System level requirements

for upgraded tracker

Potential upgrades to CMS

- CMS was designed for 10 years operation at L = 10^{34} cm^{-2}.s^{-1}
  - ~20 events per beam crossing @ 40MHz
- To operate at L = 10^{35} cm^{-2}.s^{-1}
  - ~400 events/10,000 particles per beam crossing @ 20MHz
- Rebuild tracking system - requirements and challenges
  - Greater radiation tolerance
  - Higher granularity - more pixels, and shorter strips
  - New electronic readout system
    - Take further advantage of DSM CMOS & higher speed optical links
  - Contain power budget and unit costs
  - Increase mass production and automation
  - Improve cooling performance
  - Reduce unnecessary mass

Requirements and challenges

- Physics requirements
  - Not yet better defined than LHC and may be influenced by discoveries
    - Momentum measurement & spatial resolution precision, tracking efficiency not expected to reduce
  - Electron and muon track reconstruction will still be important
  - More energetic jets with more particles and higher track density
  - Rarer channels likely to be studied
  - Worse performance than LHC is not allowed, despite nature's challenge!
  - Higher granularity & less material will evidently help

- Operational lifetime
  - Not yet well defined and will depend on machine performance, budgetary constraints, difficulties of operating experiment in very new conditions - but may be longer than originally expected
  - Even if not true, inaccessibility for maintenance requires…
  - High reliability and quality of manufacture are essential

New electronic readout system

- Potential targets for beneficial features
  - Power reduction per channel
    - if possible better than scaled with input load
  - Increased testability, redundancy
  - Improved immunity to any radiation effects, especially SEU
  - Maintain data quality, under more challenging conditions
    - increased digital activity, lower noise targets for thin sensors,..
  - Qualification has been successful but it’s always possible to improve
    - Much relies on users and small features always show up late

- Design for low power everywhere possible
  - Don’t wait to be asked!
  - Some elegance in system design may need to be sacrificed…

Requirements from sensor issues

- CMS Silicon microstrip tracker
  - ~210 m^2 of silicon, 10M channels, 75000 FE chips, 40000 optical links
  - Present silicon sensors - main parameters
    - *Substrate: <100>, n-type float-zone, phosphorus doped*
    - *p-side readout, AC coupled, with poly-Si bias resistors*

- For LHC only one type of - well understood - sensor material and readout polarity
  - For SLHC not yet known if single material or sensor type will be used
  - Large scale manufacture requires substantial, experienced companies
  - Less mature technology feasible for limited innermost region?

- Front end electronic design can't - as usual - be decoupled from sensors
  - May need multiple FE chip variants (for a time..?)
  - Sensor specifications are a required input to electronic definition

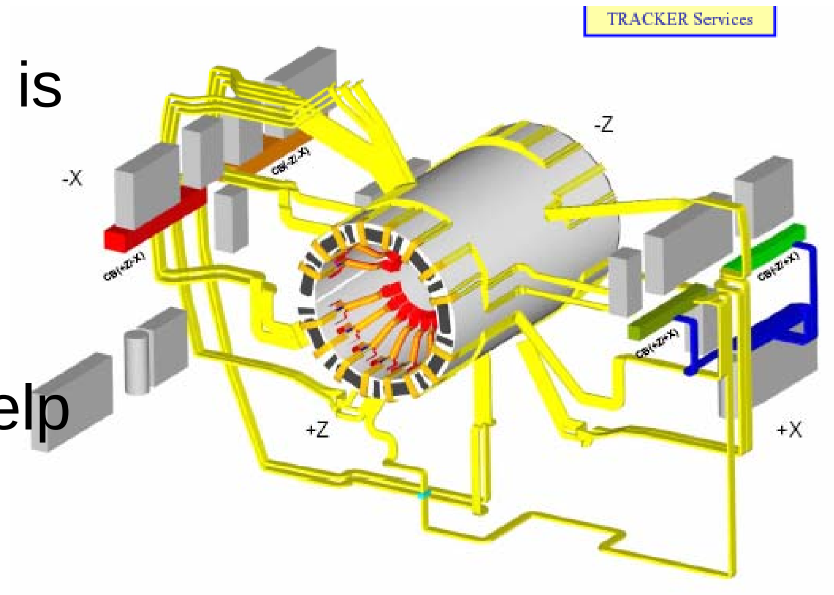
Greater radiation tolerance

- Electronics
  - Little doubt that advanced CMOS (0.13µm,…) will meet our requirements
    - What are the arguments for considering other processes?
  - Total dose qualification is time consuming
    - 10 Mrad with x-ray machine ~1 day
    - Rate effects are difficult to study
  - Effort in design required to mitigate Single Event effects
    - Access to suitable sources required (heavy ions - vacuum, ~50MeV protons, …)

- Expect issues at module level or with components
  - Handling issues, special tooling, time, etc..

Power budget & provision

- Tracker (& CMS) performance is adversely affected by material
  - Space for services is limited
  - Routes are complicated
- Reduction in currents would help
  - Increasing power budget will not make life easier



- Effort on power provision is mandatory before commitments are final

- Space & cooling in control room & cavern is also limited
  - Increase in volume of off-detector electronics should be compensated by density
  - **total** power constraints will also not relax much

Costs

- 0.13µm CMOS ASIC prototyping of full size chips is significantly more expensive
  - Access is also possible via commercial MPW
    - Convenient & affordable for small chips
  - MPW sharing of single technology has advantages
    - Foundry access, shared experience, circuits/components,…
    - But drawbacks of less predictable schedules
- Production costs almost unchanged => lower in future real terms
- Potential cost conflict between trying new ideas and containing number of iterations of large chips
- However, optical link procurement was the major CMS cost driver
  - ATLAS & CMS approaches were different last time
    - In-house/commercial   large number of links (analogue)/small number (binary)
- Clarification of link options and implications of common project

Mass production and automation

- CMS pioneered automated module assembly
  - Eventually very successful
    - 15000 in ~2 years
- But
  - Significant development time
    - Main hold-ups due to subtle component issues
  - Many crucial, detailed, labour intensive tasks
  - Testing and tooling requires development
  - Ease of task depends on number of variants
    - System assembly, installation and commissioning much less adaptable to automation
- Desirable to reduce number of module types

Cooling performance

- Increased cooling could be required for
  - Lower temperature operation for radiation mitigation/thermal runaway
  - Removing increased heat load
    - Mainly driven by sensors, and perhaps system requirements
- If either of these is required, more cooling power is necessary
  - But cooling is a significant contributor to material budget
  - So either reduce heat load, or improve engineering of cooling system
- Appraisal of required cooling and its impact
  - Desirable to compare performance of ATLAS (evaporative) vs CMS (conventional liquid) cooling schemes

Reduce unnecessary mass

- No non-essential material in tracker
  - but perhaps we could still do better in future

Installation issues

- May require to replace inner layers during lifetime
- Never too soon to think about power provision
- Ability to work in irradiated zone not yet clarified
  - Specialist tools and techniques to be developed

New challenges

- Leave this for other speakers, as unique to CMS (I think)

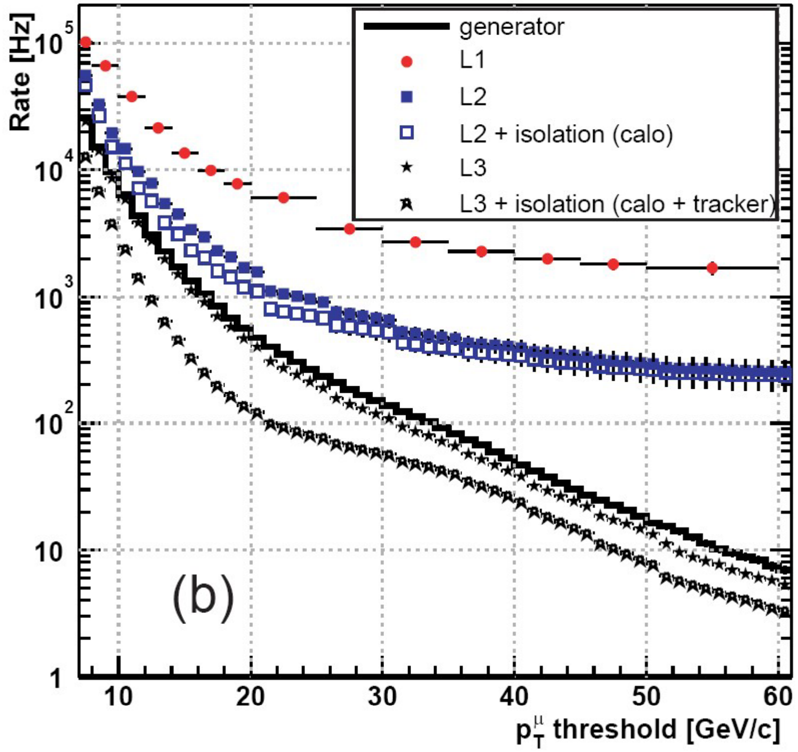
- Tracker input to L1 trigger

Muon L1 Trigger rate at

L = 10^{34} $cm^{-2}.s^{-1}$

Note limited rejection power (slope) without tracker information

But (for CMS) tracking trigger should not degrade tracking performance…



Conclusions

- General requirements are clear. More details require iteration
  - Higher granularity & less material will evidently help
  - High reliability and quality of manufacture are essential
  - Qualification has been successful but it’s always possible to improve
  - Design for low power everywhere possible
  - Sensor specifications are a required input to electronic definition
  - Effort in design required to mitigate Single Event effects
  - Effort on power provision is mandatory before commitments are final
  - Potential cost conflict between trying new ideas and containing number of iterations of large chips
  - Clarification of link options and implications of common project
  - Appraisal of required cooling and its impact