Energy Release in Air Showers

"Shower simulation input for fluorescence yield experiments"

Markus Risse and Dieter Heck
Forschungszentrum Karlsruhe, Institut für Kernphysik

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- Energy release in CORSIKA
  - ➔ study contributions in EAS:
- Which particle types ?
- Typical particle separation ?
- Which particle energies ?

➔ astro-ph/0308158 (tbp by Astropart. Phys.)

Fluorescence Light Production in EAS

$$\frac{dN_{fl}}{dl} = Y(T,\rho)\cdot \rho(h)\cdot \frac{dE}{dX}$$

$Y(T,\rho)$: **Yield [phot/MeV] (You !)**

$\rho(h) = dX/dl$: **air density (atm. models)**

$\frac{dE}{dX}$: **energy release of EAS**

Answers: (Crude) Expectations ...

- **Which particle types ?**

→ electrons & positrons most numerous charged part.

- **Typical particle separation ?**

→ N_{max} ~10^10, R_M ~100 m --> 0.3 part/mm^2 (lat.distr.!)

- **Which particle energies ?**

→ peak in electron energy spectrum slightly below E_{crit}(electr, air) ~ 80 MeV; with dE/dX~ const --> similar to number spectrum (but: small energies !)

Energy Release in EAS-MC: Why not simply Bethe-Bloch ?

- A high-energy particle might lose energy by producing another energetic particle

➔ no local energy release in air (avoid double counting)

➔ track new particle in further simulation

- Not possible (necessary) to simulate explicitly down to "zero" energy

➔ energy threshold: explicit tracking only for $E>E_{thr}$

➔ How do cut particles contribute to energy release ?

Energy Release in CORSIKA

➔ **Energy threshold**: **2 particle categories :**

$E > E_{thr}$:

- Bethe-Bloch, but ...
- continuous energy release (sub-threshold part.prod.)
- discrete production of particles above threshold

➔ **restricted stopping power**

➔ **EGS4** (+Sternheimer, LPM ...)

$E < E_{thr}$:

- before discarding: store *effectice* dE/dX (the particle *would* suffer)

- depends on particle type !

➔ **releasable energy**

Releasable Energy of Cut Particles

- stable particles: E_{kin}
- unstable particles, decay: E_{kin} + m (but: ν loss !)
- antiparticles, annihilation: E_{kin} + 2m

→ How much "available" for dE/dX ?

- electrons: E_{kin}
- positrons: annihilation gammas produced+tracked
- e.g. muons: 1/3 (2/3 lost as ν)

EAS Simulations

- variety of E, A, Θ

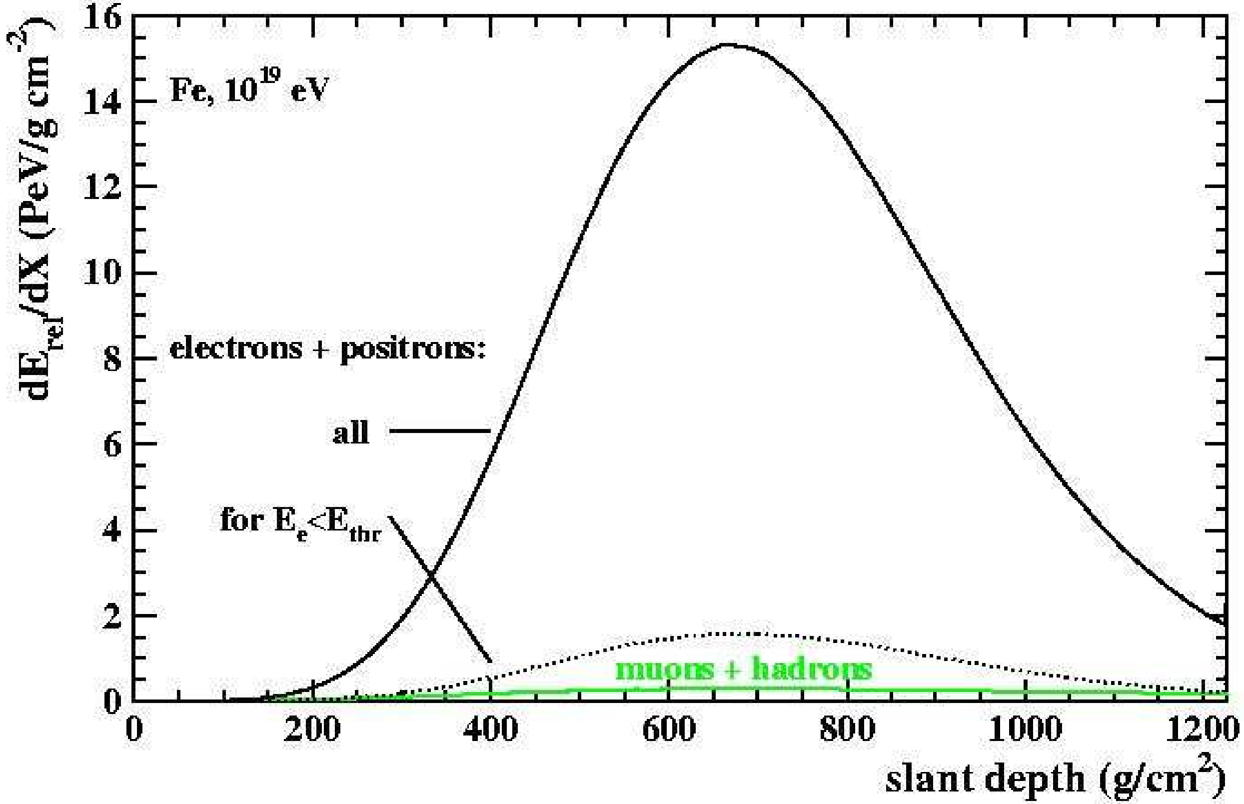
➔ conclusions quite independent

➔ here: Fe, 10 EeV, 45 deg

➔ shower age $s = 3X/(X+2X_{max})$

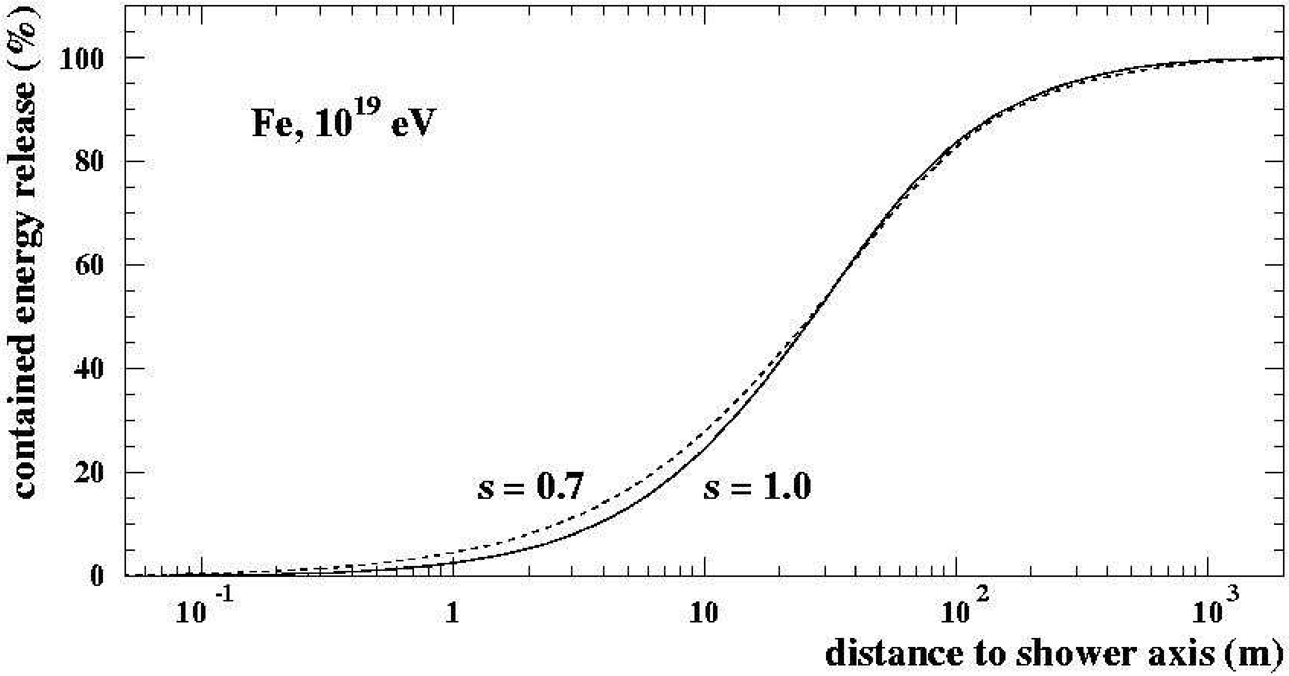
(s = 1: shower maximum)

Longitudinal Development



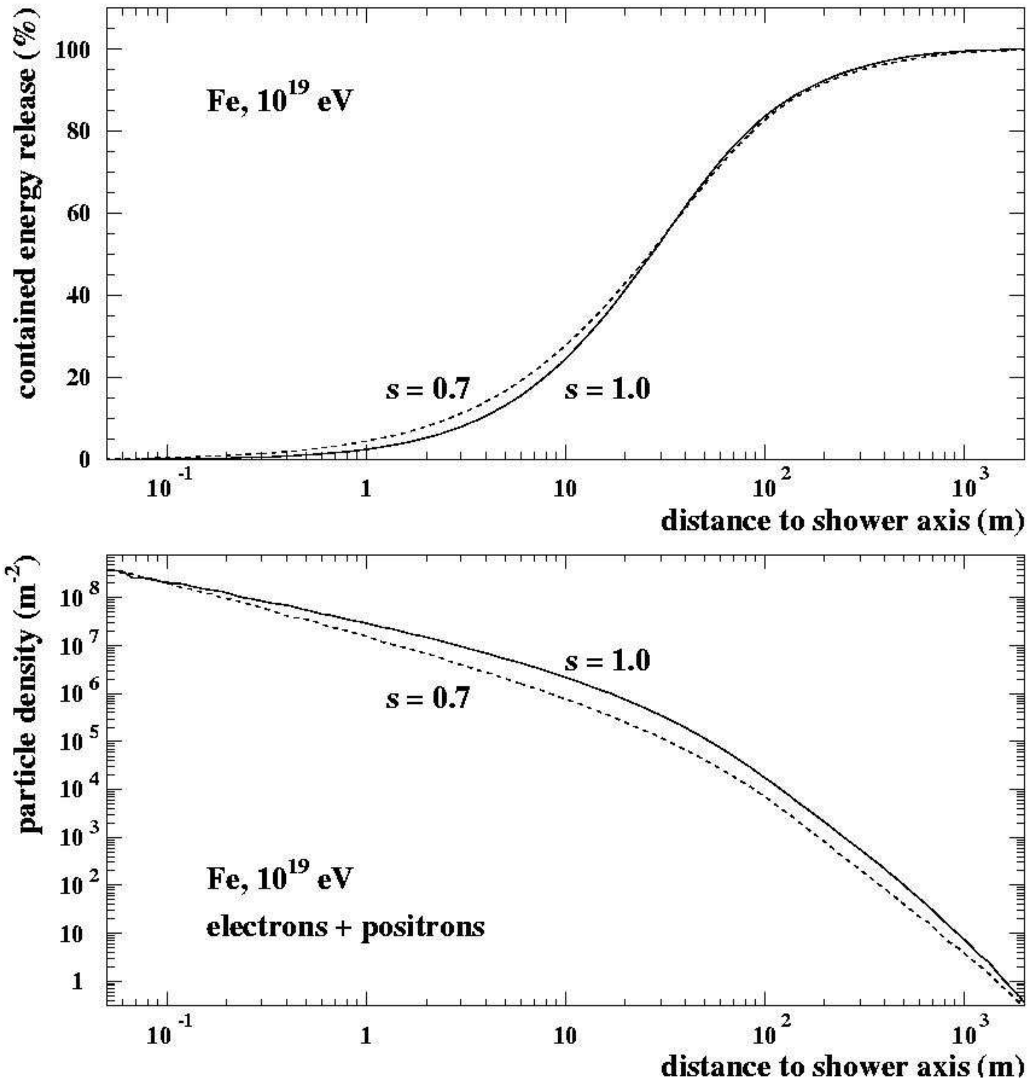
- **mostly electrons (positrons)**
- muons + hadrons: $< 3\%$
- cut electrons: $\sim 10\%$

Radial Distribution



- Below 1 m: only few %
- **1-100 m: > 80%**
- No significant age dependence

Transverse Particle Separation



- at 30 m, s = 1, 10 EeV:

  1 particle per mm^2

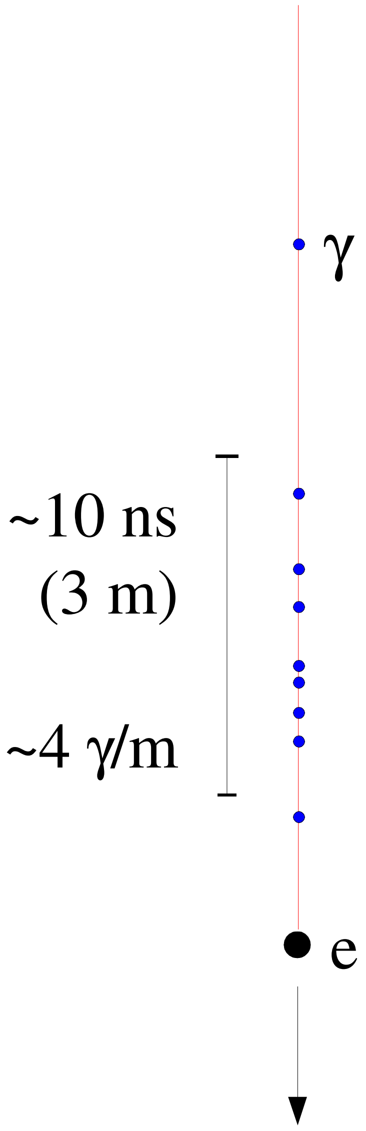
- at few m, 100 EeV:

  <d> exceeds 0.1 mm

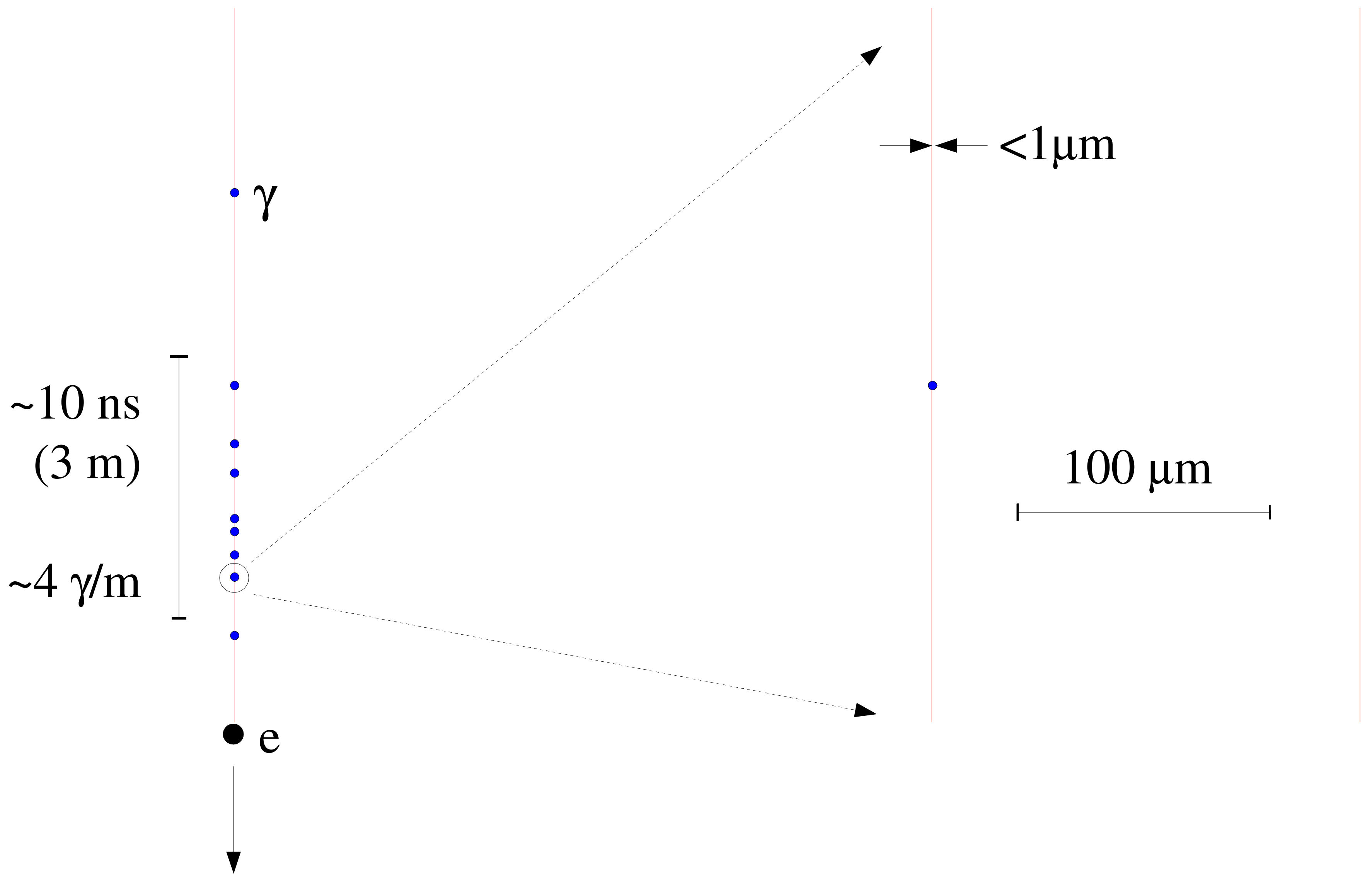
➔ width of ionization tube much smaller (<1μm)

➔ **undisturbed de-excitation**

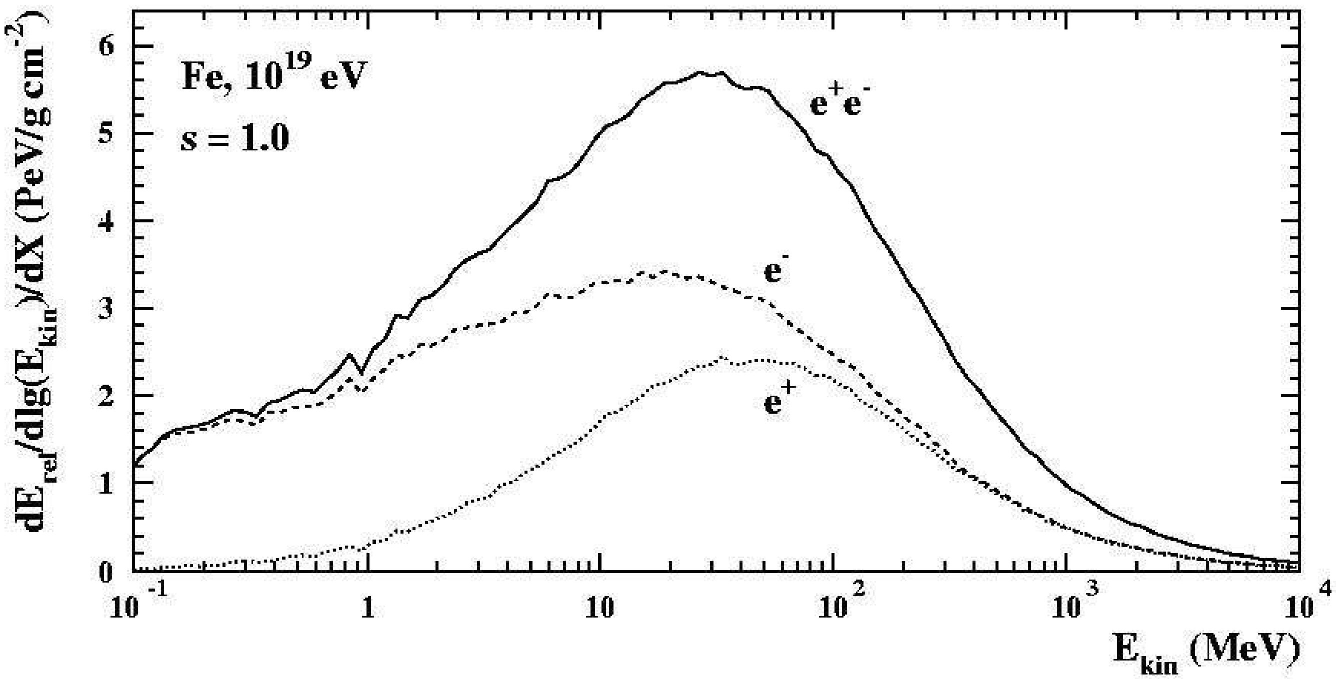
EAS Sketch



EAS Sketch

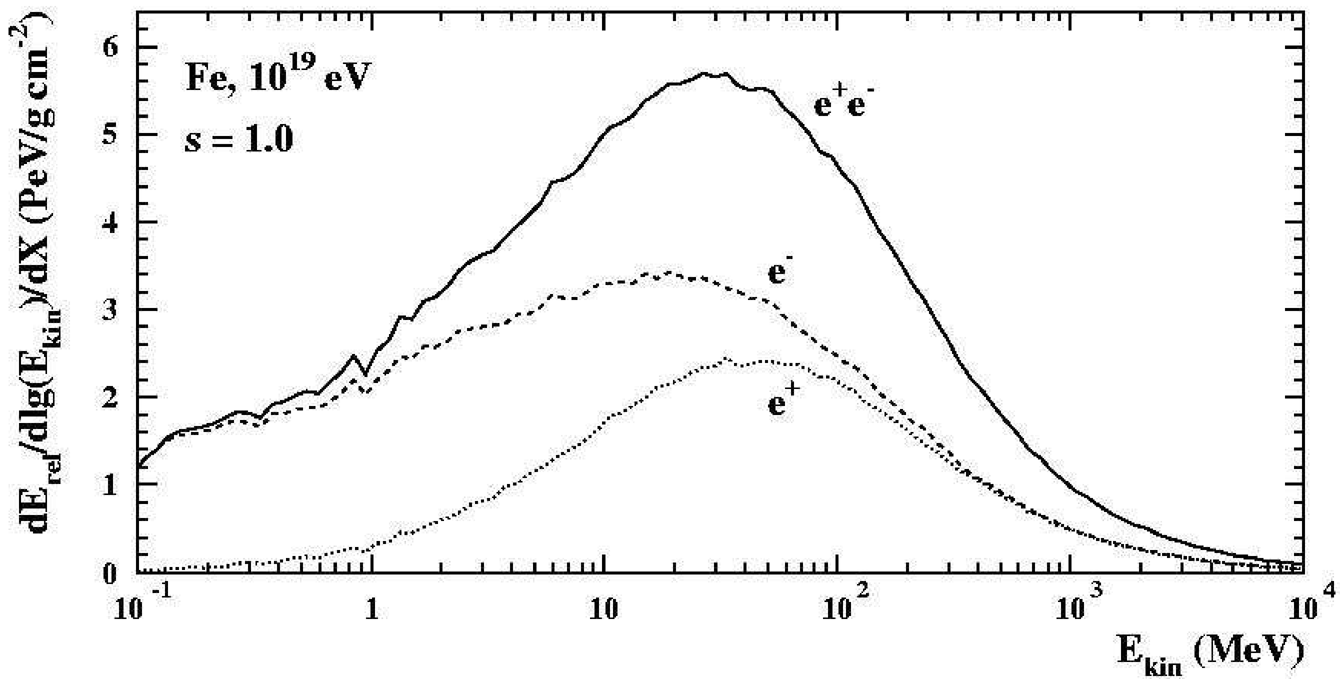


Energy Spectrum



- **sub-MeV up to few 100 MeV**
- maximum slightly below critical energy
- small E pronounced: dE/dx, dx=dX/cosϑ
- positron annihilation below few 100 MeV

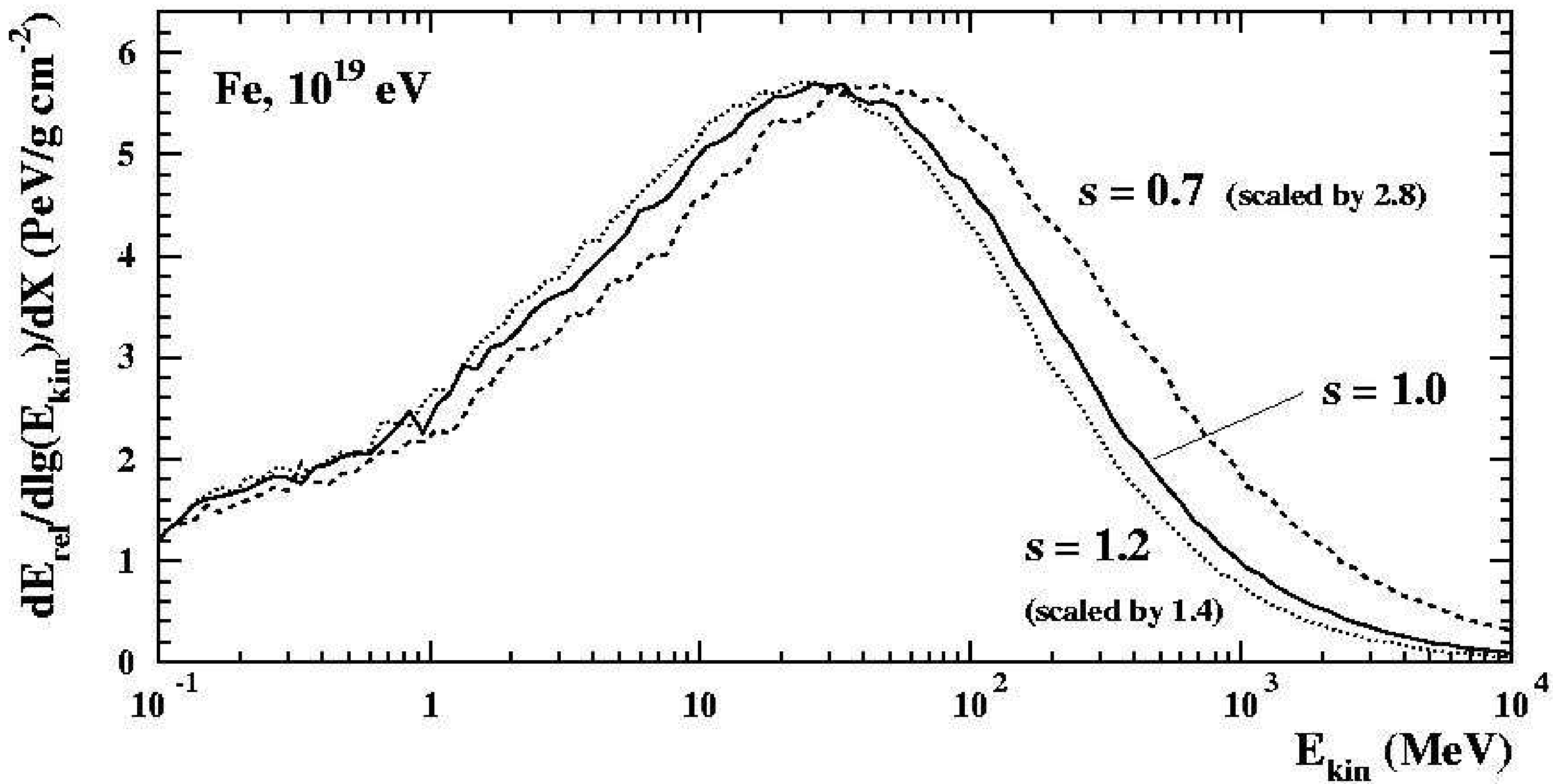
Energy Spectrum



E_{kin}/MeV	<0.1*	0.1-1	1-10	10-100	100-1000	>1000
Contr (%)	10	12	23	35	17	3

* from cut particles

Energy Spectrum and Shower Age



- fading of high-energy particles
- **no strong age dependence**

Conclusions

- **Which particle types ?**

➔ **electrons and positrons**

- **Typical particle separation ?**

➔ **''large'' -> avoid high-density beams**

- **Which particle energies ?**

➔ **sub-MeV up to few hundred MeV**