Material budget study for a CMOS VTX concept

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- A reminder of the Vertex Detector constraints
- Material budget assumed for the simulation
- Constraints from beamstrahlung background
- The CMOS vertex detector concept
- Impact of fast readout on material budget
- Simulation of the impact parameter resolution
- Conclusion

Reminder : Major constraints

- Impact parameter resolution :

  $\sigma_{I.P.} = a\ \mu m \oplus b\ \mu m / p.\sin^{3/2}\theta$ with $a < 5$ and $b < 10$

  - Very high granularity
  - Very thin (minimise multiple scattering)
  - As close as possible to the I.P.
- Machine environment : Beamstrahlung
  - Agressive fast readout ⇨ material budget ?
    - Impact on b parameter ? (BRAHMS simualtion)
  - Radiation Hardness

Material budget use in the simulation

- Beam pipe ~ 500 µm thick (TESLA TDR)
  - This corresponds to 0.14% X_0
- Sensor thickness:
  - Aim for ≤50 µm Si (use in this simulation)
    - Back thinning tests of Mimosa-5 are running
      - LBNL : Mimosa-5 chips work after thinning to 50 µm (industrial process)
      - IReS / Tracit : similar thinning of Mimosa-5 (70 µm today 40 µm)
      - SUCIMA : study for e^- of few keV detection : thinning Mimosa-5 to 15 µm (no standard process) not yet adapted for m.i.p. detection.
    - 25 µm thick sensors achievable ?
- Detector support structures :
  - Not detailed in this study.
  - Assumption: simple ladder ~ 50 µm C thick

Cooling and operation temperature

- Cooling requirements:
  - Detectors are best performing near 0° C or below
    - Less dark current namely after irradiation
    - Less shot noise
  - Room temperature operation is however not excluded
    - Opto processes and improved structures help to controll dark current
    - First promising results were archived with Mi9, Mi11, ongoing study

- A Light cooling system is studied by DESY, Univ. HH
  - Cooling agent R314a
  - Compressed gas expands in Al pipe (600 μm diameter, 50 μm thick) place under readout electronic part along the ladder : $1.2\text{x}10^{-4}$ X_0 in average
  - -12 °C achieved
  - Long term temperature stability is still to be improved

A light cooling system is not yet included in the simulation.
The cryostat is use in this study

Constraints from beamstrahlung background

Base line of the detector concept TESLA TDR

- Radius of the inner layer : 15 mm
- readout speed 50 µs
- B = 4T

Question : Is this consistant with beamstrahlung ?

Monte Carlo on beamstrahlung pairs (100 BX):

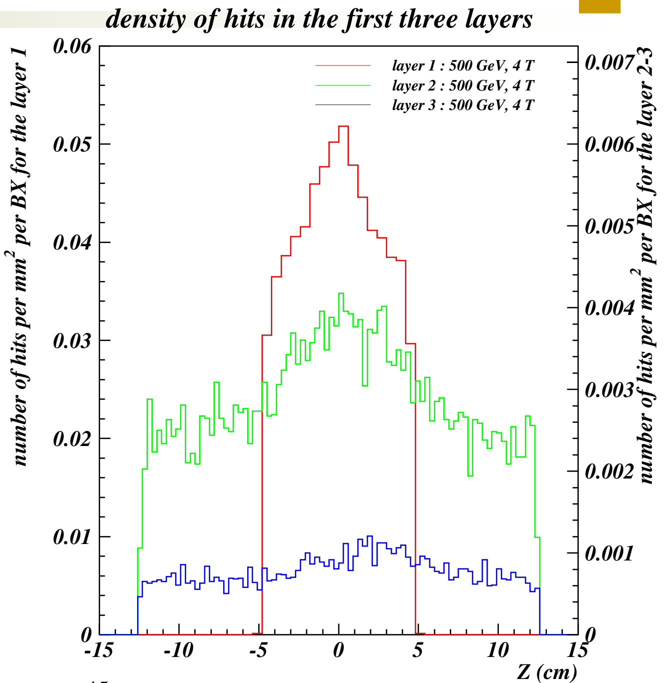
- 5 hits/mm²/BX at 90° in layer L0

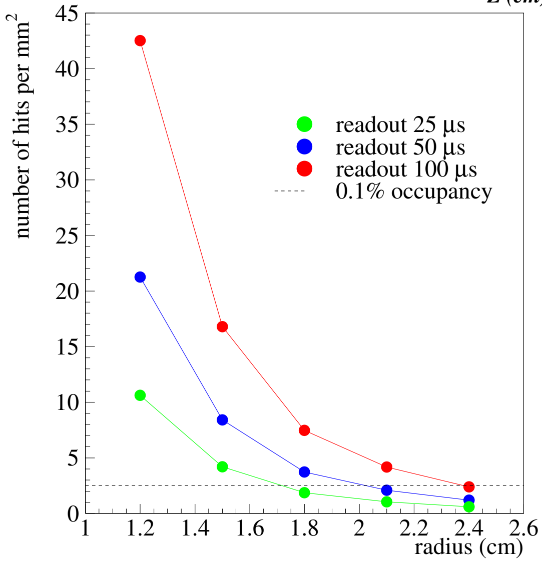
Occupancy (20µm pitch, 50µs readout):

- Cluster multi. (x 5- 10)
- Safety factor (X 3)
- ⇒ **Occupancy 5-10 %**

Conclusion: < 25 µs readout time is required in L0

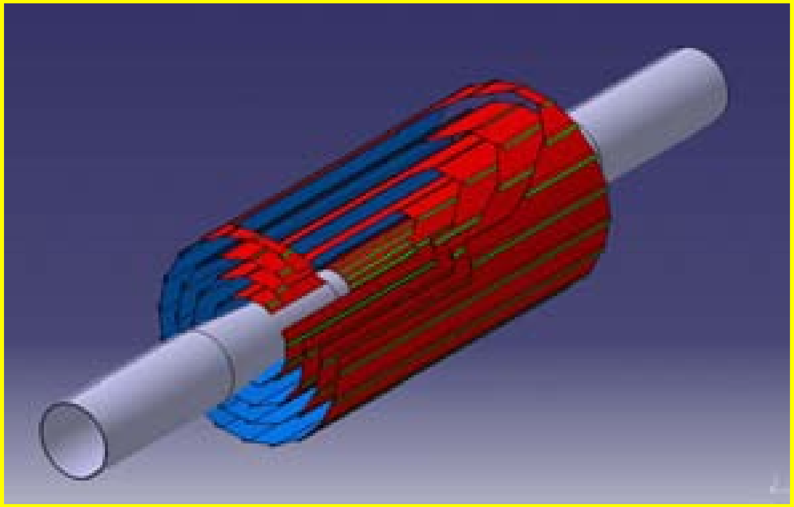
and < 50 µs readout time is required in L1





The CMOS Vertex Detector Concept

- Based on TESLA TDR geom.
  - 5 concentric layers
  - Radii ranging from 15 to 60 mm
  - Polar angle coverage |cosθ|~ 0.9 - 0.95
- But quite different
  - More aggressive readout speed
    - 25 μs for L0
    - 50 μs for L1
      - massive // processing
    - < 200 μs for L2, L3 and L4
      - ≥ 5 memory cells
  - Less pixels : ~ 300 M
    - varied pixel size depending on layer (20 to 40 μm)
  - Low power dissipation
    - P_{mean} < 3 - 30 W (duty cycle =1/200 - 1/20)



Layer	Pitch	$t_{r.o.}$	N_{lad}	N_{pix}	P_{inst}^{diss}	P_{mean}^{dis}
L0	**20 μm**	**25 μs**	20	25M	< 100 W	< 5 W
L1	**25 μm**	**50 μs**	26	65M	< 130 W	< 7 W
L2	**30 μm**	<200 μs	24	75M	< 100 W	< 5 W
L3	**35 μm**	<200 μs	32	70M	< 110 W	< 6 W
L4	**40 μm**	<200 μs	40	70M	< 125 W	< 6 W
total			142	**305M**	< 565 W	**<29 W**

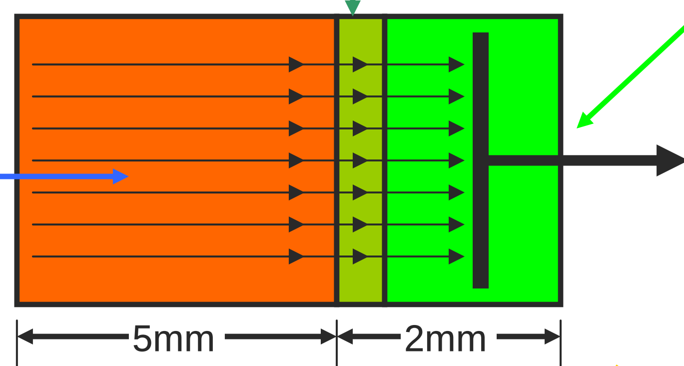
Impact of fast readout on material budget

~ 25µs readout requires:

~1000 on - chip ADCs
and/or discriminators

On - chip cluster-
finding processor

Sensor array
(~250 pixels/column)
Pixel pitch : 20 µm pitch
Readout frenq. : 10 Mhz



Output:
Cluster information
(zero surpressed)

On chip logic area can‘t be made sensitive

- small pixel size
- can´t use pmos trans. in active part

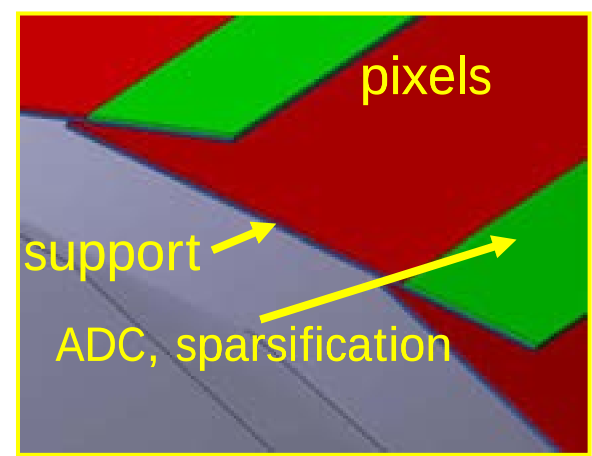
Need electronic band part

- ADC, sparsification, signal extraction

⇒ Increases material budget (except small polar angles)

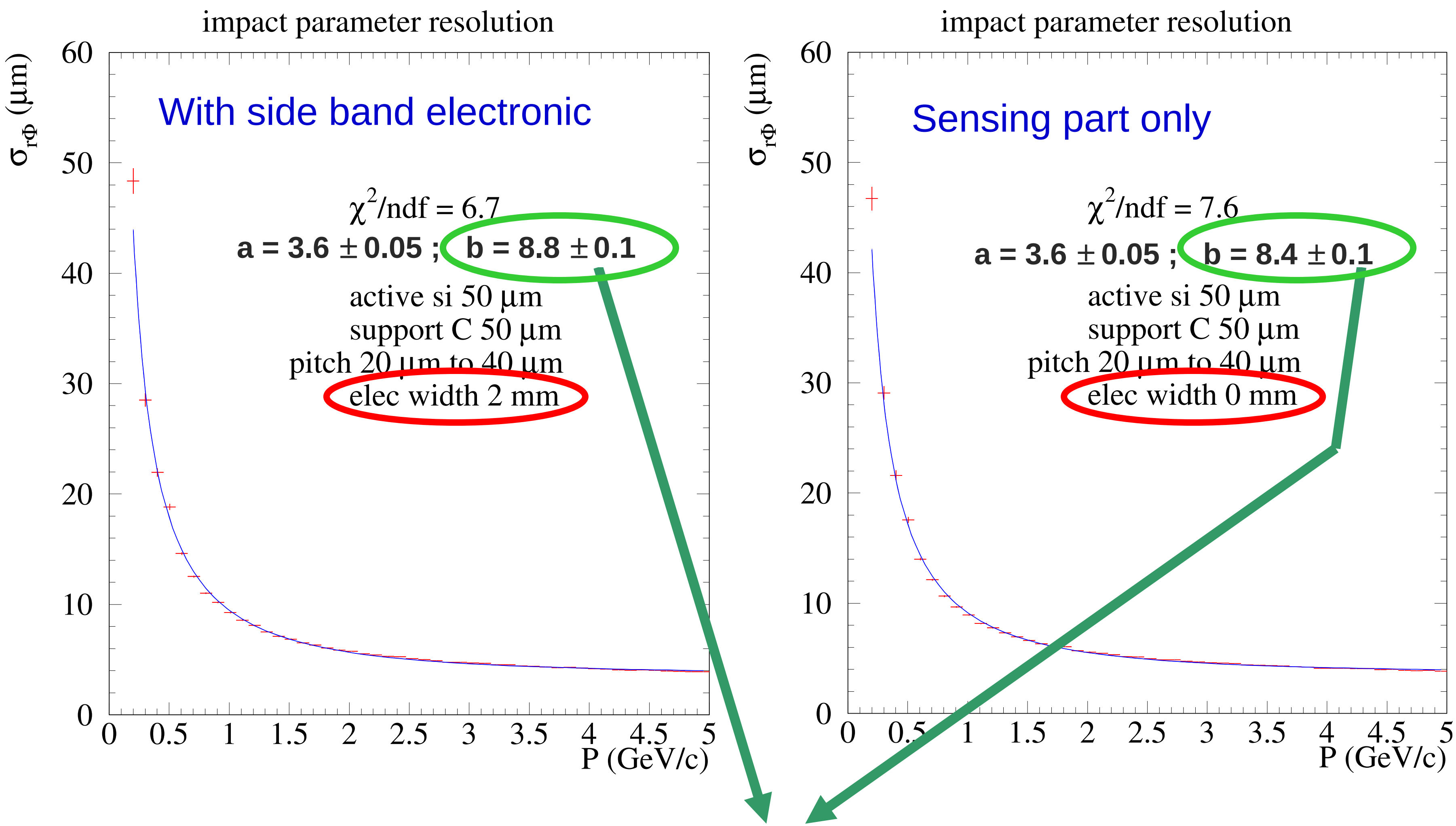
Question:

What is the impact on the b paremeter ?



Simulation Results : influence of the side band

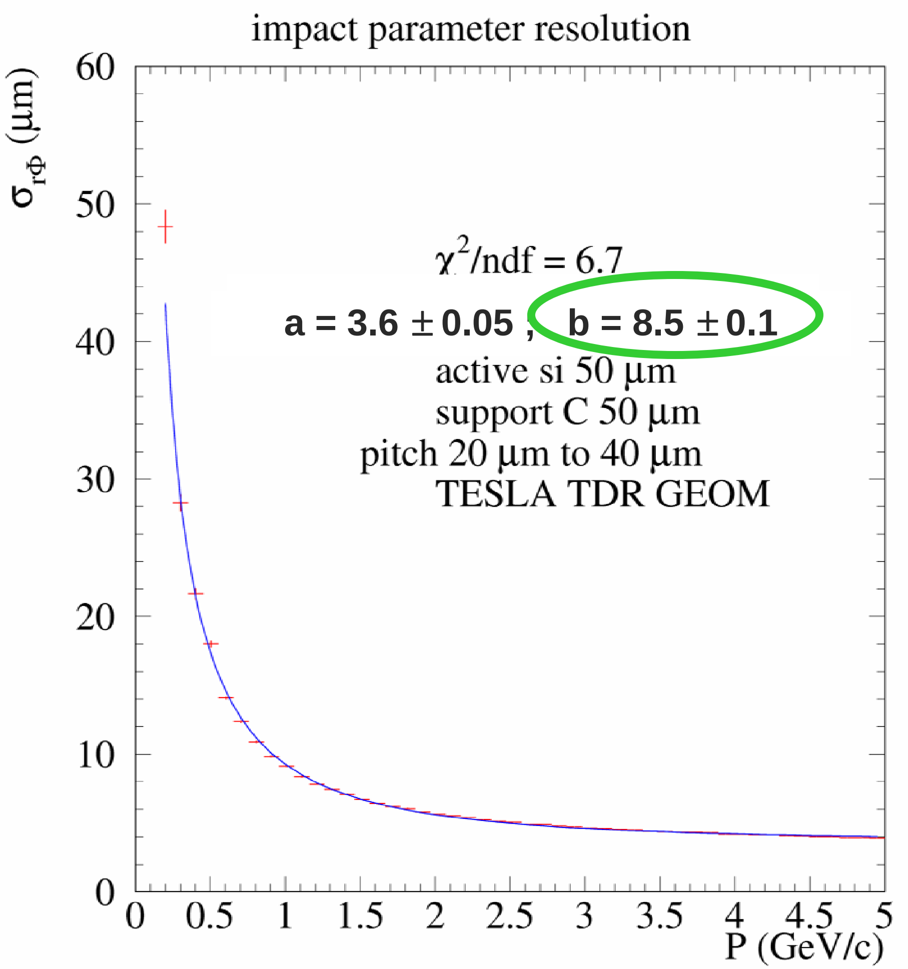
CMOS vertex detector geometry



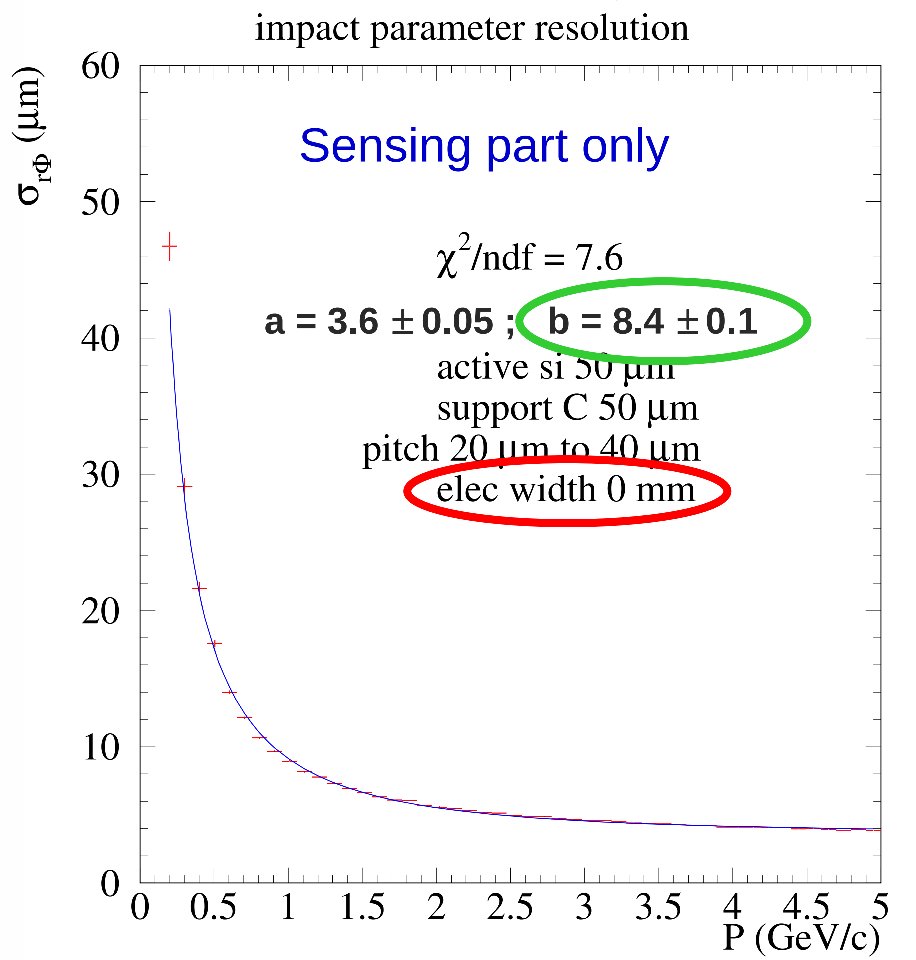
The b parameter grows by a few % only

Simulation Results : influence of the ladder number

TESLA TDR geometry :
L0 : 8 ladders width 15 mm
⇒readout speed : 50 µs

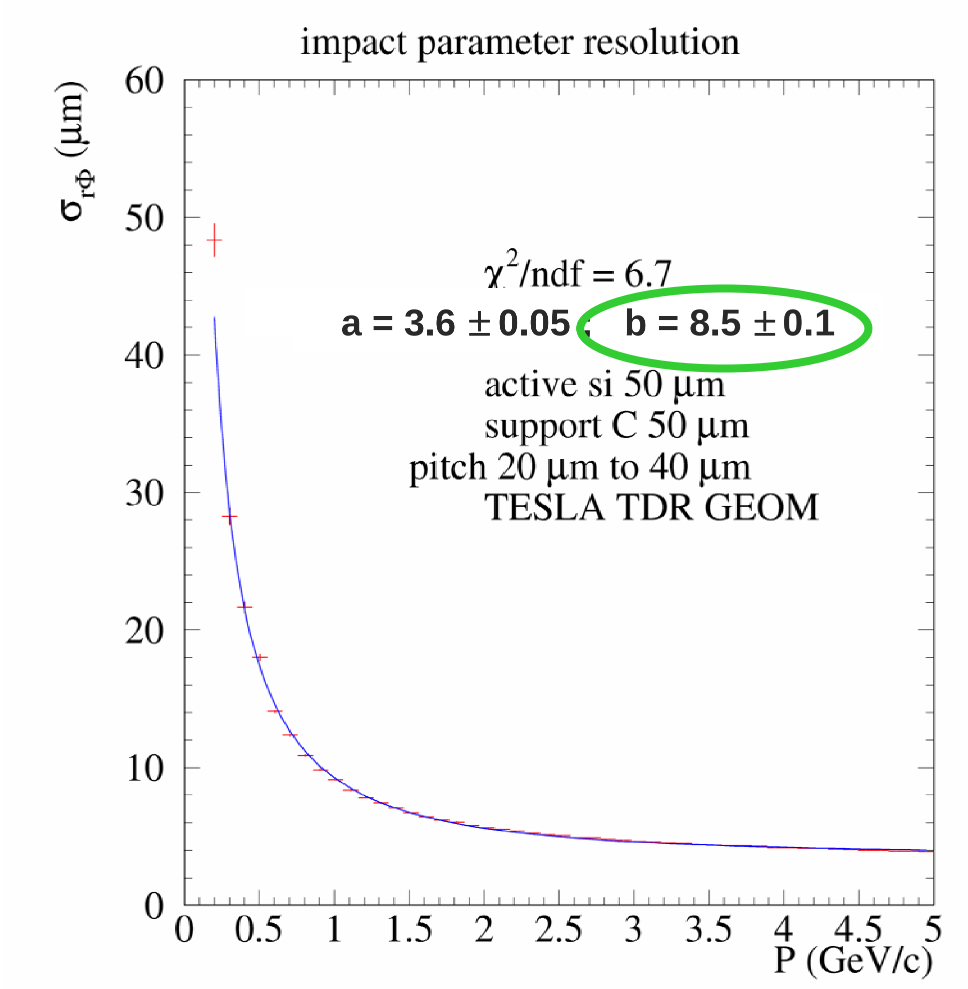


CMOS geometry :
L0 : 20 ladders width 5 mm
⇒ readout speed : 25 µs
L1 : 13 ladders width 13 mm
⇒readout speed : 50 µs



Simulation Results : influence of the radius of L0

TDR TESLA geometry
Radius L0 = 1.5 cm



TDR TESLA geometry
Radius L0 = 1.8 cm

a = 3.9 ±0.05 ; b = 9.6 ±0.1

Summaries and conclusions

- Simulations

VTX GEOM	TDR TESLA	TDR TESLA R_{L0} = 18mm	CMOS without side band	CMOS with side band
a	3.6 ± 0.05	3.9 ± 0.05	3.6 ± 0.05	3.6 ± 0.05
b	8.5 ± 0.1	9.6 ± 0.1	8.4 ± 0.1	8.8 ± 0.1

- Amount of matter coming from 2 mm electronic side band and overlapping of several ladders:
  - Modest loss in resolution : b parameter grows by few per cent
  - Two reasons :
    - Beampipe material governs b
    - The parameter b grows essentially like square root of thikness material

- Increasing the radius of the inner layer
  - b parameter is lineary dependent of this radius

Next steps:

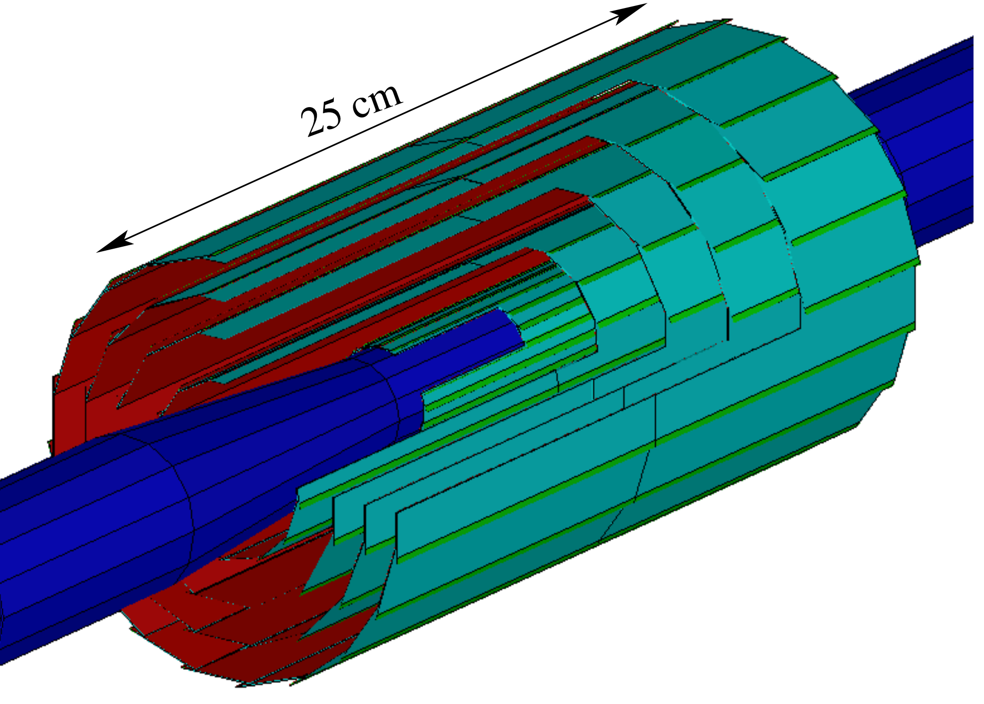
- Simulation still needs to be refined
  - More realistic mechanical support
  - Cabling
  - Light cooling system (if required)
  - Optimisation of the VTX geometry for physics
    - Number of layers ?
    - Conical part in forward region ?

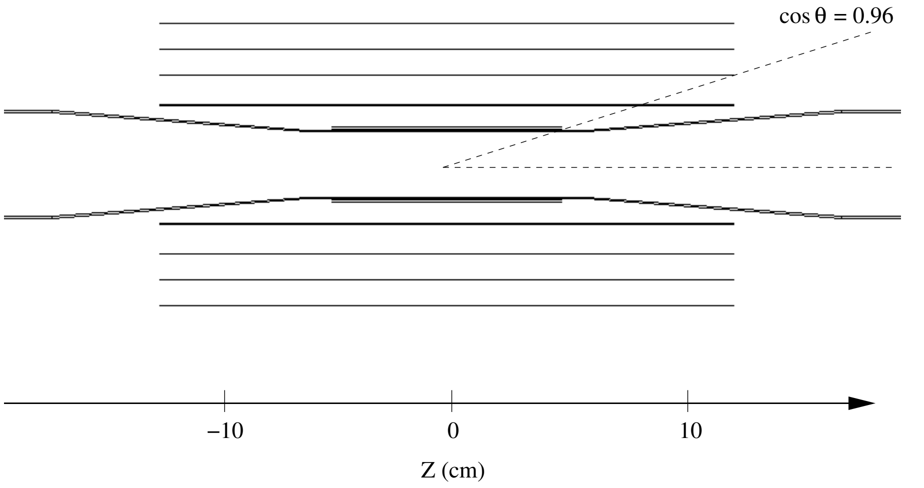
BACK UP

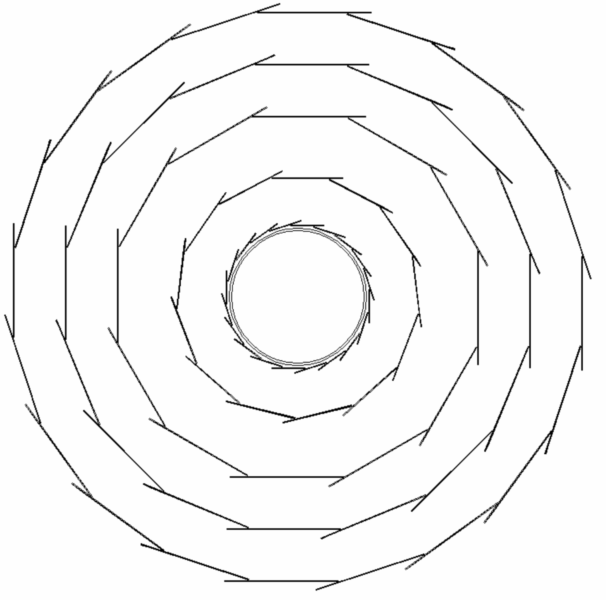
Summaries and conclusions /2

- Worldwide R&D effort
  - Sensor thickness and mechanical support tests
    - Looks to be possible to thin sensor at 50 μm (maybe twice less ?)
    - Very light mechanical support prototypes under test looks very satisfactory
    - but maybe more conservative than expected
  - Light cooling system
    - If sensors have low power dissipation and can work around 0° C
- Still lot of work to do
  - realistic but still a base line
    - pixel conical part ?
    - more realistic mechanical support
    - cabling
    - impact and optimisation of the VTX geometry for physic

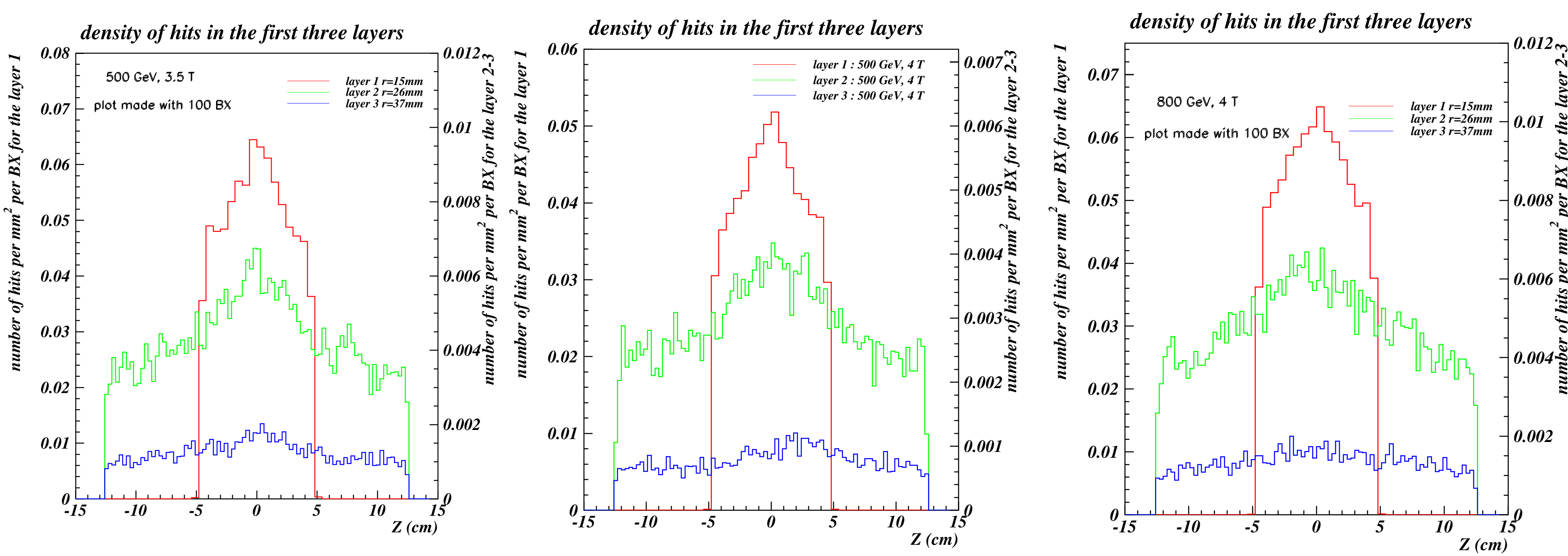
CMOS Vertex Detector implemented in BRAHMS







The Beamstrahlung pairs occupancy

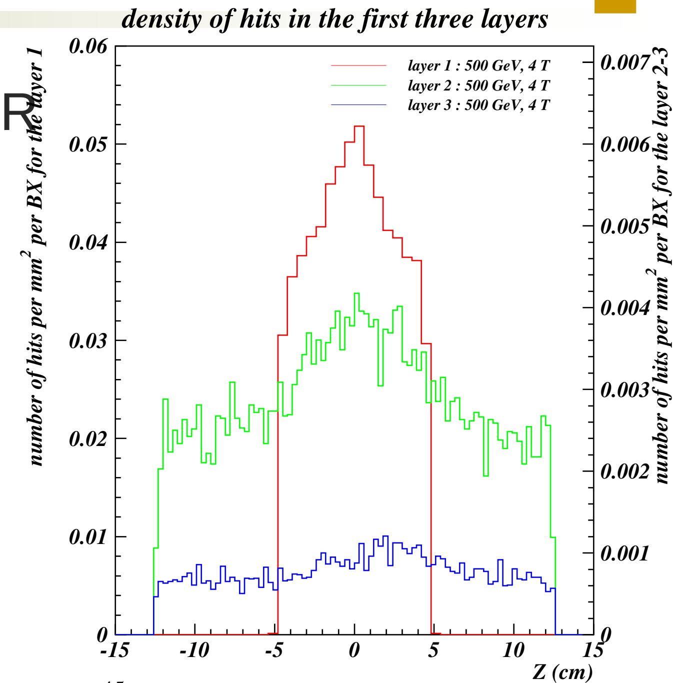


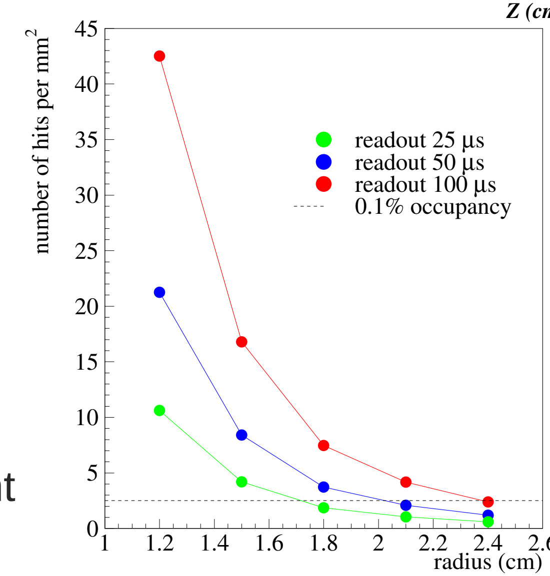
Constraints from beamstrahlung background

- Base line of the the detector concept TESLA TDR
  - Radius of the inner layer : 15 mm
  - readout speed 50 µs

Question : Is this consistant with beamstrahlung ?

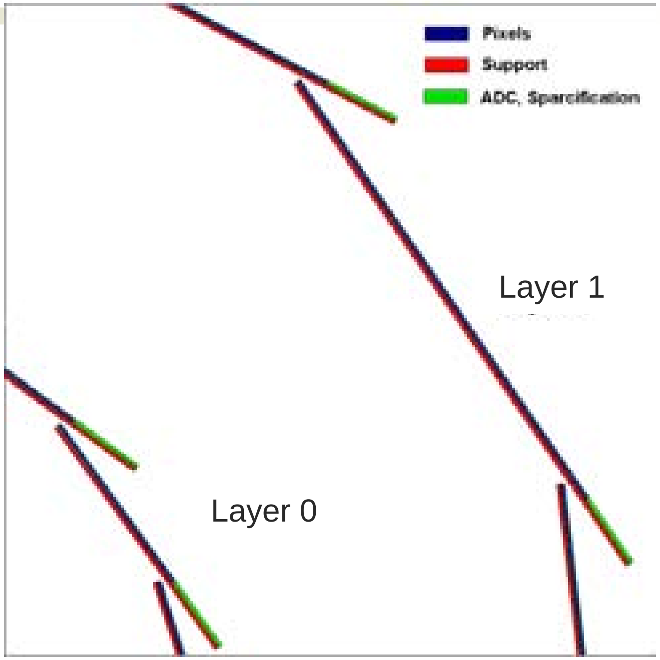
- Beamstrahlung pairs
  - M.C : 5 hits/mm²/BX at 90° in layer L0
    - Cluster multi. (x 5- 10)
    - Safety factor (X 3)
  - ⇒ Occupancy 5-10 %
  - dictates the readout speed
    - TESLA TDR : 50 µs for the first layer at 1.5 cm
  - What if BG much superior to M.C. prediction ?
    - increase the radius of the first layer
      - Not a good solution because parameter b linearly dependent of R_{L0}
      - parameter a increase too
    - Increase the readout speed : technhology dependent
      - Sensor able to work at high frequency

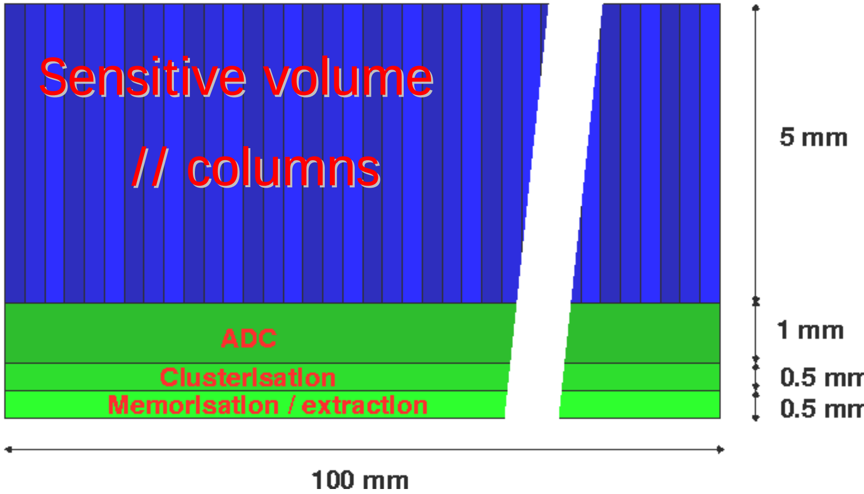




The matter inside the CMOS Vertex Detector

- How to have fast readout ?
  - small chip $\Rightarrow$more ladders than TDR geom.
- CMOS need electronic side band for digital convertion, sparsification and signal extraction
  - techonology limitation
    - amplification and CDS in pixel only
  - small size of the pixel
  - These caracteristics increase the amount of matter inside the fiducial volume
  - but there is less matter at small polar angle
- The CMOS sensor could work at < 0° C ?
  - the CMOS could work at ambiant temperature
    - thanks to the OPTO fabication process
  - radiation will increase the dark current
    - work around 0° C to keep high S/N ratio
  - Assume no cryostat needed
- The CMOS VTX implemented in BRAHMS and the impact parameter resolution calculated for different configurations
  - The sensor thickness is 50 μm supported by carbon fibre structure of 50 μm thick (LBNL tests) ~ 0.08 % X_0 (optmisitic ?)





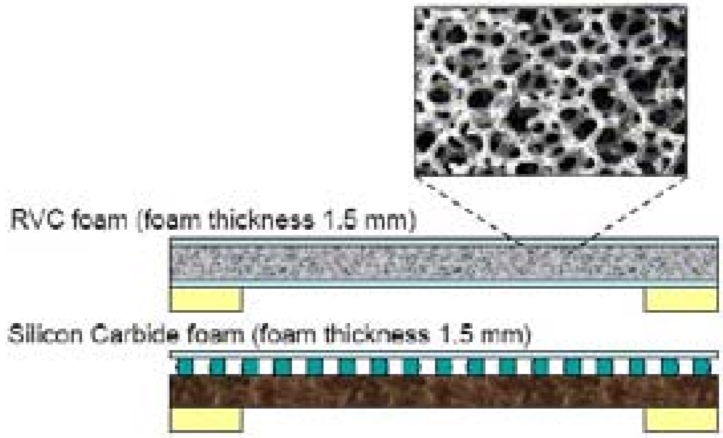
What are our components ? /2

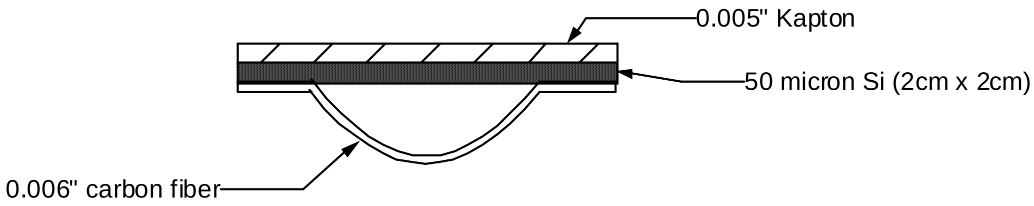
Mechanical support:

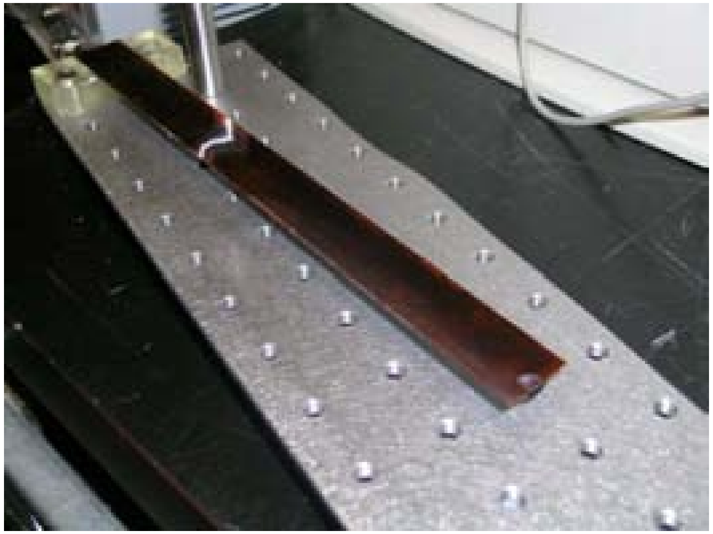
LCFI studies semi-supported sensor

RVC foam : 3.1mm = 0.05% X_0

Silicon Carbide foam : 540 µm = 0.05% X_0







LBNL prototype for STAR upgrade
carbon fiber and kapton (~ 0.03 % X_0)

A concept of a vertex detector for the ILC relying on CMOS-sensors

Damien Grandjean   Marc Winter

- Vertex Detector reminder
- How to decrease material budget ?
- Constraints from beamstrahlung background
- Study example : the CMOS Vertex Detector concept
  - The matter inside the CMOS Vertex Detector
  - Simulation Results
- Summaries and conclusions