Intrinsic properties of hadron showers and absorber materials

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The copy of this talk one can find at the http://www.desy.de/˜morgunov

Plan

1. Long–long introduction
2. Binding discrepancies v.s. GEANT4 Models
3. EM fraction v.s. GEANT4 Models
4. Binding discrepancies v.s. absorber materials
5. EM fraction v.s. absorber materials
6. Cross–correlations and connections with a visible energy

Used GEANT4 Physics Lists

QGSP+BERT 3.4

```
PionMinusInelastic  Models:                         QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                                  G4LEPionMinusInelastic: Emin(GeV)=  9.5  Emax(GeV)= 25
                                          BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 9.9
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QGSP+BERT+CHIPS 2.0

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PionMinusInelastic  Models:                         QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                                  G4LEPionMinusInelastic: Emin(GeV)=  9.5  Emax(GeV)= 25
                                          BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 9.9
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QGSP+FTFP+BERT 3.6

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PionMinusInelastic  Models:                         QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                                                    FTFP: Emin(GeV)=    6  Emax(GeV)= 25
                                          BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 8
```

FTFP+BERT 1.3

```
PionMinusInelastic  Models:                         FTFP: Emin(GeV)=    4  Emax(GeV)= 100000
                                          BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 5
```

QGSP+INCL+ABLA 0.2

```
PionMinusInelastic  Models:                         QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                                  G4LEPionMinusInelastic: Emin(GeV)=  9.5  Emax(GeV)= 25
                                          BertiniCascade: Emin(GeV)=  2.9  Emax(GeV)= 9.9
                                      INCL/ABLA Cascade: Emin(GeV)=    0  Emax(GeV)= 3
```

CHIPS

FOR ALL PARTICLES AT ANY ENERGY

Another Physics Lists do not conserve energy – it is impossible to calculate a correct binding discrepancy.

Anyway – GHEISHA for Λ and another hyperons

This information text is presented at all Physics Lists of GEANT4 except CHIPS.

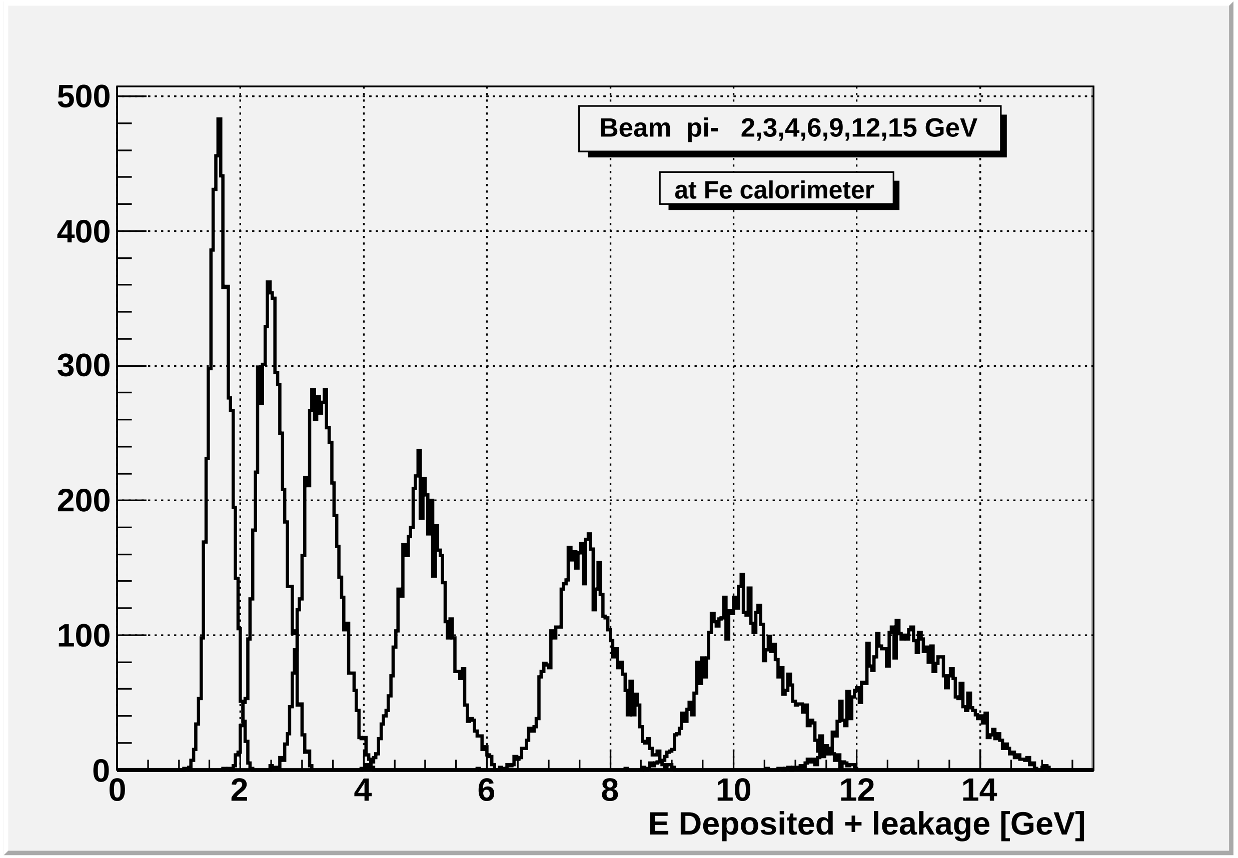
```
                         Hadronic Processes for <lambda>
                         -----------------------------------
      hadElastic   Models:                hElasticLHEP: Emin(GeV)=    0  Emax(GeV)= 100000

      hadElastic   Crs sctns:           GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000

 LambdaInelastic   Models:         G4LELambdaInelastic: Emin(GeV)=    0  Emax(GeV)= 25
                                   G4HELambdaInelastic: Emin(GeV)=   20  Emax(GeV)= 100000

 LambdaInelastic   Crs sctns:         GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
```

This means that the GHEISHA hadron inelastic code will destroy an energy conservation law in any calculations.

We are happy that the probability to create hyperons is rather small.

So, not all events will consist of such a distortion.

Energy deposited at the calorimeter volume and aside



Simple sum of the deposited energies taken for every GEANT tracking step independently on volume where it is occurred:

$$E_{dep} += \ aStep- > GetTotalEnergyDeposit();$$

Leakage is accounted as a sum of kinetic energies for particles that leave a calorimeter volume.

By the way, the sum of the deposited energies for electromagnetic cascade is a delta function at beam energy.

Nuclear Binding Energy

Binding energy of nuclide is defined as: $\mathbf{{}_z BE^A = Z * (m_p + m_e) + N * m_n - {}_z M^A}$ (Eq. 1)

where **Z** denotes the number of protons of the nuclides and **N** its number of neutrons.

A denotes the sum of **Z** and **N** (number of nucleons in the nuclide) and ${}_z M^A$ is a measured mass of isotope.

The binding discrepancy for every interaction in the hadron shower can be represented as:

$$\mathbf{dBE = \ {}_Z BE^A_{traget} - \sum_{sec.}^{nucl.} \ {}_{Z^*} BE^{A^*}} \quad \text{(Eq. 2)}$$

We will use a sum of individual discrepancies of all nuclear interactions in hadron shower: $\mathbf{\sum_{interac.}^{hadr.} dBE_i}$

This sum is equal to a growth of the calorimeter mass

after each hadron shower occurred during beam data taking.

Such a sum is the fundamental intrinsic property of the material, like ϵ, μ, X_0 or Λ_0

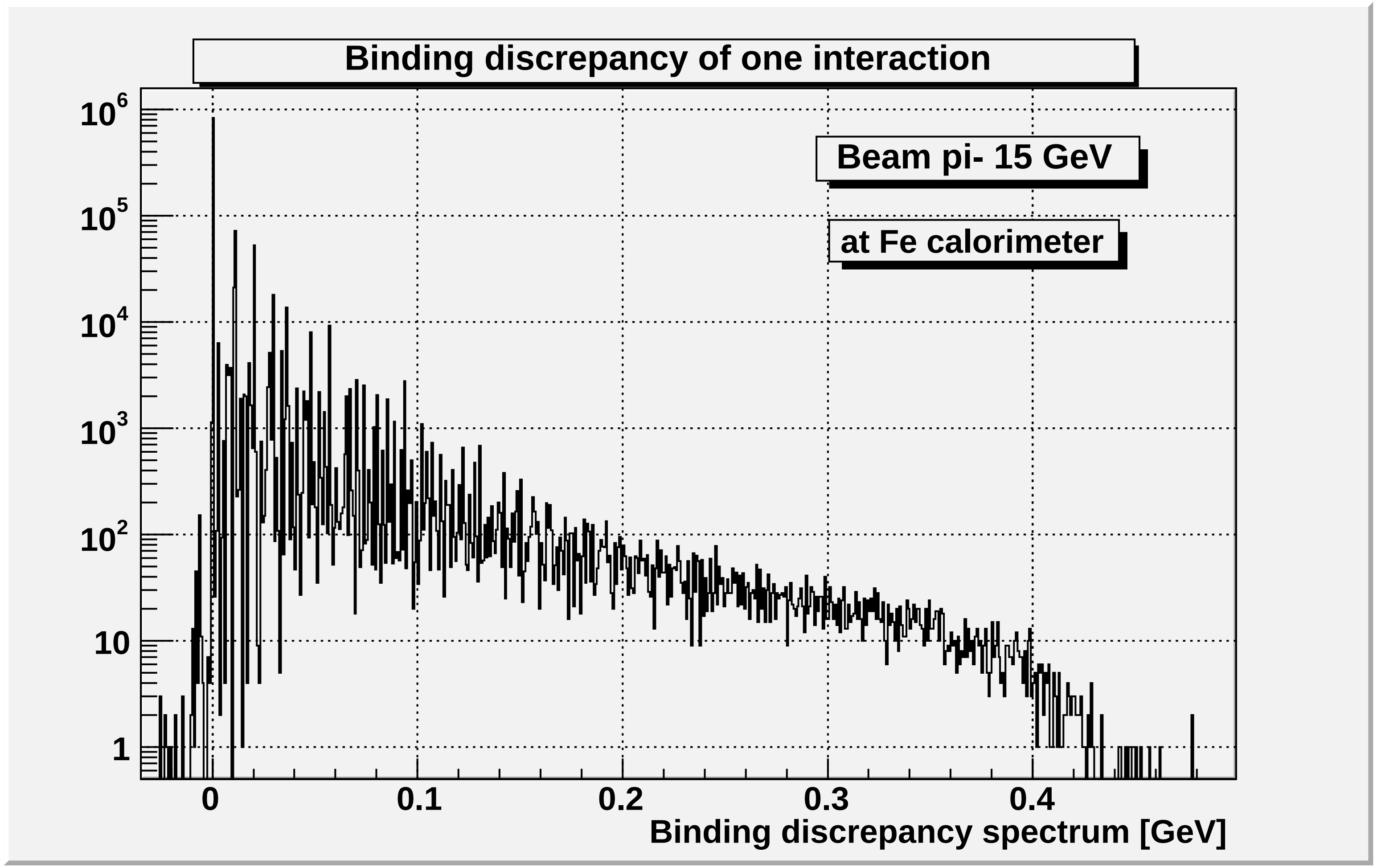
It characterizes an ability of hadron cascade energy to be converted into mass of absorber material.

This property was commonly and hardly used for a long period of time to calculate nuclear power stations and others. But it was used at low energies of projectiles (less then 20 MeV) and for small number of particles (like neutrons and gammas). Now, we will try to use it at the high energies and for all kind of known particles.

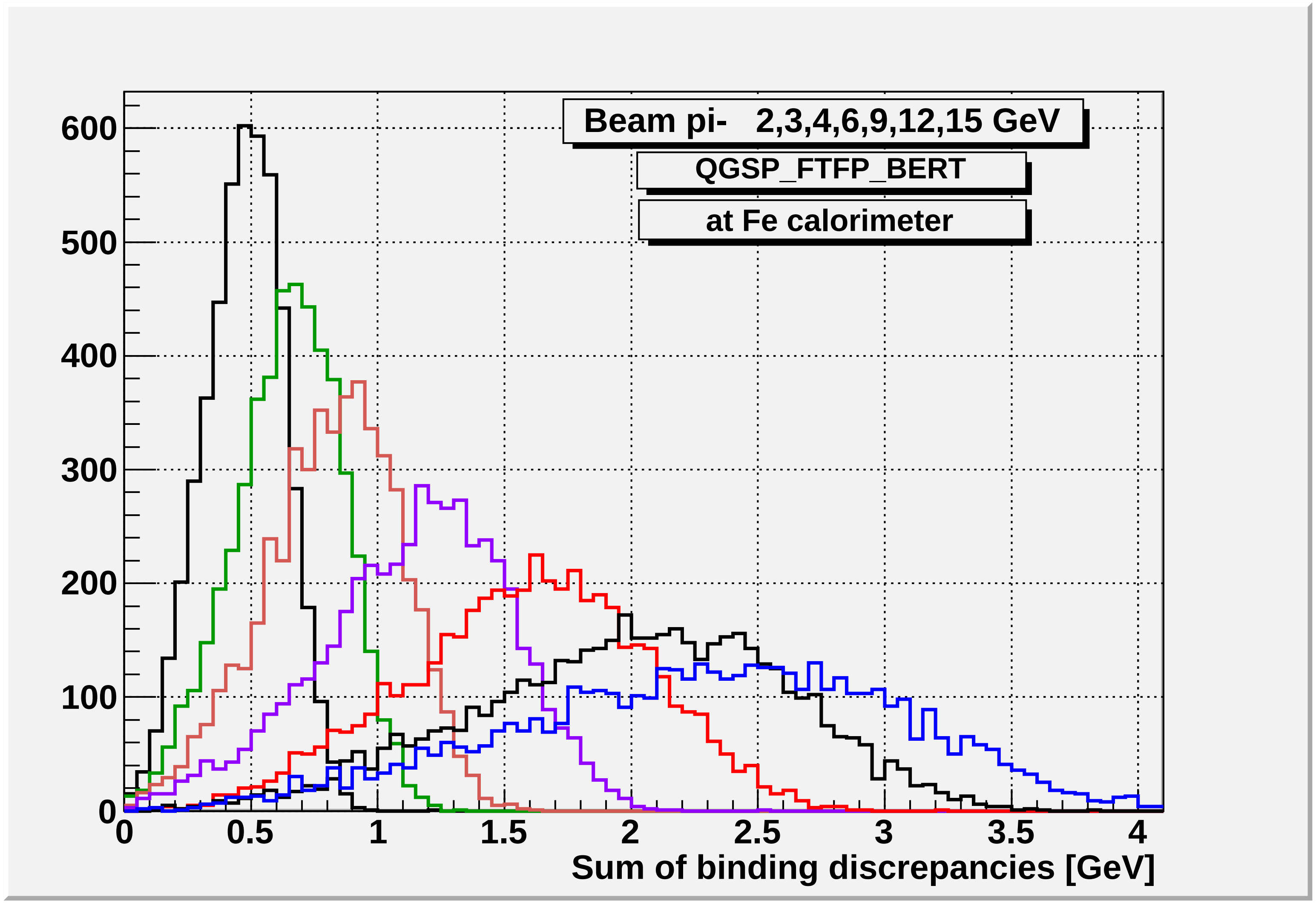
At GEANT4 one can get a binding energy for any isotope with

$$static \ \ G4NucleiProperties :: GetBindingEnergy(A, Z);$$

Binding Energy Discrepancies



Binding Energy of Hadron Shower



This is that we lost in sum of deposited energies.

Balance of energy in one interaction and in the hadron shower

Energy conservation equation for any individual nuclear interaction inside a calorimeter at lab. system looks like:

$$\mathbf{E_{proj}} + \mathbf{{}_{Z}M^{A}} = \sum_{\mathbf{sec.}}^{\mathbf{part.}} \mathbf{E_{part.}} + \sum_{\mathbf{sec.}}^{\mathbf{nucl.}} \mathbf{{}_{Z^*}M^{A^*}} + \sum_{\mathbf{sec.}}^{\mathbf{nucl.}} \mathbf{E_{kin}} \quad \text{(Eq. 3)}$$

where $\mathbf{E_{proj}}$ is a total energy of reaction projectile; $\mathbf{{}_{Z}M^{A}}$ is a target mass; $\mathbf{E_{part.}}$ total energy of "usual" particles produced at a nuclear reaction (leptons, gammas, mesons and baryons); $\mathbf{{}_{Z^*}M^{A^*}}$ is a mass of produced nuclides; $\mathbf{E_{kin}}$ is a kinetic energy of produced nuclides. Sum are along all secondaries of the reaction.

Energy balance for one event (one beam particles and hadron shower):

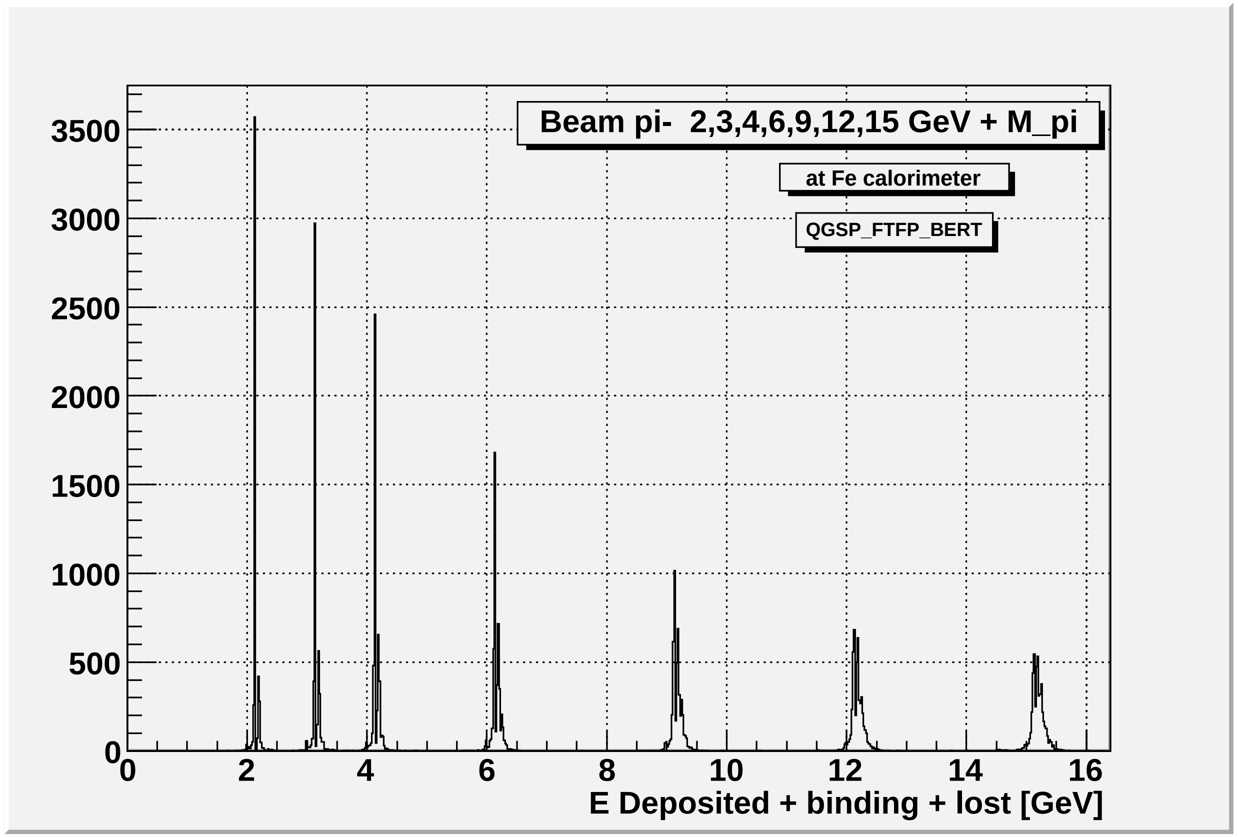
$$\mathbf{E_{beam}} = \mathbf{E_{dep.}} + \sum_{\mathbf{leak}}^{\mathbf{part.}} \mathbf{E_{kin}} + \sum \mathbf{dBE_i} \quad \text{(Eq. 4)}$$

where: $\mathbf{E_{beam}}$ is a total beam energy in the case of $\pi-$ beam and/or a kinetic energy for proton beam; $\mathbf{E_{dep.}}$ is energy deposited at the whole calorimeter volume (mainly by ionization); $\sum_{\mathbf{leak}}^{\mathbf{part.}} \mathbf{E_{kin}}$ is an energy leak from a calorimeter volume.

$\sum \mathbf{dBE_i}$ is a sum of binding discrepancies in all nuclear interactions (see Eq. 2). This energy is converted into increasing of the calorimeter mass. This is a totally invisible value, except, maybe, one would be able to measure the weight of our calorimeter ($\approx$ 8 tons) with an accuracy better than 10^{-27} gram after each beam particles passed through the calorimeter.

Total balance of calorimeter energy (prove of Eq 4.)

Simple sum of deposited energies and binding discrepancies. (This is not a delta function yet, but its near by)

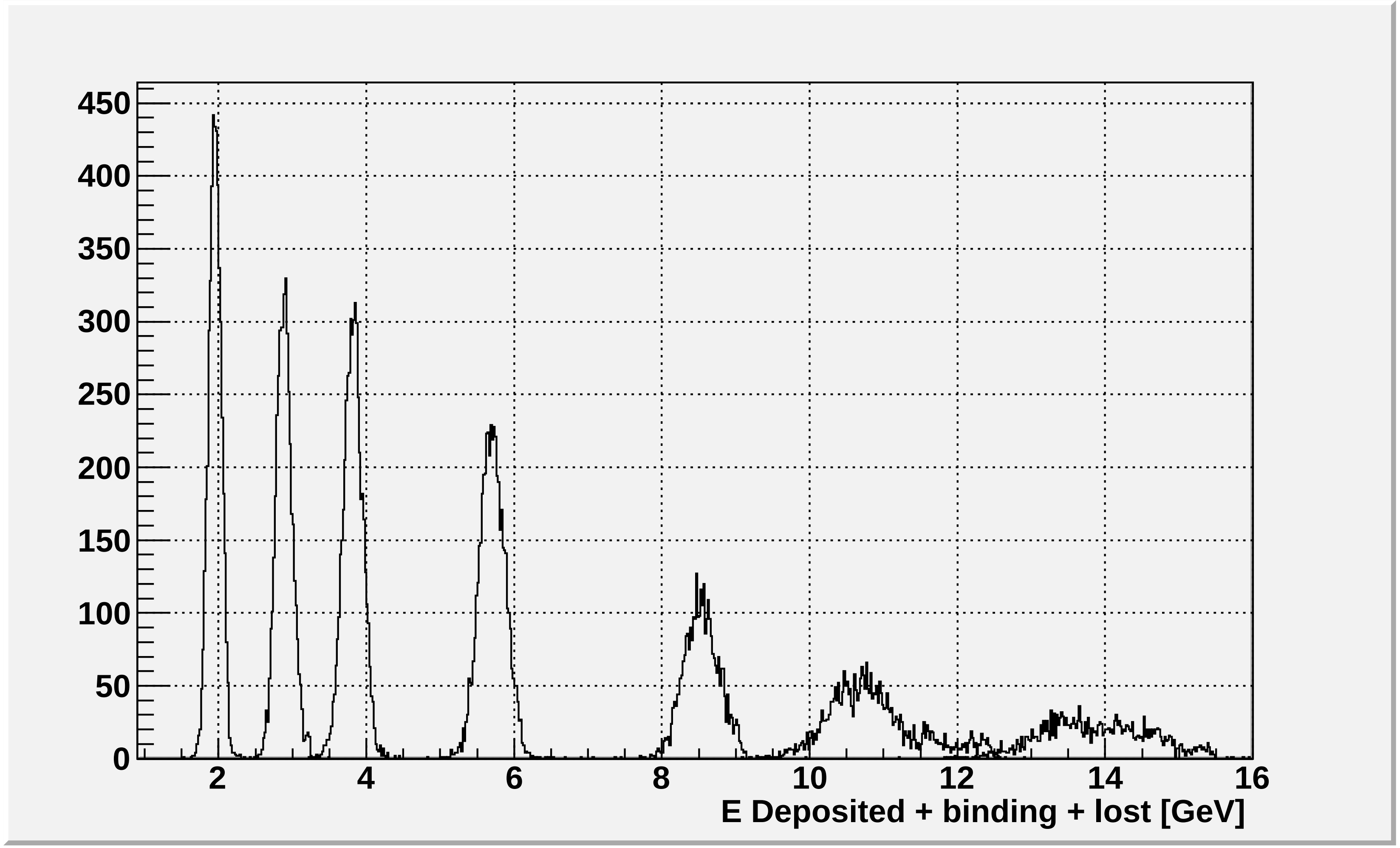


Remark 1: Some of the GEANT4 routines does not conserve energy

Remark 2: Nuclear interaction made by GHEISHA could be presented independently of the physics list if the nuclear interaction will initiated with a hyperon as a projectile.

Remark 3: GHEISHA does not conserve energy and it does not produce a secondaries nuclei.

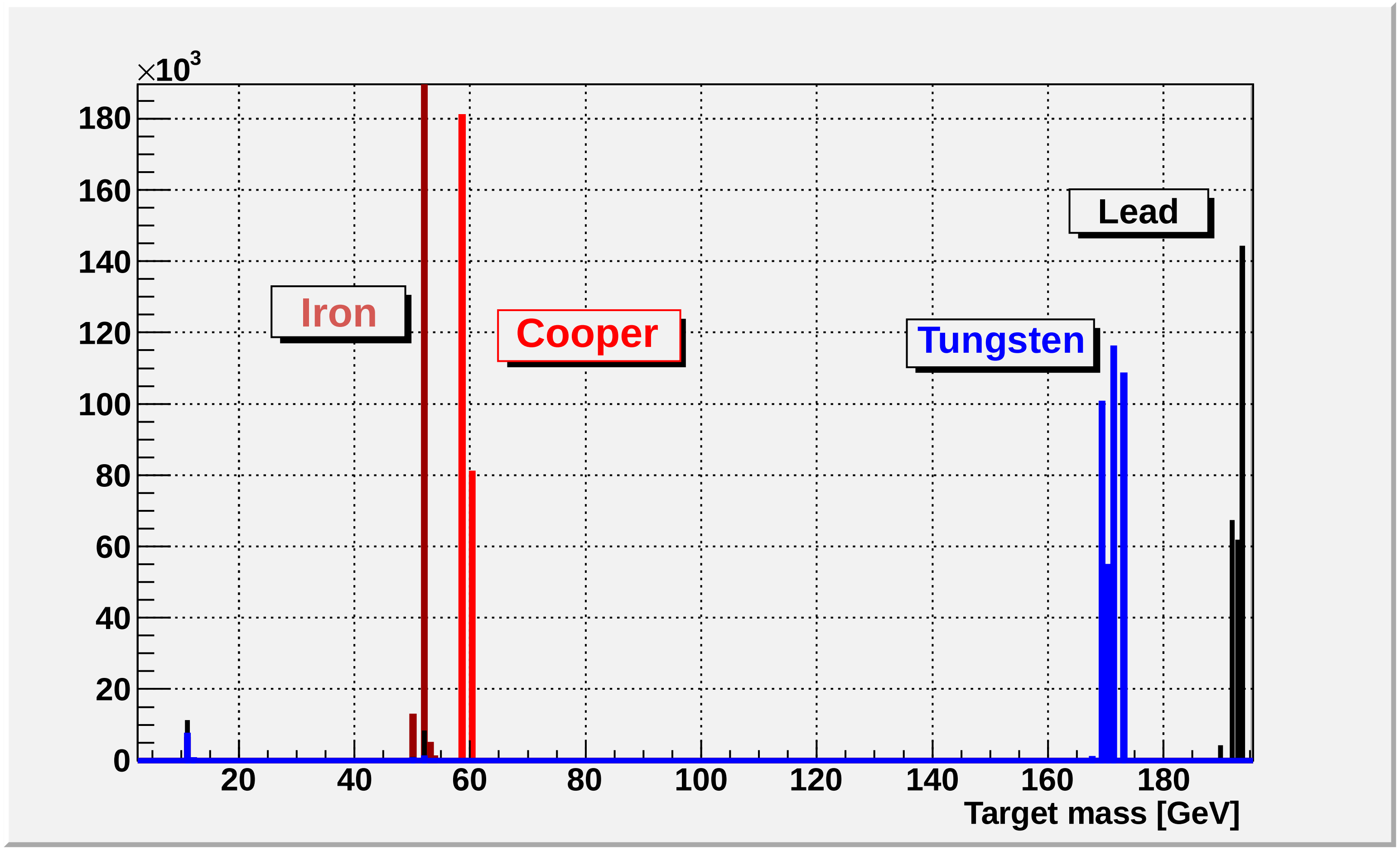
Total balance of calorimeter energy



QGSP+INCL+ABLA keeps an energy conservation much worse the than others.

That is mainly a result of GHEISHA presence. But we will use it anyway.

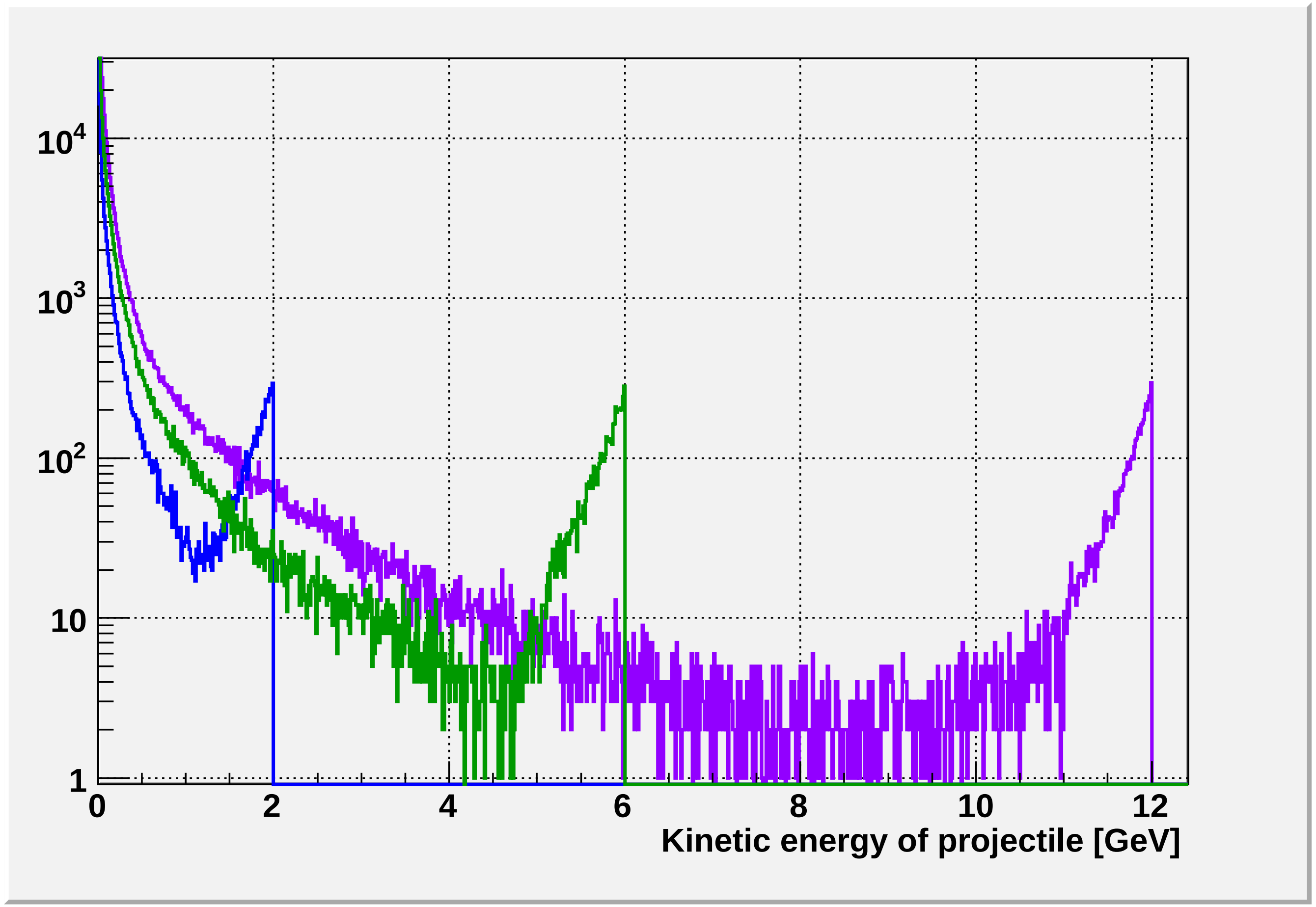
Target mass distribution



We will show four different calorimeters with Fe, Cu, W and Lead absorbers.

Natural Cooper consist of two isotopes; Iron and Lead consist of four isotopes each; natural Tungsten consist of five isotopes. (see table in Appendix)

Projectile kinetic energy distribution



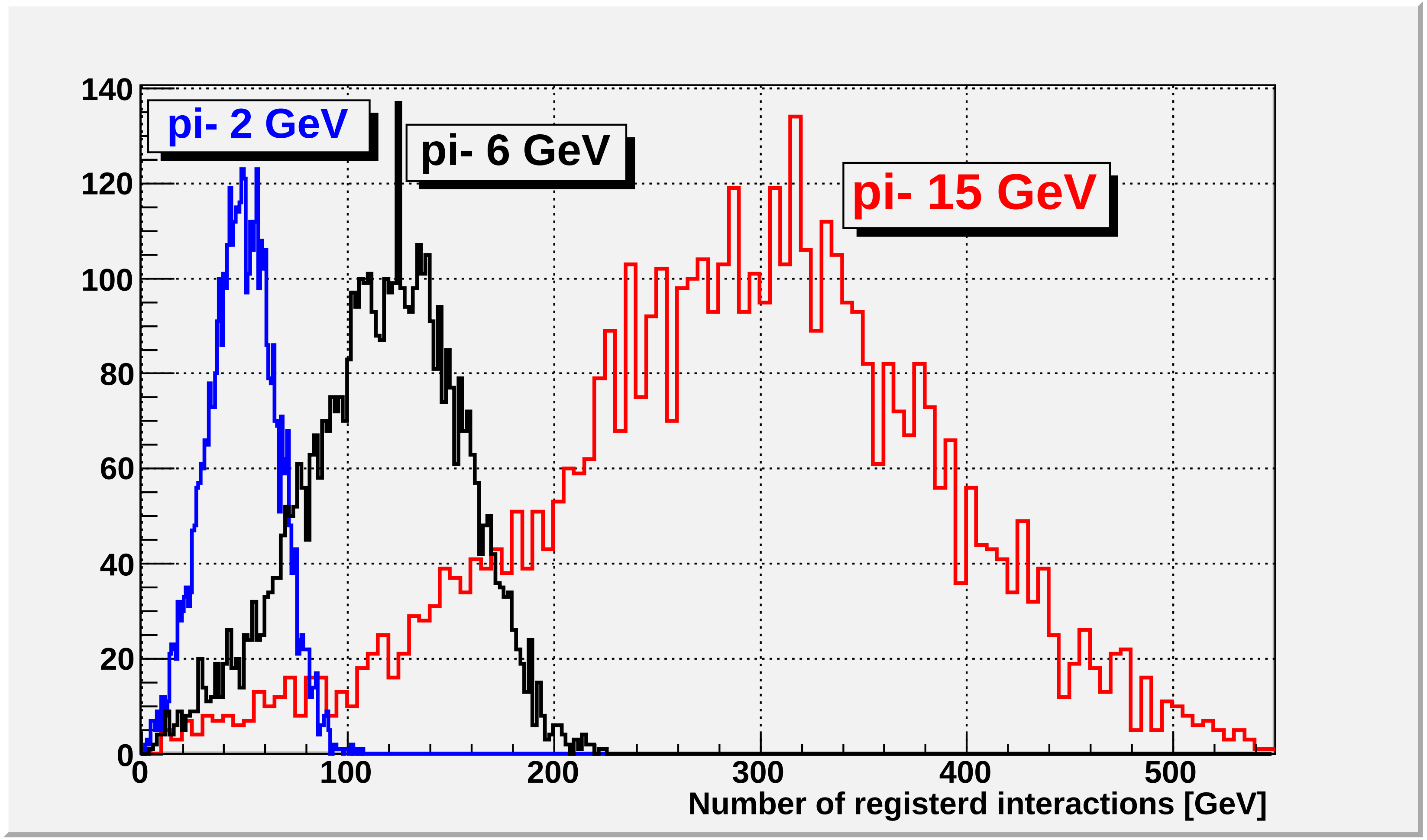
Energy of a primary track at the point of the first interaction one can see at the right hand side of the distributions.

The secondaries have 2–3 times less energy than the initial beam energy.

We will show seven beam energies; E_{kin} = 2, 3, 4, 6, 9, 12, 15 GeV.

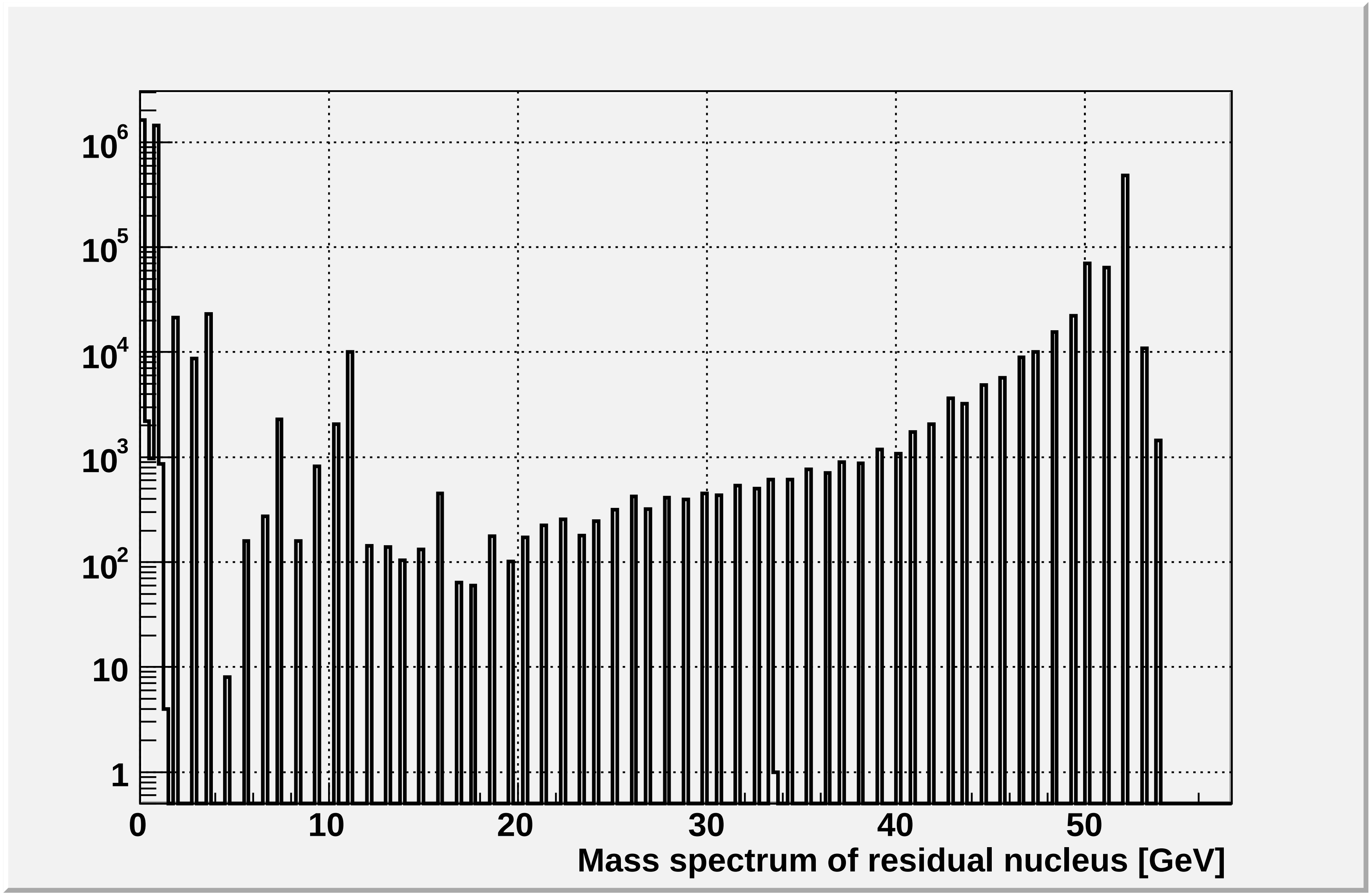
Number of hadron interactions per event

Registered interaction has a meaning: Target nuclide was found, number of secondaries larger than two and at least one nuclide or nucleon was found in the secondaries.



Average number of interaction is of about 20 / GeV at Fe absorber.

Mass distribution of residual nucleus



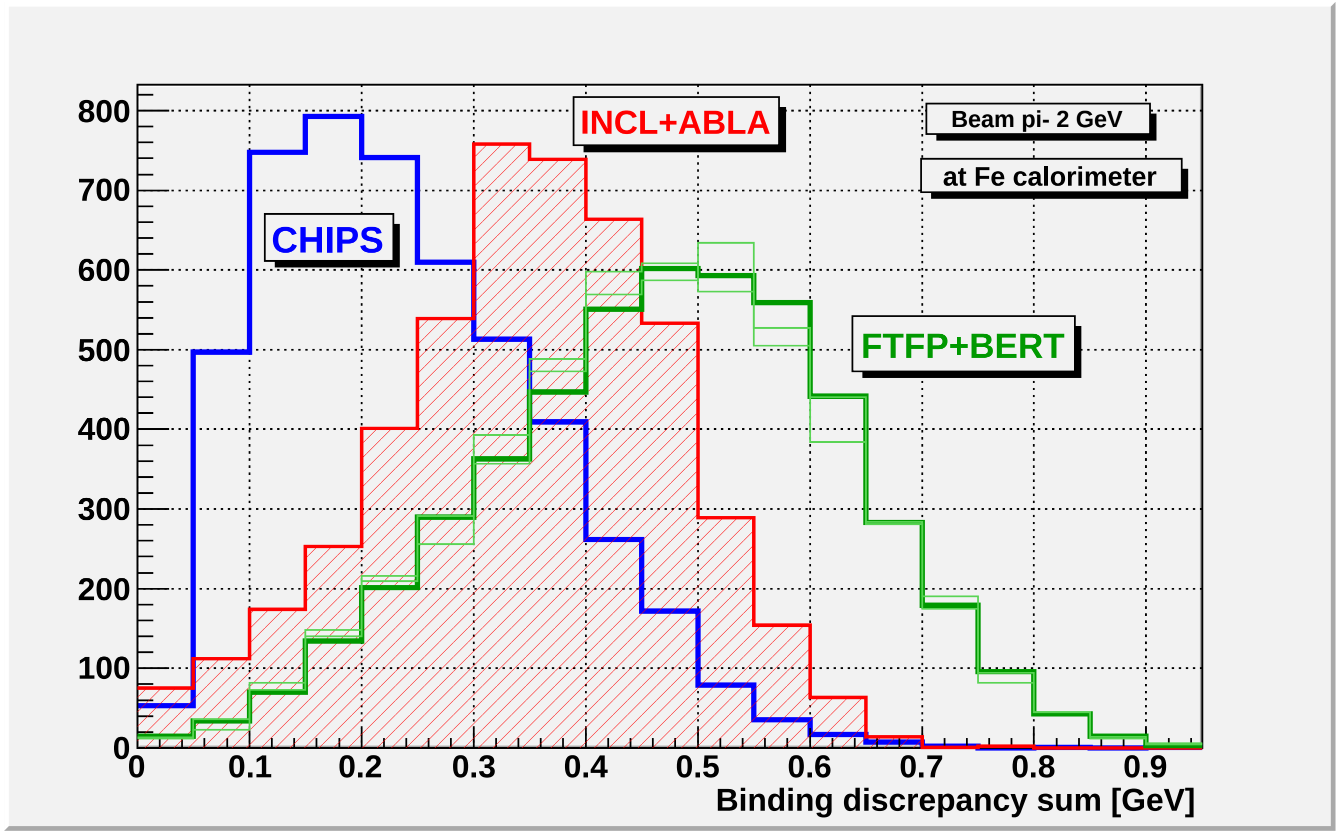
Absorber is a Natural Iron.

Introduction is finished

Questions?

Now we will go to GEANT4 hadron interaction models in details.

Binding energy discrepancy by different Models, 2 GeV



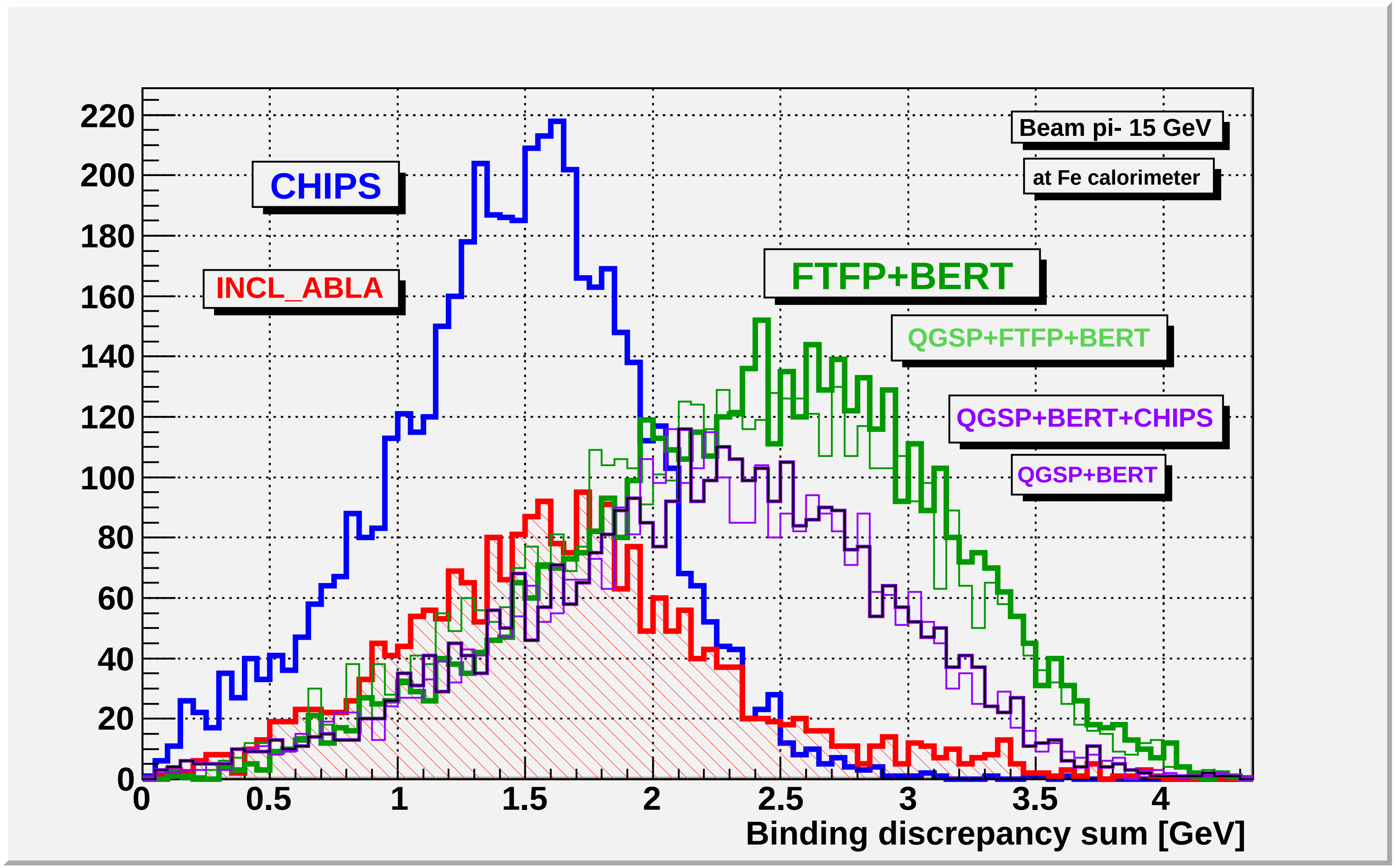
The difference in the predictions is of about factor 3 ! (but, we have that we have)

We should emphasis here that the Bertini model was used successfully during of about 40 years; but is was written for low energies, and now it is extended to higher energy voluntary.

INCL+ABLA model is the modern model, and it is used by atomic agencies of all over the world.

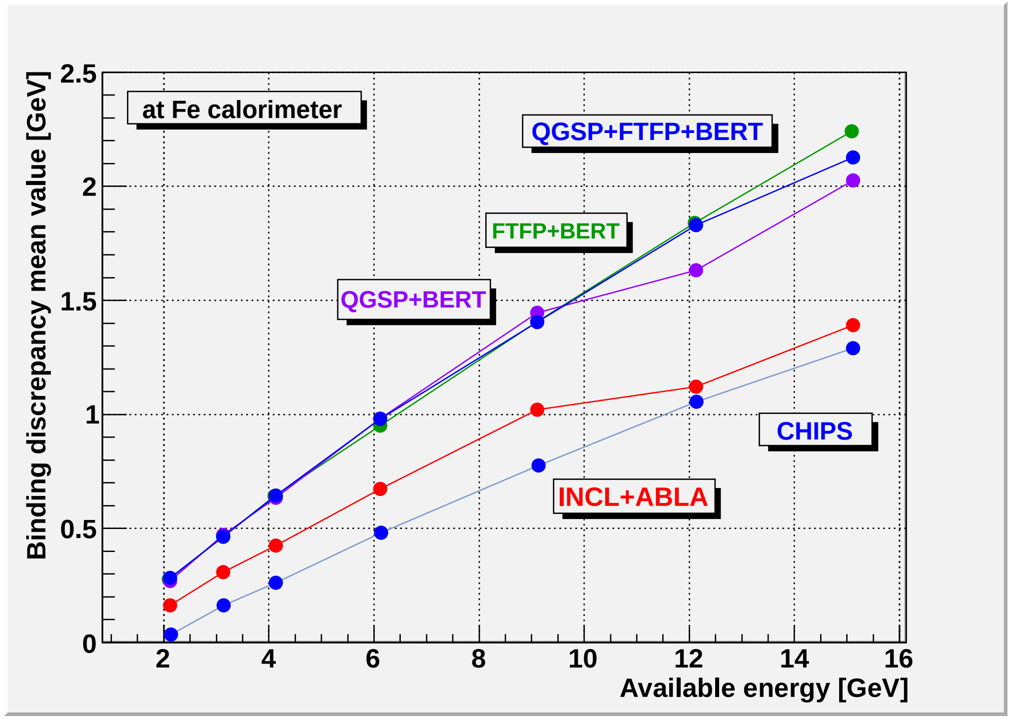
CHIPS is also very modern model with attempt to build it from the first principles.

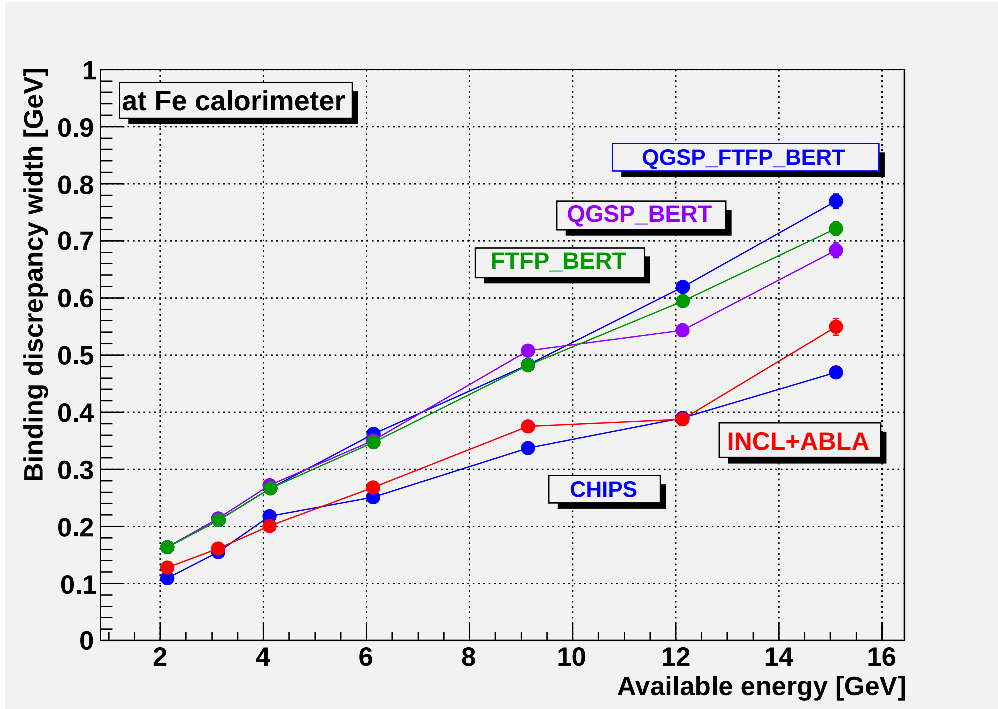
Binding energy discrepancy by different Models, 15 GeV



The difference in the predictions is of about factor 2 !

Binding energy discrepancy by different Models





The mean value of a binding energy discrepancy has a deal with the main part of so called e/pi ratio. That is not due to a different response of the calorimeter detectors to electron and hadron but it is the intrinsic properties of the hadron shower (Recall: a part of the cascade energy goes into mass of the calorimeter).

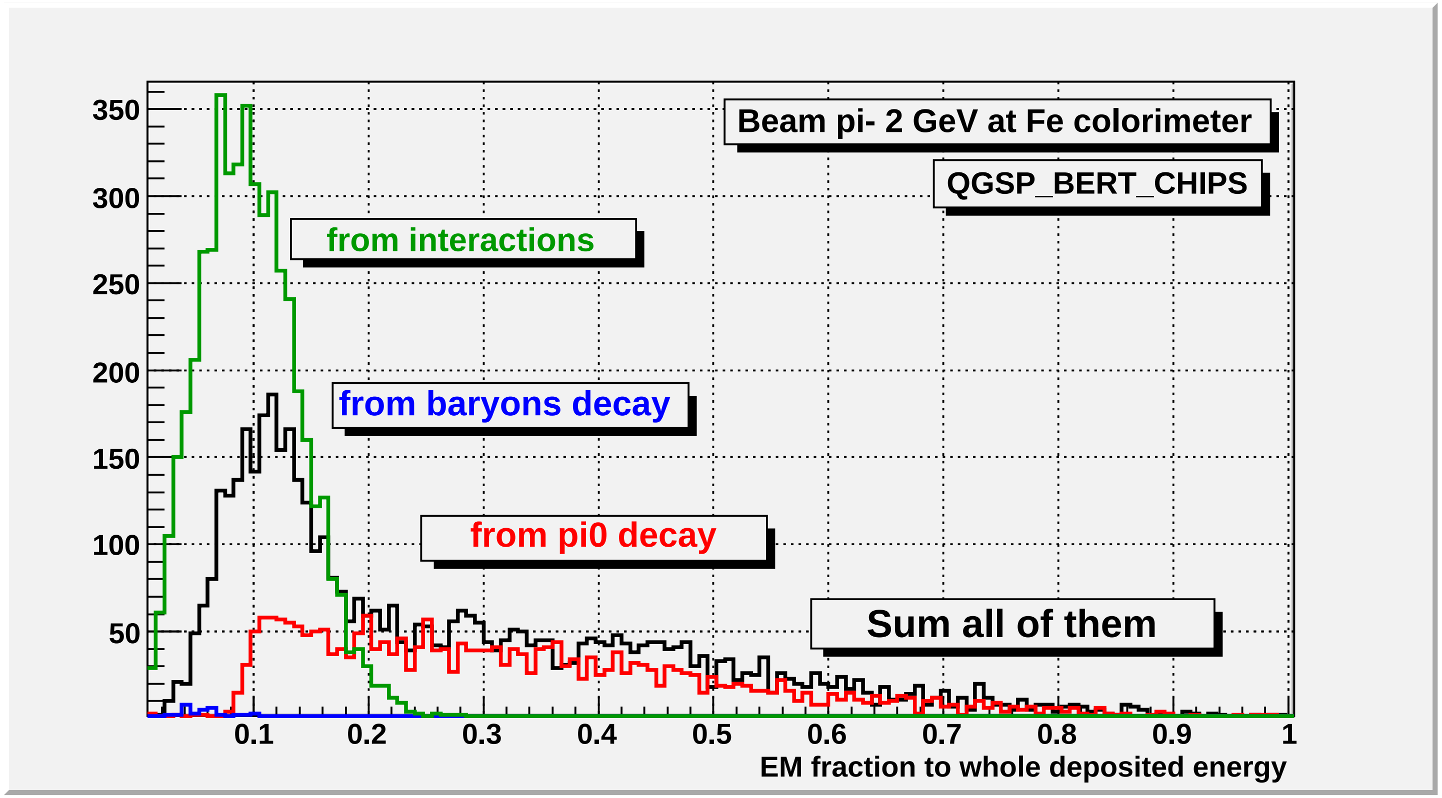
The width of binding energy discrepancy goes into hadron energy resolution straightforward.

So, the predicted e/pi ratio as well as a hadron energy resolution will be rather differ for different Physics Lists of GEANT4, as we can see at these plots.

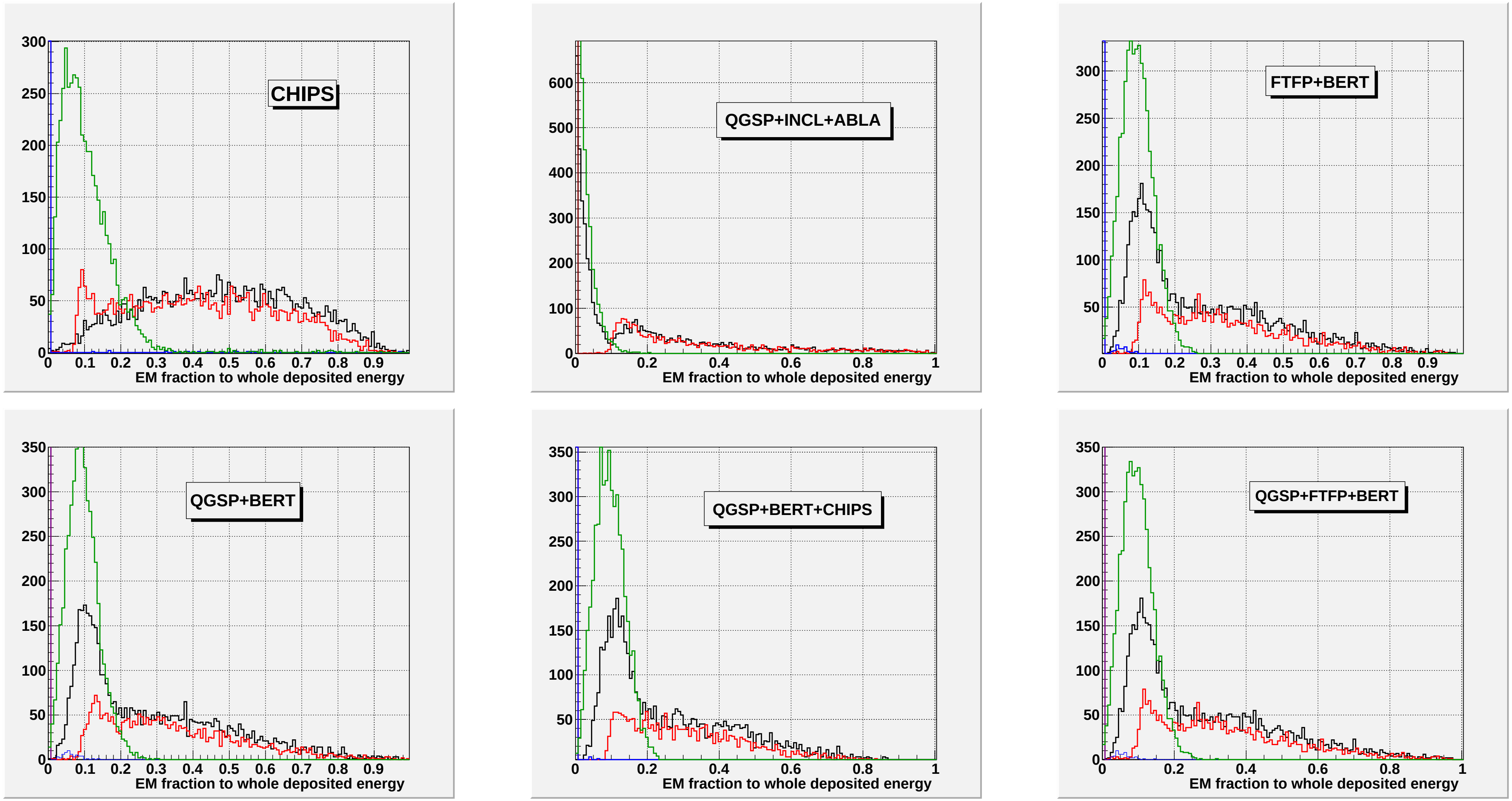
EM fraction of shower energy

Definition: **Ratio of the energy sum of gammas created by different processes (excluding EM processes) to whole deposited energy in a hadron cascade.**

1. **Gammas from decay of heavy baryons, like $\Lambda^0 \rightarrow n + \gamma$**
2. **Gammas produced at nuclear interaction**
   a) **Gammas produced by π^0 and η^0**
   b) **Individual gammas; basically come from ($n\ \gamma$) reactions and residual nuclei deexcitation**

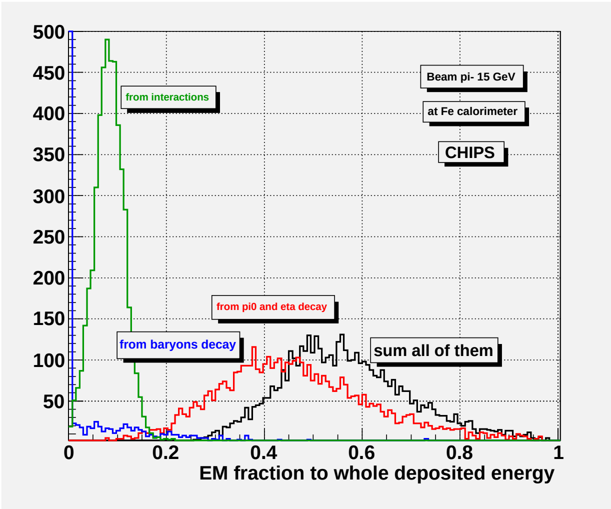


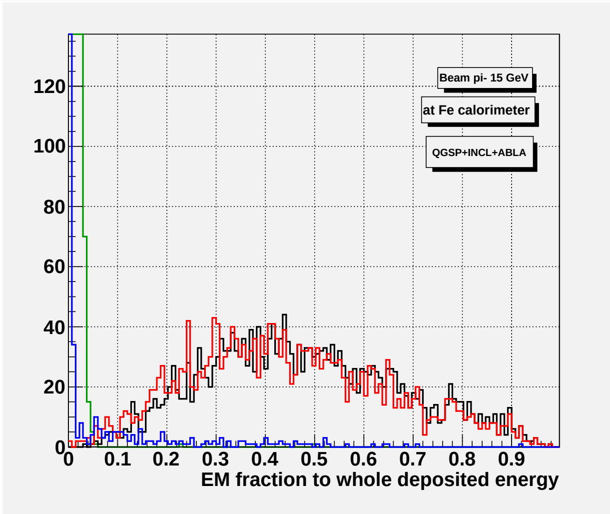
EM fraction of shower energy, 2 GeV

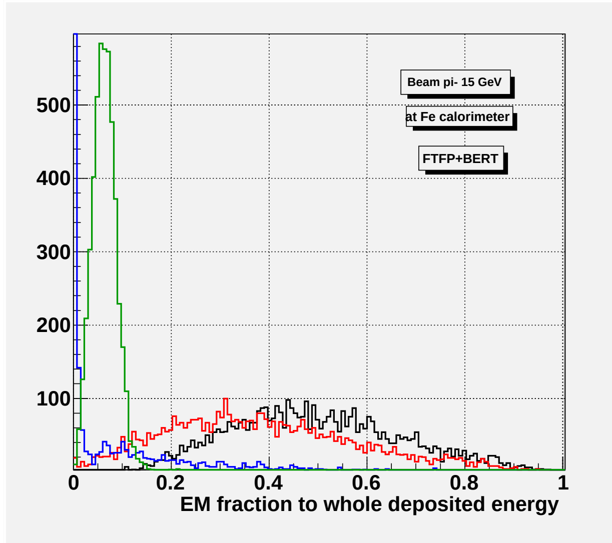


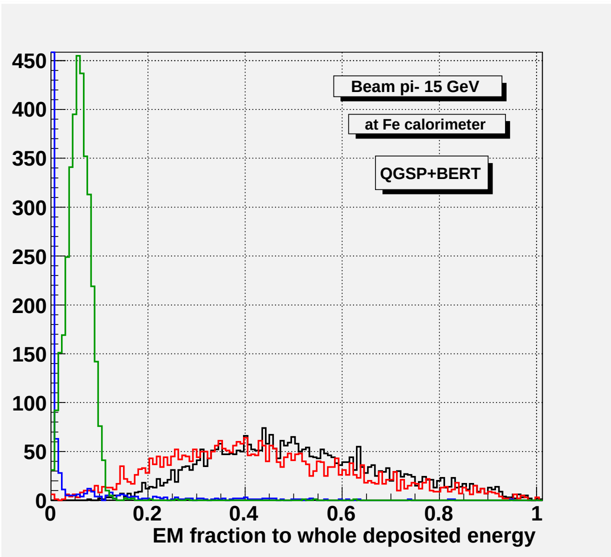
INCL+ABLA produces much less of deexcitation gammas than any other physics models.

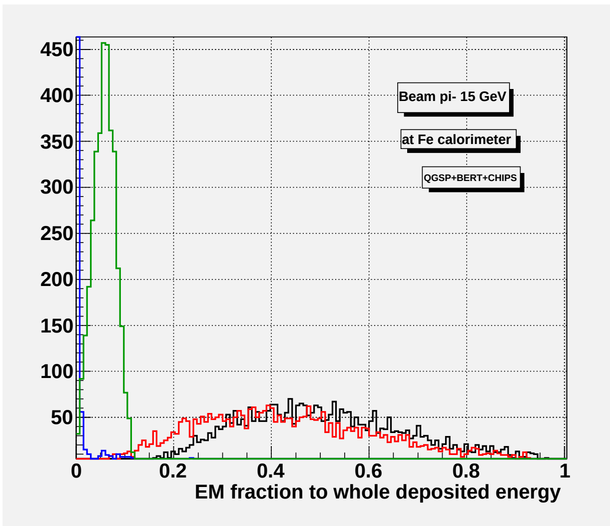
EM fraction of shower energy, 15 GeV

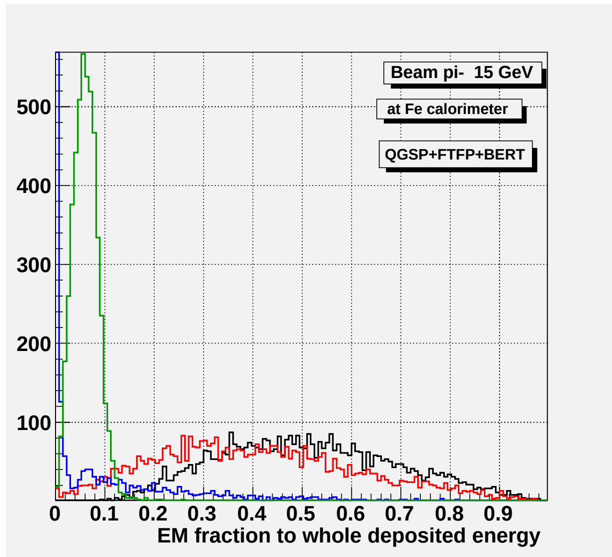




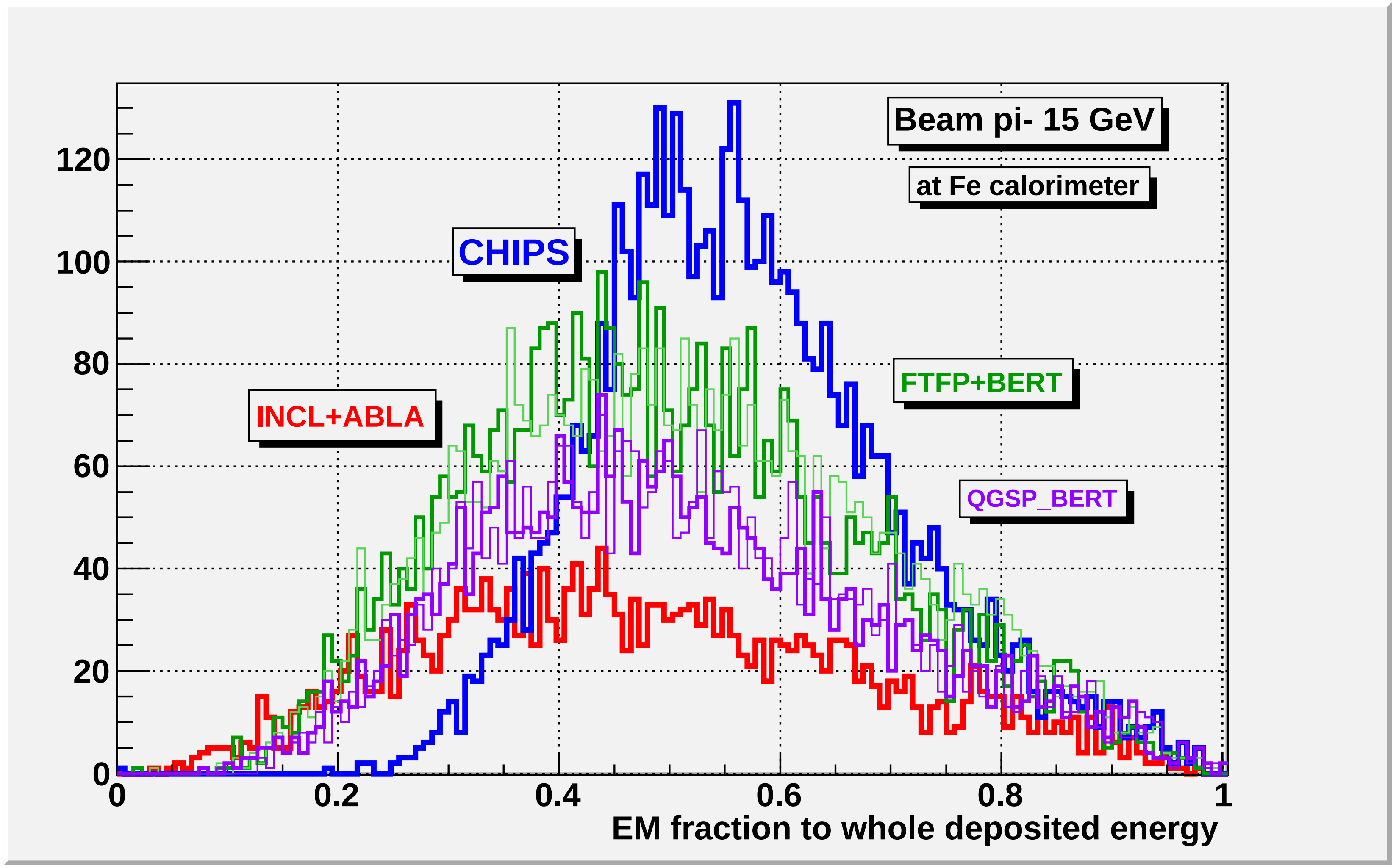






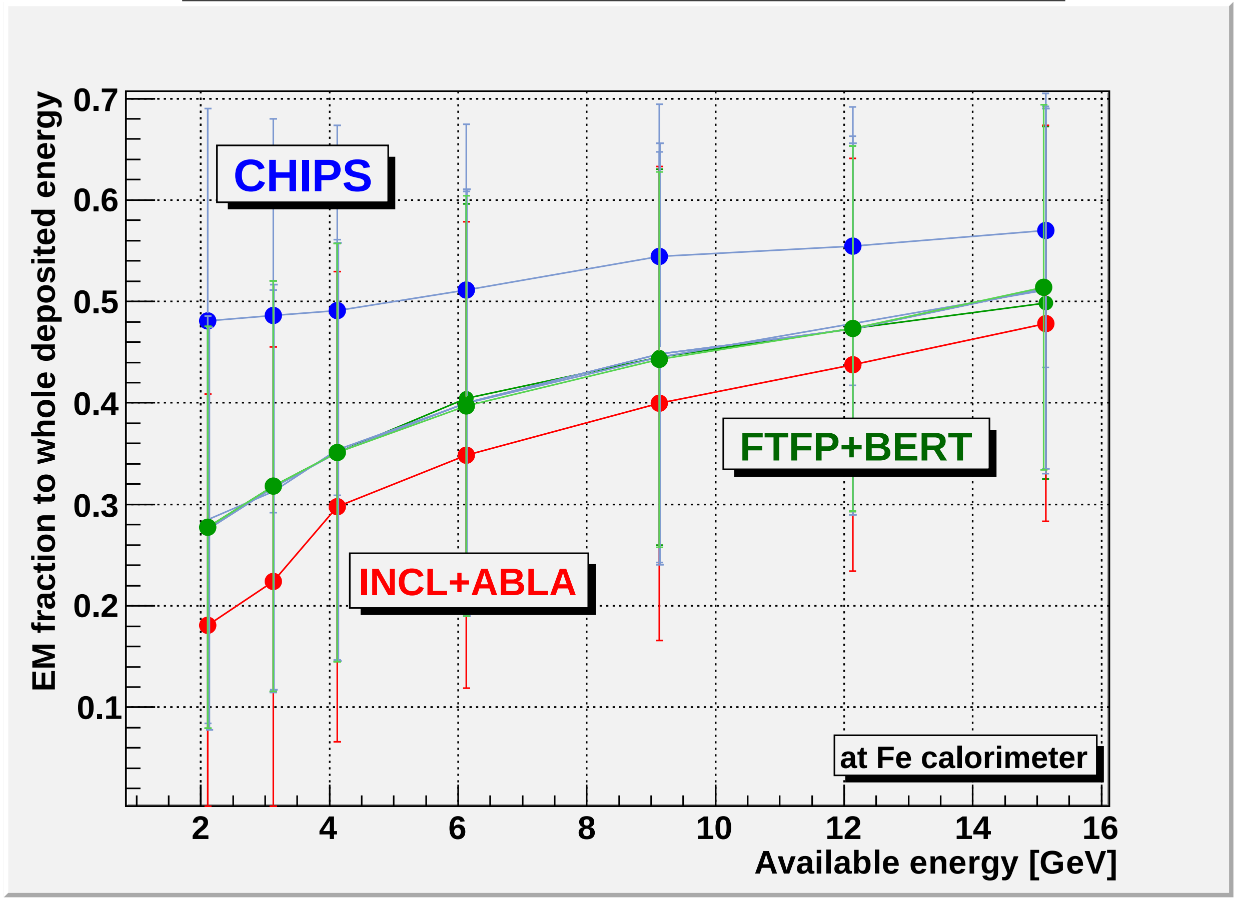


EM fraction of shower energy, 15 GeV



The difference in the predictions is of about factor 2 !

Mean values of EM fraction



CHIPS looks like incorrect in EM fraction dependency on beam energy. It shows too small slope.

FTFP+BERT and INCL+ABLA looks better, but INCL+ABLA predicts too small values; this looks like incorrect also.

Maybe above statements follow from the fact that the Bertini model was unique for very long time and we have got an accustom to its prediction. EM fraction was never measured by experiment – predictions only exist.

Intermediate Conclusion

An accuracy of the calculations of the intrinsic properties like binding energy discrepancies and the electromagnetic fraction of energy in hadron cascades is not as good as we expected for modern Physics Lists of GEANT4.

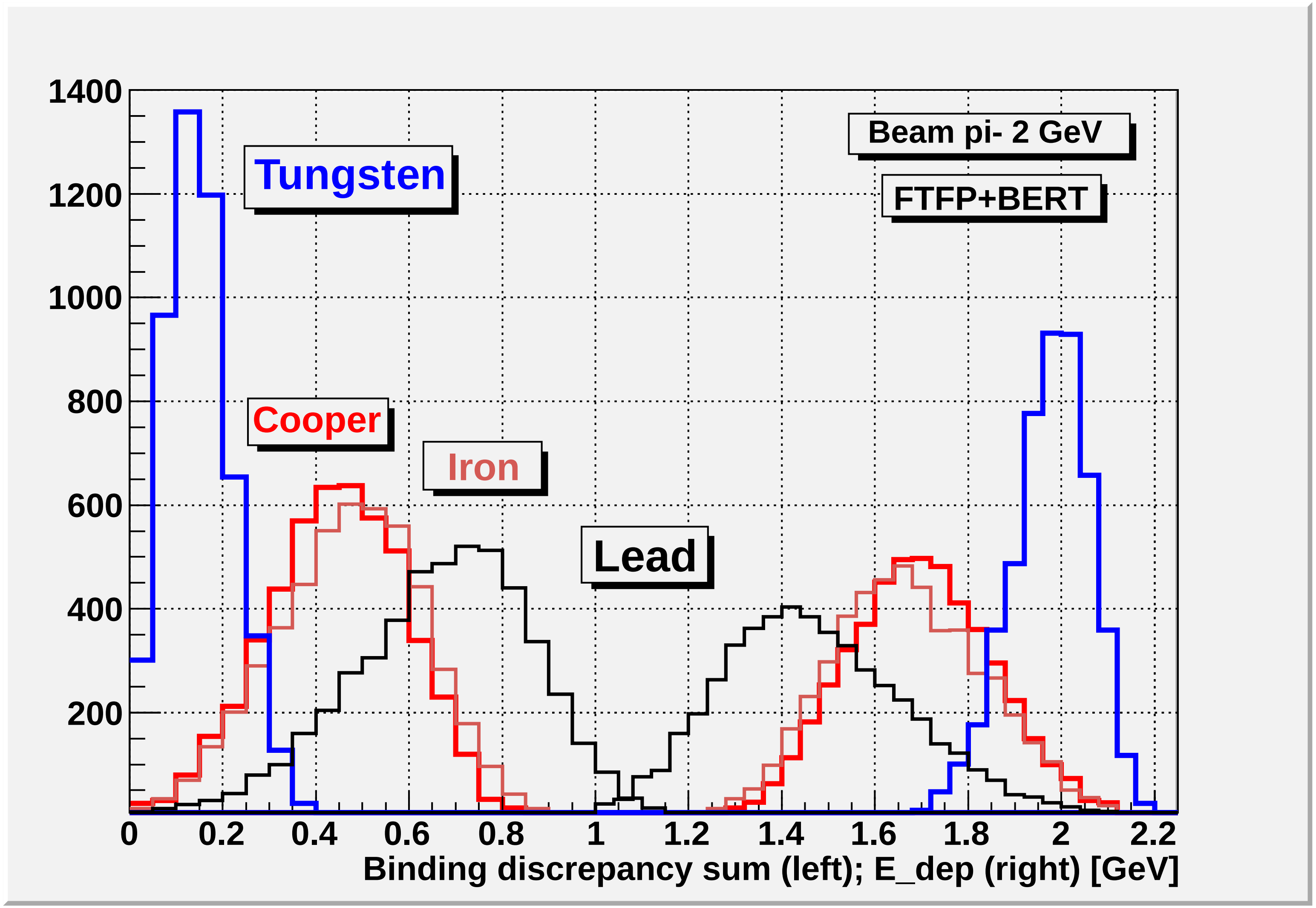
But for the first time it is enough to make a simple estimation of the absorber qualities/quantities for the next hadron calorimeter design.

Properties of the Calorimeter Absorber Materials

Today we will try to explore a new way to the hadron calorimeter design.

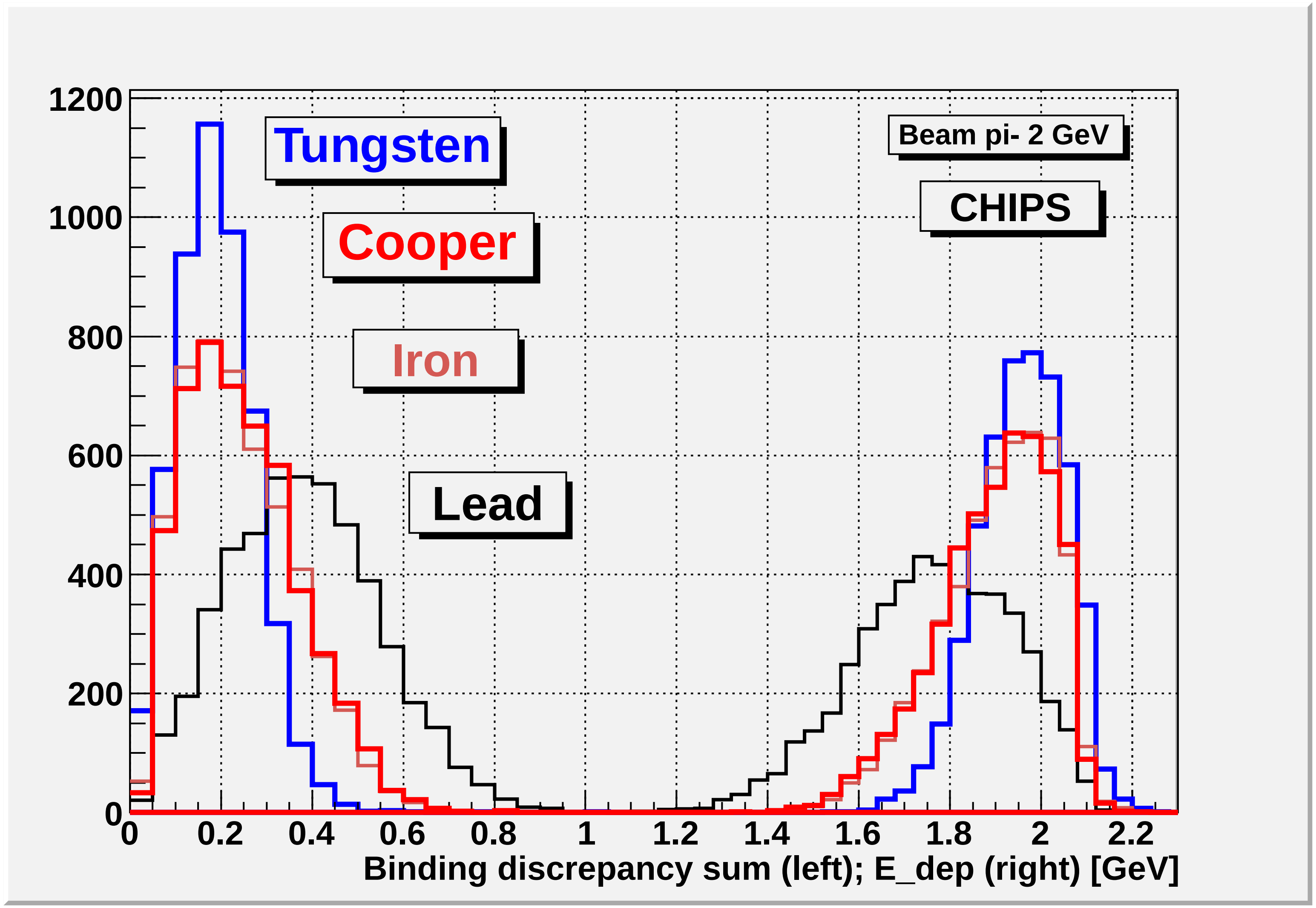
We will discuss 4 absorber materials Iron, Cooper, Tungsten and Lead.

Deposited energy and Binding discrepancy, FTFP+BERT



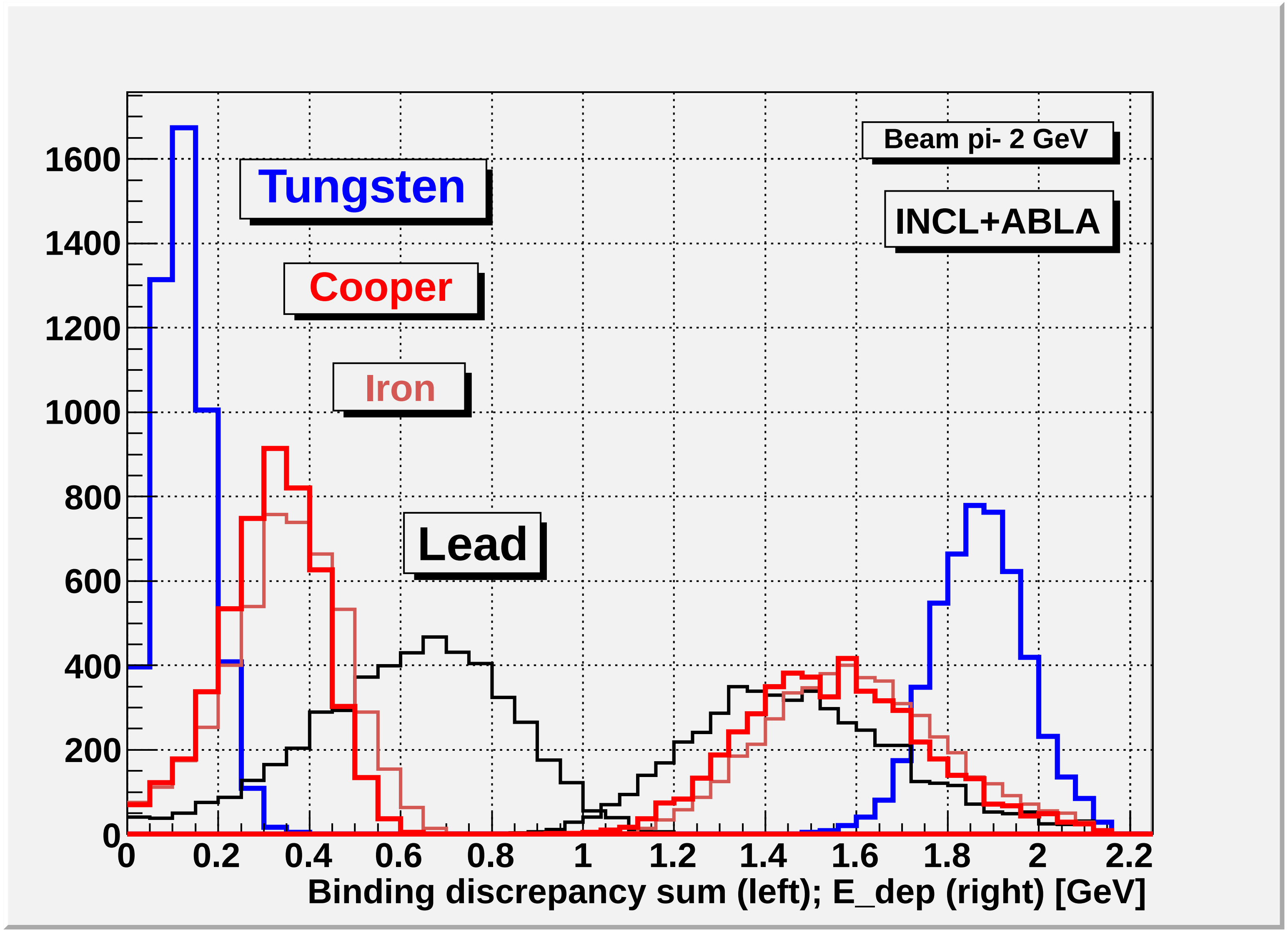
Bertini predicts unexpectedly small deviations for Tungsten binding discrepancy sum, in compare with Iron, Cooper or Lead absorbers.

Deposited energy and Binding discrepancy, CHIPS



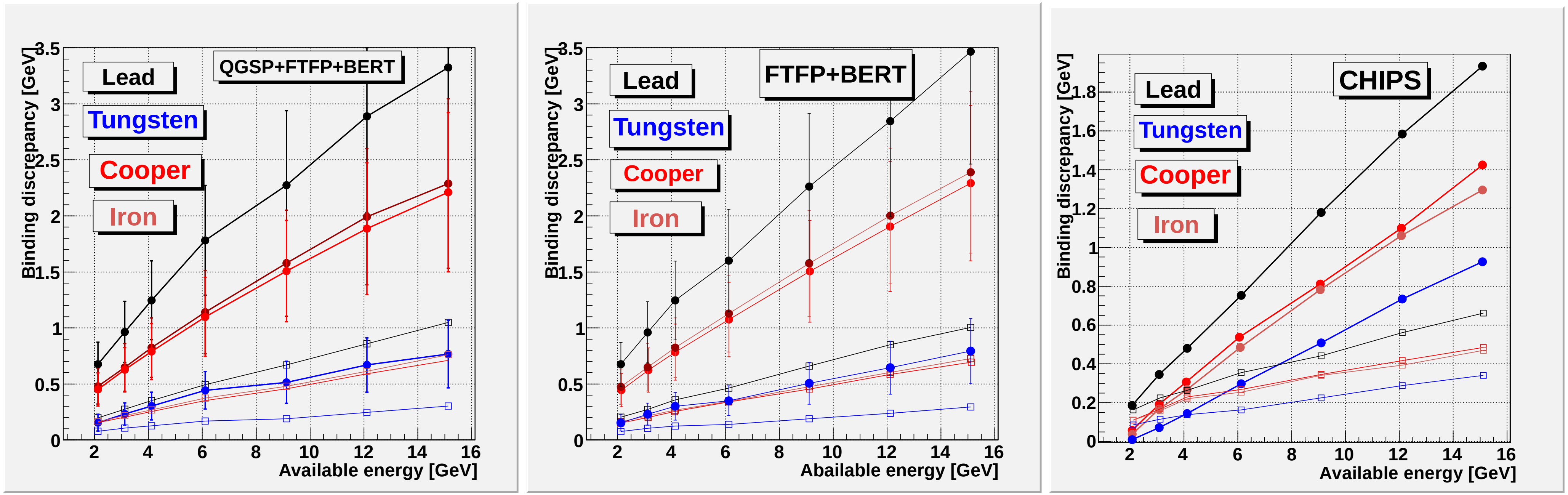
CHIPS predicts no so big difference between Tungsten and Iron in compare with FTFP+Bertini.

Deposited energy and Binding discrepancy, INCL+ABLA



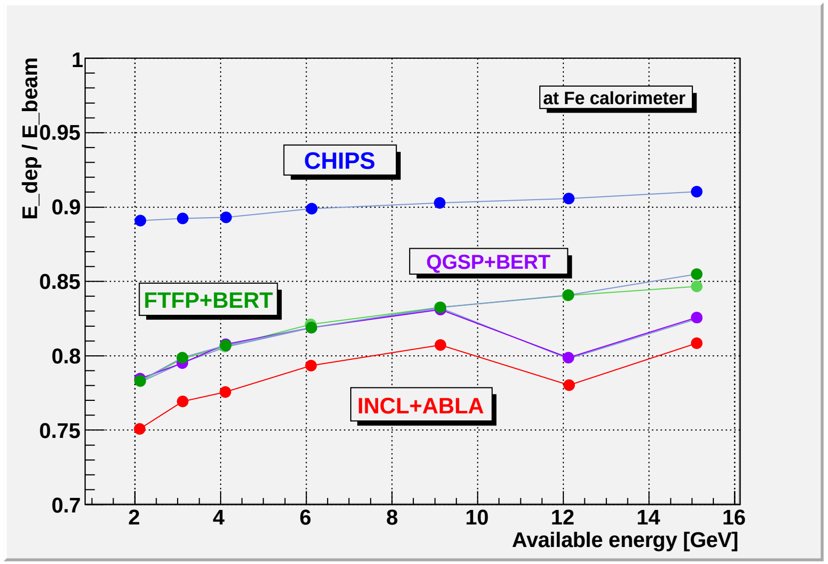
INCL+ABLA prediction is near by Bertini one.

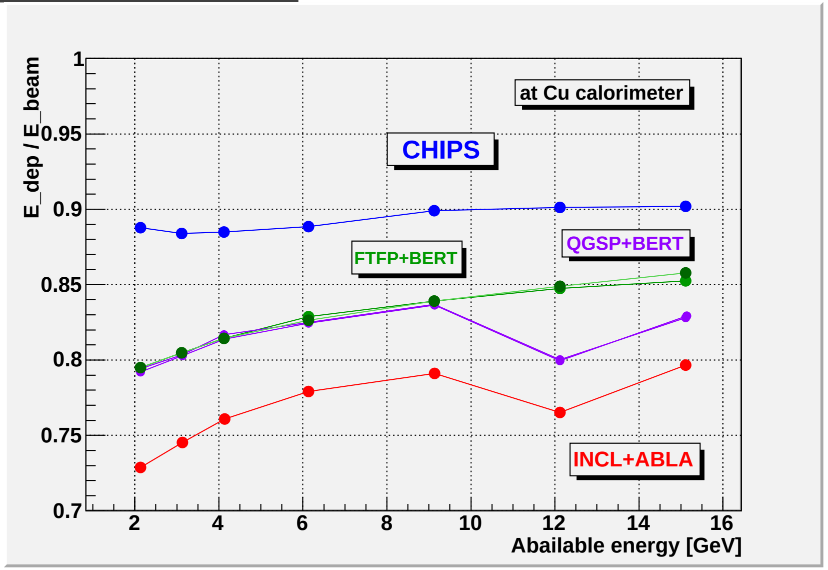
Sum of binding discrepancies

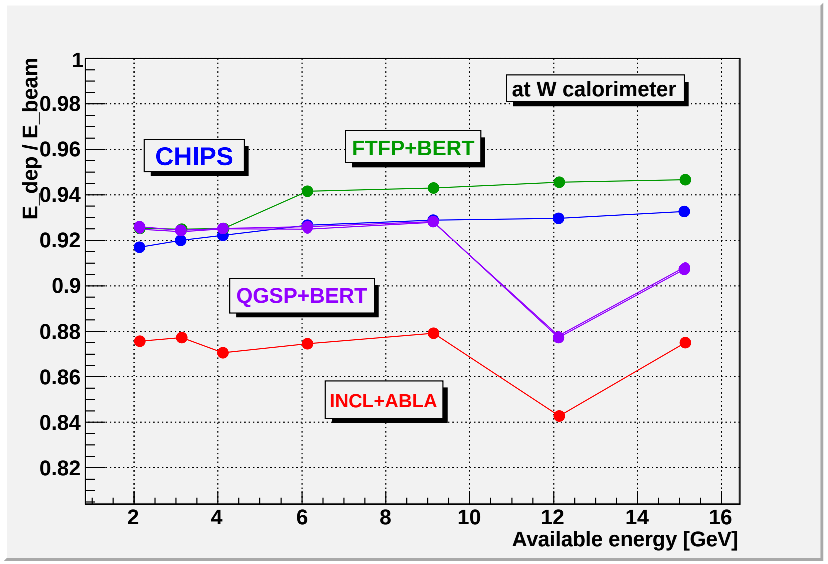


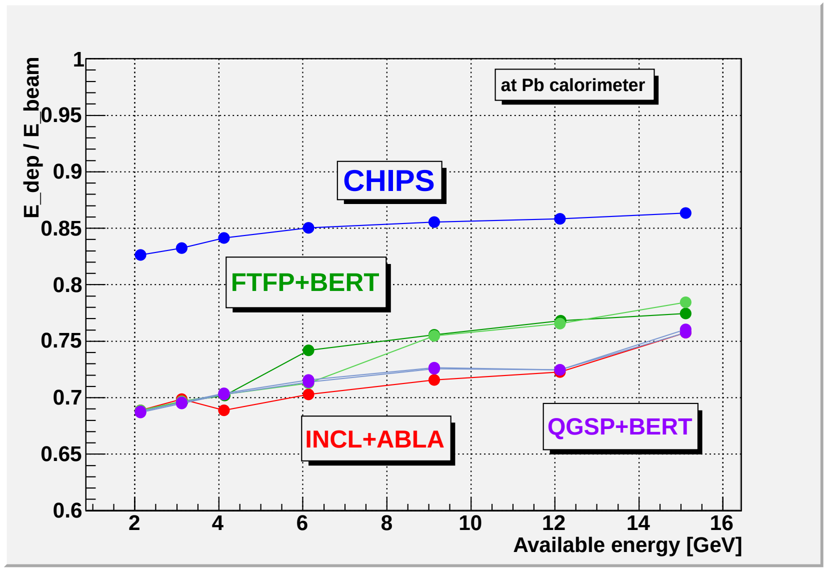
RMS of the binding discrepancy sum is shown with open markers.

Predicted Intrinsic ”pi/e” Ratio



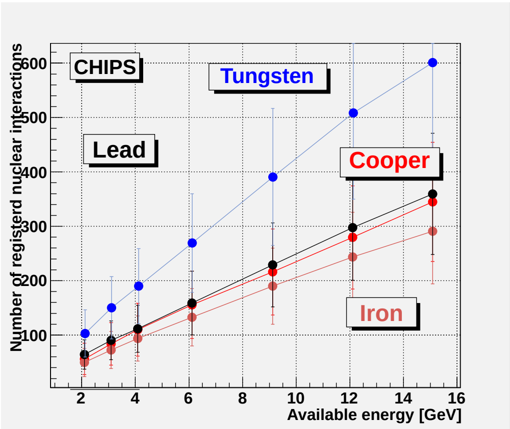


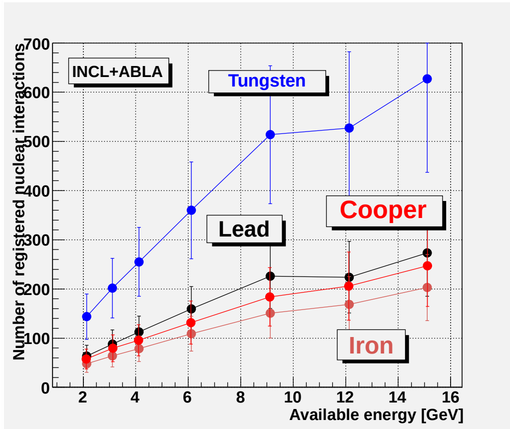


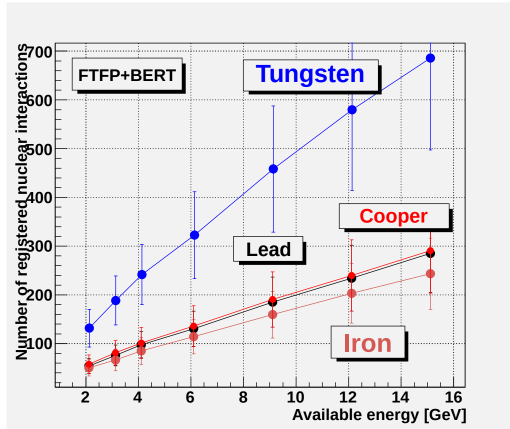


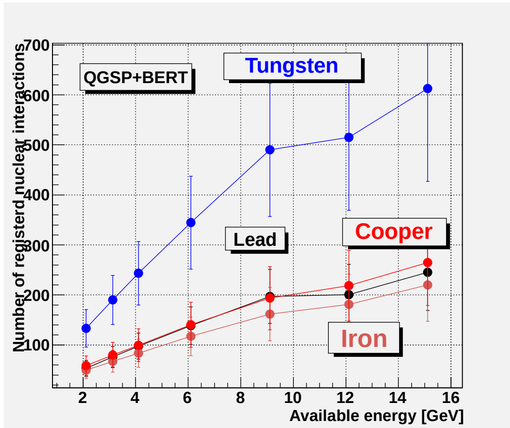
One of the interesting plots. Maybe CALICE is able to distinguish between GEANT4 models ?

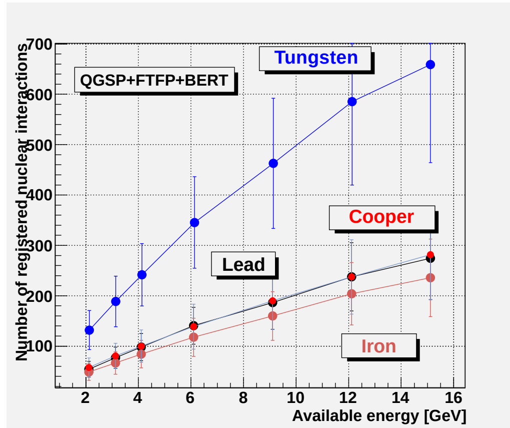
Number of interactions











Tungsten shows almost three times more nuclear interactions per GeV in compare with other materials.

Number of nuclear interactions in a hadron cascade calculated using an inelastic cross–sections.

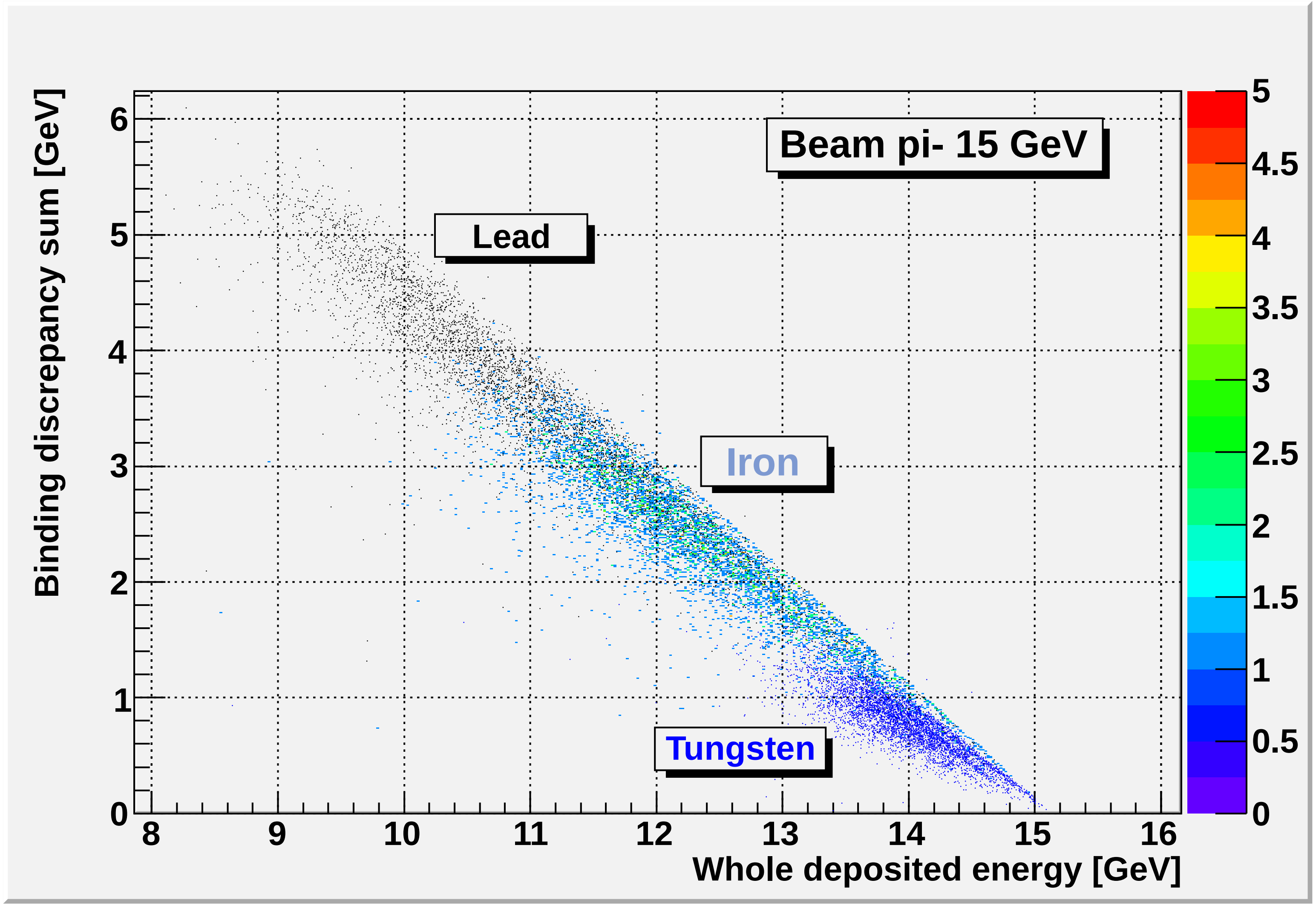
The inelastic cross–section is the most well known values. It should be the same for all nuclides and projectiles independently on the intranuclear cascade model. (Is this correct for GEANT4 ? I do not know.)

Cross–Correlations

It will be a short show just to feel a taste.

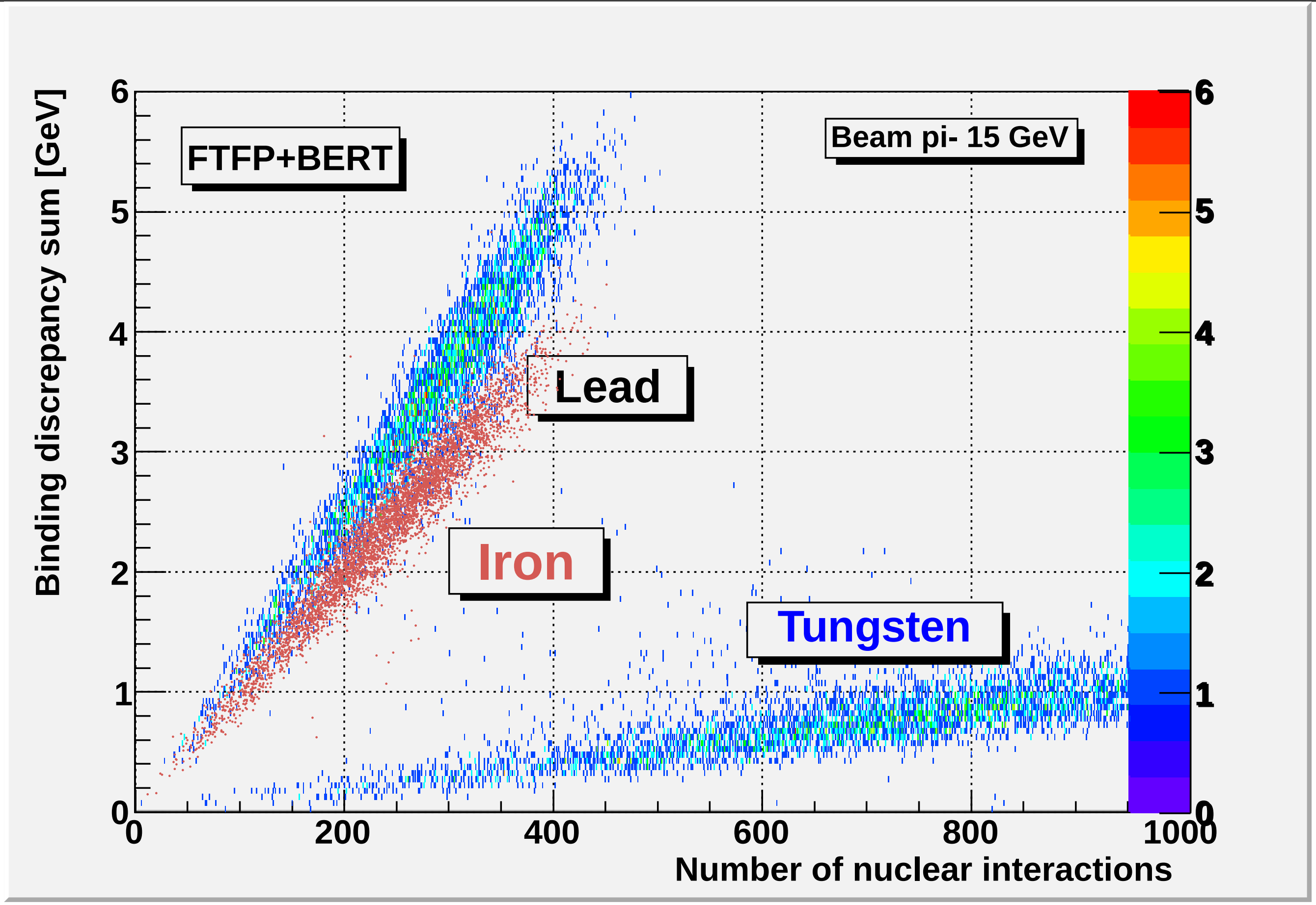
It needs much more time for detailed investigation.

Cross–Correlations



This anti–correlation shows an accuracy of the energy conservation law by GEANT4.

Sum of binding discrepancies vs N interactions



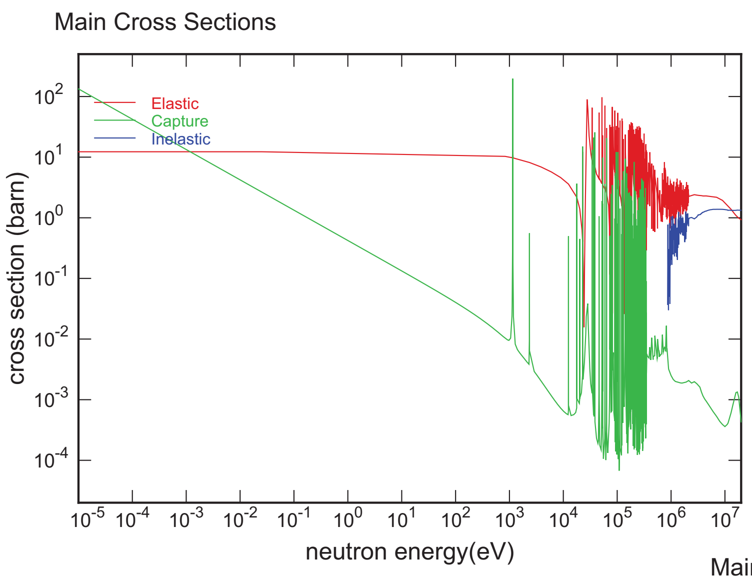
The picture of the biggest visible difference between absorber materials.

But, Tungsten is the material that does not "want" to convert a shower energy into mass of the absorber, even having much higher number of hadron interactions!

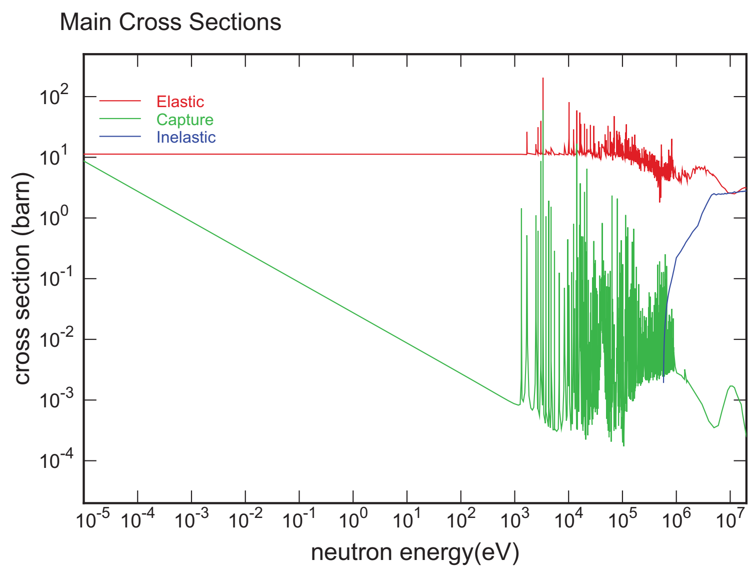
Reason for such a big difference is the values of cross-sections of so called (n,γ) reactions at low energy range.

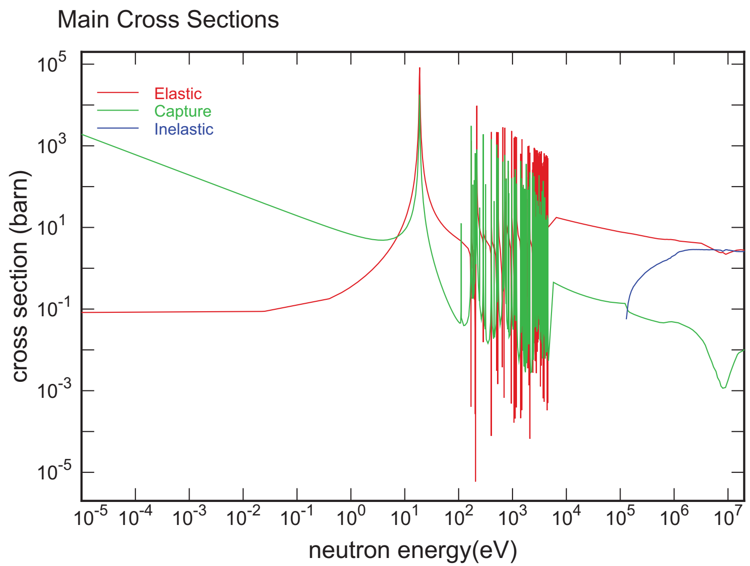
Cross-sections Fe,Pb,W. thanks to nds.iaea.

Iron



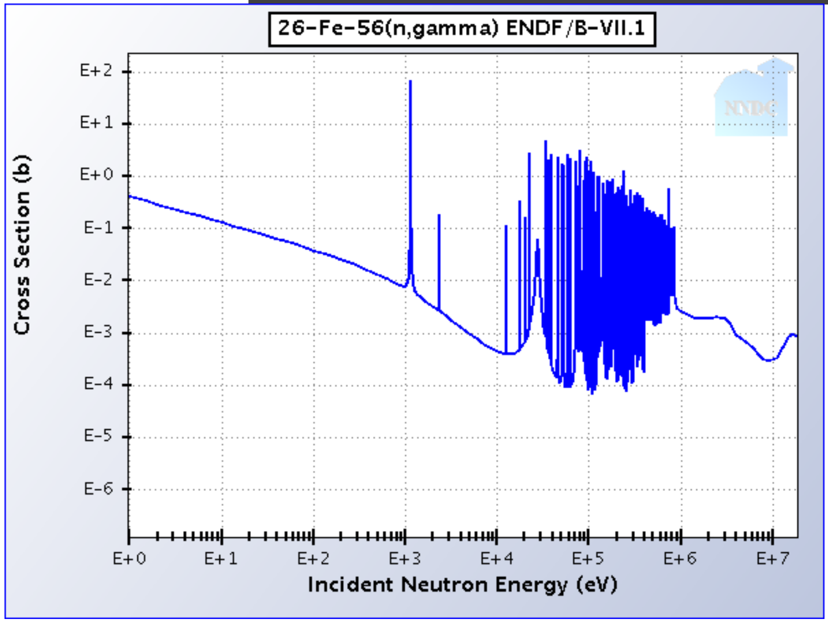
Lead

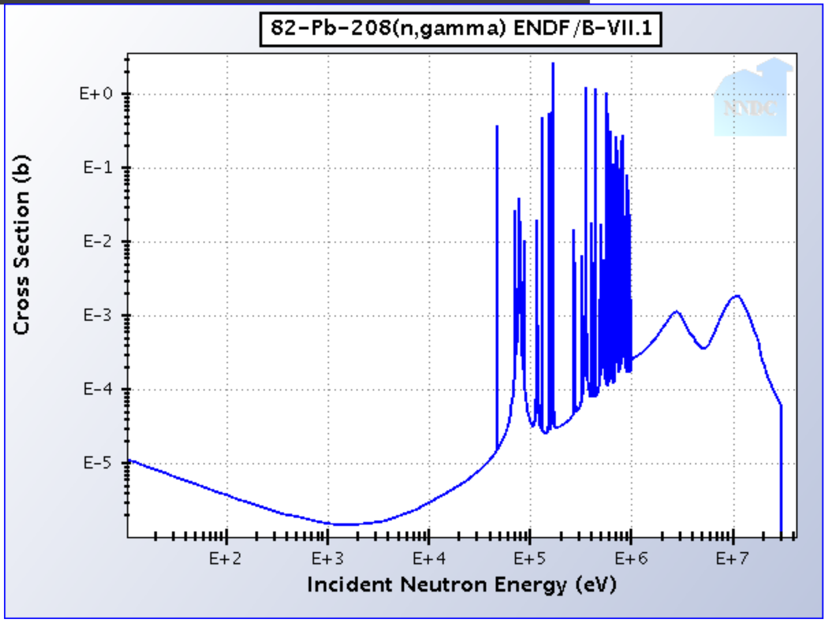


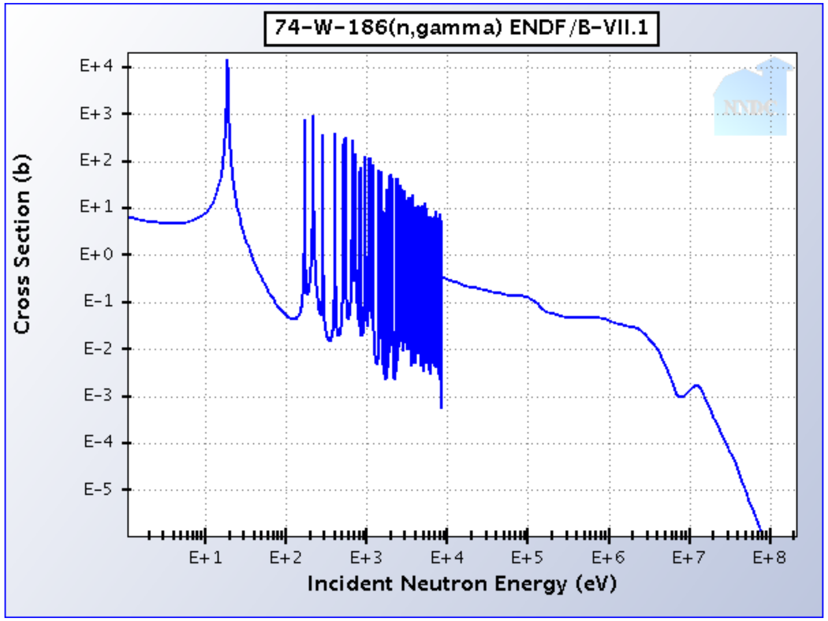


Tungsten

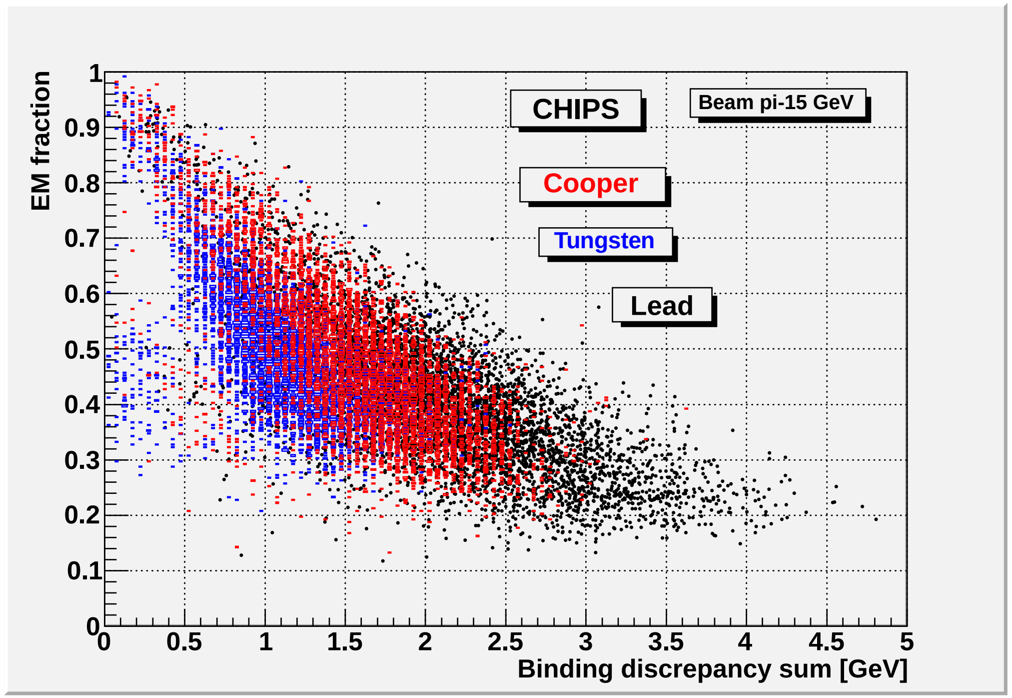
(n,γ) cross-sections, thanks to NNDC BNL.

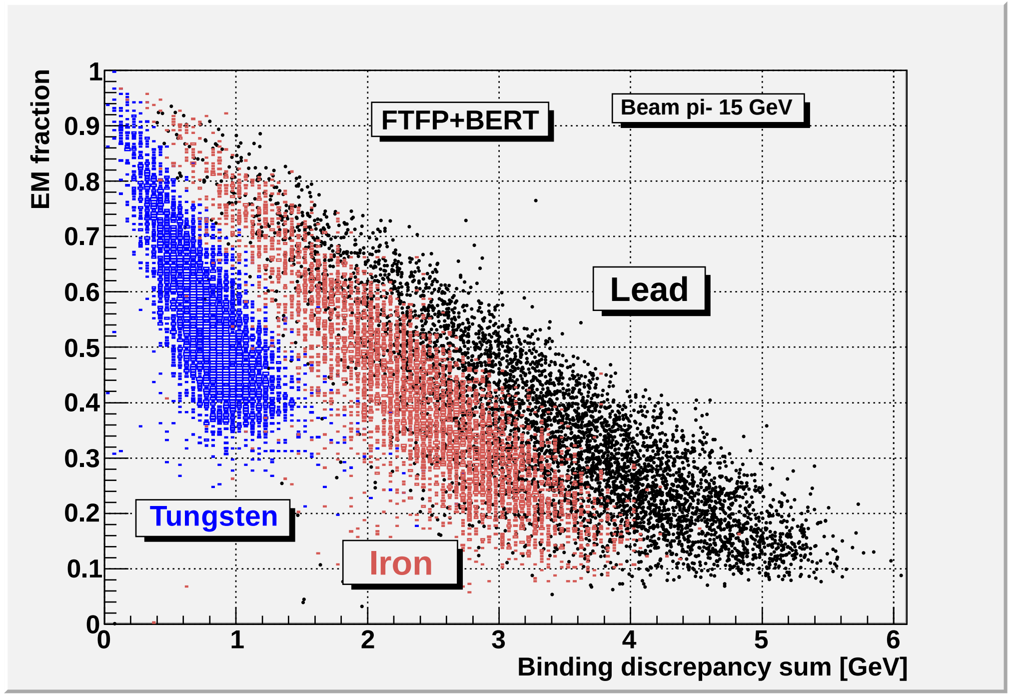






Cross–Correlations

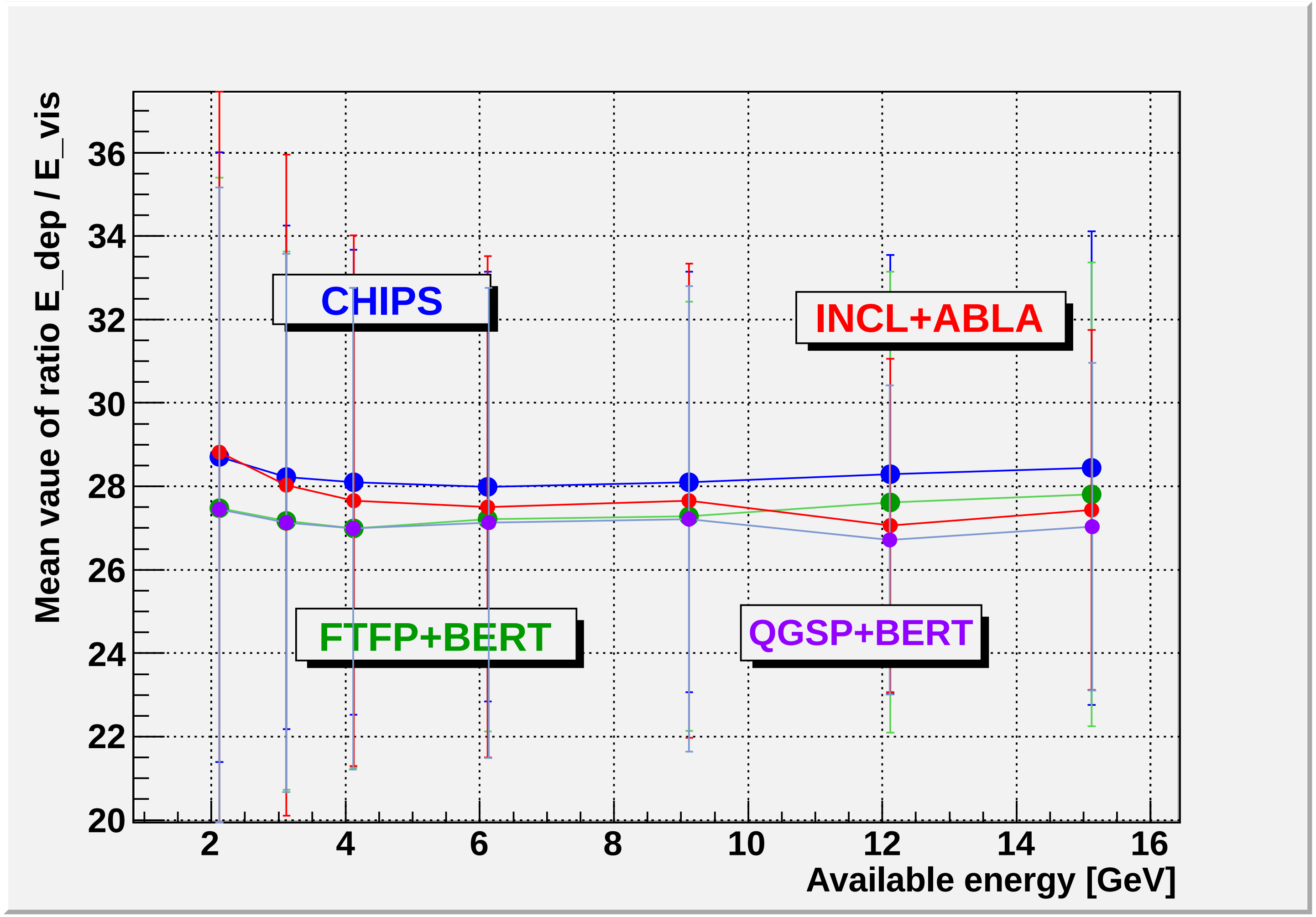




This anti–correlation shows: if a cascade energy converted/goes into electro–magnetic form than the binding discrepancies goes to zero.

How does all of this connected with visible energy?

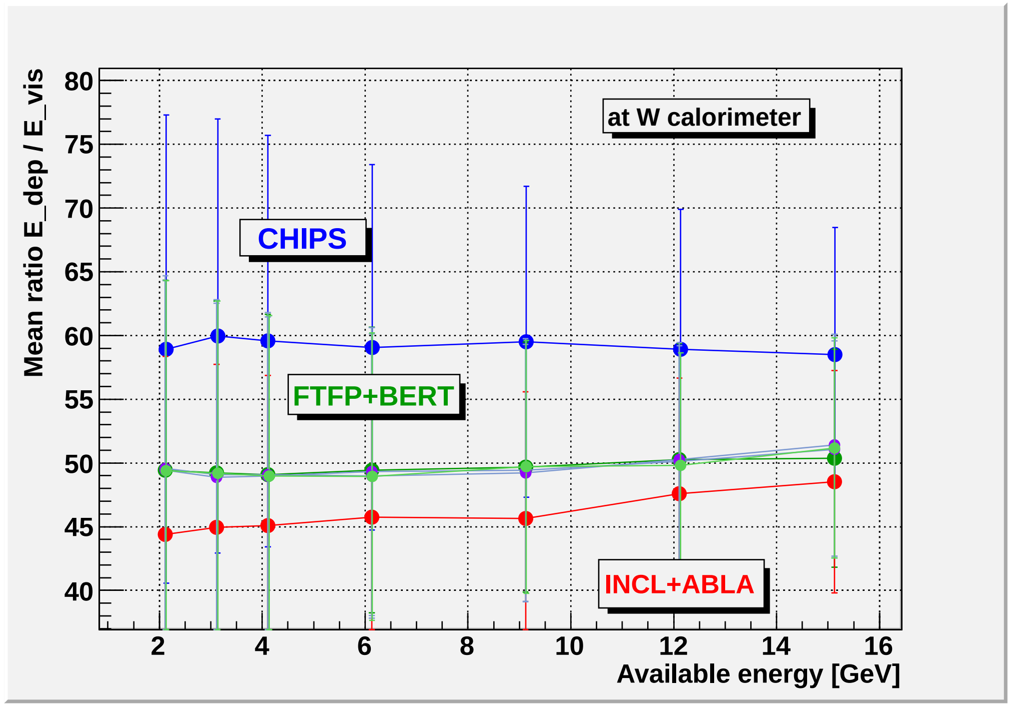
Sampling fraction for Fe calorimeter (20 mm Fe + 5 mm Scint)

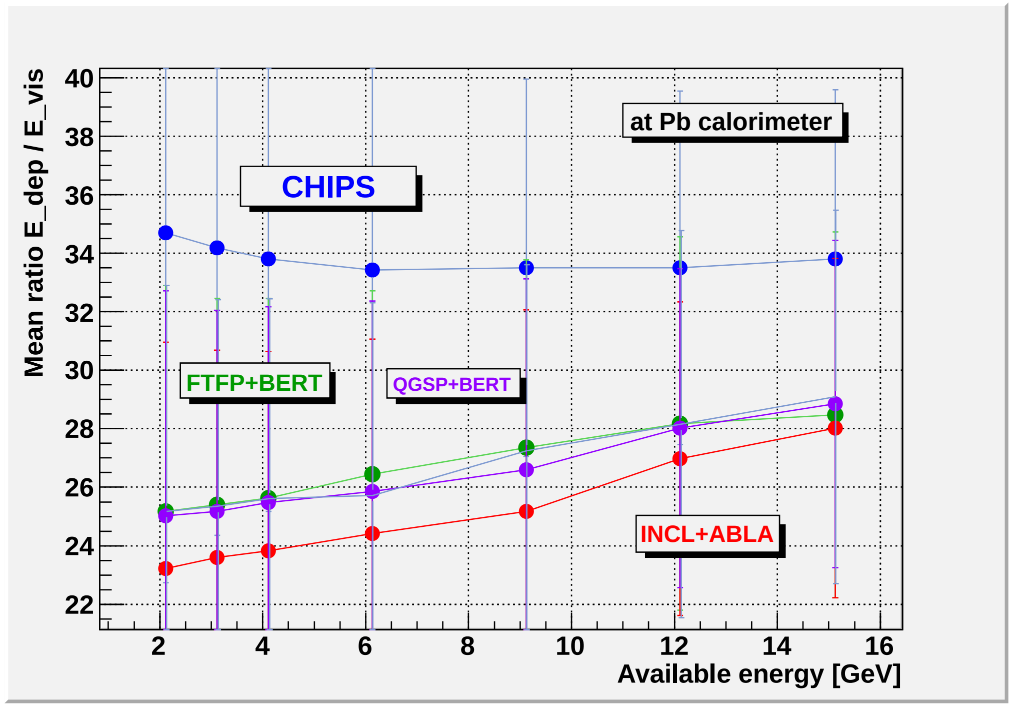


All GEANT4 models are in a tender agreement about intrinsic sampling fraction of Iron calorimeter.

Sampling fraction for W and Pb calorimeters

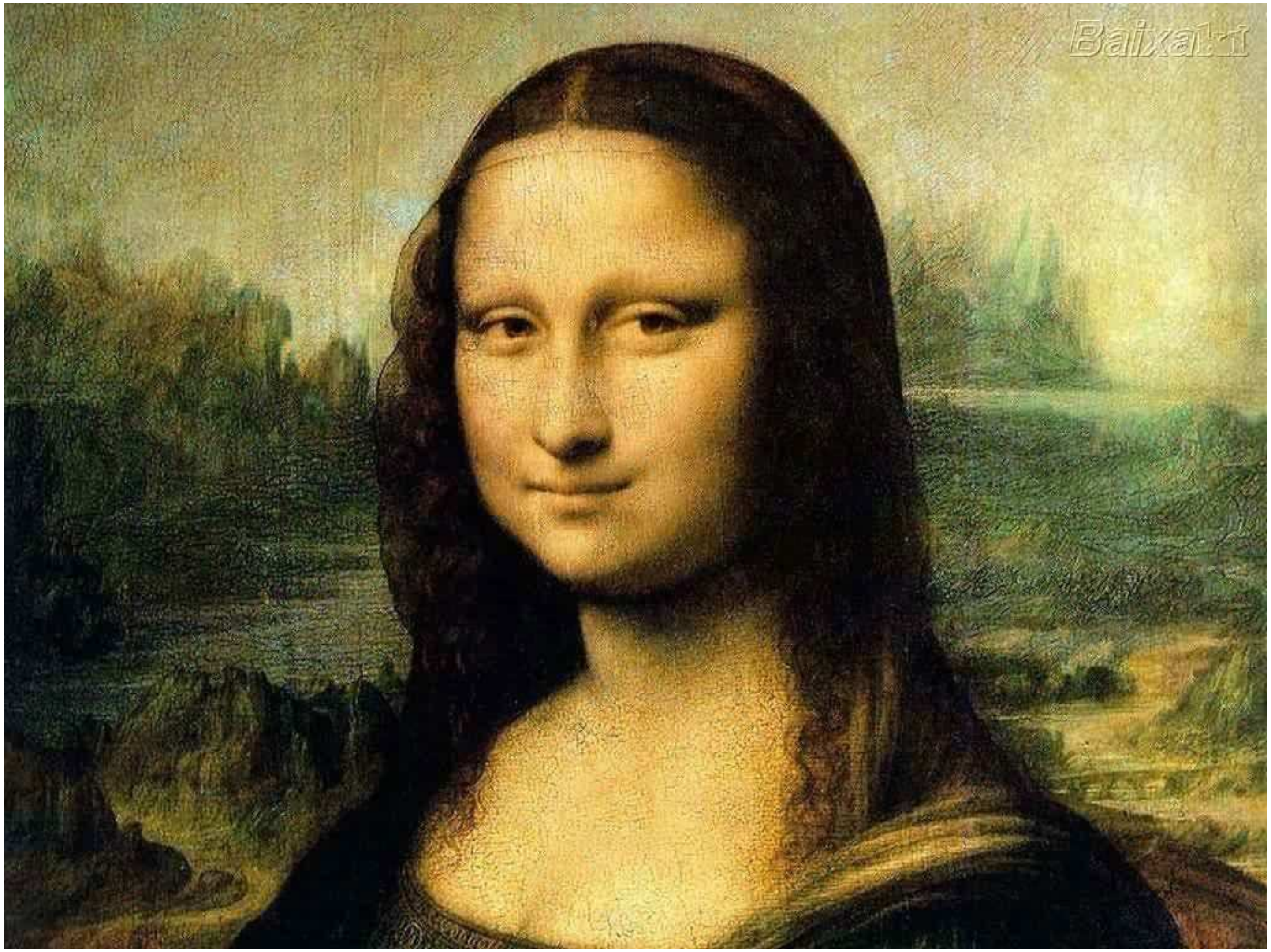
(20 mm W + 5 mm Scint) **(20 mm Pb + 5 mm Scint)**





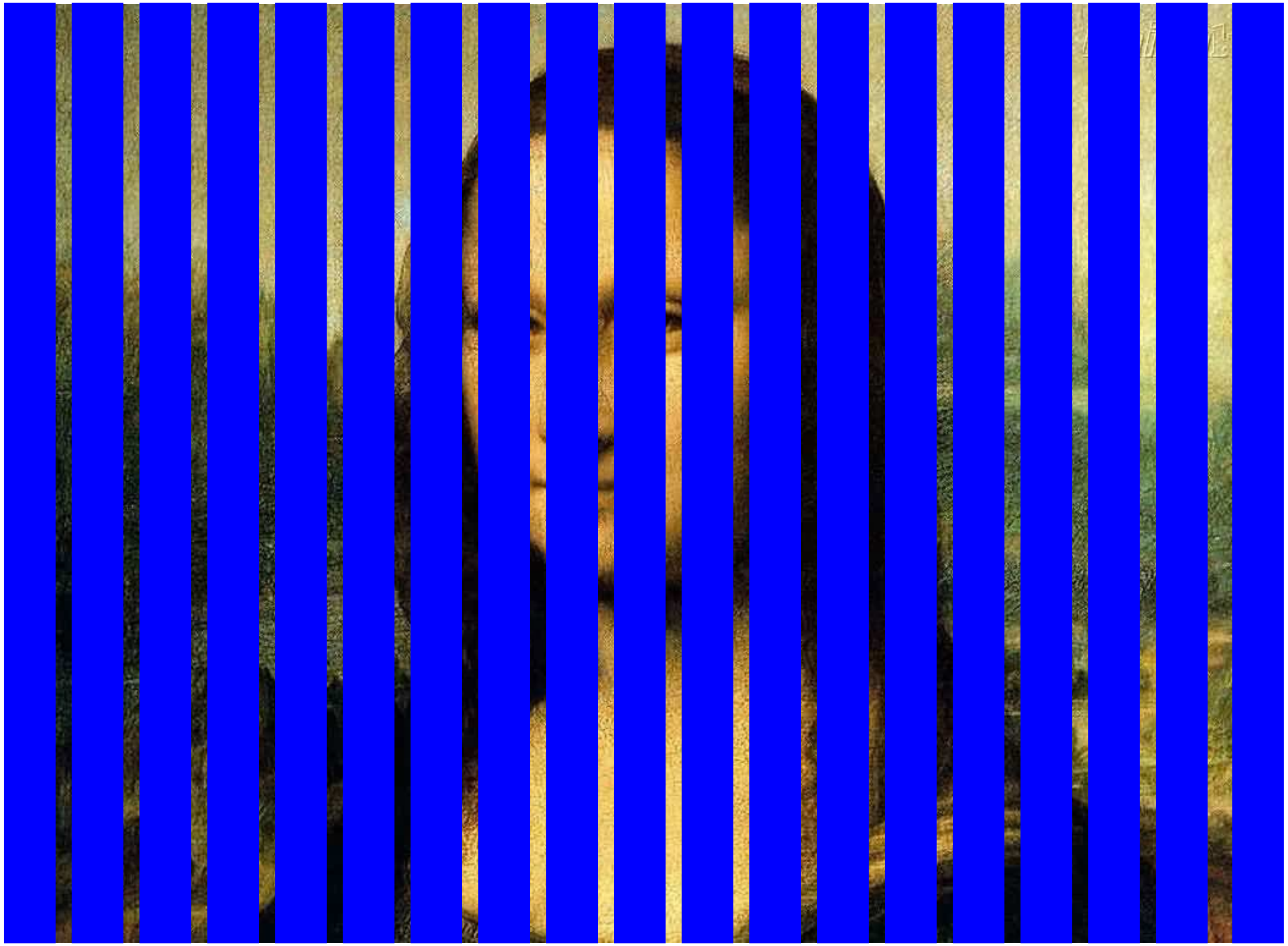
But a tiny agreement between models is finished just if we change a calorimeter material.

How does all of this connected with visible energy?



Well known face is presented here.

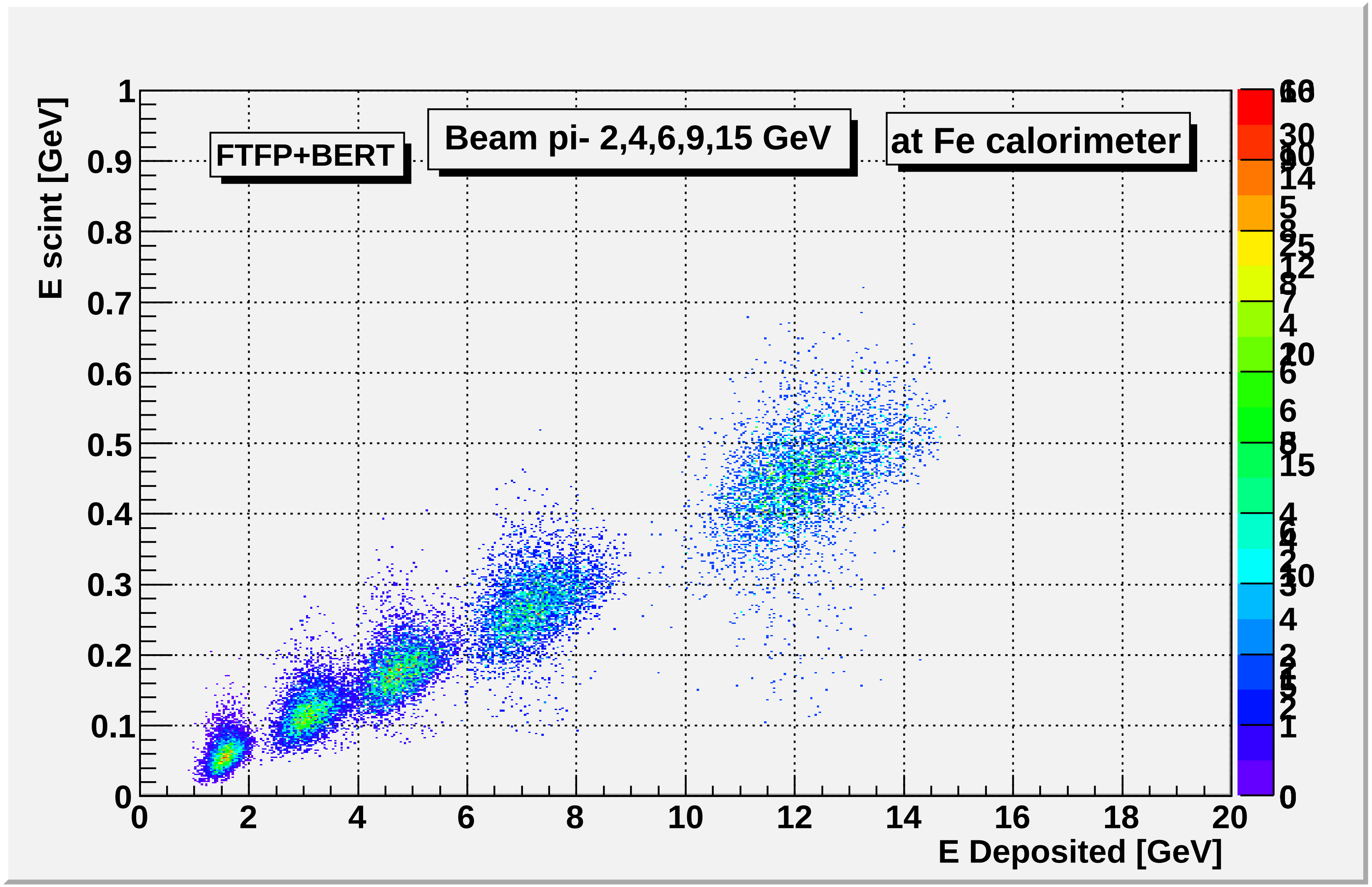
How do we see this face through the sampling calorimeter?



This is of about 10% of visibility. We should recall that the CALICE calorimeter sampling fraction is of about 3% only.

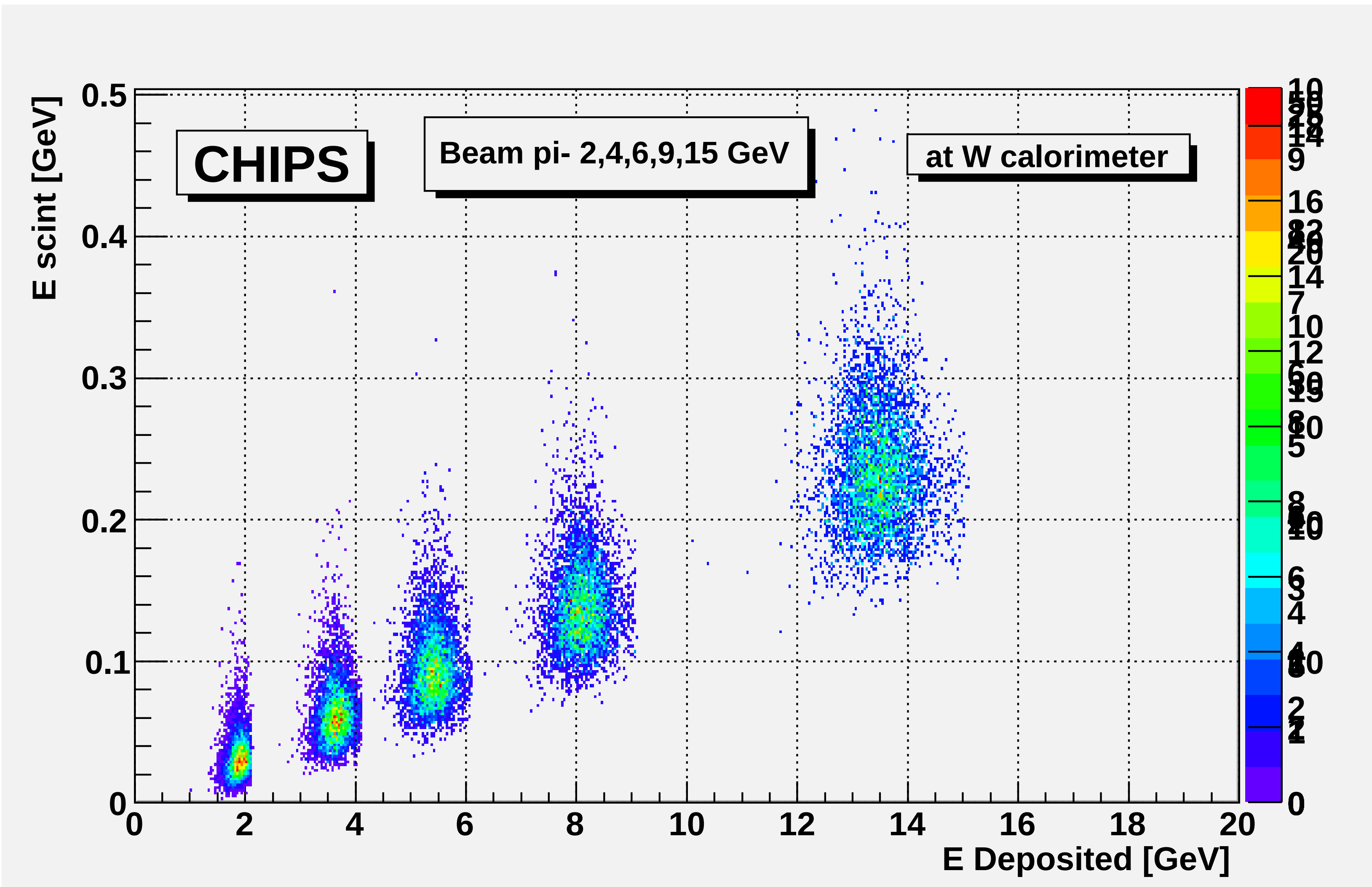
By the way this example is also concerned of any extremely high granularity detectors for sampling calorimeter.

How does all of this connected with visible energy?



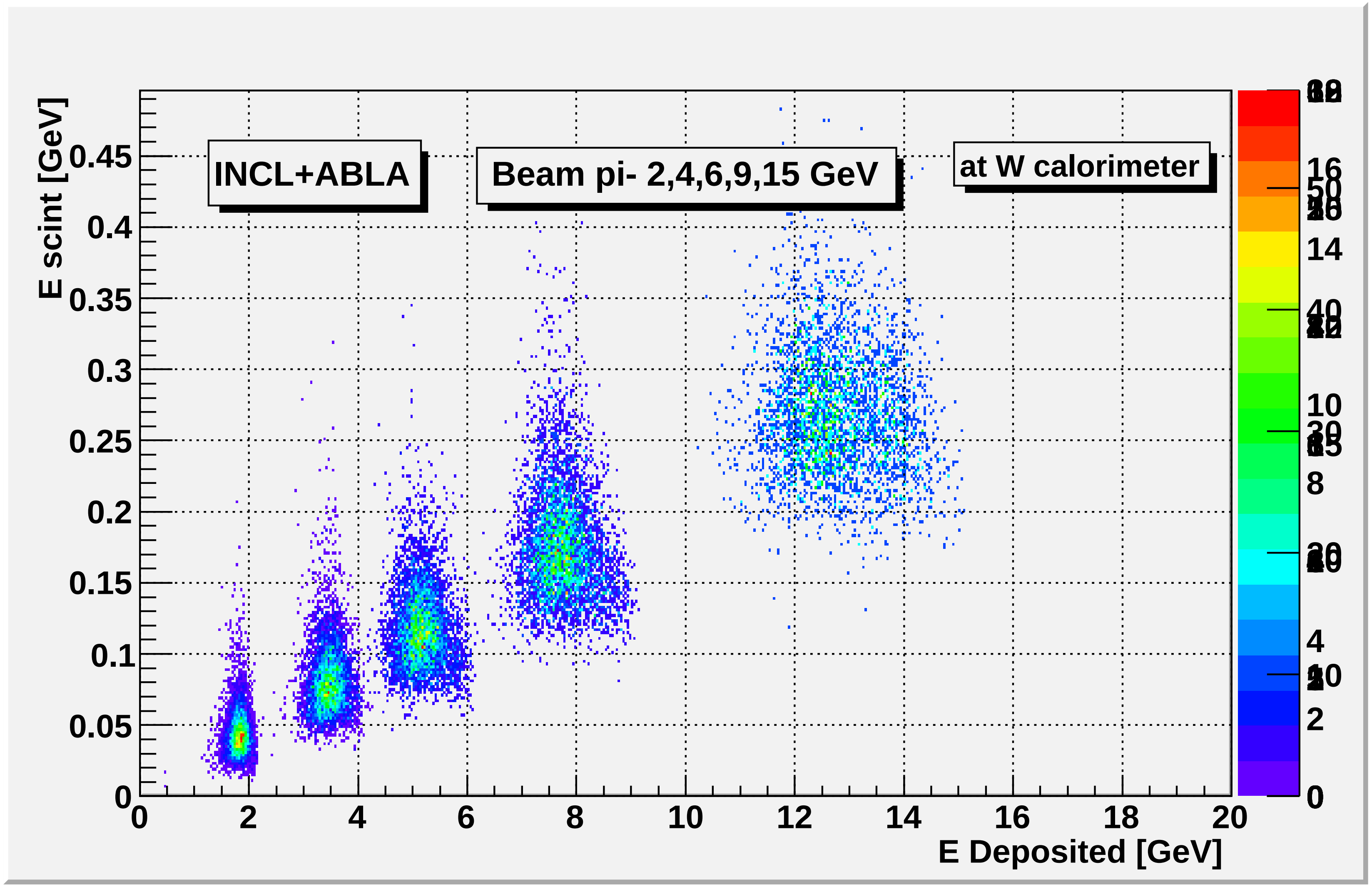
The correlations are bad as it was expected for 3% of samling fraction.

How does all of this connected with visible energy?



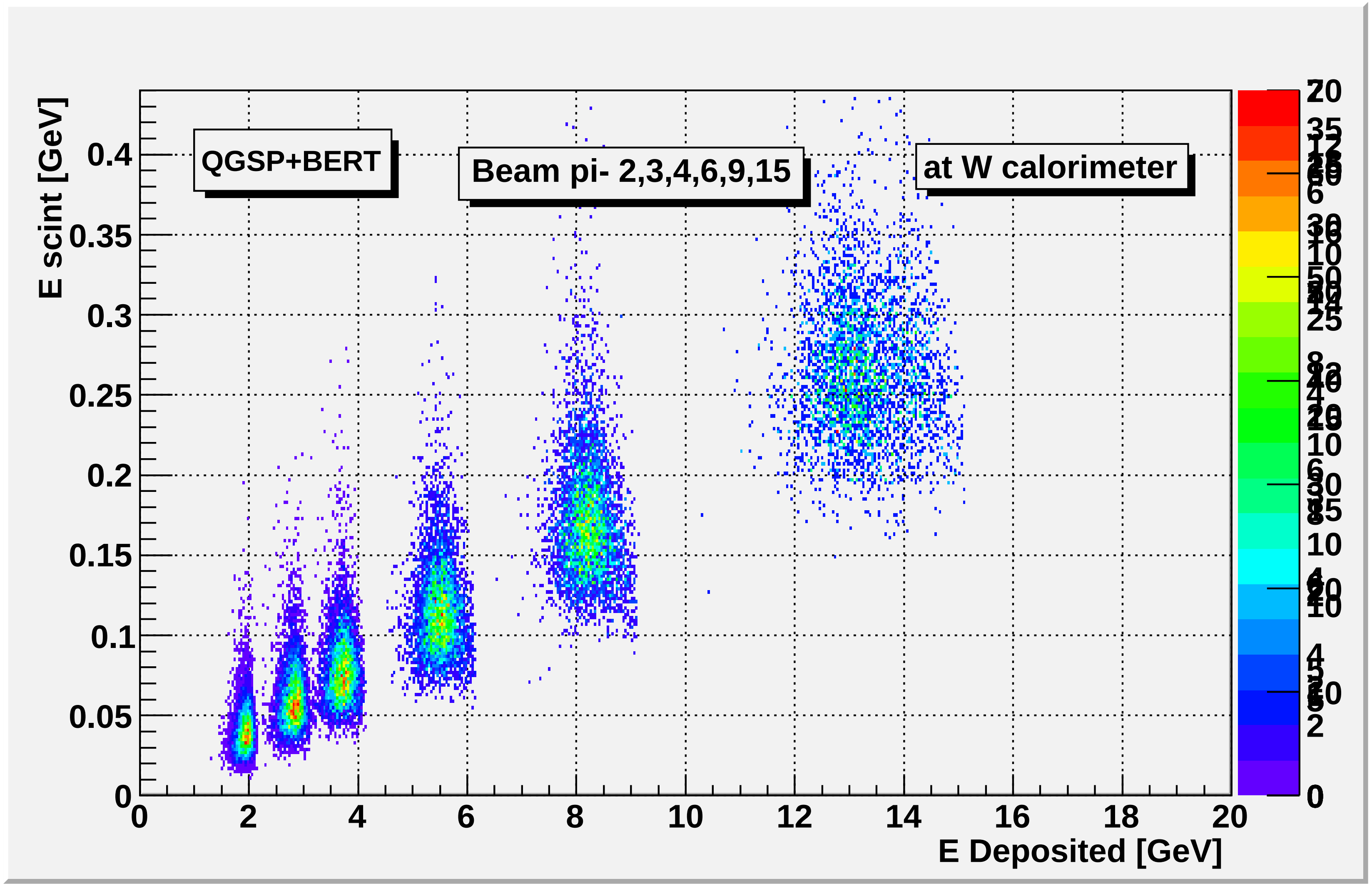
The correlations become to be invisible if we use CHIPS model for Tungsten calorimeter. We used 20mm W as an absorber and 5mm scintillator thickness. Sampling fraction of such a calorimeter is of about 60 (1.5%).

How does all of this connected with visible energy?



INCL+ABNLA also do not see any correlations at Tungsten calorimeter.

How does all of this connected with visible energy?



As well as QGSP+BERT.

Appendix

Table of Isotopes presented at the detector Geometry

Baryon :	proton[1:1]	Mass = 0.938272 [GeV]	Bind. enrg. = 0 [MeV]
Nucleus:	GenericIon[1:1]	Mass = 0.938272 [GeV]	Bind. enrg. = 0 [MeV]
Nucleus:	deuteron[1:2]	Mass = 1.87561 [GeV]	Bind. enrg. = 2.22457 [MeV]
Nucleus:	triton[1:3]	Mass = 2.80892 [GeV]	Bind. enrg. = 8.48180 [MeV]
Nucleus:	He3[2:3]	Mass = 2.80839 [GeV]	Bind. enrg. = 7.71804 [MeV]
Nucleus:	alpha[2:4]	Mass = 3.72738 [GeV]	Bind. enrg. = 28.2957 [MeV]
Nucleus:	C12[0.0][6:12]	Mass = 11.1749 [GeV]	Bind. enrg. = 92.1617 [MeV]
Nucleus:	C13[0.0][6:13]	Mass = 12.1095 [GeV]	Bind. enrg. = 97.1080 [MeV]
Nucleus:	N14[0.0][7:14]	Mass = 13.0402 [GeV]	Bind. enrg. = 104.659 [MeV]
Nucleus:	N15[0.0][7:15]	Mass = 13.9689 [GeV]	Bind. enrg. = 115.492 [MeV]
Nucleus:	O16[0.0][8:16]	Mass = 14.8951 [GeV]	Bind. enrg. = 127.619 [MeV]
Nucleus:	O17[0.0][8:17]	Mass = 15.8305 [GeV]	Bind. enrg. = 131.762 [MeV]
Nucleus:	O18[0.0][8:18]	Mass = 16.762 [GeV]	Bind. enrg. = 139.806 [MeV]
Nucleus:	Ar36[0.0][18:36]	Mass = 33.4944 [GeV]	Bind. enrg. = 306.717 [MeV]
Nucleus:	Ar38[0.0][18:38]	Mass = 35.3529 [GeV]	Bind. enrg. = 327.342 [MeV]
Nucleus:	Ar40[0.0][18:40]	Mass = 37.2155 [GeV]	Bind. enrg. = 343.810 [MeV]
Nucleus:	Fe54[0.0][26:54]	Mass = 50.2312 [GeV]	Bind. enrg. = 471.763 [MeV]
Nucleus:	Fe56[0.0][26:56]	Mass = 52.0898 [GeV]	Bind. enrg. = 492.258 [MeV]
Nucleus:	Fe57[0.0][26:57]	Mass = 53.0217 [GeV]	Bind. enrg. = 499.904 [MeV]
Nucleus:	Fe58[0.0][26:58]	Mass = 53.9512 [GeV]	Bind. enrg. = 509.949 [MeV]
Nucleus:	Cu63[0.0][29:63]	Mass = 58.6038 [GeV]	Bind. enrg. = 551.384 [MeV]
Nucleus:	Cu65[0.0][29:65]	Mass = 60.4651 [GeV]	Bind. enrg. = 569.211 [MeV]
Nucleus:	W180[0.0][74:180]	Mass = 167.582 [GeV]	Bind. enrg. = 1444.59 [MeV]
Nucleus:	W182[0.0][74:182]	Mass = 169.446 [GeV]	Bind. enrg. = 1459.33 [MeV]
Nucleus:	W183[0.0][74:183]	Mass = 170.38 [GeV]	Bind. enrg. = 1465.52 [MeV]
Nucleus:	W184[0.0][74:184]	Mass = 171.312 [GeV]	Bind. enrg. = 1472.94 [MeV]
Nucleus:	W186[0.0][74:186]	Mass = 173.178 [GeV]	Bind. enrg. = 1485.88 [MeV]
Nucleus:	Pb204[0.0][82:204]	Mass = 189.958 [GeV]	Bind. enrg. = 1607.51 [MeV]
Nucleus:	Pb206[0.0][82:206]	Mass = 191.823 [GeV]	Bind. enrg. = 1622.32 [MeV]
Nucleus:	Pb207[0.0][82:207]	Mass = 192.755 [GeV]	Bind. enrg. = 1629.06 [MeV]
Nucleus:	Pb208[0.0][82:208]	Mass = 193.688 [GeV]	Bind. enrg. = 1636.43 [MeV]

QGSP+FTFP+BERT 3.6

```
                         Hadronic Processes for <neutron>
                         -----------------------------------
      hadElastic  Models:               hElasticCHIPS: Emin(GeV)=    0  Emax(GeV)= 100000
      hadElastic  Crs sctns:           CHIPSElasticXS: Emin(GeV)=    0  Emax(GeV)= 100000
                                       GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000
NeutronInelastic  Models:                        QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                                                 FTFP: Emin(GeV)=    6  Emax(GeV)= 25
                                       BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 8
NeutronInelastic  Crs sctns:     G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                     G4CrossSectionPairGG: Wellisch-Laidlaw cross sections
                       below 91 GeV, Glauber-Gribov above
                                 G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                     G4CrossSectionPairGG: Wellisch-Laidlaw cross sections
                       below 91 GeV, Glauber-Gribov above
                                     GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
        nCapture  Models:                  G4LCapture: Emin(GeV)=    0  Emax(GeV)= 20000
        nCapture  Crs sctns:         GheishaCaptureXS: Emin(GeV)=    0  Emax(GeV)= 100000
        nFission  Models:                  G4LFission: Emin(GeV)=    0  Emax(GeV)= 20000
        nFission  Crs sctns:         GheishaFissionXS: Emin(GeV)=    0  Emax(GeV)= 100000

                         Hadronic Processes for <pi->
                         -----------------------------------
      hadElastic  Models:                hElasticLHEP: Emin(GeV)=    0  Emax(GeV)= 1
                                      hElasticGlauber: Emin(GeV)=    1  Emax(GeV)= 100000
      hadElastic  Crs sctns:      Barashenkov-Glauber: Emin(GeV)=    0  Emax(GeV)= 100000
                                       GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000
PionMinusInelastic  Models:                      QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                                                 FTFP: Emin(GeV)=    6  Emax(GeV)= 25
                                       BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 8
PionMinusInelastic  Crs sctns:   G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                     G4CrossSectionPairGG: G4PiNuclearCrossSection cross sections
                       below 91 GeV, Glauber-Gribov above
                                 G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                     G4CrossSectionPairGG: G4PiNuclearCrossSection cross sections
                       below 91 GeV, Glauber-Gribov above
                                     GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
```

QGSP+BERT 3.4

```
                          Hadronic Processes for <neutron>
                          -----------------------------------
         hadElastic  Models:              hElasticCHIPS: Emin(GeV)=    0  Emax(GeV)= 100000
         hadElastic  Crs sctns:          CHIPSElasticXS: Emin(GeV)=    0  Emax(GeV)= 100000
                                         GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000
   NeutronInelastic  Models:                       QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                                   G4LENeutronInelastic: Emin(GeV)=  9.5  Emax(GeV)= 25
                                         BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 9.9
   NeutronInelastic  Crs sctns:      G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                        G4CrossSectionPairGG: Wellisch-Laidlaw cross sections
                          below 91 GeV, Glauber-Gribov above
                                       GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
           nCapture  Models:                  G4LCapture: Emin(GeV)=    0  Emax(GeV)= 20000
           nCapture  Crs sctns:         GheishaCaptureXS: Emin(GeV)=    0  Emax(GeV)= 100000
           nFission  Models:                  G4LFission: Emin(GeV)=    0  Emax(GeV)= 20000
           nFission  Crs sctns:         GheishaFissionXS: Emin(GeV)=    0  Emax(GeV)= 100000

                          Hadronic Processes for <pi->
                          -----------------------------------
         hadElastic  Models:                hElasticLHEP: Emin(GeV)=    0  Emax(GeV)= 1
                                         hElasticGlauber: Emin(GeV)=    1  Emax(GeV)= 100000
         hadElastic  Crs sctns:       Barashenkov-Glauber: Emin(GeV)=    0  Emax(GeV)= 100000
                                         GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000
 PionMinusInelastic  Models:                       QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                                 G4LEPionMinusInelastic: Emin(GeV)=  9.5  Emax(GeV)= 25
                                         BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 9.9
 PionMinusInelastic  Crs sctns:      G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                        G4CrossSectionPairGG: G4PiNuclearCrossSection cross sections
                          below 91 GeV, Glauber-Gribov above
                                       GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
```

FTFP+BERT 1.3

```
                    Hadronic Processes for <neutron>
                    ----------------------------------
      hadElastic  Models:             hElasticCHIPS: Emin(GeV)=    0  Emax(GeV)= 100000
      hadElastic  Crs sctns:          CHIPSElasticXS: Emin(GeV)=    0  Emax(GeV)= 100000
                                      GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000
NeutronInelastic  Models:                       FTFP: Emin(GeV)=    4  Emax(GeV)= 100000
                                      BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 5
NeutronInelastic  Crs sctns:      G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                     G4CrossSectionPairGG: Wellisch-Laidlaw cross sections
                       below 91 GeV, Glauber-Gribov above
                                    GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
        nCapture  Models:                  G4LCapture: Emin(GeV)=    0  Emax(GeV)= 20000
        nCapture  Crs sctns:          GheishaCaptureXS: Emin(GeV)=    0  Emax(GeV)= 100000
        nFission  Models:                  G4LFission: Emin(GeV)=    0  Emax(GeV)= 20000
        nFission  Crs sctns:          GheishaFissionXS: Emin(GeV)=    0  Emax(GeV)= 100000

                    Hadronic Processes for <pi->
                    ----------------------------------
      hadElastic  Models:                hElasticLHEP: Emin(GeV)=    0  Emax(GeV)= 1
                                     hElasticGlauber: Emin(GeV)=    1  Emax(GeV)= 100000
      hadElastic  Crs sctns:       Barashenkov-Glauber: Emin(GeV)=    0  Emax(GeV)= 100000
                                      GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000
PionMinusInelastic  Models:                     FTFP: Emin(GeV)=    4  Emax(GeV)= 100000
                                      BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 5
PionMinusInelastic  Crs sctns:    G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                     G4CrossSectionPairGG: G4PiNuclearCrossSection cross sections
                       below 91 GeV, Glauber-Gribov above
                                    GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
```

QGSP+BERT+CHIPS 2.0

```
                              Hadronic Processes for <neutron>
                              ---------------------------------
       hadElastic  Models:                hElasticCHIPS: Emin(GeV)=    0  Emax(GeV)= 100000
       hadElastic  Crs sctns:            CHIPSElasticXS: Emin(GeV)=    0  Emax(GeV)= 100000
                                         GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000
 NeutronInelastic  Models:                         QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                                   G4LENeutronInelastic: Emin(GeV)=  9.5  Emax(GeV)= 25
                                         BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 9.9
 NeutronInelastic  Crs sctns:      G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                         G4CrossSectionPairGG: Wellisch-Laidlaw cross sections
                           below 91 GeV, Glauber-Gribov above
                                       GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
         nCapture  Models:                   G4LCapture: Emin(GeV)=    0  Emax(GeV)= 20000
         nCapture  Crs sctns:          GheishaCaptureXS: Emin(GeV)=    0  Emax(GeV)= 100000
         nFission  Models:                   G4LFission: Emin(GeV)=    0  Emax(GeV)= 20000
         nFission  Crs sctns:          GheishaFissionXS: Emin(GeV)=    0  Emax(GeV)= 100000

                              Hadronic Processes for <pi->
                              ---------------------------------
       hadElastic  Models:                 hElasticLHEP: Emin(GeV)=    0  Emax(GeV)= 1
                                         hElasticGlauber: Emin(GeV)=    1  Emax(GeV)= 100000
       hadElastic  Crs sctns:       Barashenkov-Glauber: Emin(GeV)=    0  Emax(GeV)= 100000
                                         GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000
PionMinusInelastic  Models:                        QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                                 G4LEPionMinusInelastic: Emin(GeV)=  9.5  Emax(GeV)= 25
                                         BertiniCascade: Emin(GeV)=    0  Emax(GeV)= 9.9
PionMinusInelastic  Crs sctns:     G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                         G4CrossSectionPairGG: G4PiNuclearCrossSection cross sections
                           below 91 GeV, Glauber-Gribov above
                                       GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
```

QGSP+INCL+ABLA 0.2

```
                    Hadronic Processes for <neutron>
                    ----------------------------------
   hadElastic  Models:             hElasticCHIPS: Emin(GeV)=    0  Emax(GeV)= 100000
   hadElastic  Crs sctns:          CHIPSElasticXS: Emin(GeV)=    0  Emax(GeV)= 100000
                                   GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000
NeutronInelastic  Models:                    QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                             G4LENeutronInelastic: Emin(GeV)=  9.5  Emax(GeV)= 25
                                   BertiniCascade: Emin(GeV)=  2.9  Emax(GeV)= 9.9
                                INCL/ABLA Cascade: Emin(GeV)=    0  Emax(GeV)= 3
NeutronInelastic  Crs sctns:     Wellisch-Laidlaw: Emin(GeV)=    0  Emax(GeV)= 100000
                             G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                G4CrossSectionPairGG: Wellisch-Laidlaw cross sections
                  below 91 GeV, Glauber-Gribov above
                                 GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
     nCapture  Models:                  G4LCapture: Emin(GeV)=    0  Emax(GeV)= 20000
     nCapture  Crs sctns:         GheishaCaptureXS: Emin(GeV)=    0  Emax(GeV)= 100000
     nFission  Models:                  G4LFission: Emin(GeV)=    0  Emax(GeV)= 20000
     nFission  Crs sctns:         GheishaFissionXS: Emin(GeV)=    0  Emax(GeV)= 100000

                    Hadronic Processes for <pi->
                    ----------------------------------
   hadElastic  Models:              hElasticLHEP: Emin(GeV)=    0  Emax(GeV)= 1
                                  hElasticGlauber: Emin(GeV)=    1  Emax(GeV)= 100000
   hadElastic  Crs sctns:       Barashenkov-Glauber: Emin(GeV)=    0  Emax(GeV)= 100000
                                   GheishaElastic: Emin(GeV)=    0  Emax(GeV)= 100000
PionMinusInelastic  Models:                  QGSP: Emin(GeV)=   12  Emax(GeV)= 100000
                           G4LEPionMinusInelastic: Emin(GeV)=  9.5  Emax(GeV)= 25
                                   BertiniCascade: Emin(GeV)=  2.9  Emax(GeV)= 9.9
                                INCL/ABLA Cascade: Emin(GeV)=    0  Emax(GeV)= 3
PionMinusInelastic  Crs sctns:   G4PiNuclearCrossSection: Emin(GeV)=    0  Emax(GeV)= 99900
                             G4CrossSectionPairGG: Emin(GeV)=    0  Emax(GeV)= 100000
                G4CrossSectionPairGG: G4PiNuclearCrossSection cross sections
                  below 91 GeV, Glauber-Gribov above
                                 GheishaInelastic: Emin(GeV)=    0  Emax(GeV)= 100000
```

CHIPS 1.1

CHIPS does not print such a table

Description of GEANT4 Process types

```
===> Process: Type = 1  Transportation
===> Process: Type = 1 : SubType = 91;

===> Process: Type = 2 : SubType = 1;
CoulombScat:  for  mu+
CoulombScat:  for  mu-

===> Process = Type = 2 : SubType = 10;
msc:        for e-
msc:        for proton
muMsc:      for mu+
msc:        for pi-
msc:        for GenericIon

===> Process = Type = 2 : SubType = 2; dE/dX
eIoni:      for  e-
eIoni:      for  e+
muIoni:     for  mu+
muIoni:     for  mu-
hIoni:      for  kaon+
hIoni:      for  kaon-
hIoni:      for  pi+
hIoni:      for  pi-
hIoni:      for  proton
hIoni:      for  anti_proton
ionIoni:    for GenericIon
```

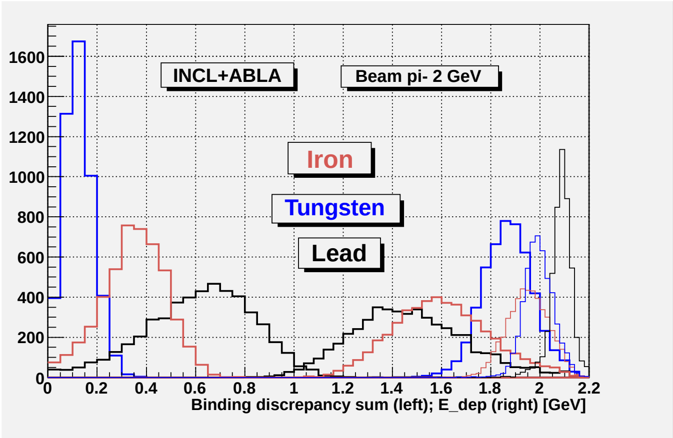
Description of GEANT4 Process types

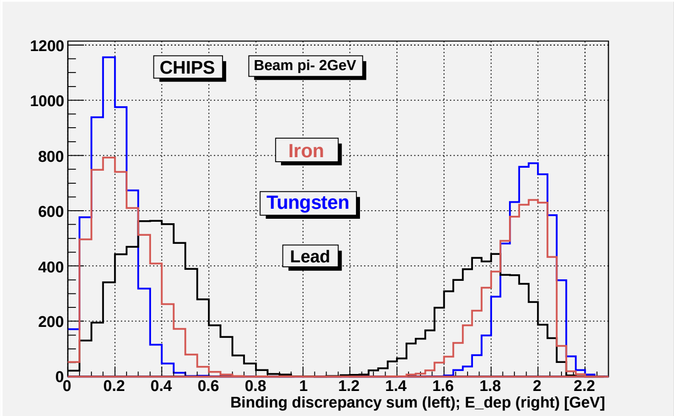
```
===> Process = Type = 2 : SubType = 3;
eBrem:     for  e-
eBrem:     for  e+
muBrems:   for  mu+
muBrems:   for  mu-
hBrems:    for  proton
hBrems:    for  kaon+
hBrems:    for  kaon-
hBrems:    for  pi+
hBrems:    for  pi-

===> Process = Type = 2 : SubType = 4;
hPairProd:  for  proton
hPairProd:  for  kaon-
muPairProd: for  mu+
muPairProd: for  mu-
hPairProd:  for  pi+
PairProd:   for  pi-

===> Process = Type = 2 : SubType = 5;
annihil:   for  e+

===> Process = Type = 2 : SubType = 12; for gammas
phot:
===> Process = Type = 2 : SubType = 13;
compt:
===> Process = Type = 2 : SubType = 14;
conv:
```

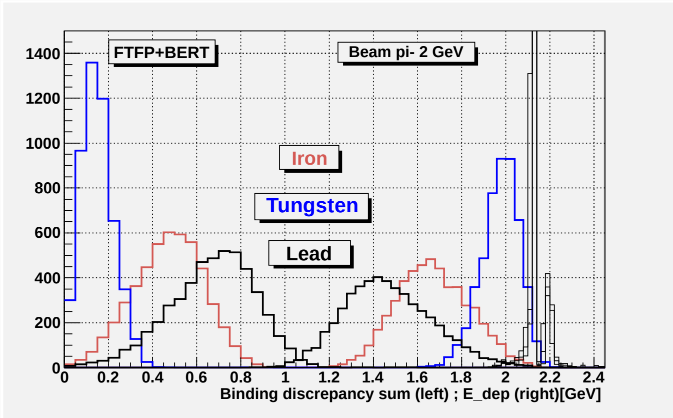
Description of GEANT4 Process types

```
ElectroNuclear   Hadronic Processes for <e->
PhotonInelastic  Hadronic Processes for <gamma>

===> Process = Type = 1 : SubType = 91; Transportation
Secondaries are protons after elasic scattering

===> Process = Type = 4 : SubType = 111;
hadElastic;

===> Process = Type = 4 : SubType = 121;
PionMinusInelastic
PionPlusInelastic
KaonPlusInelastic
KaonMinusInelastic
LambdaInelastic
ProtonInelastic
AntiProtonInelastic
NeutronInelastic
AntiNeutronInelastic
ionInelastic Hadronic for <GenericIon>

===> Process = Type = 4 : SubType = 131;
nCapture;

===> Process = Type = 4 : SubType = -1;
CHIPSNuclearCaptureAtRest; Particle: pi- (meson)

===> Process = 6 : 201 Decay;
Particle: mu+ (lepton)
Particle: pi+ (meson)
Particle: pi0 (meson)
Particle: kaon0S (meson)
Particle: triton (nucleus) ?????
```

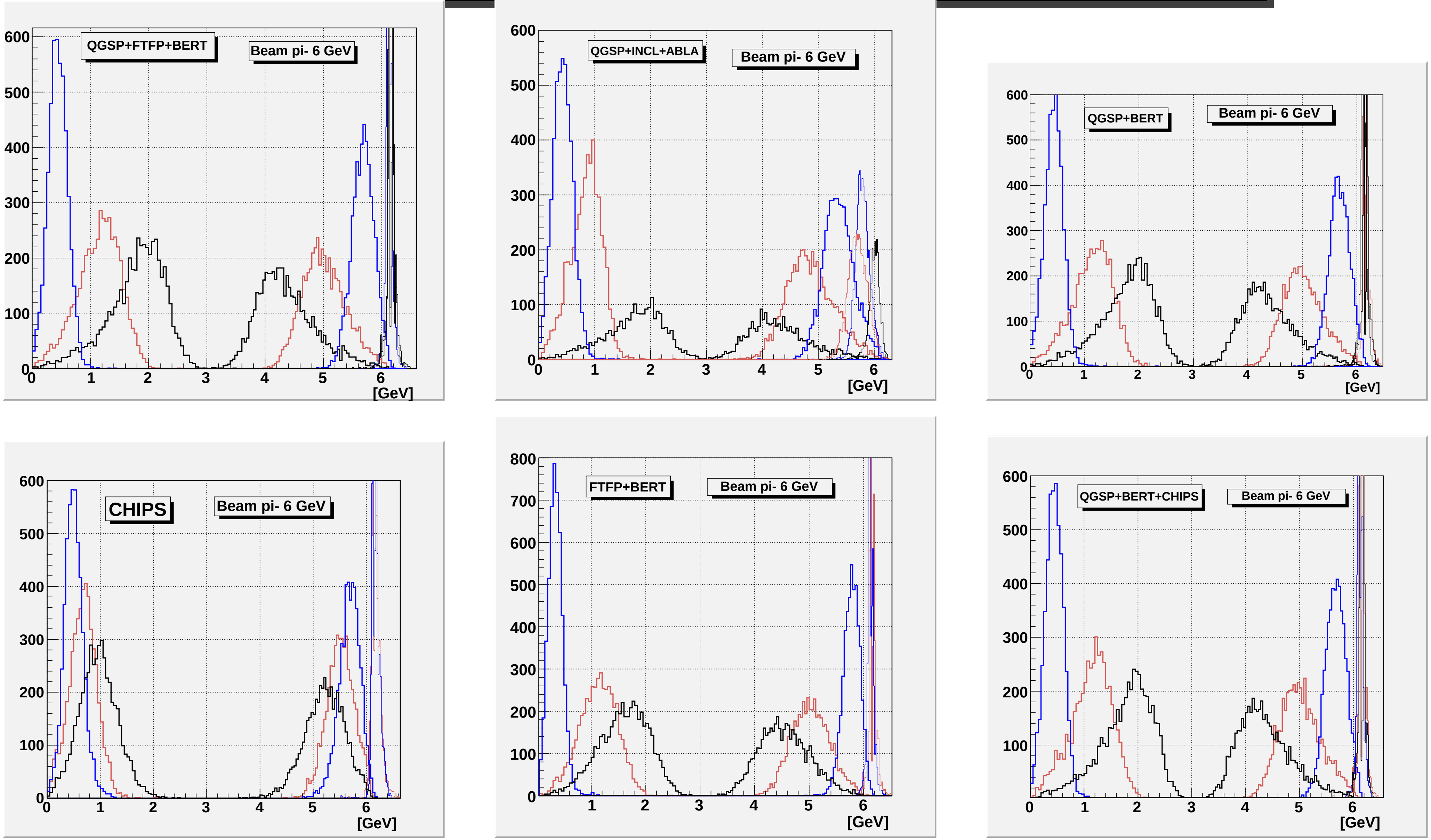
Deposited energy and Binding discrepancy, 2 GeV



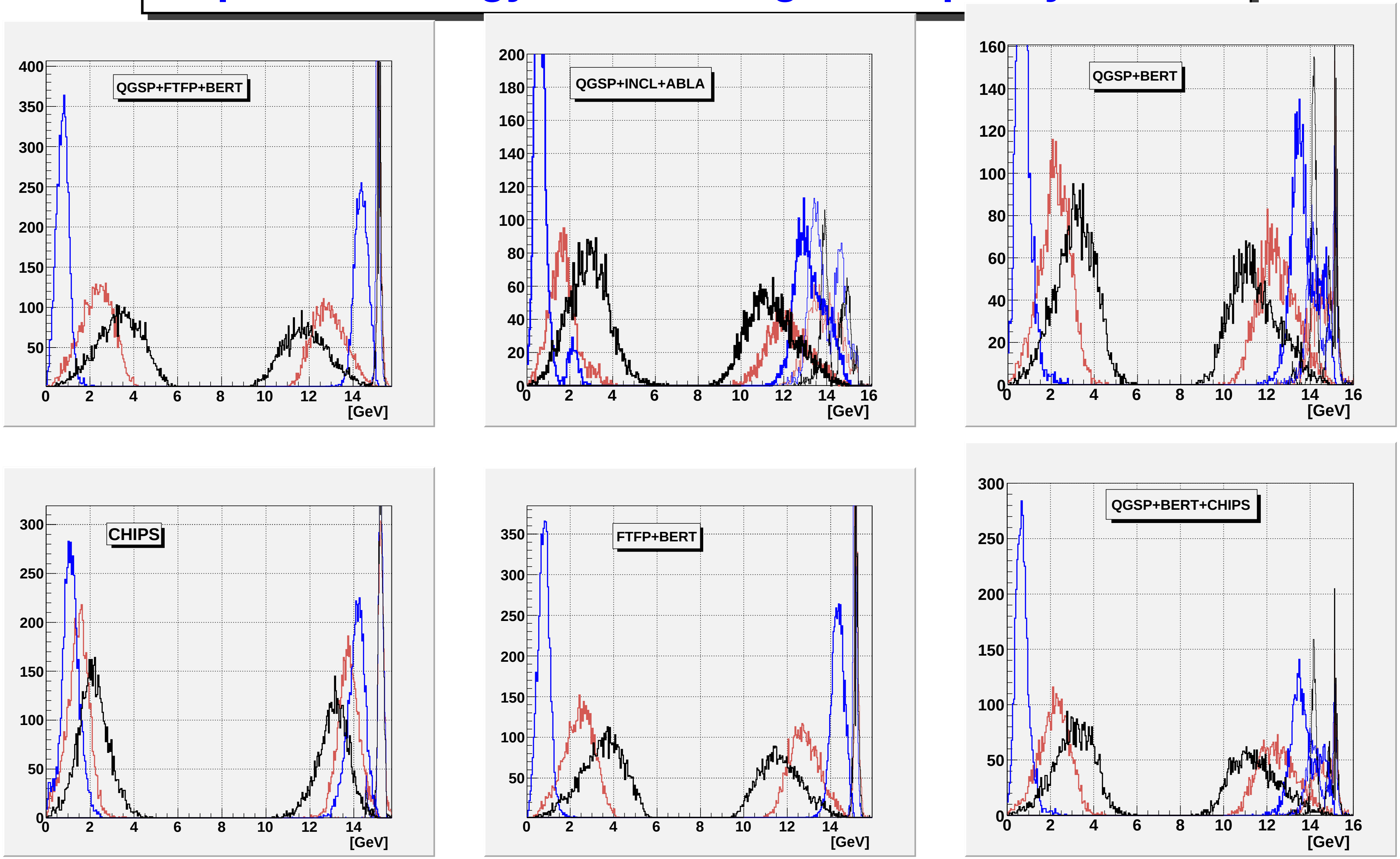




Deposited energy and Binding discrepancy, 6 GeV



Deposited energy and Binding discrepancy, 15 GeV



Example of error log, CHIPS

Many such messages:

```
     NONE CONSERGVATION at Post_Step  dE = 1.88983 [MeV]  E_dep = 1.88983 [MeV]
====  Particle: mu- (lepton) at process 4 : 151 CHIPSNuclearCaptureAtRest
 E_tot is not E=sqrt(P^2+M^2)  E_tot = 103.769 E_calc = 105.658 [MeV]

 Traget is not found   Nseco = 6 at 4 : -1 CHIPSNuclearCaptureAtRest
=>  Target is not found:    Proj: anti_proton (baryon) at 4 : 151 CHIPSNuclearCaptureAtRest
     Nsec = 6  N found nucleus = 0 Nbar = 0 Charg = -1
    Estimated mass = 0.932197 E_pre = 938.272 E_post = 1870.47 [GeV]
    Mom 0 [GeV] sec = 6 E_kin sum = 1046.83 [MeV]
       Secondaries:
     ====> pi+ (meson) E_tot = 291.76 E_kin = 152.19 [MeV]
     ====> pi- (meson) E_tot = 326.523 E_kin = 186.953 [MeV]
     ====> pi0 (meson) E_tot = 208.63 E_kin = 73.653 [MeV]
     ====> pi0 (meson) E_tot = 289.859 E_kin = 154.883 [MeV]
     ====> pi- (meson) E_tot = 261.241 E_kin = 121.671 [MeV]
     ====> pi0 (meson) E_tot = 492.456 E_kin = 357.48 [MeV]

 Traget is not found   Nseco = 4 at 4 : 151 CHIPSNuclearCaptureAtRest
=>  Target is not found:    Proj: pi- (meson) at 4 : 151 CHIPSNuclearCaptureAtRest
     Nsec = 4  N found nucleus = 2 Nbar = 10 Charg = 4
    Estimated mass = 9.32159 E_pre = 139.57 E_post = 9461.16 [GeV]
    Mom 0 [GeV] sec = 4 E_kin sum = 127.269 [MeV] ballance = 1.85328e+06[keV]
       Secondaries:
     ====> neutron (baryon) E_tot = 1007.1 E_kin = 67.5315 [MeV]
     ====> alpha (nucleus) E_tot = 3757.54 E_kin = 30.1567 [MeV]
     ====> alpha (nucleus) E_tot = 3754.81 E_kin = 27.4336 [MeV]
     ====> neutron (baryon) E_tot = 941.713 E_kin = 2.14743 [MeV]
```

Example of error log, FTFP+BERT

Many such messages:

```
 Traget is not found   Nseco = 1 at 4 : 111 hadElastic
 Traget is not found   Nseco = 1 at 4 : 111 hadElastic

 Traget is not found   Nseco = 12 at 4 : 151 muMinusCaptureAtRest
=>  Target is not found:    Proj: mu- (lepton) at 4 : 151 muMinusCaptureAtRest
     Nsec = 12  N found nucleus = 0 Nbar = 0 Charg = -7
    Estimated mass = 0.00306599 E_pre = 105.658 E_post = 108.724 [GeV]
    Mom 0 [GeV] sec = 12 E_kin sum = 105.147 [MeV]
       Secondaries:
     ====> e- (lepton) E_tot = 0.511511 E_kin = 0.000511661 [MeV]
     ====> e- (lepton) E_tot = 0.511081 E_kin = 8.17447e-05 [MeV]
     ====> e- (lepton) E_tot = 0.511102 E_kin = 0.000103022 [MeV]
     ====> e- (lepton) E_tot = 0.511131 E_kin = 0.000132379 [MeV]
     ====> e- (lepton) E_tot = 0.511173 E_kin = 0.000174049 [MeV]
     ====> e- (lepton) E_tot = 0.511234 E_kin = 0.000235238 [MeV]
     ====> gamma (gamma) E_tot = 0.000328869 E_kin = 0.000328869 [MeV]
     ====> gamma (gamma) E_tot = 0.000479682 E_kin = 0.000479682 [MeV]
     ====> gamma (gamma) E_tot = 0.0959534 E_kin = 0.0959534 [MeV]
     ====> e- (lepton) E_tot = 41.6755 E_kin = 41.1645 [MeV]
     ====> anti_nu_e (lepton) E_tot = 23.9796 E_kin = 23.9796 [MeV]
     ====> nu_mu (lepton) E_tot = 39.9054 E_kin = 39.9054 [MeV]
```

Example of error log, QGSP+INCL+ABLA

Many such messages:

```
 Traget is not found   Nseco = 8 at 4 : 121 PionMinusInelastic
 Traget is not found GHEISHA or INCL/ABLA case (4:121)
    Nseco = 8  N found nucleus = 1 Nbar = 3 Charg = 3
    Estimated mass = 2.59888 E_pre = 14833 E_post = 17431.9 [GeV]
  pi- input E = 14.8324 sum sec. E = 17.4319[GeV] diff = -2599.49[MeV]
     ====  Particle: pi0 (meson st pi) E_tot = 9994.64 E_kin = 9859.67 [MeV]
     ====  Particle: proton (baryon st nucleon) E_tot = 1239.33 E_kin = 301.061 [MeV]
     ====  Particle: pi0 (meson st pi) E_tot = 1383.23 E_kin = 1248.25 [MeV]
     ====  Particle: pi- (meson st pi) E_tot = 582.685 E_kin = 443.115 [MeV]
     ====  Particle: pi0 (meson st pi) E_tot = 164.039 E_kin = 29.0623 [MeV]
     ====  Particle: proton (baryon st nucleon) E_tot = 1213.68 E_kin = 275.412 [MeV]
     ====  Particle: proton (baryon st nucleon) E_tot = 1556.35 E_kin = 618.078 [MeV]
     ====  Particle: pi+ (meson st pi) E_tot = 1297.9 E_kin = 1158.32 [MeV]

 Traget is not found   Nseco = 12 at 4 : 151 muMinusCaptureAtRest
=>  Target is not found:    Proj: mu- (lepton) at 4 : 151 muMinusCaptureAtRest
     Nsec = 12  N found nucleus = 0 Nbar = 0 Charg = -7
    Estimated mass = 0.00306599 E_pre = 105.658 E_post = 108.724 [GeV]
    Mom 0 [GeV] sec = 12 E_kin sum = 105.147 [MeV] ballance = 1e+10[keV]
       Secondaries:
     ====> e- (lepton) E_tot = 0.511511 E_kin = 0.000511661 [MeV]
     ====> e- (lepton) E_tot = 0.511081 E_kin = 8.17447e-05 [MeV]
     ====> e- (lepton) E_tot = 0.511102 E_kin = 0.000103022 [MeV]
     ====> e- (lepton) E_tot = 0.511131 E_kin = 0.000132379 [MeV]
     ====> e- (lepton) E_tot = 0.511173 E_kin = 0.000174049 [MeV]
     ====> e- (lepton) E_tot = 0.511234 E_kin = 0.000235238 [MeV]
     ====> gamma (gamma) E_tot = 0.000328869 E_kin = 0.000328869 [MeV]
     ====> gamma (gamma) E_tot = 0.000479682 E_kin = 0.000479682 [MeV]
     ====> gamma (gamma) E_tot = 0.0959534 E_kin = 0.0959534 [MeV]
     ====> e- (lepton) E_tot = 30.166 E_kin = 29.655 [MeV]
     ====> anti_nu_e (lepton) E_tot = 34.7683 E_kin = 34.7683 [MeV]
     ====> nu_mu (lepton) E_tot = 40.626 E_kin = 40.626 [MeV]
```

Example of error log, QGSP+INCL+ABLA

Many such messages:

```
Traget is not found   Nseco = 1 at 4 : 121 NeutronInelastic
Traget is not found   Nseco = 1 at 4 : 121 PionMinusInelastic
Traget is not found   Nseco = 1 at 4 : 111 hadElastic

Traget is not found   Nseco = 4 at 4 : 121 NeutronInelastic
Traget is not found GHEISHA or INCL/ABLA case (4:121)
   Nseco = 4  N found nucleus = 1 Nbar = 12 Charg = 5
   Estimated mass = 10.2496 E_pre = 959.204 E_post = 11208.8 [GeV]
 neutron input E = 0.959204 sum sec. E = 11.2088[GeV] diff = -10249.6[MeV]
    ====  Particle: gamma (gamma st photon) E_tot = 15.5669 E_kin = 15.5669 [MeV]
    ====  Particle: gamma (gamma st photon) E_tot = 1.65476 E_kin = 1.65476 [MeV]
    ====  Particle: gamma (gamma st photon) E_tot = 0.964334 E_kin = 0.964334 [MeV]
    ====  Particle: B12[0.0] (nucleus st generic) E_tot = 11190.6 E_kin = 1.83066 [MeV]
```

Example of error log, QGSP+BERT

```
 Traget is not found   Nseco = 1 at 4 : 111 hadElastic
 Traget is not found   Nseco = 1 at 4 : 111 hadElastic
 Traget is not found   Nseco = 1 at 4 : 111 hadElastic
 Traget is not found   Nseco = 1 at 4 : 111 hadElastic

 Traget is not found   Nseco = 9 at 4 : 151 muMinusCaptureAtRest
=>  Target is not found:    Proj: mu- (lepton) at 4 : -1 muMinusCaptureAtRest
     Nsec = 9  N found nucleus = 0 Nbar = 0 Charg = -2
    Estimated mass = 0.000510999 E_pre = 105.658 E_post = 106.169 [GeV]
    Mom 0 [GeV] sec = 9 E_kin sum = 105.147 [MeV] ballance = 1e+10[keV]
       Secondaries:
     ====> e- (lepton) E_tot = 0.511012 E_kin = 1.28951e-05 [MeV]
     ====> gamma (gamma) E_tot = 2.06016e-06 E_kin = 2.06016e-06 [MeV]
     ====> gamma (gamma) E_tot = 3.66251e-05 E_kin = 3.66251e-05 [MeV]
     ====> gamma (gamma) E_tot = 1.86262e-05 E_kin = 1.86262e-05 [MeV]
     ====> gamma (gamma) E_tot = 0.000561652 E_kin = 0.000561652 [MeV]
     ====> gamma (gamma) E_tot = 0.00211814 E_kin = 0.00211814 [MeV]
     ====> e- (lepton) E_tot = 40.5916 E_kin = 40.0806 [MeV]
     ====> anti_nu_e (lepton) E_tot = 20.272 E_kin = 20.272 [MeV]
     ====> nu_mu (lepton) E_tot = 44.7921 E_kin = 44.7921 [MeV]
```

Example of error log, QGSP+BERT+CHIPS

```
 Traget is not found   Nseco = 1 at 4 : 111 hadElastic

 Traget is not found   Nseco = 17 at 4 : 121 PionMinusInelastic
 Traget is not found GHEISHA or INCL/ABLA case (4:121)
    Nseco = 17  N found nucleus = 1 Nbar = 7 Charg = 5
    Estimated mass = 5.5568 E_pre = 14794.7 E_post = 20351.5 [GeV]
  pi- input E = 14.7893 sum sec. E = 20.3515[GeV] diff = -5562.18[MeV]
     ====  Particle: pi0 (meson st pi) E_tot = 724.61 E_kin = 589.633 [MeV]
     ====  Particle: proton (baryon st nucleon) E_tot = 1924.4 E_kin = 986.13 [MeV]
     ====  Particle: pi- (meson st pi) E_tot = 681.215 E_kin = 541.645 [MeV]
     ====  Particle: pi+ (meson st pi) E_tot = 2817.39 E_kin = 2677.82 [MeV]
     ====  Particle: pi0 (meson st pi) E_tot = 980.781 E_kin = 845.804 [MeV]
     ====  Particle: pi- (meson st pi) E_tot = 4069.09 E_kin = 3929.52 [MeV]
     ====  Particle: pi- (meson st pi) E_tot = 872.638 E_kin = 733.068 [MeV]
     ====  Particle: neutron (baryon st nucleon) E_tot = 997.912 E_kin = 58.3462 [MeV]
     ====  Particle: pi0 (meson st pi) E_tot = 837.978 E_kin = 703.001 [MeV]
     ====  Particle: pi+ (meson st pi) E_tot = 368.327 E_kin = 228.756 [MeV]
     ====  Particle: pi+ (meson st pi) E_tot = 478.39 E_kin = 338.82 [MeV]
     ====  Particle: proton (baryon st nucleon) E_tot = 951.416 E_kin = 13.1443 [MeV]
     ====  Particle: pi+ (meson st pi) E_tot = 582.917 E_kin = 443.347 [MeV]
     ====  Particle: neutron (baryon st nucleon) E_tot = 1072.77 E_kin = 133.208 [MeV]
     ====  Particle: proton (baryon st nucleon) E_tot = 948.691 E_kin = 10.4191 [MeV]
     ====  Particle: neutron (baryon st nucleon) E_tot = 962.121 E_kin = 22.5553 [MeV]
     ====  Particle: proton (baryon st nucleon) E_tot = 1080.83 E_kin = 142.561 [MeV]

 Traget is not found   Nseco = 6 at 4 : 151 muMinusCaptureAtRest
=>  Target is not found:    Proj: mu- (lepton) at 4 : 151 muMinusCaptureAtRest
     Nsec = 6  N found nucleus = 0 Nbar = 0 Charg = -2
    Estimated mass = 0.000510999 E_pre = 105.658 E_post = 106.169 [GeV]
    Mom 0 [GeV] sec = 6 E_kin sum = 105.147 [MeV] ballance = 1e+10[keV]
       Secondaries:
     ====> e- (lepton) E_tot = 0.520678 E_kin = 0.00967907 [MeV]
     ====> gamma (gamma) E_tot = 0.464595 E_kin = 0.464595 [MeV]
     ====> gamma (gamma) E_tot = 1.23373 E_kin = 1.23373 [MeV]
     ====> e- (lepton) E_tot = 53.14 E_kin = 52.629 [MeV]
     ====> anti_nu_e (lepton) E_tot = 15.2723 E_kin = 15.2723 [MeV]
     ====> nu_mu (lepton) E_tot = 35.5381 E_kin = 35.5381 [MeV]
```

Example of error log, QGSP+FTFP+BERT

```
 Traget is not found   Nseco = 1 at 4 : 111 hadElastic

 Traget is not found   Nseco = 16 at 4 : 151 muMinusCaptureAtRest
=>  Target is not found:    Proj: mu- (lepton) at 4 : 151 muMinusCaptureAtRest
     Nsec = 16  N found nucleus = 0 Nbar = 0 Charg = -7
    Estimated mass = 0.00306599 E_pre = 105.658 E_post = 108.724 [GeV]
    Mom 0 [GeV] sec = 16 E_kin sum = 105.147 [MeV] ballance = 1e+10[keV]
       Secondaries:
     ====> e- (lepton) E_tot = 0.511511 E_kin = 0.000511661 [MeV]
     ====> e- (lepton) E_tot = 0.511081 E_kin = 8.17447e-05 [MeV]
     ====> e- (lepton) E_tot = 0.511102 E_kin = 0.000103022 [MeV]
     ====> e- (lepton) E_tot = 0.511131 E_kin = 0.000132379 [MeV]
     ====> e- (lepton) E_tot = 0.511173 E_kin = 0.000174049 [MeV]
     ====> e- (lepton) E_tot = 0.511234 E_kin = 0.000235238 [MeV]
     ====> gamma (gamma) E_tot = 0.000328869 E_kin = 0.000328869 [MeV]
     ====> gamma (gamma) E_tot = 0.000479682 E_kin = 0.000479682 [MeV]
     ====> gamma (gamma) E_tot = 0.000739066 E_kin = 0.000739066 [MeV]
     ====> gamma (gamma) E_tot = 0.00122571 E_kin = 0.00122571 [MeV]
     ====> gamma (gamma) E_tot = 0.00225642 E_kin = 0.00225642 [MeV]
     ====> gamma (gamma) E_tot = 0.0188035 E_kin = 0.0188035 [MeV]
     ====> gamma (gamma) E_tot = 0.0729286 E_kin = 0.0729286 [MeV]
     ====> e- (lepton) E_tot = 40.4195 E_kin = 39.9085 [MeV]
     ====> anti_nu_e (lepton) E_tot = 46.5078 E_kin = 46.5078 [MeV]
     ====> nu_mu (lepton) E_tot = 18.6331 E_kin = 18.6331 [MeV]
```

Example of error log, strange process

```
===> Process = 6 : 201  Decay; Particle: triton (nucleus)   dE = 2.98314262l8152e-10
 Mass             = 2808.921 [MeV]
 Mom              = 0 [MeV] before step
 Mom  post        = 0 [MeV] after step
 E_kin            = 0 [MeV] before step
 E_kin projectile = 0 [MeV] after step
 E_tot            = 2808.921 [MeV] before step
 sqrt(P^2 + M^2)  = 2808.921 [MeV] before step
 E_calc = E_kin+M = 2808.921 [MeV] before step
 E_projectile     = 2808.921 [MeV] after step
 sqrt(E^2 - P^2 - M^2) = 1.7271776462817e-05 [MeV]
 E_dep   = 0 [MeV] at the lastests step
 d E_kin = 0 [MeV] at the lastests step
 Number of secondarties = 0
      +++++++> 6 : 201  Decay; Particle: triton (nucleus)
   Kinetic energy secondaries = 0 [MeV] Targ. Mass = -2.808921 [GeV] True secondaries = 0
```