Recent MARS15 Developments, New Features and Event Generator Modes

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Fermilab

MAP meeting

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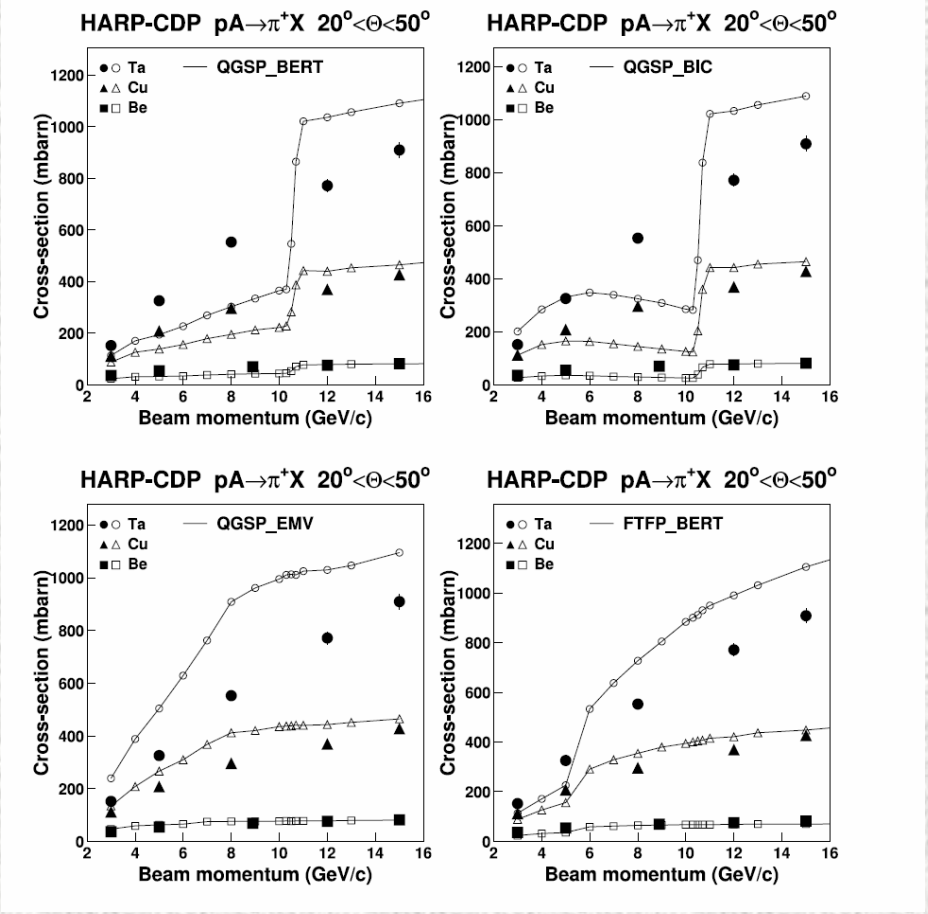
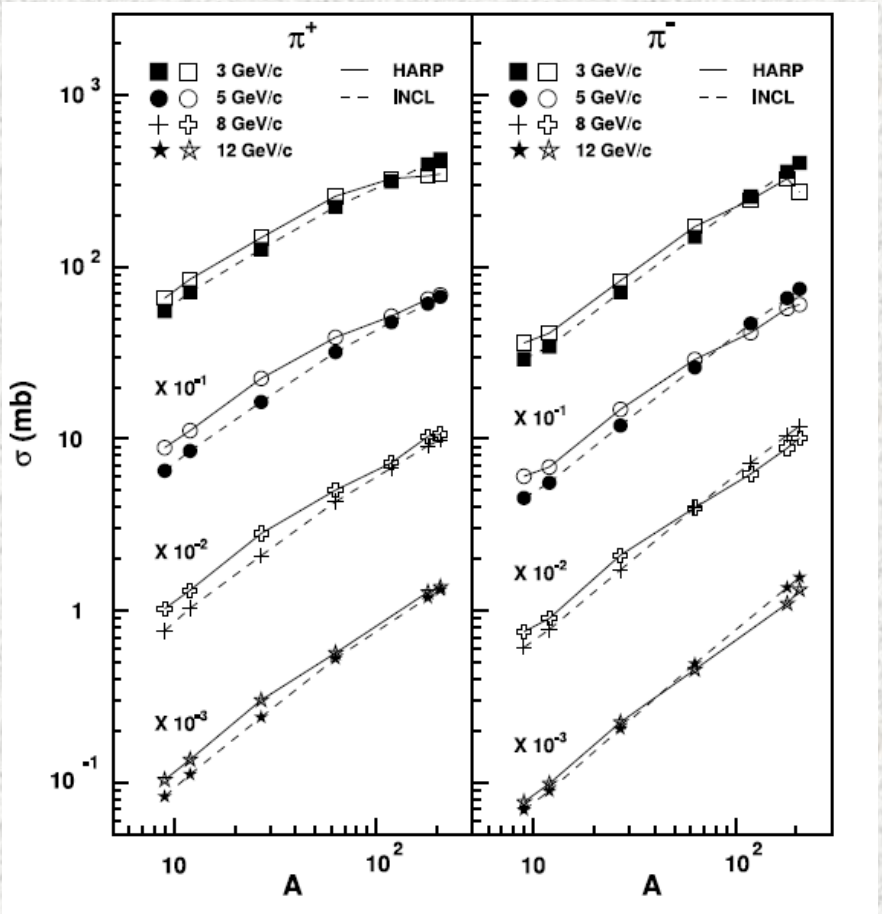
Particle Production in Nuclear Interactions

- The key for fixed target and collider experiment planning.
- The origin of the majority of beam-induced deleterious effects in machine/detector components and environment.
- OK at $E_p < 1$ GeV and $E_p > 10$ GeV.
- At intermediate energies, most interesting for the Intensity Frontier: substantial theoretical difficulties; experimental data contradict each other; the main problem with low-energy pion production that is crucial, e.g., for all Project X experiments.

Pion Production Cross-Sections at 3-15 GeV/c



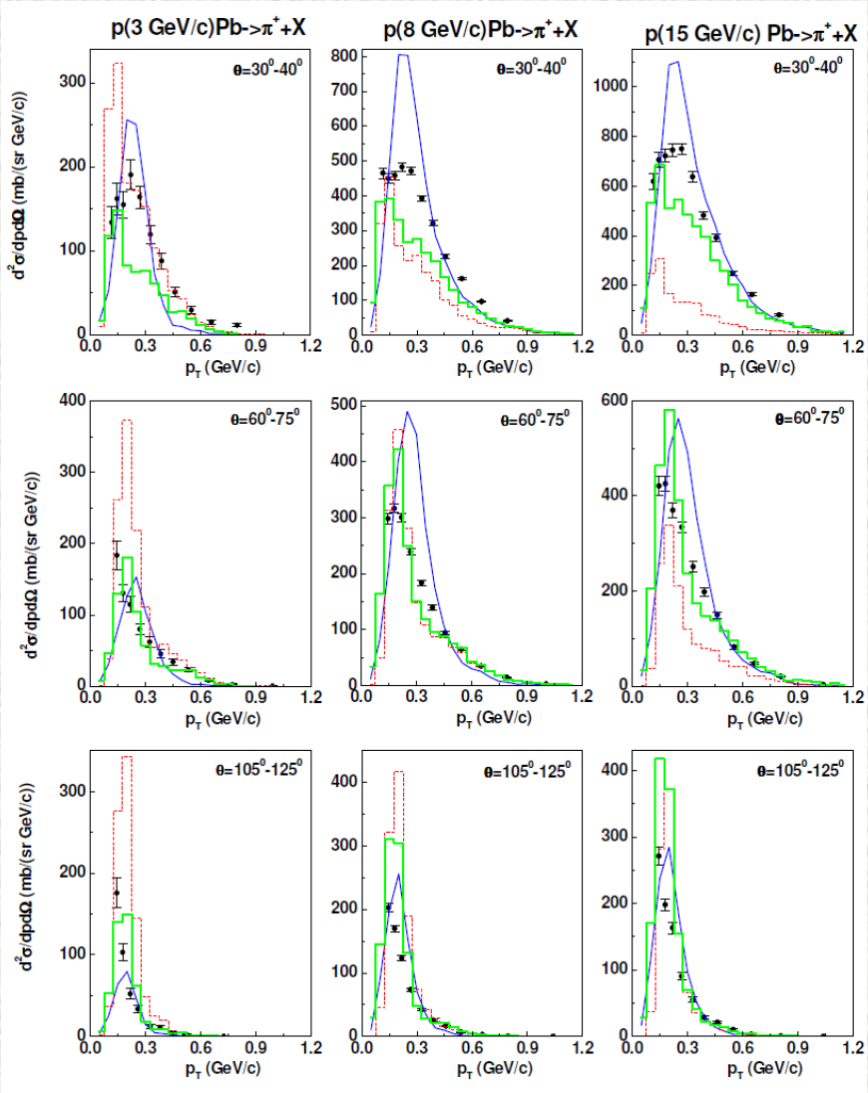


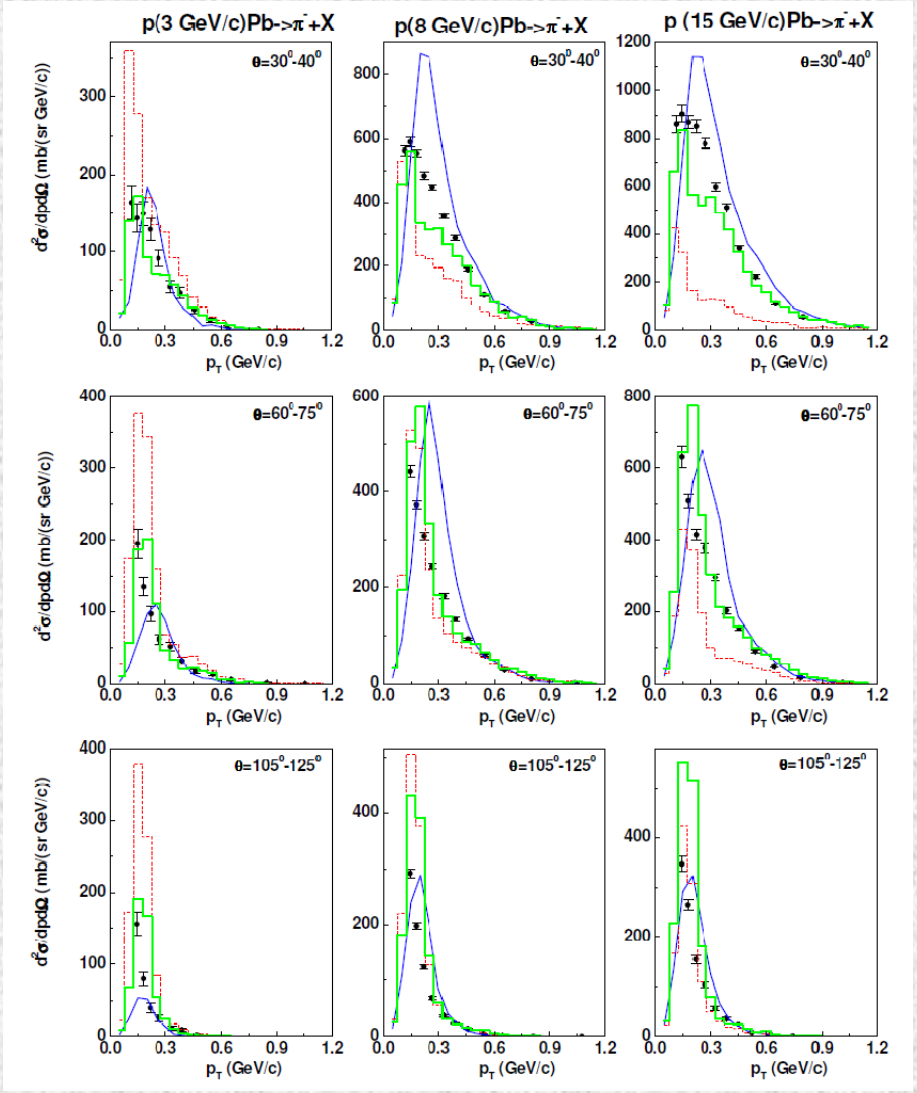
S. Pedoux, J. Cugnon

3-15 GeV/c p on Be, Cu and Ta:
GEANT4 models vs HARP

INCL-HE vs HARP

Geant4 Models vs HARP-CDP for p+Pb -> $\pi^{\pm}$ X at 3, 8 and 15 GeV/c





Green – UrQMD, **red** – Binary, **blue** – Fritiof

MARS15: Exclusive, Inclusive & Hybrid

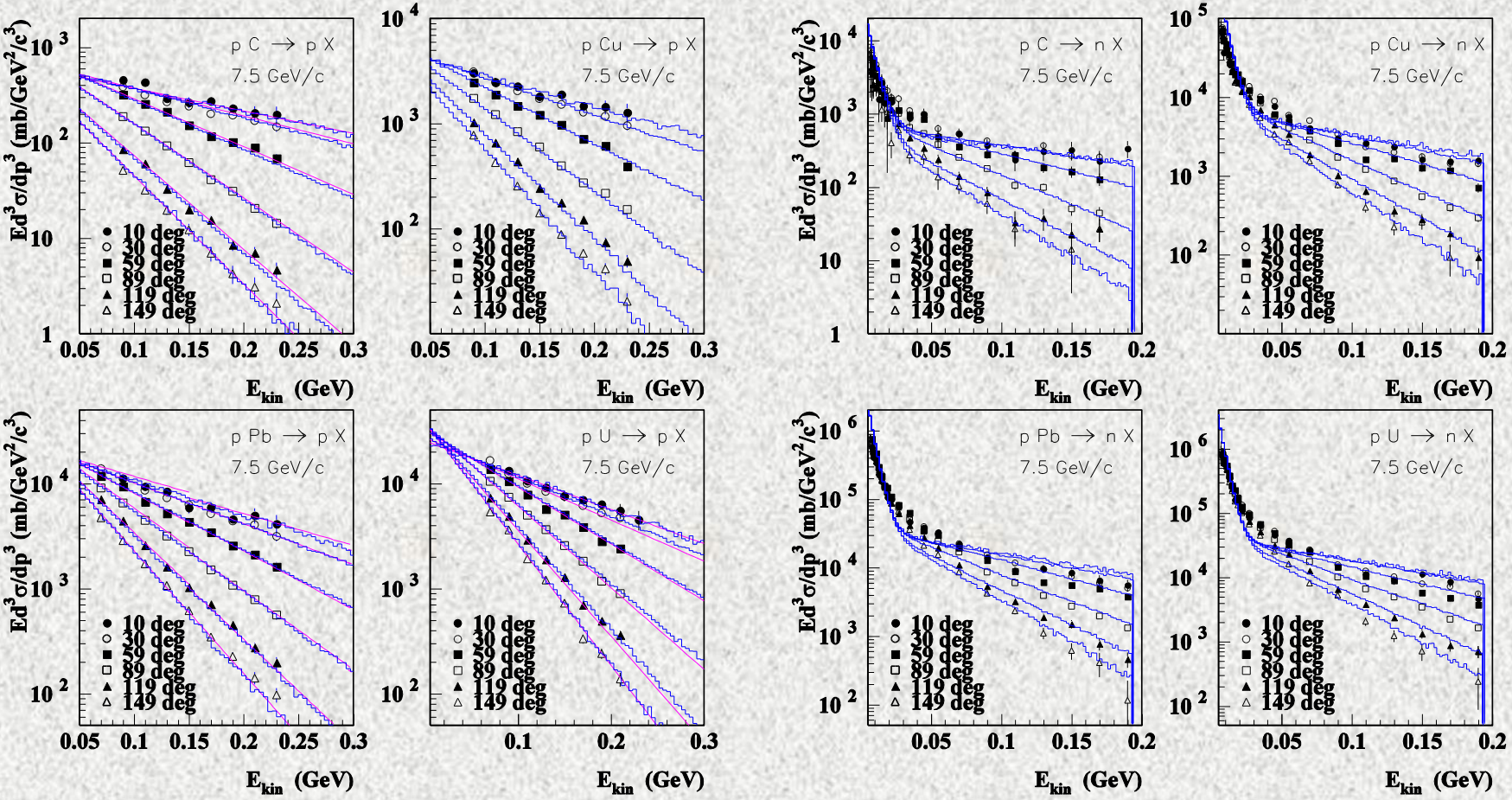
Most of processes in MARS15, such as electromagnetic showers, hadron-nucleus interactions, decays of unstable particles, emission of synchrotron photons, photohadron production and muon pair production, can be treated exclusively (analogously), inclusively (with corresponding statistical weights), or in a mixed mode.The choice of method is left for the user to decide, via the input settings.

Other variance reduction techniques used in MARS: weight-window, splitting and Russian roulette, exponential transformation, probability scoring, step/energy cutoffs.

Goal: Maximize computing efficiency $\varepsilon = t_0/t$, where t is CPU time needed to get a RMS error σ equal to the one in the reference method with CPU time t_0 provided $\sigma < 20\%$.

Low-Energy Nucleon Production in MARS15

7.5 GeV/c protons on C, Cu, Pb and U

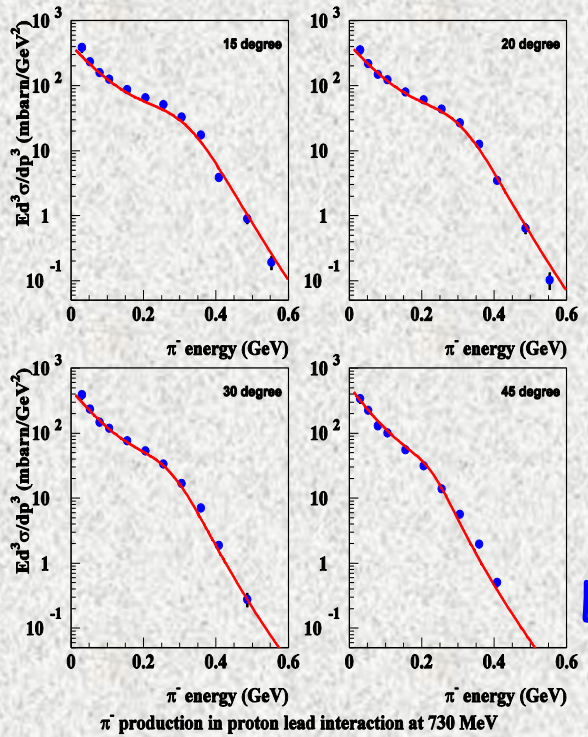


INCLUSIVE PION PRODUCTION

Example: Newest phenomenological MARS15 model for pion production in hadron-nucleus interactions at 0.7 to 12 GeV. Extension of earlier two-source model for these energies:

$$E\frac{d^3\sigma}{dp^3} = p_1(1+p_7\cos\theta)\exp\left(-\frac{T(1-p_2\cos\theta)}{p_3}\right) + \frac{p_9(1+p_8\cos\theta)}{1+p_4\exp(-T(1-p_6\cos\theta)/p_5)}$$

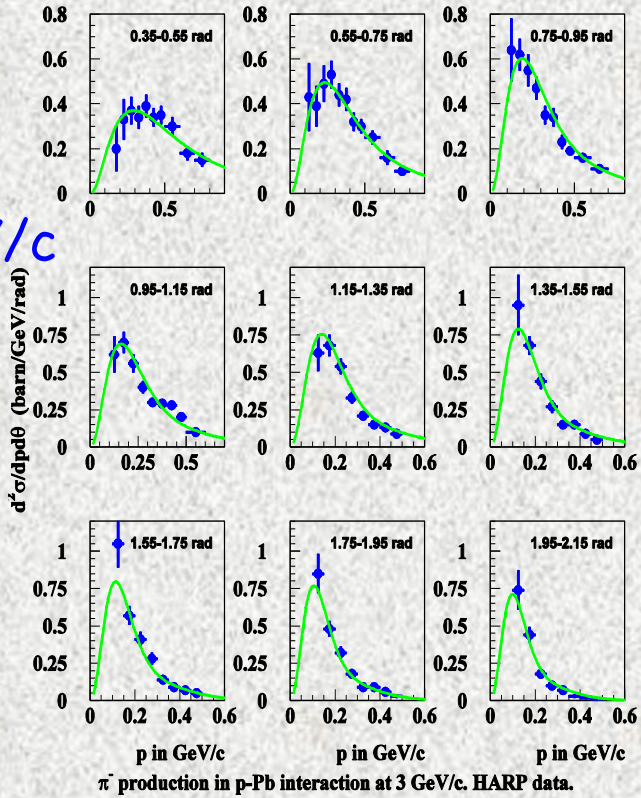
Data used: HARP, LANL, JINR and LBL.



LANL 730 MeV

p+Pb → π⁻X

HARP 3 GeV/c



MARS15 EXCLUSIVE EVENT GENERATORS

Improved Cascade-Exciton Model code, **CEM03.03**, combined with the Fermi break-up model, the coalescence model, and an improved version of the Generalized Evaporation-fission Model (GEM2) is used as a default for hadron-nucleus interactions below 5 GeV. Recent multi-fragmentation extension.

The Los Alamos Quark-Gluon String Model code, **LAQGSM (2013)**, is used in MARS15 for photon, particle and heavy-ion projectiles at a few MeV/A to 1 TeV/A. This provides a power of full theoretically consistent modeling of exclusive and inclusive distributions of secondary particles, spallation, fission, and fragmentation products.

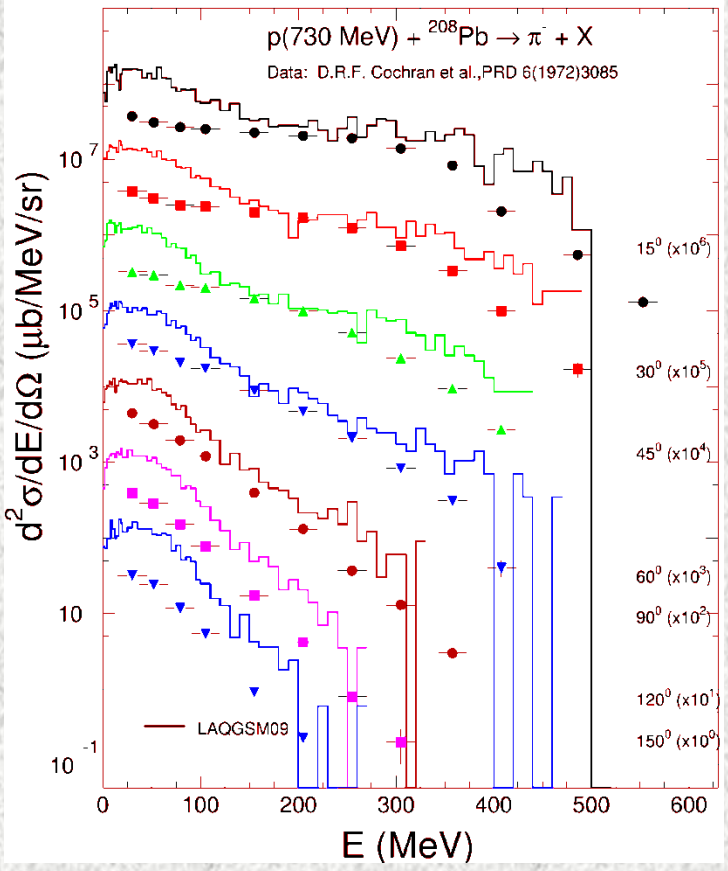
S. G. Mashnik, K. K. Gudima, A. J. Sierk, M. I. Baznat, N. V. Mokhov, "CEM03.03 and LAQGSM03.03 Event Generators for the MCNP6, MCNPX and MARS15 Transport Codes", LANL LA-UR-08-2931 (2008).

For quite some time, MARS has used the Dual-Parton Model code, **DPMJET3**, for the very first vertex in a cascade tree. This is used in our numerous studies for the LHC 7x7 TeV collider and its detectors, and at very high energies up to 100 TeV.

2012 LAQGSM Developments at E < 10 GeV by Konstantin Gudima

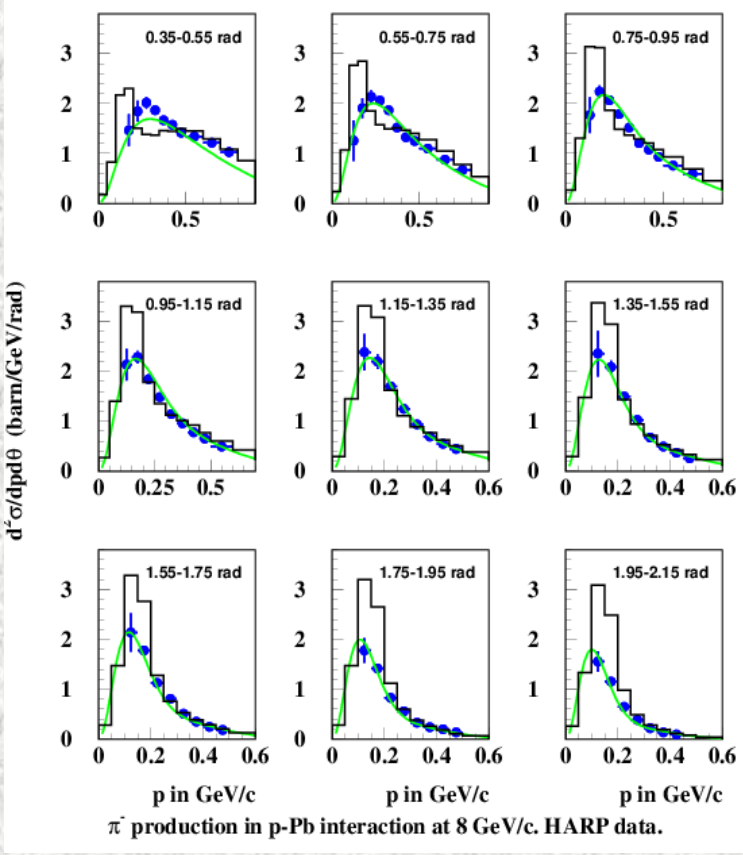
- New and better approximations for elementary total, elastic, and inelastic cross sections for NN and πN interactions
- Several channels have been implemented for an explicit description: $N+N \rightarrow N+N+m\pi$, $\pi+N \rightarrow N+m\pi$ ($m<5$), $B+B \rightarrow B+Y+K$, $\pi+B \rightarrow Y+K$, $Kbar+B \rightarrow Y+\pi$, and K+Kbar, N+Nbar pair production
- Combination of the phase space and isobar models and experimental data
- γA reactions extended down to GDR and below
- Arbitrary light nuclear projectile (e.g., d) and nuclear target (e.g., He)

Soft Pion Problem Still Remained…



p+Pb→π⁻X
at 730 MeV
and 8 GeV/c

Histograms:
LAQGSM
of 2012



Despite of overall good performance, LAQGSM till recently overestimated pion data at p < 200 MeV/c especially on heavy targets. Trivial attempts to fix the problem by increasing the pion absorption x-section did not help much damaging the whole picture. **Quantum leap in 2013 by K. Gudima.**

2013 LAQGSM Developments at E < 10 GeV by K. Gudima

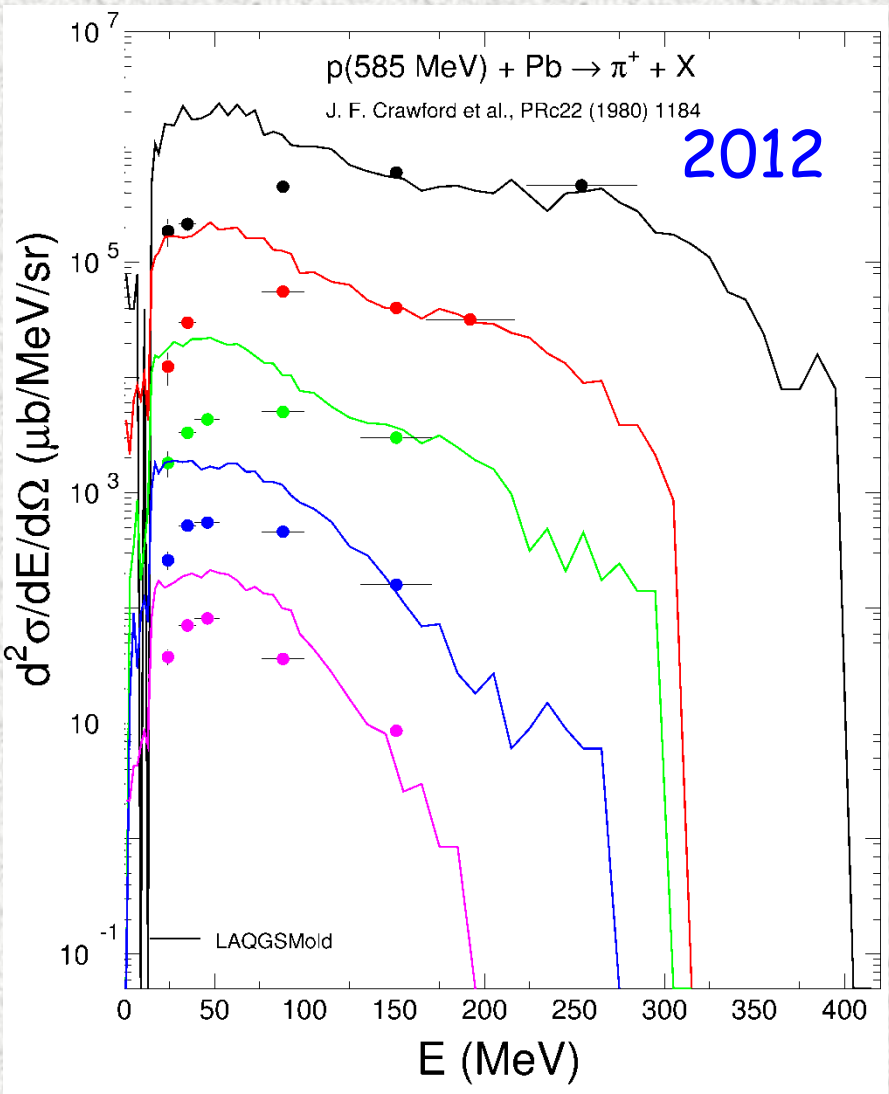
- Improved description of πN elastic scattering.
- Phenomenological parameterization of cross section of pion absorption on NN pair in nuclear medium was constructed based on π+d cross section $\sigma(A,T) = P(A) \times \sigma(\pi+d)$ with $P(A)=\alpha A^{\beta}$. Absorption probability is proportional to nucleon density squared $\rho^2(r)$.
- Improved description of pion absorption in nuclei in

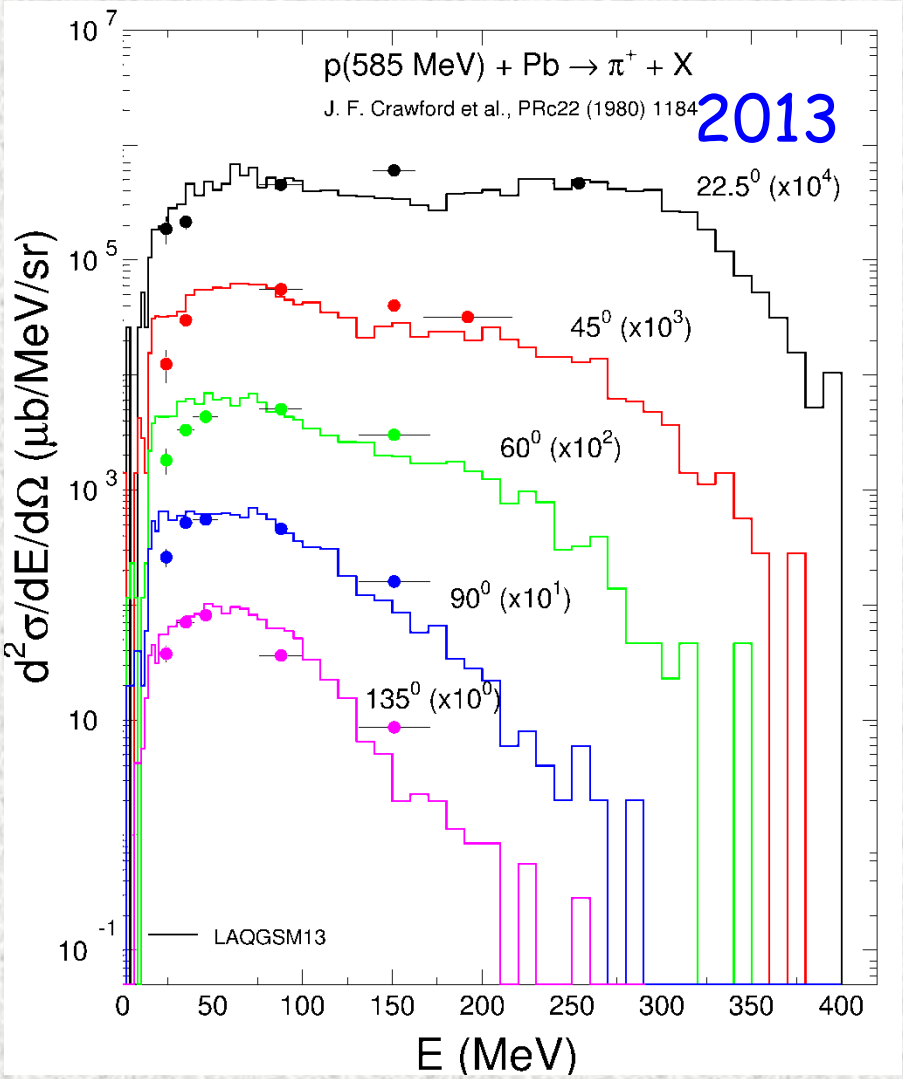
$\Delta+N \rightarrow NN$.

- New channel for pion production near threshold in

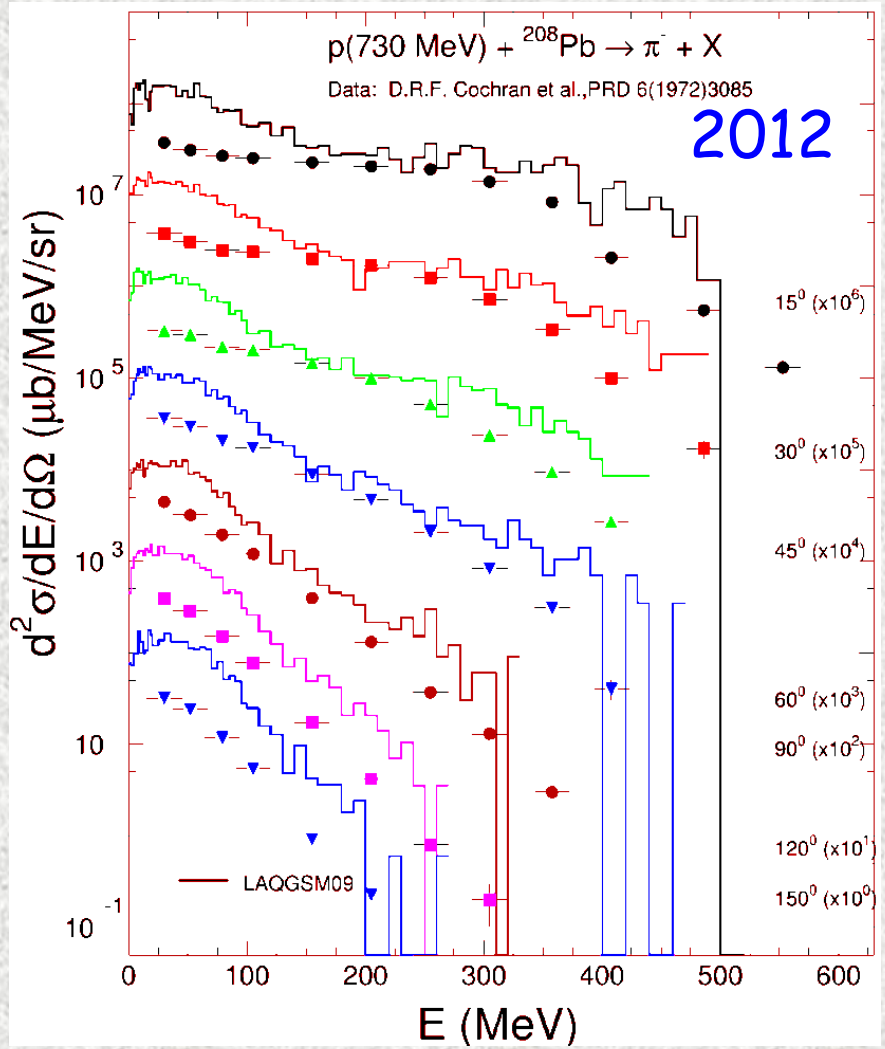
$N+N \rightarrow \pi+d$.

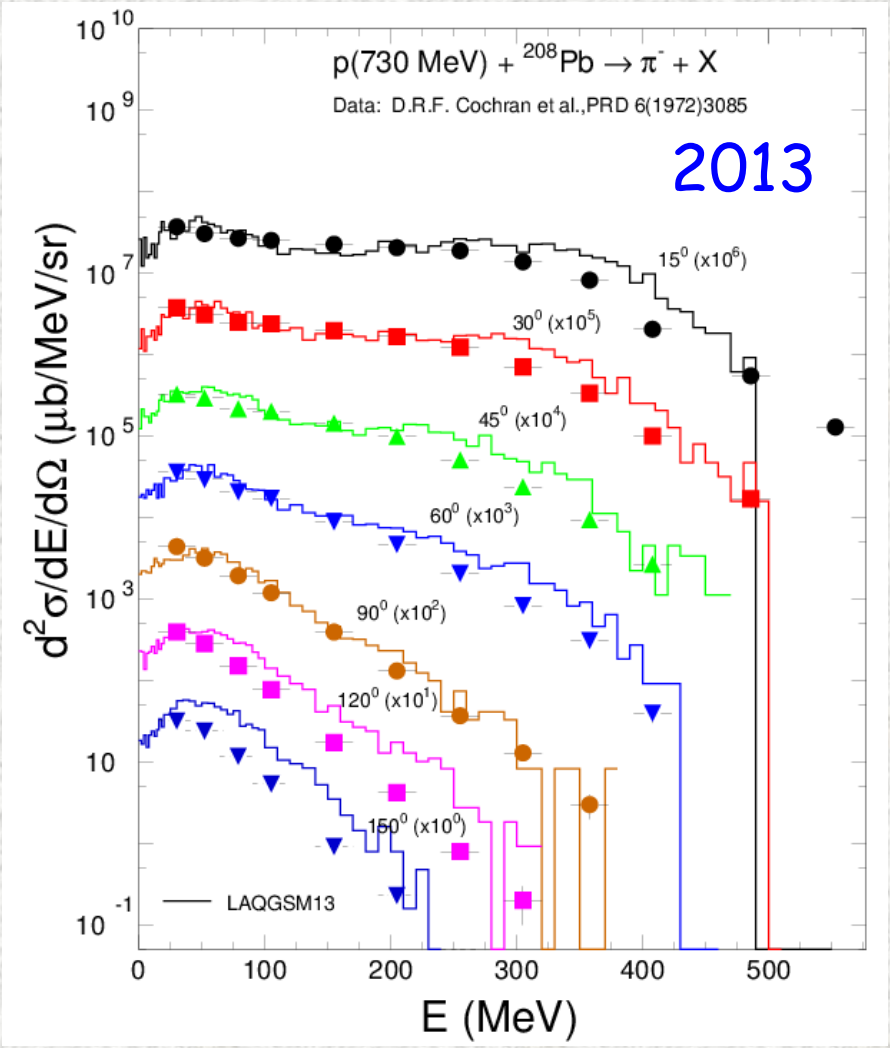
Effects of N+N → π+d and π+(NN) → N+NN+N



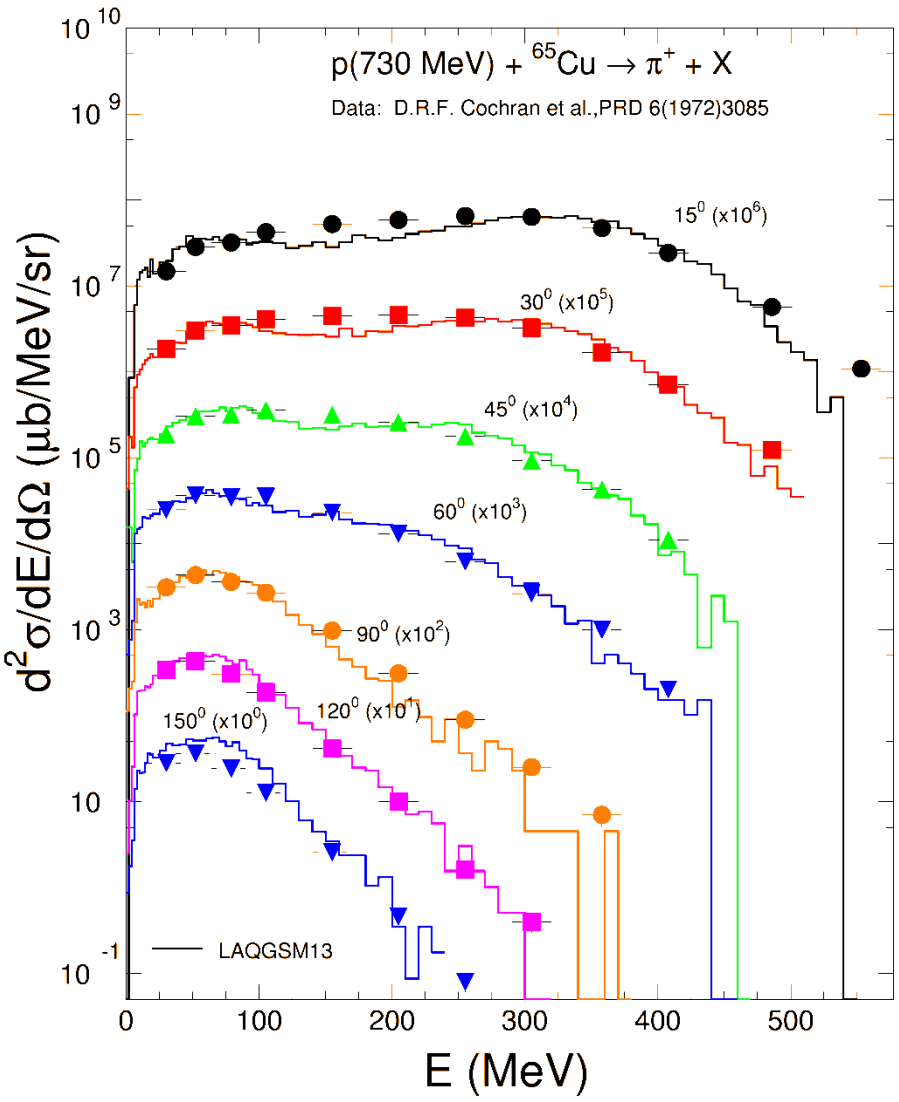


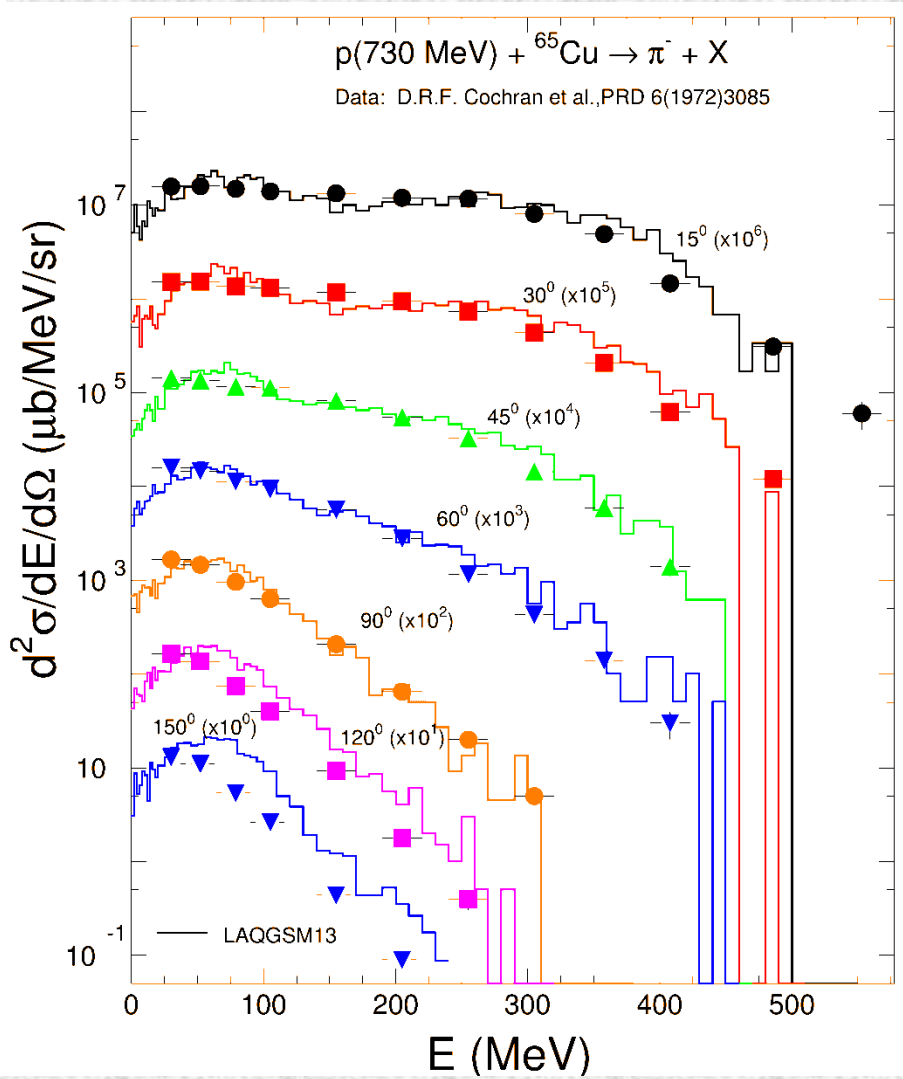
Effects of N+N → π+d and π+(NN) → N+NN+N
σ(abs)=P(A)σ(π+d)



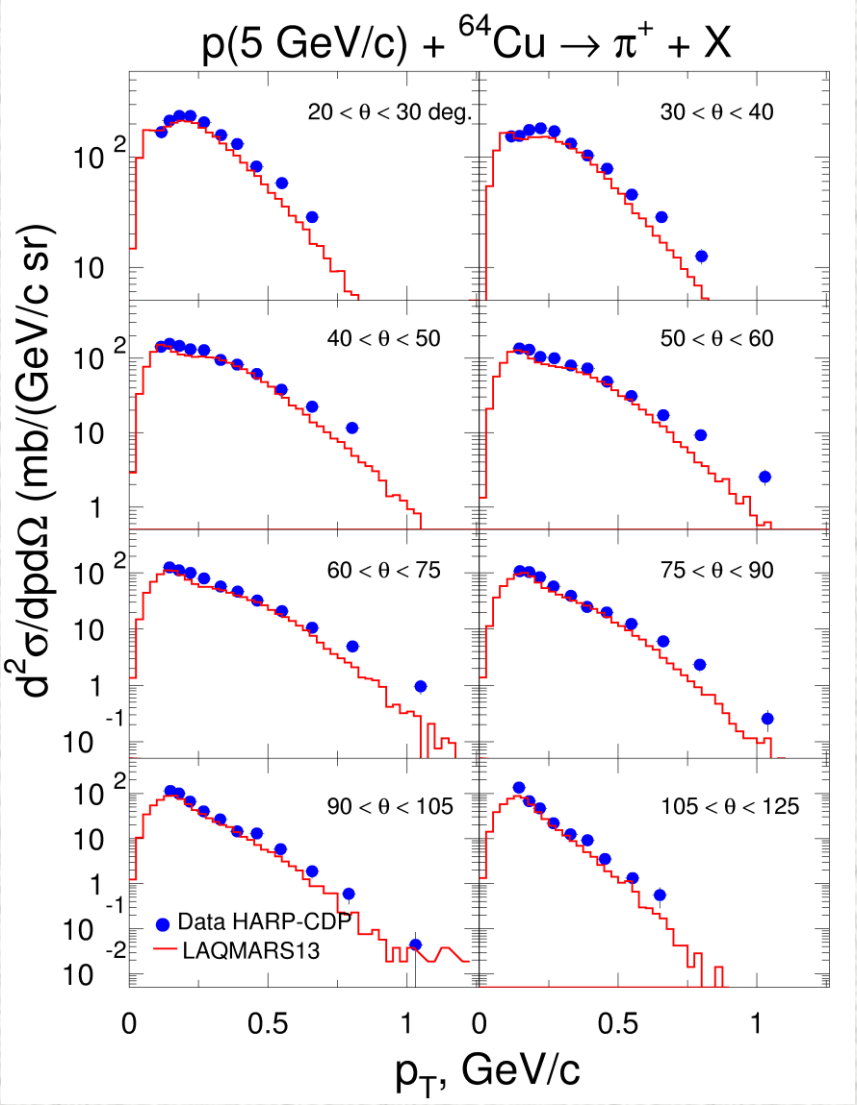


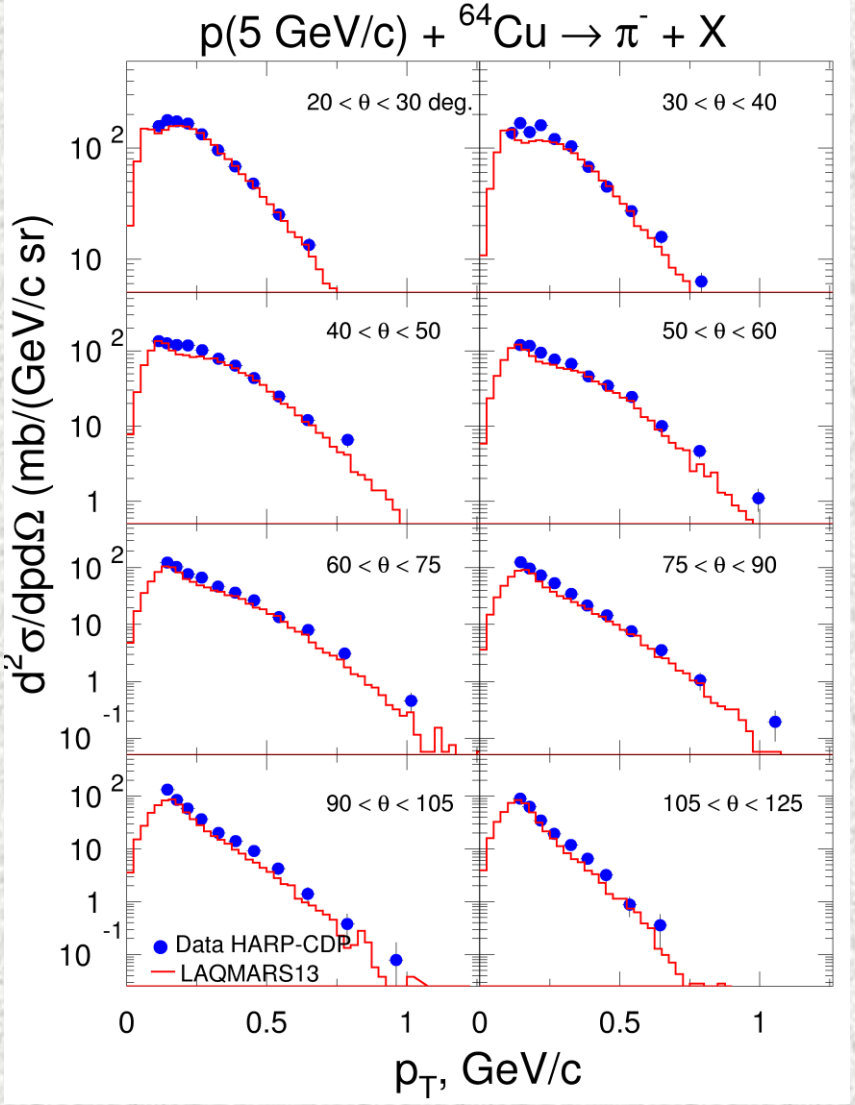
Effects of N+N → π+d and π+(NN) → N+NN+N
σ(abs)=P(A)σ(π+d) continue



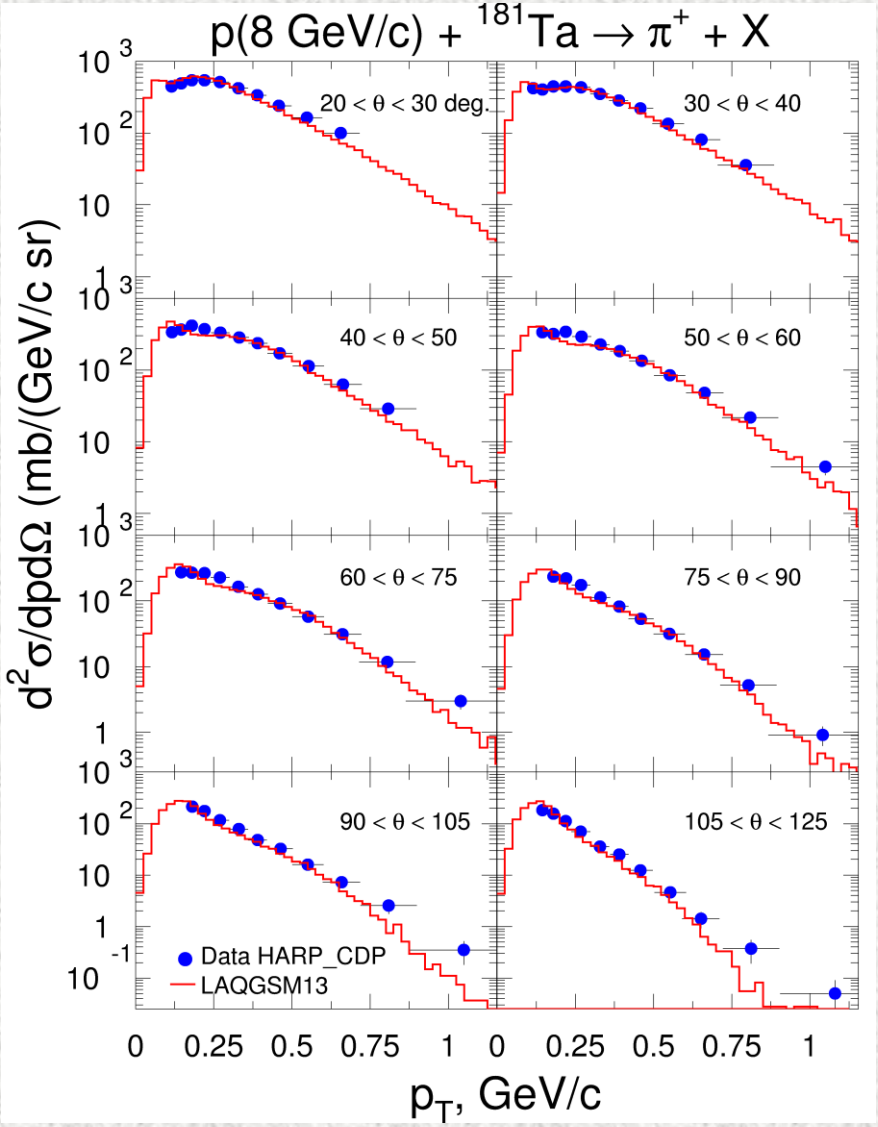


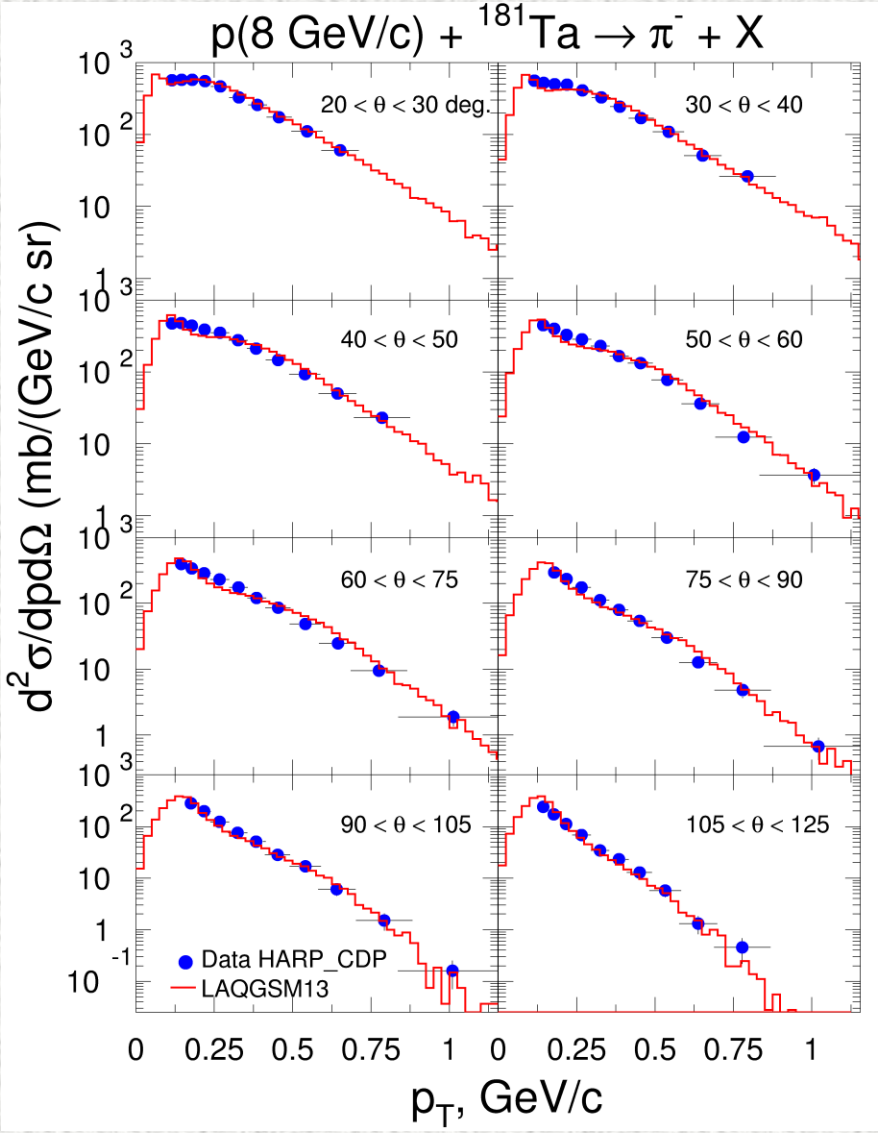
LAQGSM2013 vs HARP-CDP DATA





LAQGSM2013 vs HARP-CDP DATA





Event Generator Control in MARS1512

- ICEM 4=0 (default):
  - E_0 < 3 GeV: CEM
  - E_0 > 5 GeV: Inclusive
  - 3 < E_0 < 5 GeV: Mix-and Match
- ICEM 4=1: particle and nuclide production
  - LAQGSM at E_0 > 1 + A/65 GeV, or/and A < 3, and all pbar, K, hyperons and heavy ions
  - Otherwise: CEM
- ICEM 4=2:
  - LAQGSM

Event Generator Control in MARS1514

- ICEM 4=0: shielding-like applications
  - E_0 < 3 GeV: CEM
  - E_0 > 5 GeV: Inclusive
  - 3 < E_0 < 5 GeV: Mix-and Match
- ICEM 4=1 (default): Majority of applications, including particle production for Muon Collider applications
  - E_0 < 0.3 GeV: CEM
  - 0.3 < E_0 < 0.5 GeV: CEM/LAQGSM Mix-and Match
  - 0.5 < E_0 < 5 GeV: LAQGSM
  - 5 < E_0 < 8 GeV: LAQGSM/Inclusive Mix-and Match
  - E_0 > 8 GeV: Inclusive
- ICEM 4=2:
  - LAQGSM

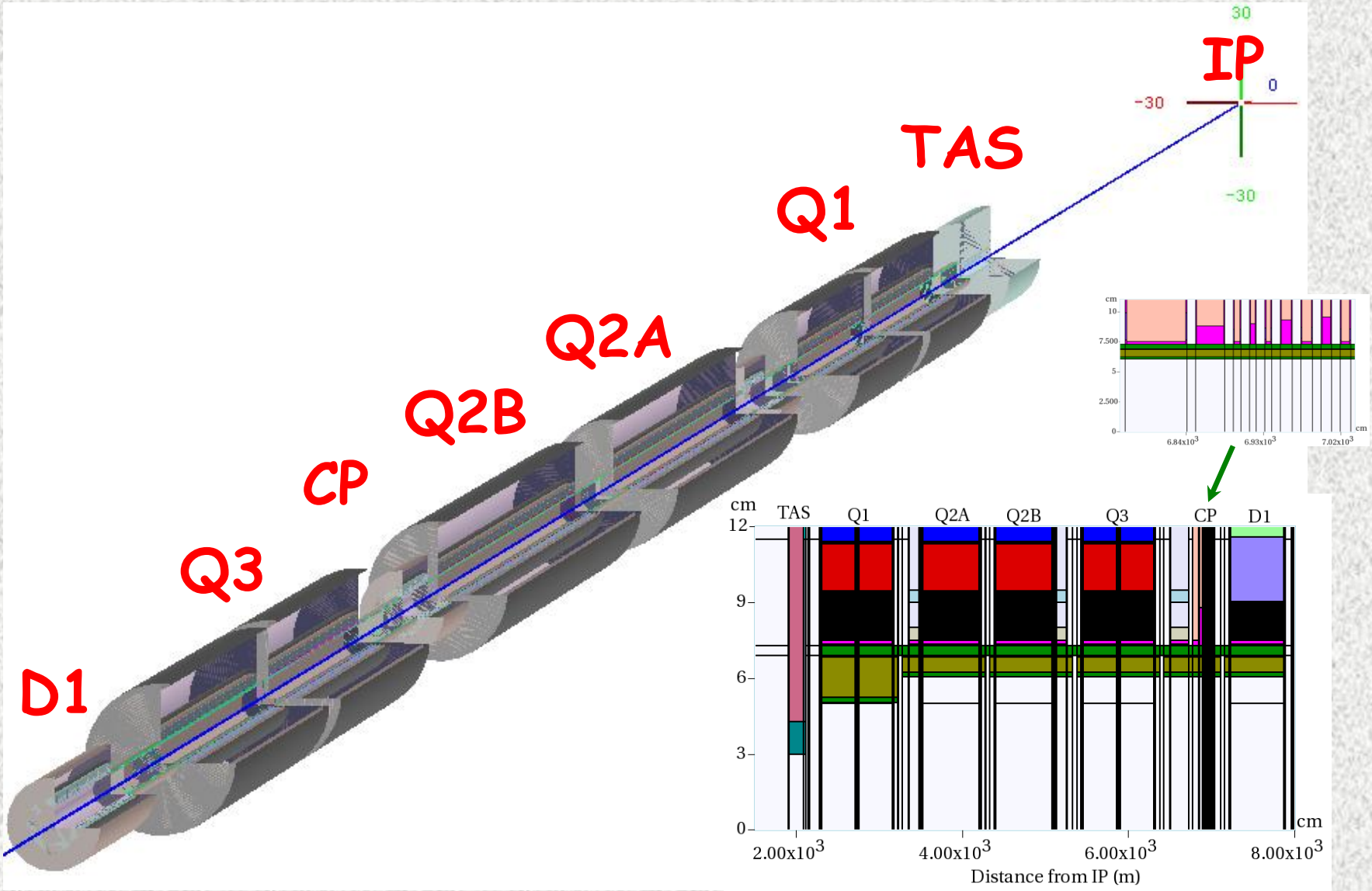
Code Predictive Power and Uncertainties

- Predictive power, capabilities and reliability of major particle-matter interaction codes used in accelerator applications are quite high.
- On particle yields, accuracy of predictions is at a 20% level in most cases, although the issues (up to a factor of 2) remain in some phase space regions. EM interactions are described at a few % level.
- Accuracy of beam-induced macroscopic effect predictions today:
  - Energy deposition effects (instantaneous and accumulated) < 15%
  - Hydrogen/Helium gas production and DPA: ~20% (with similar DPA models) to a factor of 2; still need better link of DPA to changes in material properties
  - Beam loss generation and collimation: quite good (Tevatron, J-PARC, LHC)
  - Radiological issues (prompt and residual): a factor of 2 for most radiation values, if all details of geometry, materials composition and source term are taken into account.

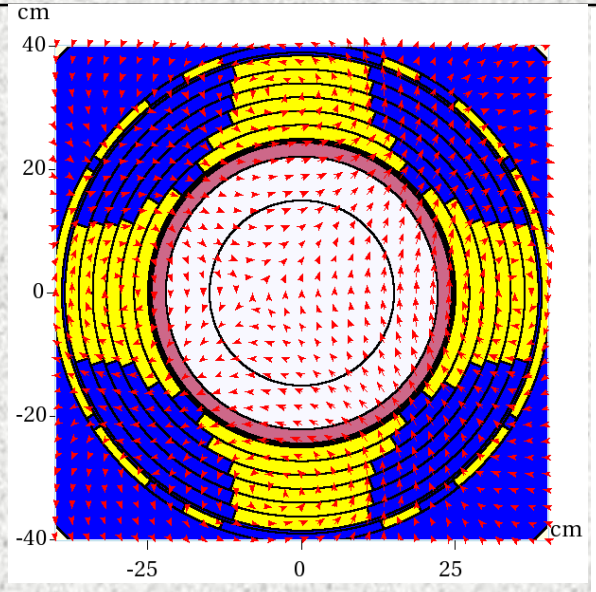
Other Improvements and Extensions in MARS1514

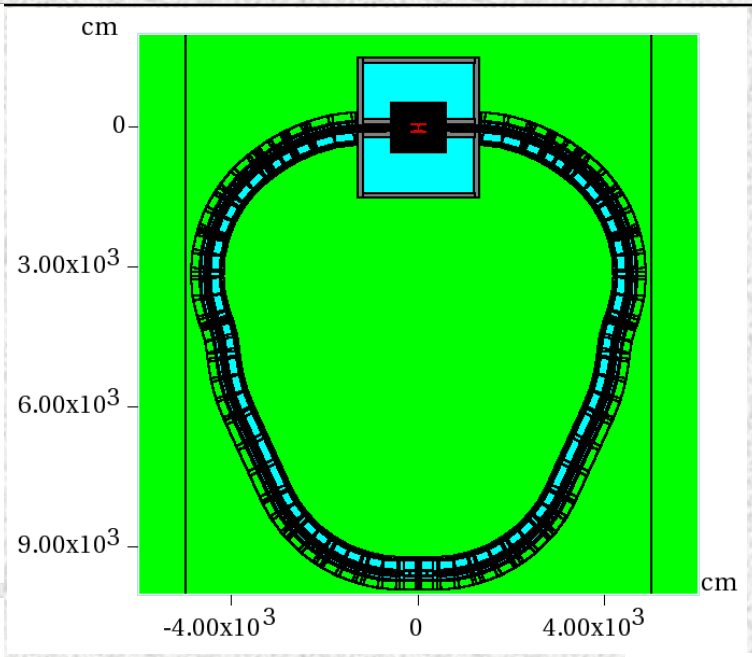
- Robust electromagnetic shower modelling down to 1 keV
- Refined DPA model with comprehensive database
- Refined highly-accurate tracking algorithms for arbitrary geometry and magnetic fields
- "Thick-shielding" mode IND(6)
- Histograming
- ROOT geometry as a basis: tracking, variety of shapes, 3D visualization, illegal overlap checking, ROOT-based MAD-MARS Beamline Builder, geometry import/export: MARS to/from GDML (HEP detectors) and MARS to/from STEP (CAD); Extended-to-ROOT geometry converter coming.

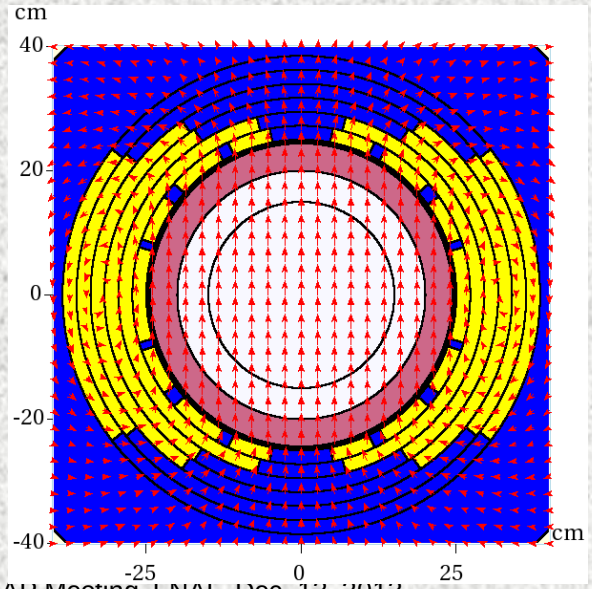
150-mm HL-LHC IT and D1: MARS15

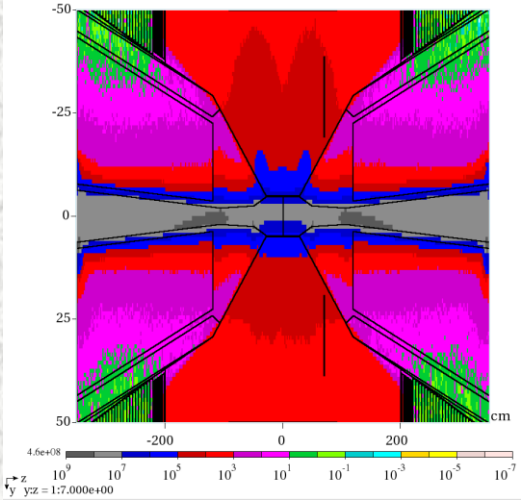


Muon Collider Higgs Factory in MARS15









MARS15 at NERSC

- MARS15(2012) installed and tested there in a single-CPU mode
- Guidance how to run/digest the code in a multiple-job mode can be found - as at the all MARS sites - in directory $MARS15/auxiliary/multiple
- MPI mode is not supported in MARS since about 7 years ago
- MCNP issues at NERSC are still not resolved
- Upgrade to MARS15(2014) will be performed within next few weeks, in the framework of the worldwide upgrade.