Geant 4

Status Report on the Varied Model Parameters Interface (Bertini)
- based on limited experience -

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Disclaimer

- **This presentation does NOT intend to discuss why parameters of one or another Geant4 model are set the way they are at present, or whether the current settings are “good” or “bad”.**

General Information

- **Strong interest from the users community**:
  - Estimate systematic errors in Geant4 predictions
  - Make MC agree with the data in the region of interest:
    - Study specific detector effects
    - Improve extrapolation to other regions
    - Minimize systematic effects
    - …
- Potential input to optimize model parameters
- Discussions: 19th Collab.Workshop, HAD group meeting (Nov.2014)
- Follow-up vote (Dec.2014):

  "In selected cases, to be evaluated by the Geant4 hadronic group, Geant4 supports changes of hadronic model parameters with partners."
- **Lots of questions from users as soon as the word leaked !**

Full statement of the policy on modifying of Geant4 hadronic model parameters

In selected cases, to be evaluated by the Geant4 hadronic group, Geant4 supports changes of hadronic model parameters with partners.

- For "support" we mean documenting which parameters can be varied and within what range, debugging in the case of problems, and performing some physics validation.
- For "partners" we mean Geant4 users willing to help the developers in this effort, to provide feedback and complete information, and to perform physics validation requested by Geant4.
- In those cases in which Geant4 does not support changes of hadronic model parameters, users are anyhow allowed to try do it themselves given that code is open, or even seek the help of individual Geant4 collaborators, but no support by the Geant4 collaboration should be expected.
- For any use of modified models, each public presentation and publication of the results must clearly state that a modified version of Geant4 has been used, and document the parameters changed and their values.
- The Geant4 Steering Board will be informed of all the decisions taken by the Hadronic Working Group on this regard.

Current Efforts (I)

- Bertini cascade model as the 1st use-case:
  - Largely employed to model processes through the MeV range and/or in the several-GeV range
  - Offers reasonably ready model configuration interface
- Collaboration with the SLAC team
- Learning curve:
  - Modification, interplay of parameters
  - Modification of parameters at the model level (single model)
  - Modification of parameters for a model in a phys.list:
    - Change of parameters vs general G4 init, propagation of changes
    - Currently available feature of the Geant4 UI
  - Initially exploring and understanding the impact of Bertini parameters modification on the physics results (currently benchmarked vs HARP data, but other datasets will also be as well)

Current Efforts (II)

- The challenge:
  - Standardize the machinery to compute systematic uncertainties due to model choice in the simulation
  - When the efforts are reasonably mature, partner with a selected group of experienced Geant4 users who would be willing to share with us the feedback from their studies and help us in these efforts
- Software tools/features at the initial phase:
  - Tools to vary intentionally exposed parameters in a controlled way, without recompiling the code
    - Convenient and uniform API
    - Documentation
  - Tools to comprehensively analyze the impact of perturbing model parameters around their current tuned values, to understand the induced uncertainties

“Pilot” toolkit

- Based on Art Framework
  - The software framework of choice throughout the Intensity Frontier community
  - Plenty of common-use feature, including job configuration language, extensive bookkeeping and I/O functionalities
- Geant4-based components:
  - Configurable model-tweaking interface
  - The interface should be general enough to be adapted to other models in the future
  - Configurable choice of geometry and physics event input
- RooMUHistos analysis package (open source):
  - https://github.com/ManyUniverseAna/RooMUHistos
  - Depends only on ROOT
  - Built-in functions for working with the case where a “central value” and a single and/or multiple perturbation(s) around that value are considered
  - Easily fits with other packages and tools, including Art Framework
  - Note: MU==ManyUniverses, where a Universe represents results obtained with one or another set of parameters
- **Does NOT contradict use of “bare” Geant4 and/or other analysis tools**

Selected Results

- Selected signature plots are included for illustrative purpose
- Additional selected results are in backup slides (incl. benchmarking vs HARP or ITEP data)
- Results are obtained as part of the toolkit development (i.e. at this point they are not an outcome of a comprehensive study)
- All results are obtained with Geant4.10.1.p02
- Statistics is relatively small – 100K event for each for MC sample
- Results come from **different rounds of work in progress**:
  - Exp.data may or may not be included
  - Color coding and/or other display/presentation details are not always consistent among different groups of plots

Varying Fermi Scale (I)

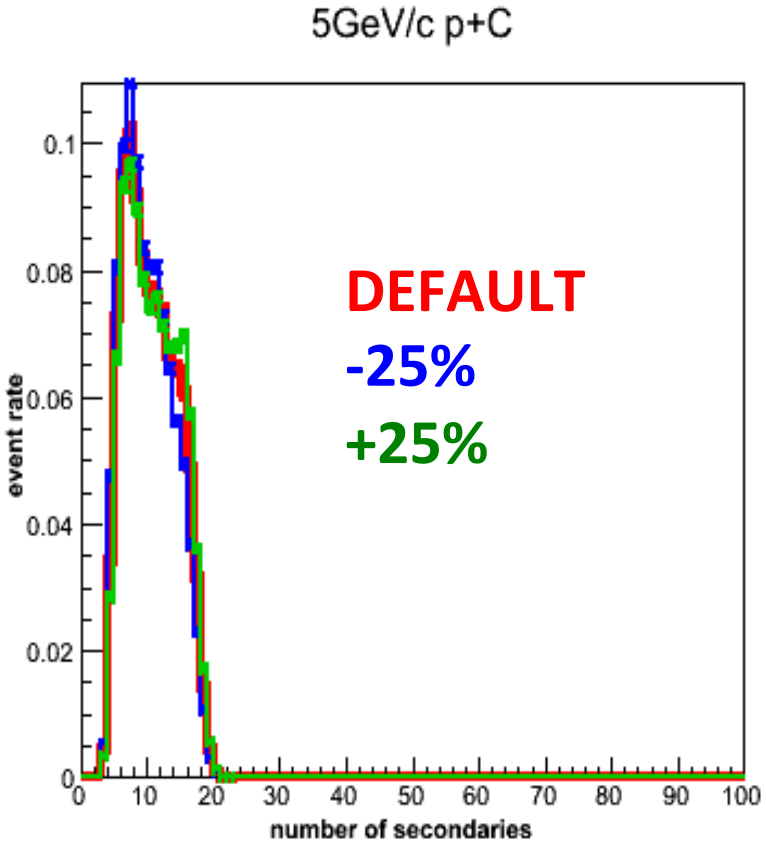
- Fermi Scale = scale factor between local nuclear density and Fermi momentum for nucleons

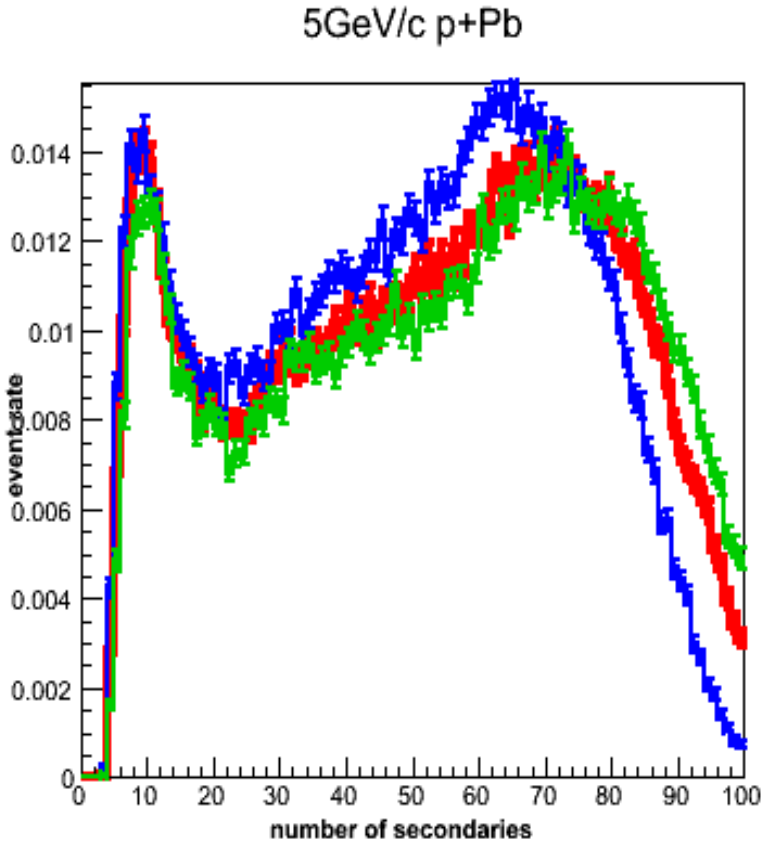
  +/-25% variation around default value

- Remember: Fermi Scale parameter is correlated with the Radius Scale parameter, i.e. fermi_scale=fermi_scale*radius_scale
- In this exercise, the radius scale is keep at its default setting

Varying Fermi Scale (II)

5GeV/c p+C and p+Pb, interaction multiplicity



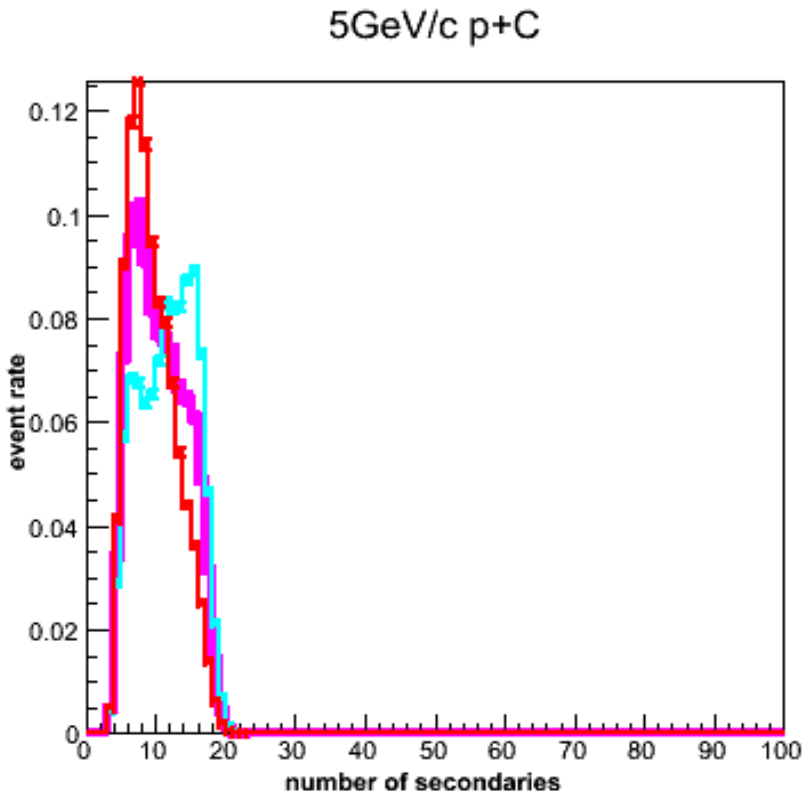


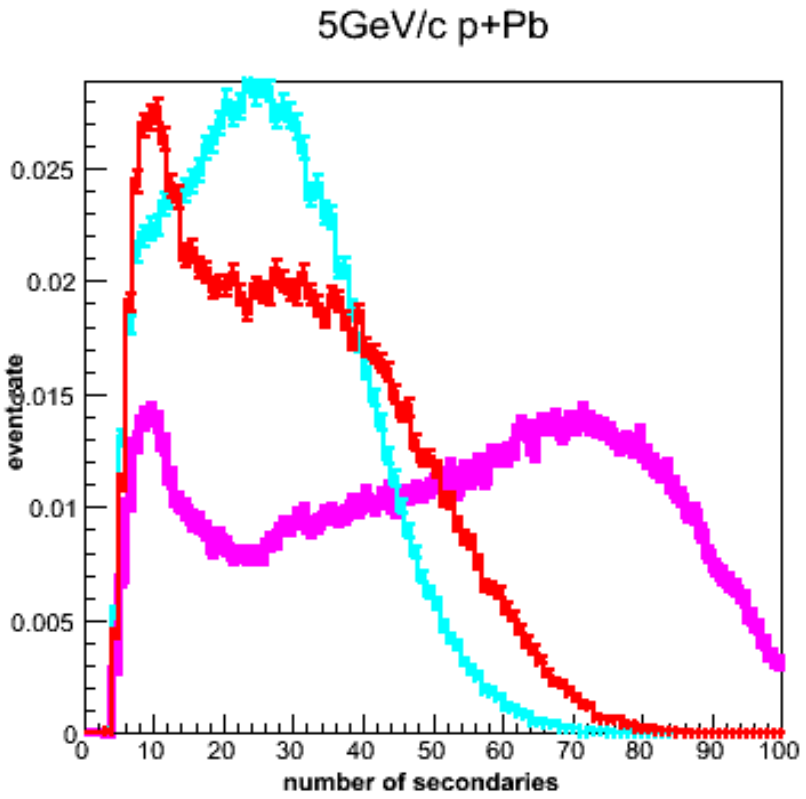
Varying Radius Scale and Cross Section Scale (I)

- Radius Scale = scale factor for the nuclear radius
  - Default setting: radius_scale=2.8197 fm
  - "Literature value": 1 fm (rsc1)
- Remember: several other parameters, including Fermi Scale, are multiplied by the Radius Scale (this is hardcoded for now), thus changing radius scale will inevitably change those parameters
- Q: But if we change the nuclear radius, should we also adjust the cross-sections ???
  - NOTE: at least the "knob" is there…
- Cross Section Scale = scale factor for the total cross sections
  - Default setting: xsec_scale=1
  - Attempted change: $1/(2.8197)^2=0.1258$ → ~0.1 (xsc01) ???
- If curious, look in backup slides what it does to momentum or kinetic energy spectra of secondary particles (pions, proton, neutrons)

Varying Radius Scale and Cross Section Scale (II)

5GeV/c p+C and p+Pb, interaction multiplicity





DEFAULT

RadScale=1fm

RadScale=1fm + XSecScale=0.1

Selected Observations

- Based on a very limited number of variants one sees:
  - Variations of some of the Bertini parameters induce relatively small perturbations of the physics results even if the variation is not negligible
  - Variation of some other Bertini parameters may induce a substantial effect on the simulated physics observables
  - The effect may or may not depend of the target nucleon
- We are not at the point of proposing a "better tune"…
- …but even this early, limited exercise indicates that a comprehensive study of multiple variants of a model will give important information towards the systematic uncertainties in the simulated results
- For example, we can "guess" about possible practical implications:
  - Use of Bertini in the simulation of a Neutrino beamline that employs a light target (C, Be) might induce relatively modest uncertainties
  - Use of Bertini in modeling Mu2e beamline (W target) might induce somewhat larger uncertainties
- Obviously, a lot more work, both coding and analysis, is still needed

Summary

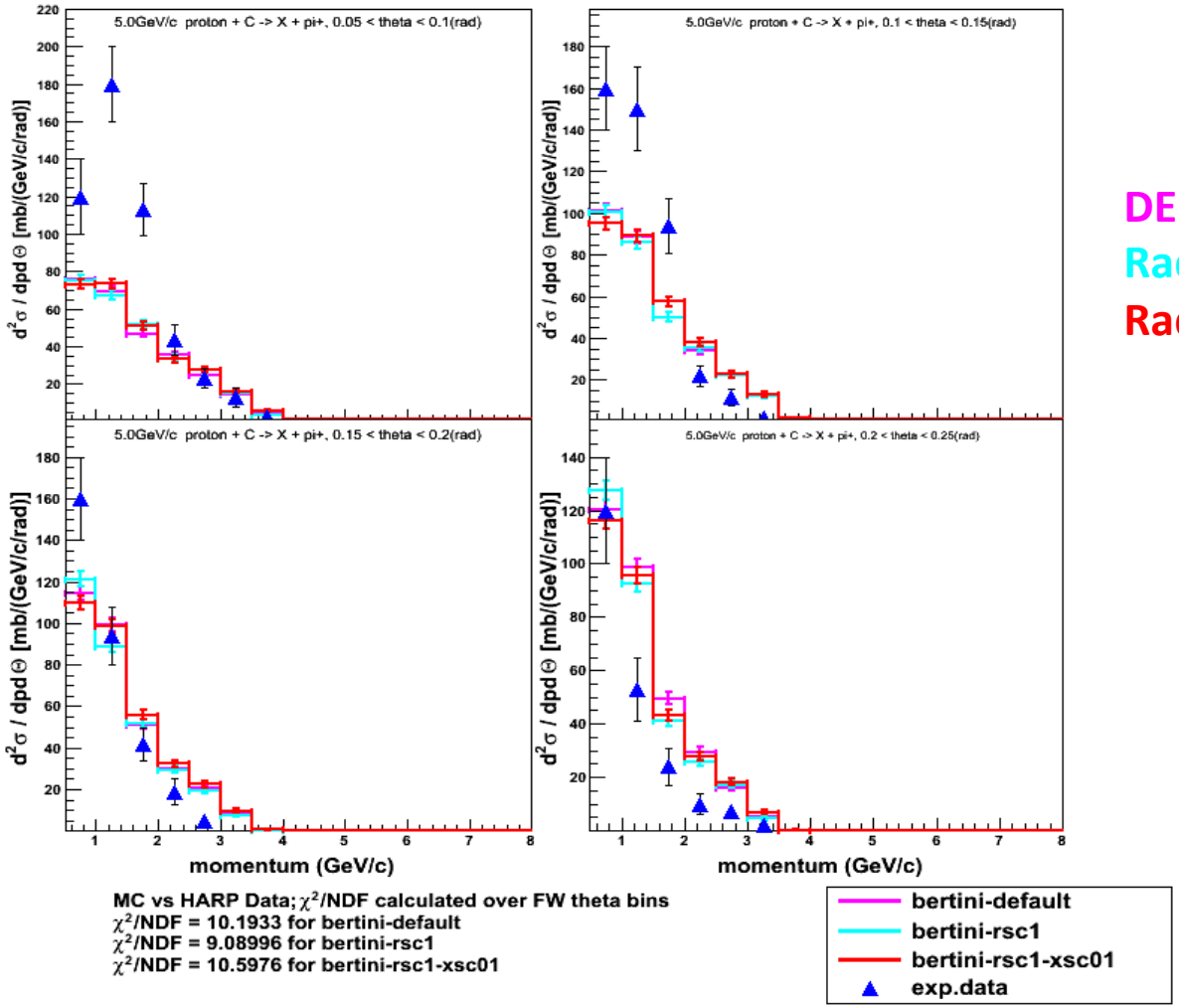
- Allowing modifications of the Geant4 hadronic models parameters is an important aspect and a serious challenge
- Important decision is taken in December 2014
  - Largely in response to numerous requests from users
  - Will benefits the Geant4 collaboration and the users community
- Work has started, using Bertini, in collaboration with the SLAC team
- More work is in the plans:
  - Improve statistical analysis of multiple variants of the Bertini model, including the use of **full potential** of the proposed RooMUHistos package
  - Refine details of the simulation and analysis toolkit in development, as needed
  - Revisit specific details of the involved Bertini (and/or general Geant4) core infrastructure, as needed
  - Other aspects may come up as we move forward
- Big task even for a single model:
  - Lots of analysis work is needed to estimate the uncertainties in the simulation
  - Getting experienced Geant4 users involved will help the efforts !
- We hope to expand the concept on the other models in the future

BACKUP SLIDES

Varying Radius Scale and Cross Section Scale(B-I)

5GeV/c p+C -> pi+, forward production (FW)

Momentum (GeV/c) spectra; data from HARP



DEFAULT

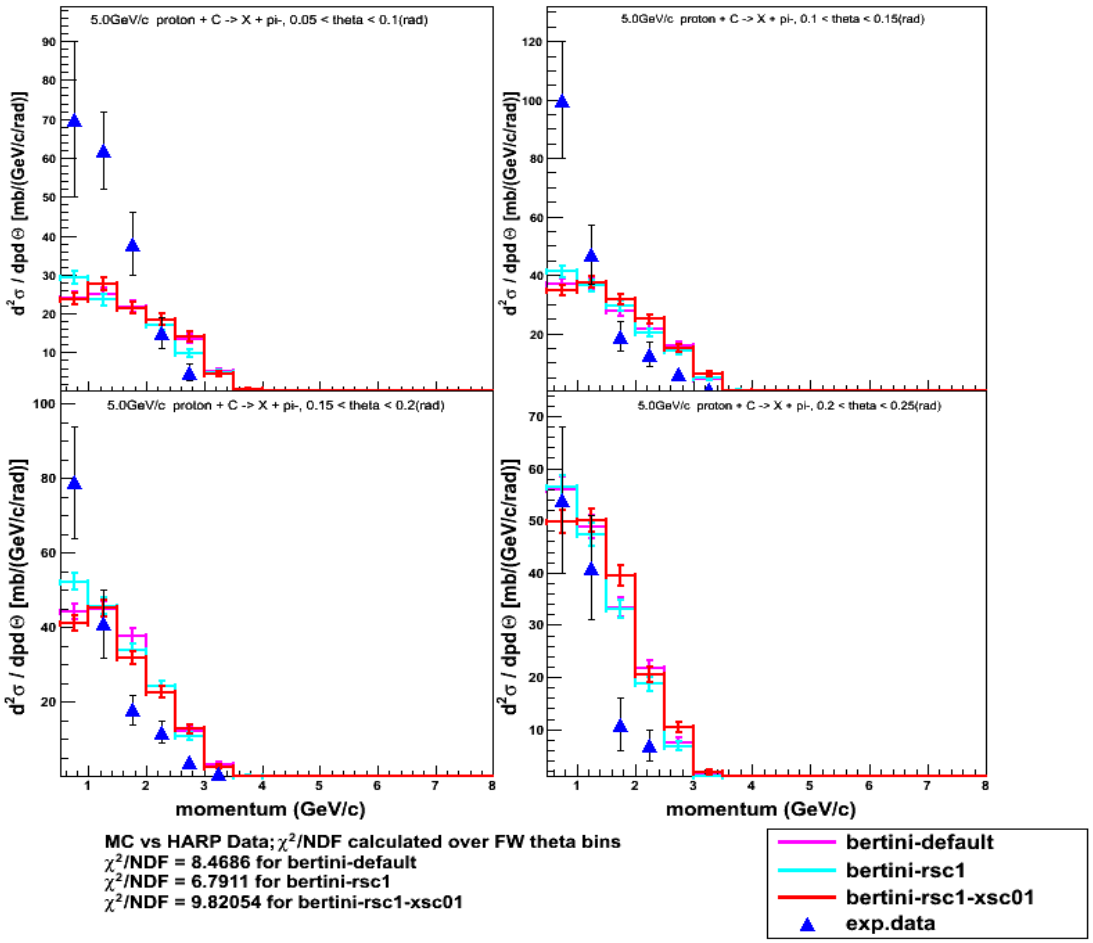
RadScale=1fm

RadScale=1fm + XSecScale=0.1

Varying Radius Scale and Cross Section Scale(B-II)

5GeV/c p+C -> pi-, forward production (FW)

Momentum (GeV/c) spectra; data from HARP



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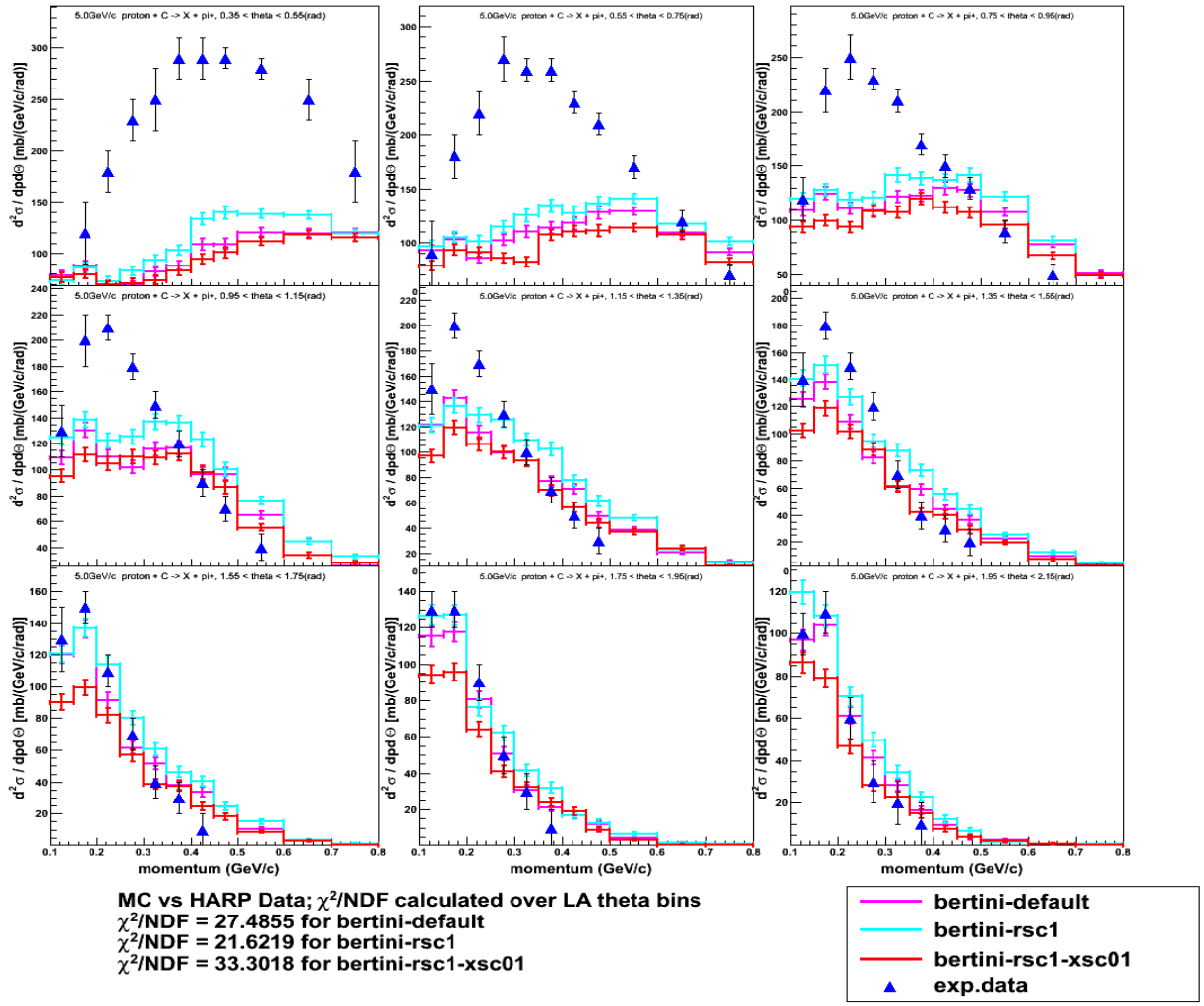
Varying Radius Scale and Cross Section Scale (B-III)

5GeV/c p+C -> pi+, large angle production (LA)

Momentum (GeV/c) spectra; data from HARP



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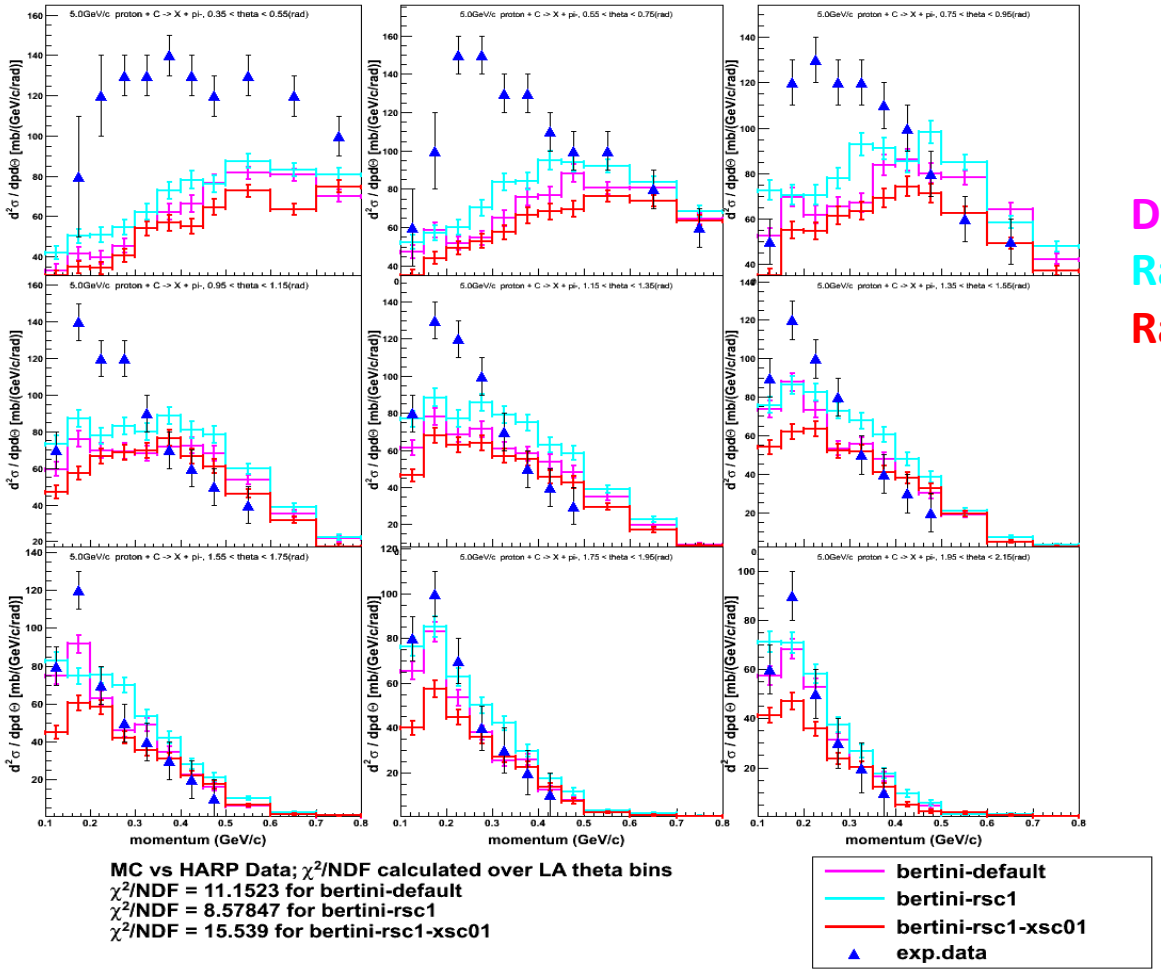
Varying Radius Scale and Cross Section Scale (B-IV)

5GeV/c p+C -> pi-, large angle production (LA)

Momentum (GeV/c) spectra; data from HARP



DEFAULT

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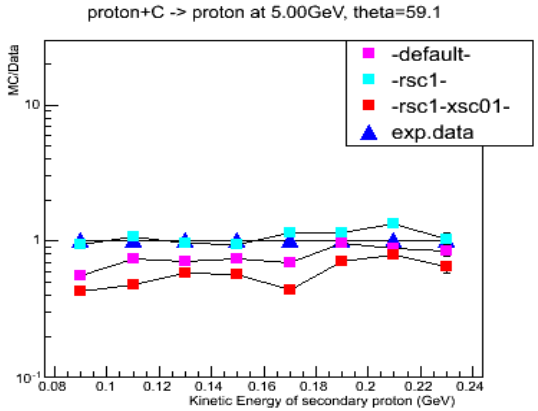
Varying Radius Scale and Cross Section Scale (B-V)

5GeV/c p+C -> p, n

MC/Data vs kinetic energy (GeV); data from ITEP-1980



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DEFAULT

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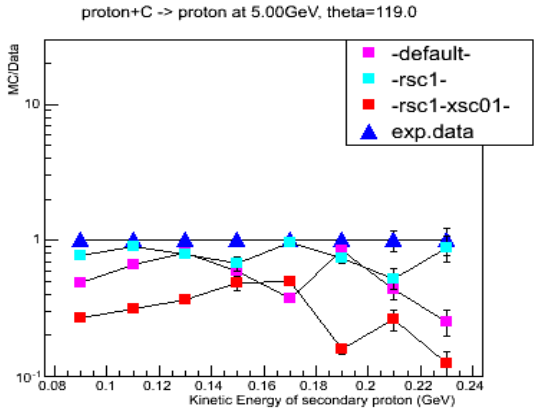

MonteCarlo vs (ITEP) Data
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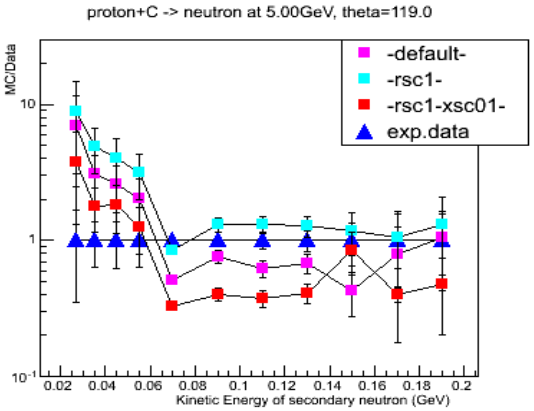
χ^2/NDF = 1.88107 for -rsc1-
χ^2/NDF = 29.6384 for -rsc1-xsc01-

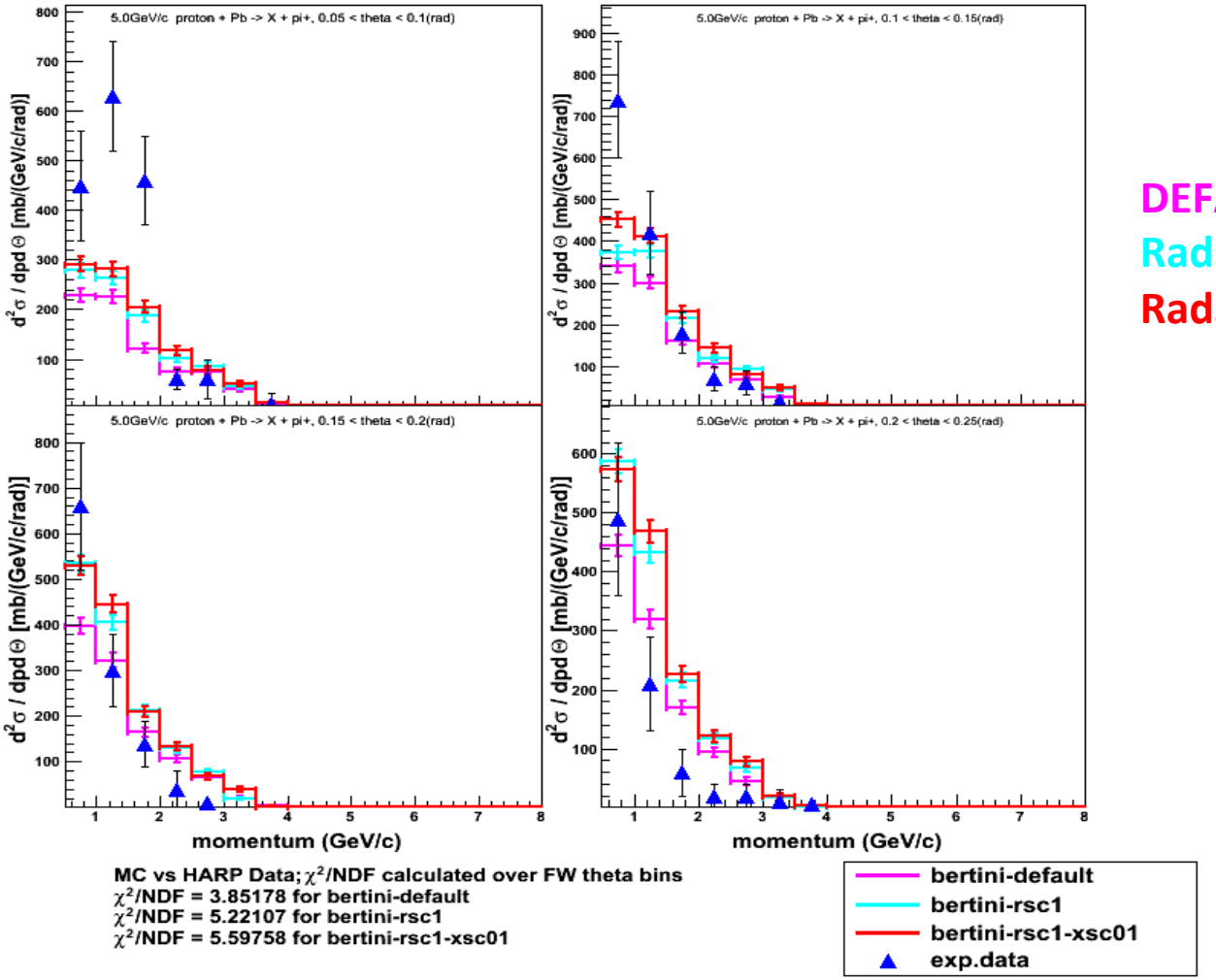


MonteCarlo vs (ITEP) Data
χ^2/NDF = 14.0892 for -default-
χ^2/NDF = 25.8037 for -rsc1-
χ^2/NDF = 11.2475 for -rsc1-xsc01-

Varying Radius Scale and Cross Section Scale (B-VI)

5GeV/c p+Pb -> pi+, forward production (FW)

Momentum (GeV/c) spectra; data from HARP



DEFAULT

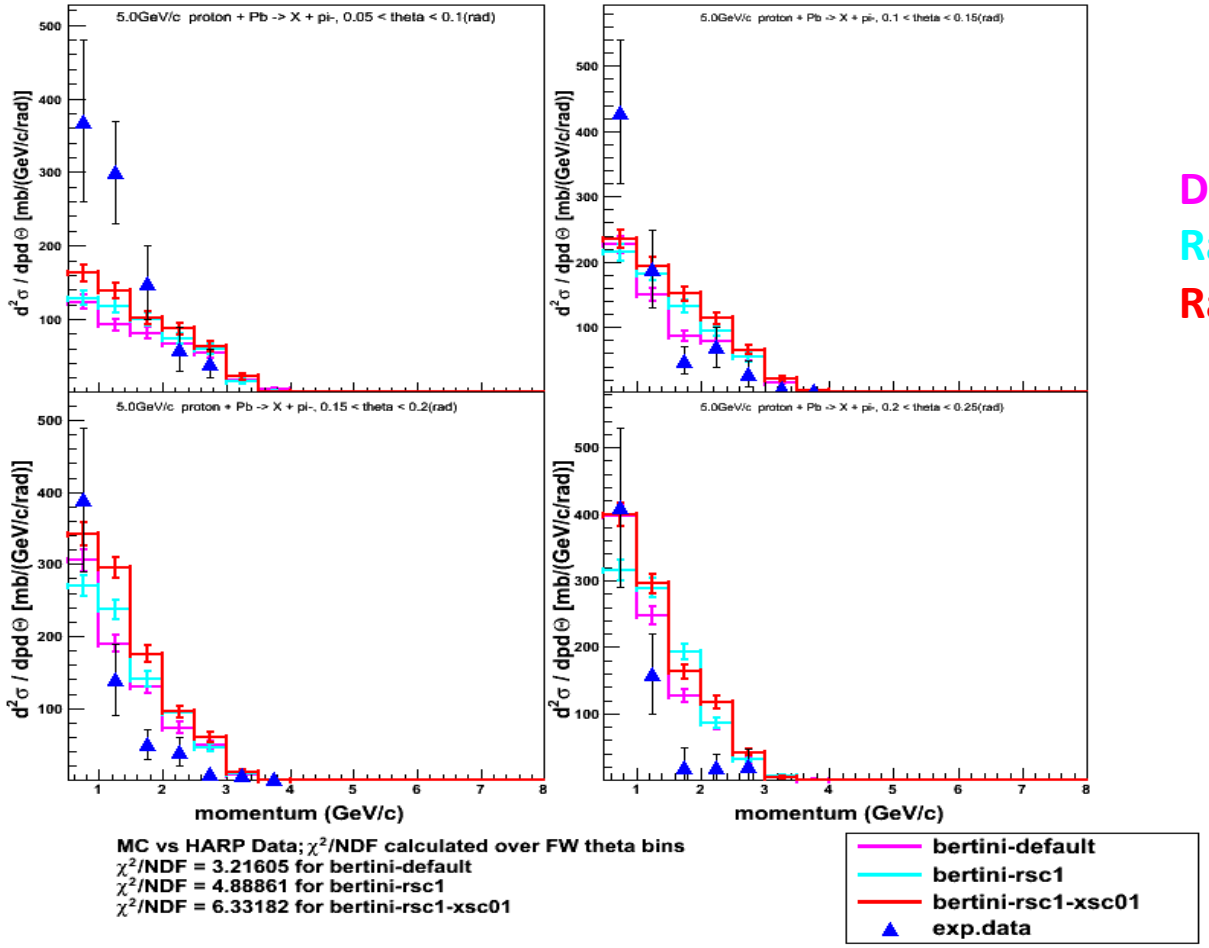
RadScale=1fm

RadScale=1fm + XSecScale=0.1

Varying Radius Scale and Cross Section Scale (B-VII)

5GeV/c p+Pb -> pi-, forward production (FW)

Momentum (GeV/c) spectra; data from HARP



DEFAULT

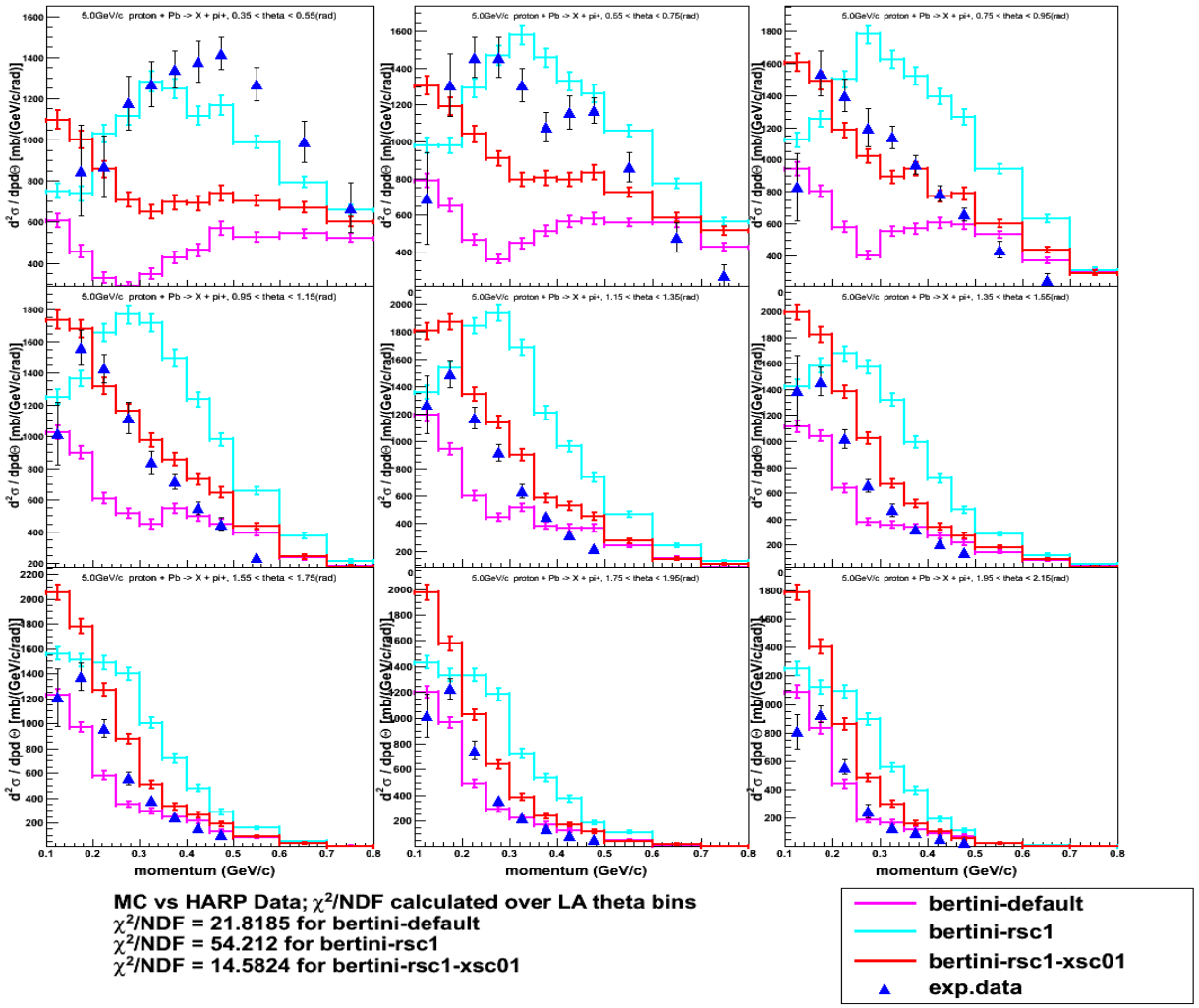
RadScale=1fm

RadScale=1fm + XSecScale=0.1

Varying Radius Scale and Cross Section Scale (B-VIII)

5GeV/c p+Pb -> pi+, large angle production (LA)

Momentum (MeV/c) spectra; data from HARP



DEFAULT

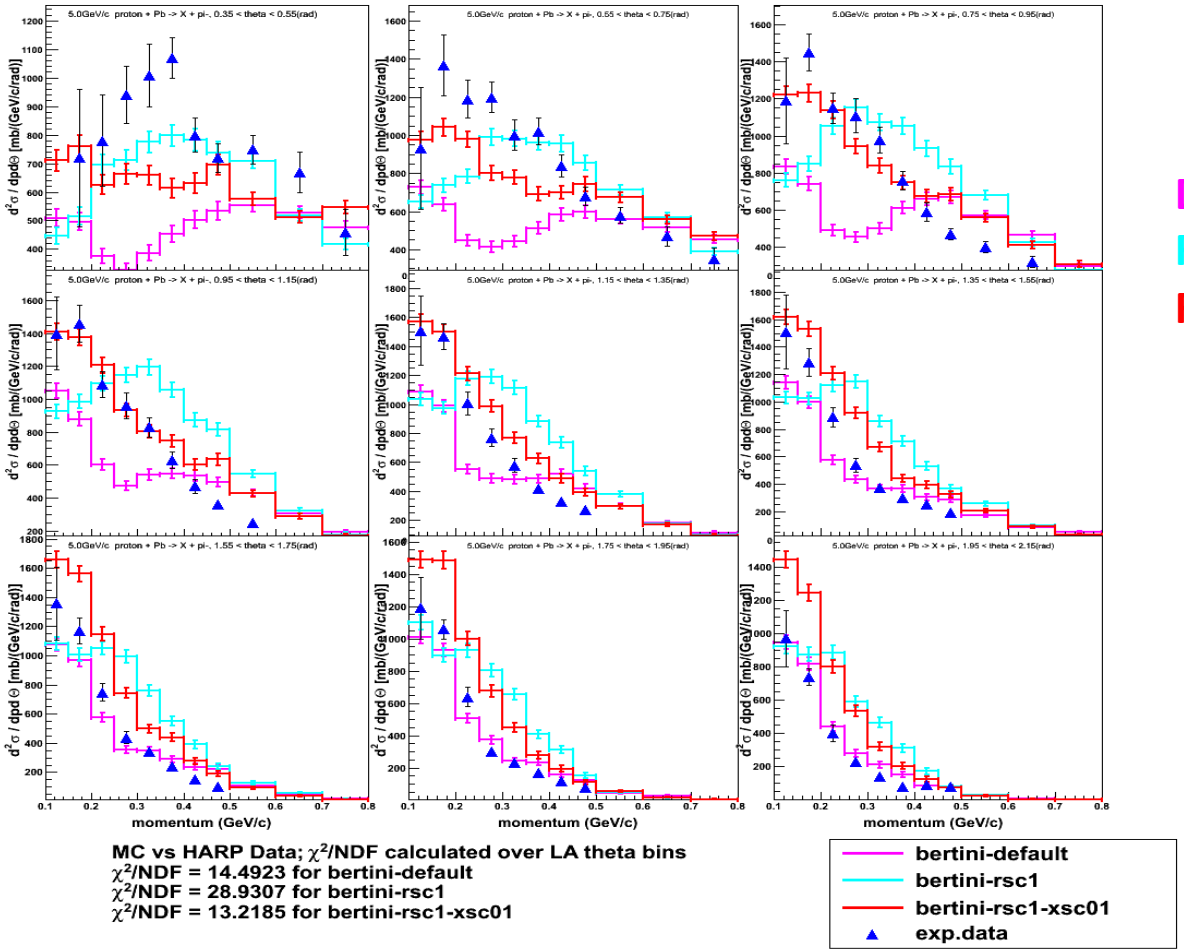
RadScale=1fm

RadScale=1fm + XSecScale=0.1

Varying Radius Scale and Cross Section Scale (B-IX)

5GeV/c p+Pb -> pi+, large angle production (LA)

Momentum (MeV/c) spectra; data from HARP



DEFAULT

RadScale=1fm

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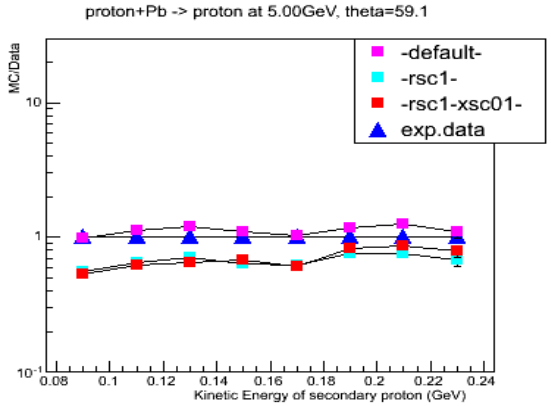
Varying Radius Scale and Cross Section Scale (B-X)

5GeV/c p+Pb -> p, n

MC/Data vs kinetic energy (GeV); data from ITEP-1980



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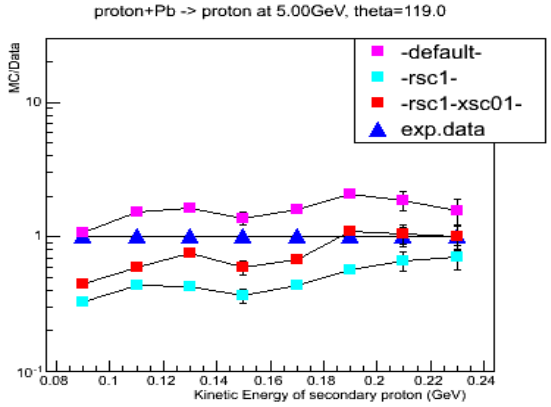
DEFAULT

RadScale=1fm

RadScale=1fm + XSecScale=0.1



MonteCarlo vs (ITEP) Data
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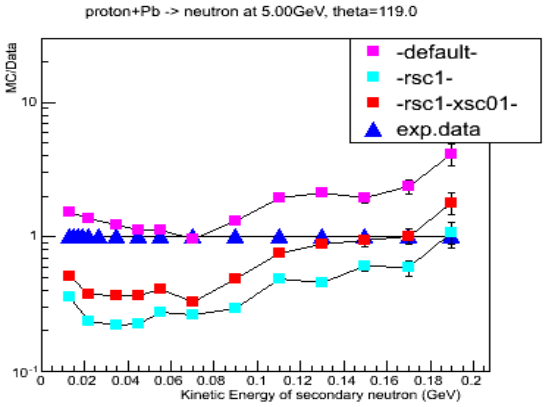
χ^2/NDF = 28.4605 for -rsc1-
χ^2/NDF = 17.3196 for -rsc1-xsc01-



MonteCarlo vs (ITEP) Data
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χ^2/NDF = 68.8178 for -rsc1-xsc01-