Study of e^+e^- final states

ECAL Upgrade II Workshop

IJCLab, Orsay
13/12/2022

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Outline

- $B^+ \to K^+e^+e^-$
- $B^0 \to K^{*0}e^+e^-$
- $Z \to e^+e^-$

F. Betti

$B^+ \to K^+e^+e^-$

- Goal: study of **bremsstrahlung** photons reconstruction in Upgrade II configuration (Front and Back sections, modules tilted, timing both in SPACAL and Shashlik)

- Determine **time resolution** for bremsstrahlung ECAL clusters → **low-energy** regime

- Study performance of **timing cuts** to suppress pile-up contamination

- Data sample obtained by merging the output of Run 3 detector + Hybrid ECAL simulation of:
    - **Signal** Particle Gun $B^+ \to K^+e^+e^-$
    - **Minimum Bias** with $\mathscr{L} = 1.5 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$

- **L, S, E** correction implemented during reconstruction (3x3 clustering)

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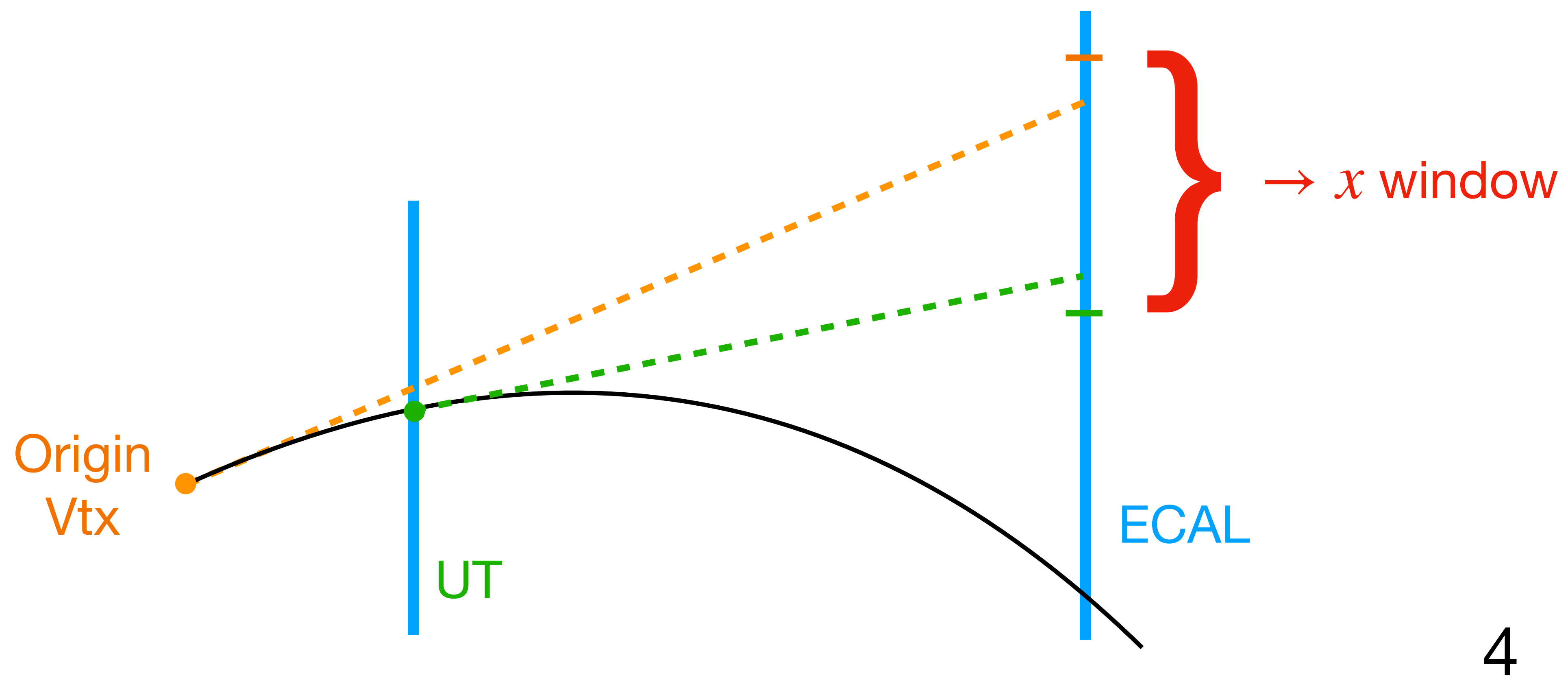
$B^+ \to K^+ e^+ e^-$ — bremsstrahlung recovery

- A simplified version of LHCb bremsstrahlung **recovery** algorithm has been implemented
- Use $\vec{p}(e^\pm)$ at $z = 7.8$ m (*i.e.* after magnet) to emulate $\vec{p}(e^\pm)$ measured by tracking
- True $\vec{p}(e^\pm)$ at production vertex and UT are used in the **extrapolation** to the ECAL surface
- Select clusters with **seed** with $E_\mathrm{T} > 50$ MeV



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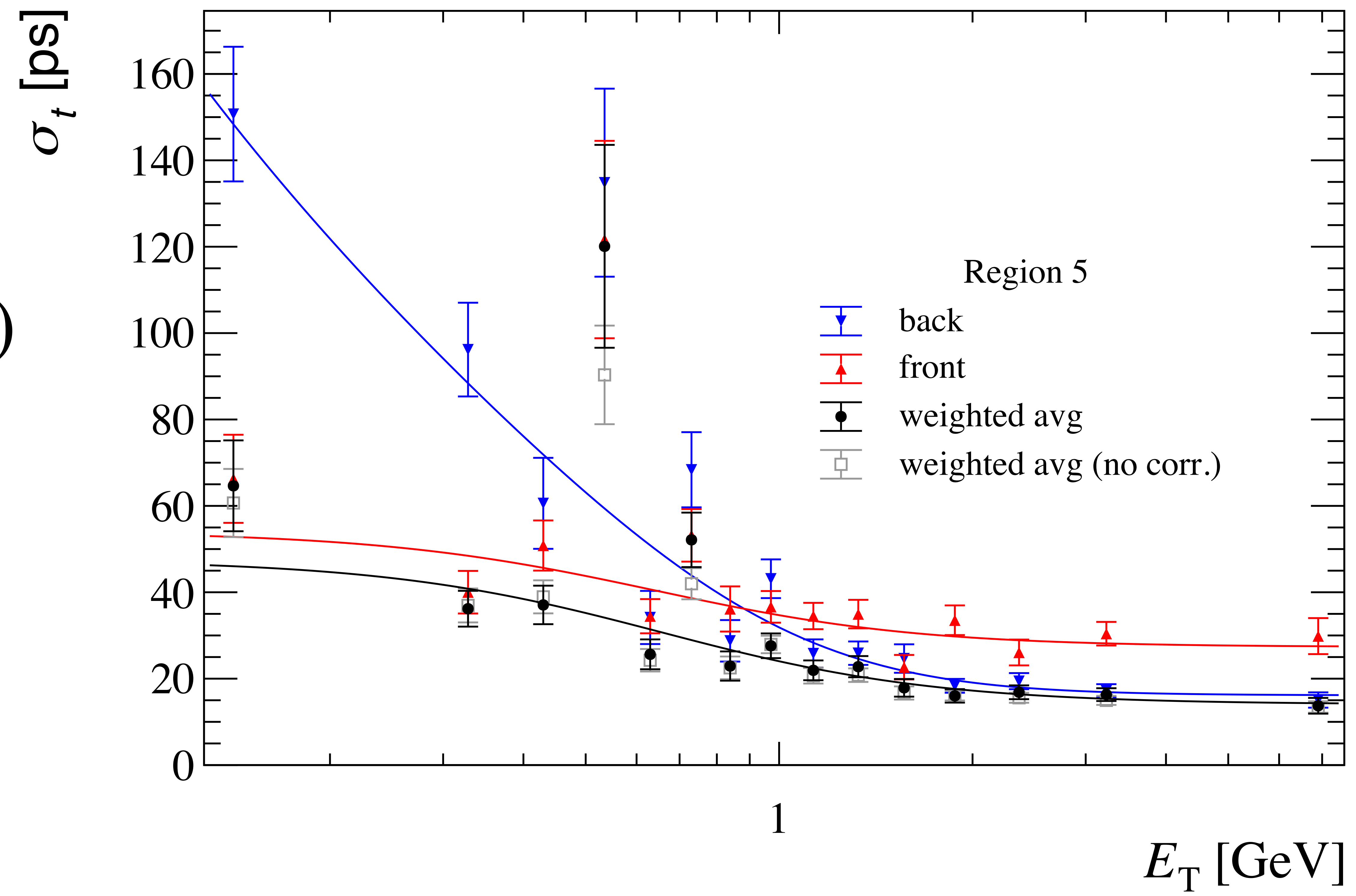
$B^+ \to K^+e^+e^-$ – time resolution and selection

- $t_{\mathrm{F(B)}}$ = cluster **seed time** of Front (Back) section
- t_{true} is the **true** arrival time of the γ
- In bins of E_{T}, fit **2D** distribution $(t_{\mathrm{F}} - t_{\mathrm{true}}, t_{\mathrm{B}} - t_{\mathrm{true}})$ with a bivariate gaussian → takes into account correlation between Front and Back ⇒ obtain combined t_{FB} and combined resolution
- Extrapolate from the $e^{\pm}$ production vertex time t_{vtx} (with and without $20\ \mathrm{ps}$ smearing) to get **expected** arrival time t_{exp} to ECAL
- Apply a **selection** on $\Delta t = t_{\mathrm{FB}} - t_{\mathrm{exp}}$



$B^+ \to K^+e^+e^-$ — B^+ mass

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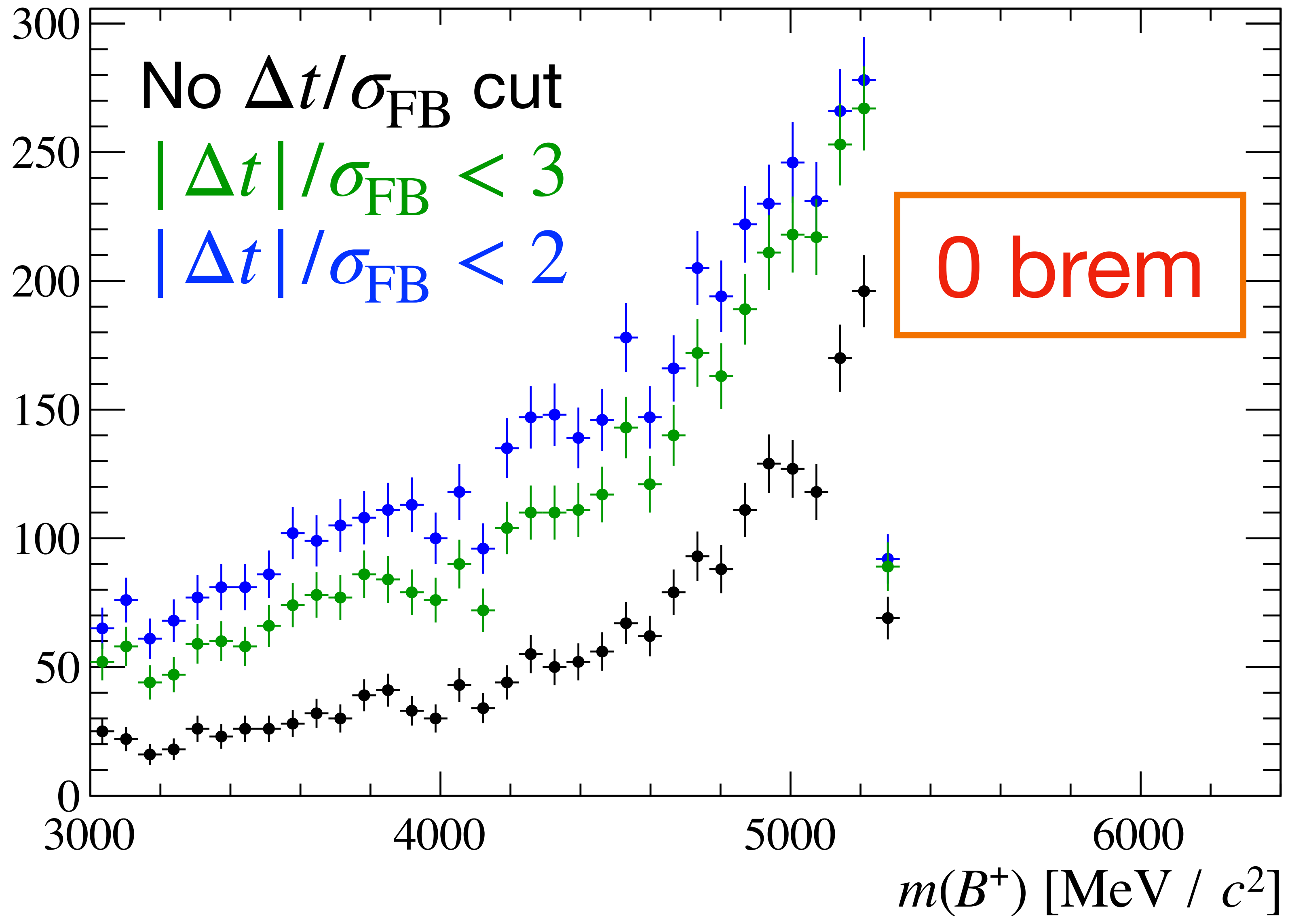
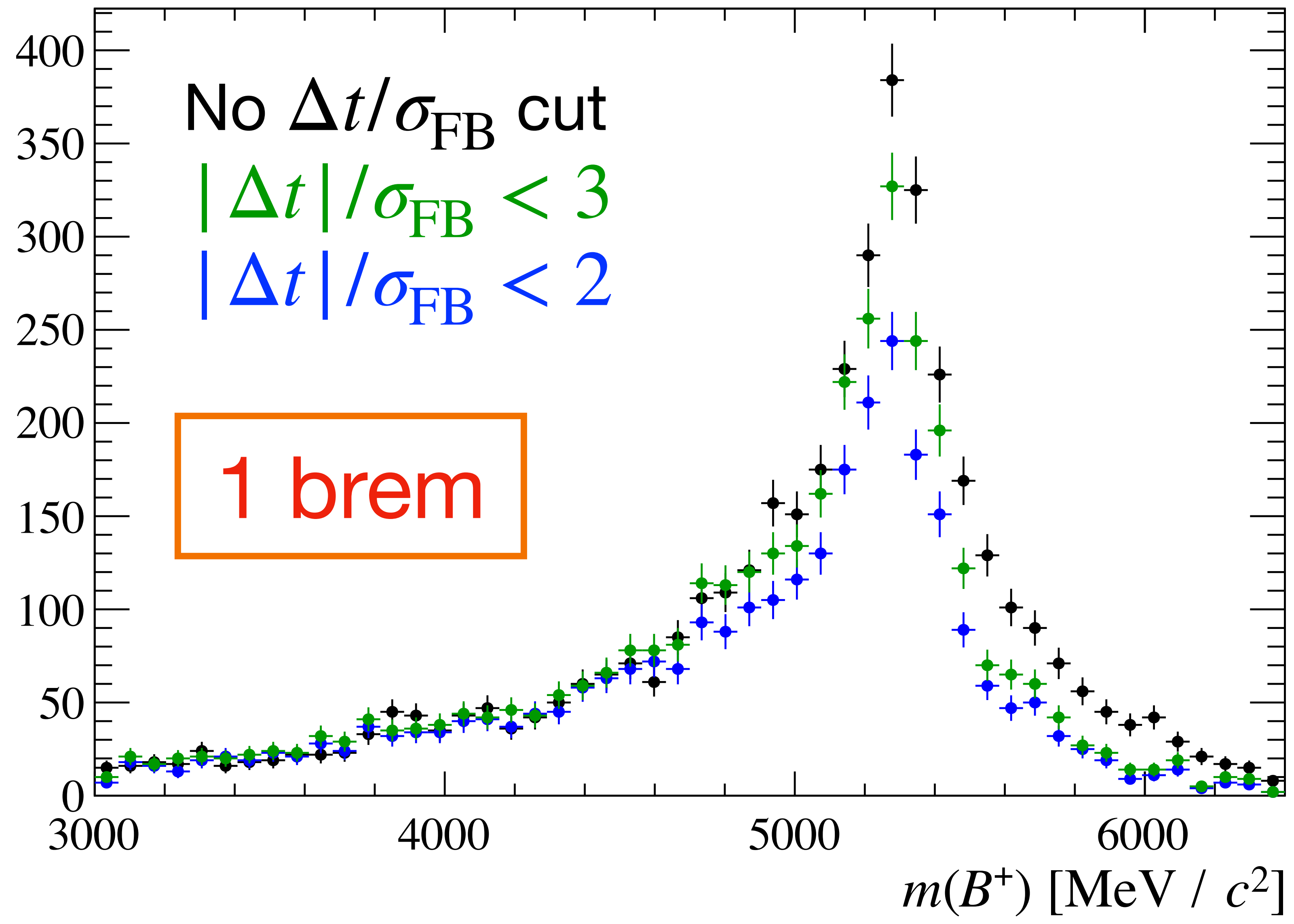
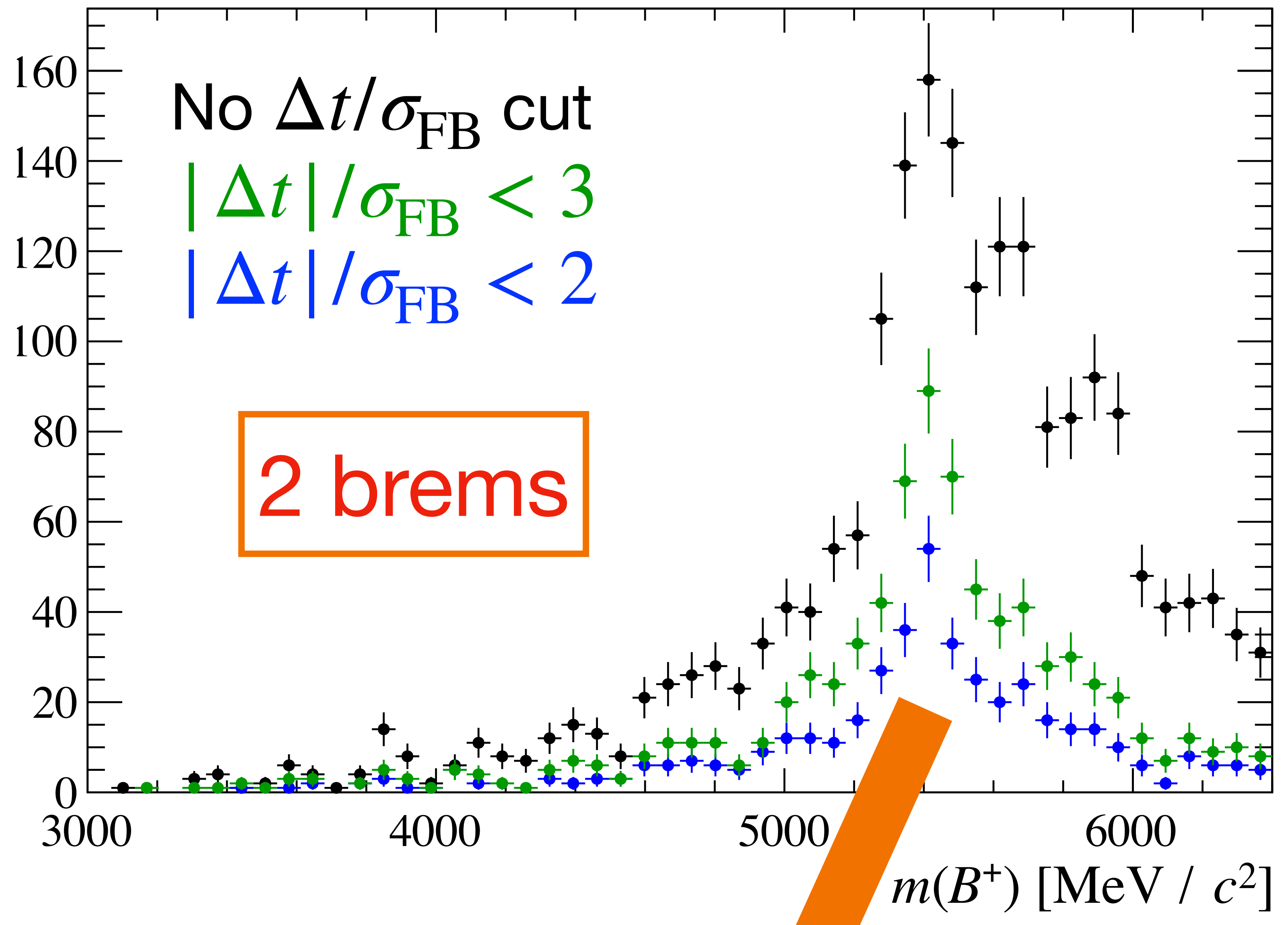
N brems	Ratio wrt total
0	25%
1	47%
2	25%

0.5% **smearing** is applied to true momenta of the $K^+e^+e^-$

No t_{vtx} smearing







High-mass tail, mainly due to pile-up, is significantly suppressed

$B^+ \to K^+e^+e^-$ — B^+ mass

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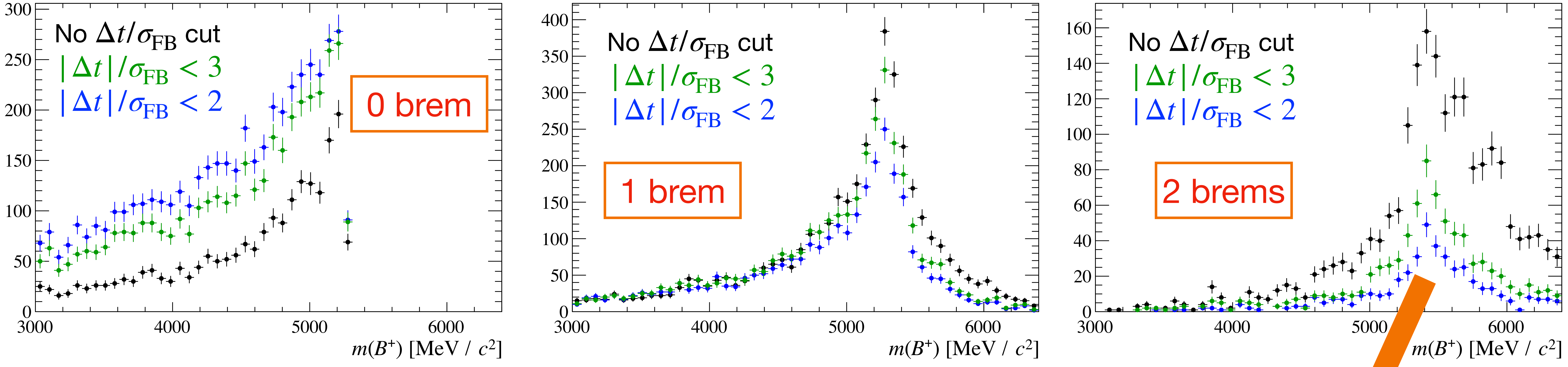
t_{vtx} smearing = 20 ps



20 ps t_{vtx} smearing has a very small effect

High-mass tail, mainly due to pile-up, is significantly suppressed

$B^+ \to K^+ e^+ e^-$ — future steps

- Use simulation framework developed by VELO team to include **luminosity decay** and vertex time resolution (see talk by Laurent)
- Implement bremsstrahlung recovery algorithm introduced in **Run 3** (see talk by Carla)
- Study the potential of directly implementing **time** information in bremsstrahlung recovery
- Study the $e - \pi$ **discriminating** power using E/p

Daniele Manuzzi
Stefano Perazzini

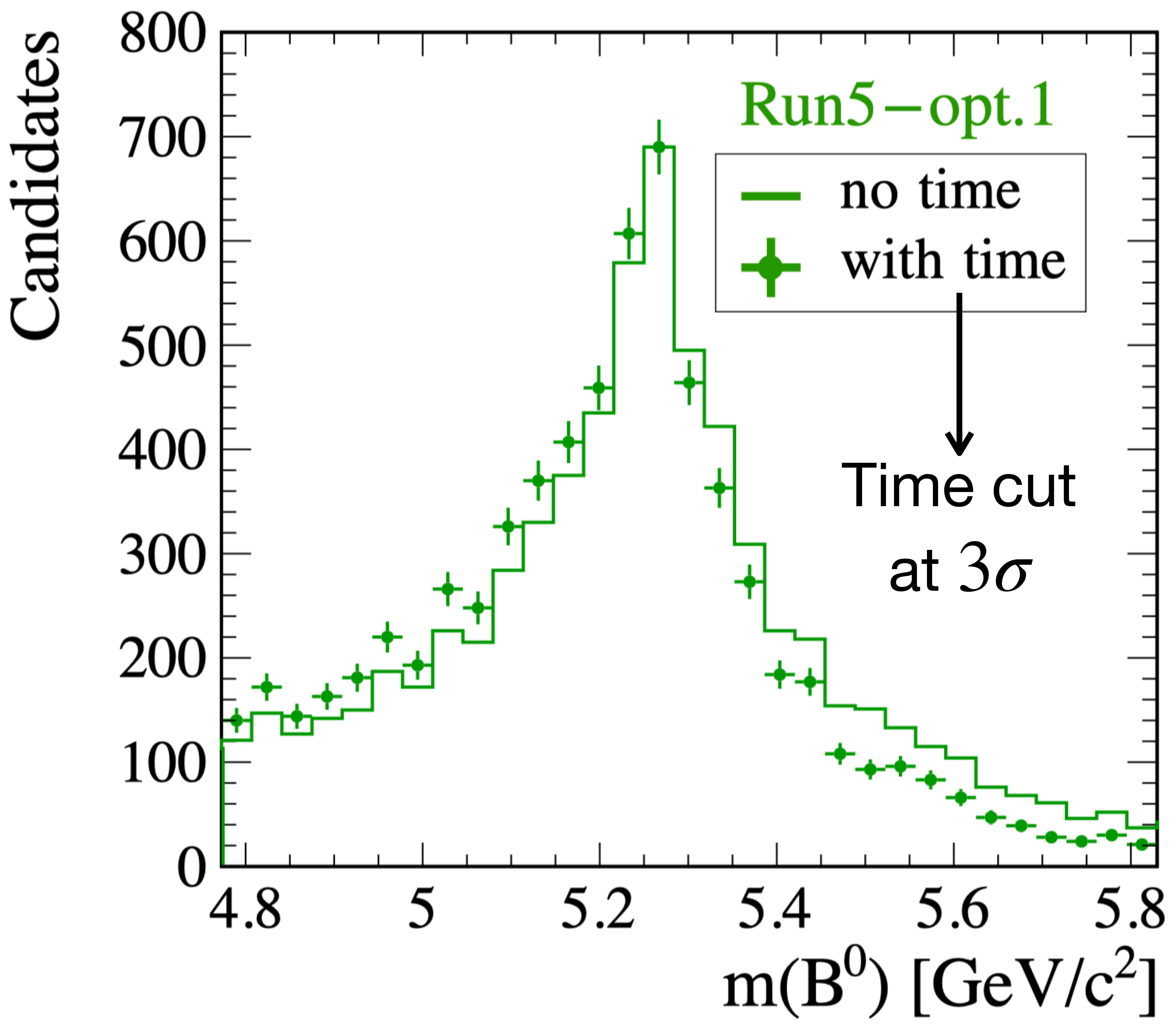
$B^0 \to K^{*0} e^+ e^-$

- Goal: study of timing effect in **bremsstrahlung** photons reconstruction and E/p for $e - \pi$ discrimination ($B^0 \to K^{*0} \pi^+ \pi^-$)
- Different framework: **homogeneous** Geant4 simulation (see talk by Daniele)
- **Pile-up**: $\mathscr{L} = 1.5 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$ peak luminosity + luminosity decay
- **Time resolution** implemented through smearing

Daniele Manuzzi
Stefano Perazzini

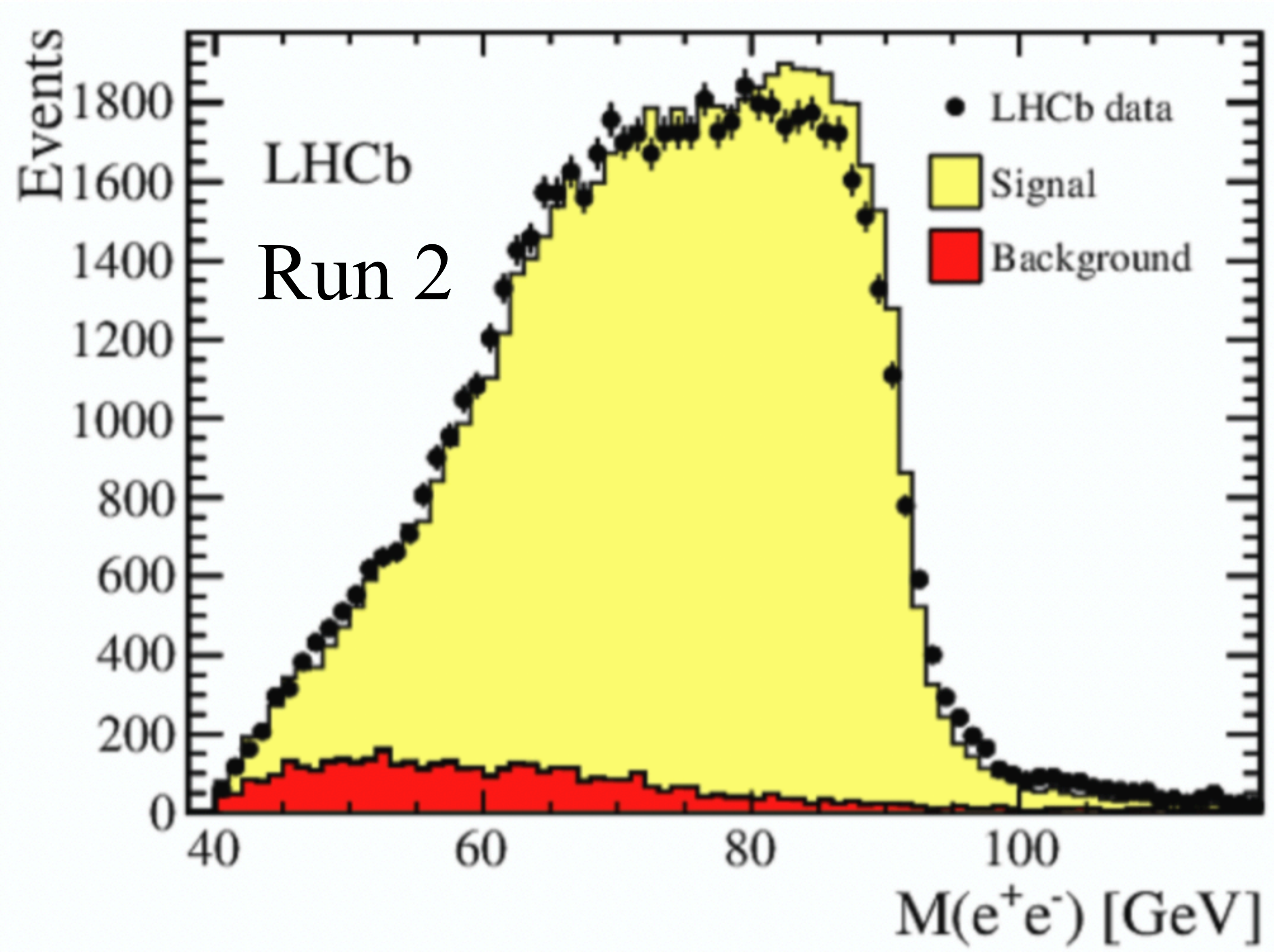
$B^0 \to K^{*0} e^+ e^-$

- Timing cut has **small effect** (significantly smaller than in $B^+ \to K^+ e^+ e^-$ study)
- $B^+ \to K^+ e^+ e^-$ study shows **larger** distribution $\Rightarrow$ to be **understood better**



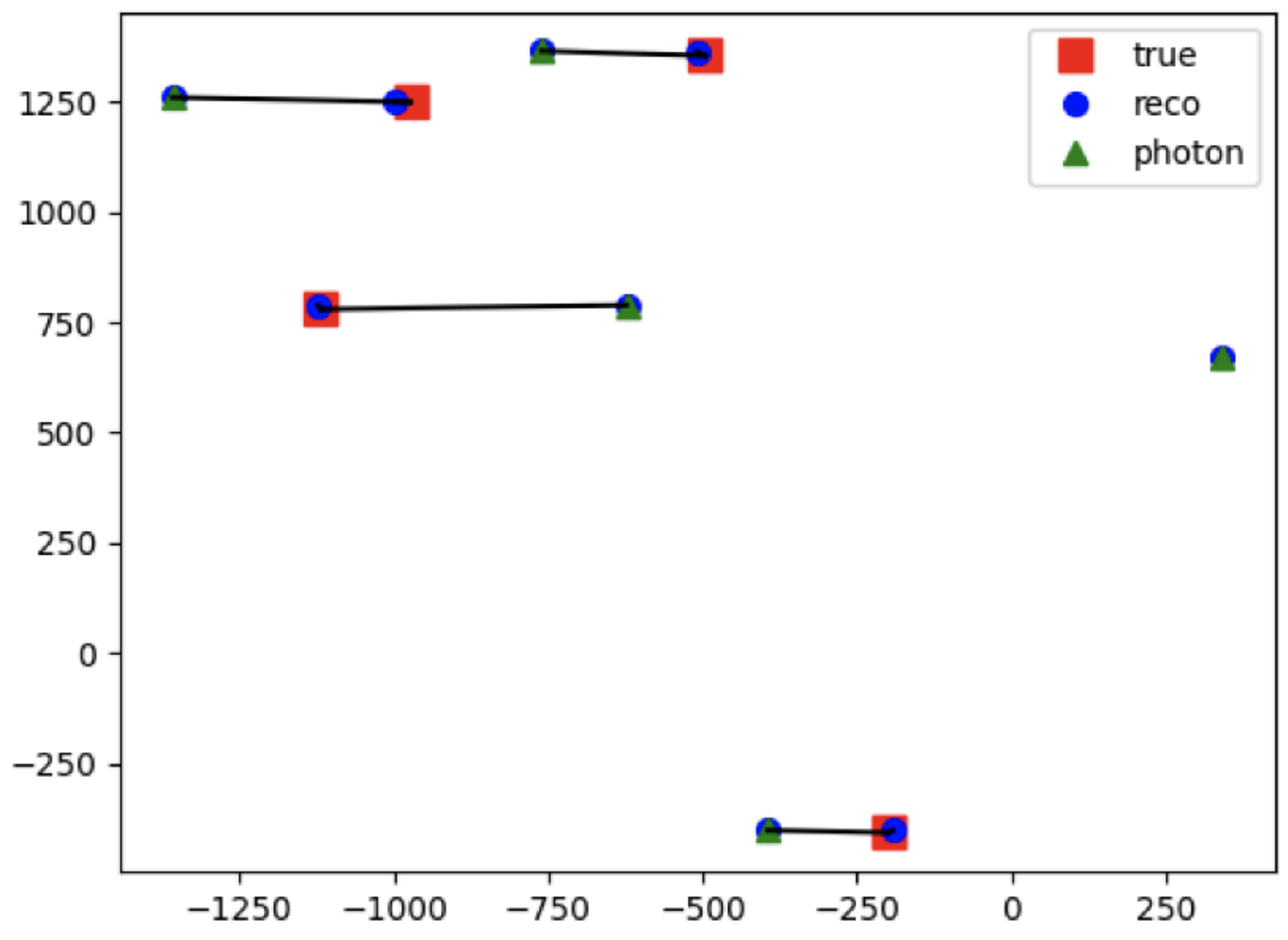
$Z \to e^+e^-$

- Goal: study and improve reconstruction of electrons with **very high energies** in Upgrade II configuration (Front and Back sections, modules tilted)
- For the FTDR, a study was already performed by using the homogeneous simulation
- Data sample: 10^5 **Particle Gun** electrons with $1\ \mathrm{GeV} < E < 100\ \mathrm{GeV}$ through Run 3 detector + Hybrid MC
- L, S, E correction not implemented yet during reconstruction (3x3 clustering)

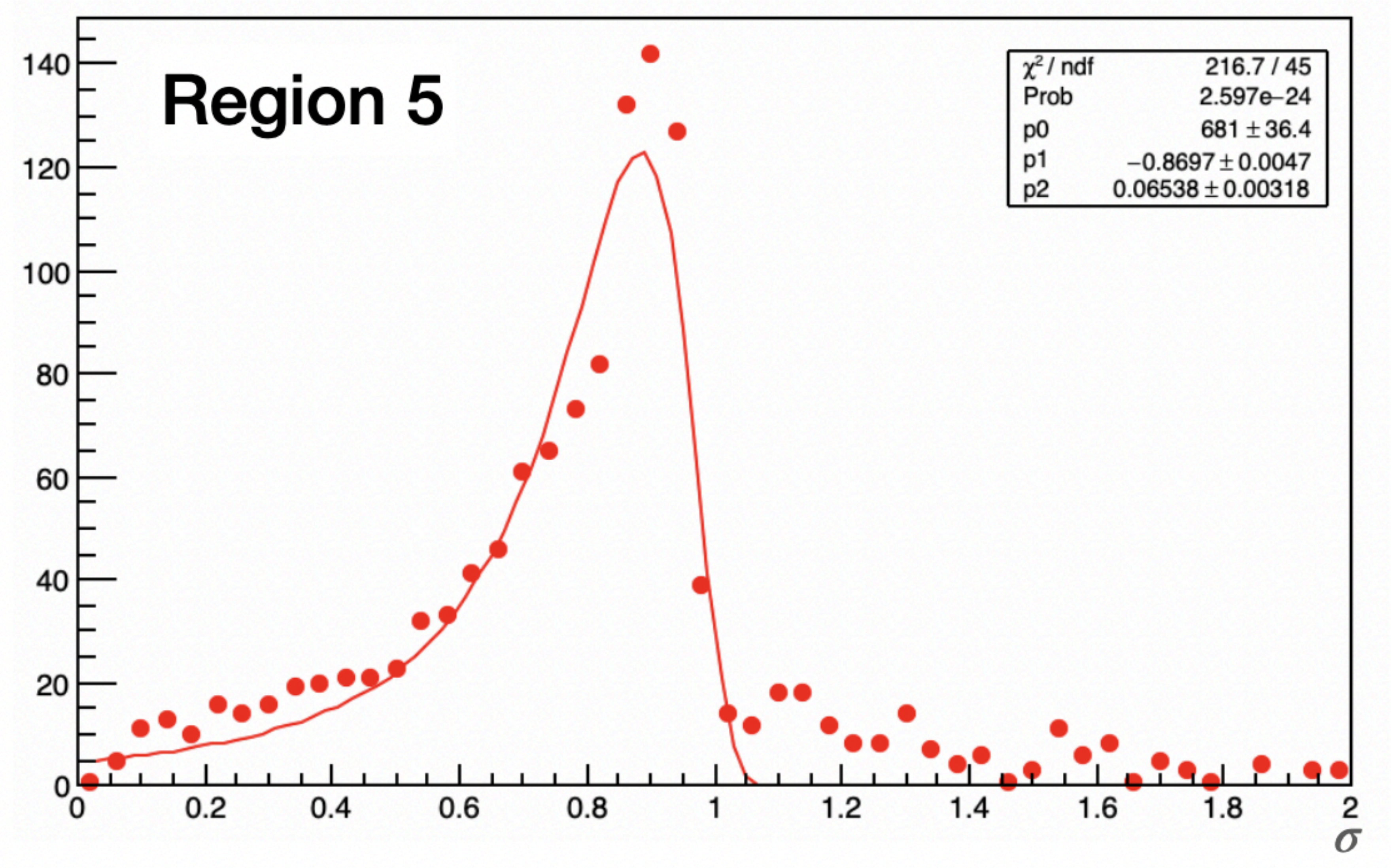


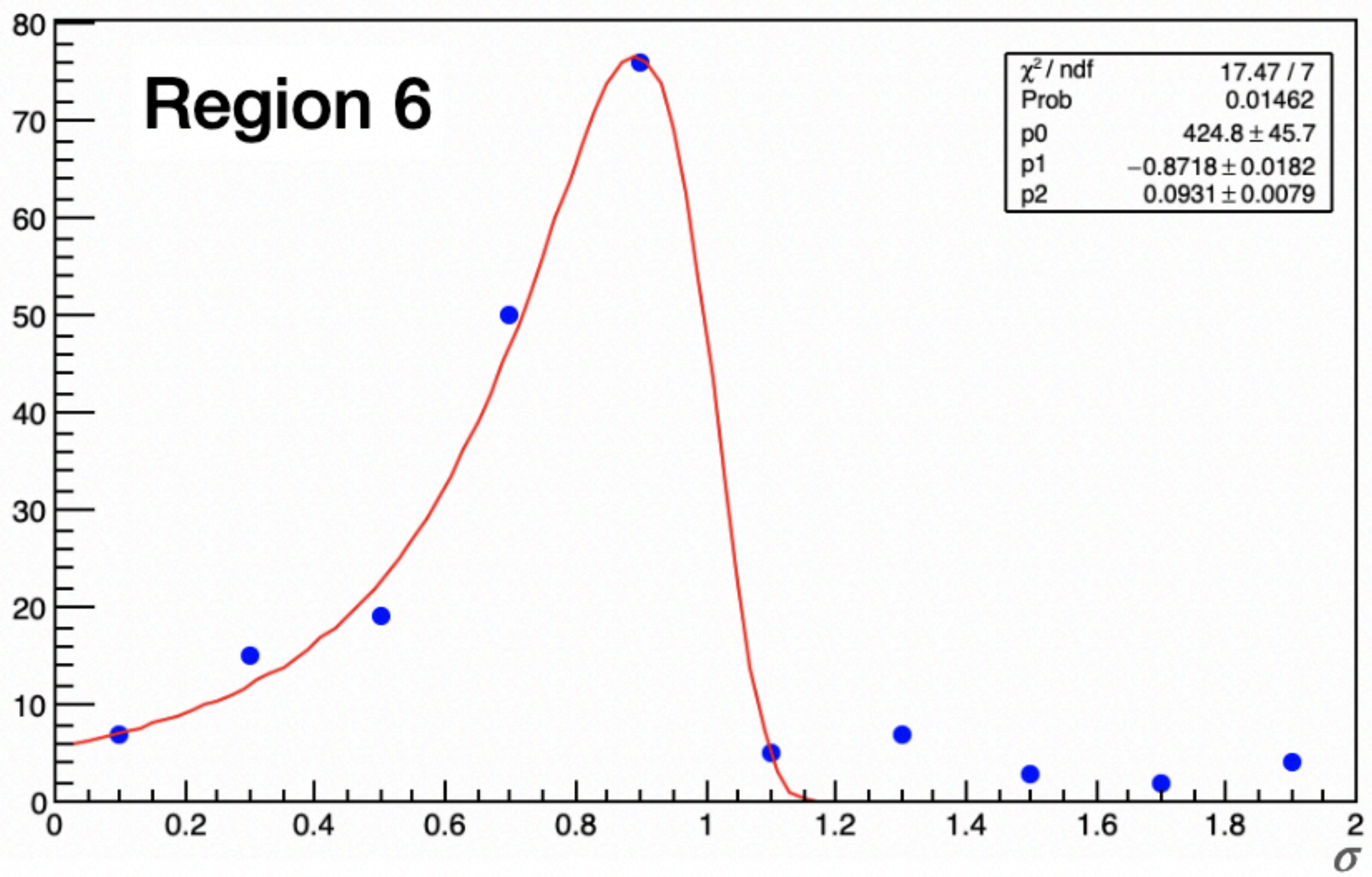
Davide Zuliani

$Z \rightarrow e^{+}e^{-}$ — Electron reconstruction



- Dedicated procedure to **match** clusters to true electrons (linear sum assignment problem)
- **Bremsstrahlung** photons are recovered
- This method can be used also for **other physics processes**





$$\sigma = \frac{E_{reco} - E_{true}}{E_{true}}$$

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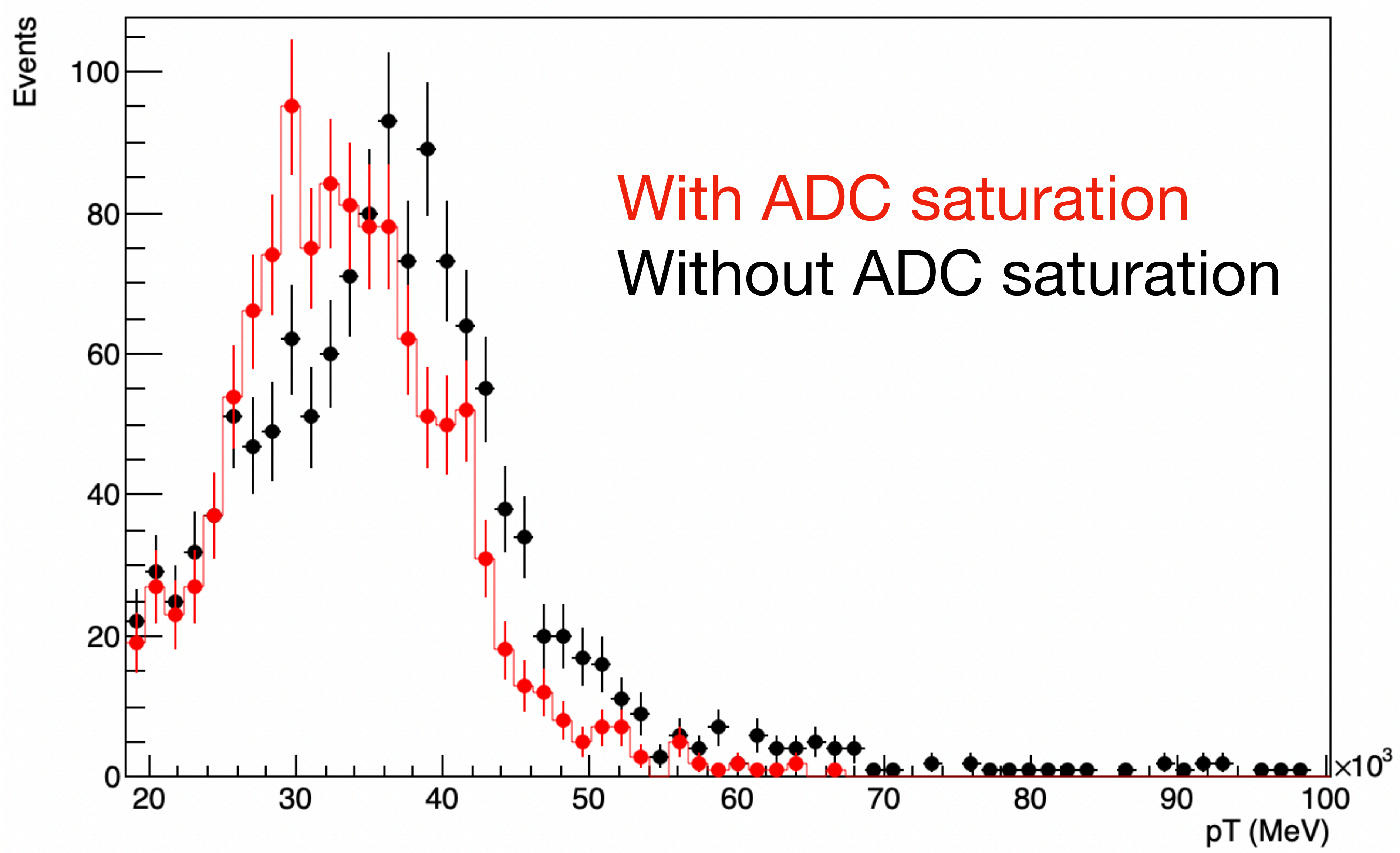
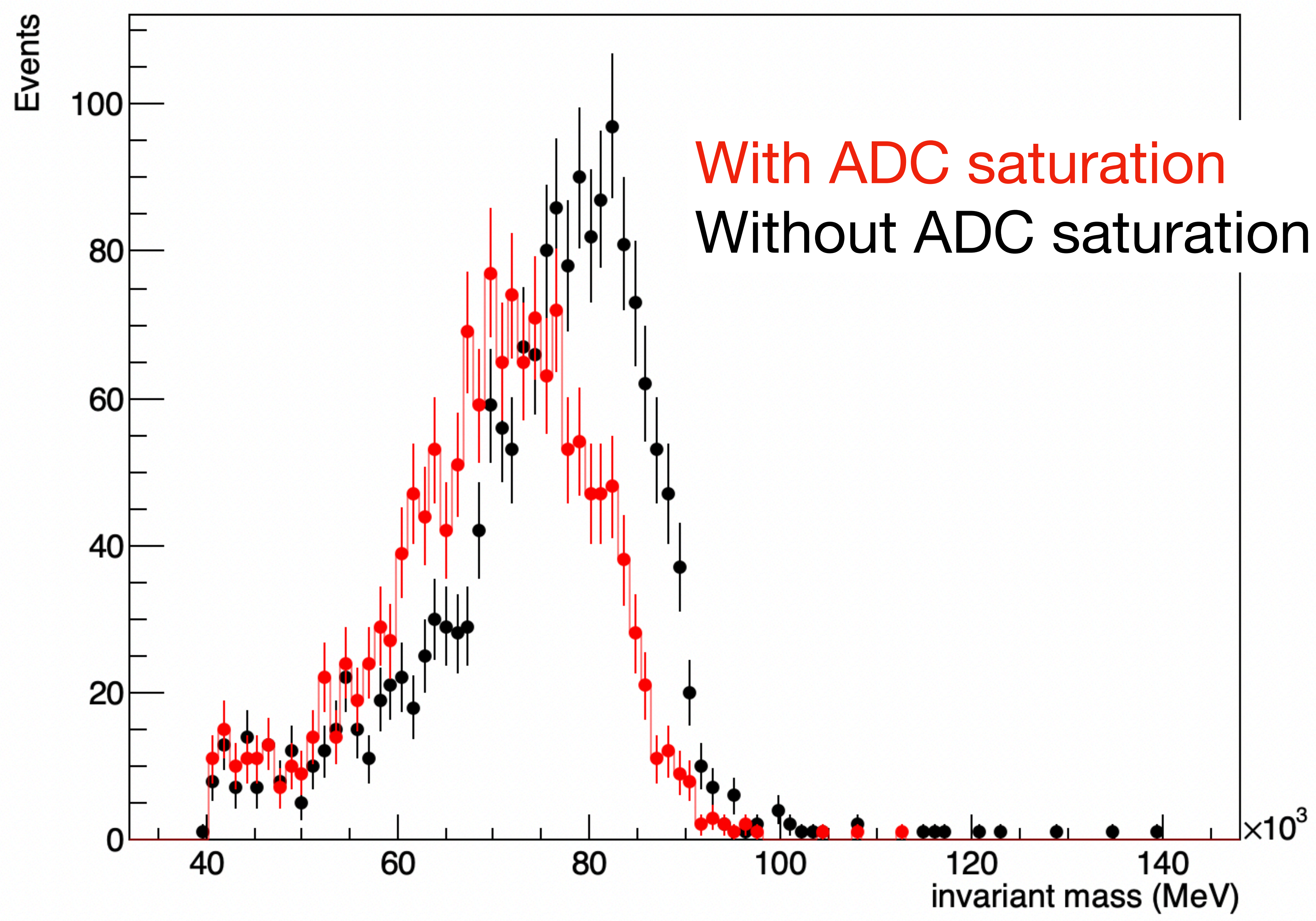
$Z \to e^+e^-$ — ADC saturation



- ADC **saturation** relevant for high p_T electrons
- $E_{T,max} = (20 + 14 \sin\theta)$ GeV
- Effect studied using sample obtained by merging the output of Run 3 detector + Hybrid ECAL simulation of:
  - Signal **Particle Gun** $Z \to e^+e^-$
  - **Minimum Bias** with $\mathscr{L} = 1.5 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$



$Z \to e^+e^-$ — future steps

- Fit **energy resolution** on Particle Gun electrons as a function of the energy
- Improve **association** between bremsstrahlung photon and related cluster
- Implement **L, S, E** correction
- Use the results from Particle Gun electrons studies to improve reconstruction of $Z \to e^+e^-$

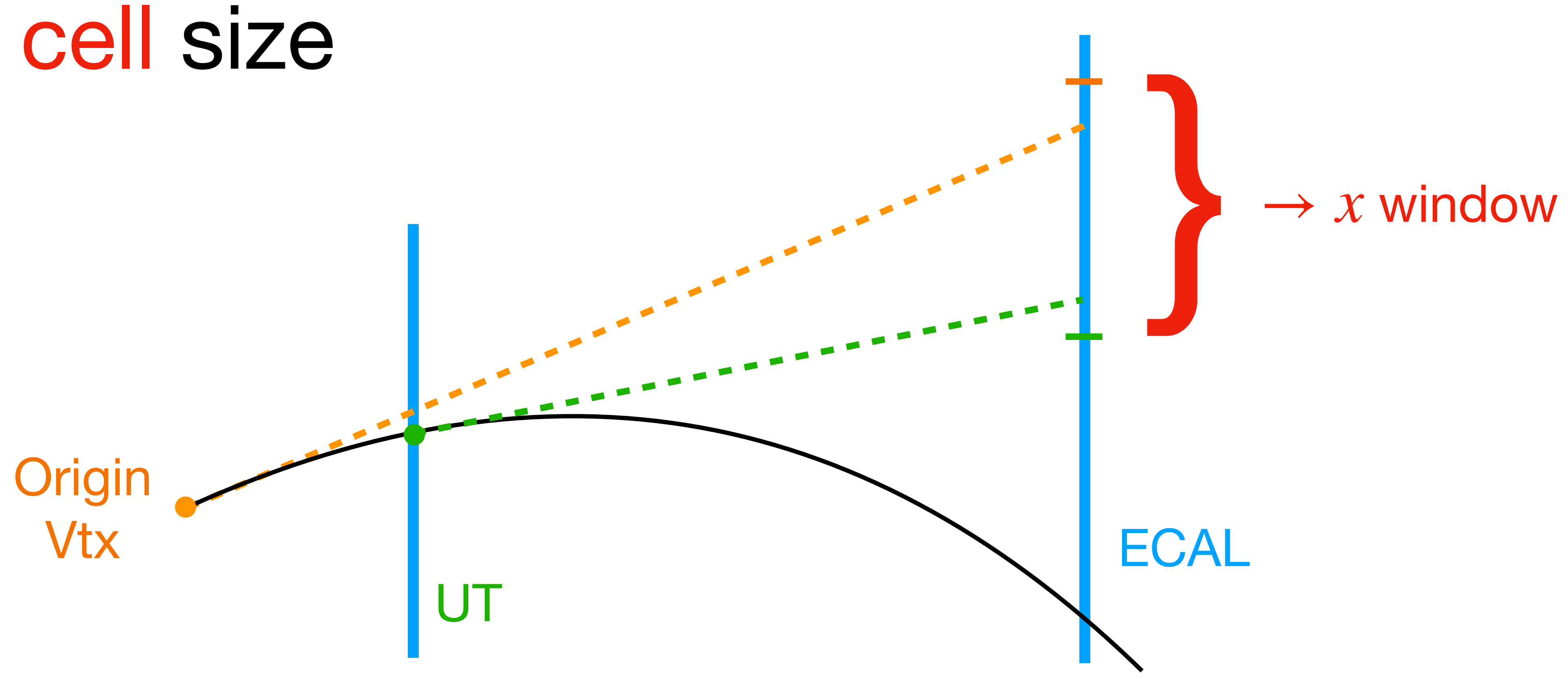
Conclusions

- Lot of activity ongoing in the study of decay modes involving e^+e^- pairs, in both high- and low-energy regime
- Different simulation frameworks are used and compared
- More work needed to understand if timing cuts can help in suppressing pile-up in bremsstrahlung recovery
- Framework ready for $Z \to e^+e^-$, expected lot of progress in the next months

Backup

Extrapolation from UT

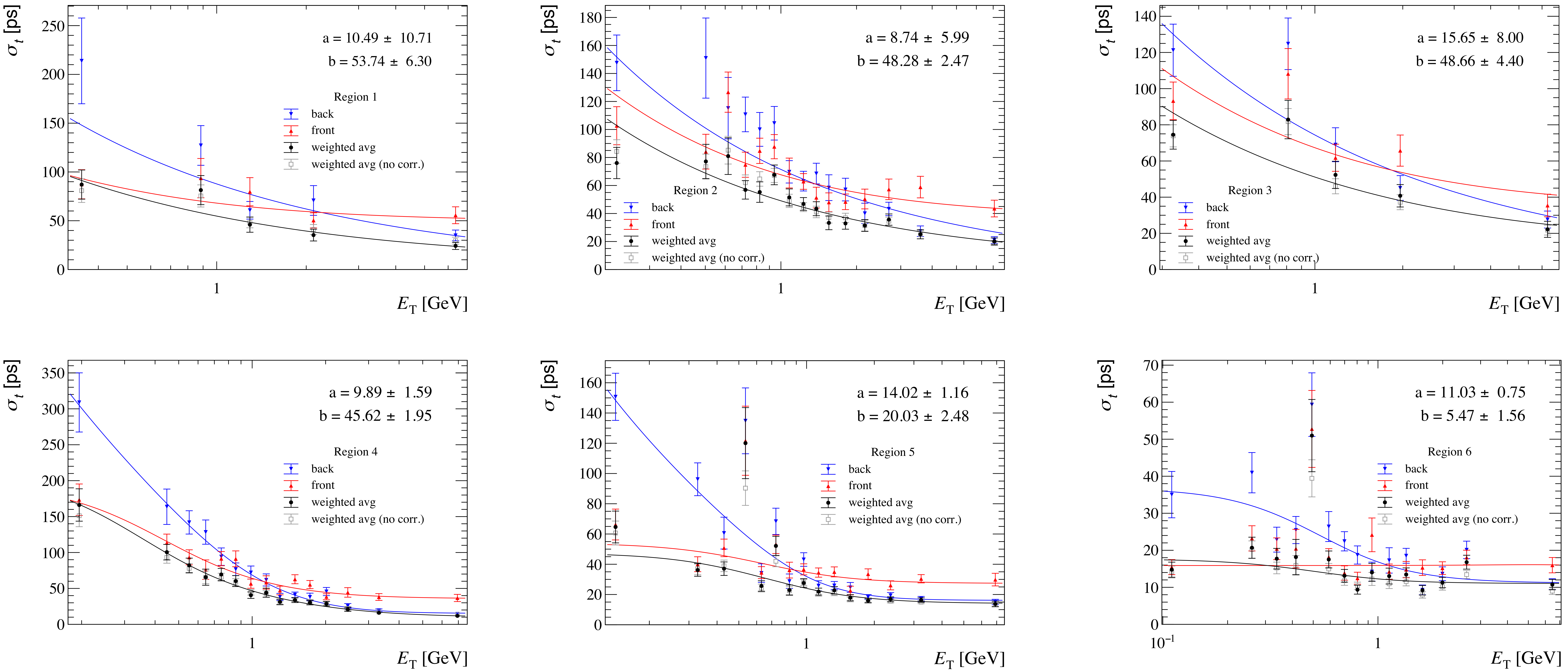
- Until now, I was looking for clusters in a 1x1 cells window around the direction of electron extrapolated from its origin vertex
- The Run1-3 algorithm actually looks in a window obtained from two extrapolated electron directions: one from origin vertex, the other from the UT ($z = 2660$ mm)
- The actual algorithm takes into account:
  - The uncertainty on x, y of the starting point → neglected here ($\mathcal{O}(10)$ μm)
  - The uncertainty on the track slope → neglected here
  - The *spread* of the cluster → assumed to be 0.5 x cell size



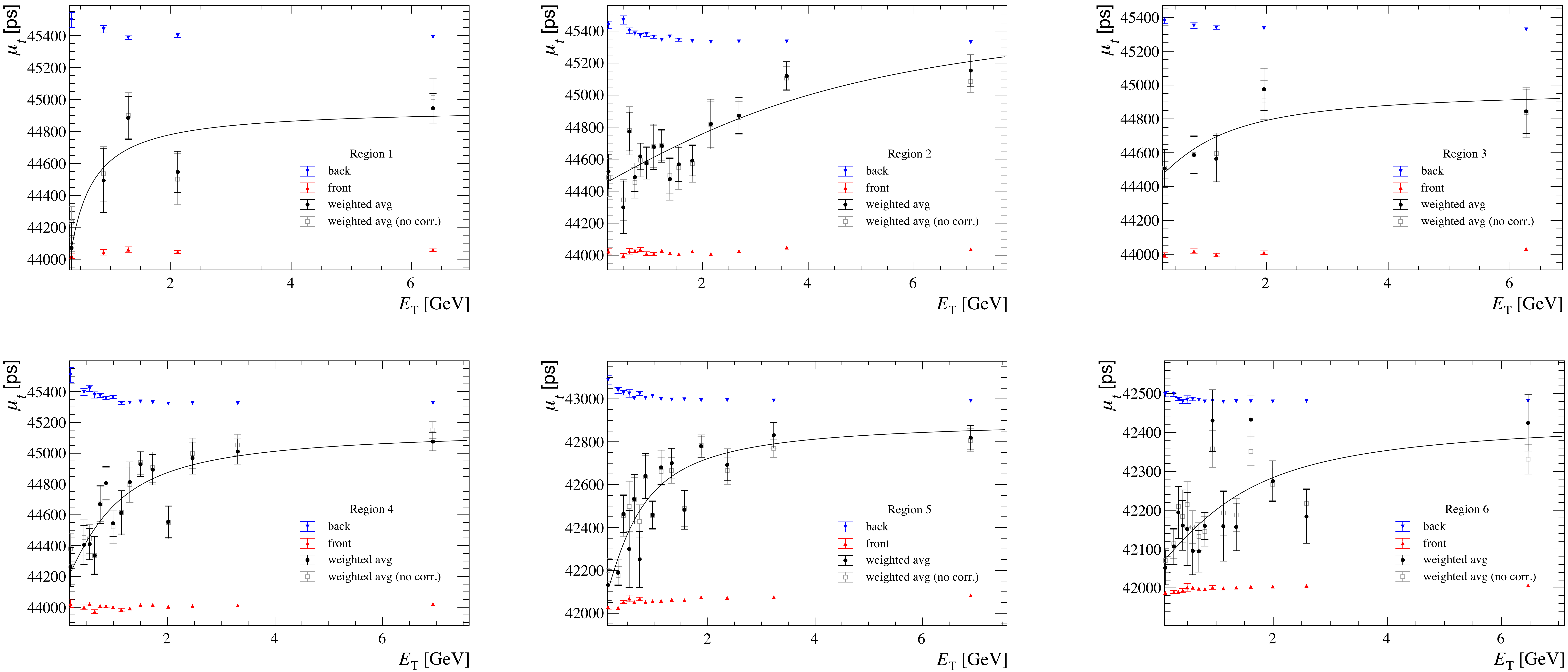
Timing cut

- For each event of **signal+MB** sample, combine reconstructed t_B and t_F using $t_{FB} = \dfrac{(\sigma_B^2 - \rho\sigma_F\sigma_B)t_F - (\sigma_F^2 - \rho\sigma_F\sigma_B)t_B}{\sigma_F^2 + \sigma_B^2 - 2\rho\sigma_F\sigma_B}$ which $\sigma_{B,F}$ and ρ obtained in previous step
- Apply cut on $\dfrac{t_{FB} - t_{expected} - \mu_{FB}}{\sigma_{FB}}$, where $t_{expected}$ is obtained **propagating** the true time of B decay (**no smearing** applied yet)

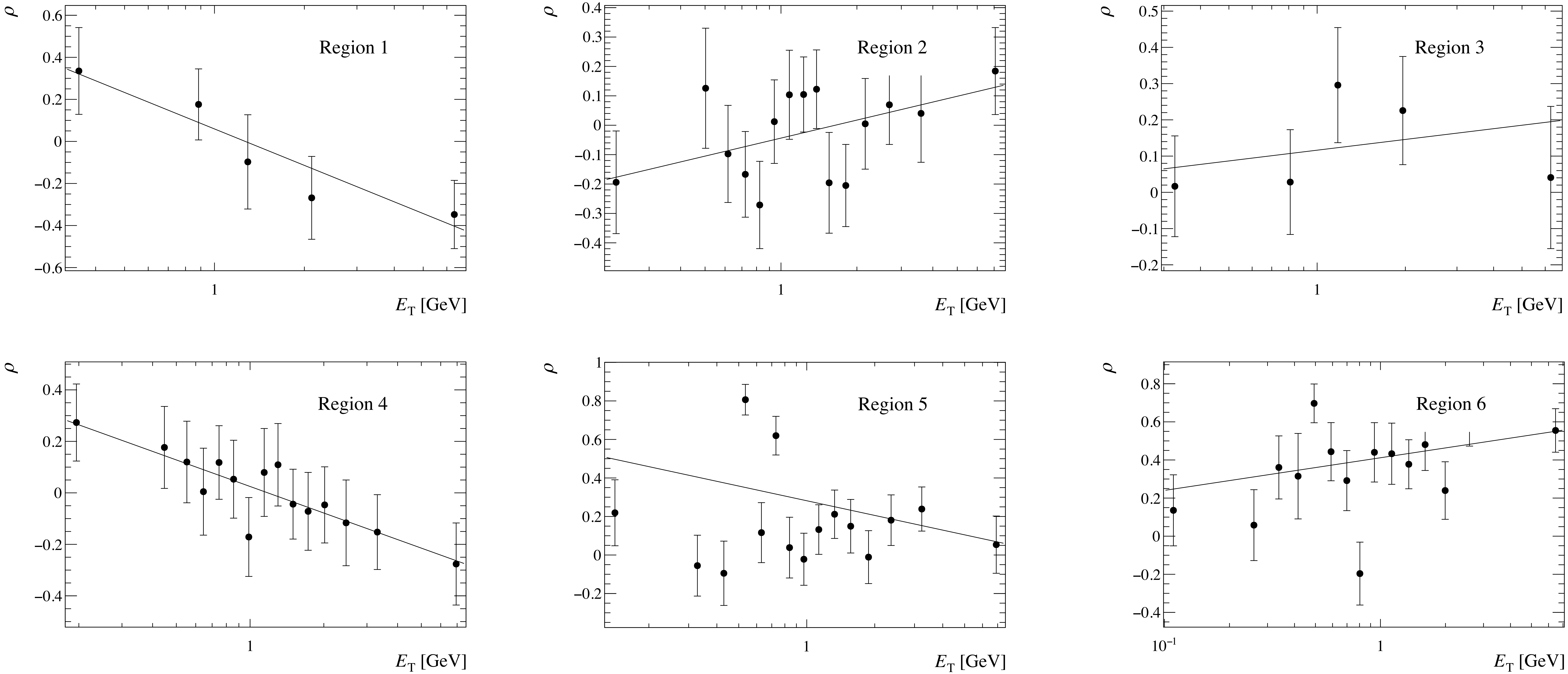
Time resolution



Time resolution



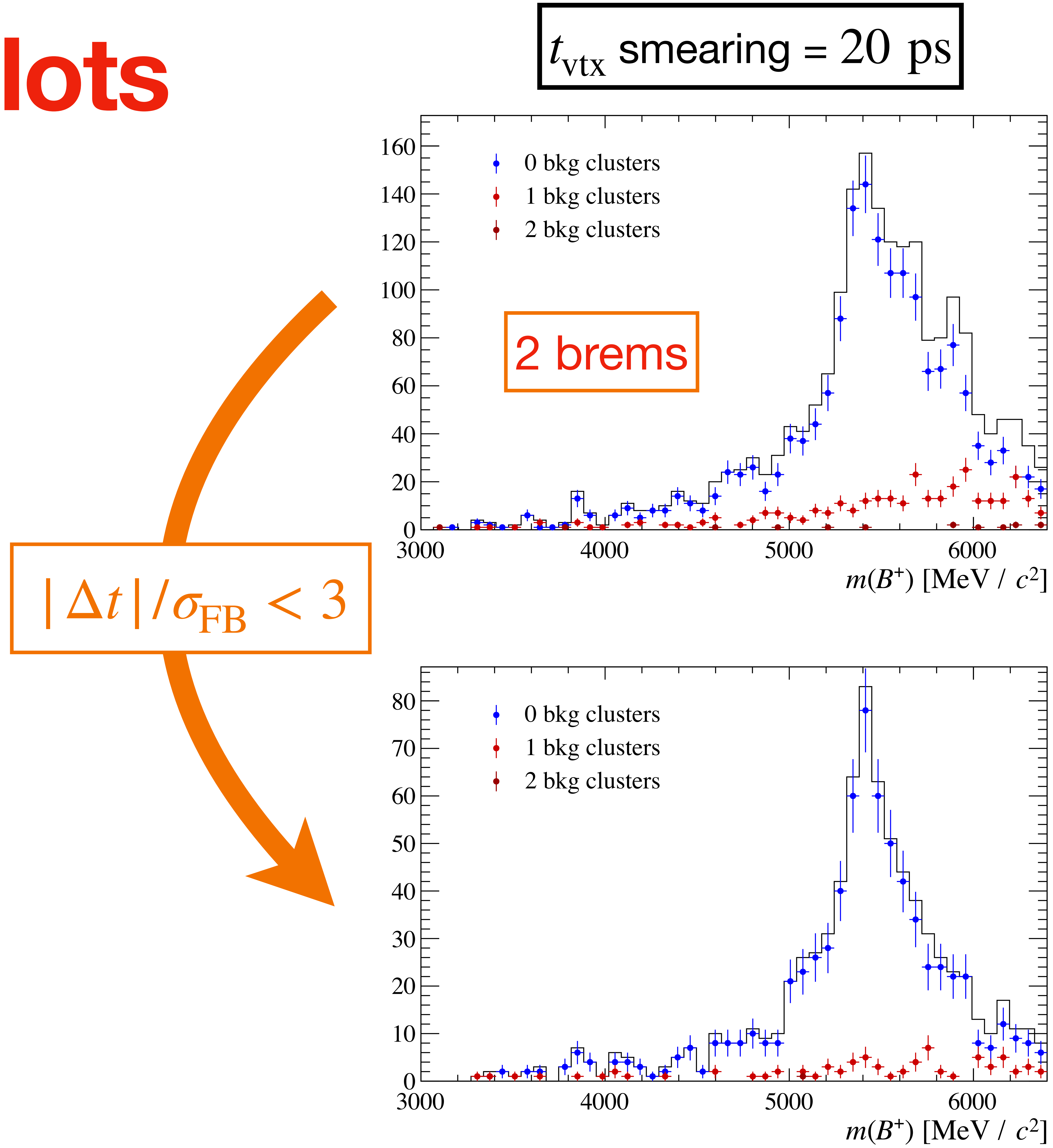
Time resolution



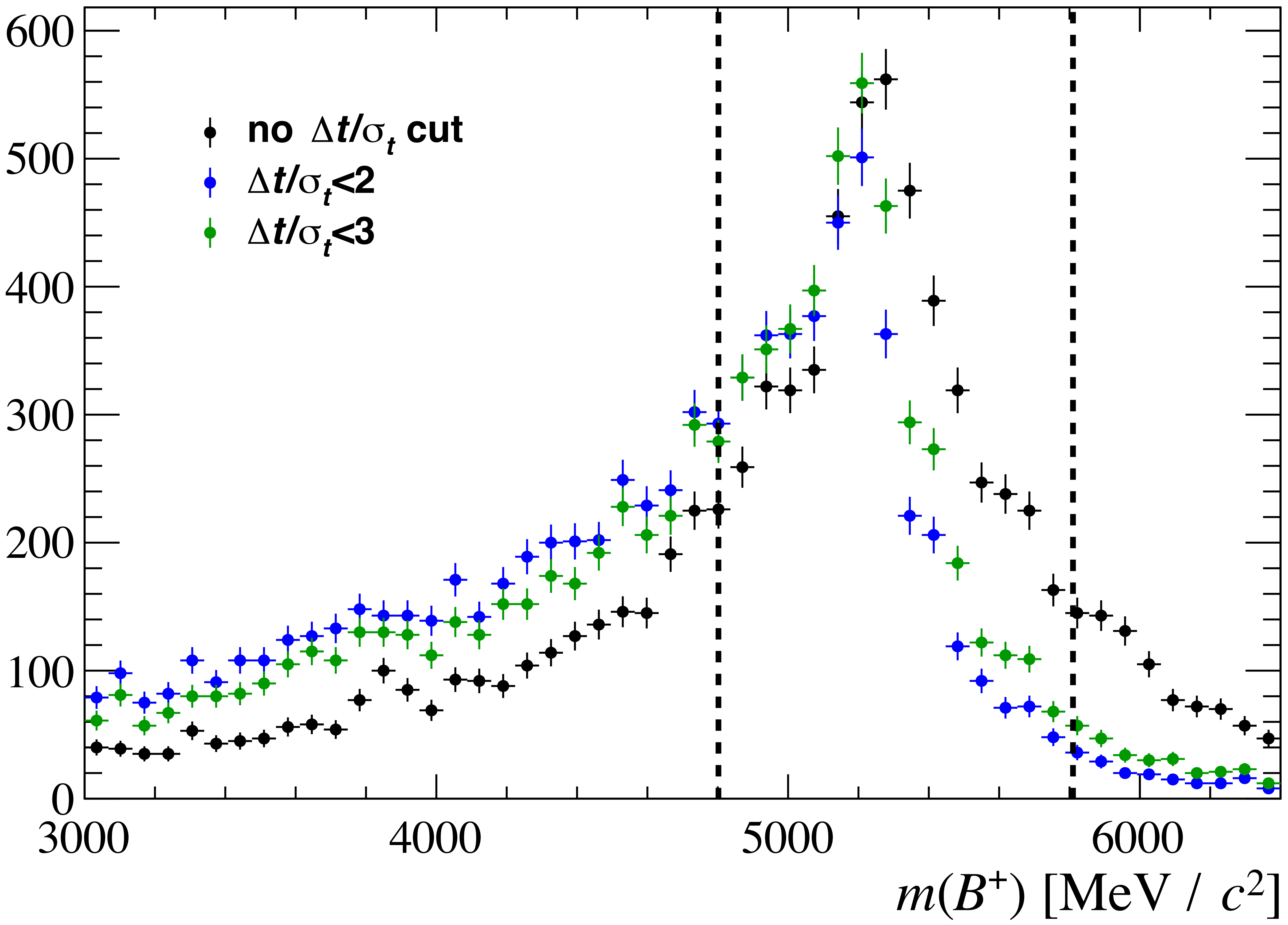
$B^+ \rightarrow K^+e^+e^-$ mass plots

- Signal cluster = cluster associated to true signal γ, but it can include also energy released by pile-up particles

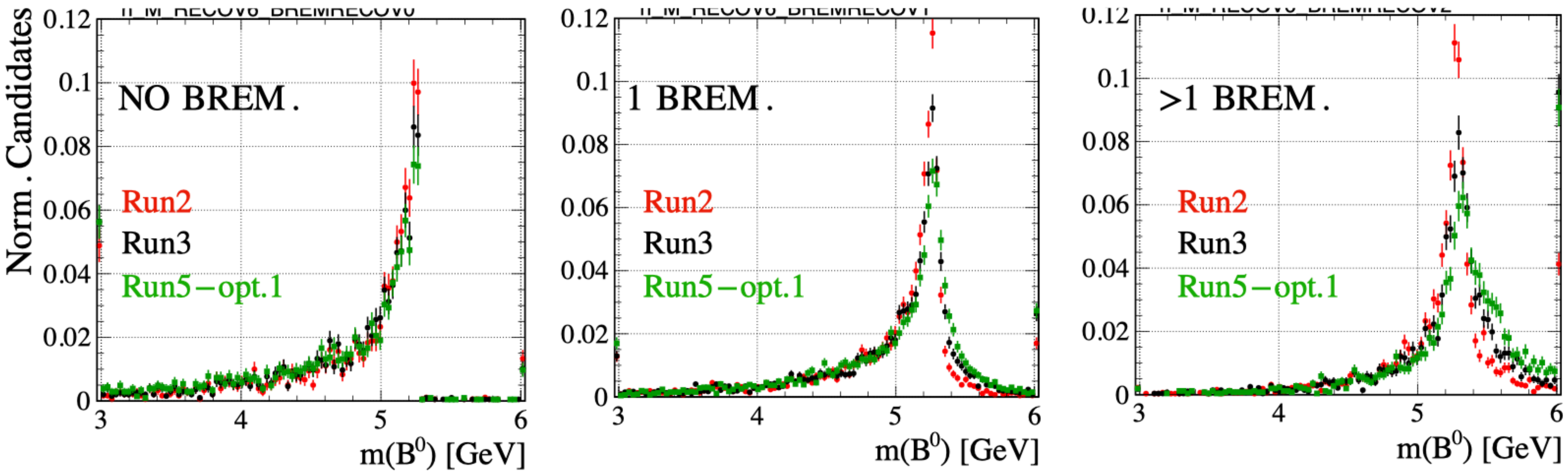
- High-mass tail mainly due to signal clusters affected by the presence of pile-up (to be checked better)



$B^+ \to K^+e^+e^-$ mass plots

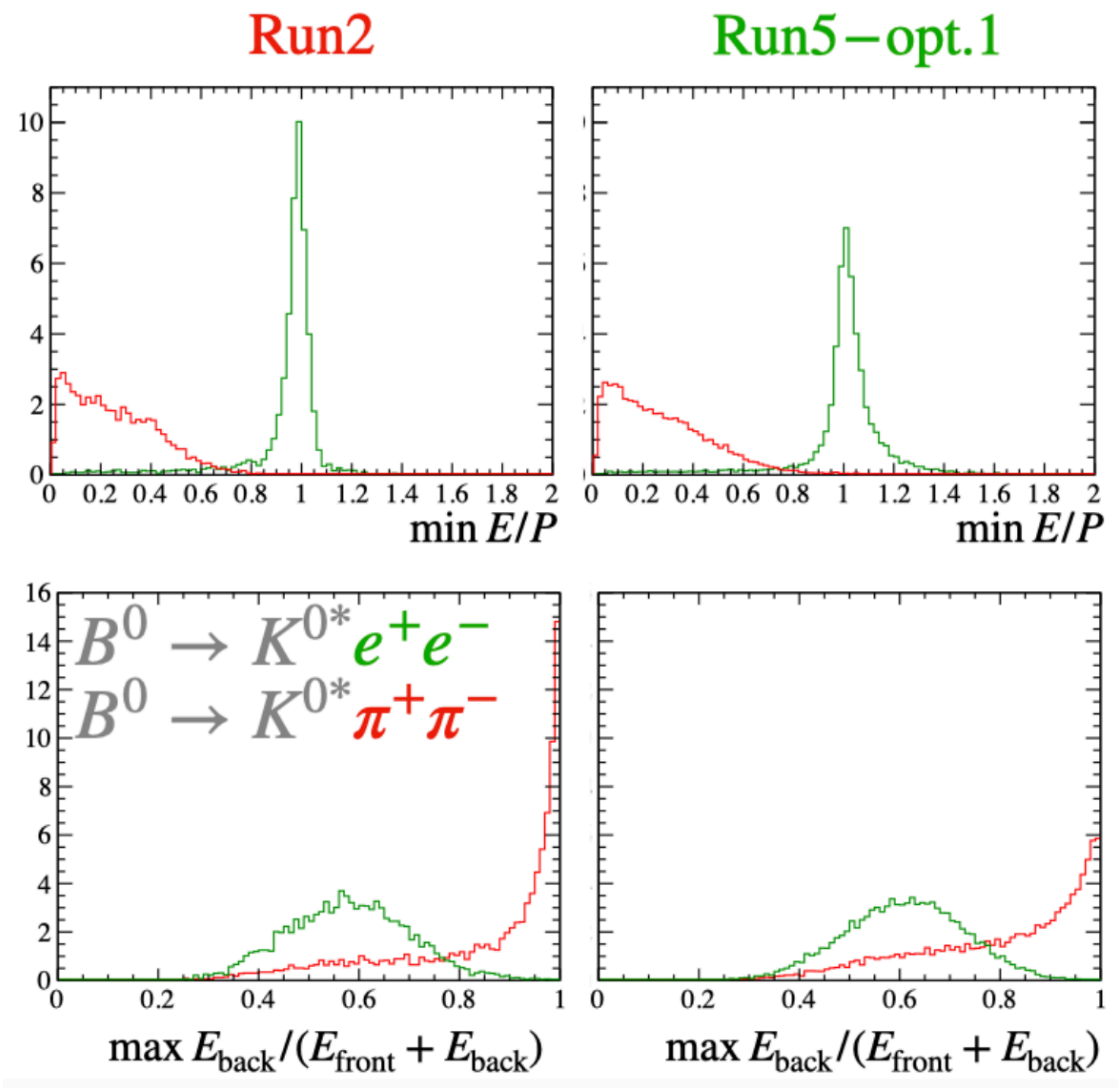


$B^0 \to K^{*0} e^+ e^-$



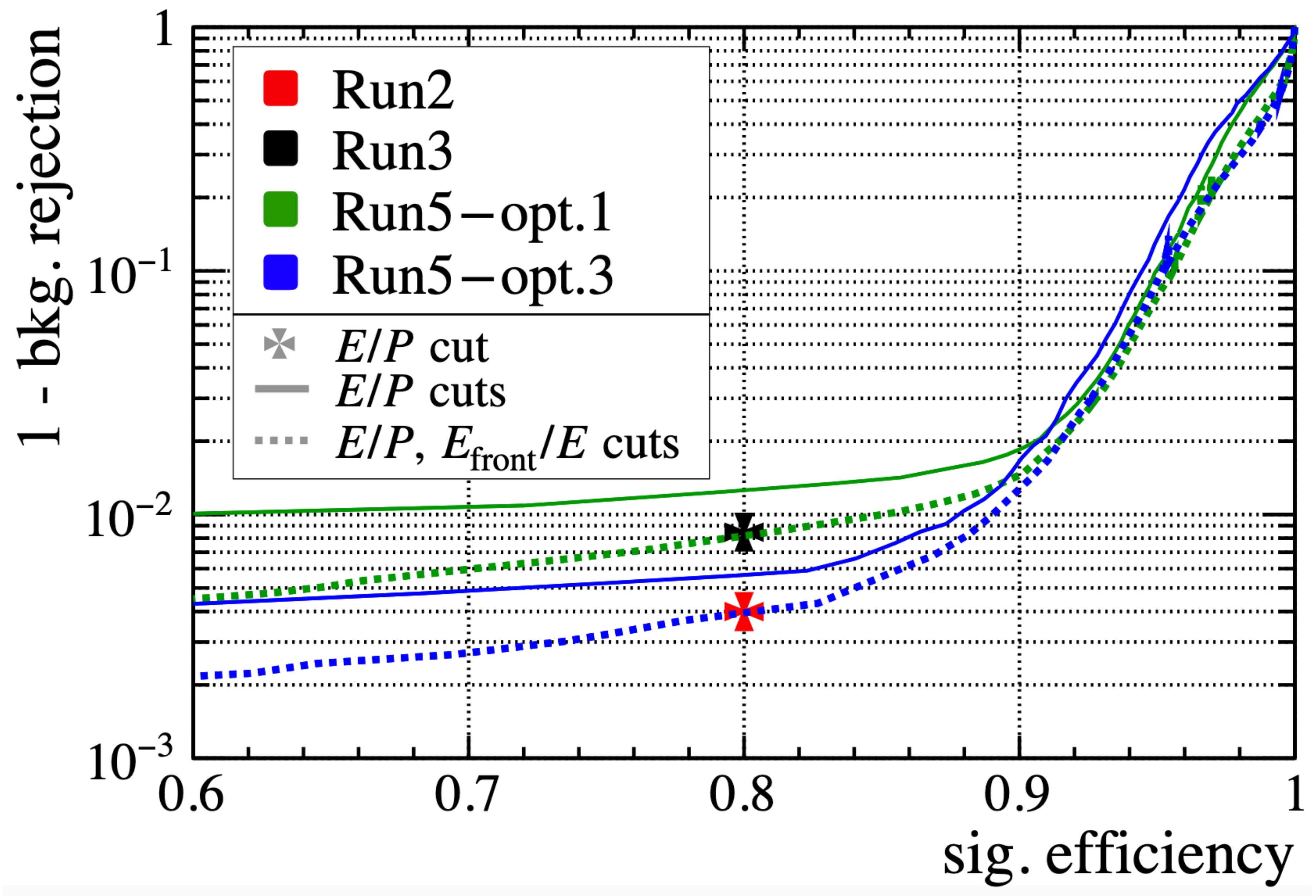
	0 brem	1 brem	>1 brem
Run1	19 %	48 %	33 %
Run3	21 %	49 %	30 %
Run5−opt.1	22 %	49 %	29 %

$B^0 \to K^{*0} e^+ e^-$



- Using E_{front}/p helpful in improving background rejection
  $\Rightarrow$ longitudinal segmentation important in $e - \pi$ discrimination

- Run 2 performance is not reached with the baseline chosen configuration (Run 5 - opt. 1)



$Z \to e^+e^-$ energy resolution