Study of Multiplicity in Geant4 Hadronic Models

Dennis Wright
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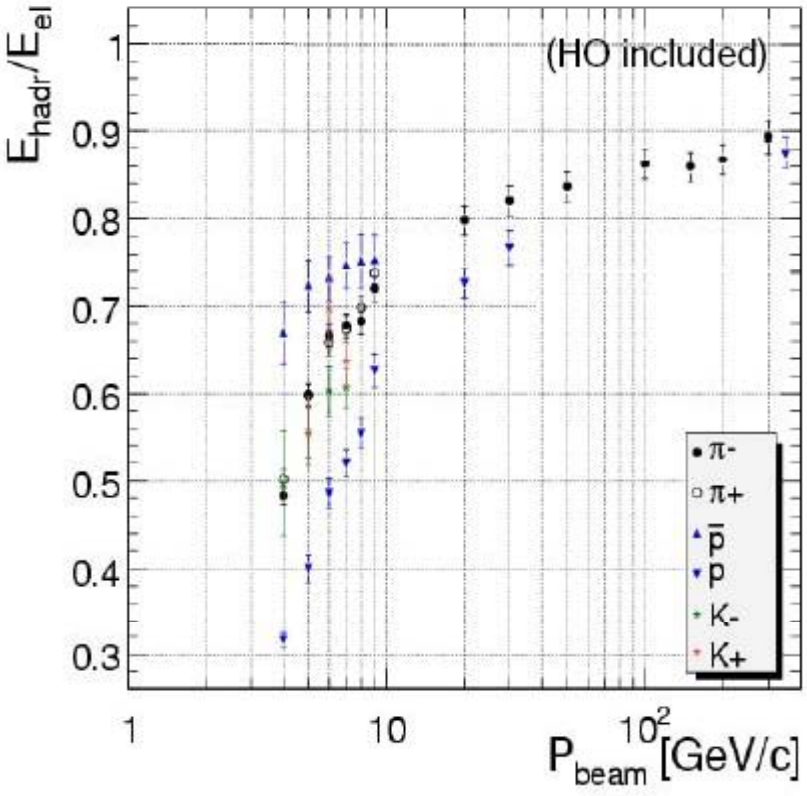
A Reminder of the Problem

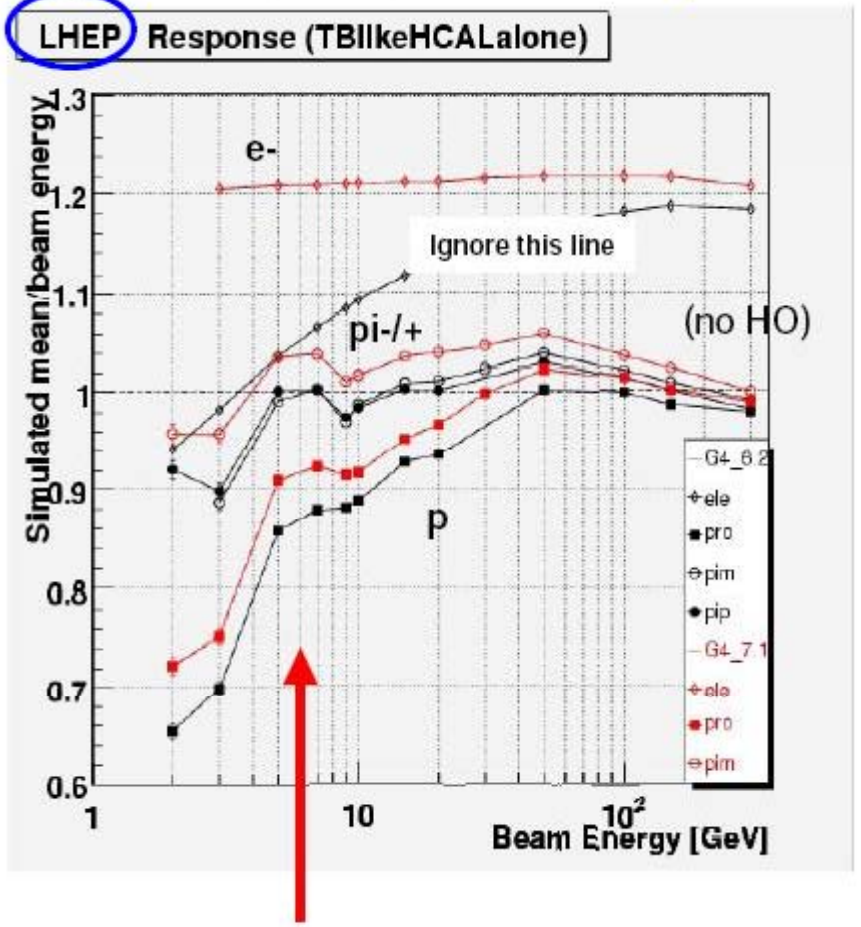
- CMS reports too much energy deposited by Geant4 in $PbWO_4$ crystals at incident π^- energies below 10 GeV
  - see slide 3
- charged particle spectra are too hard and show a bump or shoulder at 5-9 GeV
  - see slide 3
- nucleon multiplicities at first interaction point are not monotonically increasing with energy, but instead vary widely
  - see slide 4

HCAL Alone

TB2006 Data



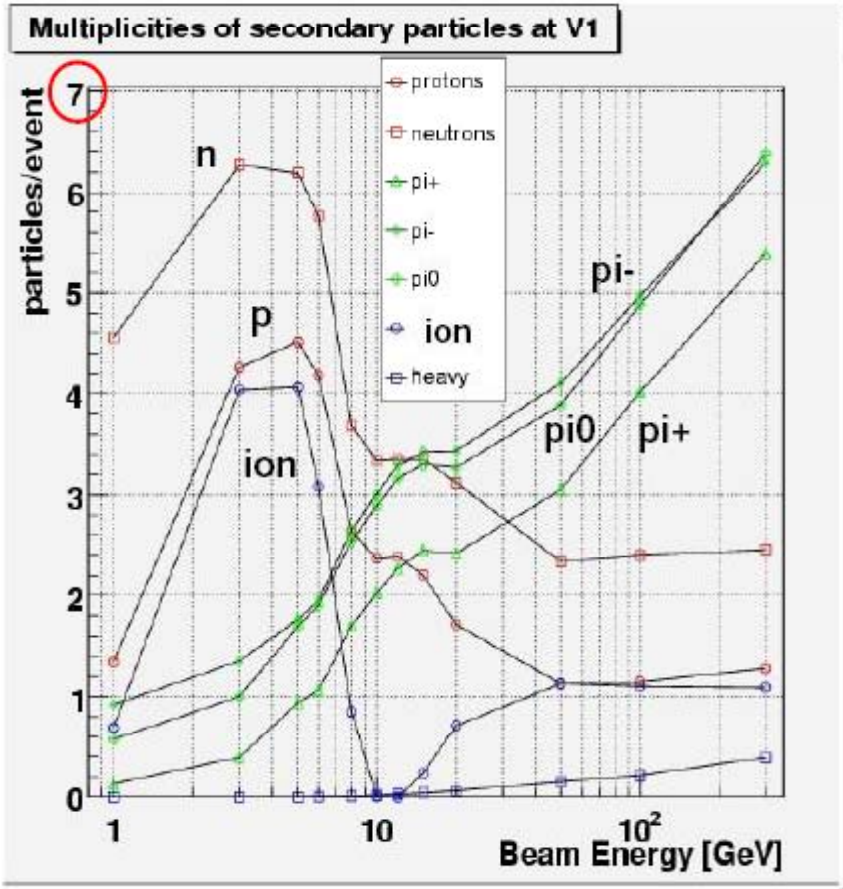
G4 (6.2, 7.1) for TB2004 setup



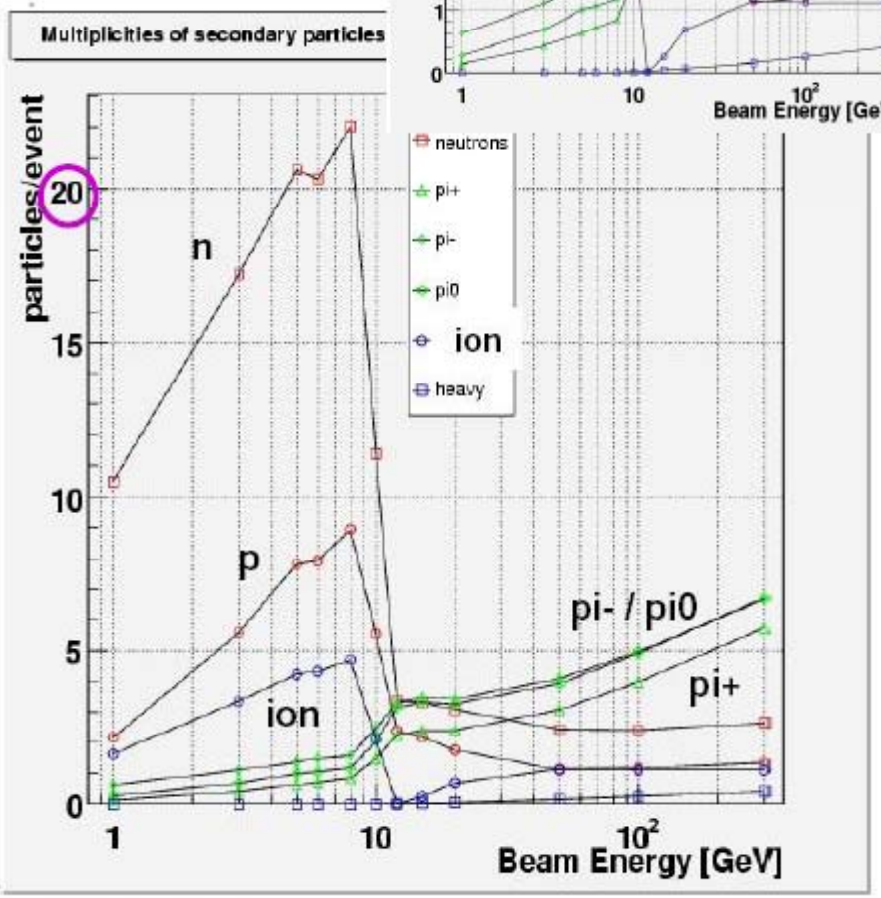
Seen in sampling calorimeter !
Energy spectrum also too hard?

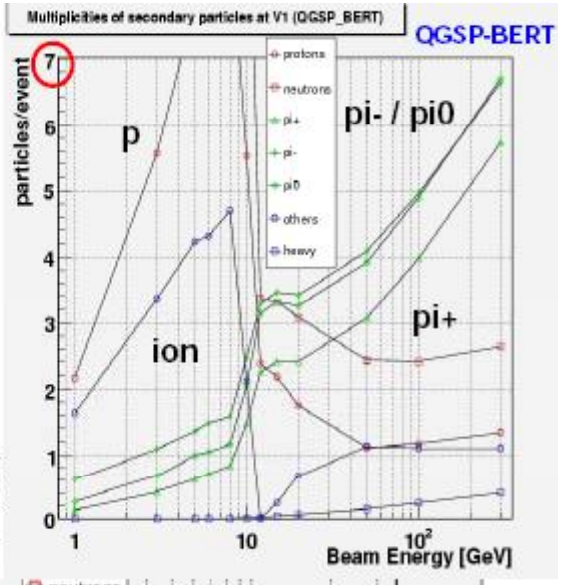
Multiplicity of Secondary Particles at First Interaction Point

QGSP



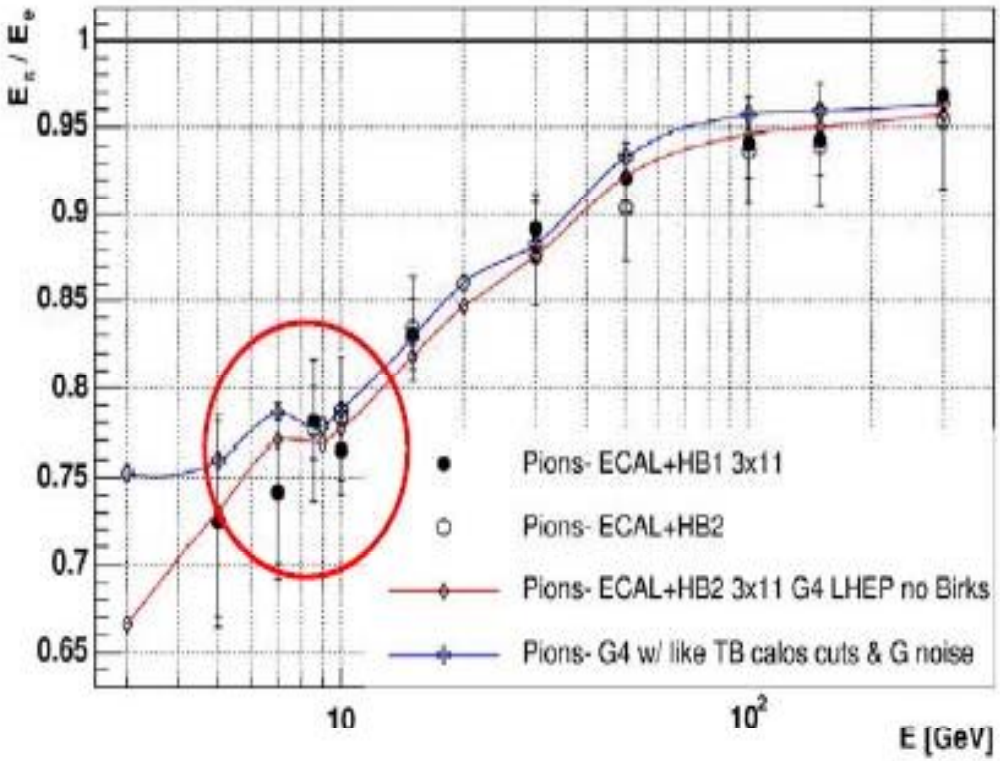
QGSP-BERT





Too much neutrons / protons / ions ?

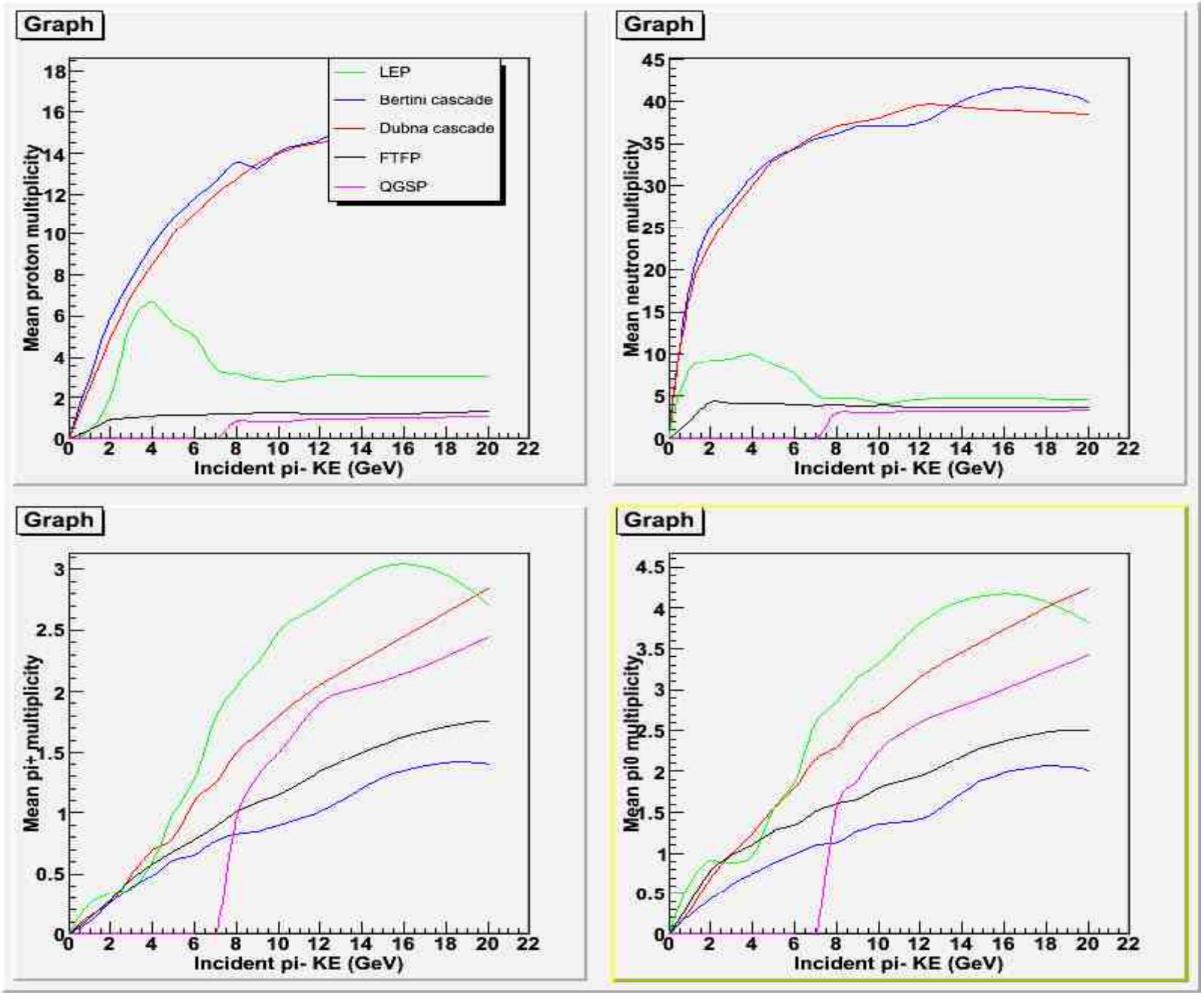
pi/e TB HB2 vs G4 LHEP (no Birks law)



Examining the Models

- Physics lists used by CMS:
  - QGSP, QGSP_BERT
- Examine problem by looking at individual models used in the physics lists. For pions below 12 GeV:
  - QGSP physics list is LEP
  - QGSP_BERT physics list is BERT for 0 – 9.9 GeV, LEP for 9.5 – 12 GeV LEP
  - Also look at FTFP, QGSP models and Dubna cascade
- Plot produced particle multiplicities for each model
  - process-level test, so only one interaction/event

Multiplicity vs. π^- KE for p, n, π^+, π^0



Comments on Multiplicity Plots (1)

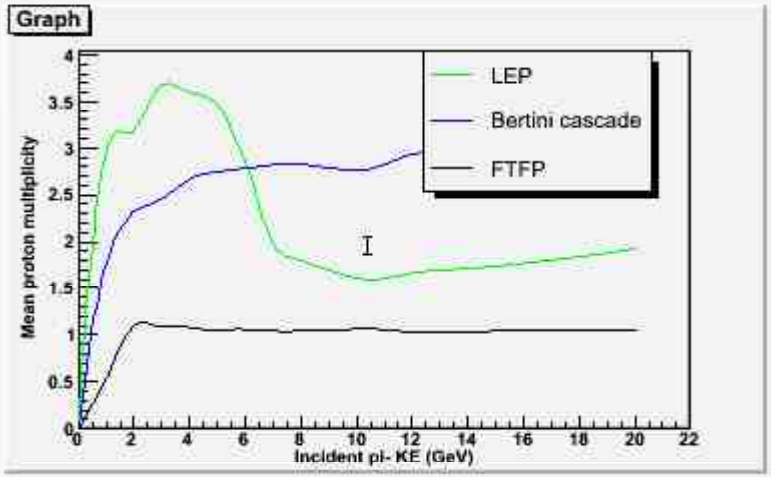
- Pions:
  - all models, except LEP above 15 GeV, produce monotonically increasing numbers of pions vs. energy
  - this is expected, although numbers vary significantly with model
- Nucleons
  - cascades increase rapidly with energy, then plateau
  - LEP model rises rapidly up to 4 GeV, then drops and levels off
    - rise and fall due to protons with p < 1 GeV/c
  - this reproduces the CMS QGSP result for first interaction point
  - the sharp transition seen in QGSP_BERT is also explained by switching from the Bertini curve to the LEP curve over the range 9.5 to 9.9 GeV

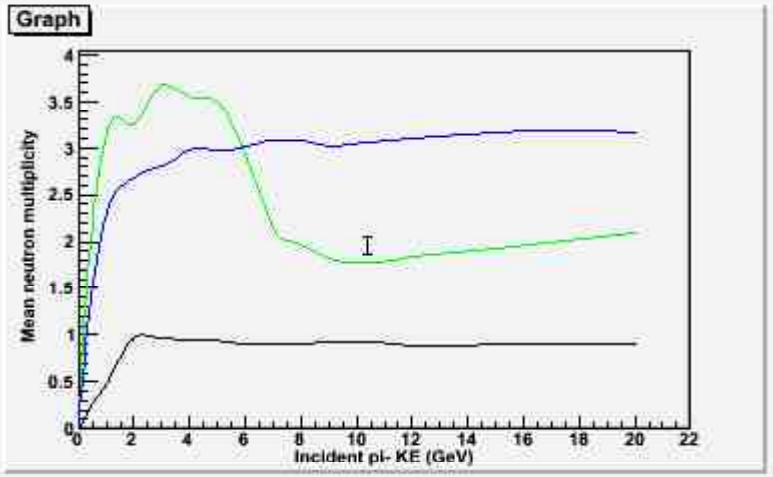
Comments on Multiplicity Plots (2)

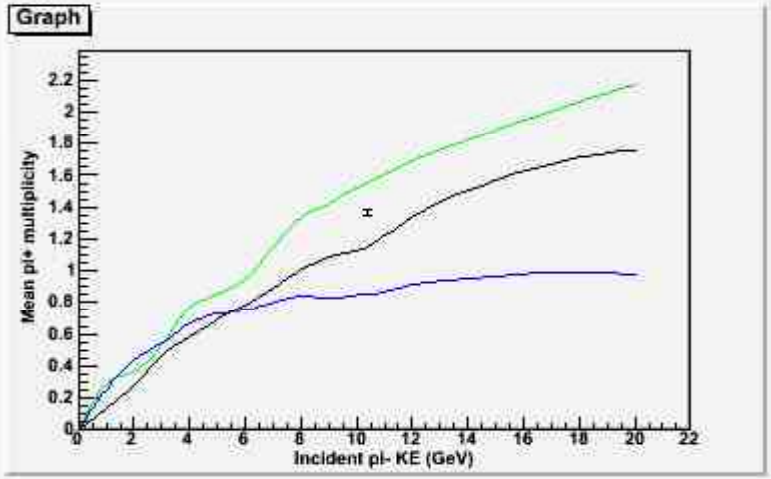
- According to conventional wisdom, there should not be a drop in nucleon multiplicity
- In LEP there is a reason given for the dip (Fesefeldt's tech. note)
  - formation zone
  - absorption of nucleons on “heavy molecules”
  - removing these corrections makes LEP look qualitatively like a cascade model (no drop, a monotonic increase of multiplicity)
- Any joining of cascade with string model in Geant4 will produce such a drop
- Is the drop real?
- Look for data

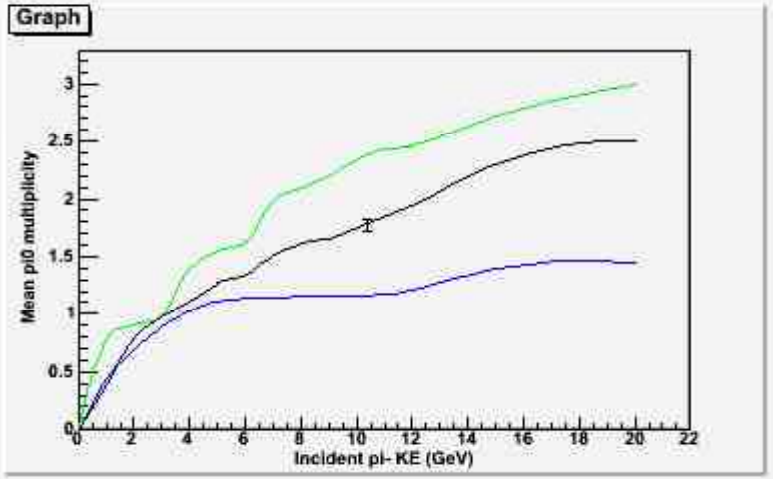
Neon Bubble Chamber (thin target) Data

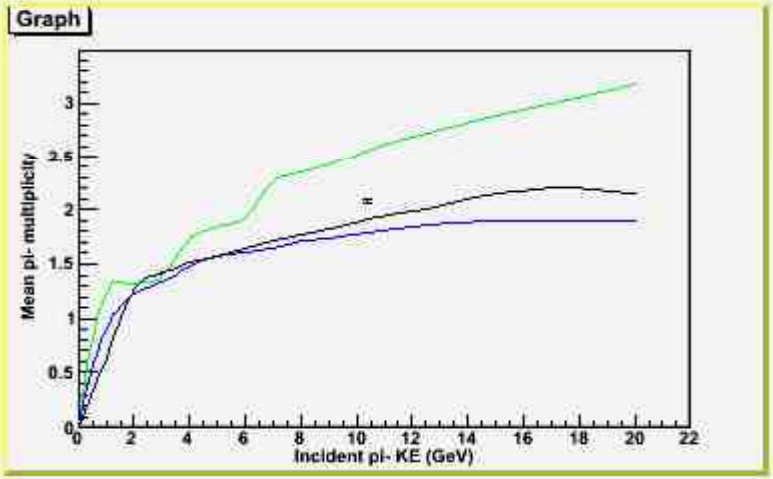
- 10.5 GeV/c $\pi^{+/-}$ on Ne
  - W.M. Yeager et al., Phys. Rev. D16, 1294 (1977)
- average multiplicities measured for p, $\pi^{+/-}$
  - deduced for n, π^0
- Compare to Bertini, LEP, FTFP
  - slide 10
- Other thin target data at 6, 9 GeV, from emulsions are ambiguous
- Thick target data exists, but not as helpful


Graph
LEP
Bertini cascade
FTFP
Mean proton multiplicity
Incident pi- KE (GeV)


Graph
Mean neutron multiplicity
Incident pi- KE (GeV)


Graph
Mean pi+ multiplicity
Incident pi- KE (GeV)


Graph
Mean pi0 multiplicity
Incident pi- KE (GeV)


Graph
Mean pi- multiplicity
Incident pi- KE (GeV)

Comments on Neon Comparison

- Nucleons
  - LEP: good agreement
  - FTFP: too low
  - Bertini: too high
- Pions
  - FTFP: good agreement
  - LEP: too high
  - Bertini: too low

Reasons for the Rise and Fall of Multiplicities with Energy

- Test: for Bertini and FTFP models, look at multiplicities for particles with p > 0.5 GeV/c
  - energy region 5 < E < 9 GeV (where the models overlap)
- Result:
  - nucleon multiplicities agree well for both Bertini and FTFP over this range
  - without momentum cut nucleon multiplicity in Bertini is 2 – 3 times that of FTFP
- Conclusion:
  - rise and fall are due to low energy particles only
  - not the case for LEP models

Discussion

- The single data point at 10.5 GeV/c indicates that Bertini has too many low energy nucleons, while FTFP (and probably QGSP) has too few
- If data point is correct AND there is no real drop in multiplicities with energy, then Bertini and LEP both have too many low energy nucleons
  - would confirm CMS result
- Would be useful to be able swap precompound models
  - use G4PreCompound in Bertini, etc.
  - could then see which model is at fault

Conclusions

- We reproduce the rise and dip in proton multiplicities seen at the first interaction point by CMS
- The rise and fall in QGSP is due to parameterizations in LEP
- The rise and fall in QGSP_BERT is due to the transition from Bertini to LEP over the range 9.5 < E < 9.9 GeV
  - the same behavior would occur in coupling Bertini to either QGSP or FTFP models
- Widening the transition between Bertini and LEP from 9.5-9.9 GeV to 5.0-9.9 GeV (QGSP_TRV) will smooth out the abrupt change in multiplicities but there will still be a decrease with energy
- Cascades too high above 5 GeV? String models too low? Precompound model too low?