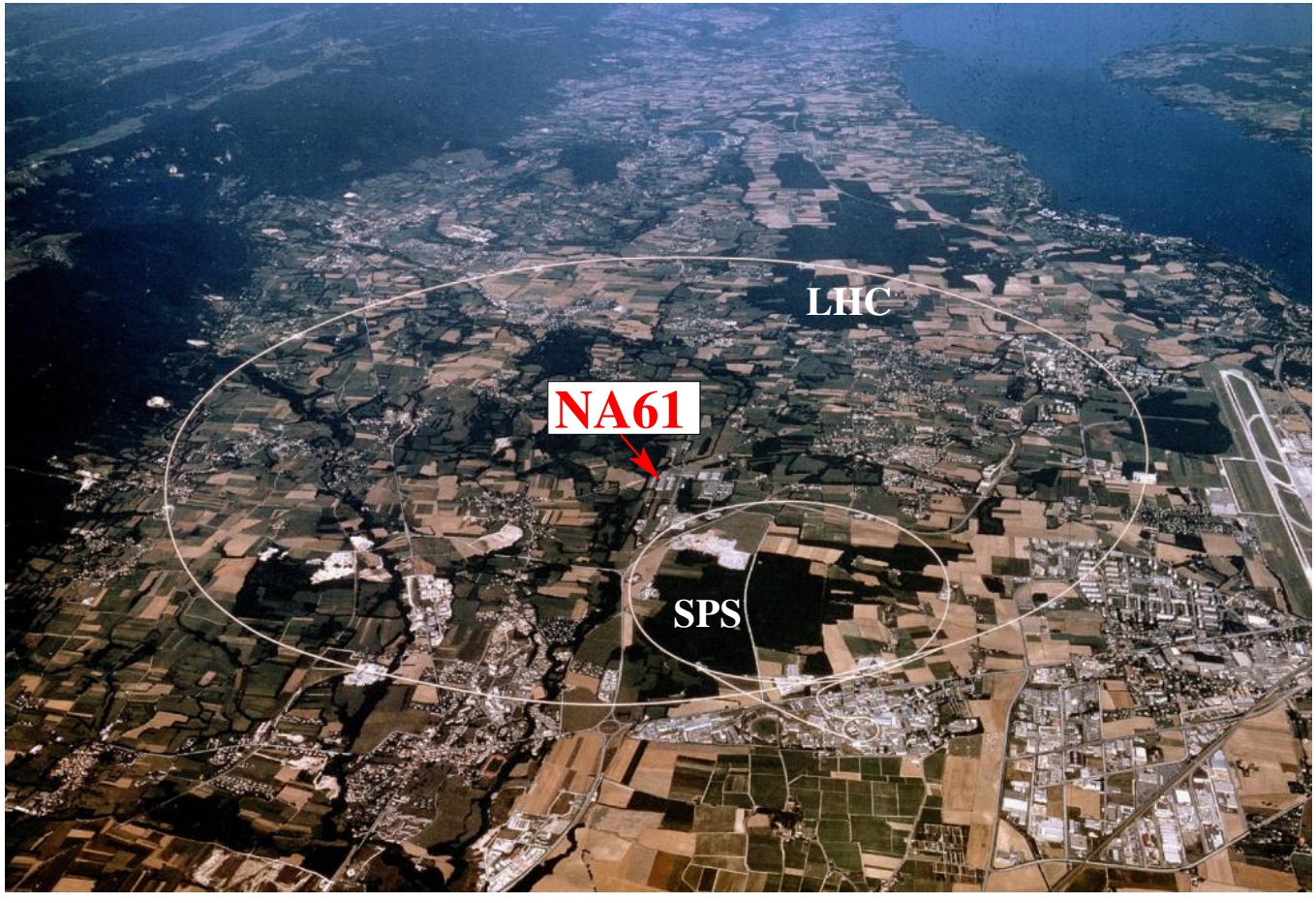
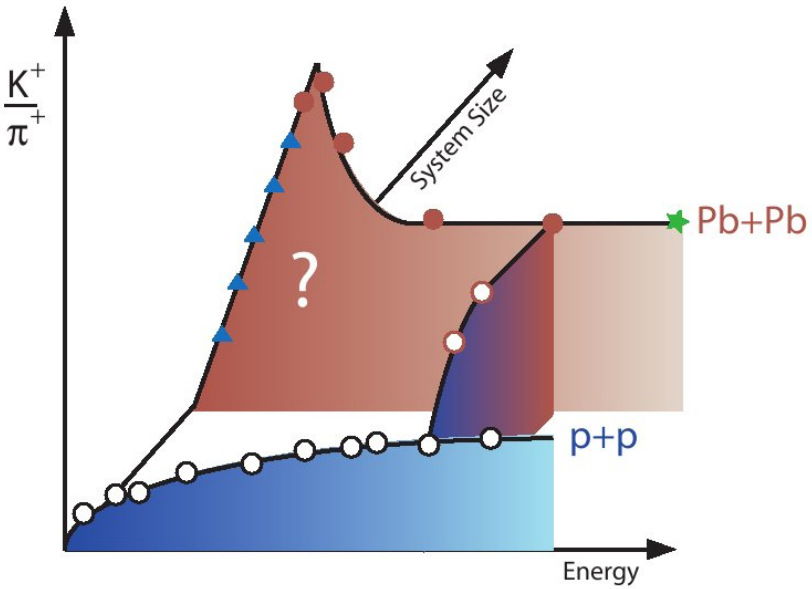
Results from NA61/SHINE

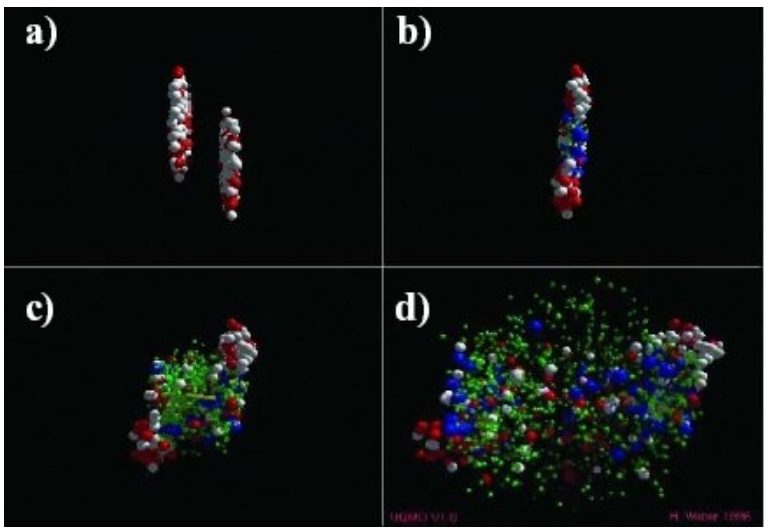
M. Unger* for the NA61 Collaboration

*Karlsruher Institut für Technologie



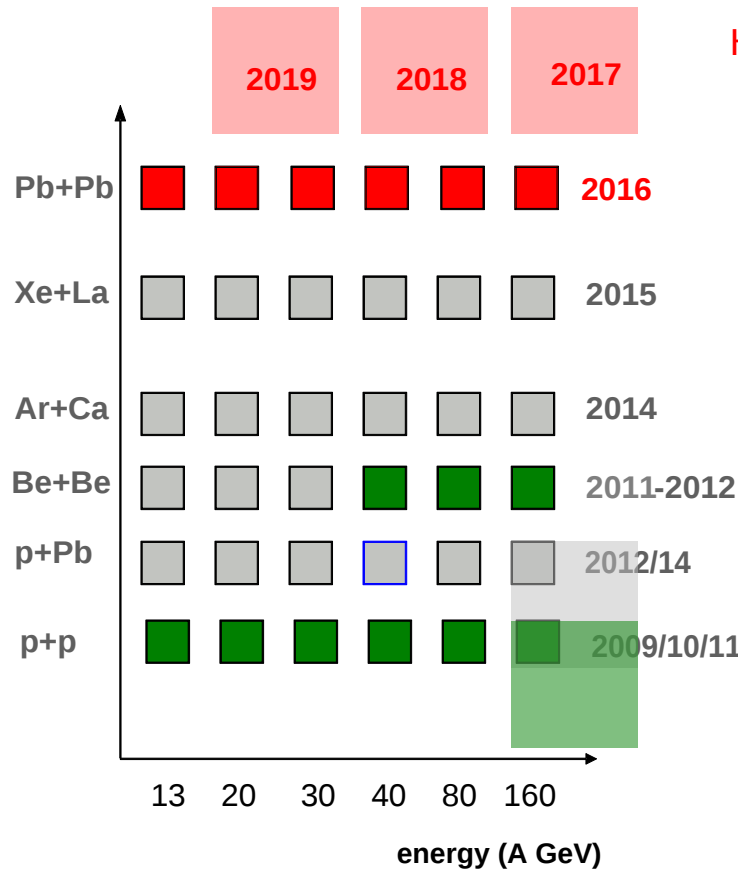
NA61 Physics Program - a) Heavy Ions





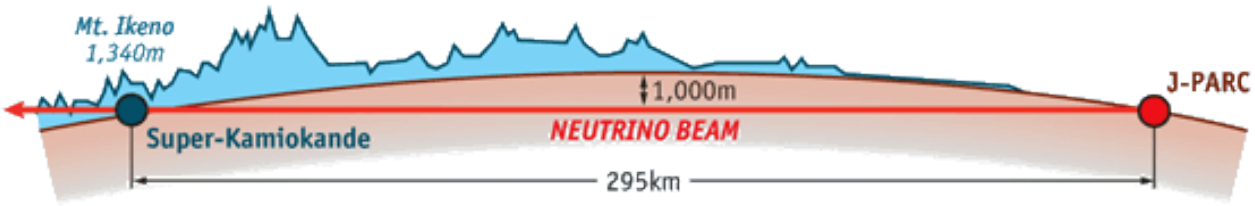
Onset of deconfinement and search for the critical point of strongly interacting matter

extensive scan of system size and energy:



NA61 Physics Program - b) Hadro-Production Measurements for Neutrino Experiments

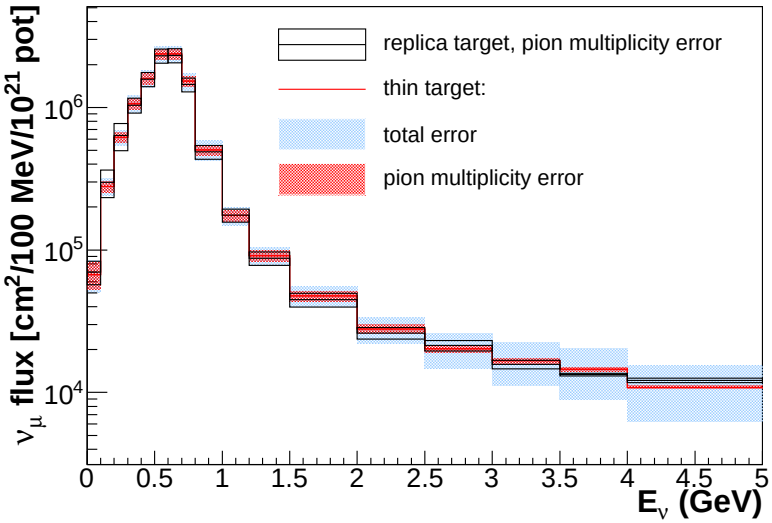
ν-beams for long-baseline neutrino oscillation experiments



T2K replica target at NA61
l=90 cm, ∅=2.6 cm, $\lambda_{\text{int}} = 1.9$

(extension of ν-program for LAGUNA-LBNO and US experiments (MINERνA, MINOS, NOνA) under discussion)

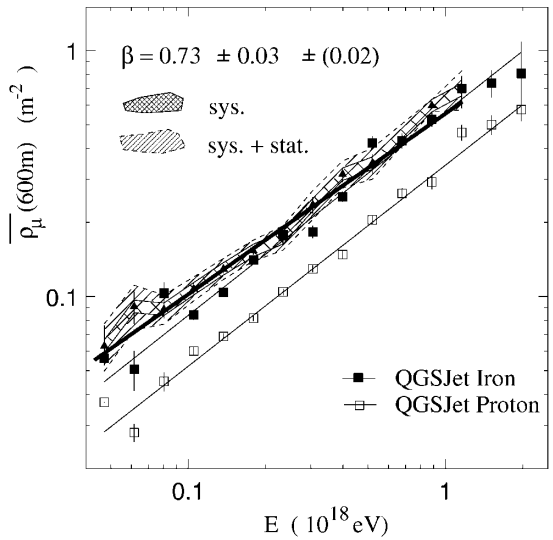
reweighting of T2K beam MC to match NA61 measurements:



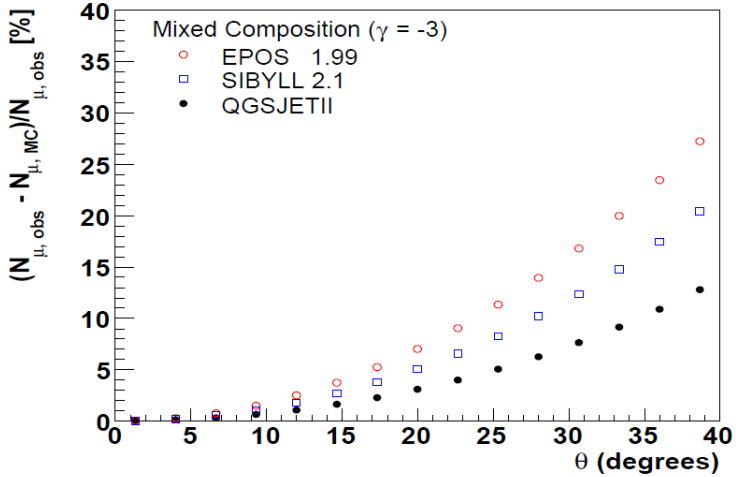
CERN-PH-EP-2012-188, submitted to NIM

NA61 Physics Program - c) Hadro-Production Measurements for Air Shower Experiments

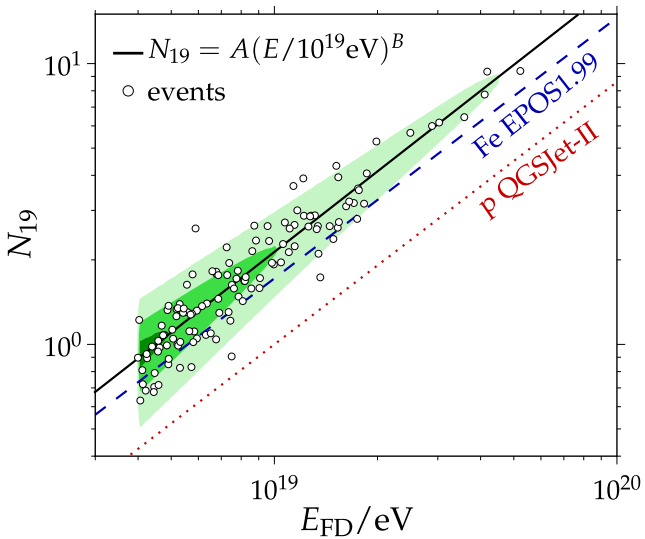
HiRes/MIA



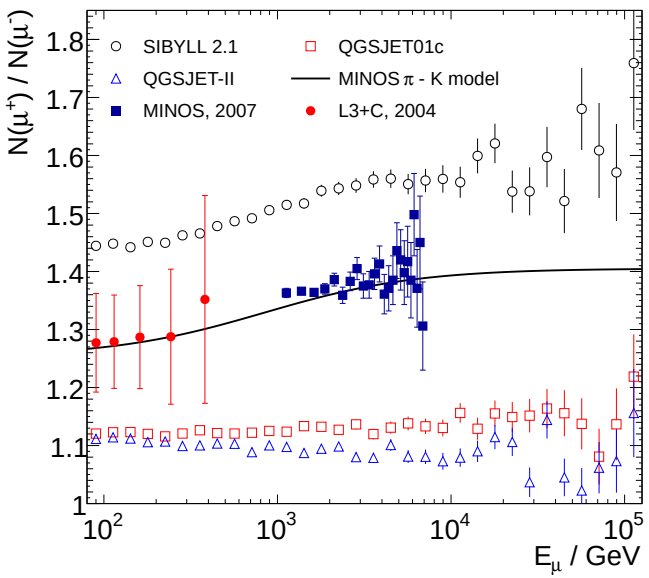
KASCADE-Grande



Pierre Auger Observatory



L3+C/MINOS



arXiv:1206.6710

Muons in UHE Air Showers

energy of last interaction before decay to μ

$$\text{air shower} \rightarrow \text{hadron} + \text{air} \rightarrow \pi/K + X$$

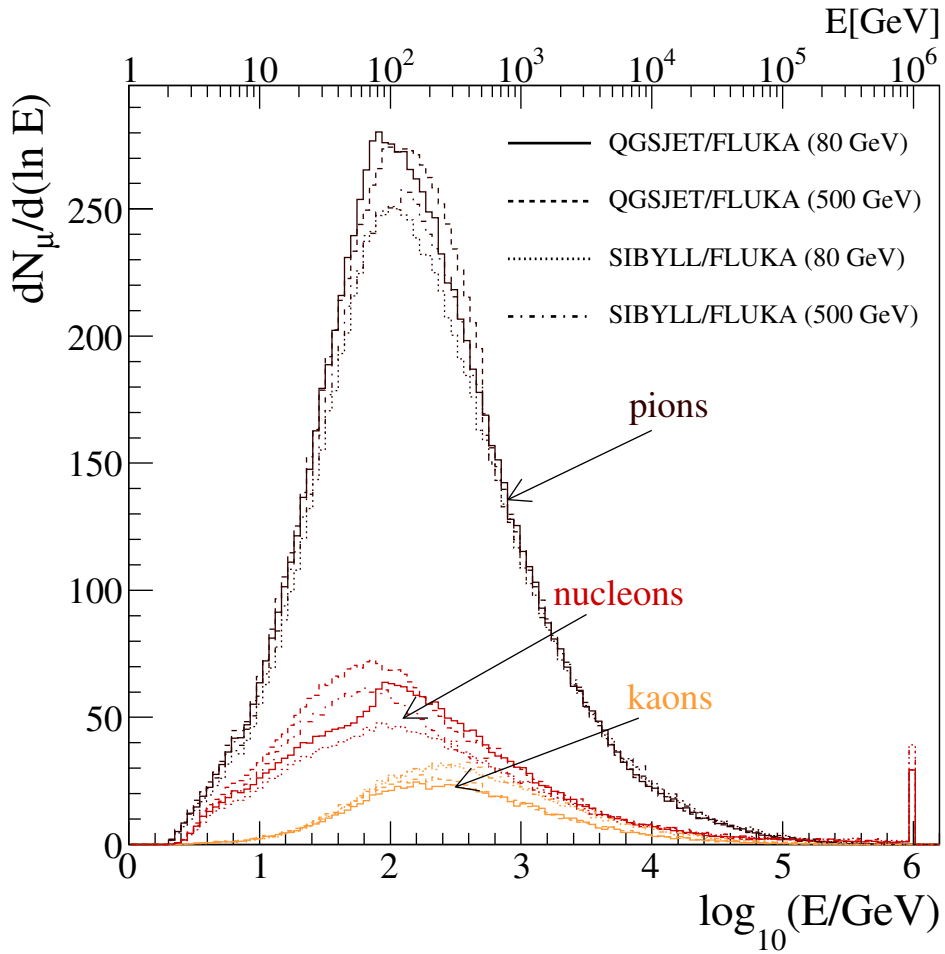
$$\searrow$$

$$\mu + \nu_\mu$$

low energy air shower

e.g. KASCADE:

- $E_0 = 10^{15}$ eV
- $r =$ 40-200 m
- $E_\mu \geqslant 250$ MeV



Muons in UHE Air Showers

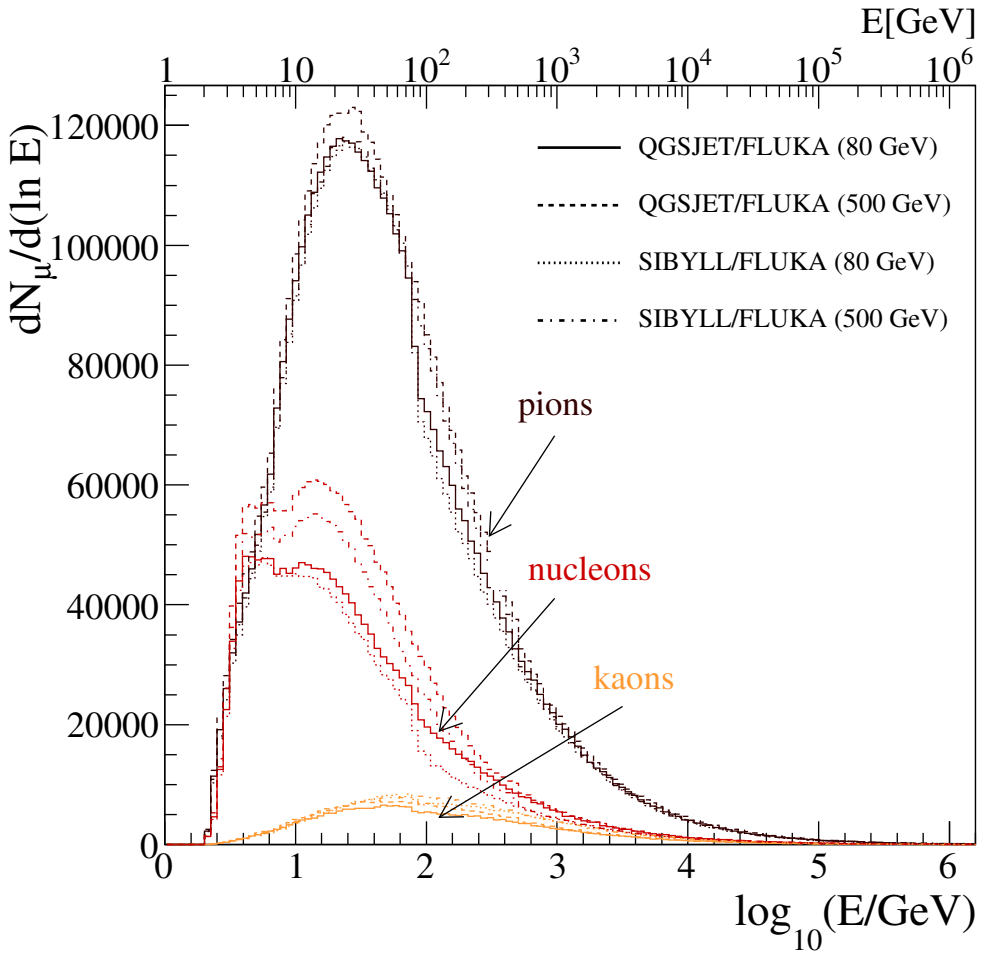
energy of last interaction before decay to μ

$$\text{air shower} \rightarrow \text{hadron} + \text{air} \rightarrow \pi/K + X \searrow \mu + \nu_\mu$$

low energy air shower

e.g. KASCADE:

- $E_0 = 10^{19}$ eV
- $r = 1000$ m
- $E_\mu \geqslant 150$ MeV

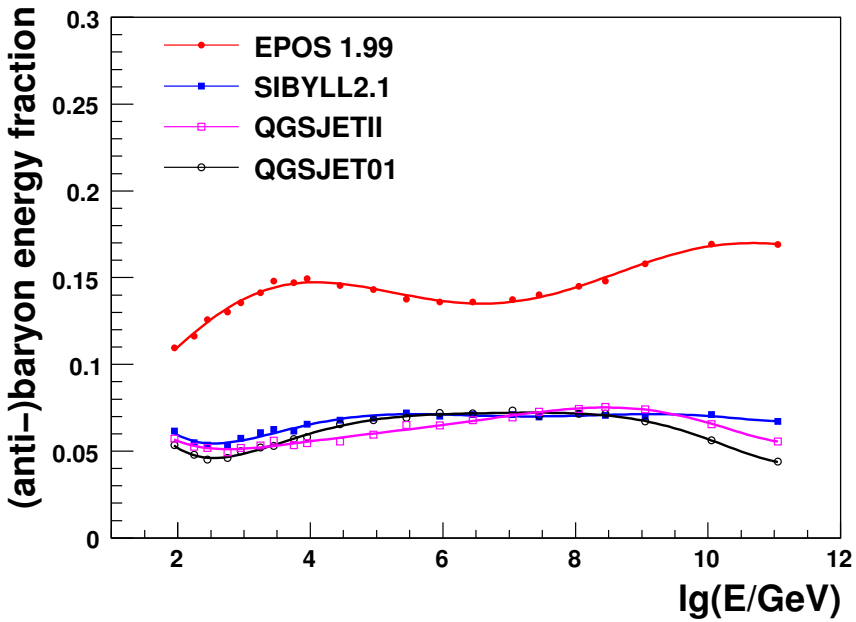


Muons in UHE Air Showers

number of muons depends on energy fraction of produced hadrons

- $\pi^0 \rightarrow$ electromagnetic shower
- $\pi^{\pm}$
- $\rho^0 \rightarrow \pi^+\pi^-$
- (anti-) baryons

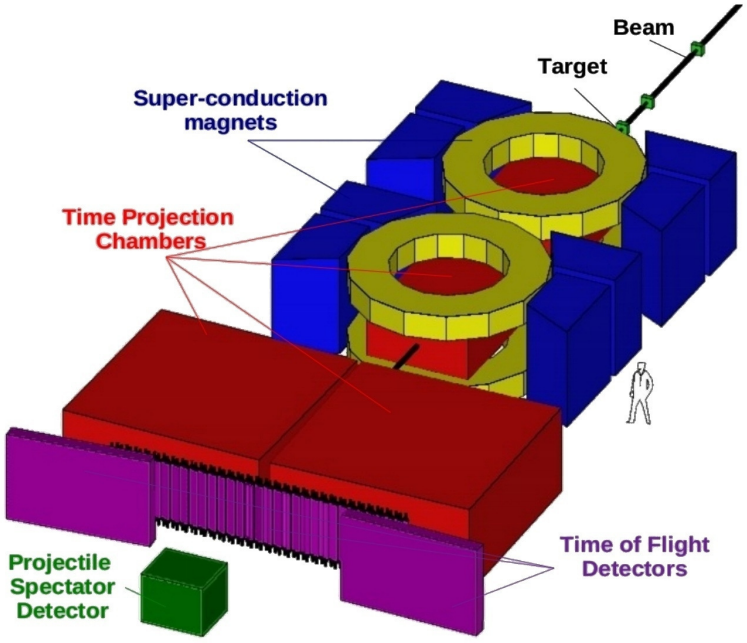
$\Big\} \rightarrow$ hadronic shower

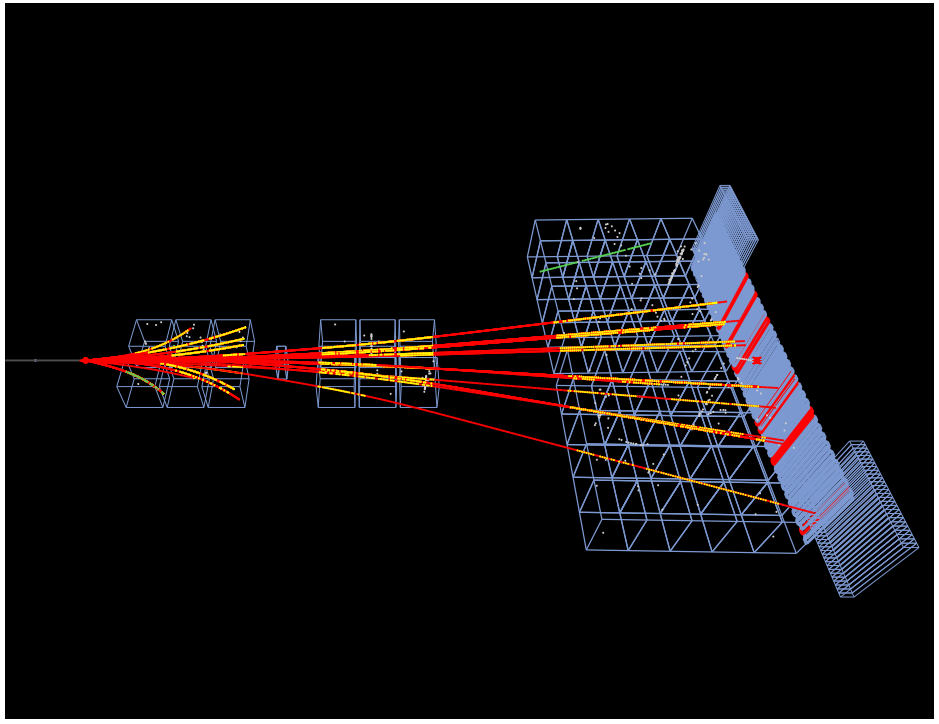


moreover, p_T distribution of parent meson determines radial distribution of muons at ground (given muon production height)

NA61/SHINE Experiment at SPS

π^-+C interaction at 350 GeV/c

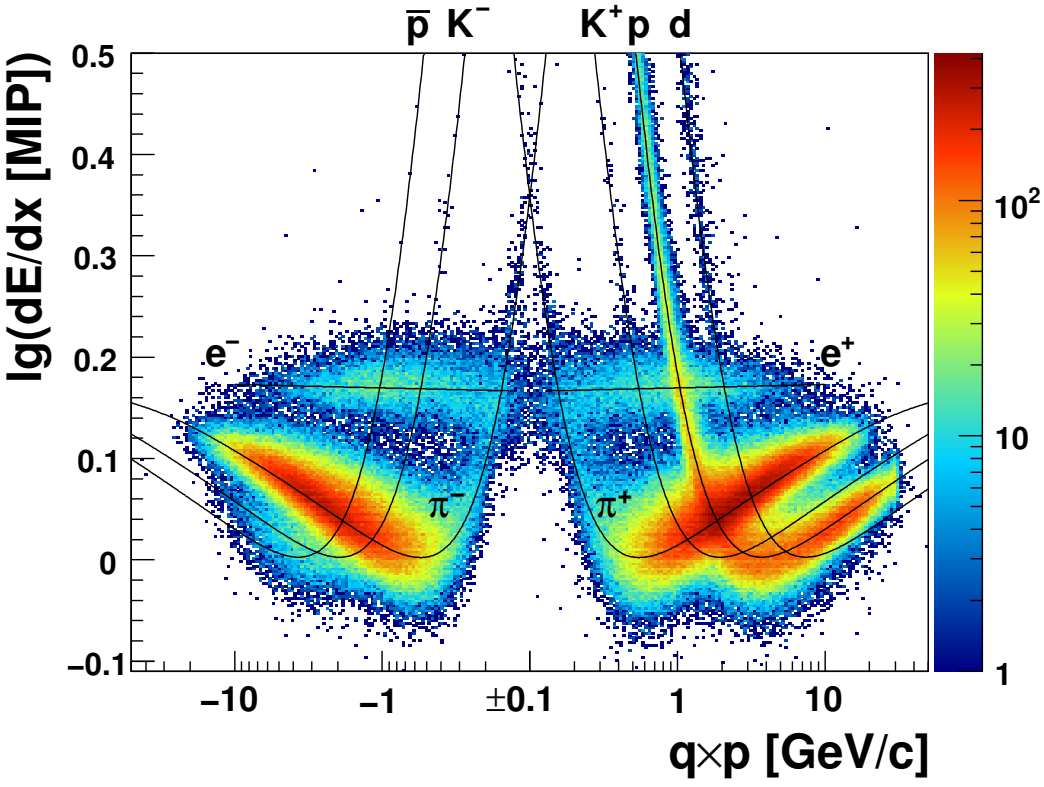




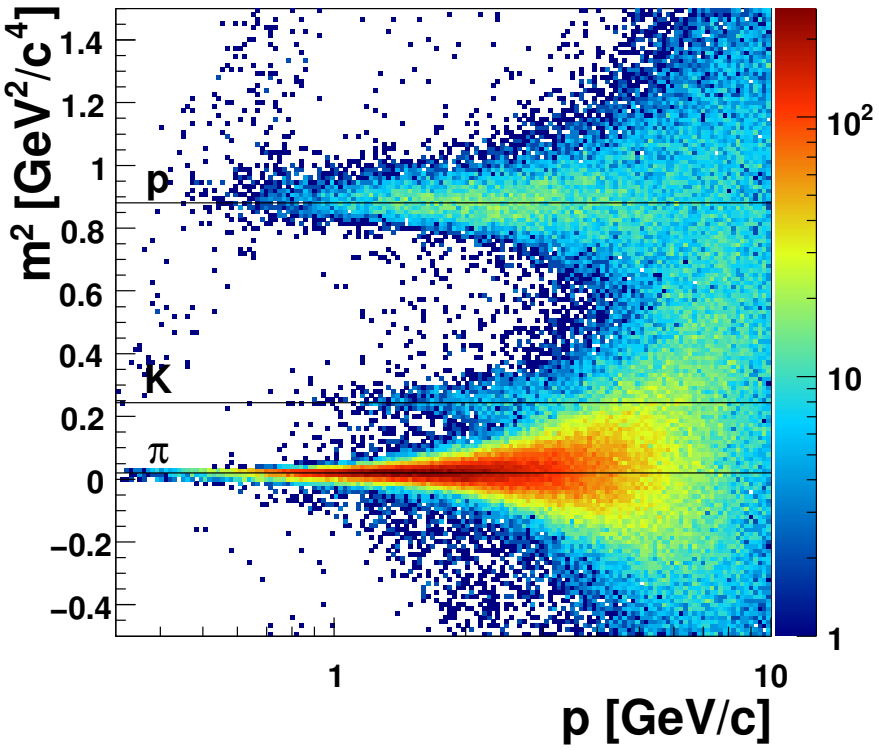
- large acceptance $\approx$ 50% at $p_T \leqslant 2.5\,\mathrm{GeV/c}$
- momentum resolution: $\sigma(p)/p^2 \approx 10^{-4}(\mathrm{GeV/c})^{-1}$
- tracking efficiency: $>$ 95%

Particle Identification

energy deposit in TPC:



time of flight:



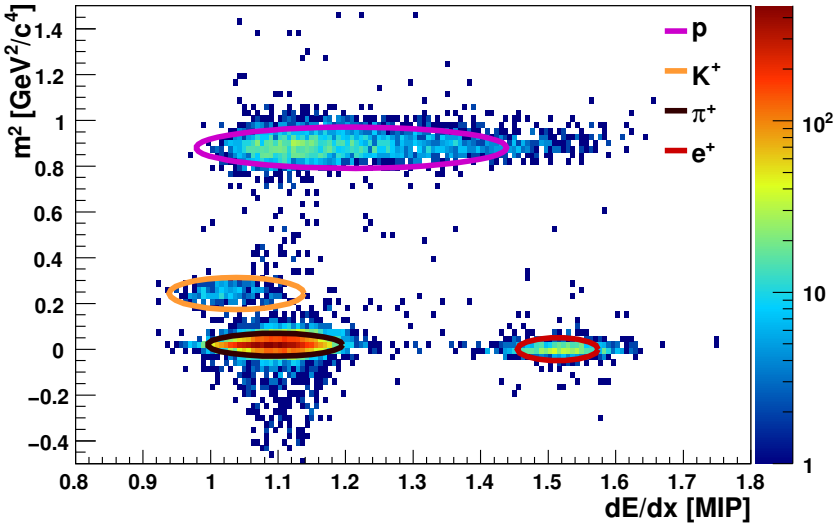
$\sigma\left(\frac{dE}{dx}\right)/\frac{dE}{dx} \approx 4\%$

$\sigma(t) \approx 100\,\mathrm{ps}$

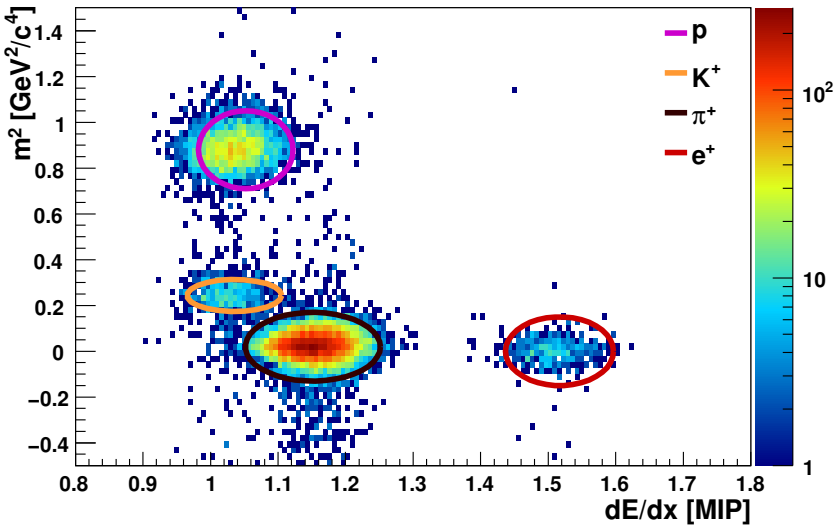
example plots from p+C at 31 GeV/c (2007 data)

Particle Identification

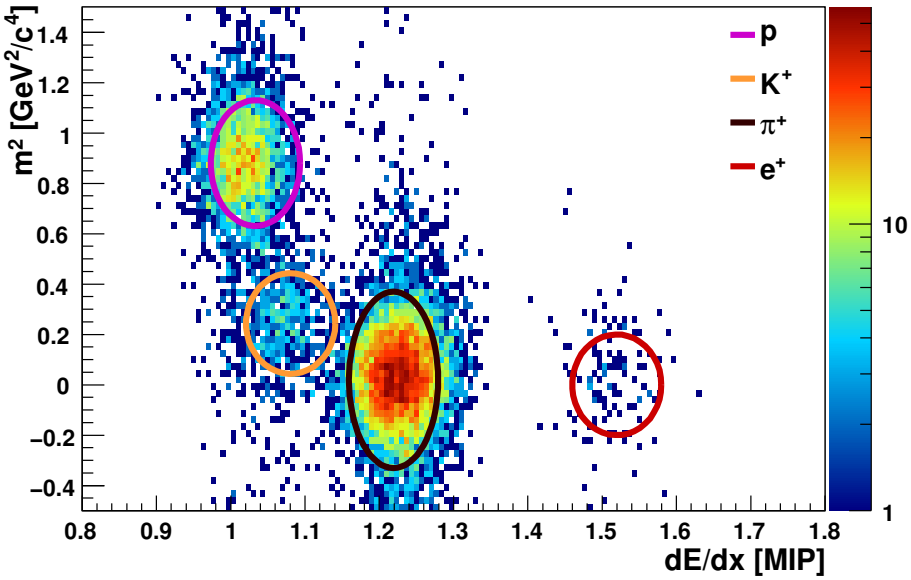
1 GeV/c < p < 2 GeV/c

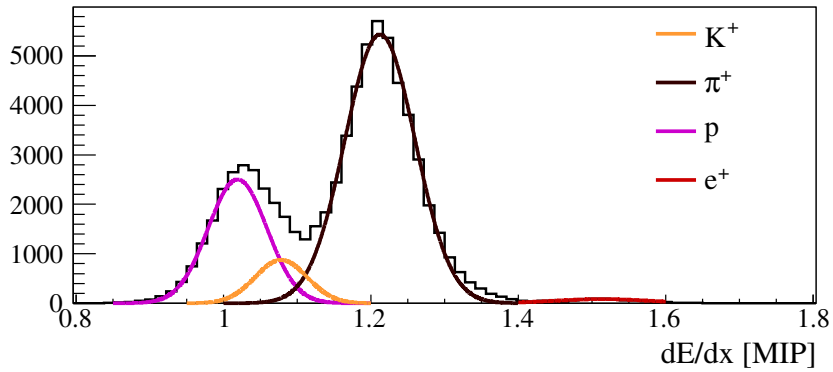


2 GeV/c < p < 3 GeV/c

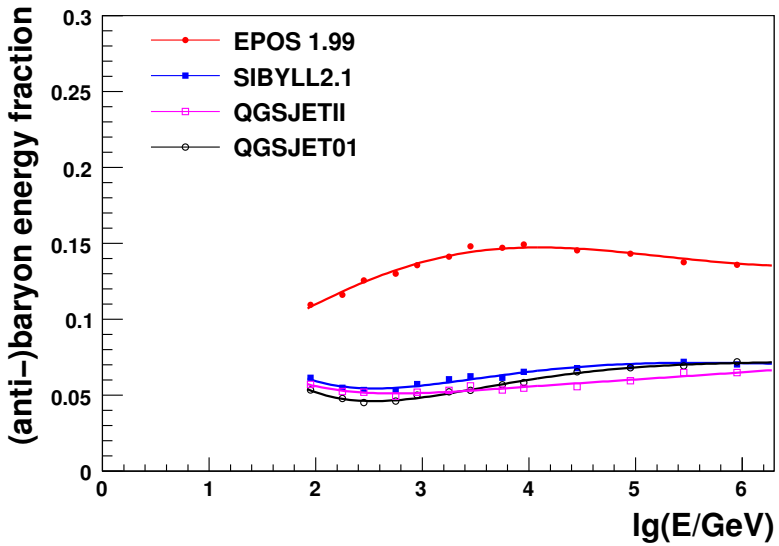


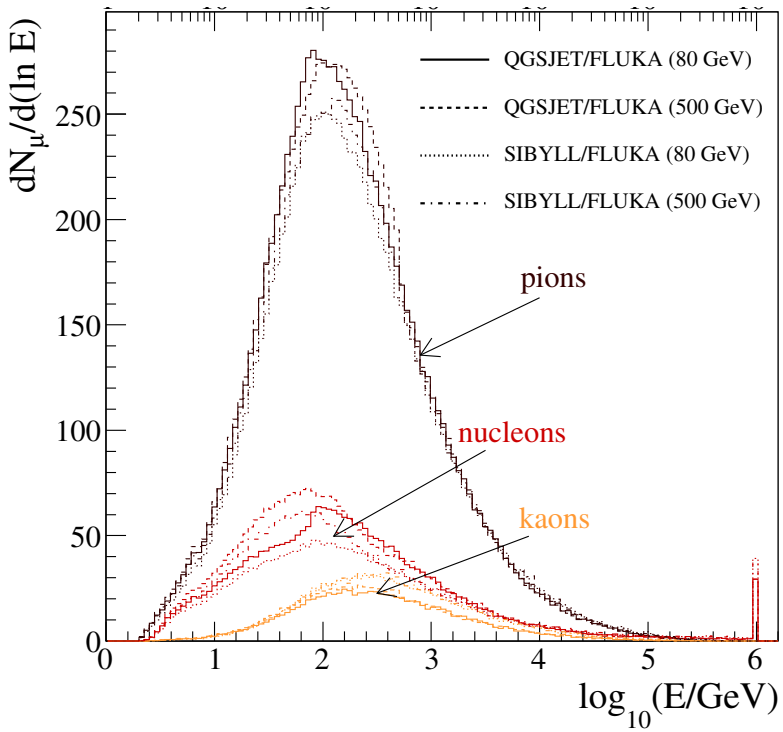
4 GeV/c < p < 5 GeV/c





NA61 hadron production data (hadron-nucleus)





	p	yr	N_{trig}
π^-+C	158	2009	5.5
π^-+C	350	2009	4.6
p+C	31	2007	0.7
p+C	31	2009	5.4
p+p	13	2010	0.7
p+p	13	2011	1.4
p+p	20	2009	2.2
p+p	31	2009	3.1
p+p	40	2009	5.2
p+p	80	2009	4.5
p+p	158	2009	3.5
p+p	158	2010	44
p+p	158	2011	15
p+Pb	158	2012	4.5

- beam momentum p in [GeV/c],
- number of triggers N_{trig} in [10^6] (~85% interaction triggers and ~15% beam triggers)

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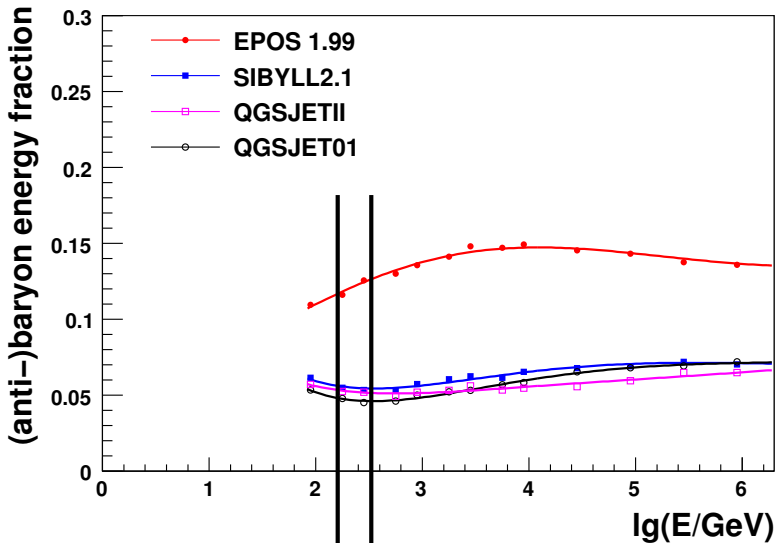

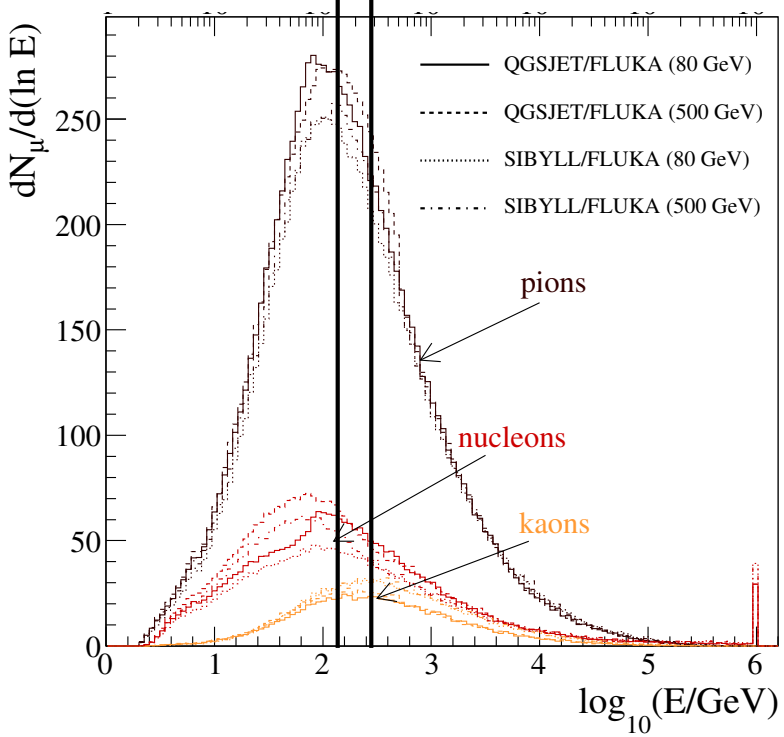

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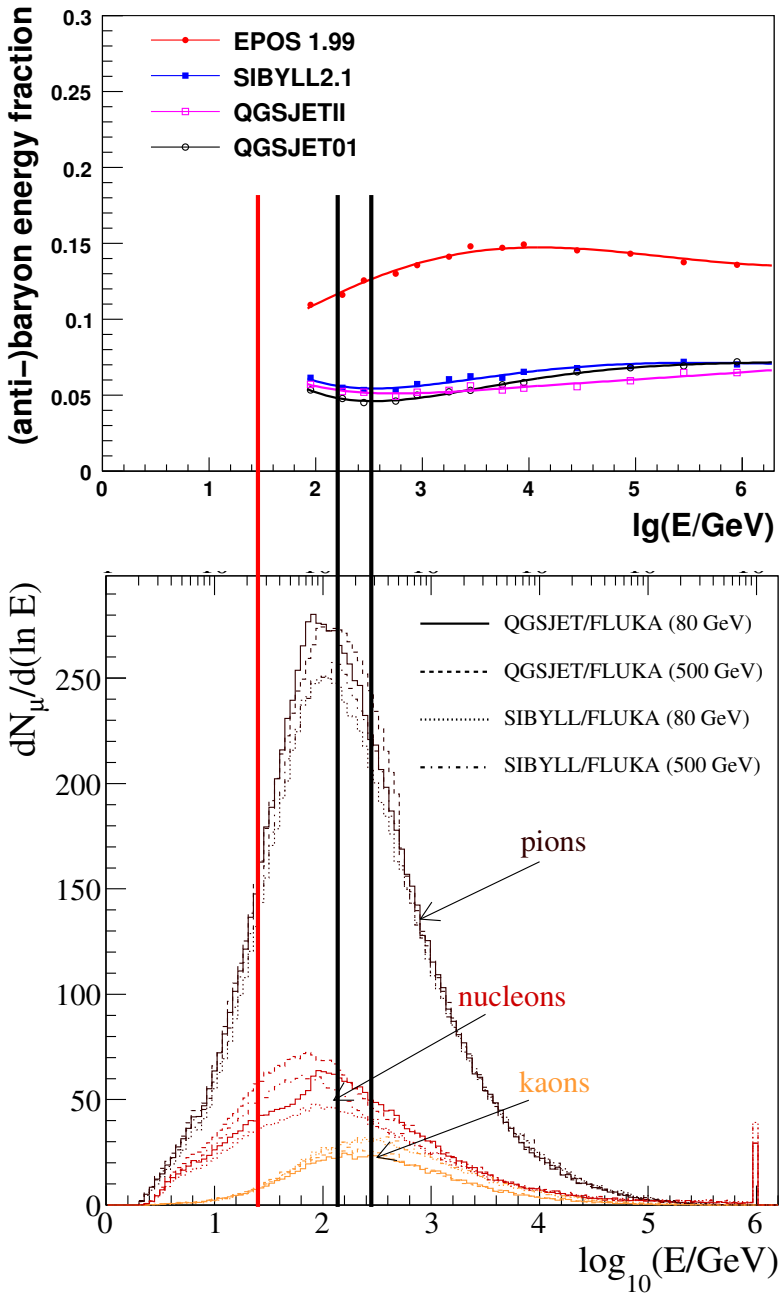

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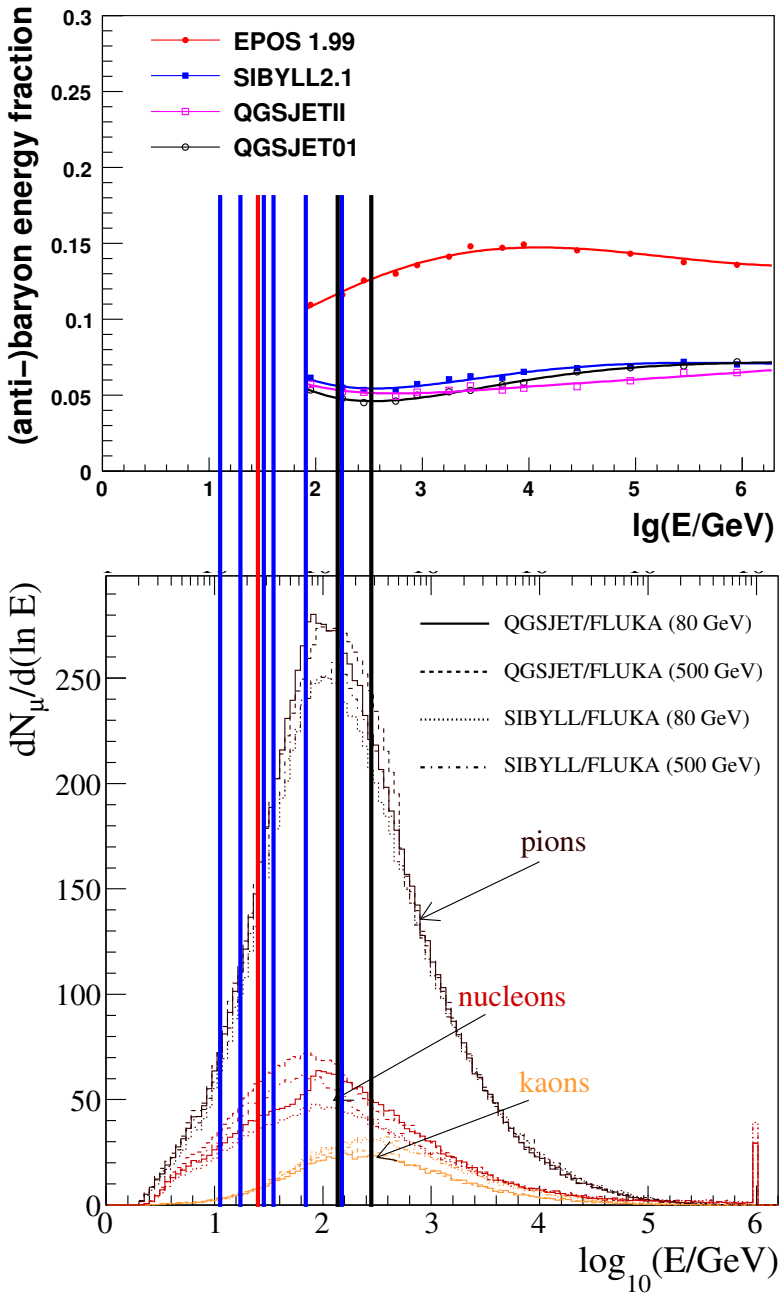

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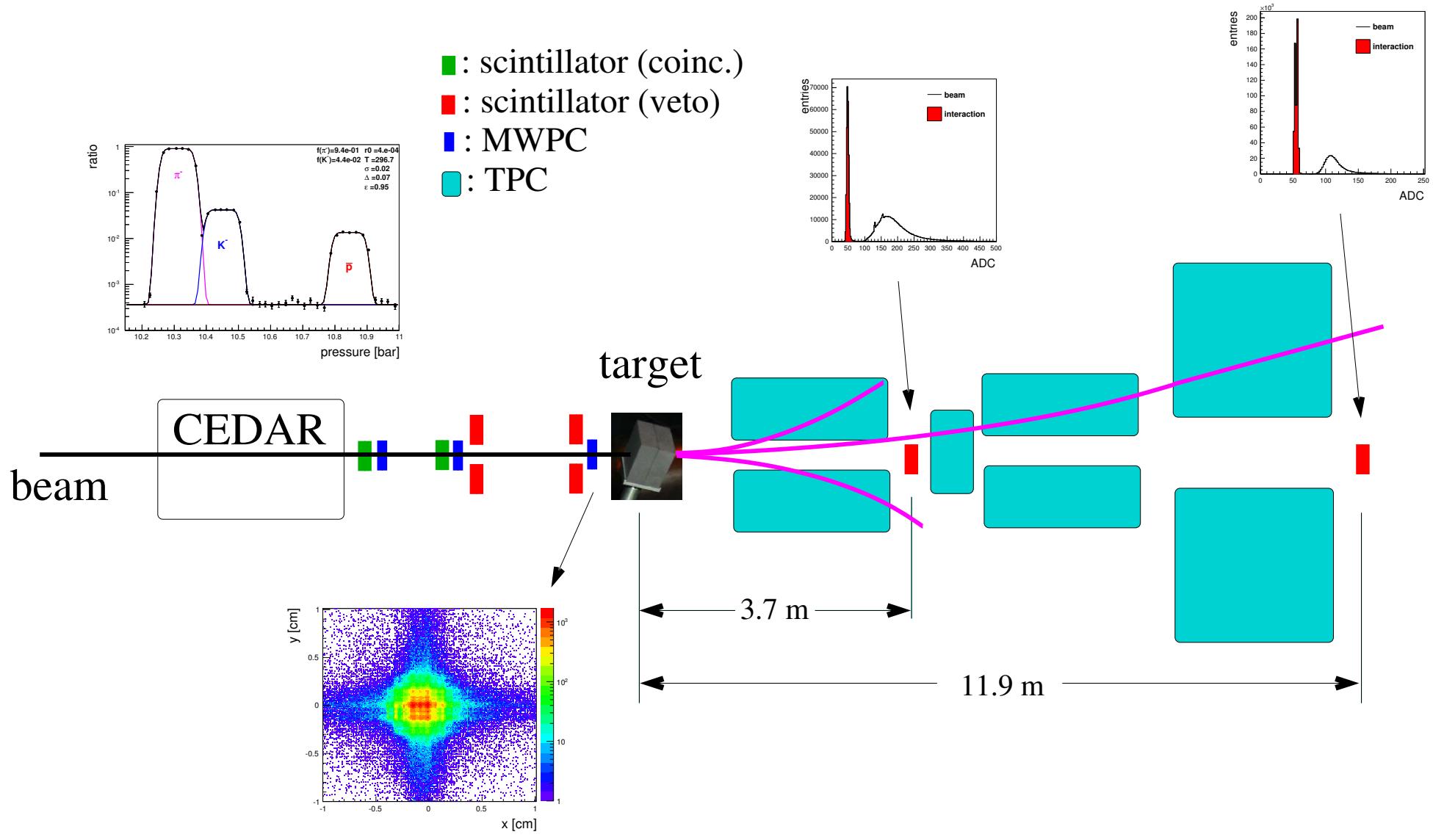
- beam momentum p in [GeV/c],
- number of triggers N_{trig} in [10^6] (~85% interaction triggers and ~15% beam triggers)

Cross Section Measurements with NA61

Schematic of Beam Line:

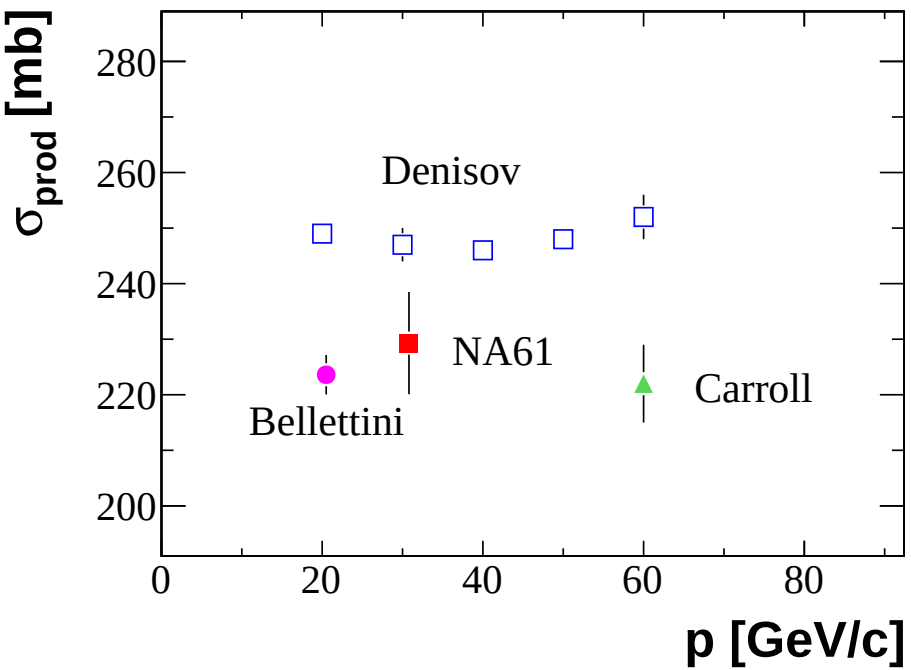


Cross Section Measurements with NA61

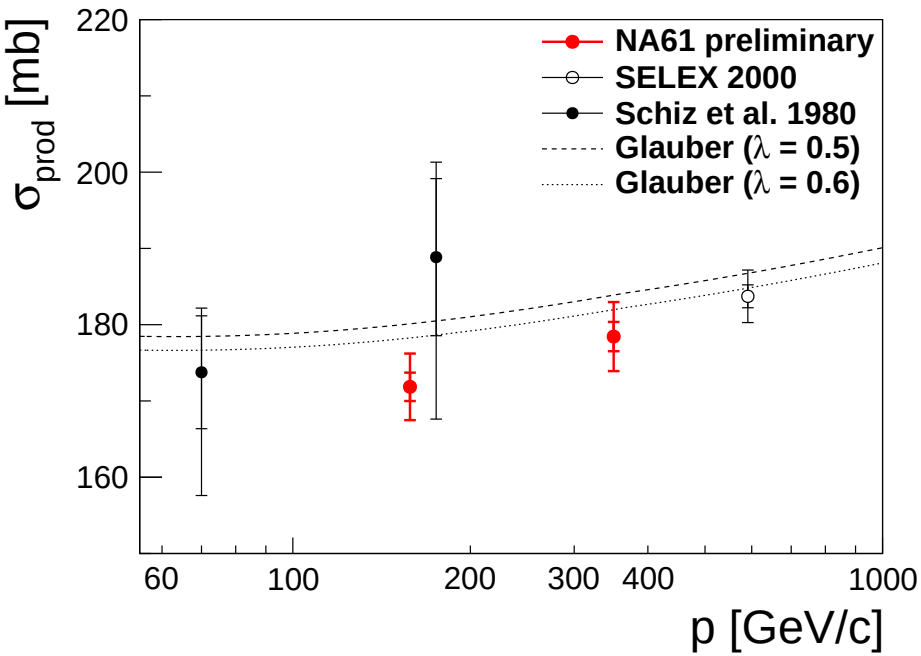
production cross sections:

$$\sigma_{\text{prod}} = \sigma_{\text{tot}} - \sigma_{\text{qela}} - \sigma_{\text{ela}}$$

p+C at 31 GeV/c



π^-+C at 158 and 350 GeV/c



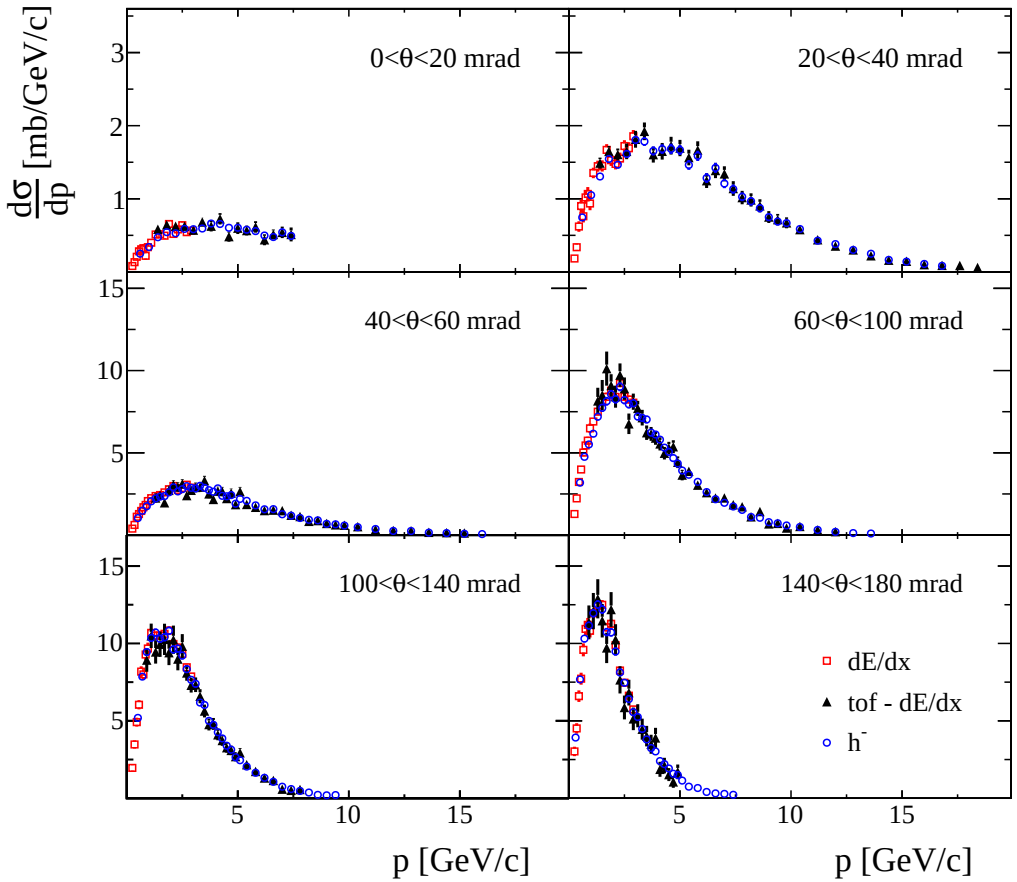
Analysis of 2007 data (p + C at 31 GeV/c)

three independent analyses:

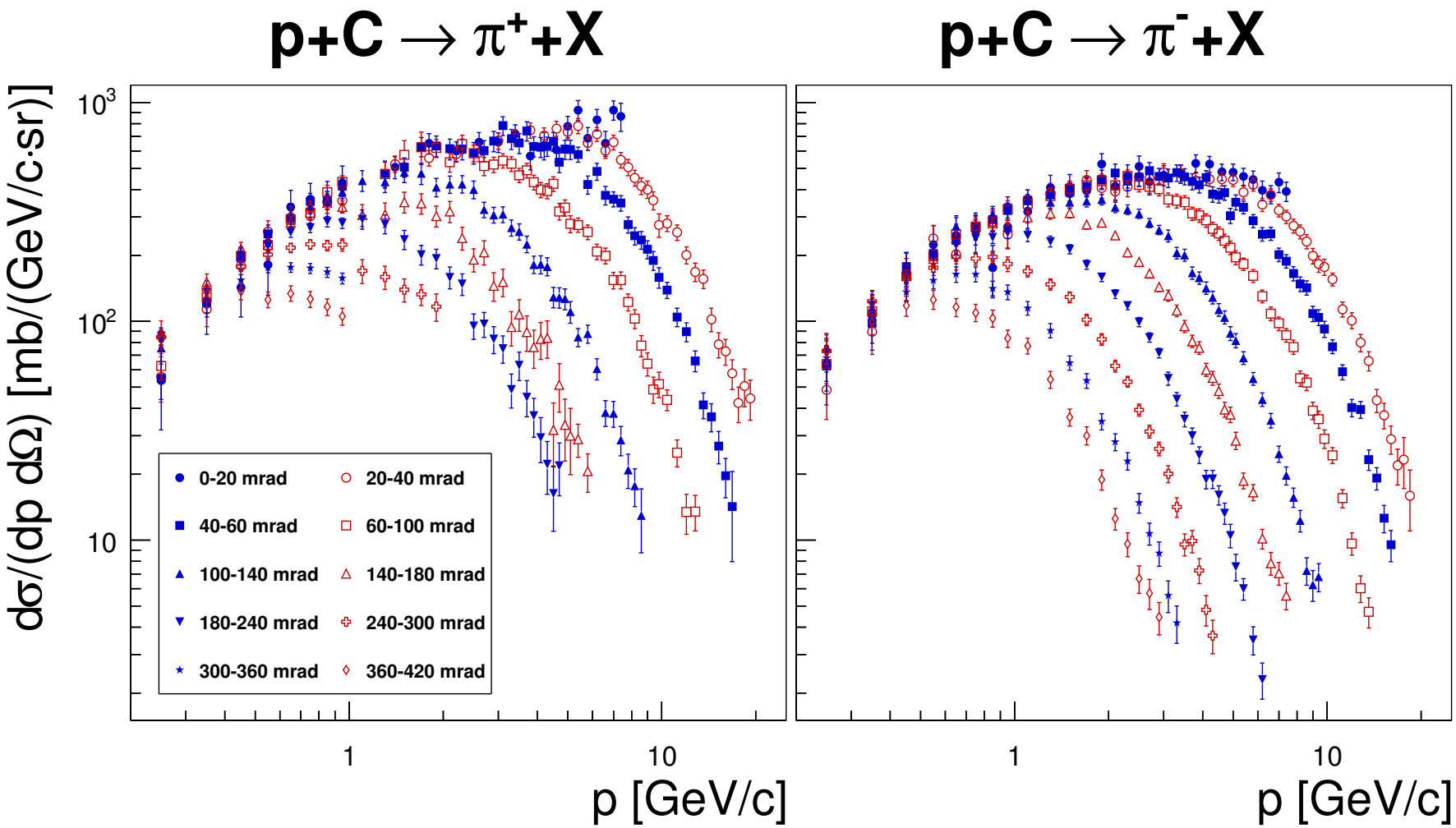
- negative hadrons (model corr.)
- dE/dx-only at low *p*
- dE/dx and TOF at medium *p*

spectrum corrections

- acceptance $\geqslant$ 99%
- reconstruction efficiency $\geqslant$ 96%
- pion decay $\leqslant$ 10%
- feed-down $\leqslant$ 10%

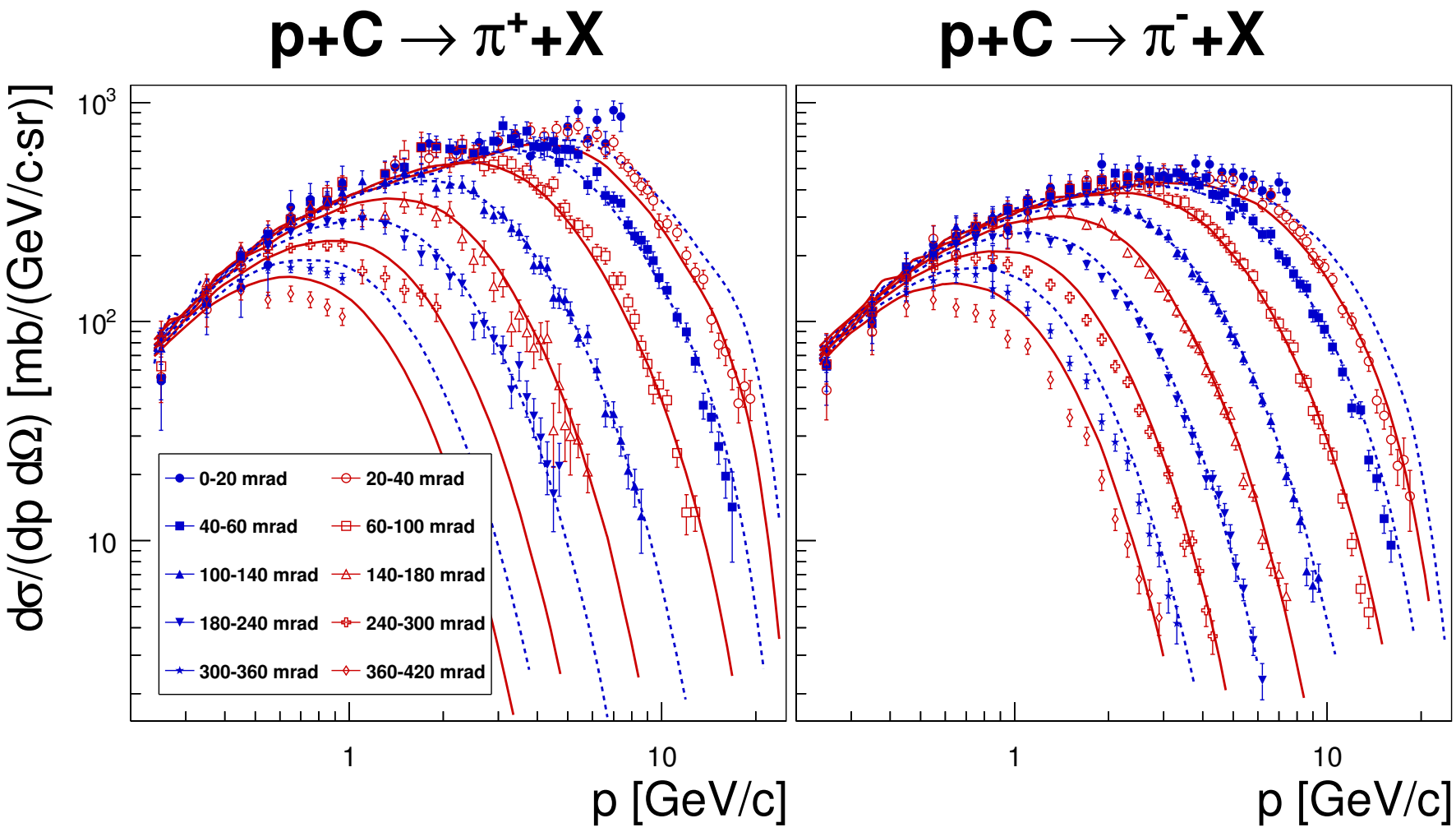


Inclusive $\pi^{\pm}$ spectra in p+C at 31 GeV/c



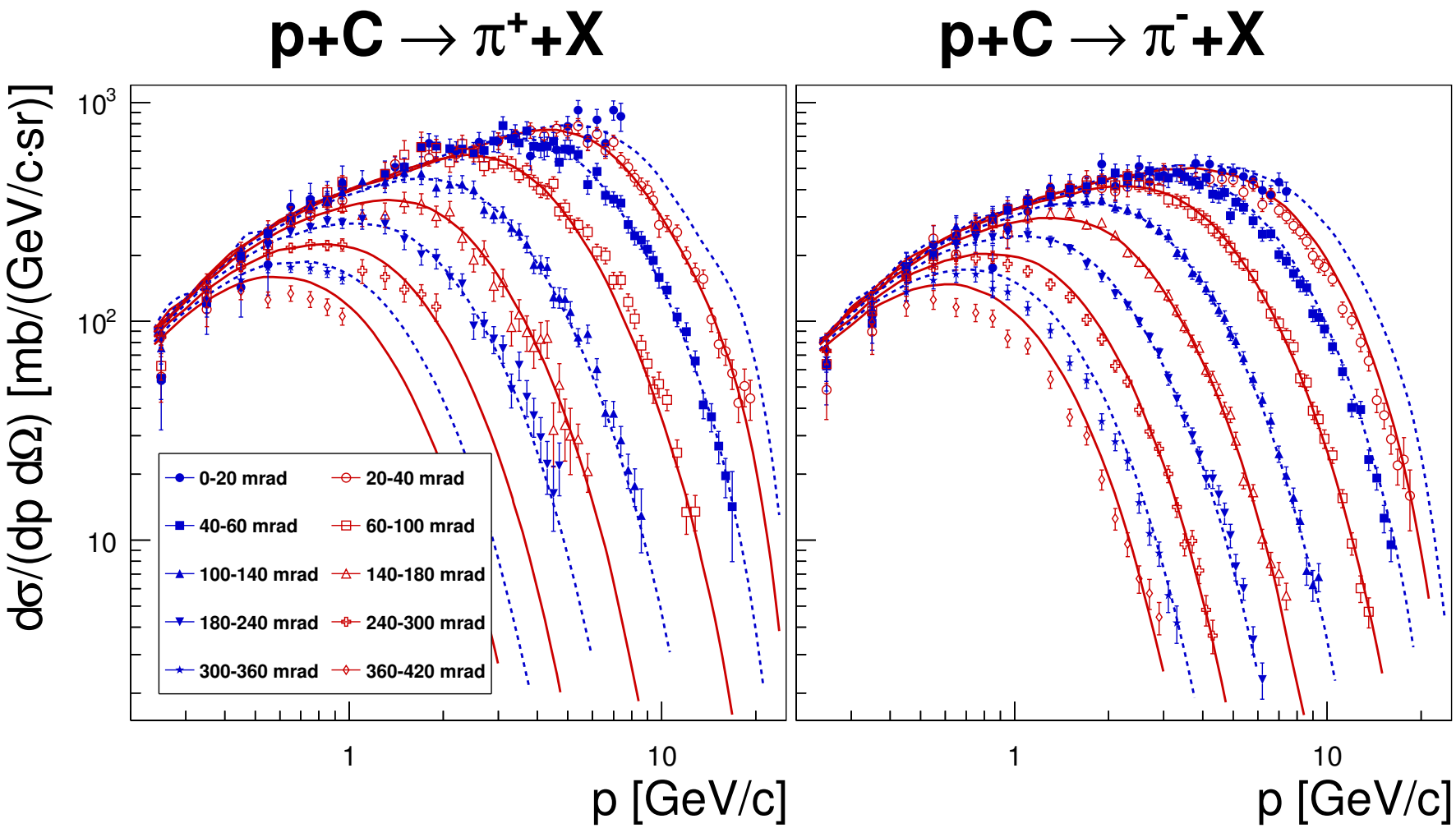
NA61/SHINE, Phys. Rev. C84 (2011) 034604

Inclusive $\pi^{\pm}$ spectra in p+C at 31 GeV/c



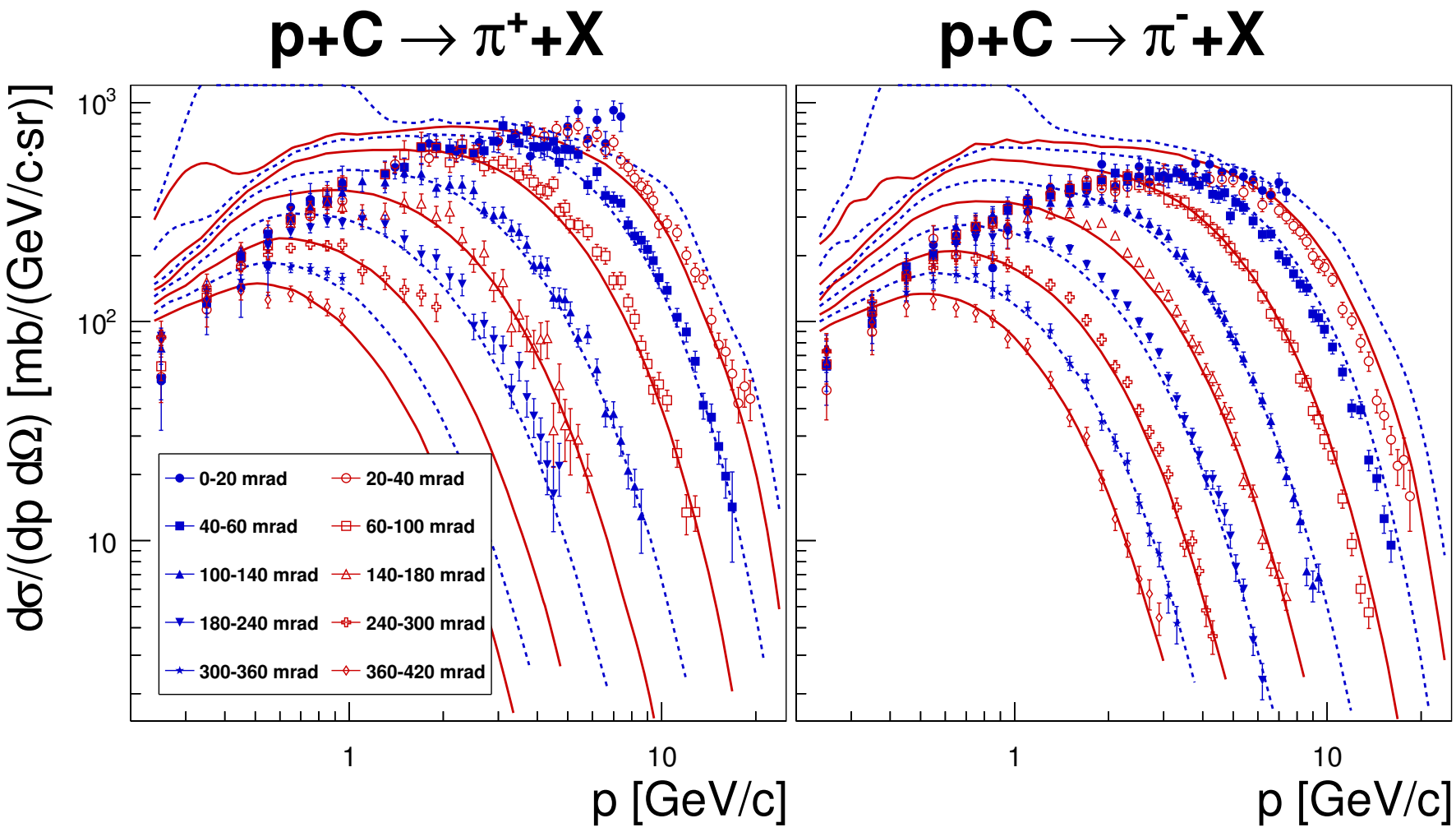
comparison to FLUKA2008.3b

Inclusive $\pi^{\pm}$ spectra in p+C at 31 GeV/c



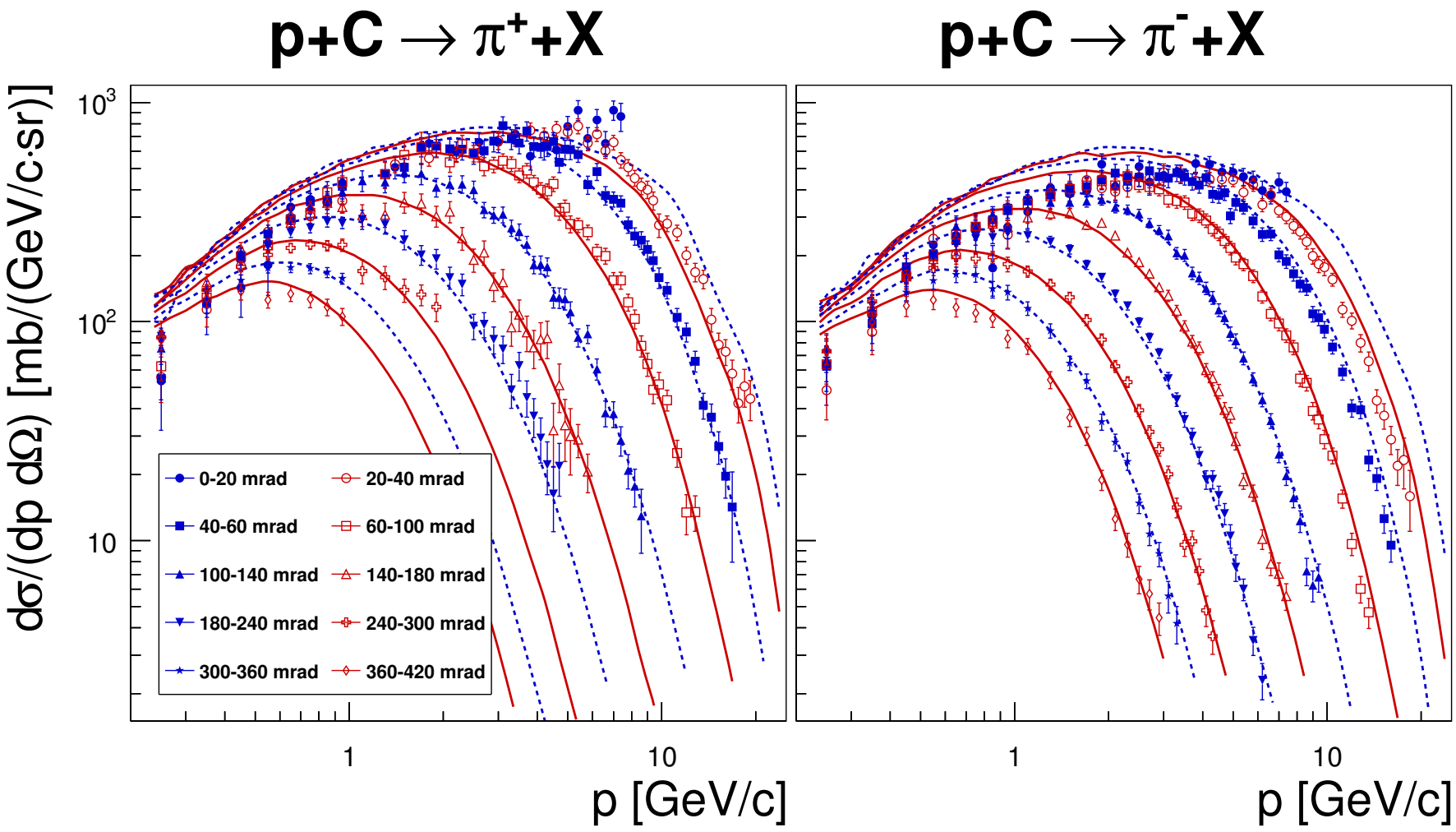
comparison to FLUKA2011.2.8

Inclusive $\pi^{\pm}$ spectra in p+C at 31 GeV/c



comparison to UrQMD1.3.1

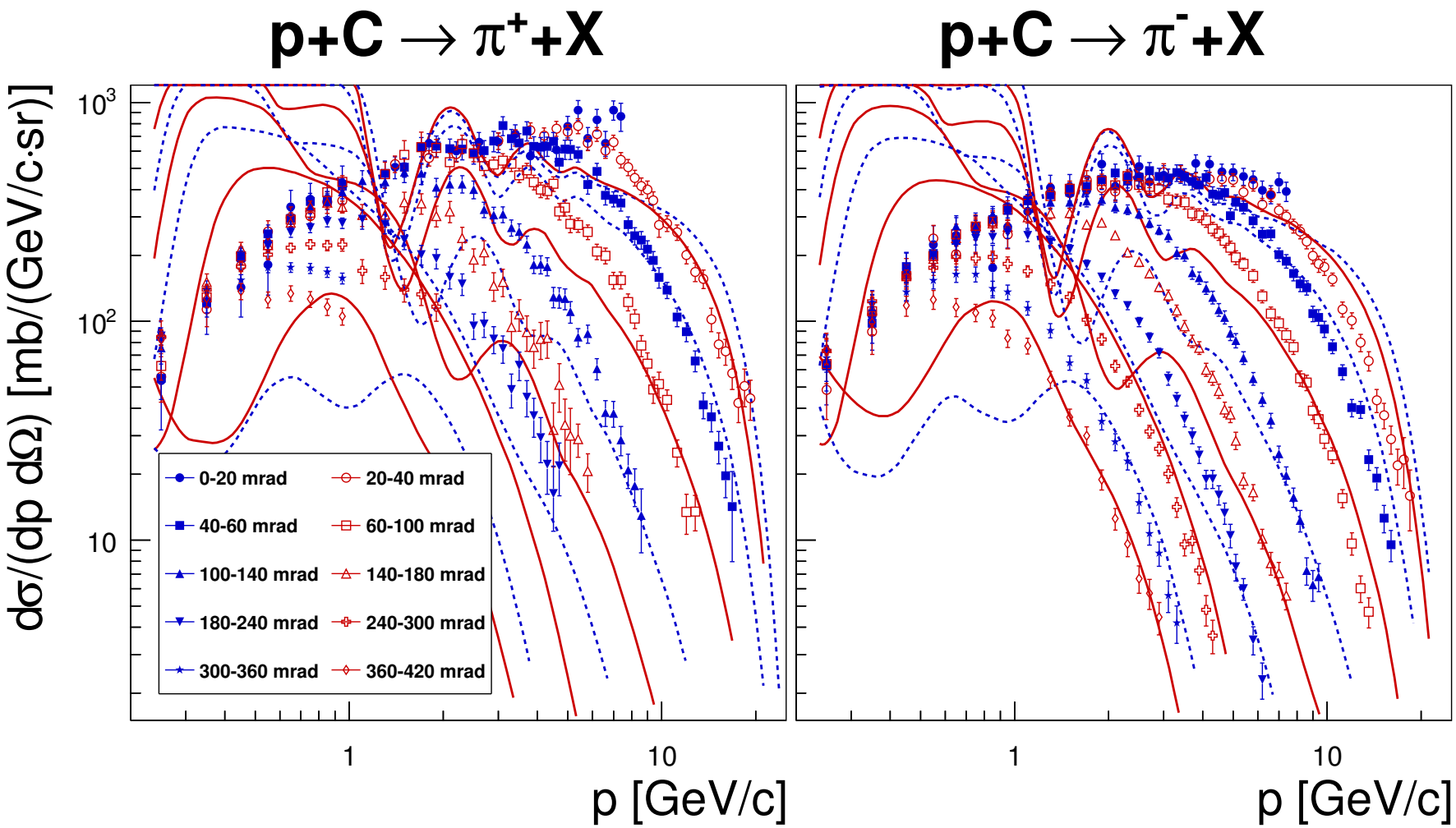
Inclusive $\pi^{\pm}$ spectra in p+C at 31 GeV/c



comparison to patched UrQMD1.3.1

(V. Uzhinsky, arXiv:1107.0374v1 [hep-ph])

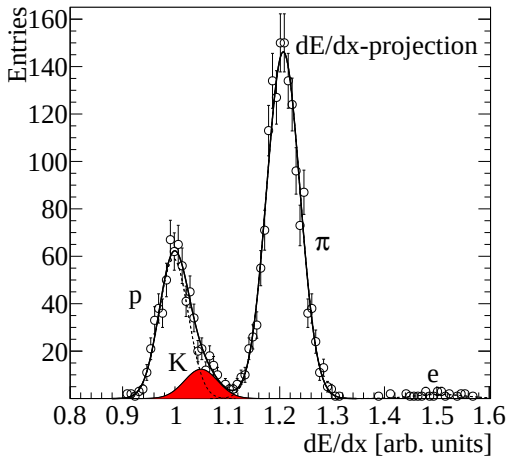
Inclusive $\pi^{\pm}$ spectra in p+C at 31 GeV/c

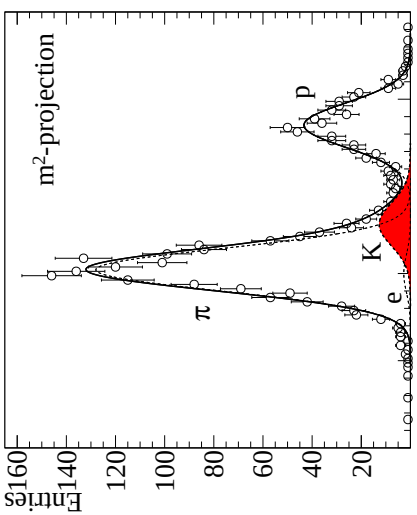


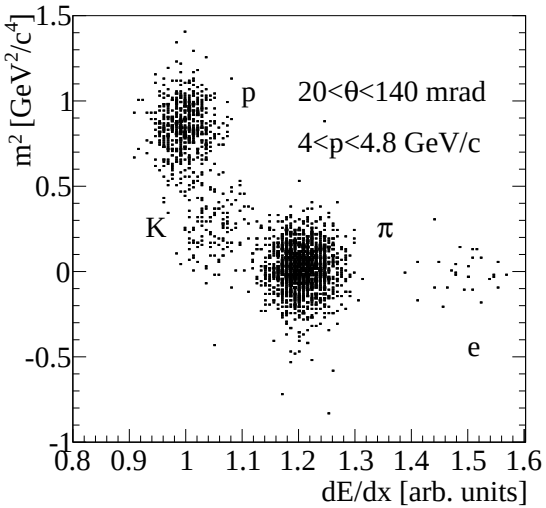
comparison to Gheisha2002

Results on Kaon Production in p+C at 31 GeV/c

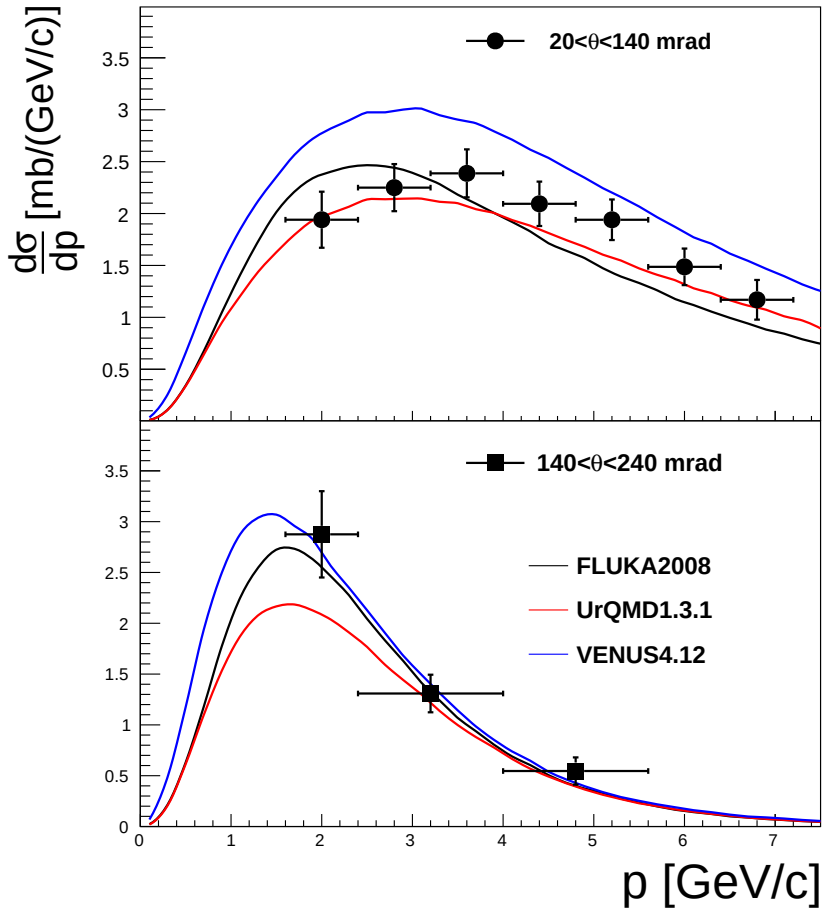
two-dimensional fit:







K^+ Yield:

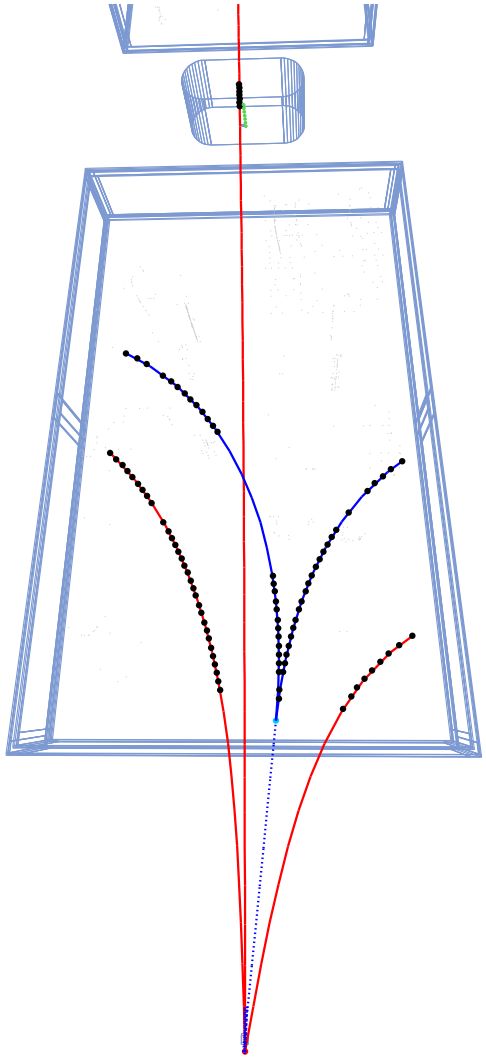


NA61/SHINE, Phys. Rev. C85 (2012) 035210

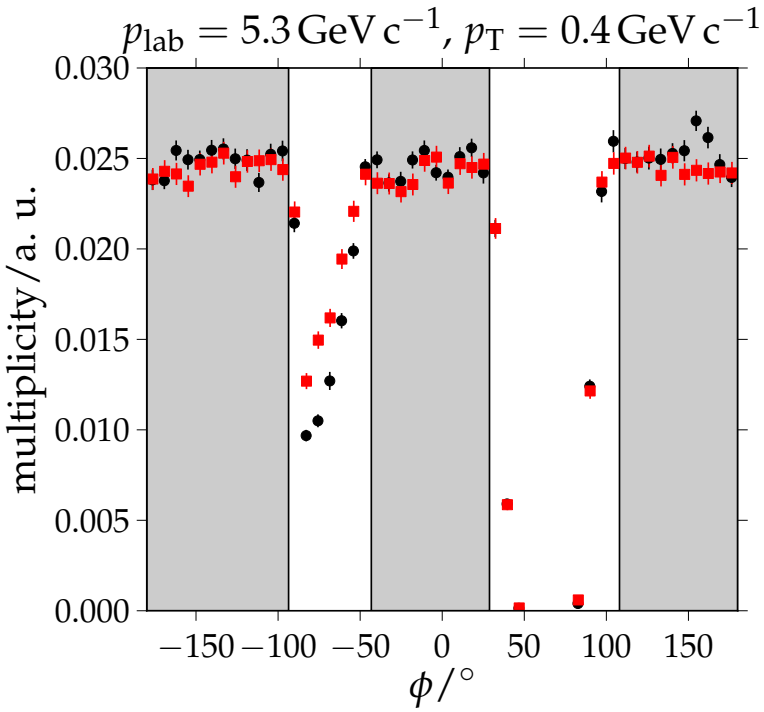
Analysis of π^-+C data

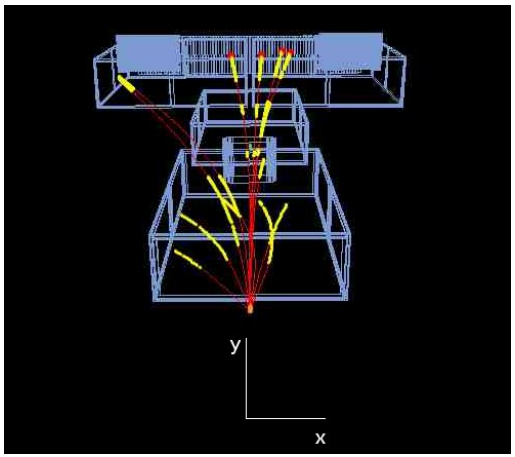
- currently: charged hadrons (no PID)
- tracks from main vertex
- correct for
  - feed-down
  - secondary interaction
  - track loss

  using MC, but *no* correction $h^- \rightarrow \pi^-$
- fiducial ϕ cuts for geometrical acceptance
- zero-bias data set (beam trigger) to correct min-bias data



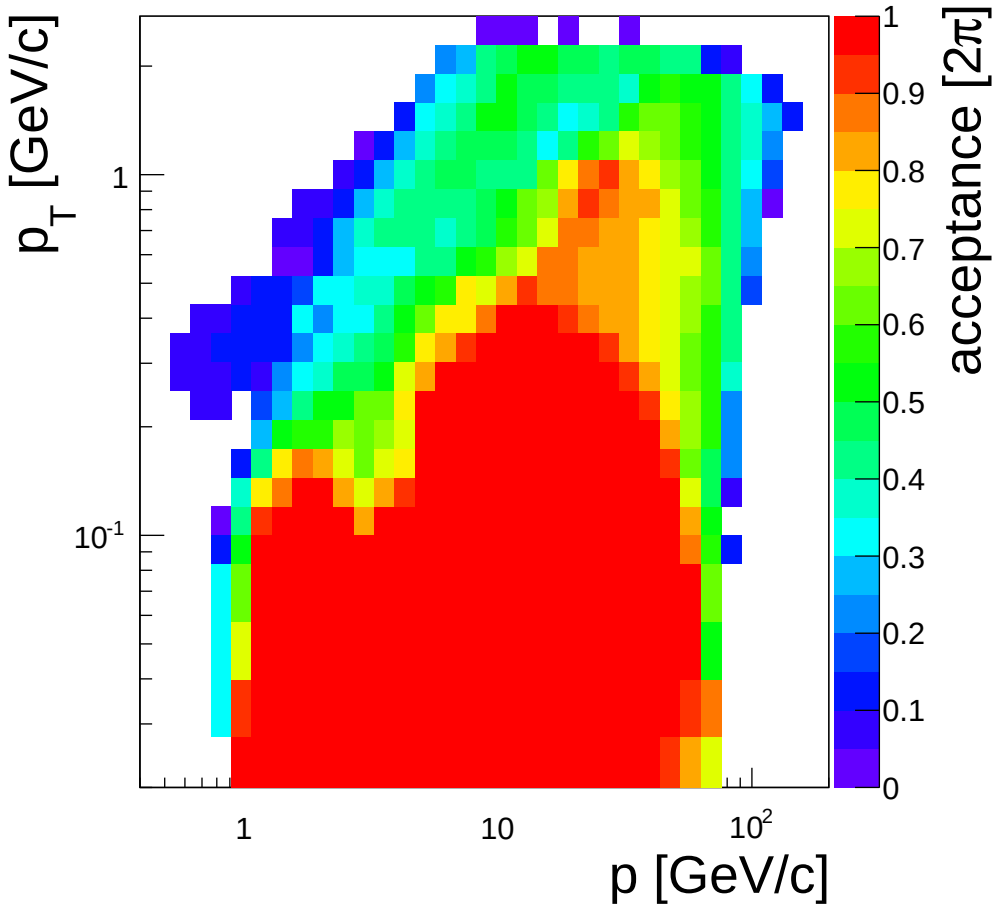
Analysis of π^-+C data





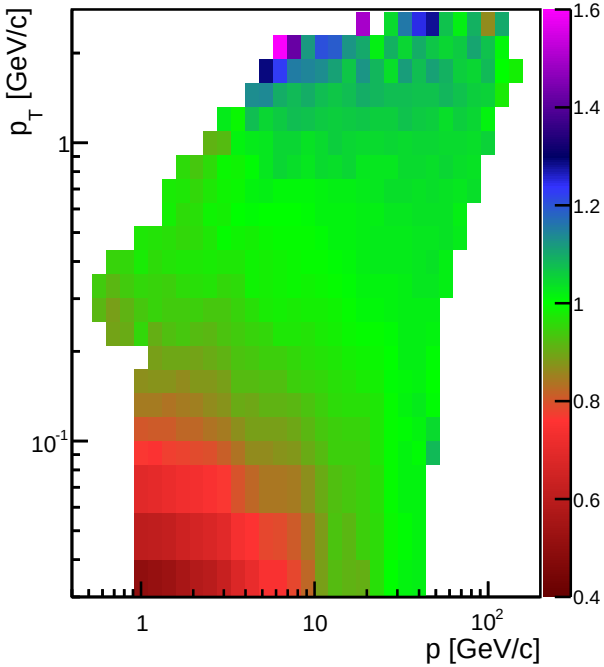
define geometrical acceptance:
accept only tracks in Φ-bins with
⩾90% efficiency.

example: positive tracks

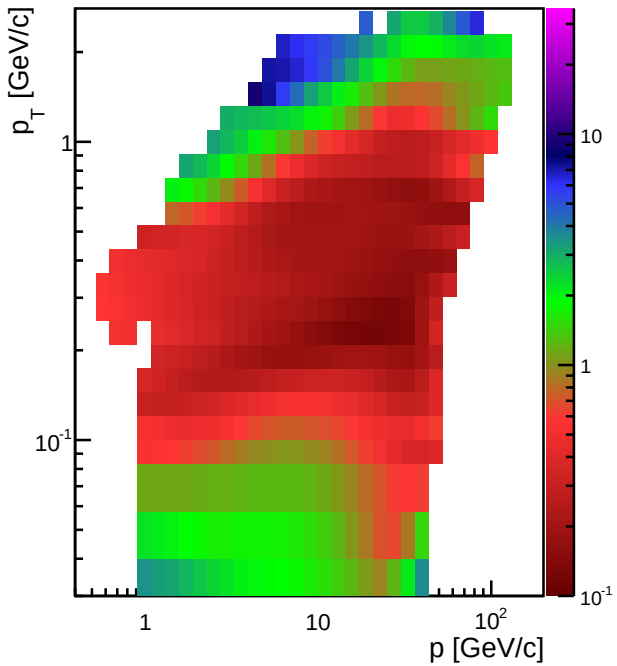


π^-+C Correction and Uncertainties

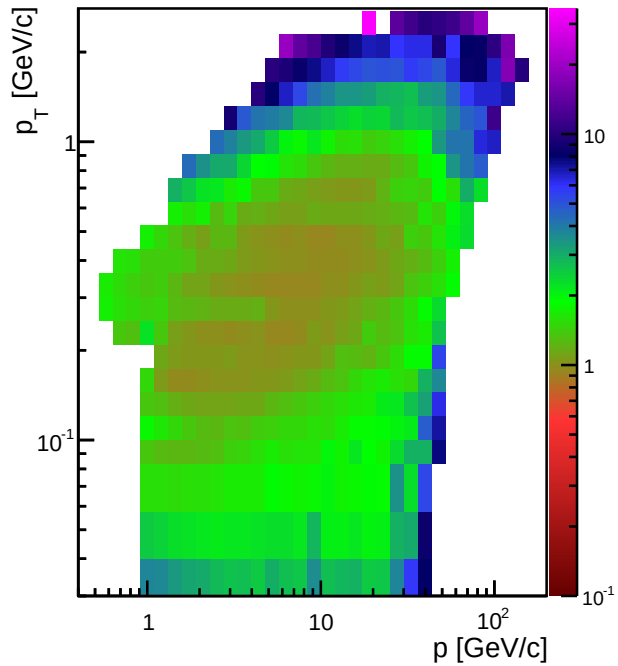
MC correction factor



model systematics [%]



total systematics [%]

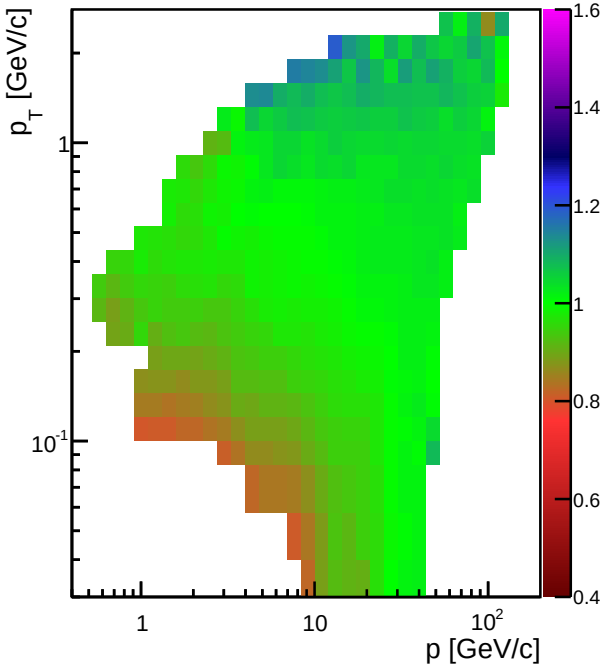


(example: h^-, 158 GeV/c)

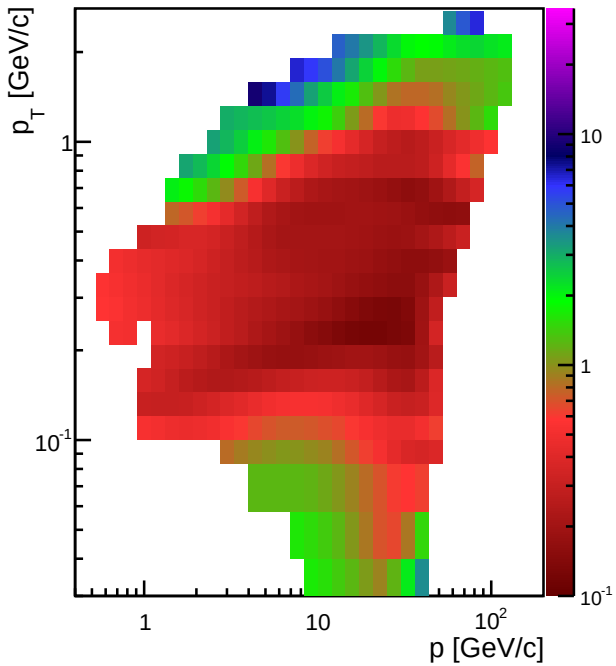
- $e^{\pm}$ contamination at low p, p_T
- model systematics from Δ(VENUS/EPOS) of individual contributions
- total systematics:
  model correction, normalization, trigger bias, calibration, track topology

π^-+C Correction and Uncertainties

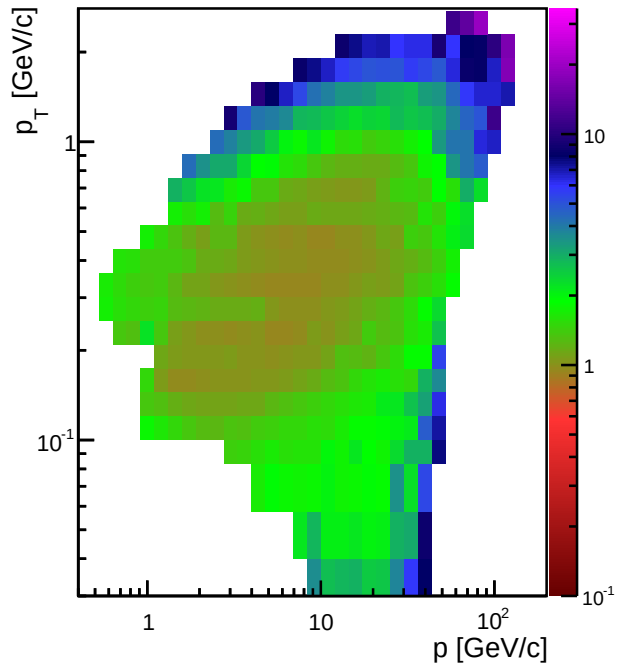
MC correction factor



model systematics [%]



total systematics [%]

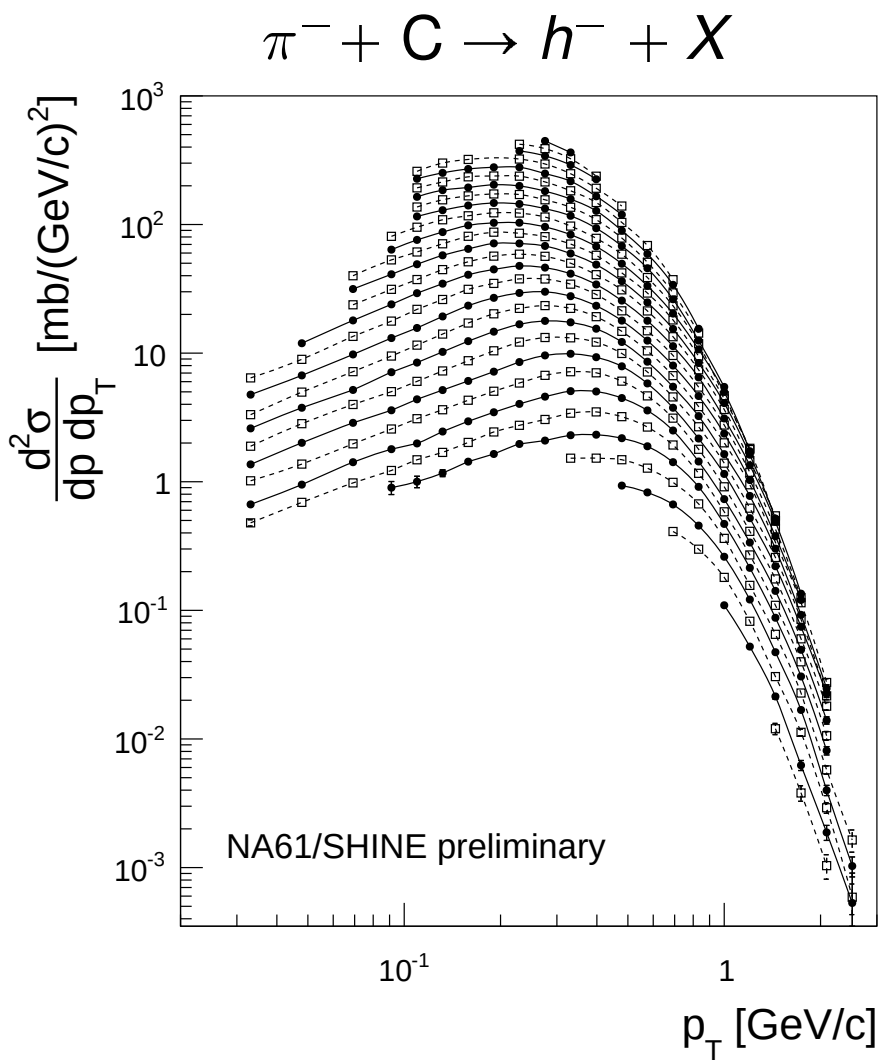


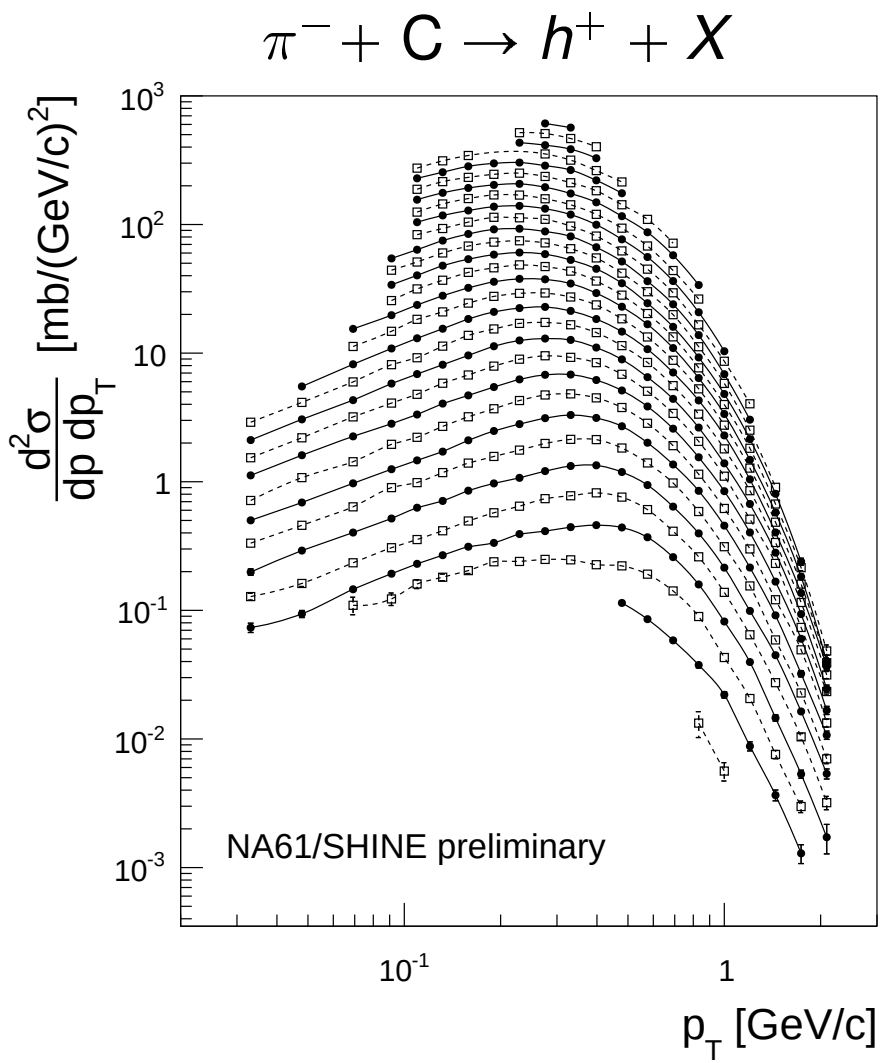
(example: h^-, 158 GeV/c)

- $e^{\pm}$ contamination at low p, p_T
- model systematics from Δ(VENUS/EPOS) of individual contributions
- total systematics:
  model correction, normalization, trigger bias, calibration, track topology

require |C-1| < 0.2 and sys.tot. < 20%

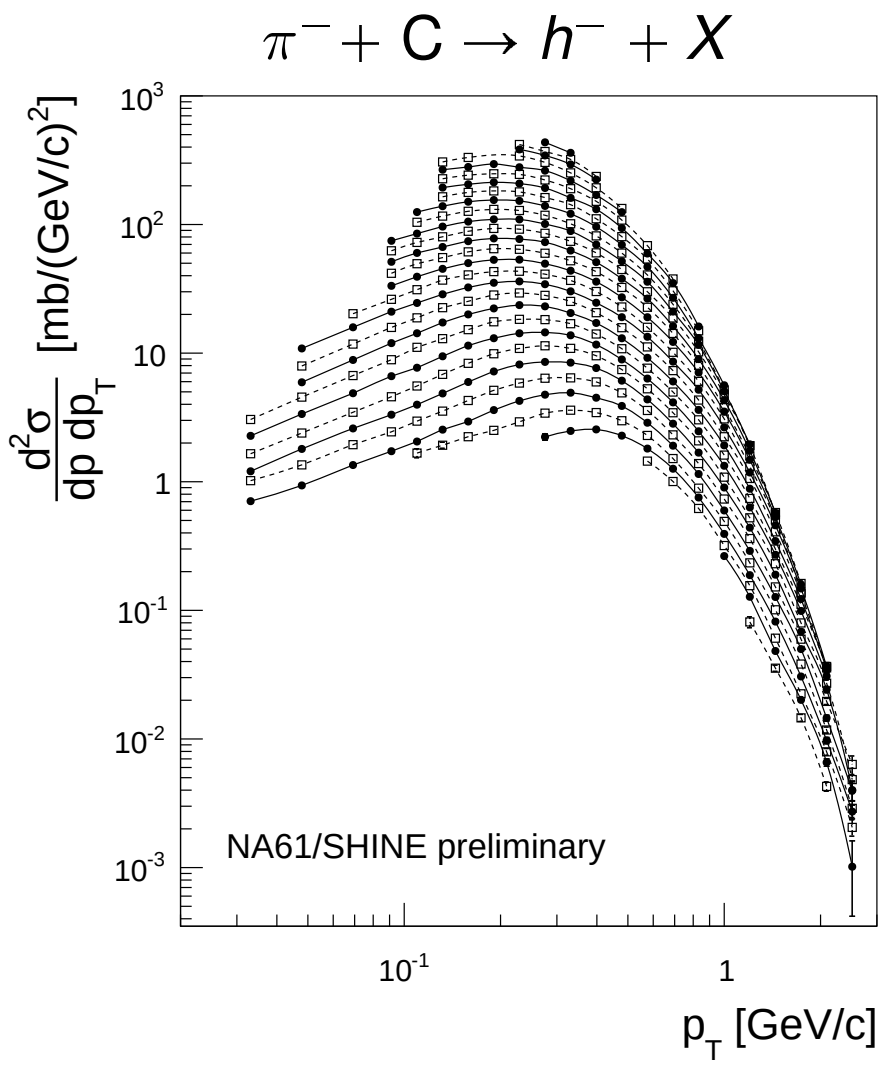
Charged Hadron Production in π^-+C at 158 GeV/c

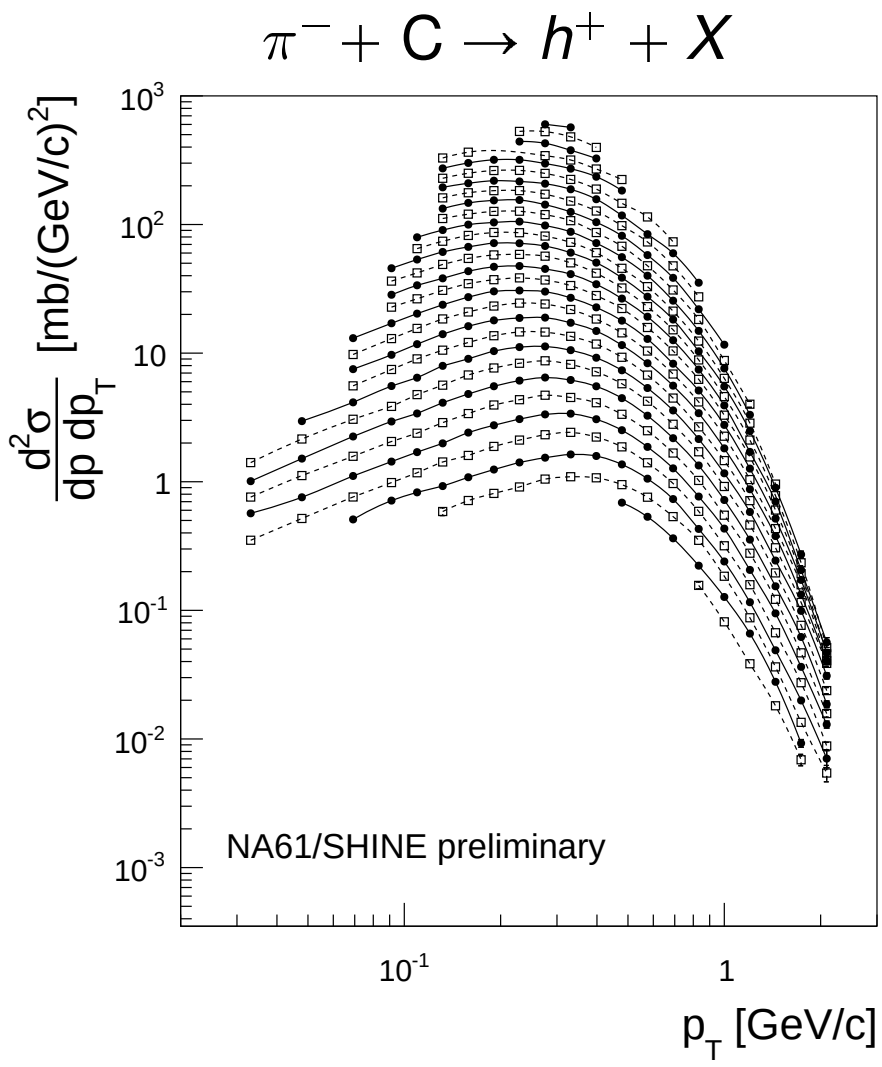




$p = 0.6 \ldots 121$ GeV/c in steps of $\lg p/(\mathrm{GeV}/c) = 0.08$

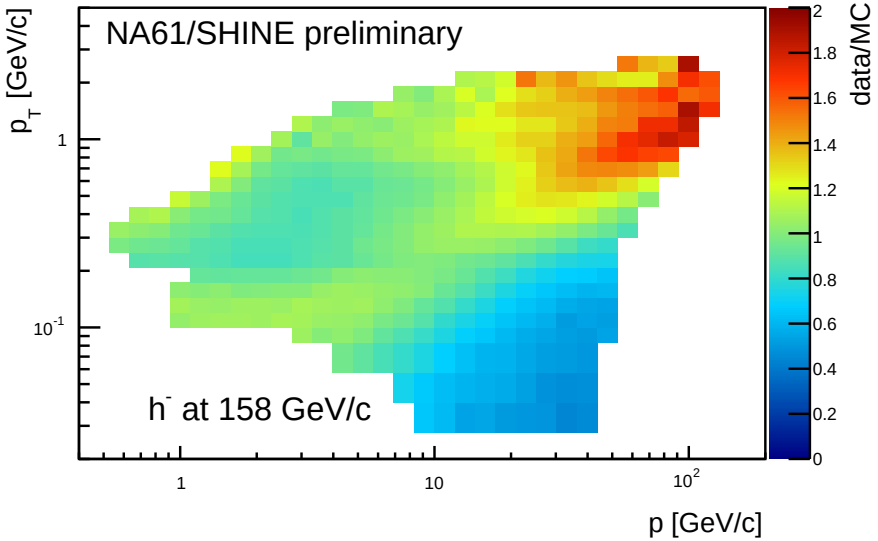
Charged Hadron Production in π^-+C at 350 GeV/c

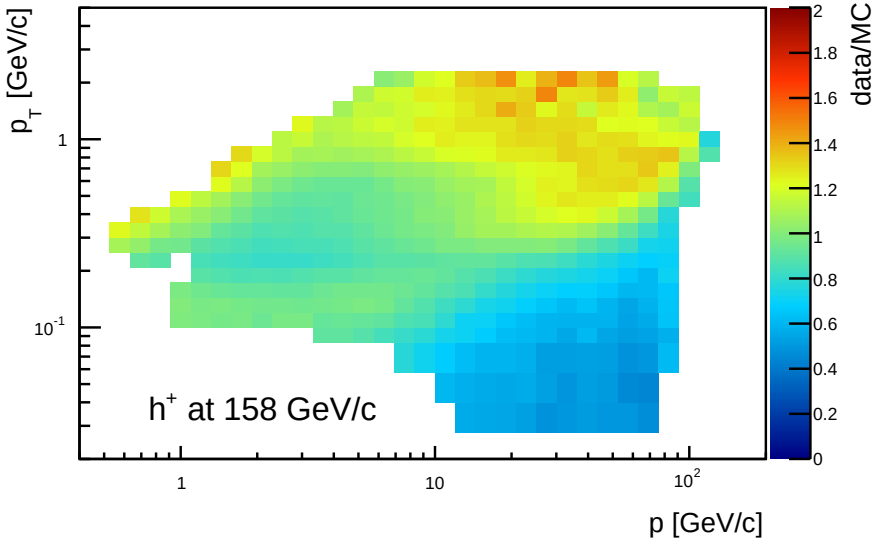


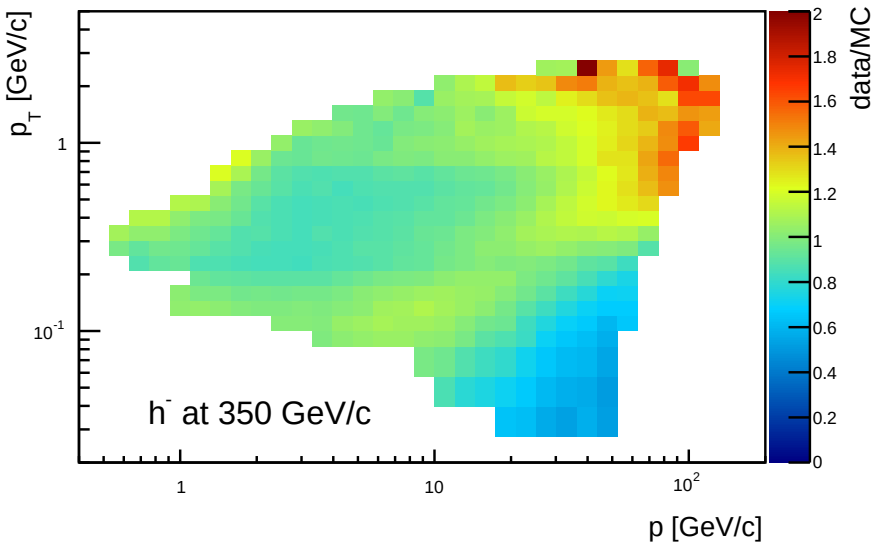


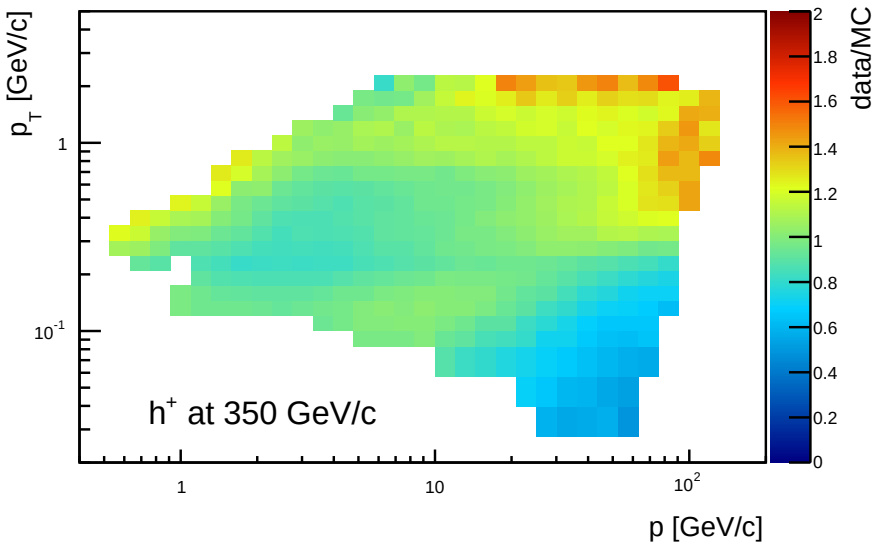
$p = 0.6 \ldots 121$ GeV/c in steps of $\lg p/(\mathrm{GeV}/c) = 0.08$

Comparison to QGSJetII

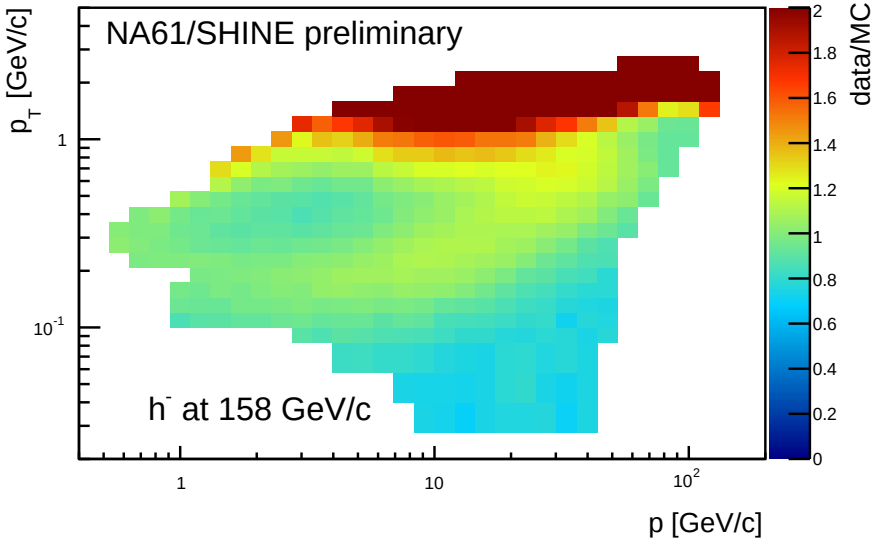


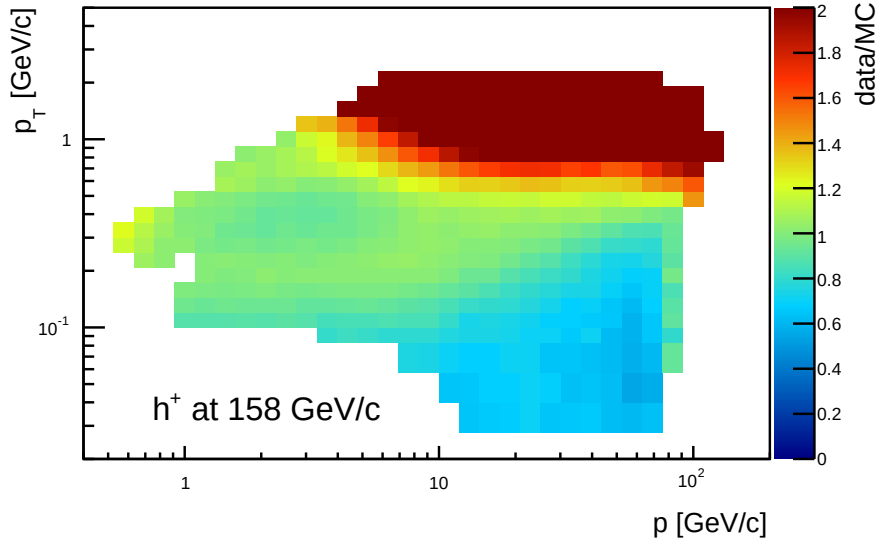


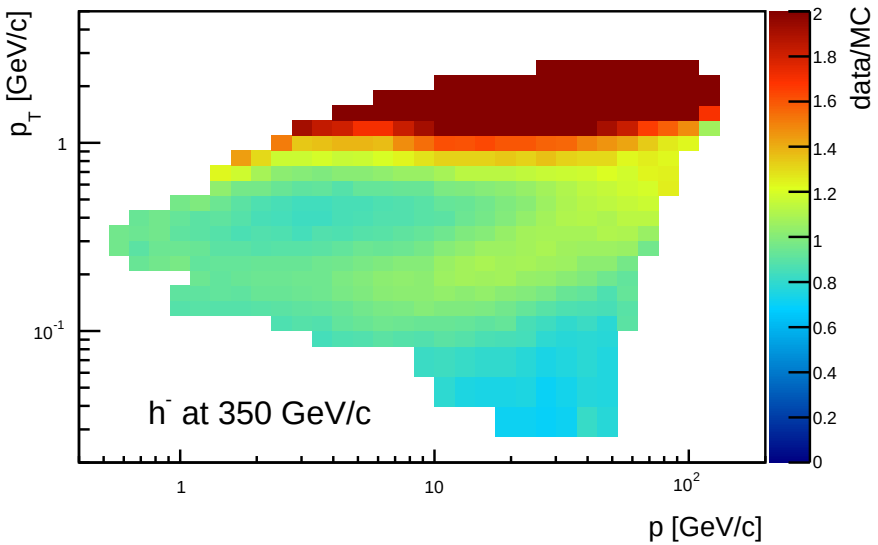


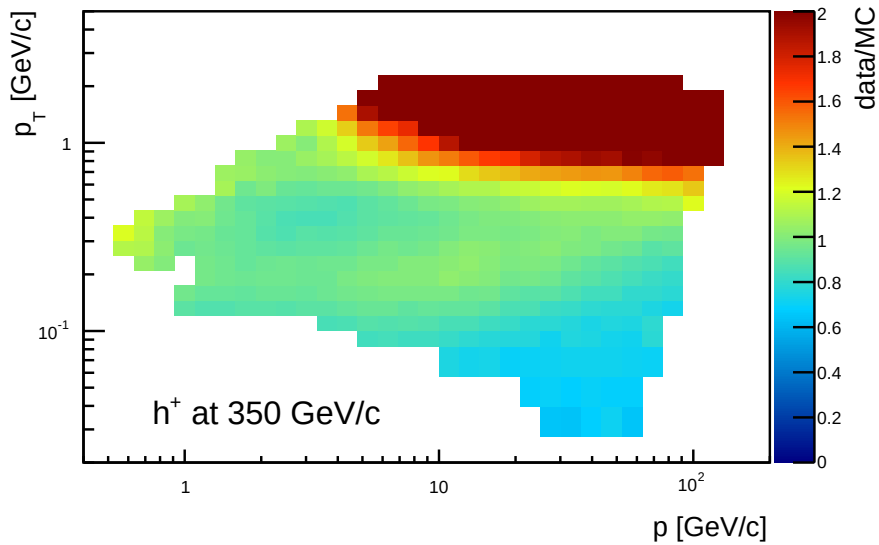


Comparison to Sibyll2.1

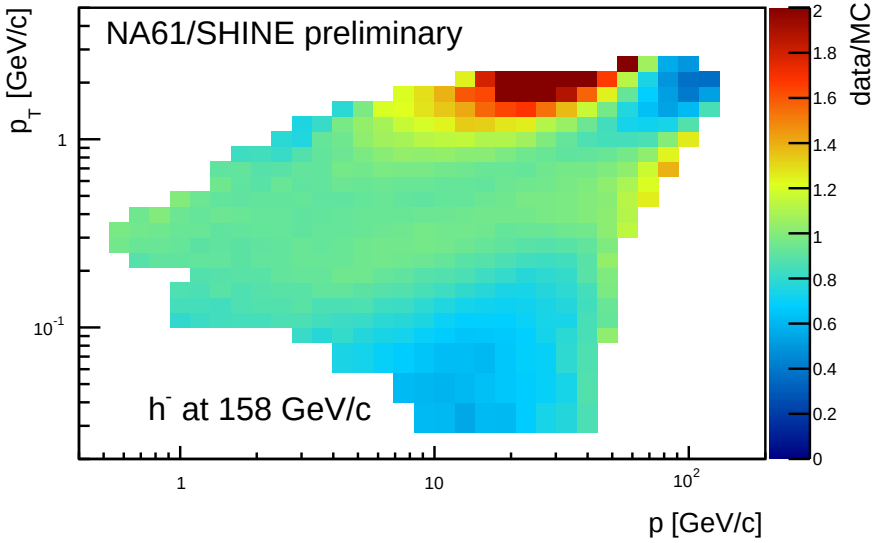


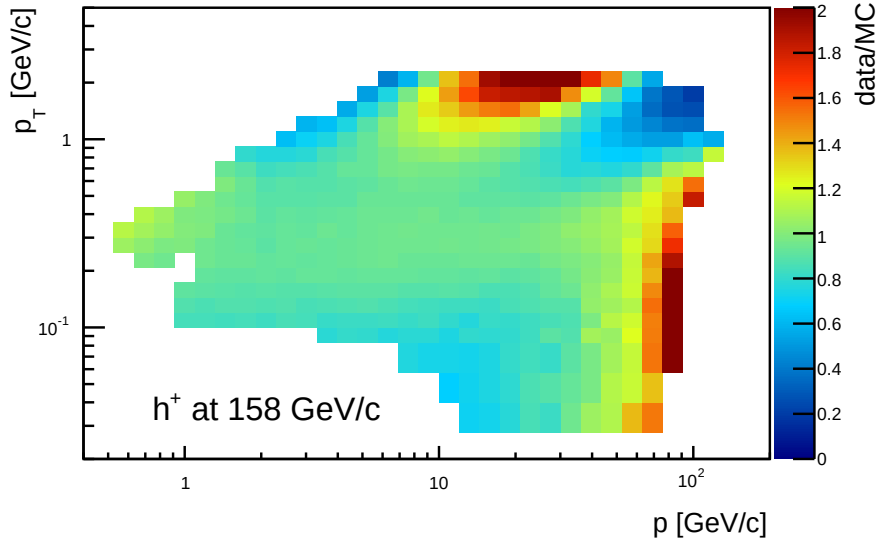


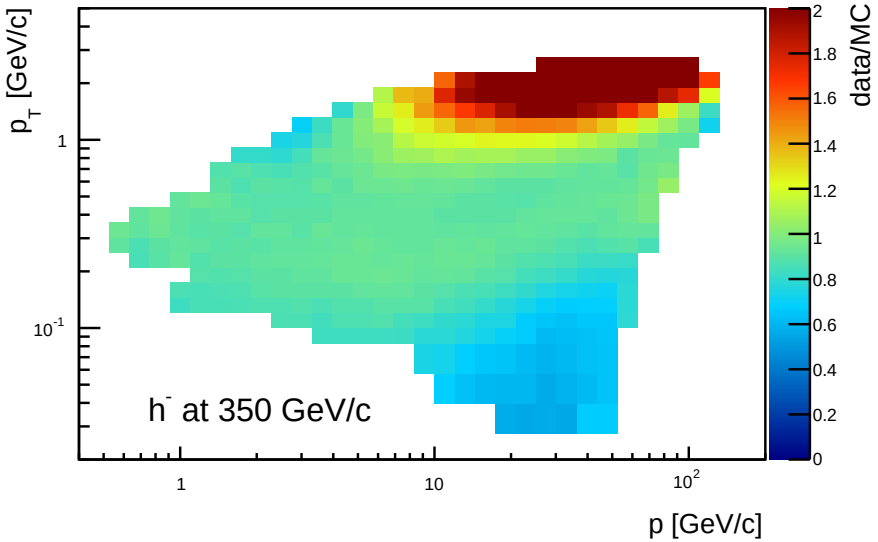


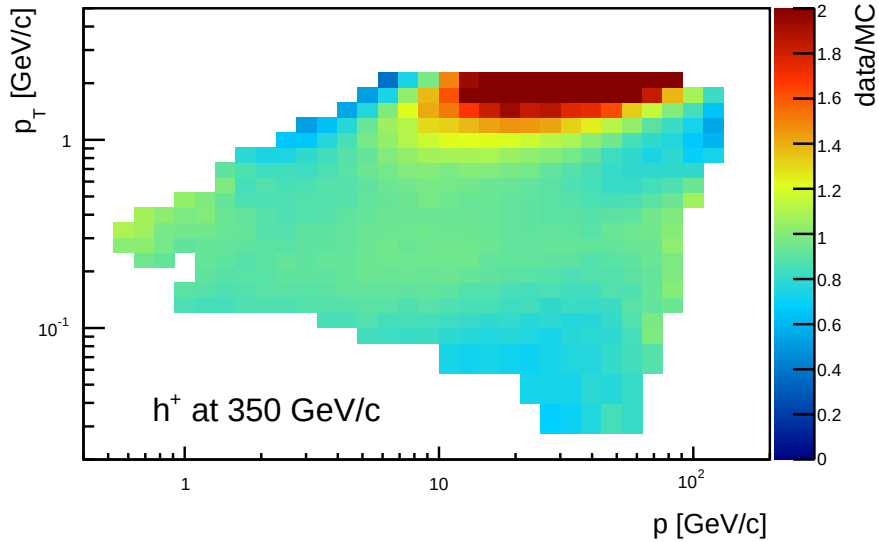


Comparison to UrQMD1.3.1 (patched)

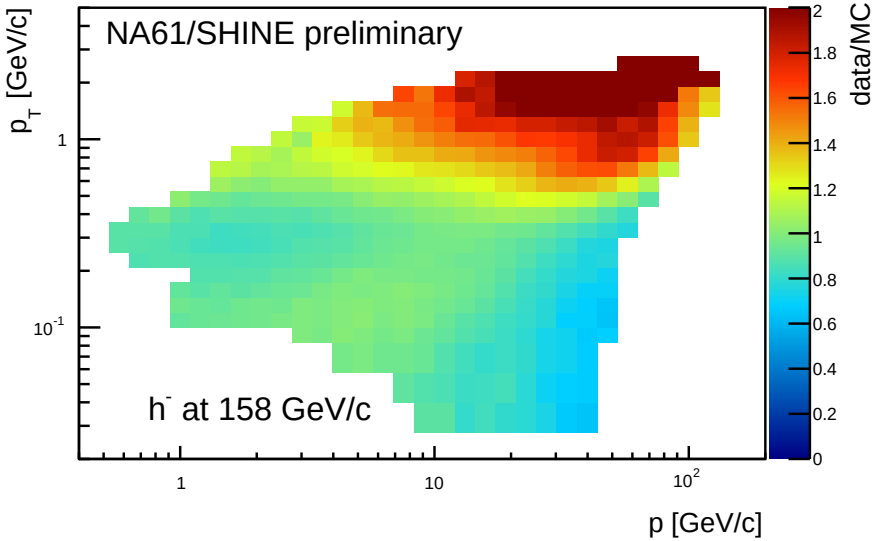


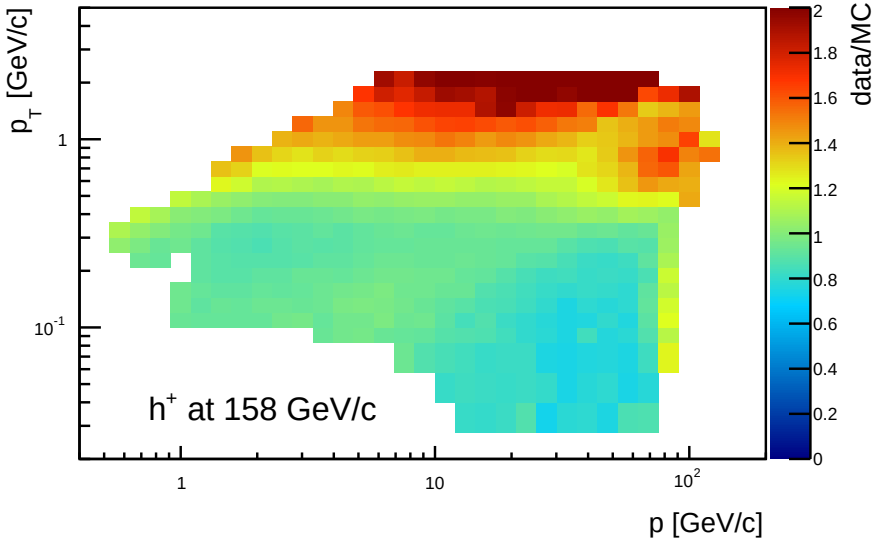


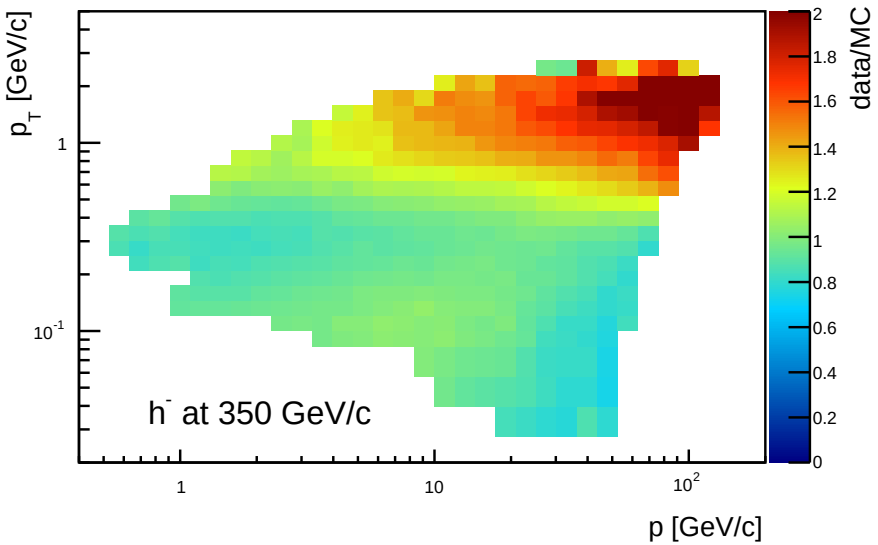


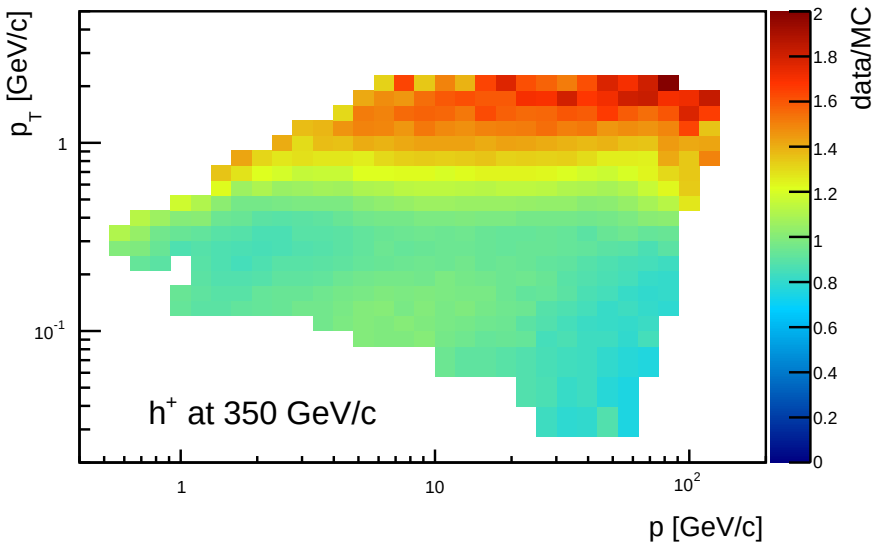


Comparison to EPOS1.99

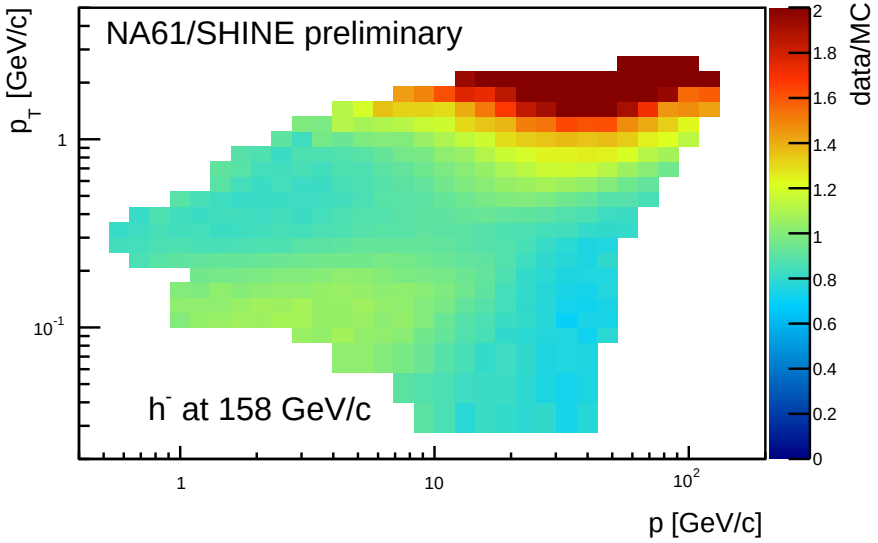


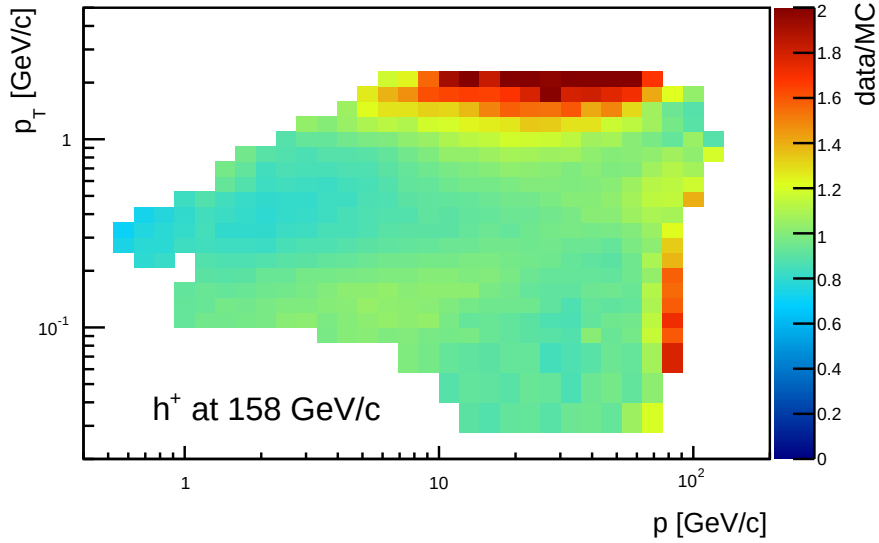


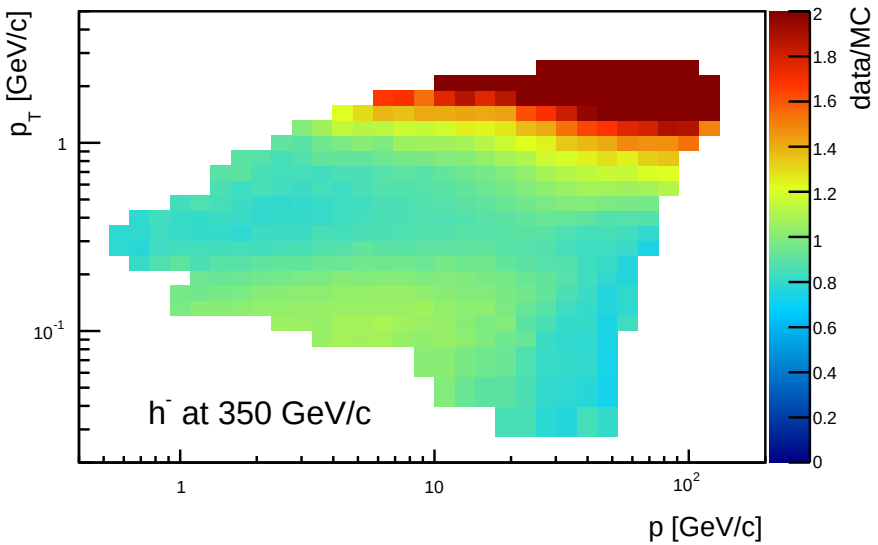


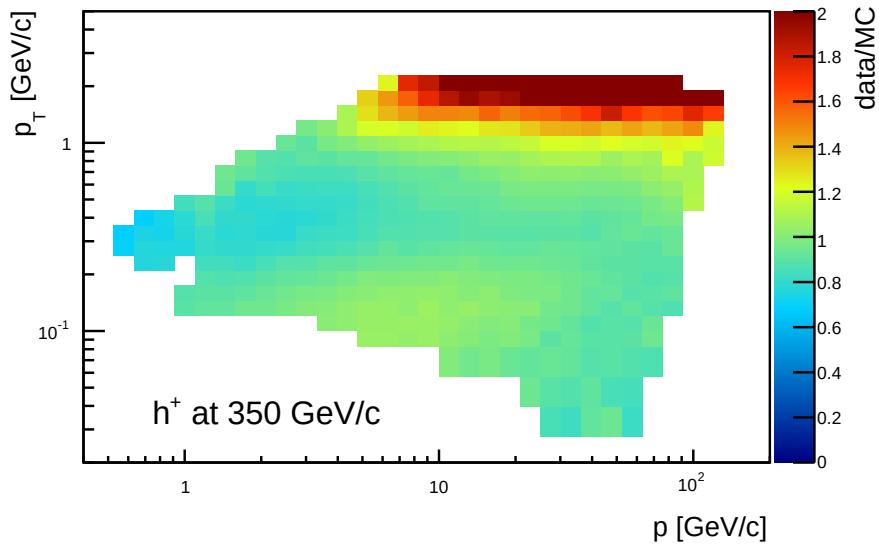


Comparison to Fluka2011

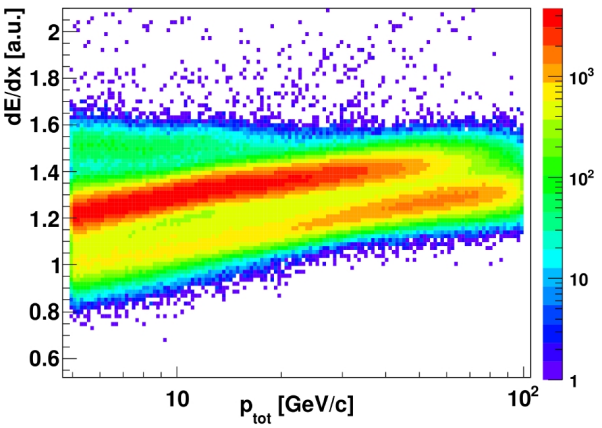


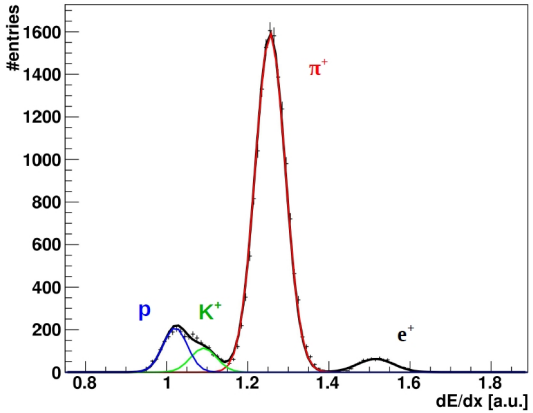


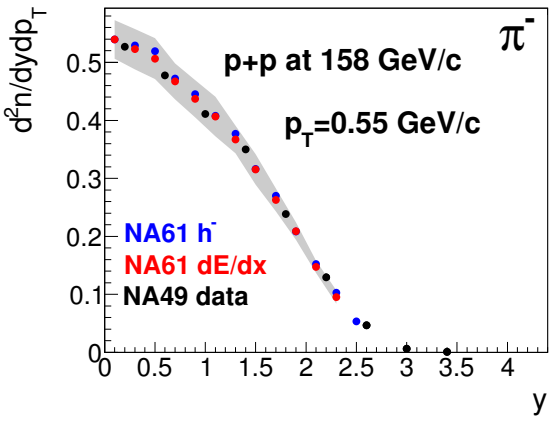


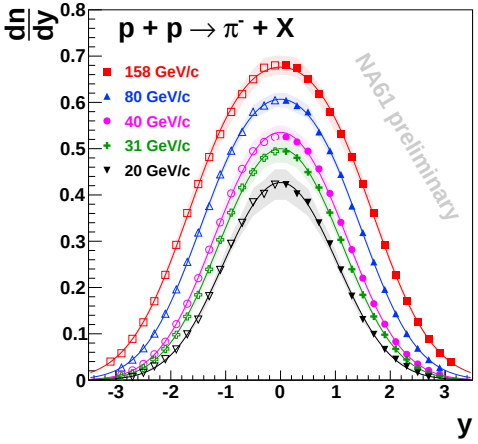


$\pi^{\pm}$- and K^{-}-Spectra from p+p Energy Scan



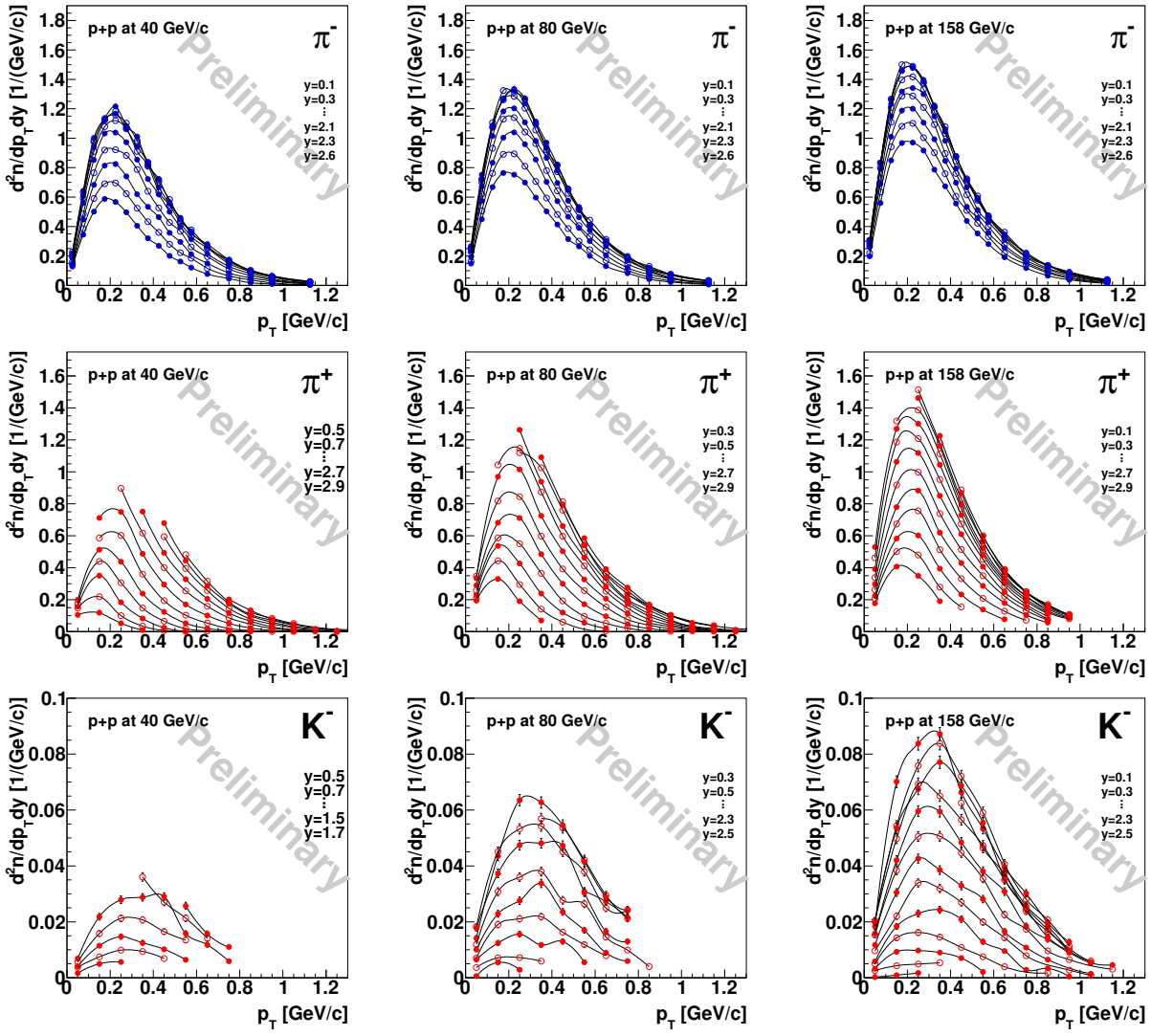






- reference data for system size scan
- h^{-} and dE/dx analysis
- good overall agreement with NA49 at 158 GeV/c
- extensive data set for model-tuning

$\pi^{\pm}$- and K^{-}-Spectra from p+p Energy Scan



- reference data for system size scan
- h^{-} and dE/dx analysis
- good overall agreement with NA49 at 158 GeV/c
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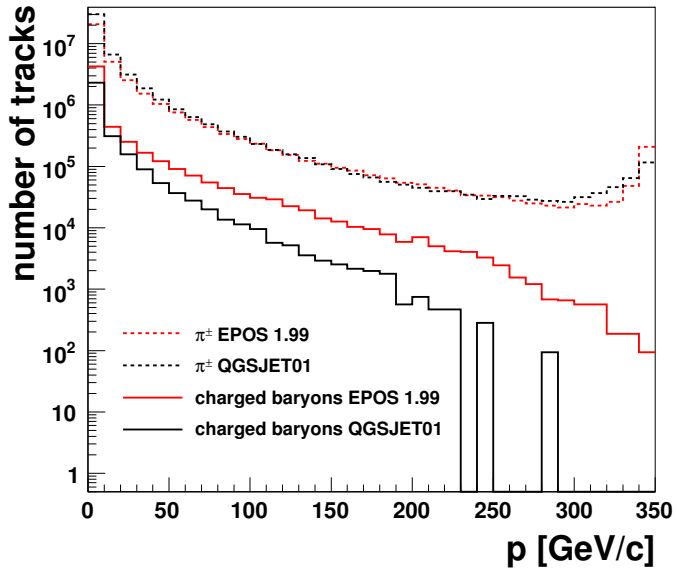
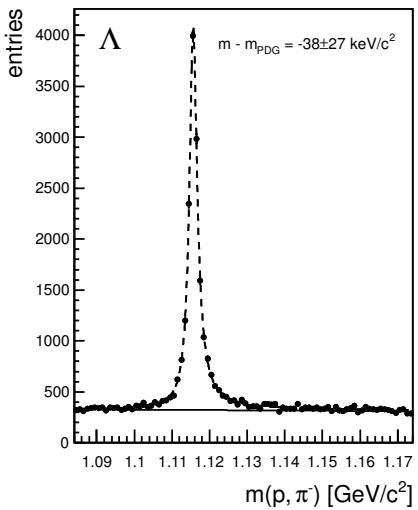
Stay Tuned!

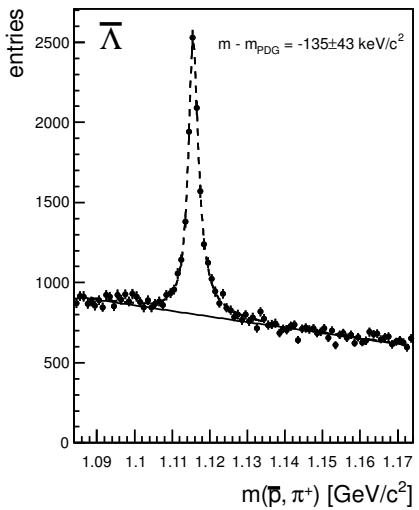
- p+C update
  → factor 10 more statistics
- π+C with dE/dx pid
  →(anti-)baryon production
- full p+p scan
- strange baryons
- ρ_0-mesons
- K^-+C interactions
- ...

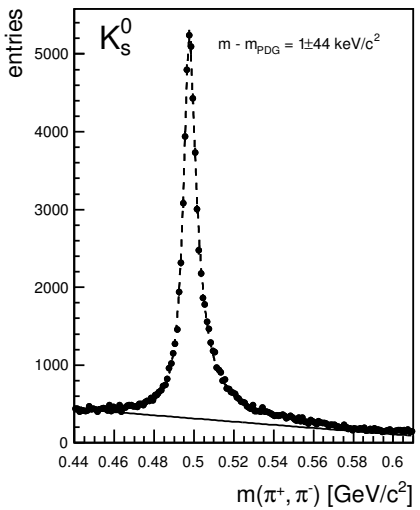
expected baryon difference in π+C



V0s in π+C







Summary of NA61 Results

- $\pi^{\pm}$ and K spectra from p+C at 31 GeV/c
  - published
  - already used for T2K beam MC
  - FLUKA and UrQMD retuned
  - first preliminary K_s^0-yields (not shown today)

- charged hadron spectra from π^-+C at 158 and 350 GeV/c
  - preliminary
  - lab-measurement of last stage of UHECR air showers
  - too few particles in models at high p_T

- $\pi^{\pm}$ and K spectra from $p + p$ at 40, 80 and 158 GeV/c
  - preliminary
  - provides reference data for system size scan
  - extensive data set for CR model-tuning