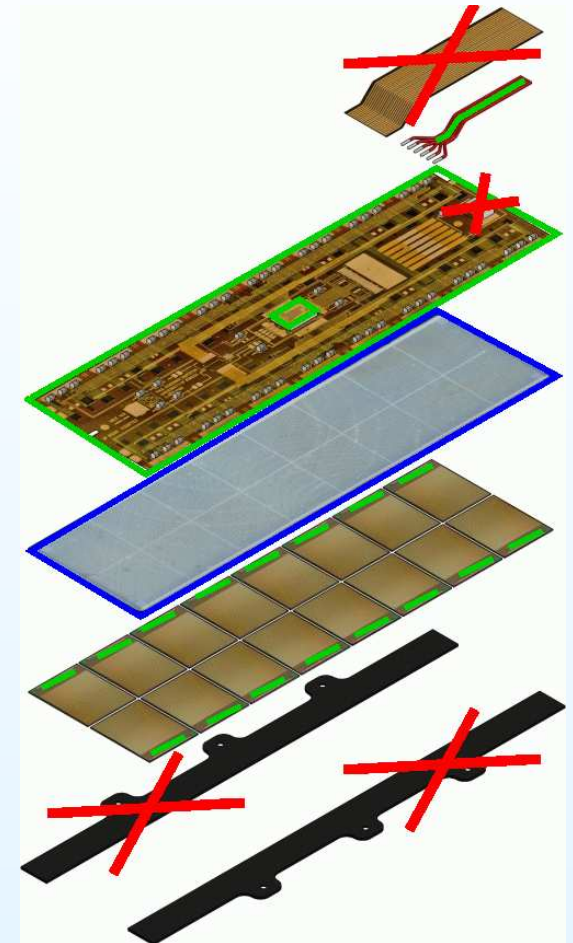
modified ROC:

- enlarge buffers
→ reduced inefficiency
- digitisation on chip
→ digital output

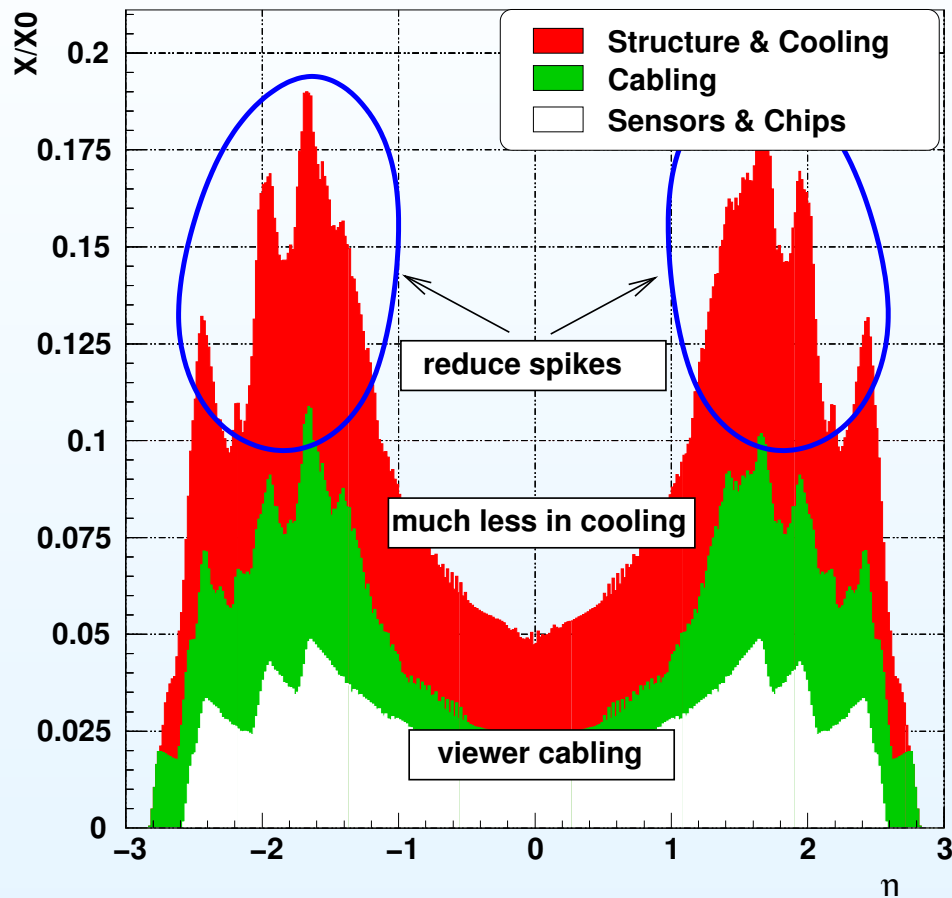
new module controller/flex hybrid:

- parallel readout of all chips & buffer events
→ 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 manifolds
- 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
- backtraceability:
 - module to components
- defines mounting position
- web - Interface

Module Assembly Record

2D-Label MO 096	DB-ID Module ID: DB	FM Address: Number
Position: Layer: 1 2 3 Z-Pos.: 1 2 3 4 Ladder: <input type="text"/>	Ending Print: Sector: <input type="text"/> Module: <input type="text"/>	pos Z <input type="radio"/> neg Z <input type="radio"/> pos X <input type="radio"/> neg X <input type="radio"/>
Sensor S8245-03-1	Bump <input type="text"/>	HDI h075202-6
ROC Tray place Label	Reflow <input type="text"/>	Power Cable PWRC-5
Raw <input type="text"/>	Grade A B C	Cables <input type="text"/>
Basestrips BS-X281-1	Basestrips <input type="text"/>	Kapton Cable F360-1
Underfill <input type="text"/>	HDI <input type="text"/>	TBM TBM <input type="text"/>
		Wire HDI <input type="text"/>
		HDI-Test <input type="text"/>
		Grade A B C
		Wire Module <input type="text"/>
		Final <input type="text"/>
		TBM-Cover <input type="text"/>
		Grade A B C

PSI Pixel Barrel Production Database

module	DB-ID	FM
M0001	S7691-23-3	MBFRAGT-201
M0002	S7691-23-2	MBFRAGT-111
M0003	S7690-17-3	MBFRAGT-31
M0004	S7691-23-4	MBFRAGT-151
M0005	S7690-17-2	MBFRAGT-161
M0006	S7690-20-1	MBFRAGT-202
M0007	S7690-02-2	MBFRAGT-12
M0008	S7691-01-2	MBFRAGT-251
M0009	S7691-01-2	MBFRAGT-81
M0010	S7691-23-1	MBFRAGT-191
M0011	S7691-01-1	MBFRAGT-32
M0012	S7691-06-3	MBFRAGT-121
M0013	S7691-08-1	MBFRAGT-122
M0014	S7691-12-3	MBFRAGT-62
M0015	S7691-23-3	MBFRAGT-52
M0016	S7690-02-1	MBFRAGT-21
M0017	S7691-13-2	MBFRAGT-22
M0018	S7691-24-1	MBFRAGT-441
M0019	S7690-26-2	MBFRAGT-162
M0020	S7691-10-3	MBFRAGT-451
M0021	S7691-13-1	MBFRAGT-112
M0022	S7691-10-2	MBFRAGT-371
M0023	S7691-08-1	MBFRAGT-252
M0026	S7691-21-2	MBFRAGT-13
M0027	S7691-21-2	MBFRAGT-13
M0028	S7691-16-2	MBFRAGT-14
M7660-02-3	S7690-03-3	MBFRAGT-1
M7660-17-1	S7690-17-1	MBFRAGT-62

Details for module M0007:

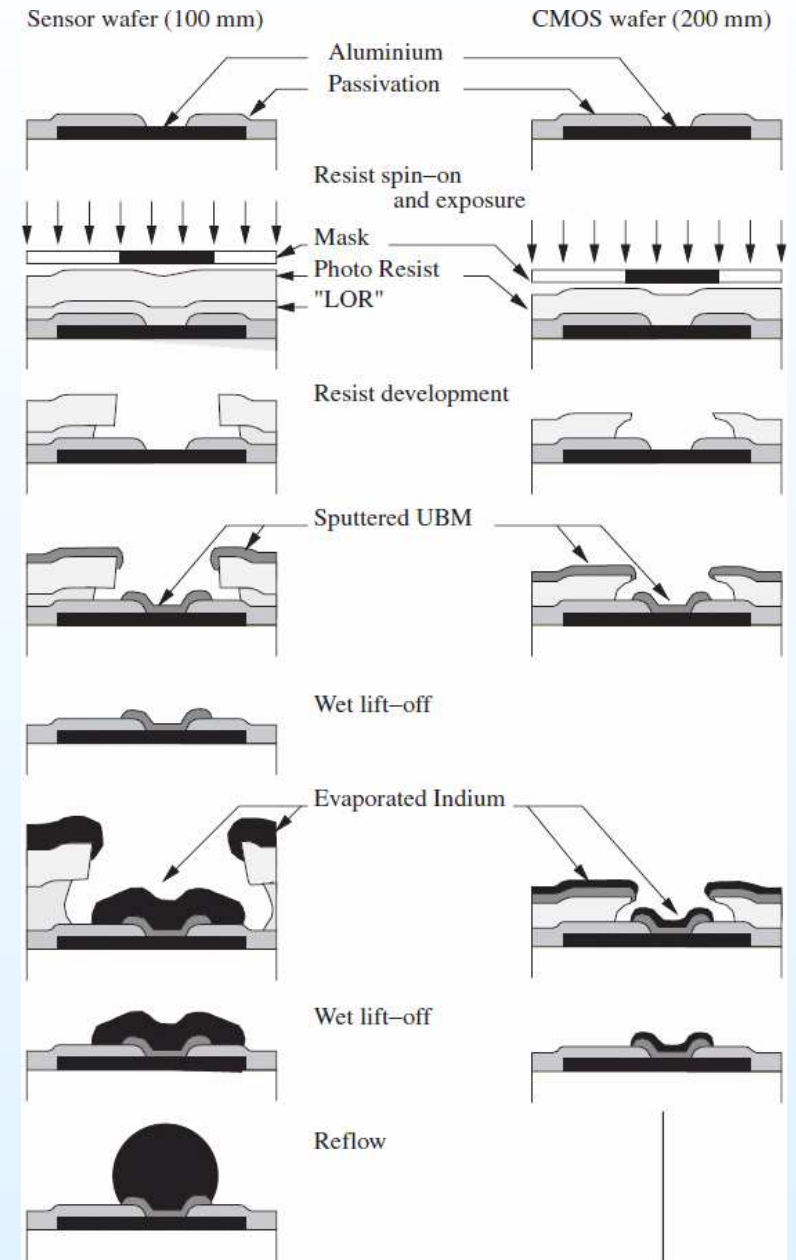
- name: M0007
- type: full sheet
- incl: M54861-7
- integratable: F360-6
- tree: MBFRAGT-12
- parent_module: F360-3
- parent_fm: S7690-02-2
- inc_type: MBFRAGT-12
- tree: S7691-01-2 S7691-01-1 S7691-01-3 S7691-01-4 S7691-01-5 S7691-01-6 S7691-01-7 S7691-01-8 S7691-01-9 S7691-01-10 S7691-01-11 S7691-01-12 S7691-01-13 S7691-01-14 S7691-01-15 S7691-01-16 S7691-01-17 S7691-01-18 S7691-01-19 S7691-01-20 S7691-01-21 S7691-01-22 S7691-01-23 S7691-01-24 S7691-01-25 S7691-01-26 S7691-01-27 S7691-01-28 S7691-01-29 S7691-01-30 S7691-01-31 S7691-01-32 S7691-01-33 S7691-01-34 S7691-01-35 S7691-01-36 S7691-01-37 S7691-01-38 S7691-01-39 S7691-01-40 S7691-01-41 S7691-01-42 S7691-01-43 S7691-01-44 S7691-01-45 S7691-01-46 S7691-01-47 S7691-01-48 S7691-01-49 S7691-01-50 S7691-01-51 S7691-01-52 S7691-01-53 S7691-01-54 S7691-01-55 S7691-01-56 S7691-01-57 S7691-01-58 S7691-01-59 S7691-01-60 S7691-01-61 S7691-01-62 S7691-01-63 S7691-01-64 S7691-01-65 S7691-01-66 S7691-01-67 S7691-01-68 S7691-01-69 S7691-01-70 S7691-01-71 S7691-01-72 S7691-01-73 S7691-01-74 S7691-01-75 S7691-01-76 S7691-01-77 S7691-01-78 S7691-01-79 S7691-01-80 S7691-01-81 S7691-01-82 S7691-01-83 S7691-01-84 S7691-01-85 S7691-01-86 S7691-01-87 S7691-01-88 S7691-01-89 S7691-01-90 S7691-01-91 S7691-01-92 S7691-01-93 S7691-01-94 S7691-01-95 S7691-01-96 S7691-01-97 S7691-01-98 S7691-01-99 S7691-01-100
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- parent_fm: S7691-01-97
- parent_fm: S7691-01-98
- parent_fm: S7691-01-99
- parent_fm: S7691-01-100

Bumpbonding - Processing

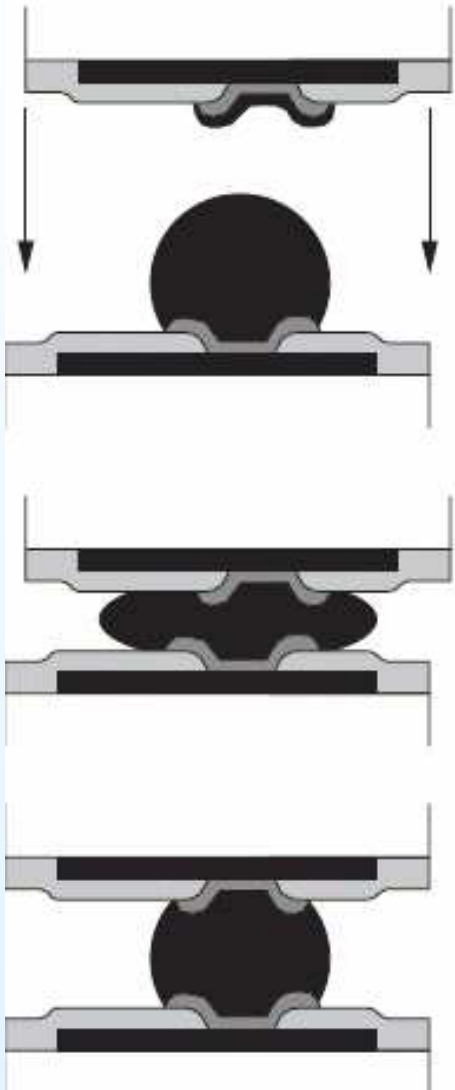
- add UnderBumpMetal*
 - sputter
- add bump material*
- (thinning of CMOS)

*step requires (several) photolithographic steps

- reflow
 - heat
 - special atmosphere



Bumpbonding - Flip - Chip



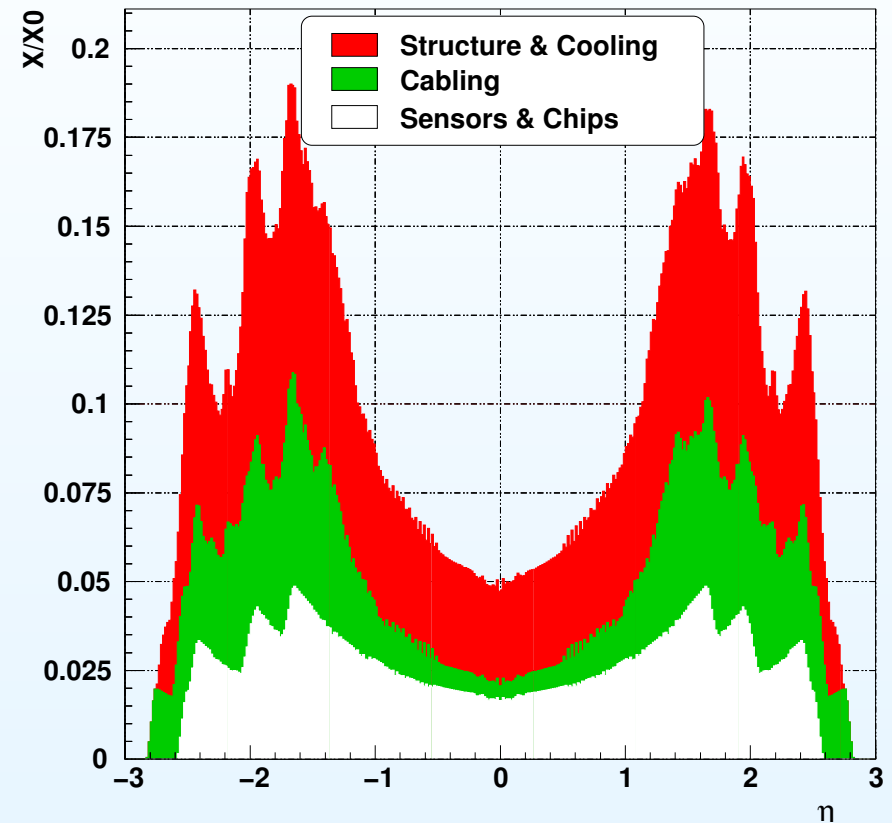
- flip-chip
 - pressure
 - (heat)
- 2. reflow

CMS Pixel Indium process

Current Pixel Barrel - Mean Values

more detailed look at present pixel barrel:

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



SLHC Tracker Performance

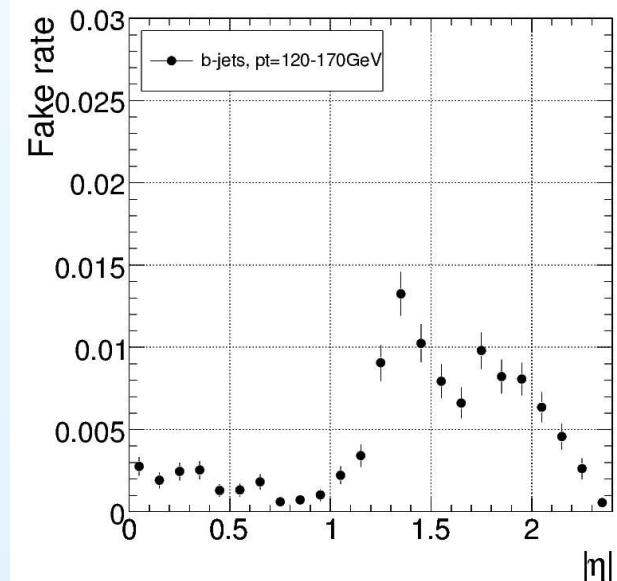
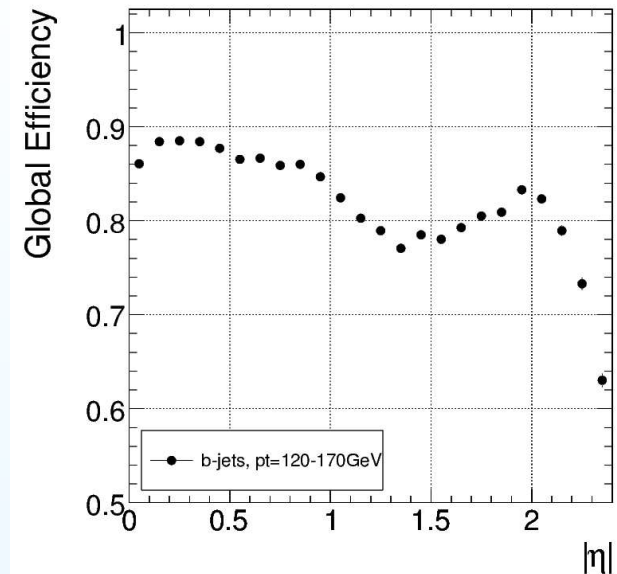
expected performance of CMS tracker:

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

(wish ?) for SLHC:

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

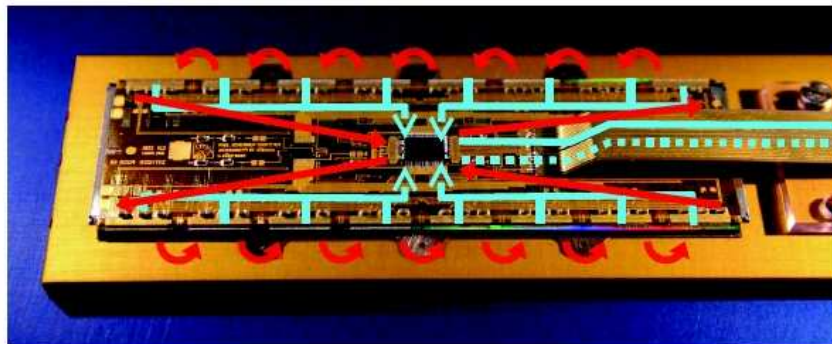
⇒ much lighter design !!!



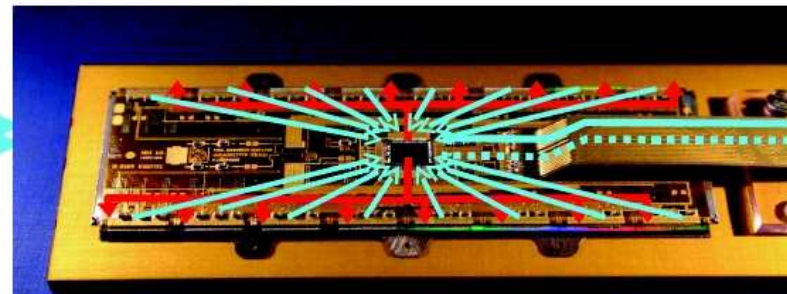
Evolutionary upgrade

- Innermost pixel layer has to be replaced 2yrs @ $10^{34}\text{cm}^{-2}\text{s}^{-1}$
- 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 $L = 3 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ (8cm @ $10^{35}\text{cm}^{-2}\text{s}^{-1}$)
- Longer trigger latency will require further actions

Present TBM Read Out Scheme



Future TBM Read Out Scheme



[Kästli]

Data Loss Mechanisms

- LHC: $10^{34} \text{ cm}^{-2}\text{s}^{-1}$
11cm/7cm/4cm layer
 total data loss at
 100kHz L1:

- **0.8%**
- **1.2%**
- **3.8%**

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%

Timestamp Buffer full:

0 / 0.001% / 0.17%

Readout and double column reset:

0.7% / 1% / 3.0%
 for 100kHz L1 trigger rate

