CMS Tracker Upgrade Issues and Plans

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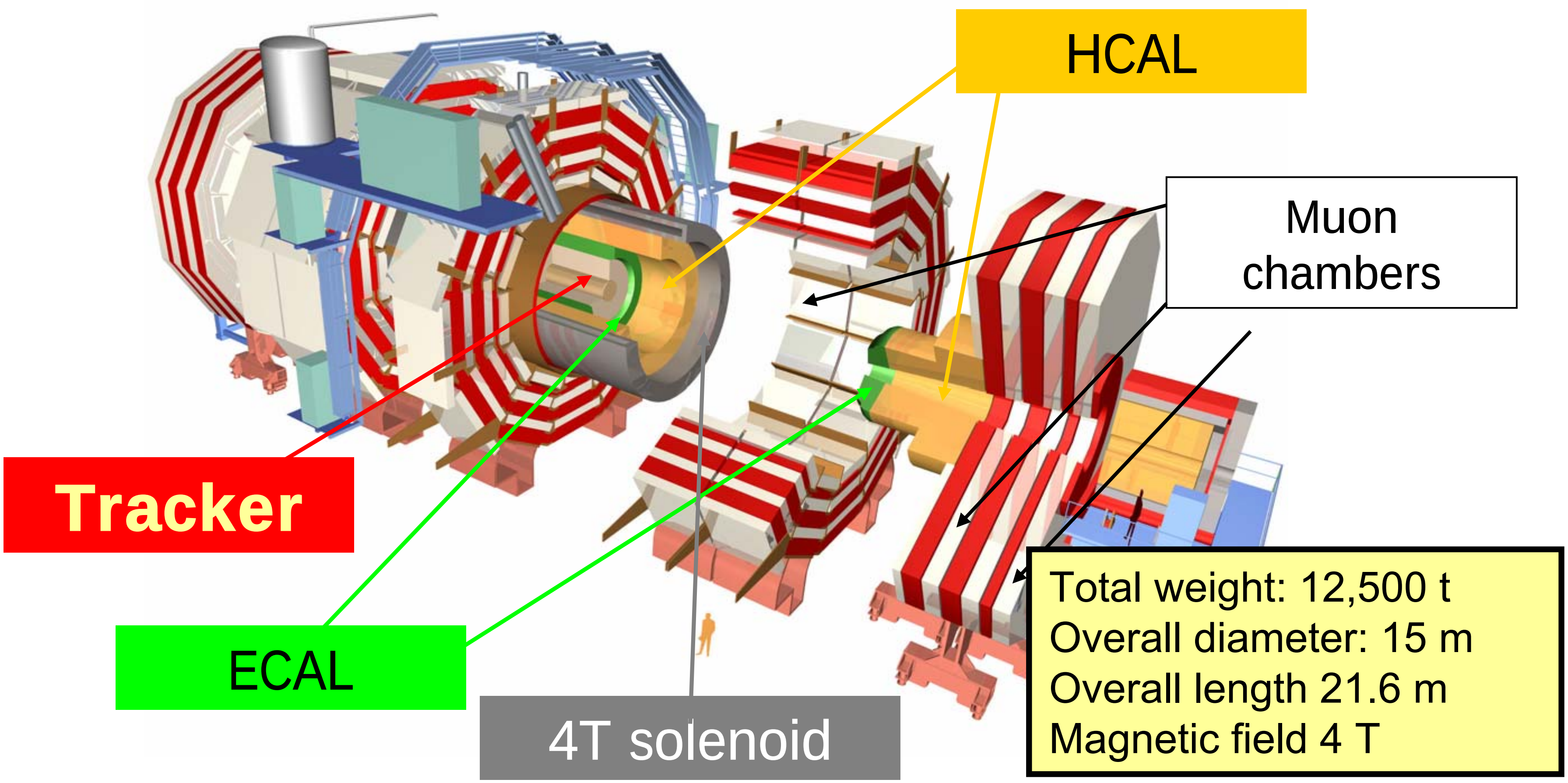
on behalf of the

CMS Tracker Collaboration

CMS

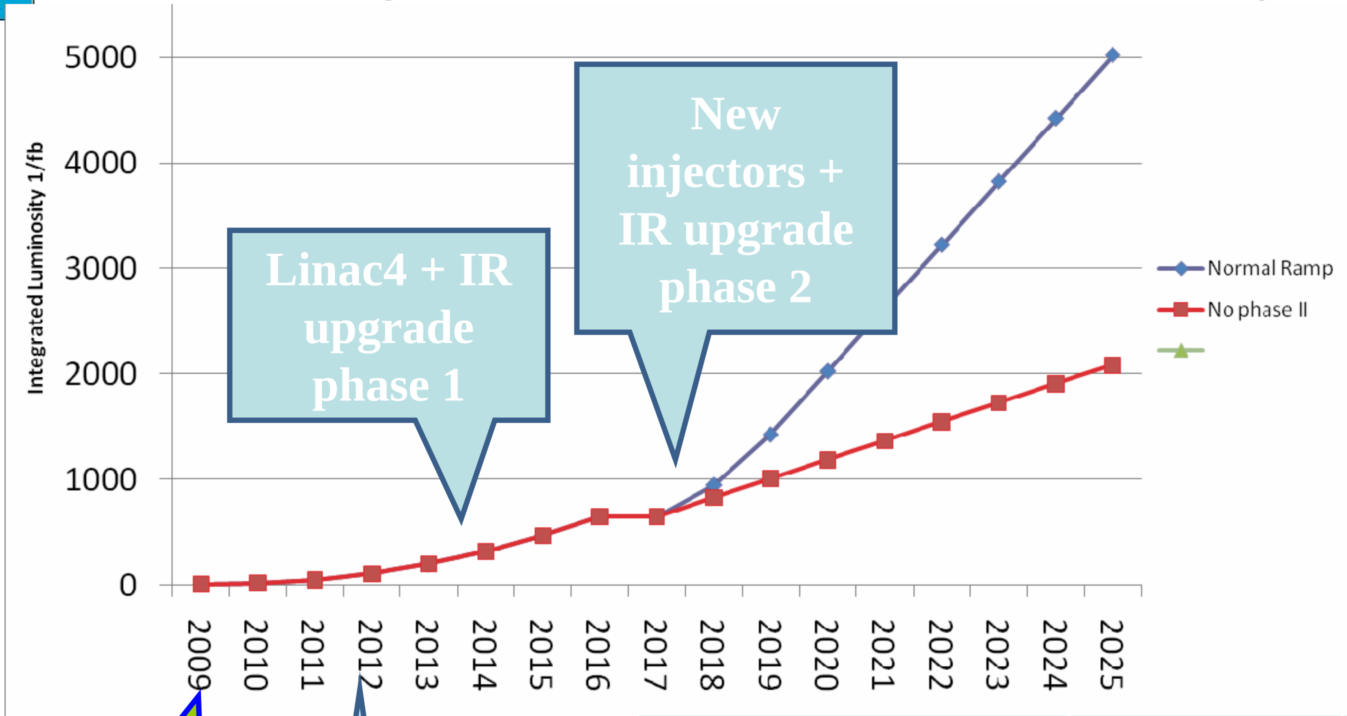


First beam in LHC: September 10th
First collisions at 10TeV: October, 2008

Why Upgrade?

- Assume basic discoveries done 2017 (Higgs, SUSY,…?)
- Then, more precise measurements of couplings, properties of SUSY particles, …
- Study of low-rate phenomena such as $H \rightarrow \mu\mu$, FCNC of top, …
- Luminosity increase (current design 10^{34} cm^{-2} s^{-1}) needed and planned in two phases
  - Phase I (~2013):
    Tuning of machine parameters to get $2 \cdot 10^{34}$ cm^{-2} s^{-1}
    Replacement of pixel detector
  - Phase II (~2018):
    LHC and the pre-accelerators have to undergo major changes
    Luminosity up to 10^{35} cm^{-2} $s^{-1} \rightarrow$ **SLHC**
    Complete new tracker
- Design and construction of new detectors takes time (CMS Tracker plans started 1994)
  - 5 years R&D
  - 2 years Qualification
  - 3 years Construction
  - 6 months Installation and Ready for Commissioning
- Can and have to profit from R&D done already
- Will benefit from lessons learnd with current tracker

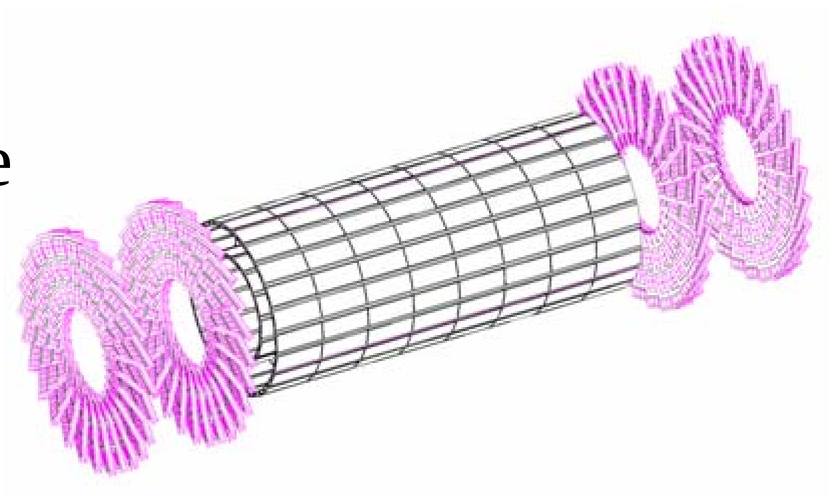
Integrated Luminosity



	LHC	SLHC (Phase 2)
peak luminosity	10^{34} cm^{-2} s^{-1}	10^{35} cm^{-2} s^{-1}
integrated luminosity	100 fb^{-1}/year	1000 fb^{-1}/year
c.m. energy	14 TeV	14 TeV
bunch crossing interval	25 ns	50 ns (?)
# pp events / crossing	~20	~400
# particles in tracker	~1 000	~20 000

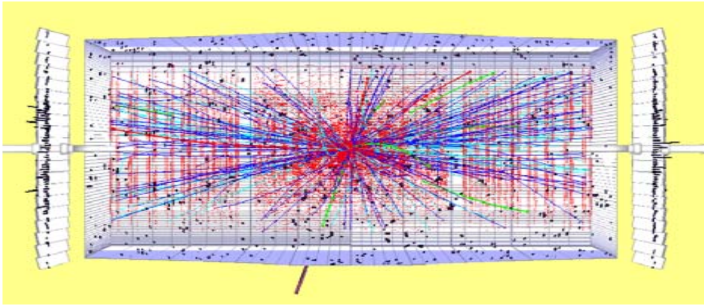
Phase I (2013)

- Luminosity ramp up to ~ 2 $10^{34} cm^{-2} s^{-1}$
- Upgrade of inner pixels only
- New pixel detector could have
  - different sensor material (p-type bulk) and pixel size
  - larger read-out buffer
  - μ-twisted pair cables instead of kapton cables to save material budget and efford
  - CO_2 cooling
  - a fourth barrel layer (prepare for population in Phase II?)

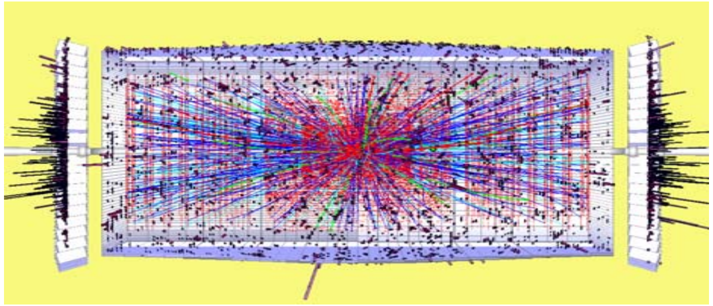


Phase II Issues

- High occupancy
  - change sensor design:
    finer pitch, shorter strips
- Higher radiation levels
  - choose best sensor material
  - ASICs ok, but well established
    0.25µm CMOS process not accessible
- Keep level 1 trigger rate at 100kHz
  - Tracker data available for L1 trigger
- Reuse most of power cables and cooling pipes
  - max. current in cables limited
    → alternative powering scheme
- Reduce material budget
  - design tracker considering all aspects from sensor design over read-out and powering to support structures



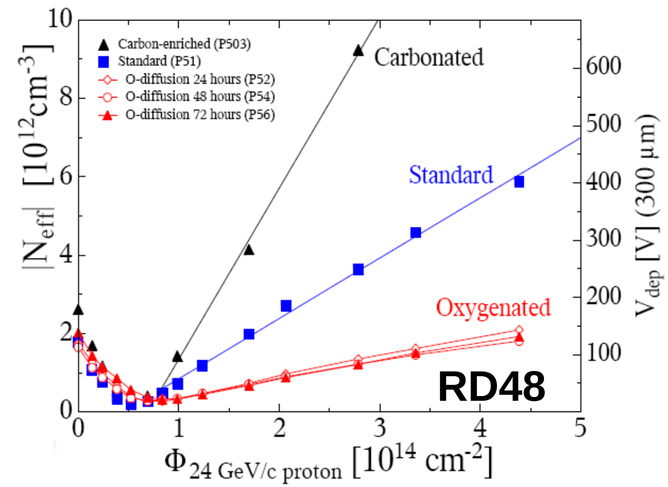
10^{34} $cm^{-2}s^{-1}$, 20 mbe/bx

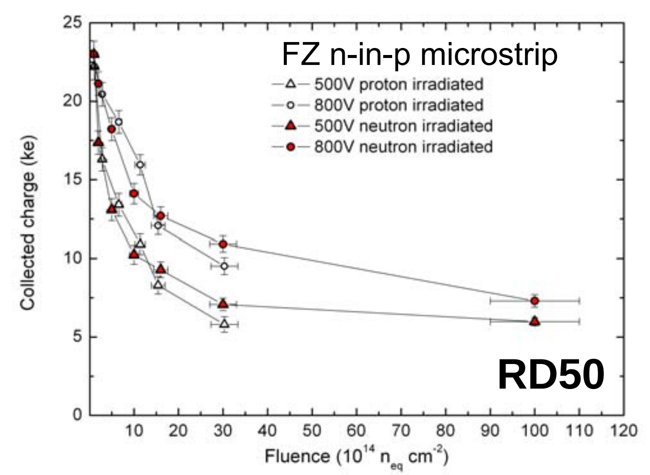


10^{35} $cm^{-2}s^{-1}$, 400 mbe/bx

Sensor R&D I

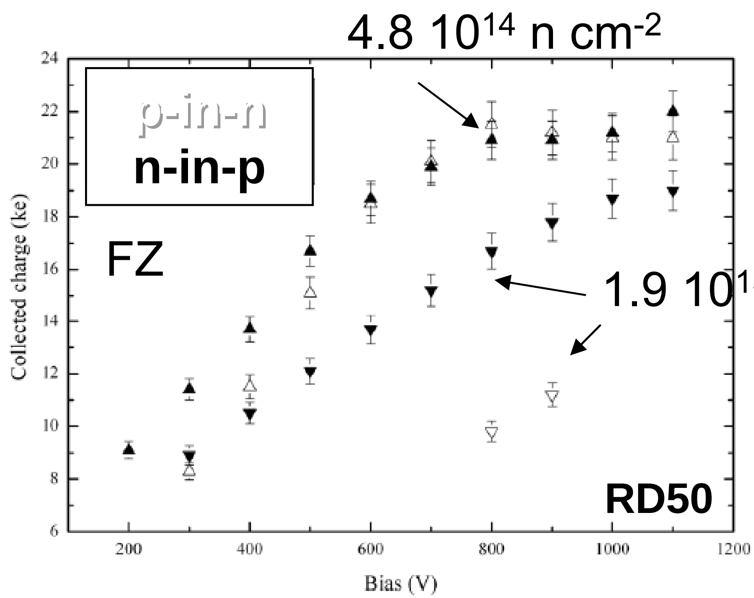
- R&D has made progress understanding radiation damage mechanisms
- Goal is to identify one single sensor type in planar technology for the outer region (best current guess p-MCz 2.5cm strips) and one more pixelated for the inner tracker.
- Oxygenated material has shown less V_{fd} increase after irradiation with charged hardons
- CCE studies showed encouraging signal after very high radiation fluence

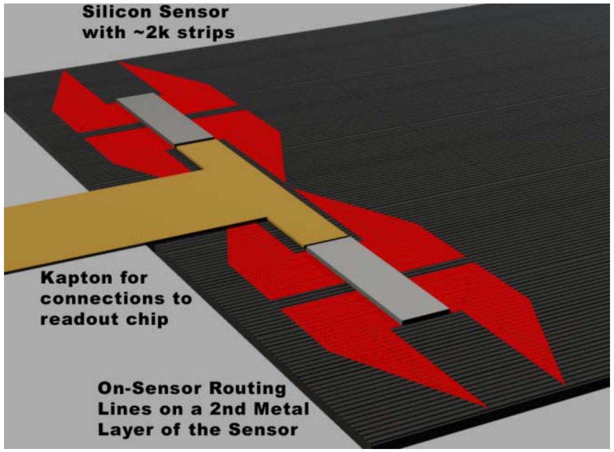




Sensor R&D II

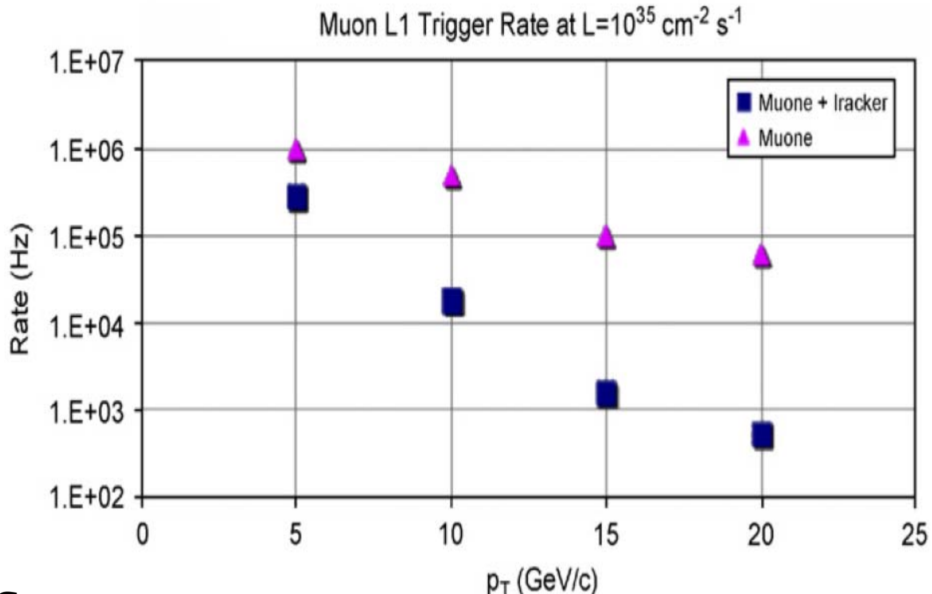
- Going for p-type bulk
  - no SCSI
  - electron read-out
  - needs strip isolation by p-stop/p-spray
    - simul. of optimal combination ongoing
    - minimum pitch 50µm (25µm for p^+ in n)
  - larger Lorentz angle
    - thinner sensors?
- DC coupling
  - cheaper
  - needs current compensating ASICs (lower T or thinner sensors to reduce leakage current)
- Special routing for large sensors with short strips
  - double metal layers
  - bump bonding





L1 Trigger Challenge

- Keep 100kHz trigger rate without loss of physics information
- Confirmation of isolated high-p_T muons
- Reduce fake e/γ candidate by matching with inner track/vertex
- High-p_T hits close to/in jets helps identifying taus and bs



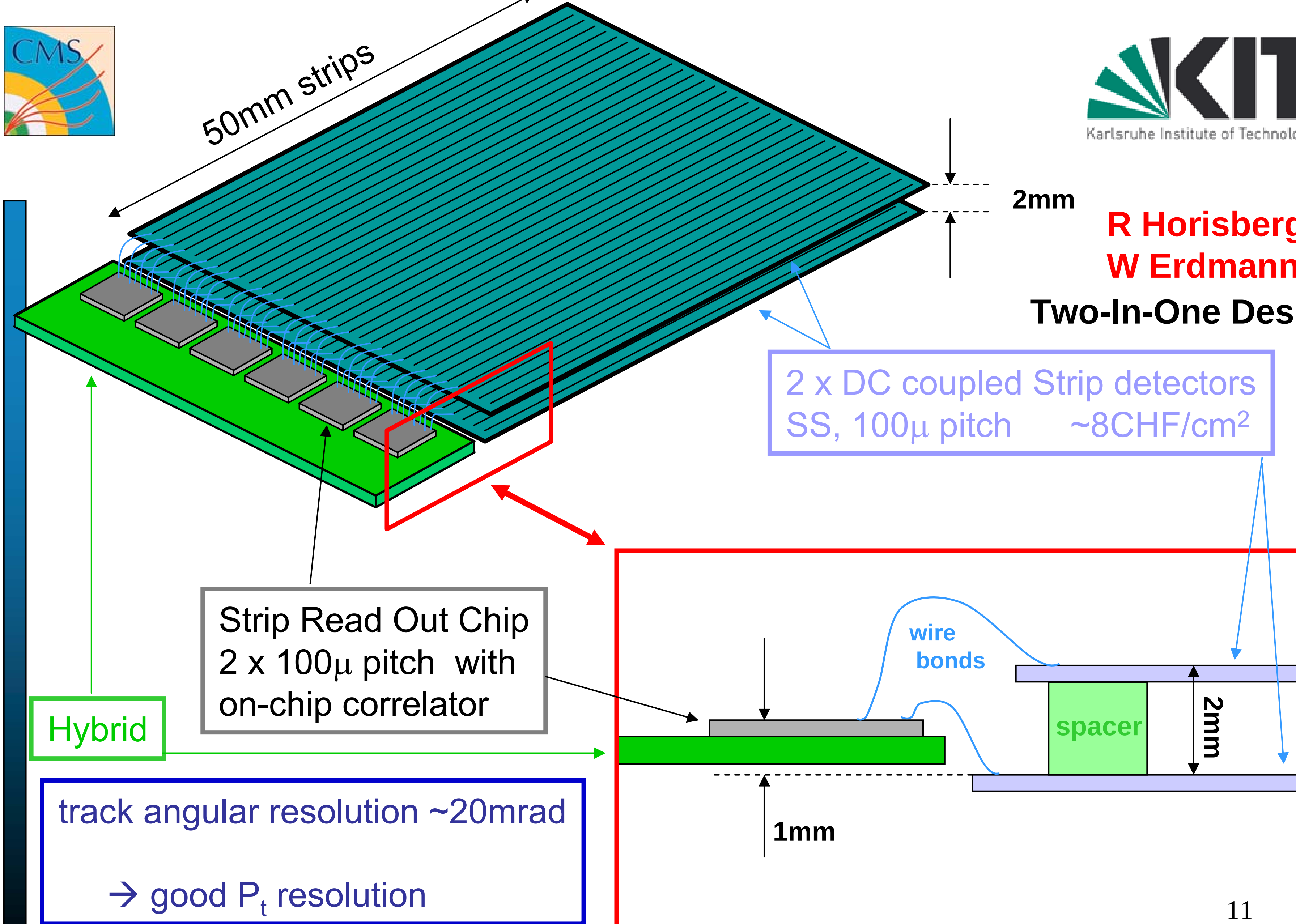
Simulation using pixel stack

Low-p_T Discrimination

- Time constraints do not allow complete tracking
- Reduce data volume by applying p_T cuts
- Possible approaches:
  - cluster width
    low momentum tracks have larger cluster
  - closely spaced “trigger layers”
    difference in hit positions in both layers acts as discriminant for p_T; larger lever

R Horisberger
W Erdmann

Two-In-One Design



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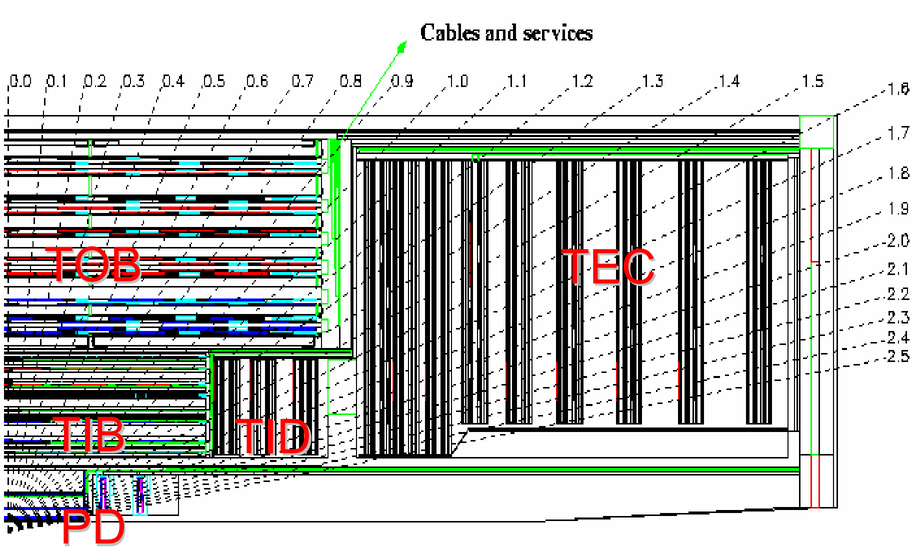
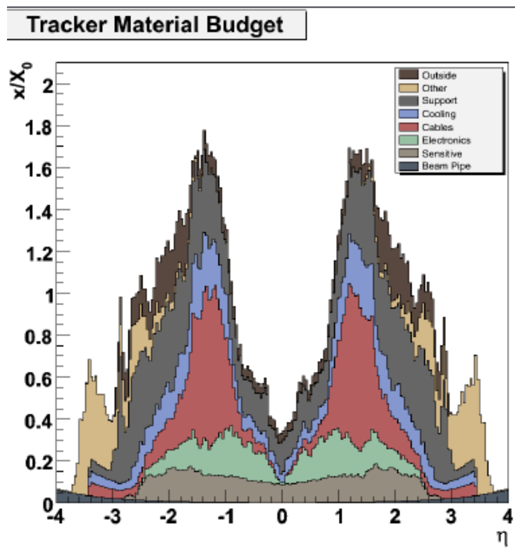
W.E. / R.H.

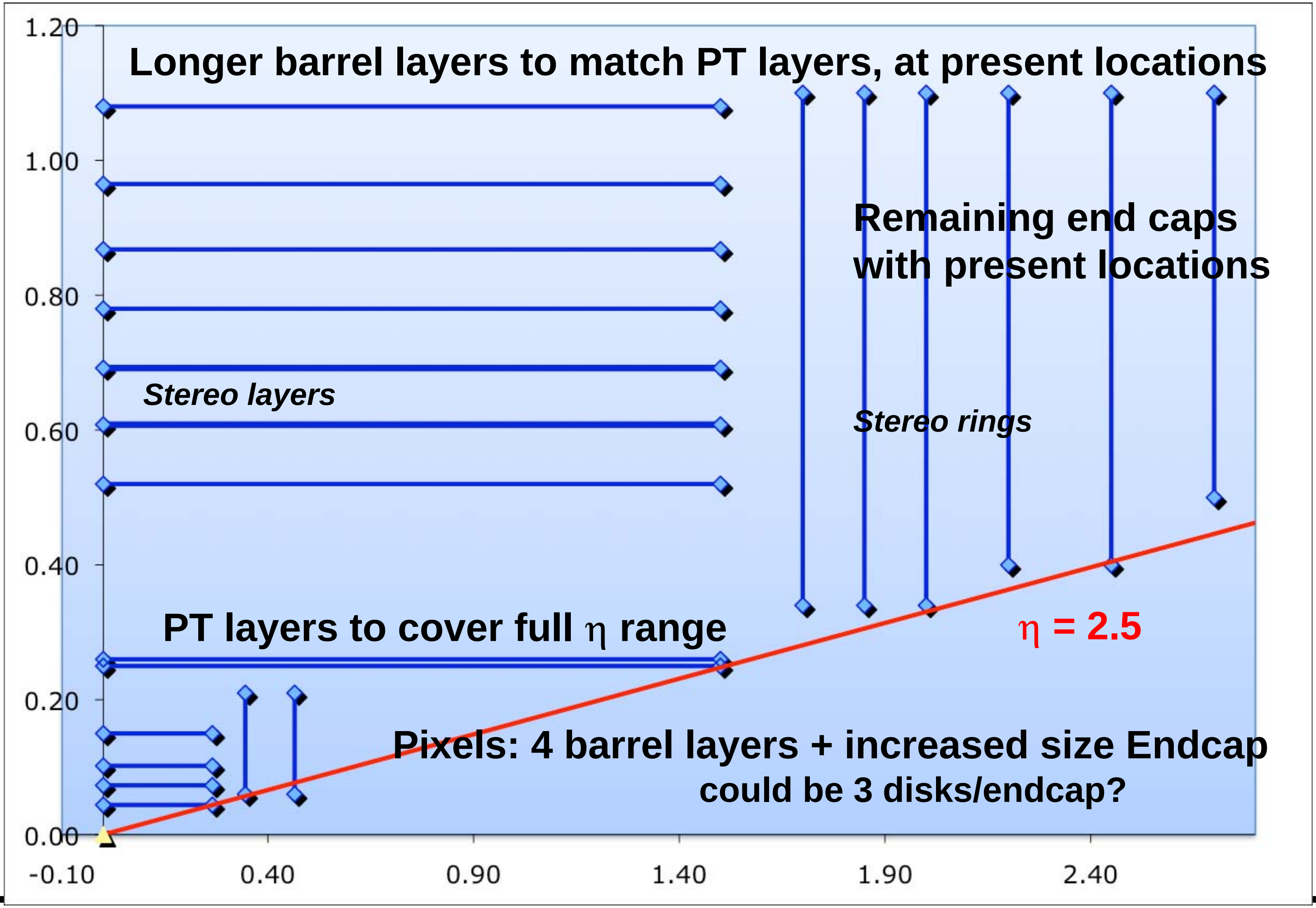
Strawman Designs

- At the moment several strawman designs are proposed
- They are simulated, modified and discussed critically in the community
- Important aspect is to account for all requirements and find an optimal solution regarding performance



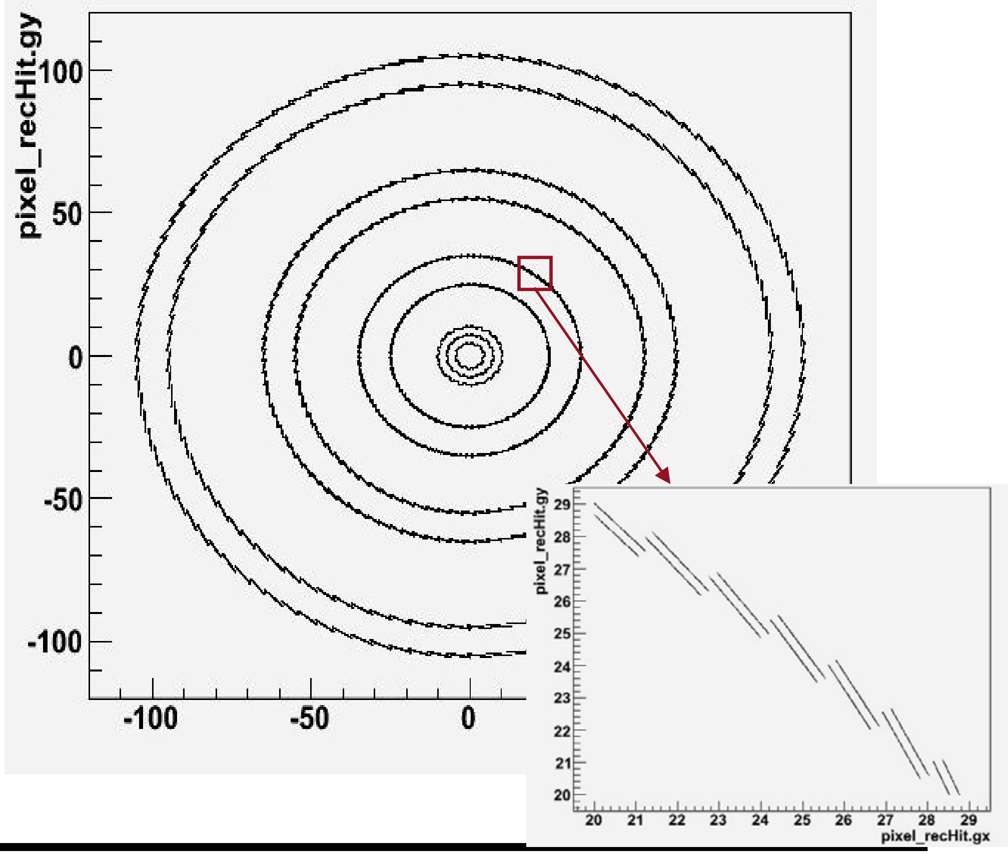


Strawman A


Longer barrel layers to match PT layers, at present locations
Remaining end caps
with present locations
Stereo layers
Stereo rings
PT layers to cover full η range
η = 2.5
Pixels: 4 barrel layers + increased size Endcap
could be 3 disks/endcap?
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.10
0.40
0.90
1.40
1.90
2.40

Strawman B

- 3 Superlayers, each with two layers of pixel doublets (12 hits), layers are same length in z as std TOB
  - 140 x 300 µm²
  - 300 x 300 µm²
  - 600 x 300 µm²
- 3 barrel pixel layers as in std CMS
- TEC and FPix as in std CMS
- Superlayers have 1158M channels, 121 m² (9M std)



Power delivery I

- Smaller feature size will result in smaller readout chip supply voltage (1.2V@0.13µm)
- Power per channel will decrease for next generation readout chips
  (2.7µW/ch. → 0.5µW/ch)
- Number of channels will increase, but have to be kept minimal to be compatible with tracking requirements (simulations!)
- Total readout power expected to be ~25-35kW (Strawman A)
  - in same range as present system so larger currents at front-ends required (lower voltage)

Power delivery II

- With higher radiation damage sensor power becomes important
  - thinner sensors
    - finer granularity should allow adequate noise performance
    - no changes to layout
    - material budget benefits, too
  - lower temperature
    - higher cooling power, i.e. thicker pipes
    - CO_2 cooling might help
- We need higher voltages to reduce currents and losses in cables
- Radical solutions required
  - serial powering or DC-DC conversion
  - neither are proven and many problems remain to be solved

New Powering Concepts

- Serial Powering possible, but
  - modules on different ground
  - AC coupled read-out
  - loss of complete chain?
- DC-DC conversion
  - studies started in CMS
  - find efficient, radiation hard, low-noise, 4T tolerant converter (not standard)
  - ferrits saturate and air coils radiate noise and/or are large, when not properly shielded
  - capacitor-based technoloy ?

CO_2 Cooling

- Could solve many of our problems
- Advantages over C_6F_{14}
  - High heat transfer coefficient → smaller contacts (material budget)
  - High latent heat → more heat load, no/smaller manifold pipes (powering)
  - Low viscosity → pipes could be smaller (material budget)
  - Lighter and cheaper than C_6F_{14} (material budget)
  - Possible lower operation temperature (-50°C) (leakage current, rad. hardness)
- LHCb VELO uses CO_2, but choices made do not directly apply to CMS
- Cooling R&D in CMS has started
  - connection techniques
  - leak- and pressure testing
  - integration of cooling pipes
  - thermal expansion
  - …

Conclusion

- Planning of a new tracker for very high luminosity at SLHC has started (and not too early)
- New designs are being investigated following an holistic appoach
- Material budget should be reduced, while more channels have to keep occupancy low, but without increasing power or degrading performance…
- Big challenges:
  - power delivery
  - trigger information for L1
- But don't forget radiation hard sensors and electronics …
- The community has many experts with many years of experience. Together with the lessons learnd from the current tracker we are confident to meet the requirements.

CMS Tracker Upgrade Organisation

Steering Group
Working Group convenors
G Hall D Bortoletto R Horisberger M de Palma
P Sharp M Mannelli GM Bilei

- **Sensors**
  G Bolla
  A Messineo
- **Simulations & Software**
  H Cheung
  A Tricomi
  - **Triggering**
    developing
- **Readout system**
  H-C Kaestli
  K Gill
  - **Power**
    K Klein
    n tbd
- **Material budget Engineering, Services**
  S Koenig
  A Onnela

Tracker web pages
http://cmsdoc.cern.ch/Tracker/Tracker2005/TKSLHC/index.html
Tracker Upgrade Wiki pages
https://twiki.cern.ch/twiki/bin/view/CMS/SLHCTrackerWikiHome

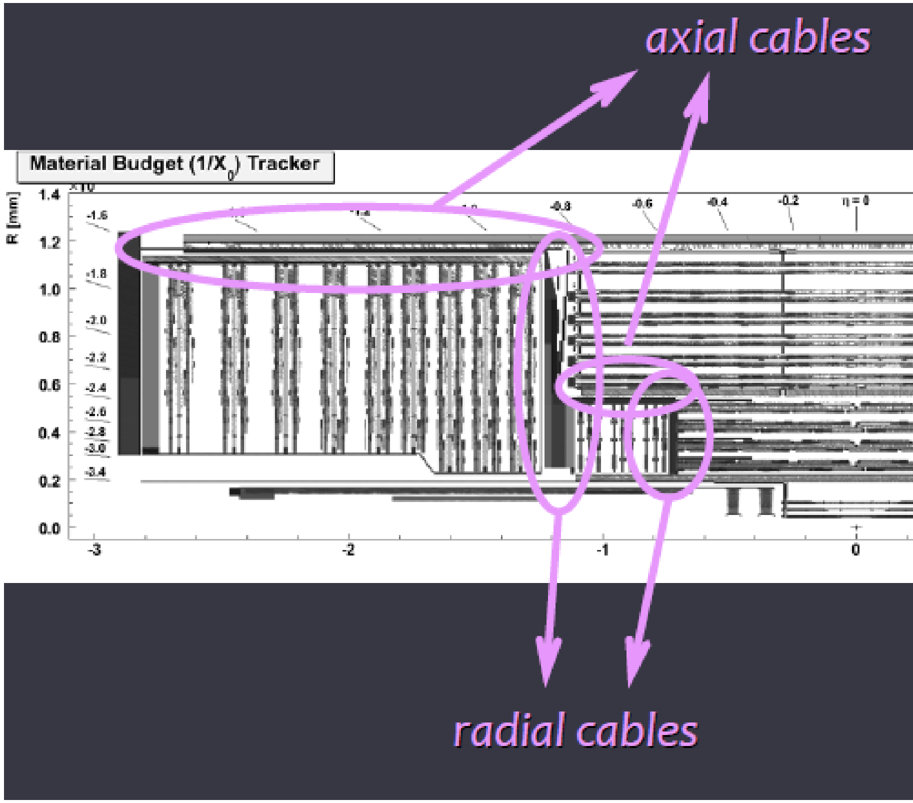
Backup

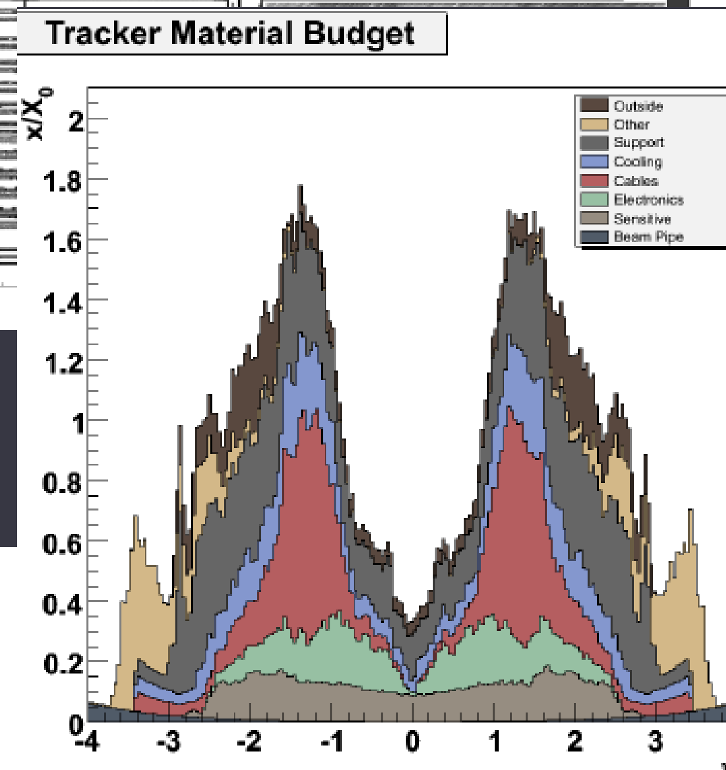
Power estimates

- Some extrapolations assuming 0.13μm CMOS
  - Pixels 58μW -> 35μW/pix
    - NB sensor leakage will be significant contribution
  - Outer Tracker: 3600 μW -> 700μW/chan
    - Front end 500μW (M Raymond studies)
    - Links 170μW (including 20% for control)
  - PT layers: 300μW/chan - most uncertain
    - Front end 50μW (generous extrapolation from pixels)
    - Links 100μW (including 20% for control)
    - Digital logic 150μW (remaining from 300μW)
    - 100μm x 2.5mm double layer at R ≈ 25cm => 11kW
- More detailed studies needed
  - sensor contribution not yet carefully evaluated
  - internal power distribution will be a significant overhead

Radiography

R. Ranieri



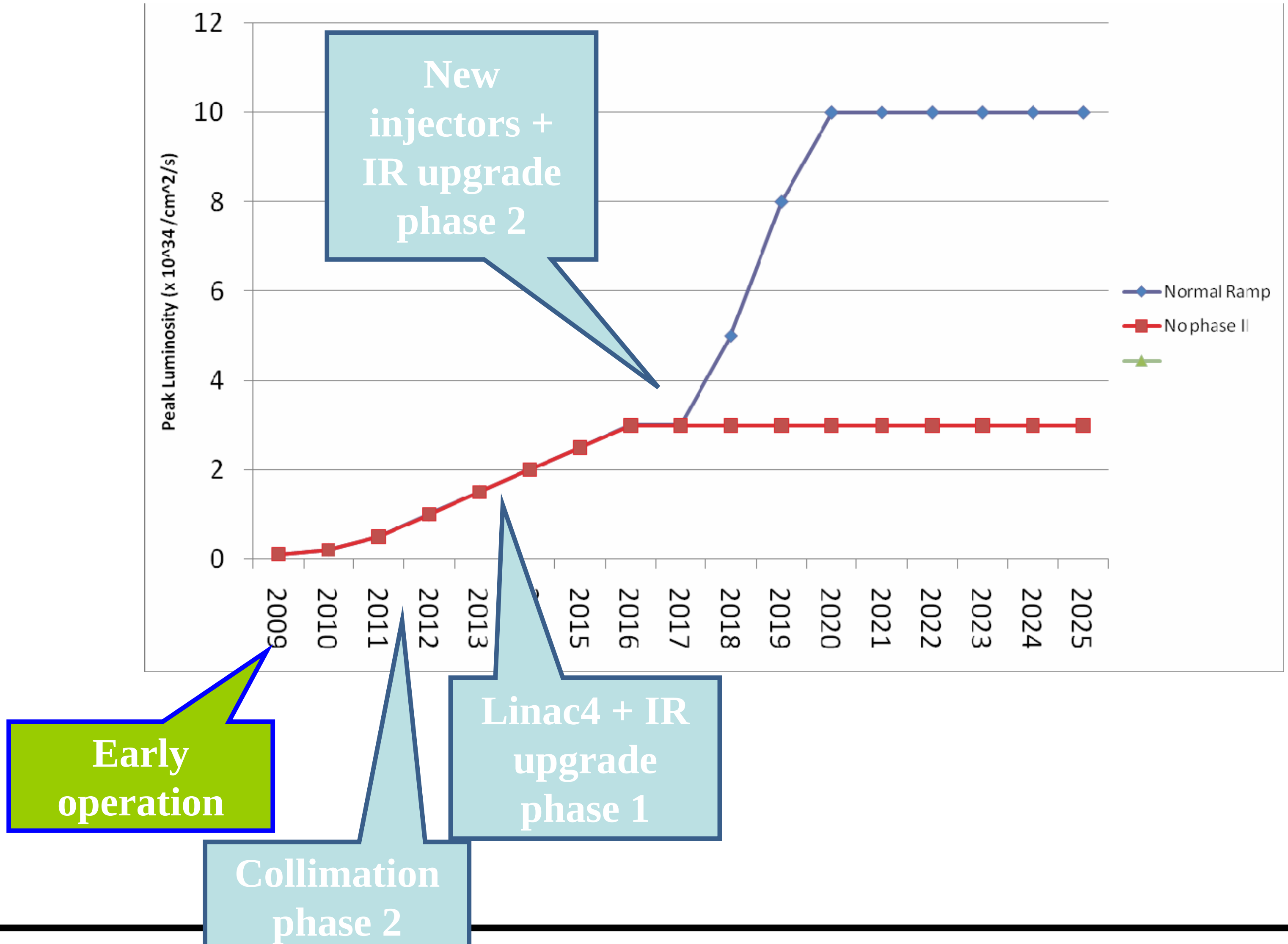


Main contribution:
cables, cooling and support
between barrel and endcaps

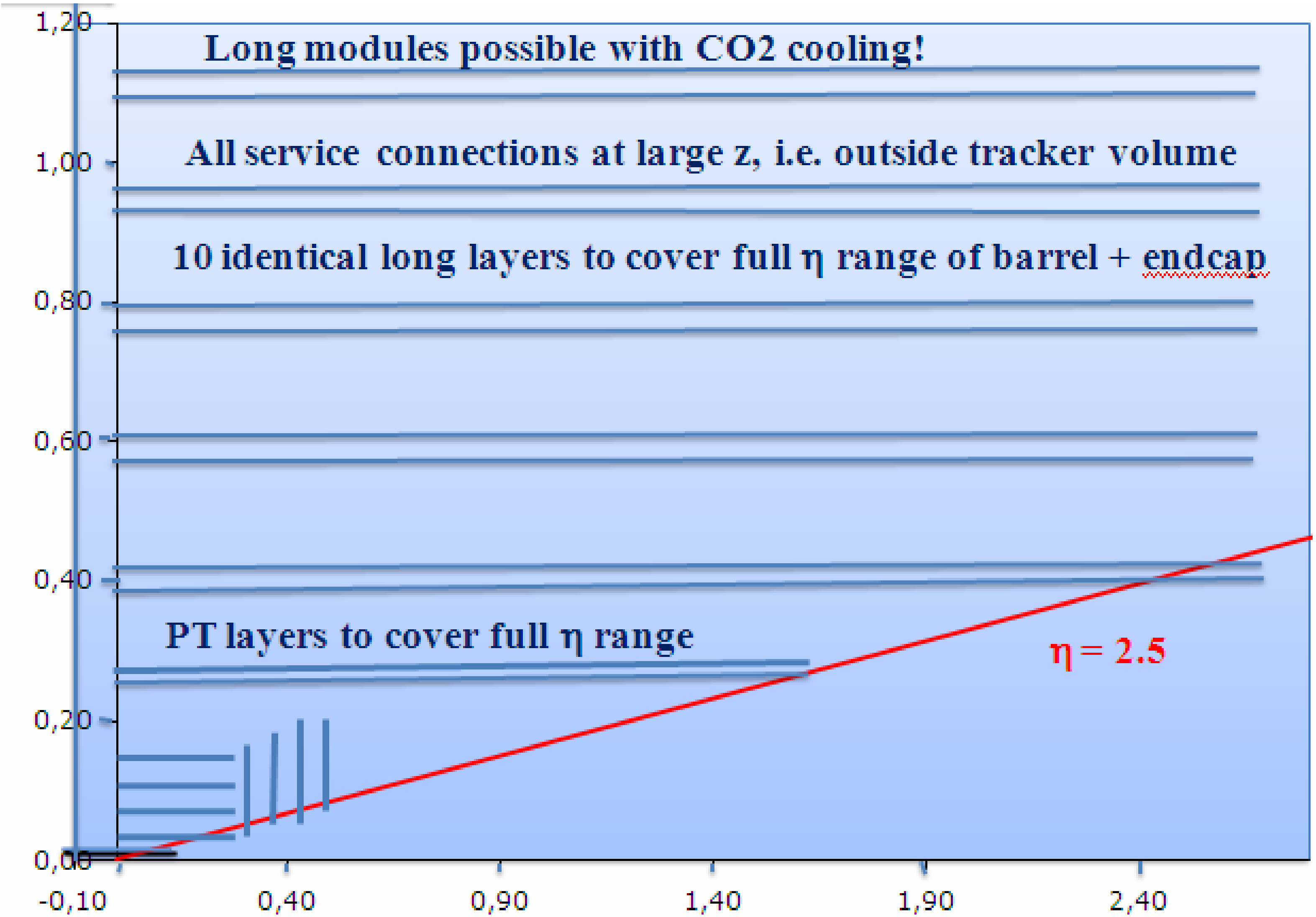
R&D Projects

Proposal title	Contact	Date	Status
Letter of intent for Research and Development for CMS tracker in SLHC era	R Demina	14.9.06	Approved
Study of suitability of magnetic Czochralski silicon for the SLHC CMS strip tracker	P Luukka, J Härkönen, R Demina, L Spiegel	31.10.07	Approved
R&D on Novel Powering Schemes for the SLHC CMS Tracker	L Feld	3.10.07	Approved
Proposal for possible replacement of Inner Pixel Layers with aims for an SLHC upgrade	A Bean	31.10.07	Approved
R&D in preparation for an upgrade of CMS for the Super-LHC by UK groups WP1: Simulation studies/ WP2: Readout development/ WP3: Trigger developments	G Hall	31.10.07	Approved
The Versatile Link Common Project	F Vasey, J Troska	11.07	Received
3D detectors for inner pixel layers	D Bortoletto, S Kwan	12.07	Received
Proposal for US CMS Pixel Mechanics R&D at Purdue and Fermilab in FY08	D Bortoletto, S Kwan	12.07	Received
R&D for Thin Single-Sided Sensors with HPK	M Mannelli	7.2.08	Received
An R&D project to develop materials, technologies and simulations for silicon sensor modules at intermediate to large radii of a new CMS tracker for SLHC	F Hartmann, D Eckstein	6.3.08	Received
Development of pixel and micro-strip sensors on radiation tolerant substrates for the tracker upgrade at SLHC	M de Palma	9.4.08	Received
Power distribution studies	S Kwan	15.6.08	Received
Cooling R&D for the Upgraded Tracker	D Abbaneo	21.07.08	Received

Peak Luminosity



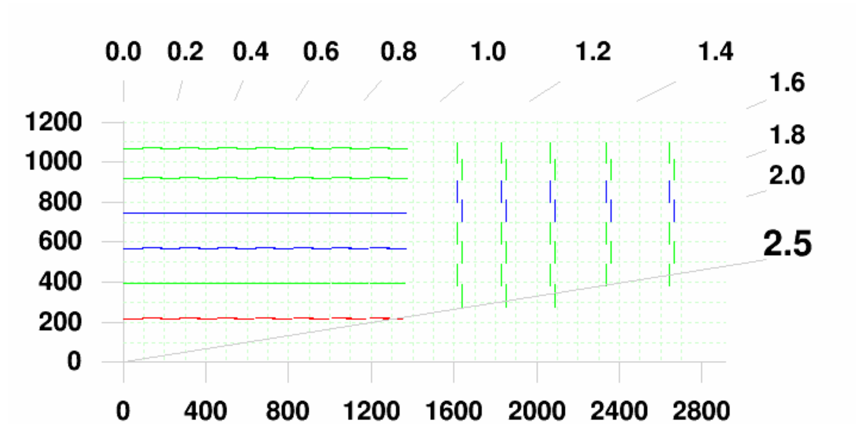
Strawman "C"



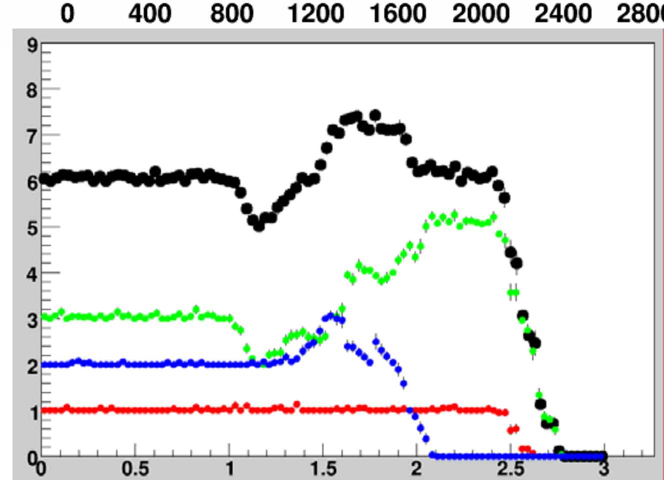
Long modules possible with CO2 cooling!
All service connections at large z, i.e. outside tracker volume
10 identical long layers to cover full η range of barrel + endcap
PT layers to cover full η range
η = 2.5
1,20
1,00
0,80
0,60
0,40
0,20
0,00
-0,10
0,40
0,90
1,40
1,90
2,40

Tracker Upgrade Layout Tool

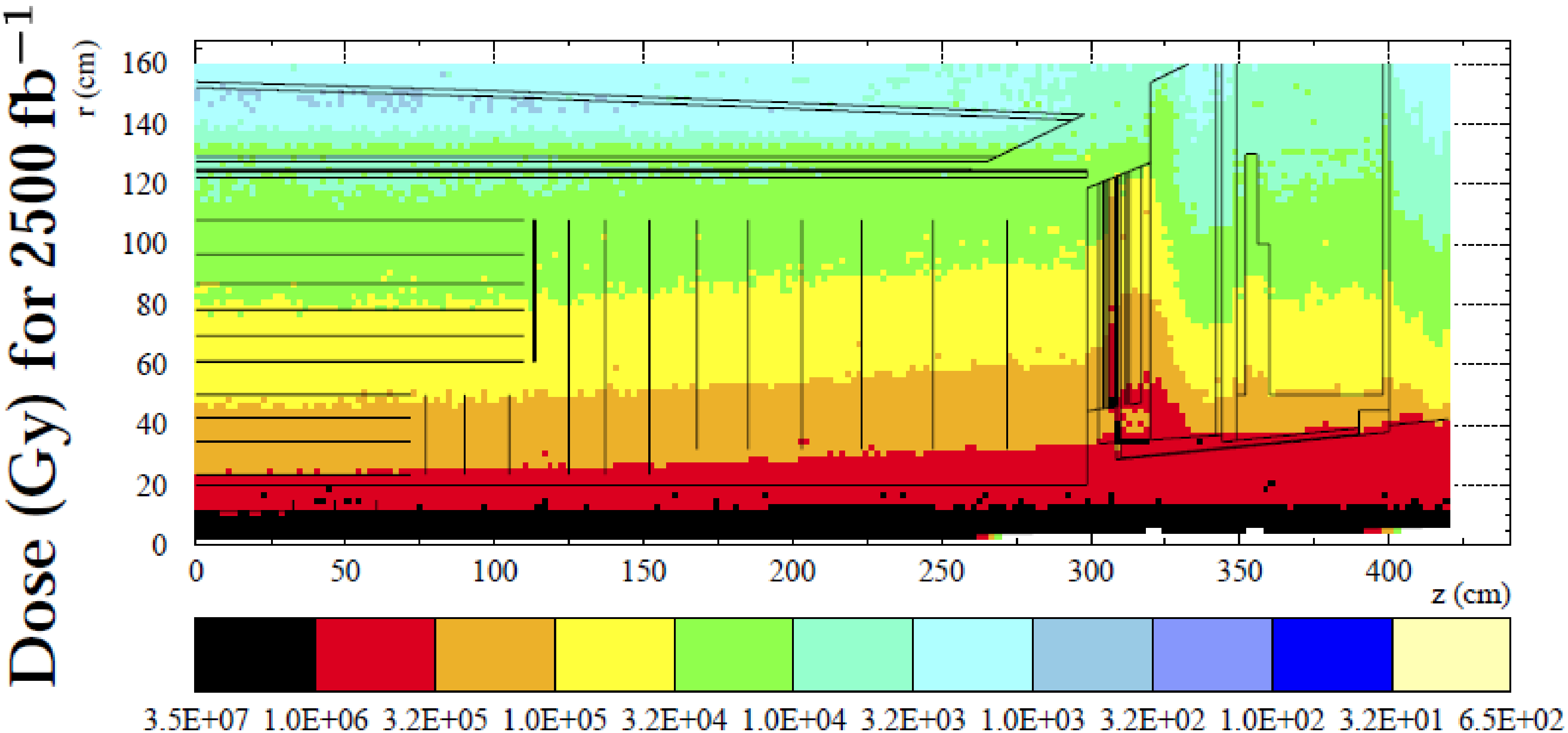
- Flexible geometry definition using different module types



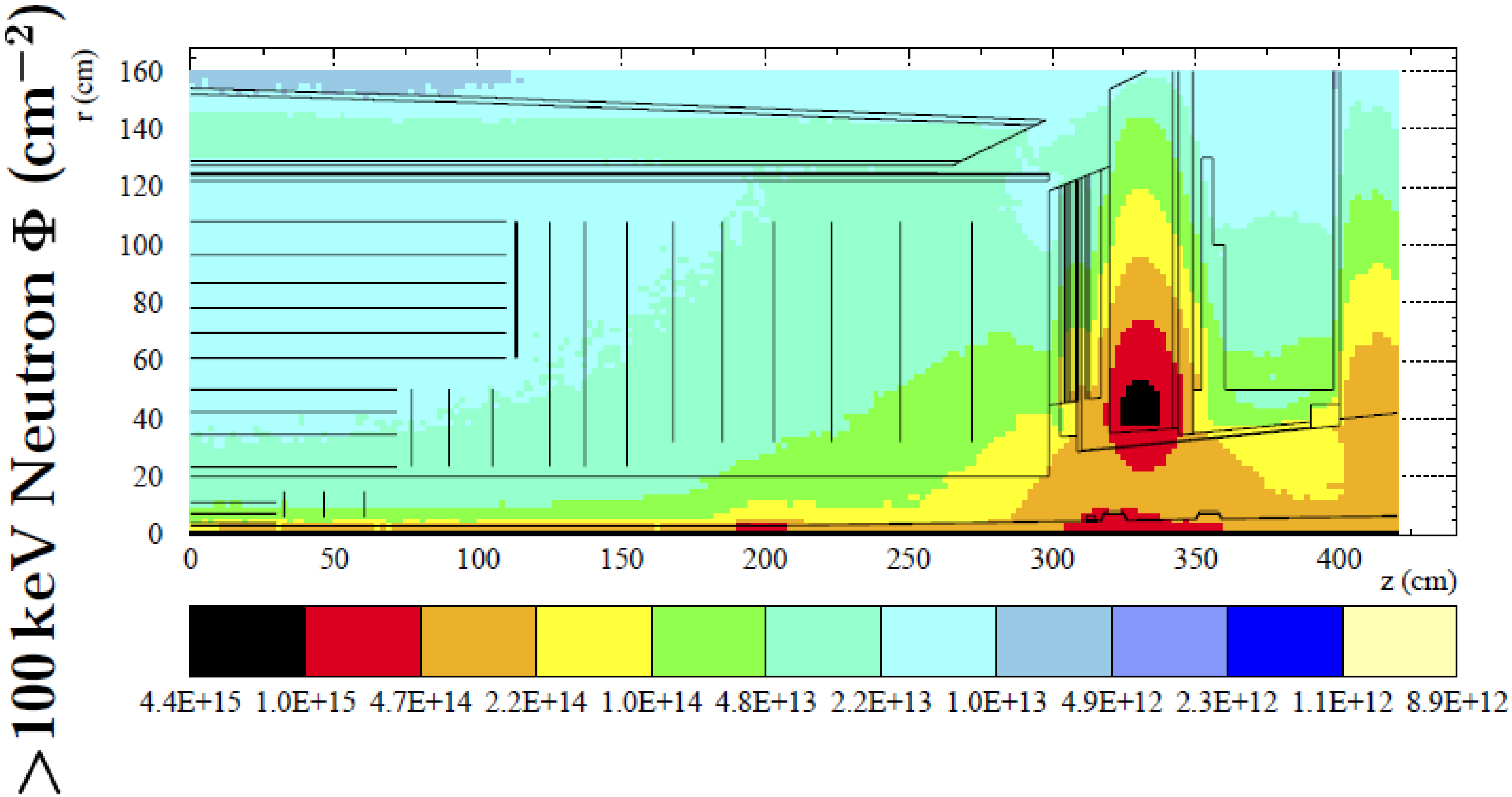
- Output:
  - material budget
  - occupancy
  - bandwidth
  - costs



Dose at 2500fb^{-1}



$F_{neutrons}$ at 2500fb^{-1}



$F_{ch.\ hadrons}$ at $2500 fb^{-1}$