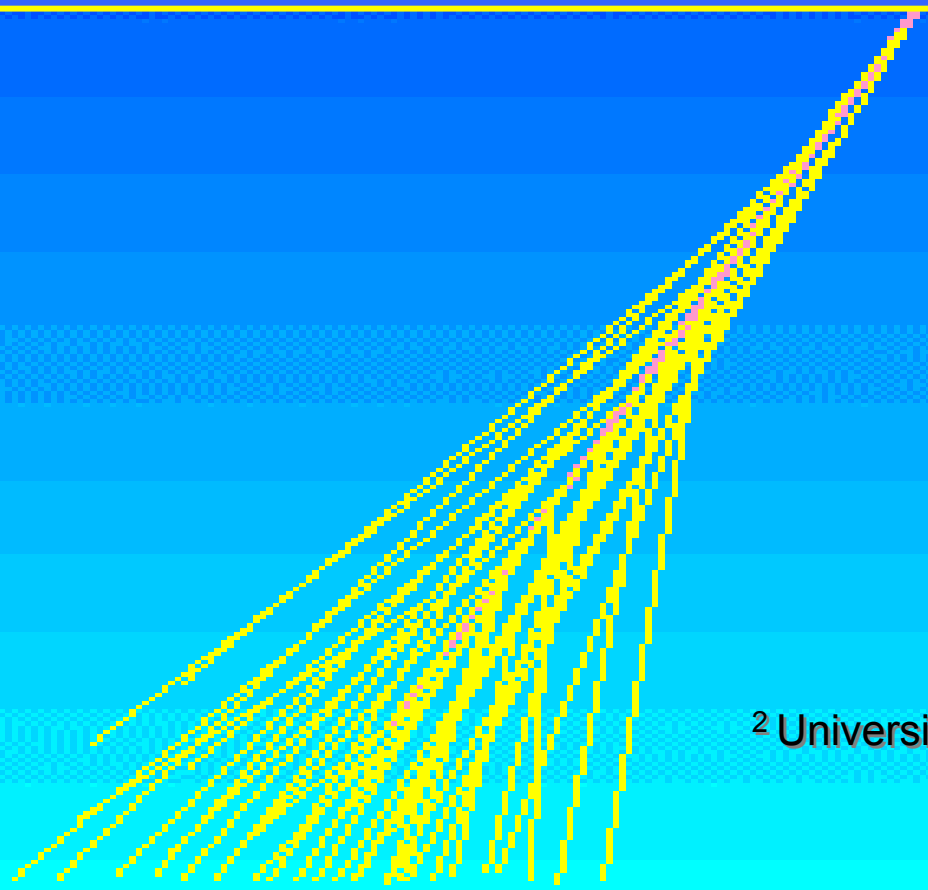
Muon production in extensive air showers and its relation to accelerator measurements



Christine Meurer[1]
Johannes Blümer[2]
Ralph Engel[1]
Andreas Haungs[1]
Markus Roth[2]

[1] Forschungszentrum Karlsruhe/Germany
[2] University of Karlsruhe/Germany

Outline

- Muons in extensive air showers (EAS)
- Relation of muons to hadronic interactions
- Comparison: EAS – fixed target experiment
- Investigation of phase space
- Existing accelerator measurements
- Conclusions

Motivation

HELMHOLTZ GEMEINSCHAFT

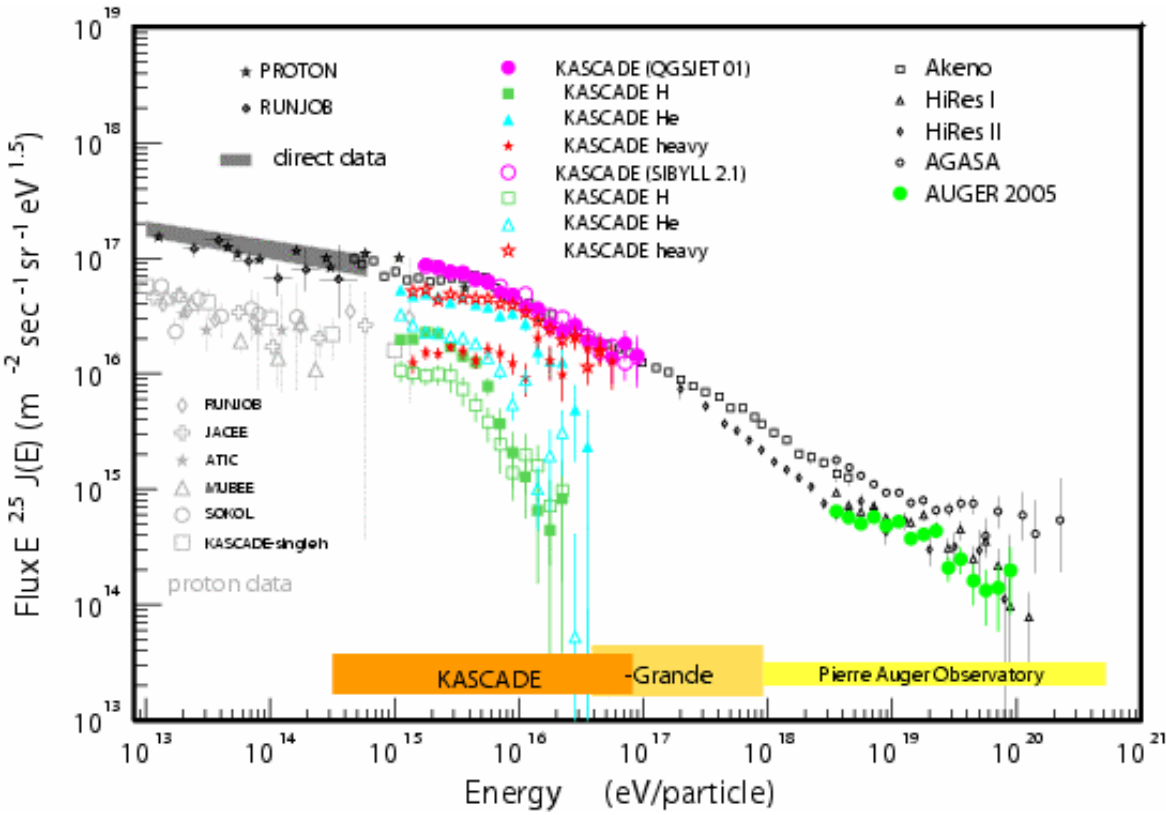
Interpretation of CR data relies heavily on MC simulations

MC uncertainties arise predominantly from hadronic interaction models

Muons are one of the main ingredients to infer E, A

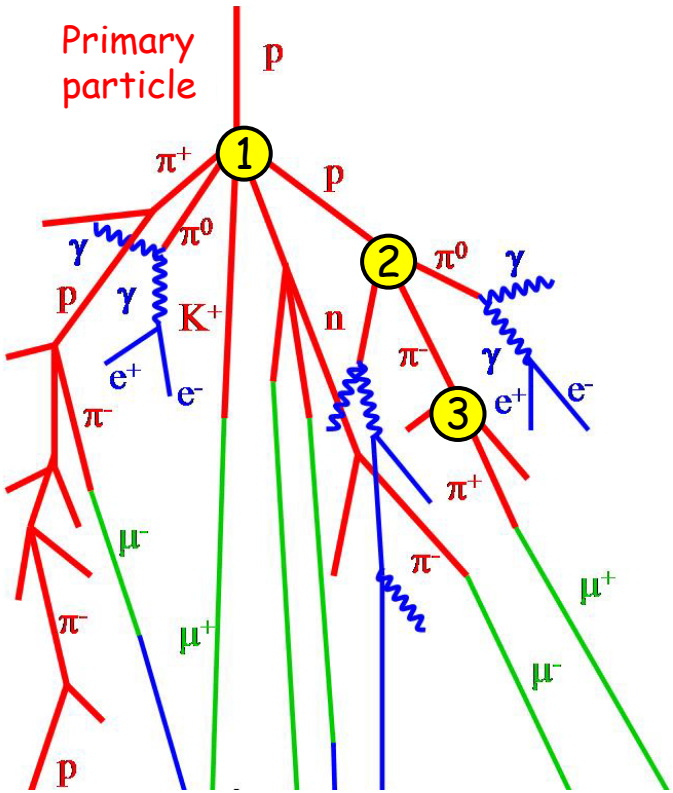
Muon component is very sensitive to hadronic interactions

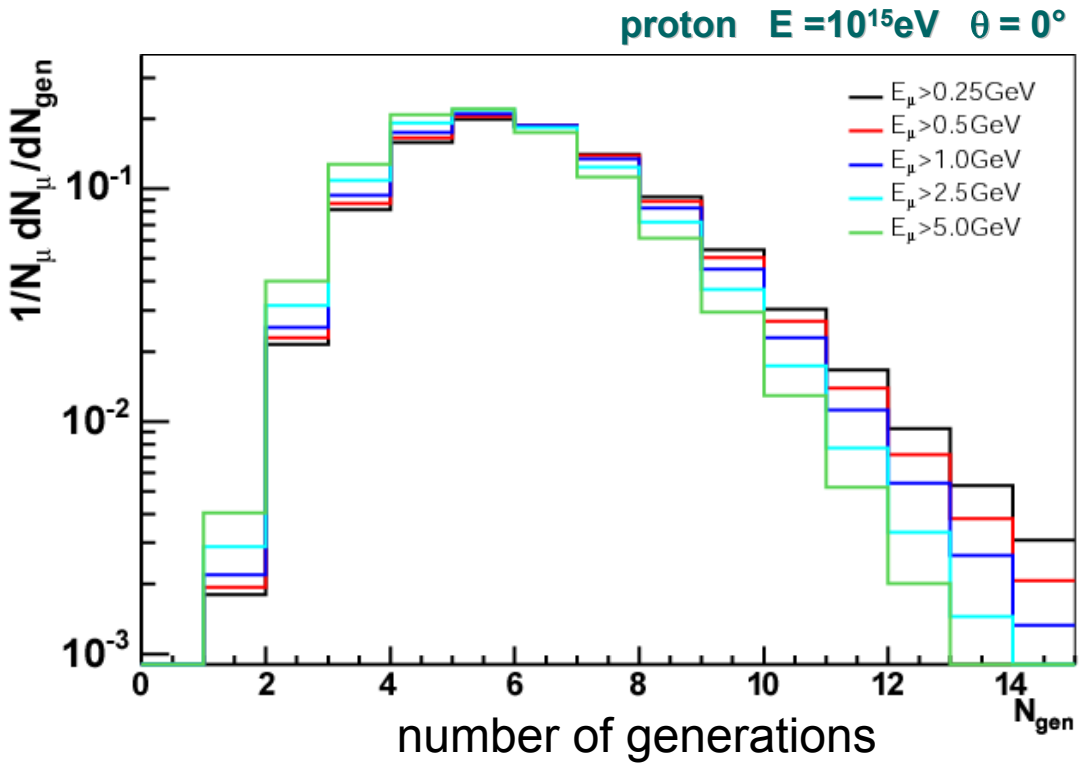
(see T. Pierog's talk)



Which hadronic interactions are of major importance for muon production?

Muon production in EAS

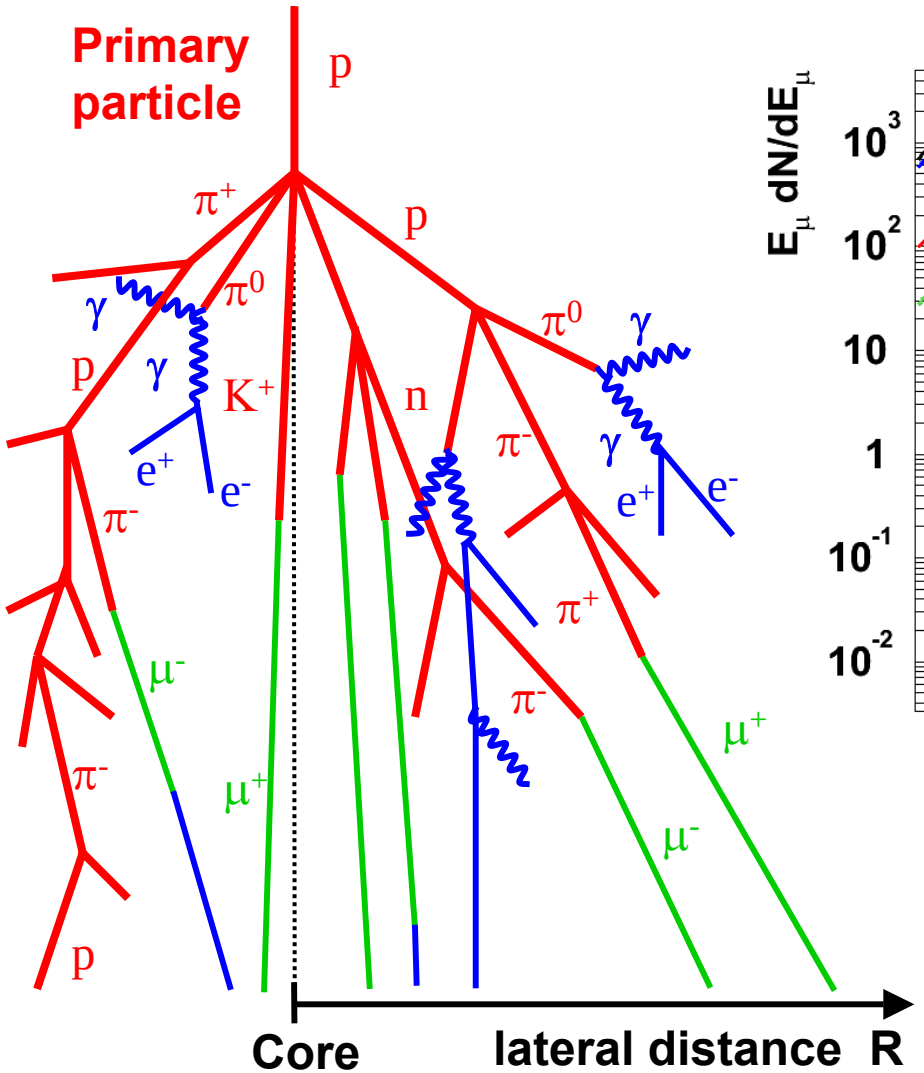


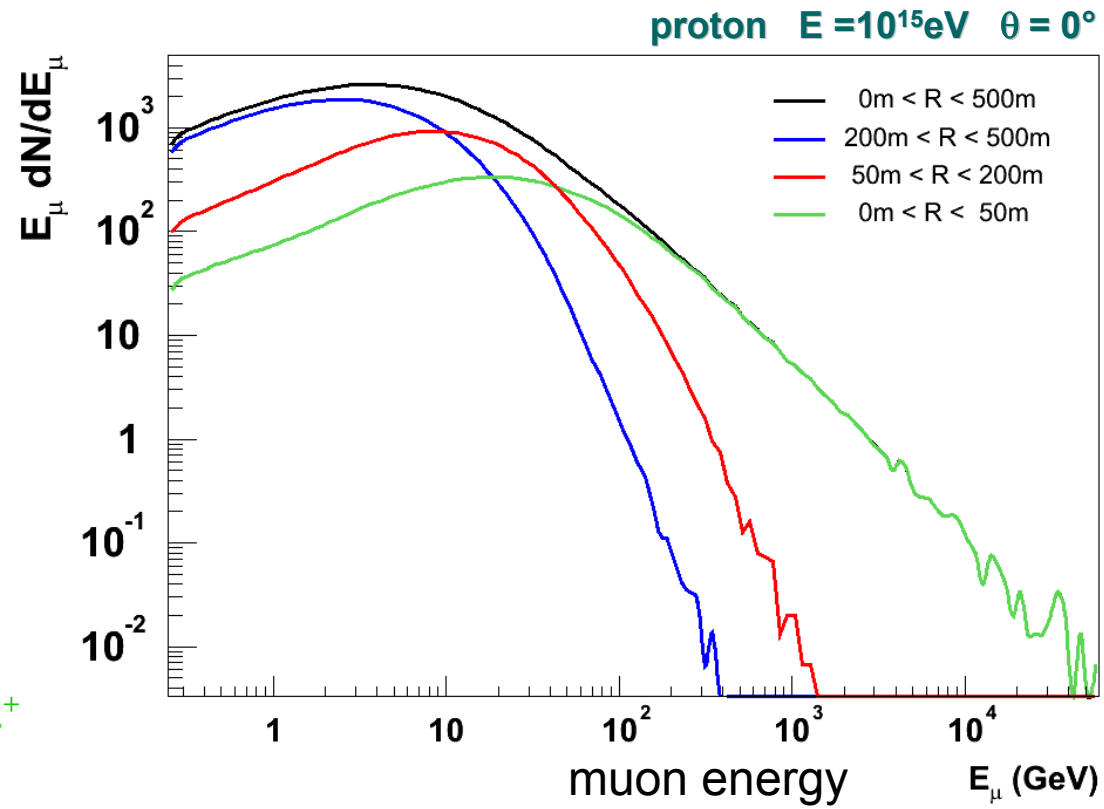


- On average 6 interactions before muon production
- Number of generations increases with smaller muon energy threshold

CORSIKA simulations:
- QGSJet 01
- GHEISHA

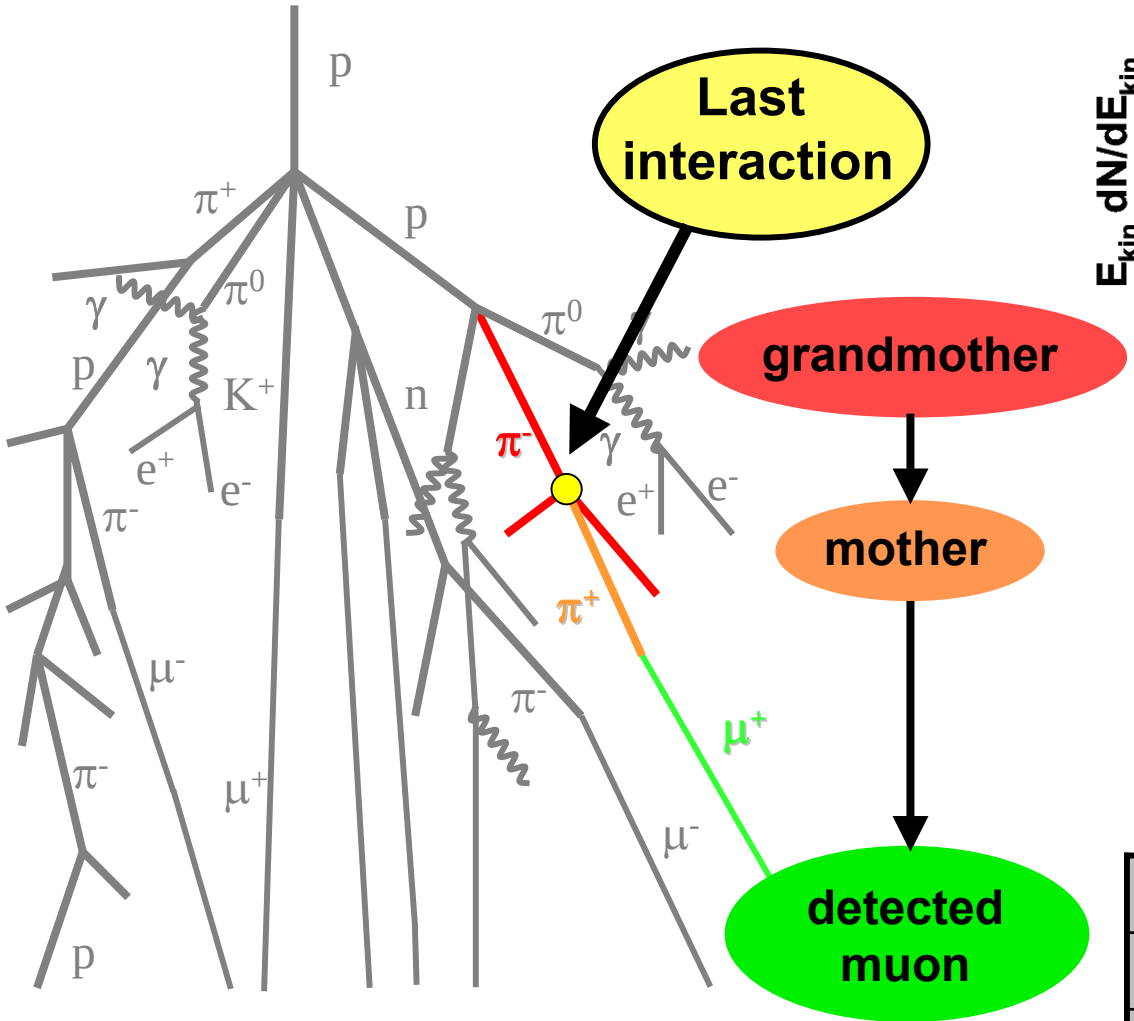
Muon energy on ground

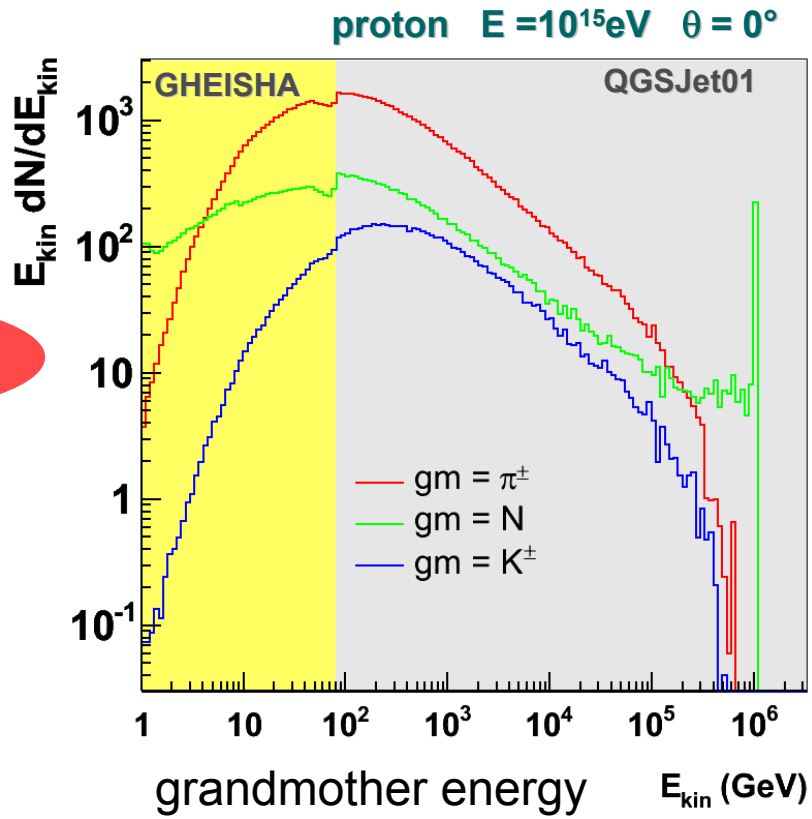




$\langle E_\mu \rangle$ smaller for larger distances

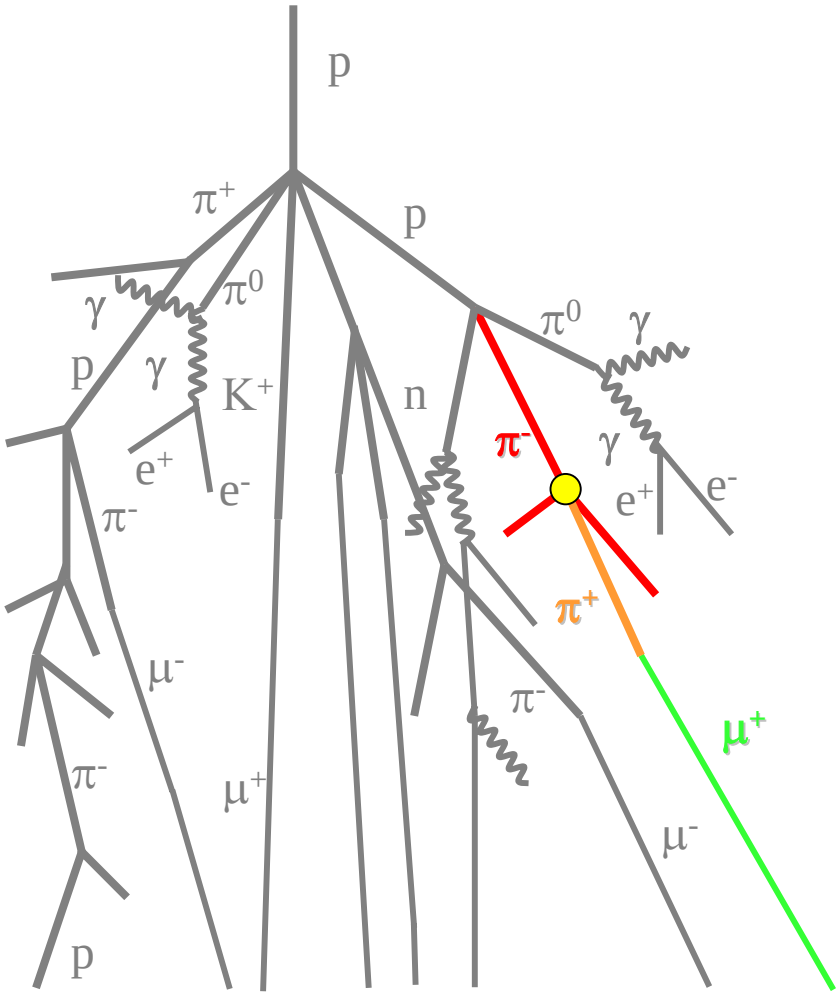
Last hadronic interaction



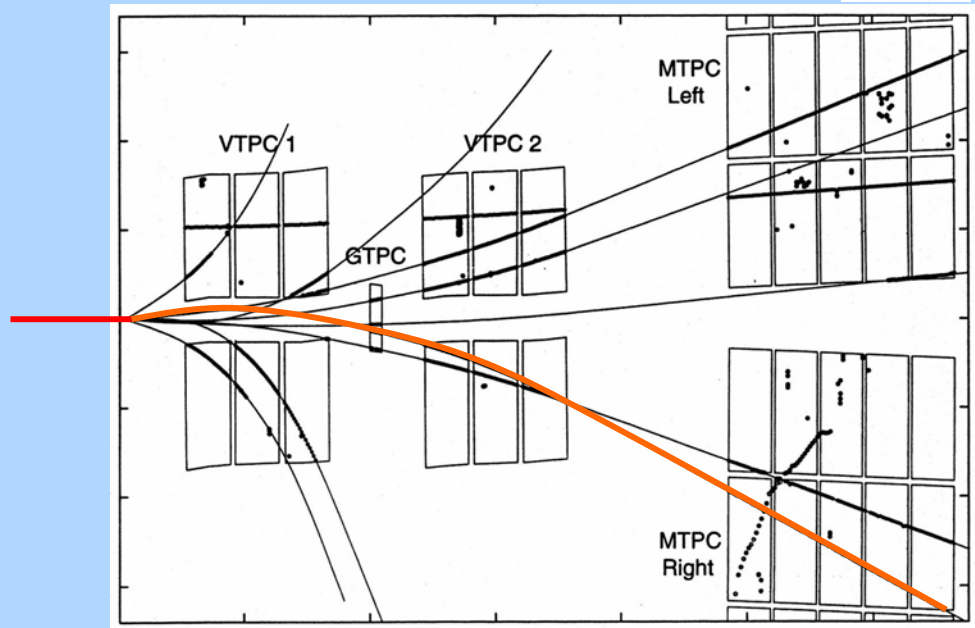


	grandmother	mother
pion	72.3%	89.2%
nucleon	20.9%	-
kaon	6.5%	10.5%

EAS vs fixed target experiment



p+C @ 158GeV



Grandmother particle = beam particle

Mother particle = secondary particle

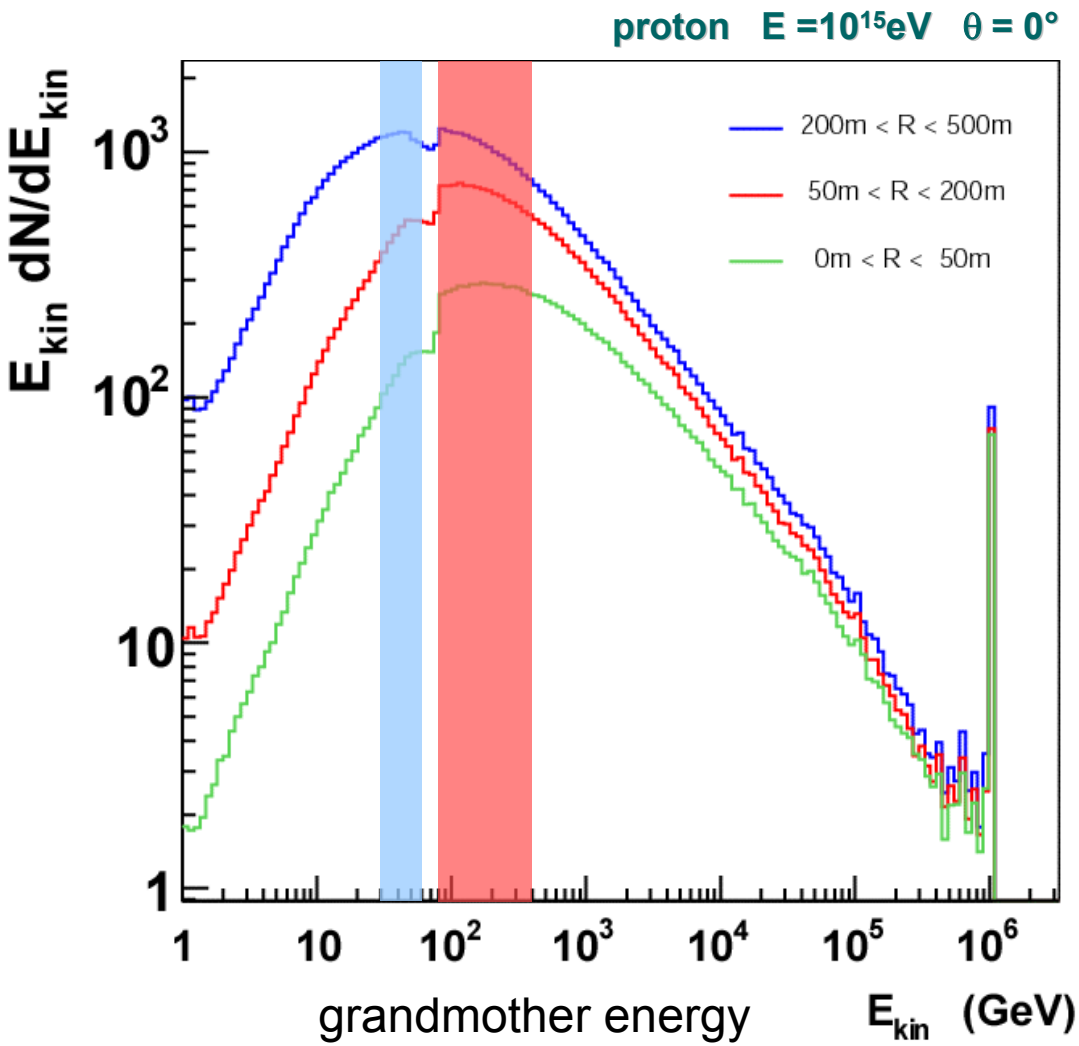
- **+ Several targets**
- **+ Forward direction accessible**
- **+ Relevant energy range: 10-400 GeV**

Selection of lateral range and energy

HELMHOLTZ GEMEINSCHAFT

Energy of grandmother particle $\langle E_{kin} \rangle$ smaller for larger distances

Experiment	KASCADE	Grande
R(m)	50-200	200-500
Energy range (GeV)	80-400	30-60
$\langle E_{kin} \rangle$ (GeV)	160	40

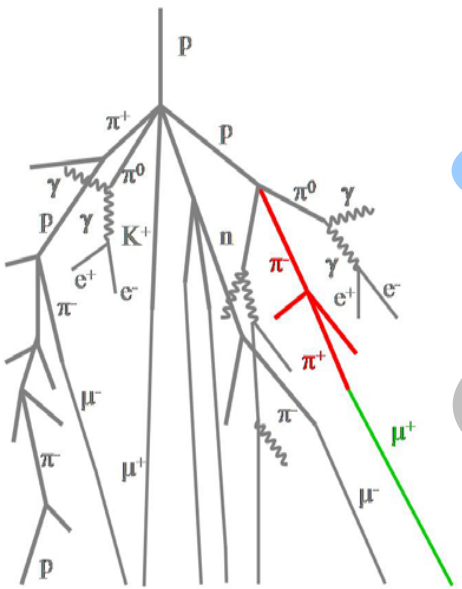


Expected differences in phase space

HELMHOLTZ GEMEINSCHAFT

EAS simulation:
CORSIKA
$E_{grandmother}$=80-400GeV

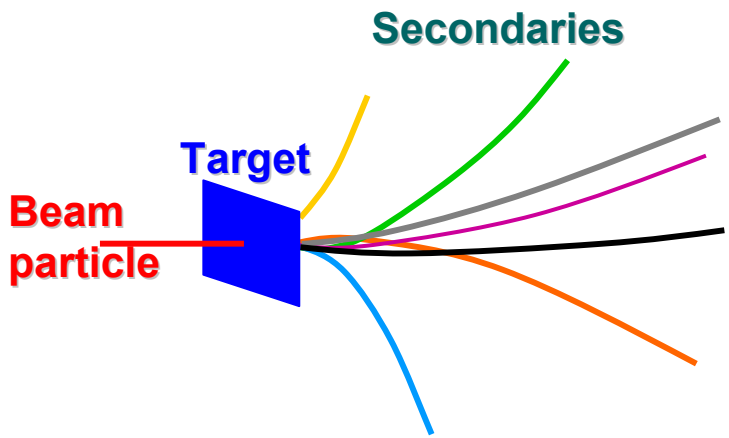
Simulation of single collisions with QGSJET:
p+air, p+C, E_{beam}=160GeV



Interplay between

Pion-/Kaon decay

Interaction with air nuclei



Particle	Energy (P_{decay} ~ $P_{interaction}$)
Pion	130 GeV
Kaon	600GeV

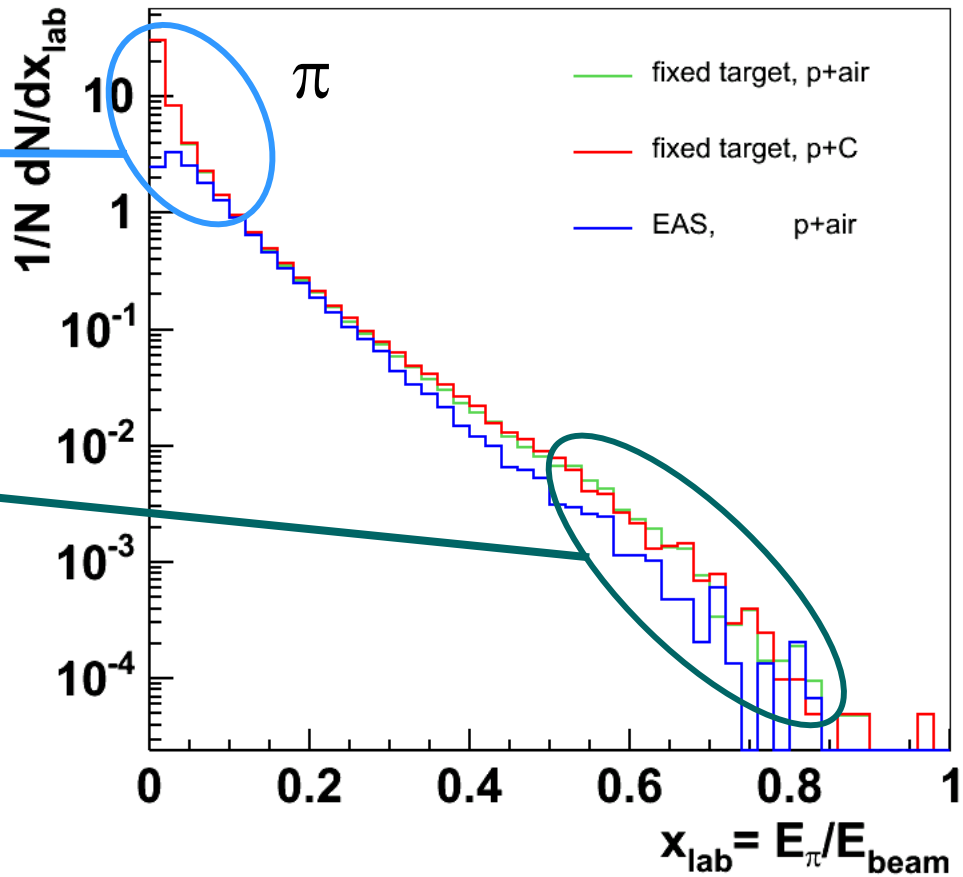
Fixed target: secondary particles (pions, kaons) measured directly

x_{lab} of secondary pions

KASCADE range: 50-200m
Nuclons (~160GeV) + Air

Energy loss/ muon decay: muons not detected

No pion decay, but further interactions

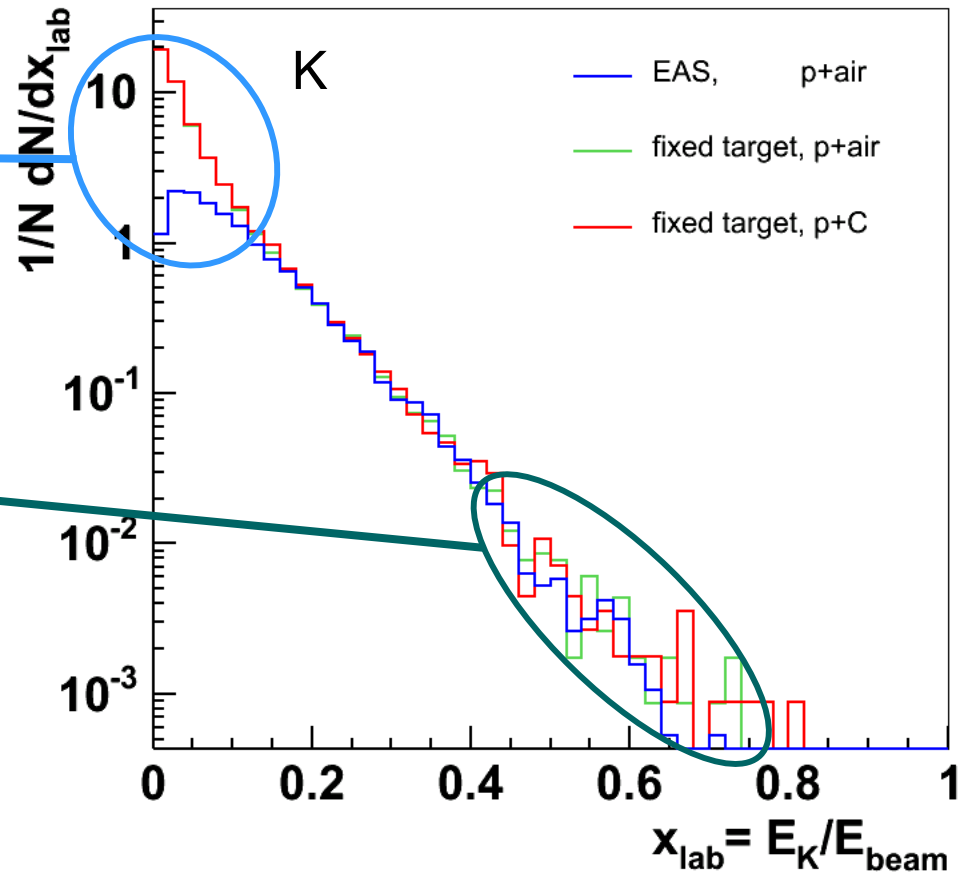


x_{lab} of secondary kaons

KASCADE range: 50-200m
Nucleons (~160GeV) + Air

Energy loss/ muon decay: muons not detected

No significant differences because of further interactions → decay energy of kaons higher than for pions



Rapidity of pions

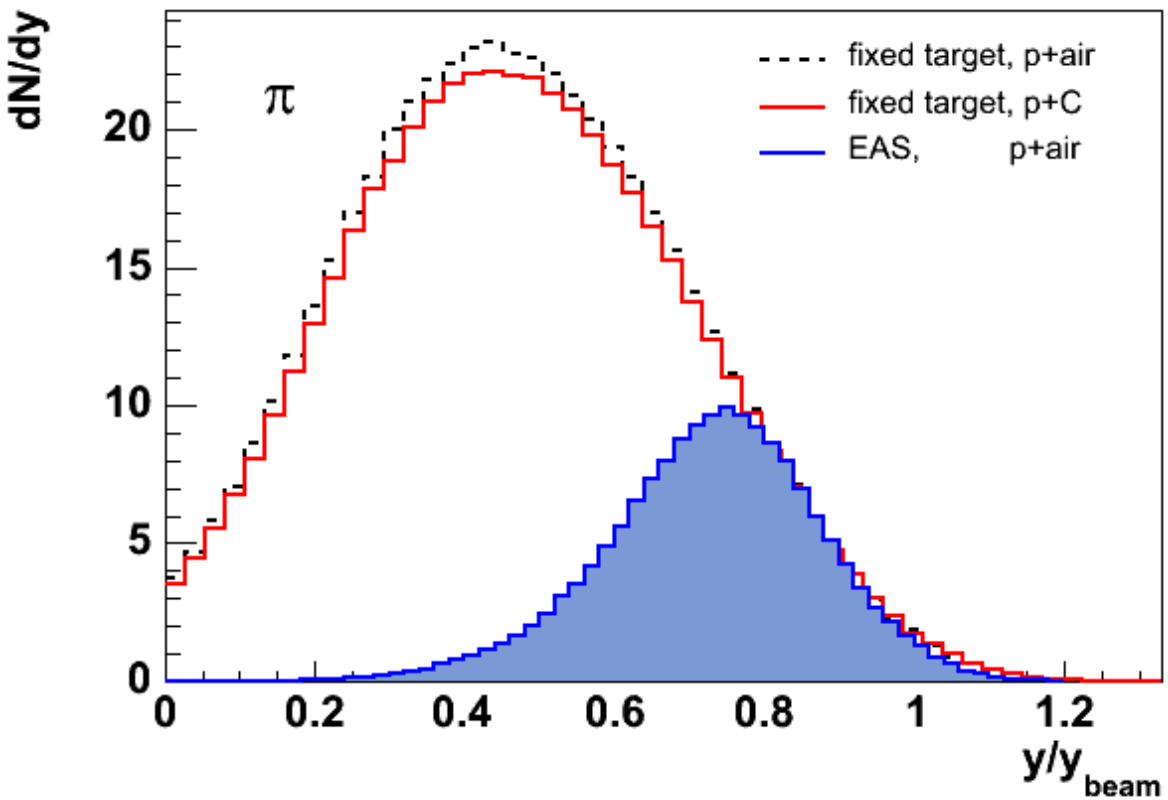
KASCADE range: 50-200m
Nucleons (~160GeV) + Air

Rapidity:

$$y = \ln\left(\frac{E + p_z}{m_\perp}\right)$$

Interesting range:
$0.3 < y/y_{beam} < 1.1$

Forward hemisphere dominating

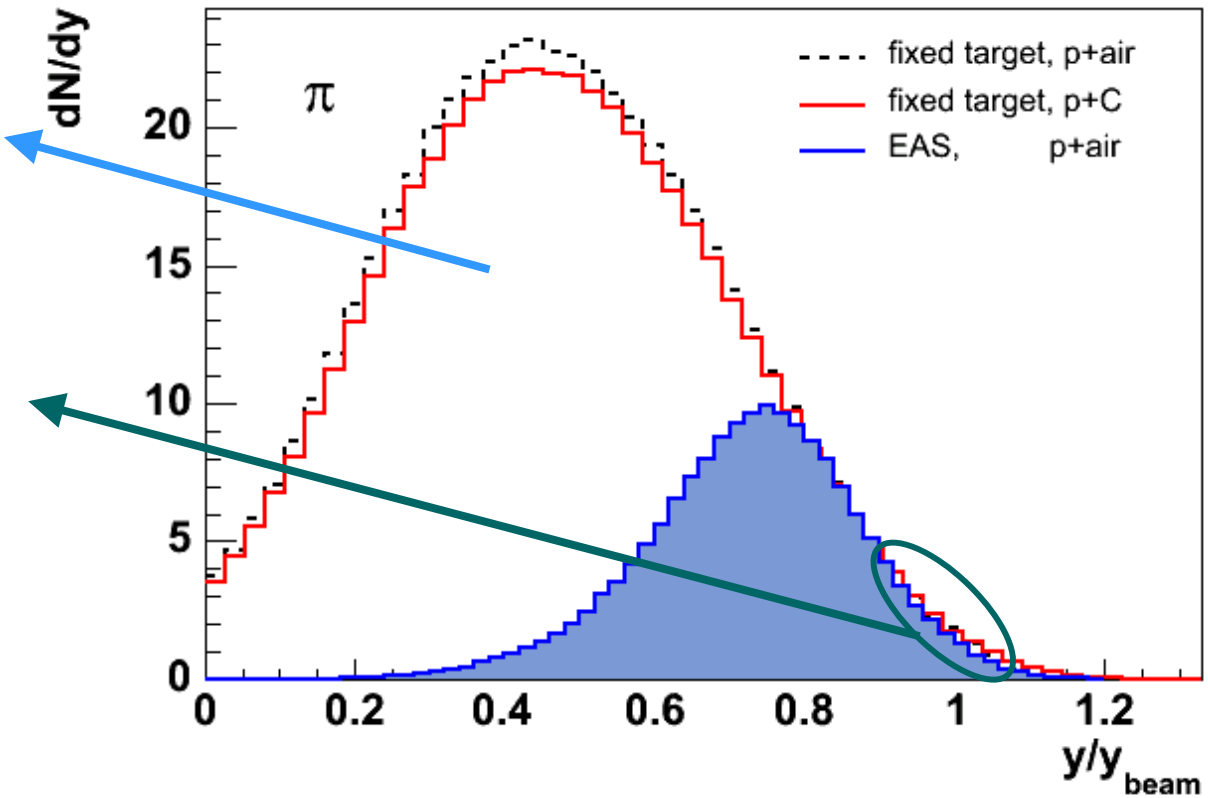


Rapidity of pions

KASCADE range: 50-200m
Nucleons (~160GeV) + Air

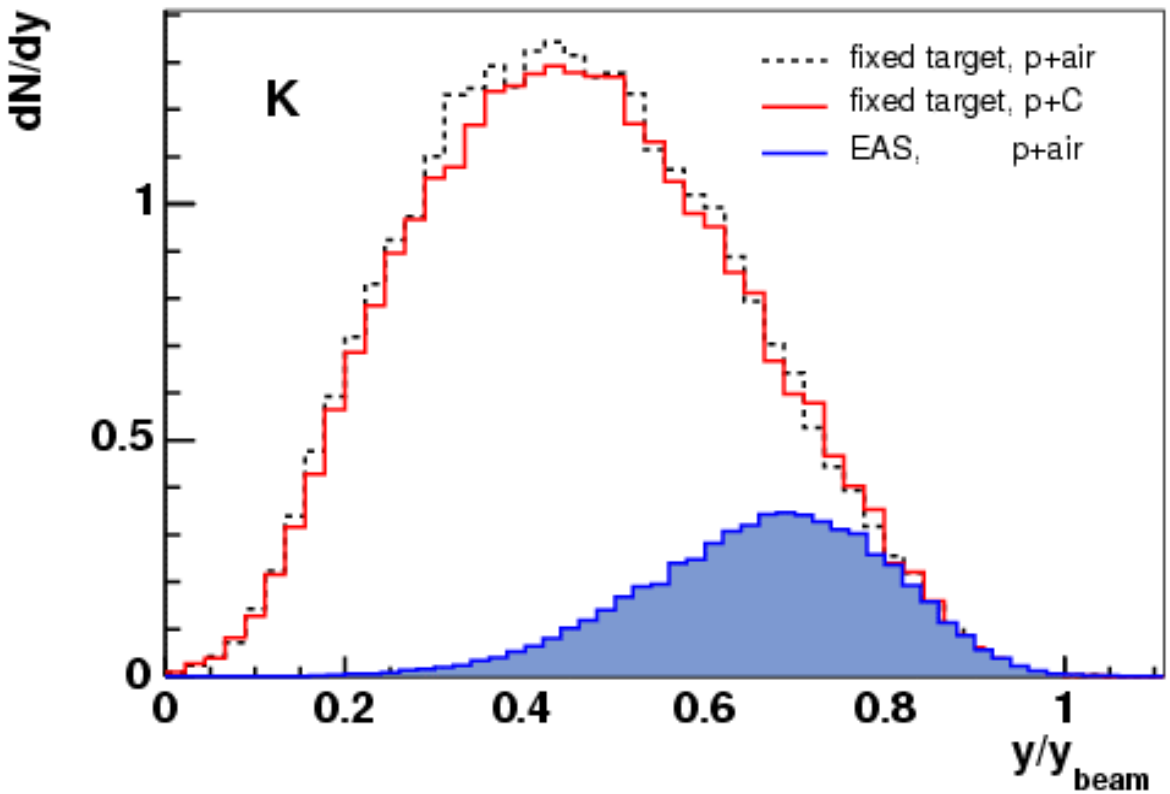
Energy loss/ muon decay: muons not detected

No pion decay, but further interactions



Rapidity of kaons

KASCADE range: 50-200m
Nucleons (~160GeV) + Air



Interesting range:
$0.3 < y/y_{beam} < 1.1$

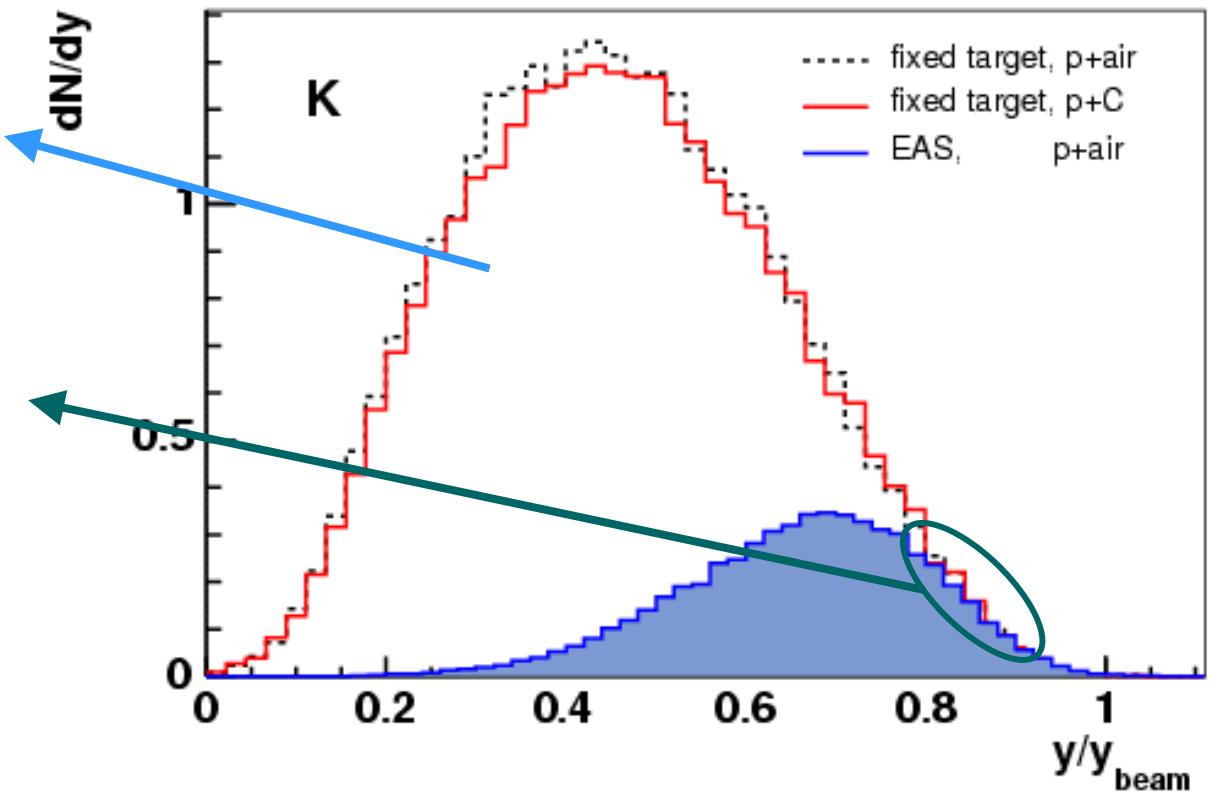
Forward hemisphere dominating

Rapidity of kaons

KASCADE range: 50-200m
Nucleons (~160GeV) + Air

Energy loss/ muon decay: muons not detected

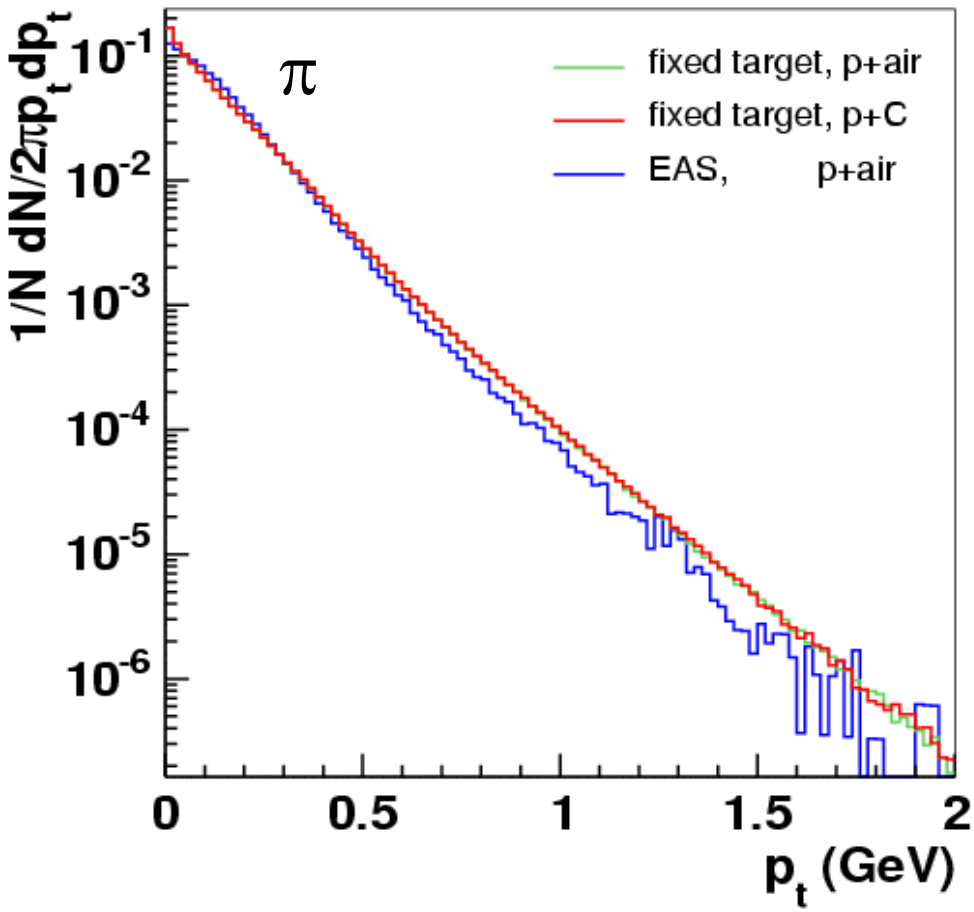
No significant differences because of further interactions → decay energy of kaons higher than for pions



Transverse momentum of pions

KASCADE range: 50-200m
Nucleons (~160GeV) + Air

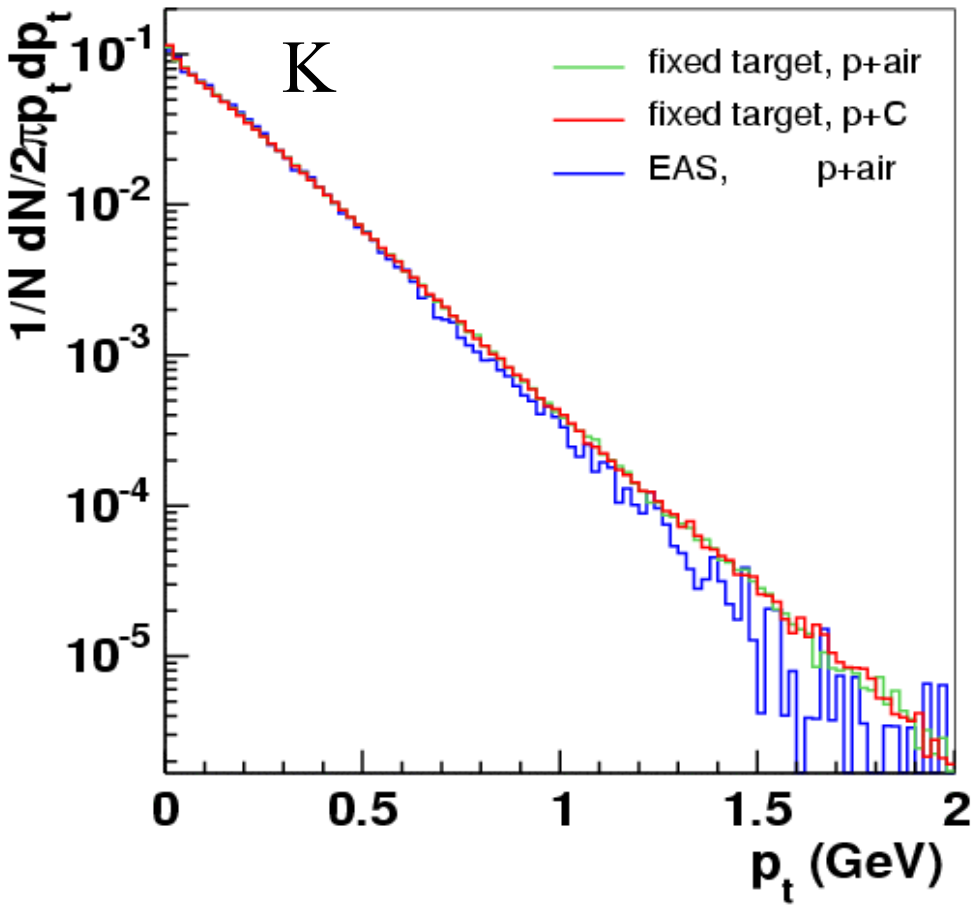
p_t distribution in EAS similar to p_t distribution in fixed target simulation.
→ Low transverse momenta of interest



Transverse momentum of kaons

KASCADE range: 50-200m
Nucleons (~160GeV) + Air

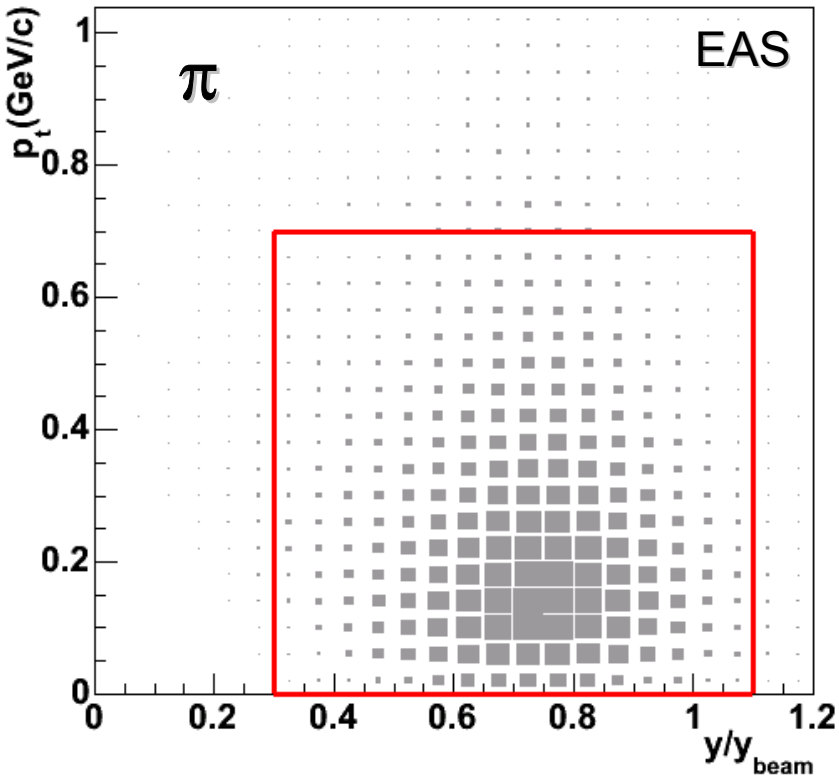
p_t distribution in EAS similar to p_t distribution in fixed target simulation.
→ Low transverse momenta of interest

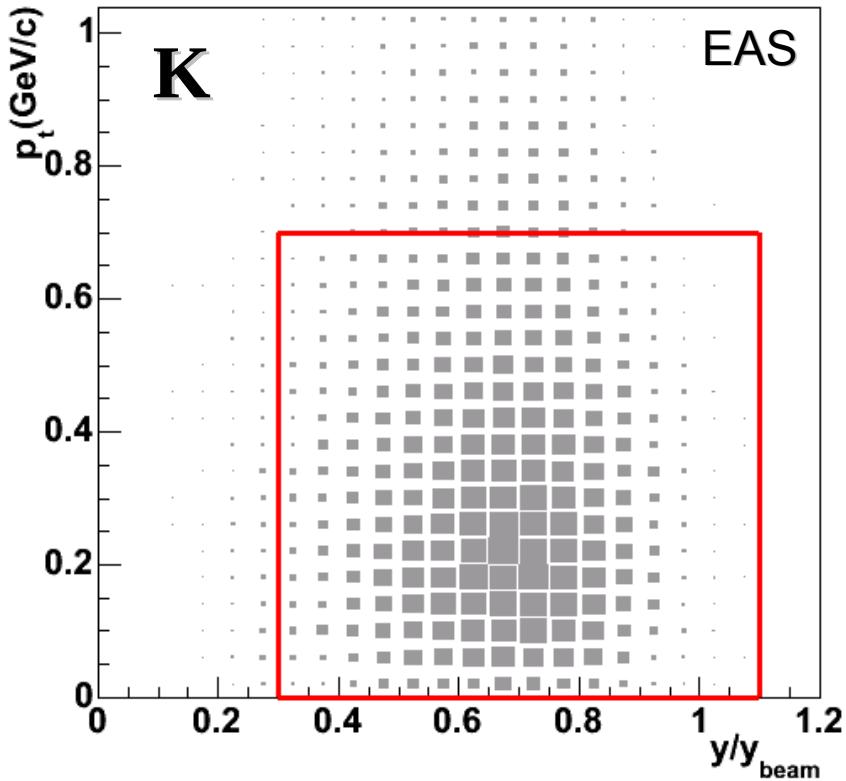


Phase space: E~160GeV

HELMHOLTZ GEMEINSCHAFT

KASCADE range: 50-200m; Nucleons (~160GeV) + Air



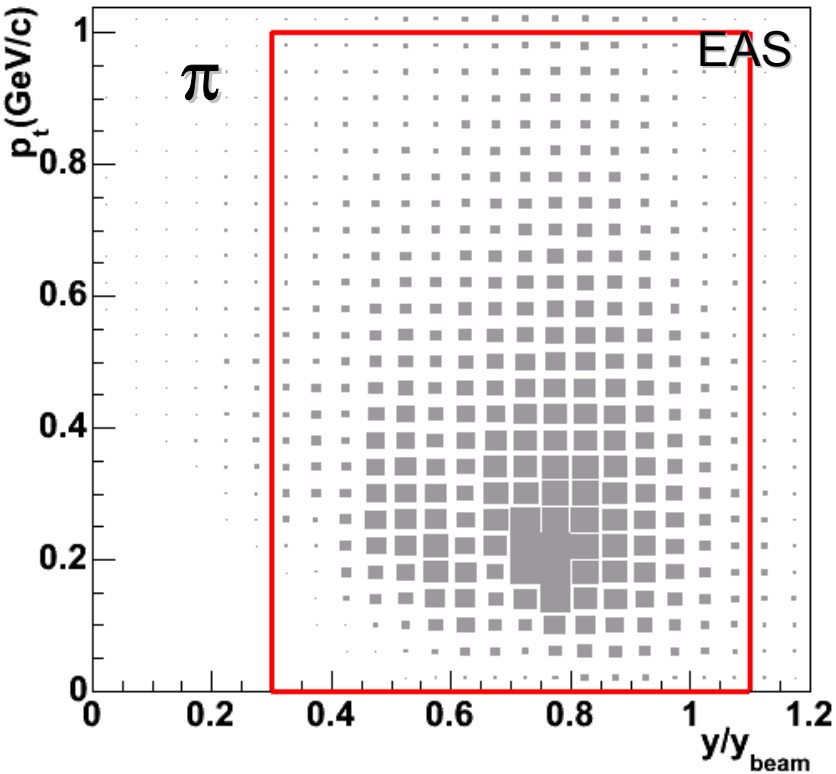


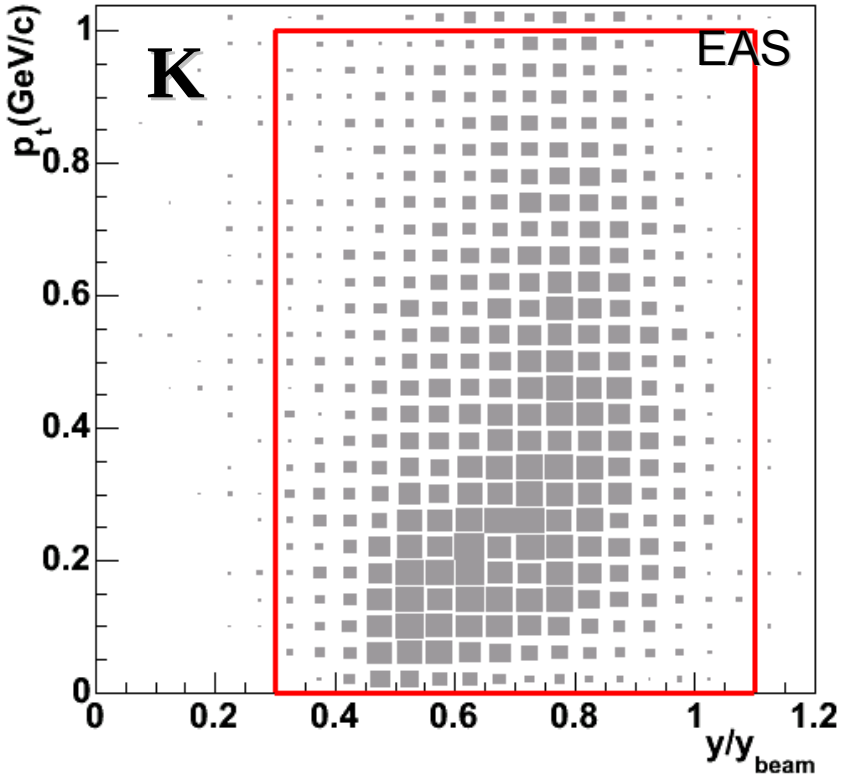
y/y_{beam}	0.3-1.1
p_t(GeV)	0.0-0.7

Phase space: E~ 40GeV

HELMHOLTZ GEMEINSCHAFT

KASCADE-Grande range: 200-500m; Nucleons (~40GeV) + Air



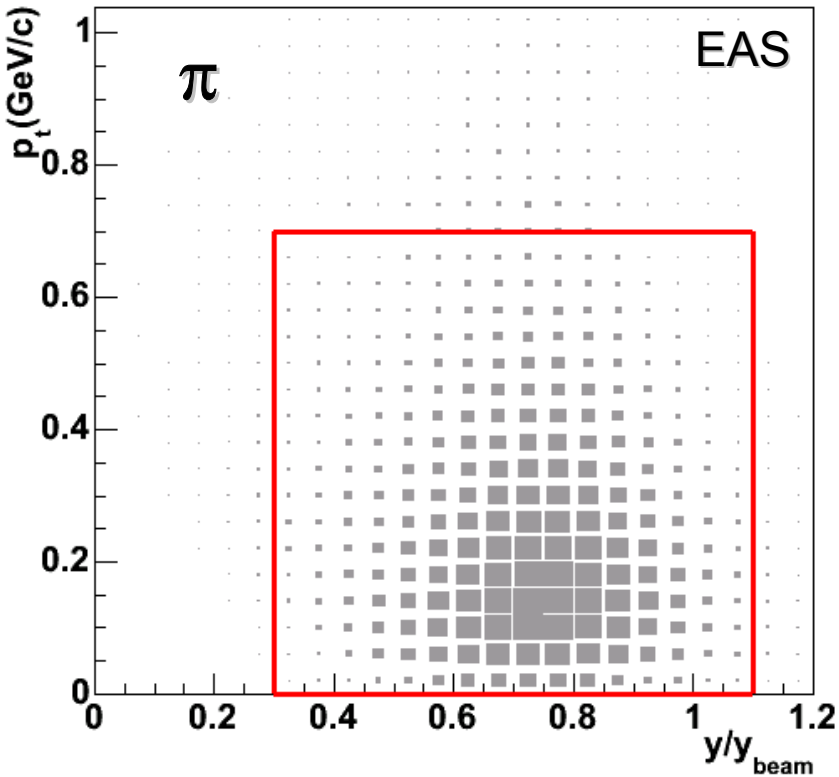


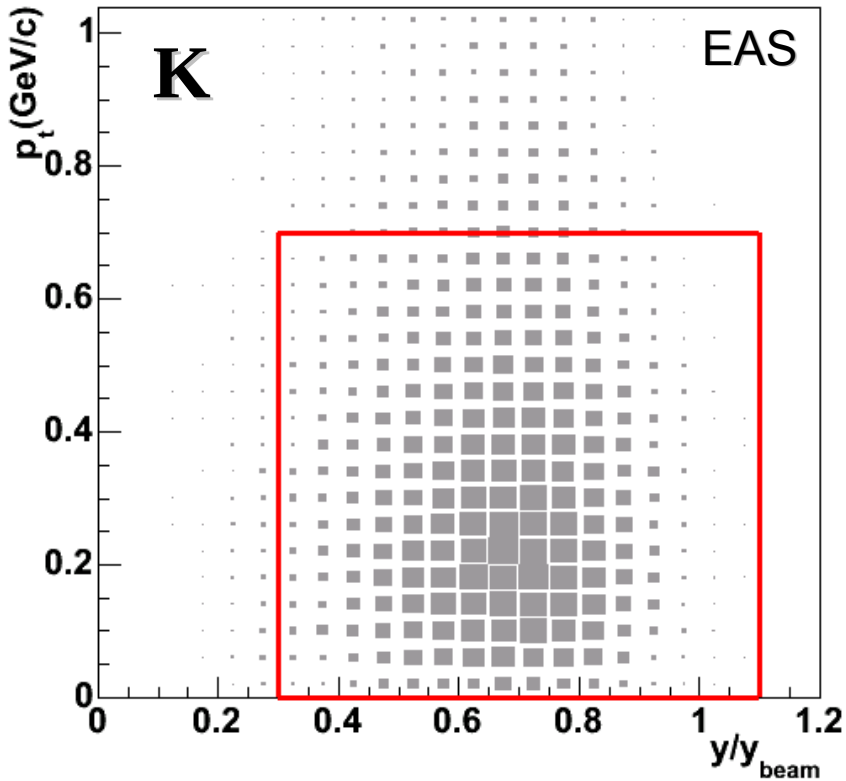
y/y_{beam}	0.3-1.1
p_t(GeV)	0.0-1.0

Vertical shower: 0°

HELMHOLTZ GEMEINSCHAFT

KASCADE range: 50-200m; Nucleons (~160GeV) + Air



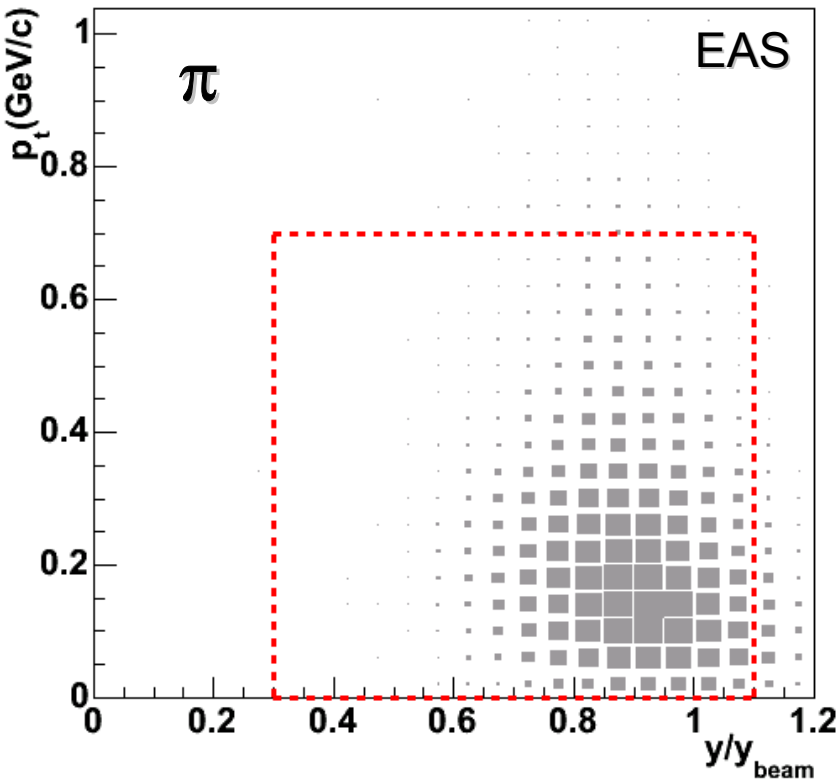


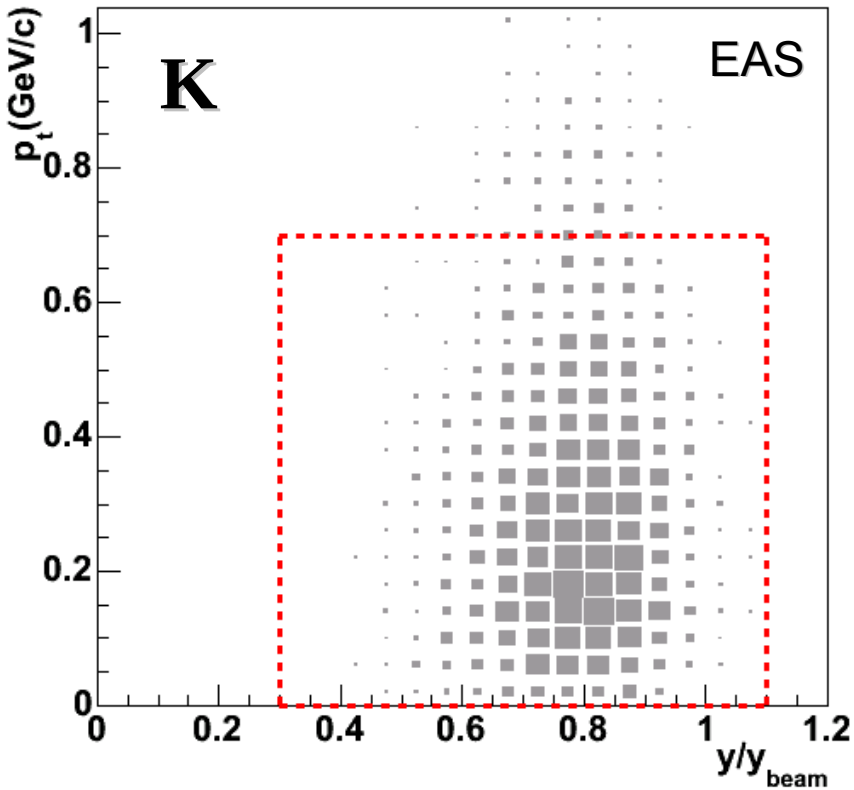
y/y_{beam}	0.3-1.1
p_t(GeV)	0.0-0.7

Inclined shower: 60°

HELMHOLTZ GEMEINSCHAFT

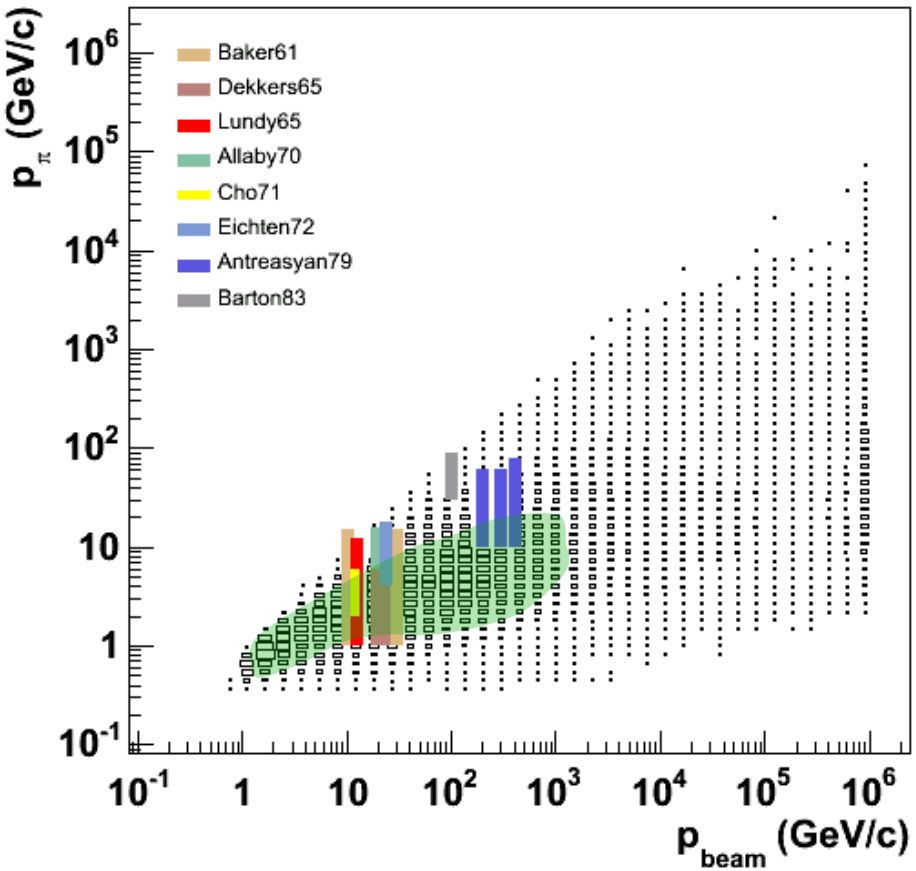
KASCADE range: 50-200m; Nucleons (~160GeV) + Air

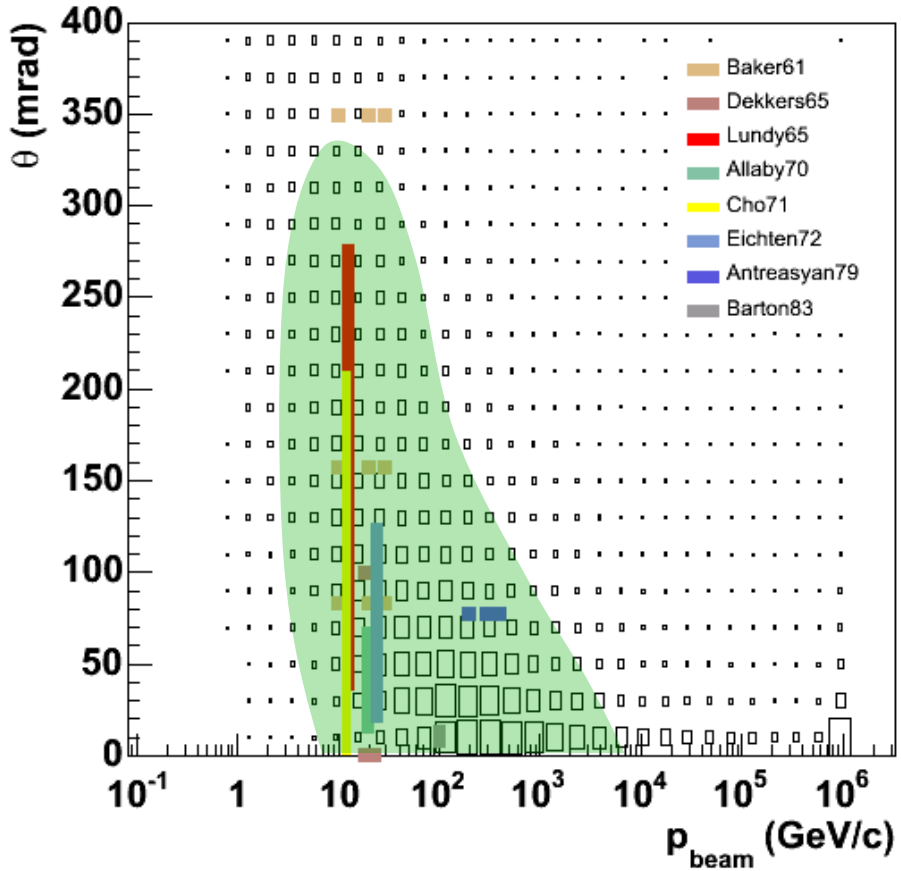




Forward hemisphere even more important for inclined showers

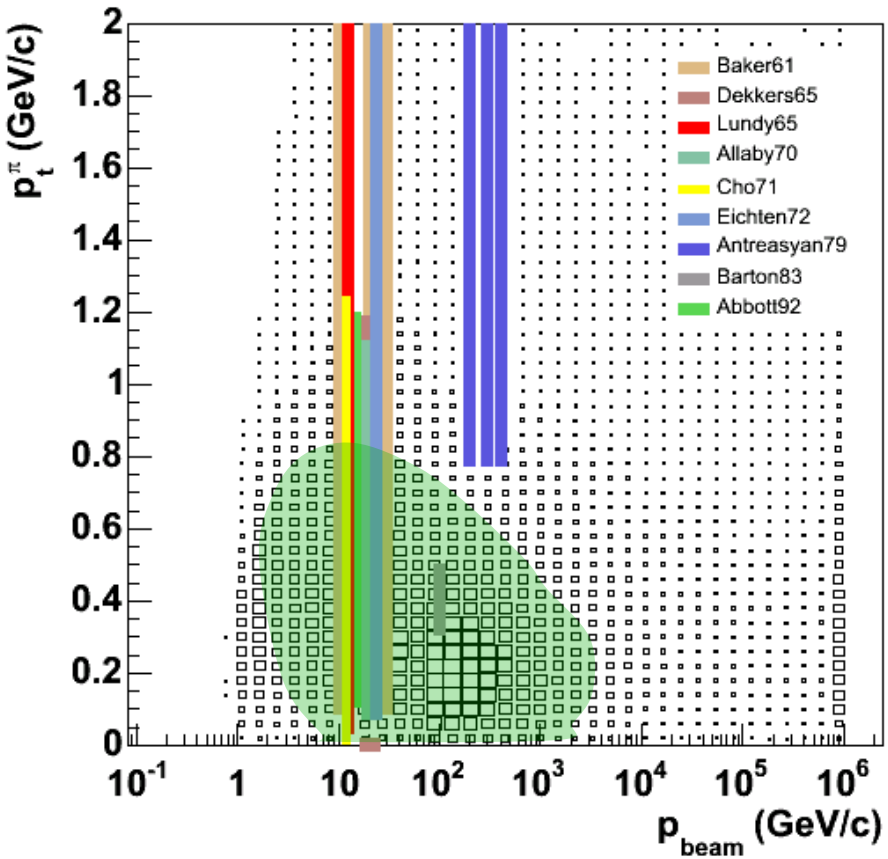
Existing accelerator data

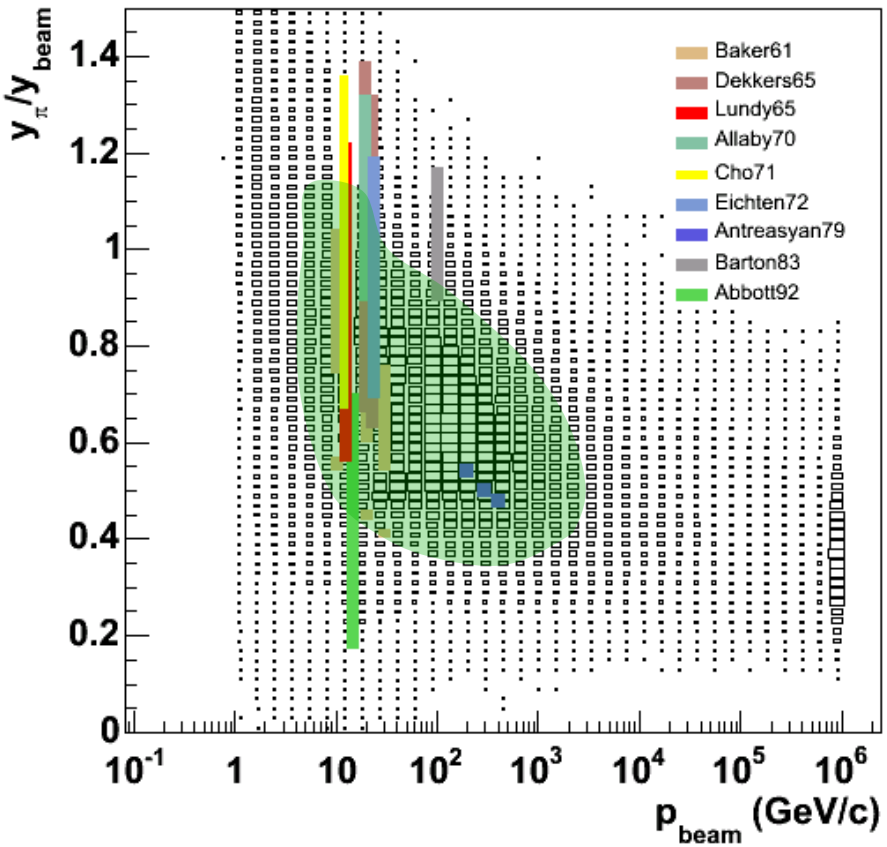




Data: p+Be → π+X and p+C → π+X
EAS: p+air → π+X

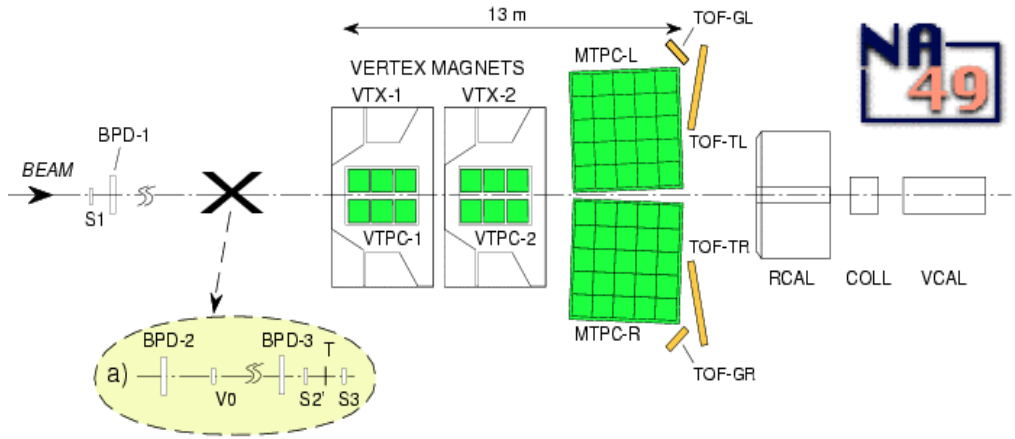
Conversion: p, θ → p_t, y

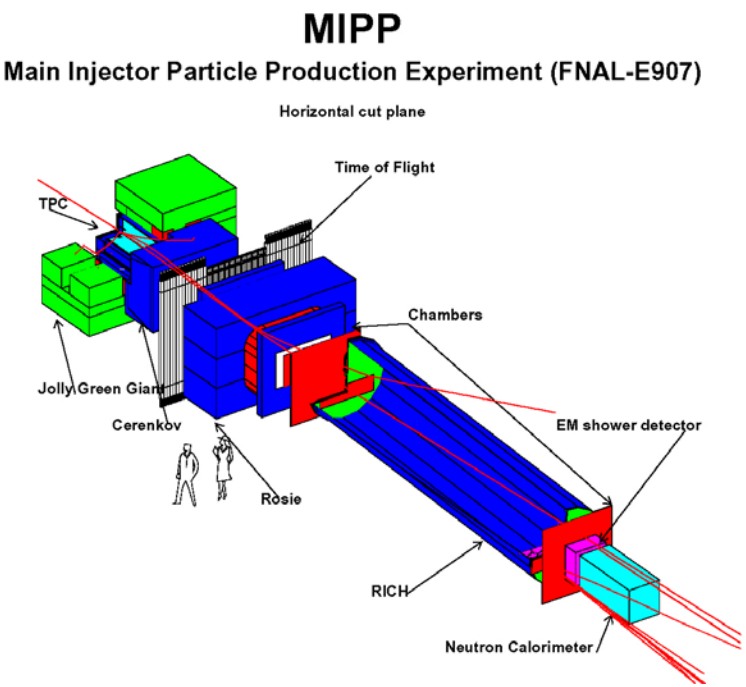


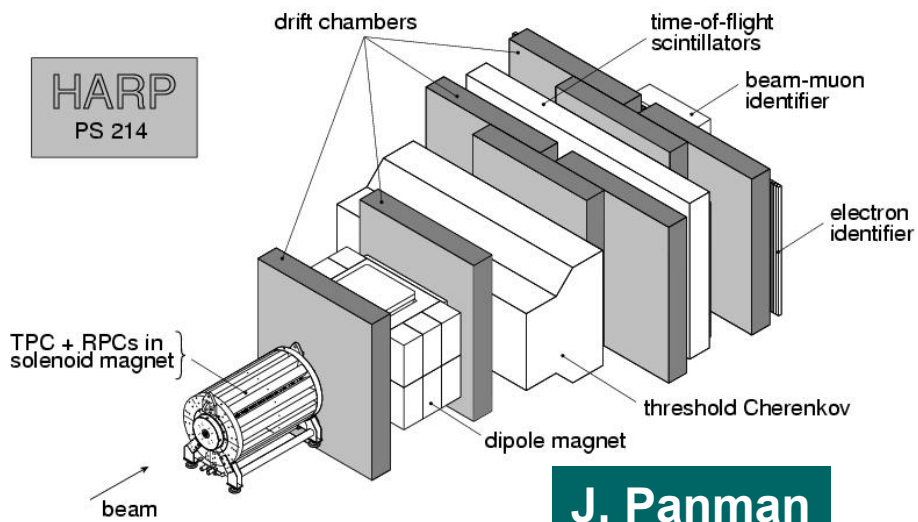


Needed measurements

$\langle E_{beam} \rangle$	10-1000 GeV
p_t	0.0-1.0 GeV
y/y_{beam}	0.3-1.1







J. Panman

Conclusions

- **Interpretation of CR data relies heavily on MC simulations**
- **Muons are main ingredients to infer E, A**
- **Similarity between hadron production in EAS and fixed target experiments**
- **Relevant hadronic interactions for muon production are in the**
  - **energy range: 10 – 1000 GeV**
  - **phase space region: low p_t and forward direction**
- **Only a few measurements available in phase space region important for EAS**
- **Region accessible by fixed target experiments like, for example, HARP, NA49 and MIPP**

References

[Baker61]	Phys. Rev. Lett. 7 (1961) 101	(AGS)
[Dekkers65]	Phys. Rev. B 137 (1965) 962	(CERN)
[Lundy65]	Phys. Rev. Lett. 14 (1965) 504	(ZGS)
[Allaby70]	CERN Yellow Report 70-12 (1970)	(CERN)
[Cho71]	Phys. Rev. D 4 (1971) 1967	(ZGS)
[Eichten72]	Nucl. Phys. B 44 (1972) 333	(CERN)
[Antreasyan79]	Phys. Rev. D 19 N3 (1979) 764	(Fermilab)
[Bartom83]	Phys. Rev. D 27 (1983) 2580	(Fermilab)
[Abbott92]	Phys. Rev. D 45 (1992) 3906	(AGS)