Geometric Alignment of the SND Detector

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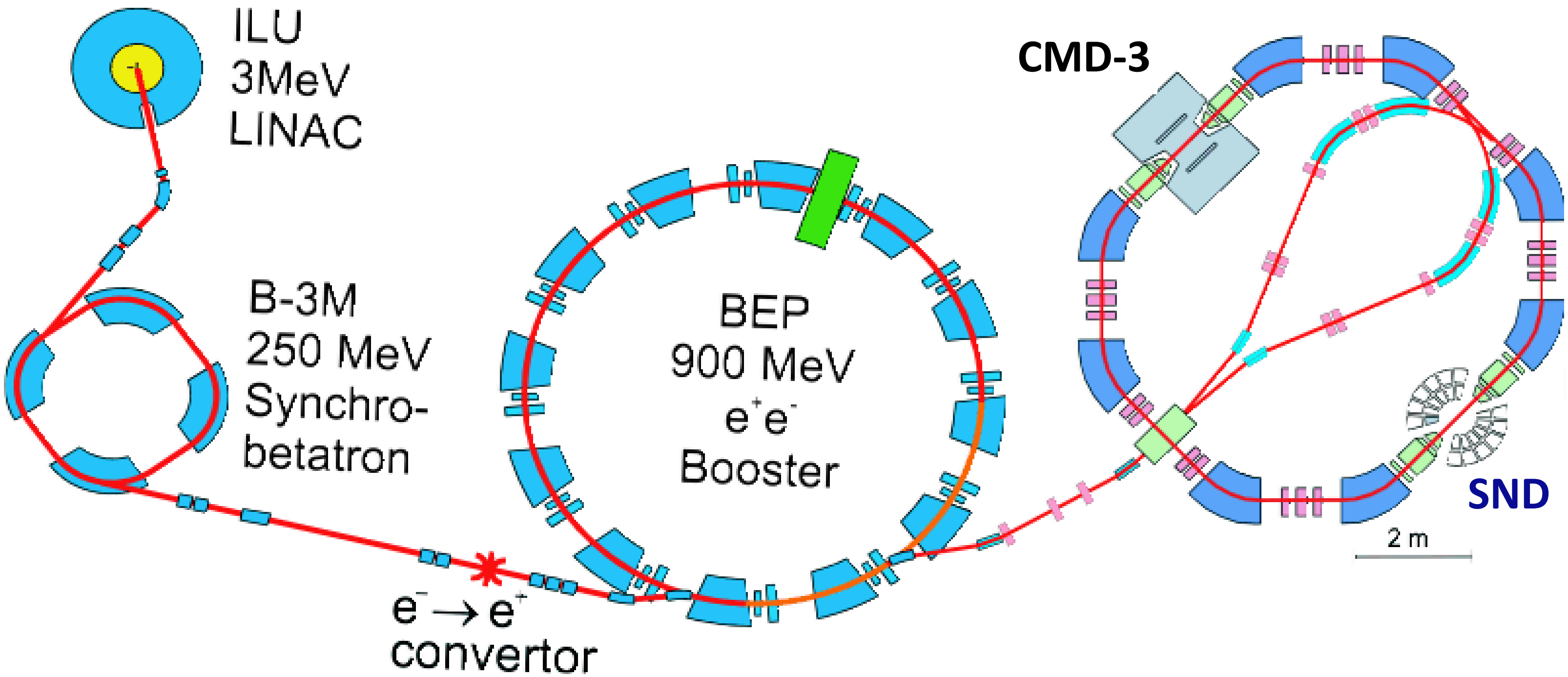
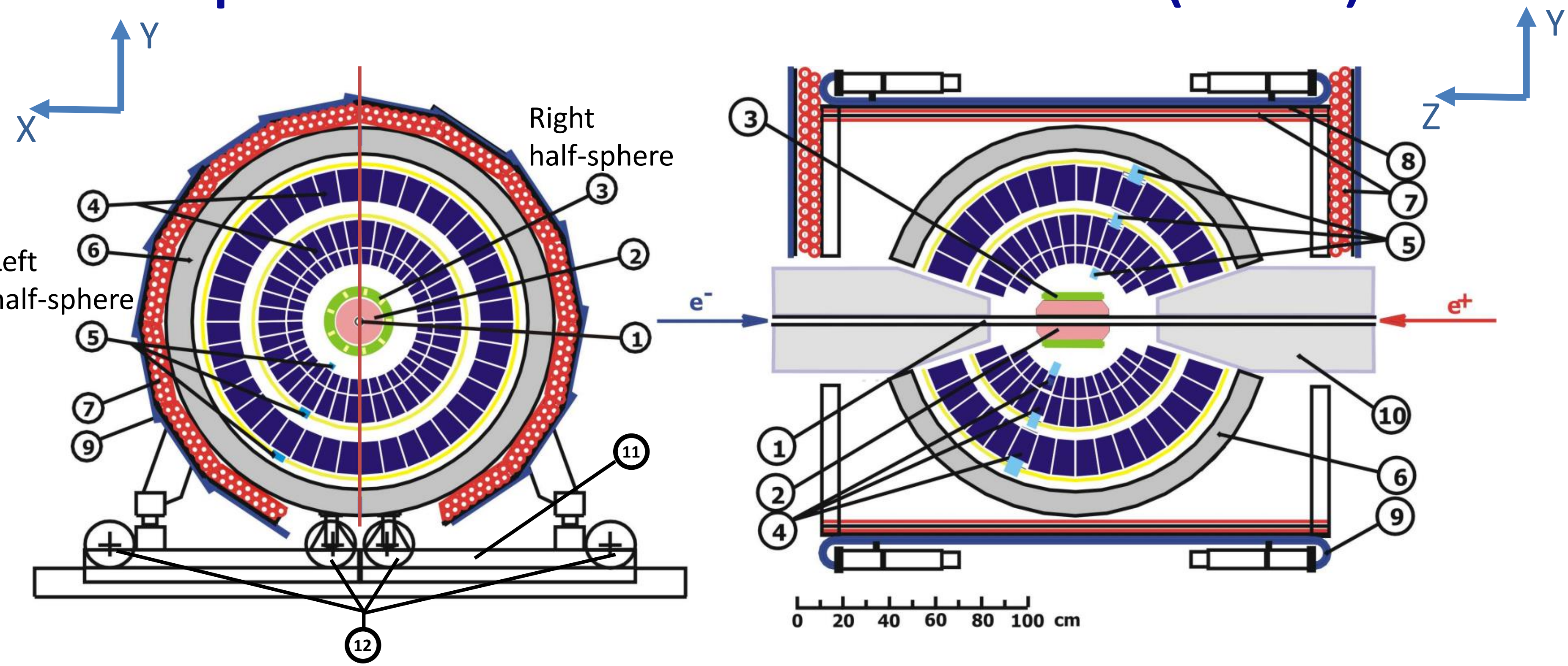
VEPP-2000



VEPP-2000:

- $e^{+}e^{-}$ collider at BINP, Novosibirsk;
- for the hadronic cross section measurement experiments;
- $E_{c.m.s.} = 0.4 - 2$ GeV;
- 2 interaction points: the CMD-3 and SND detectors.

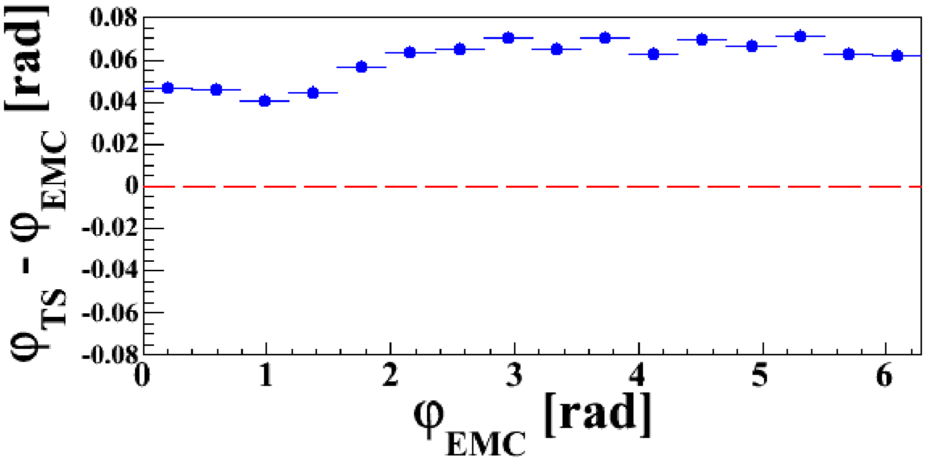
Spherical Neutral Detector (SND)

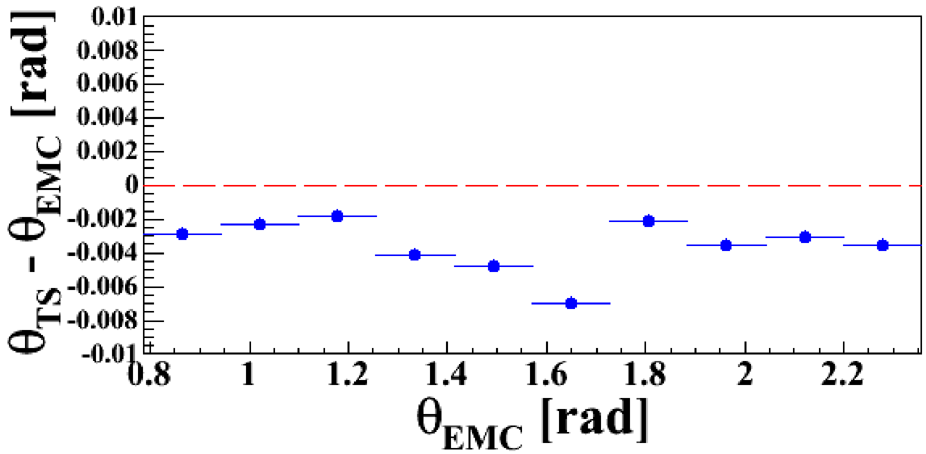


SND scheme: 1—vacuum pipe, **2—tracking system (TS)**, 3—Cherenkov counter, **4–5—electromagnetic calorimeter (NaI (Tl)) (EMC)**, 6 —iron absorber, 7–9—muon detector, 10—focusing solenoids, **11 - rails, 12 – wheels**.

- The EMC is assembled/disassembled on 2 half-spheres;
- The reference coordinate system is the TS (as the most accurate).

Motivation for alignment





φ_{TS}/θ_{TS}- azimuth/polar TS angle
$\varphi_{EMC}/\theta_{EMC}$- azimuth/polar EMC angle
$e^+e^- \rightarrow e^+e^-$ data

<u>What we see:</u>

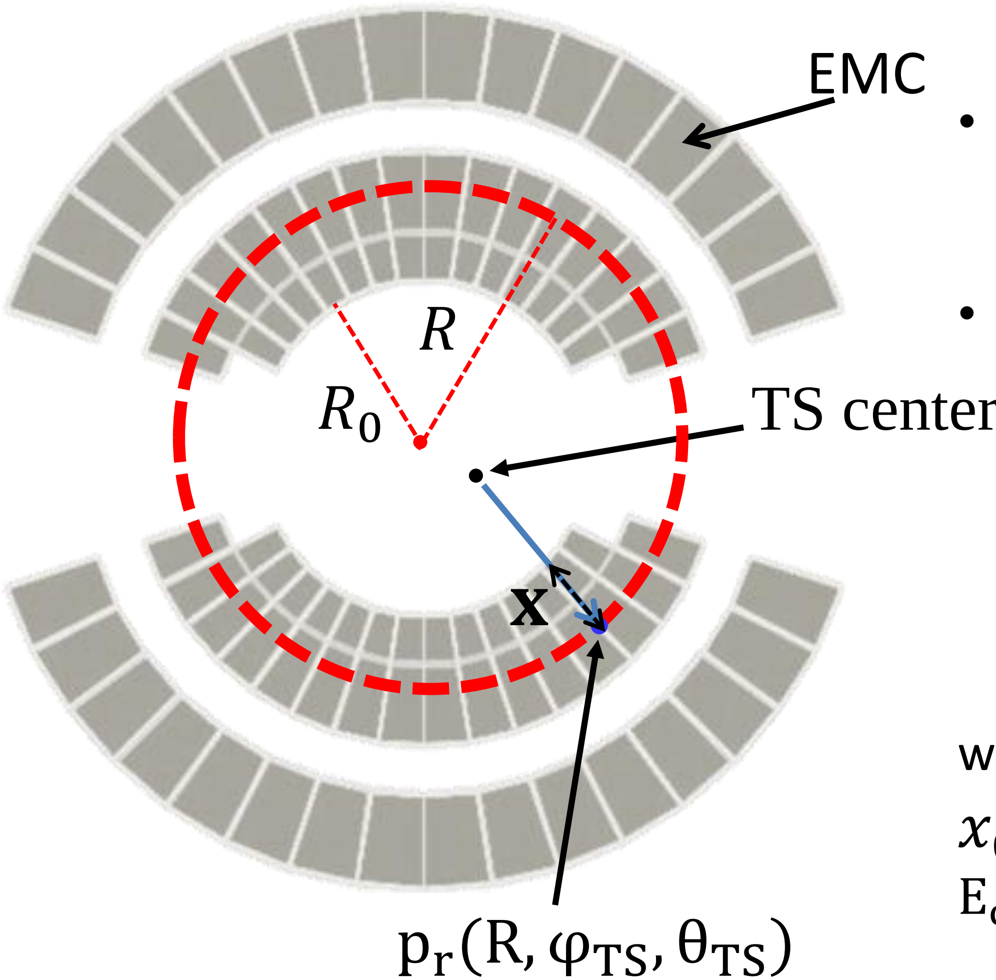
- There is a difference between angles reconstructed in the TS and in the EMC due to misalignments (~mm, ~0.01 rad);

<u>Why it's important:</u>

- Misalignments can result in kinematic discrepancy in an event because:
  - The TS measures angles of charged particles (π^+, π^-, K^+, K^-);
  - The EMC measures angles of neutral particles (γ, π^0);

<u>Solution</u> – a software alignment procedure using $e^+e^- \rightarrow e^+e^-$ data (allow us to obtain angles reconstructed both in the TS and in the EMC).

Angles from the TS: $\varphi_{TS}, \theta_{TS}$



- Angles from the two subsystems should be compared on the same radius (R);
- R is estimated for the TS angles using **x** – the distance of the maximum of the longitudinal shower distribution:

$$\frac{x}{x_0} = 1.0\left(\ln\frac{E}{E_c} - 0.5\right)$$

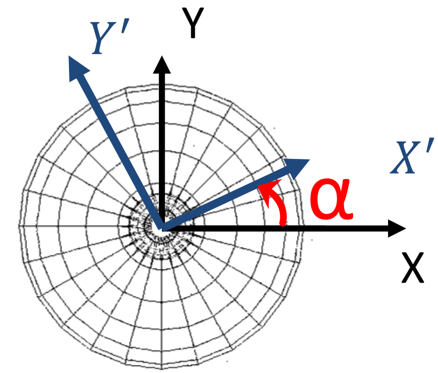
where

x_0 - radiation length;

E_c - critical energy;

Parametrization of the EMC position

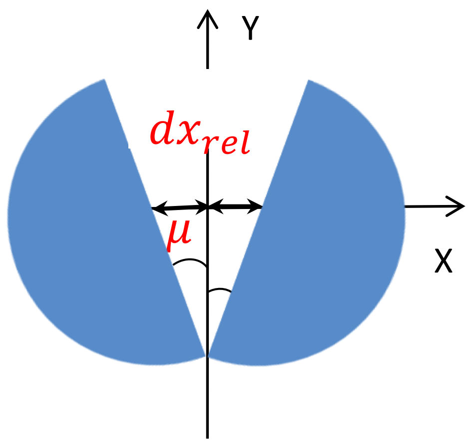
- <u>Global EMC position:</u>
  - Global rotation (3): α; β_1, β_2 - direction of the Z';
  - Global shift (3): dx, dy, dz;



- <u>EMC half-spheres relative position:</u>
  - Separation of the EMC 2 half-spheres (3):

    μ, τ, dx_{rel}

    τ = 0 (direction of the separation)



  - More relative parameters (3):
    - β_{rel} - a relative rotation of a half-sphere around the X axis;
    - dy_{rel} - a relative shift of a half-sphere along the Y axis;
    - dz_{rel} - a relative shift of a half-sphere along the Z axis.

Mathematical model

- Total number of alignment parameters: 12;
- Model functions are constructed using them:

If $\boldsymbol{p_0}(R, \varphi_{\boldsymbol{p_0}}, \theta_{\boldsymbol{p_0}})$ is an point of the aligned EMC,

Then a point of the misaligned EC is $\boldsymbol{p_1} = \boldsymbol{T} \cdot (\boldsymbol{T_\omega} \cdot \boldsymbol{T}_{\beta_{rel}} \cdot \boldsymbol{p_0} + \boldsymbol{s_{rel}}) + \mathbf{s}$ **,** where

$\boldsymbol{T}(\alpha, \beta_1, \beta_2)$ – a global rotation matrix,

$\boldsymbol{T_{rel}}(\mu, \tau, \beta_{rel})$ – a relative rotation matrix,

$\boldsymbol{s_{rel}}(dx_{rel}, dy_{rel}, dz_{rel})$ – a relative shift vector,

$\mathbf{s}(dx, dy, dz)$ – a global shift vector.

Finally,

$f_\varphi(\varphi_{\boldsymbol{p_0}}, \theta_{\boldsymbol{p_0}}) = sin(\varphi_{\boldsymbol{p_1}} - \varphi_{\boldsymbol{p_0}})$ corresponds to $\sin(\varphi_{\boldsymbol{TS}} - \varphi_{\boldsymbol{EMC}})$,

$f_\theta(\varphi_{\boldsymbol{p_0}}, \theta_{\boldsymbol{p_0}}) = (\theta_{\boldsymbol{p_1}} - \theta_{\boldsymbol{p_0}})$ corresponds to $\theta_{\boldsymbol{TS}} - \theta_{\boldsymbol{EMC}}$.

*the direction of the relative transformations ($\boldsymbol{T_{rel}}, \boldsymbol{s_{rel}}$) is determined by $sign(\cos(\varphi_{\boldsymbol{s}}))$.

Retrieving alignment parameter values

- Parameter values are obtained by minimizing the χ^2 function:

$$\chi^2 = \sum_i \left\{ \left(\frac{\langle \sin(\varphi_{TS_i} - \varphi_{EMC_i}) \rangle - f_\varphi(\varphi_{EMC_i}, \langle \theta_{EMC_i} \rangle)}{\sigma_{\varphi_i}} \right)^2 + \right.$$
$$\left. + \left(\frac{\langle \theta_{TS_i} - \theta_{EMC_i} \rangle - f_\theta(\varphi_{EMC_i}, \langle \theta_{EMC_i} \rangle)}{\sigma_{\theta_i}} \right)^2 \right\}$$

  - $i \in [1, 160]$ (a 2D bin index);
  - φ_s, θ_s- angles reconstructed in the EMC;
  - $\varphi_{TS}, \theta_{TS}$- angles reconstructed in the TS;
  - $\langle \quad \rangle$ - average over $e^+e^- \to e^+e^-$ selected events;
  - f_φ and f_θ - model functions;
  - ${\sigma_{\varphi\backslash\theta}}_i^{\,2} = {{\sigma_{\varphi\backslash\theta}}_i^{\,2}}_{stat} + \sigma_{sys}^2$.

- Parameters are determined by the first 2 layers.

Calibration procedure:

1. $e^+ e^- \to e^+ e^-$ event selection:

   - Charged particle number = 2;
   - $0{,}8 \cdot E_{beam} < E_{particle} < 1{,}1 \cdot E_{beam}$;
   - $\Delta\varphi = abs\left(\pi - abs(\varphi_{TS\_1} - \varphi_{TS\_2})\right) < \frac{\pi}{18}$.

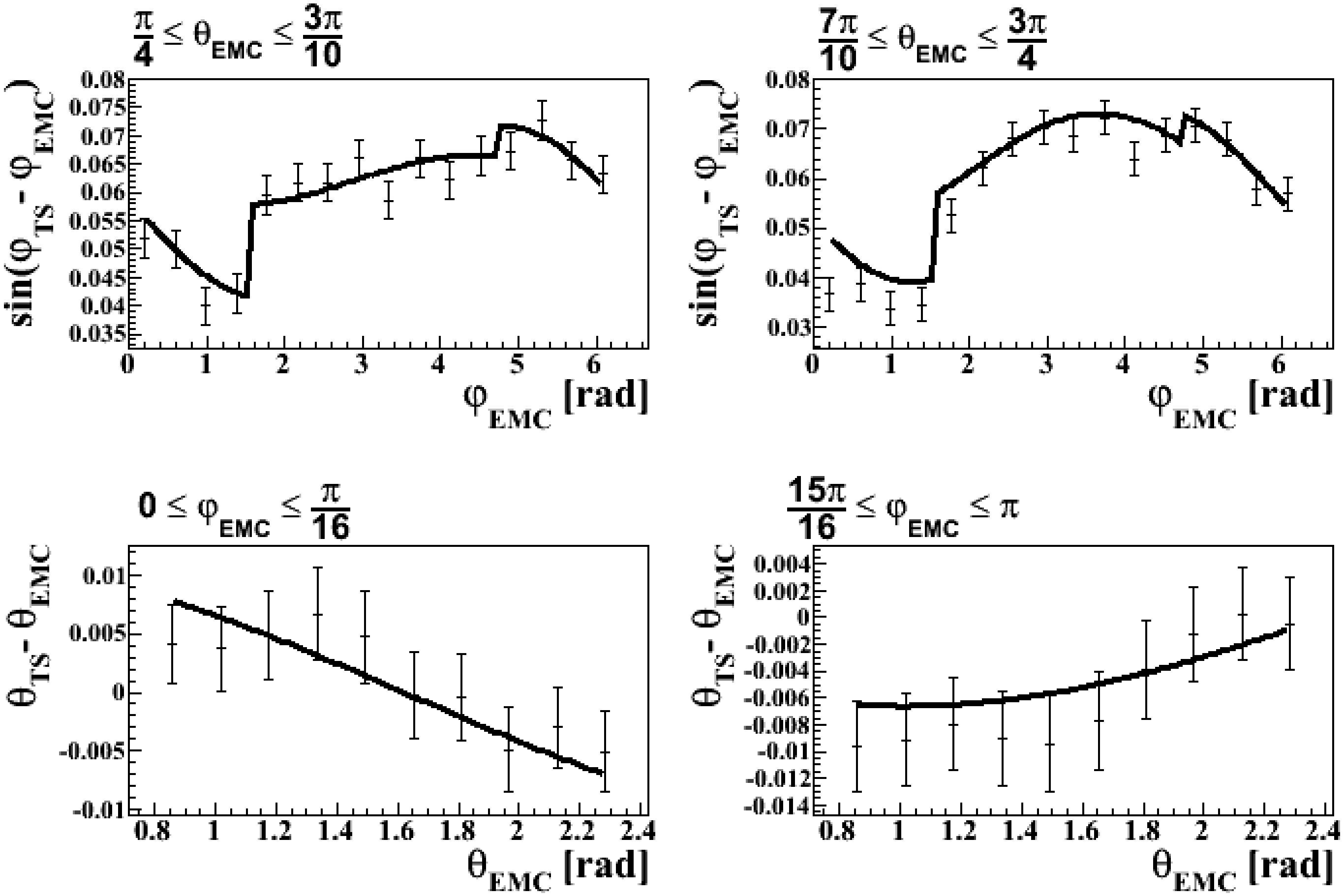
2. Minimization and retrieving alignment parameter values;

3. Saving the parameter values to the conditions data base;

4. Applying the values in Reconstruction and Simulation.

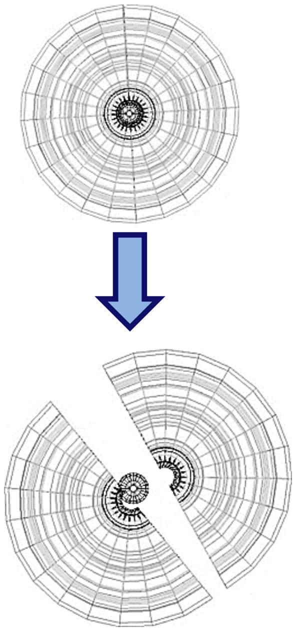
Fit results

- The model is in good consistent with data: $\frac{\chi^2}{Ndf} \sim 1 \div 1.5$

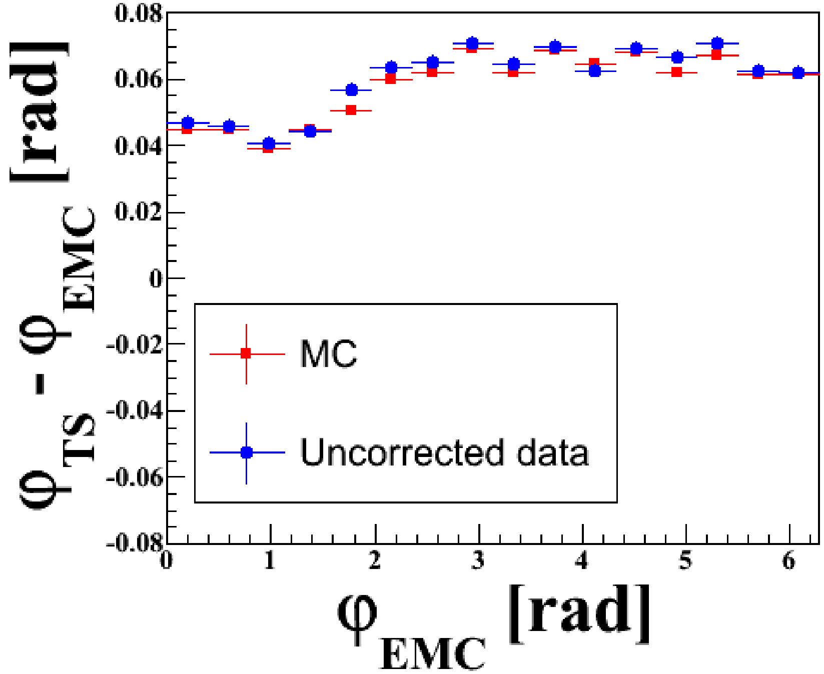


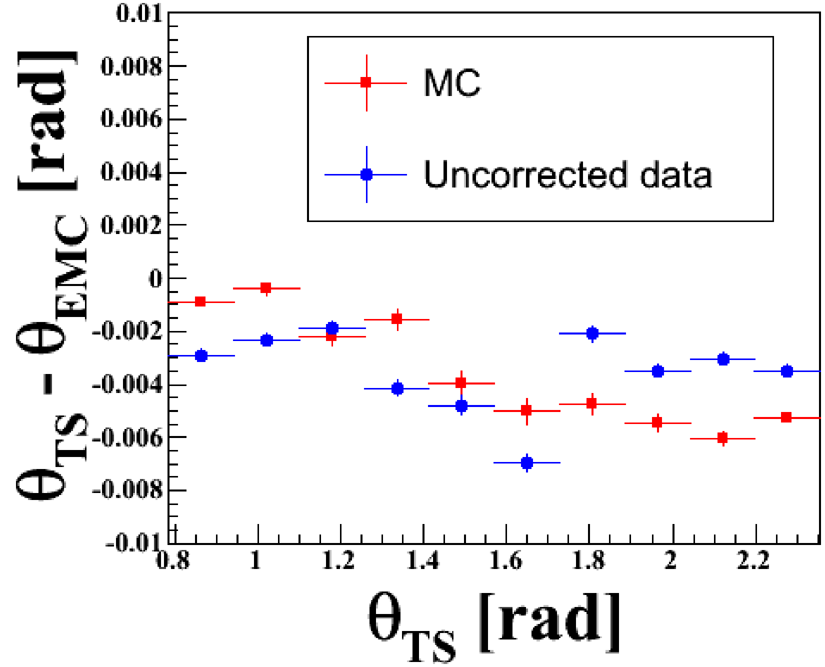
$e^+e^- \rightarrow e^+e^-$ data, E = 612.5

Validation with MC



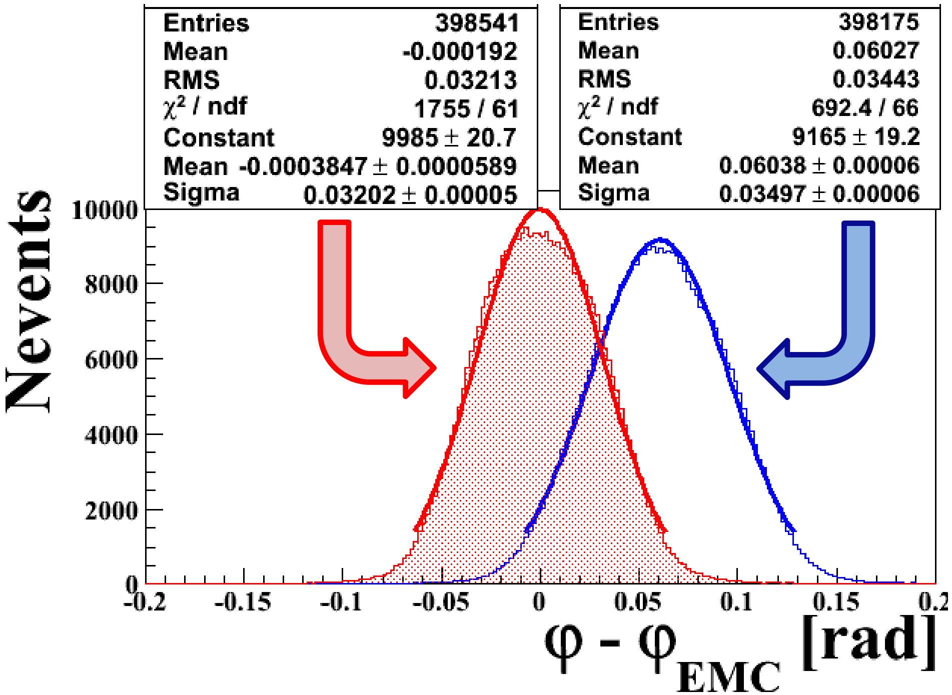
- MC with obtained alignment parameters:
  - Is based on the Geant4 package;
  - Takes into account damaged counters and recorded machine background;
  - Uses nested volumes hierarchy hence no need to place single crystals;
- Comparison with data demonstrates that the math model is consistent with it:



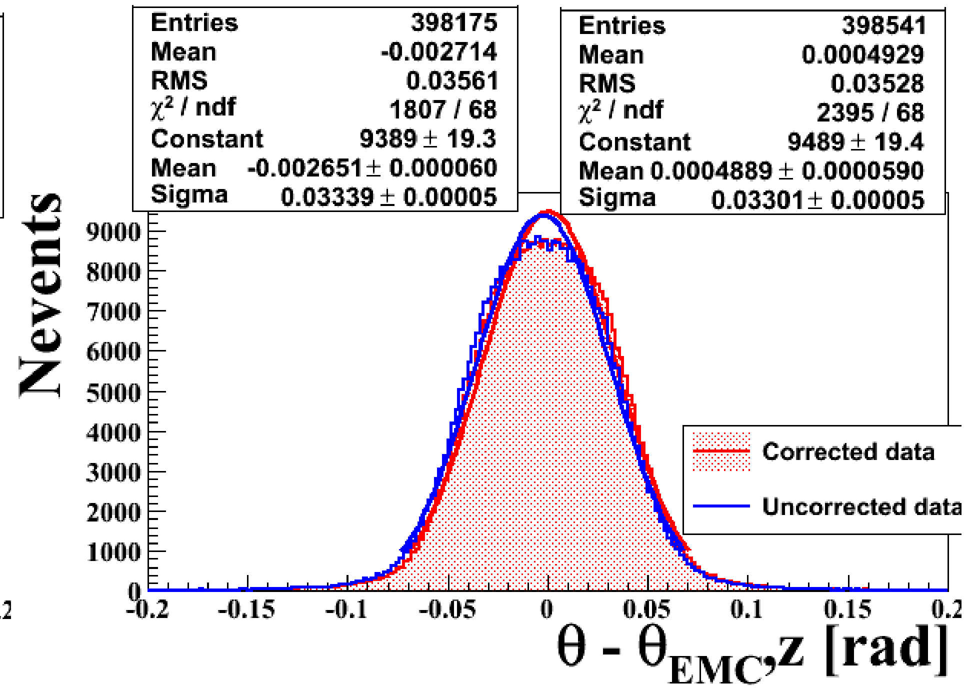


Corrections: $e^+ e^- \to e^+ e^-$

After correction: Before correction:



Before correction: After correction:



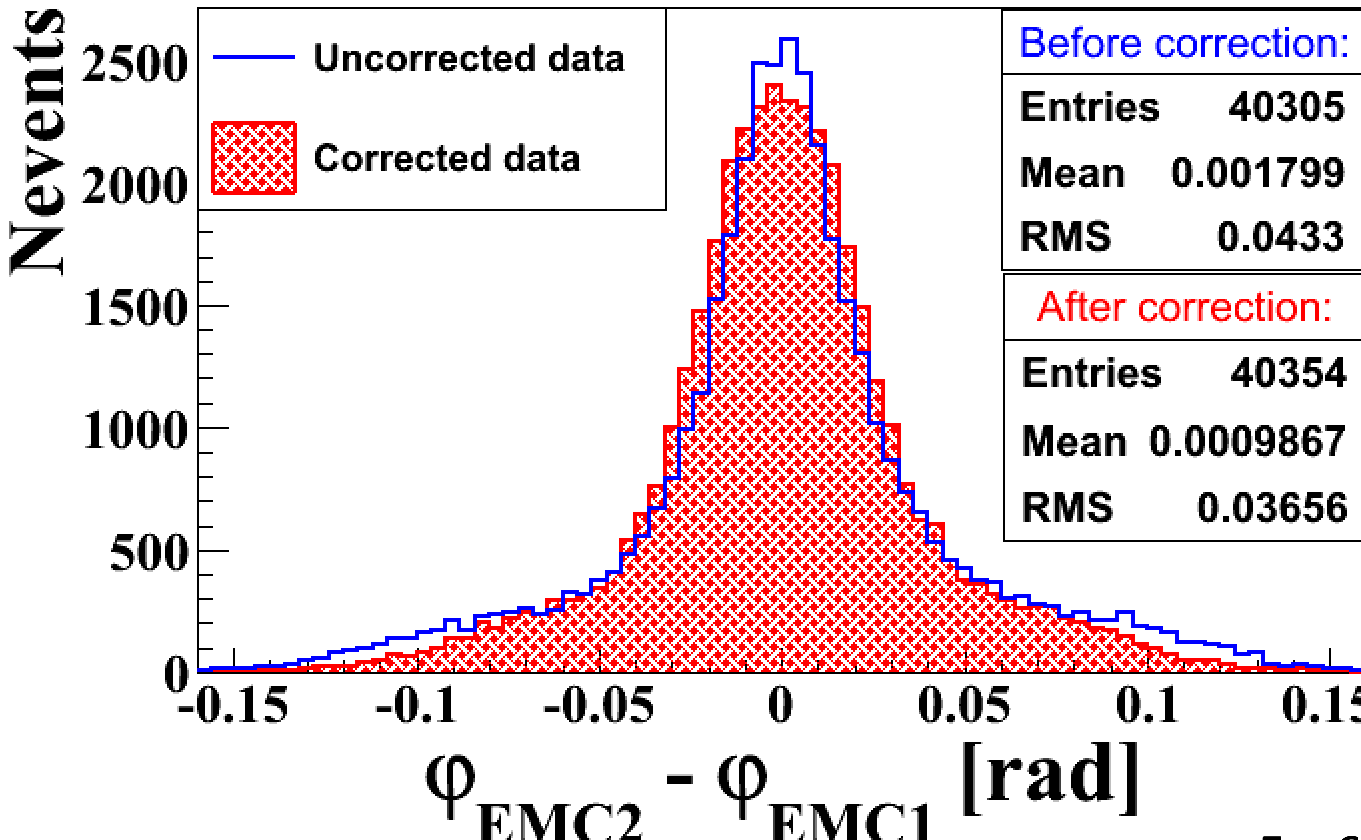
Where

φ, θ – an azimuth/polar angle reconstructed in TS;

$\varphi_{\mathrm{EMC}}/\theta_{\mathrm{EMC}}$ - an azimuth/polar EMC angle.

E = 612.5 MeV

Corrections: $e^+ e^- \to 2\gamma$

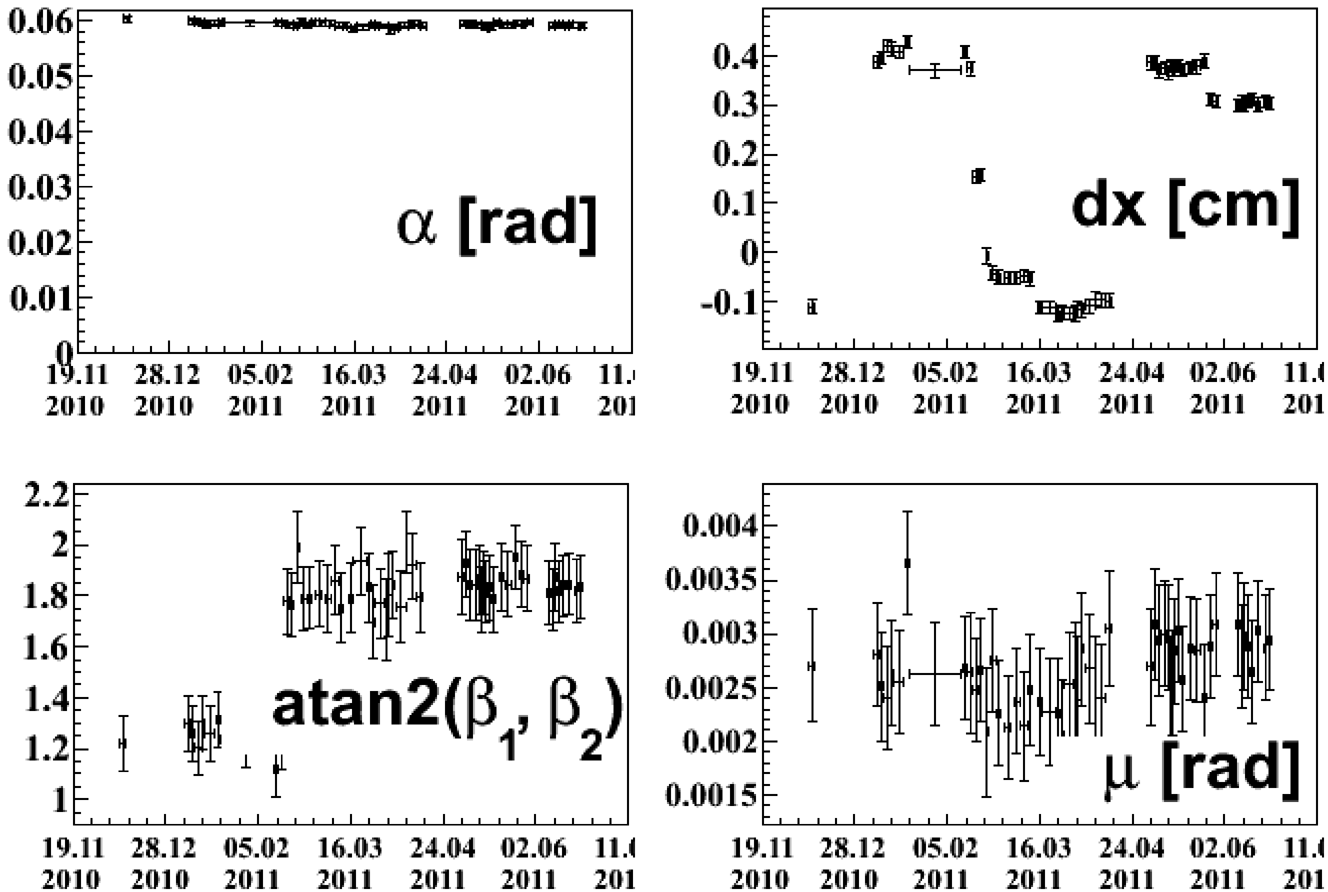


E = 612.5 MeV

<u>Event selection:</u>

- Charged particle number = 0;
- Neutral particle number = 2;
- Muon veto;
- $\frac{\pi}{5} < \theta_{EMC} < \frac{4\cdot\pi}{5}$;
- $E_{particle} > 0.7 \cdot E_{beam}$.

Parameters during Run 2010:



- α (the global rot. around the Z axis) stays stable during the season;
- dx (the global shift along the X axis) changes slightly due to disassembling/assembling the detector.

Summary:

- The alignment procedure for the SND detector was designed, implemented and validated with MC;

- The procedure was successfully applied to the Run 2010 data:
- As a result of corrections:
  - the $\varphi_{\mathbf{TS}} - \varphi_{\mathbf{EMC}}$ bias absolute value decreased from 60.38 to 0.38 mrad ;
  - the $\varphi_{\mathbf{TS}} - \varphi_{\mathbf{EMC}}$ RMS decreased from 34.97 to 32.02 mrad (8.4%);
  - the $\theta_{\mathbf{TS}} - \theta_{\mathbf{EMC}}$ bias absolute value decreased from 2.7 to 0. 5 mrad;
  - the $\varphi_{\mathbf{EMC\_1}} - \varphi_{\mathbf{EMC\_2}}$ $(\mathbf{2}\gamma)$ RMS decreased from 43.3 to 36.56 mrad (15.6%);

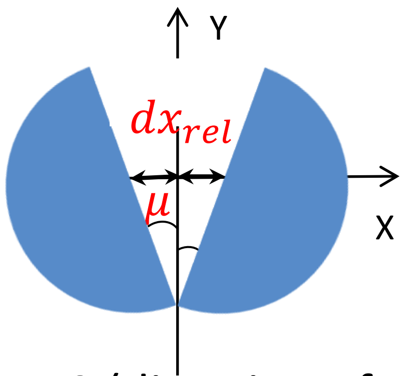
- The results of geometric calibration are used in data analysis.

Thank you for your time!

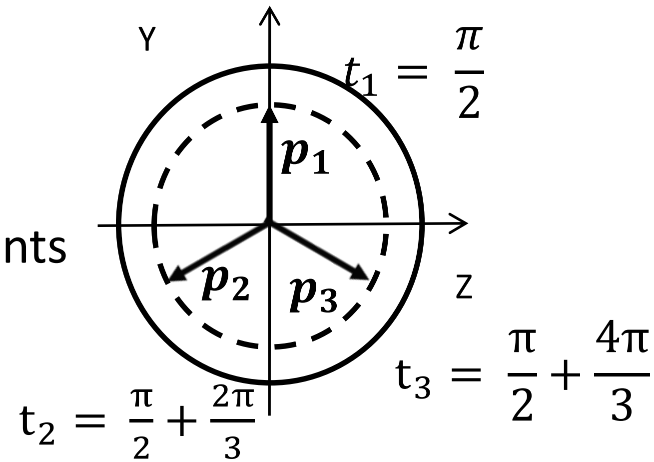
Parametrization of the EMC position

- <u>EMC half-spheres relative position:</u>
  - Separation of the EMC 2 half-spheres (3):

$$\mu, \tau, dx_{rel} \text{ OR } dp_1,\ dp_2,\ dp_3$$



$dp_1,\ dp_2,\ dp_3$ - distances between 2 half-spheres in points $p_i, i = 1, 2, 3.$



τ = 0 (direction of the separation)

- Parameter correlation coefficients (abs >0.8) :
  - α , dy_{rel} = -0.845;

σ_{sys}^2 estimation:

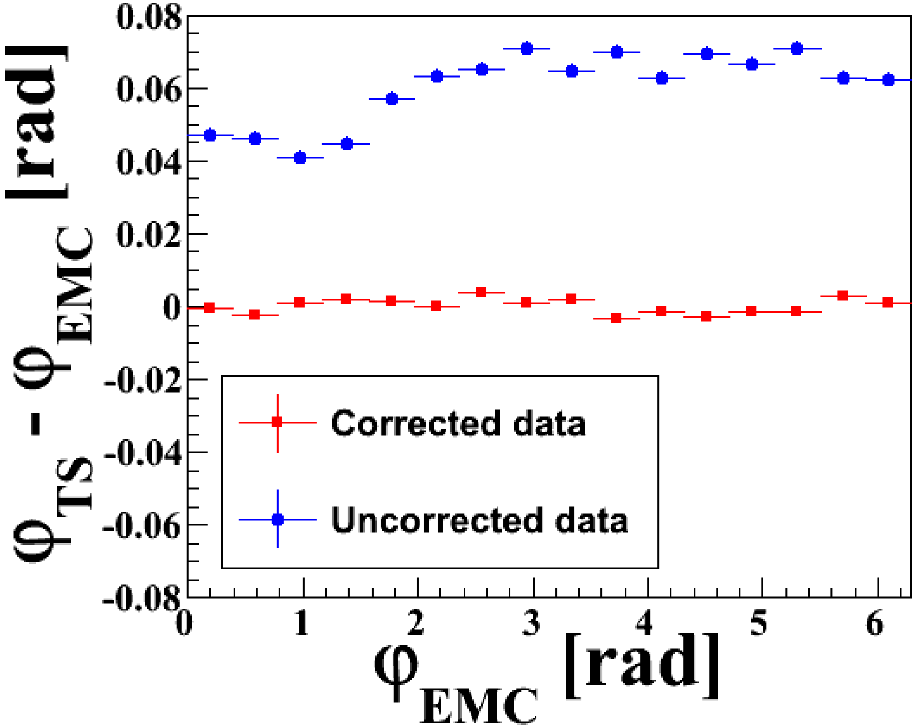
- Comes from:
  - The EMC DNL;
  - Possible effects of single crystal relative misalignments;
  - Uncertainty of the 3rd layer position.
- Estimation:
  - If we modify the χ^2 function :

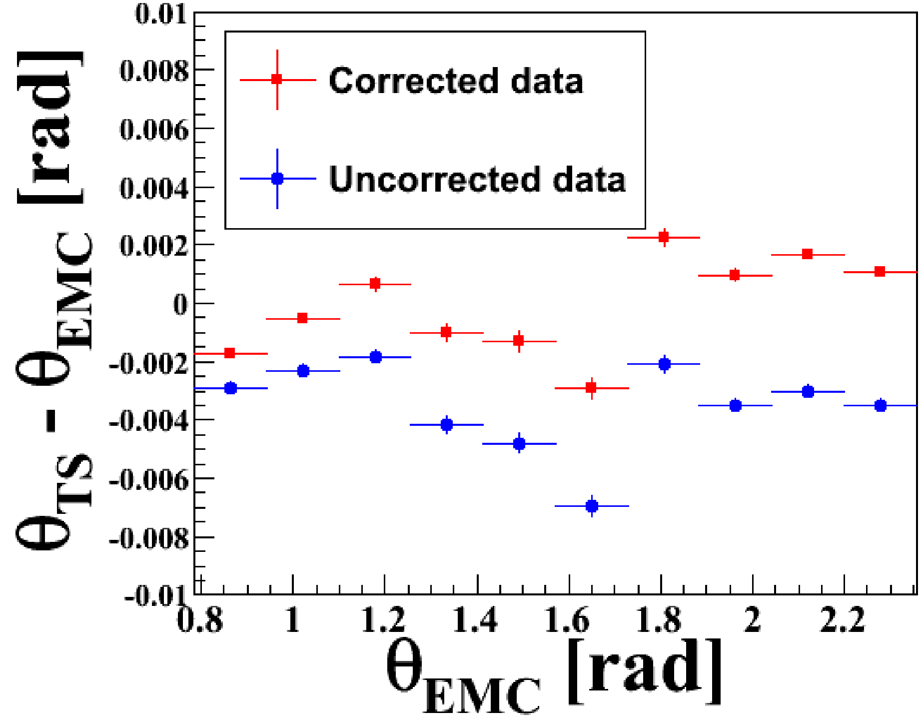
$$\chi^2 = \sum_i \left\{ \left(\frac{\langle \sin(\varphi_{TS_i} - \varphi_{EMC_i}) \rangle - f_\varphi(\varphi_{EMC_i}, \langle \theta_{EMC_i} \rangle) + a}{\sigma_{\varphi_i}} \right)^2 + \right.$$

$$\left. + \left(\frac{\langle \theta_{TS_i} - \theta_{EMC_i} \rangle - f_\theta(\varphi_{EMC_i}, \langle \theta_{EMC_i} \rangle) + a}{\sigma_{\theta_i}} \right)^2 \right\}$$

- We can estimate $\boldsymbol{a} \sim \left(\frac{\chi^2}{Ndf} - 2\right) \cdot \frac{Ndf}{\sum_i \frac{1}{\sigma_{\varphi_i}^2} + \frac{1}{\sigma_{\theta_i}^2}} \sim 10^{-6}$

Corrections: $e^+ e^- \rightarrow e^+ e^-$





E = 612.5 MeV

Environment, tools and instruments:

- Offline SND framework;
- GCC;
- C++ ISO/IEC 14882:2003;
- Scientific Linux 5;
- CERN ROOT package;
- CLHEP package;
- Python.