Karlsruhe Institute of Technology

bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

Simulation of electron incident on silicon for KATRIN

Tag des SFB/TR 27 MPI-K Heidelberg 10.07.2009

Insitut für experimentelle Kernphysik

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Outline

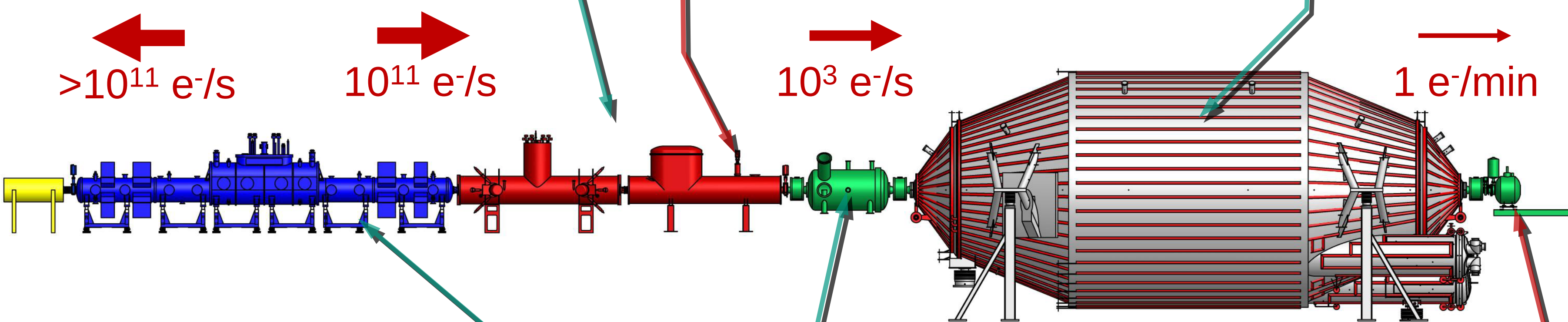
- **Motivation**
- **Detector response**
- **Simulations and Comparisons**
- **Summary and Outlook**

KATRIN – experimental setup

Transport Section
Tritium Retention
Turbopumps + Cryotraps

Forward Beam
Monitor Detector

Main Spectrometer
U = -18.3 … -18.6 kV
ΔE=0.93 eV



Plus other Silicon detectors (SDD, PIN, …) in proof-of-principle and commissioning experiments!

Pre-Spectrometer
U = -18.3 kV

Focal Plane Detector (FPD)

Detector response

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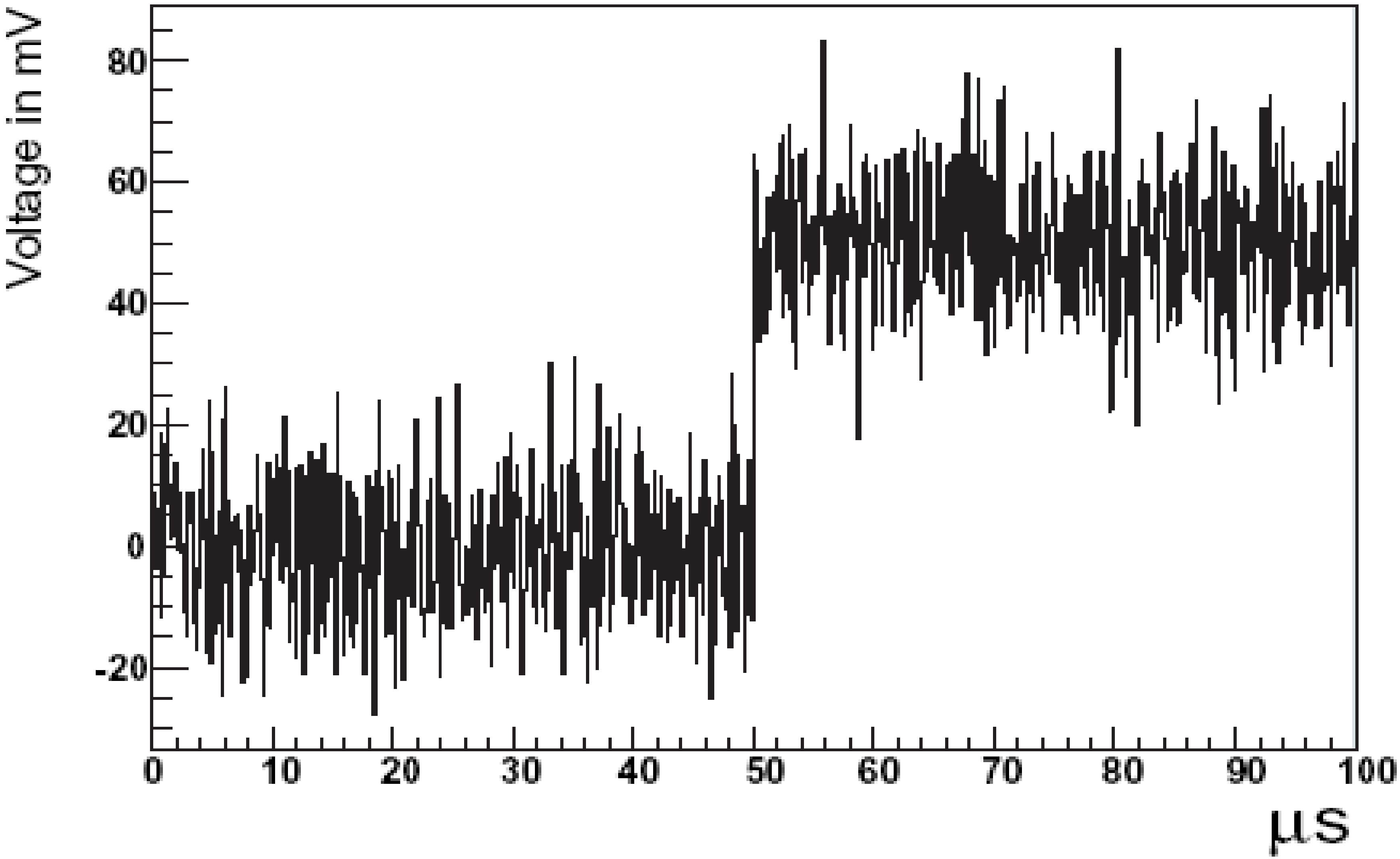
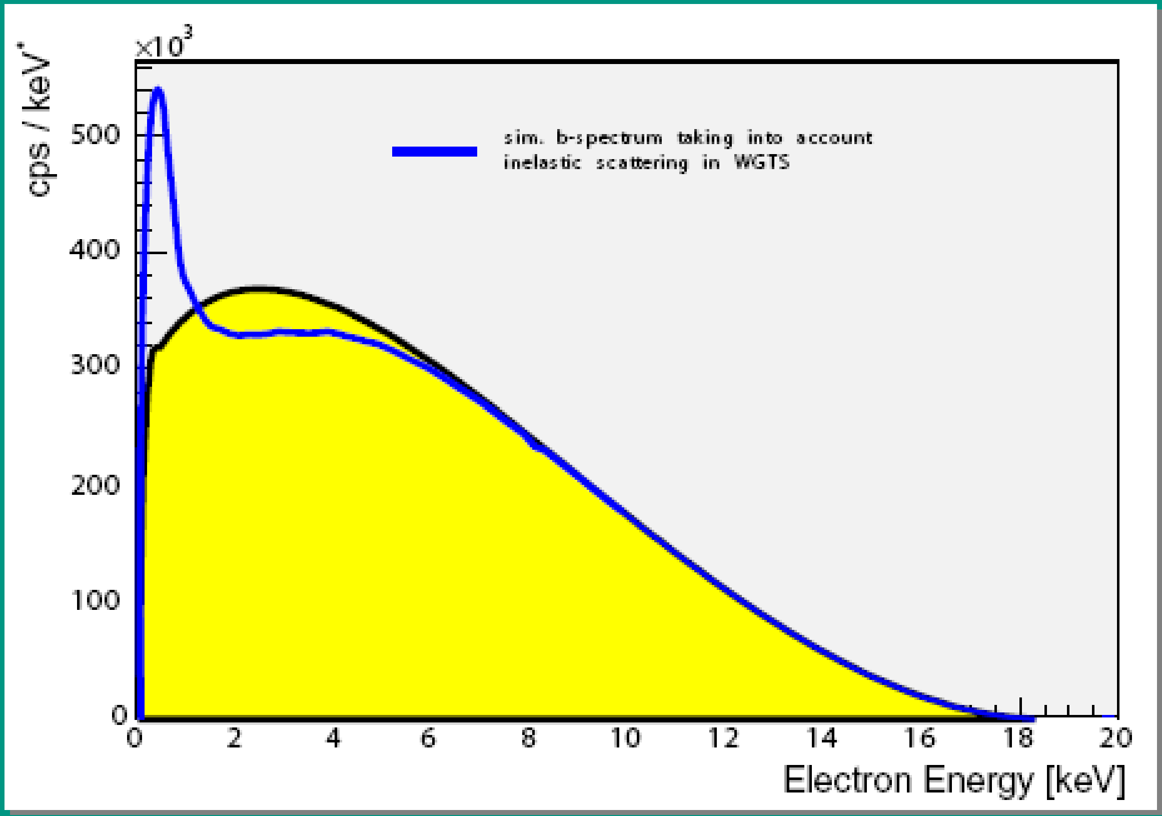
- **The detector response describes the measured or expected detector observables to an incident monoenergetic particle as function of**
  - Particle type
  - Incident energy
  - Angle of incidence
  - Arrival time
- **In case of KATRIN this depends on:**
  - Insensitive detector areas (deadlayer)
  - Electro-magnetic configuration
  - Intrinsic noise (leakage current, fano noise,…)
  - Electronic noise (Preamps, …)
  - Detailed geometry

Detector response



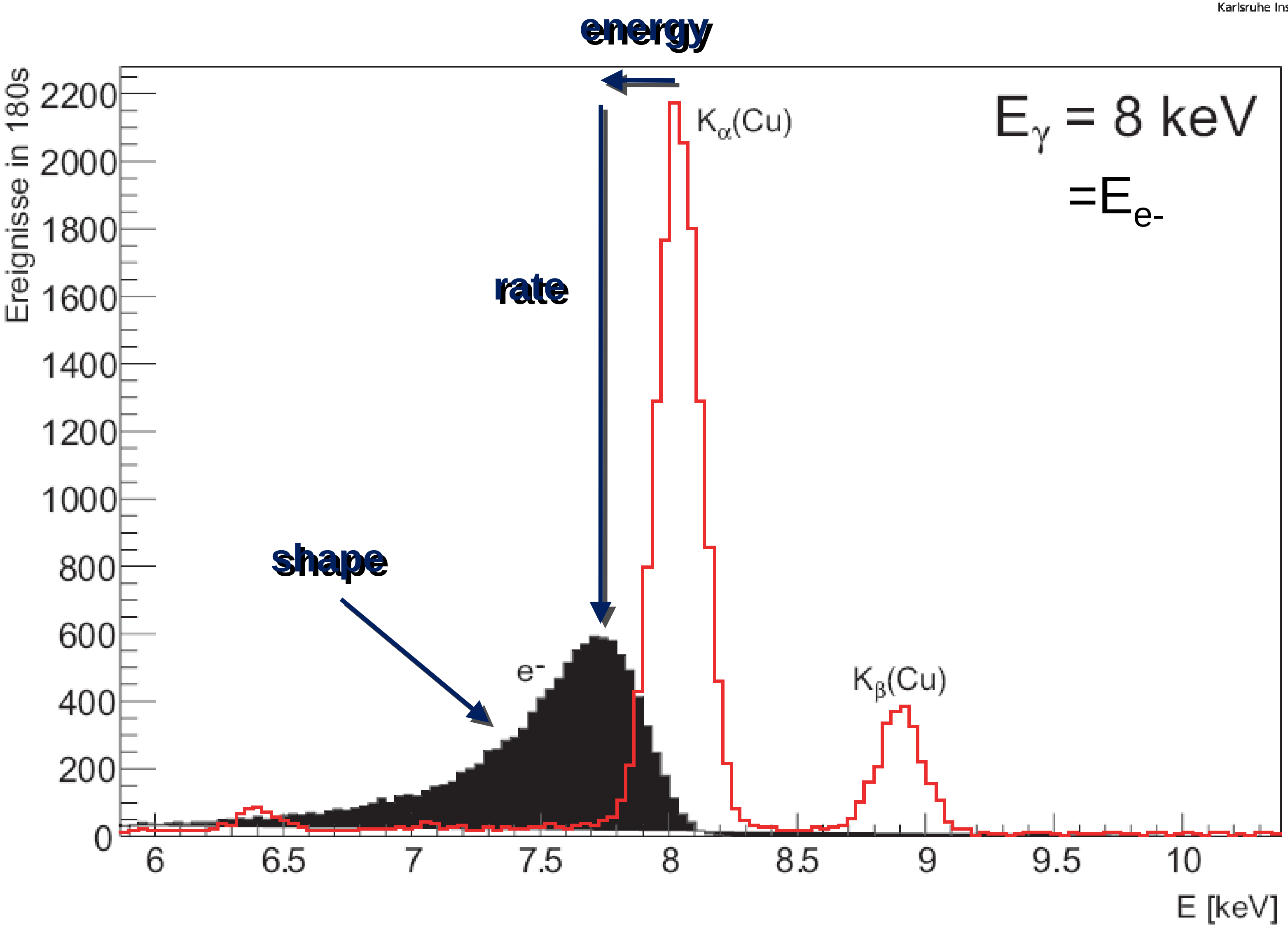
Detector Response – Why?



- **The low energy part of the tritium b-spectrum carries information on source properties**

COMPARE EXISTING SIMULATIONS:
Geant4, PENELOPE2008, custom MC, …

Electrons vs. X-rays – the problem



Geant4

- High Energy Physics origin (CERN)
- Has two low-energy extensions
  - PENELOPE2001
  - LowEnergy Package
- Large parts of the KATRIN global simulations are done in G4
  - Detector background by Michelle Leber (CENPA)
  - New em-field tracking classes by TJ Corona (MIT)
  - Complete FPD model already exists
  - …
- Complex geometries, many physics processes and materials
- Secondary production

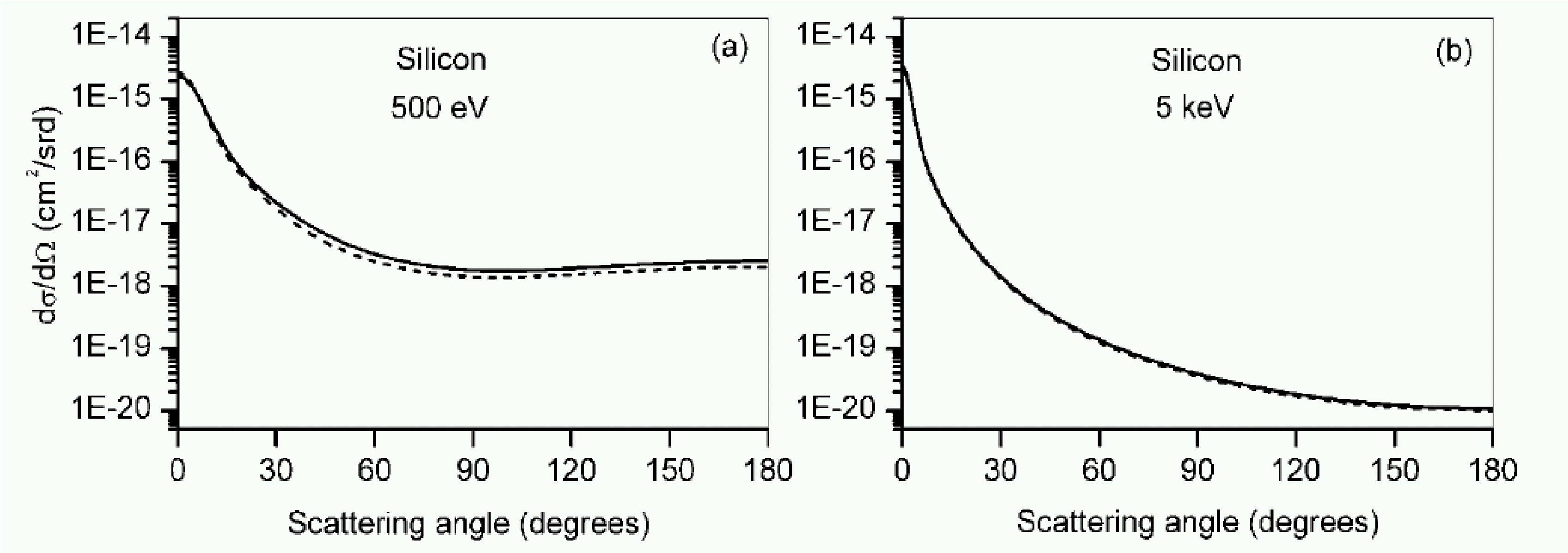
LowEnergy Package generally produced „better" results.
All plots shown are G4 LE Package and the physics list recommended by the G4 LE group.

Monte Carlo Recipe for custom MC

- **Use full event-by-event simulations**
- **Ingredients (use best quality availabe):**
  - **Inelastic collision cross sections**
  - **Elastic collision cross sections**
- **If not sufficient for KATRIN add:**
  - **Delta-rays**
  - **Auger electrons**
  - **Fluorescence**
  - **Bremsstrahlung**
  - **Phonon scattering**
  - **Surface escape process**
  - **Charge carrier motion (for E<3/2 E_g)**
  - **Signal generation**
  - **Front-end electronics**
  - **Electronic Noise**
  - **…**

Challenging at these energies!
General purpose codes might
not be good enough.

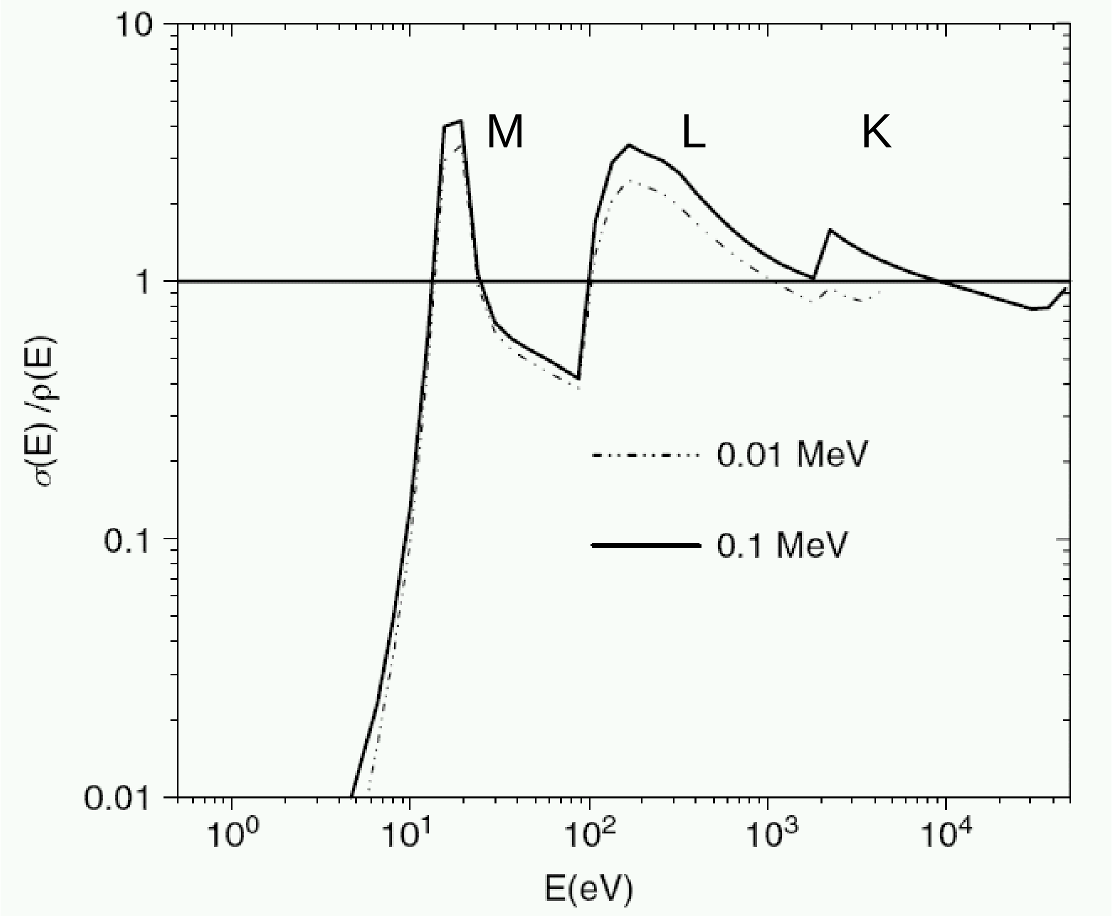
Cross Sections used by custom MC



- **Elastic Cross Sections**
  - **Calculated with ELSEPA Code**

    (F. Salvat et al. Comp. Phys. Com. 165 (2005) 157–190)
  - **Derived by relativistic partial-wave calculations of elastic scattering by a local central interaction potential V(r)**
  - **Included in NIST Database**

Cross Sections used by custom MC

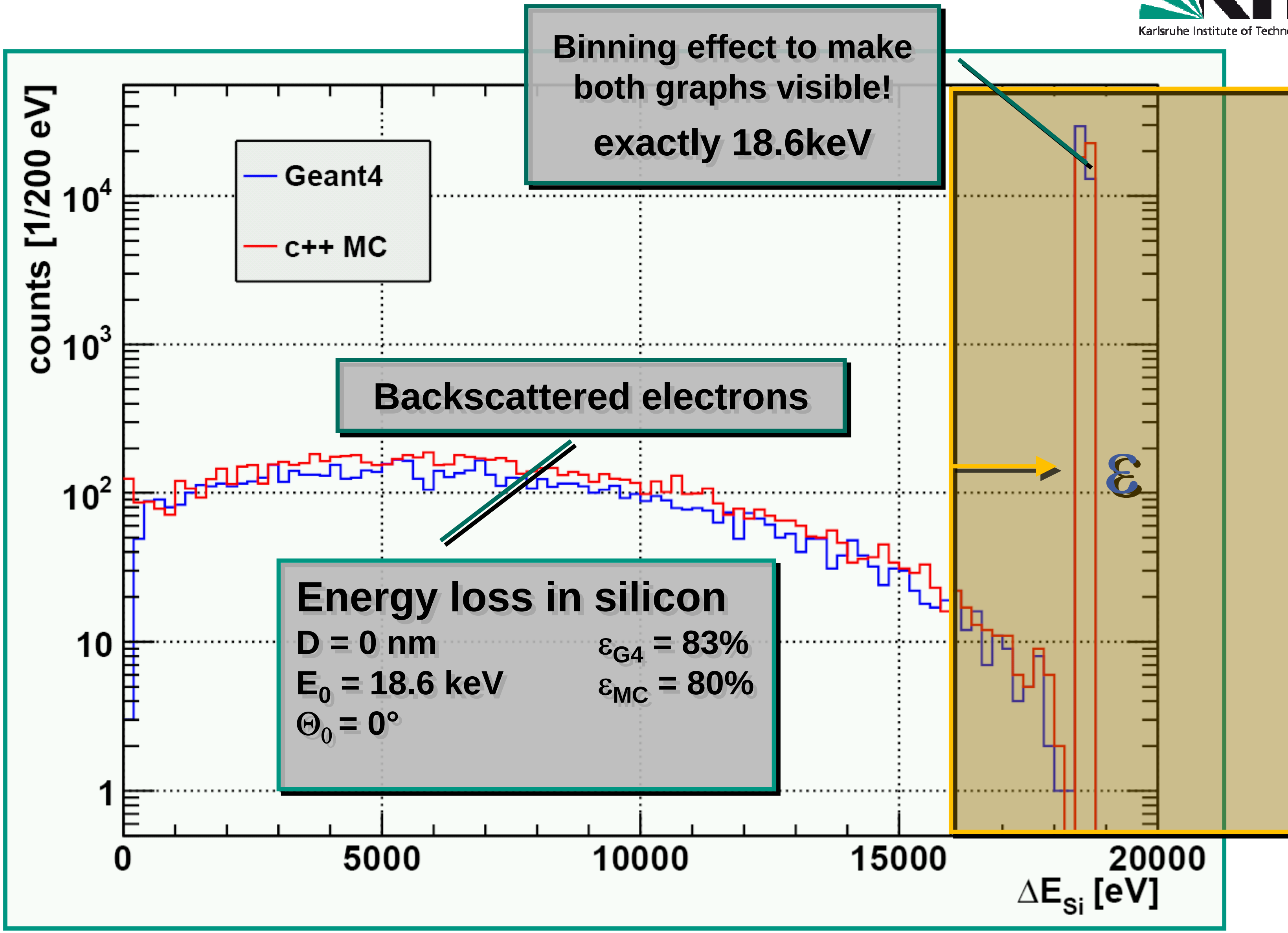


- **Inelastic Cross Sections**
  - **Calculated by Hans Bichsel** (Rev. Mod. Phys. 60 (1988) 3)
  - **Derived by Bethe-Fano Theory**

ToDo

- Energy loss in silicon
- Deadlayer effects
- Incident angles
- Electro-magnetic design
- Backscattering/Comparison to experiment

Energy loss in silicon



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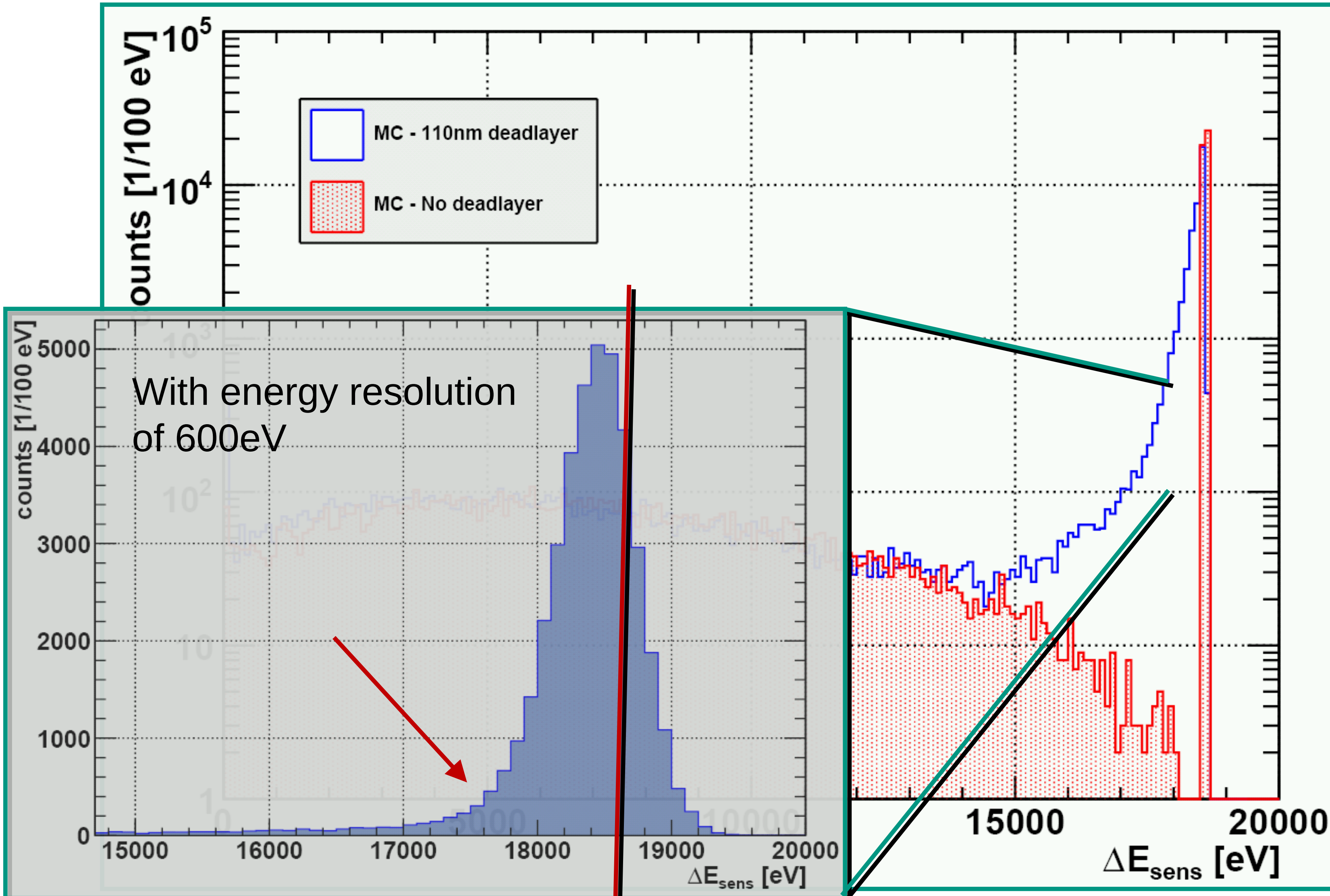
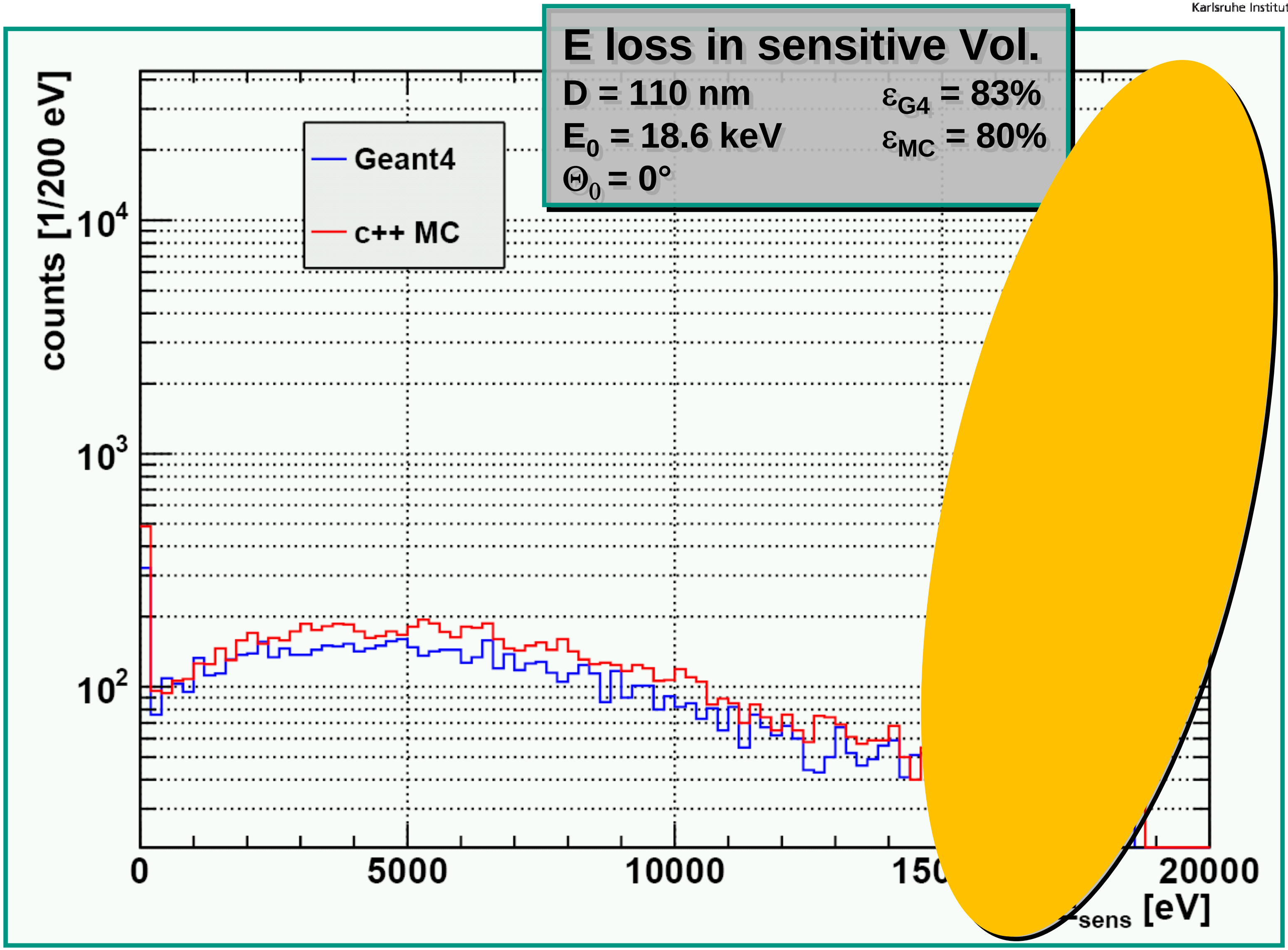
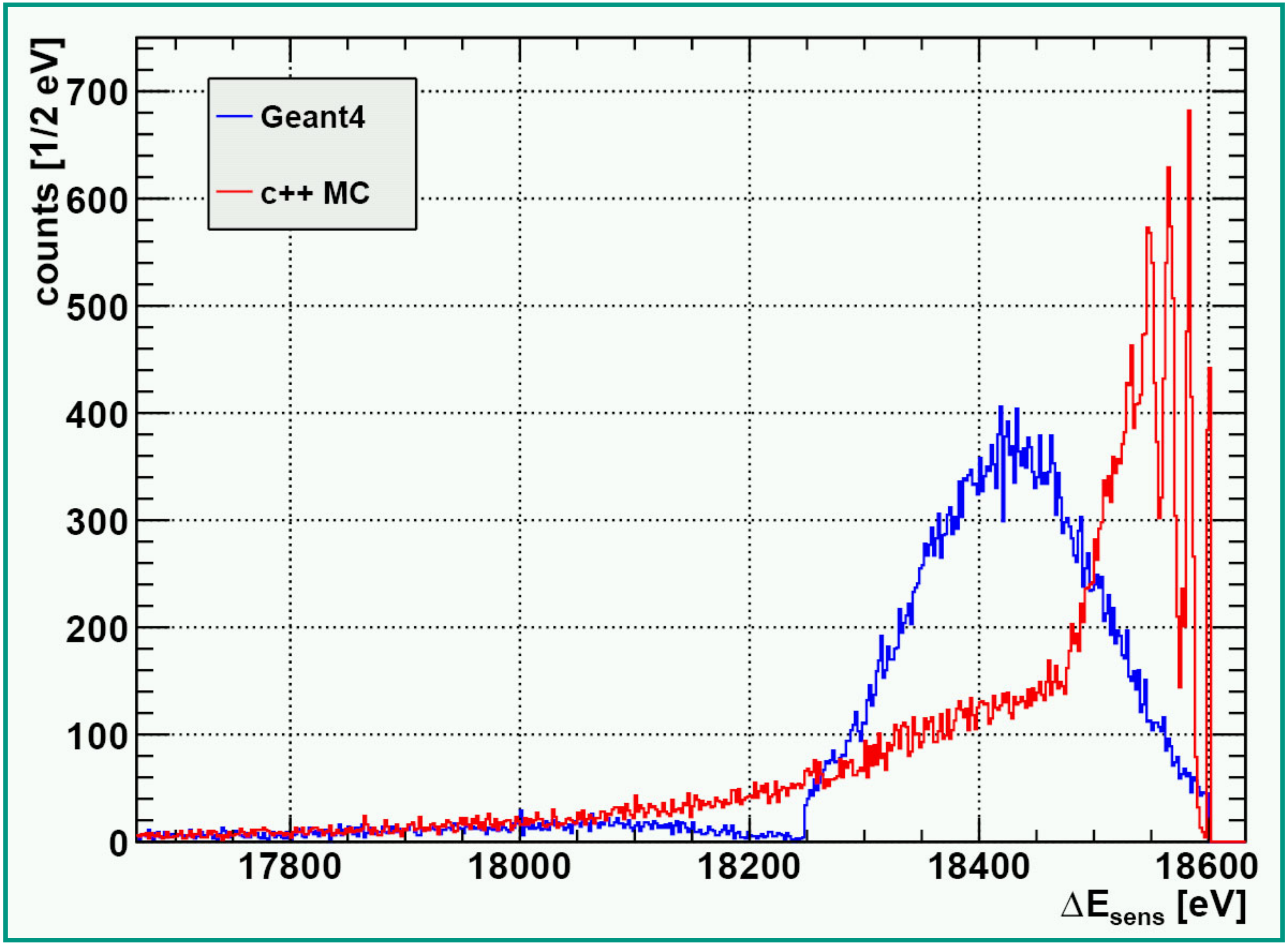
Energy loss in sensitive volume – deadlayer effect



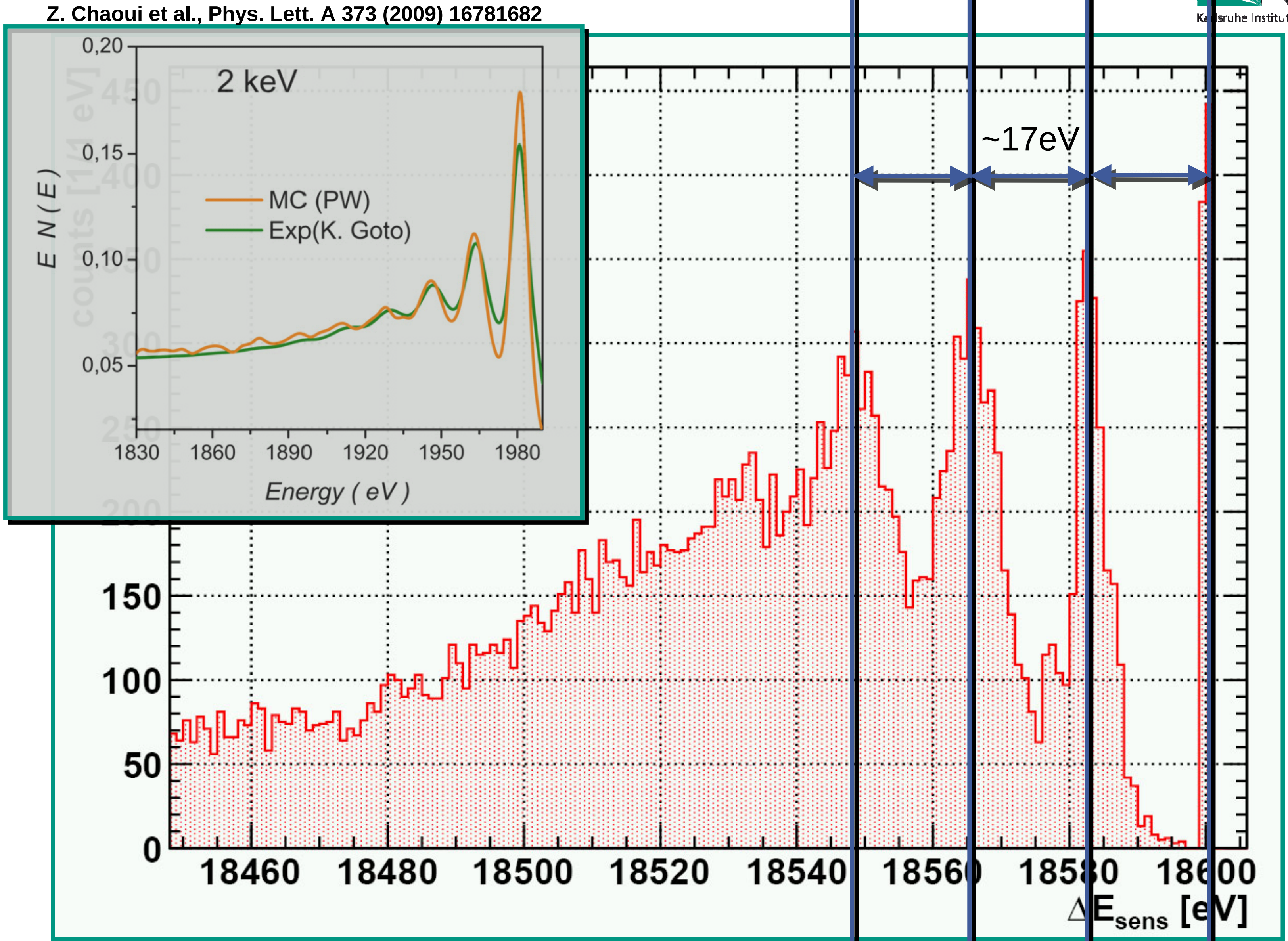
Energy loss in sensitive volume



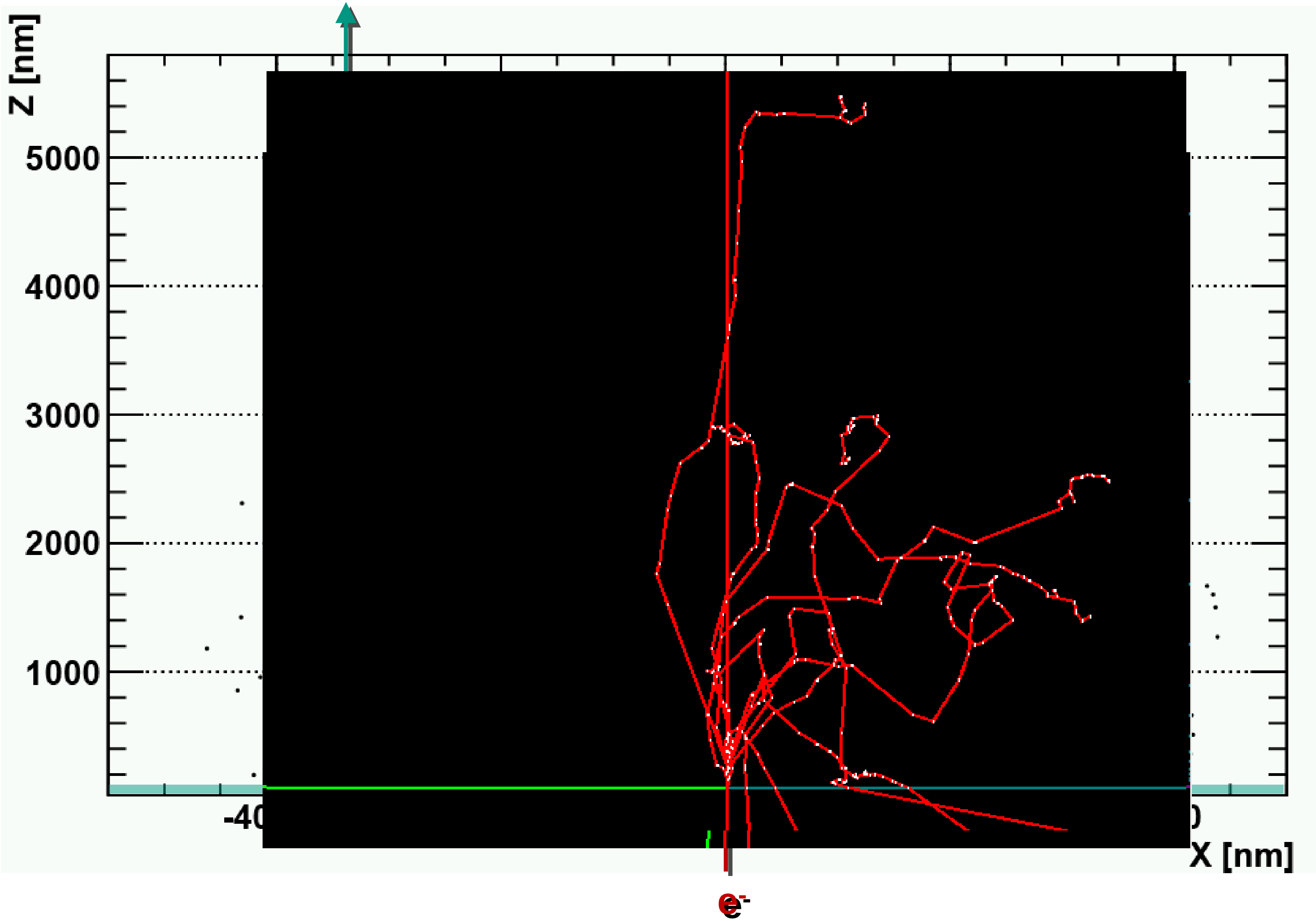
Energy loss in sensitive Volume - Zoom



Energy loss in sensitive Volume - Zoom



Electrons stopped in Si – E < 150 eV



ToDo

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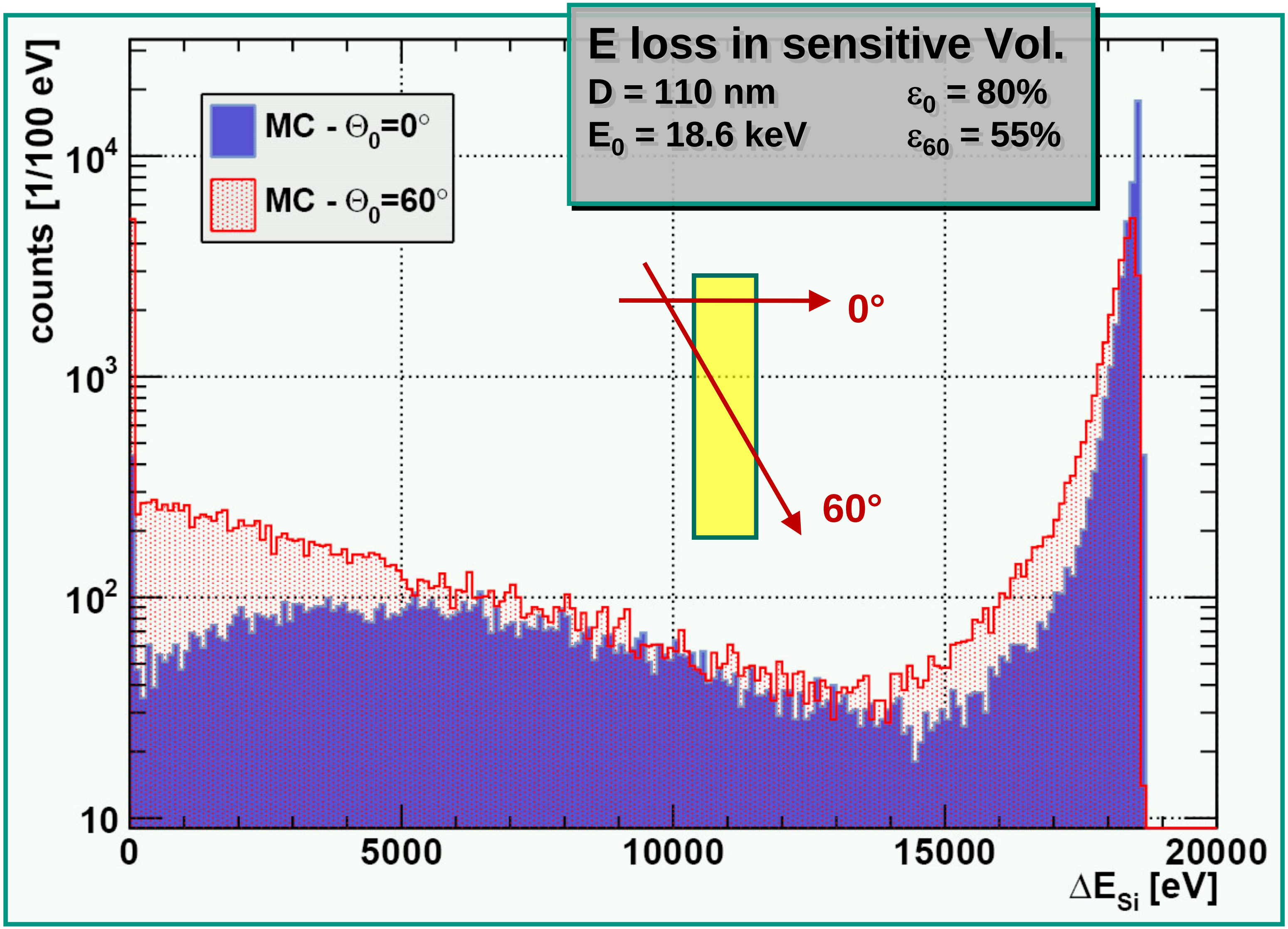
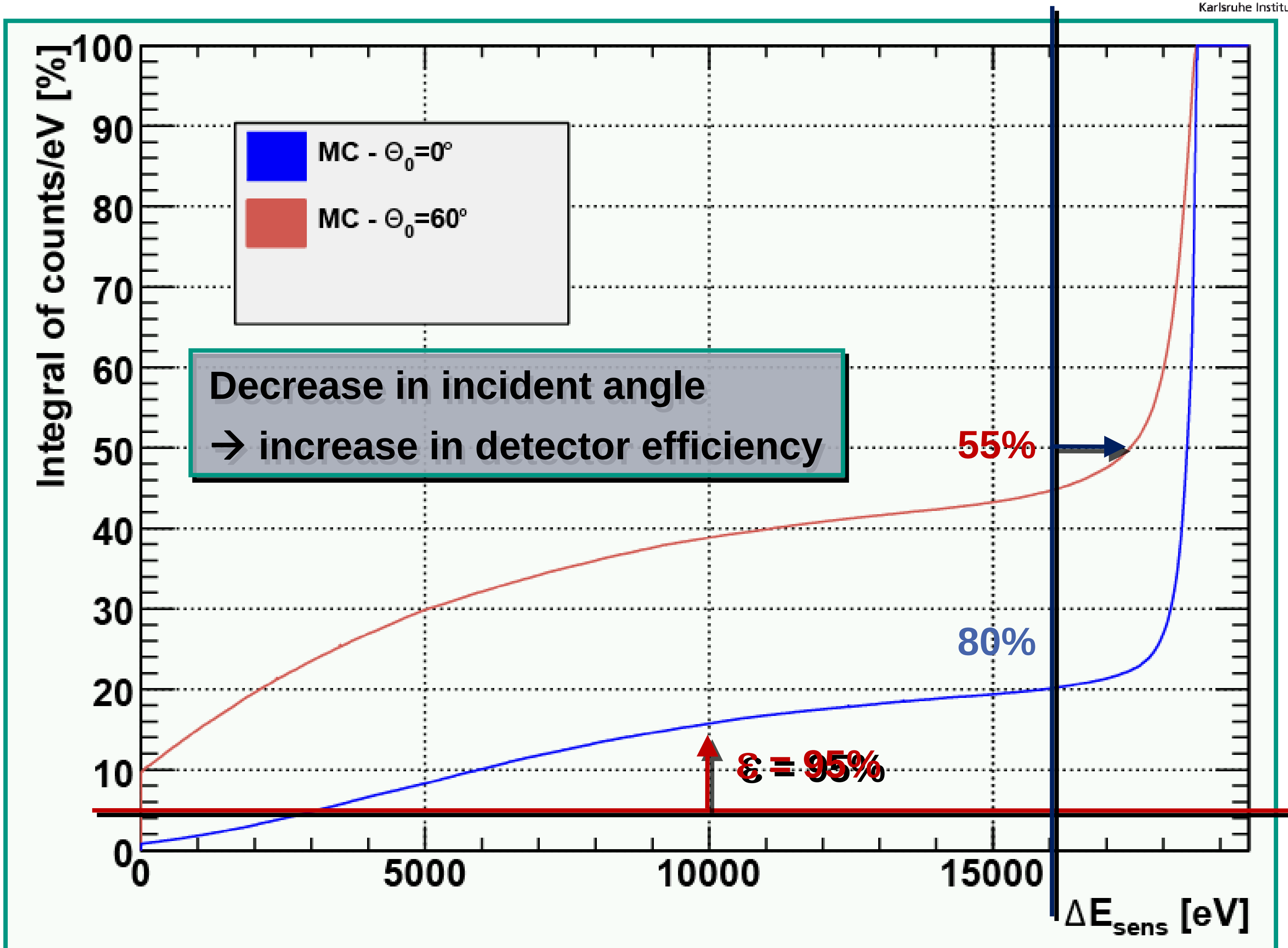
Energy loss in sensitive Volume – $\Theta_0 = 60°$





Integral of counts/eV [%]
100
90
80
70
60
50
40
30
20
10
0
0
5000
10000
15000
ΔE_sens [eV]
MC - Θ0=0°
MC - Θ0=60°
Decrease in incident angle
→ increase in detector efficiency
55%
80%
ε = 95%

ToDo

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- Deadlayer effects
- Incident angles
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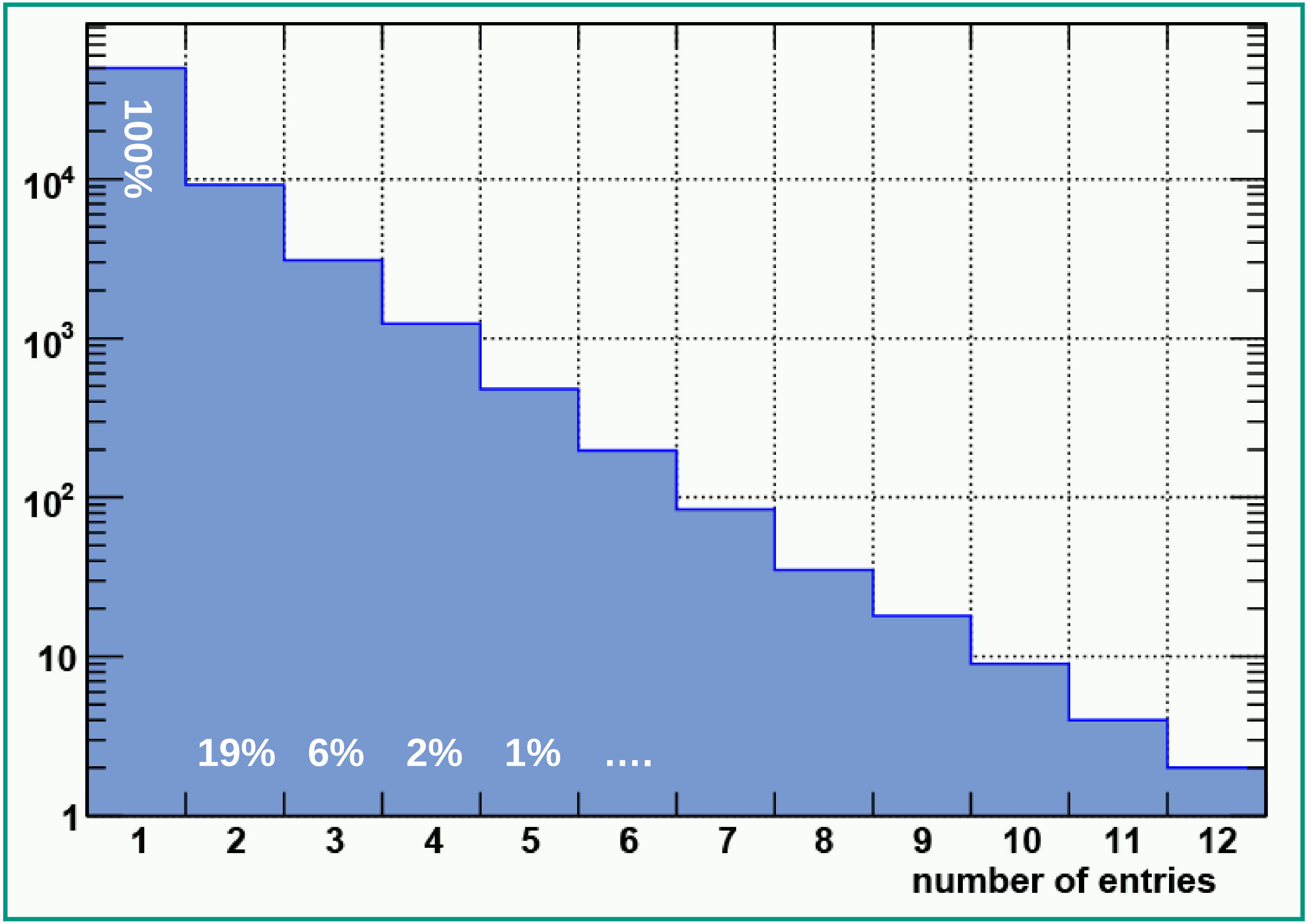
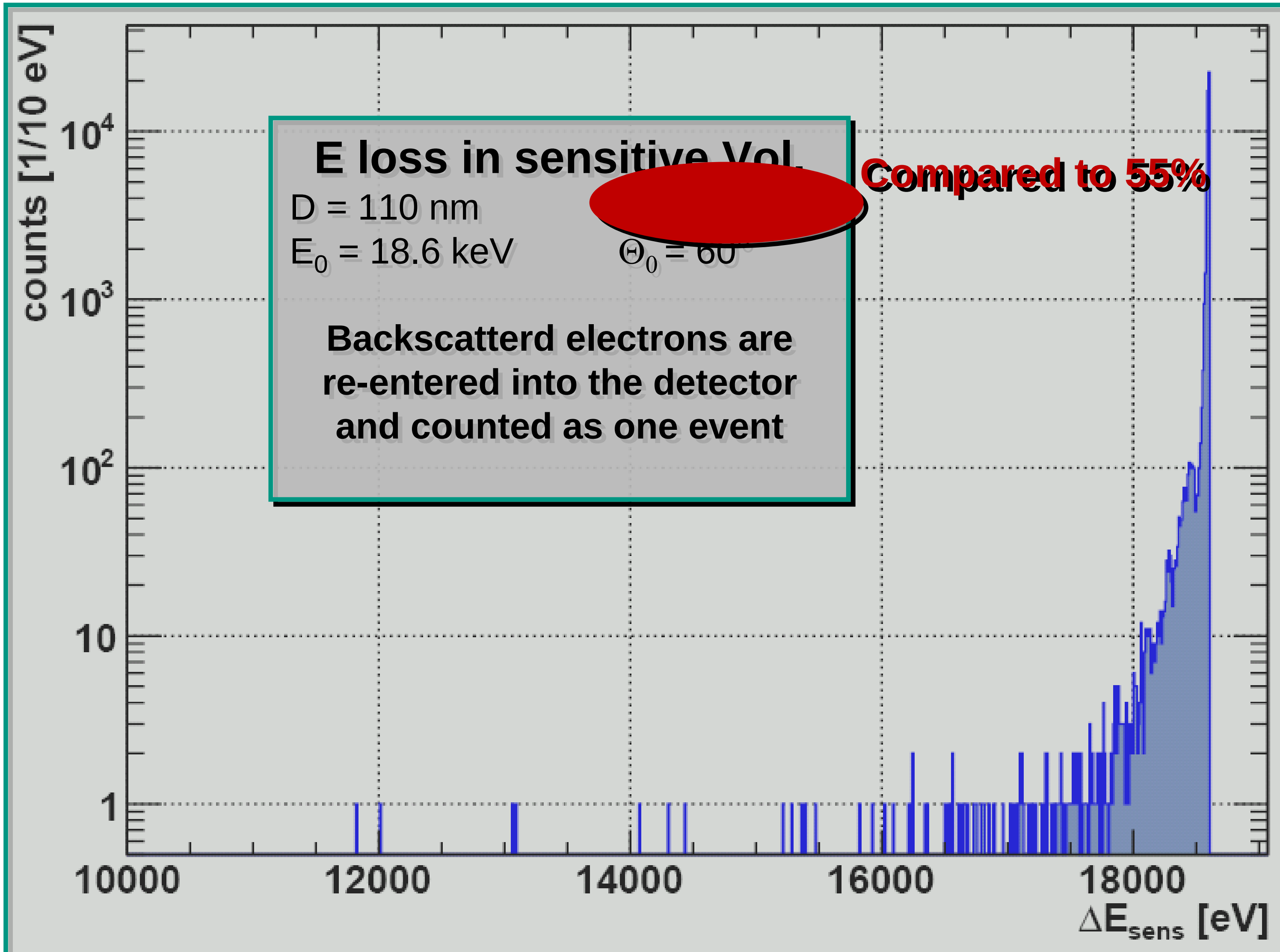
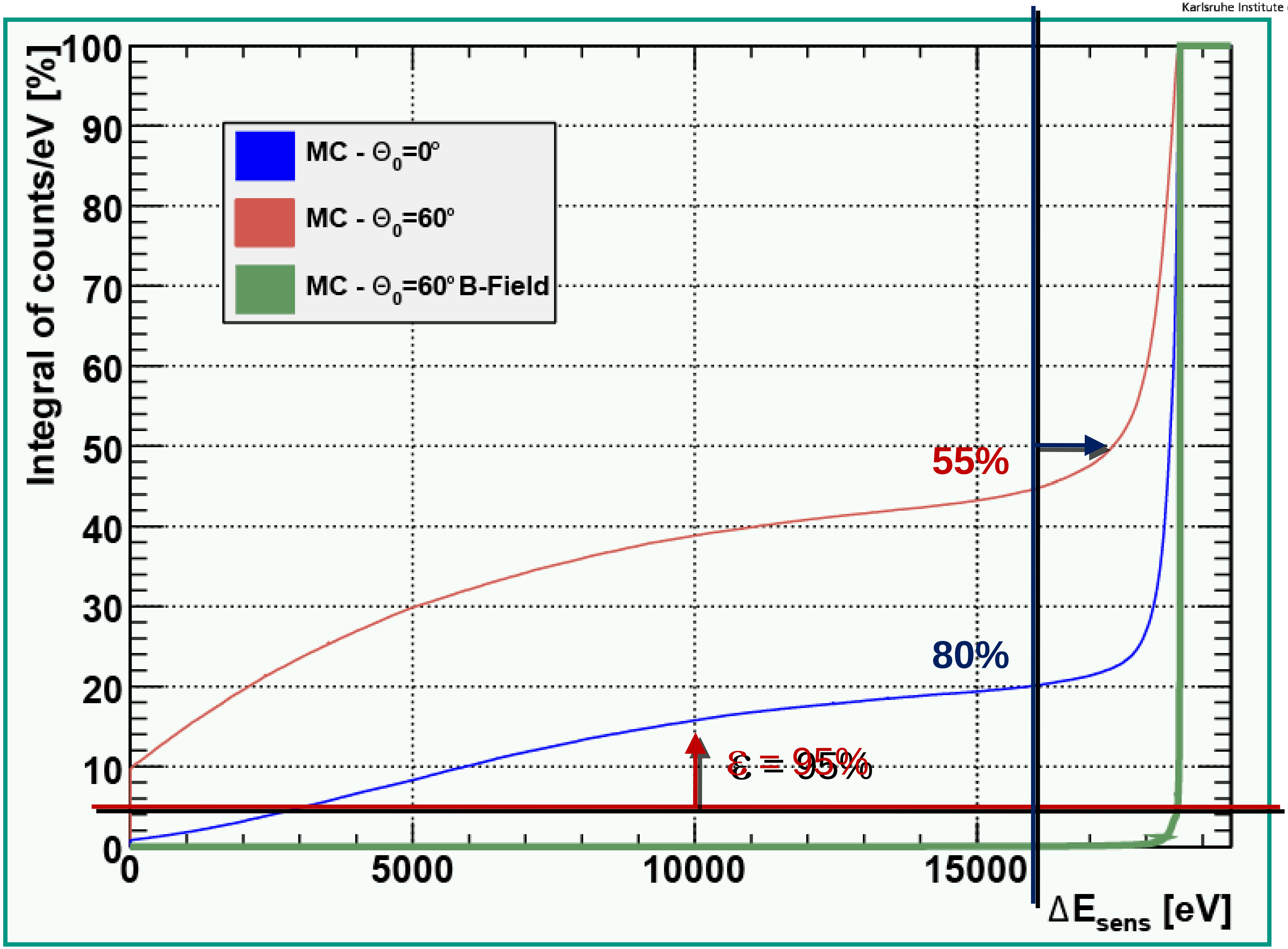
Backscattering – re-entries



Backscattering – re-entries

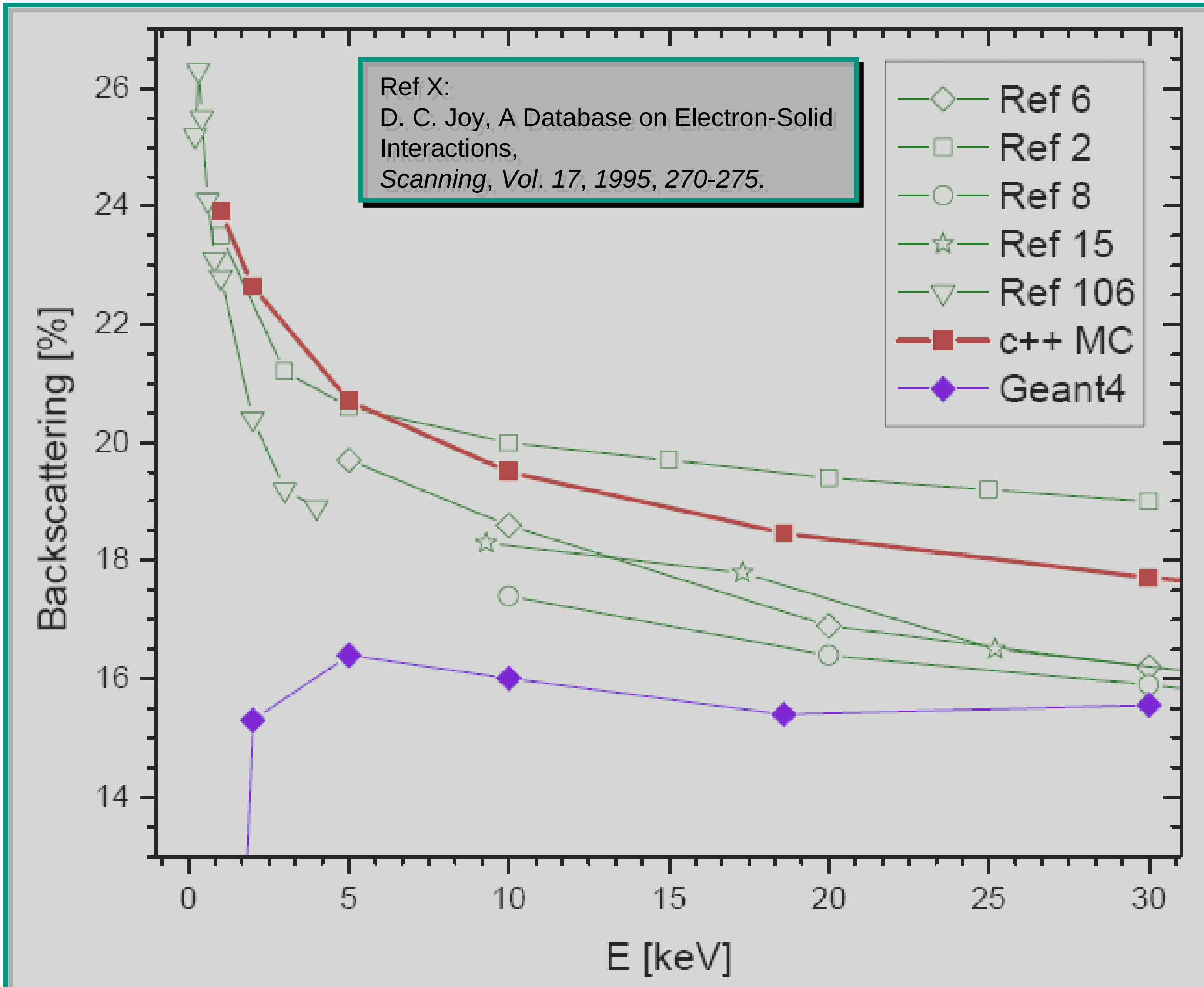



Integral of counts/eV [%]
100
90
80
70
60
50
40
30
20
10
0
0
5000
10000
15000
ΔE_{sens} [eV]
MC - Θ_0=0°
MC - Θ_0=60°
MC - Θ_0=60° B-Field
55%
80%
ε = 95%

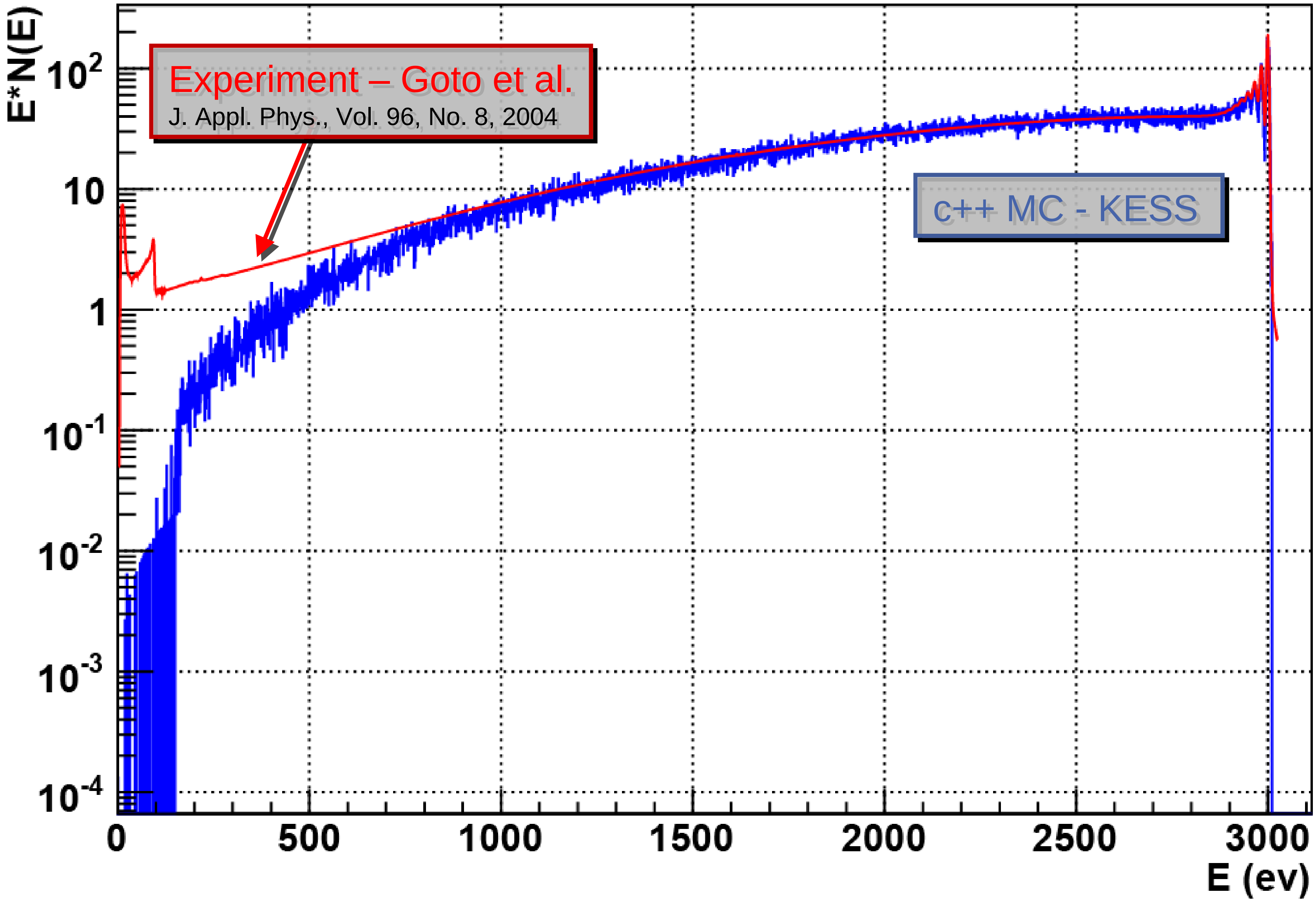
ToDo

- Energy loss in silicon
- Deadlayer effects
- Incident angles
- Electro-magnetic design
- Backscattering/Comparison to experiment

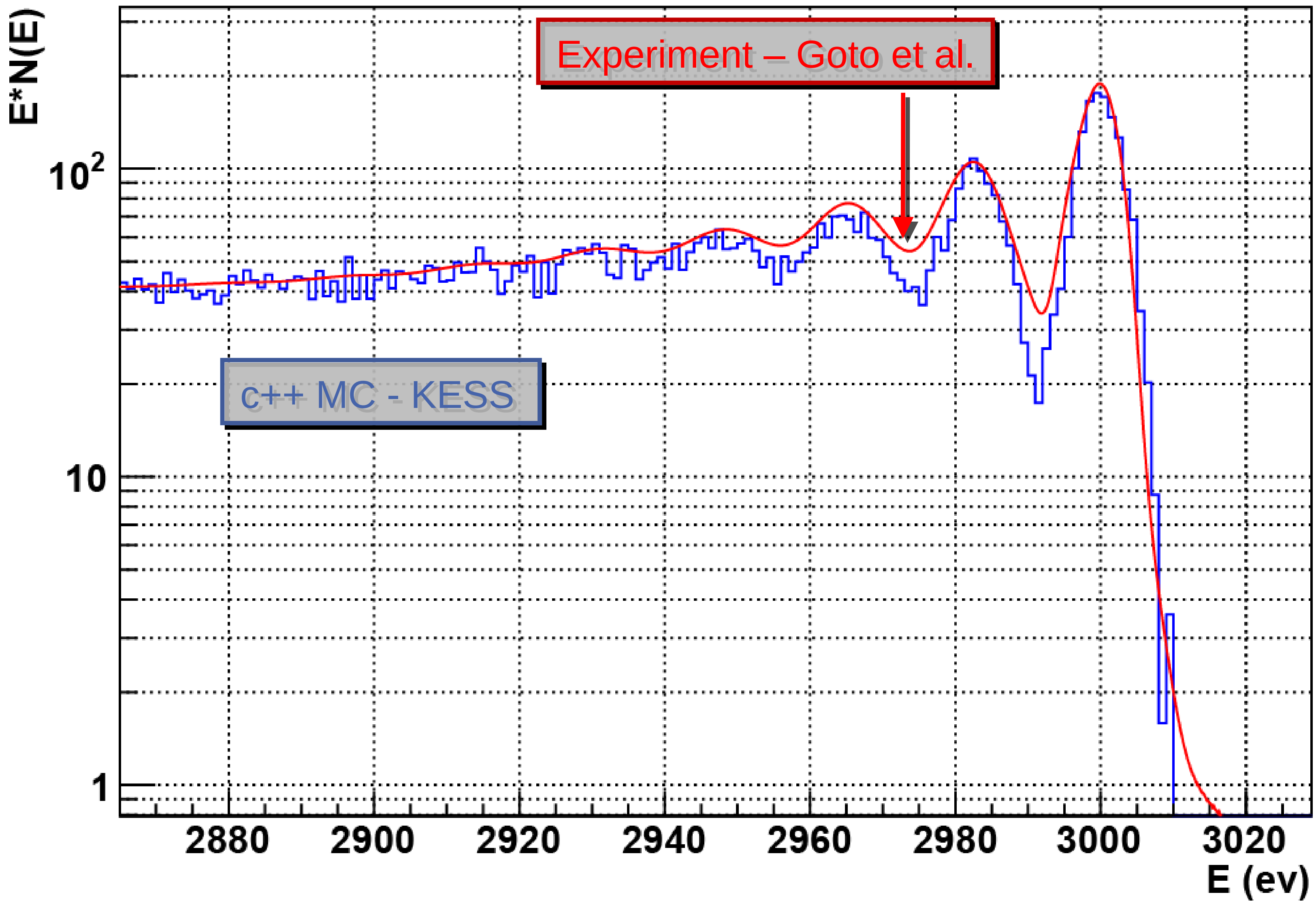
Backscattering – Experiments – DC Joy database



Backscattered energy - Experiment



Backscattered energy - Experiment



Summary + Outlook

- **FPD system introduces unique questions**
  - **Systematics on m_ν, calibration, double-counts, …**
- **Geant4 is not suitable for our problem**
  - **E. Poon et al. Phys. Med. Biol. 50 (2005) 681–694**
  - **E. Poon et al. Med. Phys. 32 (2005) 6 1696-1711**
  - **…**
- **KESS (c++ MC) evaluated vs. Data and simulations**
  - **good agreement E > 1keV**
  - **Atomic relaxation and Delta-ray production ~60% finished**
- **PENELOPE2008 Simulations show same trend as KESS below 1 keV**

Fin

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Thank you!