Precision Inner Tracking Systems at the SLHC

Session: Tracking with Solid State Detectors

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Outline

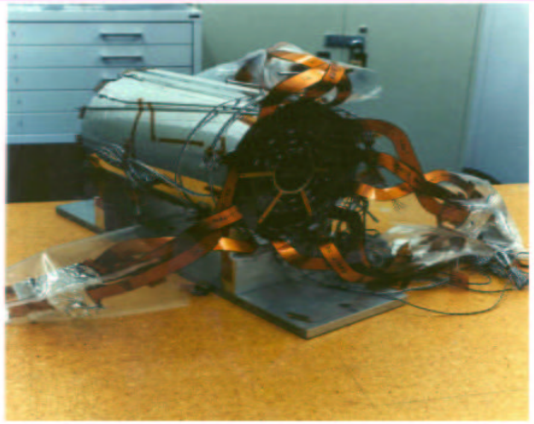
- Introduction
- Physics goals and motivation for tracking
  - LHC baseline
  - SLHC@10^{35}
- Technical background
- Baseline trackers for ATLAS and CMS
- Issues for running @10^{35}
  - Technical requirements
  - Physics performance requirements
- Tracker design for SLHC@10^{35}
- New technical directions

Introduction

- Optimized trackers at 10^{35} require significant changes from present designs.
- Motivate by physics requirements.
- 10^{35} targets new physics at high p_T. B physics program is at low luminosity.
- 1 year @: 10^{34} = 100 fb^{-1}, 10^{35} = 1000 fb^{-1}
- Constrain designs by performance requirements, operating environment, and technical specs at 10^{35}.
- Perspective is for precision solid state detectors

Historical Note

- First silicon tracker for a hadron collider was proposed ~1985 by the INFN Pisa group for CDF at Fermilab the "SVX"
  - 4 layers of silicon microstrips, 2-7 cm radii
  - 50K channels
  - Expected luminosity was 10^{29} (100 nb^{-1}), (dose ~few KRad)
  - Primary purpose was to discover top by (real) W→tb
  - Not expected to do any significant B physics
- Many were skeptical about this application
  - "it will flood the rest of the detector with secondaries" (UA1 experience)
  - "it will be impossible to maintain required mechanical precision"
  - "it will be inefficient"
  - "it will burn up due to radiation"
  - "it will be unreliable or never work at all"
  - "anyway there is no physics to do with it…"



LHC Baseline 10^{34}, 300 fb^{-1}

- Generally accepted outcome of the baseline program
  - B physics program (at low luminosity) complete
  - Precision Standard Model program (W,t studies) complete
  - QCD: inclusive jet production up to E_T=3.6 TeV
  - The SM Higgs boson is found if it exists
  - SUSY, if at the EW scale, is found
  - Limits on (or discovery of) various exotica
    - New gauge bosons
    - Heavy quarks
    - Compositeness
    - Extra Dimensions

Physics Goals for SLHC @ 10^{35}

- Expectations are based upon the ATLAS & CMS studies for LHC upgrade
  - Physics in ATLAS at a possible upgraded LHC, Azuelos et al, ATL-COM-PHYS-2000-030 (March 8, 2001)
  - Physics Potential and Experimental Challenges of the LHC Luminosity Upgrade, hep-ph/0204087
  - 3000 fb^{-1}, 14 TeV
- QCD studies, compositeness
- Strongly coupled WW system
- Searches
  - Extra dimensions
  - New gauge bosons
  - Excited quarks
- Triple gauge boson couplings
- Rare top decays
- Higgs physics
- Supersymmetry

QCD Studies Compositeness

- Relies on measurement of jets
  - dN/dE_T
  - $\cos\Theta$
- Extend E_T reach from 3.6 to 4.2 TeV
- Extend compositeness scale from 40 to 60 TeV
- Calorimetric measurement, no direct use of tracking
- Calibration of calorimeters at SLHC using tracks?

Strongly Coupled WW System

- In case of no light (< 1 TeV) Higgs the WW scattering becomes strong.
- Study production of W+W- pairs, leptonic decays.
- Background rejection uses jet tag and veto
  - Significantly degraded by jet pile-up effects at 10^{35}
- Tracking of muons and electrons are required for any increase in significance at high luminosity

Searches

- New gauge bosons
  - Example is Z’→ μμ, ee
  - SLHC extends reach by ~ 30% if μ,e are included
  - Key challenge is electron ID to included ee channel in search
- Excited quarks
  - Measure effects of excited quark decay
    - q* → qg,qγ
  - Measurement is primarily calorimetric

Extra Dimensions

- Dynamics from shift of gravity to TeV scale
- Signal is production of jets or γ with E_T^{miss}
- Measurement constrains δ (# extra dim) and M_D, the scale of gravity.
- SLHC increases reach~30% (9–12 Tev @ δ=2)
- Measurement is primarily calorimetric

- Triple gauge boson couplings
  - Probe the WWγ and WWZ vertex
  - SM expectations are modified by new physics.
  - Increased luminosity offers statistics and therefore increased sensitivity
  - Final states are $l\nu\gamma$ and $ll\nu$
  - Ability to track and identify electrons is a major statistics driver.
- Rare top decays
  - Certain FCNC decays are too small in the SM to be seen even with an SLHC
  - If detected could be a probe of new physics
  - Requires full machinery of b tagging and top reconstruction. Use of second top as a tag leading to b jets, for example.

Higgs Physics

- SM Higgs will be found at the LHC (if there)
- Special topics for an SLHC
  - Rate limited decays
  - Increased precision on couplings
  - Higgs pair production
  - Self couplings
- Higgs program relies on fully functional detector with tracking, lepton ID, b tagging

Supersymmetry

- Particle content (MSSM)
  - Spin ½
    - 4 neutralinos
    - 4 chargeinos
    - Higgs sector h,H,A,H+,-
    - Gluinos
  - Spin 0
    - squarks, sleptons
- R parity
  - Preserves B,L conservation
  - $R=(-1)^{3(B-L)+2S}$
  - SUSY particles are produced in pairs
  - Lightest supersymmetric particle (LSP) is stable
- Additional "hidden" sector to provide SUSY breaking

Supergravity Models (SUGRA)

- Squarks and gluinos are heavy but strongly coupled, dominate cross section. LSP is $\tilde{\chi}_1^0$, weakly interacting, classic E_T^{miss} signature.
- LSP is produced in association with lepton pairs or SM Higgs which decays to bb. $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 h, \quad h \rightarrow b\bar{b}$
- Require lepton identification and b tagging with precision vertex tracking.

Gauge Mediated Models (GMSB)

- Gluino is LSP. Phenomenology dominated by NLSP and whether it decays in or outside the detector.
- 4 main scenarios depending upon various parameters
  1. $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ gluino in association with photon or photon plus lepton pairs, $c\tau=1.2$
  2. $\tilde{\chi}_1^0$ long lived, if decays in volume γ does not point.
  3. NLSP is stau, $c\tau=52$ μm, want to track inside jets
  4. NLSP is stau, $c\tau=1$ km, 2 “stable” particles per event which look like μ with $\beta<1$
- Requires lepton identification, lepton/γ discrimination, track multiplicity and p_T inside jets, TOF

R Parity Violation

- E_T^{miss} signature is lost.
- Unstable $\tilde{\chi}_1^0$ decays
  - qqq
  - $l^+l^-\nu$
  - qql,qqν
- Requires lepton ID, b anti-tag

SUSY at 10^{35}

- If SUSY is relevant (hierarchy problem) expect some part of the spectrum seen at the baseline LHC.
- There can be a heavier part (squarks and gluinos) only accessible at 10^{35}. Mass reach extends from 2.5 to 3 TeV. Basic measurement is mostly calorimetric.
- But “the background to SUSY is SUSY”.
- Particular exclusive decay chains require full tracking capabilities.
- The decay $\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q, \quad \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 h, \quad h \rightarrow b\overline{b}$ is an example from the SUGRA mediated scenario.
- Requires b tagging and reconstruction

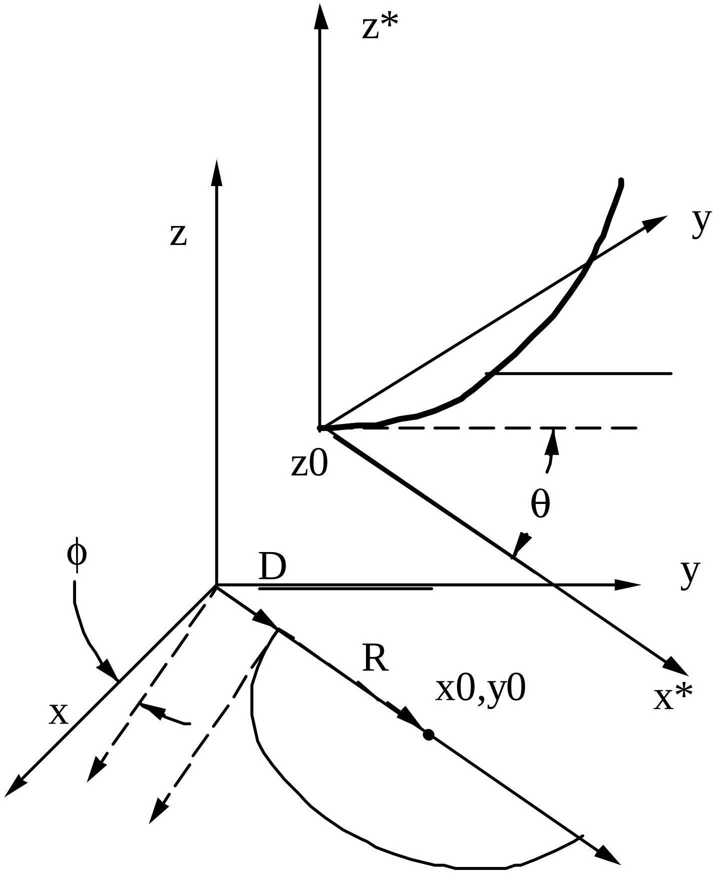
Conclusions on Physics Shopping List

- Some of the proposed topics are calorimetric
  - Will calorimeter systematics depend upon tracking capability?
- Tracking will be of particular importance for
  - Strong WW system
  - Search for new gauge bosons
  - Top physics
  - Higgs physics
  - Supersymmetry
- Largest impact is on the Higgs and SUSY sectors.

Technical Background

- Basic constraints on tracking systems
  - Geometry
  - Material
  - Point resolution
- Point resolution and multi-hit response
  - The problem of 2D
- Silicon detectors
  - Principle, structures
  - Radiation issues
  - Signal processing issues

Trajectory



$$x = x0 + R\cos\lambda$$

$$y = y0 + R\sin\lambda$$

$$z = z0 + R\lambda\tan\theta$$

- Charged particle in a magnetic field B=Bz
- 3D Helix : 5 parameters

C = half curvature (1(sgn)/R)

z_0 = offset

d = signed impact parameter (distance of closest approach)

Azimuth ϕ = angle of track at closest approach

θ = dip angle

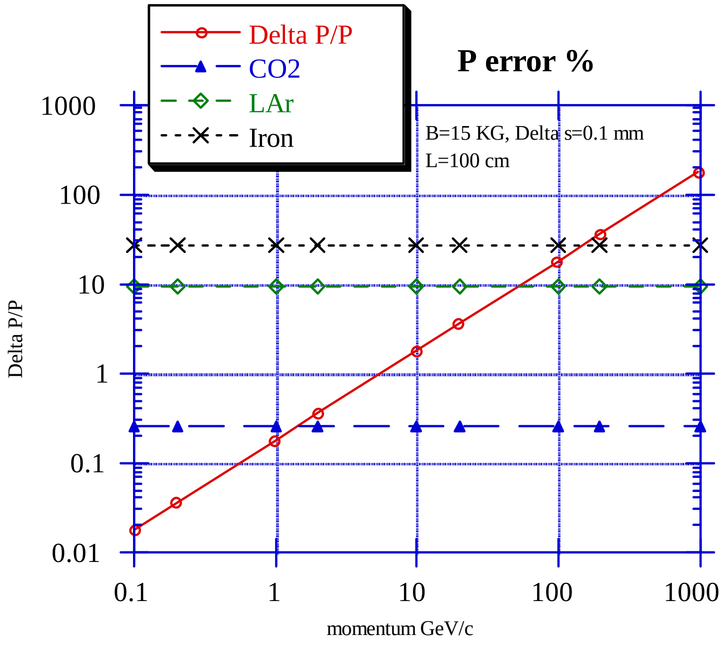
Momentum resolution

$$\left(\frac{\Delta p}{p}\right)_{sagitta} = \frac{8p\Delta s}{0.3BL^2\cos\theta}$$

$$\left(\frac{\Delta p}{p}\right)_{MCS} = \frac{52.8}{B\sqrt{LX_0\cos\theta}}$$

$$\frac{\Delta p}{p}_{TOTAL} = \left(\left(\frac{\Delta p}{p}\right)^2_{saggita} + \left(\frac{\Delta p}{p}\right)^2_{MCS}\right)^{\frac{1}{2}}$$

- Minimize sagitta error
- Maximize B,L
- Minimize material

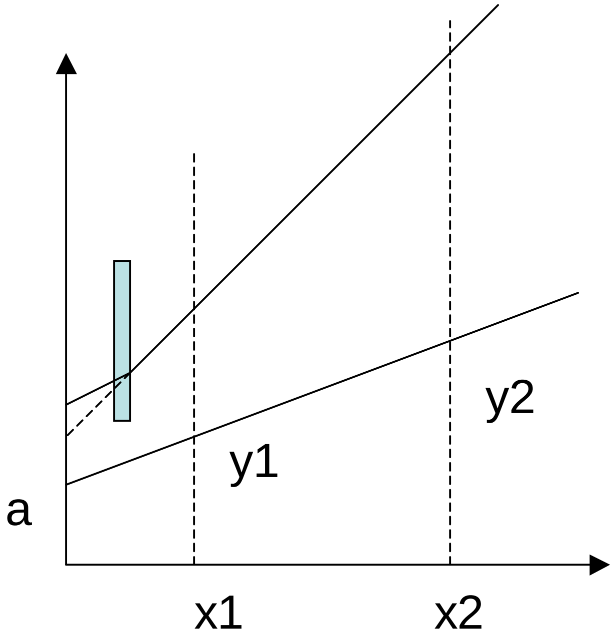


Vertex Resolution

$x1, x2 =$ measurement planes

$y1\ , y2 =$ measured points, with errors δy

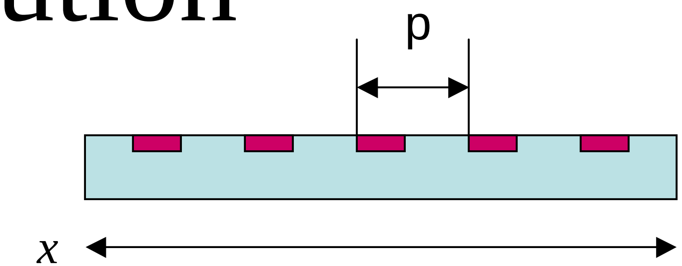
$$\delta a = \frac{\delta y}{2}\sqrt{1+\frac{8\bar{x}}{\Delta x}}$$



for good resolution on angles (ϕ and θ) and intercepts (d, z_0)

- Precision track point measurements
- Maximize separation between planes for good resolution on intercepts
- Minimize extrapolation - first point close to interaction
- Material inside 1st layer should be at minimum radius (multiple scattering)

Point Resolution



- Discrete sensing elements (binary response, hit or no hit), on a pitch *p*, measuring a coordinate *x*

$$\sigma_x = \frac{p}{\sqrt{12}}$$

- Discrete sensing elements (analog response with signal to noise ratio S/N) on a pitch *p*, where f is a factor depending on pitch, threshold, cluster width

$$\sigma_x \sim fp(\frac{N}{S})$$

Multi-hit performance

- Binary response (hit or no hit), on pitch *p*, two hit separation requires an empty element.
  - Wide pitch → most hits are single element, separation = *2p*
  - Narrow pitch → double element hits, separation = *3p*
- Analog response: can use local minima in a merged cluster
- The problem of 2 dimensions:
  - crossed array of *n* elements each on pitch *p* gives equal resolution on both coordinates.
    - m hits → m^2 combinations with $m^2 - m$ false combinations
  - Small angle stereo geometry, angle α
    - False combinations are limited to the overlap region but resolution on second coordinate is worse by $1/\sin(\alpha)$

2D

- Pixel structure: *n* x *m* channels
  - Ultimate in readout structure
  - Expensive in material, system issues, technology
- Pixels and strips can also be thought of as 2 extremes of a continuum (super-pixels, short-strips,…..)
  - Some potential for optimizations of performance vs. complexity but needs to be analyzed on a case by case basis
- Novel 2D structures with 1D readout which rely on assumptions about hit characteristics

Silicon Detectors

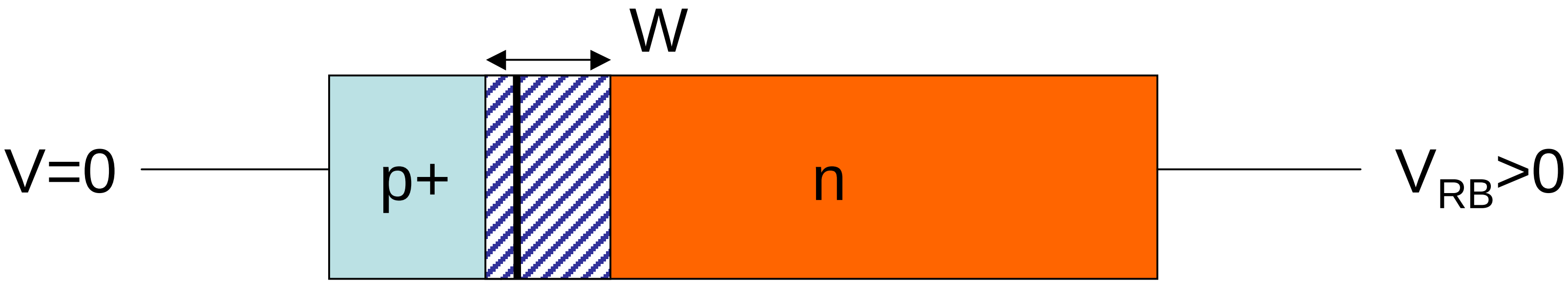
- Semiconductor band structure → energy gap
- Asymmetric diode junction: example p(+) into contact with n (Na>>Nd)
- Space charge region formed by diffusion of free charges, can be increased with "reverse bias“

$$\text{junction width}: W = \sqrt{2\mu\rho\varepsilon\left(V_{BI} + V_{RB}\right)} = 0.5\mu m\sqrt{\rho\left(V_{BI} + V_{RB}\right)}$$

$$\mu = \text{electron mobility}, \varepsilon = 11.9\varepsilon_0$$

$$\rho = \text{resistivity of n type material} = \frac{1}{\mathrm{e}\mu N_D} \approx 1 - 10k\Omega\, cm$$

$$V_{BI} = \text{built in potential} \left(\sim 0.8 \text{ V}\right) \quad V_{RB} = \text{applied reverse bias}$$



•Levels near the mid-gap can generate a leakage or dark current

$$I_L = \frac{en_i(\sigma v_{thermal} N_T)WA}{2}$$

n_i = intrinsic carrier concentration

σ = recombination cross section

$v_{thermal}$ = carrier thermal velocity

N_T = trap density

A = junction area

which depends upon temperature and trap density (defects)

- Noise: statistical fluctuations in I_L are a noise factor
- Issue of thermal run-away: power dissipated in silicon $=V_{RB}I_L$
  - ➢ Power dissipation heats the silicon, increases I_L
  - ➢ Thermal conduction paths are critical

Position Sensitive Structure

Single sided configuration
Pixel readout

Charge sensitive
Preamp + shaping,
signal processing,
pipelines, digitization

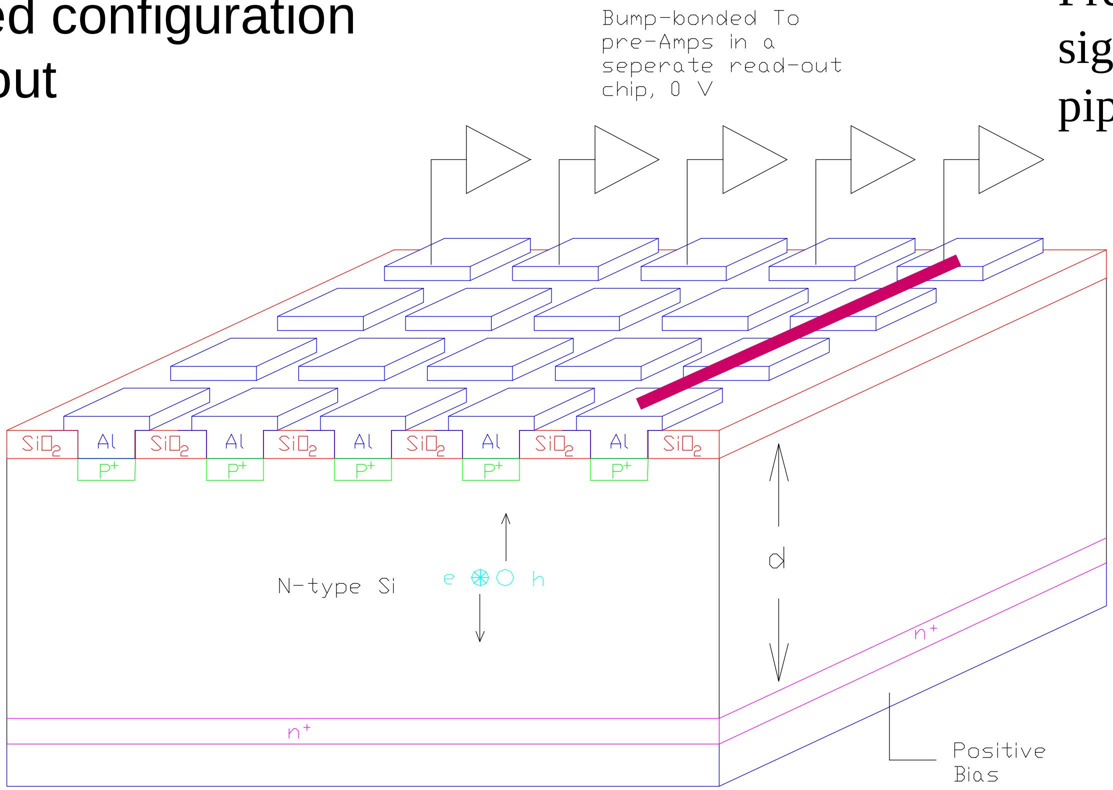


Diagram courtesy of Z.Li and V.Radeka

Radiation Effects

- Ionization
  - Incident particle interacts with atomic electrons
  - e/h pairs created, then recombine
  - Transient effect
    - Actual signal formation
    - Single event upset condition in circuits
    - Charge trapping at Si/SiO2 interface (largely controlled by rad-hard circuit designs or thinner oxides)
- Incident particle interacts with atom
  - Displacement damage – permanent or slow to reverse

Radiation Effects

- Damage to the periodic lattice creates mid-gap states
  →increased leakage current (noise, thermal run-away)

$$\Delta I = \alpha V \Phi$$

Damage constant $\alpha \approx 2 - 3\times 10^{-17}\ \frac{Amp}{cm}$

Volume $V \approx 2\times 10^{-3} cm^3$

Incident Flux $\Phi \approx 10^{14} - 10^{15}\ particles/cm^2$ @ LHC

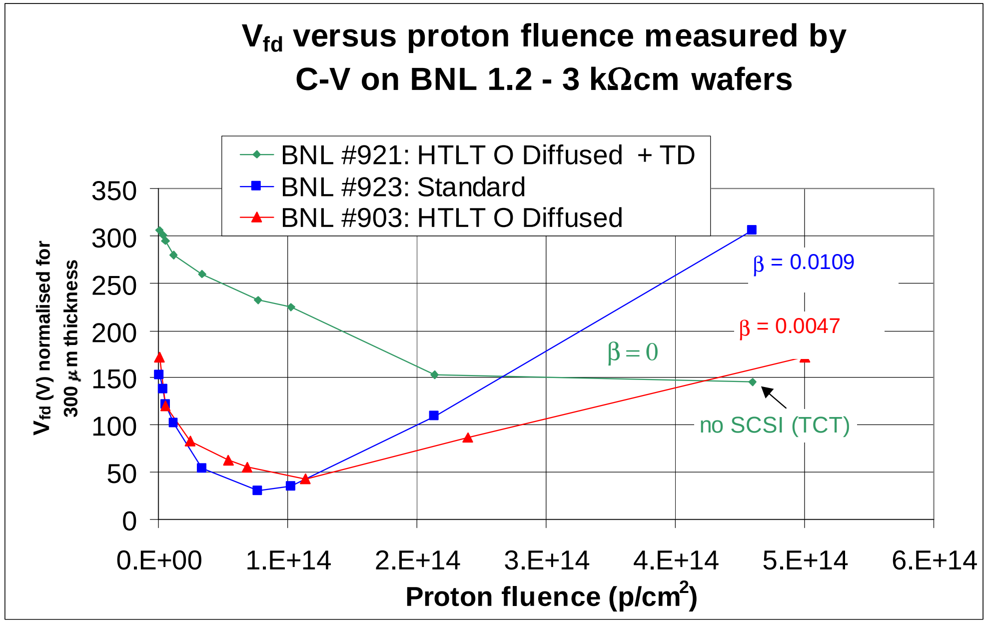
$\Rightarrow \Delta I \approx 2\mu A @ 0^o C$ (current doubles every 7 degrees)

- Reduction in charge collection efficiency (CCE)
  - Ratio of collection and charge trapping time constants

Charge collection

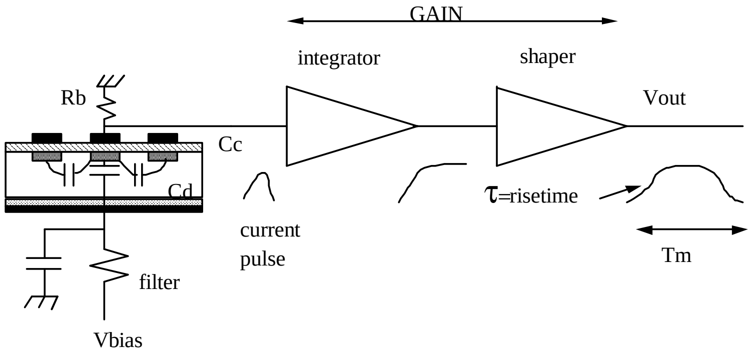
Fluence Φ [cm^{-2}]	w @ 600V [um]	τ_c / τ_t	Q estimated [k e^-]	Q measured [k e^-]
$2 * 10^{14}$	300	3/10	19.4 86 %	82% Casse et al
$8 * 10^{14}$	300	3/2.5	13.0 58%	65% Casse et al
10^{16}	140	1.4/0.2	1.3 6%	≈full simulations Also V. Eremin
10^{16}	50 at 100V	0.5/0.2	7.4 33%	3-D detectors

- Creation of new acceptor states or removal of donor states
  - Effective change of resistivity
  - Semiconductor type inversion: n becomes p
  - Depletion voltage changes in proportion to absolute value of number of effective acceptors ➔ higher voltage operation required



V.Radeka
Z. Li
B.N.L

Signal Processing Issues



- Signal: expressed as input charge, typically 25,000 pairs (4 fC)
- Leakage current: typically blocked DC by coupling capacitance, but $R_B C_B >> T_M$
  - Before(after) radiation damage ~ 1 nA(1ma)
  - AC component is seen by pre-amp
- Noise fluctuations ~ Gaussian σ_N
  - Leakage Current
  - Preamp “input noise charge”, white noise, decreases with pre-amp current, increases with faster risetime where *a*,*b* are constants and C_D is the detector capacitance
  - Bias resistor: source of thermal noise
- Noise fluctuations non-Gaussian due to coherent or position dependant pickup. System issue – grounding and shielding.
  - Can sometimes be controlled with local or off-line pedestal subtractions event by event.

$$\sigma_N \propto \sqrt{I_{LEAK} T_M}$$

$$\sigma_N \propto a + bC_D$$

$$\sigma_N \propto \frac{1}{R_{BIAS}}$$

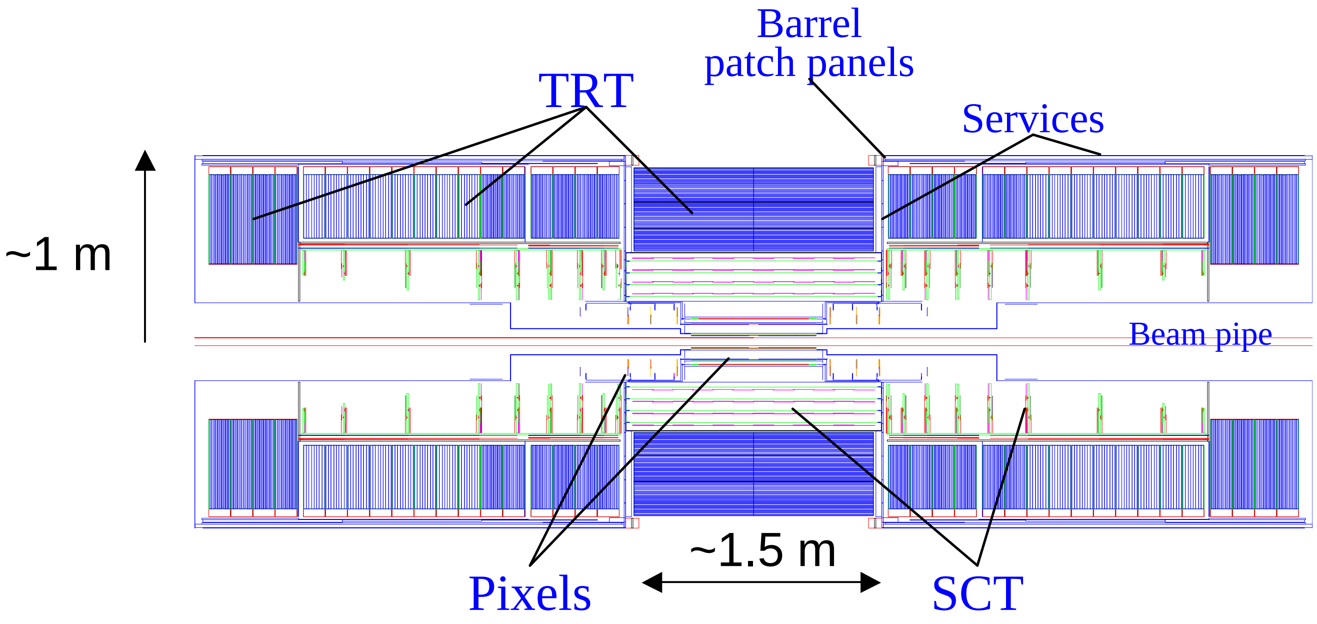
Silicon Collider Detectors

- 1st generation: LEP and CDF vertexers, $L=10^{29}$
  - 2-4 layers, single sided DC coupled silicon or early double sided, ~50K channels
  - Charge integration + S/H, analog readout, 3 μm radsoft CMOS and NMOS
  - Rad soft components (~25 KRad)
- 2nd generation: LEP and CDF , $L=10^{30}$ (~100 KRad)
  - AC coupled detectors, improved double sided structures
  - Rad hard components, 1.8 μm radhard CMOS
  - Early pixel implementations
- 3rd generation: CDF2a, D0, and B factories , $L=10^{31}$ (few MRads, 10^{12}-10^{13}/cm^2)
  - Early examples of trackers
  - Complex double sided constructions, ~500K channels
  - On chip storage pipelines, ADC's, digital readout, 0.8 μm radhard CMOS
- 4th generation: ATLAS, CMS trackers, CDF2b , $L=10^{32\text{-}34}$ (~10 MRads, 10^{14}-10^{15}/cm^2)
  - Large scale systems (5-10M channels), uniform designs, mass construction methods
  - Return to single sided detectors (radiation hardness and HV operation: SSC/LHC R&D)
  - New IC processes (Maxim, DMILL, 0.25 μm), fast front ends, deep pipelines
  - Engineered, large pixel systems for vertexing
- 5th generation: New trackers for $L=10^{35}$ (~100 MRad, 10^{14}-10^{16}/cm^2)
  - Very large scale systems, simplifications
  - New rad hard sensor structures and materials
  - Lower mass supports and services
  - Increased azimuthal AND longitudinal segmentation, pixel structures move to larger radii
  - Further evolution of IC (0.13,0.09 μm, heterostructures…) technology

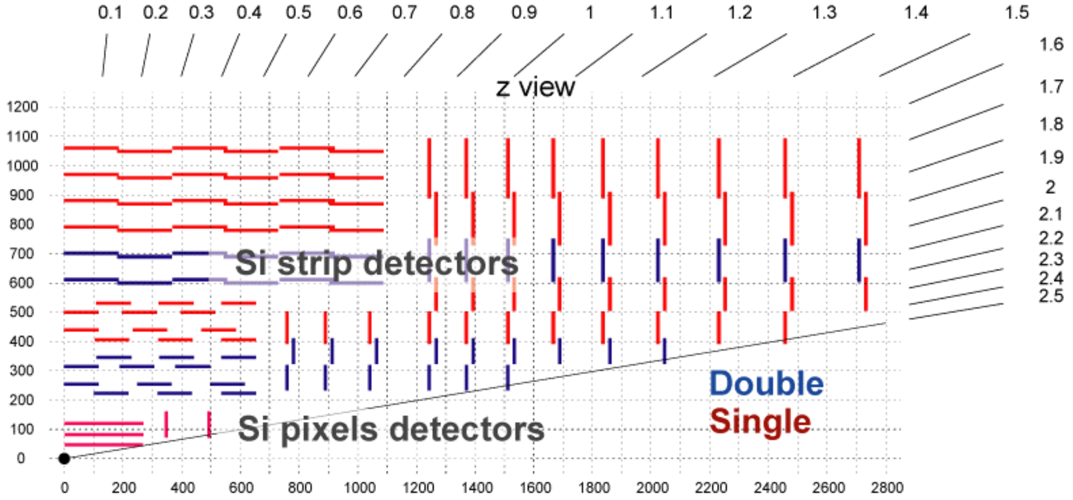
Parameters LHC, SLHC

	LHC	SLHC
$\sqrt{s}$	14 TeV	14 TeV
L	10^{34}	10^{35}
Bunch spacing Δt	25 ns	12.5 ns
σ_{pp} (inelastic)	~ 80 mb	~ 80 mb
N. interactions/x-ing	~ 20	~ 100
($N=L\ \sigma_{pp}\ \Delta t$)		
$dN_{ch}/d\eta$ per x-ing	~ 150	~ 750
$<E_T>$ charge particles	~ 450 MeV	~ 450 MeV
Track density	1	10
Pile-up noise in cal	1	~3
Dose central region	1	10

But 12.5 is nearly DC

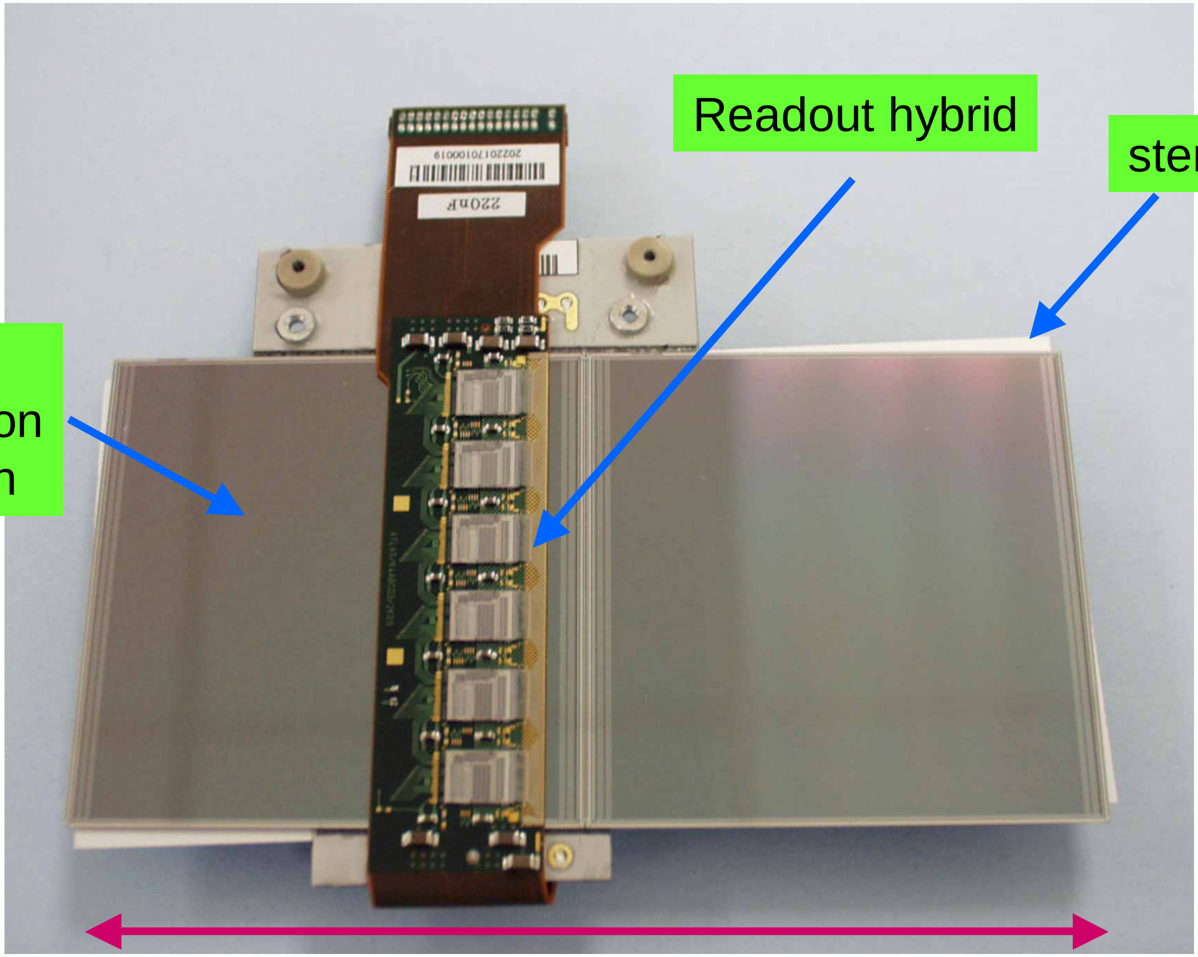


The ATLAS
Inner tracker



The layout of the CMS inner tracker

Modularity (ATLAS example)



Readout hybrid

stereo

Sensors
768 strips on
80 um pitch

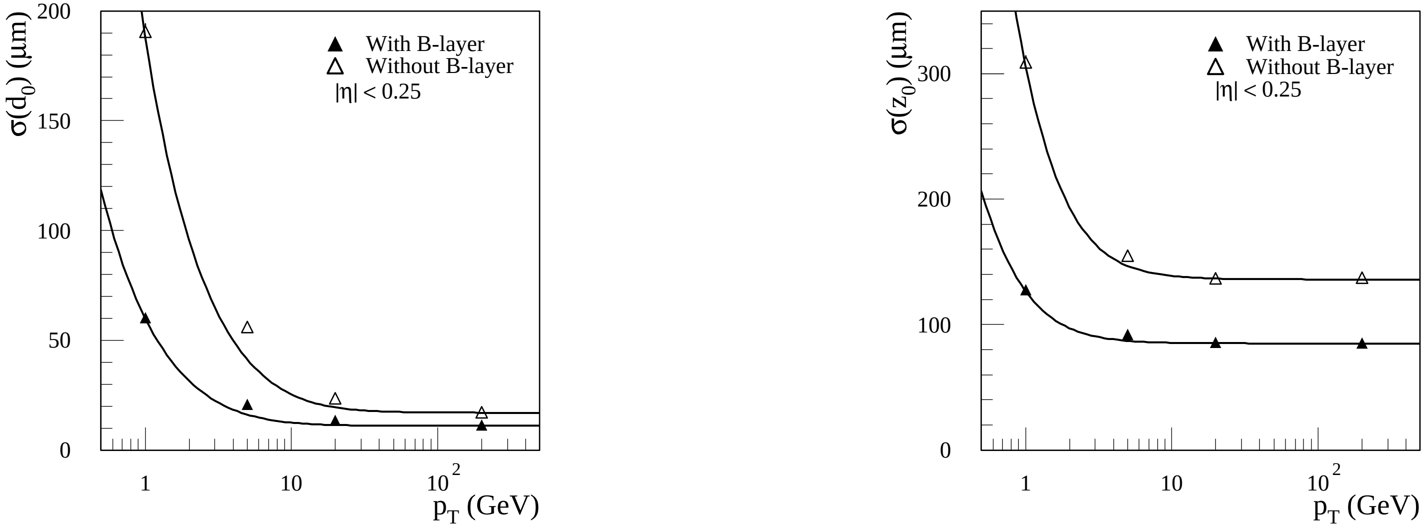
12 cm

ID Selected Performance Specifications*

- Coverage
  - Angular coverage $|\eta| \leq 2.5$
  - Number of precision hits ≥ 5
  - Number of straw hits = 36 (effective 1 point resolution of 70 μm at ~75 cm)
- Resolution
  - $p_T\sigma(1/p_T) < 0.3$ at p_T=500 and $|\eta| \leq 2$, <0.5 $|\eta|=2.5$
  - Impact parameter σ_{d0} as good as possible
  - Polar angle $\sigma(\theta) \leq 2$mrad
  - Longitudinal intercept $\sigma(z)<1$mm
- Reconstruction efficiencies
  - isolated tracks $p_T \geq 5$, $\geq 95\%$, fake rate < 1%
  - all tracks $p_T \geq 1$ in $\Delta R \leq 0.25$ around high p_T isolated track $\geq 90\%$, <10% fakes
  - Electrons $p_T \geq 7$, $\geq 90\%$
- B tag efficiency $\geq 40\%$, non-b rejection of > 50

*ATLAS view

Intercepts


σ(d$_0$) (μm)
200
150
100
50
0
1
10
10^2
p$_T$ (GeV)
▲ With B-layer
△ Without B-layer
|η| < 0.25
σ(z$_0$) (μm)
300
200
100
0
1
10
10^2
p$_T$ (GeV)
▲ With B-layer
△ Without B-layer
|η| < 0.25

Specifications modified for 10^{35}

- Coverage
  - Angular coverage $|\eta| \leq 2.5$
  - Number of precision hits ≥ 9(?) to provide same p_T resolution and efficiencies
  - Number of straw hits = 36 (effective 1 point resolution of 70 µm at ~75 cm)
- Resolution
  - $p_T \sigma(1/p_T) < 0.3$ at p_T=500 and $|\eta| \leq 2$, <0.5 $|\eta|$=2.5
  - Impact parameter σ_{d0} as good as possible
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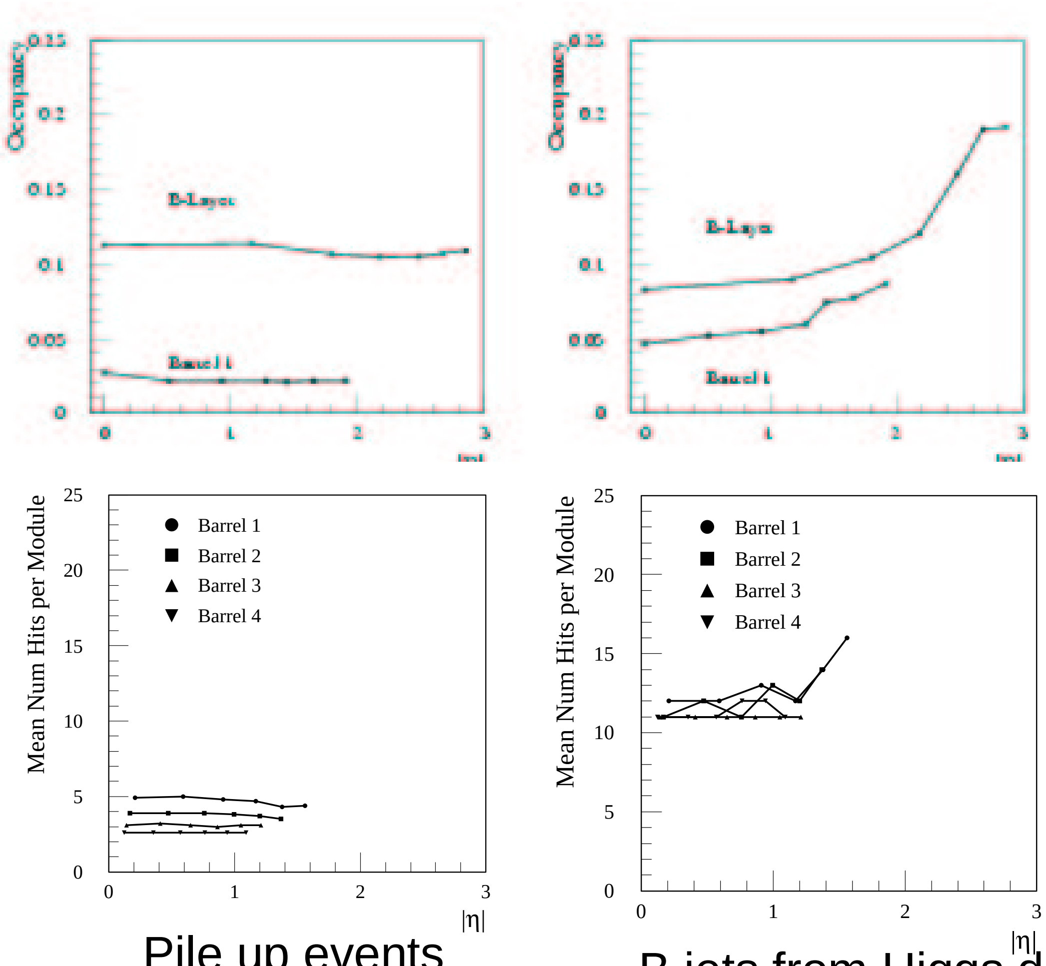
  - Electrons $p_T \geq 7$, $\geq 90\%$
- B tag efficiency $\geq 40\%$, non-b rejection of > 50

Occupancy vs η and radius 10^{34}

Pixels
(column pair occ)

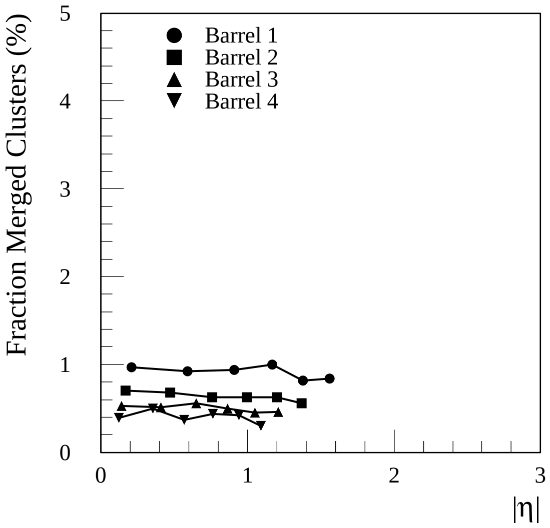
Strips
(hits/module)



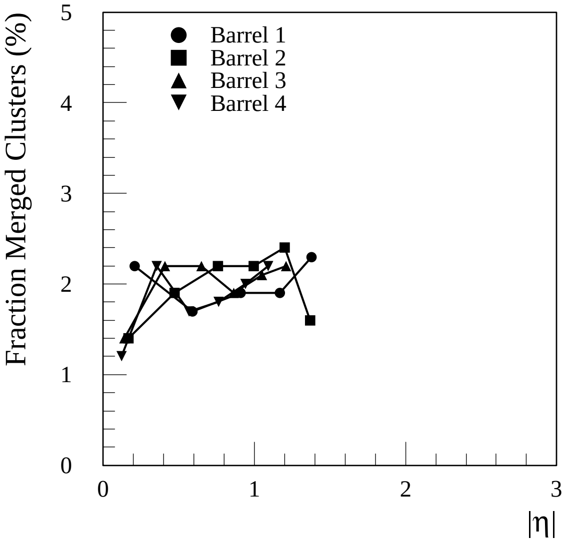
Pile up events

B jets from Higgs decay

SCT Merged clusters vs η and radius 10^{34}



Pile up events



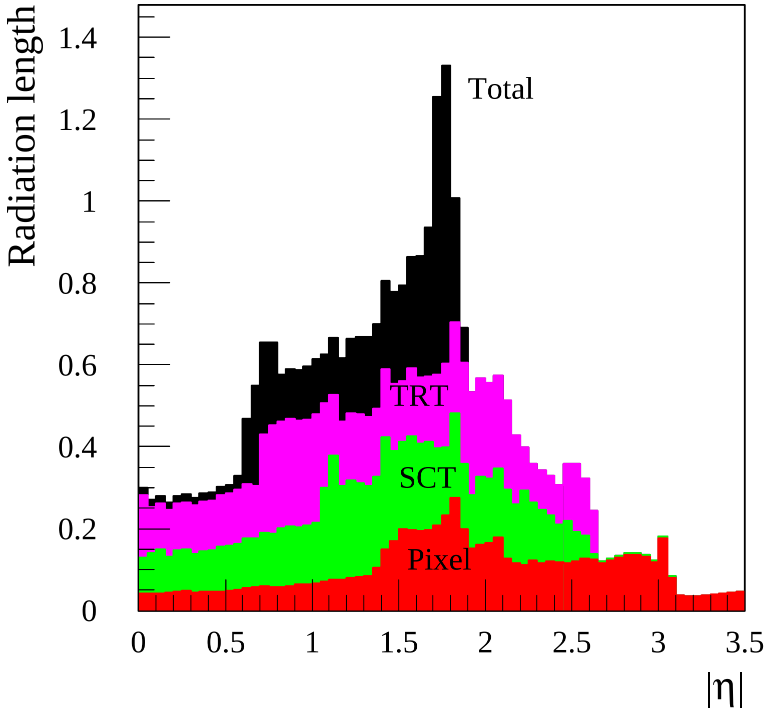
B jets from Higgs decay

Technical Specifications

- The retained or modified performance specs at 10^{35} drive a new set of technical specs for the tracker.
  - Occupancy: As shown, for 10^{34}, occupancies and cluster merging are less severe (x2) in pile up events than in B jets from Higgs decay. At 10^{35} the situation reverses by ~x5
    - Require greater segmentation, more modularity, faster electronics
  - Longitudinal resolution: would like to resolve vertex for all ~200 (effective) pile up events
    - Segmentation may already be sufficient
  - Secondary particles and interactions: rates scale with luminosity
    - Material reduction challenge.
  - Survival: radiation levels increase x10
    - Radiation resistance of sensors, electronics, and materials

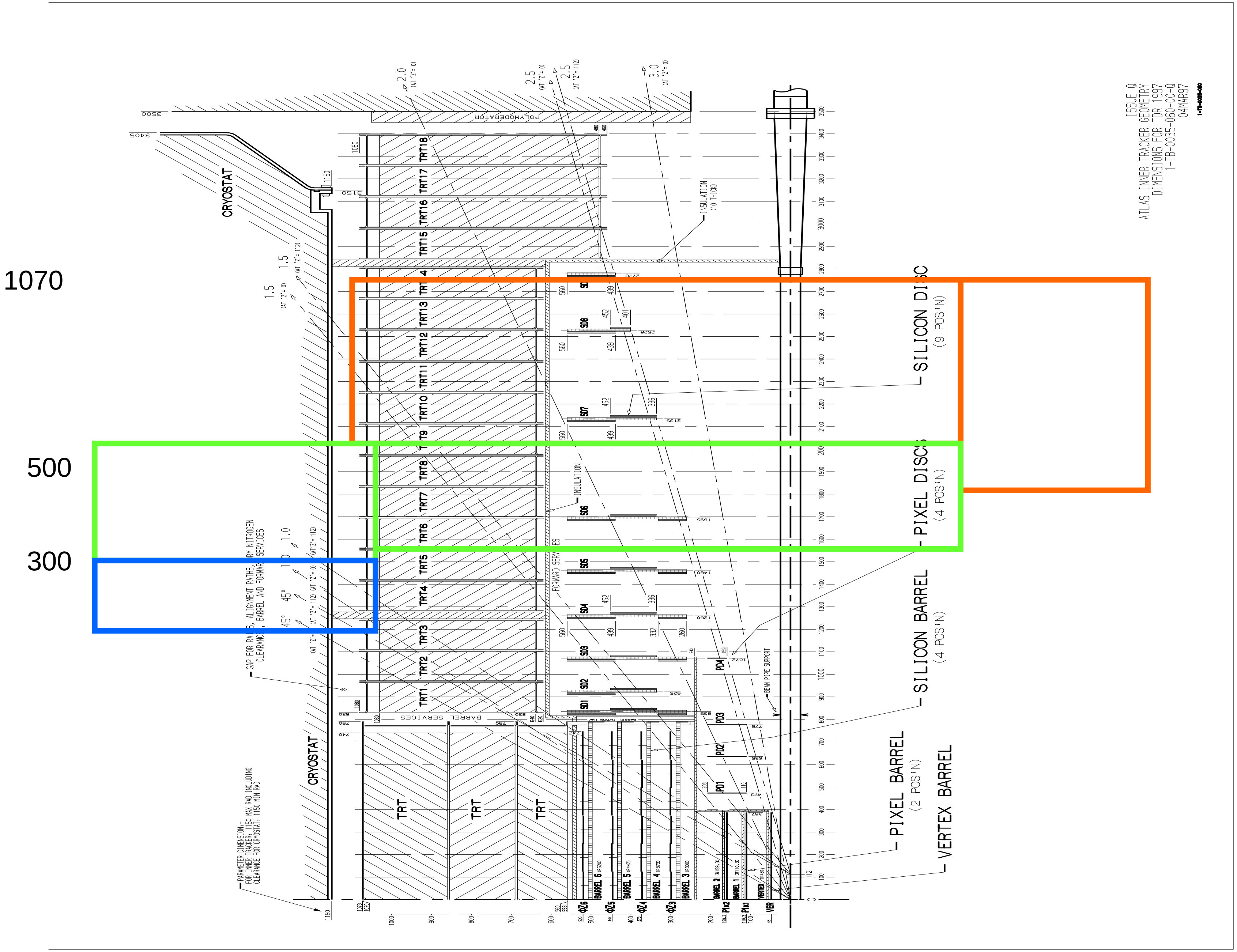
Material in baseline tracker

- Silicon alone is 0.3% X_0
- 4 double layers 2.4%
- Atlas module is 1.2%
- Present 4 SCT layers at $\eta=0$ are ~10%
  - – 7.6% is support, cooling, and services.
  - – Challenge is to reduce this further.
  - – Overdesign?



Elements of an SLHC Tracker

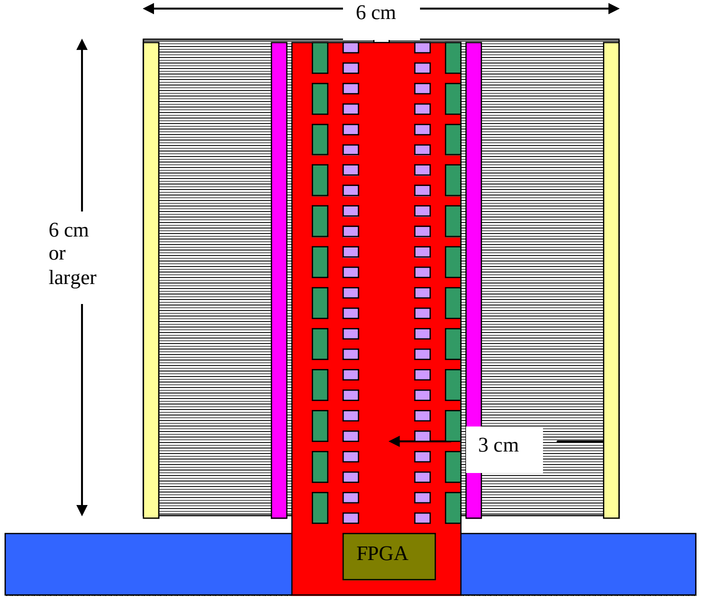
- 3 regions, fluences
  - < 20 cm: inner region 10^{16} /cm^2
  - 20 < r < 50 cm: intermediate region 10^{14}-10^{15} /cm^2
  - > 50 cm: outer region 10^{12}-10^{13} /cm^2
- Segmentation
- Mass
- Radiation
- Scale – construction
  - ~60 m^2 → ~200 m^2, 4K modules → ~20K modules
- Serviceable


1070
500
300
SILICON DISC (9 POS'N)
PIXEL DISCS (4 POS'N)
SILICON BARREL (4 POS'N)
PIXEL BARREL (2 POS'N)
VERTEX BARREL
CRYOSTAT
POLYMODERATOR
TRT
FORWARD SERVICES
BARREL SERVICES
INSULATION (10 THICK)
BEAM PIPE SUPPORT
ISSUE Q
ATLAS INNER TRACKER GEOMETRY
DIMENSIONS FOR TDR 1997
1-TB-0035-060-00-Q
04MAR97

Outer Region

- Presently occupied by straws for ATLAS and single sided silicon for CMS.
- Need increased longitudinal segmentation to reduce occupancy and enable pattern recognition.
- Resolution on z_0 and $cot\theta$ already provided by intermediate and inner layers if not degraded further.
- Radiation hardness required similar to present silicon layers ie: HV operation already achieved.
- Example (A.Seiden) is to split current 6 cm sensors into 3 cm units (σ_z = 9mm).
- Major challenge is scale and logistics (~140 m^2).

Outer tracking modularity



Legend

▤	3cm strips, 80um pitch	🟩	64 Channel ASIC
🟨	Biasing Resistors	🟪	By-pass caps, resistors etc
🟪	Bonding Pads	◼	FPGA, LED
🟥	Hybrid	🟦	Mounting, Power, Optical Fibre, Cooling

Intermediate Region

- Presently occupied by silicon strip trackers with length ~6 cm and small angle stereo.
- Increased segmentation in ϕ and/or z required.
- Pixel structures (super-pixels, short strips)
- Enhanced radiation hardness
  - Thinned silicon (150 μm) (material reduction!)
  - Engineered materials (ROSE, RD50…)
  - Front end chips

Inner Region

- Presently occupied by pixel layers and innermost silicon layers.
- Unprecedented radiation levels.
- Increase segmentation of pixels
  - Enabled by evolution of IC process 0.25→0.13 μm
- Decrease material – improve cooling, increase shared services
- Sensors
  - Further thinning
  - New structures
  - Engineered or alternate (n in p) materials
  - Cryogenic silicon
  - Non-silicon (diamond, SiC…)
- Expect to just replace it once/year?

Beyond SLHC

- Further steps are energy and/or luminosity increases.
- Energy
  - To preserve momentum resolution increase granularity in ϕ, B field, radius
- Luminosity
  - Increase granularity in ϕ and z to handle occupancy
  - Technologies move again to larger radius
  - Need yet another approach for R < 20 cm….
  - Electronics to deal with ~DC beam

New Technical Directions

- In support of tracking systems which operate at very high luminosity a number of new technical directions should be explored.
  - Rad hard devices and electronics
  - Lower mass materials, supports, services
  - Segmentation
  - Large area coverage
  - Data readout, transmission, and processing (triggers)
- Basis for a new set of R&D initiatives. Not to early to start.
- Support for stable engineering infrastructure. Microelectronics as an example.

Radiation Hardness

- Rad hard silicon materials – Rose, RD50,…
- Cryogenic detectors
- Non-silicon materials – Diamond
- Operational scenarios – partial depletion, thin..
- Properties of deep sub-micron IC processes
- Circuit designs and architectures
- Active pixel sensors
- New configurations (3D…)

Radiation Hard/Tolerant Si Detectors for HEP Experiments

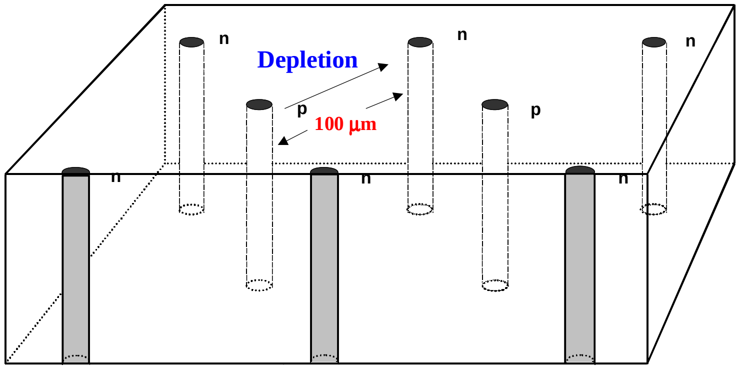
New detector structures for more radiation tolerance

From 3d detectors **to**

Lateral depletion only

Non-planar, difficult technology

(Etch or drill of holes in wafer needed)



Sherwood I. Parker et al., UH
511-959-00

(slide courtesy of V.Radeka)

Novel semi-3d detectors

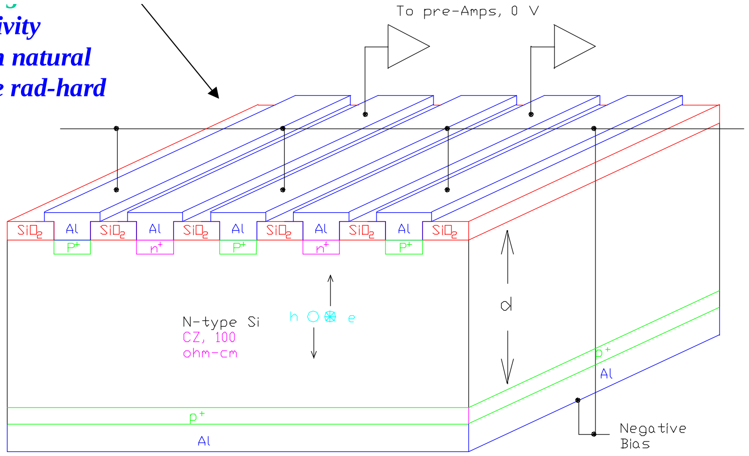
Depletion laterally and from both sides

Planar technology

Reduction of full depletion voltage by a

factor of 4 without losing active volume

Cheap, low resistivity
CZ materials with natural
High [O] --- more rad-hard



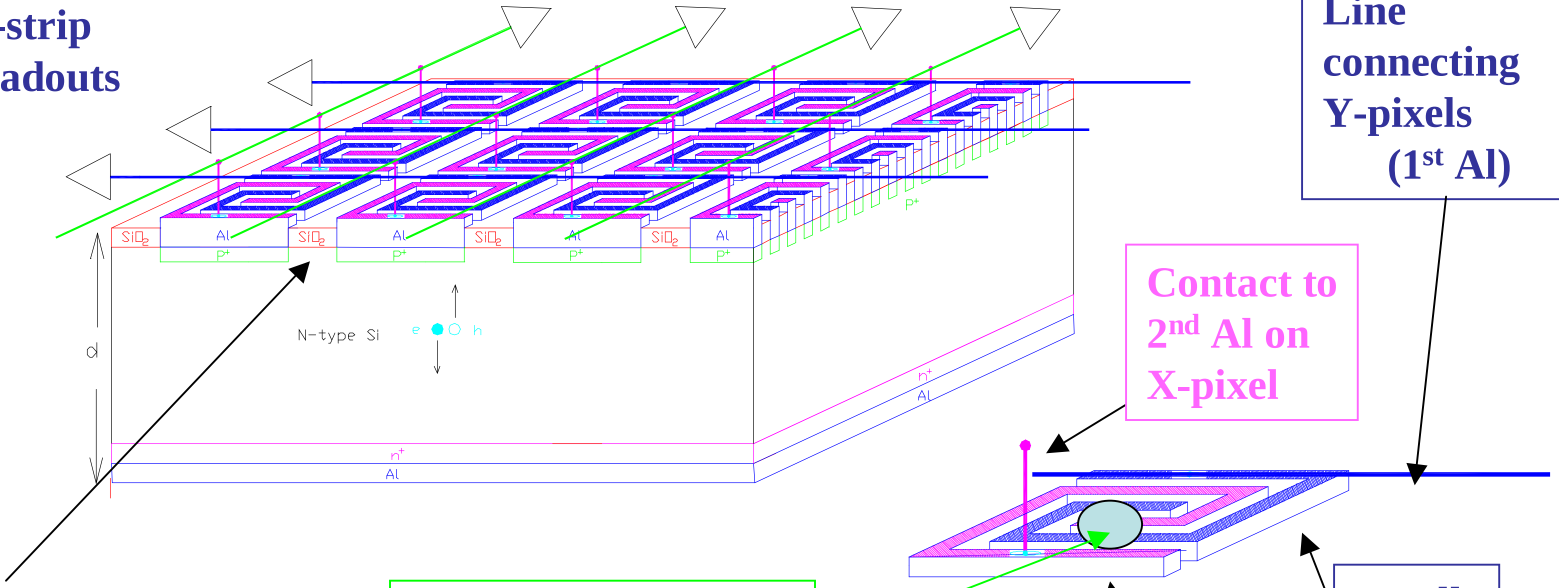
Z. Li et al, 9th Vienna Conf. on Instrumentation, Vienna, Austria, 19-23 February (2001)
Nucl. Instrum. & Meth. A478 (2002) 303-310.

Brookhaven group
Z.Li

Segmentation

- Silicon strip sensor designs and geometries
- Pixel geometries
- Pixel-Strip transition
- Z readout methods
- Front end readout electronics in evolving processes
  - 0.25, 0.13… mm
  - SiGe
- Interconnections
  - bump bonding methods at finer pitch (r < 20 cm
  - Pixel readout of superpixel geometry

Interleaved Stripixel Detector (ISD)
-illustration of the concept (BNL Group Z.Li)



X-strip readouts (2nd Al)

Y-strip readouts

Line connecting Y-pixels (1st Al)

Contact to 2nd Al on X-pixel

The gaps between pixels are enlarged for clearer illustration

FWHM for charge diffusion

Y-cell (1st Al)

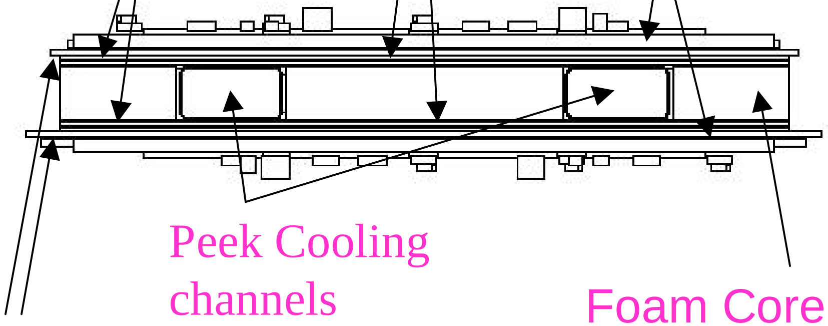
X-cell (1st Al)

Lower Mass

- Large area and precision low mass mechanics
- Alignment technology (lasers, sensors)
  - Drop stiffness requirements in favor of active monitoring and feedback (lesson from the telescope builders).
- Low mass electrical and mechanical components including discretes & substrates
  - Power distribution schemes, current mode power with local regulation, less redundancy, grounding issues
  - Technologies for hybrid circuits – thick, thin films, laminates
- Cooling technology – materials, coolants, delivery systems
  - Simplified coolant distribution
  - Heat pipe schemes
  - Cooling integrated with FE electronics
  - Reduced power consumption

Example of reduced mass structure for silicon detectors

Includes cooling, services and most of support



Embedded electrical
Bus cable

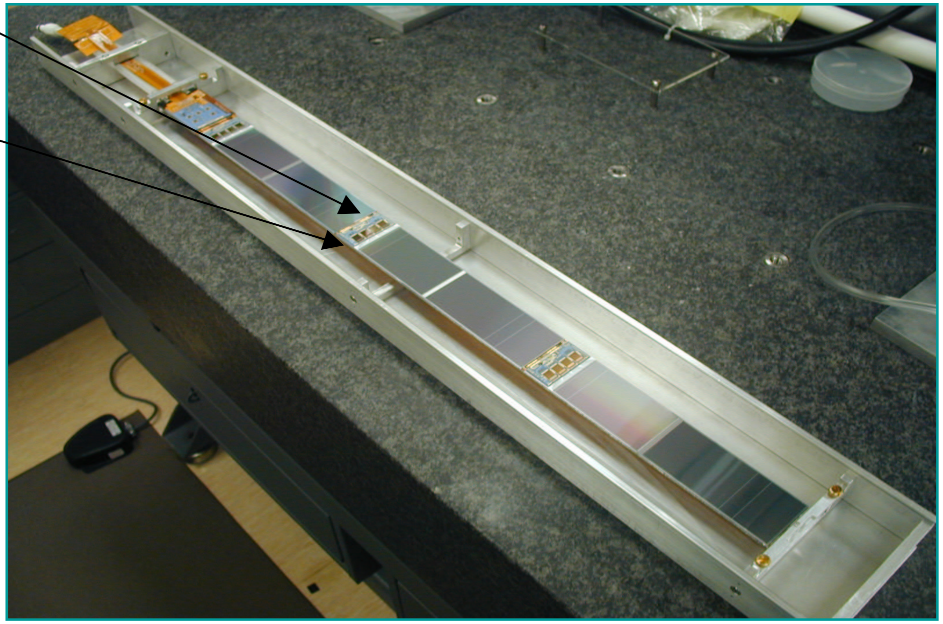
Carbon Fiber Skin

Hybrid electronics

Peek Cooling
channels

Foam Core

Silicon Sensors
4mm separation



Material/stave:

- 1.8% RL
- 124 grams

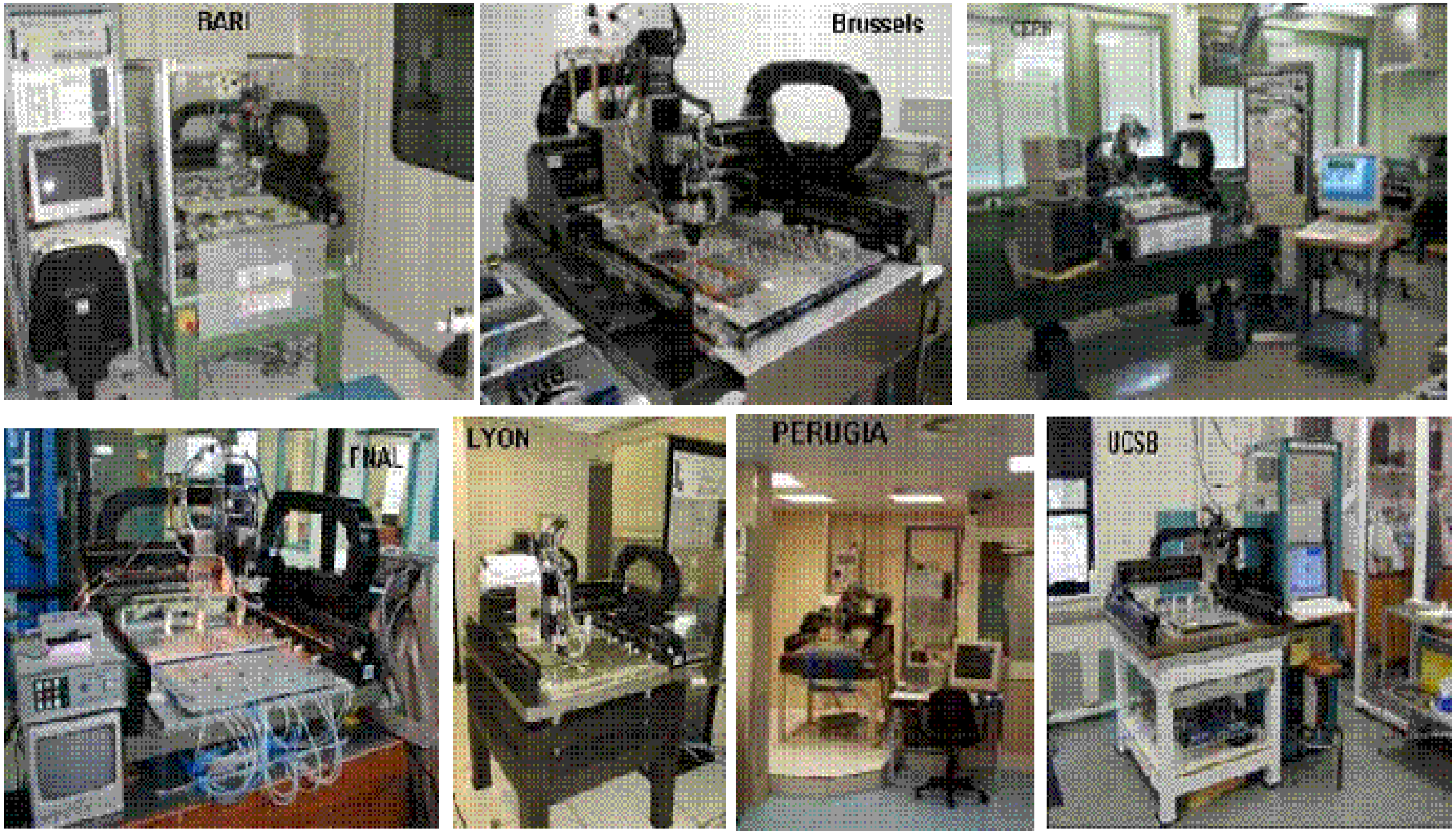
Fraction of Total RL:

- Hybrids 13%
- Sensors 39%
- Bus Cable 17%
- CF/Coolant 29%

Large Area Coverage

- Robotic assembly and test methods
- Large area and precision low mass mechanics
- Project organization
- Reliability and redundancy methods

Example of robotics & large scale organizational success: CMS assembly with identical systems at 7 sites to produce ~20K modules



Data readout, transmission, and processing

- Optical data transmission
- Wireless data transmission
- Pattern recognition and data reduction methods
- Large area and fine line lithographic methods
  - Cables to link sensors to remote front end chips
  - Power cables
  - Signal distribution networks
- Fast track trigger processors
  - Vertex triggers (CDF SVT)
  - Momentum measurement

Conclusions

- Physics case for precision tracking at SLHC
- Want to maintain LHC performance specs
- Key issues
  - Occupancy
  - Material
  - Radiation
- SLHC tracker is all solid state and contains 3 distinct tracking regions
- Comprehensive program of technical development is required and should start now

Conclusions

- Issues for concern
  - “it will flood the rest of the detector with secondaries”
  - “it will be impossible to maintain required mechanical precision”
  - “it will be inefficient”
  - “it will burn up due to radiation”
  - “it will be unreliable or never work at all”
  - “anyway there is no physics to do with it…”
- Past experience has shown this not to be the case