SiTest : Validation of GEANT4 Electromagnetic Models for thin layers of Silicon

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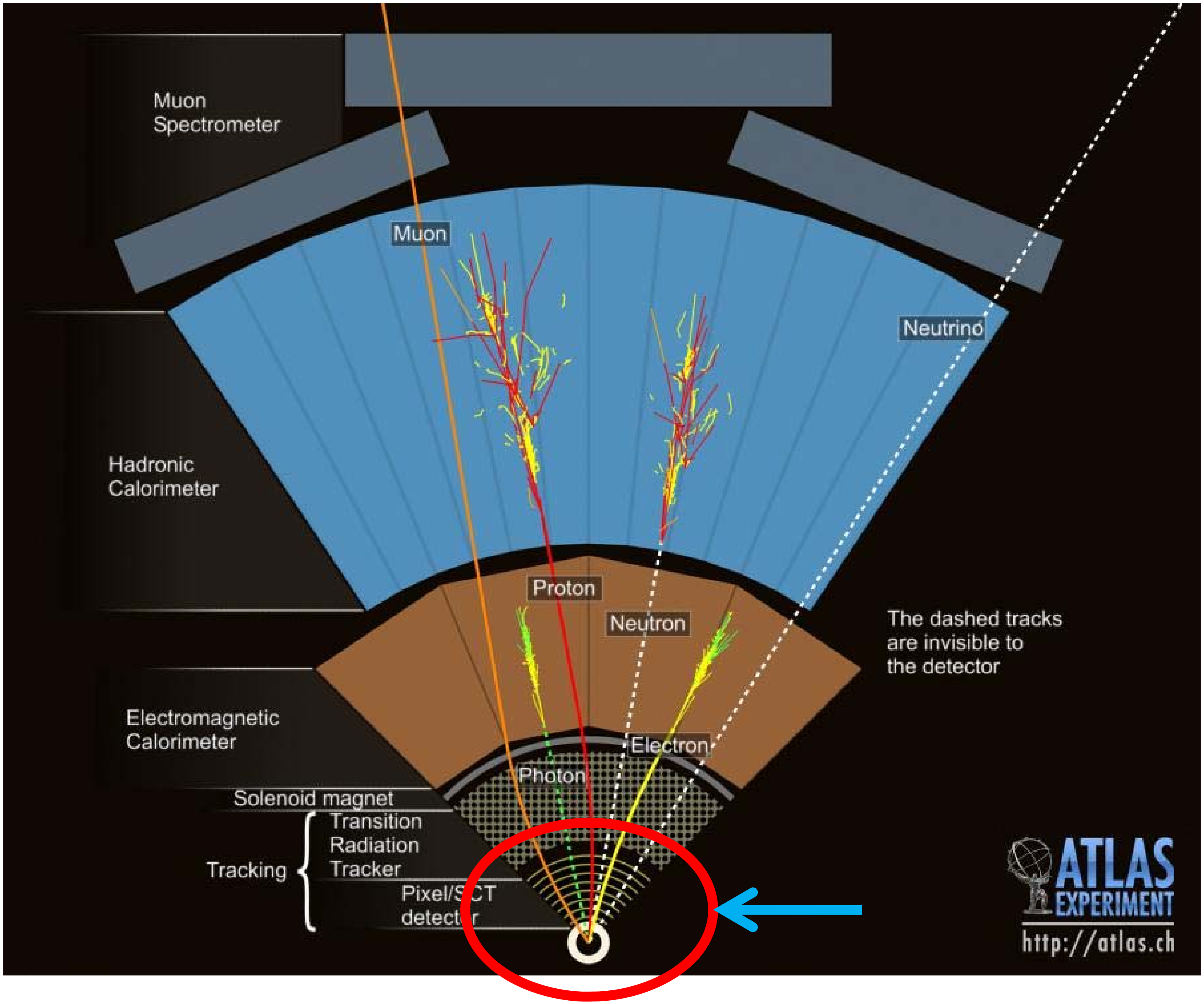
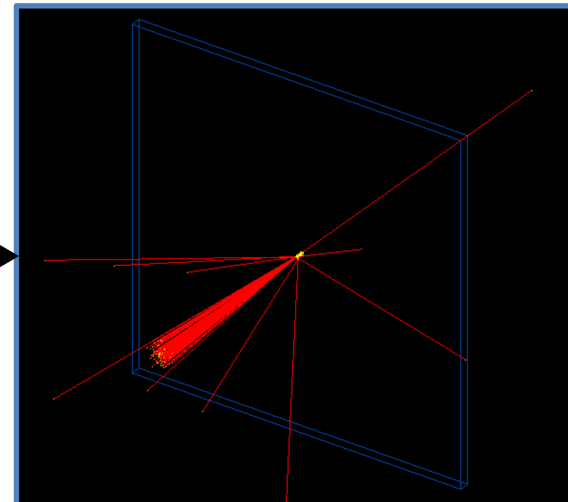
GEANT4



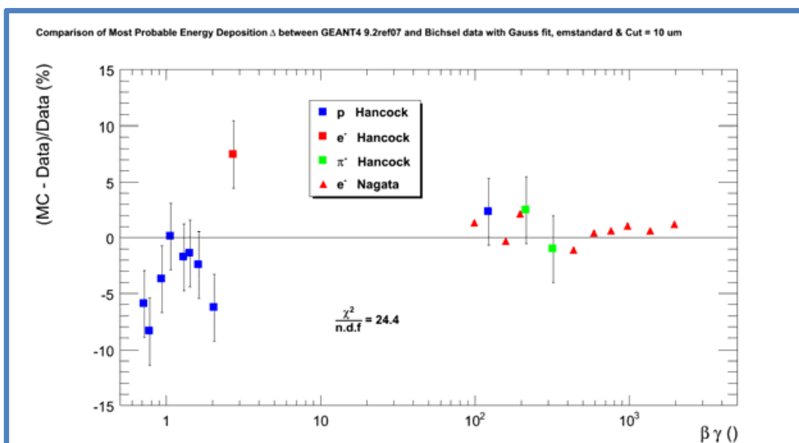
Muon Spectrometer
Hadronic Calorimeter
Electromagnetic Calorimeter
Solenoid magnet
Tracking
Transition Radiation Tracker
Pixel/SCT detector
Muon
Neutrino
Proton
Neutron
Electron
Photon
The dashed tracks are invisible to the detector
ATLAS EXPERIMENT
http://atlas.ch

My Summer Job

```
int main(int argc,char** argv) {

  //choose the Random engine
  CLHEP::HepRandom::setTheEngine(new CLHEP::RanecuEngine());

  //Construct the default run manager
  G4RunManager * runManager = new G4RunManager();

  //set mandatory initialization classes
  runManager->SetUserInitialization(new DetectorConstruction());

  //G4PhysListFactory factory;
  //G4VModularPhysicsList* phys = factory.ReferencePhysList();
  runManager->SetUserInitialization(new PhysicsList());

  runManager->SetUserAction(new PrimaryGeneratorAction());

  //set user action classes
  runManager->SetUserAction(new RunAction());
  runManager->SetUserAction(new EventAction());

  //get the pointer to the User Interface manager
  G4UImanager* UI = G4UImanager::GetUIpointer();
  G4VisManager* visManager = 0;

  if (argc==1)   // Define UI terminal for interactive mode
    {
#ifdef G4VIS_USE
      //visualization manager
      visManager = new G4VisExecutive;
      visManager->Initialize();
#endif
```



		t	T	$\beta\gamma$	σ_n	w	w_i	w_x	${}_i\Delta_p$	${}_x\Delta_p$
Kolata *et al.* (1968)										
	p	196	38	0.29	8	140.2	141.5	141	537	534
	p	196	42.4	0.30	8	138.3	139.4	139	484	485
			average differences				$\langle r_w \rangle = -0.3$			$\langle r_p \rangle = 0.2$
Maccabee *et al.* (1968)								≈±3%		±2%
	α	245	895	0.73	9	197.0	198.4	200	671	678
	α	884	910	0.74	10	598.3	598.8	619	2587	2610
	p	464	730	1.47	10	53.8	60.6	59.6	161	157
					15		68		163	
	p	1 772	730	1.47	10	188.4	190.4	184	664	659
			average differences				$\langle r_w \rangle = 0.3 \pm 3$			$\langle r_p \rangle = 0.3 \pm 2$
Aitken *et al.* (1969)										
	p	2 160	315	0.89	20	333.6	338.0	360	1246	1329
	π	2 160	65.3	1.07	20	281.2	286.5	296	1031	1061
	e	2 160	458	897	20	166.8	176.1	176	686	687
					10		169.2		683	
			average differences				$\langle r_w \rangle = 3$			$\langle r_p \rangle = -3$
Hancock *et al.* (1983, 1984)								±8%		±3%
	p	300	220	0.72	5	66.5	67.9	71	192	210
	p	300	254	0.78	4	60.6	61.6	68	174	196
	p	300	350	0.94	5	50.3	52.2	56	142	153
	p	300	433	1.07	4	45.1	46.4	48	126	131
	p	300	600	1.3	5	39	41.4	44	108	115
	p	300	700	1.43	5	36.8	39.4	40	102	108
	p	300	850	1.62	5	34.6	37.3	38	95	102
	p	300	1195	2.04	4	31.7	33.5	37	87	97.2
	e	300	0.98	2.73	4	29.5	31.5	32.5	81.4	87
	p	300	114 000	123	4	29.6	31.5	30	85.1	85.5
	π	300	29 900	215	4	29.8	31.6	29.6	85.6	85.6
	π	300	44 900	322	4	29.8	31.7	29.6	85.7	88.8
					3		30.9		84.9	
			average differences				$\langle r_w \rangle = -1 \pm 6$			$\langle r_p \rangle = -5 \pm 4$
Esbensen *et al.* (1978)										1.5±5 %
	p	900	1 280	2.13	4	85.0	85.7		277	279
	p	900	5 135	6.4	4.3	73.9	74.9		254	252
	p	900	14 100	16	4.3	75.0	75.9		268	259
	K	900	5 530	12.1	4	73.5	74.4		260	254
	K	900	14 500	30.4	4	74.1	74.9		267	264
	π	900	1 865	14.3	4	73.6	74.4		261	262
	π	900	5 860	43	4	74.4	75.2	76.4	269	264
	π	900	14 900	107	4	75.0	75.8		272	264
			average differences				$\langle r_w \rangle = 1.6$			$\langle r_p \rangle = 1.4 \pm 1.5$



My Validation Test : SiTest

- Energy Deposit Spectrum : Energy left by the primary and secondary particles in the layer.

- SiTest is an automatic test that compares GEANT4 simulation of the energy deposit spectrum with experimental data (*Bichsel Review*)

- Test is performed using shell scripts (*bash and tcshell are available*)
- Fitting and plotting procedure are done using ROOT scripts

My Validation Test : SiTest (2)

- G4 Version : 9.2 ref07 (*Other versions can be used*)
- EM Models : Standard EM PhysicsList (default and opt. 3) and PAI Model (*Other models can be compared*)
- Detector : Thin Silicon layer of :
  - 300 um (Hancock Data)
  - 1565 um (Nagata Data)

- PAI Model (V. Grichine) : Calculates the ionization process, within a step length, the number of secondary particles created using photoabsorption and ionization cross-section for every atomic shell.

- Data : Hans Bichsel, *Straggling in thin silicon detectors,* Rev. Mod. Phys. **60**, 663 - 699 (1988)

Standard EM PhysicsList

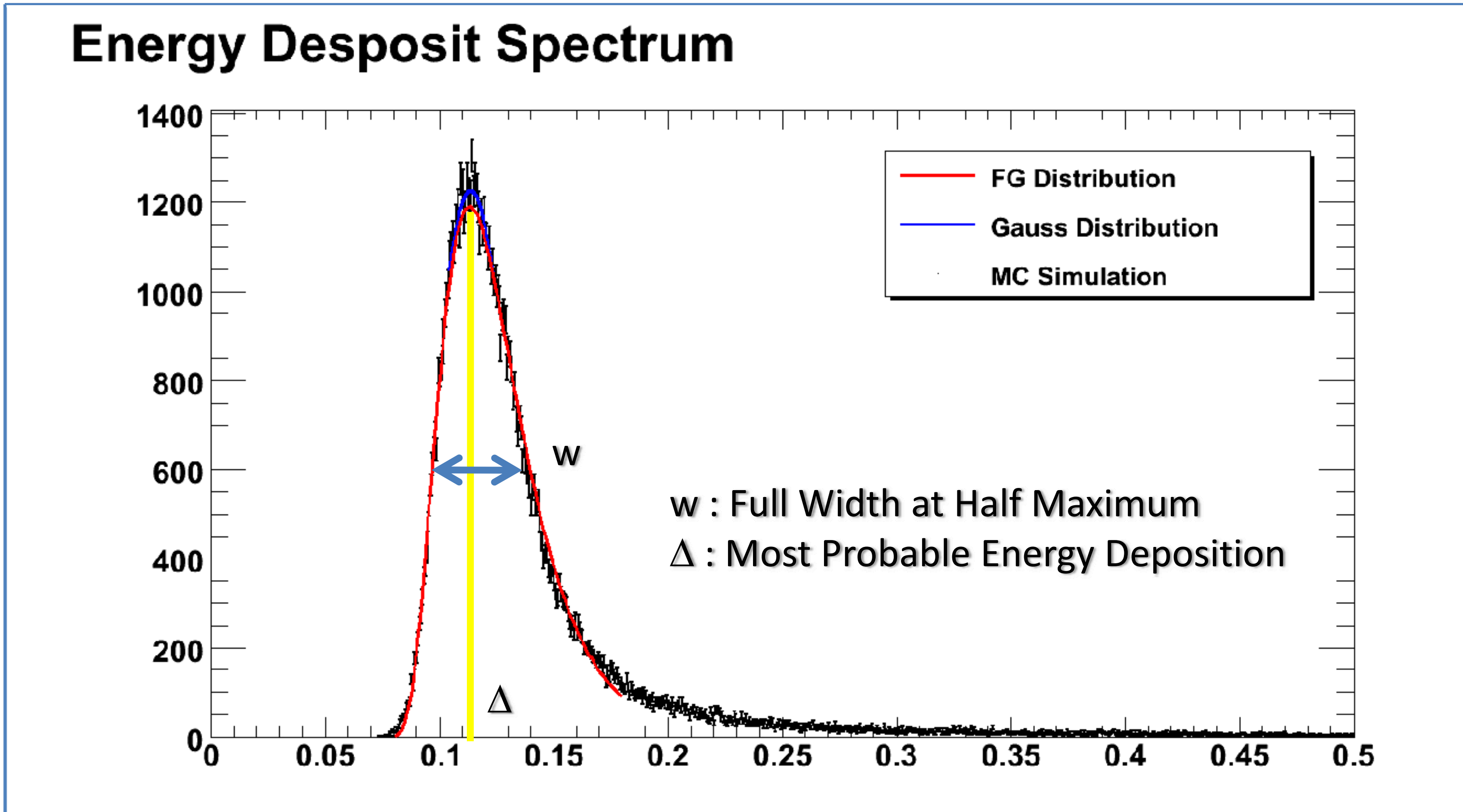
- Mean Energy Deposit : Bethe-Bloch Model
- Fluctuation : Universal Fluctuation Model (L. Urban)

- Cut-in-range : Only secondary particles that have enough energy to travel more than the cut-in-range, will be created and simulated (creation of delta-e^-)

- Contribution of the less energetic ones, will be calculated according to theoretical/phenomenological models

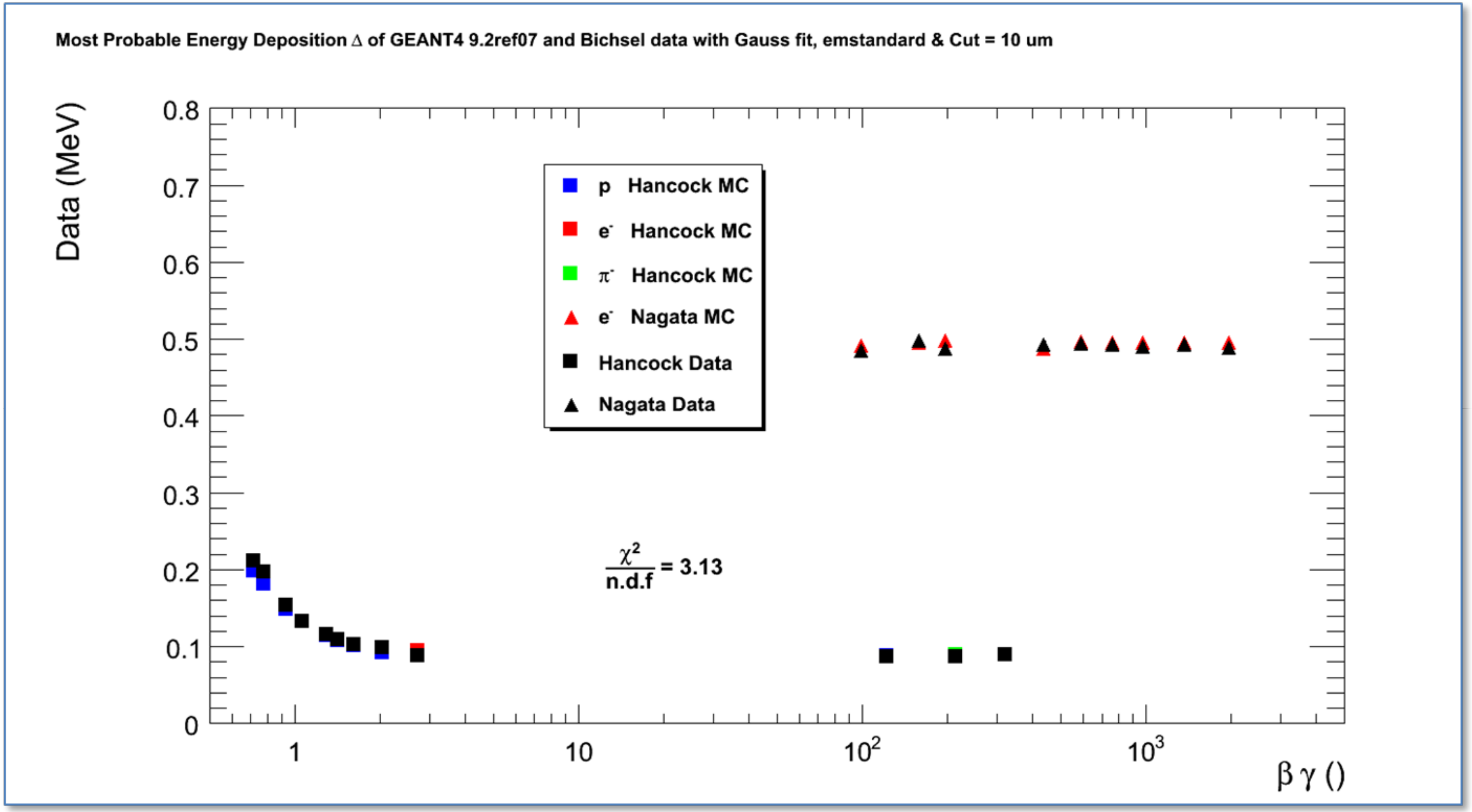
Energy Deposit Spectrum

- <u>Energy Deposit Spectrum</u> : Thin Detector



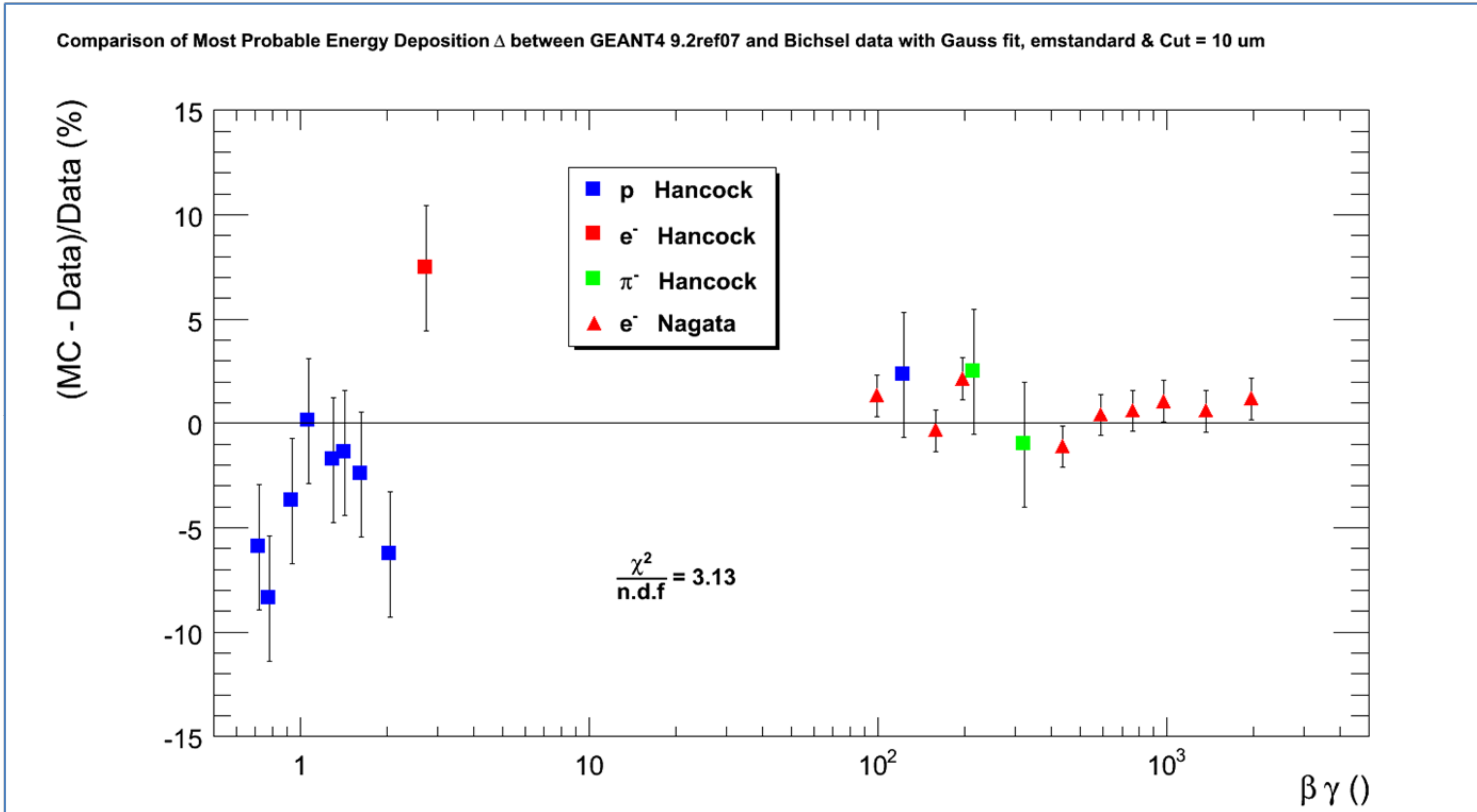
Results : Most Probable Energy Deposition Δ

GEANT4 Simulation



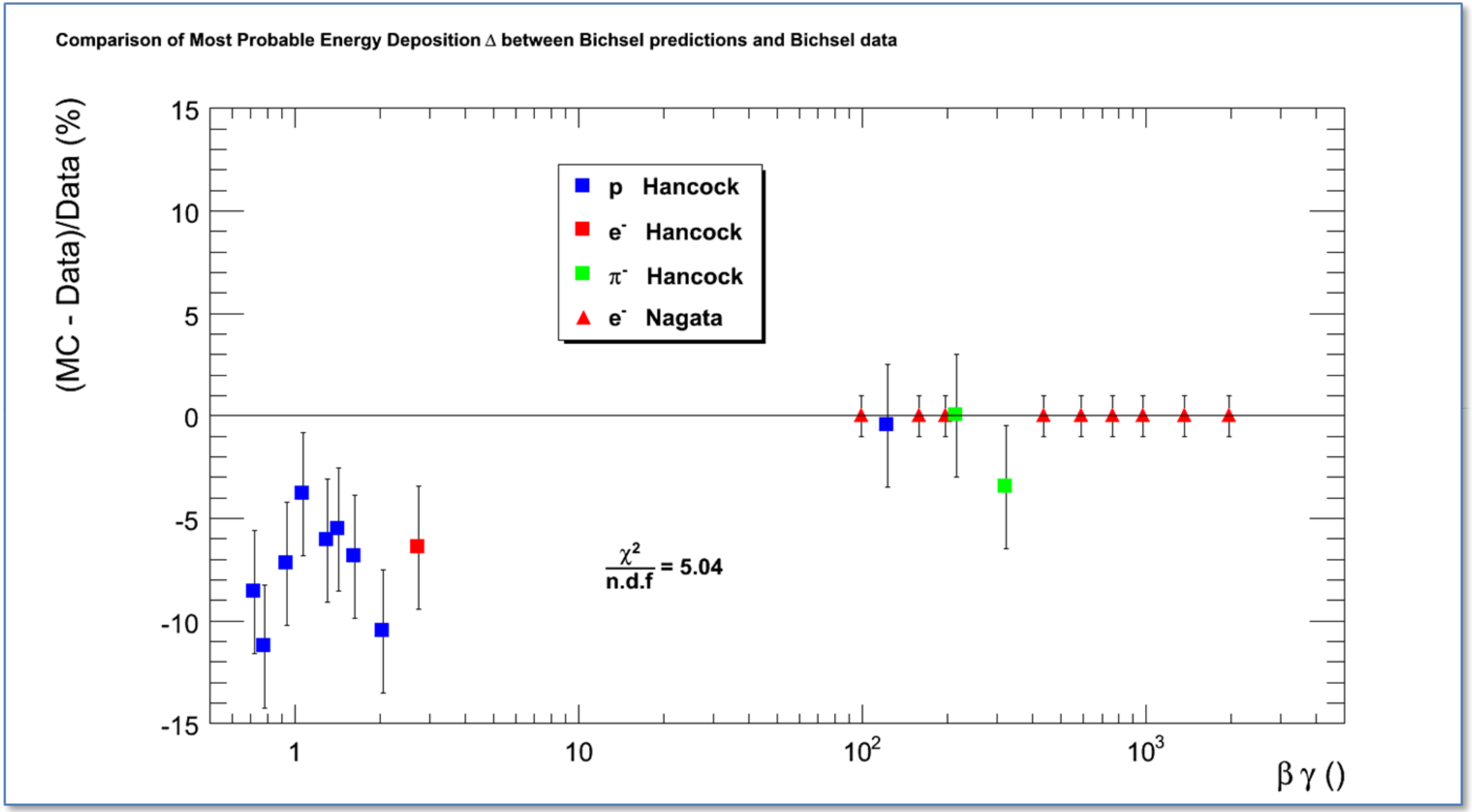
Results : Most Probable Energy Deposition Δ

GEANT4 Simulation



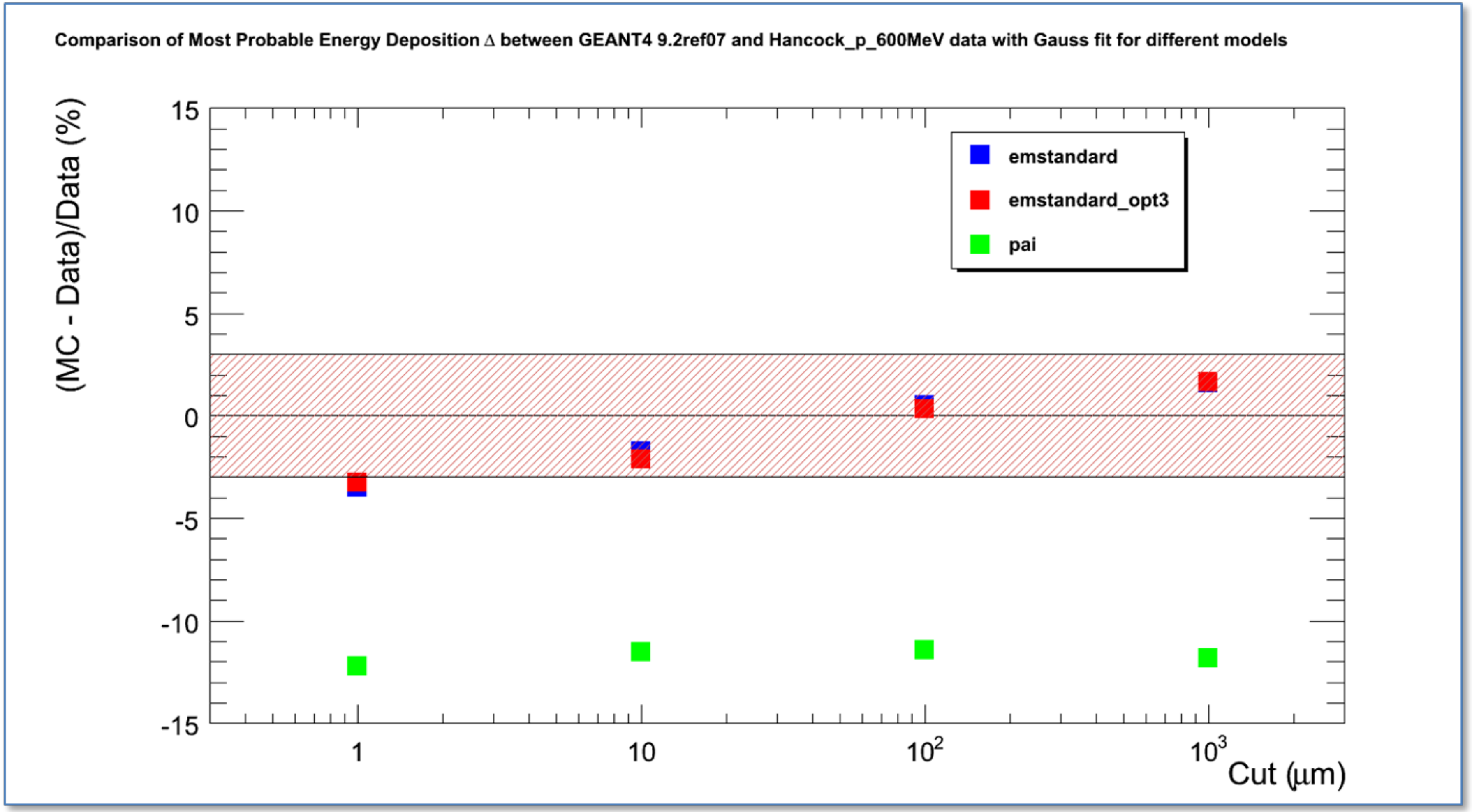
Results : Most Probable Energy Deposition Δ

Bichsel Predictions



Results : Most Probable Energy Deposition Δ

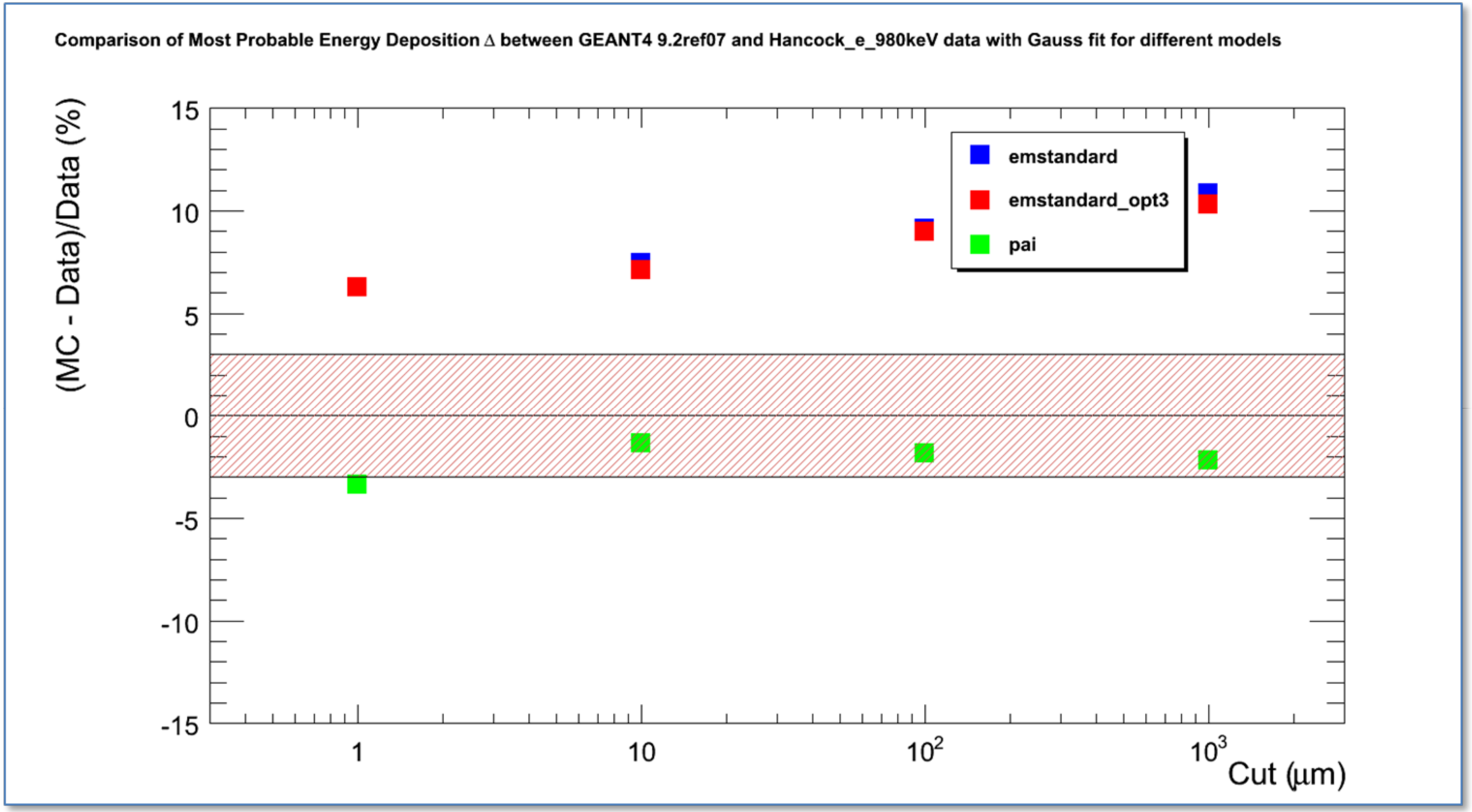
G4 Sim. Problematic Point : p 600 MeV



→ Strong cut dependence

Results : Most Probable Energy Deposition Δ

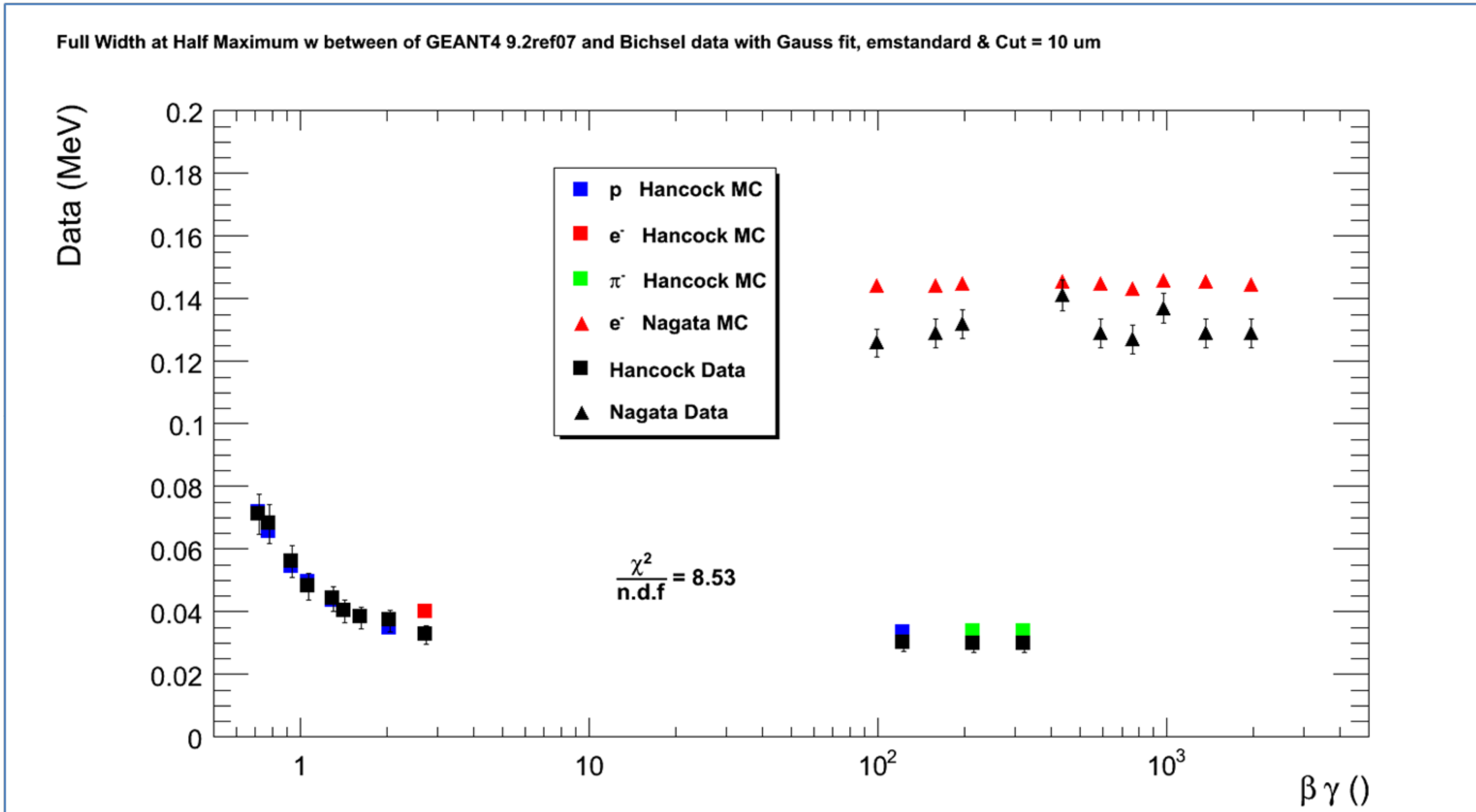
G4 Sim. Problematic Point : e^- 980 keV



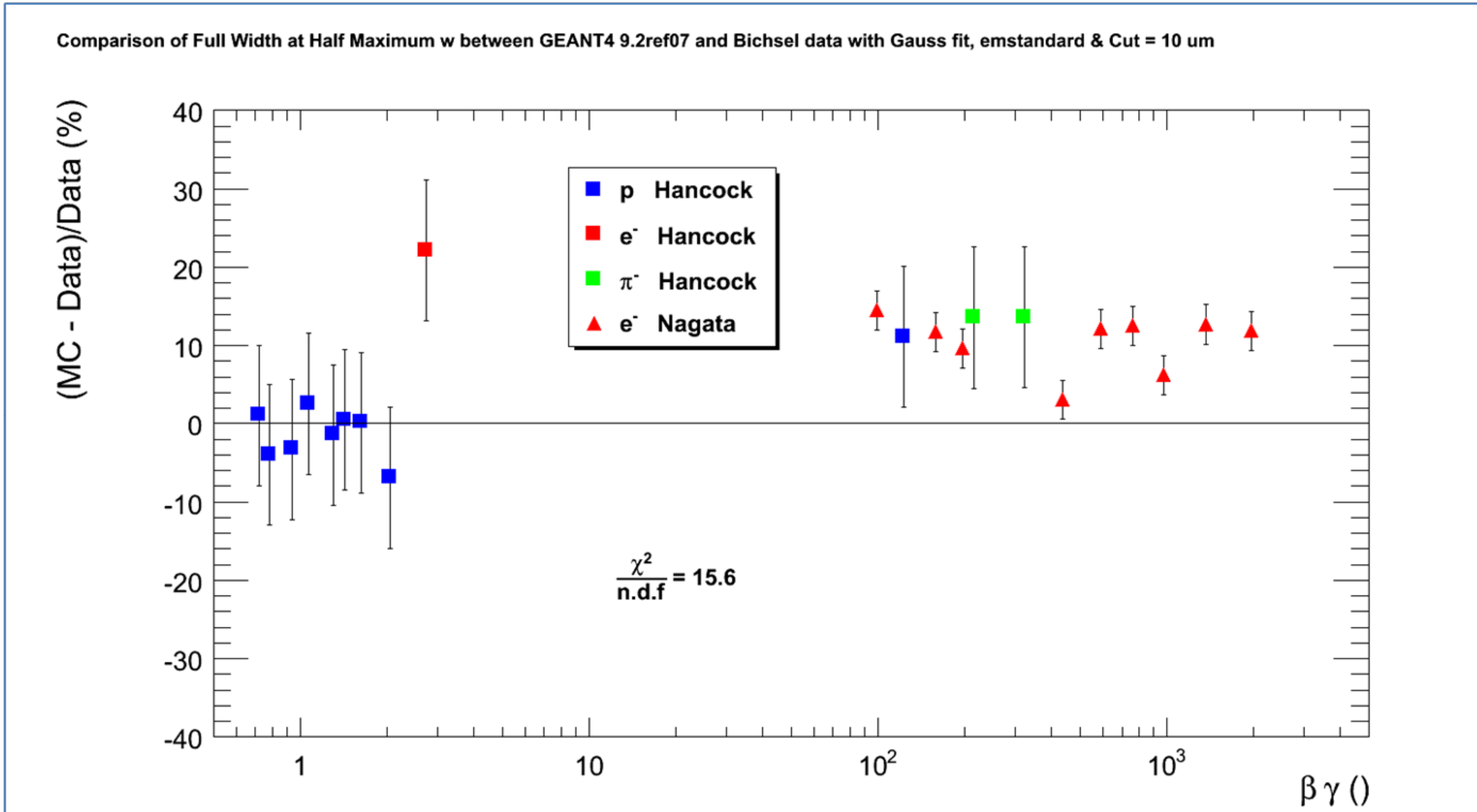
→ EM Standard PhysicsList is not in good agreement but PAI yes

Results : Full Width at Half Maximum w

GEANT4 Simulation

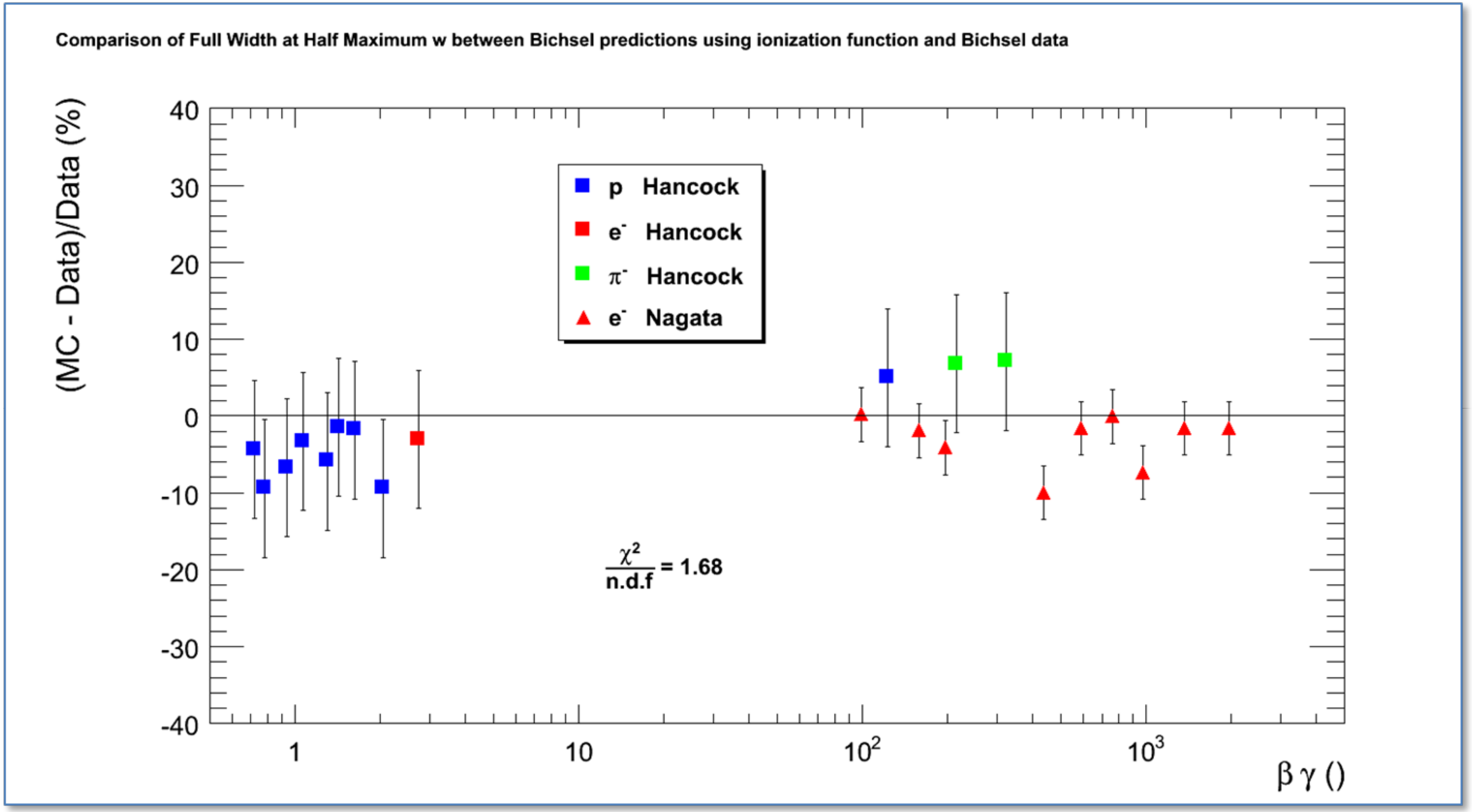


Results : Full Width at Half Maximum w
GEANT4 Simulation



Results : Full Width at Half Maximum w

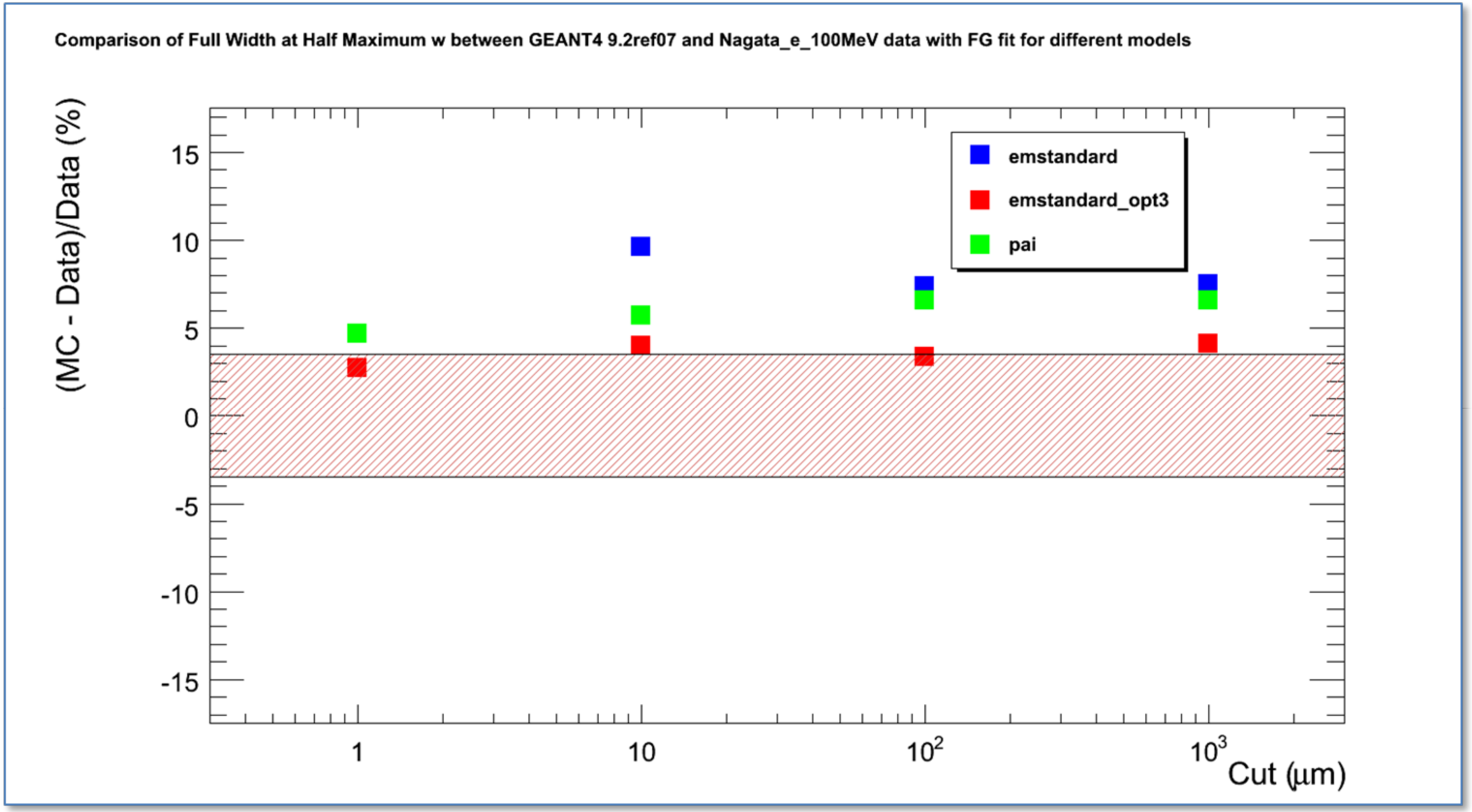
Bichsel Predictions (ionization function)



→ Good results compare to EM Standard PhysList

Results : Full Width at Half Maximum w

G4 Sim. Problematic Point : e^- 100 MeV



→ EM Standard opt.3 better than default one

Conclusion

- Validation of EM Models of GEANT4 for thin layers of Silicon is important for tracking systems (that become more and more essential nowadays in HEP → LHC).
- Methods to fit the Energy Deposit Spectrum were studied (Gauss for the peak position and FG for the FWHM).

- Results for the Mean Probable Energy Deposit show that for EM Standard PhysicsList, there is discrepancies for low energetic particle between G4 Simulation and Data.
- Bichsel Predictions give no good value of Δ for these low energetic particles. Systematics of Bichsel Data ?
- PAI Model is able to give a good value for Δ for e^- 980 keV.

Conclusion (2)

- Results for the Full Width at Half Maximum show that for EM Standard PhysicsList, there is discrepancies for high energetic particle and e^- 980 keV between G4 Simulation and Data.
- Bichsel Ionization function is able to give good results for w. Possible new parameterization of G4UniveralFluctuation ?
- EM Standard PhysicsList opt. 3 gives much better results than default one for w of high energetic particles.

- The results of the SiTest is/can be source of discussion, models investigation, models stability and perhaps improvement of the corresponding GEANT4 Models (Contact with Authors).
- The SiTest has been created within the summer student project and is included into GEANT4 Test Facility to compared different Models and Releases.

Novosibirsk Function

$$FG(E) = Ae^{-\frac{1}{2}\left\{\ln^2\left[1+\Lambda\tau\left(E-E_0\right)\right]/\tau^2+\tau^2\right\}}$$

where

$$\Lambda = \frac{\sinh\left(\tau\sqrt{\ln 4}\right)}{\left(\sigma\tau\sqrt{\ln 4}\right)}$$

E_0 = Peak Position
σ = Width
τ = Tail Parameter

GEANT4 EM PhysicsLists

- emstandard
- emstandard_opt1
- emstandard_opt2
- emstandard_opt3
- emstandard_local
- livermore
- livermore_old
- penelope
- pai
- pai_photon