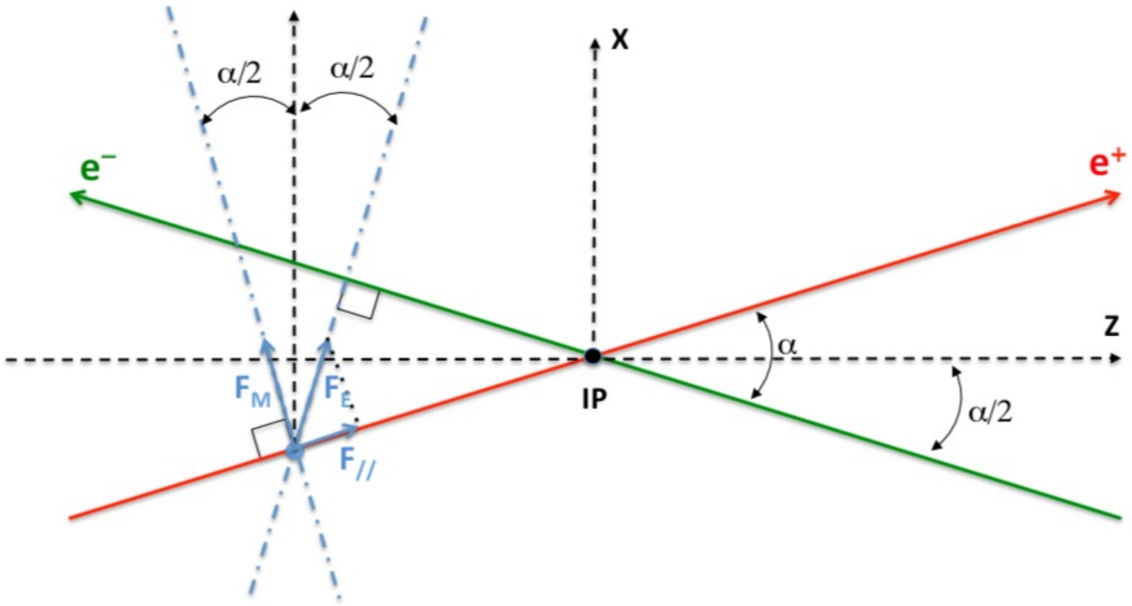
“Absolute” detector alignment

Reminder: Crossing angle α

Slide from previous talk

- **Beams cross at an angle α in the horizontal plane**
  - **The horizontal plane is defined as the plane subtended the two beams**



$$s = (p_e^+ + p_e^-)^2$$

$$e^+ \left(E_e^+ \sin\frac{\alpha}{2}, 0, \quad E_e^+ \cos\frac{\alpha}{2}, E_e^+ \right)$$

$$e^- \left(E_e^- \sin\frac{\alpha}{2}, 0, -E_e^- \cos\frac{\alpha}{2}, E_e^- \right)$$

$$\sqrt{s} = 2\sqrt{E_e^+ E_e^- \cos\frac{\alpha}{2}}$$

with $E_e^\pm = E(1 \pm \epsilon)$, $\sqrt{s} = 2E\sqrt{1-\epsilon^2}\cos\frac{\alpha}{2}$

- The z axis is the bisector of the two beam directions
- The y axis is perpendicular to the (x,z) plane
  - ➔ Polar angle θ defined wrt the z axis
  - ➔ Azimuthal angle φ defined in the (x,y) plane

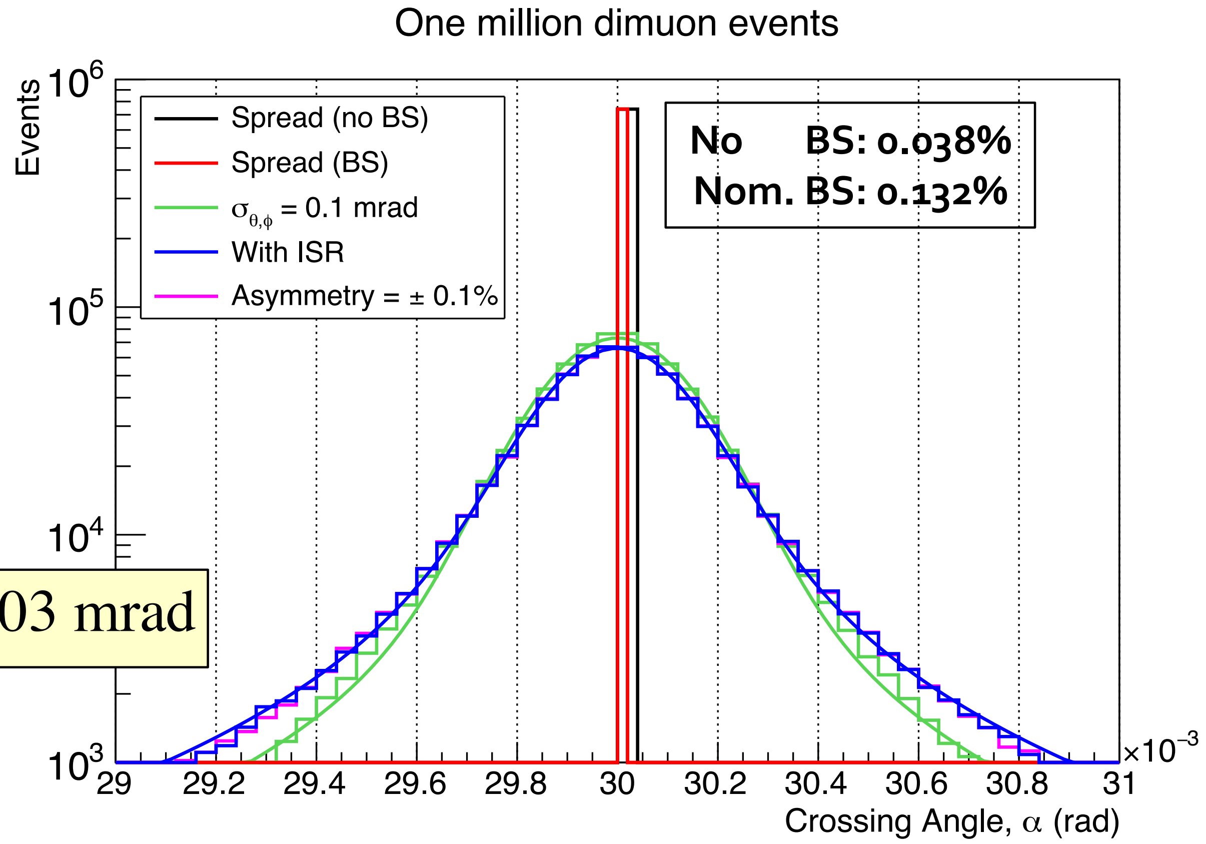
Why is alignment needed ?

- All the numbers presented in the previous talk were derived from the muon angles
  - Determined with respect to (X,Y,Z) axes as defined by the beams
    - The Z axis is the bisector of the two beam directions
    - The (X,Z) plane contains the two beams
    - The Y axis is perpendicular to the (X,Z) plane
      - ➔ Called "natural frame" in the following
  - Any bias in the knowledge of the (x,y,z) axes will systematically affect the muon angles
    - And all derived quantities like $\sqrt{s}$, $\sqrt{s}$ spread, masses, etc.
  - This requires an alignment of the (local) detector frame with the natural frame
    - Or vice versa, of course.

Reminder: Crossing angle determination

- With 10^6 dimuon events (every 5 minutes at the Z pole)

$$\alpha = 2\arcsin\left[\frac{\sin(\varphi^- - \varphi^+)\sin\theta^+\sin\theta^-}{\sin\varphi^-\sin\theta^- - \sin\varphi^+\sin\theta^+}\right]$$



$$\langle\alpha\rangle = 29.9998 \pm 0.0003 \text{ mrad}$$

- Spread sensitive to anything happening in the transverse plane
  - φ resolution, p_T of emitted photons, and of course (X,Y,Z) axes knowledge

Influence of misalignment on α

- Empirically, the spread of the α distribution tends to increases
  - With anything happening in the transverse plane

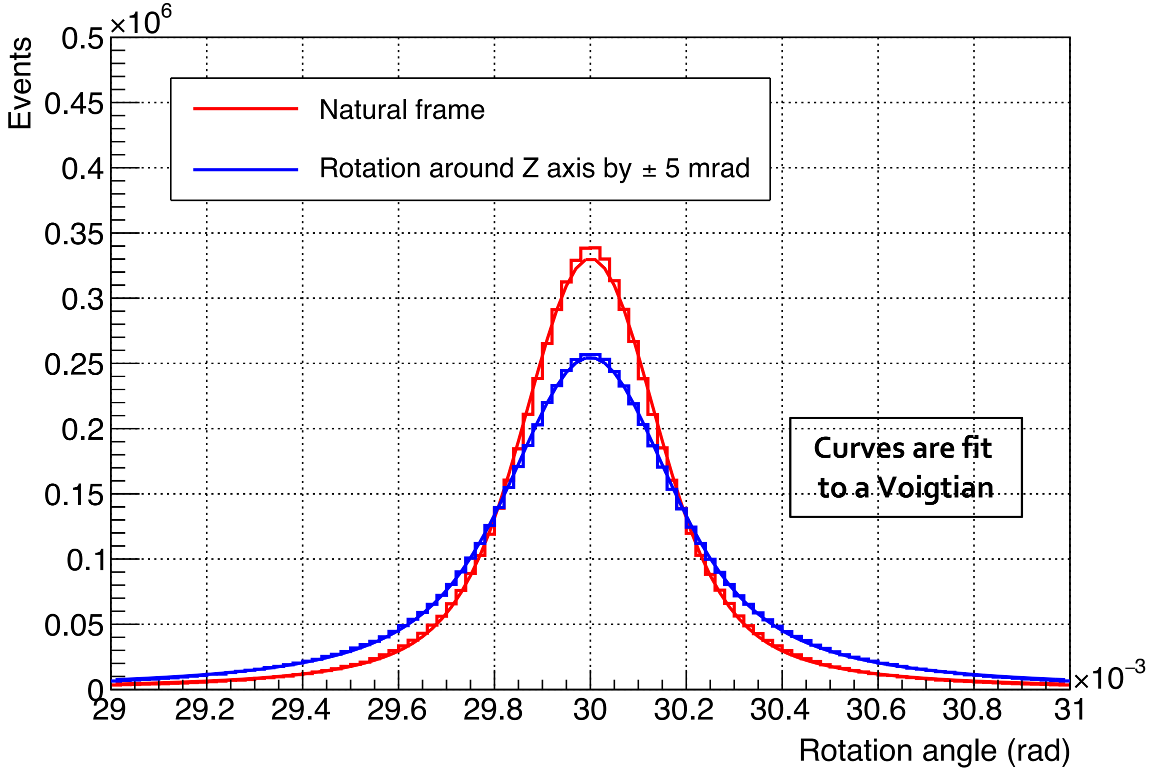
- Example: rotation around the Z axis changes both X and Y directions
  - Similarly
    - A rotation around X changes the Y axis
    - A rotation around Y changes the X axis

- Provides an alignment tool
  - By minimizing the α spread
    - Most sensitive variable: Voigtian width

      A Voigtian profile is the convolution of a Gaussian and a Breit Wigner

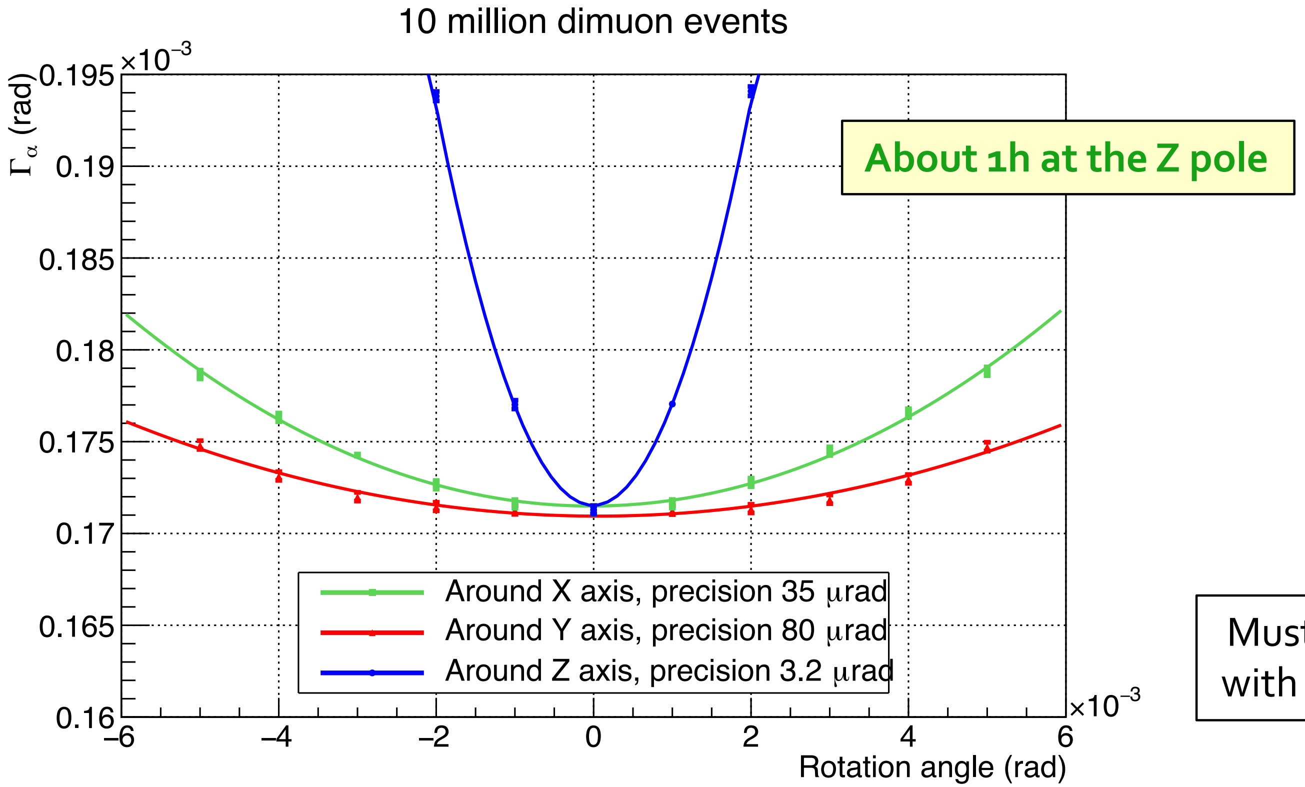
    - Maybe try with the half-height width ?
      - ➔ Detailed simulation needed here to check

10 million dimuon events



Sensitivity of the alignment method

- Minimize the spread of the α distribution to find the three Euler angles



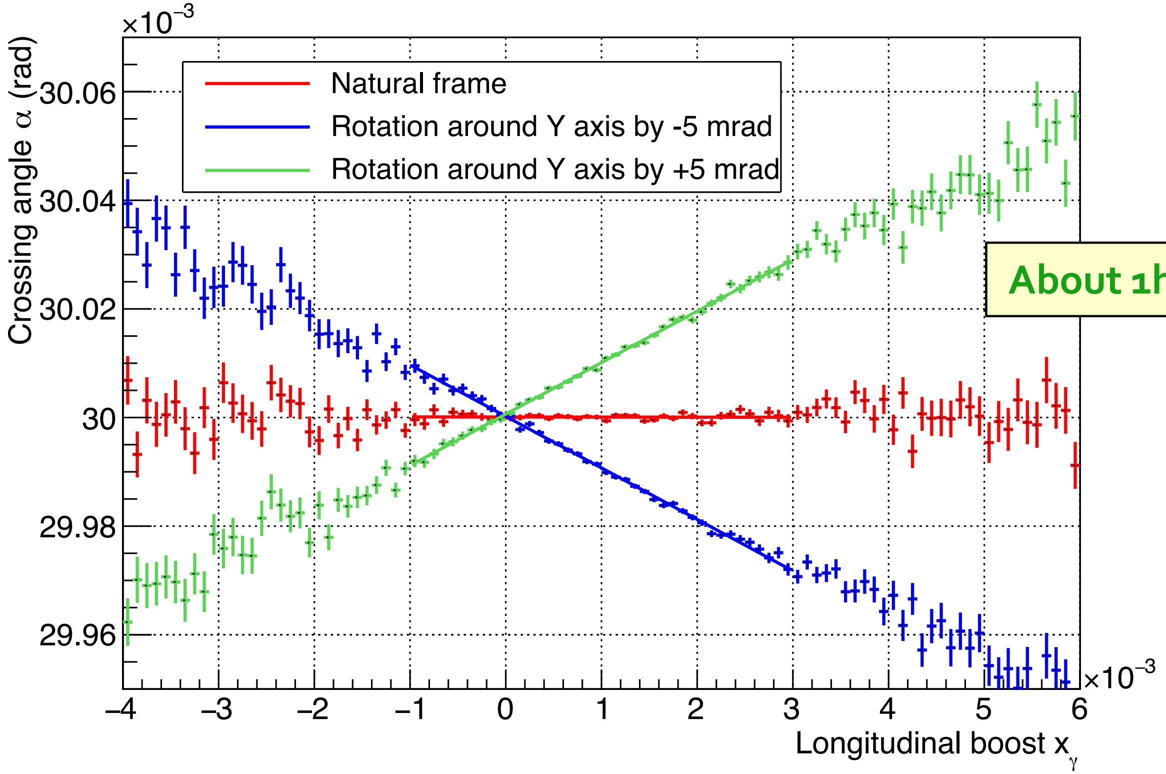
Must check the sensitivity with a detailed simulation!

- Important note: the natural spread of a is dominated by the φ resolution (here 100 μrad)
  - Alignment precisions improve quadratically with the φ resolution (defines detector requirement)
- The Y axis rotation angle is determined with a bias close to the φ resolution with 10^7 events

Improving the alignment around the Y axis

- Not much happens with a rotation around Y
  - The important (X,Z) plane, which contains the beams, remains untouched
  - However, the X and Z information get mixed by such a rotation
    - Resulting in a strong (linear) correlation between <α> and <x_γ>!

10 million dimuon events

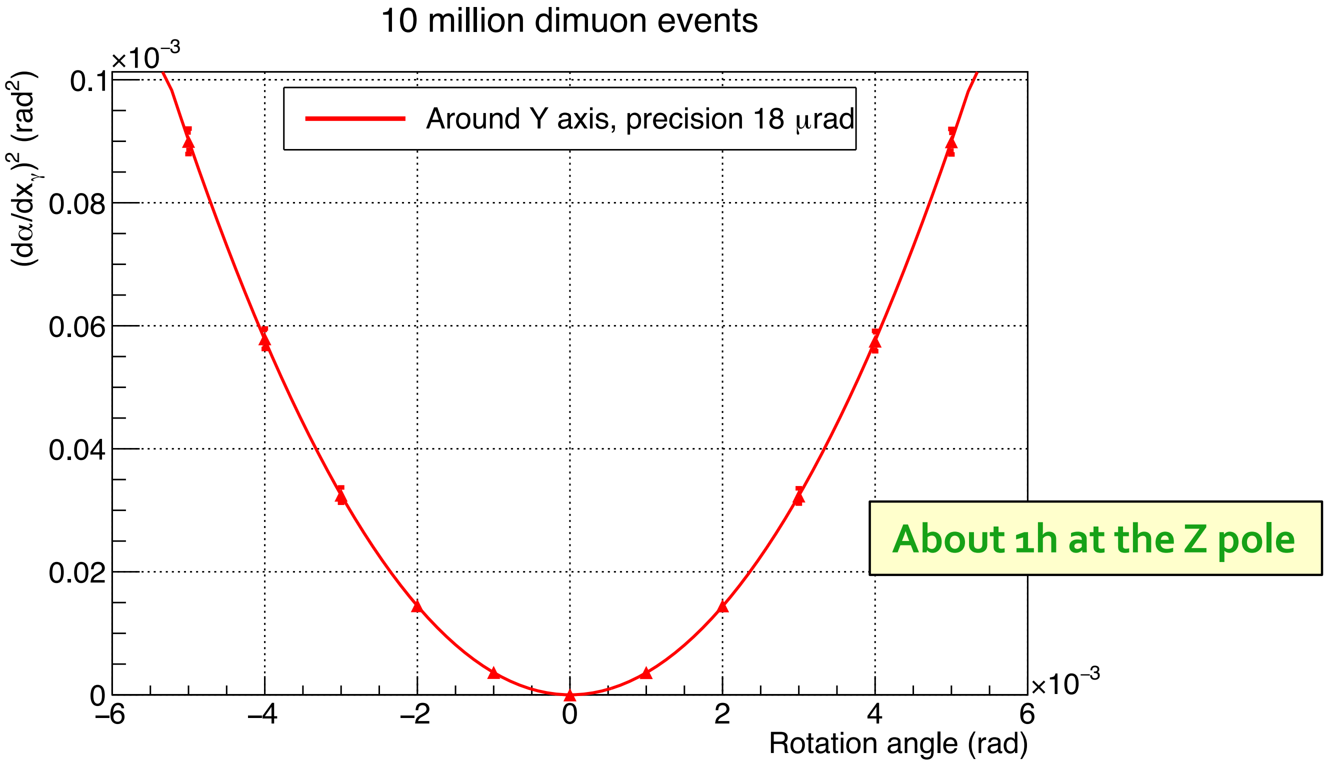


About 1h at the Z pole

In this profile plot, a boost ε of 0.1% is included

Improving the alignment around the Y axis

- **Alignment obtained by minimizing the correlation between x_γ and α:**



- **Improves the precision on that crossing angle by a factor of five.**
  - **With all the above, reach a precision of 0.1 μrad on α and of 10^{-7} on x_γ**
  - **Variation of the x_γ spread already insignificant with 100 times less events**

Remark about angular resolution

- Angular resolution assumed to be 0.1 mrad uniformly over the detector
  - It won't be the case in real life: may want to weigh the events accordingly
    - With a larger weight for events with a better angular resolution
- Q: How to measure the angular resolution to 10% or better
  - For any value of θ and ϕ ?
- A: Take a muon track in dimuon events
  - Refit it with the odd hits, on the one hand, and with the even hits, on the other
    - And compare the angles
  - Need only 100 tracks in each (θ , ϕ) bin for a 10% precision
    - 10^6 dimuon events = 5 minutes at the Z pole = bins of 3×3 $(\text{mrad})^2$
  - Expected to be stable in time
    - Precision (or bin size) improves with dimuon statistics
- Try ! (The IDEA detector may do wonders here)

Remark about detector acceptance

- One of the largest systematic uncertainty for the determination of $R_\ell = \frac{\sigma(Z \to \text{hadrons})}{\sigma(Z \to \text{leptons})}$
  - Especially the geometrical acceptance for lepton pairs
    - The expected statistical precision on this key observable is 3 10^{-6} !
      - ➔ Used as input to $\Gamma_{\ell\ell}$, α_S, N_ν …

- All numbers obtained so far use muons only above 10 degrees of the Z axis
  - May want to try to use lower angle muons (leptons)
    - And use the alignment method to define the acceptance
  - Angular resolution probably worse for lower angle leptons
    - Statistics may also be an issue

- Try !

A lot of work ahead !

- But also a lot of fun (speaking from experience)
  - And a possibility for many single-author publications

- IMPORTANT ! A tutorial is foreseen on Thursday afternoon (Marcin Chrząszcz)
  - Learn how to generate, simulate, analyse dimuon events and more in FCCSW
    - Come with your computer !
  - And apply what you have learnt to determine $\sqrt{s}$, spread, boost, angles, axes, etc.