ECAL time performance with di-electron events:

follow up to questions

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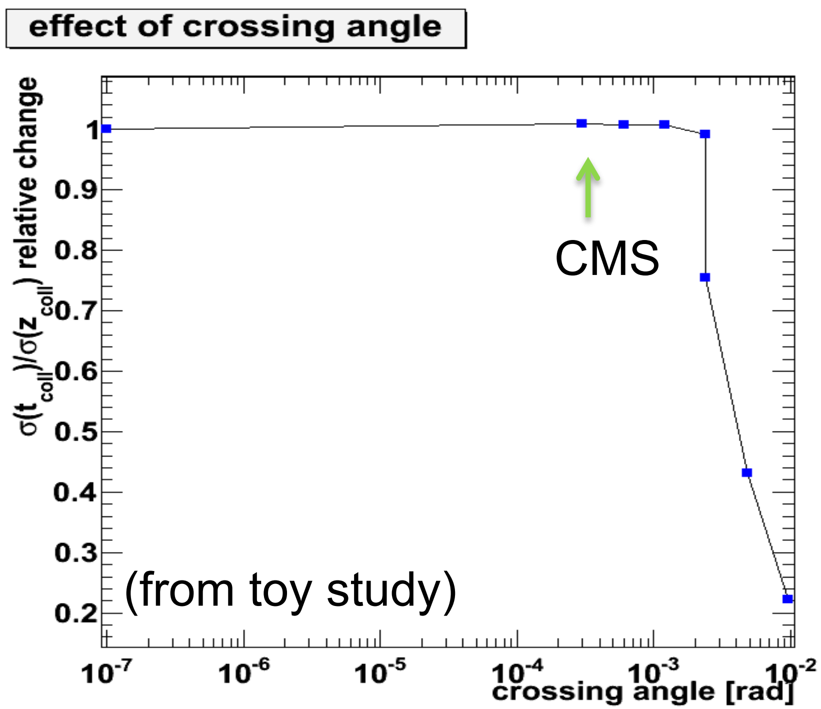
Follow up

- Questions received during the Apr 26th talk:
  - **Q1** How much does the crossing angle affect the relationship $\sigma(t_{coll}) = \sigma(t_z)/c$ (slide 8)? [P. Meridiani]
    - **A1 negligibly for the CMS crossing angle**
  - **Q2** Can the unexpected EB-coherent time oscillation (slide 9) be measured also from the EB-EE di-electrons? [M. Pieri]
    - **A2 yes; measurement from EB-EE**
  - **Q3** The precision of (t_1-t_2) varies with the signal amplitude of the two seeds; can this be the origin of the non-Gaussian tails in the EB distribution (slide 7)? [S. Ledovskoy]
    - **A3 partly; dependence of the resolution on 1) signal amplitude and on 2) different level of time stability across the ECAL supermodules, indicate that in the inclusive di-electron samples there are subsets with different expected $\sigma(t_1-t_2)$**

Q1 impact of the crossing angle

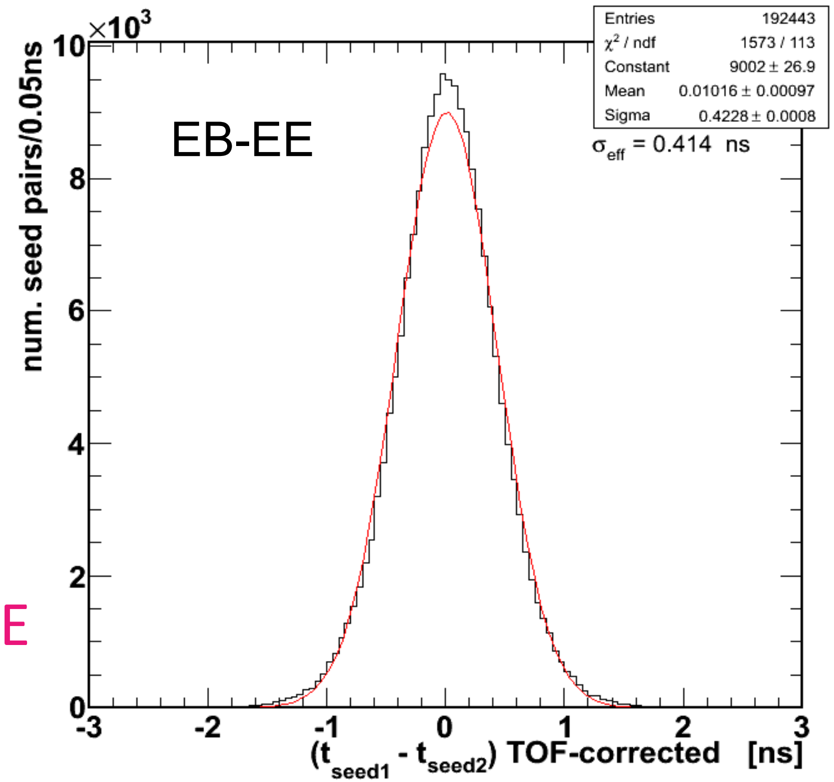
- For head-on colliding bunches, analytical relationship (slide 18):
  - $\sigma(t_{coll}) = \sigma(t_z)/c$ (i)
- But there's a crossing angle at CMS: 300 μrad
  - Modifies collisions' space and
- By how much does the crossing angle alter (i)?
  - Negligibly, up to 1000 μrad
- **Answewr1**: expression (i) is a good approximation to estimate $\sigma(t_{coll})$ from the size of luminous region



Q2 EB-coherent oscillation

- The EB-coherent time oscillation measured from di-electrons with both 'legs' in the barrel (slide 19), can be measured also using mixed endcap-barrel candidates, under the assumption that there's no such oscillation in EE

- For EB-EE electron pairs:
  - $\sigma^2_{EBEE}(t_1 - t_2)$ = precision^2(EB) + precision^2(EE) + σ^2 (coherent-EB)
  - $(414\ \text{ps})^2 = (282\ \text{ps})^2 + (190\ \text{ps})^2 + \sigma^2$(coherent-EB)
  - → σ^2(coherent-EB) = 237 ps



- **Answer2**: EB-coherent time oscillation measured also with EB-EE (240 ps) candidates, in agreement with EB-EB (250 ps)

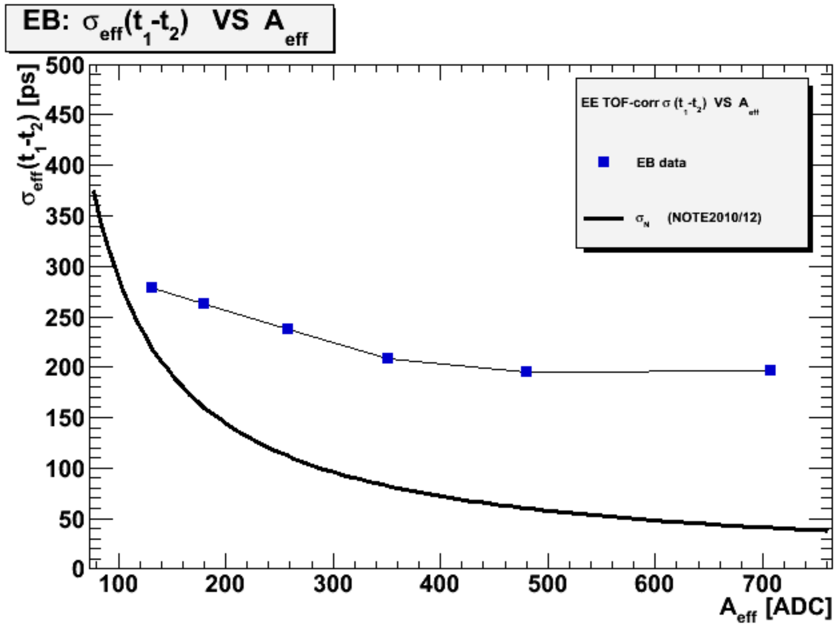
Q3 precision vs amplitude

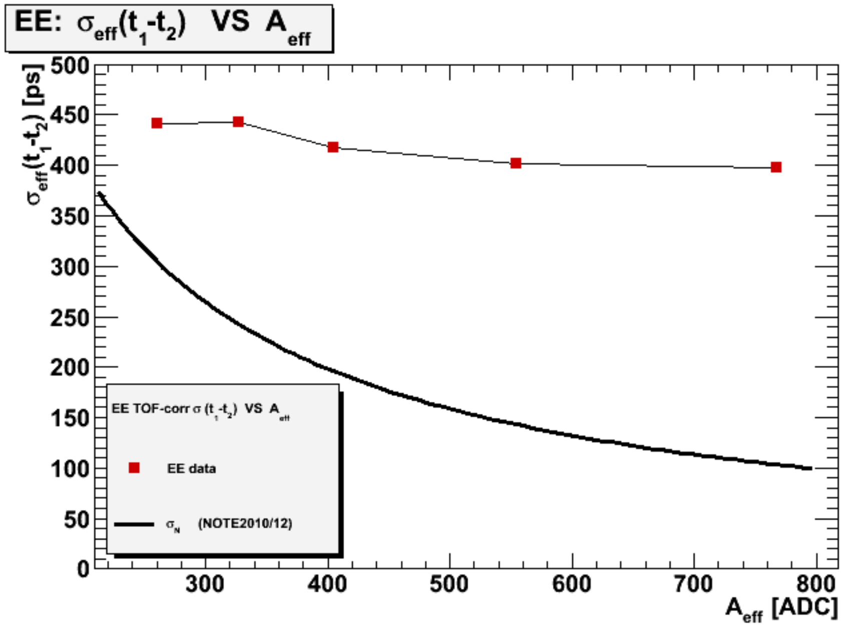
- Amplitude dependence of time resolution parameterized in CRAFT paper and AN2010/012 :
  - sum in quadrature of a noise and a constant term
- Adopt that scheme and parameterize the precision on the time difference of a di-electron system with
  - $A_{1/2}$:= ADC counts of seeds

$$A_{eff} = A_1 A_2 \sqrt{A_1^2 + A_2^2} \quad \sigma^2(t_2 - t_1) = \left(\frac{N\sigma_n}{A_{eff}}\right)^2 + 2C^2$$

- Bin available di-electrons pairs according to A_{eff} and quantify variation in precision across the bins

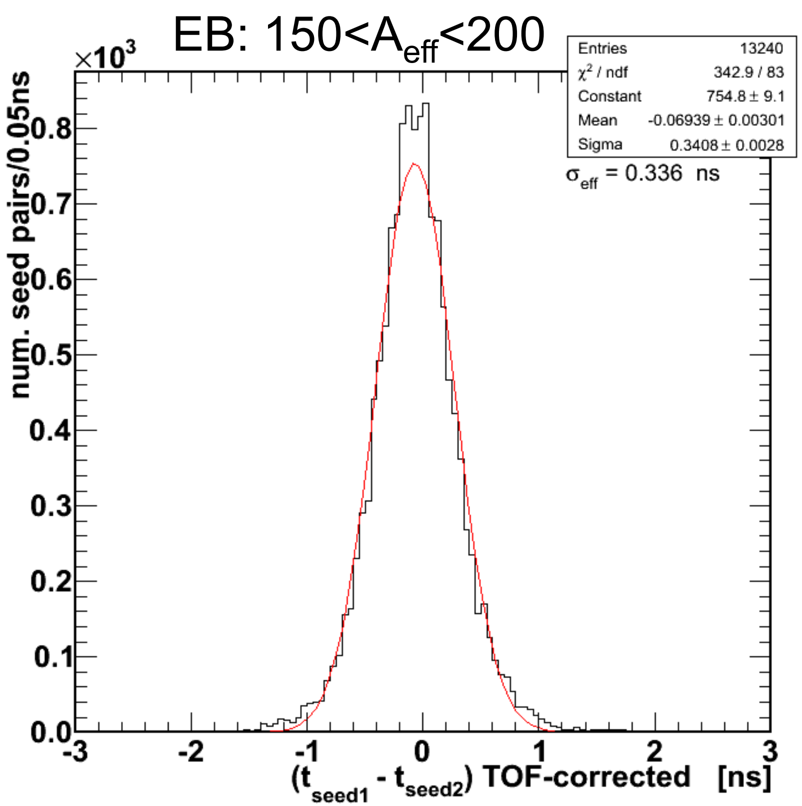
Q3 precision vs amplitude

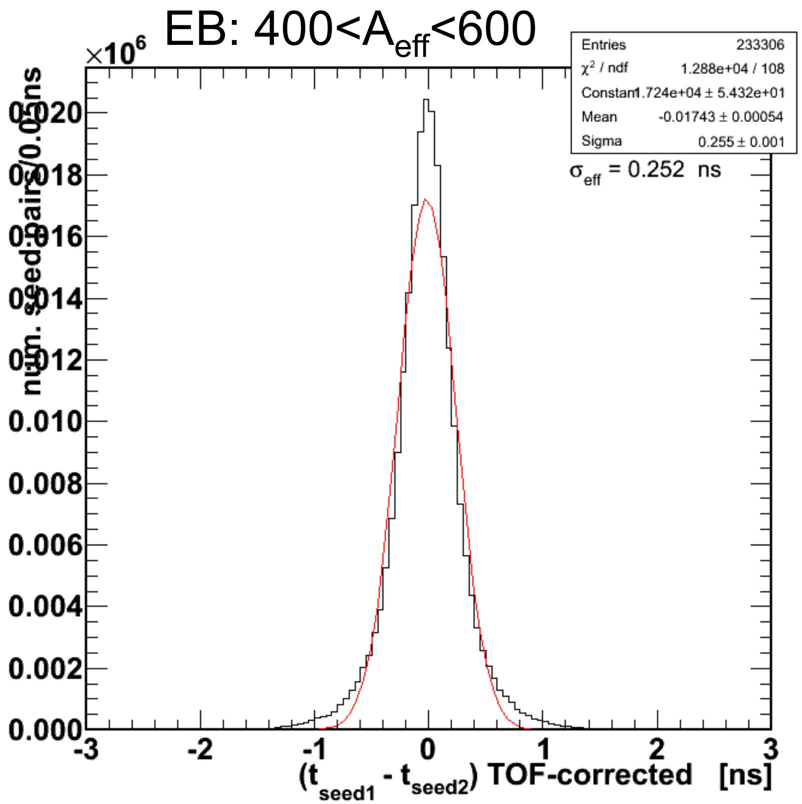




- Noise term drawn for reference according to AN2010/012
- Marked A-dependence in the barrell
  - Plateau is √2 X constant term
- Less dependence for endcaps (larger constant term)

Q3 precision vs amplitude



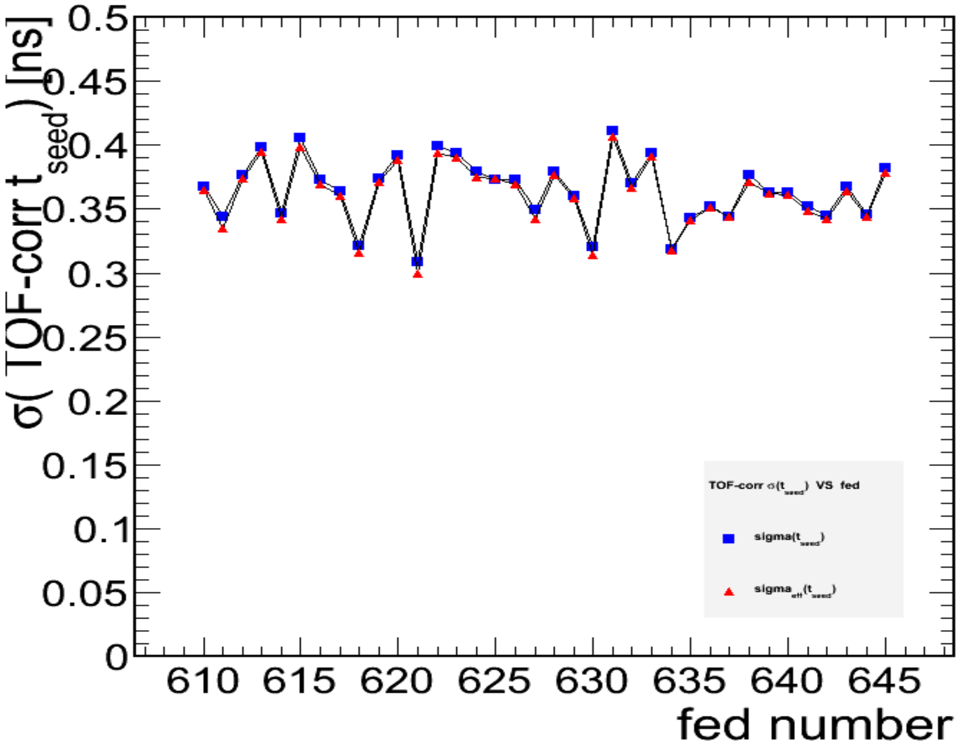


- Significant decrease in the width of the distribution core, increasing A_{eff}
- Excess in the tails still partly visible

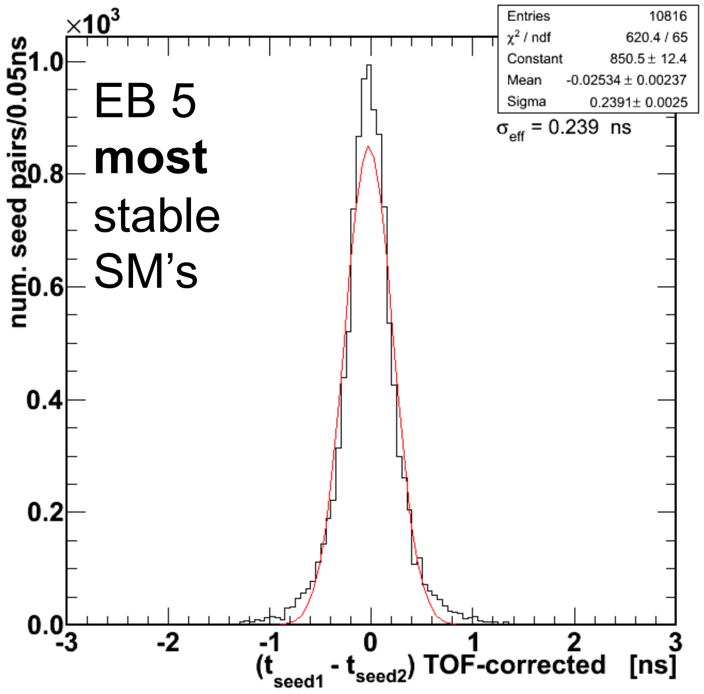
Q3 regional dependence of precision

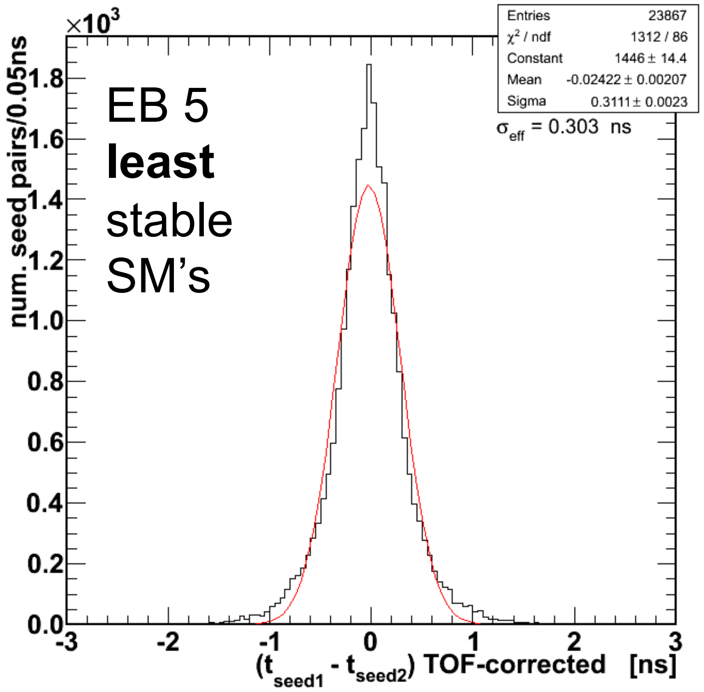
- Tof-corrected $\sigma(t_{seed})$ varies significantly across supermodules, 310→398 ps:
  - Instability specific to sub-regions occurring within each IOV of the time calibration

- Precision of di-electron time difference is affected by the combination of the electrons' position in EB



Q3 regional dependence of precision





- Regional variations of the precision on (t_1-t_2)
  - 239 / 303 ps when restricting to the 5 most/least stable supermodules
- Excess in the tails still visible
  - Instabilities on a smaller granularity than supermodule, e.g. at the level of token ring or 5x5?

Q3 conclusion

– **Answer3** dependence of precision on:
  - signal amplitude
  - varying stability of ECAL supermodules

indicates two independent sub-sets with different levels of precision in the inclusive di-electron sample

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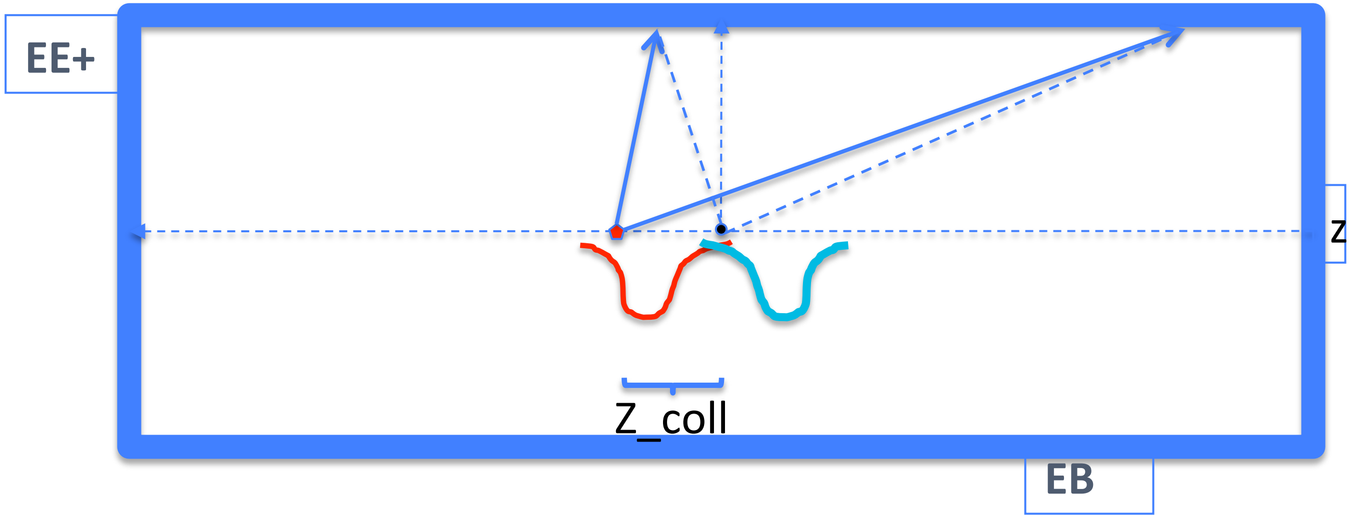
ITEP/CERN

ECAL DPG
April 26th , 2012

Introduction and outline

- Key messages for the ECAL paper, sec. 3.4:
  - Synchronization of readout kept in 2011 stable < 2 ns to assuring no impact on amplitude reconstruction with weights
    - Monitoring and hardware+offline calibration [1] → **not discussed today**
  - Qualify width of the RECO time:
    - Relevant for time-based signal cleaning
      - reconstructed time of ele1/ele2 from Z decays → **'absolute time'**
  - Qualify resolution of RECO time:
    - Relevant for EXO searches [2][3] (and Higgs vertex?)
      - time difference of ele1-ele2 from Z decays → **'time difference'**
- Today:
  - Extend the analysis presented at ECAL DPG of Sept 15th, 11 [4] to the whole 2011 data set and whole ECAL
  - Propose 2 sets of plots for ECAL paper and address questions emerged in the first paper review

Definitions and geometry



- ECAL reco time defined to be 0 on average for collisions developing at nominal IP
- **Finite size of the luminous region** gives raise to:
  - difference from nominal **time of flight**:

    → potential physics cases e.g. with displaced photon production (DPG Jan)

    → Hgg vertices (talk HIG January [5] – 1.5% efficiency rel. gain)

    Smearing to be removed to estimate performance
  - the **crossing** of the bunches has a **finite duration** → smearing of collision time

Definitions and strategy

- Time of flight from nominal collision point to ECAL absorbed into the definition of the ECAL time calibration

  - $\mathbf{T_{shower} = t_{coll} + t_{o.f.}}$
    - $T_{o.f.} = t_{o.f.,\ \mathbf{nominal}} + \delta t_{o.f.}$
  - $T_{shower} = t_{coll} + (t_{o.f.,\mathbf{nominal}} + \delta t_{o.f.})$
    - $T_{shower} - t_{o.f.,\ \mathbf{nominal}} =: t_{RECO}$
  - $\mathbf{t_{RECO} = t_{coll} + \delta t_{o.f.}}$

- To study performance of reconstruction, one can use **two electrons** originating from the same vertex and study the difference between:
  - $\mathbf{(t^2_{seed} - \delta t^2_{o.f.}) - (t^1_{seed} - \delta t^1_{o.f.})}$

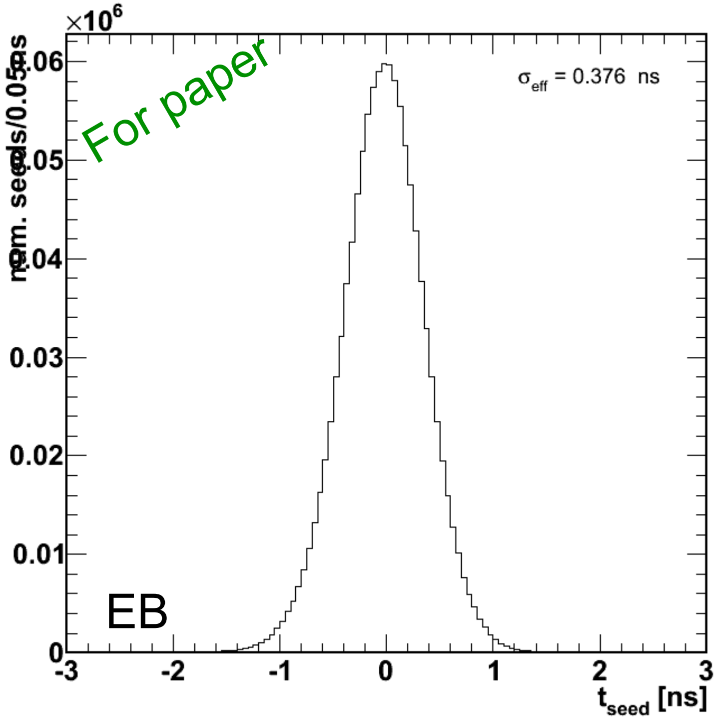
Dataset and selection

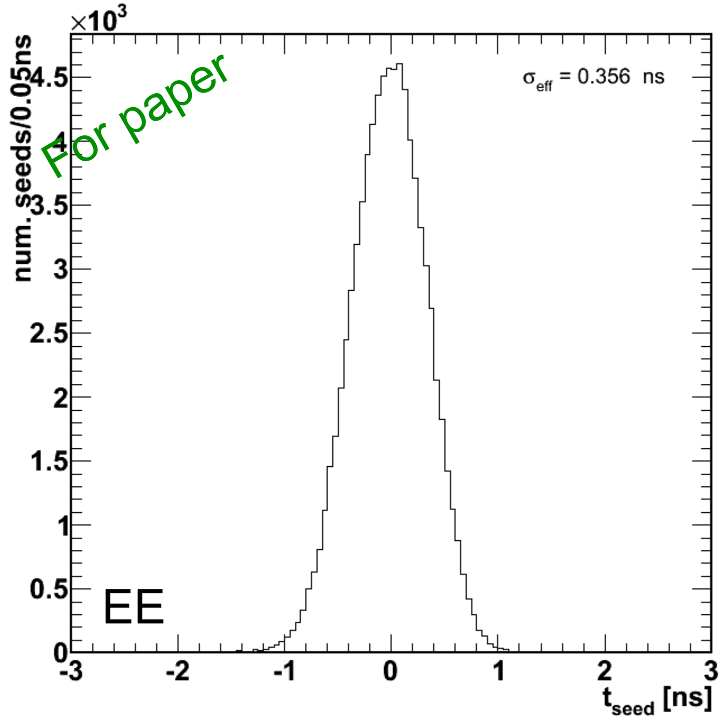
- /DoubleElectron/Run2011X-16Jan2012-v1/AOD ,
  the full 2011 dataset 4.7 fb^{-1}

- Di-electron selection:
  - Electron WP85
  - $E_T > 10$ GeV
  - $|m(e_1,e_2) - m_Z| < 20$ GeV/c^2

- Time estimator:
  - In the paper → this analysis, $\mathbf{t_{seed}}$ used as estimator for $\mathbf{t_{RECO}}$
    - Average energy 29/67 GeV in EB/EE
  - Similar studies conducted for second-amplitude crystal and error-weighted combination of crystals in supercluster (see Sept 15th, 11 [4])

t_{seed}

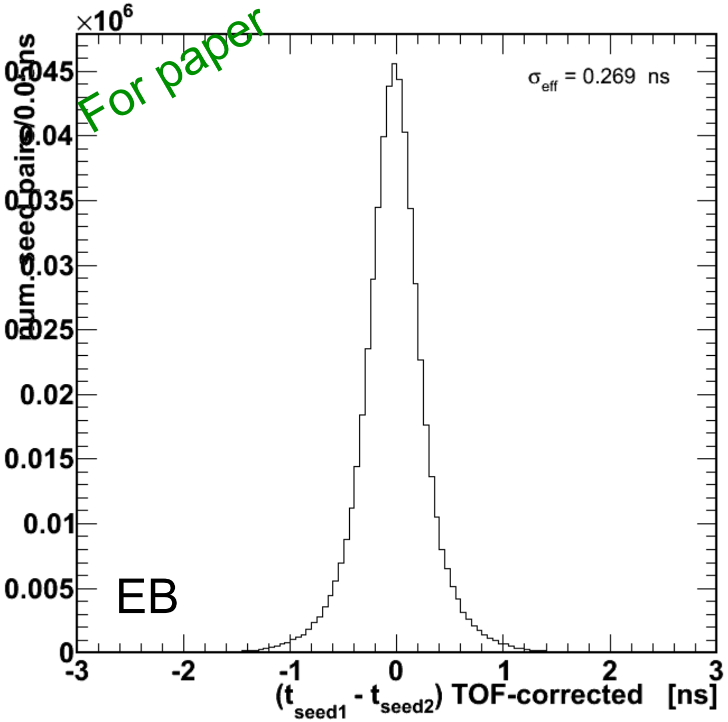


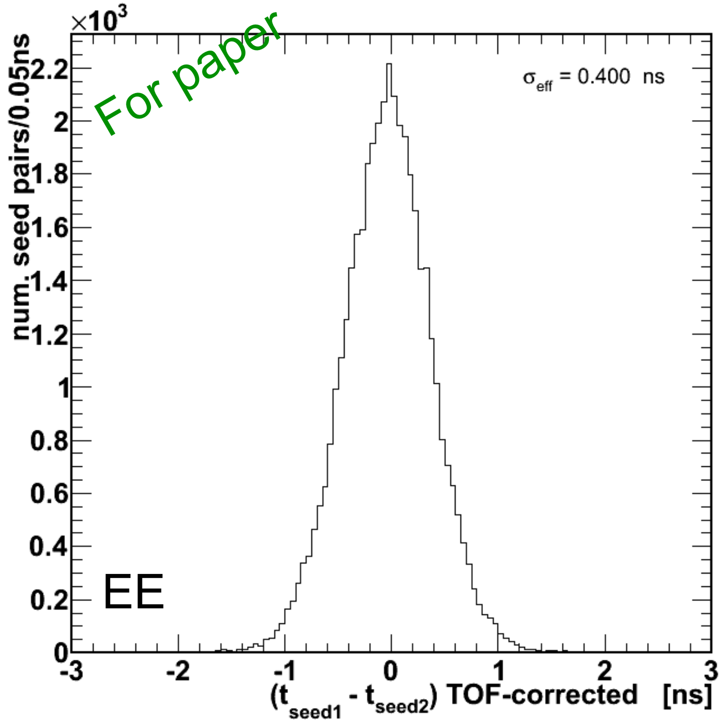


- Width, measured with σ_{eff}, ascribed to:
  - TOF variations
  - collision time
  - single crystal time error

	σ_{eff} (t_{seed}) [ps] abs time
EB	376
EE	356

TOF-corrected $(t_1\text{-}t_2)$





- TOF and t_{coll} removed
- → choose $\mathbf{(t_1\text{-}t_2)/\sqrt{2}}$ as estimator of single crystal time resolution

	σ_{eff} (t_{seed}) [ps] abs time	σ_{eff} $(t_1\text{-}t_2)/\sqrt{2}$ [ps] single precison
EB	376	190
EE	356	282

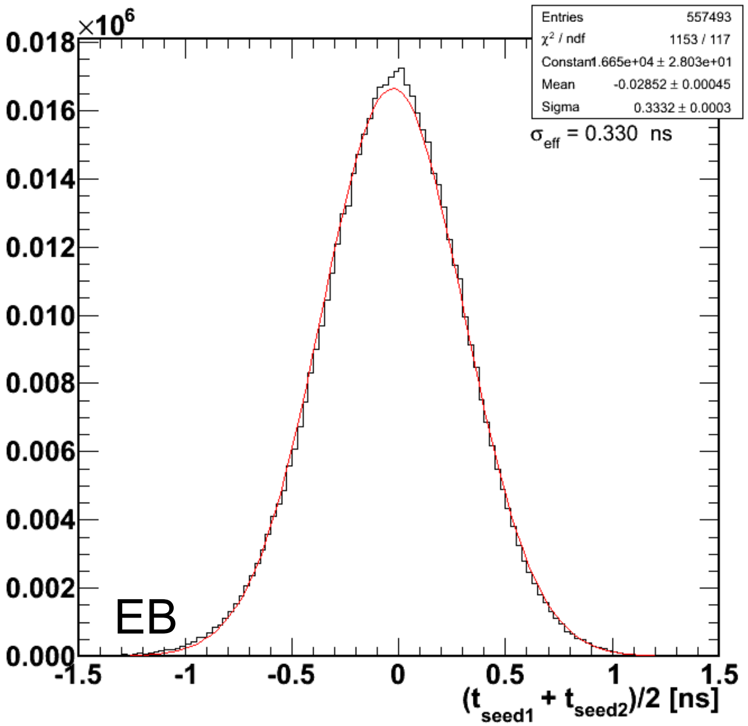
Closure test: measure $\sigma(t_{coll})$

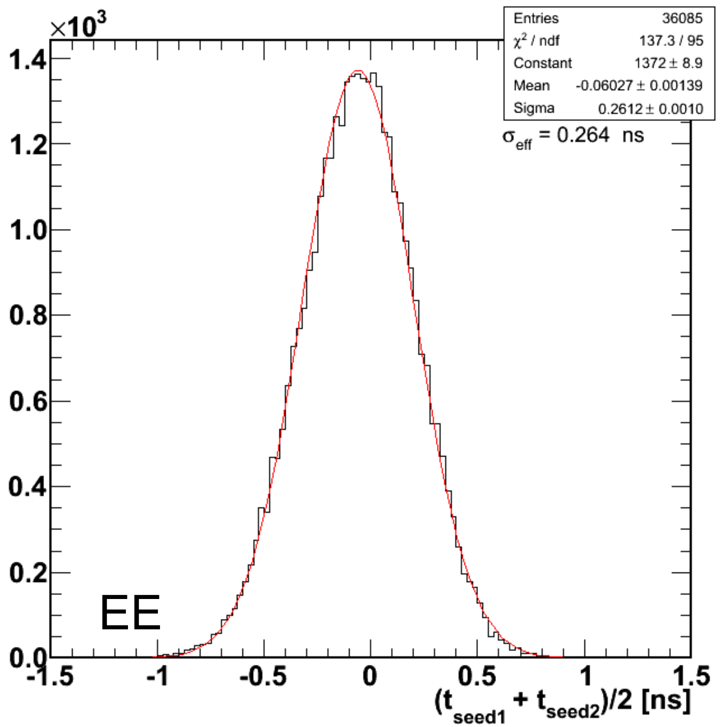
- Width of the luminous region: 5.5 cm
- Longitudinal density of the bunches Gaussian

  → $\sigma(t_{coll}) = \sigma(t_z)/c = 175$ ps

- Measure $\sigma(t_{coll})$ using:
  - TOF-corrected $(t_1+t_2)/2$
  - take into account single measurement precision
    - $\sigma^2(t_{coll}) = \sigma^2(\ (t_1+t_2)/2\ ) - [\ \sigma^2(t_1-t_2)\ ]/4$
- and assess consistency, within the errors, of time-based measurement with the measurement from pure geometry

$\sigma(t_{coll})$ from $(t_1+t_2)/2$





- Extra time oscillation coherent in EB
  - 250 ps in quadrature
- Closure for EE
- → instrumental origin

	σ_{eff} (t_{seed}) [ps] abs time	σ_{eff} (t_1-t_2)/√2 [ps] single precison	σ_{eff}((t_1+t_2)/2) [ps]	σ_{eff}(t_{1coll}) [ps]
EB	376	190	330	301
EE	356	282	264	169

$\sigma(t_{coll})$ from $(t_1+t_2)/2$ (ii)

- Could the TOF corrections be the problem?
  - Repeat exe. splitting collisions near/far to/from IP
    - $|z|< 2$ cm
    - $z<-5$, $z>5$

	σ_{eff} (t_{seed}) [ps] abs time	σ_{eff} (t_1-t_2)/√2 [ps] single precison	$\sigma_{eff}((t_1+t_2)/2)$ [ps]	$\sigma_{eff}(t_{1coll})$ [ps]
EB	376	190	330	301
EB z<-5	390	190	325	**298**
EB z>5	366	189	322	**296**
EB|z|<2	390	190	335	**307**
EE	356	282	264	169
EB z<-5	386	289	269	**175**
EB z>5	381	283	258	**162**
EB|z|<2	349	283	262.	**169**

  - $\sigma(t_{coll})$ does not depend on vertex location

$\sigma(t_{coll})$ from $(t_1+t_2)/2$ (iii)

- Does $\sigma(t_{coll})$ depend on η in EB?
  - Repeat exe. splitting in the four module

	σ_{eff} (t_{seed}) [ps] abs time	σ_{eff} (t_1-t_2)/√2 [ps] single precison	σ_{eff}((t_1+t_2)/2) [ps]	σ_{eff}(t_{1coll}) [ps]
EB	376	190	330	301
EB mod1	356	258	323	**296**
EB mod2	366	263	326	**298**
EB mod3	385	267	331	**303**
EB mod4	392	277	337	**307**
EE	356	282	264	169

  - No significant η-dependence within EB
  - Marked difference between mod4 and EE
    - Origin unclear
    - Evgueni suggests the possibility that the two TTCex modules may have different stabilities

Conclusions

- **For the ECAL paper**, sec. 3.4:
  - width of the RECO time
    - Relevant for time-based signal cleaning
  - resolution of RECO time
    - Relevant for EXO searches [2][3] (and Higgs vertex?)

	σ_{eff} (t_{seed}) [ps] abs time	**σ_{eff} (t_1-t_2)/√2 [ps] single precison**
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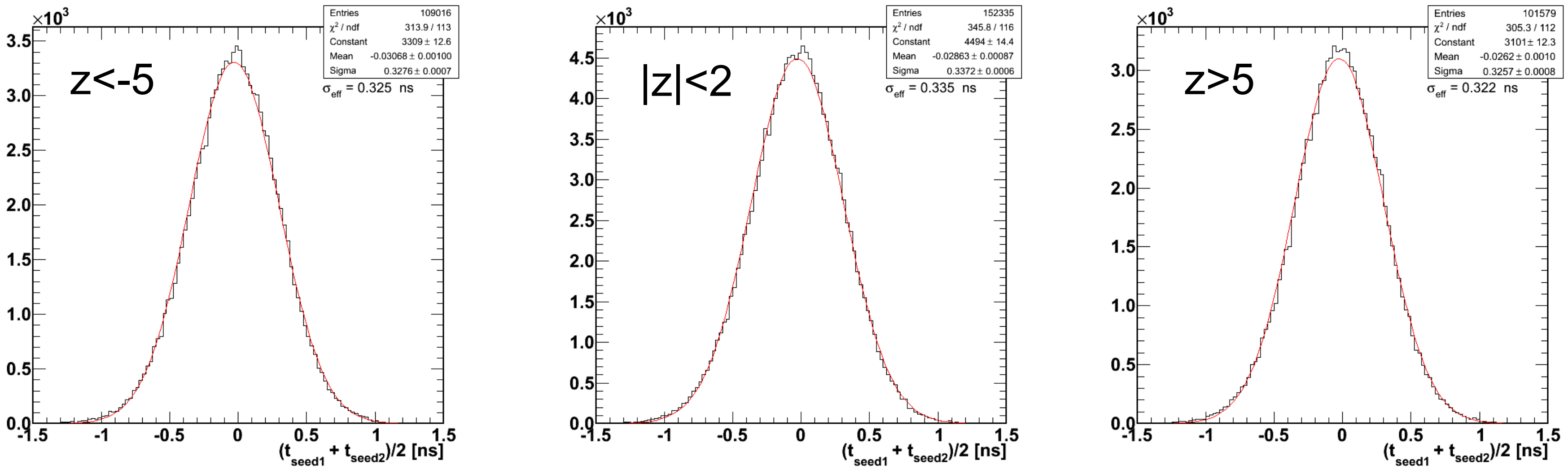
- **Consolidation of results**: measurement of (t_{coll}) as closure test:
  - Matches expectations in EE
  - Unexpected EB-coherent oscillation 250 ps (in quadrature)

- BACK UP

$\sigma(t_{coll})$ from TOF-corr. $(t_1+t_2)/2$ (II)

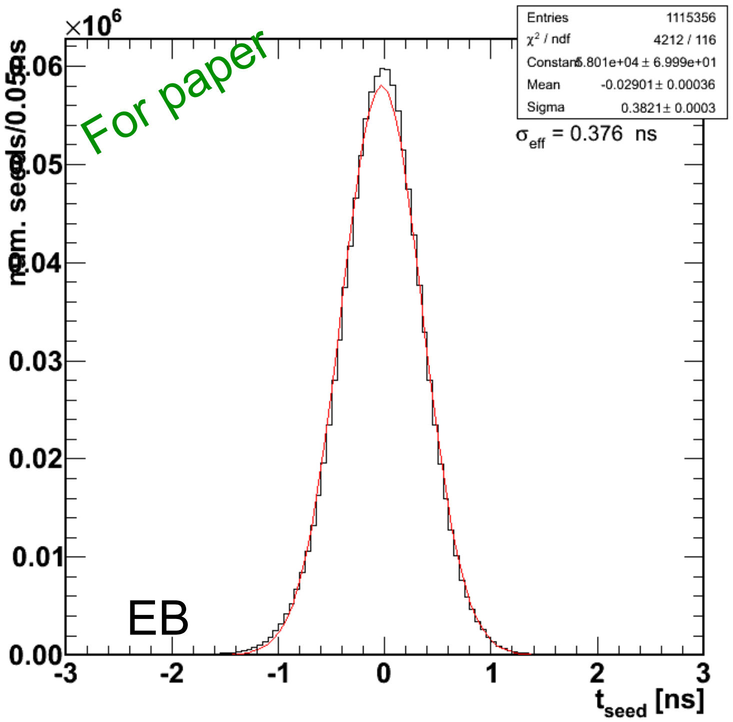
- Repeat exercise splitting collisions near/far to the IP
  - |z|< 2 cm
  - z<-5 , z>5

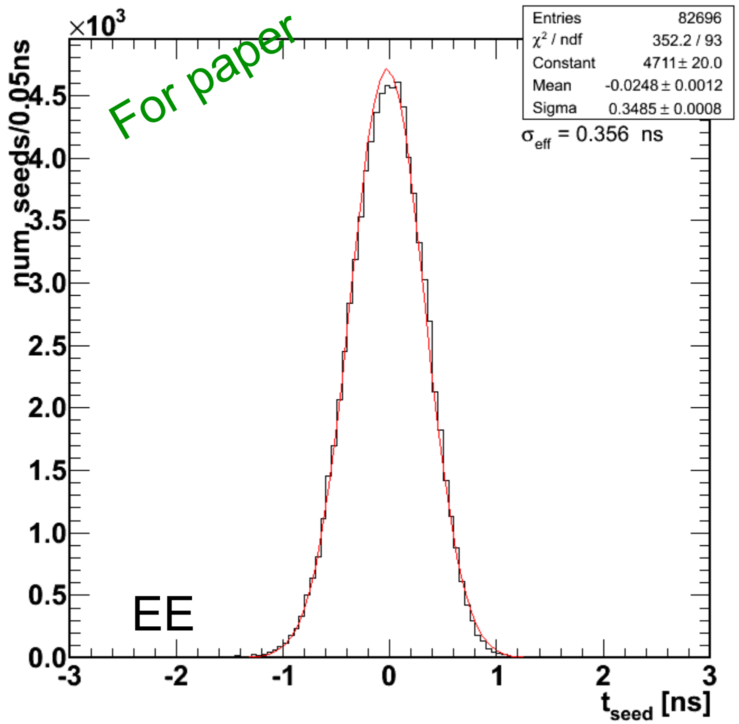


Evgueni's suggestion about EB

- "It is difficult to say where is instability because CMS electronics was not designed to work in sub-nanosecond range."
- "But I believe the most probably the difference in TTCex modules. We have one TTCex module for barrel and one for endcap."
- "I can try to measure the variation in time between the outputs of that modules if it is important, but I don't think it can be improved, because such variations are below the maximal values in technical specification of modules. "

t_{seed}





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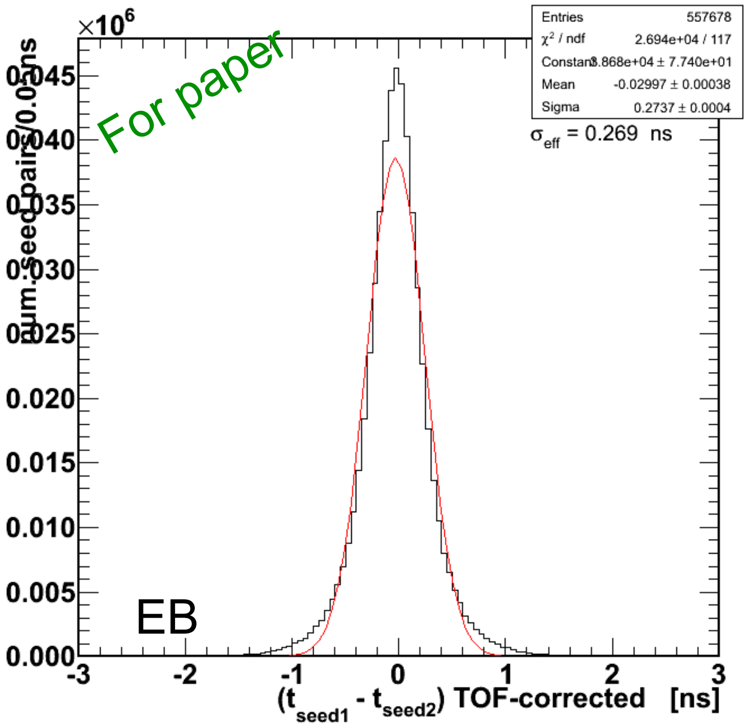

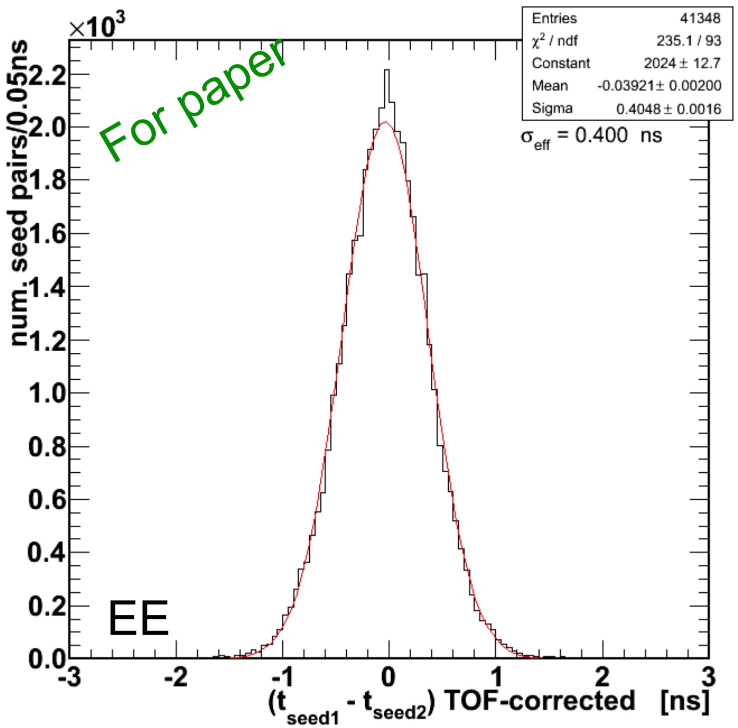

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- → choose **$(t_1-t_2)/\sqrt{2}$** as estimator of single crystal time resolution

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