GEANT3-GEANT4 Hadronic Response Comparisons

$\bar{\mathrm{P}}$ANDA Collaboration Meeting

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Motivation

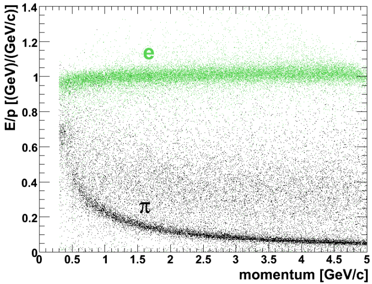
eID critical observables

- Time-like proton form factors
- Signal: $p\bar{p} \rightarrow e^+e^-$
- Main background: $p\bar{p} \rightarrow \pi^+\pi^-$
- $\frac{\sigma_{p\bar{p}\rightarrow e^+e^-}}{\sigma_{p\bar{p}\rightarrow \pi^+\pi^-}} \approx 10^{-6}$
- Main differentiator: calorimeter energy
- Tail of hadronic distribution critical

Objectives

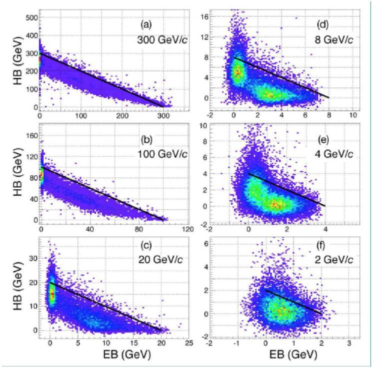
- Check systematic difference in hadronic response between GEANT3 and GEANT4
- Check sensitivity of hadronic response to changes in physics lists
- Check effect of other GEANT4 options on hadronic response tail

arXiv/0907.4478

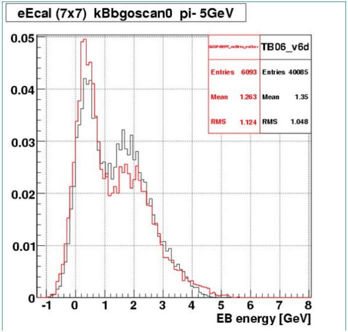


q^2 [GeV/c]^2		8.2	12.9	16.7
no cut		10^8	10^8	$2\cdot10^8$
PID cuts	Loose	425	$1.2\cdot10^3$	$3\cdot10^3$
	Tight	31	70	120
	Very Tight	2	5	6
kinematic fit(CL)		$8\cdot10^5$	10^6	$2.5\cdot10^6$

Previous GEANT4 validation studies



- Extensive validation by various experiments
- CMS reference: π^- test beam data
- Best results with QGSP_BERT_EMV

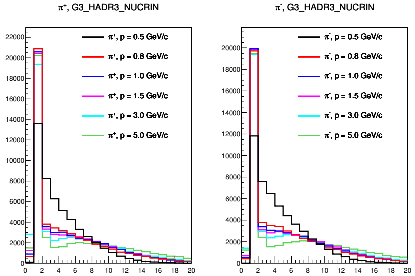


- Energy deposit in HCal vs. ECal
- Bertini cascade does good job reproducing high end tail
- Caveat: Minimum π^- test beam energy at 2 GeV

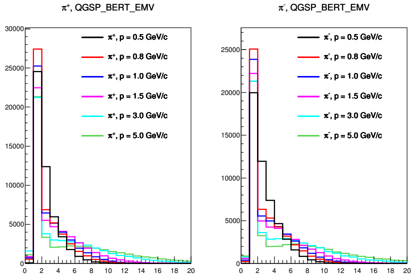
PandaROOT setup

- April 2013 release used (with non-uniformity of light collection turned off)
- Events
  - 50k π^+ and 50k π^- for each physics list
  - Uniform in $\phi \in (0, 360^\circ)$ and $\theta \in (85^\circ, 95^\circ)$
  - Acceptance cut to exclude $\phi \in$ (-100°,-90°) and $\phi \in$ (90°,100°)
  - Each setup at 5 different momenta (in GeV/c: 0.5, 0.8, 1.0, 1.5, 3.0 and 5.0)
  - All tracks start from $(v_x, v_y, v_z) = 0.0$
- Detector setup for transport stage
  - G4 data files were taken directly from G4 website
  - EMCal only setup used for most comparisons
  - For sanity check, full panda setup compared to EMCal only in a few setups
- Plotted quantity: E_{reco}/E_{true}
  - E_{true}: Energy of simulated pion track ($\sqrt{p^2 + m^2}$)
  - E_{reco}: Energy of closest cluster simulated pion direction in θ direction

Cluster multiplicity



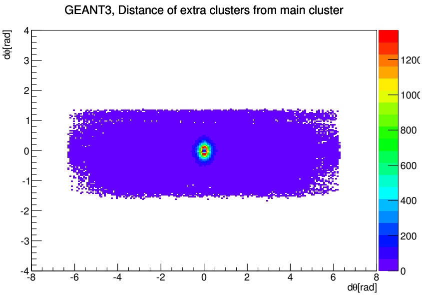
GEANT3, PandaROOT default (HADR=3)



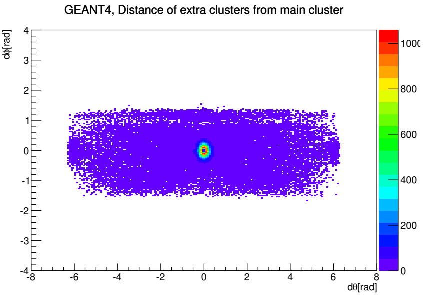
GEANT4, PandaROOT default (QGSP_BERT_EMV)

- Cluster multiplicity as a function of simulated pion momentum
- Narrower (especially at low energy) going from GEANT3 to GEANT4

Cluster multiplicity



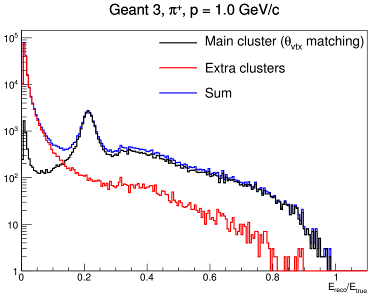
GEANT3, PandaROOT default (HADR=3)



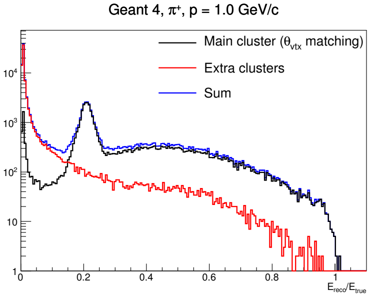
GEANT4, PandaROOT default (QGSP_BERT_EMV)

- Cluster multiplicity as a function of simulated pion momentum
- Narrower (especially at low energy) going from GEANT3 to GEANT4
- Spatial distribution centered at track θ_{vtx}, GEANT4 more tightly packed than GEANT3

Cluster multiplicity



GEANT3, PandaROOT default (HADR=3)

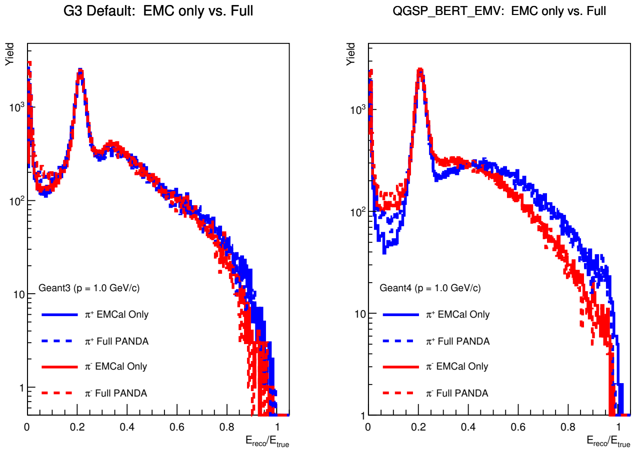


GEANT4, PandaROOT default (QGSP_BERT_EMV)

- Cluster multiplicity as a function of simulated pion momentum
- Narrower (especially at low energy) going from GEANT3 to GEANT4
- Spatial distribution centered at track θ_{vtx}, GEANT4 more tightly packed than GEANT3
- Simple association by proximity: cluster closest to track θ_{vtx} (realistic in real data)

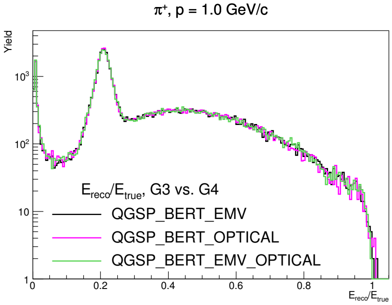
Check on some simulation options

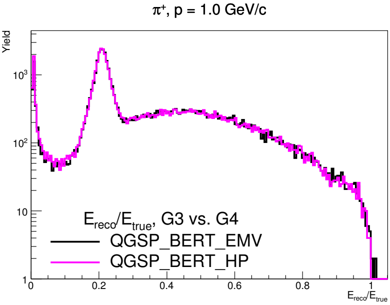
Full PANDA simulation vs. EMCal only



- Slight difference at low E_{reco}/E_{true} but the high end tail looks very similar
- Large gain in CPU usage with EMCal only simulation
- For purpose of comparison, will use EMCal only simulation consistently

Optical physics and high precision neutron transport



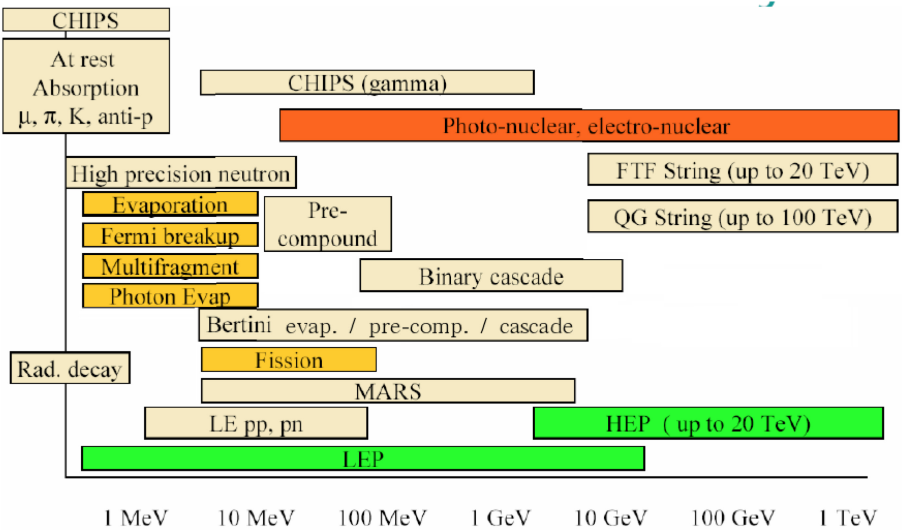


- EMV: performance tuned EM cutoff parameters
- HP: High precision cross section data for low energy neutron transport and capture
- OPTICAL: Switch for usage of full optical physics
- None of these options affect hadronic response

GEANT3 vs. GEANT4

GEANT4 Hadronic Physics Lists

- Options depending on inelastic hadronic interaction and cascade, nuclear de-excitation, fission, evaporation models with varying validity ranges



GEANT4 Hadronic Physics Lists

- Options depending on inelastic hadronic interaction and cascade, nuclear de-excitation, fission, evaporation models with varying validity ranges

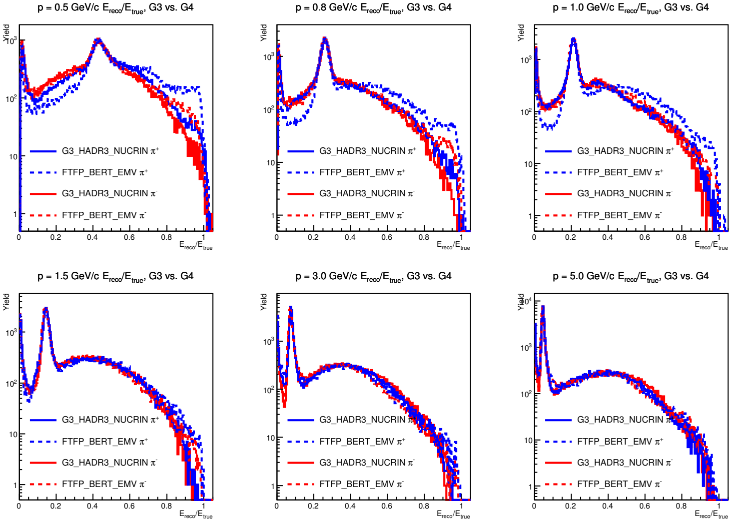
- Parametrized models based on GHEISHA (LEP, HEP)
- Theory driven models
  - High energy: Quark Gluon String (QGS>10 GeV) and Fritiof (FTF>10 GeV)
  - Low energy: Bertini (BERT<10 GeV), Binary (BIC<5 GeV), Liege (INCL<3 GeV)
- Various combination of the above with an excitation handler (fission, evaporation)
  - **QGSP_BERT** and **FTFP_BERT** (Bertini for LE interaction)
    → P="Precompound model": HE parametrization for nuclear de-excitation
  - **QGSP_BIC** (Binary cascade for LE interaction)
    → P same as above, no FTFP_BIC list available
  - **QGS_BIC** and **FTF_BIC**
    → (Binary cascade used for nuclear de-excitation for the high energy model)
  - **QGSP_INCLXX**:
    → Liege model used below 3 GeV
- Soon to be removed options (in GEANT4.10)
  - **LHEP**: both high and low energy interactions use parametrized models
  - Chiral Invariant Phase Space (CHIPS) model for all nuclear de-excitations **QGSC_BERT**, **QGSC**

Validity ranges for a π^+ projectile

	Low Energy			High Energy		
Phys. List	h-N	de-ex.	R($\pi^\pm$)	h-N	de-ex.	R($\pi^\pm$)
QGSP_BERT	Bert. LEP	Bert. LEP	0 - 9.9 9.5 - 25	QGS	Prec.	12 - ∞
QGSP_BIC	LEP	LEP	0 - 9.9	QGS	Prec.	12 - ∞
QGS_BIC	Bin. LEP	Bin. LEP	0 - 1.3 1.2 - 25	QGS	Bin.	12 - ∞
FTFP_BERT	Bert.	Bert.	0 - 5	FTF	Prec.	4 - ∞
FTFP_BERT_TRV	Bert.	Bert.	0 - 12	FTF	Prec.	3 - ∞
FTF_BIC	Bin.	Bin.	0 - 5	FTF	Bin.	4 - ∞
LHEP	LEP	LEP	0 - 5	HEP	HEP	4 - ∞
QGSP_INCLXX	INCL++ Bert.	INCL++ Bert.	0 - 3 2.9 - 9.9	HEP QGS	HEP Perc.	9.5 - 25 12 - ∞

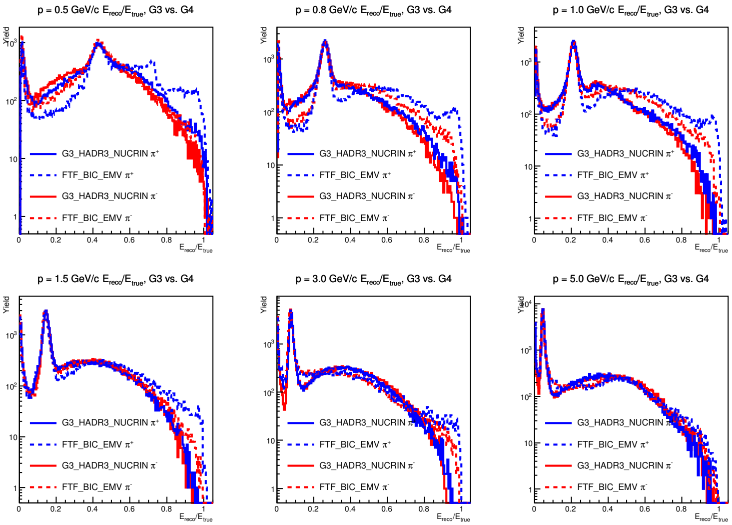
h-N: Hadron-Nucleus interaction
de-ex: Nuclear de-excitation
R: Range

G3 vs. G4 (FTFP_BERT_EMV)



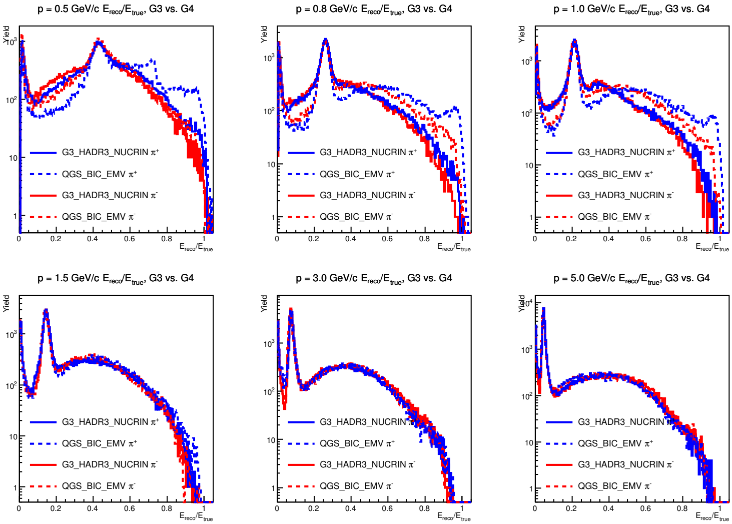
FTFP_BERT	Bert.	Bert.	0 - 5	FTF	Prec.	4 - ∞

G3 vs. G4 (FTF_BIC_EMV)



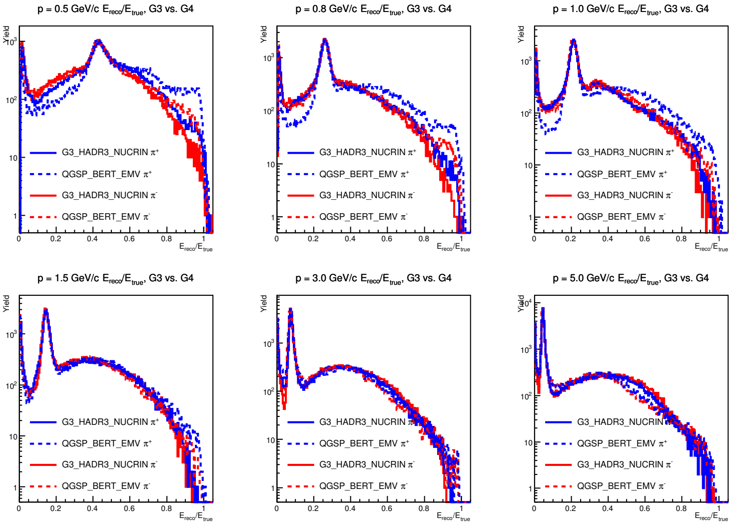
FTF_BIC	Bin.	Bin.	0 - 5	FTF	Bin.	4 - ∞

G3 vs. G4 (QGS_BIC_EMV)



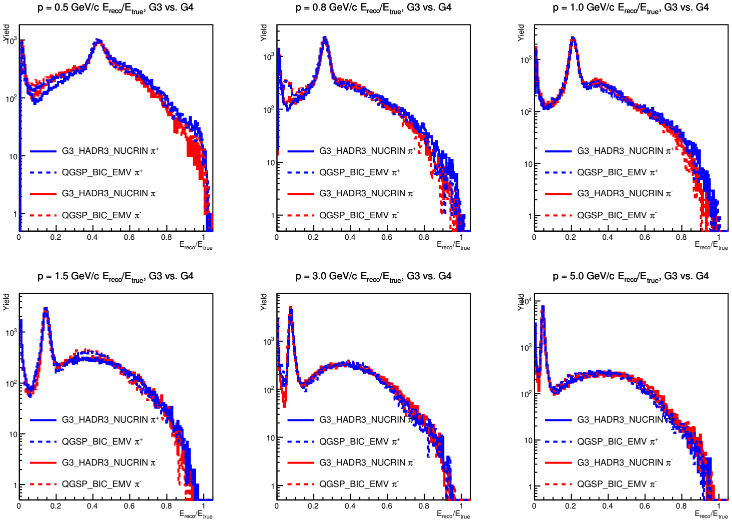
QGS_BIC	Bin. LEP	Bin. LEP	0 - 1.3 1.2 - 25	QGS	Bin.	12 - ∞

G3 vs. G4 (QGSP_BERT_EMV)



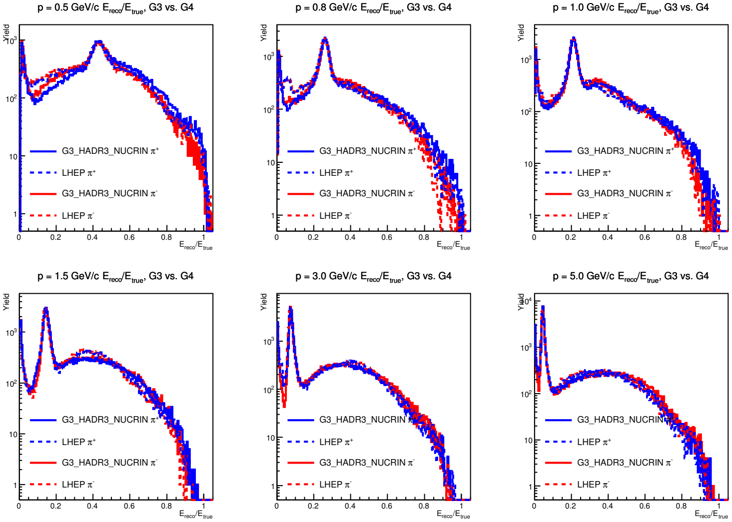
QGSP_BERT	Bert. LEP	Bert. LEP	0 - 9.9 9.5 - 25	QGS	Prec.	12 - ∞

G3 vs. G4 (QGSP_BIC_EMV)



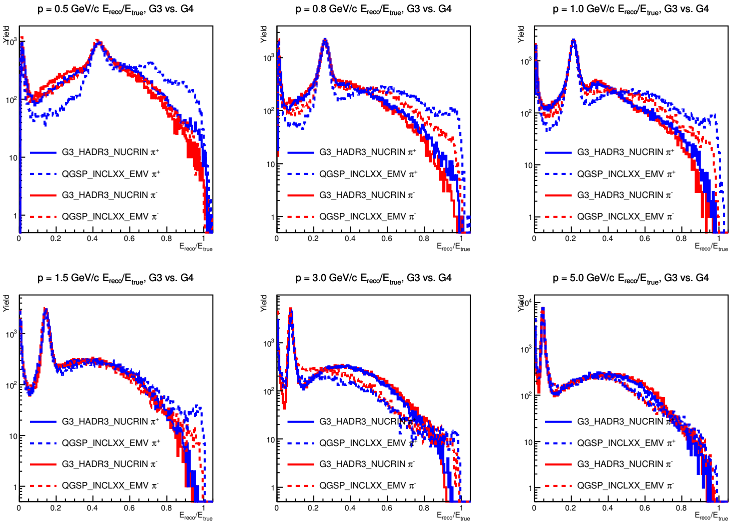
QGSP_BIC	LEP	LEP	0 - 9.9	QGS	Prec.	12 - ∞

G3 vs. G4 (LHEP)



LHEP	LEP	LEP	0 - 5	HEP	HEP	4 - ∞

G3 vs. G4 (QGSP_INCLXX_EMV)



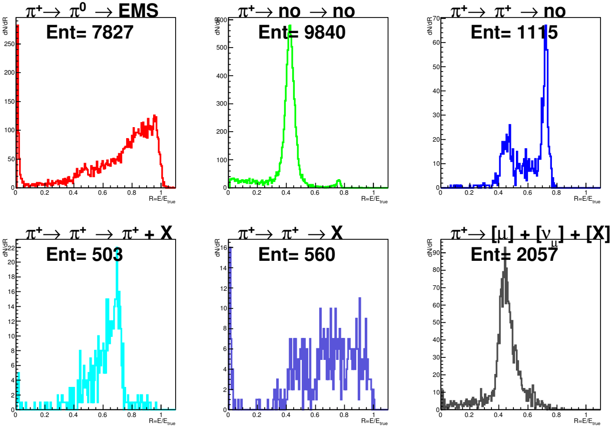
QGSP_INCLXX	INCL++ Bert.	INCL++ Bert.	0 - 3 2.9 - 9.9	HEP QGS	HEP Perc.	9.5 - 25 12 - ∞

Summary

- Main change from G3 to G4 lists is the difference between π^+ and π^- response
  - Probably due to stronger charge exchange reaction component in G4
  - Up to factor x10 difference in some cases on the high end tail
  - Models using LEP at low energy look closest to G3 (LHEP, QGP_BIC)
  - Models using BIC and Bertini have larger difference between π^+ and π^-
  - At 0.5 GeV BIC has pronounced peak at E_{rec}/E_{true} ≈0.7 (less with Bertini)
- Significant difference in the high end tail component
  - Can have implication to PID (needs quantitative analysis)
  - In lack of other means to validate hadronic models, a conservative approach would be picking a model with largest tail (G4, BIC/BERT/INCL)

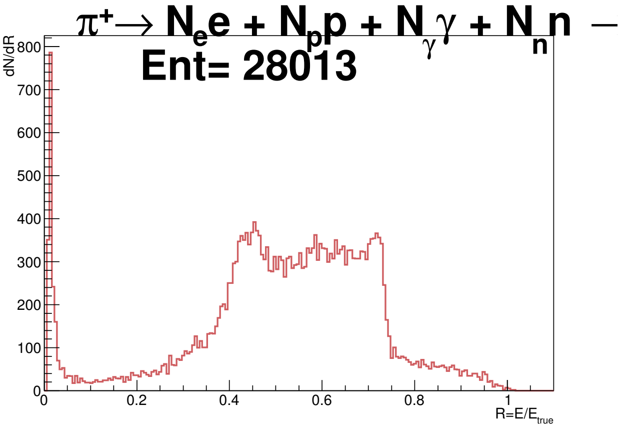
Backup

Composition of QGS_BIC_EMV π^+ 1 GeV



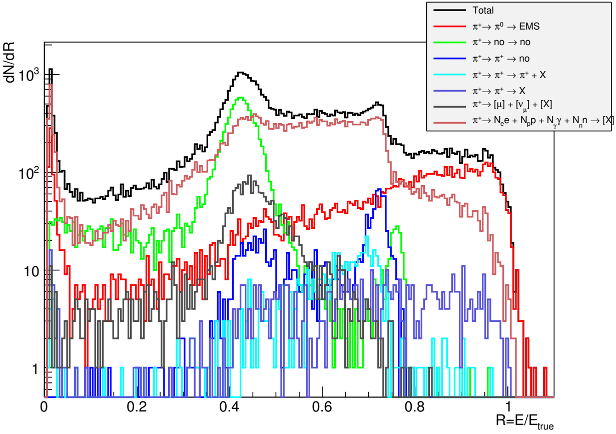
Easily identifiable events: (containing a π^0 and EM shower or π^+ or μ and ν_μ in the final state). Events with π^0 are indicators of a charge exchange. Events with a π^+ indicate punch-through π. Events with a μ or ν_μ probably are from stopped π^+ that decays.

Remaining component



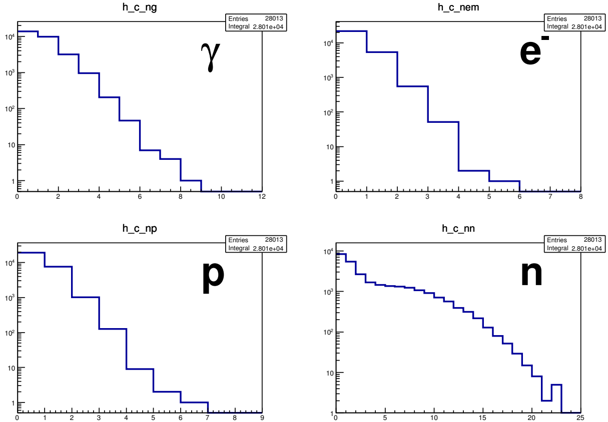
Everything else (some number of e,p,n and γ in the final state)

Composition of (QGS_BIC_EMV π^+ 1 GeV)



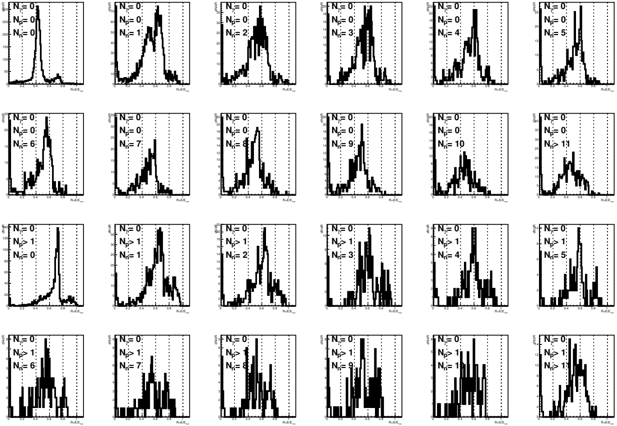
Overlay

e,p,n,γ counts in "remaining"

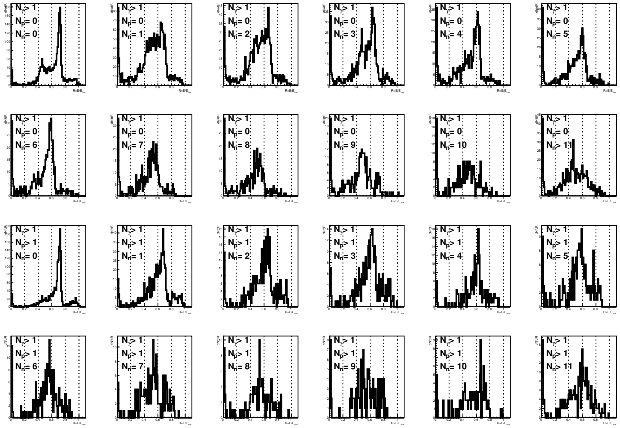


Multiplicity distribution of e,p,n and γ in events that don't contain π^0, π^+, μ or ν_{mu} in the final state

Remaining yield vs. N_γ, N_p and N_n



Remaining yield vs. N_γ, N_p and N_n



Hadronic response decomposition