Geometric structures in hadronic cores of extensive air shower observed by KASCADE

The KASCADE Collaboration

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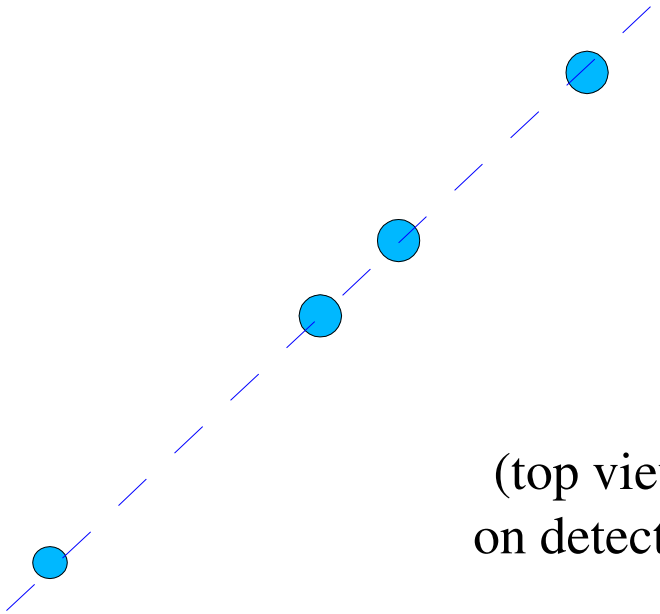
- **Aligned event structures: Anything unusual?**
- **Distances between hadrons: Connection to p_t**

→ *PhD thesis of Anna Risse*

→ *Phys. Rev. D 71, 072002 (2005)*

Motivation: Aligned event structures

Alignment:
observed secondaries
form line shape patterns



(top view
on detector)

- **Theory:** Alignment by
  - QCD jet production (Halzen & Morris, 1990)
  - exotic hadron production processes (e.g. Royzen, 1994)

➔ *If observed: information about hadron production ?*

Alignment: Observations (starting >20 years ago)

“Unusual“ events:

- PAMIR (emulsion chambers at ~600 g cm^{-2}, E_{part} ~few TeV):

  excess of aligned events for showers >8-10 PeV

- Concorde flight: most-energetic shower (~10 PeV)
- another >10 PeV shower in balloon borne emulsion

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Fraction of aligned events agree to background:

- PAMIR at few PeV
- lower-energy Concorde events
- RUNJOB (balloon) 0.01-0.1 PeV
- NA22 (CERN) 250 GeV, pi-Au

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(Some) Interpretations:

- **Exotic processes above energy threshold 8-10 PeV**:
  antishadow scattering mode; semihard double inelastic diffraction;
  new particle w long mean free path produced in new interaction;
  secondaries with high transverse momentum p_t
- **Excess: Statistical fluctuation?**

Alignment & KASCADE

Situation unclear: Alignment features exist, but ...

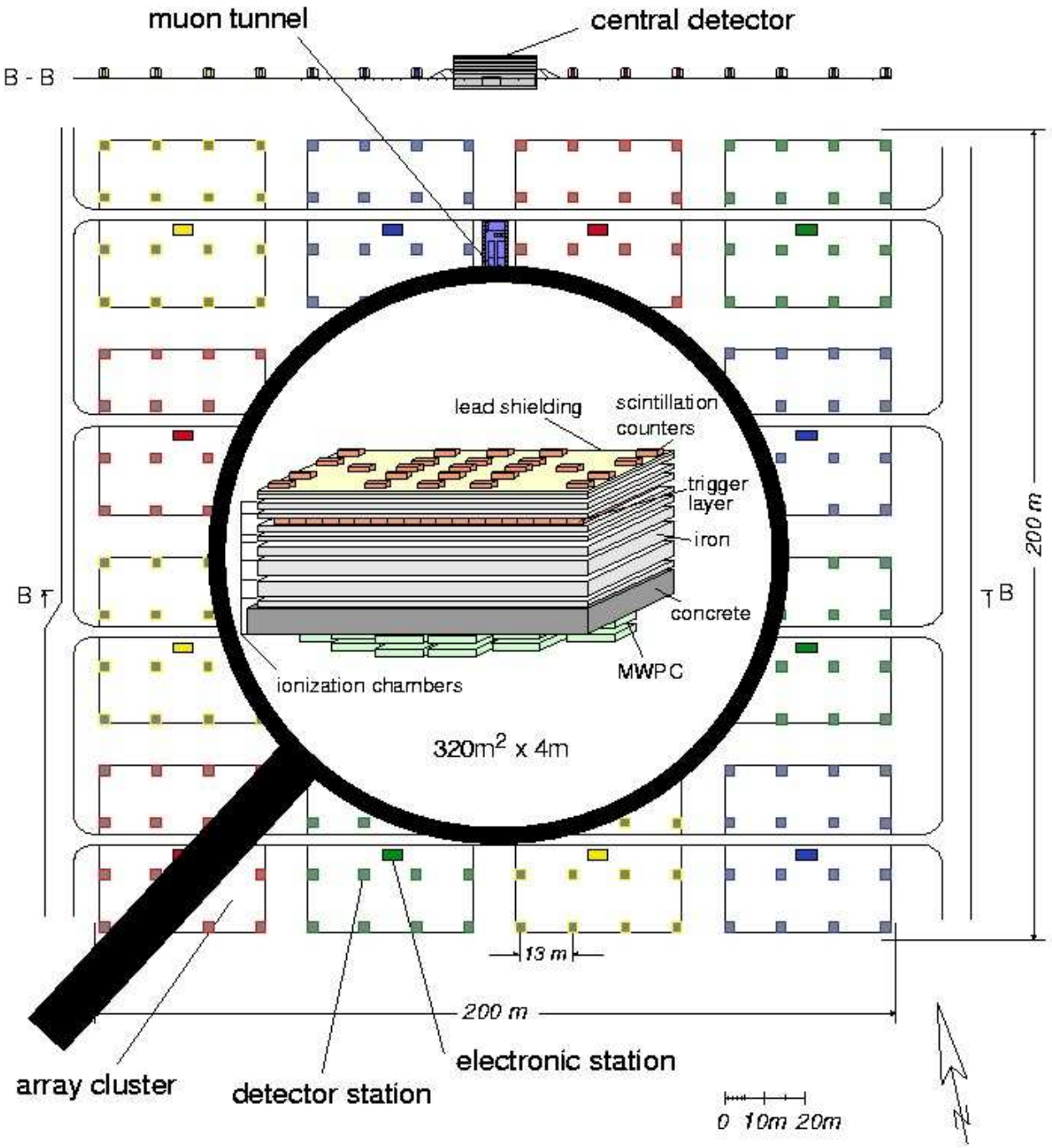
- Can observations be related to hadron production?
- Need for new physics? (Maybe above energy threshold?)

KASCADE:

- Observes individual hadrons in shower cores
- Covers claimed threshold energy of 8-10 PeV

→ **Compare data to simulations and background estimation.**

KASCADE



- **array (252 stations):**

showers >0.5 PeV

direction ~1 deg

primary energy ~25%

shower core ~1.5 m

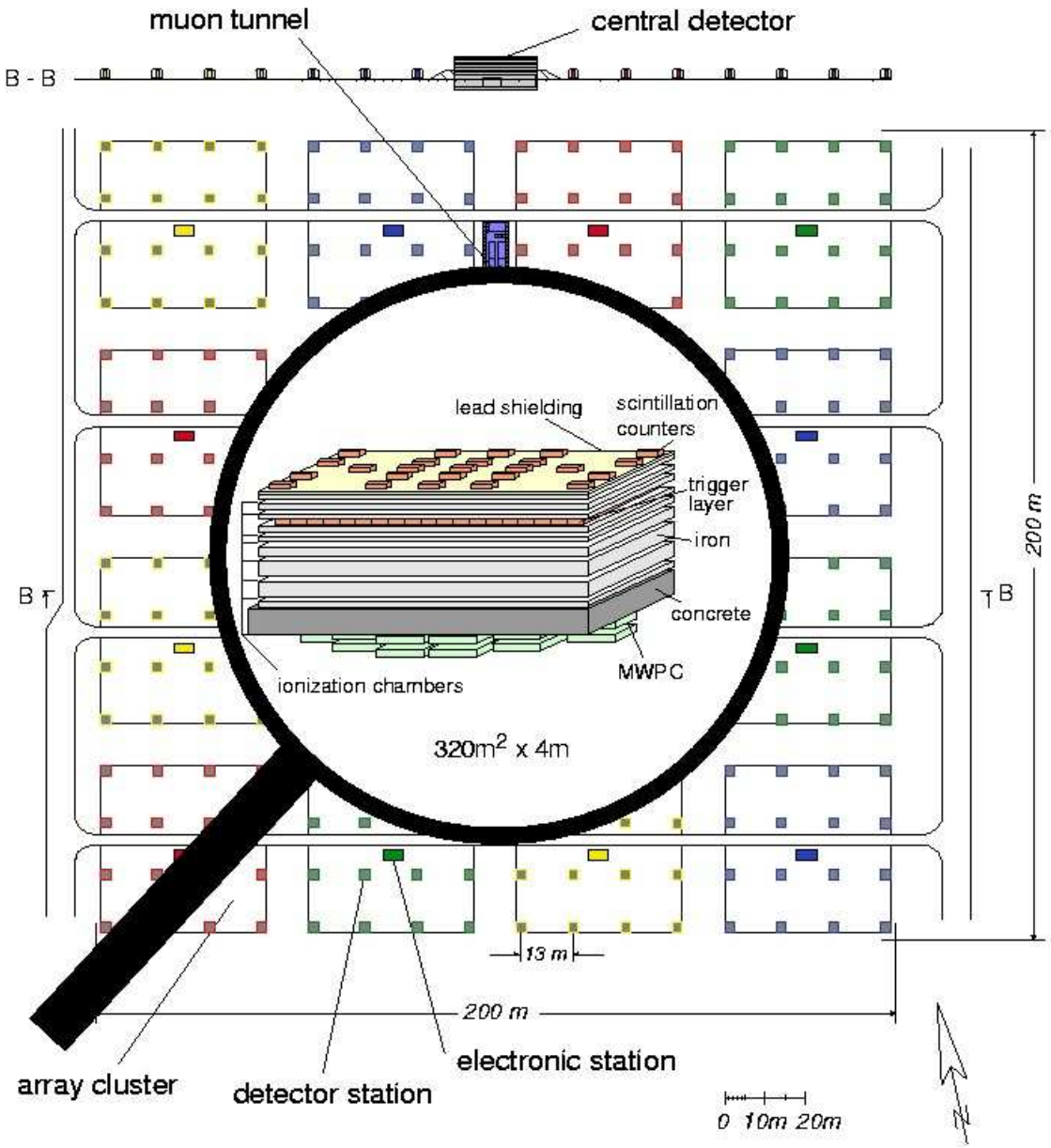
- **320 m^2 calorimeter:**

hadrons >50 GeV

hadron energy ~ 20%

hadron position ~15 cm

Data selection



- 05/1998 - 04/2001
- primary energy >1 PeV
- zenith angle < 30 deg
- shower core inside calorim. (>3 m from boundary)
- at least 4 hadrons with energies >100 GeV

➔ **4489 events**

➔ after transf. into shower plane, for each event:

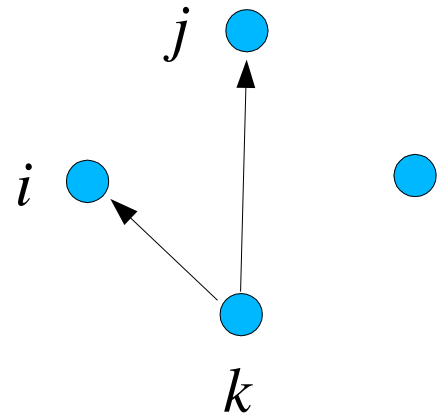
➔ λ_4 **(now)** and d_4^{max} (later)

Quantifying alignment: Lambda_4

$$\lambda_4 = \frac{1}{24} \cdot \sum_{i \neq j \neq k}^{4} \cos 2\varphi_{ij}^{k}$$

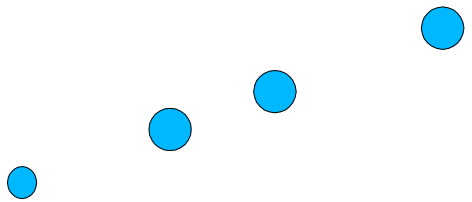
φ_{ij}^{k} : angle between lines connecting particle k to i and j

- take 4 (most-energetic) hadrons
- sum all possible angles



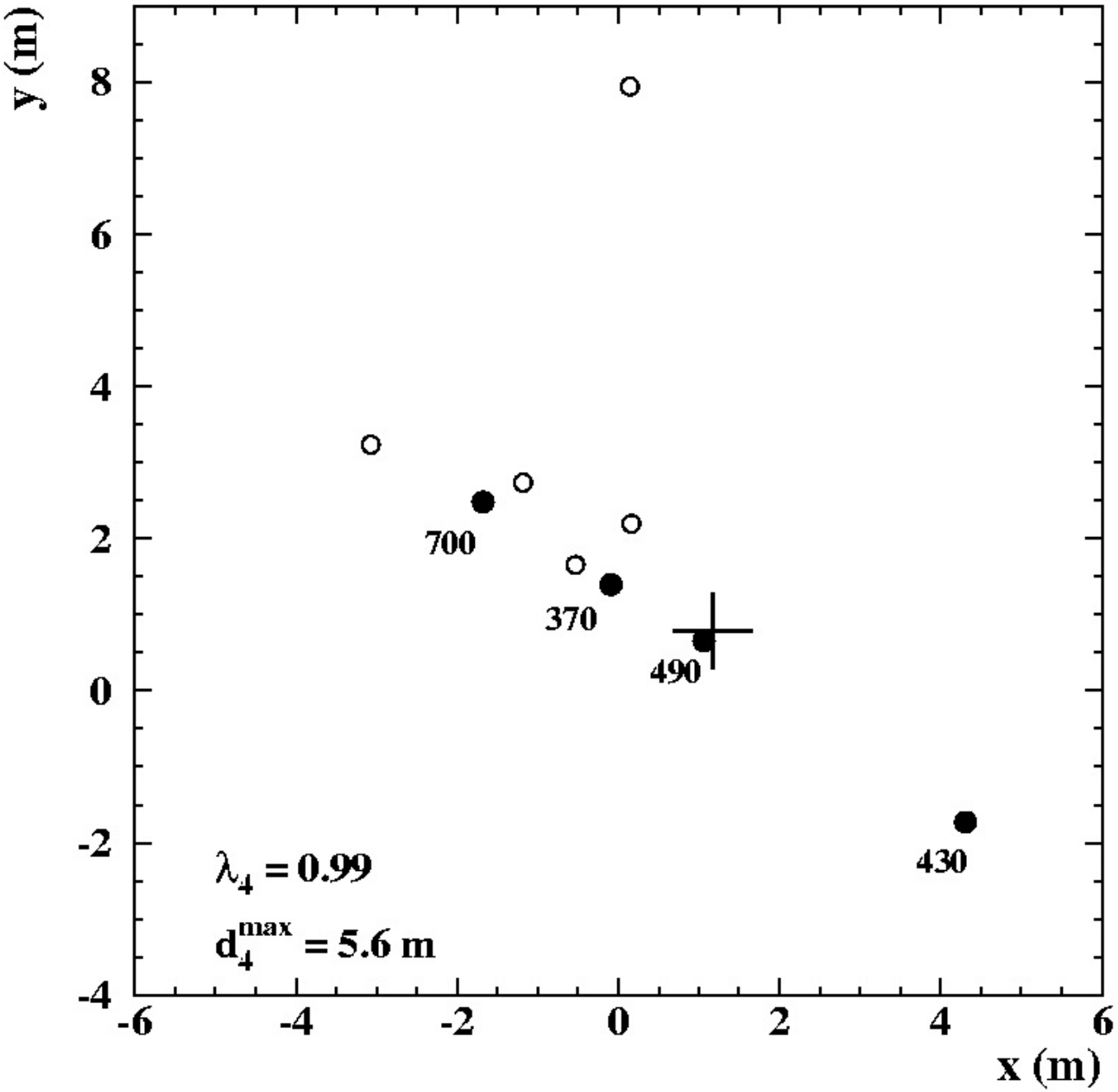
- isotropic: λ_4 -> -1/3
- perfect alignment: λ_4 -> 1

➔ "aligned event": $\lambda_4 > 0.8$



Aligned event observed by KASCADE

top view on calorimeter:

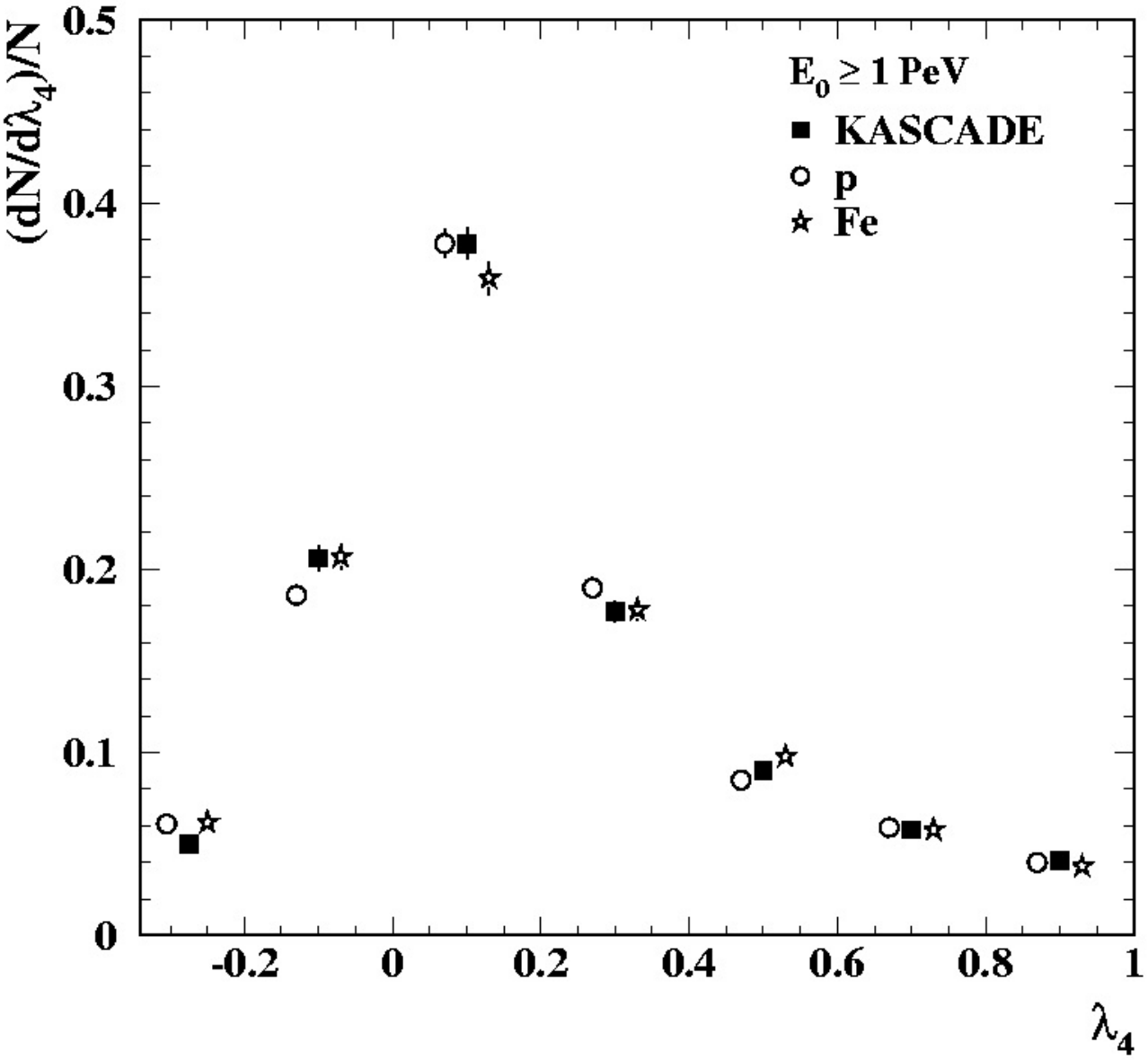


- hadrons incident on calorimeter
- energies given for 4 most-energetic hadrons
- cross: shower core reconstr. by array

➔ **Aligned events are observed !**

➔ *Q: More often than expected ...?*

Lambda_4 distribution: Data vs simulation



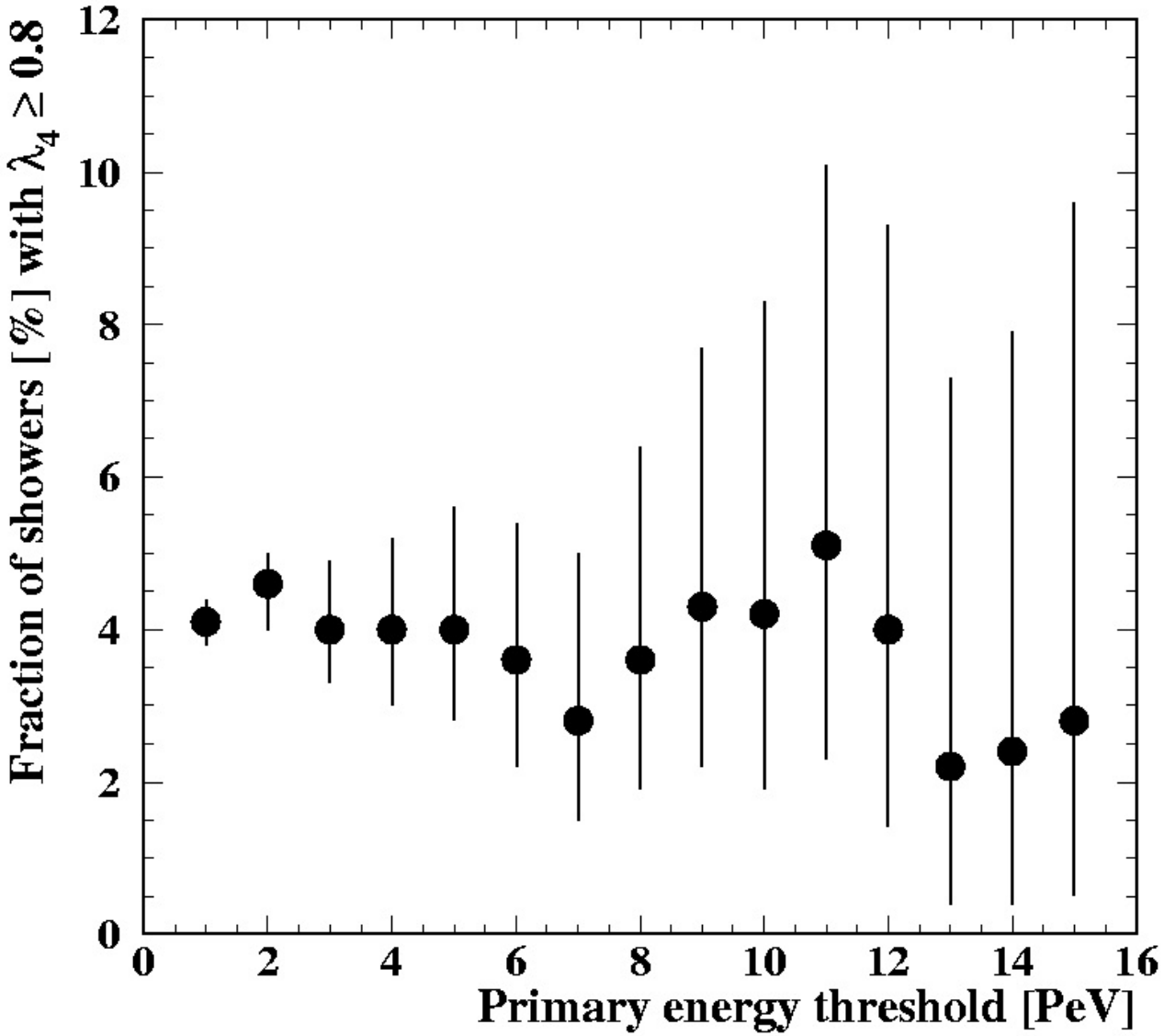
(simulations shifted horizontally)

~agreement between:

- **data & simulation**
  - ➔ no need for new physics
- **p and Fe primaries**
  - ➔ indication of minor sensitivity to hadronic features

➔ *Does the fraction of aligned events depend on primary energy?*

Fraction of aligned events vs shower energy



- **no indication of threshold behaviour**

Sensitivity to (standard model) physics?

- Is there a connection alignment <-> hadronic interaction features?

  E.g. jet production (directionality!), and/or large p_t ?

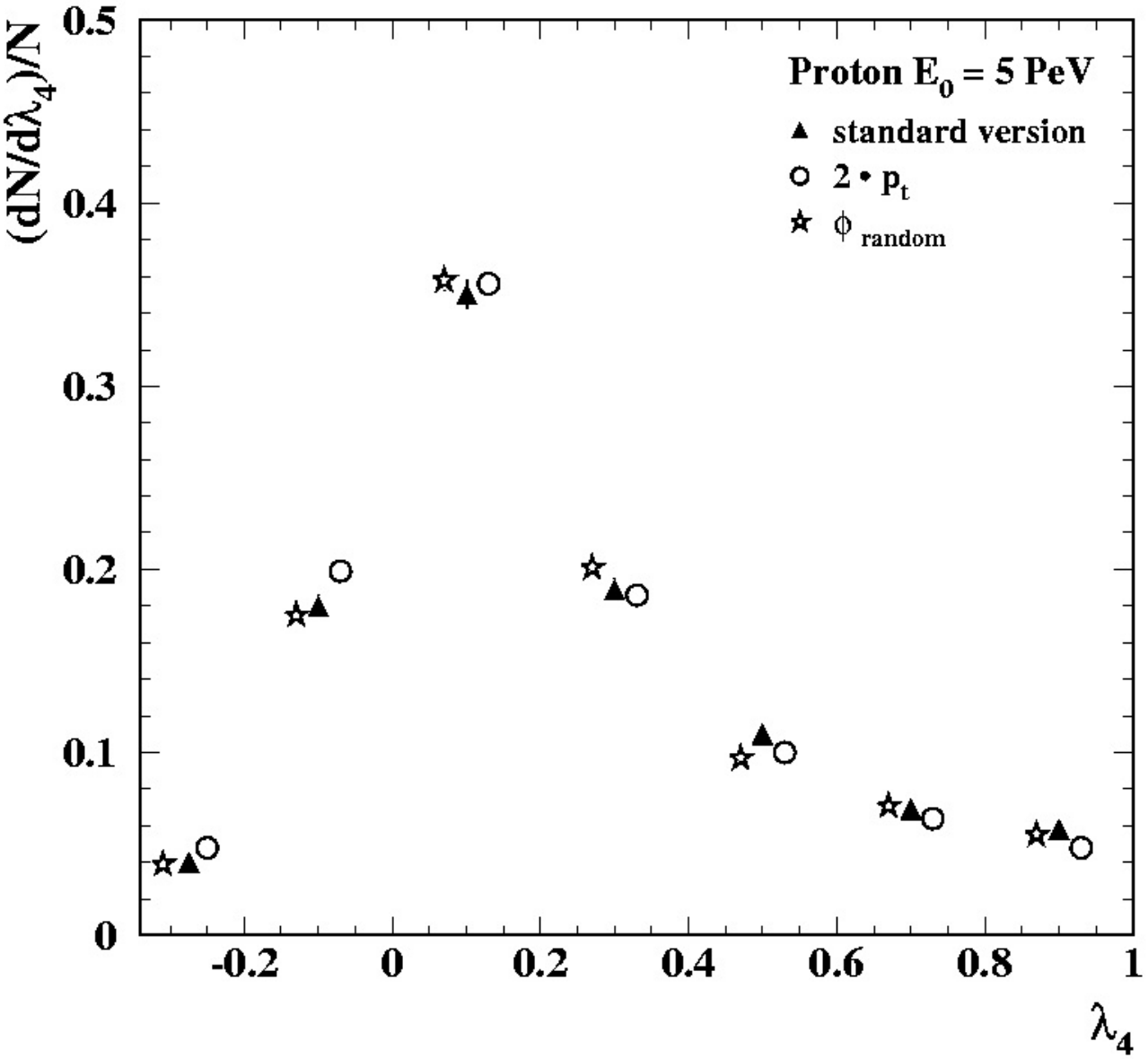
➔ **Check sensitivity by artificial modifications in simulation:**

(i) increase p_t of secondaries by factor 2

(ii) random azimuth angle (in cms of collision) of secondaries

➔ compare simulation results to standard version

Sensitivity to jet production or p_t ?

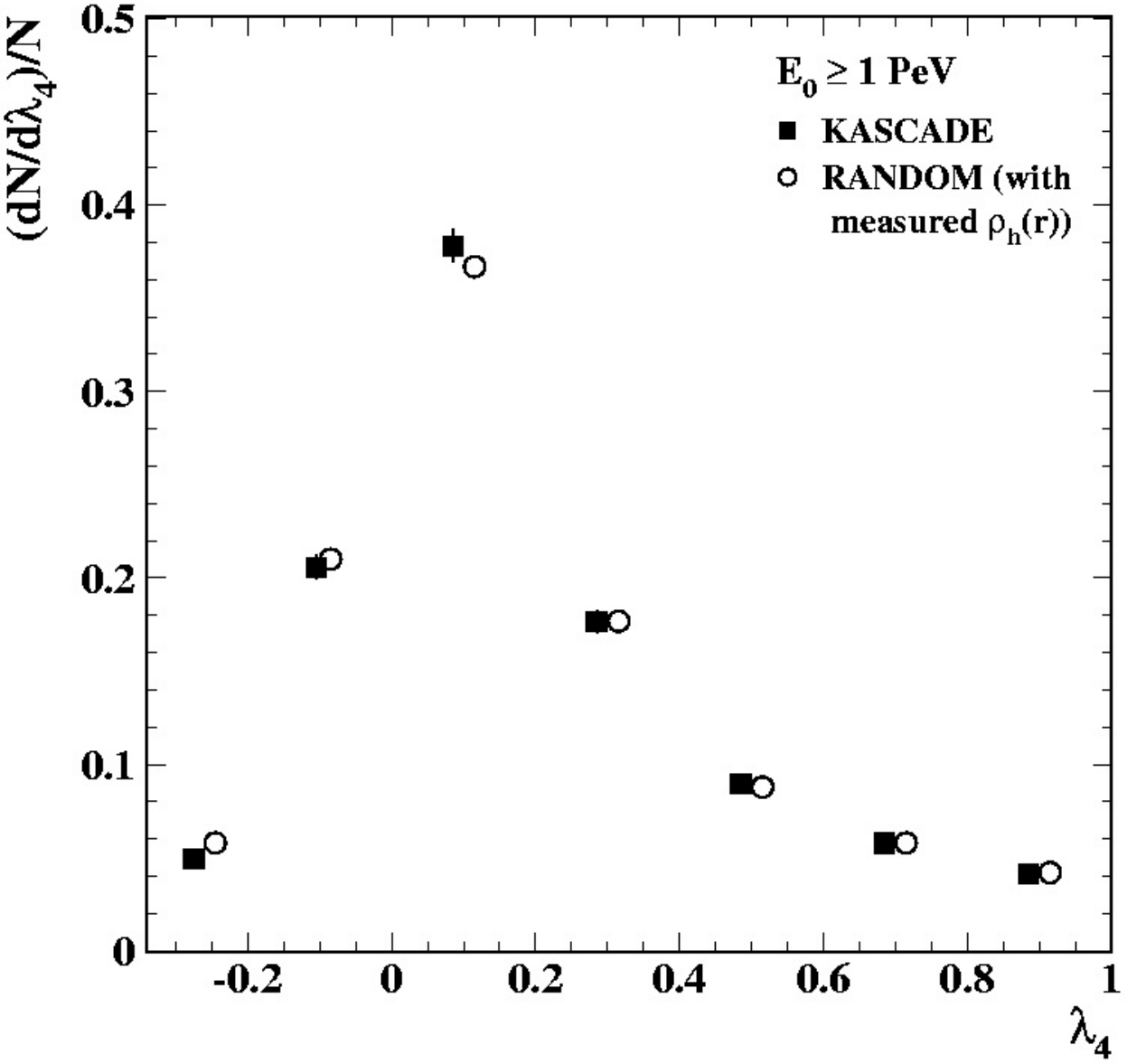


(fixed primary energy)

- no significant change in modified versions
- **no sensitivity** to jet production features or large p_t
- even "random azimuth" leads to aligned events

➔ *Does the observed distribution just follow from random sampling?*

Observed vs random distribution



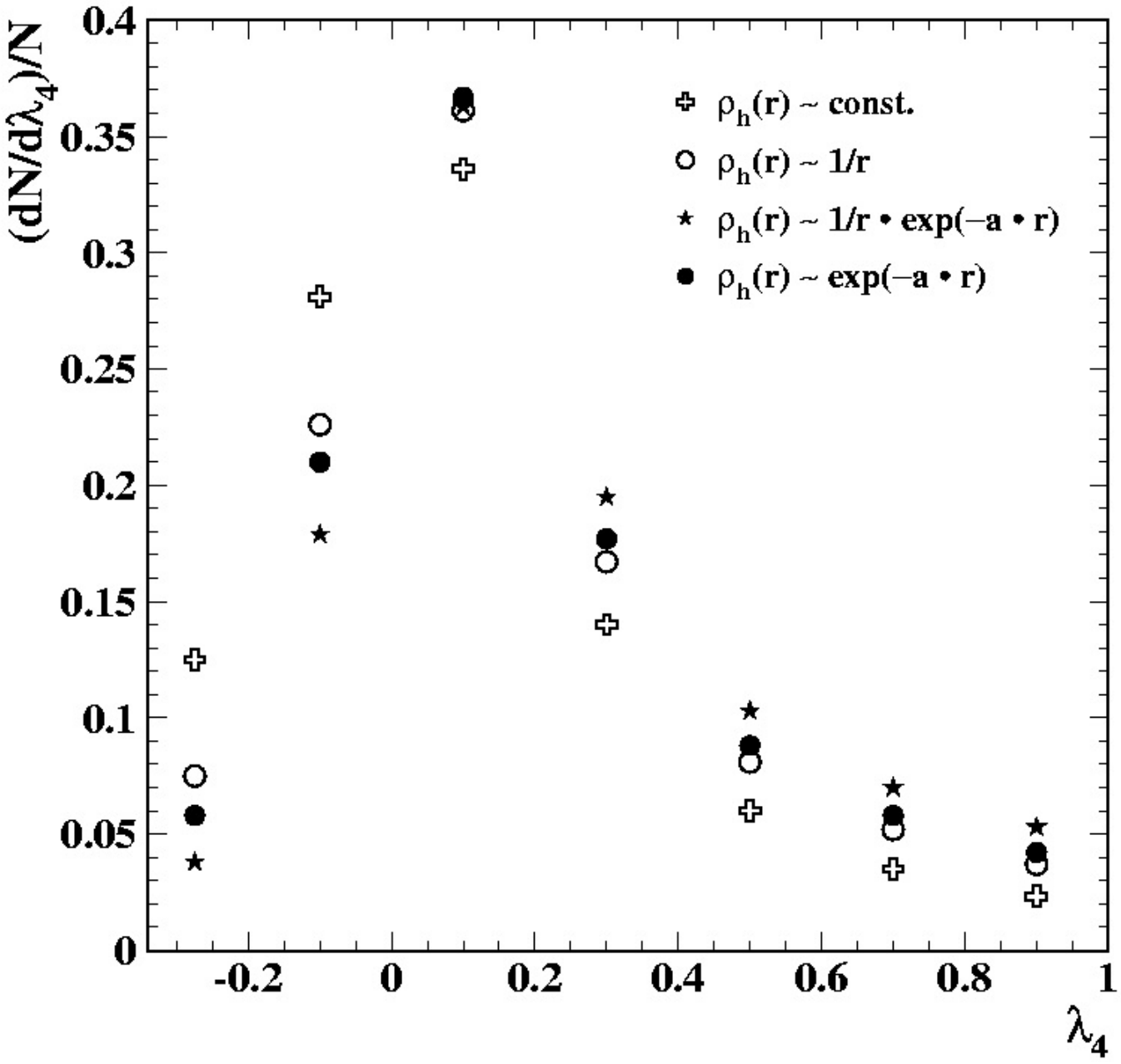
random distribution:

- ➔ generate events with 4 "hadron" positions around "shower core"
- random azimuth angle
- random distance acc. to measured hadron lateral distribution

- ➔ **obs. λ_4 distribution ~ random distribution !**

- ➔ *sensitivity to lateral distribution?*

"Random" simulations and lateral distribution



- modest changes even for very unrealistic choices
- differences from diff. lateral distrib. hardly measurable

Aligned events at KASCADE

- Aligned events are observed
- Reproduced by simulations (-> no new physics needed)
- No sensitivity of fraction of aligned events (or shape of λ_4 distribution) to jet production (doubled p_t, randomized azimuths)
- Observed distribution well reproduced by random positioning of hadrons (very minor sensitivity on shape of lateral distribution)

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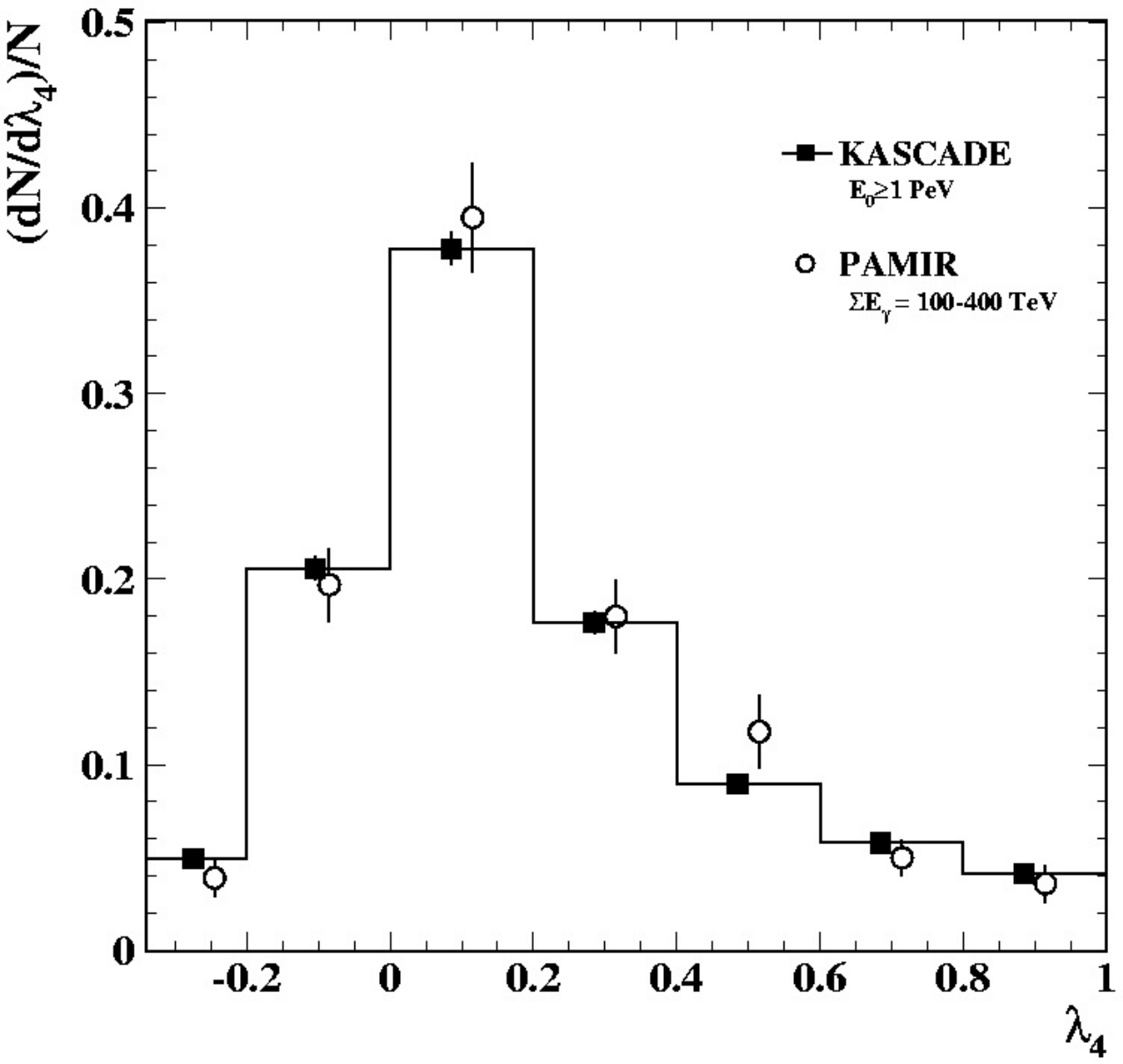
➔ Not necessarily in contradiction to alignment excesses in other observables, at different observation levels or primary energies

➔ e.g.: KASCADE @ 1020 g cm^{-2}, hadrons >100 GeV

PAMIR @ 600g cm^{-2}, electromagn. component >few TeV

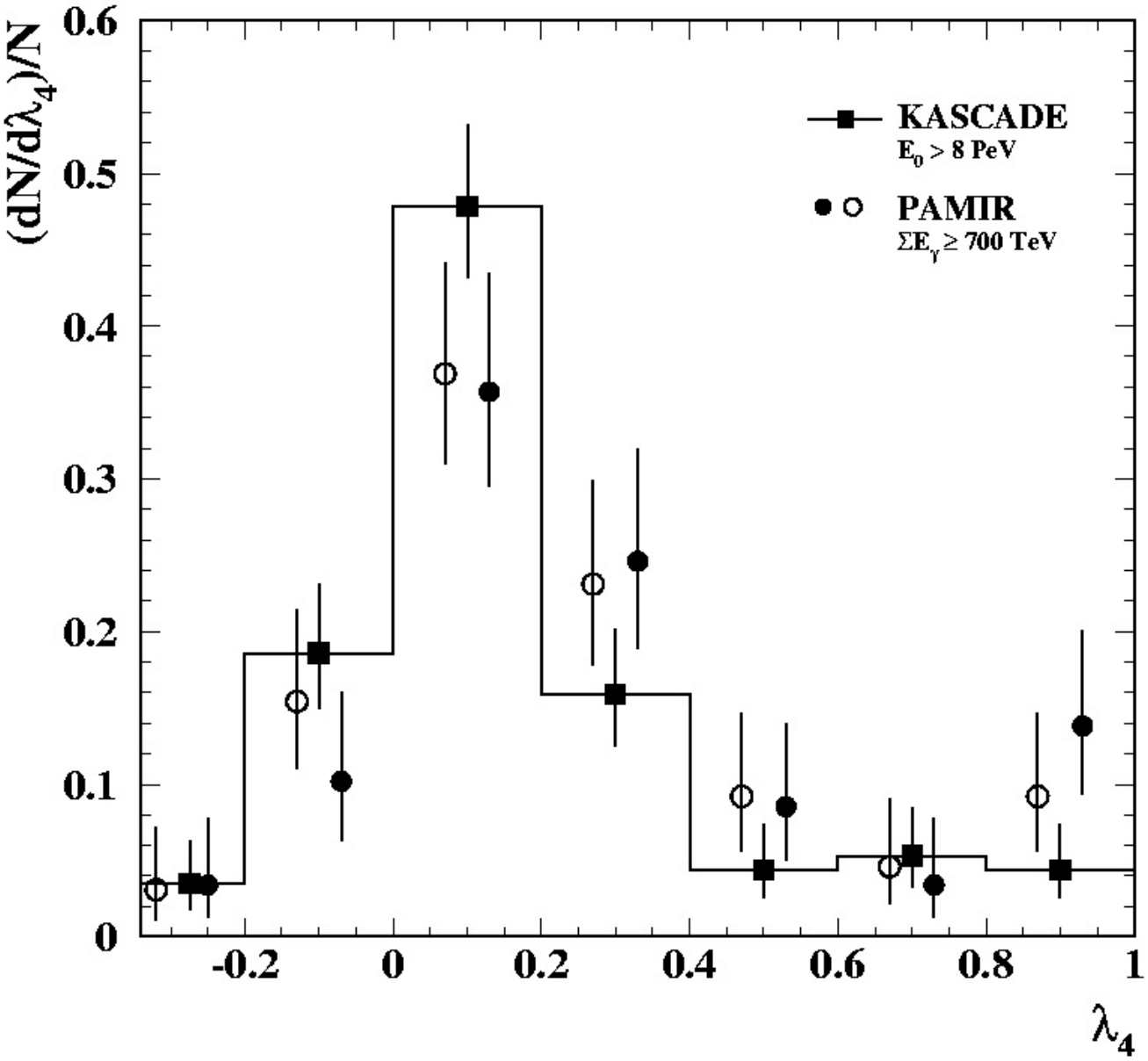
➔ *Comparison to PAMIR λ_4 distribution*

Below claimed alignment threshold of 8-10 PeV



- no significant differences

Above claimed alignment threshold of 8-10 PeV



PAMIR symbols: same data, different analyses

- difference in fraction of aligned events: ~1.5 stand. dev.

→ PAMIR~KASCADE ~random distribution

Observables <-> hadron interaction features

- λ_4 (at KASCADE): no significant sensitivity
- Observables with sensitivity: E.g.
  - hadron number, energy sum, ... (Journ. Phys. G, 1999)
  - hadron & trigger rates ... (Journ. Phys. G, 2001)

→ **Now: Hadron distances d_4^{max} <-> production height, p_t**

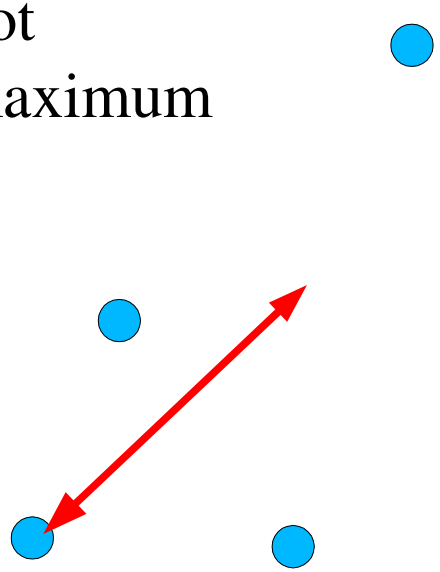
  - **sensitivity expected !**

A geometric observable with sensitivity: d_4^{max}

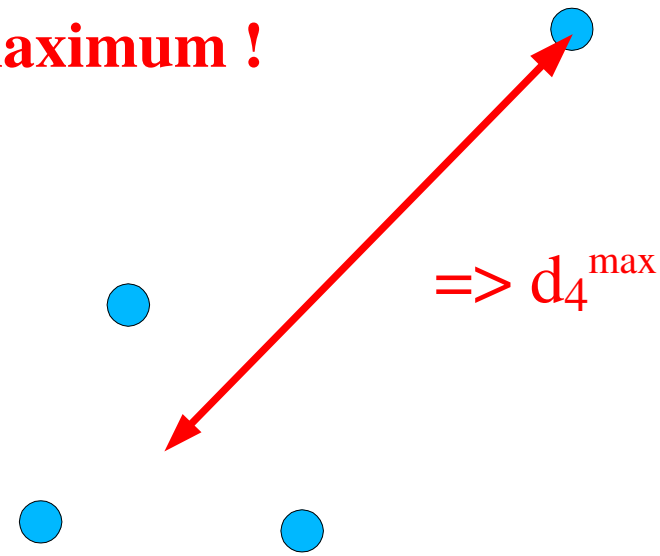
- same selection criteria, same 4 hadrons per event
- a distance measure in hadronic shower cores:

d_4^{max} : max. distance of 1 hadron to geometric center of the 3 others

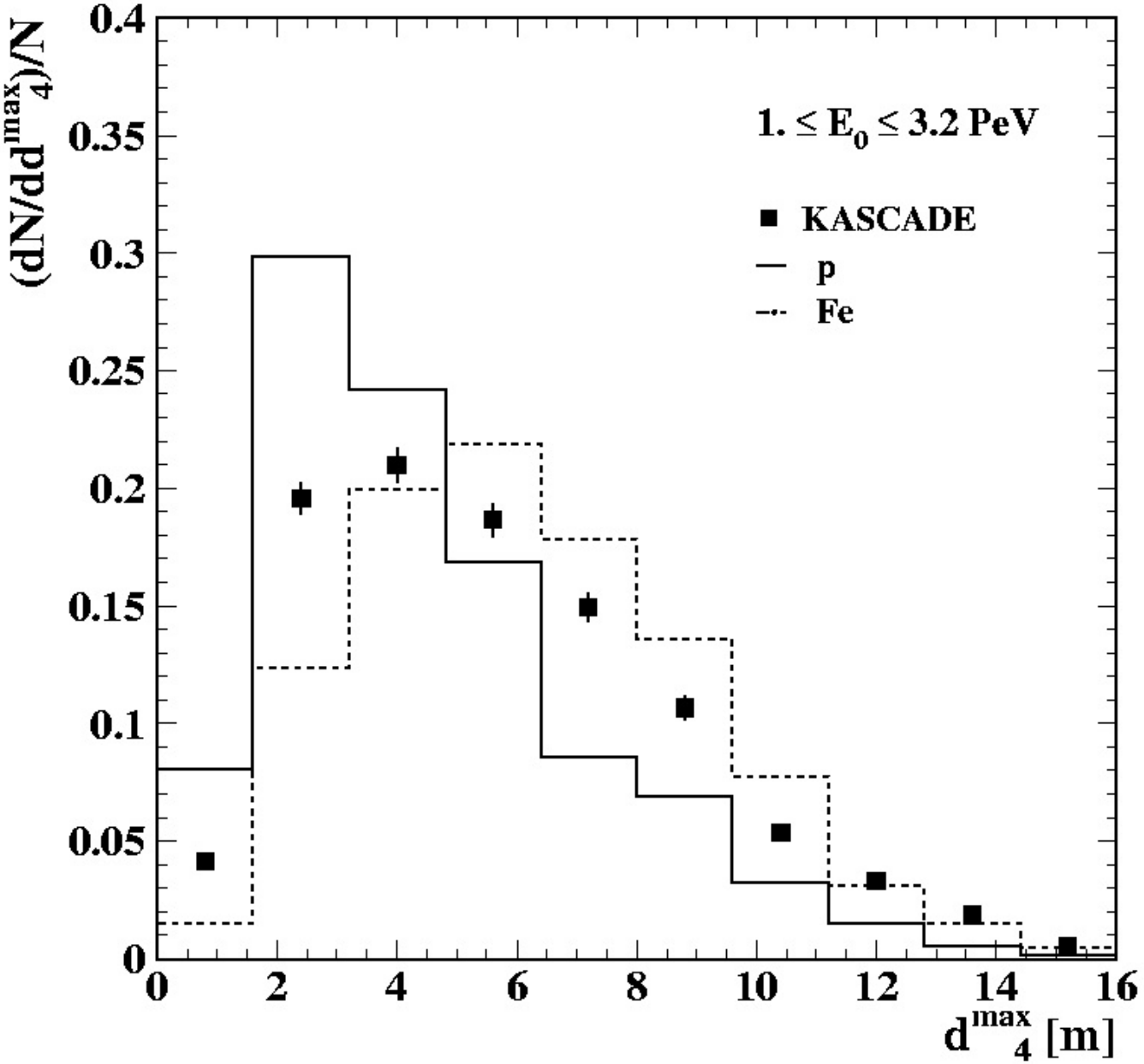
not
maximum



maximum !



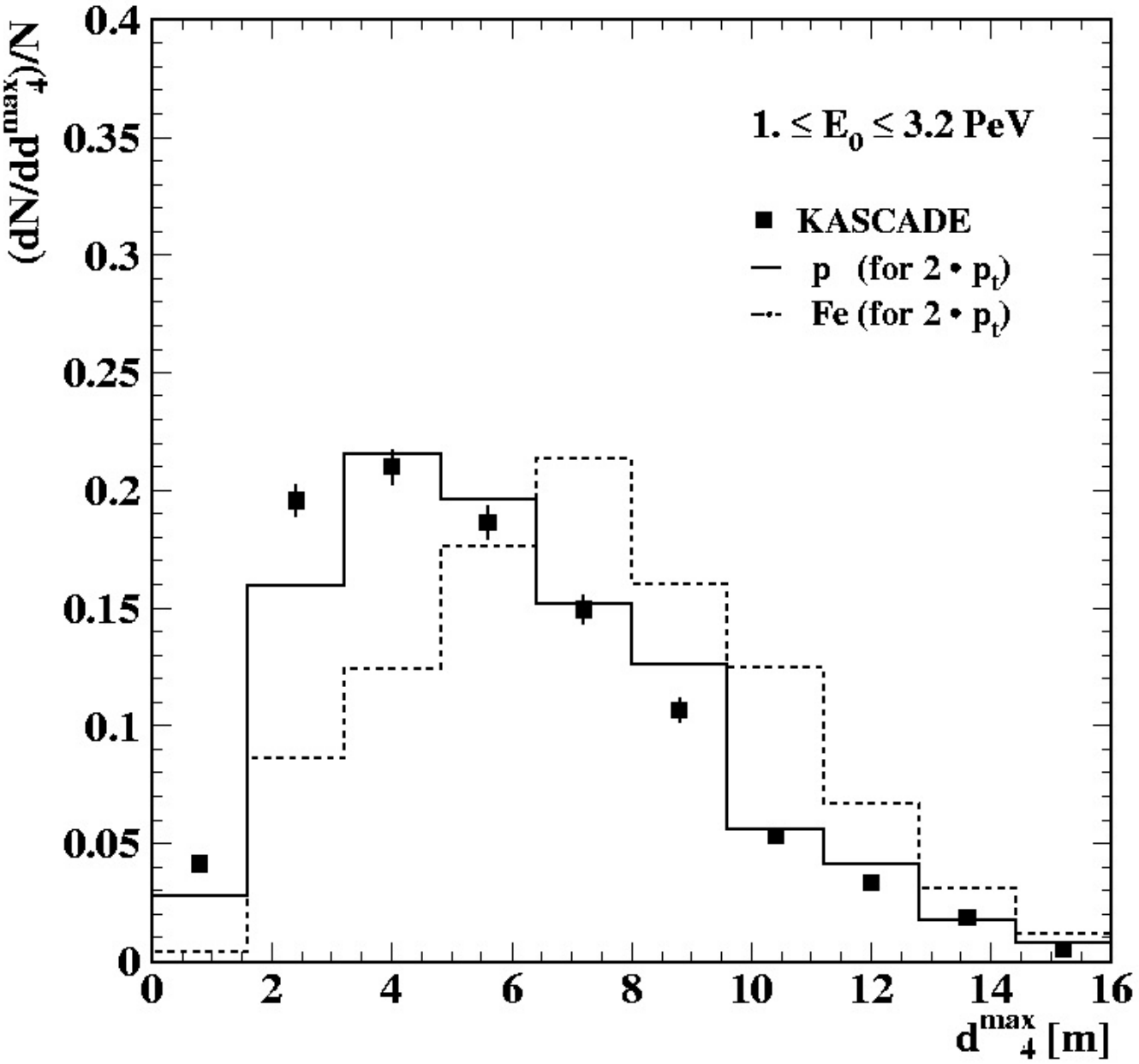
KASCADE data & simulation



- data bracketed by extremes (p and Fe)
- differences betw. p and Fe (contrary to λ_4!): protons deeper in atm. => secondaries still more confined

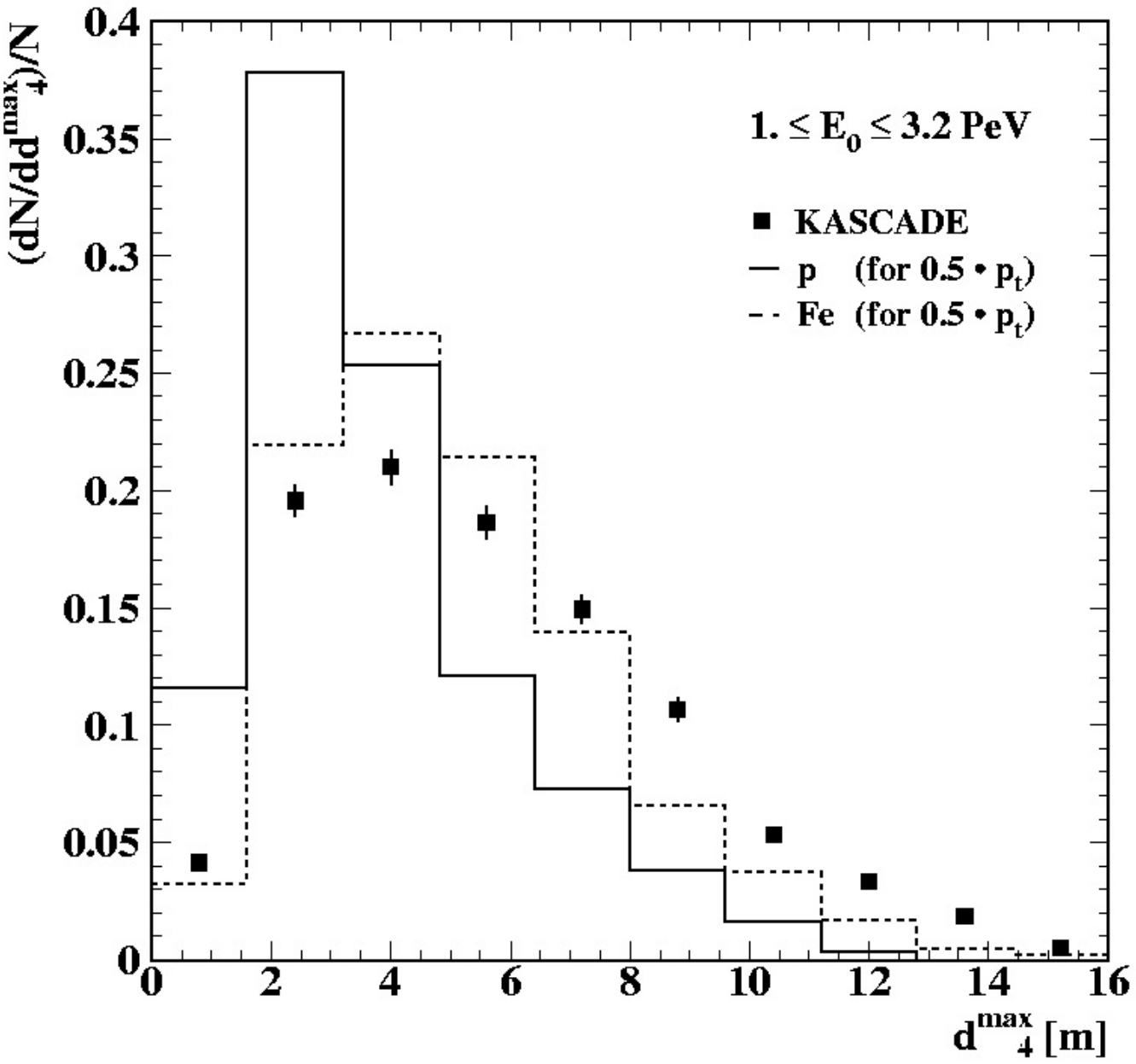
→ *connection* d_4^{max} & p_t

Simulation: Increase p_t of secondaries by factor 2



- ✔ distributions broader
- ➔ events with small d_4^{max} not reproduced (even for pure p) !
- ➔ scenario of doubled p_t in high-energy hadron interactions disfavoured by data

Simulation: Reduce p_t of secondaries by factor 2



- ✔ distributions narrower
- ➔ events with large d_4^{max} not reproduced (even for pure Fe) !
- ➔ scenario of half p_t in high-energy hadron interactions disfavoured by data

standard p_t seems not grossly wrong !

Conclusions: Geometric hadron structures at KASCADE

Alignment:

- Observed
- Reproduced by simulations (-> no new physics needed)
- No sensitivity to jet production (doubled p_t, randomized azimuths)
- Reproduced by random positioning of hadrons
- Alignment distributions KASCADE ~ PAMIR

Distances:

- Sensitive to p_t and primary particle
- Data disfavour p_t differing by factor 2 from standard values