

Report to Delta Review: Hadronic Physics

19 January 2009

CERN

Outline

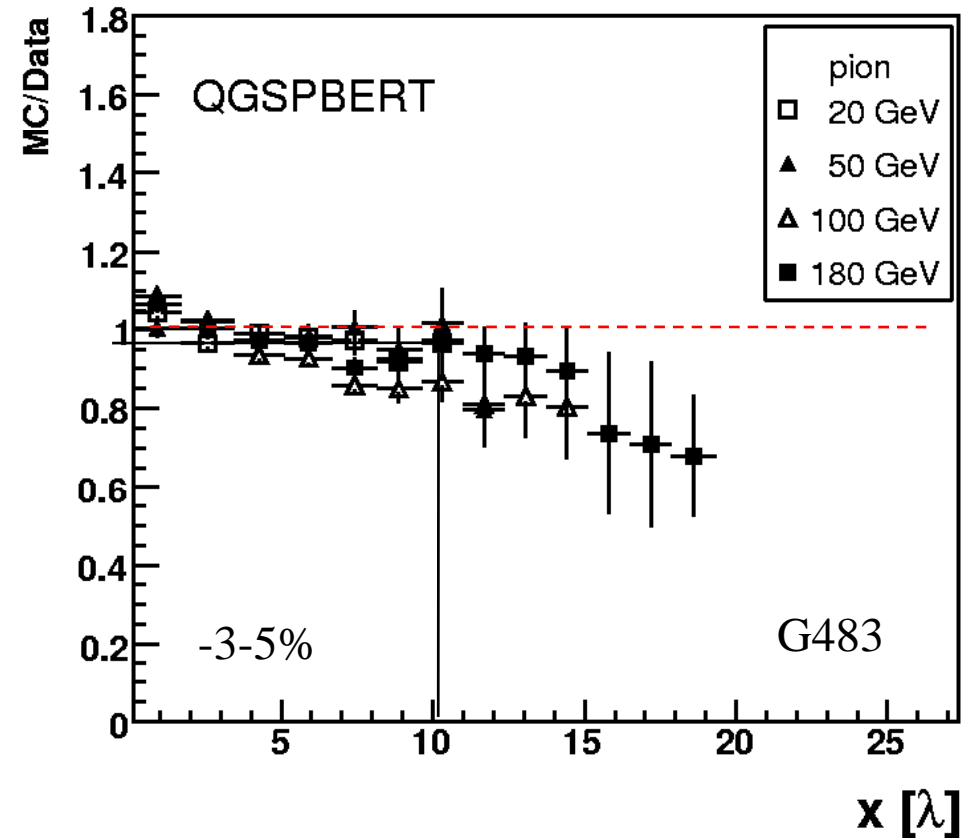
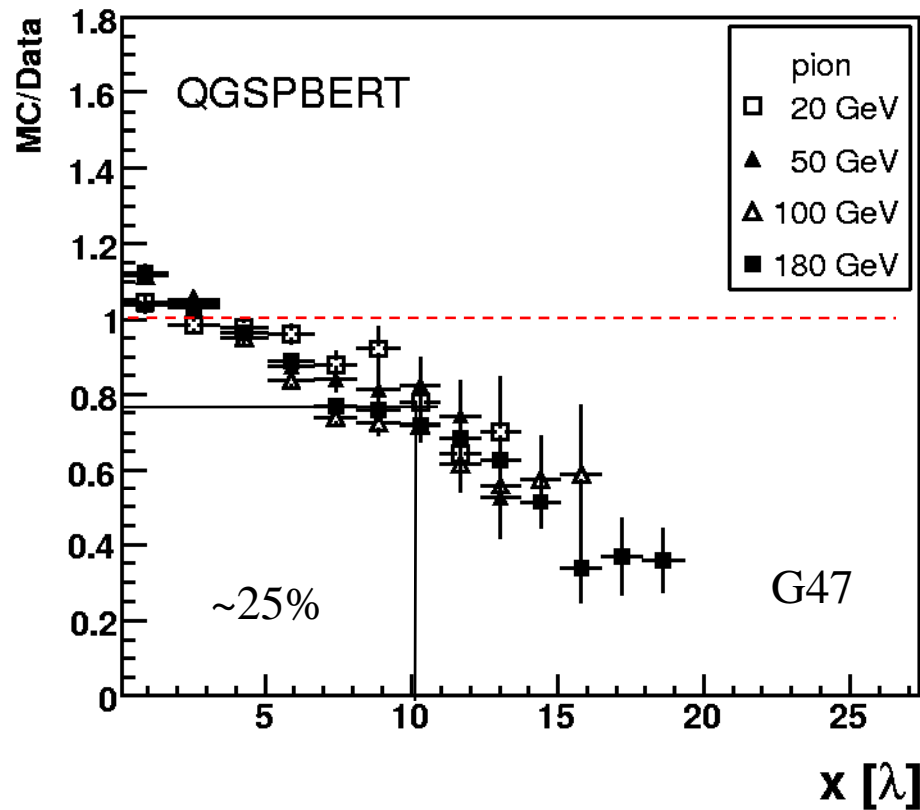
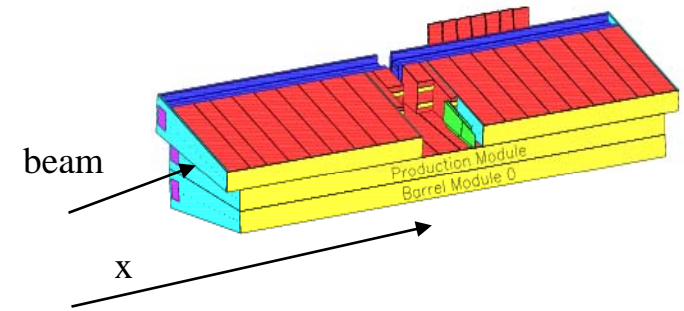
- Hadronics highlights since 2007 review
- Responses to reviewers' recommendations 6,7,8, and 9

Hadronics Highlights Since 2007 Review

Hadronics Highlights (1)

- May 2007 (release 8.3)
 - improved treatment of FTF model for baryon-nucleus interactions
 - quasi-elastic channel added to QGS
- June 2007 (release 9.0)
 - improved cross sections, Barashenkov cross sections added
 - Doppler broadening in HP neutron models can be switched off to improve speed
- September 2007
 - longer shower shapes achieved, much better agreement with CMS, ATLAS test beam data
 - medium energy validation suite released

Longitudinal Shower in TileCal Pion G47 vs G483

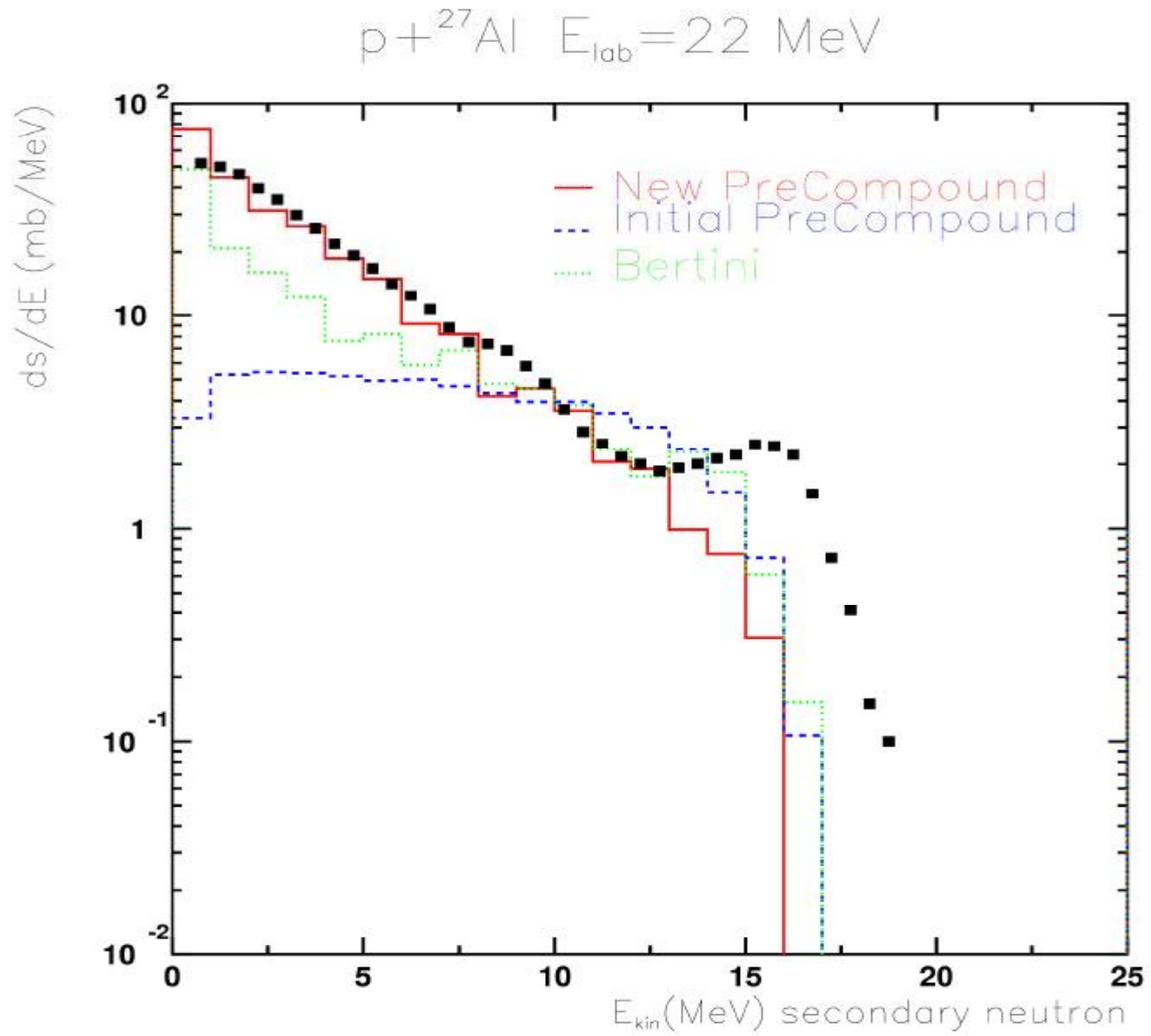


New Geant4 version has longer showers due to quasi-elastic scattering
 Good agreement with data for pions. [Slide provided by T. Carli, ATLAS](#)

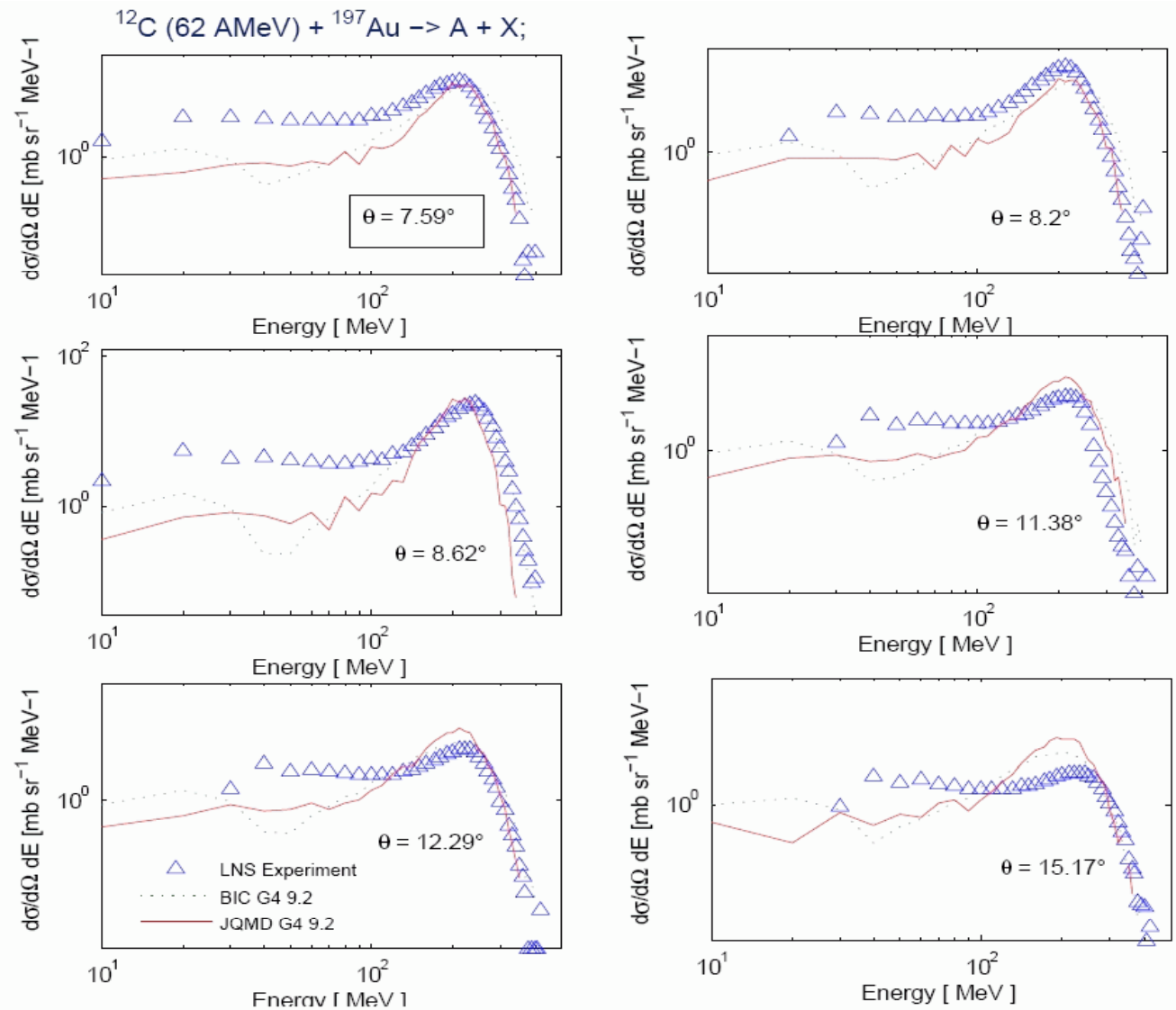
Hadronics Highlights (2)

- December 2007 (release 9.1)
 - Binary cascade modified to allow re-interaction of particles from HE collisions
 - alpha release of INCL (cascade) and QMD (nucleus-nucleus) models
 - bug fixes and revision of theory in G4Precompound and G4Evaporation models
 - improved treatment of FTF model for meson-nucleus interactions
- May 2008
 - missing Fermi momentum added to quasi-elastic scattering
 - tuning of FTF model parameters
 - coupling of FTF and BIC models, tuning of formation time
- July 2008
 - Ion-ion validation suite development (high and low energies)

Improved Precompound model ($p + {}^{27}\text{Al} \rightarrow n X$) 22 MeV



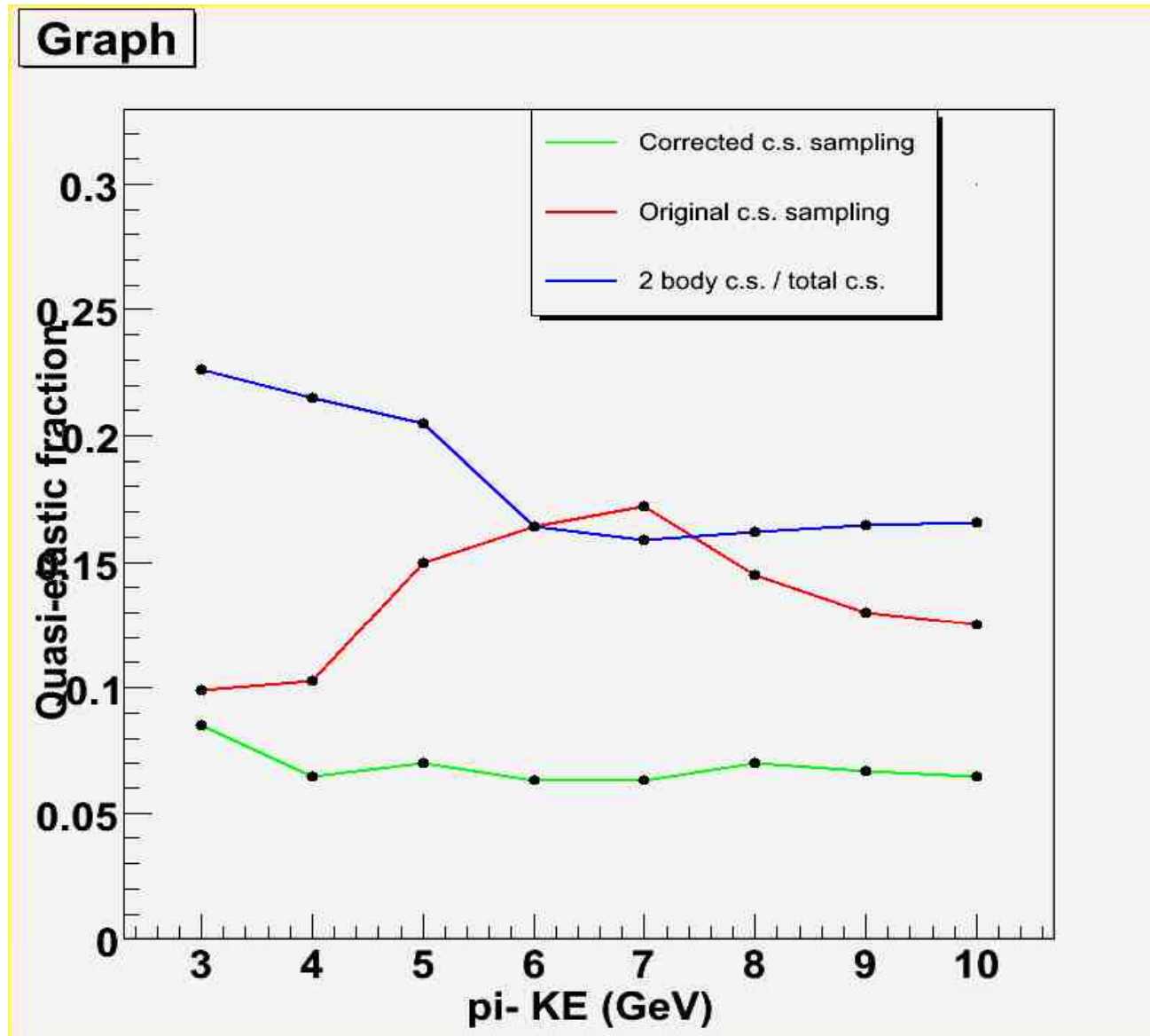
Low Energy Ion-ion Validation (LNS)



Hadronics Highlights (3)

- September 2008
 - bug fixes in LHEP models to remove oscillatory behavior seen by HARP
- October 2008
 - Coulomb barrier added to Bertini cascade
- November 2008
 - found cause of large quasi-elastic scattering in Bertini cascade (fix expected to reduce discontinuities observed in calorimeter energy response)
- December 2008 (release 9.2)
 - full release of INCL/ABLA models (alternative to Bertini, Binary cascades)
 - first improvements to unify nuclear mass tables

Bertini Quasi-elastic Fix (6 GeV π^- on Pb)



Responses to Reviewers' Recommendations

Recommendation 6: Dialog with FLUKA, Provide Users Best of Geant4 and FLUKA

- Informal discussion held
 - sufficient common ground not yet found
- Spoken with key users who requested this:
 - they are currently not actively seeking to invest in this convergence
- Effort to create interface, if possible, is significant
 - manpower for development and validation
 - problems with support
- Effort planned in CERN Simulation Project to improve existing FLUGG package
- Root Virtual Monte Carlo is already known to users and provides for portability of applications between Geant4 and FLUKA

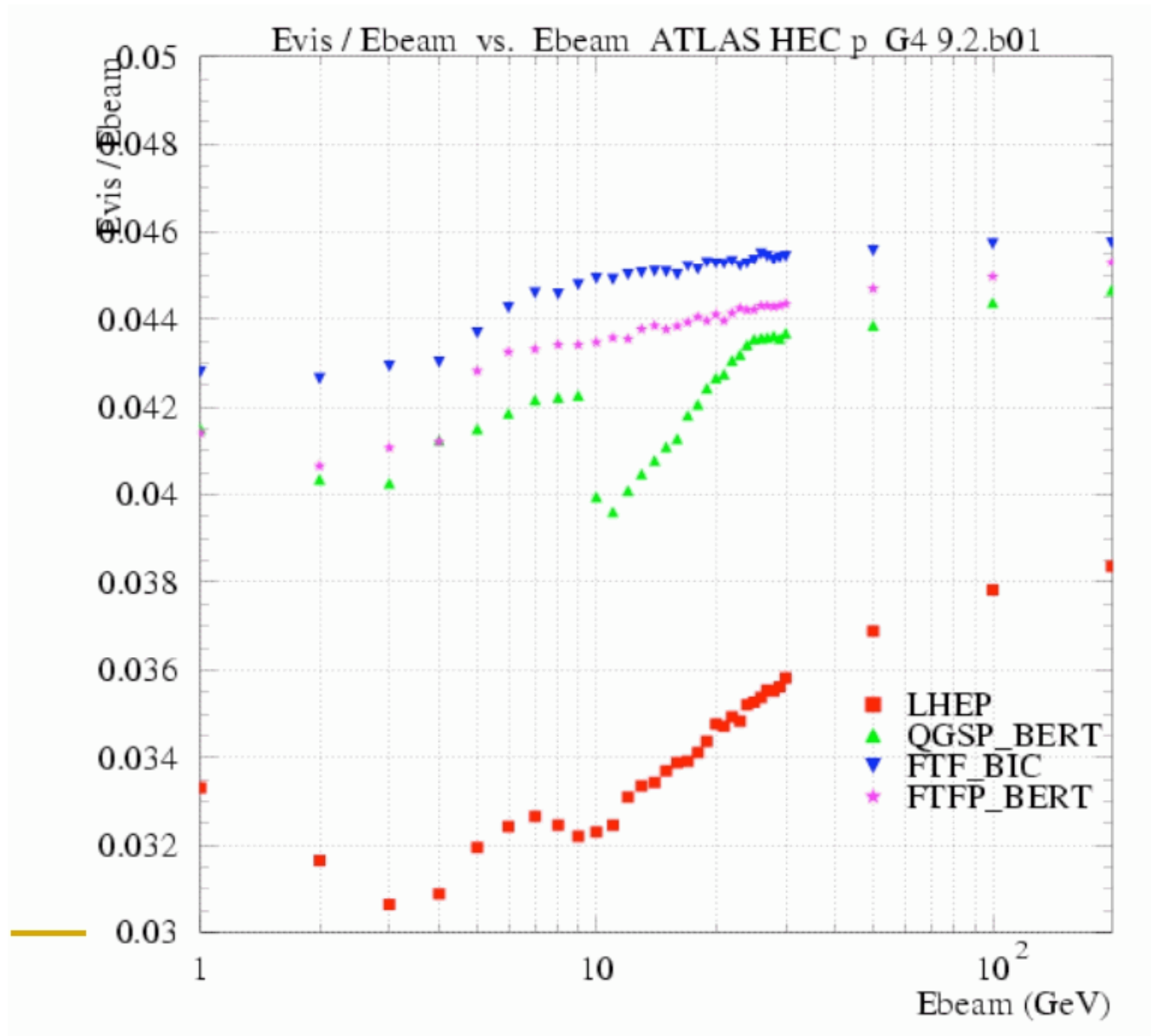
Recommendation 7: Develop detailed plans to improve the hadronic package

- Treated later in sections:
 - Hadronic Plans for 2009, 2010-2012
 - Addendum (milestones 2009, 2010-2012)

Recommendation 8: put in place a set of simple benchmarks

- simplified calorimeters
 - <http://lcgapp.cern.ch/project/docs/noteShowerShapes.pdf>
 - <http://lcgapp.cern.ch/project/docs/noteUpdateShowerShapes.pdf>
 - 3 benchmarks with simplified geometry
 - simple cylinder 10λ in length, $R = 150$ cm
 - Stack of ~ 100 planar layers scored in 10 radial rings => get longitudinal and lateral shower information
 - Cu-LAr (ATLAS HEC), brass-scint. (CMS HCAL), Fe-scint. (ATLAS TileCal)
 - measure E_{vis} , E_{tot} , σ_E / E , e/π , various fractions of total energy deposit
 - p , π^- , e^- beams of 1, 30, 100, 300 GeV

Simplified Calorimeters (ATLAS HEC)



Recommendation 8: put in place a set of simple benchmarks

- 5 more sets of benchmarks listed here
 - details in hadronic validation talk
- low energy and cascade region (test30)
 - 44 benchmarks from 22 MeV to 3.0 GeV
 - <http://cern.ch/vnivanch/verification/verification/hadronic/test30>
- inclusive pion production (test35 -HARP data)
 - 36 benchmarks from 3 to 13 GeV
 - <http://cern.ch/vnivanch/verification/verification/hadronic/test35>
- neutron yield (test45)
 - 3 benchmarks at 50 MeV
 - <http://cern.ch/vnivanch/verification/verification/hadronic/test45>

Recommendation 8: put in place a set of simple benchmarks

- medium energy and cascade region (proton incident)
 - 4 benchmarks (more to be added) from 1.4 – 14.6 GeV
 - http://geant4.fnal.gov/hadronic_validation/validation_plots/thin_target/hadronic/medium_energy/index.shtml
- high energy (test43) (pion and proton incident)
 - 5 benchmarks from 100 to 400 GeV
 - http://geant4.fnal.gov/hadronic_validation/validation_plots/thin_target/hadronic/high_energy/index.shtml

Recommendation 9: physics models that serve needs of space community

- QMD model for nucleus-nucleus collisions essentially complete (see plots in hadronic validation talk)
 - beta release with Geant4 9.2
 - valid from 50 MeV/n to 5 GeV/n, protons to Uranium
 - first validations against triple differential cross sections (energy, angle, fragment mass) complete
 - more underway (see talk by T.Koi <http://kds.kek.jp/sessionDisplay.py?sessionId=15&slotId=0&confId=2027#2008-10-09>)
- String models
 - nucleus-nucleus variant of FTF model ($E > 3$ GeV/n, target and projectile masses $1 < A < 240$) under development
 - nucleus-nucleus variant of QGS model ($E > 10$ GeV/n, target and projectile masses $1 < A < 240$) beginning in 2010

Recommendation 9: physics models that serve needs of space community

- Interfaces

- JQMD $50 \text{ MeV/n} < E < 5 \text{ GeV/n}$, pions and protons to U

- [http:// hadron31.tokai-sc.jaea.go.jp/jqmd](http://hadron31.tokai-sc.jaea.go.jp/jqmd)

- DPMJET $5 \text{ GeV/n} < E < 1000 \text{ TeV/n}$, $2 \leq A \leq 58$

- <http://>

- [geant4Hadronics.wikispaces.com/space/showimage/DPMJET-II.5 20080703.ppt](http://geant4Hadronics.wikispaces.com/space/showimage/DPMJET-II.5%20080703.ppt)

- PHITS $50 \text{ MeV/n} < E < 100 \text{ GeV/n}$, neutrons and protons up to U

- [http:// phits.jaea.go.jp](http://phits.jaea.go.jp)

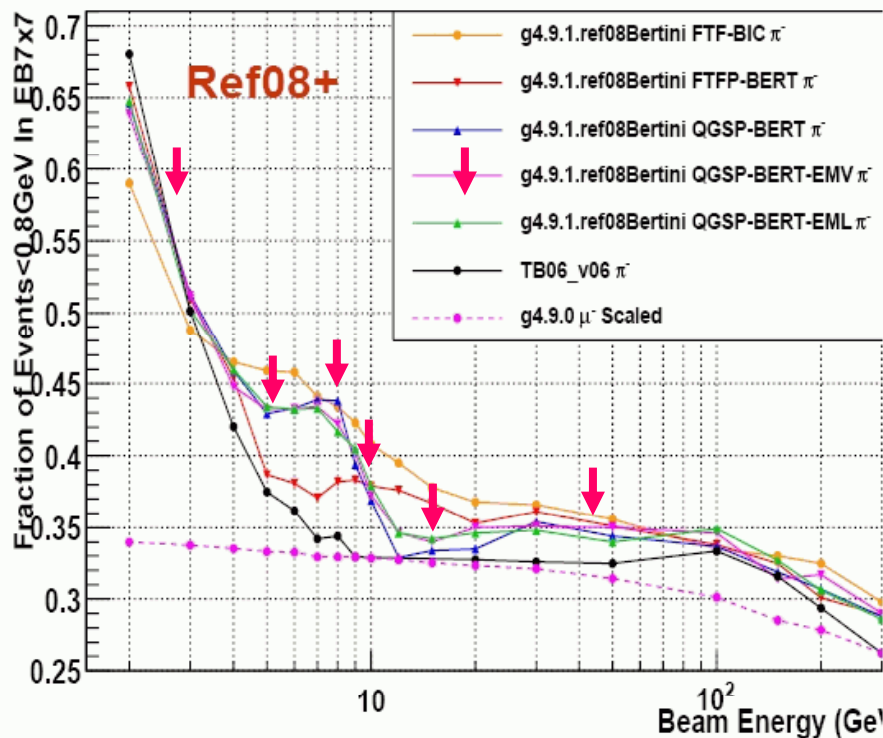
Hadronic Plans for 2009 and 2010-2012

Hadronics Working Group Major Tasks

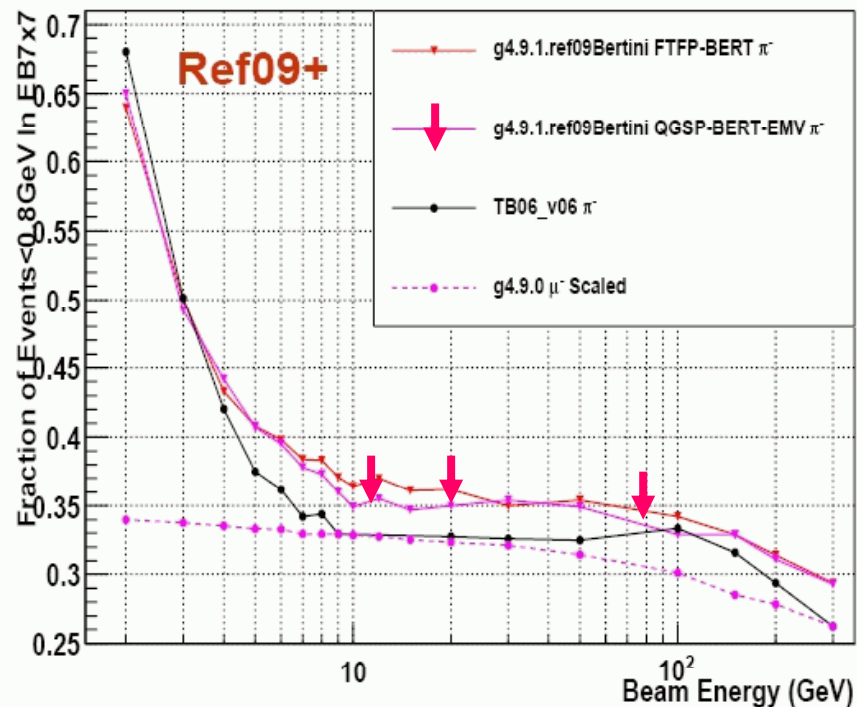
- Shower shapes and energy response for HEP
 - discontinuities in energy response, particle multiplicities (underway)
 - coupling string models to cascade models in 5 – 15 GeV region (underway)
 - improvement of QGS model, including implementation of new diffraction cross section calculations (underway)
 - model matching
 - improvement of quasi-elastic scattering in models
 - QGS, Bertini (underway but delayed due to lack of manpower)
- Low energy behavior
 - pion absorption in nuclei (important below 4 GeV) (started)
 - production of protons below 200 MeV (started)
 - improve approximate neutron transport (elastic and capture)
 - improve negative particle stopping



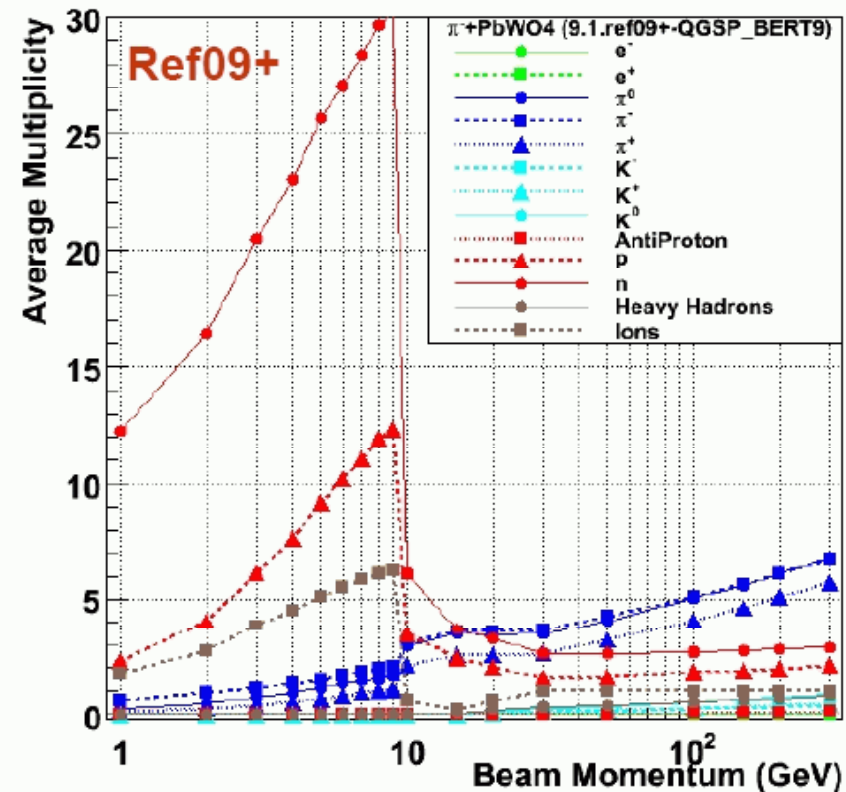
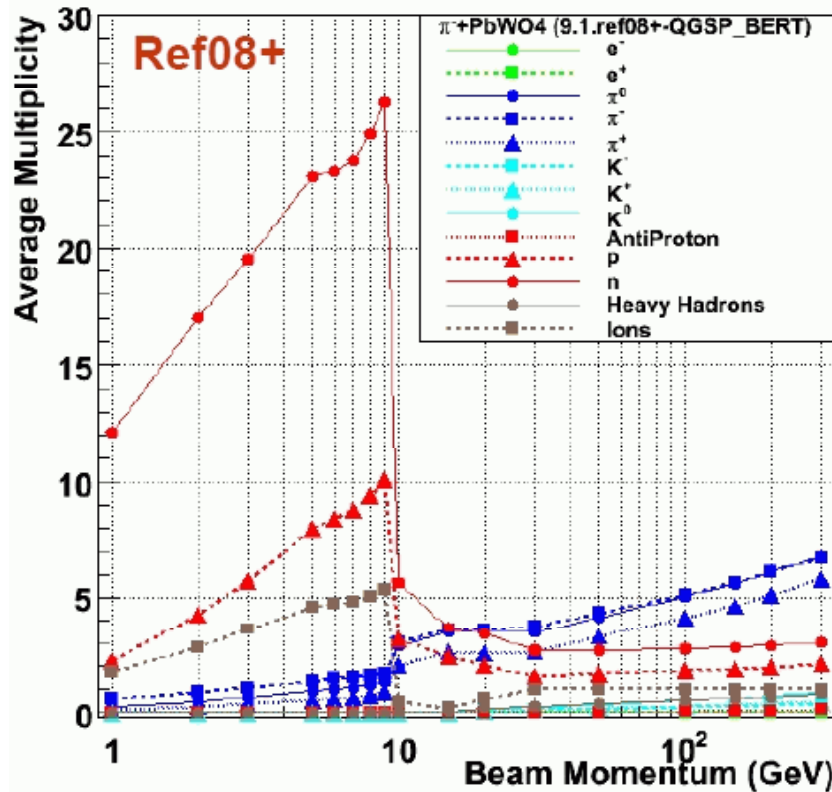
MIP fraction G4.9.1.ref08Bertini (old lists)



MIP fraction G4.9.1.ref09Bertini



□ The discontinuity around 9 GeV is greatly reduced and there is improved agreement with the data



Change for neutrons, protons and ions (increase) – more at higher energies

Hadronic Major Tasks (2)

- Cross section review
 - review of high energy external cross sections complete
 - review of low energy cross sections needed
 - review of internal cross sections (used by models) (underway)
 - set up easy printout and plotting of cross sections
 - examine for discontinuities (underway)
- Validation
 - continue existing effort, expand existing validations, add new validation suites for stopping particles and ion-ion
 - compare results with other MC codes (deferred due to lack of manpower and expertise in other codes)
 - prepare validation benchmarks for Hadronic Shower Simulation Workshop (time to be determined)

Hadronic Major Tasks (3)

- Testing
 - completion of system tests (underway)
 - select set of unit tests which can be run as regression tests (not yet started - deferred until 2010)
 - complete energy/momentum tests (underway)
 - devise tests for quantities not usually examined (sanity check) (not yet started - deferred until 2010)
- Documentation
 - document model implementations (not yet started – deferred at least until 2010)
 - completion of model descriptions and validity ranges (underway)

Hadronic Major Tasks (4)

- New models
 - FTF and QGS nucleus-nucleus collision models
 - full release of QMD and improvements (underway)
 - alternative to high precision neutron model, based on ENDL (underway, but delayed from end of 2008)
 - improve and validate charge exchange process (underway, but deferred)
 - RPG (GHEISHA replacement) (started but deferred – was originally to be completed by end of 2008)

Manpower

- items listed as delayed are late due to lack of manpower
- items listed as deferred will not be completed by 2009 or will not be started in the near future
 - loss of FTEs
 - loss of expertise
- currently looking for funding
- also looking for new collaborators to increase expertise in physics modeling and validation

FTE Gains and Losses 2007 through 2009

- Losses

– Binary cascade	-0.5
– string models	-0.5
– Bertini cascade, LHEP	-0.8
– CHIPS low energy, quasi-elastic	-0.8
– precompound/evaporation	-0.4
– validation/model testing	-0.7
– nucleus-nucleus/low energy	-0.5
– Total losses	-4.2 FTE

FTE Gains and Losses 2007 through 2009

- Gains
 - validation (medium energy) 1.4 (FNAL)
 - validation (high energy and shower shapes) 0.5
 - precompound/evaporation 0.5
 - validation (low energy/medical) 0.3 (INFN Catania)
 - Total gains 2.7 FTE
- Net:
 - loss of 1.5 FTE

Major Deliverables and Resources

- High-priority deliverables
 - study and repair of problems which disrupt smooth simulated calorimeter energy response
 - identify reasons for differences in shower shape lengths and widths between Geant4 simulation and test beam data from ATLAS, CMS
 - complete validation suite for all energy regions
 - regular validation of hadronic models against thin target and full-setup data
- Resources
 - from 2007 review through mid-2009, hadronics group will lose 1.5 FTE
 - loss in the area of the above-listed deliverables 2007 through 2009 is 1.5 FTE

Smooth Energy Response (1)

- remove discontinuities in visible energy, multiplicity
 - validation reveals factors of 2 - 5 differences in multiplicity for QGSP_BERT around 9-10 GeV (the region where Bertini cascade blends into LEP (Gheisha-style) models)
 - visible energy also appears to have dips and wiggles in same region (where none are expected)
- main tasks:
 - study of distribution-matching between cascade and string models
 - review of internal cross sections in string and cascade models
- potential additional tasks (could evolve with time):
 - develop/test re-interaction of particles from string models (Binary cascade)
 - theoretical or parameterized method for smoothly turning off the Bertini cascade in the range 5 – 15 GeV

Smooth Energy Response (2)

- required resources:
 - expertise in QGS, FTF, Bertini, Binary models
 - 2.5 FTE-years:
 - Required
 - 1.0 distribution matching
 - 0.5 cross section review
 - Potential additional
 - 0.5 re-interaction of particles
 - 0.5 Bertini high energy cut-off

Shower Composition and Shape (1)

- lengthen and broaden simulated showers
- main tasks:
 - improve energy response characteristics (see previous slide)
 - study and improve pion production, especially π^0
 - improve diffraction in proton-nucleus collisions (both in QGS and FTF)
- potential additional tasks:
 - study neutron and charged particle capture (affects lateral shape)
 - develop alternative to replace LEP/Gheisha neutron transport model
 - study and improve precompound and nuclear physics, especially for protons below 200 MeV

Shower Composition and Shape (2)

- required resources:
 - expertise in low energy neutron propagation, precompound/evaporation models and nuclear physics
 - 2.25 FTE-years:
 - 0.50 pion production study
 - 0.50 proton diffraction (especially QGS)
 - 0.25 neutron/charged particle capture study
 - 0.75 development of improved neutron capture and transport model
 - 0.25 precompound/evaporation, nuclear physics study

Completion of Hadronic Validation Suites

- main tasks:
 - complete medium energy suite with metrics and automation
 - develop similar suites for high energy, stopping particle and heavy ion validation
- required resources:
 - 2.00 FTE-years:
 - 0.50 medium energy suite completion (automation)
 - 0.75 development of high energy suite
 - 0.25 development of stopping particle suite
 - 0.50 development of heavy ion validation suite

Regular Hadronic Validation

- main tasks:
 - run all validation suites for each release
 - post results
 - maintain scripts, directories, documentation, etc.
- required resources (continuing):
 - 0.75 FTE:
 - 0.15 test30, test35, test45 validations
 - 0.15 medium energy validation
 - 0.15 high energy validation
 - 0.15 stopping particle validation
 - 0.15 heavy ion validation

Resources

- Effort required to complete major tasks:
 - smooth energy response 2.50 FTE-years
 - longer, broader showers 2.25 FTE-years
 - completed validation suites 2.00 FTE-years
 - Total 6.75 FTE-years

- running validation 0.75 FTE continuing

Addendum

Hadronic Milestones for 2009 and 2010-2012

Changes in Hadronic Effort

End of 2007	Mid - 2009	
8.0 FTE	6.5 FTE	Total hadronic effort
1.2	2.3	Validation
3.7	2.2	Models/shower shapes
1.6	0.5	Other development: INCL/ABLA, RPG, HP neutron alternative, very high energy models
1.5	1.5	Code maintenance, testing, user support, documentation, release preparation, result presentation

Resources

- Milestones assume current FTE levels
- In many cases high priority items will not be completed until 2010 or 2011
- Additional effort required to advance these items (marked by ** in milestones) by ~1 year:
 - QGS expertise (replacement + new) 0.5 FTE
 - replace Binary cascade lost effort 0.3 FTE
 - replace Bertini cascade lost effort 0.6 FTE
 - replace low energy expertise 0.4 FTE
 - model integration/testing (replacement + new) 0.6 FTE
 - Total 2.4 FTE

Hadronics Milestones 2009 (1)

- Feb
 - complete IAEA spallation benchmarks
- Mar
 - complete latest validation against changes in Bertini cascade
- May
 - complete study of cascade turn-off in Bertini
- Jun
 - medium energy validation suite completed
- Aug
 - ion-ion validation suite completed
- Sep
 - implementation of developer tests for energy/momentum conservation in all hadronic models

Hadronics Milestones 2009 (2)

- Oct
 - completion of QGS model revision
- Nov
 - Hadronic Shower Simulation Workshop benchmarks completed (?)
 - ENDL-based model for high precision neutrons implemented
- Dec
 - high energy validation suite completed
 - precompound model improvements completed
 - cross section review completed

Hadronics Milestones 2010-2012 (1)

- Jun 2010
 - SATIF benchmarks completed
 - testing and validation of Propagate interface in Binary cascade
 - Bertini cascade turn-off implemented **
 - regular benchmarking against MCNPX
- Dec 2010
 - distribution matching study complete **
 - pion production study complete **
 - neutron/charged particle stopping study complete
 - proton diffraction implemented (QGS + FTF) **
- Jun 2011
 - stopping particle validation suite complete
 - RPG model complete

Hadronics Milestones 2010-2012 (2)

- Dec 2011
 - implementation of distribution matching algorithms **
 - improved approximate neutron propagation and capture process
 - Hadron Shower Simulation Workshop benchmarks
- Jun 2012
 - IAEA benchmarks
 - development freeze for documentation month
- Dec 2012
 - very high energy ($> \text{TeV}$) string model additions
 - low energy ($< 50 \text{ MeV/n}$) nucleus-nucleus models
 - SATIF benchmarks