Computing Performance Results and Issues: CMS

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On behalf of the CMS Collaboration

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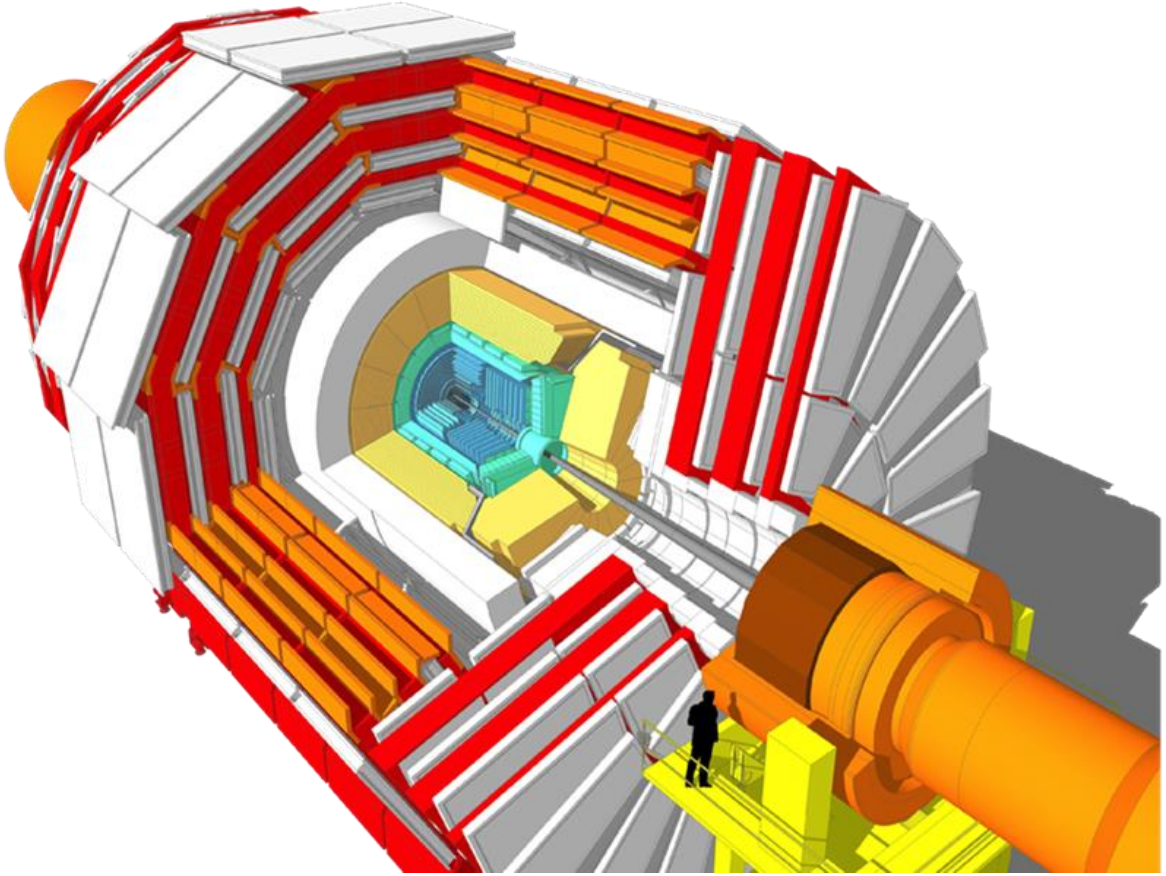
Outline

- CMS full simulation for Run3
- CPU performance evolution
  - CMS-DP/2023-063
- Test-beam validation results
  - CMS-DP/2023-064

- *Progress with Phase2 simulation for CMS and fast simulation methods will not be discussed*



CMS FullSim for Run-3 LHC

- Run-2 simulation production
  - MT mode from 2017
  - Geant4 10.4p03 + VecGeom since 2018 (legacy MC production)
  - The configuration of physics includes
    - FTFP_BERT_EMM Physics List
    - Russian roulette method
    - HF (forward hadronic calorimeter) shower library
- References:
  - *D.J. Lange et al., J. Phys.: Conf. Ser. 608, 012056 (2015)*
  - *M. Hildreth et al., J. Phys.: Conf. Ser. 664, 072022 (2015)*
  - *M. Hildreth et al., J. Phys.: Conf. Series 898, 042040 (2017)*
  - *V. Ivanchenko and S. Banerjee, EPJ Web of Conf. 214, 02012 (2019)*

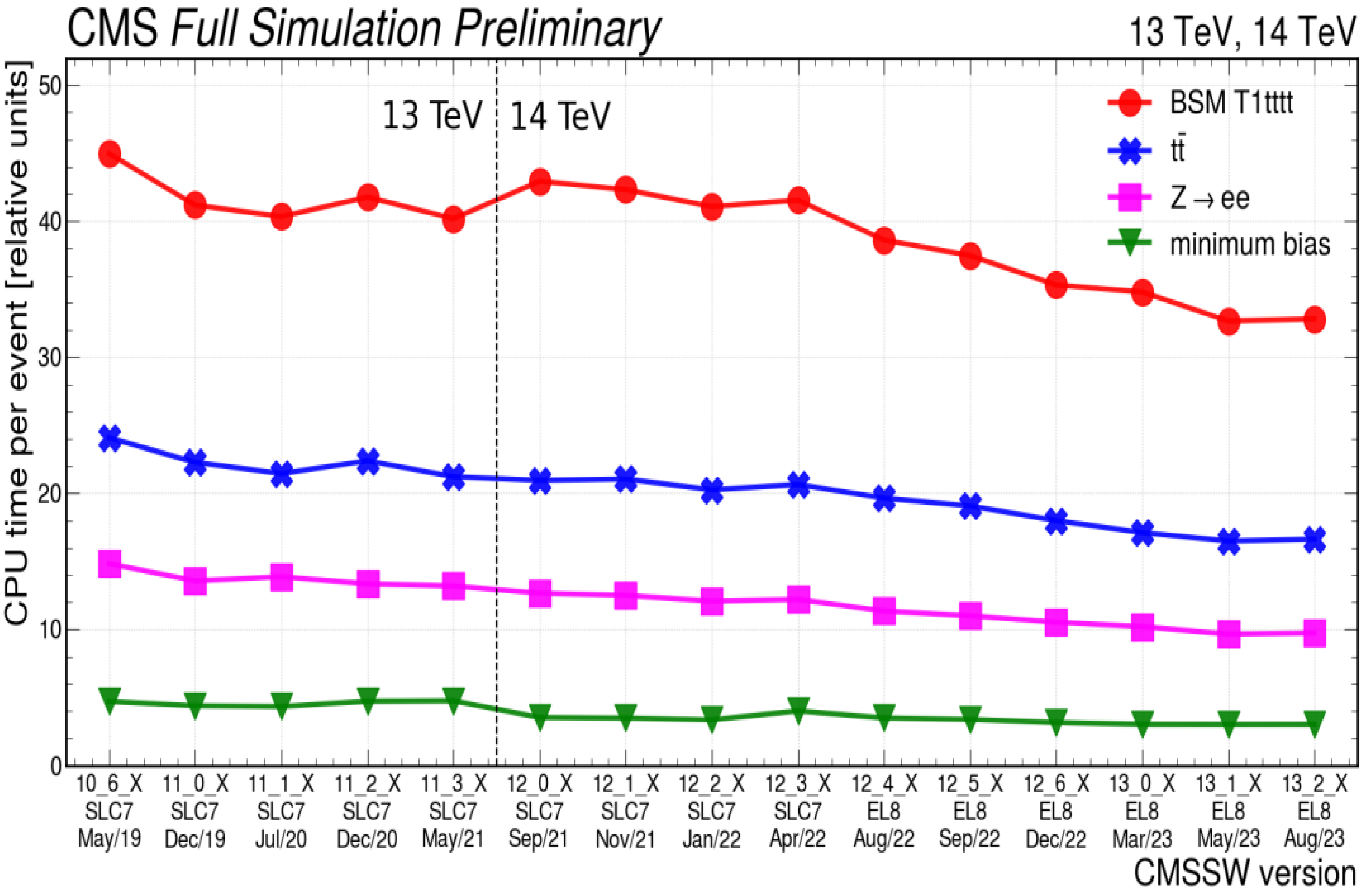
- Run-3 simulation production
  - For 2022 and 2023 experiment
    - DD4hep geometry description
    - Geant4 10.7.p02 + CMS private patches
  - In 2023 added to the base-line
    - Gamma general process
    - LTO library build
    - Geant4 11.1.p01
  - Adopted for 2024 experiment
    - Geant4 11.1.p02
    - Extra cut on photoelectric effect
    - G4TransportationWithMsc process
- References:
  - *CMS/DP-2018/045 (2018)*
  - *CMS/DP-2020/050 (2020)*
  - *S. Banerjee and V. Ivanchenko, Web of Conferences 251, 03010 (2021)*
  - *V. Ivanchenko et al., Web of Conferences 251, 03016 (2021)*
  - *CMS/DP-2023/063 (2023)*
  - *CMS/DP-2023/064 (2023)*

CMS simulation performance for Run-2

- CMS efforts to speed-up simulation are permanent
  - Using optimal compilers
  - Using the most recent Geant4
- Several optimizations were introduced to Geant4 configuration for CMS
  - Simulation production for CMS Run-2 is 4-5 times faster than the Geant4 default FTFP_BERT

Run-2 simulation performance

	Relative CPU usage	
Configuration	Minbias	$t\bar{t}$
No optimizations	1.00	1.00
Static library	0.95	0.93
Production cuts	0.93	0.97
Tracking cut	0.69	0.88
Time cut	0.95	0.97
Shower library	0.60	0.74
Russian roulette	0.75	0.71
FTFP_BERT_EMM	0.87	0.83
All optimizations	0.21	0.29

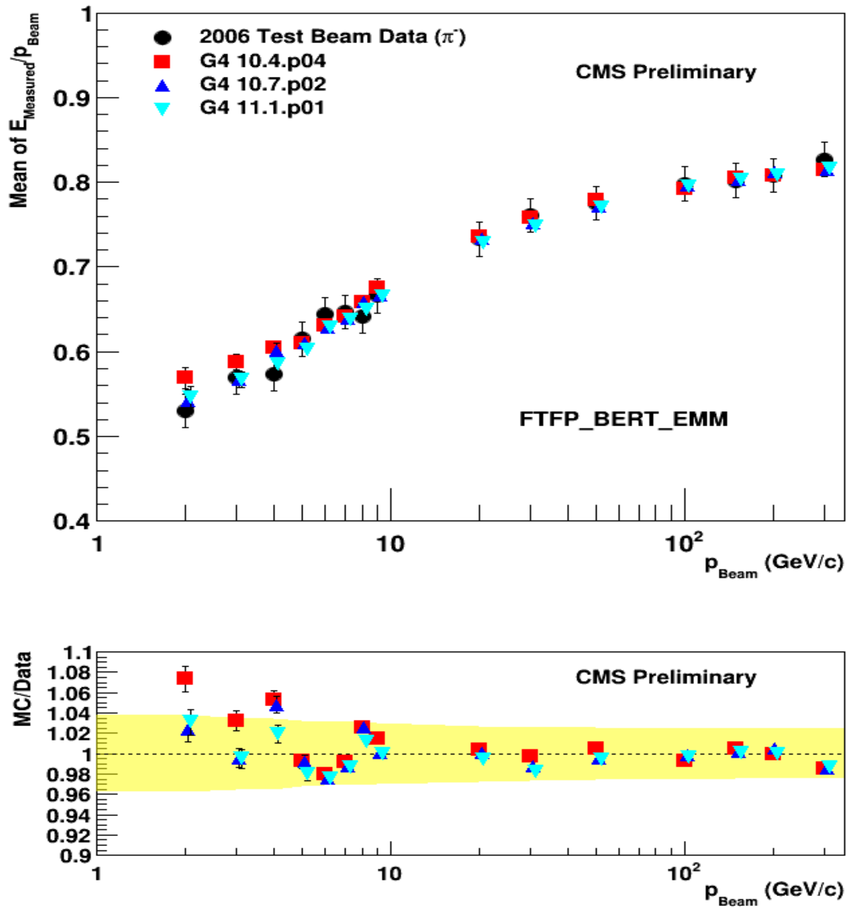


During the ~4 years between the versions 10_6_X and 13_2_X the CPU time has improved for the processes: minimum bias by 36 %, ttbar by 32 %, BSM T1tttt by 27 % and Z -> ee by 32 %.

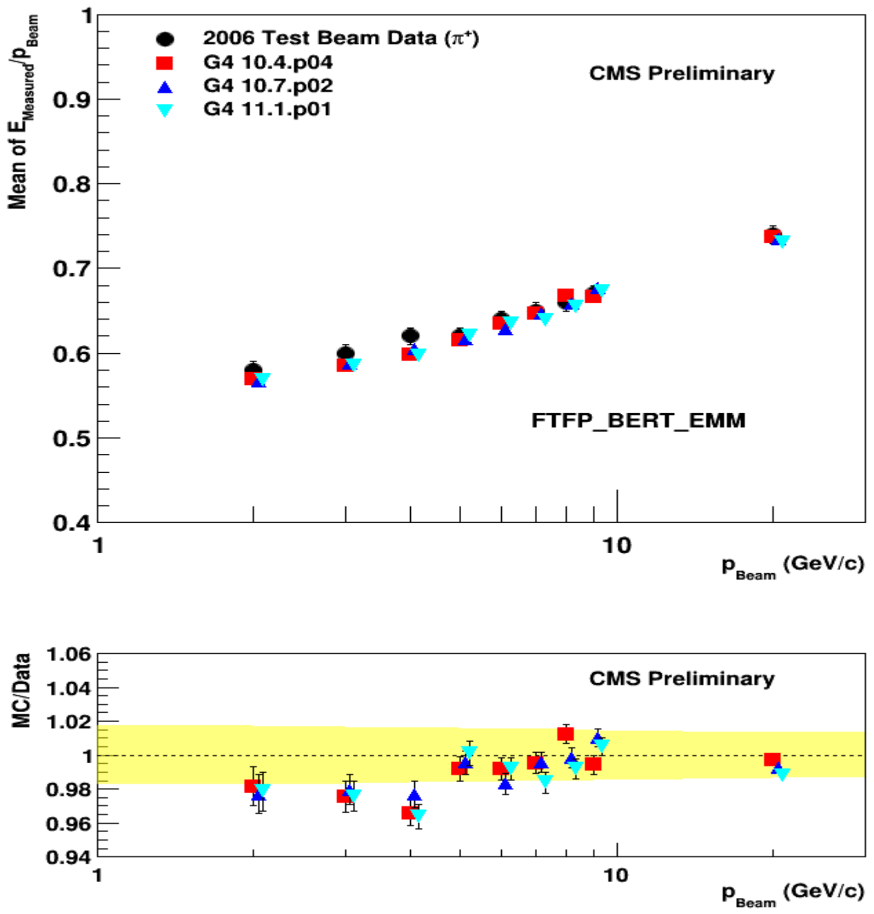
Improvements come from

- New Geant4 version
- Updated software platform el8_amd64_gcc11
- LTO build
- Advanced EM physics options

Mean response with pions

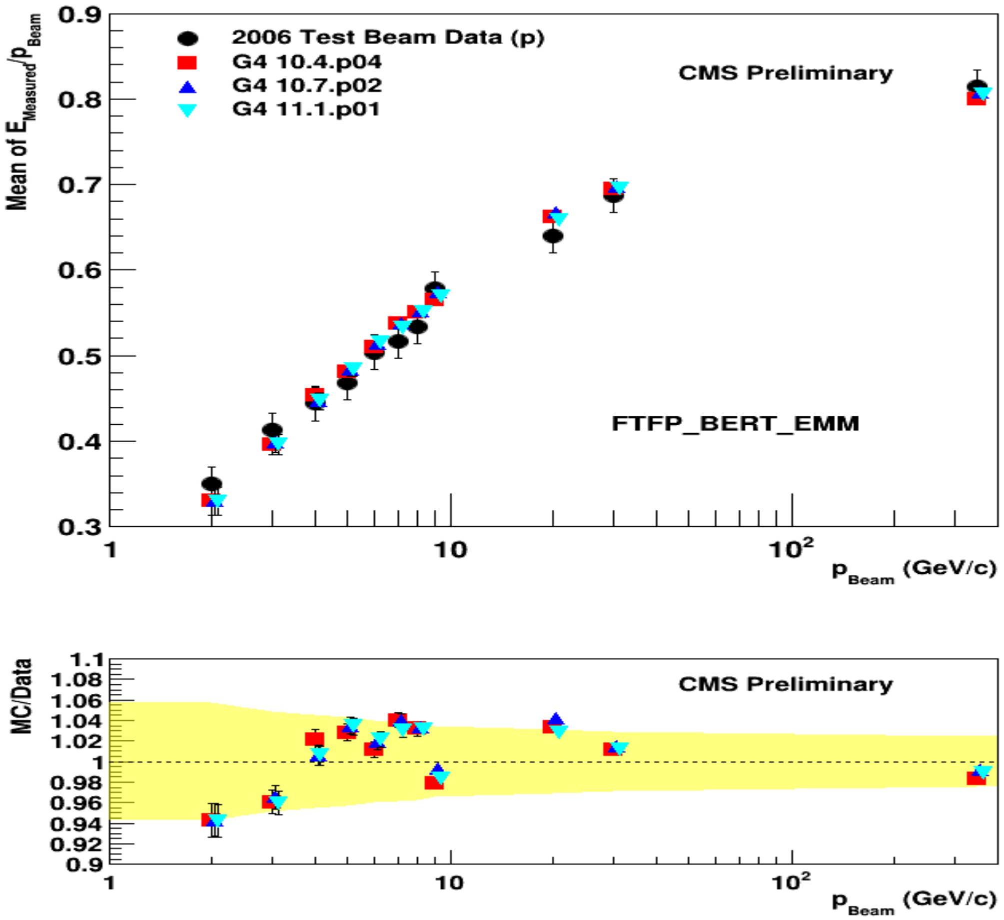


(Top) The mean response for negative pions as a function of momentum compared to MC predictions; (bottom) Ratio of MC to data for negative pions as a function of momentum. The yellow band shows one standard deviation of the data.

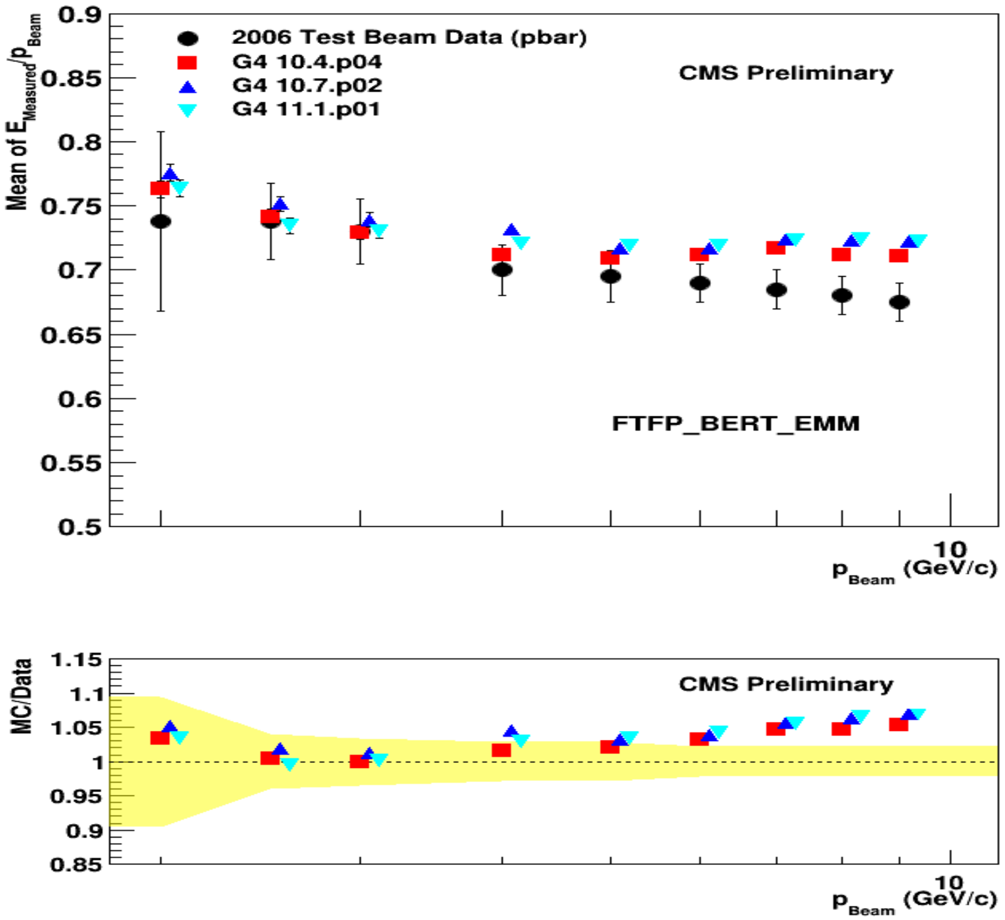


(Top) The mean response for positive pions as a function of momentum compared to MC predictions; (bottom) Ratio of MC to data for positive pions as a function of momentum. The yellow band shows one standard deviation of the data.

Mean response with protons/antiprotons

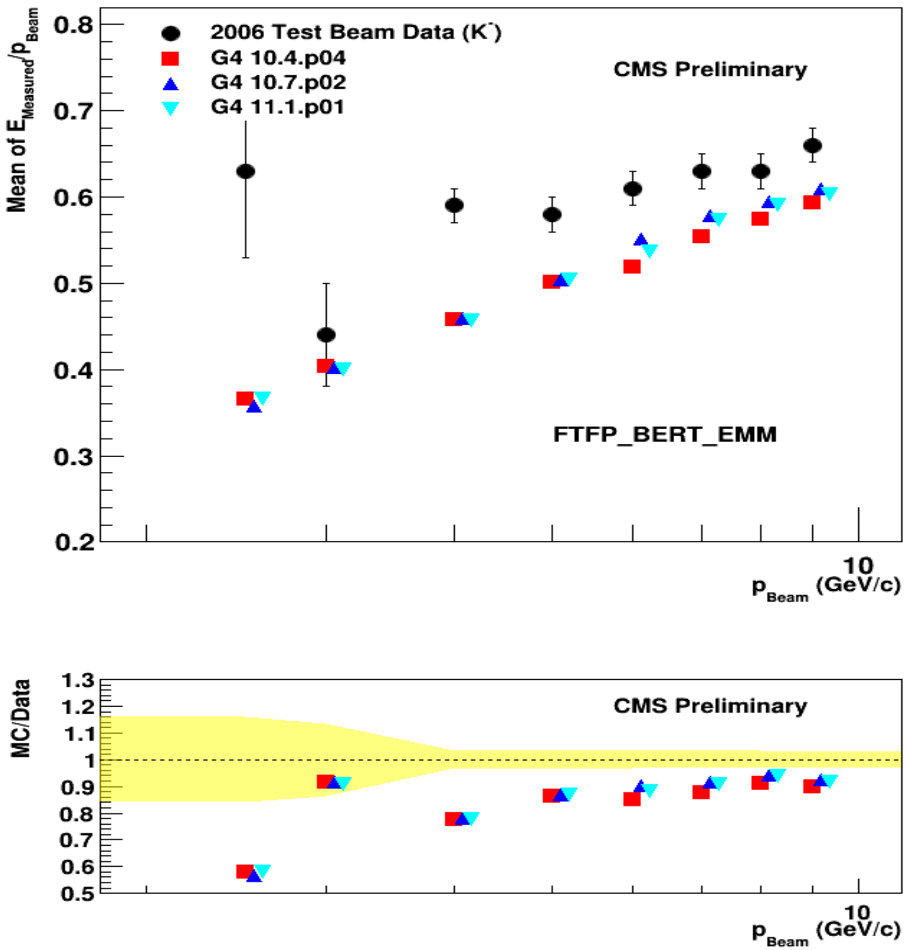


(Top) The mean response for protons as a function of momentum compared to MC predictions; (bottom) Ratio of MC to data for protons as a function of momentum. The yellow band shows one standard deviation of the data.

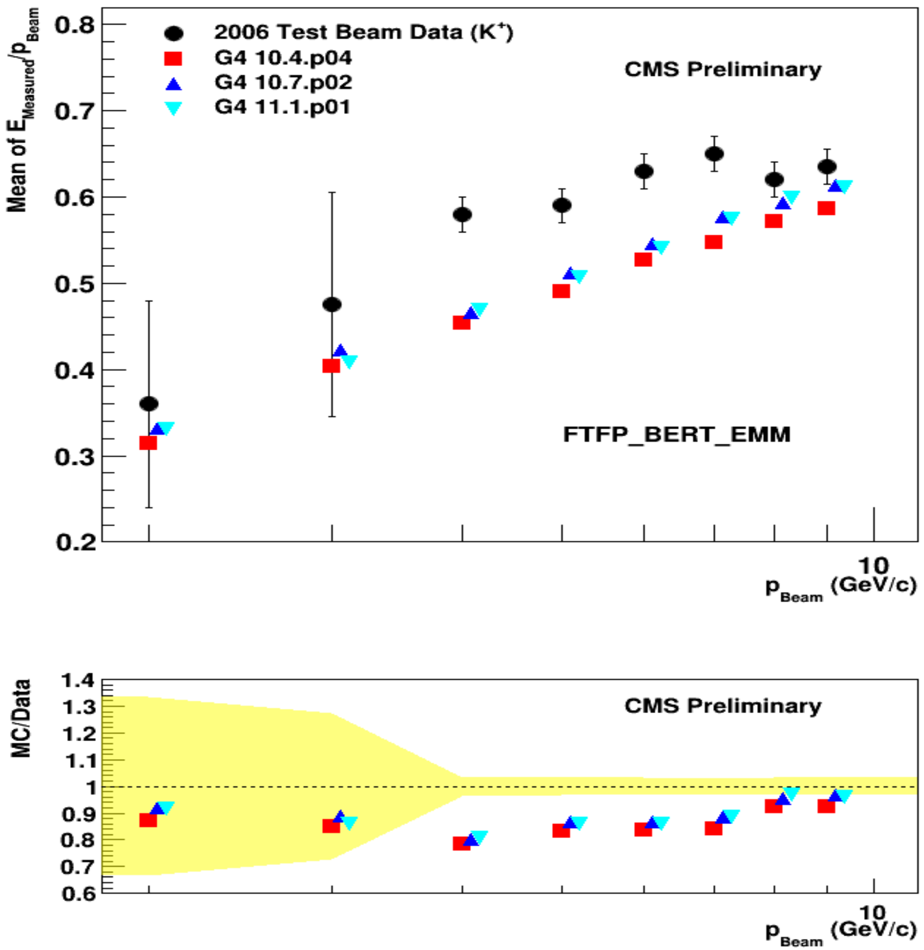


(Top) The mean response for anti-protons as a function of momentum compared to MC predictions; (bottom) Ratio of MC to data for anti-protons as a function of momentum. The yellow band shows one standard deviation of the data.

Mean Response for kaons

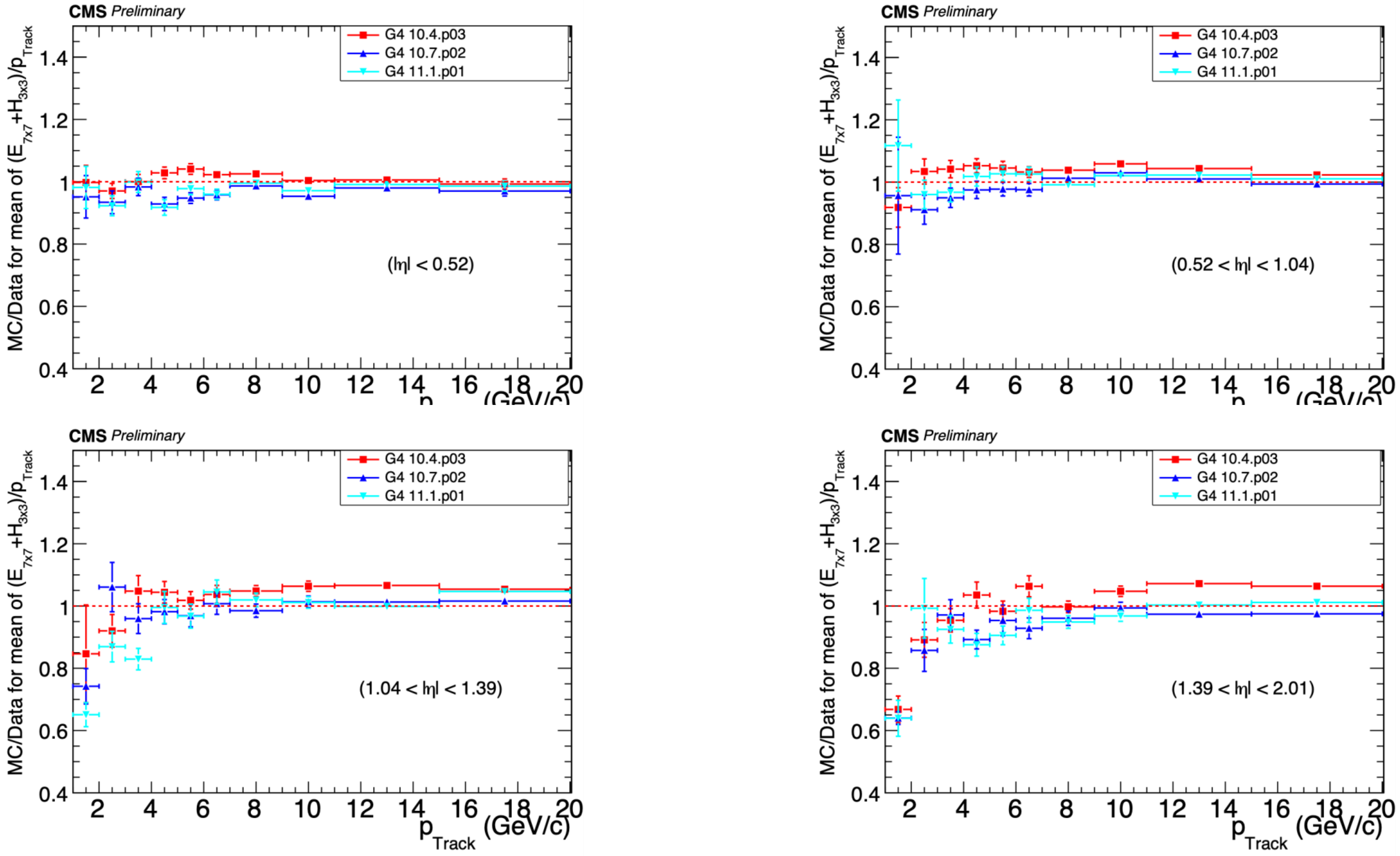


(Top) The mean response for negative kaons as a function of momentum compared to MC predictions; (bottom) Ratio of MC to data for negative kaons as a function of momentum. The yellow band shows one standard deviation of the data.



(Top) The mean response for positive kaons as a function of momentum compared to MC predictions; (bottom) Ratio of MC to data for positive kaons as a function of momentum. The yellow band shows one standard deviation of the data.

Combined Calorimeter Energy Ratio (Narrow Matrix) for low pile-up run



The ratio of the mean energy response in a narrow matrix of ECAL and HCAL between MC and data for four regions of the calorimeter: central barrel (top left); side barrel (side barrel); transition region (bottom left); endcap (bottom right).

Summary

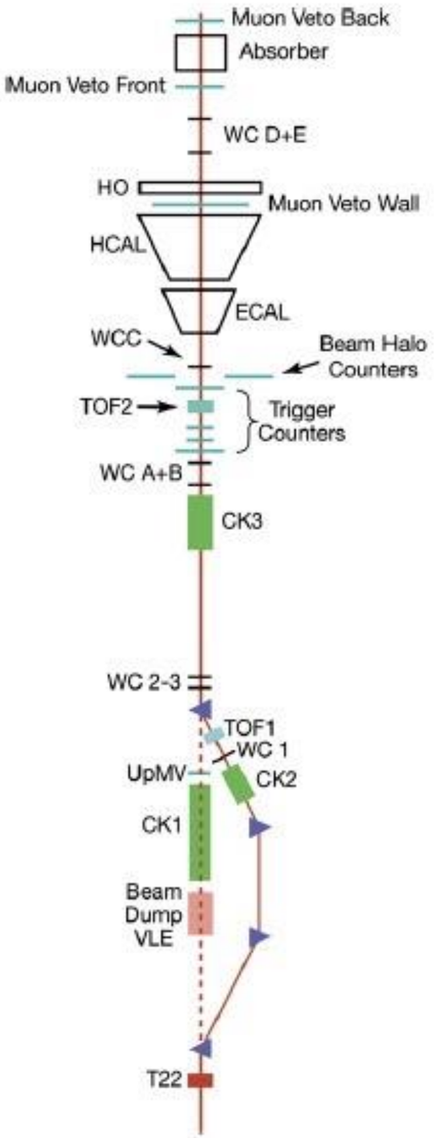
- CMS uses for 2022-2023 productions Geant4 10.7.p02
  - CPU speed-up ~25 % versus Run-2
- CMS adopted Geant4 11.1.p02 for 2024
  - CPU speed-up ~30 % versus Run-2
  - It is the current default Geant4 version for CMS
- Results of test-beam analysis are good in general
  - Pion and proton are within uncertainty (~3 %)
  - The is a small difference between pi+ and pi- below 10 GeV
  - Anti-proton signal above 5 GeV is overestimated for ~5 %
  - Kaon signal below 10 GeV is underestimated for ~10 %
  - There is underestimation of RMS below 5 GeV

Backup slides

2006 TestBeam Data CMS/DP-2023-064

- CMS collected data with a prototype of the Barrel Hadron Calorimeter and a supermodule of the barrel Electromagnetic Calorimeter in the H2 test beam area at CERN in 2006.
- Special action was taken to go to low energy hadron beam down to 1 GeV using a secondary target.
- The analysis utilized particle identification using data from TOF counters and Cherenkov detectors up to an energy of 9 GeV.
- The results consist of mean energy response (measured as the ratio of the total energy in the calorimeter to the beam momentum) as a function of beam momentum for different beam types, the energy resolution and some energy distributions for particles of a given type at a given momentum.
- Results from this test beam were published and have been used in many comparisons presented in earlier notes.

CMS 2006 TestBeam is used for regular validation of FullSim



Isolated Charged Particles

- Compare the ratio of calorimeter energy measurement to track momentum for isolated charged hadrons between data and MC.

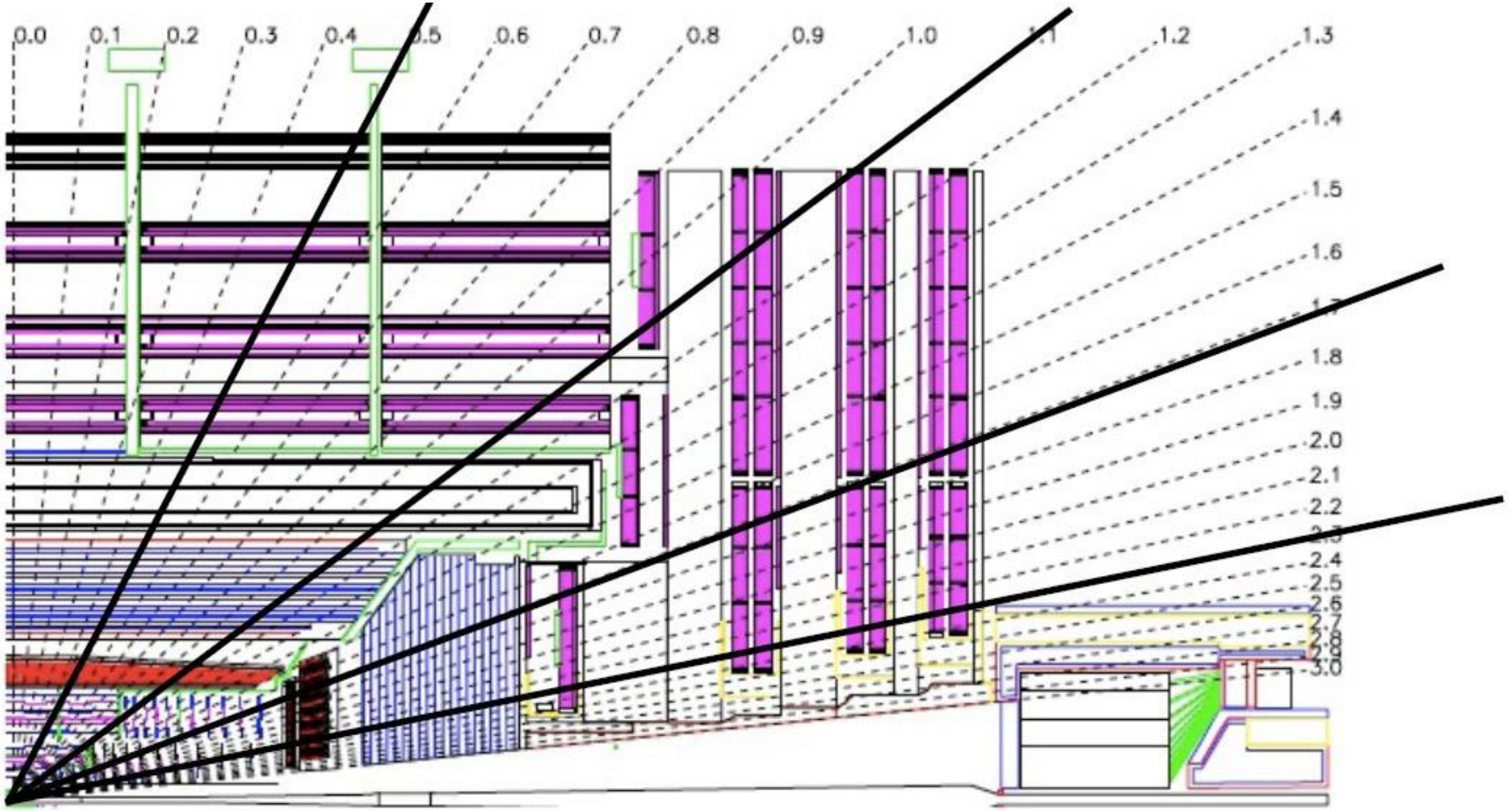
- Select good charged tracks reaching the calorimeter surface.

- Impose isolation of these charged particles:
  - propagate track to calorimeter surface and study momentum of tracks (selected with looser criteria) reaching ECAL (HCAL) within a matrix of 31x31 (7x7) (in the η-φ plane) around the impact point of the selected track. Demand no other track in the isolation region.
  - study energy deposited in an annular region in ECAL (HCAL) between 15x15 and 11x11 (7x7 and 5x5) matrices for neutral isolation. Demand energy in either annular region to be less than 2 GeV.

- Measure the energy in a matrix of NxN cells around the point of impact. Two versions of the NxN matrix are defined for ECAL and HCAL:
  - ECAL uses 7x7 or 11x11 matrix
  - HCAL uses 3x3 or 5x5 matrix

- The methodology was developed using 7 TeV data and analysis of the 2016 low pileup data plus the comparisons with earlier Geant4 model predictions were presented in a few earlier CHEP conferences.

Quadrant of the CMS



- Four partitions in the CMS detector are used in the measurement of the calorimeter response.
- Cell sizes in the calorimeter:

	$\Delta\eta$	$\Delta\varphi$
ECAL	0.0174	0.0174
HCAL	0.087	0.087