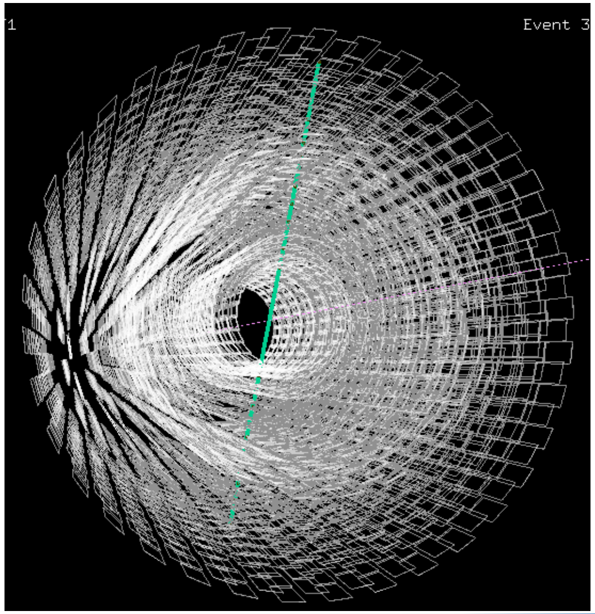


CMS Tracker Upgrade programme

Thanks to many CMS Tracker collaborators, past and present, too numerous to acknowledge individually

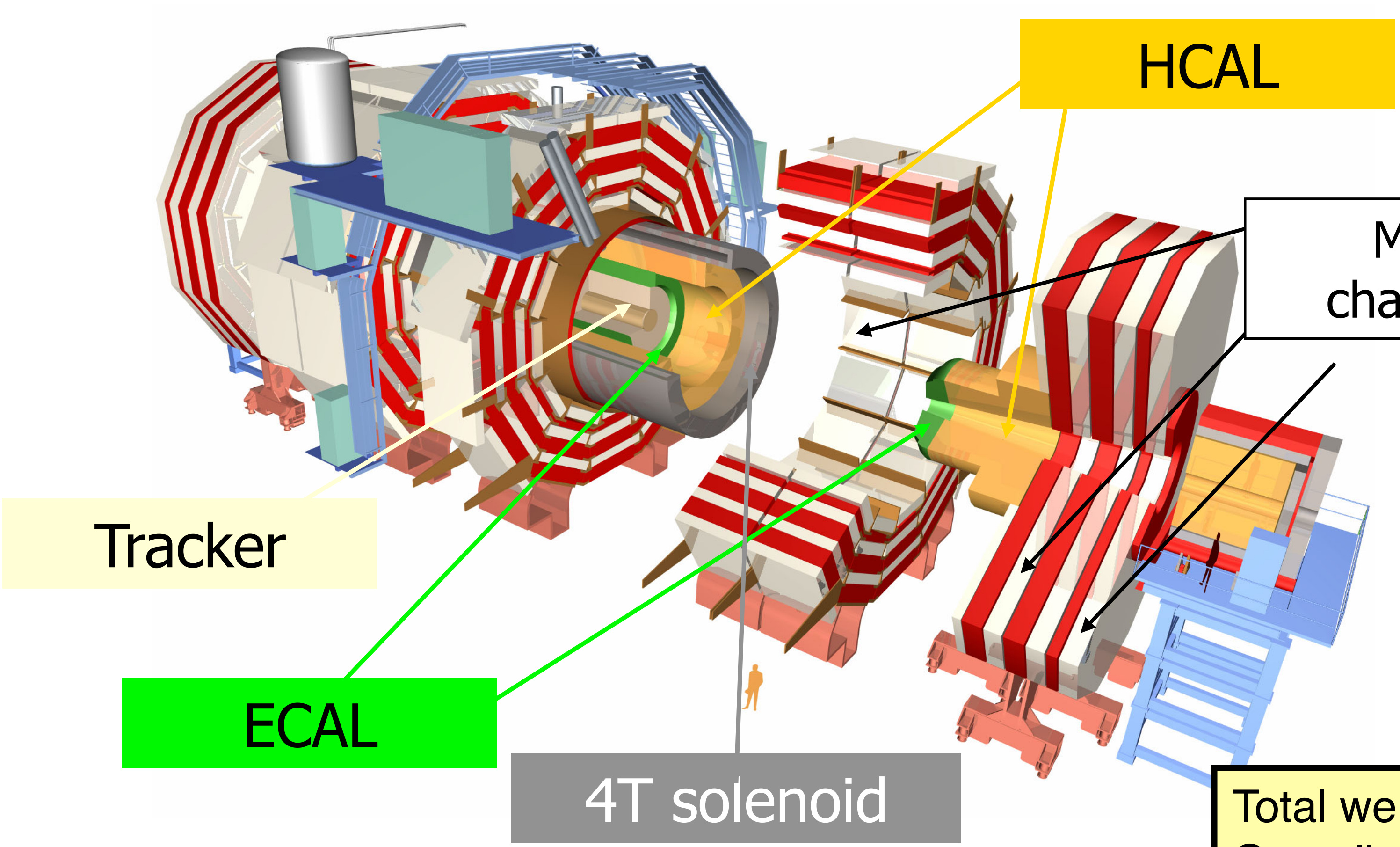
Tracker web pages

http://cmsdoc.cern.ch/Tracker/Tracker2005/TKSLHC/index.html

Tracker Upgrade Wiki pages

https://twiki.cern.ch/twiki/bin/view/CMS/SLHCTrackerWikiHome

CMS Compact Muon Solenoid



First operation during 2008

pp collisions at 10 TeV CM energy

Total weight: 12,500 t
Overall diameter: 15 m
Overall length 21.6 m
Magnetic field 4 T

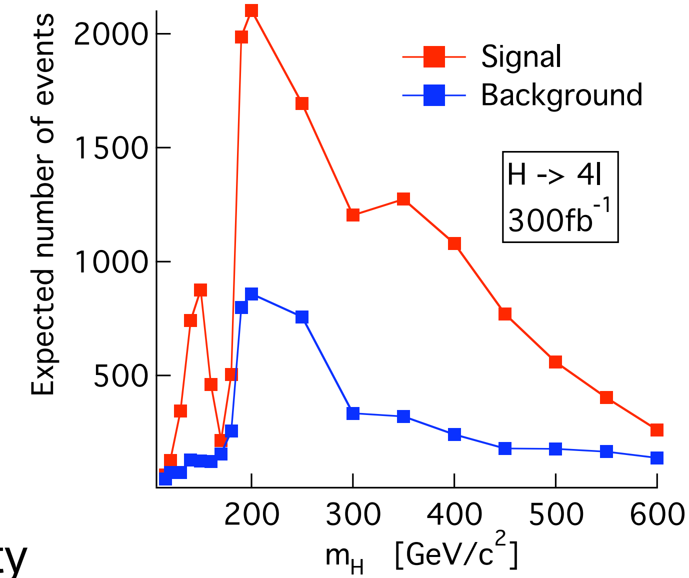
Upgrade to CMS

- CMS was designed for 10 years operation at $\mathcal{L} = 10^{34}\ cm^{-2}.s^{-1}$
  - Max L1 trigger rate 100kHz & decision latency ≈ 3.2µs
- To operate at $\mathcal{L} = 10^{35}\ cm^{-2}.s^{-1}$
  - most of CMS will survive & perform well with few changes
    - But expect to upgrade trigger electronics & DAQ
- Notable exception is tracking system
  - Higher granularity is required to maintain current performance
  - Greater radiation tolerance, especially sensors
    - ASIC electronic technologies will be adequate but

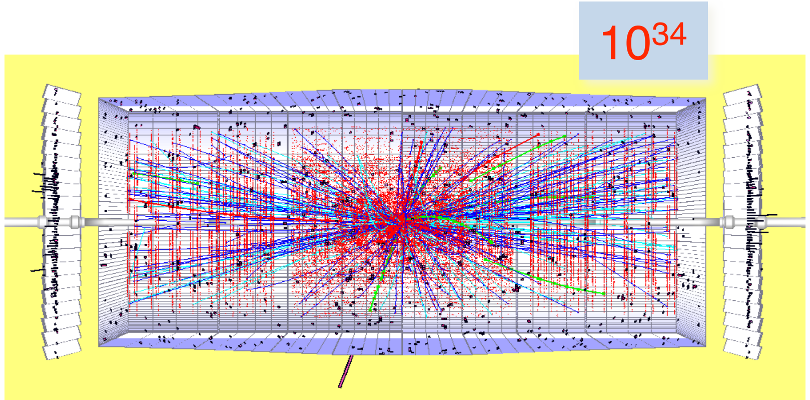
      0.25µm CMOS, pioneered by CMS, will probably not be accessible
  - L1 trigger using tracker data is essential
- Only time today to discuss major issues

Reminder of why this is needed

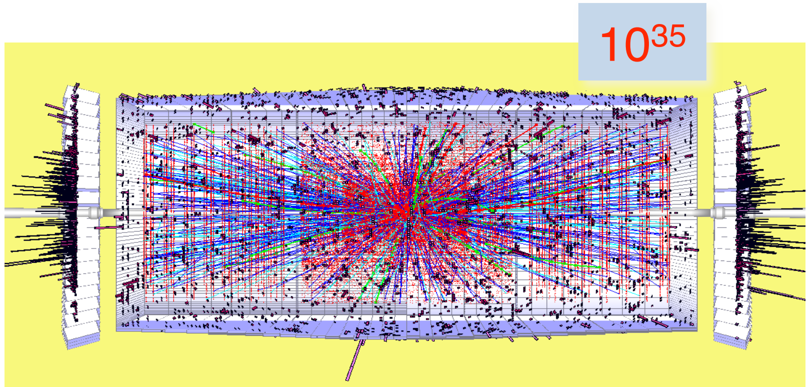
- Limited statistics – eg:
  - and time to reduce errors
- However, the environment is very challenging:



- H→ZZ → μμee, M_H= 300 GeV vs luminosity



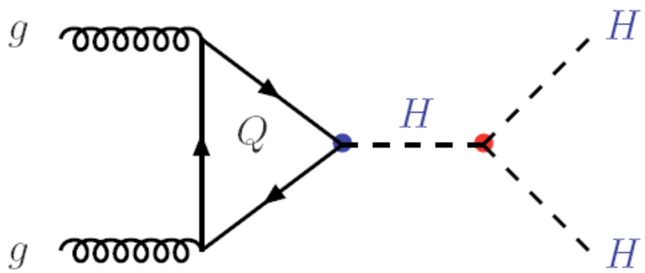
Full LHC luminosity
~20 interactions/bx



Proposed SLHC luminosity
~300-400 interactions/bx

Physics requirements

- Essentially unknown until LHC data make it clear
  - general guidance as for LHC – granularity, pileup, …
  - but improving statistics in rare and difficult channels could be vital
- eg: whatever Higgs variant is discovered, more information on its properties than LHC can provide will be needed



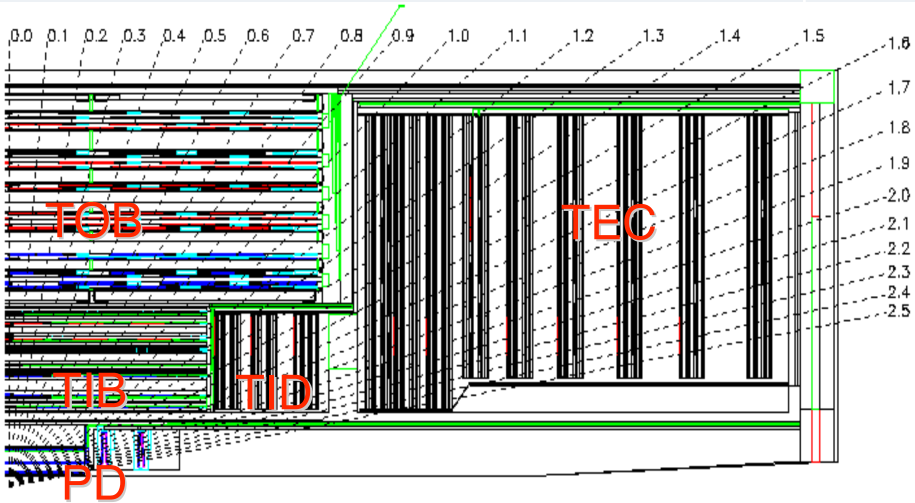
- Expected HH production after all cuts in 4W -> $\boldsymbol{l}^{+/-}\boldsymbol{l}^{+/-}$ + 4j mode
  - σ = 0.07-018 fb^{-1} for m_H = 150 – 200 GeV
  - with 3000fb^{-1} ≈ 200 – 600 signal events
  - plus significant background

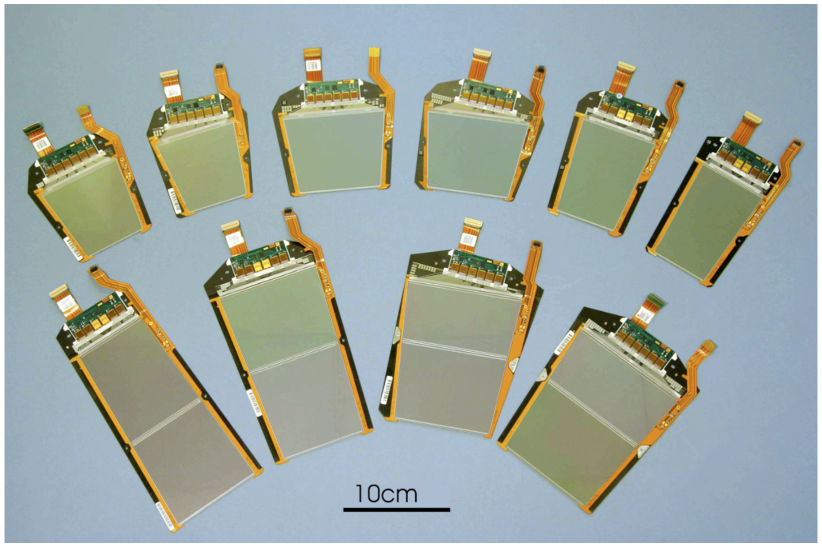
- An excellent detector is essential…
- …even better than LHC to cope with particle density & pileup
  - which should also be flexible to adapt to circumstances

Current Tracker system

- Two main sub-systems: Silicon Strip Tracker and Pixels
  - pixels quickly removable for beam-pipe bake-out or replacement

Microstrip tracker	Pixels
~210 m^2 of silicon, 9.3M channels	~1 m^2 of silicon, 66M channels
73k APV25s, 38k optical links, 440 FEDs	16k ROCs, 2k olinks, 40 FEDs
27 module types	8 module types
~34kW	~3.6kW (post-rad)





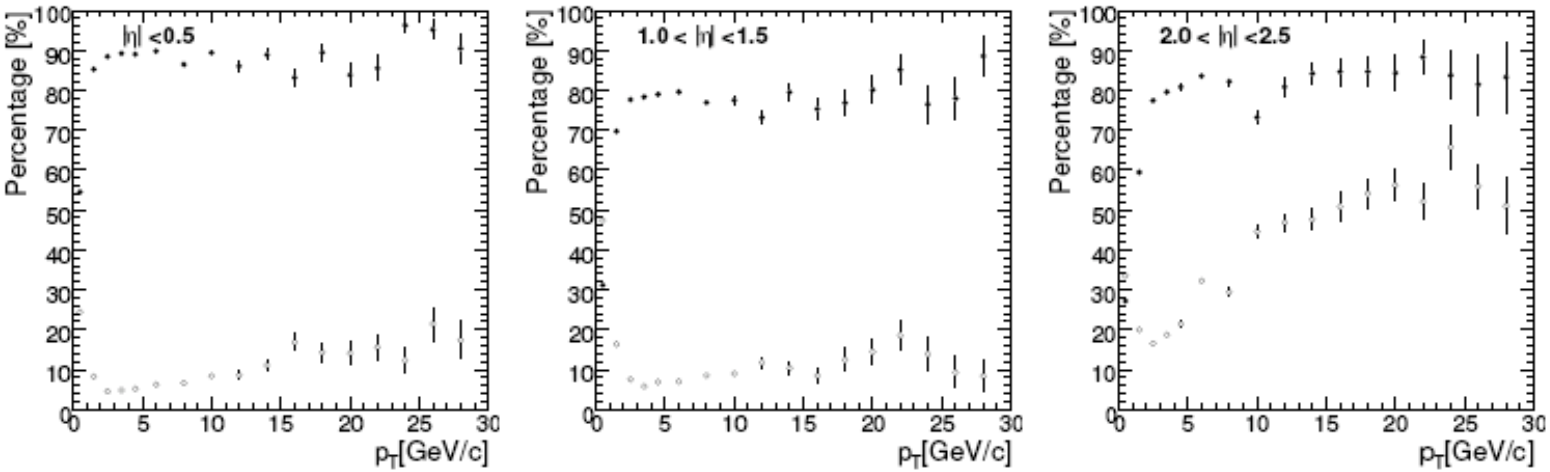
A better tracker for SLHC?

- Present detector looks to be very powerful instrument
- No physics reason to improve spatial and momentum measurement precision
  - Key point is to maintain tracking and vertexing performance
- Heavy ion tracking simulations are encouraging:
  - Track density similar to SLHC
  - Extra pixel layer would restore losses
- Must optimise layout of tracker for
  - CPU-effective track finding
  - Trigger contributions
- Weakest point in present system is amount of material
  - Electron & photon conversions
  - Hadronic interactions

Heavy ions – tuned for high efficiency

Ferenc Sikler

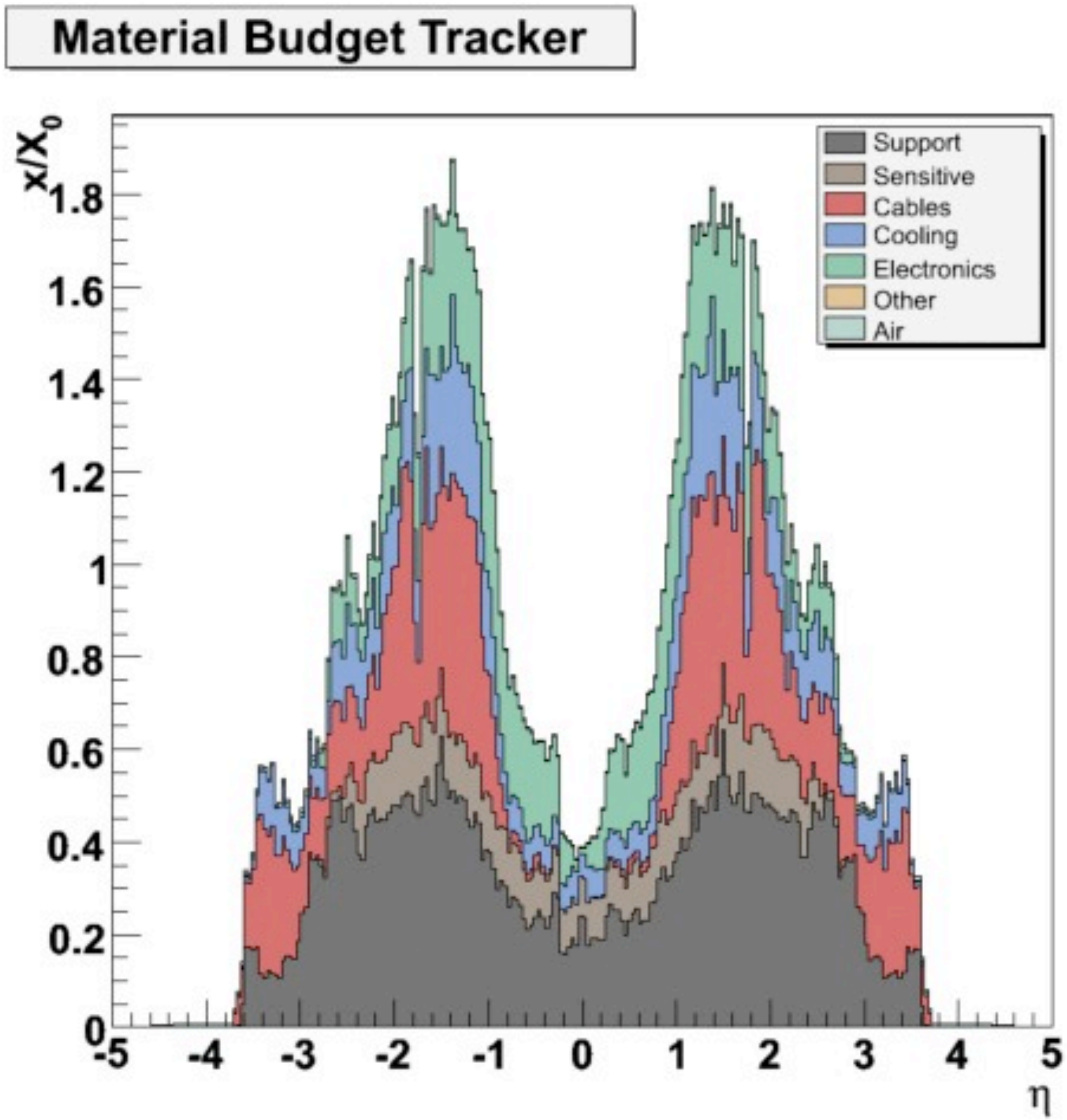
● efficiency ○ fake rate



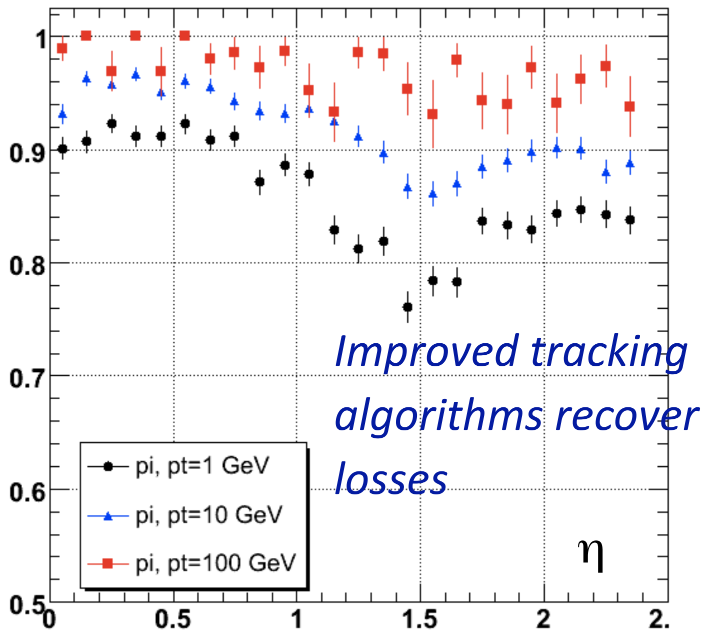
Required to have at least 12 hits with stereo hits split

- Heavy ion performance of present tracker is remarkably good
  - Pixel seeding using 3 layers loses ~10%
  - but some pp events are more demanding, especially jets
- Granularity of tracker must increase anyway
  - because of leakage current/noise after irradiation as well as tracking

Material and its consequences



Pion track finding efficiency vs η

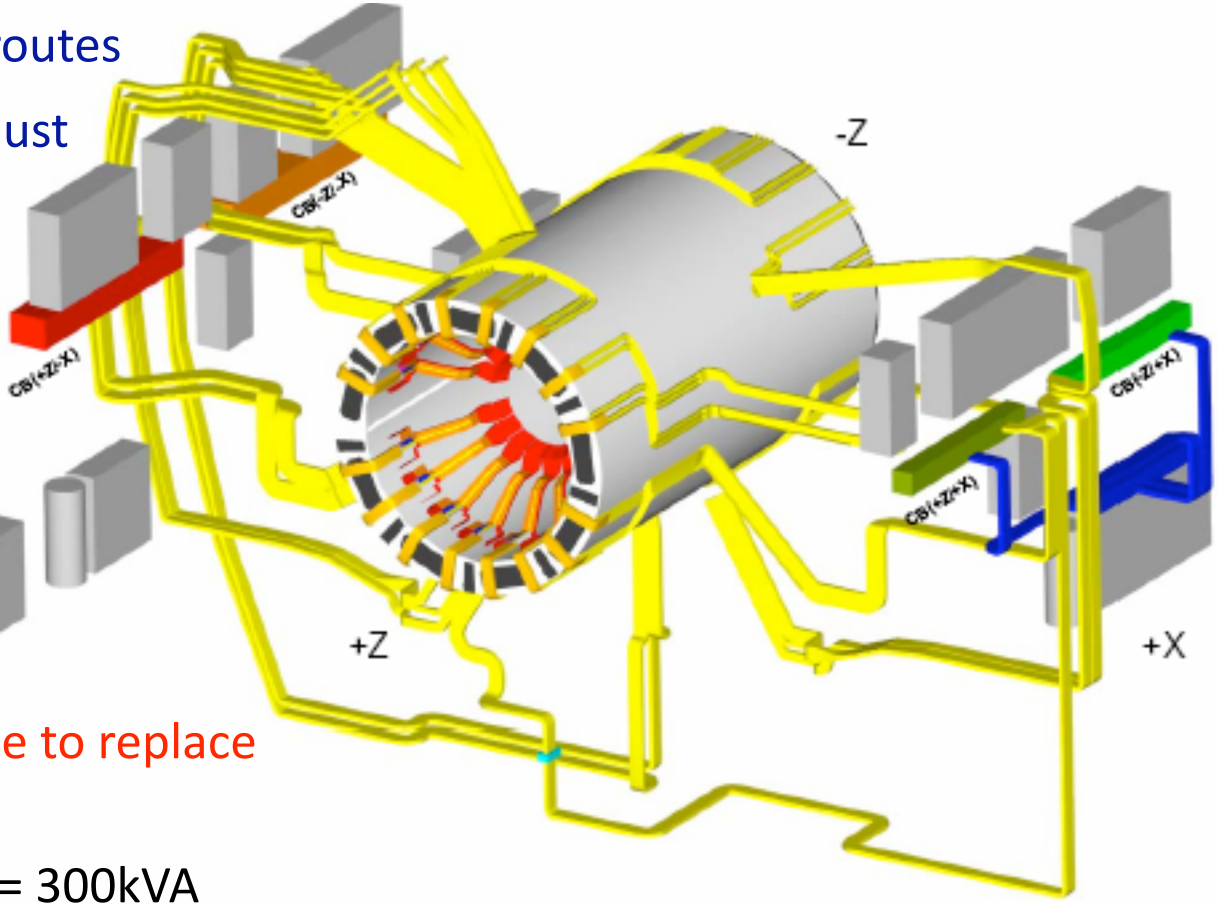


- Reducing power would be beneficial
  - can routing improve?
- Present power requirements
  - inner microstrips: 400 $W.m^{-2}$
  - pixels: ~2700 $W.m^{-2}$ (pre-rad)

Tracker services

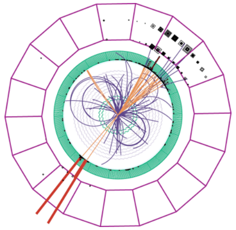
- Major constraint on upgraded system
  - Complex, congested routes
  - Heat load of cables must be removed
  - $P_{cable} = R_{cable}(P_{FE}/V_s)^2$
  - Cable voltage drops exceed ASIC supply voltages
    - limited tolerance to voltage excursions

Installation of services was one of the most difficult jobs to complete CMS



It will probably be impossible to replace cables and cooling for SLHC

$P_{FE} \approx 33kW$ I=15,500A $P_S = 300kVA$



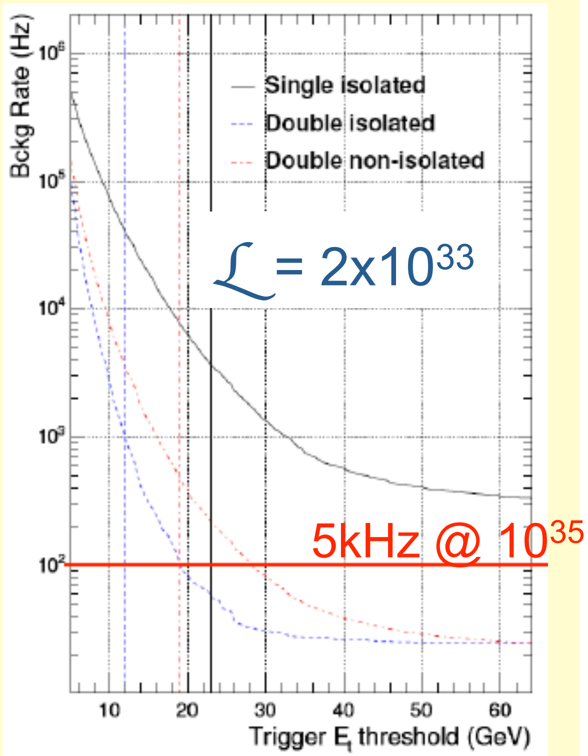
Why tracker input to L1 trigger?

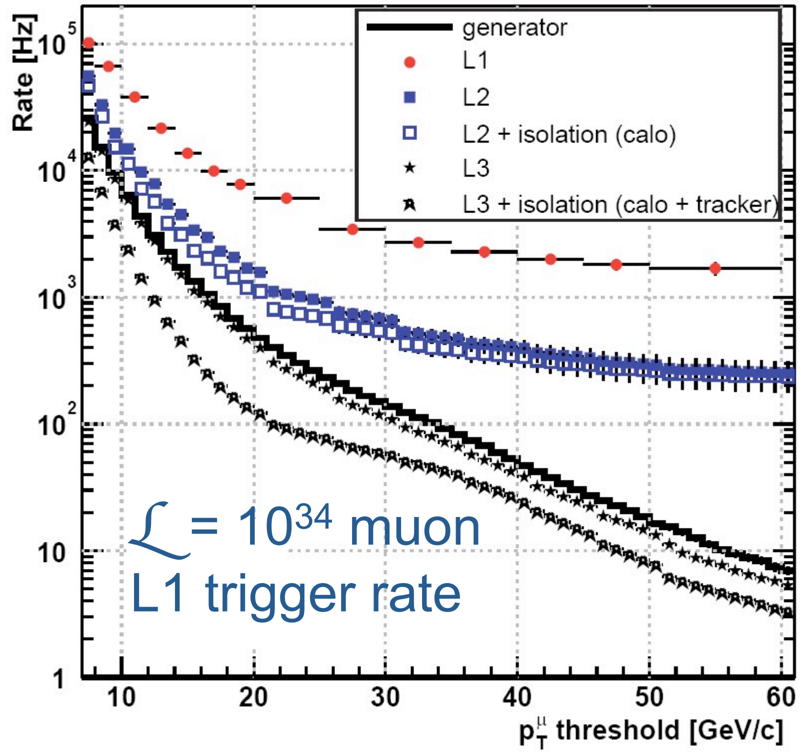
- Single μ and *e* L1 trigger rates will greatly exceed 100kHz
  - similar behaviour for jets
    - increase latency to 6.4μs but maintain 100kHz for compatibility with existing systems, and depths of memory buffers

Single electron trigger rate

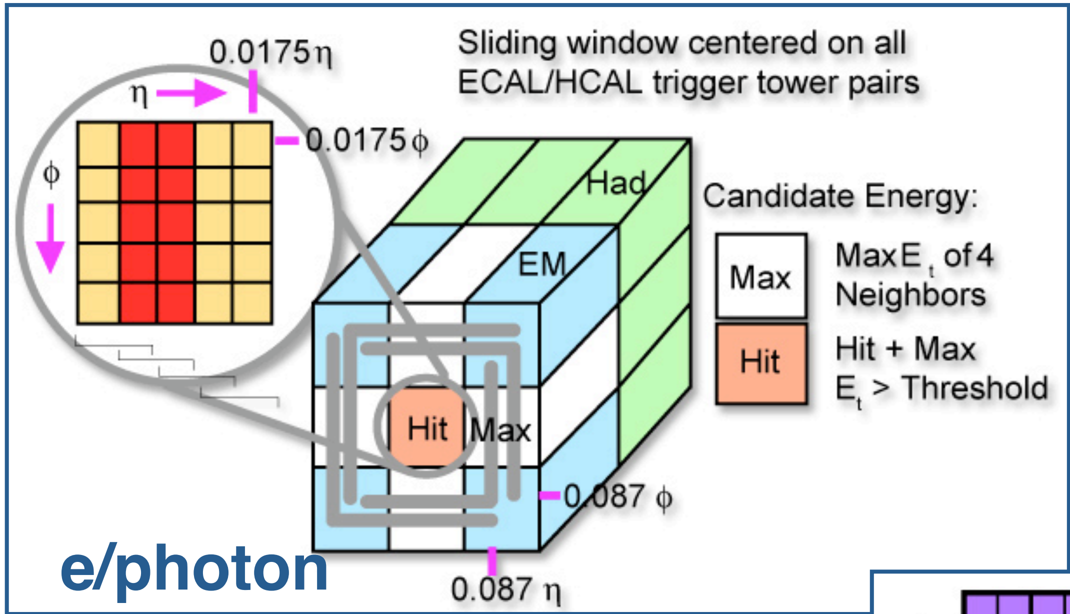
$\langle p_T \rangle \approx$ few GeV/bx/ trigger tower

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



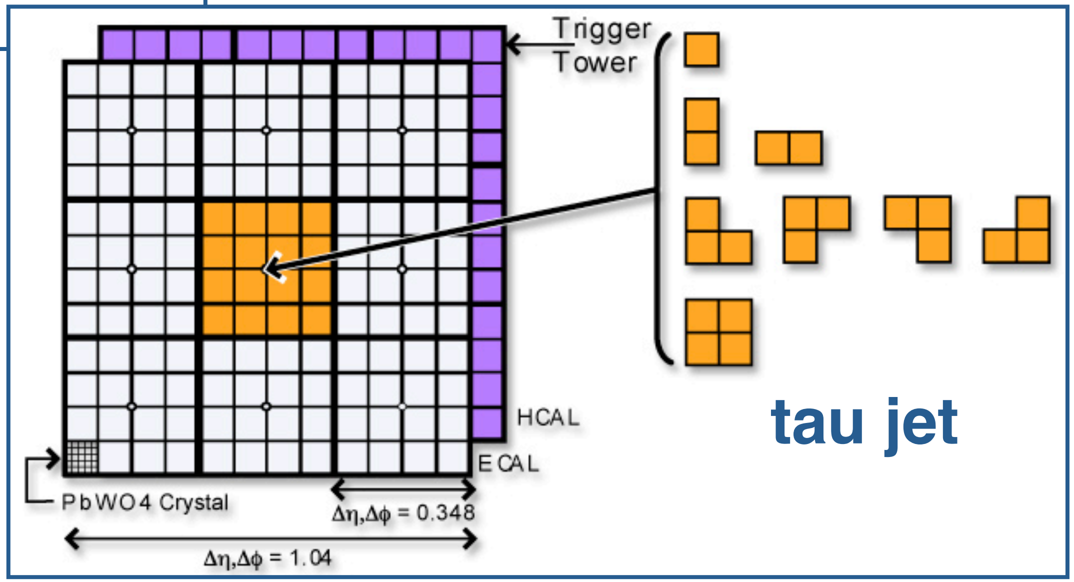


Calorimeter Algorithms



- Electron/photon
  - Large deposition of energy in small region, well separated from neighbour

- tau jet
  - Isolated narrow energy deposition
  - simulations identify likely patterns to accept or veto

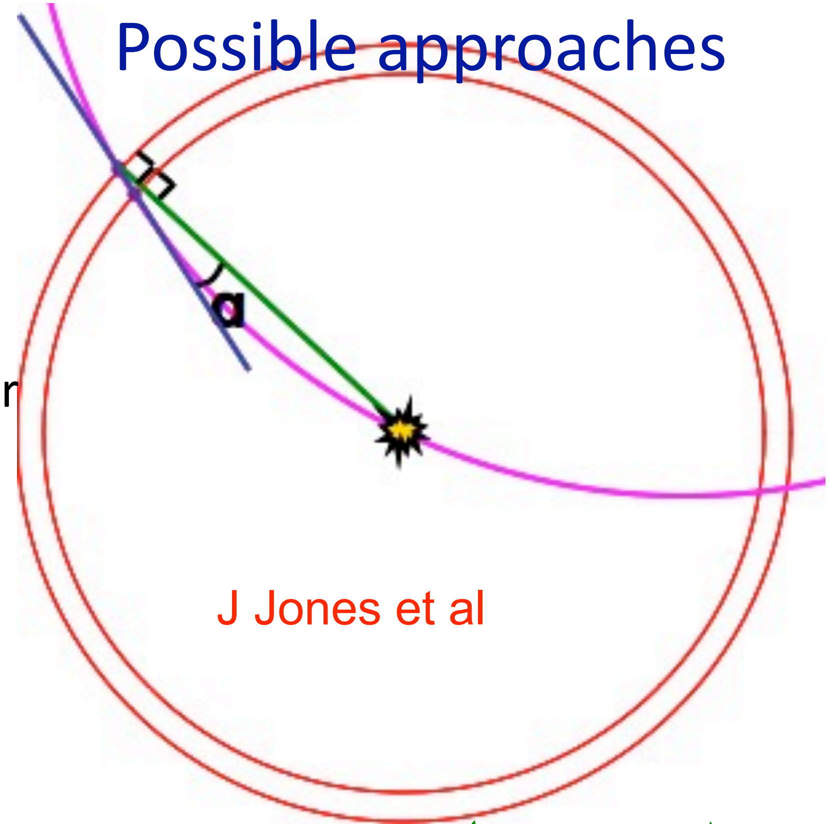


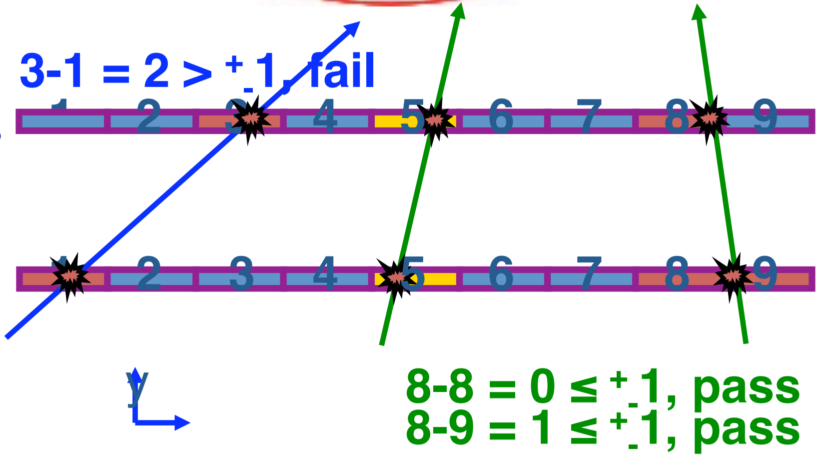
The track-trigger challenge

- Impossible to transfer all data off-detector for decision logic so on-detector data reduction (or selective readout) essential
  - The hit density means high combinatorial background
  - Trigger functions must not degrade tracking performance
- What are minimum track-trigger requirements? (My synthesis)
  - single electron - an inner tracker point validating a projection from the calorimeter is believed to be needed
  - single muon - a tracker point in a limited $\eta-\phi$ window to select between ambiguous muon candidates & improve p_T
    - because of beam constraint, little benefit from point close to beam
  - jets – information on proximity/local density of high p_T hits should be useful
  - separation of primary vertices (ie: 300-400 in ~15cm)
  - a combination of an inner and outer point would be even better

Possible approaches

- Use cluster width information to eliminate low p_T tracks (F Palla et al)
  - thinner sensors may limit capability
- Compare pattern of hits in contiguous sensor elements in closely spaced layers
  - p_T cut set by angle of track in layer
  - simple logic
- Simulations support basic concept
  - but with unrealistically small elements for a practical detector
- can it be applied with coarser pixels?
  - understanding power & speed issues requires more complete electronic design
- try to send reduced data volume from detector for further logic
  - eg factor 20 with p_T > ~2GeV/c?





Planning an Upgrade Project

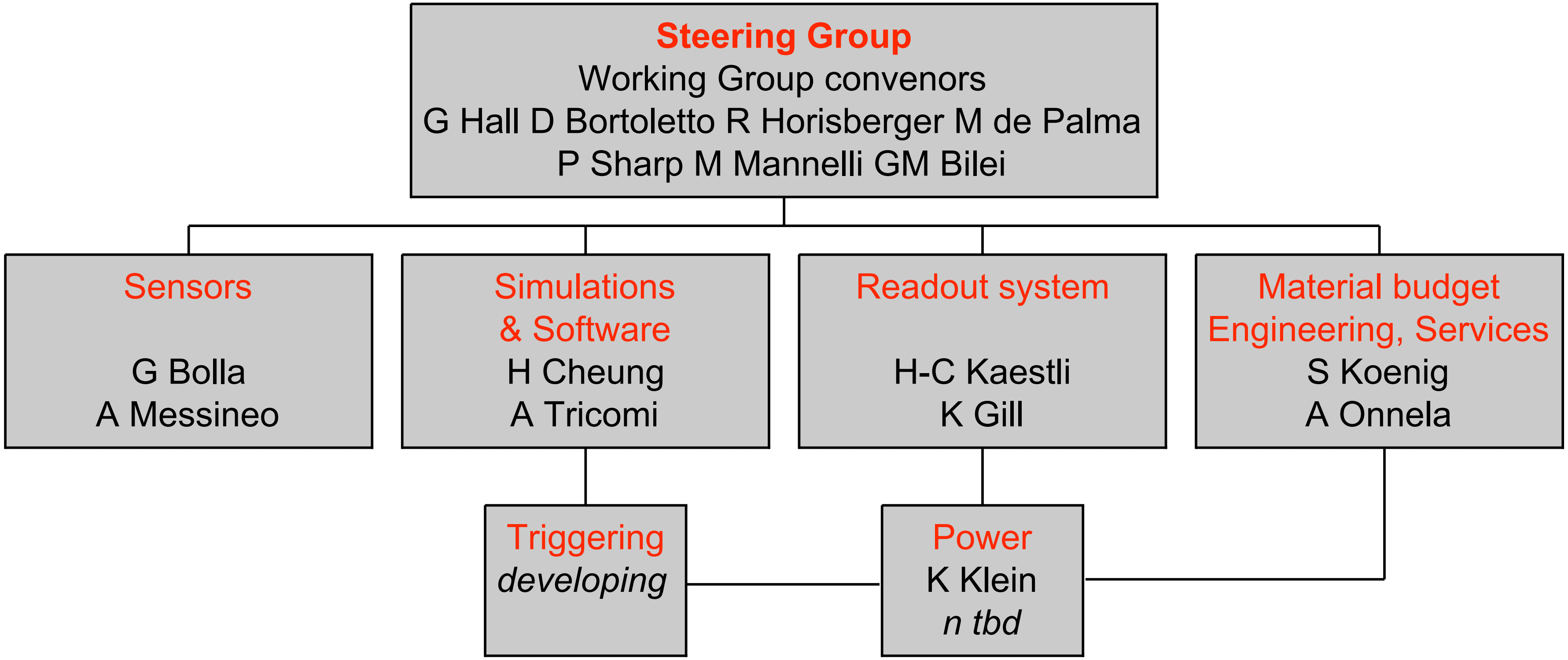
- The SLHC planning assumption
  - Phase I to 2 x 10^{34} around 2013
  - Phase II to 10^{35} incrementally from ~2017

- Developing and building a new Tracker requires ~10 years
  - 5 years R&D
  - 2 years Qualification
  - 3 years Construction
  - 6 months Installation and Ready for Commissioning

- NB – even this is aggressive
  - System design and attention to QA are important considerations from a very early stage
  - Cost was a driver for LHC detectors from day one

Working Group organisation

- CMS Tracker R&D structure
  - active for 12-18 months



new power group met in May tracker week for first time

Tracker related 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

Simulations

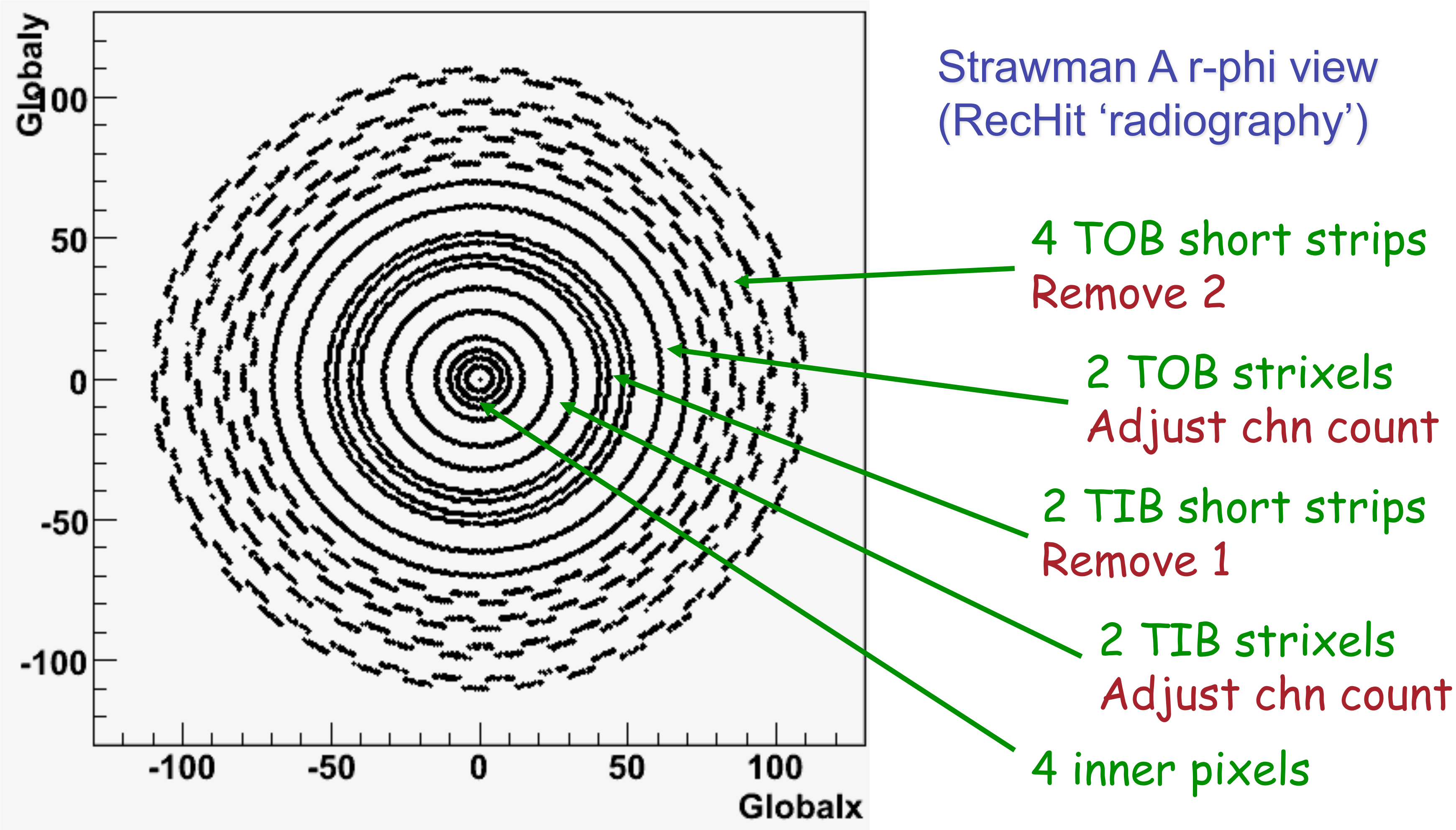
- Present design suffered from limited simulations
  - we did not know how many layers would provide robust tracking
    - we might have installed fewer outer layers, with present knowledge
  - our pixel system was a late addition, which has an important impact
  - the material budget estimate was not as accurate as desired
    - although important uncertainties in components, power distribution, etc
- A new tracker might be "easy" to design based on experience
  - but provision of trigger information adds a major complication
  - and the tools to model CMS at $\mathcal{L} = 10^{35}$ were not in place
  - and there are major uncertainties in power delivery, sensor type, readout architecture,…
- What is clear?
  - start from pixels with 4 barrel layers and expanded endcap
  - study PT (doublet) layers to contribute to trigger

Goals of the Simulations Group

- Perform simulations & performance studies: Must simulate
  - The physical geometry, including numbers & location of layers, amount of material, "granularity" (e.g. pixels, mini-strips, size and thickness)
  - The choice of readout, (e.g. technology, speed, latency, numbers of bits)
  - Types of material, or technology (e.g. scattering, radiation hardness, noise)
  - Tracking strategy and tracking algorithm
  - Trigger strategy, trigger technology, and trigger algorithm
- Develop a common set of software tools to assist these studies
  - For comparisons between different tracking system strategy/designs
  - For comparisons with different geometries, and with CMS@LHC
  - To include sufficient detail for optimization (realistic geometry, etc.)
  - For comparisons between different tracking trigger strategy/designs
- Develop set of common benchmarks for comparisons
- Maximize the overlap of these common software tools with those in use for CMS@LHC (assist current efforts where possible)
- Get good integration between Tracker and (Tracking) Trigger design

More Realistic Strawman A

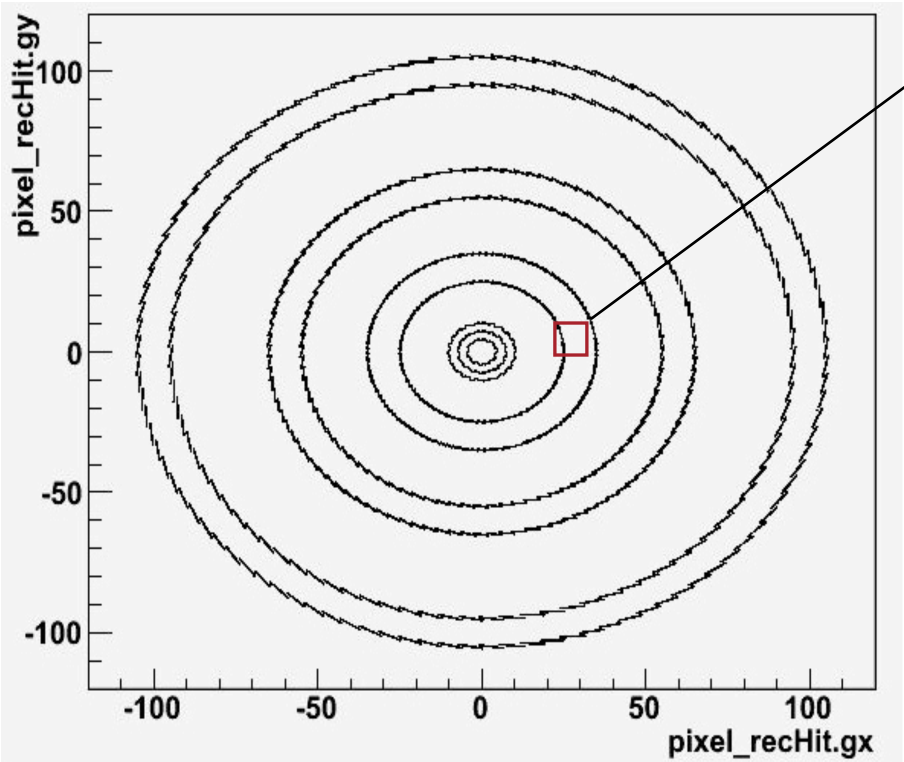
- A working idea from Carlo and Alessia
  - Take current Strawman A and remove 1 “TIB” and 2 “TOB” layers

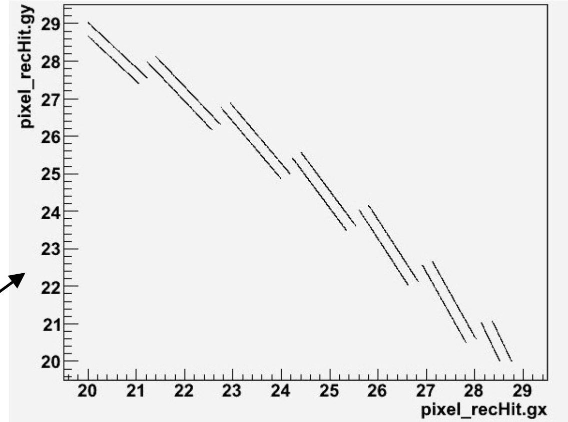


More Realistic Strawman B

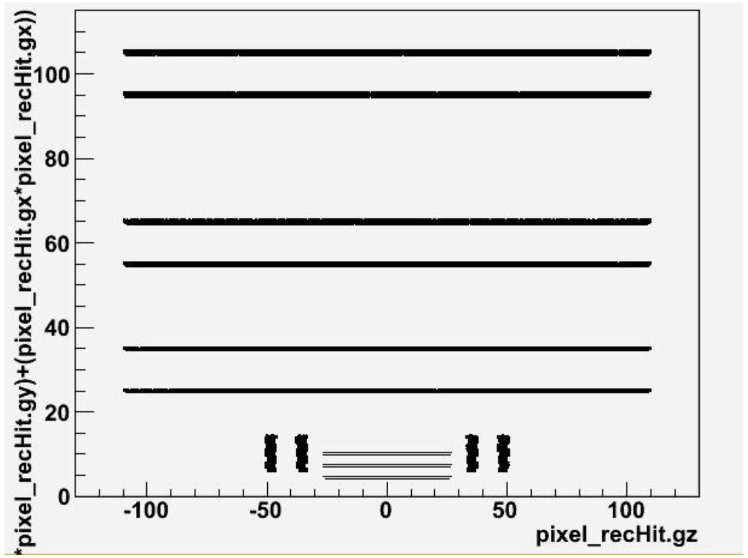
- Adjust granularity (channel count) of Strawman B layers
  - Keep the TEC for now until someone can work on the endcaps

Strawman B r-phi view
(RecHit 'radiography')





r-z view



Future 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

Power delivery

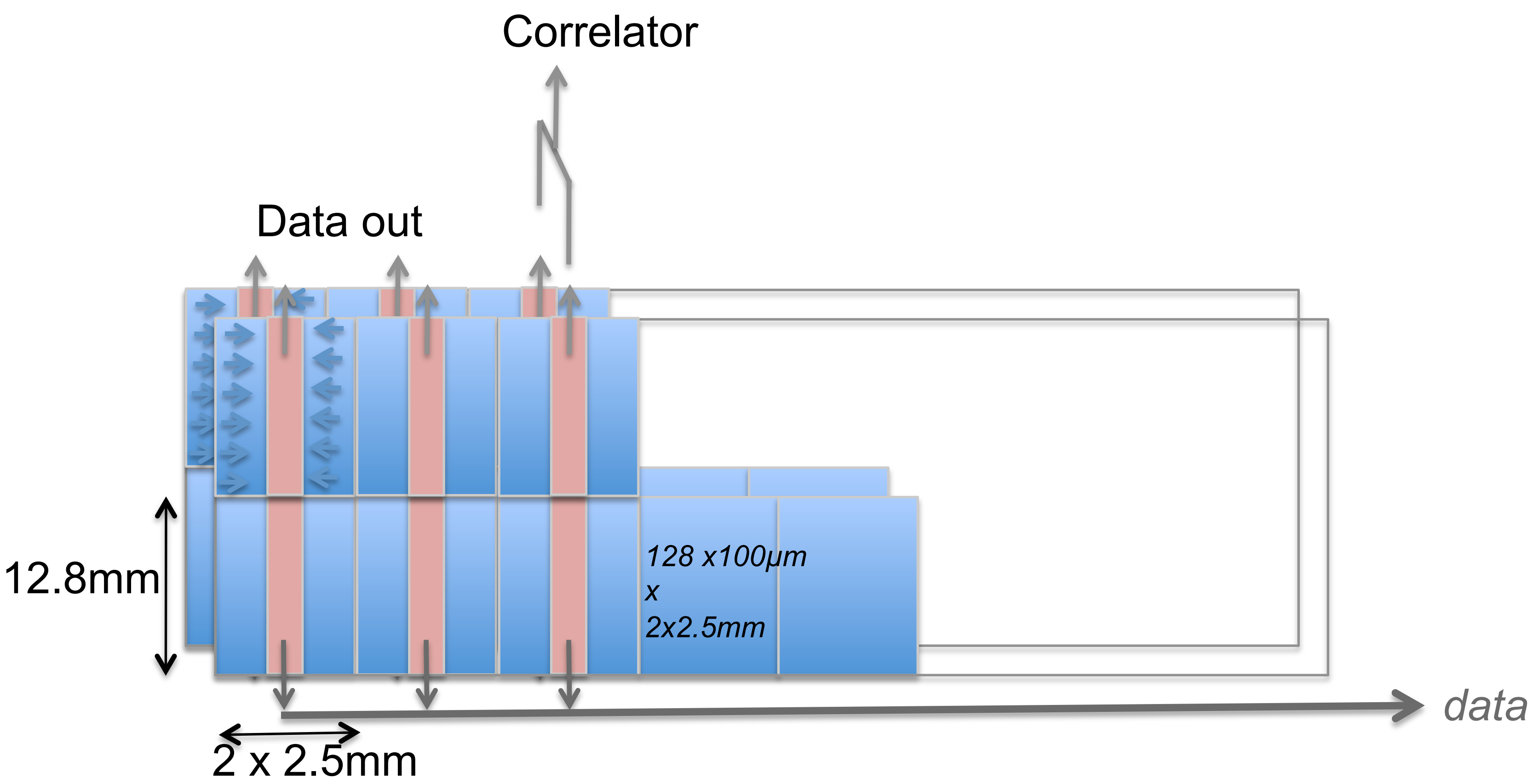
- Perhaps the most crucial question
  - although estimates of power are still imprecise, overall requirements can be estimated
  - we must reduce sensor power with thin sensors
    - finer granularity should allow adequate noise performance
  - and attempt to limit channel count to minimum compatible with tracking requirements (simulations!)
- total readout power expected to be ~25-35kW
  - in same range as present system so larger currents required
- Radical solutions required
  - serial powering or DC-DC conversion
  - neither are proven and many problems remain to be solved

Conclusions

- CMS is trying systematically to develop a new Tracker design
  - using simulations to define new layout
- We are very satisfied with the prospects for the present detector
  - but would like to reduce the material budget
  - and achieve similar performance
- The largest challenges are
  - power delivery and distribution
  - provision of triggering data
- but this does not mean that many other aspects of the new system will be as easy as last time (!)
  - expect developments of sensors, readout, readout,…
- and it also needs a large, strong team.

BACKUPS

Example PT module

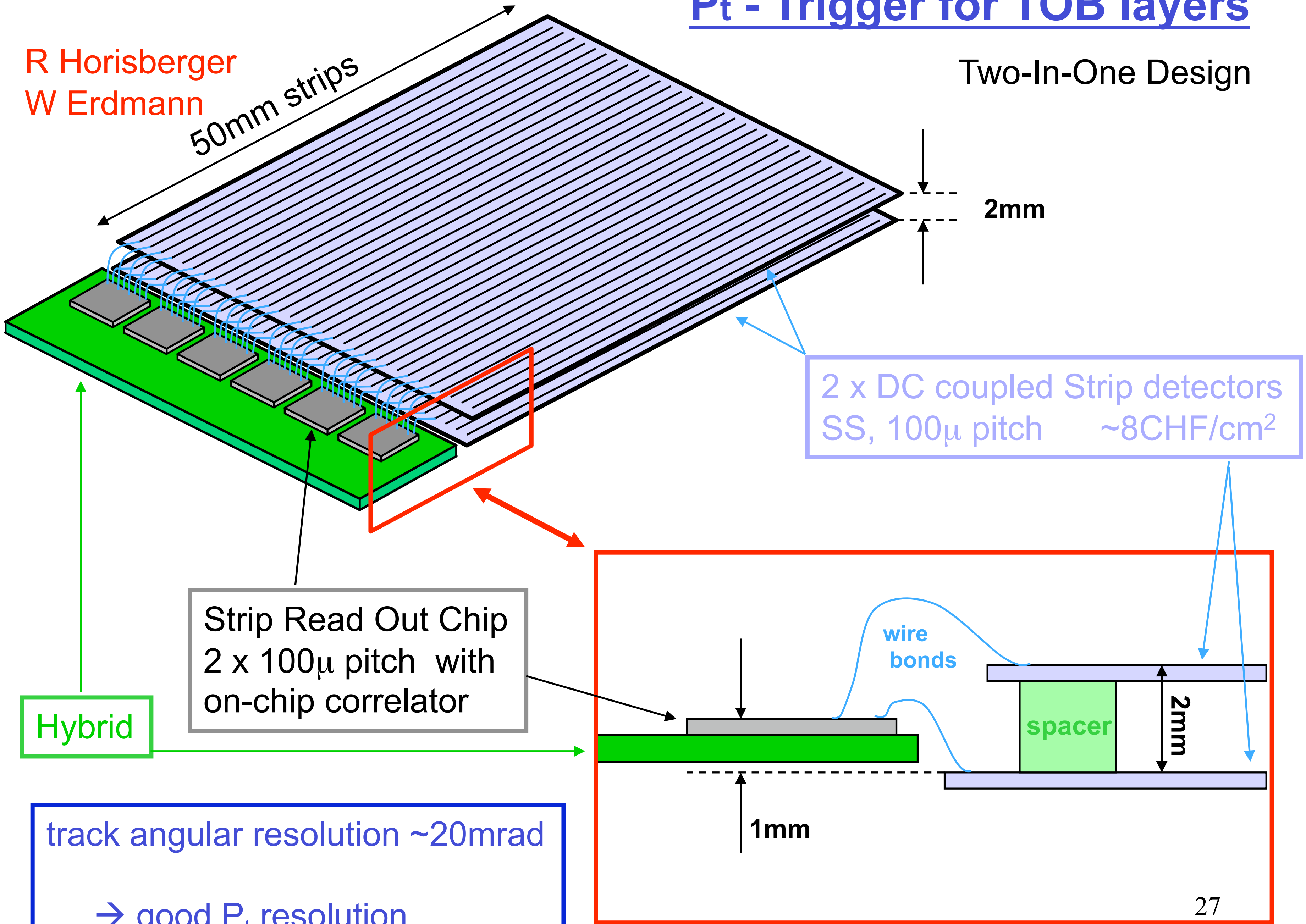


Such a design has potential for inexpensive assembly, using wire bonding, with low risk and easy prototyping

P_t - Trigger for TOB layers

Two-In-One Design

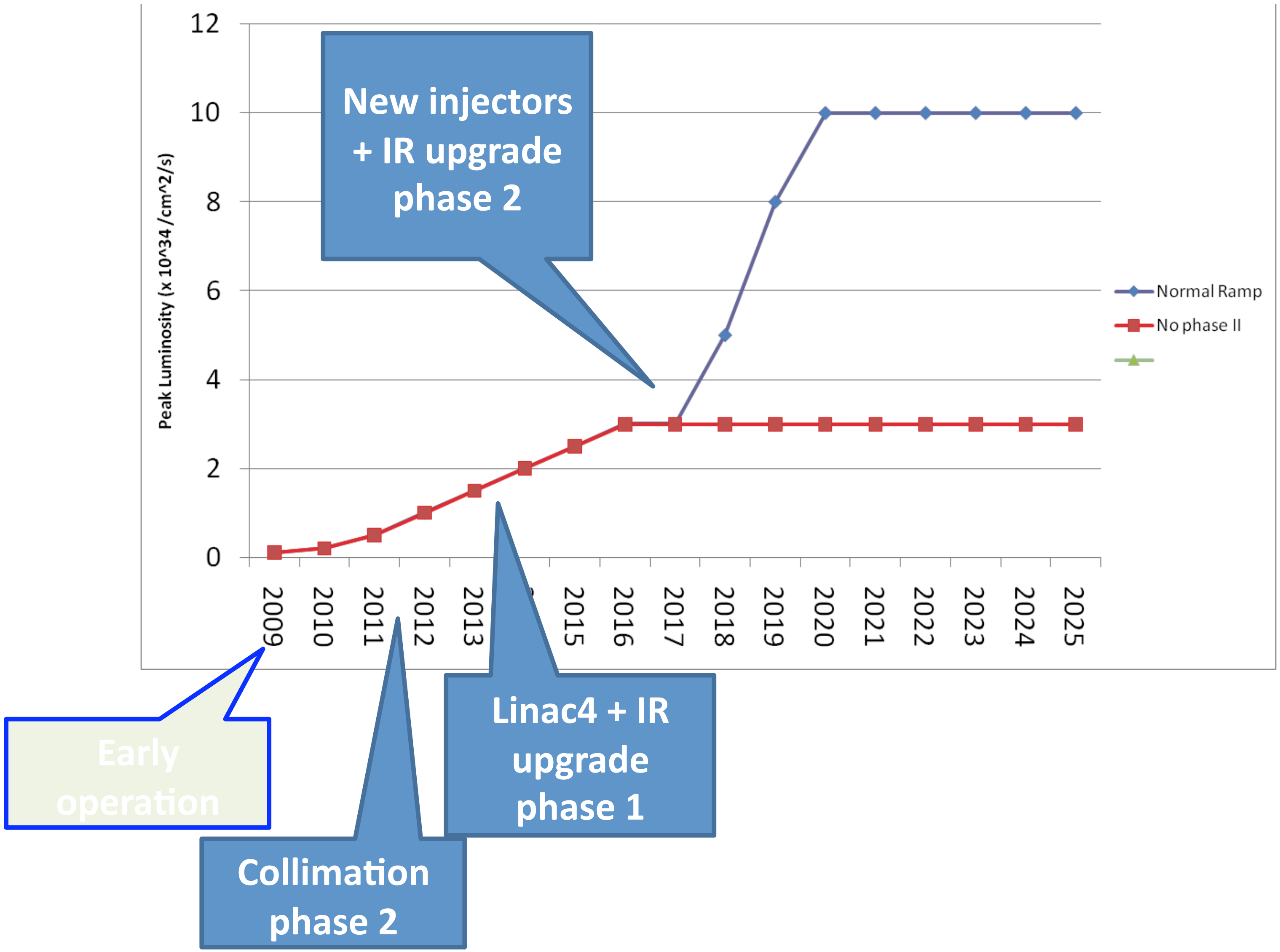
R Horisberger
W Erdmann



track angular resolution ~20mrad

→ good P_t resolution

Peak luminosity…



Integrated luminosity…