ATLAS Inner Detector

J. Beyer – ATLAS-SCT

Max Planck Institut für Physik

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IMPRS Workshop

MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Layout

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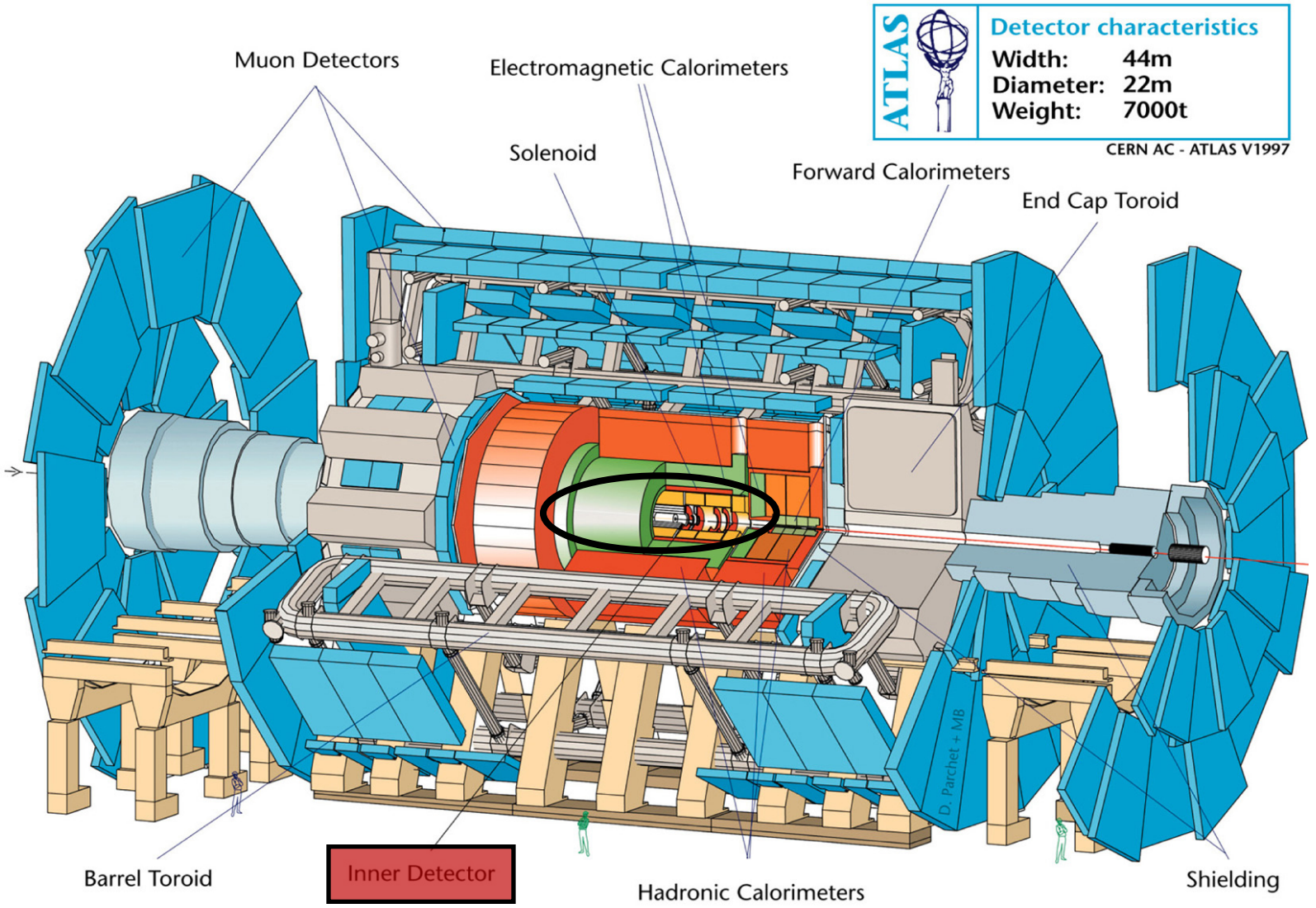
Overview

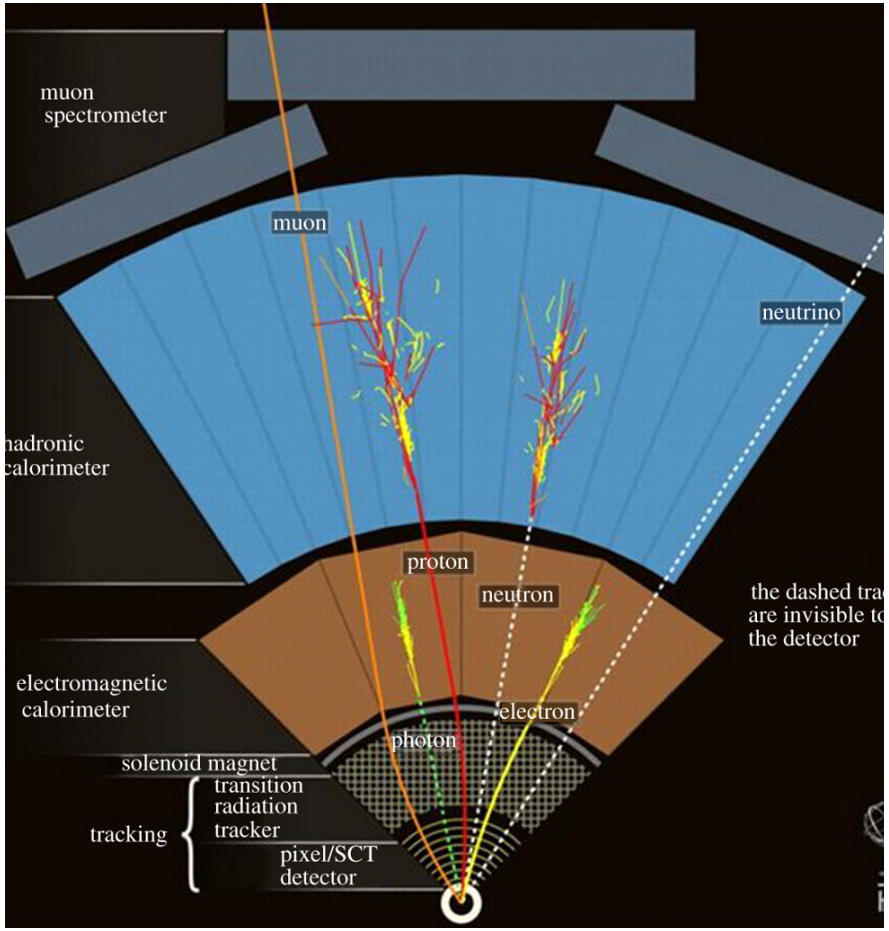
Inner Detector

- -Pixel Detector
- -Strip Detector
- -Transition Radiation Tracker

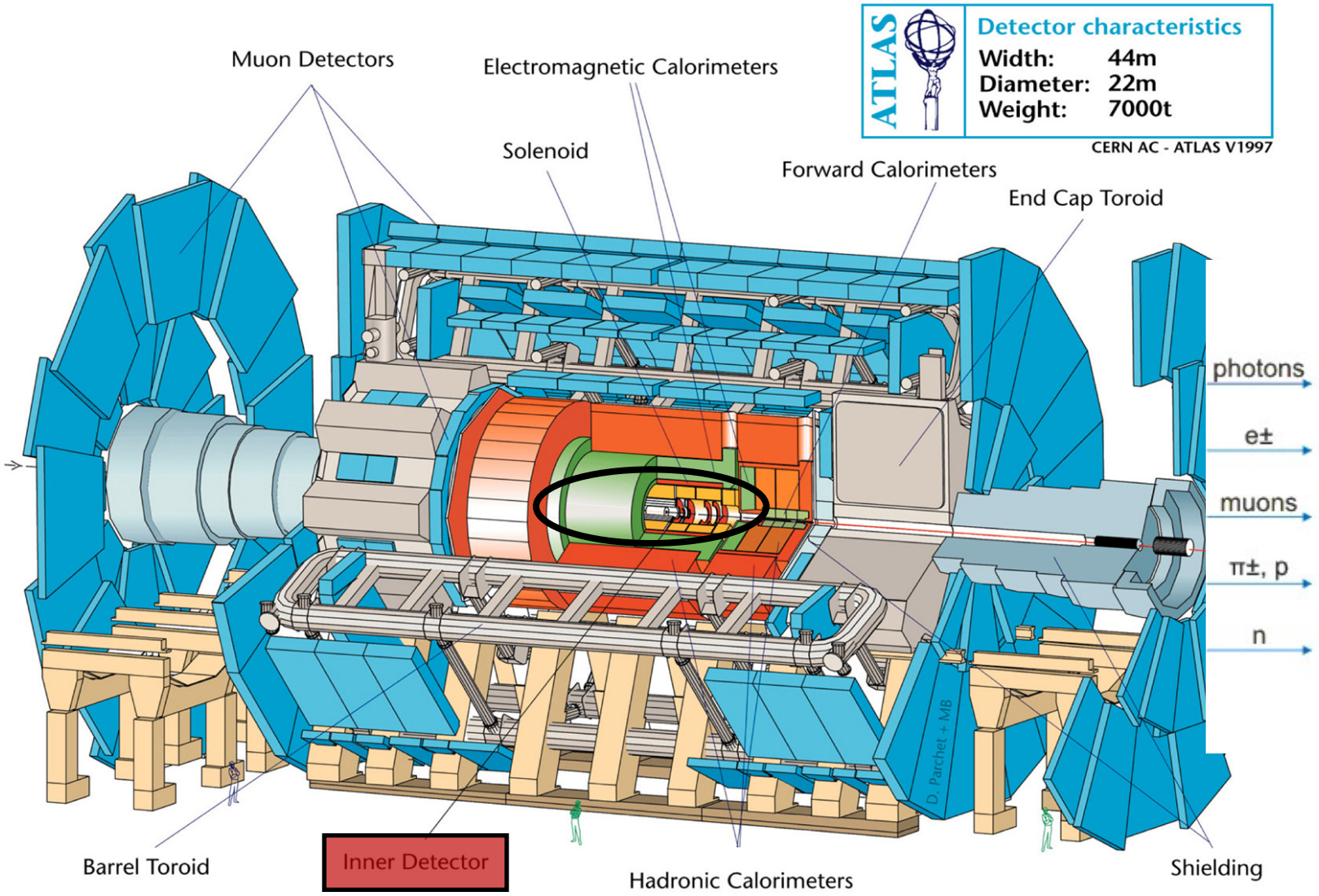
Conclusion

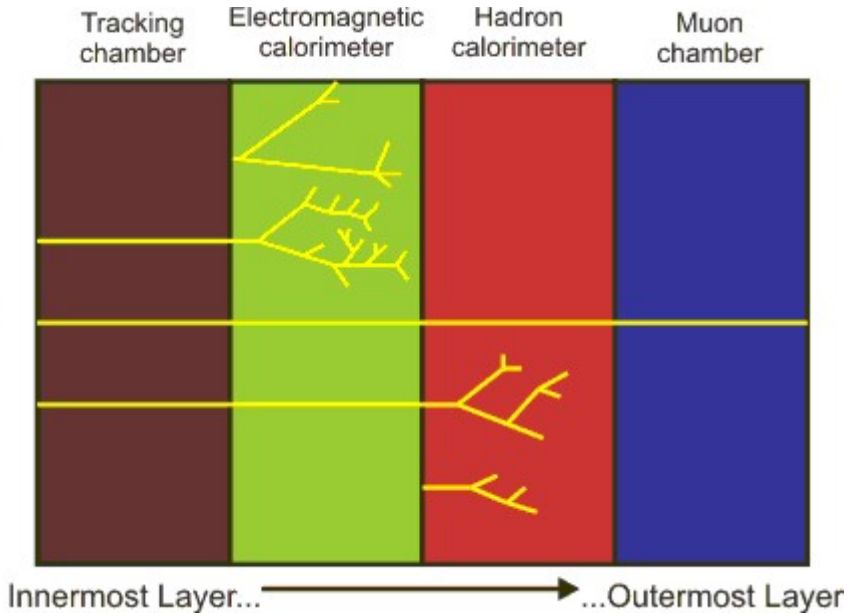
ATLAS Detector





ATLAS Detector





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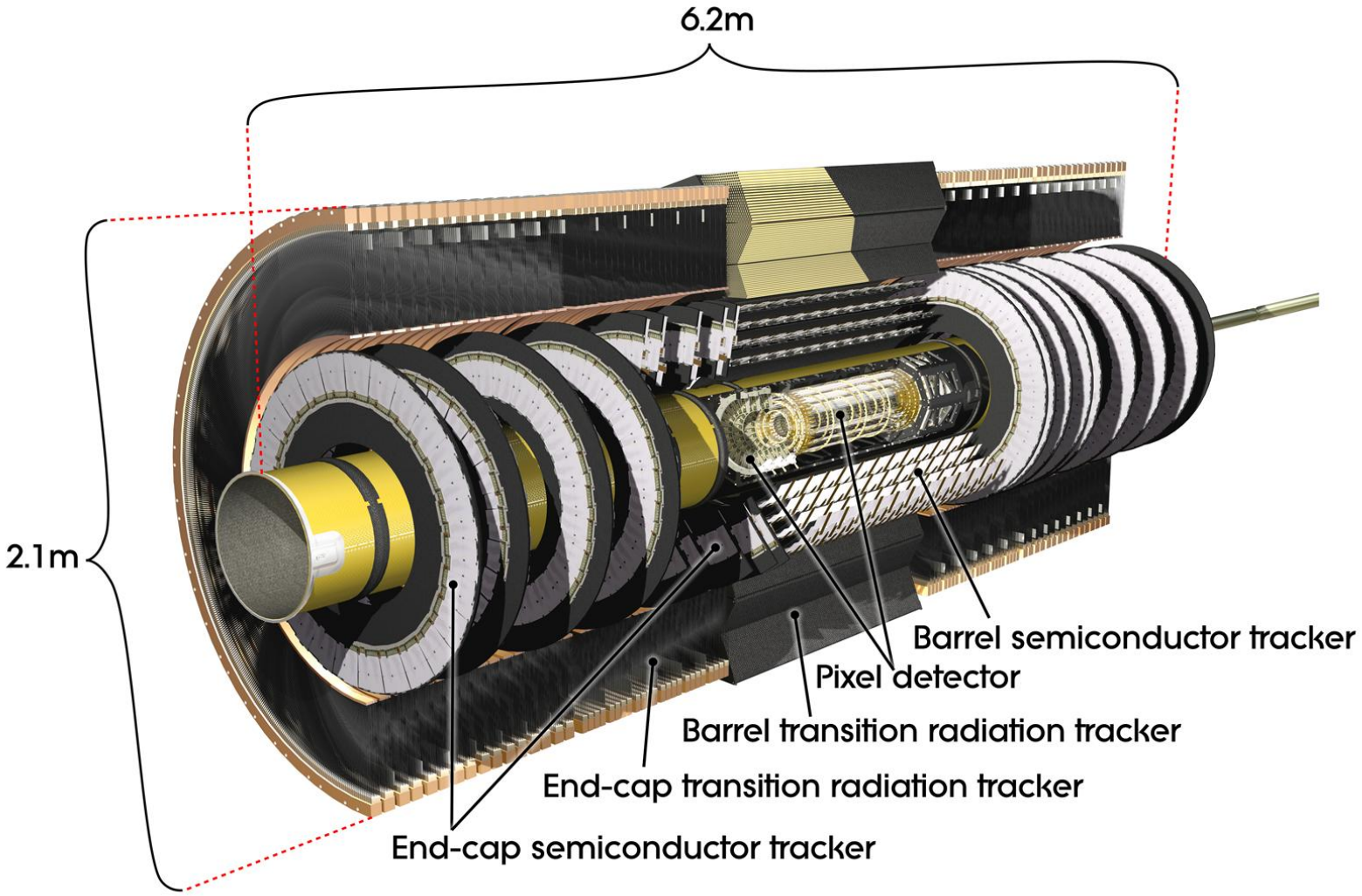


Inner Detector:

- innermost part of ATLAS
- situated in a 2T solenoidal magnetic field
- barrel and disk regions
  - hermetically coverage
  - perpendicular hits

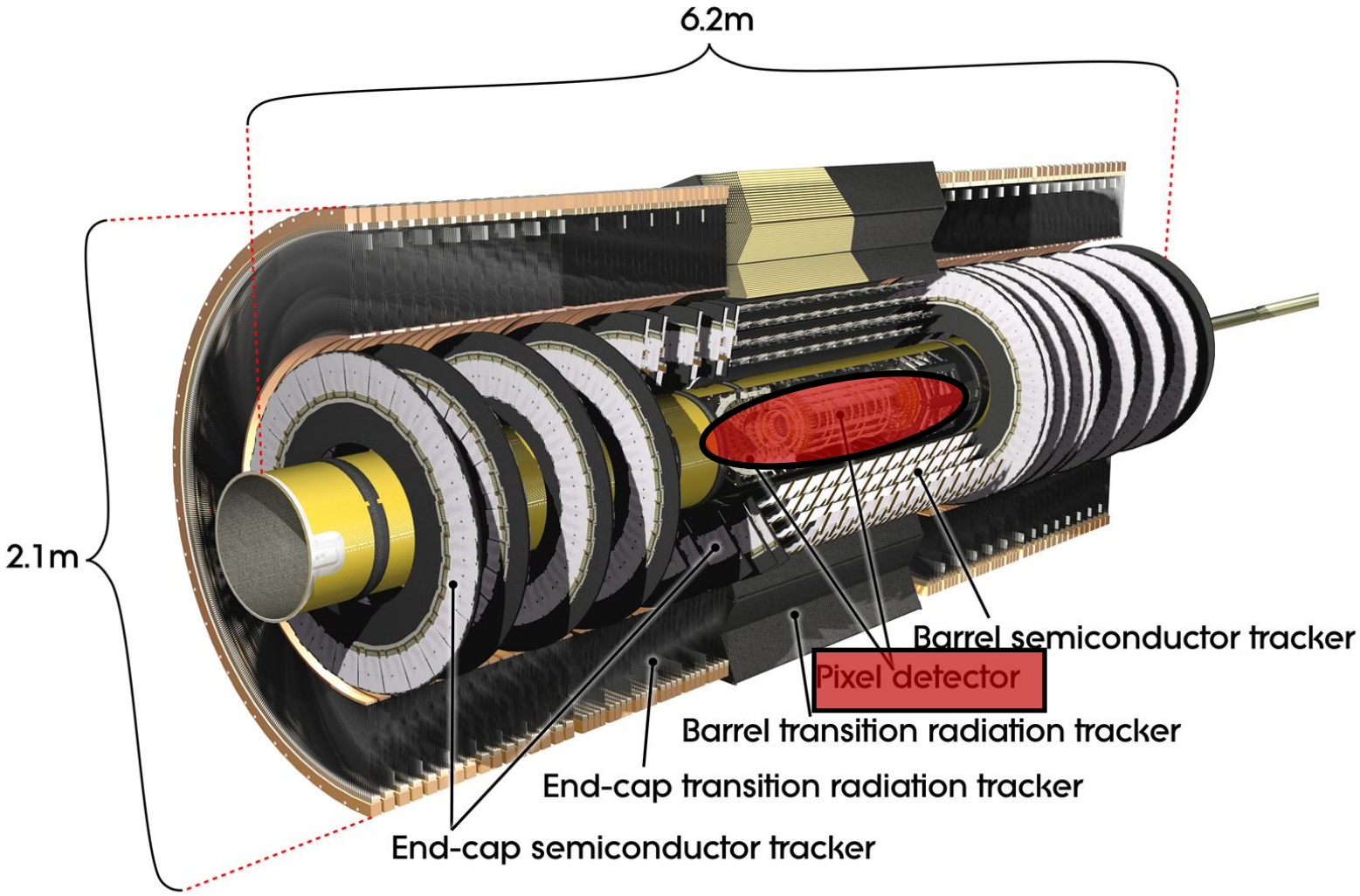
Function:

- track reconstruction of charged particles
- momentum reconstruction
- vertex finding / b-tagging
- particle identification

Components:

- Pixel Detector (PD/PIXEL)
  - 4 space-points
- Strip Detector (SCT)
  - 4 space-points
- Transition Radiation Tracker (TRT)
  - 36 space-points

ATLAS Inner Detector



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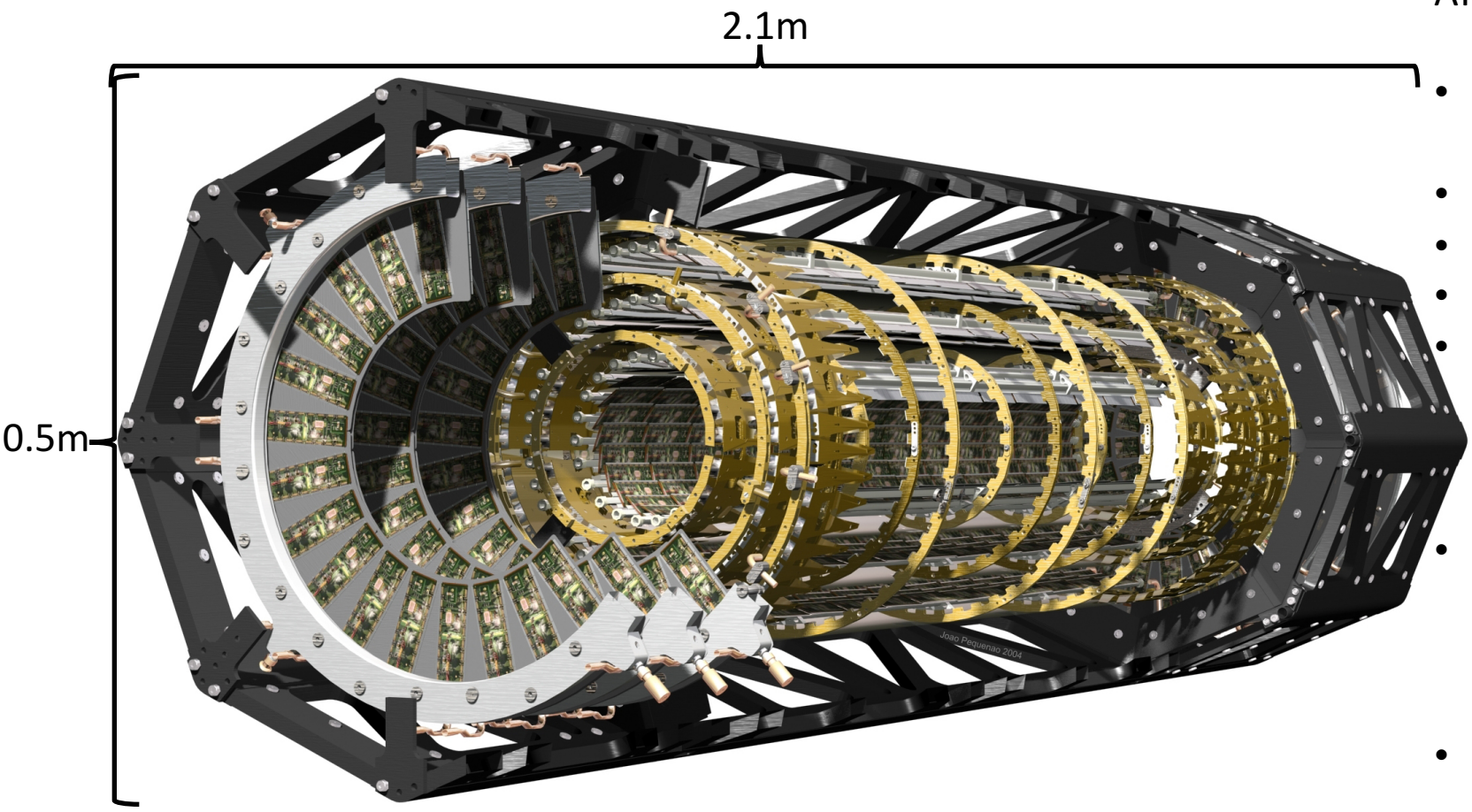
ATLAS Pixel Detector



ATLAS Pixel Detector:

- originally 3 barrel layers (PIXEL)
  - Insertable B-Layer is #4
- 3 disks per side
- hybrid pixel detector modules
- 80.4 (+24.1)M channels
- 10 µm resolution in Rφ and 110 (72) µm in z
  - given by pixel cell size

- needs to cope with highest
  - track density –> high granularity
  - rate –> precise timing

- crucial for
  - impact parameter resolution
  - b-tagging

Excursion: Resolution

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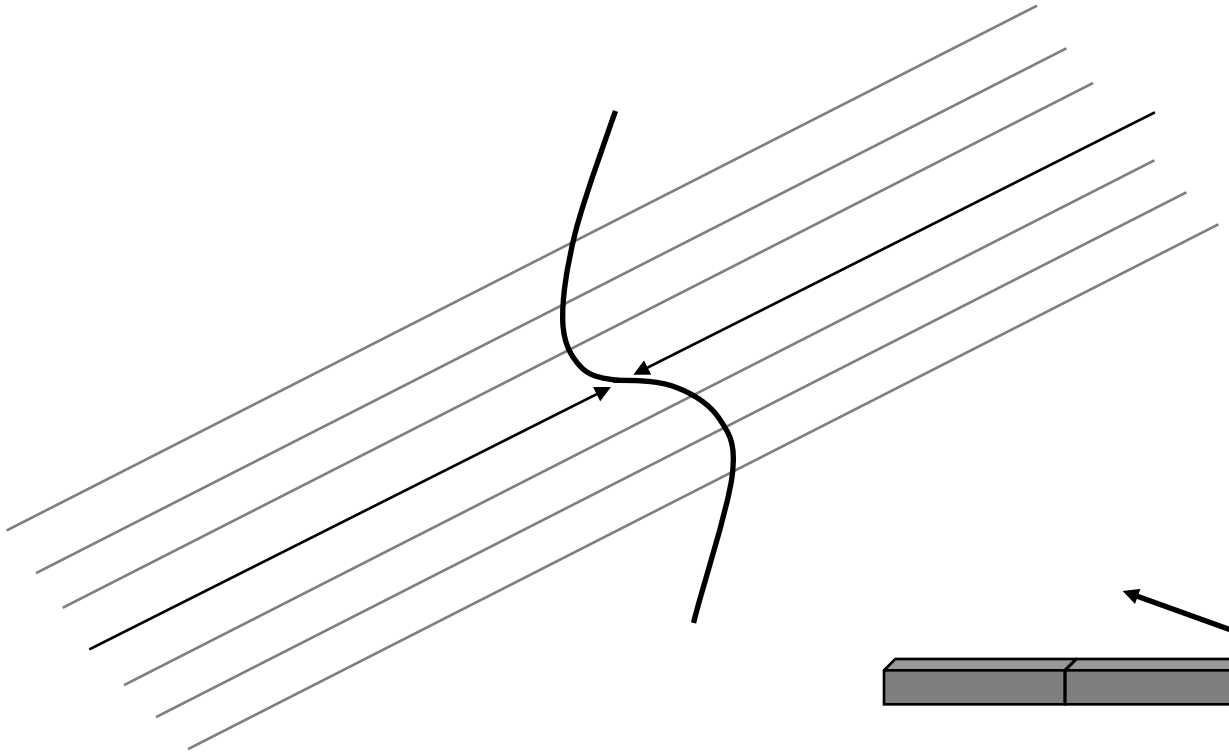
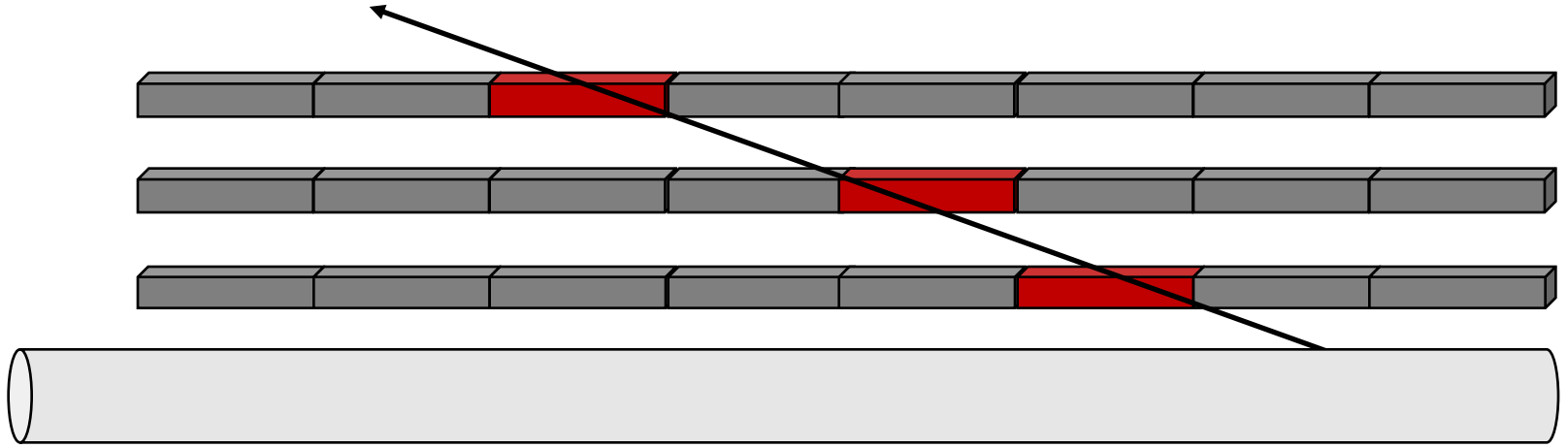


Necessary Resolution:

- low along the beam pipe (z)
  - straight line



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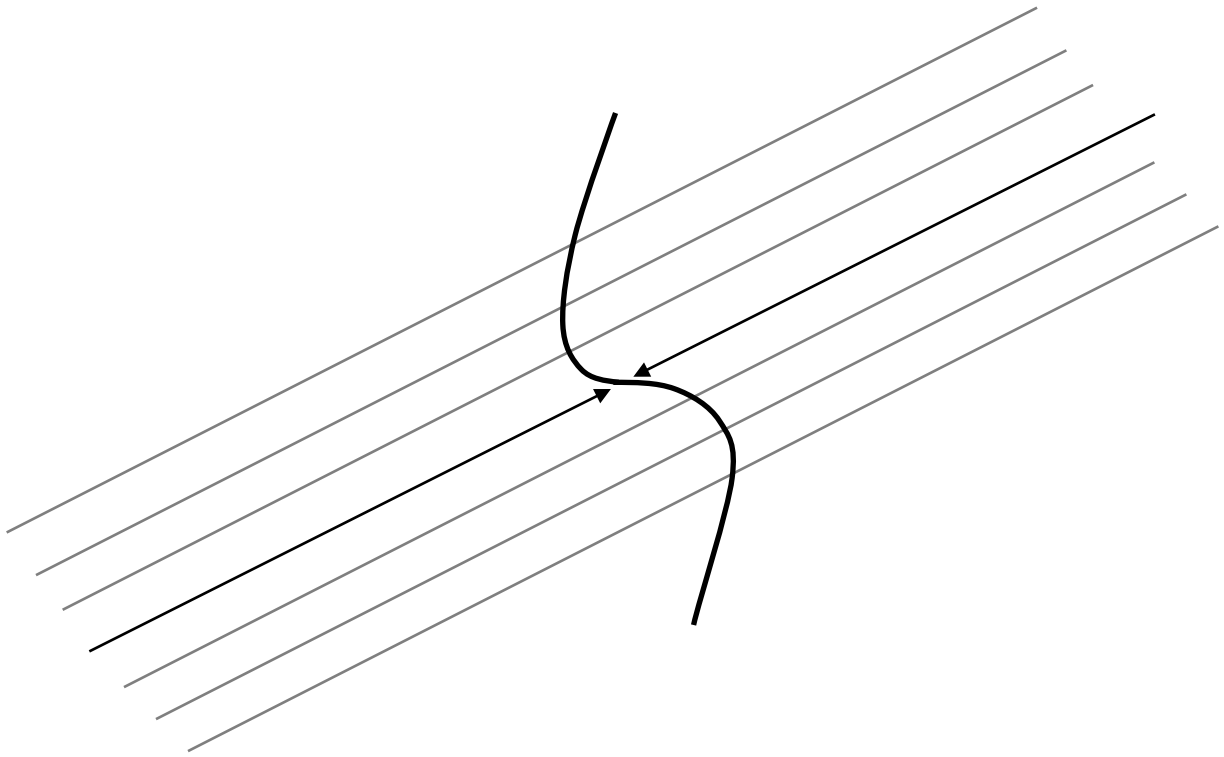
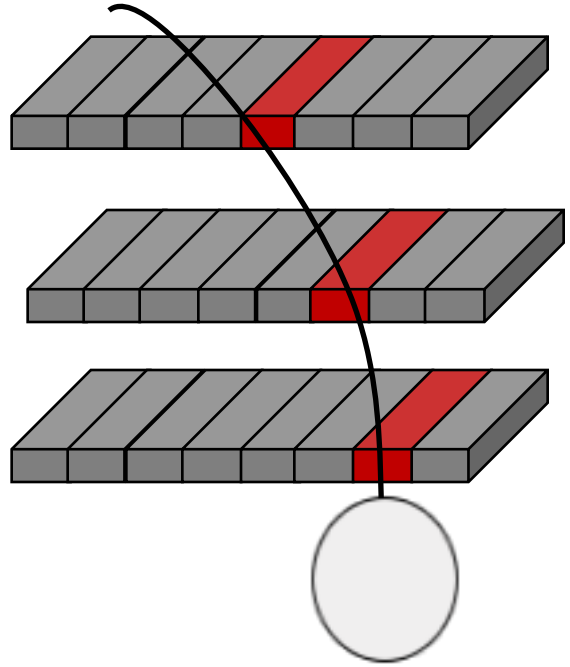
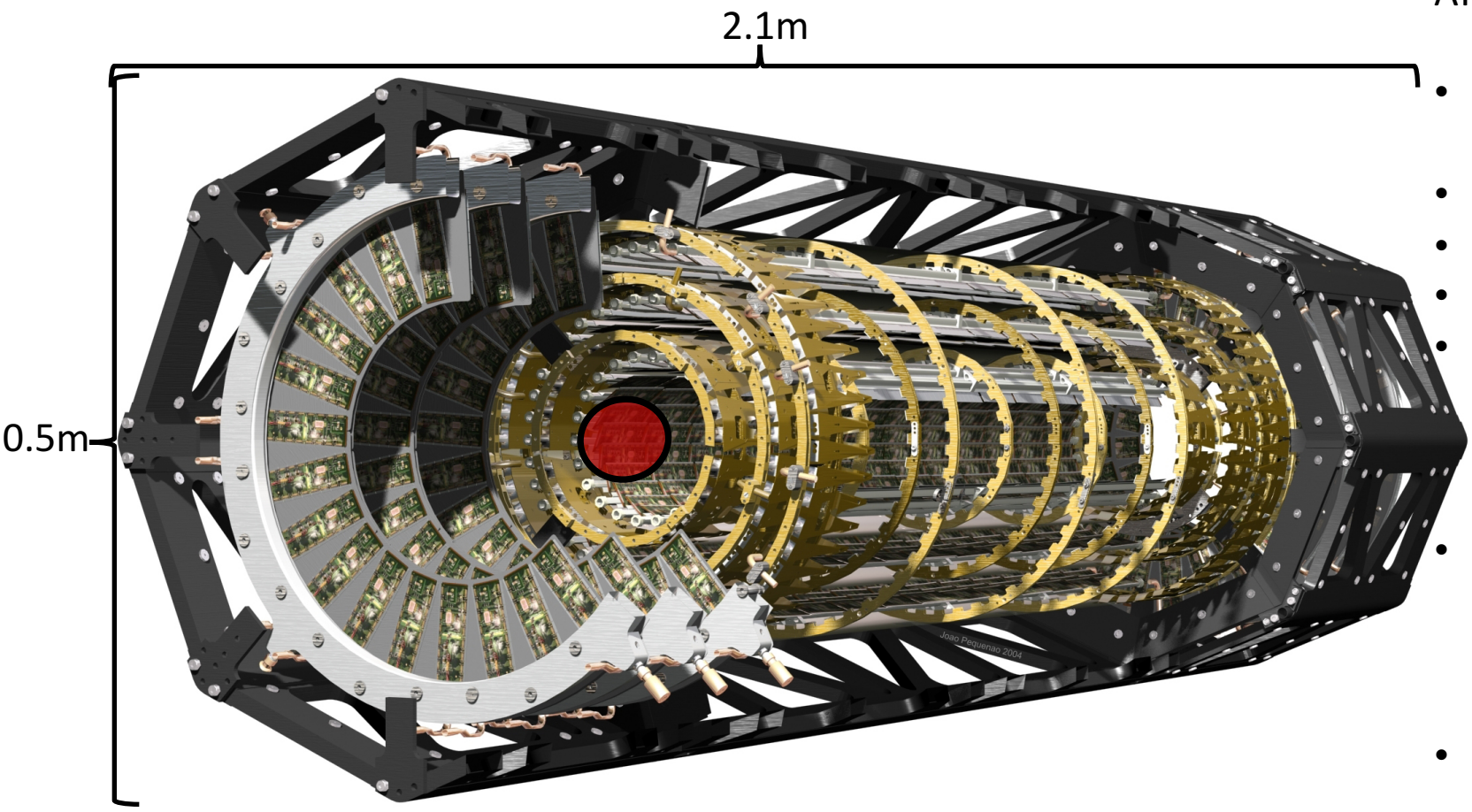


Necessary Resolution:

- low along the beam pipe (z)
  - straight line
- high in bended direction (Rφ)
  - measure curvature for p_T



ATLAS Pixel Detector



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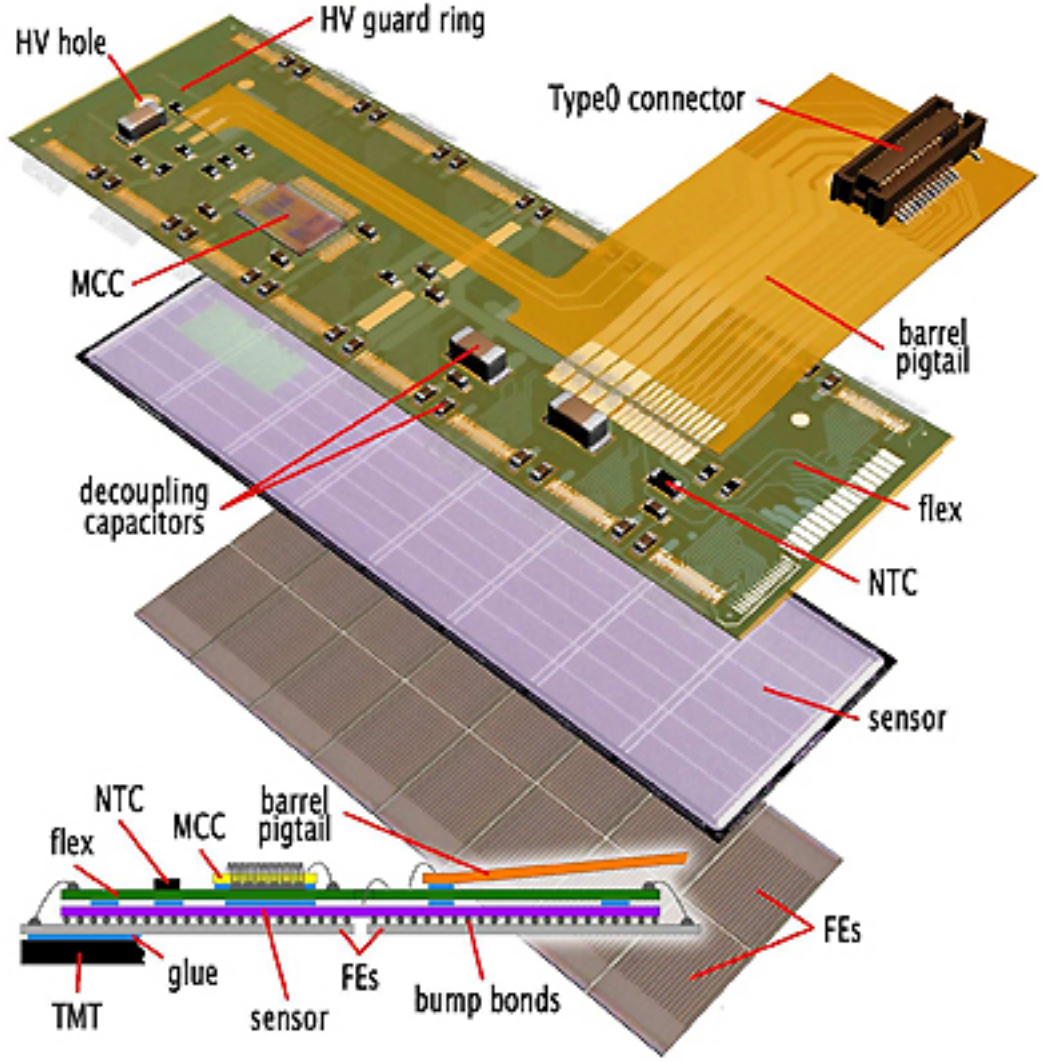
- crucial for
  - impact parameter resolution
  - b-tagging

ATLAS Pixel Detector



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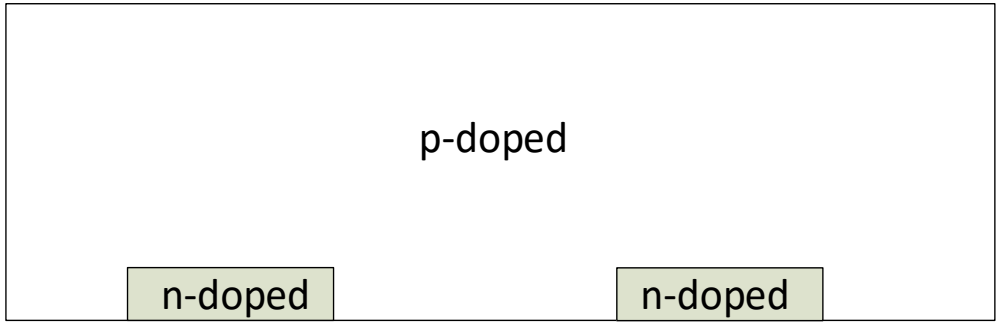
Semiconductor Pixel Detector

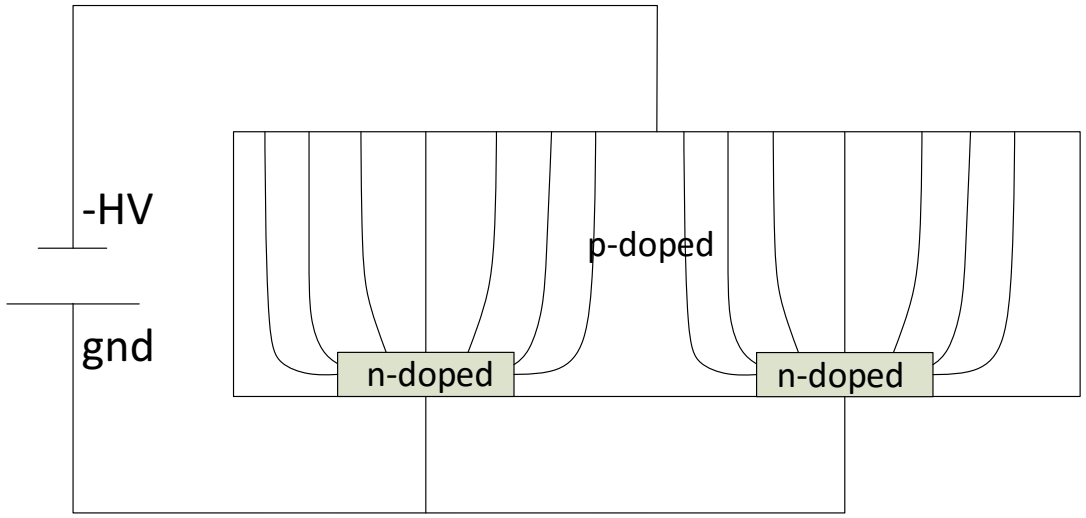


sensor

Silicon sensor:

- n-type electrode
  - collection of electrons (fast)
- typically high purity (high resistivity) bulk material
- current ATLAS technology: n-in-n
- next generation sensor technology: p-type substrate
  - available in industry
  - potential cost reduction

Semiconductor Pixel Detector

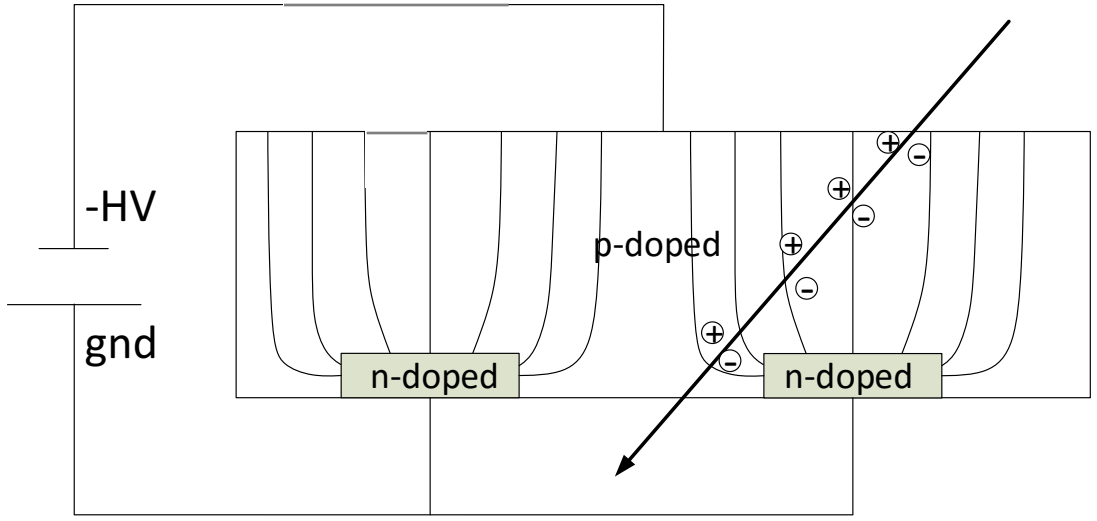


sensor

Detection mechanism:

- apply high bias voltage in reverse direction
- E-field builds up from junction to backside
- E-field collects all free charge carriers
  - $U_{bias} > U_{depl}$

Semiconductor Pixel Detector

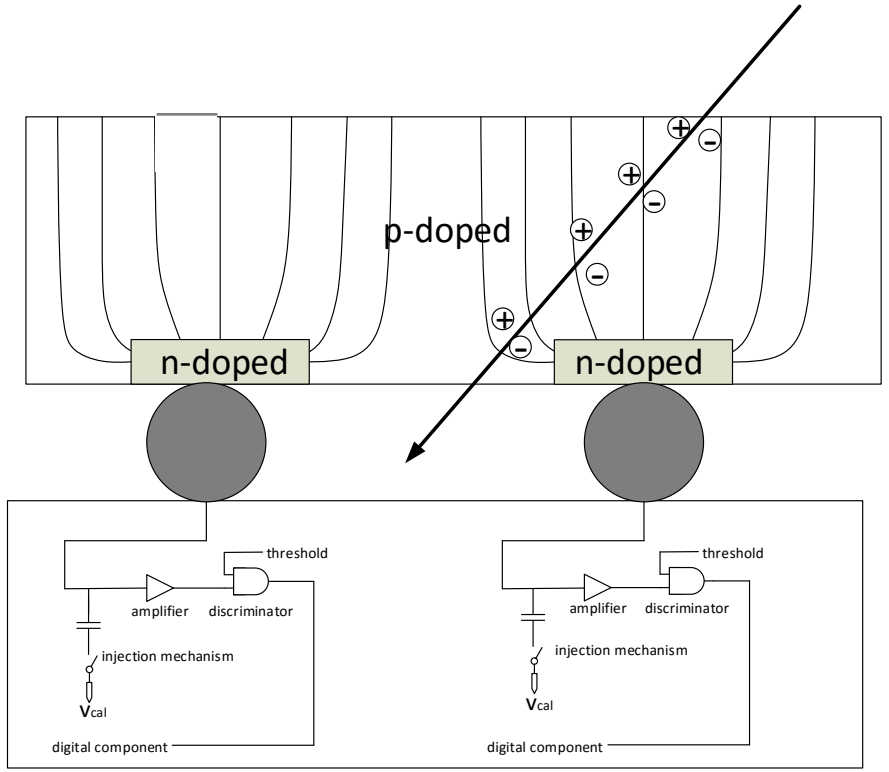


sensor

Detection mechanism:

- apply high voltage in reverse direction
- E-field builds up from junction to backside
- E-field collects all free charge carriers
  - $U_{bias} > U_{depl}$
- charged particles generate electron/hole pairs
- electrons move towards the electrode and induce a signal

Semiconductor Hybrid Pixel Detector



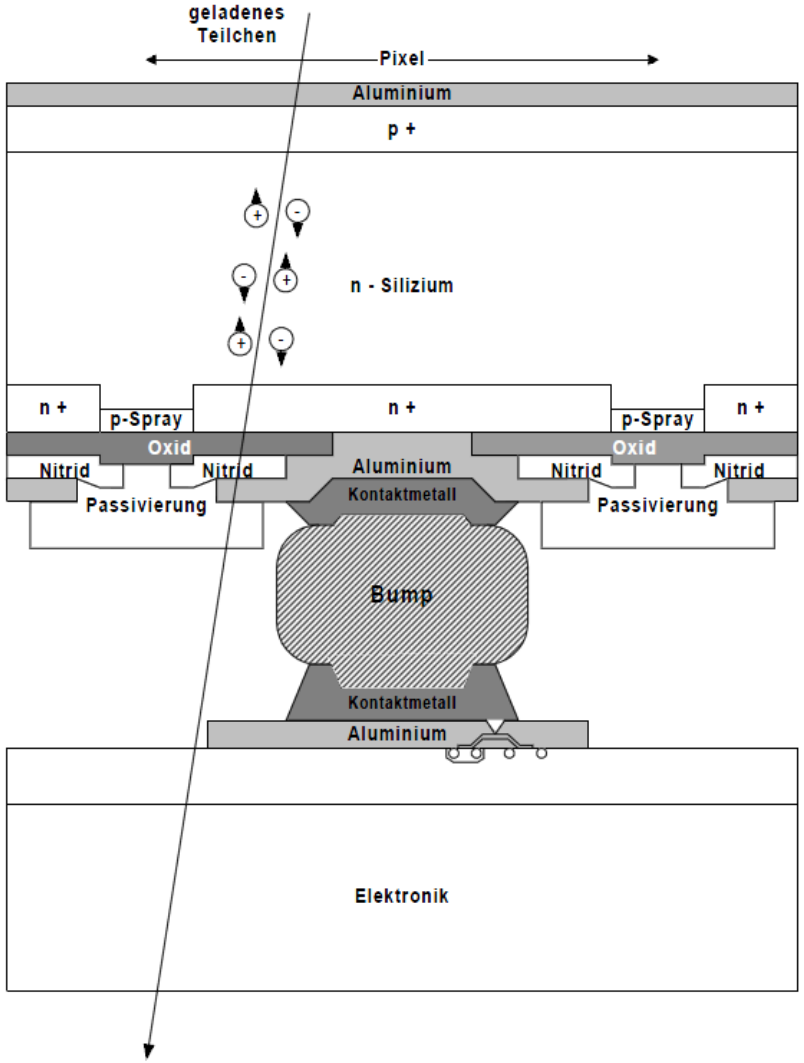
sensor

front-end

Detection mechanism:

- apply high voltage in reverse direction
- E-field builds up from junction to backside
- E-field collects all free charge carriers
  - $U_{bias} > U_{depl}$
- charged particles generate electron/hole pairs
- electrons move towards the electrode and induce a signal
- signal is read-out via an attached front-end chip
  - -> hybrid pixel detector

Hybrid Pixel Detectors



- hybrid pixel detectors are composed of sensor and read-out chip connected by solder bump-bonds
- monolithic pixel detectors combine read-out and sensor in one chip
- hybrid approach is most powerful in terms of speed and radiation tolerance

- ATLAS uses hybrid pixel detectors only:
  - PIXEL: 400x50 μm^2 pixel size, n-in-n
  - IBL: 250x50 μm^2 pixel size, n-in-n

Solder Bump-Bonds

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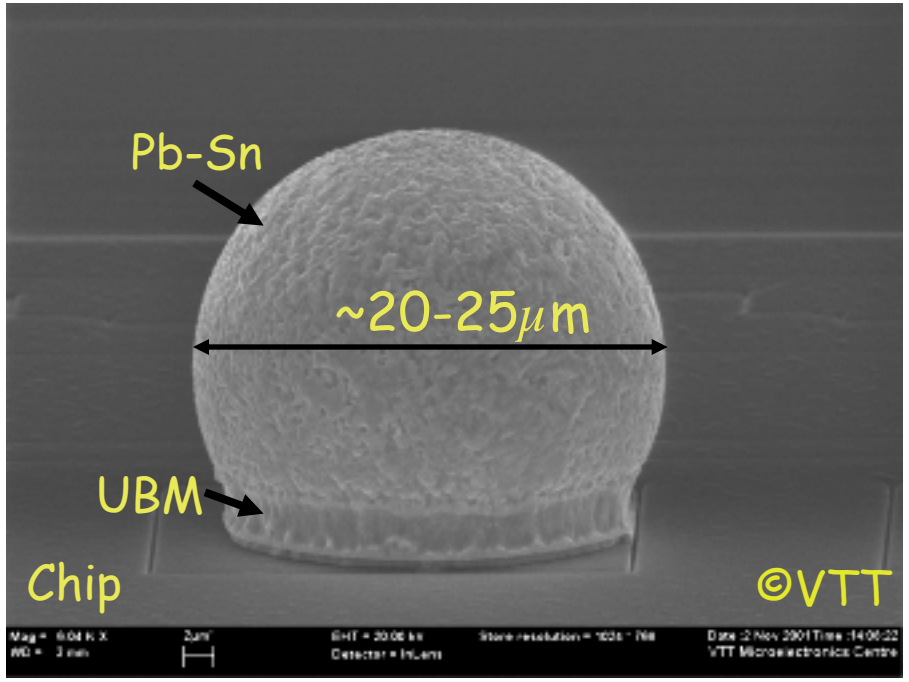
a) Sputter etching and sputtering of the plating base / UBM

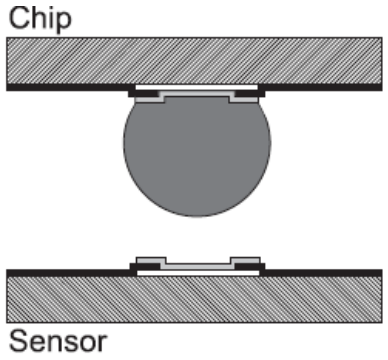
b) Spin coating and printing of Photoresist

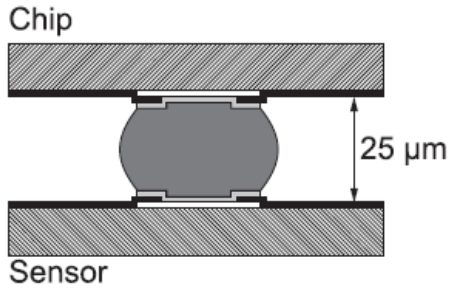
c) Electroplating of Cu and PbSn

d) Resist stripping and wet etching of the plating base

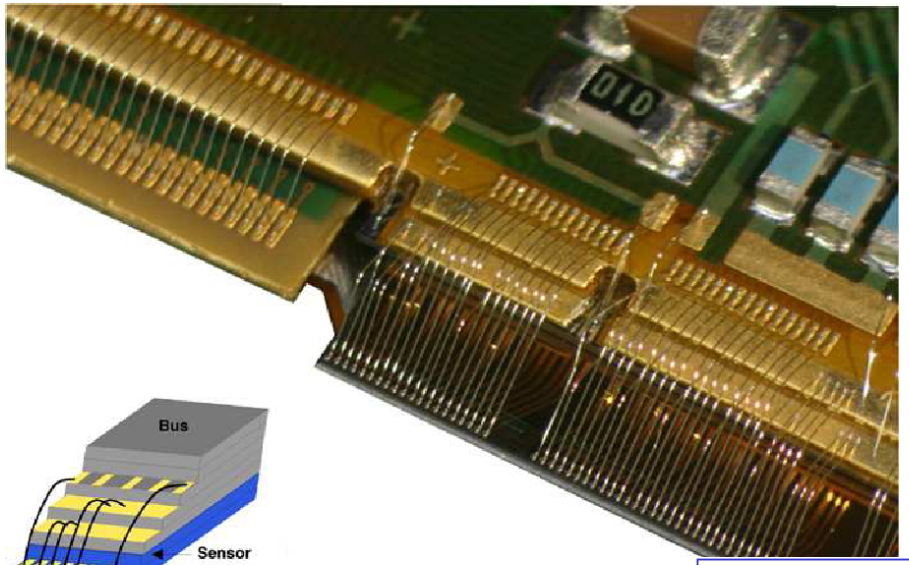
e) Reflow

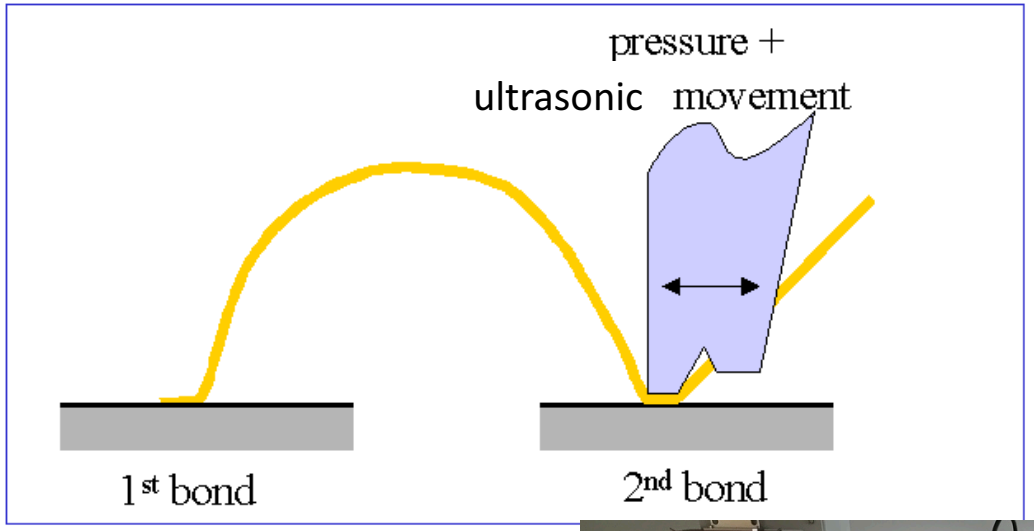


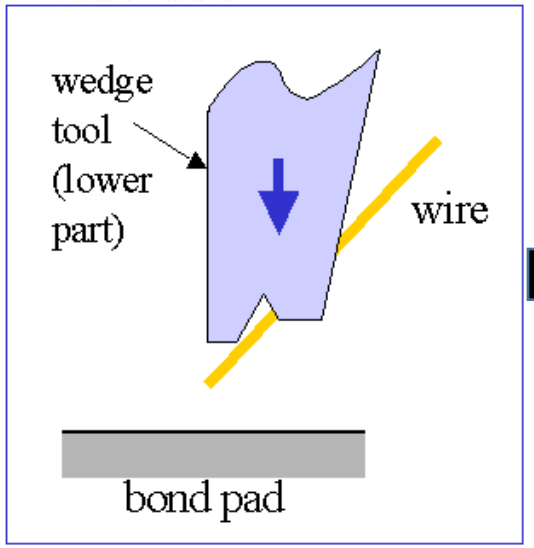


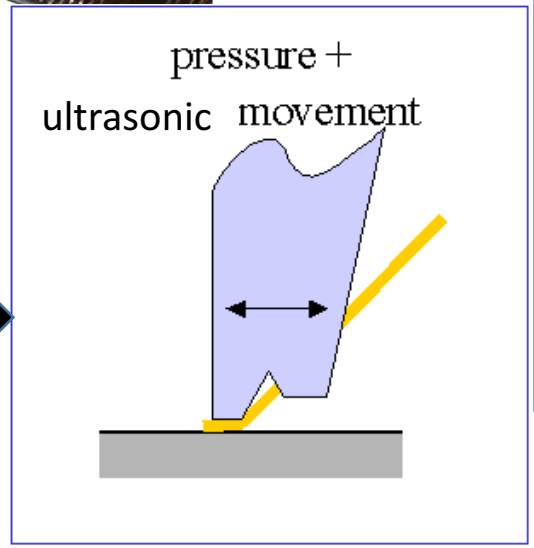


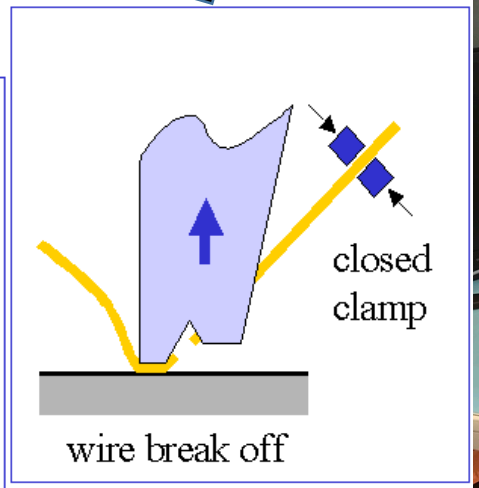
Wire Bonds

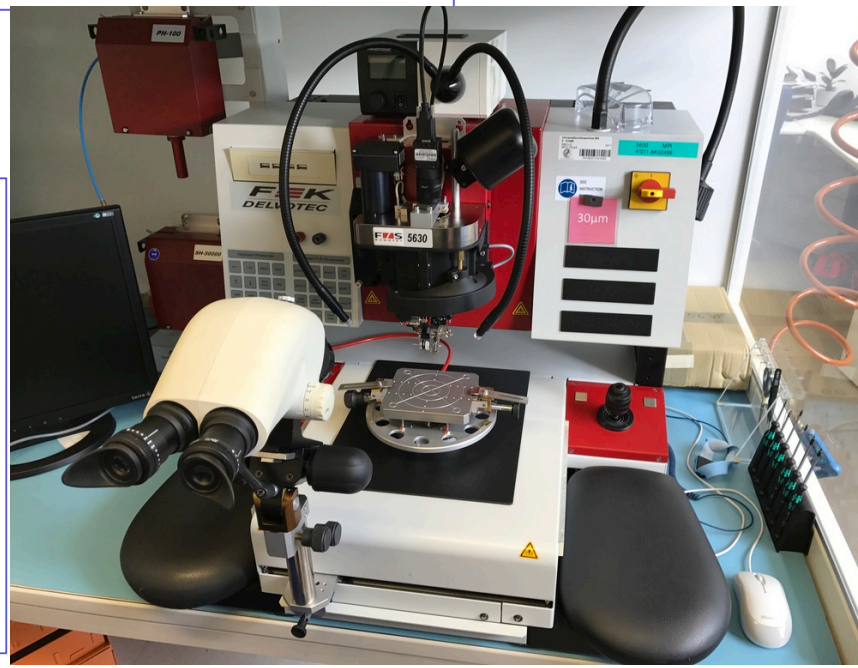










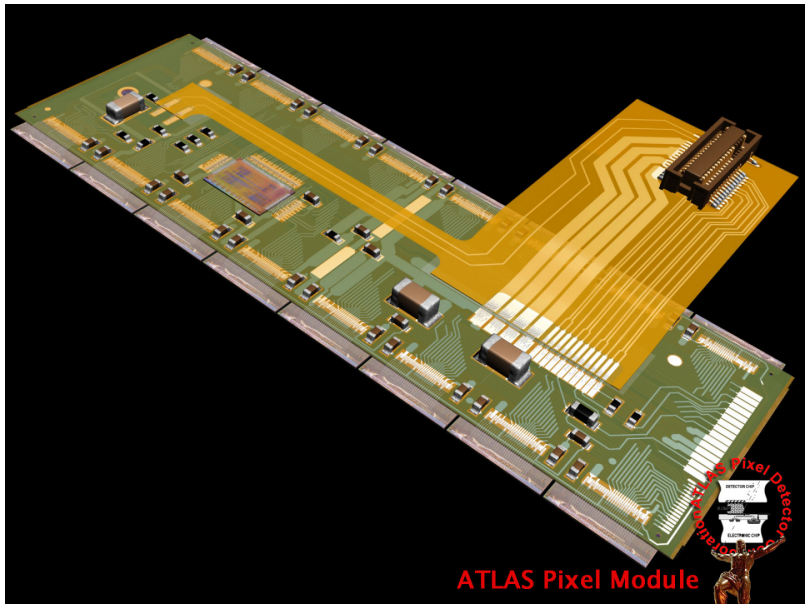


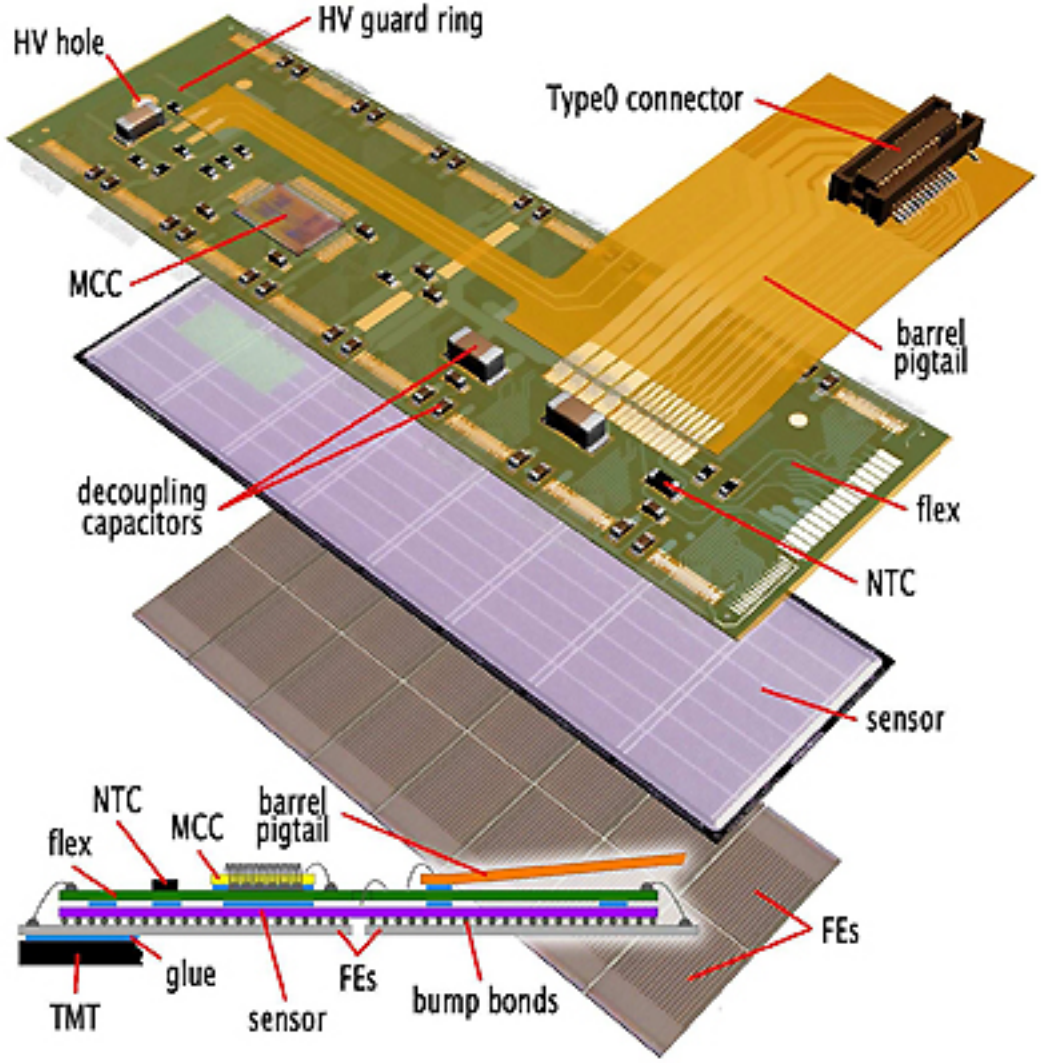
Wire bonds are necessary to transmit:
- data and control signals
- power

ATLAS Pixel Modules

Components:

- 1 sensor
- 16 FE chips
- flex circuit print
- module controller chip (MCC)





ATLAS Strip Detector

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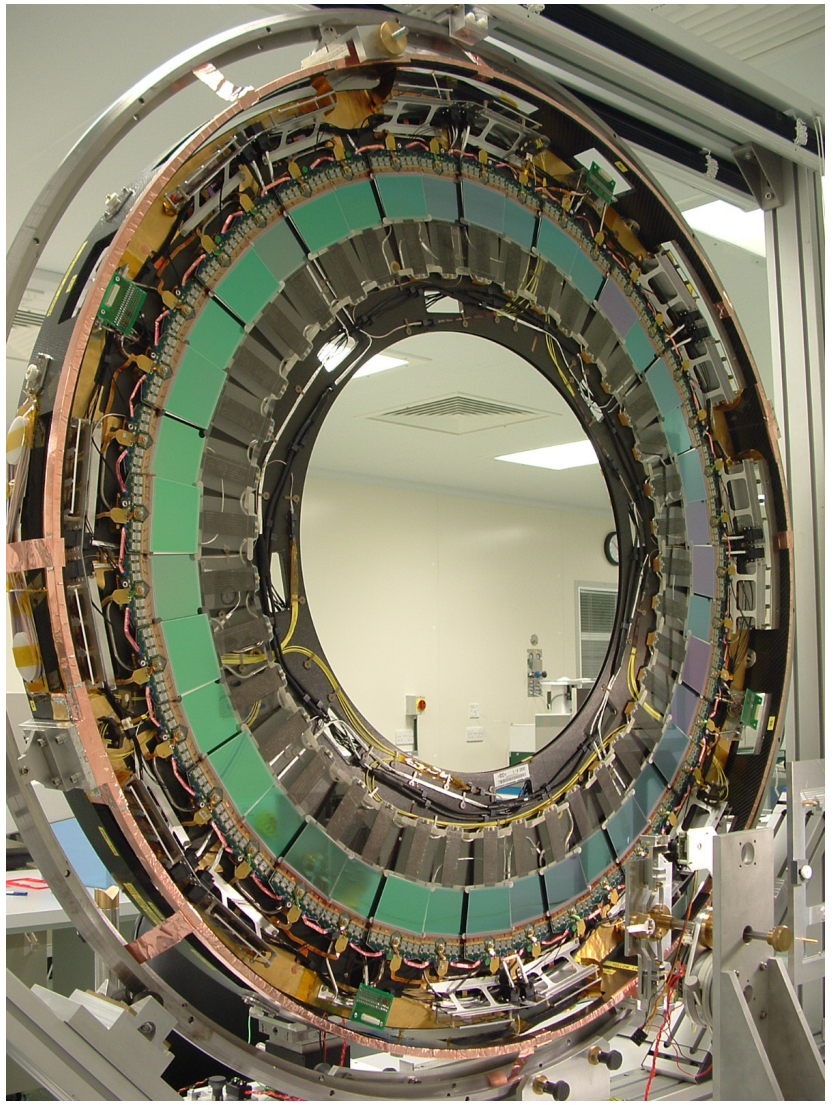
ATLAS SCT
- double-sided modules
- 6.3M channels
- 16 µm resolution in Rφ and 580 µm in z

- 4 barrel layers
  - 80 µm pitch strips
- 9 disks per side
  - 70-90 µm pitch strips

- 30% of disk modules produced at MPP!

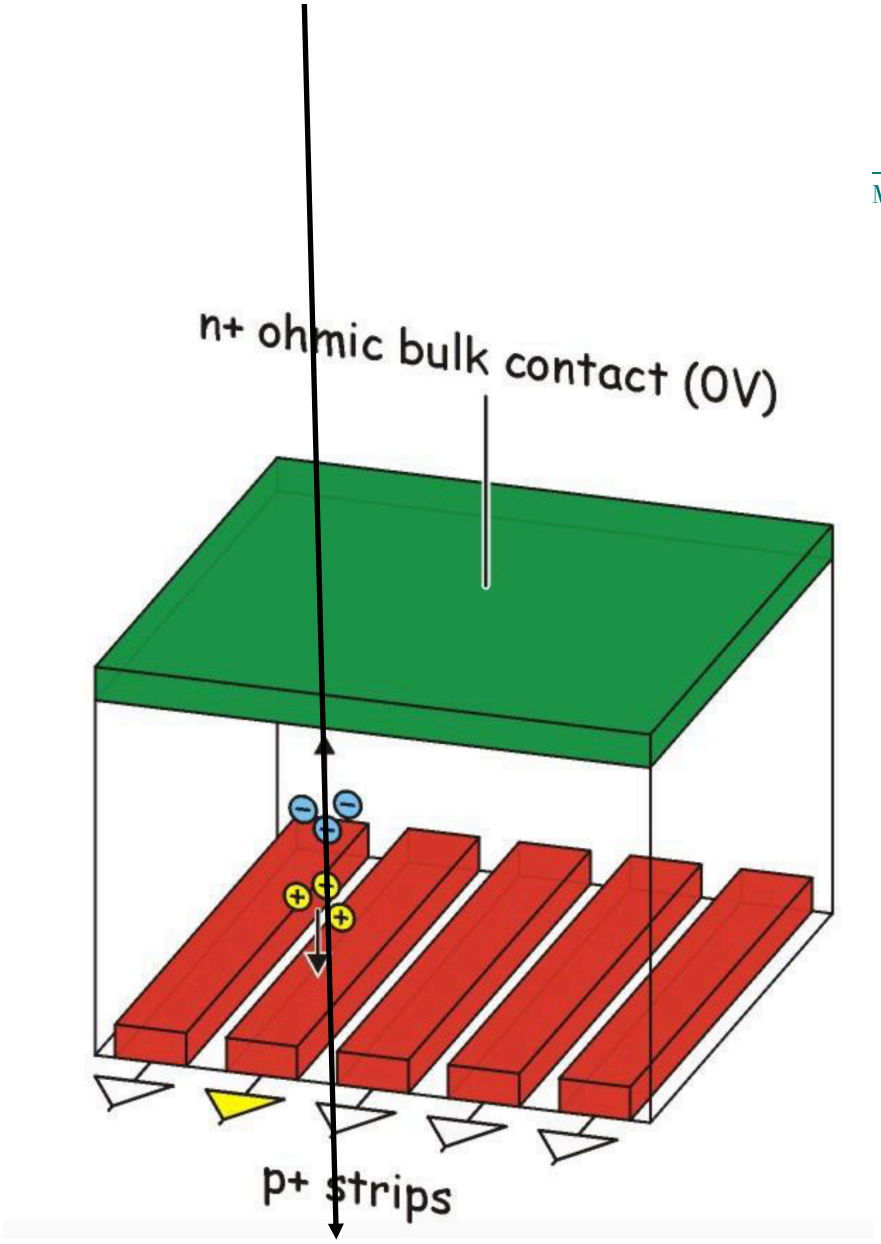
Function:
- cover large area (61.1m^2)
- best compromise of cost and precision



Strip Detector

Working principle:

- strip detector is pixel detector with long pixels
  - resolution in one direction bit worse
  - resolution in other direction much worse
- only 1D information given!
- read-out each single strip



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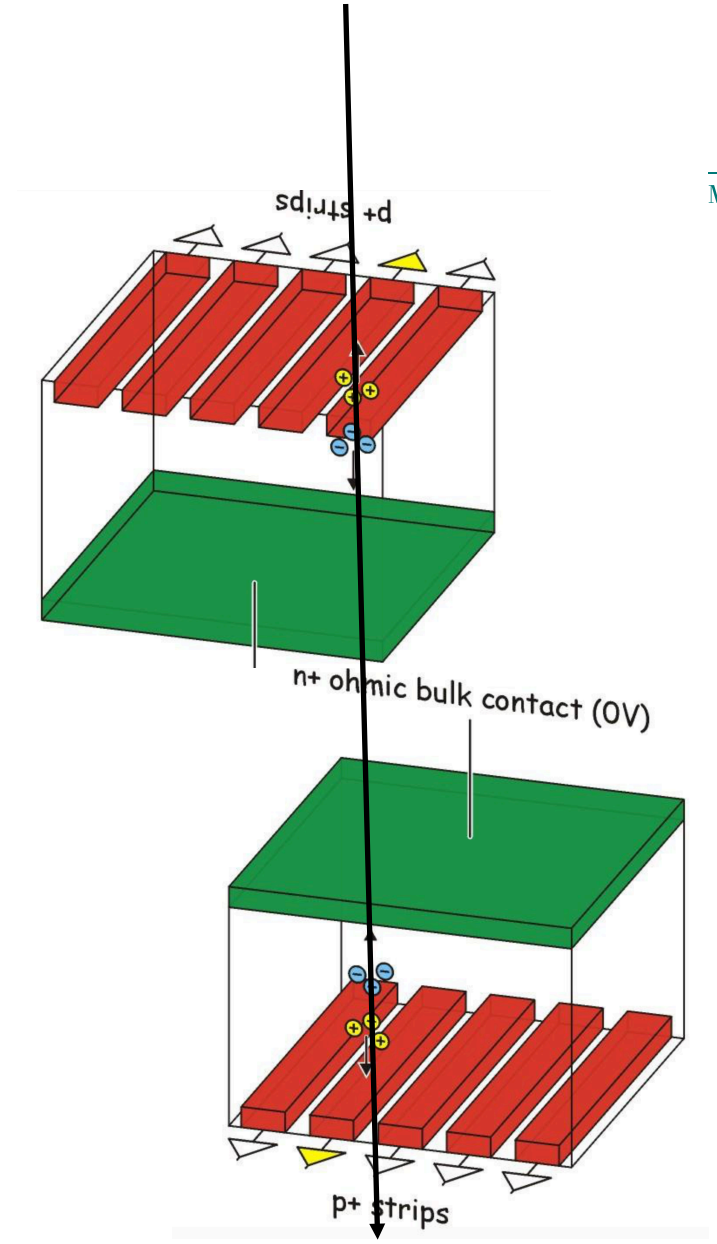
Improvements:
- use another rotated sensor on top
- ATLAS uses rotation angle of 40 mrad
- 2D information by combination



ATLAS Transition Radiation Tracker

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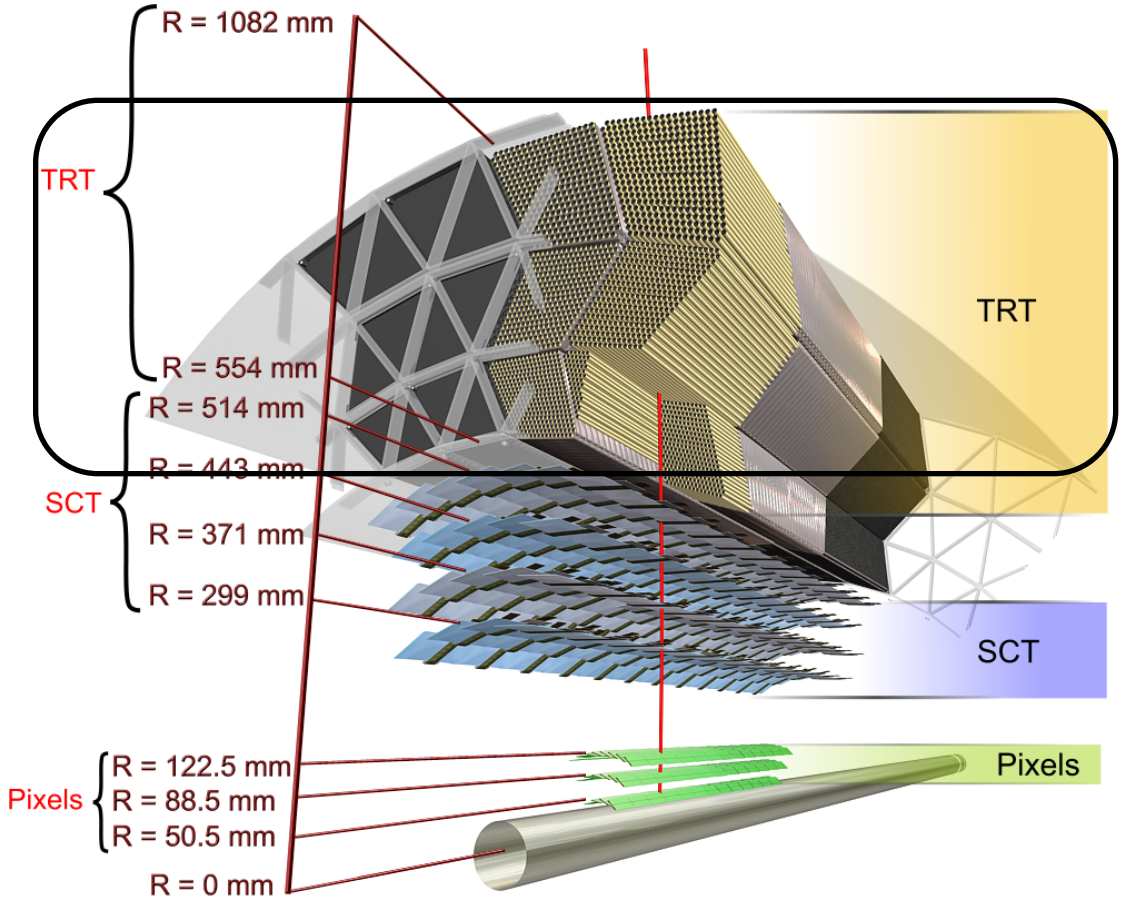
ATLAS TRT

- separated into barrel and disks
- barrel with straws parallel to beam
- disks with straws perpendicular to beam
- 400k channels
- straws have diameter of 4mm
- 170 μm resolution in Rφ, 40-75cm length

Function:

- provide tracking at large radii
- particle identification via TR
- trigger information
- best cost-effectiveness



Transition Radiation Detector

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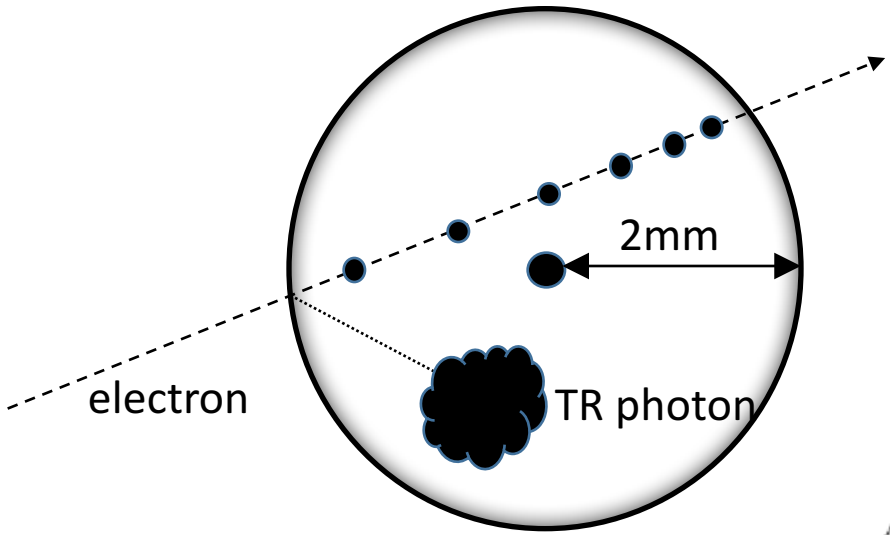
Theory:

- charged particles emit gamma radiation (x-ray energies) when entering a different media
- intensity given by $I = \frac{\gamma\, q^2\, (\omega_1 - \omega_2)^2}{3c}$
- with $\gamma = \frac{E}{mc^2}$
- mass of a particle can be calculated for known energy
- used here for electron/hadron identification

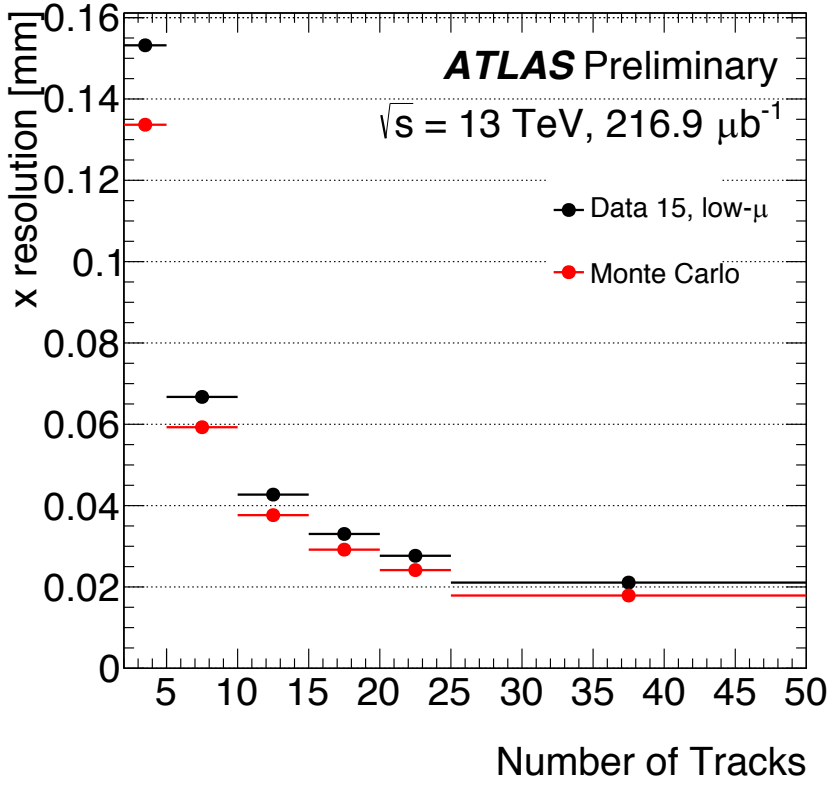
Experiment:

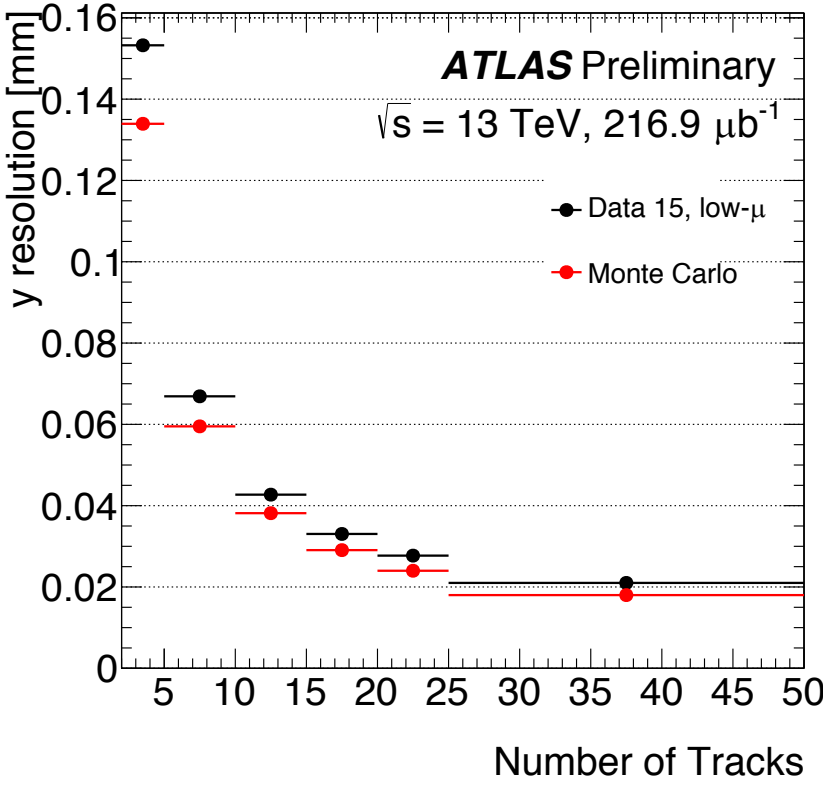
- thin straw tubes with anode wire as proportional counter
- two threshold read-out
  1. low threshold for ionization
  2. high threshold for TR-photons

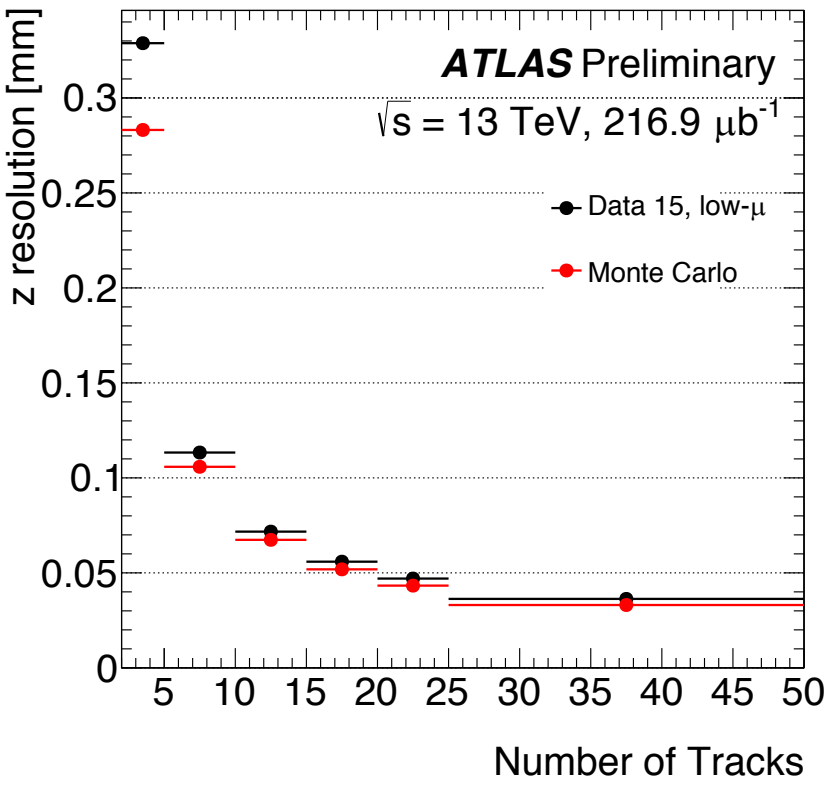


ATLAS ID Performance

Primary vertex resolution

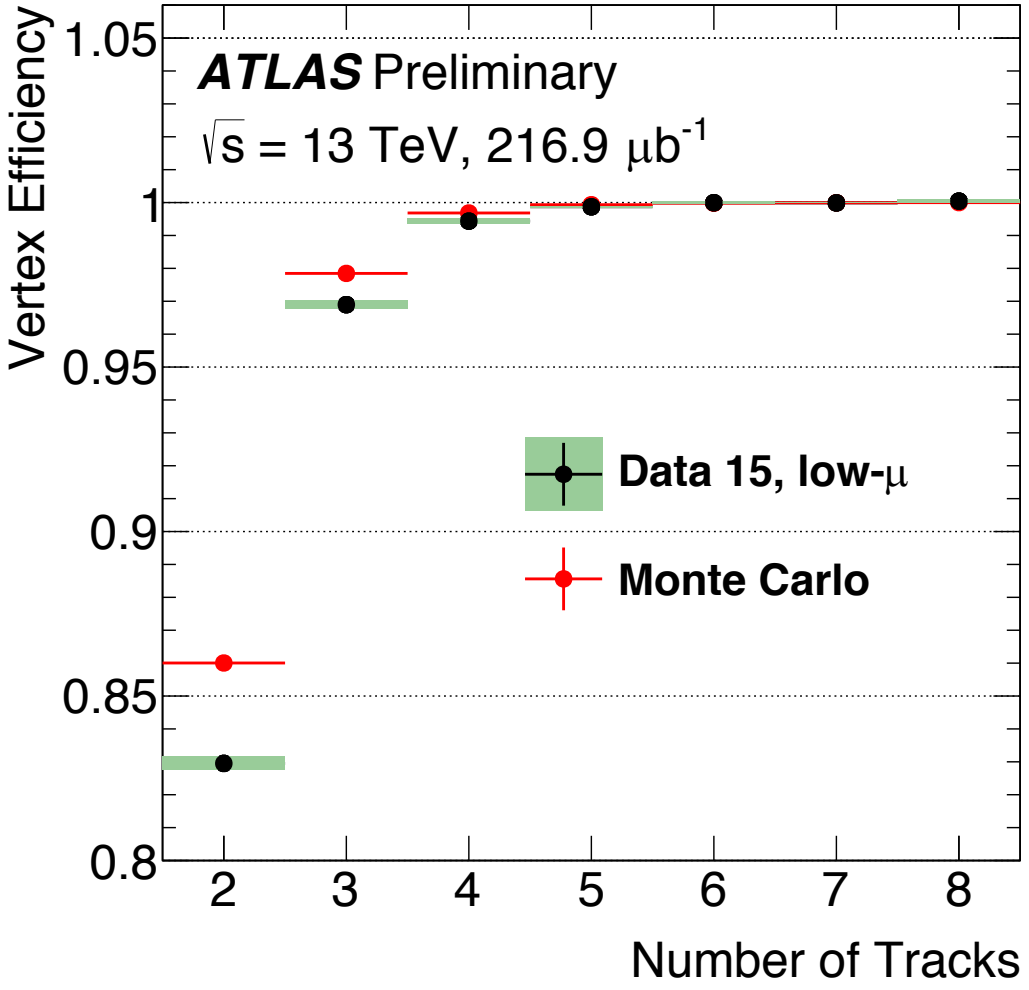






ATLAS ID Performance

Vertex reconstruction efficiency



ATLAS Inner Tracker (ITk) Upgrade

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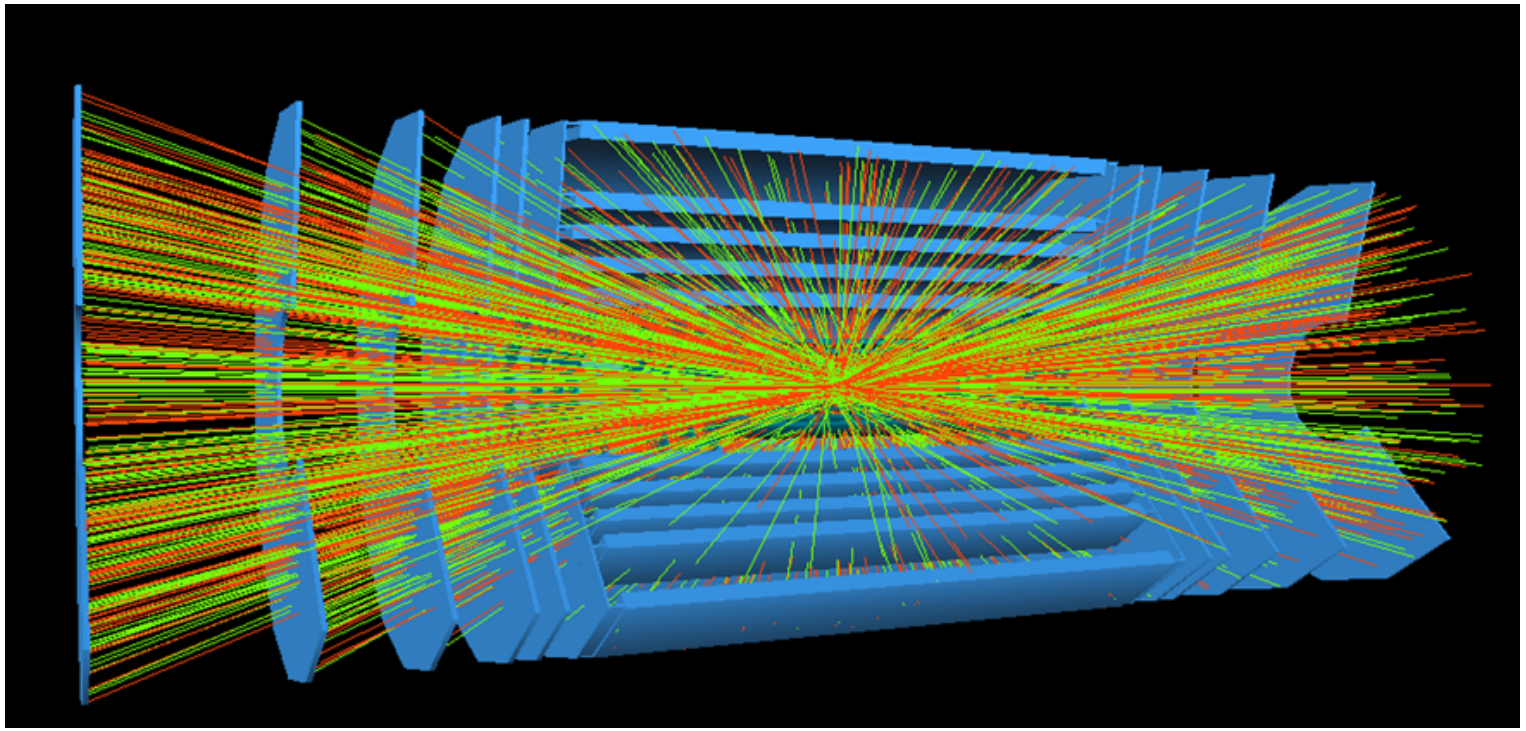
ITk:

- new tracking system facing HL-LHC
- concept foresees all silicon detector
  - 5 pixel layers
  - 4 strip layers

- main challenges
  - increased occupancy
    - $<\mu>=24 \rightarrow <\mu>=200$
  - more radiation damage
    - 5e15 n_{eq}/cm^2 → 14e15 n_{eq}/cm^2



Conclusion

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Inner Detector:

- composed of
  - Pixel Detector
  - Strip Detector
  - Transition Radiation Tracker

	Rφ – Resolution [μm]	**z– Resolution [μm]**
PD	10	110
SCT	16	580
TRT	170	750.000-1.500.000

- used for
  - precise tracking (including (secondary) vertex finding, impact parameter, p_T, …)
  - particle identification

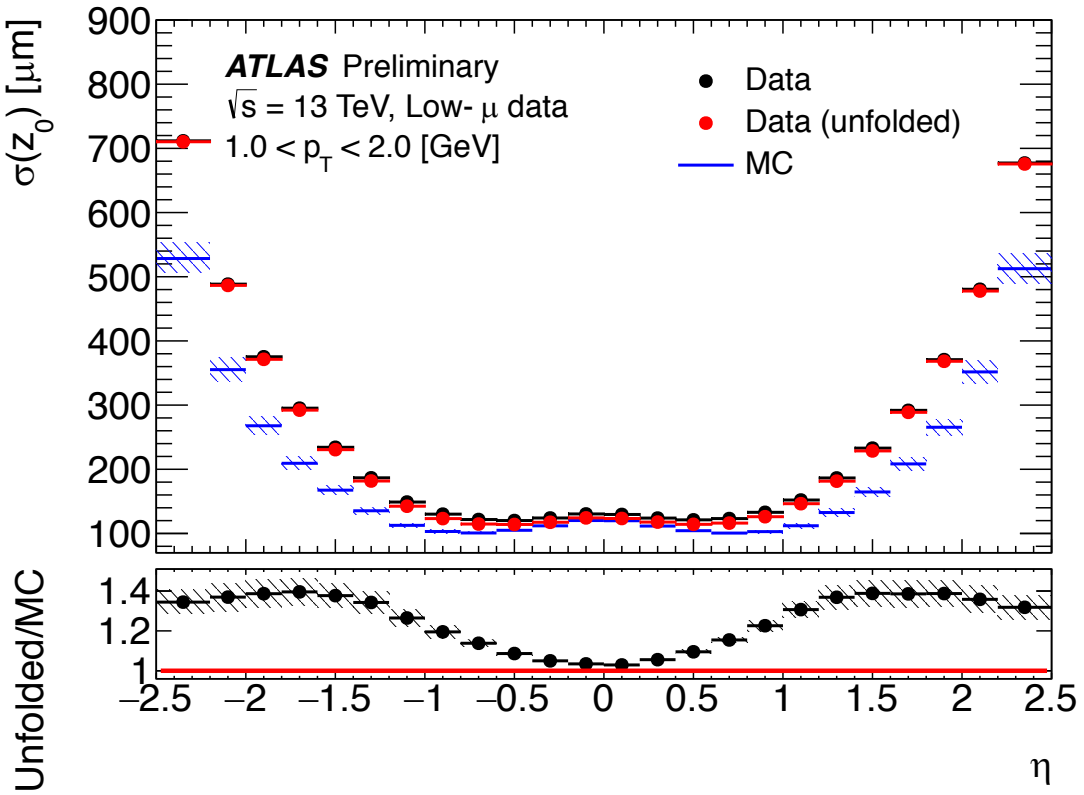
- reaches primary vertex resolution of 20 μm / 20 μm / 50 μm (x/y/z)

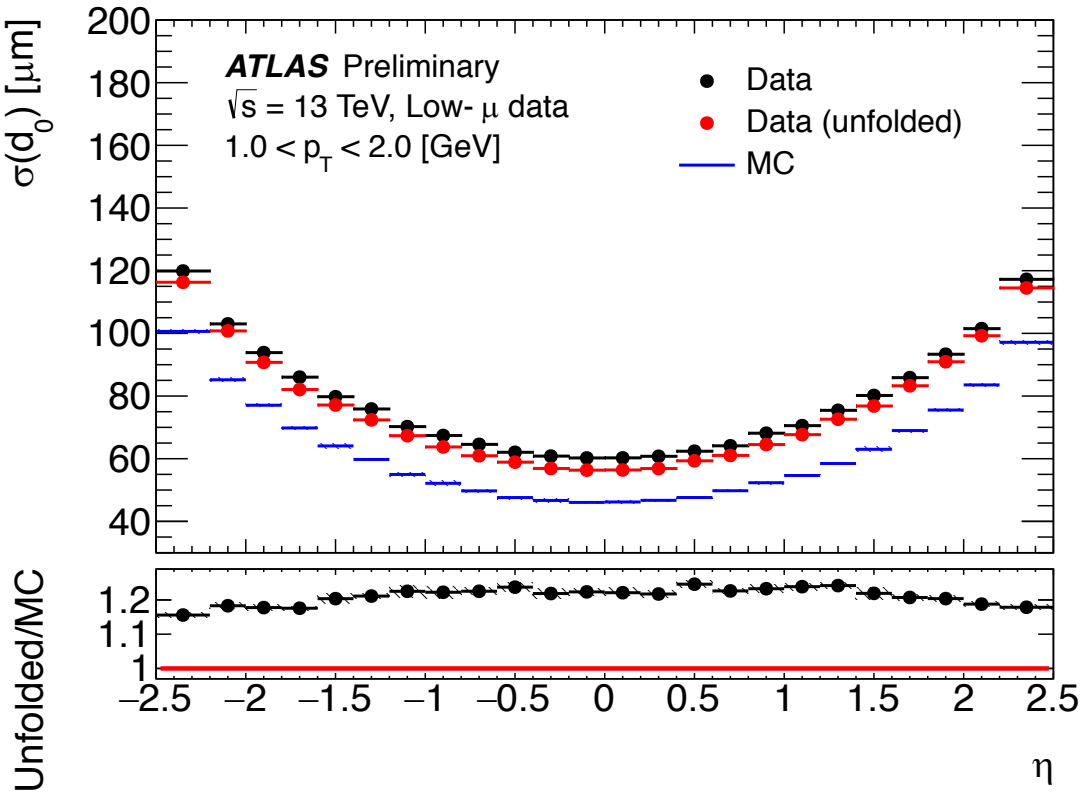
- will be replaced by the ITk

Thank you for your attention!

ATLAS ID Performance

Impact parameter resolution





Silicon Strip Detector

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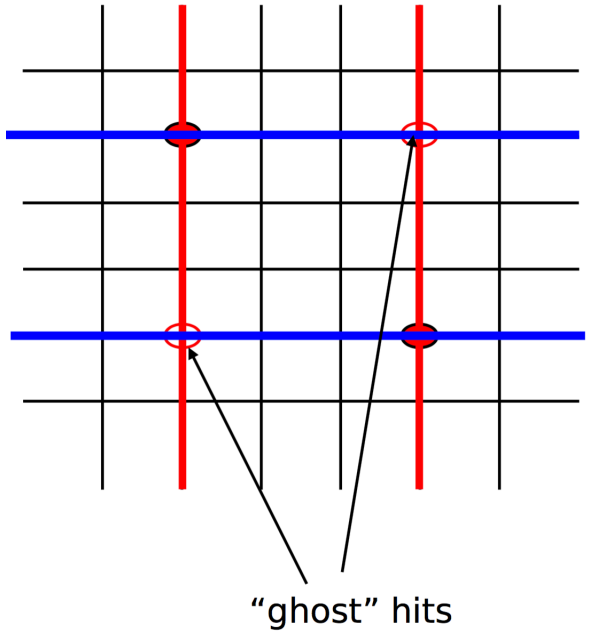
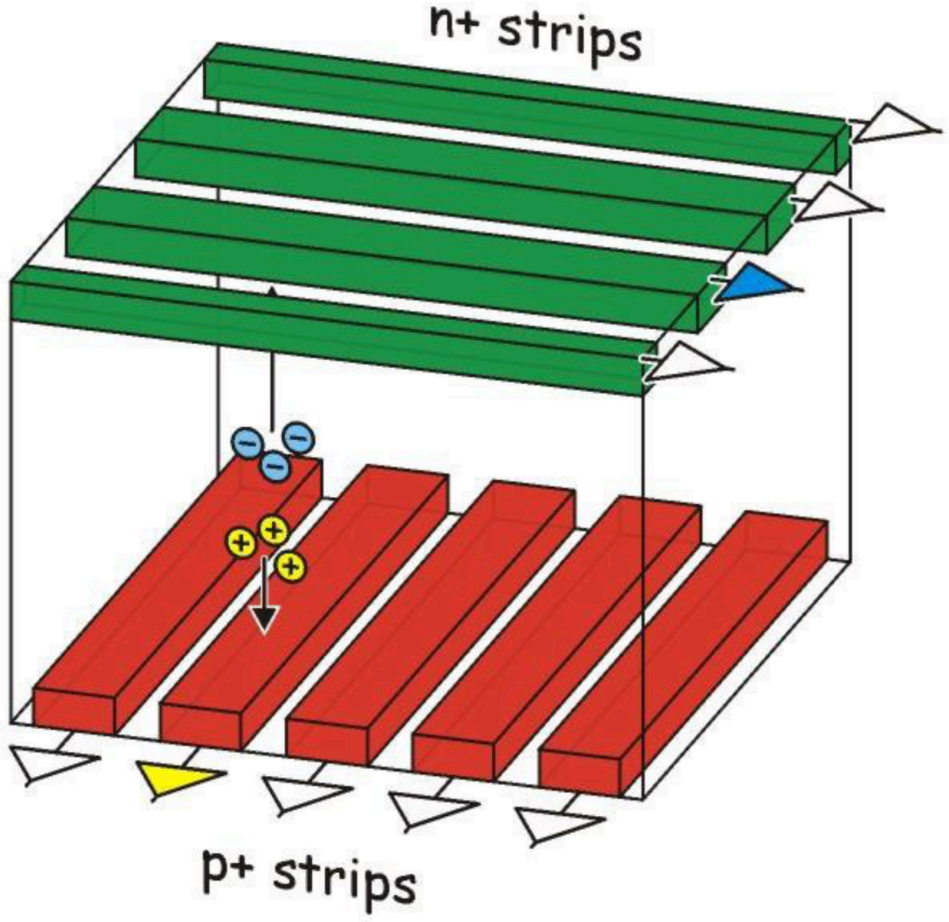
Working principle:
- one segmented side / one homogeneous side
- read-out each single strip
- no 2D information given!

Improvements:
- segment both sides and tilt them (ATLAS: 40mrad)
- 2D information is given, but





Transition Radiation Detector

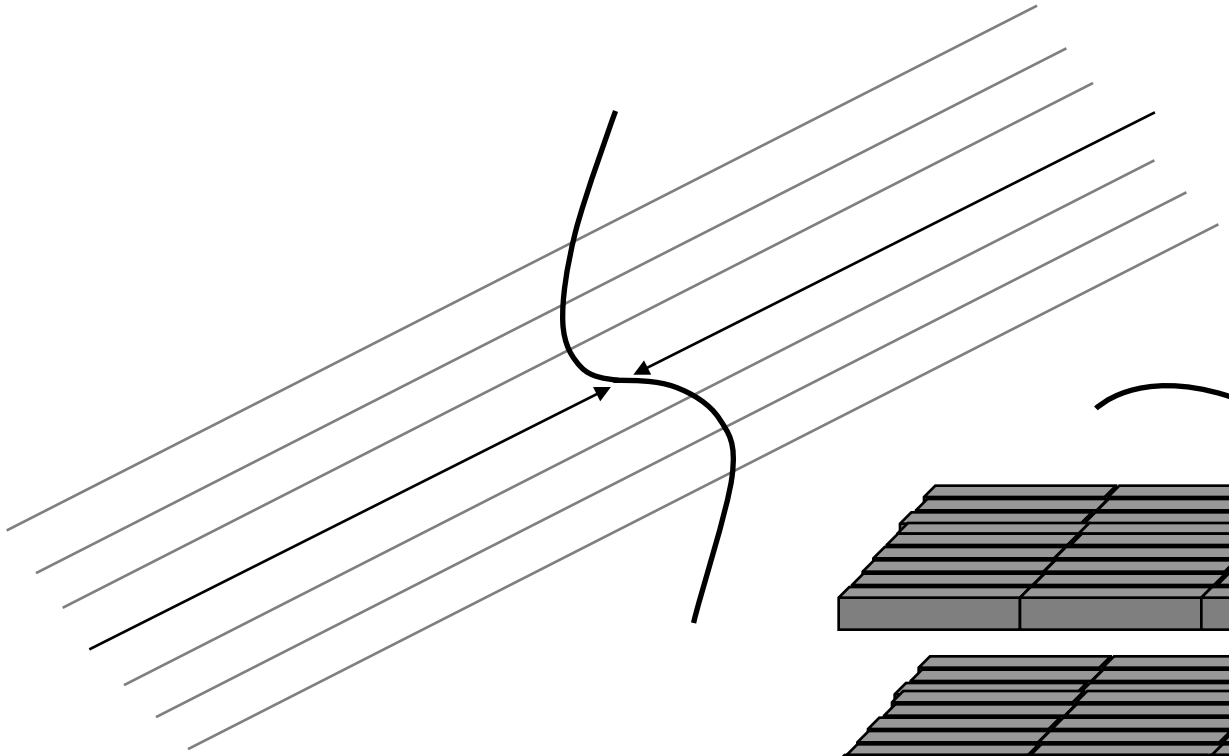
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Straw tubes:

- straw tubes are operated as proportional counters
- anode is 31 μm thin gold-plated tungsten wire
- cathode is tube
  - 60 μm multilayer film of carbon-polymide-aluminium-Kapton-polyurethan
- Xe-CO_2-O_2 (70-27-3) gas used to convert TR x-ray photons and to create free charge carriers by penetrating ionizing particles

ATLAS Pixel Detector

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)



Necessary Resolution:

- low along the beam pipe
  - straight line
- high in bended direction
  - measure curvature for p_T