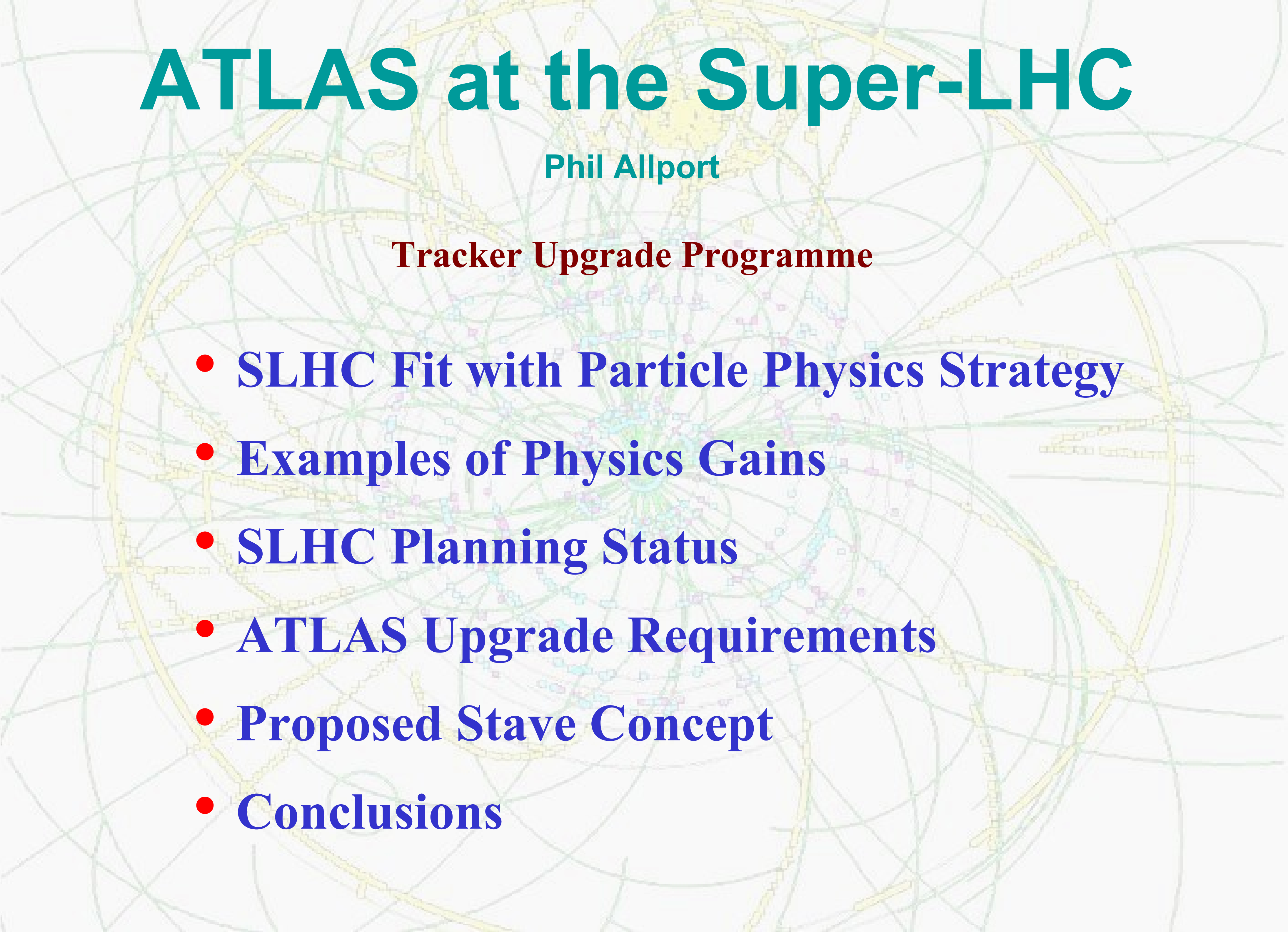


ATLAS at the Super-LHC

Phil Allport

Tracker Upgrade Programme

- SLHC Fit with Particle Physics Strategy
- Examples of Physics Gains
- SLHC Planning Status
- ATLAS Upgrade Requirements
- Proposed Stave Concept
- Conclusions

SLHC Fit with Particle Physics Strategy

Particle physics is involved in key programmes helping address these fundamental questions

- The Properties of the Strong Nuclear Force

  HERA → ALICE (LHC+Upgrades) → ILC + LHeC
- The Origin of the Matter–Anti-matter Asymmetry in the Universe

  BaBar → LHCb(+Upgrades) + T2K → b + ν Factories
- The Unification of Particles and Forces Including Gravity

  Tevatron → ATLAS + CMS (LHC) → ILC + SLHC
- The Origin of Mass

  Tevatron → ATLAS + CMS (LHC) → ILC + SLHC
- The Properties of Neutrinos

  SNO → Minos → T2K → ν Factory + $0\nu\beta\beta$

(Here SLHC means pp at 10×LHC Luminosity)

Examples of Physics Gain

(Physics case for **10 × luminosity** much better known after LHC start-up.)

See Eur. Phys. J. C39(2005)293

- Precision Standard Model physics with 10 × data (sensitive to new physics)
  - Higgs couplings
  - Triple and quartic gauge couplings
  - Strongly coupled vector-boson scattering (if there is no Higgs)
  - Rare top decays through FCNC

- Extended mass reach for new particles (by ~0.5 to 1 TeV):
  - Heavy Higgs-bosons, extra gauge bosons, resonances in extra-dimension models, SuperSymmetry particles (if relatively heavy).

- SuperSymmetry (if relatively light, already discovered at LHC)
  - complete the particle spectrum
  - access rare decay channels and measure branching ratios
  - improve precision (e.g. to test against WMAP results)

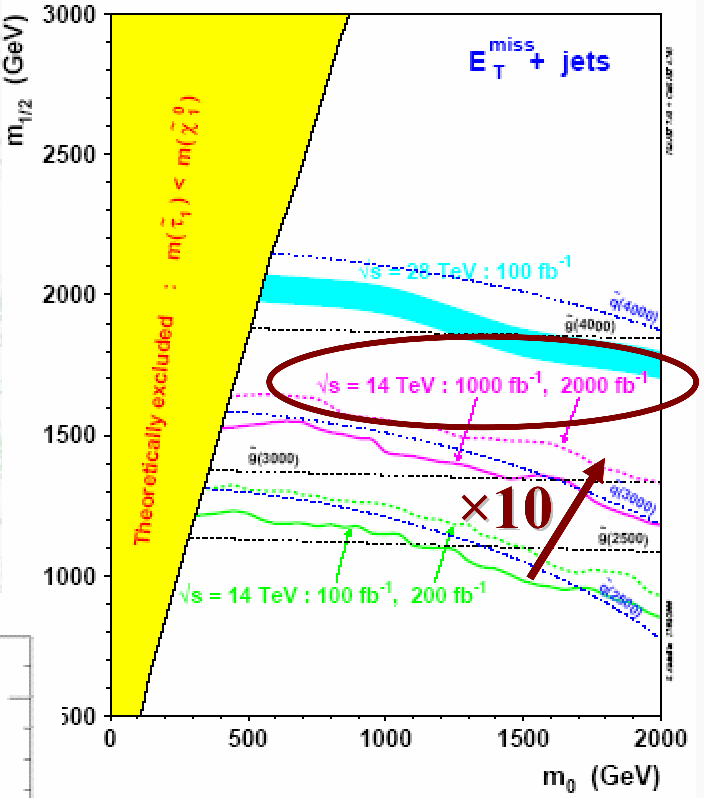
- Because of statistics and mass reach, SLHC is to a large degree complementary to the ILC − only LHC/SLHC can pair produce particles with mass ≥ 0.5 TeV.

Examples of Physics Gain

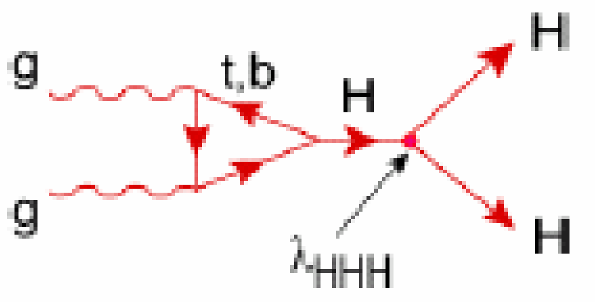
Assumed SLHC Operating Parameters

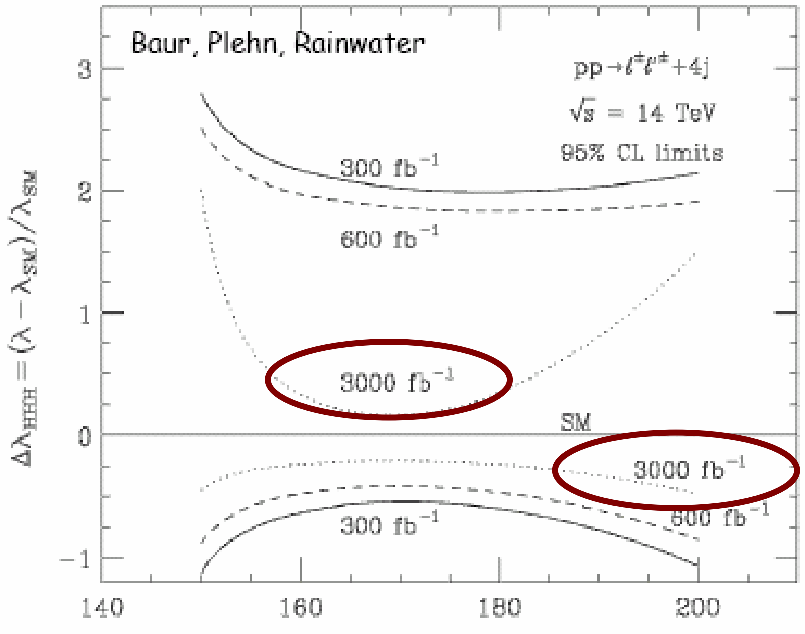
	LHC	SLHC	
$\sqrt{s}$	14 TeV	14 TeV	
Luminosity $\mathcal{L}$	10^{34} cm^{-2}s^{-1}	10^{35} cm^{-2}s^{-1}	
Bunch spacing Δt	25 ns	12.5 ns	assumed here (see below)
σ_{pp} inelastic	$\sim$ 80 mb	$\sim$ 80 mb	
Interactions/Xing N	$\sim$ 20	$\sim$ 100	
dN$_{ch}$/dη per X-ing	$\sim$ 150	$\sim$ 750	
$< E_T >$ charged particles	$\sim$ 450 MeV	$\sim$ 450 MeV	

Interactions/Xing: $N = \mathcal{L} \times \sigma_{pp} \times \Delta$



Improved mass reach for discovery of SuperSymmetry by ~500GeV (50%) with increased luminosity



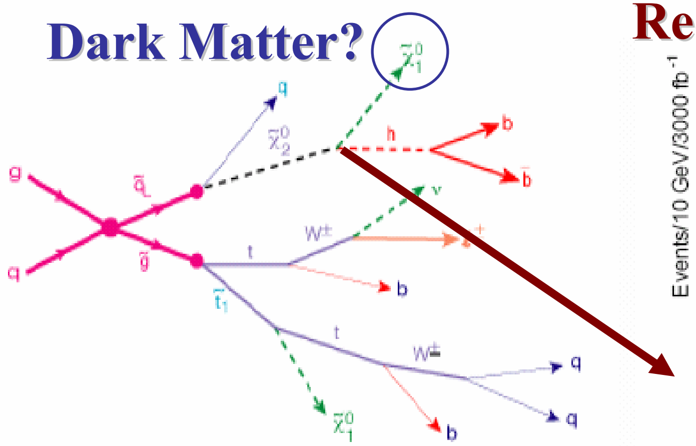


Sensitivity to variation from SM predictions for Higgs self-coupling

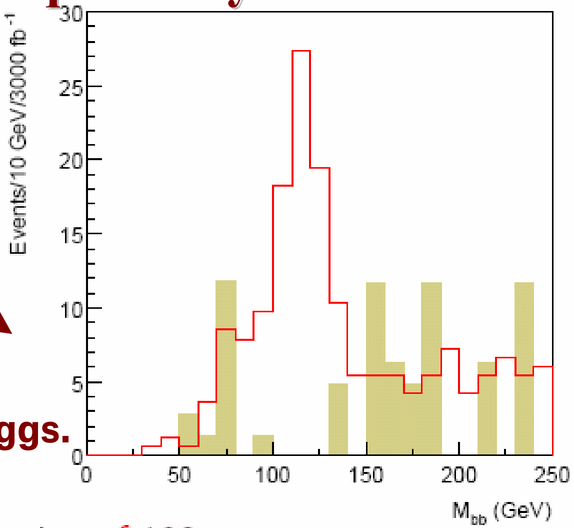
Examples of Physics Gain

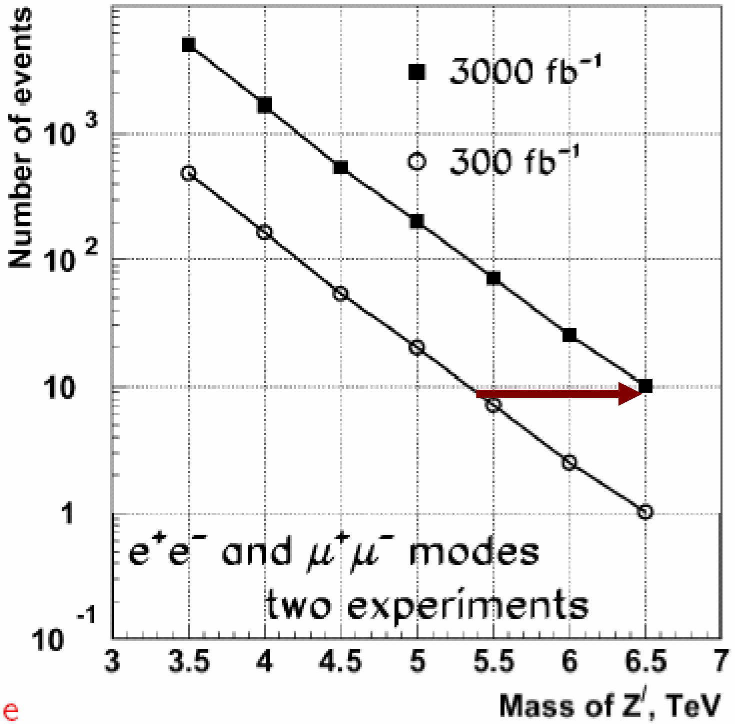
Require two b-tagged jets and reconstruct peak from $h \to bb$ decay

Dark Matter?



Requires 5 years of SLHC

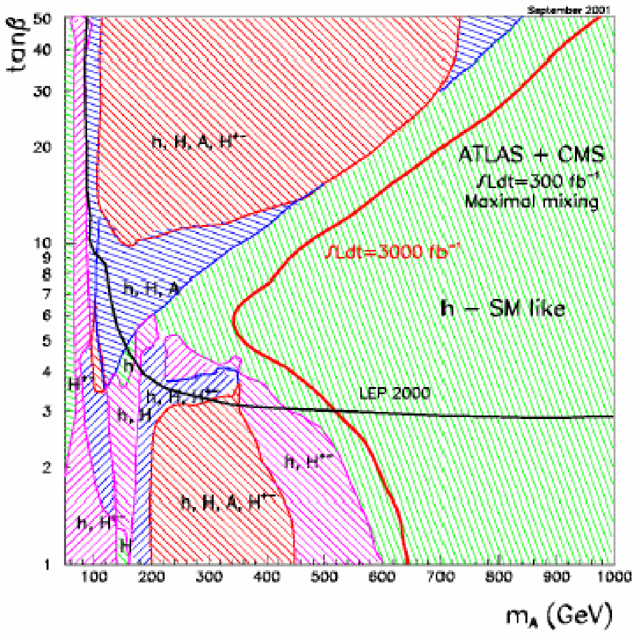




Measure coupling of neutralino to Higgs.
Determine its higgsino component.

Plot assumes $\epsilon_b = 60\%$ for light jet rejection of 100

In green region with 300 fb^{-1} per experiment only SM-like Higgs observable



If only one Higgs observed:

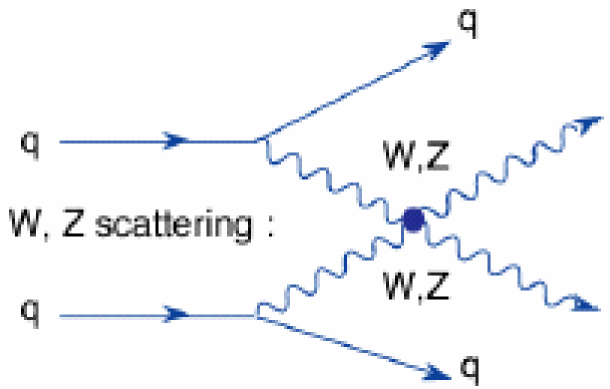
Difficult to distinguish MSSM from SM

Loose main handle on $\tan\beta$ measurement

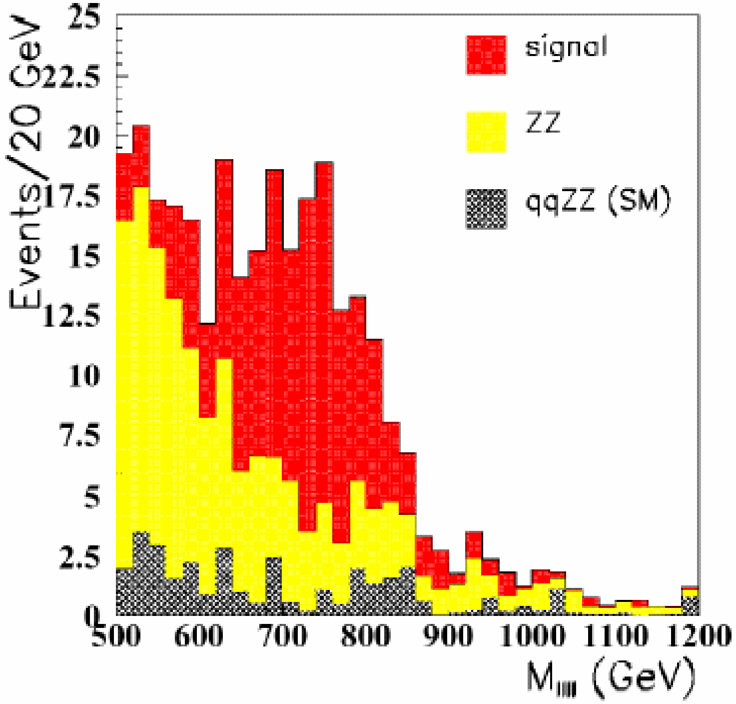
Red curve shows the 5σ discovery limit for an additional heavy higgs for an integrated luminosity of 3000 fb^{-1} per experiment

Improved exploration of SuperSymmetry parameter space and greater sensitivity to any new resonant state *eg* heavier version of Z^0

Examples of Physics Gain

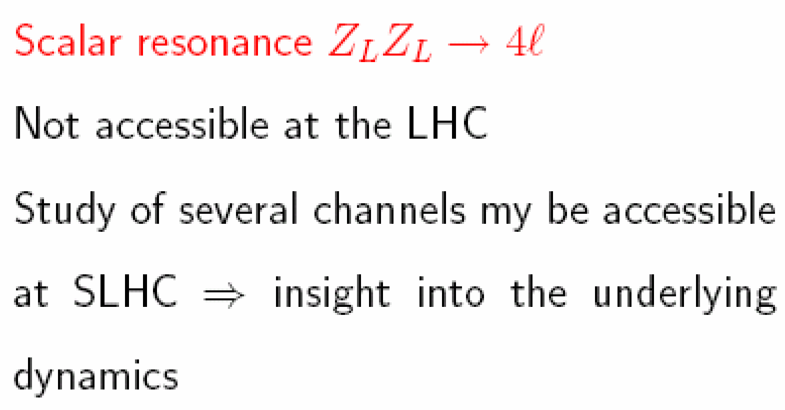


Requires 5 years of SLHC



In absence of clear Higgs at LHC, SLHC statistics could be needed to probe the W, Z scattering process which has diverging cross-section in SM without Higgs.

It is therefore particularly sensitive to whatever new physics must exist to keep this process finite.



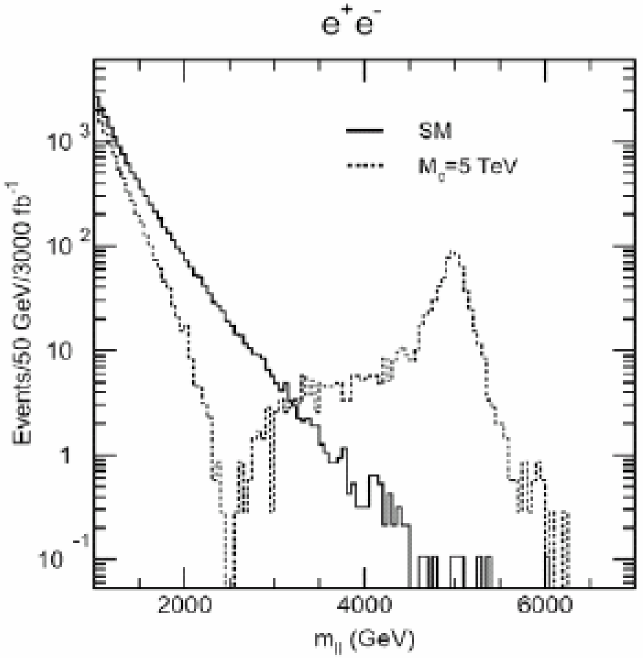
Scalar resonance $Z_L Z_L \to 4\ell$

Not accessible at the LHC

Study of several channels my be accessible at SLHC ⇒ insight into the underlying dynamics

Examples of Physics Gain

Theories with compactified extra space-time dimensions (ED): signatures are Kaluza-Klein (KK) resonances of SM fields in "bulk"



Example:

ED with compactification scale $R = 1/M_c \sim \text{TeV}^{-1}$

SM gauge fields can propagate in "bulk" $\Rightarrow$

KK resonances of γ, Z, W with masses M_c, $2M_c$, ..

In figure γ/Z resonance for 3000 fb^{-1} and $M_c = 5$ TeV

Note also negative interference with Z/γ for $m_{\ell\ell} < M_c$

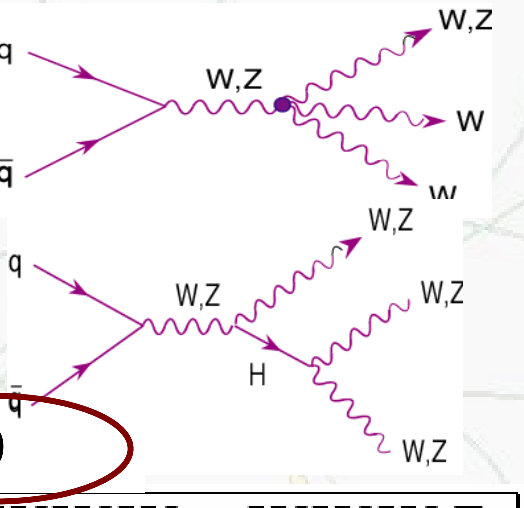
Reach ~6 TeV for 300 fb^{-1}, 7.7 TeV for 3000 fb^{-1} for peak observation

Improved sensitivity to signature for "large" (not Planck scale) extra dimensions and anomalous couplings of top quark.

Expected 99% CL confidence limits in units of 10^{-5}

Channel	LHC (600 fb^{-1})	SLHC (6000 fb^{-1})
$t \to q\gamma$	0.9	0.25
$t \to qg$	61	19
$t \to qZ$	1.1	0.1

Examples of Physics Gain



Test non-Abelian structure SM / Sensitive to new physics
Mostly still statistics limited after 5 years LHC

example: quartic gauge coupling rates with 6000

Process	WWW	WWZ	ZZW	ZZZ	$WWWW$	$WWWZ$
N(m_H=120 GeV)	2600	1100	36	7	5	0.8
N(m_H=200 GeV)	7100	2000	130	33	20	1.6

TGC parameter sensitivity LHC/SLHC/ILC

Coupling	14 TeV 100 fb^{-1}	14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	28 TeV 1000 fb^{-1}	LC 500 fb^{-1}, 500 GeV
λ_γ	0.0014	0.0006	0.0008	0.0002	0.0014
λ_Z	0.0028	0.0018	0.0023	0.009	0.0013
$\Delta\kappa_\gamma$	0.034	0.020	0.027	0.013	0.0010
$\Delta\kappa_Z$	0.040	0.034	0.036	0.013	0.0016
g_1^Z	0.0038	0.0024	0.0023	0.0007	0.0050

λ parameters better at SLHC, κ parameters at ILC

The LHC programme

The results are impossible to predict
(no Higgs (yet); a light Higgs; a heavy Higgs;
SUSY – Higgses, sleptons, squarks (light, heavy);
extra dimensions; ...)

but

the LHC is likely to reveal new fundamental mass scales
in the region 0.114 - >~ 1 TeV

Its findings will highlight the next physics opportunities
at the energy frontier

The LHC programme upgrade

1. **Efficient running of the LHC complex** requires consolidation of the injectors, in particular of the Proton Synchrotron (1959), but also of the SPS

2. **The next step at the energy frontier** could be a very high luminosity hadron collider at LHC energy (SLHC)
   - higher statistics
   - higher mass reach

   This requires major modifications of the injector complex and the LHC hardware and new R&D on detectors (higher irradiation on trackers)

Maximization of LHC Luminosity

(L1) - Minimize turn-around time by improving reliability / minimizing duration of stops

(L2) - Remove bottle-necks towards ultimate luminosity

(SL) - Refine / select scenario for SLHC (start in ~ 2015)

LHC: "Maximize integrated luminosity" (2007- 2015)

- Phase 0: without hardware changes in the LHC
  - Improve injectors (⇒ actions L1 and L2) to increase brightness N_b/ε up to ultimate:

    → $L_0 = 2.3 \times 10^{34}$ cm^{-2} s^{-1} & $\int Ldt \sim 1.5 \times$ nominal (= 100 fb^{-1} / year)
  - increase the dipole field from 8.33 to 9 T: ↑ E_{max} = 7.54 TeV
- Phase 1: with major hardware changes in the LHC (IR, RF, collimation, dump, …)
  - modify the insertion quadrupoles and/or layout: ↓ β^* = 0.25 m → more R&D needed in higher field magnets
  - increase crossing angle θ_c by $\sqrt{2}$: ↑ θ_c = 445 μrad
  - halve bunch length with new high harmonic RF system in the LHC:

    → $L_0 = 4.6 \times 10^{34}$ cm^{-2}s^{-1} & $\int Ldt \sim 3 \times$ nominal (= 200 fb^{-1} / year)
  - double the number of bunches [⇒ new RF systems in the injectors (including SPS if 12.5 ns bunch spacing)] & increase θ_c:

    → $L_0 = 9.2 \times 10^{34}$ cm^{-2}s^{-1} & $\int Ldt \sim 6 \times$ nominal (= 400 fb^{-1} / year)

Reference LHC Luminosity Upgrade: workpackages and tentative milestones

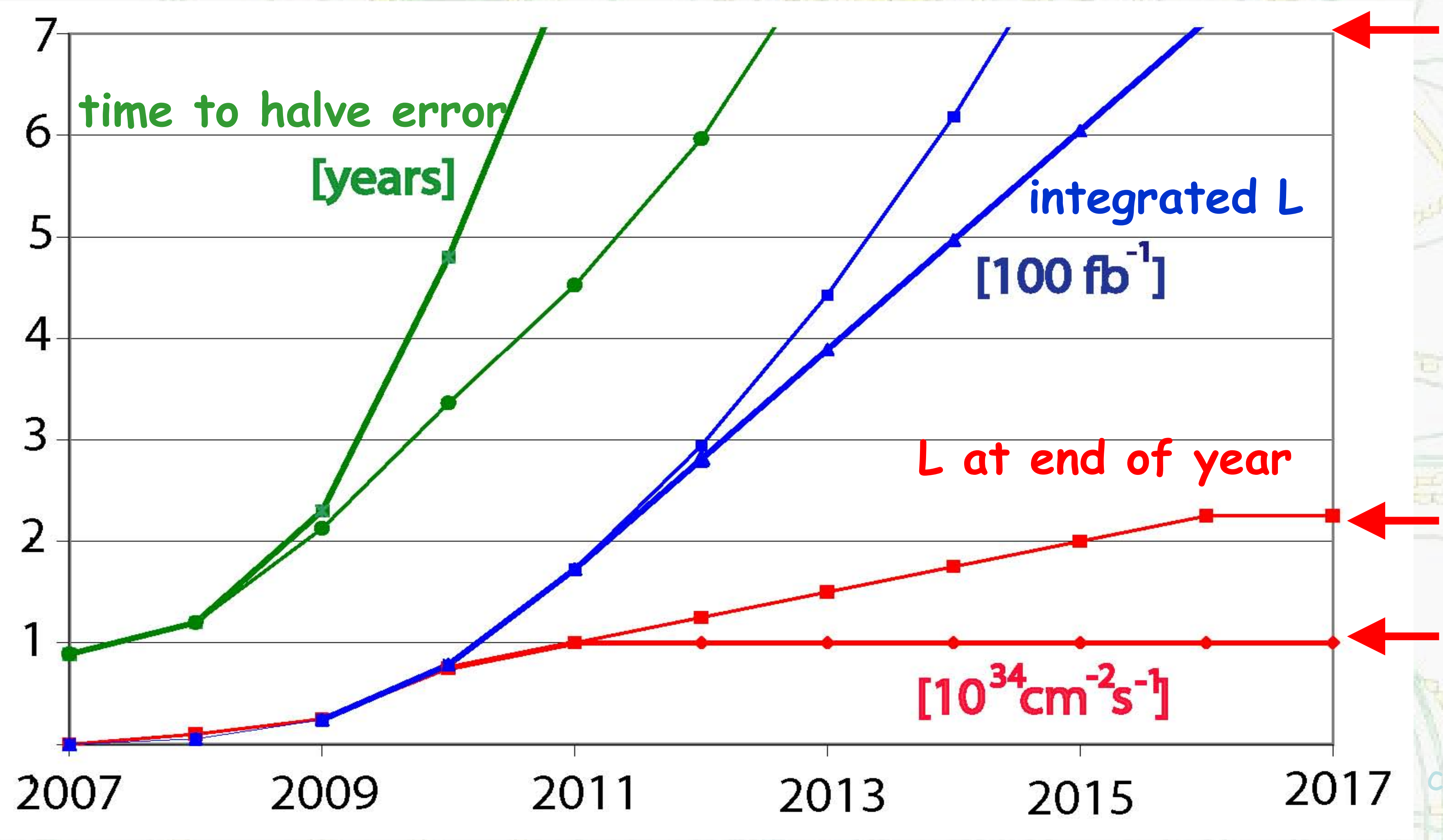
accelerator	WorkPackage	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	after 2015
LHC Main Ring	Accelerator Physics	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟩	🟩		
	High Field Superconductors	🟥	🟥	🟨	🟨	🟨	🟩	🟩	🟩			
	High Field Magnets		🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	Magnetic Measurements			🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	Cryostats					🟥	🟨	🟨	🟩	🟩	🟦	
	Cryogenics: IR magnets & RF		🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	RF and feedback	🟥	🟨	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	Collimation&Machine Protection	🟥	🟨	🟨	🟩	🟦	🟥	🟥	🟥	🟥		
	Beam Instrumentation	🟥	🟥	🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟦	
	Power converters					🟥	🟨	🟨	🟩	🟩	🟦	
SPS	SPS kickers			🟥	🟥	🟥	🟨	🟨	🟩	🟦		
	Tentative Milestones	Beam-beam compensation test at RHIC	SPS crystal collimation test	LHC collimation tests	LHC collimation tests	Install phase 2 collimation	LHC tests: collimation & beam-beam			Install new SPS kickers	new IR magnets and RF system	
	Other Tentative Milestones	Crab cavity test at KEKB	Low-noise crab cavity test at RHIC	**LHC Upgrade Conceptual Design Report**		LHC Upgrade Technical Design Report	Nominal LHC luminosity 10^34			Ultimate LHC luminosity 2.3x10^34	beam-beam compensation	Double ultimate LHC luminosity 4.6x10^34

LHC Upgrade Reference Design Report

R&D - scenarios & models	🟥
specifications & prototypes	🟨
construction & testing	🟩
installation & commissioning	🟦

Reference LHC Upgrade scenario: peak luminosity 4.6x10^34/(cm^2 sec)
Integrated luminosity 3 x nominal ~ 200/(fb*year) assuming 10 h turnaround time
new superconducting IR magnets for beta*=0.25 m
phase 2 collimation and new SPS kickers needed to attain ultimate LHC beam intensity of 0.86 A
beam-beam compensation may be necessary to attain or exceed ultimate performance
new superconducting RF system: for bunch shortening or Crab cavities
hardware for nominal LHC performance (cryogenics, dilution kickers, etc) not considered as LHC upgrade
R&D for further luminosity upgrade (intensity beyond ultimate) is recommended: see Injectors Upgrade

Timescale of LHC upgrade



Quad radiation damage limit ~700 fb^{-1}

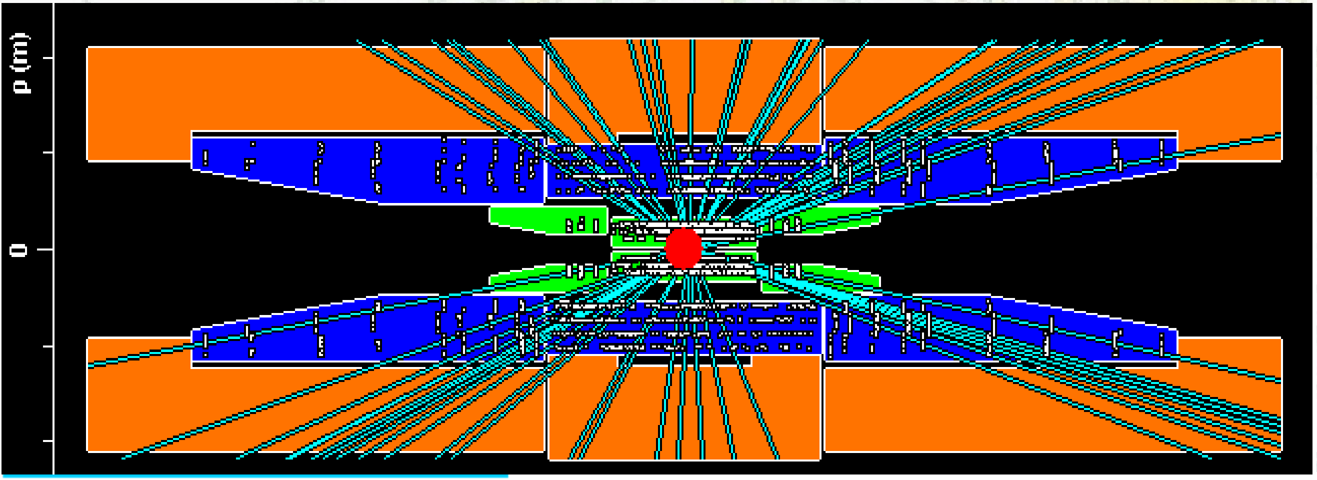
ultimate luminosity

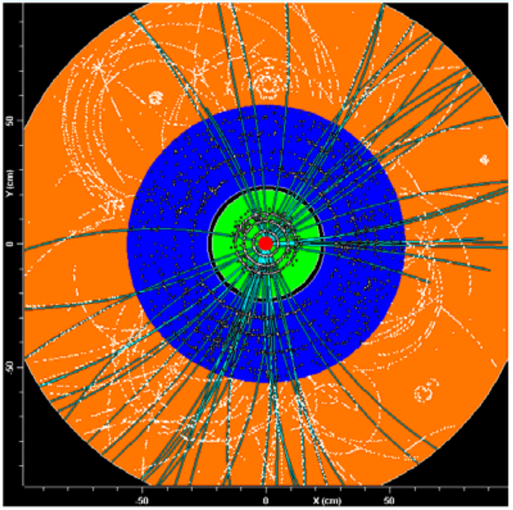
design luminosity

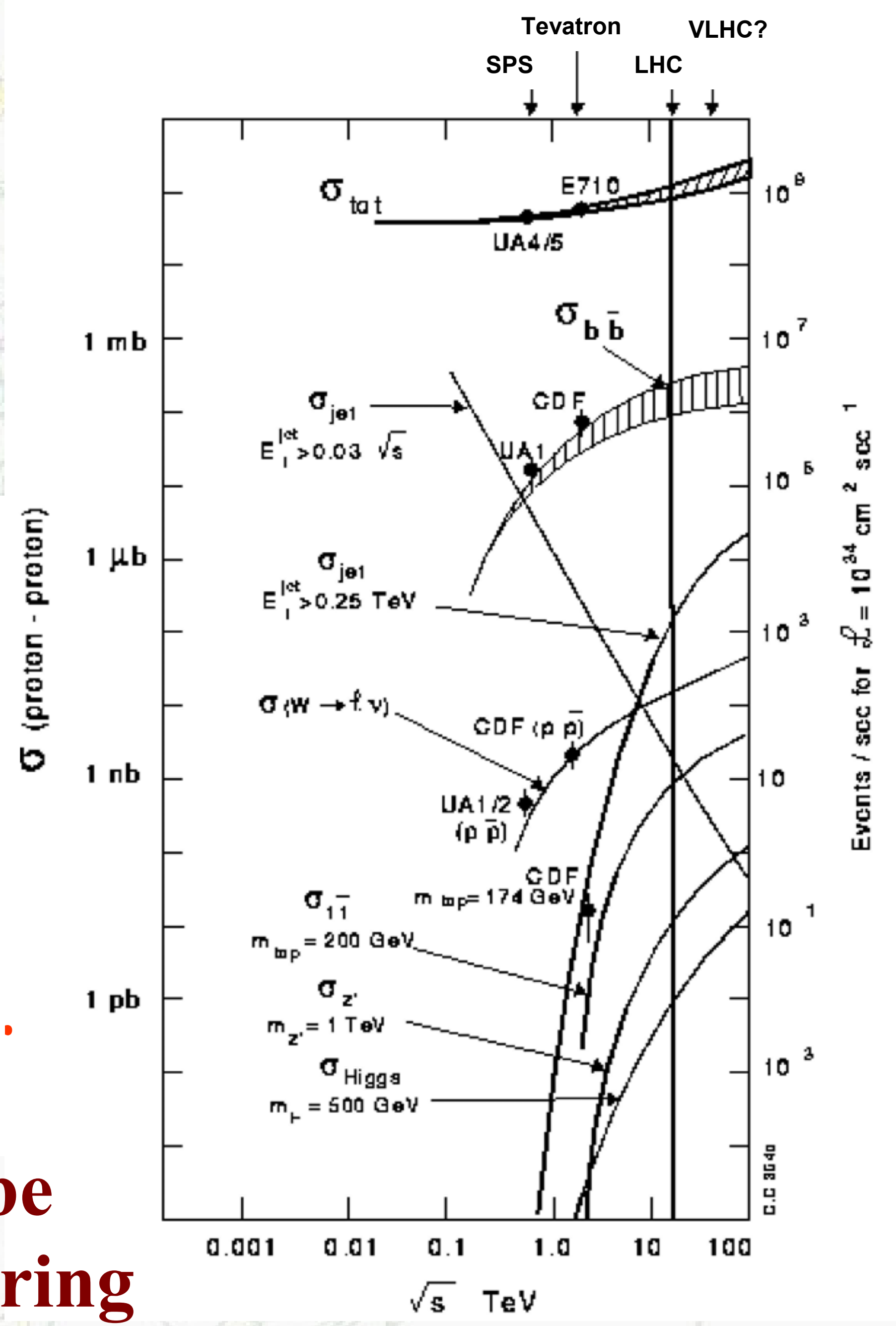
courtesy J. Strait

- the **life expectancy of LHC IR quadrupole magnets** is estimated to be **<10 years** owing to high radiation doses
- the **statistical error halving time** will exceed 5 years by 2011-2012
- therefore, it is reasonable to plan a **machine luminosity upgrade based on new low-ß IR magnets before ~2015**

Physics Issues at the LHC







Events at LHC give huge numbers of particles passing through the detectors

Example of Higgs particle production in association with t t-bar to measure H → b b-bar

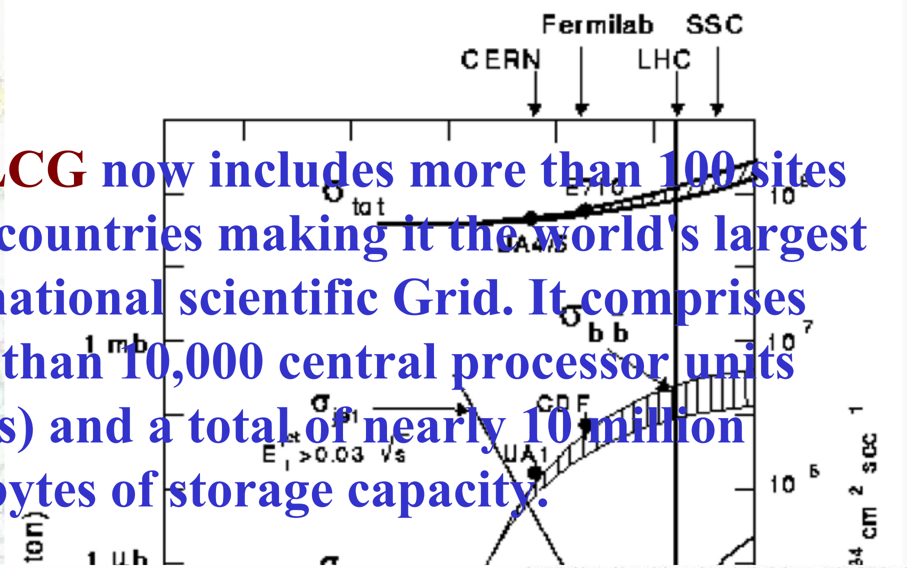
Vital to measure Higgs decays to test Standard Model

→ With >200 tracks per interaction registered in millions of electronic channels, interpretation calls for sophisticated tools

2000 physicists from 34 countries will be analysing the huge data samples, requiring access to highly distributed storage and processing power

Data Processing Issues at the LHC

The problem of the data deluge at the LHC both prompted sophisticated on-detector data reduction using a multi-tiered filtering “event triggering” and developments to harness internationally distributed large processing arrays and mass-storage, “Grid technologies”.



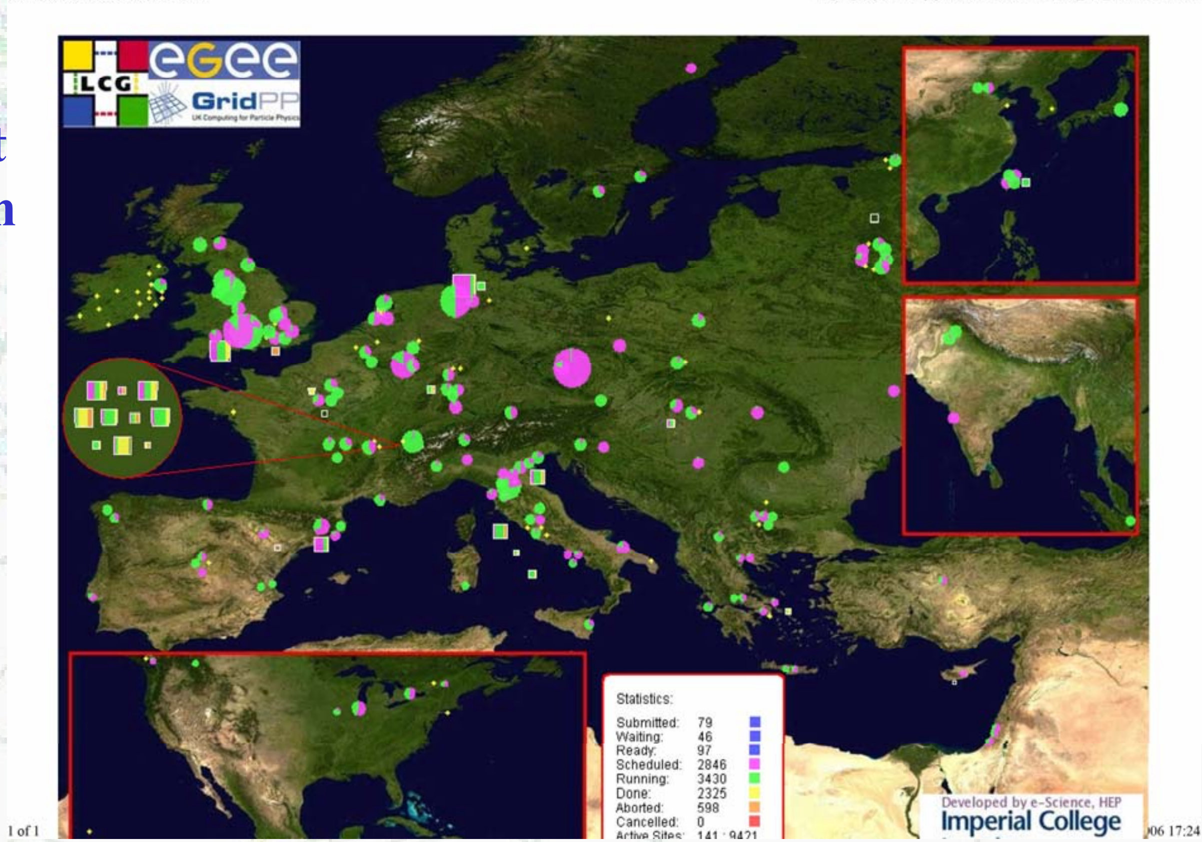
The LCG now includes more than 100 sites in 31 countries making it the world's largest international scientific Grid. It comprises more than 10,000 central processor units (CPUs) and a total of nearly 10 million Gigabytes of storage capacity.

‘The Large Hadron Collider (LHC), currently being built at CERN near Geneva, is the largest scientific instrument on the planet. When it begins operations in 2007, it will produce roughly 15 Petabytes (15 million Gigabytes) of data annually, which thousands of scientists around the world will access and analyse.

The mission of the LHC Computing Grid (LCG) Project is to build and maintain a data storage and analysis infrastructure for the entire high energy physics community that will use the LHC.’

embeded RTM Jobs task 1024x768

http://gridportal.hep.ph.ic.ac.uk/rtm/embeded_rtm_1024x768.html



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ATLAS Upgrade Requirements

To keep ATLAS running more than 10 years the inner tracker will need to be replaced. (Current tracker designed to survive up to 700 fb^{-1})
For the luminosity-upgrade the new tracker will have to cope with:

- **much higher occupancy levels**
- **much higher dose rates**

To build a new tracker for 2015, work needs to start now.

Timescales:

- **R&D until 2009 leading into a full tracker proposal (TDR) in 2009/2010**
- **Construction phase to start in 2010.**

To cope with the requirements of SLHC, Level-1 and HLT work on upgrades will need to start in 2009.

- **Bunch-crossing identification, low-latency data transmission and algorithm execution at higher clock rates for level-1, data buffering and communication, and the overall software strategy for the high level triggers are all items that will require investigation.**

Other ATLAS Systems

Trigger Electronics:

- "Front-end electronics can probably stay" (clock speed? deeper pipelines?)
- Extensions to trigger capability needed
- Need to maintain L1 output rate (more data per event)
  - Must upgrade detector backend electronics
    - adapt clock speed to bunch-crossing rate
    - increase bandwidth to deal with more data per event
  - Modify trigger algorithms to deal with high occupancy (and increase thresholds)

L-Ar:

- Some performance degradation due to high rates. (e.g. electron isolation suffers from 200 min. bias events.)

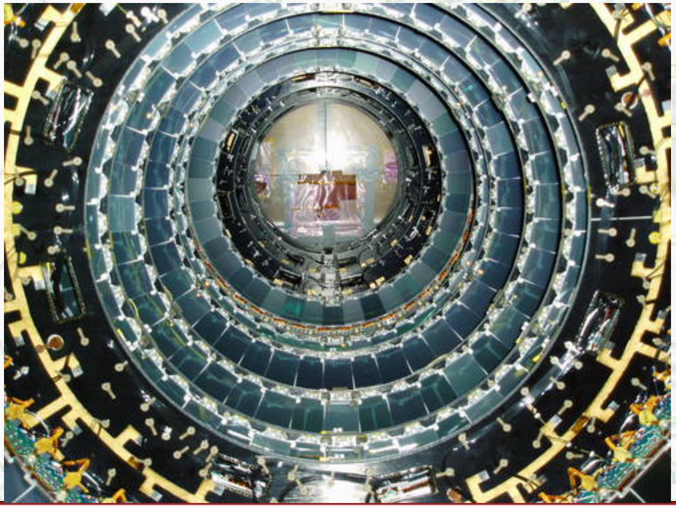
TileCal:

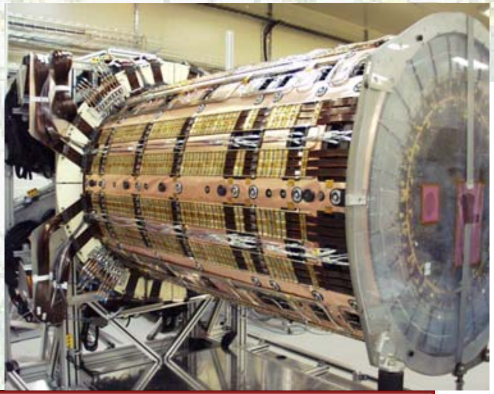
- Some radiation damage scintillators
- Challenging calibration with strong increase in pile-up

Muon systems:

- MDT's some degradation in performance due to high rates, in particular in the forward regions:
  - May need additional shielding forward region
  - Aging/radiation damage needs confirmation for SLHC operation
- RPC's, TGC's: Need an upgrade?

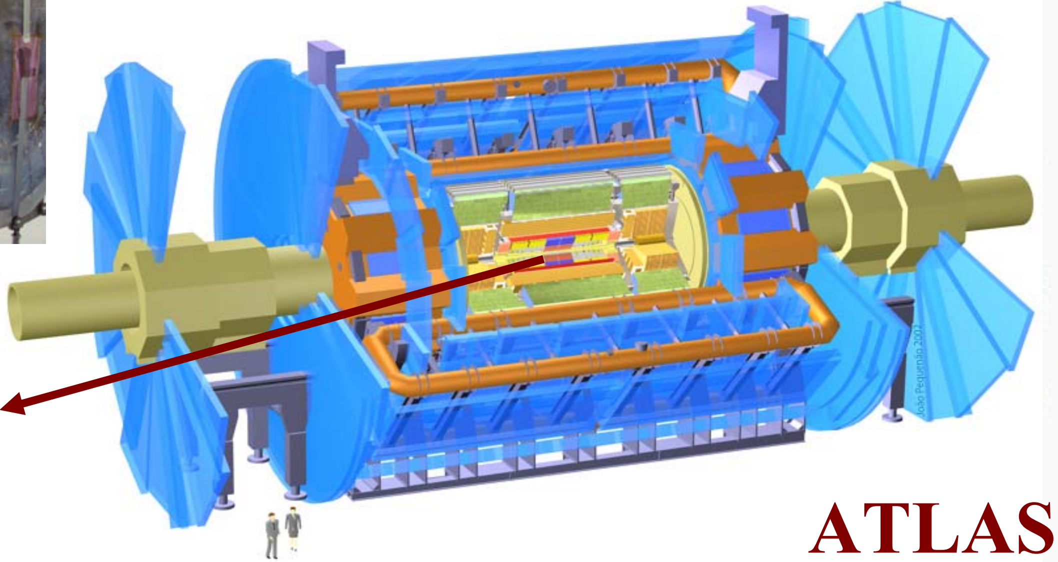
The ATLAS Silicon Central Tracker

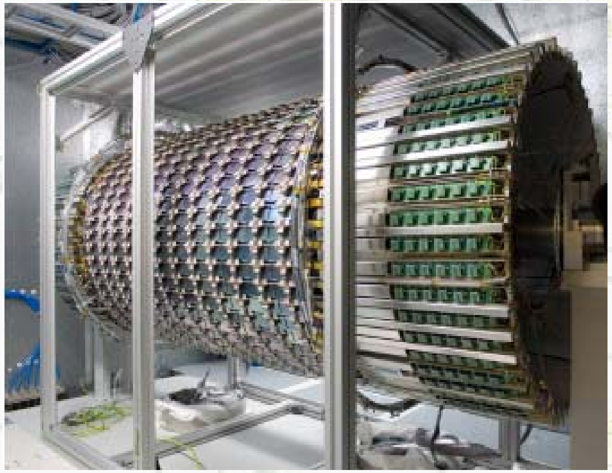


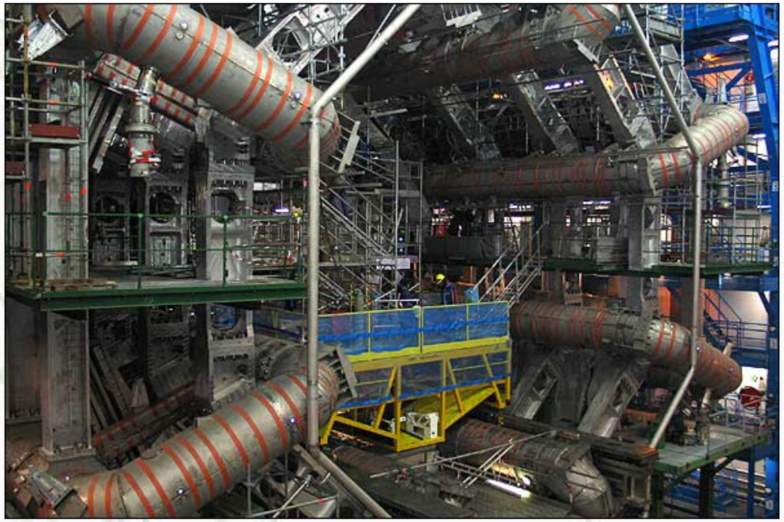


4 barrels assembled at Oxford, 9 disks of EndCap-C assembled at Liverpool and 9 disks of EndCap-A assembled at NIKHEF

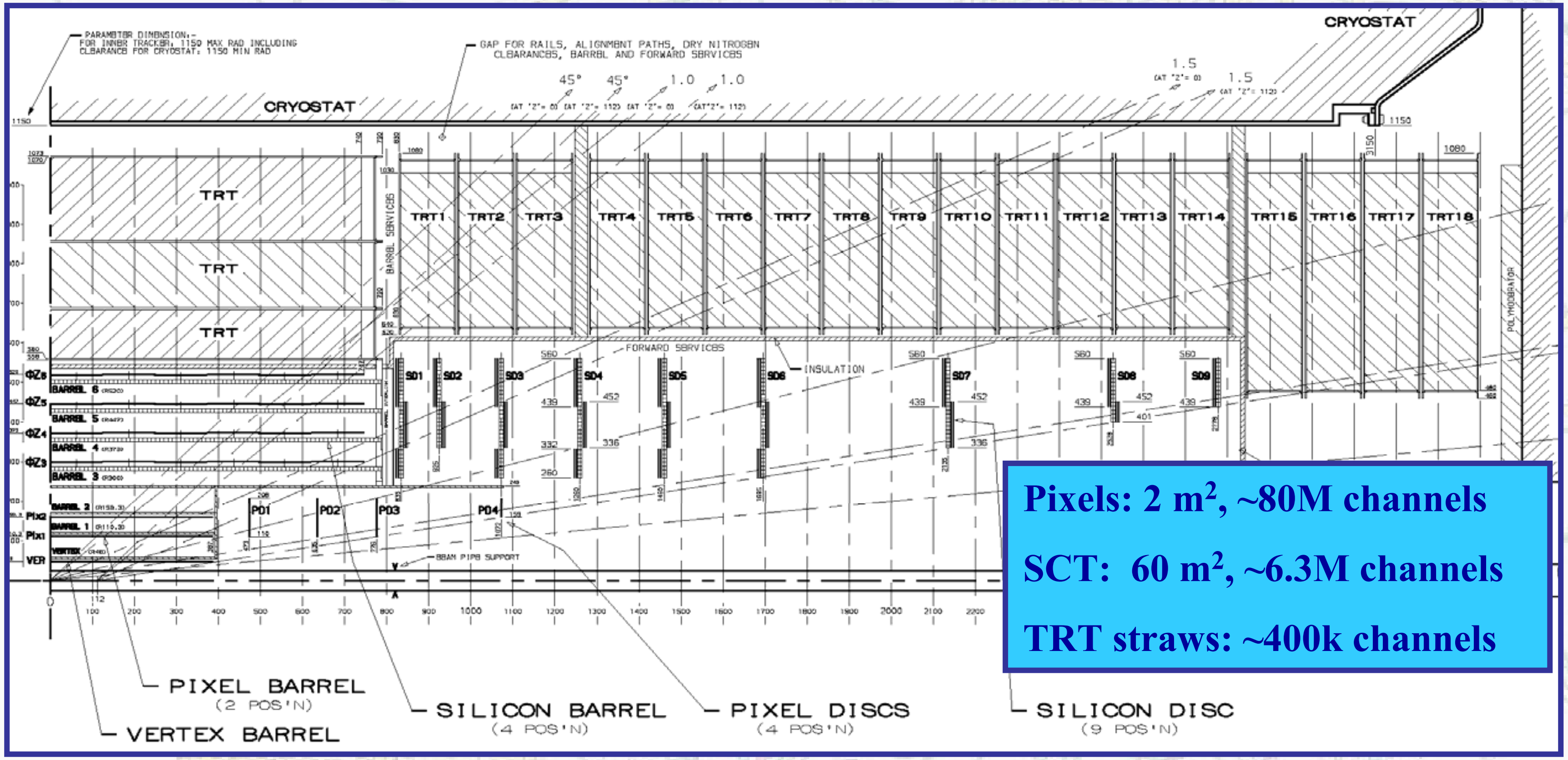
UK participation in sensor design, module design, irradiation studies, module prototyping and production, final alignment systems, data acquisition and engineering components.







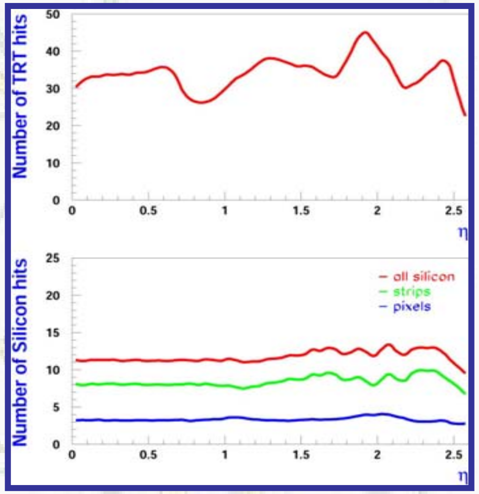
Current Inner Tracker Layout

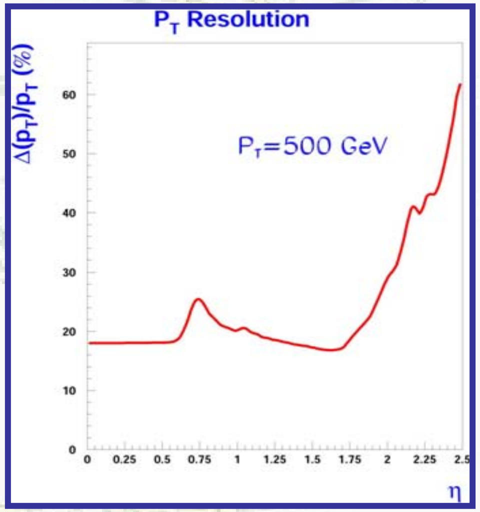


Pixels: 2 m^2, ~80M channels

SCT: 60 m^2, ~6.3M channels

TRT straws: ~400k channels





Pixels (50 μm × 400 μm): 3 barrels, 2×3 disks $\quad 4.7\text{cm} < r < 20\text{cm}$

- Pattern recognition in high occupancy region
- Impact parameter resolution (in 3d)

Radiation hard technology: n^+-in-n Silicon technology, operated at -6°C

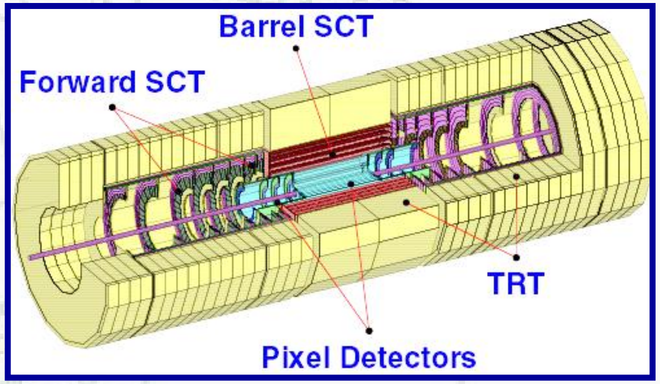
Strips (80 μm × 12 cm) (small stereo angle): "SCT" 4 barrels, 2×9 disks

- **pattern recognition** **$30\text{cm} < r < 51\text{cm}$**
- **momentum resolution**

p-strips in n-type silicon, operated at -7°C

TRT 4mm diameter straw drift tubes: barrel + wheels $\quad 55\text{cm} < r < 105\text{cm}$

- Additional pattern recognition by having many hits (~36)
- Standalone electron id. from transition radiation

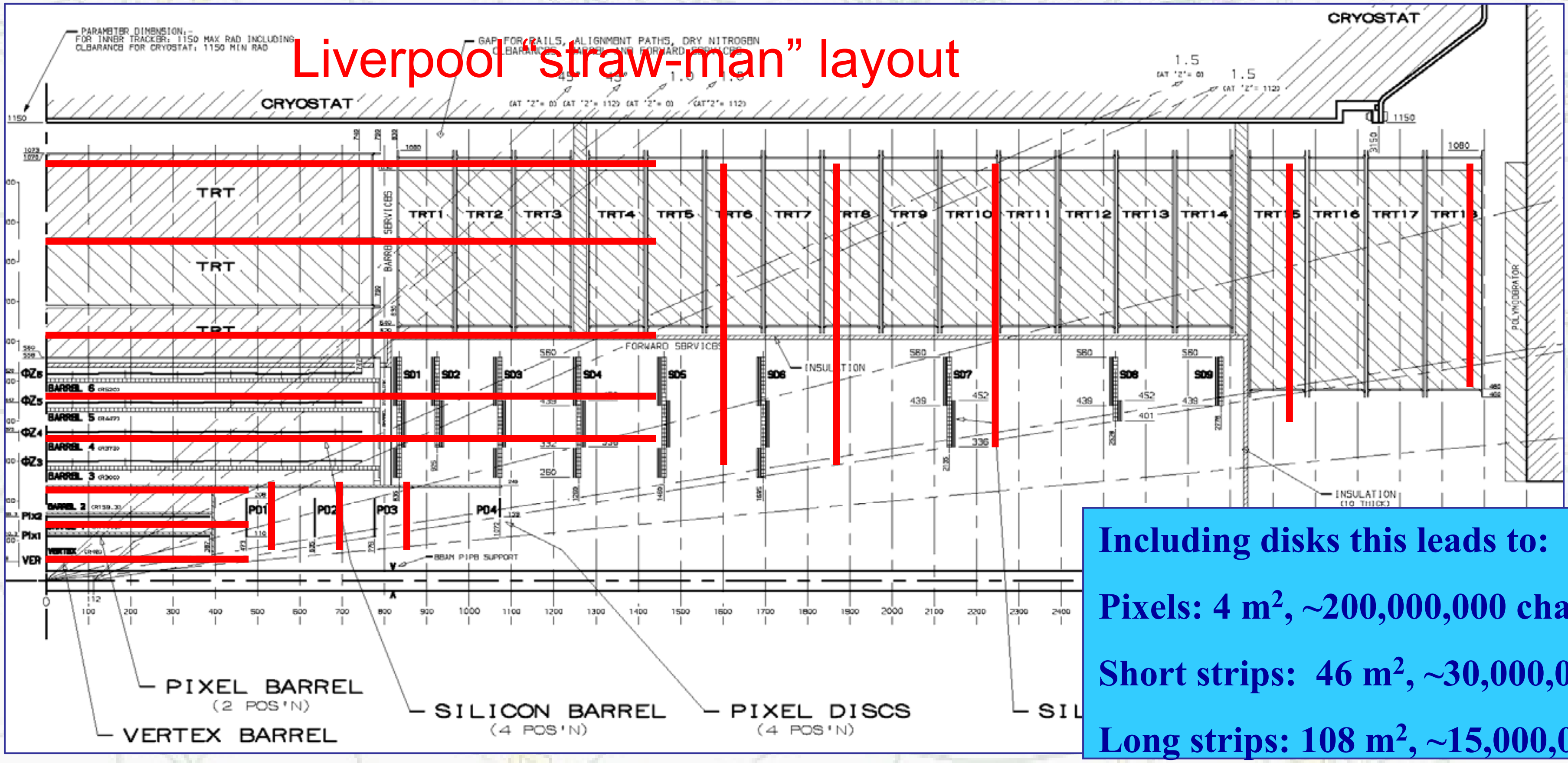


Example SLHC Tracker Layout

Some layout proposals have been made.

All Silicon tracker

Pixels:	**r=6cm, 15cm, 24cm**	**z=±50cm**
Short (3cm) μ-strips (single layer?):	**r=35cm, 48cm, 62cm**	**z=±144cm**
Long (12 cm) μ-strips (stereo layers):	**r=84cm, 105cm**	**z=±144cm**


Liverpool “straw-man” layout

Including disks this leads to:

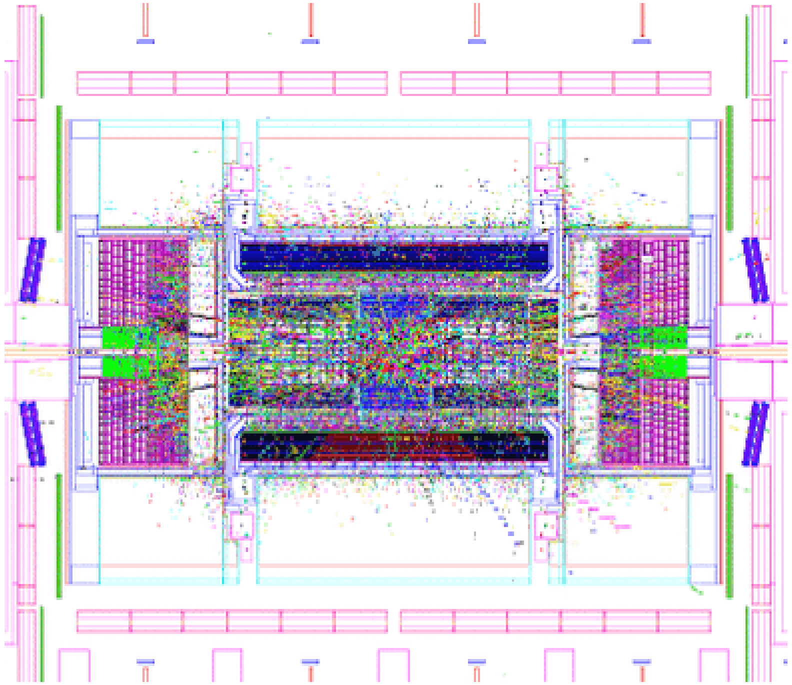
Pixels: 4 m^2, ~200,000,000 channels

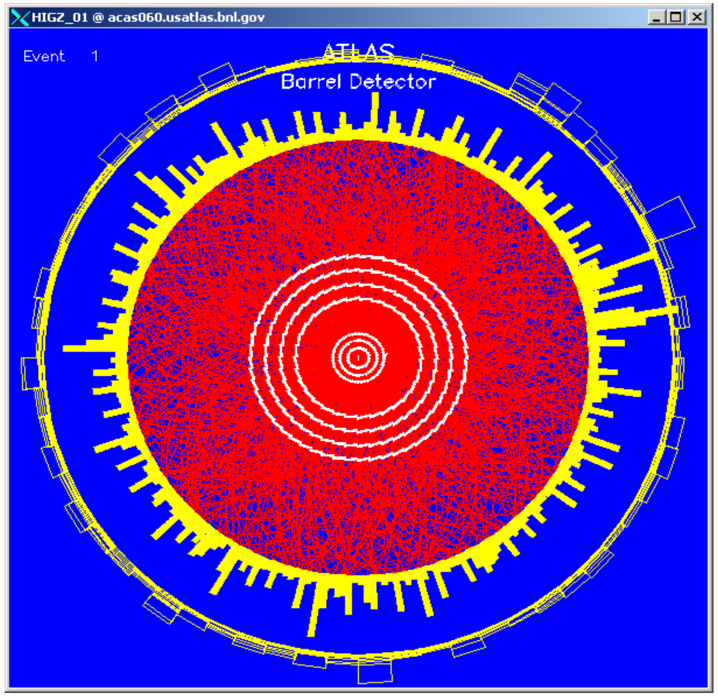
Short strips: 46 m^2, ~30,000,000 channels

Long strips: 108 m^2, ~15,000,000 channels

Single Beam-Crossing Occupancy

Expected Pile-up at Super LHC





$N_{ch}(|y|\leq 0.5)$

- 230 min.bias collisions in bunch
- ~ 10000 particles in $|\eta| \leq 3.2$
- mostly low p_T tracks

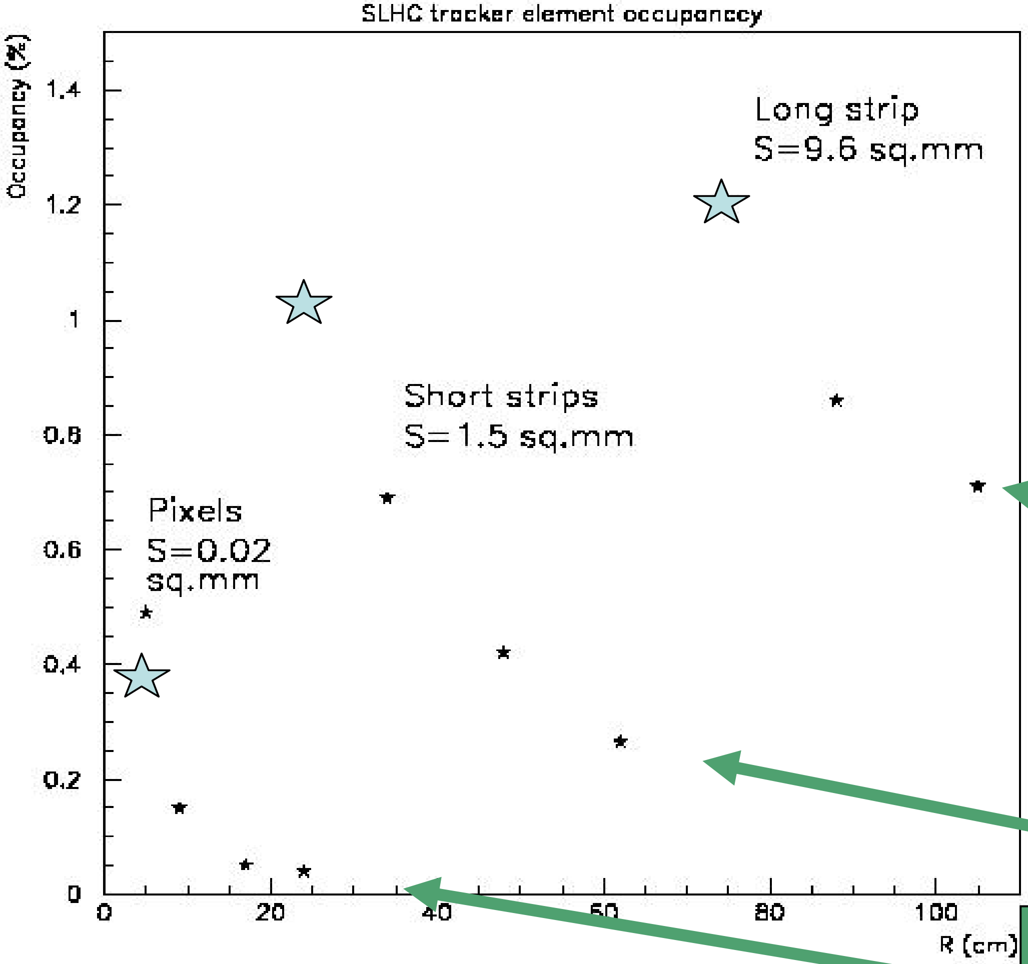
Note: numbers based on factor 10 increase in luminosity but still 25 ns bunch crossing. May be better for shorter bunch crossing time, depending on whether detectors can run at 80MHz

Occupancy Constraints on Upgrade Tracker

SLHC predicted occupancy

Pile-up simulation studies looking at occupancy levels to determine appropriate implant segmentation at different radii for the SLHC tracker.

Needed to define geometry of any proposed super-module concept.



Long strips:
12cm×80μm

Short strips:
3cm×50μm

Pixels:
400 μ m×50μm

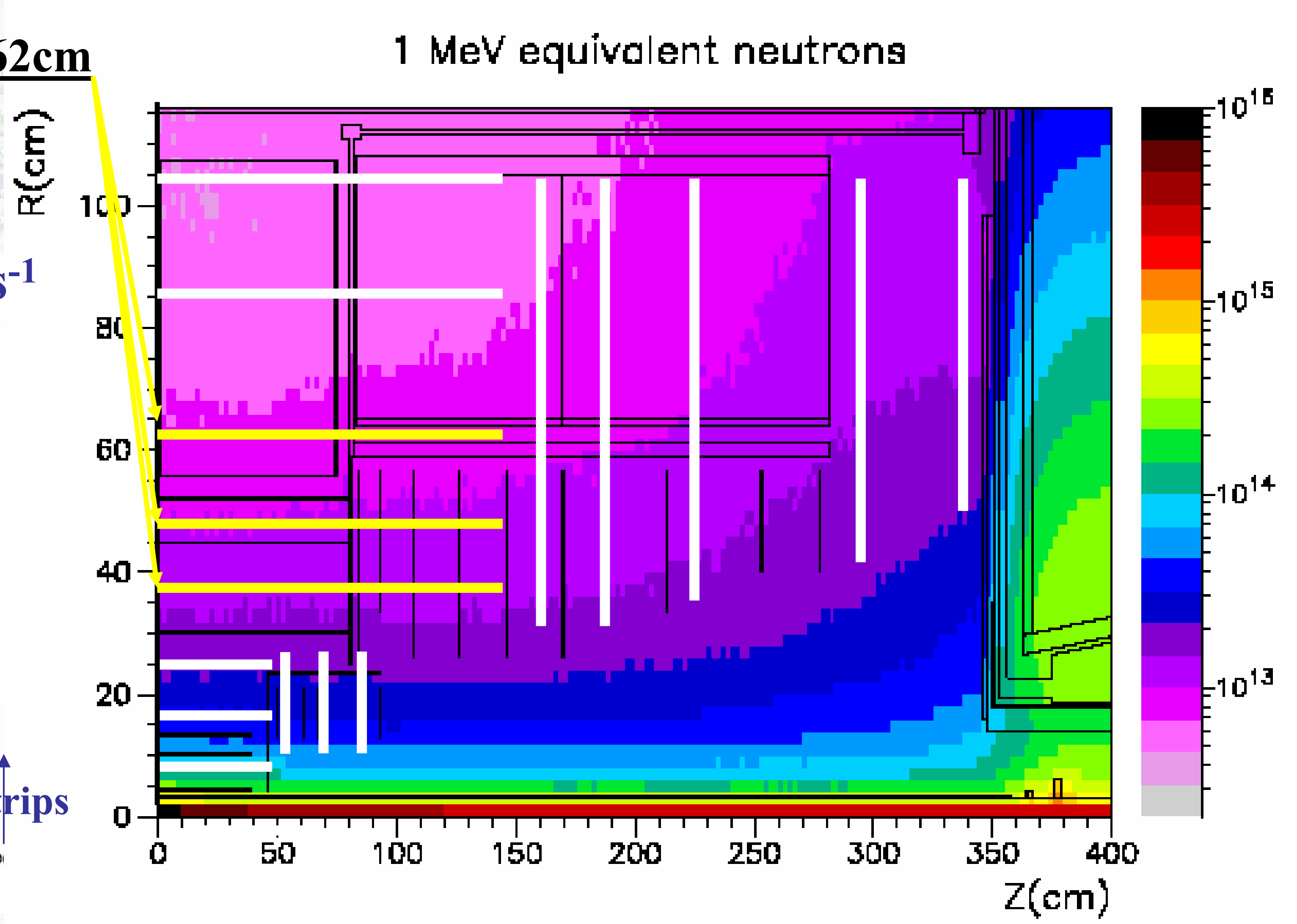
Tracker Region Irradiation

ATLAS HLSG study proposal

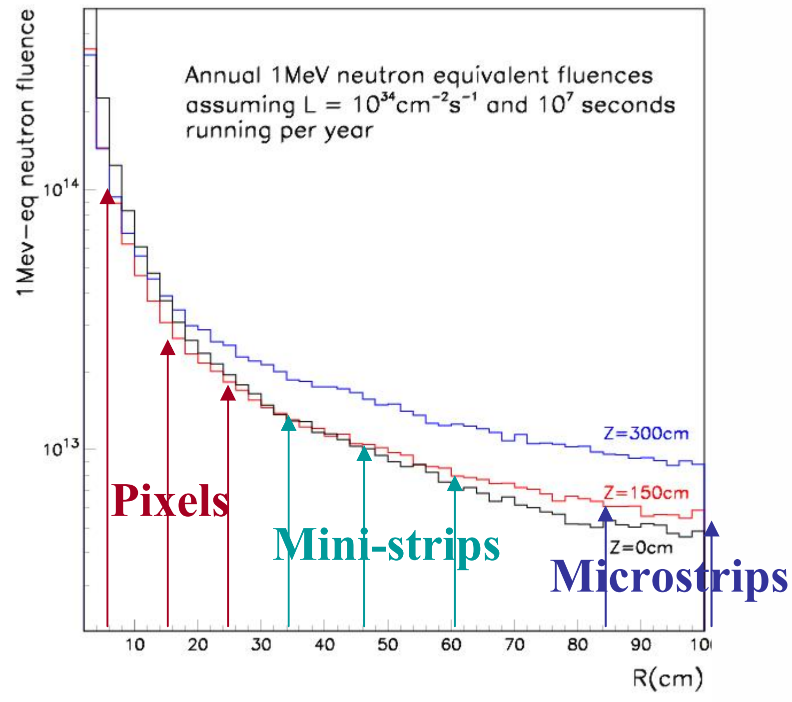
Possible radii of new tracker:

Pixels: r=6cm, 15cm, 24cm
Mini-strips: r=35cm, 48cm, 62cm
Microstrips: r=84cm, 105cm

Need to multiply by 10 then number of years of SLHC operation →Doses up to 100Mrad (1MGy) at SCT radii



Annual Doses at $10^{34}cm^{-2}s^{-1}$



SLHC dose estimates (in 1 MeV neutron equivalent fluence)

Flux scales with luminosity.

(Thermal neutron flux depends on added moderator material to compensate for loss of neutron moderating effects of TRT.)

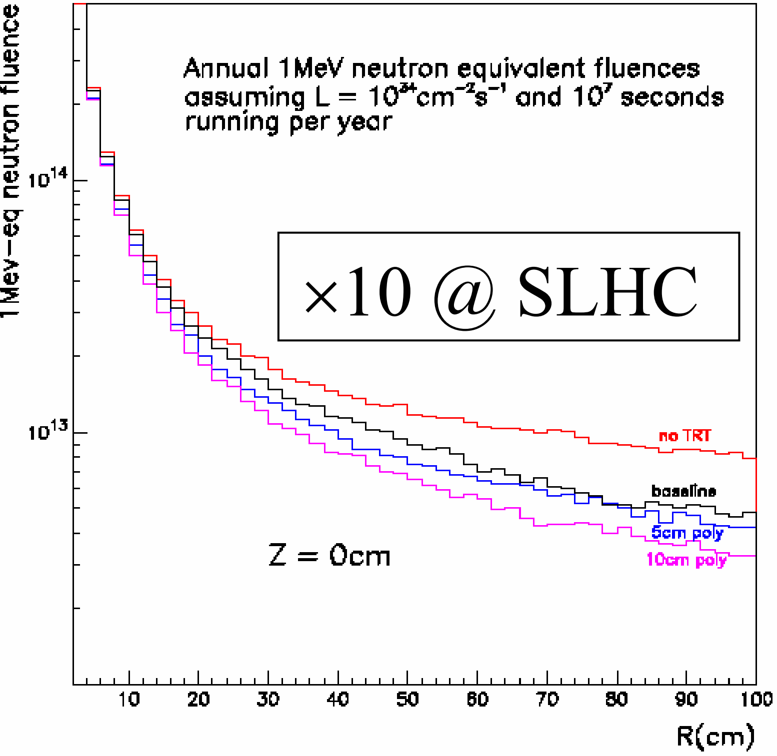
Assume overall factor 10 increase.

Assuming 10 years of SLHC running (~6000fb^{-1}).

Pixels	Max. annual dose	10 years (~6000 fb^{-1})
Disks, r=9-25 cm, z=50-85 cm	$\sim8\times10^{14}\,n_{eq}/cm^2$	$\sim8\times10^{15}\,n_{eq}/cm^2$
barrel, r=6 cm	$\sim2\times10^{15}\,n_{eq}/cm^2$	$\sim2\times10^{16}\,n_{eq}/cm^2$
barrel, r= 15 cm	$\sim4\times10^{14}\,n_{eq}/cm^2$	$\sim4\times10^{15}\,n_{eq}/cm^2$
barrel, r= 24 cm	$\sim2.5\times10^{14}\,n_{eq}/cm^2$	$\sim2.5\times10^{15}\,n_{eq}/cm^2$

Short strips	Max. annual dose	10 years (~6000 fb^{-1})
disks, r=35-80 cm, z=150-300 cm	$\sim1.3\times10^{14}\,n_{eq}/cm^2$	$\sim1.3\times10^{15}\,n_{eq}/cm^2$
barrel, r= 35 cm	$\sim1.4\times10^{14}\,n_{eq}/cm^2$	$\sim1.4\times10^{15}\,n_{eq}/cm^2$
barrel, r= 48 cm	$\sim1\times10^{14}\,n_{eq}/cm^2$	$\sim1\times10^{15}\,n_{eq}/cm^2$
barrel, r= 62 cm	$\sim8\times10^{13}\,n_{eq}/cm^2$	$\sim8\times10^{14}\,n_{eq}/cm^2$

Long strips	Max. annual dose	10 years (~6000 fb^{-1})
disks, r= 80-100 cm, z= 150-300 cm	$\sim1\times10^{14}\,n_{eq}/cm^2$	$\sim1.\times10^{15}\,n_{eq}/cm^2$
barrel, r= 84 cm	$\sim6\times10^{13}\,n_{eq}/cm^2$	$\sim6\times10^{14}\,n_{eq}/cm^2$
barrel, r= 105 cm	$\sim5\times10^{13}\,n_{eq}/cm^2$	$\sim5\times10^{14}\,n_{eq}/cm^2$



×10 @ SLHC

Assumptions made on SLHC running vary:
5 years – 10 years SLHC operation, with/without safety margin for radiation levels

Operating Silicon Sensors at SLHC doses

For LHC doses (SCT):

- Main failure mode is when full depletion voltage grows beyond breakdown voltage. *Undepleted region low field → poor charge collection.*

For the SLHC doses (middle radii):

- Will not be able to operate (conventional) silicon fully depleted ($V_{DEP} >> 1000V$) However, *p-type* silicon with n-strips (collecting electrons) *can work* as the *undepleted region is semi-insulating after heavy irradiation.*

- Trapping is dominant radiation effect on sensor performance.

Optimize for charge collection efficiency CCE not for V_{DEP}

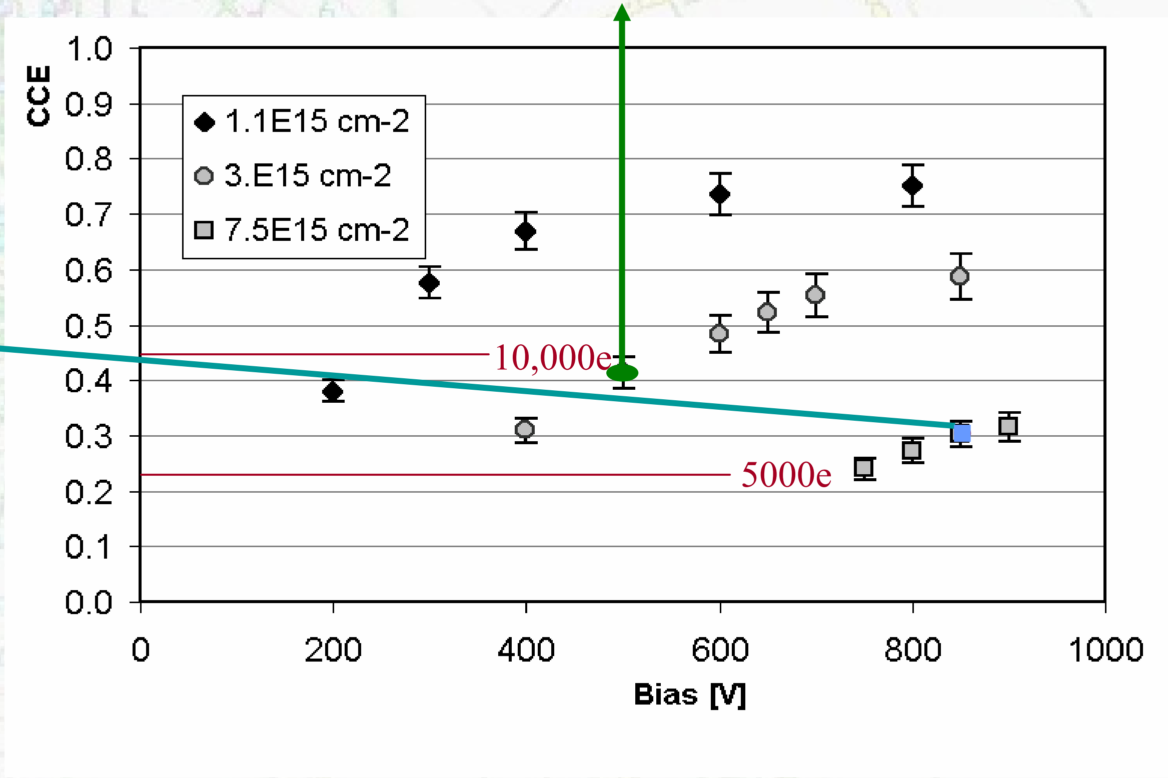
- High currents threaten stable operation (thermal runaway)

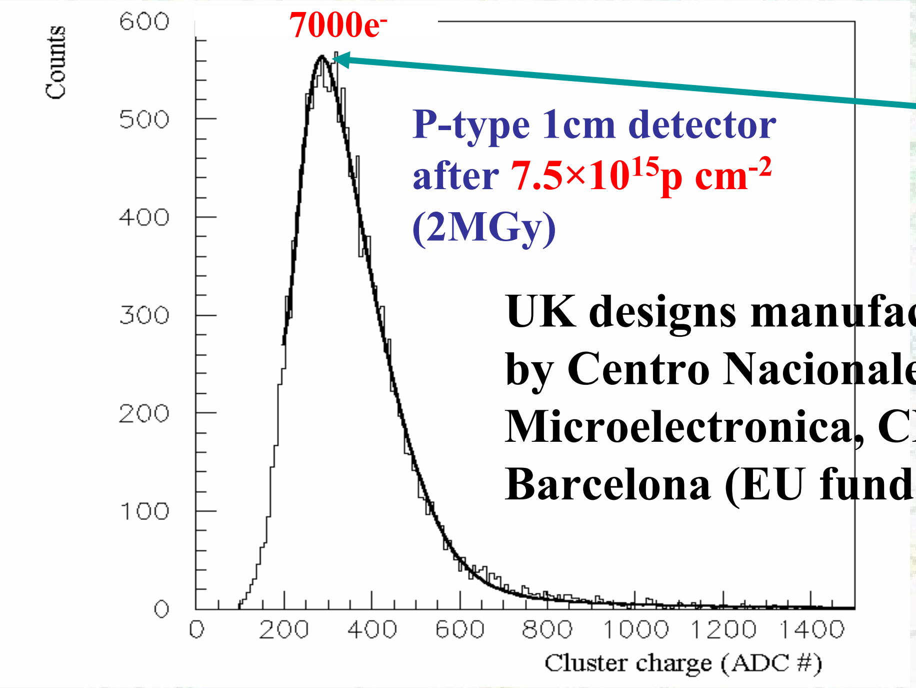
Require robust cooling to reduce currents and remove heat

Silicon R&D Towards Super-LHC

UK groups in RD50 lead the programme to develop detectors able to withstand the ten times LHC radiation doses at the proposed luminosity upgrade (Super-LHC)
An ambitious target for SLHC microstrips would be survival of ~3 ×10^{15} p/cm (1MGy) with Signal/Noise > 10.

After a radiation dose of 3×10^{15}p cm^{-2}, signal seen in p-type silicon is still 10,000e^{-} at 500V and noise for 3cm length strips would be 900e^{-}





P-type 1cm detector after 7.5×10^{15}p cm^{-2} (2MGy)

UK designs manufactured by Centro Nacionale Microelectronica, CNM, Barcelona (EU funded)

Pulse height distribution of a miniature n+-in-p detectors with ^{106}Ru β-source, after exposure at the CERN-PS to 7.5×10^{15}p cm^{-2} with LHC speed electronics.

This technology promising for SLHC. P-type wafers being prototyped with Micron (good IV performance etc)

Increase in Leakage Current with Dose

Flux dependence leakage current:

$$I = \alpha \, \Phi_{eq} \, V$$

- **Independent of bulk type**
- **Temperature dependent. Common to use $\alpha_{20°C}$ and calculate temperature dependence using:**

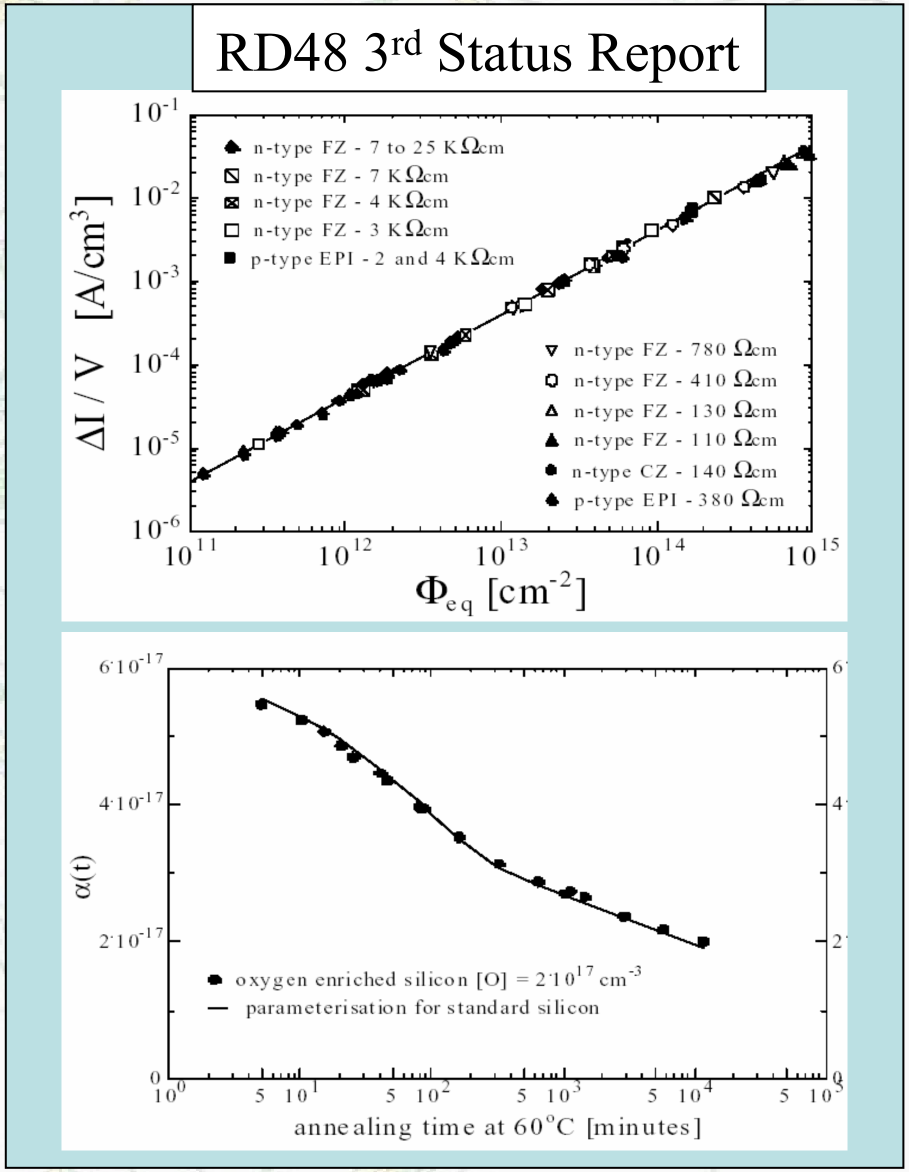
$$I(T) = I_{20^\circ C} \left(\frac{T}{293} \right)^2 \exp\left[-\frac{E_{gap}}{2k_B} \left(\frac{293 - T}{293\,T} \right) \right]$$

- **Annealing time dependent. $\alpha_{20°C}$ is:**

4E-17A/cm ⇒ ~400 days

5E-17A/cm ⇒ ~100 days ⇐ used here

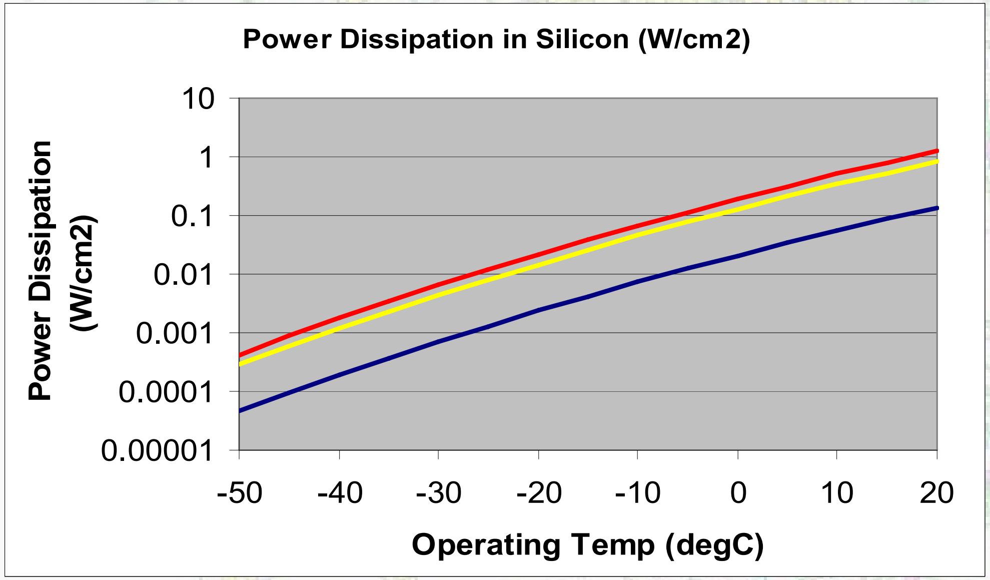
5.5E-17A/cm ⇒ ~25 days

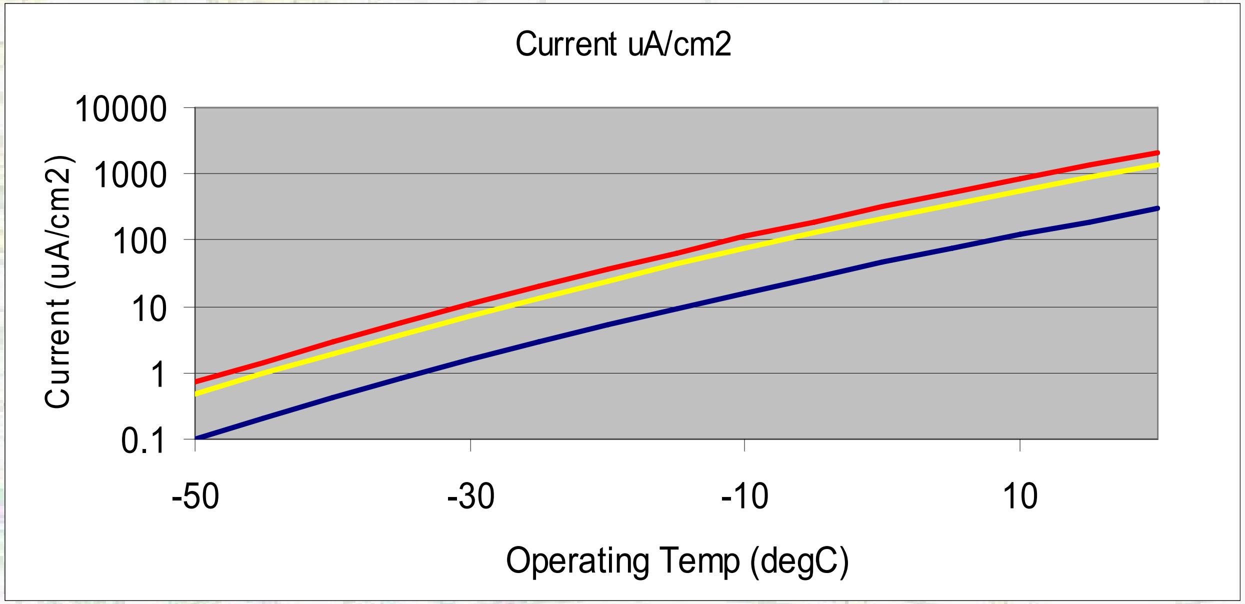


RD48 3rd Status Report

Current & Power Dissipation

Innermost short strip radius:





— LHC: flux = 2×10^{14} n_{eq}/cm^2, bias = 450V, 300μm

— SLHC: flux = 1.4×10^{15} n_{eq}/cm^2, bias = 600V, 300μm

— SLHC: flux = 1.4×10^{15} n_{eq}/cm^2, bias = 600V, 200μm

Temperature	-40°C	-30°C	-20°C	-10°C	0°C	10°C	20°C
LHC (mW/cm^2)	0.19	0.70	2.4	7.2	21	54	135
SLHC (mW/cm^2)	1.8	6.5	22	67	192	508	1260

Currents: × 7
Power: × 10

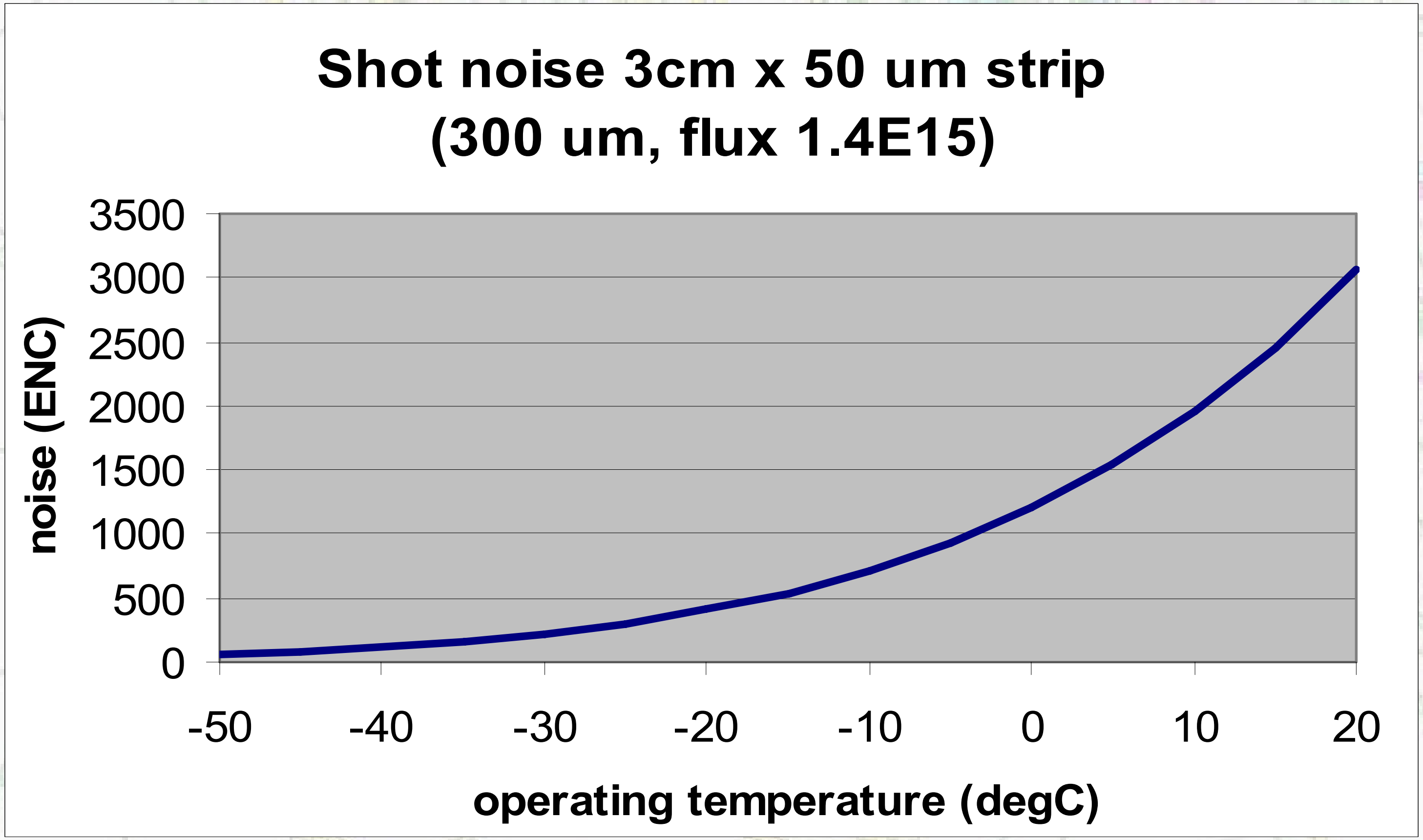
SLHC: to keep power dissipation same as LHC would need to run ~20°C colder.

Note: no longer needed to keep sensors cold outside operation! (At SLHC we will not operate sensors fully depleted, therefore reverse annealing is not a major issue.)

Shot Noise

High leakage current also adds to the noise.

$$\text{shot noise (ENC)} \approx \sqrt{12\, I_{\text{detector}}\,(\text{nA})\; t_{\text{shaping}}\,(\text{ns})}$$ **(Spieler, PDG 2004)**



This gets added in quadrature to other noise contributions.

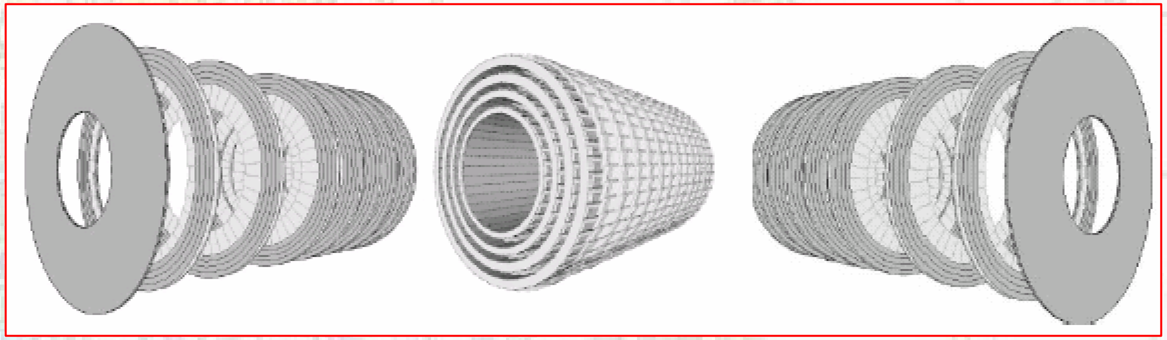
In short strip region probably need to keep total noise below ~1000ENC (for 25 ns shaping time).

To keep shot noise contribution below ~400enc, need to keep the operating temperature below -15°C to -20°C.

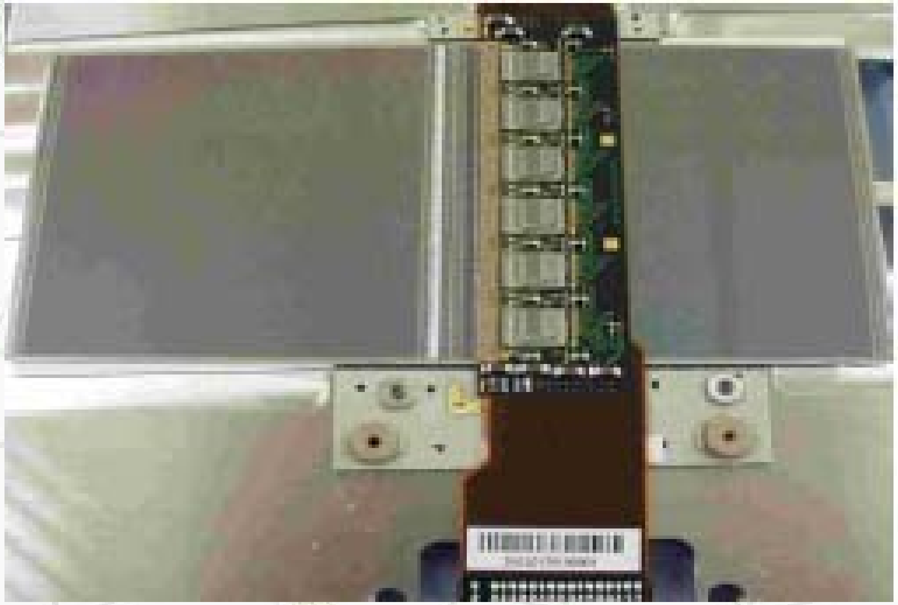
(Shot noise reduced by 20% for 200µm thick sensor.)

Possible Super-LHC Module Design

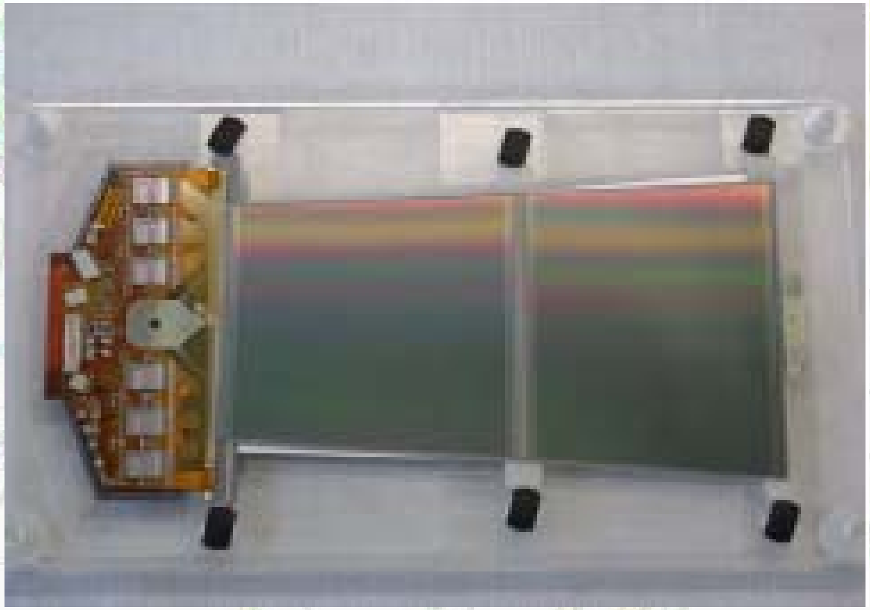
ATLAS Tracker Based on Barrel and Disc Supports



Effectively two styles of modules (with 12cm long strips)



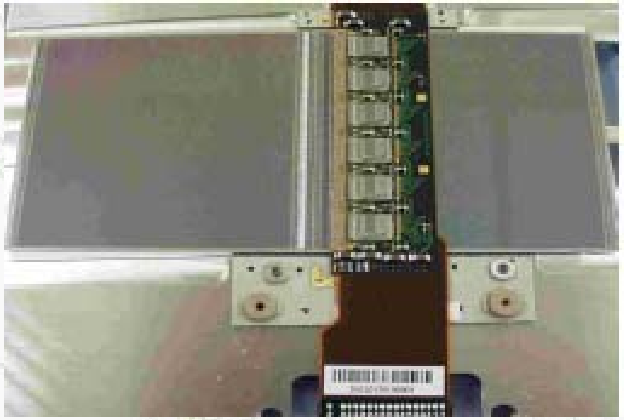
Barrel Modules



Forward Modules

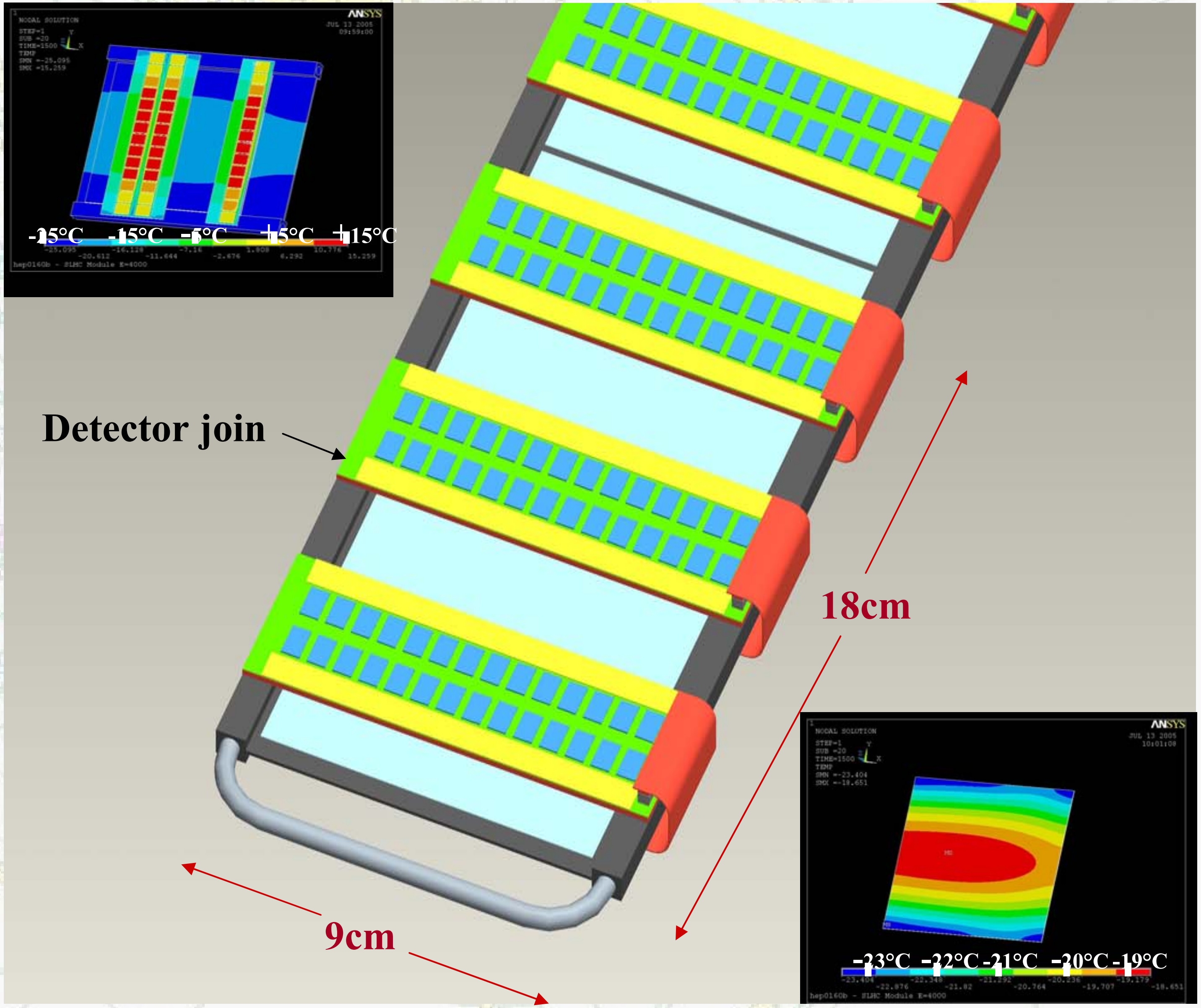
Possible Mini-strip Super-Module Design

SLHC 'Stave' concept based on current ATLAS barrel module with bridging structure for hybrid and TPG baseboard

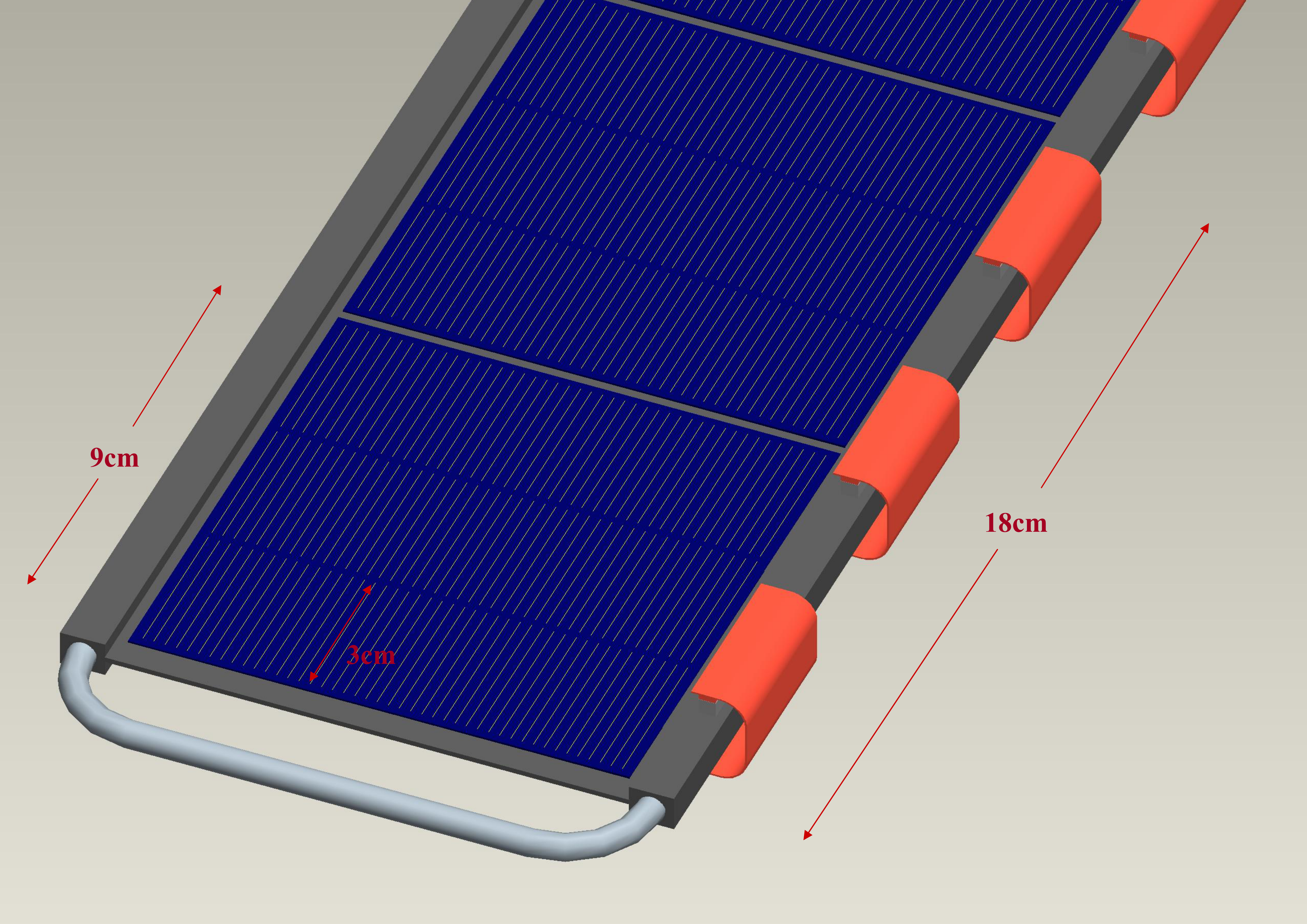


Initial thermal simulations promising but need more realistic studies backed up by prototyping

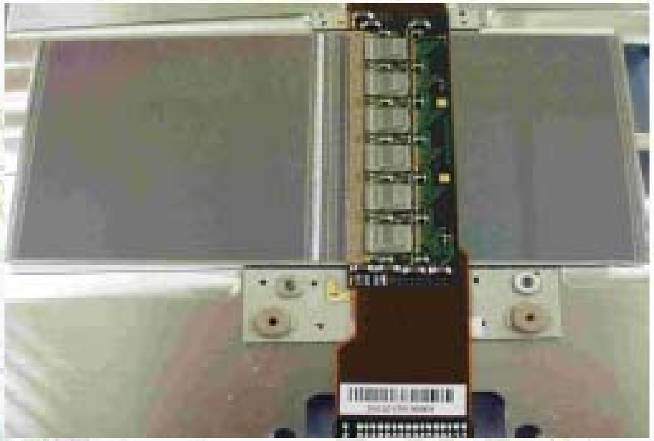
Fro middle radii, need to develop a stave/super-module, irradiate it and demonstrate read-out with fully functional integrated cooling and opto-electronics



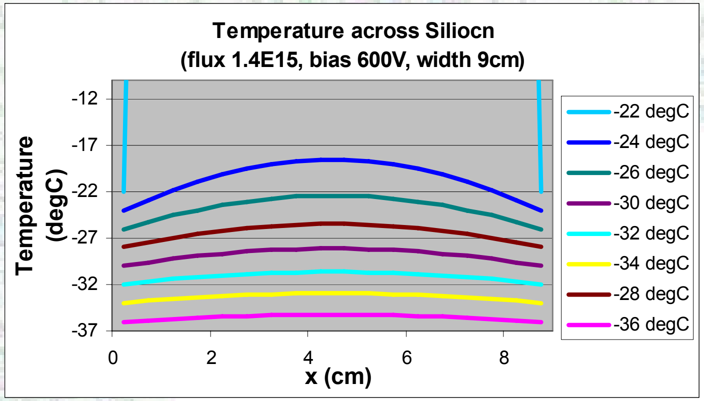
Z=0 End of 144cm Length Stave with 9cm Sensor Width


9cm
18cm
3cm

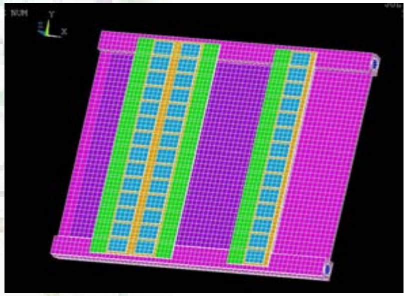
Possible Mini-strip Super-Module Design

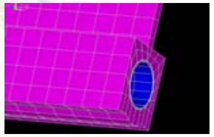


Ideas based on current ATLAS barrel design with bridging structure for electronics hybrid and TPG baseboard using
50µm pitch (φ)
3cm mini-strips
giving 9×9cm
single-sided sensors.

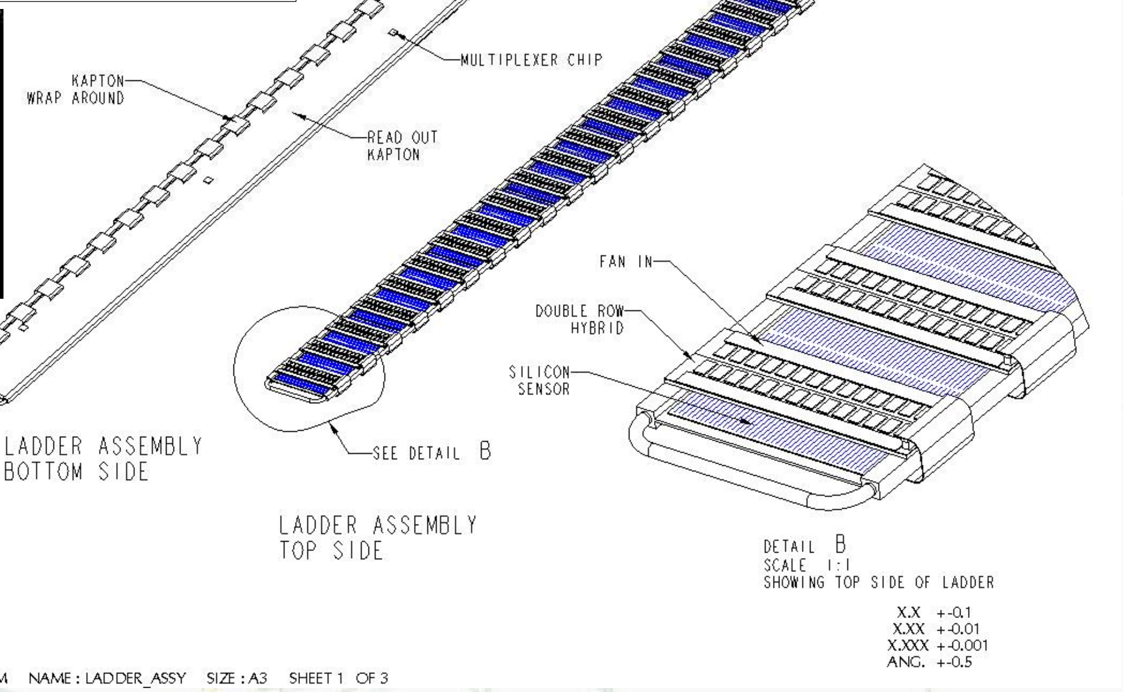


Each sensor has 3 sets of 3cm strips which could be DC coupled electronics.





Indications from initial simulation are that thermal runaway can be avoided with ≤ -30°C coolant.



Motivations for Stave Designs

Advantages
- Single unit with all services (included cooling) integrated.
- All performance aspects can be tested prior to assembly.
- Lends itself naturally to distributed production.
- Ease of assembly, removal, repair and replacement.
- Less thermal and electrical connections.
- Tapered staves for forward region naturally offer lower width (better cooling) at low radii.
- Forward staves could be inclined to reduce scattering material and optimise coverage.

Disadvantages
- Danger of more scattering material when including support space-frame/cylinder.
- Harder to ensure minimal distance between overlapping modules in a given layer.
- Different services are forced to address the same set of sensors/hybrids.
- Need to ensure space-frame structure is highly stable and rigid.
- Metrology of final object less straightforward.

Forward region assumed to require radial sensors, so 7 different types of 10cm long objects needed in all designs. With the tapered stave concept, these would go from 10cm width at 100cm radius down to 3cm at 30cm radius, subtending 5.7^{o} so that 64 such units would be needed to give 2π coverage at each *z* position.
Outer radii assumed to have extra small angle stereo layers to give space-point for both other barrels and high radius on forward tapered staves.

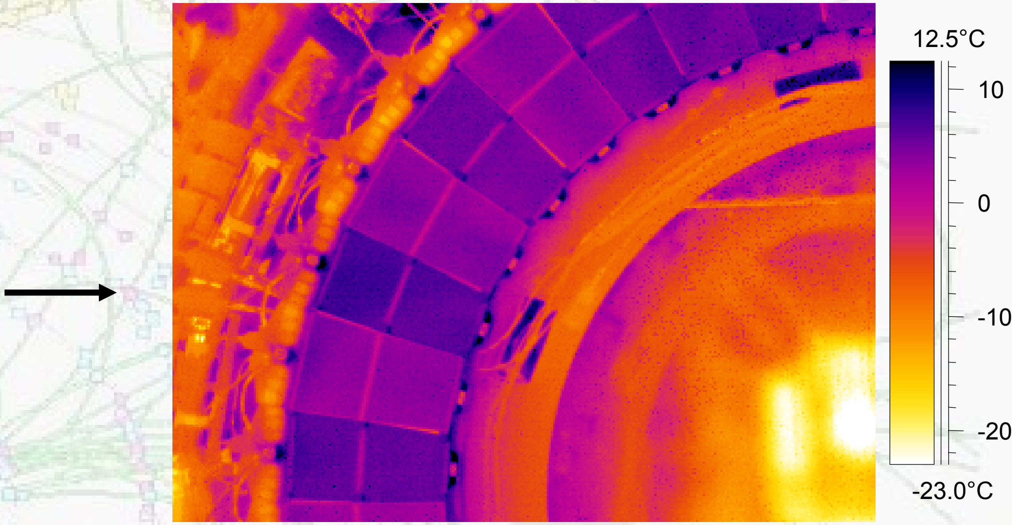
Cooling Challenges

SCT experience C_3F_8 evaporative cooling system

- constant temperature throughout cooling lines
- high cooling capacity (limited flow)

Also

- successful thermal separation hybrid and sensors.



Challenges for the SLHC:

- more modules / more power dissipation
- may need to keep silicon temperature at -25°C.
  - **strong constraint on thermal separation hybrid and sensor**

Proposals for study:

- sensors on high thermal conductivity spine/base (TPC,CC)
- Use two-phase cooling again. Limited number of coolants available
  - C_3F_8
  - CO_2 (high cooling capacity with very thin pipes)

Front-end Electronics, Power, Readout

Front-end electronics

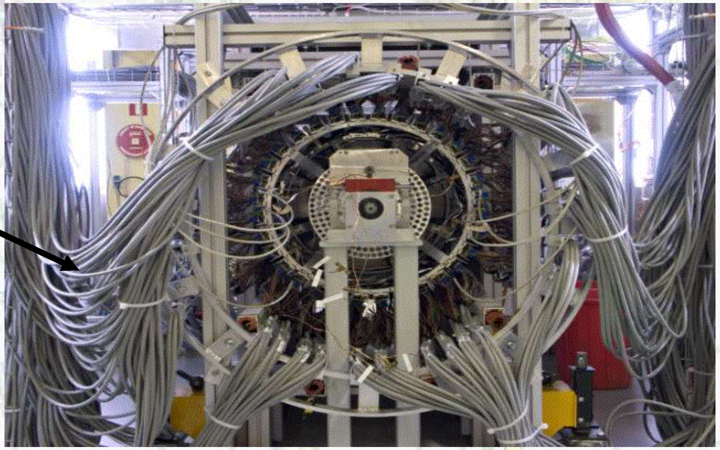
- ABCD-next: port ABCD to 0.25 μm and then to 0.13 μm CMOS
- SiGe-biCMOS: also 0.25 or 0.13 μm

In both cases deep sub-micron:

- Radiation hard
- Reduced power dissipation per chip (but more chips, still ×2 power increase)
- Low driving voltages (large voltage drop, or thick cables)

Power distribution:

Cannot afford to have thousands more of these



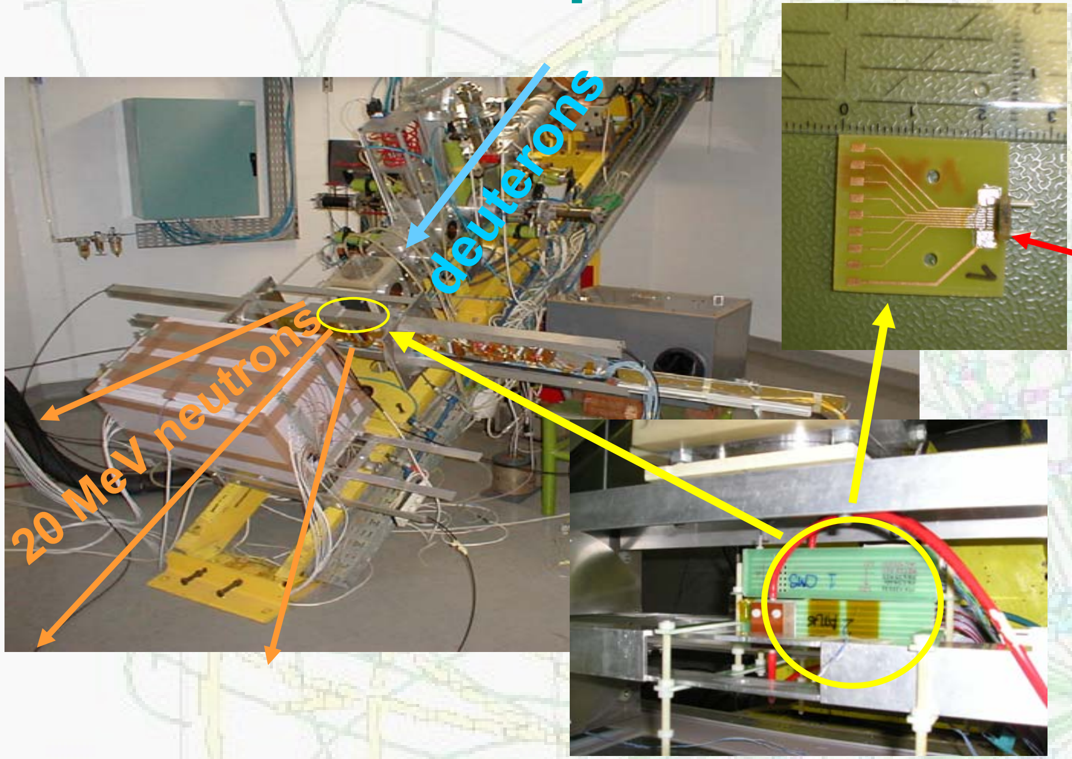
- shared power to modules.
- DC-DC conversion near the modules.

Data output:

Similar problem, more channels limited space.

Use shared high speed optical links. (SLHC requires customised solutions)

First ATLAS Optoelectronics SLHC Radiation Test Results



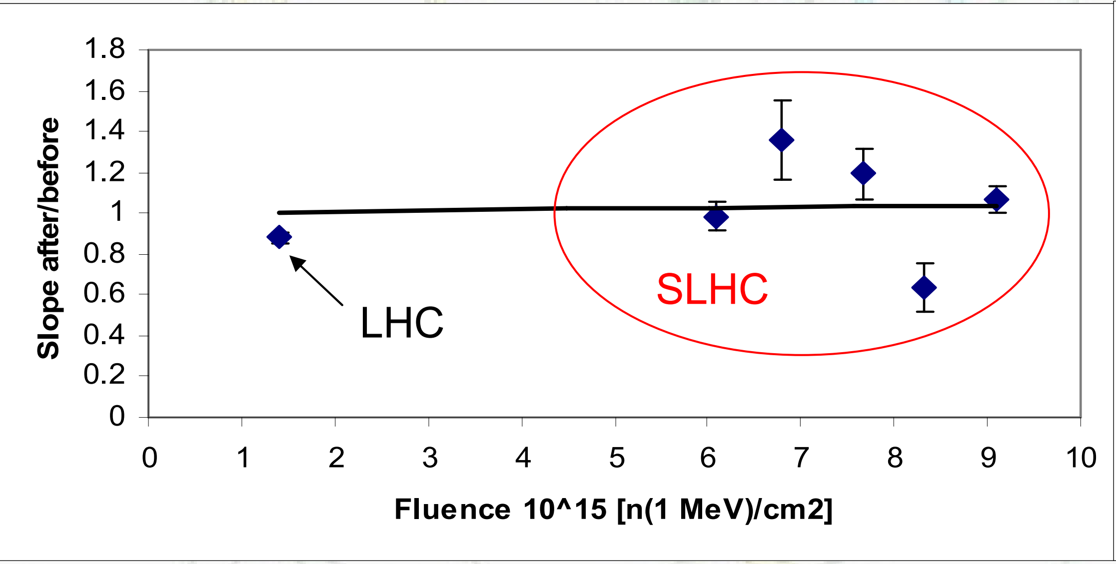
1st test in collaboration with CMS March 06: Irradiation programme went very well.

VCSELs irradiated up to 10^{16} n(1MeV/cm^2) and annealed for 4 weeks. Devices were monitored during radiation and annealing.

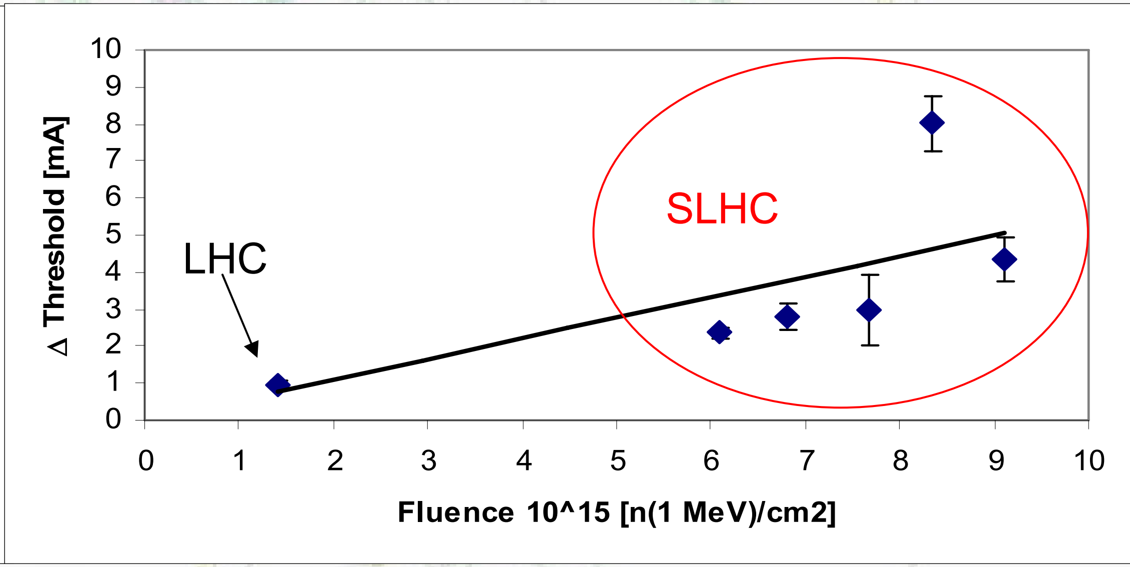
Need much more statistics at high fluences

Future tests with VCSELs, Si-*p-i-n* and fibres required for SLHC prototype stave.

No change in slope efficiency



Threshold increases



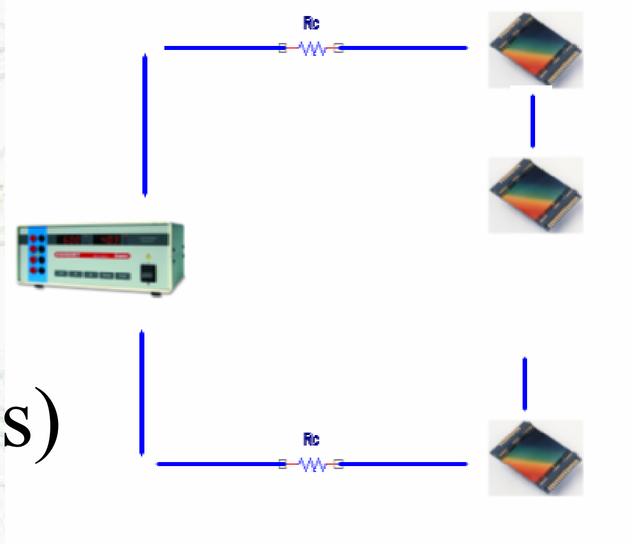
Power Management and Serial Powering

- Features of ATLAS SCT
  - 6 M channels
  - 50 kW of power
  - 50% of power loss in cables
  - separate analogue and digital power lines for each module
  - material of power and cooling services dominates detector material
- Challenge for SLHC tracker
  - 60 M channels
  - cannot bring in 10-fold number of cables
  - ~80% power loss in cables for SLHC electronics
  - material of power cables ruins tracking resolution/reconstruction
- **Serial powering possible solution to this problem**

Serial Powering

- Power n modules from a single current source

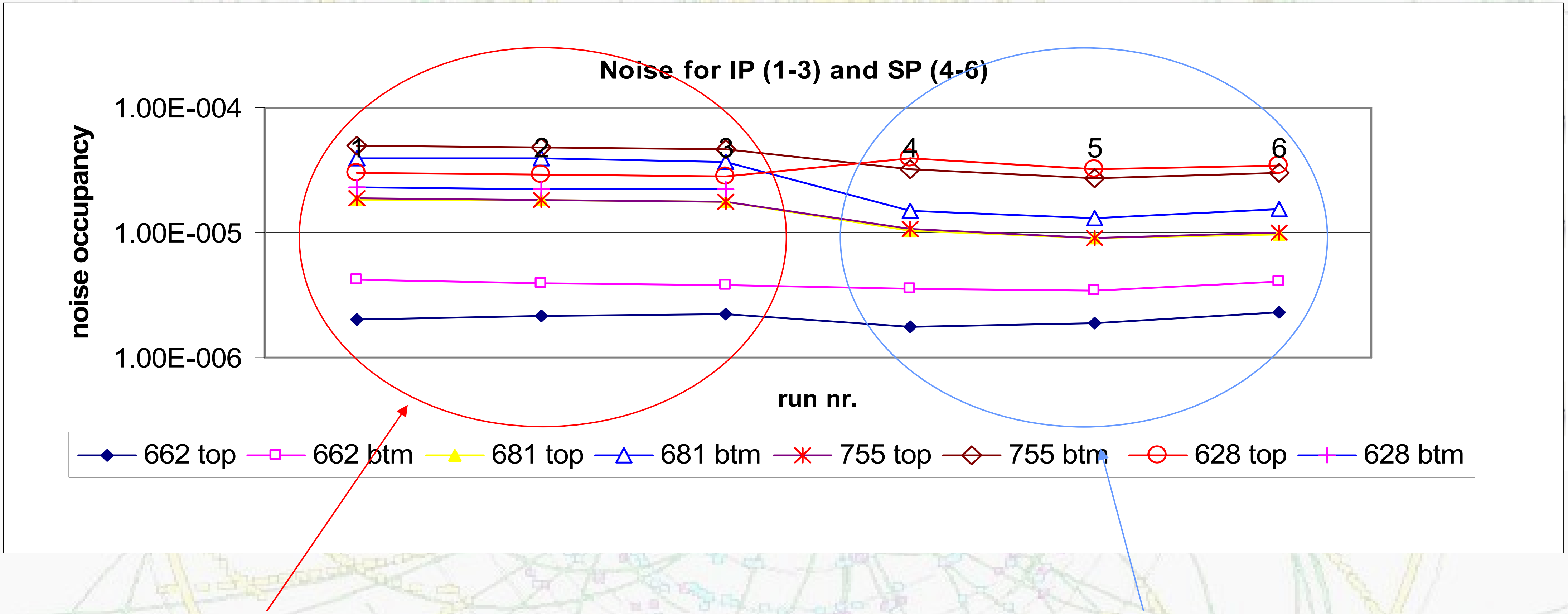
  - number of cables reduced by factor 2n
  - much reduced power losses in cables
  - much reduced material
  - reduced costs (power supplies, power bills)



- UK initiated R&D programme

  - obtained PPARC seed-corn funding
  - first results very promising (no extra noise with serial power)
  - goal is proof of principle for a large scale application (crucial for SLHC tracker and elsewhere)

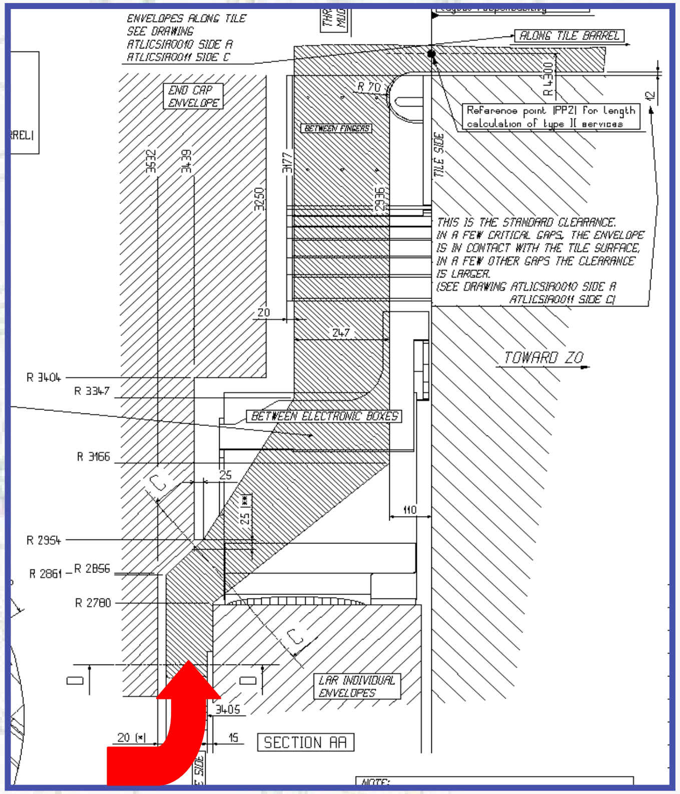
First Published Serial Powering Results



- First 3 runs with independent powering and last 3 runs with serial powering for 8 ATLAS barrel modules
- For this bench-test (studies on prototype stave structures required) serial powering works well with no difference in noise performance

Other Tracker Challenges (mainly for middle and outer radii)

Replacement inner tracker will need to fit in the same space as the current one.



The same goes for the services. (Almost factor 10 more channels in SCT/TRT region)

Limited time for building system with many modules

Should make something that's easy to build.

Where possible use experience of the current build.

- Build something similar or completely different?

ATLAS Tracker Upgrade Summary

Likely date for SLHC luminosity upgrade to 10^{35} $cm^{-2}s^{-1}$ is around 2015.
Preparations for required inner tracker replacement already urgent.

Sensor technology:

- Sensor solutions may exist but urgently require commercial prototyping:
  n-side readout silicon pixels/strips could provide 10 years operation.
- b-layer at 6cm radius may require 3D or other exotic technologies.

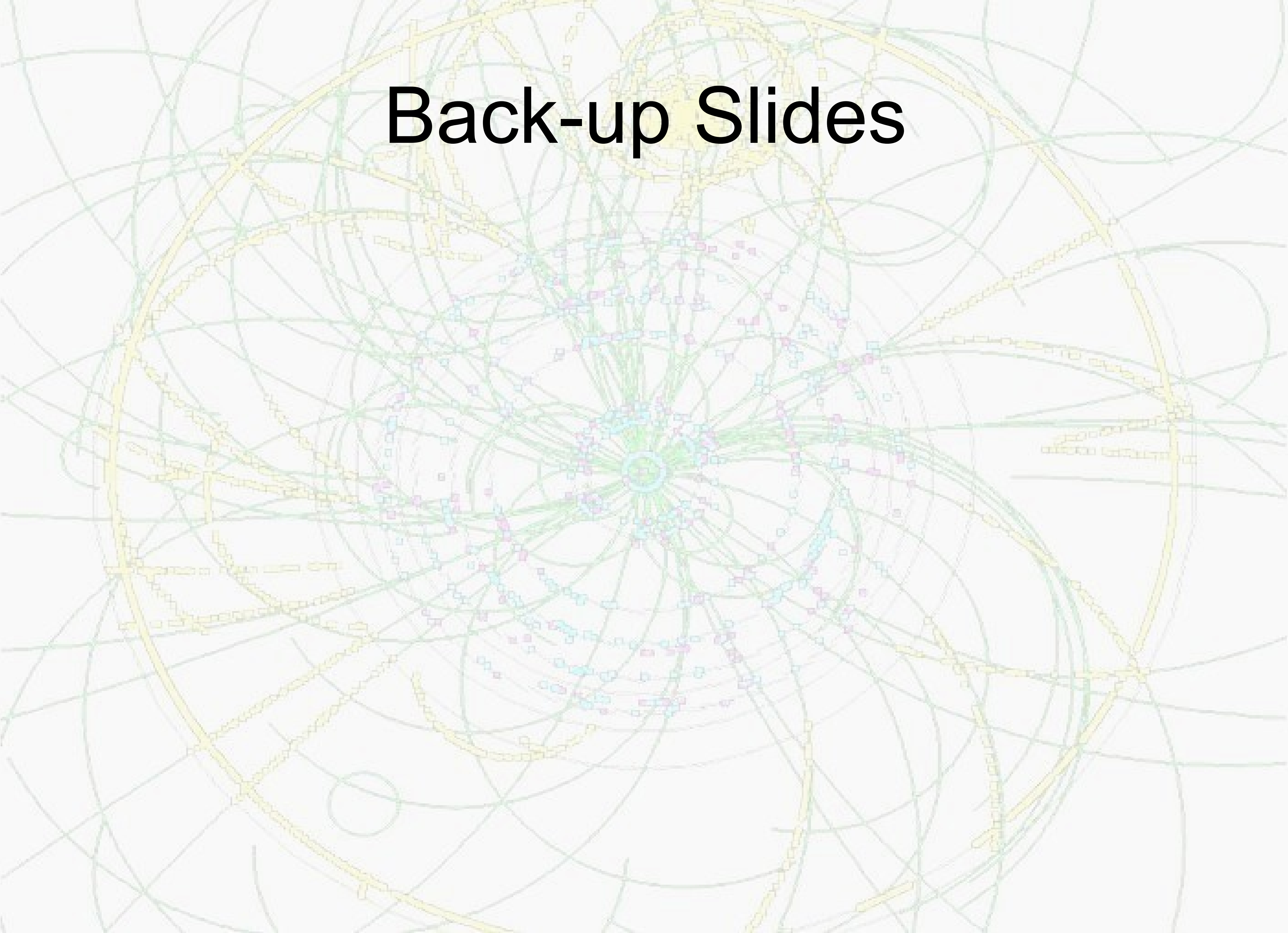
Need to operate sensors much colder than at the LHC (around -25°C?).

Front-end electronics: deep sub-micron rad-hard technologies needed

Engineering issues may be the biggest challenge:

- require integrated design of module/stave with full services incorporated
- need to work on cooling, electrical power distribution and optical read-out
- limited time to build large tracker requiring many innovative technologies

Back-up Slides

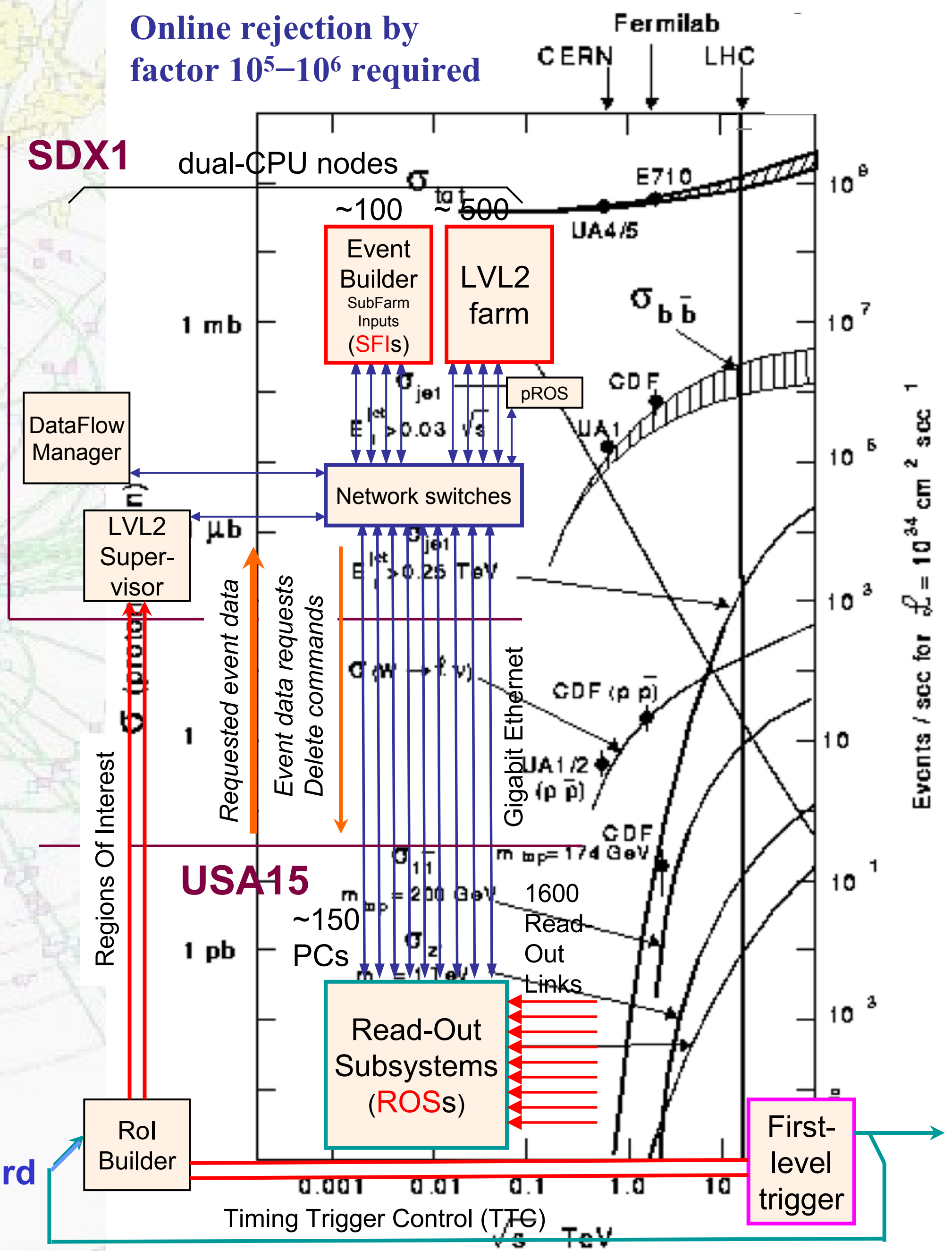


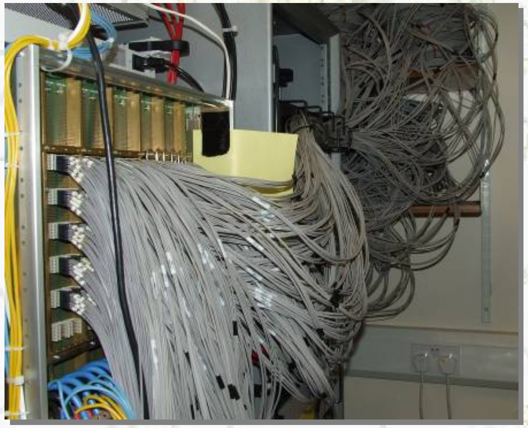
Data Processing Issues at the SLHC

Online data filtering (triggering) issues even harder at SLHC with 10 × event rate

The UK has led the level-1 calorimeter trigger project and played major roles in high-level trigger development and software production.

The UK has strong expertise in exactly those areas which form the major part of the ATLAS trigger high luminosity upgrade.


Online rejection by factor 10^5–10^6 required



Level-1 400-Mbit/s serial 4-channel input links from programmable source modules

ATLAS Second Level Trigger Card

Other ATLAS Systems

Trigger Electronics:

- "Front-end electronics can probably stay" (clock speed? deeper pipelines?)
- Extensions to trigger capability needed
- Need to maintain L1 output rate (more data per event)
  - Must upgrade detector backend electronics
    - adapt clock speed to bunch-crossing rate
    - increase bandwidth to deal with more data per event
  - Modify trigger algorithms to deal with high occupancy (and increase thresholds)

L-Ar:

- Some performance degradation due to high rates. (e.g. electron isolation suffers from 200 min. bias events.)

TileCal:

- Some radiation damage scintillators
- Challenging calibration with strong increase in pile-up

Muon systems:

- MDT's some degradation in performance due to high rates, in particular in the forward regions:
  - May need additional shielding forward region
  - Aging/radiation damage needs confirmation for SLHC operation
- RPC's, TGC's: Need an upgrade?

LHC Luminosity Profile