# Upgrade2 ECAL performance with $B^0 \to \pi^+\pi^-\pi^0$

D. Manuzzi, S. Perazzini

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# Outline

- Introduction

- Highlights of "Homogenous" simulation from Bologna

- $B^0 \to \pi^+\pi^-\pi^0$ performances
    - Figures of merit: Efficiency vs. Significance $(S/\sqrt{S+B})$
  - FTDR result
  - Results with variable time resolution
  - Results with Dalitz plot requirements

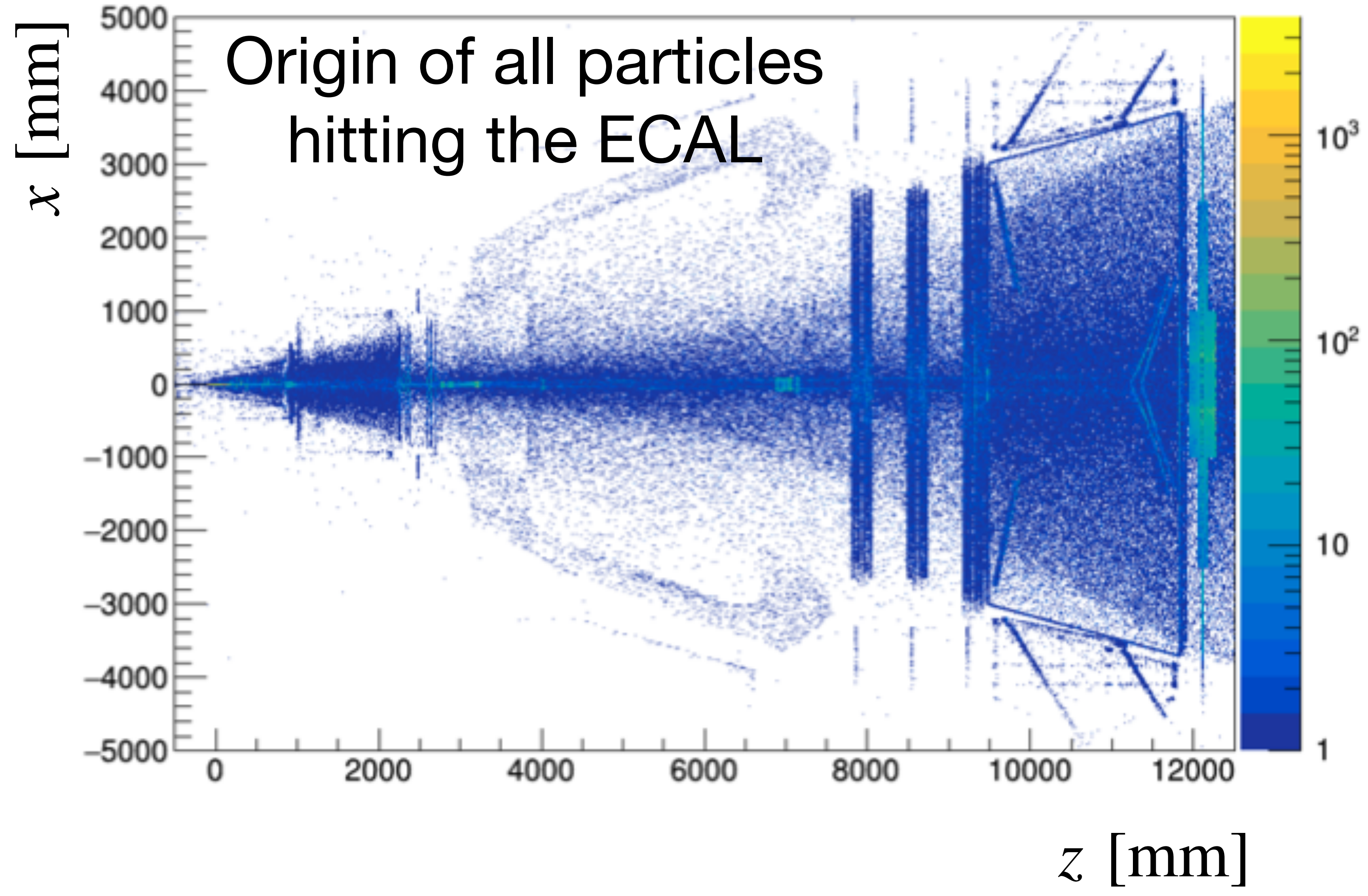
# Motivations to study $B^0 \to \pi^+\pi^-\pi^0$

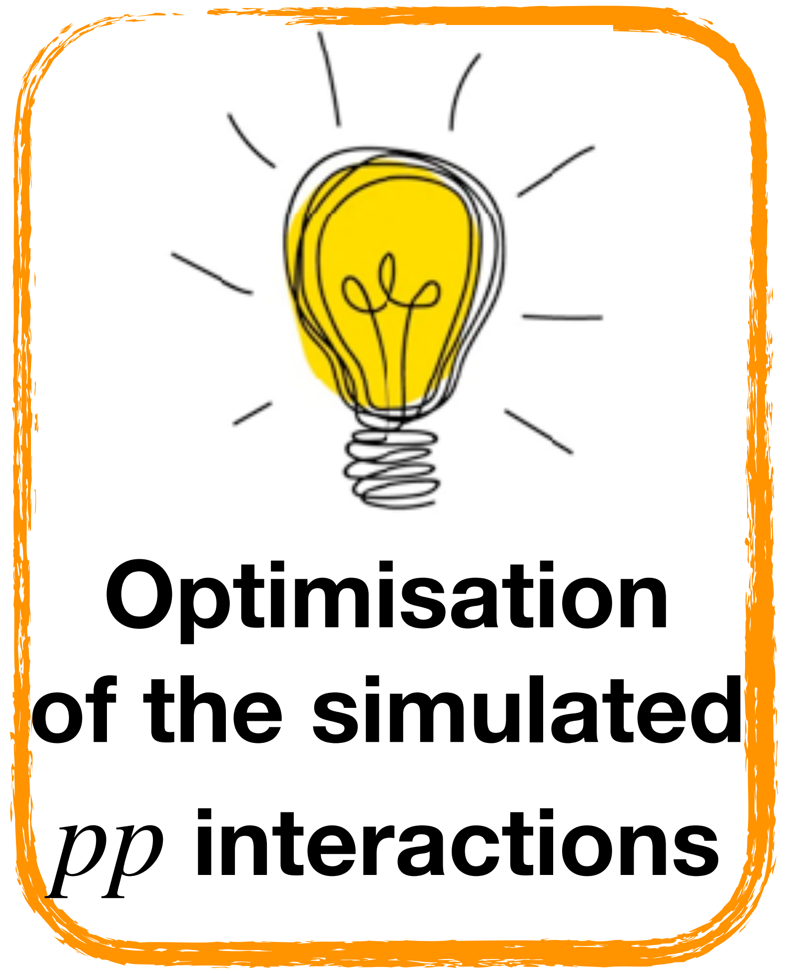
- **Relevant mode to measure the $\alpha$ angle of the Unitarian Triangle**
  - Complementary to $B \to \pi\pi, \rho\rho$ analysis

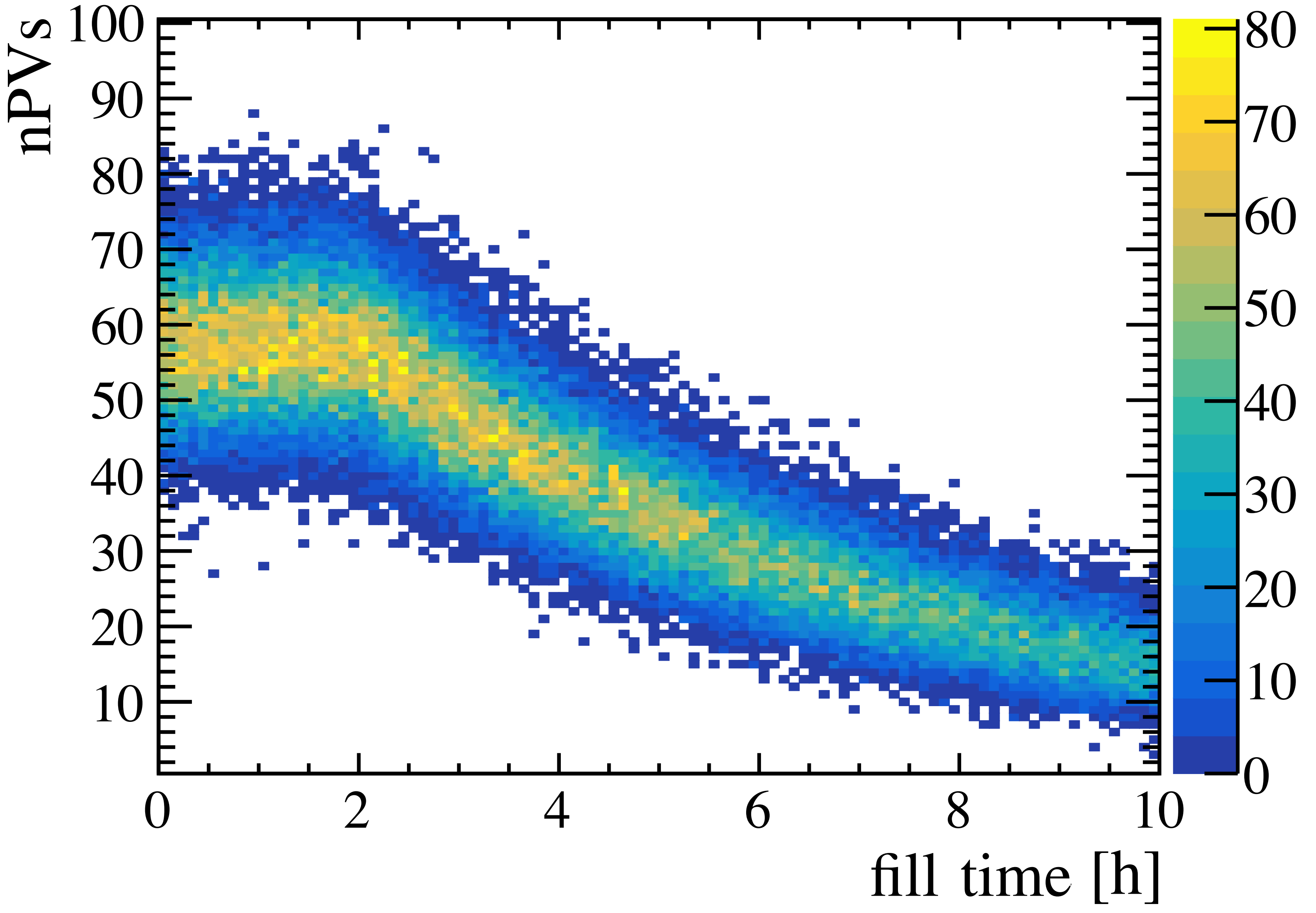
- Opportunity to study the reconstruction of both **merged** and **resolved** $\pi^0$
  - Large increase of comb. bkg. expected in U2 for resolved $\pi^0$
  - Large benefit expected from timing

- Documentation
  - LHCb-2003-91: performance of $\gamma$ and $\pi^0$ reconstruction with simulated $B^0 \to \pi^+\pi^-\pi^0$
  - CERN-THESIS-2013-051: preliminary study on 2010 data

# Origin-vertex simulation



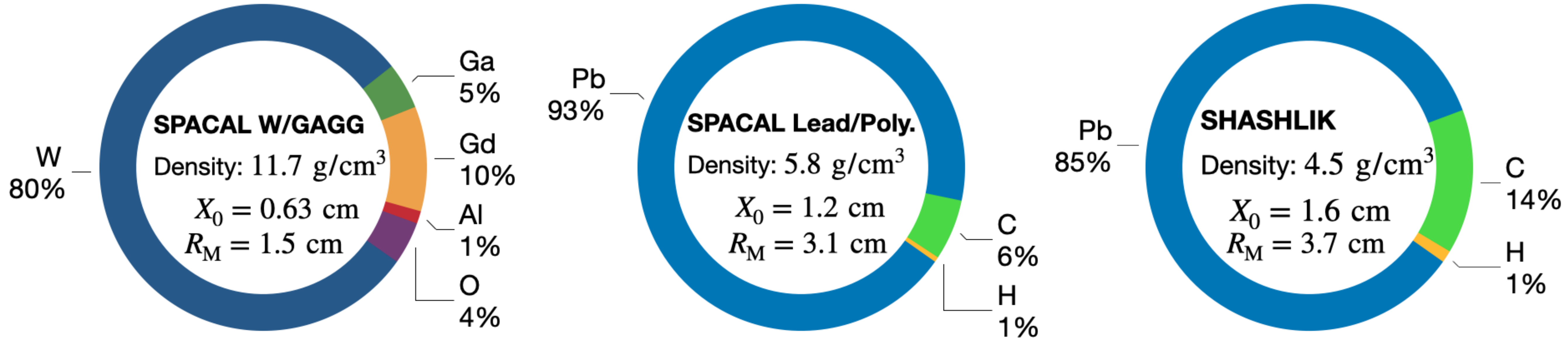



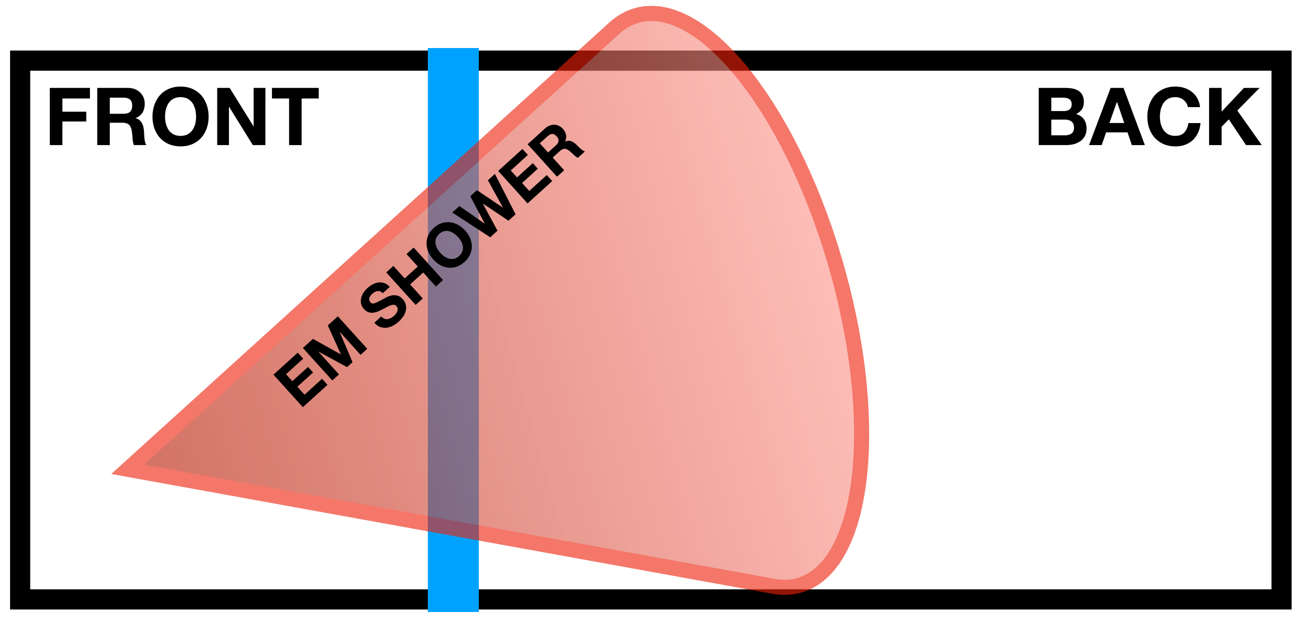

1. Pythia is used to generate the primary *pp* interactions
   - The time spread of the PV is included
2. The particle flux at ECAL surface is given by Gauss
   - Geant4 is used to propagate particles inside LHCb
   - All tracked particles are organised depending on their PV
3. Luminosity decay
   - "*nPVs*" is randomly chosen, depending on the luminosity degradation expected in Run5 conditions
4. PV bootstrap ♻ RECYCLE of min. bias MC events
   - Events are built merging:
     - 1 signal PV
     - $nPVs - 1$ not-signal PVs, randomly extracted from a the previously generated PV dataset

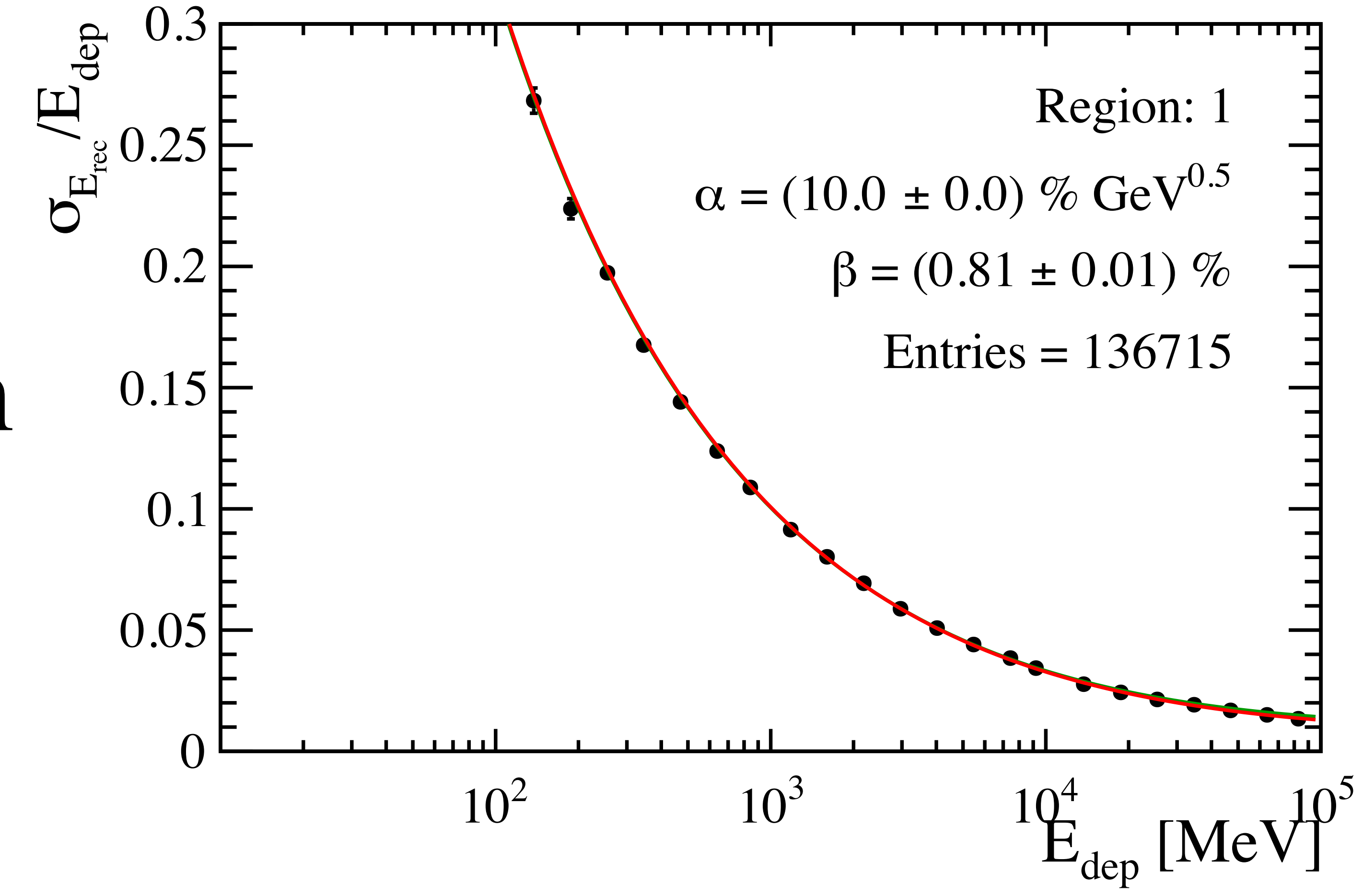
# ECAL simulation

- ECAL homogenisation
  - Homogeneous materials with average composition are simulated instead of the detailed geometry of the cells
- The shower development is simulated by Geant4
  - The effects of the angle of incidence and time spread of the showers are considered
- Energy deposits are clustered depending on the cell granularities and saved on disc
  - The longitudinal segmentation is considered
  - Energy resolution simulated with a **random rejection** of the energy deposits
- Time of charged particles crossing the separation between front and back sections is saved
  - The time measured by each cell is the **average of these times** + **gaussian smearing**

OFFLINE



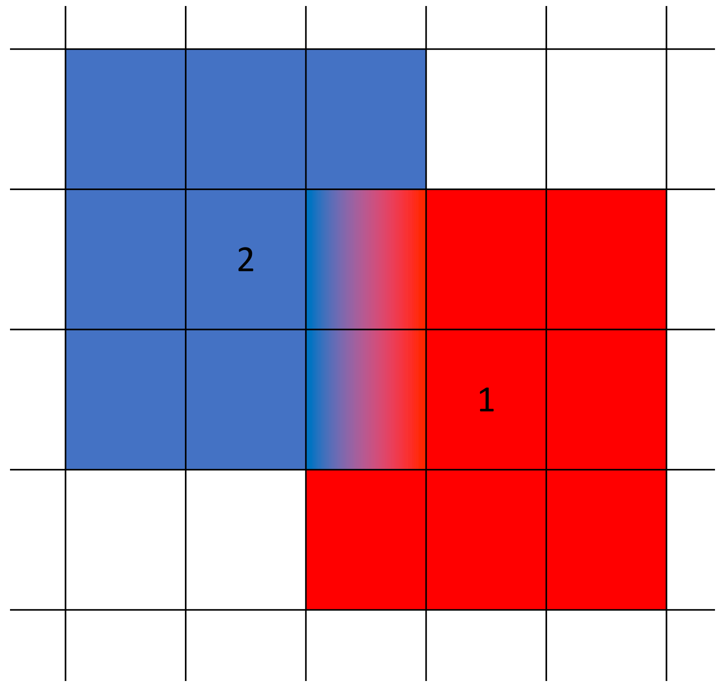




**Flexible inclusion of the resolution effects**

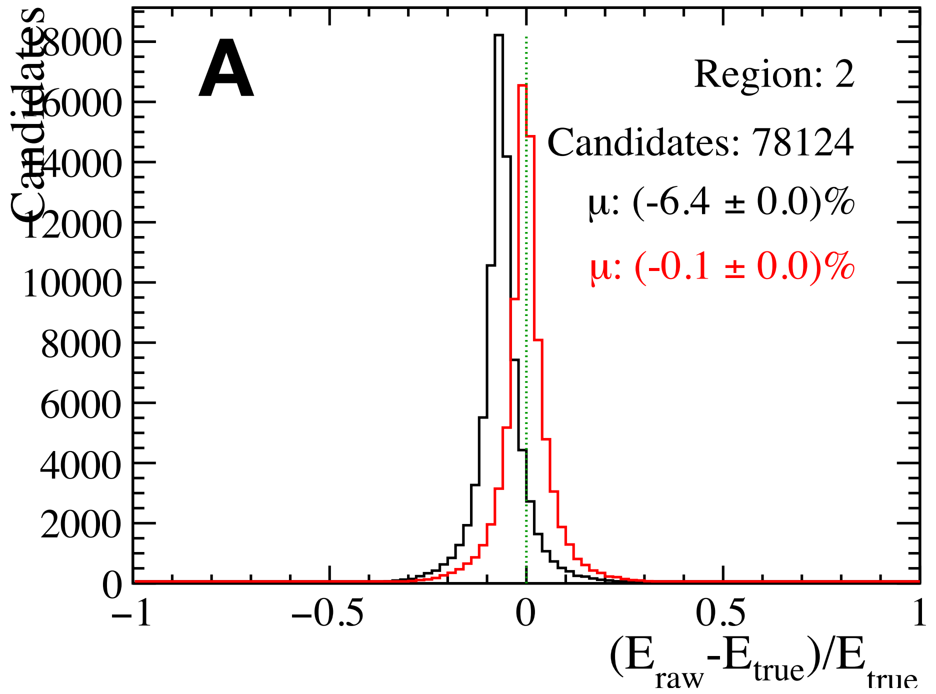
# ECAL reconstruction

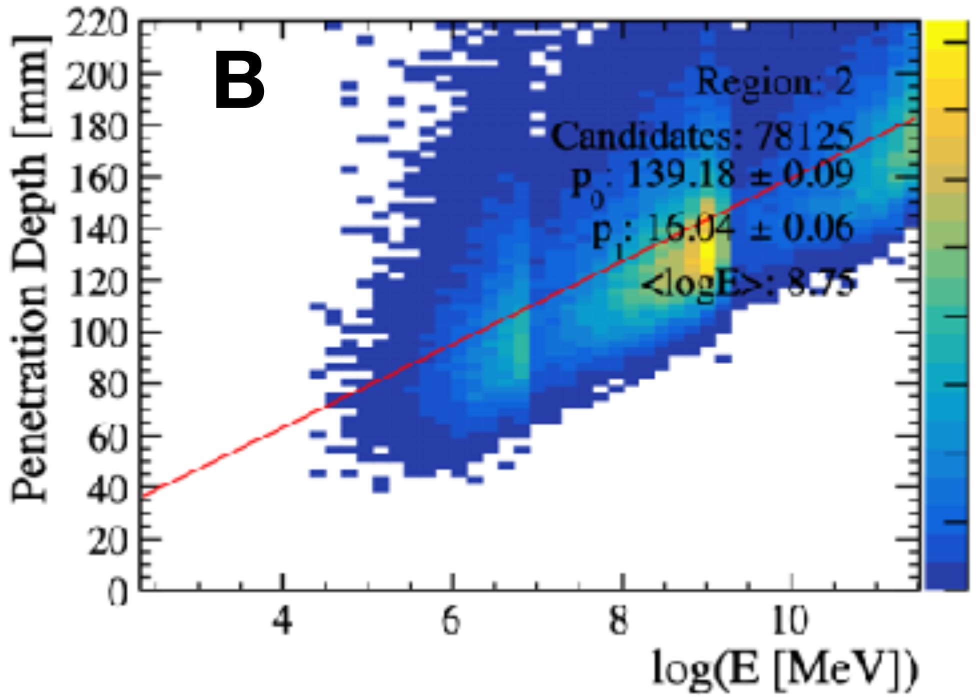
- Cluster reconstruction
  1. Seeds: local maxima
  2. $3 \times 3$ clusters
  3. Energy redistribution

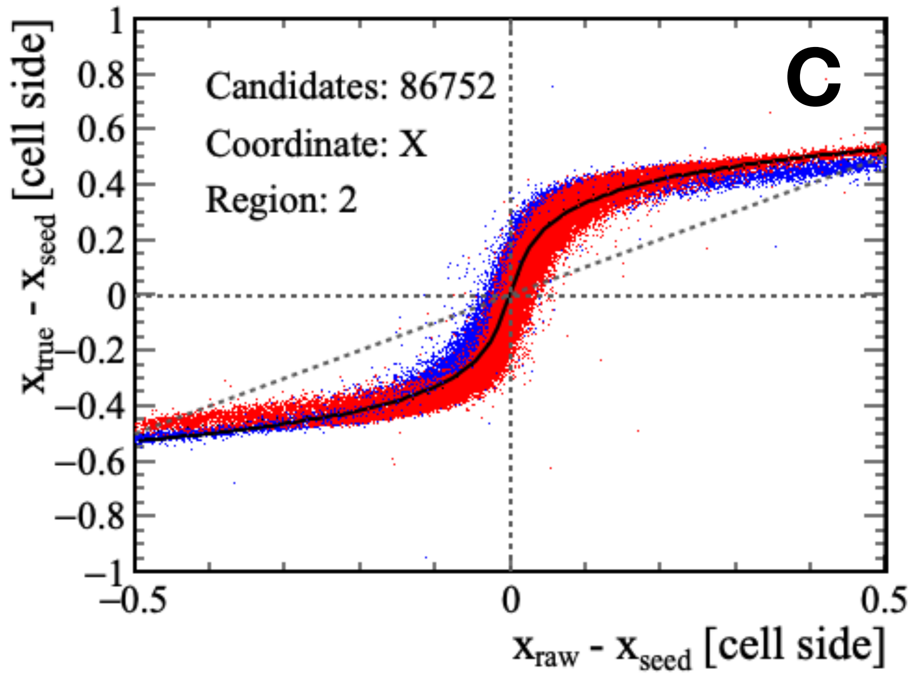



**Replication of Run2 reconstruction procedure**

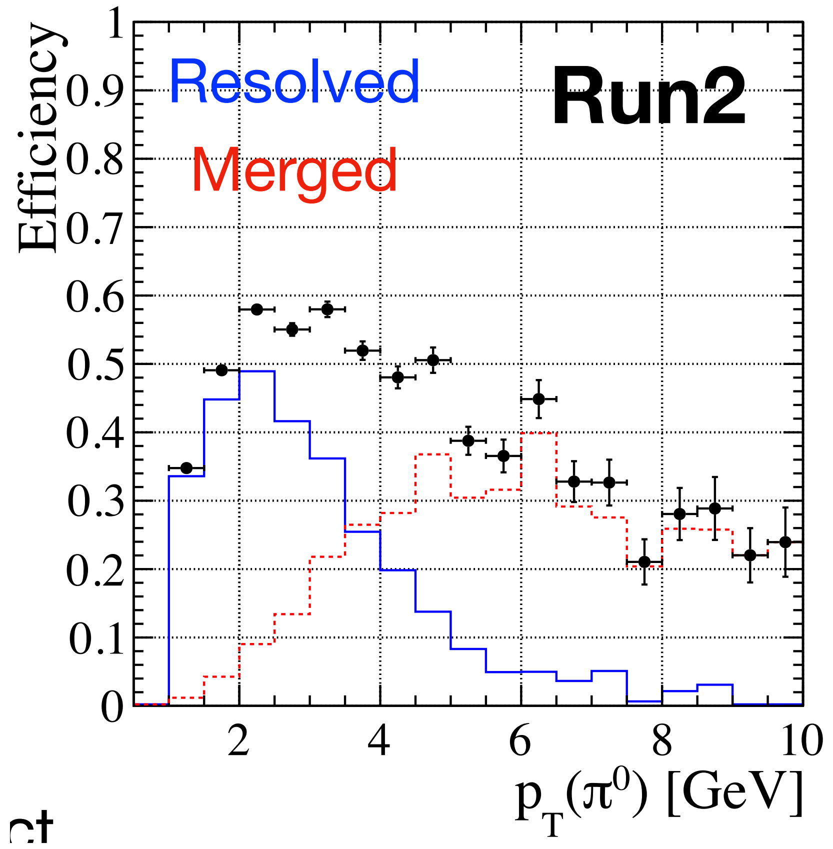
- Calibrations
  A. Energy leakage
  B. L-shape
  C. S-shape
  D. Time [backup slides]

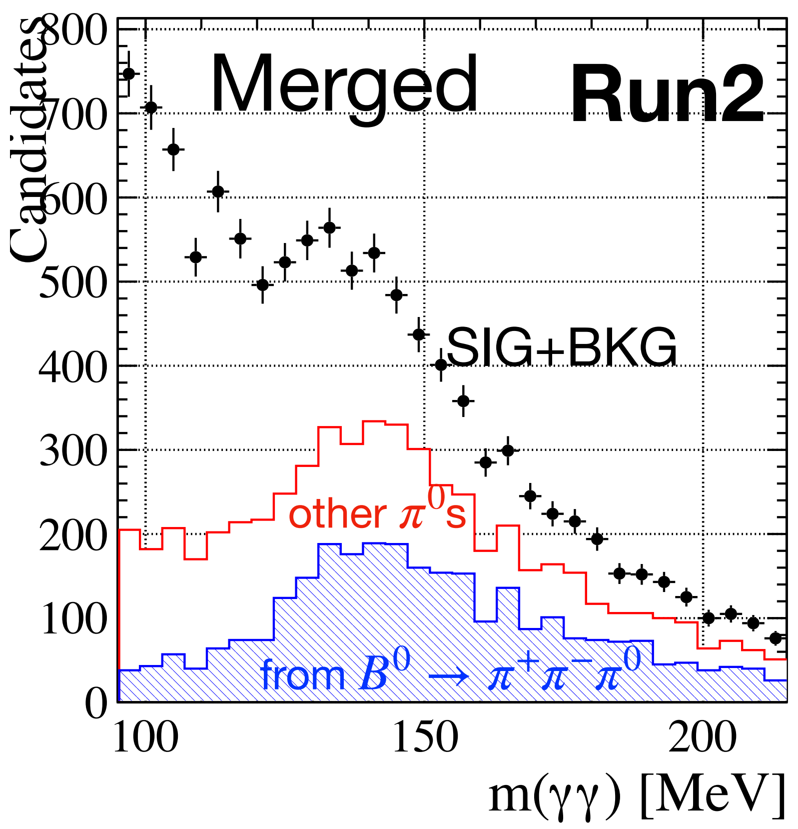


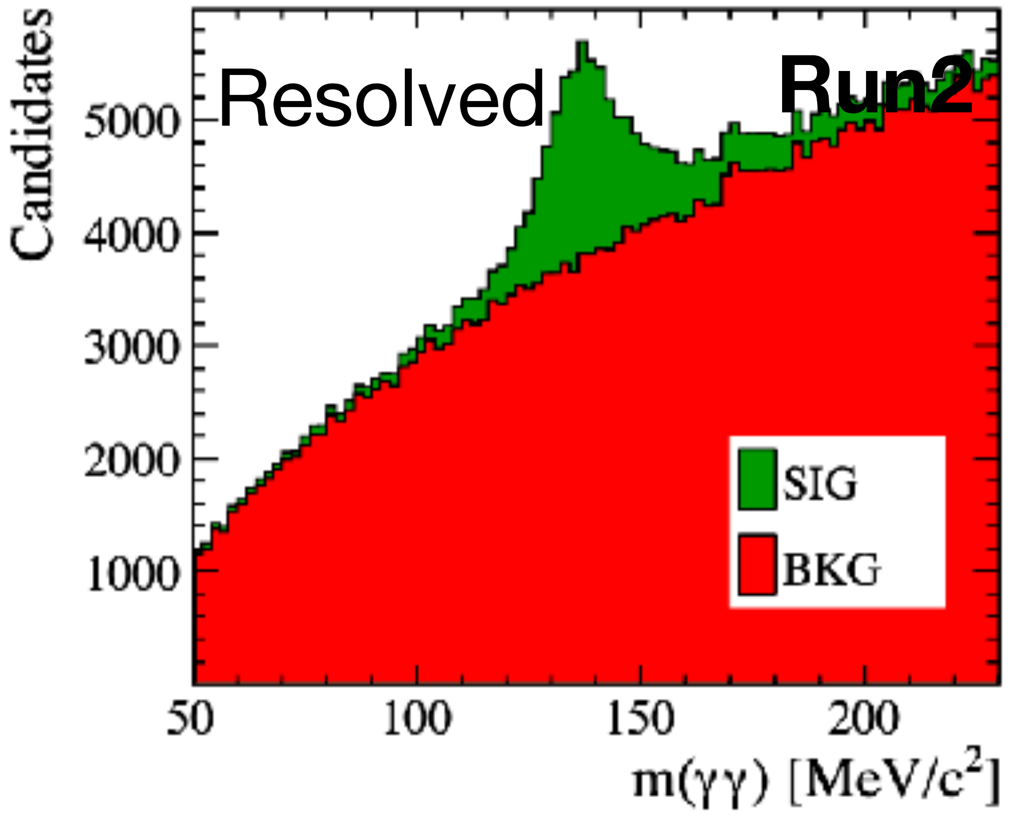



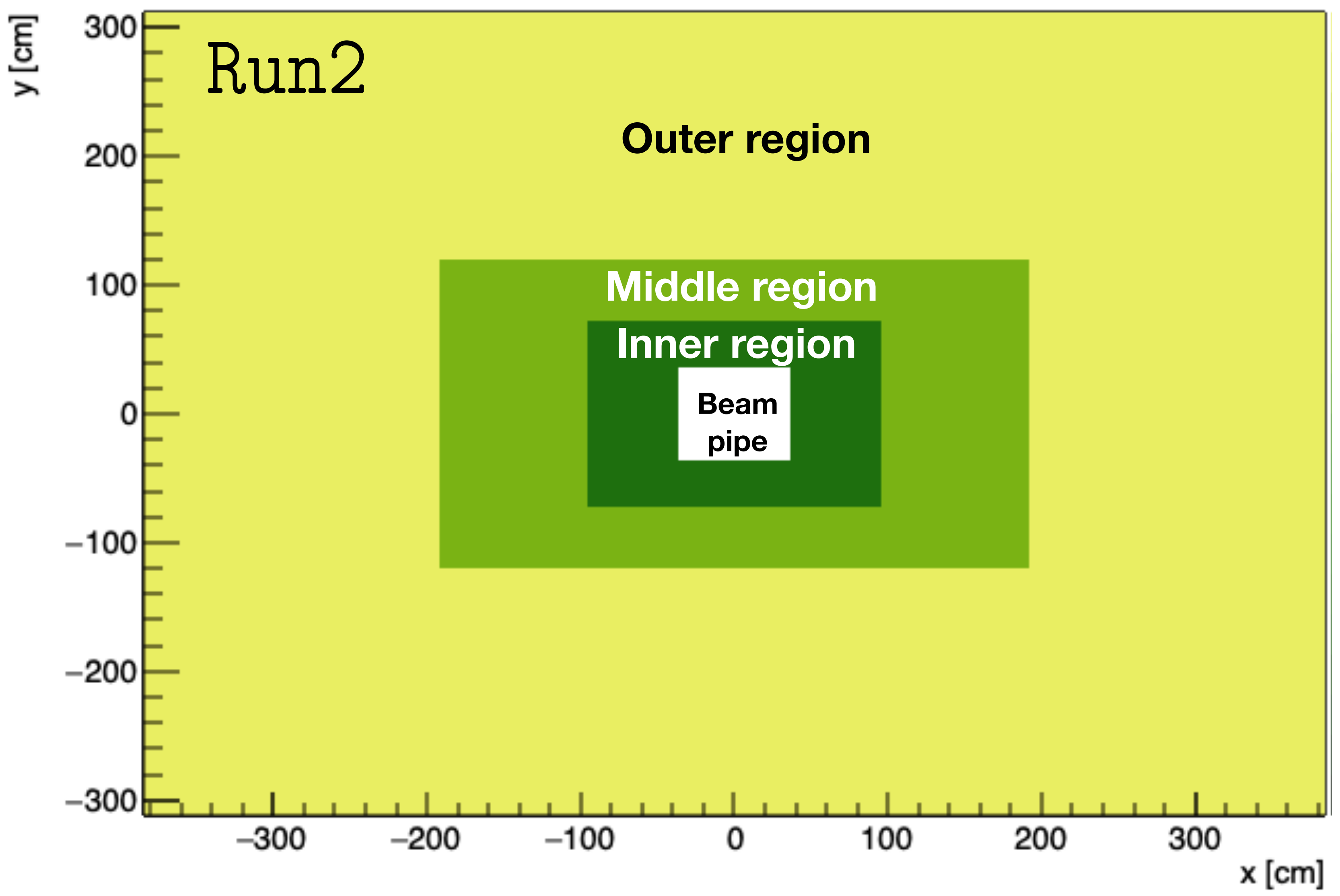

- $\pi^0$ reconstruction
  - Merged
  - Resolved

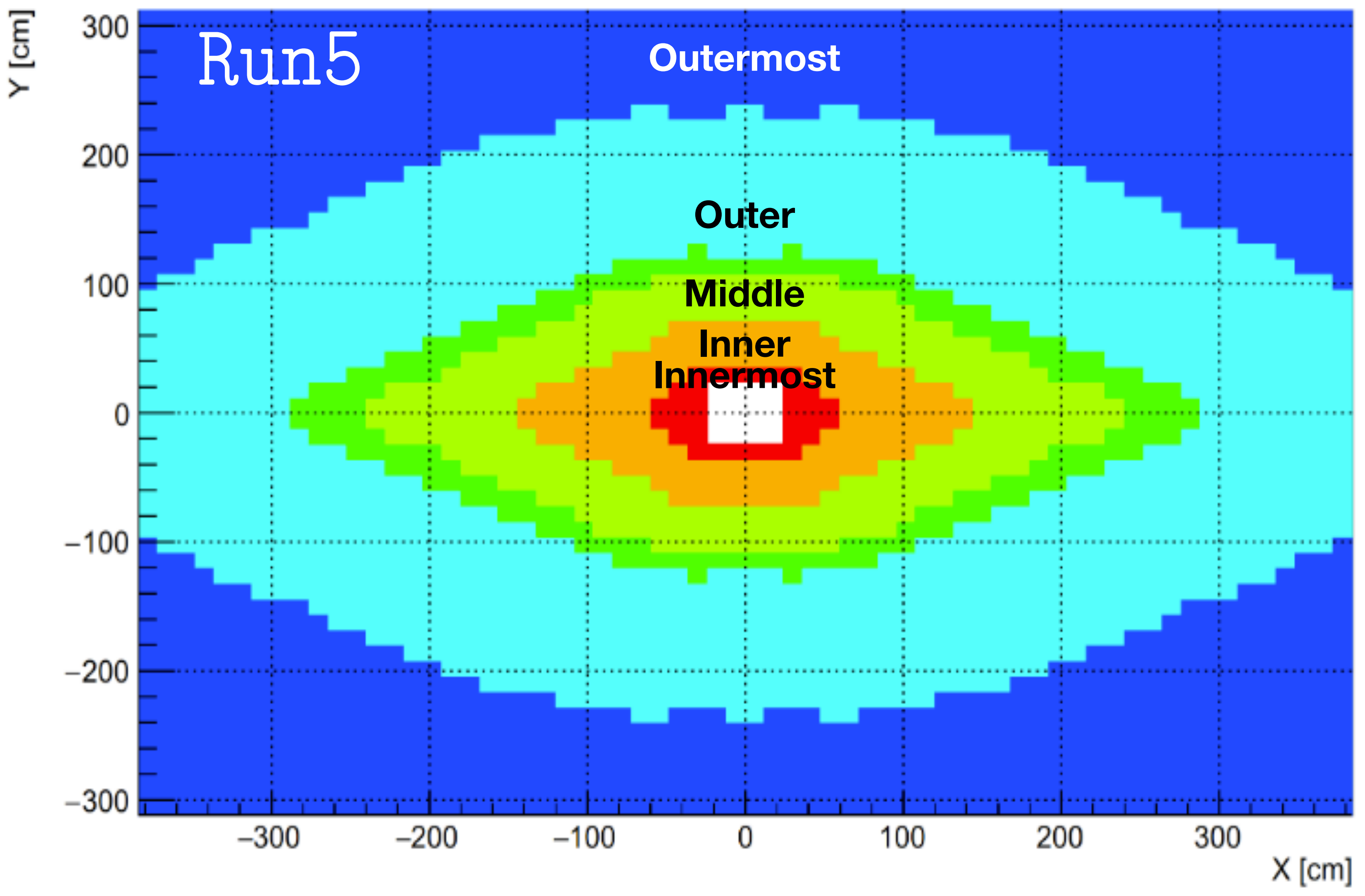


# Tested ECAL configurations




| Region name | Region index | CURRENT Run2 Cell side [mm] | CURRENT Run2 $R_M$ [mm] |
|---|---|---|---|
| Inner | 0 | 40 | 35 |
| Middle | 1 | 60 | 35 |
| Outer | 2 | 120 | 35 |

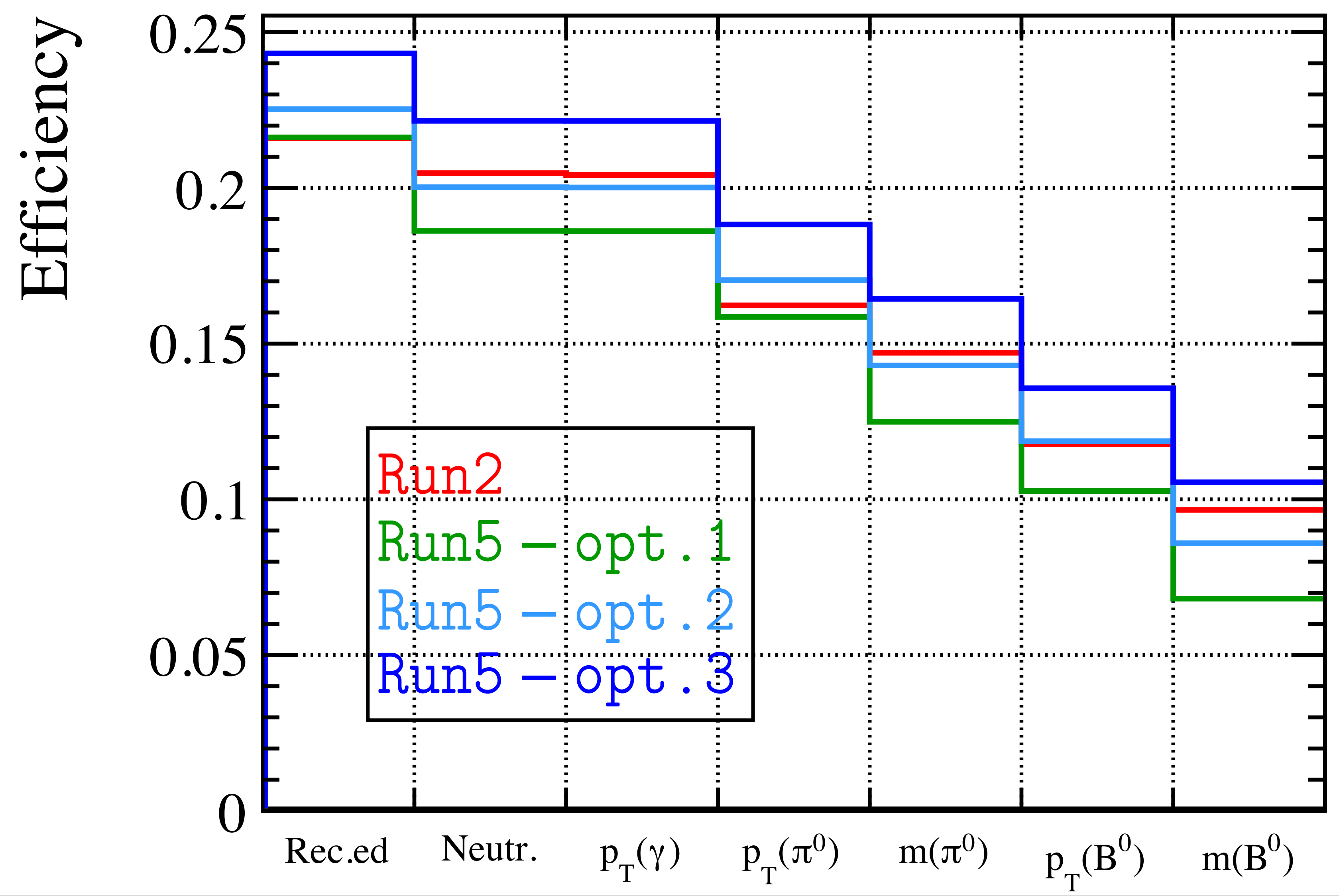
| Region name | Region index | U2 BASELINE Run5-opt.1 Cell side [mm] | U2 BASELINE Run5-opt.1 $R_M$ [mm] | BETTER OUTER Run5-opt.2 Cell side [mm] | BETTER OUTER Run5-opt.2 $R_M$ [mm] | EVEN BETTER Run5-opt.3 Cell side [mm] | EVEN BETTER Run5-opt.3 $R_M$ [mm] |
|---|---|---|---|---|---|---|---|
| Innermost | 0 | 15 | 15 | 15 | 15 | 15 | 15 |
| Inner | 1 | 30 | 30 | 30 | 30 | 15 | 15 |
| Middle | 2 | 40 | 35 | 40 | 35 | 40 | 35 |
| Outer | 4 | 60 | 35 | 40 | 35 | 40 | 35 |
| Outermost | 5 | 120 | 35 | 60 | 35 | 60 | 35 |

# $B^0 \to \pi^+\pi^-\pi^0$ selection

**ASSUMPTION:** perfect tracking

| Merged $\pi^0$ | Resolved $\pi^0$ |
|---|---|
| $\gamma$-track distance $> 1$ cell side<br>$p_{\mathrm{T}}(\gamma) > 200\,\mathrm{MeV}/c$ | |
| $p_{\mathrm{T}}(\pi^0) > 2.5\,\mathrm{GeV}/c$<br>$m(\pi^0) \in [75, 195]\,\mathrm{GeV}/c^2$ | $p_{\mathrm{T}}(\pi^0) > 1.5\,\mathrm{GeV}/c$<br>$m(\pi^0) \in [110, 170]\,\mathrm{GeV}/c^2$ |
| $p_{\mathrm{T}}(B^0) > 3\,\mathrm{GeV}/c$<br>$m(B^0) \in [5.1, 5.5]\,\mathrm{GeV}/c^2$ | $p_{\mathrm{T}}(B^0) > 2.5\,\mathrm{GeV}/c$ |

[from stripping selection used in CERN-THESIS-2013-051]

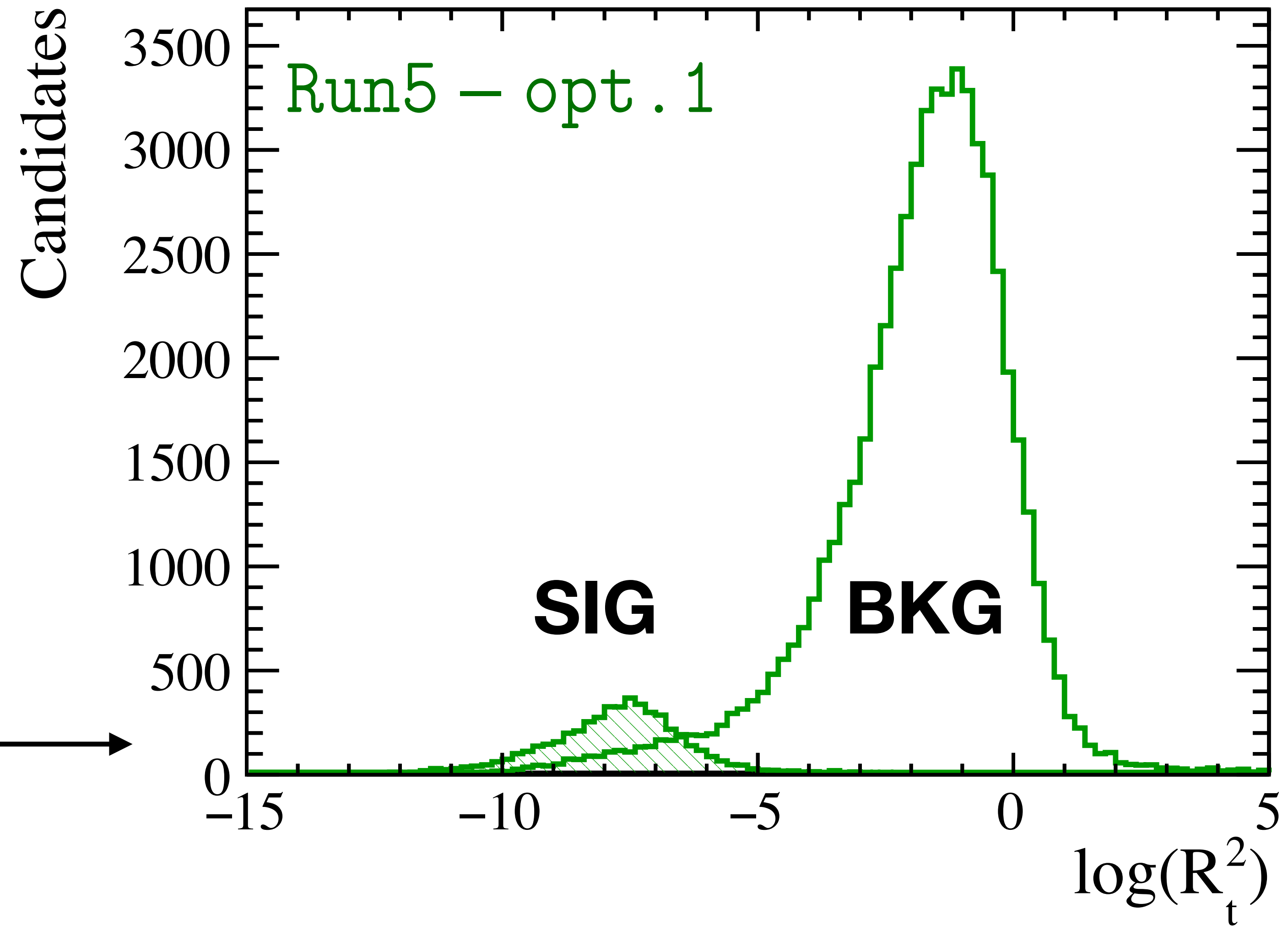



**Efficiency denominator is the number of generated events**
(80k for all config.s)

**Time info. from tracking assumed to be more precise than the one from the calo**

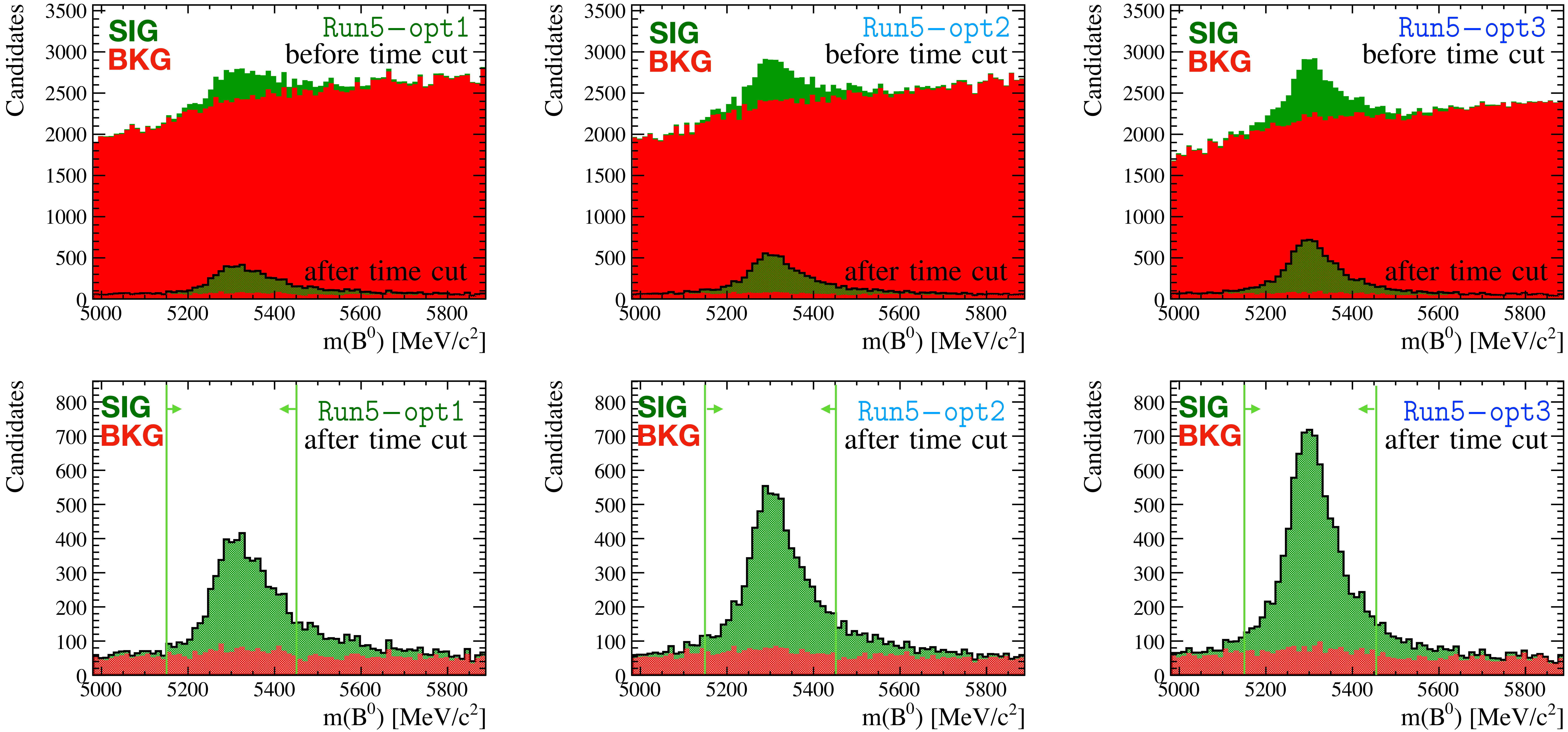
$$t_{1,2}^{\text{expect.}} = \sqrt{(x_i^{ECAL} - x_B^{\text{end}})^2 + (y_i^{ECAL} - y_B^{\text{end}})^2 + (z_i^{ECAL} - z_B^{\text{end}})^2} + t_B^{\text{end}}$$

$$R_t^2 = (t_1^{ECAL} - t_1^{\text{expect.}})^2 + (t_2^{ECAL} - t_2^{\text{expect.}})^2$$




**Background is due to multiple candidates not matched with the signal**
(mainly combinatorial for resolved $\pi^0$ from the rest of the event)

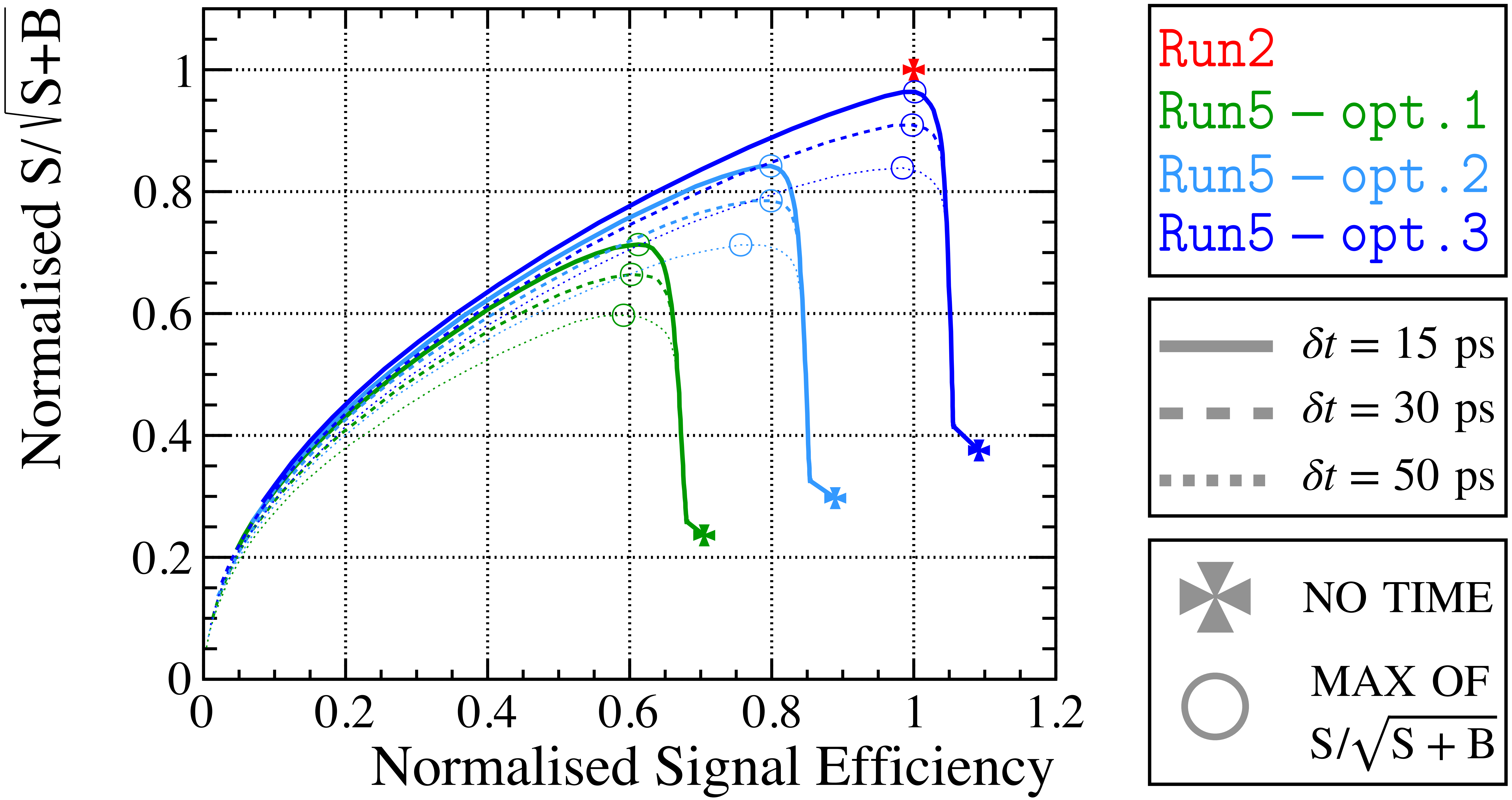
# Invariant mass plots



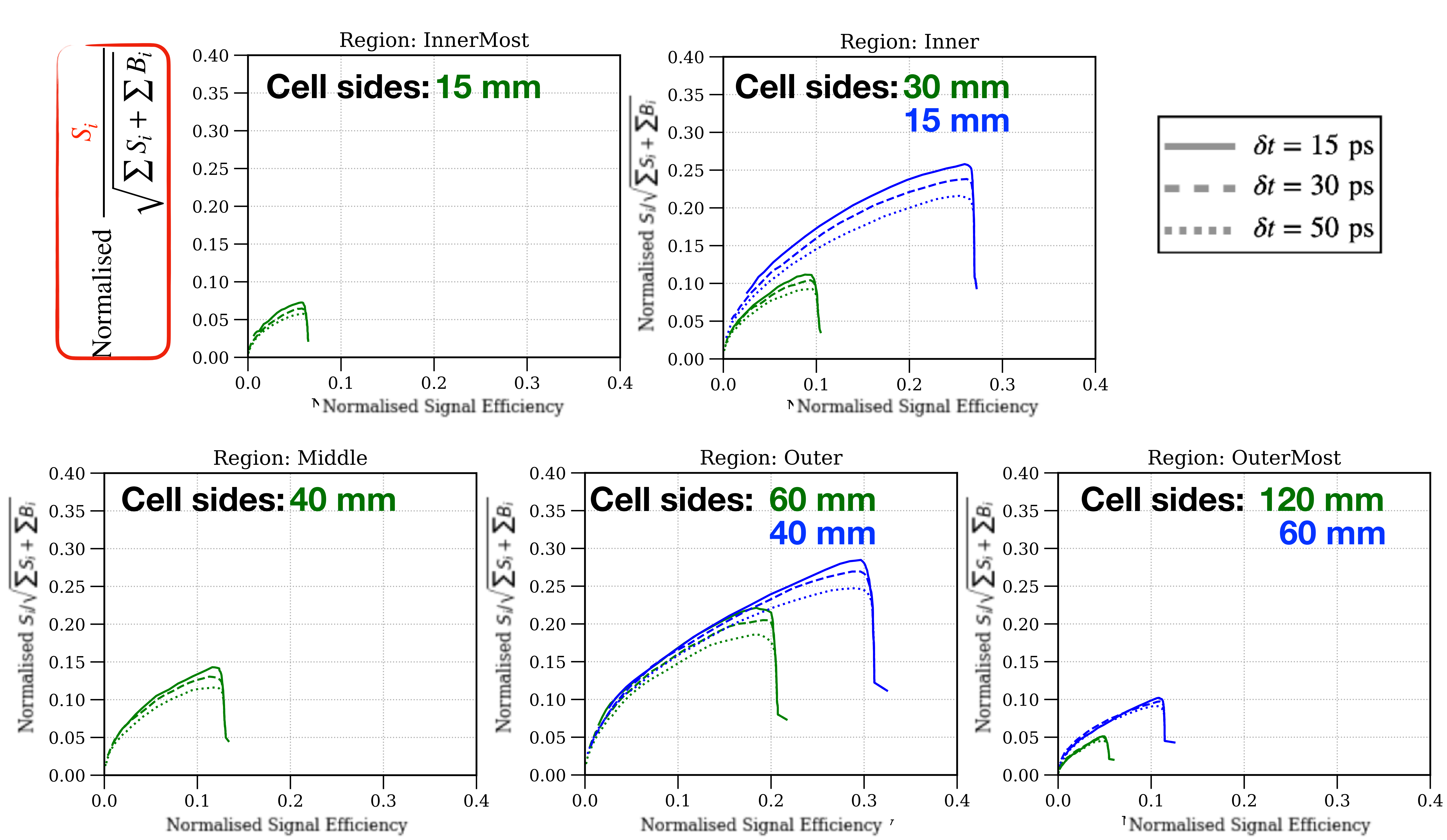
# Global $B^0 \to \pi^+\pi^-\pi^0$ performance

**Each point of the curves represents a particular cut on $R_t$**

**Normalisation:**
simulated Run2 performances



# Performance per region

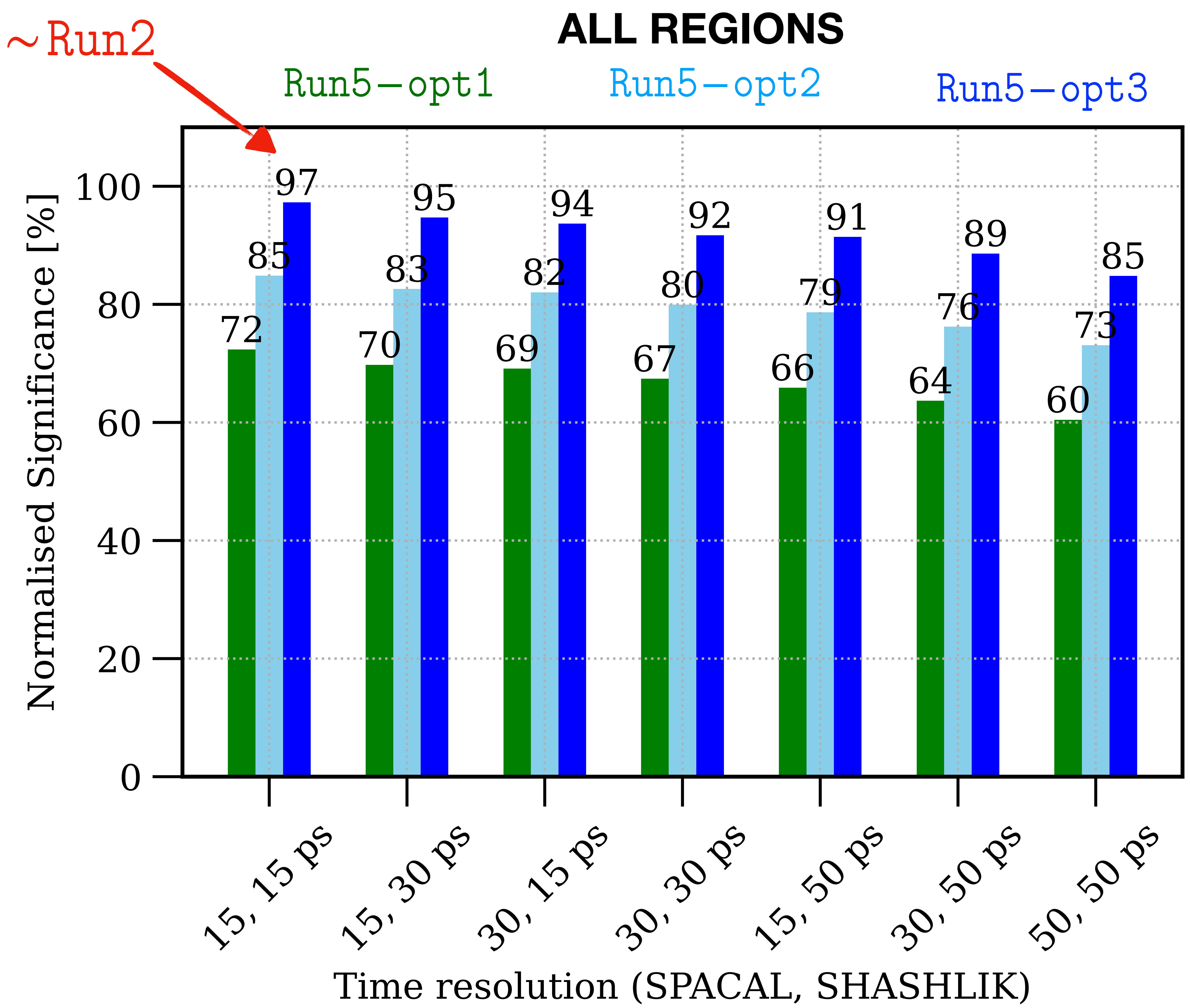



- Significance denominator: same a previous slide
- Significance numerator: signal yield per region

- Performance benefit from better granularity
- The inner the region, the larger the advantage from better time resolution
- Contribution to reconstructed signals:
  - *Outer* more relevant than *Inner*
  - *InnerMost* almost similar to *OuterMost*

Signal candidates with final-state $\gamma$s hitting different regions are **neglected** (~10%)

# Significance with mixed time resolution




- $S/\sqrt{S+B}$ is normalised to Run2 total

- Here the $R_t$ cut is optimised independently for each region and time resolution

- Performance degradation with poorer time resolution, <u>but</u>:
  - 15, 30 ps ≈ 30, 15 ps
  - 30, 30 ps ≈ 15, 50 ps

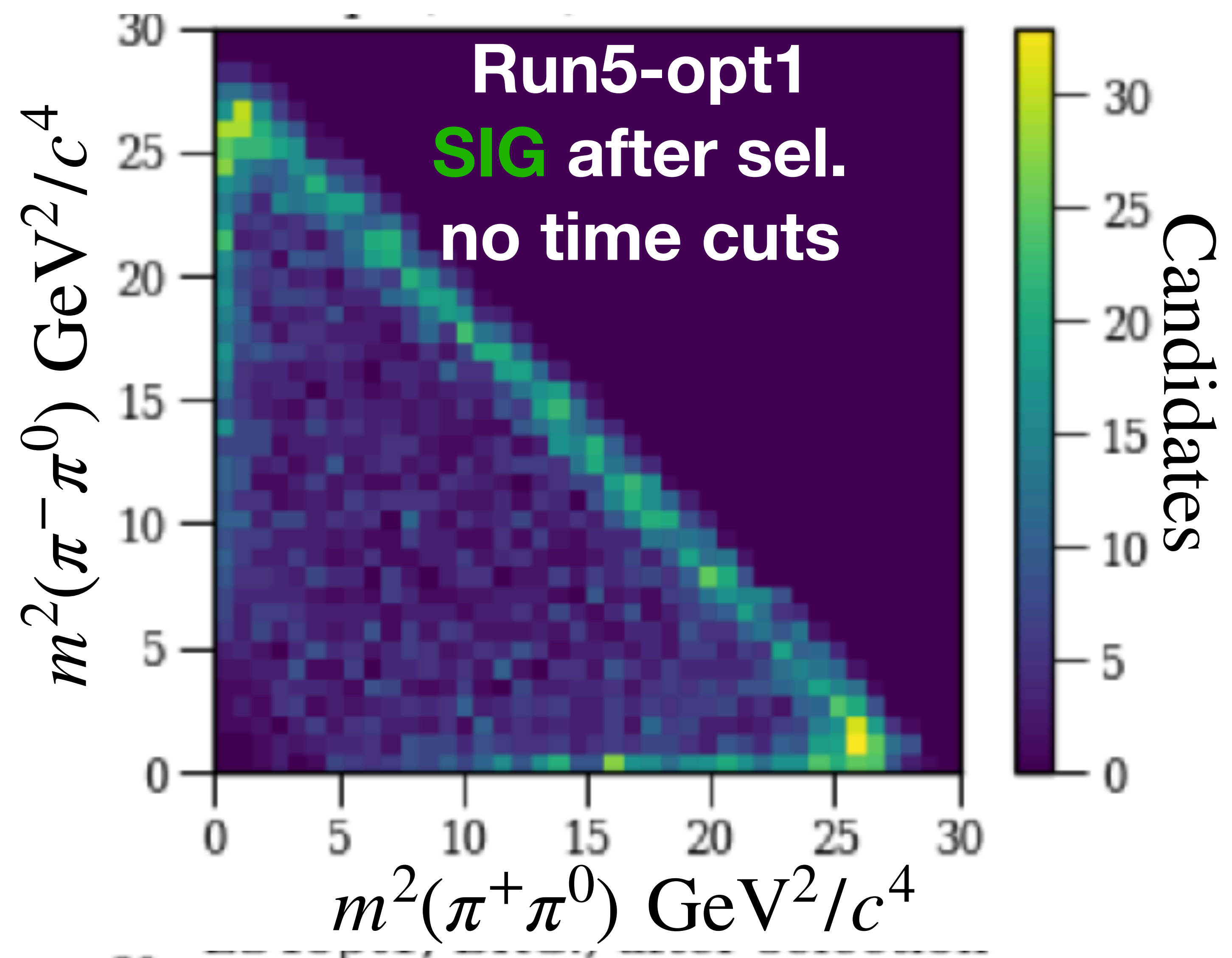
Signal candidates with final-state $\gamma$s hitting different regions are **considered**

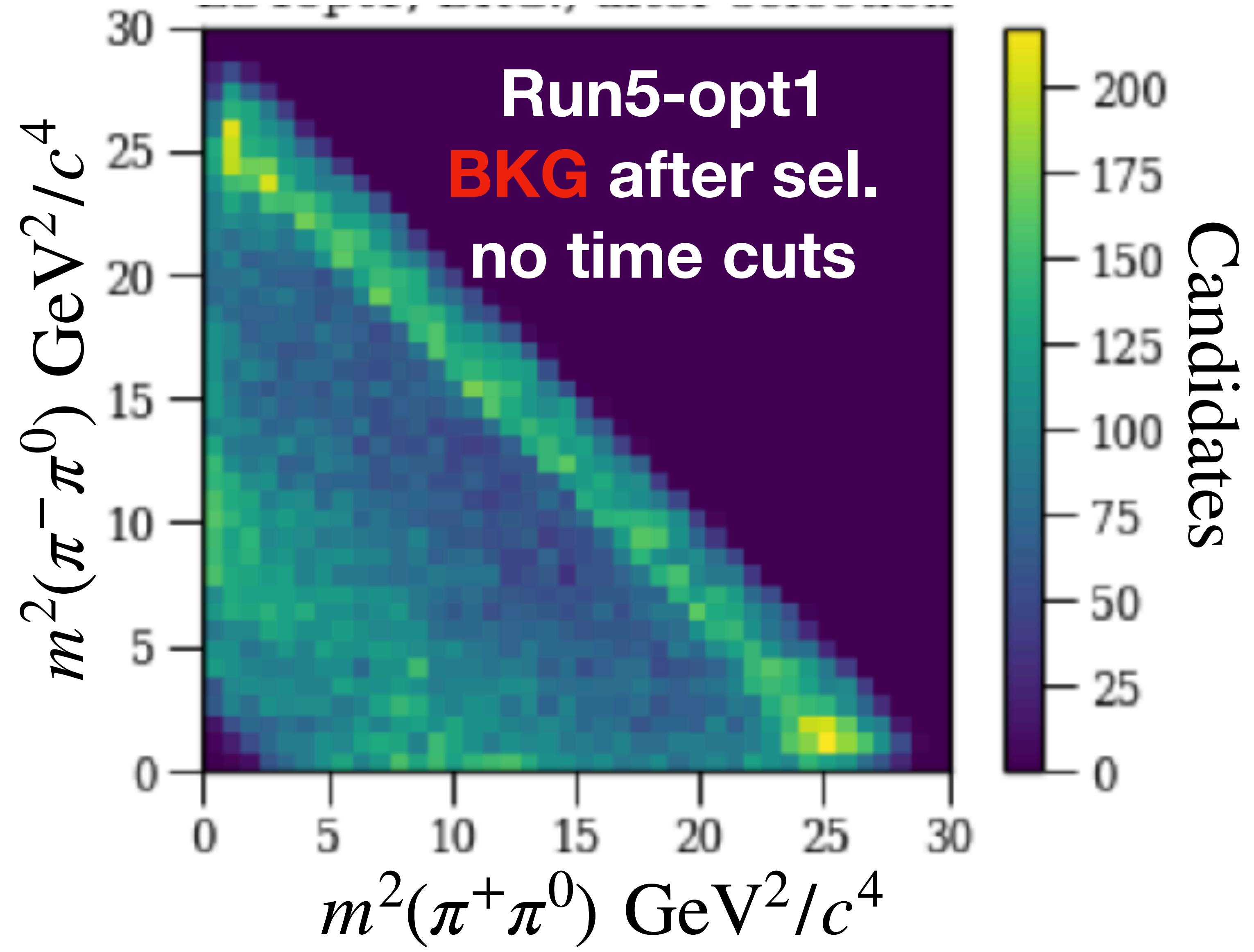
# Dalitz plot per region

- Not all the regions of the Dalitz plane are equally relevant to measure the CPV observables

- This simulation assumes a **flat squared-Dalitz model**
  - Higher SIG statistics in the more relevant regions (resonance interference)

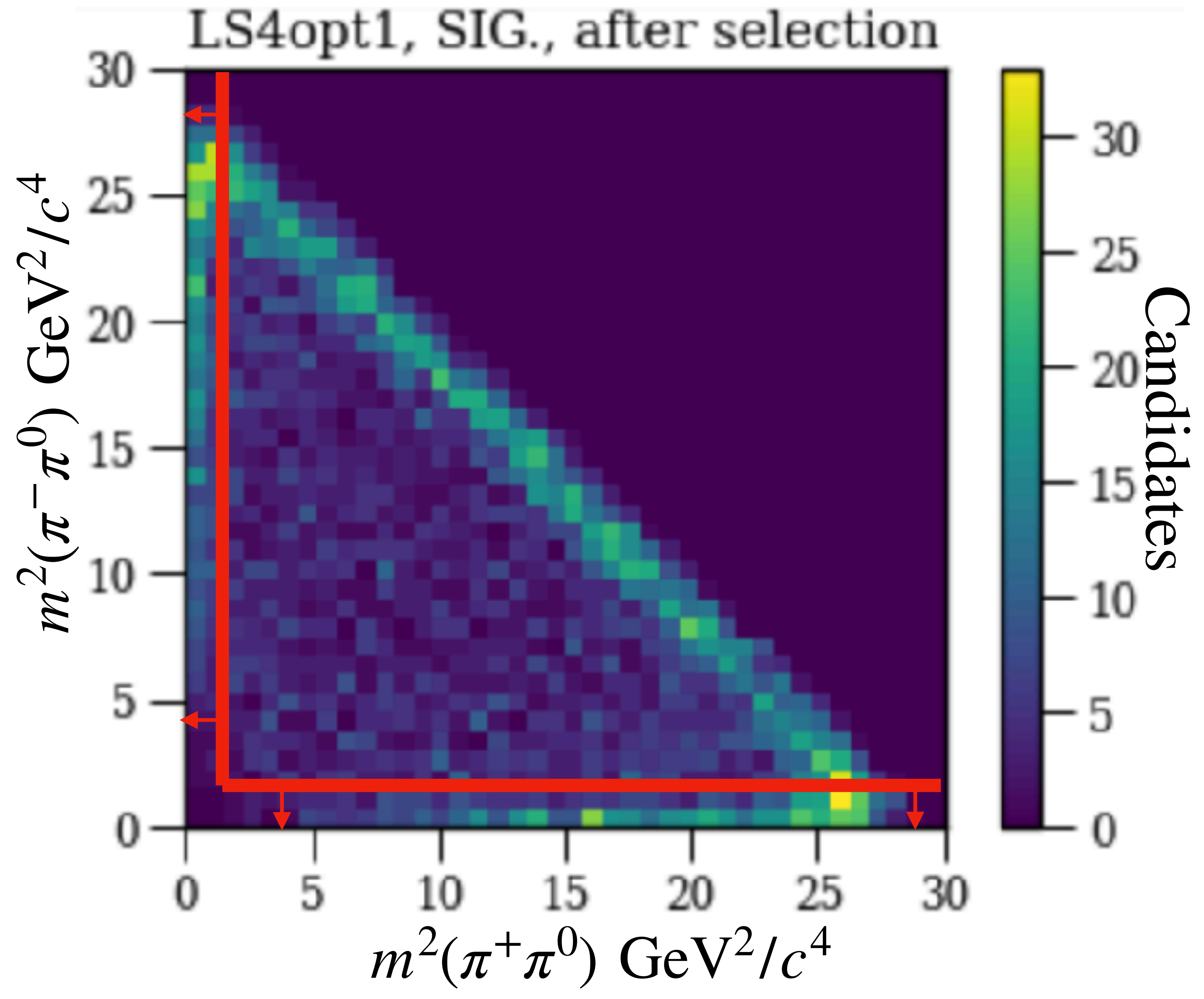
- The Dalitz distribution of the BKG could be different from SIG

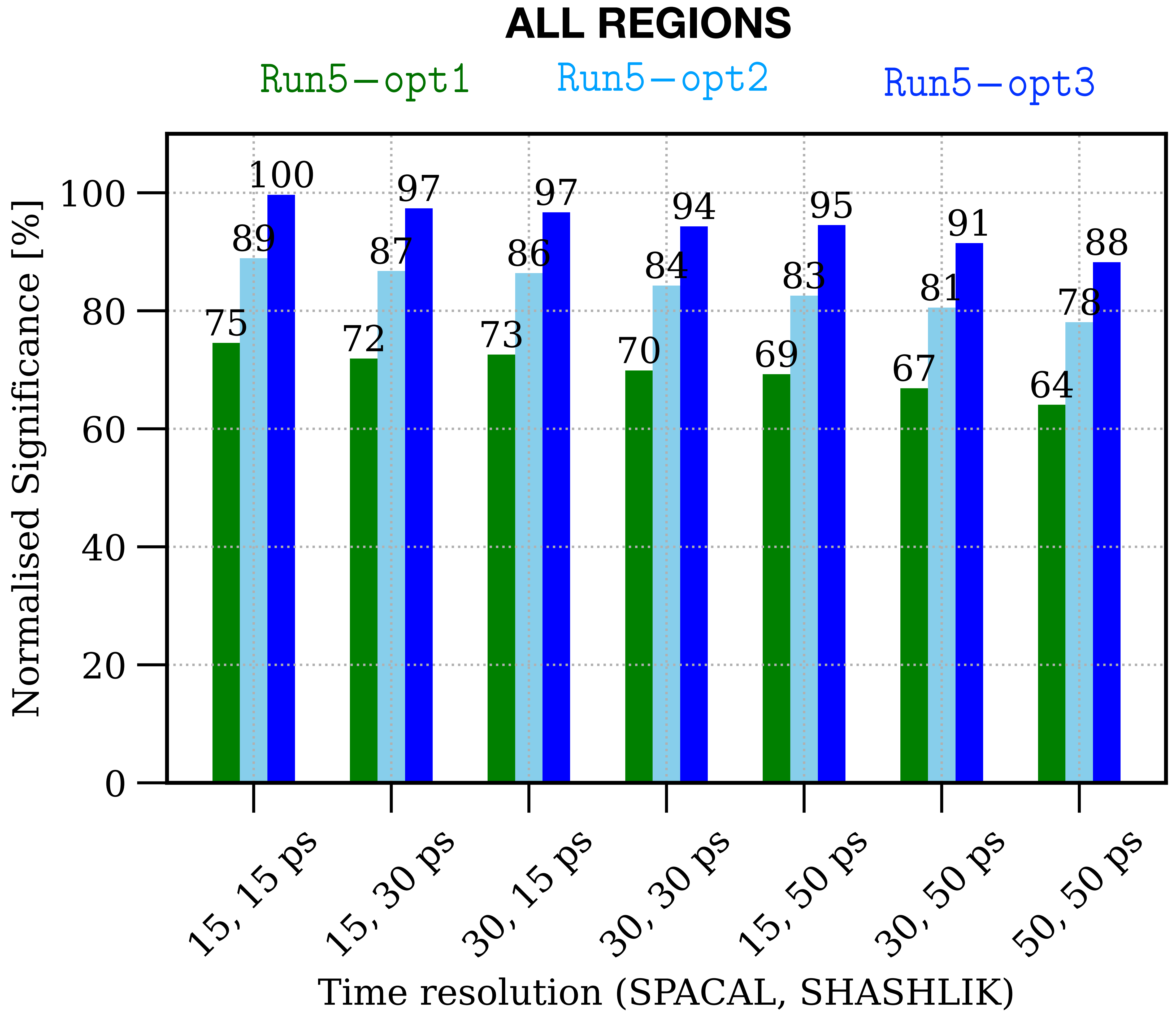


# Dalitz plot performance

- Additional requirement:
  $\min[m(\pi^+\pi^0), m(\pi^-\pi^0)] < 1.2\ \mathrm{GeV}/c^2$
  [CERN-THESIS-2013-051]




- $S/\sqrt{S+B}$ is normalised to Run2 total
- The $R_t$ cut is optimised independently for each region and time resolution

**No dramatic difference wrt the analysis considering the total Dalitz plane**

**To do:** enlarge the simulated sample to repeat this study depending on the ECAL region

# Summary and conclusions

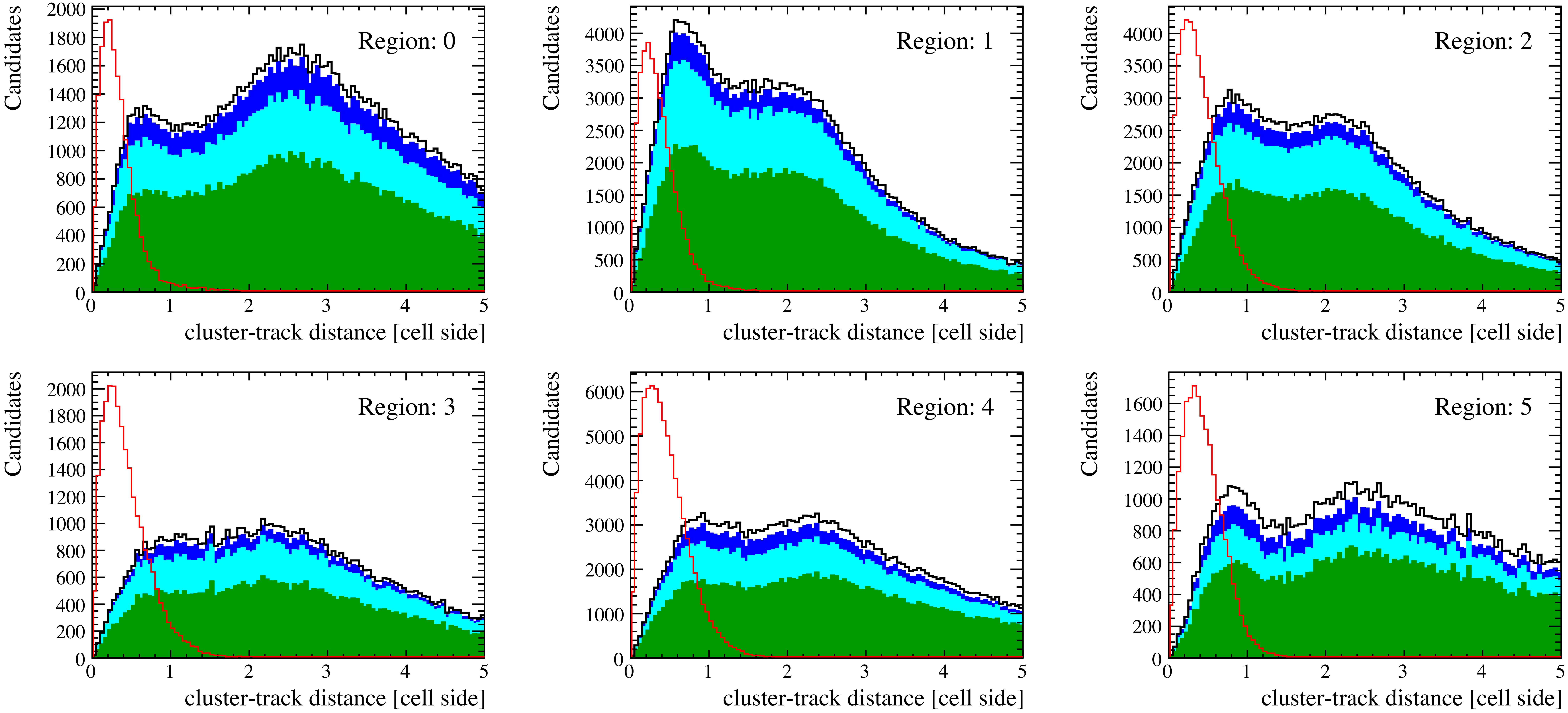
- The $B^0 \to \pi^+\pi^-\pi^0$ reconstruction performances are an important **benchmark for the U2 ECAL**

- The current simulation results suggest the critical need of R&D to **improve the ECAL reconstruction algorithms** in U2

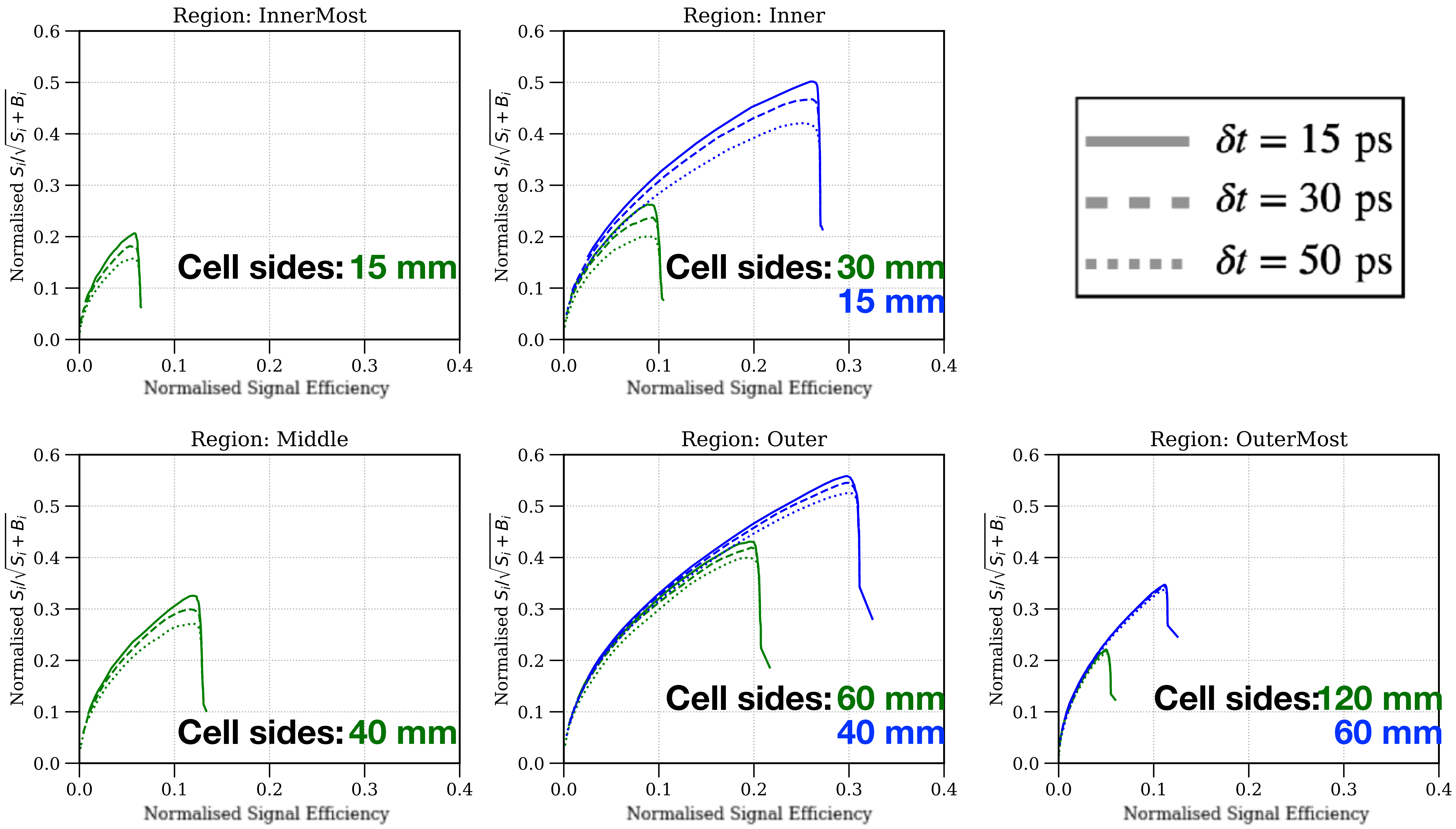
- Degradation of timing performance have not a negligible impact either in outer regions

- Analysis of Dalitz region corresponding to $\rho^{\pm}\pi^{\mp}$ final state shows similar performances to the analysis involving in the total Dalitz plane
  - Requirements on Dalitz quantities reduced quite a lot the statistics. More accurate studies with higher statistics are necessary
    - Necessary to move towards studies on more relevant observables (e.g. *CPV*)

# Backup


Candidates
Region: 0
cluster-track distance [cell side]
Candidates
Region: 1
cluster-track distance [cell side]
Candidates
Region: 2
cluster-track distance [cell side]
Candidates
Region: 3
cluster-track distance [cell side]
Candidates
Region: 4
cluster-track distance [cell side]
Candidates
Region: 5
cluster-track distance [cell side]

# Performance per region




- $Eff_i$ and $S_i/\sqrt{S_i + B_i}$ are normalised to Run2 total
- Performance benefit from granularity increase
- The inner the region, the larger the advantage from better time res.
- Performance contribution:
  - Outer > Inner
  - InnerMost ≈ OuterMost

Signal candidates with final-state $\gamma$s hitting different regions are **neglected** (~10%)

Region 0
Region 1
Region 2
Region 3
Region 4
Region 5