Overview on Calorimeter Simulation for Upgrade Ib/II

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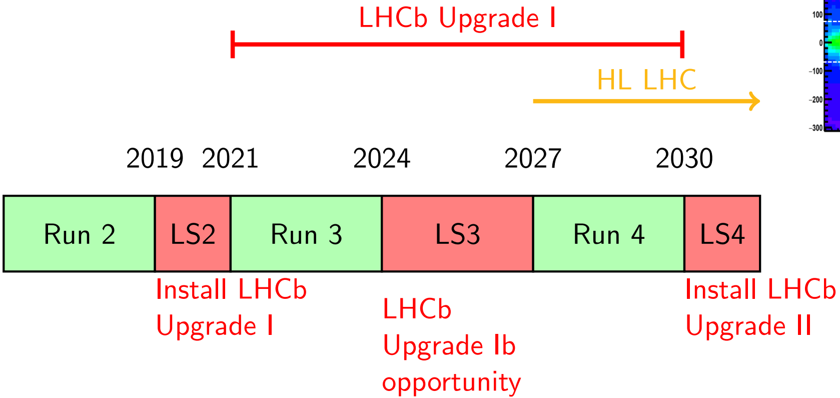
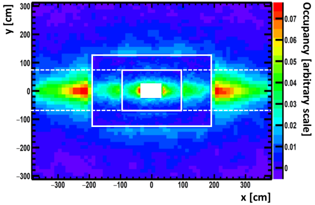
March 22, 2018

- A reminder

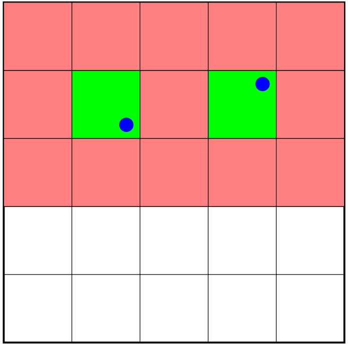




- Upgrade Ib gives the opportunity to partially replace ECAL
- Provides important input into Upgrade II detector
- Simulation studies must be performed to help evaluate possible new detector capabilities

Upgrade Ib/II environment

- Occupancy in ECAL will increase dramatically
- Resolution will degrade
- Can change material (smaller Molière radius) and change cell size
- Clusterization techniques can get you so far (e.g. 2×2, swiss cross)
- Can timing help to resolve the remaining ambiguities?
- Many complex considerations beyond this simple picture



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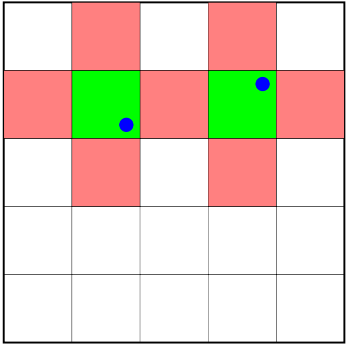

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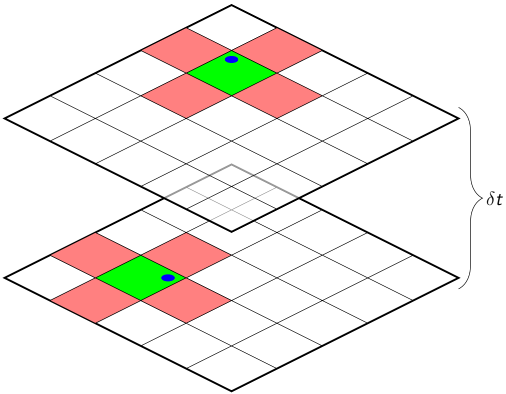
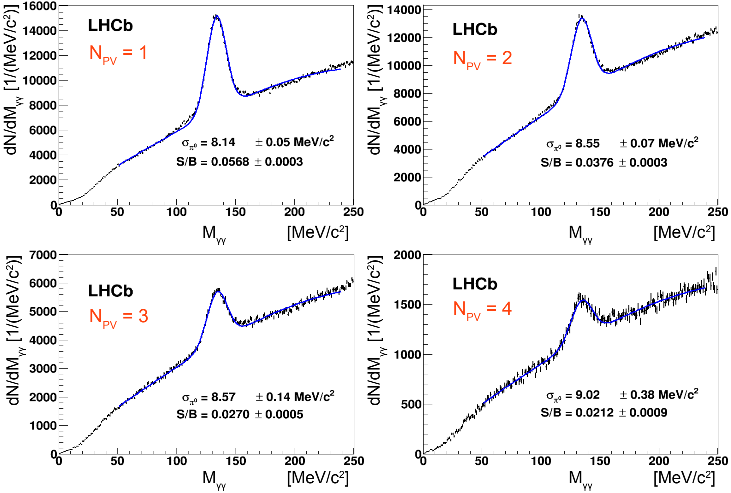


Setting the stage

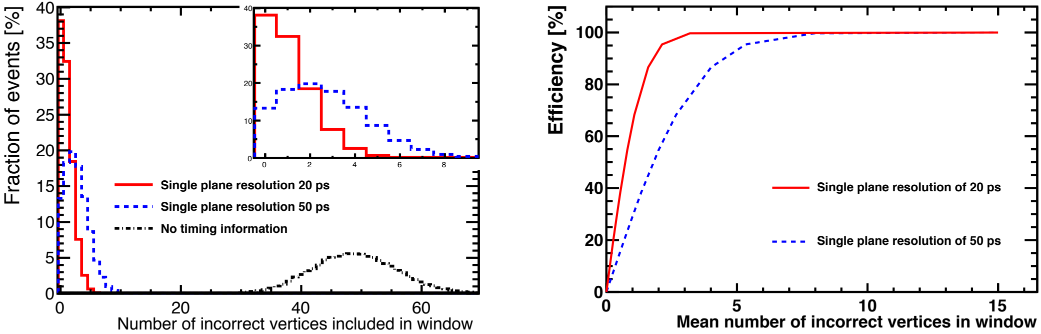
- Example: π^0 mass resolution as a function of PV in Run II simulation (from UpgradeII EOI)



- Already see degradation of S/B, as well as resolution

One example of timing

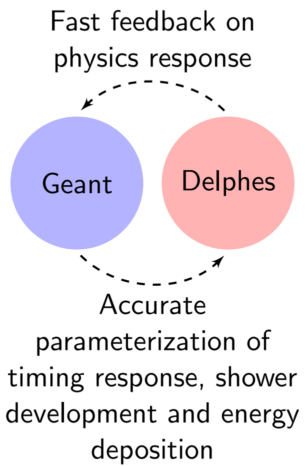
- Association of clusters to PV benefits from timing
- Example: 50 interactions per bunch crossing



- Mean number of incorrect primary vertices giving rise to background hits reduced to 1.1 for three planes with 20 ps timing resolution

Multifold Simulation Approach

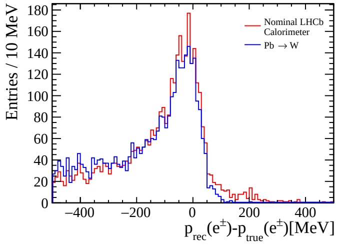
- Simultaneous development in two directions:
  - Full simulation in Geant 4
  - Fast simulation using Delphes
- Fast and full simulation have a symbiotic relationship
- Pushing both projects at once is of utmost importance
- Main questions to answer:
  - How does performance scale with occupancy?
  - How does timing influence the ability to separate signal from background, especially given HL-LHC environment?
  - What detector granularity and response maximizes the physics output while minimizing the cost?
- Goal: Dream big, understand limitations quickly



Geant4 Studies

- Use work by F. Dettori et al. as a starting point
- Reproduce results: change calorimeter material to W. [From M. Röhrken]
- Goal: have generic framework to easily interchange between detector configurations at full simulation level
  1. Implement Gauss level cross-checks for compatibility between fast/full simulation
  2. Provide clusterization independent of digitization conditions
  3. Implement generic digitization for more accurate representation of entire software chain
- Next steps
  - Have comparison for spacial and energy resolution as a function of detector type
  - Have comparison from single-particle level to complete physics event output with fast simulation
- Imperative for tuning of fast simulation

$p(e^{\pm}) = 10$ GeV



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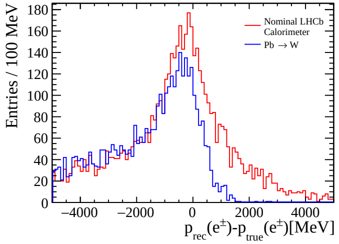
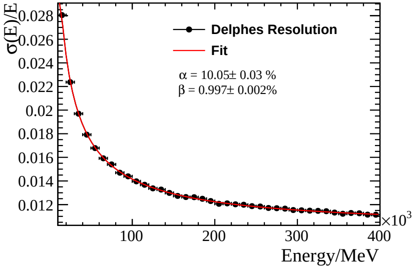


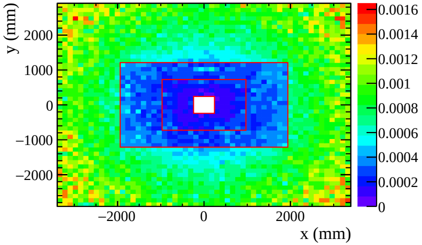
Delphes Simulation

- Delphes is a fully parameterized detector simulation
- Use work by B. Siddi with Delphes as a starting point
  - Start with HepMC particles produced by Gauss
  - Propagate charged particles through LHCb magnetic field
  - Apply efficiency and resolution tunings to match full simulation
  - Write protoparticles directly to the TES
- Extension to neutral protoparticles straightforward
- Use Delphes calorimeter towers as building blocks to make current LHCb calorimeter as proof of principle
- Parameterize energy deposits in neighboring cells
- Next steps: Have full chain tested using $B_s^0 \to \phi\gamma$

Energy Resolution: $\sigma(E) = \frac{\alpha}{E} \oplus \beta$



Spacial Resolution $\delta(\cos\theta)$



Future plans

- With full and fast simulations at hand, begin comparing physics output for different use cases
- Define benchmark physics comparison cases, to name a few

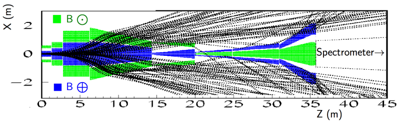
Channel	Use Case
π^0 inclusive	test merged/resolved π^0 resolution
$B_s^0 \to \phi\gamma, \phi \to K^+K^-$	single γ resolution studies
Ke^+e^- aka $R(K)$	di-electron, higher momentum
$D_s \to \phi\pi, \phi \to e^+e^-$	di-electron, lower momentum
$B^+ \to K^+\pi^0$	single π^0, high momentum
$D^{*0} \to D^0\pi^0, D^0 \to K^-\pi^+$	single π^0, low momentum

- Goal: Provide meaningful metrics to help advise on detector choices

Further down the road

- Possible applications of ML techniques to inform
  - Enhanced cluster reconstruction
  - Detector layout optimization
- From A. Ustyuzhanin

Muon Shield Design Case (an example)



- Bayesian optimization: "designed" magnets, that are 25% lighter
- Used metrics, which combines both cost (weight) and physics performance (muon background).

http://iopscience.iop.org/article/10.1088/1742-6596/934/1/012050/meta

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Cluster reconstruction with ML

Well-understood problem:
- Energy Resolution, Particle Identification

Things to undestand:
- Additional design constraints? Pileup?
- Physics channels? Are there any baselines?
- Parametrized detector model (DELPHES/GEANT)?

Challenges:
- Metric that naturally combines physics and cost
- Include Timing
- Is it possible to optimize for design and algorithm simultaneously?

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- Can something similar be done for the ECAL?
- Topics require defined metric
- Full and fast simulation maturity is a prerequisite

Conclusions and looking forward

- A lot of work has been done to bring fast and full simulations up to speed
- Real work is just beginning, but we are closing in on tackling physics goals
  - Geant level studies has framework defined. Incorporation of differing geometries next hurdle
  - Delphes studies are progressing towards completion
  - Down the road, possible ML optimization of clusterization and detector design
- More help is always welcome

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