Simulation of Energy Deposit in the AirLight Chamber

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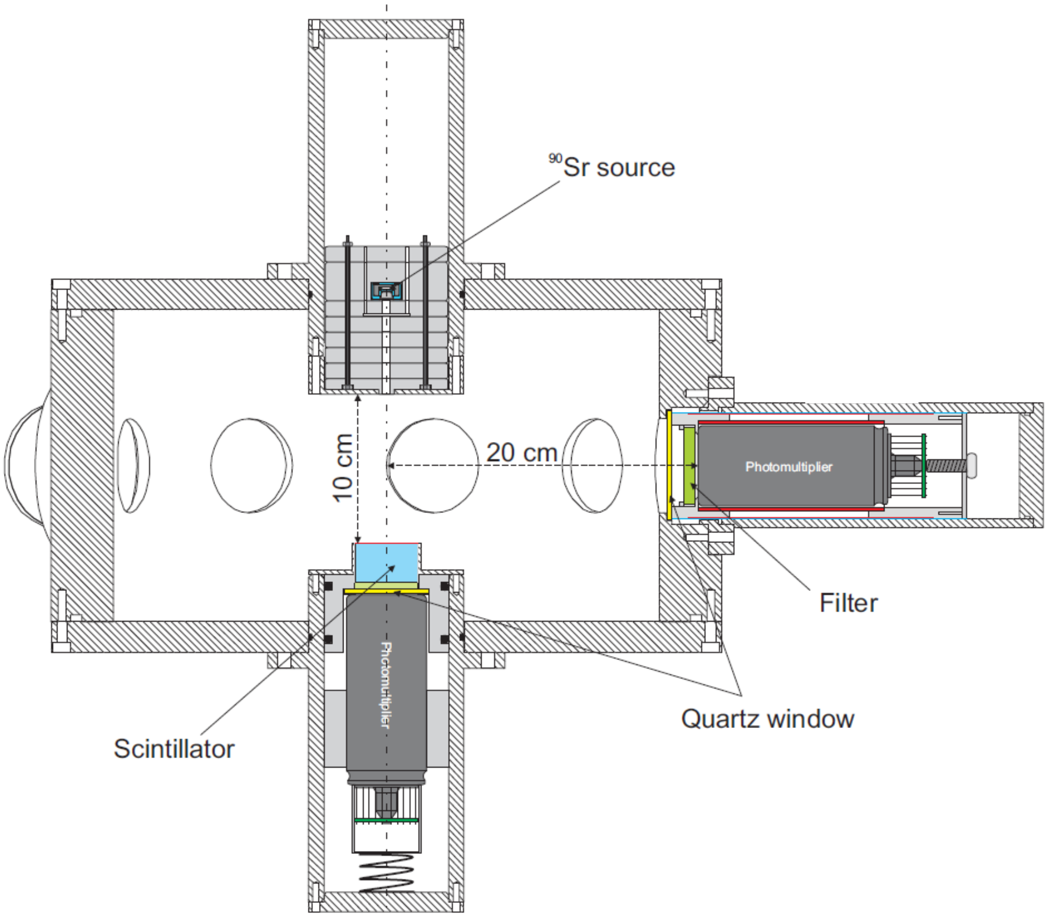
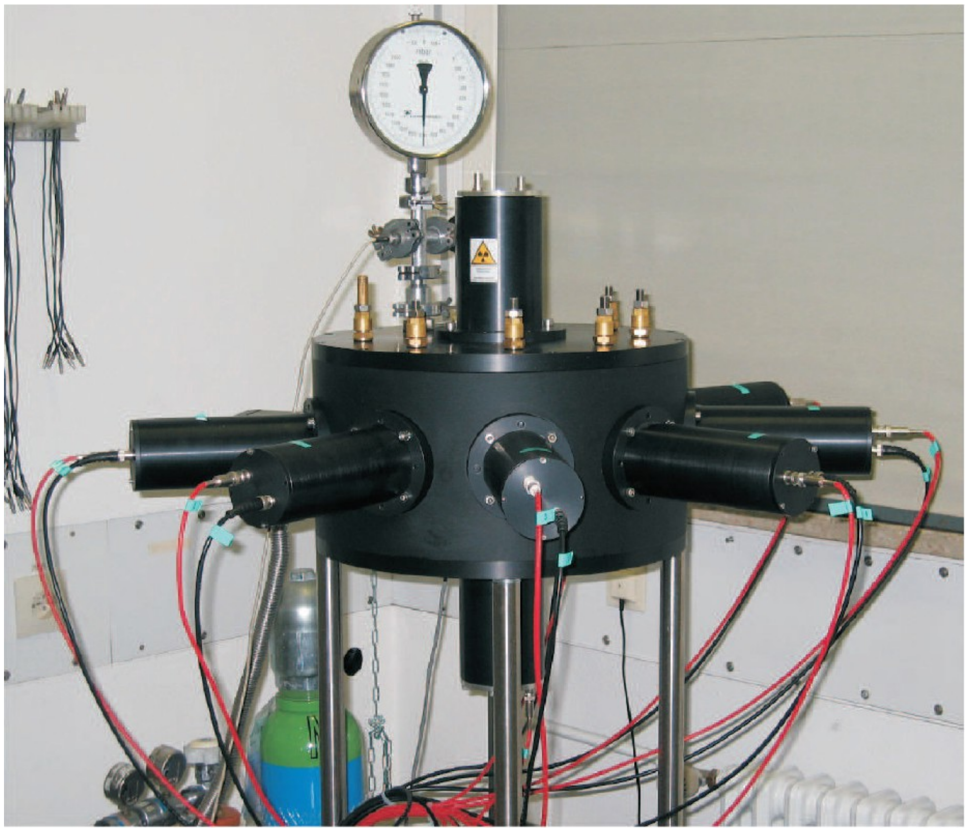
Outline

- The AirLight Experiment
- The issue with the deposited energy
- Geant4 cross-checks
  - Toy simulations
  - AirLight simulation
- Conclusions

The AirLight Experiment

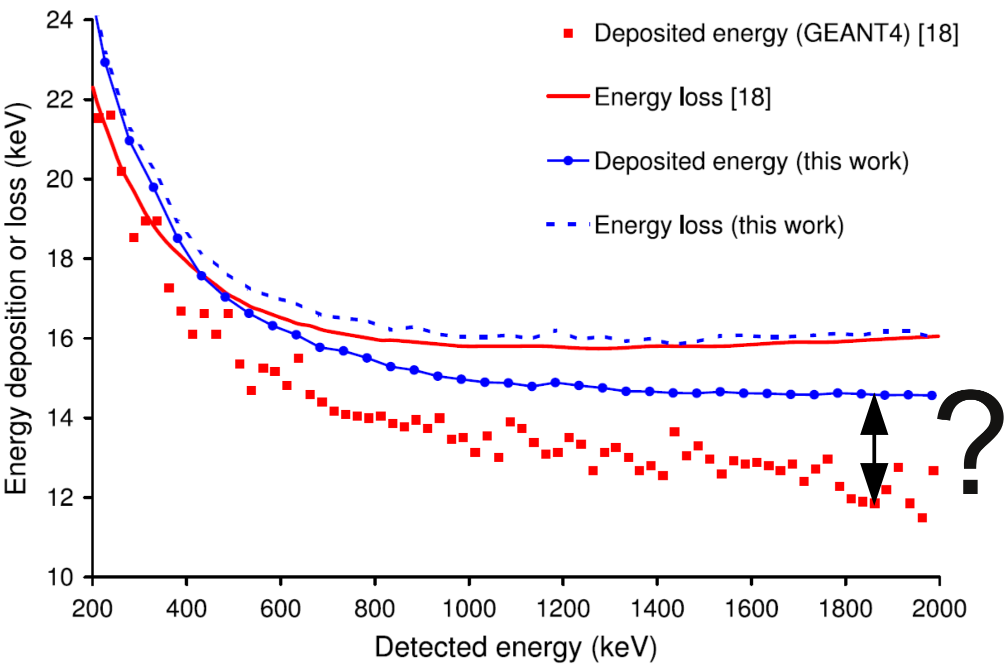


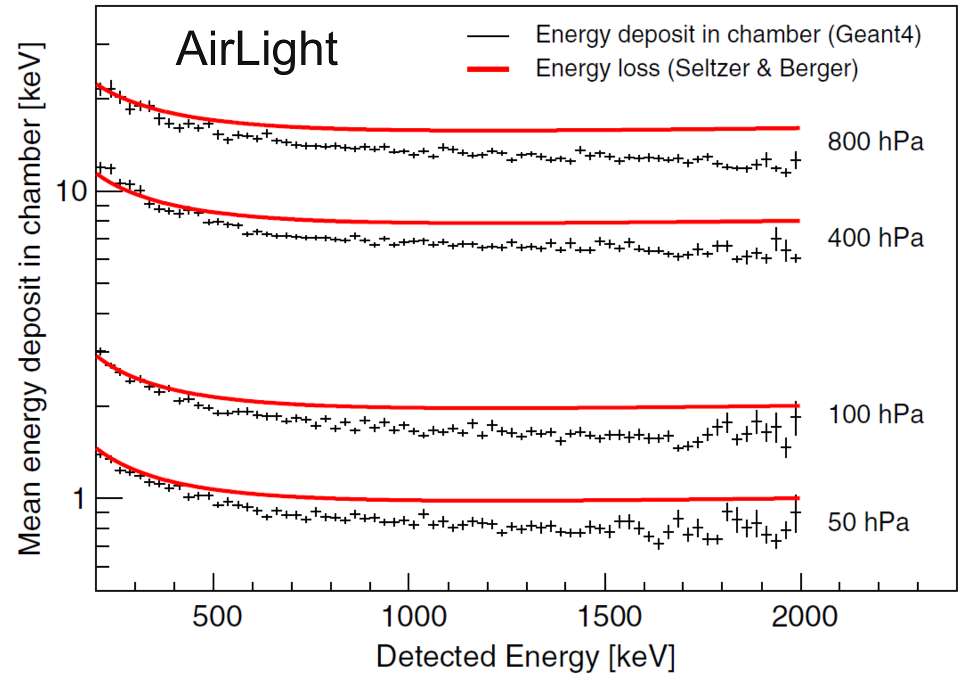


- Sr-90 Source (37 Mbq) → 10 – 20 kHz @ Scintillator
- Energy range: 0.2 – 2.0 MeV
- 7 wavelength ranges: MUG-6, 317 nm, 340 nm, 360 nm, 380 nm, 394 nm, 430 nm

There seems to be a problem ...

[J. Rosado et al. Astropart. Phys. 34 (2010) 164 – 127]





- Deposited energy in AirLight (at 800 hPa) appears to be 5 – 20 % too low ?!
- Discrepancy gets smaller at lower pressures

Geant4 cross-checks

- Three stages:
  - (1) Injection of electrons in infinite volume → verify dE/dX per step, range
  - (2) Electrons stopped after 10 cm in limited volume → simple AirLightSim
  - (3) Full AirLight Simulation

- Simulation conditions (if not other stated):
  - Geant4 version 7.1.p01
  - Low energy EM-model
  - Air conditons: p = 800 hPa, T = 20°C (density = 9.33E-4 g/cm3)

- Comparison with NIST energy loss and range tables (http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html)

Reminder: Restricted Energy Loss in G4

- Ionization energy loss process separated in:
  - Continous energy loss below production threshold T_{cut}:

$$\frac{dE(E, T_{cut})}{dx} = n \cdot \int_0^{T_{cut}} T \cdot \frac{d\sigma(E,T)}{dT}\, dT$$

+ straggling

  - Discrete delta-electron production above production threshold T_{cut}:

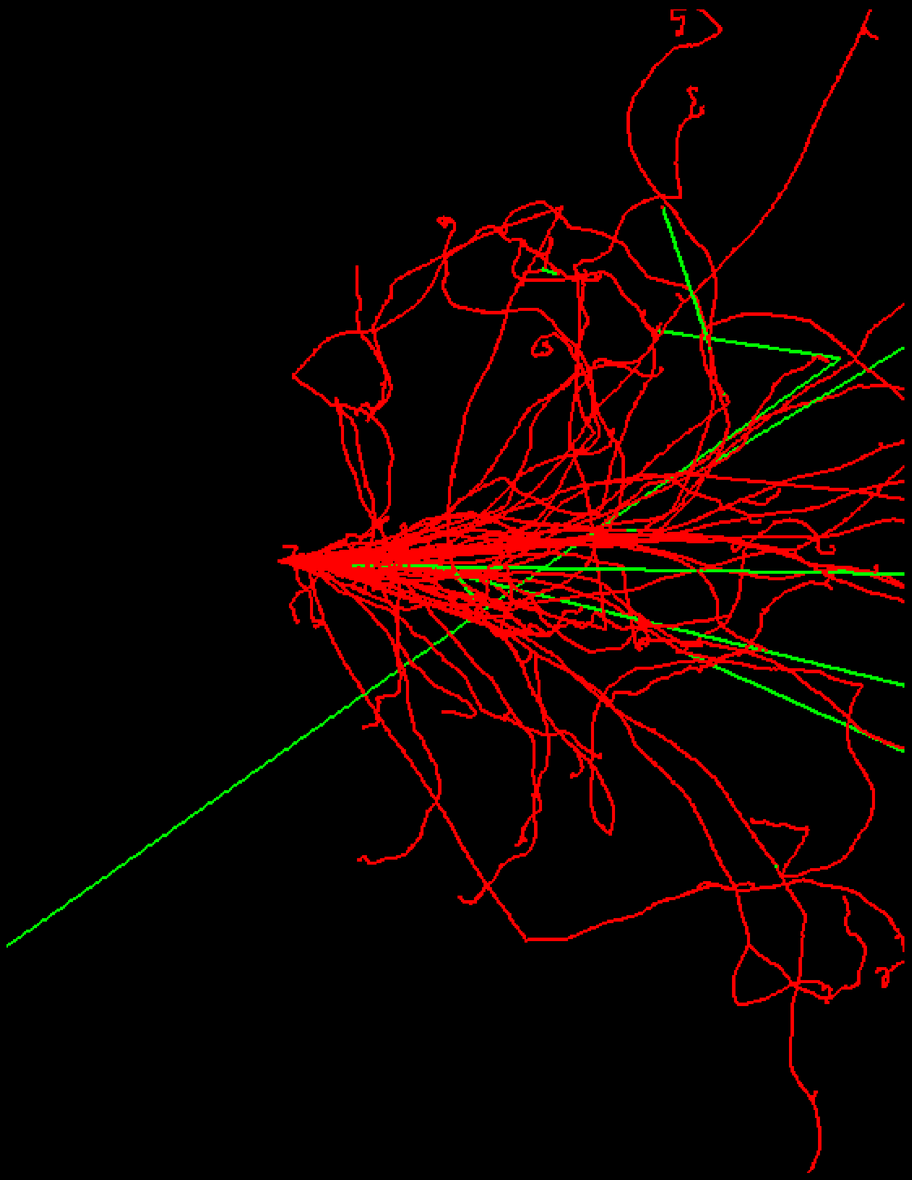
$$\sigma(E, T_{cut}) = \int_{T_{cut}}^{T_{max}} \frac{d\sigma(E,T)}{dT}\, dT$$

- Production thresholds as range cuts

$$R(T_{cut}) = \int_{T_{cut}}^{0} \frac{dE}{\left(\frac{dE(E)}{dx}\right)} \quad \longrightarrow \quad T_{cut}(R)$$

same R in each material
→ different T_{cut}

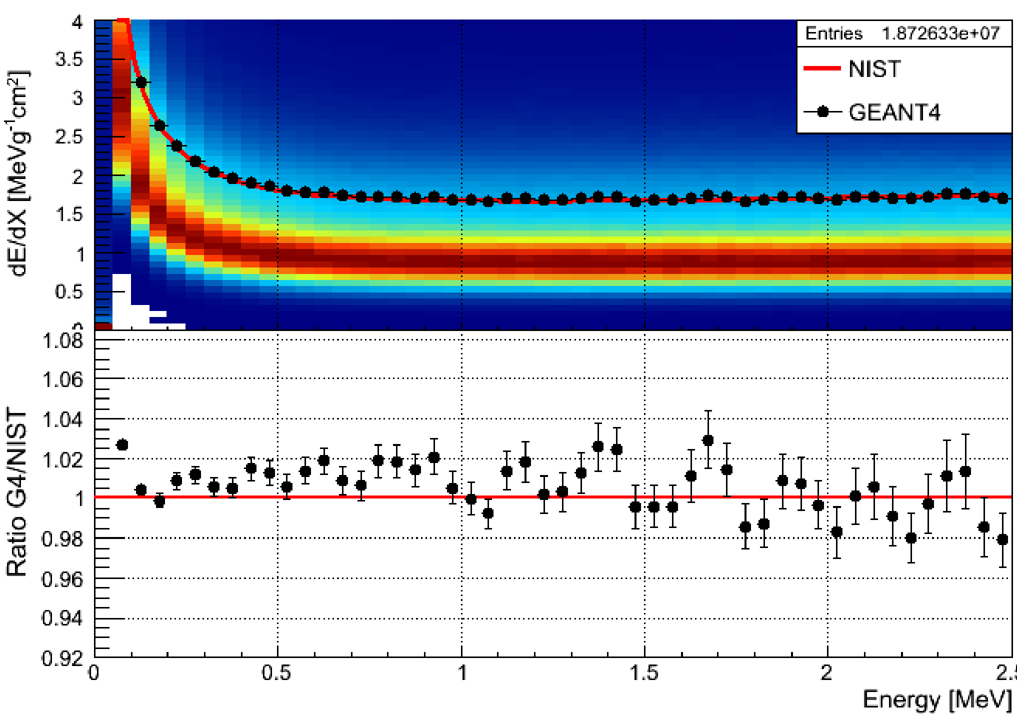
(1) dE/dX along step/track



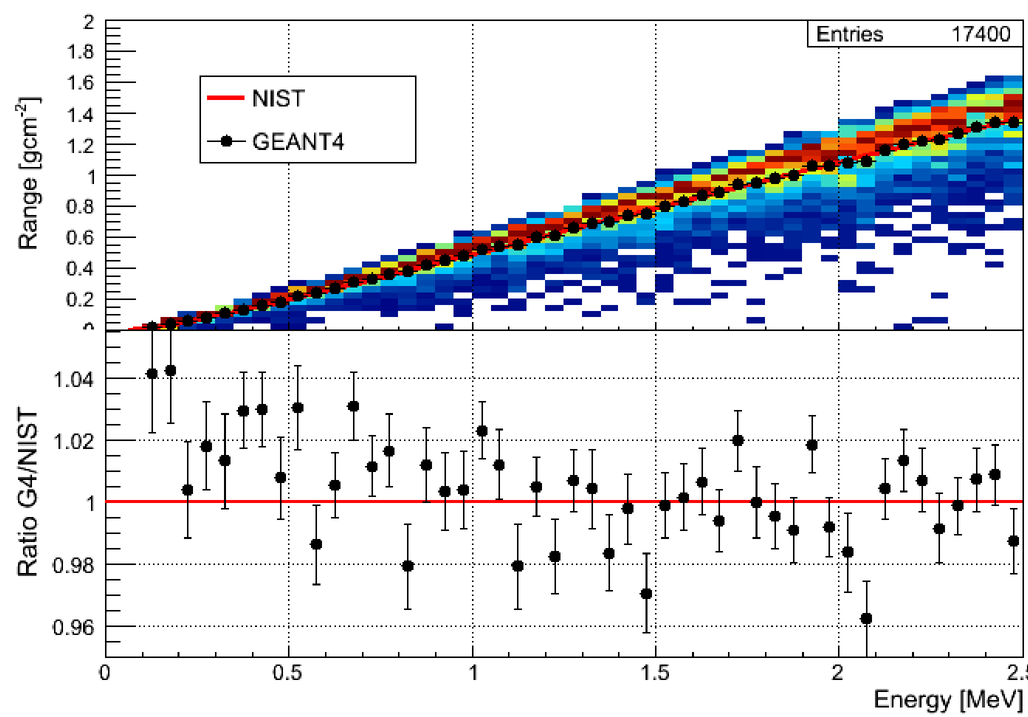
(1) dE/dX along step/track

- Injection of e- in infinite (huge) volume, huge range cuts (10km) → no secondaries
- Extract dE/dX for each step (Energy loss = E2 – E1) → Mean dE/dX
- Summing length of each step along track → Range

Mean Energy Loss

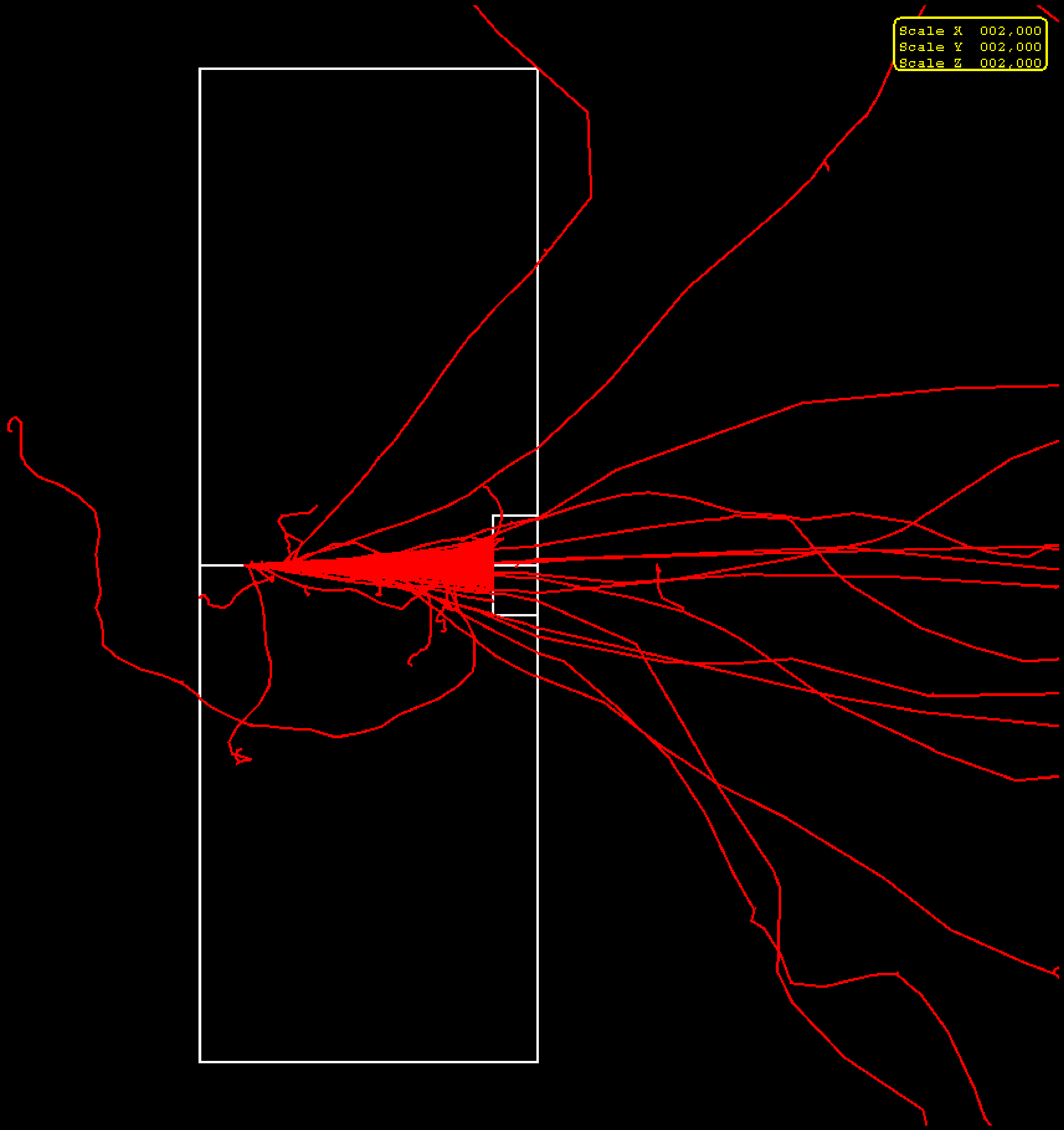


CSDA Range



→ Agreement within a few (1-2) per cent.

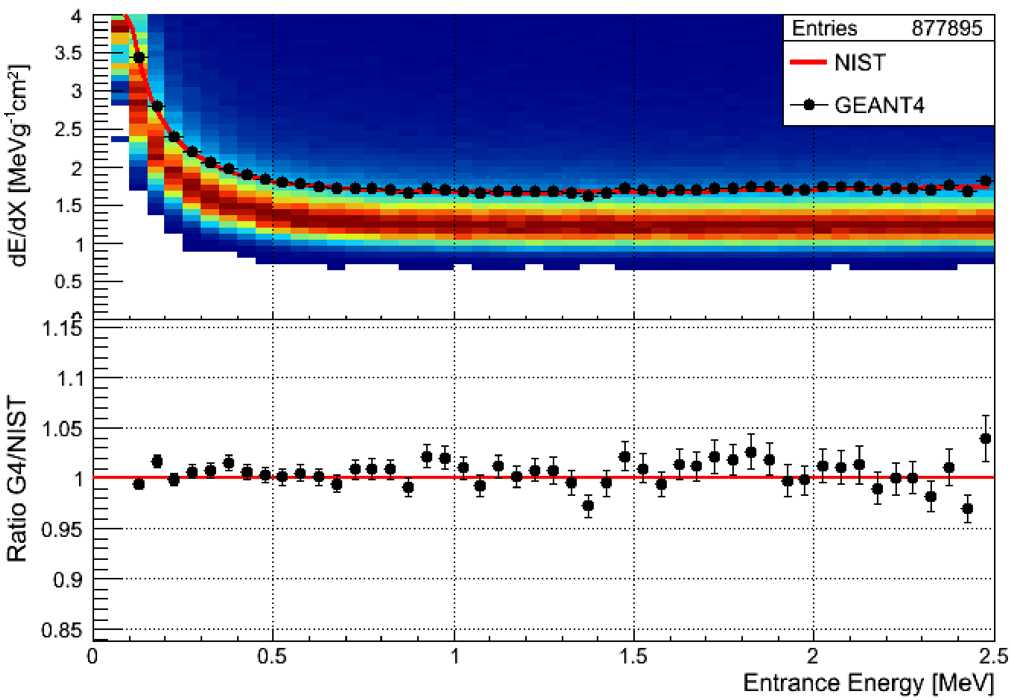
(2) dE/dX along 10 cm beamline



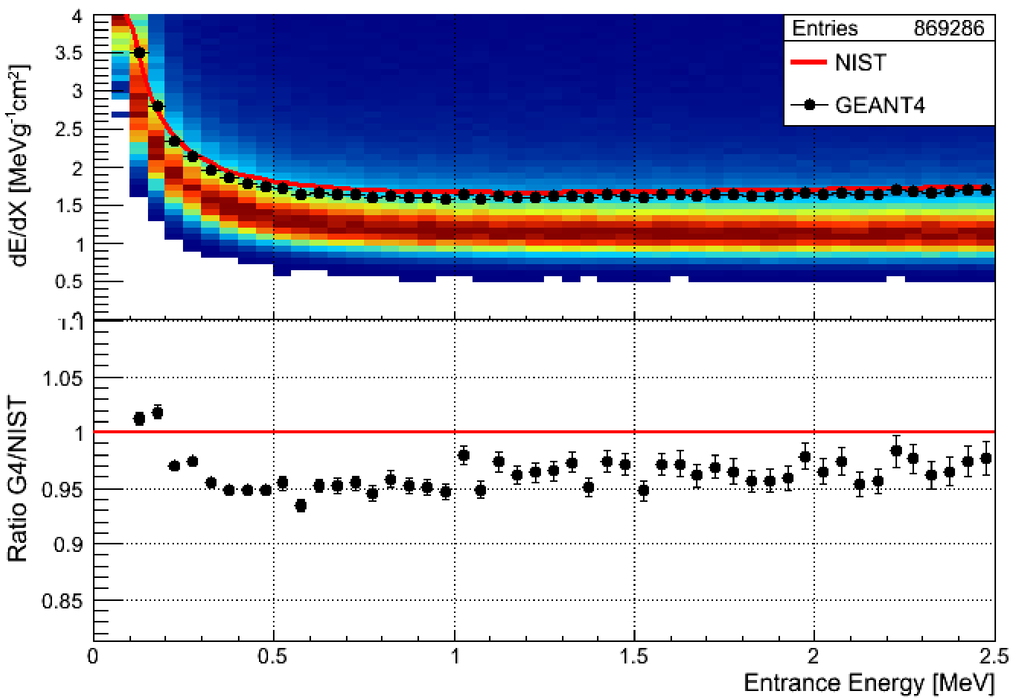
(2) dE/dX along 10 cm beam

- Infinite (huge) volume
- Stopping primary electrons at scintillator position (after 10 cm)
- Summing deposited energy of all electrons (primary + secondaries)

Range cut 10km (no secondaries)



Range cut 1mm (with secondaries)

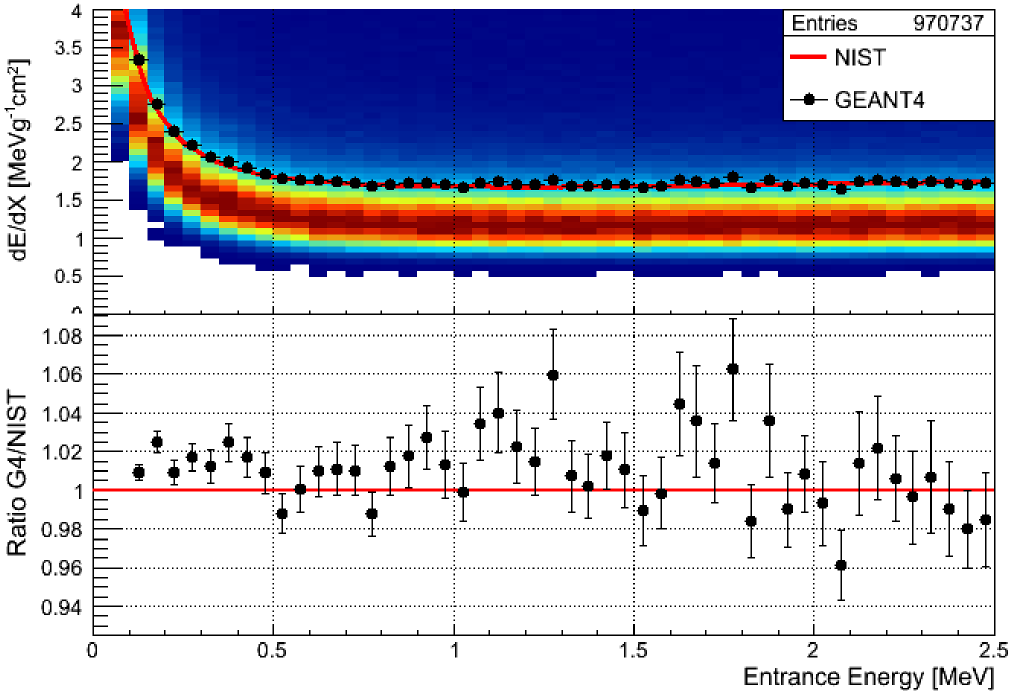


→ Average energy deposit 4 - 5 % too low if delta electrons are generated.

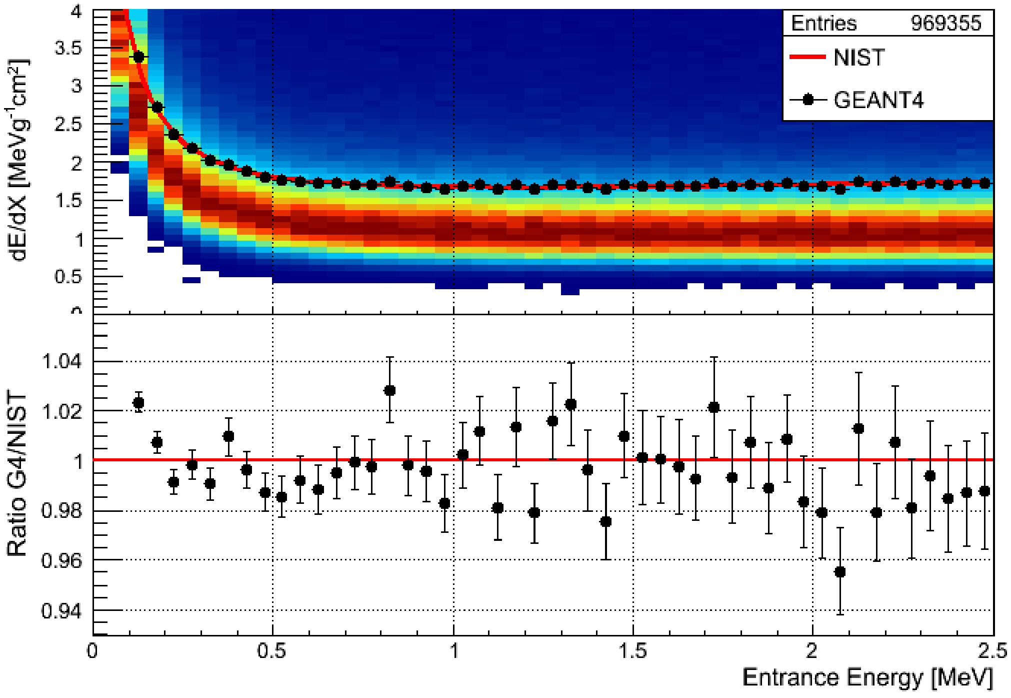
→ Problem with restricred energy loss straggling?

(2) dE/dX along 5 cm beam

Infinite volume, range cut 10km



Infinite volume, range cut 1mm

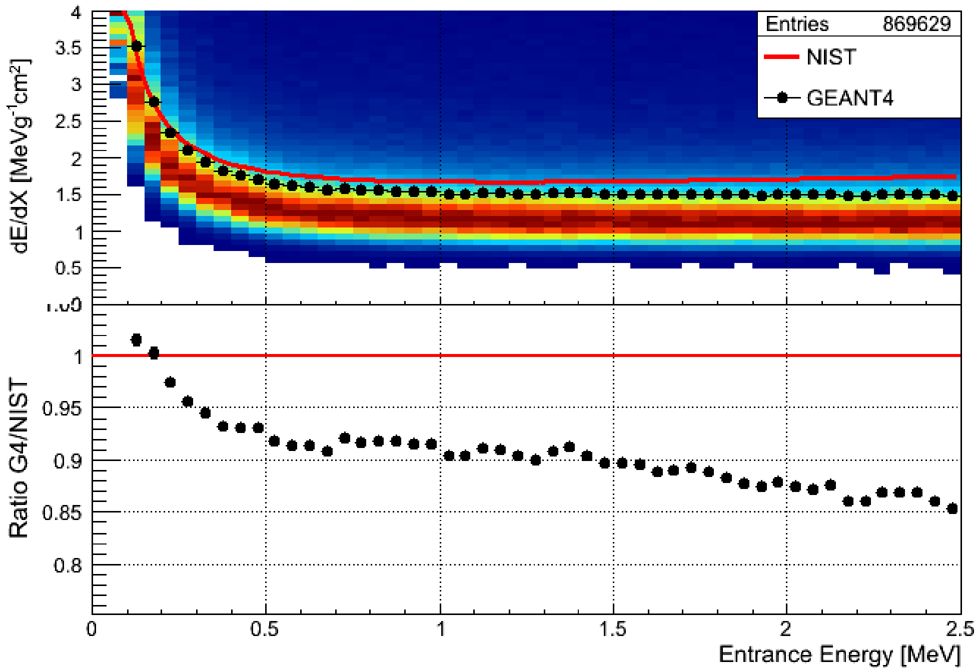


→ With 5 cm beam line everything seems to be ok !?

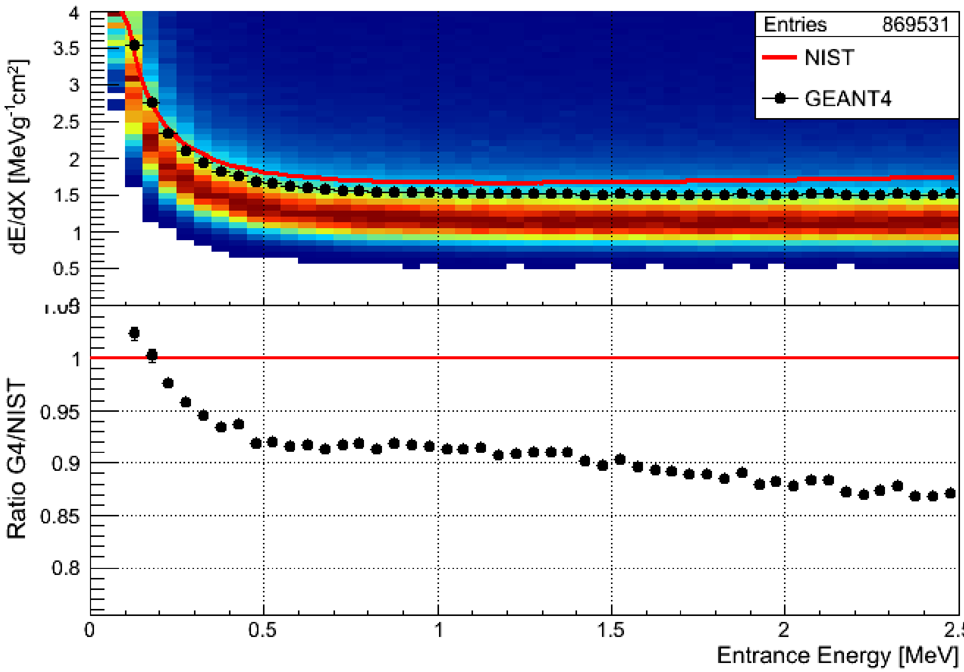
(2) dE/dX in limited Volume

- Beam length: 10 cm
- Range cut: 1 mm
- Stop all electrons at the scintillator or the volume boundaries

Volume radius = 20 cm



Volume radius = 100 km

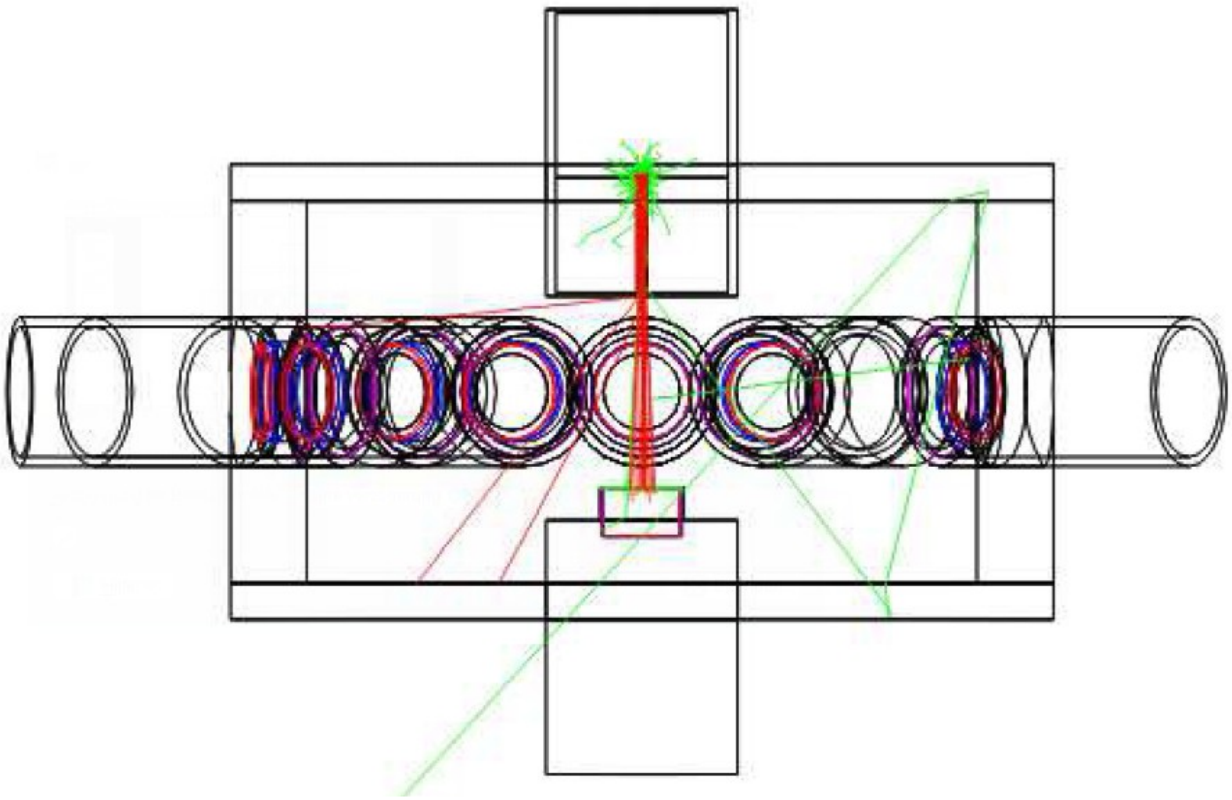


→ Reduction of energy deposit mainly due to escaping delta electrons in forward direction!

(2) Summary of simple simulation

- Average energy loss along single steps agrees within 1 – 2 %
- Average energy loss along 10 cm beam line with secondary production about 4 – 5 % too low.
  - Reason unclear (maybe struggling), without secondaries everything is ok
  - Along 5 cm beam line everything seems to agree
- Reduction of energy deposit in limited volumes mainly due to escaping delta electrons in forward direction.

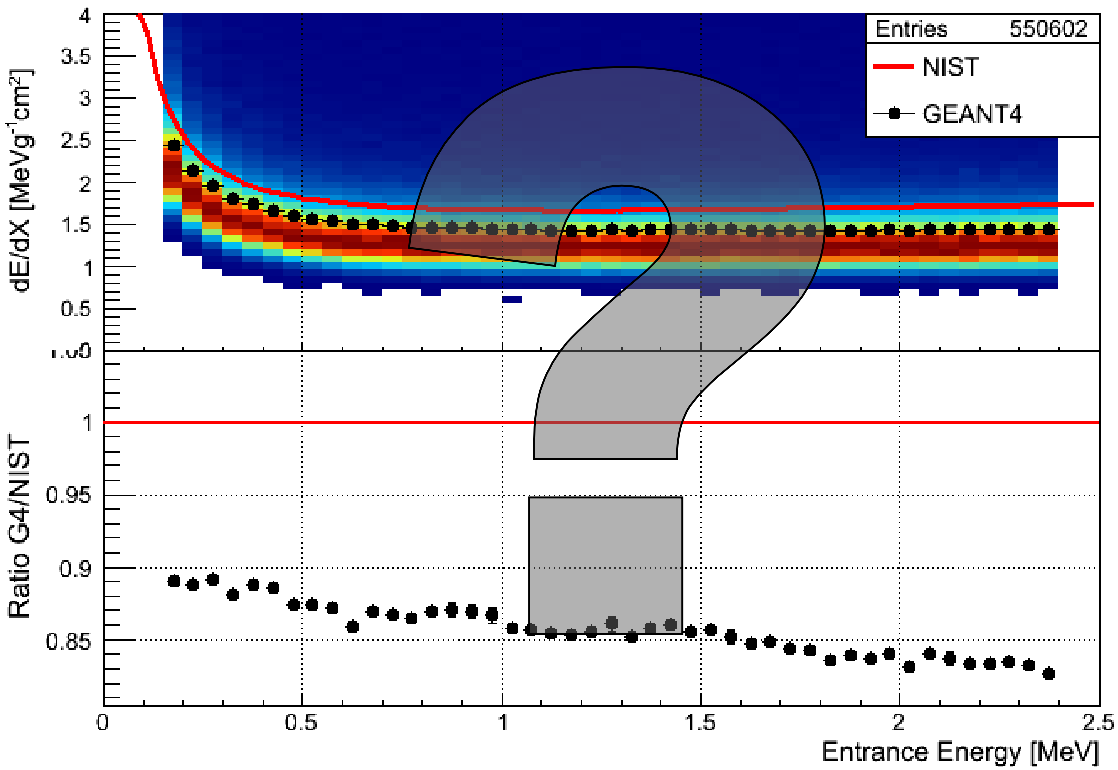
(3) Verification of AirLight Simulation



Deposited Energy vs. Entrance Energy

- Electrons generated on axis (flat energy spectrum)
- No secondaries (range cut: 10 km) → energy deposit = energy loss
- No multiple scattering → straight trajectories
- No backscattering from scintillator

Should reproduce Bethe-Bloch




```
--> Particle Gun:                eCollFlat
--> Window status:               disabled
--> Filter status:               disabled
--> PMT Reflectivity:            0.00 %
--> Beam length:                 100.00 mm
--> Collimator length:           62.00 mm
--> Collimator width:            5.00 mm
--> N2 mass fraction:            88.74 %
--> O2 mass fraction:            11.26 %
--> Ar mass fraction:            0.00 %
--> Gas temperature:             20.00 �C
--> Gas pressure:                800.00 mbar
--> Gas density:                 0.00093 g/cm3
--> Generated Events:            1000000
--> Valid Events:                550645
--> # Events in Scintillator:    550625
--> # Photons:                   3559466
--> # Photons in Chamber:        3549708
--> # Coin. Photons in Chamber:  3547858
```

?

→ Mean energy loss about 15% too low!

→ About 45 % of events are not valid ?!

That's the culprit ...

emacs@albert.site <2>

File Edit Options Buffers Tools C++ Help

```cpp
void AirLightSimScintillatorSD::ProcessHitOnFoil(const G4Step* aStep)
{
  /**
   * This routine is called by UserSteppingAction when a particle hits
   * the foil in front of the scintillator comeing from the gas volume
   */

  if(!active) return; // if detector inactive return

  // Not for optical photons --> Otherwise event abortion (see below)
  if(aStep->GetTrack()->GetDefinition() == G4OpticalPhoton::OpticalPhoton()) return;

  if(fCurrentHit)
  {
    // Check if particle already hit the foil before. If so, exit this routine!
    if(fCurrentHit->GetTrackID() == aStep->GetTrack()->GetTrackID()) return;
  }

  // Create new current hit if foil was hit for the first time by this track
  NewHit(aStep);

  if(fCurrentHit)
  {
    fCurrentHit->SetFoilEnergy(aStep->GetTrack()->GetKineticEnergy());
  }
  else
  {
    // Attention: Optical photon hits will cause the abortion of the event if not filtered out before!
    fEventManager->GetNonconstCurrentEvent()->SetEventAborted();
    fEventManager->AbortCurrentEvent();
  }
}
```

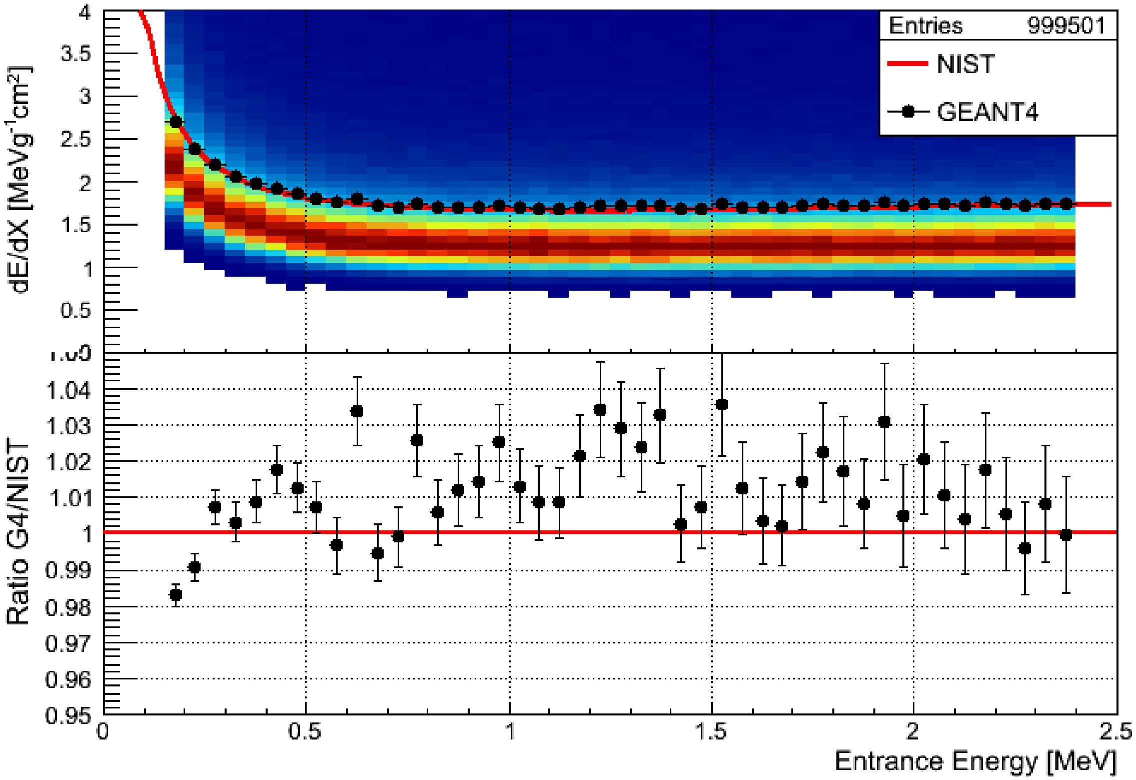
--:--- AirLightSimScintillatorSD.cc   66% (184,17)   (C++/l Abbrev)---

Workaround

Not for optical photons!

After bugfix

w/o secondaries, w/o multiple scattering, w/o backscattering




```
AirLightSim Run Settings:
--> Particle Gun:                eCollFlat
--> Window status:               disabled
--> Filter status:               disabled
--> PMT Reflectivity:            0.00 %
--> Beam length:                 100.00 mm
--> Collimator length:           62.00 mm
--> Collimator width:            5.00 mm
--> N2 mass fraction:            88.74 %
--> O2 mass fraction:            11.26 %
--> Ar mass fraction:            0.00 %
--> Gas temperature:             20.00 �C
--> Gas pressure:                800.00 mbar
--> Gas density:                 0.00093 g/cm3
--> Generated Events:            1000000
--> Valid Events:                1000000
--> # Events in Scintillator:    999723
--> # Photons:                   0
--> # Photons in Chamber:        0
--> # Coin. Photons in Chamber:  0
```

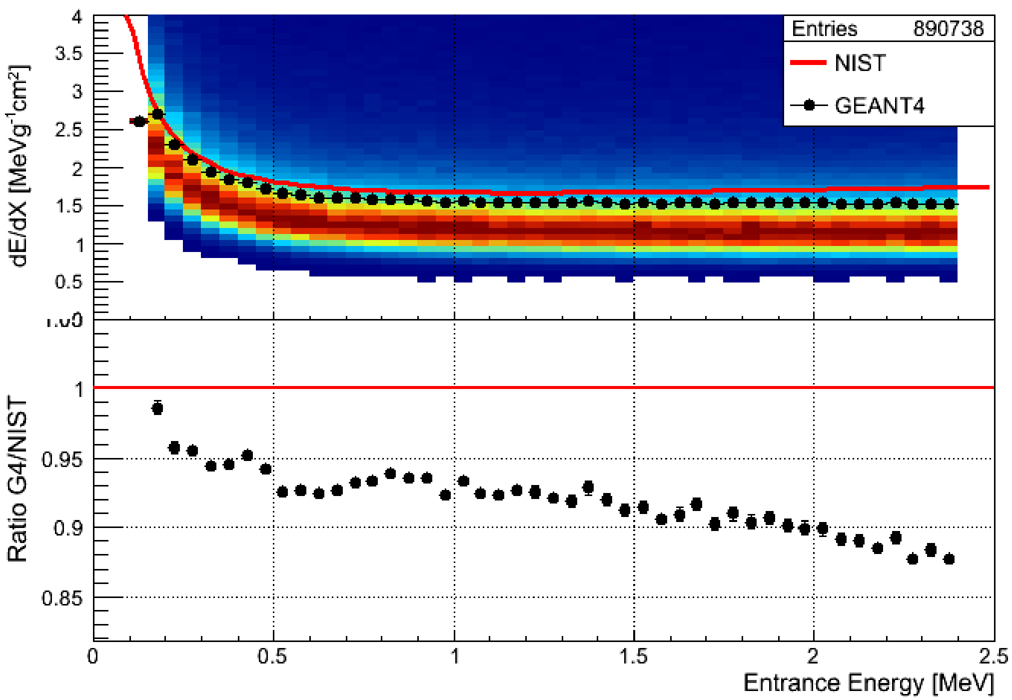
ok!

- Mean energy deposit agrees within 1-2 %
- Method for extracting dE/dX seems correct!

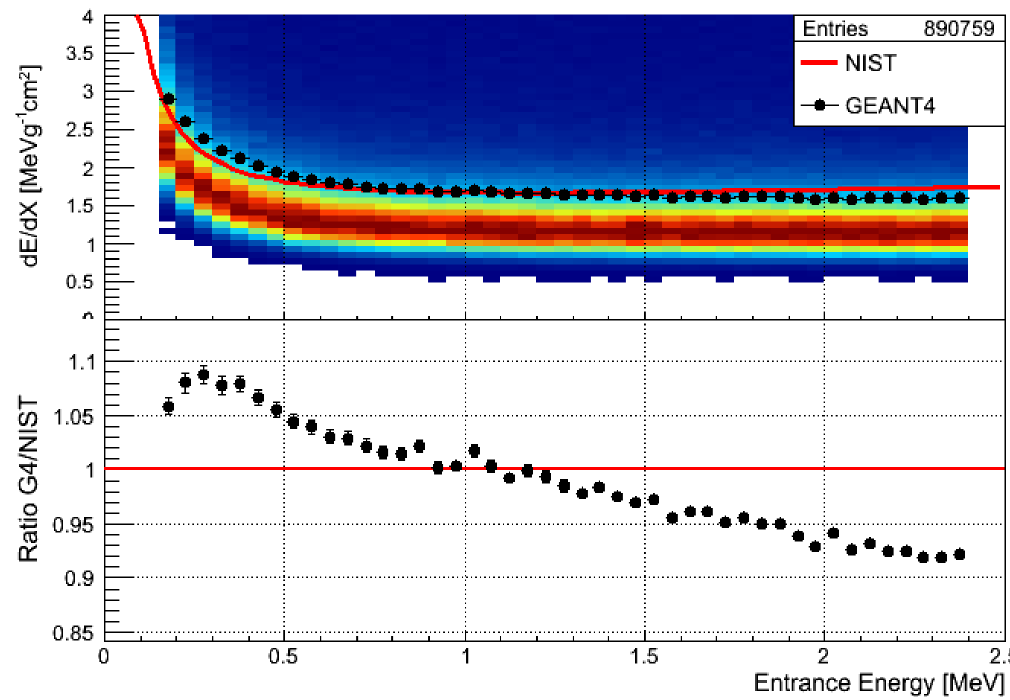
Influence of Delta-Electrons

- Electrons generated on axis (flat energy spectrum)
- With secondaries (range cut: 1 mm)
- With multiple scattering

w/o backscattering from scintillator



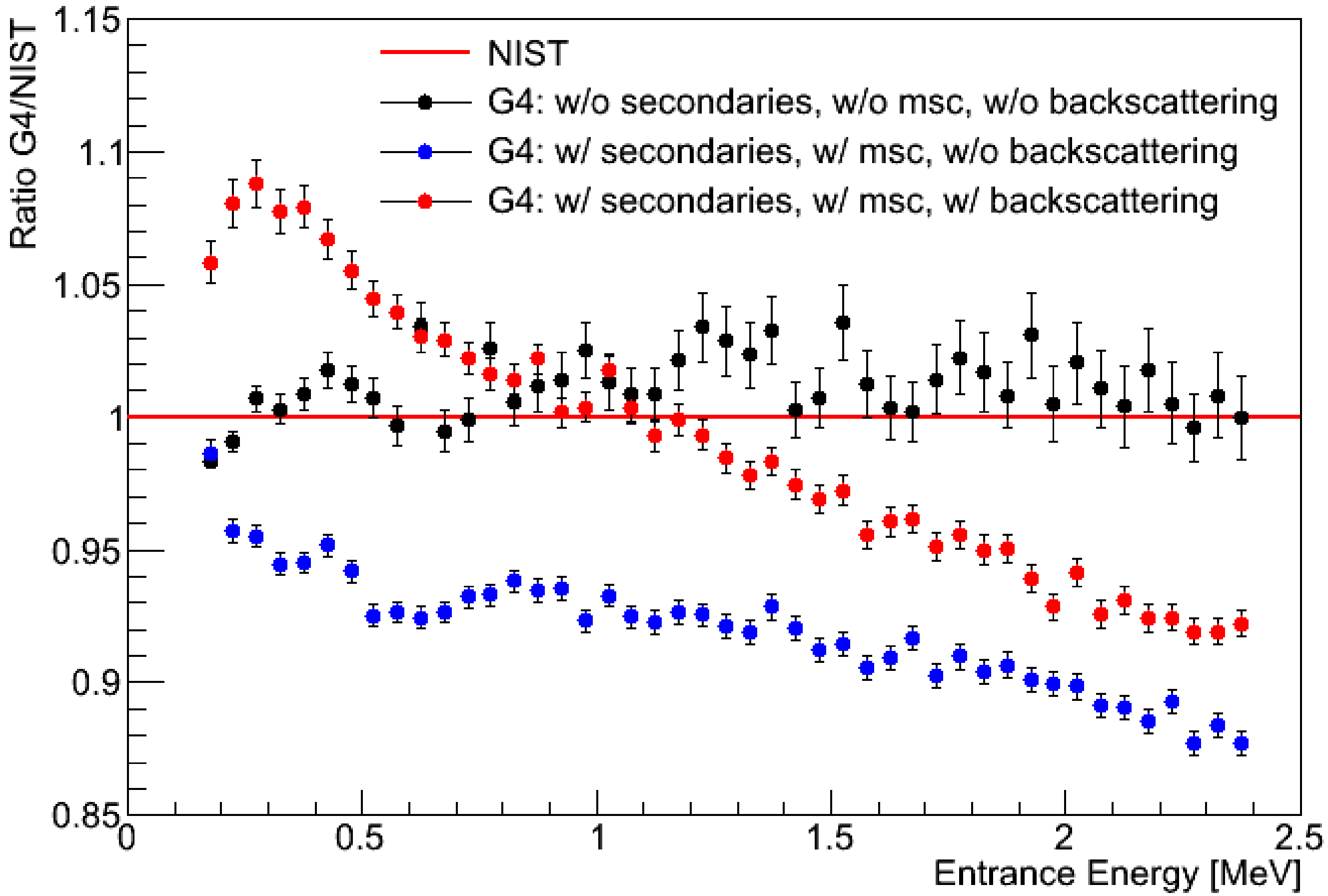
w/ backscattering from scintillator



→ Reduction of energy deposit due to escaping delta electrons (mainly in forward direction)

→ Enhancement of energy deposit due to repulsing electrons from scintillator

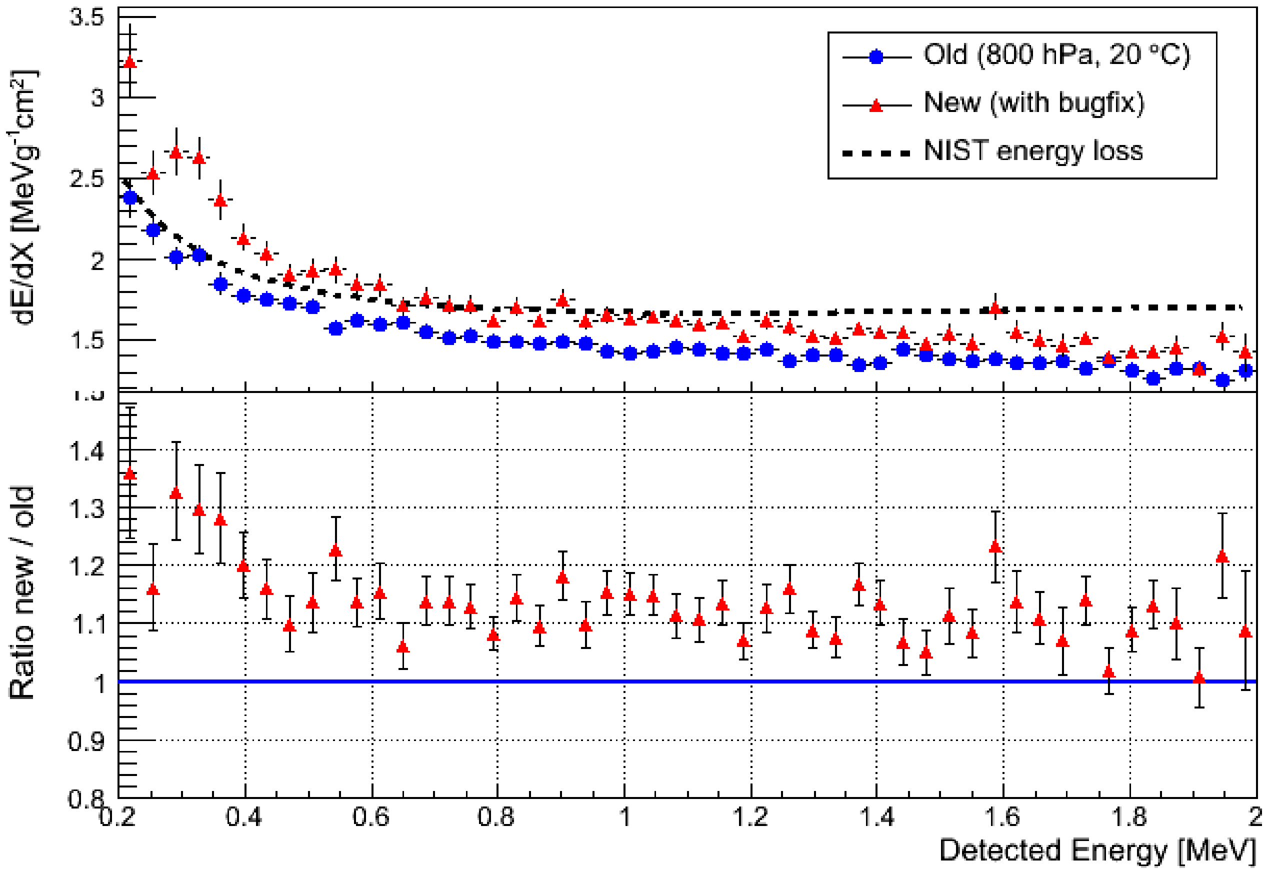
All Effects at a Glance



- Mean dE/dX ~ 1-2 % too large → GEANT4 issue?
- Decreasing energy deposit due to escaping delta electrons.
- Backscattering from scintillator needs to be taken into account.

Energy Deposit vs. Detected Energy

- Simulation with „realistic“ model of Sr-90 source (takes long).
- Including delta-electrons, multiple scattering + backscattering.
- Comparison with old AirLight data at 800 hPa (blue dots/line).



→ New results about 10 – 15 % higher!

Why didn't I realize this before?

```
AirLightSim Run Settings:
--> Particle Gun:                eSr90
--> Window status:               disabled
--> Filter status:               disabled
--> PMT Reflectivity:            0.00 %
--> Beam length:                 100.00 mm
--> Collimator length:           62.00 mm
--> Collimator width:            5.00 mm
--> N2 mass fraction:            88.74 %
--> O2 mass fraction:            11.26 %
--> Ar mass fraction:            0.00 %
--> Gas temperature:             20.00 �C
--> Gas pressure:                800.00 mbar
--> Gas density:                 0.00099 g/cm3
--> Generated Events:            300000000
--> Valid Events:                299936778
--> # Events in Scintillator:    49226
--> # Photons:                   34273373
--> # Photons in Chamber:        952511
--> # Coin_ Photons in Chamber:  306801
```

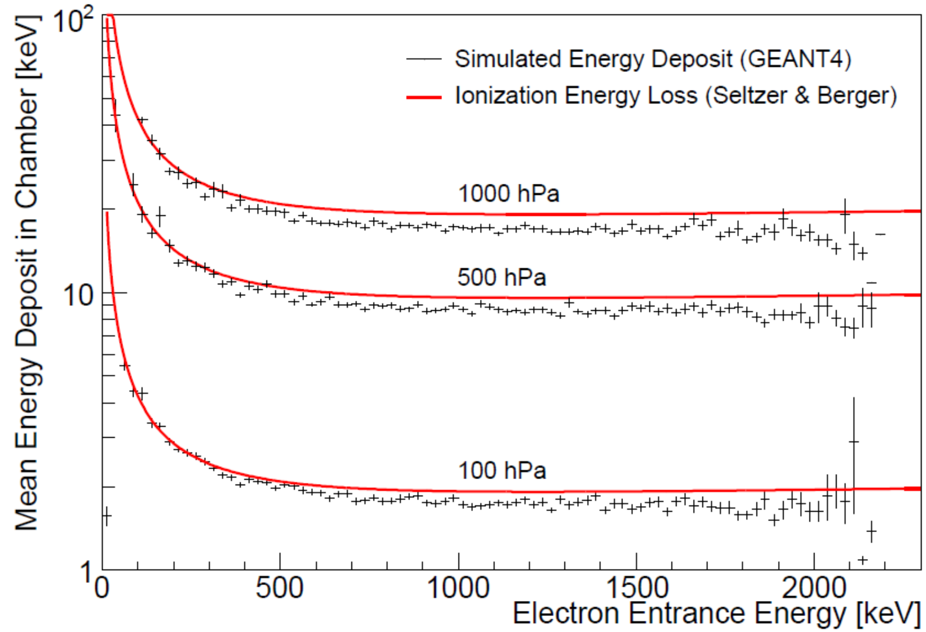


Fig. 4.8: Simulated energy deposit profiles over the entrance energy, compared to Seltzer and Berger parametrization.

In total only 0.02 % invalid events ...
… but this corresponds to 40 - 50 % of all events reaching the scintillator!

(1) I was not worried by 0.02 % of invalid events

(2) Energy deposit profiles seemed reasonable to me

Fl. Yield error is actually smaller

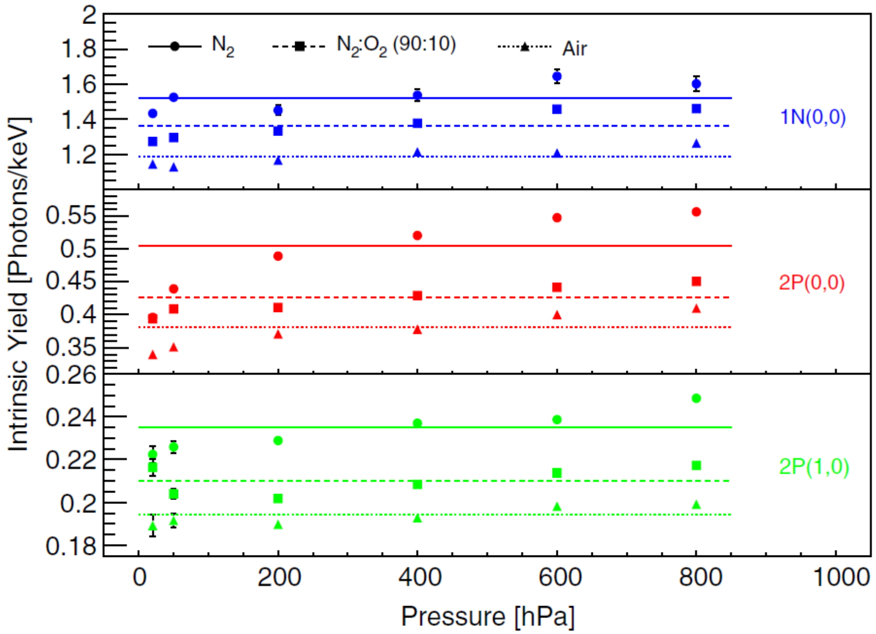


Fig. 15. Pressure dependence of the intrinsic fluorescence yield which presumably is due to experimental deficiencies. The horizontal lines correspond to the values quoted in Table 6 and denote the weighted average of the data points.

Table 5
Systematic uncertainties due to the observed pressure dependence of the intrinsic fluorescence yield

Gas	2P(0,0) (%)	2P(1,0) (%)	1N(0,0) (%)
N_2	12	4	5
N_2:O_2 (90:10)	5	3	5
Dry air	7	2	4

- Error decreases with pressure because of less photon emission in simulation.
- Problem has been noted before as pressure dependence of intrincic yield
  - was not understood
  - therefore using averaged values
  - partially included in systematic errors

Conclusions

- Discrepancy in energy deposit profiles due to bug in AirLight simulation.
  - AirLight Flurecsence Yield about 7 % too large

    (should be covered by systematic errors, but better recalculate everything)

- Simulation reproduces Bethe-Bloch within 4 – 5 % after bugfix.
  - Remaining discrepancies not understood
    → Problem with low-energy em-model (straggling) ?

- Escaping delta-electrons (in forward direction) and backscattering are not negligible.