Methodology of Physics Simulation Software

CALOR 2000

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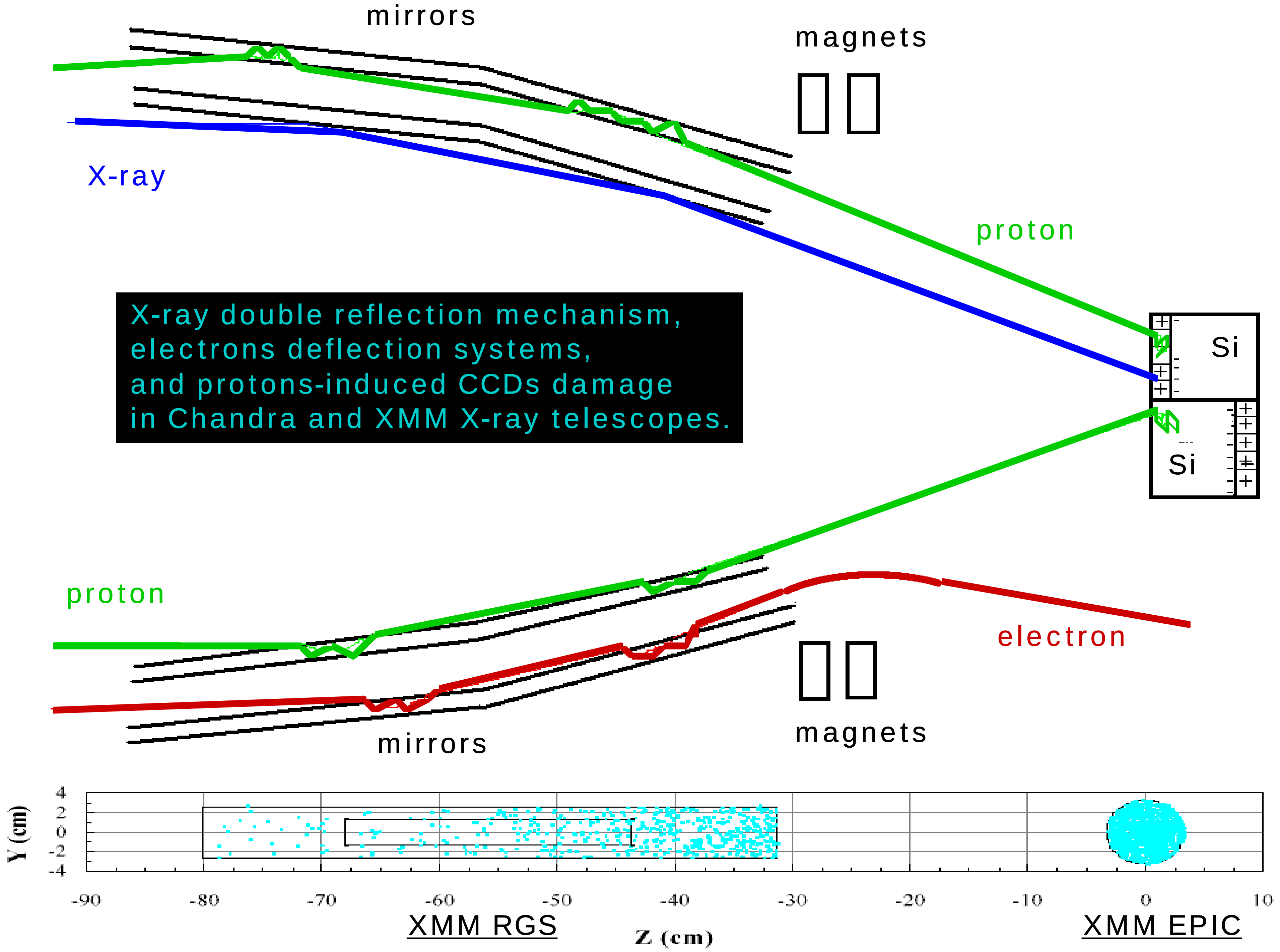
A mission critical application

- ESA, December 1999:

  1st production launch Ariane 5.
- Payload: XMM X-ray telescope.
- Objectives of software simulation:
  - discover sources of radiation-induced degradation experienced by CCDs of another x-ray telescope;
  - compute radiation levels for XMM's CCDs and determine protection procedures before launch.

Physics models transparency

- Open source analysis of GEANT4 multiple scattering model in the limit of corrected Rutherford scattering (TRIM).
- Tests on GEANT4 integrators in B field to certify ~100micron accuracy on ~10m trajectories.
- Open source analysis of GEANT4 energy loss parameters to guarantee tracking accuracy on ~10s nm paths in the mirrors coating.
- Particles' back-tracking by GEANT4 stepping history recording.


mirrors
magnets
X-ray
proton
X-ray double reflection mechanism,
electrons deflection systems,
and protons-induced CCDs damage
in Chandra and XMM X-ray telescopes.
Si
Si
proton
electron
magnets
mirrors
Y (cm)
Z (cm)
XMM RGS
XMM EPIC

Simulation predictive power

- Flux (at 1.3 MeV) on XMM RGS spectrometer:

  = 0.7 million protons / cm2 / month.
- Flux (at 200 keV) on XMM EPIC camera:

  = 60 million protons / cm2 / month.
- **=>** EPIC camera needs to be protected.
- Before XMM launch, decision to close Al doors on EPIC when orbit will cross radiation belts.
- XMM correctly operating in orbit with no damage since almost 1 year.

Validation concepts

- In software engineering, validation of software is wrt the user requirements.
- “Validation” of HEP simulation software results is usually wrt physics data.
- But, even assuming results are OK, how many software parameters were used to allow the program to fit the data ?
- And if need to validate simulation results ***before*** knowing the physics data (see XMM case) ?

Software Reliability Model

- **SRM** is defined to quantify the reliability and validability of delivered simulation software to the fulfillment of certain conditions.
- Increasing levels of reliability and validability correspond to the fulfillment of more stringent conditions.

SRM levels

- *Level 0*: Different object code is provided and used for different use-cases.
- *Level 1*: The same publicly distributed object code is used for different use-cases.
- *Level 2*: Different source code is provided and used for different use-cases.
- *Level 3*: The same publicly distributed source code is used for different use-cases.
- *Level 4*: The same public source code also exposes all the parameters which influence the results.

Results Validability Model

- **RVM** is defined to quantify the reliability and validability of produced simulation results to the fulfillment of certain conditions.
- Increasing levels of reliability and validability correspond to the fulfillment of more stringent conditions.

RVM levels

- *Level 0*: Simulation results match known exp. results using parameterisations based on those data.
- *Level 1*: Simulation results match known, but independent, experimental results.
- *Level 2*: Simulation results match known exp. results and are (re)produced by random users.
- *Level 3*: Simulation results match known exp. results with a controlled number of parameters.
- *Level 4*: Simulation results correctly anticipate unknown experimental results.

GEANT4 methods (1)

- The fundamental GEANT4 requirement is to make the physics modelling transparent to the user, so that he/she can understand ***HOW* the results are produced**, hence improving the scientific validation process.

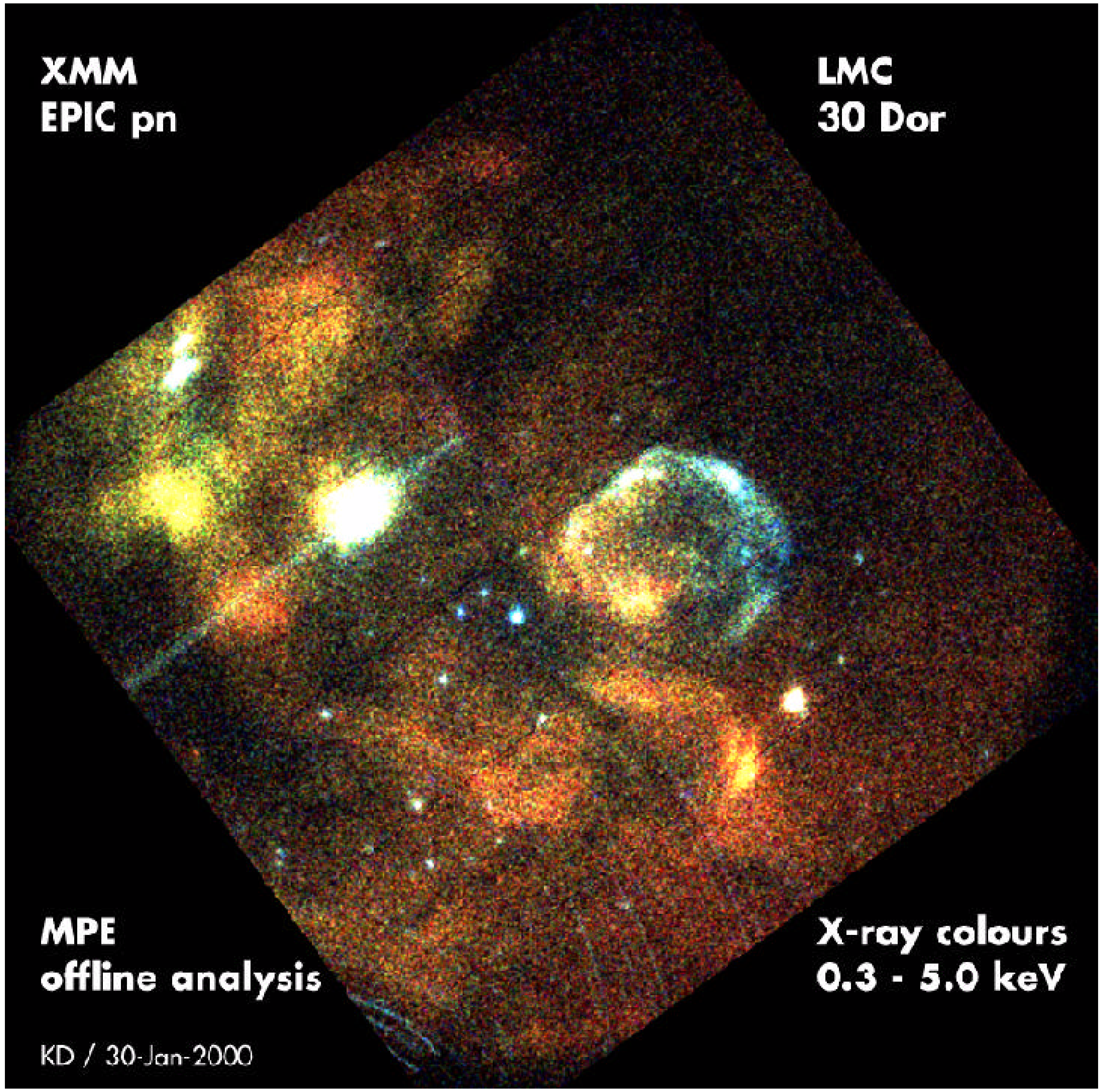
- **No** numbers must be hard-coded in formulae and algorithms, but only variables and constants should be used. Constants are initialized to their numerical value followed by the given physical units.
- An extensive set of units is defined in GEANT4 and **all the numerical quantities are expressed through units explicitely**. Consequently, the full GEANT4 physics is independent from the units chosen by the user.

GEANT4 methods (2)

- The way **cross sections** are calculated (via analytical formulae, data files, etc.) is clearly exposed via Object-Oriented design and it is separated from the way they are accessed and used in the algorithms.

- Similarly to cross-sections, the way **final states** are computed is separated from the tracking and can be split in models by energy range, particle type and material.

- Open interface to **<u>data</u>** libraries: **ENDF/B, JENDL, FENDL, CENDL, ENSDF, JEF, BROND, EFF, MENDL, IRDF, SAID, EPDL, EEDL, EADL, SANDIA, ICRU, ...**


XMM
EPIC pn
LMC
30 Dor
MPE
offline analysis
X-ray colours
0.3 - 5.0 keV
KD / 30-Jan-2000