Precompound models compared with 90 MeV pA data

Mikhail Kosov, 12th Geant4 Workshop (GB, Sep. 2007)

Dataset and models (general)

- Data: A.M.Kalend et al., Phys.Rev.C28(1983)105.
  - Targets: Al, Bi (other targets: Ni, Zr, Pb, Th).
  - Spectra of neutrons, protons, d, t, He^3, and α .
  - θ: 20^o,30^o,45^o,60^o,75^o, 90^o,105^o,120^o ,140^o .
- The data are compared with Preco, Bertini, Binary, LEProt (LHEP), CHIPS, QLowEn
  - Preco satisfactory describes p&n, but not d,t,He^3,α
  - On Al Binary is close to Preco, on Bi loses θ-dep.
  - Bertini is good for p&n (no fragments), good for Bi.
  - LHEP is angular independent, does not have He^3.
  - CHIPS & QLowEn are satisfactory in all the scope.

Time performance of models (10^{-3} s/ev)

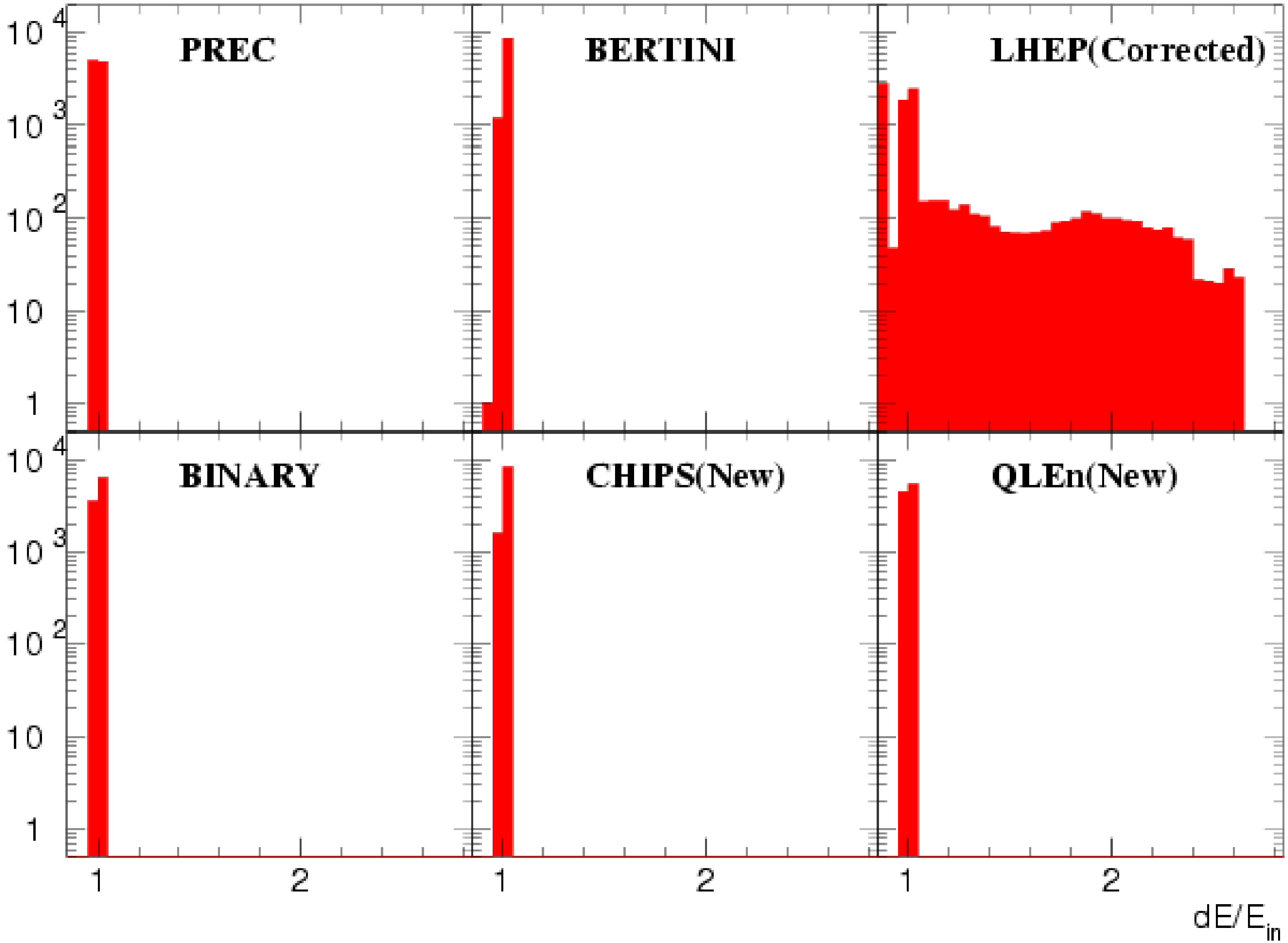
- Measurements are made on Pentium IV 2.4 GHz CPU with the overhead of the "test19" test program. Quantum numbers, Energy, and Momentum conservation check is ON only for CHIPS processes G4QCollision (CHIPS) & G4QLowEnergy (QLowEn)
- Initialization of Bertini, Binary, PreCompound and LHEP is made as in the corresponding Physics Lists (Geant4 kernel).

Model	Al	Bi
PreCom	3.65	5.57
Binary	5.36	13.6
Bertini	2.09	2.57
CHIPS	12.7	15.5
LHEP	0.37	0.44
QLowEn	0.46	0.55

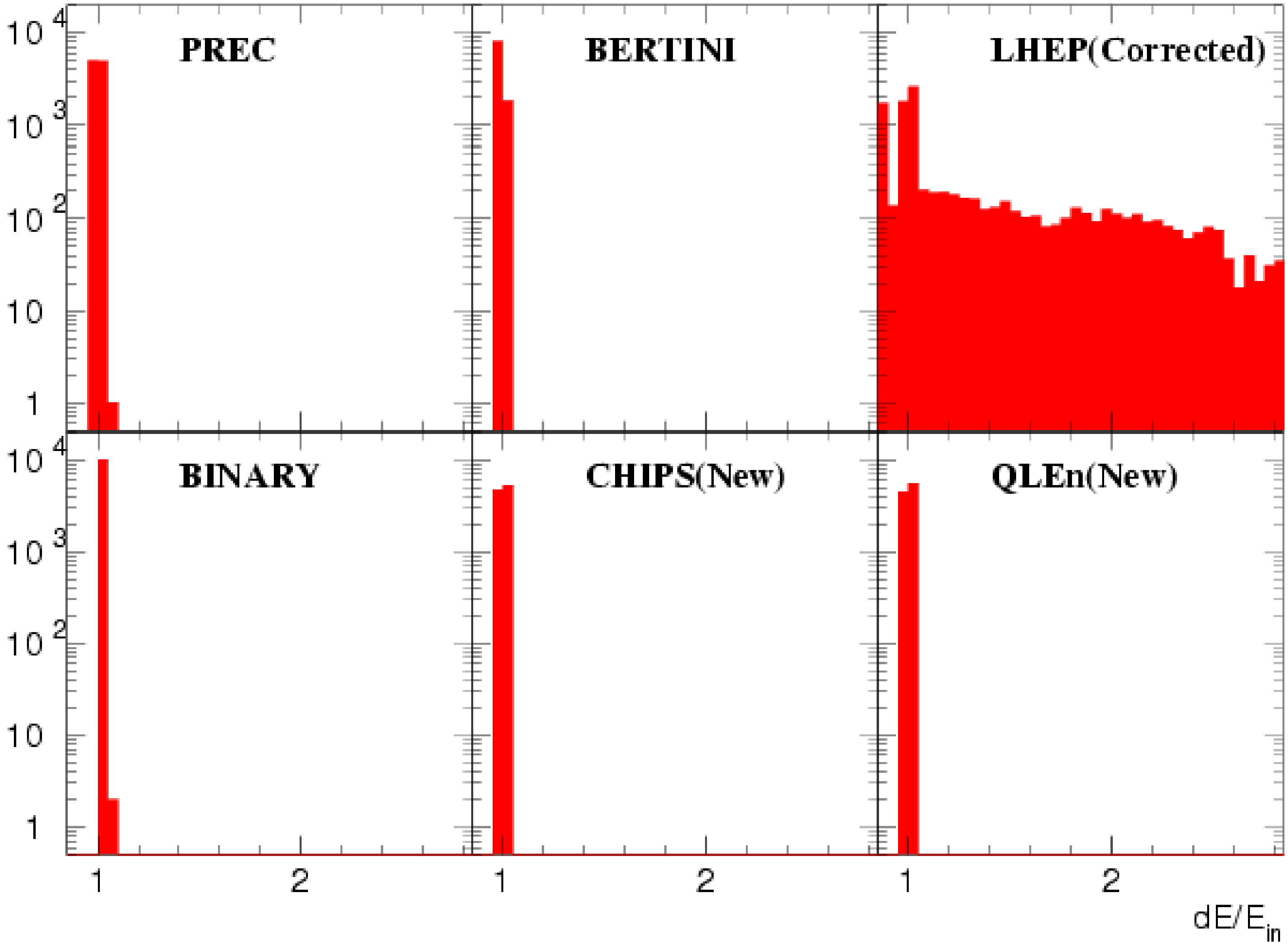
Quantum numbers & E/M conservation

- The LHEP model was corrected in the test:
  - Momentum, Charge, Baryon Number are lost
  - Test creates a missing residual to correct them
  - Energy is still not conserved. To what extend?
- After LHEP correction all models conserve charge and baryon number in all events.
- Corrected LHEP conserves 3-momentum with the δ-function accuracy by definition.
- The energy of the added fragment is small.

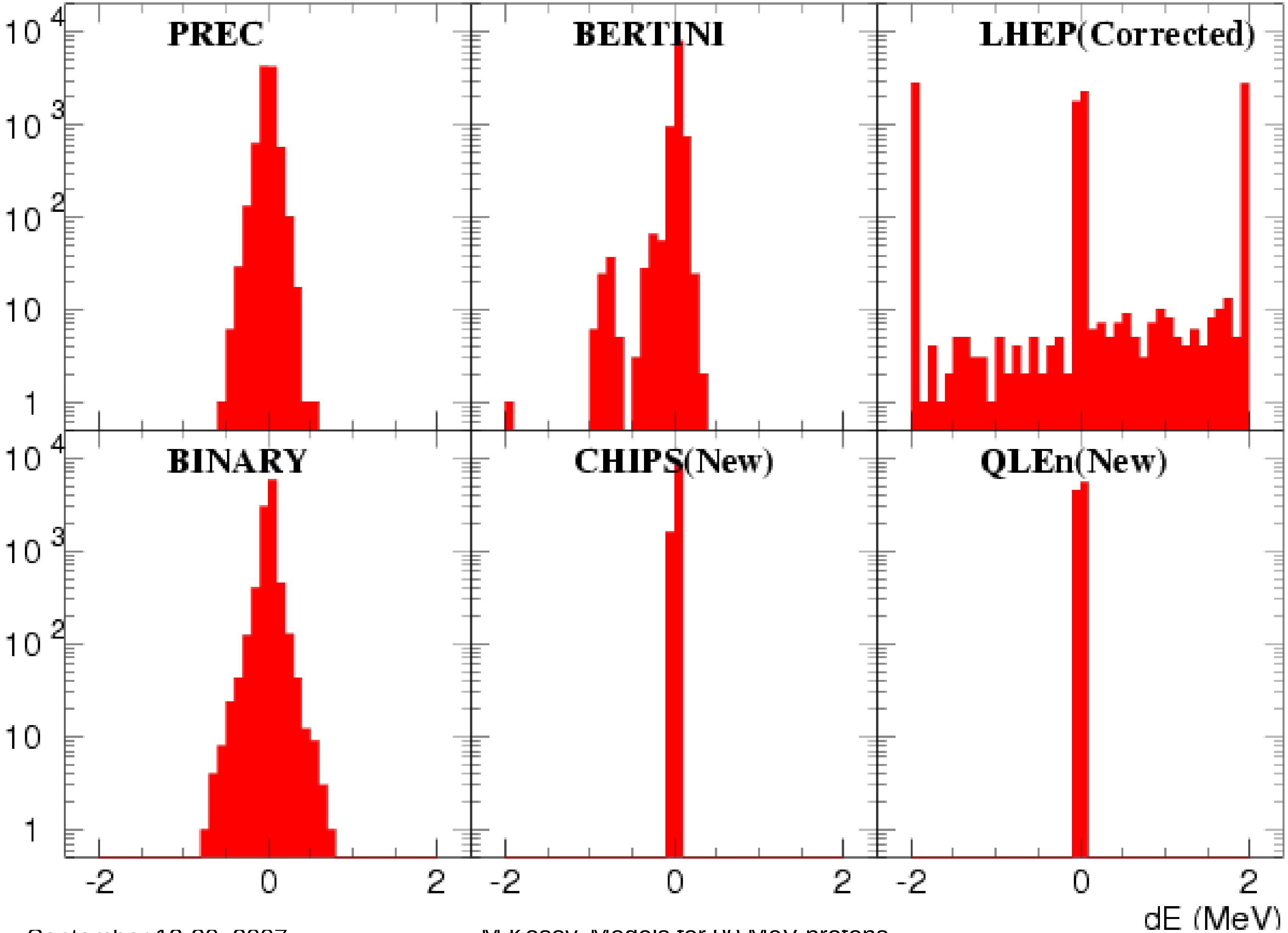
Relative energy conservation in different Geant4 models (pAl,90 MeV)



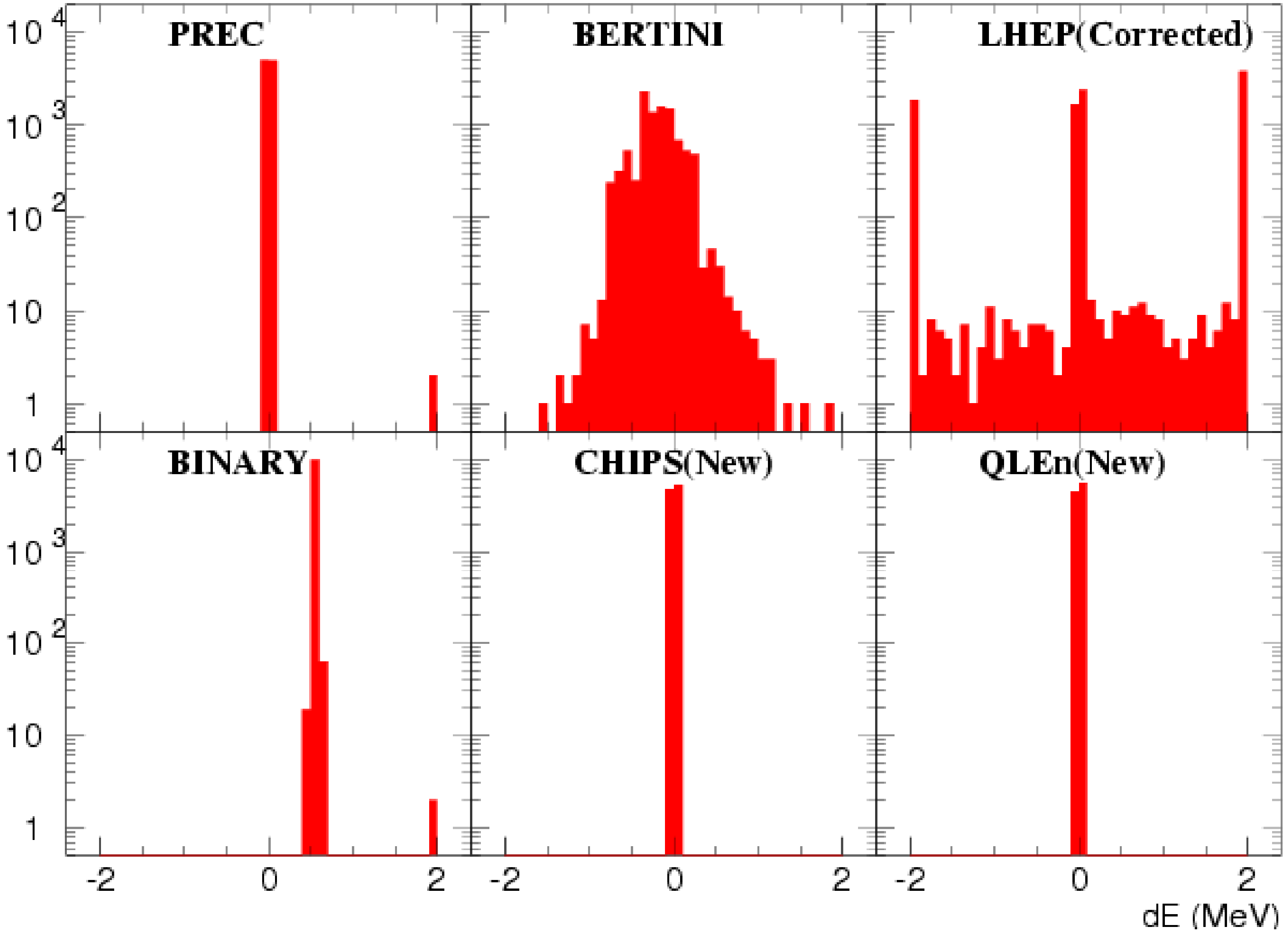
Relative energy conservation in different Geant4 models (pBi,90 MeV)

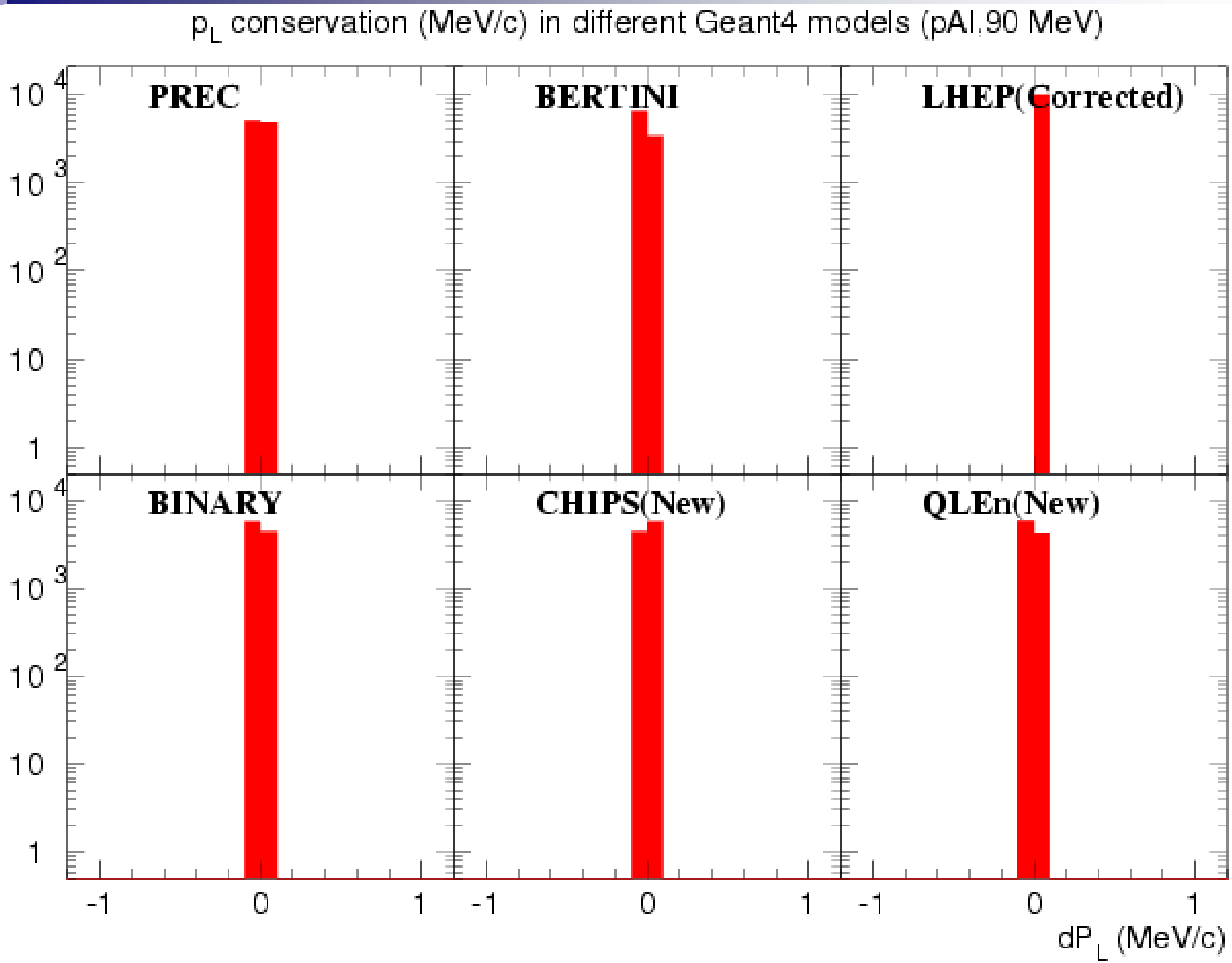


Energy conservation (MeV) in different Geant4 models (pAl,90 MeV)

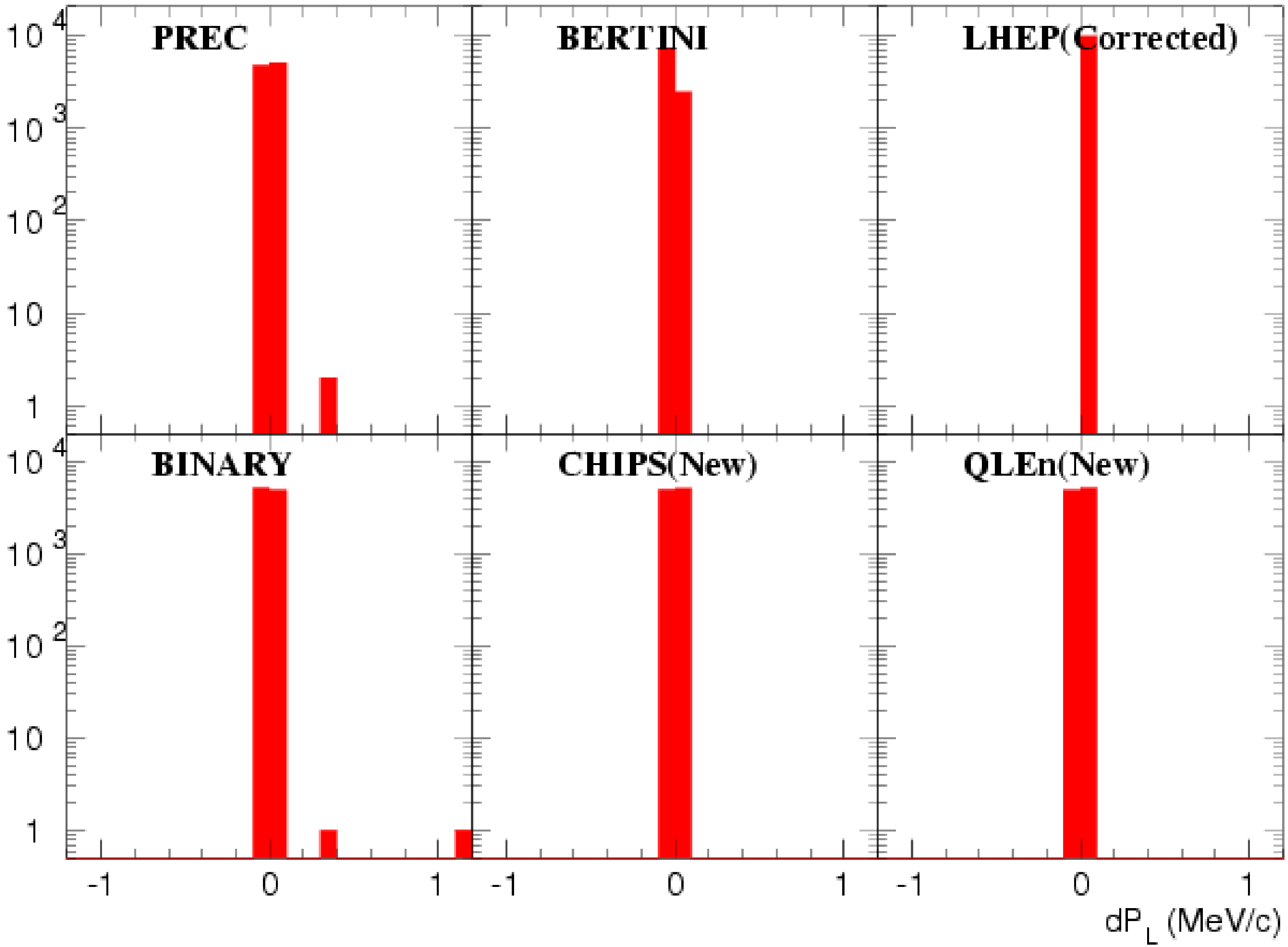


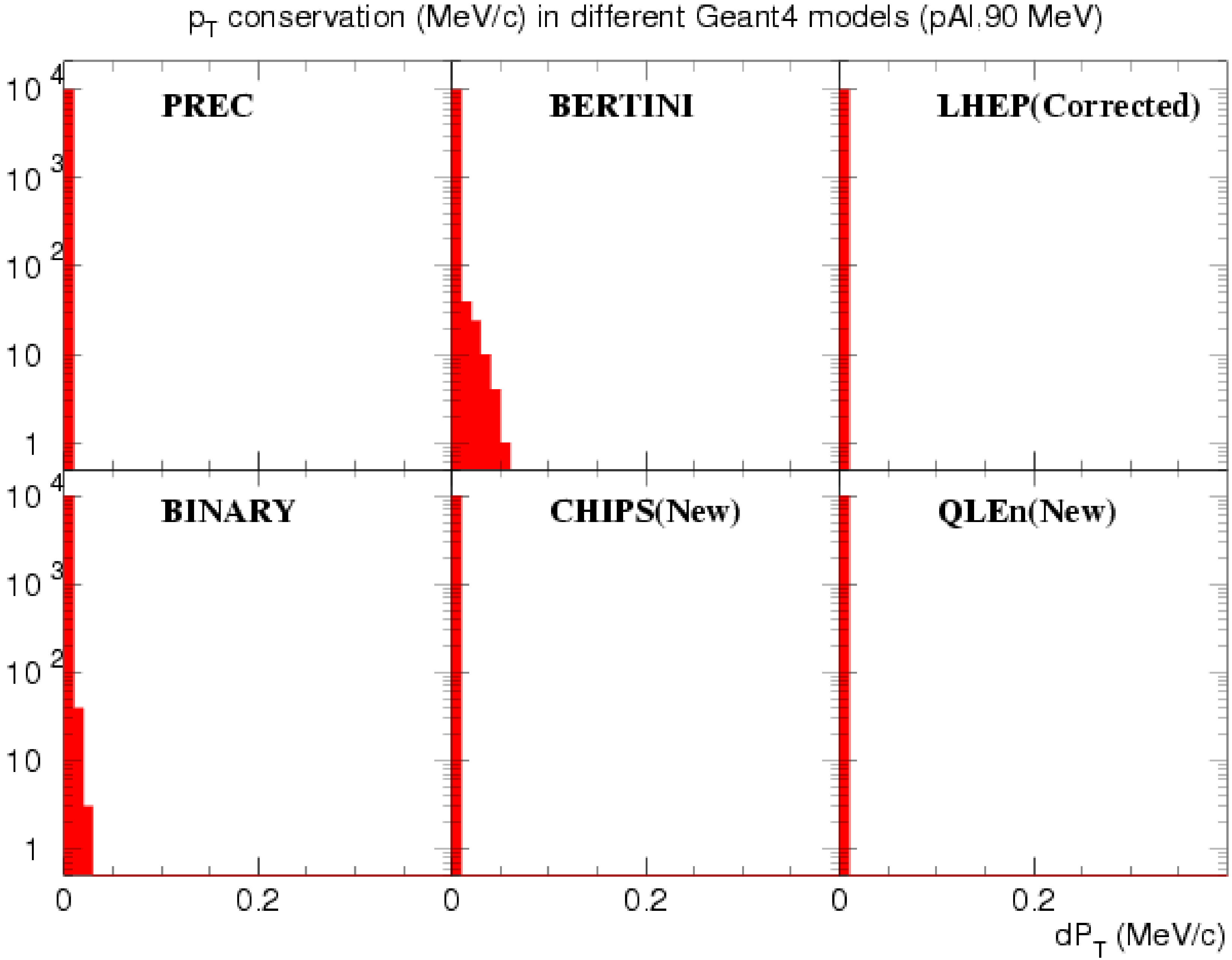
Energy conservation (MeV) in different Geant4 models (pBi,90 MeV)




p_L conservation (MeV/c) in different Geant4 models (pAl,90 MeV)
PREC
BERTINI
LHEP(Corrected)
BINARY
CHIPS(New)
QLEn(New)
10^4
10^3
10^2
10
1
-1
0
1
dP_L (MeV/c)

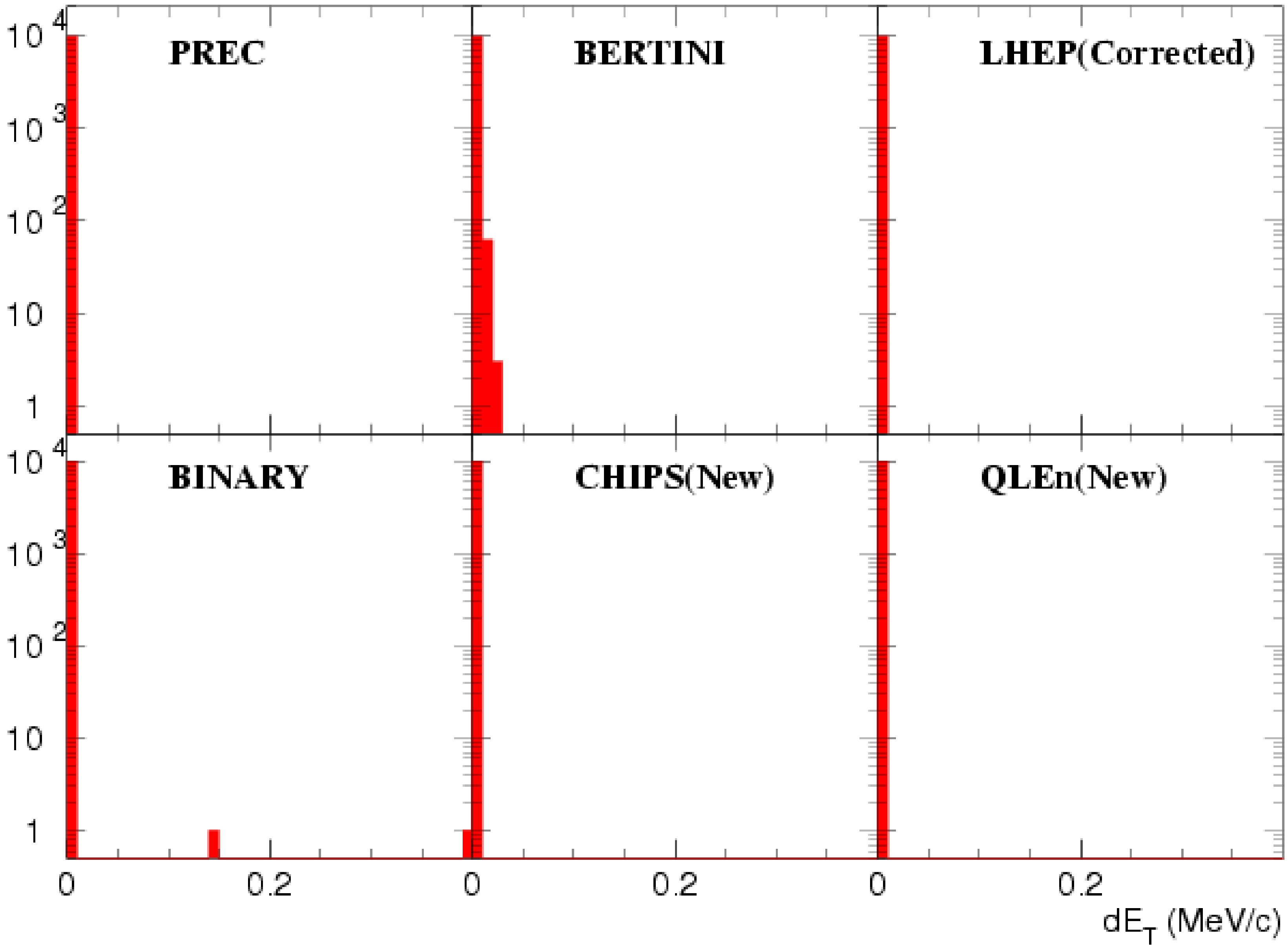
p_L conservation (MeV/c) in different Geant4 models (pBi,90 MeV)



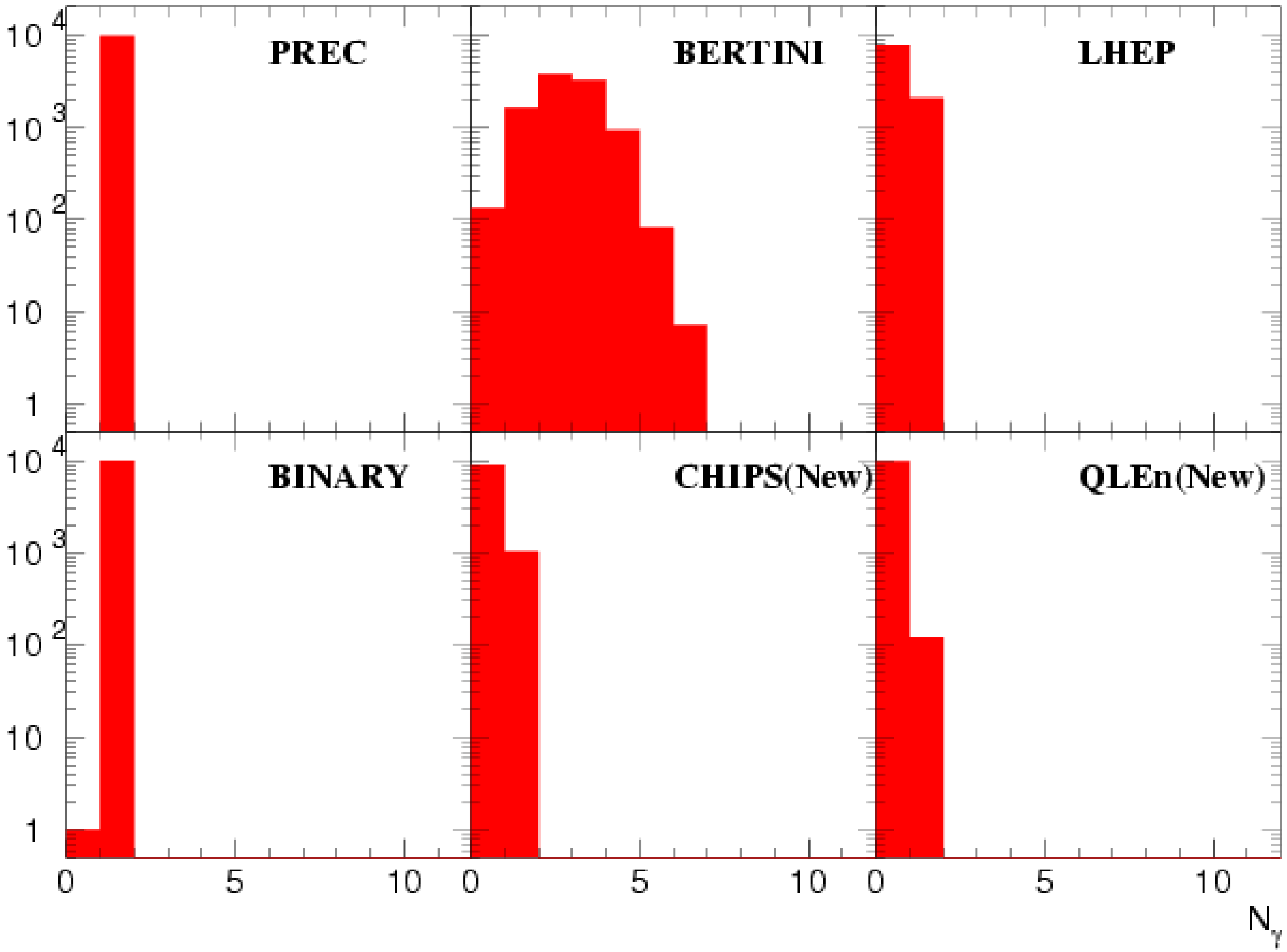


p_T conservation (MeV/c) in different Geant4 models (pAl,90 MeV)
PREC
BERTINI
LHEP(Corrected)
BINARY
CHIPS(New)
QLEn(New)
10^4
10^3
10^2
10
1
0
0.2
dP_T (MeV/c)

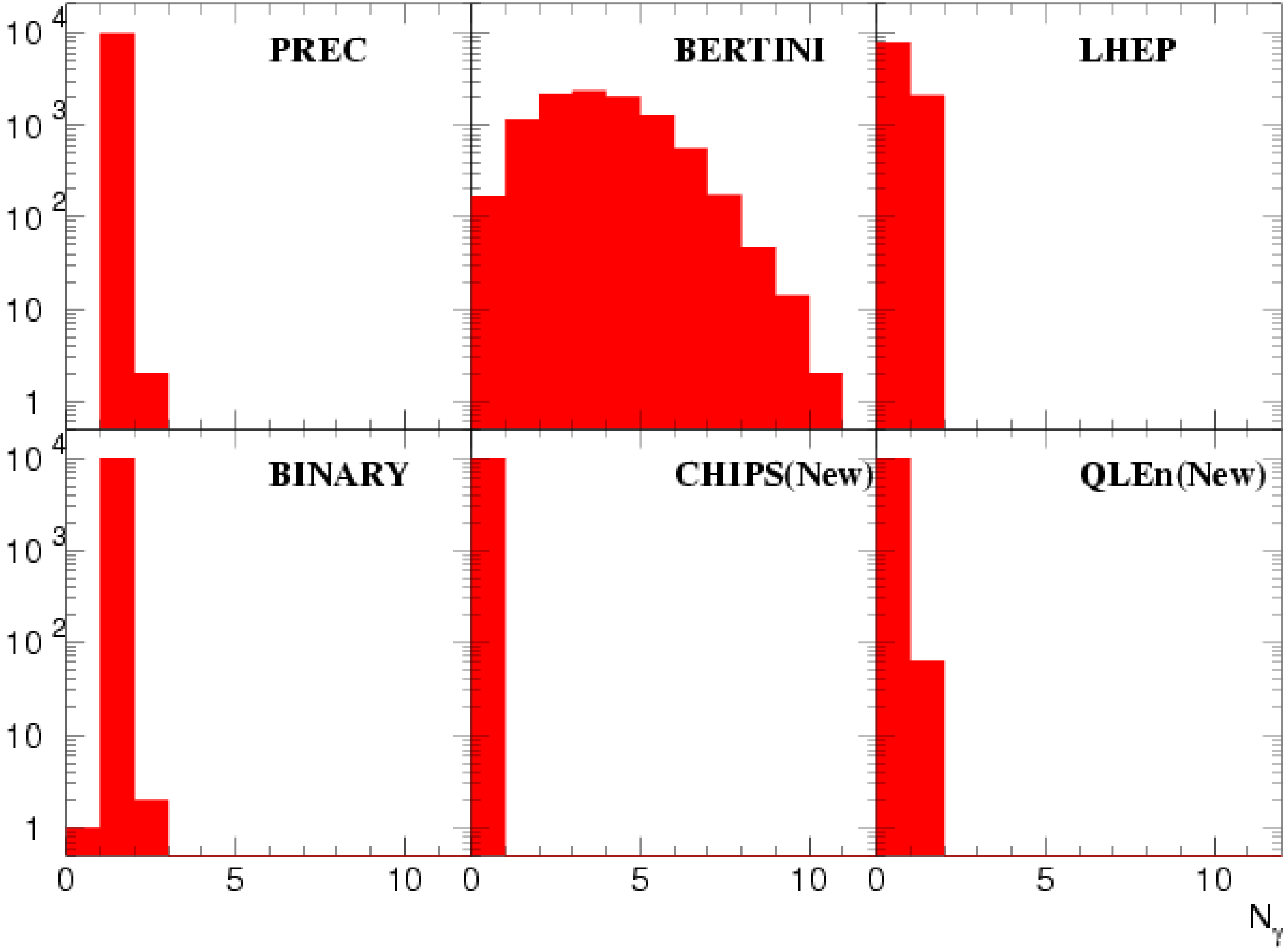
p_T conservation (MeV/c) in different Geant4 models (pBi,90 MeV)



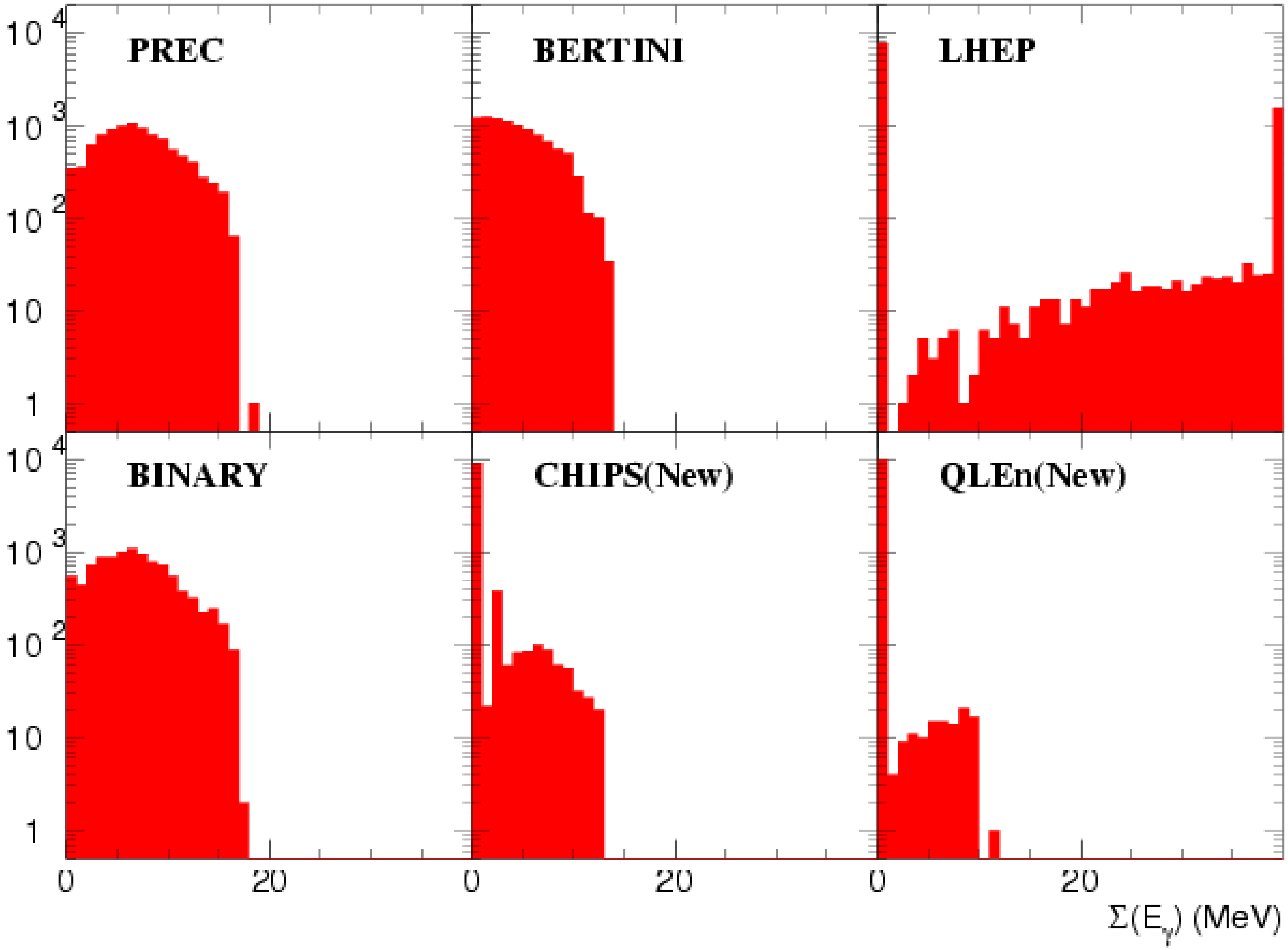
Multiplicity of photons in different Geant4 models (pAl 90 MeV)



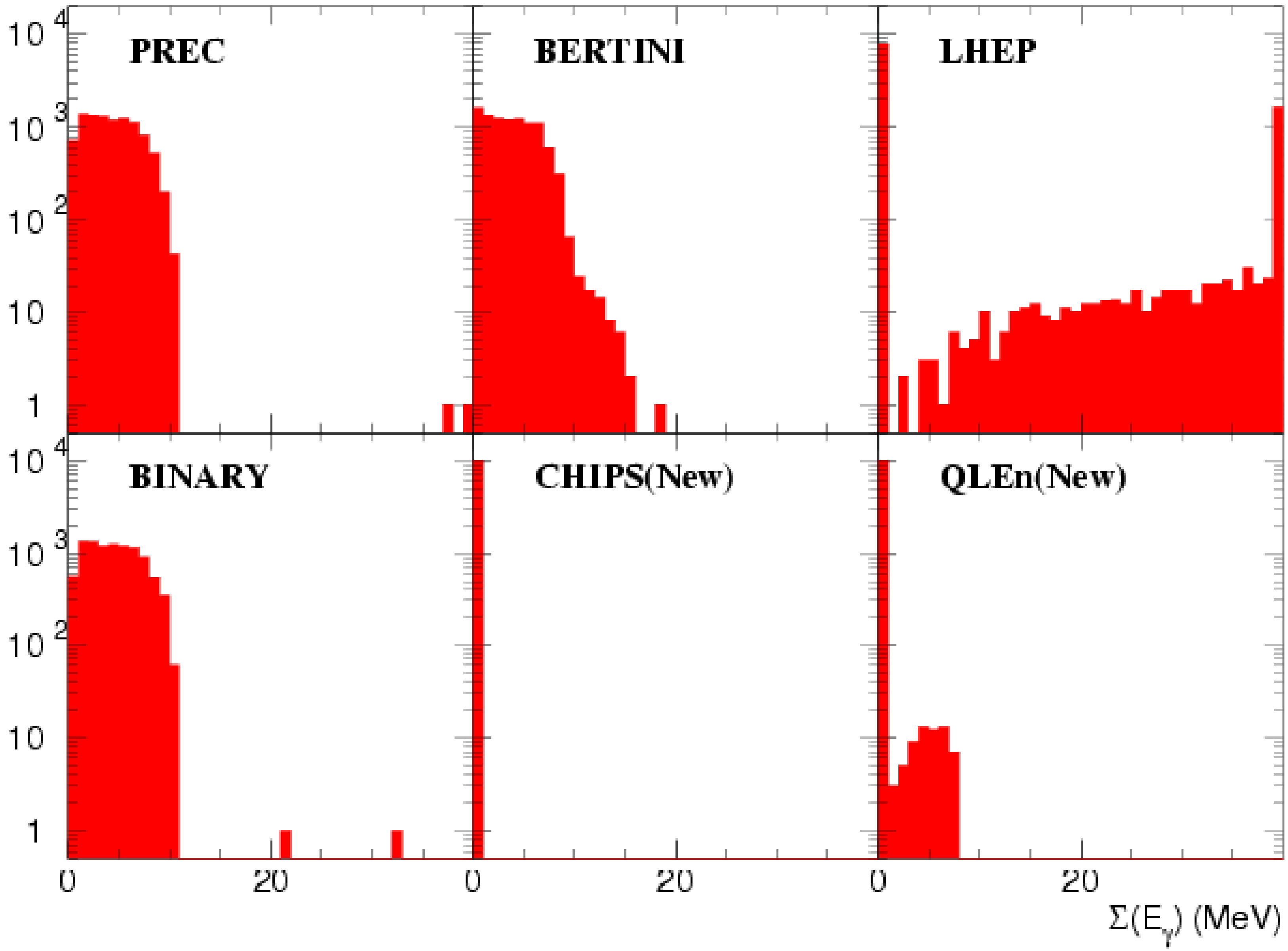
Multiplicity of photons in different Geant4 models (pBi,90 MeV)



Total energy of photons in different Geant4 models (pAl,90 MeV)



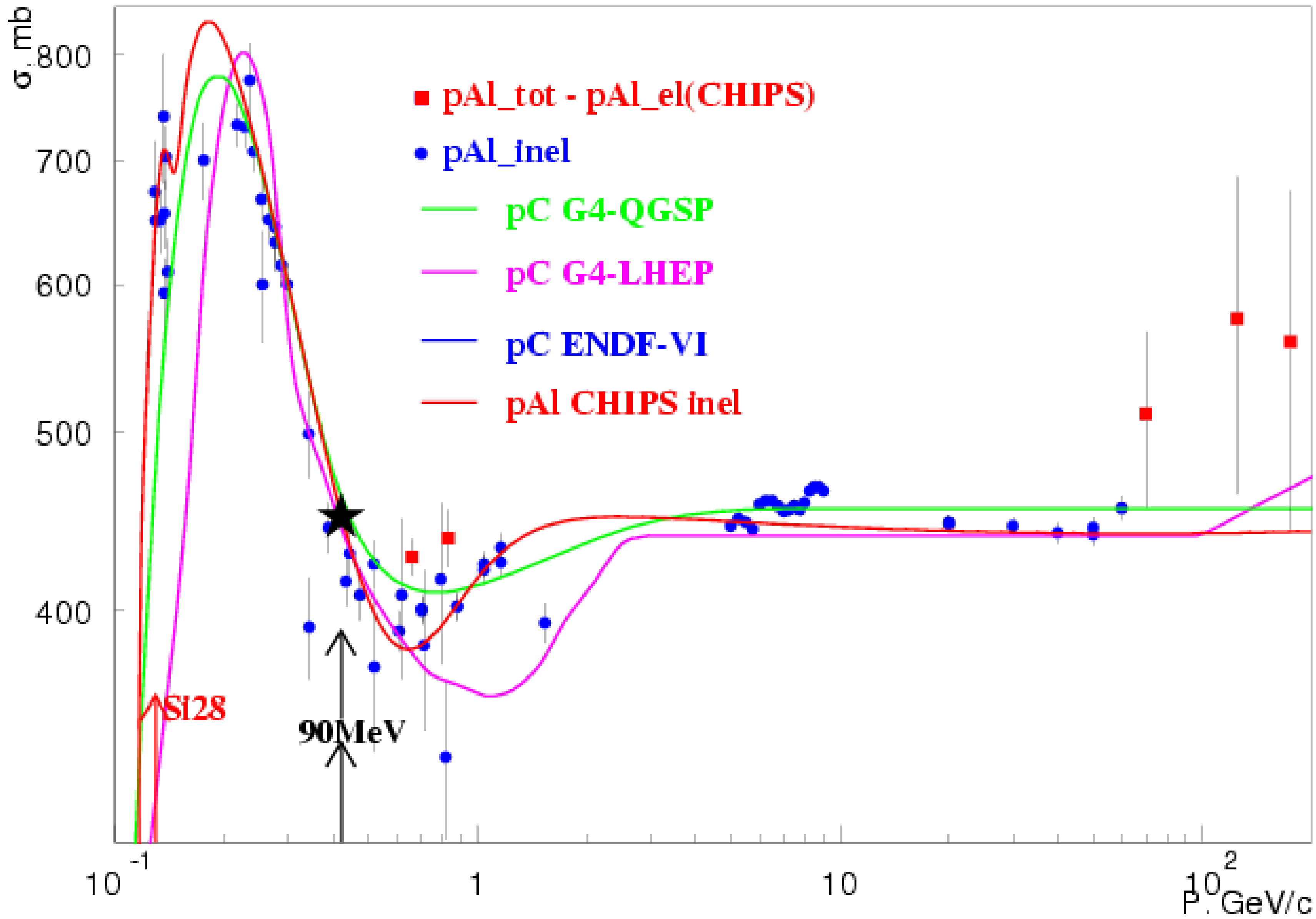
Total energy of photons in different Geant4 models (pBi.90 MeV)

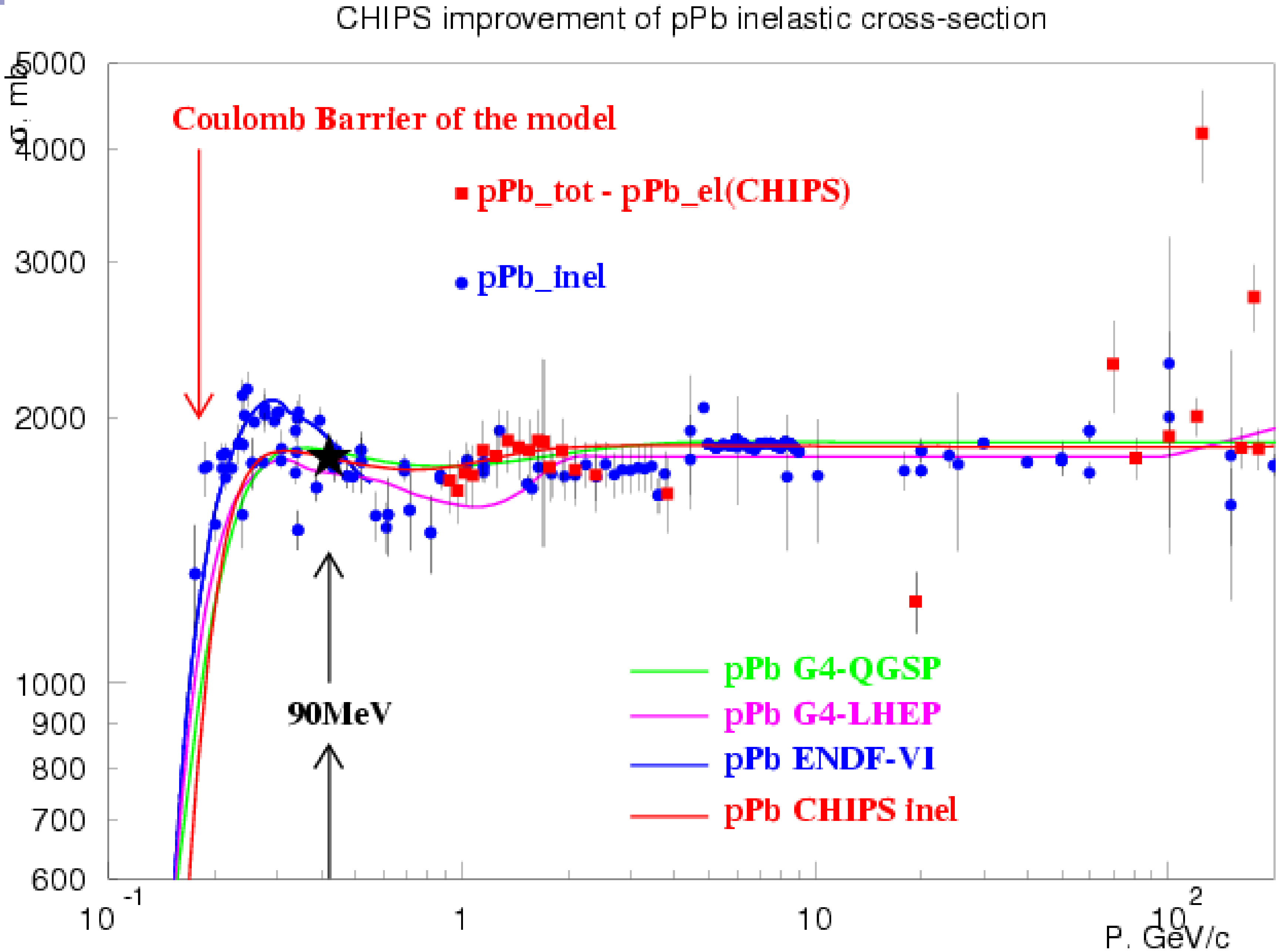


Intermediate conclusions

- LHEP is not just wrong, it is misleading
  - It easy triples the projectile energy: spoils resolution;
  - It provides high energy photons: spoils damage sim;
  - It does not produce residual nuclei: spoils activation.
- Other old models have obvious weak points:
  - E/M conservation can be better (BINARY per milbugs);
  - BINARY spoils PreCompaund: shifts ΔE on Bi (!);
  - Spend too much energy producing photons.
- New CHIPS models are perfect in Energy/Mom conservation and the energy spent to the photons is small (it is saved for the fragment production)

CHIPS improvement of pAl inelastic cross-section

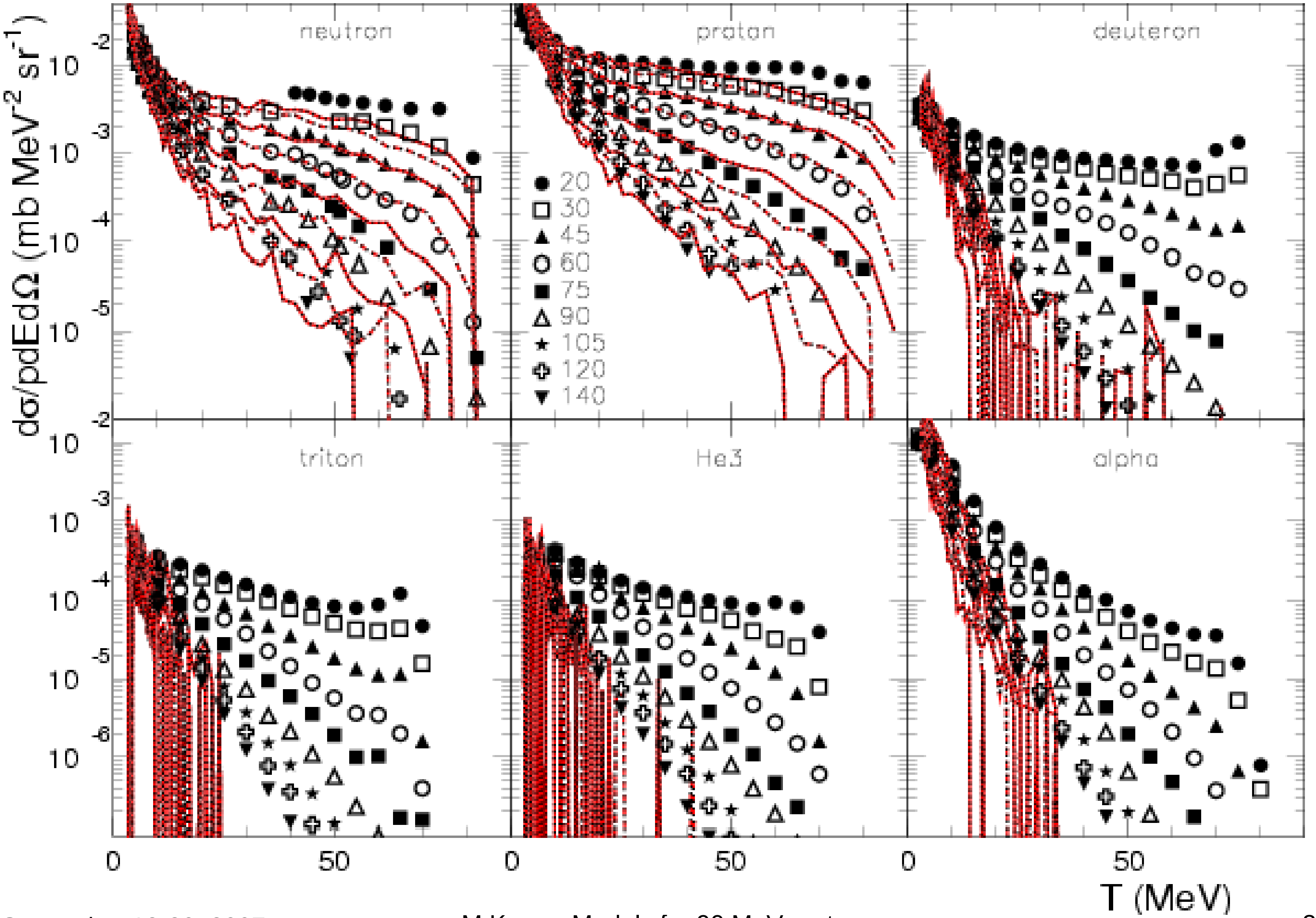



CHIPS improvement of pPb inelastic cross-section
σ, mb
5000
4000
3000
2000
1000
900
800
700
600
Coulomb Barrier of the model
pPb_tot - pPb_el(CHIPS)
pPb_inel
90MeV
pPb G4-QGSP
pPb G4-LHEP
pPb ENDF-VI
pPb CHIPS inel
10 -1
1
10
10 2
P, GeV/c

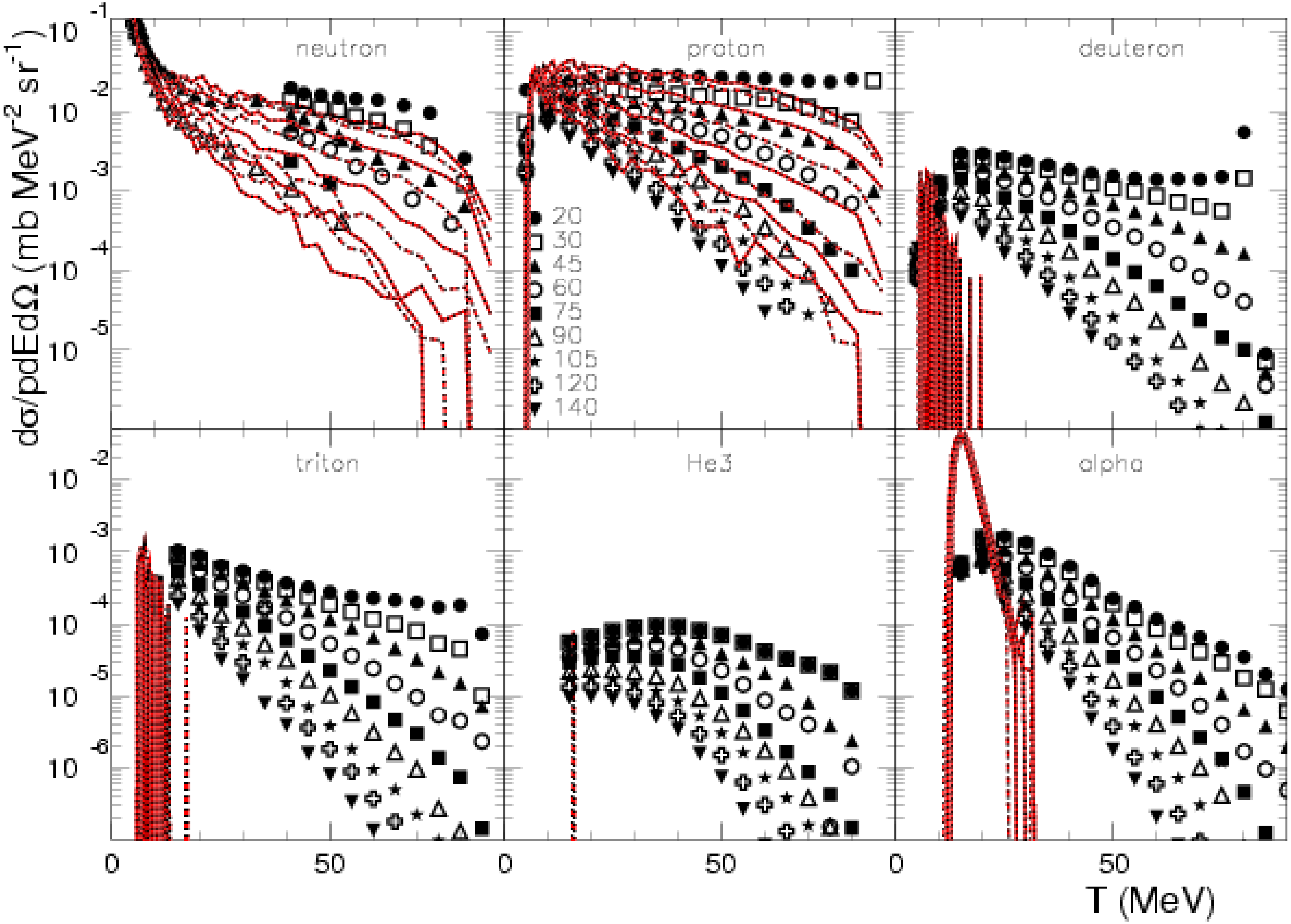
Comments about Precompound models

- The classic pre-compound model (in Bertini)
  - Evolution of excitons (production/recombination).
  - Radiation probability is integrated over all excitons.
  - Isotropic by definition. No fragments. Long time.
- Improvement of the classic model (G4PreCo)
  - Personalization of excitons, angular dependence.
  - Excitons are not reflected from the boundary (fast).
  - Fragments are implemented while they are bosons
  - Tuned for the only nucleon as a projectile.
  - Breaks Lorentz Invariance (can not be at rest).

$^{27}Al(p,f)X$, E = 90MeV, θ = 20,30,45,60,75,90,105,120,140^0 (PREC)



$^{209}Bi(p,f)X$, E = 90MeV, θ = 20,30,45,60,75,90,105,120,140^0 (PREC)



Comments about G4 Binary Cascade.

- Comparison with a pure PreCompoundModel
  - Binary uses PreComp as a back-end decay model.
  - AL with a big separation energy: only PreComp.
  - Bi with a small separation energy: no PreComp.
  - Hence provides smaller angular dependence on Bi.
  - Produce more forward neutrons (?). Much slower.
- Interfacing to the G4PreCompoundModel
  - Breeds nucleons & trys to separate them from Nucl.
  - On Al the separation energy is big: back collection
  - On Bi the separation energy is small: skip collection

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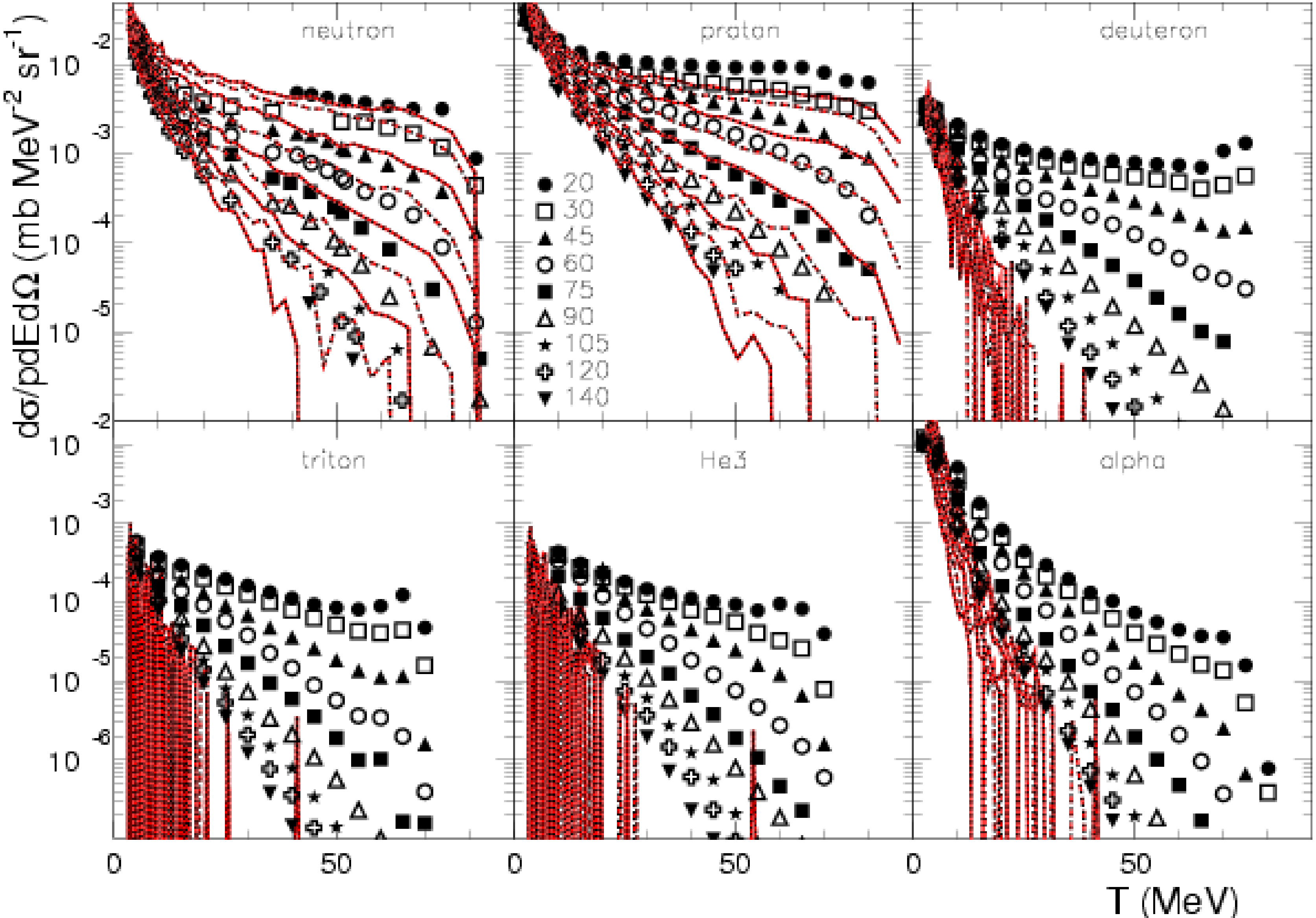
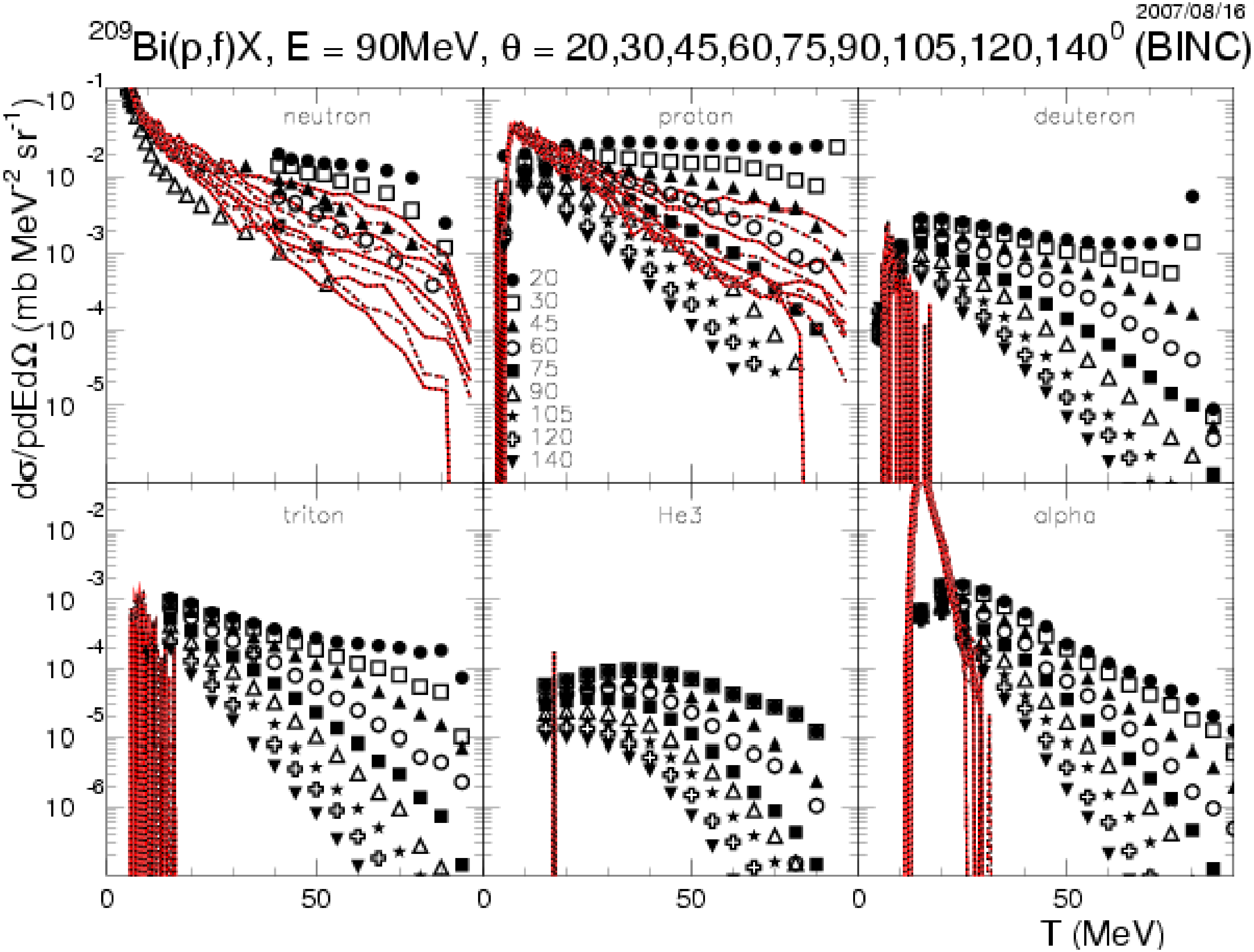
$^{27}Al(p,f)X$, E = 90MeV, θ = 20,30,45,60,75,90,105,120,140^0 (BINC)



^{209}Bi(p,f)X, E = 90MeV, θ = 20,30,45,60,75,90,105,120,140^0 (BINC)



Comments about G4 Bertini Cascade

- The G4 Bertini Cascade (among others) has:
  - A Cascade Part drops at low momentum (CB?)
  - A classic Pre-Compound Part (CB, 10% of Evapor)
  - An Evaporation Part (no Coulomb Barrier = CB !)
  - Why not in Evaporation if it is in PreComp? Energy
  - Isotropic evaporation of fragments (d,t,He^3,α only).
- Necessary improvements in Bertini
  - CB should be implemented and the model retuned
  - Coalescence should provide high energy fragments
  - Energy conservation should be improved; SU(3).

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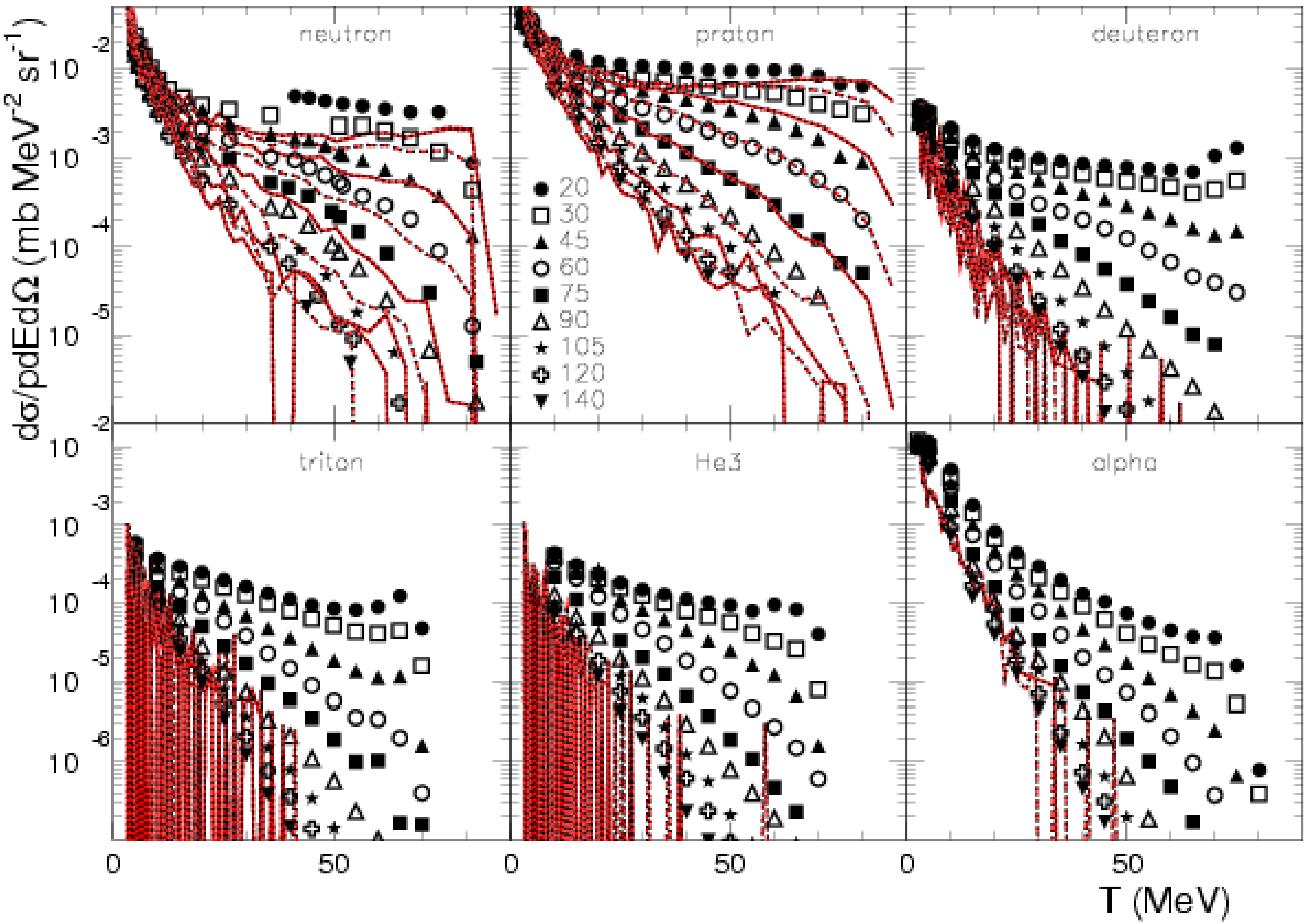
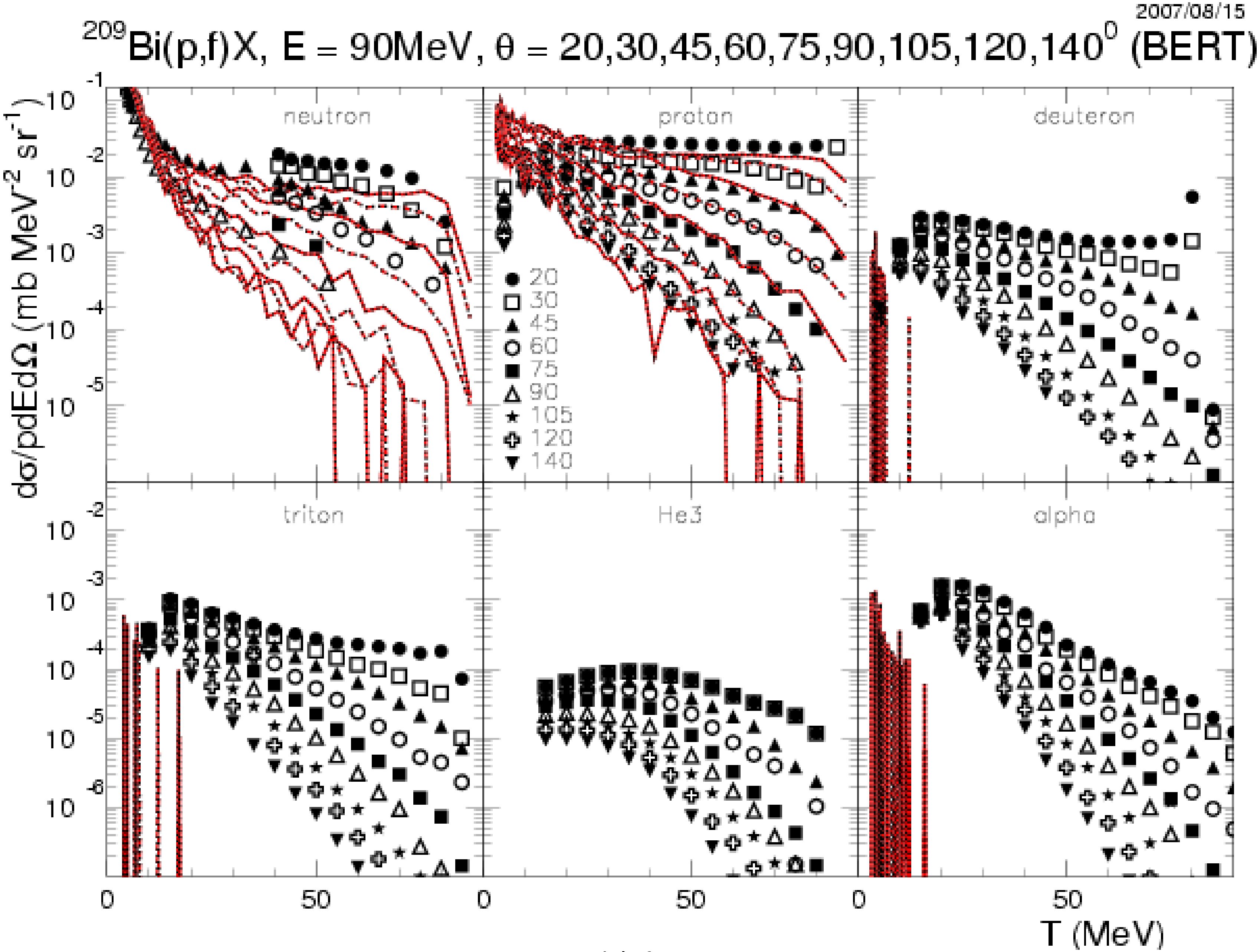
^{27}Al(p,f)X, E = 90MeV, θ = 20,30,45,60,75,90,105,120,140^0 (BERT)





^{209}Bi(p,f)X, E = 90MeV, θ = 20,30,45,60,75,90,105,120,140^0 (BERT)
dσ/pdEdΩ (mb MeV^{-2} sr^{-1})
neutron
proton
deuteron
triton
He3
alpha
20
30
45
60
75
90
105
120
140
T (MeV)

Comments about LHEP

- It is roughly a factor of 10 faster than other.
- It combines two models, smearing them.
  - A fast cascade (similar to evaporation)
  - A CASP algorithm of 3-particle decay
  - Produces a lot of gammas
  - Does not produce He3 at all
  - All spectra are practically isotropic in CMS
- Smearing of two models makes it difficult to improve each LE model separately.

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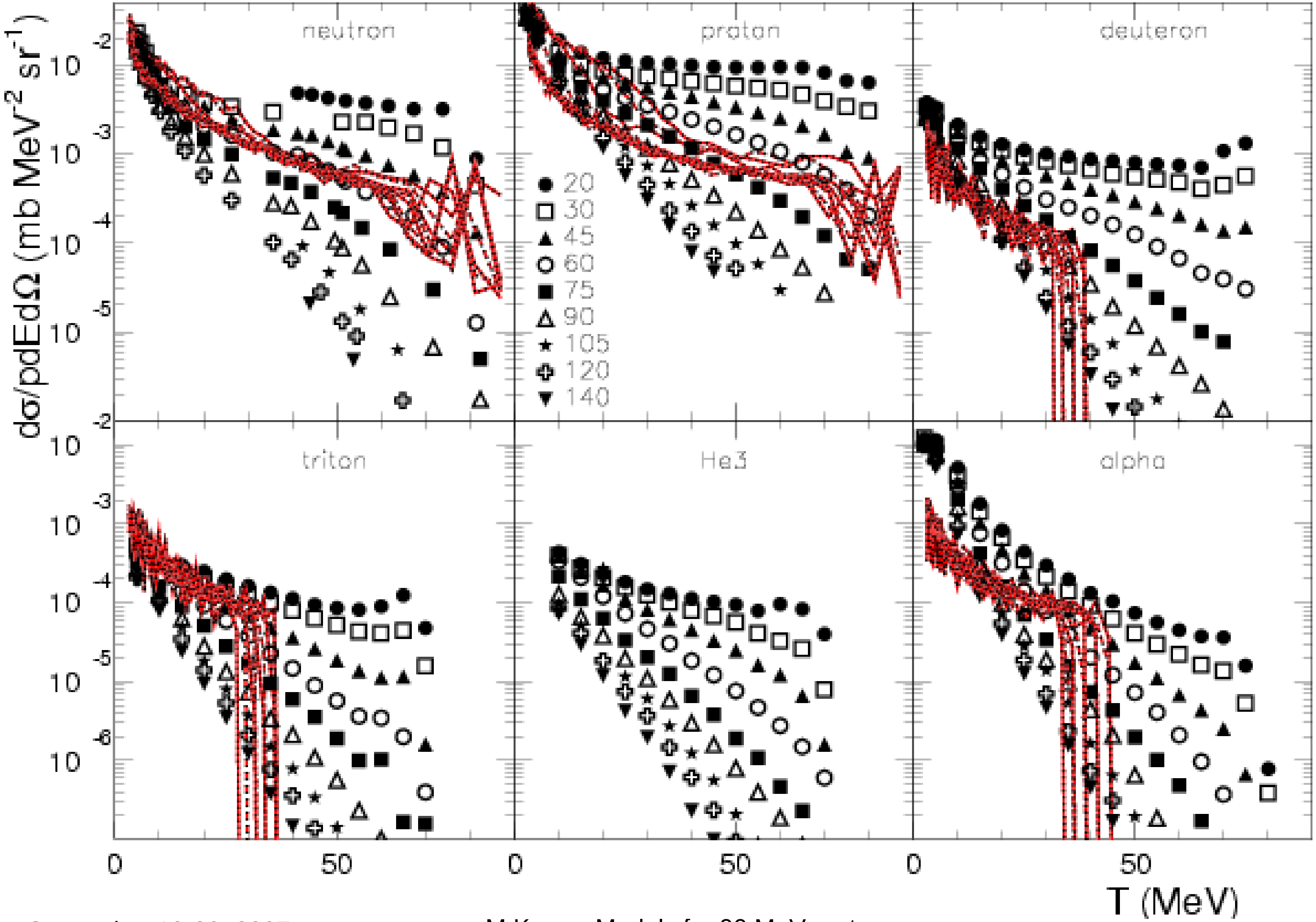
^{27}Al(p,f)X, E = 90MeV, θ = 20,30,45,60,75,90,105,120,140^0 (LHEP)



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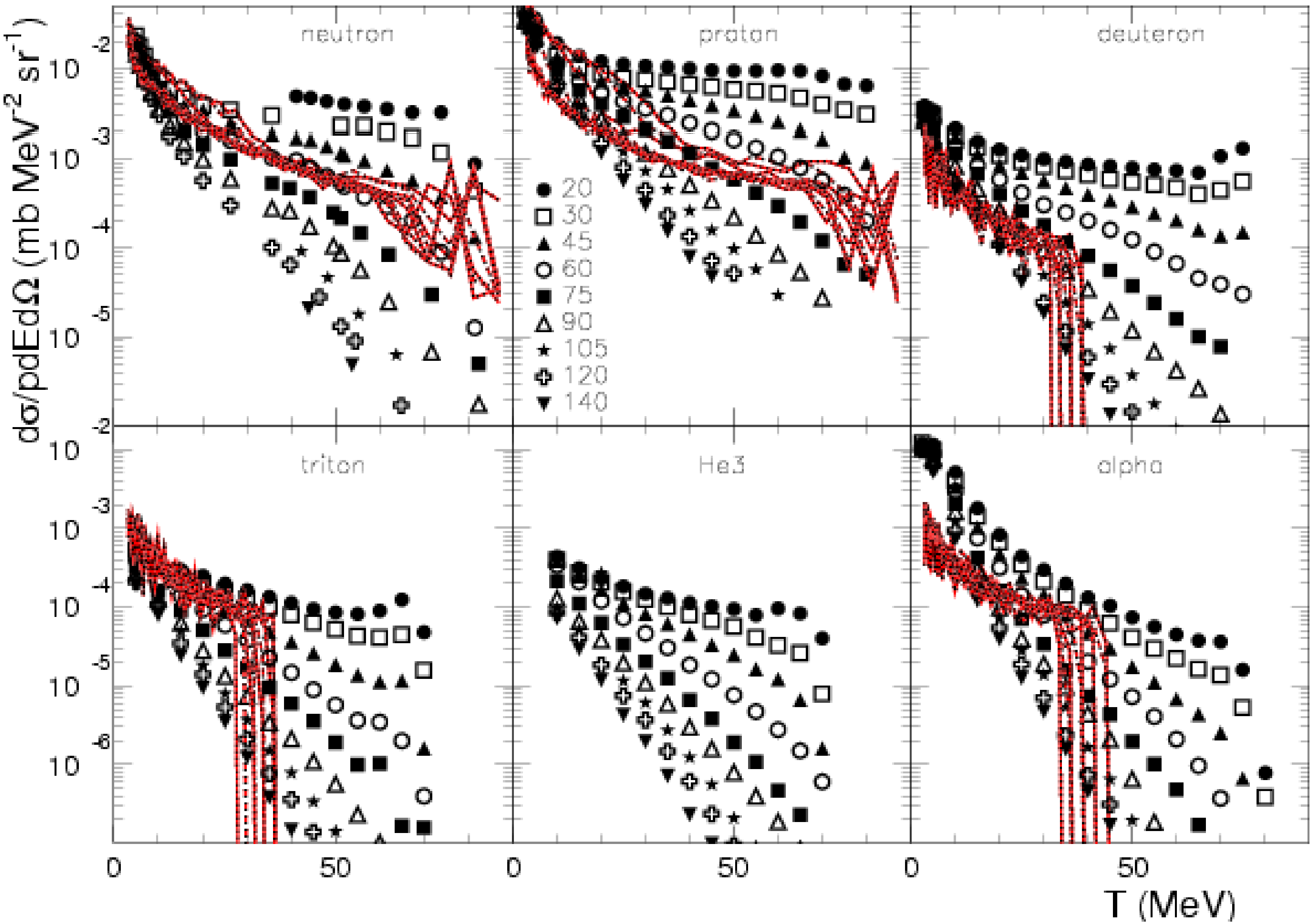

Conclusion

- All G4 models except LHEP fit angular spectra of protons & neutrons @90MeV (Binary is the worst)
- No one old generator fits nuclear fragment spectra
- LHEP is the fastest generator but does not have He^3
- Bertini is the fastest of the comprehensive models, but it does not have a Coulomb Barrier for fragments
- Bertini spends too much energy on photons
- G4PreCompoundModel produces too many α's on Bi
- Binary looks worse than the G4PreCompoundModel
- Forward yield is badly reproduced by all G4 Models