Target Simulations for Hadron, Electron and Heavy-Ion Beams

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2nd High-Power Targetry Workshop
Oak Ridge, TN
October 10-14, 2005

OUTLINE

- Targetry Issues
- Modeling Code Reqs
- Code Capabilities for Hadron, Electron and Heavy-Ion Beams

TARGETRY ISSUES

To achieve adequate parameters of secondary beams at any accelerator facility, it is necessary to produce and collect large numbers of particles. Examples: neutrons at SNS, positrons at linear colliders, antiprotons at Tevatron, and pions/kaons in ν-experiments. List of targetry issues includes:

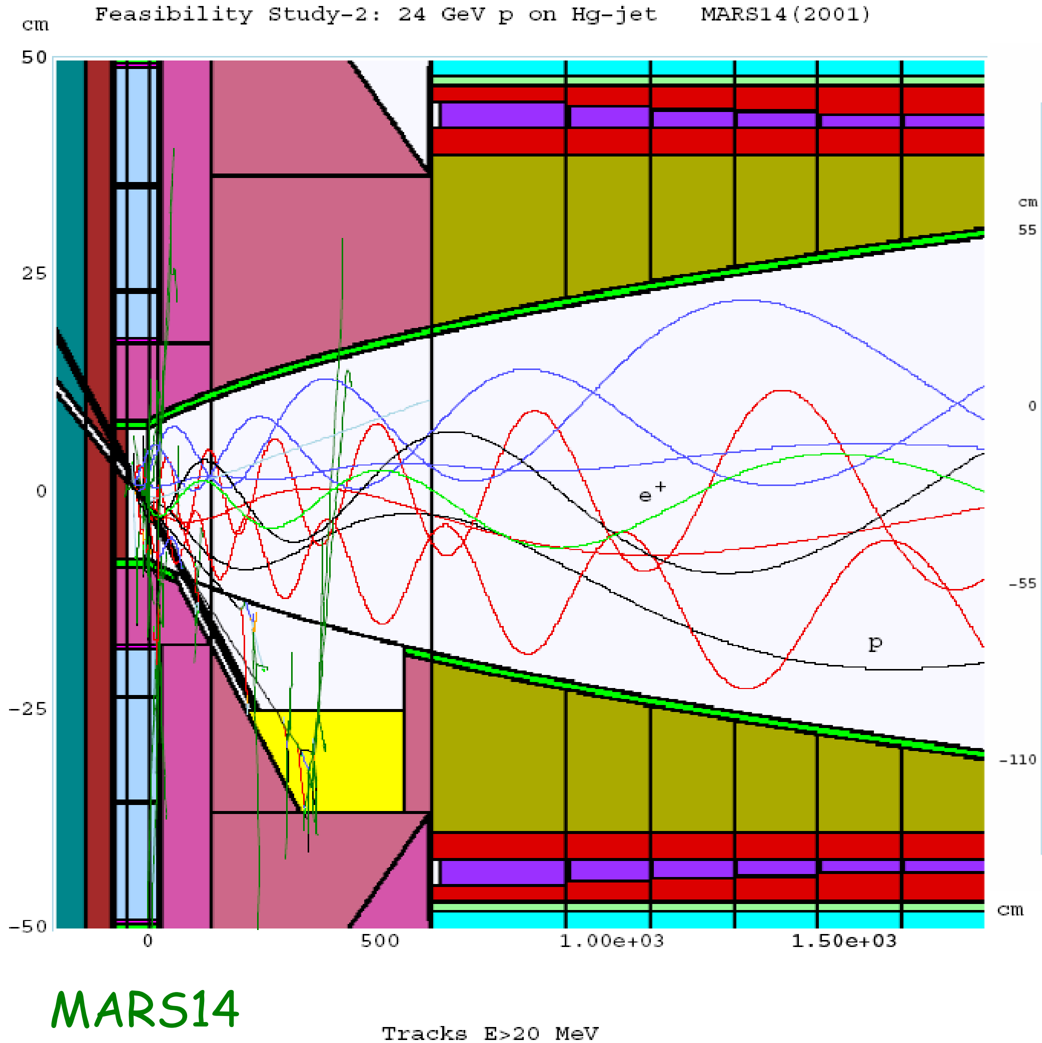
- Production and collection of maximum numbers of particles of interest.
- Suppression of background particles transported down the beamline.
- Target and beam window operational survivability and lifetime: compatibility, fatigue, stress limits, erosion, remote handling and radiation damage.
- Protection of a focusing system including provision of superconducting coil quench stability.
- Stability, heat loads, radiation damage and activation of materials near the beam.
- Spent beam handling, and numerous shielding issues from prompt radiation to ground-water activation.

TARGETRY AND SIMULATION CODES

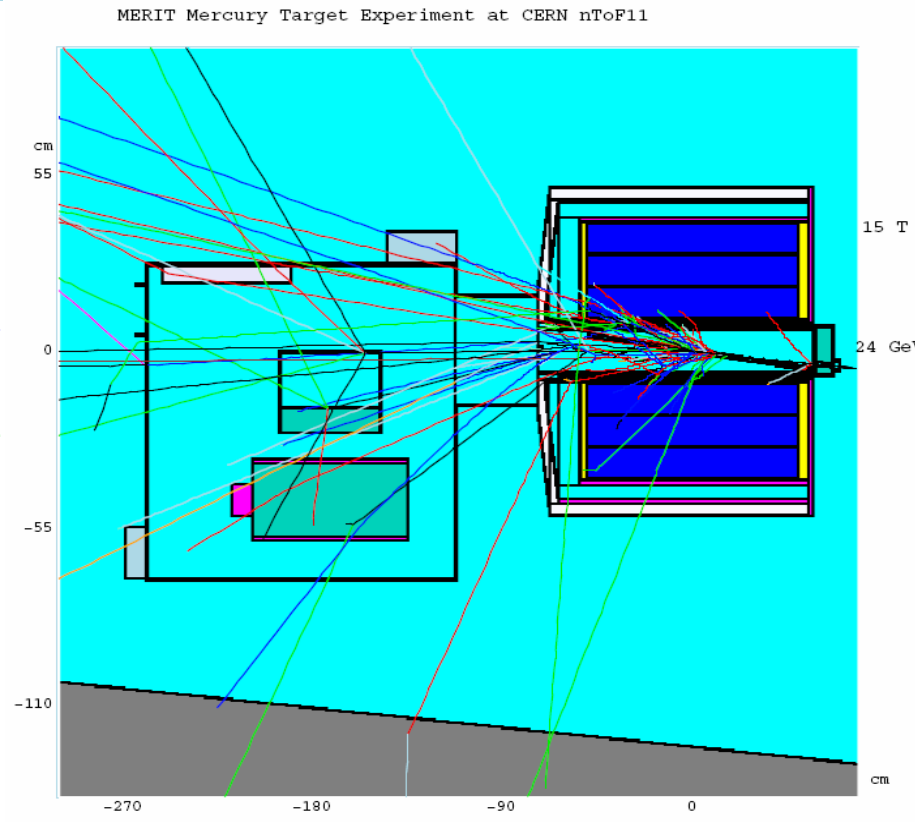
These issues are especially challenging for those setups involving intense bunched energetic proton, electron or heavy-ion beams. Most of these issues are addressed in detailed Monte Carlo simulations, therefore, predictive power and reliability of corresponding codes is so crucial. This talk is a quick overview of capabilities of the **widely-used general-purpose codes** (in their most recent versions) with respect to the targetry needs.

In other talks of these two sessions we will hear on status of the main transport codes as well as on recent studies in such important areas as prediction of material response and radiation damage via DPA modeling.

NEUTRINO FACTORY AND MERIT EXPT TARGETS



MARS14



MARS15

SIMULATION CODE REQS

1. Reliable description of x-sections and particle yields from a fraction of eV to many TeV for hadron and heavy-ion projectiles (event generators).
2. Leading particles (elastic, diffractive and inelastic).
3. π^0 – production (EMS) and K^0 – production (ν_e).
4. Annihilation, stopped hadrons and muons.
5. Nuclide inventory, residual dose, DPA, hydrogen and helium production.
6. Multiple Coulomb scattering (not a simple Gaussian or Molier).
7. Hadron, muon and heavy- ion electromagnetic processes with knock- on electron treatment and – at high energies – bremsstrahlung and direct pair production (not a simple dE/ dx).
8. Full accurate modeling of electromagnetic showers (EMS) with hadron/muon photo-production.
9. Accurate transport from micron-size to ~30 nuclear interaction lengths.
10. Accurate tracking in magnetic field.
11. User-friendly geometry, histograming and GUI.
12. Interfaces to MAD, ANSYS and hydrodynamics codes.

GENERAL-PURPOSE CODES (2005)

Criteria for this express-analysis:

1. General-purpose widely-used code.
2. Event generators with consistent soft and hard multiparticle production in *hA* , (*AA*), γ *A* and ν *A* at MeV to many TeV.
3. Full particle transport from a fraction of eV to many TeV in complex target/ accelerator/ detector/ shielding systems.
4. Codes are actively developed, supported and discussed at conferences last decade.

HADRON BEAM CODES

- **FLUKA** – INFN: DPMJET/PEANUT
- **GEANT4** – CERN: QMD
- **MARS15** – FNAL: CEM/LAQGSM/DPMJET/Inclisive
- **MCNPX** – LANL: Tables/CEM, no EMS, no magnetic field, work towards high energies in progress
- **PHITS** – JAERI: QMD (EMS? Magnetic field?)
- **SHIELD** – INP Troitsk: INC/QGSM, no EMS, no magnetic field, simple geometry

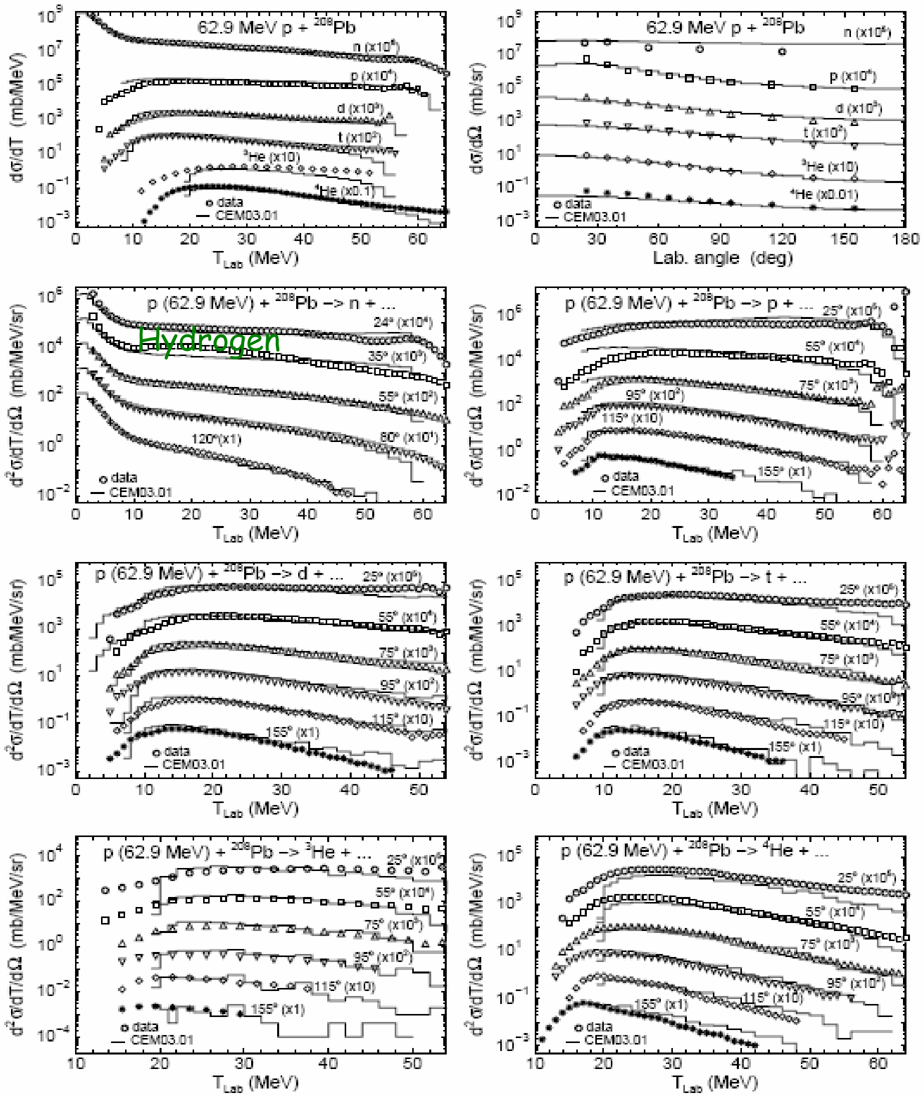
MCNP5 is very close. **HETC** and **LAHET** are not considered.

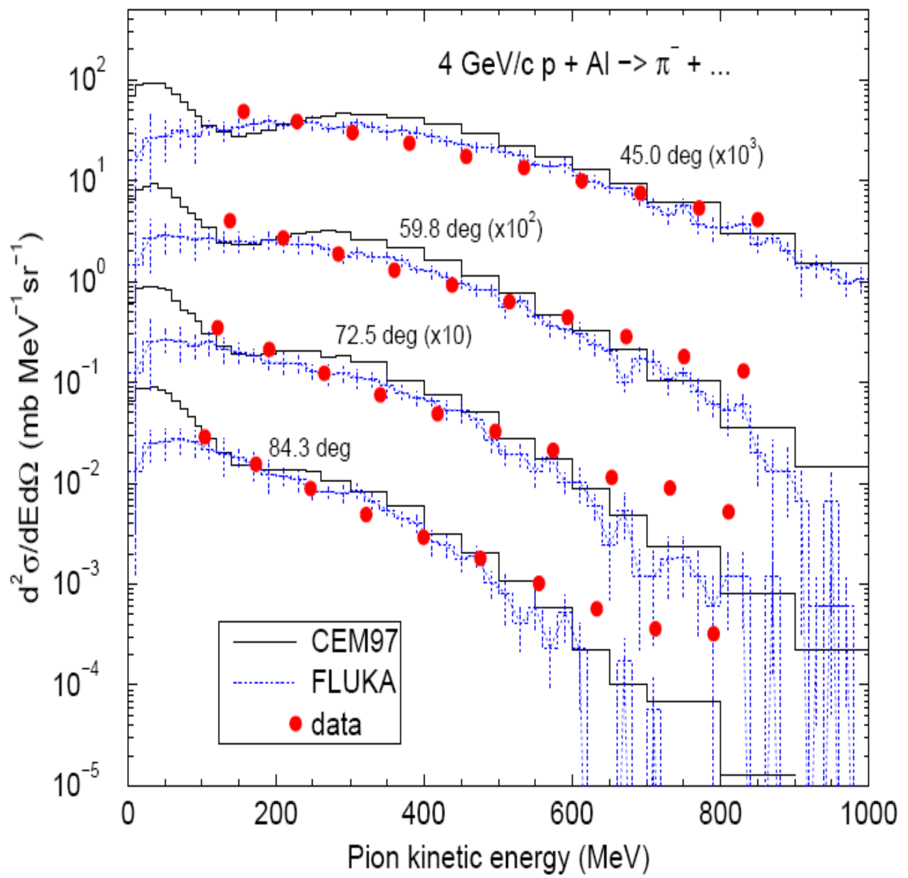
HADRON BEAM CODE STATUS

Most of these codes meet the above reqs, except for deficiency with EMS and magnetic field in some of them.

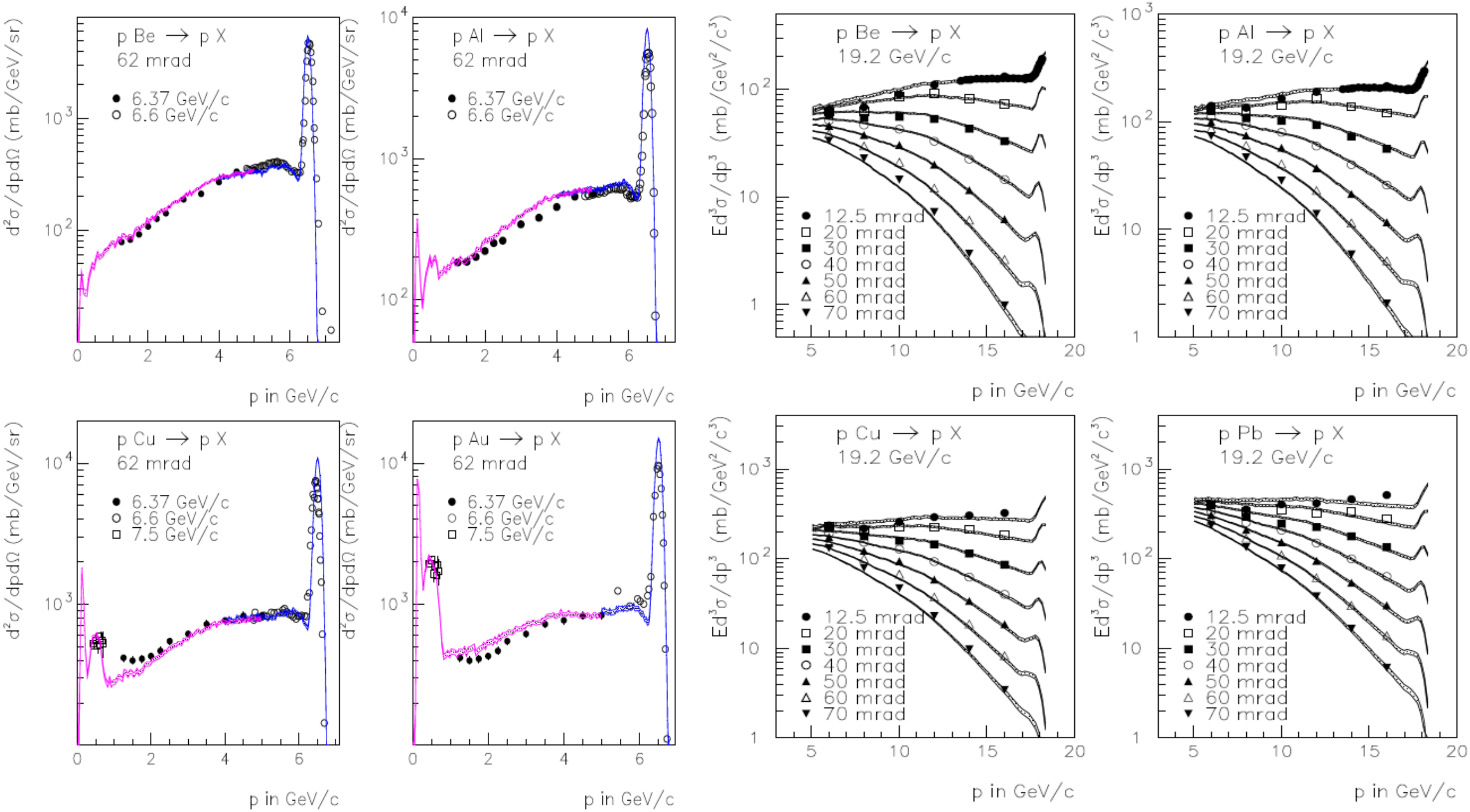
1. In most applications particle yields are predicted with <30% accuracy.
2. Energy deposition at shower core:
   - Source term: 30% in well-defined cases
   - Simplifications in geometry, materials and magnetic fields: unknown, but up to a factor of 2 to 3 typically
   - Good simulation code physics and algorithms: a few % to 30% typically
3. Prompt dose and fluxes in thick shielding: a factor of 2.
4. Residual dose rate: within a factor of 2 to 3.

PARTICLE YIELDS AT INTERMEDIATE ENERGIES



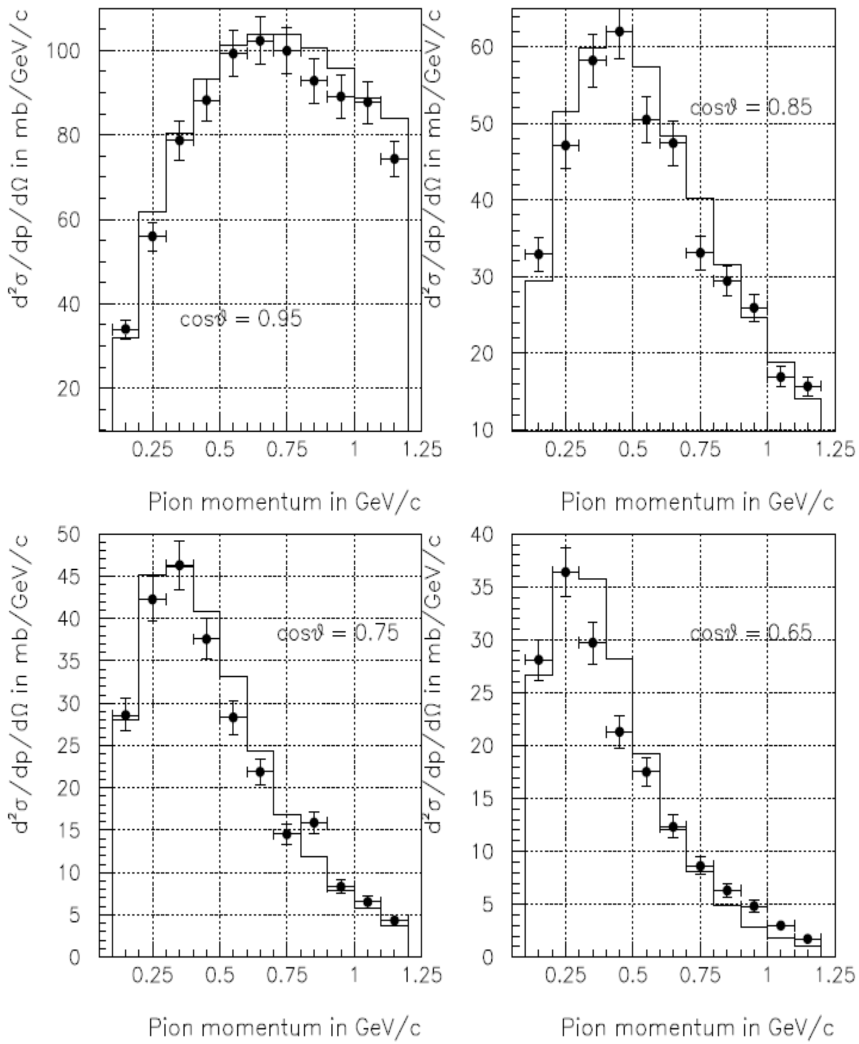


PARTICLE YIELDS AT HIGH ENERGIES (1)

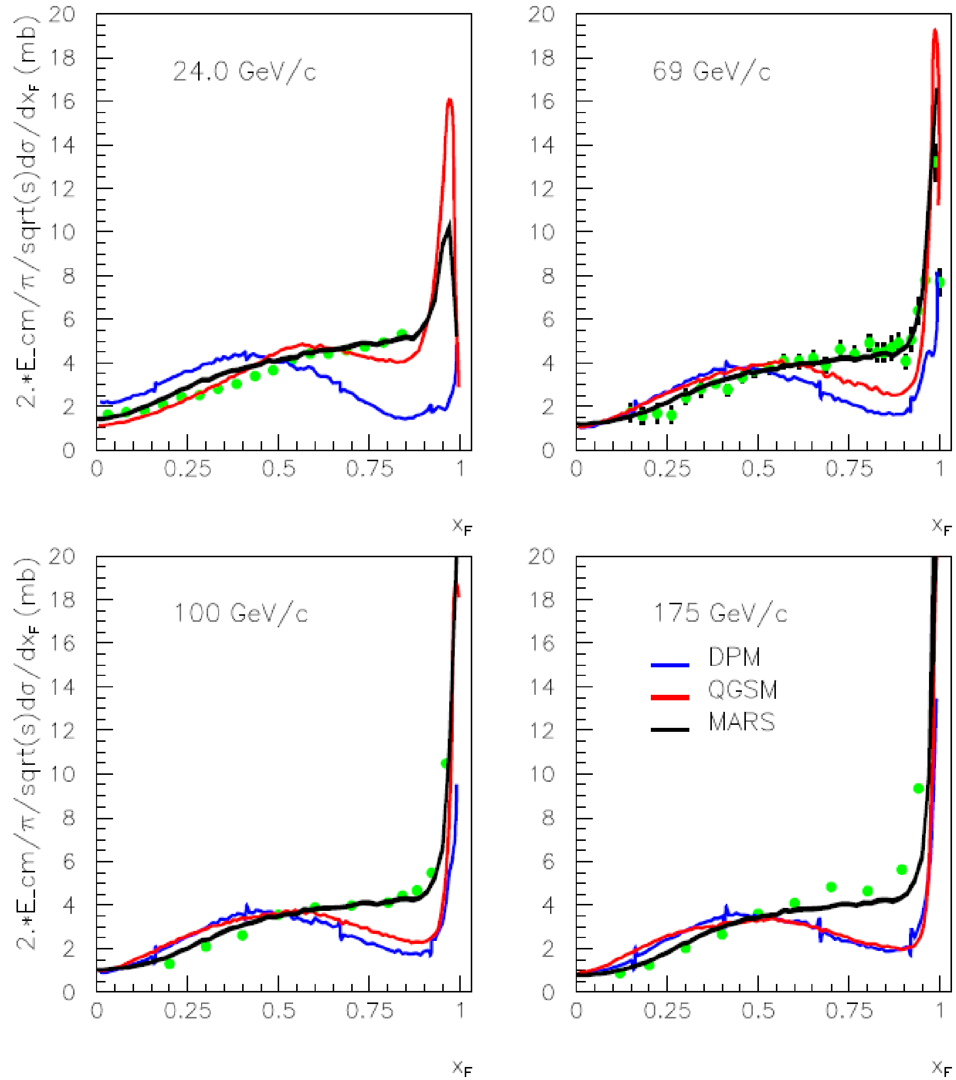


MARS15 vs data

PARTICLE YIELDS AT HIGH ENERGIES (2)

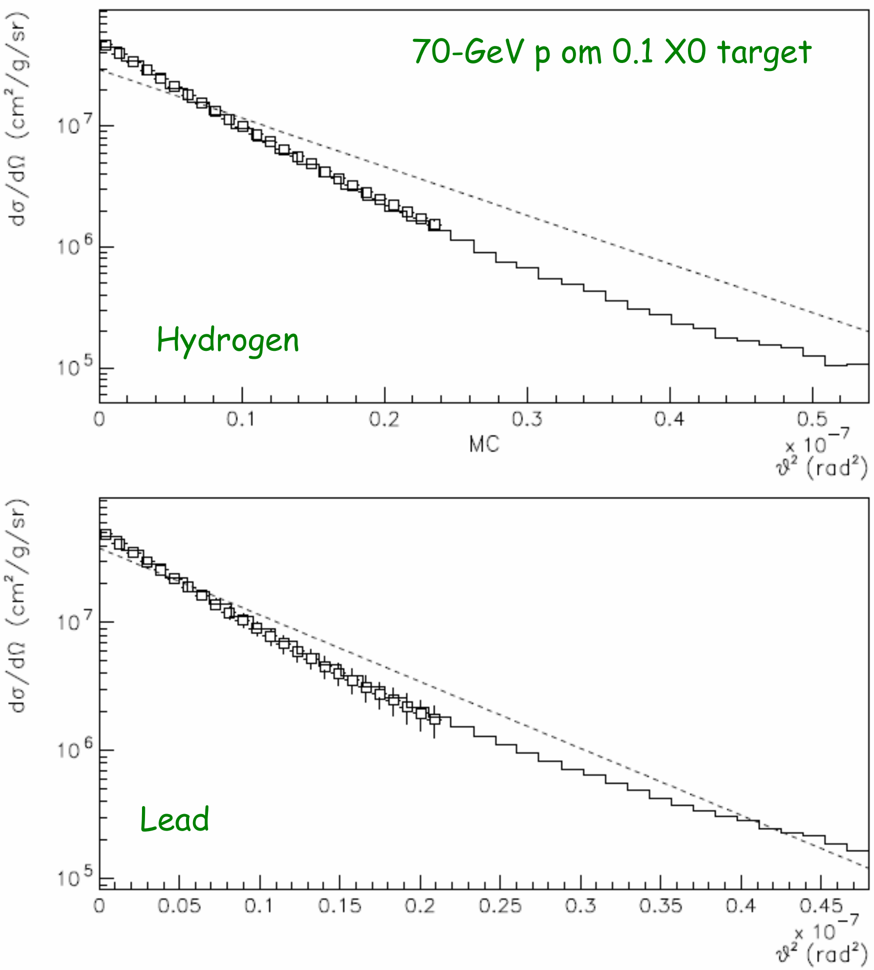


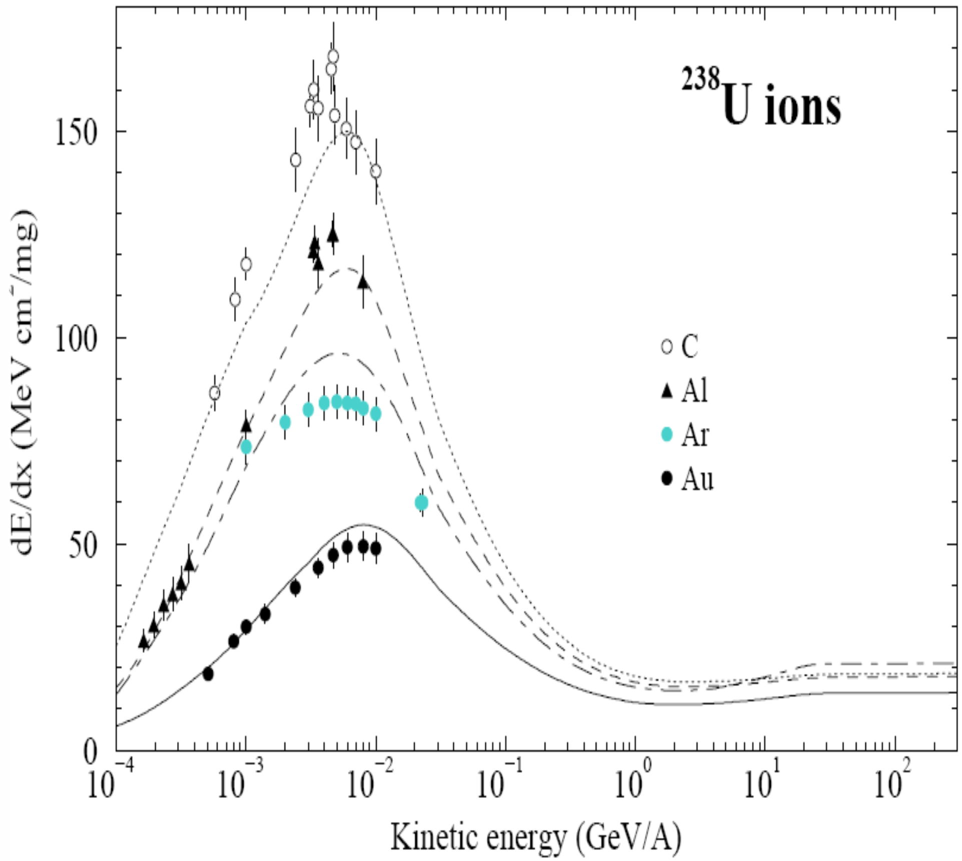
Negative pion production in proton berillium interaction at 12.3 GeV/c



MARS15 vs E910

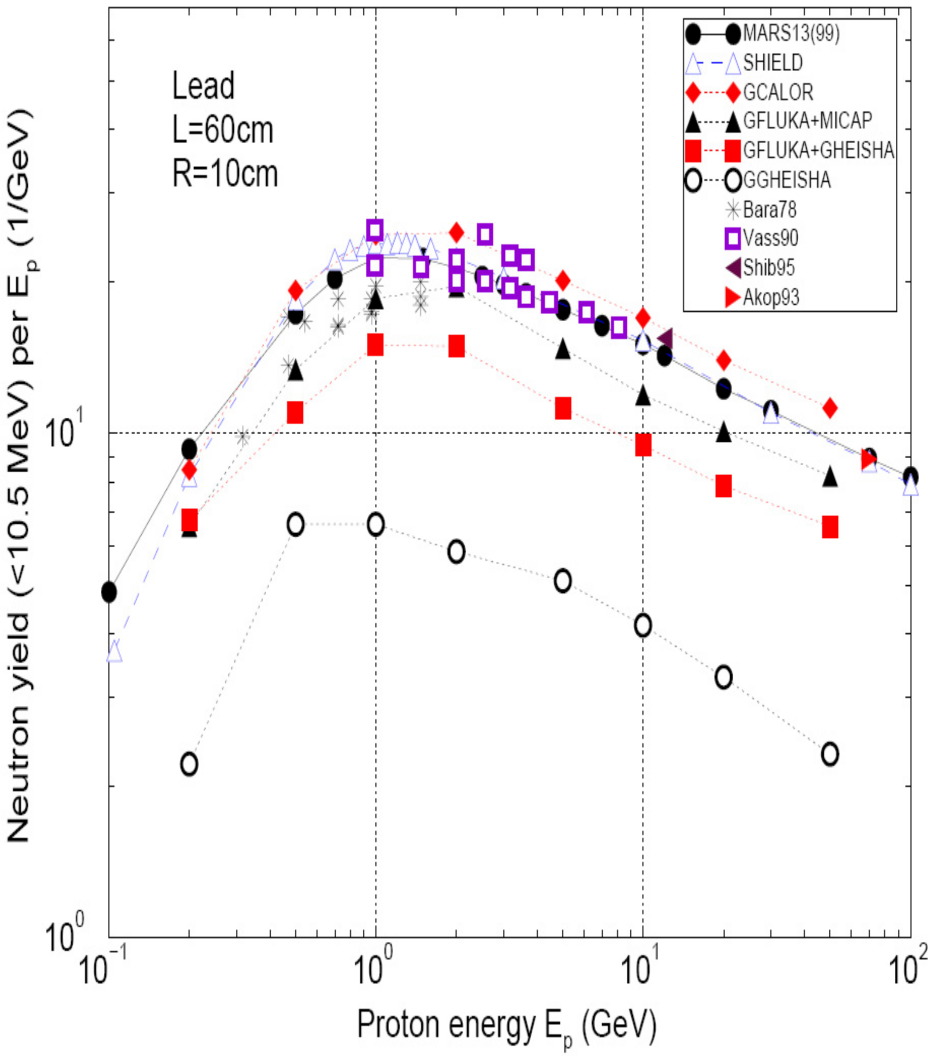
COULOMB SCATTERING AND dE/dx

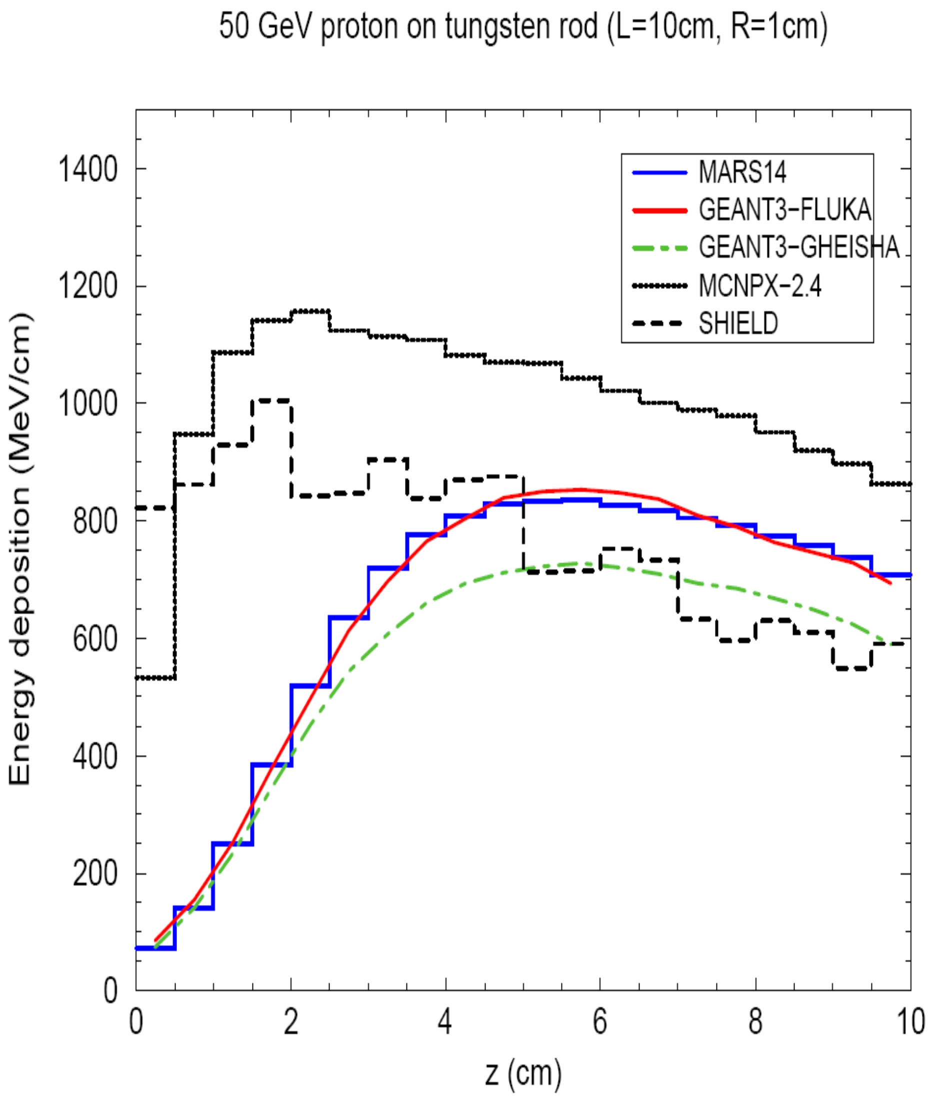




MARS15 vs data

NEUTRON YIELD AND ENERGY DEPOSITION





0.8-GeV (ISIS) and 10-GeV proton beams in thick shielding

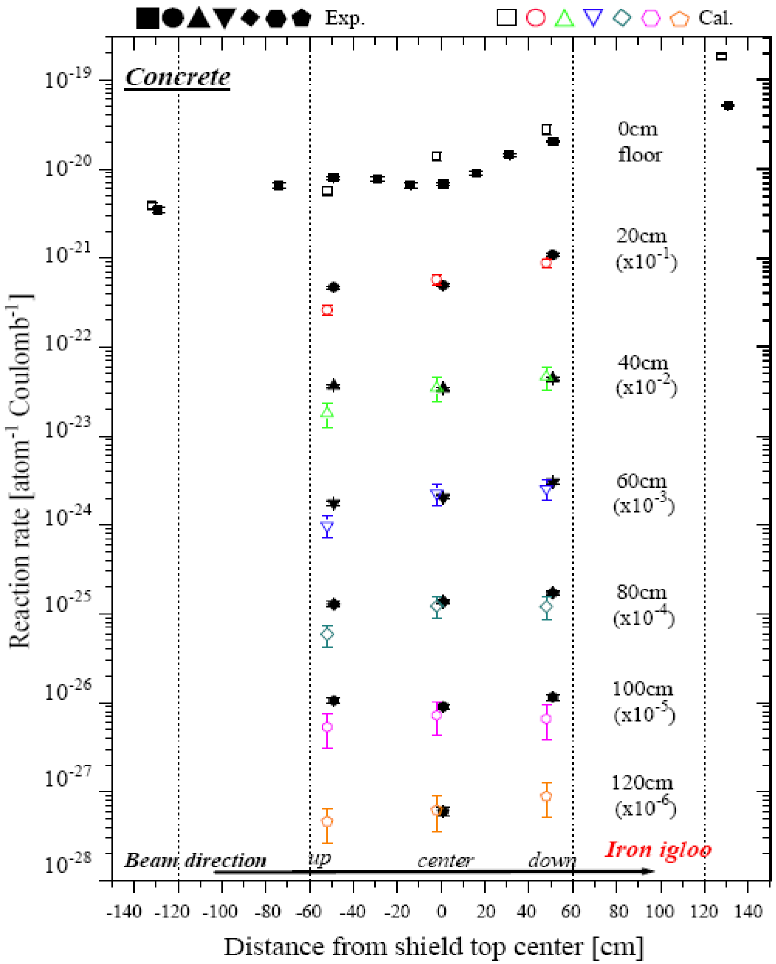


Fig. 16. Comparison between the calculated and measured $^{12}C(n, 2n)^{11}C$ reaction rates above the shield top behind the additional concrete shield along the up-down axis (X-axis).

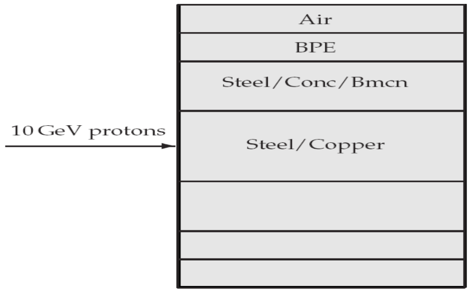
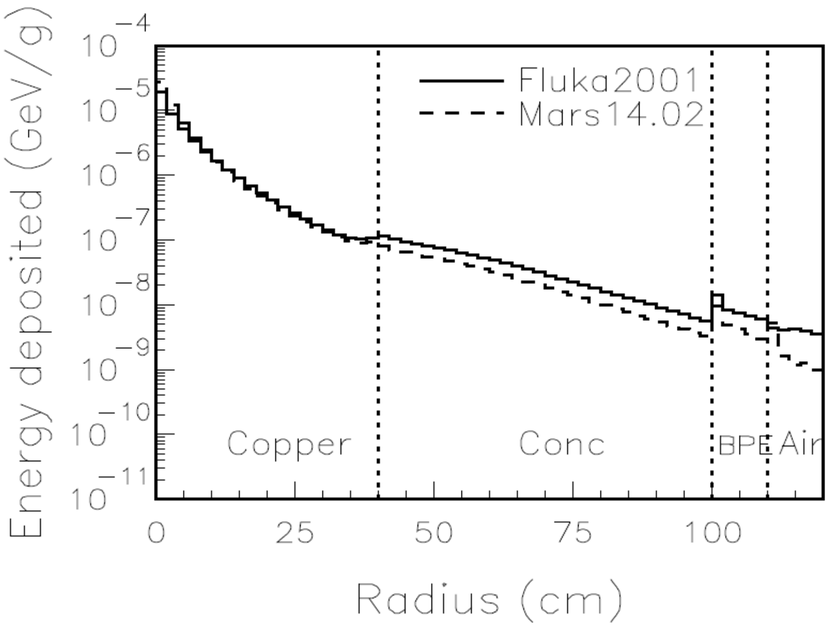


Figure 2. Target geometry used in FLUKA vs MARS comparisons. The induced lateral cascades are representative of the situation in the ATLAS and CMS forward-shieldings.



ELECTRON BEAM CODES

- EGS4 – SLAC/KEK: still "industry standard"
- ITS
- PENELOPE – F. Salvat (Barcelona): State-of-the-Art at energies 100-eV to 1 GeV
- Those in FLUKA, GEANT4 and MARS15
- MCNP5 and MCNPX – at modest energies

These codes are in a pretty good shape, with predictive accuracy on a percent level, in most cases in a pretty good agreement with data and with each other. Standalone EMS codes don't have hadron and muon production capabilities.

NEUTRON SPECTRA FOR 2-GEV ELECTRON BEAM

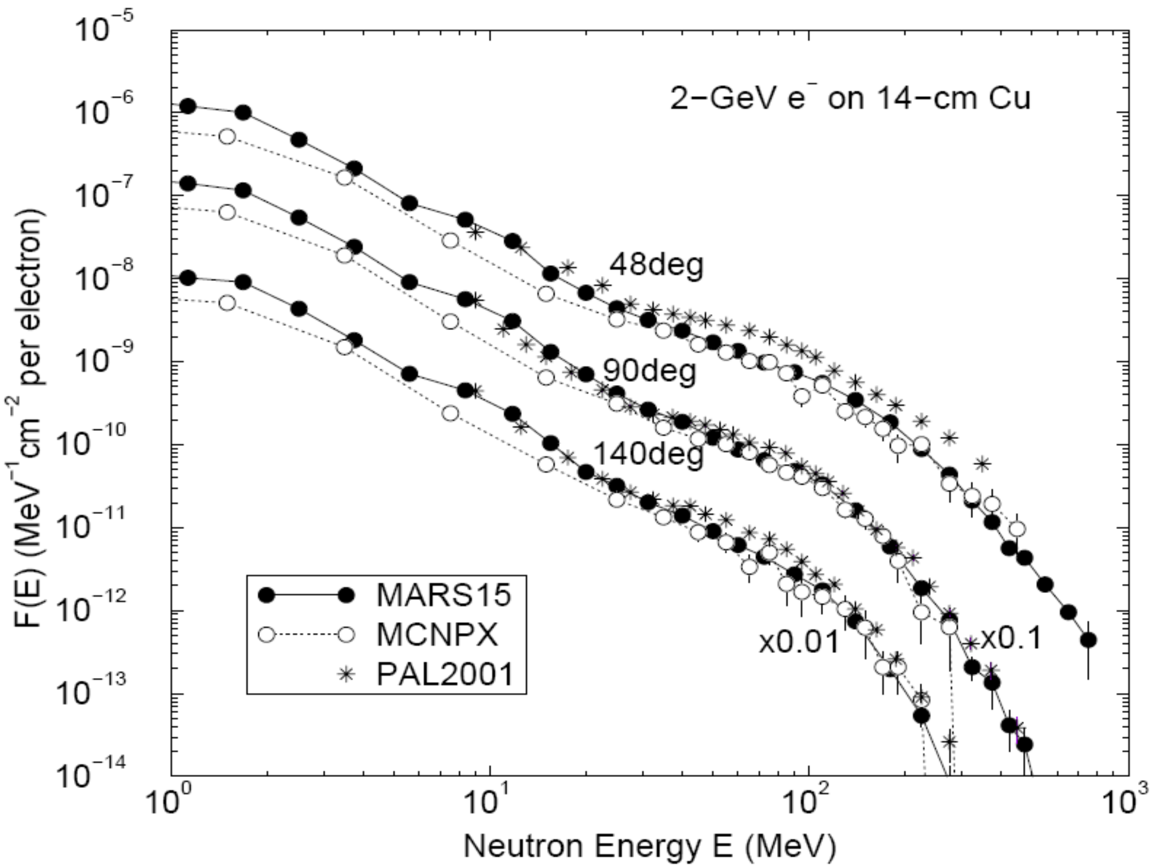


FIGURE 8. Neutron spectra calculated with MARS15 and MCNPX at three angles for a 2-GeV electrons on a thick copper target *vs* data [22].

HEAVY-ION BEAM CODES

- **FLUKA** – INFN: DPMJET-based
- **GEANT4** – CERN: limited HI, full HI capability coming
- **MARS15** – FNAL: LAQGSM-based
- **MCNPX** – LANL: limited HI, full HI capability coming soon
- **MCNPX5**– LANL: HI capability coming
- **PHITS** – JAERI: QMD-based
- **SHIELD** – INP Troitsk: QGSM-based

NASA codes are not considered here.

PARTICLE YIELDS in 0.56 and 8 GeV/A REACTIONS

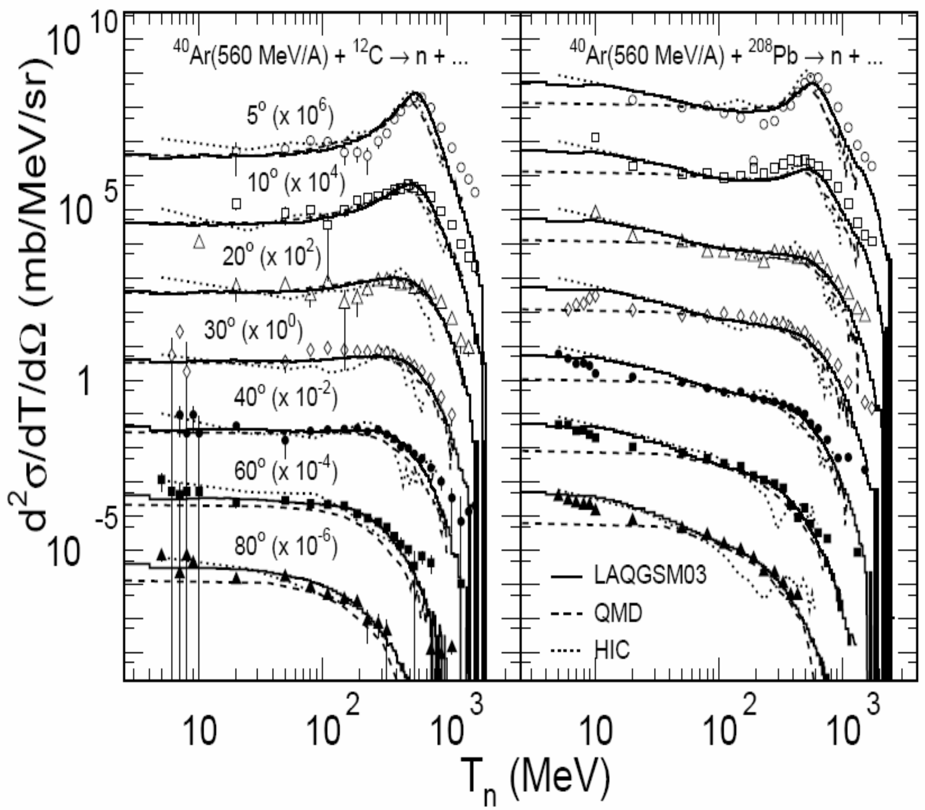


FIGURE 3. Differential cross-sections of neutrons in 560 MeV/A $Ar+C$ and $Ar+Pb$ reactions as calculated with LAQGSM03, JQMD [12] and HIC [13] codes *vs* data [14].

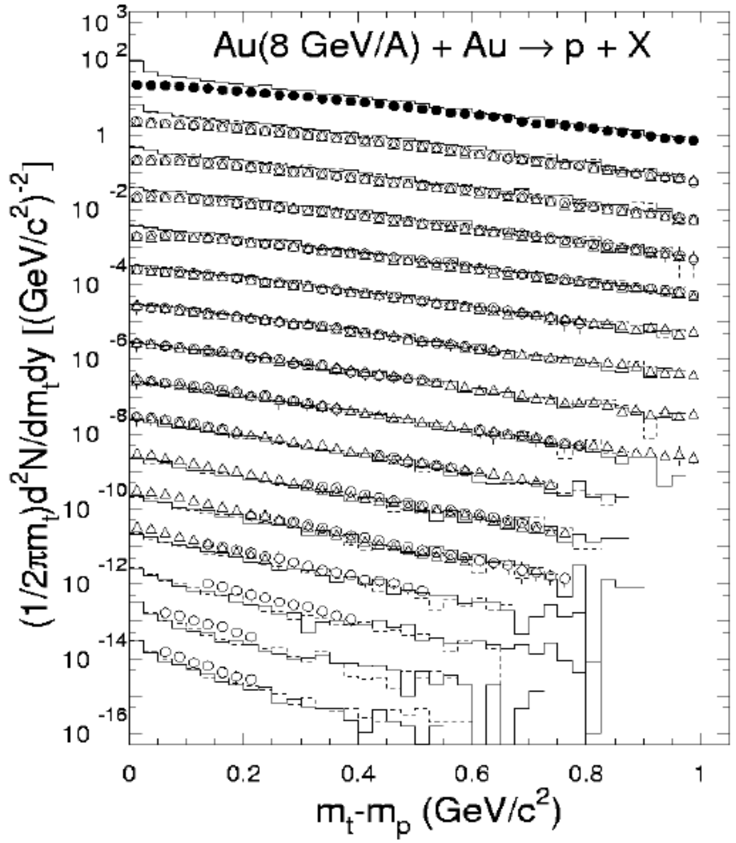


Figure 4. Invariant proton yield per central $Au+Au$ collision at 8 GeV/A as calculated with LAQGSM03 (histograms) and measured in Ref. (12) (symbols). Solid lines and open circles is forward production, dashed lines and open triangles is backward production. Midrapidity (upper set) is shown unscaled, while the 0.1 unit rapidity slices are scaled down by successive factors of 10.

NUCLIDE AND NEUTRON YIELD FOR HEAVY-IONS

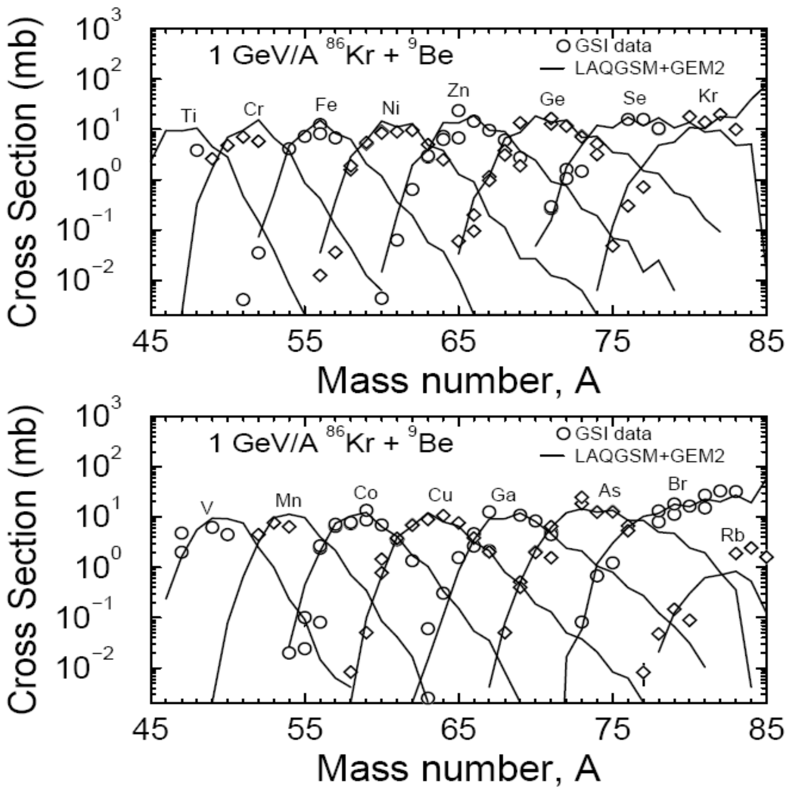
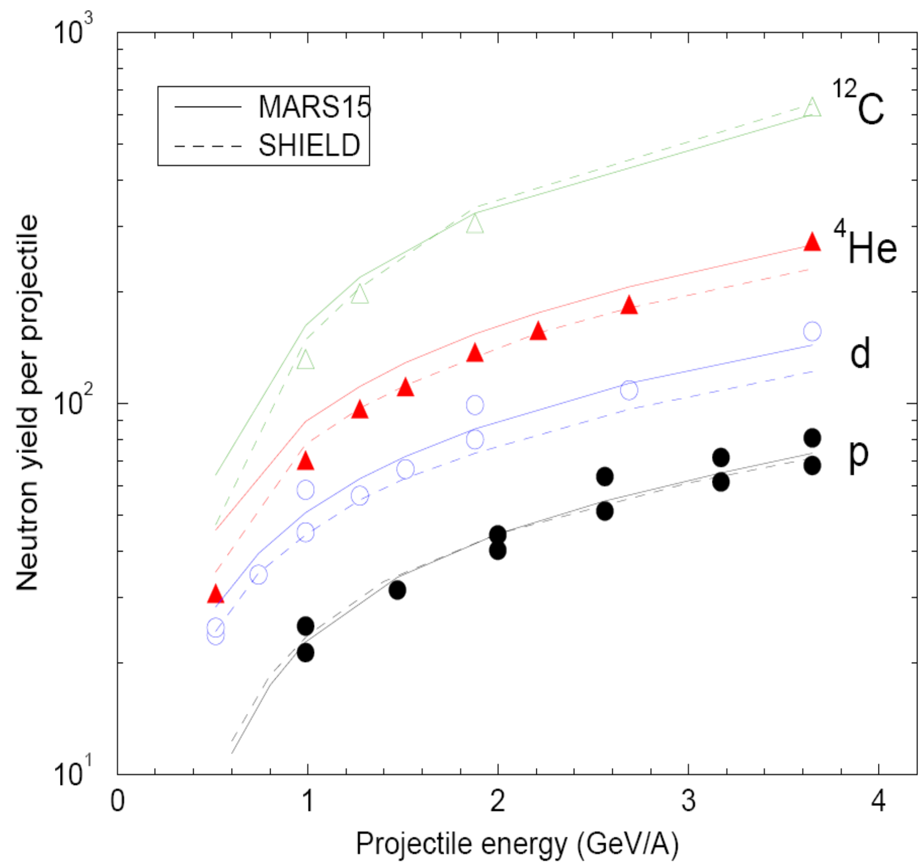


FIGURE 4. Mass yield in $^{86}Kr + ^{9}Be$ reaction at 1 GeV/A as calculated with LAQGSM03 and measured in Ref. [15].



Total neutron yield (E<14.5 MeV) from a lead cylinder (L=60 cm, R=10 cm) vs ion beam energy

SUMMARY

The reliable particle production and transport simulation codes capable to solve corresponding targetry issues are in hands.

From our summary on simulations at the First High-Power Targetry Workshop in 2003. We need:

- Better, faster electromagnetic shower algorithms coupled to hadron transport codes (MCNPX and SHIELD first of all!).
- Heavy-ion transport capability!
- DPA, hydrogen and helium production as a standard option.
- Better, faster nuclide production and residual dose rate options.
- International benchmarking on energy deposition in targets at the level of "neutronic" activity.

There is a substantial progress here, but more work is still needed. I am looking forward to hearing the talks at this workshop.