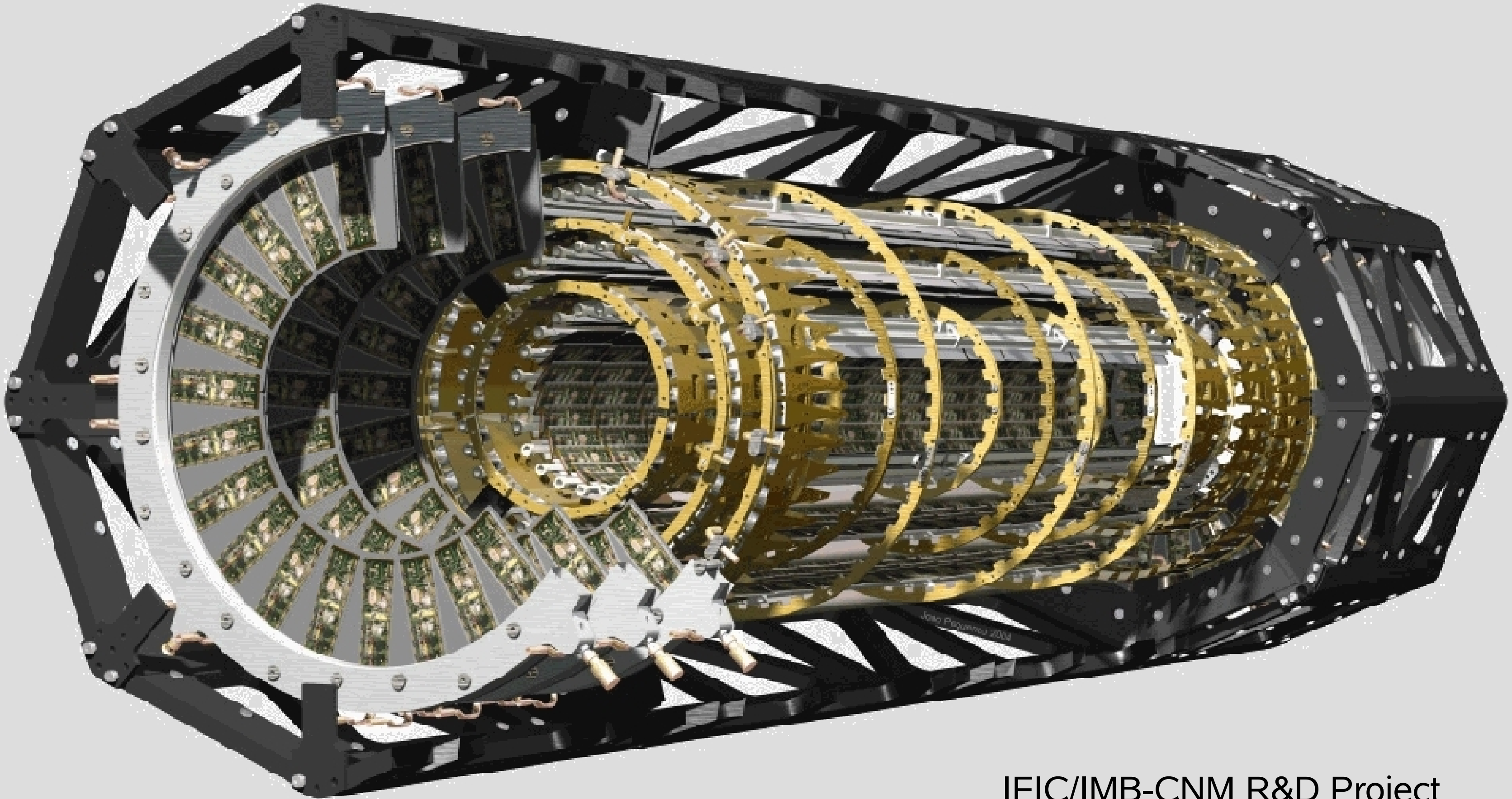
ATLAS Tracker Upgrade for the SLHC

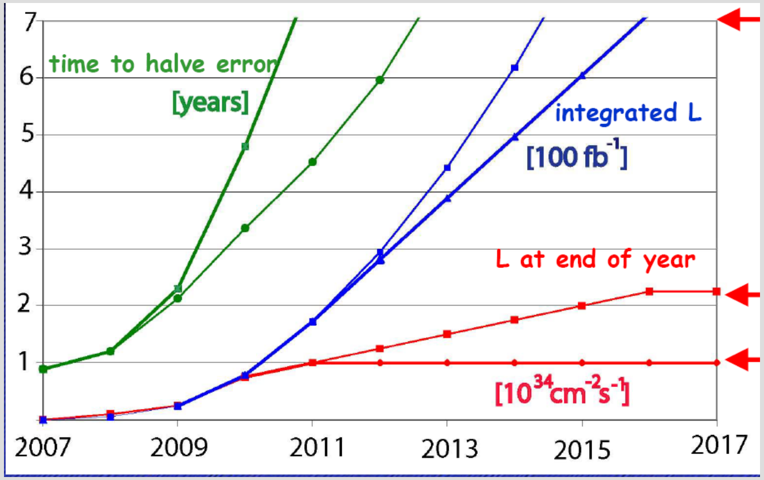


IFIC/IMB-CNM R&D Project

Carlos Lacasta

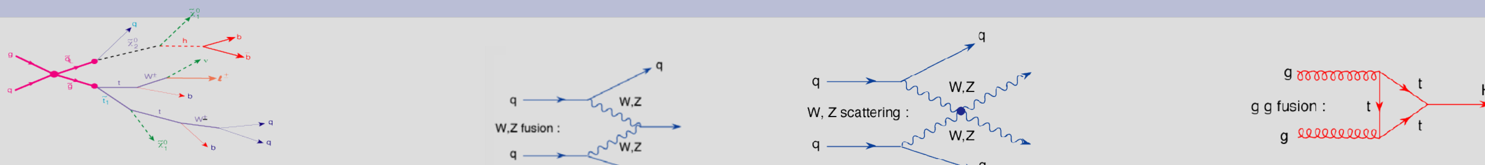
The LHC upgrade

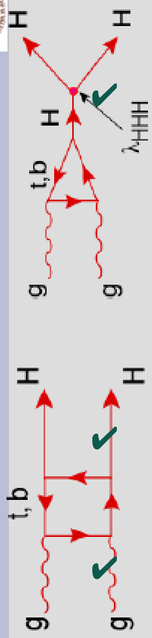
- The *standard* LHC operation is
  - 3 years @ 10^{33} cm^{-2} followed by
  - 7 years @ 10^{34} cm^{-2} providing ~100 fb^{-1}/year
- A more recent machine scenario shows the luminosity ramping up from 10^{34} cm^{-2} by an additional 0.25×10^{34} per year to a maximum of 2.3×10^{34} cm^{-2} (*ultimate)*
  - In this scenario, some components in the interaction region will have reached their rad. hard. limit and may need replacement by 2014.
- By 2012, the time needed to halve the statistics error will be ~8 years
- Could we profit the intervention to make an upgrade that increases the luminosity by up to an order of magnitude ?:
  - $10^{34} \rightarrow 10^{35}$ cm^{-2} s^{-1}



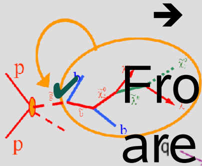
Courtesy J. Strait

Physicist's motivations





- The LHC is the first collider to run above the electroweak symmetry breaking scale
  - ➔ LHC data will revolutionize our understanding of the mass generation mechanism
  - ➔ Many other discoveries are possible:
    - ➘ Pair production of new particles with masses exceeding the ILC beam energy
    - ➘ Super-symmetry, extra dimensions, ... etc.
- Difficult to plan the best strategy for LHC after 2015
  - ➔ Need first LHC data
- Nevertheless, certain important facts are already known,
  - ➔ A staged upgrade of the LHC luminosity is the best route for high energy frontier
    - ➘ Increase of 20-30% in mass reach
    - ➘ Improve precision of a number of measurements:
      - Higgs couplings, rare top decays, triple and quartic gauge boson couplings,...
  - ➔ ATLAS ID will be approaching its design lifetime in terms of radiation survival



- From ATLAS experience on R&D and production, at least 10 years are needed from detector concept to switch on.
  - ➔ R&D phase should start now if SLHC is to become reality.

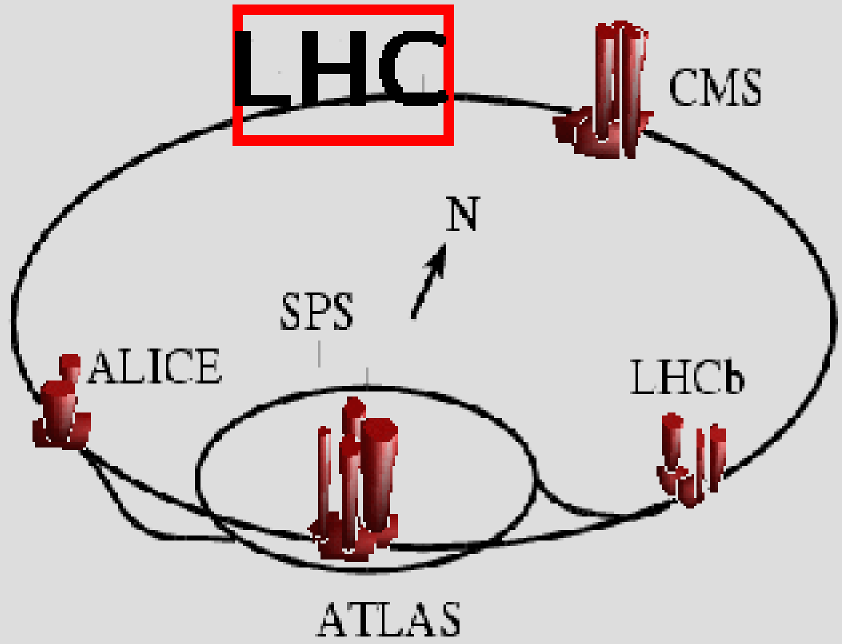
The Machine Upgrade

Parameter	Nominal	A			B		C
		Ultimate	IR-upgrade	IR-upgrade-Piwinski			
n_b	2808	2808			4680	7020	936
N_p [10^{11}]	1.15	1.7		2.6	1.7		6.0
ΔT_{sep} [ns]	25	25			15	10	75
I [A]	0.58	0.86		1.32	1.43	2.15	1.0
Profile (z)	Gauss.	Gaussian			Gaussian		Flat
σ_z [cm]	7.55	7.55	3.78	7.55	3.78		14.4
β^* [m]	0.55	0.5	0.25		0.25		0.25
θ_c [μrad]	285	315	445	485	445		430
σ_{lum} [cm]	4.5	4.3	2.2	4.3	2.2		3.6
Piwinski param.	1.43	1.50		3.27	1.50		5.5
L [10^{34}cm^{-2}s^{-1}]	1.0	2.3	4.6	7.2	7.7	11.5	8.9
Events/crossing	19	44	88	132	88		510

- Several scenarios
  - The ultimate comes almost for free pushing the machine to the limits
  - Other scenarios will require a replacement of the focusing system and move the quadrupoles closer to the IP.
    - Some play with the bunch length, the crossing angle of the beams, the bunch intensity and some other parameters...
  - In any case, after the intervention in the IR, machine protection and collimation are an issue

SLHC

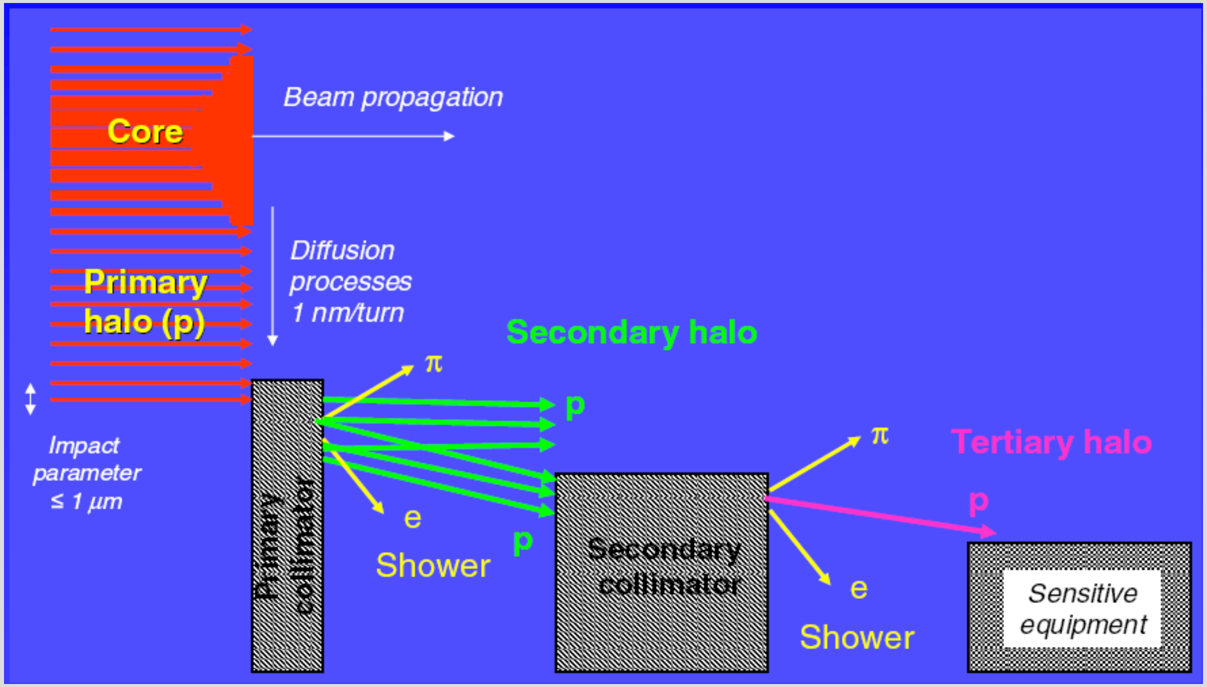
A non-linear Collimation System for



A. Faus-Golfe J. Resta López D. Schulte F. Zimmermann

The role of a collimation system

- The CS for LHC must
  - Prevent beam-loss induced quenches of superconducting LHC magnets
  - Minimize activation of accelerator components outside the dedicated collimation insertions
  - Ensure an acceptable background in the detectors
  - Withstand the impact of 8 bunches in the case of an *irregular* beam dump
  - Not produce intolerable wake fields that might compromise the beam stability

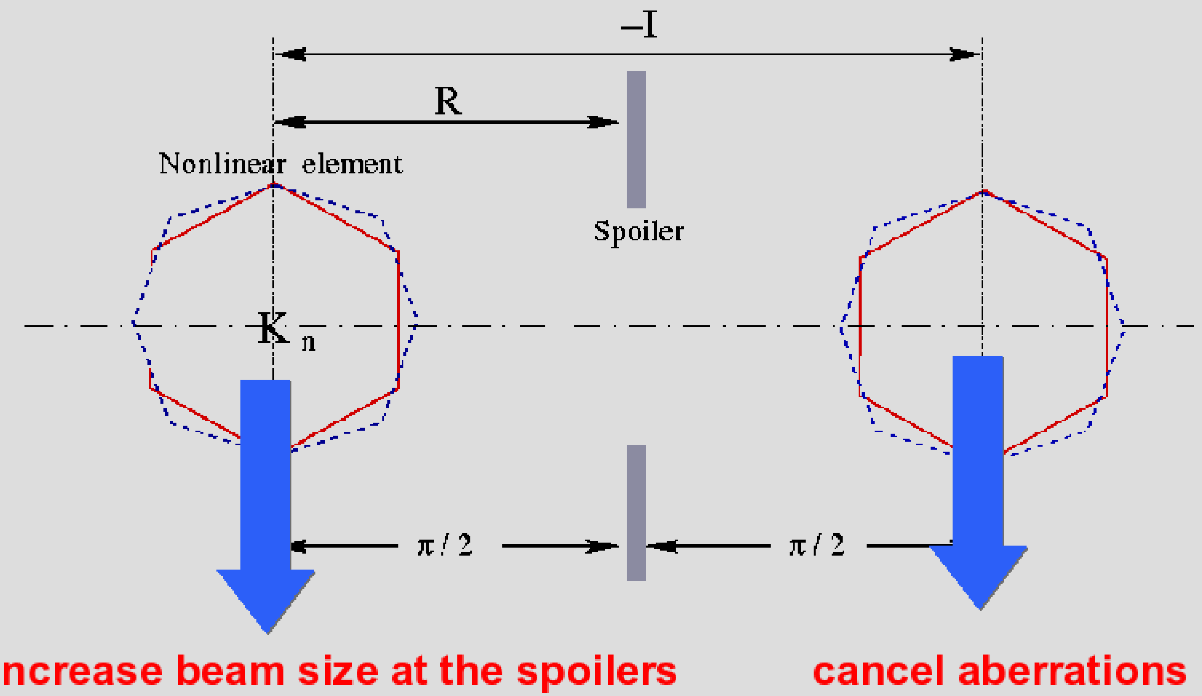


Why a non-linear CS ?

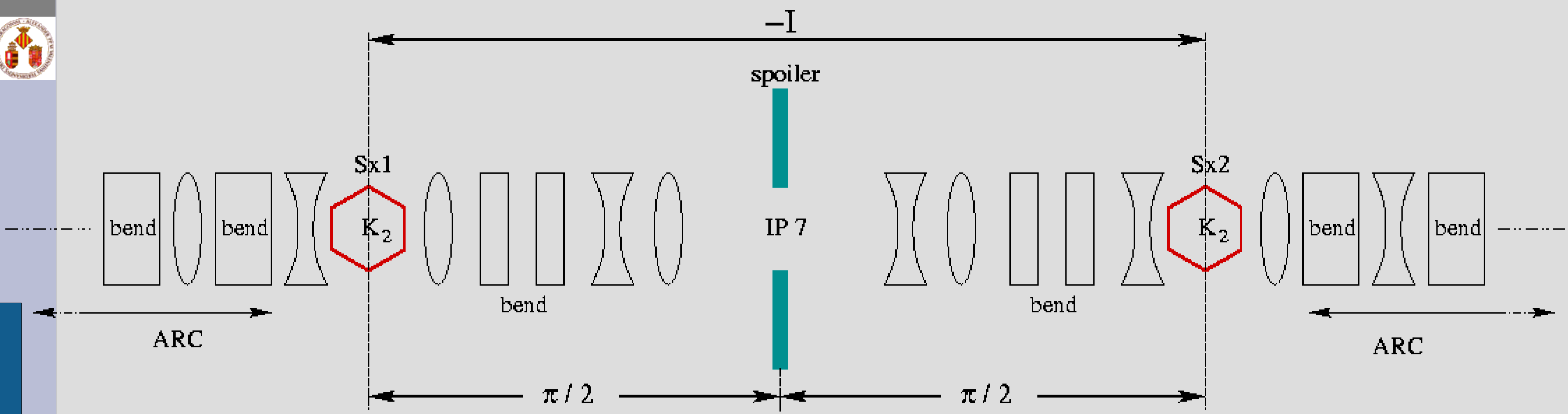
- A large aperture of the mechanical collimators is desired in order to avoid unacceptable high transverse resistive impedance from the collimators and to fulfill the requirements, with the corresponding loose of efficiency. A possible solution to this trade-off could be a non-linear collimation, as used in the linear colliders.
- LHC requirements on a CS are very similar to those of a linear collider operating at a center of mass energy of 1 TeV. Since our group has designed a similar system for CLIC, it thus *logical* to try and apply the same concept to the SLHC.

Non-linear CS: basic scheme

- Main idea: deflection in a non-linear element (skew-sextupole)

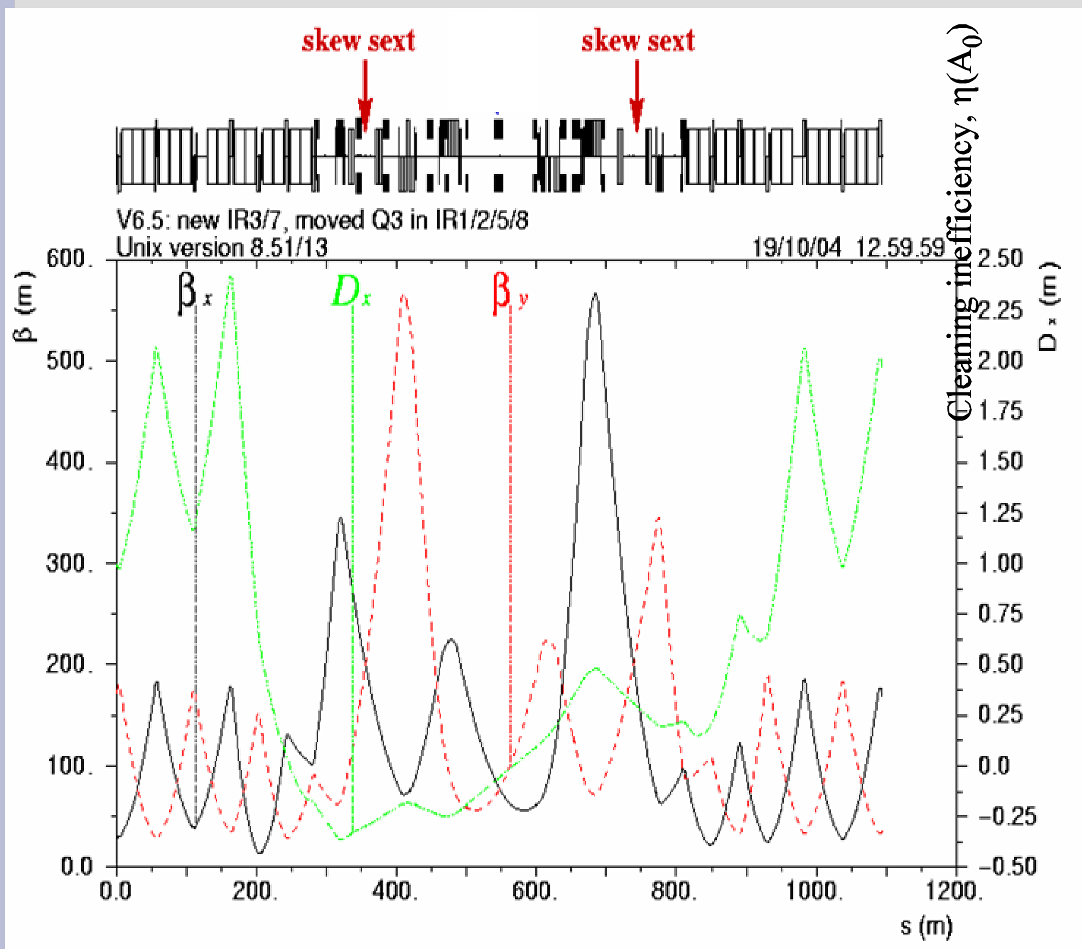


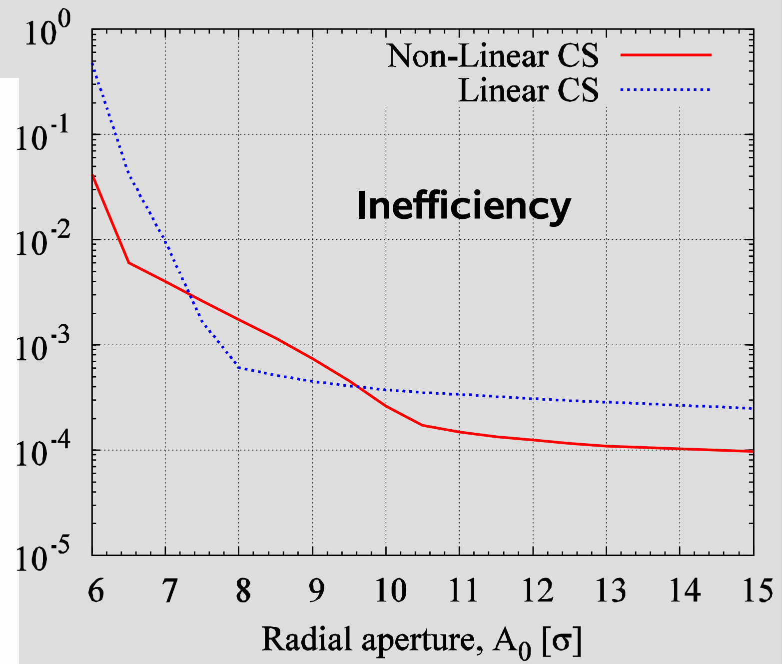
Betatron collimation: optics



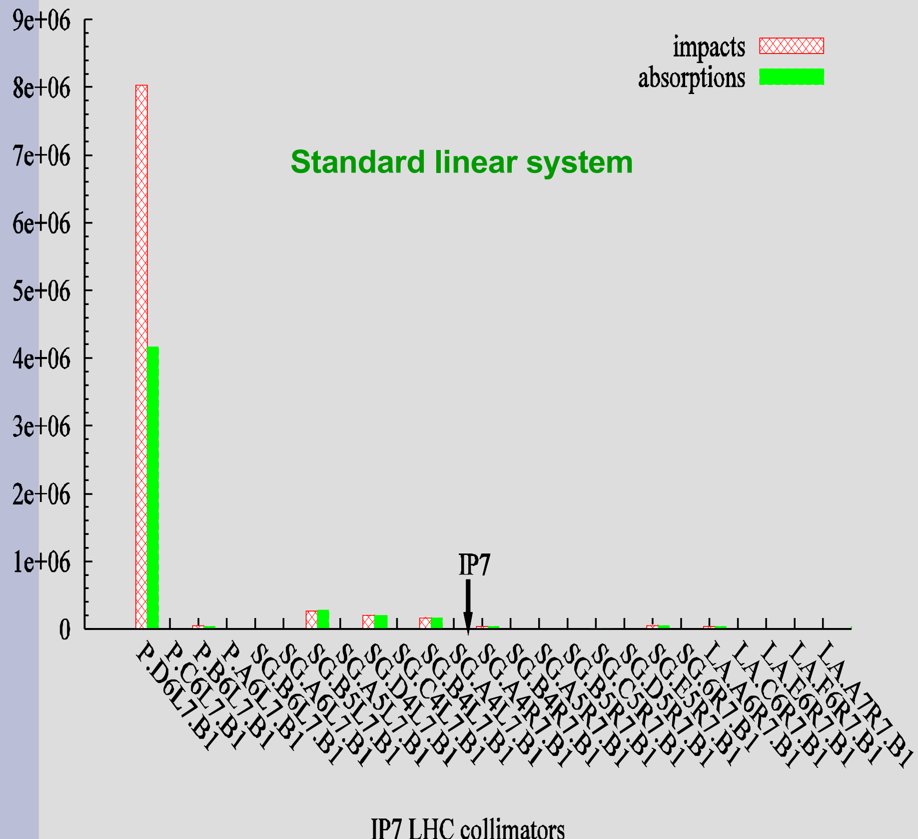
- The LHC momentum spread is 2 orders of magnitude smaller than in CLIC and cannot be exploited for widening the beam during collimation.
- Emittance growth from SR is insignificant and, therefore, does not constrain the design of the collimation system
- The geometric vertical emittance in about 3 orders of magnitude larger than in CLIC.

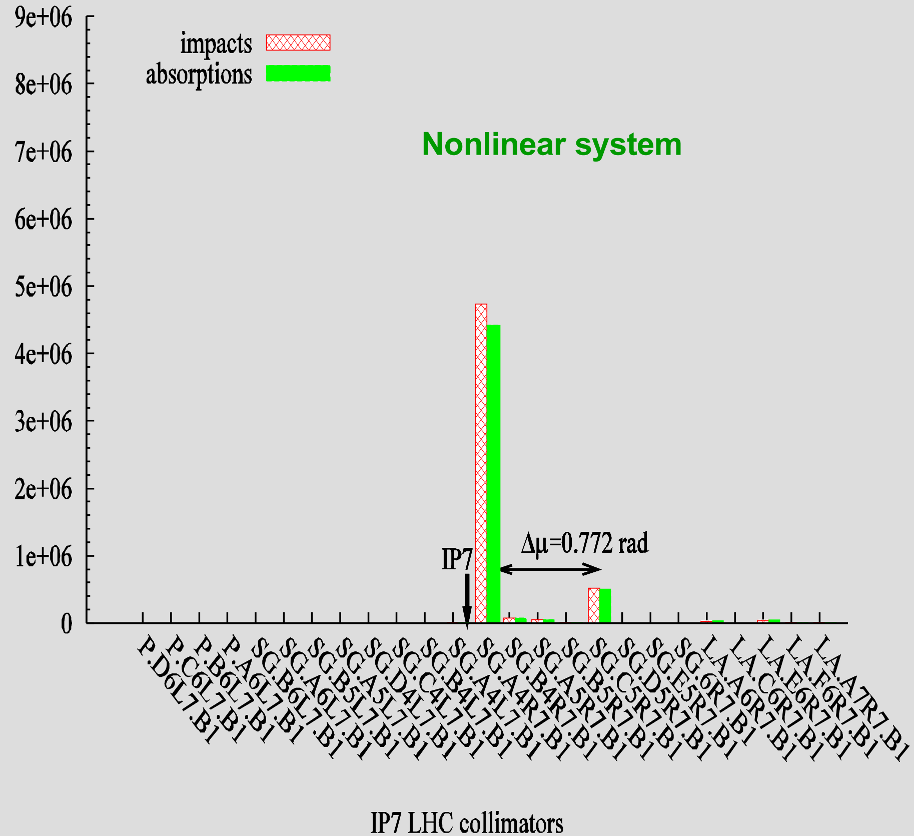
Betatron collimation





Betatron collimation





A non-linear CS for LHC

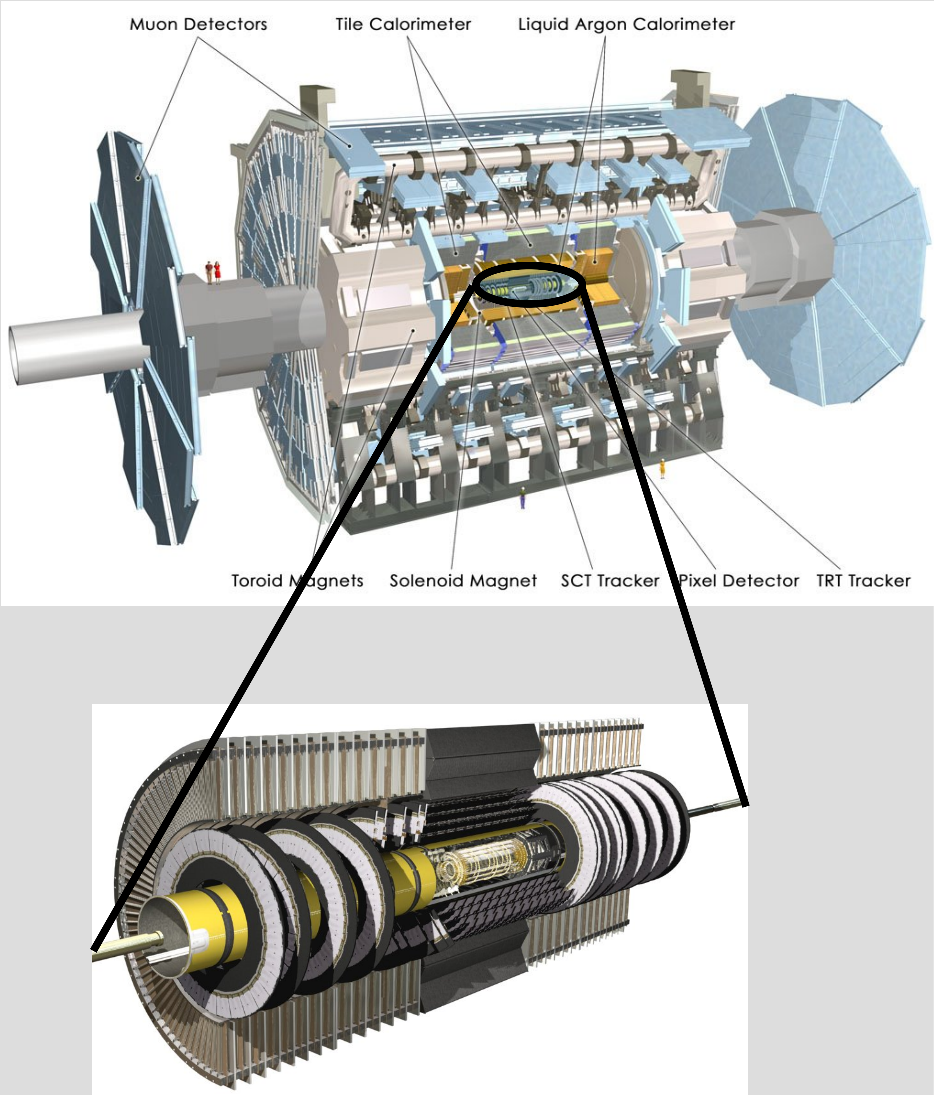
- Further work:
  - Optimize the collimator's gap to save in impedance budget
  - More multiparticle tracking studies

2-6 October 2006 CARE-HHH-APD Workshop:

Towards a Roadmap for the Upgrade of LHC and GSI Accelerator Complex IFIC-Valencia, Spain

SLHC

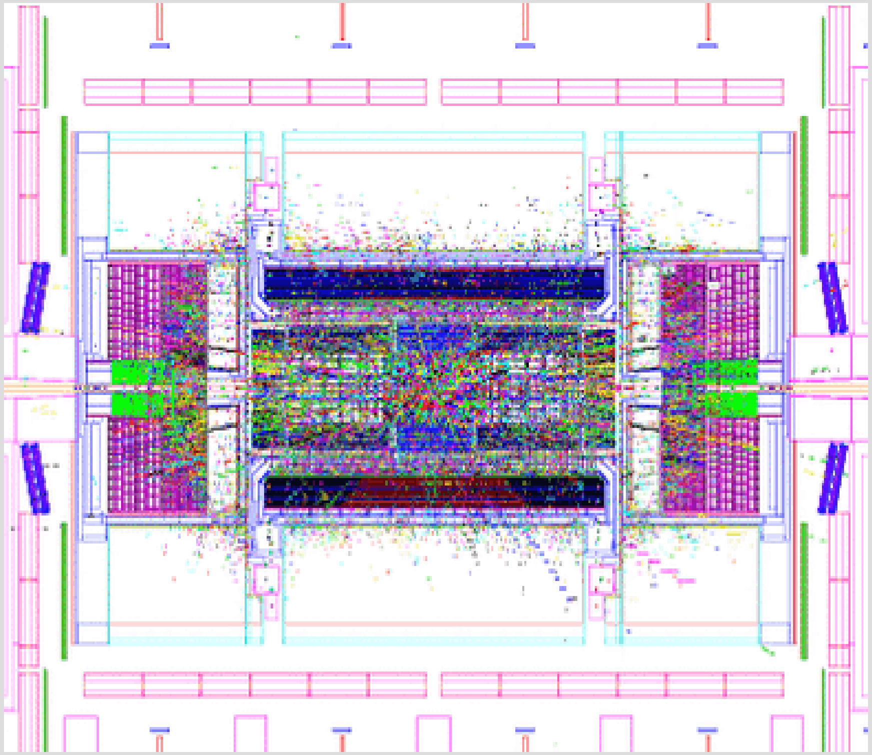
The ATLAS Tracker @ SLHC

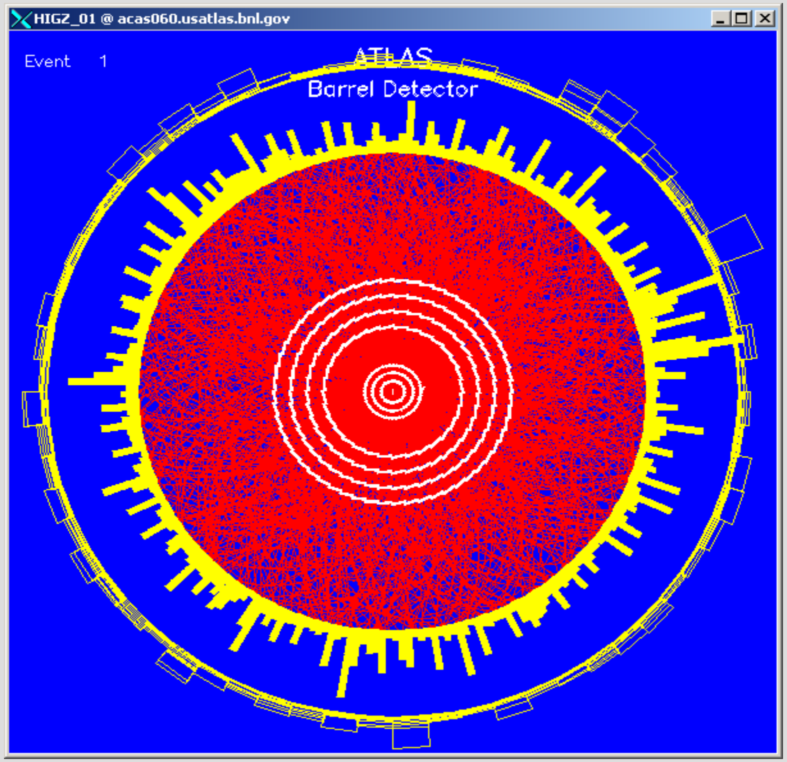


- We will have, w.r.t. LHC
  - L ~ 10^{35} $cm^{-2}s^{-1}$ (x10),
  - Bunch crossing: 10, 15, 25 [or 75] ns
  - An new all-silicon concept with about 200 m^2 of sensors
    - no TRT in sATLAS
  - The current ATLAS ID size, where the new tracker should fit.
  - The need to cope with higher (x10) **radiation levels and occupancies**
    - **RD50 collaboration** setup in 2002 to provide with the technology guidelines
  - ...less that 10 years to develop the concept, the technology and build it.
- Wish list
  - Same performance as LHC tracker
  - An affordable concept both in terms of cost an technology

Occupancy

- ~10000 charged particles in $|\eta| \leq 3.2$
- Mostly low p_T tracks
- Higher granularity required to maintain the occupancy
  - Area 5 times smaller at the same radius
  - Far more readout channels
  - Challenging power budget and services concepts.





Radiation levels

Radiation backgrounds can be just scaled up (x10) to a certain extent.

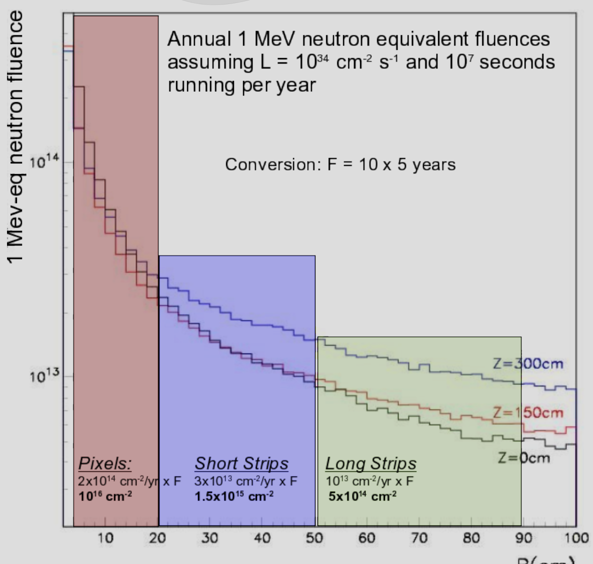
Some properties of the radiation field may be different, like the absence of the TRT which has a beneficial moderating property for neutrons.

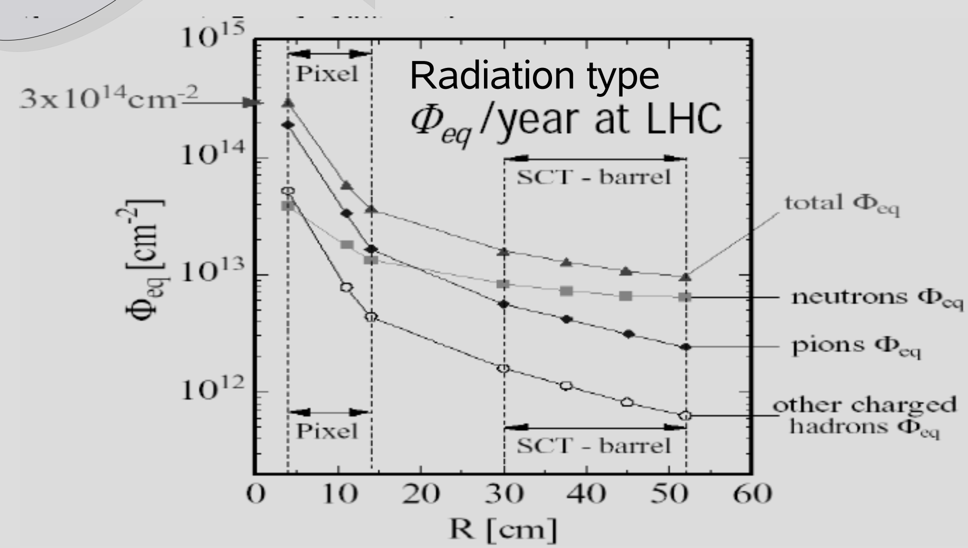
The tracker

Pixel-like:
R < 20 cm
$\Phi_{eq} \sim 10^{16}$ cm^{-2}
ch. had.: 90%

Short strips:
20 cm <R < 50 cm
$\Phi_{eq} \sim 1.5\times10^{15}$ cm^{-2}
mixture (n/c):
50-50%, 80-20%

Long Strips:
R > 50 cm
$\Phi_{eq} \sim 5\times10^{14}$ cm^{-2}
neutrons: 80%



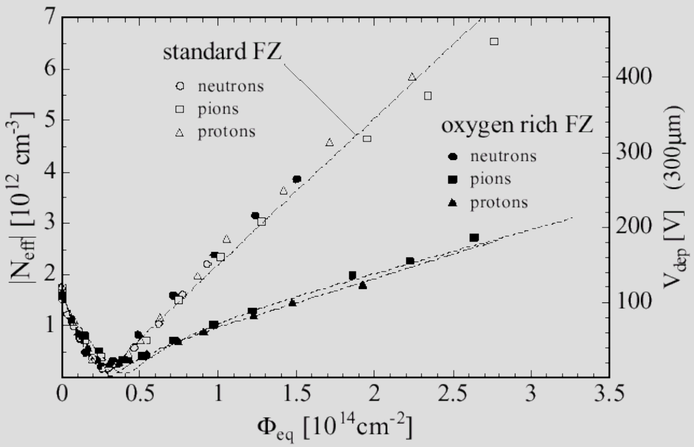


IFIC-CNM R&D project

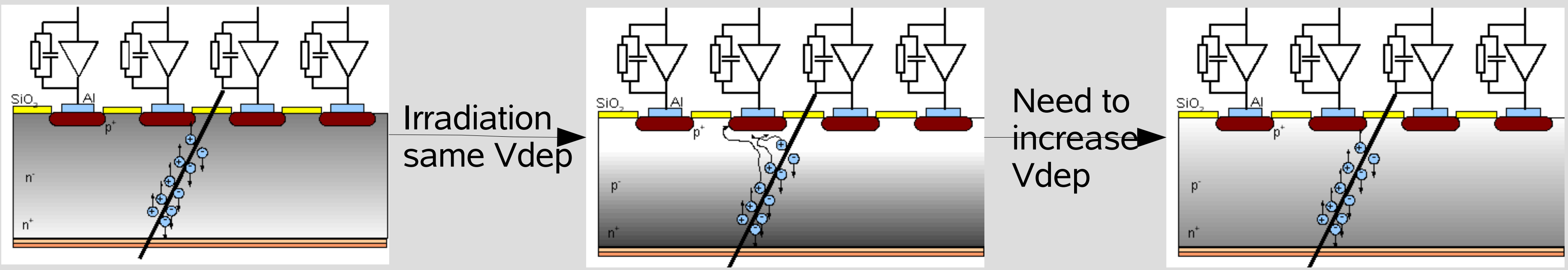
- IFIC and IMB-CNM have started a R&D project trying to address some of the issues:
  - R&D on sensors within the RD50 collaboration
    - Short strip n-in-p sensors
    - 3D silicon sensors for the pixel at low radii
  - Readout electronics
  - Module design

Irradiation in Silicon Strip Sensors

- ✔ Effects of irradiation:
  - ➔ Increase of leakage current
  - ➔ Trapping
  - ➔ Bulk type inverts to effectively p^- type
    - ➘ Full Depletion voltage increases



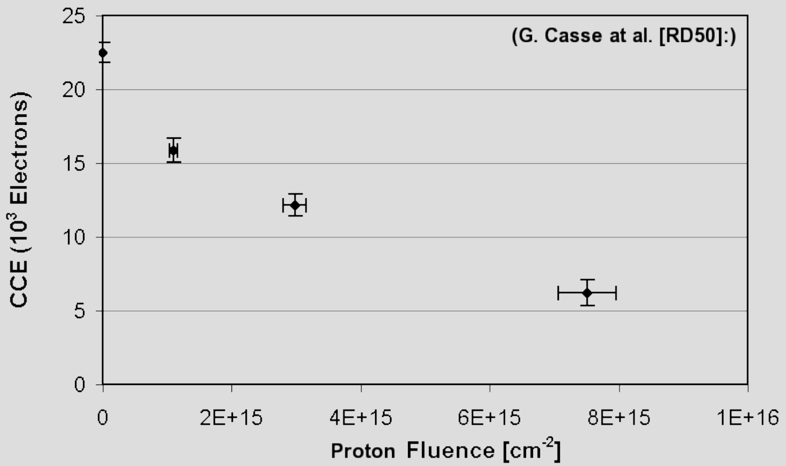
P in n detectors (p readout)



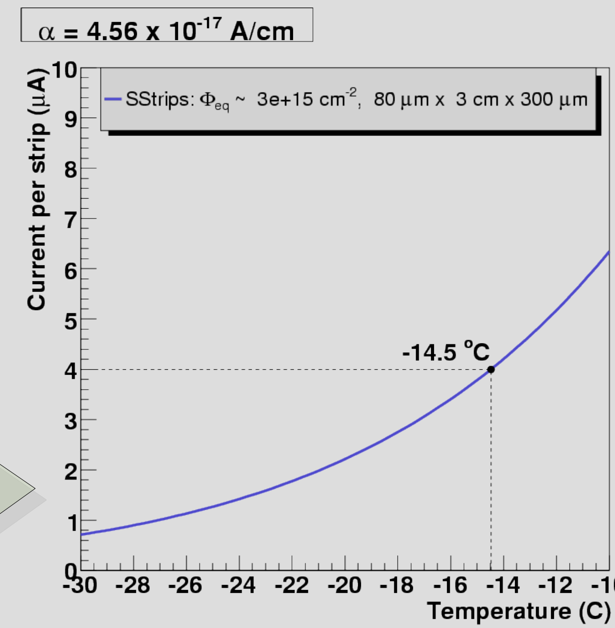
n readout (n implant on either p or n substrate)
The high electricfield is always on the electrode side.
Can run undepleted
Collect electrons, which are 3 times faster and, therefore, effect of trapping is smaller.

Short strips

- $\Phi_{eq} \approx 1.5 \times 10^{15}$ cm^{-2}
- Use short strips (3 cm) to maintain the same occupancy as in the SCT-
- n^+ readout seems necessary for the expected fluences.
  - Very promising results on -n-in-p strip detectors
    - ~7000e signal @ 7.5x10^{15}, with constant noise for all fluences.
    - ABCD-like noise with 4μA/strip is ~1200 e^-ENC, giving S/N>10

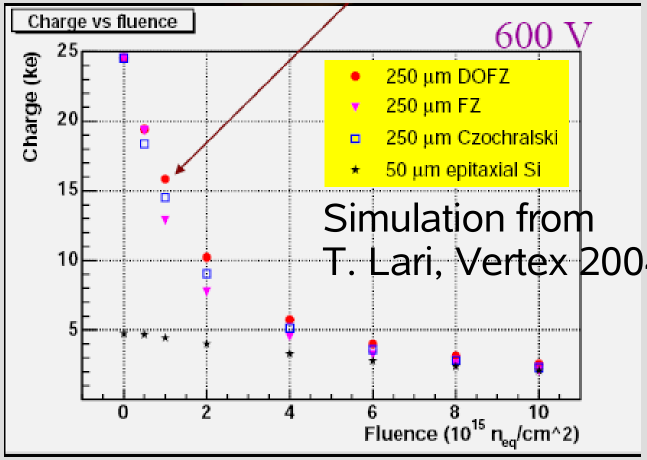


n^+p modules needed T ~ -25°C at highest dose
FE limit on current/strip (<4μA/strip) requires T <~ 15°C

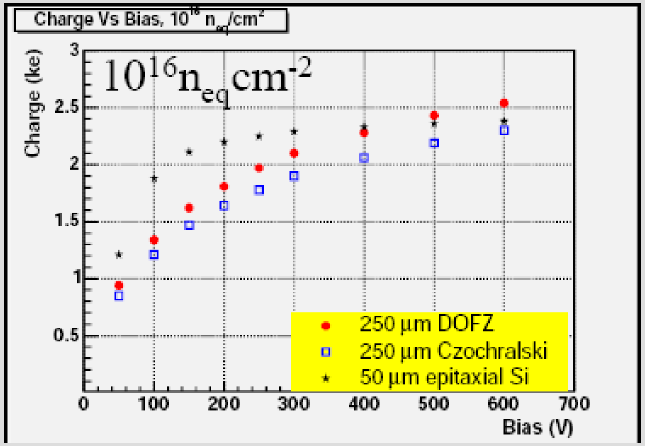


Pixels

- Tolerant to $\Phi_{eq} \approx 10^{15} - 10^{16}$ cm^{-2}
- NIEL dominated by charged hadrons: ~90 %
  - Oxigenation may help in a *standard* pixel concept
    - DOFZ, Cz and epi-Si are possible candidates
- Simulation shows that:
  - For R>10cm, $\Phi_{eq}<4\times10^{14}$ and Q>5000e
    - Could be handled with a S/T ~ 5
  - For R<10cm, the situation worsens and after $\Phi_{eq}\sim10^{16}$
    - Trapping dominates: Q~2300 e
    - Quite challenging: noise and threshold uniformity are a real issue...
    - We may consider either a new technology or a "removable" layer...

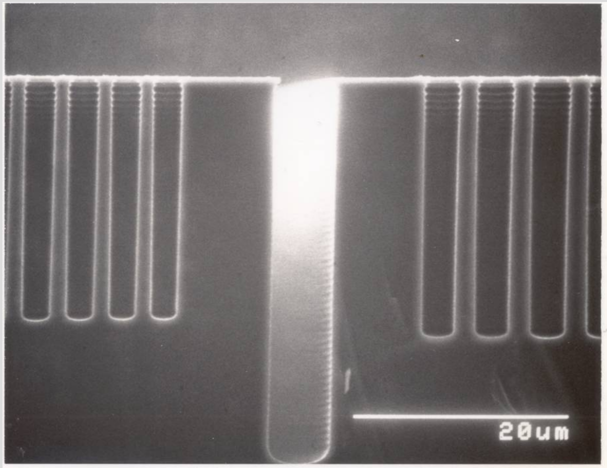


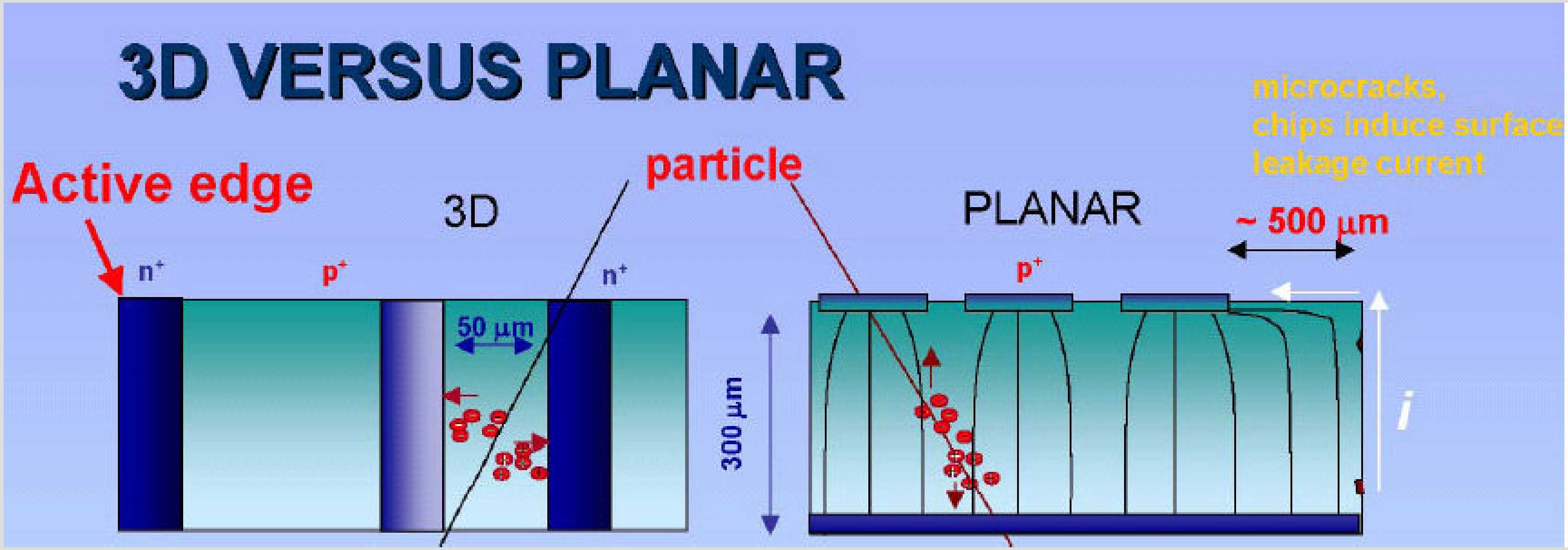
Simulation from
T. Lari, Vertex 2004



New concepts for pixels

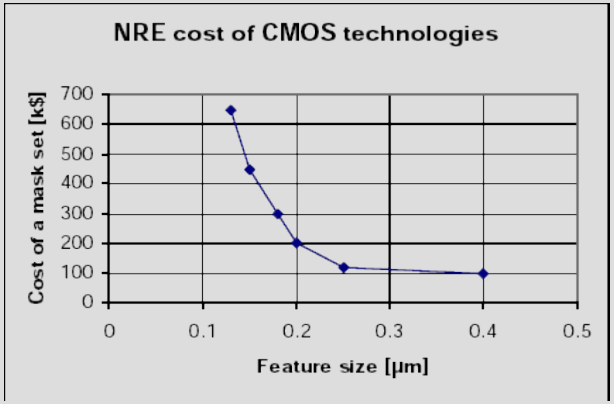
- 3D silicon pixel sensors are a promising technique to reduce the effect of trapping.
- Fabrication process fairly advanced and mastered by IMB-CNM
  - Not yet in the state of transferring to industry

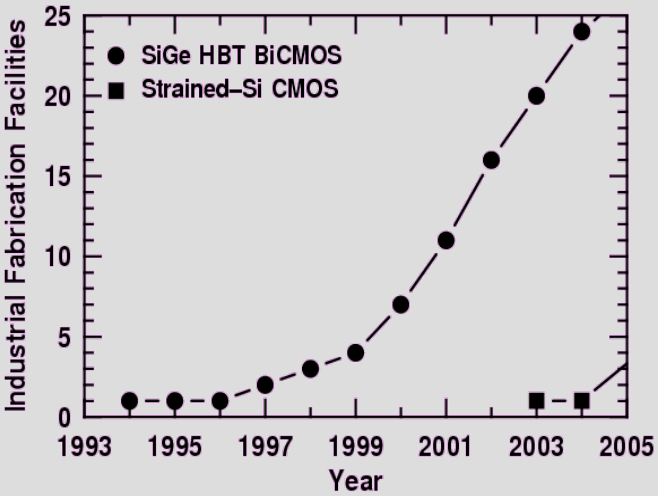




Readout Electronics

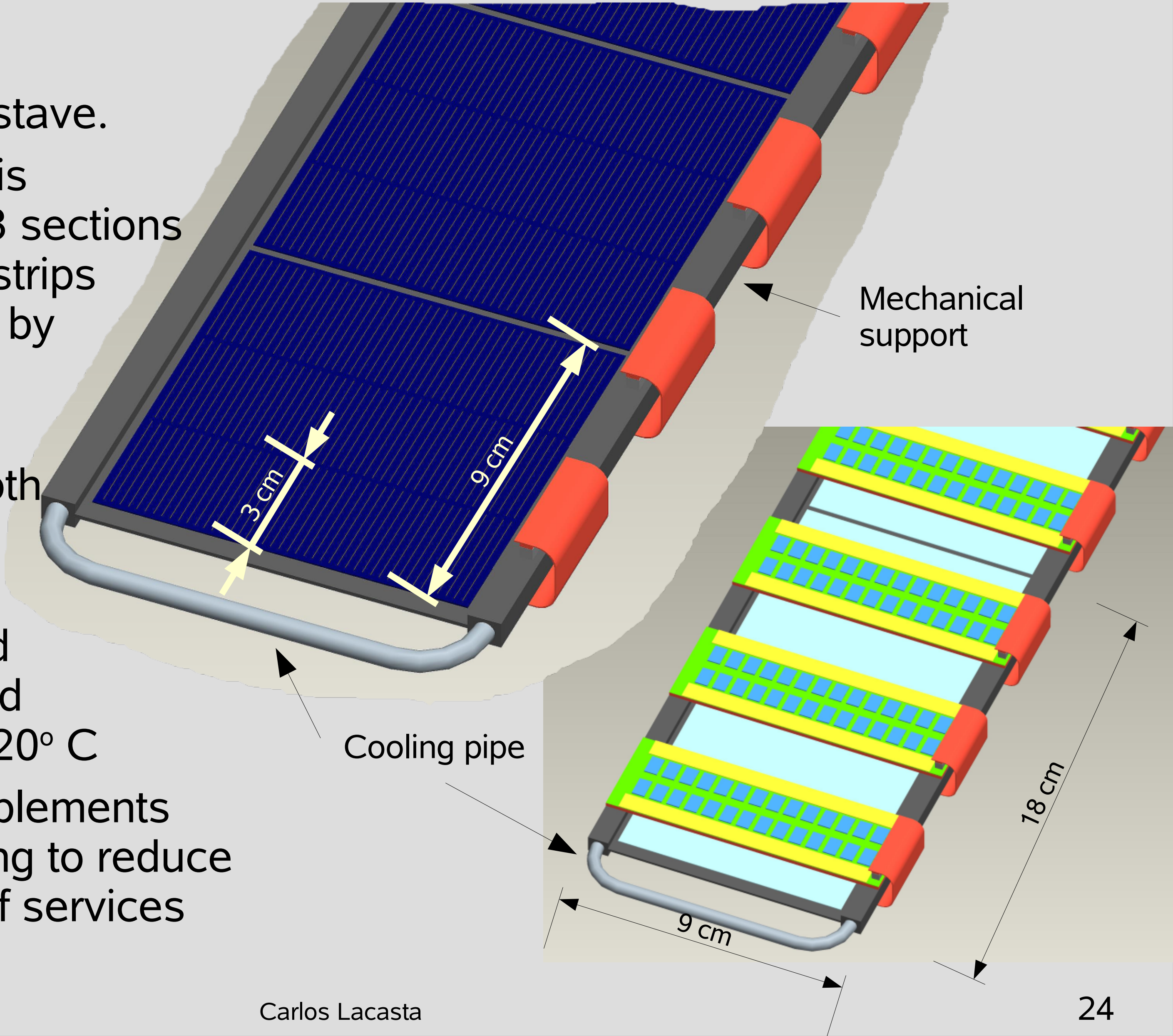
- Main issues are
  - Technology selection
    - From the past experience with DMILL, a commercial process is preferred
  - Power management
- Possible Technologies are
  - CMOS at very deep submicron technologies
    - First evaluations of 130 nm have shown good rad. hard. characteristics:
      - Linear transistors are promising,
      - Might not need enclosed transistors
      - Not latch-up observed
      - But higher SEU sensitivity
  - SiGe BiCMOS
    - Has the bipolar speed and low power for high capacitive loads at the front-end together with the CMOS for the back-end in the same ASIC.
    - Wireless communications have spawned many BiCMOS technologies with enhanced SiGe.
      - Need to validate those technologies for radiation hardness and power savings.





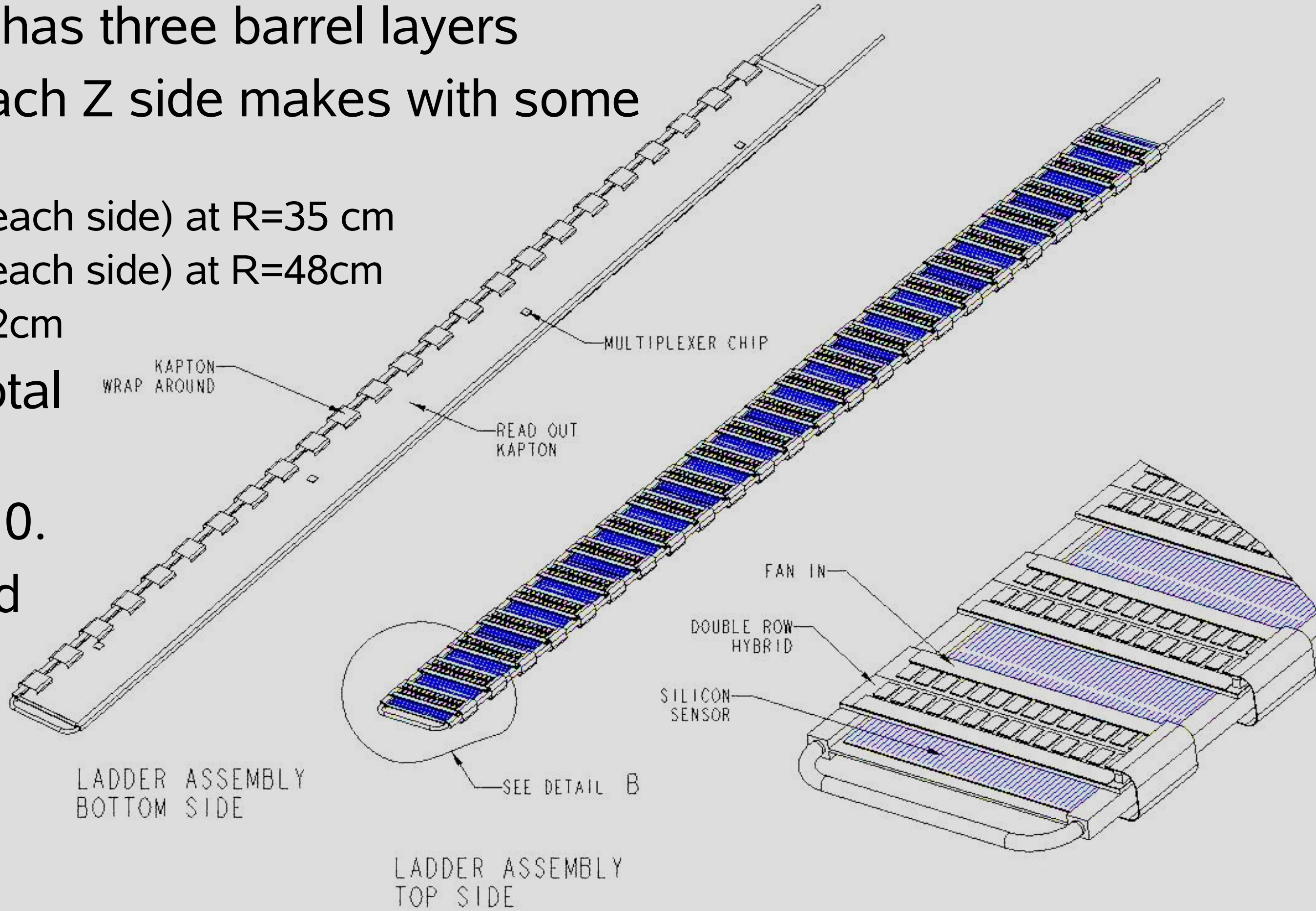
Super Module

- A 9 cm wide, 144 cm long stave.
- Each sensor is 9x9 cm with 3 sections of 3 cm long strips each readout by 14 ASICS
- The cooling runs along both sides of the stave.
- Sensors need to be operated at less than -20º C
- The stave implements serial powering to reduce the number of services required.



Super Module

- Planned layout has three barrel layers
- One layer on each Z side makes with some overlap
  - 60 staves (30 each side) at R=35 cm
  - 80 staves (40 each side) at R=48cm
  - 104 stave at 62cm
- 244 staves in total
- First prototype planned for 2010.
- Final details and layout provided by experience at LHC



Conclusion

- An upgrade of the LHC for an increase of luminosity by a factor 10 is currently being investigated.
- CERN will not take a firm decision until about 2009 after the first data from the LHC has been analyzed
- Timescale is around 2014
- It will require a brand new inner detector for ATLAS and CMS
  - R&D + production + installation can take as long as ~10 years
  - RD50 collaboration was set in place in 2002 for the investigation of new sensor technologies.
  - ATLAS has setup a steering group that is calling right now for R&D projects
  - R&D phase has already started...