Run III data analysis

Tommaso Spadaro

Overall scheme

Analysis pillars:

- Measurement of e^+ beam quadri-momentum
- Selection of e^+e^- and $\gamma\gamma$ final states
- Measurement of beam energy spread
- Independent measurement of POT

Open possibilities:

N (e^+e^-) / POT vs √s as in Darmé et al., PRD 106 (2022) 11 , 115036

N ($e^+e^- + \gamma\gamma$) / POT vs √s

N (e^+e^-) / N ($\gamma\gamma$) vs √s

Goal: % level total systematic error (excl. components indep. of √s)

Basic assumptions (counting exp.)

Statistics collected (after data quality cuts): 10^{10} POT / point

Beam momentum spread: σ_E = 0.7 MeV/c → 0.25% beam spread

47 points, e^+ momentum bins spaced by ΔE = 0.75 MeV/c ~ σ_E

Span of expected limits due to binning is < 10%

Signal counts expected per point: $S = 560 \times (g_{ve} / 3 \times 10^{-4})^2$

Background (B) expected per point

BG Process	# of Ev.	# of Ev. in Acc.	Acc.
$e^+e^- \to e^+e^-$ (t-ch.)	$5.4 \cdot 10^7$	$6.9 \cdot 10^4$	0.13%
$e^+e^- \to e^+e^-$ (s-ch.)	$3.2 \cdot 10^4$	$6.4 \cdot 10^3$	20%
$e^+e^- \to \gamma\gamma$	$2.9 \cdot 10^5$	$1.3 \cdot 10^4$	4.5%

Darmé et al

$S / B \sim 0.8\% \times (g_{ve} / 3 \times 10^{-4})^2$

$S / \sqrt{B} \sim 2 \times (g_{ve} / 3 \times 10^{-4})^2$ → discovery for $g_{ve} > 4.7 \times 10^{-4}$

Uncertainty σ_B on B negligible only if $\sigma_B / B << 1/\sqrt{B} = 0.4\%$

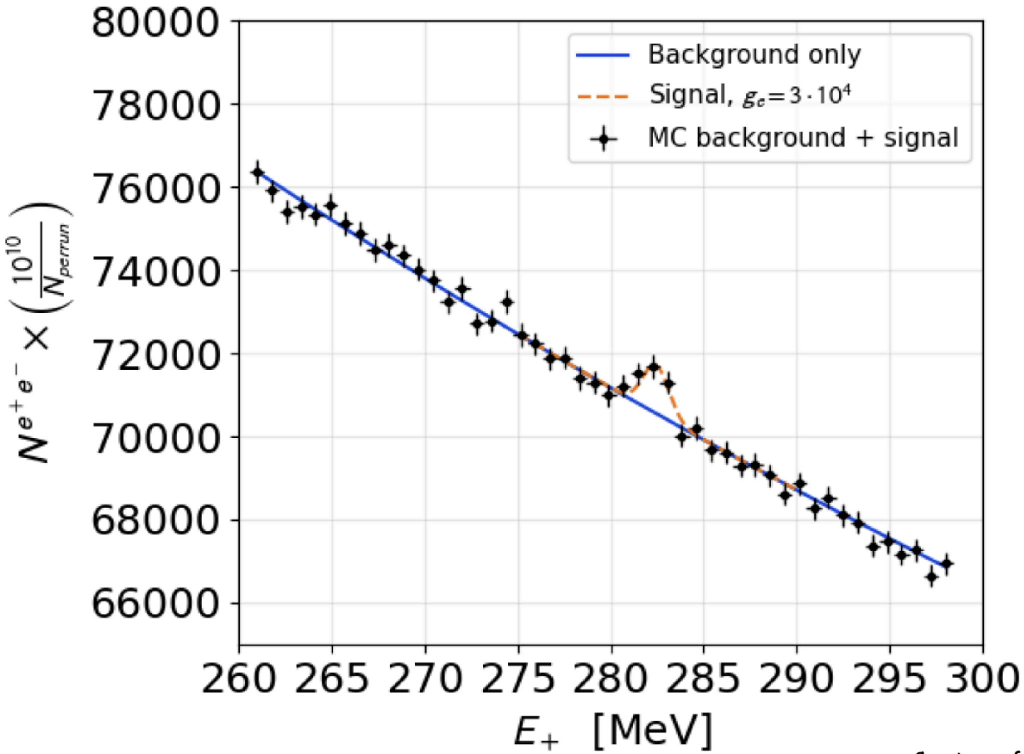
e.g. $\sigma_B / B = 1\%$ → discovery sensitivity worsens by a factor of 3

More realistical example

The excess should spread on N points (three or more)

The impact of the background uncertainty reduces [with √N?]

Uncertainty σ_B on B negligible for σ_B / B ~ 1%, to be proved with toys



Darmé et al

Courtesy of L. Darmé

IMHO: the background model is clear → side band to be used as cross check

Possible open observables

N (e^+e^-) / POT vs √s

- $\gamma\gamma$ background negligible if $\varepsilon_{TAG}(\gamma) > 95\%$
- Need control of systematic error from e^{+-} vs γ PID
- Need control of systematic error from acceptance
- Need control of systematic error from POT

N (e^+e^- or $\gamma\gamma$) / POT vs √s

- No error from PID
- Background increased by 20% → **significance worse by 8%**
- Need control of systematic error from ee, $\gamma\gamma$ acceptance and POT
- Observable less theoretically clean

N (e^+e^-) / N ($\gamma\gamma$) vs √s

- No error from POT, partial cancellation of syst. error from acceptance
- Need control of PID mis-id
- % level statistical error in the normalization → **significance worse by x3**

Back to fundamentals

Analysis pillars:

- **Measurement of e^+ beam quadri-momentum**
- Selection of e^+e^- and $\gamma\gamma$ final states
- Measurement of beam energy spread
- Independent measurement of POT

Beam momentum, methods:

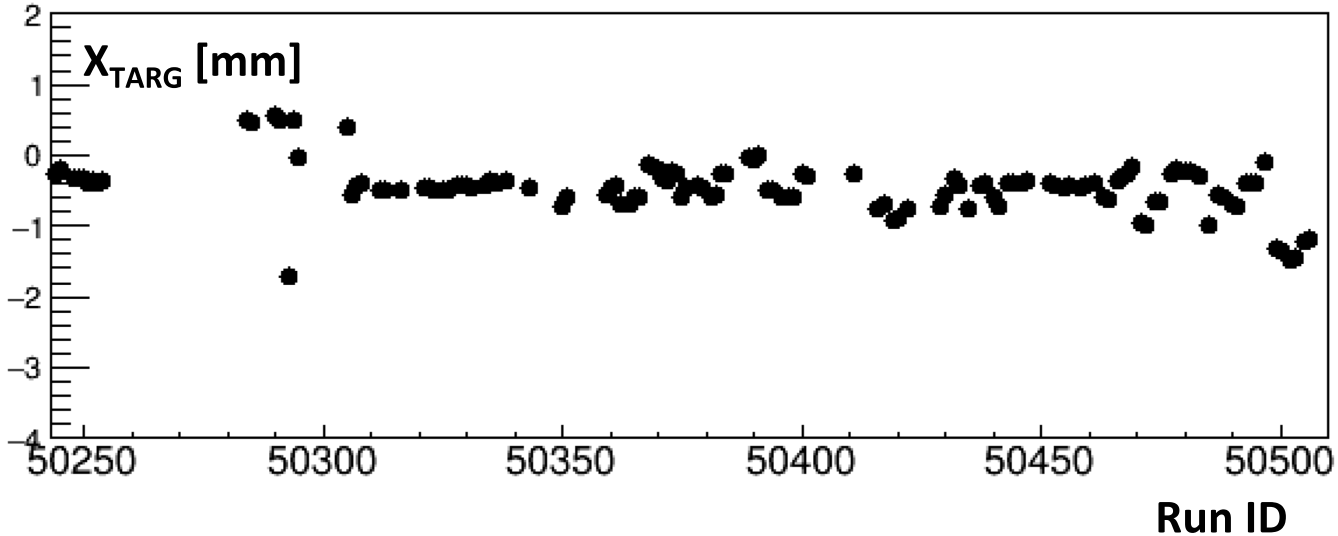
Absolute energy scale: from BTF Hall probe DHSTB01 magnet

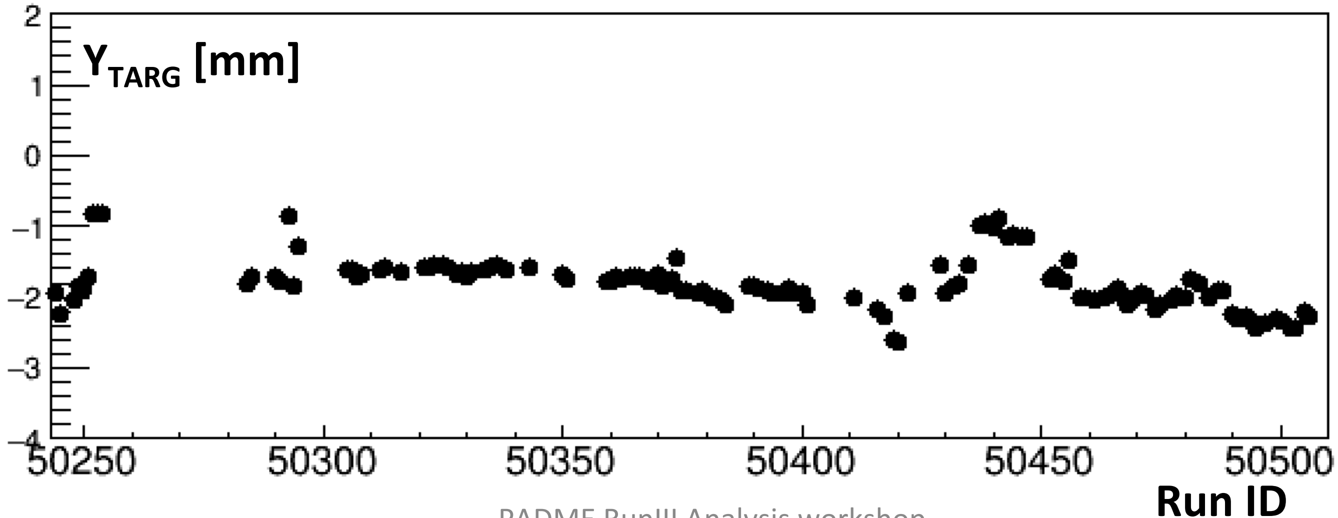
Beam direction:

- ECal COG of two cluster events − target average position
- Kinematics: ee/$\gamma\gamma$ directions + should be back-to-back in the c.m. frame
- TimePix average spot − target average poition (avail. per run)

Beam direction – target position

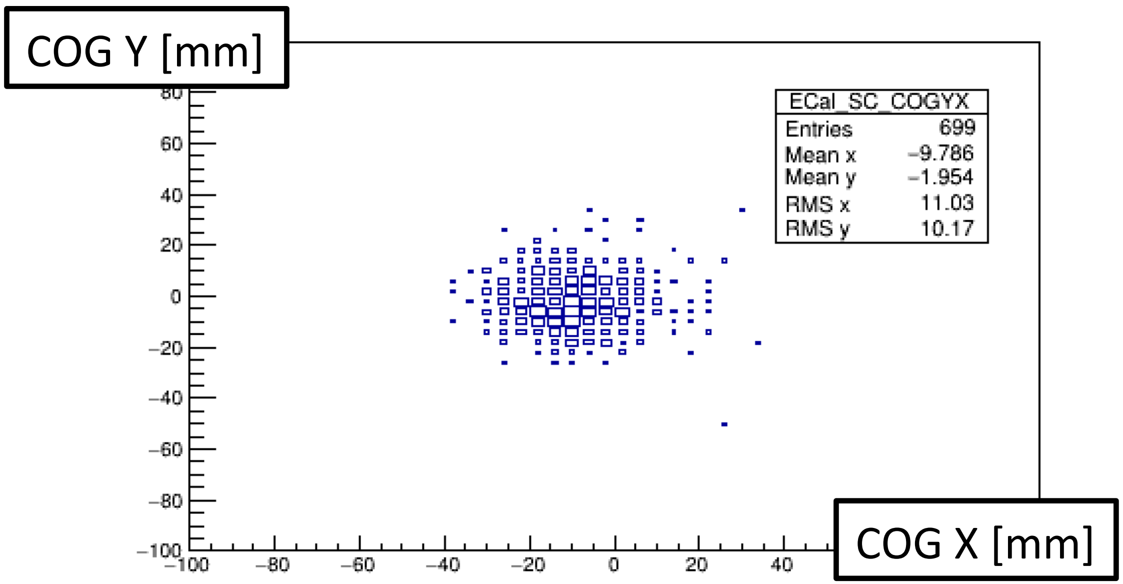
Target reconstruction as for 2020 data, stability at mm level → 0.3 mrad





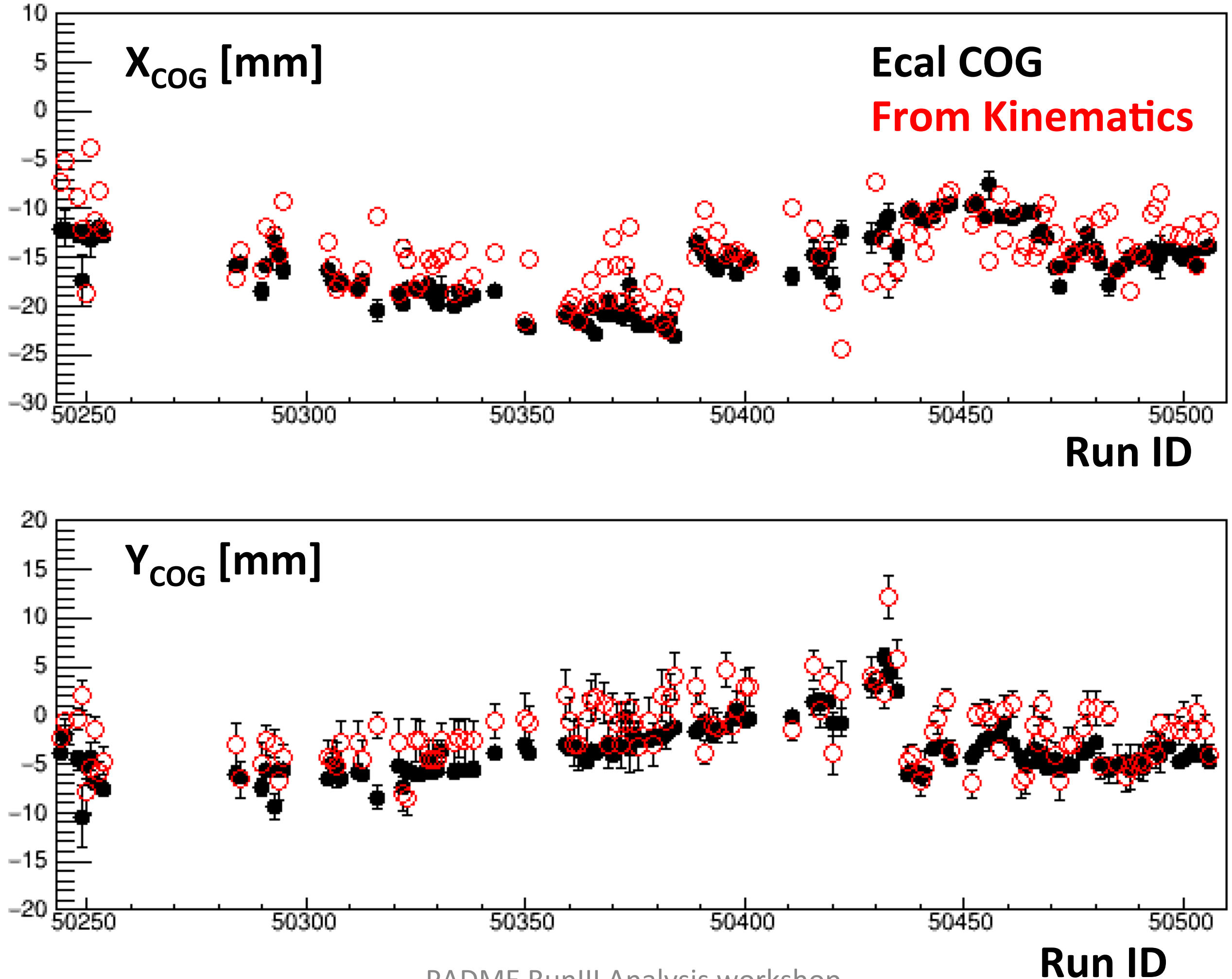
ee / γγ final states in ECal

- Standard scattering search applied with fixed cuts:
  - Energy < 200 MeV
  - 140 < Radius < 200 mm
  - Two-cluster distance > 60 mm, relative time < 5 ns
- Fixed starting points:
  - z_{CLU} = 2508 mm + 175 mm (from the survey), z_{TARG} = -1028 mm



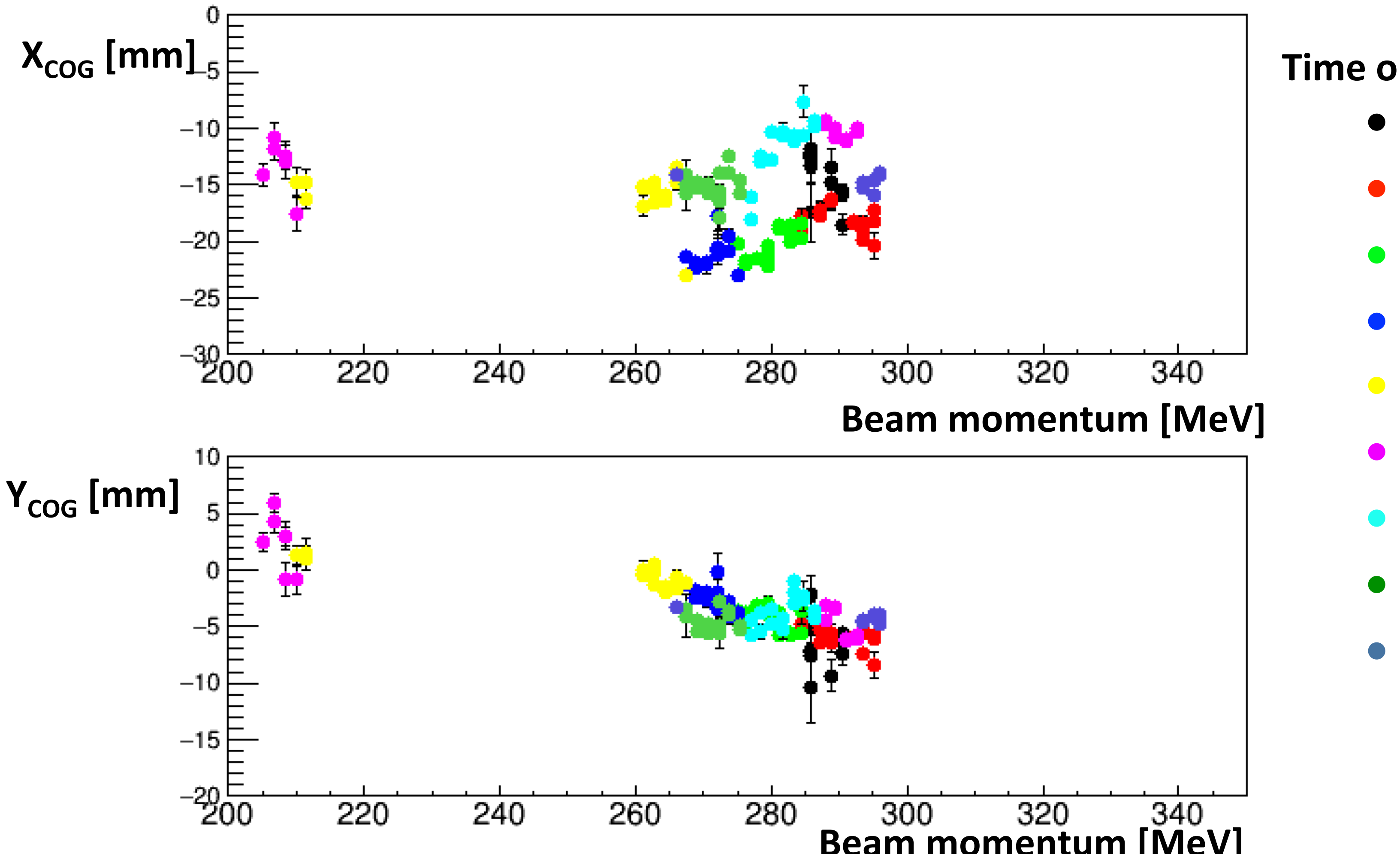
Beam direction - COG

Systematic variations at the level of 10 mm → 3 mrad
Clearly must and can be corrected at the acceptance level



Beam direction - COG

Variations in y completely correlated to beam momentum [quadrupole set]
Variations in x due to setup choice → effect on acceptance @ several %



Back to fundamentals: selection

Analysis pillars:

- **Measurement of e^+ beam quadri-momentum**
- **Selection of e^+e^- and $\gamma\gamma$ final states**
- Measurement of beam energy spread
- Independent measurement of POT

Tools needed:

Absolute energy scale of the Ecal: cosmic rays + ee/gg kinematics

Geographical evaluation of the Ecal energy response

Stability of energy response along the data taking

Precise book keeping of dead/problematic Ecal cells along the data taking

Ecal absolute efficiency: tag & probe method

Etag – Ecal matching: time and energy response for Etag, efficiency + mistag

Back to fundamentals: beam spread

Analysis pillars:

- Measurement of e^+ beam quadri-momentum
- Selection of e^+e^- and $\gamma\gamma$ final states
- **Measurement of beam energy spread**
- Independent measurement of POT

Tools needed:

TimePix beam spots @ run level, analysis and book keeping

Cross check with Ecal COG → stability of spot position, total energy

Back to fundamentals: POT

Analysis pillars:

- Measurement of e^+ beam quadri-momentum
- Selection of e^+e^- and $\gamma\gamma$ final states
- Measurement of beam energy spread
- **Independent measurement of POT**

Tools needed:

Lead glass response and beam time shape, to be cross checked against Ecal

If Etag-Ecal matching OK, might cross check (@5% overall) expected $\sigma(ee \rightarrow \gamma\gamma)$

Back to fundamentals: other tests

Analysis pillars:

- **Measurement of e^+ beam quadri-momentum**
- **Selection of e^+e^- and $\gamma\gamma$ final states**
- **Measurement of beam energy spread**
- **Independent measurement of POT**

Fundamental tests for analysis validation

1. **Consistency of other observables within errors**
2. **Match QED cross section to low-momentum side band**
3. **Evaluate systematic error related to intensity fluctuations (beam time shape)**
4. **Is the beam spread distribution a Gaussian? If not, adresss the impact**
5. **Is the beam energy / direction varying along the spill?**
6. **Address effect of correlations of beam position/direction/energy**
7. …

Decisions to be taken ASAP

1. Which observable is of the highest priority, IMHO is: N(ee || gg) / N_{POT}

2. Analysis is to be made blind? If so, we might add a fake 20% error to N_{POT}

3. Will we re-use reconstruction algorithms from 2020 analysis? IMHO no

Critical review of Ecal reconstruction vs rewriting?

Tuning of Etag reconstruction is obviously needed, maybe major changes

Lead glass reconstruction, probably OK after dedicated validation

If we decide to completely rewrite Ecal reconstruction algorithms:

If man-power allows, the algorithm developed in Sofia might be tested [Instruments 2022, 6, 46 https://doi.org/10.3390/instruments6040046]

We might improve the time response, using all cells in a cluster

We might want to re-tune the Ecal clustering algorithm

Conclusions

The data is of very good quality: a very interesting result should be possible

We can be ambitious in terms of analysis objectives (1% systematic error)

We need to be aggressive in terms of time scale, with the goal of achieving a preliminary result by noon / the end of 2023

We need to work in synergy, avoiding as much as possible any duplication

If we focus on one observable, the other two will be used as cross-checks

If need arise of an independent analysis, we might split in terms of Ecal reconstruction algorithms (very ambitious goal)