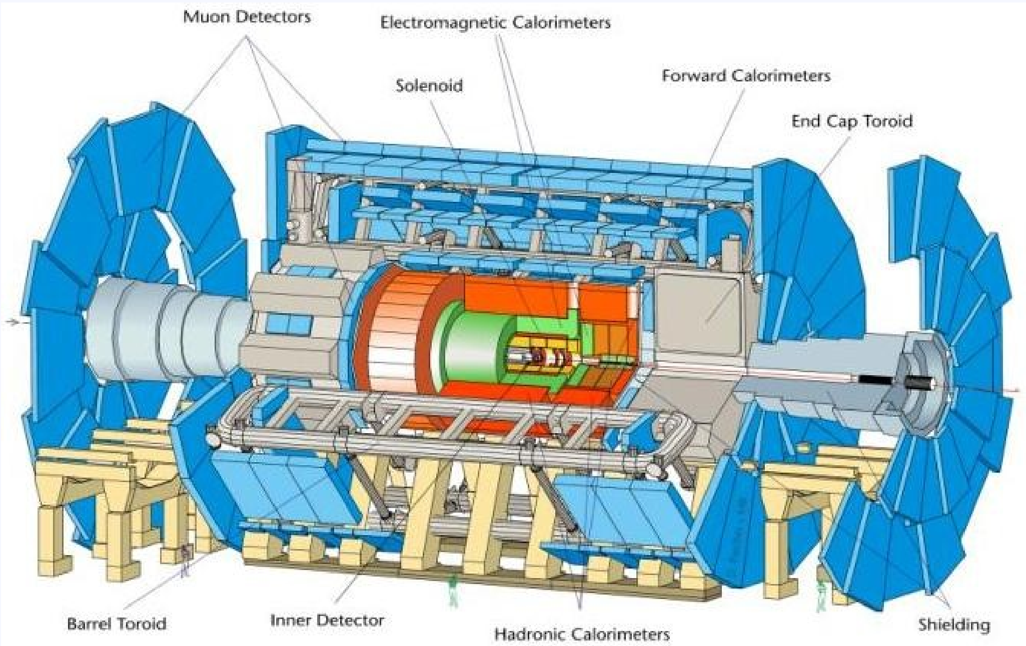
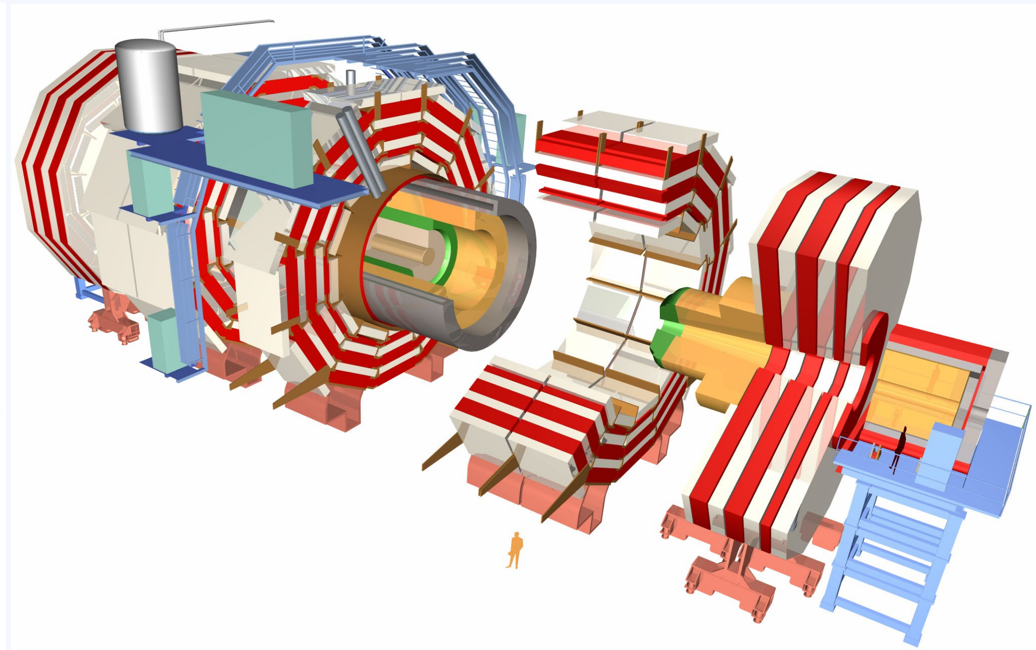
ATLAS and CMS Detector Upgrades for sLHC

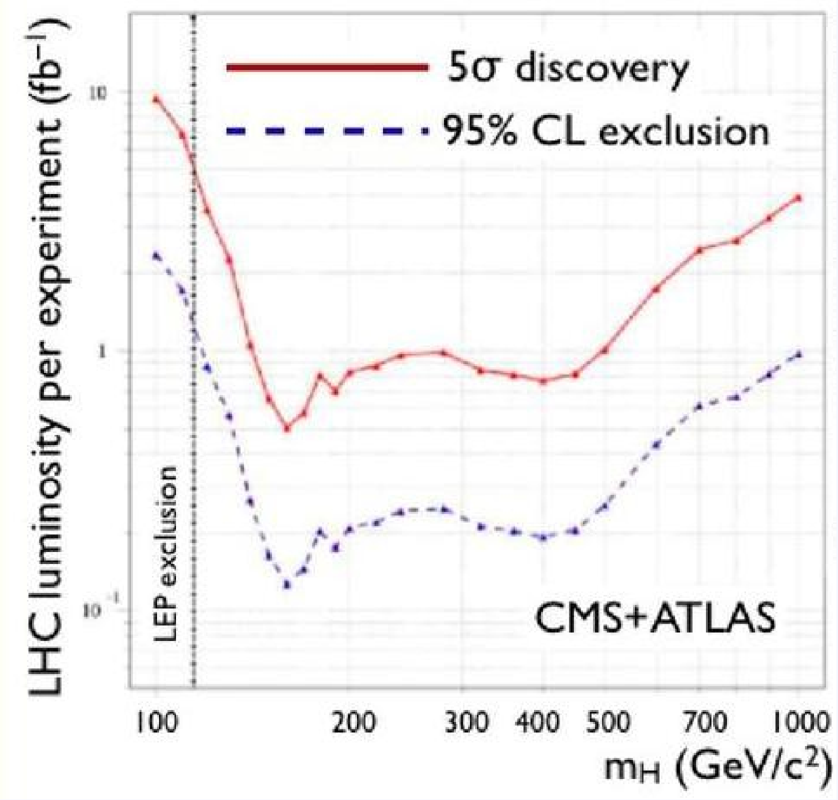




Physics Goals
Machine Conditions
Detector Changes

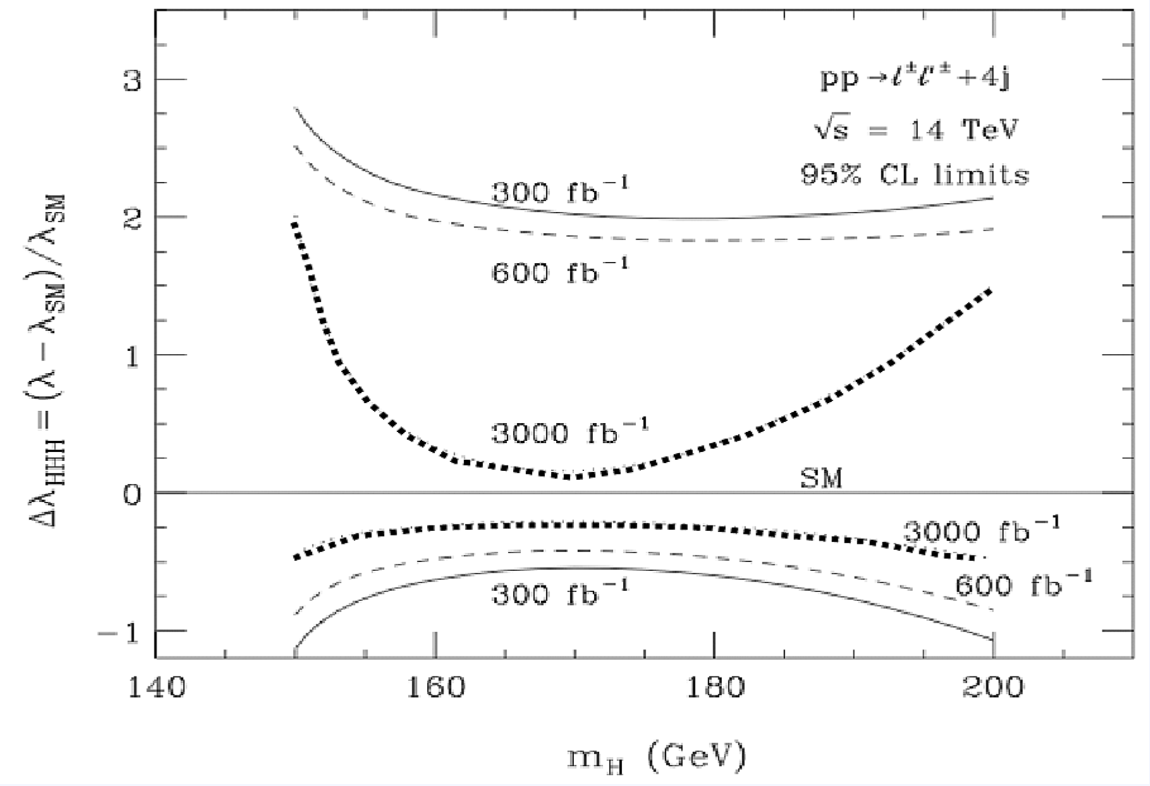
LHC and sLHC

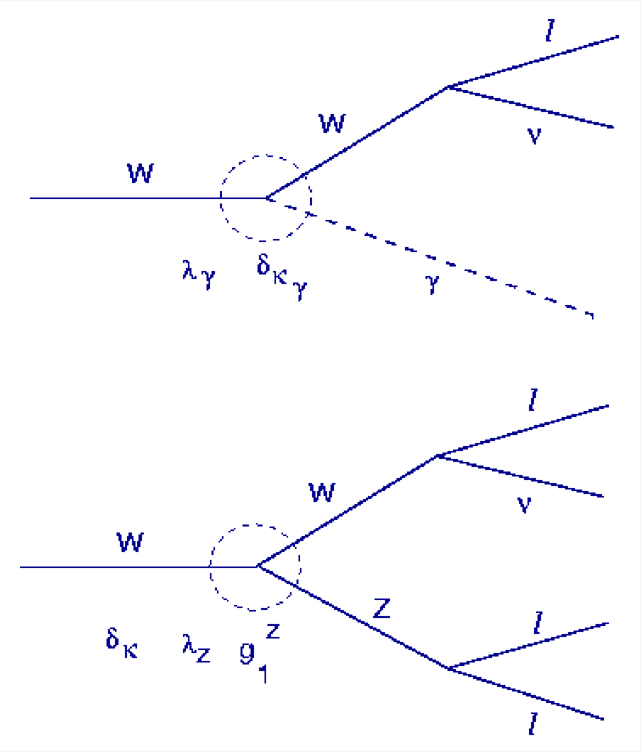
- LHC is foremost a discovery machine
  - In ~2 years will take enough data (10 fb^{-1}) to discover SM Higgs or rule it out
  - After ~8 years will have ~700 fb^{-1}, enough to discover SUSY to ~1 TeV, W'/Z' to ~5 TeV, many other possibilities
- But just what has been found?
  - Needs much more data
    - Measurement of many parameters
      - Deviation from SM values ==> New physics; needs high precision
    - SUSY spectroscopy
- More data will also extend the discovery range to higher masses and rare processes
  - References:
    - [Michelangelo Mangano at SLHC Kick-of]
    - [F. Gianotti et al, Eur.Phys.J.C39:293-33]



Higgs found? Measure e.g. Triple Gauge Couplings

- SM fixes couplings; most general forms have 5 extra parameters possible.
  - sLHC can significantly reduce error bars on most.
- Higgs self-coupling also much better measured at sLHC

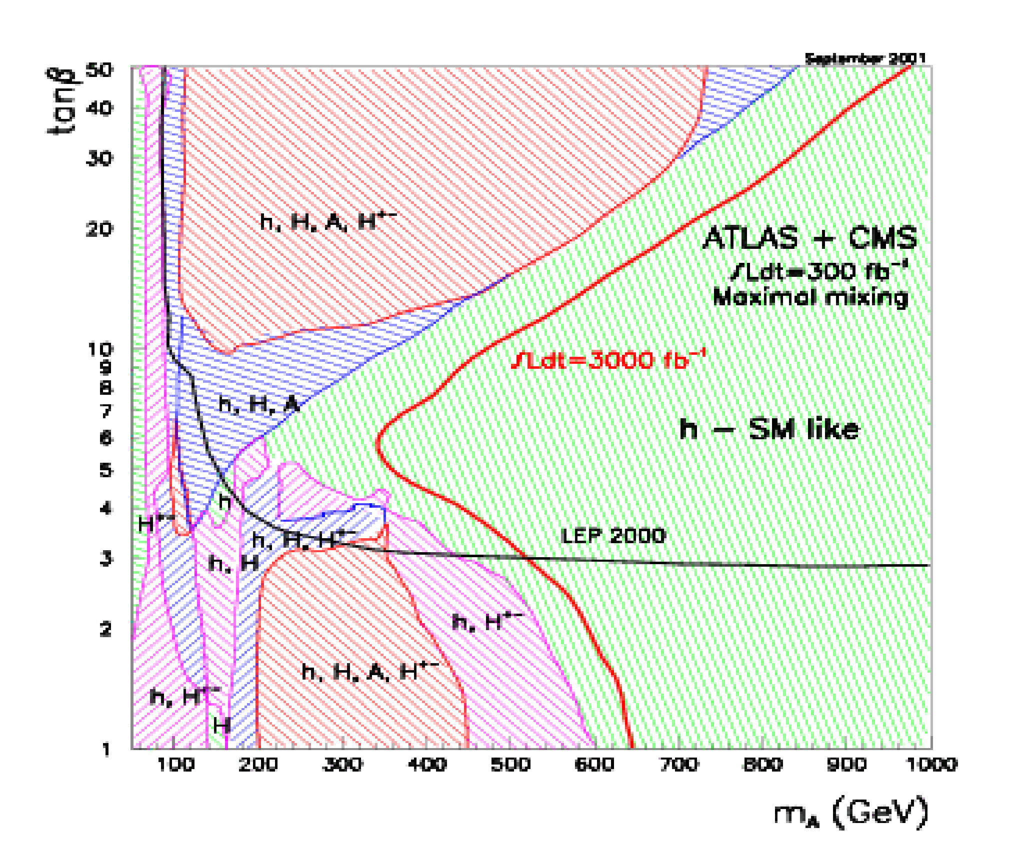




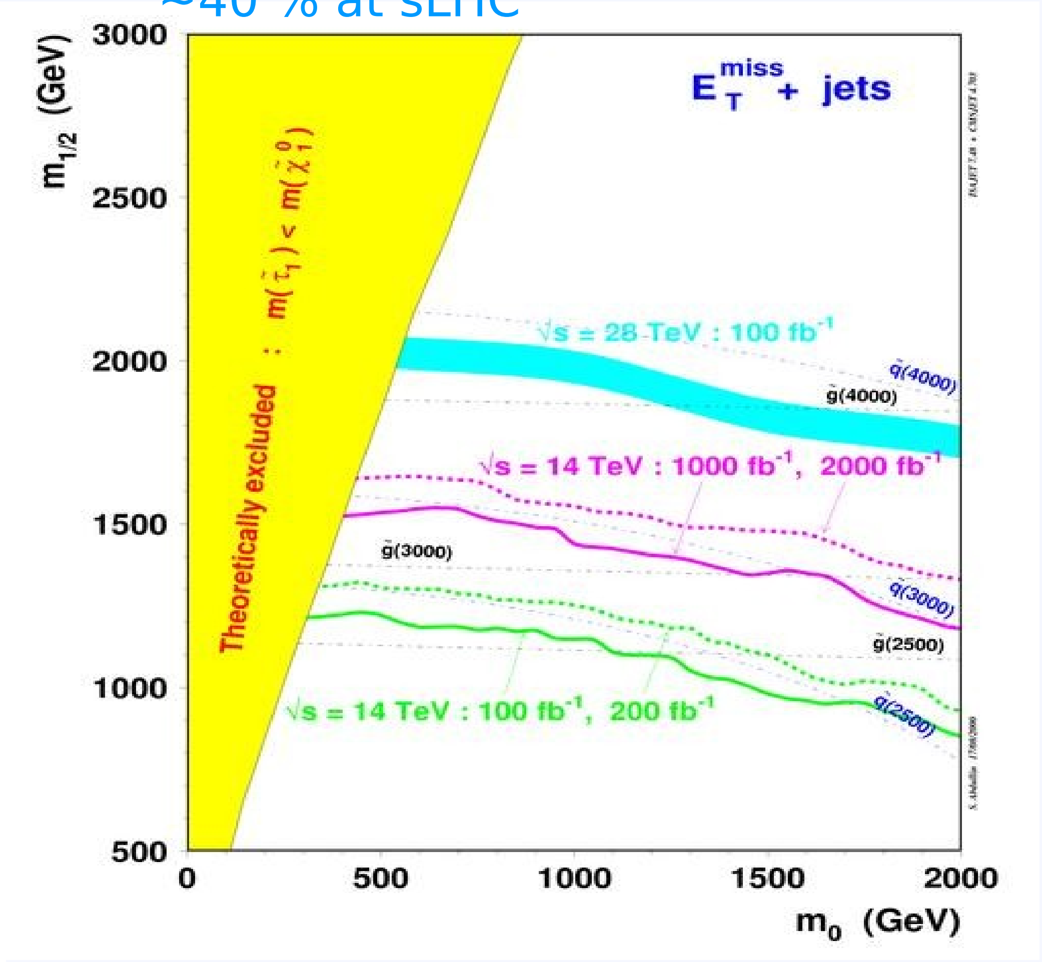
Coupling	100 fb-1	1000 fb-1
$\lambda\gamma$	0.0014	0.0006
λz	0.0028	0.0018
$\Delta\kappa\gamma$	0.0340	0.0200
$\delta\kappa z$	0.0400	0.0340

SUSY

- How many Higgs? sLHC boosts the region in which more than one can be observed. E.g. MSSM model:

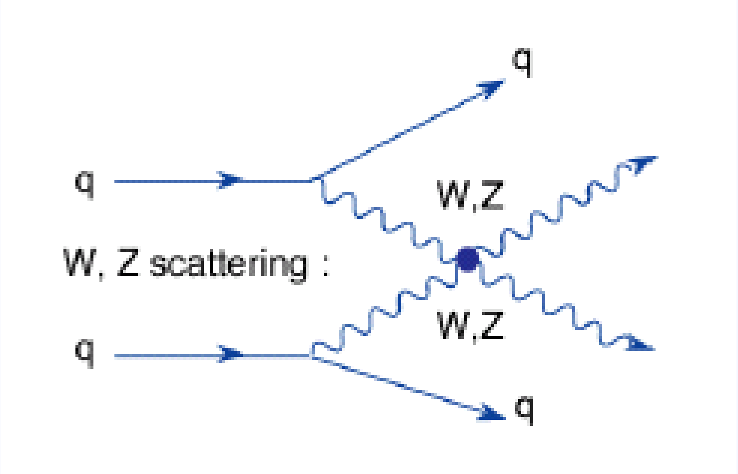


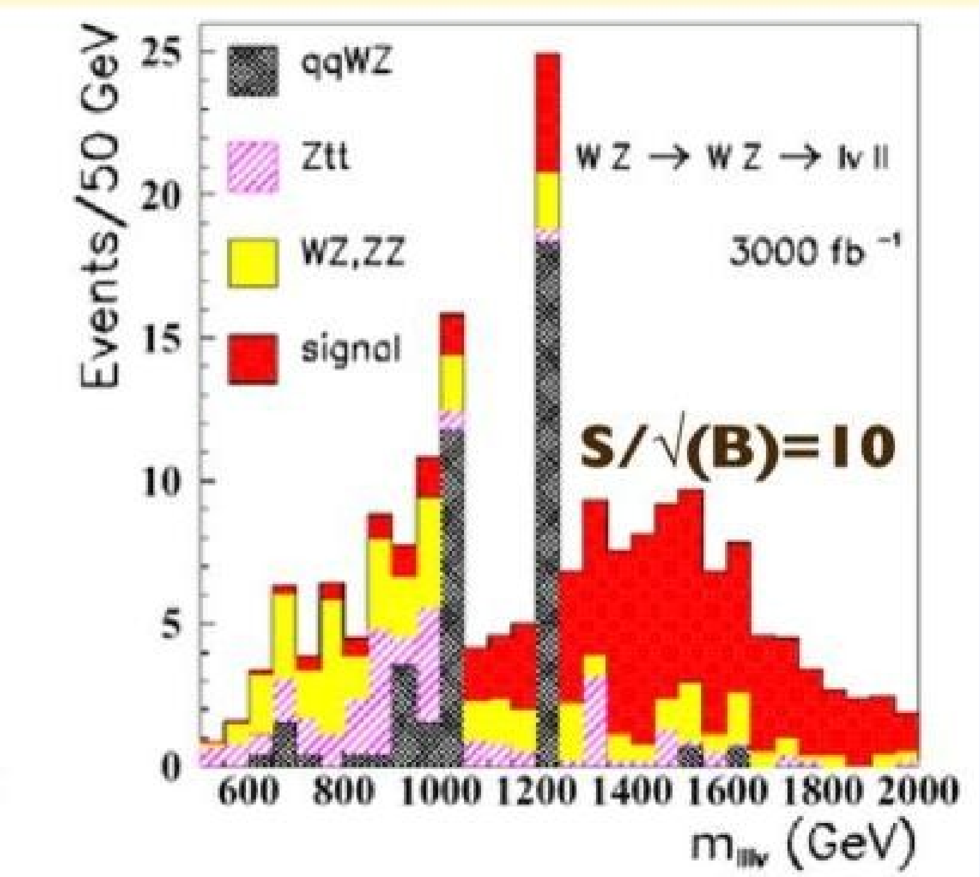
- SUSY particles
  - Either already found at LHC, and sparticle spectroscopy at sLHC
  - Or extend mass range for discovery ~40 % at sLHC



No Higgs?

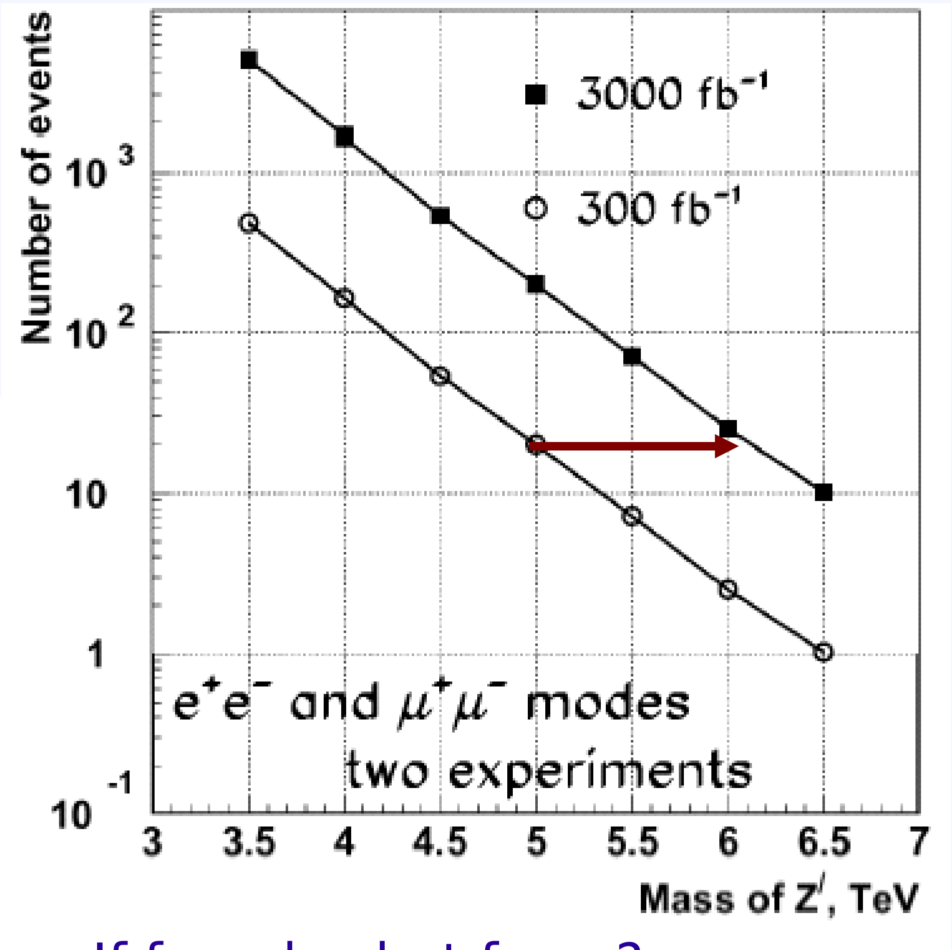
- Then strong vector boson scattering needed ~1 TeV
- Low statistics at LHC (few events); clear signal at sLHC even for 1.5 TeV WZ or ZZ resonance

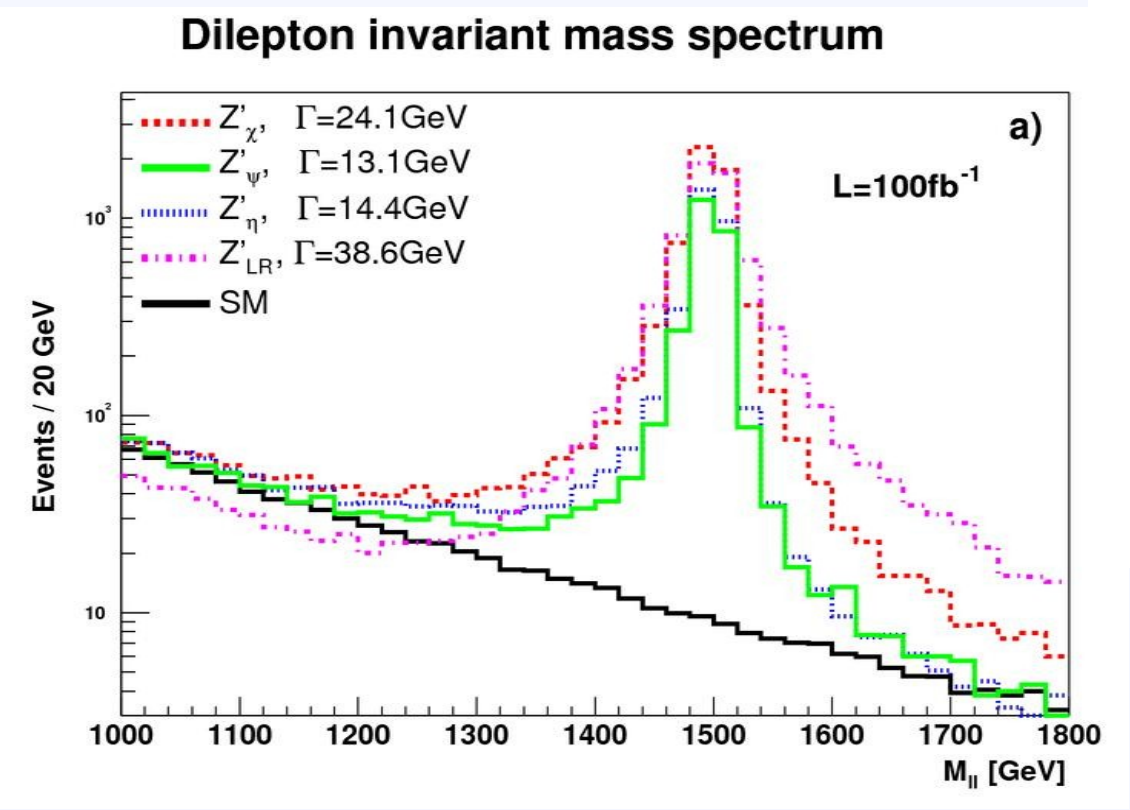




New Forces; W' and Z'

- Increased mass reach from higher statistics and tails of PDF
- 5 TeV reach at LHC --> 6 TeV at sLHC

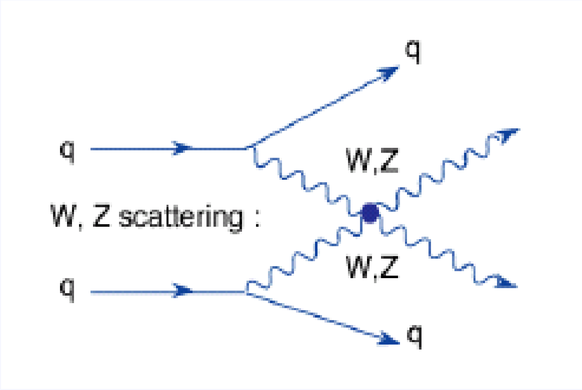


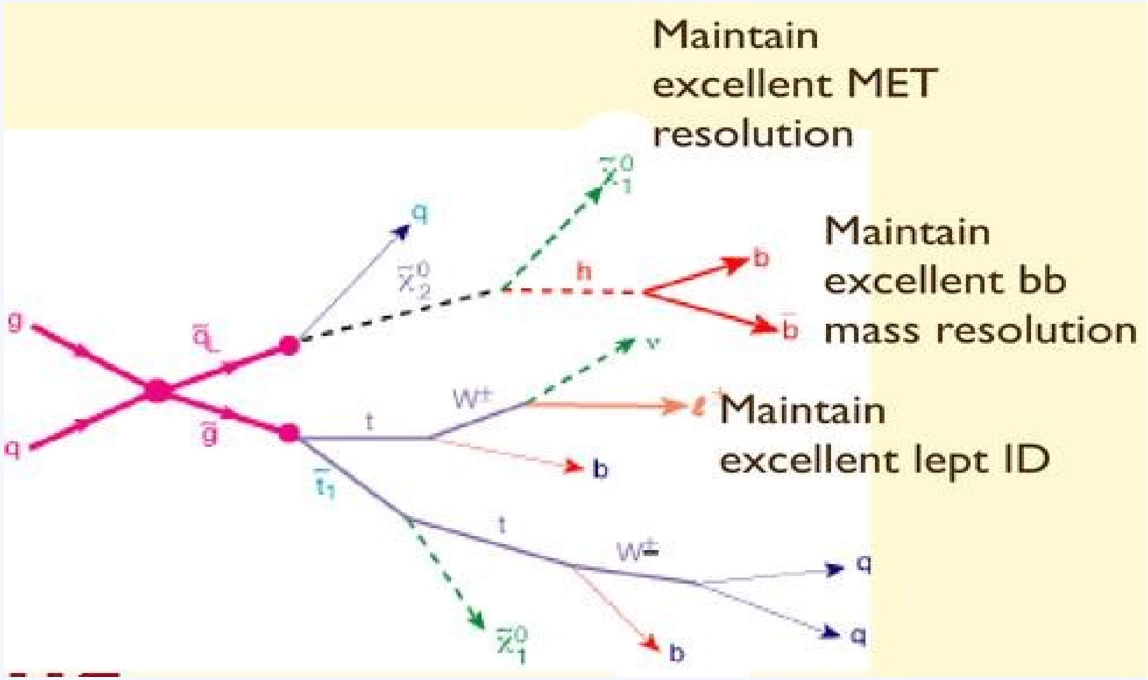


- If found, what force?
- Peak shape and asymmetries (Dittmar et al) with high statistics can distinguish between models

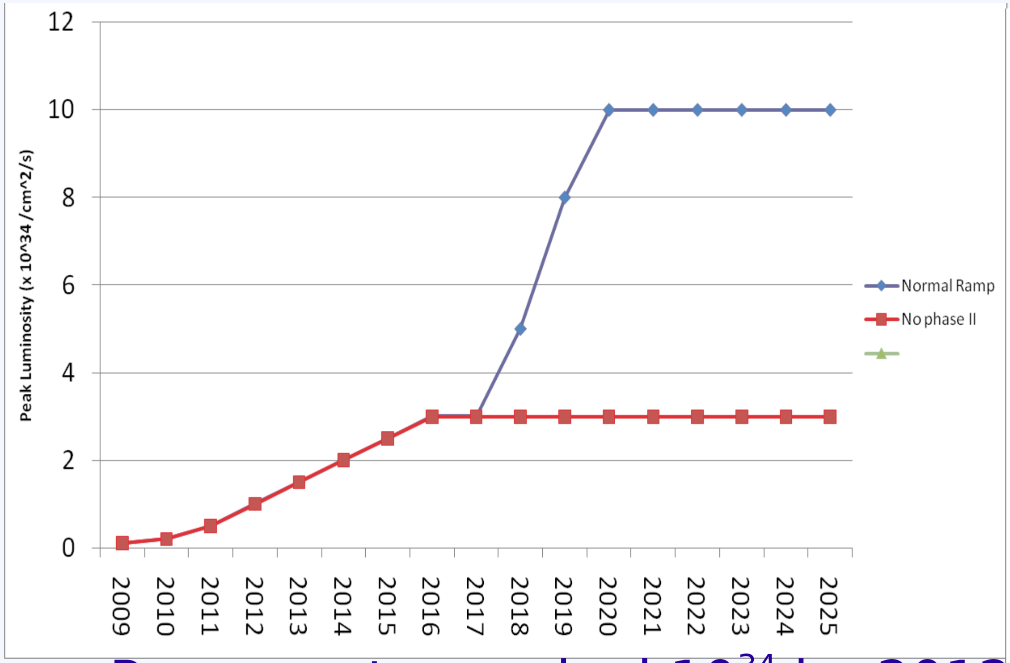
Physics Requirements for Detectors at sLHC

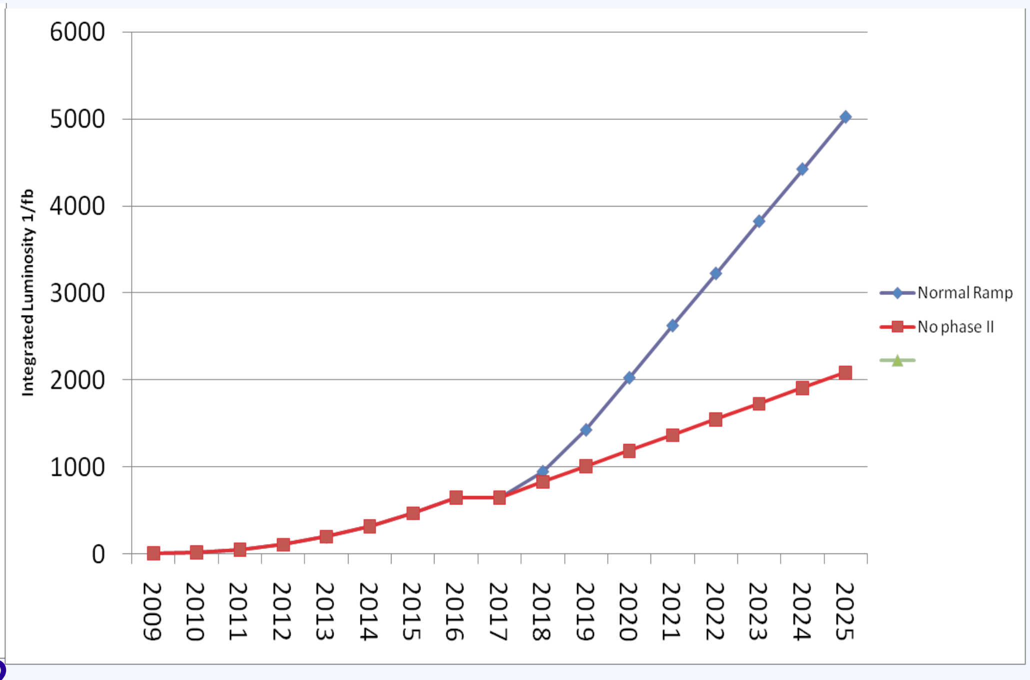
- Detector performance needs to be maintained despite the pile-up!
  - High-mass (~TeV) can tolerate some degradation; low back grounds
  - But WW scattering (Higgs couplings or vector boson fusion) needs forward jet reconstruction and central jet veto
  - Vertex, missing Et, pt resolution remain important, and efficiencies, for many channels of interest
  - Electron ID and muons for W/Z, W'/Z', and SUSY





LHC Anticipated Peak and Integrated Luminosity





- Ramp up to nominal 10^{34} by 2012
- Phase 1 starts with 6 – 8 month shutdown end 2012
  - Peak luminosity 3 x 10^{34} cm^{-2} s^{-1} at end of phase 1
- Phase 2 will start with an 18 month shutdown for detector changes at end of 2016
  - Peak 10 x 10^{34} cm^{-2} s^{-1} in phase 2
- 3000 fb^{-1} data each detector in phase 2

Schedule

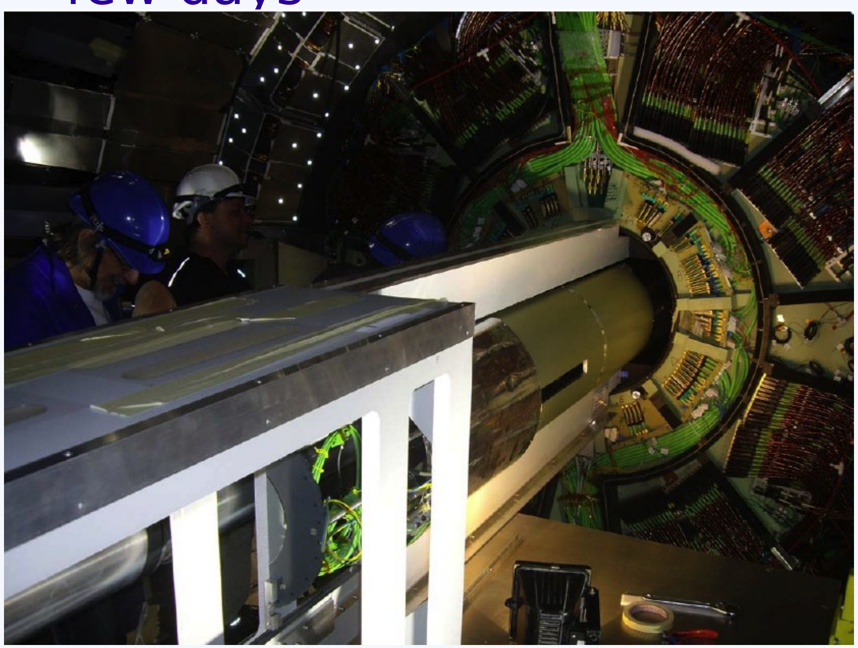
- Machine evolution may differ from the given best estimate
  - More risk to downside
  - But also possibility things can go faster
  - ATLAS and CMS Inner trackers will need replacing 2016 or soon after and these are very long timescale projects
    - Work has started, and needed to
    - Detector developers, engineers etc. are available
    - Simulation experts less so, a challenge
- Aim to pursue detector development with end 2016 as target
  - If more time becomes available, of course we should benefit using more advances in detector technology
- Need experience of running detectors and seeing detector performance
- Need physics results
- Aim for Technical Proposals (with options) for detector upgrades in 2010 and tracker TDRs 2011 – or difficult to meet 2016

Detector Plans – Phase 1

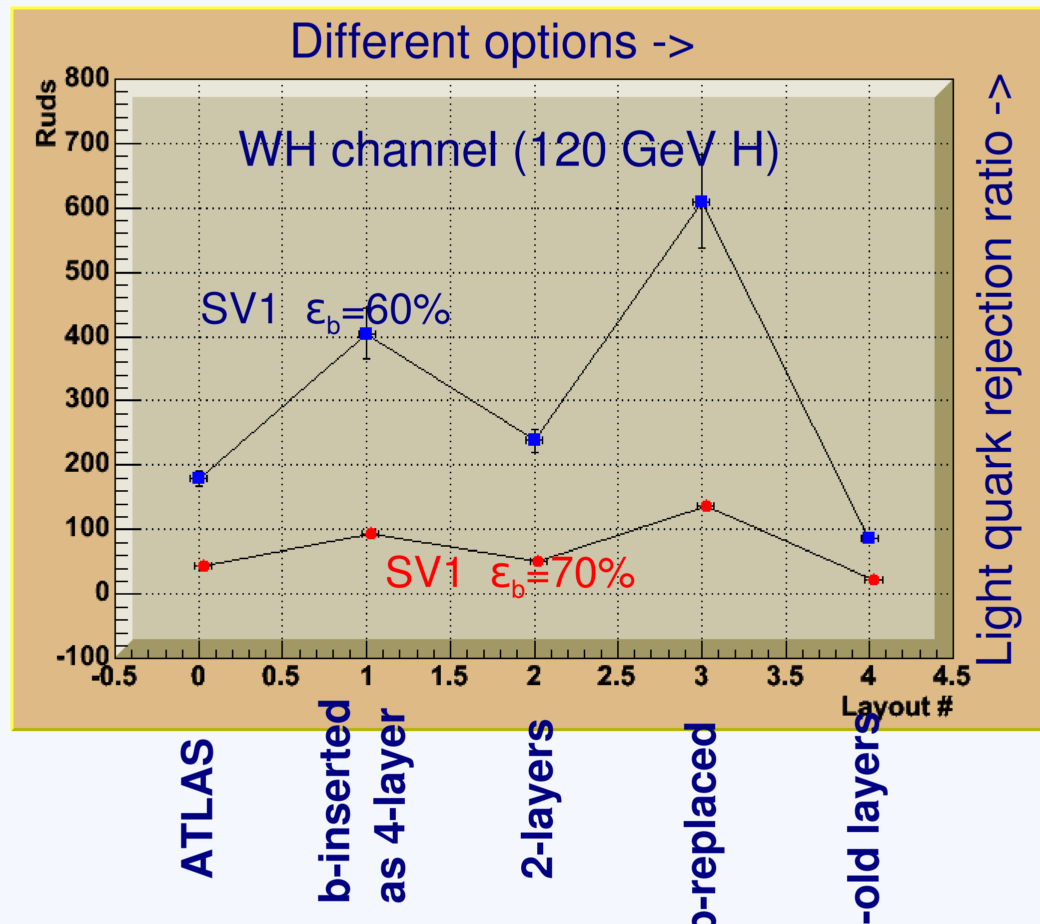
- Limited time for installation – 6 to 8 months in 2012/13 shutdown
- Small increase in peak rate above previous estimates (2 --> 3 x 10^{34})
- Total integrated luminosity similar to previous expectations ~700 fb^{-1}
  - Limited changes needed; some completion of staged items e.g. CMS muons
- Main changes are in pixels, where B-layers reach radiation limit and high rates cause lost hits
  - CMS hope to replace the whole pixel detector; at least the B-layer
  - ATLAS pixel takes ~ 1 year to replace B-layer
    - Instead ATLAS will insert a new B-layer inside the current detector, along with a new smaller diameter beam pipe, in 2012/13 shutdown
- TDAQ
  - Both experiments will continuously upgrade TDAQ to cope with rates and take advantage of new processing power
  - Both will look at topological triggers – combining different trigger elements, e.g. muon with no jet
  - Other ideas e.g. fast track finding (associative memory) at LVL2

Phase 1 changes - Pixels

- CMS investigate options from b-layer only to 4 layers instead of 3, 130 nm readout chips with DC-DC converters (twice as many modules as now)
- Can insert and connect in few days



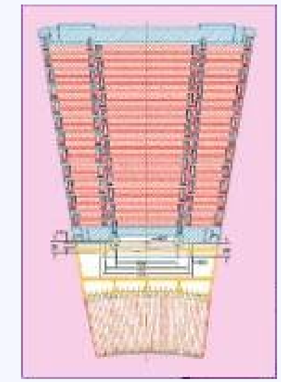
- Atlas can maintain or improve vertexing inserting new B-layer:
  - Smaller b-layer radius 50 --> 37 mm; smaller pixels (400 --> 250 micron long) beats extra material

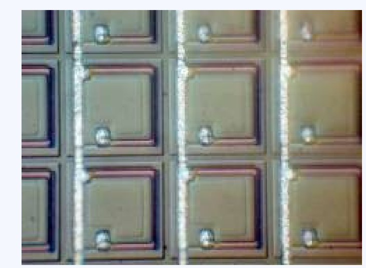


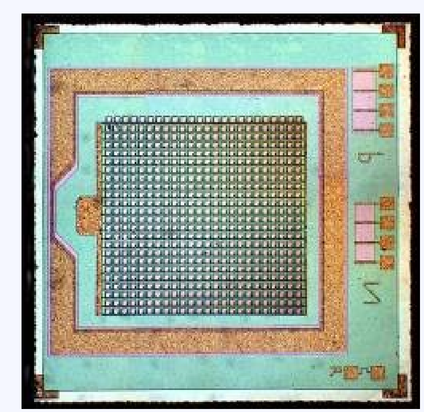
SiPM for CMS Tile Calorimeter

- Currently tower all added together – no possibility to allow for darkening of front layers
- Dynamic range of hybrid photo multipliers insufficient for muons and noise issues
- Replace with SiPM (avalanche photo diodes)
  - No noise
  - Big dynamic range
  - Keep fibres, can retrofit fast
  - More possibilities for segmentation

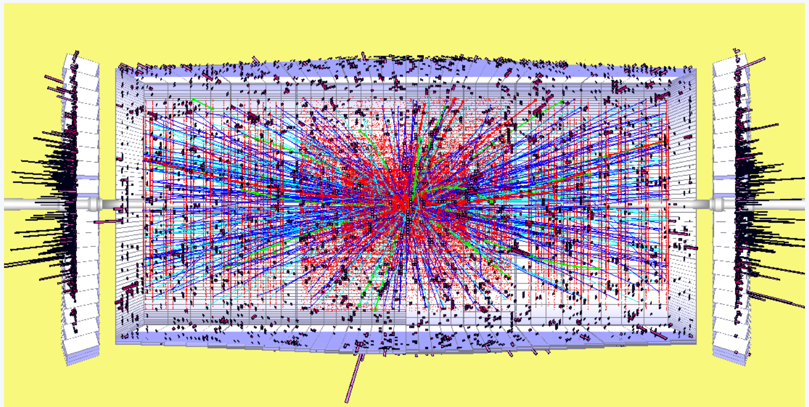
~17 layers alternating brass and scintillator

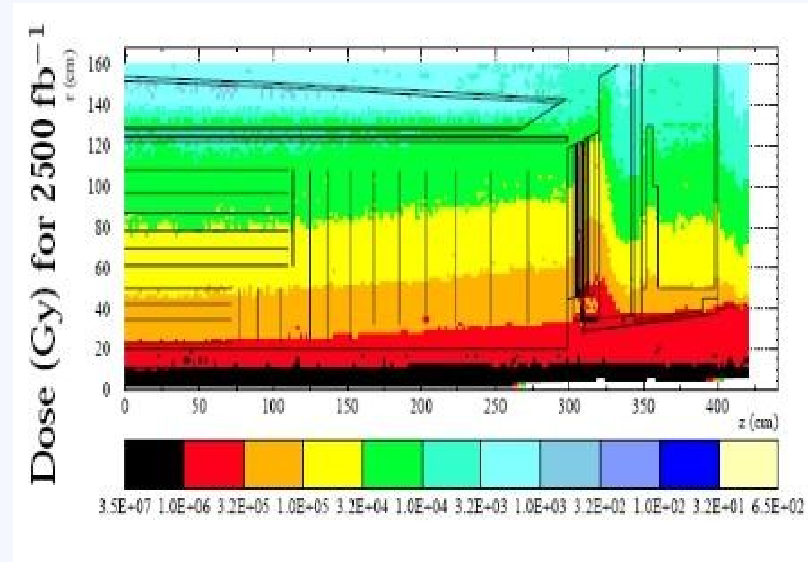




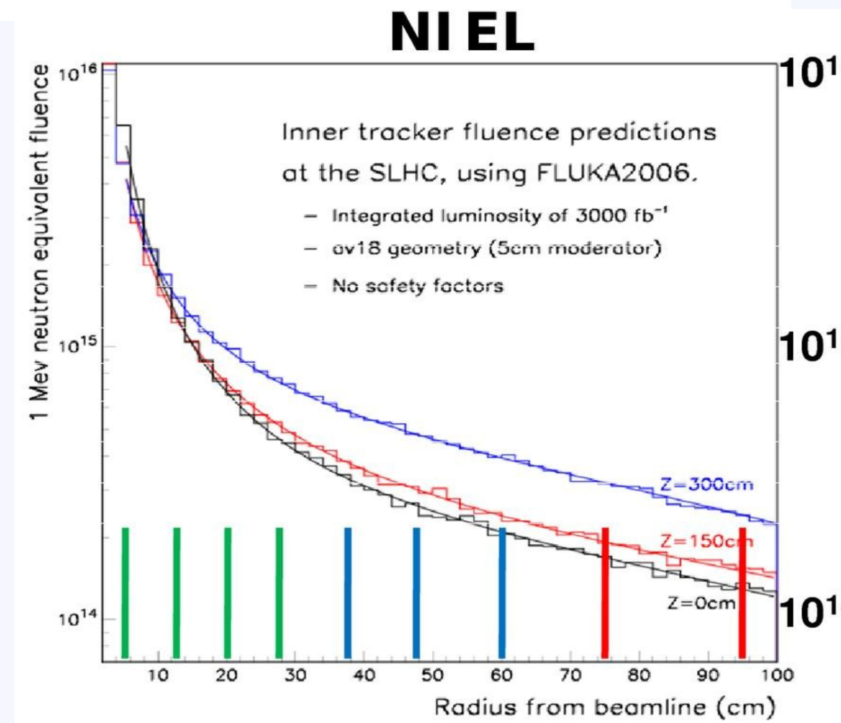


What are the conditions at Phase II/sLHC?





- 300 – 400 pile-up events at start of spill (unless luminosity levelling)
- Want to survive at least 3000 fb^{-1} data taking
- B-layer at 37 mm:
  - ~30 tracks per cm^{-2} per bunch crossing
  - Few 10s of MGray
  - $>10^{16}$ 1 MeV n-equivalent non-ionising

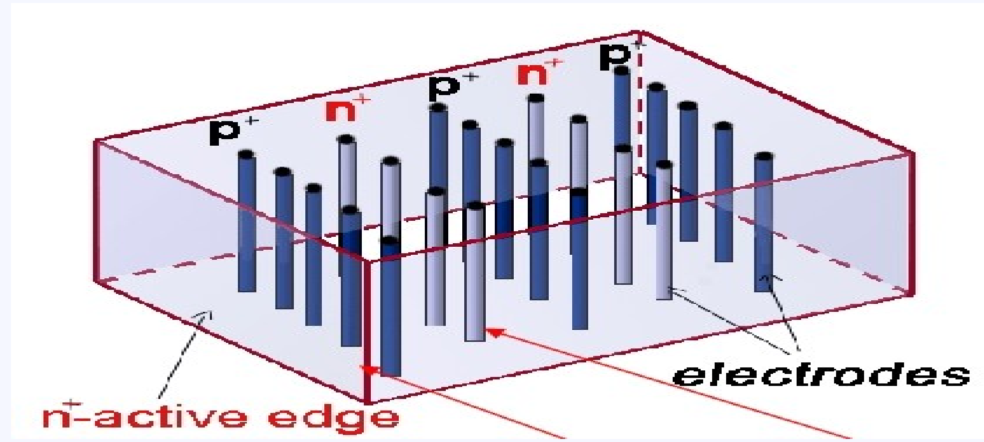


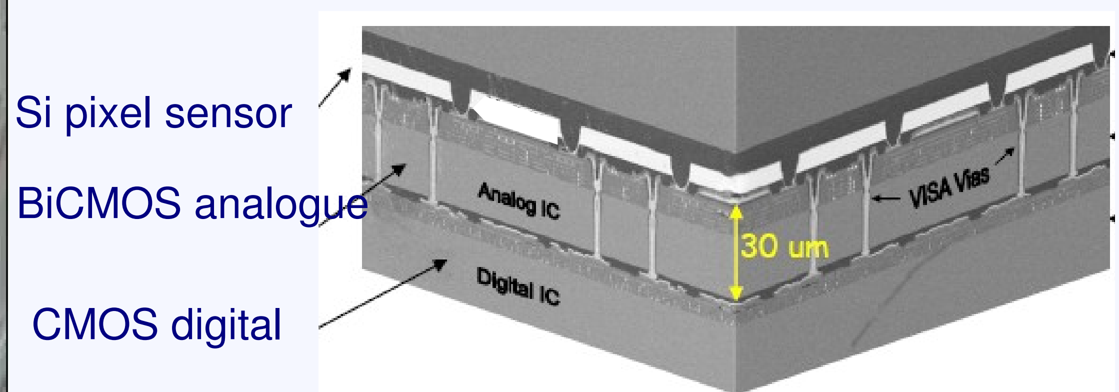
Detector Changes for Phase 2

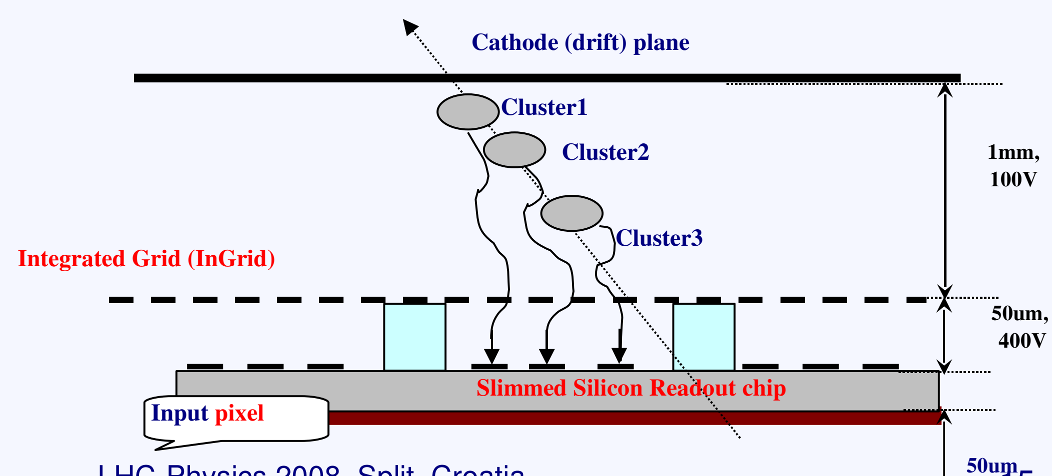
- Most of ATLAS and CMS will cope well at sLHC
  - Keep magnet systems, most parts of muon systems and calorimeters
  - But inner trackers in both experiments need complete replacement
    - Radiation damage limit will have been reached
      - Need to replace them even if no sLHC!
    - Higher rates cause dead time (e.g. ATLAS TRT)
    - Need finer granularity detectors for good pattern recognition
  - And parts (especially electronics) of all systems need upgrading, even if most of the basic detector parts remain

Inner detectors - B-layers

- Most challenging for track density, radiation damage, SEU
- Highest requirements: efficiency, coverage, position resolution
- Sensors: current planar-Si sensor technology is not rad-hard enough to survive to end of sLHC. Either new sensors, or replace every few years
  - 3D silicon, thin silicon, diamond, MPGD (Gossip) as alternatives
- Smaller beampipes --> b-layer closer to beam

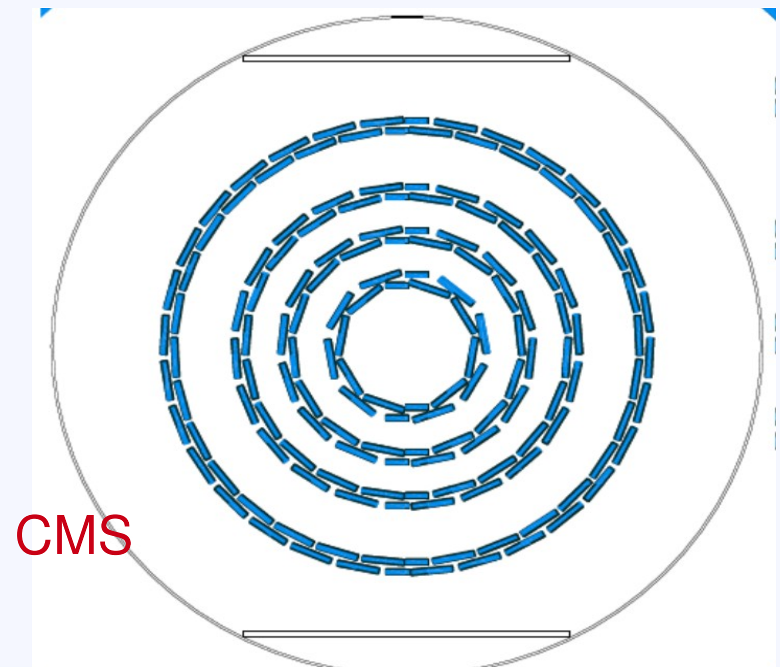


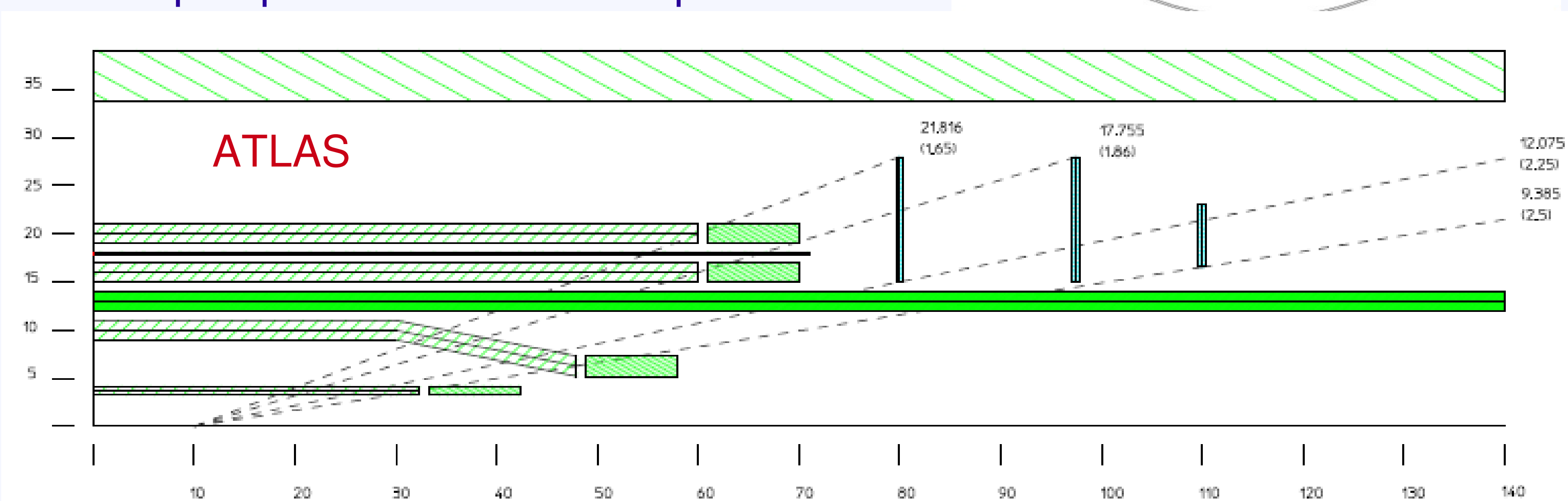




Pixel Detectors

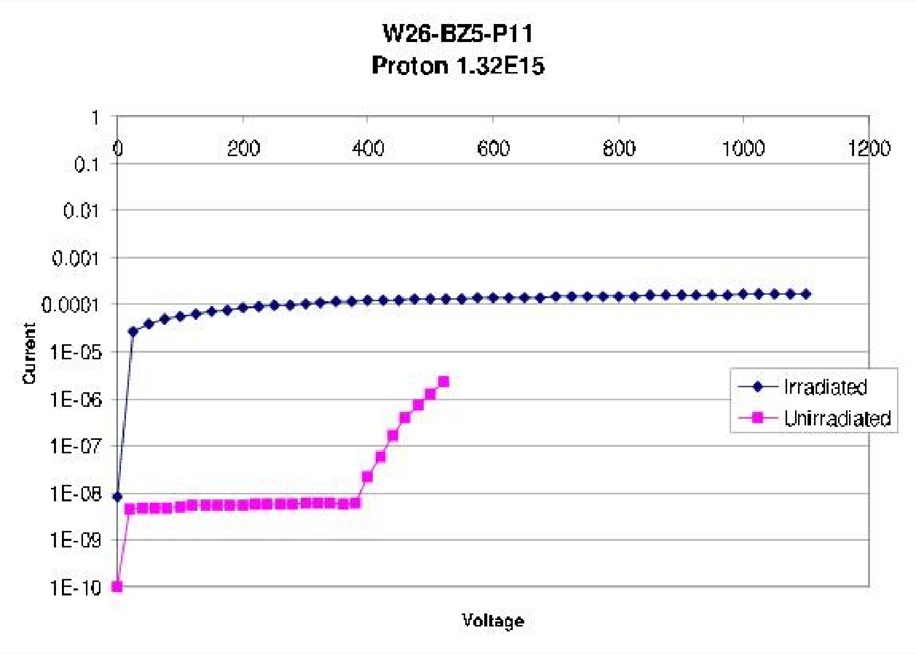
- Read-out architecture and front-end chips under development
  - 130 nm; low power; minimum pixel length; high data rates
- High power levels -> look at new cooling, including CO2
- Lighter mass supports and services?
- Cheaper production – more pixels?

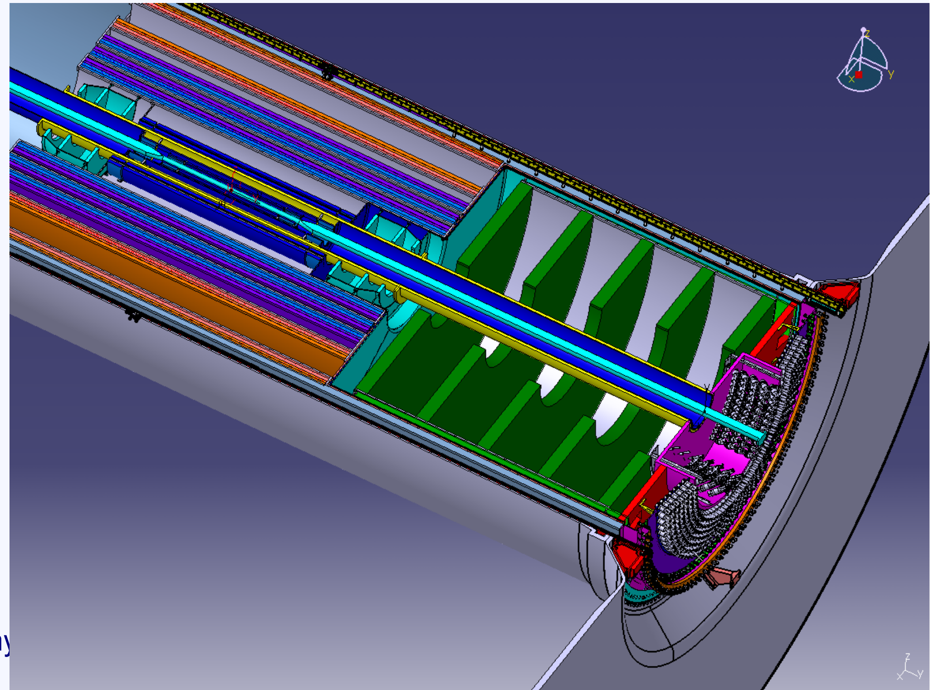




New Strips Detectors

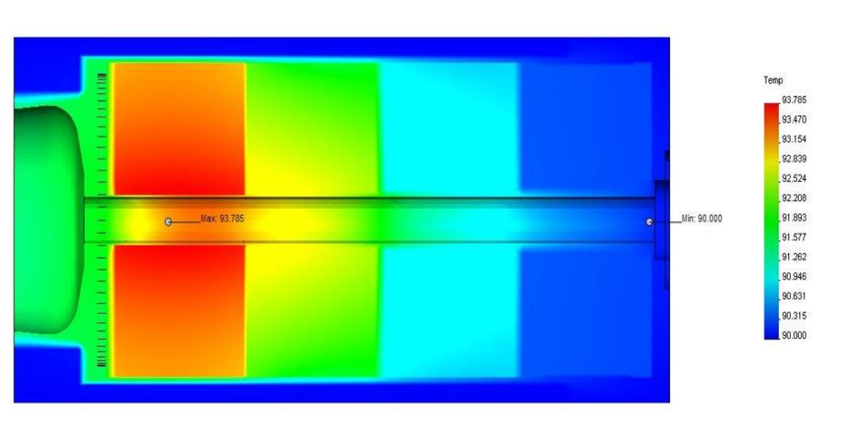
- Switch to n-in-p sensors
  - At high dose, may not achieve full depletion
  - Still have readout junction in the depleted region, no big signal loss
  - Prototype sensors reach 1000 V after irradiation -> good charge collection efficiency
- Short strips (~25 mm) at inner region for lower occupancy or strixels
- Mechanics and assembly
  - low radiation length
  - Rapid installation: insert complete ID's (new for ATLAS)
- Powering: Serial or DC-DC *must*
- High speed, low power, low mass data transfer





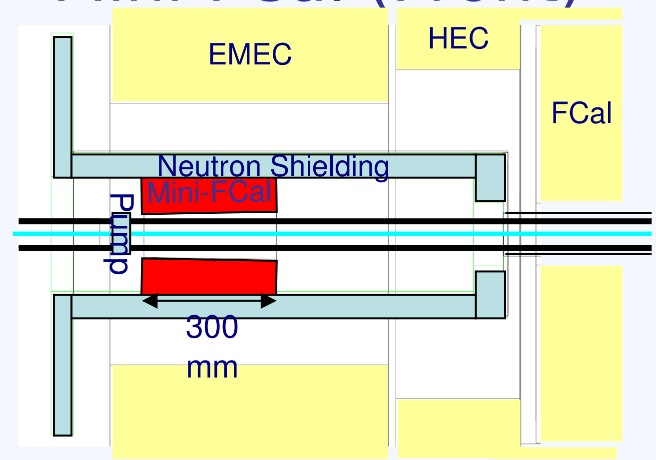
Electromagnetic Calorimeters

- Most regions of both experiments perform very well at sLHC
  - Optimise signal processing for higher pile-up
- Some CMS crystals and VPT may darken as function of integrated luminosity, starting from high eta regions inwards
  - Difficult to access



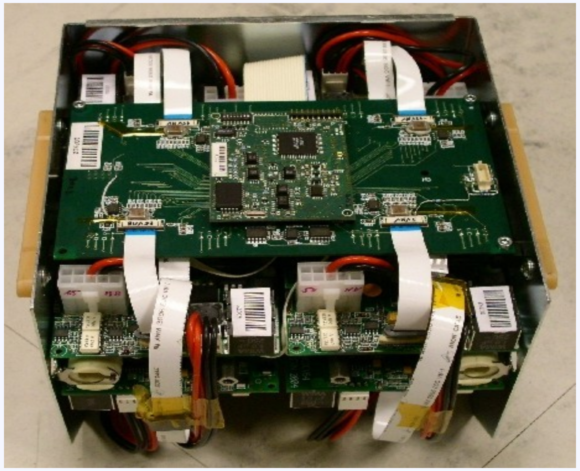
- ATLAS forward calorimeter may suffer a number of problems:
  - Boiling of LAr, ion build up between electrodes, voltage drop over HV resistor
  - Studies underway; If these show action is needed, two solutions considered:
    - Warm calorimeter in front of current calorimeter
    - Open cryostat, insert complete new FCAL with smaller gaps and more cooling

Mini-FCal (Front)



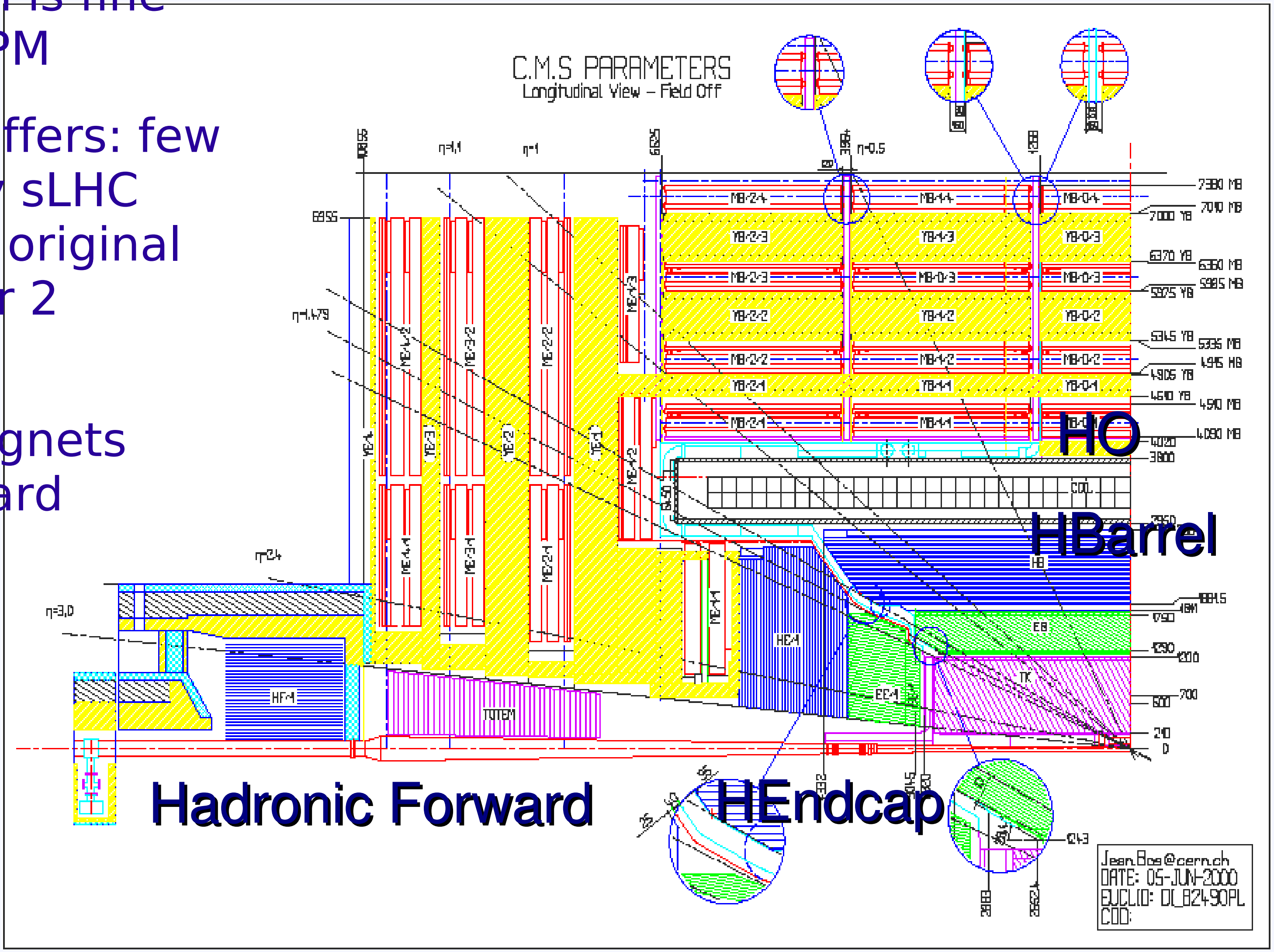
Hadronic Calorimeters

- Atlas tiles, fibres, PM: expected to survive
  - Small decrease in performance after 7 years LHC running
  - Even at the end of sLHC running they will be working fine - though worst regions may have significantly less light
  - So do not expect major detector parts to be changed
- ATLAS Readout Electronics: rad hardness, maintainance, trigger needs - all benefit from new readout
- Power supplies – rad hardness and repairability issues so replacement plans



Hadronic Calorimeters - CMS

- Most of hadron cal is fine especially with SiPM
- Forward region suffers: few towers blacked by sLHC (tower 1 ~ 4 % of original light output; tower 2 ~23%)
- Also, machine magnets ("D0") block forward calorimetry

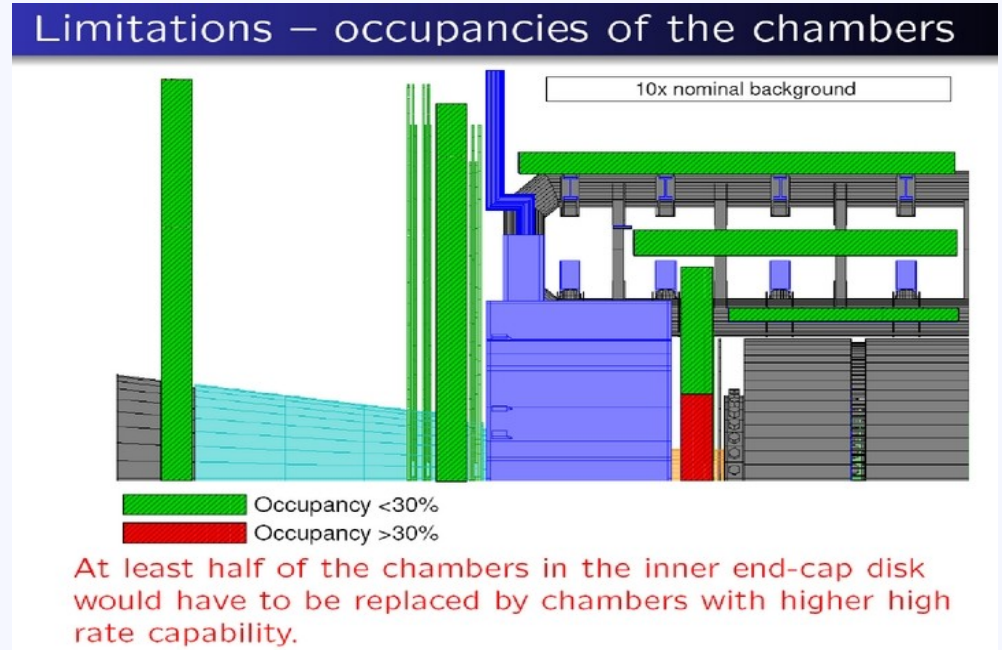


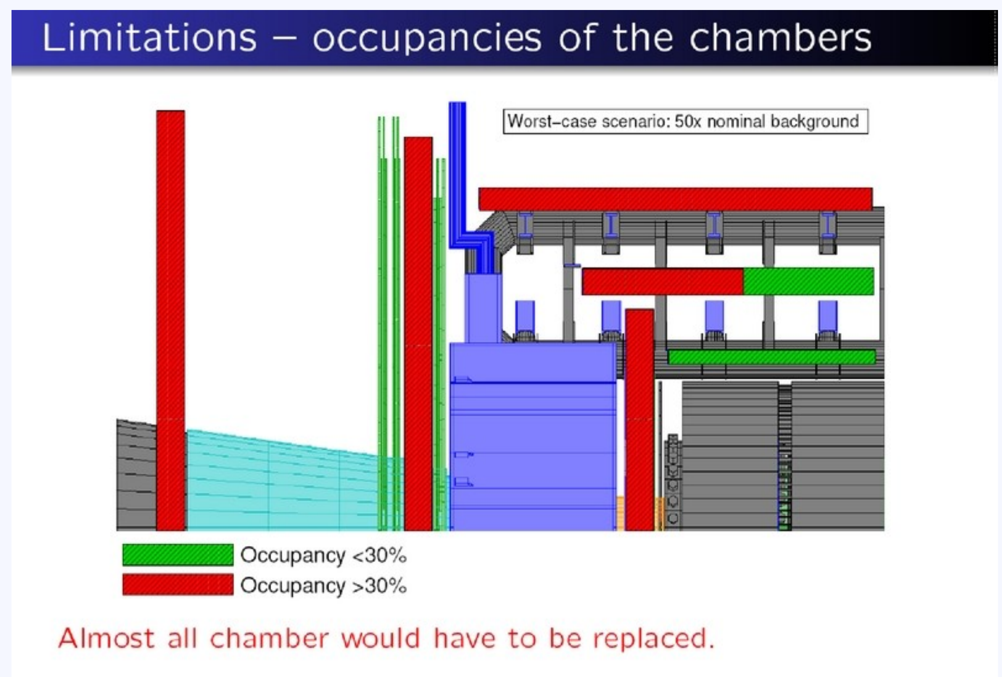
Muon Systems

- CMS has a lot of shielding, rate probably OK for current chambers
  - Need to see backgrounds to confirm; possibly $\eta > 2$ need changing, or limit trigger region to below this
  - New readout electronics? FPGA not rad hard enough
- ATLAS air core toroids have higher backgrounds; need to replace forward chambers (CSCs mainly) at nominal background.
  - Very important to measure actual background to see how much of "safety factor 5" is used up to see if significantly more needs replacing
- Both experiments are looking into improved shielding
  - Difficult : current design is highly optimised
  - Other possibility is to develop single chambers to do both triggering and precision read-out: thinner chambers leave more space for shielding
    - TGC's or Micromegas for ATLAS

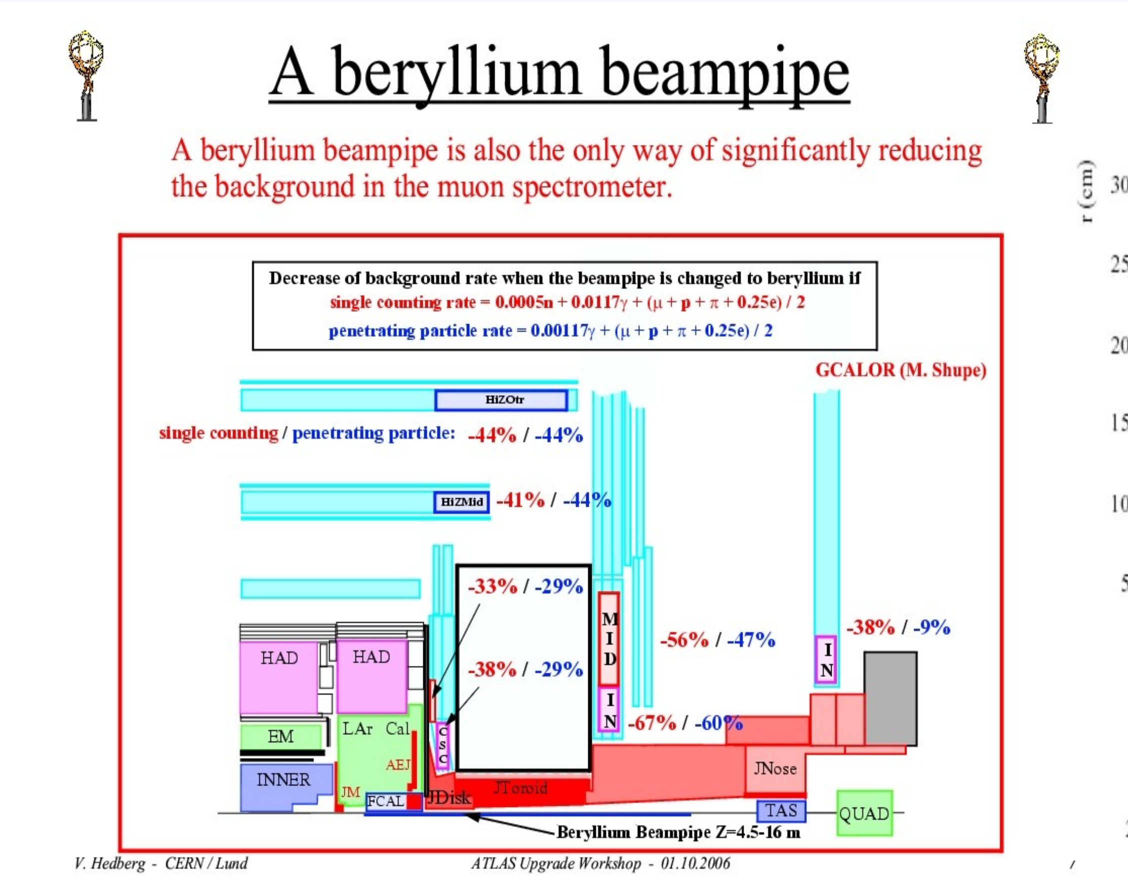
ATLAS Muon Chamber Replacement Range

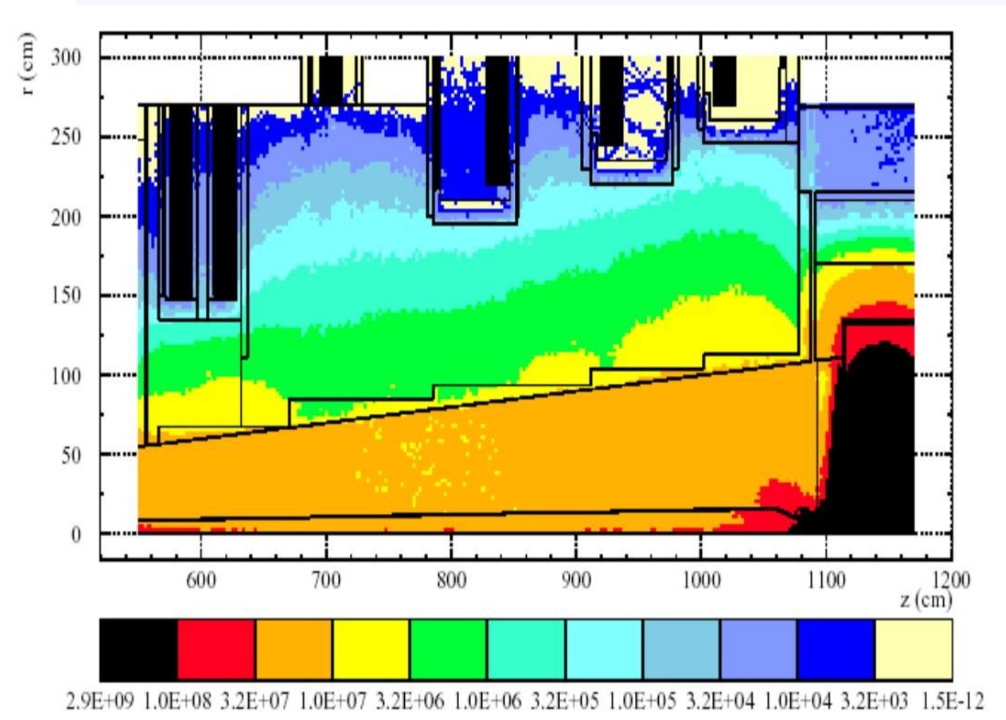
- Depending on backgrounds, either minimal or very large fraction of Atlas muon system needs replacing, unless backgrounds can be reduced (in relation to luminosity)
- Both Atlas and CMS have to wait for data





Beam-pipe and shielding





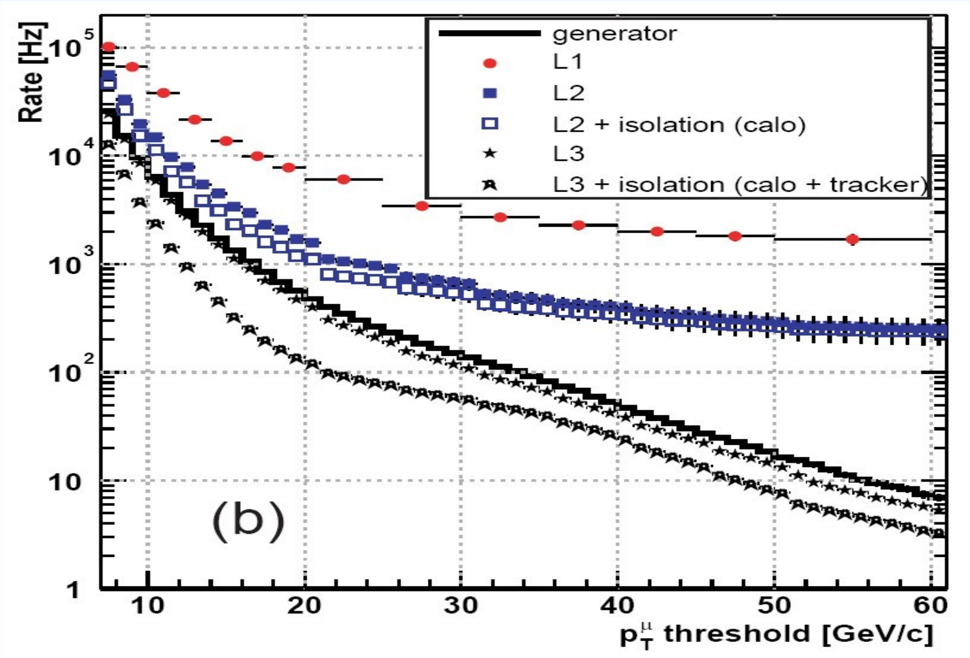
- All-Be beam pipe reduces muon BG considerably
    - Expensive beampipe, but **much** cheaper than new muon chambers
- CMS consider more shielding to $\eta = 2$
    - Add borated polythene; better shielding of PMTs

Triggers

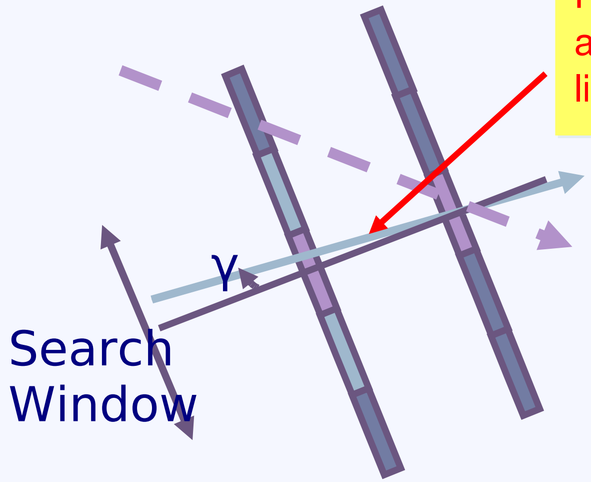
- In both experiments the goal is to maintain trigger rates.
  - Still challenging! You have to reject 10 times more events at LVL1, and process much more data at LVL2 (pile-up --> bigger events)
- Continuous process of replacing and increasing processor hardware
- Consider increasing level-1 latency: the time available to actually run the trigger increases rapidly as LVL1 latency increases

Track triggers at Level-1

- Muon trigger rate ~constant above ~20-30 GeV/C; both ATLAS and CMS
- Cannot improve muon situation at CMS; difficult at ATLAS (new muon trigger chamber layer with higher resolution?)
- Several ideas CMS and ATLAS to investigate inner tracker triggers
  - both P_t and vertex displacement triggers

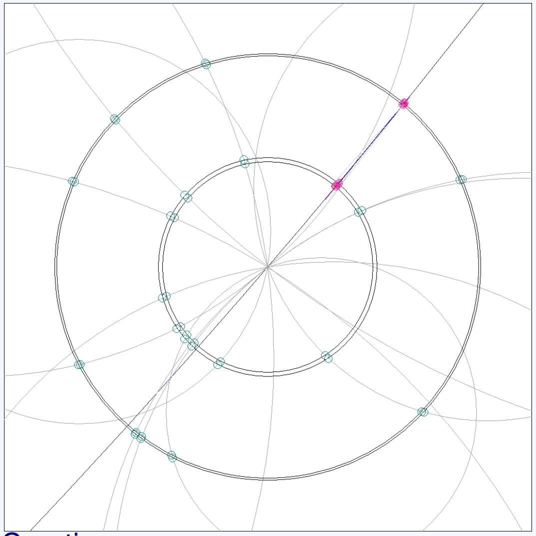


CMS muon trigger rate



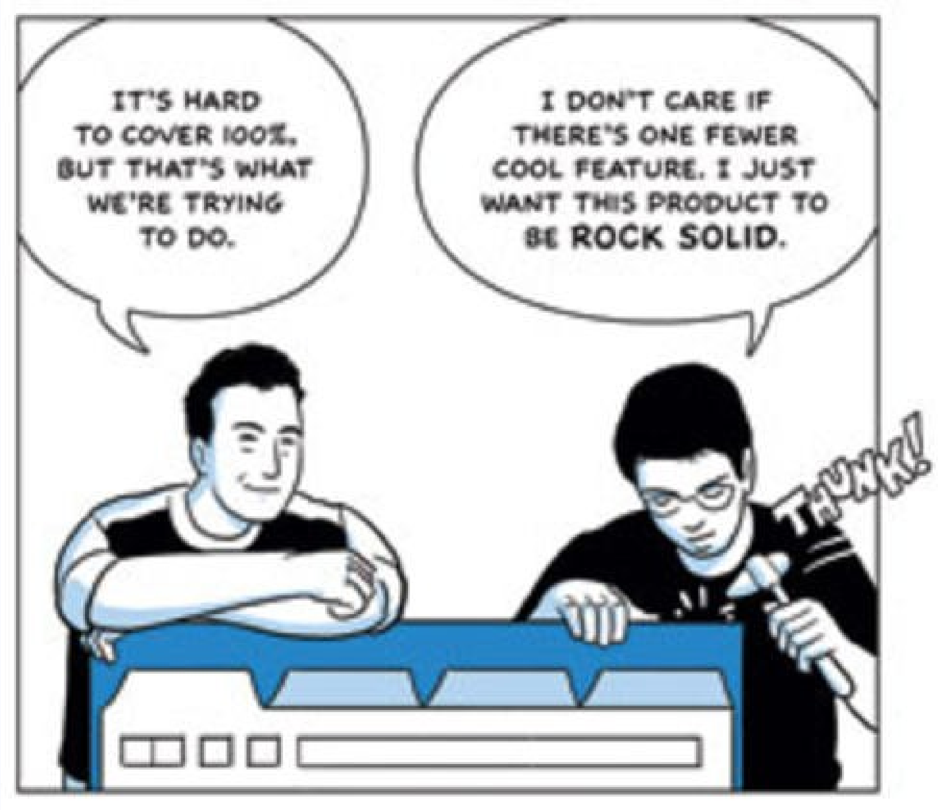
High momentum tracks are straighter so pixels line up

Pairs of stacked layers can give a P_T measurement



Summary

- There is every hope there will be a rich field of physics to explore at the LHC into the 20's
  - Need LHC results
- The LHC expects
  - Phase-1 upgrade 2012 leading to 3 x 10^{34} cm^{-2} s^{-1} peak luminosity
  - Phase-2 upgrade starts end 2016 leading to 10 x 10^{34} cm^{-2} s^{-1} peak luminosity
- Atlas and CMS require major upgrades (even without Phase-2) installed in long shutdown 2017
- R&D underway to meet the challenges
  - Need experience with current detectors



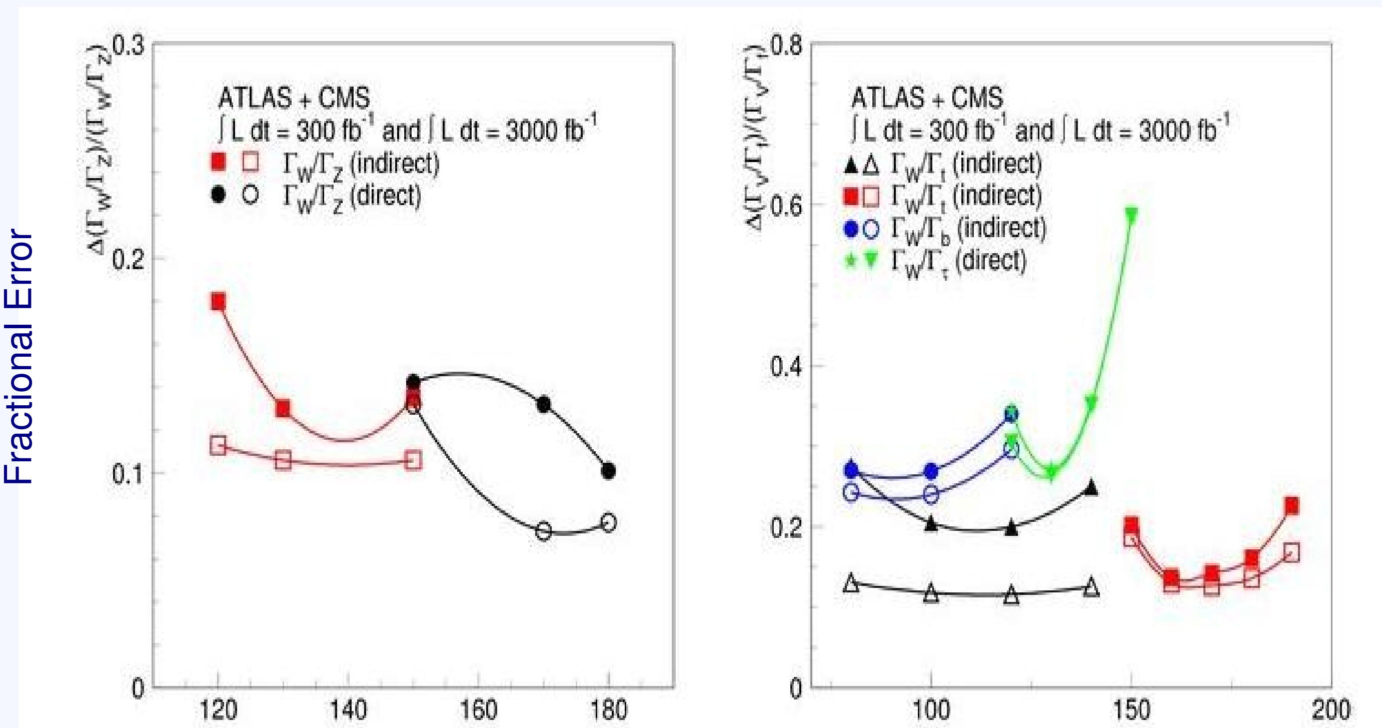
This project has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement nº212114

backup slides

If Higgs Found

- Measure (ratios of) BR to less common states
- Deviations from SM → new physics
- Some are systematics-limited already at LHC, but significant improvement in others

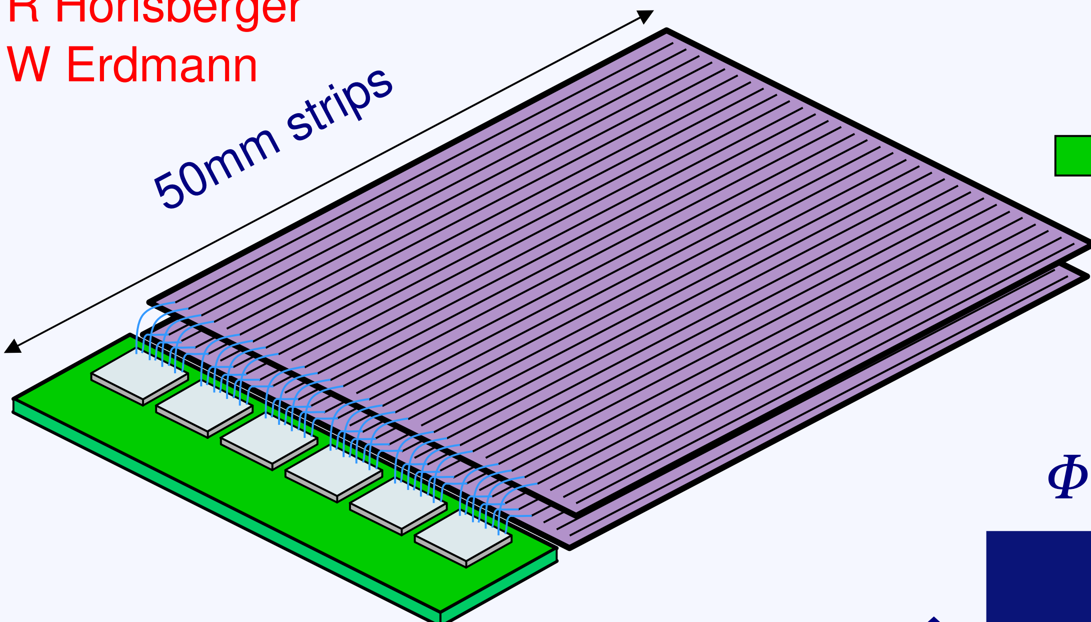
Fractional Error

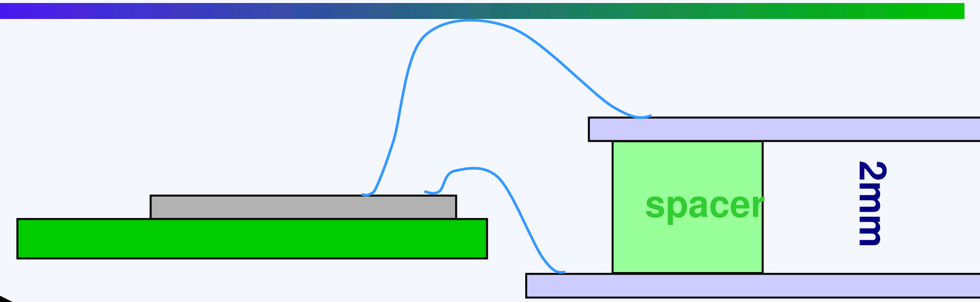


Higgs Mass (GeV) →

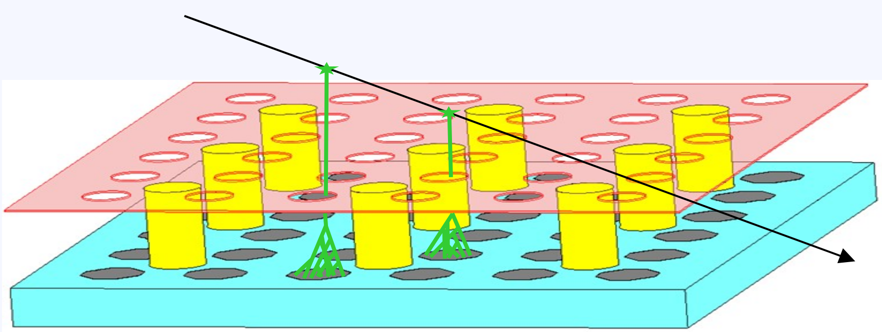
Other track trigger ideas…

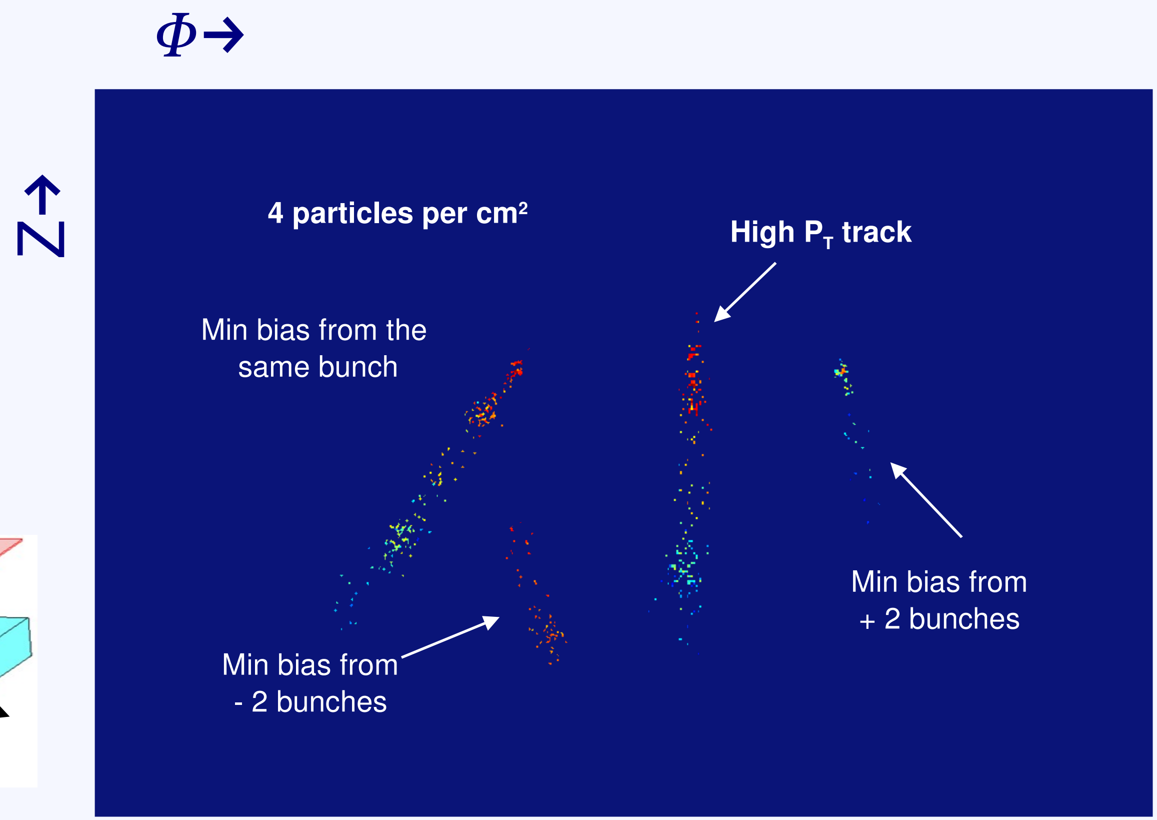
R Horisberger
W Erdmann





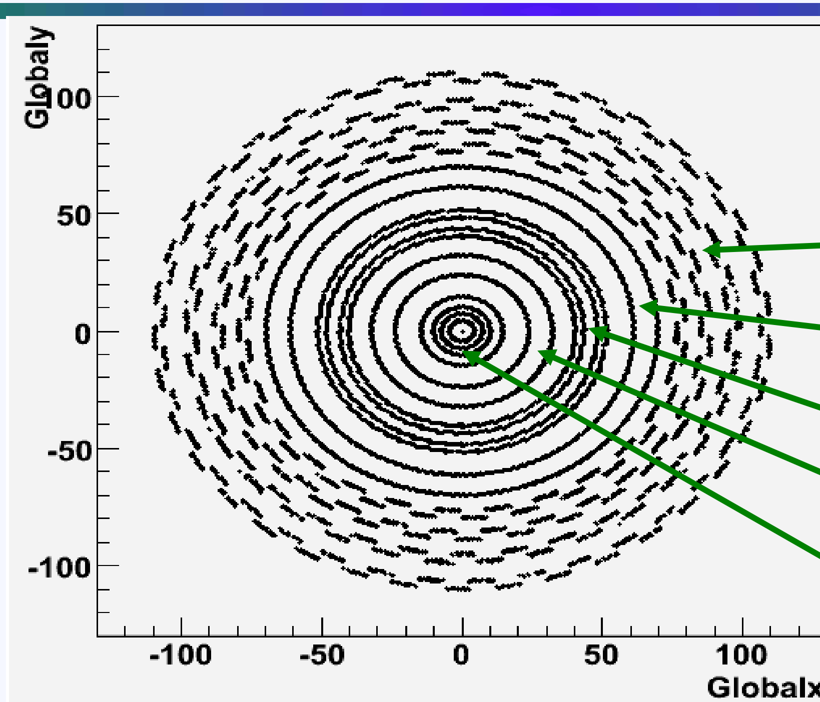
A Romaniuk et al – micromegas using InGrid on pixel readout, 17 mm drift gap at outer radius of inner tracker
Can give good Pt for trigger





ID Layouts: More granularity

- CMS
  - More layers; reduction under investigation



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

4 TOB short strips
Remove 2
2 TOB strixels
Adjust chn count
2 TIB short strips
Remove 1
2 TIB strixels
Adjust chn count
4 inner pixels

- Atlas
  - 4 pixels
  - 3 double SS
  - 2 double LS