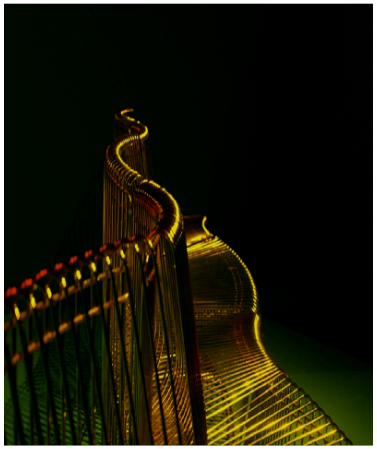
ATLAS Inner Detector upgrade

Sergio Gonzalez Sevilla (University of Geneva)

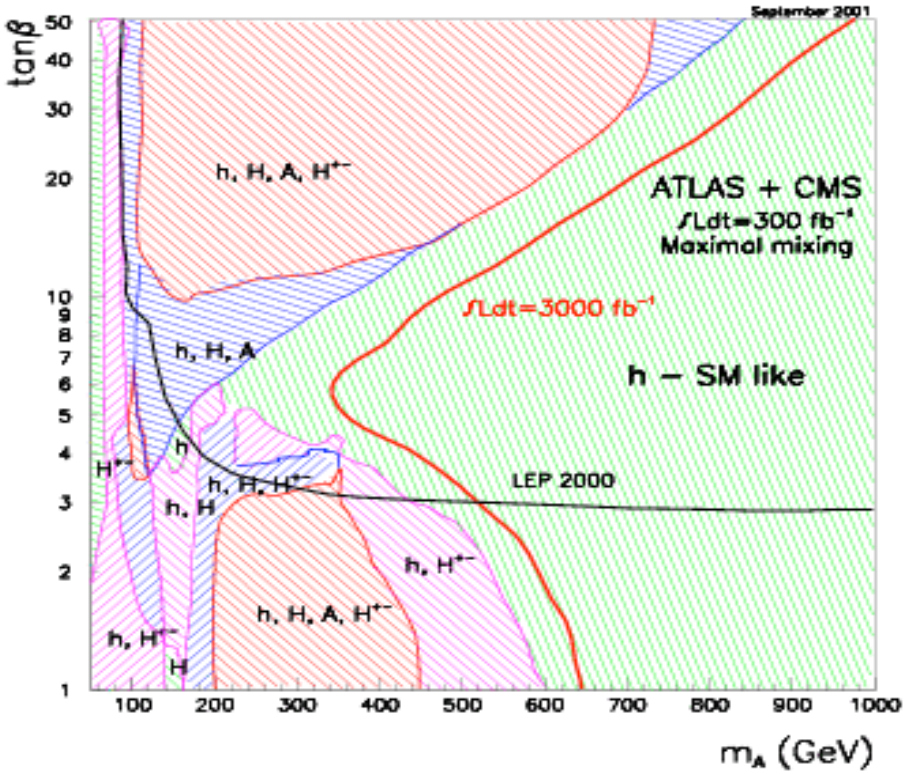
on behalf of the ATLAS Inner Detector upgrade community

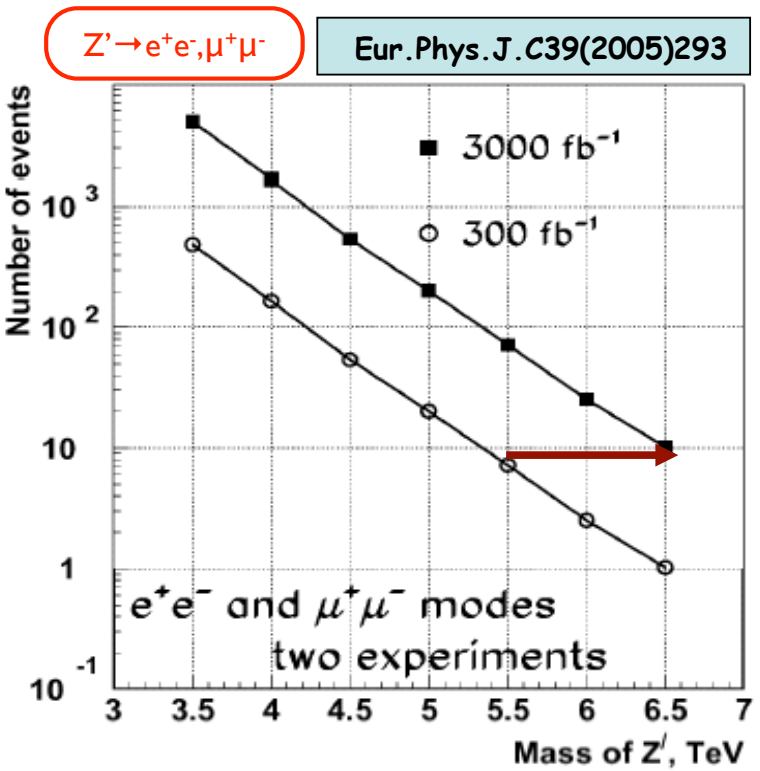
3rd LHC Alignment Workshop
CERN - 15/16 June 2009



Physics motivations for a LHC upgrade

- Improve measurements of new phenomena seen at the LHC
  - Higgs couplings to bosons and fermions and self-couplings
  - properties of SUSY particles
- Detect/search low-rate phenomena inaccessible at the LHC
  - $H \to \mu^+\mu^-$ (BR~$O(10^{-4})$), $H \to Z\gamma$ (BR~$O(10^{-3})$ in M_H~100-160 GeV)
- Increase sensitivity to new high-mass scales
  - extra gauge bosons (Z', W') appearing in various extensions of the SM symmetry group



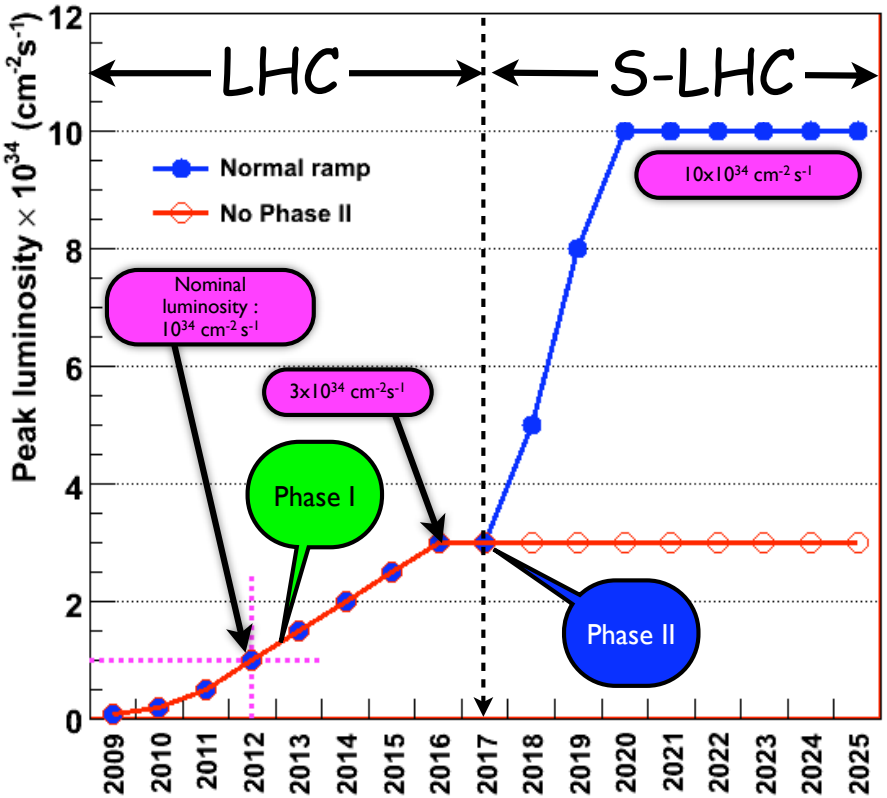


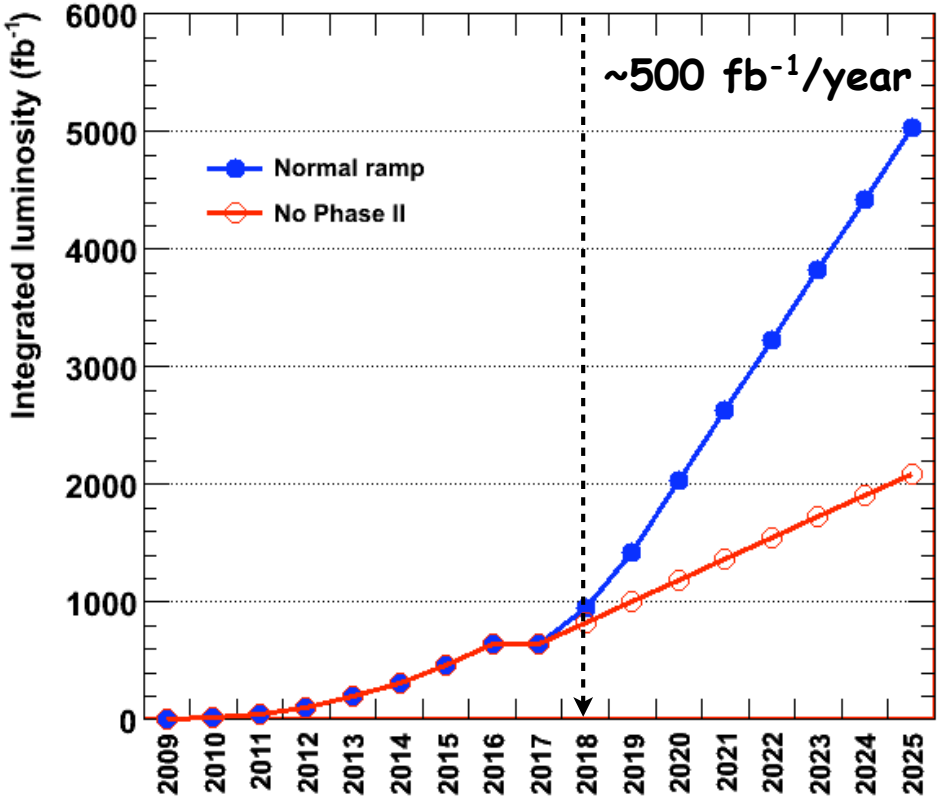
LHC luminosity increase

- Two-phased increase in the LHC peak luminosity
  - Phase I (2013) ➡ $\mathcal{L}=3\times10^{34}$ cm^{-2}s^{-1}
    - B-layer replacement
  - Phase II (2017) ➡ $\mathcal{L}=10\times10^{34}$ cm^{-2}s^{-1}
    - ATLAS ID upgrade

Upgrade of ATLAS and CMS experimental insertions
New large aperture quadrupoles + relevant modifications to other magnets
Upgrade or replacement of LHC injectors (160 MeV Linac4)

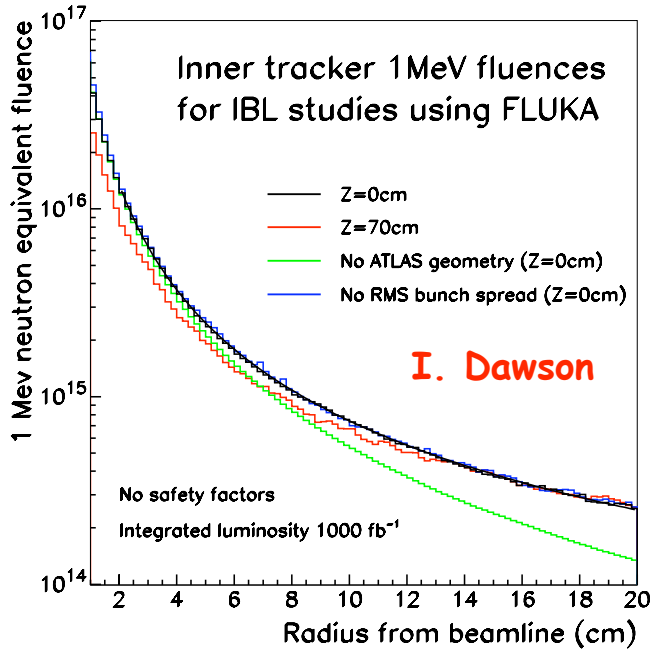
New 4 GeV Low Power Superconducting Linac (LPSPL) and 50 GeV Proton Synchrotron (PS2)
Subsequent upgrade of the LPSPL to a multi-MW high power SPL
Associated modifications to the SPS





B-layer issues

- B-layer operational (ε>95%, single hit) up to a total dose twice the nominal design lifetime
  - ~5 years @10^{34} $cm^{-2}s^{-1}$
    - 1 year nominal LHC lumi (100 fb^{-1}): ~ 15 Mrad TID for current B-layer @5.0cm
- Marginal operation until 2016 ➡ intervention during the 2012/2013 shutdown
- Requirements and constraints
  - Physics: b-tagging
    - pattern recognition, hit resolution, material budget
  - Radiation background
  - Time...
- Other requirements
  - IBL peak lumi = 3x10^{34} $cm^{-2}s^{-1}$
  - Int. lumi seen by IBL = 550 fb^{-1}



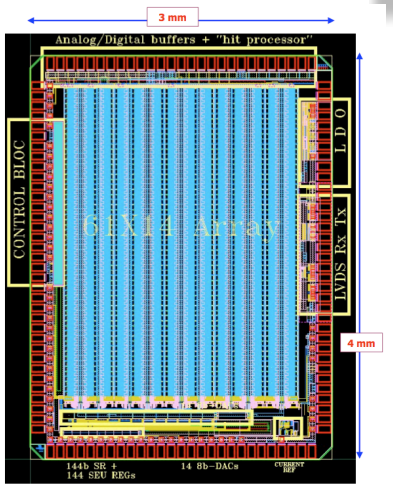
Estimated 1 MeV n_{eq} fluence for IBL:

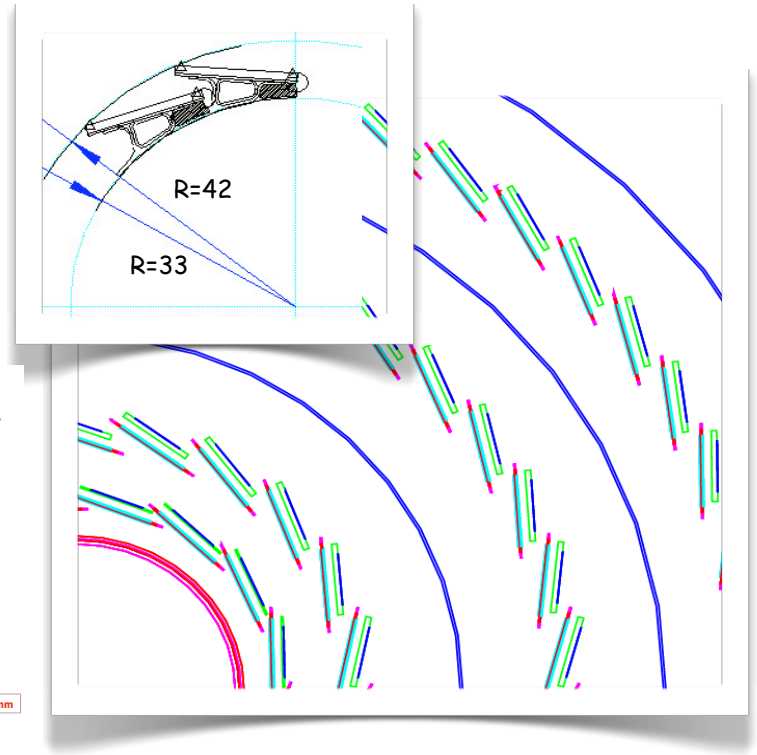
Φ_{1MeV} = 2.4 x 10^{15} [n_{eq}/cm^2]

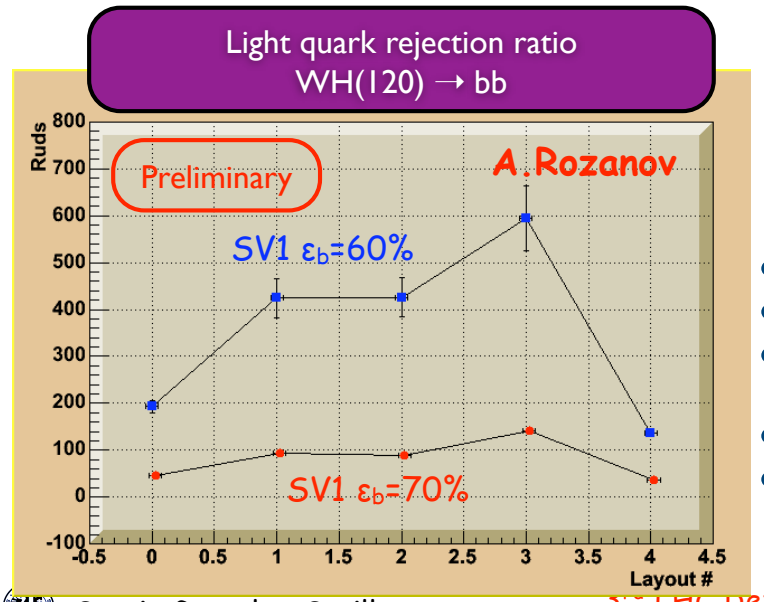
- dominated by pions from IP
- R=3.7 cm and IL=550 fb^{-1}
- No safety factors included

Phase I: insertable Pixel B-layer

- Most probably, new beam-pipe
  - R=25 mm, 0.7% X_0
  - though expensive, significant reduction of MS background
- Smaller radius B-layer (R=3.7cm) to be inserted in the existing ATLAS Pixel detector and integrated with BP
- New module design:
  - 16 staves, 15 modules/stave
  - New readout ASIC FE-I4 chip
    - 130 nm CMOS, 50 μmx250 μm
  - Novel radhard sensors (3D) ?
- New local support structures (CC foam)



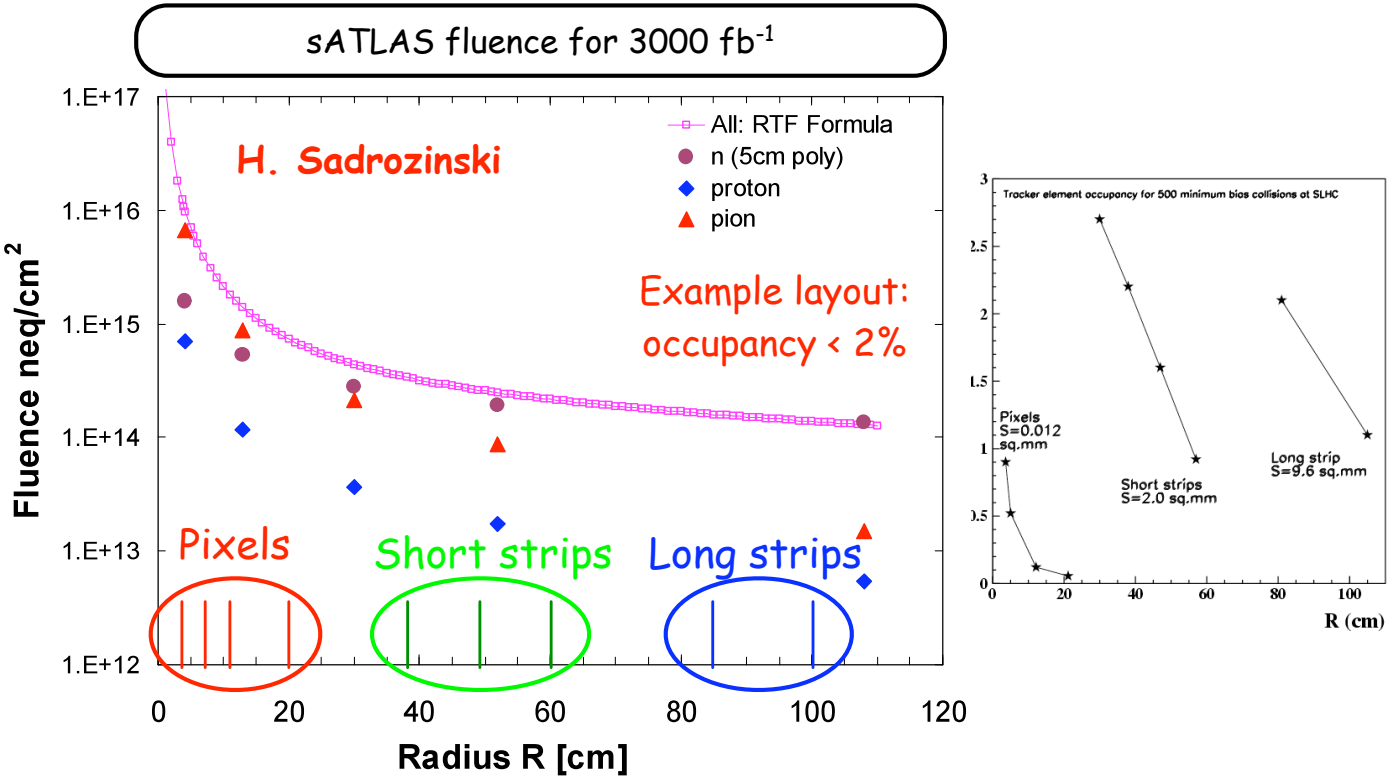


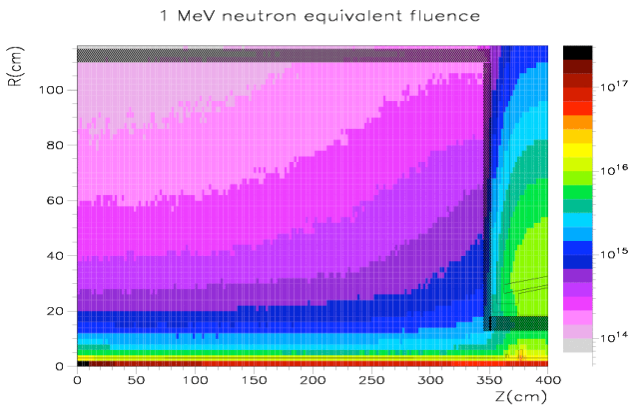


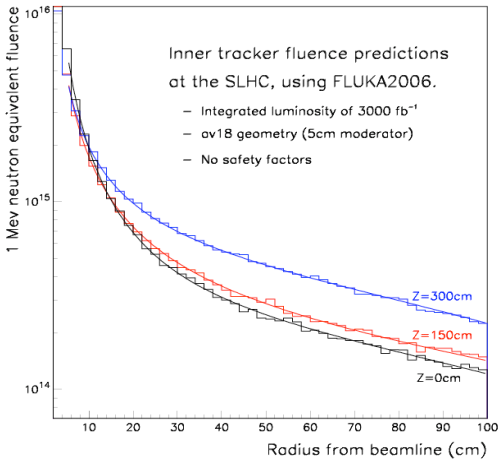
- **0**: current ATLAS
- **1**: **new inserted 4th B-layer (R=3.7)**
- **2**: two Pixel layers
  - new B@R=3.7 + barrel layer @R=8.9 + one disk
- **3**: replace old B-layer by new B-layer (R=5.05cm)
- **4**: 2-old layers
  - old-type new B@R=5.05 + barrel layer @R=8.9cm + one disk

Phase II: a new ATLAS tracker

- Increase in pile-up events from ~23 to ~300-400
  - Radiation damage
  - $>10^5$ particles $|\eta|<3.2$ ➡ occupancy in the TRT ~100%
- **Build a completely new ATLAS Inner Detector !!**
  - Pattern reco, good tracking eff+low fake rate, minimise occu
    - better detector granularity
  - silicon-based tracker: **pixels** and **strips** (short and long)







1 MeV equivalent neutron fluences assuming an integrated luminosity of 3000 fb^{-1} and 5 cm of moderator lining the calorimeters.

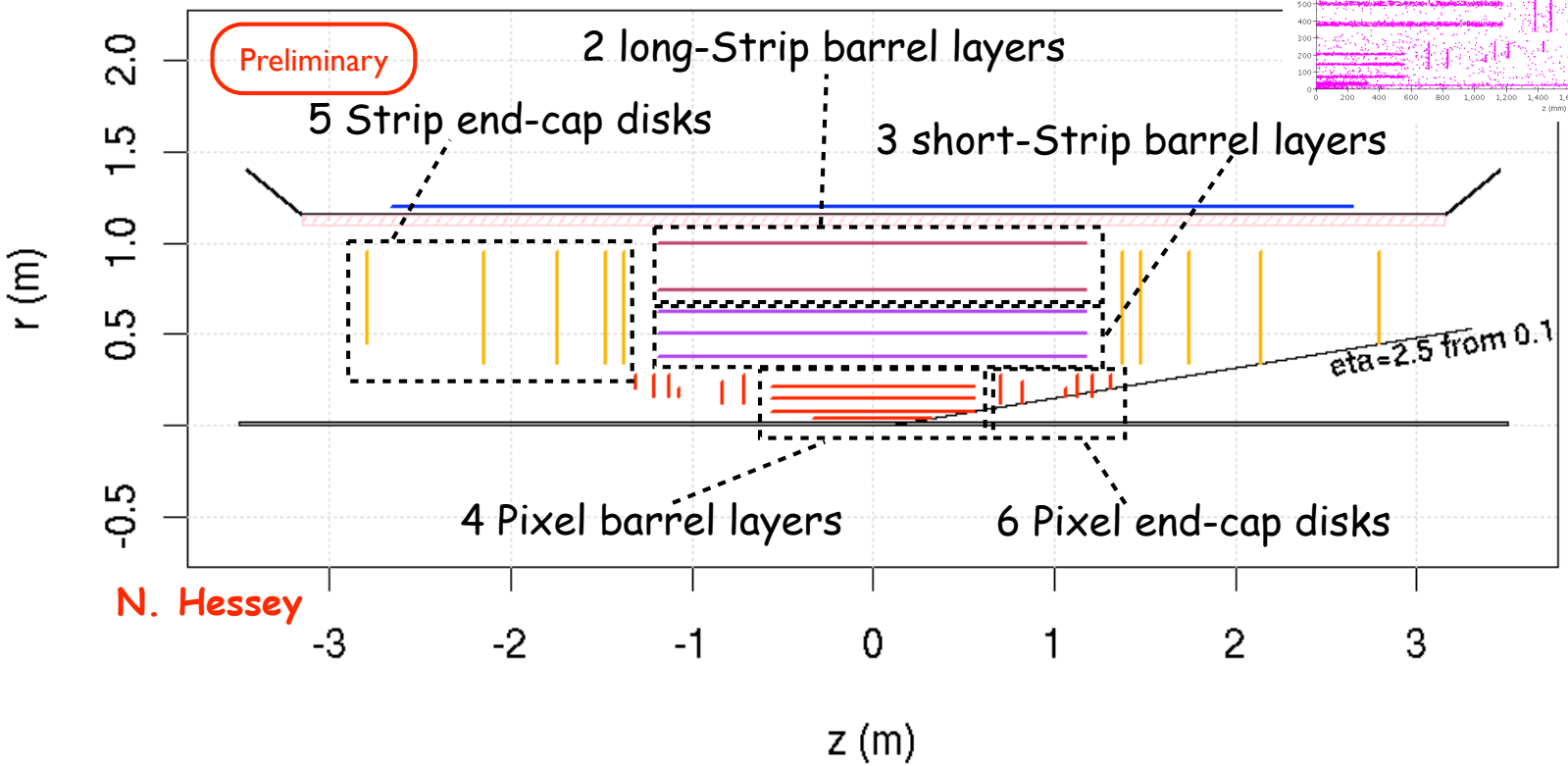
I. Dawson

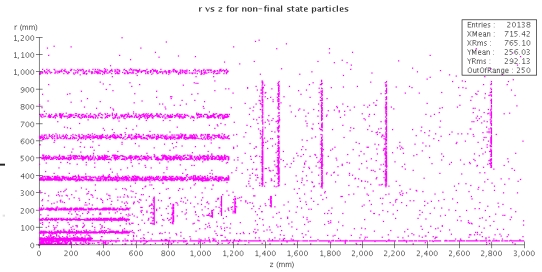
ATLAS Radiation Taskforce Report

$\Phi=1.3\times10^{17}/r^2+4.8\times10^{15}/r+9.9\times10^{13}-3.6\times10^{11}r$ [n_{eq}/cm^2]

Strawman layout

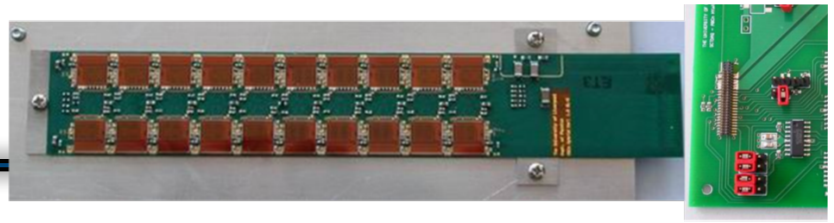
- Not "the" layout...
  - much work in progress
    - main purpose: help simulation studies to go-on
- Fixed barrel length
  - simpler from the engineering point of view than a semi-projective layout
  - Pixel barrel length ~ 1120 mm, Strip barrel length ~ 2350 mm
- 9-hit coverage |η|<2.5



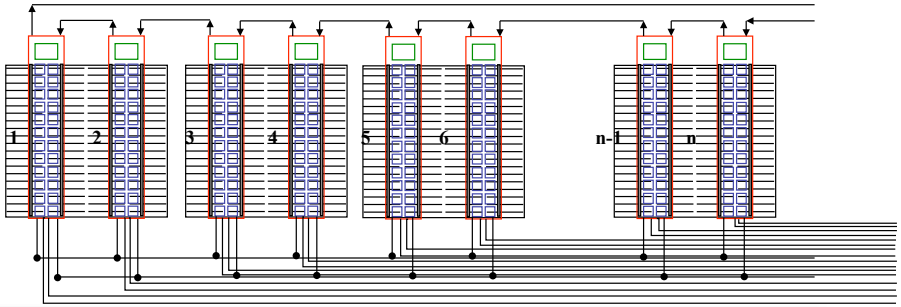


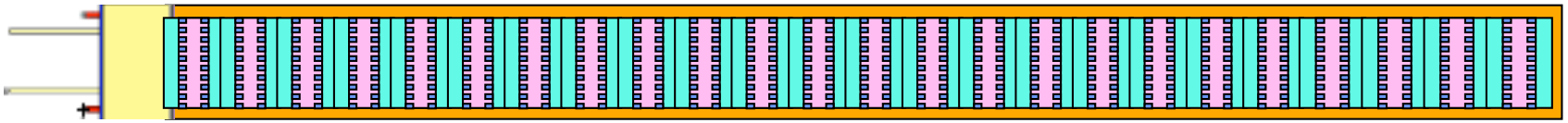
Rz map of secondaries
(non-final state particles)

Barrel module integration



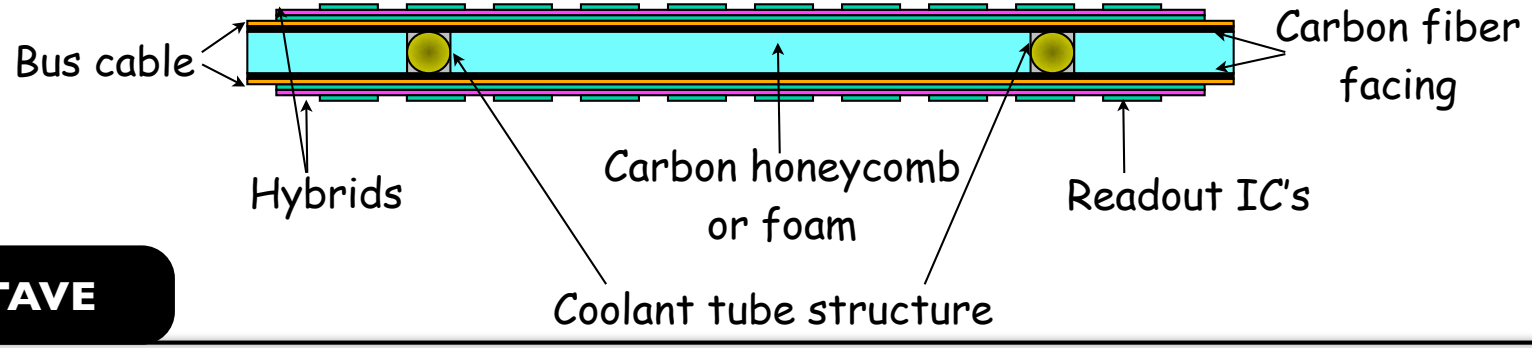
- Stave concept for barrel strip layers
  - 24 hybrids (one side), 20 chips/hybrid arranged in two columns of 10. V_{ABCN}=2.5V, I_{hyb}~2.5 A
  - Powering schemes under study
    - Serial powering (saving in cables)
    - DC-DC conversion



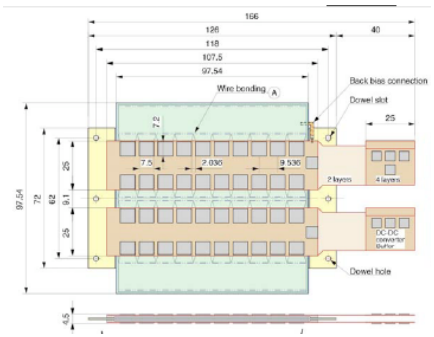


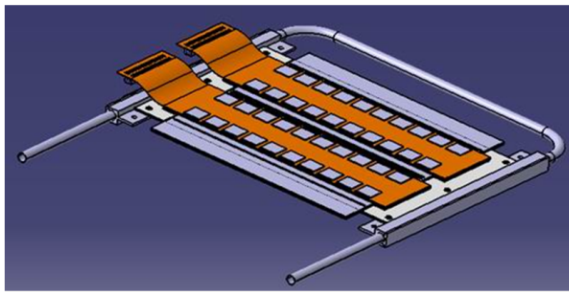
C. Haber

1.2 m



STAVE





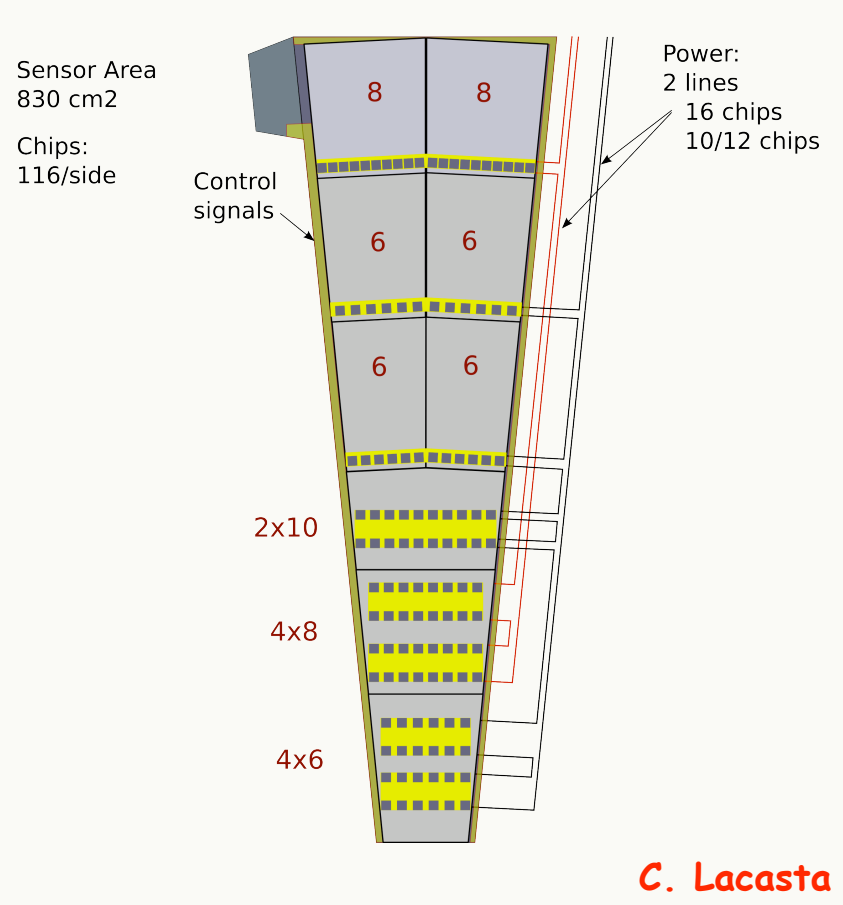
Y. Unno

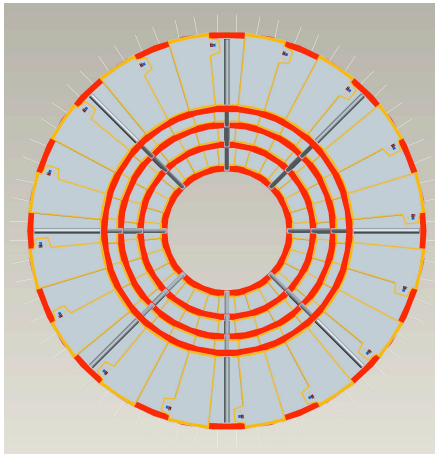
Inspired from SCT barrel
Double-sided module

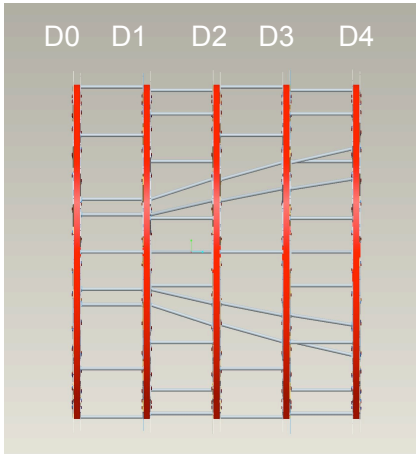
SUPER-MODULE

Strip end-cap disks

- 9 sensors, 6 different shapes
- Serial powering with 2 different lines
- For the moment, 8 different hybrids



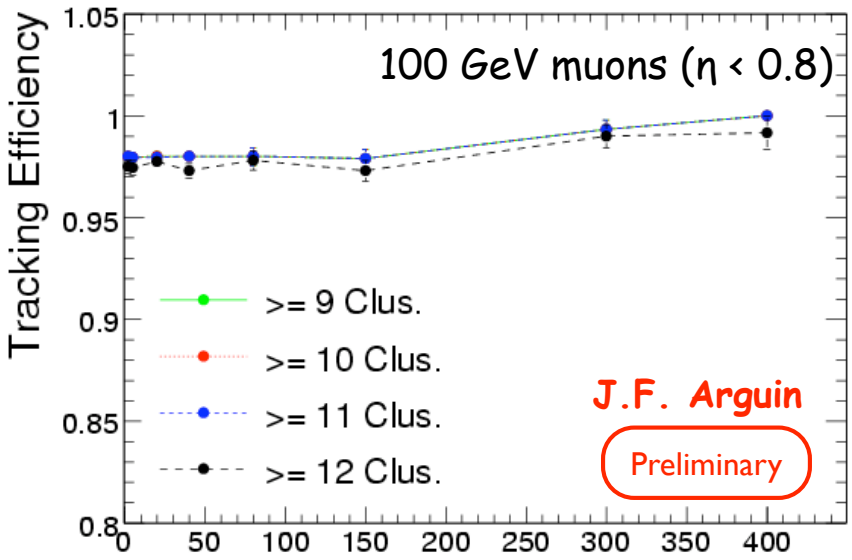




- Sensors mounted on petals and disks made of petals
  - Coverage from R=340 mm to R=950 mm
  - 5 disks
  - 32 petals/disk
    - 4 different petals
  - Number of sensors/petal
    - max=18
    - min=12

Some (preliminary) simulation results

- Track quality cuts as a **starting point** for SLHC studies
  - $|d_0|<1$ mm, d_0 corrected to the primary vertex position
  - $|z_0-z_{prim_vtx}| \times \sin\theta < 2$ mm (loose B-tag cut at 10 mm)
  - $p_t > 1$ GeV, $\chi^2/ndf<5$
- Addional quality cuts on the number of Pixel/Strip hits and/or holes used to remove fakes
  - depending on layout ➡ to be optimized
- Looking as well as optimizing CPU processing time
  - tracking tuning
    - constraining seeds
    - tune for heavy ion collisions will certainly help in this context



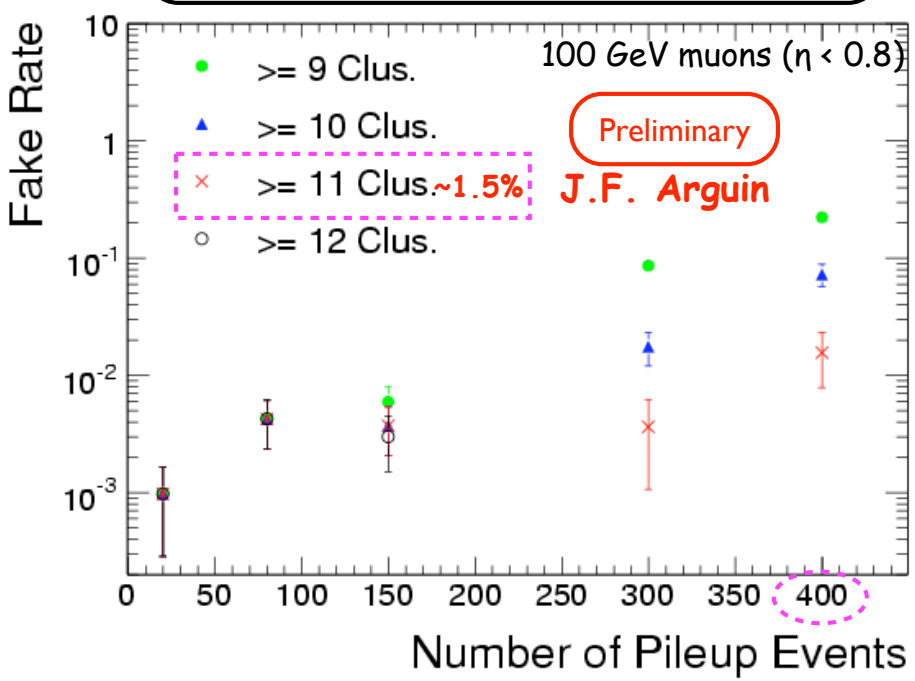
Generator cuts
- $|\eta|<2.5$
- truth $p_T > 1$ GeV

Efficiency
- fraction of matched hits >= 50%

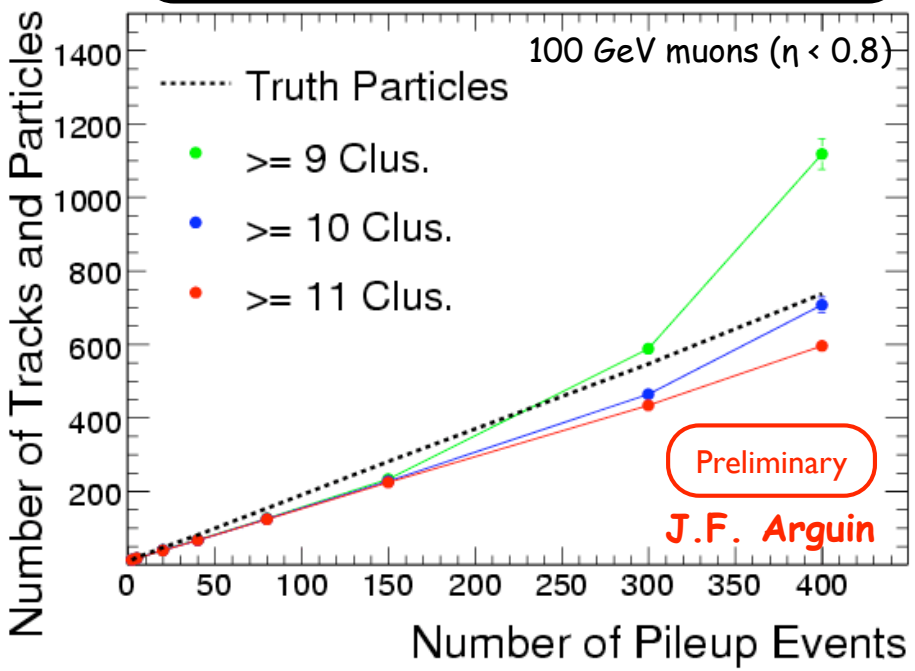
Fake rates

- Different methods to have an estimate of fake rate
  - truth match probability
    - tracks without associated truth or matched probability < 50%
  - comparison tracks vs truth particles
    - robust method independent of truth matching scheme

Truth match probability method

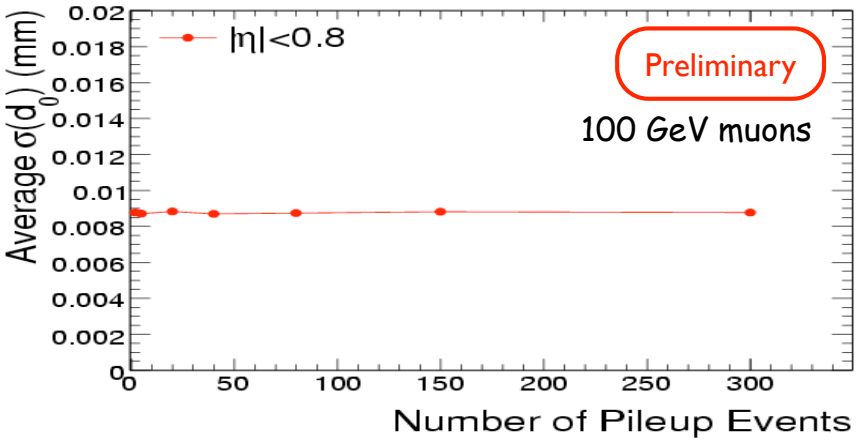


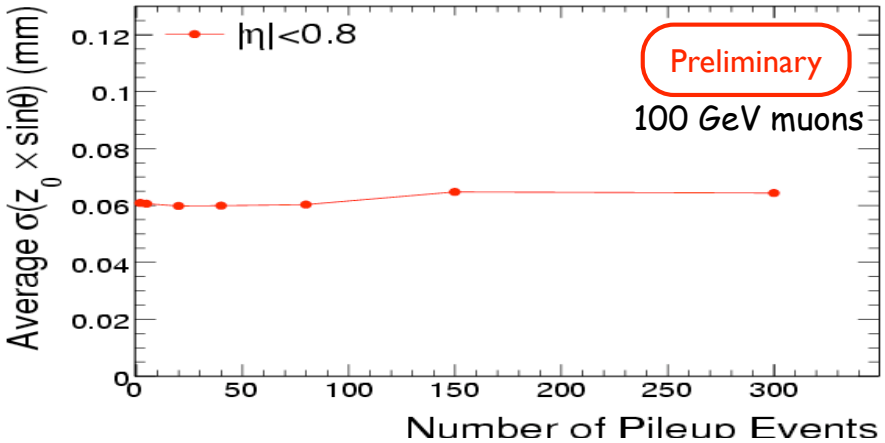
Comparison track vs truth method

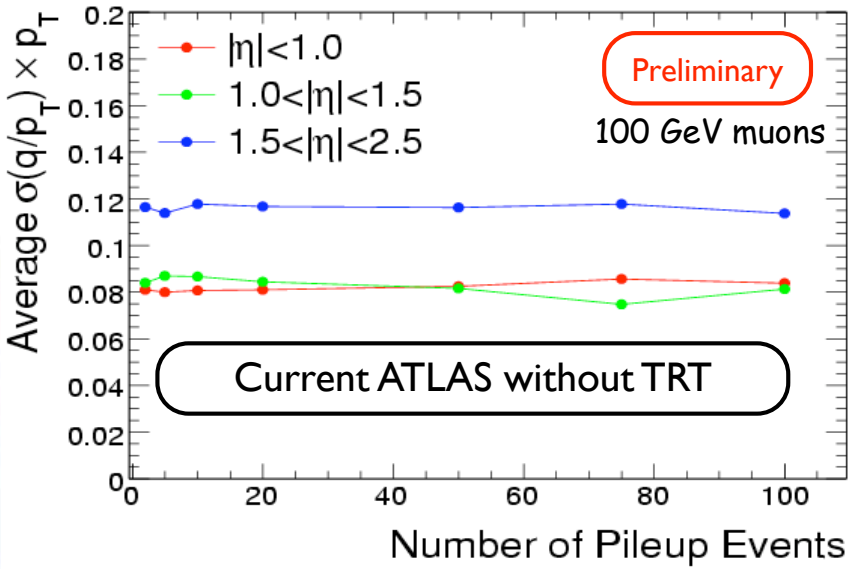


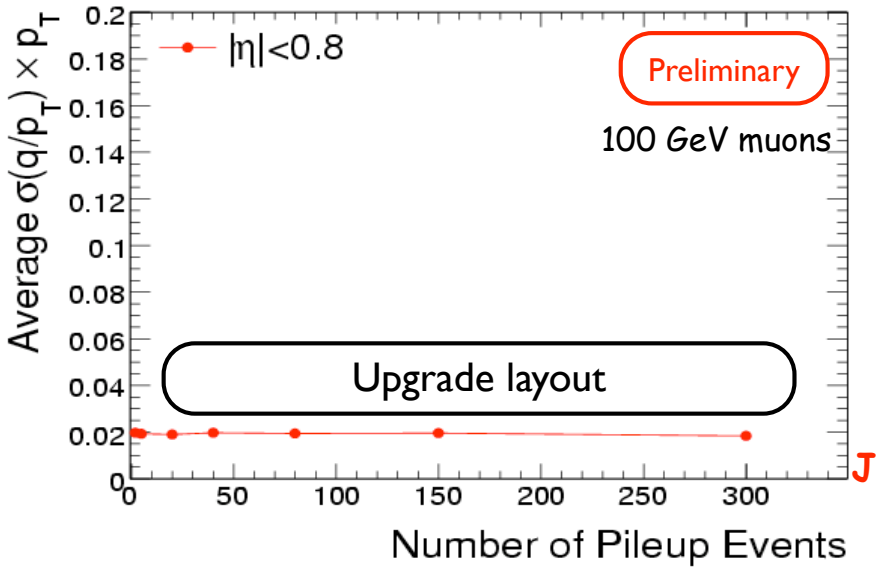
Resolution

- Comparison of working upgrade layout with current ATLAS (silicon-only, no TRT)
  - better impact parameter resolutions
  - much better q/pt resolution (~2%)
    - even true if compared with the TRT in (~3-4%)







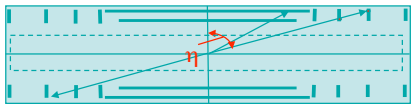


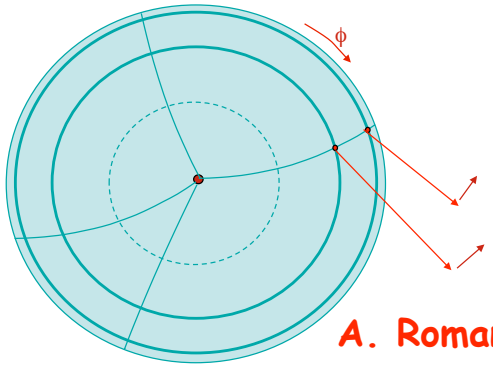
J.F. Arguin

Track triggers

- Higher occupancy, challenge for L1 triggers
  - raise L1 rate ➡ difficult to go above 100 kHz
  - rely on multi-object triggers ➡ large fraction of lost events
  - possibility of raise p_T thresholds (~60 GeV single e/μ triggers) ➡ impact on physics
- First level track trigger
  - matching with calo or muon detector objects
  - correlation of multiple trigger objects (leptons and/or jets) with same pp interaction in z

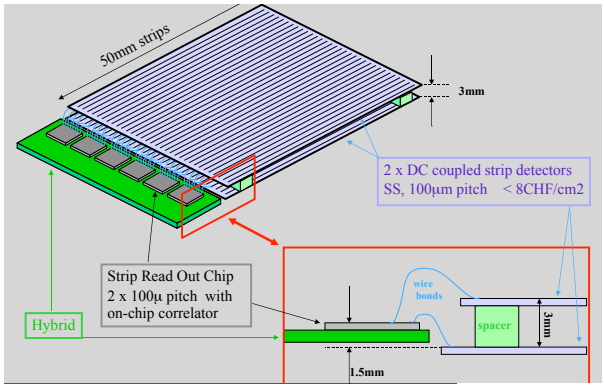
Gaseous detector





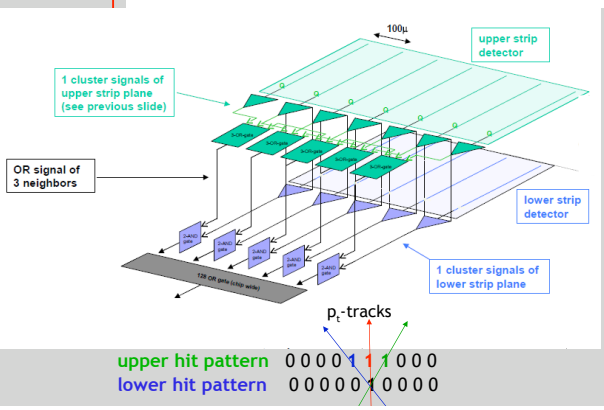
A. Romaniouk

1.- Precision space points: X,Y
2.- Vector directions: η,Φ



Two-in-one silicon module design

1.- strip cluster width detection
2.- 2-layers hit pt correlation

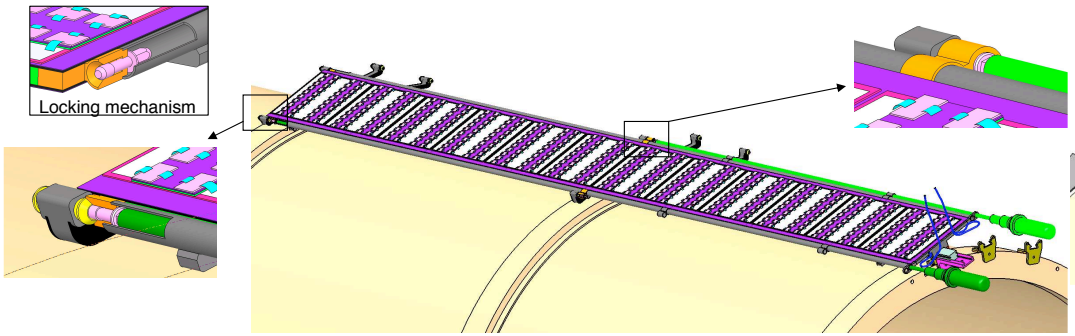


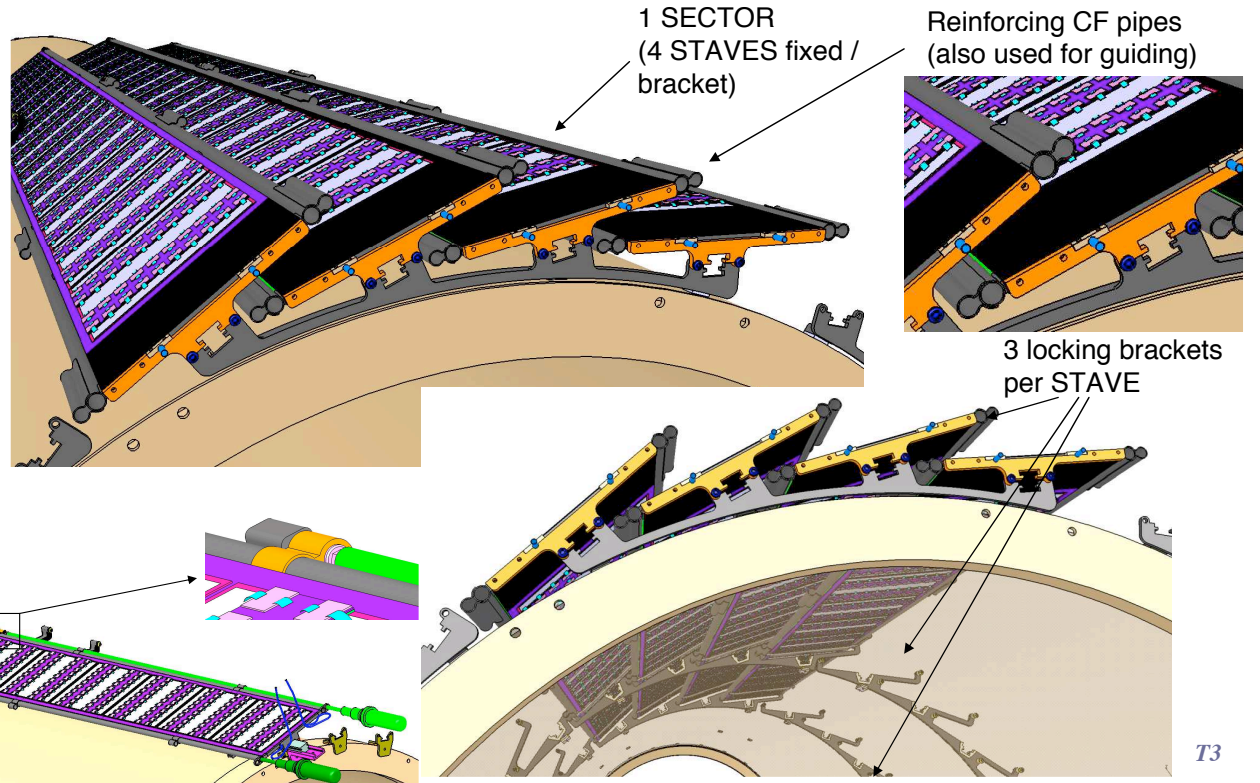
W. Erdmann &
R. Horisberger

Remarks concerning alignment

- Very rough estimate: 2.0×10^4 silicon strip-sensors
  - current SCT has 1.5×10^4 in ~4000 modules
  - significant increase in number of Pixel modules as compared with current Pixel detector
- Most probably, build tolerances will be less stringent
  - rely more on track-based software alignment
    - alignment based on sub-structures (in addition to other levels) will be definitely needed

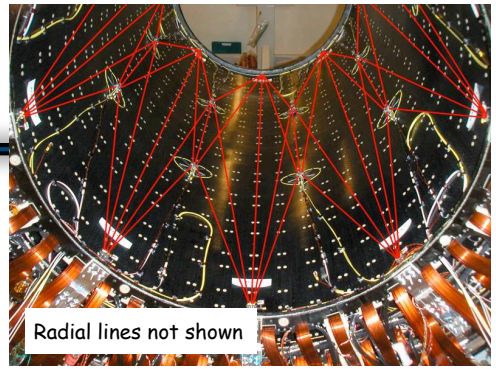
- **Example**: stave end-insertion concept
  - stave fixed to barrel at 3 points (brackets) along z
    - z_0, z_{600} and z_{1200} (clamping position)
    - slight z-movement allowed for z_0 and z_{600}





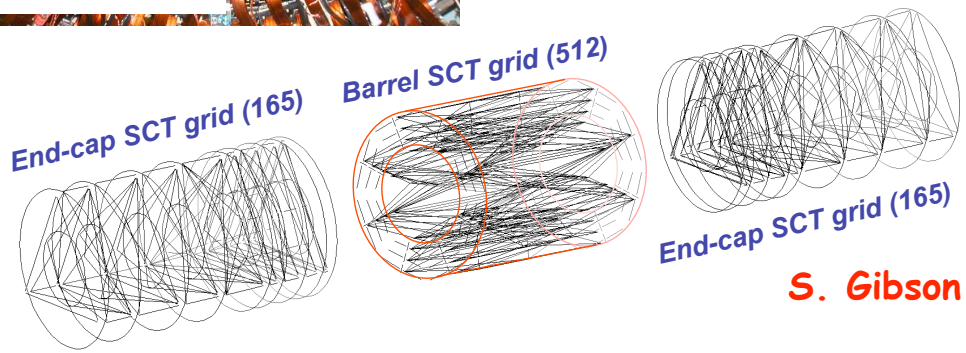
F. Cadoux

Hardware alignment



Distance measurement between grid nodes precise < 1 μm

- Current ATLAS SCT barrel equiped with a laser alignment system
  - Frequency Scanning Interferometry (FSI)
  - 842 grid lines measured simultaneously
  - repeated grid measurements monitor **shape changes** of the SCT
  - Main functions
    - time dependent corrections
    - improve alignment of weak modes



S. Gibson

- It would be very helpful for a better upgraded layout understanding to know if a hardware alignment system is needed
  - if FSI shows significant movements on a time-scale basis faster than track-based alignment can correct for ➡ strong indication of the need to design a harware-based alignment system
  - importance of kinematic mounts to minimise internal distortions ?
  - if needed:
    - monitoring structures or silicon sensors themselves ?
      - for the latter option, such an alignment system need to be designed **NOW !!**
  - need solid data to base a decision !!

Decision in favour or against a new hardware alignment system is the most urgent of all alignment questions for the design of an upgraded ID layout

Summary

- Recall that the ID upgrade program starts with B-layer replacement in 2013
  - but no major differences with the existing Pixel detector
- For Phase II, new ATLAS ID required
  - Most of what've presented is "work in progress"
    - layout not decided yet
      - although clear that will be silicon-only (prohibitive TRT occupancies)
    - numbers very preliminary, simulation studies on-going to decide which are the best options
      - playing with number of layers, tilt angles, etc.
- From the alignment point of view
  - major concern now is to know if need to implement a hardware alignment system
    - impact on layout studies, to be addressed asap...
  - number of silicon modules will definitely increase with respect current ATLAS ID
    - once the alignment of the present detector is understood and under control, would be required to think in how to align a larger system
      - 64 bits technology mature enough (to say the least)
      - new alignment algorithms ?
      - tracking tuning to deal with huge pile-up...
  - will probably rely more on track-based alignment
- Certainly, the work spent in the present detector will pay-off in the future !!