Atlas Upgrade Opportunity

Mainly about Gas Tracking and related topics

D. Underwood

April 11, 2008

This is a talk to solicit reactions and start discussion

Topics:

- **Atlas Upgrade Hardware projects -**
  - **Tilecal, trigger, tracking ???**
- **Why any interest in GAS tracking (GEM, Micromegas, etc)?**
- **What detectors exist?**
- **Where is Gas tracking in use or being built ?**
- **Tracking Problems in SLHC in general**
- **Comparison of Gas and Silicon**
- **What is the Purpose of tracking at the time of SLHC?**
- **Possible LDRD**
- **A toy Proposal**
- **Link to Pages of references**

Areas to investigate for gas-based (etc) tracking in Atlas

1) Forward

- Occupancy fairly low, ~1/cm^2 / crossing, so wider and longer strips could be used
- Geometry of disks is easy with GEM, Flat planes, R-phi strips
- Easier to cover > 30 M^2 of area
- Similar to COMPASS, TOTUM, STAR, HERA-B, LHC-B CMS, etc Gas Tracking

2) Outer Barrel

- Some development of GEM would allow many more layers
- basic rate capability, rad hardness seem OK
- large areas to cover , maybe > 50 M^2 for 8 layers

3) Inner detector

- New technology such as GOSSIP (RD51) or Diamond

4) What developments lead to low-mass services?

- Low power, Room temp, displaced electronics?

An old but useful overview:

"Outline of R&R activities for ATLAS at an upgraded LHC" edited by S. Tapprogge, Jan 2005

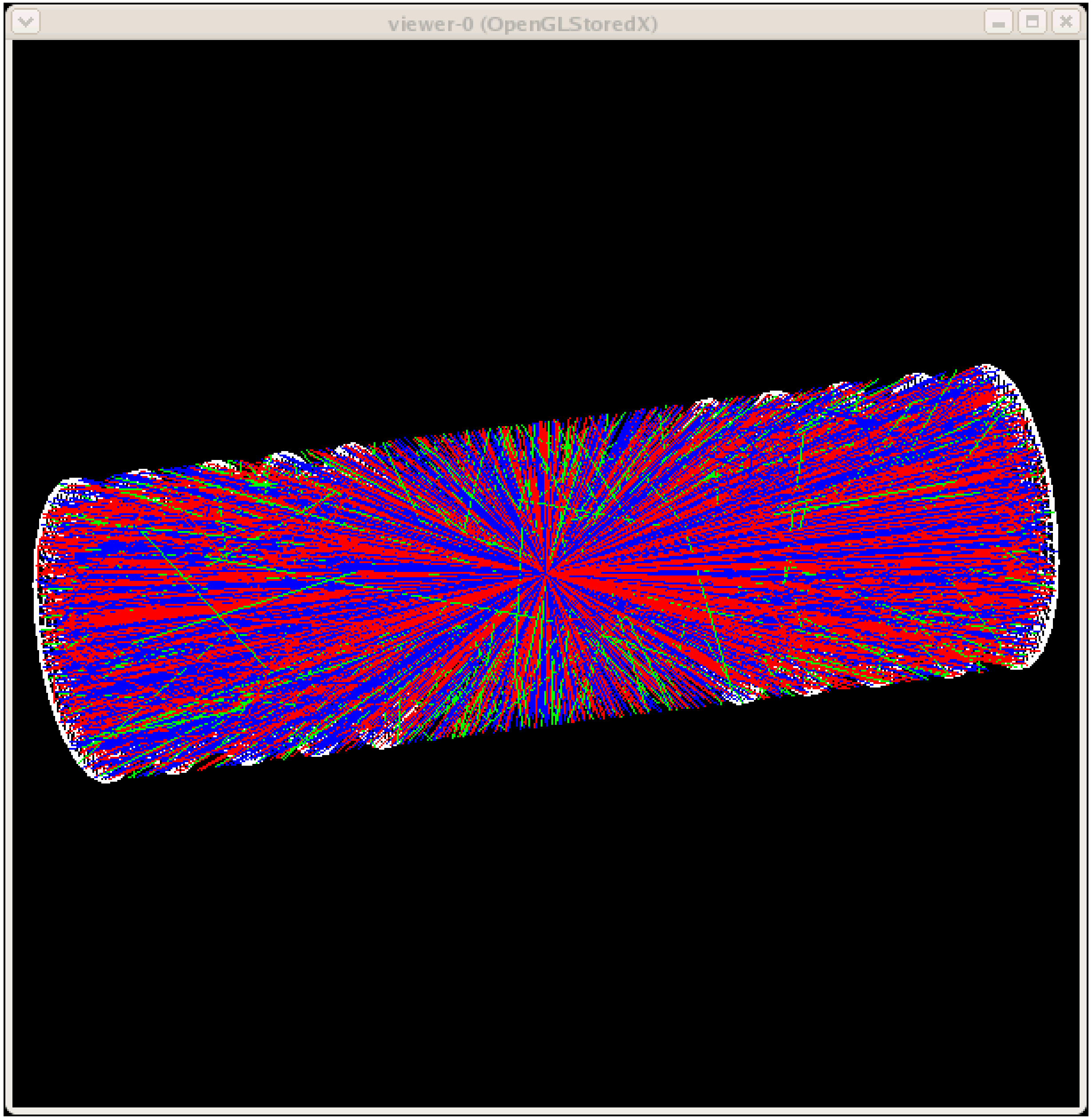
Nikhef - A really nice talk about LHC upgrades

http://agenda.nikhef.nl/getFile.py/access?contribId=s1t1&resId=0&materialId=0&confId=a0614

400 events in one crossing

The main problems with Radiation and Occupancy are near the VTX. (350 MHz/cm^2 for 40 MHz bunches)

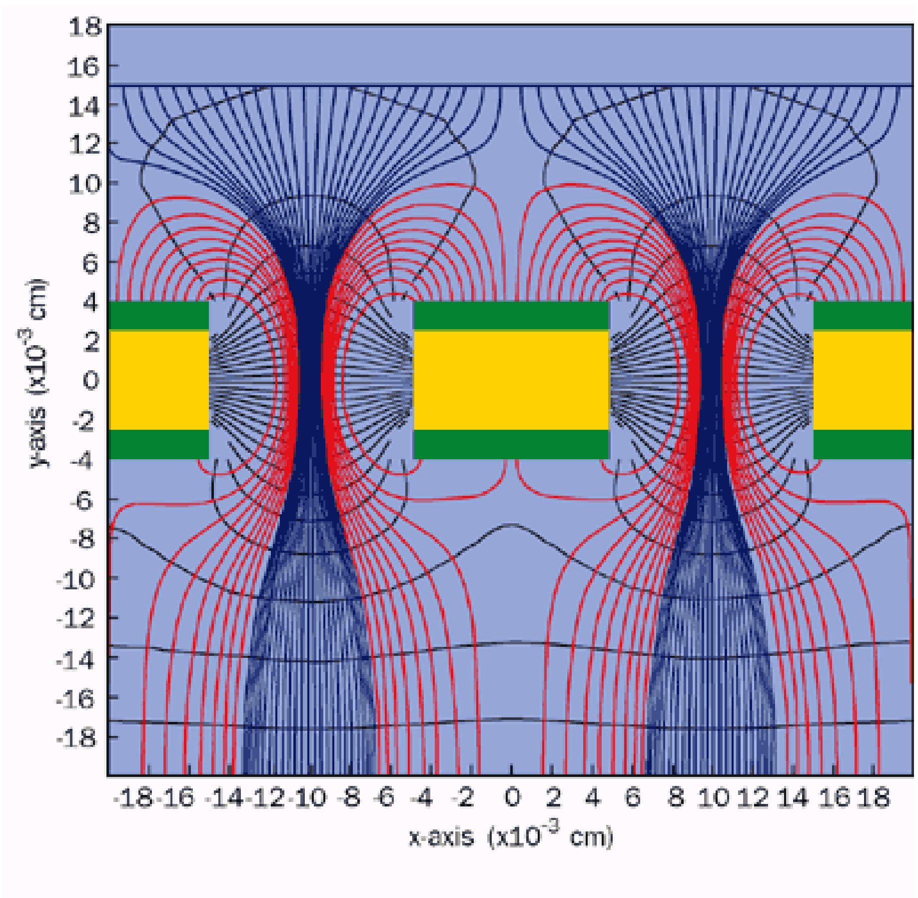
The Forward tracking is down to about 1 track / cm^2 / crossing



What is a GEM foil ?

Let us eliminate wires: wireless wire chambers

1996: F. Sauli: *Gas Electron Multiplier (GEM)*



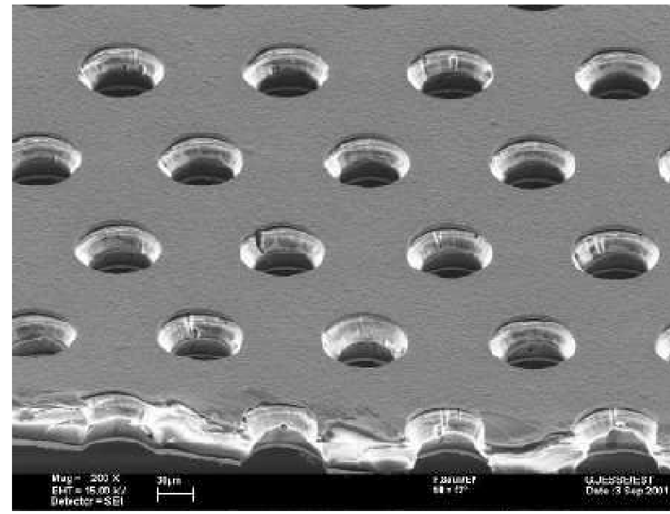


Fig. 7

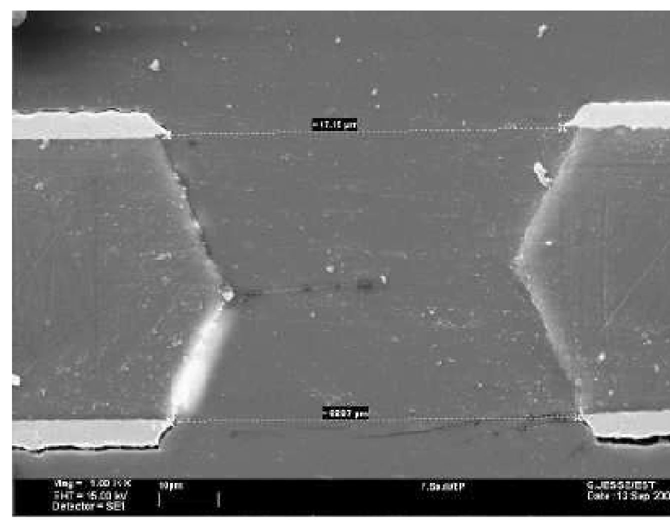
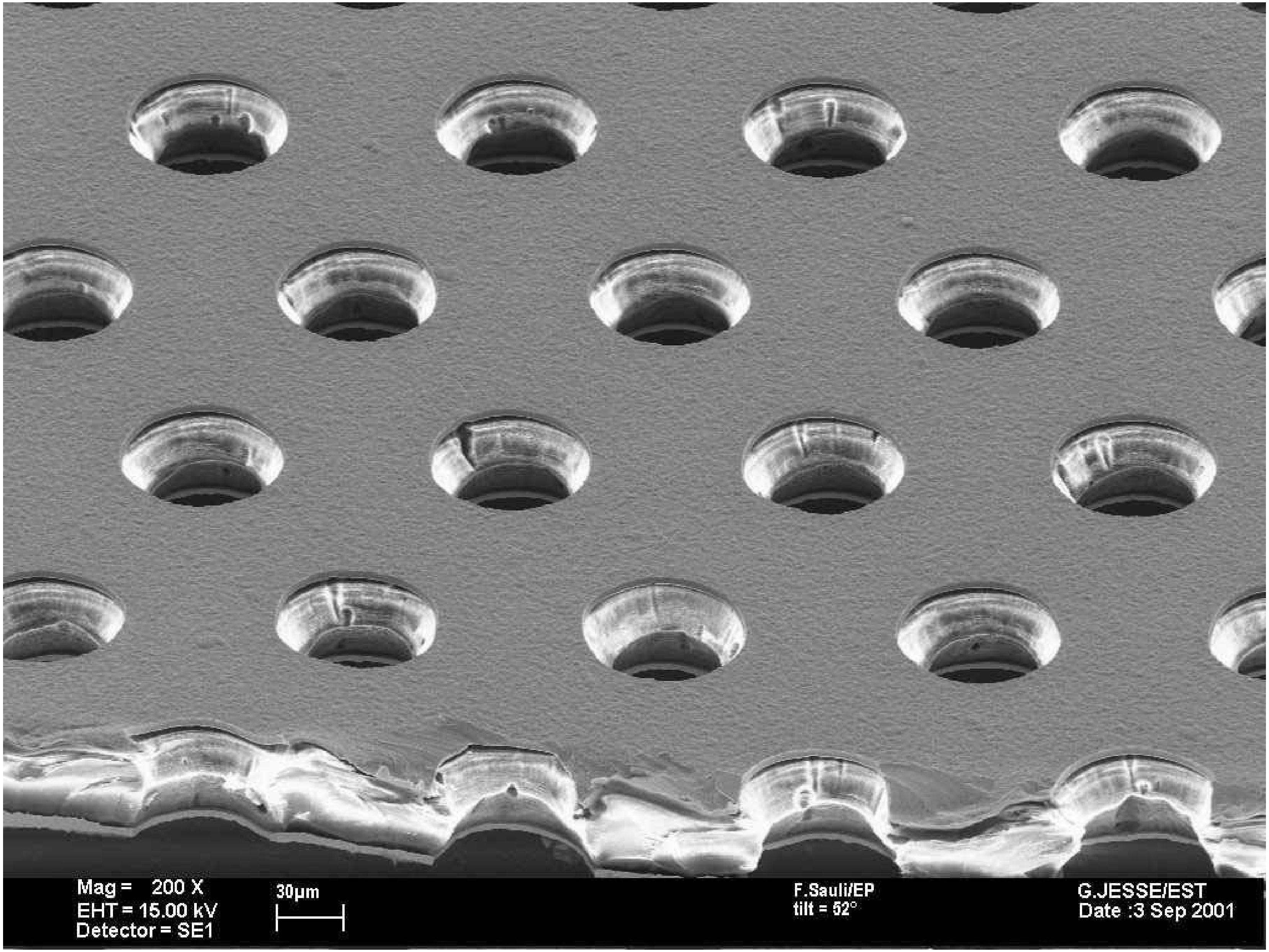


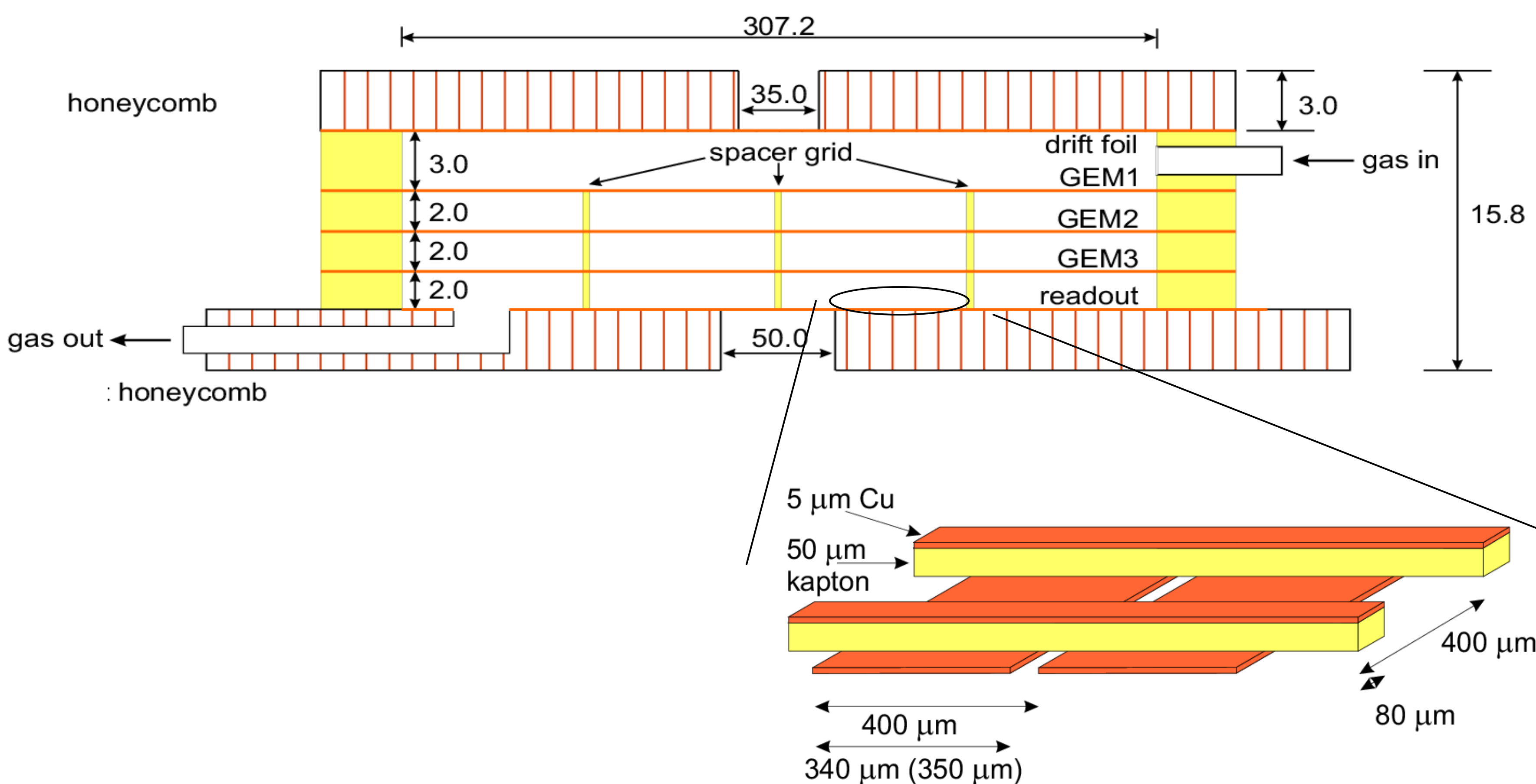
Fig. 8


Mag = 200 X
EHT = 15.00 kV
Detector = SE1
30µm
F.Sauli/EP
tilt = 52°
G.JESSE/EST
Date :3 Sep 2001

Typical Existing GEM chamber now.

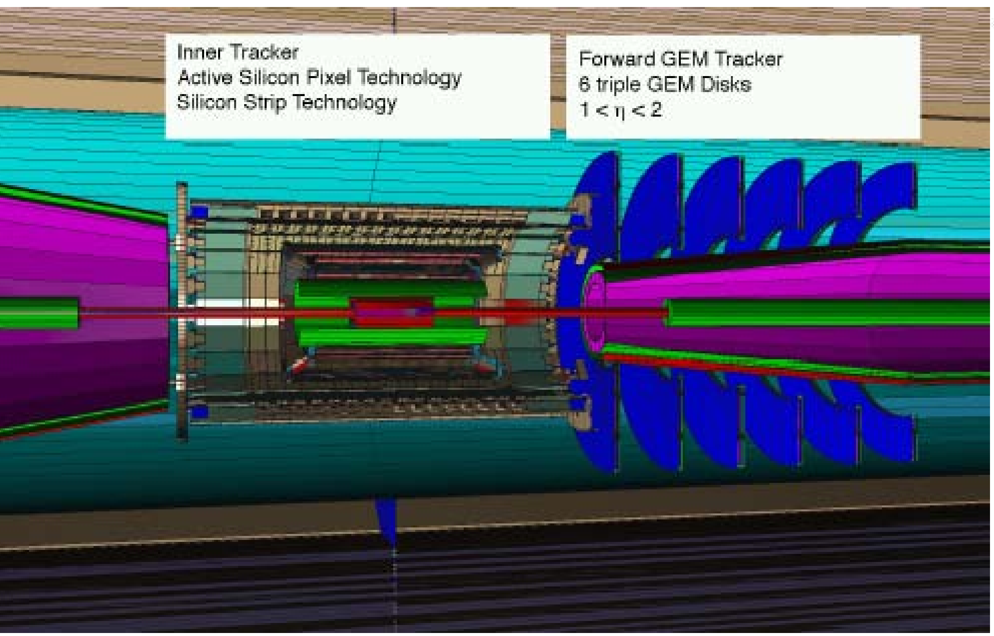
The 5 layers of polyimid plus the 9 layers of 5 u copper add up to about the same percentage of an X0 as a layer of silicon.

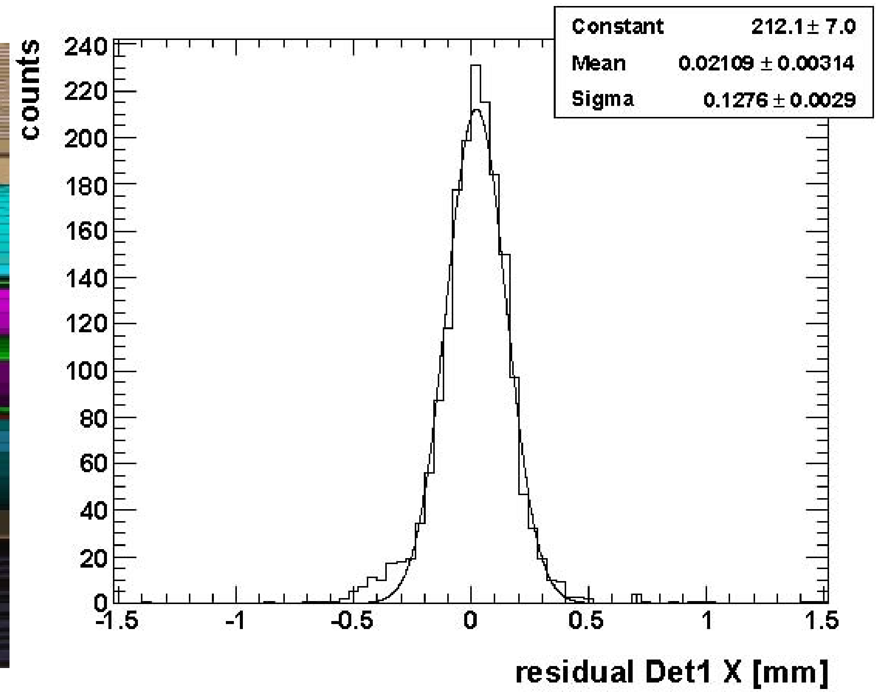
But the copper can be thinned a factor of 5



Triple-GEM Detectors for the Forward Tracker in STAR

.F. Simon, J. Kelsey, M. Kohl, R. Majka, M. Plesko, D. Underwood, T. Sakuma, N. Smirnov, H. Spinka and B. Surrow (MIT, Yale, ANL)





Fermilab Test Beam

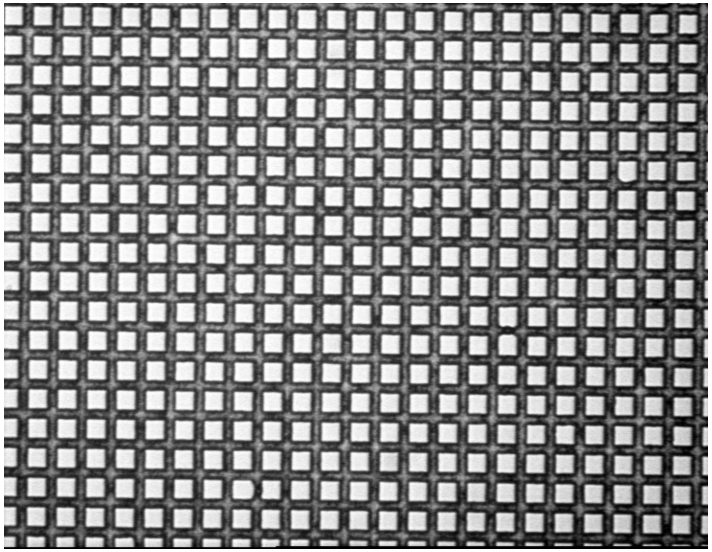
IEEE NSS

Approved Upgrade in STAR

Strips up to 35 cm x 800 u for Lum of 10^33

Based on occupancy

1995 *Giomataris* & Charpak: MicroMegas



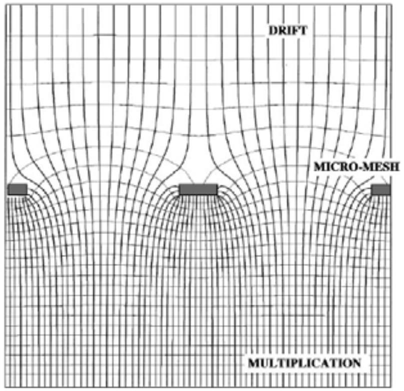
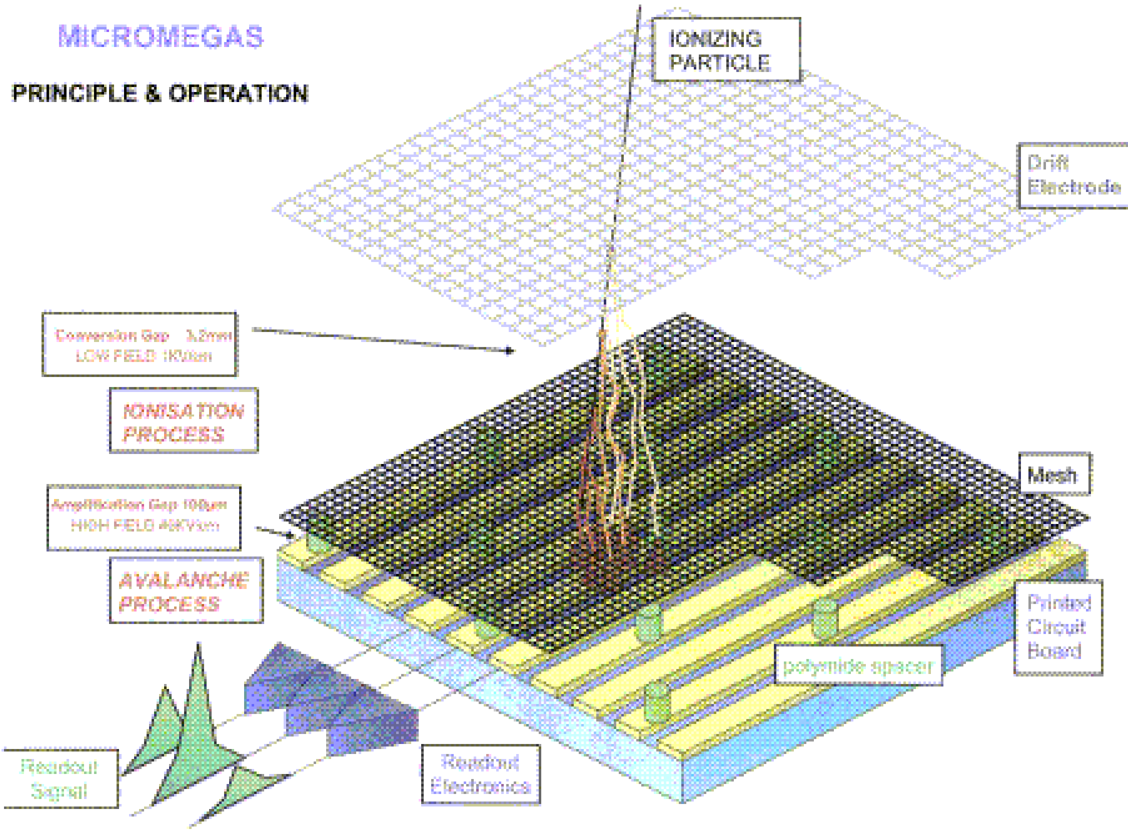


Figure 28 Schematics and electric field map in the micromegas. A metallic mi cromesh separates a low-field, or drift, region from the high-field multiplication region



Micromegas can do 14 u and extreme rate, radiation, but eventual HV sparking.

Two fixes: semiconductor layer (RD51 GOSSIP) or GEM preamp.

Rad Hardness and rate capability

LHCB GEM was tested to withstand equivalent of 2 coulombs at a gain of 6000 over 10 years. They quit the test when they got this far.
The rate capability should be 3 or 4 MHz/cm^2
It satisfies these requirements even with a corrosive gas containing CF4.
Alfonsi, et. al. IEEE papers in 2004, 2005. The gas was used to get 25 ns resolution.

Atlas Disks 1.2 meter forward of interaction point with 400 background events per crossing would have almost 1 event/cm^2 per crossing (worst case mean plus 3 sigma and inner edge of closest disk). This is about
40 Mhz/cm^2. Carlos Lacasta, Atlas Wiki for SuperAtlasTracker. (nice simulations)
This is for rates,- -for the Rad hardness and aging, use the mean, not 3 sigma.
Use shorter readout strips for the higher occupancy

Atlas inner pixel detector like GOSSIP (gas, not silicon) would have about 500 x10^6 tracks/cm/sec. RD51 Gossip upgrade document.
If we assume 6 ions per track, and gain of 6000 this is 1.8x10^13 electrons per second, or 350 coulombs per year.

If we go outward to 30 cm, the area is about 10^4 cm^2, so probably less than 2 Coulombs.

Existing Tracking using 3 GEM foils per readout plane and 400 u strips gives about 50 u resolution.

This resolution seems fine for much of the barrel type tracking, although one would have to consider what strip widths and lengths would be appropriate for occupancy.

(forward silicon proposed 2 cm strips, and barrel silicon longer.)

Silicon detectors developed for LHC are damaged by 10^15 to a few x 10^16 neutrons

(Some others are damaged at 10^12)

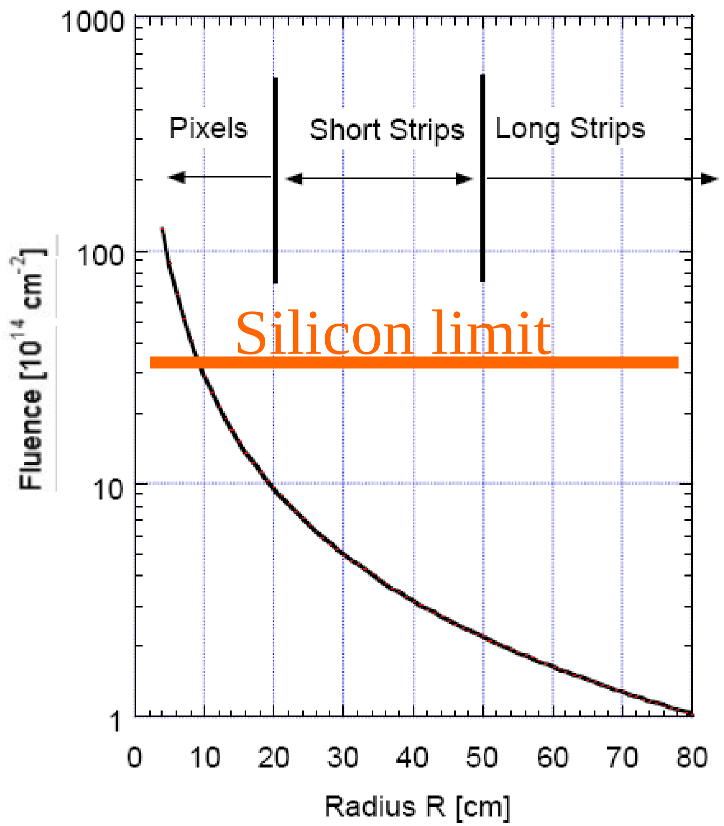
The GEM foil material is OK at over 10^18

Abstract

SU-8 photosensitive epoxy resin was developed for the fabrication of high-aspect ratio microstructures in MEMS and microengineering applications, and has potential for use in the construction of novel gaseous micropattern radiation detectors. ………After exposure to a reactor core neutron fluence of 7.5×1018 n cm−2, the new material showed a high level of resistance to radiation damage, comparable to Kapton film.

GEM type detectors are potentially more rad-hard than silicon, because the materials are passive, no charge trapping, p-n reversals, crystal displacements, etc.

Radius [cm]	Fluence [cm^{-2}]	Specification for Collected Signal (CCE in 300 um)	Limitation due to	Detector Technology
> 50	10^{14}	20 ke^- (~100%)	Leakage Current	"present" LHC SCT Technology, "long" strips
20 - 50	10^{15}	10 ke^- (~50%)	Depletion Voltage	"present" LHC Pixel Technology ? "short" strips -"long" pixels
< 20	10^{16}	5 ke^- (~20%)	Trapping Time	RD50 - RD39 - RD42 Technology 3-D



Compare to GEM tests so far

of 2 Coulombs/cm^2 with no degredation

Silicon here 10^15 x10^4 e ~ 2 Coulomb.

(but it degrades – typical factor 2 or 3)

For GEM , assume a little higher gain:

6 ions and gain of 6000

Gives 36K electrons

10^15 tracks/cm^2 -> 6 Coulomb

Predicted LHC Neutron levels SLHC might be less than 10x this

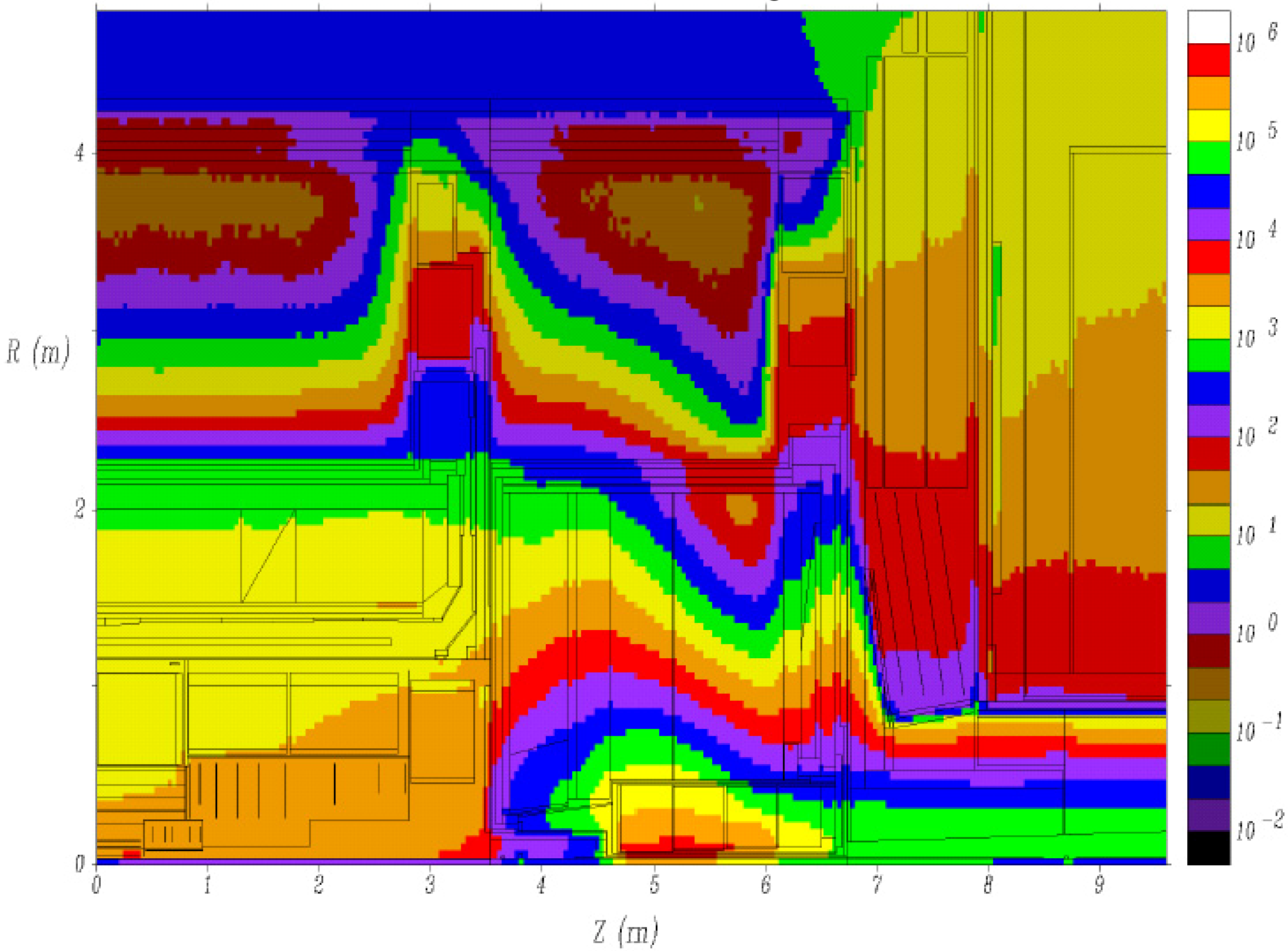


Figure 4-1: The neutron flux (kHz/cm²) in a quarter of the inner detector, the calorimeters and the small muon wheel (Ref. 8.9).

Why GEM, Micromegas, GOSSIP, etc?

- Rad hard – GEM demonstrated essentially no damage at level where Silicon is damaged, Micromegas/GOSSIP much better, but more demonstrations needed. Also, there may be a possibility to move readout chips outward.

- Low mass – Detector itself of 5 kapton-copper layers is similar to silicon now, demonstrated possibility of a factor of 3 or so better. Also, possibility to move readout chips, perhaps in a low-mass way.

-Large areas with small features – good for pi segments forward, barrel segments with less overlap,

-30 cm x 40 cm etc.

-Flexibility in readout strip orientation – e.g. R-Phi with tapered phi strips, without having to overlap small pieces of detector

Some Problems in SLHC we could look into for an Upgrade Project

1) What is purpose of tracking at SLHC?

Missing Et, Jets, electrons, muons, photon isolation cuts,

vertex finding, calibration of calorimeter, ….

2) What is the purpose of the inner detector in SLHC?

At 400 events/25 ns crossing, is B trigger by vtx viable?

3) Rad-Hardness of inner Detector

4) Number of layers of tracking for track finding

(CMS study claims 8-10 needed)

5) Trigger on high momentum tracks (Or just record it all ?)

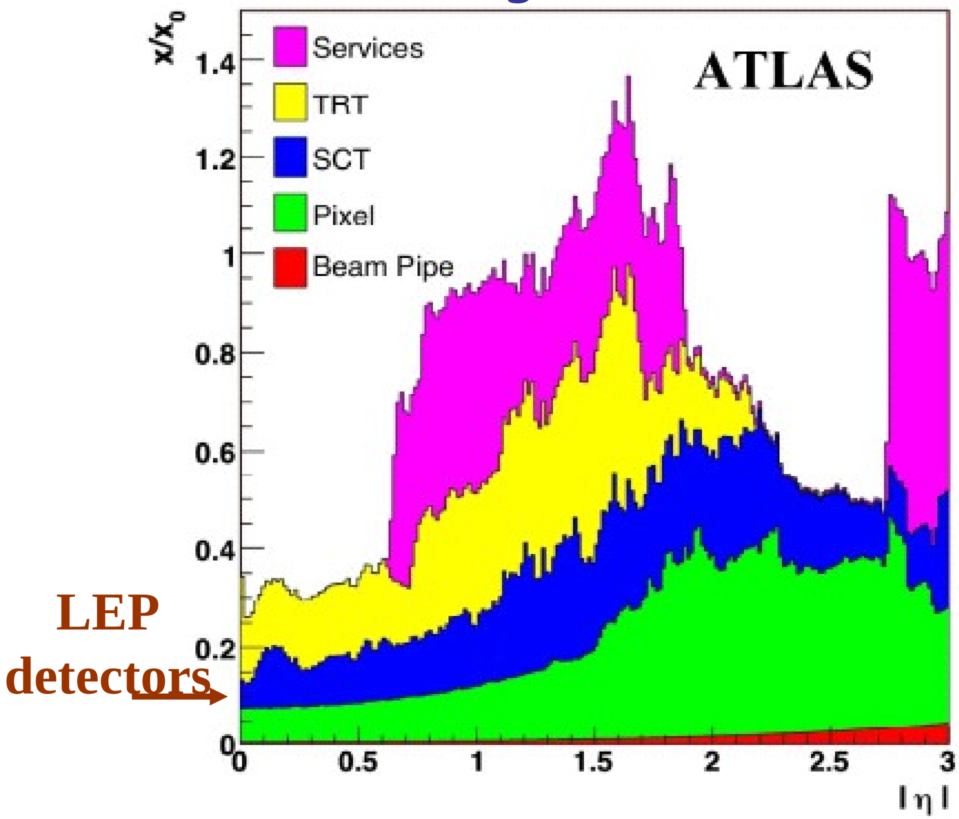
6) Total amount of material associated with inner detector

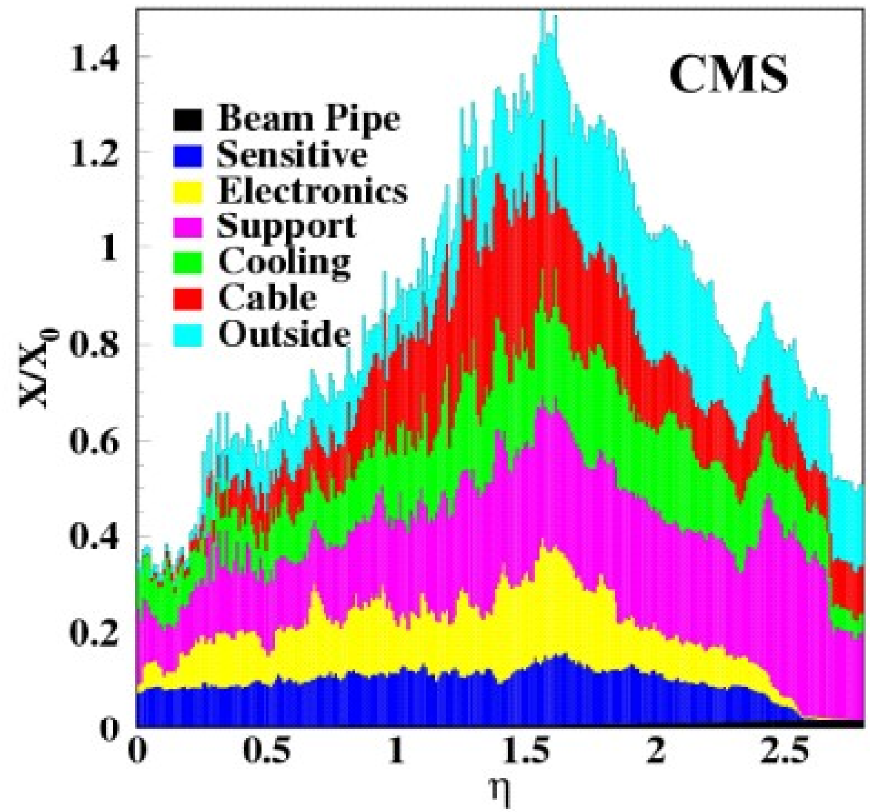
ATLAS/CMS: from design to reality

Amount of material in ATLAS and CMS inner trackers

Weight: 4.5 tons

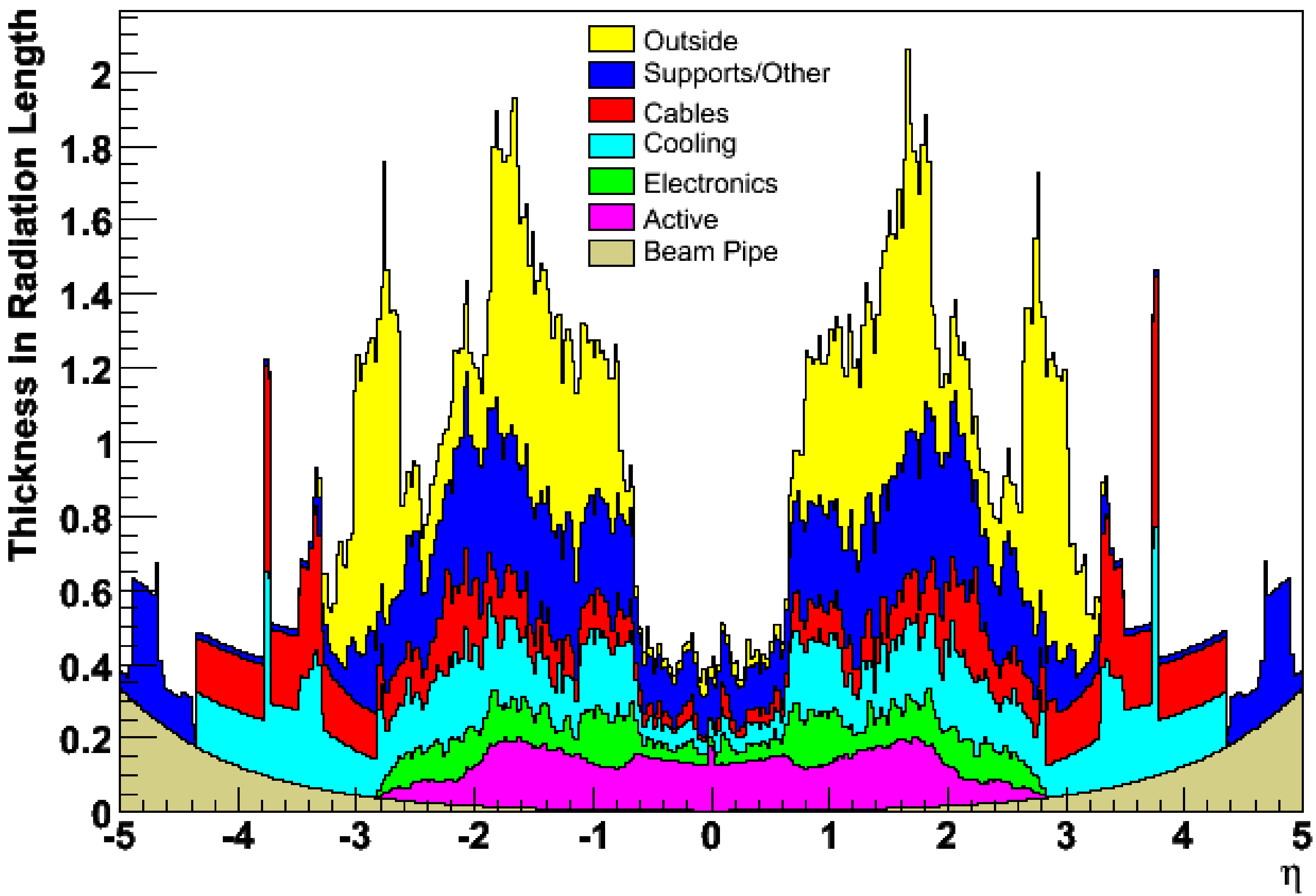
Weight: 3.7 tons





- Active sensors and mechanics account each only for ~ 10% of material budget
- Need to bring 70 kW power into tracker and to remove similar amount of heat
- Very distributed set of heat sources and power-hungry electronics inside volume: this has led to complex layout of services, most of which were not at all understood at the time of the TDRs

https://twiki.cern.ch/twiki/bin/view/Atlas/InDetMaterial



ATLAS/CMS: from design to reality

TABLE 5 Evolution of the amount of material expected in the ATLAS and CMS trackers from 1994 to 2006

Date	ATLAS $\eta \approx 0$	$\eta \approx 1.7$	CMS $\eta \approx 0$	$\eta \approx 1.7$
1994 (Technical Proposals)	0.20	0.70	0.15	0.60
1997 (Technical Design Reports)	0.25	1.50	0.25	0.85
2006 (End of construction)	0.35	1.35	0.35	1.50

The numbers are given in fractions of radiation lengths (X/X_0). Note that for ATLAS, the reduction in material from 1997 to 2006 at $\eta \approx 1.7$ is due to the rerouting of pixel services from an integrated barrel tracker layout with pixel services along the barrel LAr cryostat, to an independent pixel layout with pixel services routed at much lower radius and entering a patch panel outside the acceptance of the tracker (this material appears now at $\eta \approx 3$). Note also that the numbers for CMS represent almost all the material seen by particles before entering the active part of the crystal calorimeter, whereas they do not for ATLAS, in which particles see in addition the barrel LAr cryostat and the solenoid coil (amounting to approximately $2X_0$ at $\eta = 0$), or the end-cap LAr cryostat at the larger rapidities.

- **Material increased by ~ factor 2 from 1994 (approval) to now (end constr.)**
- **Electrons lose between 25% and 70% of their energy before reaching EM calo**
- **Between 20% and 65% of photons convert into e^+e^- pair before EM calo**
- **Need to know material to ~ 1% X_0 for precision measurement of m_W (< 10 MeV)!**

Is a different detector a path to less mass in services? .

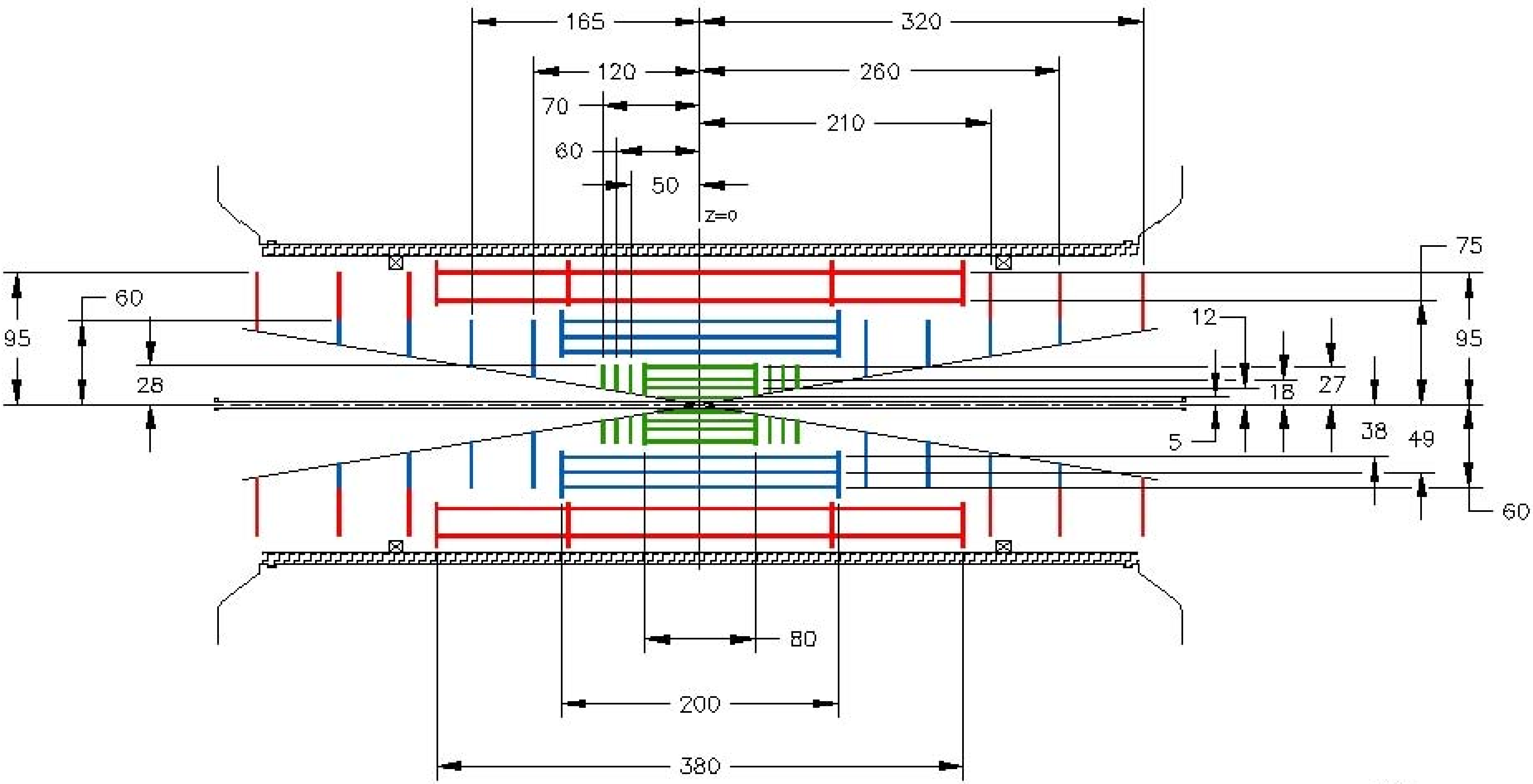
1) For Gas detectors - Could cables, cooling , mechanical structure for Gas detectors have less material or have the material displaced? These dominate the material in the present detector.

2) Large GEM foils could eliminate or minimize tiling, and could have signals routed on the back of the readout foil.

3) Study thinning of metal, low mass signal plane, low mass cables, etc.

Perhaps use some of the same technology – beyond flex circuits to photo lithography?

4+3+2 (Pixel, SS, LS) - Strawman



A Silicon straw-man has only 2 outer tracking layers

BROOKHAVEN NATIONAL LABORATORY

For an Atlas Upgrade, areas to be investigated / developed might include

1) Signal transmission away from the crossing area.

2) Electronics chips which would sample more than the 3 times per crossing of current chips, perhaps continuously in a pipeline, and which would provide trigger output,

3) short readout strip geometries suitable for Atlas,

3) low mass signal connections, and

4) Appropriate mechanical support structures.

We could also think about the overall triggering using tracking.

There is expertise around for some aspects of this project.

There is a person in the Nano Materials fabrication area at Argonne who is a world expert on things like foils and etching.

There is a Professor at Purdue (Shipsey) who has run many lab tests over many years on combinations of GEM, micromegas, etc.

People at RAL developed the currently used readout chip.

There is a person at Jlab who is developing the mechanical aspects to make cylindrical GEM detectors instead of planes.

GEMS are considered a stable technology. They are manufactured at CERN, and TechEtch in Massachusetts .

Talk with Derrick Mancini at ANL Nano-Materials

GEMs, Diamond interesting to them

Technology transfer can be done with a company which has local people.

An immediate thing they could look into would be closer Hole spacing in GEM foil for better space resolution, either in pure GEM detector or preamp for Micromegas.

Thinning the copper to the correct geometry is easy if the correct method is used instead of chemical etching.

The current GEM fabrication is based on PC board type flex circuit technology. One could do finer features and larger areas with photo-lithography as used in LCD TV screens.
Start-up costs would be higher.

They are already working on Diamond and UNCD. The only drawback he sees at the moment is a higher detector current due to the material resistance.

(I found a paper with Chem. Vapor deposited Diamond with high resistance)

Nano-Materials, cont.

What aspects did I have to explain to someone from a different background in detectors?
100 square meters of coverage
rate and radiation environment
- **-1 to 40 MHz / cm2 GEM, up to 400 MHz/cm2 inner detector,**
- **- 10^16 neutrons/cm2 over 10 years**
- **-many coulombs of signal / cm2 over 10 years**

low mass requirement of both detectors and services
mass of cooling services if the detector draws current
I didn't get to readout electronics issues

Other issues:

Does CERN have a patent? (Yes, but only applicable if you follow their receipe)

Short term and longer term funding for R&D.

Material Purchases for LDRD

Need Electrostatic program, 2D and 3D, and manpower to use it. Recommended by ANL nano-fab, also in use by GEM group at Yale,

Also DGU collaborated with HEP Accelerator group on this kind of calculation for talk on GEM readout attached to RPC.

This is to be used both to evaluate different strip readout geometries, and to investigate the possibility of foils with slightly smaller features for better space resolution.

Also, to investigate signal transmission with thin foil on kapton.

2) Need GEM foils and chamber to use them, in order to gain experience and to test configurations, rates, signal shapes, effect of various shaping electronics, try out different strip planes, etc. Purchase from Tech-Etch.

3) Need a source of X-Y readout strips, and a way to check the possibility of making part of the electrical signal routing on the same insulating layer.

4) In short term, Need to improve some existing FPGA codes in hardware we have to do more realistic readout.

5) Need more APV25 chips, and also anything else that might work.
eg, does the Fermilab chip used by UTA have a trigger output?

LDRD money:

Engineering structure
Engineering gem
Consulting on foils and etching ANL nano-fab and Tech-etch company
Engineering Electric field of readout (purchase program)
Engineering finding chips for prototyping
Finding chips to study triggering
Engineering finding/designing low mass connections
GEM foils, gas, gas system, HV supply, FEE, DAQ, ...
Testing at ANL Chem division Linac for high rate
Scint. Counters for testing with cosmics
Travel Purdue (GEM, micromegas), Massachusetts (GEM and readut plane)
Chicago trigger, Indiana trigger, California (silicon) ?

Toy Proposal

1) If you have to sacrifice something, sacrifice coverage near the vertex. You probably can't do a B trigger on the vtx with 400 events in the same event anyway.

2) GEM foils and similar detectors can be made in large areas. Much less of a tiling problem.

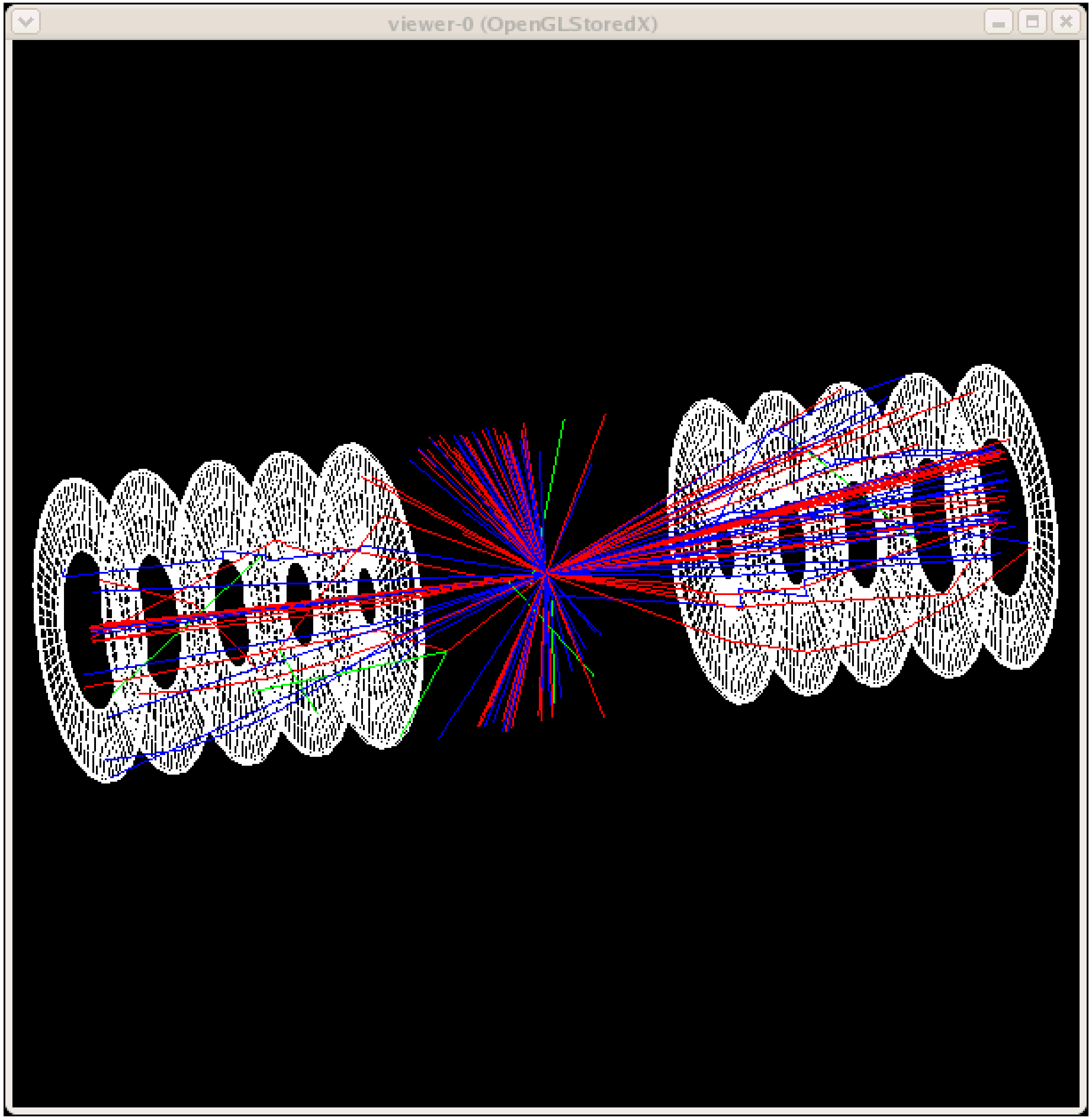
3) Investigate bringing all the signals out to the inner radius of the magnet solenoid where the radiation on FEE is down orders of magnitude

4) Investigate routing of signals on the GEM readout foils and similar cables, so there are no extra services making X0 material. No silicon, no cooling,

5) Do the mechanical support from the outside of the Disks, Cones, etc

6) Use approx. vertical slices of detector like the tiles in Tilecal where appropriate.

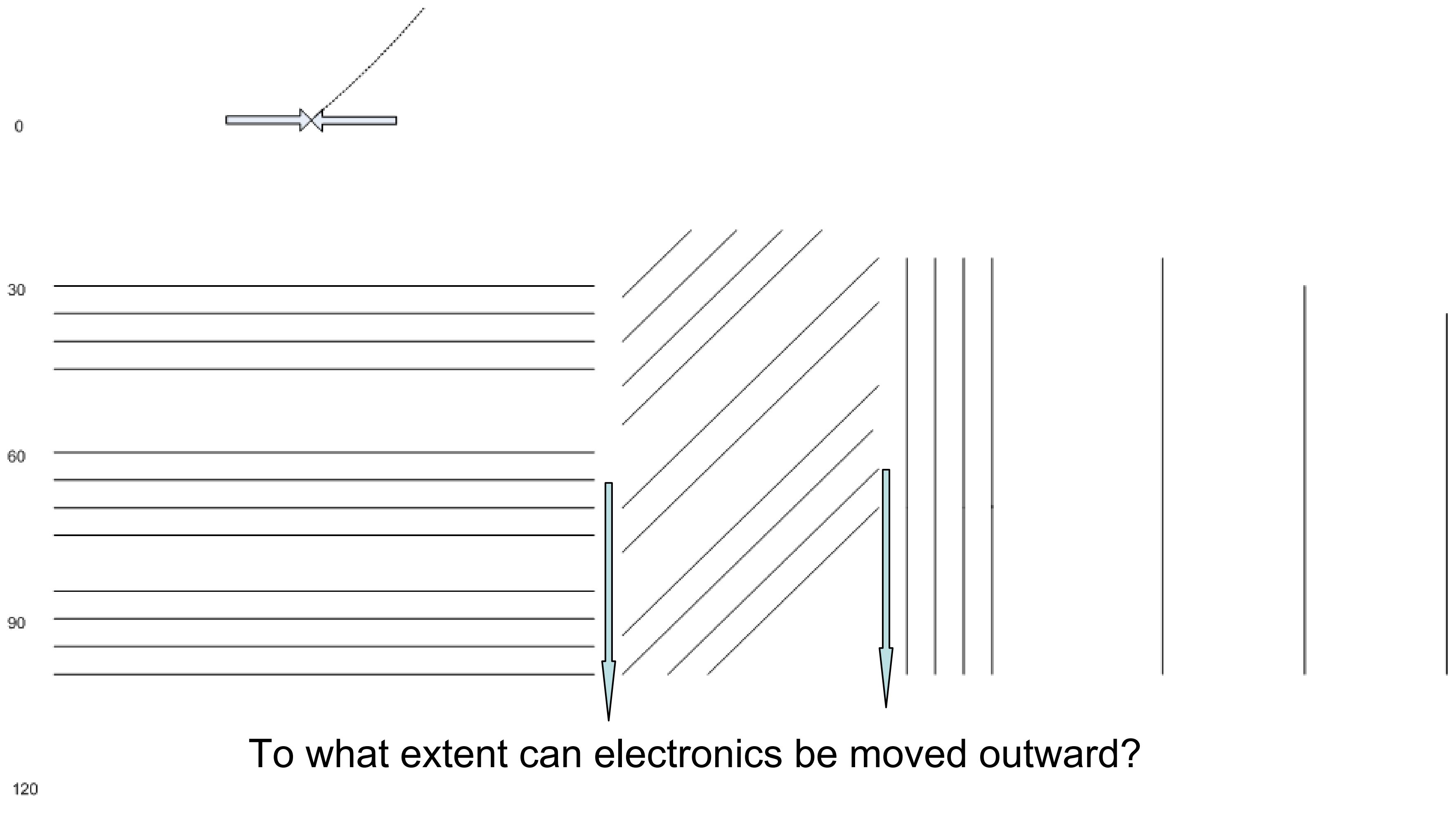
Proposed forward Silicon for SLHC



Note how many pieces of silicon

GEM or similar gas detector

Barrel, Cone and Plane
All supports and cables radial to outside
Closest distance to IP is 30 cm
Panels up to 30 cm x 30 cm



To what extent can electronics be moved outward?

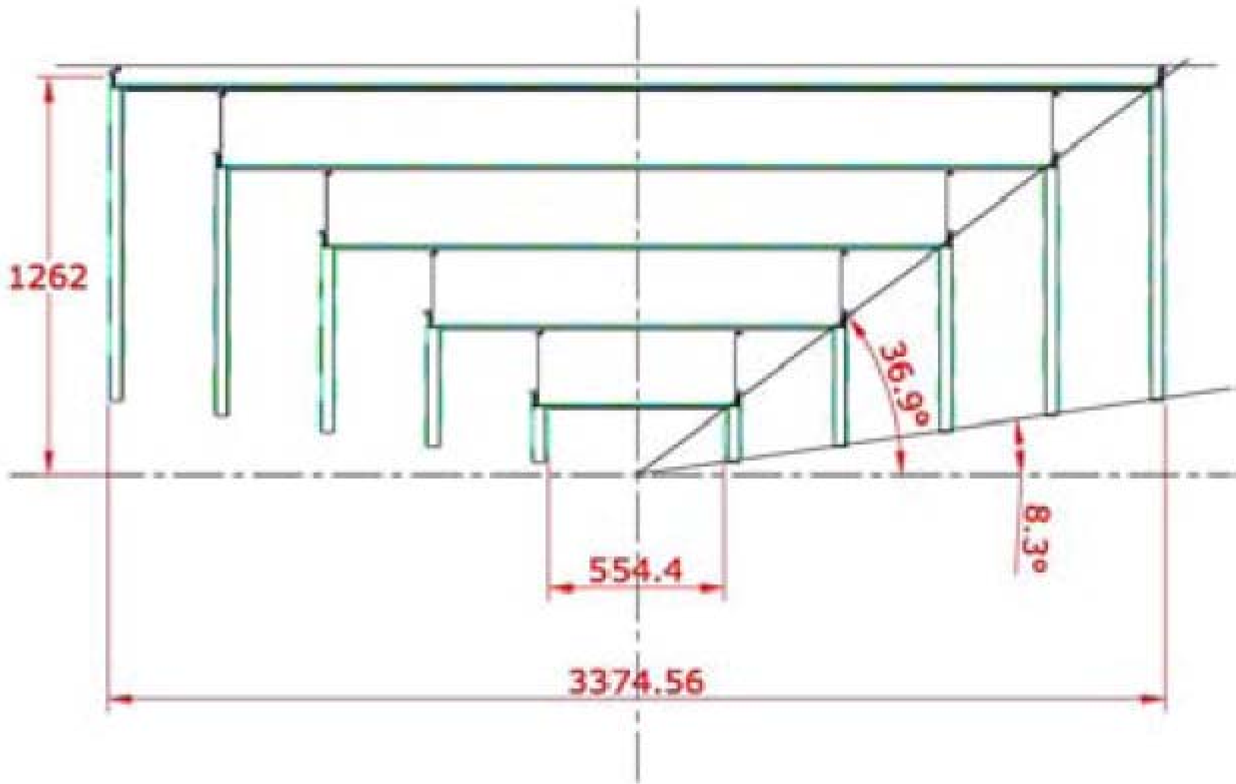
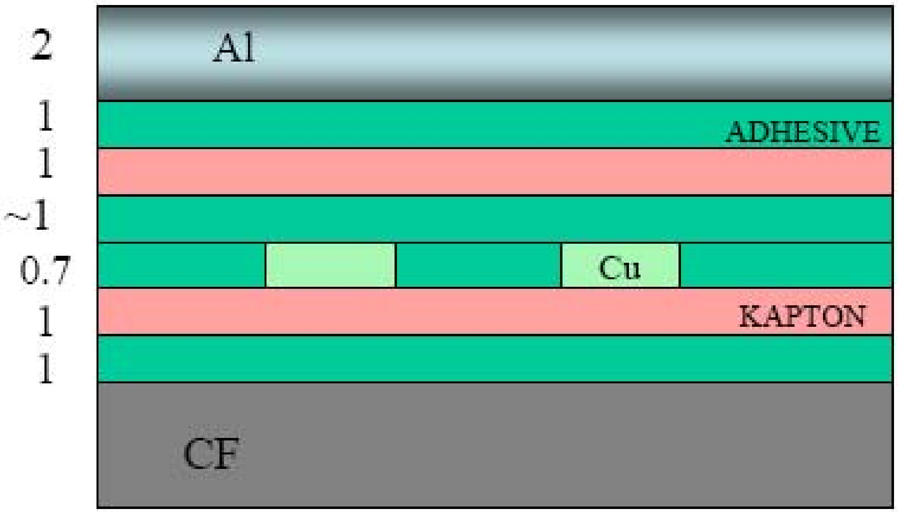


Figure 1: The layout of a proposed all-silicon tracker for the ILC (dimensions are mm). Nested, closed, carbon-fiber/rohacell cylinders are supported via spoked carbon-fiber rings and tiled with small low-mass silicon sensor modules. The material in these three regions (barrel, endcap, support rings) is discussed in Section 2.2.

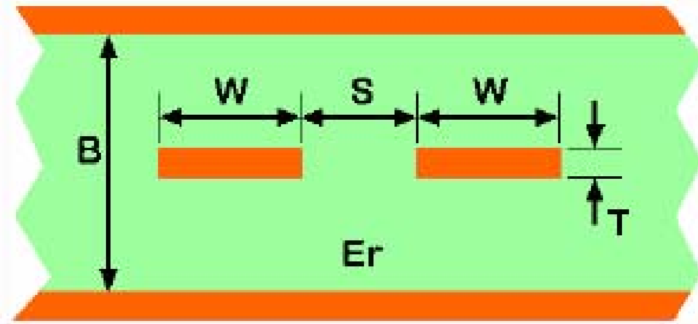
Bus Cable Geometry and Impedance

Materials: Al foil 2mil, Dupont LF0100, Shinetsu CA333 2 mils, Cu 18 um, Kapton 1 mil, Adhesive



>>Matches measured impedance

Differential Stripline Impedance Calculator



Notes:
1) Calculation assumes traces are centered vertically
2) S/T > 5.0

Enter dimensions:

Trace width (W)	3	mils
Trace thickness (T)	.7	mils
Trace spacing (S)	4	mils
Distance between planes (B)	5	mils
Relative Dielectric constant (Er)	3.6	

Compute Z

Differential Trace Impedance	72.9	ohms

Couple this to further measurements – see J.Nielsen talk of 12/11

A possible Medical Application

For PET imaging with gamma rays, there are several advances possible in order to obtain finer spatial resolution in a high rate environment.

- In conventional systems, the crystals which convert the gamma rays to light have to be large enough to have a high efficiency. This limits the spatial resolution. Only one layer can be used because of the mass and volume of the attached phototubes. GEM detectors can function as large area phototubes with very low mass, so that multiple layers of small crystals with readout can be used in order to get finer spatial resolution.

2) The readout can be done in pixels or short strips optimized for resolution and rate capability. With strips, two dimensions are obtained simultaneously. Low-mass routing of signals so that readout chips could be many cm away would make this application even more attractive.

3) The GEM detectors also operate in high magnetic fields, allowing the possibility of combined MRI and PET with the equivalent of the phototube inside the magnet.

Problems of doing something at Argonne, vs Advantages

Problems:

1) **Silicon in general is a well established technology, and there is a basis for going further.**
2) **Competition from large groups with better funding, both for Silicon and GOSSIP. Universities can use some private funding when DOE is lean, and European groups have more stable funding.**
3) **One needs to either do ASIC development or partner with someone who does it.**

   (or be lucky/clever in piggybacking on silicon electronics

4) **We don't have much experience or reputation in tracking.**
5) **We need collaborators.**
6) **Lab overhead is a problem in getting work here.**

Advantages we have

Competence in Physics and in Project management

Better Electronics and Mechanical engineering than most university groups

Nano-fabrication experts at Argonne

2 collaborators already work on GEMS, MIT(RHIC) and UTA(ILC)

Possible collaborators for LDRD -

Nano Fabrication

ANL Physics Division (for J-Lab)

Fermilab chip design

Resources: RD41, RD51, Shipsey at Perdue, COMPASS ,

CMS development, LHC-B, etc

ADDITIONAL SLIDES

- xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

What to do:

Study what physics could be done in SLHC, and what changes might be needed.

Talk to other people in Atlas interested in Gas tracking (RD51, etc)

Learn even more about both Silicon and Gas tracking (40 ref for this talk)

LDRD at Argonne:

i) consult on thinning GEM foil

ii) find a way to do irridiation studies

iii) Look at electronics engineering aspects

iv) look at mechanical aspects

Look into different Upgrades as well.

Micromegas, GOSSIP, and combined Micromegas + GEM

1) Gossip for Atlas (van der Graff)
http://www.nikhef.nl/~d90/gossip/UpgradeValencia.ppt

2) GEM+Micromegas (Ian Shipsey)
www.physics.purdue.edu/mscg/publications/Age_study_micro_GEM_preamp.pdf

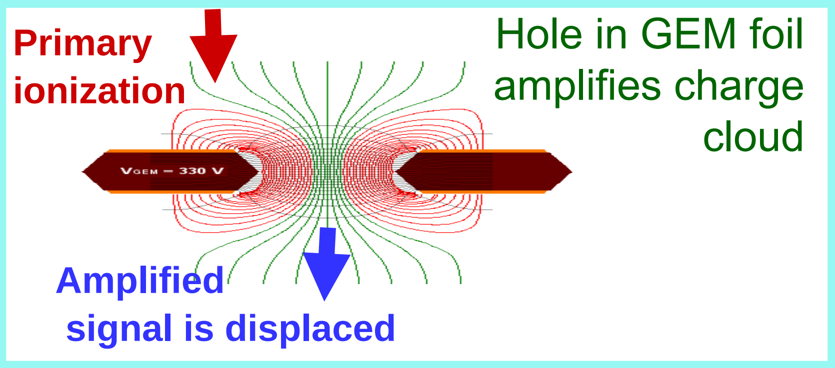
3) GEM + Micromegas in HERA-B and LHC-B

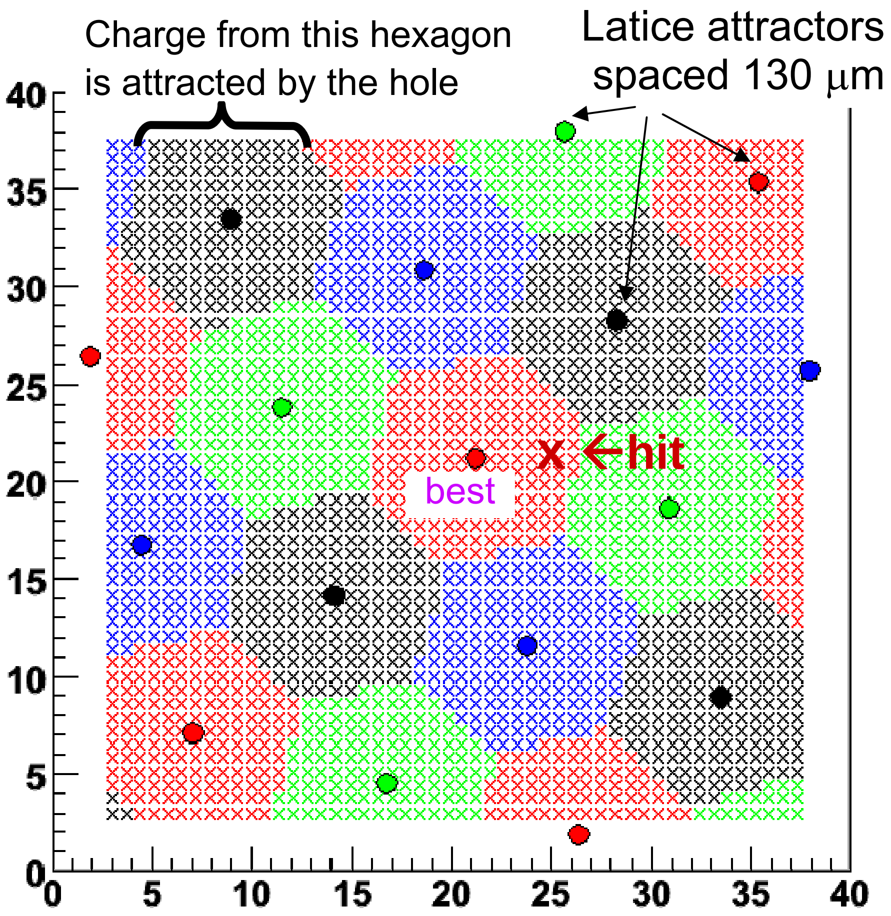
4) "Spatial resolution in Micromegas detectors", J. Derre et al, NIM-A 459 #3 (2001) 523-531

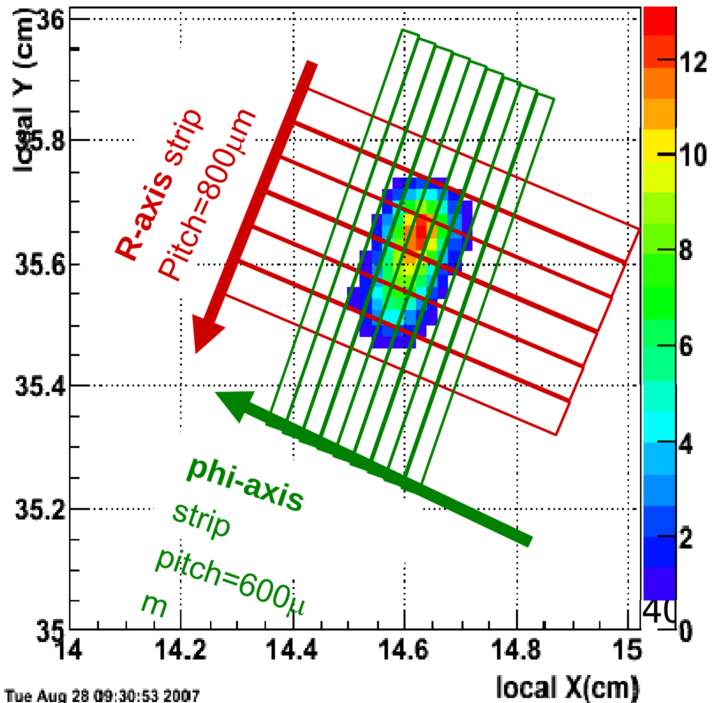
5)

Detailed Simulation of GEM Response (1)

1. ionization and charge amplification
2. spatial quantization on GEM grid
3. charge collection by strip planes
4. 1D cluster reconstruction







Ref for radiation damage in Silicon

1) Silicon detectors for the next generation of high energy physics experiments: expected degredation" http://arxiv.org/pdf/physics/0512275

2) Radiation Hardness of the HERA-B Silicon Micro-strip Detectors II Nuovo Cimento …………..2x10^13 MIP/cm^2 to 2.7 x 10^14 MIP/cm^2

3) Tracking detectors for the LHC upgrade", NIM-A, 552 (2005) 1-6

4) Recent Advances in the development of radiation hard semiconductor detectors for S-LHC", NIM-A 552 (2005) 7-19

5) NIM A vol 552 issues 1-2 p 19-24

References for Aging, Rad-Hardness, Occupancy, for GEM

1) Aging measurements with the Gas Electron Multiplier (GEM) NIM-A, 515 (2003) 249-254

2) Performance of GEM detectors in high intensity particle beams", NIM-A470 (2001) 548-561

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