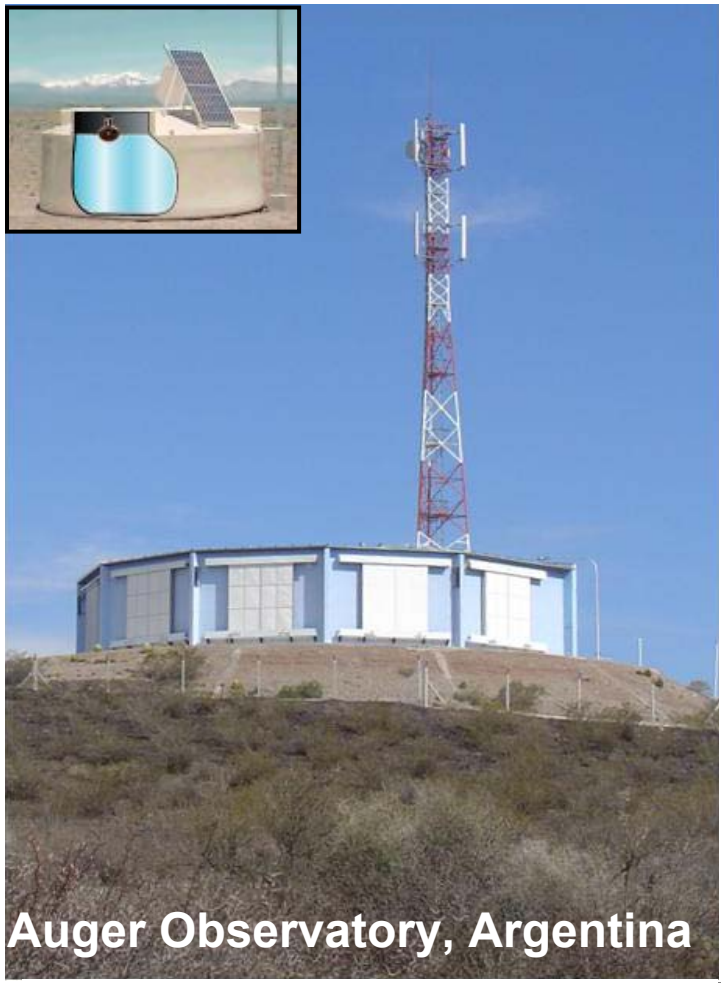
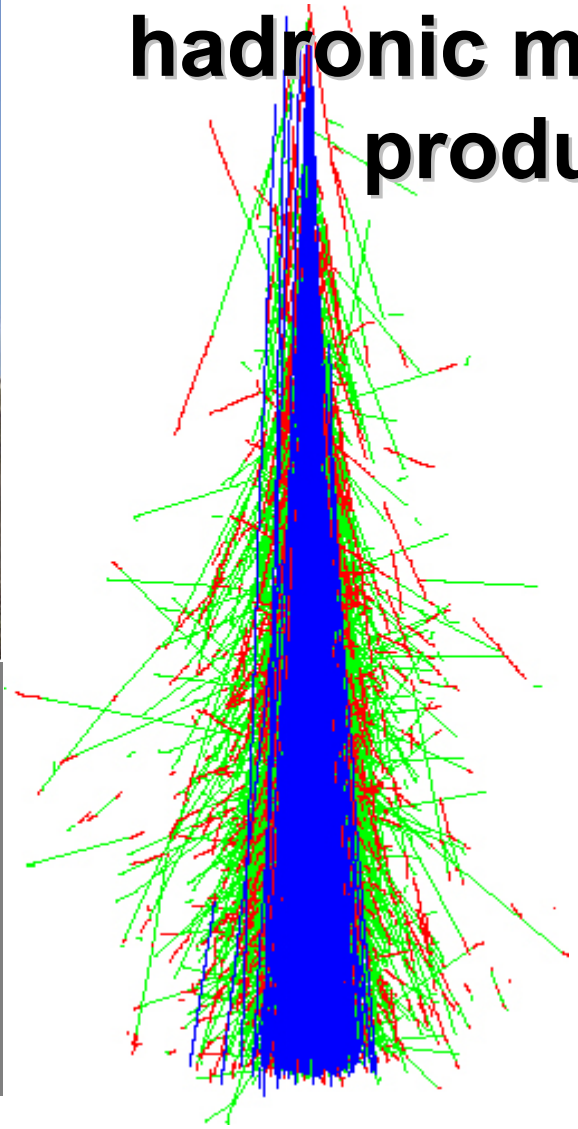
The muon component in extensive air showers and its relation to hadronic multiparticle production


Auger Observatory, Argentina

Christine Meurer
Johannes Blümer
Ralph Engel
Andreas Haungs
Markus Roth

and
the HARP Collaboration




HARP Detector, CERN

Outline

- Relation of muons in extensive air showers (EAS) to hadronic interactions
- Comparison: EAS – fixed target experiment
- Investigation of phase space
- Existing accelerator data
- New measurements: NA49 and HARP
- Conclusions and outlook

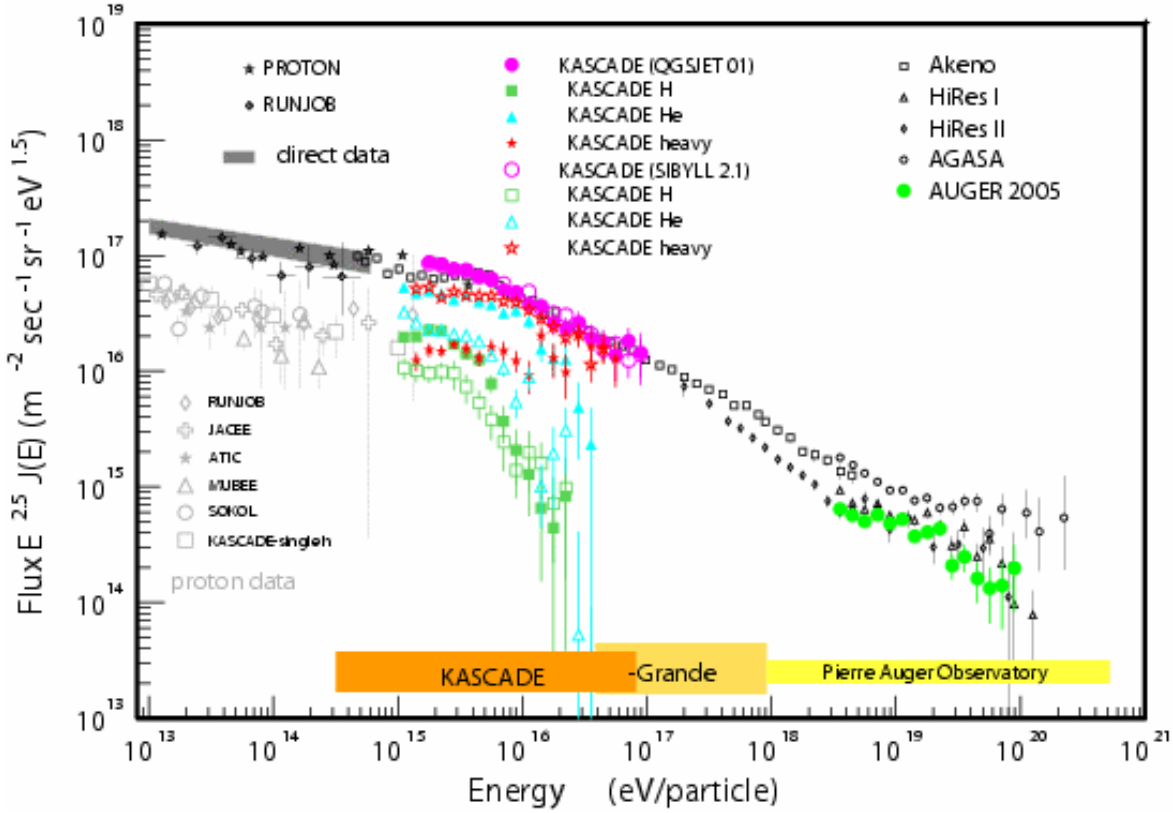
Motivation

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

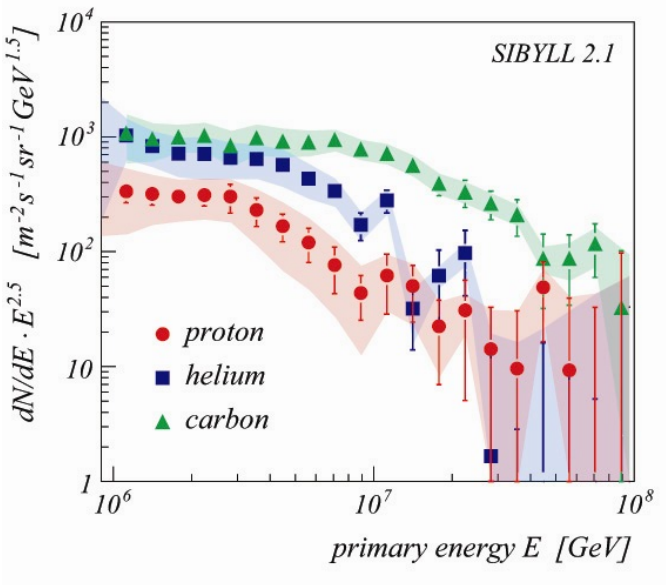
Muon component is very sensitive to hadronic interactions

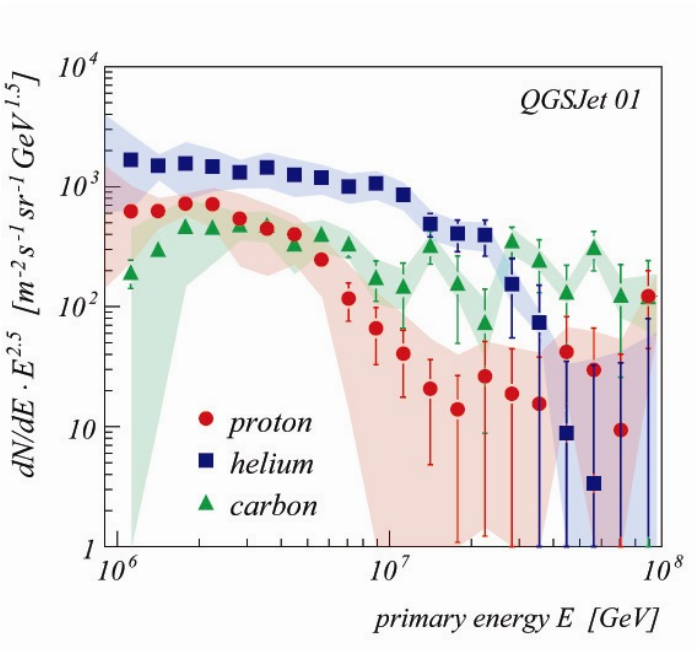


Which hadronic interactions are of major importance for muon production?

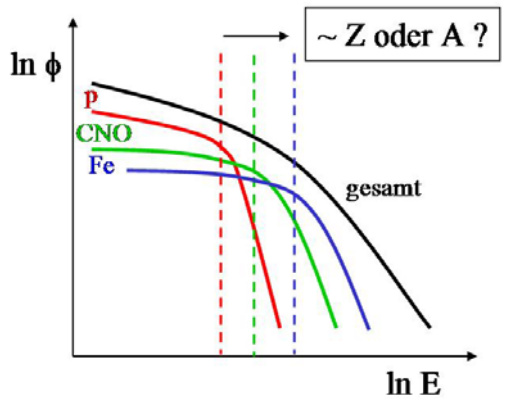
Composition at the knee

Differences mainly due to muon production

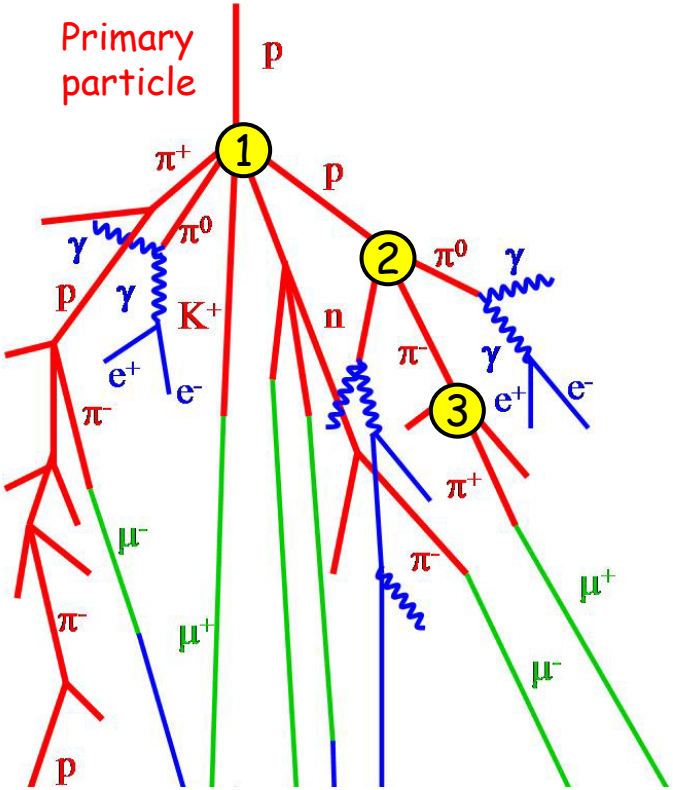


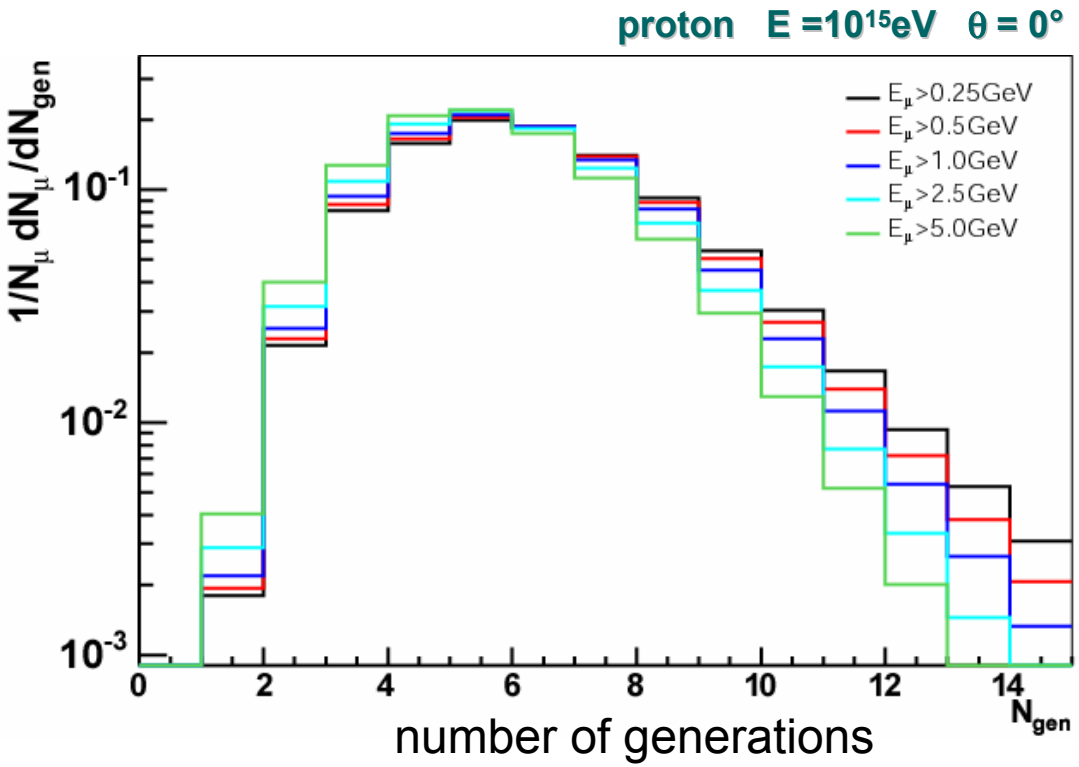


KASCADE
T. Antoni et al.
Astroparticle Physics



Muon production in EAS

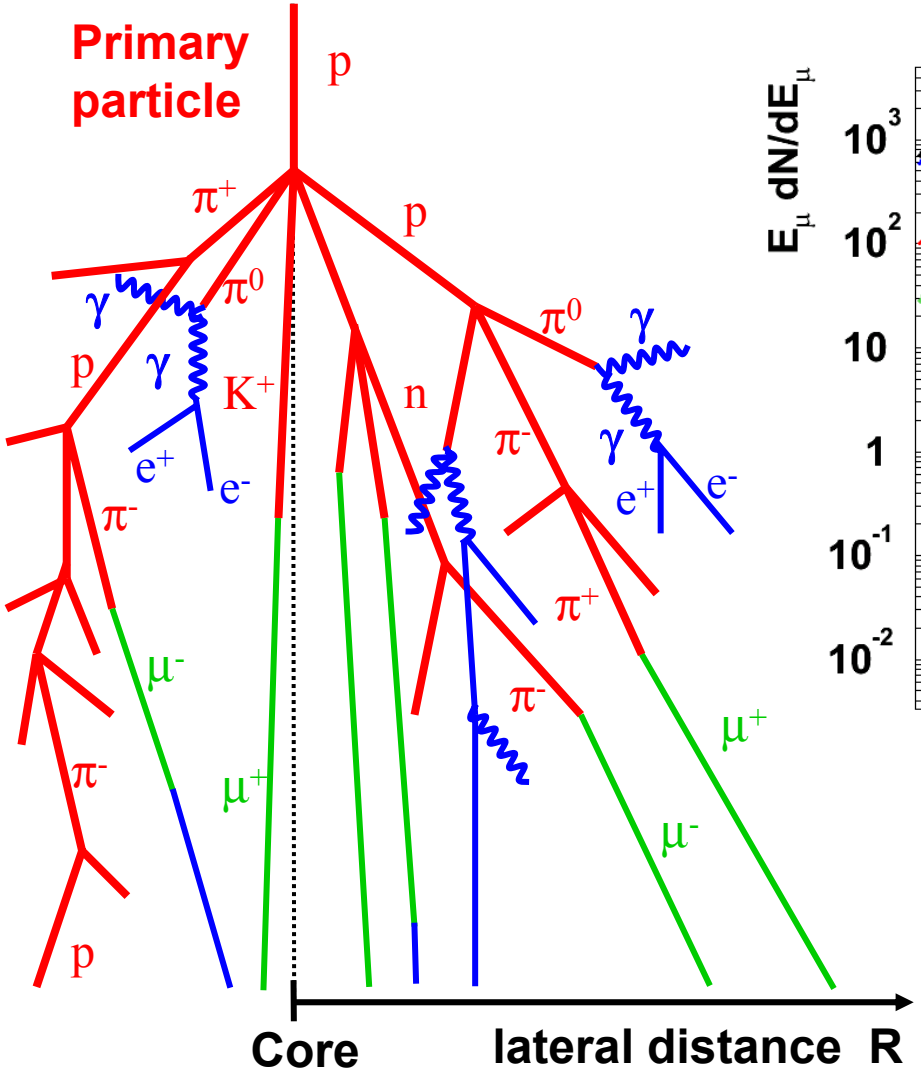


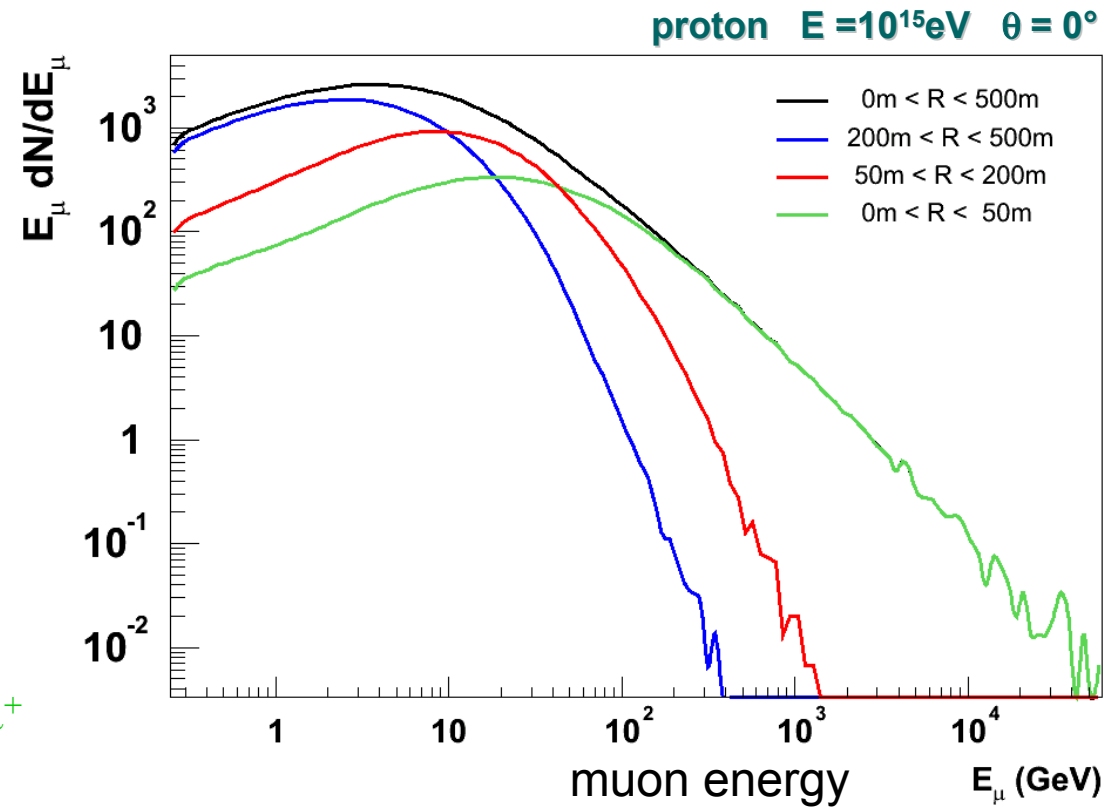


- **On average 6 interactions before muon production**
- **Number of generations increases with smaller muon energy threshold**

CORSIKA simulations:
- **QGSJET-01**
- **GHEISHA**

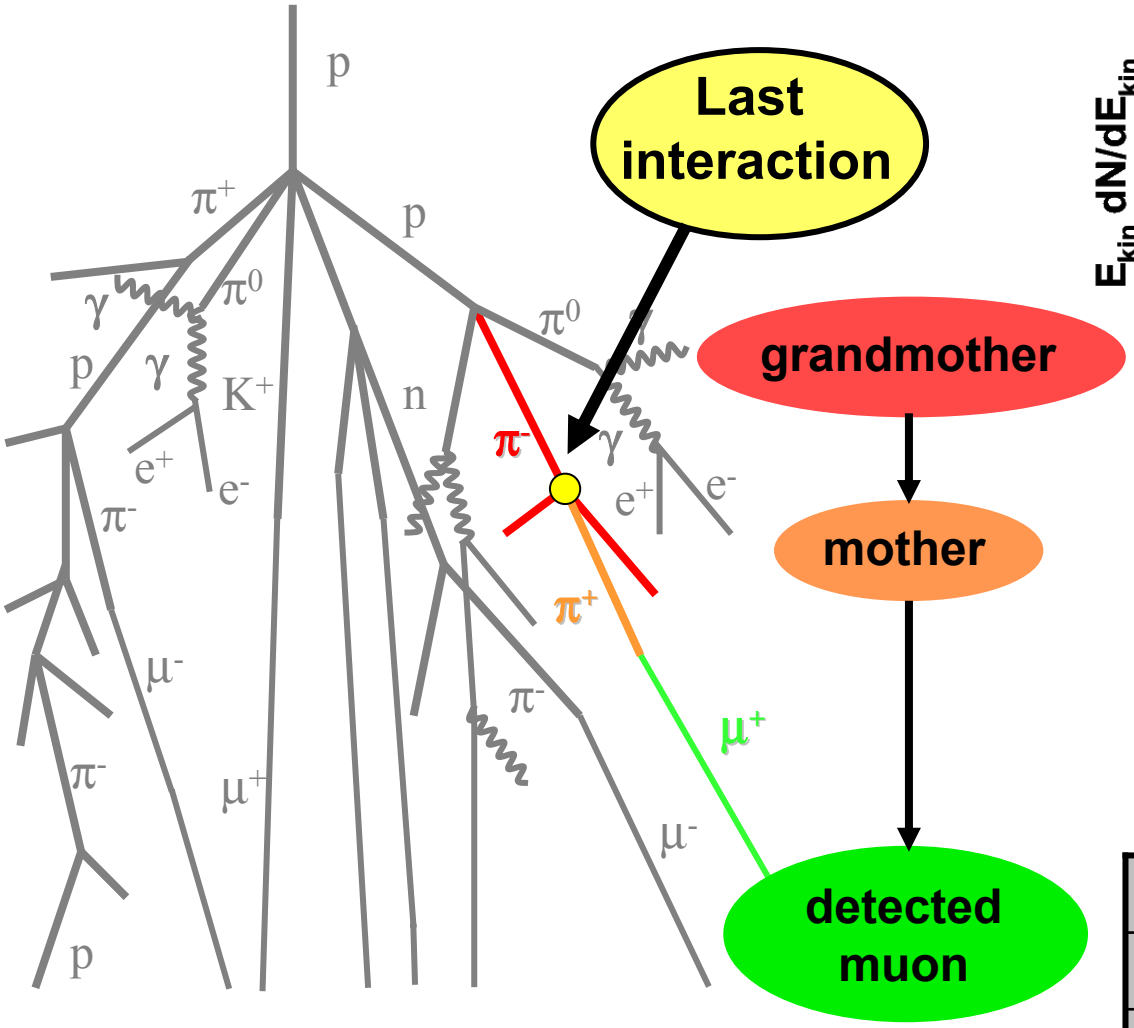
Muon energy on ground

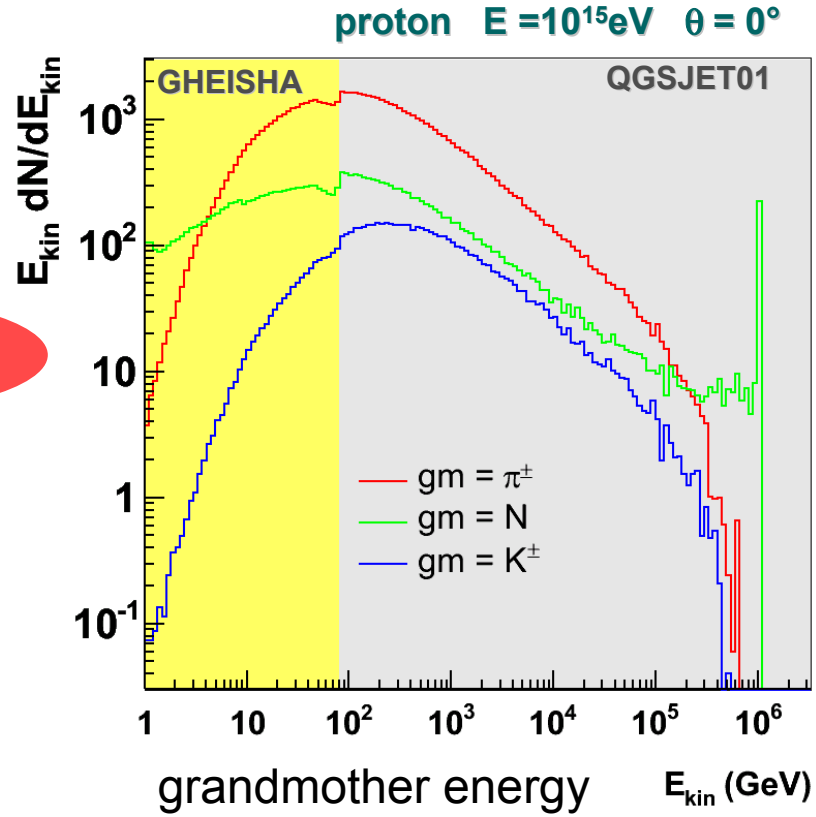




$\langle E_\mu \rangle$ smaller for larger distances

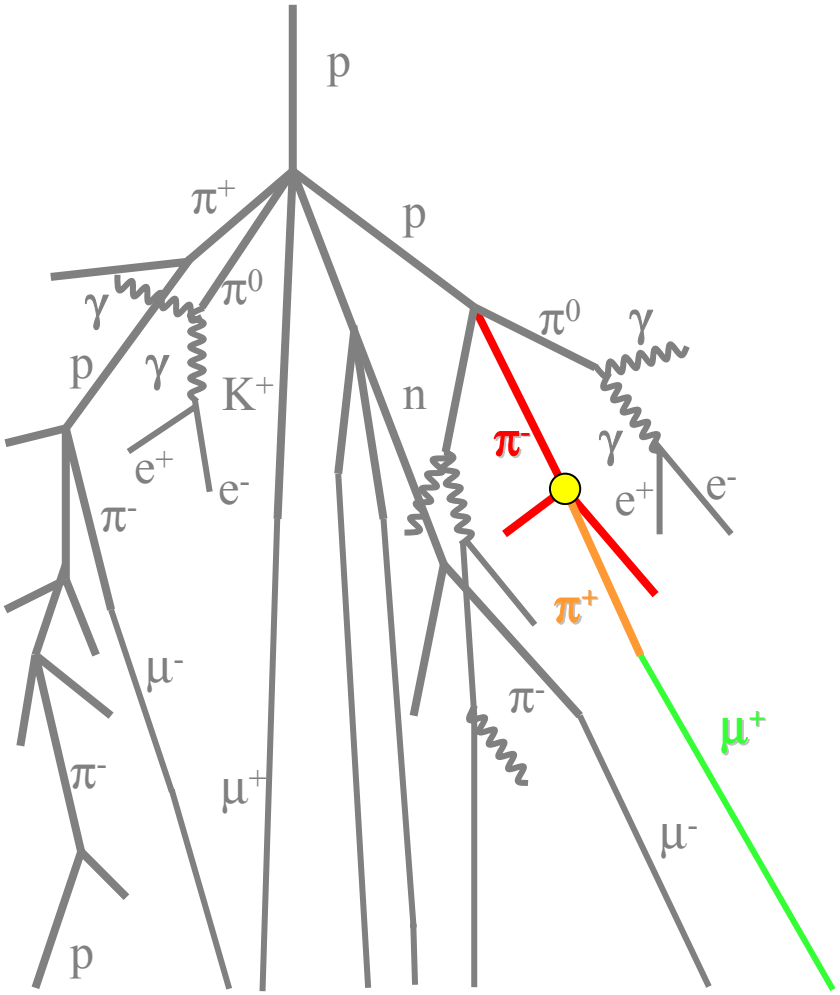
Relation of muons to hadronic interactions

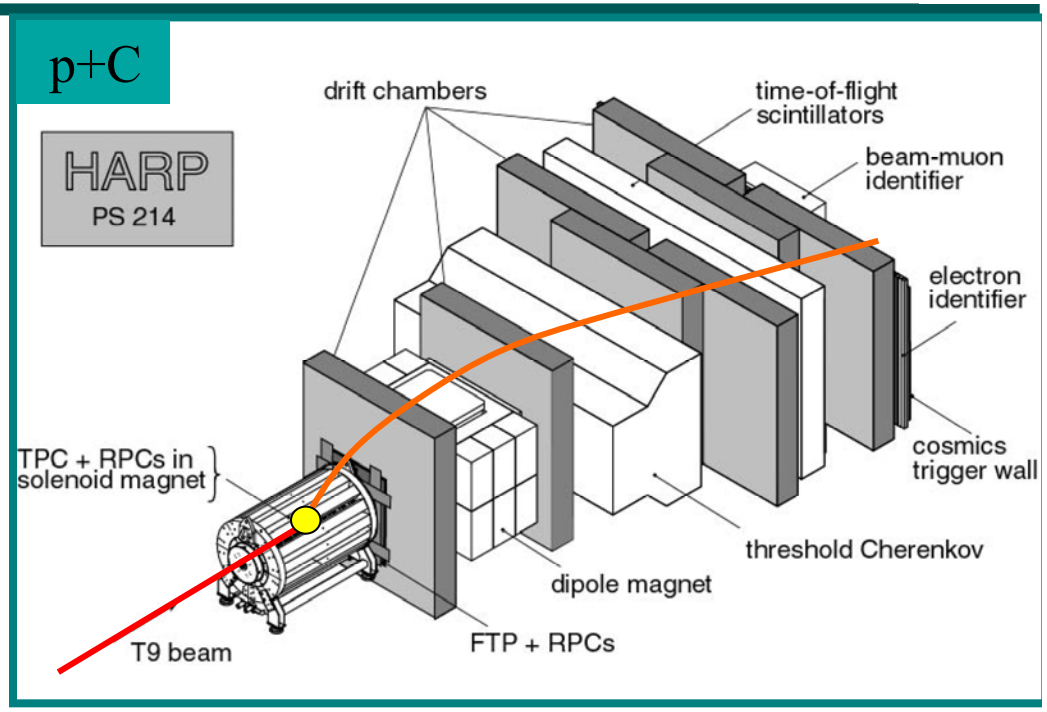




	grandmother	mother
pion	72.3%	89.2%
nucleon	20.9%	-
kaon	6.5%	10.5%

EAS vs fixed target experiment





Grandmother particle = beam particle

Mother particle = secondary particle

- **+ Several targets**
- **+ Forward direction accessible**
- **+ Relevant energy range: 8-1000 GeV**

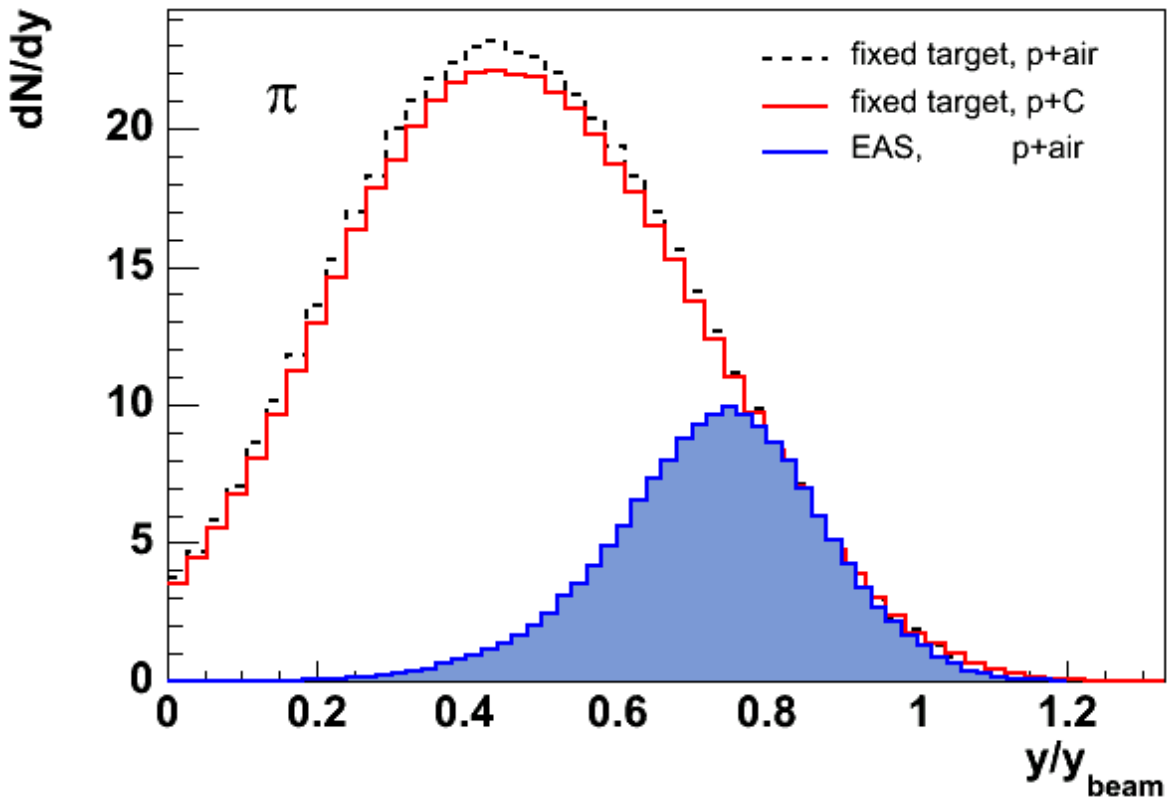
Rapidity of pions

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

Fixed target: p(160GeV) + air, p(160GeV) + C
(QGSJET-01) $y_{beam} = 5.8$

Rapidity:

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



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

Forward hemisphere dominating

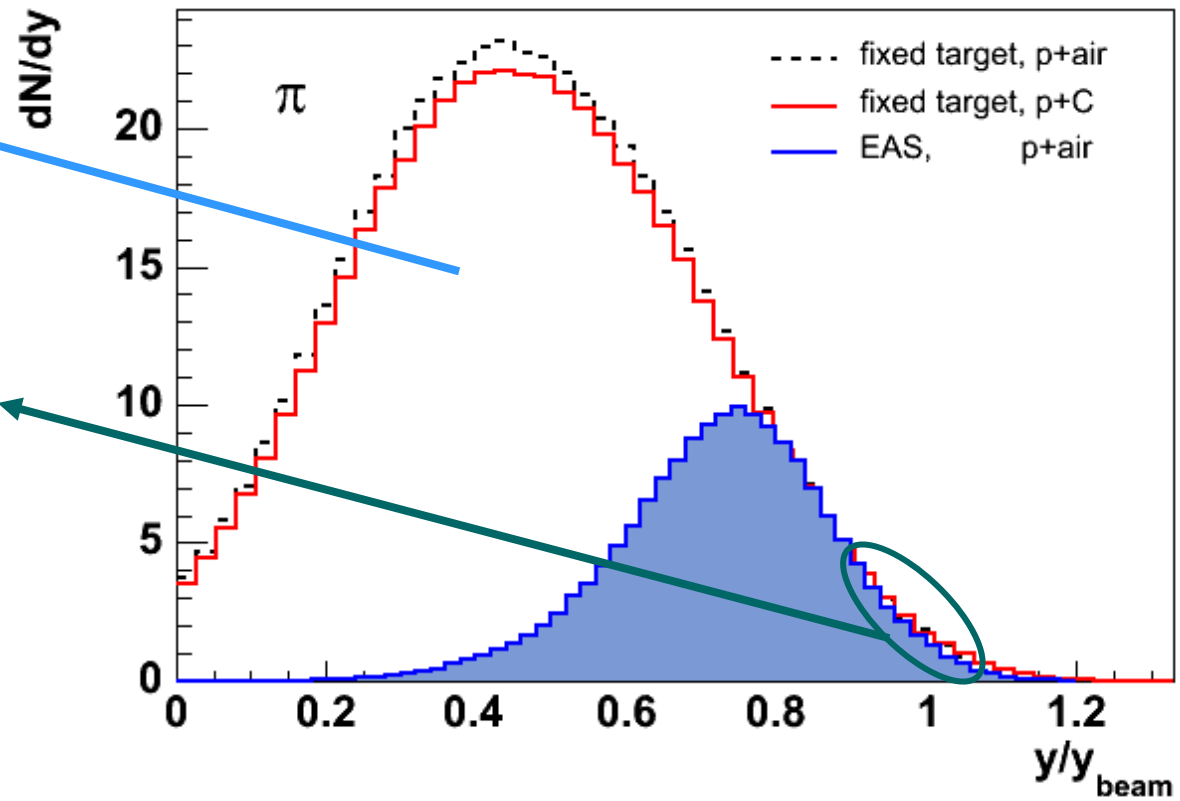
Rapidity of pions

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

Fixed target: p(160GeV) + air, p(160GeV) + C
(QGSJET-01) y_{beam} = 5.8

Energy loss/ muon decay: muons not detected

No pion decay, but further interactions



Rapidity of kaons

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

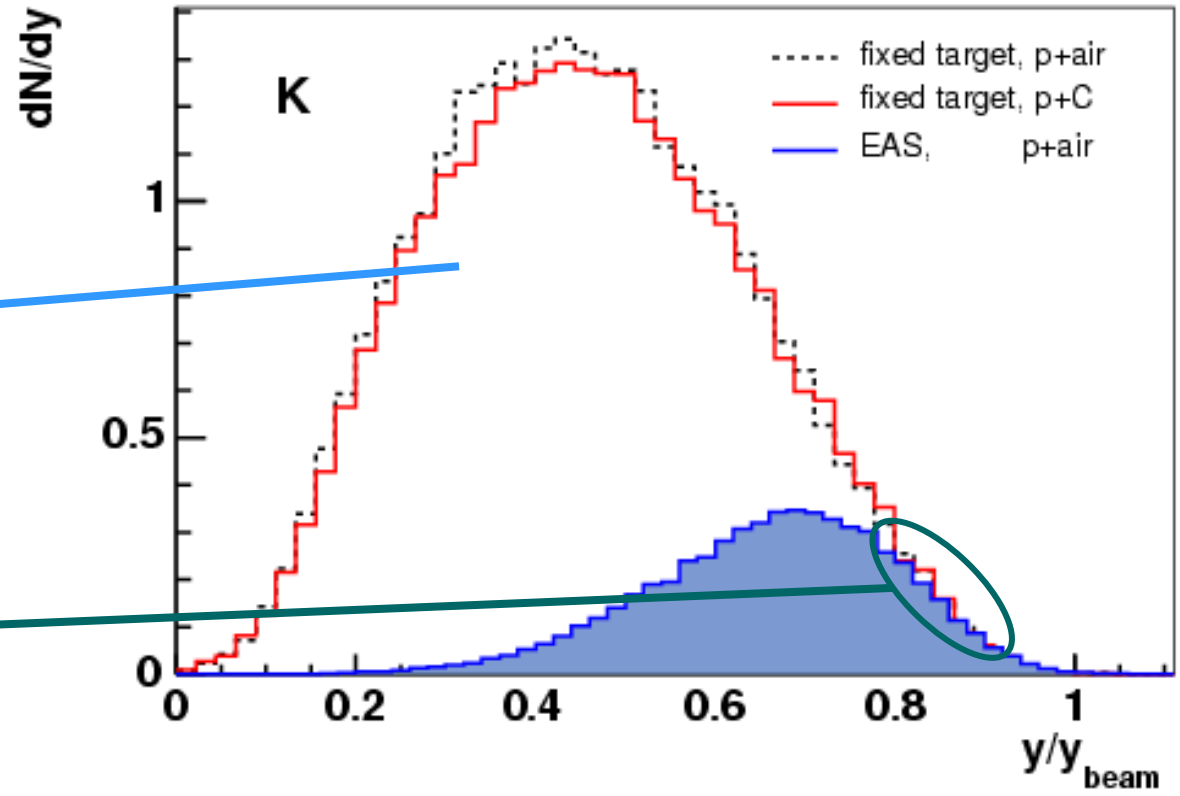
EAS: **KASCADE range: 50-200m**
Nucleons (~160GeV) + air

Fixed target: **p(160GeV) + air, p(160GeV) + C**
(QGSJET-01) **$y_{beam} = 5.8$**

Forward hemisphere dominating

Energy loss/ muon decay: muons not detected

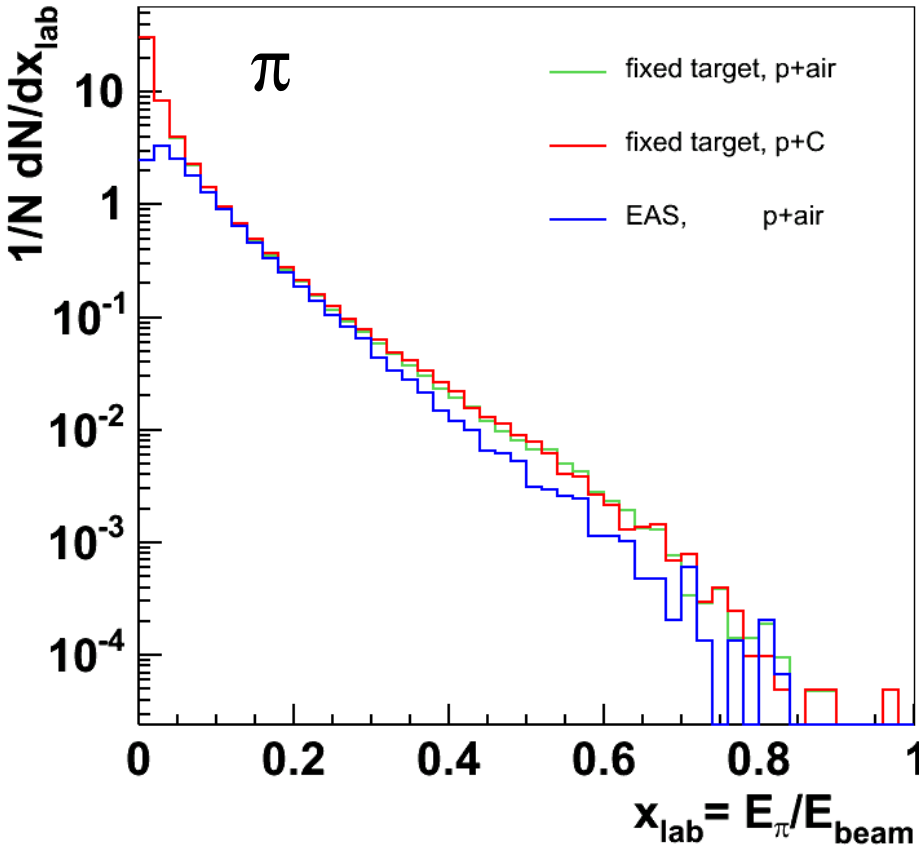
No significant differences because of further interactions → decay energy of kaons higher than for pions

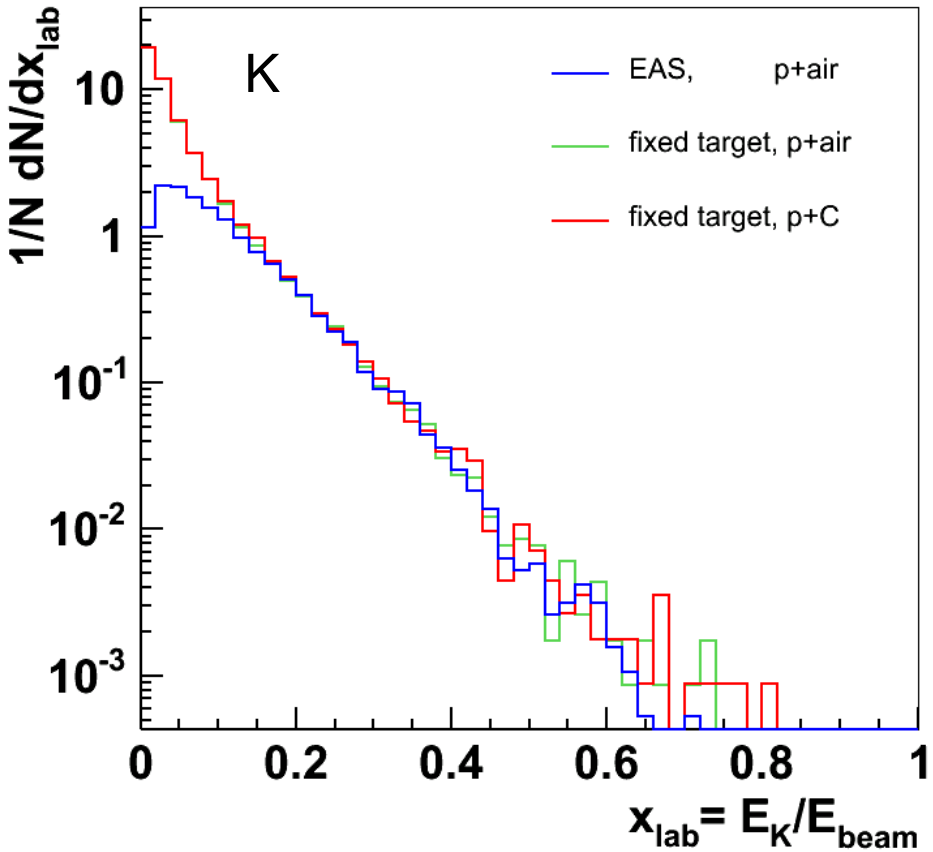


x_{lab} of secondary π and K

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

Fixed target: p(160GeV) + air, p(160GeV) + C
(QGSJET-01) y_{beam} = 5.8

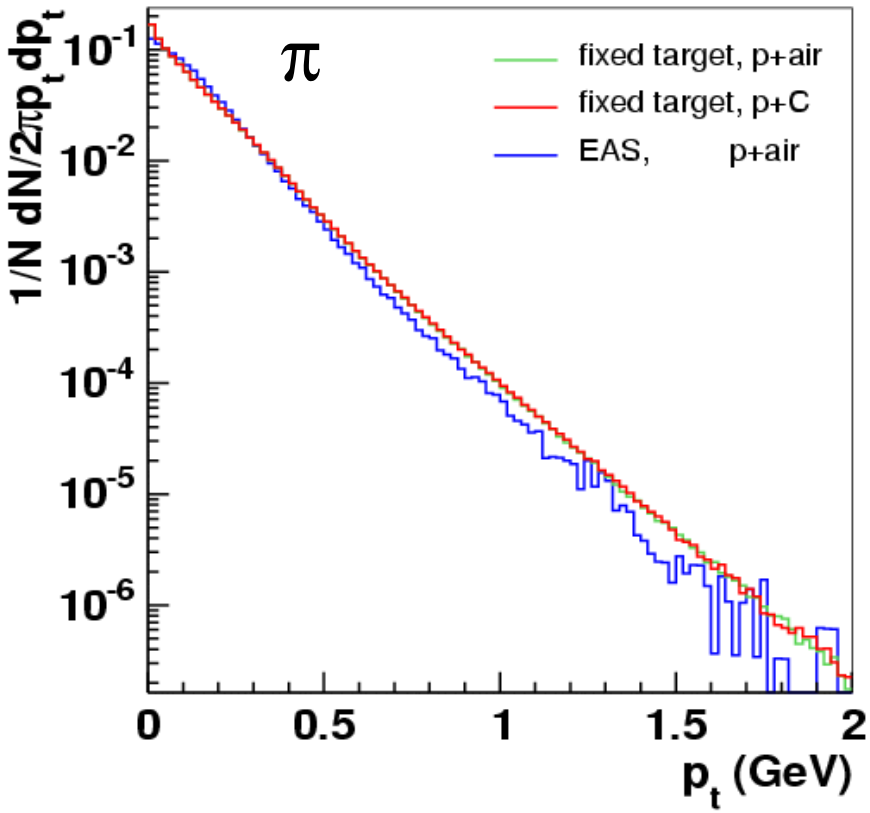


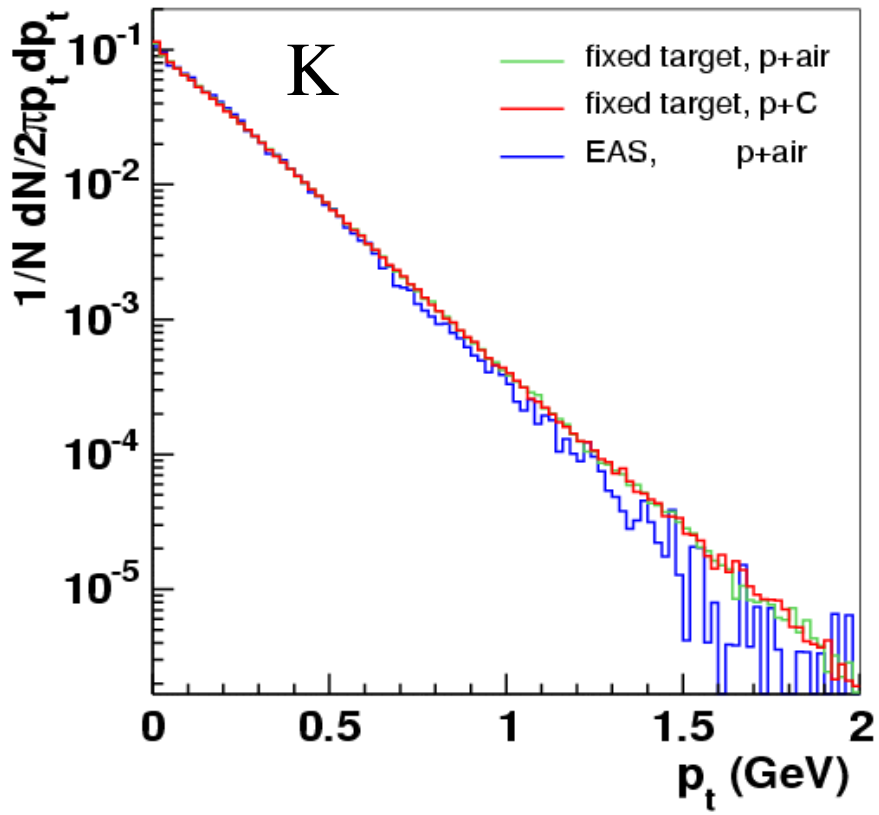


Transverse momentum of π and K

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

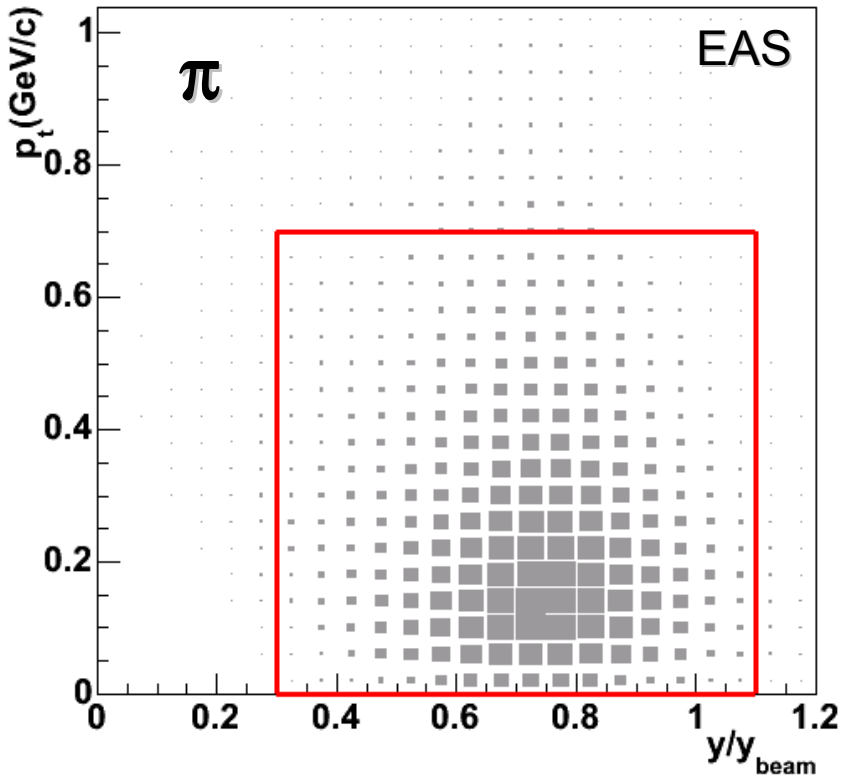
EAS:	KASCADE range: 50-200m Nucleons (~160GeV) + air
Fixed target: (QGSJET-01)	p(160GeV) + air, p(160GeV) + C y_{beam} = 5.8

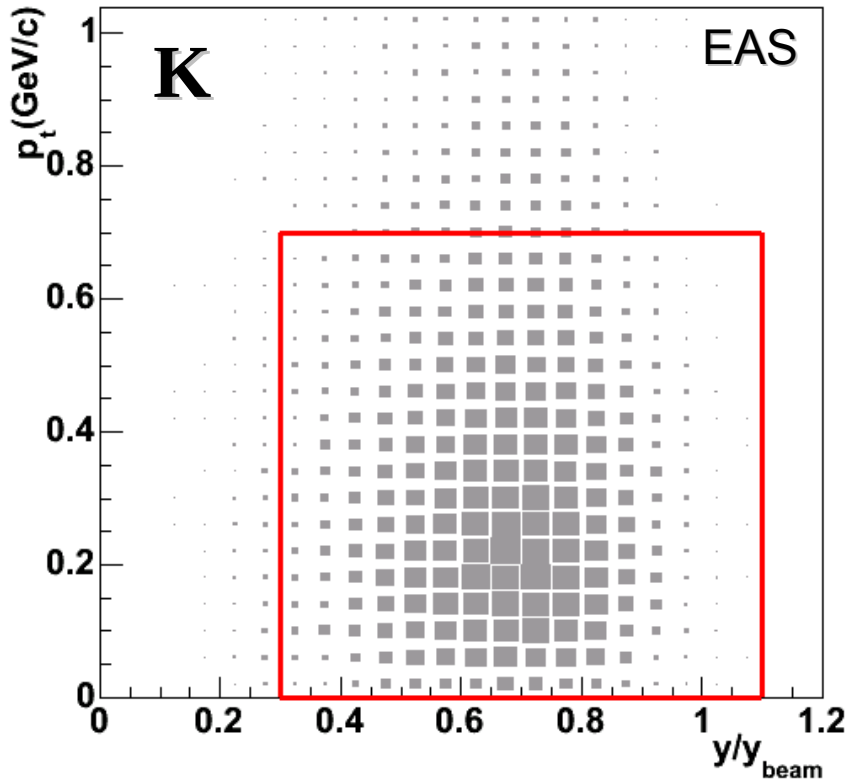




Phase space: E~160GeV

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

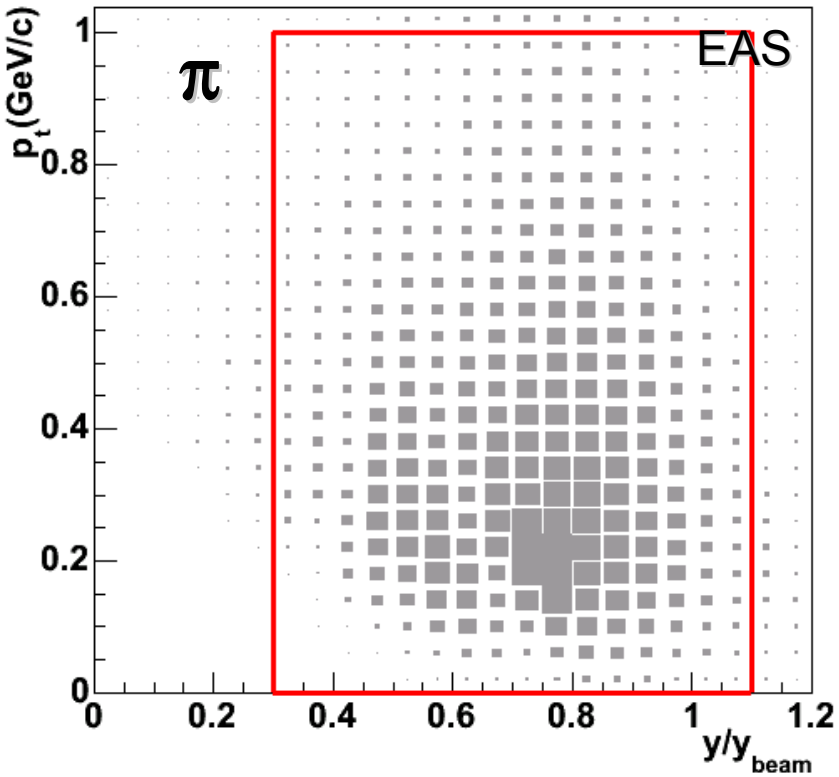


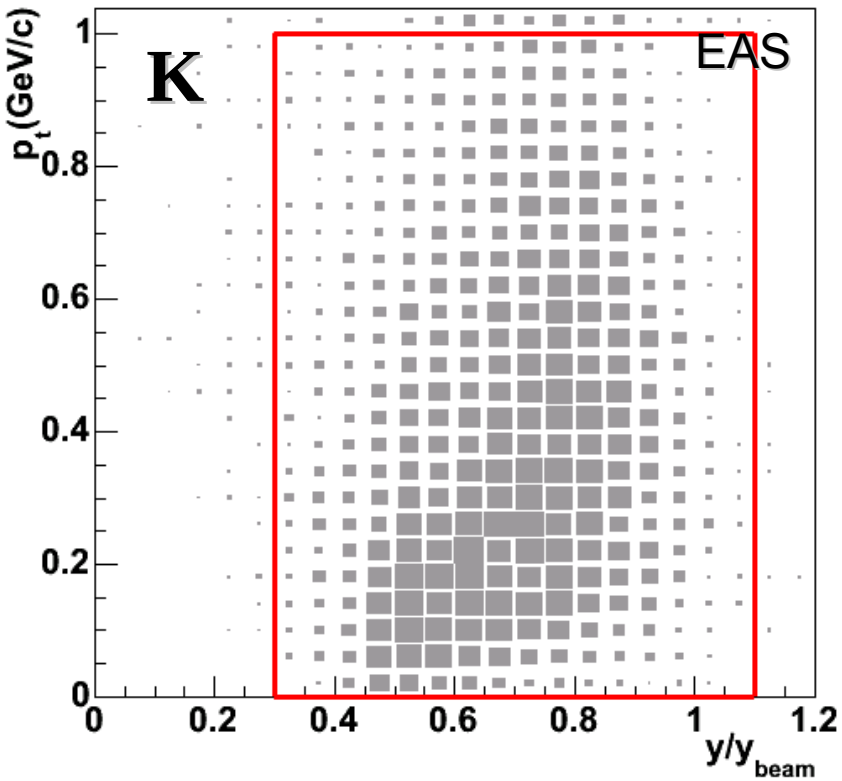


y/y_{beam}	0.3-1.1
p_t(GeV)	0.0-0.7

Phase space: E~ 40GeV

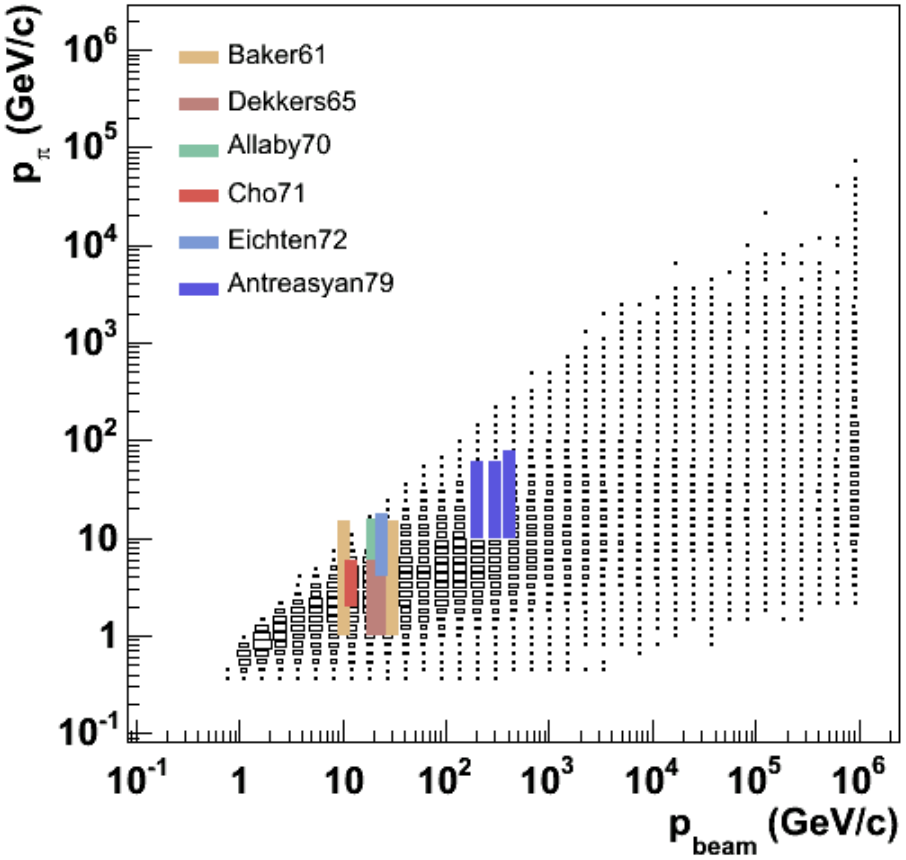
KASCADE-Grande range: 200-500m; Nucleons (~40GeV) + Air

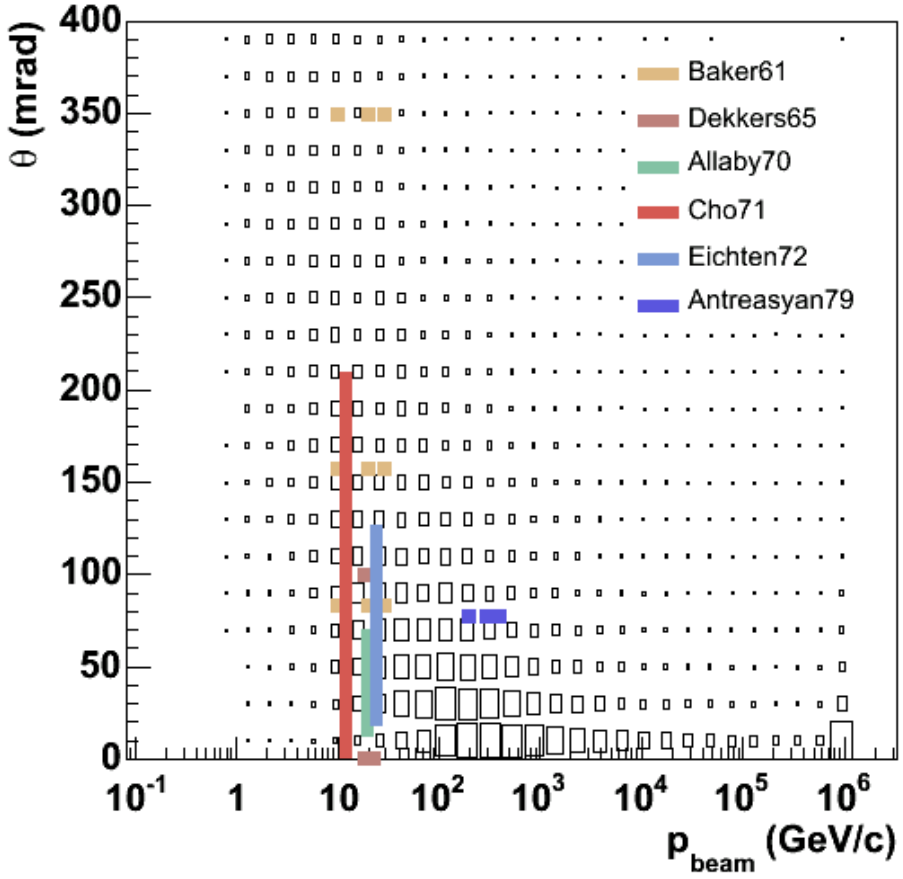




y/y_{beam}	0.3-1.1
p_t(GeV)	0.0-1.0

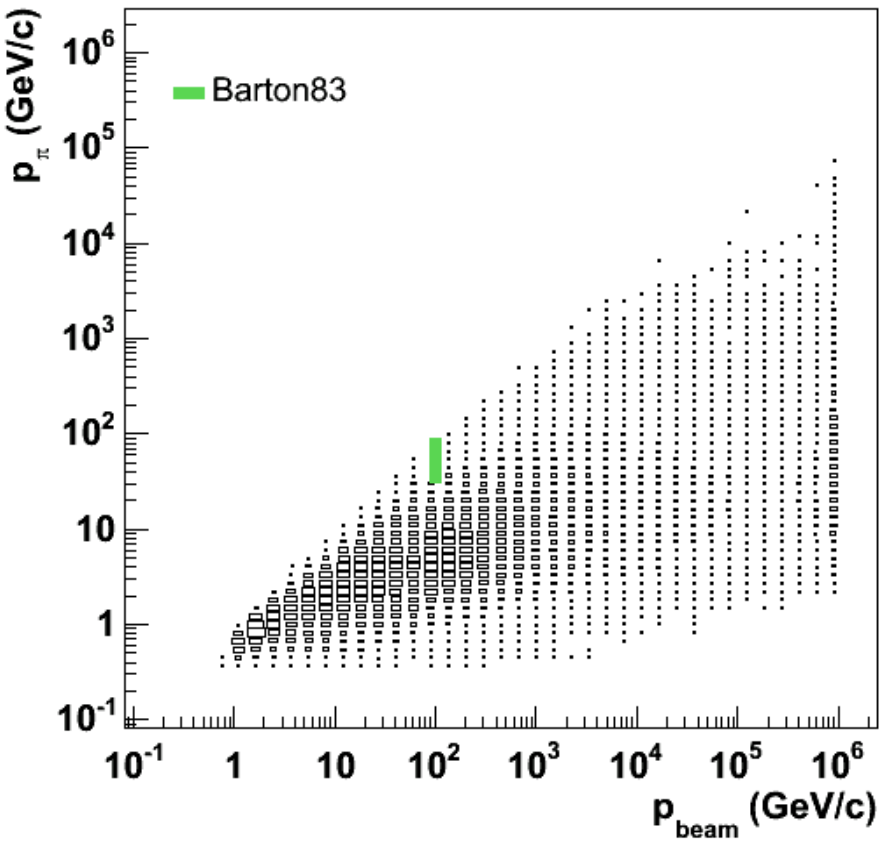
Existing accelerator data: p+Be

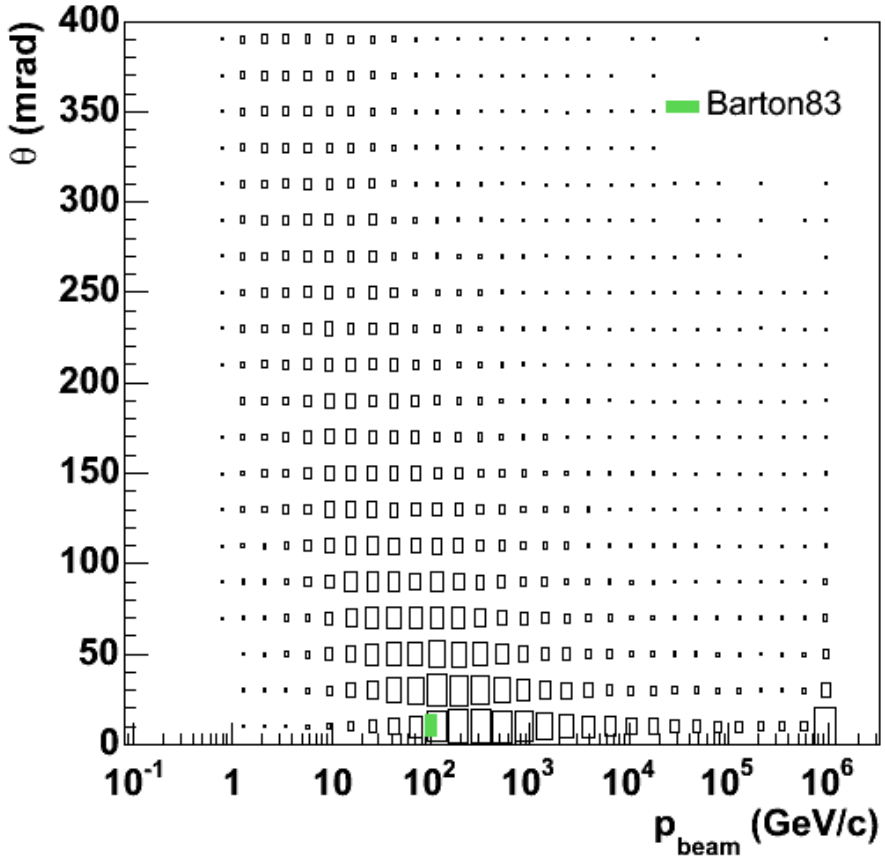




Data: p+Be → π+X
EAS: p+air → π+X

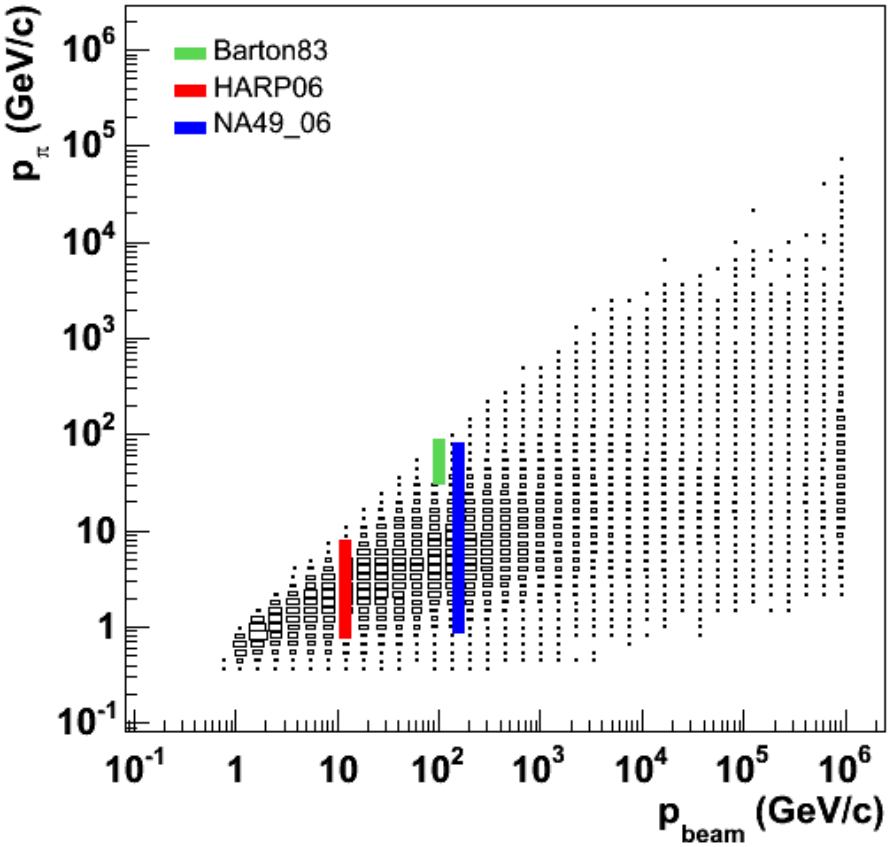
Existing p+C data: Barton et al.

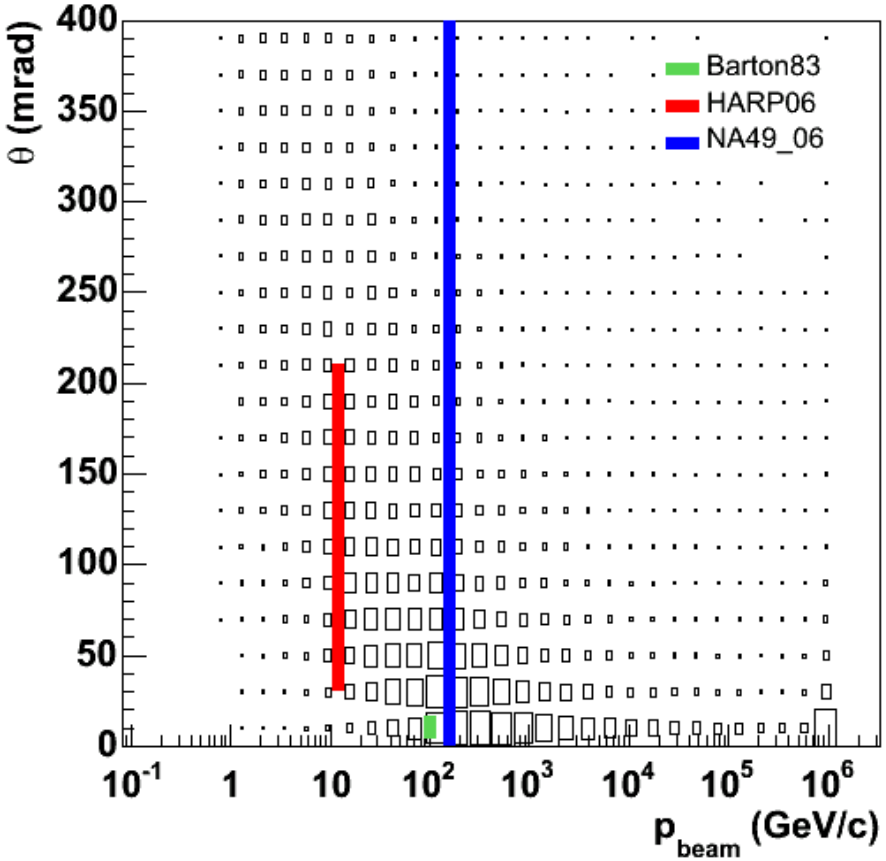




Data: p+C → π+X
EAS: p+air → π+X

New p+C data: NA49, HARP

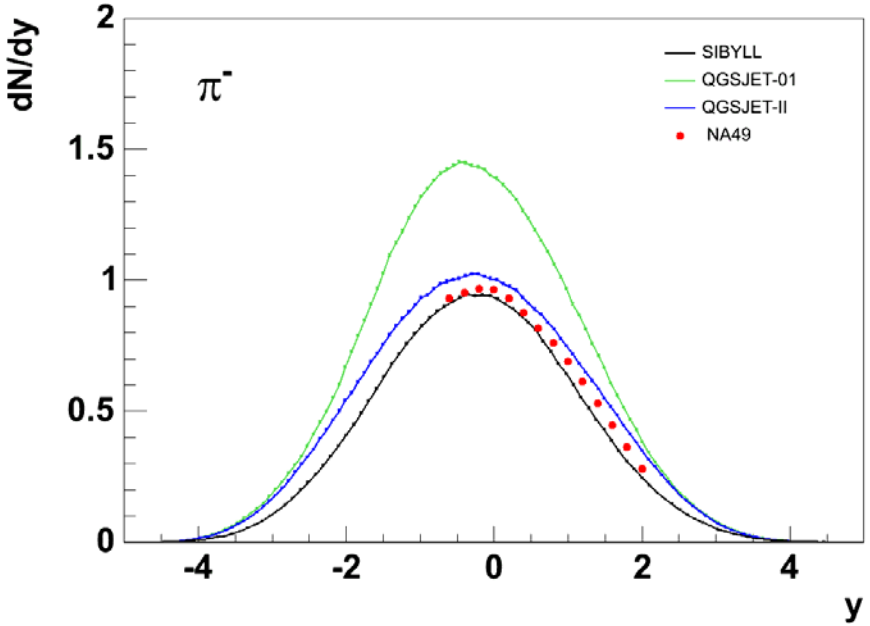




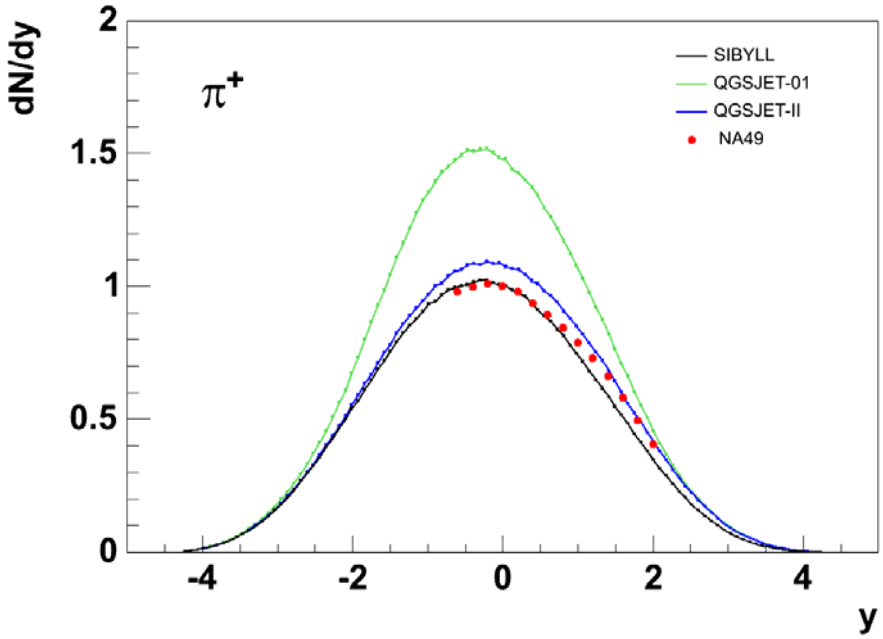
Data: p+C → π+X
EAS: p+air → π+X

Existing: proton beam → 21% of grandmother particle
Still needed: pion beam → 72% of grandmother particle

NA49: p+C @ 158 GeV/c



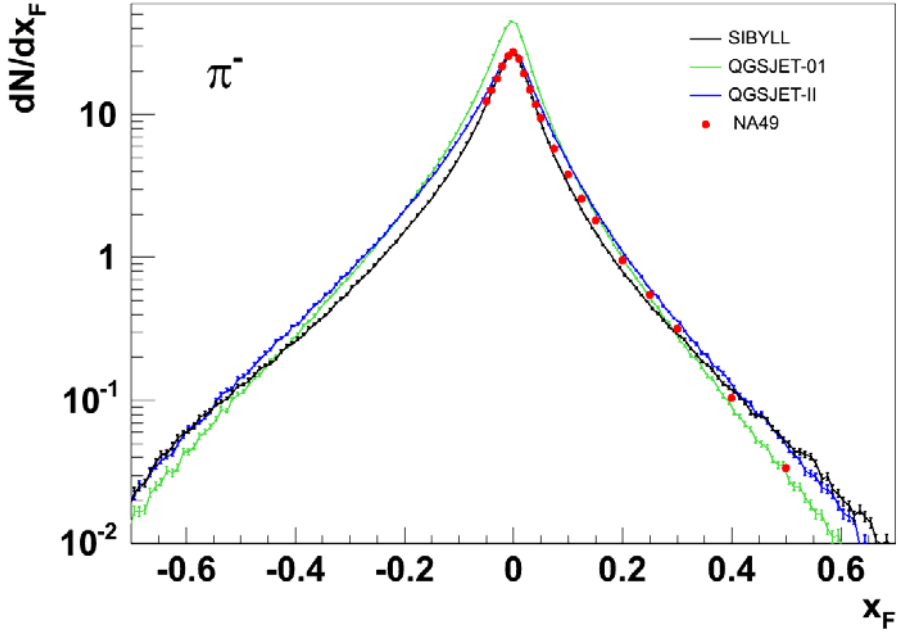
Comparison: models – data:
SIBYLL and QGSJET-II:
reasonable agreement with data
QGSJET-01:
overestimation of factor ~ 1.5



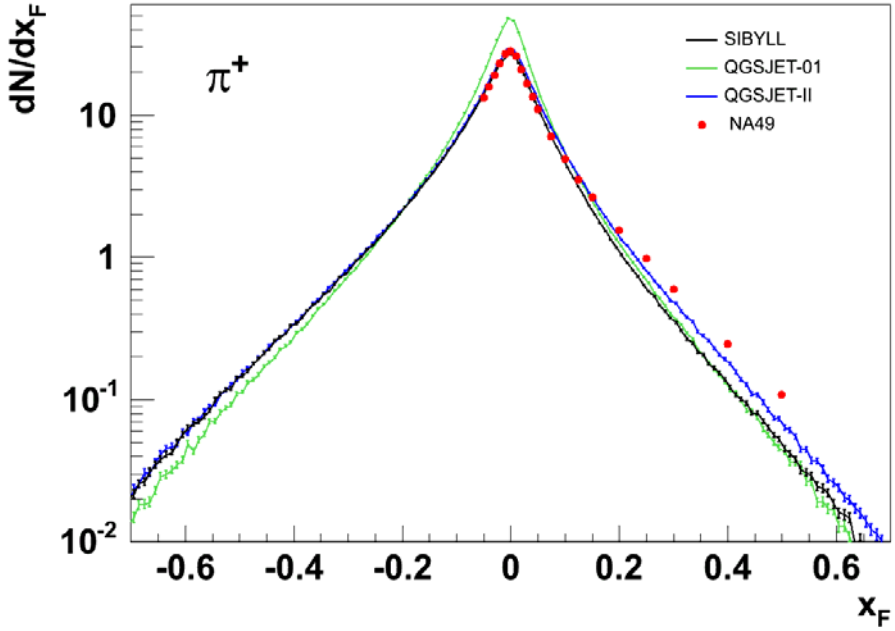
Error of NA49 data:
stat. error ~ 5%
syst. error ~ 5%

C.Alt et al. (NA49 collaboration) hep-ex/0606028

NA49: p+C @ 158 GeV/c



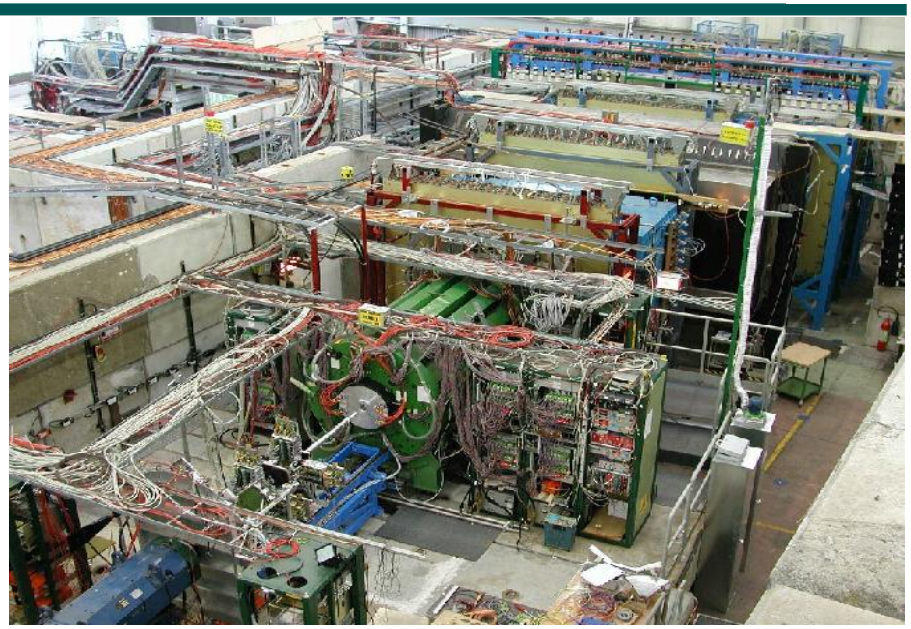
QGSJET-01: soft π-spectra
QGSJET-II: hard π-spectra



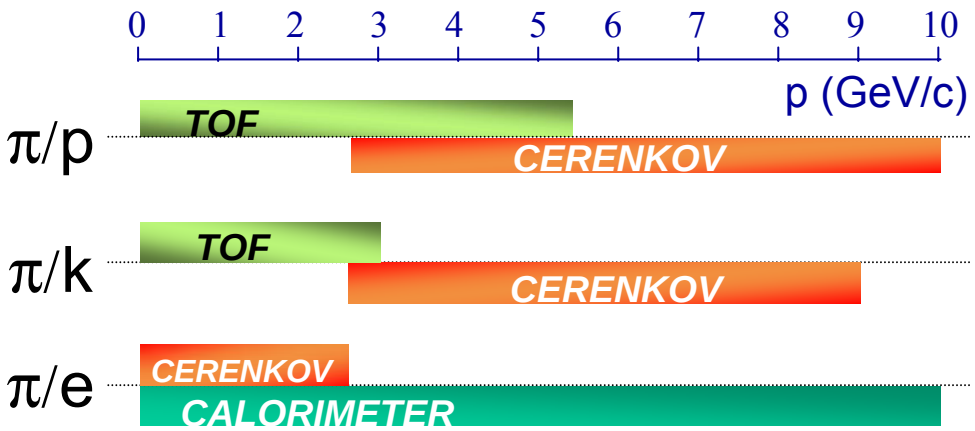
C.Alt et al. (NA49 collaboration) hep-ex/0606028

HARP: p+C @ 12 GeV/c

Ongoing analysis: p+C @ 12 GeV/c
Selection of secondary particles (π^+, π^-) in forward hemisphere using the drift chambers.
No of events: 1,000k
No of events after cuts: 450k



Separation of particle types using different detector components



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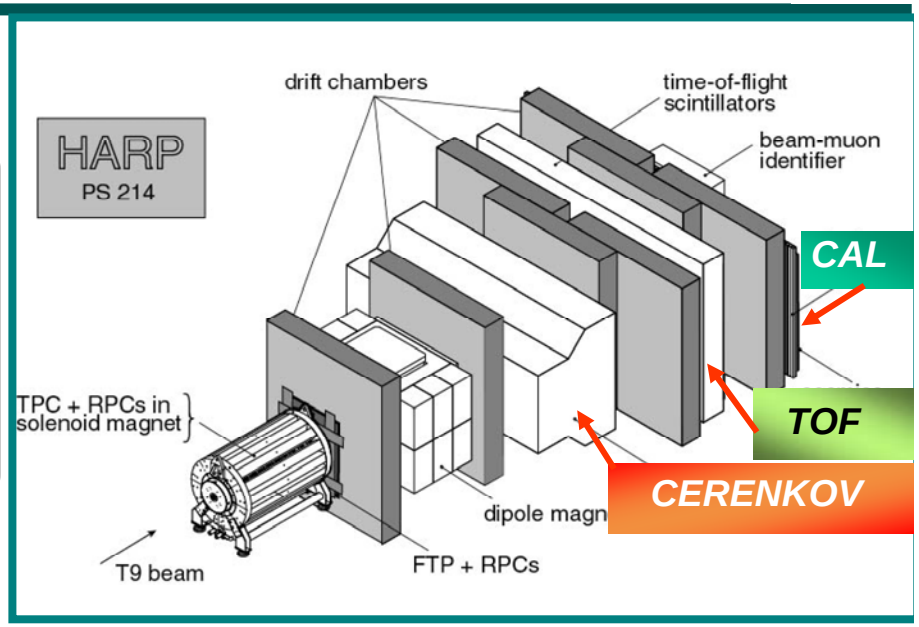
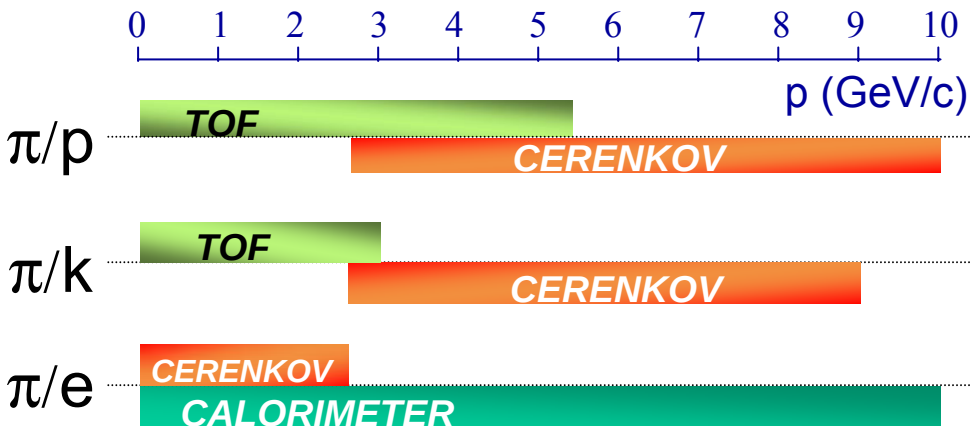
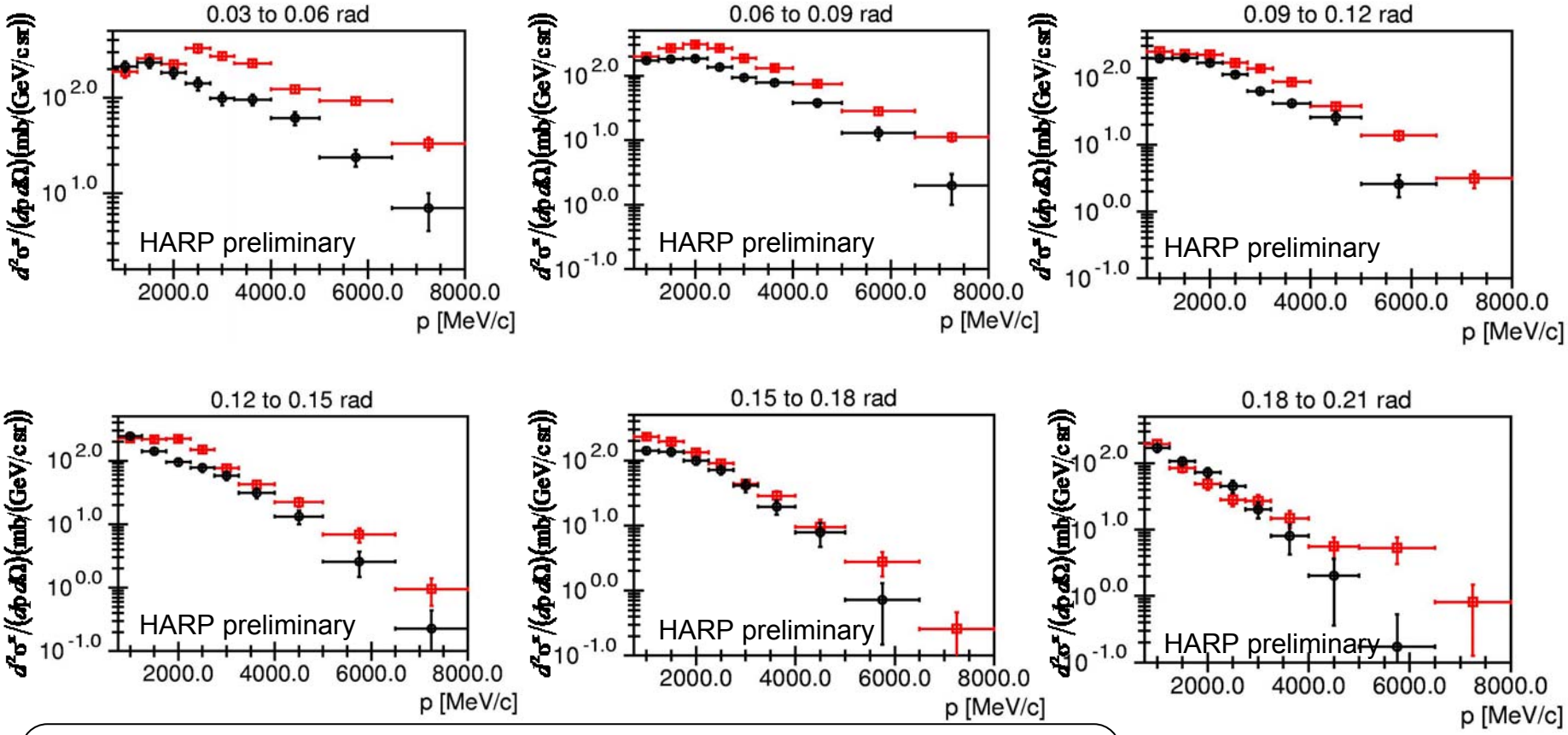


Separation of particle types using different detector components



$p+C \rightarrow \pi^{\pm}+X$, p_{beam}=12 GeV/c

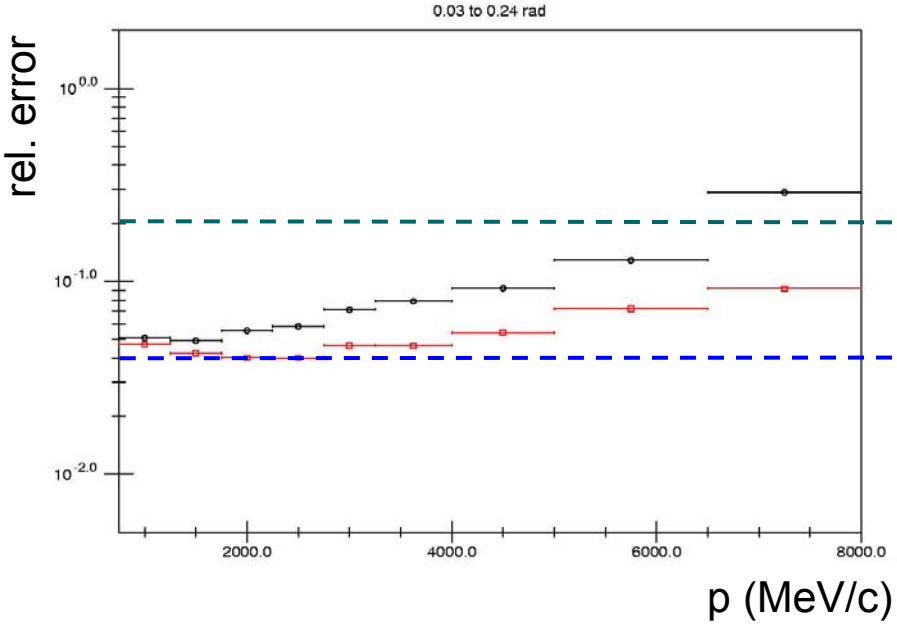


- π^+: leading particle effect
- Comparison with models in preparation
- Error: stat. and syst. error
  → syst. error: kaon subtraction in progress

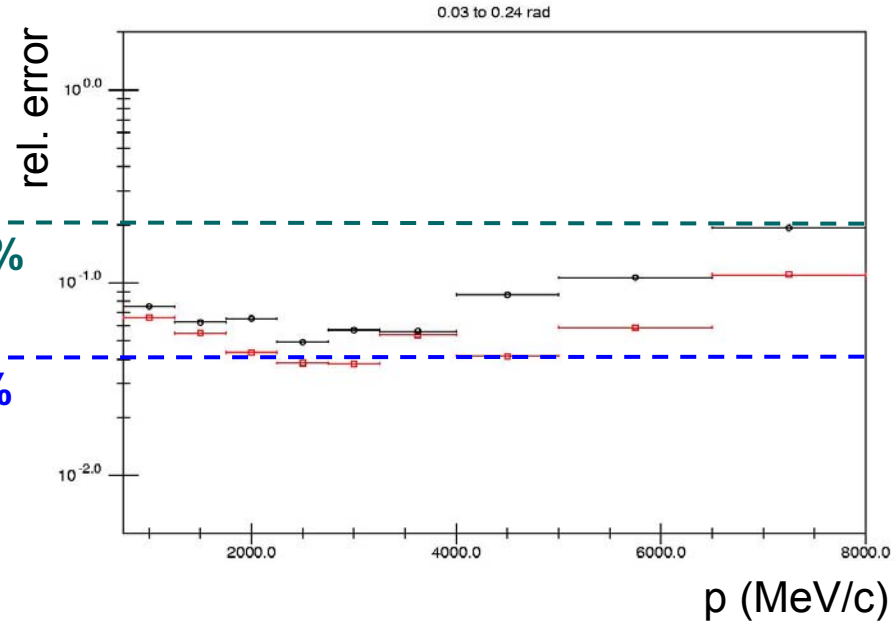
π^-, π^+

Error estimation

Stat. error



Syst. error



20%

4%

Dominant contributions to syst. error:

- Tertiary subtraction
- Momentum scale

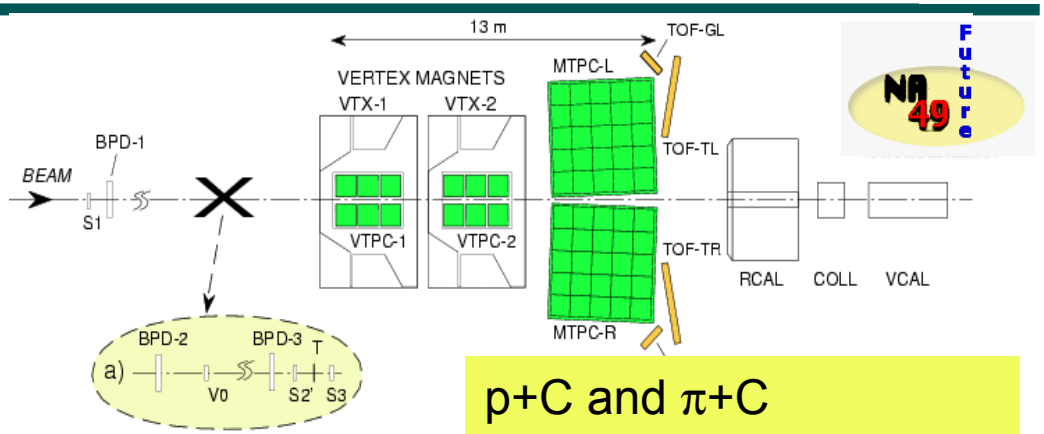
π^-, π^+

Conclusions

- **Interpretation of CR data relies heavily on MC simulations**
- **Muons are main ingredients to infer E, A**
- **Fixed target experiments are very important for understanding of muon production in extensive air showers**
- **Relevant hadronic interactions for muon production are in the**
  - **energy range: 8 – 1000 GeV**
  - **phase space region: forward hemisphere**
- **New (2006) fixed target measurements:**
  - **NA49: p+C @ 158GeV/c**
  - **HARP: p+C @ 12 GeV/c**
- **Comparison: data – models: SIBYLL and QGSJET-II in good agreement with data, QGSJET-01 overestimation of factor ~ 1.5 in dN/dy**
- **<u>Outlook:</u> further measurements/analyses planed by NA49, HARP and MIPP**

Planed future measurements/analyses

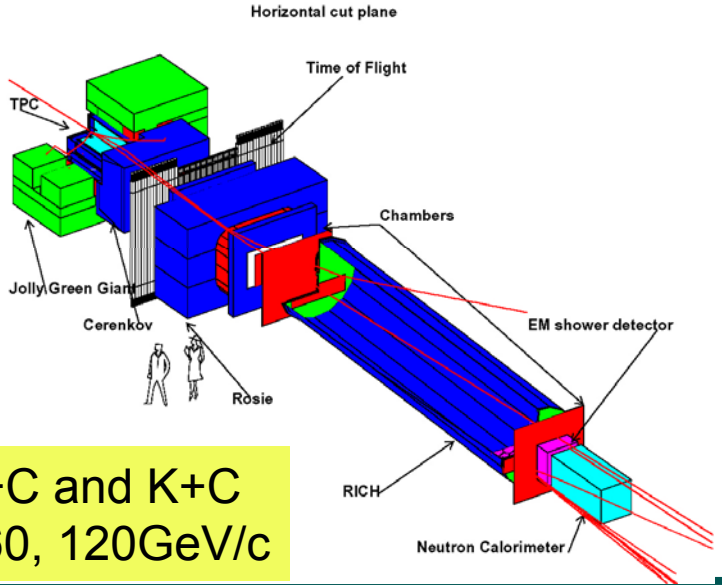
Energy range and phase space of interest	
$\langle E_{beam} \rangle$	8-1000 GeV
p	0.5-11.0 GeV/c
θ	0-300 mrad



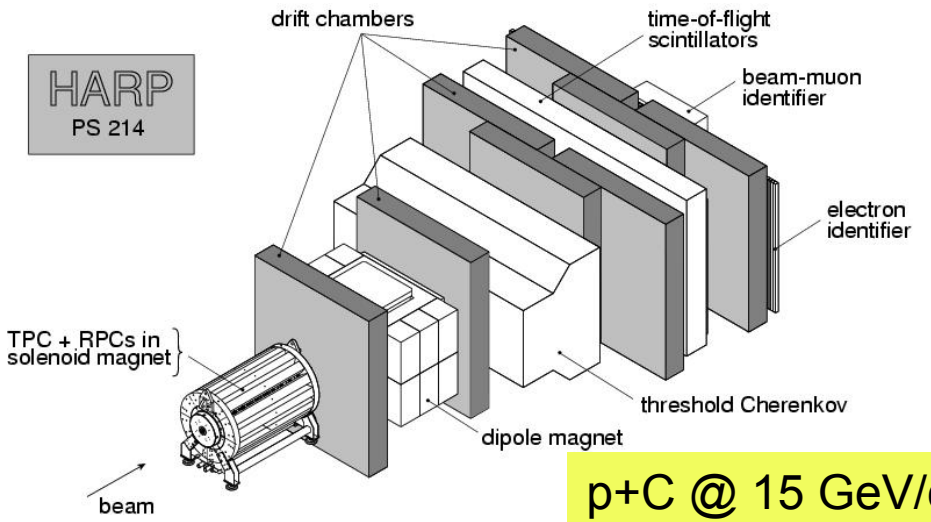
p+C and π+C
@ 30, 40, 50, 158GeV/c

MIPP

Main Injector Particle Production Experiment (FNAL-E907)



p+C, π+C and K+C
@ 20, 60, 120GeV/c



p+C @ 15 GeV/c
π+C @ 12 GeV/c

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