Status of Geant4 in CMS and combined calorimeter test-beam studies

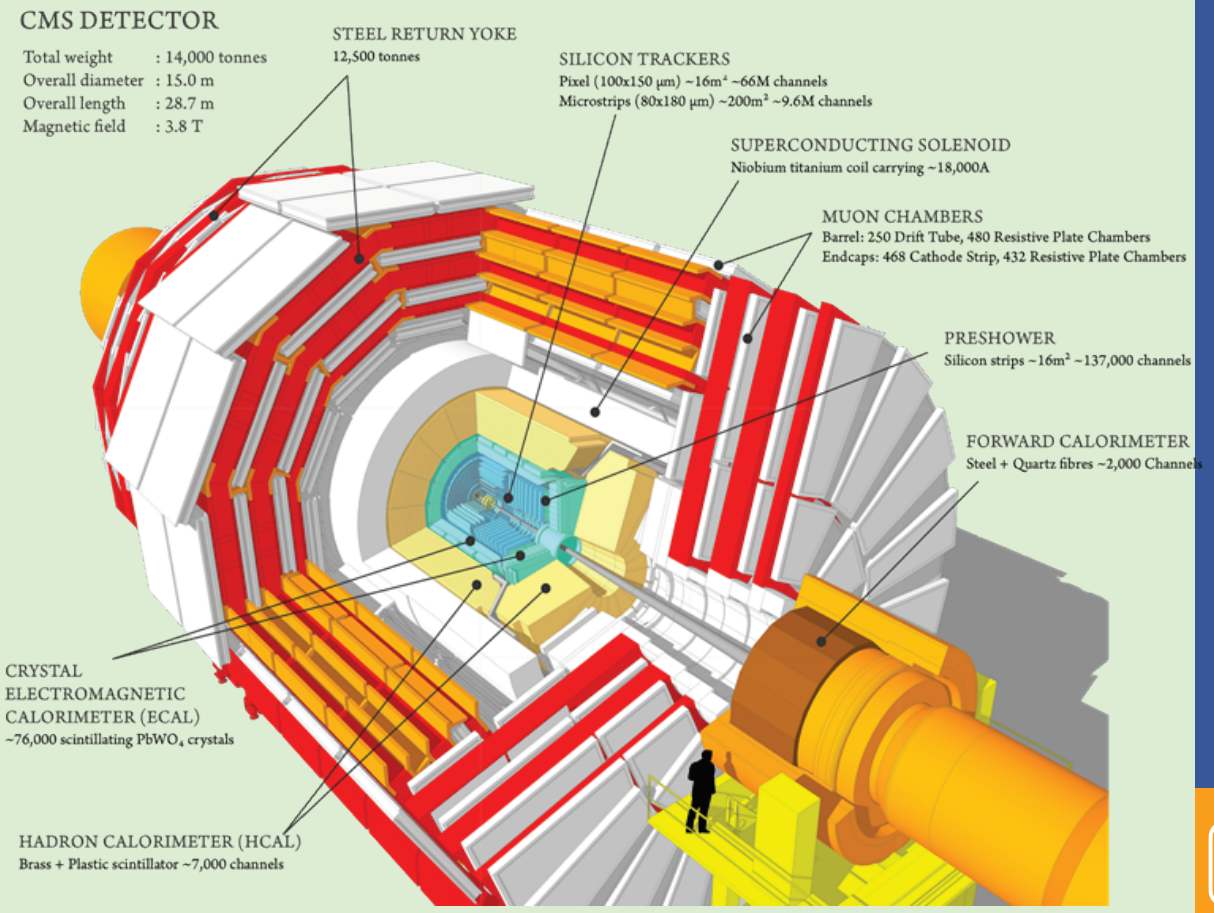
V. Ivanchenko, CERN, for CMS Simulation group

26 June 2017

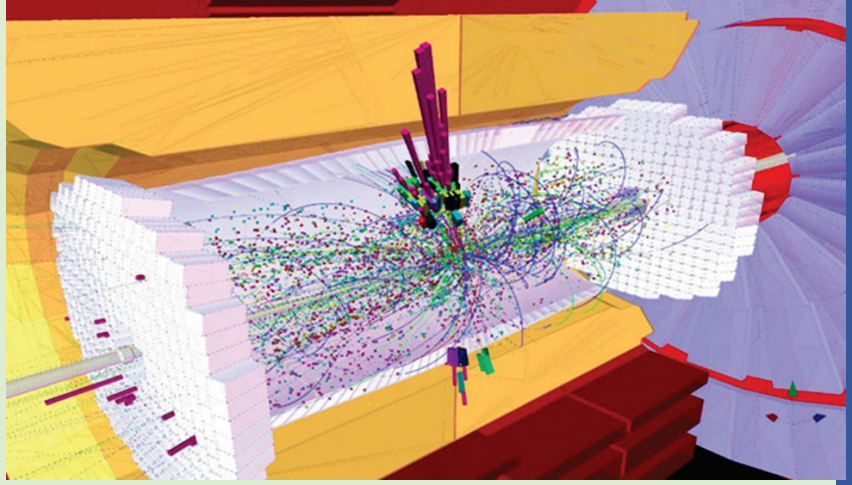
Outline

- Geant4 in CMS
  - CMS Physics Lists
- Standalone calorimeter test
- Combined calorimeter test-beam 2006
- Neutron background study
- Summary

- Comparisons versus collider data will be discussed in the talk of S. Banerjee

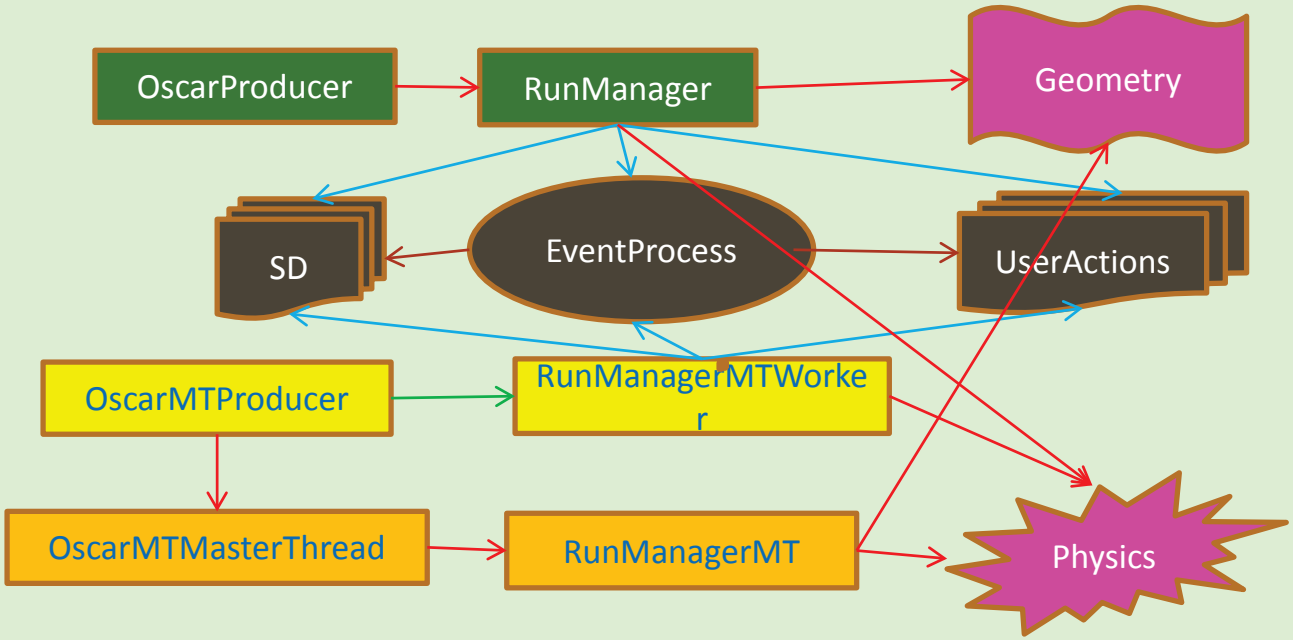


Geant4 in CMS



- Run-1 FullSim for 7 - 8 TeV data analysis
  - Geant4 9.4p03 (+ CMS patches)
  - slc5_amd64_gcc462
  - About 7B events produced
- Upgrade TDR
  - Geant4 9.6p02 (+ CMS patches)
  - slc5_amd64_gcc481
  - slc6_amd64_gcc481
- Run-2 FullSim 2015-2016 for 13 TeV data analysis
  - Geant4 10.0p02 + CMS patches, sequential mode
  - slc6_amd64_gcc491
  - About 16B events produced
- Multi-threading mode was prepared but not used for massive production 2015-2016

Migration of CMS simulation to multi-threading mode



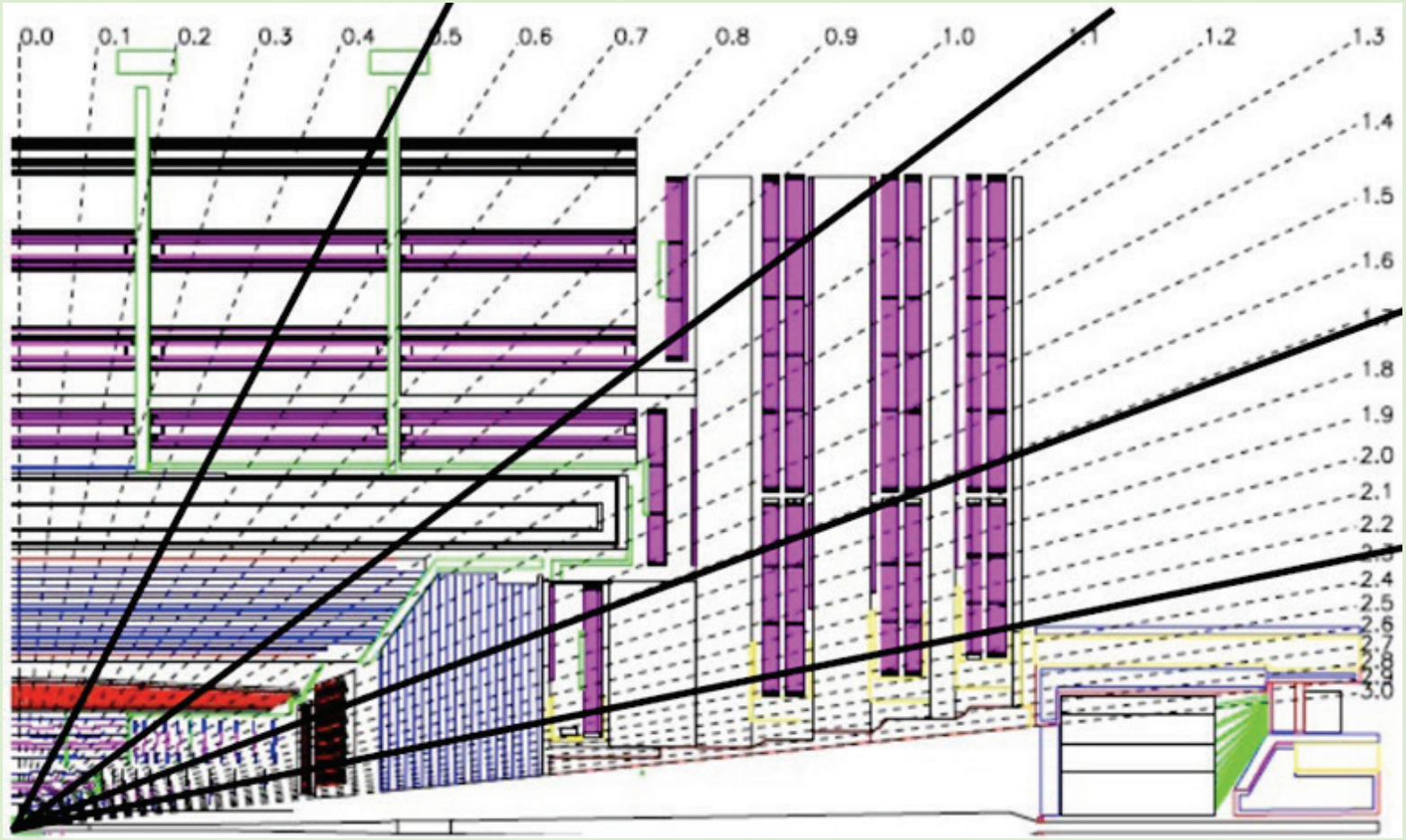
- Sequential and MT schemas are shown
  - Main difference is in initialisation
  - Arrows show initialisation relations
- Geometry, physics, user actions, and SD share the same code
- For 2017 MT is the default mode

CMS Simulation for 2017

- Simulation may be updated because previous cannot be used
  - New pixel tracker is installed
    - see talk of K. Pedro for more details
  - Multi-threaded model is the default
- The choice of the Geant4 version 10.2 was made
  - MT part of Geant4 was significantly improved
  - Many fixes in various parts of Geant4
  - Updated compilers
- Detailed study of Geant4 physics were carried out which will be discussed below

Geant4 Physics List in CMS

- For Run-1 and Run-2 productions CMS custom Physics List QGSP_FTFP_BERT_EML was used
  - Custom builders for EM and hadronic physics
  - Was validated using test-beam data and the detector data
    - Performed before run-1 for 9.4
    - Performed before run-2 for 10.0
  - EML is special more fast configuration of EM physics for CMS
- For Run-2 2017 FullSim production a new custom Physics List was established FTFP_BERT_EMM
  - Geant4 10.2p02 + CMS patches
  - Based on Geant4 default FTFP_BERT
  - Special configuration of EM physics
    - Simplified multiple scattering step limit everywhere except HCAL
    - Default multiple scattering configuration for HCAL
    - CPU performance of QGSP_FTFP_BERT_EML and FTFP_BERT_EMM are similar
      - FTFP_BERT is about ~20% slower
- This choice was made after substantial validation efforts described in the following slides



STANDALONE COMBINED CALORIMETER STUDY

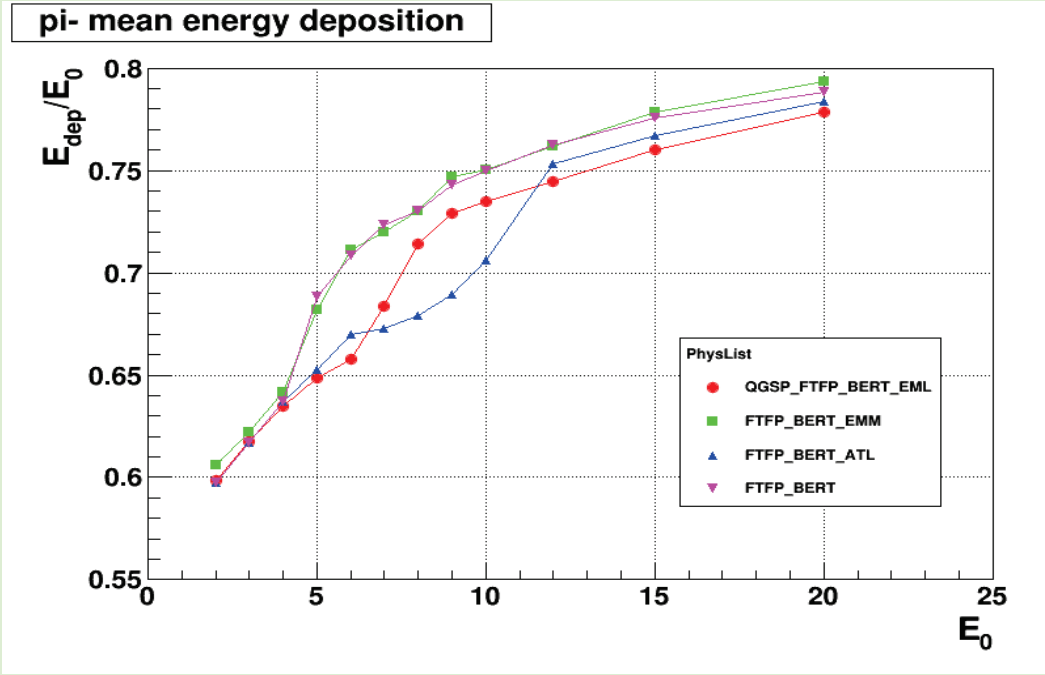
Vladimir Ivanchenko (CERN)

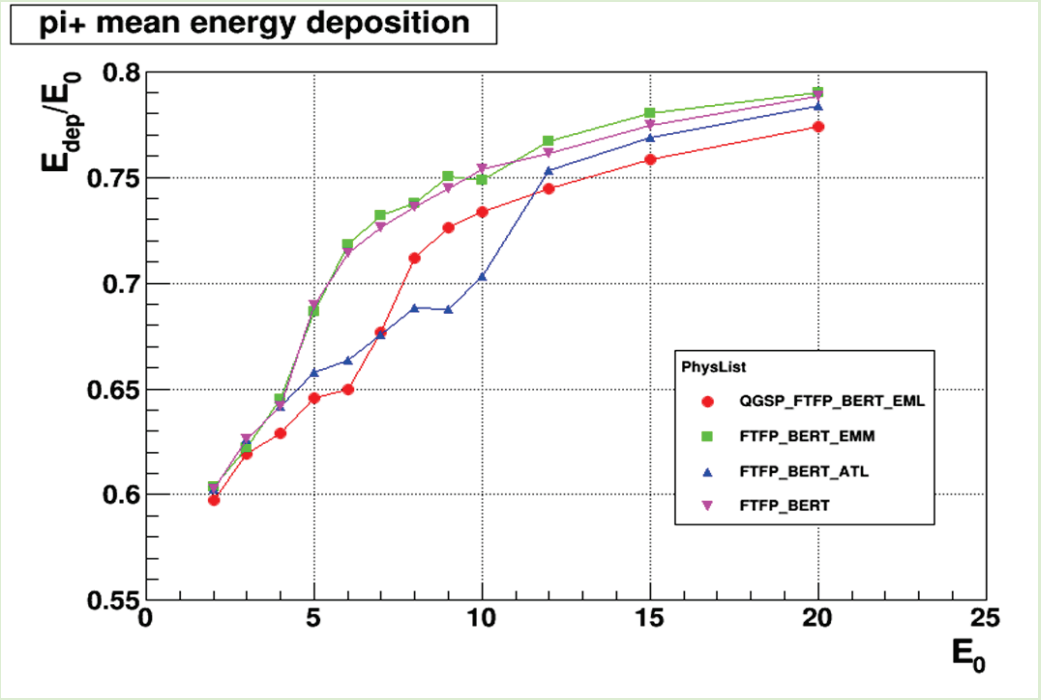
Standalone test of combined calorimeter

- Standalone Geant4 application (test46) is a part of Geant4 testing
  - $PbWO_4$ crystals -1st part with sizes approximately of CMS ECAL
  - Sampling structure of 17 layers Brass/Scintillator with sampling fraction ~0.01
- Various Physics Lists configurations are studied
  - Simulated ECAL + HCAL signal
    - $Evis = E_{ECAL} * f_{ECAL} + E_{HCAL} * f_{HCAL}$
    - $f_{ECAL} = 1.01$, $f_{HCAL} = 95.5$ (FTFP_BERT_EMM)
  - Normalisation of HCAL response is done as in TB2006 by 50 GeV e- in HCAL
- Results for Geant4 10.2p01 are shown in following slides

Pion beam

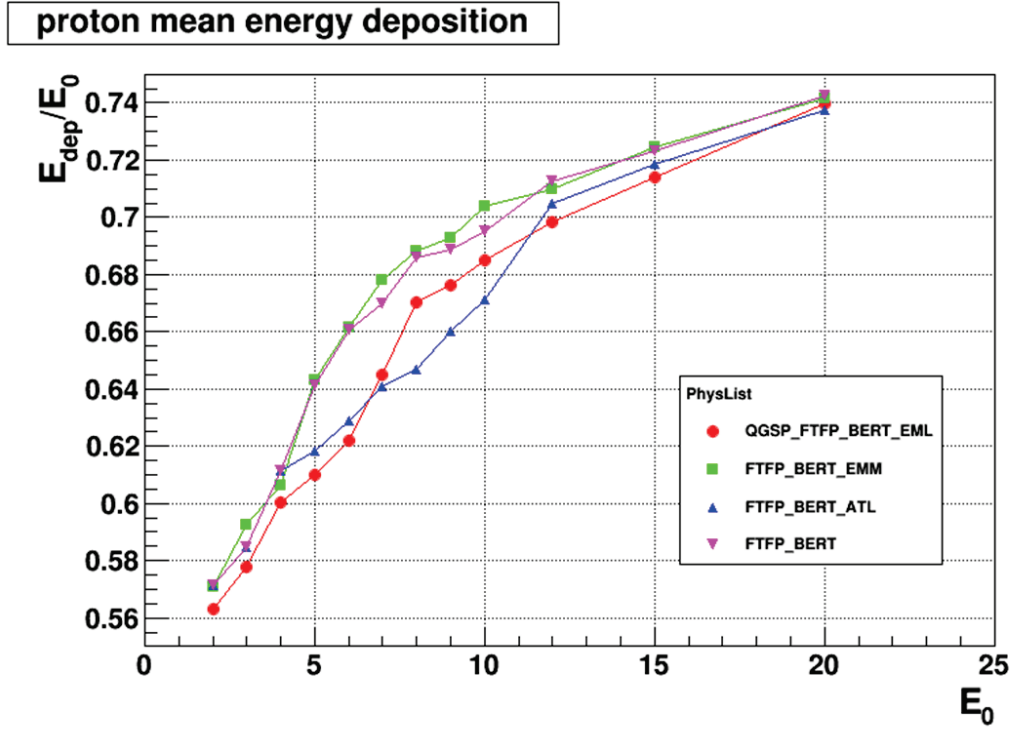
- Geant4 10.2p01
- Strong dependence of response on
  - FTF/Bertini transition
  - EM options
- FTFP_BERT_EMM
  - Coincide with FTFP_BERT
  - increased visible energy
- FTFP_BERT_ATL
  - Unphysical shape in transition region

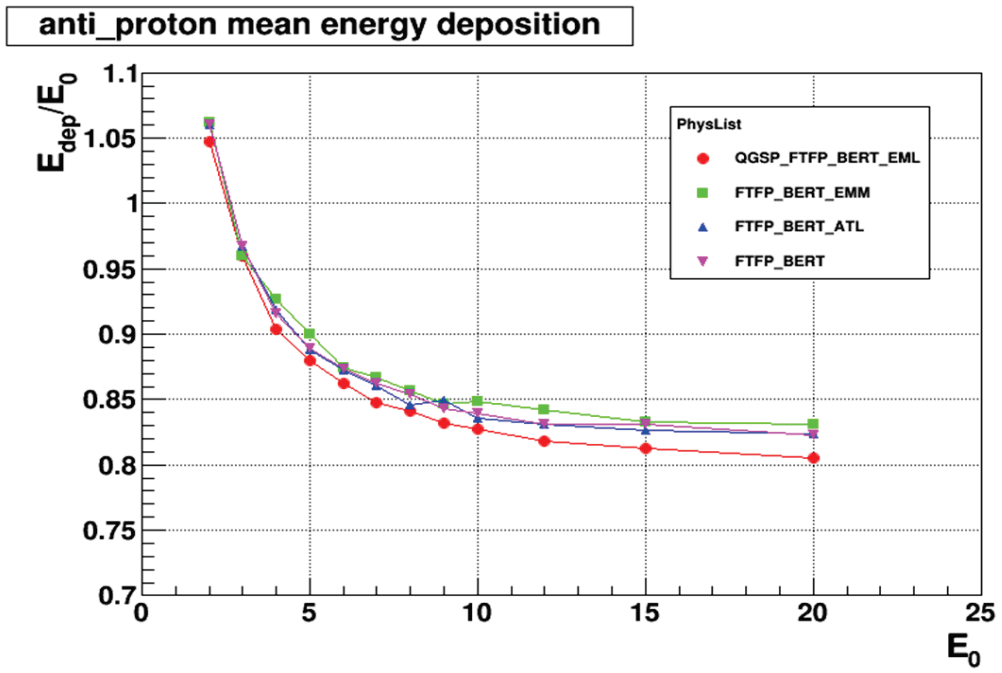




p/pbar beam

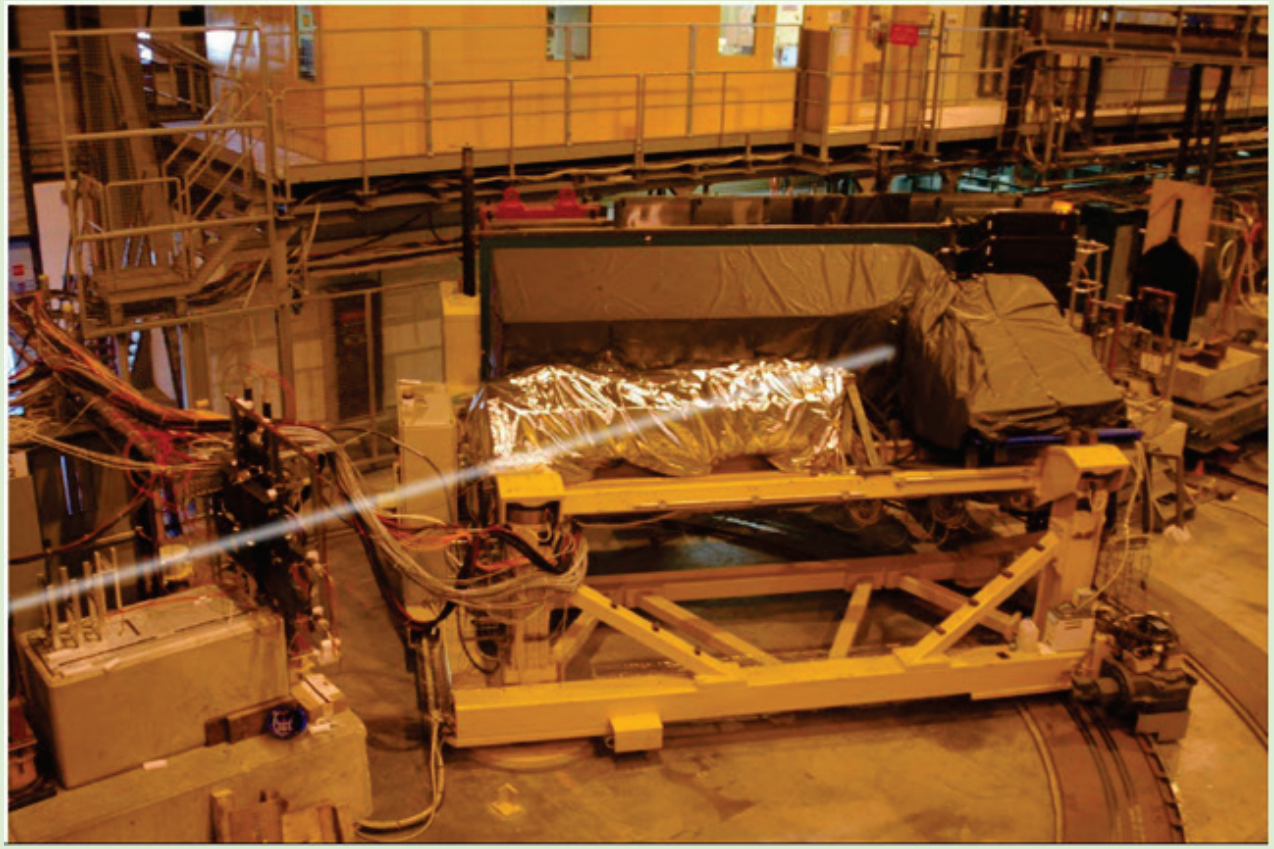
- Geant4 10.2p01
- For protons less dependence of response on Physics List than in the pion case
- Stable results for pbar
- FTFP_BERT_EMM
  - Coincide with FTFP_BERT
  - increased visible energy
- QGSP_FTFP_BERT_EML
  - Lowest visible energy





Conclusions on standalone test beam study

- New EM option EMM equivalent default EM physics and provide the same CPU performance as EML
  - The response on EM component of hadronic shower in HCAL is increased
- Difference beween various Physics Lists is seen in the energy interval 5-15 GeV
  - FTFP_BERT_ATL significantly reduces the response compared to FTFP_BERT
- Using standalone test we studied calorimetr response for different configurations of FTF model
  - Several patches on top of Geant4 10.2p01 and 10.2p02 were tested
  - A decision was made to configure FTF in a way to be most close to the previous Geant4 version 10.1p02
- This final configuration was used for 2006 test-beam analysis

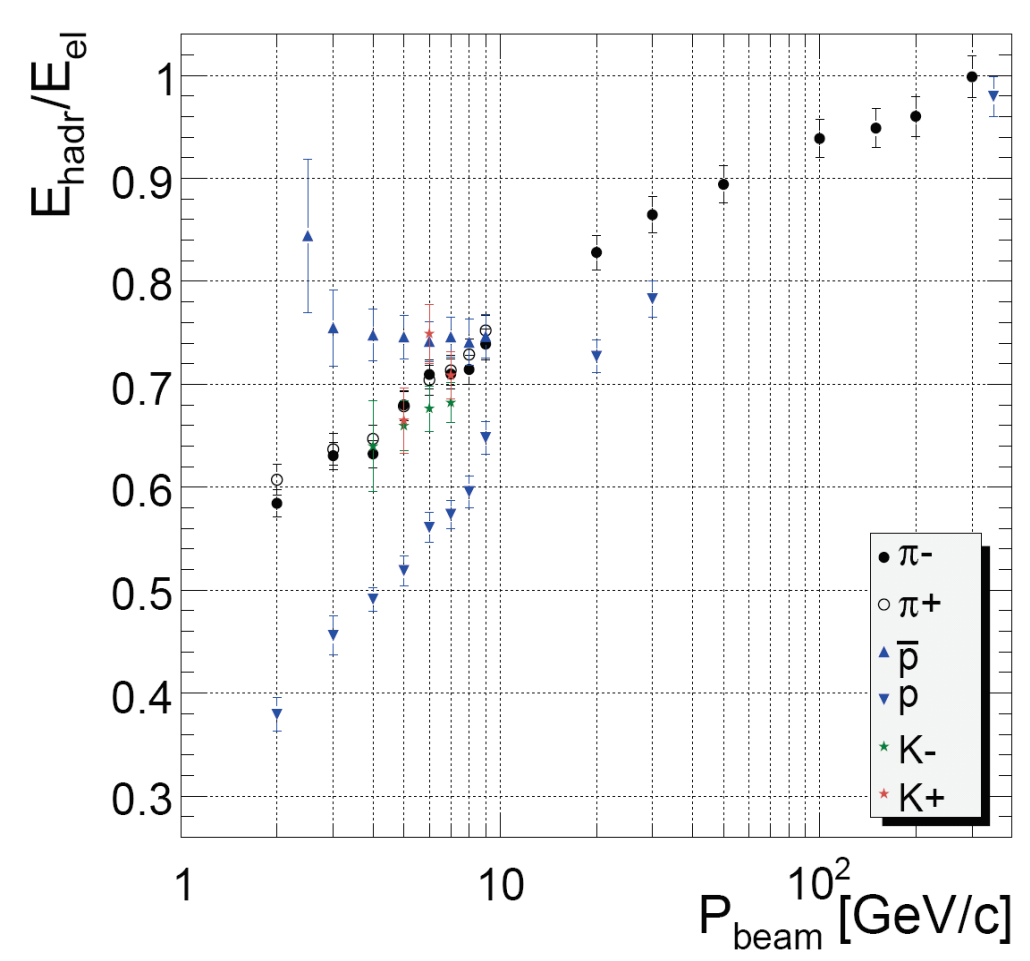


COMBINED CALORIMETER TEST-BEAM 2006

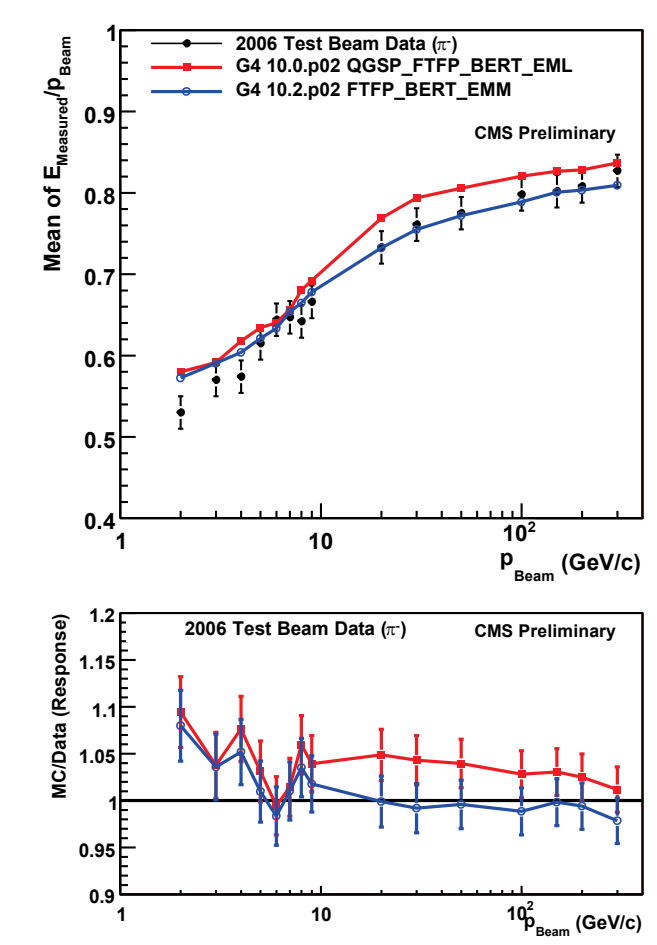
Serguei Bytukov (IHEP), Vladimir Ivanchenko (CERN),
Sunanda Banerjee (FNAL) reported at CHEP'2016

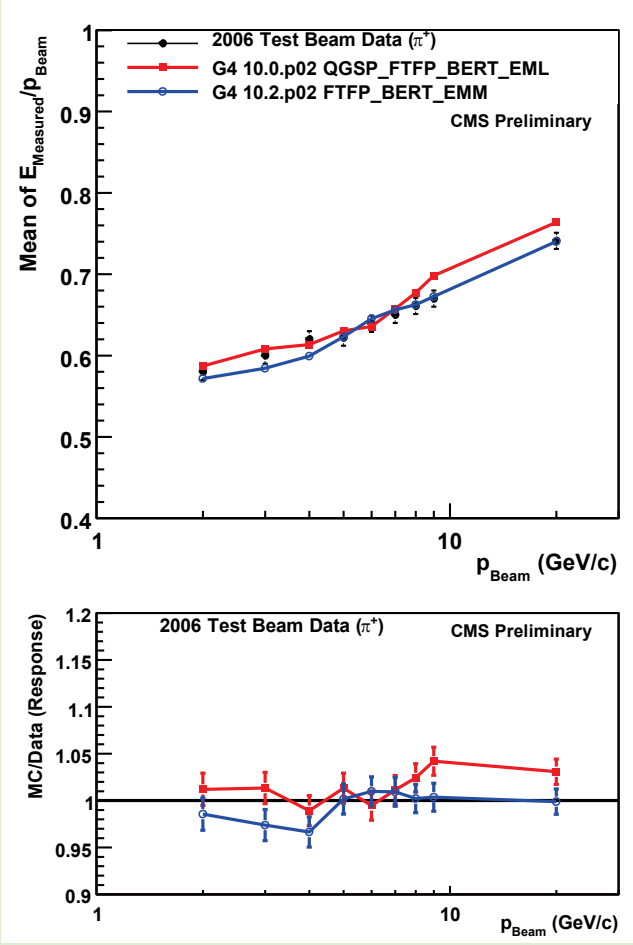
2006 TestBeam Data

- CMS Notes 2008/025, 2008/034, 2010/007
- CMS collected data with prototype of barrel HCAL and barrel ECAL super-module in the H2 test beam area at CERN during 2006.
  - Special action was taken to go down to 1 GeV hadron beam
  - Beam particle identification from Cherenkov and TOF detectors
- Measured mean energy deposition, width and energy fractions in ECAL and HCAL



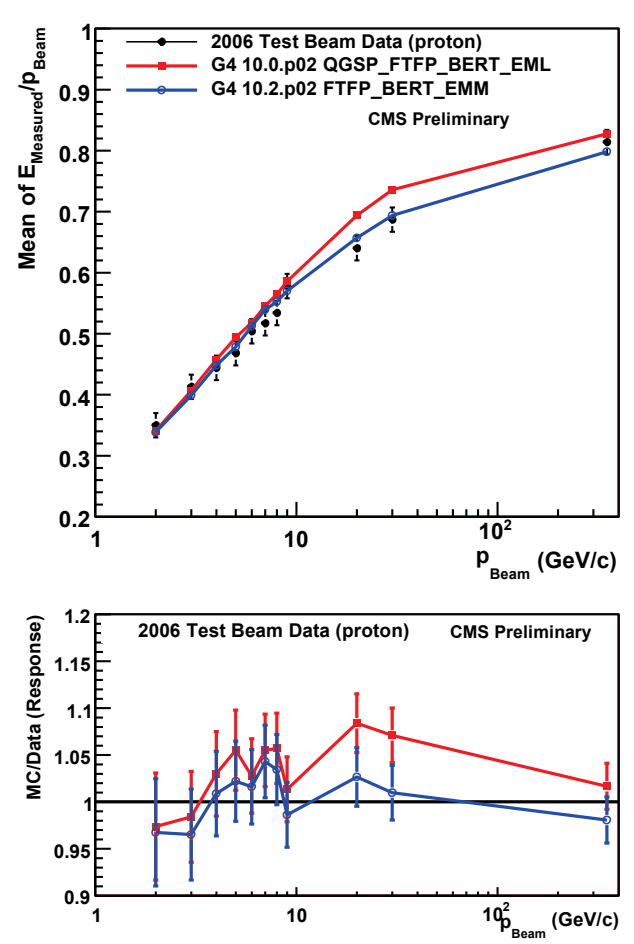
Mean response with pions

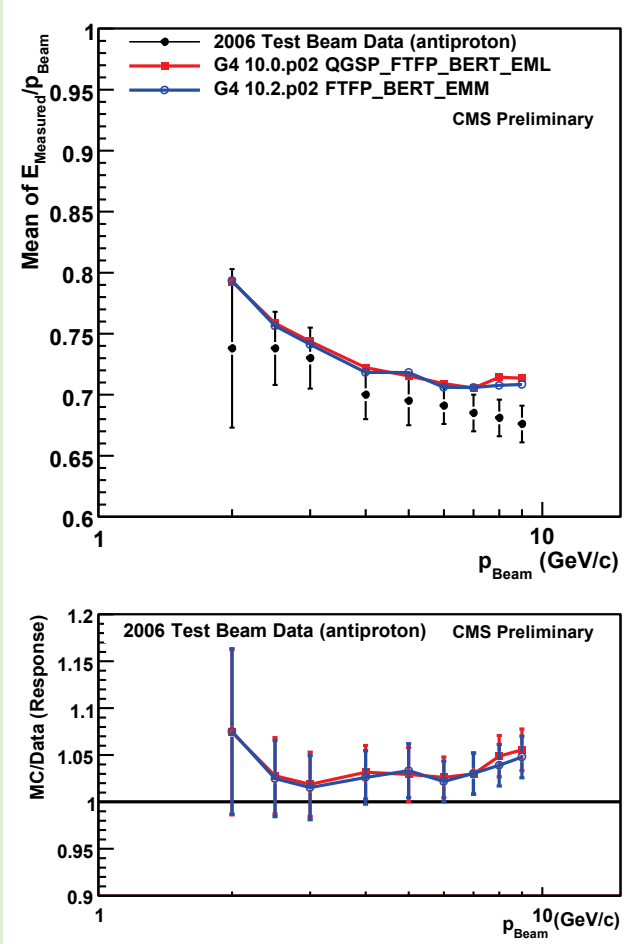




Main improvement for E > 10 GeV due to use FTFP and EMM

Mean response with p and pbar





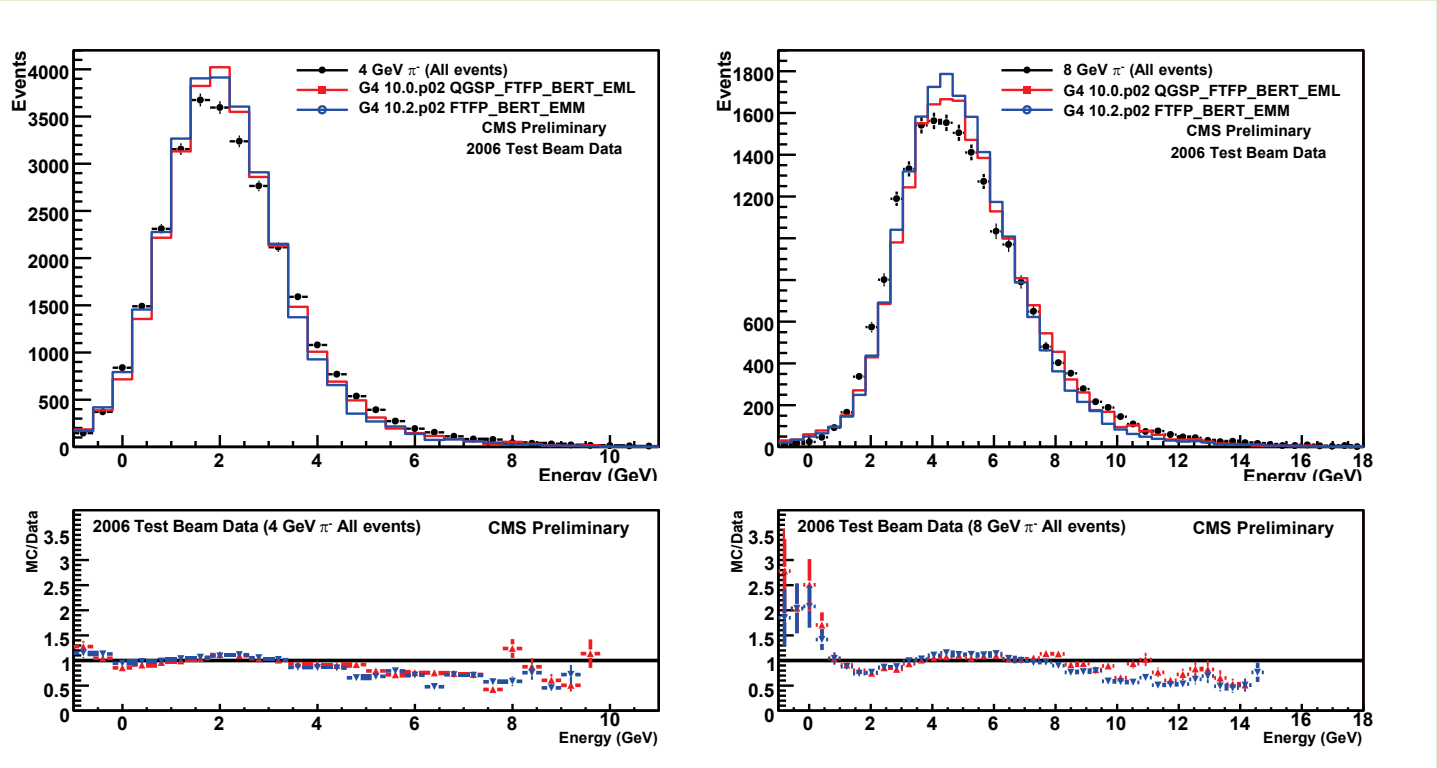
Main improvement for E > 10 GeV due to use FTFP and EMM

Summary from mean response

- The level of agreement between data and MC improve in the new model for pions
  - More discrepancies for pbar and kaons
- pp collisions at high energies produce mostly pions
  - one expects to have a better agreement between data and MC with the new physics list and 10.2.p02

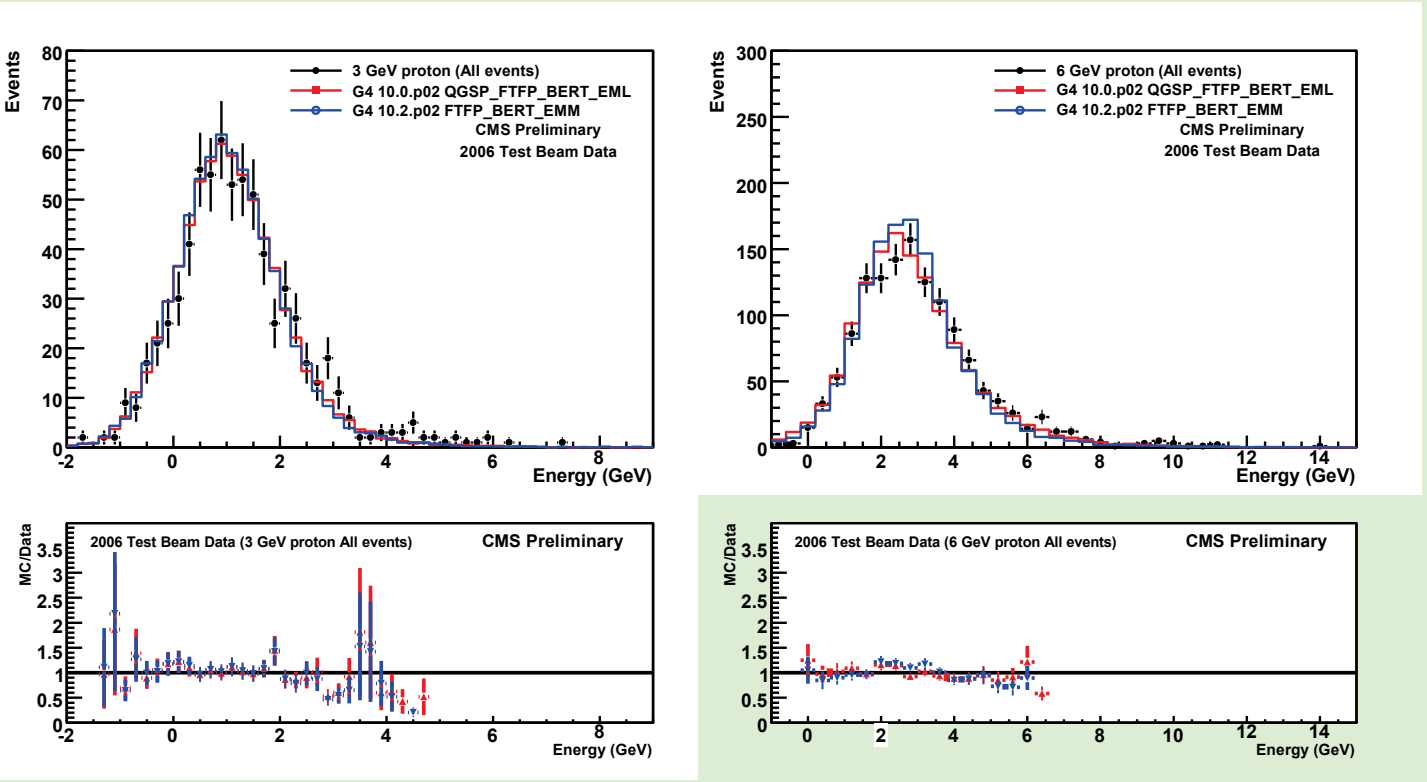
	Pi-	Pi+	p	pbar
G4 10.0p02 QGSP_FTFP_BERT_EML	(3.6 ± 0.6)%	(1.9 ± 0.5)%	(4.3 ± 1.0)%	(3.5 ± 0.8)%
G4 10.2p02 FTFP_BERT_EMM	(1.8 ± 0.7)%	(1.0 ± 0.5)%	(2.2 ± 1.1)%	(3.1 ± 0.8)%

Energy specra for pions

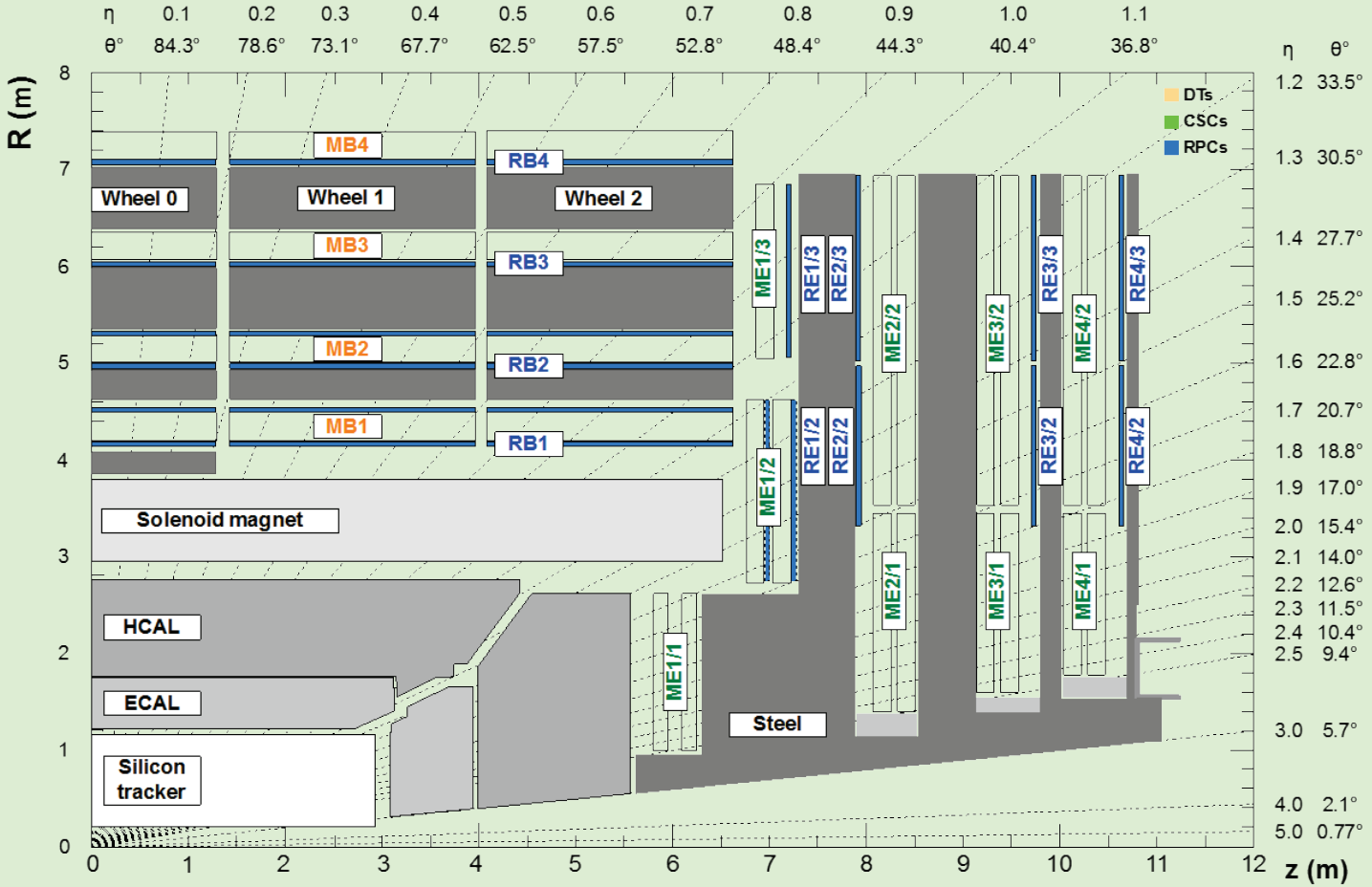


Total energy measured for negative pion beams of 4 GeV/c and 8 GeV/c
Fairly good agreement (better than 8% on average) observed in the energy distribution with the data having a slightly longer tail than the MC

Energy spectra for pions



Energy distribution for protons at 3 and 6 GeV/c
Both versions of Monte Carlo provide a decent (within 10% on average)



Christian Schnaible, Abhigyan (Riju) Dasgupta, Bob Cousins

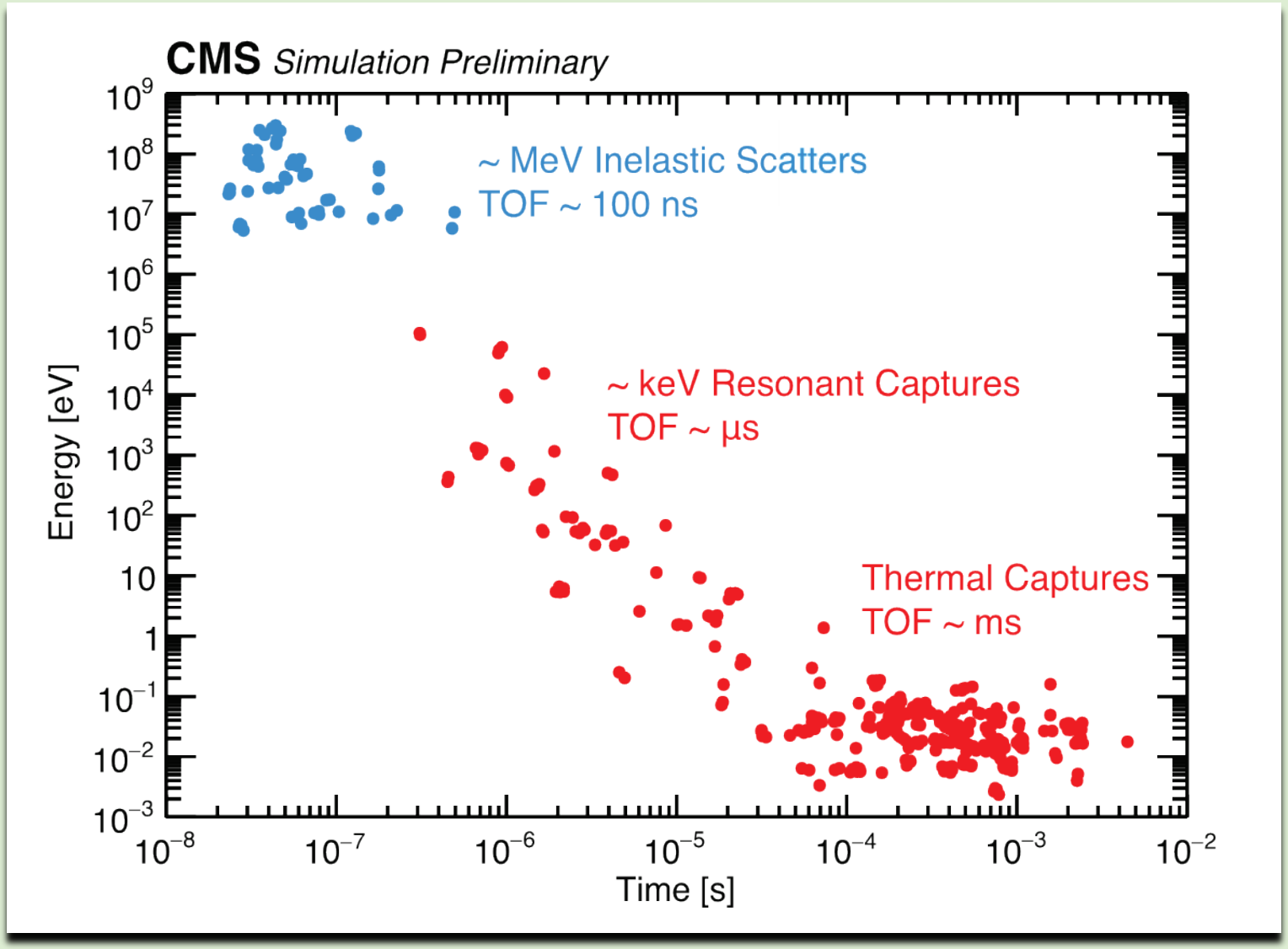
University of California, Los Angeles

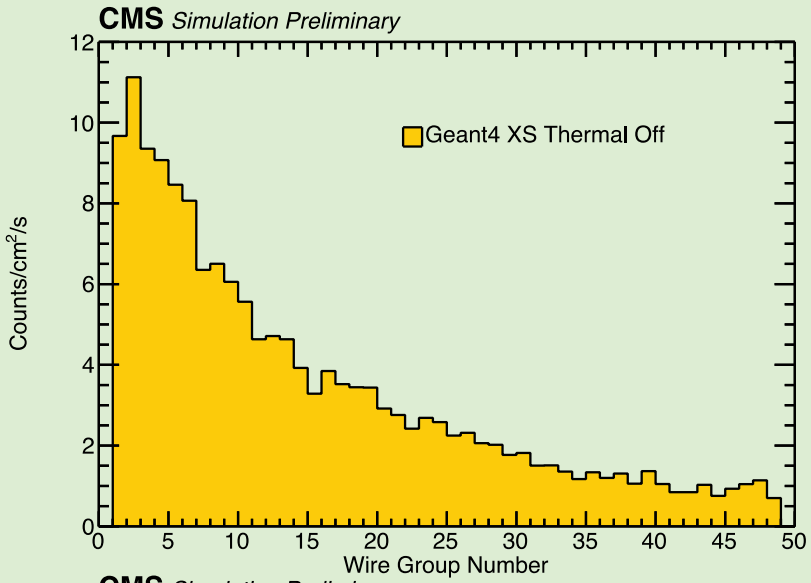
NEUTRON BACKGROUND STUDY

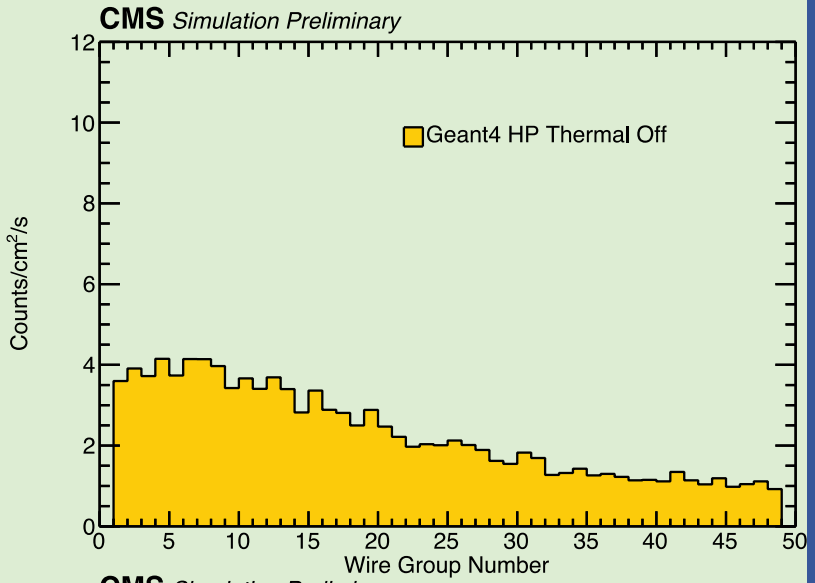
CMS FullSim for neutron background study

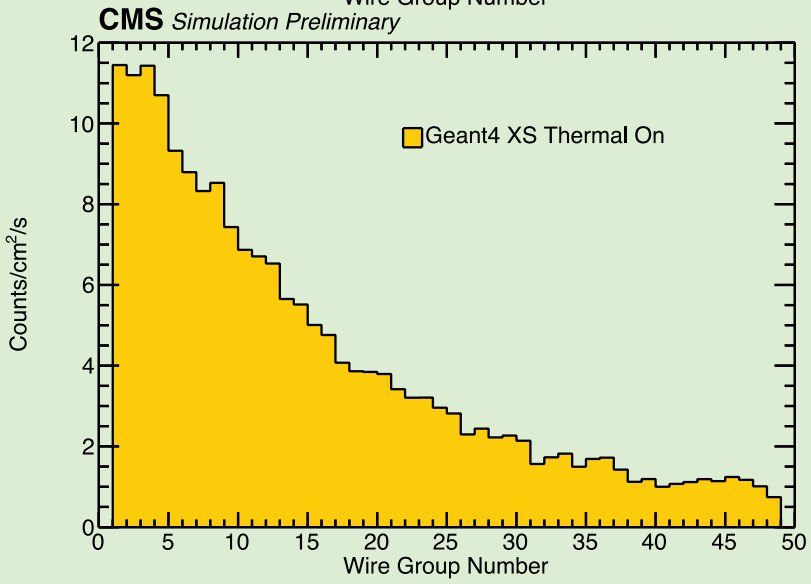
- Simulation of QCD events with time limit 0.1 second instead of 500 ns
  - All time cuts are extended
- Disabled several special shortcuts of simulation
  - Russian roulette
  - HF shower library
  - Tracking cuts
- Special Physics Lists
  - Atomic de-exsitation module enabled
  - XS Physics List with XS neutron cross sections
  - HP Physics List with HP neutron cross sections and final state
  - Thermal neutron scattering below 4 eV as an option
  - Radioactive decay is not enabled

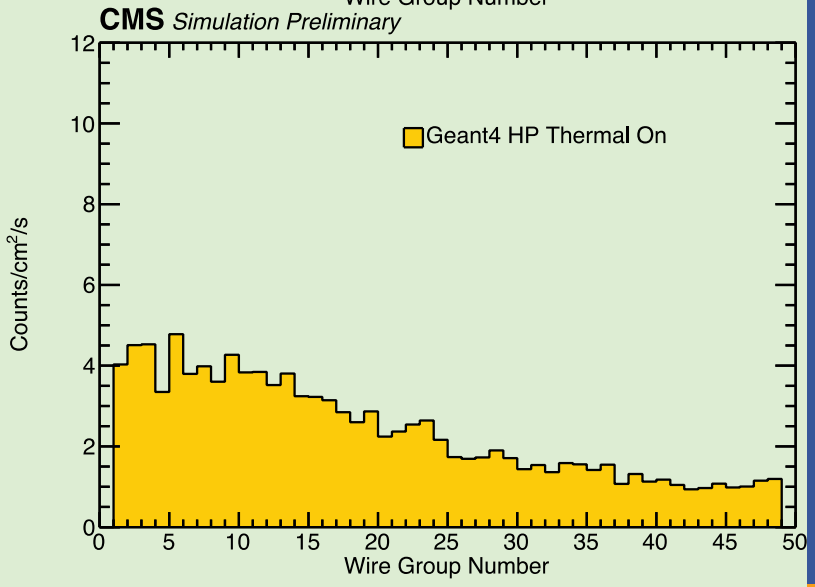
Energy of neutrons making hits in CSC muon chambers versus time at 13 TeV



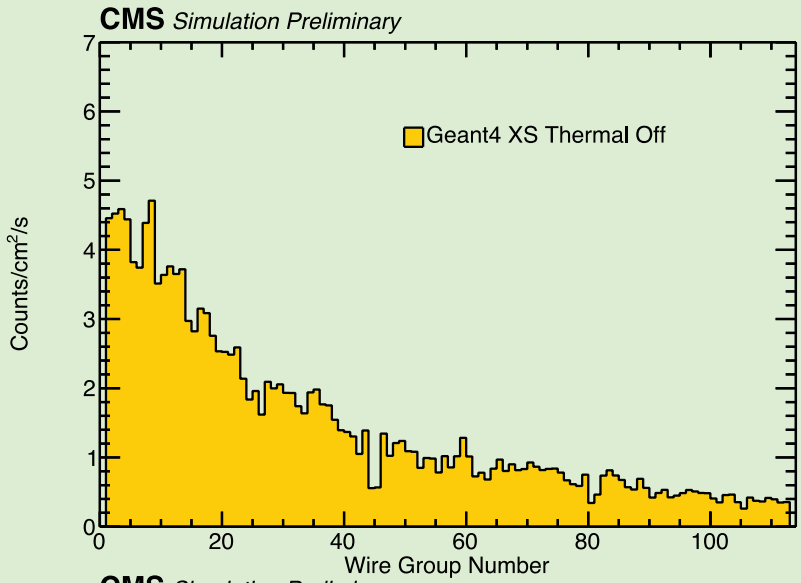


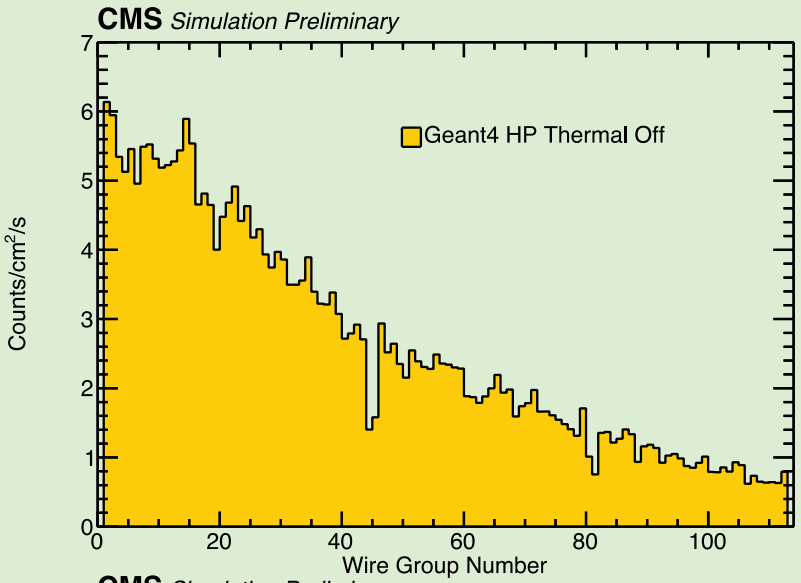


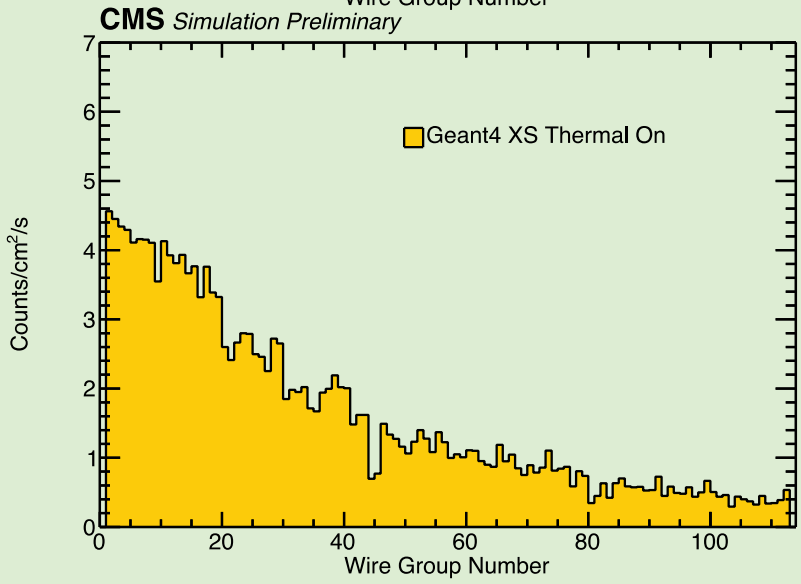


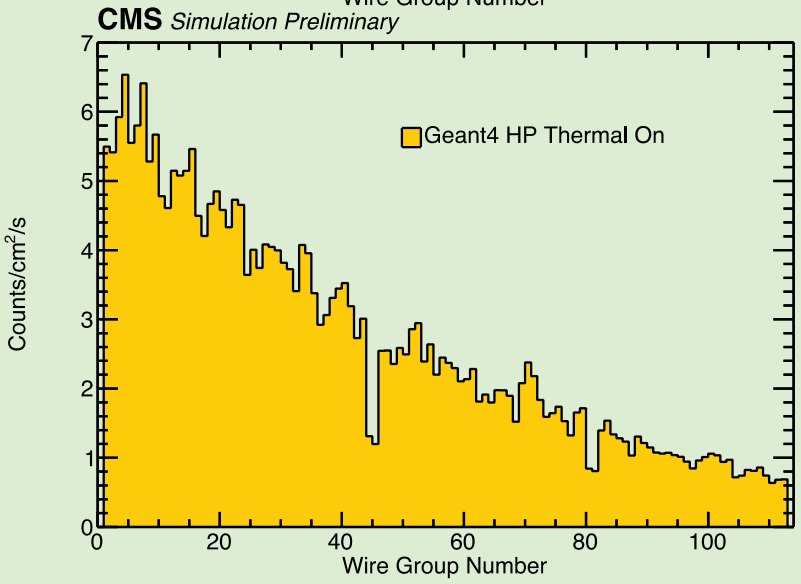


CMS end-cap Cathode Strip Chamber anode wire hits for the inner ring of the first station (ME1/1). Figures compare HP and XS Physics Lists with and without a Geant4 thermal neutron scattering routine enabled. Simulated minimum-bias proton-proton collisions at 13 TeV and the 2015 CMS simulated geometry

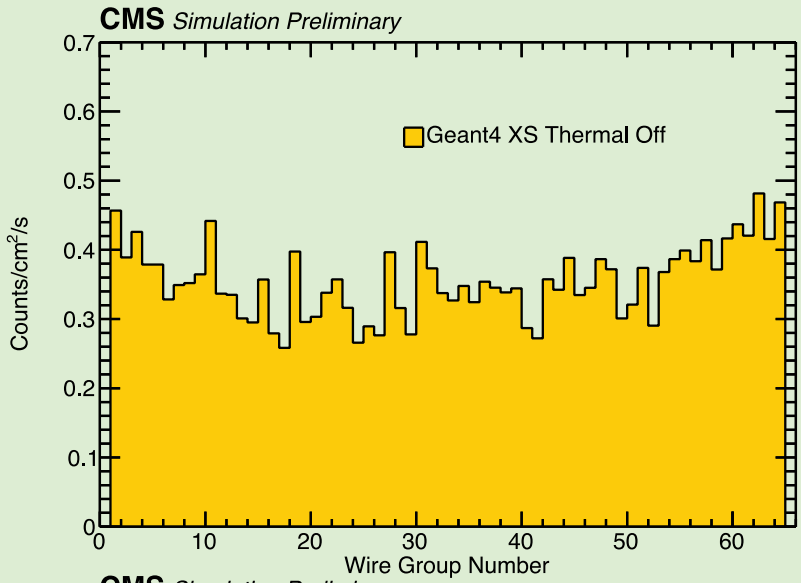


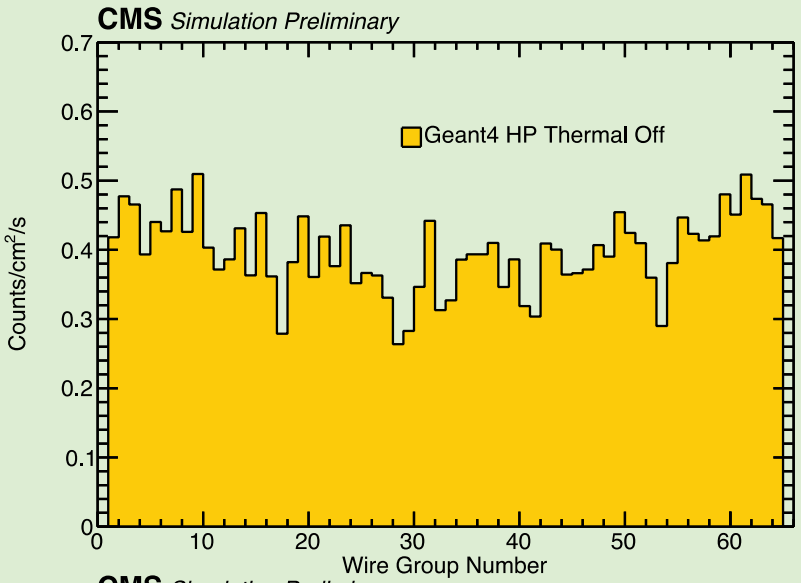


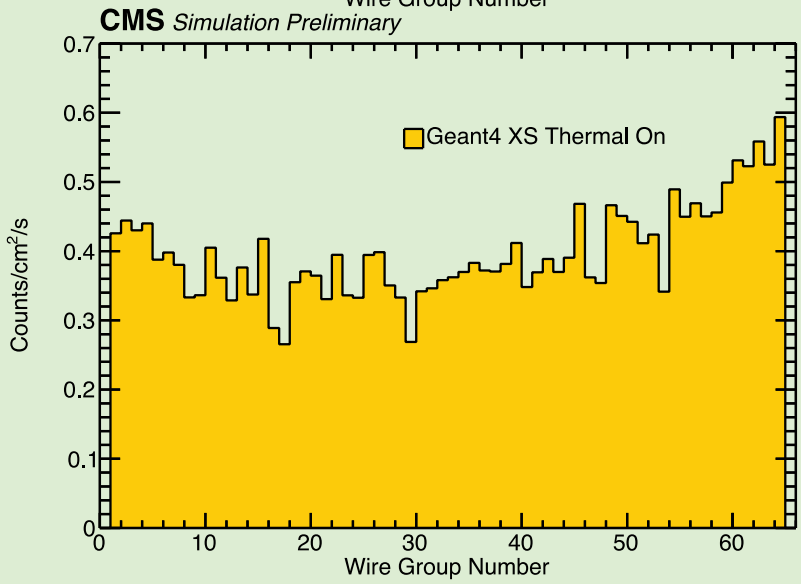


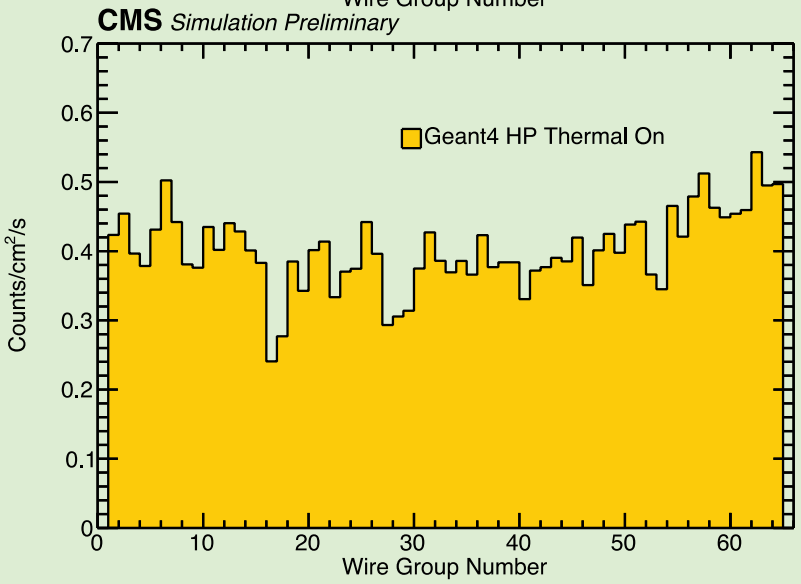


CMS end-cap Cathode Strip Chamber anode wire hits for the inner ring of the second station (ME2/1). HP and XS Physics List with and without a Geant4 thermal neutron scattering routine enabled. Minimum-bias proton-proton collisions at 13 TeV and the 2015 CMS simulated geometry









CMS end-cap Cathode Strip Chamber anode wire hits for the outer ring of the fourth station (ME4/2). HP and XS Physics Lists with and without a Geant4 thermal neutron scattering routine enabled. Minimum-bias proton-proton collisions at 13 TeV and the 2015 CMS simulated geometry

Summary

- For 2017 simulation production CMS will use Genat4 10.2p02 in multi-threaded mode
  - FTF model configuration is similar to 10.1p02
  - FTFP_BERT_EMM Physics List is the current default
- CMS calorimeter consists of two very different parts ECAL and HCAL
  - The response is very sensitive to Geant4 hadronic model configuration
  - CMS suggests Geant4 hadronic group to use test46 for regular validation of Geant4 reference versions
  - CMS simulation group will perform regular tests using TB2006
- Results of simulation of hits in CSC muon chambers using XS and HP neutron physics agree within factor two
  - Simulation of thermal neutron scattering does not change hits
  - Some details of simulation of neutron background for regular simulation will be described in M. Hildreth talk tomorrow

Outlook

- CMS has a program of detector upgrade (see talk of K. Pedro)
- For 2018 simulation we consider a possibility of usage future Geant4 version 10.4
  - Expected more performant geometry and tracing in field
  - CMS plan to test VecGeom library
  - Expected better EM/hadronic physics
    - CMS required intensive tests of 10.4 by Geant4 team before the release
- For 2023 the new HGCal calorimeter and other upgrades
  - More test-beam data
  - CMS expect more Geant4 efforts for validation of EM and hadronic physics for new HGCal calorieter