Detector Requirements and case studies

From the Mid-term report to the Final one

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Introduction

The detector requirements for a Higgs factory have been extensively studied by the Linear collider community.

They need to be revised for FCC-ee:

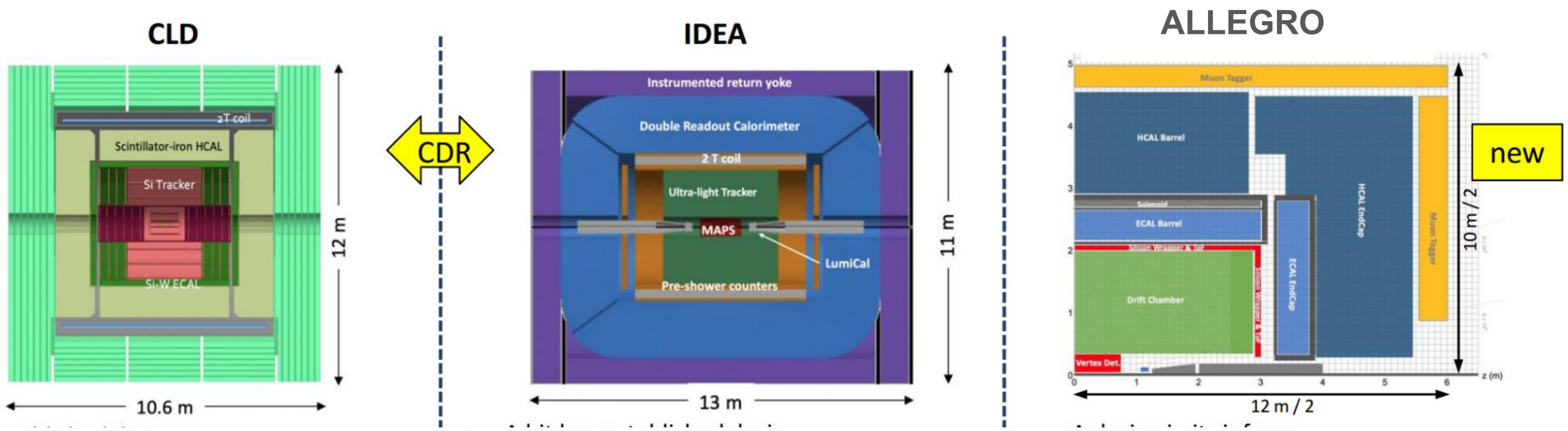
- Different experimental environment
- Huge statistics at the Z for precision Electroweak and Flavor measurement which brings specific challenges
- Exquisite precision on EWK measurement at the Z and WW put also considerable demands on the control of systematic uncertainties due to acceptance, construction quality and stability
- Specific discovery potential for BSM very weakly coupled particles should be considered as well in the detector design

The mid-term report contained a summary of the first round of these studies.

Overall analysis setup

Up to now:

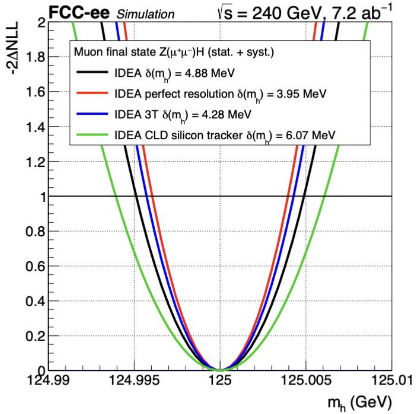
- rely on Delphes FastSimulation with baseline card on the IDEA detector performance
- analysis tools able to provide variations of resolutions to study dependence or precision or sensitivity



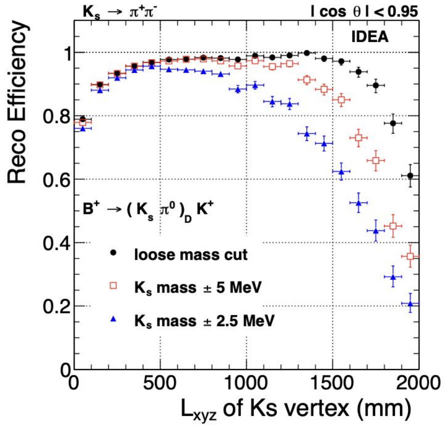
Tracking & Vertexing - Examples considered

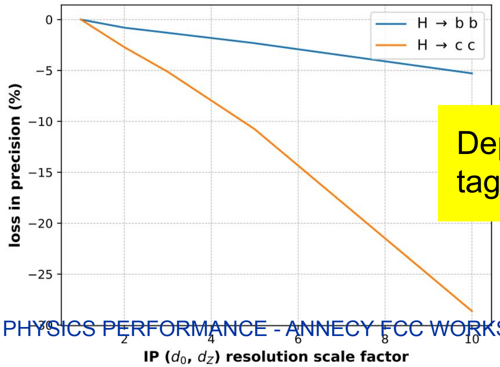
- Higgs mass from recoil in $Z \to \mu\mu$
- LFV $Z \to \tau\mu$
- $e^+e^- \to \mu\mu(\gamma)$ at the Z and above
- $K_s \to \pi^+\pi^-$
- $B \to K^*\tau\tau$
- $e^+e^- \to \gamma\gamma$
- Flavor tagging and $H \to c\bar{c}$
- Tau lifetime
- Higgs coupling to heavy flavour: bottom and charm
- Vertex reconstruction in the measurement of the $B \to K^*\tau\tau$ branching ratio

Higgs recoil with Z->mumu - mass resolution

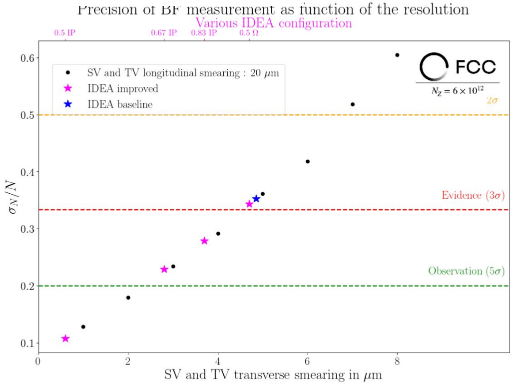


Ks reconstruction eff. Vs. Lxy





Dependence of b & c tagging on IP resolution



BR precision B->K*tt vs SV/TV resolution

FCC-ee specific case showing limitations of current performance

Tracking - Preliminary conclusions

- **large number of measurement points along the tracks is crucial for an efficient reconstruction of Ks, Λ's or other long- lived particles**
  - bonus for an experiment with a stronger focus on flavour or BSM physics.
- **The momentum resolution offered by both tracker designs looks adequate for Higgs measurements.**
  - This statement probably holds as well for most electroweak measurements, with the notable exception of the Z width measurement.
- **For flavour physics at the Z peak, where lower momenta tracks are involved, a low mass, gaseous tracker is advantageous since the momentum resolution is minimally affected by multiple scattering.**
  - Optimisation studies are ongoing to further improve the momentum resolution of the CLD tracker.

Vertexing - Preliminary conclusions

- The measurement of the impact parameters of tracks is driven by the performance of the vertex detector (VXD), as it provides very precise spatial points, in the tracker layers closest to the beam line. **A precise measurement of these parameters is the key for reconstructing vertices, for efficient identification of heavy quarks and tau leptons, and for a powerful measurement of lifetimes.**
- Crucial aspects:
  - contribution of multiple scattering dependent on the material budget of the vertex and beam-pipe
  - The radial distance of the first layer of the vertex detector
- **Two examples have been shown where the physics outcome of FCC-ee would gain of having better vertex detector performances than the one provided by the baseline detectors considered so far.**
  - Engineering studies indicate that the material of the vertex detector layers, compared to that of the baseline IDEA detector, can realistically be achieved.
  - It should be noted that these requirements, tighter than the ones presented for a linear collider detector, will have to be reached despite the additional constraints set by the FCC-ee environment on the readout electronics of the detector

Next steps - Tracking and Vertexing

- New design of the tracker detector (with mechanical structure) implemented in FullSimulation will allow:
  - Check performance due to different material distribution. Optimize design.
  - Test realistic effects of **beam induced background** on the outer tracker (in particular Drift Chamber)
- Develop **new track reconstruction** strategies for the IDEA concept and re-evaluate physics performance (efficiencies and acceptances)
- In addition:
  - Determination of the **stability of the momentum scale for low-pt tracks** at the 10^{-7} from in-situ monitoring of dimuon resonances (⇒ affects the Z width uncertainty)
  - **Tighter constraints on angular resolution** might come from the acceptance studies recently started to determine acceptance in-situ
  - **Further studies for the assessment of uncertainties in the determination of the electroweak observables** (heavy quark, Γ_Z,…)

Inclusive Rb meas.
Selvaggi - Tue afternoon

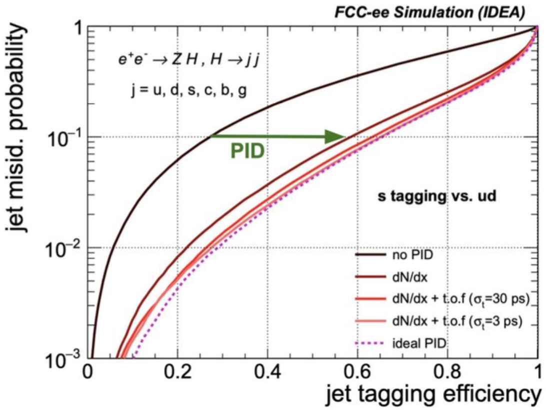
Exclusive Rb meas.
Roehrig - Tue afternoon

Requirements from B->K$\tau\tau$ -*
Miraillles - Tue afte

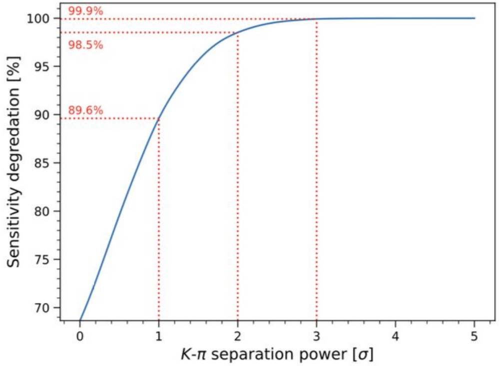
Particle ID - Examples considered

- The PID performance has been studied in the following examples:
  - Strange tagging and Higgs coupling to strange quarks
  - Separation of K± from π± and measurement of $b \to s\nu\bar{\nu}$
  - Separation of K± from π± and measurement of $B_s \to D_s K$

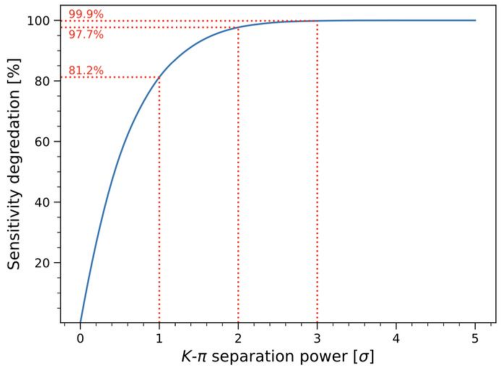
Dependence of strange tagging on PID



$B^0 \to K^{*0}\nu\bar{\nu}$

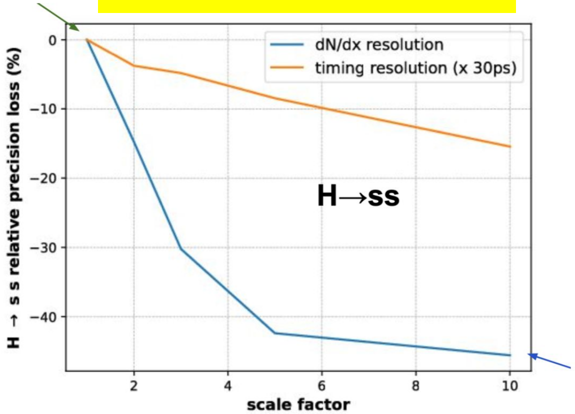


$B_s^0 \to \phi\nu\bar{\nu}$



Dependence of pi/K separation power

Dependence of H->ss on tagging on PID & timing



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Particle Identification - Preliminary conclusions

- **Charged hadron PID is not only needed for flavour physics.** The potential for **constraining the Higgs coupling to strange quarks** provides a strong motivation for having PID, up to high momenta, for all detectors.
  - The large range to be covered, extending from O(150)MeV to 40GeV, is challenging.
- Current studies show that the π/K separation that should be offered by the cluster counting approach (dN/dx), in the IDEA drift chamber, is promising (to be confirmed by Test Beams)
  - In the absence of specific energy loss measurements in the tracker, a design exists for a compact RICH detector, which looks promising
  - Time-of-flight (TOF) measurements, in a single layer at a distance of about 2 meters from the interaction point, fill the gap, around 1 GeV, where the energy loss function is close to its minimum

Next steps - Particle Identification

- Role of PID in flavor tagging ($B_s / \overline{B_s}$), using low momentum kaons:
  - Measurements of *gamma* from $B_s \rightarrow D_s K$ and *beta* from $B_s \rightarrow J/\psi\phi$ might be good benchmark
-
- Tau Branching Ratios: PID at high momenta
  - In particular for *tau→e* to 10^{-5} the calorimeter information might not be enough to achieve needed *e/pion* separation

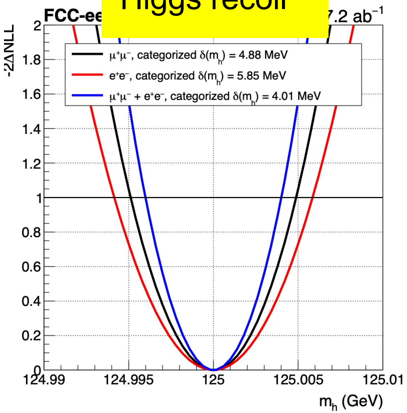
PID tools - Coccaro
Tue afternoon

Tagger and ML reconstruction
Garcia - Tue afternoon

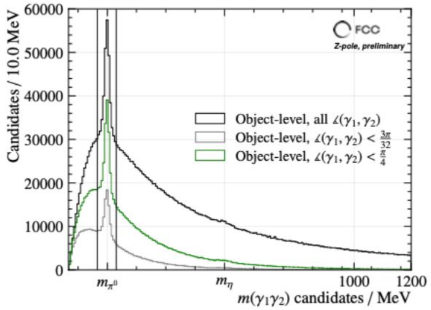
Electromagnetic Calorimeter - Examples considered

- The ECAL performance has been studied in the following examples:
  - Measurement of the Z coupling to νe
  - Sensitivity to Lepton Flavor Violation (cLFV): Z → μe and τ → μγ
  - πo reconstruction in flavour physics
  - Requirements on geometrical acceptance for $e^+e^- \rightarrow \gamma\gamma$ and $\ell^+\ell^-$ events at Z
  - Bremsstrahlung recovery
  - Requirements from $\pi^0 \rightarrow \gamma\gamma$ reconstruction in τ decays
  - Requirements from πo → γγ reconstruction in heavy-flavour jets in EWK processes

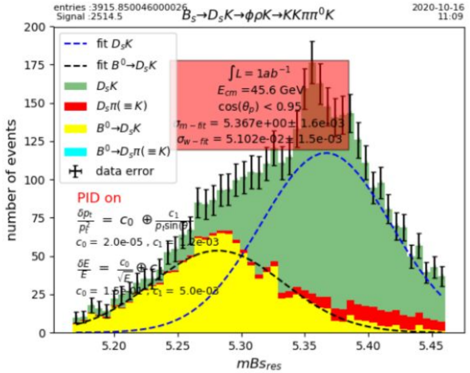
Higgs recoil

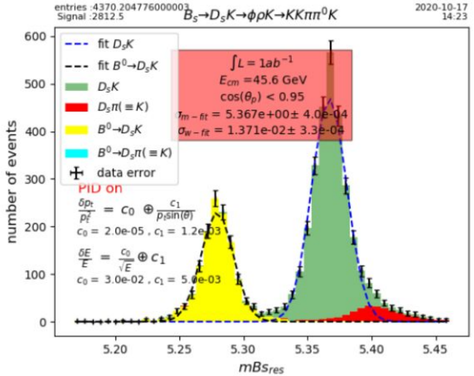


Pi0 reconstruction in Z->bb events

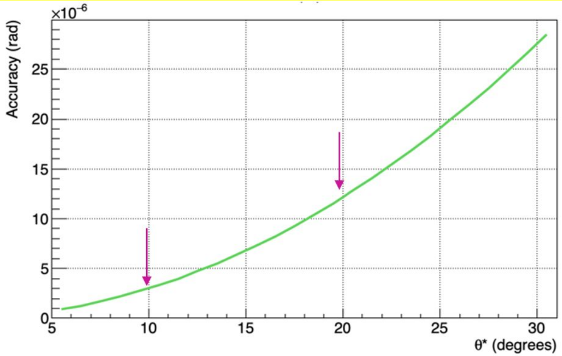


Improved separation in Bs->DsK (with neutral)





Accuracy on photon acceptance vs polar angle cut



Electromagnetic calorimeter - Preliminary conclusions

- Various technologies and designs have been considered for the studies (fast and full simulation) of the requirements on the electromagnetic calorimeter:
  - A Dual Readout (DR) calorimeter that uses scintillation and Cerenkov fibres to measure at the same time the EM and HAD deposits.
  - A variant of this concept with an EM crystal section with dual-readout capabilities placed in front of the DR calorimeter
  - A high granularity ECAL built as a sandwich of tungsten plates and silicon sensors as in CLD
  - A high granularity noble liquid ECAL as in ALLEGRO
- These concepts have different characteristics for energy resolution, granularity and position resolution.
- **An electromagnetic calorimeter with improved energy resolution (such as few %) and high granularity (1 × 1 cm), is crucial for the efficient and precise identification of $\pi0$s both in the lower energy range in the context of flavour processes and in the higher energies electroweak ones with heavy flavour jets.**
- **The efficient reconstruction of low energy photons will also improve the overall hadronic jet energy resolution** with particle flow.
- Such characteristics are also important for **new physics signatures with photons**, such as ALPs.

Next Steps - Electromagnetic calorimeter

Possible benchmarks:

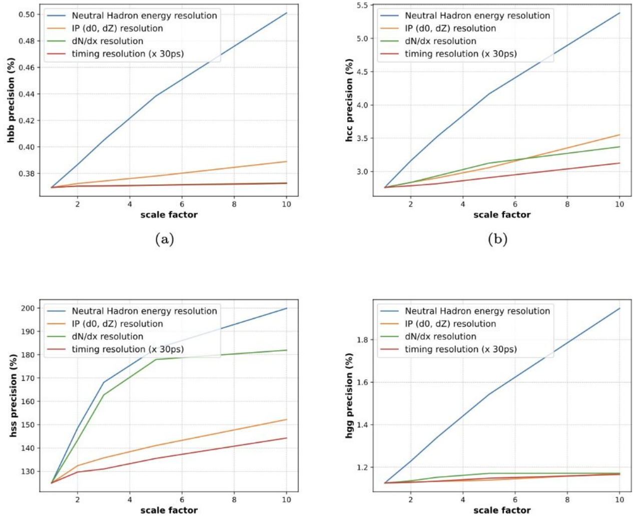
- **Tau polarization:** dependence on π^0 reconstruction (crucial at LEP)
- **Luminosity with $\gamma\gamma$** : clear constraints on acceptances and angular measurements
- **ALPS and multiphoton** final state with low energy
- Effect of (low energy) **photon and pi0 reconstruction on jet resolution** in particle flow reco.

e/gamma separation for luminosity measurement with diphotons - Wilson- Wed afternoon

Hadronic Calorimeter - Examples considered

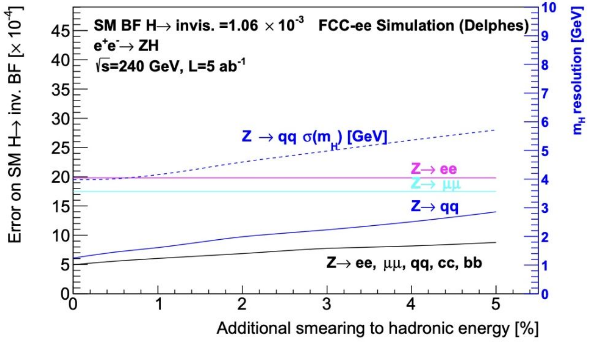
- The HCAL performance has been studied in the following examples:
  - Higgs hadronic final states
  - Higgs invisibile width
  - Search for Heavy Neutral Lepton

Dependence of H hadronic BRs

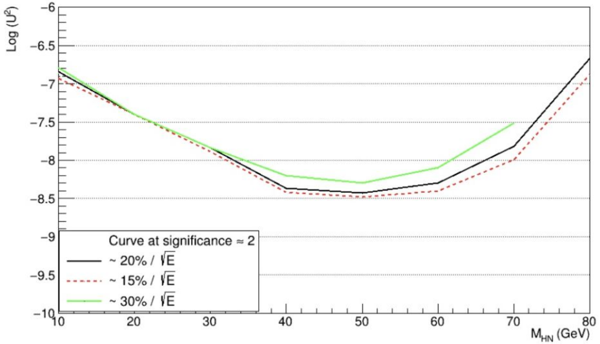


(a) (b) (c) (d)

Dependence of error on H invisible BR



Dependence of sensitivity for HNL



HNL - Valle Tue morning

Hadron calorimeter - Preliminary conclusions

- *a state-of-the-art event reconstruction in the new software based on the particle flow approach is not yet available, as it requires a full simulation of the detector concepts still in progress.*
- Right now is challenging to determine specific requirements using DELPHES.
  - **smearing the resolution on the hadronic energy at the analysis level** allows to obtain a preliminary estimate of the dependence of the analysis result as a function of the resolution.
- In the context of the processes with hadronic final states studied (Higgs and BSM), we observe a **strong dependence on the calorimeter resolution for those regions with a low signal to noise,** where it is important to have a good separation between the signal, (such as colour singlet boson, or the invisible mass of the event) and the background distribution.
  - These preliminary requirements seem to be satisfied by the proposals in the current baseline.

Next steps - Hadron calorimeter

- **Significant work on event reconstruction in FullSim is needed**

- Availability of Full Simulation response will allow to explicitly determine the dependence of the results on the calorimeter resolution exploring **the effects of low level objects response** from the calorimeter clustering, to the determination of the PF candidates, or the assignment of candidates to a specific hadronic decay.
- We need to perform studies to understand the details of the **effect of background** on the overall performance (worse at low S/N).

- Possible benchmarks:
  - Separation of colour singlet bosons or missing energy resolution
  - Multijet events to be used to test the needs for angular resolution

Considerations on Muon Detector

Main objective: identify muons with high efficiency + tail-catcher for had showers

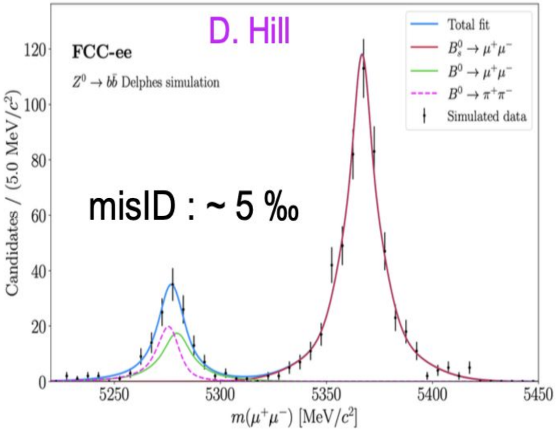


Figure of merit: ID efficiency vs $\pi \to \mu$ misID probability

Example benchmark: control of pion contamination in measurement of B -> mumu

Standalone measurement of track's momentum:

- Useful to identify pions that decay in flight and reduce the pion contamination
- Also relevant for LLPs that decay outside of the tracker volume
- Requirements on standalone resolution need to be quantified.

Considerations on Precise Timing

Few motivations for precise timing measurement have been explored, likely this will be expanded significantly next year with the FullSimulation:

- **TOF measurements:**
  - For PID: see earlier, e.g. at 2m from the IP, in dedicated layer or in SiW Ecal
  - Determination of mass and lifetime of new massive particles
- **Time measurements very close to the IP**
  - Allows a determination of the ”event t0”
    - Robust reference for the TOF measurements
    - Width of t0 distribution -> independent determination of the BES
    - Exploit correlation between t0 and longitudinal position (within the bunch) of the interacting electrons
  - Achieving precise timing measurements in the innermost layer of the VXD, without compromising heavily the material budget, will probably be a challenge
- **Time measurements in the calorimeters**
  - Handles to exploit the shower development in space and time
    - Possible benefit remains to be studied in detail
  - DR calo: precision timing -> longitudinal segmentation

HNL mass from timing - Polesello - Tue afternoon

Summary and next steps

- **The content in the Mid-Term was largely based on original work**
- Focus has been spent in stretching as far as possible the possibilities to extract significant detector requirements from Delphes simulation.
  - Several notes are available in CDS documenting the studies. Becoming public to the PED FS group members.

- **Several benchmark studies have already been identified that are essential to inform optimal design strategies and be shared with the Detector group**
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- **An influx of new resources is necessary** to speed up the work, in particular to be able to profit of the FullSimulation:
  - A strong software group to provide tools on a timely fashion is essential
  - A clear support to motivate the detector performance studies is needed