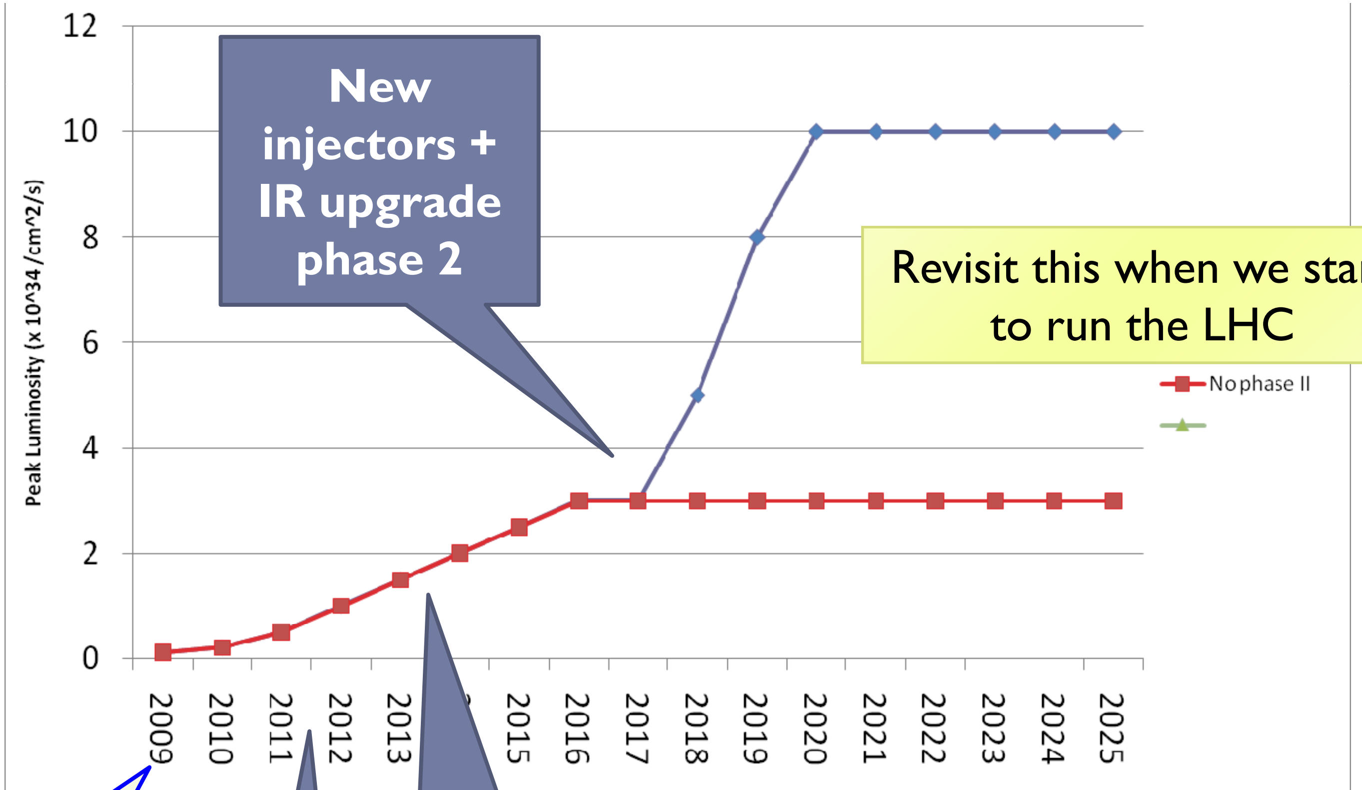
CMS Upgrades Progress

LHCC February 2009 Meeting

Agreed Scenario for Peak luminosity (CMS/ATLAS/Machine/LHCC)



New injectors + IR upgrade phase 2

Revisit this when we start to run the LHC

Early operation

Linac4 + IR upgrade phase 1

Collimation phase 2

Upgrades required to keep CMS operating at maximum potential throughout

Agreed at the May 2008 Upgrades Workshop
http://indico.cern.ch/conferenceDisplay.py?confId=28746

Upgrade Scope

System	Phase 1	Phase 2
Pixel	New Pixel Detector (1 or 2 iterations?)	
Tracker	FEDs?	New Tracking System (incl Pixel)
HCAL	Electronics + PD replacement	HF/HE?
ECAL	TP (Off Detector Electronics) ?	EE?
Muons	ME4/2, ME1/1 ,RPC endcap, Minicrate spares, some CSC Electronics	Electronics replacement
Trigger	HCAL/RCT/GCT to μTCA	Complete replacement

Documents

Work Plan agreed at the May Workshop

Phase I Upgrades

- Concept
  - mid 2008
- LOI/TP
  - mid 2009
- TDR
  - Early 2010

Phase 2 Upgrades

- Strawman
  - Mid 2009
- TP/LOI
  - Mid 2010
- TDR
  - 2012

November Workshop at FNAL

- Meeting held 19-21 November 2008 at FNAL
  - http://indico.cern.ch/conferenceDisplay.py?confId=41832
  - Checkpoint to assess progress towards 2009 milestones
  - Goals for the meeting
    - follow progress, concentrate on phase I, some look at critical Phase 2 areas
    - establish the workplan for the coming 6 months
      - Key output for this workshop: a program of work which helps us arrive at a planning for the Phase I upgrades.
- Excellent levels of attendance and quality of discussion indicate what a success this meeting was
  - Around 150 participants many from outside the US
  - Workshop atmosphere
    - Good to think outside of the box – CMS has been successful by being ambitious
- Real progress has been made in identifying key areas to focus effort on in the coming months
  - Also a chance to look at "cross-disciplinary" areas

Workshop – Working Groups

- Five main working groups
  - Tracking
  - Trigger
  - HCAL
  - ECAL
  - Muons
- Plenary discussions on
  - Simulations
  - Electronics Issues

Tracking Working Group

- Sensors
  - Radiation issues
  - Progress on R/D
- Simulation and Layout
  - Discussion of potential geometries which may be candidates for strawman, and tools for evaluating layouts
- Power
  - Progress on DC-DC convertors for SLHC
  - Prospects for Serial Power distribution

Material Budget, Power Consumption key issues for a new tracker
Tracker upgrade team has been actively studying these areas

Detailed list of tasks:Tracker

Next six months

- PSI
  - Detailed design of new BPIX mechanics
  - Fabricate rapid prototype model and cassette with rails for insertion tests
- CERN
  - start conceptual CO_2 cooling design verification test
  - test setup for measurements and characterization of CO_2 flow in small tubes
- FNAL
  - continue to work with thermal analysis to determine optimum tube size
  - calculate heat leak and pressure drop in supply / return lines
  - Investigate chillers and centrifugal pumps
  - Further FEA checks on thermal stresses and displacements with module glued on substrate
- Purdue
  - Continue study of module, cooling tube and electronics layout with FNAL to optimize mechanical design
  - Test radiation hardness of candidate adhesives/thermal interface materials
  - Begin integration of optics, vacuum, and glue dispensing to motion control system (on order) for semi-automated module assembly
  - Prepare to assemble mech grade module prototypes to evaluate adhesives, ... oling and procedure

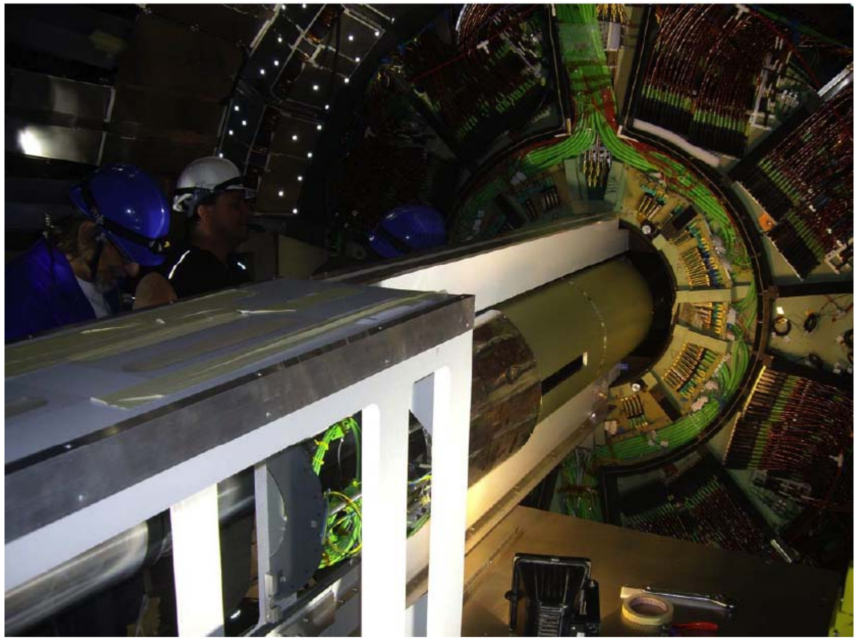
Study in Phase I (3 or 4 Layer Pixel replacement) areas which lead to solutions for phase II (e.g. cooling, DC/DC conversion)

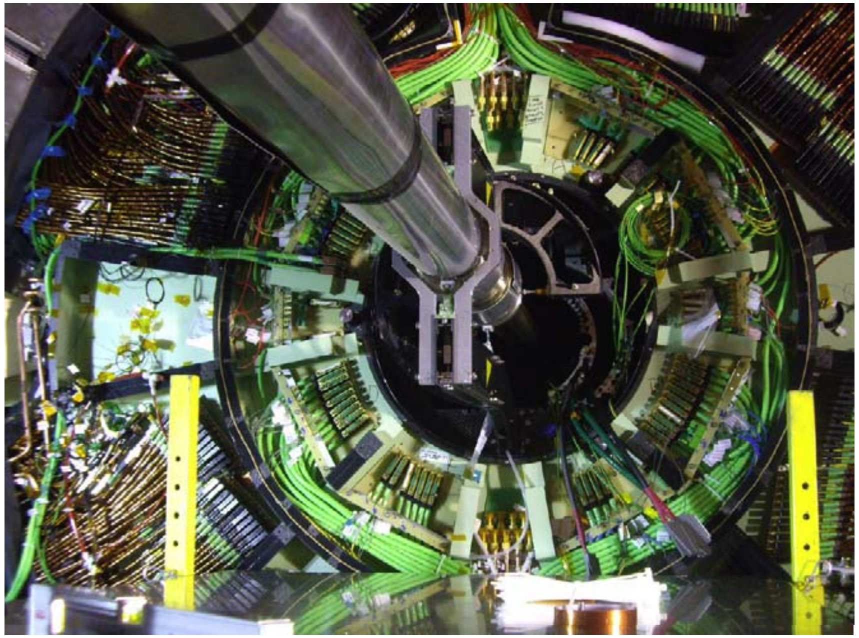
Cross-Project R/D

- The upgrades present an opportunity to develop across project boundaries.
  - Many of these possibilities were exposed/discussed the workshop – some examples follow
- This is a good moment to look for these synergies, before the projects become too balkanized.
  - There is a lot of will to try to look for common solutions
  - We have learned lessons, and can apply those to upgrades

Phase I: CMS Pixel system can be removed in a very short time period

Insertion of Pixel system



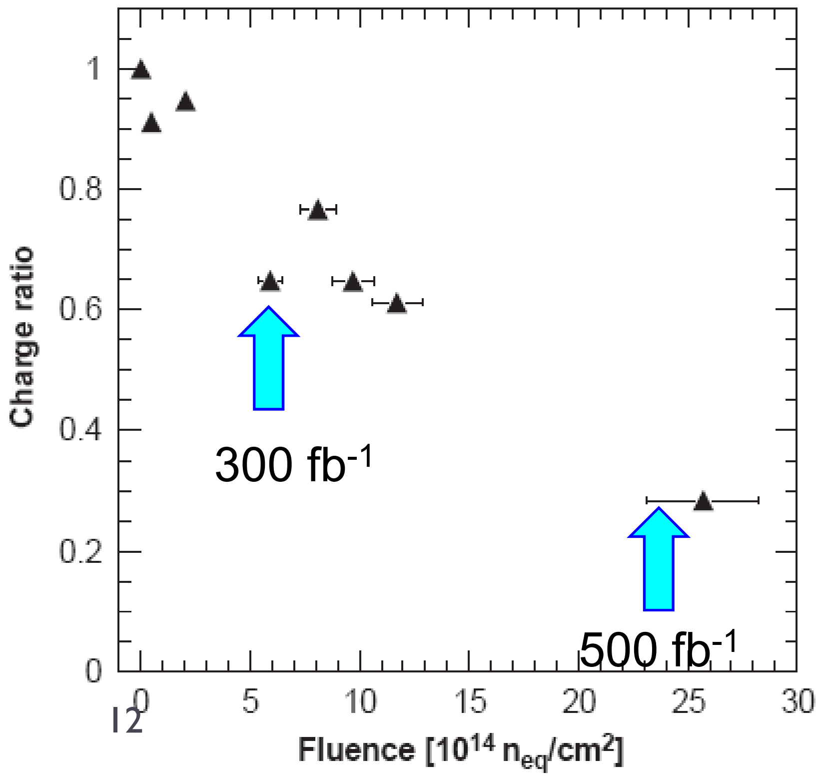


Insertion of the Pixel was done in a few
Hours- can be done removed in any shutdown

Limitations in Phase 1

Note that the table assumes L=60 fb^{-1} at 1×10^{34} $cm^{-2}s^{-1}$ but if machine works well we could get L=100 fb^{-1}/year at 1×10^{34} $cm^{-2}s^{-1}$ in 2012

- Radiation damage due to integrated luminosity.
  - Sensors designed to survive $6\times10^{14} n_{eq}/cm^2$ (~ 300 fb^{-1}).
  - n-on-n sensors degrade gradually at large fluences



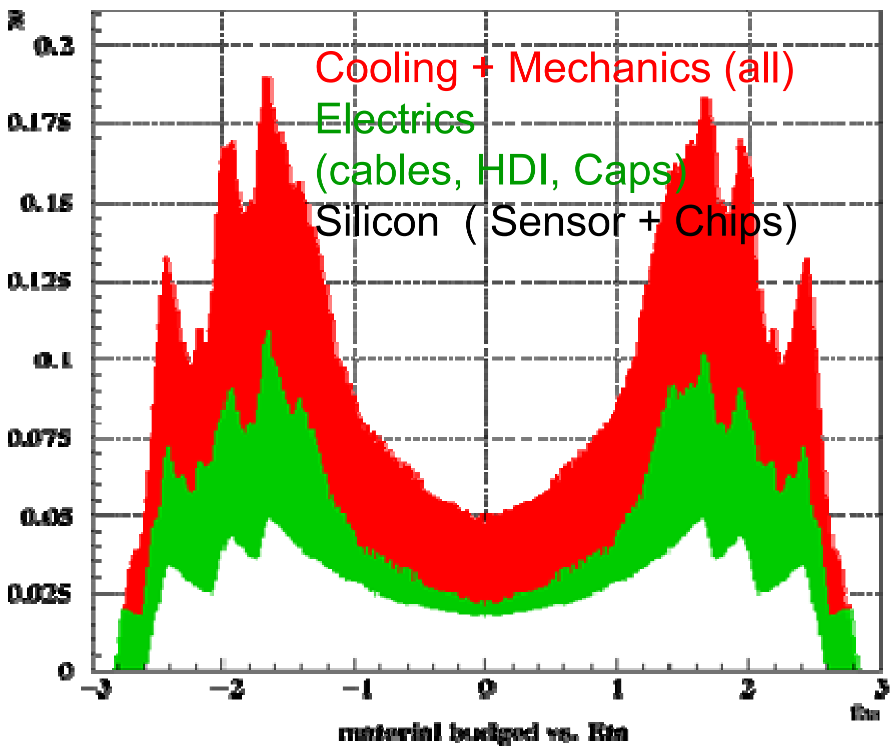
Normal Ramp

Year	Peak Lumi (x 10^{34})	Annual Integrated (fb^{-1})	Total Integrated (fb^{-1})
2009	0.1	6	6
2010	0.2	12	18
2011	0.5	30	48
2012	1	60	108
2013	1.5	90	198
2014	2	120	318
2015	2.5	150	468
2016	3	180	648
2017	3	0	648
2018	5	300	948
2019	8	420	1428
2020	10	540	2028
2021	10	600	2628
2022	10	600	3228
2023	10	600	3828
2024	10	600	4428
2025	10	600	5028

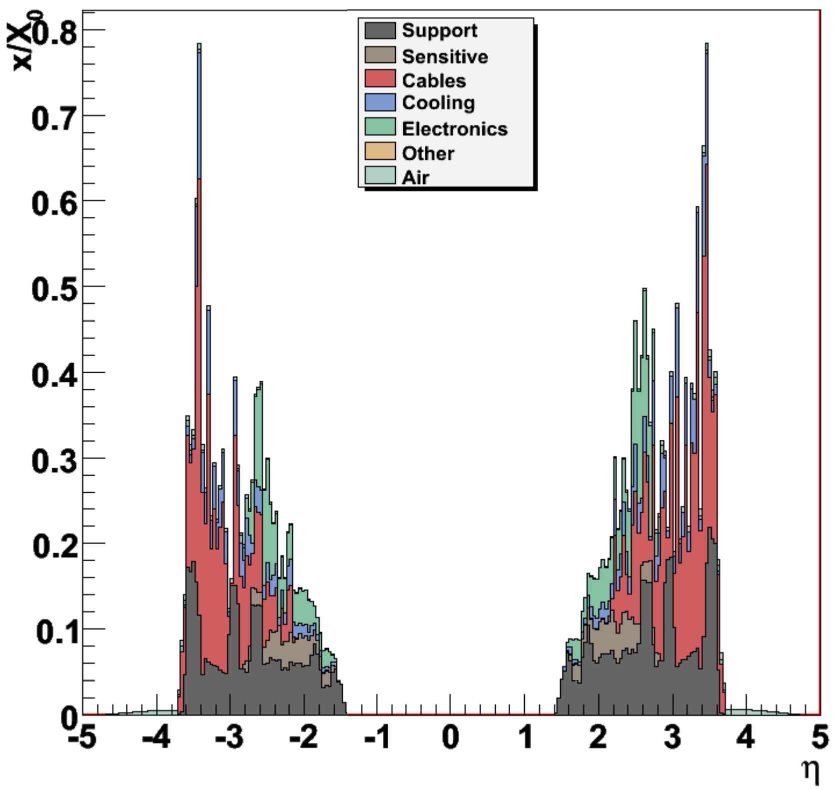
Garoby LHCC July 1, 2008

Limitations in Phase 1

BARREL PIXELS



ENDCAP PIXELS



- Material budget both in endcap and barrel
  - Significant contribution from mechanical supports, cables

BPIX Options for 2013 replacement/upgrade

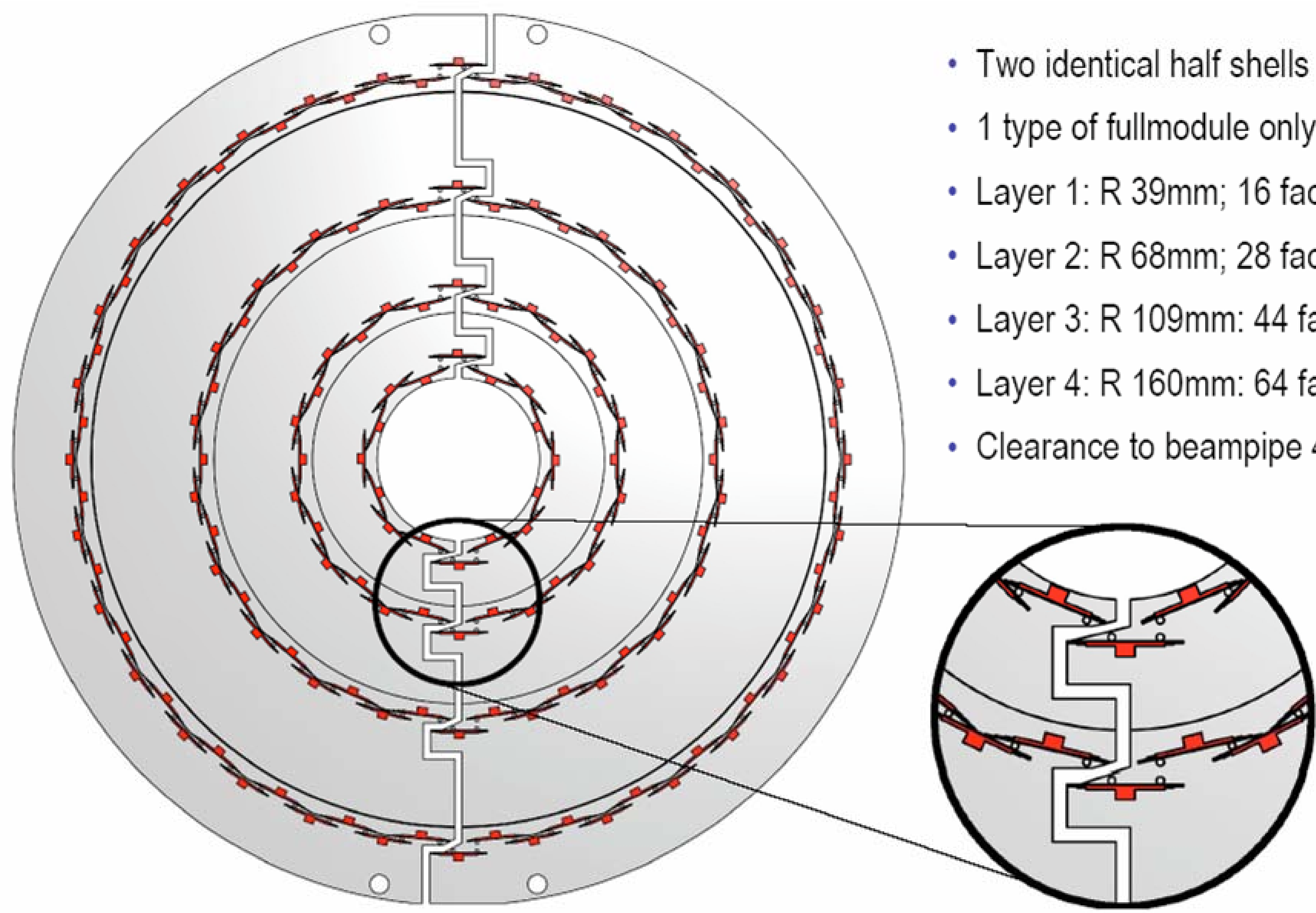
Slide from
21. May 2008

Option	Layer/Radii	Modules	Cooling	Pixel ROC	Readout	Power
as 2008: 0	4, 7, 11cm	768	C_6F_{14}	PS46 as now	analog 40MHz	as now
1	4, 7, 11cm	768	C_6F_{14}	2x buffers	analog 40MHz	as now
2	4, 7, 11cm	768	CO_2	2x buffers	analog 40MHz	as now
3	4, 7, 11cm	768	CO_2	2x buffers	analog 40MHz μ-tw-pairs	as now
4	4, 7, 11cm	768	CO_2	2xbuffer, ADC 160MHz serial	digital 320MHz μ-tw-pairs	as now
5	4, 7, 11, 16cm	1428	CO_2	2xbuffer, ADC 160MHz serial	digital 640 MHz μ-tw-pairs	DC-DC new PS

After many discussions, considerations & iterations

- **4 layer pixel system 4, 7, 11, 16 cm** → 1216 full modules
- **CO2 cooling based**
- **Ultra Light Mechanics**
- **BPIX modules with long 1.2m long microtwisted pair cables**
- **Shift material budget from PCB & plugs out of tracking eta - region**
- **ROC buffers for 1.5 x 10^{34} and serial binary readout @160 MHz**
- **Serialized binary optical readout at 320 MHz to old, modified px-FED**
- **Recycle & use current AOH lasers → 320MHz binary transmission**
- **Same FEC's , identical TTC & ROC programming**
- **Keep LV-power supply & push more current through cables**

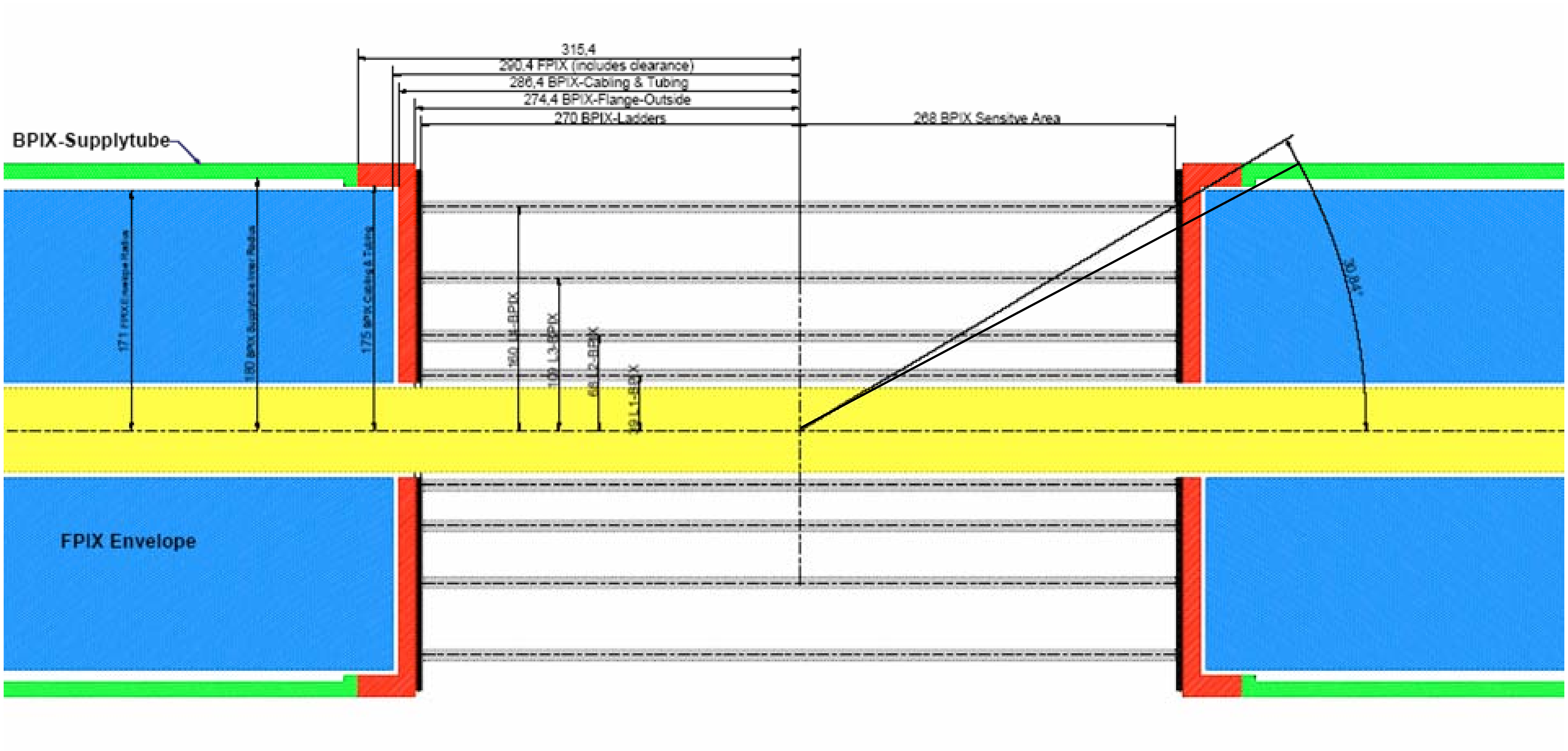
BPIX Upgrade Phase 1 (2013) , 4 Modules long



- Two identical half shells
- 1 type of fullmodule only
- Layer 1: R 39mm; 16 faces
- Layer 2: R 68mm; 28 faces
- Layer 3: R 109mm: 44 faces
- Layer 4: R 160mm: 64 faces
- Clearance to beampipe 4mm

BPIX/FPIX Envelope Definition for 4 Layer Pixel System

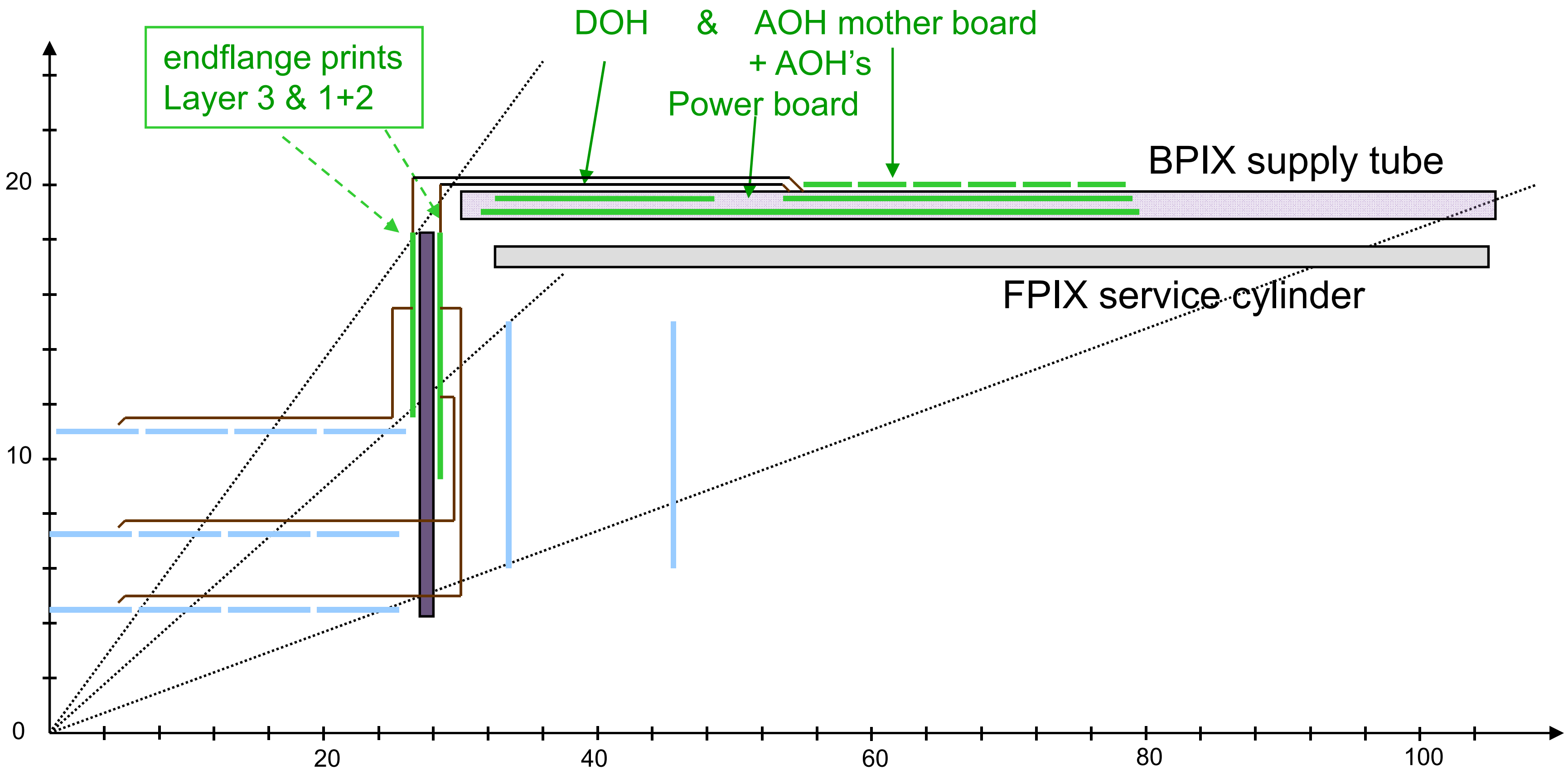
All barrel layers 4 module long → small eta hole of $\Delta\eta \sim 0.08$ at $\eta=1.288$



Various iterations forth and back by R.H. / Silvan Steuli / Kirk Arndt

→ no further changes since 2.12.2008 !

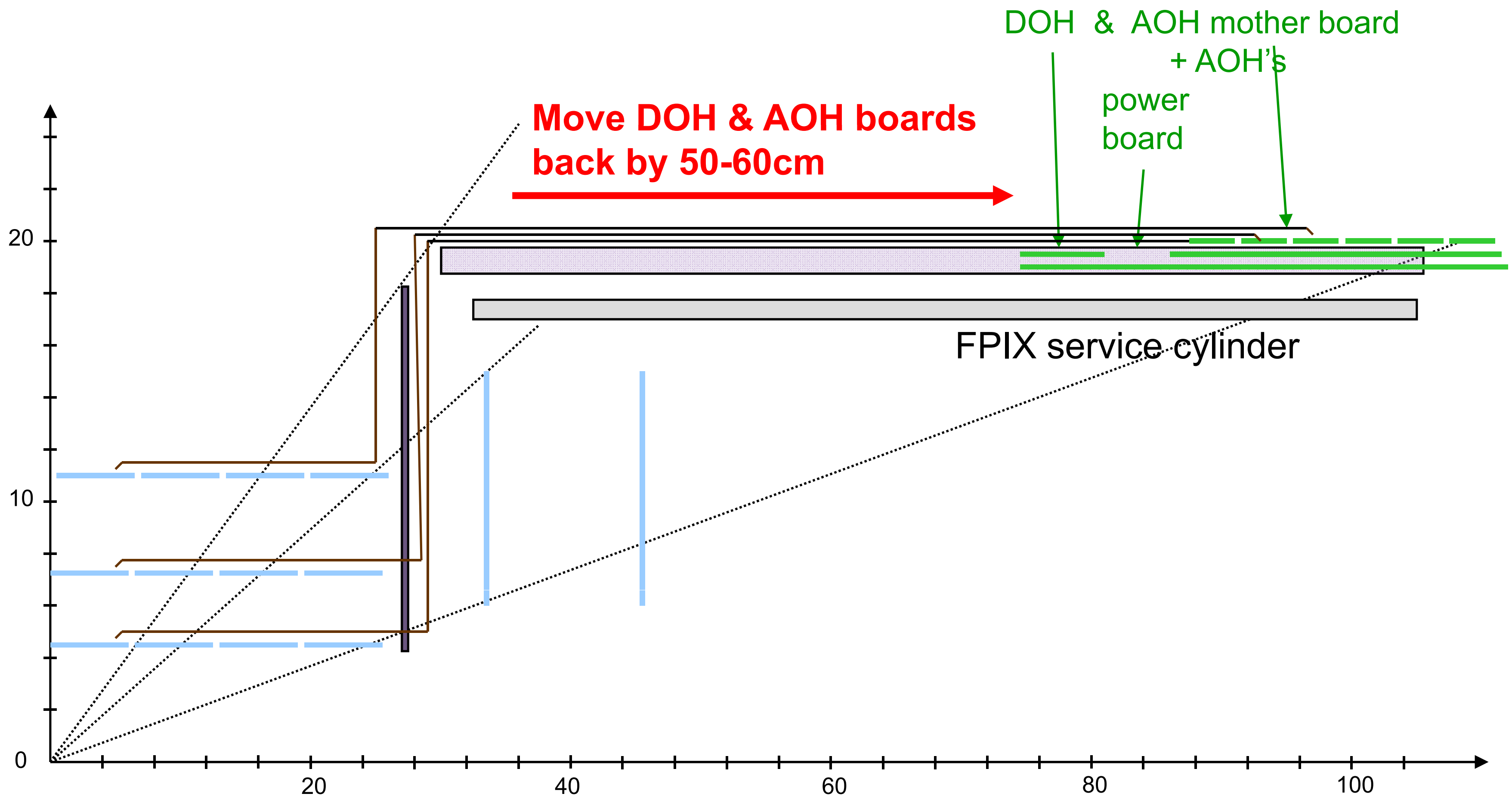
Current Pixel System with Supply Tubes / Cylinders



BPIX Cabling & flexible cooling pipes

Shift PCB/Plug Material out of tracking Volume

- Modules with long pigtails (1.2m) CCA wires   16x(2x125µ)



BPIX Upgrade   Phase 1 (2013) , 4 Modules long

2. Dec 2008

Cost estimate for following system:

radius [mm]	**length** [#mod]	**faces**	**#modules**
160	**8**	**64**	**512**
109	**8**	**44**	**352**
68	**8**	**28**	**224**
39	**8**	**16**	**128**

3 layer system
704 modules

Total number of good modules to be fabricated : **1216**

Module assembly yield 68% ➔   **1788 + 12% spares → 2000 modules**

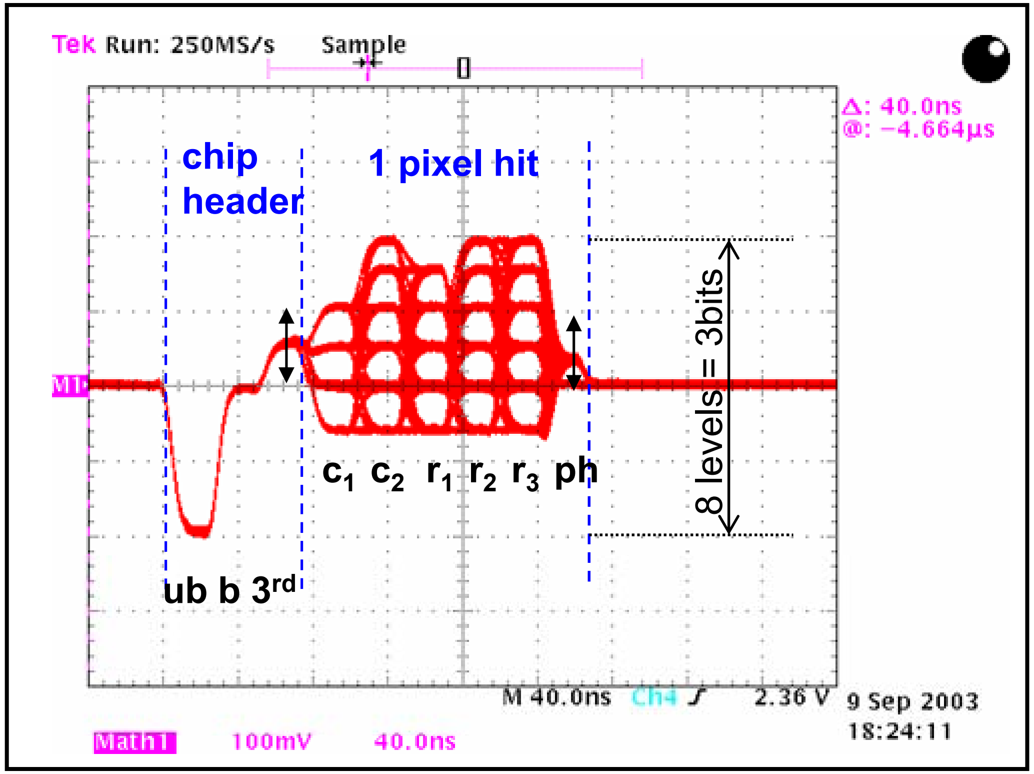
Present BPIX: 768 modules needed .vs. ~1100 fabricated

Transparecy 21.May 2008

New weight of replacement/upgrade BPIX detector (2013)

	Present BPIX	New 2013 BPIX	Comments
Empty mechanics	1103 g	550 g	possible, with ~ 94g for 1.5mm/1.4mm pipes
384 Module	872 g	522 g	1.36g/mod no SiN strips 75µ ROC no HV-cap
384 Signal cable	167g	7 g	2 x (2x125µ CCA)
384 Power (6x250µ CCA)	82g	68 g	5x250µ CCA
384 Power plug	16g	0 g	none
32 Print	499 g	32 g	radial power cable to ST
Cooling (C_6F_{14})	810 g	83 g	CO_2 in 1.45mm diam. pipe
Silicon tube incl. fluid	372g	5 g	CO_2 pipes to supply tube
Total	3921g	1267 g	factor 3.1 down

Present analog coded data transfer of pixel system



Pixel uses analog coded digital pixel readout

Pixel address 5 x 3 bit

Pulse height 1 x 8 bit

→ **total 23 bits/ pixel hit**
in 6 clock cycles

→ 160 Mbits/sec link speed

resp. 1300 pJ/bit

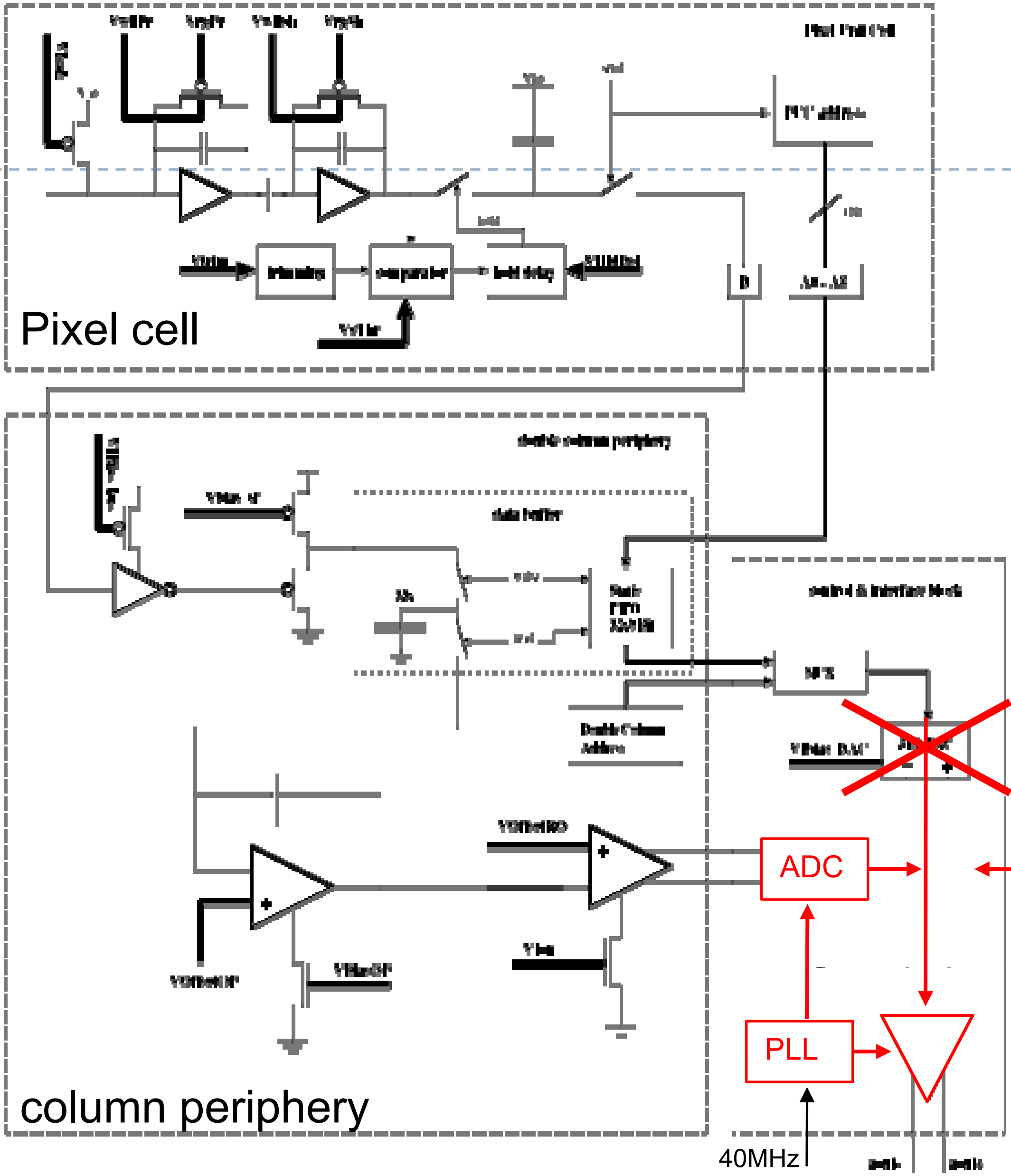
Why a digital readout?

- In 4 layer barrel pixel system we will have 1216 modules (128 / 224 / 352 / 512)
- We will have to re-use existing fibres from PP1 out.
- → can only use one fibre per module everywhere (see later today). Now 2 fibres per module for layer 1 and 2
- Present analog links too slow. Hard to make faster.
- Seems more feasible with digital links

Bandwidth limitation

- Bandwidth of present analog links ≈ 40MHz · 2.5 bits (6 levels) = 100MBit/sec
- It is used ≈ 50% @ 4cm and 100kHz L1A
- Doubling the data volume will exceed the available bandwidth§ since
  - We can't use 100% of peak bandwidth
  - We have no additional fibres we could use
- Solutions:
  - 80 MHz analog: not really. Probably feasible but non-trivial and painfull (next slide)
  - Digital link at 160 or 320 MBit/sec. Also non-trivial but more standard. First prototype components ready

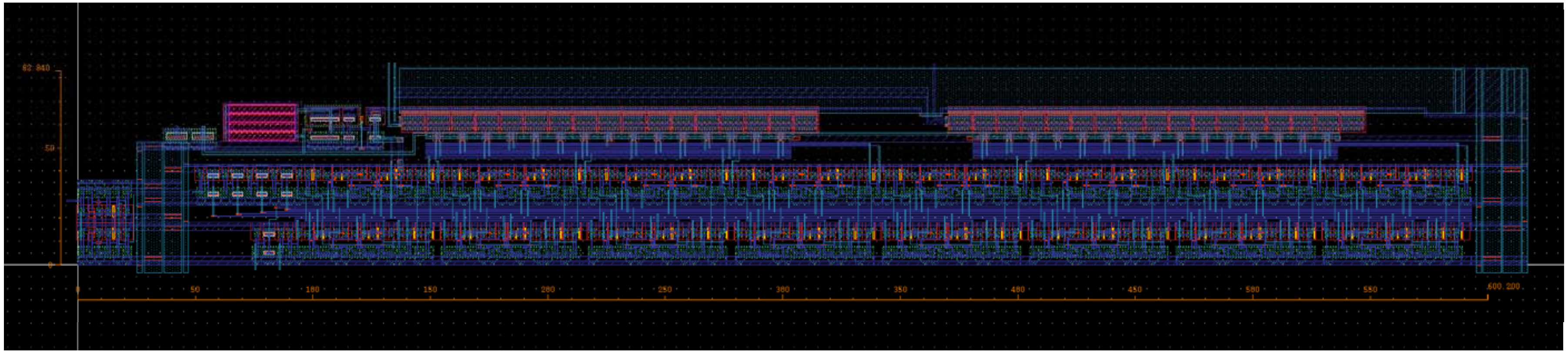
§ Present S-links will not take twice the data rate either



- All changes in the ROC periphery
- No modification of the complex and well debugged chip core (double columns)!

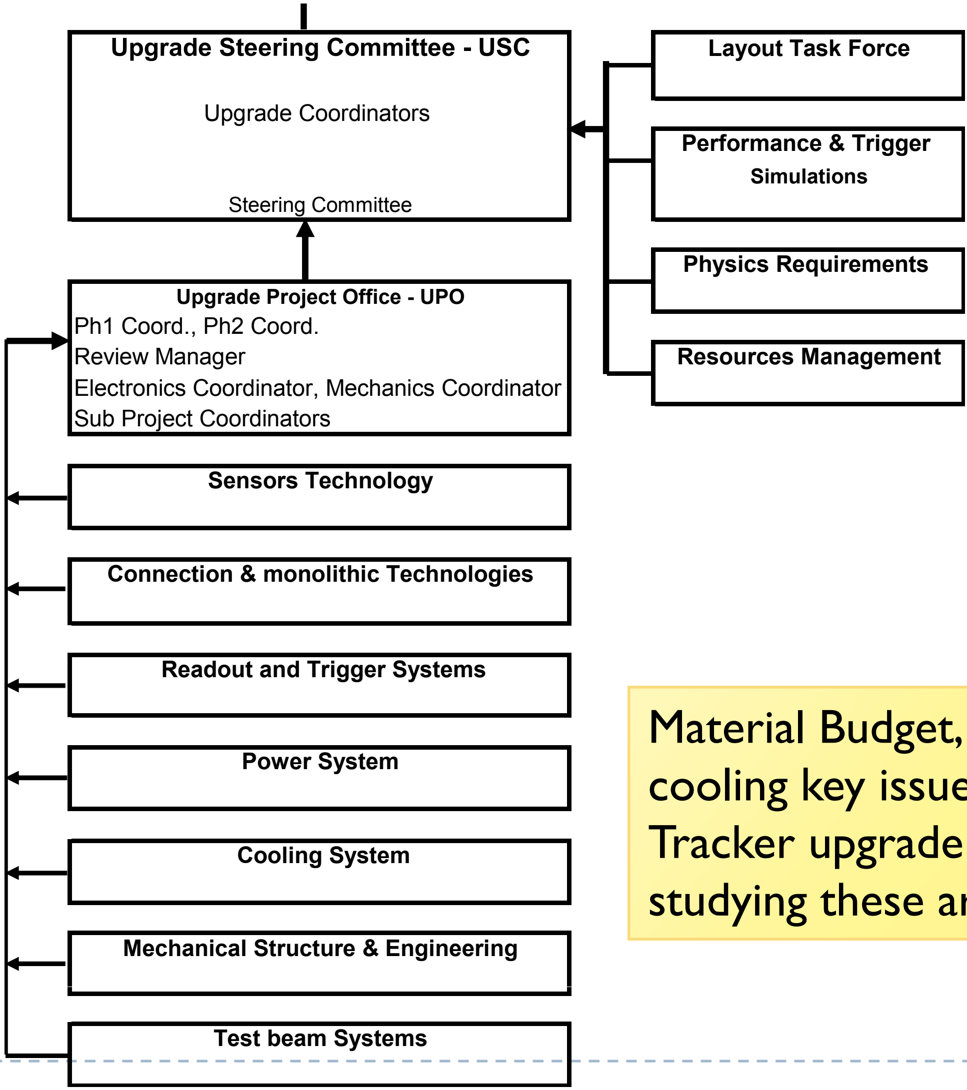
Modified logic

ADC



- Improved 8 Bit version to be submitted in February 09
  - Added sample/hold circuit at input
  - 8 bit DAC
  - Added capacitance to power rails
- Design by Beat Meier & Irakli, almost finished

Moving to Phase II
Tracker - Draft Upgrade Structure



Material Budget, Power Consumption, cooling key issues for a new tracker
Tracker upgrade team has been actively studying these areas

Power Task Force

Mandate

“The Task Force will review all the currently proposed solutions for powering an upgraded CMS Tracker and will **propose a baseline solution** and **one back-up solution** for powering the upgraded Tracking Systems. [...]”

P. Sharp (chair), F. Arteche, G. Dirkes, F. Faccio, L. Feld, F. Hartmann, R. Horisberger, M. Johnson, K. K., M. Mannelli, A. Marchioro, B. Meier, M. Raymond.

5 Meetings, many presentations on benefits and issues of DC-DC conversion and Serial Powering – after all, no convincing case for a change to Serial Powering. Summary report presented by Peter at summary meeting (30th of January)

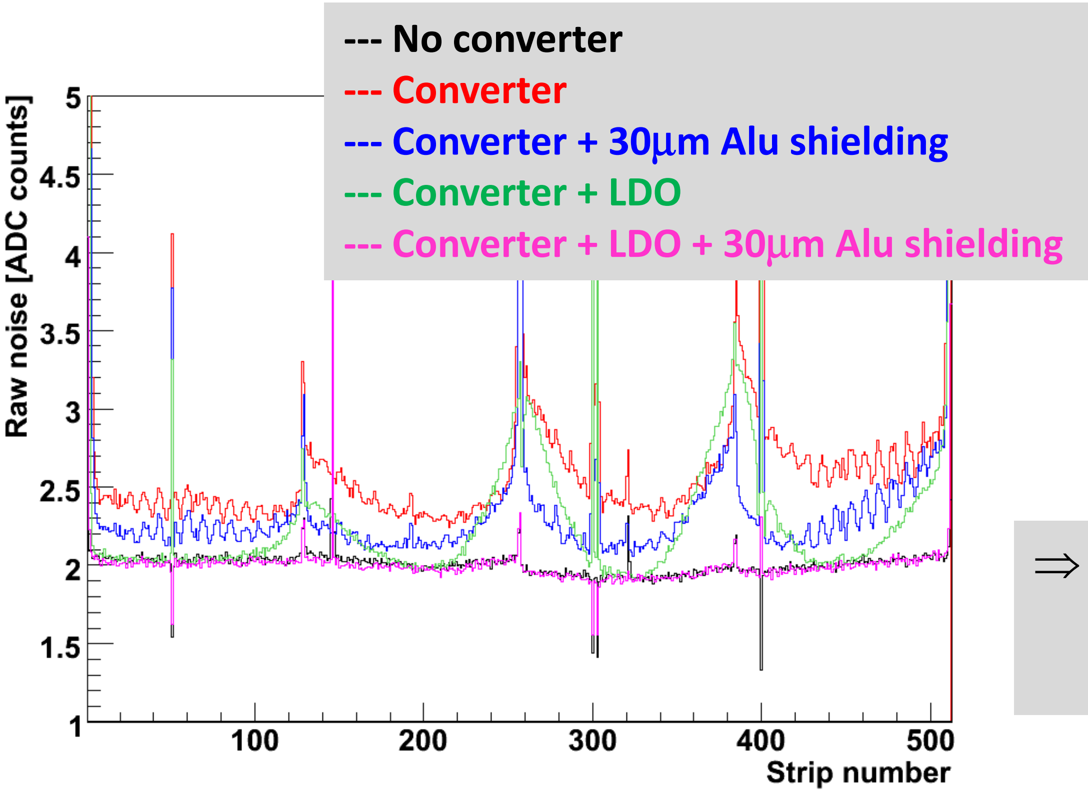
Recommendation

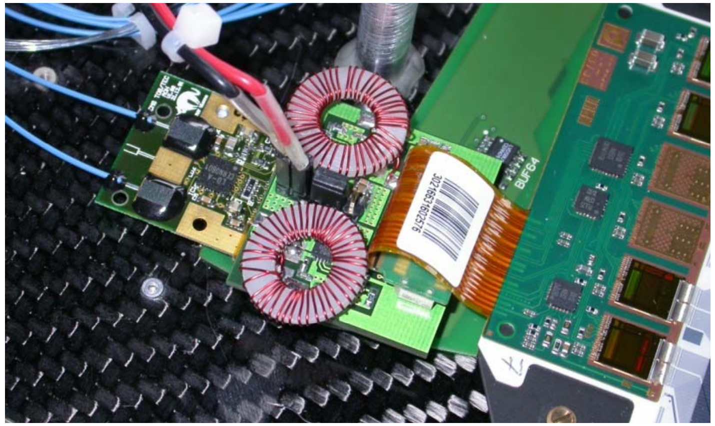
“The ‘Task Force’ recommends that the **baseline powering system** for an upgraded CMS Tracking system **should be based on DC-DC conversion**, with **Serial Powering maintained as a back-up solution**. [...]
It is important that design decisions taken during this process do not preclude reverting to the back-up solution at a later date.”

System Test with DC-DC Converters

- Results summarized by Lutz in October meeting

  http://indico.cern.ch/getFile.py/access?contribId=0&resId=0&materialId=slides&confId=41790





⇒ Noise of Enpirion converters can be controlled by combination of shielding and filtering (LDO).

- Studies with commercial buck converters documented in Jans thesis CMS TS-2009/003

  "System Test Measurements with a DC-DC Conversion Powering Scheme for the CMS Tracker at SLHC"

Activities

Topic / Scheme	Electronics development	System tests	Material budget
DC-DC conversion	**Non-isolated inductor-based:** CERN (technology, chip development, simulation); Aachen (PCB); Bristol (air-core coil)	Aachen (strips)	Aachen
	Transformer-based: Bristol	Fermilab, Iowa, Mississippi (pixels)	
	Charge pump: PSI (pixels); not covered for strips		
	Piezo-electric transformer: -		
Serial powering	(Fermilab)	Fermilab, Iowa, Mississippi (pixels); Rochester? (strips)	Aachen
Implementation	Karlsruhe (Powering via cooling pipes)		
Power supplies	not covered		

C02 Cooling for phase II

- Almost essential to re-use the current cooling pipes on YB0, can this be done?
- Met with CERN safety commission to discuss issues
- Looks possible, agreed plan of validation with CERN safety

Summary

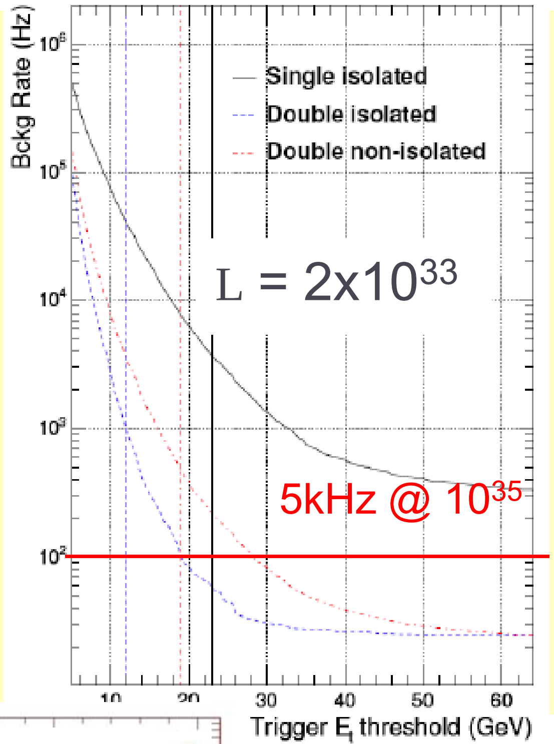
- With this system design, max coolant temp at 15 degrees C and safety valve at 57 bar, the currently installed copper tubes can be approved by CERN safety
- We will build one equivalent circuit for destructive testing by CERN safety
- We will pressure test the installed copper tubes with gas at 1.25x57=71 bar

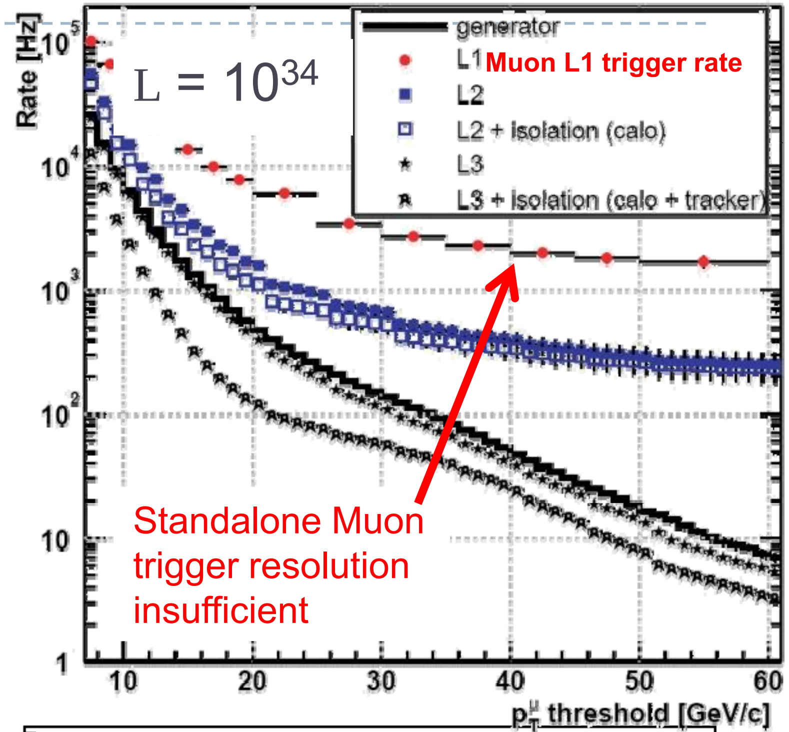
28 January 2009 Hans Postema - CERN 24

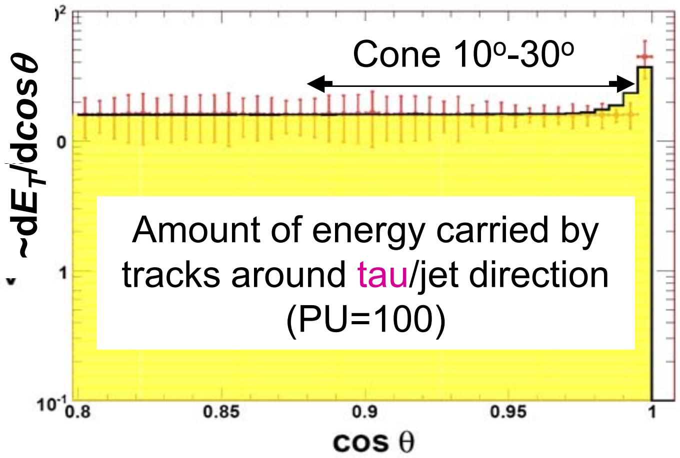
Tracking needed for L1 trigger @ 10^{35}

Single electron trigger rate

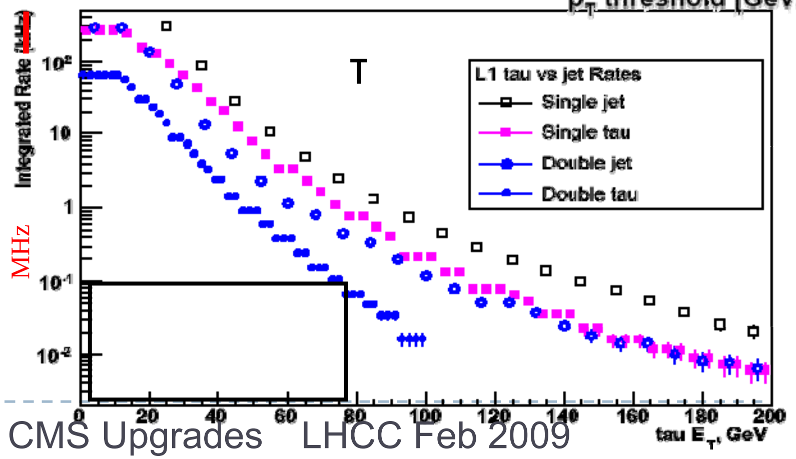
Isolation criteria are insufficient to reduce rate at L = 10^{35} $cm^{-2}.s^{-1}$





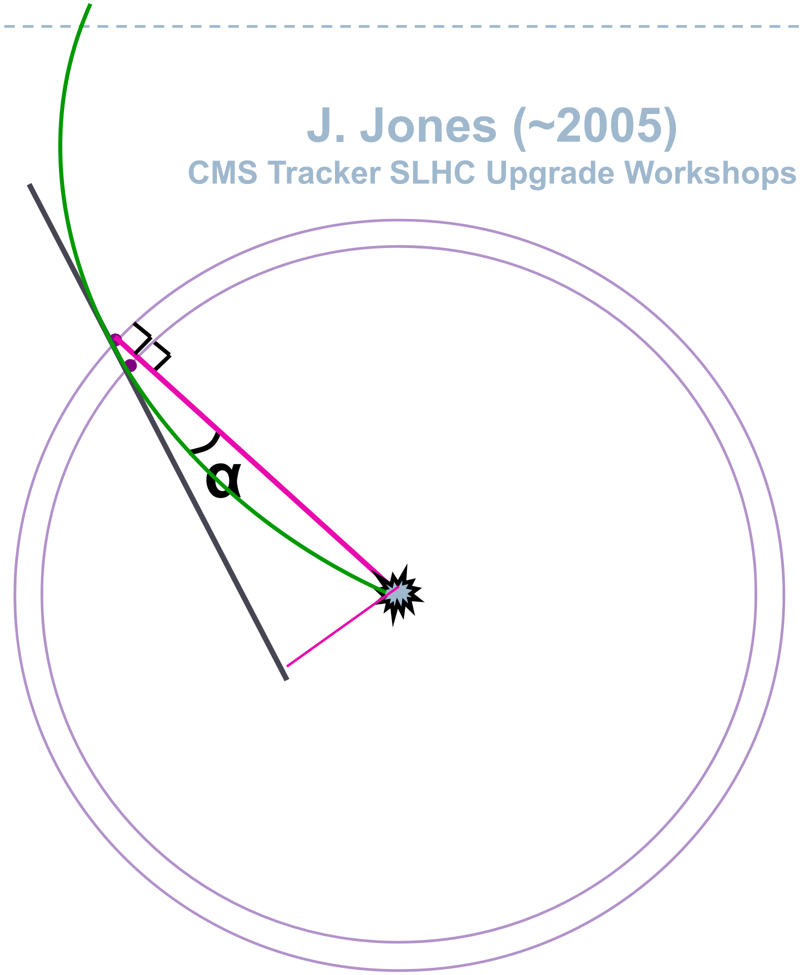


We need to get another x200 (x20) reduction for single (double) tau rate!



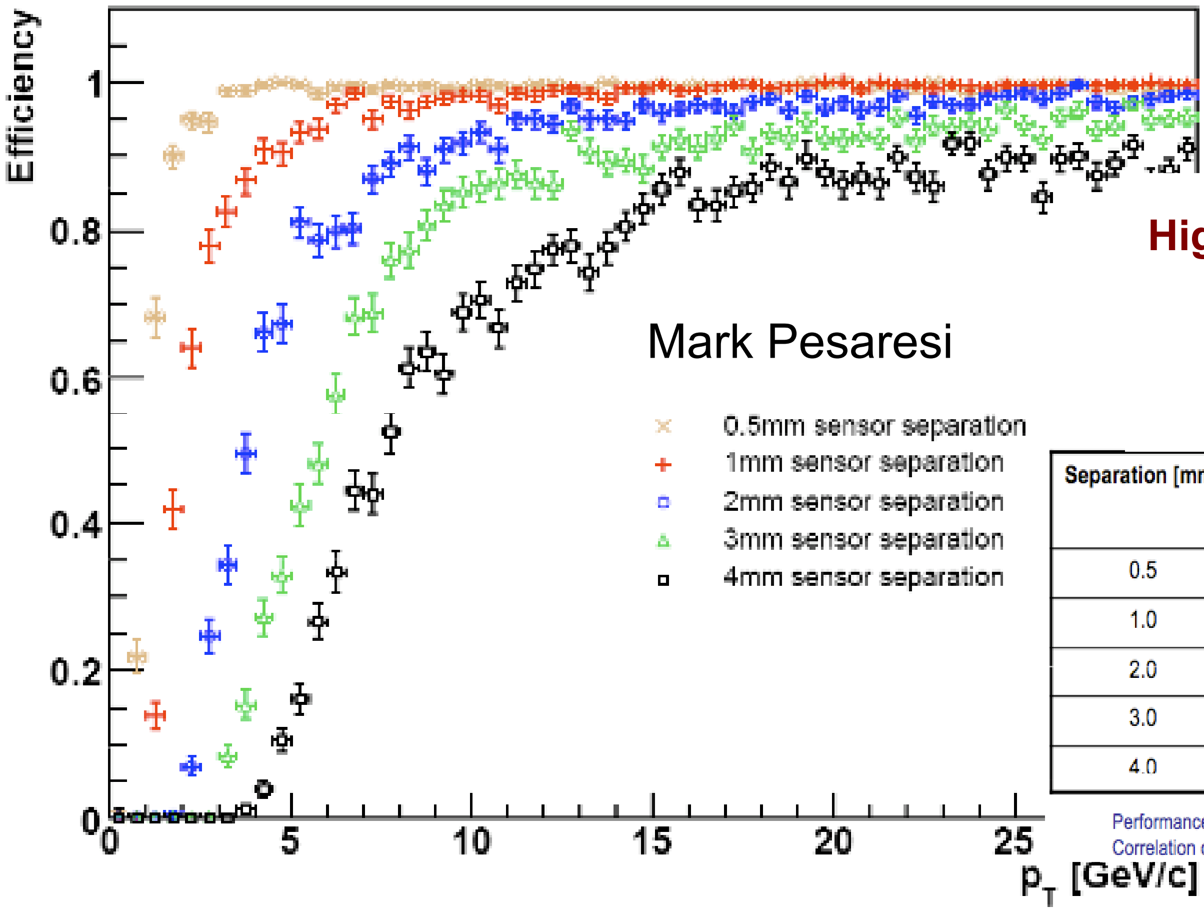
Local Occupancy Reduction with Local Track Vectors

- Pairs of Sensor Planes, for local Pt measurement
- High Pt tracks point towards the origin, low Pt tracks point away from the origin
- Use a Pair of Sensor Planes, at ~ mm distance
  - Pairs of Hits provide Vector, that measure angle of track with respect to the origin
  - Note: angle proportional to hit pair radius
- For Trigger Keep only Vectors corresponding to high Pt Tracks



Recent results for a Stack of closely spaced sensors: pitch ~ 100um*2.4mm

(M. Pesaresi)



p_T discriminating performance of a stacked layer at r=25cm for various sensor separations using 10,000 di-muon events with smearing

High rejection factors possible

Much Sharper Threshold
For Low Threshold Value

Separation [mm]	Max Efficiency [%]	Fake [%] (or average number/event)	Reduction Factor
0.5	99.05	0.73 (12.22)	8.04
1.0	99.35	4.14 (25.58)	22.26
2.0	97.745	17.83 (18.74)	95.99
3.0	96.00	39.08 (23.76)	210.28
4.0	92.95	47.27 (32.39)	254.35

Performance of a detector stack at r=25cm for sensors with pitch 100μmx2.37mm. Correlation cuts optimised for high efficiency

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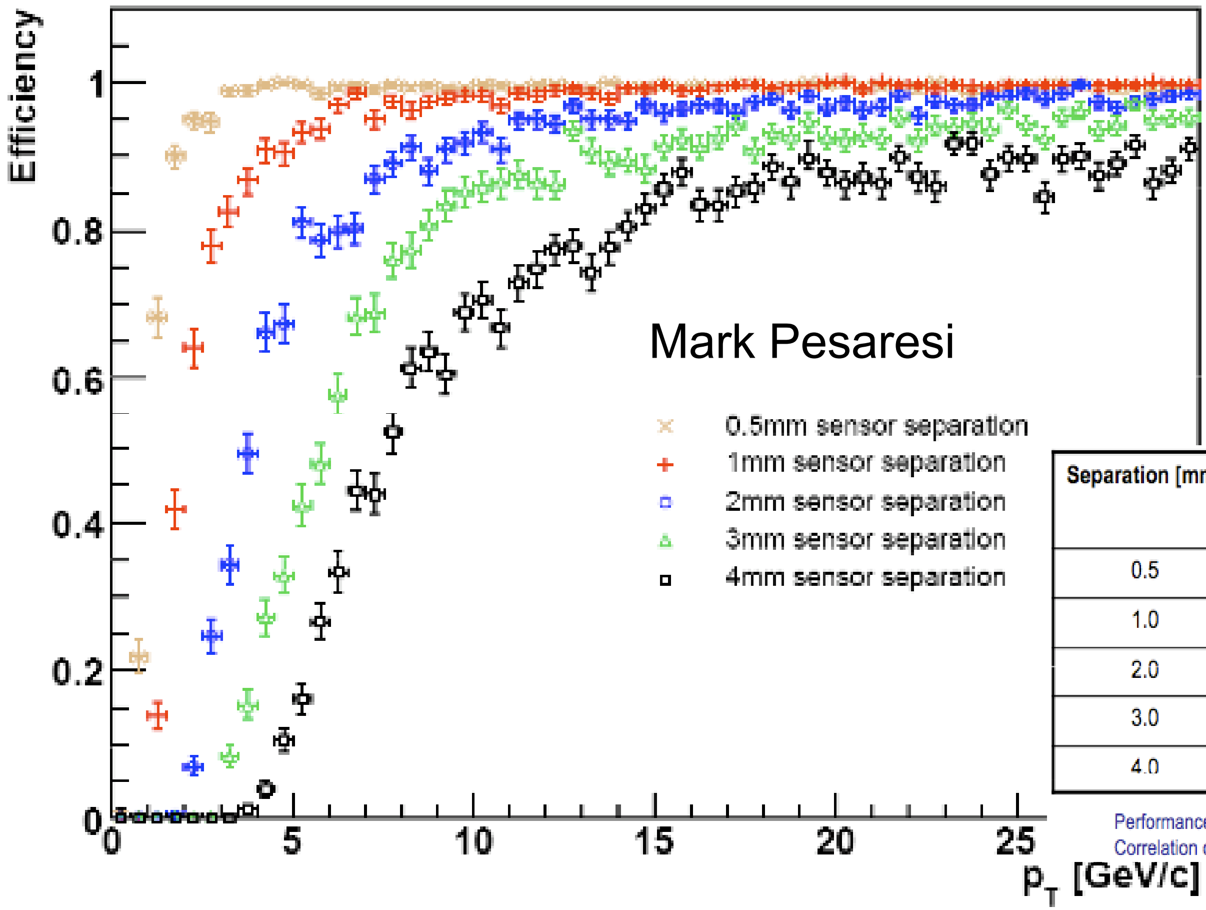

p_T discriminating performance of a stacked layer at r=25cm for various sensor separations using 10,000 di-muon events with smearing

No useful discrimination at Pt ~ 20 GeV

Separation [mm]	Max Efficiency [%]	Fake [%] (or average number/event)	Reduction Factor
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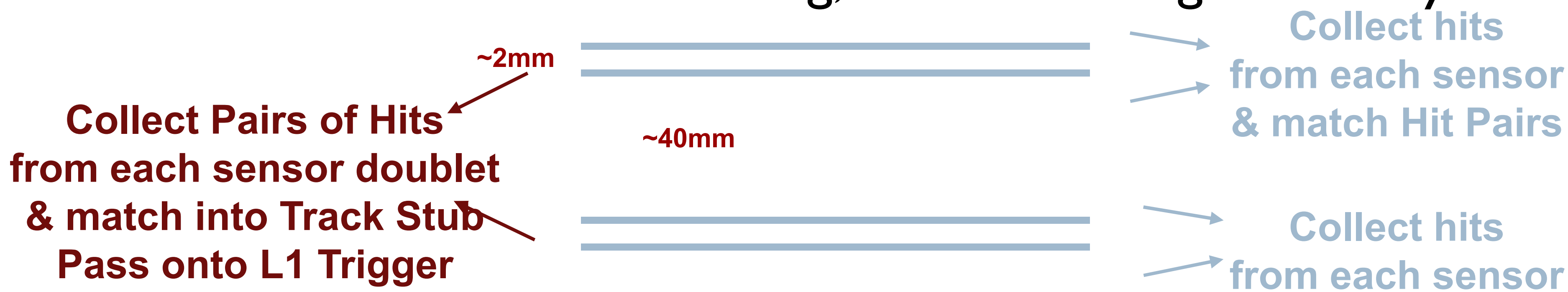
Performance of a detector stack at r=25cm for sensors with pitch 100μmx2.37mm. Correlation cuts optimised for high efficiency

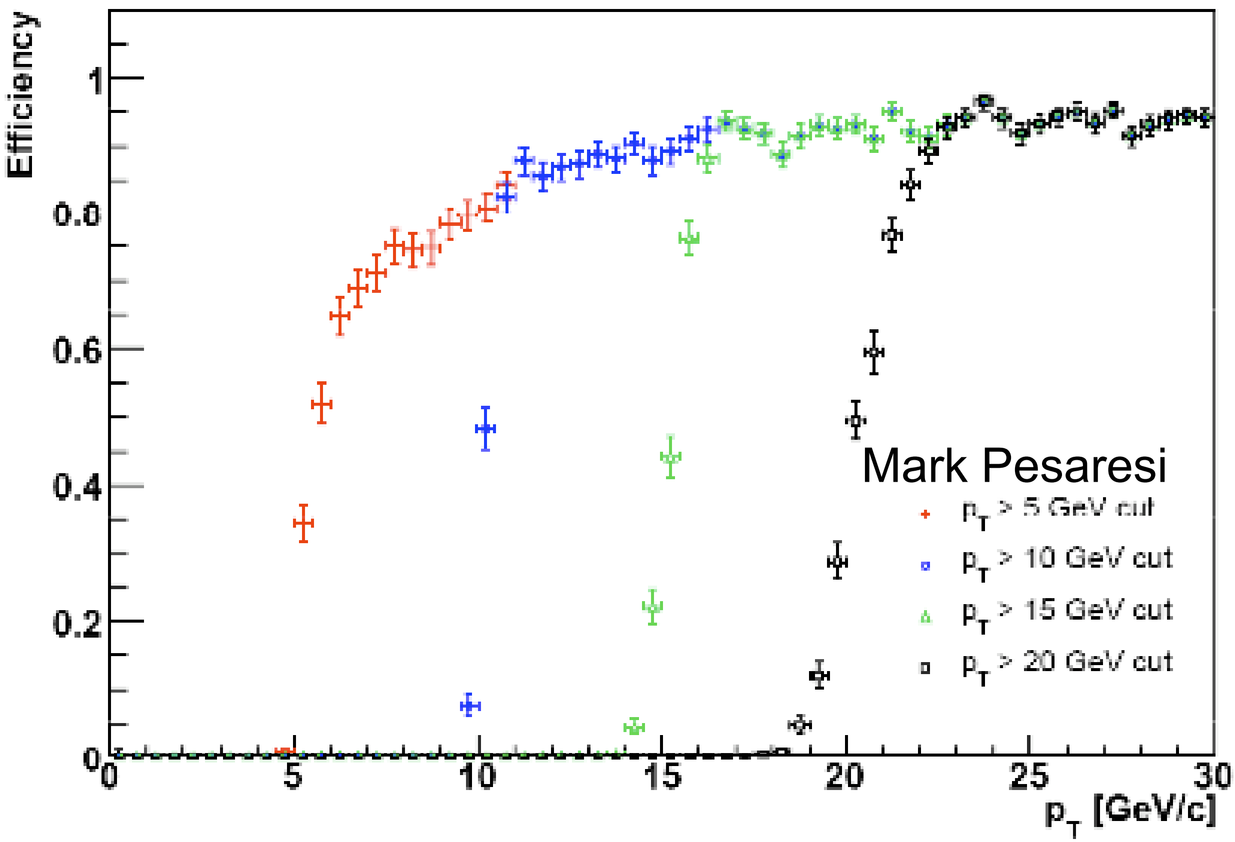
Local Occupancy Reduction
a Hierarchical scheme with Double Stacks

Local Information Gathering, and Processing Hierarchy



- **Within a Stacked-Sensor Module**
  - Collect Hits from each Sensor
  - Match into Hit Pairs & Reject Hit Pairs from Very low Pt Tracks: Pt < ~ 1GeV
  - Nb one datum / Hit Pair
- **Within a Double Stack**
  - Collect Hit Pairs from each Sensor Doublet Module
  - Match into Track Vectors & Reject Track Vectors with Pt < ~ 2GeV
- **Transmit to USC for High Pt & Isolation L1 Track Trigger Primitives**

Recent results for a pair of Double Stacks spaced ~ 10cm apart (M. Pesaresi)



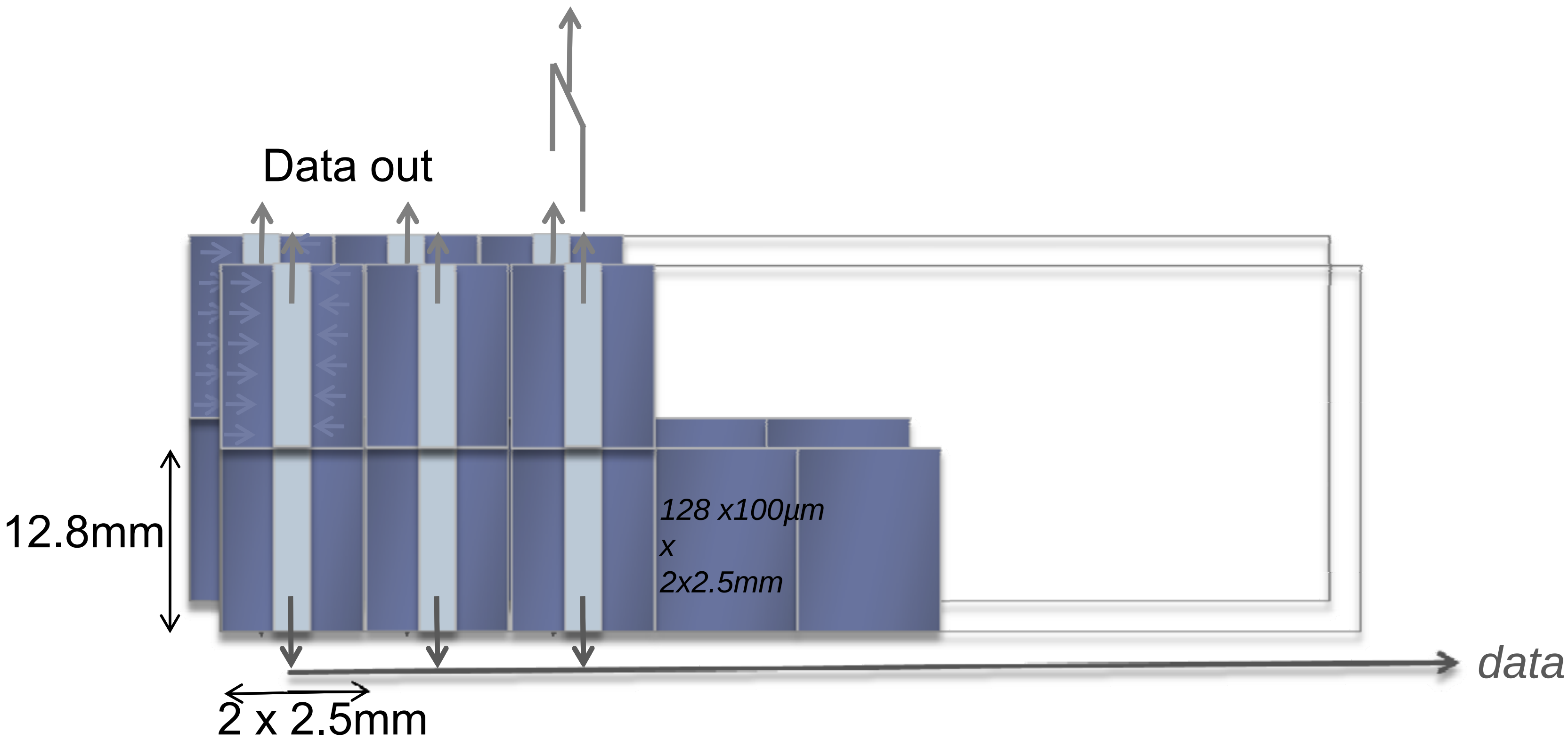
p_T discriminating performance using double stacks for 10,000 0-30GeV di-muon events with smearing

Excellent discrimination up to Pt ~ 20 GeV

Issues for using Tracker in L1 Trigger

- Where would triggering layers have to be?
- How many layers are needed?
- How to build these layers?
- Studying various options for the layers and layouts
  - Intensive development of simulations
    - Tracking performance
    - Triggering performance
  - R/D on technologies
  - Layout task force studying performance of several different options
    - Report later this year.

Example PT module For inner layers

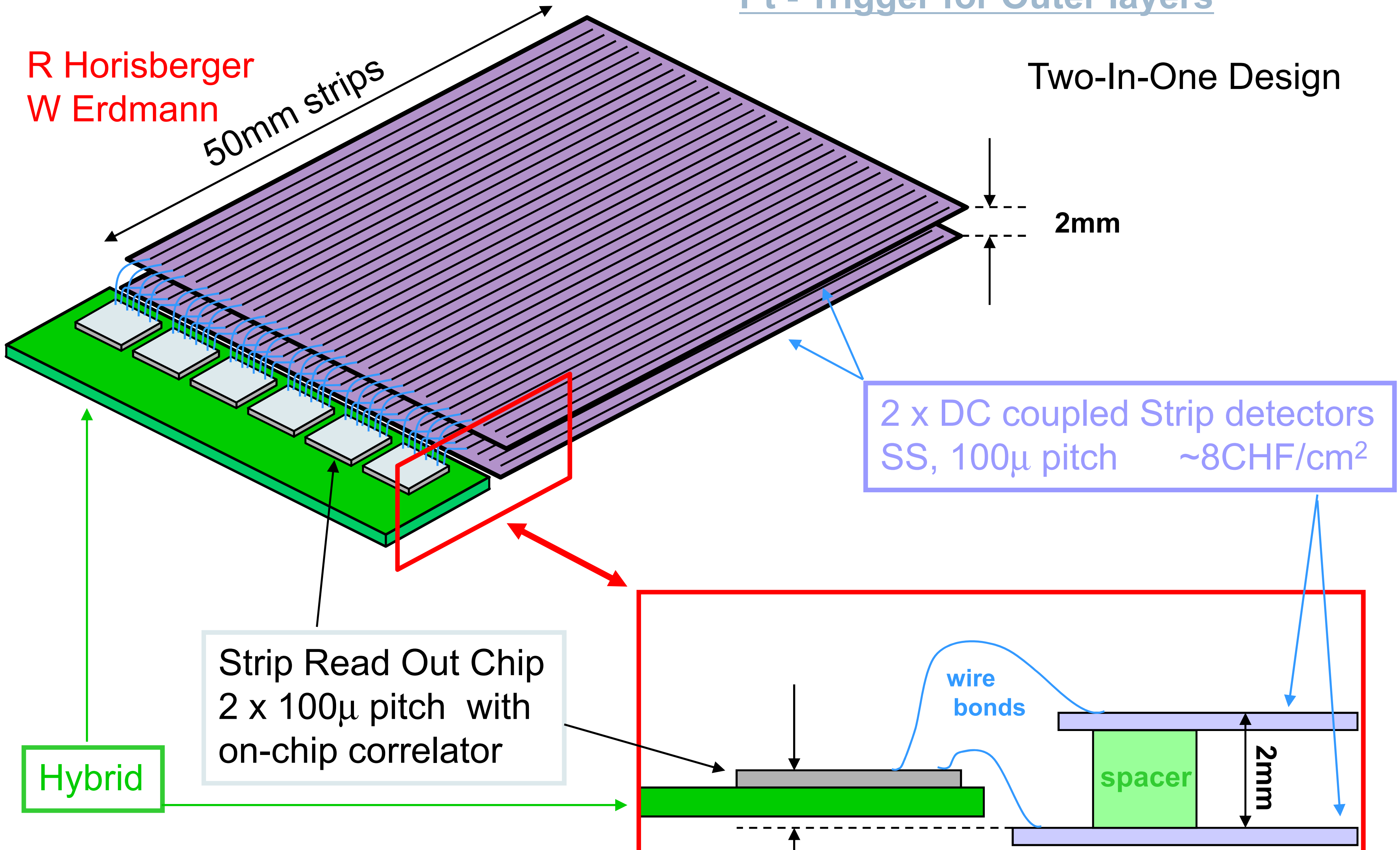


Such a design has potential for inexpensive assembly, using wire bonding, with low risk and easy prototyping

Pt - Trigger for Outer layers

R Horisberger
W Erdmann

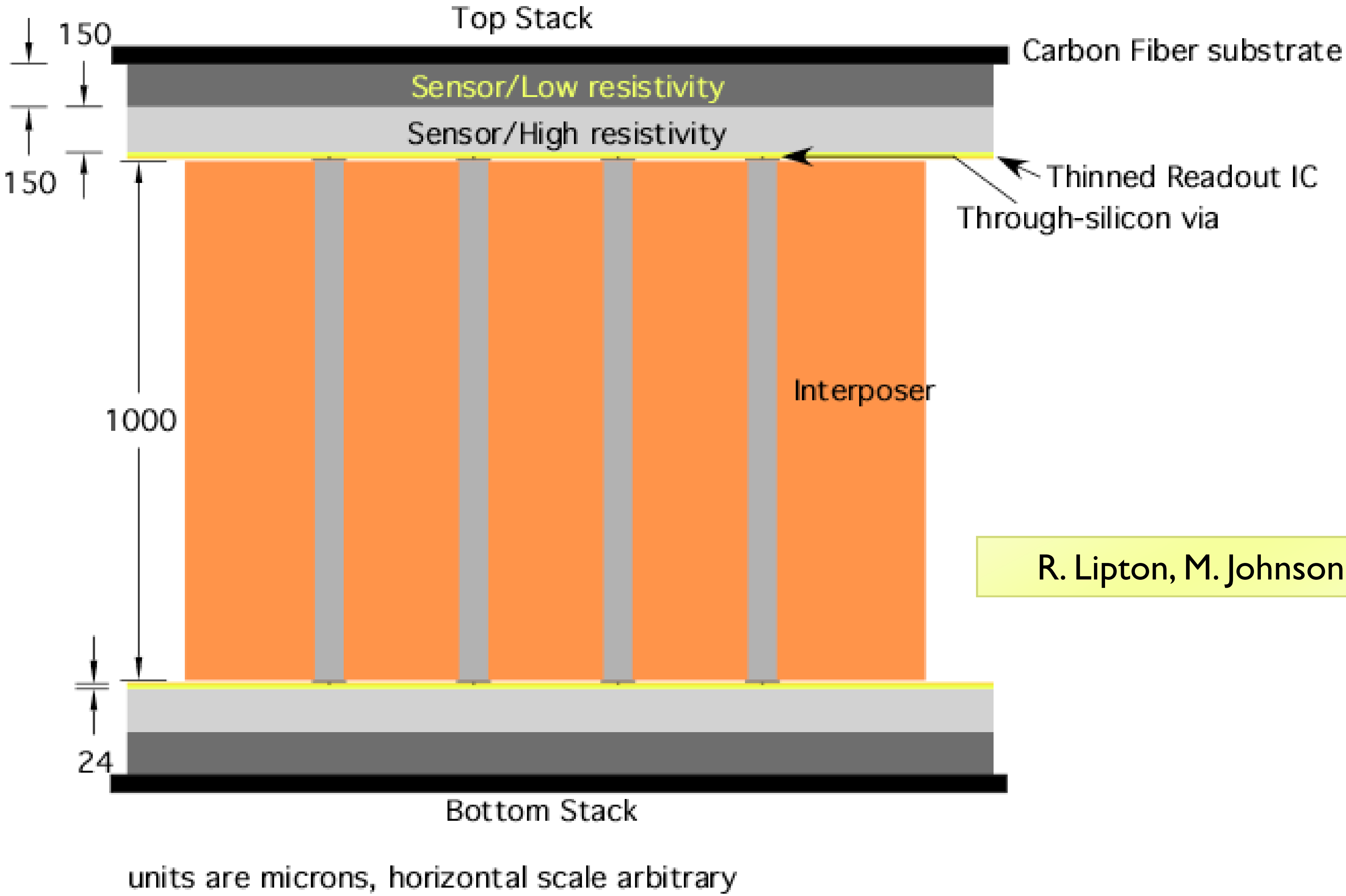
Two-In-One Design



track angular resolution ~20mrad

→ good P_t resolution

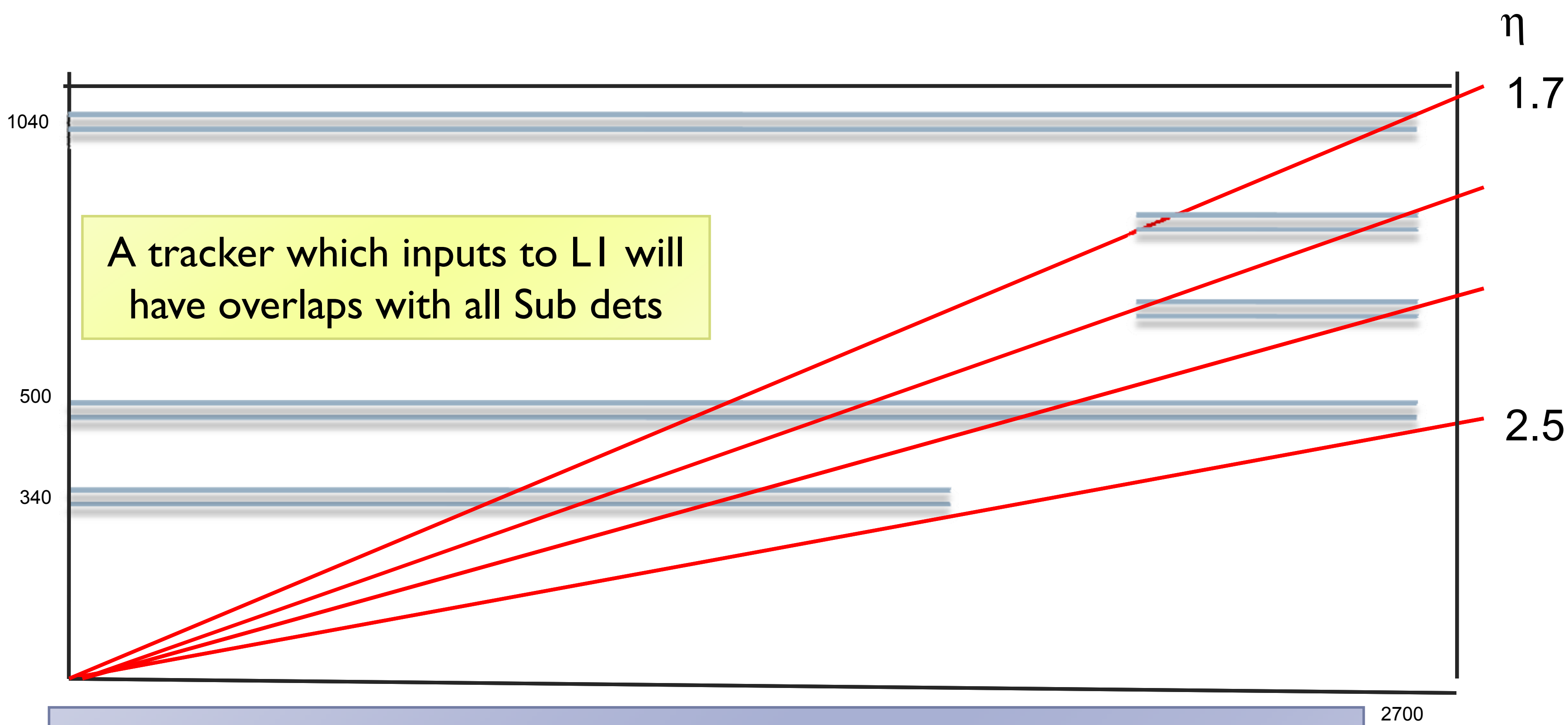
3D Solution



R. Lipton, M. Johnson

Conceptual Drawing of Rod

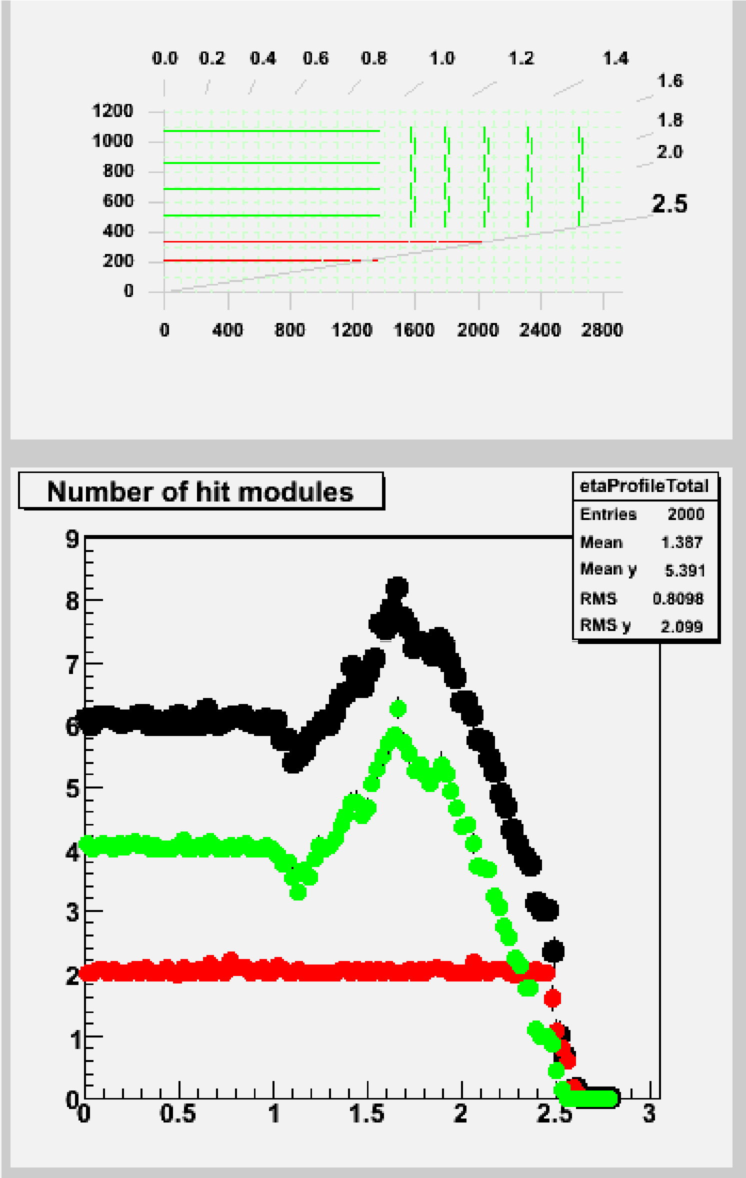
Example:
Layout for the Tracking Trigger Project

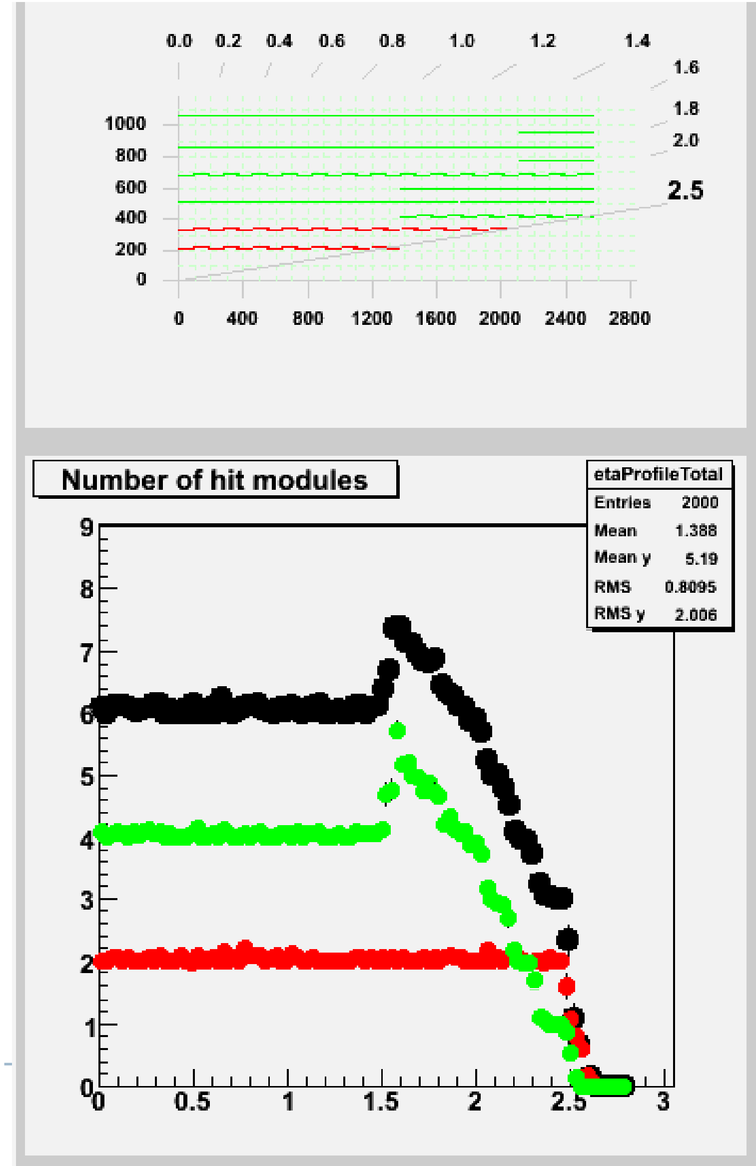


- A conceptual layout for a tracking detector was proposed
  - Trigger groups to understand what could be achieved with stubs
  - Tracker produces stubs to feed the Trigger
- Layout concept for stacked rods proposed
  - study groups to look at the practical aspects – What questions do we need to answer to understand if this can be built?

Examples with two "Pt" layers at lower radii

Layout Task Force
D. Abaneo





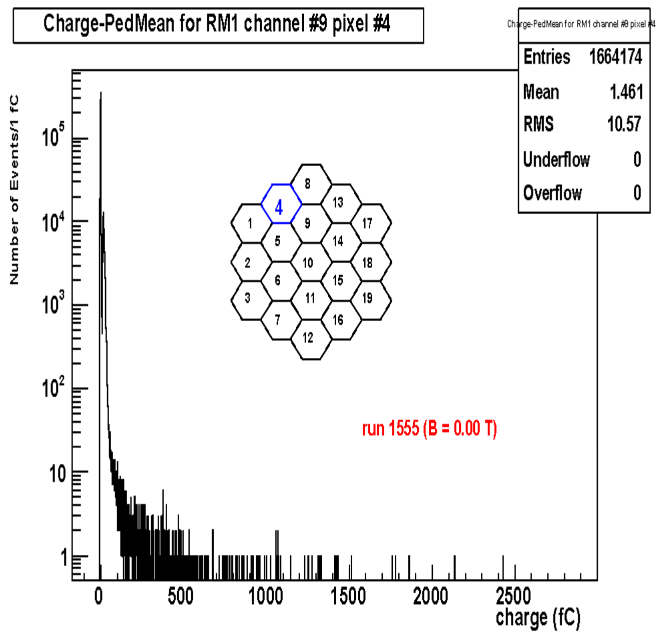
Trigger

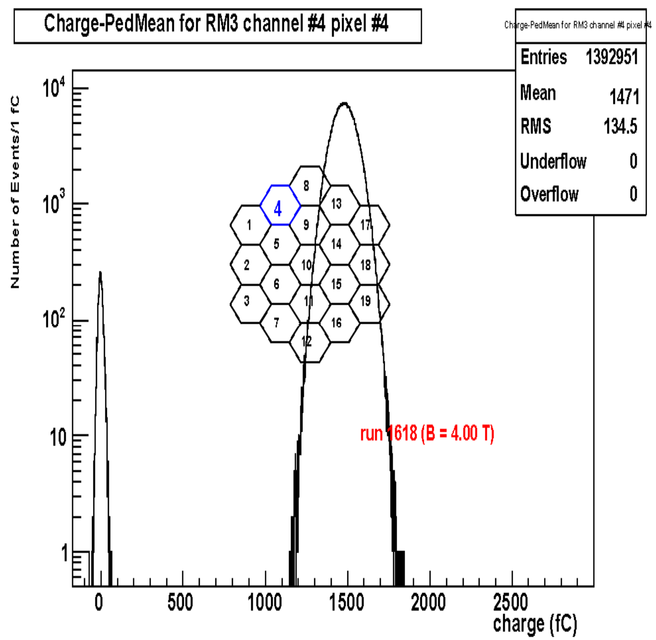
- Technologies for Phase I upgrades
  - Micro TCA implementations
  - The hope is to develop a common infrastructure for use in trigger upgrades
    - Reduce the large number of standards currently in use in the trigger system
    - Increase reliability/flexibility
- Tracking Trigger discussions
  - Possible candidate architectures
  - Simulations
  - Key R/D for phase II
    - Need to establish which ideas most likely to be successful and dedicate sufficient resources to determine viability
      - Can it be implemented
      - How well does it work
      - Power/Material implications

Figure 1: micro TCA crate with single high backplane

Calorimeters

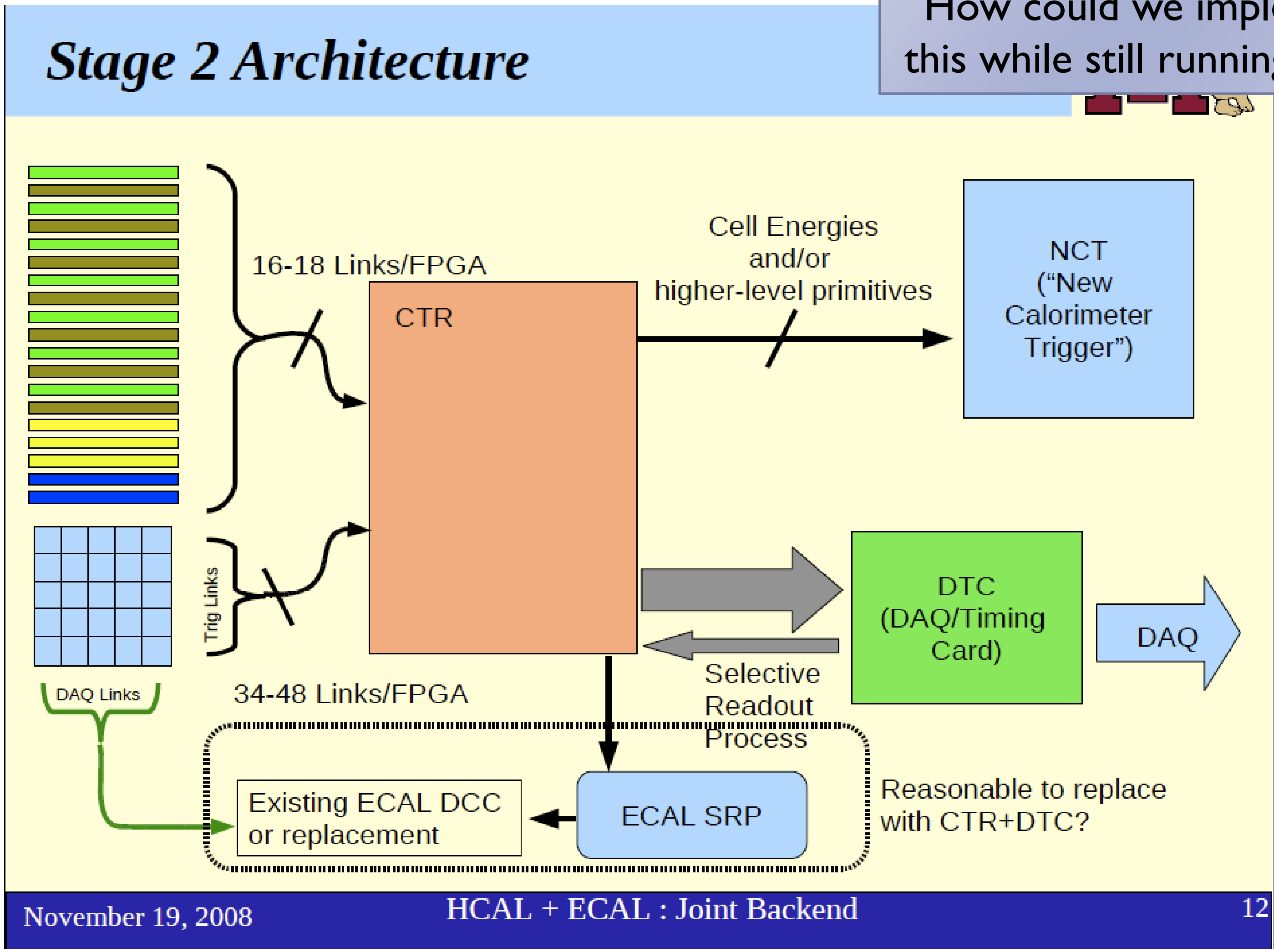
- HCAL
  - Progress on using Silicon PMs as a new Photo Detector
  - New off detector electronics
  - Upgrade strategies
- ECAL
  - Data on radiation damage to crystals and VPTs in the EE
    - Establish what will be the performance at SLHC
  - Simulations of SLHC and EE
    - How well will the EE perform given any performance degradation
  - ECAL/HCAL joint electronics issues
    - e.g. Trigger electronics





Possible Common ECAL/HCAL Off Detector Electronics

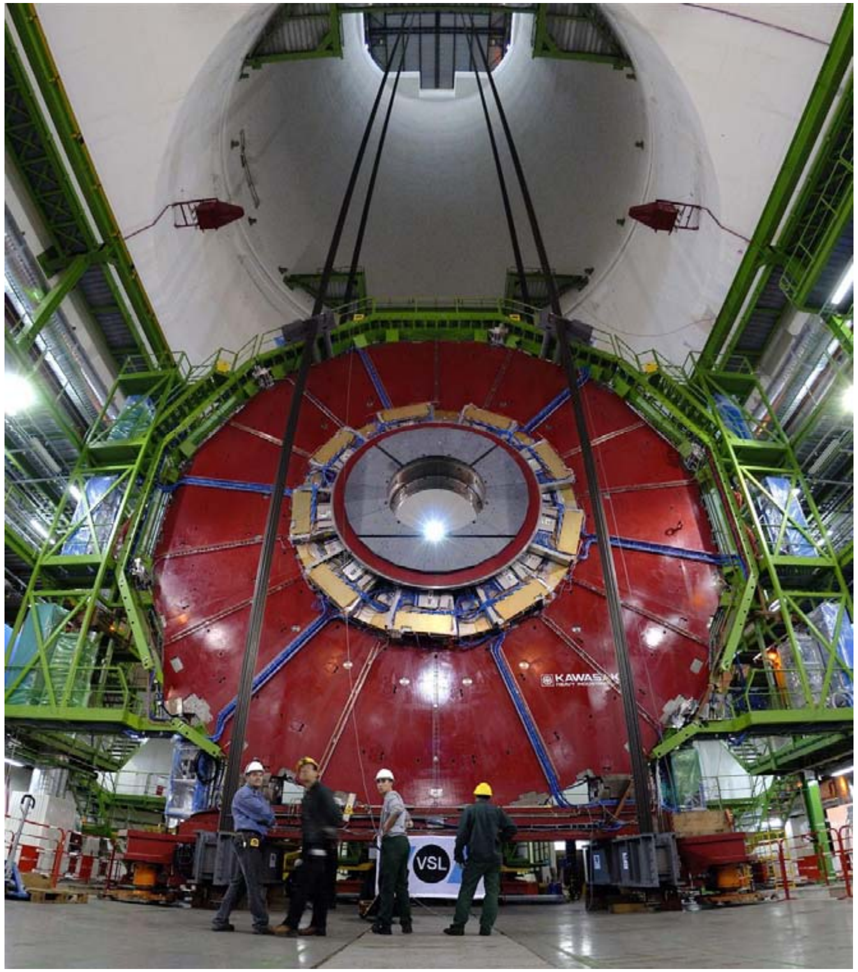
Is this the right direction?
How could we implement this while still running CMS?



J. Mans

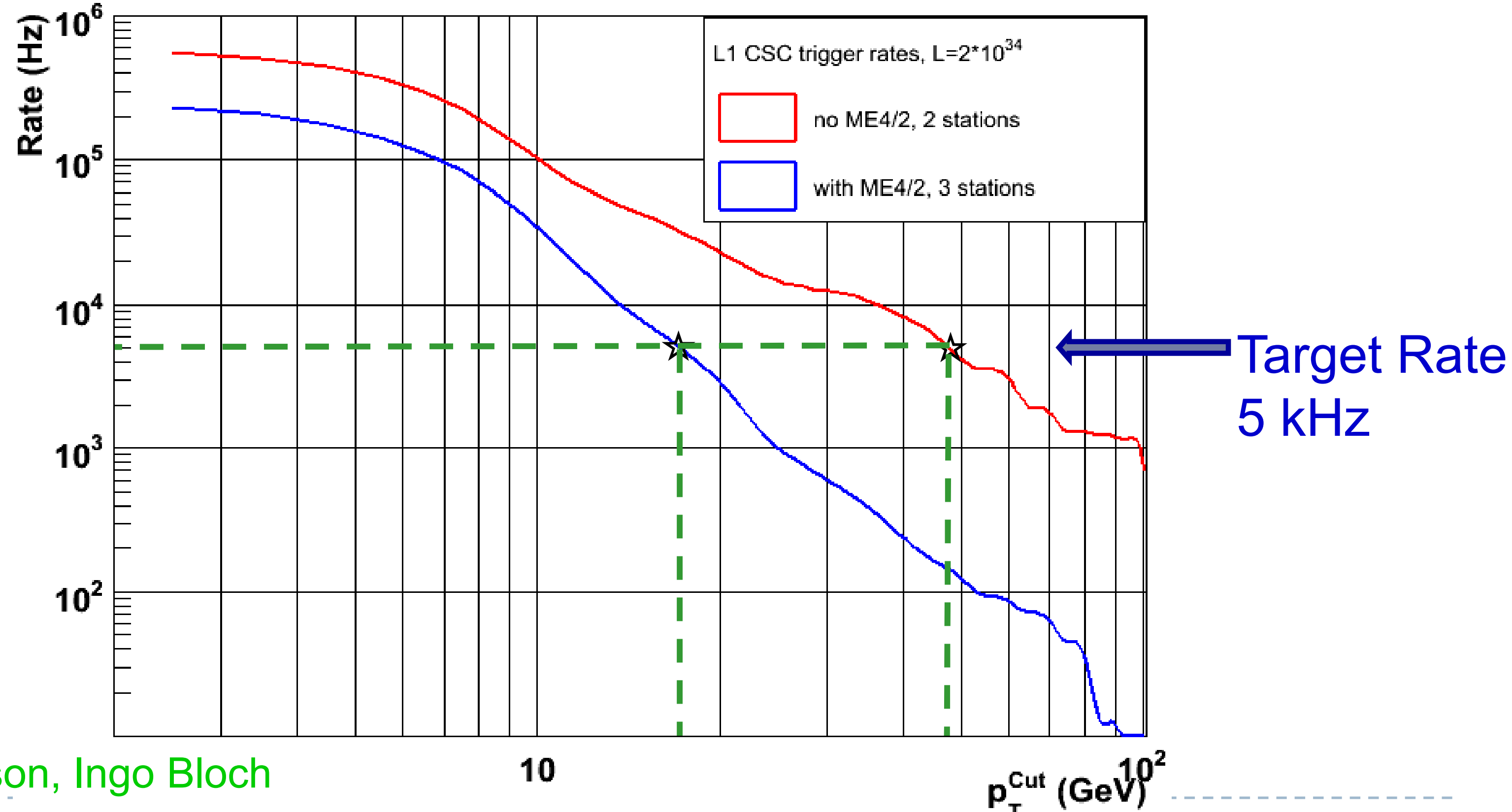
Muons

- Planning for Phase I upgrades
  - CSC production
  - RPC production
- Planning for installation
- Concepts for using the Muon system in a tracking trigger



Phase 1 : Muons ME4/2 upgrade motivation

- Compare 3/4 vs. 2/3 stations:
  - (Triggering on *n* out of *n* stations is inefficient and uncertain)
- Recent simulation with & without the ME4/2 upgrade:
  - The high-luminosity Level 1 trigger threshold is reduced from 48 → 18 GeV/c



Rick Wilkinson, Ingo Bloch

ME4/2 Upgrade Schedule

- t_0 -- CD2 approval, money flows, begin work on Bldg 904
- t_0+3 months -- orders sent out for all parts
- t_0+6 months -- production tooling shipped to CERN and assembled in Bldg 904
- t_0+9 months -- chamber parts delivered, shipped to CERN
- t_0+12 months -- production begins at Bldg 904 at 2 CSCs/month
- t_0+15 months -- production ramps to 4 CSCs/month
- t_0+ 18 months -- FAST site begins assembly & testing at CERN (Bldg 904?), spare CFEB boards installed on ME4/2s
- t_0+24 months -- 42 CSCs finished and tested -- ready for installation of 1st endcap, recover 200 CFEB boards from ME1/1s
- t_0+33 months -- all 76 CSCs finished
- t_0+36 months -- final 36 chambers ready for installation on 2nd endcap

Future meetings

- Upgrade Days
  - Meetings scheduled once per month
    - Keep momentum
    - Track progress
  - Topics which cross detector groups, or go into depth on a particular topic
    - Examples : Sensor R/D, HCAL/ECAL common readout electronics, tracking trigger issues
- Upgrade Workshop 13-15 May 2009 CERN

Conclusions

- CMS is progressing on R/D for phase 1 and defining the scope for phase 2 upgrades
- A substantial program of R&D is well underway
- The coming years will see development of detailed project plans for the phase I upgrades (TDRs), and main areas of R/D for phase II progressing.
- Need to work with the LHCC to understand the revised timescale for phase 1 and phase 2