Comparison of performances of candidate ITk layouts

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master Physique Subatomique Astroparticules

LAPP 40 ans

OUTLINE

Introduction
- CERN - LHC

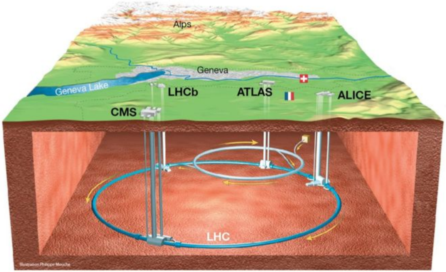
ATLAS - Inner Tracker
- Future Inner Tracker (ITk) - Upgrade motivations
- Future Inner Tracker (ITk) - Upgrade characteristics

Simulation
- 2D plot - location of material in RZ plane
- 1D plot - weight of the detector (X_0 plot)
- Physics performances

Conclusion

CERN - LHC

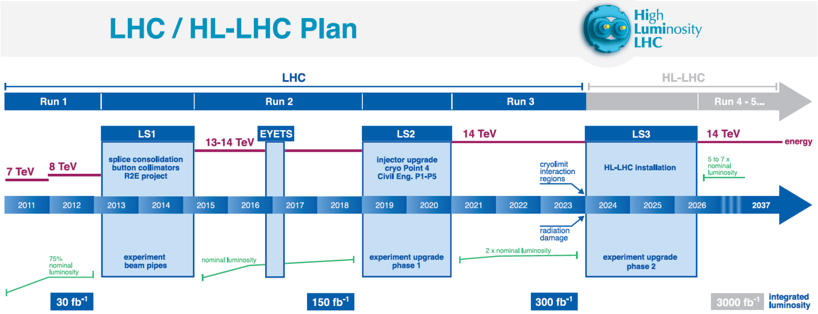
- Near Geneva (Switzerland), laboratory on Nuclear Physics and Particle Physics
- Built the largest and the most powerful (p/p) circular collider



- LHC has a circumference of 27km
- Located 100m below the ground
- Collides protons and also Pb

LHC - high luminosity program

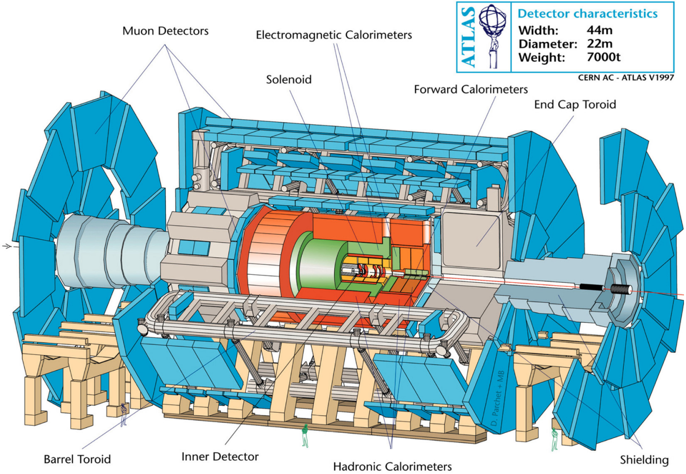
LHC nominal : 14 TeV, $1 \times 10^{34} cm^{-2} s^{-1}$

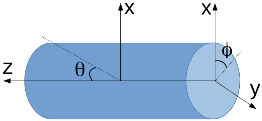


- Higgs discovered with Run 1 data (7-8 TeV)
- LHC has reached the unprecedented center-of-mass energy of 13TeV in 2015

- High Luminosity program aims to increase by a factor 10 the integrated luminosity (up to 300 fb^{-1} per year)
- Increases DATA → reduce statistical errors
    - make precise measurement / search on rare channel

ATLAS

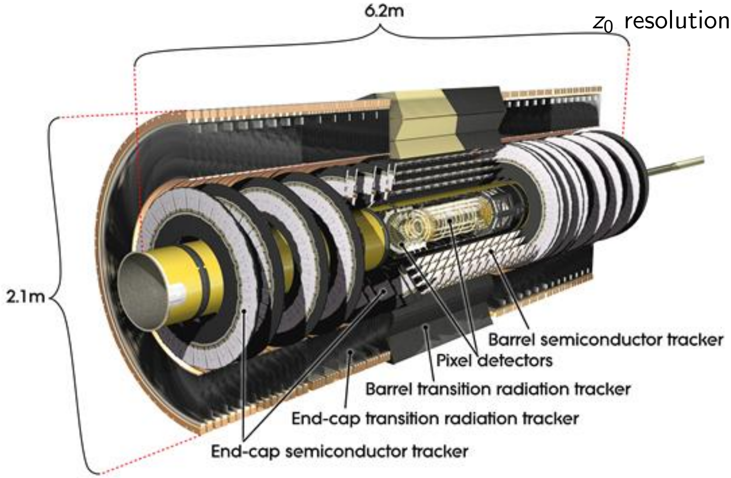




Pseudorapidity $\eta \equiv -ln \mid tan(\frac{\theta}{2}) \mid$

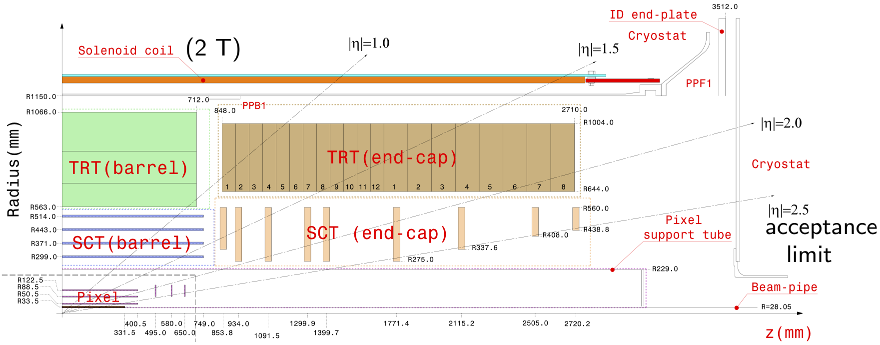
3D-view of the current Inner Tracker

d_0 resolution $\approx 10\mu m$
z_0 resolution $\approx 50\mu m$



3 sub-detectors : Pixel detector (granularity = 50x400 [μm])
Semiconductor Tracker (SCT - granularity = 80 [μm] strip)
and Transition Radiation Tracker (TRT - granularity = 40 diameter 1440 length [mm])

Longitudinal view of the Inner Detector



- Angular acceptance : $\eta = 2.7$

Required performances for Inner Tracker (current and future)

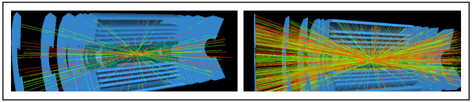
To design an ITk, physicists need to be focused on :

- the granularity, ITk measures momentum and direction of all tracks
- the spatial resolution in order to detect the beginning of particle jets (lifetimes)
- weight to ensure that tracking detector will not cause to many multiple scattering, lose of particles due to interactions, i.e., minimize secondary hits
- angular acceptance in order to observe jets in the forward region
- radiation hardness, efficiency

Inner Tracker (ITk) - Upgrade motivations

Upgrade : in a tougher environment, we want to keep, at least, the same reconstruction performances of tracks (efficiency, p_T, primary and secondary vertices)

- High Luminosity $\rightarrow$ + pile-up (from 20 to 200 inelastic pp collisions), + occupancy (more hits)
  - TRT will be abandoned (cell size/granularity too high)
  - Pixel and SCT : OK (Silicon $\rightarrow$ radiation tolerance)
- Current ITk designed for an instantaneous luminosity of $\mathcal{L} = 1 \times 10^{34}\ cm^{-2}s^{-1}$ and at the HL-LHC $\mathcal{L} = 7.5 \times 10^{34}\ cm^{-2}s^{-1}$ is expected

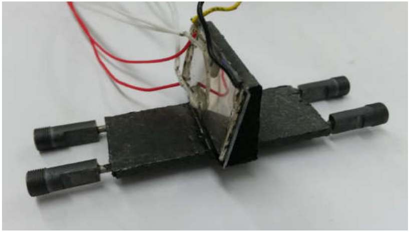


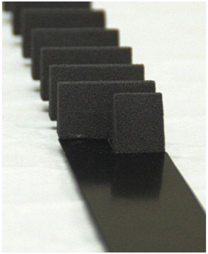
- Search in the forward region
  - increase angular acceptance
- That leads to an increased radiation environment, a more complicated tracking reconstruction

$\Longrightarrow$ the Inner Tracker has to be replaced and improved (upgrade)

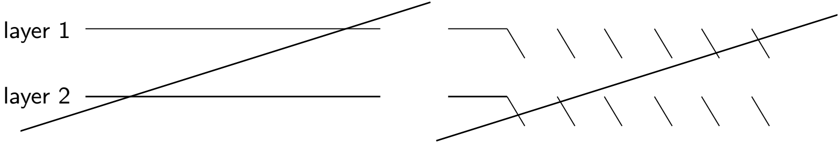
Inner Tracker (ITk) - Upgrade characteristics

- ITk will be designed only with Silicon because of its radiation tolerance
- Covers a larger region (expl : VBF process - $H \rightarrow 4l$) from $| \eta | \leq 2.7$ (current ITk) to $| \eta | \leq 3.2$ or 4
- Innovative upgrade $\rightarrow$ *Alpine Pixel Detector*
  - Challenge : Tracking performance and cooling

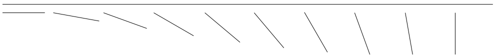


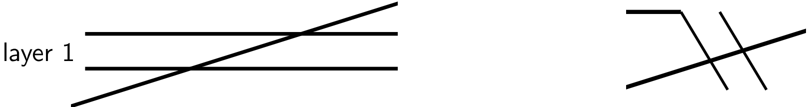


Geometry aspect of the Alpine pixel sensor

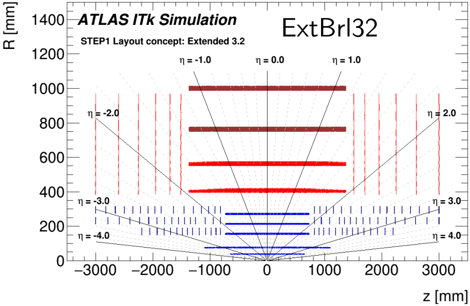


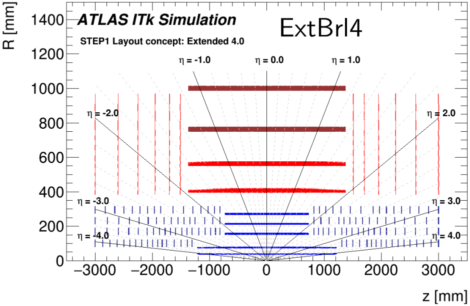
- Simulation of particle's trajectory at 20° ($\eta = 1.7$)
- Idea of inclined sensor : cross sensor orthogonally (important at large η) $\rightarrow$ tracking performances
- Particle can hit more sensors $\rightarrow$ + precision BUT more material are hit !? sensor's thickness !
- Less sensors $\rightarrow$ less electrical cables & reduction of sensor area $\rightarrow$ reduction of passive material
- Reduce amount of material of sensors (cost)

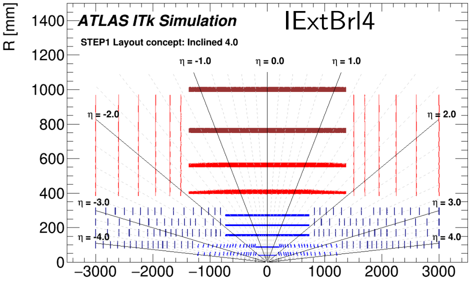


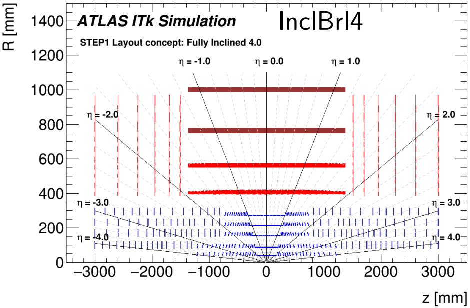


4 candidate layouts for the upgrade ITk





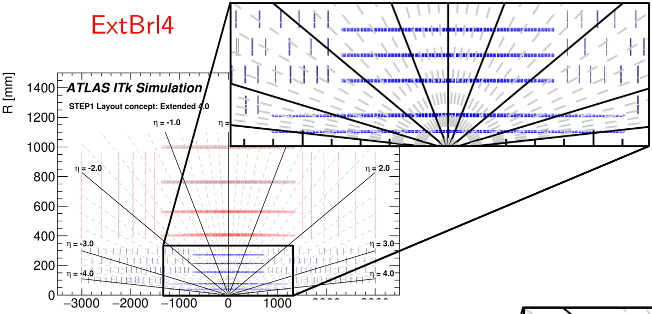


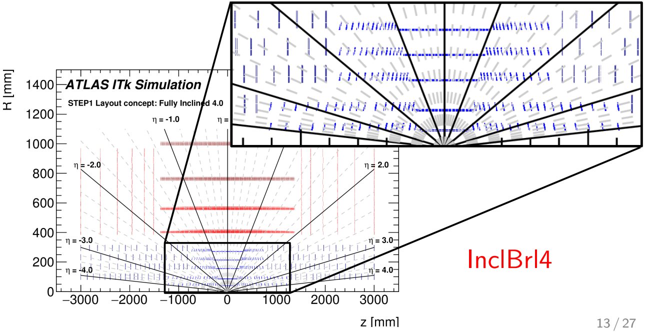


Blue = pixel; red = SCT

4 candidates of ITk for the upgrade layout

ExtBrl4



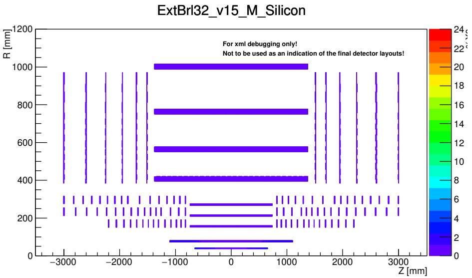


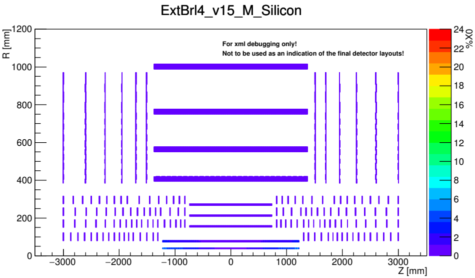
InclBrl4

2D plot

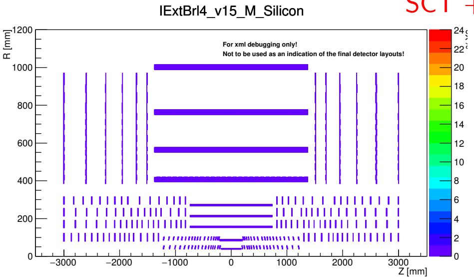
- First tools to simulate and reconstruct ITk in order to compare layouts (began at the start of 2016)
- Goal : compare of performances → I worked on first geometry versions → debugging period
- I participated to the development of 2D plot to show where/what the matter is
- In order to see the detector's geometry OR if matter is missing (for debugging purpose too)
- Simulation with GEANT4, use of geantinos (particle does not interact with matter, no mass, no charge)
- Geantinos are sent in every direction through detector then simulation records the crossing material (type, position) to reconstructed material distribution

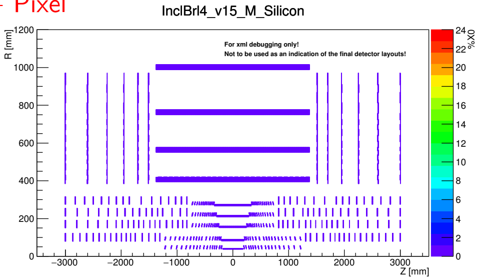
4 layouts - RZ Silicon (active part)



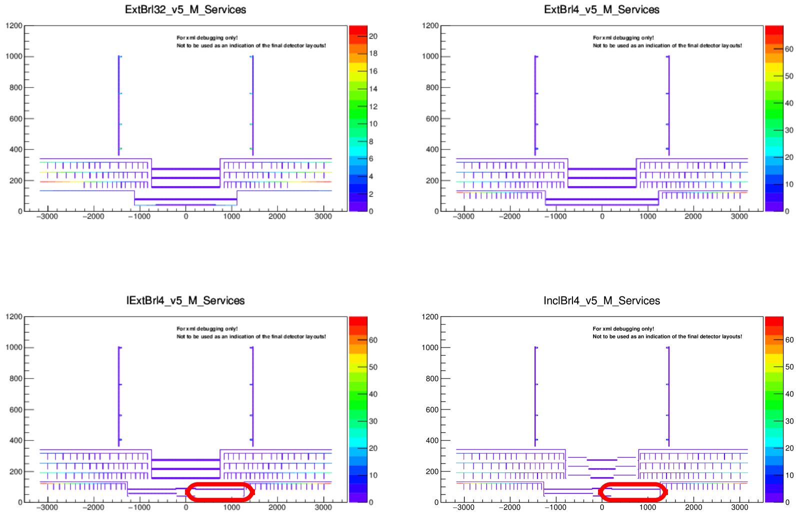


SCT + Pixel





4 layouts - RZ CarbonFiber



Missing parts !

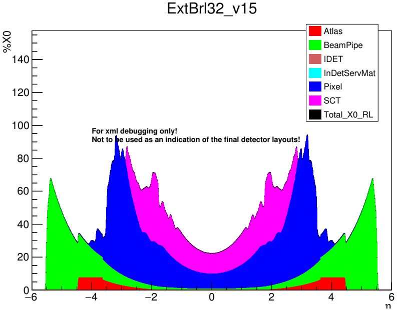
1D-plot (X_0 plot)

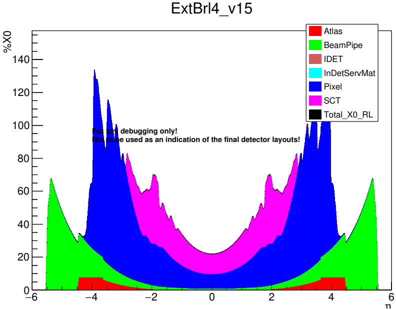
X_0 plot (radiation length) $\Rightarrow$ the amount of material sensitive to electromagnetic interaction

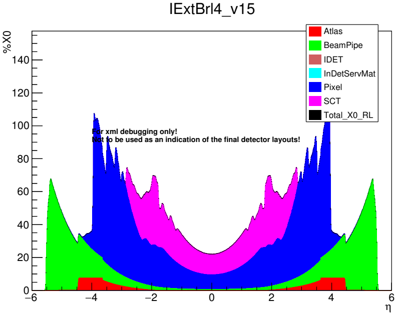
$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{1}{X_0} E \Rightarrow E(x) = E_0 e^{-x/X_0} \quad (1)$$

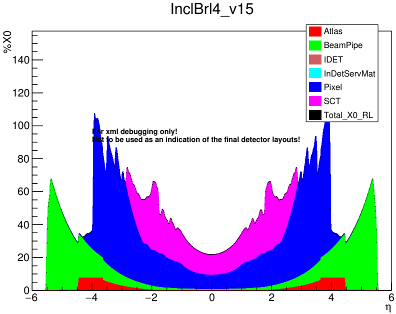
- Use of the attenuation formula
- 1 X_0 $\Leftrightarrow$ length over an e^- looses $1/e$ of its energy;
- 1 X_0 $\Leftrightarrow$ $\frac{7}{9}$ of the mean free path for e^-/e^+ production by a γ
- Represent the material 'cost' for particle to pass

1D plot - Total X0 against η per detector volume

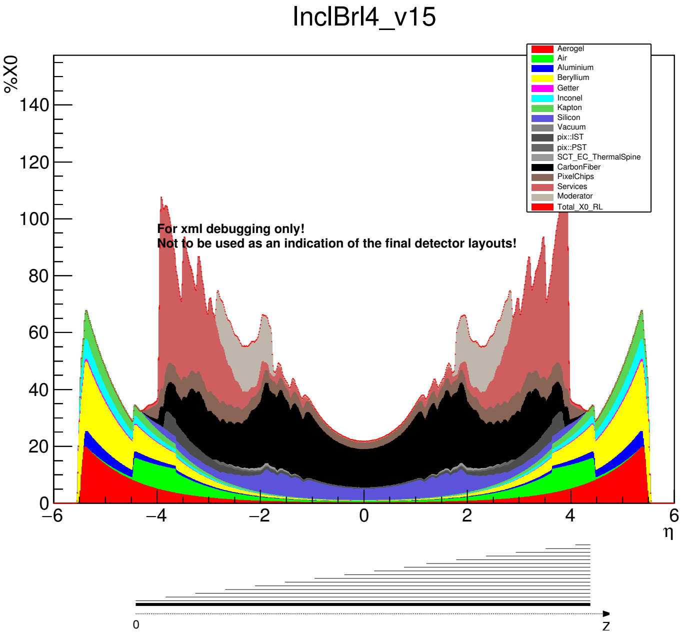




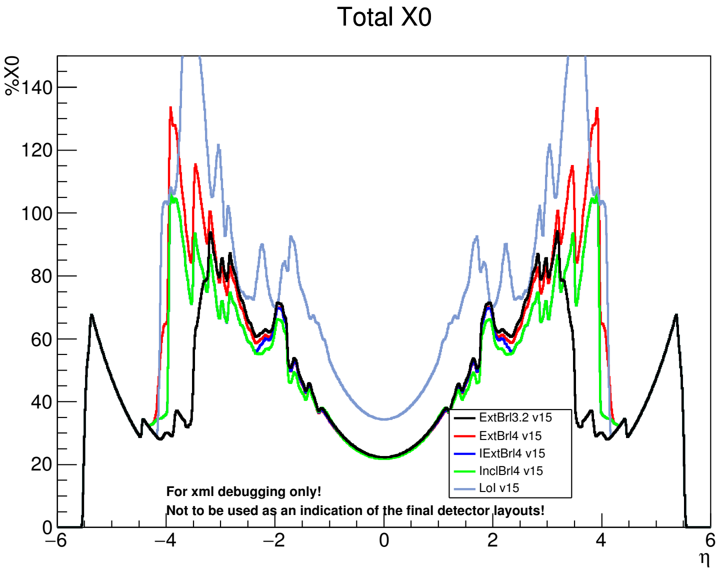




1D plot - Total X0 against η per material



How are we going to compare

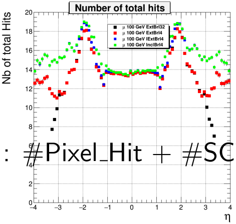


Physics performances

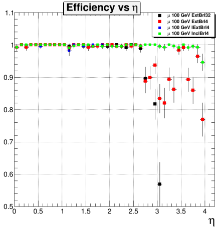
- ITk measures momentum and direction of all tracks
  - with a good spatial (temporal) resolution $\rightarrow$ impact parameters
  - limit material (X_0 plot) to reduce multiple scattering and lose of particle's energy

- For the simulation, I used sample of single μ-lepton and e^- at $p_T = 10 - 100\ GeV$, whose paths trough the detector was simulated

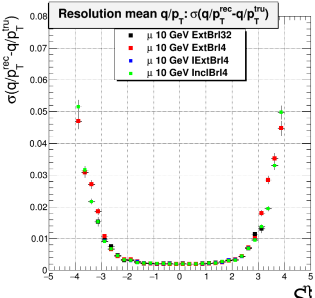
- We have a good efficiency to say that simulation is good enough to give clues on physics performances

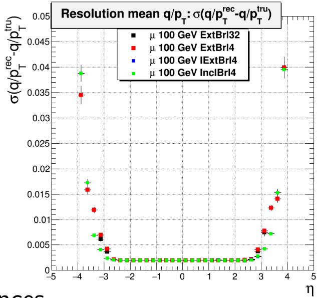


cut : $\#\text{Pixel\_Hit} + \#\text{SCT\_Hit} \leq 11$

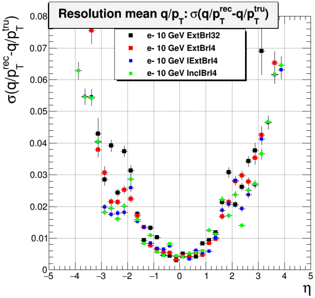


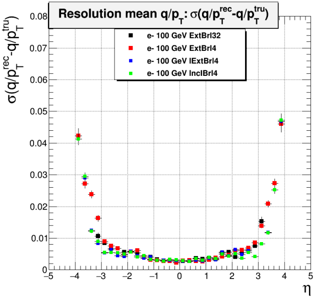
Physics performances - q/p_T against η



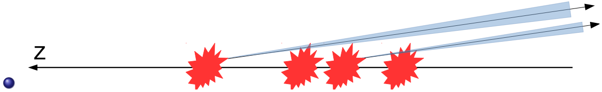


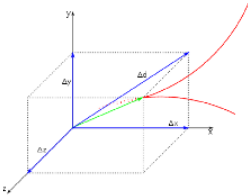
Similar performances

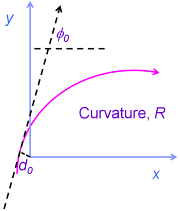


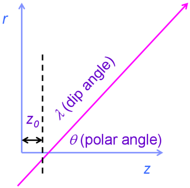


Spatial resolution - Impact parameters



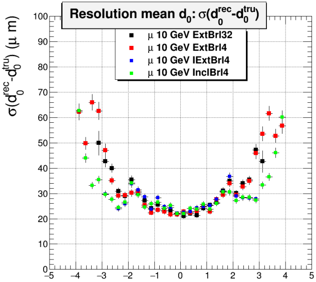


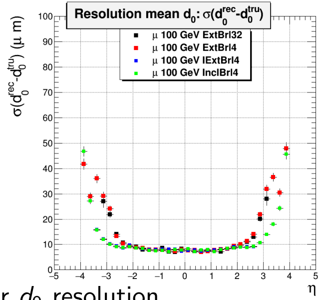




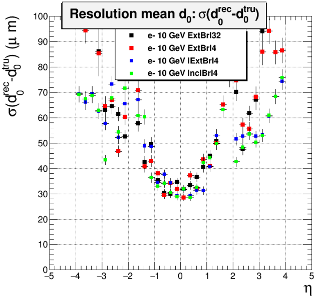
- In (x,y) plan, d_0 $\Leftrightarrow$ closest point : particle's curvature / collision point
  - to measure decay point for τ-lepton, B-hadrons, . . .
- z_0 $\Leftrightarrow$ value of z where d_0 is evaluated
  - to separate primary vertices of pile-up events from hard scattering event

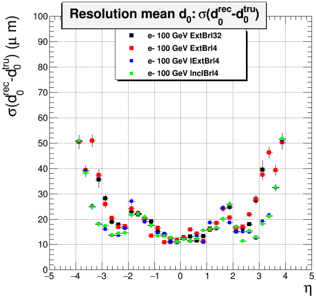
Spatial resolution - d_0 against η



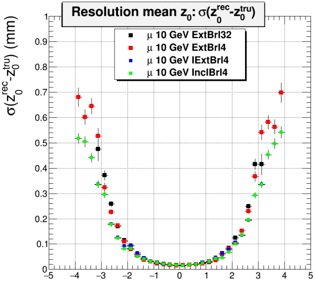


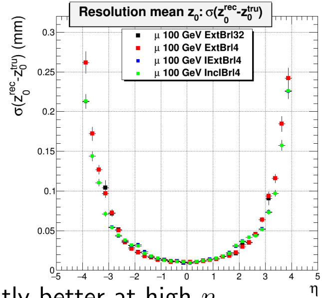
Inclined layouts have better d_0 resolution



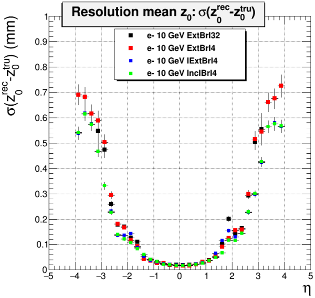


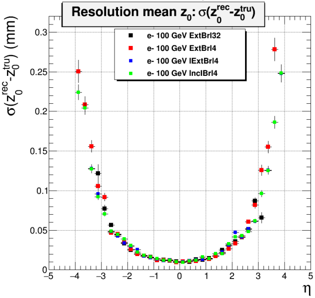
Spatial resolution - z_0 against η



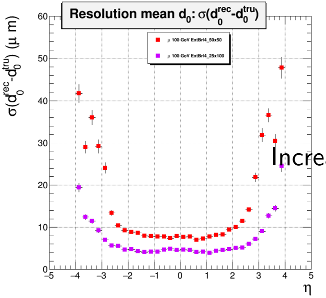


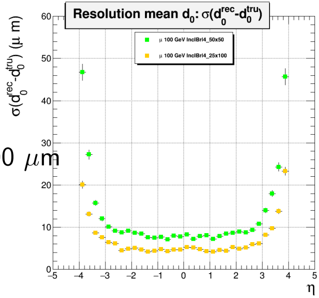
Inclined layouts seem to be lightly better at high η



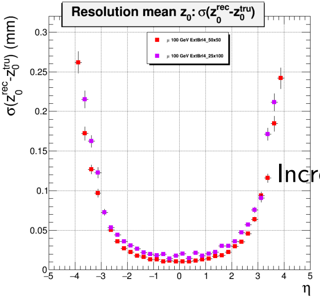


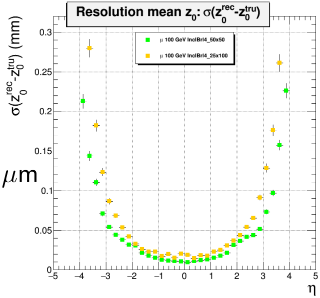
Spatial resolution - change of the size of pixel's sensor





Increase of a factor 2 for 25x100 μm





Increase of a factor 2 for 50x50 μm

Conclusion

- Single particle currently show better tracking performances for inclined layout
- Tracking improvements are still expected
- To be evaluated with more complex events (expl : tt)
- Electron performances to be evaluated on combination with calorimeters
- At the end of 2016, choice of the layout
- At the end of 2017, Technical Design Report will define the baseline layout

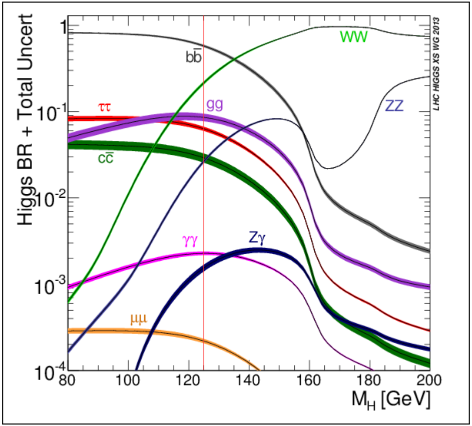
Thanks for your attention !
Questions ?

BACK-UP

Introduction

- Internship at Laboratory of Annecy-le-Vieux of Particle Physics (LAPP)
- LAPP works on big experiences : AMS, HESS, CTA, Virgo, Stereo, SuperNEMO, WA105, R&D on future collider, LHCb and ATLAS
- ATLAS group at LAPP works on data analyses ($H \to \gamma\gamma,\ \gamma\gamma$ at 750 GeV, $WZ \to 3l,\ Z' \to 2l$), on LAr calorimeter and on tracking system

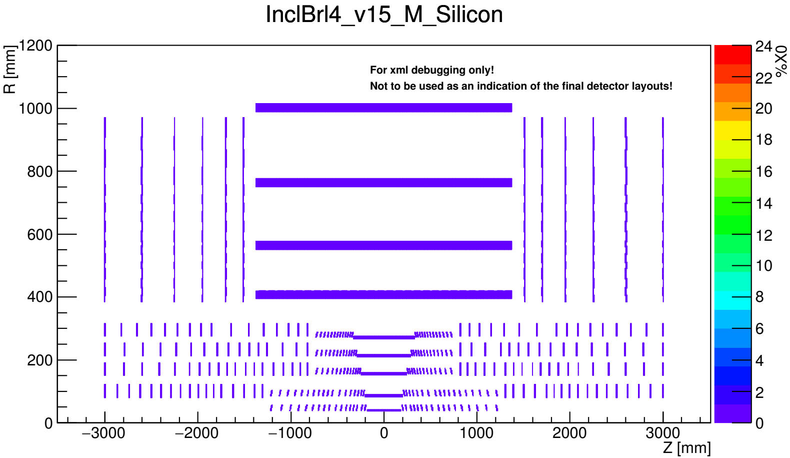
HL-LHC - Physics motivation



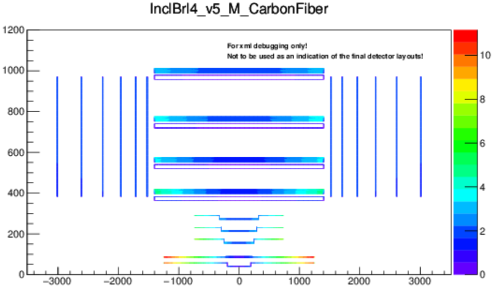
- Improves precision on already observed decay mode ($H \to ZZ, \gamma\gamma, WW, \tau\tau, bb$)
- Observation on rare Higgs decays mode and rare Higgs production mode
- Searches on rare channel :
  - $WH/ZH,\ H \to \gamma\gamma$
  - $t\bar{t}H,\ H \to \gamma\gamma$
  - $H \to \mu\mu$

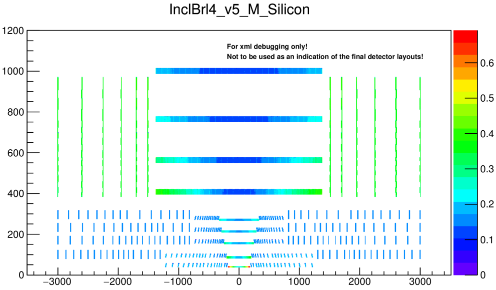
- High luminosity $\to$ more data

RZ Silicon InclBrl4

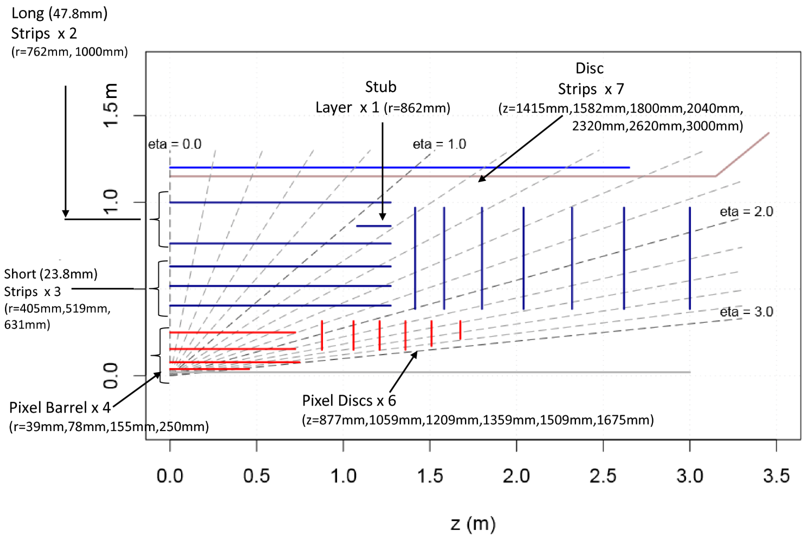


RZ Support structure vs Sensor - InclBrl4





LoI



Long (47.8mm)
Strips x 2
(r=762mm, 1000mm)
Stub
Layer x 1 (r=862mm)
Disc
Strips x 7
(z=1415mm,1582mm,1800mm,2040mm,
2320mm,2620mm,3000mm)
eta = 0.0
eta = 1.0
eta = 2.0
eta = 3.0
Short (23.8mm)
Strips x 3
(r=405mm,519mm,
631mm)
Pixel Barrel x 4
(r=39mm,78mm,155mm,250mm)
Pixel Discs x 6
(z=877mm,1059mm,1209mm,1359mm,1509mm,1675mm)
0.0
1.0
1.5 m
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
z (m)

VBF process