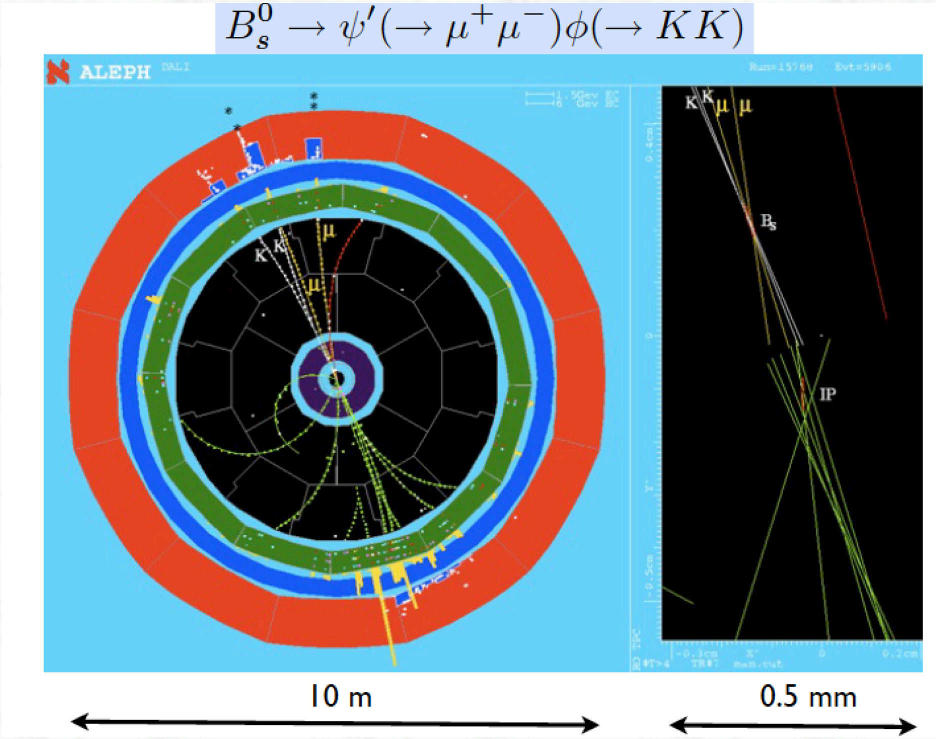
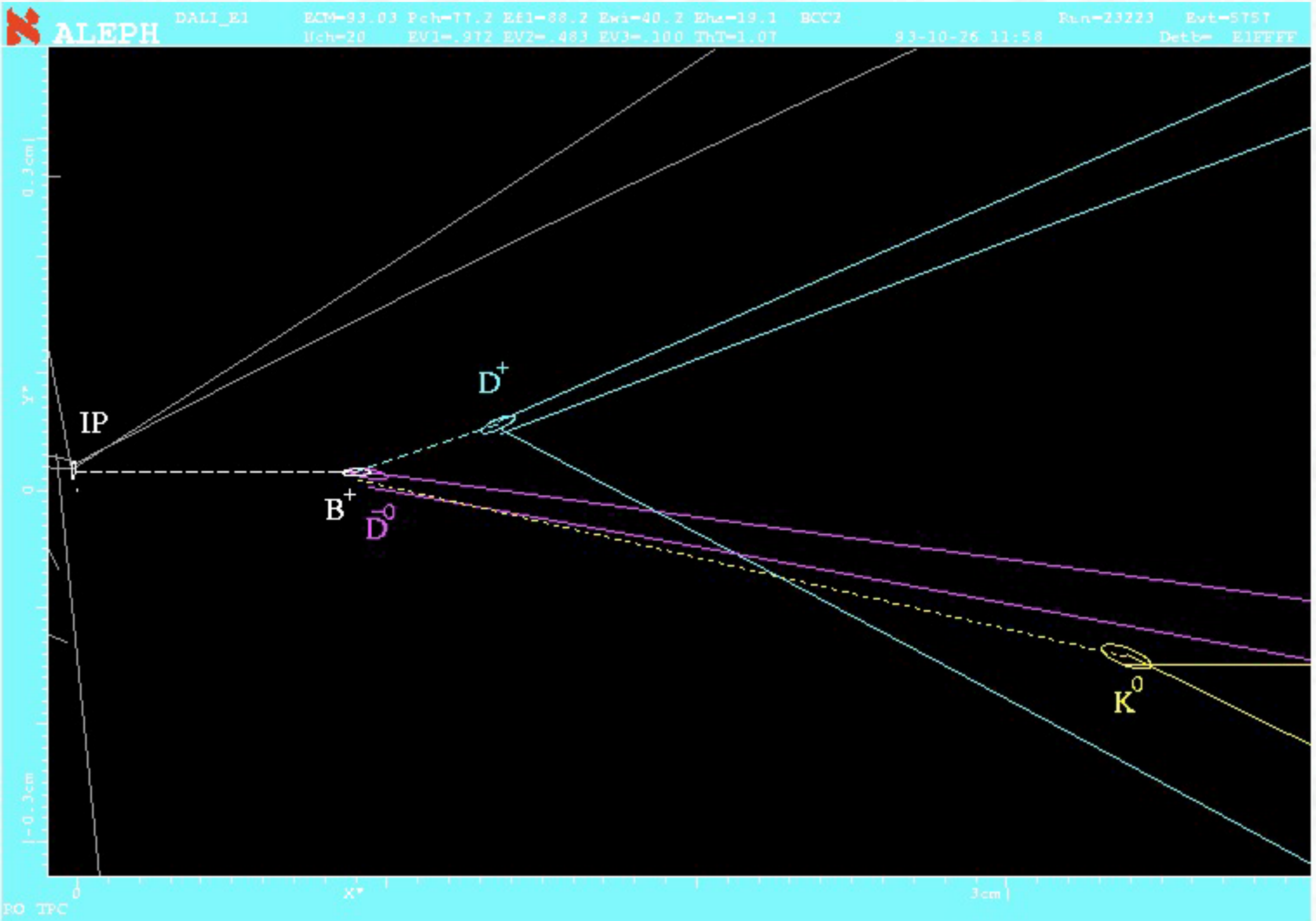
6.6 Vertexing and impact parameter measurement



An example of a fully reconstructed B-meson decay in the ALEPH experiment

Track measurements with a precision of a few μm near the interaction point improve the momentum measurement and allow to determine the decay vertex. This is especially important for B-hadrons

(typical lifetime of about 1.5 ps)



The life time of B-mesons can be measured from the decay length L, if the momentum of the B-meson (γ-factor) is measured as well.

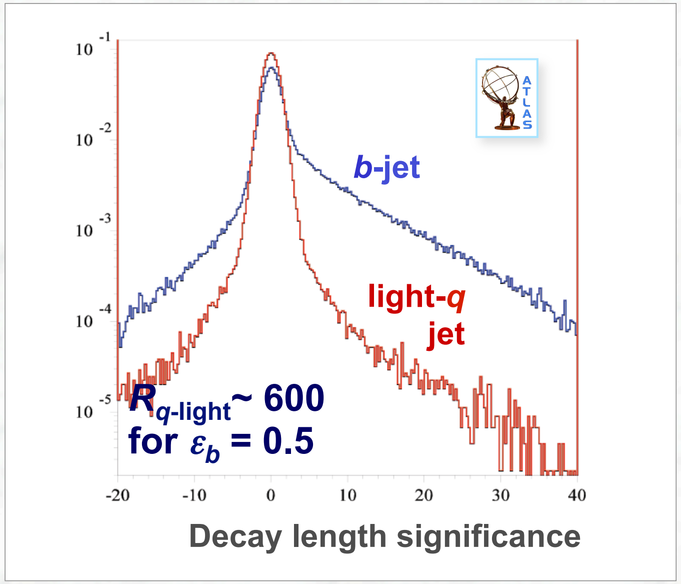
Impact parameter measurement

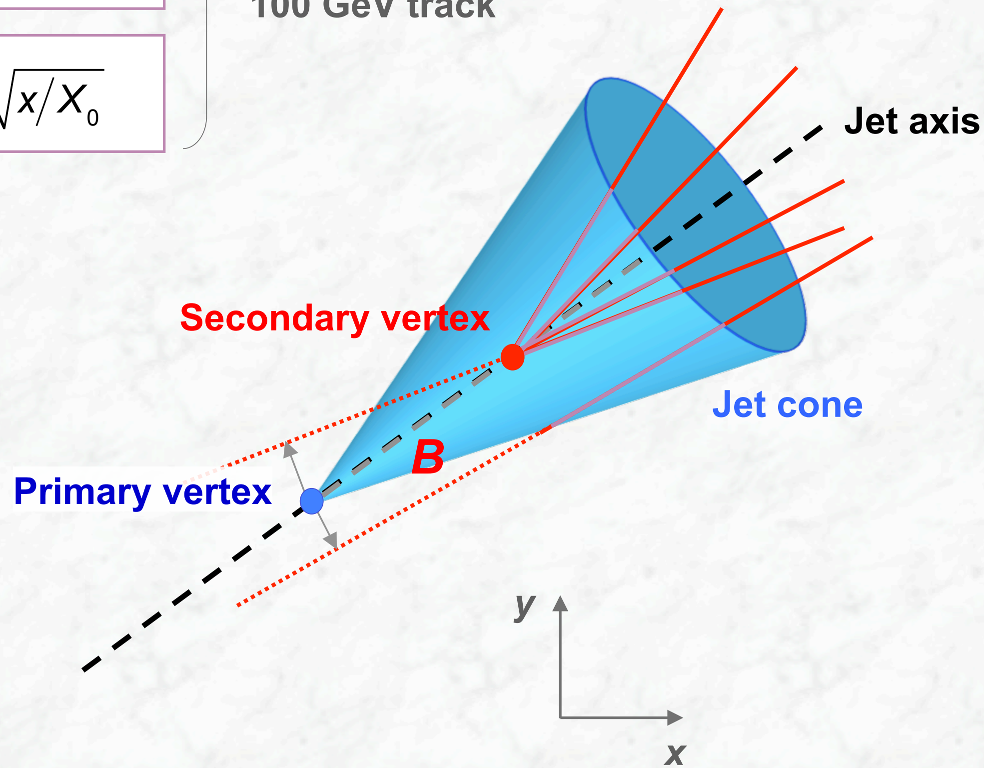
The innermost silicon detector must provide the required *b*-tagging efficiency

Good vertex resolution is achieved by placing the **innermost (*B*) layer close to the beam pipe**, and **the next layer farer to it** (lever arm), and by an excellent *B*-layer resolution

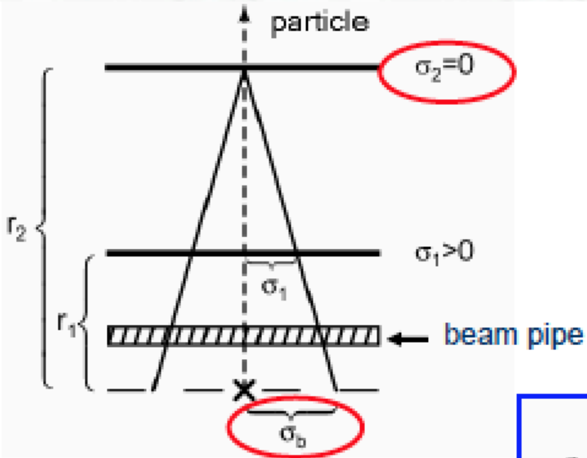
Small multiple scattering term: $\sigma_{MS} \sim \frac{1}{p}\sqrt{x/X_0}$

Expected transverse IP resolution ~13 μm for 100 GeV track





Estimation of the impact parameter resolution (2-point approximation):



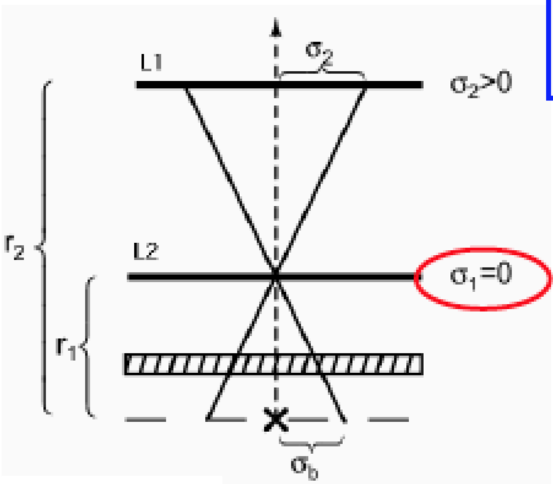
$$\frac{\sigma_b}{\sigma_1} = \frac{r_2}{r_2 - r_1}$$

small !

small !

$$\sigma^2 = \left(\frac{r_1}{r_2 - r_1}\,\sigma_2\right)^2 + \left(\frac{r_2}{r_2 - r_1}\,\sigma_1\right)^2 + \sigma_{MS}^2$$

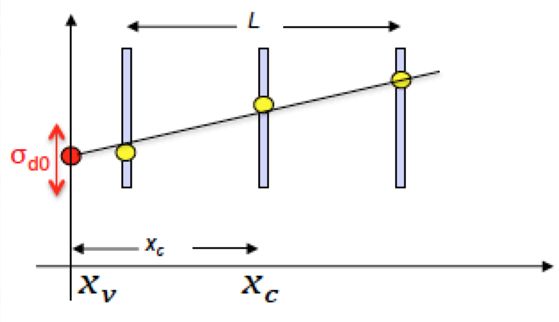
small x/X_0



$$\frac{\sigma_b}{\sigma_2} = \frac{r_1}{r_2 - r_1}$$

$$\sigma_{MS} \sim \frac{1}{p}\sqrt{\frac{x}{X_0}}$$

More general case of N measurement points:



- N points,
- precision σ_{mess} at each point

(linear extrapolation)

$$\sigma_{d_0} = \frac{\sigma_{\rm mess}}{\sqrt{N}}\sqrt{1+\frac{12(N-1)}{(N+1)}\frac{x^2}{L^2}}$$

where $r := \frac{x_0}{L}$

$$\sigma_{d_0} = \frac{\sigma_{\rm mess}}{\sqrt{N}}\sqrt{1+r^2\frac{12(N-1)}{(N+1)}+r^4\frac{180(N-1)^3}{(N-2)(N+1)(N+2)}+r^2\frac{30N^2}{(N-2)(N+2)}}$$

(parabolic track model, B field)

To optimize the impact parameter resolution:

- High precision measurement, small σ_{mess}
- Large lever arm (L)
- Place first detector plane as close as possible to the interaction point → small x
- Gain with number of layers, however, only ~1/√N

→ Silicon strip and pixel detectors are essential !

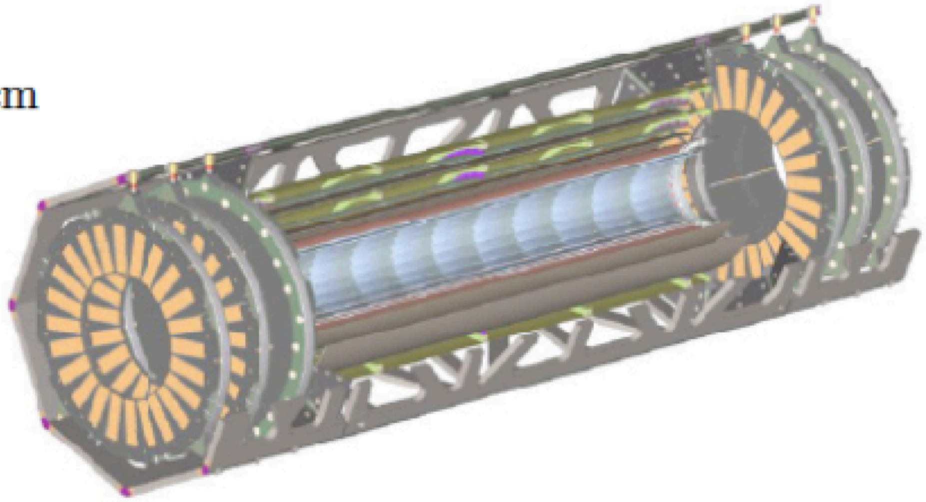
Example: ATLAS pixel detector *)

$$N = 3,\ \sigma = 10\,\mu\text{m},$$

$$x_1 = 4.7\,\text{cm},\ x_2 = 9.1\,\text{cm},\ x_3 = 13.5\,\text{cm}$$

$$L = 8.8\,\text{cm},\ r = x_2/L = 1.03$$

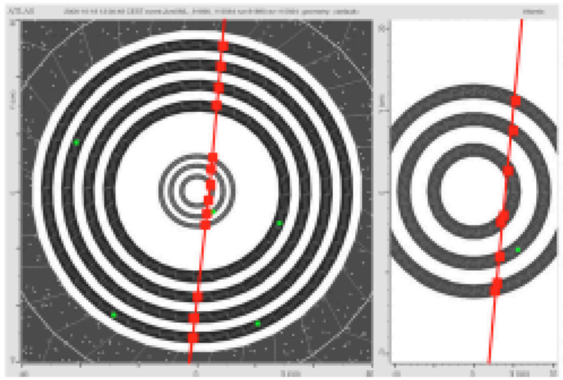
$$\sqrt{1 + \frac{12(N-1)}{(N+1)} r^2} = 2.65$$



Impact parameter resolution

$$\sigma_{d_0} = 15.7\,\mu\text{m} \quad \text{(linear, i.e. no field)}$$

$$\sigma_{d_0} = 45.5\,\mu\text{m} \quad \text{(extrapolation with B-field)}$$



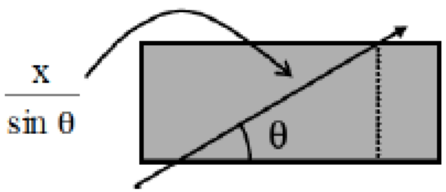
Note

- if curvature is used for extrapolation with N=3 the error on d_0 gets larger by a factor ~2.9.
- however, curvature is measured by the entire inner detector => error on d_0 similar to linear case

* from N. Wermes, Lectures at BND School 2015

Impact parameter resolution, including multiple scattering *)

- For low momentum tracks the momentum resolution and the impact parameter resolution are dominated by multiple scattering
- The amount of material actually traversed by the particles depends on the polar angle



- the momentum resolution tends to

$$\frac{\sigma_p}{p^2} \rightarrow k_p \frac{\sqrt{x/X_0}}{p\sqrt{\sin\theta}}$$

- the impact parameter resolution tends to

$$\sigma_{d_0} \rightarrow k_{d_0} \frac{\sqrt{x/X_0}}{p\sqrt{\sin\theta}}$$

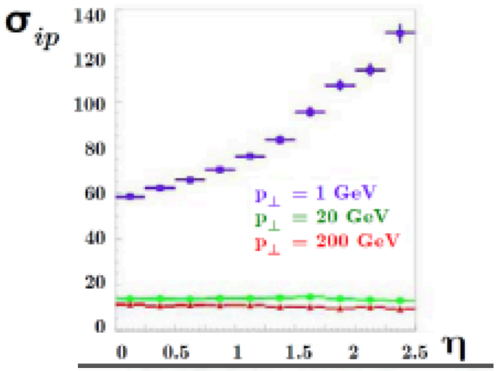
- Since the MS error and the point measurement error are independent of each other, the total error is the sum in quadrature of the 2 terms with and w/o MS
- For the ATLAS detector Monte Carlo studies have shown that the resolutions on momentum and impact parameter can be parametrized as

$$\frac{\sigma_{p_T}}{p_T^2} = 0.00036 \oplus \frac{0.013}{p_T\sqrt{\sin\theta}}(\mathrm{GeV})^-1$$

or

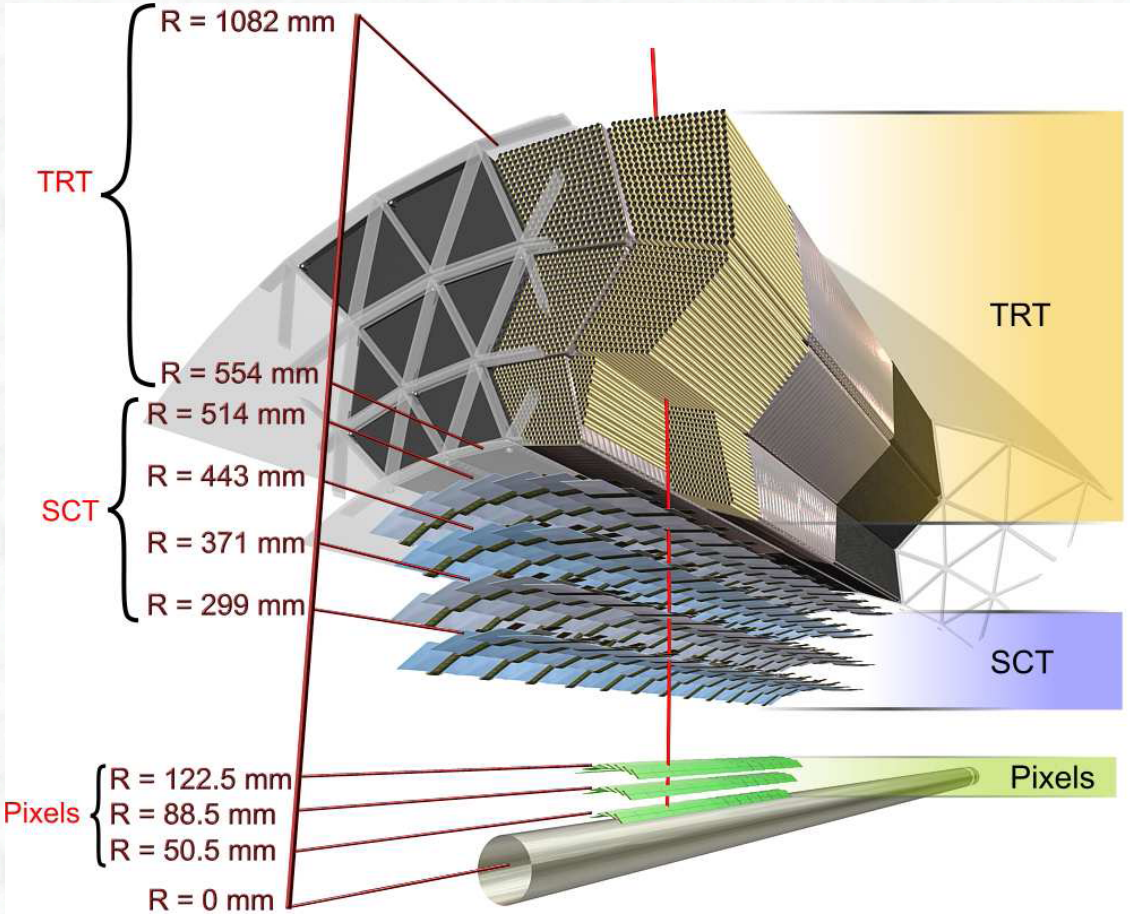
$$\frac{\sigma_{p_T}}{p_T} = 0.04\% \, p_T \oplus \frac{1.3\%}{\sqrt{\sin\theta}}(\mathrm{GeV})^-1$$

$$\sigma_{d_0} = 11\mu m \oplus \frac{73\mu m}{p_T\sqrt{\sin\theta}}$$

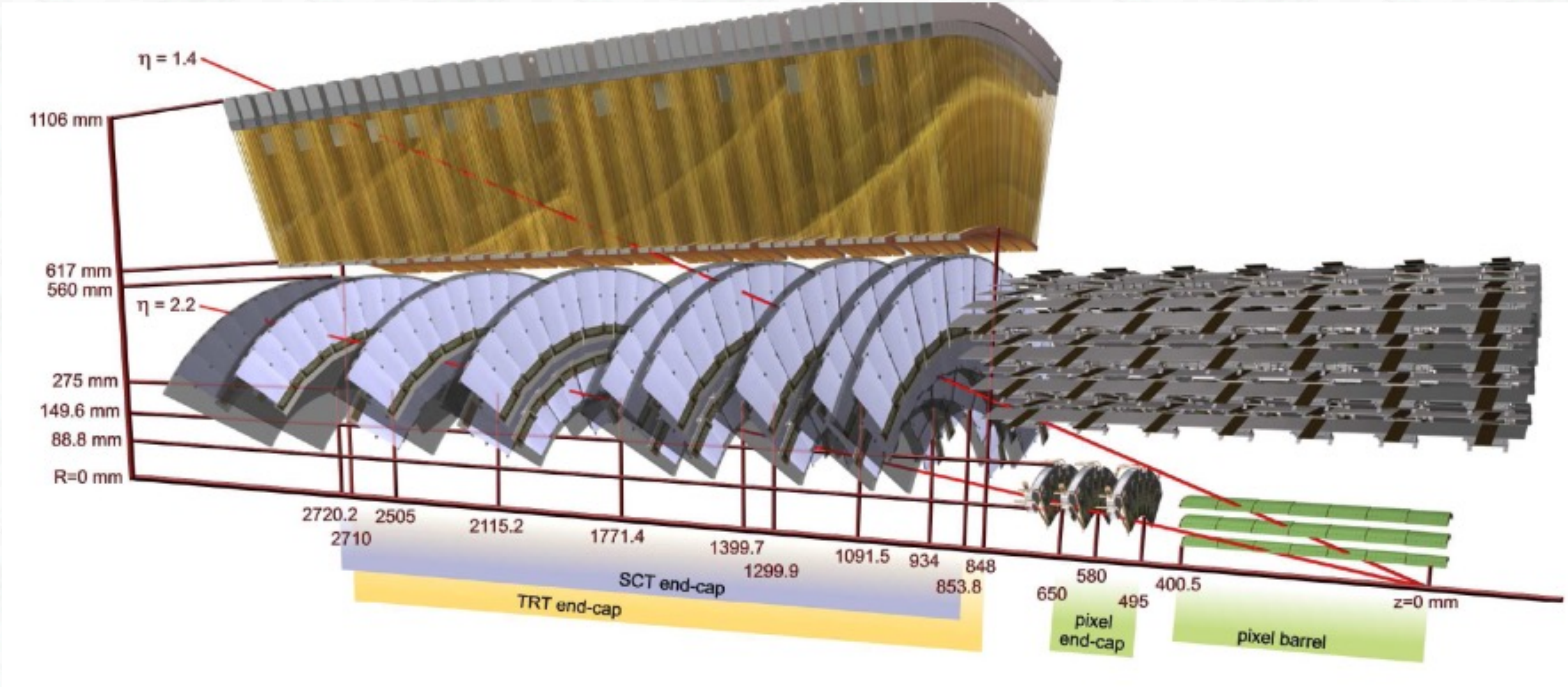


* from N. Wermes, Lectures at BND School 2015

6.7 The ATLAS and CMS Central Tracking Detectors

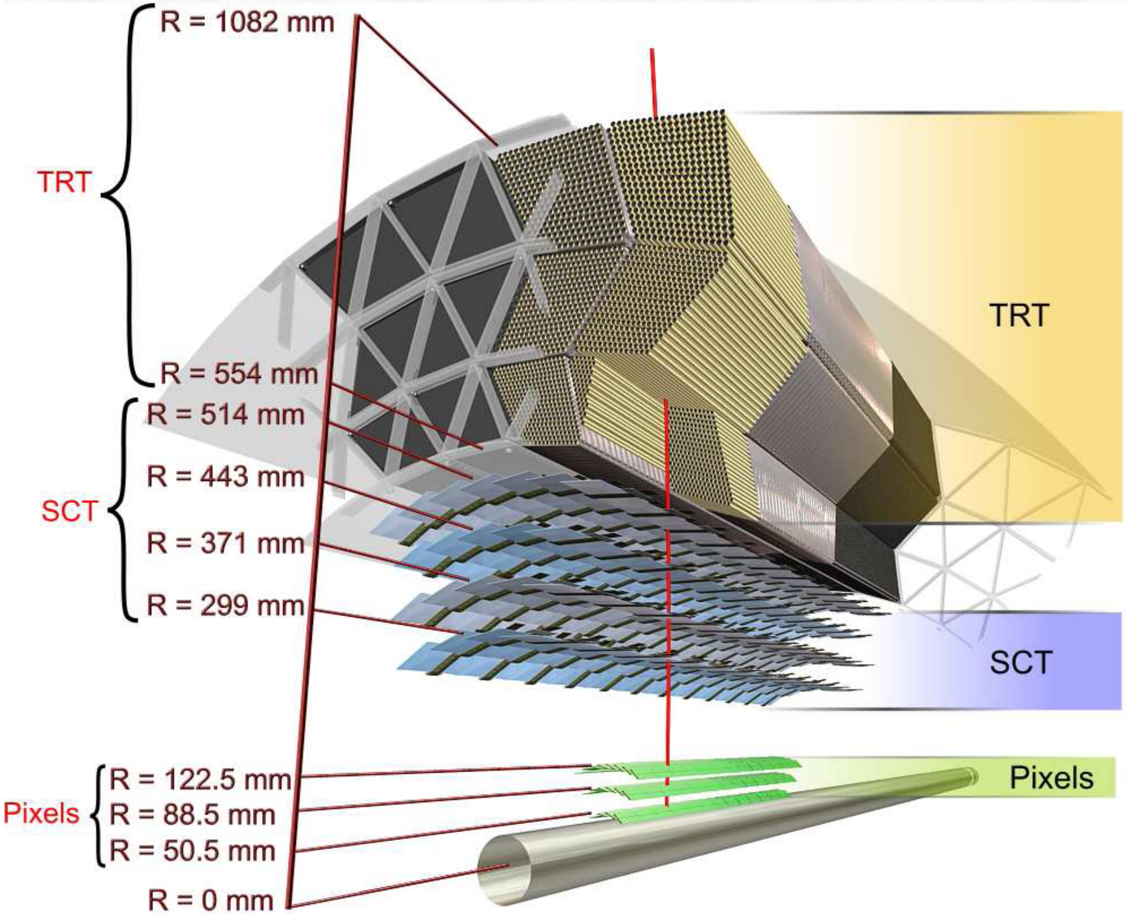


The ATLAS Inner Detector (one end-cap)



η	0	0.9	1.4	1.7	2.5	3.7	5
θ	90°	44°	28°	21°	9.4°	2.8°	0.8°

The ATLAS Inner Detector

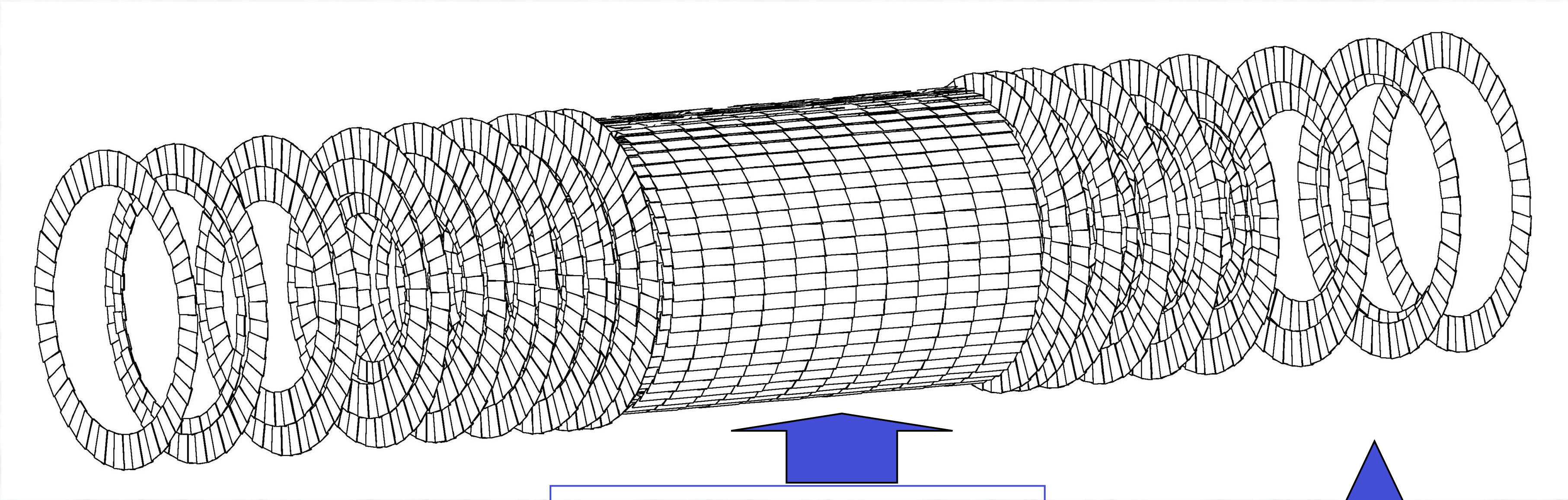


	R- ϕ accuracy	R or z accuracy	# channels
Pixel	**10 μm**	**115 μm**	**80.4M**
SCT	**17 μm**	**580 μm**	**6.3M**
TRT	**130 μm**		**351k**

$$\sigma/p_T \sim 0.05\%\ p_T \oplus 1\%$$

Example: ATLAS Si-Tracker SCT

5.6m x 1.04m



4 cylindrical barrels with 2112 modules

Endcaps: 1976 modules on 2·9 disks

Only Silicon shown