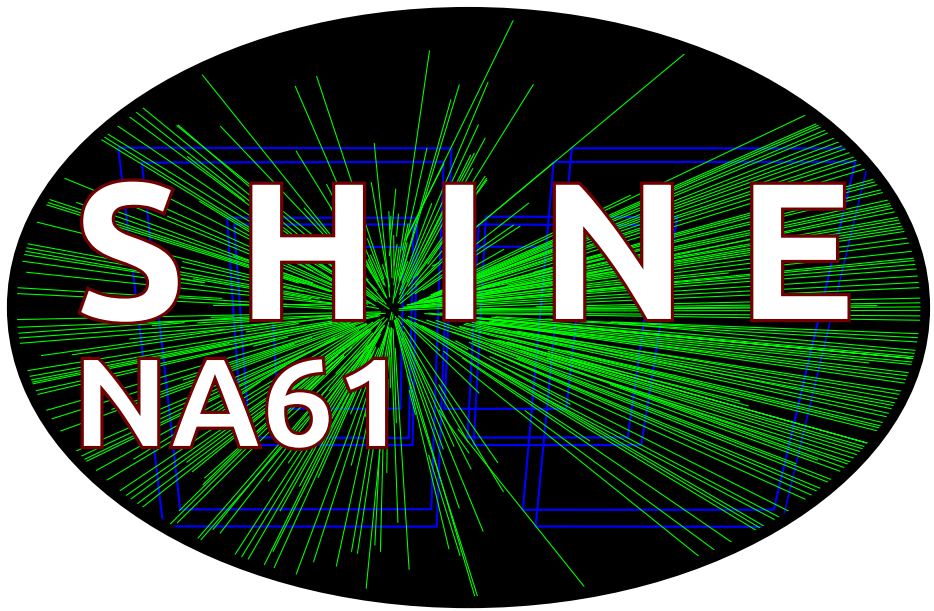
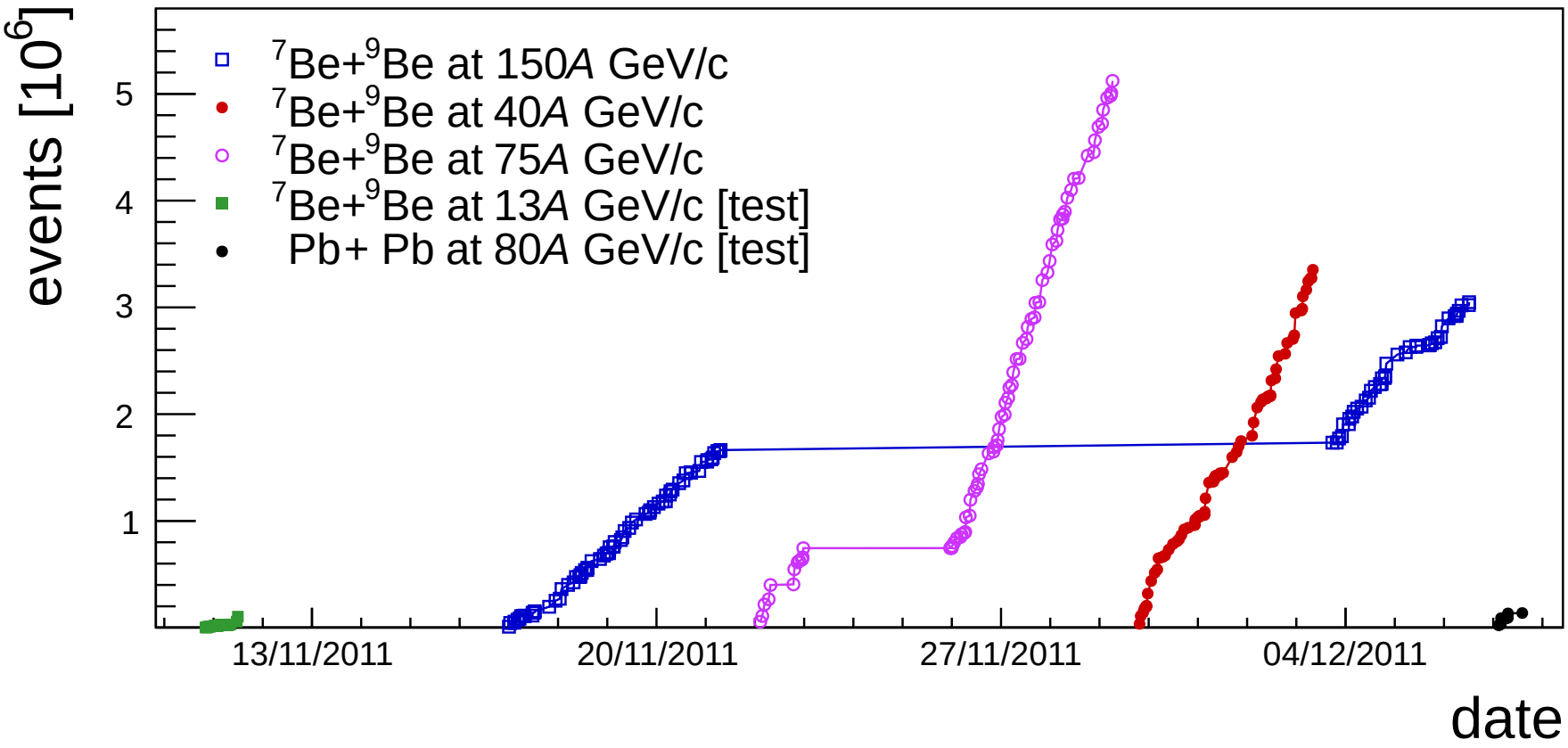
NA61/SHINE: Status, Results and Plans (October 2011 - October 2012)

M. Unger* for the NA61/SHINE Collaboration

* Karlsruher Institut für Technologie



Data Taking: Nucleus-Nucleus Interactions



- ^{7}Be+^{9}Be production runs at 40*A*, 75*A* and 150*A* GeV/c
- ^{7}Be+^{9}Be test runs at 13*A* GeV/c
- Pb + Pb test runs at 80*A* GeV/c

Data Taking: Nucleus-Nucleus Interactions

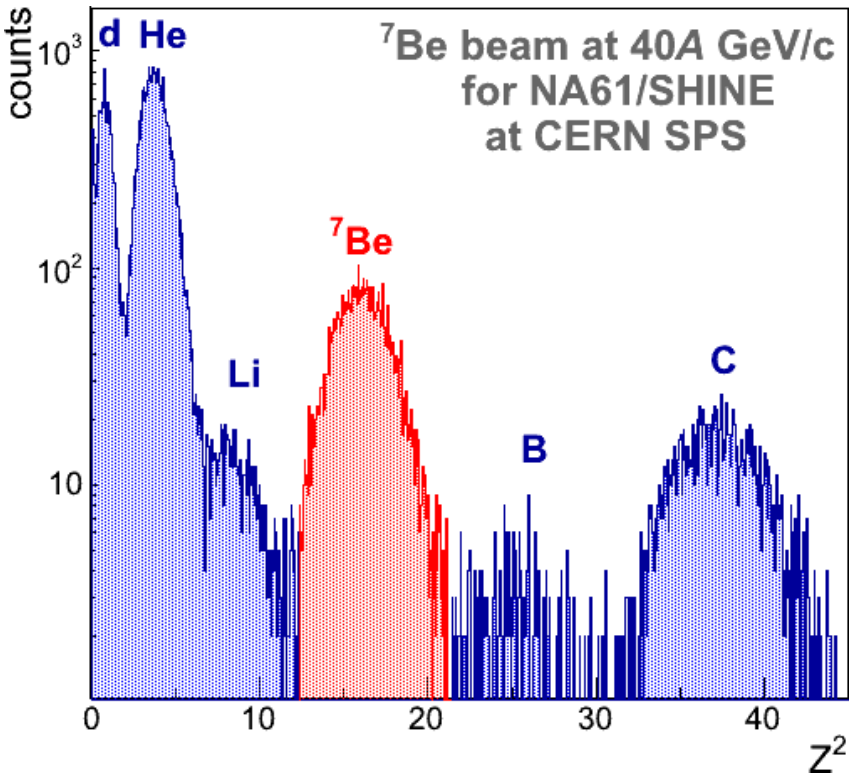
CERN COURIER

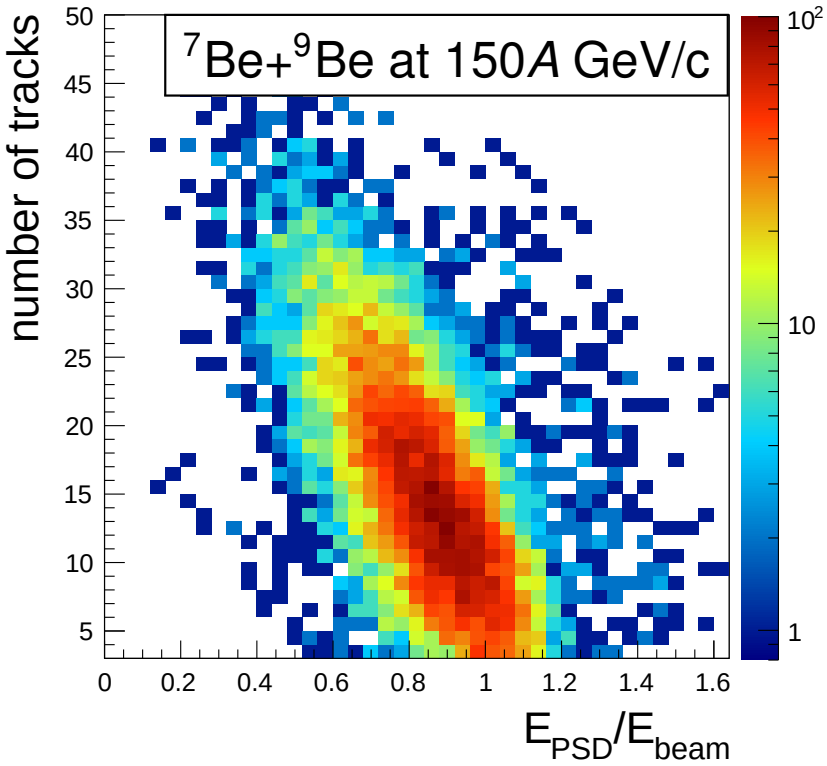
Apr 27, 2012

Light work with heavy ions

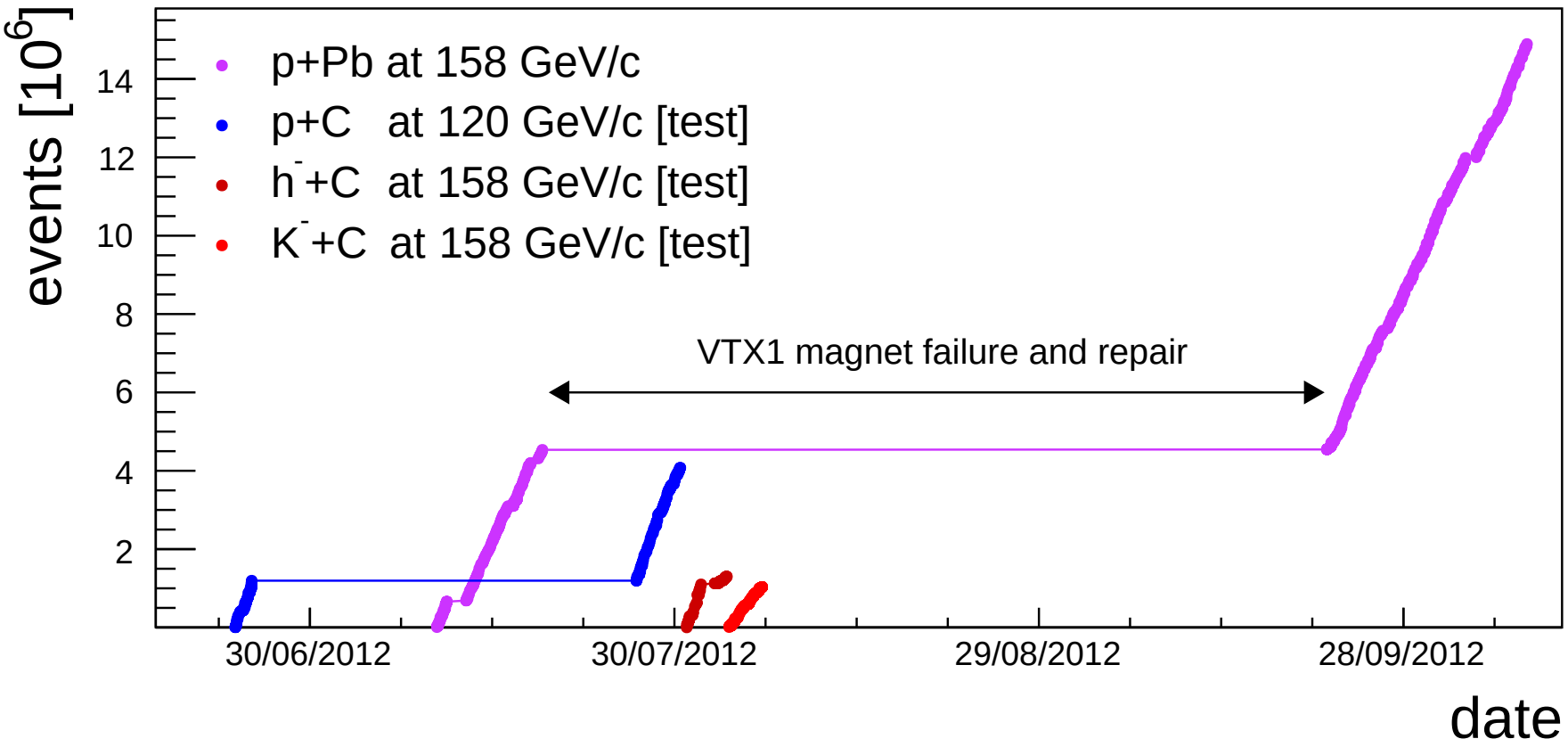
H. Stroebele & I. Efthymiopoulos

uncorrected distribution, less than 1% of total statistics:





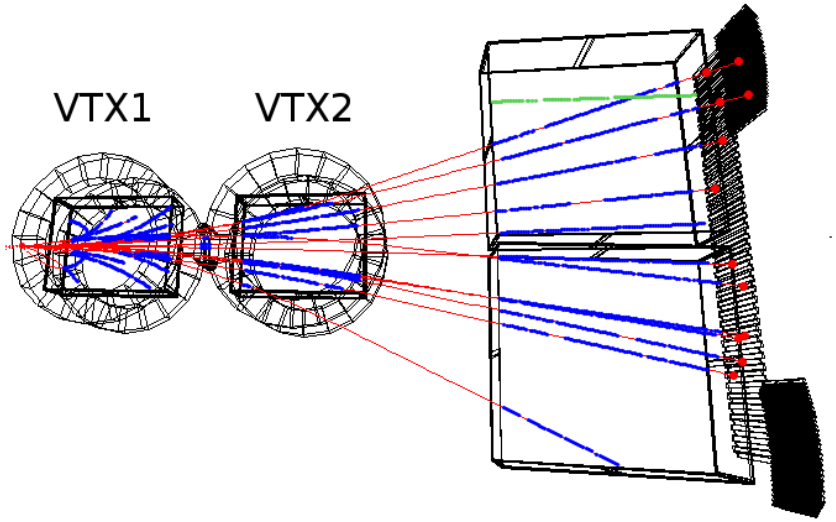
Data Taking: Hadron-Nucleus Interactions



- p+Pb production runs at 158 GeV/c – unique reference data for heavy ion physics
- p+C test runs at 120 GeV/c for US ν-program
- h^-/K^- test runs at 158 GeV/c for cosmic ray interactions

Data Taking: Hadron-Nucleus Interactions

Problems with VTX1/2 magnets



at startup:

- electronics upgrade by CRIO group
- damage of He pump in VTX1
- water in VTX2 electronics

→ magnets were ready to use only at 3rd of July

during data taking:

- vacuum leak on thermal screen of VTX1
- ramp down and warm up
- fix leak, cool down, ramp up

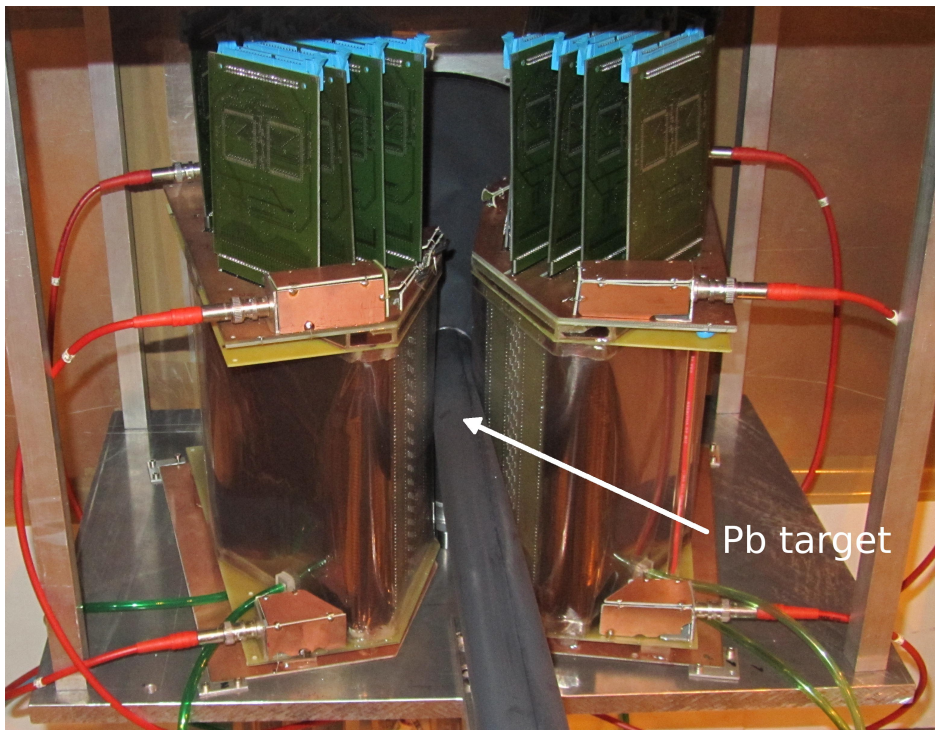
→ VTX1 not available between 19th July - 15th September

shift of LS1 → part of lost *p*+Pb recovered, Be+Be in Dec-Feb 2012/13

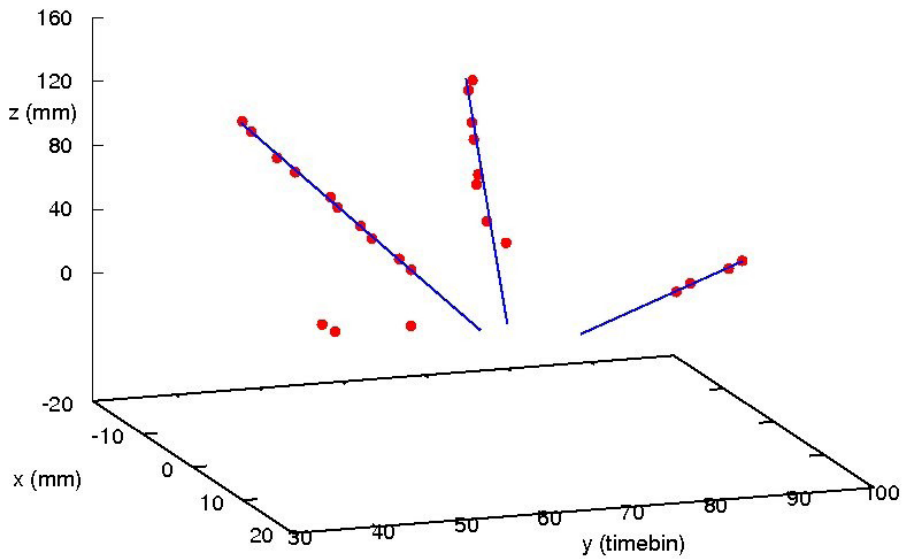
Data Taking: Hadron-Nucleus Interactions

Low Momentum Particle Detector (LMPD):

Measurement of event-centrality via counting of ‘grey protons‘



LMPD installation around Pb target (inside Tedlar® He-tube)



example of rec. clusters and tracks

Detector Upgrades

Projectile Spectator Detector (PSD)

transverse acceptance extended in 2012 (needed for low energy runs)

current upgrades:

- TOF HV
- TPC calibration pulser
- TPC gas monitoring

under consideration:

readout upgrade during LS1 for

- TOF
- BPD
- beam counters
- PSD

using DRS chip from PSI
(= 5 GHz waveform digitizer)

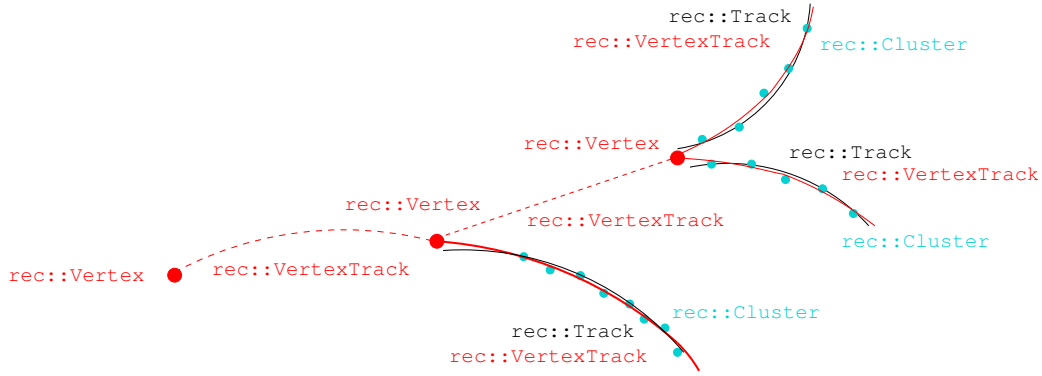
Software Development

CernVM Software Appliance

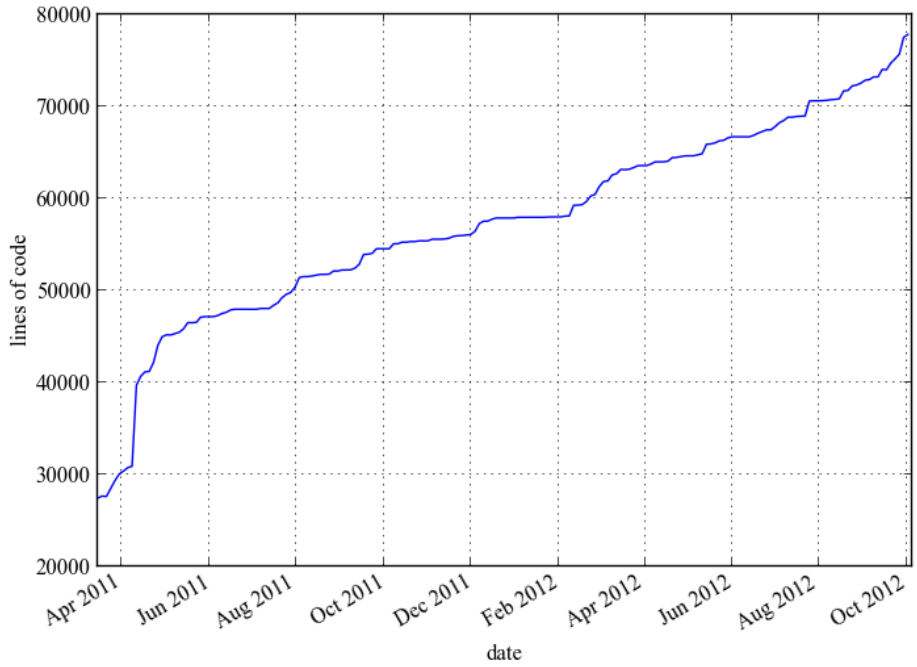
- successful port of legacy software to VM
- production infrastructure ready by end of 2012

- development of new SHINE Offline framework ongoing
- first native applications (PSD and LMPD reconstruction)
- new ROOT DSTs used in data analysis

persistent bi-directional trees:



lines of code (C++ only):



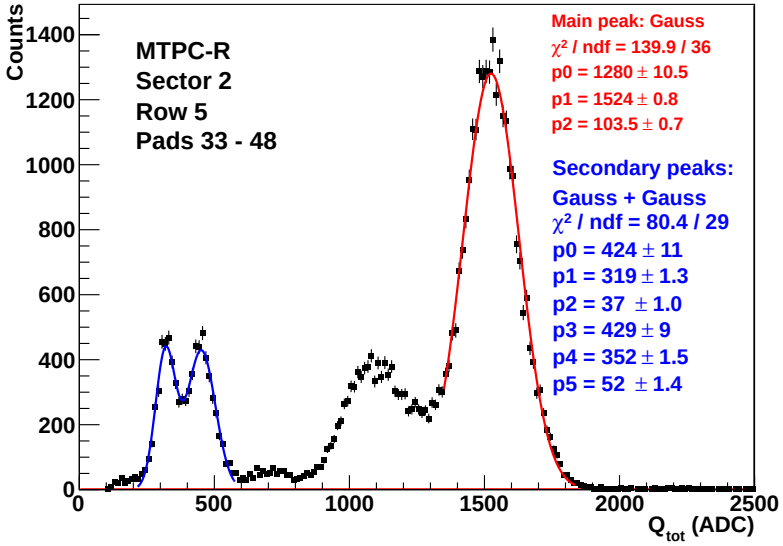
Calibration

Status:

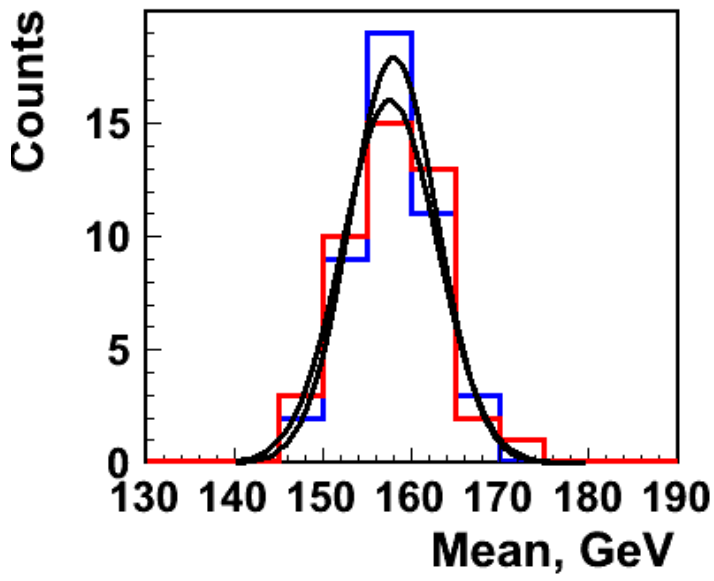
- 2009 data sets fully calibrated (minor improvements pending)
- preliminary calibration of 2010/11 data sets
- TPC pad gains from Krypton decay (10^6 events per chamber collected in 2010/12)
- PSD calibration with
  - 100 GeV/c $\mu-$ beam
  - 158 GeV/c proton beam

  and tests at T10 PS beam line

Krypton spectrum in MTPC-R:



mean rec. E_{proton} per module:



Results

Published/Submitted:

- *Pion emission from the T2K replica target: Method, results and application*, submitted to Nucl. Instrum. Meth. A. [2007 data]
- *Measurement of Production Properties of Positively Charged Kaons in p+C Interactions at 31 GeV/c*, Phys.Rev. C85 (2012) 35210. [2007 data]
- *Measurements of Cross Sections and Charged Pion Spectra in p+C Interactions at 31 GeV/c*, Phys.Rev. C84 (2011) 34604. [2007 data]

In preparation:

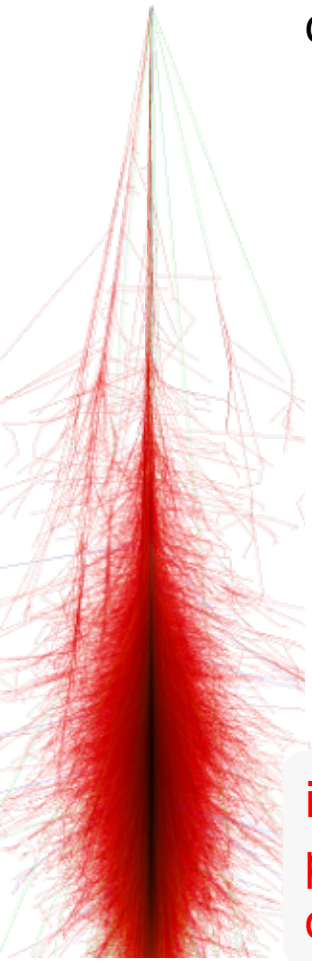
- NA61 detector and beam
- K^0_S and Λ in p+C at 31 GeV/c [2007 data]
- π^- spectra from p+p scan via h^- method [2009 data]

Preliminary data releases:

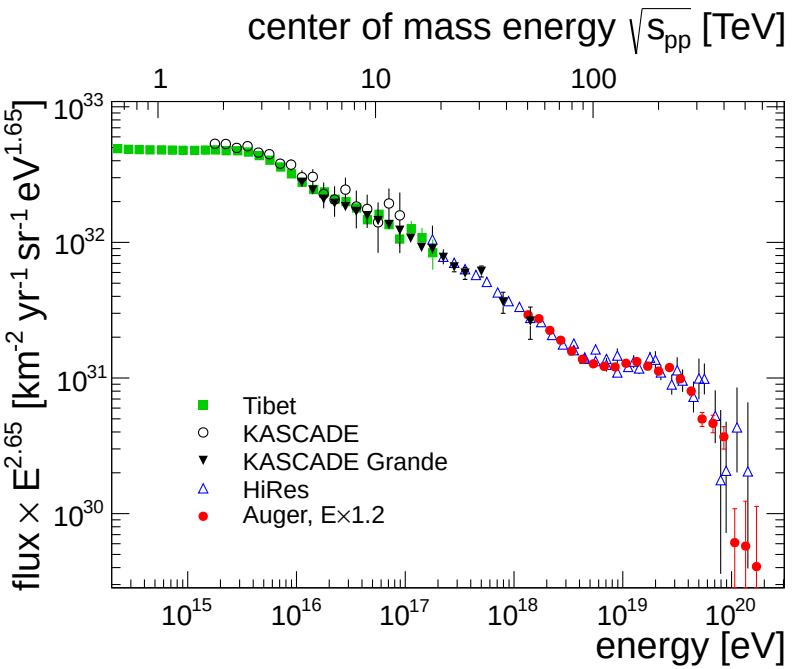
- π^-+C runs for cosmic ray experiments [2009 data]
- p+C runs for T2K [2007/9 data]
- p+p energy scan for heavy ion physics [2009 data]

NA61 Measurements for Cosmic Ray Experiments

Air shower measurements at ultrahigh energies

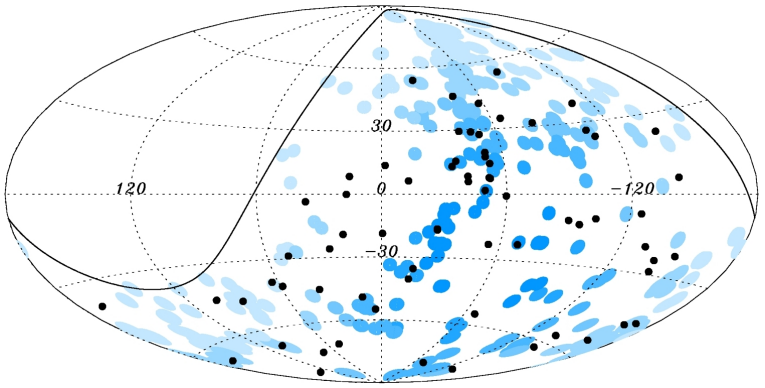


cosmic ray flux

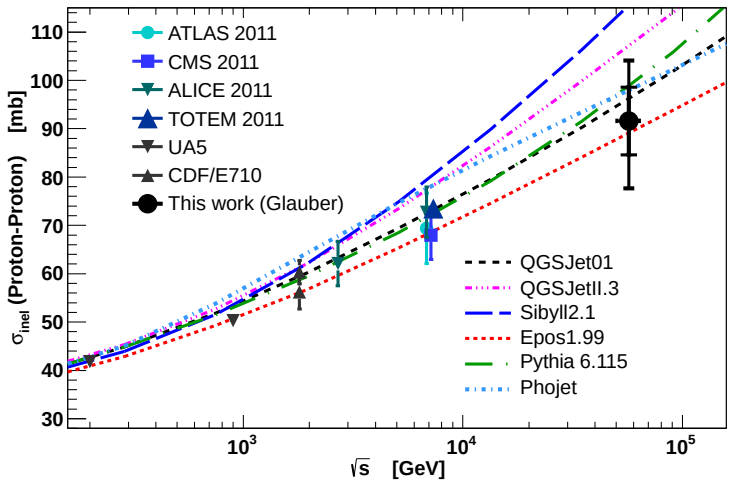


improve understanding of low energy part of air showers using particle production data at SPS energies!

astrophysics



particle physics beyond LHC



Muons in UHE Air Showers

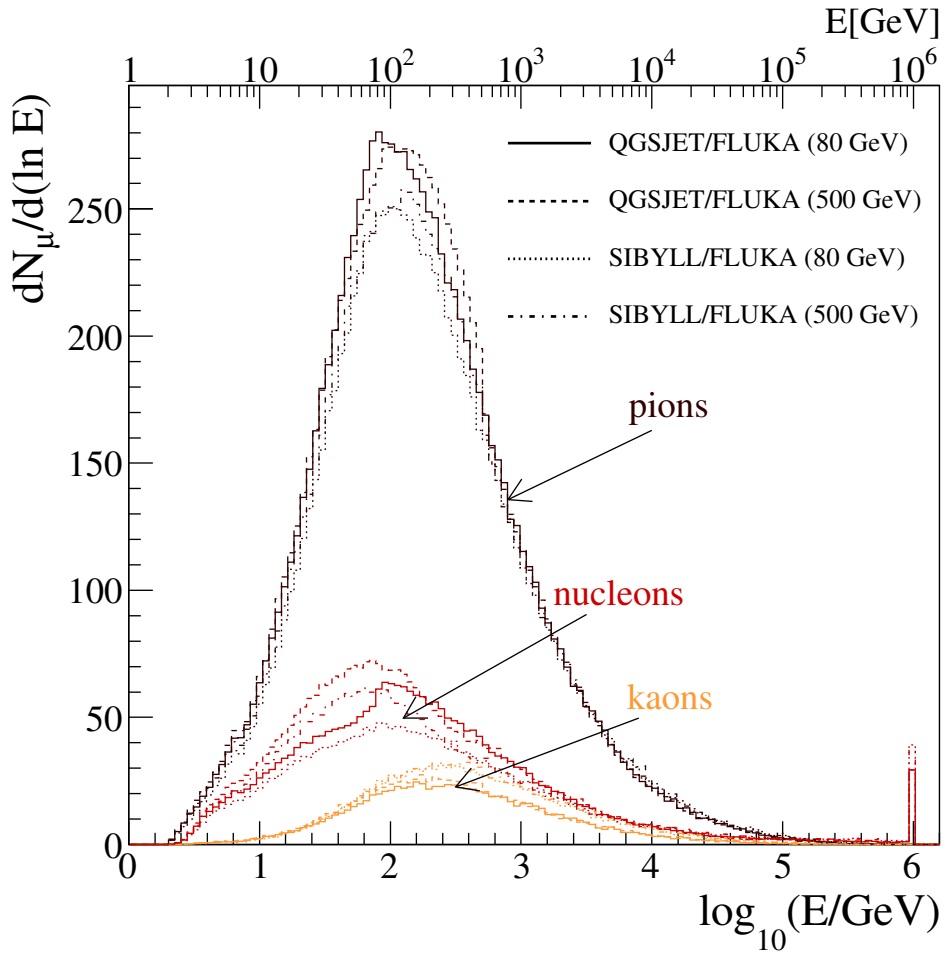
energy of last interaction before decay to μ

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

Low energy air shower:

e.g. KASCADE:

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



Muons in UHE Air Showers

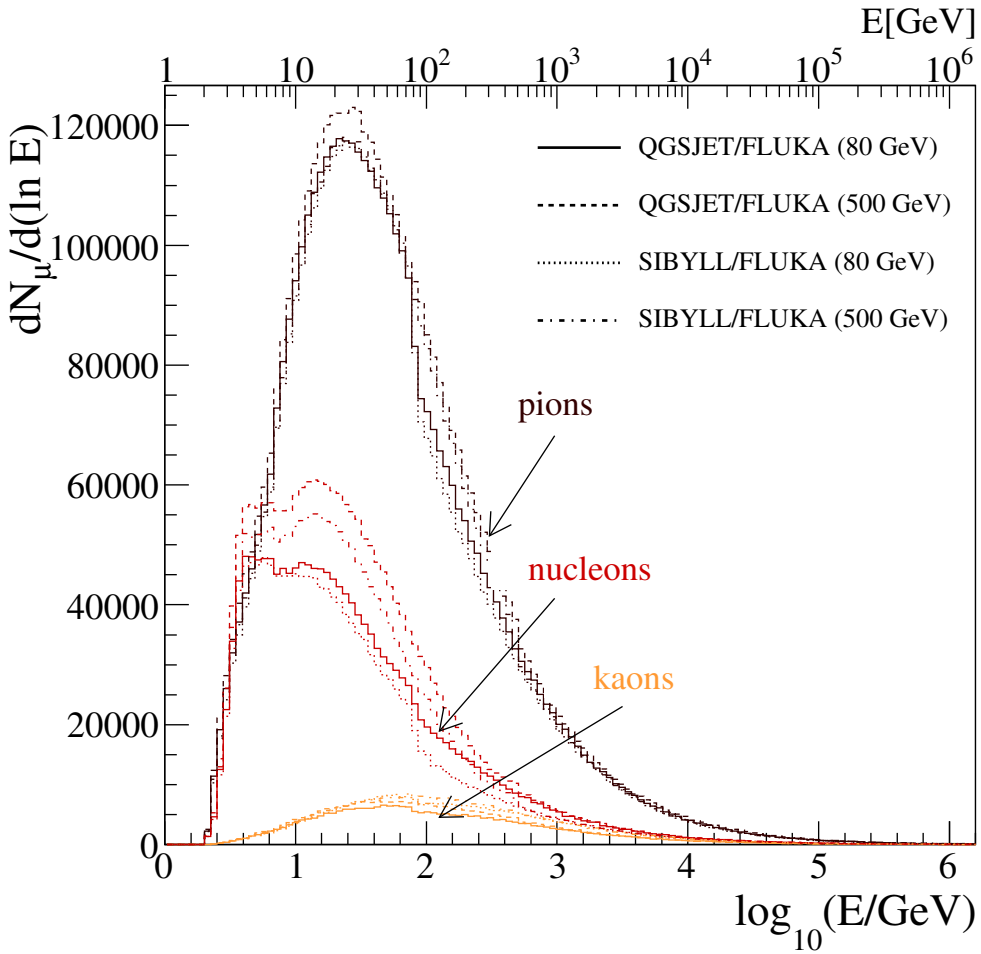
energy of last interaction before decay to μ

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

High energy air shower:

e.g. P. Auger Observatory:

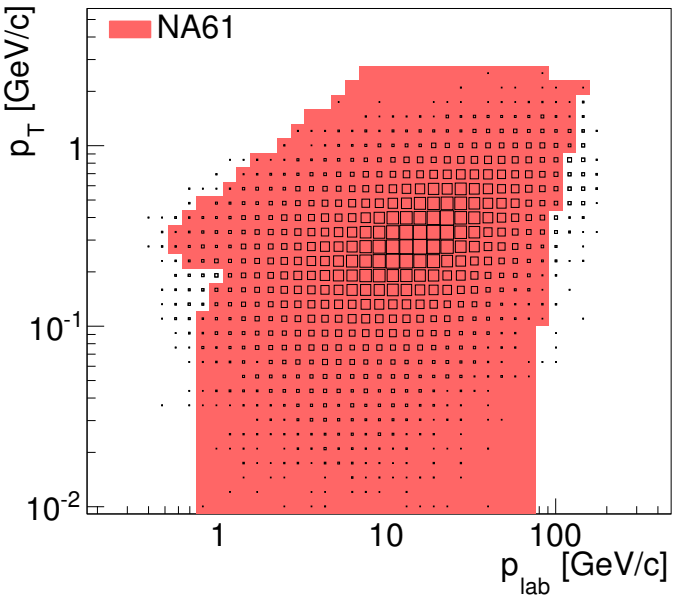
- $E_0 = 10^{19}$ eV
- $r = 1000$ m
- $E_\mu \geq 150$ MeV



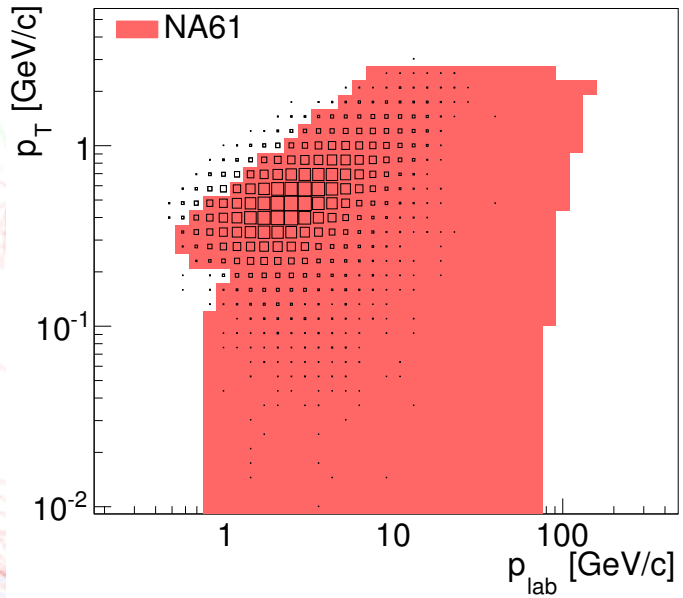
Muons in UHE Air Showers

Muon production at fixed energy of grand-mother particle

KASCADE:



Auger:

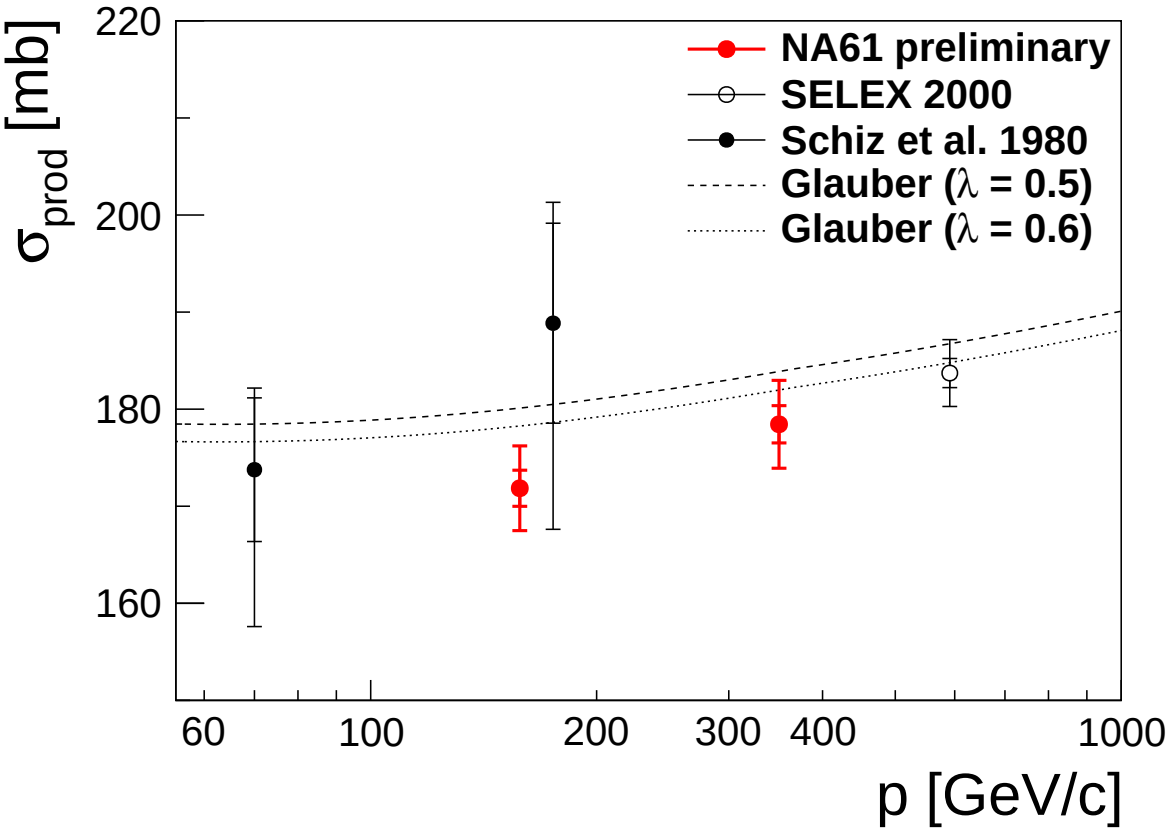


- boxes: air shower
- red area: NA61 acceptance
- $E_{\mathrm{grand}} = 158$ GeV

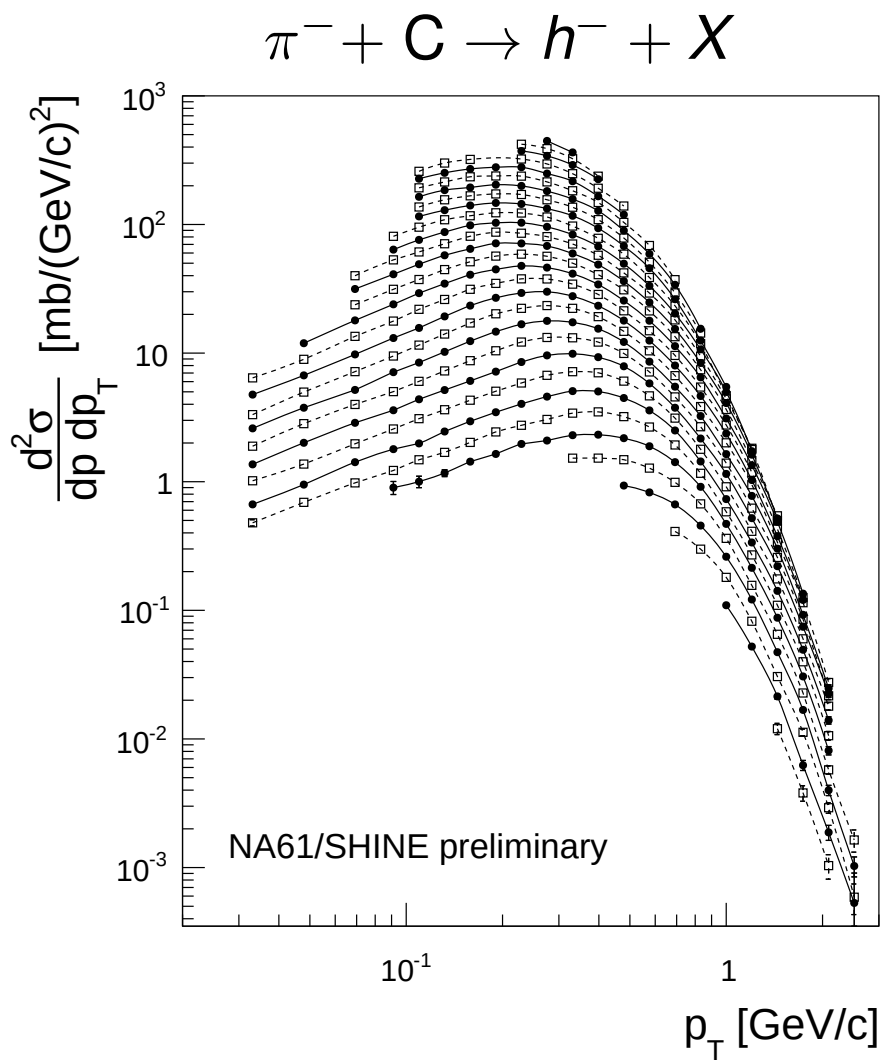
NA61 Measurements for Cosmic Ray Experiments

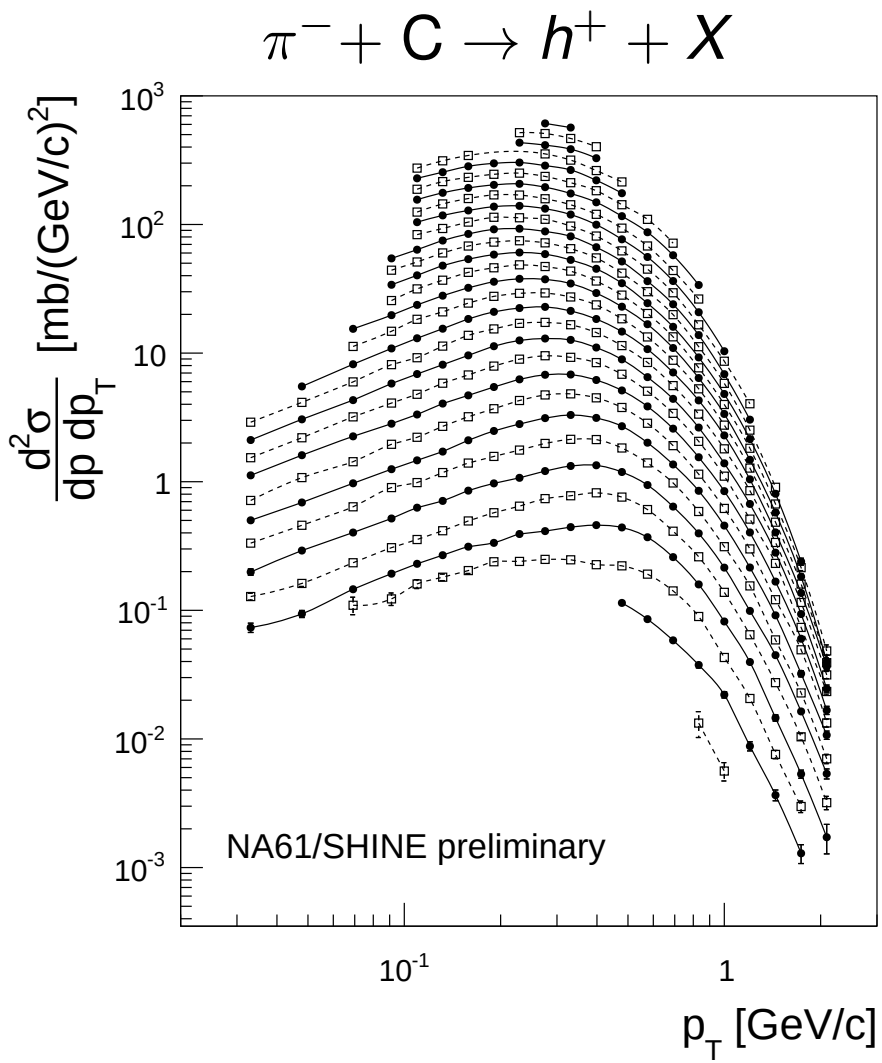
Production Cross Section in π^-+C Interactions

- using NA61 beam counters, veto scintillators, GAP-TPC
- correction for lost interactions, σ_{ela}, σ_{qela} (model dependent)



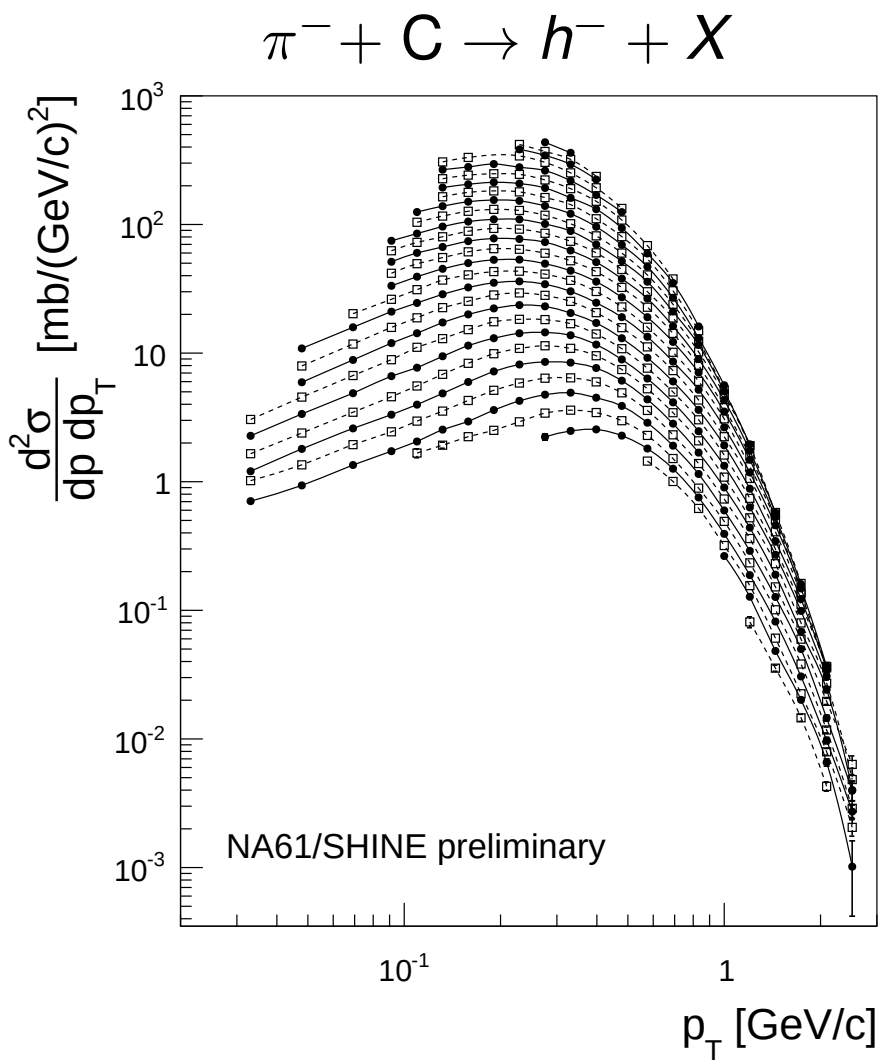
Charged Hadron Production in π^-+C at 158 GeV/c

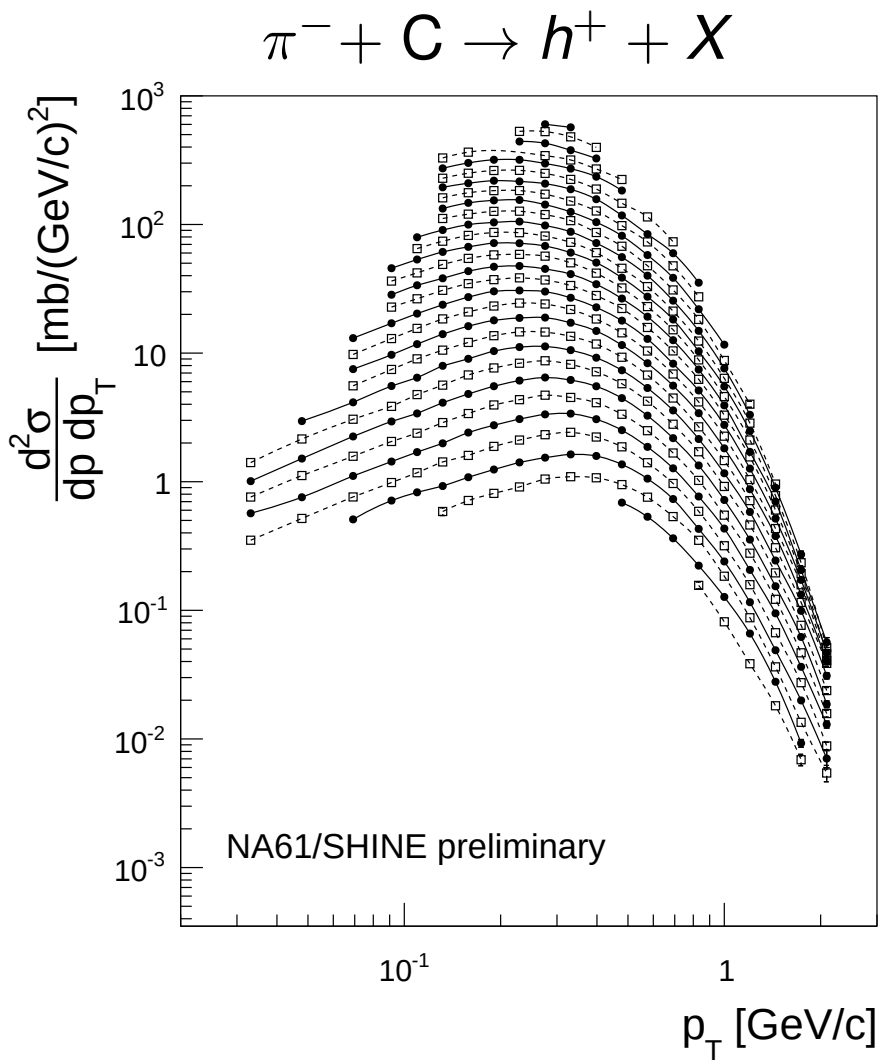




p = 0.6 . . . 121 GeV/c in steps of $\lg p/(\mathrm{GeV}/c) = 0.08$

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

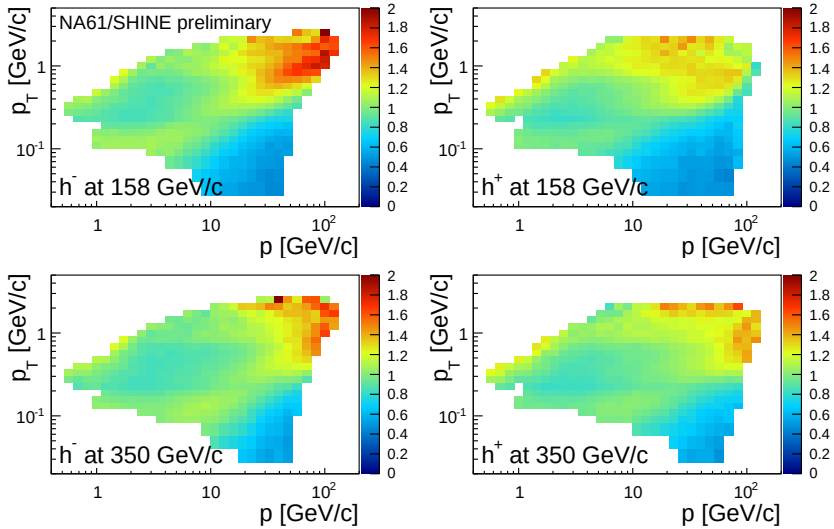




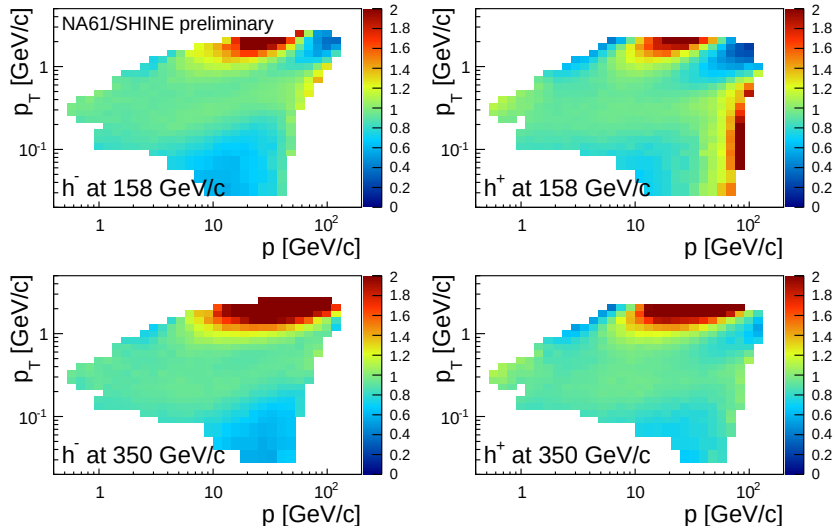
$p = 0.6 \ldots 121$ GeV/c in steps of $\lg p/(\mathrm{GeV}/c) = 0.08$

Comparison to Hadronic Interaction Models

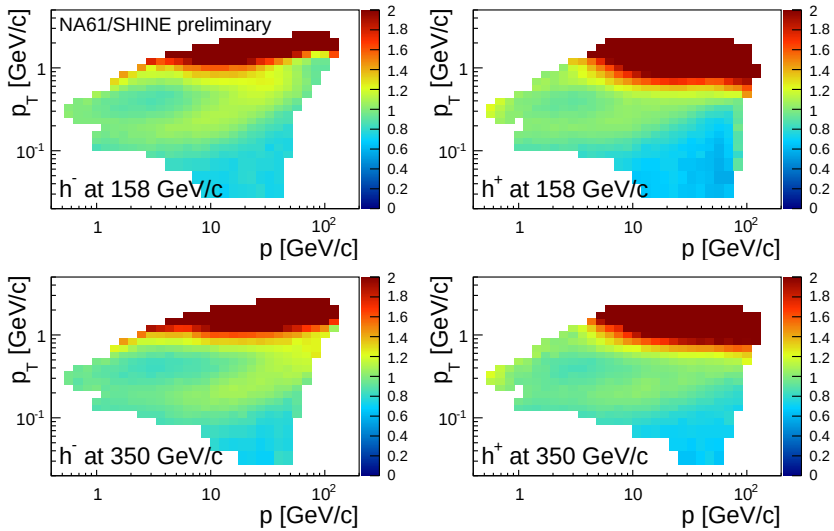
QGSJetII-03



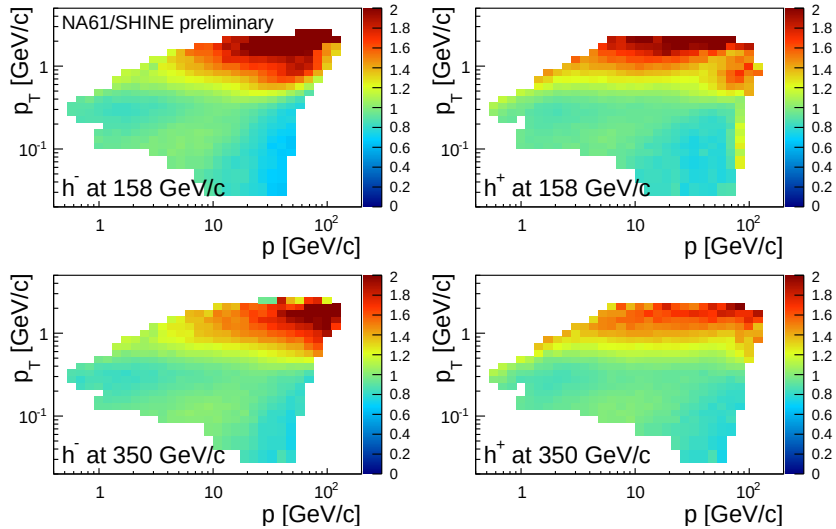
UrQMD1.3.1_patched



Sibyll2.1



EPOS1.99



colors: data/MC, dark red: ≥ 2, dark blue: ≤ 0.3

NA61 Measurements for T2K

PRL 107, 041801 (2011) Selected for a Viewpoint in *Physics*
PHYSICAL REVIEW LETTERS week ending 22 JULY 2011

Indication of Electron Neutrino Appearance from an Accelerator-Produced Off-Axis Muon Neutrino Beam

K. Abe,[49] N. Abgrall,[16] Y. Ajima,[18,†] H. Aihara,[48] J. B. Albert,[13] C. Andreopoulos,[47] B. Andrieu,[37] S. Aoki,[27]
O. Araoka,[18,†] J. Argyriades,[16] A. Ariga,[3] T. Ariga,[3] S. Assylbekov,[11] D. Autiero,[32] A. Badertscher,[15] M. Barbi,[40]

measurement in the off-axis near detector.

We compute the neutrino beam fluxes (Fig. 1) starting from models and tuning them to experimental data. Pion production in (p, θ) bins is based on the NA61 measurements [21], typically with 5%–10% uncertainties. Pions produced outside the experimentally measured phase

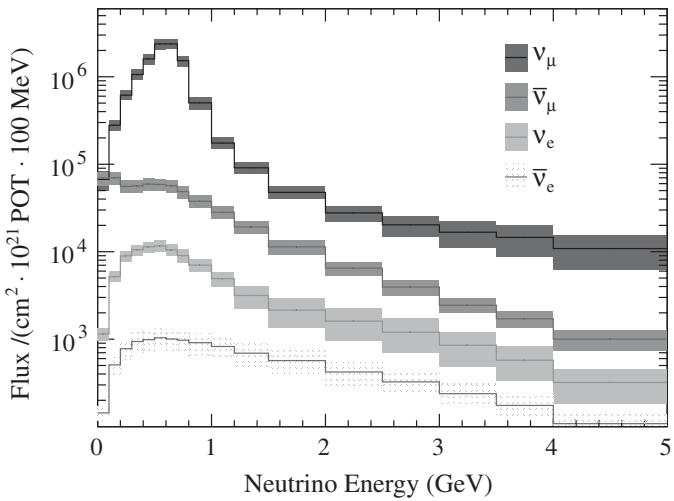
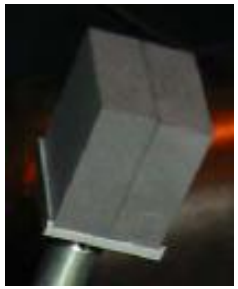


FIG. 1. Predicted neutrino fluxes at the far detector, in absence of oscillations. The shaded boxes indicate the total systematic uncertainties for each energy bin.

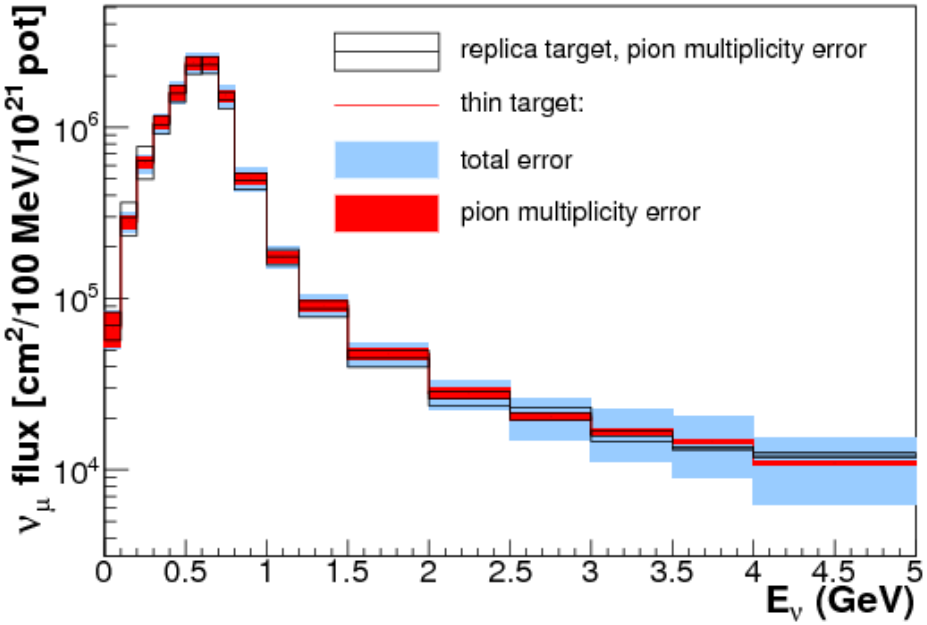
NA61 Measurements for T2K

First complete example of application of long-target data for neutrino flux predictions!

thin target (l =2 cm, λ_{int} ~0.03)



replica target (l =90 cm, λ_{int} ~1.9)



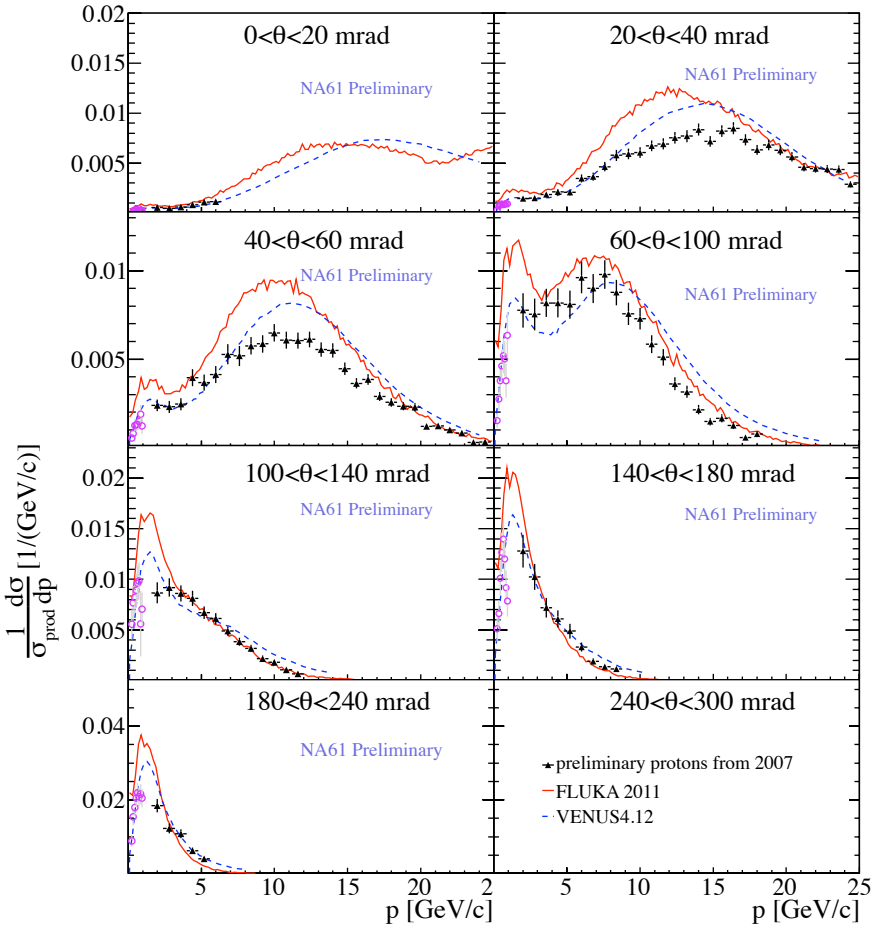
re-weighted ν_μ-flux sim. at T2K far detector

CERN-PH-EP-2012-188, arXiv:1207.2114 [hep-ex], submitted to NIM

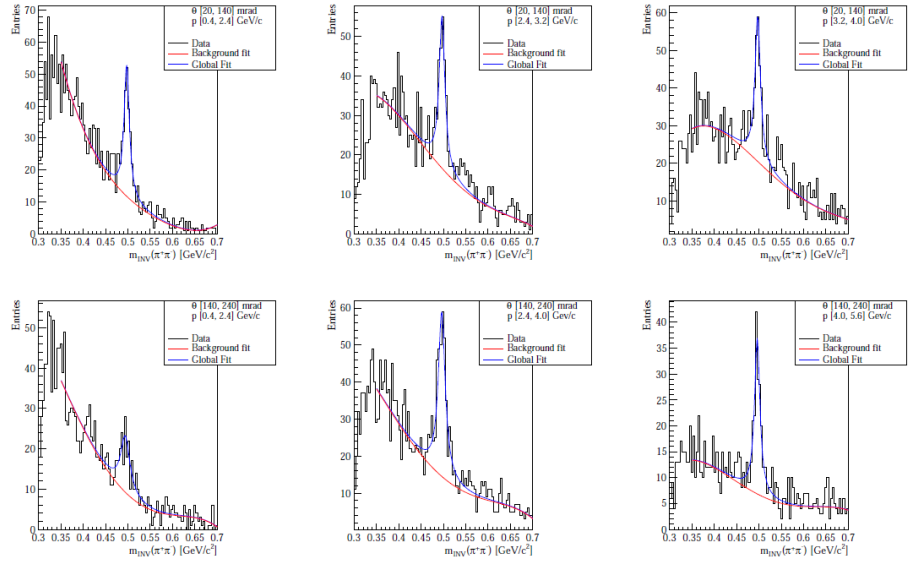
NA61 Measurements for T2K

2007 data, p+C at 31 GeV/c

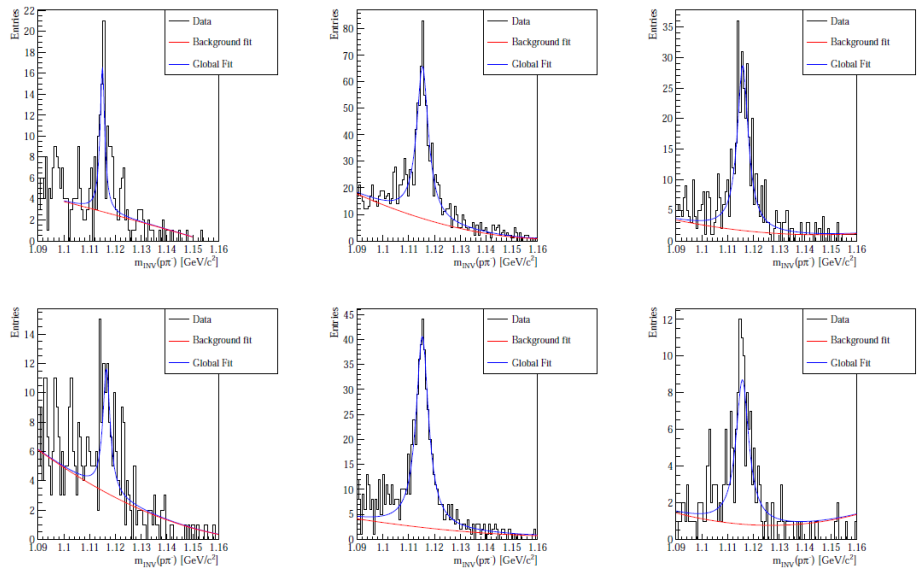
proton production spectra:



K^0_S from $m(\pi^+, \pi^-)$



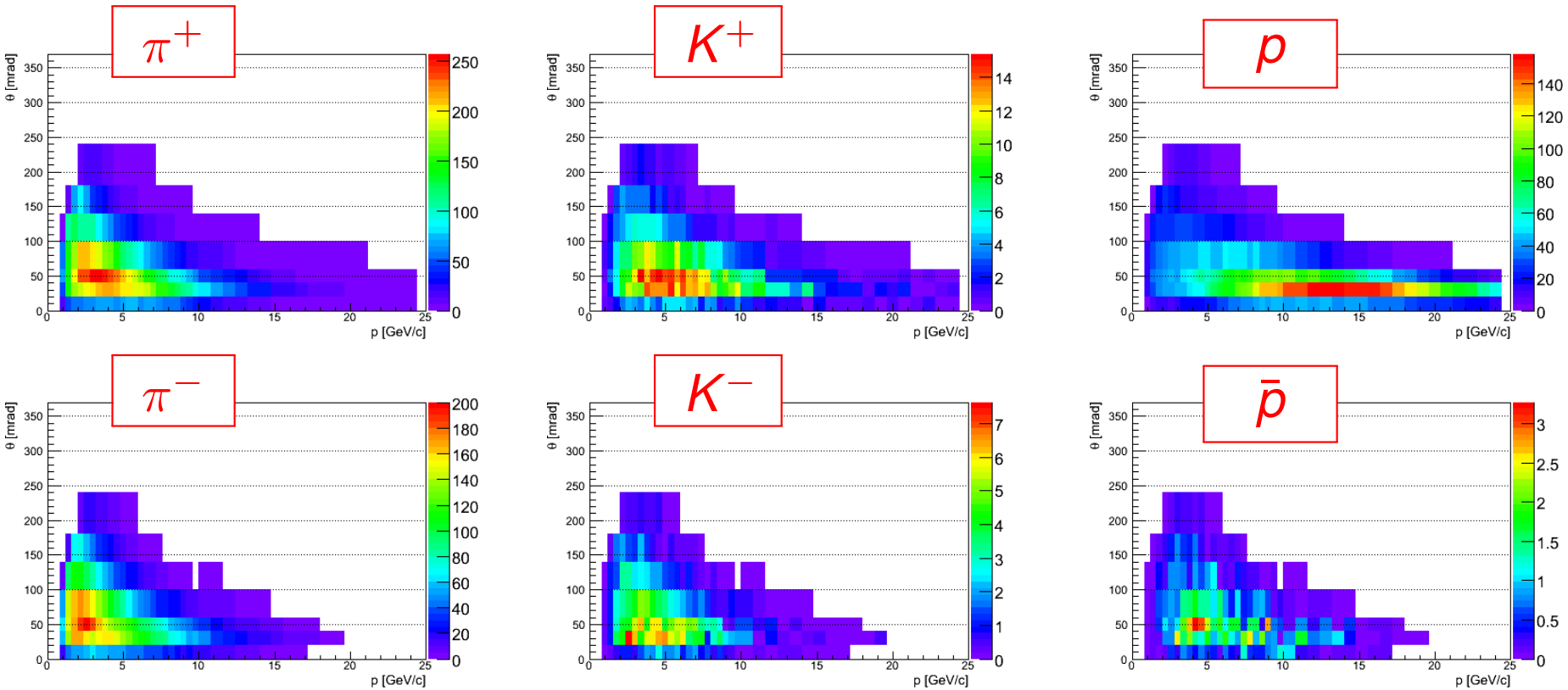
Λ from $m(p, \pi^-)$



NA61 Measurements for T2K

ongoing analysis of 2009 thin target data

- factor 10 more statistics as 2007 data set
- simultaneous extraction of $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$ (only $\pi^{\pm}$, K^{+} and p with 2007 data)

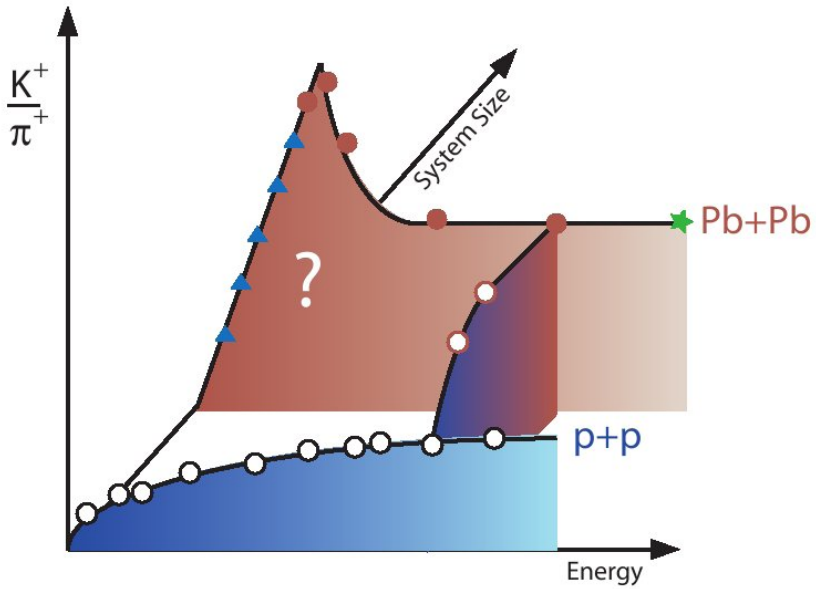


raw particle yields – release of corrected spectra end 2012

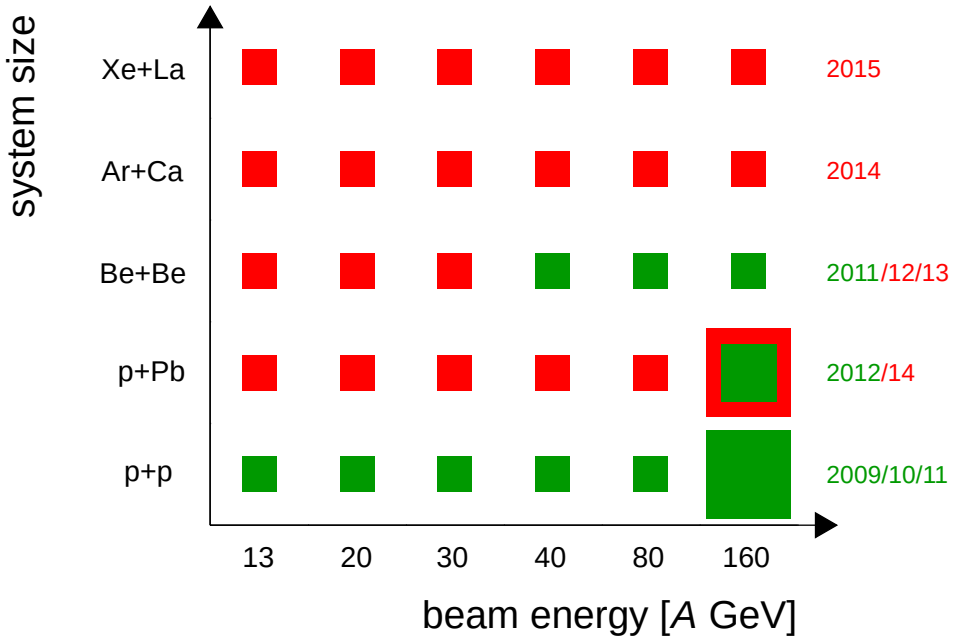
NA61 Heavy Ion Program

Study of the onset of deconfinement and search for the critical point of strongly interacting matter

previous data:



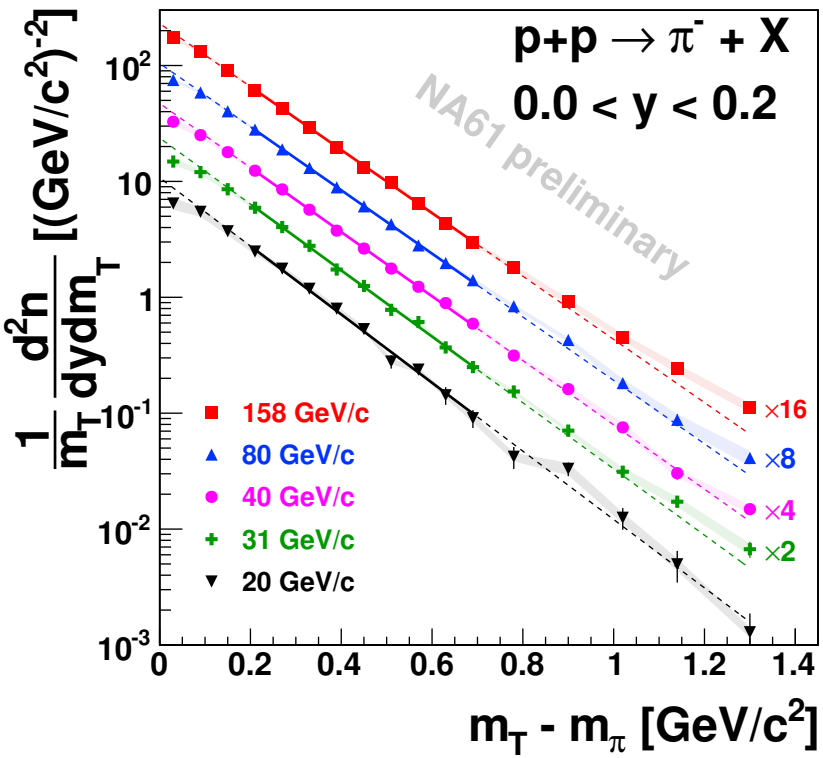
NA61 scan of system size and energy:



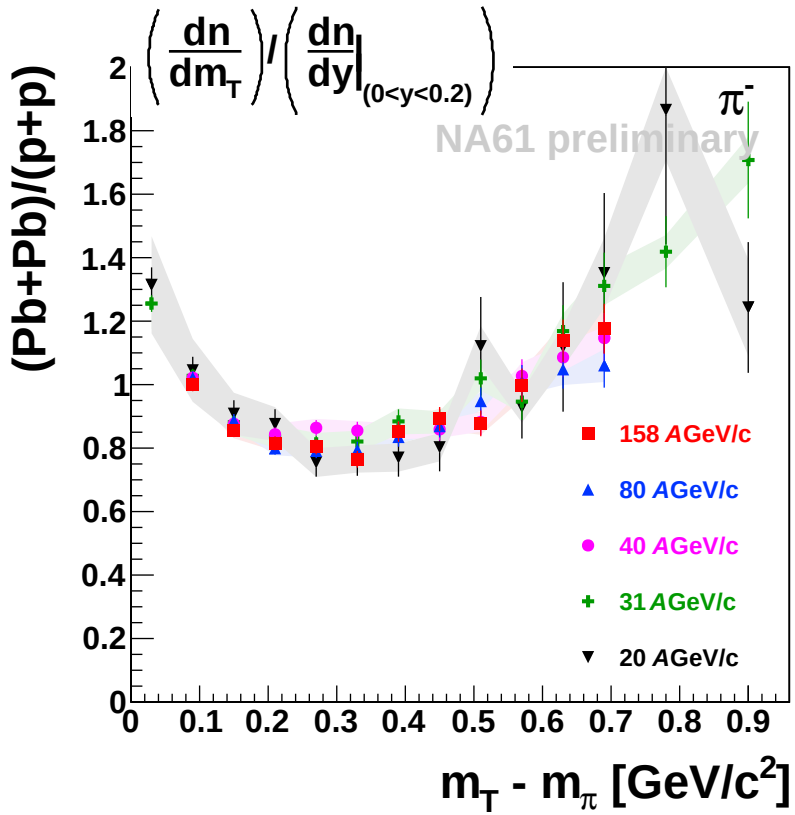
beam schedule as of 2011

π^- from h^- results, $p+p$ at 158 GeV/c (2009 data)

m_T spectra at mid-rapidity



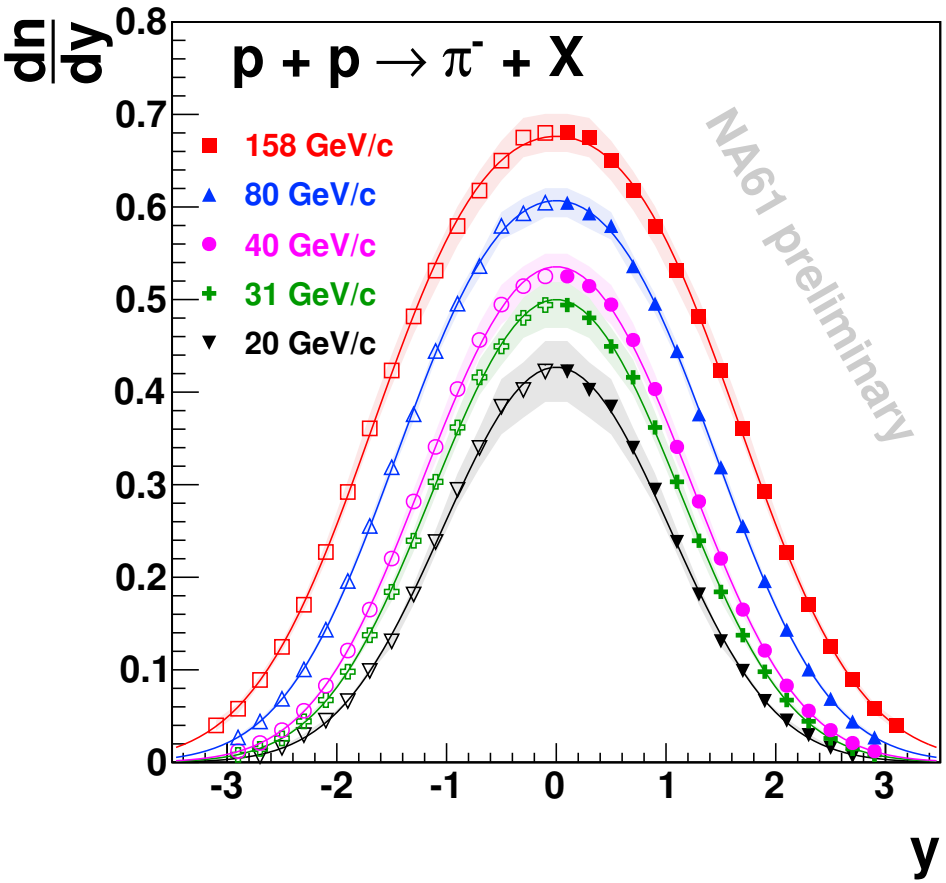
(NA49 Pb+Pb)/(NA61 p+p)



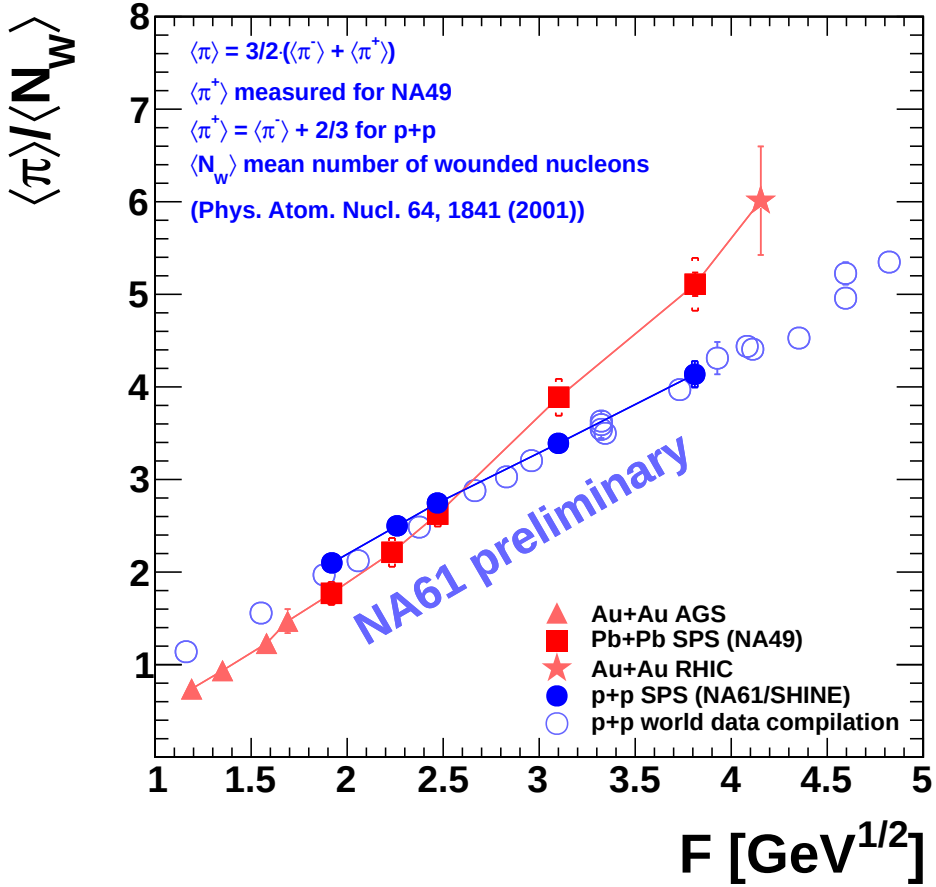
significant shape-difference wrt. Pb+Pb, independent of energy.

π^- from h^- results, $p+p$ at 158 GeV/c (2009 data)

m_T-integrated π^--spectra

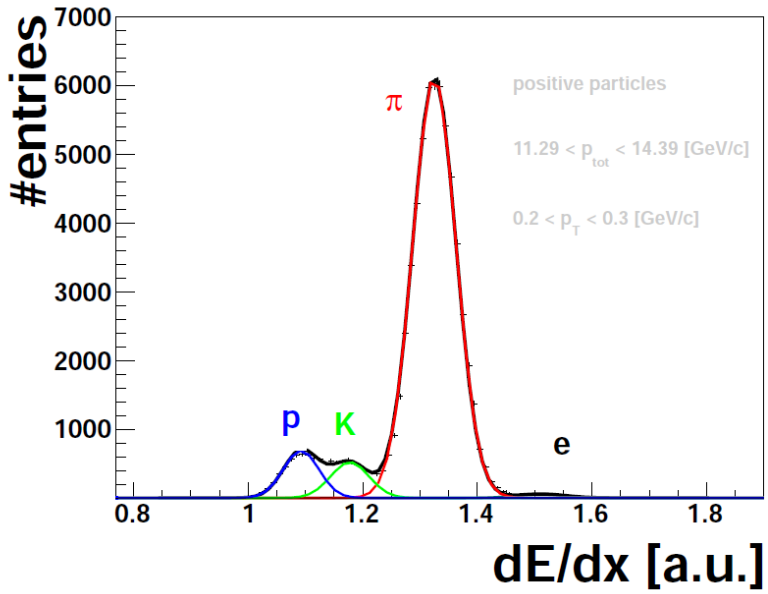


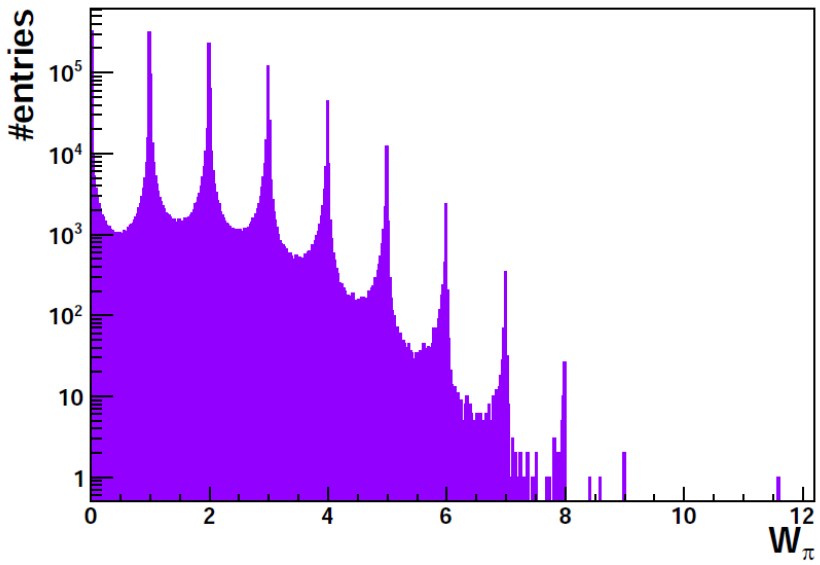
comparison to prev. p+p, Pb+Pb



- large y-acceptance, small syst. and stat.
- precision (still to be improved) already sufficient for study of onset of deconfinement

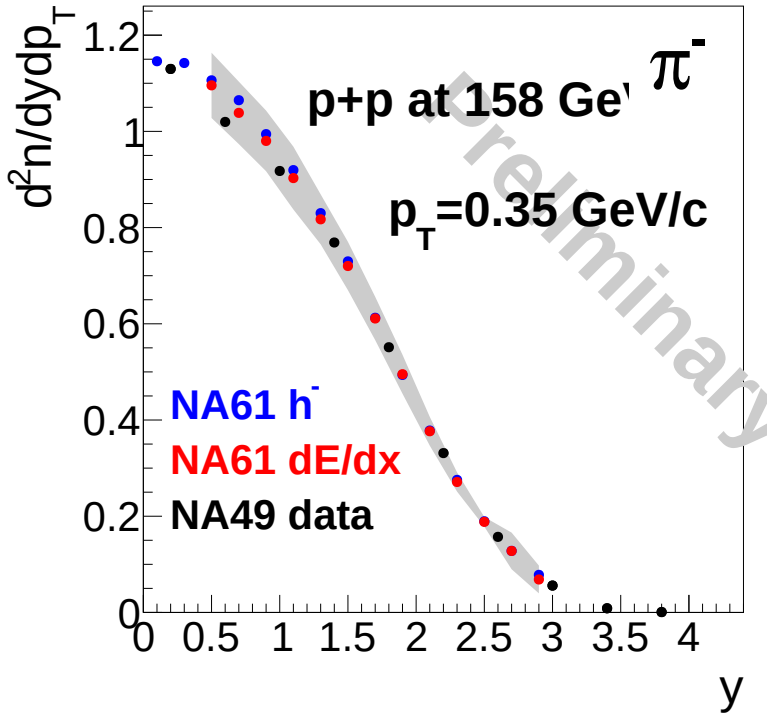
Results using PID, $p + p$ at 158 GeV/c (2009 data)





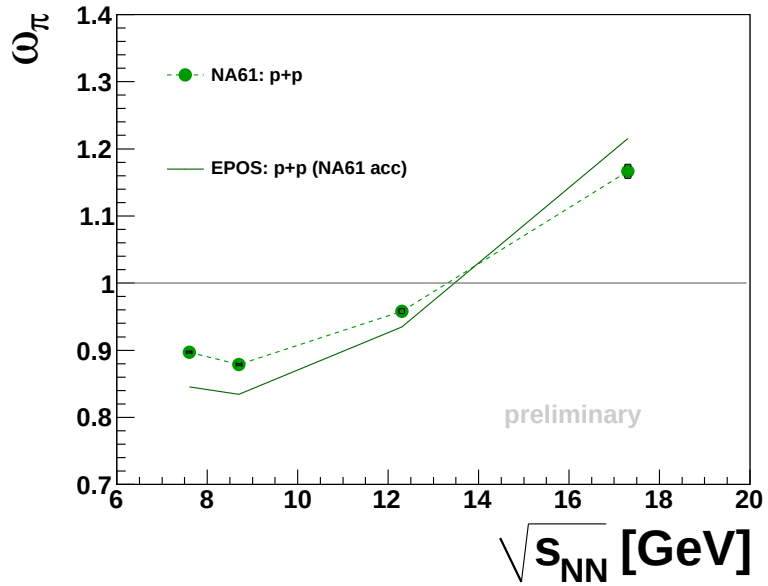
p+*p* at 80 GeV/c

$\pi^-(h^-)_{\mathrm{NA61}}$ vs. π^-_{NA61} vs. π^-_{NA49}



- event-by-event 'particle counting' using dE/dx fits (identity method)
- $\rightarrow$ unfolded moments (mean, variance, . . .)

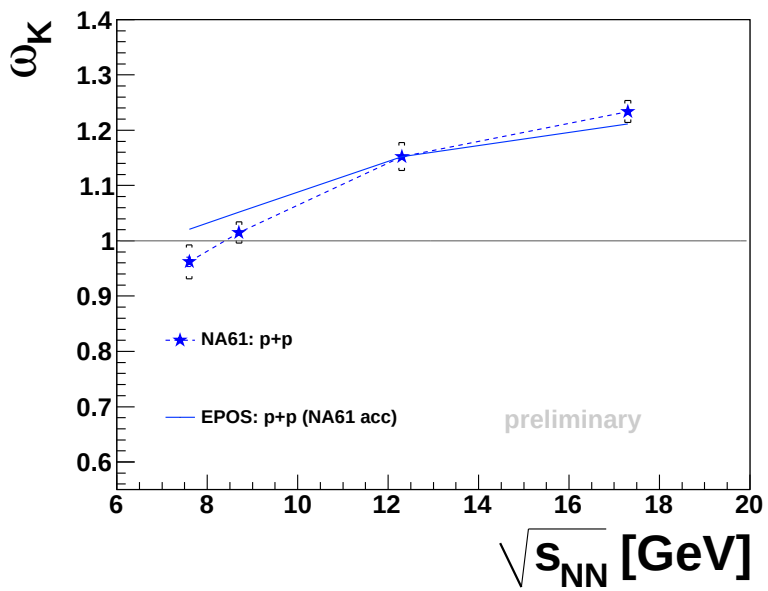
Multiplicity fluctuations in $p + p$ interactions (prel.)

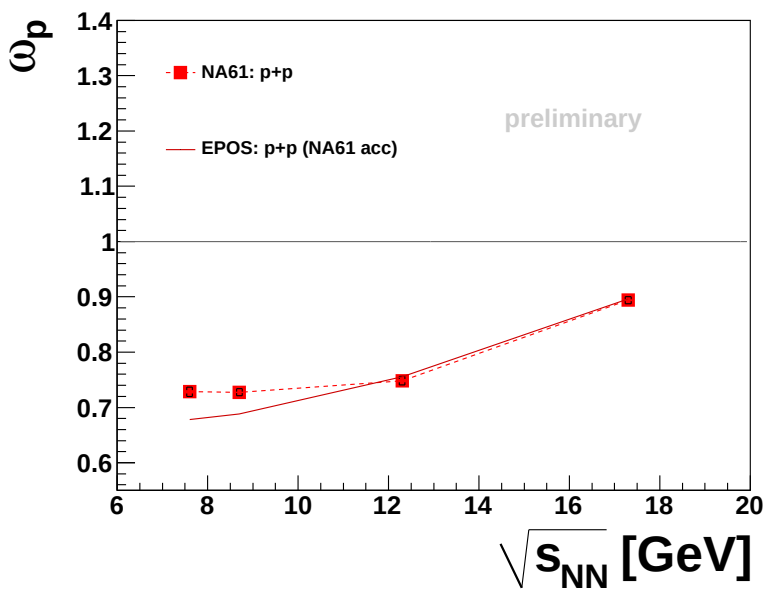


- scaled variance:

$$\omega_i = \frac{\langle N_i^2 \rangle - \langle N_i \rangle^2}{\langle N_i \rangle}$$

- for Poisson: $\omega_i = 1$





Data Taking Plan

Schedule as of 2011:

Beam Primary	Beam Secondary	Target	Energy (A GeV)	Year	Days	Physics
Pb			13, 20, 30			
	^{7}Be	Be	13, 20, 30	2012/2013	14/28 days	CP, OD
Ar		Ca	13, 20, 30, 40, 80, 158	2014	6×8 days	CP, OD
p			400			
	p	Pb	13, 20, 30, 40, 80, 158	2014	6×7 days	CP, OD
p			400			
	p	Pb	158	2014?	30? days	High p_T
Xe		La	13, 20, 30, 40, 80, 158	2015	6×8 days	CP, OD

(CP – Critical Point, OD – Onset of Deconfinement)

- highest physics priority for Ar beams
- further delays seriously endanger success of heavy ion program
- keep ahead of competition from RHIC (Au+Au energy scan in 2015-2017, 'BES phase II')

Summary and Outlook

NA61 activities Oct. 2011 - Oct. 2012

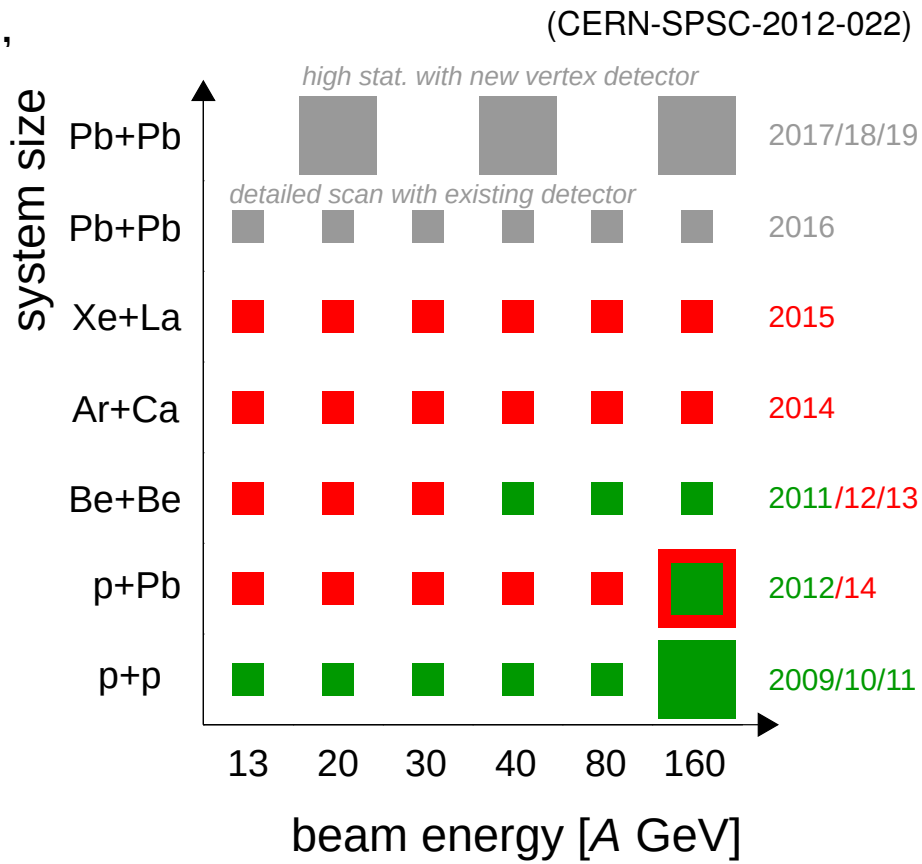
- Be+Be and p+Pb data taking
- publications using 2007 data
- prel. release of results with 2009 data, publications in preparation

Next important step

- proceed with heavy ion program

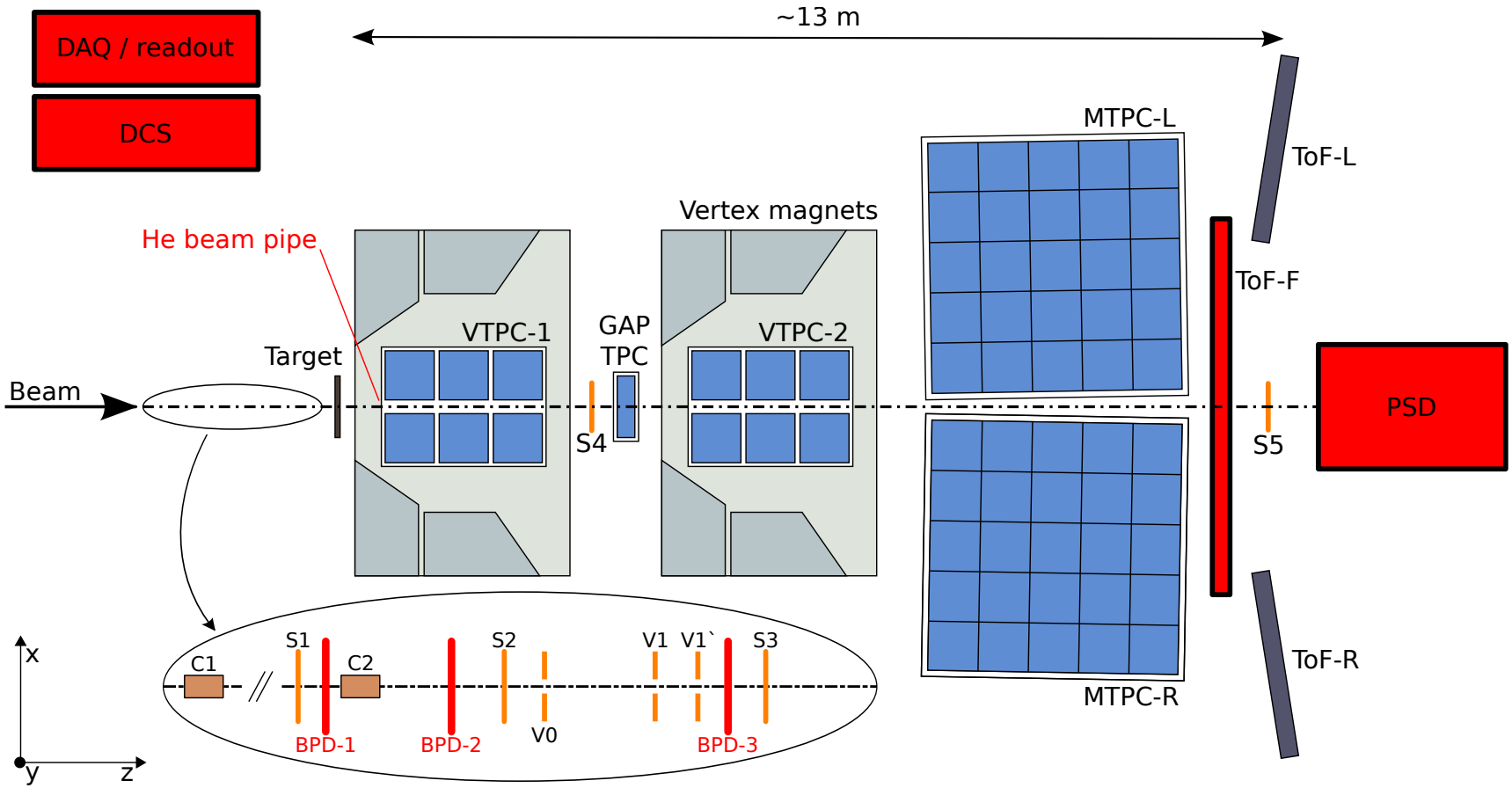
Extend NA61 physics program?

- hadro-production measurements
  - US ν-program
  - LAGUNA-LBNO
- Pb+Pb energy scan
- open charm in high stat. Pb+Pb with new vertex-detector



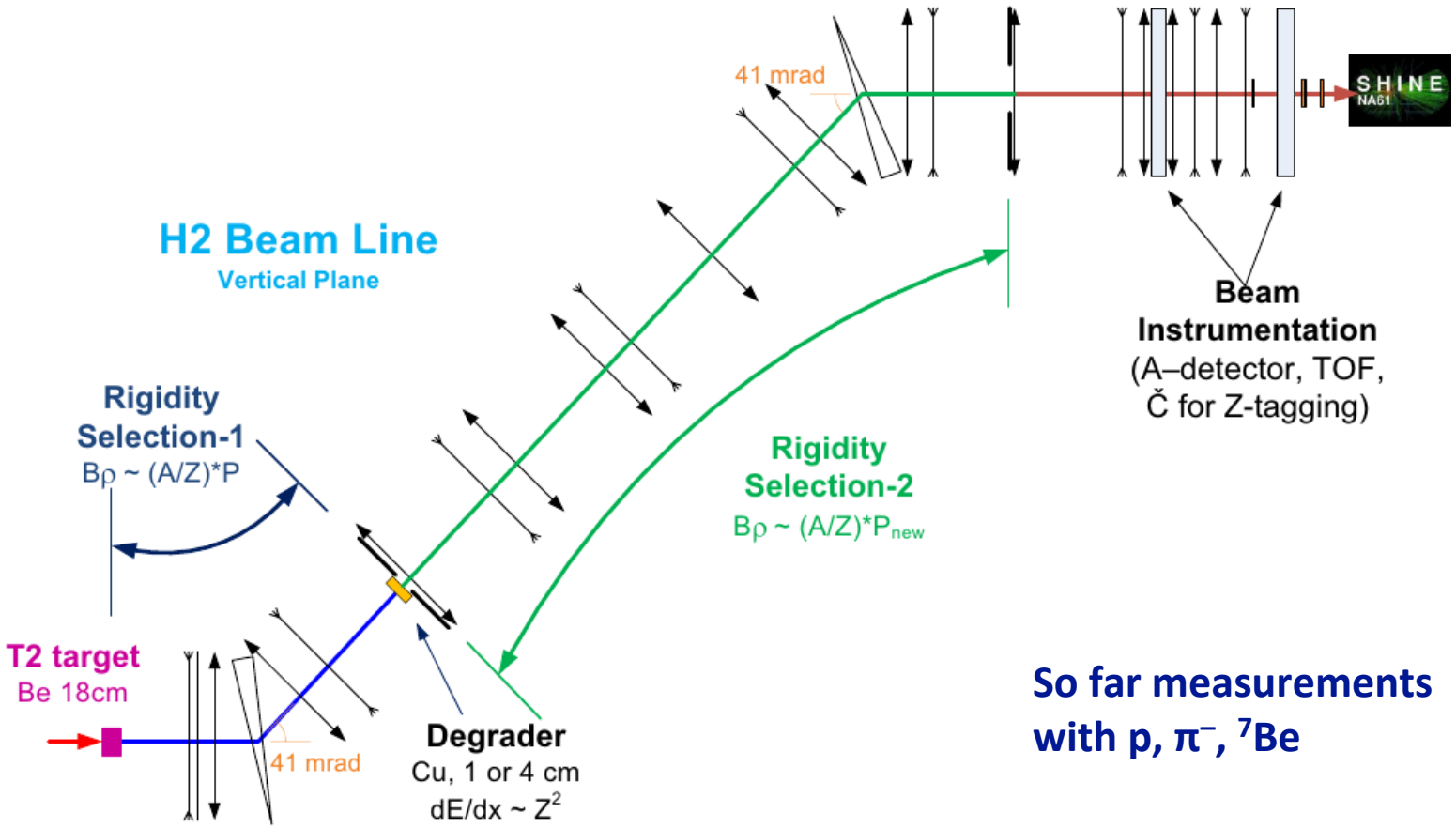
. . . additional slides . . .

Detector components and layout



NA49 detector (1994 – 2002) used after some upgrades and enhancements (marked red)

SPS secondary particle beam



SPS proton
or lead beam

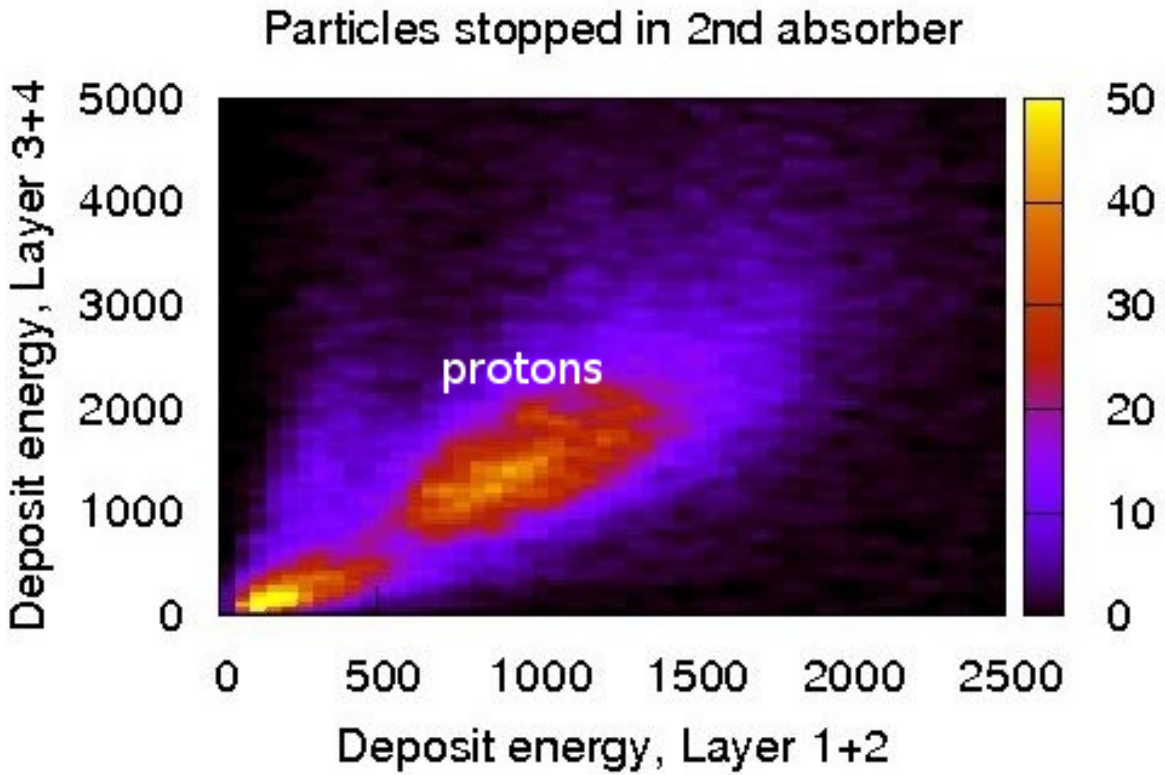
So far measurements
with p, π^-, ^{7}Be

Different energies and secondary particles or spallation products from ion beams possible

NA61 Calibration Procedure

- **T0-offset corrections:** pad by pad, TPC by TPC corrections
- **T0 calibration:** - scale calibration based on TOF-L geometry (TPC-TOF alignment)
- **BPD geometry:** residual corrections to the survey geometry
- **Vdrift smoothing:** smoothing of the measured Vdrift using p, T, HV measurements
- **Vdrift scaling:** based on alignment
- **Vdrift(t) calibration:** time dependent residual corrections base on bottom position
- **GTPC Vdrift:** based on alignment
- **TPC geometry:** corrections to the survey TPCs+GTPC geom
- **BPD-TPC geometry/alignment:** reference BPD positions
- **res. corrections to TPC points:** points positions corrections based on standard tracking procedure
- **magnetic field:** using Λ, K_0 invariant mass distributions
- **dE/dx calibration:** using truncated mean for the cluster charge including various detector effects
- **TOF-L/R:** data based geometry and time corrections
- **TOF-F:** data based geometry and time corrections

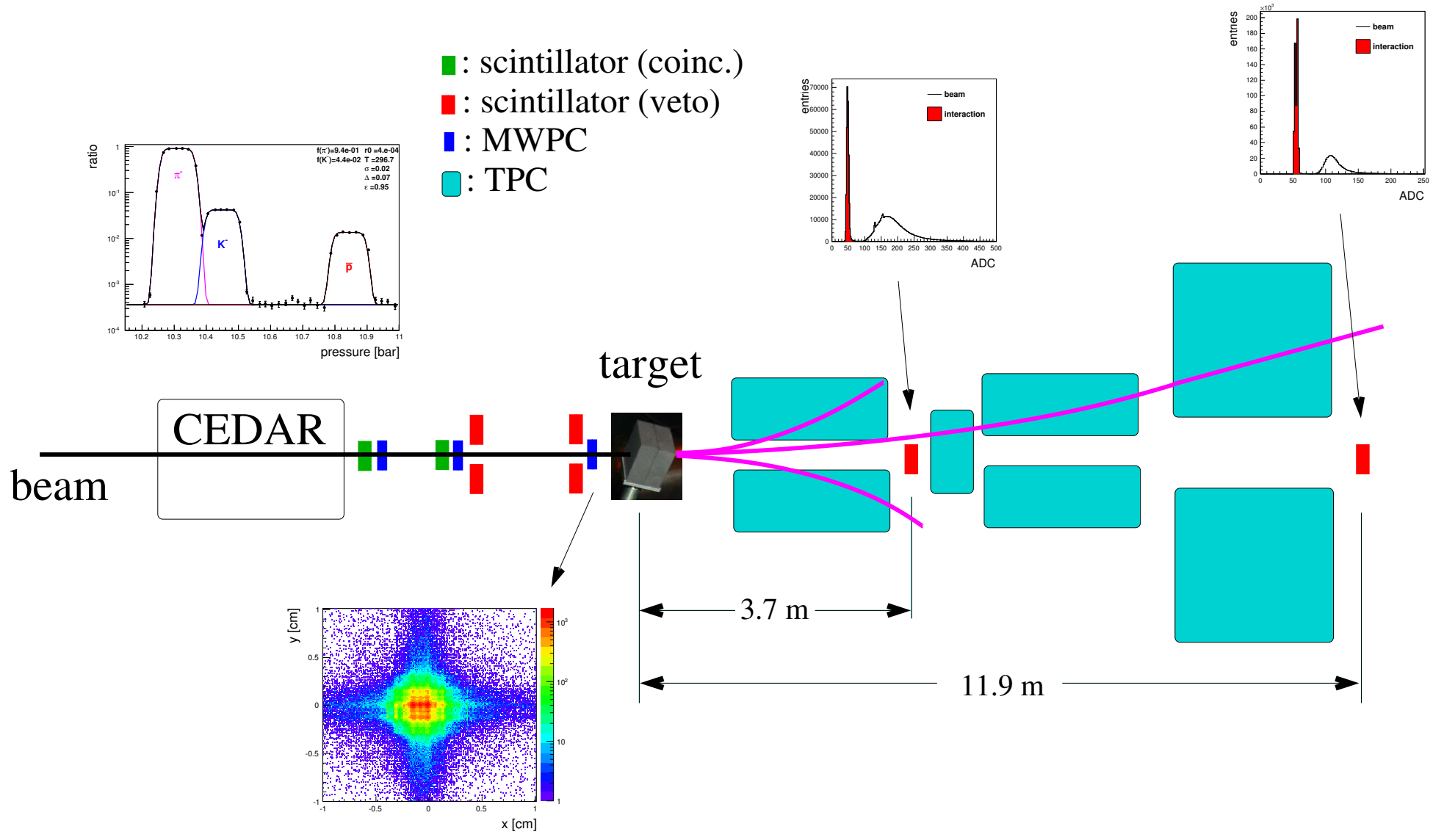
LMPD particle identification



four absorber layers, dynamic range ≈ 75 MeV/c to 300 MeV/c

Cross Section Measurements with NA61

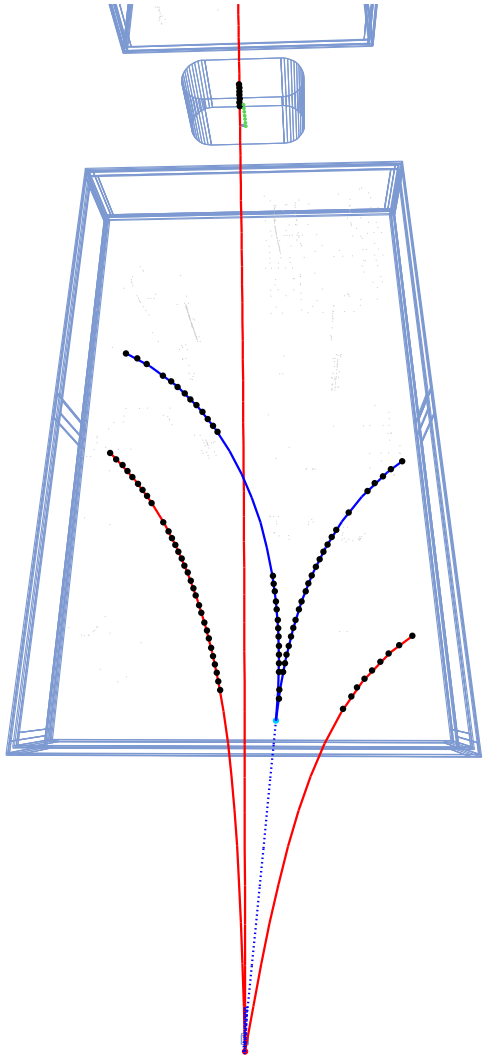
Schematic of Beam Line:



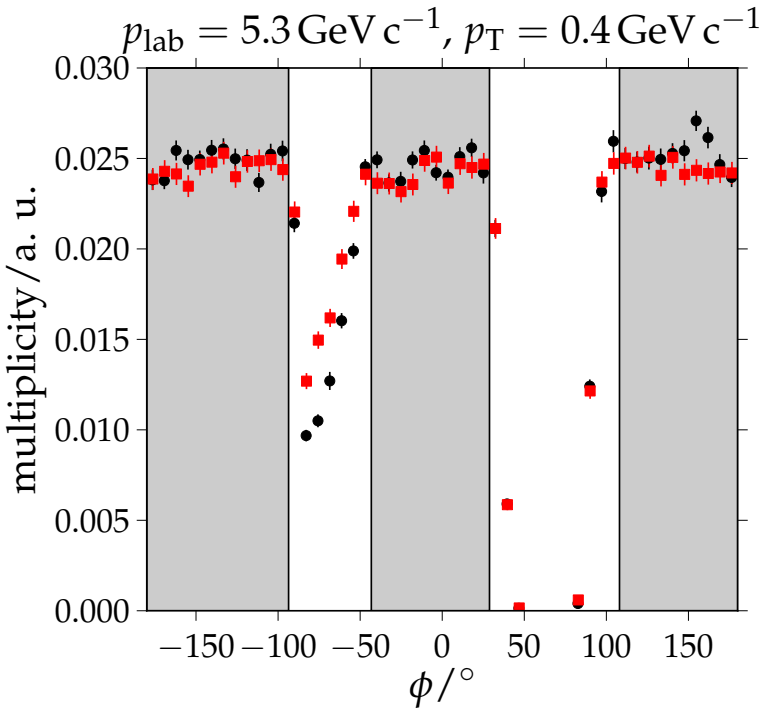
Analysis of π^-+C data

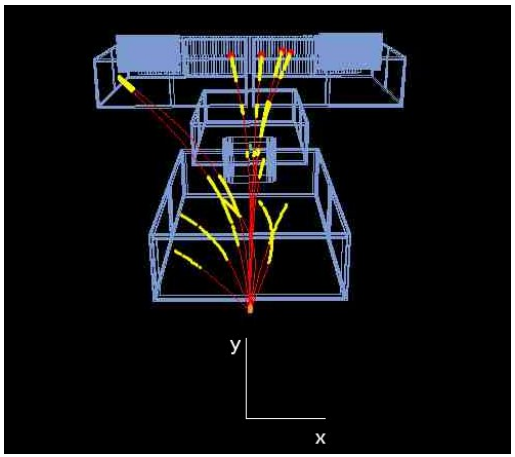
- currently: charged hadrons (no PID)
- tracks from main vertex
- correct for
  - feed-down
  - secondary interaction
  - track loss

  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



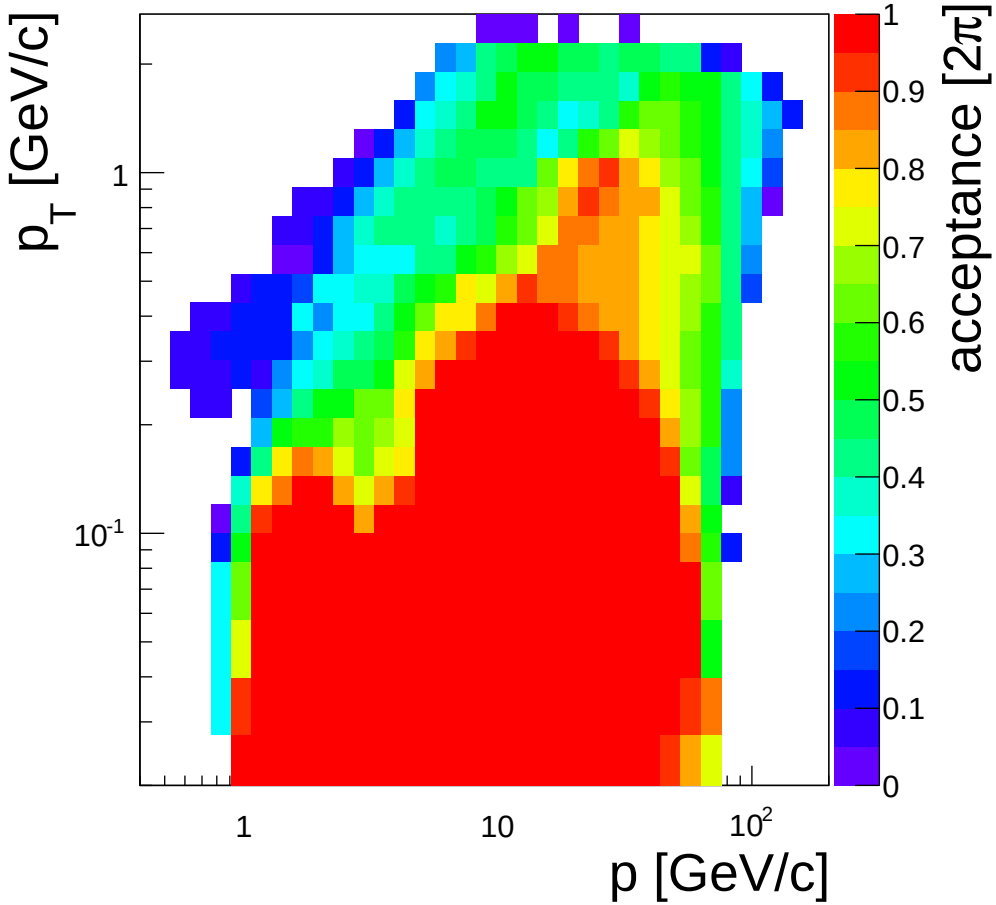
Analysis of π^-+C data





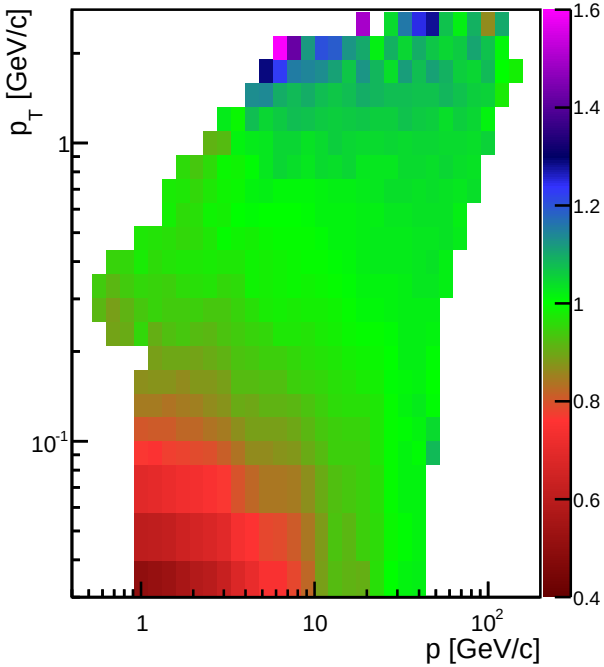
define geometrical acceptance:
accept only tracks in Φ-bins with ≥90% efficiency.

example: positive tracks

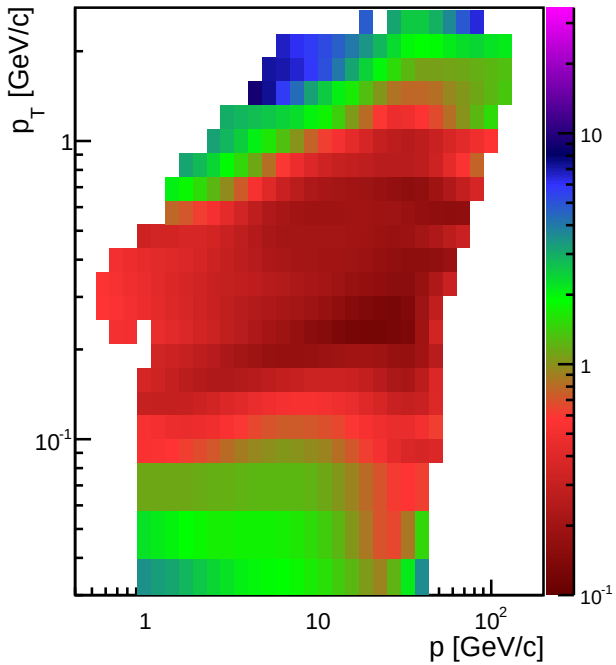


π^-+C Correction and Uncertainties

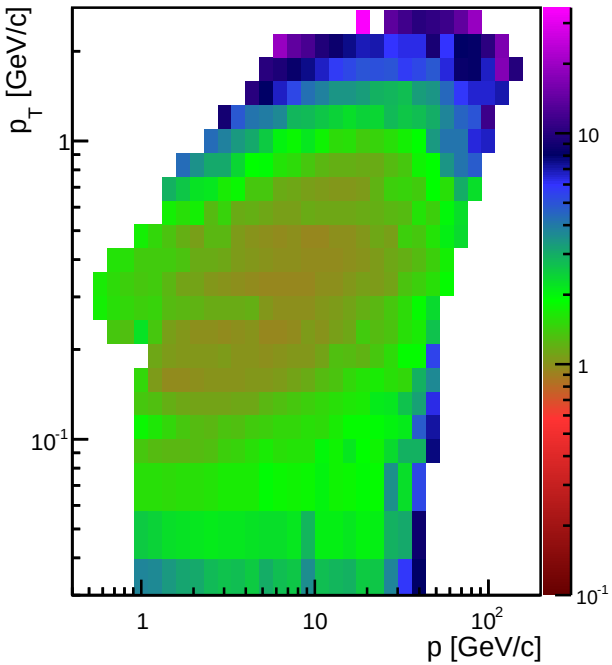
MC correction factor



model systematics [%]



total systematics [%]

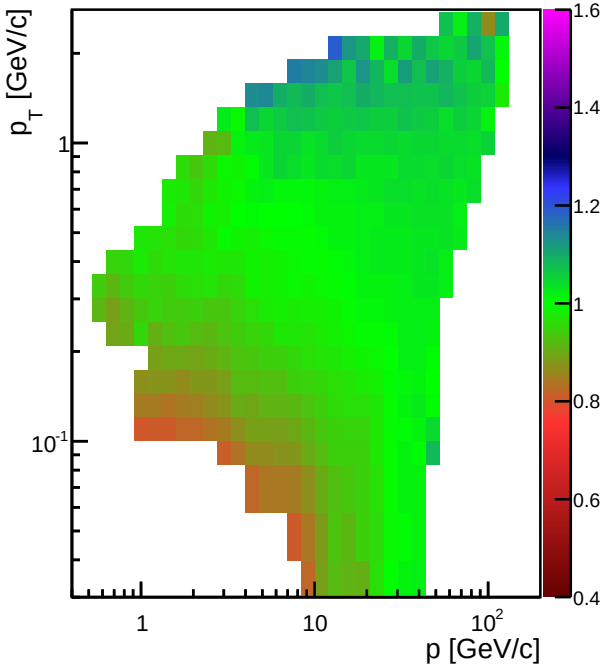


(example: h^-, 158 GeV/c)

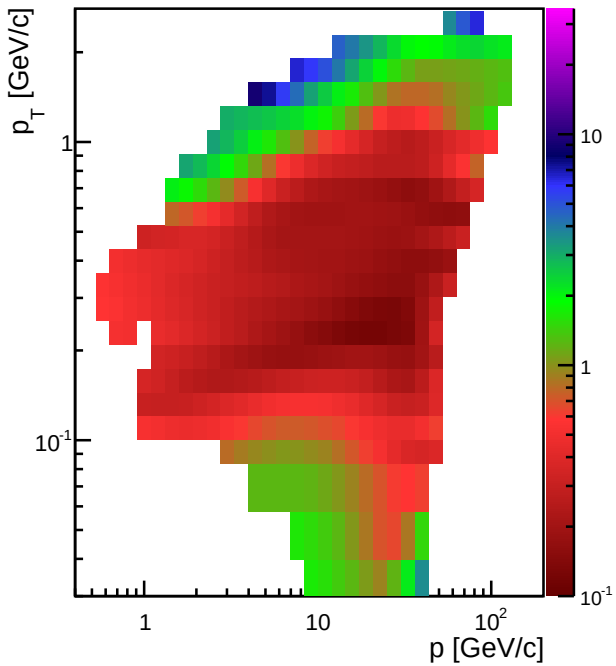
- $e^{\pm}$ contamination at low p, p_T
- model systematics from Δ(VENUS/EPOS) of individual contributions
- total systematics:
  model correction, normalization, trigger bias, calibration, track topology

π^-+C Correction and Uncertainties

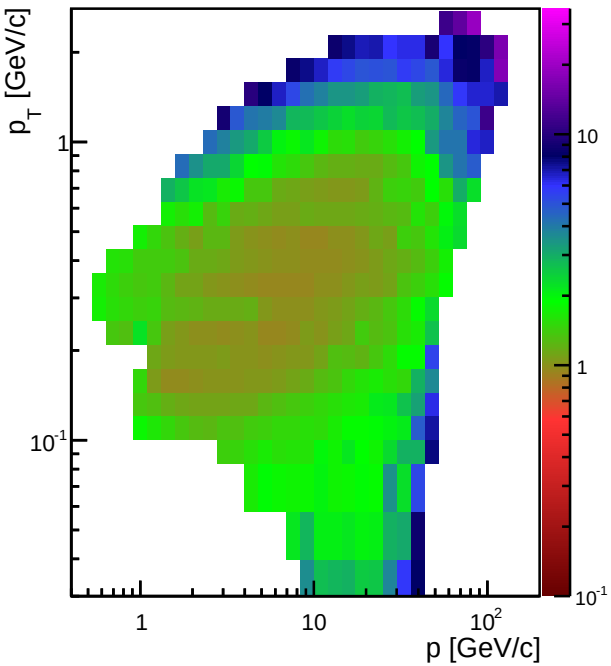
MC correction factor



model systematics [%]



total systematics [%]



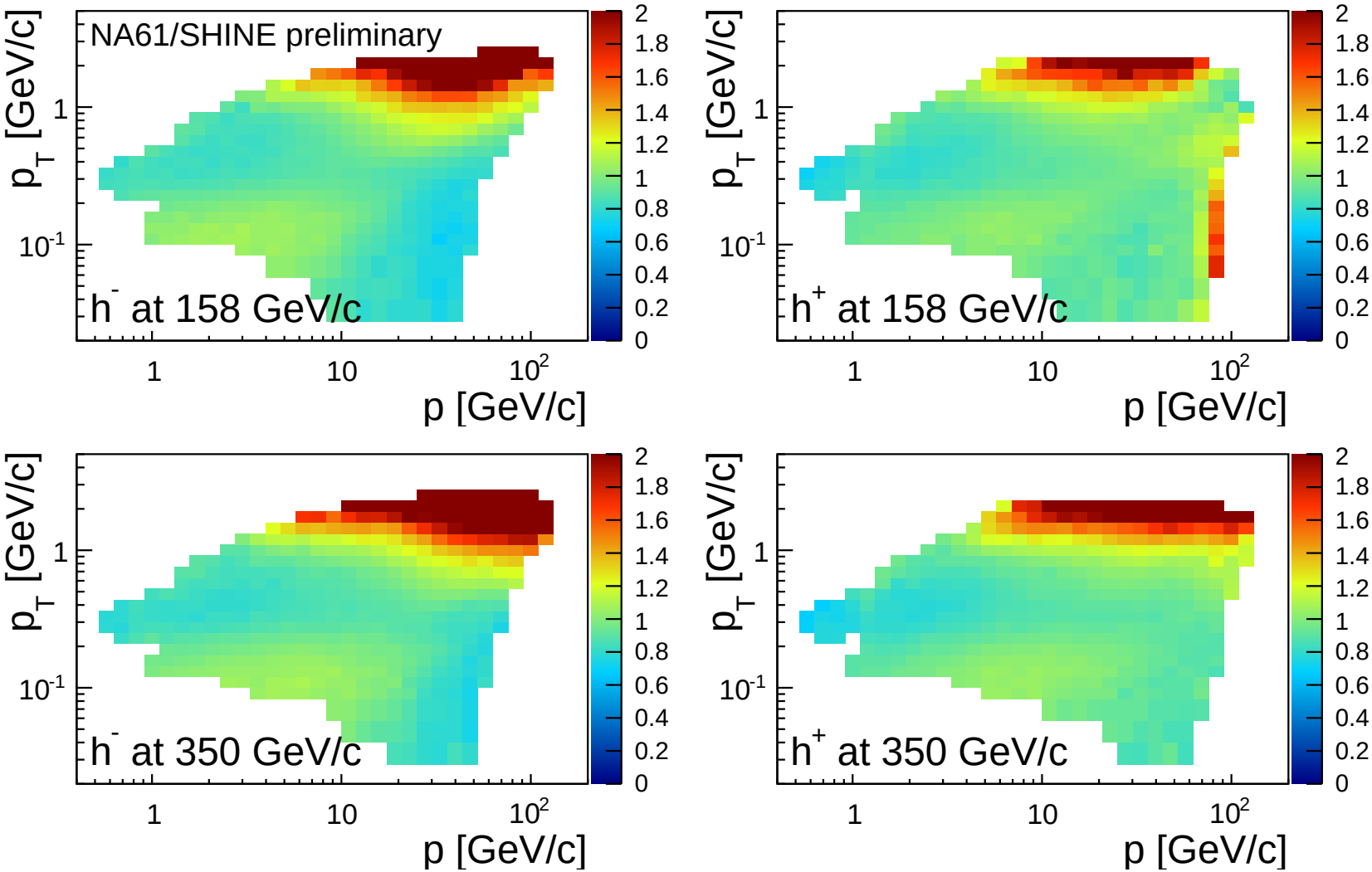
(example: h^-, 158 GeV/c)

- $e^{\pm}$ 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%

Comparison of $\pi + C$ results to FLUKA2011

approval by FLUKA collaboration pending



colors: data/MC, dark red: ≥ 2, dark blue: ≤ 0.3

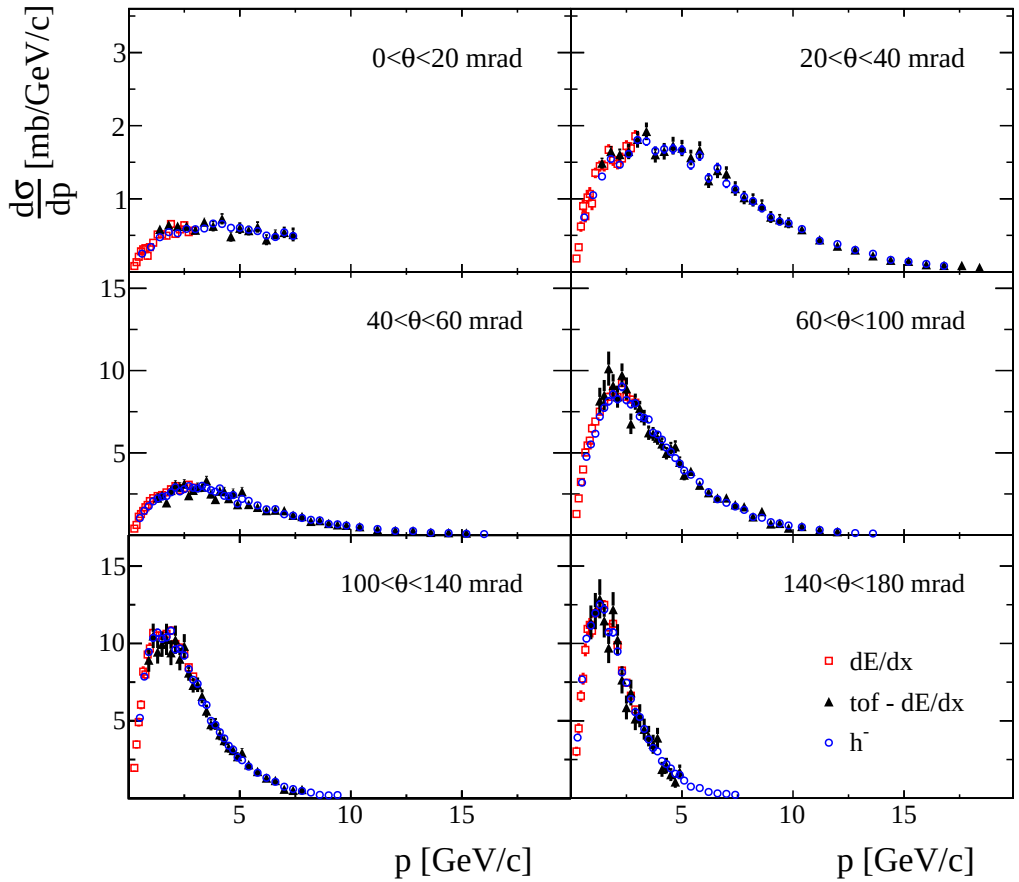
Analysis of 2007 data (p + C at 31 GeV/c)

three independent analyses:

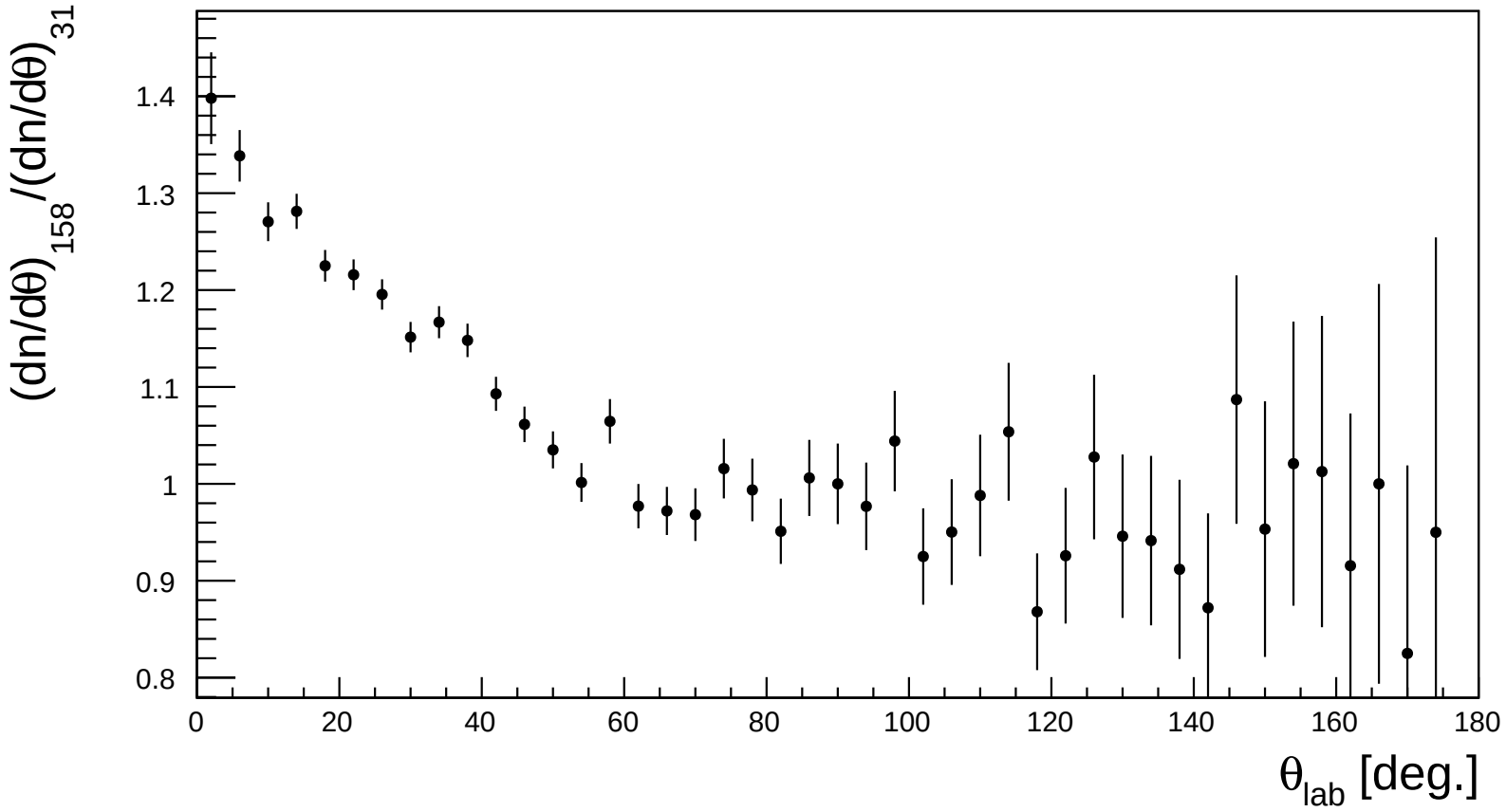
- negative hadrons (model corr.)
- dE/dx-only at low *p*
- dE/dx and TOF at medium *p*

spectrum corrections

- acceptance $\geq$ 99%
- reconstruction efficiency $\geq$ 96%
- pion decay $\leq$ 10%
- feed-down $\leq$ 10%



FLUKA2009 prediction of p+C (158 GeV)/(31 GeV)



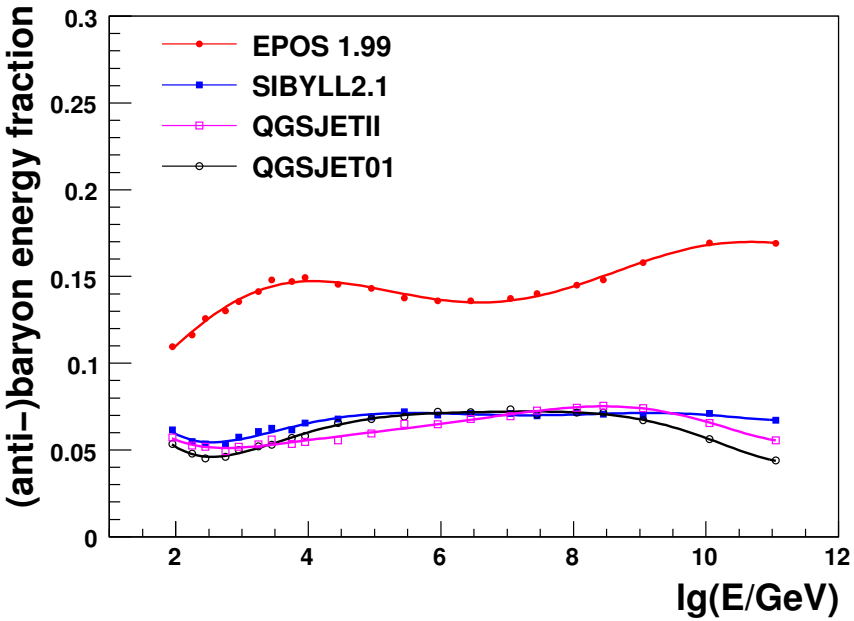
$\pi^+ + \pi^-$, $0.5 < p/(\mathrm{GeV/c}) < 0.8$

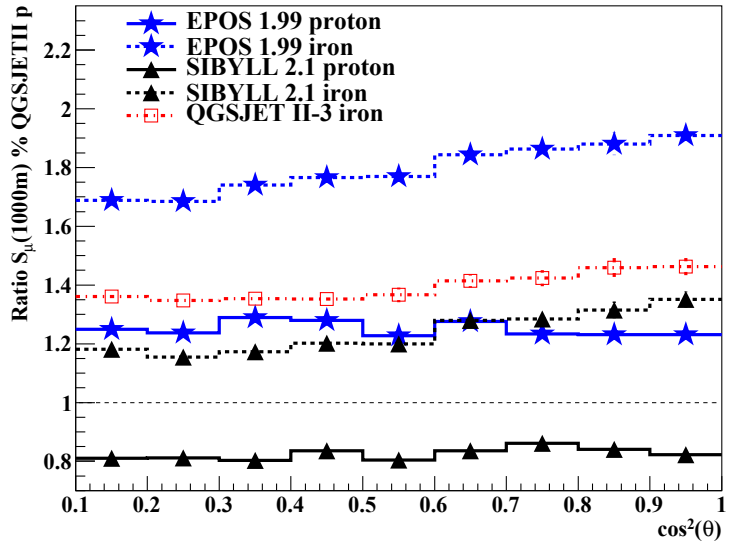
Muons in UHE Air Showers

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





T. Pierog, Proc. ICRC09