Interface machine-détecteur: les enjeux de la détection à haute énergie et à haute luminosité

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Near Future Colliders

	LHC	HL LHC	ILC-baseline (staged CLIC)	TLEP (LEP3, superTristan, Chinese, Russian,USA)	VHE LHC
Energy	13-14 TeV	14 TeV	250, 500 GeV	240, 350 GeV	80-100 TeV
Luminosity	300 fb^{-1}	3000 fb^{-1}	250, 500 fb^{-1}	10000,1400fb^{-1}	3000 fb^{-1}
Size	27 km	27 km	31 km	80 km	80 km

See talk by Roy Aleksan

Fundamental or Composite Higgs

- Higgs composite bound state of fermions f
- Typical deviations from SM:

  $\delta\ g_{HVV} = 1 - (3\text{-}9)\%(1\ \text{TeV}\ /f)^2$

Physics reach Higgs couplings

	LHC	HL LHC	ILC-baseline (miniCLIC)	TLEP (superTristan, Chinese, Russian,USA)	VHE LHC
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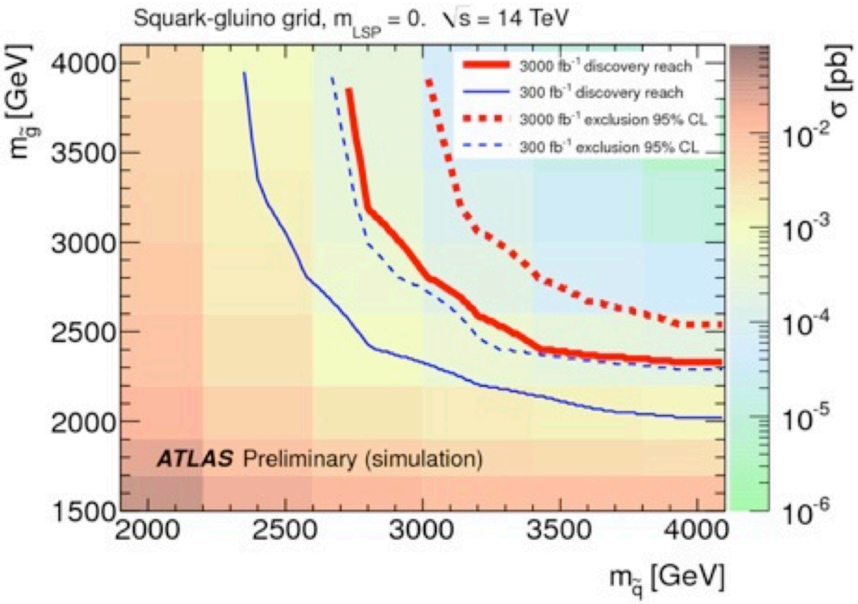
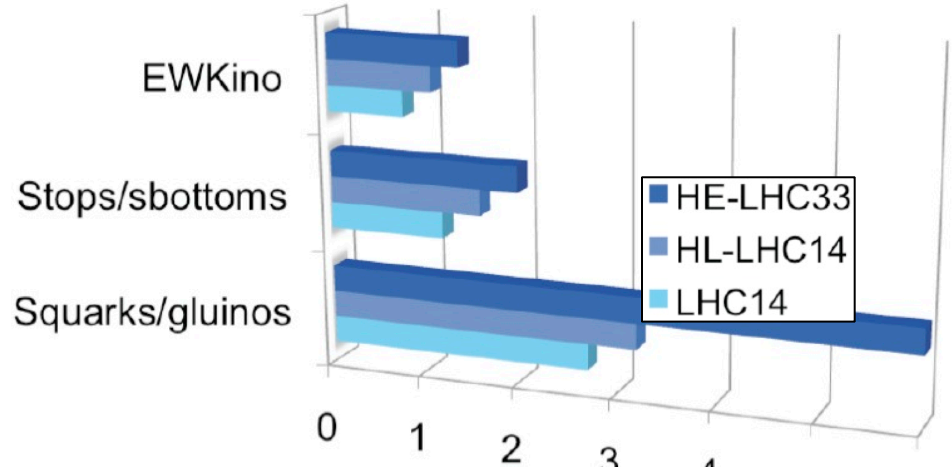
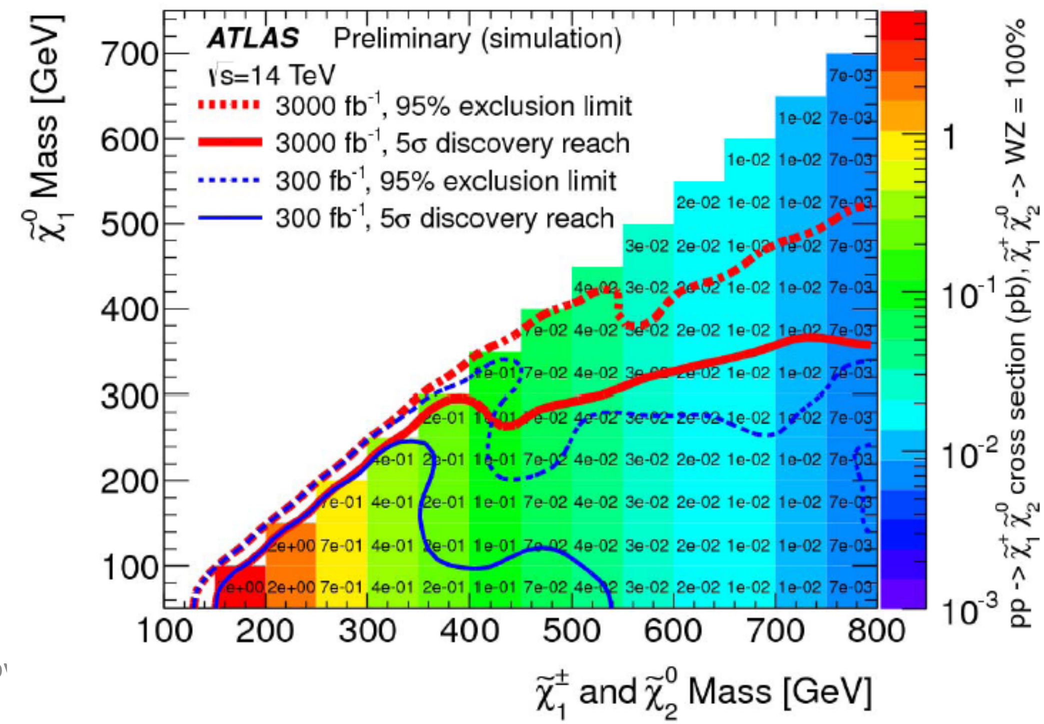
Luminosity	300 fb^{-1}	3000 fb^{-1}	250, 500 fb^{-1}	10000,1400fb^{-1}	3000 fb^{-1}
g_{HZZ}	13%	1-5%	1%	0.2%	
g_{HWW}	11%	1-5%	1%	0.25%	
g_{Hbb}	21%	3-11%	2%	0.22%	
$g_{H\tau\tau}$	13%	2-5%	1.8%	0.4%	
$g_{H\gamma\gamma}$	7%	2-5%	4%	1.4%	
$g_{H\mu\mu}$	<30%	<10%	16%	7%	
g_{Htt}	14%	4-8%	10%	30%	<1%
g_{HHH}	---	<30%	44% - 2000fb^{-1}	----	<5%

Physics reach







Physics reach New Physics

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Luminosity	300 fb^{-1}	3000 fb^{-1}	250, 500 fb^{-1}	10000,1400fb^{-1}	3000 fb^{-1}
Unitarity V_LV_L scattering ZZ resonance 500GeV g=1	2.4 σ	7.5 σ	-	-	Many σ
ZZ resonance 1TeV g=1.75	1.7 σ	5.5 σ	-	-	Many σ
Stop/Sbottom	1 TeV	1.4 TeV	-	-	>>2 TeV
Squarks/gluinos	2.6 TeV	3.1 TeV	-	-	>>6 TeV
Chargino	360 GeV	900 GeV	-	-	>> 1 TeV
Neutralino	100 GeV	300 GeV			>> 0.5 TeV

Physics reach New Physics

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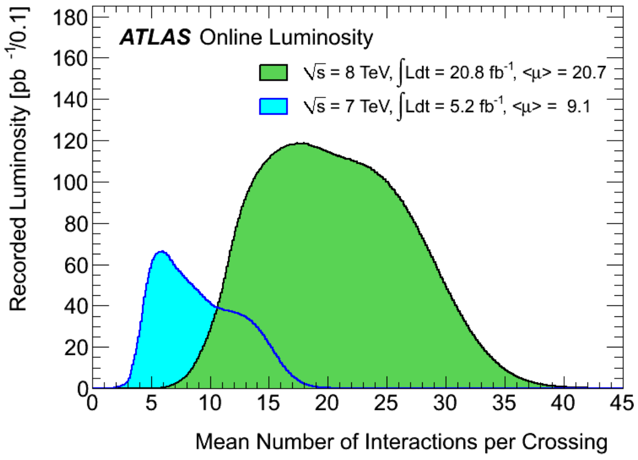
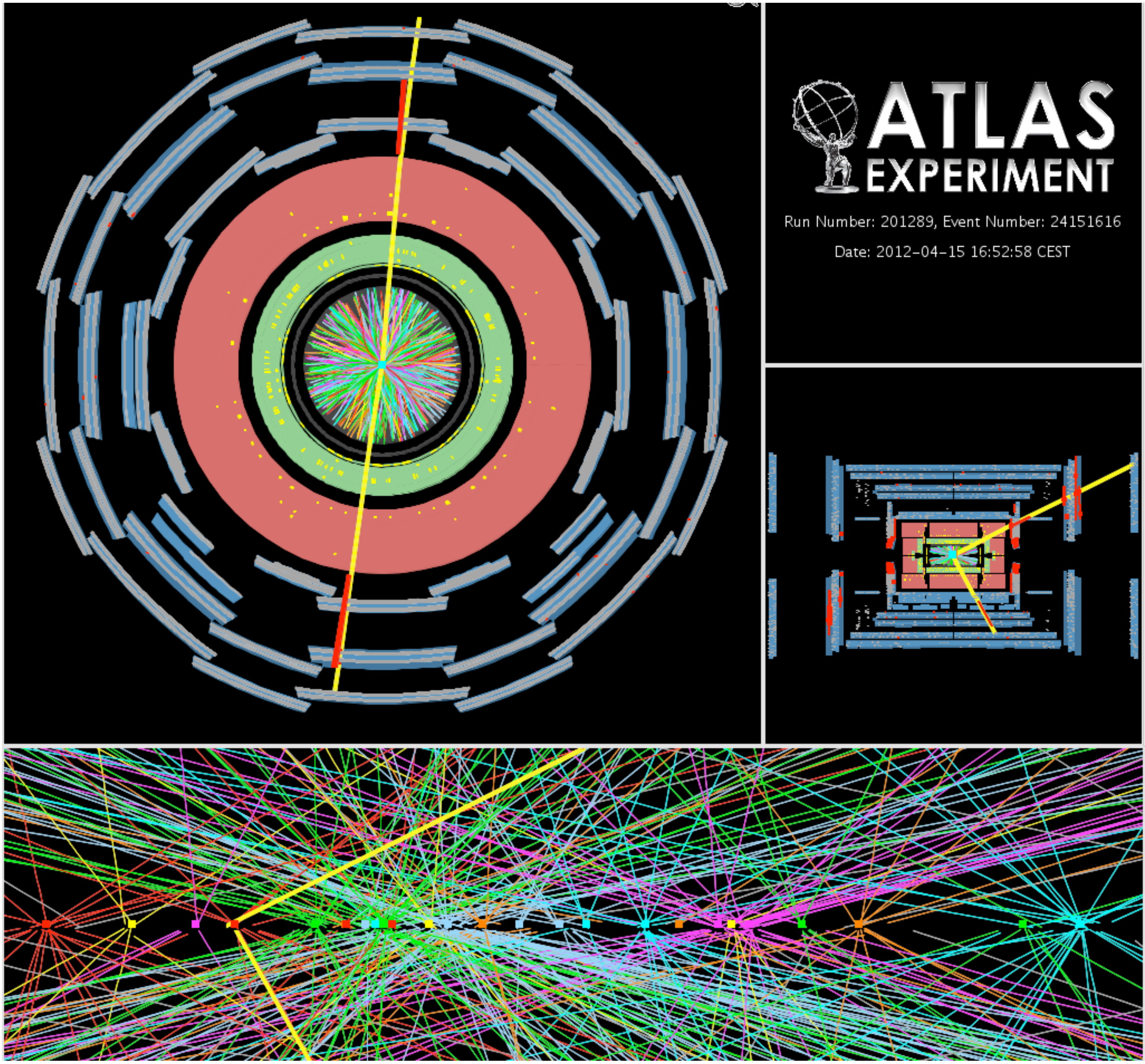
Luminosity	300 fb^{-1}	3000 fb^{-1}	250, 500 fb^{-1}	10000,1400fb^{-1}	3000 fb^{-1}
Extra dimension gluongKK->tt, lepton+jet	4.3TeV	6.7 TeV	-	-	>> 7 TeV
Z' topcolour->tt, lepton+jet	3.3 TeV	5.5 TeV	-	-	>> 6 TeV
Z' Sequential SM ->ee	6.5 TeV	7.8 TeV	-	-	>> 8 TeV
Z' Sequential SM ->μμ	6.4 TeV	7.6 TeV	-	-	>> 8 TeV

Main challenges of HL LHC

- New Linac4 under construction: improved beam brightness and emmitance
- Reduce beam size at IP (β^*=0.55m->0.15m): new quadrupole triplet with larger aperture 140T/m, 150 mm (13T, 8m)
- Protect SC dipoles from diffractive protons and electrical distribution feedboxes.
- Improve and level luminosity. SC RF Crab cavity for beam bunch rotation.
- At 8 TeV and 50ns BC LHC collider overpassed design parameters. To be confirmed at 13-14 TeV and 25 ns BC (more problems with UFO and electron cloud).
- Detector should stand very high radiation (up to 1000 MRad in inner pixels), high occupancy, high trigger rates and very high pile-up of 135 minimum bias events (200 with safety factors). Factor 5-10 more difficult than at nominal LHC.
- Conclusion: main challenge at HL LHC are the detectors capable to get the performance close to nominal LHC in the environment with high pile-up and high radiation dose

Challenging LHC Environment at L=7 10^{33}



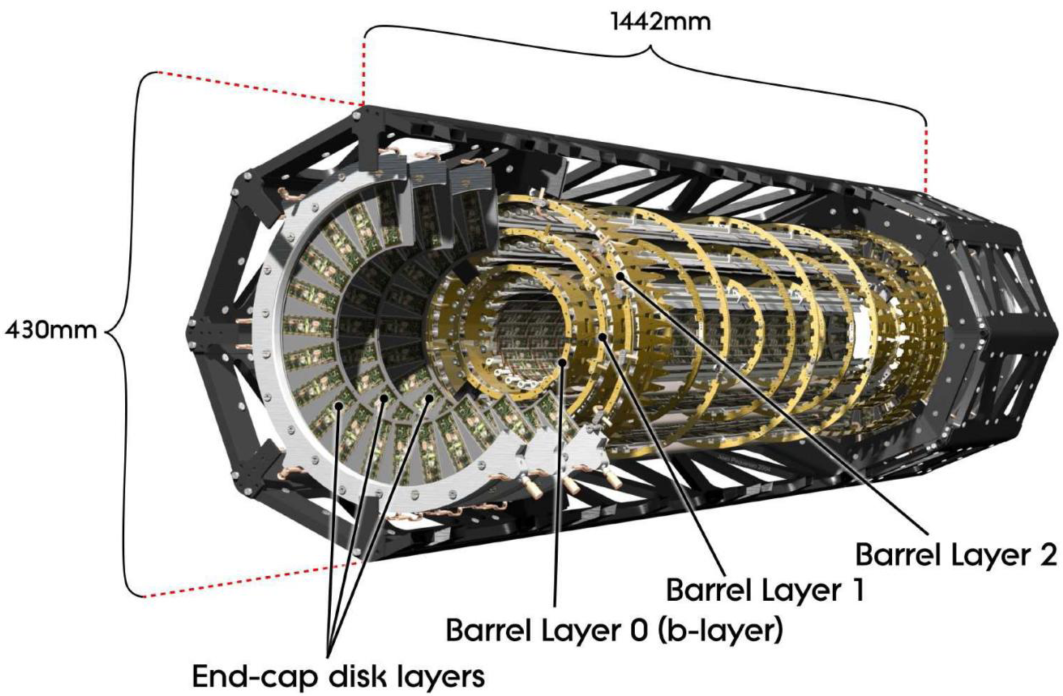


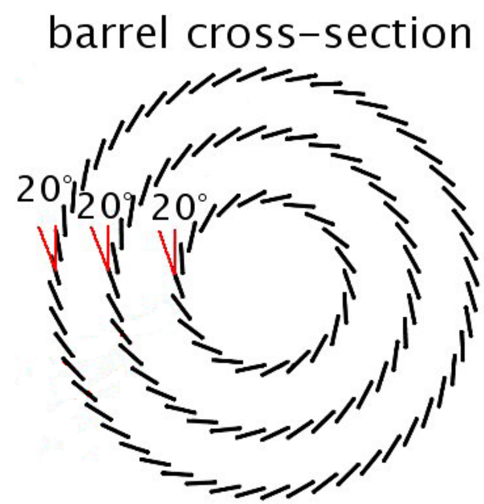
High pile-up due to 50 ns Bunch Crossing

Example: Z-boson with 25 reconstructed pile-up vertices

Current ATLAS Pixel Detector

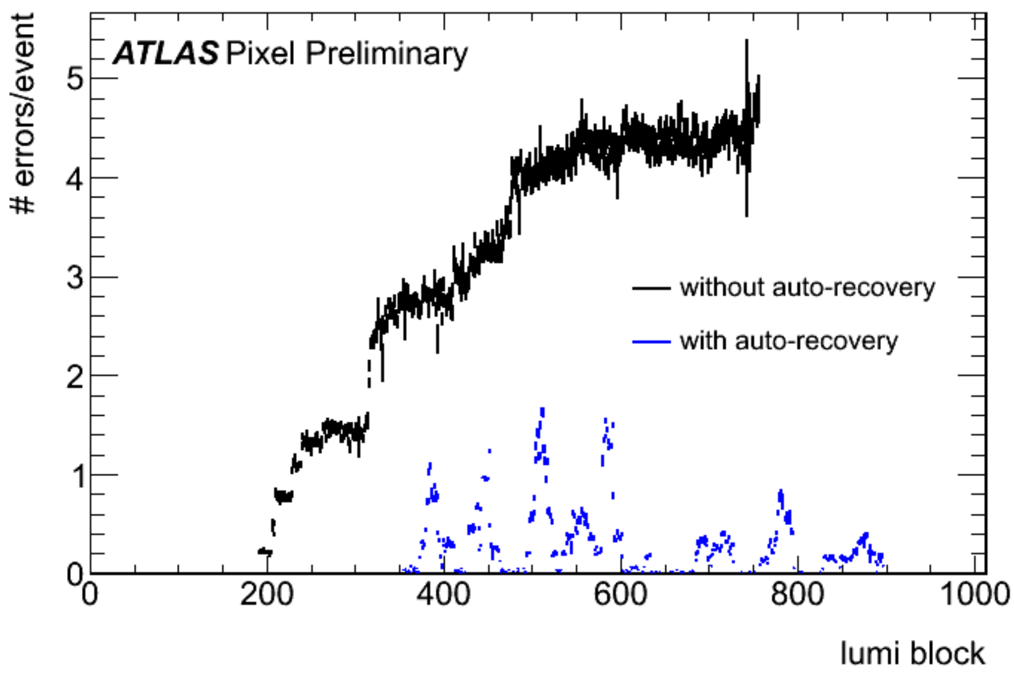
- 3 hit-system for $|\eta| < 2.5$, 3 barrel layers , 2 x 3 end-cap discs
- 1744 modules, 80M readout channels
- Innermost barrel b-layer(layer-0) at R=5 cm
- Radiation tolerance 50 MRad ($\sim 10^{15}\ n_{eq}\ cm^{-2}$)
- Design luminosity $L=1\ 10^{34}\ cm^{-2}\ s^{-1}$
- Temperature T=-5/-13 ^{o}C by evaporative (C3F8) cooling





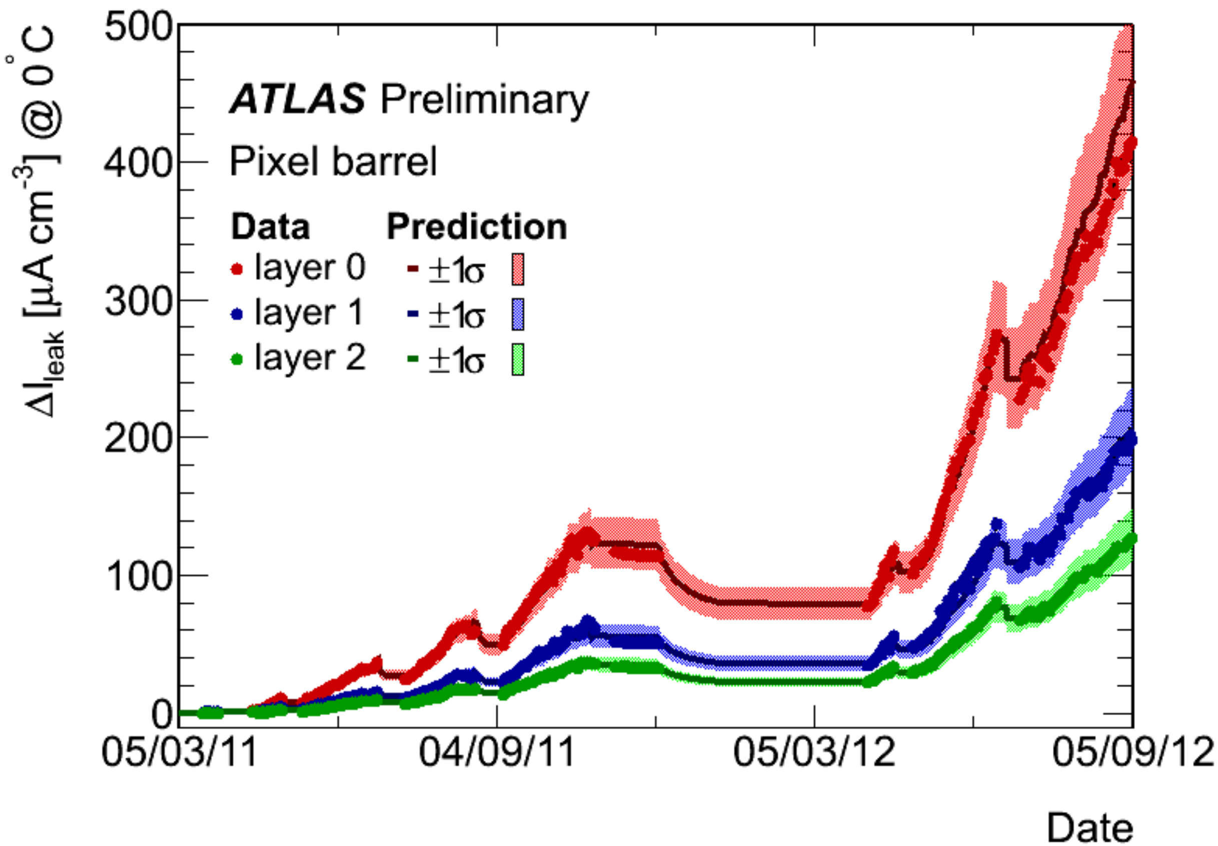
Readout Limitations

- number of module de-synchronizations at the beginning of each fill
- Today occupancy up to 2-4 10^{-4}

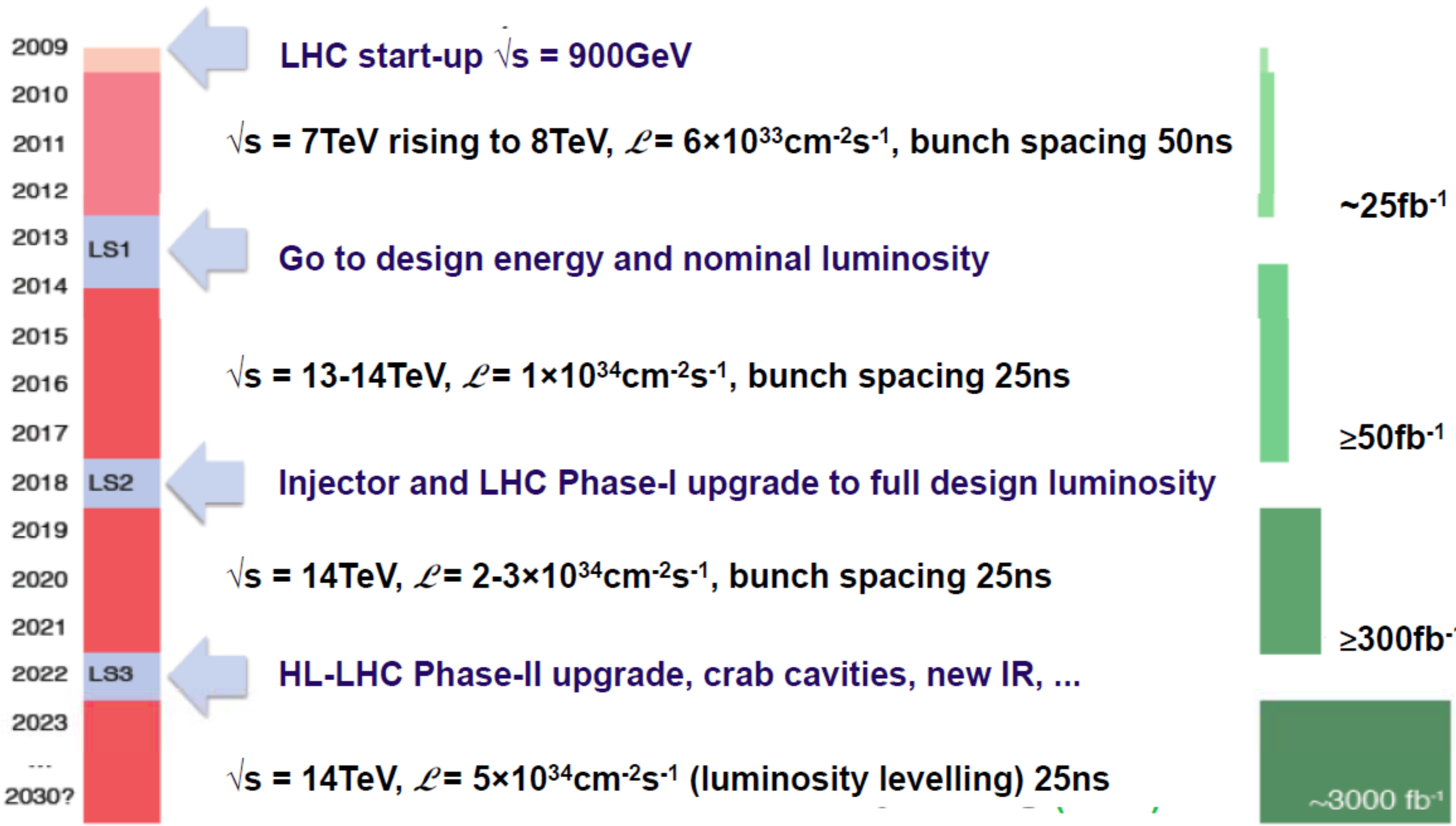


Radiation Induced Leakage Current

- Prediction scaled by 25% (b-layer 15%)
- Average per layer, normalized to T=0° C



LHC Plans



2009
2010
2011
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2013
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2015
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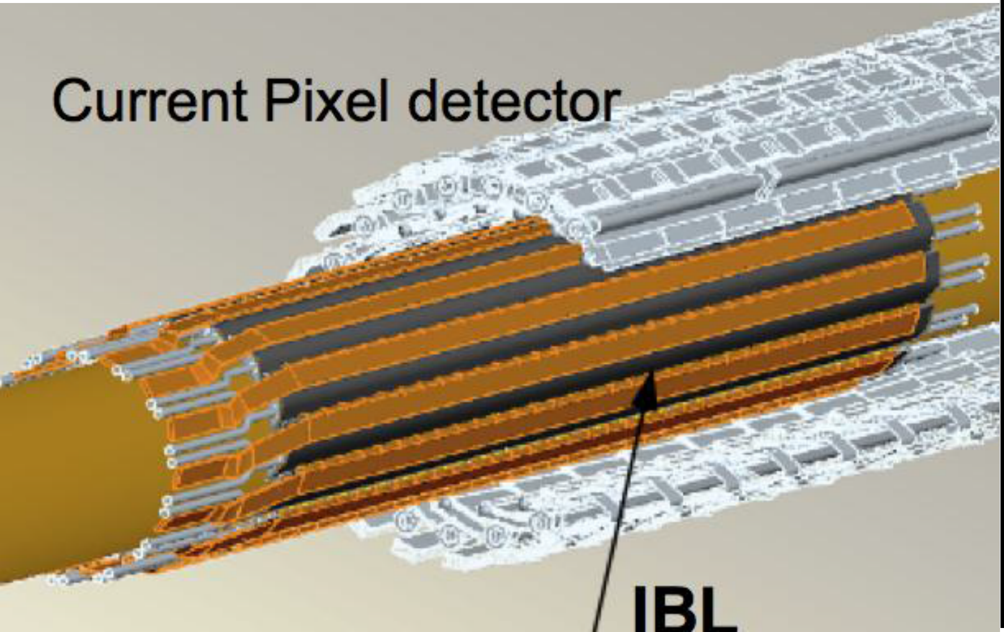
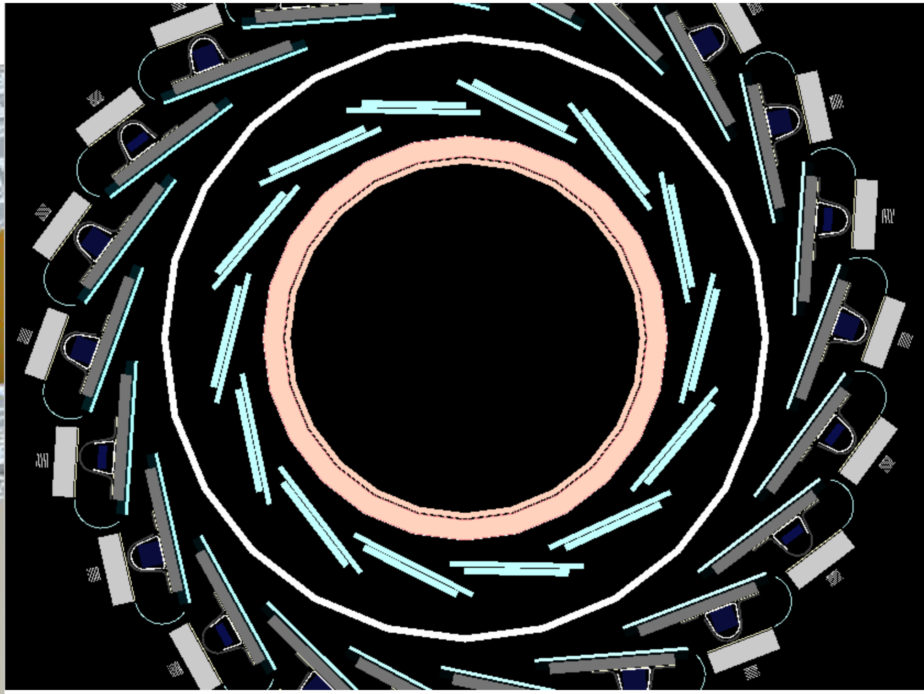
2017
2018
2019
2020
2021
2022
2023
...
2030?
LS1
LS2
LS3
LHC start-up √s = 900GeV
√s = 7TeV rising to 8TeV, $\mathcal{L}$= 6×10^33 cm^-2 s^-1, bunch spacing 50ns
Go to design energy and nominal luminosity
√s = 13-14TeV, $\mathcal{L}$= 1×10^34 cm^-2 s^-1, bunch spacing 25ns
Injector and LHC Phase-I upgrade to full design luminosity
√s = 14TeV, $\mathcal{L}$= 2-3×10^34 cm^-2 s^-1, bunch spacing 25ns
HL-LHC Phase-II upgrade, crab cavities, new IR, ...
√s = 14TeV, $\mathcal{L}$= 5×10^34 cm^-2 s^-1 (luminosity levelling) 25ns
~25fb^-1
≥50fb^-1
≥300fb^-1
~3000 fb^-1

Upgrades in 2013-2014

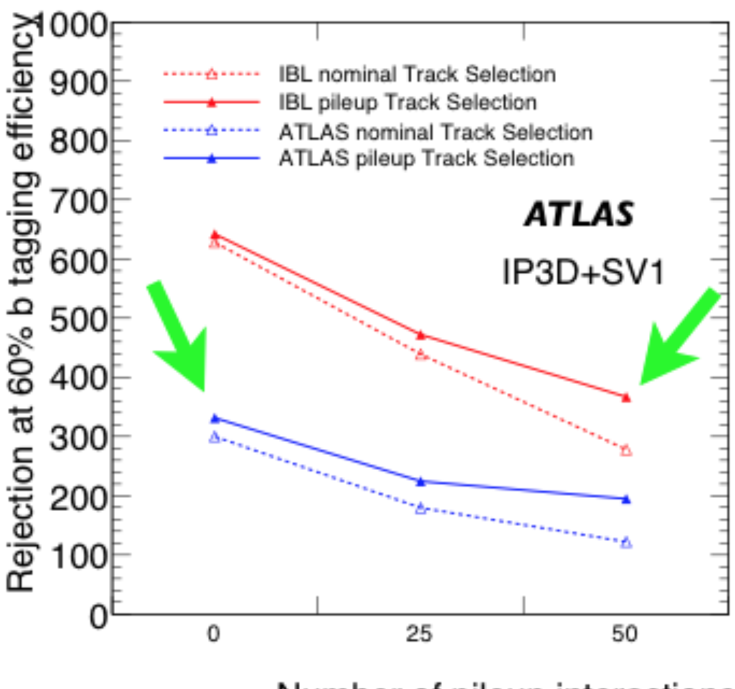
- Repair of inactive modules: bring pixel detector to the surface and repair up to 4% of links by installing new services (nSQP)
- Install fourth pixel layer: Insertable B-Layer (IBL) at R= 3.3 cm

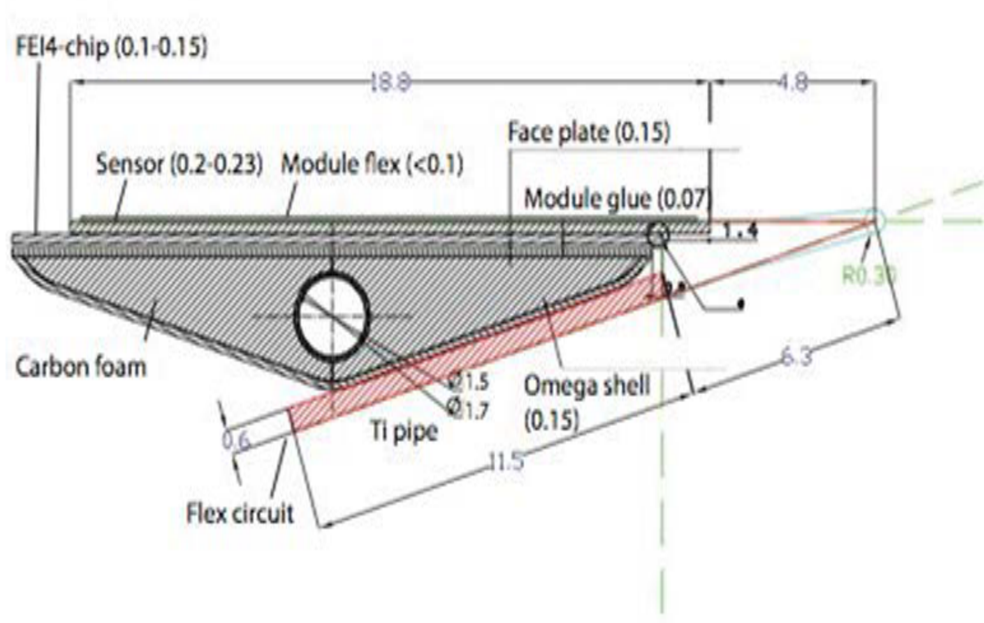




Insertable B-Layer

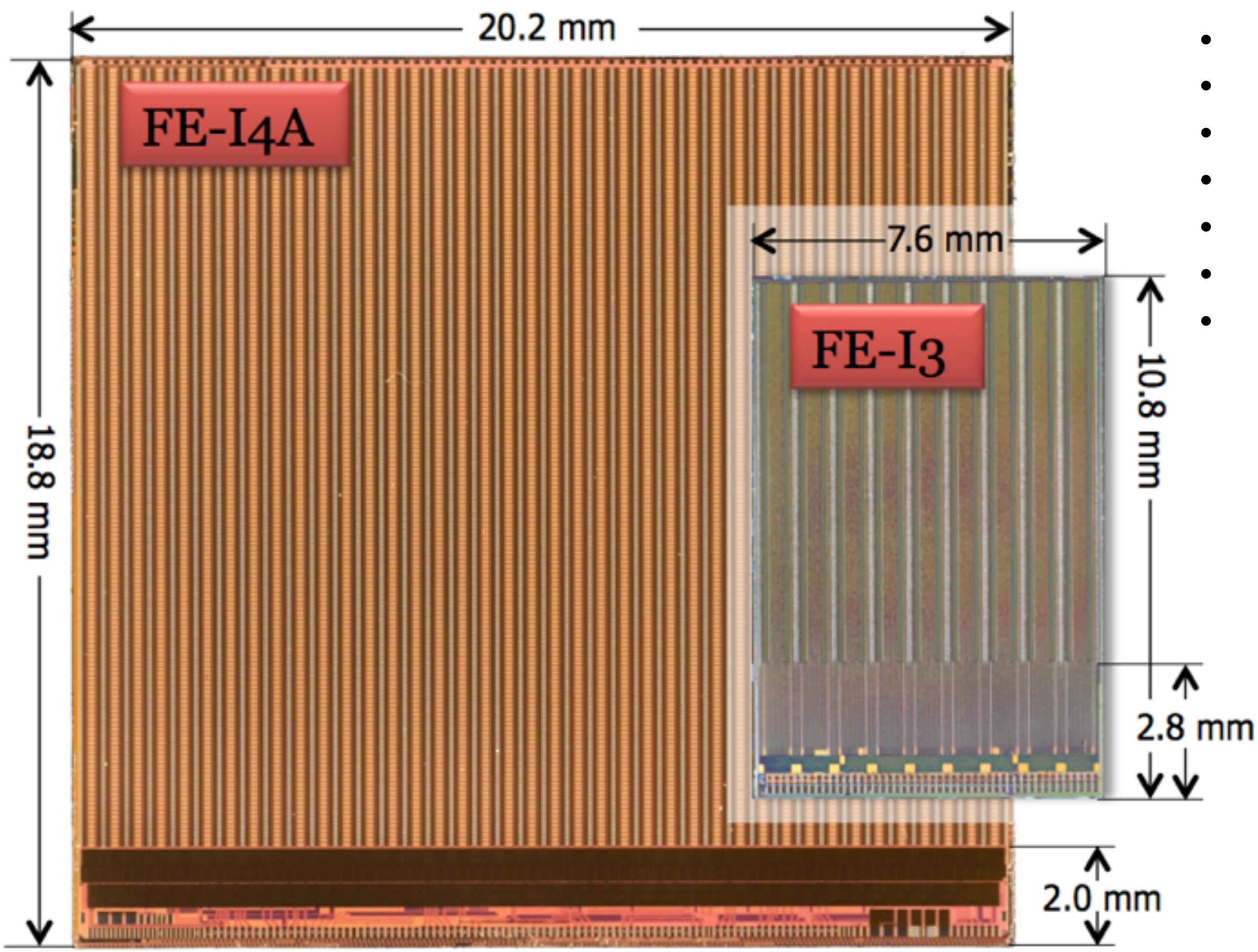
- Small beam pipe R=2.65 cm
- Small b-layer radius R=3.3 cm
- Low material budget of 1.9% X0
- Smaller pixel z-pitch of 250 µm
- Higher radiation dose tolerance of 250 Mrad
- Fourth hit in pixel tracking
- 14 staves with 32 FE-I4 chips per stave, CO_2 cooling with Ti pipes
- Planar n-in-n (two chips) and 3D n-in-p (one chip) sensor modules
  - See talks of Anna Macchiolo (planar) and Clara Nellist (3D)





FE-I4 Chip

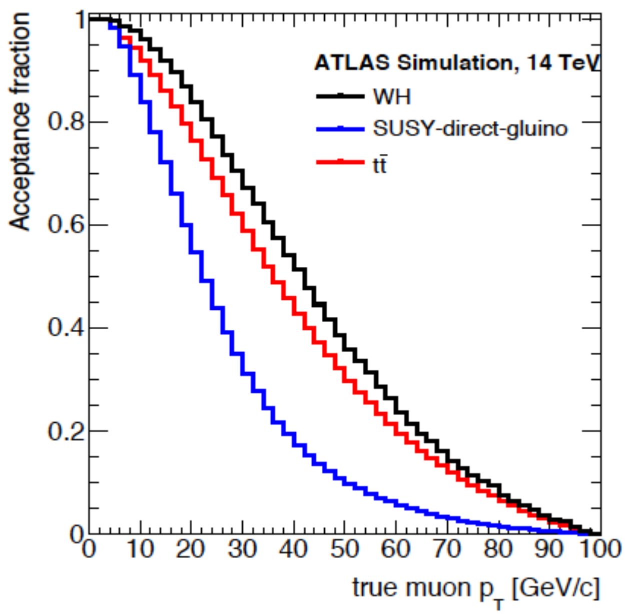
- Largest hybrid pixel chip in HEP 80 col x 336 rows of 50x250 µm pixels
- 26880 pixels, 80M transistors, up to 200 kHz trigger rate
- maximize active area, reduce bump bonding cost
- distributed memory, zero suppression inside pixels, small size periphery
- time-walk improved by digital treatment inside 4 pixel regions



- 130 nm CMOS
- 150 µm thickness
- Charge by 4 bits ToT
- 160 Mb/s readout
- Power 200 mW/cm^2
- Total dose tested up to 750 MRad
- SEU error cross-section $<10^{-15}$ cm^2

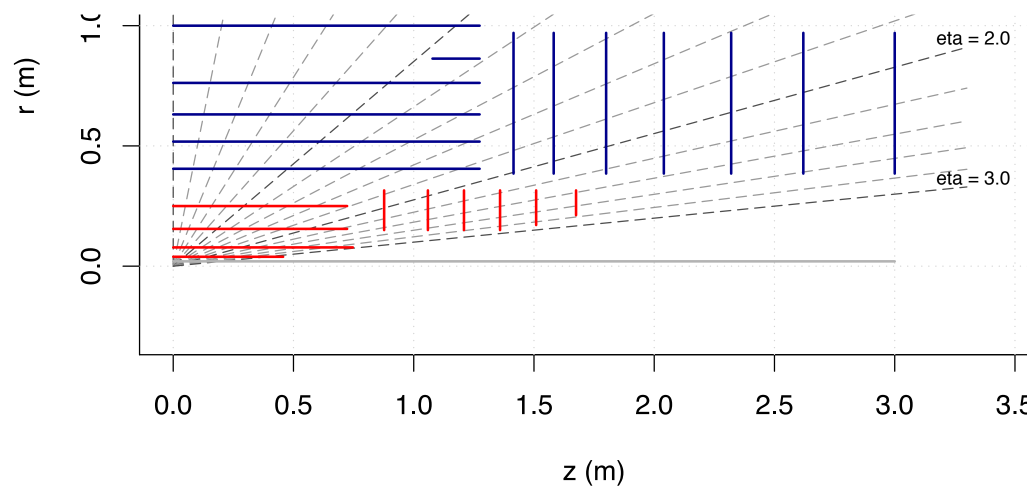
Phase-I Upgrade

- **ATLAS for a L1 rate upper limit of 100kHz until Phase-II, the impact of high luminosity is to require combinations of higher thresholds, pre-scaling, multi-object/topological triggering ATLAS target single lepton rates each ≤~20kHz at p_T ~20 GeV as indicative of required performance to retain good sensitivity to key channels (such as those including vector bosons, like WH, WW, searches etc)**
- **ATLAS: Early tracking information (from FTK) to be used to enhance HLT capabilities**
- **CMS: new 4 layer pixel system (250nm)**



Inner tracker Upgrade for HL LHC

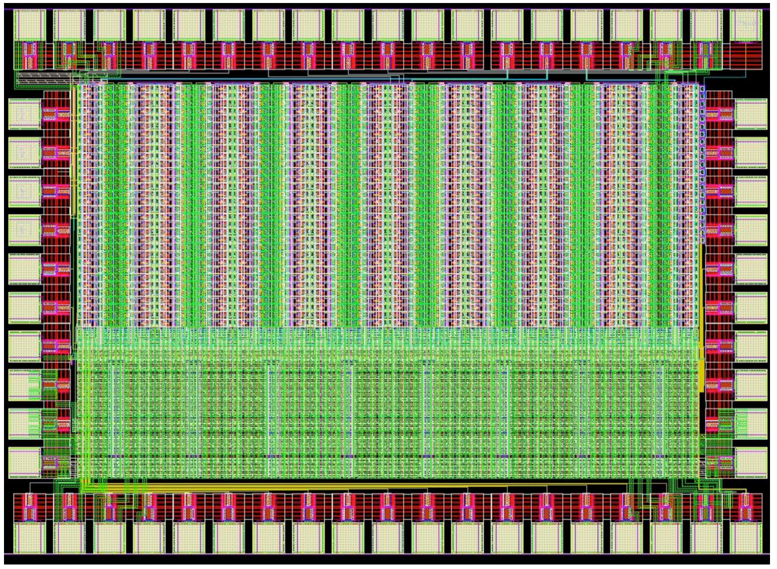
- Physics: Higgs (BR's, self coupling, spin, CP), WW/ZZ scattering, SUSY at ~1.5 TeV, 3-5 TeV W' and Z', quark substructure and unexpected
- New Tracker based on Pixels and Si strips
- LoI submitted to LHCC for running after Phase-II in 2023-2033 with 3000 fb^{-1}
- Option for early pixel upgrade in Phase-I from 2019, if needed by physics reach
- Leveled luminosity of 5 x 10^{34} cm^2 s^{-1}
- Total dose up to 700 MRads in Inner Pixels
- Classical LoI layout with four barrel pixel layers (400M pixels)



Pixel RD for HL LHC

- Pixel sensors: planar , 3D, diamond
- Pixel FE electronics: FE-I4-C, 65nm (RD53 ATLAS-CMS), 3D electronics
- Options with HV CMOS capacity coupled monolithic pixels
- Multi-chip modules, integrated flex/cables into staves
- Services: serial powering, Gigabit links
- Light mechanics/cooling (I-beam, flat, IBL-like), alternative layouts (conical, shingled)

65 nm pixel test chip



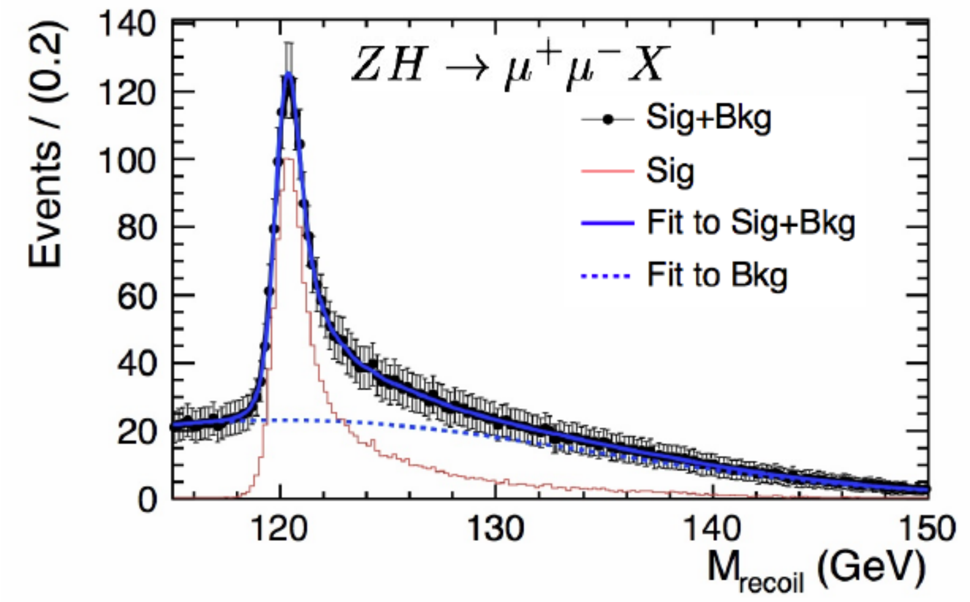
Phase-II Upgrades

- ATLAS: **A track trigger capability using a RoI driven L0 (400 kHz, 6μs latency)/L1(200kHz, 20μs latency)scheme, where the fast track finding within the RoIs could be implemented using FTK-like technologies. Exploit Gbits links.**
- **ATLAS:Electronics upgrades exploiting current trends in data transmission should allow calorimeter (LAr and TCAL) data from every beam-crossing to be shipped off-detector for more sophisticated trigger processing. Fine granularity and Electron-Track matching**
- **ATLAS:Upgrades to the muon electronics should similarly allow improved resolution at L1, significantly reducing the rates from mis-measured muon candidates.**
- **CMS: New Si tracker with L0 track triger using local Si strip track pT triggers. Very challenging project.**

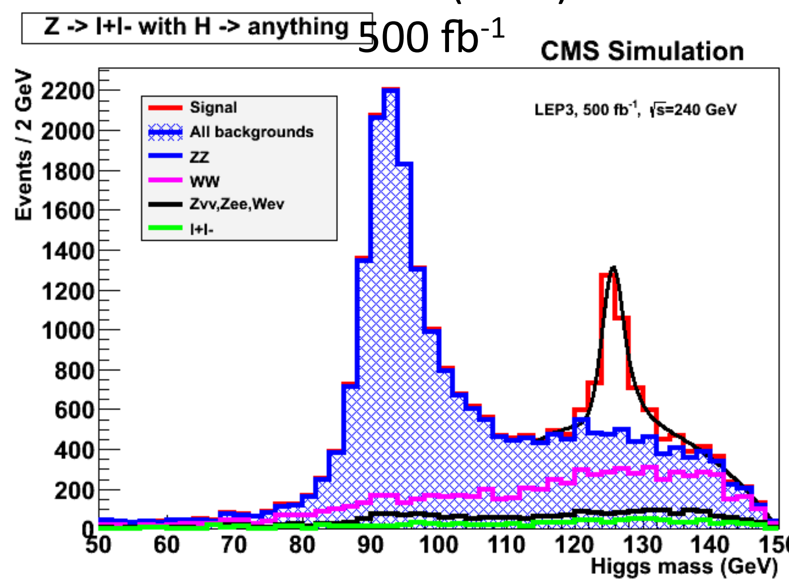
ILC and TLEP missing mass

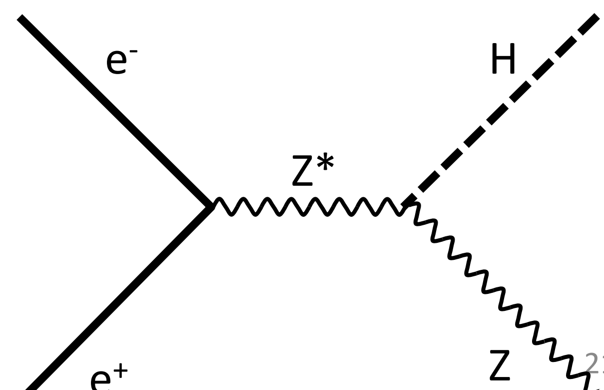
- Strong point:Missing mass with Z-tagging

ILC, high resolution detector



LEP3(TLEP) CMS
500 fb^{-1}



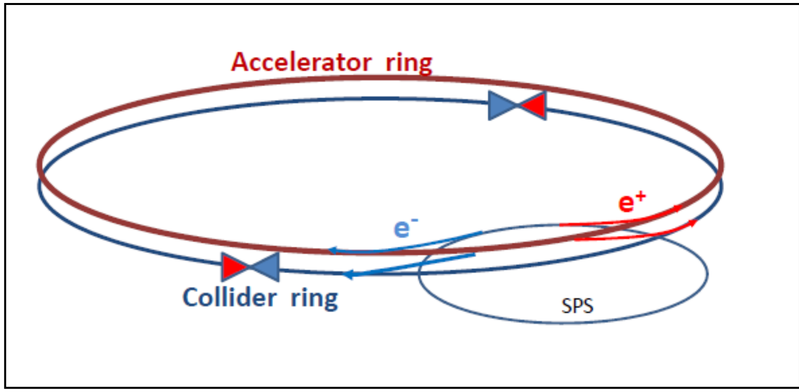


Main challenges of ILC

- Detector RD is mature, low repetition rate of 5Hz allow software triggering in between beam trains, pulsed power for low material tracker. Radiation tolerance and readout speed by orders of magnitude smaller than at HL LHC.
- Superconductive cavities: mature RD, main challenge in large scale production. Good experience with XFEL.
- Real challenge is nano beam size (σ_y ~ 6 nm) with 2×10^{10} e / bunch. If not, low luminosity …
- ATF2 at KEK has a goal 37 nm at 1.28 GeV since 2009. March 2013 achieved 65 nm.
- Conclusion: main challenge in the collider, not detector

Main challenges of TLEP

- Detector RD benefits from ILC. Radiation tolerence and readout speed by orders of magnitude smaller than at HL LHC.
- Beam lifetime only 16 min. Need efficient top-up injector. Tow rings: accelerating and colliding.
- Beam size (σ_y ~ 140 nm) is much more relaxed that at ILC 6 nm, but 30 times smaller than at LEP2
- Conclusion: main challenge is in the collider, not detector



Two dangers to be avoided

- High performance detector with excellent identification and resolution, design collision energy, but low luminosity. Result: low physics impact due to low statistics.
- Design collision energy, high luminosity, but severe detector limitations in triggering, identification, background suppression. Result: low physics impact due to low efficiency and high backgrounds.
- Moral: accelerator RD and detector RD should be well balanced to achieve optimal physics results. Our aim is not to construct Accelerator "Rolls-Rolls" or Detector "Ferrari" , but optimal machine-detector interface to achieve maximum physics reach.

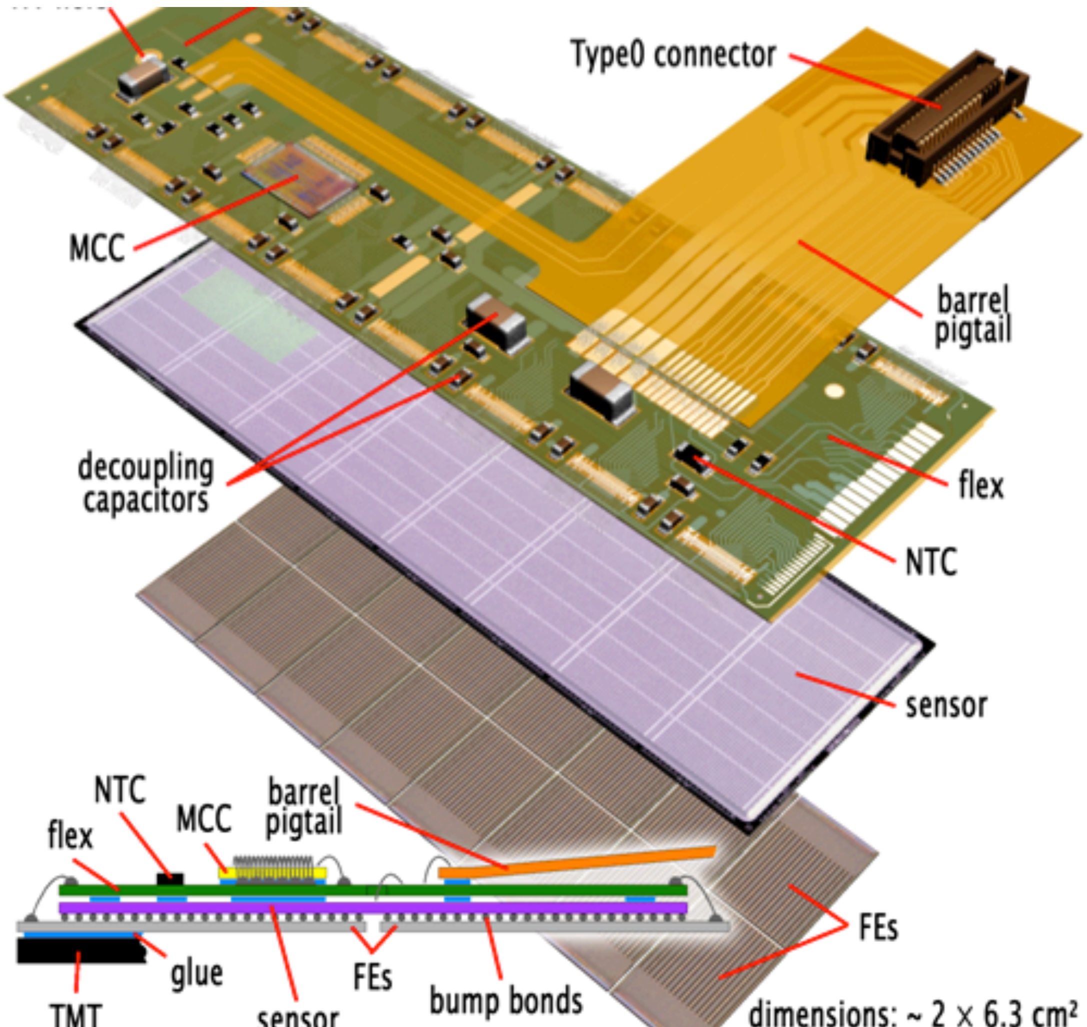
Conclusions

- European Strategy: highest priority for HL LHC
- LHC Phase-0 upgrade 2013-2014. ATLAS fourth pixel layer IBL.
- ATLAS submitted LoI HL LHC Upgrade Phase-I (2018)and Phase-II (2023). TDRs in preparation.
- CMS preparing Upgrade Proposal for LHCC
- ILR TDR presented in June 2013
- TLEP studies accelerates in 2013, VHE_LHC studies will start in 2014
- Urgent priority: continue intensive detector RD for HL LHC and accelerator RD for electron positron colliders (ILR,TLEP) and VHE LHC

Backup material

Pixel Module

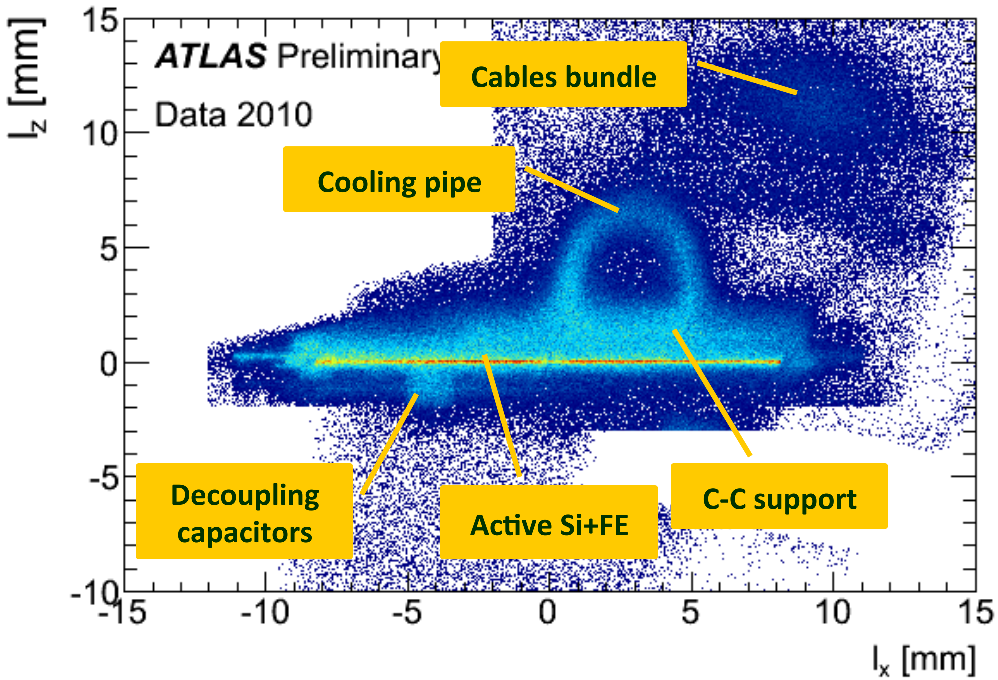
- Sensor: planar 250 μm thick n-on-n sensor
  - Typical pixel size 50 x 400 μm^2 (50 x 600 μm^2 pixels in gaps between FE chips)
  - Bias voltage 150 V (up to 600 V)



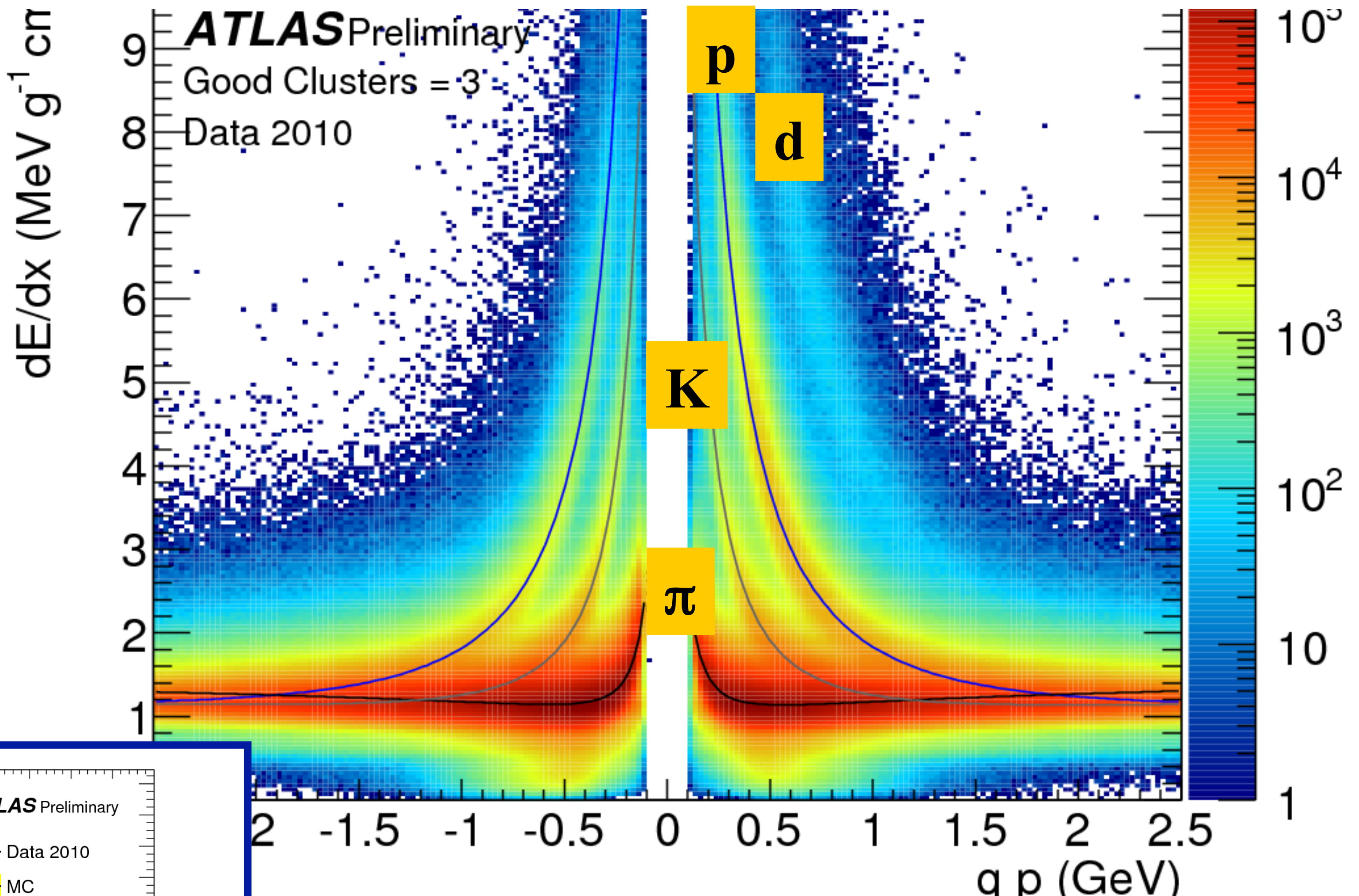
- Readout:
  - 16 FE chips, 2880 pixels each
  - 47232 (328 x 144) pixels
  - Zero suppression in the FE chip
  - Controller (MCC) builds module event
  - Charge measured by means of Time over Threshold
  - Data transfer 40 – 160 Mbit/s depending on layer

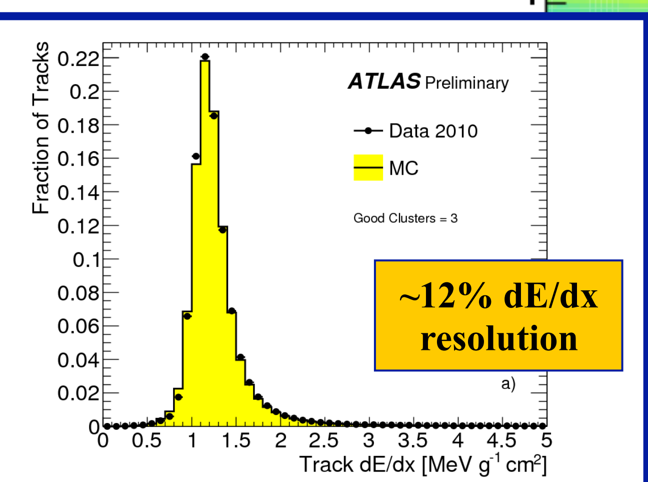
Hadron-Imaging of Pixel Detector

- Secondary hadron vertex distribution is used for accurate material mapping



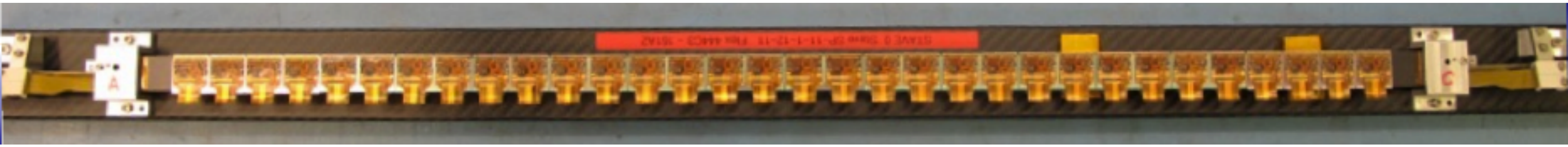
dE/dx Measurement

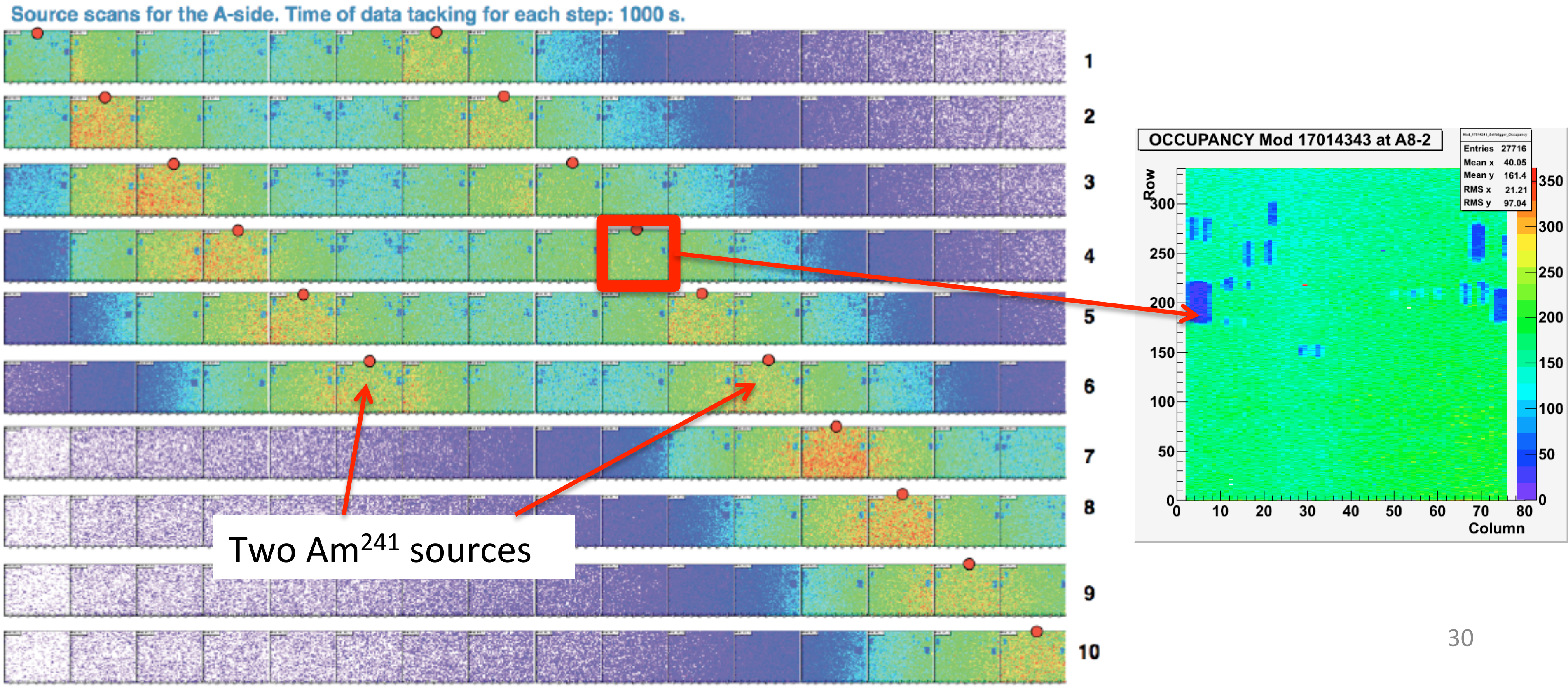




IBL Status

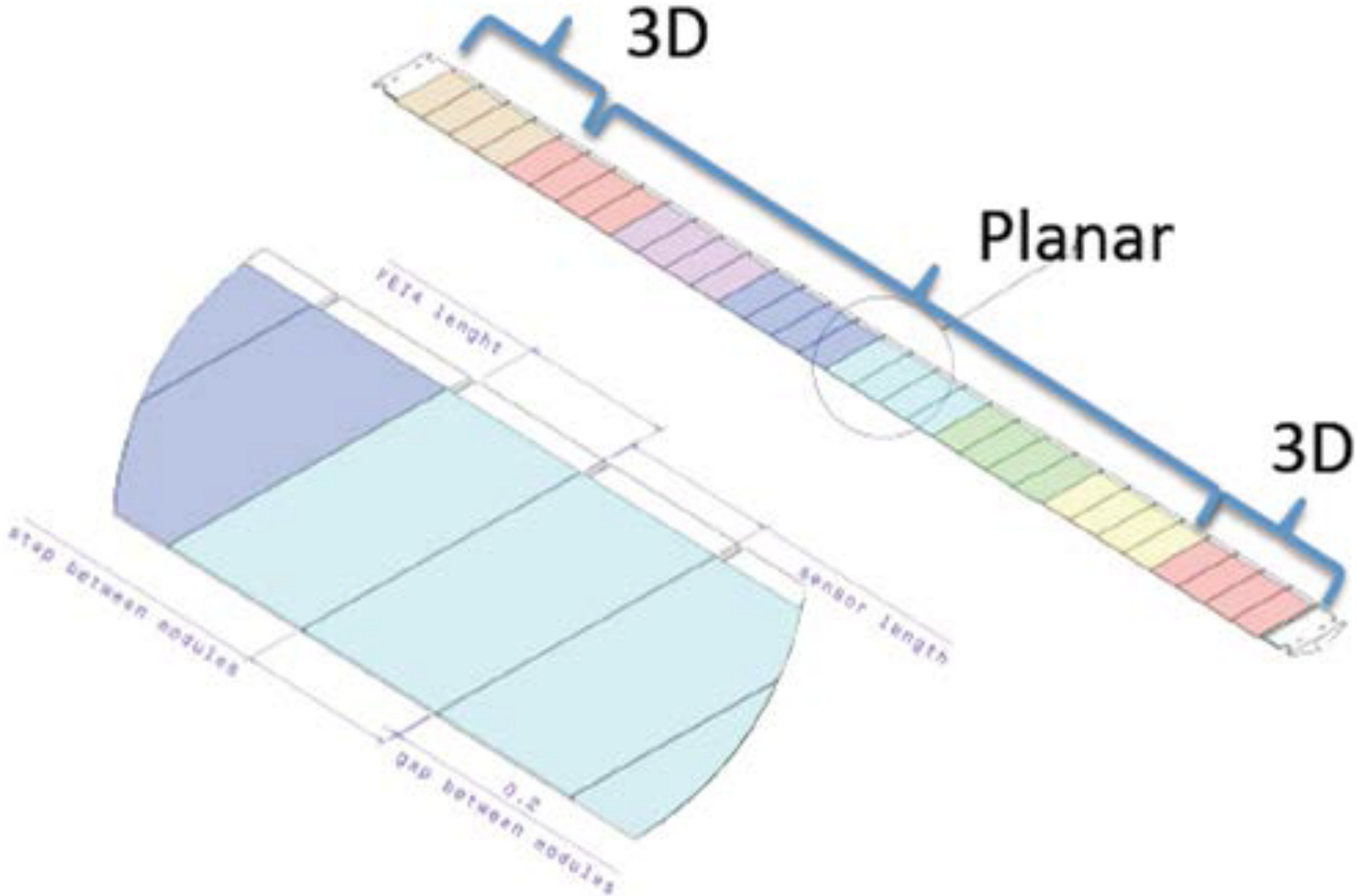
- Two staves 0A and 0B produced and tested: Am^{241} scans
- Challenge: finish 14 staves production autumn 2013
- Install IBL in ATLAS beginning 2014





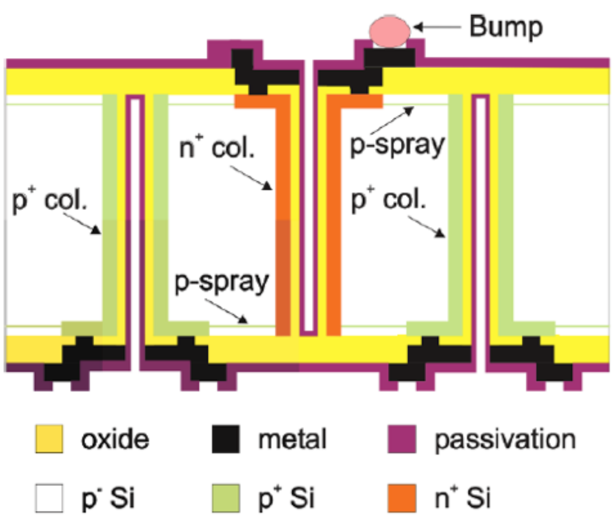
IBL sensors

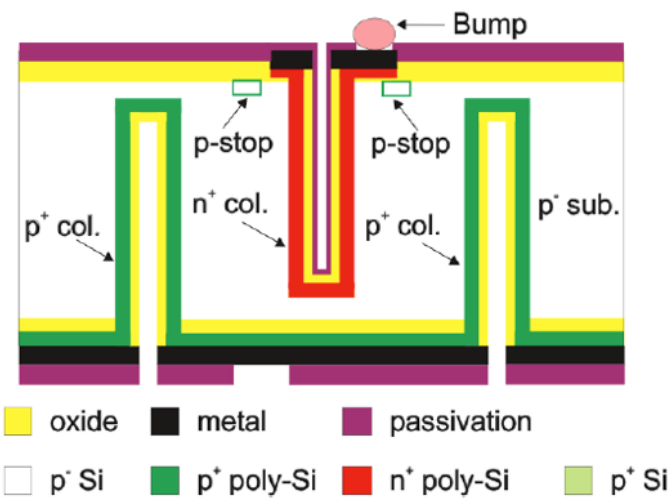
- 75% planar and 25% 3D



3D sensors

- n-in-p bulk 230 µm 3D sensors on 4’’ FZ p-type wafer
- low depletion voltage of 20 V (up to 160V after irradiation)
- slim edge 200 µm
- one chip modules
- FBL(Trento) and CNM(Barcelona) producers





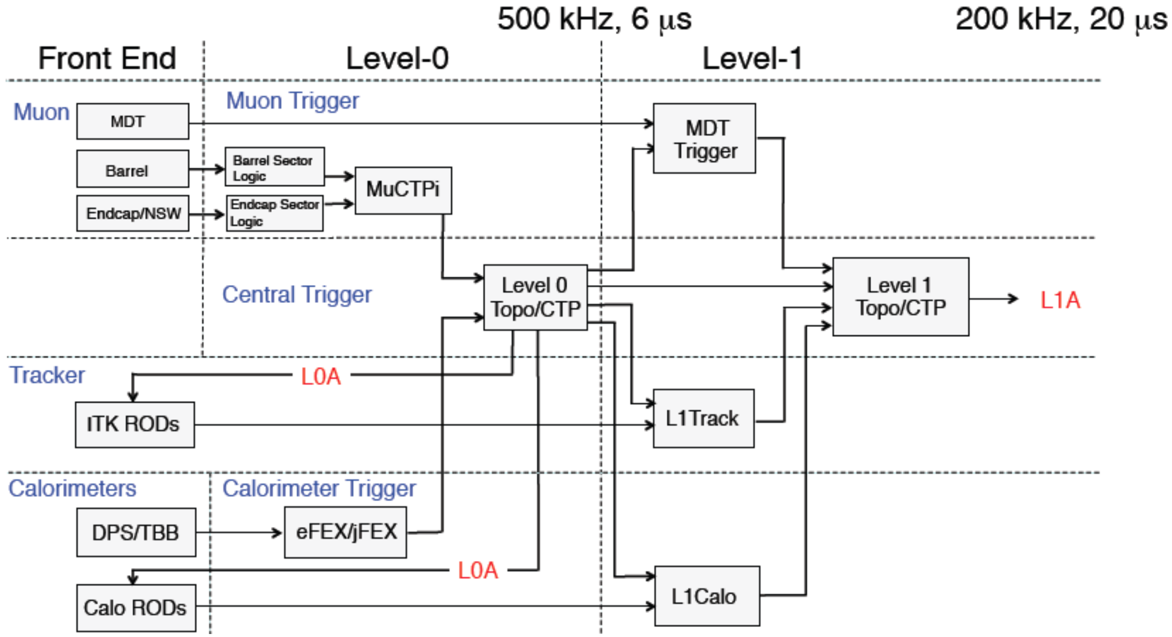
Phase-II: Split TDAQ L1 Scheme

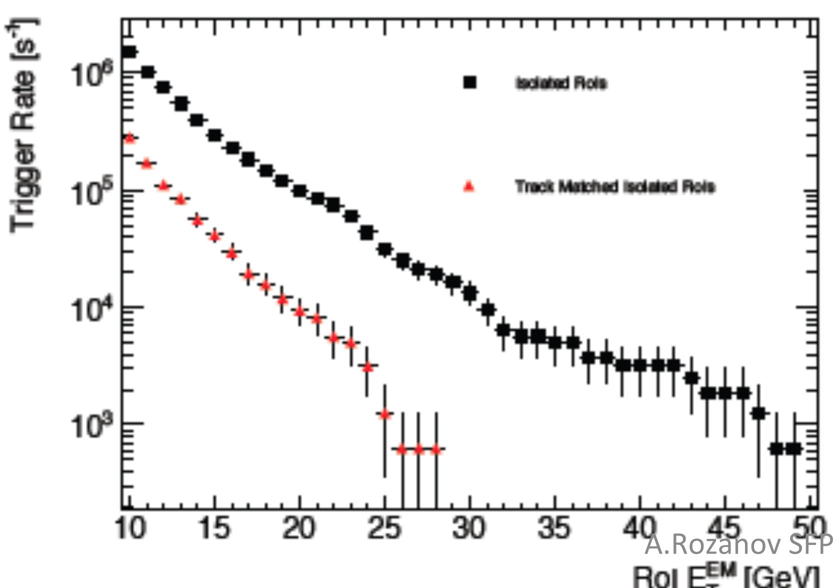
Simulation studies show that including a track trigger complements muon and EM triggers

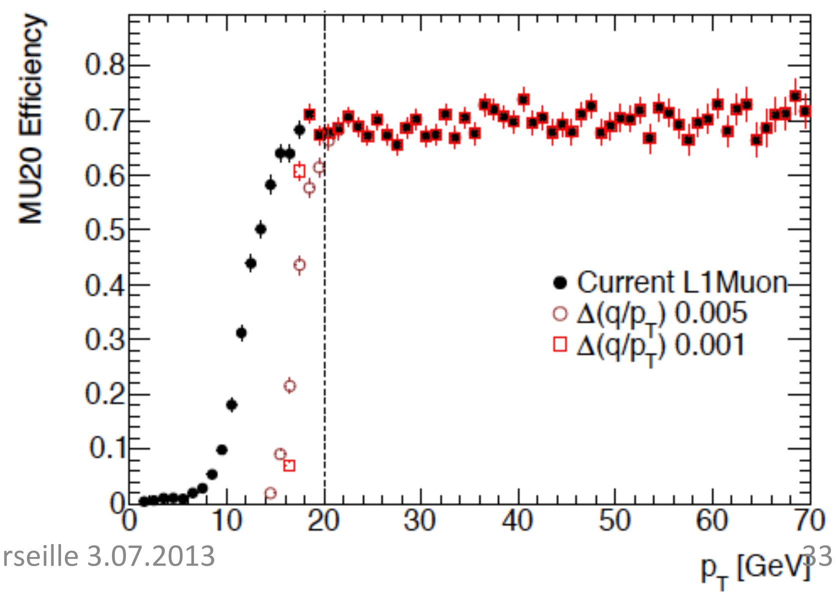
- **Improves muon P_T resolution**
- **Improves EM identification by matching to track**

Implemented as 2-level scheme reusing Phase-I L1 trigger improvements for new L0

FTK technology could be used to perform fast track fit in RoI







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