Neutron background predictions and measurement at ATF2 beamline

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Outline

- Introduction : from ILC to ATF2
- Experimental setup and measurement apparatus
- Simulation setup
- Experimental effects
- Measurements around the ATF2 beam DUMP
- Summary

Introduction (1)

- Most of the background simulations for next generations of linear collider are using GEANT4 toolkit.
  - Many detailed studies have already been done through many codes :
    - BDSIM, Mokka, etc ...
- How well the MC can predict neutron background present in next linear collider.
- What about its production timing ?

NLC background sources

- Machine produced background before IP
  - Beam tails (halo) from linac
  - Synchrotron radiation
  - Muons
  - Beam-gas scattering
- Beam Beam background @ IP
  - Bremsstrahlung
  - Coherent/incoherent pair production
  - Hadron production
- Spent beam background
  - Backscattering of particles (specially neutrons)

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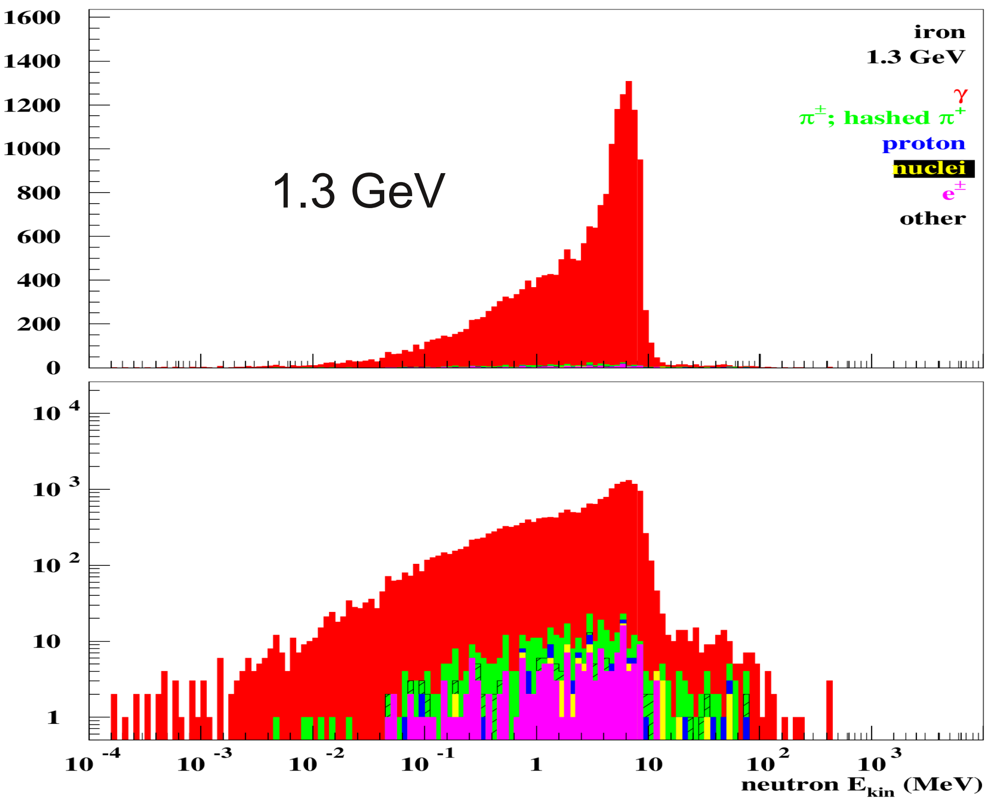
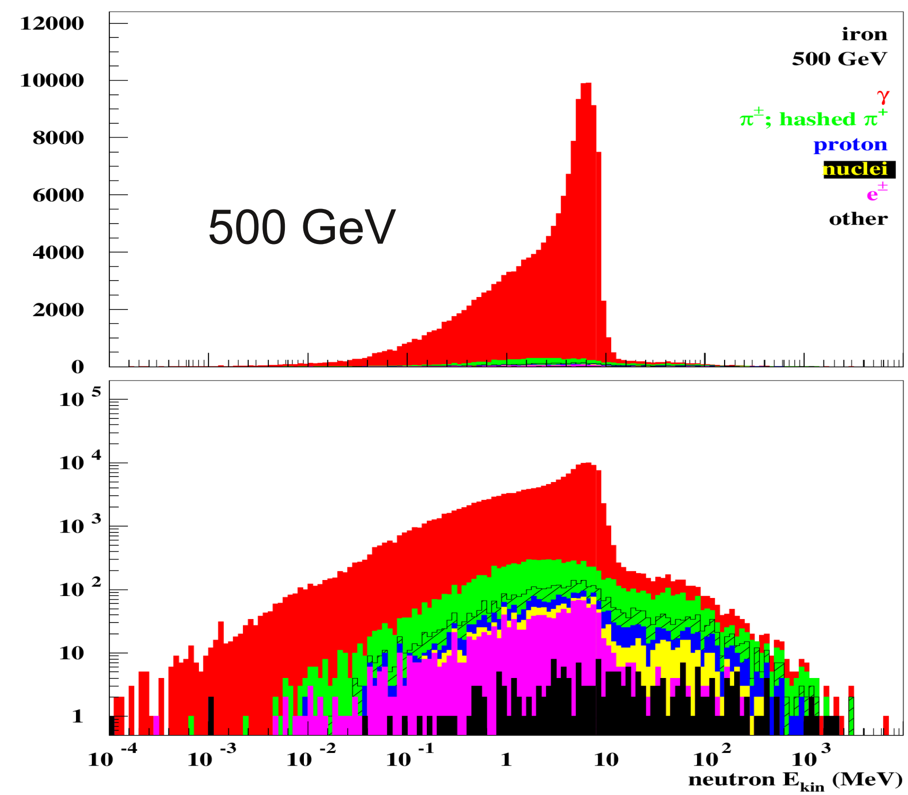
Neutron production : From NLC to ATF2

- The 1.3 GeV e- beam at ATF2 ending in an iron beam DUMP permit the possibility to test in real accelerator environment how G4 can handle neutron transport and productions.
- How could a 1.3 GeV electron beam neutrons production can be compared to the next generation of linear collider neutron background levels ?
  - Which regime is dominating the photo-nuclear neutron production ?
  - Which process is dominating the neutron production ?

Neutron production @ different e- incident energy on iron

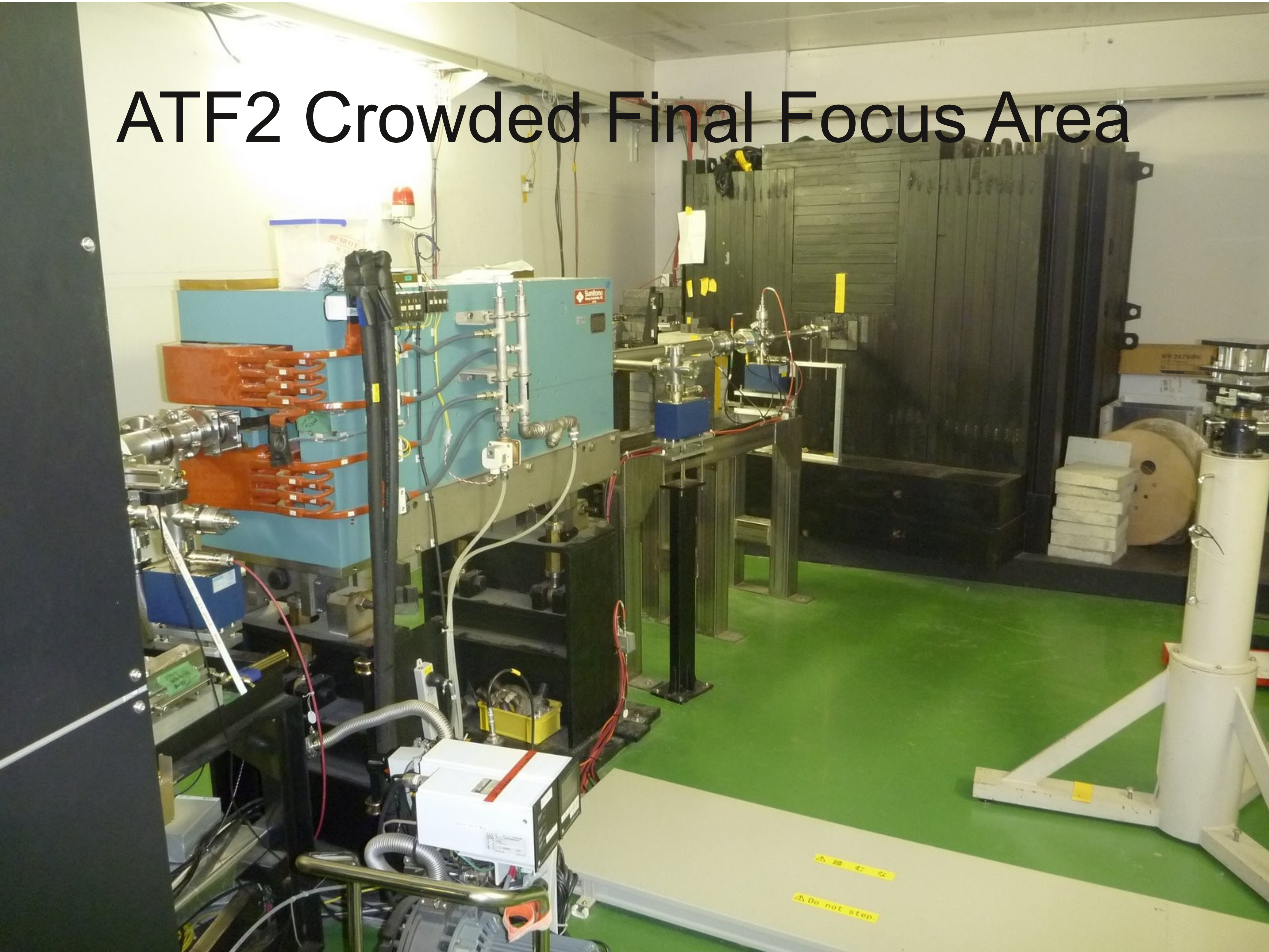




- Most of the neutrons are produced via photo-nuclear effect
- Produced neutron kinetic energy mainly < 10 MeV
- ATF2 can produce the major part of the neutron spectrum accessible at 500 GeV

EXPERIMENTAL SETUP AND MEASUREMENT APPARATUS

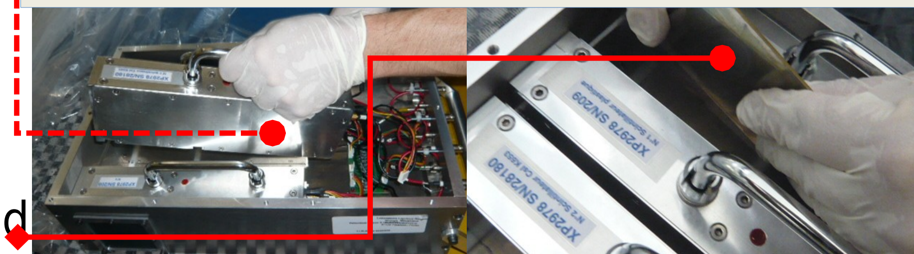
ATF2 Crowded Final Focus Area



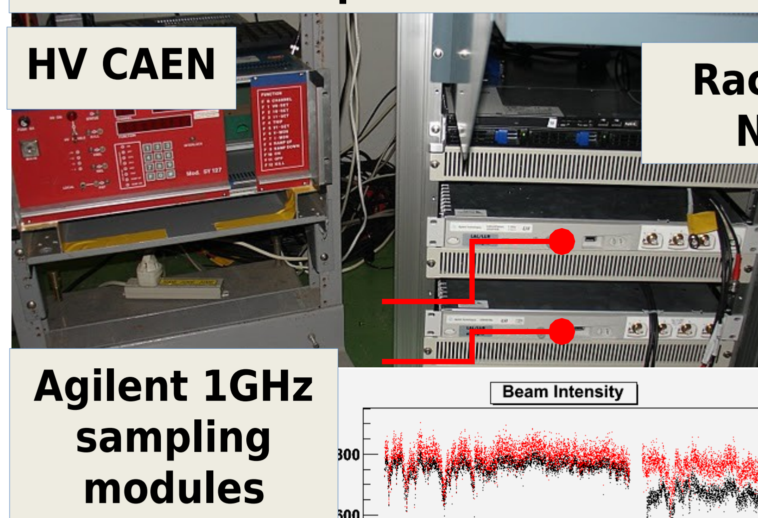
Experimental setup and apparatus

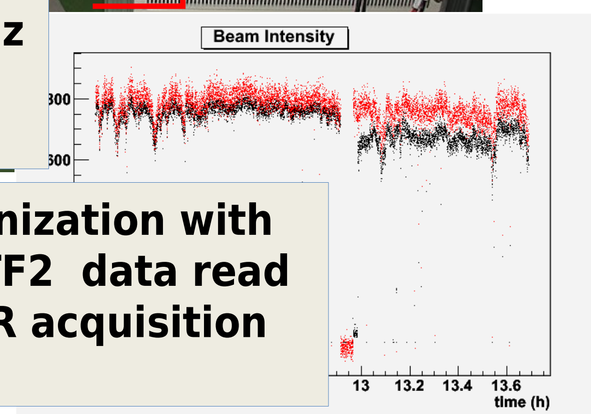
- **Made a set of 8 simple detectors = {scintillator + photomultiplier}**
  - That can be used alone
  - Or assembled in boxes to form « mini-calorimeters » with longitudinal segmentation (with W insertion if needed)
- **Scintillator = plastic or pure CsI**
  - CsI crystal equipped with filter to cut the slow light component
  - Fast : allows TOF
  - Distinguish background sources
  - Separate (prompt) EM and (delayed) neutron backgrounds
  - Different response to neutrons:
    - Plastic sensitive to fast neutrons
    - Intermediate neutrons for CsI
- **Record the time-dependent signal**
  - 1e signal waveform, sampling at 1 GHz
  - Absolute amplitude and time dependent signal shape tell about neutron production and transport in beam dump

Detectors (example with using a box)



Acquisition





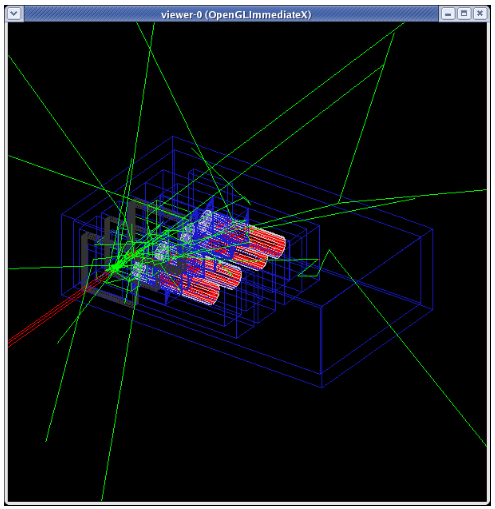
Synchronization with ATF2 : ATF2 data read from LLR acquisition

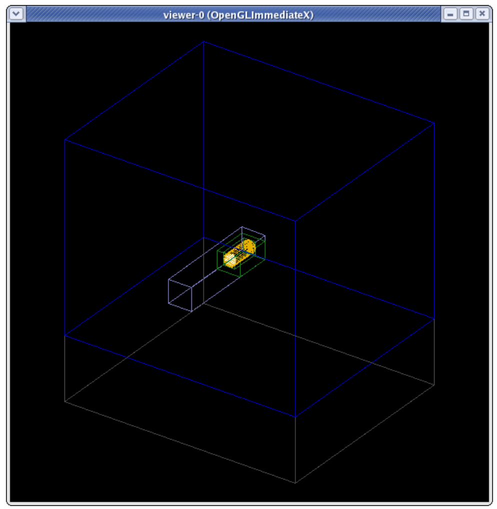
Simulation

Simulation setup (I)

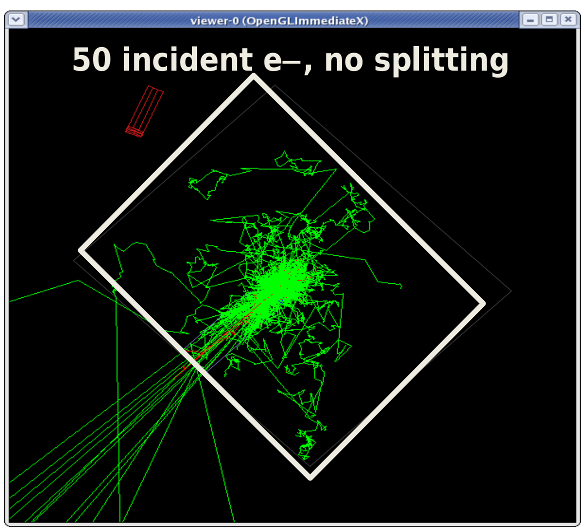
- G4 version 4.9.0
- Physics lists : QGSP_BERT_HP && QGSP_BIC_HP
  - QGSP
    - Quark Gluon string with Precompound
    - Precompound (P) calls nuclear de-excitation routine
    - 12 GeV - 50 TeV (QGS)
  - BERT
    - BERT : BERTini cascade Unique evaporation model to de-excite the remnant nucleus up to ~10 GeV
  - BIC
    - Binary cascade, Based on 2-->2 or 2--> interactions, Up to ~10 GeV
  - HP
    - High precision neutron
    - Allow precise transportation of neutrons
- Implement detailed description of measurement modules, and realistic description of beam dump
- Use **"splitting" technique**, also called "**geometrical biasing**" To get workable statistics

Simulation setup (II)

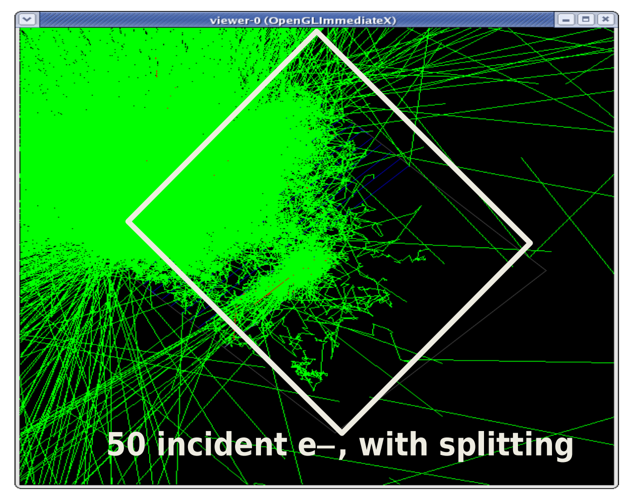




- Implement detailed description of measurement modules, and realistic description of beam dump
- Use “splitting” technique, also called “geometrical biasing”
  - To get workable statistics



~3 order of magnitudes more Efficient. (12 slices)



Experimental effects

- Experimental effects can be large
  - And are still under work at present
- Effects under study:
  - Calibration
    - Calibration done with cosmic rays
- Cable attenuations :
  - Neutron average signal is slow signal and should not be affected but calibration coefficients measured with cosmic rays should be more affected (expected to be < 30%).
- Scintillation saturation (Birks' effect) in plastic scintillators
  - Large effect for neutrons !
  - Fast neutrons detected as n → p, with high dE/dx for p

Size of Birks saturation effect

Birks law: describes the scintillator response

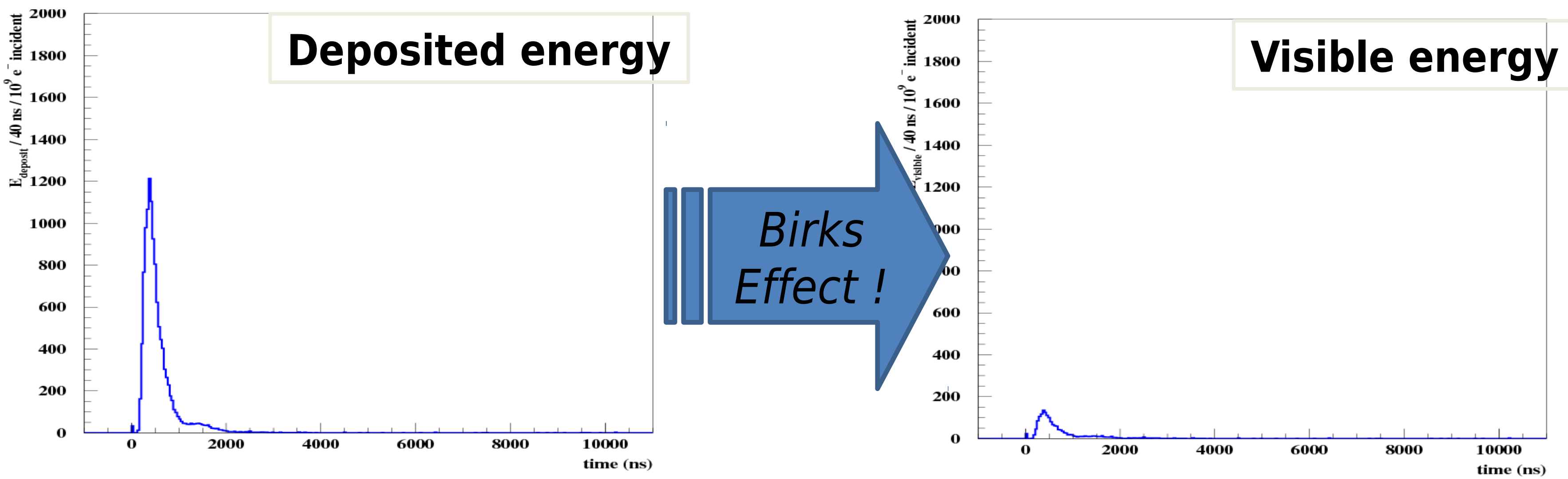
$$\frac{dE_{vis.}}{dx} = \frac{dE/dx}{1 + k_B\, dE/dx}$$

$kB \sim 10^{-2}$g.cm^{-2}.MeV^{-1}

$$\frac{dE_{vis.}}{dx} = \frac{dE/dx}{1 + k_B\, dE/dx + c(dE/dx)^2}$$

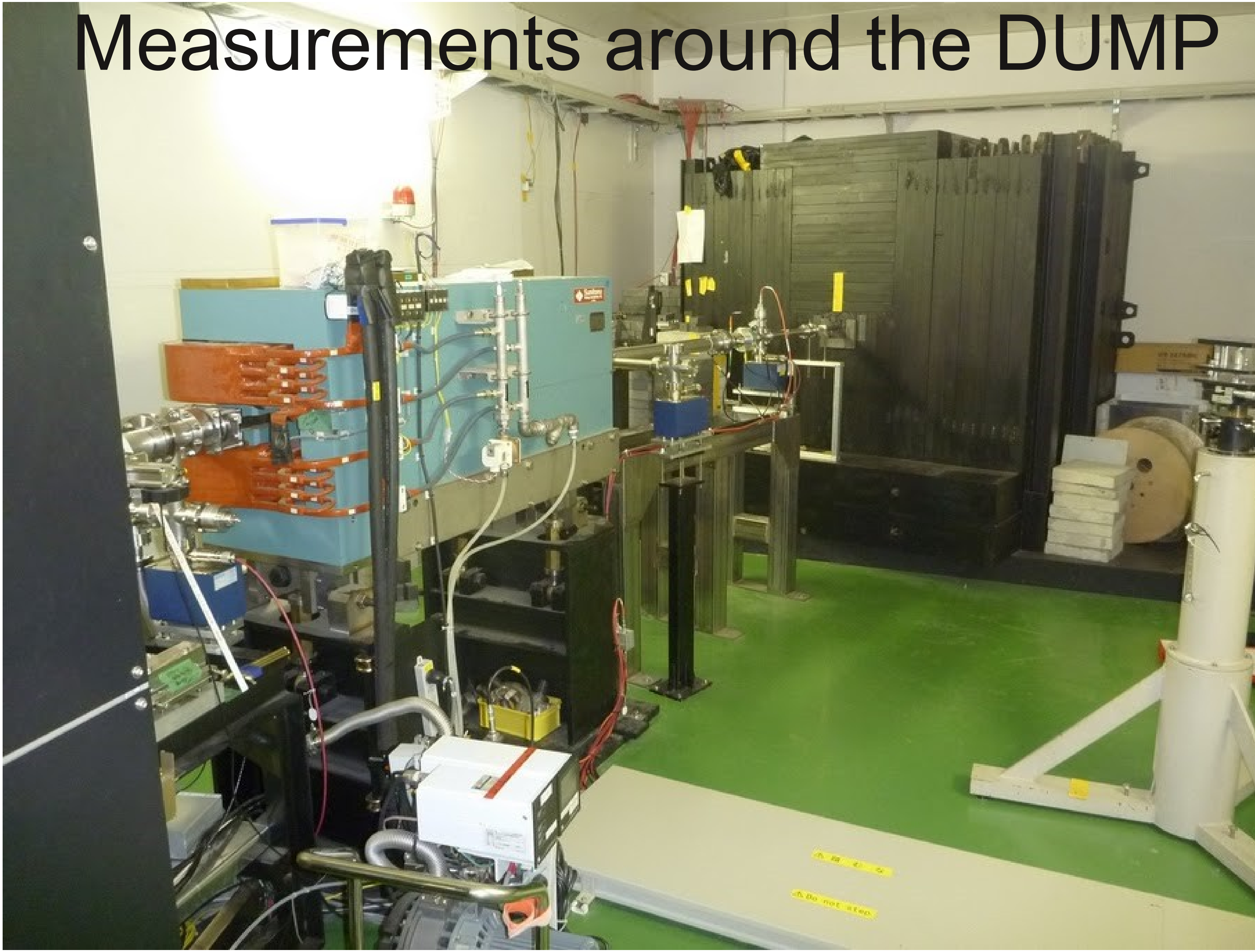
$c \sim 10^{-5}$(g.cm^{-2}.MeV^{-1})^2

value in BC-408 plastic, as measured in Chinese Physics C (HEP & NP), 2010, **34**(7) 988-992

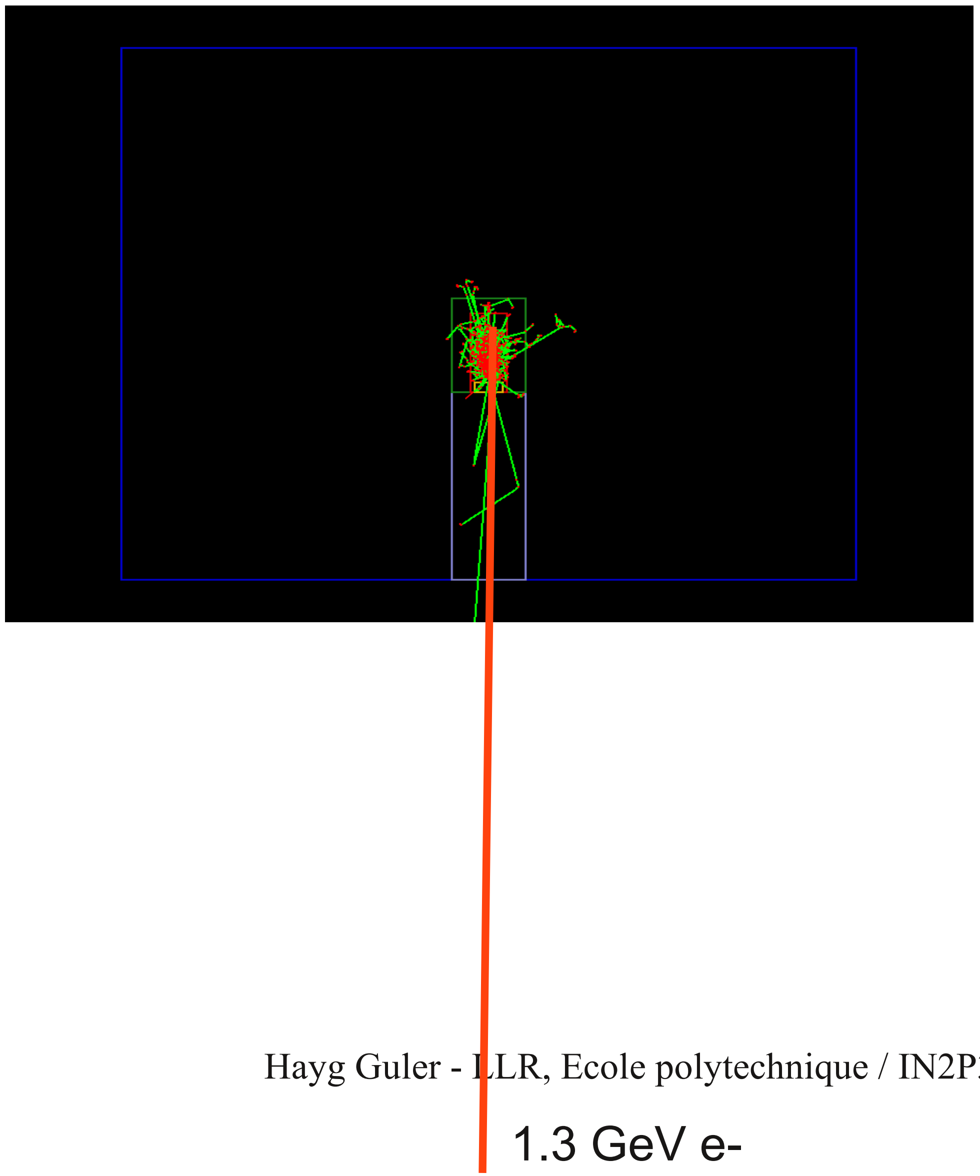


- Very large effect (factor ~ 10)
- Small error on the factors can have huge effect on visible energy

Measurements around the DUMP



What are we testing by measuring neutron production around the DUMP ?



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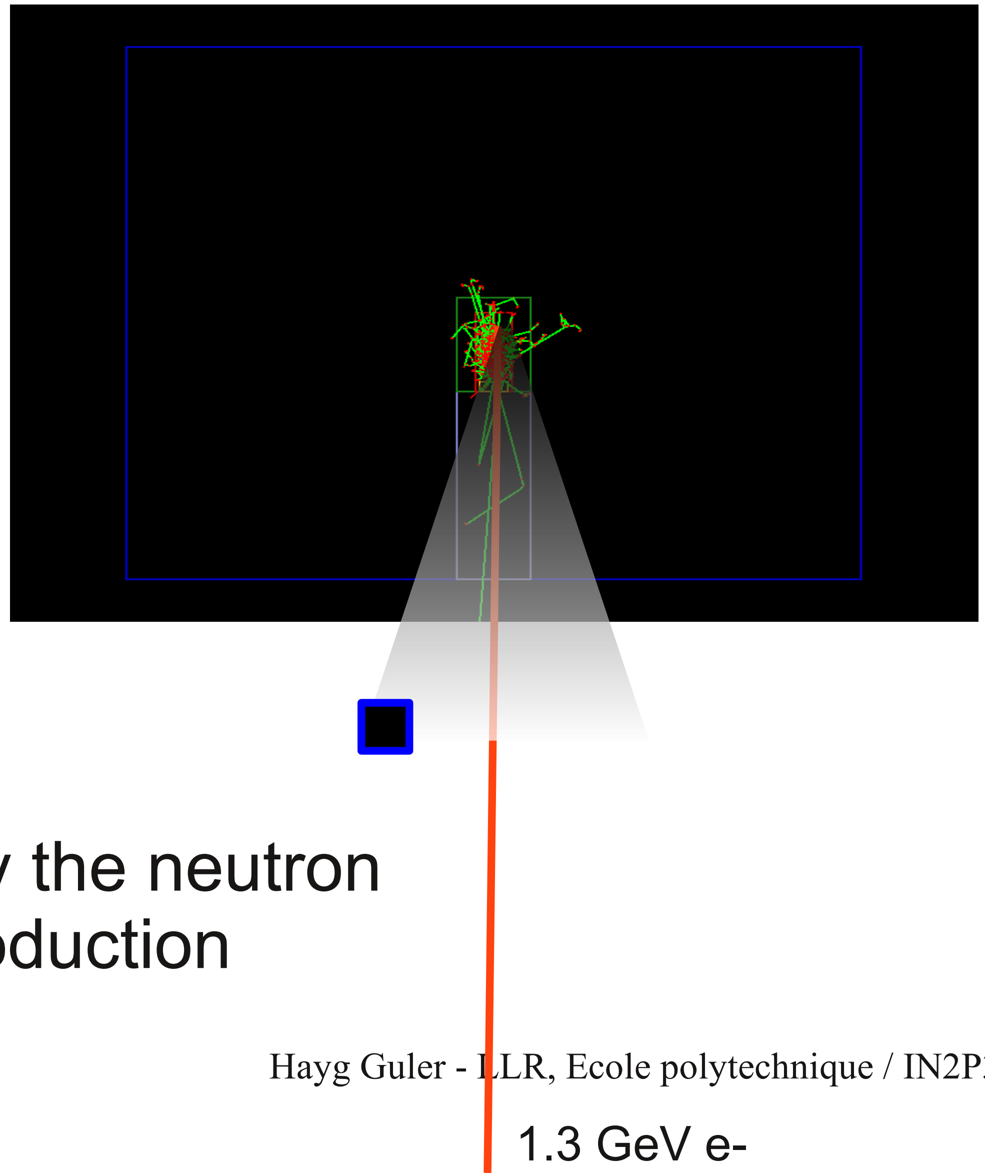

Test mainly the neutron (photo-)production

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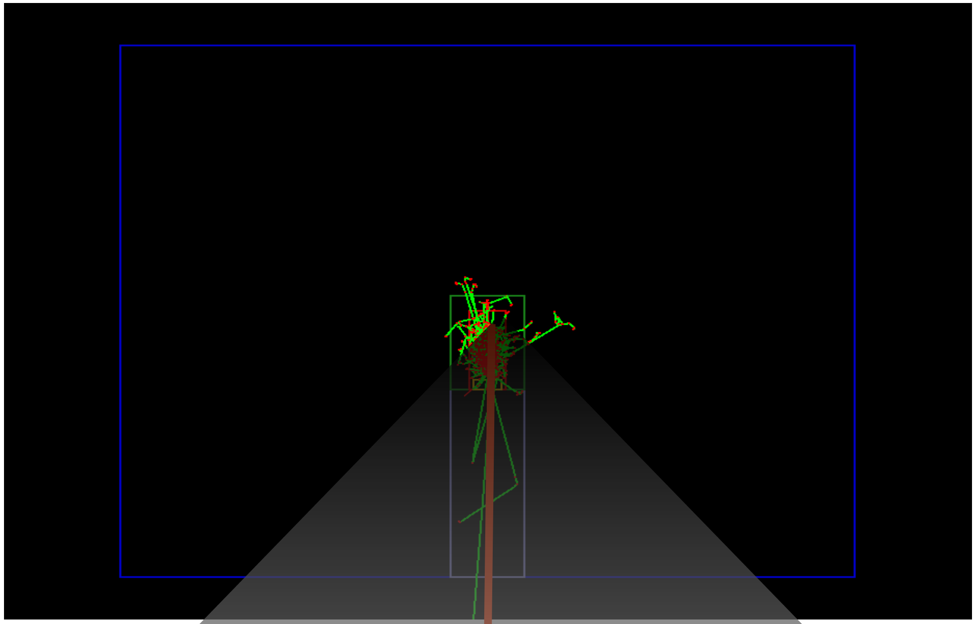

Test the neutron (photo-)production and also the transport.

1.3 GeV e-

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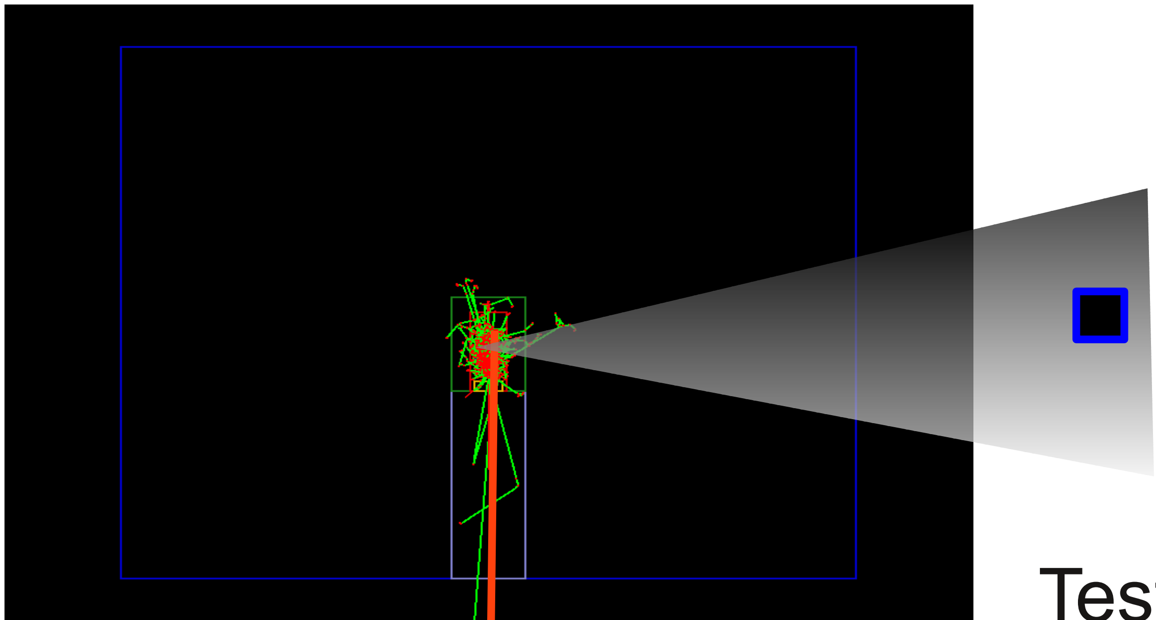
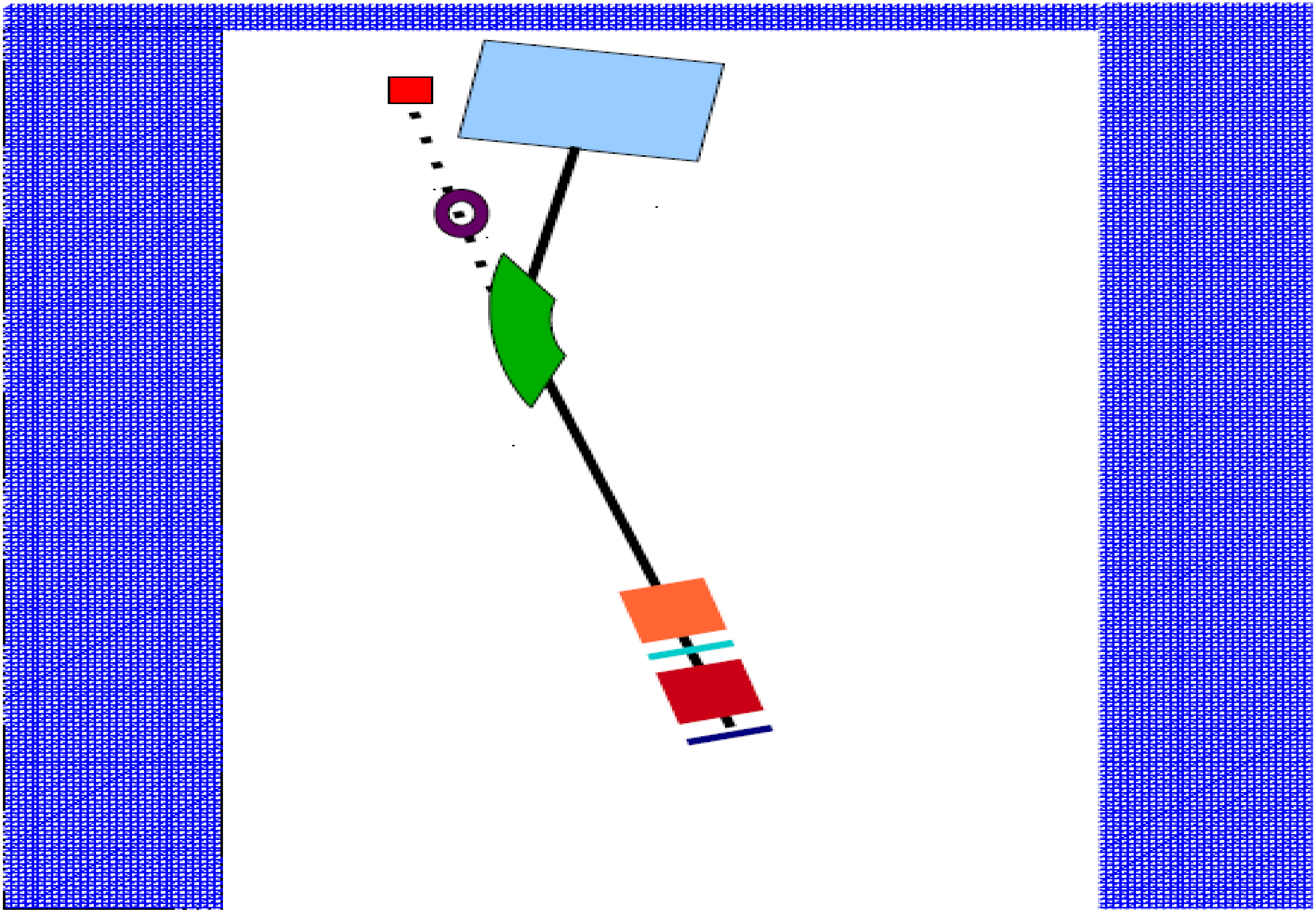


Test mainly the neutron transport

Measurement places



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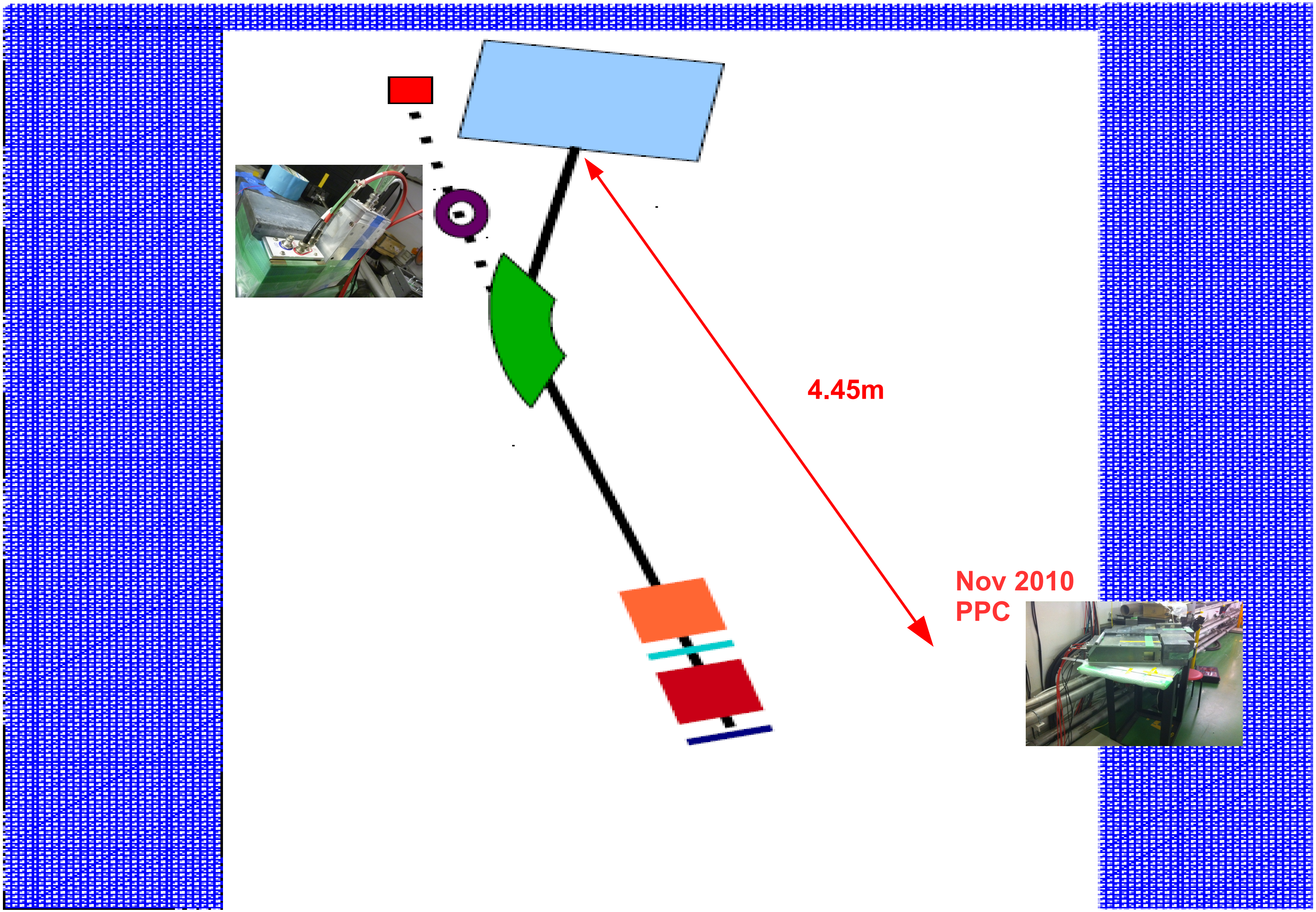
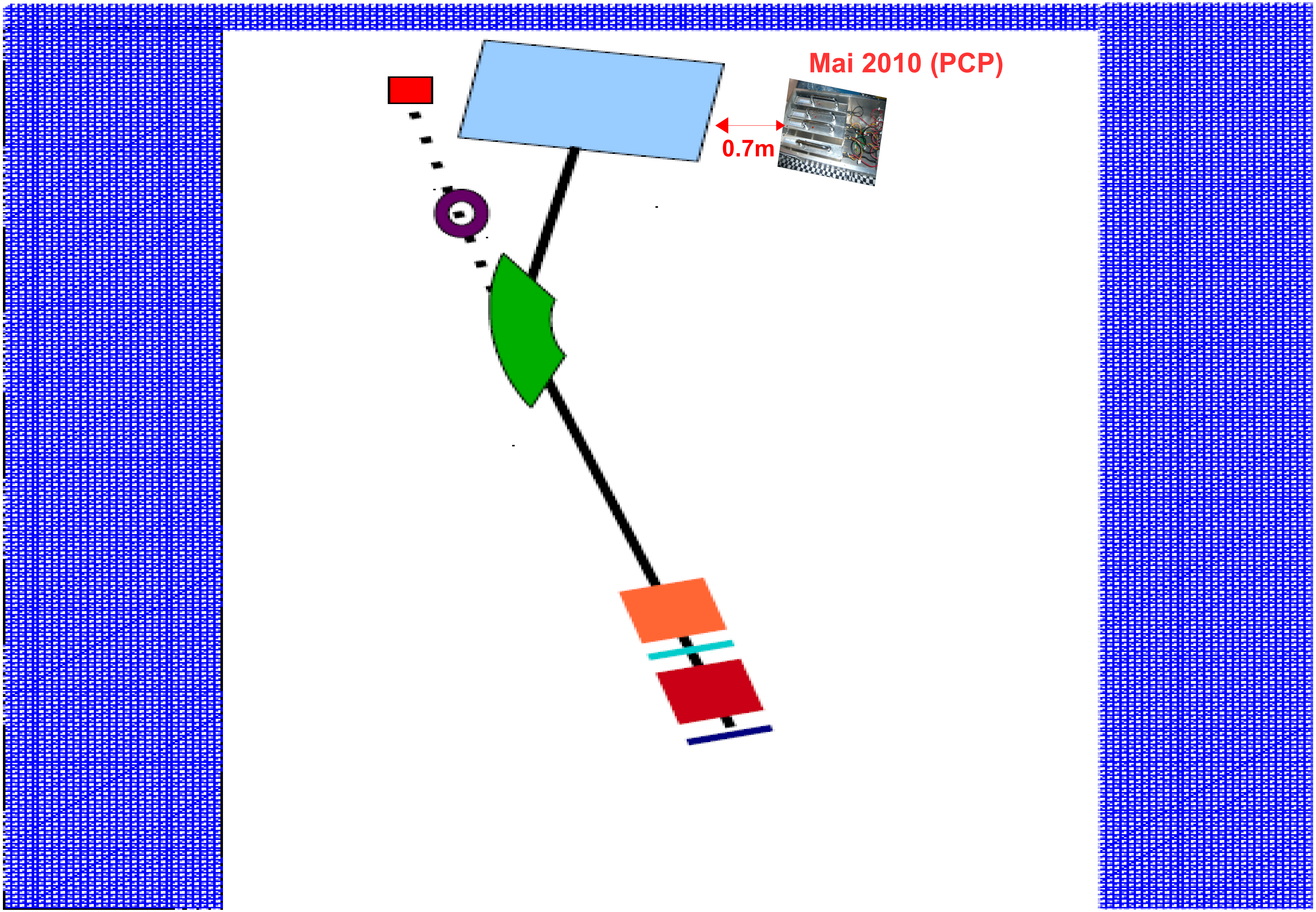


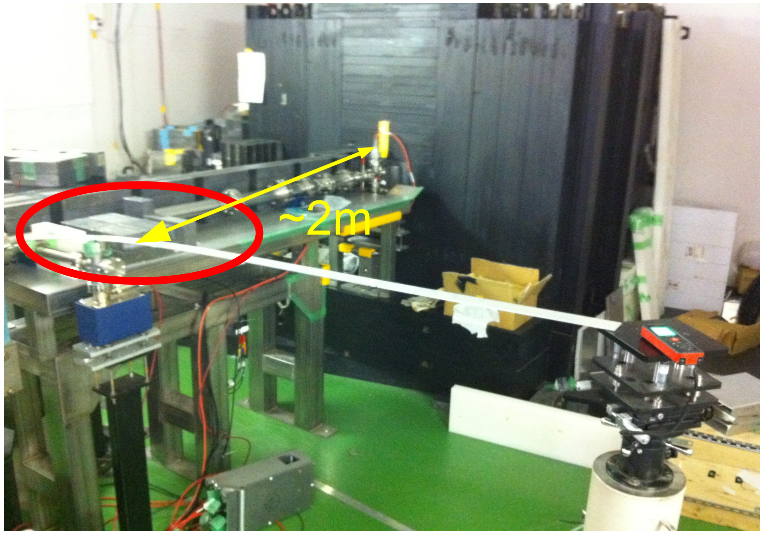
Measurement places

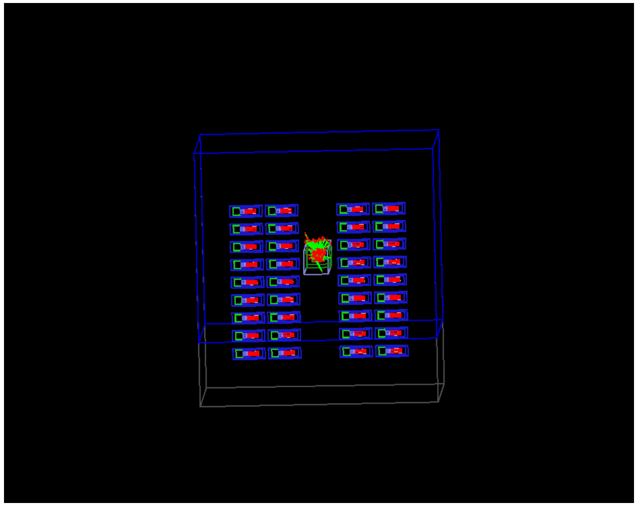


MC/Data comparison procedure

- Data : from ($f_{sampling}$ =1 GHz) oscilloscope
- WF : 10 k-points (Amplitudes in V)
  - Seen over 50Ω cable
  - $Qi = Vi / 50\Omega / f_{sampling} / |e|$
  - Normalize by the beam charge (given in pc)
- MC : E_{dep} (MeV) for 1 incident electron
  - Normalized by Ndets (used in simulation)
  - Project in
    - Histogram binning : 40ns width
- Calibration factor given in 10^9 e^- / MeV

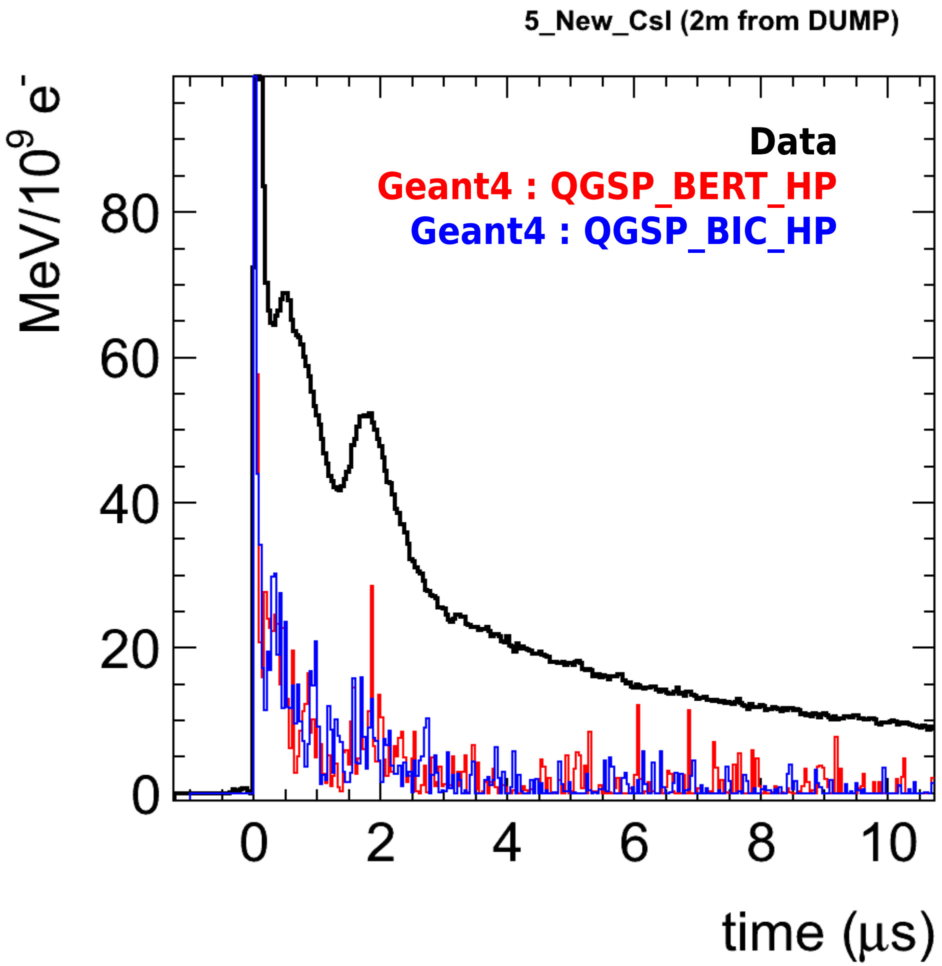
CsI on “DUMP Table”





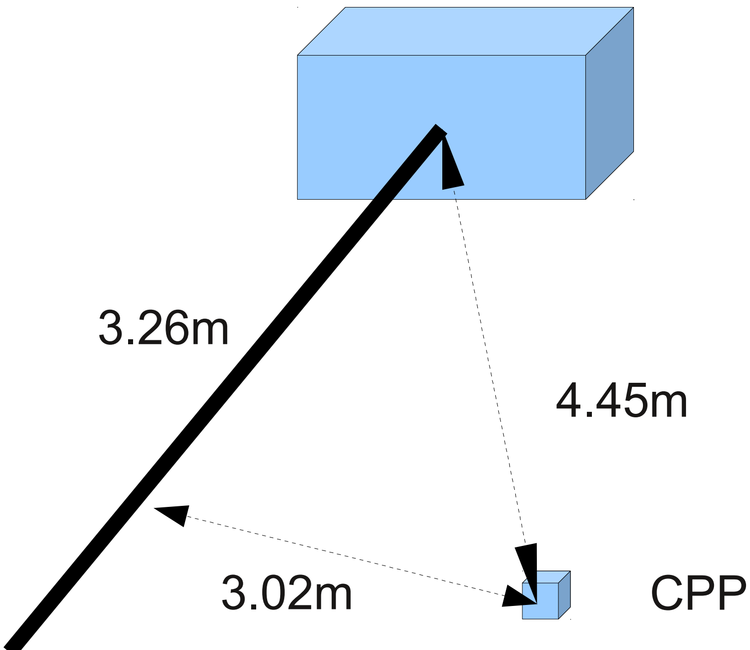
- Region more sensitive to neutron production
  - Neutrons are not traversing a lot of iron
  - The production is less sensitive to transportation
- Geant4 simulation done with duplicating as much as possible the detection module
  - Improve the statistics
  - Can also use the geometry splitting method (not used here)

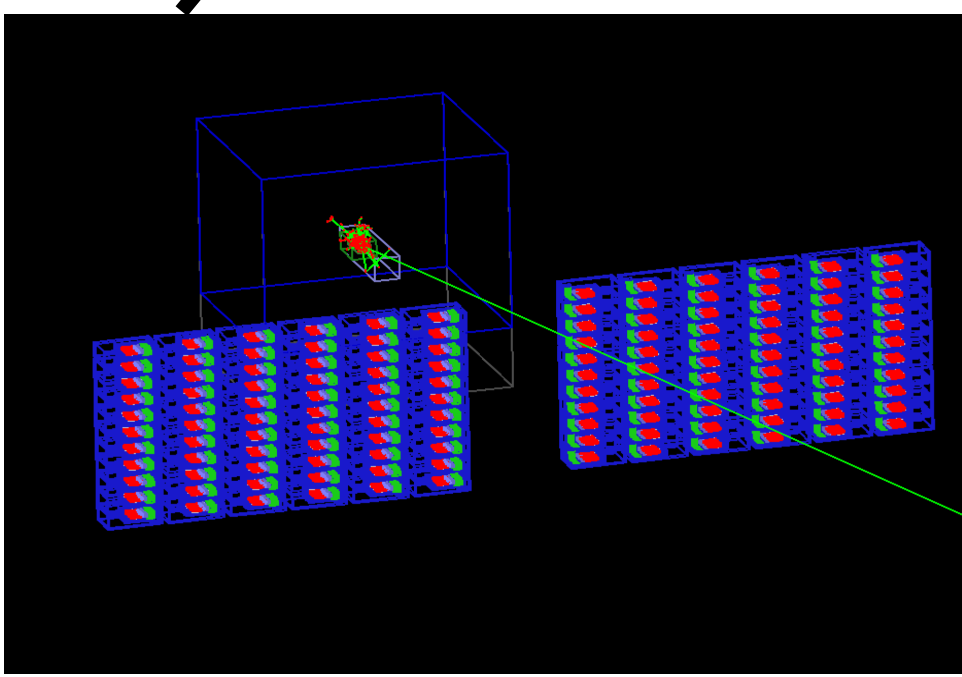
CsI at 2m from DUMP



- High gain photomultiplier : cross check with low gain modules.
- Comparison to pure MC output and would need to smear it with detector resolution.
- Gross features are produced by the simulation
  - Time structure is reproduced, but …
  - G4 underestimates the data by a factor ~ 5

Data vs MC (4.4m from DUMP)

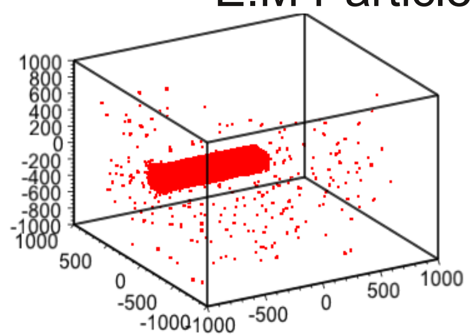




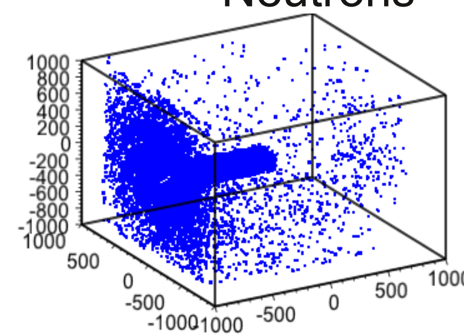
R,

- Module box in front side of the DUMP and further away (~4.4m)
  - Sensitive to neutron photo-production
  - Also to transportation (neutron traversing some iron dump)
- In G4 (4.9.4) simulation, use many detectors to improve statistics
  - 50 M (incident e-) simulated
  - No splitting method used to improve the statistics
- E.M particles are mainly exiting from the DUMP hole. Neutrons are produced from the whole DUMP exit plan.

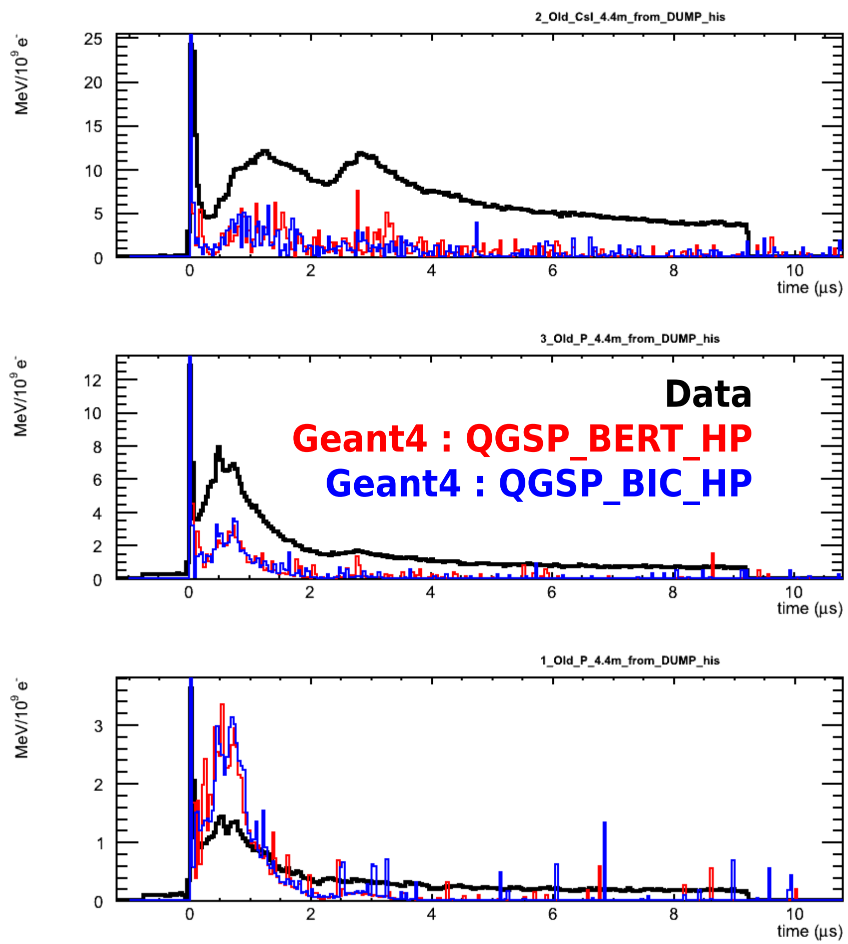
E.M Particles



Neutrons

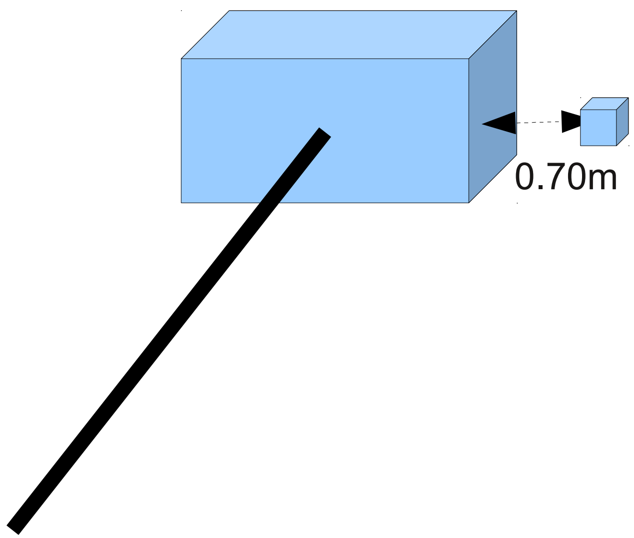


4.4 m from DUMP



- Region sensitive to both neutron production and transport
- Higher distance to the DUMP would also affect WF shape and stretch its structure.
- Gross features are produced by simulation but still big differences.
  - TOF mainly reproduced (bumps at correct timing)
  - G4 under estimate CsI by a factor ~5

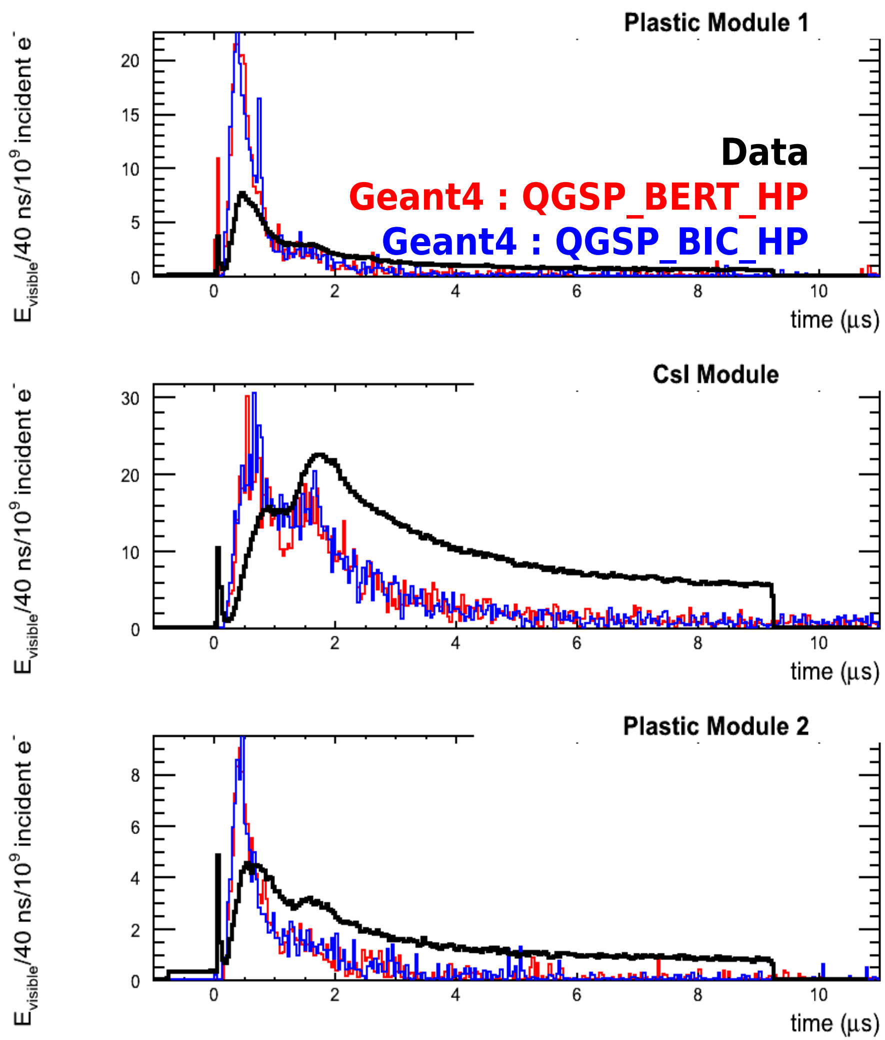
Right Side of the DUMP



- Geometry biasing used : 12 slices and multiplication factor = 2
- Region dominated by transport
- Shielding to protect against huge E.M background from the downstream beam line (against saturation)
- Detector order :

  P-C-P

Right side of the DUMP



- Neutron production dominated by transport effect
  - Needed geometry biasing to produce neutrons from G4
- Both G4 models are consistent to each other
- High energetic neutrons is over estimated in G4 while slow neutrons are underestimated.
- Not yet understood if the discrepancy comes from the simulation of the production or from the way that G4 handles the detector efficiency (including also saturation effects in plastics).

Summary

- Studies are on going at ATF2 to evaluate how well Geant4 can predict the neutron production and transport.
  - Difficulties with the measurements around the ATF2 DUMP because we are sensitive to both.
  - Parallel measurements using AmBe source can be complementary (known spectrum but need to trigger on signal itself).
- Measurements around the DUMP :
  - Simulation cannot reproduce the Data (factor 2 to ~5)
  - Gross feature (bump time positions) are reproduced by simulation
  - Two physics lists (most adapted to the neutron energy regime) are used
- First answers concerning the reliability of Geant4 to predict neutron background levels for MDI for the next linear colliders.

Possible reasons of the MC/Data difference

- Cable attenuations :
  - Neutron average signal is slow signal and should not be affected but calibration coefficients measured with cosmic rays should be more affected.
  - Error on calibration coefficients are evaluated using short cables and the error is < 30%
- Neutron production in the DUMP or detector efficiency ?
  - Still open. Neutron production discrepancy can affect all detectors. Need to measure R1=sig_D1/sig_D2 to be independent on neutron production.
- Birks effect in Plastics ?
  - Should by confirmed by using AmBe source.
-

Plastic Module on Shintake collimator

- New high gain photomultiplier module
- Distance to the DUMP ~ 2m and symmetrical position to new CsI module w.r.t beam pipe.
- Access to the fast neutrons