Alignment of double sided ladders and mini-vectors

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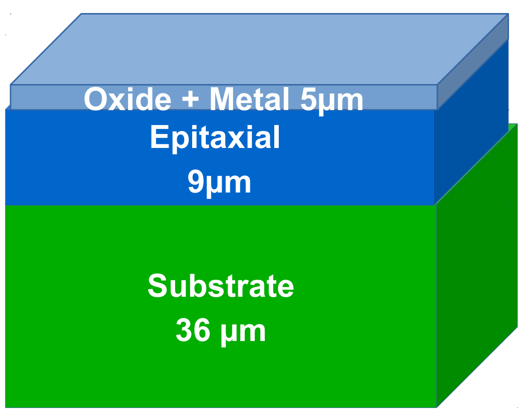
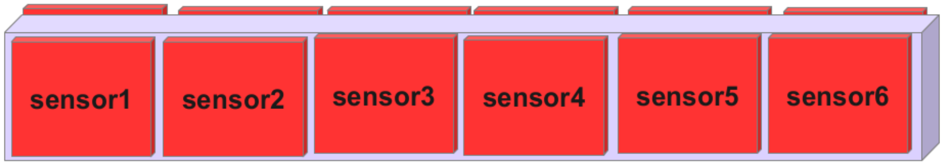
mimosaSensor

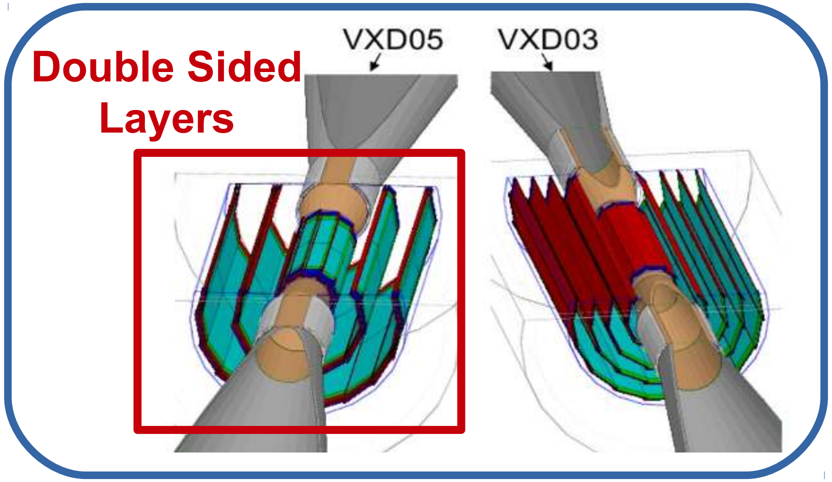


ladderPLUME

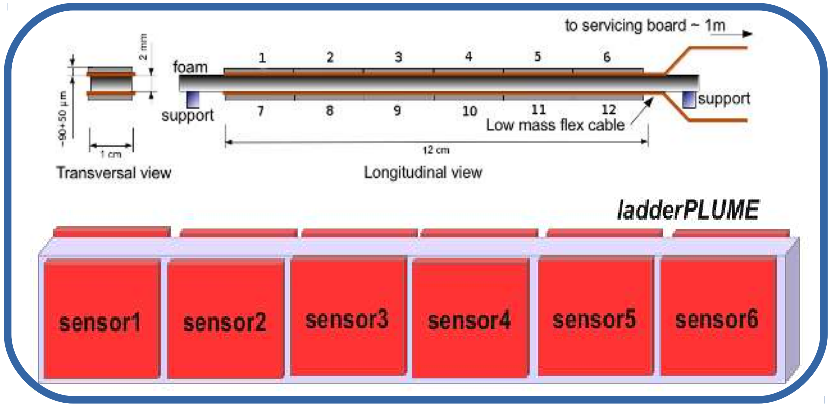


Outline

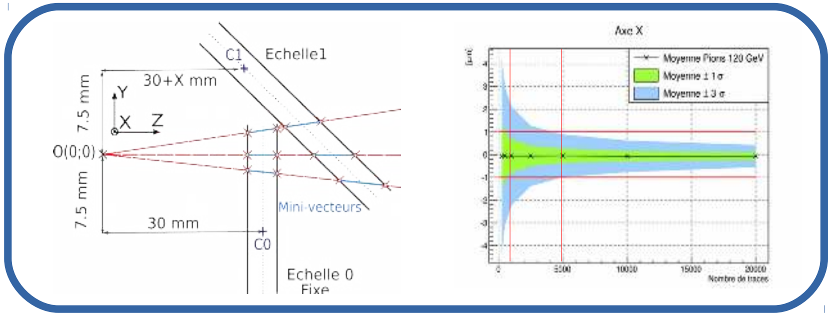
- **Motivations for double sided setup**
  - *ILC*
  - *Double sided layers*
  - *Mini-vectors*



- **Simulations of double sided ladders**
  - *Tools :*
    - *GEANT4*
    - *Charge carriage tool*
    - *Digitizer*

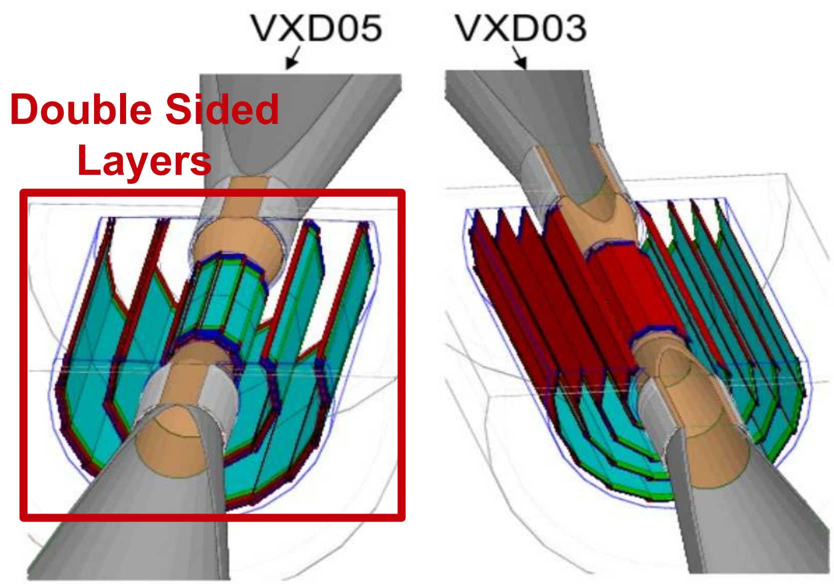


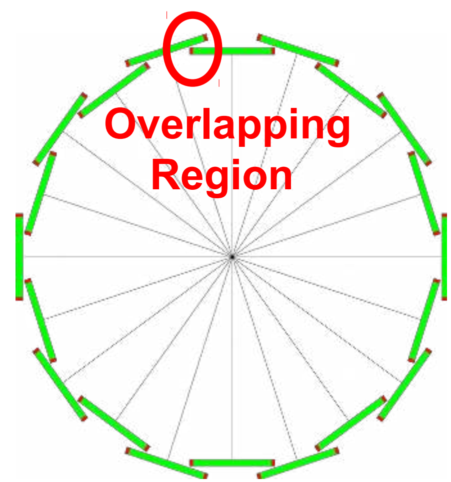
- **Alignment**
  - Local alignment of ladders
  - *Local alignment on the* ***overlapping region*** *of two* ***double sided layer***



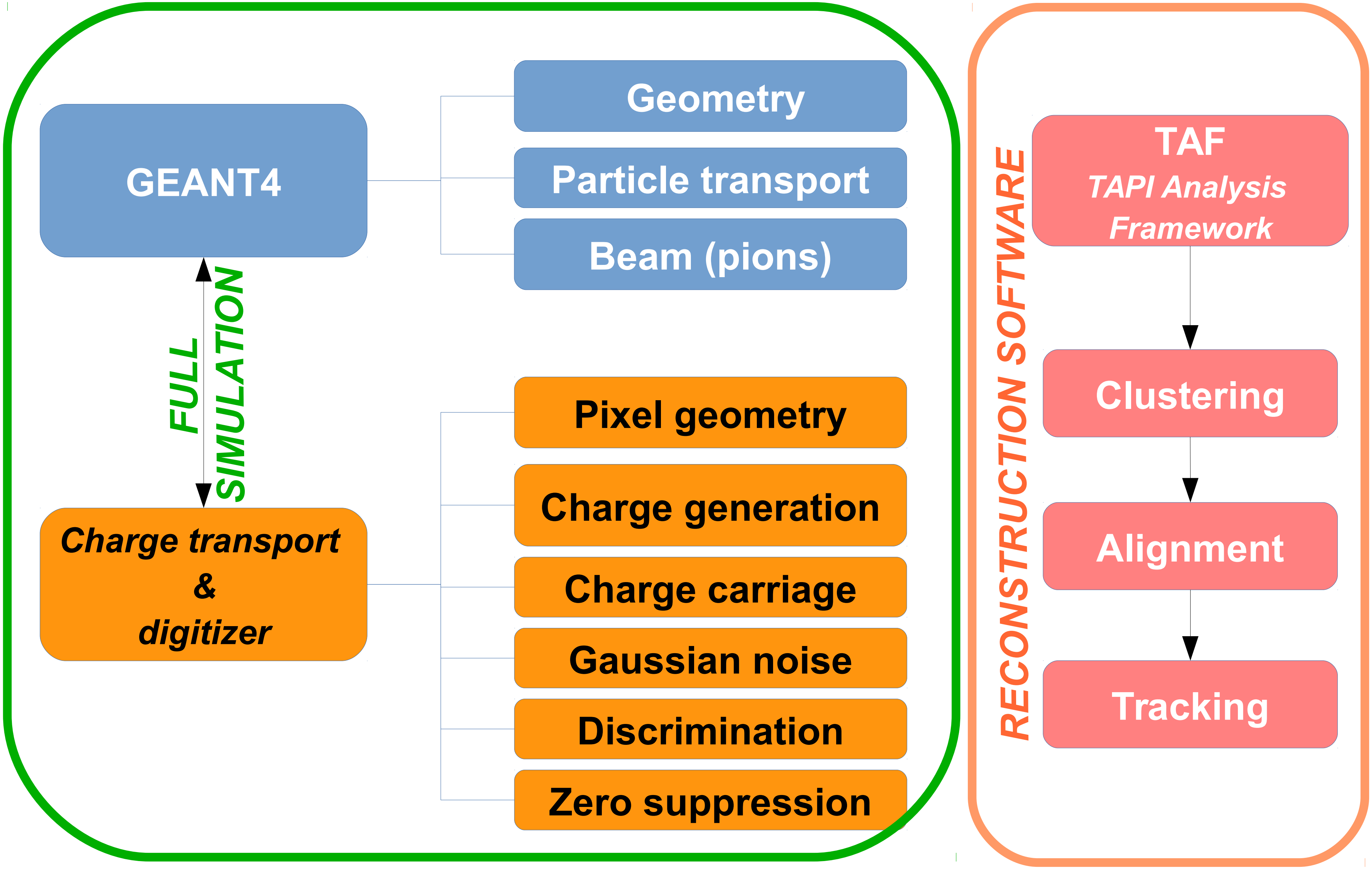
Motivations for double sided setup

- Context : ILC Vertex detector
- Geometry of the vertex detector :
  - 5 single layers OR 3 double sided layers.
- Focus on 3 ***double sided layers***
  - ***Material budget reduction.***
    - 1 support for 2 layers.
  - **1 track → 2 hits → 1 mini-vector**
  - ***Mini-vectors : potential improvment on pattern recognition***
- Goal : Standalone alignment on the overlapping region of two consecutive ladders in the same doubel layer.
- **Tool : Geant4 simulation**
  - Sensor simulation
  - Double sided ladder simulation



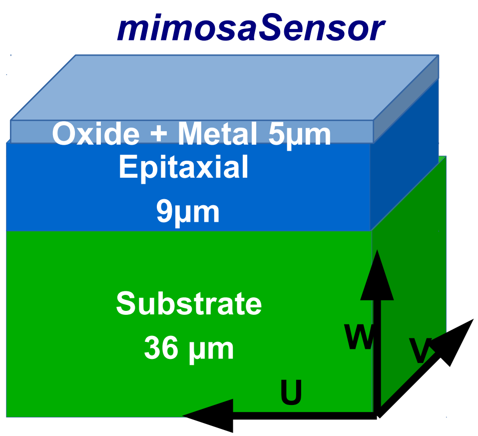


Tool : DigiCMOS (GEANT4) + TAF (Reconstruction)



Simulation : GEANT4

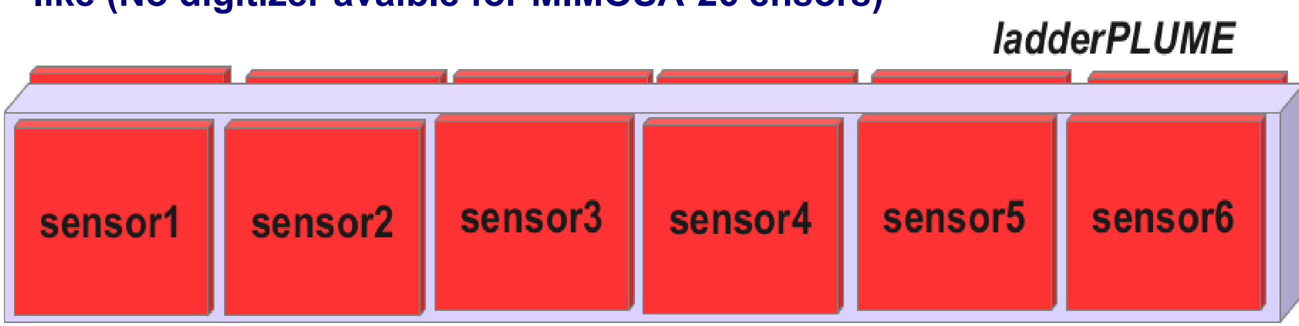
- ***CMOS sensors with GEANT4 :***
  - MIMOSA sensors : 3 layers design
    - **Substrate layer** (silicon) + **Epitaxial layer** (silicon) + **Oxide+Metal layer**
    - **Total thickness = 50 µm**
  - ***Energy deposition { Landau (MPV =80e⁻/µm) }***
  - Geometry modules :
    - ***Single sensor*** (MIMOSA-28 like)
    - ***Single and double sided ladders* (PLUME)**
    - ***Modular tool : New modules for a new geometries.***
  - ***Charge carriage & digitizer for MIMOSA-28 sensors (DIGMAPS)***



CMOS sensor simulated geometry

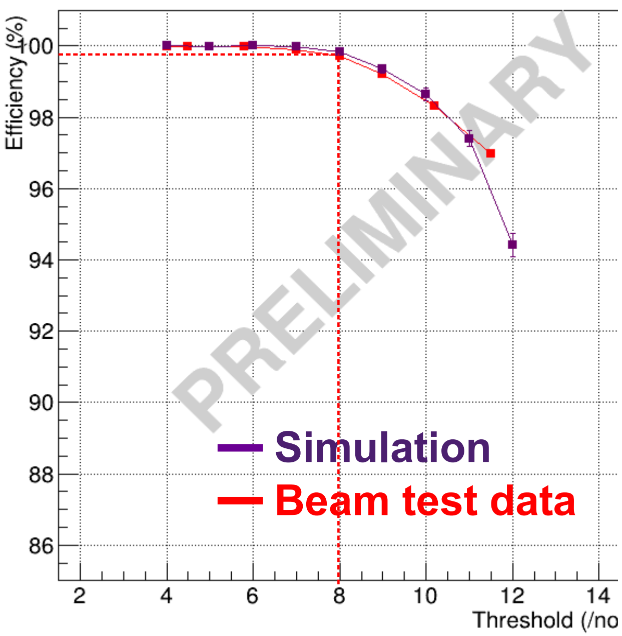
- Double sided ladder simulation : PLUME ladder (Pixel Ladders with Ultra-low Material Embedding)
  - Built with **12 sensors** MIMOSA-28 like, 6 per side
  - Gap between two sensors = 420 µm
  - *Support = **2 mm** SiC (Density 8 %)*
  - ***Spatial resolution = 3.5 µm*** *(normale incidence)*

Real PLUME Ladder : 12 MIMOSA-26 Simulation : 12 MIMOSA-28 like (No digitizer avaible for MIMOSA-26 ensors)

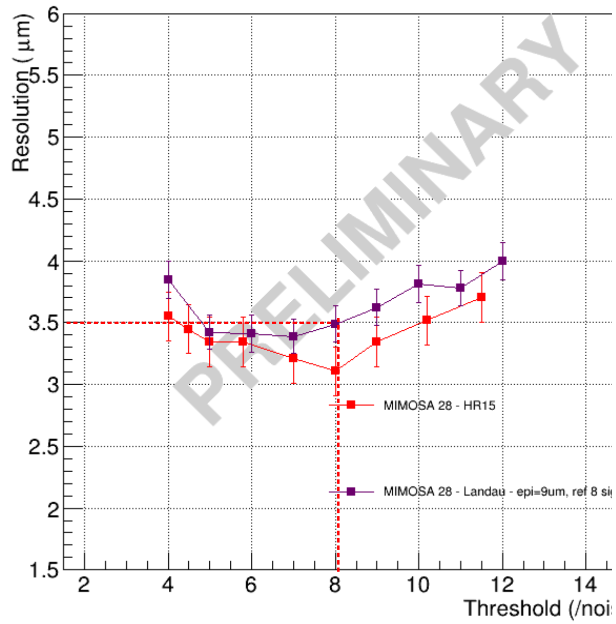


Simulation tool performances

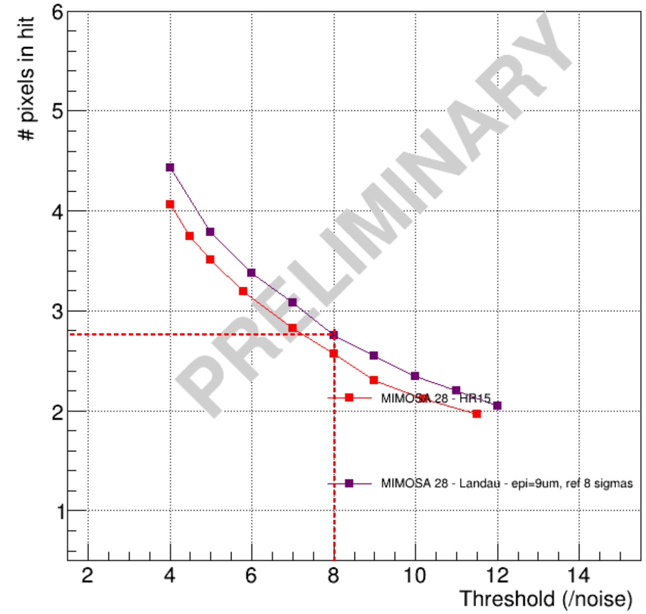
Efficiency vs Threshold



Resolution vs Threshold



Pixel multiplicity vs Threshold



- **Data based charge carriage** (Due to unknown on epi thickness, dopage profil, etc...)
- **Fine tuning of simulation parameters** (Energy distribution, epitaxial layer, charge transport, etc...)
- **Binary output (comparison with a threshold) + Zero suppresion**
- **Results :**
  - Comparison between simulation and test beam data of MIMOSA 28 HR15.
  - **Data and simulation agreement *better than 10 % (10 % for multiplicity)***.
  - ***Single sensor model response validated.***
  - Spatial resolution = **3.5 µm** (Normale incidence) | Efficiency > 99.5 %
  - Mean Cluster Mult.= 2.8 px (Normale incidence)

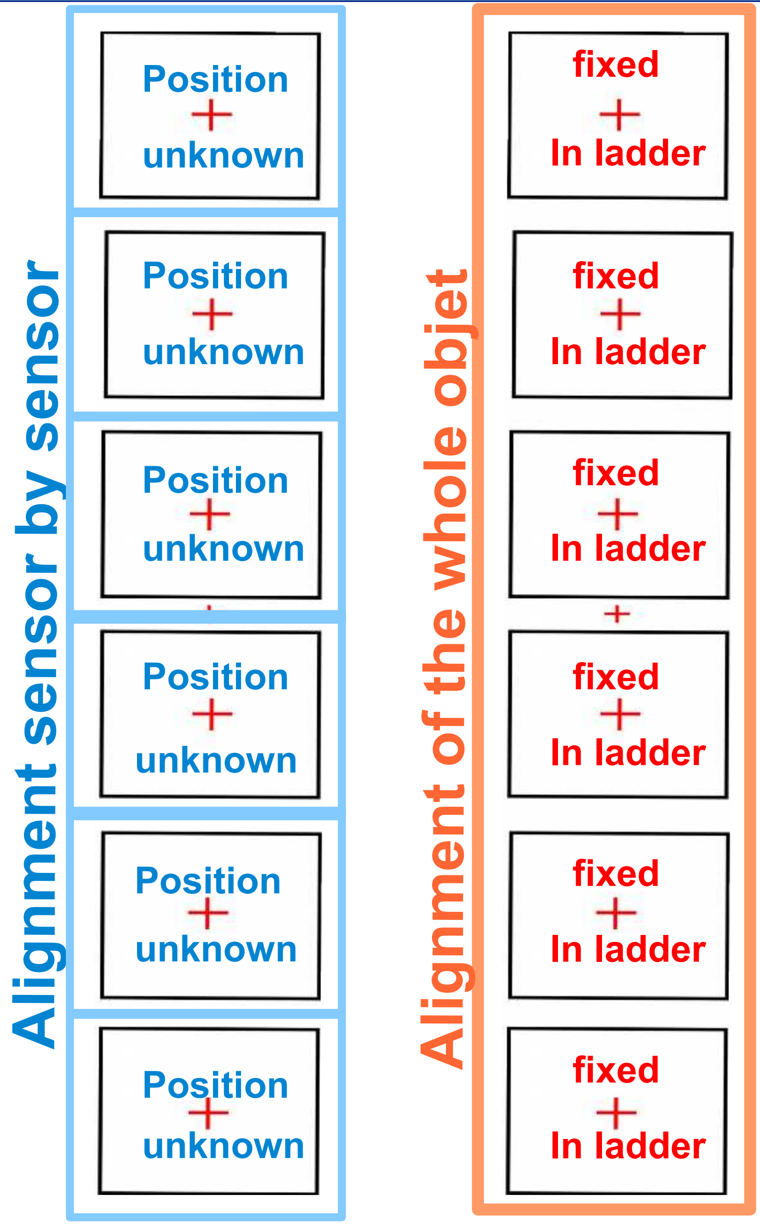
Alignment

- *TAF* : **Framework for *test beam analysis* and *simulated data analysis*.**

- ***Alignment of compoite objects* like PLUME ladders or SALAT planes**

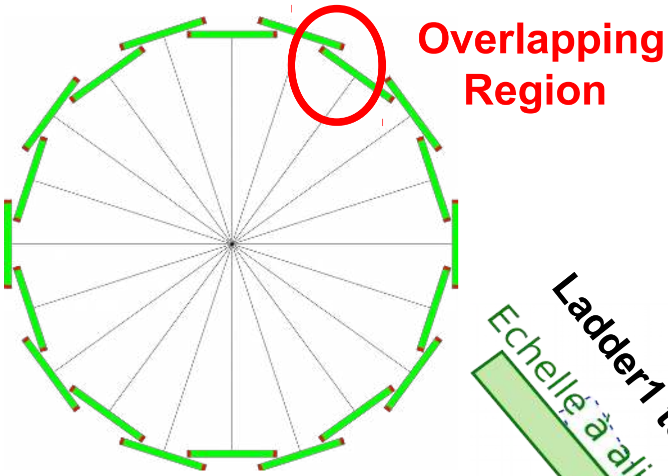
- **2 possible strategies of alignment :**
  - ***Alignment sensor by sensor*** in a composite object
  - Return each sensor tilts and positions
  - ***Alignment of the whole object***
    - Relative sensor position well known.
    - Return object tilts and positions
    - Already used in SALAT beam test analysis.

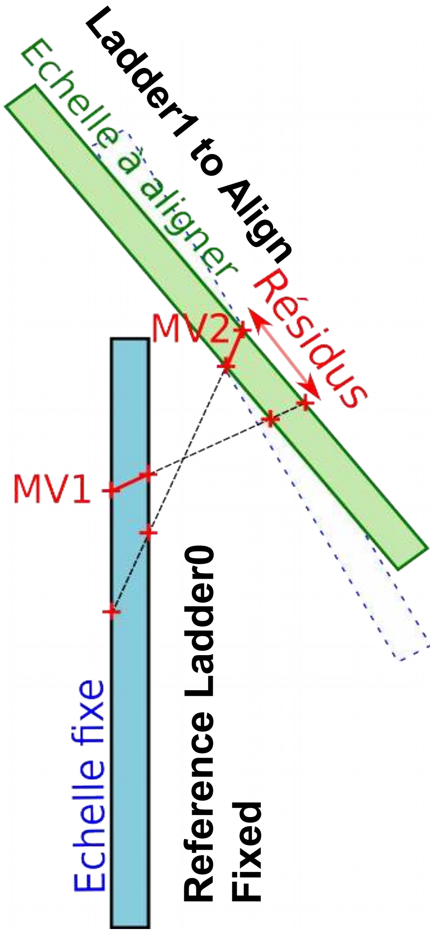
- **Alignment description :**
  - ***Track based alignment*** (straight tracks).
  - ***Local Chi² alignment.***
  - Chi² = sum(residuals(x,y,z)²/(resolution(x,y,z)²)) over tracks
  - Chi² minimisation (ROOT : Minuit)



Alignment with mini-vectors

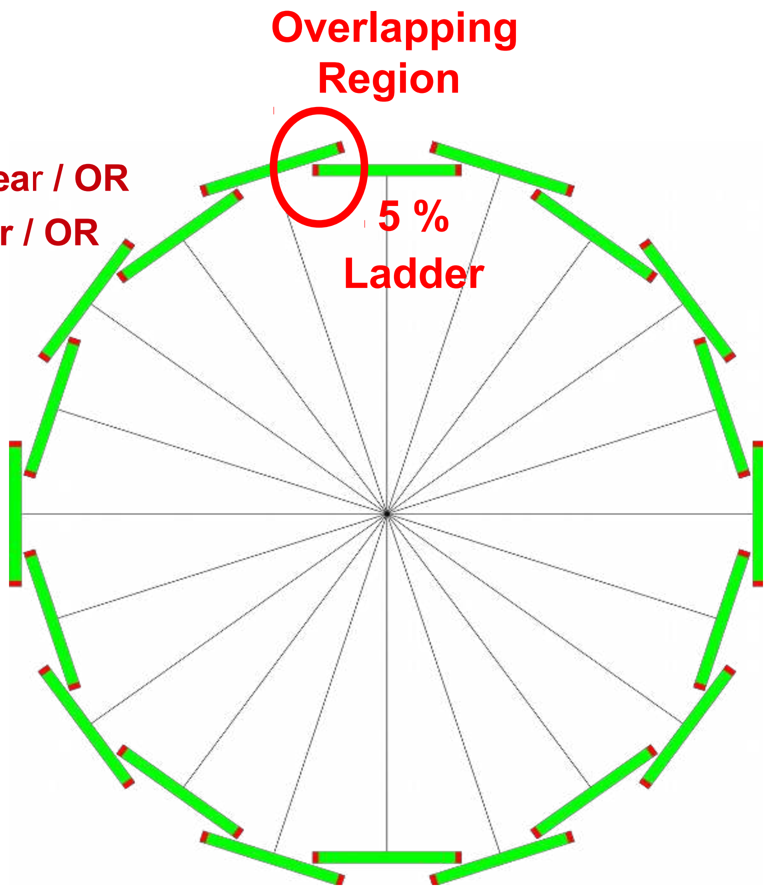
- **Alignment with mini-vectors**
  - On the ***overlapping region*** of two consecutive ladders
  - First studies of tracking with mini-vectors → efficacity improvement at low momentum (See Georgios Voutsinas, DESY).
  - ***Potential improvment on pattern recognition at low momentum***
  - ***Idea : Standalone alignement with mini-vectors***
- **Reconstruction of mini-vectors**
  - **A *hit on the first side* with the *closest hit of the other side*.**
- **Method of alignment with mini-vectors**
  - On the **overlapping region (OR).**
  - Fixed reference (ladder0) + Misaligned ladder (ladder1)
  - Spatial residuals = Projection of the mini-vectors of the fixed ladder on the other ladder
  - Residuals = spatial residuals + mini-vectors tilt residuals.
  - Alignment = Chi2 Minimisation.
- **Let's see the statistic …**





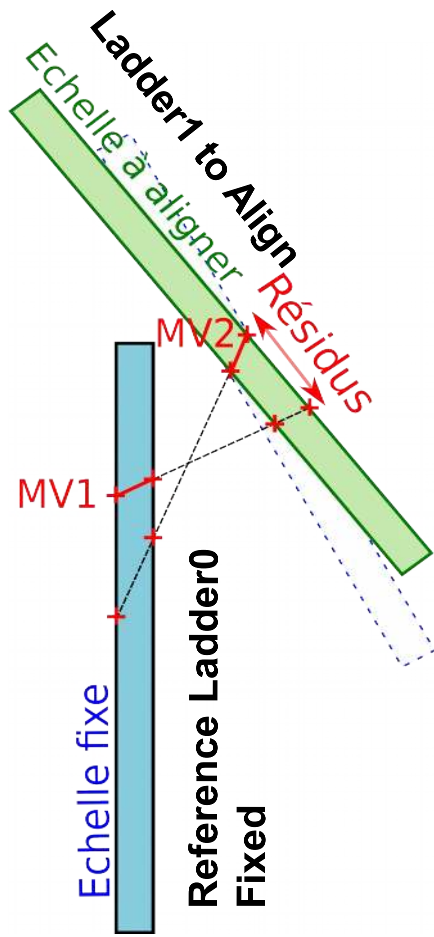
Statistic (Order of magnitude only)

- ***Order of magnitude for Statistic for 1 Overlapping Region***
- ***We want a minimum increase of material budget so :***
  - ***1 OR = 5 % Ladder Surface***
- ***Hard processes***
  - $L=1.8 \times 10^{34}\ cm^{-2}\ s^{-1}$
  - **e+ e- → μ+ μ- (500 GeV)** : **Around 1400/2800 μ per Year / OR**
  - **e+ e- → qq (500 GeV)** : **8000/16000 particles per Year / OR**
- Very Optimistic : ***Beamstrahlung*** (see after)
  - **Around 7500/20000 e-/+ per Hour /OR**
  - But **Low Momentum particles in a magnetic field**
- ***GigaZ option***
  - $L=10^{33}\ cm^{-2}\ s^{-1} \rightarrow 10^{9}$/Year
  - Example : Z → μμ (3.5%) + Z → ee (3.5%)
  - **Around 15000/25000 particles per Month / OR**
- ***Photon collider option***
  - $L=10^{34}\ cm^{-2}\ s^{-1}$ / 500 GeV
  - Ex : σ(γ γ-> μ+μ-μ+μ-) ≈ 150 pb (TDR Tesla)
  - **Around 40000...80000 μ per Month / OR**
- **Sum** of tracks from different processes

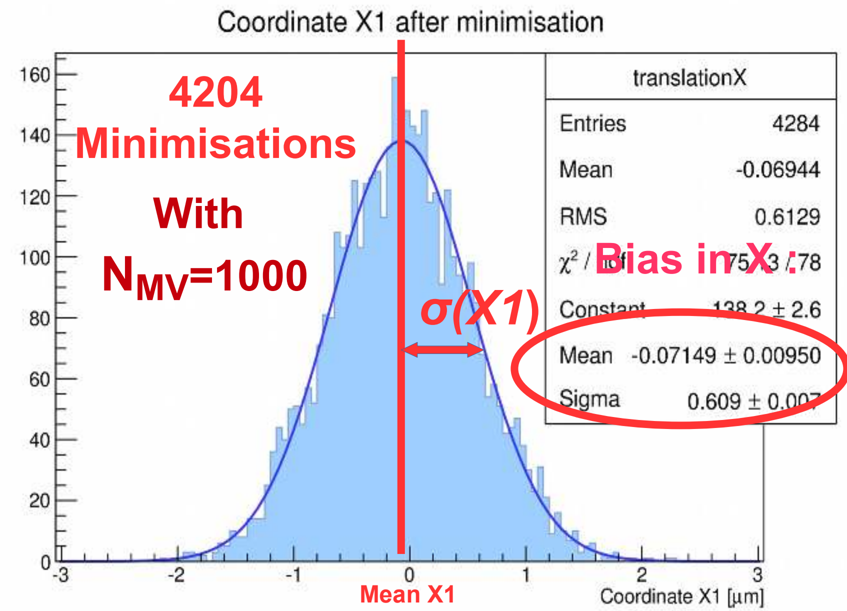


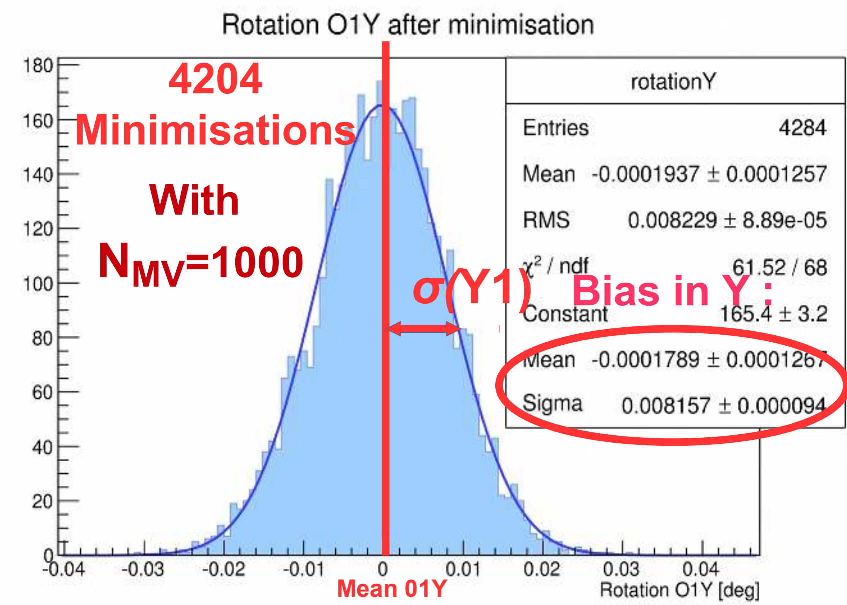
Configuration : Pions High Momentum (120 GeV/c)

- **Alignment with mini-vectors : Step 1 = Proof of principle with high momentum particles.**
- Relative tilt between ladders = **30 deg** (Rotation X)
- OR ≈ 10 % Ladder size
- Beam
  - Negative pions 120 GeV/c
  - Distributed in a cone
    - Vertex position O(X,0,0) : random position in X axis
    - Opening angle = Random[0,15] deg
- Mini-vectors association
  - 2 mini-vectors in the overlapping region.
  - Association by pairs before minimisation
  - Proof of principe with **Perfect associations** of mini-vectors
- Monte Carlo position of ladder 0 (fixed) and 1 (ladder to align) :
  - **O0(X0,Y0,Z0) = (0-7500,30000) µm**
  - **O1(X1,Y1,Z1) = (0,7500,35000) µm**
- Relative Monte Carlo Rotations between ladder 1 and ladder 0 :
  - **RotX = 30 deg, RotY = 0 deg, RotZ = 0 deg**



- Alignment with 6 degrees of freedom
  - 3 Translations : X, Y, Z,
  - 3 Rotations : Rot X, Rot Y, Rot Z
- Initial misalignment :
  - Translations of the center O1 (Ladder 1)
    ΔX = +200 µm, ΔY = -200 µm, ΔZ = +200 µm
  - Rotations about the center O1 :
    ΔRotX = +0.5 deg, ΔRotY = -0.5 deg, ΔRotZ = +0.5 deg
- Estimation of the alignment precision :
  - ***N minimisations*** with ***different samples***
  - ***N_{MV} mini-vector pairs*** per sample.
- For each variable after 1 minimisation → 1 entry in each histogram (6 DoF = 6 Histos).
- **Bias = (Histogram *Mean* - Monte Carlo Values)**
- **Precision = Histogram *Width (1 σ)***

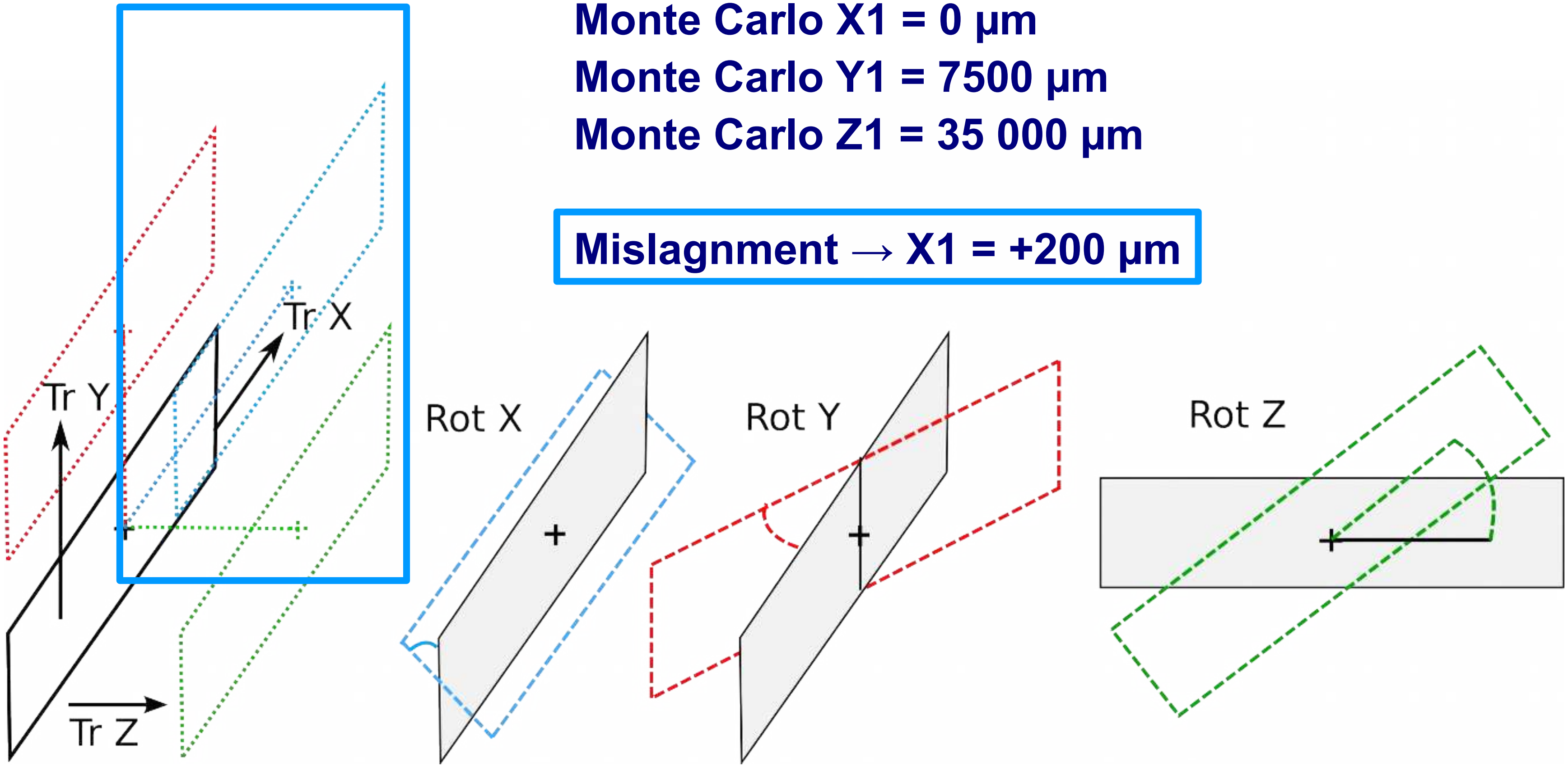




Parameter X1

Translation Center O1(X1, Y1, Z1)
Monte Carlo X1 = 0 µm
Monte Carlo Y1 = 7500 µm
Monte Carlo Z1 = 35 000 µm

Mislagnment → X1 = +200 µm



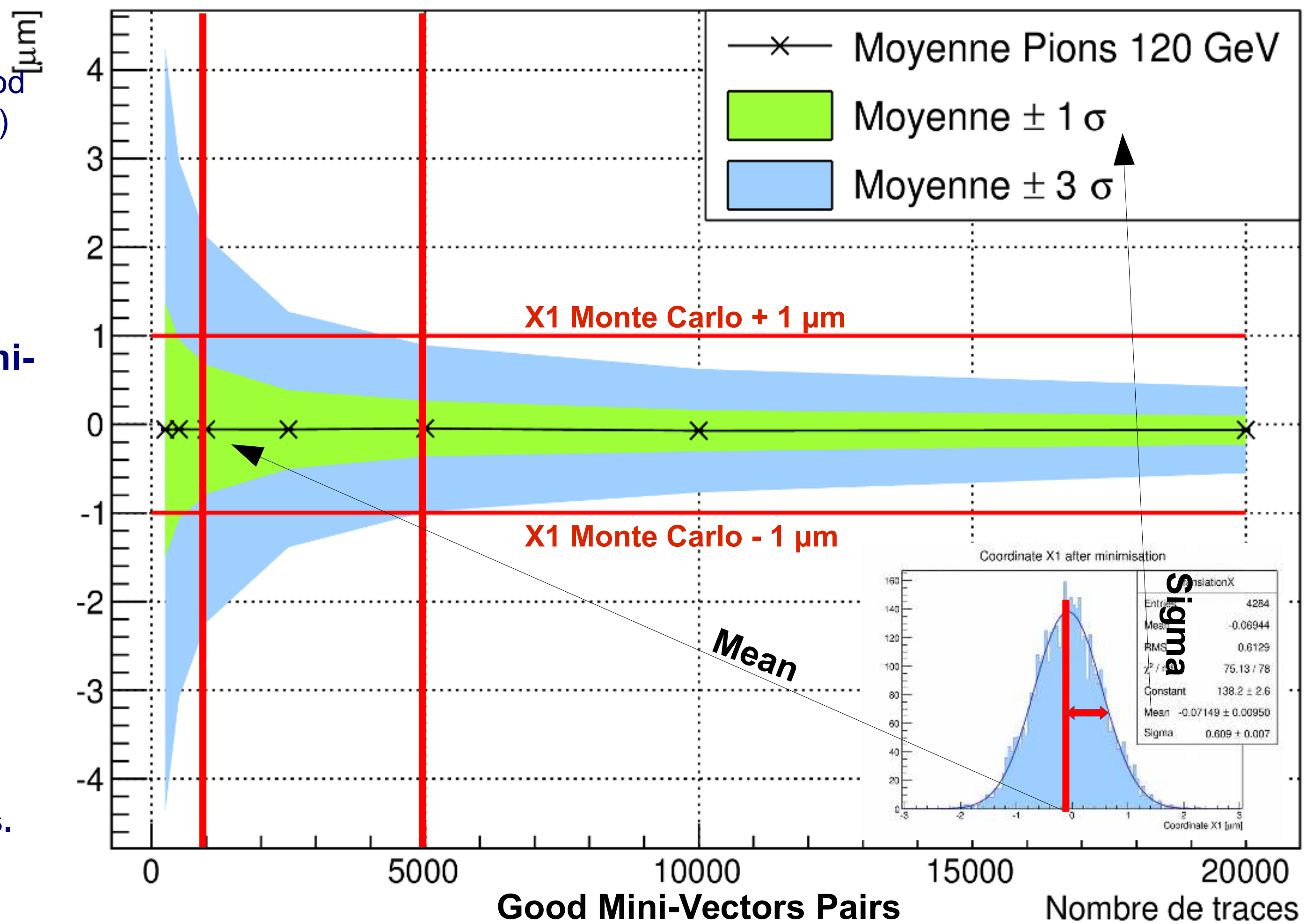
Alignment with mini-vectors : Results

- Ladder Center X1 position:
  - Mean vs statistic (deviation from MC values)
  - Width vs statistic (method precision : ***± 1 σ***, ***± 3 σ .***)
- Starting from **1000** good pairs of mini-vectors
  - ***precision (1 σ) better than 1 µm***
- **≤ 5000 good pairs of mini-vectors**
  - ***Precision (3 σ) better than 1 µm***
- **Y1 Position :**
  - **Similar results**
- **Z1 Position**
  - **Bias = -10 µm → weak mode**
  - **Bias reduction → increasing tiltY of MVs.**
  - New Precision ***(1 σ)*** **<** **2µm** with **1000 mini-vector pairs**

Position after minimisation in function of statistics

Axe X

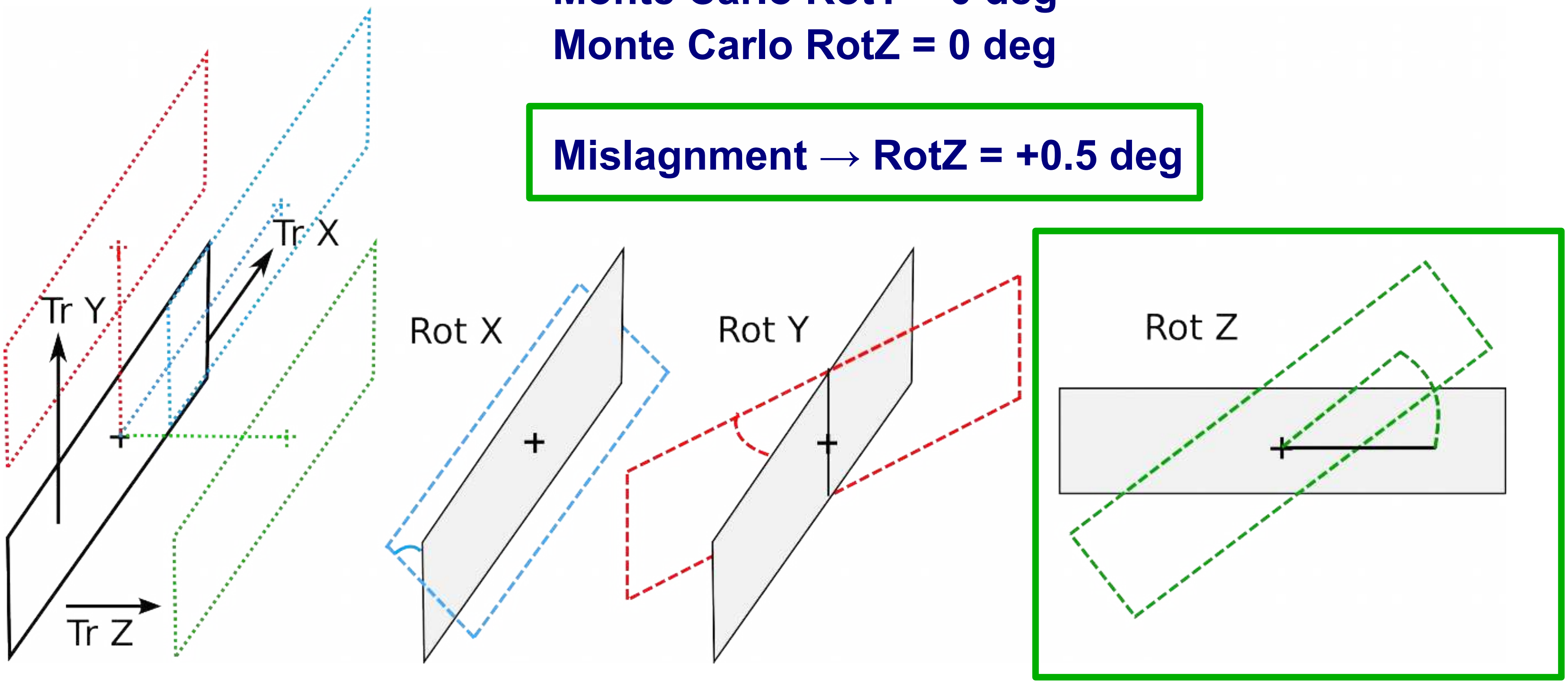
Preliminary Results



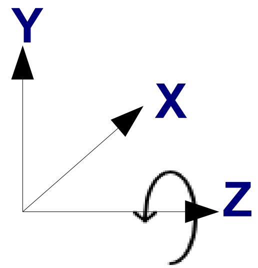
Parameter RotZ

Rotation Center O1 : Rotation O1Z
Monte Carlo RotX = 0 deg
Monte Carlo RotY = 0 deg
Monte Carlo RotZ = 0 deg

Mislagnment → RotZ = +0.5 deg

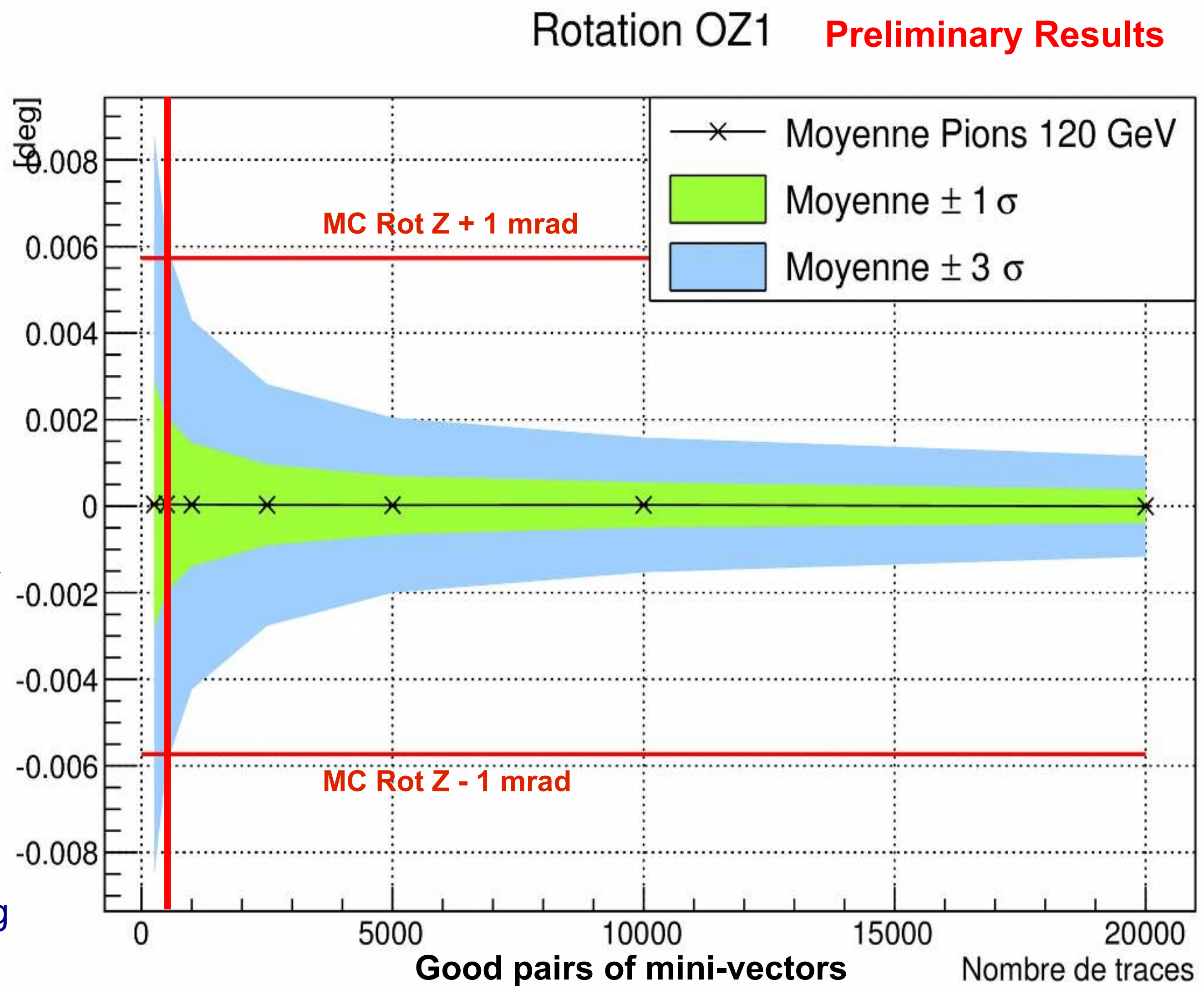


Alignment with mini-vectors : Results



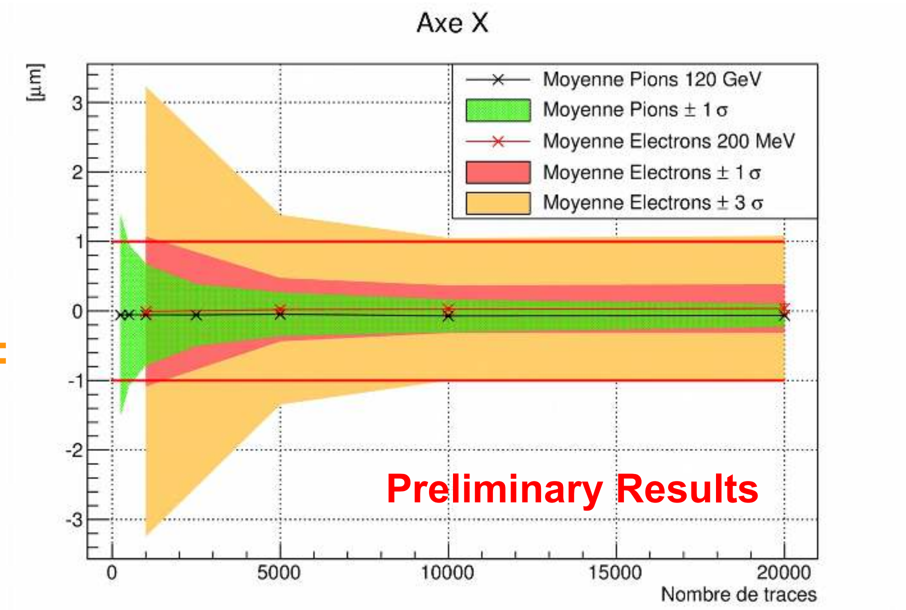
- **Rotation Axis Z :**
  - Mean vs statistic
  - Width vs statistic
- Red lines : Monte Carlo Value ± *1 mrad*
- **≥ 500 good pairs** of mini-vectors and more
  - No bias
  - ***precision (3σ) better than 1 mrad***
- **Rotation Axis Y :**
  - No bias + precision (1σ) < 1 mrad with ≥ 2500 MV pairs
- **Rotation Axis X :**
  - Small bias = -0.01 deg
  - **Width < 1mrad** (1σ) with ≥ **2500 Mvs pairs**

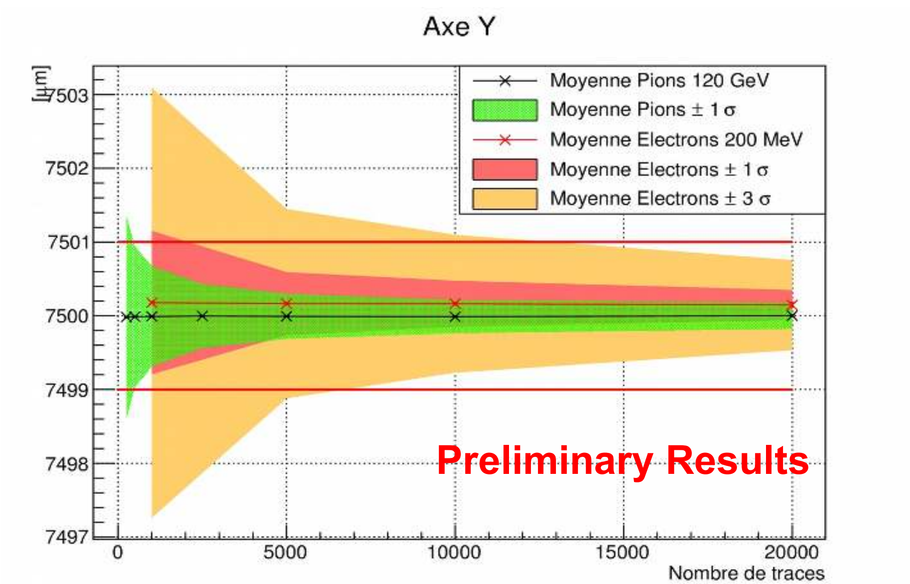
Position after minimisation in function of statistics

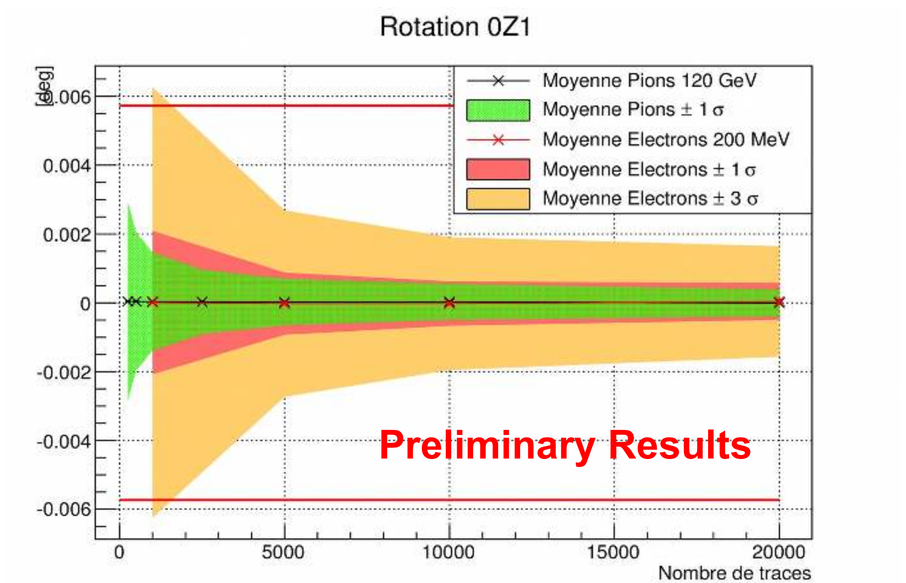


Low Momentum Electrons (200 MeV/c)

- **Same configuration as before**
- **No magnetic Fiels B=0 and perfect mini-vectors associations**
- **Electrons** : **P = 200 MeV/c known**
- **Green : 120 GeV/c pions (± *1 σ*)**
- ***Red : 200 MeV/c electrons (± 1 σ), Orange (± 3 σ)***
- Straight tracks + **Multiple scattering** effect :
  - **No bias** or **small bias**.
  - Small loss in precision

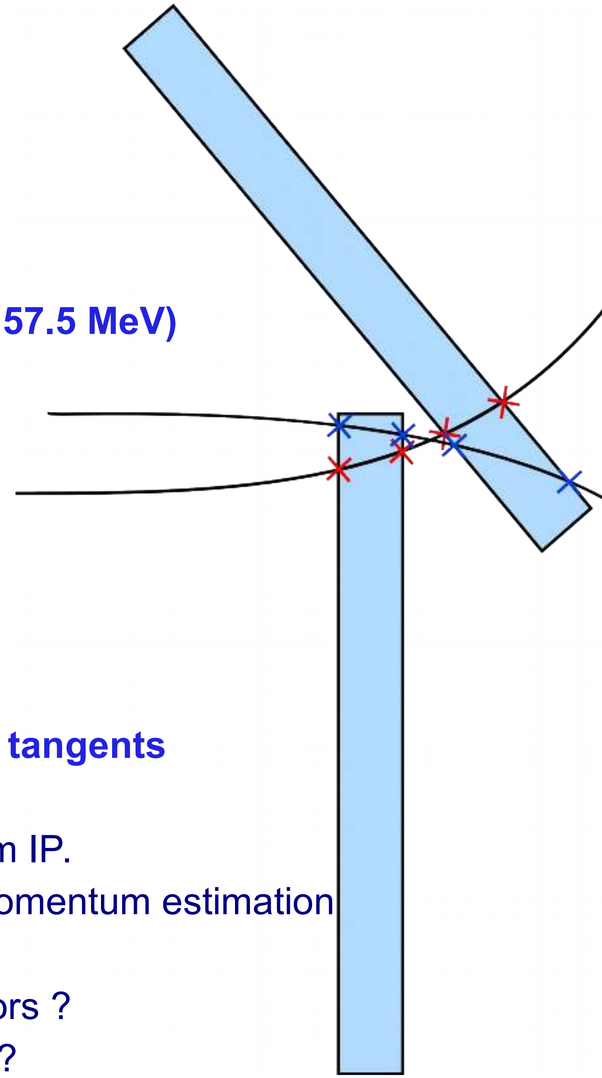






Alignment in real case (ILD + Beamstrahlung ?)

- **Step 2 : Standalone alignment with beamstrahlung and mini-vectors**
- **Beamstrahlung**
  - **High statistic in small amount of time**
  - **But Low momentum**
    - In **Magnetic Field** : Helices
    - **Multiple Scattering**
    - Very Low Momentum : Particles loopers.
  - **Use high transverse momentum beamstrahlung (>200 MeV ?)**
  - **SIT projections (Layer 1 : Pt_min = 80.5 MeV Layer 2 : Pt_min = 157.5 MeV)**
- **Statistic** :
  - **P_T>200 MeV** : Around **10000 MVs pairs in 1 or few Hours**
- Can we **select these high momentum tracks** with **mini-vectors** ?
  - **Very Ambitious**
- **Mini-vectors**
  - 2 points of measure
  - **local track direction**
  - **2 cluster shapes, one per side => Input and Output Tilts => Helix tangents**
  - Association by couple of mini-vectors = **4 points**
  - Search region for higt Pt tracks : Mostly in a cylinder of R=15 mm from IP.
  - If not standalone alignment : Pt > 200 MeV SIT + TPC information momentum estimation
- **Opened questions :**
  - Can we reconstruct these helices (high pt momentum) with mini-vectors ?
  - If we can, what is the resolution of the alignment with beamstrahlung ?



Summary and outlook

- **Full simulation chain for :**
  - Single sensors
  - Double sided ladders (PLUME)
  - SALAT sensors
  - Others …
- **Detector response based on the beam test data**
- **Alignment with mini-vectors : proof of principe validated**
  - Precision on the center (X1, Y1) < 1 μm.
  - Precision on Z1 < 2 μm.
  - Precision on tilts < 1 mrad.
  - With Few 10 000 mini-vectors pairs.

- **Outlook : Studies of this alignment method with low momentum particle and magnetic field : Work In Progress.**
- **Outlook : Global alignment of the double sided layer**

Thank you for your attention !

Thank you !

Statistic (Order of magnitude only)

- ***Order of magnitude for Statistic for 1 Overlapping Region***
- ***We want a minimum increase of material budget so :***
  - ***1 OR = 5 % Ladder Surface***
- ***Hard processes***
  - $L=1.8x10^{34}$ cm^{-2} s^{-1}
  - **e+ e- → μ+ μ- (500 GeV)** : **Around 1400/2800 μ per Year / OR**
  - **e+ e- → qq (500 GeV)** : **8000/16000 particles per Year / OR**
- Very Optimistic : ***Beamstrahlung*** (see after)
  - **Around 7500/20000 e-/+ per Hour /OR**
  - But **Low Momentum particles in a magnetic field**
- ***GigaZ option***
  - $L=10^{33}$ cm^{-2} s^{-1} → 10^{9}/Year
  - Example : Z → μμ (3.5%) + Z → ee (3.5%)
  - **Around 15000/25000 particles per Month / OR**
- ***Photon collider option***
  - $L=10^{34}$ cm^{-2} s^{-1} / 500 GeV
  - Ex : σ(γ γ-> μ+μ-μ+μ-) ≈ 150 pb (TDR Tesla)
  - **Around 40000...80000 μ per Month / OR**
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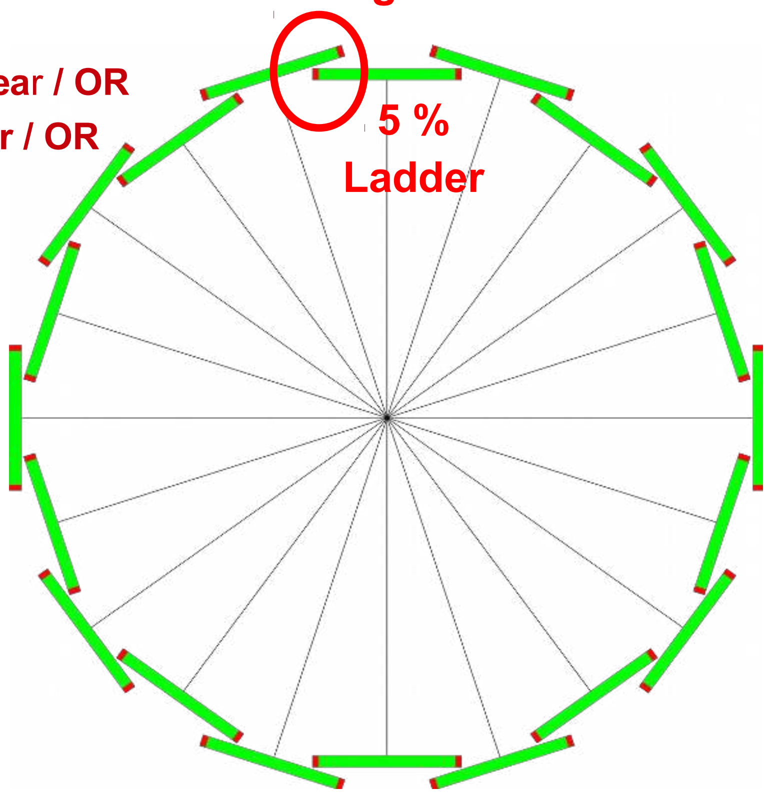
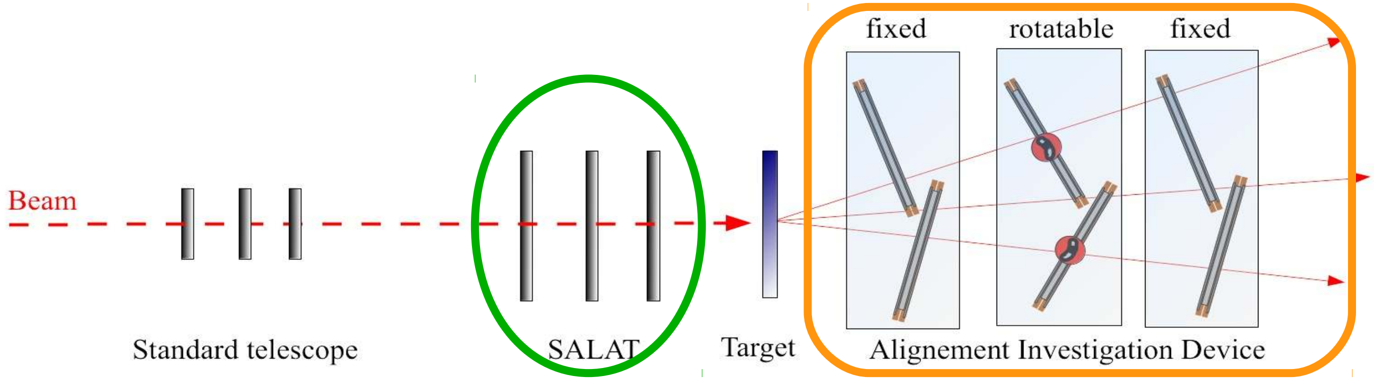
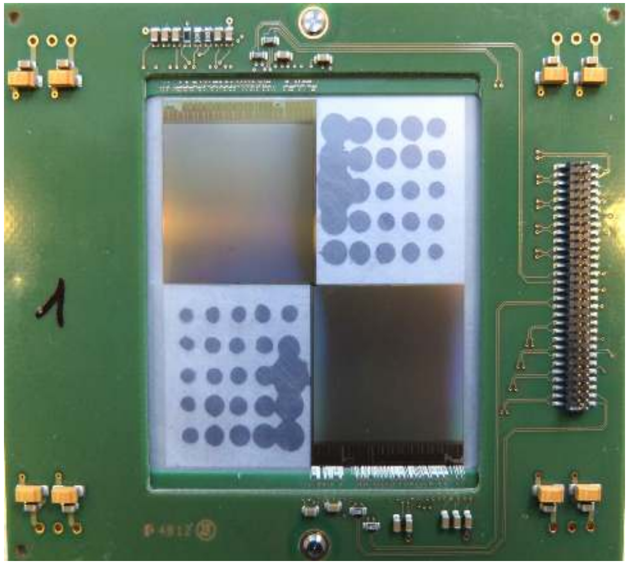


Thesis context : AIDA beam telescope



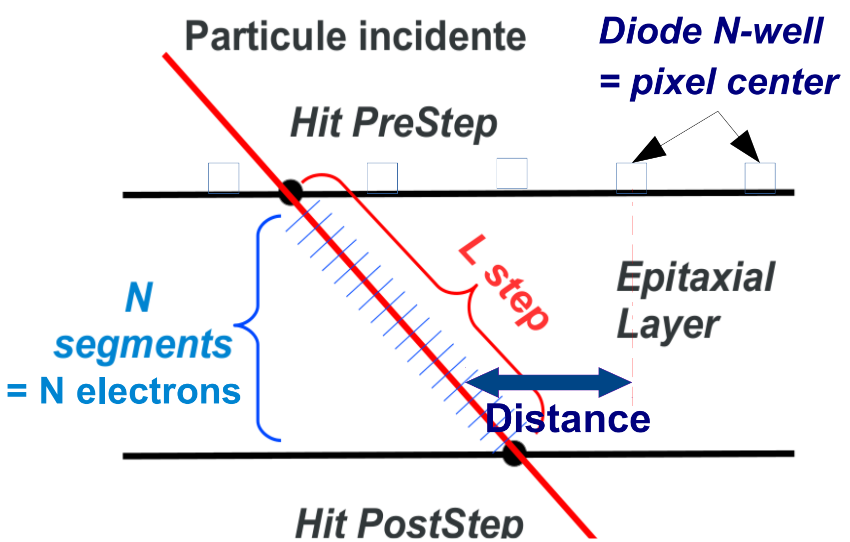
- AIDA : R&D futur detectors
- Vertex detector context → New beam telescope
- **SALAT : Single Arm Large Area beam Telescope**
- **AID box : Alignment Investigation Device**
  - Goal : ***Study of a vertex detector sector.***
  - Double sided ladders (PLUME, see latter)
- **Need a Monte Carlo simulation of these objects**
- **Studies on alignment**
  - Alignment of the whole ladder.
  - On the same layer, on the same ***overlapping region*** between two consecutive ladders → ***With mini-vectors.***

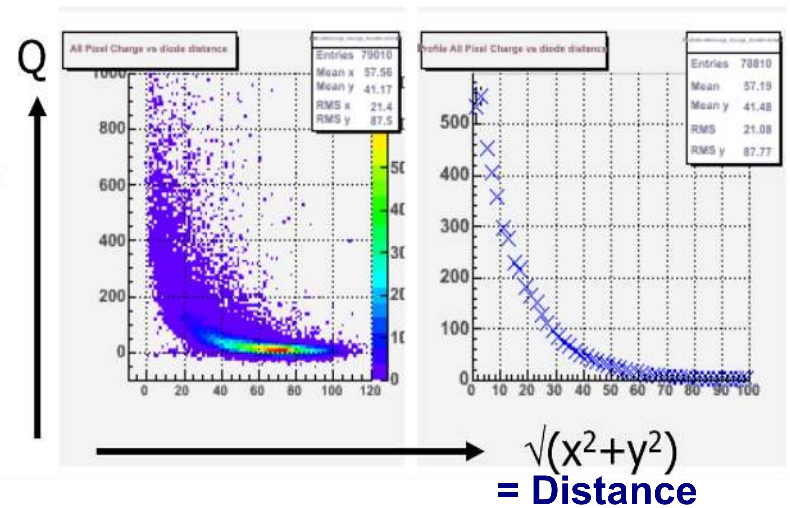


A SALAT super-plane

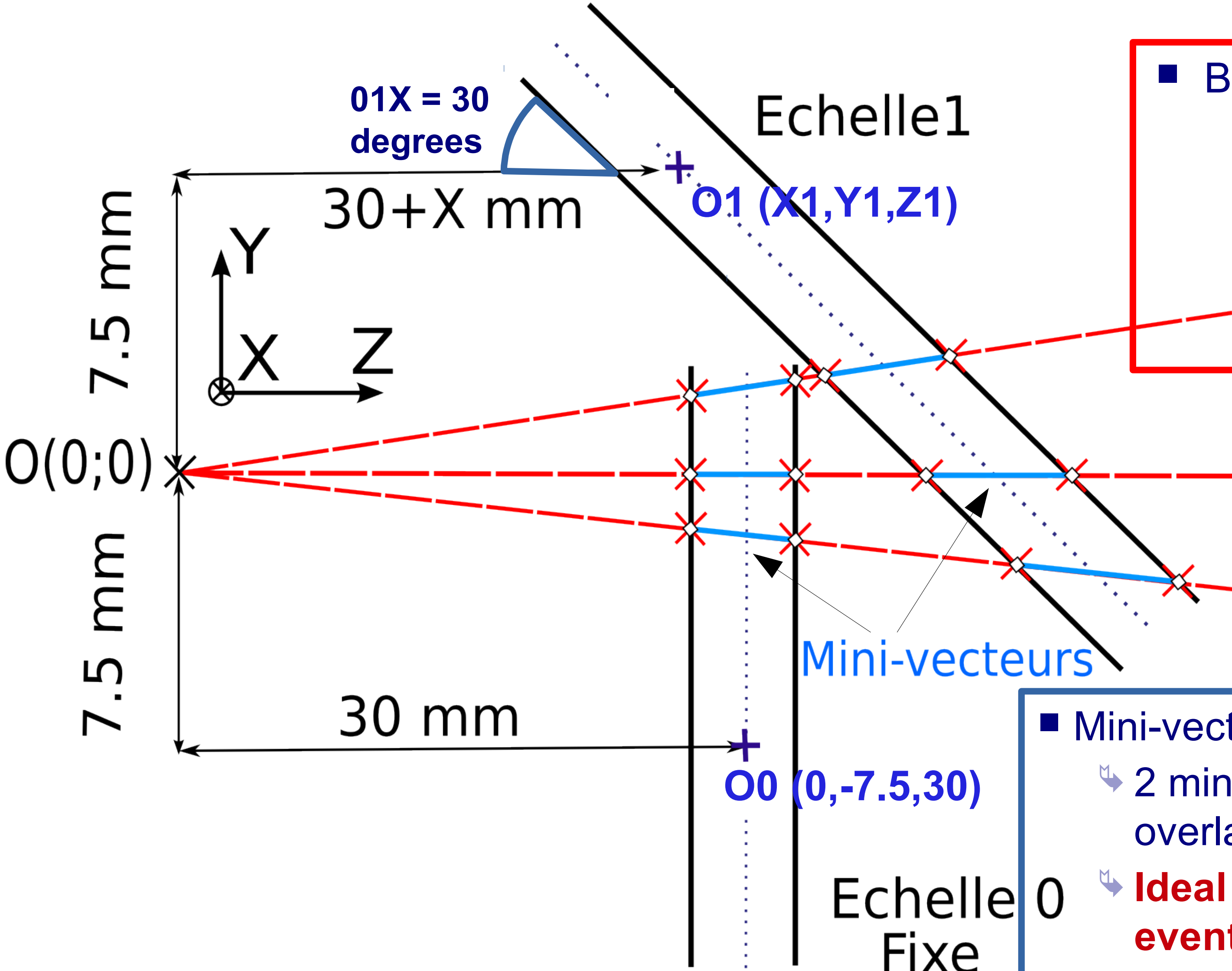
CMOS sensor response from energy deposition to digitization

- **Charge transport and digitizer**
  - **Pixels geometry** description
    - ***MIMOSA-28 : 20.7 x 20.7 µm²***
  - Very small depleted region → **thermal diffusion** of the charge carriers.
  - **Charge carriage simulation not possible** due to too many unknowns (doping profil, thicknees epi layer, etc ...)
  - **Data based charge transport model :**
    - from previous beam tests
    - Analog and digital output sensors
  - **Noise = *Gaussian noise*** (Mean = 13.7 e⁻)
  - ***Discriminator + Zero-suppresion***
    - pixel charge comparison with a threshold
    - Zero suppression
    - **Binary Output**





Configuration : Pions High Momentum (120 GeV/c)



- Beam = Cone
  - Vertex O(X,0,0)
  - Opening angle = Random[0,15] deg
  - Neg Pions 120 GeV/c

- **ΔZ = X = 5 mm**
- **ΔY = 15 mm**
- **ΔX = 0 mm**

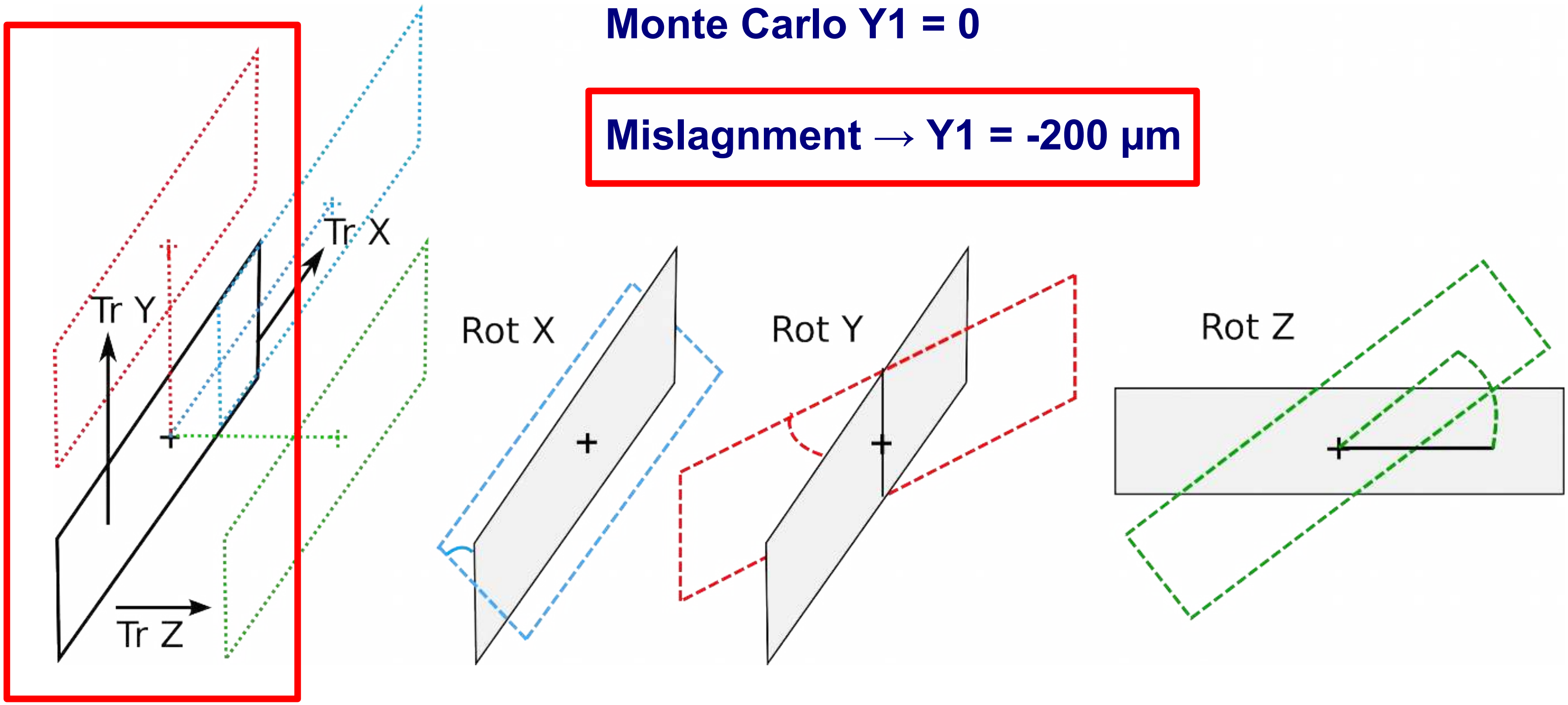
- Mini-vectors association
  - 2 mini-vectors in the overlapping region.
  - **Ideal case : (1 track per event)**
  - Cut in distance and Mvs tilts.

Parameter Y1

Translation Center C1 : Coordinate Y1

Monte Carlo Y1 = 0

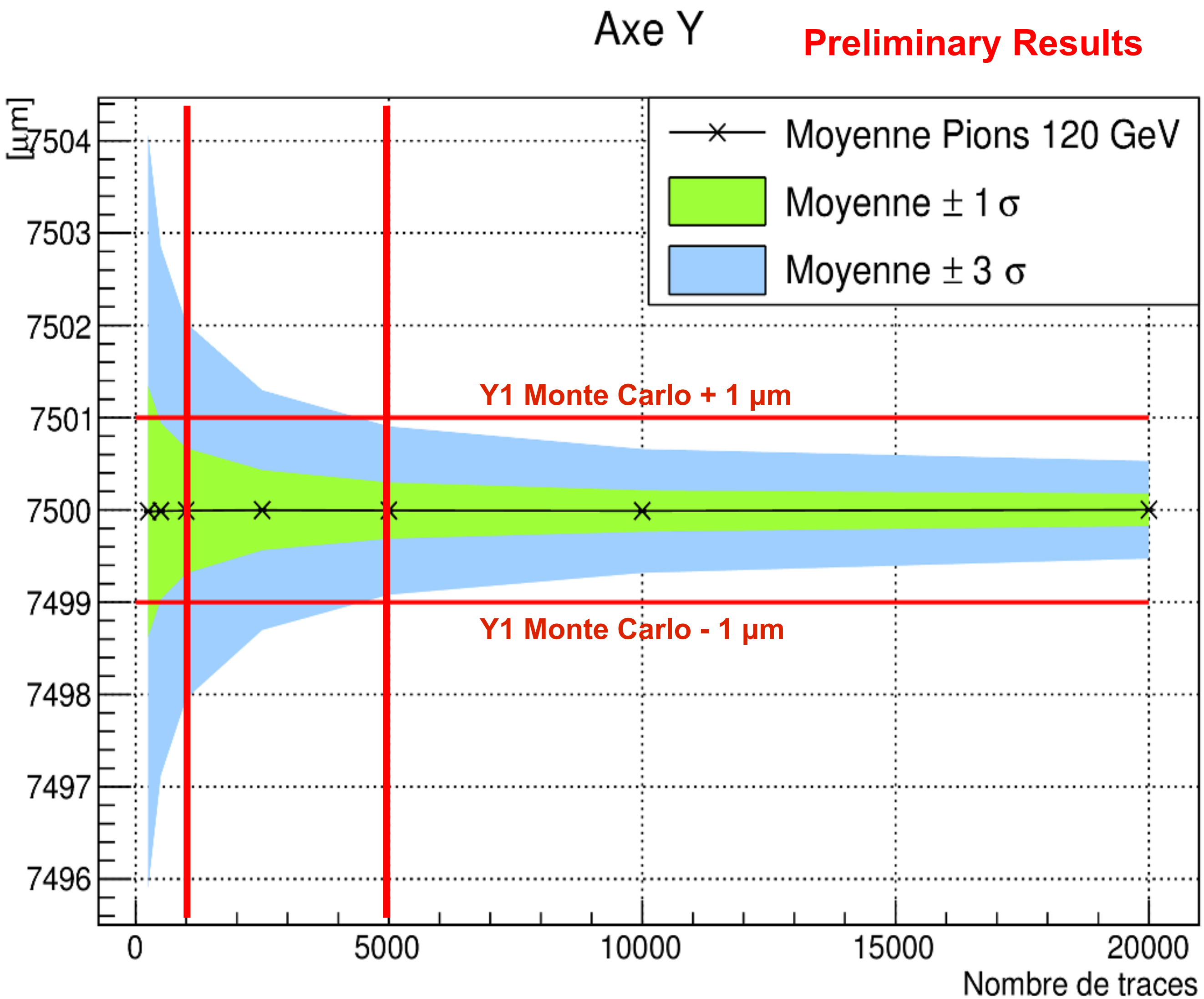
Mislagnment → Y1 = -200 µm



Alignment with mini-vectors : Results

Position after minimisation in function of statistics

- **Position Y1 :**
  - Monte Carlo Y1 = 0
  - Mean vs statistic (deviation from MC values)
  - Width vs statistic (method precision : ± *1 σ*, ± *3 σ* .)
- **1000** good couples of mini-vectors
  - ***precision (1 σ) better than 1 µm***
- **5000** good couples of mini-vectors
  - ***Precision (3 σ) better than 1 µm***

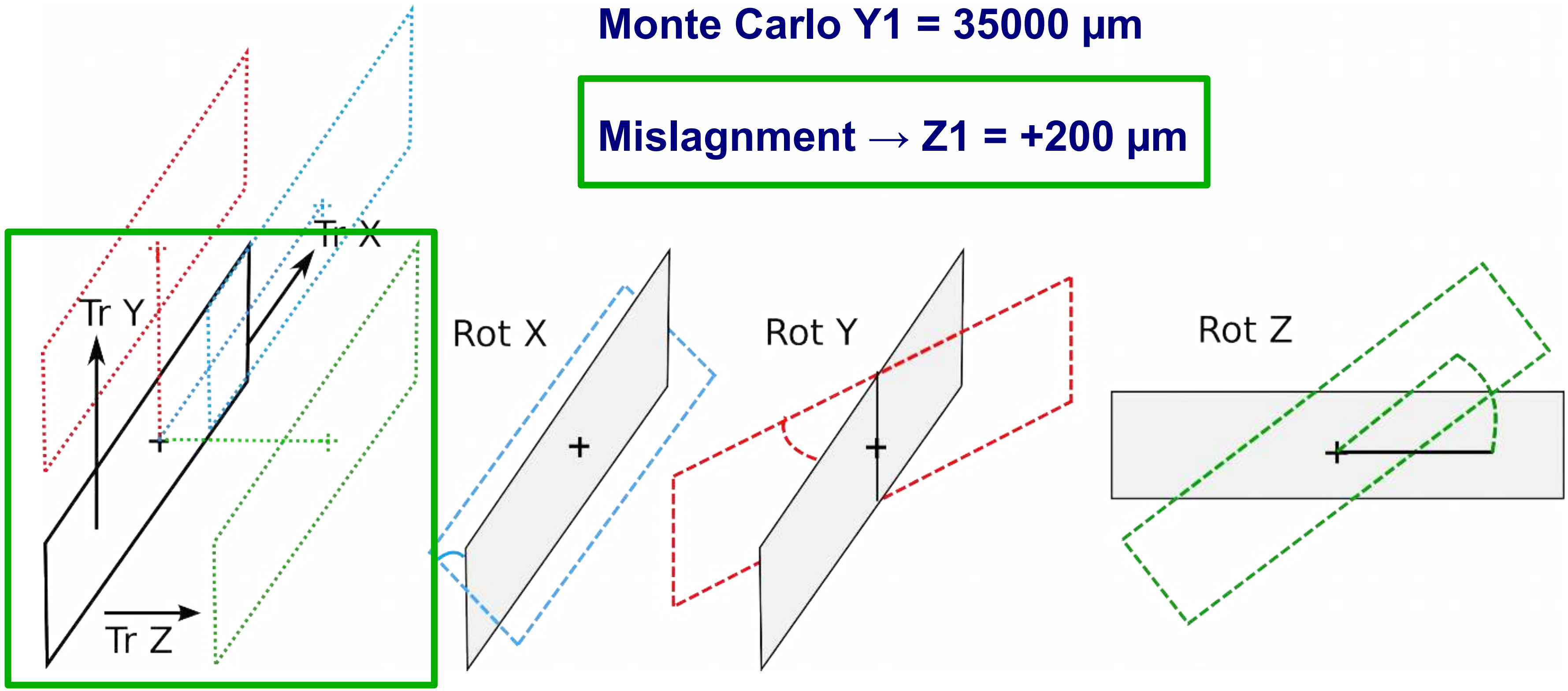


Good tracks = Good couples of mini-vectors

Parameter Z1

Translation Center O1 : Coordinate Z1
Monte Carlo Y1 = 35000 µm

Mislagnment → Z1 = +200 µm

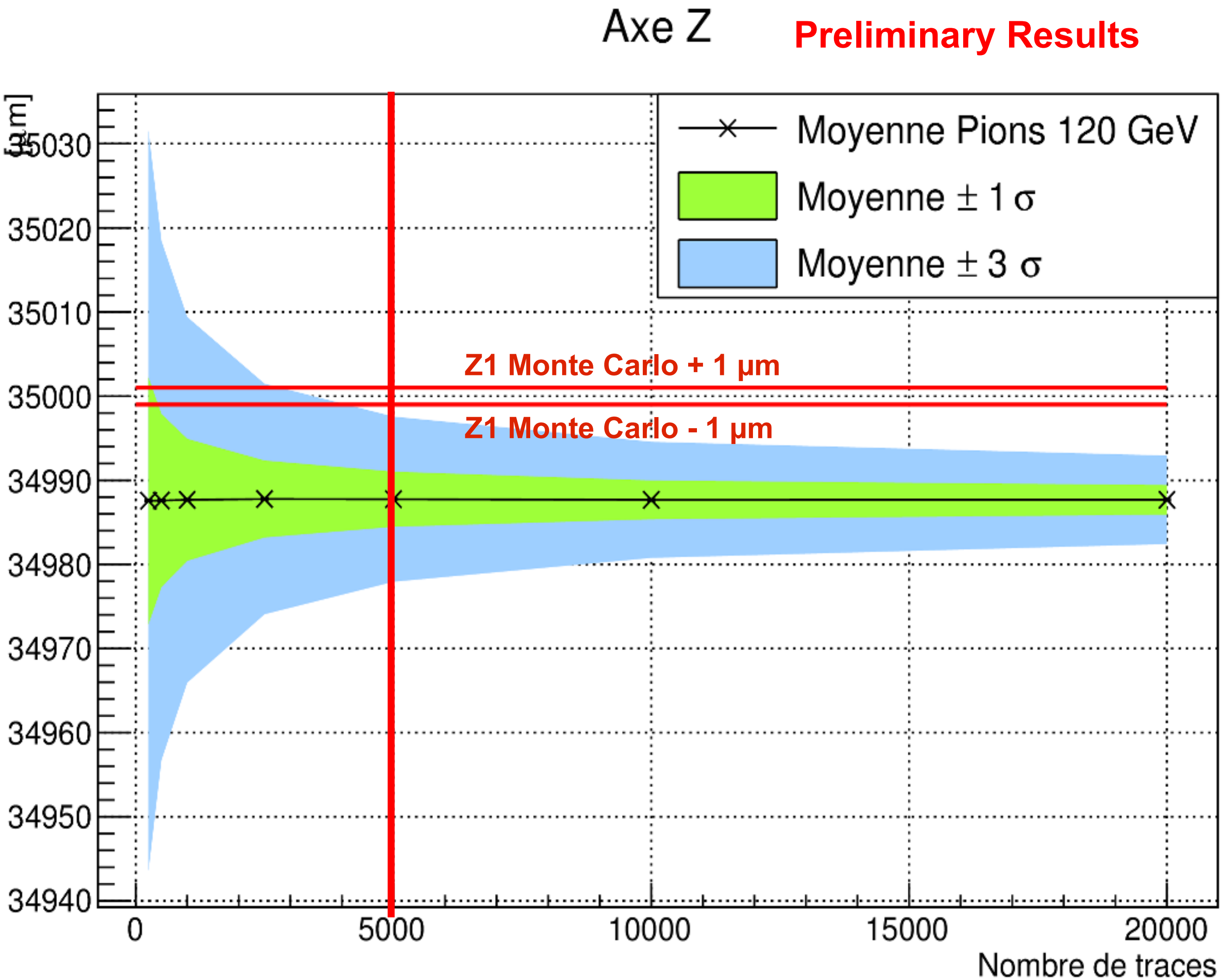


Alignment with mini-vectors : Results

- **Position Z1 :**
  - Monte Carlo Z1 = 0
  - Mean vs statistic
  - Width vs statistic (± *1 σ*, ± *3 σ* .)
- Mean = ***Bias*** around ***-10 μm.***
  - Result of a ***weak mode***
  - Constant bias → can be sustracted
- ≥ 5000 couples of MVs
  - ***Width (3 σ) = ± 10 μm***
- Bias reduction :
  - More tilt in Y direction for Mini-vectors
  - Bias suppresion
  - Precision (*1 σ*) < 2μm with 1000 couples

Position after minimisation in function of statistics

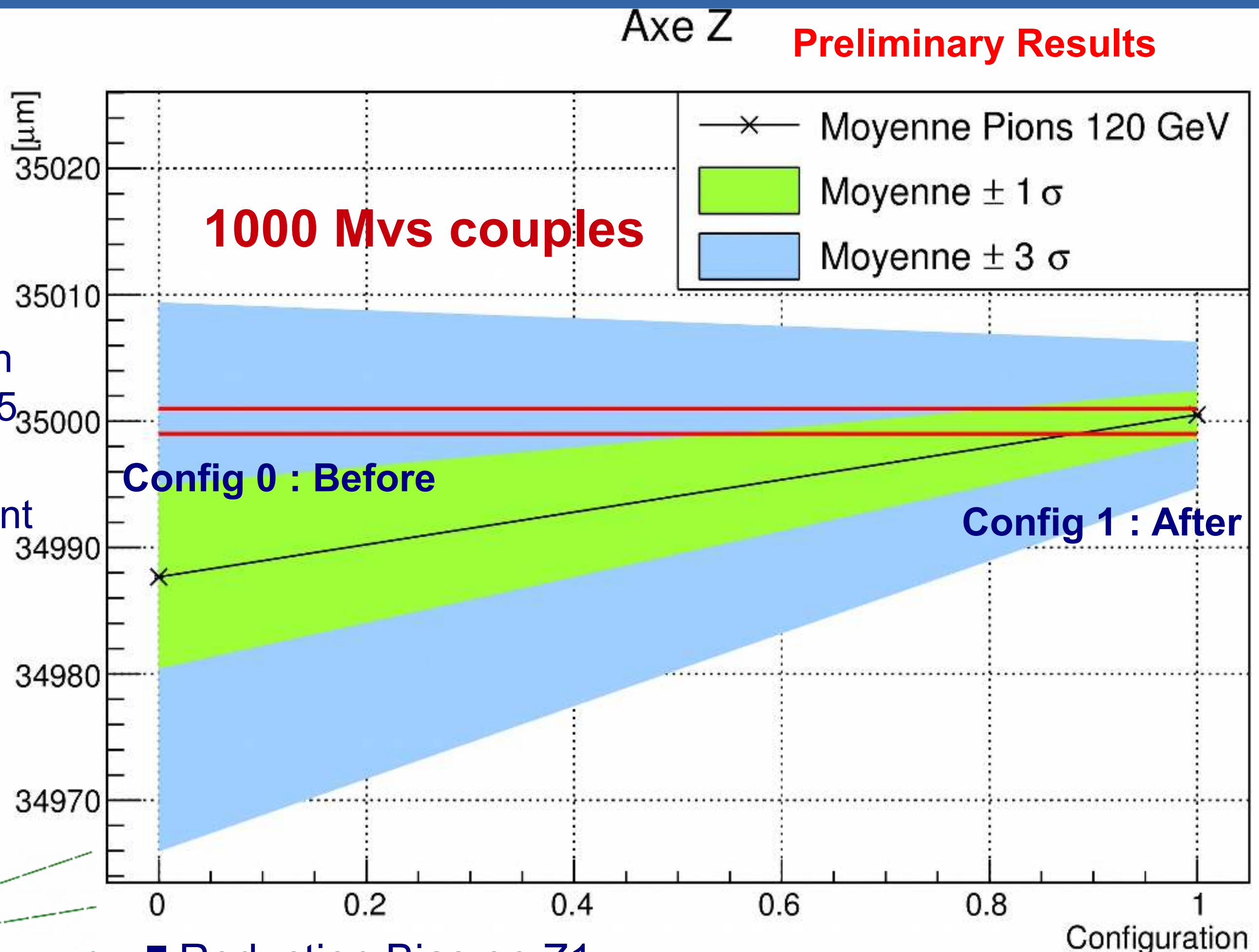
Preliminary Results

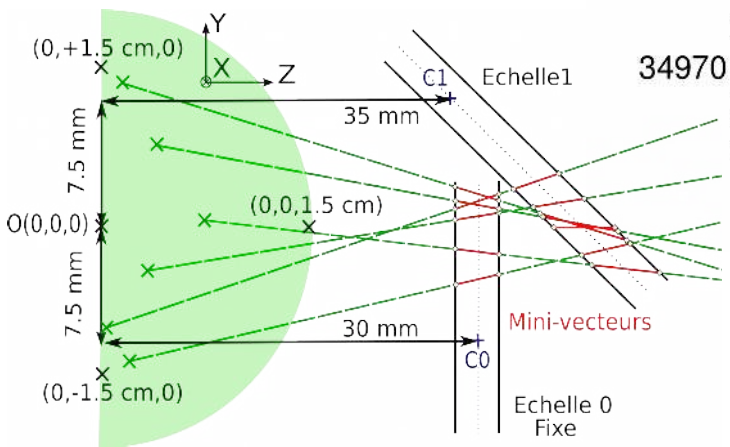


Good tracks = Good couples of mini-vectors

Bias reduction : Z axis

- **Bias on Z1**
- **Configuration 0**
  - As before (1000 Mvs couples)
- **Configuration 1**
  - Cone Vertex : start in an half cylinder of radius 15 mm.
  - MVs TiltY more important
  - 1000 Mvs couples
- **Bias reduction**
- Weak mode suppression



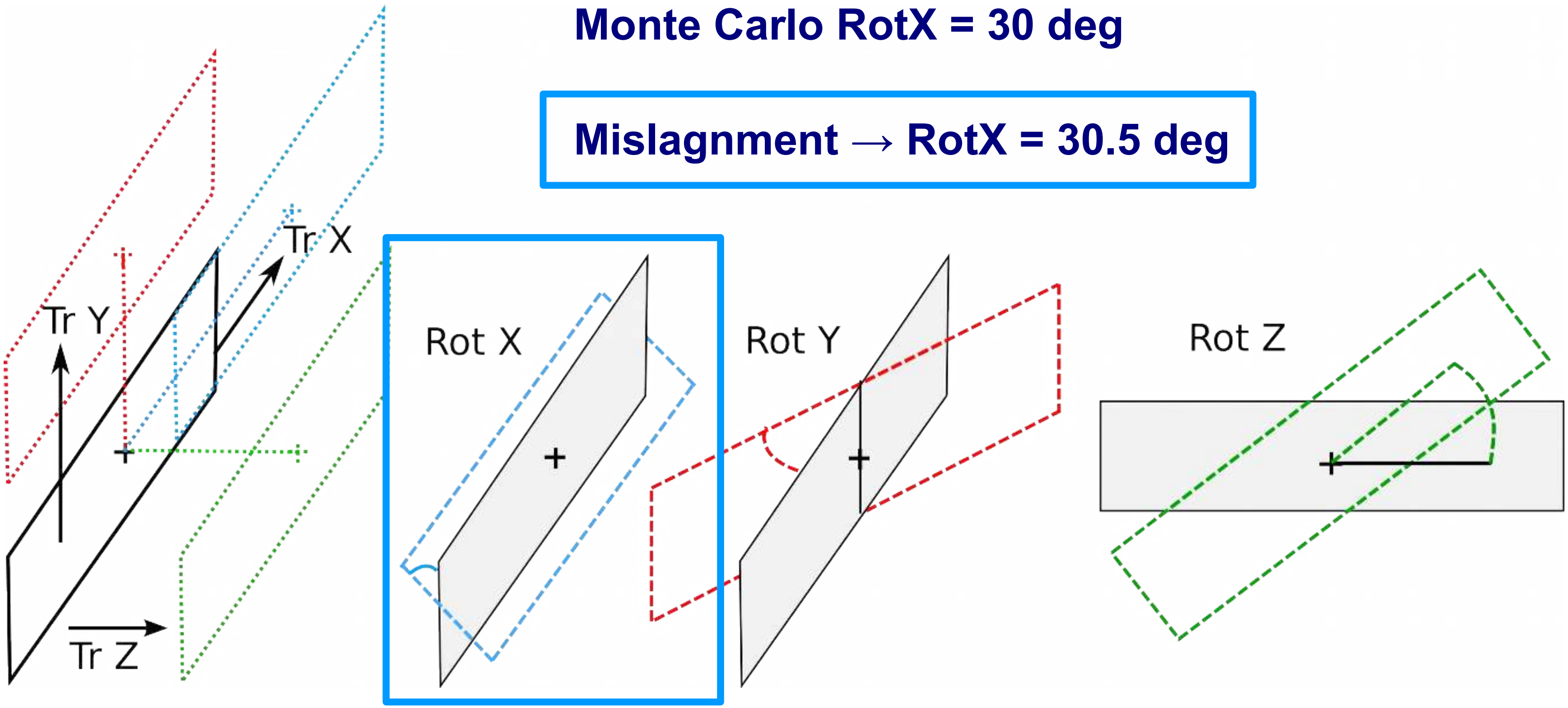


- Reduction Bias on Z1 :
  - With 1000 MVs couples → precision 1.5 µm
- And : Best precision in rotation O1Y
  - With 1000 MVs couples : precision (3 *σ*) : 3.5 mrad → 1.2 mrad

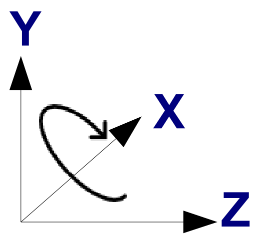
Parameter RotX

Rotation Center C1 : Rotation C1X
Monte Carlo RotX = 30 deg

Mislagnment → RotX = 30.5 deg

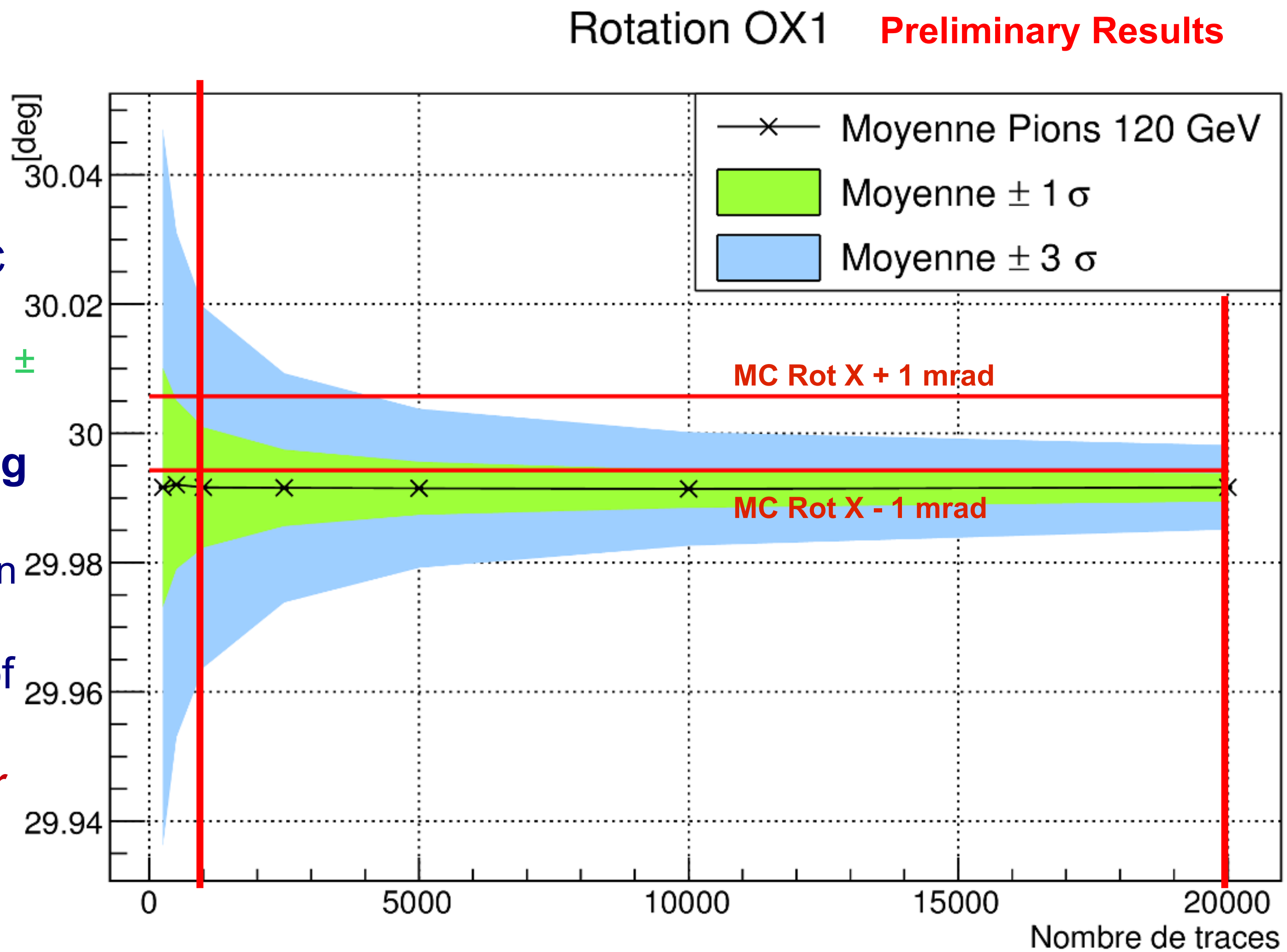


Alignment with mini-vectors : Results



- **Rotation 01X** :
  - Deviation from MC values vs stat
  - method precision : ± *1 σ*, *± 3 σ.*
- **Small bias : 0.01 deg**
  - Small weak mode.
  - Constant bias : can be substracted
- **1000** good couples of mini-vectors
  - ***Width (1 σ) better than 1 mrad***
- **20 000** good couples of mini-vectors
  - ***Width (3 σ) better than 1 mrad***

Position after minimisation in function of statistics

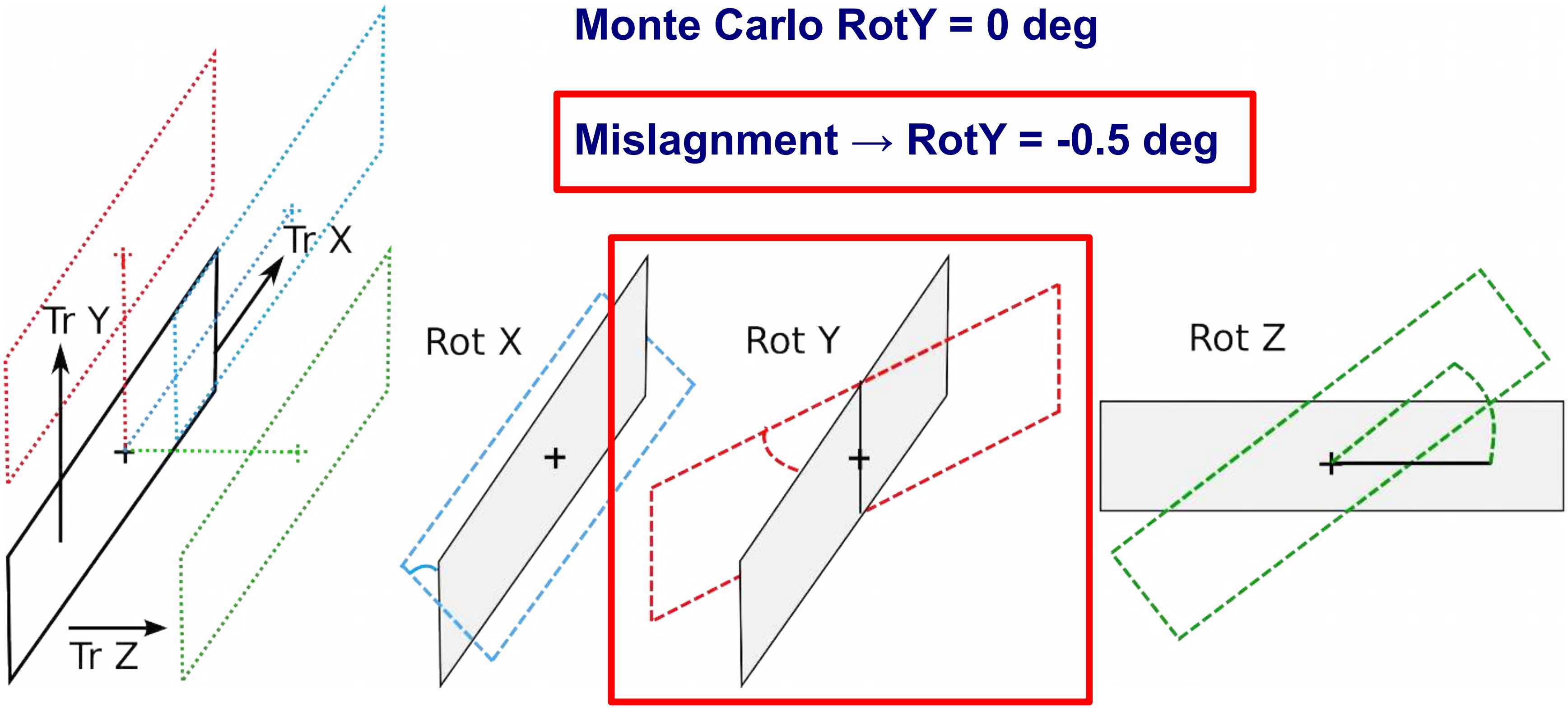


Good tracks = Good couples of mini-vectors

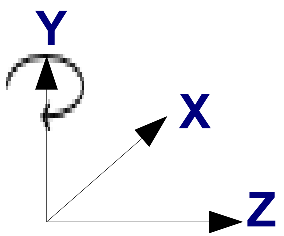
Parameter RotY

Rotation Center C1 : Rotation C1Y
Monte Carlo RotY = 0 deg

Mislagnment → RotY = -0.5 deg

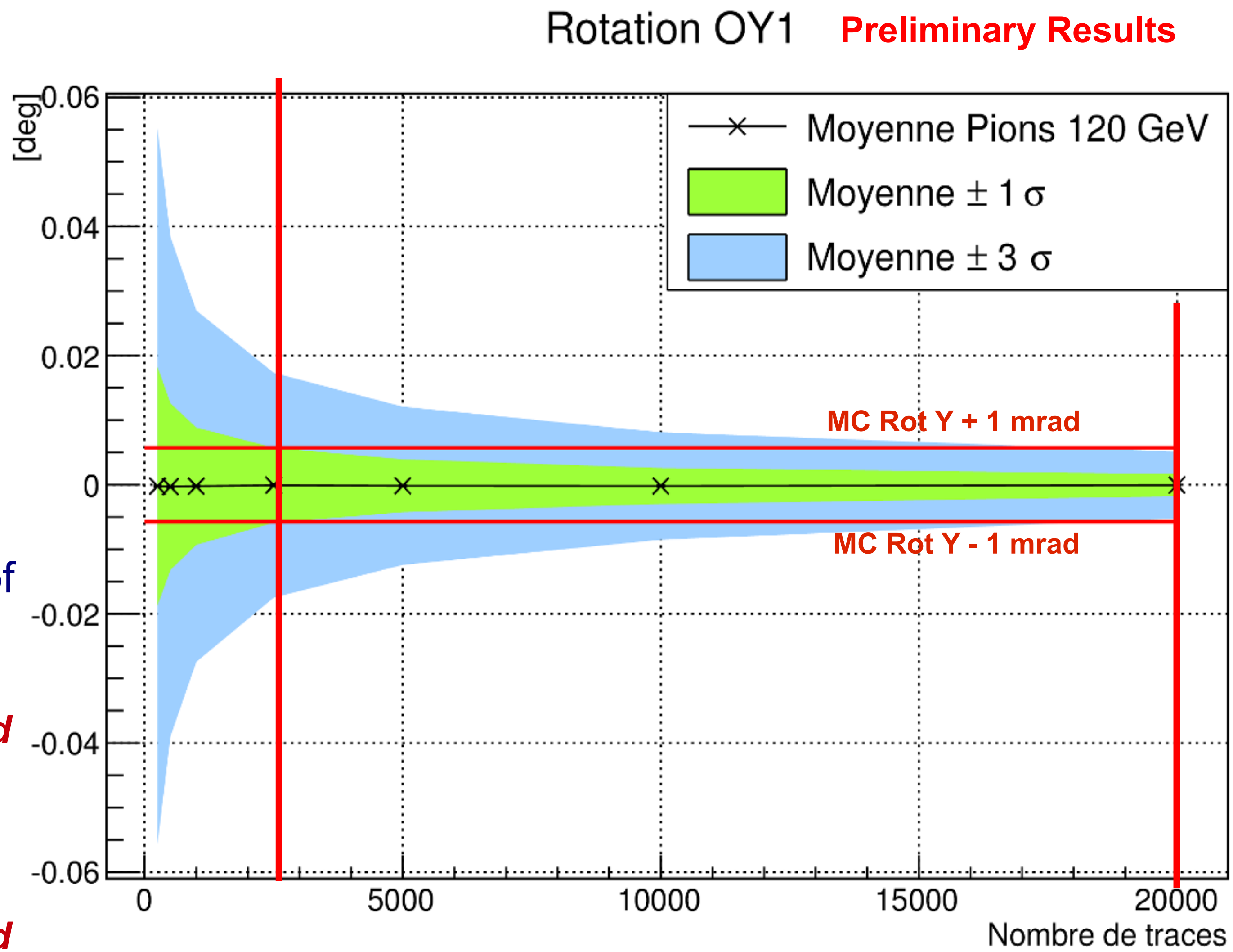


Alignment with mini-vectors : Results



- **Rotation 01Y :**
  - Mean vs statistic (deviation from MC values)
  - Width vs statistic (method precision : ± 1 σ, ± 3 σ .)
- **2 500** good couples of mini-vectors
  - ***precision (1 σ) better than 1 mrad***
- **20 000** good couples of mini-vectors
  - ***Precision (3 σ) better than 1 mrad***

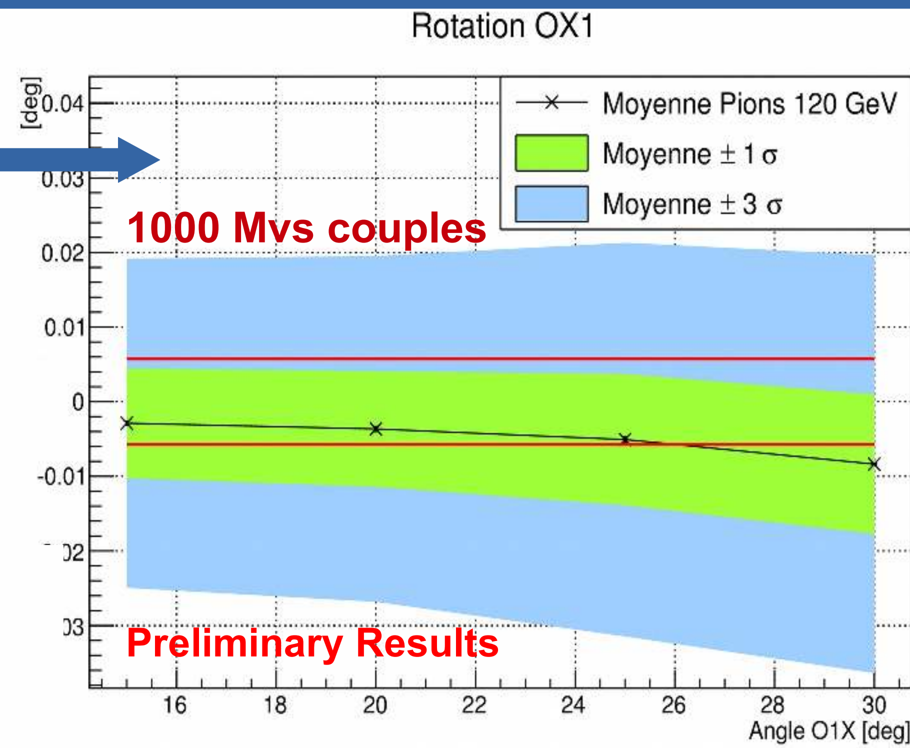
Position after minimisation in function of statistics

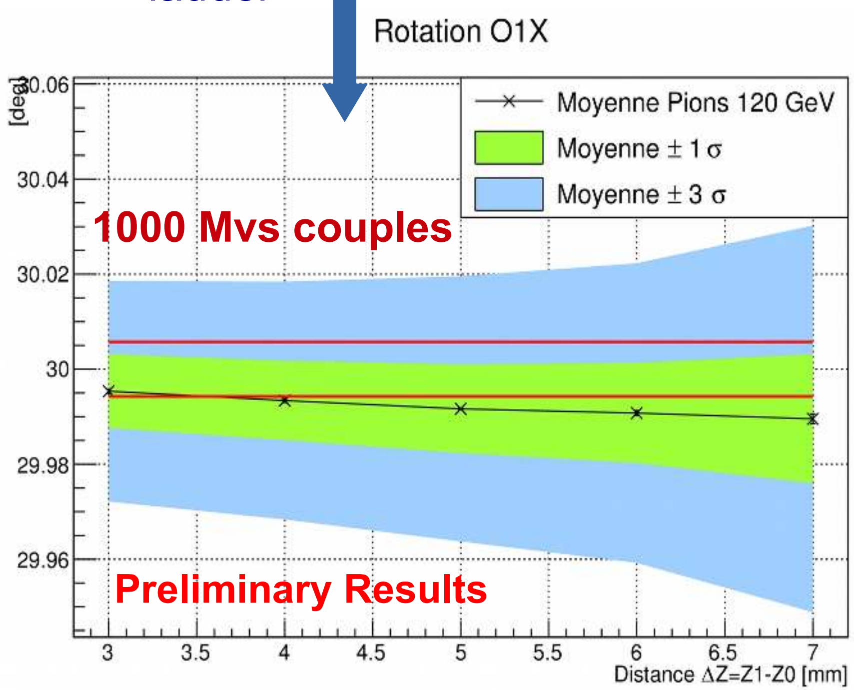


Good tracks = Good couples of mini-vectors

Bias reduction : Rotation O1X

- Bias on rotation O1X
- Reduction of the ladder1 tilt on O1X
  - Smaller distance between the two ladder
- Reduction of the distance between the 2 centers
  - Smaller distance between the two ladder





- Small bias reduction
  - Always a small weak mode
- Other solution :
  - Increase the overlapping region (In progress).
- Bias reduction strategy
  - Mixing these three solutions

SIT

- 2 Double Layer
- Rin = 153 mm 2 double layers 7.0μm
- Rout = 300 mm Si-strip sensors ±7.0μm
- z = 644 mm
- Ptmin = 80.5 MeV
- Ptmax = 157.5 MeV

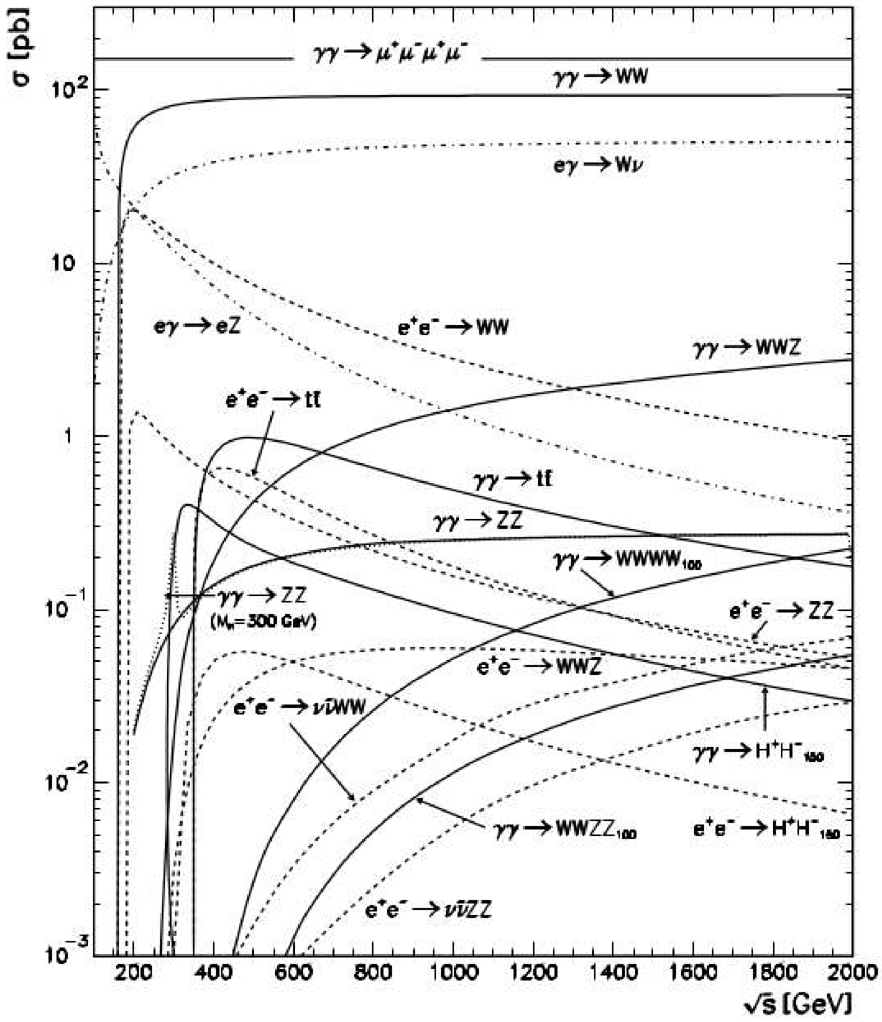
Statistic estimations : geometry

DBD/TDR values

Double Layer	Layer	Radius (mm)	|z| (mm)	|cos(θ)|	σ(µm)	Readout time (µs)
1	1	16	62,5	0,97	2,8	50
	2	18	62,5	0,96	6	10
2	3	37	125	0,96	4	100
	4	39	125	0,95	4	100
3	5	58	125	0,91	4	100
	6	60	125	0,9	4	100

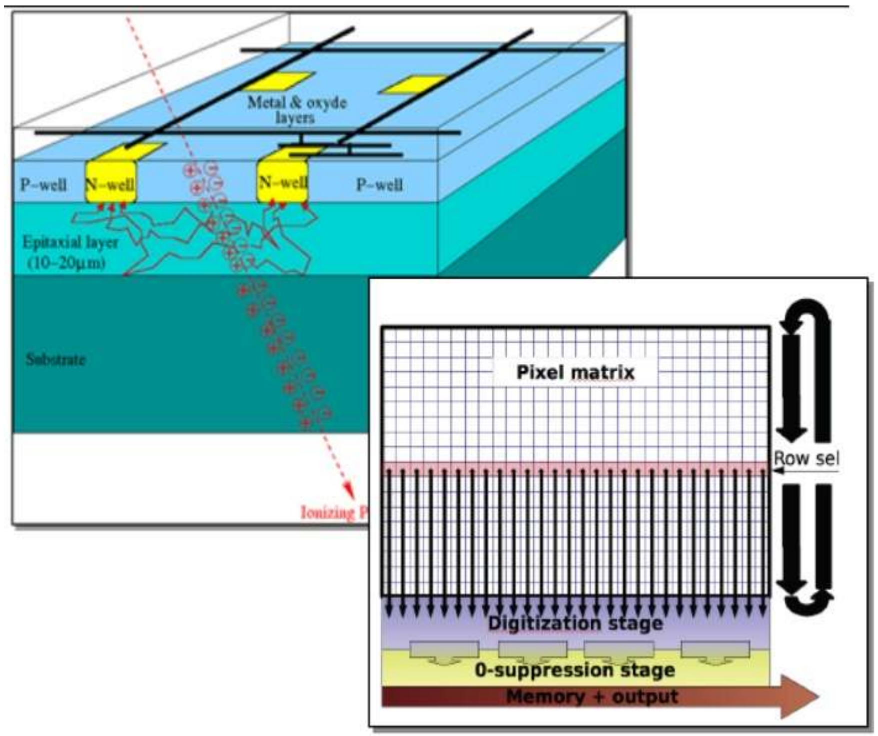
Double Layer	Layer	Surface (cylinder) (cm²)	Circumference (mm)	Ladders per double sided layer	Ladder Height (mm)	Angle (degree)
1	1	62,83	100,53	10	10	36
	2	70,69	113,10	10	10	36
2	3	290,60	232,48	12	20	30
	4	306,31	245,04	12	20	30
3	5	455,53	364,42	18	20	20
	6	471,24	376,99	18	20	20

Photon collider



MIMOSA CMOS sensors

- Operating principle
  - Signal in the epitaxial layer ≈ 1000 e-.
  - Thermal diffusion (very small depleted region)
  - Reflection at interfaces
  - Continuous collection of charges (no dead time)
- Advantage
  - Granularity : 3-4 µm with pitch of 20 µm
  - Material budget : sensors thinned down to 50 µm.
  - CMOS = Industrial process



- Readout time, power consumption.
  - Rolling shutter mode → T = T(row) * Number of Row
  - Low power consumption (≈ µW per pixel)
- Digitization and zero suppression
  - Digitization (end column)
  - Zero suppression (end column)

Chi2

$$\chi^2 = \sum_{Traces} \left(\frac{(U_{ext} - U_{MV1})^2}{\sigma_U^2} + \frac{(V_{ext} - V_{MV1})^2}{\sigma_V^2} + \frac{(\Delta R_X)^2}{\sigma_{R_X}^2} + \frac{(\Delta R_Y)^2}{\sigma_{R_Y}^2} \right)$$

$$R_X = \frac{x_2 - x_1}{z_2 - z_1} = \frac{\Delta x}{\Delta z} \qquad \sigma_{R_X}^2 = \frac{2\sigma_{\Delta x}^2}{(\Delta z)^2} + \frac{(\Delta x)^2 \sigma_{\Delta z}^2}{(\Delta z)^4}$$

$$R_X = \frac{y_2 - y_1}{z_2 - z_1} = \frac{\Delta y}{\Delta z} \qquad \sigma_{R_Y}^2 = \frac{2\sigma_{\Delta y}^2}{(\Delta z)^2} + \frac{(\Delta y)^2 \sigma_{\Delta z}^2}{(\Delta z)^4}$$

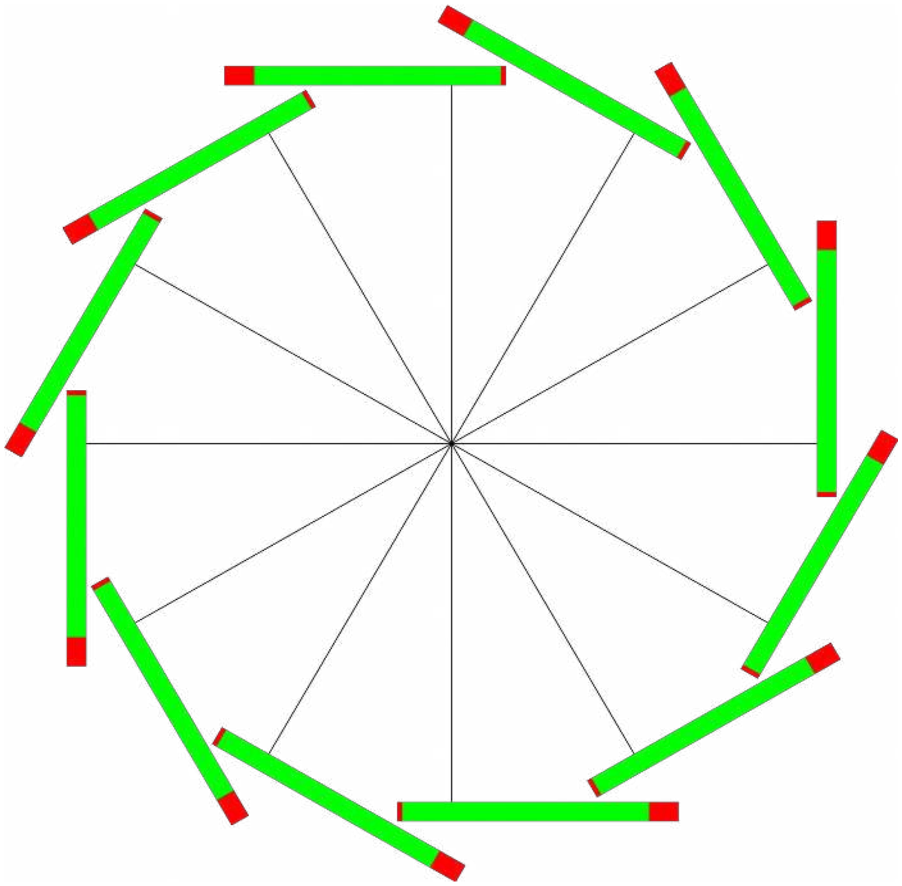
→ σ_U = 3.5 µm (Nomal incidence) or value at incidence θu

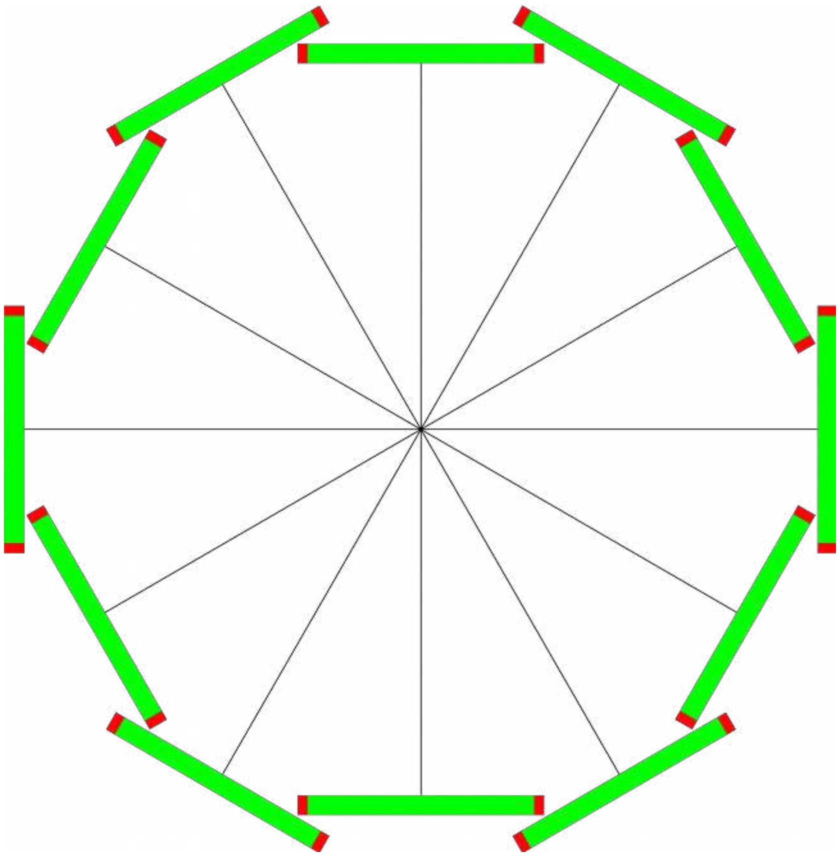
→ σ_V = 3.5 µm (Nomal incidence) or value at incidence θv

→ Δx, Δy, Δz = mini-vector size in x, y and z.

Double Sided Layer Geometry : 2 Options

- Option 1 : 1 readout area.





- Option 2 : 2 readout areas.