Muon Collider Workshop

# Plan for future studies

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**for**
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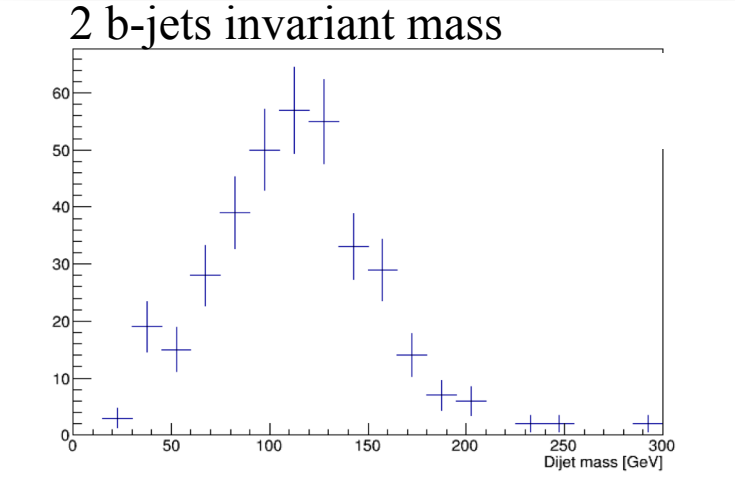
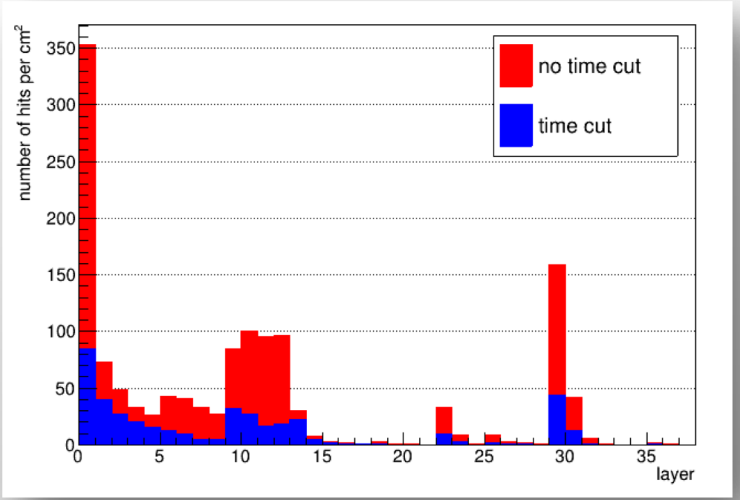
# Where we are

- Detector for muon collider is different from any current or conceived detector up to now, because muon decays.
- MAP developed a realistic simulation of beam-induced backgrounds in the detector for 62.5 GeV and 750 GeV muon beams.
- Results presented by N. Bartosik and L. Sestini demonstrated physics measurements can be done with 750 GeV muon beams using one of the most difficult physics process $\mu^+\mu^- \rightarrow H\nu\bar{\nu} \rightarrow b\bar{b}\nu\bar{\nu}$

Everything is done with full simulation




With the proper detector to exploit time information to cut beam-induced background




We plan to publish the results

# Where we want to arrive with a full simulation

Demonstrate that at muon collider it is possible to determine the Higgs potential by measuring trilinear and quadrilinear self coupling

$$V = \frac{1}{2}m_h^2 h^2 + (1 + k_3)\lambda_{hhh}^{SM} v h^3 + (1 + k_4)\lambda_{hhhh}^{SM} h^4$$

**Trilinear coupling, $k_3$**

- $\sqrt{s} = 10\ TeV, \mathcal{L} \sim 10^{35} cm^{-2} s^{-1}$
- 10 ab$^{-1}$

$k_3$ sensitivity ~ 3%

Best sensitivity ~5% FCC combined (arXiv:1905.03764)

**Quadrilinear coupling, $k_4$**

- $\sqrt{s} = 14\ TeV, \mathcal{L} \sim 10^{35} cm^{-2} s^{-1}$
- 20 ab$^{-1}$

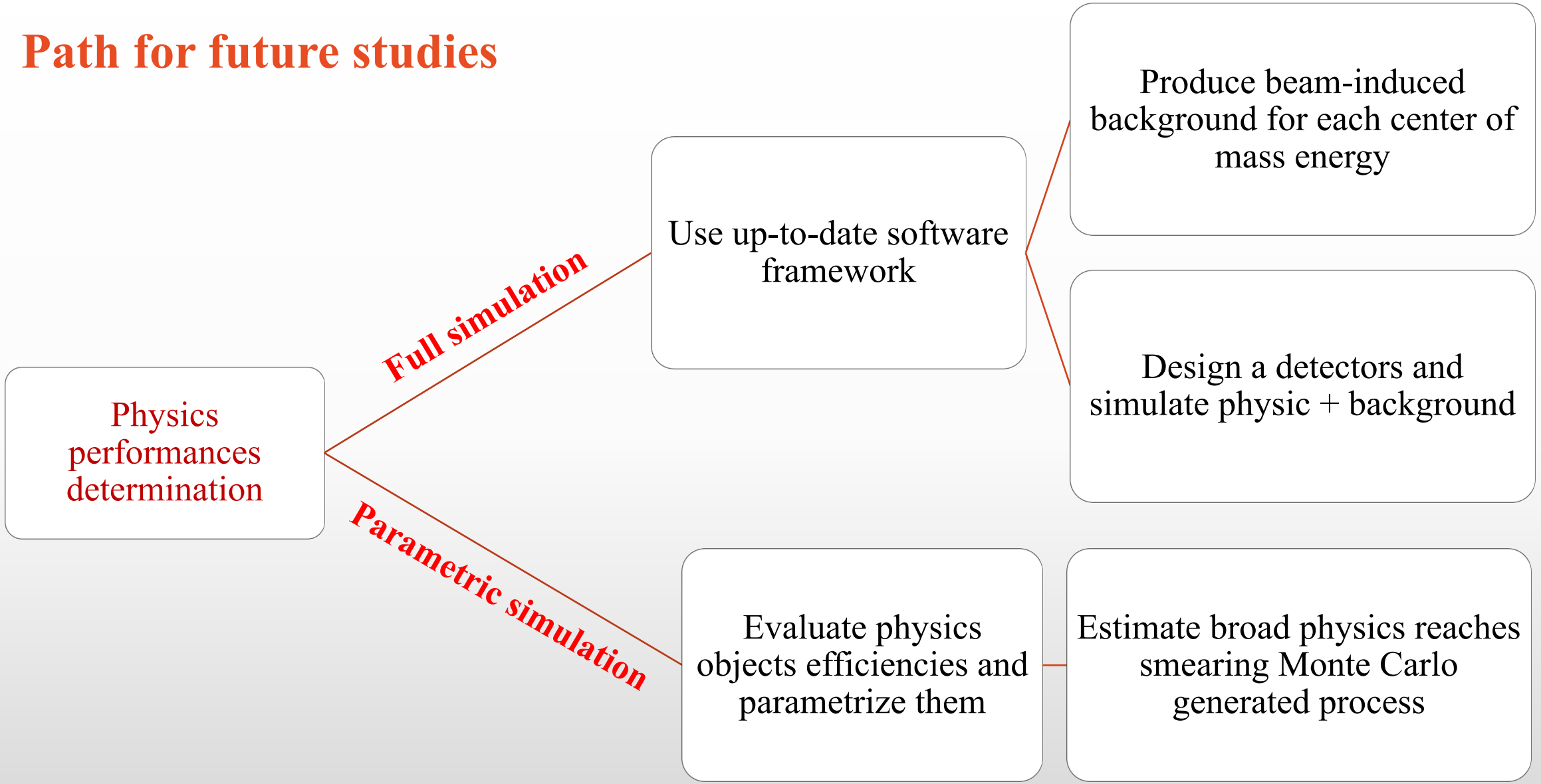
$k_4$ sensitivity $few$ 10%

FCC-hh in a optimistic scenario 30 ab$^{-1}$

$\lambda_4 = \in [\sim -4, \sim +16]$@68% $C.L.$ (arXiv:1905.03764)

This just looking at the Higgs sector! Top, new physics sector still to be opened

# Path for future studies

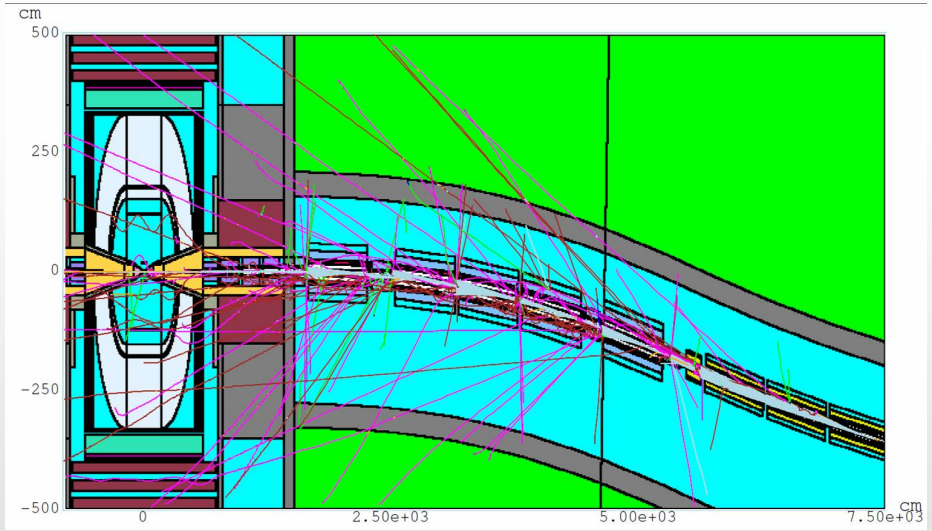


# Full Simulation: beam-induced background

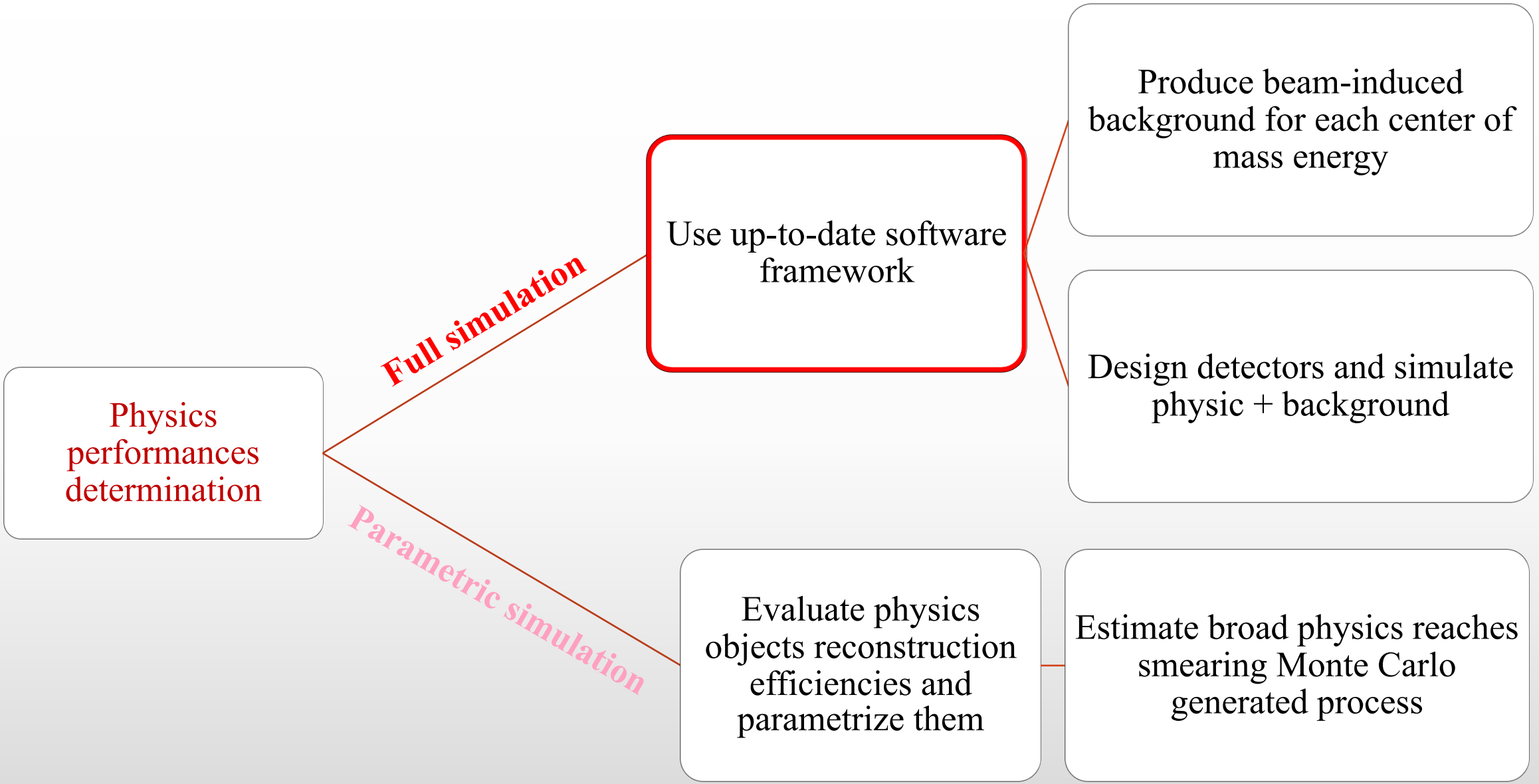
MAP developed a realistic simulation of beam-induced backgrounds in the detector:

- implemented a model of the tunnel ±200 m from the interaction point, with realistic geometry, materials distribution, machine lattice elements and magnetic fields, the experimental hall and the machine-detector interface (MDI);
- secondary and tertiary particles from muon decay are simulated with MARS15 then transported to the detector borders

In particular, the two tungsten nozzles, cladded with a 5-cm layer of borated polyethylene, play a crucial role in background mitigation inside the detector.




**For each collider energy the machine elements, the MDI and interaction region have to be properly designed and optimized.**

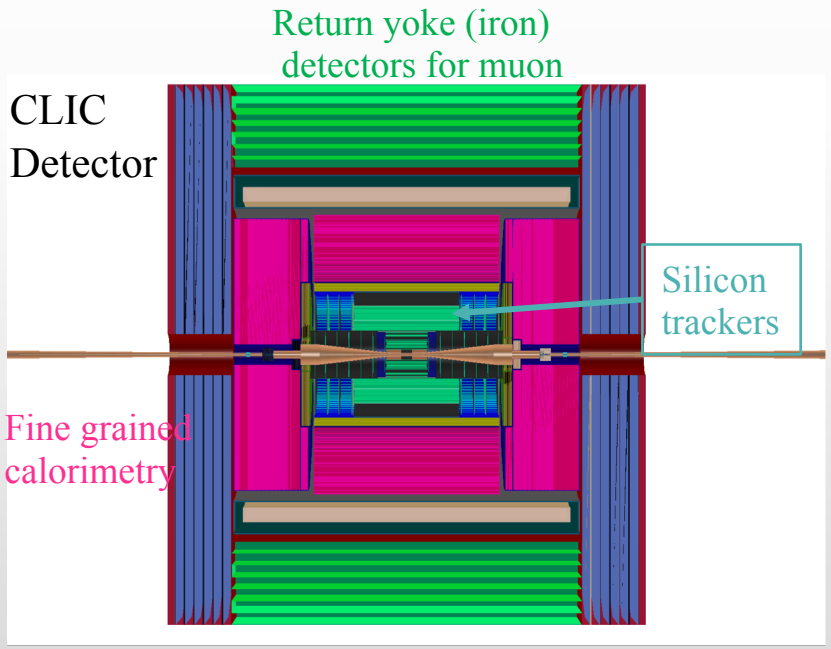

Physics performances determination
Full simulation
Use up-to-date software framework
Produce beam-induced background for each center of mass energy
Design detectors and simulate physic + background
Parametric simulation
Evaluate physics objects reconstruction efficiencies and parametrize them
Estimate broad physics reaches smearing Monte Carlo generated process

# Full Simulation: up-to-date framework

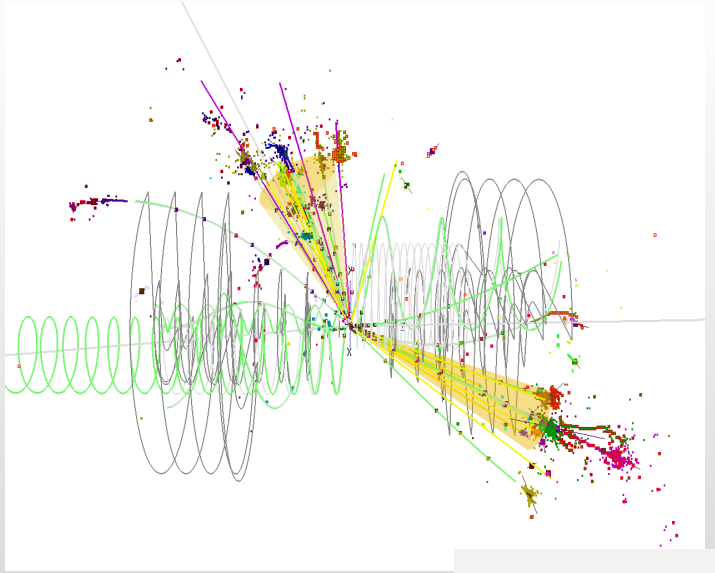
A project to create a Future Collider Software framework is in progress,  we aim to be part of it.
Therefore, moving to the iLCsoft

- GEANT4 for detector description and simulation
- MARLIN for physics objects reconstruction, tracks and jets at the moment

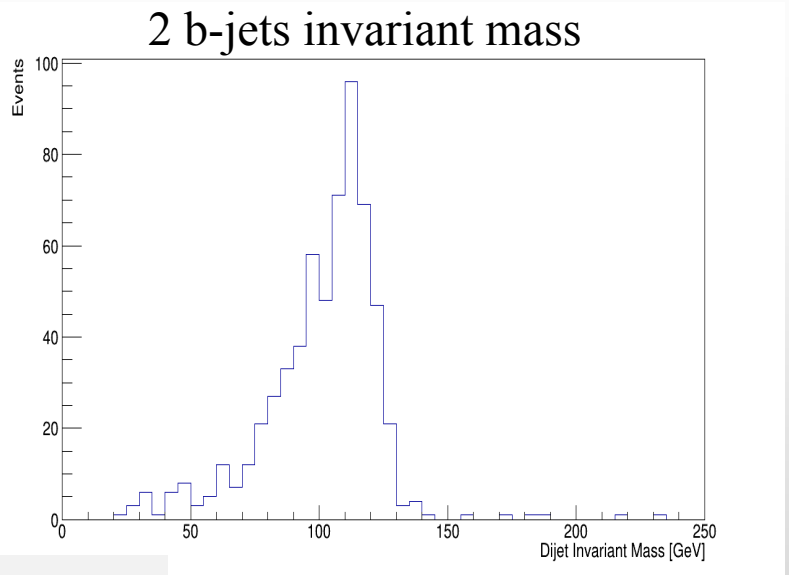
Practice with the framework: reconstruct signal $\mu^+\mu^- \rightarrow H\nu\bar{\nu} \rightarrow b\bar{b}\nu\bar{\nu}$ $@\sqrt{s} = 1.5\ TeV$ in the CLIC detector



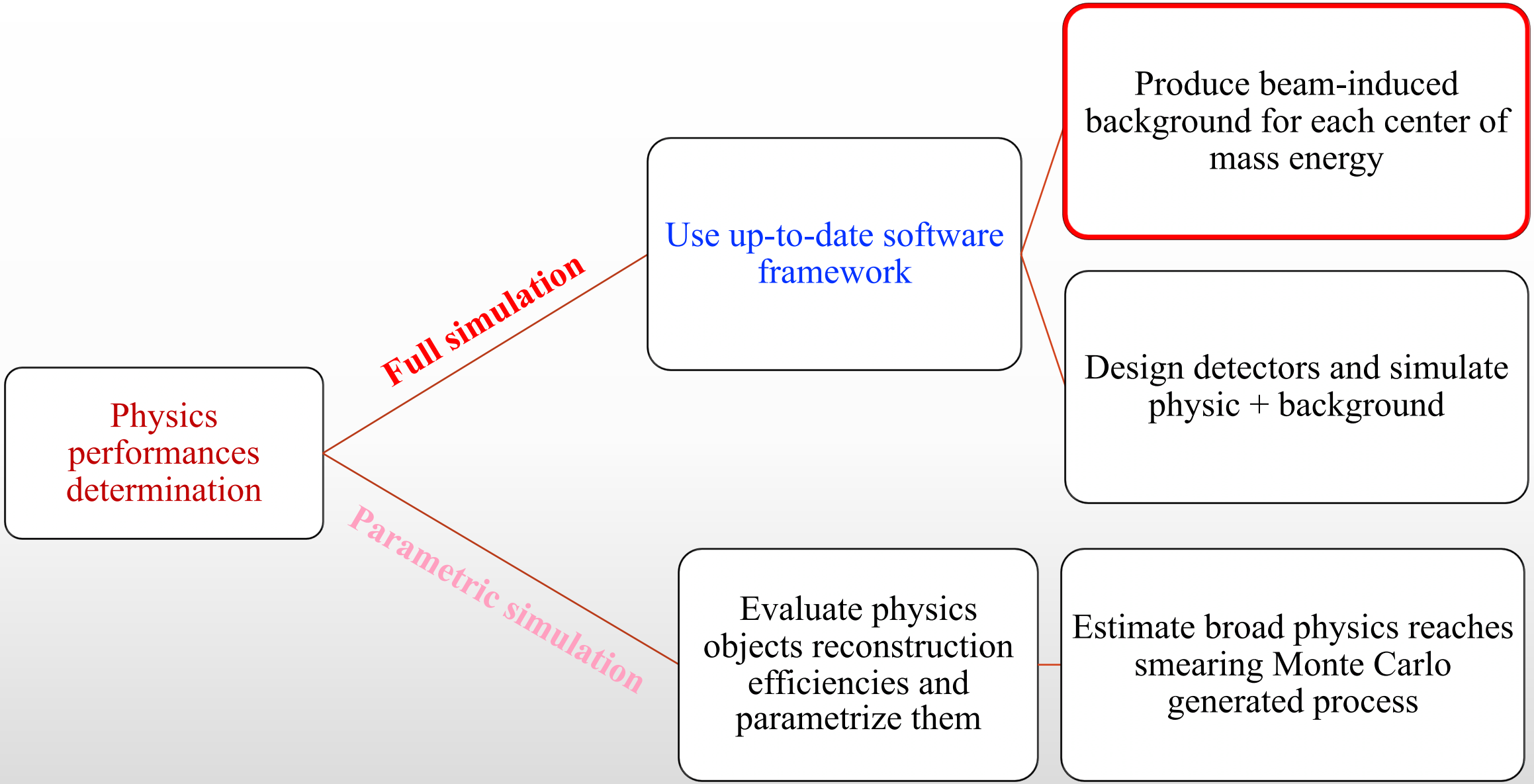

Successful simulation and tracks and jet reconstruction



2 b-jets invariant mass




Laura Buonincontri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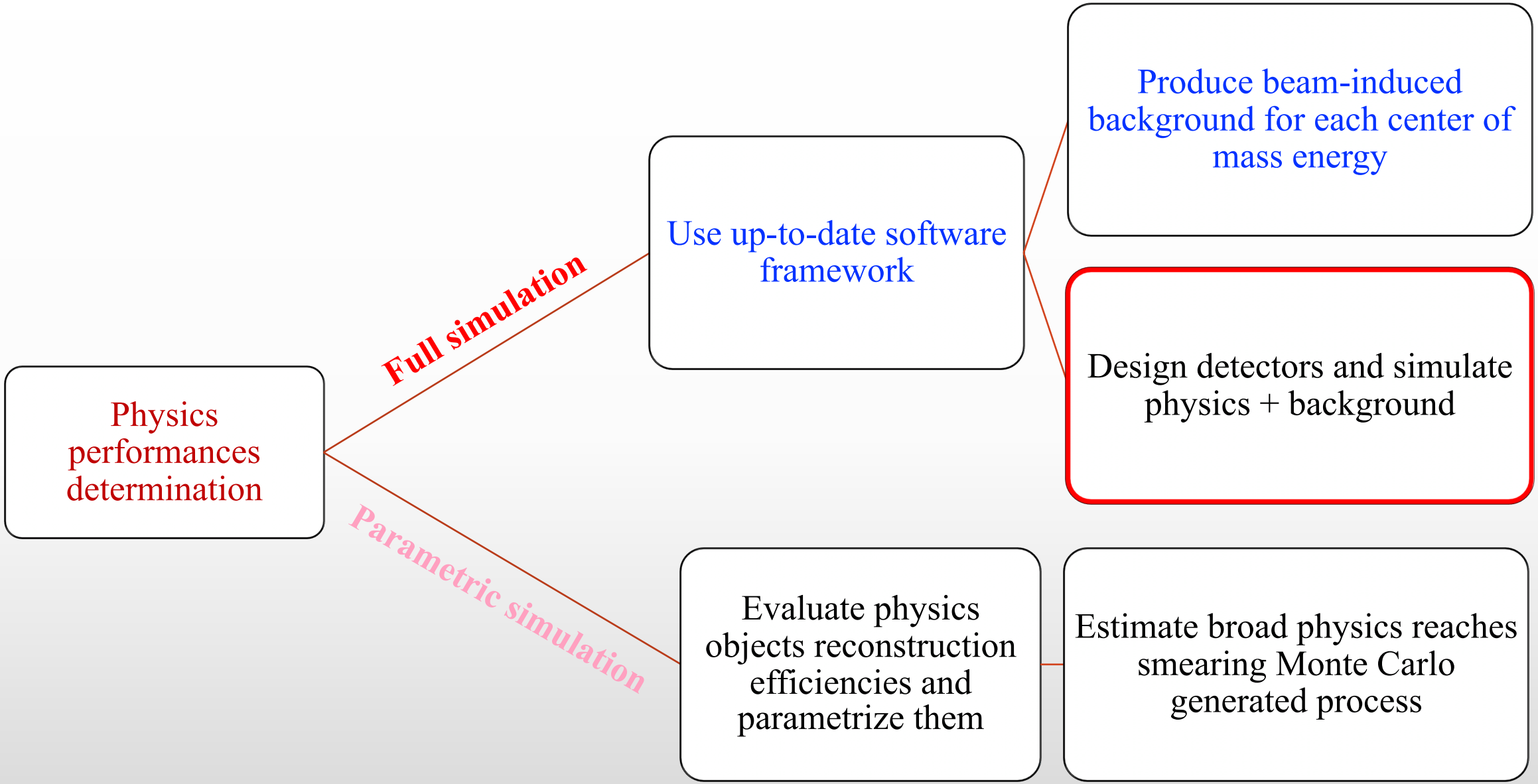
# Full Simulation: Produce beam-induced background for each center of mass energy

- We are planning to
  - produce beam-induced background using FLUKA, MAP used MARS15 and results were verified against FLUKA
  - use the MAP MDI for the available machine designs

- FLUKA experts are working to produce a software framework to easily
  - read MDI description for each center of mass energy
  - produce beam-induced background data

- These files will be read by iLCsoft and superimposed to the physics signal process

- We would like to start from MAP MDI and detector design for collider at $@\sqrt{s} = 1.5\ TeV$ to reproduce previous results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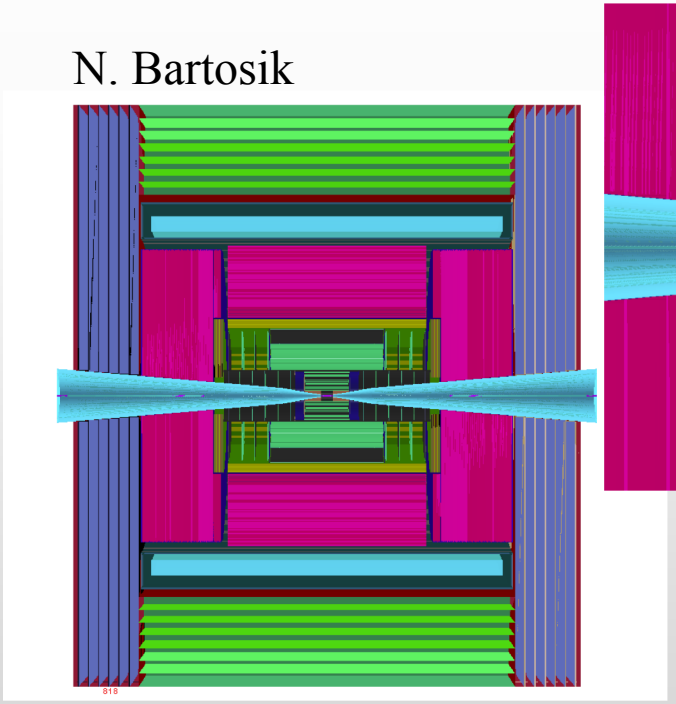
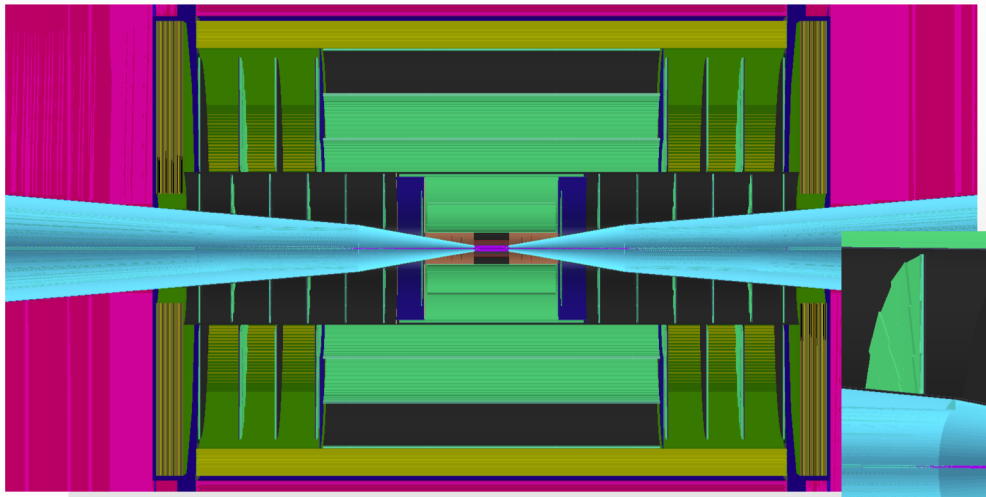
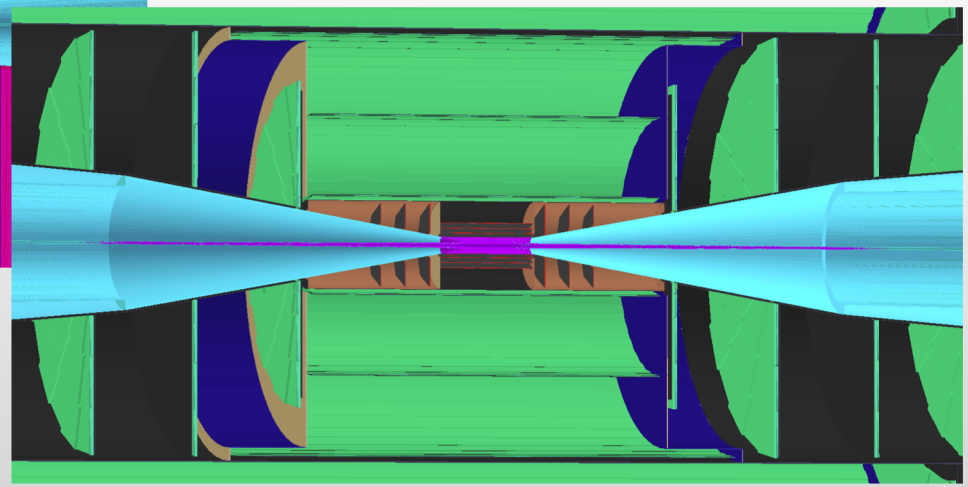
# Full Simulation: Design detectors, study physics benchmarks

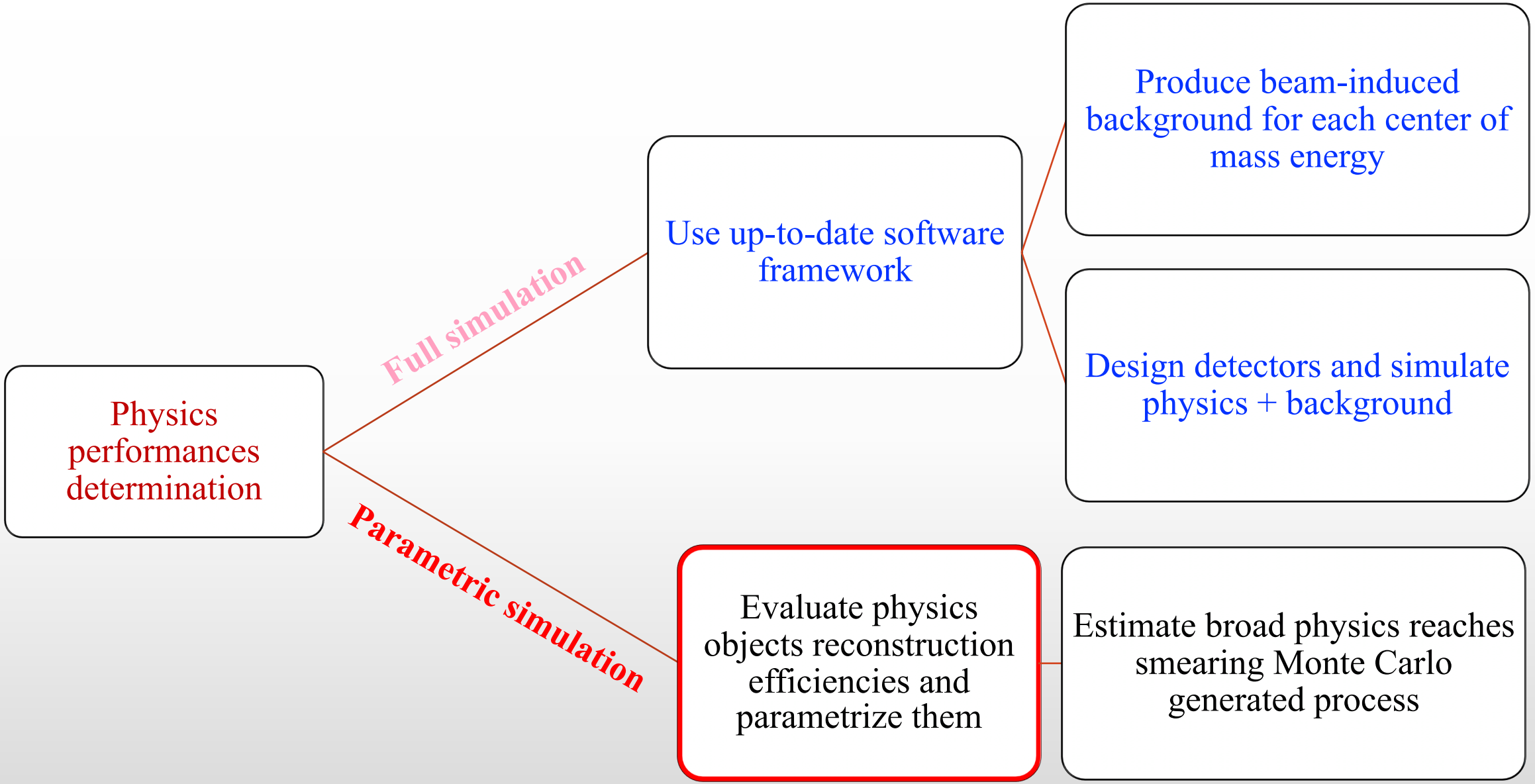
- Design a detector in detail will be the task of a collaboration, we aim to sketch it for physics studies.
- Nozzle angle depends on center of mass energy, beam intensity and interaction region lattice, therefore detector depends on all of them.
- We will start from what we learned so far with MAP simulation and reconstruction for collider at $@\sqrt{s} = 1.5\ TeV$ to reproduce previous results
- Study physics benchmarks

N. Bartosik





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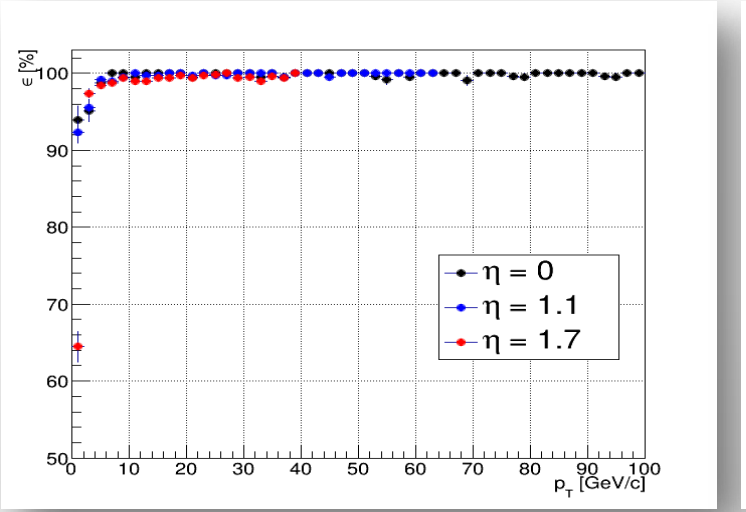
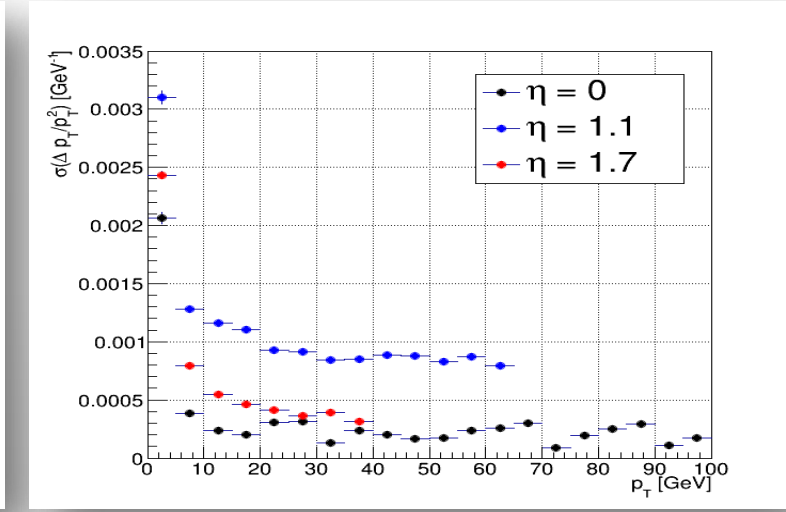
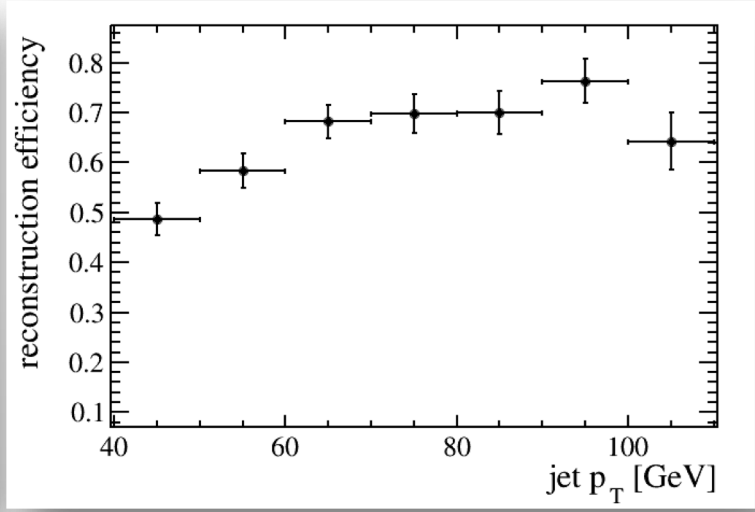
# Parametric simulation: evaluate physics objects efficiencies

With MAP software we determined preliminary physics objects reconstruction efficiencies and resolutions $@\sqrt{s} = 1.5\ TeV$

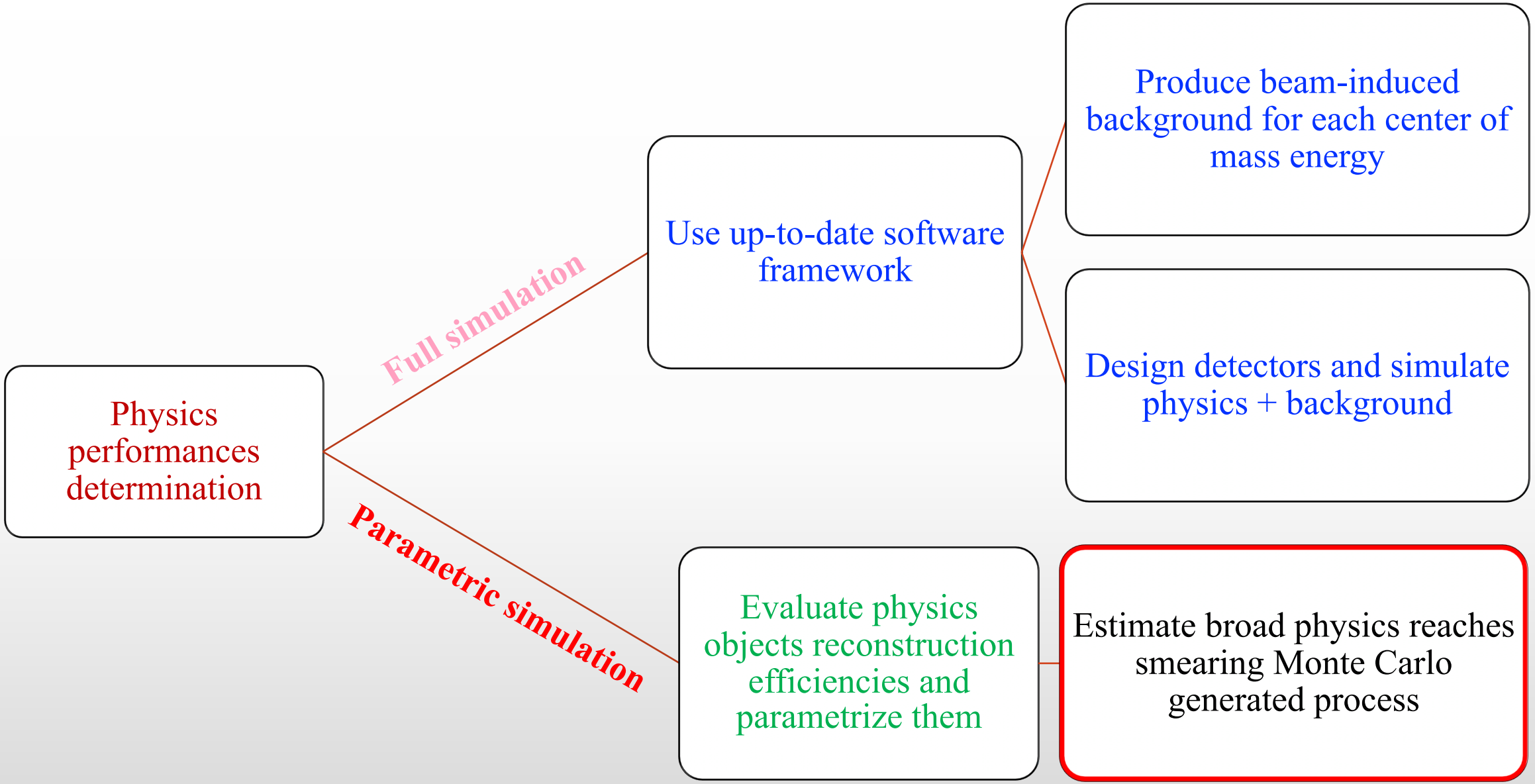



We plan to

- re-do them with the new framework
- evaluate efficiencies and resolution for other center of mass energies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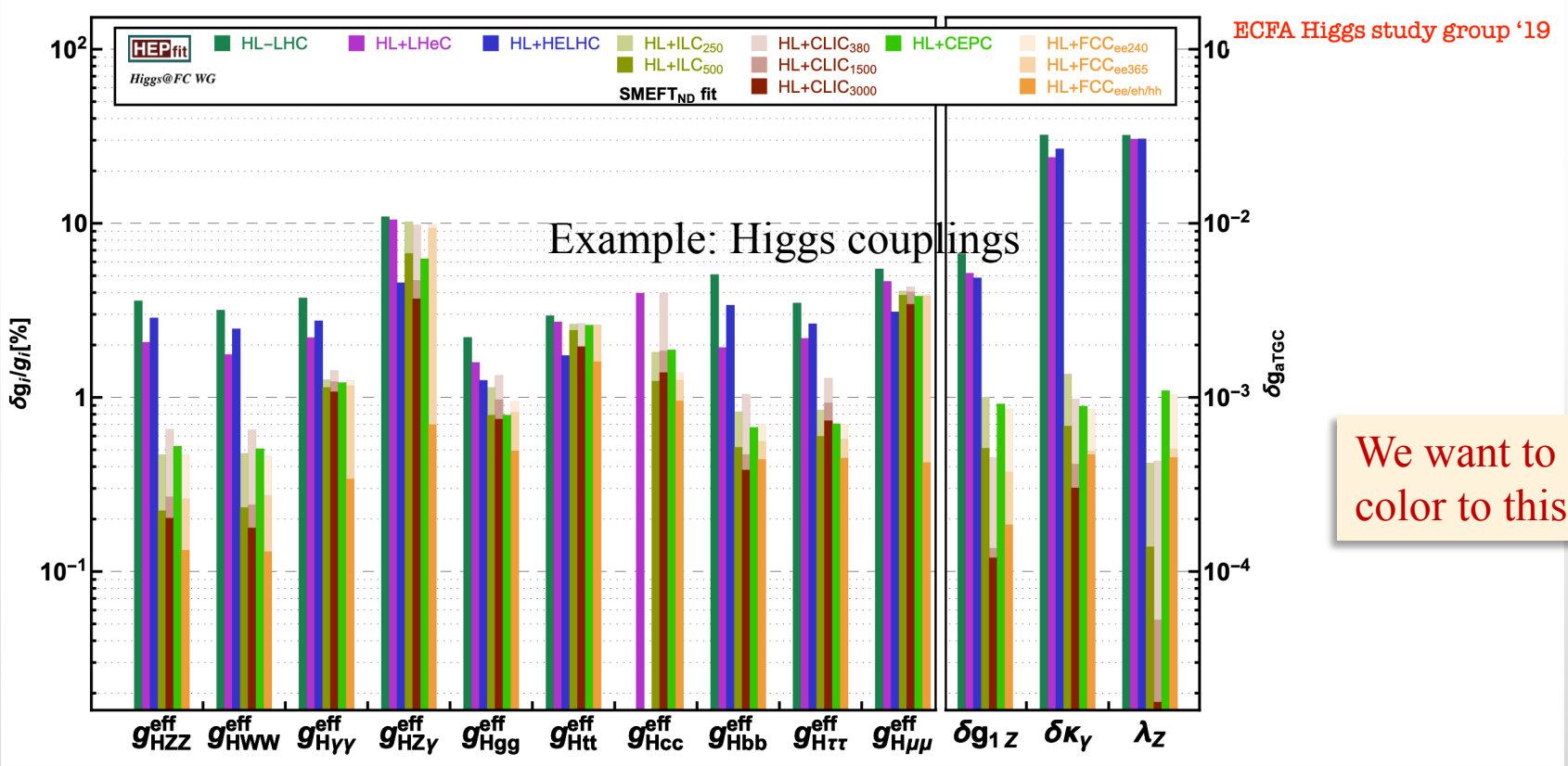
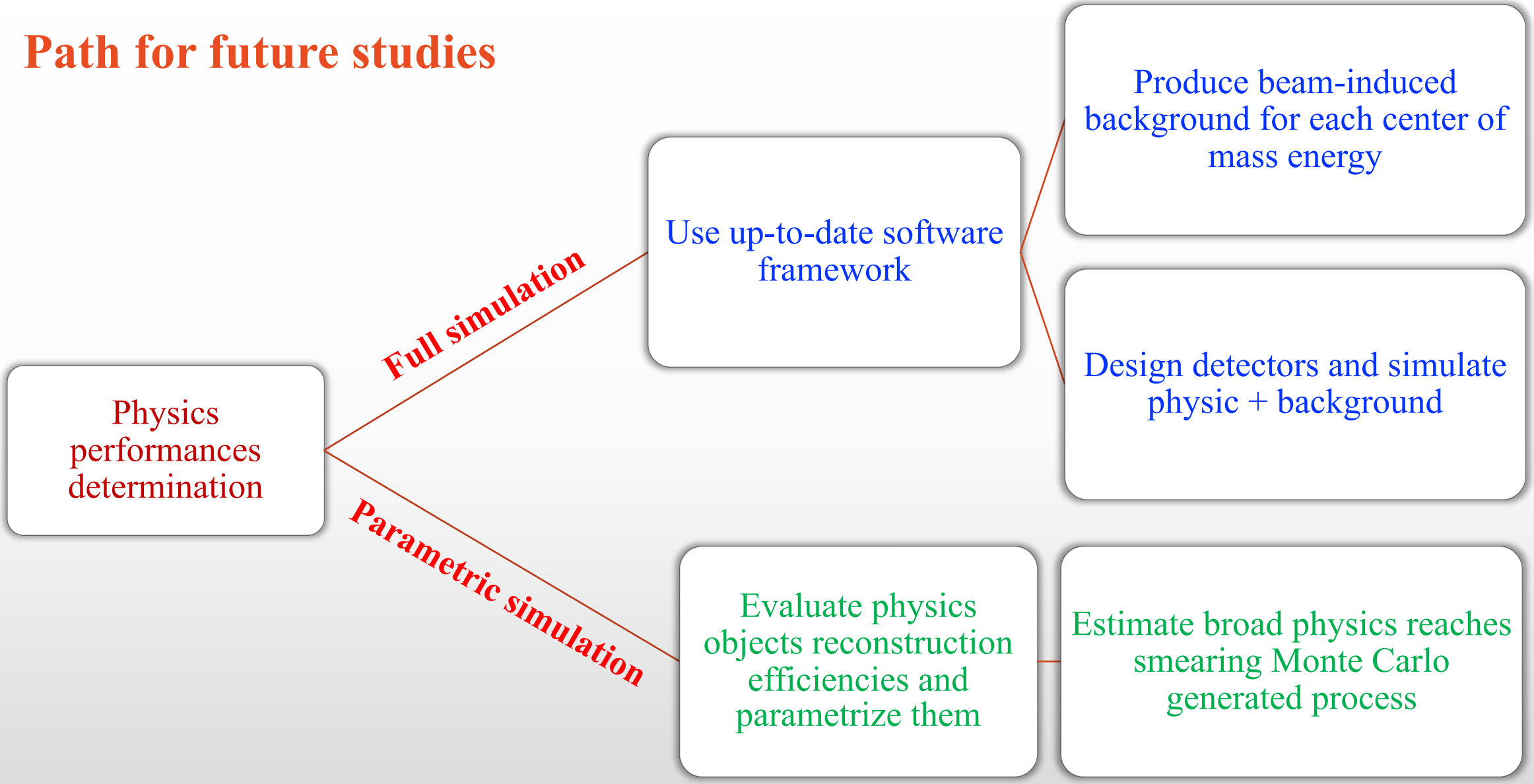
# Parametric simulation: Estimate physics performances

Generate physics process (H, tt, NP, EWK …), apply efficiencies and acceptance cuts à la Delphes and determine reaches

Example: Higgs couplings



# Path for future studies