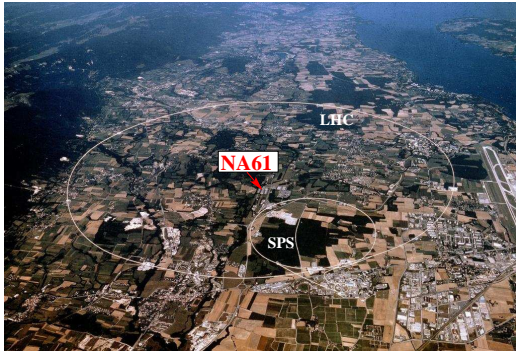


Hadron Production at Fixed Target Energies and Extensive Air Showers

M. Unger* for the **NA61 Collaboration**

*Karlsruher Institut für Technologie

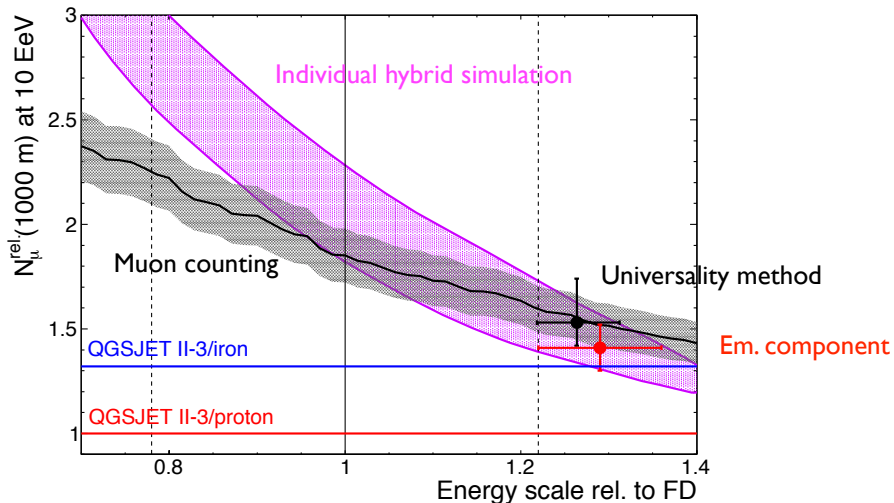


NA61/SHINE:

- Heavy Ions
(see P. Staszal, #895)
- Neutrinos/T2K
(see S. Bravar, #997)
- Cosmic Rays
(this talk!)

Muons in UHE Air Showers

Example: Muons at 10^{19} eV (Pierre Auger Observatory)



(Auger Coll., ICRC 2009, arXiv:0906.2319 [astro-ph])

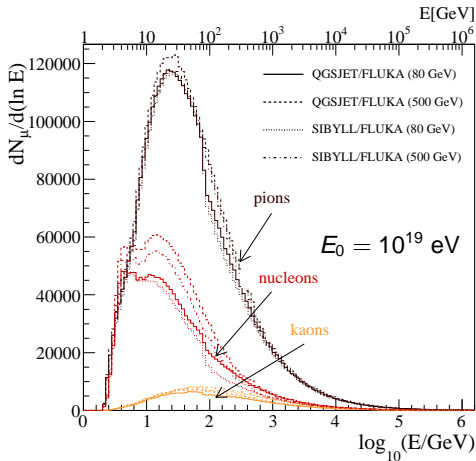
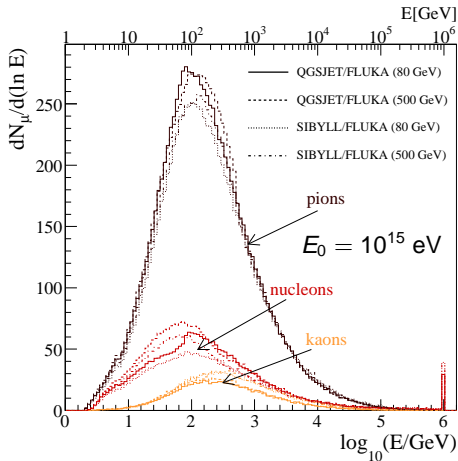
Muons in UHE Air Showers

air shower cascade: energy of last interaction before decay to μ



$\mu + \nu_{\mu}$

CORSIKA simulation:

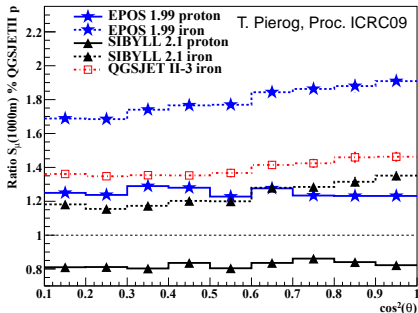
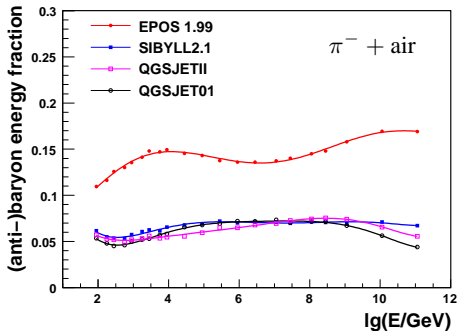


Muons in UHE Air Showers

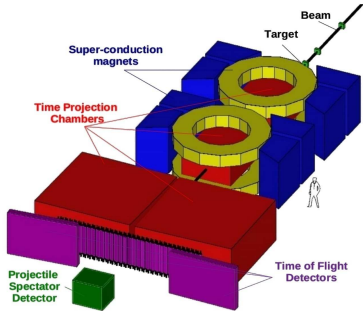
number of muons depends on energy fraction of produced hadrons

- π^0 → electromagnetic shower
 - π^\pm
 - (anti-) baryons
- } → hadronic shower

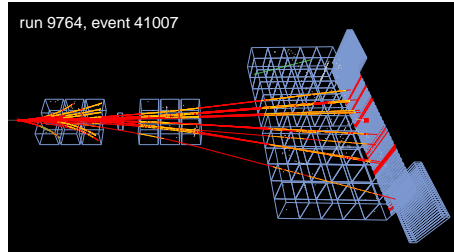
$$f(\pi^0)/f(\pi^\pm) \approx \frac{1}{2}$$
$$f(\text{baryon}) = ??$$



NA61/SHINE Experiment at SPS



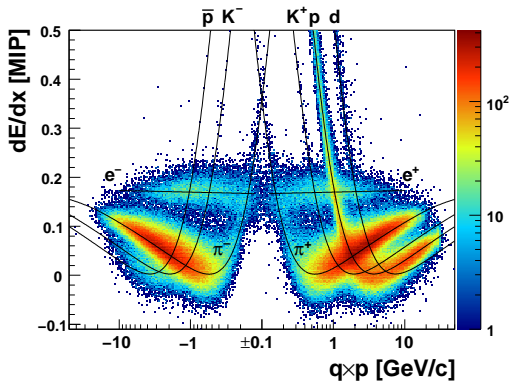
π^- -C interaction at 350 GeV/c



- large acceptance $\approx 50\%$ at $p_T \leq 2.5 \text{ GeV}/c$
- momentum resolution: $\sigma(p)/p^2 \approx 10^{-4}(\text{GeV}/c)^{-1}$
- tracking efficiency: $> 95\%$

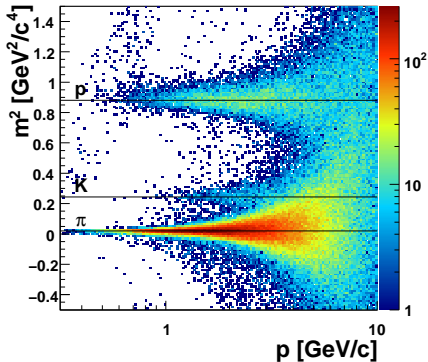
Particle Identification

energy deposit in TPC:



$$\sigma \left(\frac{dE}{dx} \right) / \frac{dE}{dx} \approx 4\%$$

time of flight:

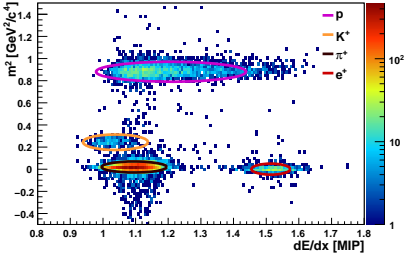


$$\sigma(t) \approx 100 \text{ ps}$$

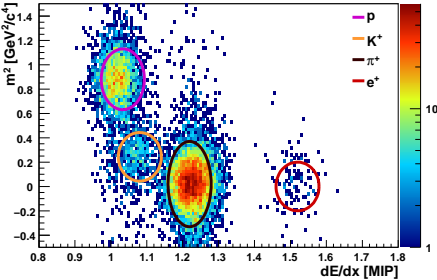
(data from 2007 T2K pilot run ($p+C$ at 31 GeV/c))

Particle Identification

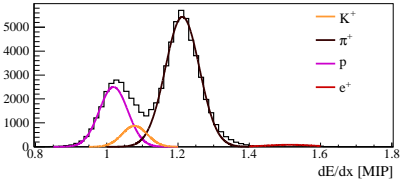
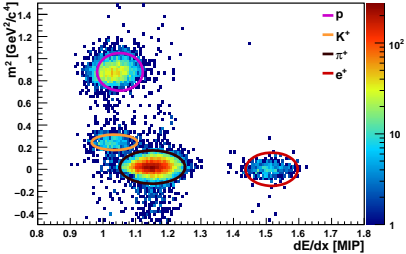
1 GeV/c < p < 2 GeV/c



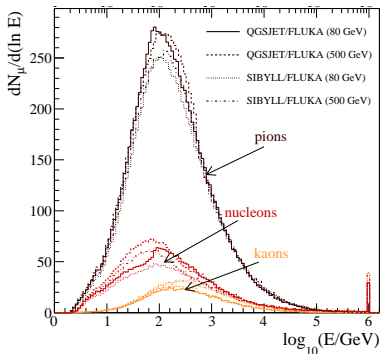
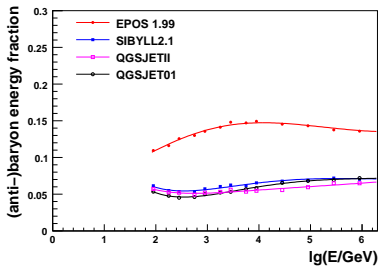
4 GeV/c < p < 5 GeV/c



2 GeV/c < p < 3 GeV/c



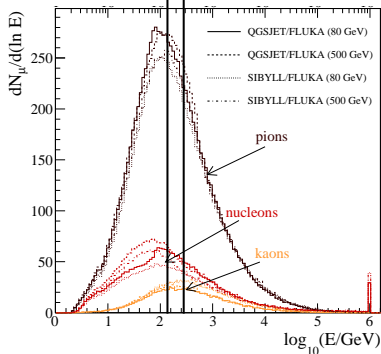
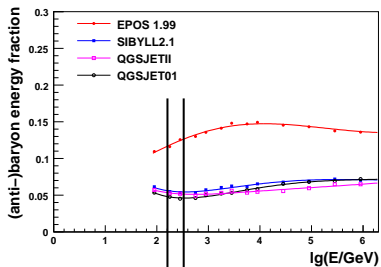
NA61 hadron production data



	p	yr	N_{int}
$\pi^- \text{C}$	158	2009	3.6
$\pi^- \text{C}$	350	2009	4.7
$p\text{C}$	31	2007	0.6
$p\text{C}$	31	2009	4.8
$p\text{C}$	158	2010	3*
pp	13	2010	3*
pp	20	2009	1.7
pp	30	2009	2.6
pp	40	2009	4.2
pp	80	2009	3.6
pp	158	2009	2.8
pp	158	2010	60*

beam momentum p in [GeV/c],
 interaction triggers N_{int} in $[10^6]$
 *expected interaction triggers

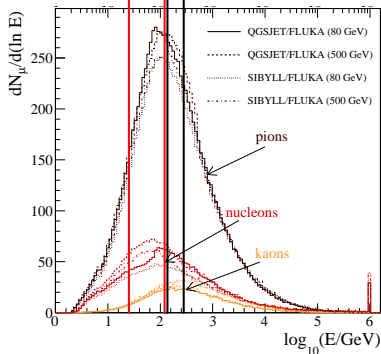
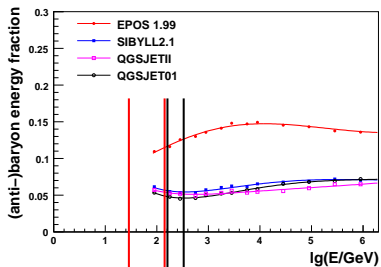
NA61 hadron production data



	p	yr	N_{int}
π^- C	158	2009	3.6
π^- C	350	2009	4.7
pC	31	2007	0.6
pC	31	2009	4.8
pC	158	2010	3*
pp	13	2010	3*
pp	20	2009	1.7
pp	30	2009	2.6
pp	40	2009	4.2
pp	80	2009	3.6
pp	158	2009	2.8
pp	158	2010	60*

beam momentum p in [GeV/c],
 interaction triggers N_{int} in $[10^6]$
 *expected interaction triggers

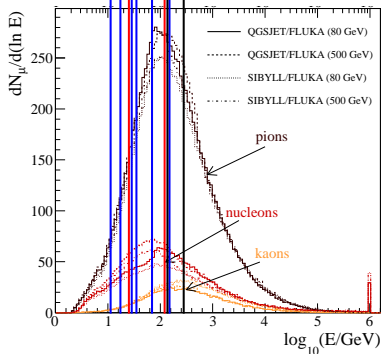
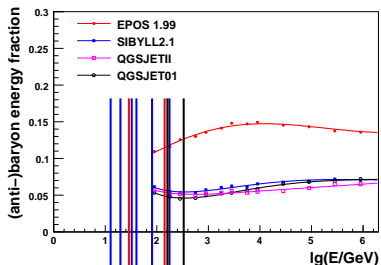
NA61 hadron production data



	p	yr	N_{int}
π^- C	158	2009	3.6
π^- C	350	2009	4.7
pC	31	2007	0.6
pC	31	2009	4.8
pC	158	2010	3*
pp	13	2010	3*
pp	20	2009	1.7
pp	30	2009	2.6
pp	40	2009	4.2
pp	80	2009	3.6
pp	158	2009	2.8
pp	158	2010	60*

beam momentum p in [GeV/c],
 interaction triggers N_{int} in $[10^6]$
 *expected interaction triggers

NA61 hadron production data

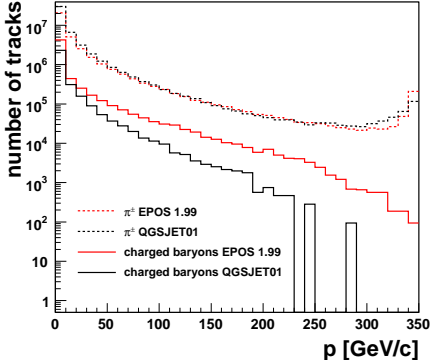


	p	yr	N_{int}
π^- C	158	2009	3.6
π^- C	350	2009	4.7
pC	31	2007	0.6
pC	31	2009	4.8
pC	158	2010	3*
pp	13	2010	3*
pp	20	2009	1.7
pp	30	2009	2.6
pp	40	2009	4.2
pp	80	2009	3.6
pp	158	2009	2.8
pp	158	2010	60*

beam momentum p in [GeV/c],
 interaction triggers N_{int} in $[10^6]$
 *expected interaction triggers

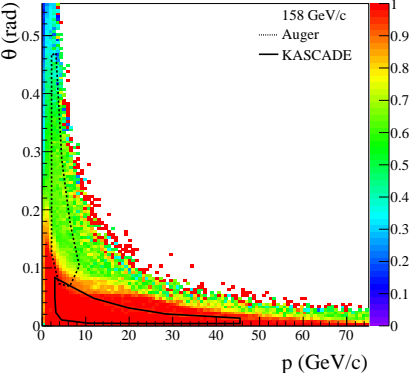
Expectations for π -C Data

**predicted number of tracks at
350 GeV/c:**



(generator level, no det. sim.)

acceptance at 158 GeV/c:



Analysis of 2007 data (p + C, 31 GeV/c, preliminary)

three independent analyses:

- negative hadrons (model corrected)
- dE/dx-only at low momentum (rel.-rise region in preparation)
- dE/dx and TOF at medium momenta

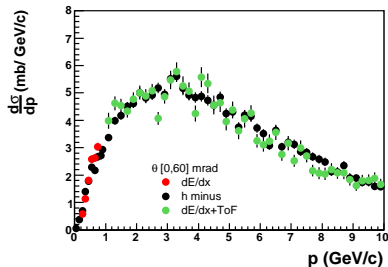
spectrum corrections, $|1 - \varepsilon|$:

- acceptance $\leq 1\%$
- reconstruction efficiency $\leq 4\%$
- pion decay $\leq 10\%$
- feed-down $\leq 10\%$

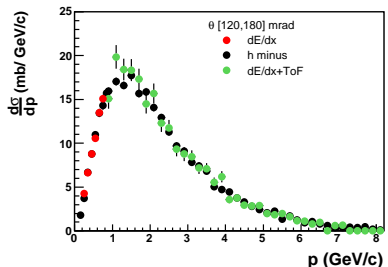
absolute normalization (trigger cross-section)

current overall syst. uncert. $\leq 20\%$

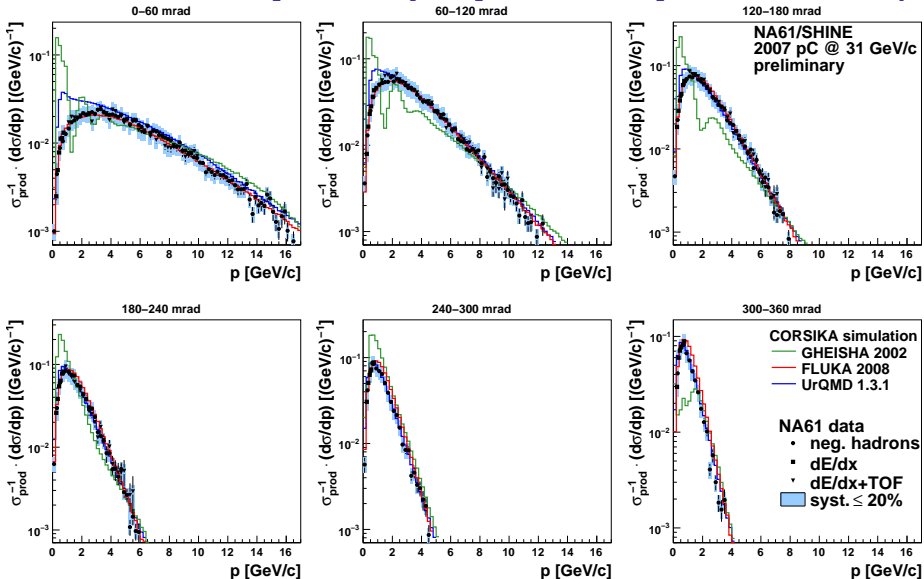
π^- results



π^- results

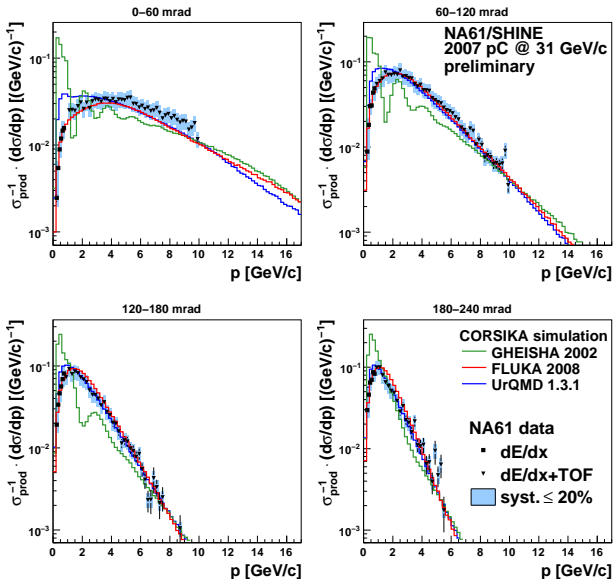


Inclusive π^- spectra (07 pilot run, p + C, 31 GeV/c)



pion production: $\frac{1}{\sigma_{\text{prod}}} \frac{d\sigma}{dp}$, where $\sigma_{\text{prod}} = \sigma_{\text{inel}} - \sigma_{\text{gel}}$

Inclusive π^+ spectra (07 pilot run, p + C, 31 GeV/c)



pion production: $\frac{1}{\sigma_{\text{prod}}} \frac{d\sigma}{dp}$, where $\sigma_{\text{prod}} = \sigma_{\text{inel}} - \sigma_{\text{qel}}$

Summary

muons in UHE air showers

- produced at SPS fixed target energies
- last interactions dominated by pions
- theoretical uncertainties from baryon production

NA61/SHINE

- measurement of particle production spectra
- special 'cosmic runs': π^- -C at 158 and 350 GeV/c
- p-C at 31 and 158 GeV/c
- p-p scan from 13 to 158 GeV/c
- first preliminary p+C $\rightarrow \pi$ spectra at 31 GeV/c