The NA61/SHINE long target pilot analysis for T2K

N.Abgrall

UNIVERSITÉ DE GENÈVE

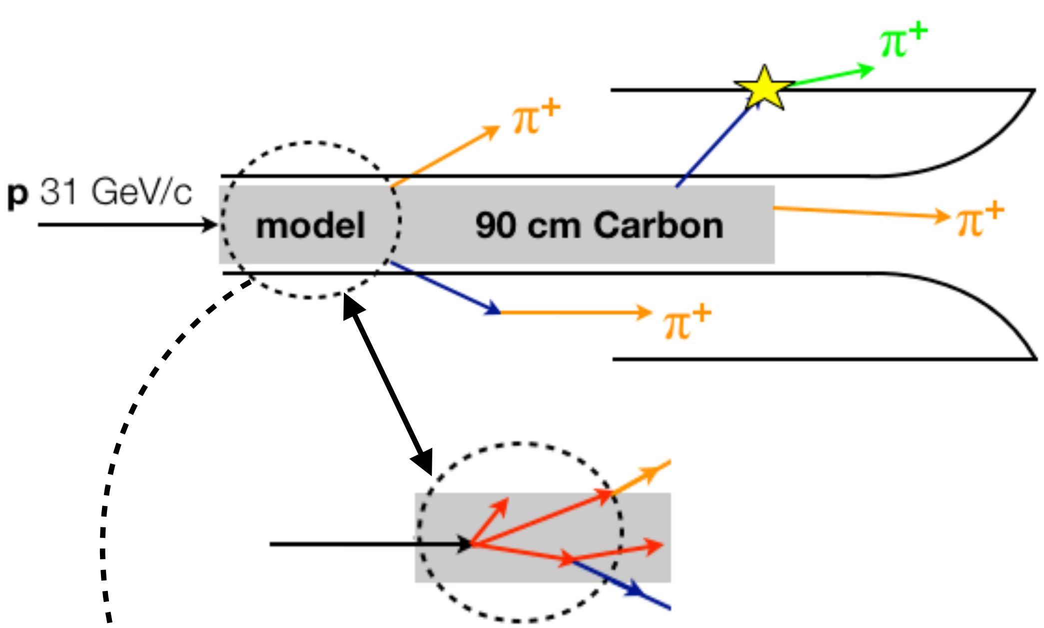
- T2K neutrino flux in terms of hadron production
- the NA61/SHINE setup
- the 2007 LT measurements
    - feasibility
    - particle identification
    - analysis binning
- LT based π^+ re-weighting factors for the T2K hadronization model
- NA61 vs T2K beam+target configurations
- next steps
- conclusions

Neutrino flux in T2K & hadron production measurements

~95% of the ν_μ flux at SK comes from π^+ decay. Need to look at different sources to understand which fraction could be constrained by auxiliary hadron production measurements. **~50%** of the ν_e flux from μ^+ decay produced in the same π^+ decays ---> ν_e flux partly constrained by the same data !

T2K simulation

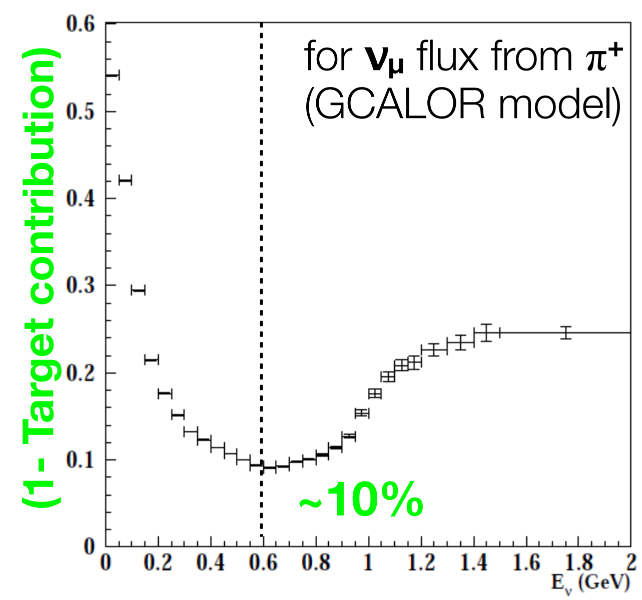
NA61 measurements



model prim.+sec. interactions in one go

~90%

Target contribution ⟷ **Long target measurements**



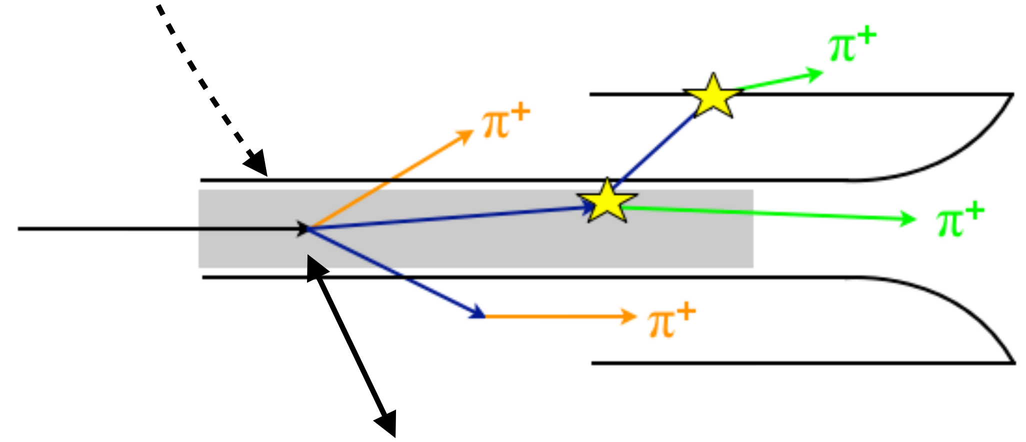
- reconstruct tracks without vertex constraint
- backward extrapolation to the surface of the target in bins of (p,θ,z)
- re-weight multiplicity of all π exiting the target in the T2K beam simulation

"PILOT analysis" presented here

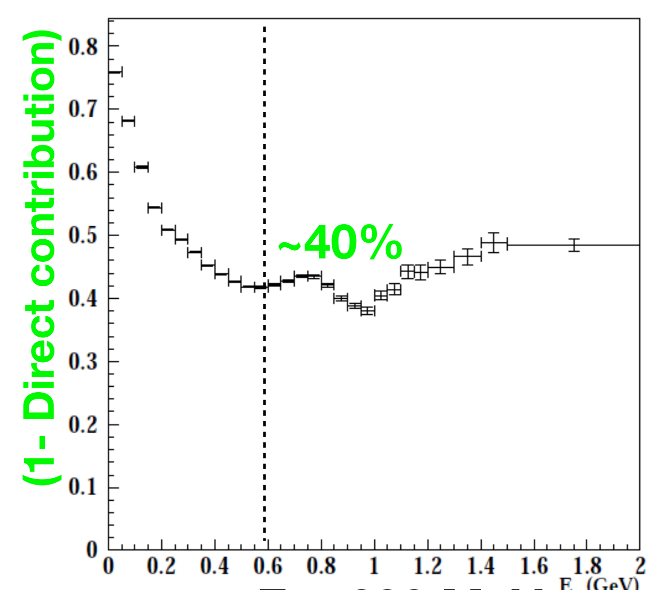
(first time we try to constrain ν flux predictions with long target data !)

~60%

Direct contribution ⟷ **Thin target measurements**



only model p+C ⟶ π^+ + X



E_ν ~600 MeV

- reconstruct tracks fitted at primary vertex in target in bins of (p,θ)
- π inclusive production cross sections *(see talk+poster by M. Posiadala)*
- re-weight multiplicity of secondary π simulated by the T2K model *(see next talk by V. Galymov)*

"standard approach"

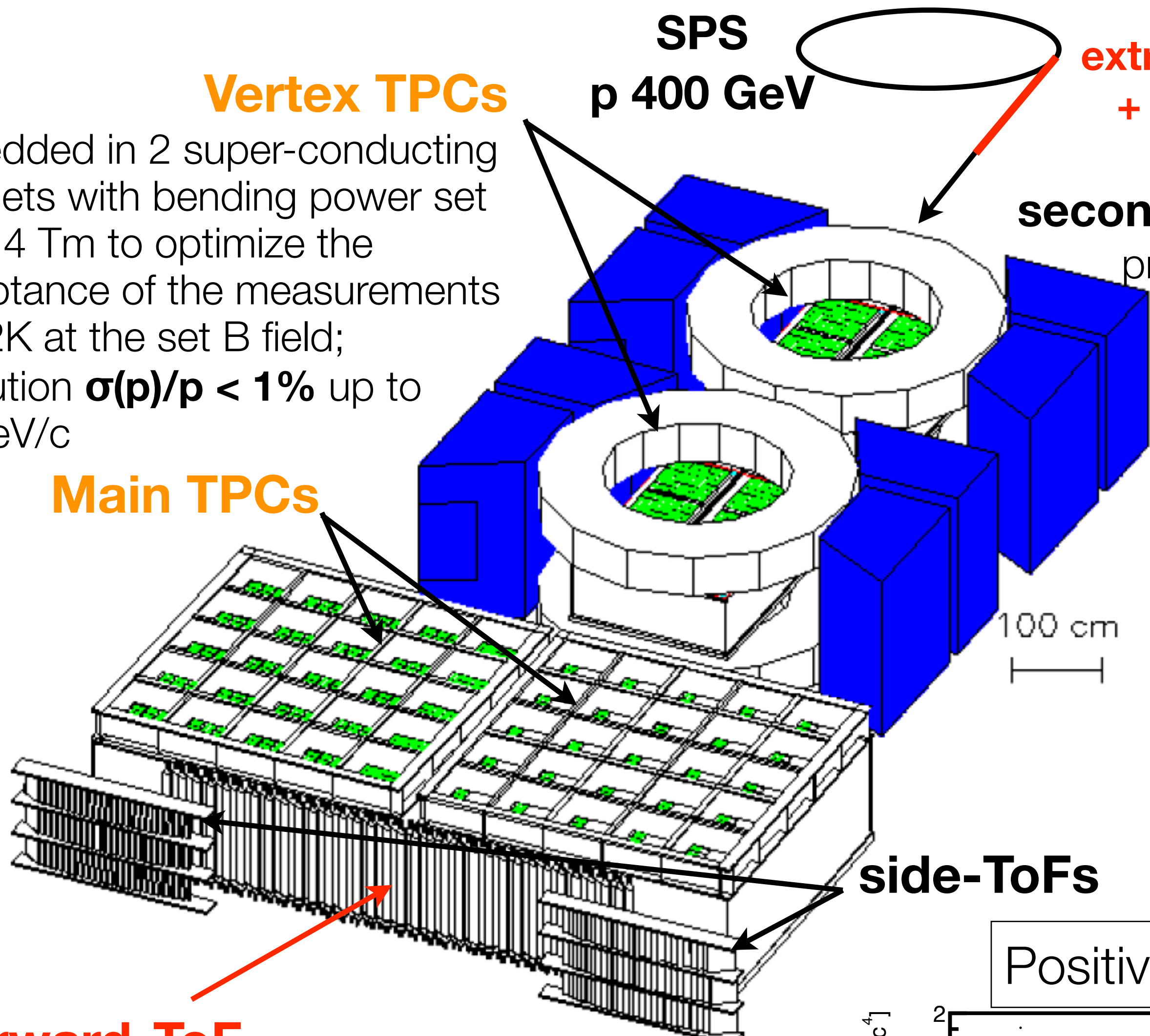
(e.g. SPY --> NOMAD, HARP --> K2K, MiniBooNE)

The NA61/SHINE setup in PID capabilities

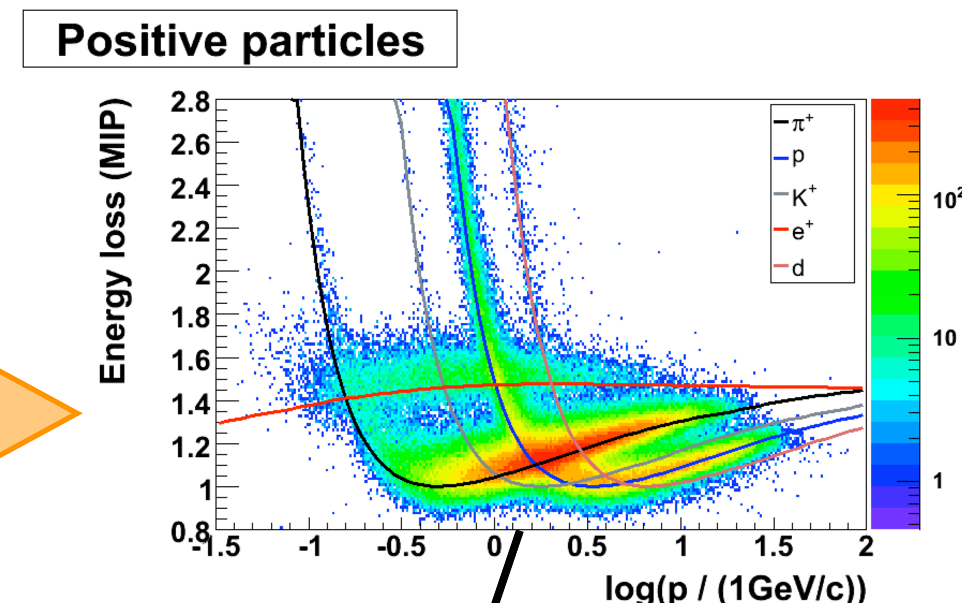
Short description of the NA61 setup (for more details see talk & poster by M. Posiadala, S. di Luise).
Particle identification in NA61 is based on both **energy loss** and **time-of-flight** measurements.

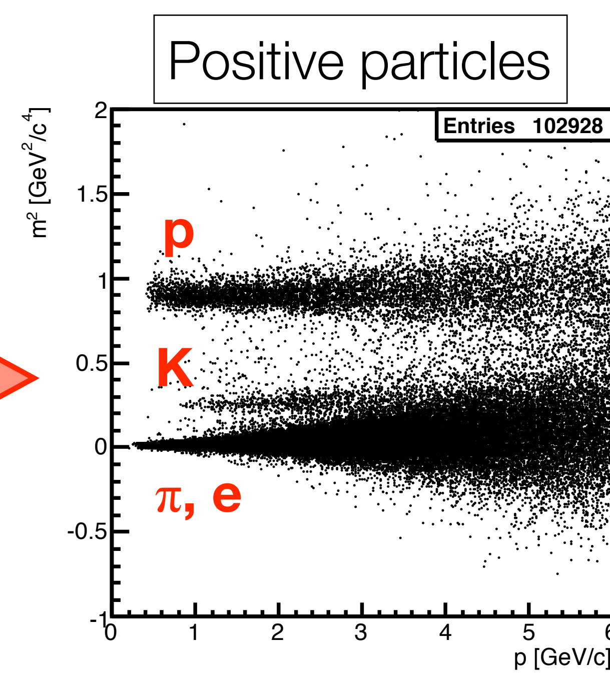
Vertex TPCs
embedded in 2 super-conducting magnets with bending power set at 1.14 Tm to optimize the acceptance of the measurements for T2K at the set B field; resolution **σ(p)/p < 1%** up to 12 GeV/c

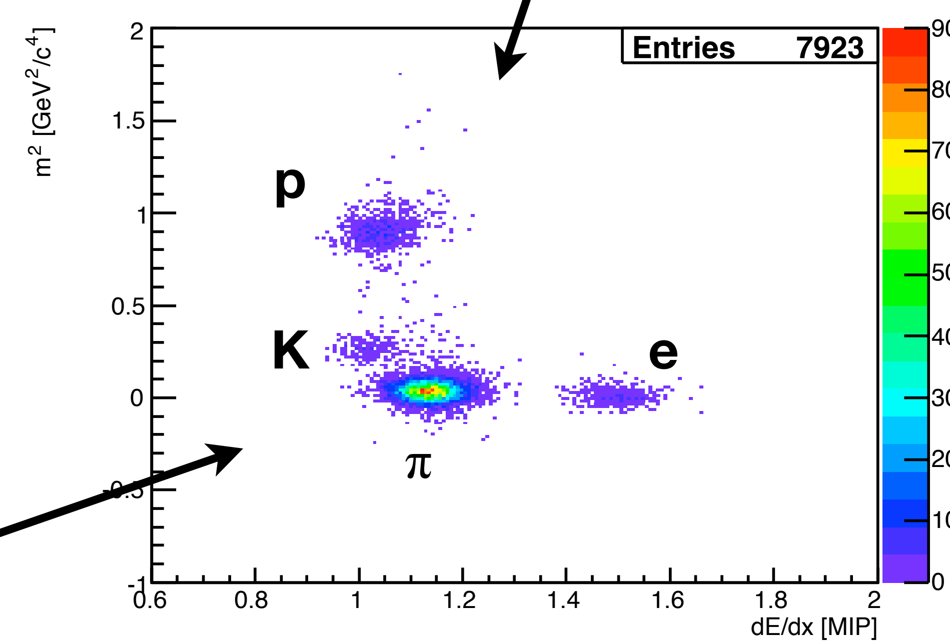
Main TPCs



forward-ToF
especially constructed to enlarge the acceptance of the measurements for T2K;
used in the LT analysis;
resolution **σ ~115 ps**





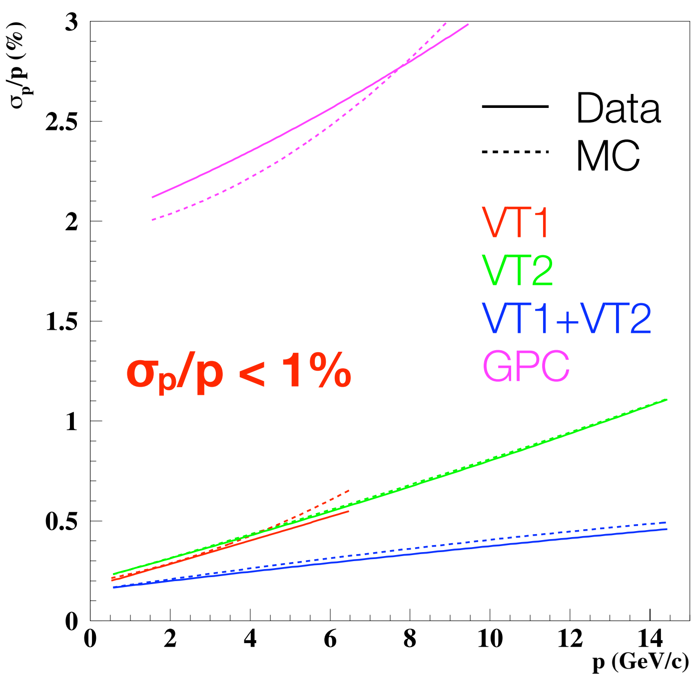


Combined measurement of ToF and dE/dx yields an efficient PID over a large momentum range ---> analysis of the LT

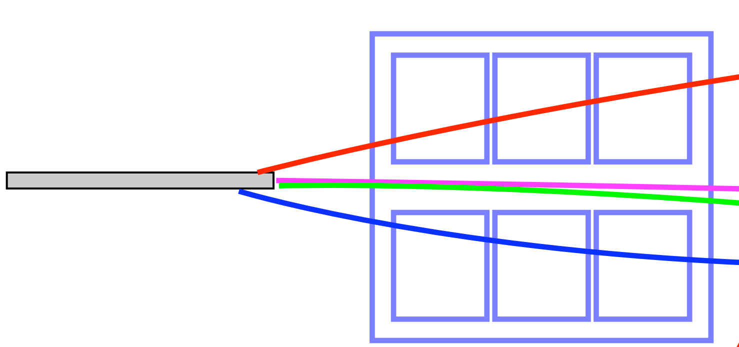
The NA61/SHINE long target measurements

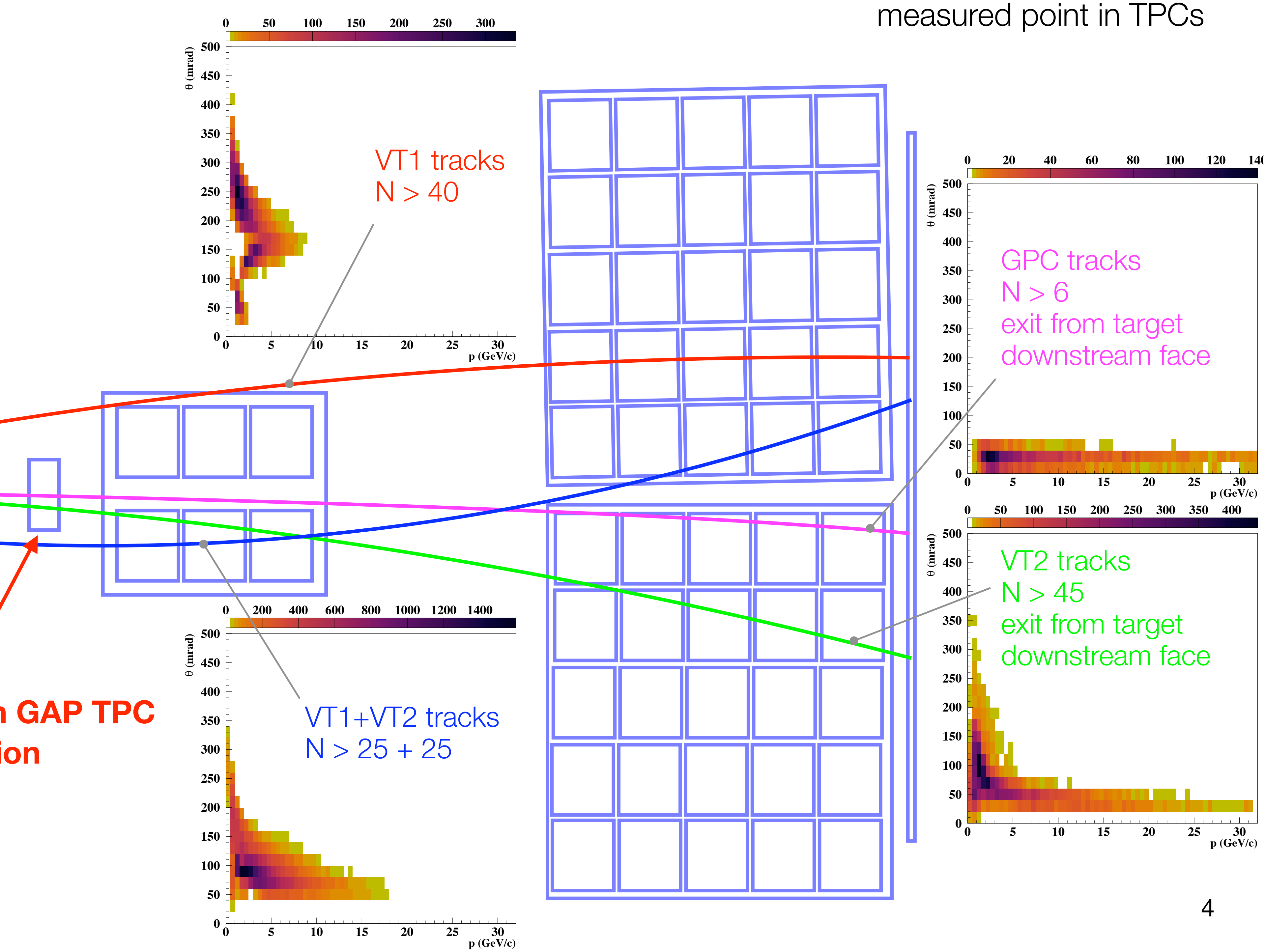
Feasibility of the measurements is based on:

1. achievable resolution of track parameters
2. maximal coverage in (p,θ)
3. backward extrapolation to the surface of the target
4. knowledge the beam & target relative alignment
5. normalization to protons on target



- topologies based on momentum measurement (single or double spectrometer)
- topology dependent track quality cuts to optimize p and θ resolutions at first measured point in TPCs



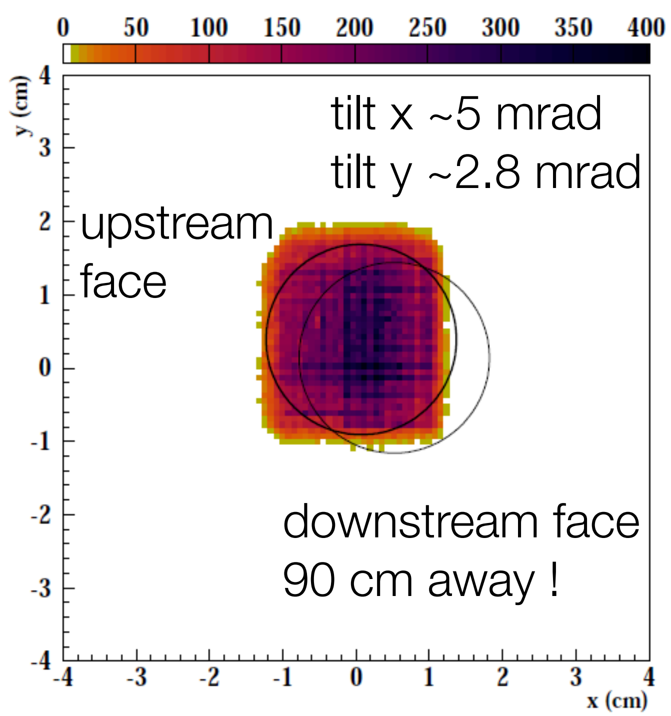


First NA61/SHINE analysis with GAP TPC
Important to cover forward region

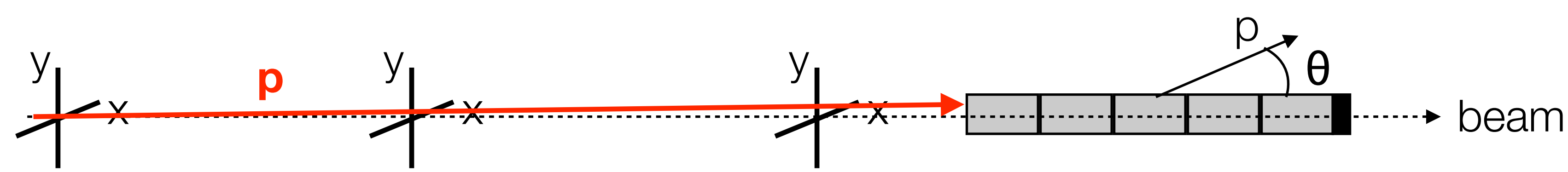
The NA61/SHINE long target measurements

Feasibility of the measurements is based on:

1. achievable resolution of track parameters
2. maximal coverage in (p,θ)
3. knowledge of the beam & target relative alignment
4. backward extrapolation to the surface of the target
5. normalization to protons on target



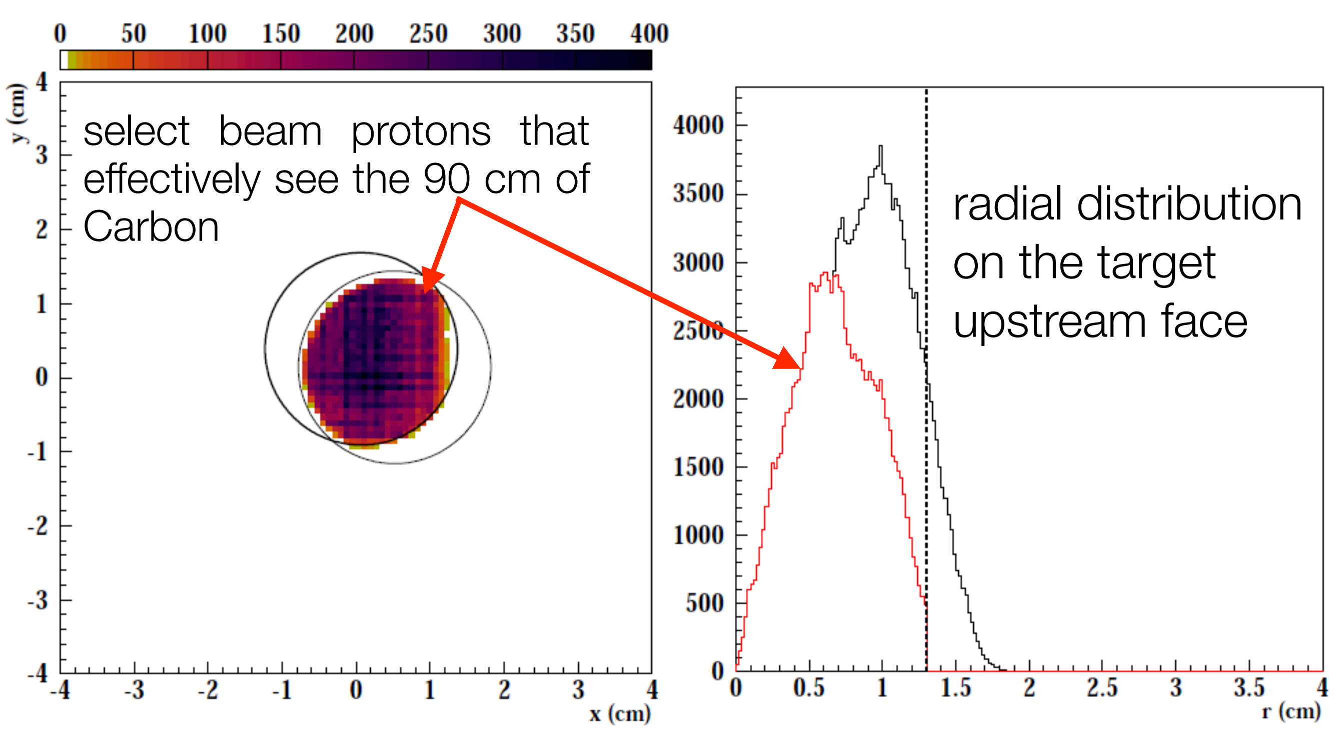
- 2007 target alignment procedure not precise enough (improved in 2009/2010 !)
- analysis based on effective 90 cm target

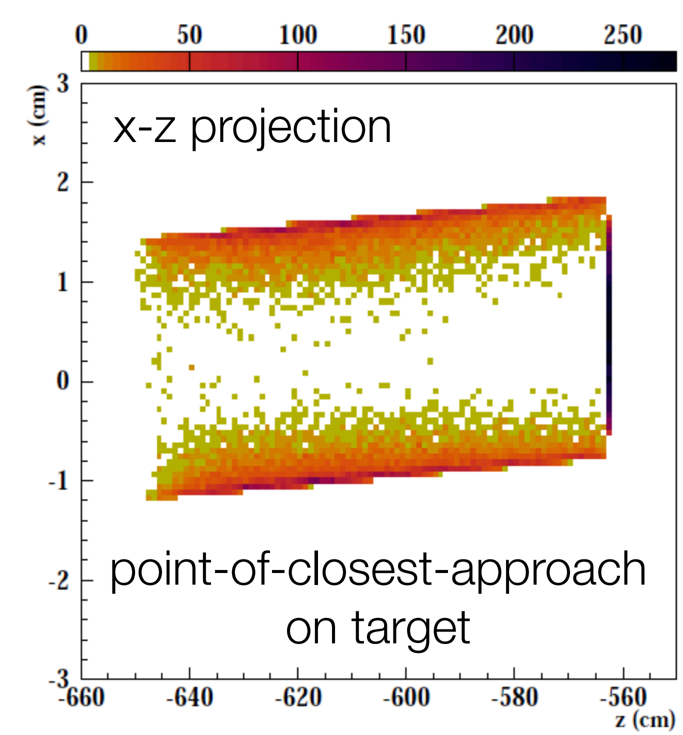


- trajectory of each beam proton precisely reconstructed and extrapolated on the upstream face of the target
- set of beam quality cuts

→ **Normalization to # of p.o.t.**

- target is divided in 6 bins:
  - 5 longitudinal bins of 18 cm
  - downstream face
- TPC tracks extrapolated back on the surface of the target with determination of a point-of-closest approach





$\sigma_p/p < 3\%$

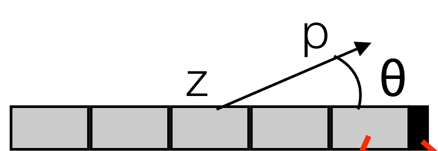
$\sigma_z < 5$ cm

Tilts of the target accounted for in the extrapolation procedure

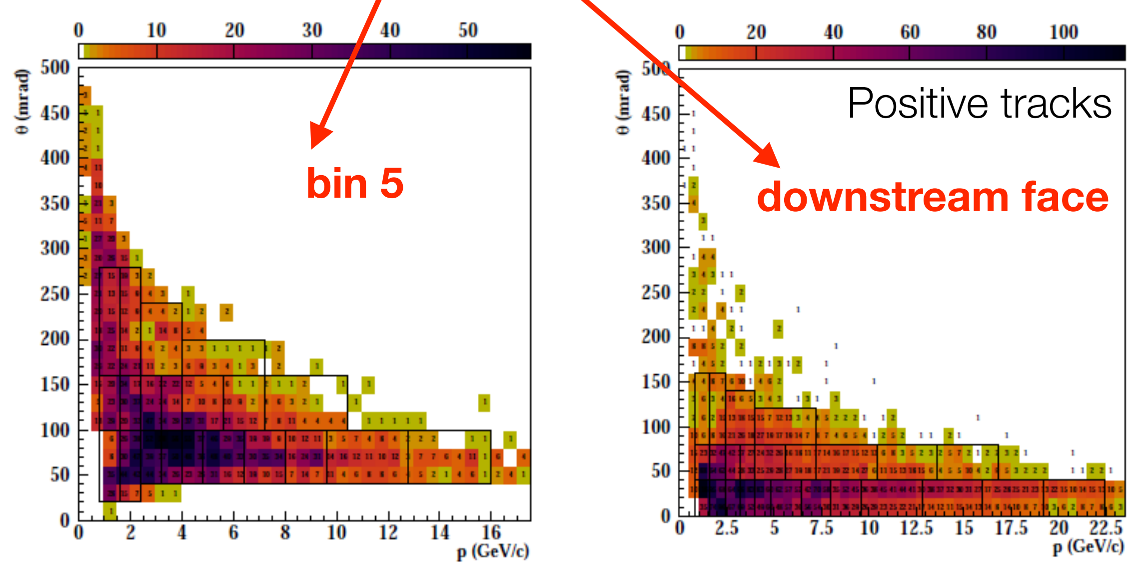
The NA61/SHINE long target measurements

The **analysis binning in {p,θ,z}** is based on:

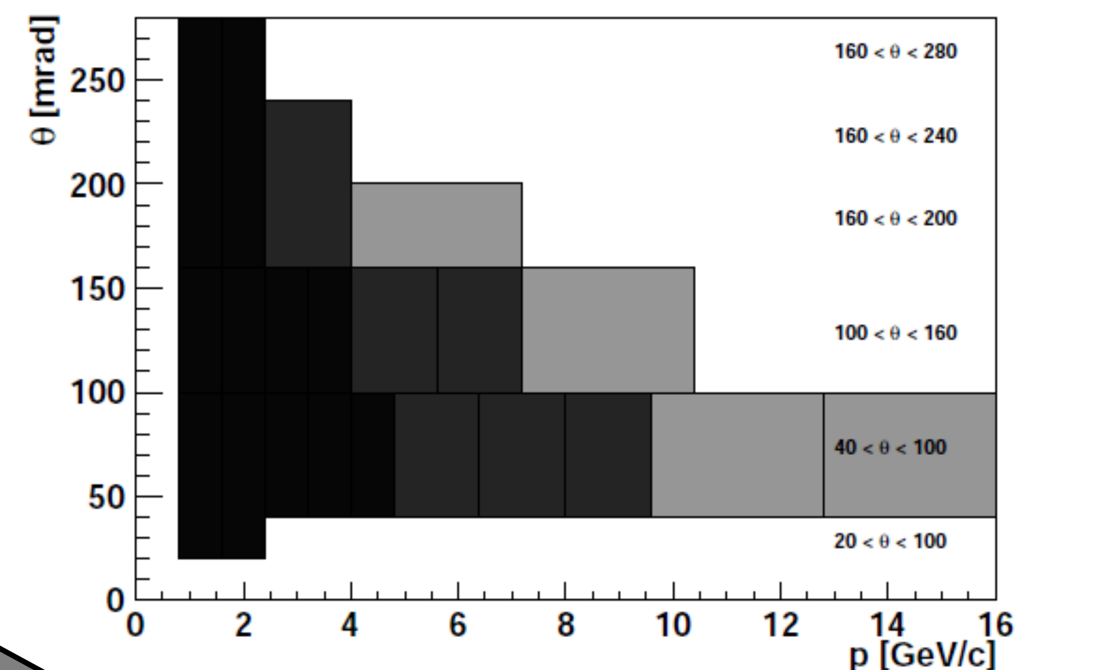
- coverage after track quality cuts that maximize the resolution of the track parameters on target
- appropriate bin size in regions where the dE/dx varies strongly with momentum
- uniform acceptance



Target divided in 6 longitudinal bins
p, θ, z extrapolated on the surface
of the target.

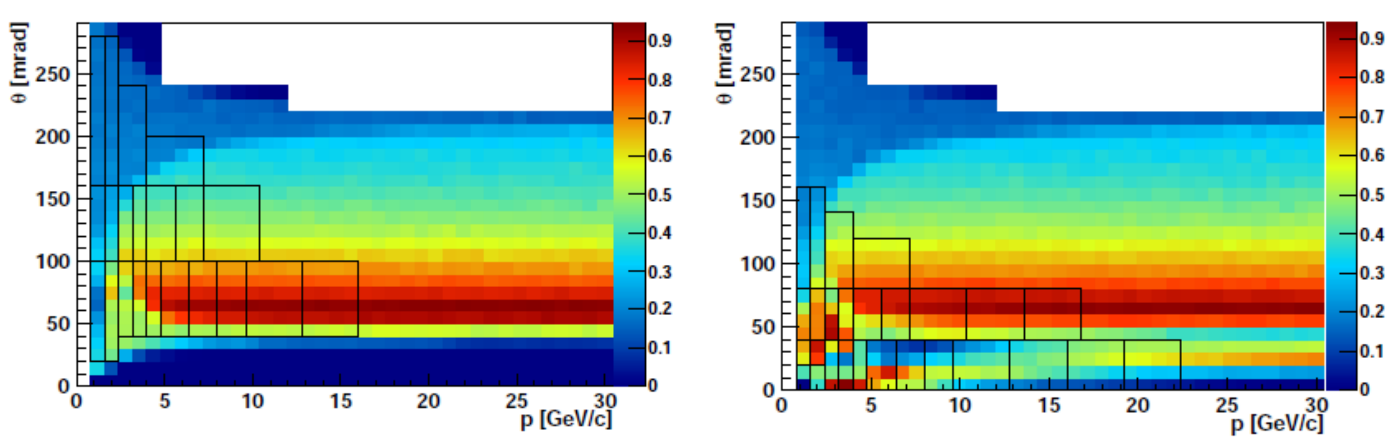


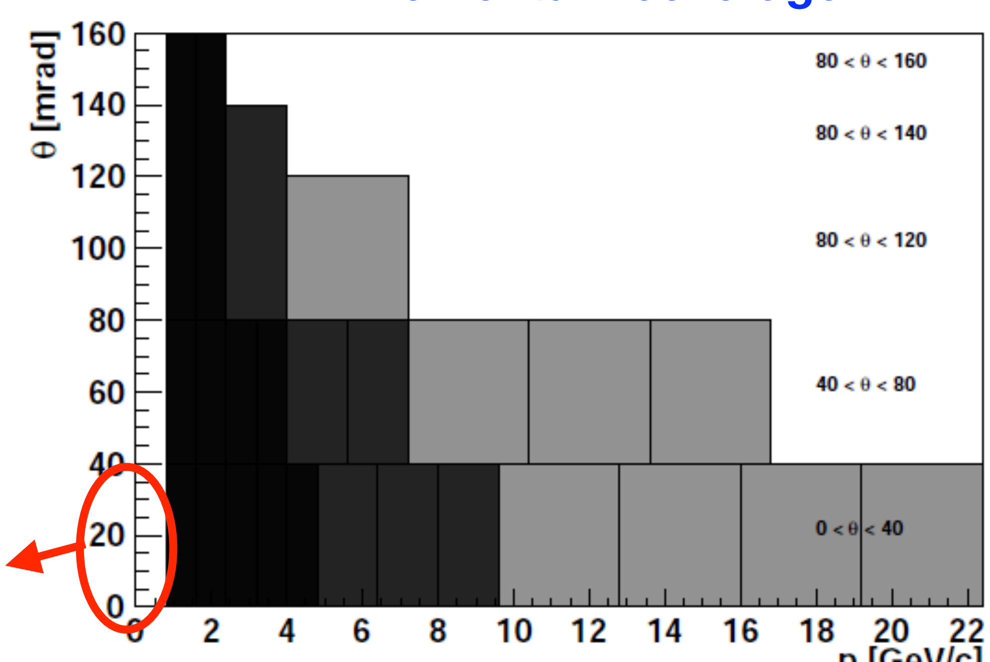
Analysis binning for first 5 longitudinal bins



Analysis binning for downstream face of the target --> coarser angular binning, higher momentum coverage

Acceptance based on tracks quality cuts used for the analysis

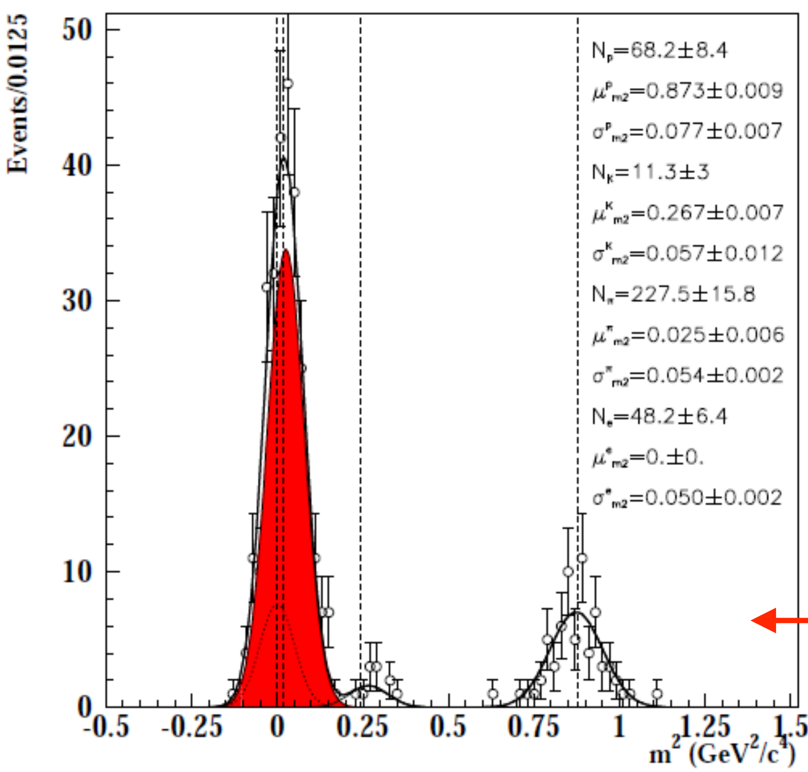


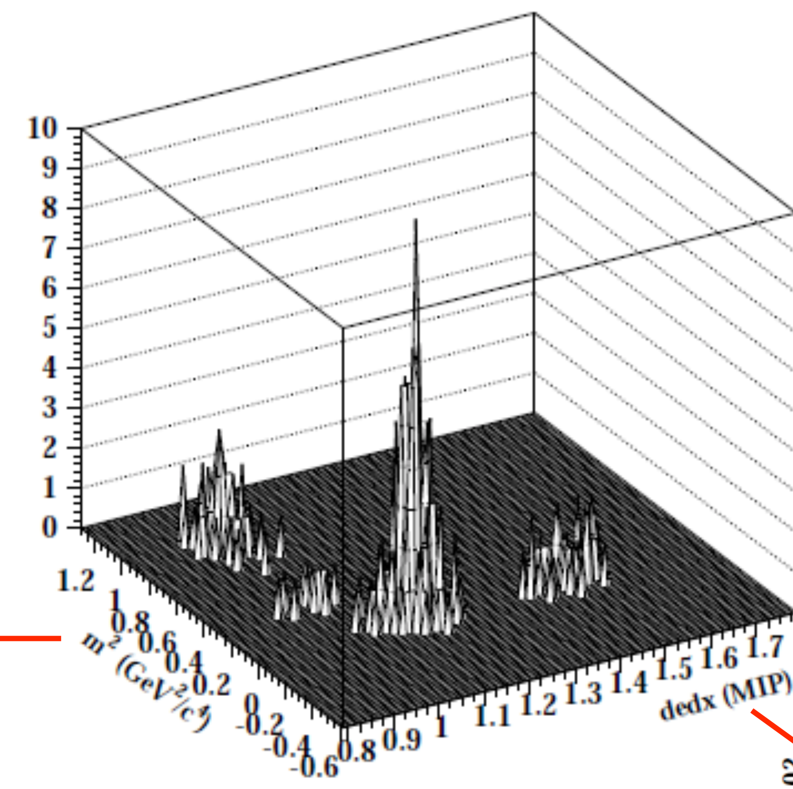


Forward region covered by GAP TPC

The NA61/SHINE long target measurements

Particle identification based on the combined ToF & dE/dx method developed for the thin target data.

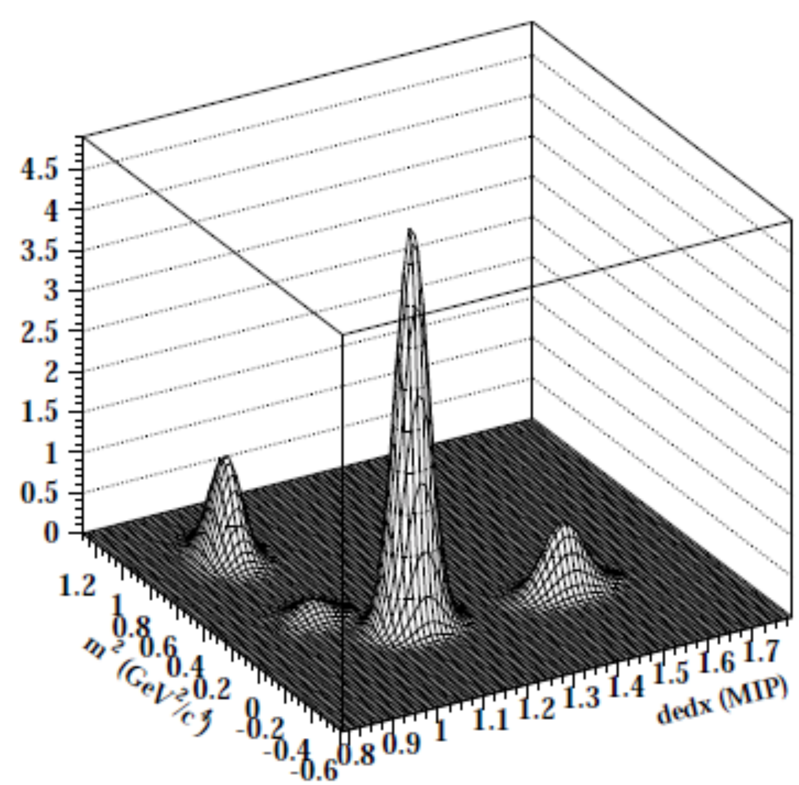


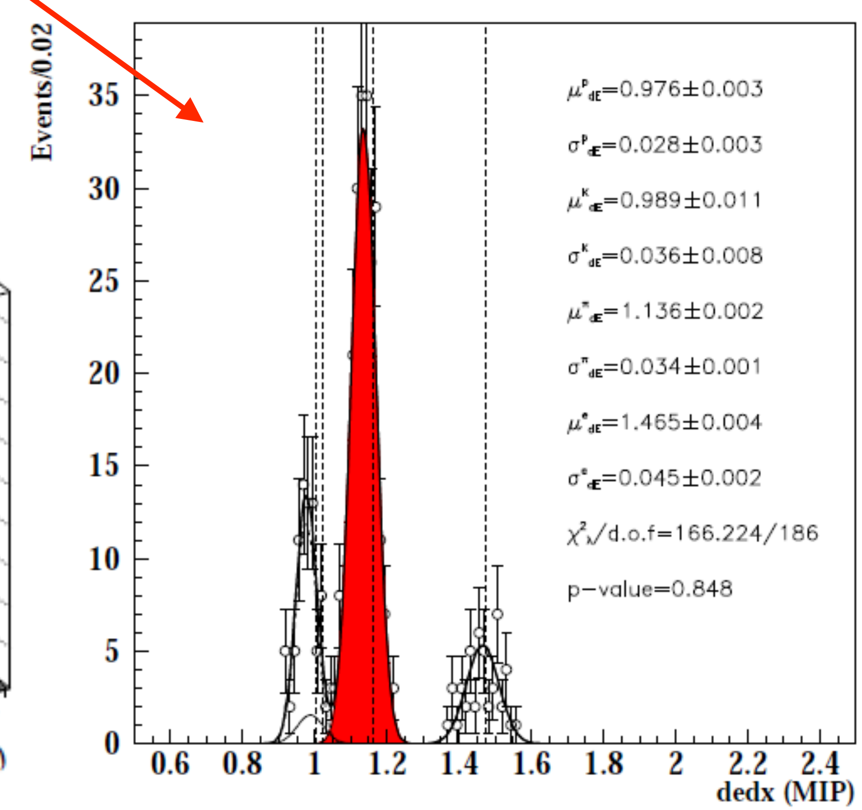


- Time-of-flight signal used to compute a mass squared value, m2
- Energy loss in the TPCs to compute a truncated mean charge, dedx
- Fill 2D m2 vs dedx distributions for each (p,θ,z) bin on target

- 2D likelihood minimization
- extract π **component** from the fit

e.g.: 40 < θ < 100 mrad
2.4 < p < 3.2 GeV/c



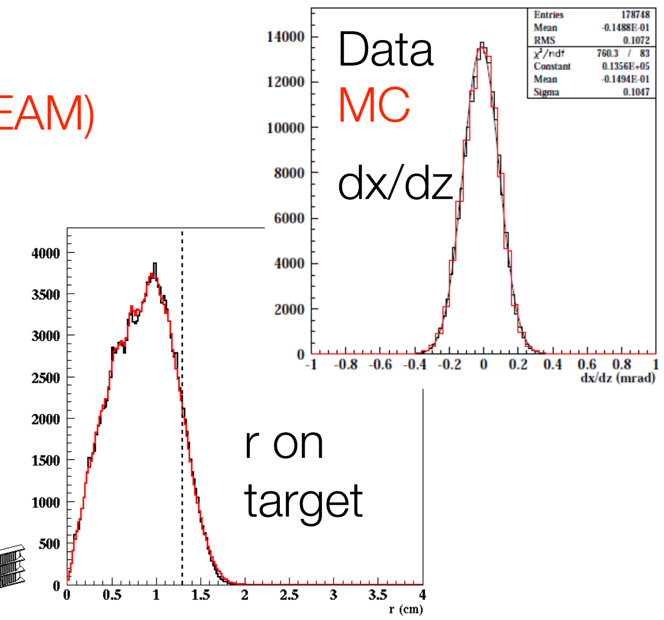


The NA61/SHINE long target measurements

Comparison of raw π^+ yields extracted from the NA61 data and from the T2K hadronization model

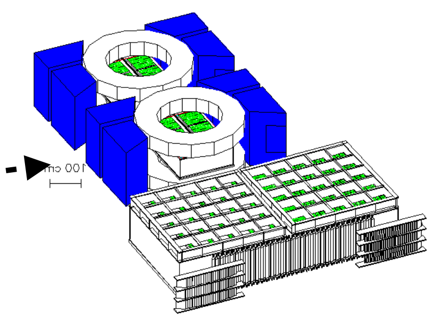
NA61 data ⟷ **NA61 simulation with T2K model**

- standalone FLUKA simulation of p+C at 31 GeV/c, same as that used in the T2K beam simulation (JNUBEAM)
  - NA61 full target geometry
  - beam profile and divergence from NA61 data
- Outgoing tracks --> input to NA61 simulation chain



FLUKA pC 31GeV/c

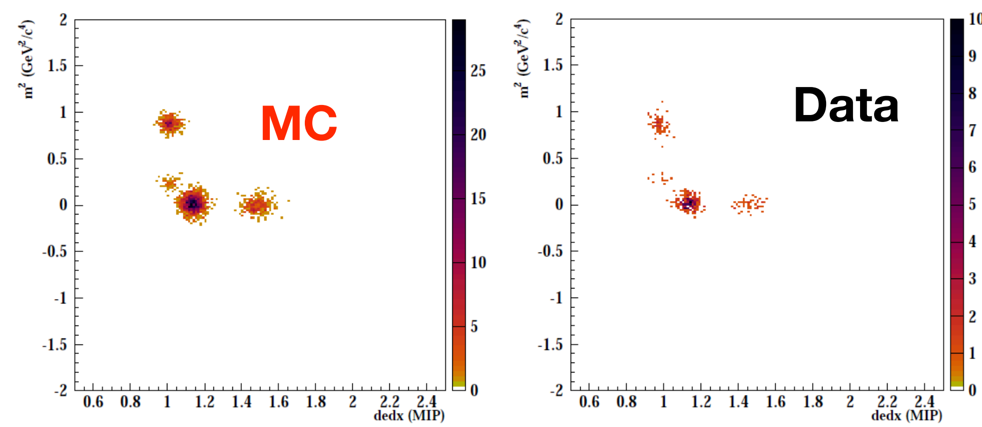
p → NA61 replica



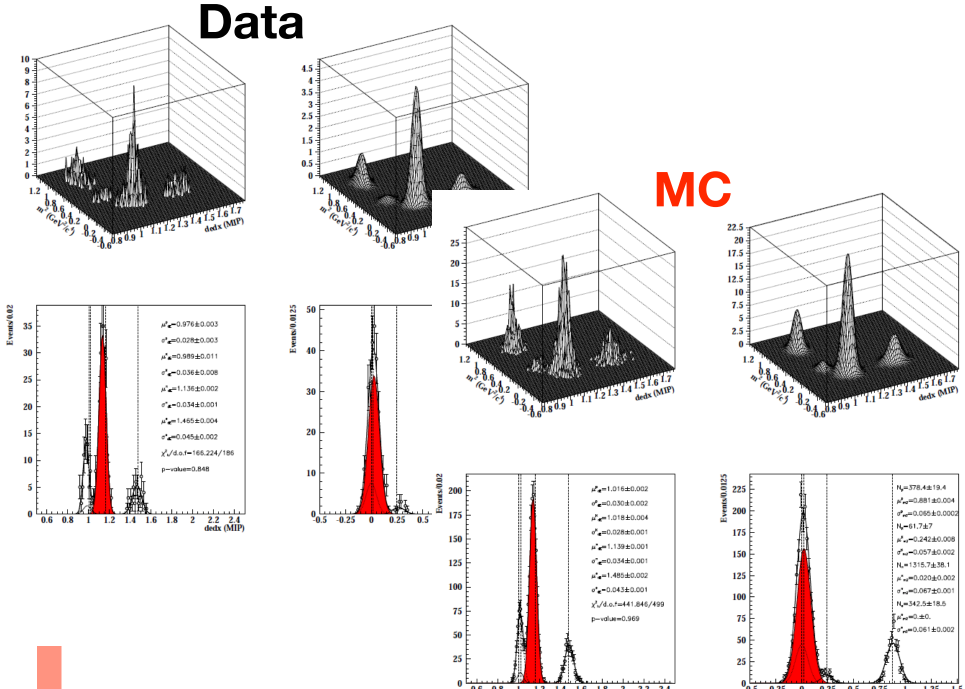
Reconstruction

- mass squared and truncated mean charge assigned to reconstructed tracks based on parametrizations of data

e.g.: 40 < θ < 100 mrad
2.4 < p < 3.2 GeV/c



Same procedure for PID

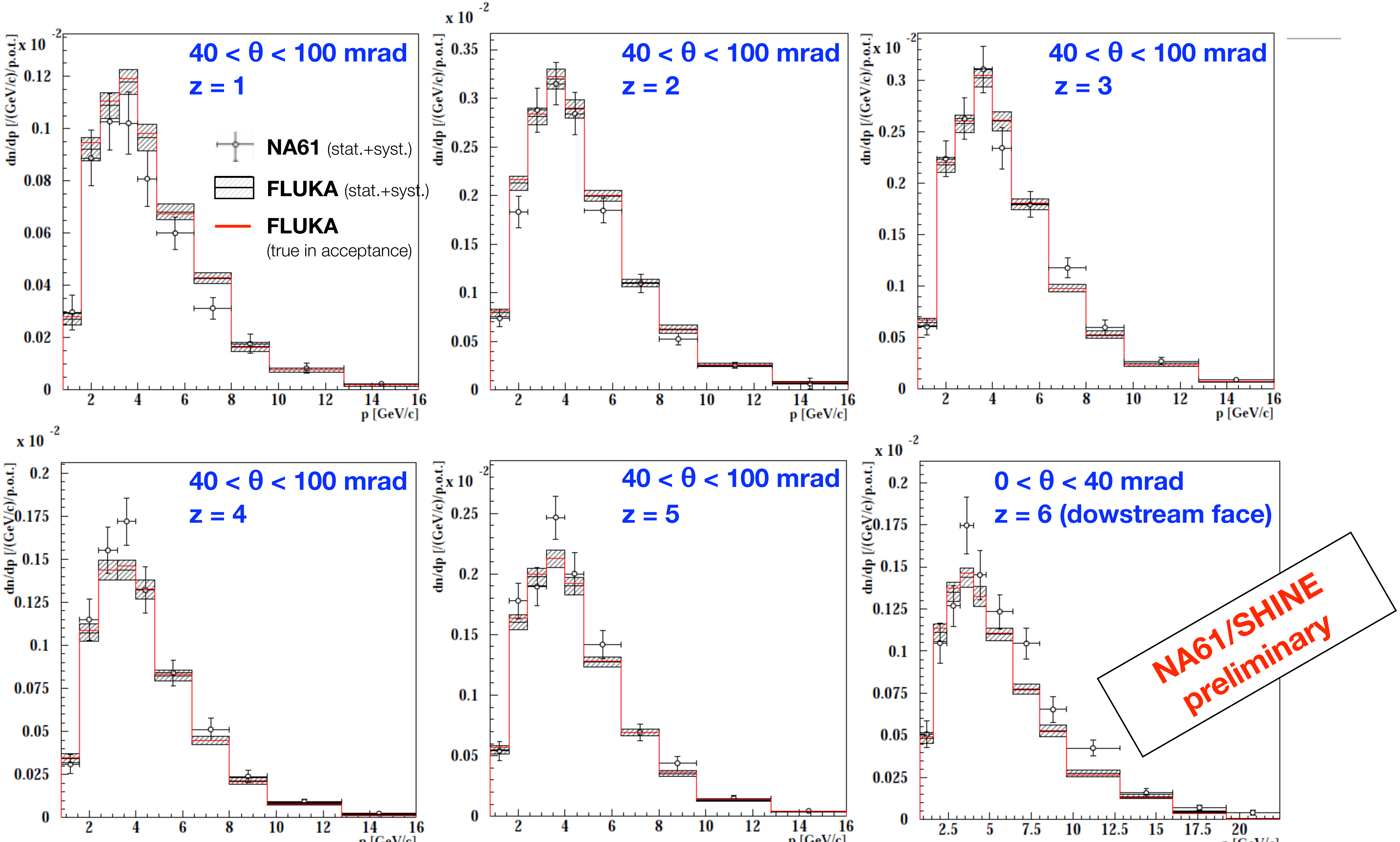


Monte-Carlo to data comparison:

- usually, extract yields from data and apply all necessary corrections to produce absolute yields and compare with true independently simulated yields. e.g. 2007 thin target data: all MC based corrections ~5-10% syst.
- here, **comparison at raw data level --> all MC based corrections cancel**
- however, syst. uncertainty from particle identification is attributed to both data and MC yields, in principle < sum over all other corrections e.g. 2007 LT data: ~6% syst. (with very poor statistics data set !)

Reconstructed π^+ yields in NA61 & T2K model

Comparison of raw π^+ yields extracted from the NA61 data and from the T2K hadronization model



LT based π^+ re-weighting factors for T2K

Re-weighting factors for the LT π^+ production simulated by FLUKA are calculated from the extracted yields after reconstruction. The time-of-flight efficiency is the only non-MC based correction that needs to be applied to data.

Re-weighting factors for π^+ are defined as:

$$w(p,\theta,z) = \frac{n_\pi^{NA61}}{n_\pi^{FLUKA}}(p,\theta,z) \times \left\{ \frac{C_{ACC}^{FLUKA}}{C_{ACC}^{NA61}}(p',\theta',z') \times \frac{C_{LOSS}^{FLUKA}}{C_{LOSS}^{NA61}}(p',\theta',z') \times \frac{C_{FDW}^{FLUKA}}{C_{FDW}^{NA61}}(p,\theta,z) \times \frac{\epsilon_{REC}^{FLUKA}}{\epsilon_{REC}^{NA61}}(p,\theta,z) \times \frac{\epsilon_{EXT}^{FLUKA}}{\epsilon_{EXT}^{NA61}}(p,\theta,z) \times \frac{\epsilon_{TOF}^{FLUKA}}{\epsilon_{TOF}^{NA61}}(p,\theta) \right\}$$

$$w(p,\theta,z) = \frac{1}{\varepsilon_{TOF}^{NA61}(p,\theta)} \times \frac{N_\pi^{NA61}}{N_\pi^{FLUKA}}(p,\theta,z) \times \frac{N_{POT}^{FLUKA}}{N_{POT}^{NA61}}$$

Systematic uncertainties attributed to:

Systematic error	dependence	estimation	value
Particle identification	p	MC	1-5%
Normalization	global	Data	1.4%
ToF efficiency	(p,θ)	Data	$< 3\%$
Beam momentum	global	MC	$< 3\%$
Target density	global	MC	$< 3\%$
Target alignment	global	MC	3%

Main contribution at high momentum (Particle identification)

Will be reduced with more stat. and new calibration for LT runs (ToF efficiency)

Upper bounds. Need to run simulations with more stat. (Beam momentum, Target density)

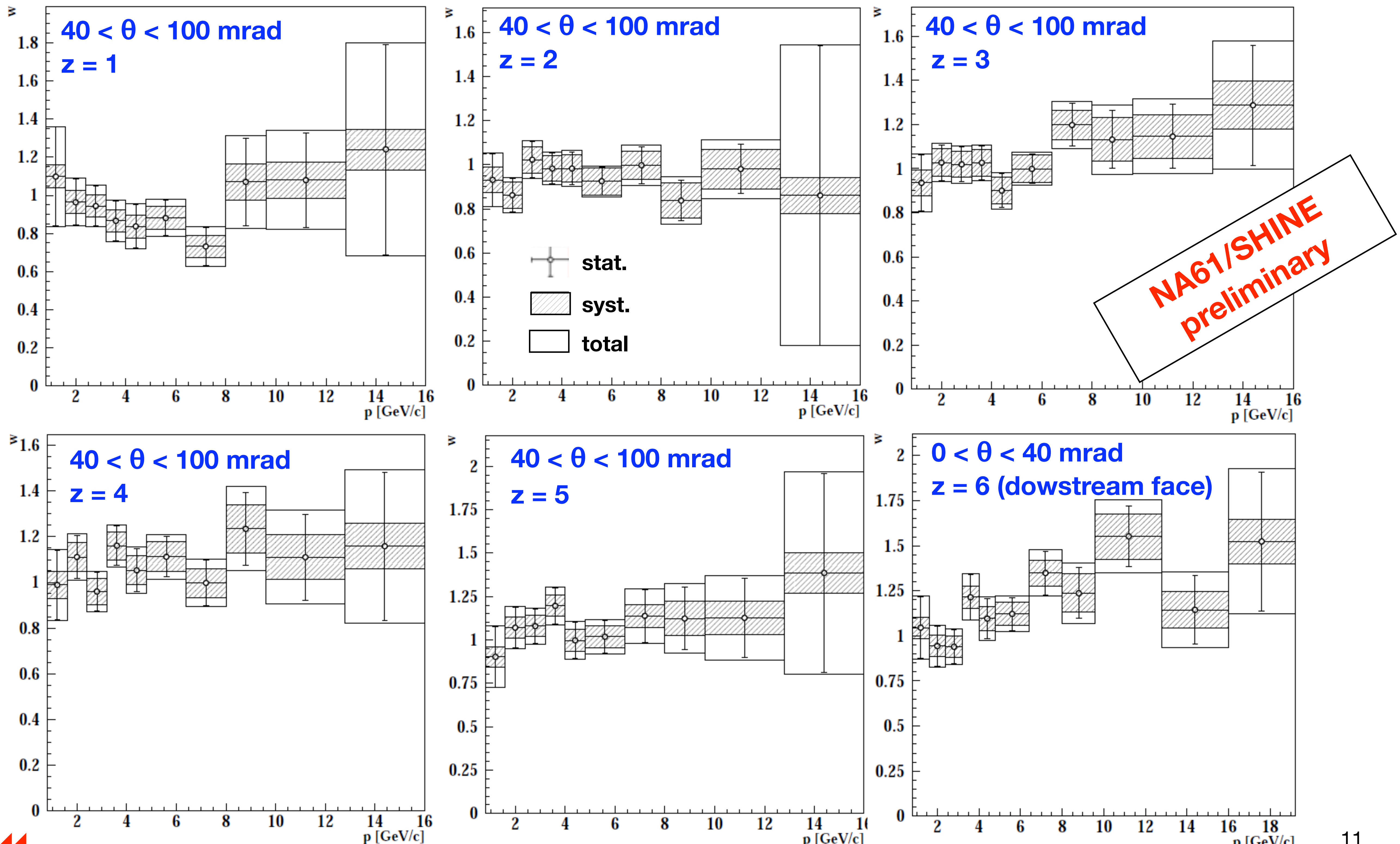
Second largest contribution, will be reduced in 2009/10 (Target alignment)

The overall uncertainty is typically: **±10% (stat.) ±6% (syst.)**

dominates 2007 results (stat.)

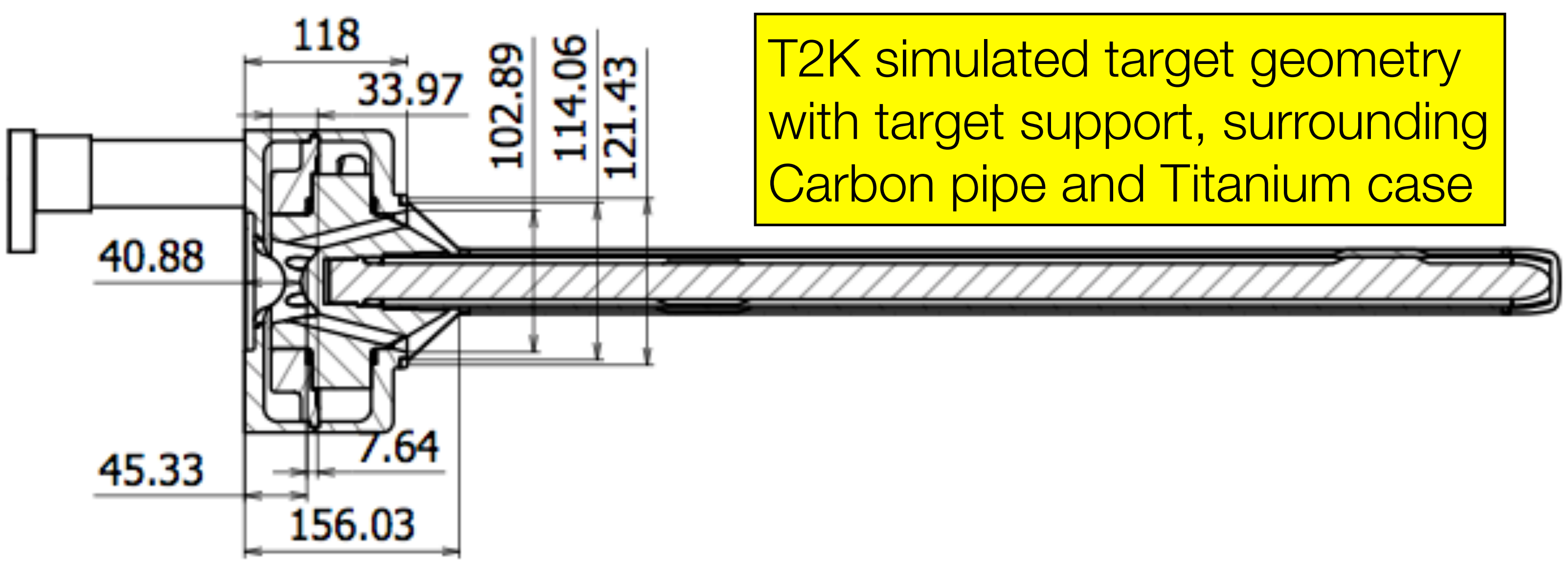
reduce < 5% for 2009/2010 data (syst.)

LT based π^+ re-weighting factors for T2K



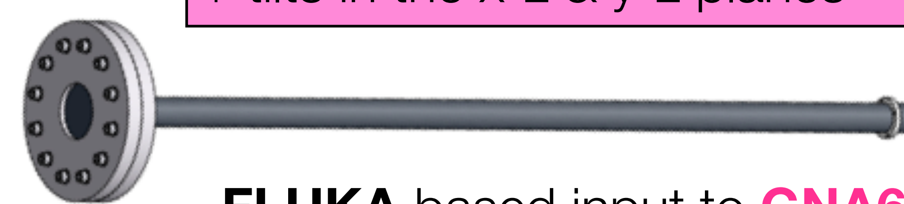
NA61 vs T2K configurations

Develop procedure to implement the re-weighting factors for the LT π^{+} production simulated by FLUKA within the T2K beam simulation (JNUBEAM).

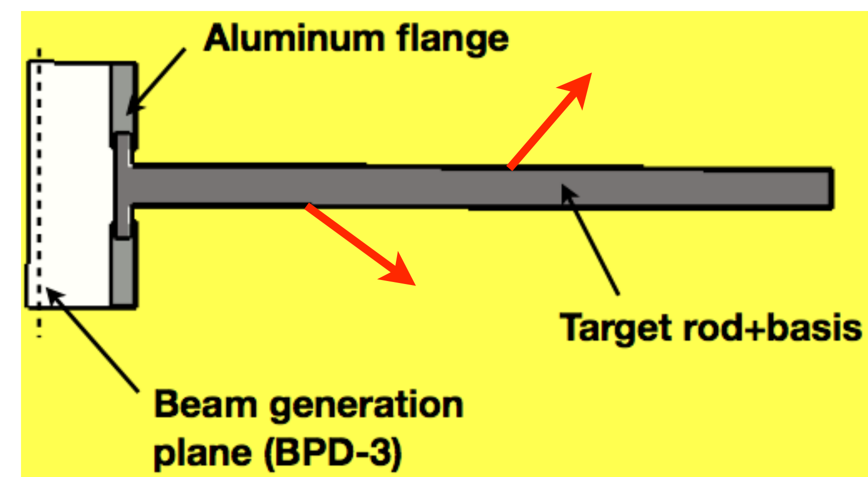


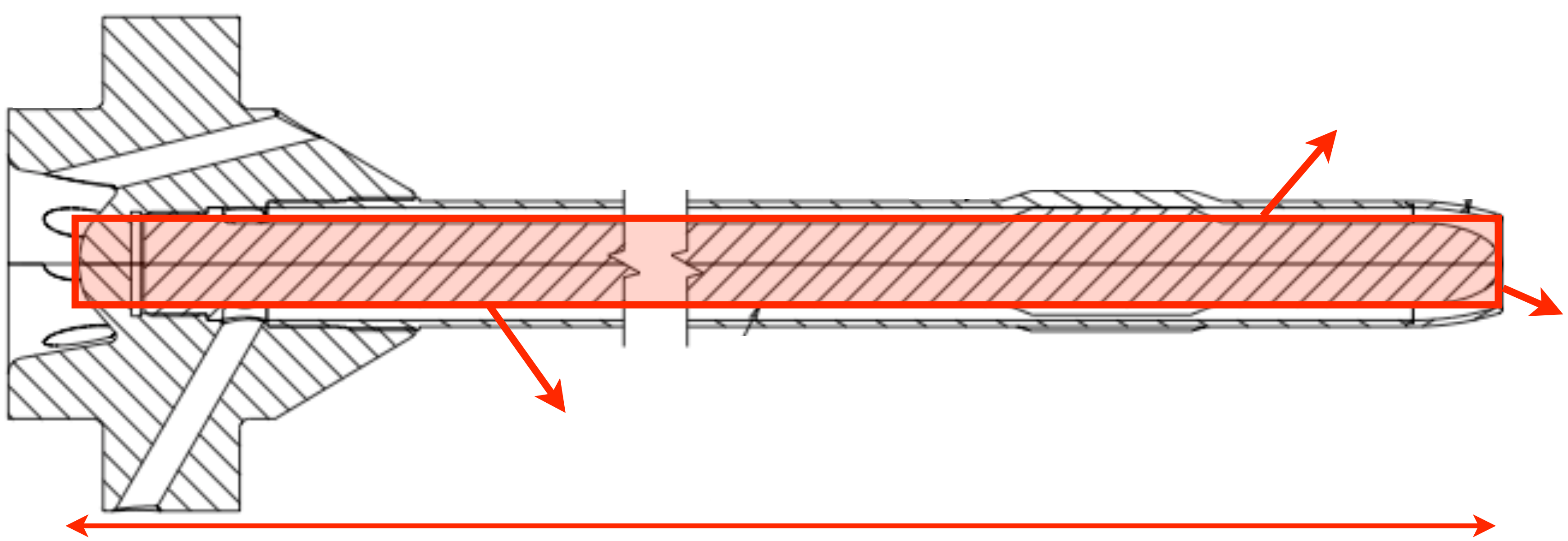
T2K simulated target geometry with target support, surrounding Carbon pipe and Titanium case

NA61 simulated target geometry with Aluminum support flanges + tilts in the x-z & y-z planes



FLUKA based input to **GNA61**





simple 90 cm long Carbon rod simulated in **FLUKA** for input to JNUBEAM (Carbon budget fairly similar to that of the more complicated real geometry)

→ re-interactions of outgoing particles in the surrounding structures handled by **GCALOR**

Dedicated study showed that the hadron production in surrounding basis and flanges is completely negligible.

NA61-based re-weighting factors can be applied to the simplified target simulation in JNUBEAM.

NA61 vs T2K configurations

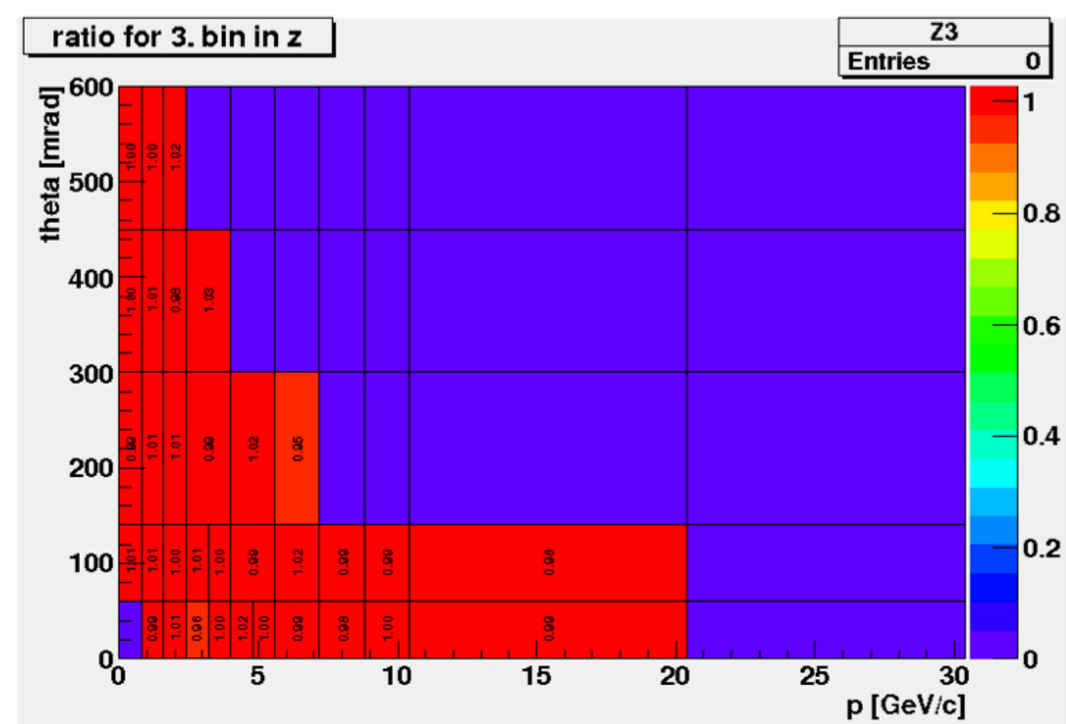
Our FLUKA standalone simulation is used to understand systematics related to differences between the T2K beam+target configuration and the NA61 measurements

Systematic error	dependence	estimation	value
Particle identification	p	MC	1-5%
Normalization	global	Data	1.4%
ToF efficiency	(p, θ)	Data	$< 3\%$
Beam momentum	global	MC	$< 3\%$
Target density	global	MC	$< 3\%$
Target alignment	global	MC	3%

Compare π+ yields in {p,θ,z} bins for simulation w/ and w/o studies effect.

If variations < 5% (required precision on the NA61 measurements), consider global systematic uncertainty.

e.g. alignment study, longitudinal bin 3



Studies include effects of:

- different target geometry, i.e. simple rod in the T2K beam simulation vs replica target in NA61
- different alignment wrt beam axis, i.e. aligned target in T2K, tilted target in NA61
- different target density, i.e. 1.804 g/cm^3 for T2K target, 1.831 g/cm^3 for NA61 replica target
- beam momentum uncertaint (consider difference between set and measured values in NA61 as maximal possible deviation)

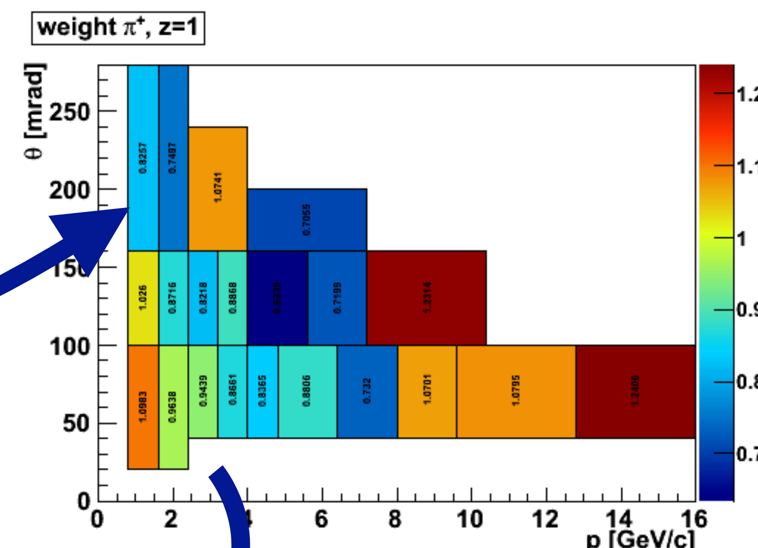
Next steps

Develop procedure to implement the re-weighting factors for the LT π^+ production simulated by FLUKA within the T2K beam simulation (JNUBEAM).

e.g. probably something like that:

1) FLUKA simulation for T2K

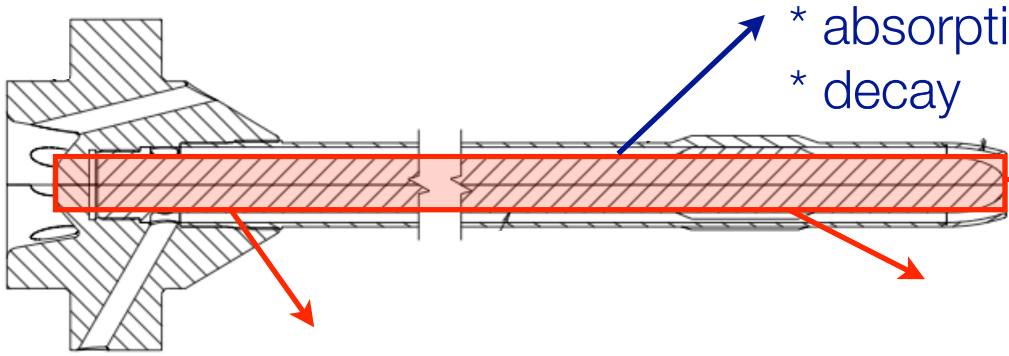
π^+ in (p,θ) coverage of NA61 ---> **w** (p,θ,z)



π^+ out of (p,θ) coverage of NA61 ---> w = 1
but keep track of production uncertainty

2) NA61 corrected π production on target
= input to JNUBEAM

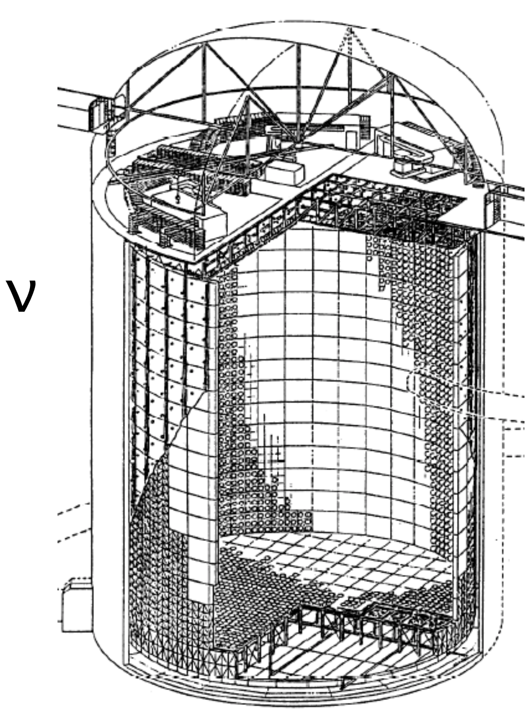
π^+ * re-interaction
* absorption
* decay



store relevant information along the event history

ν
ν
ν

SK



⟶ propagate weights to each following generation

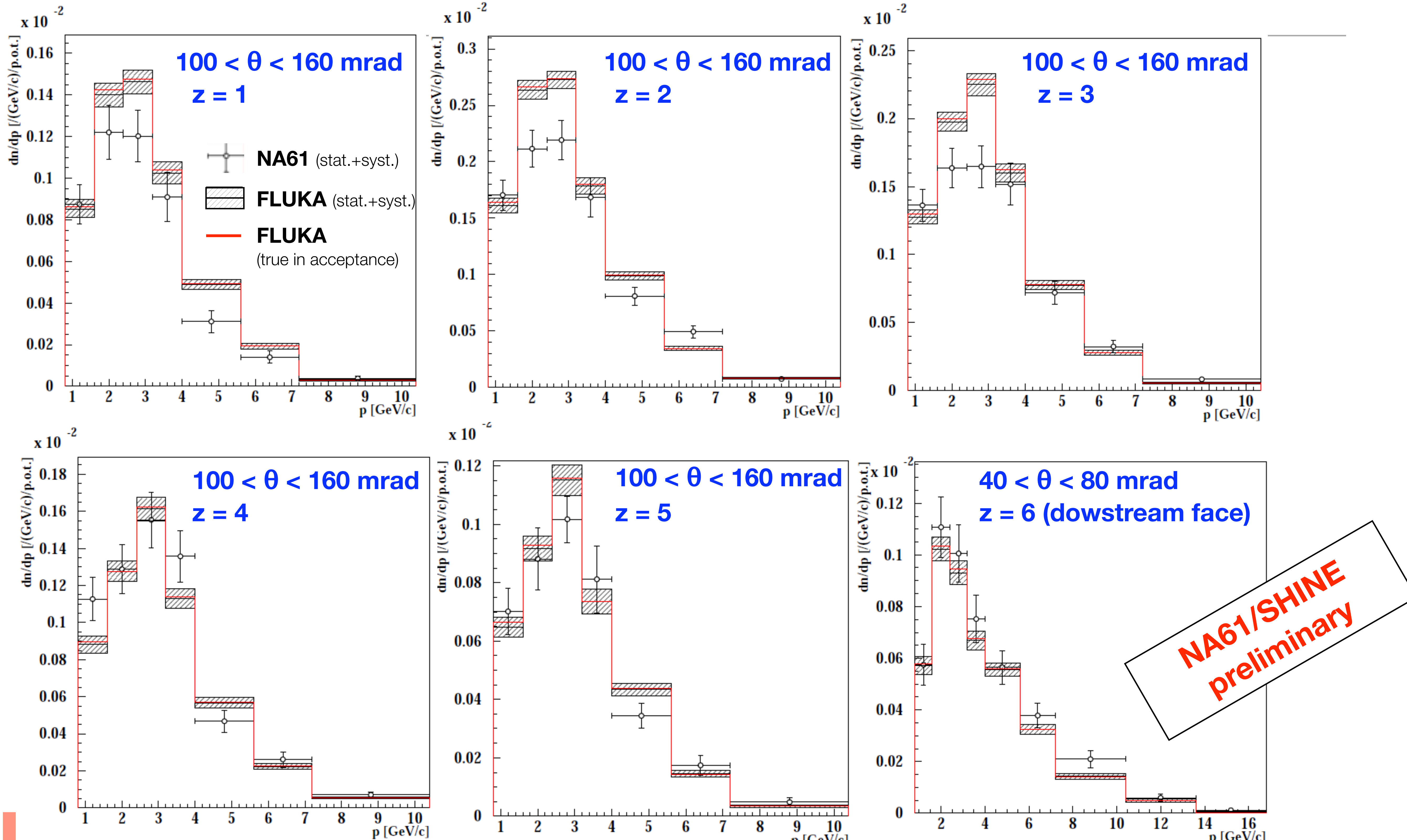
Conclusions

- First preliminary results of the NA61 long target **2007 pilot analysis**
  - π^+ reconstructed at the surface of the T2K replica target
  - T2K model corrected within the sim+rec environment of NA61 which allows to compare MC and data without further corrections ---> reduces systematics !
  - uncertainty of current results dominated by statistics !
- Further improvements expected for 2009/2010 data sets:
  - **much more statistics --> account for beam profile (radial re-weighting)**
    --> extract kaon production, protons
  - **better control of target alignment**
  - **dedicated ToF calibration**
- **First trial to constrain neutrino flux from long target data !**
  - **re-weight the π+ production at the level of both prim+sec interactions in the target**
  - **might develop more fancy treatment combining both LT+thin target re-weighting**

Backup slides

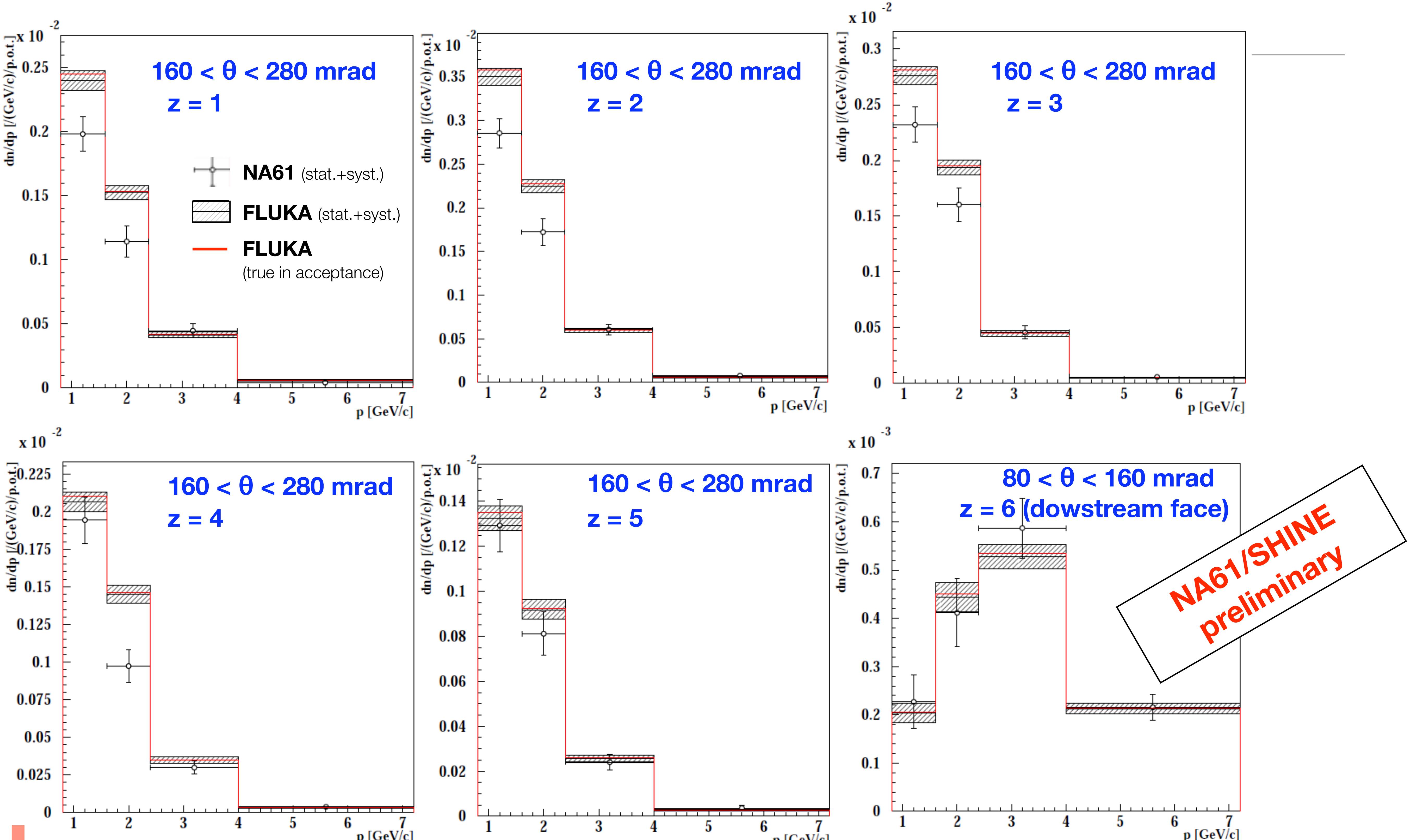
Reconstructed π^+ yields in NA61 & T2K model

Comparison of raw π^+ yields extracted from the NA61 data and from the T2K hadronization model

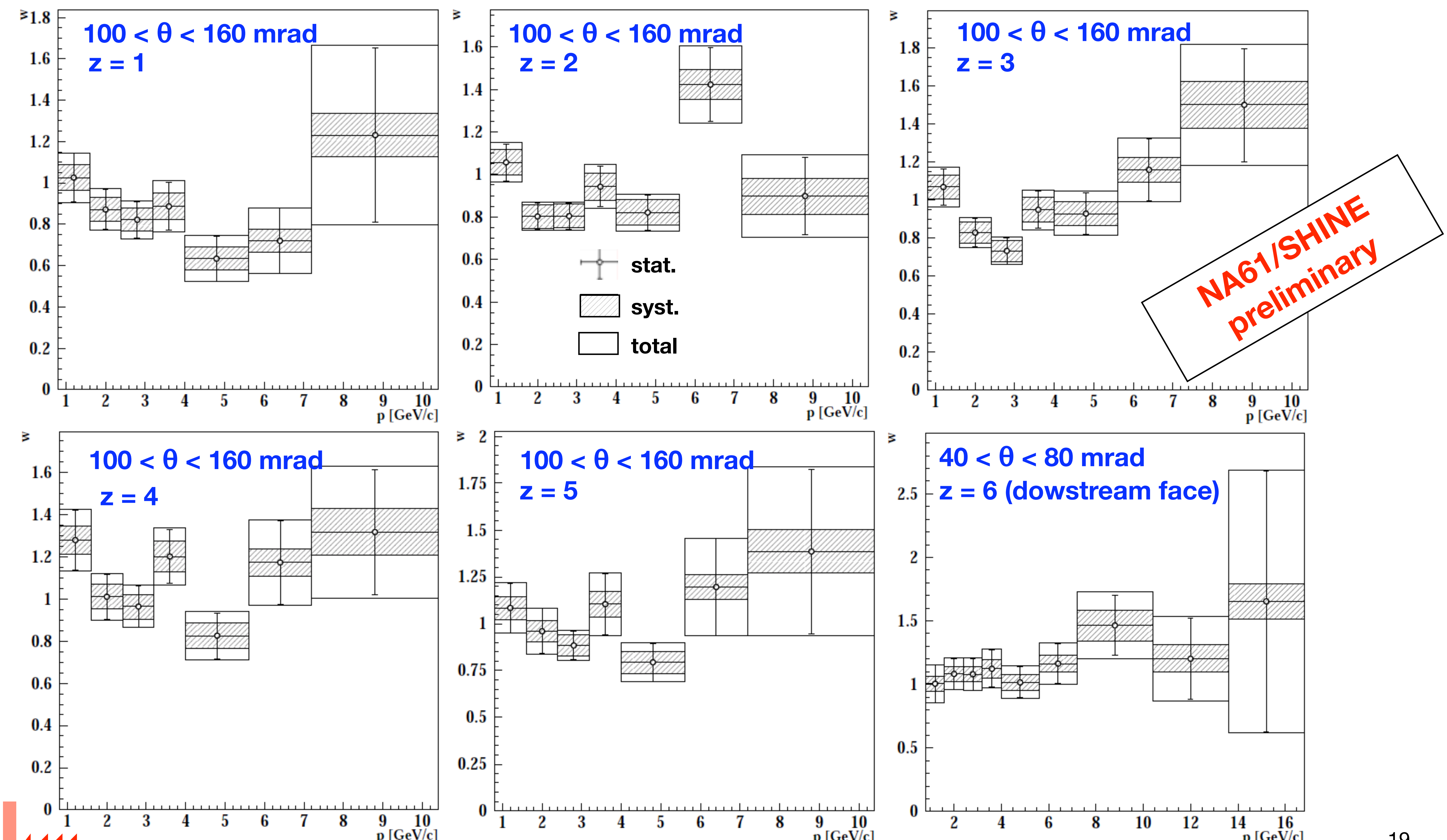


Reconstructed π^+ yields in NA61 & T2K model

Comparison of raw π^+ yields extracted from the NA61 data and from the T2K hadronization model



LT based π^+ re-weighting factors for T2K



LT based π^+ re-weighting factors for T2K