PicoCal simulations and benchmarking

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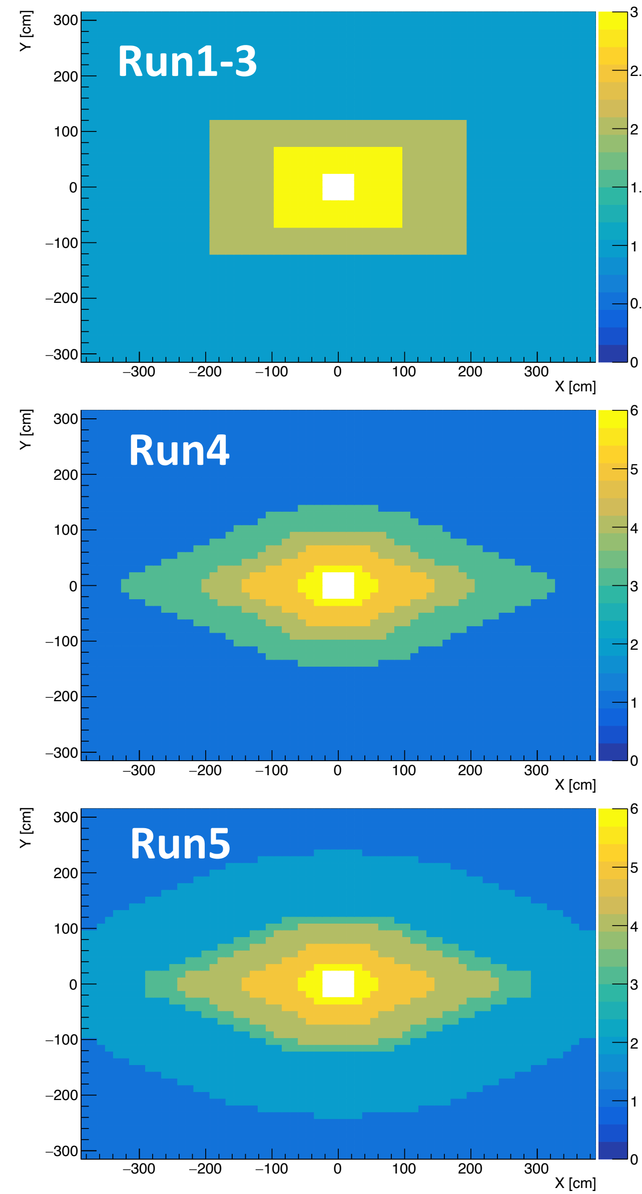
ECAL Upgrade scenarios

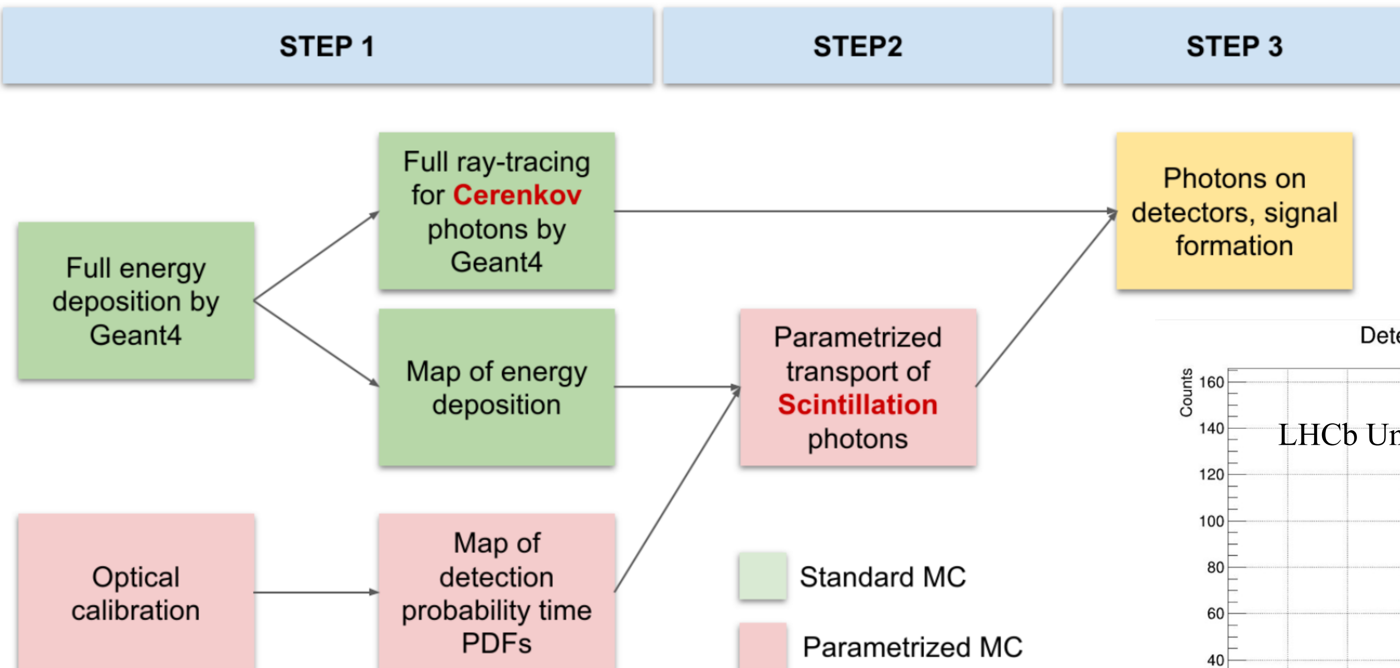
- Run 1-3: $4\times4/6\times6/12\times12\ \mathrm{cm}^2$ Shashlik
- Run 4 (Upgrade Ib):
  - ✓Innermost: $2\times2\ \mathrm{cm}^2$ SPACAL W+Poly.
  - ✓Second inner: $3\times3\ \mathrm{cm}^2$ SPACAL Pb+Poly
  - ✓Outer: $4\times4/6\times6/12\times12\ \mathrm{cm}^2$ Shashlik
  - ✓No longitudinal segmentation
  - ✓Timing readout for SPACAL only (option with timing in Shashlik will also be checked)
- Run 5 (Upgrade II):
  - ✓Innermost: $1.5\times1.5\ \mathrm{cm}^2$ SPACAL W+GAGG
  - ✓Second inner: $3\times3\ \mathrm{cm}^2$ SPACAL Pb+Poly
  - ✓Outer: $4\times4/6\times6/12\times12\ \mathrm{cm}^2$ Shashlik
  - ✓With longitudinal segmentation
  - ✓Dual timing readout for all modules

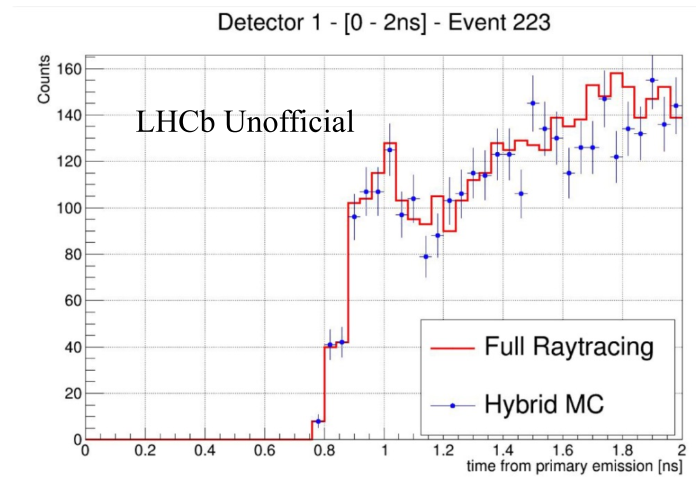


Simulation framework

Marco Pizzichemi

- In simulation, optical photons ray-tracing needed, but extremely CPU-consuming
  ⇒ parametrized strategy developed



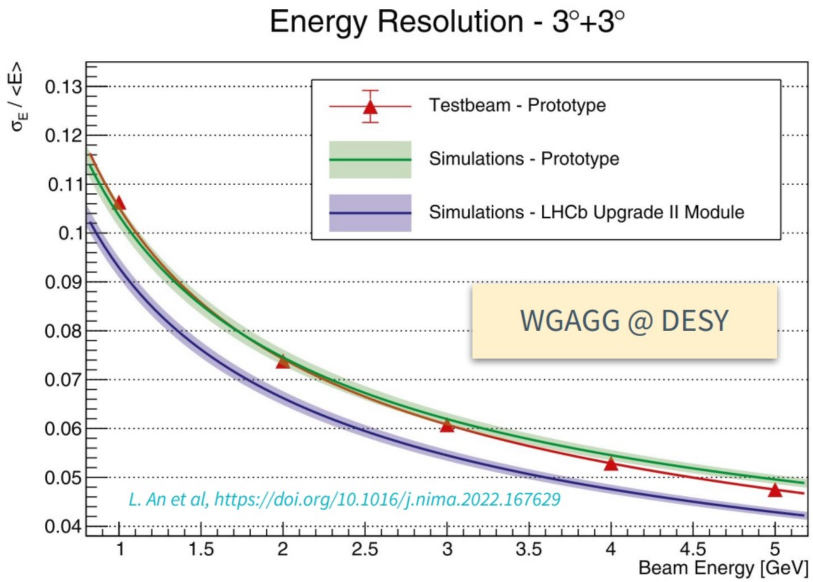


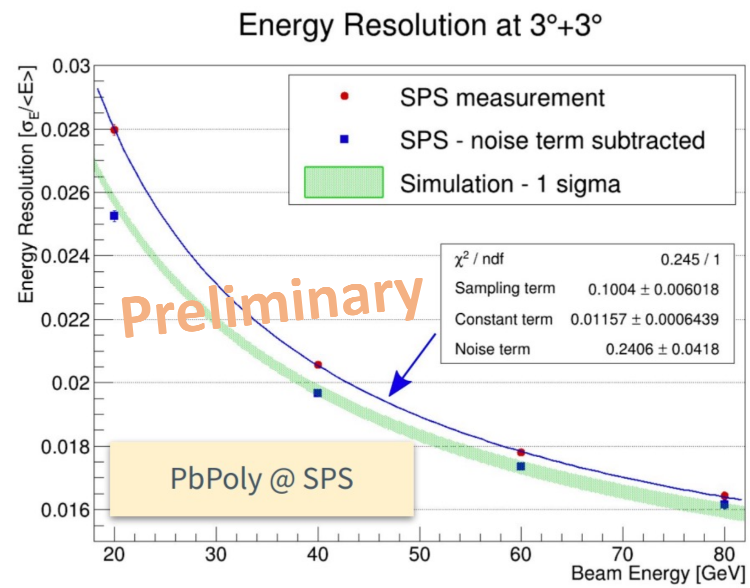
- **Hybrid-MC**: Geant4 simulation of energy deposit and parametrized transport of scintillation photons
  ⇒ gain in computation time by up to a factor 1000

- Available for both single module study and full-ECAL setups from Run3 to Run5

Comparison with test beam data

Marco Pizzichemi





$$\sigma(E)/E \approx \text{Sampling}/\sqrt{E} \oplus \text{Constant}$$

		Measurements on TB modules [%]	MC simulations on TB modules [%]	MC simulations on optimized modules [%]
WGAGG	*Sampling term*	10.6 ± 0.1	10.2 ± 0.1	9.2 ± 0.1
	Constant term	1~2	1.98 ± 0.04	1.18 ± 0.03
PbPoly	*Sampling term*	10.0 ± 0.6	10.3 ± 0.1	9.7 ± 0.1
	Constant term	1.16 ± 0.06	0.94 ± 0.04	0.56 ± 0.05

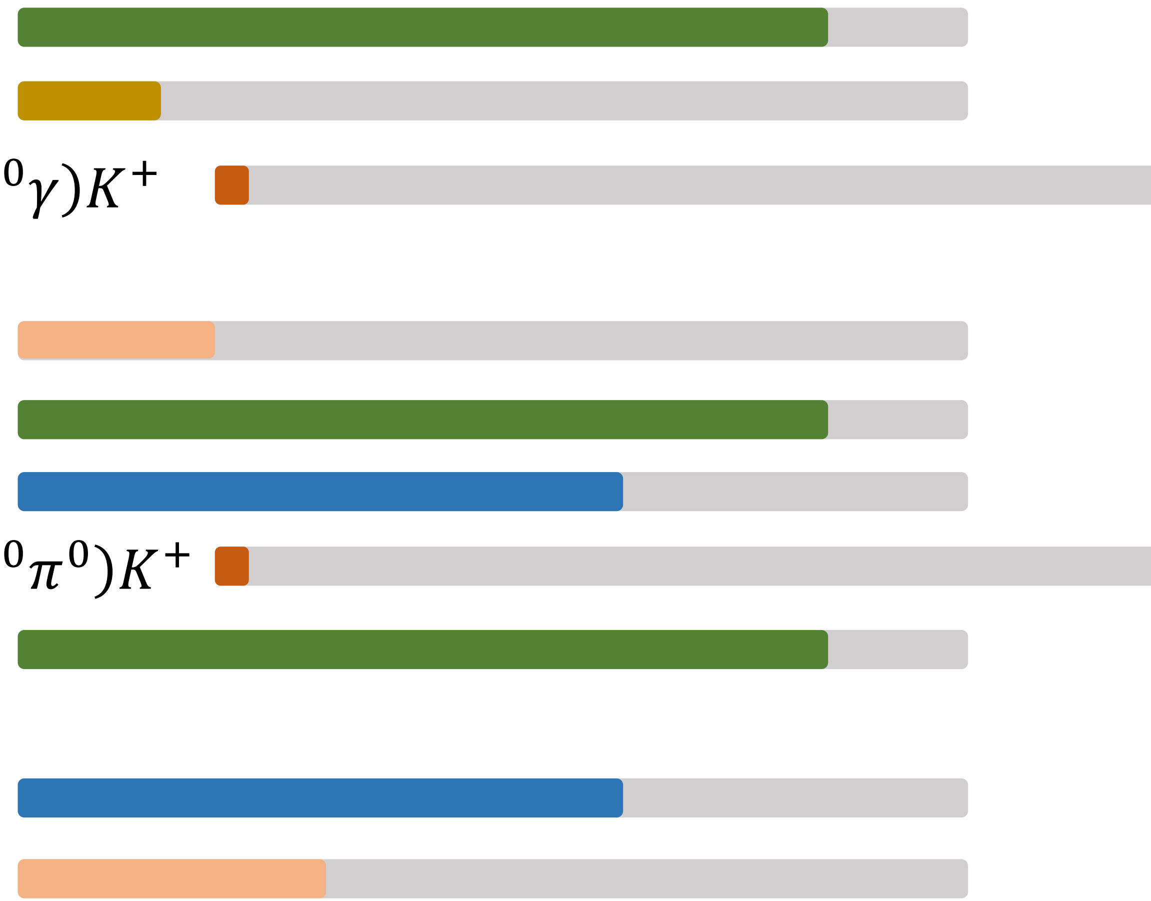
- Hybrid MC reproduces well the testbeam results after including the separation material
- Modules in ECAL will be designed with optimized separation, e.g. thin reflector foil
- Expected energy resolution in optimized modules in line with requirements

Benchmarking physics modes

To cover physics modes involving photon, electron and π^0 with different energy coverage, background level, vertex constraint …

In progress

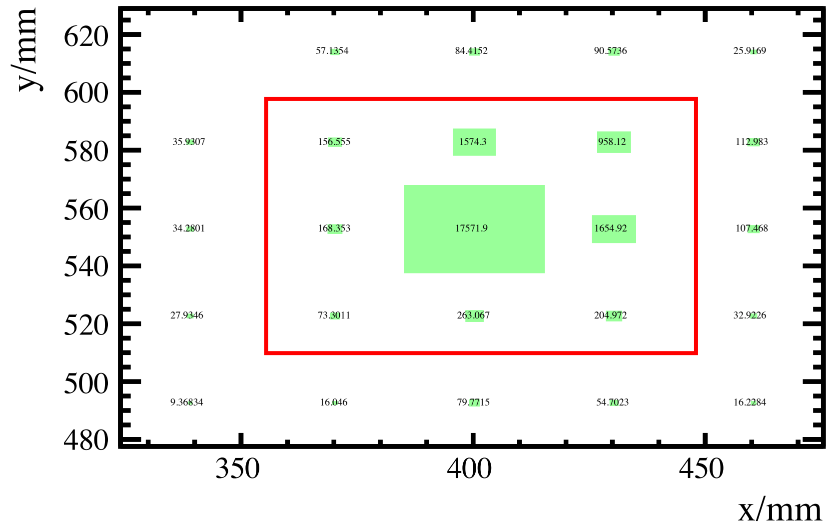
- **Single photon**
  - ✓ $B^0 \to K^{*0}\gamma$
  - ✓ $\chi_{c1} \to J/\psi\gamma$
  - ✓ $B^+ \to D^{*0}(\to D^0\gamma)K^+$
- **$\pi^0 \to \gamma\gamma$**
  - ✓ $D^0 \to \pi^+\pi^-\pi^0$
  - ✓ $B_s^0 \to J/\psi\pi^0$
  - ✓ $B^+ \to K^+\pi^0$
  - ✓ $B^+ \to D^{*0}(\to D^0\pi^0)K^+$
  - ✓ $B^0 \to \pi^+\pi^-\pi^0$
- **Electron**
  - ✓ $B^+ \to K^+e^+e^-$
  - ✓ $Z \to e^+e^-$



Reconstruction algorithm

➢3×3 cells clustering

✓cell with larger deposit energy than all its neighbor cells taken as **seed cell**; 3×3 cells surrounding seed cell taken as a cluster



✓Seed cell with E_{T} threshold of $50\ \mathrm{MeV}$

✓**Energy in front and back cell summed up; timing taken as that of seed cell**

✓Corrections to position and energy of the clusters are implemented

✓Algorithm to utilize ***long. segmentation (for Run 5)***, ***timing info*** etc. and its effect on performance to be studied

➢Machine learning (ML) approach

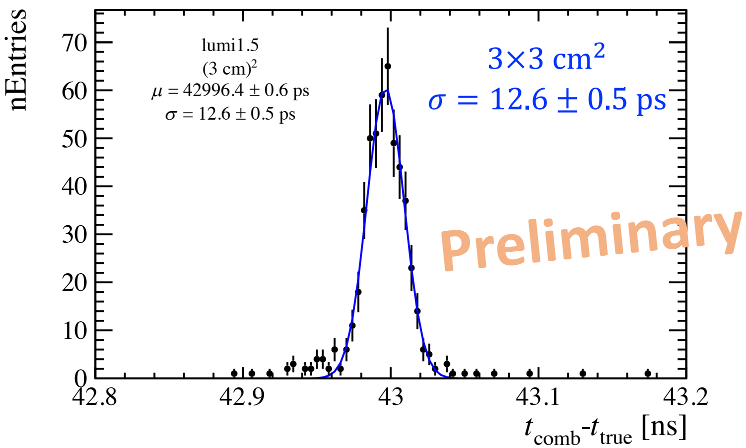
✓Three sets of regressors are trained to estimate: *position, *energy, *time

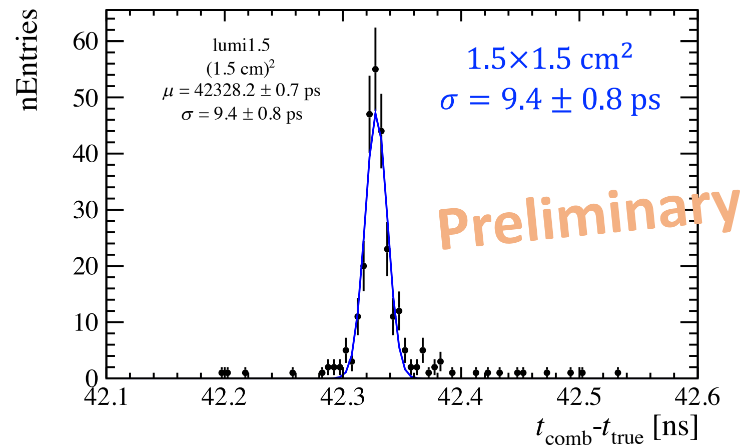
✓The ML input is Geant4 responses in cells of shape **5x5**(x *number of layers*)

✓Applied to $B_s^0 \to J/\psi\pi^0$ only so far

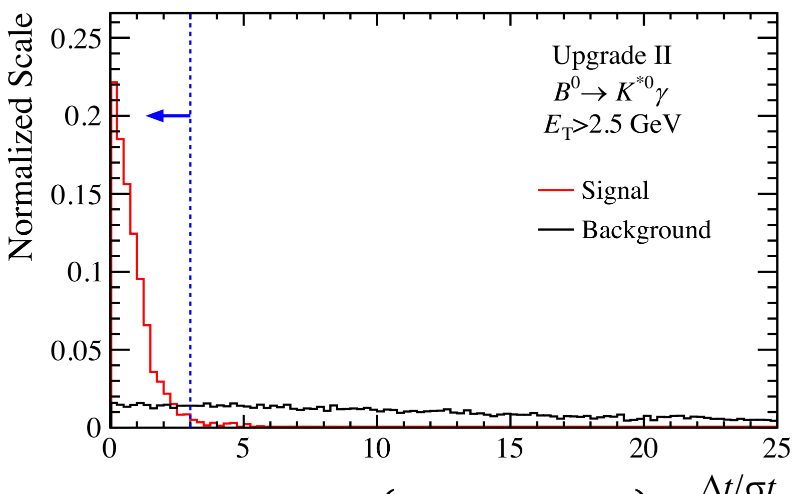
$B^0 \to K^{*0}\gamma$ – timing study

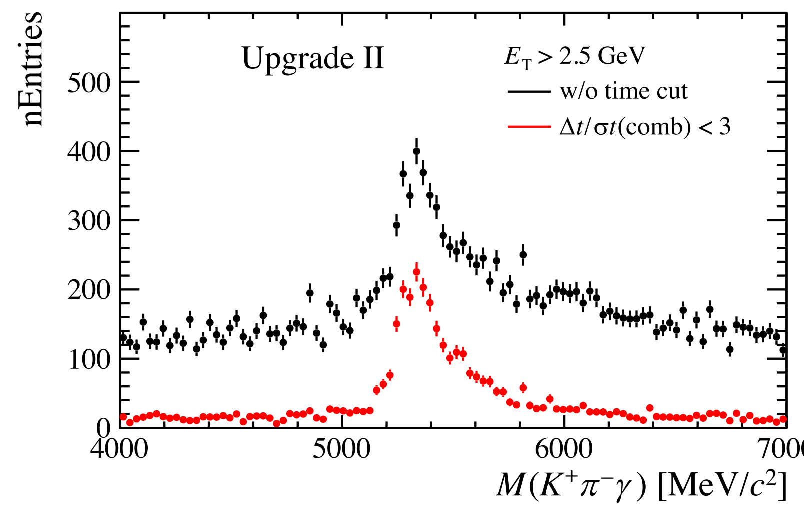
- Studies performed for Upgrade II with peak luminosity of $\mathcal{L} = 1.5\times10^{34}\ \mathrm{cm^{-2}s^{-1}}$
- Timing resolution obtained as weighted average of front & back section time





- The timing cut is effective in reducing background



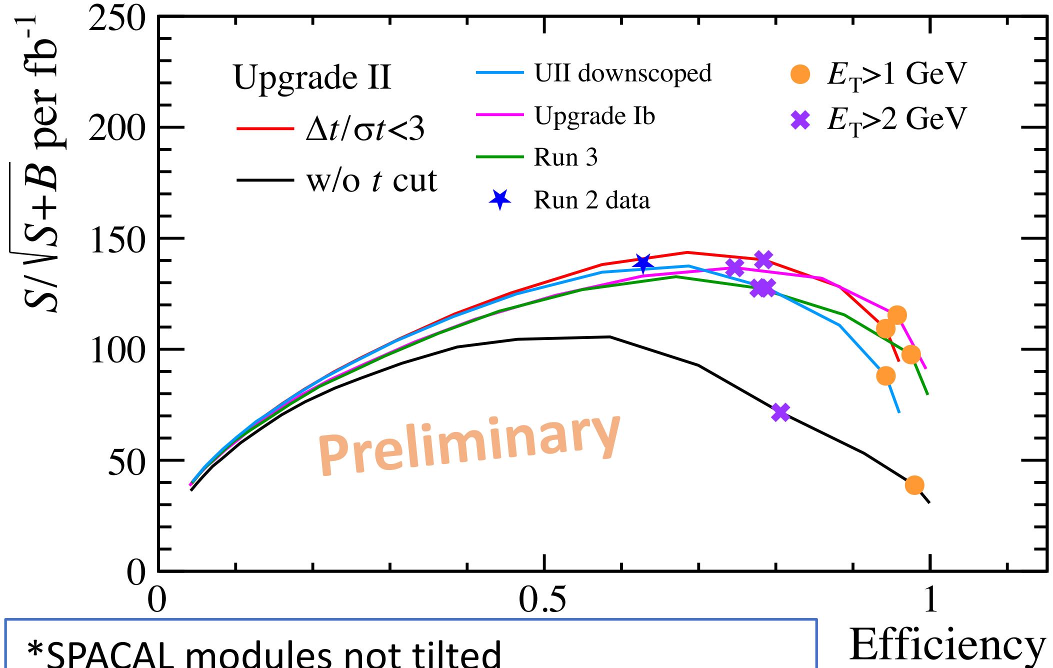


$$\Delta t = t_{\mathrm{rec}} - (t_{\mathrm{prod}} + t_{\mathrm{flight}})$$

$B^0 \to K^{*0}\gamma$ – performance comparison

✓The same bkg. level and tracking efficiency for K^{*0} are assumed for all setups

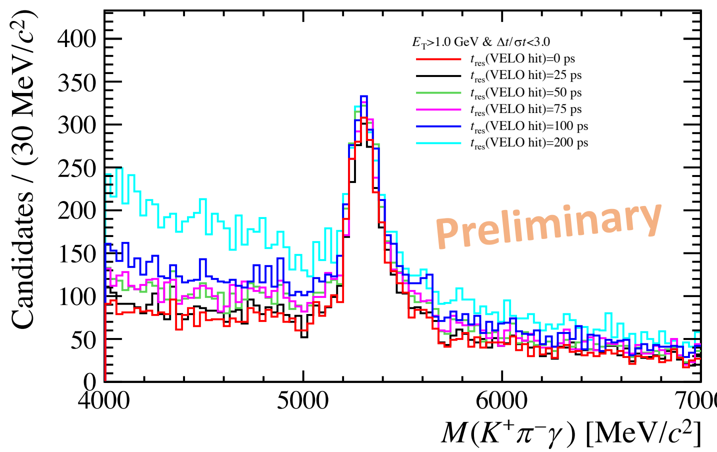
✓Timing resolution of K^{*0} vertex assumed to be 0



- Timing cut effective for Upgrade II
- With timing cut, Upgrade II performance can reach that of Run2
- Upgrade II downscoped option has a downscaled performance
- Upgrade Ib can improve performance wrt Run3

*SPACAL modules not tilted
*UII downscoped: Upgrade II w/o long. seg.
*Upgrade Ib: no timing info
*Run 3: radiation damage not considered

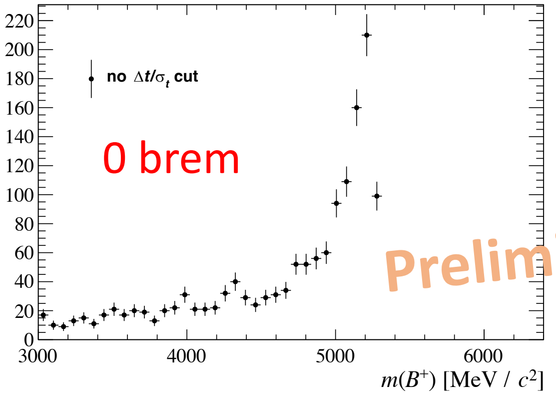
➢Effect of timing resolution from tracking system is being studied with joint VELO-ECAL simulation
[See Timothy David Evans' talk for more details]

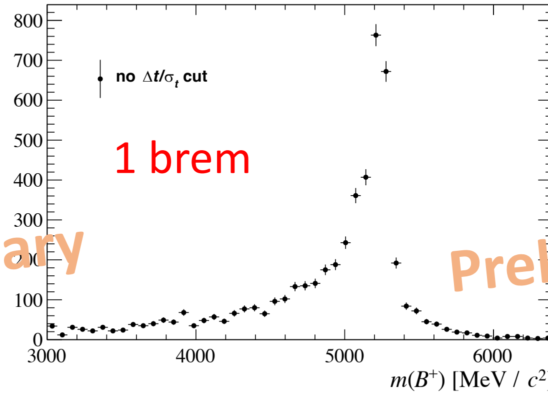


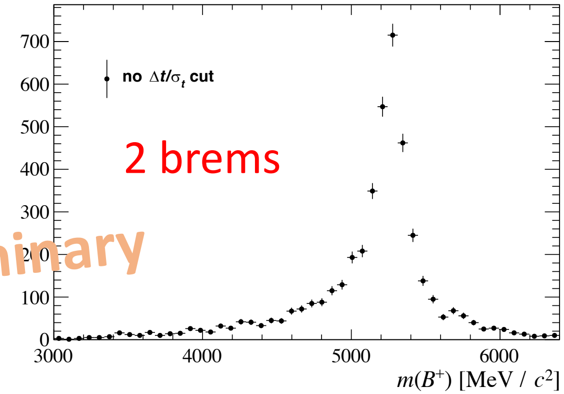
$B^+ \to K^+e^+e^-$

Federico Betti

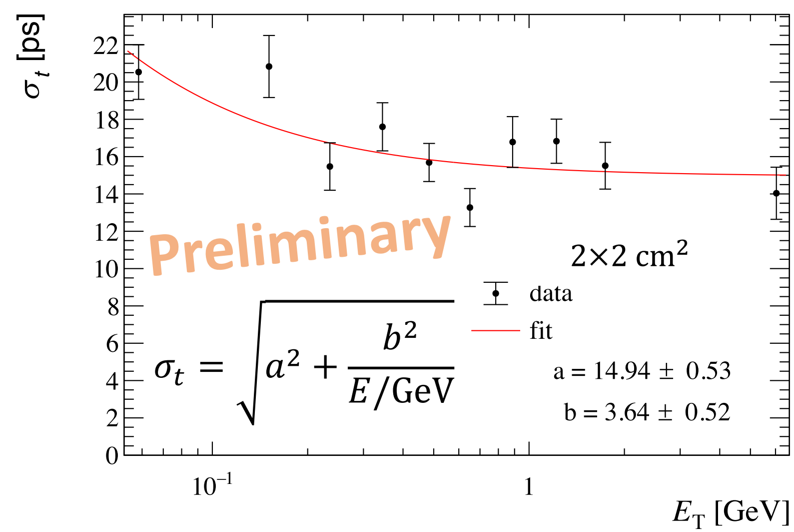
- Goal is to study reconstruction of bremsstrahlung photons in Upgrade II
- Latest study based on Run 4 (SPACAL modules rotated) with pile-up included







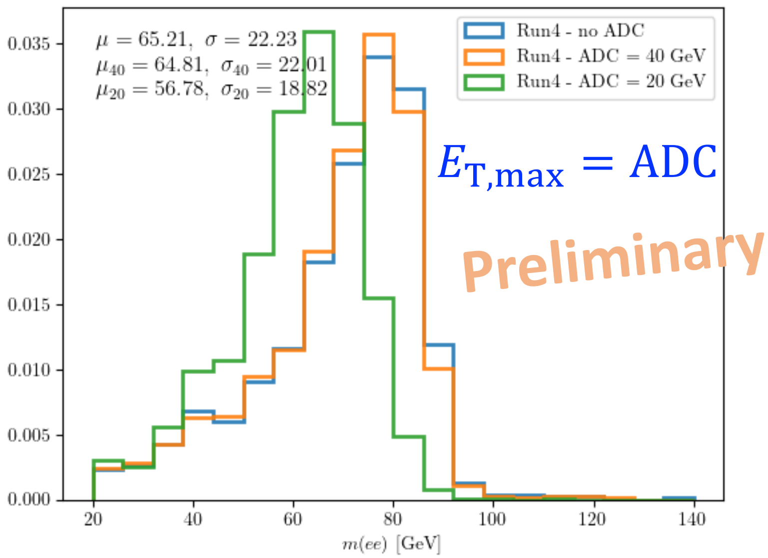
- Impact of timing cuts to suppress pile-up contamination is being studied
  - ✓ Timing resolution of bremsstrahlung photons from $B^+ \to K^+e^+e^-$ is studied
    ⇒ low energy regime

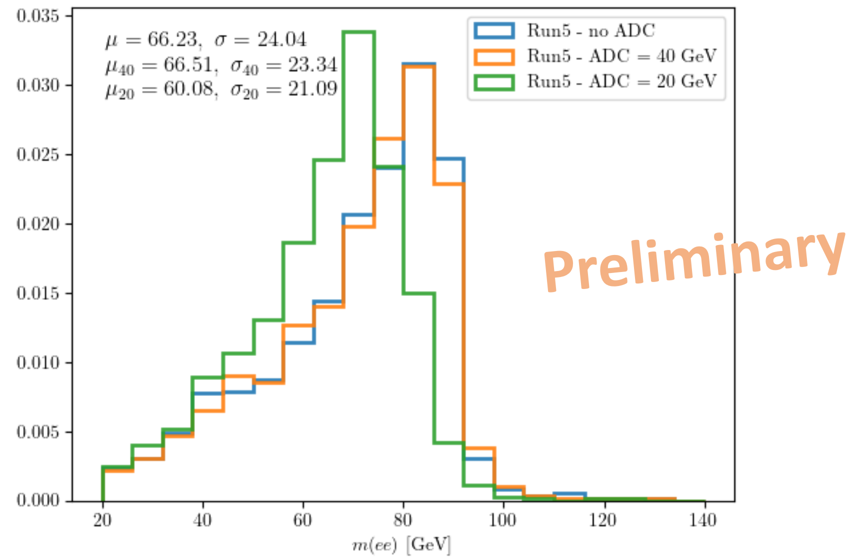


$Z \to e^+e^-$

Davide Zuliani

- Goal is to study and improve reconstruction of electrons with very high energies for Upgrade II
- **ADC saturation** is relevant for high p_{T} electrons and checked for Run 4 & 5 (SPACAL rotated)
  - ✓ With ADC = 40 GeV, the invariant mass distribution is almost the same with no saturation (as reference, Run 2 ADC ~ 10 GeV; Run 3 ADC ~ 20 GeV)
- There is still room to improve energy corrections at very high energy (most brem. photons are inside electron cluster)



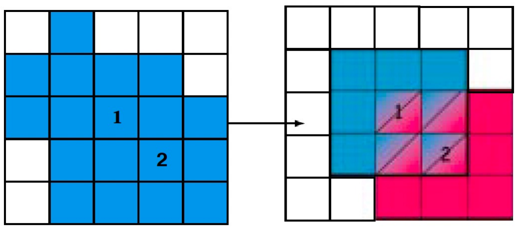


- Future steps
  - ✓ Study energy resolution of electrons as a function of energy
  - ✓ Improve the reconstruction of $Z \to e^+e^-$

$D^0 \to \pi^+\pi^-\pi^0$

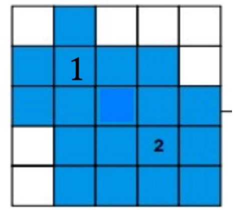
Sascha Stahl, Sasha Zenaiev

- Merged $\pi^0 \to \gamma\gamma$

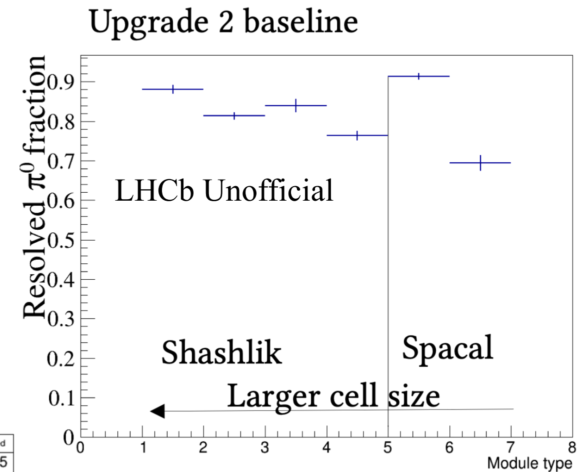


Single cluster 2 interleaved subclusters

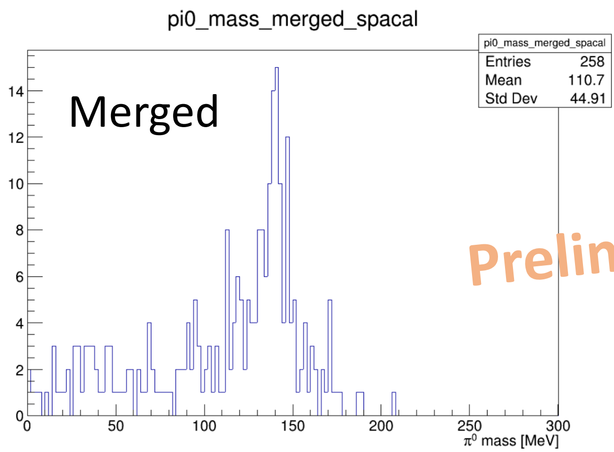
- Resolved $\pi^0 \to \gamma\gamma$

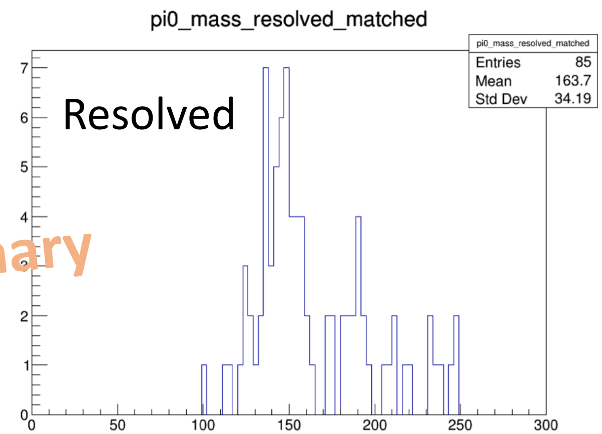


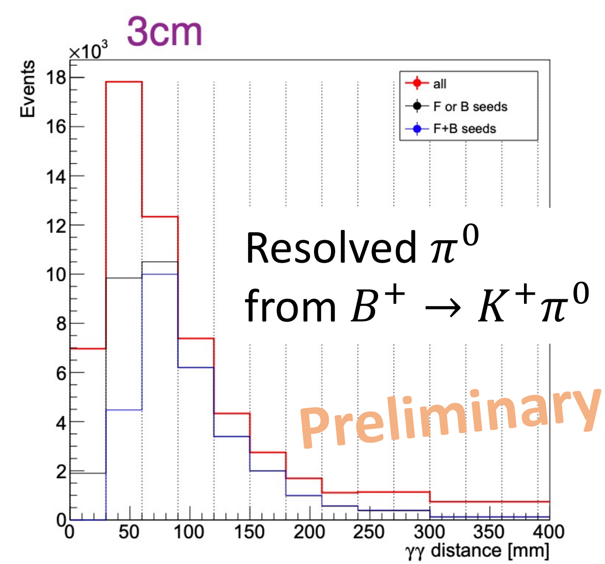
Two clusters



✓ Lower momenta
$\Rightarrow$ more resolved







✓ Following approach from Run1/2 to add a sub-cluster

✓ Use of timing can give improvement

✓ Simple combination of two photons

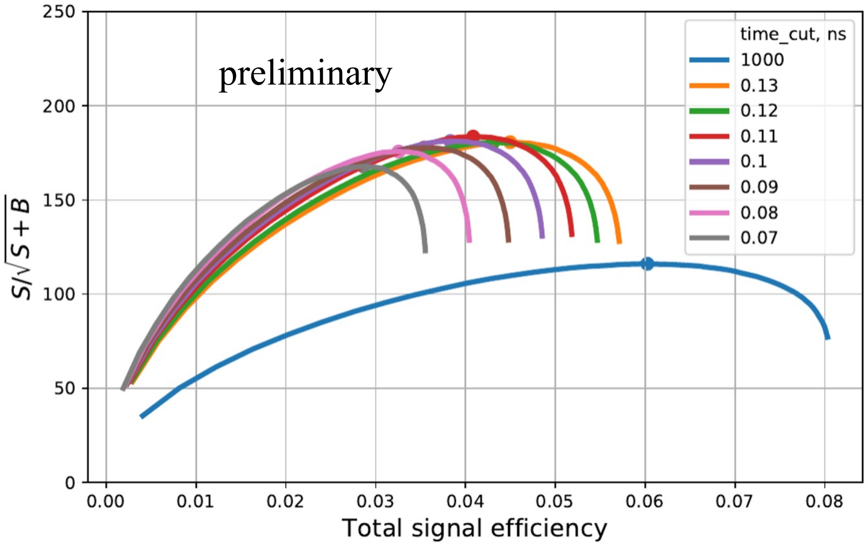
✓ Long. segmentation is promising to help with it

$B_s^0 \to J/\psi\pi^0$ - ML approach

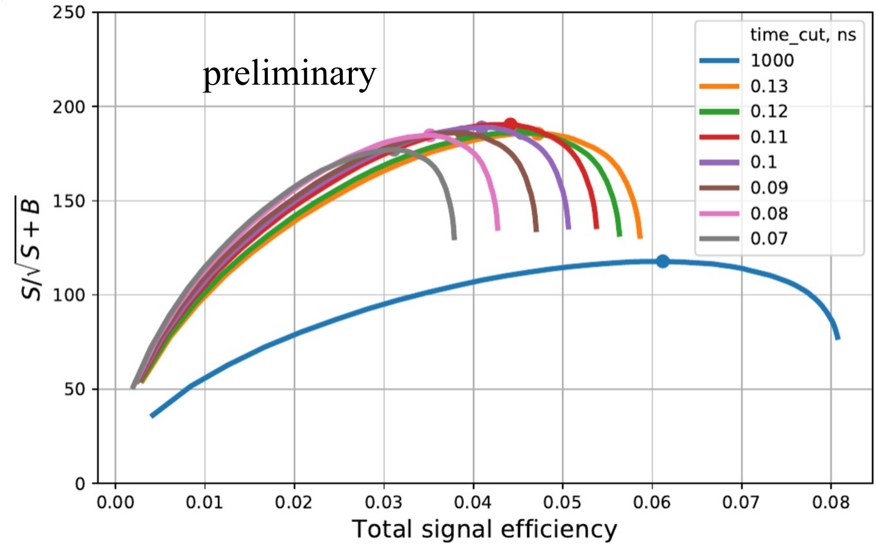
Alexey Boldyrev, Denis Derkach, Fedor Ratnikov, Andrey Shevelev

- Performance with resolved π^0 studied for Upgrade II

Upgrade II downscoped (single layer)



Upgrade II baseline (long. segmented)

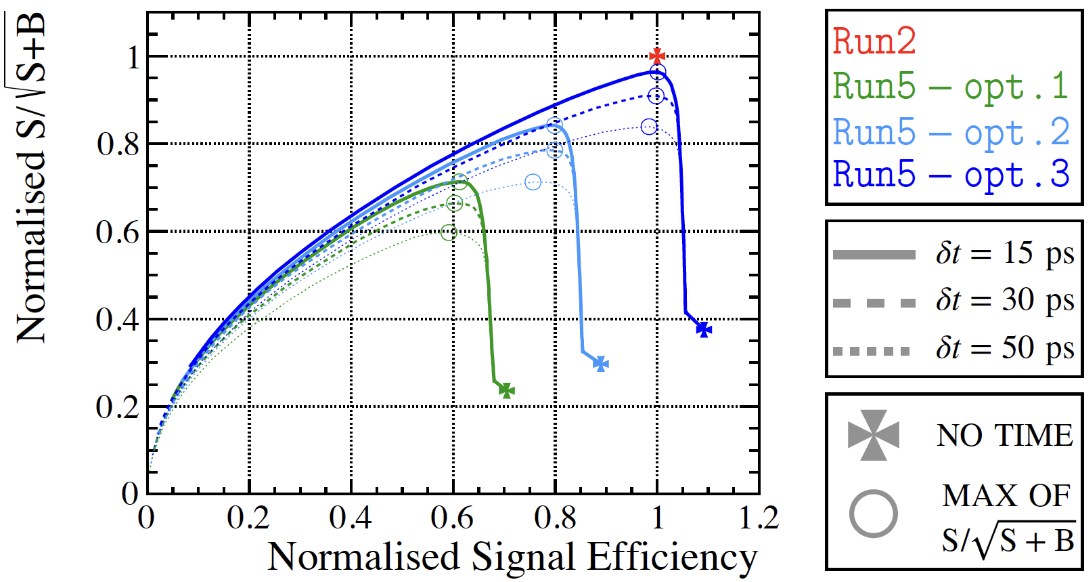


- Timing and long. segmentation help improve the performance
- Update to using hybrid-MC samples is ongoing (realistic simulation of time development in shower).
  There is also room for improvement using more sophisticated ML approaches for the long. segmentation

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

Daniele Manuzzi, Stefano Perazzini

- The study is based on “Homogenous” simulation from Bologna
  - ✓Homogeneous materials with average composition
  - ✓Shower development simulated by Geant4
  - ✓Energy resolution simulated with random rejection of energy deposits
  - ✓Time resolution simulated by Gaussian smearing



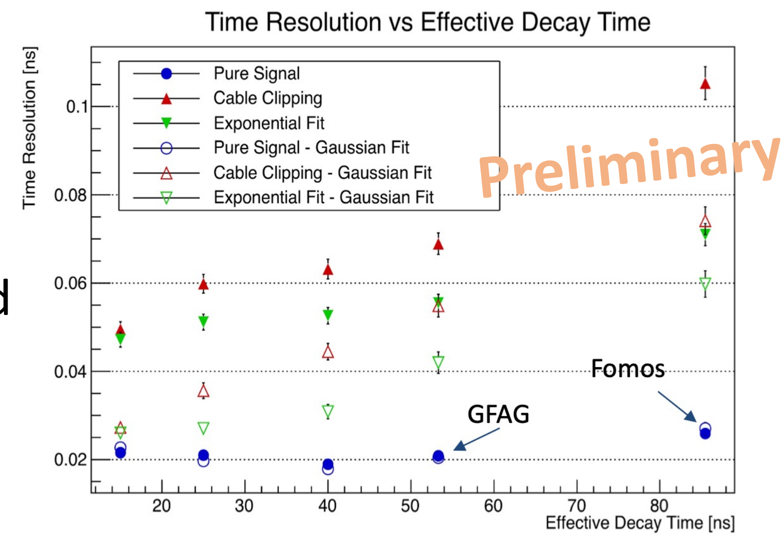
Region name	Region index	U2 BASELINE: Run5-opt.1 Cell side [mm]	U2 BASELINE: Run5-opt.1 R_M [mm]	BETTER OUTER: Run5-opt.2 Cell side [mm]	BETTER OUTER: Run5-opt.2 R_M [mm]	EVEN BETTER: Run5-opt.3 Cell side [mm]	EVEN BETTER: Run5-opt.3 R_M [mm]
Innermost	0	15	15	15	15	15	15
Inner	1	30	30	30	30	15	15
Middle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

- The results suggest the critical need of R&D to improve the ECAL reconstruction algorithms in Upgrade II

Other studies

- Simulation study of spillover effects
  - ✓ Spillover effects are mitigated for crystals with faster decay time
  - ✓ Pulse shaping techniques are important
  - ✓ The effect on physics study is to be quantified

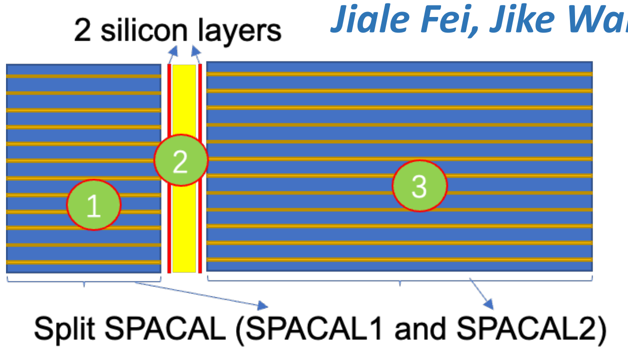
Loris Martinazzoli, Stefano Perazzini, Marco Pizzichemi, Vincenzo Vagnoni

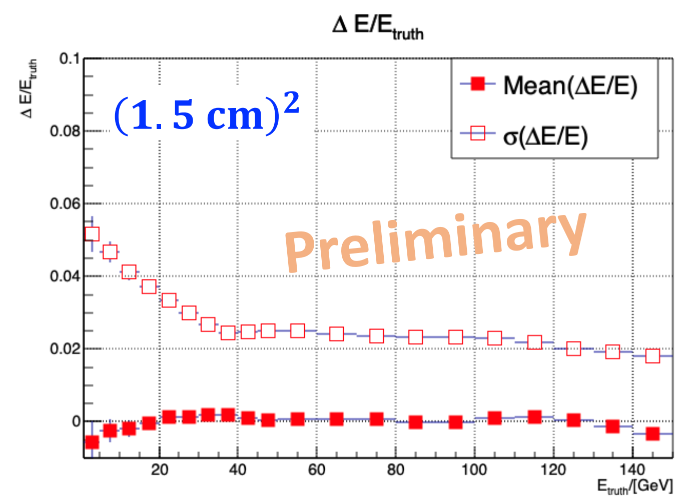


5 GeV $e^{\pm}$

- Simulation study with additional silicon timing layer

Jiale Fei, Jike Wang, Xiangyu Wu



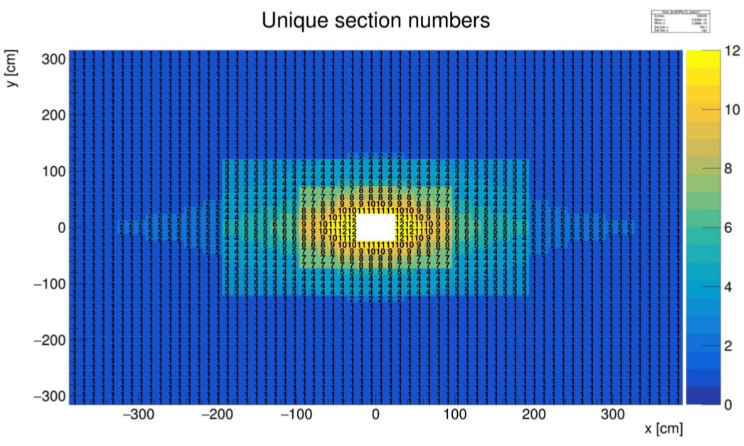


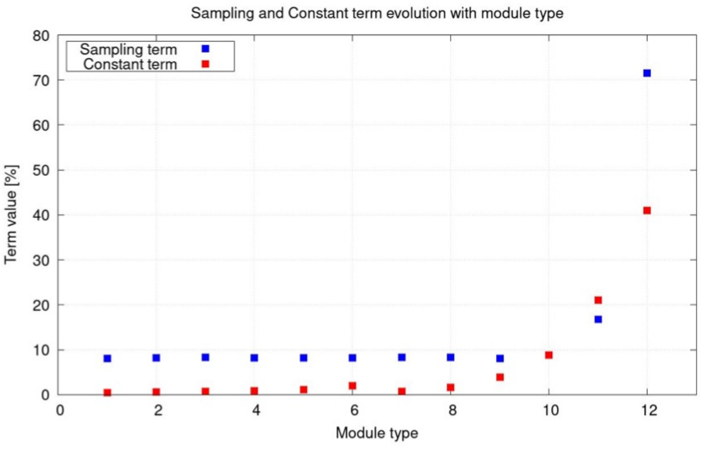
- ✓ Silicon layer: cell size $5\times5\ \mathrm{mm}^2$; thickness $0.5\ \mathrm{mm}$
- ✓ Cooling layer (Cu): thickness $6\ \mathrm{mm}$

✓ Studies ongoing to fully exploit the potential of silicon layers

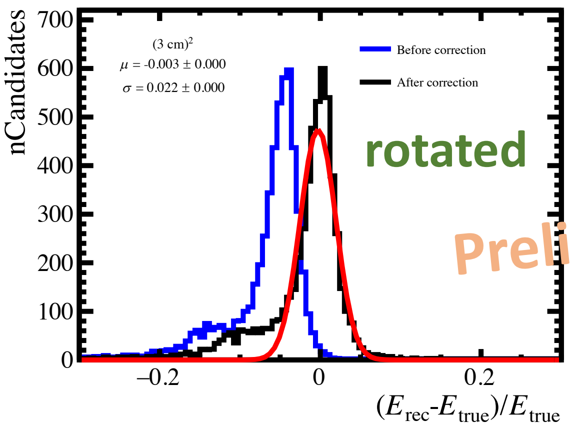
Towards Upgrade Ib FTDR

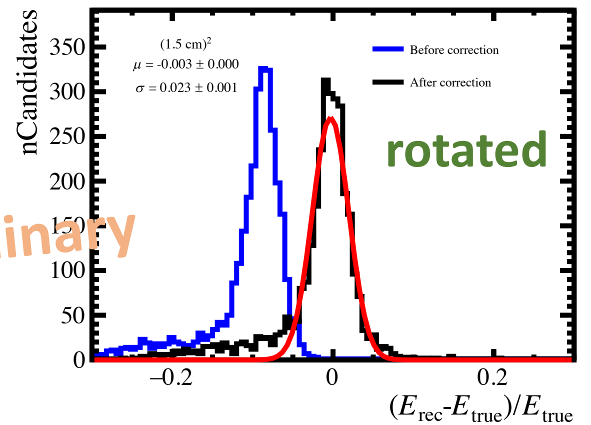
- ➢Simulation configuration is prepared including radiation damage expected at the end of Run 3 to compare with Upgrade Ib
  - ✓Current ECAL divided in 12 sections with different degraded light output derived from irradiation studies





- ➢Reco. & energy+position corrections in place for end of Run 3 including radiation damage and rotated SPACAL modules





Summary and prospects

- A hybrid-MC framework is well established for ECAL simulation study
- Many benchmarking physics modes are being studied for ECAL Upgrade scenarios
  - Single photons: $\boldsymbol{B^0 \to K^{*0}\gamma}$
  - Electrons: $\boldsymbol{B^+ \to K^+ e^+ e^-}$, $\boldsymbol{Z \to e^+ e^-}$
  - Neutral pions: $\boldsymbol{D^0 \to \pi^+\pi^-\pi^0}$, $\boldsymbol{B_s^0 \to J/\psi\pi^0}$, $\boldsymbol{B^+ \to K^+\pi^0}$, $\boldsymbol{B^0 \to \pi^+\pi^-\pi^0}$

  and more are on the way, e.g. $\chi_{c1} \to J/\psi\gamma$, $B^+ \to D^{*0}(\to D^0\gamma/\pi^0)K^+$
  - ✓Timing information is necessary and effective to improve the performance
  - ✓It is crucial to optimize the reconstruction algorithm to fully utilize long. segmentation, timing info etc.

- Essential basics for Upgrade Ib study are in place; preparation of FTDR is underway

- There are still a lot to do for ECAL upgrade sim/reco study. You are welcome to join!

Back up

Pulse shaping techniques

Loris Martinazzoli, Stefano Perazzini, Marco Pizzichemi, Vincenzo Vagnoni

- Time stamp is measured using a CFD technique
- Two pulse shaping techniques:
  - Exponential fit to the baseline used to subtract spillover
  - Cable clipping:

$$V_{out}(t) = \frac{1}{2}\left(V_{in}(t) - r \cdot V_{in}(t - \delta_t)\right)$$