Simulation of ATLAS Transition Radiation

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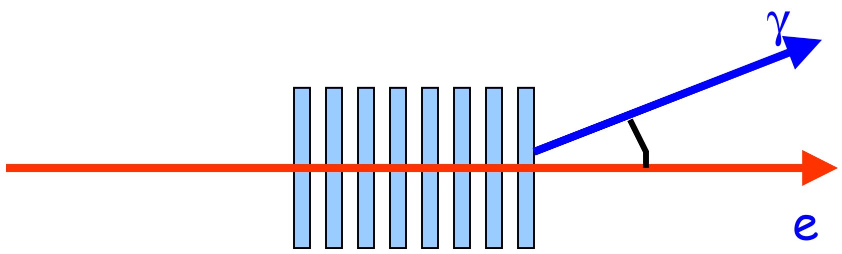
- Transition Radiation
- TR implementations
  - Native Geant4
  - TRT G3
  - TRT G4
- Comparisons with Test Beam
- Some details on ionisation model (PAI) ; comparison G3/G4

Work reported: MD & Jakob Langgaard [NBI]

Transition Radiation (i)



Transition Radiation:
Radiation from ultra-relativistic particles crossing boundary between two media with different dielectric constants

Radiator: Assembly of foils so that particle meets many (periodic) boundaries

Radiation from one interface described by double differential

$$\frac{d^2N}{d\omega d\theta^2} = \frac{\alpha\theta^2}{\pi\omega}\left|\frac{1}{\gamma^{-2}+\zeta_1^2+\theta^2} - \frac{1}{\gamma^{-2}+\zeta_2^2+\theta^2}\right|^2$$

ω: photon energy
θ: emission angle

$\zeta = \omega_p / \omega$

ω_p: plasma energy of medium

Transition Radiation (ii)

Radiation from **radiator** with many (periodic) boundaries:

$$\frac{d^2N_{rad}}{d\omega d\theta^2} = \frac{d^2N}{d\omega d\theta^2} R$$

R-factor known for periodic and some kinds of non-periodic radiators

Radiation very much forward peaked ($\sim 1/\gamma$) :

- θ unmeasurable in practice
- Need to integrate out θ^2-dependence to find energy spectrum $dN/d\omega$

Periodic radiator: R contains the factor

$$\frac{\sin^2(n\Delta\phi/2)}{\sin^2(\Delta\phi/2)}$$

$\Delta\phi$ = phase difference between wave emitted at entry/exit of foil

Transition Radiation (iii)

How to integrate out θ^2 -dependence:

1. **Analytic approach**

   [Garibian ('60), Cherry et al. & Artru et al ('73)]

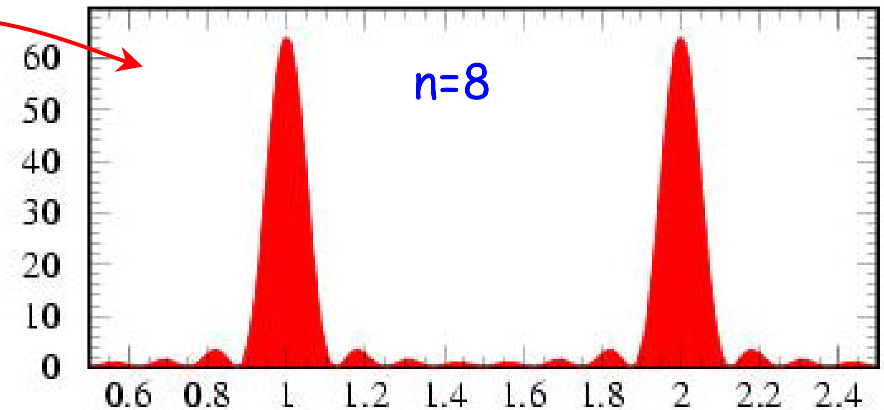
2. **Numeric approach:** "Native" Geant4 method

   [Geant4 team, V.Grichine (2000)]

Analytic approach

Integration over θ^2 performed by noticing the identity

$$\lim_{n\to\infty} \frac{1}{n}\frac{\sin^2 nx}{\sin^2 x} = \sum_i \delta(x/\pi - i)$$



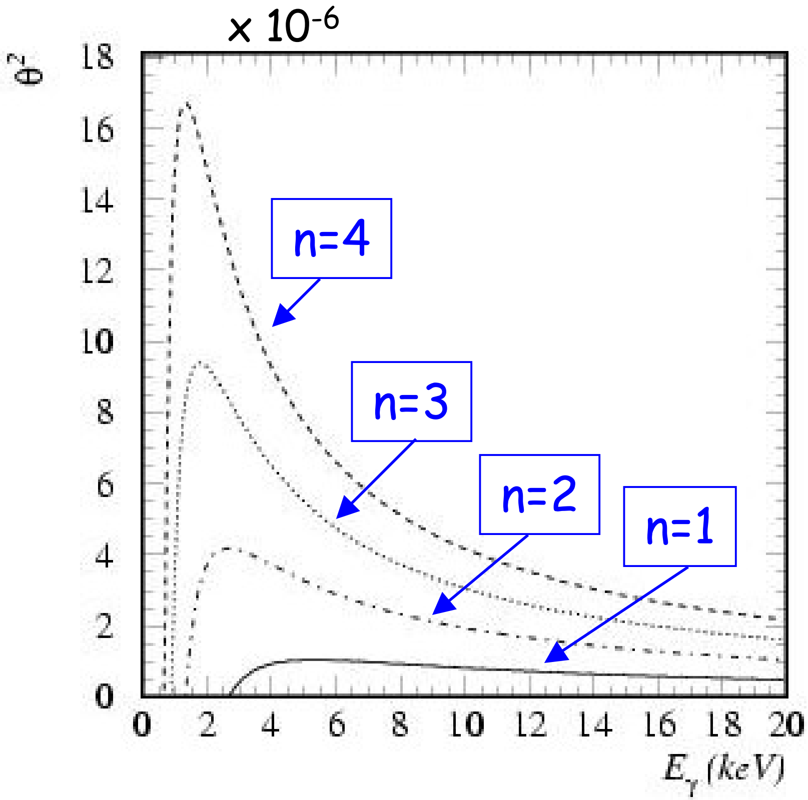
I.e. integration over angle becomes sum of delta functions

Example: ATLAS TRT

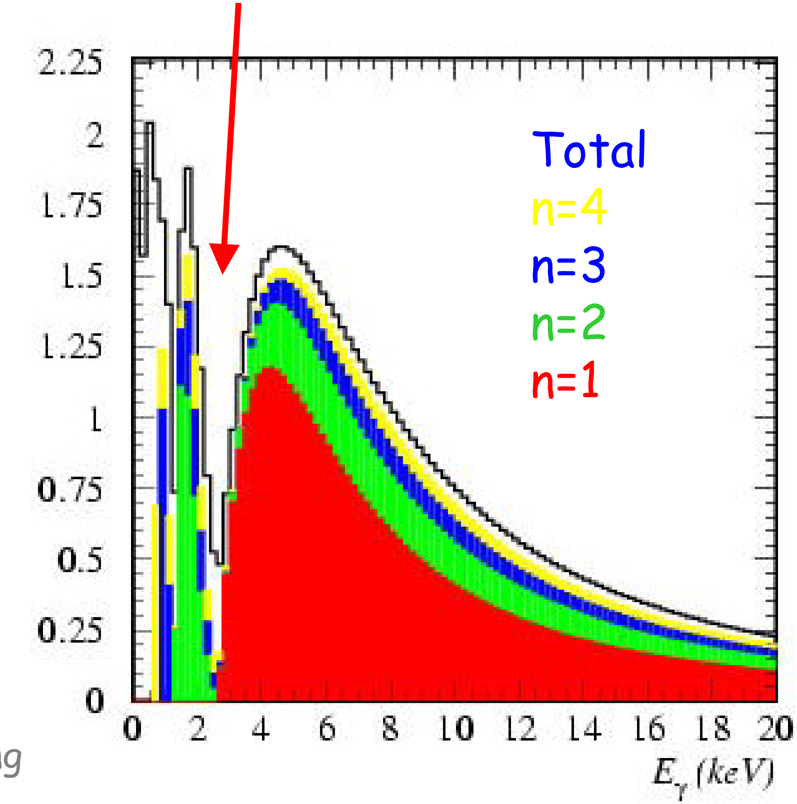
Example: TRT TestBeam geometry: end-cap-like regular radiator:

36 foils of 15 μm CH_2 ; gaps of 207 μm CO_2

δ-functions outline traces in the θ^2 vs. E_γ plane



- Lower n-values contribute most.
- Notice characteristic dip where n=1 contributions turns on



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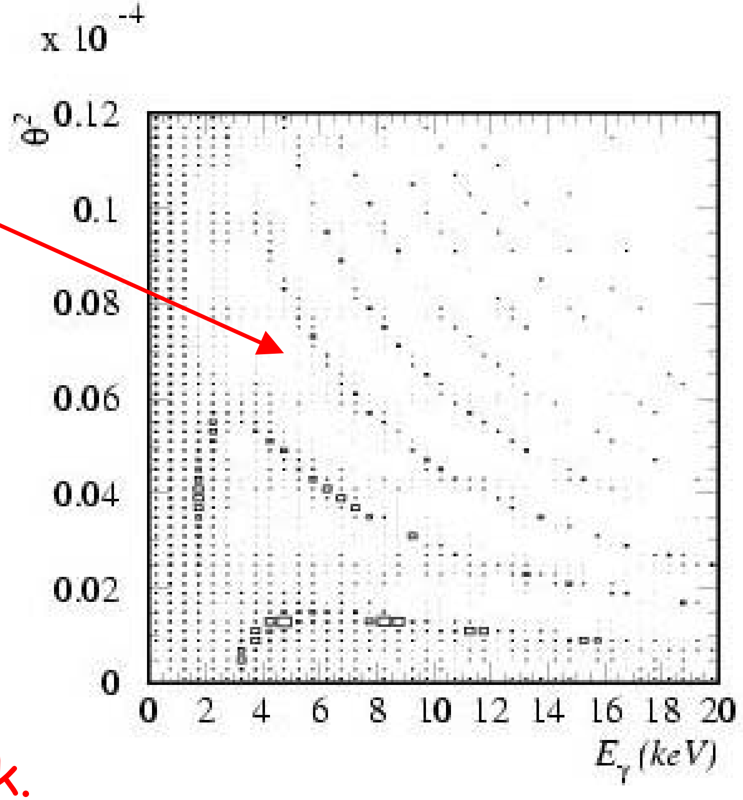
“Native” Geant4 Transition Radiation

Geant4 comes with “build-in” TR functionality: (V.Grichine)
- integration over emission angle done numerically: no δ-function approximation



In practice: integrate this wildly varying kernel at program *initialization* and tabulate energy spectrum as function of particle γ-factor of; lookup + interpolation during processing.

Problem: Kernel depends on detailed radiator geometry (foil/gap thicknesses):
- What about inclined tracks ?
- What about barrel TRT, where radiator geometry varies wildly from track to track.

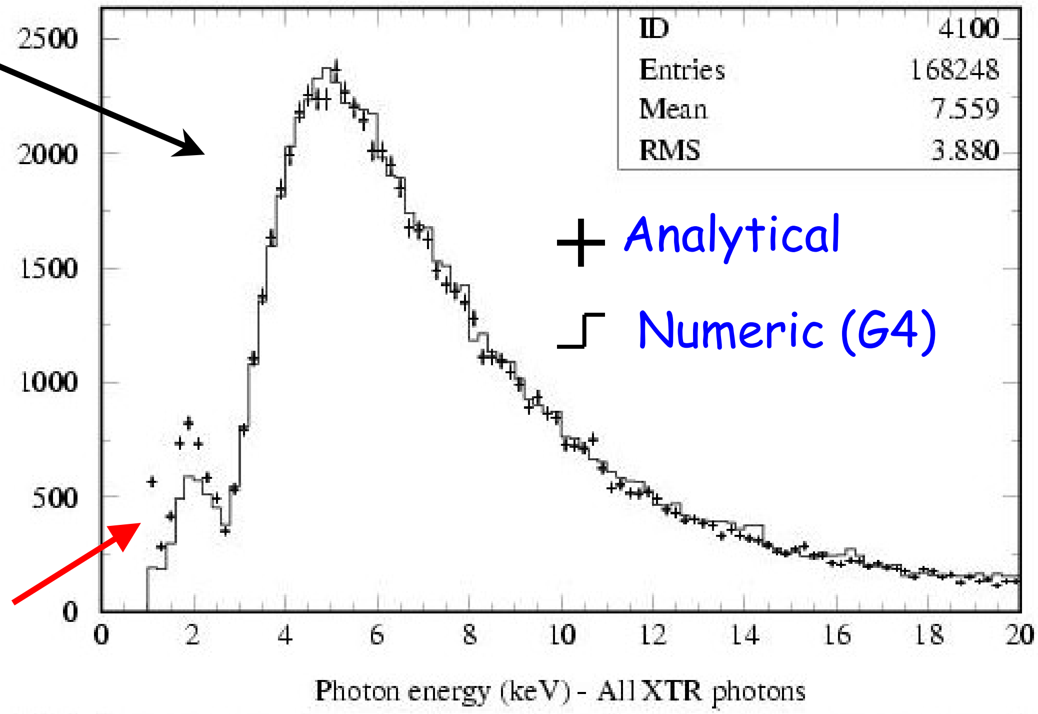
Anyway, hard to integrate kernel with precision.
And what about upper limit on θ^2 [Summer 2003: $10^{-6} \rightarrow 10^{-3}$]

Comparison: G4 vs. Analytical Calculation

Simulate 200,000 passages of 20 GeV electron through test beam radiator:

Impressive agreement between energy spectra of generated photons

Energy of all generated photons



Small difference at low energy (probably due to re-absorption in radiator material): No practical importance, since kapton of straw walls block these anyway

Numeric vs. Analytic Method

- Since numeric and analytic methods agrees on spectrum (regular radiator) we choose the more flexible analytic method:
  - ✓ Energy spectra are calculated "on the fly" when track crosses radiator: inclination angle + difficult barrel geometry "automatically" accounted for.
  - ✓ Already proven to work for Geant3 (P.Nevski)
- However have to be aware:
  - × Performance: calculating "infinite" sum of δ-functions
    - terms rapidly decreasing, so no real issue
  - × Analytic method less obvious for irregular radiators
    - in G3: pretend regular radiator and scale to test beam
    - Possible to use G4 numeric method as test bench and learn how to tune analytic method ?

Analytic Method for TR in Geant4

Implementation in TRT full and test beam simulation:

- In PhysicsList.cc :

  G4VProcess* pXTR = new TRTTransitionRadiation("XTR");

  ProcessManager->AddDiscreteProcess(pXTR);

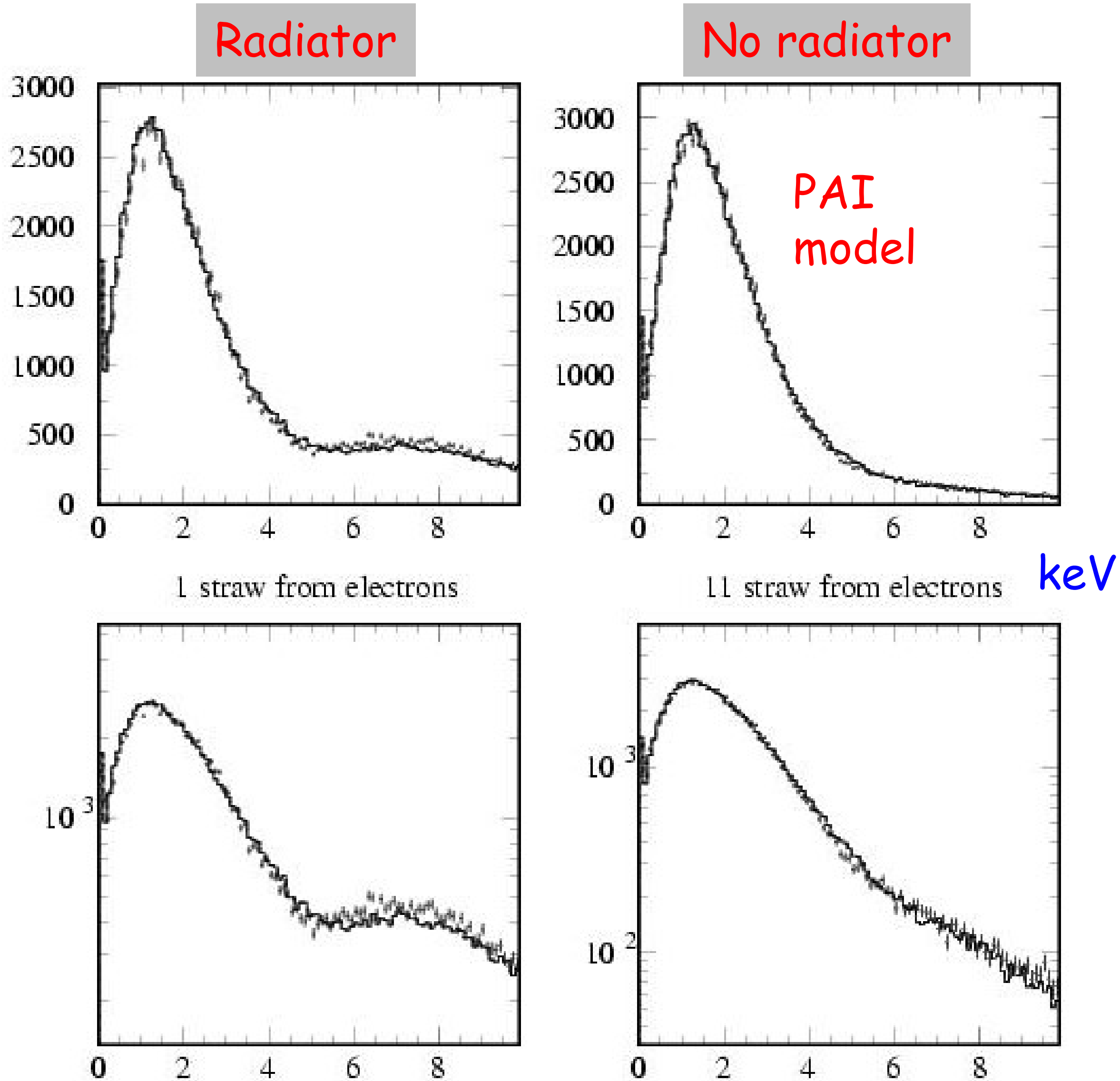
  - Method TRTTransitionRadiation (action is in PostStepDoIt):
    1. Check whether within one of (10) volumes defined as a radiator
    2. If inside radiator: get appropriate geometry (foil/gap thickness)
    3. Calculate photon spectrum for these parameters (γ, geometry, …)
    4. Generate discrete photons and hand them over to G4
  - Possible to choose between two "kernels" (actually identical results)
    - Nevski: Based on Cherry et al.
    - MD: Based on Artru et al.
- Notice: Radiator geometry has to be known to PhysicsList
- Soon to be released

Transition Radiation Methods Overview

	TRT G3 [P.Nevski]	G4 Native	TRT G4 [NBI]
θ^2-integration	Analytic "on the fly"	Numeric at initialization	Analytic "on the fly"
γ emission	Calculate spectrum and propagate this through detector	Discrete γ's	Discrete γ's
γ propagation and absorption in material + gas	Private algorithm working on spectrum. Discretization only at Xe absorption level	Discrete γ's handled by G4	Discrete γ's handled by G4

Test Beam comparison: TRT G3

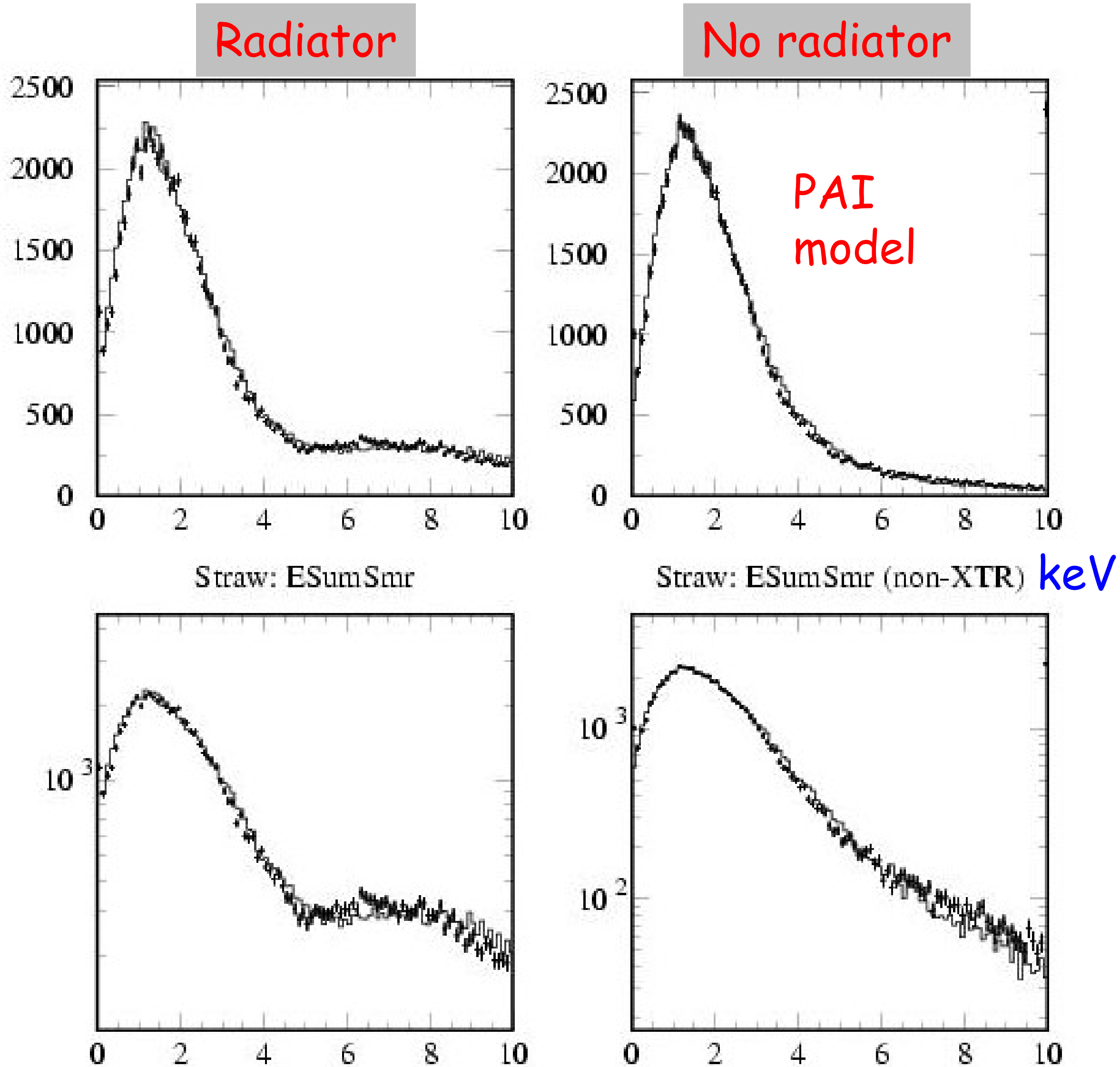
TRT G3 TR implementation (Nevski)



20 GeV electrons: energy deposit in straw

Test Beam comparison: TRT G4

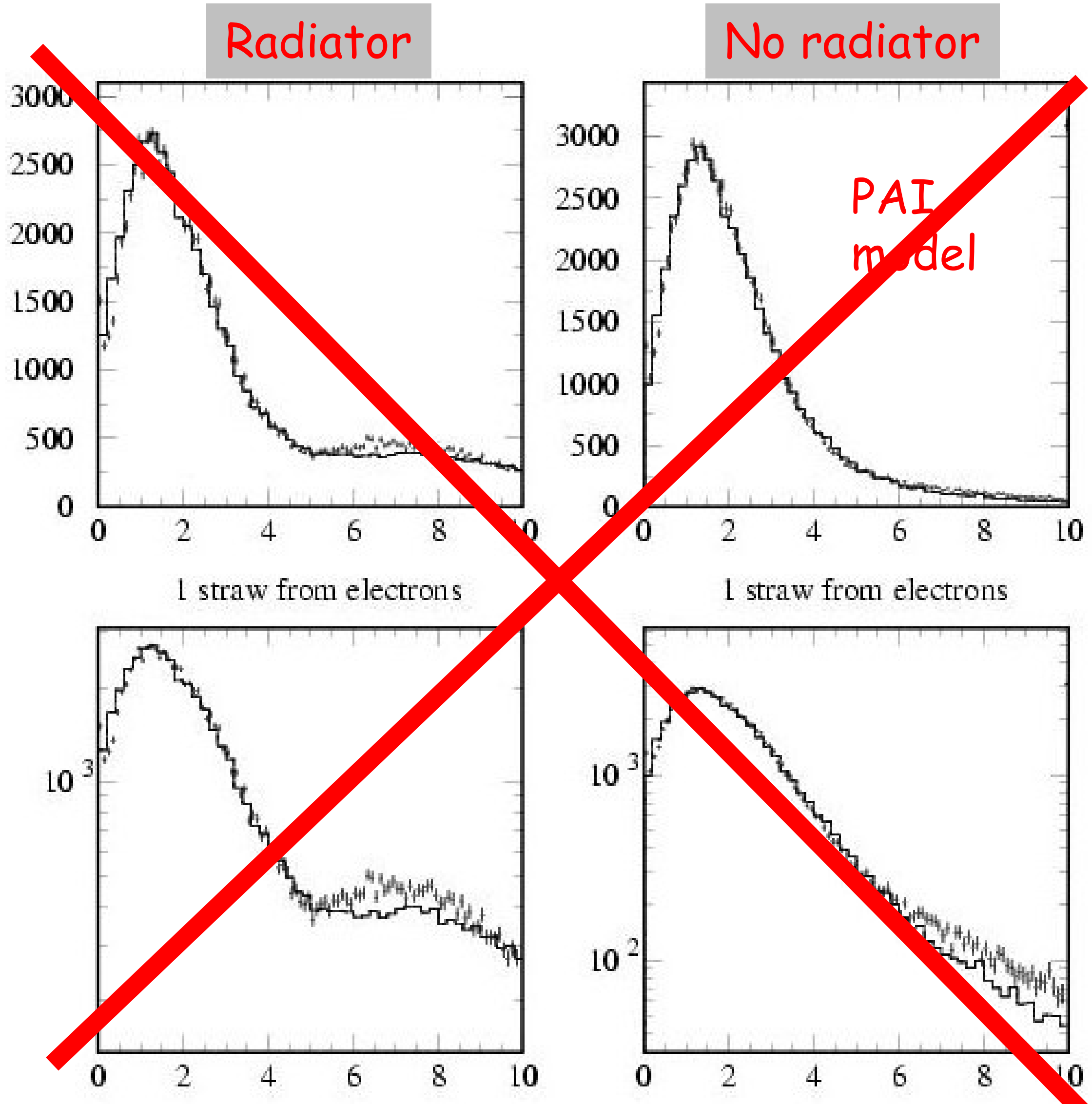
TRT G4 TR implementation



20 GeV electrons: energy deposit in straw

Test Beam comparison: G4 Native

Standard G4 TR implementation



Would have liked to show you these, but why not same agreement as on previous slide, since starting from same generated photon spectrum, and identical propagation through inactive materials and gas. Discrepancy somewhere...? Have to check

Status

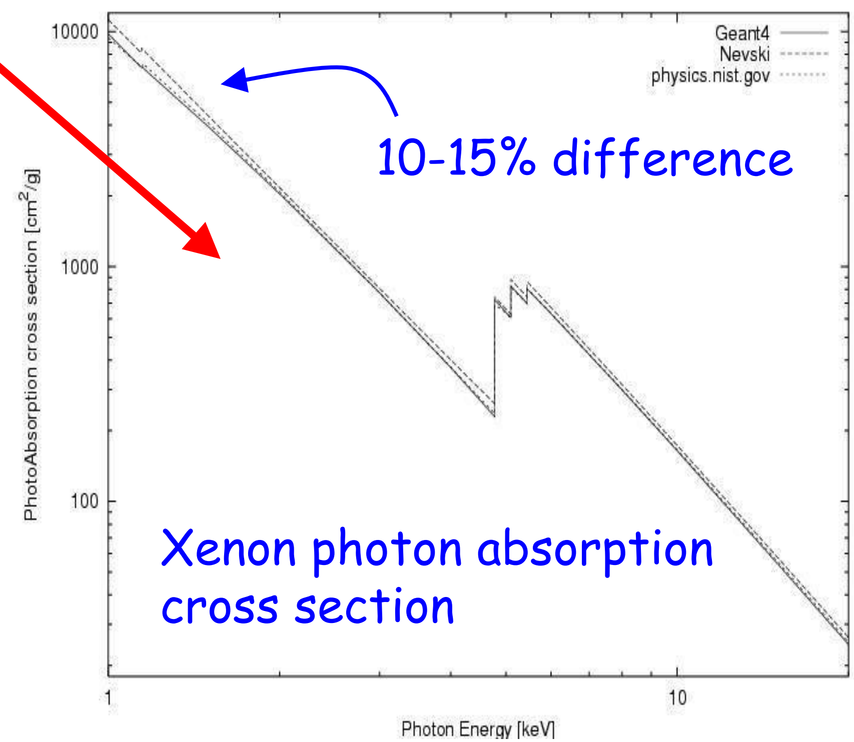
Transition Radiation process for TRT is getting there.

Still some loose ends...

Systematic checking needed:

- Materials G3 vs. G4
- Absorption cross sections G3 vs. G4
- ...

Barrel radiator needs study: 2003 and combined testbeam

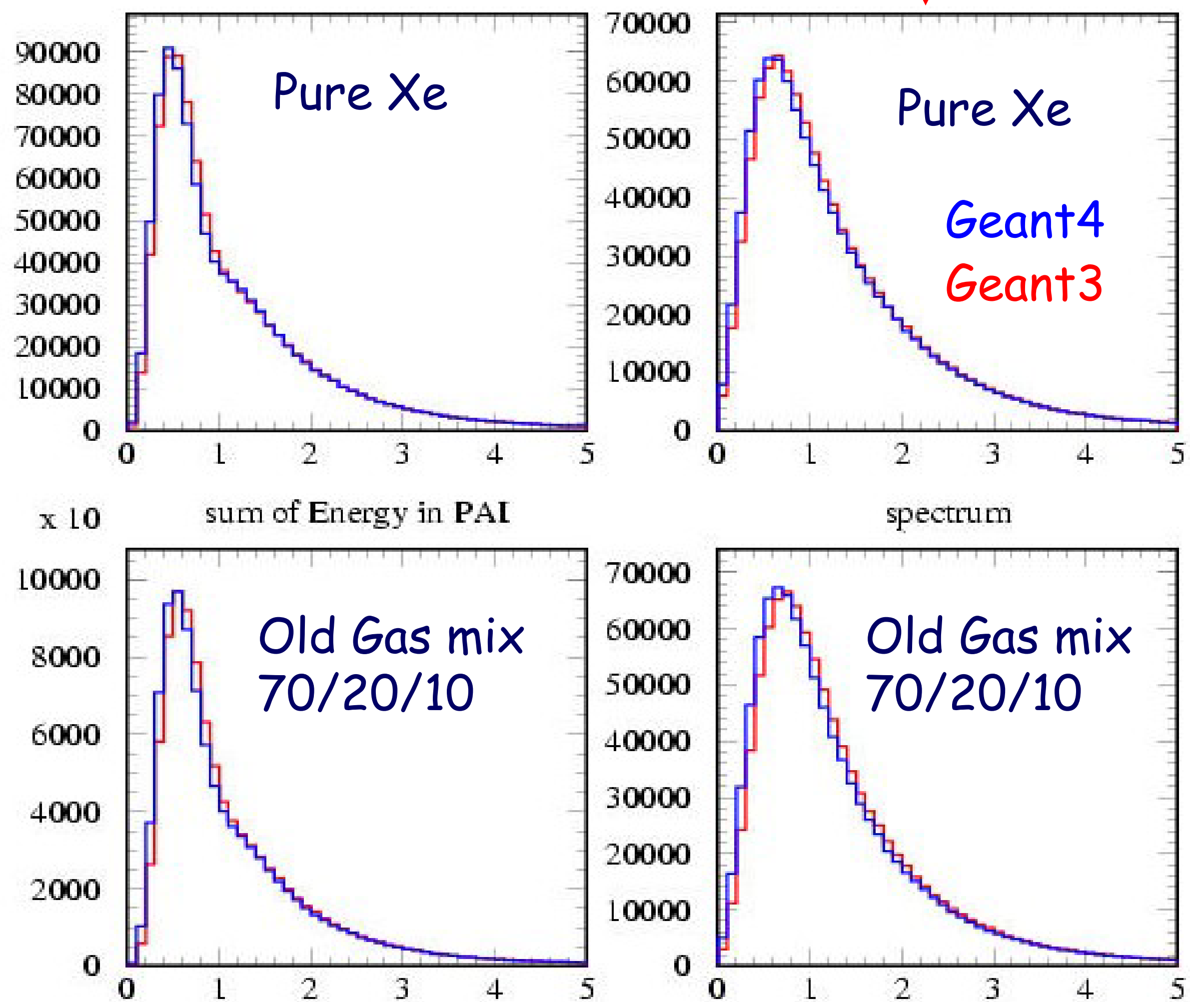


PAI Model - G3 vs. G4

m.i.p: γ = 4

Raw straw signal

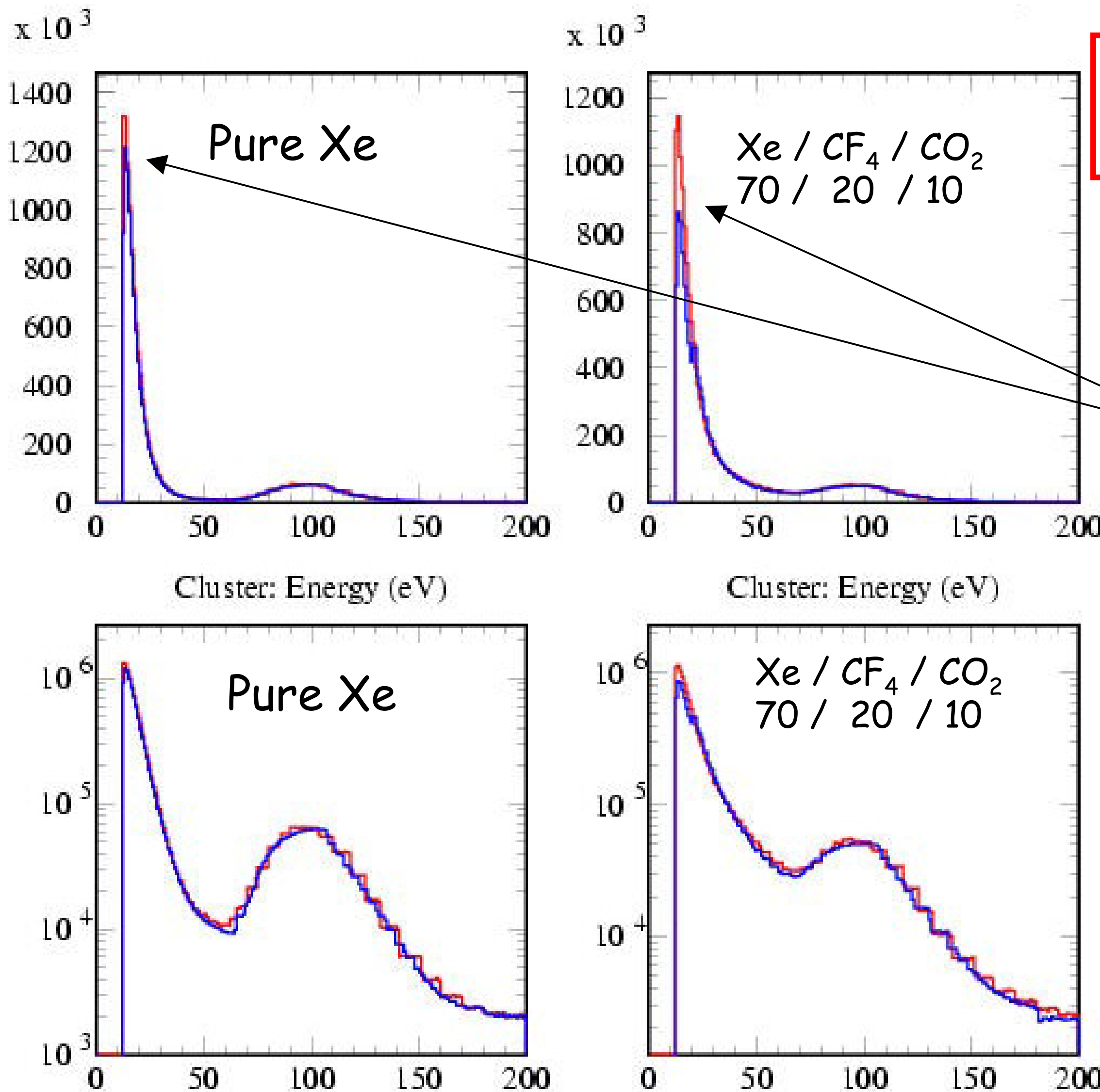
After gas amplification



Conclusions:

- Slight G3/G4 difference in PAI model.
- Peak ~20-50 eV lower in G4 than G3.
- Effect larger in Gas mixture than in pure Xe
- Same difference at higher γ values

PAI Model – Cluster Energies



Geant4
Geant3

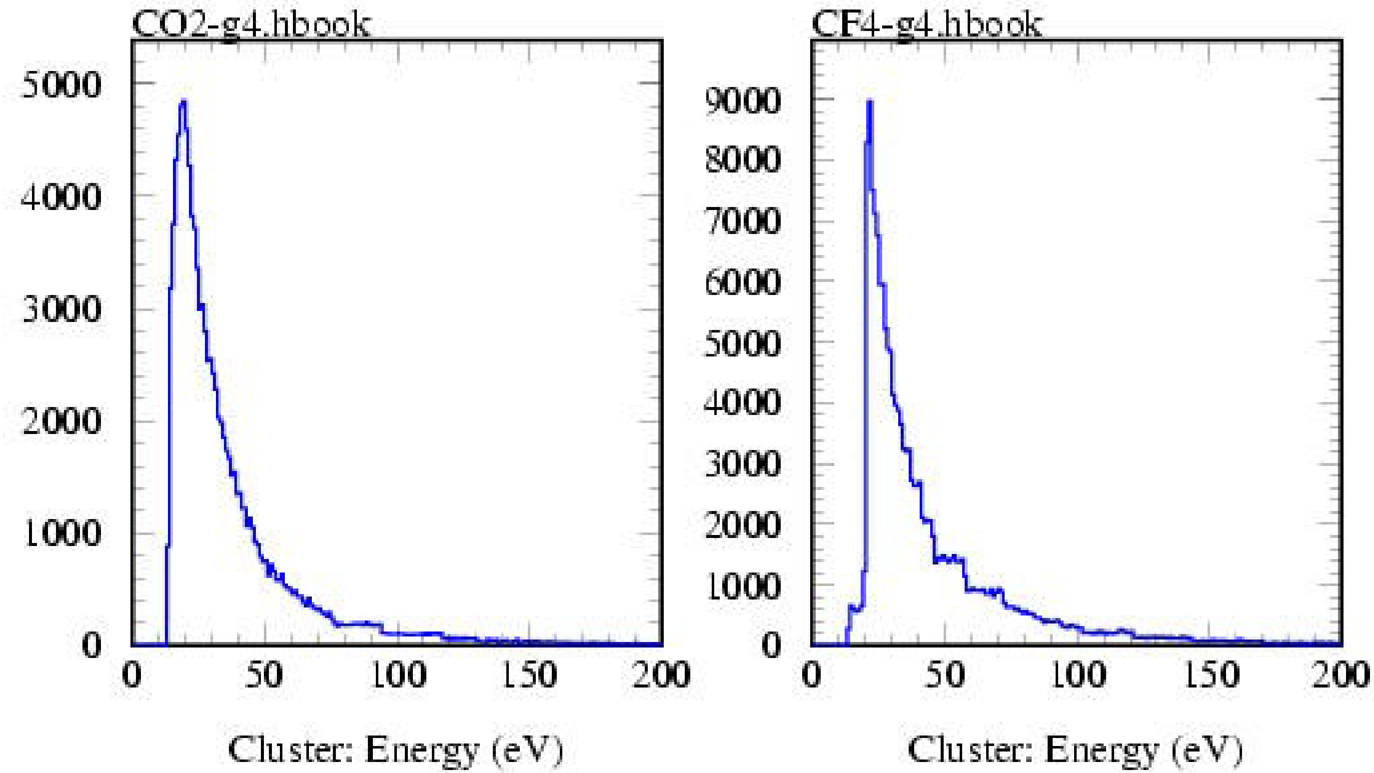
Discrepancy:

- G4 gives considerably less clusters below ~20 eV than G3

-worse for gas mixture

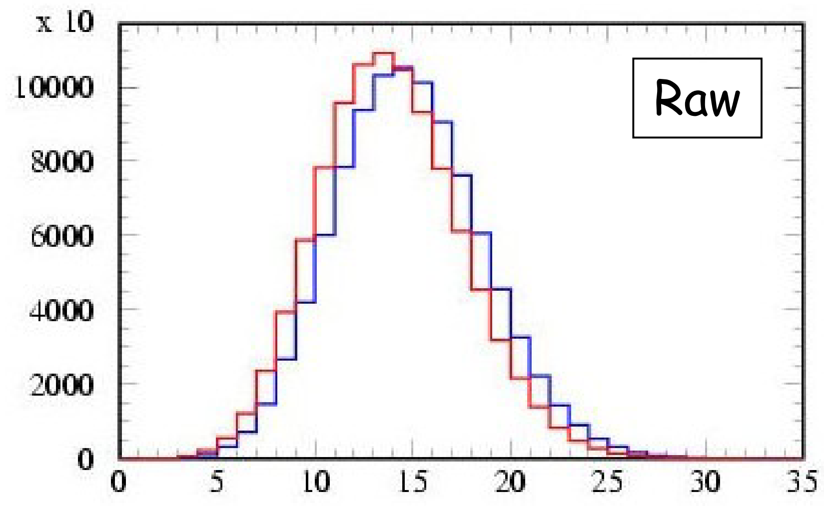
In general better agreement at higher energies

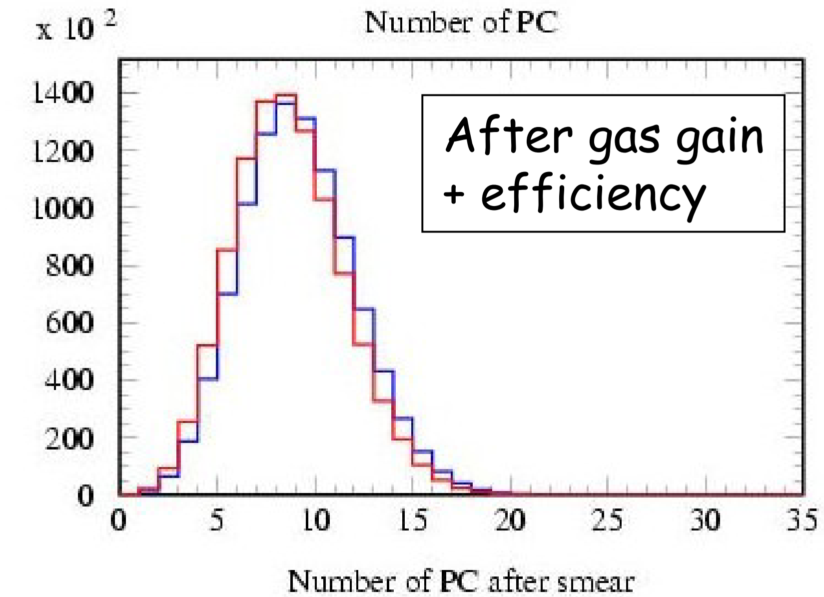
PAI Clusters in Minor Gas Components



Number of Primary Ionization clusters

Geant4
Geant3





- Number of primary ionization clusters lower by ~7% in G4
- Mean free path ~7% higher

Summary

- Geant4 comes with "native" TR generator
  - Numeric integration over emission angle
  - Not easy for practical use
  - Can be used as benchmark for simple geometry
- Implemented G3-like method
  - Analytic integration over emission angle
  - Generates discrete photons treated by G4
  - Runs in full TRT and test beam simulation (release soon)
  - Generates "identical spectrum to "native" G4
  - Resonable agreement with test-beam data
  - Need some further studies, especially of barrel radiator
- Some G3/G4 difference between Photon Absorption Ionization model observed
  - Cluster energy spectra differ at low energy (< 20 eV)