Status report of NA61

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on behalf of the Swiss groups

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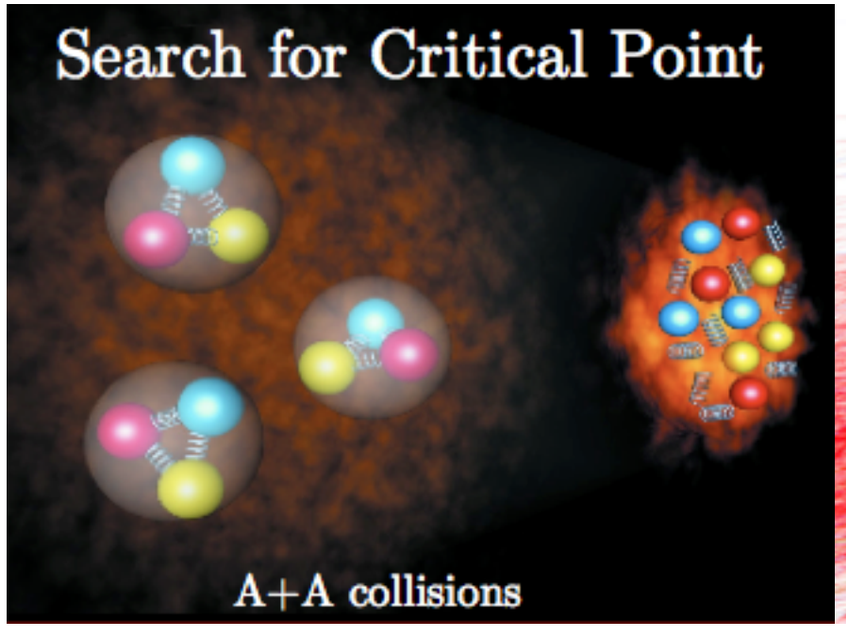
UNIVERSITÉ
DE GENÈVE

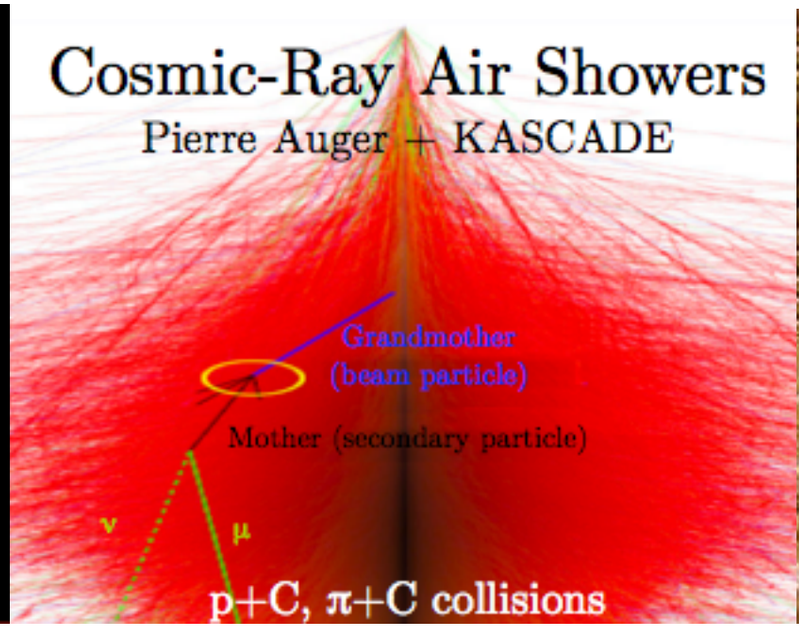
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

- The NA61 collaboration
- Hadroproduction measurements for the T2K neutrino experiment
- The Swiss groups within NA61:
  - hardware & software contributions
  - analysis contributions

The NA61 collaboration



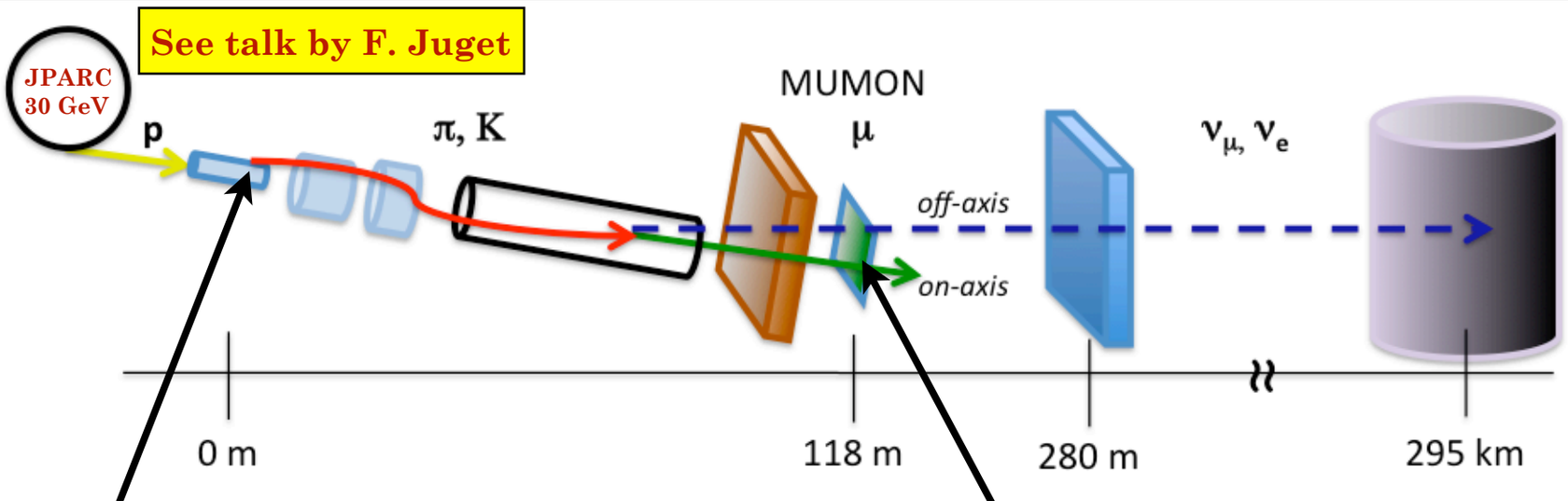


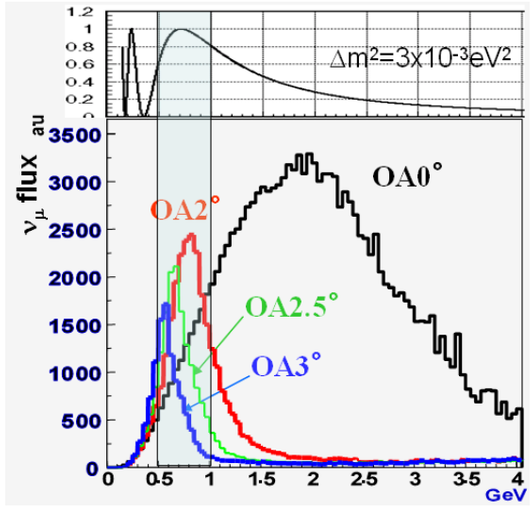
NA61/SHINE (SPS Heavy Ion and Neutrino Experiment)

Originally approved at CERN
in 2007.
Scientific program is now approved
until 2014.

Collaboration of:
125 scientists
24 institutes
13 countries

Hadroproduction measurements for T2K





Off-axis ν beam, peak energy at oscillation maximum ~650 MeV

Measurements of pion/kaon production from 30 GeV protons on Carbon with both thin & long targets:

- **Tuning of GFLUKA model currently used in the T2K beam simulation program**
- **Study of neutrino flux predictions in terms of the NA61 measurements**
- **Study of required statistics for 2010 replica target data to fulfill the T2K physics goals**

Measurements of forward pion/kaon production (<40mrad):

- **producing muons w/ p > 5 GeV/c giving signal in MUMON**
- **important to monitor beam direction !**

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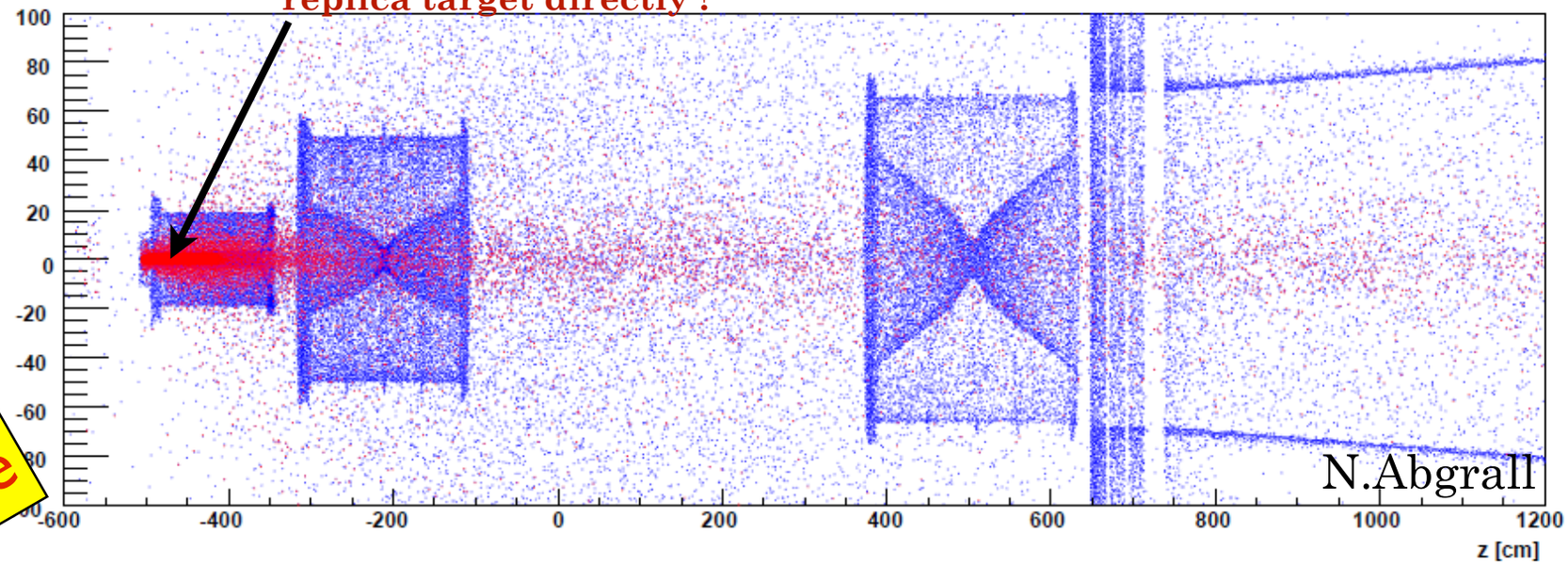
~90 % of both ν_μ and ν_e fluxes at peak energy coming from parents produced in the target: measure production from replica target directly !



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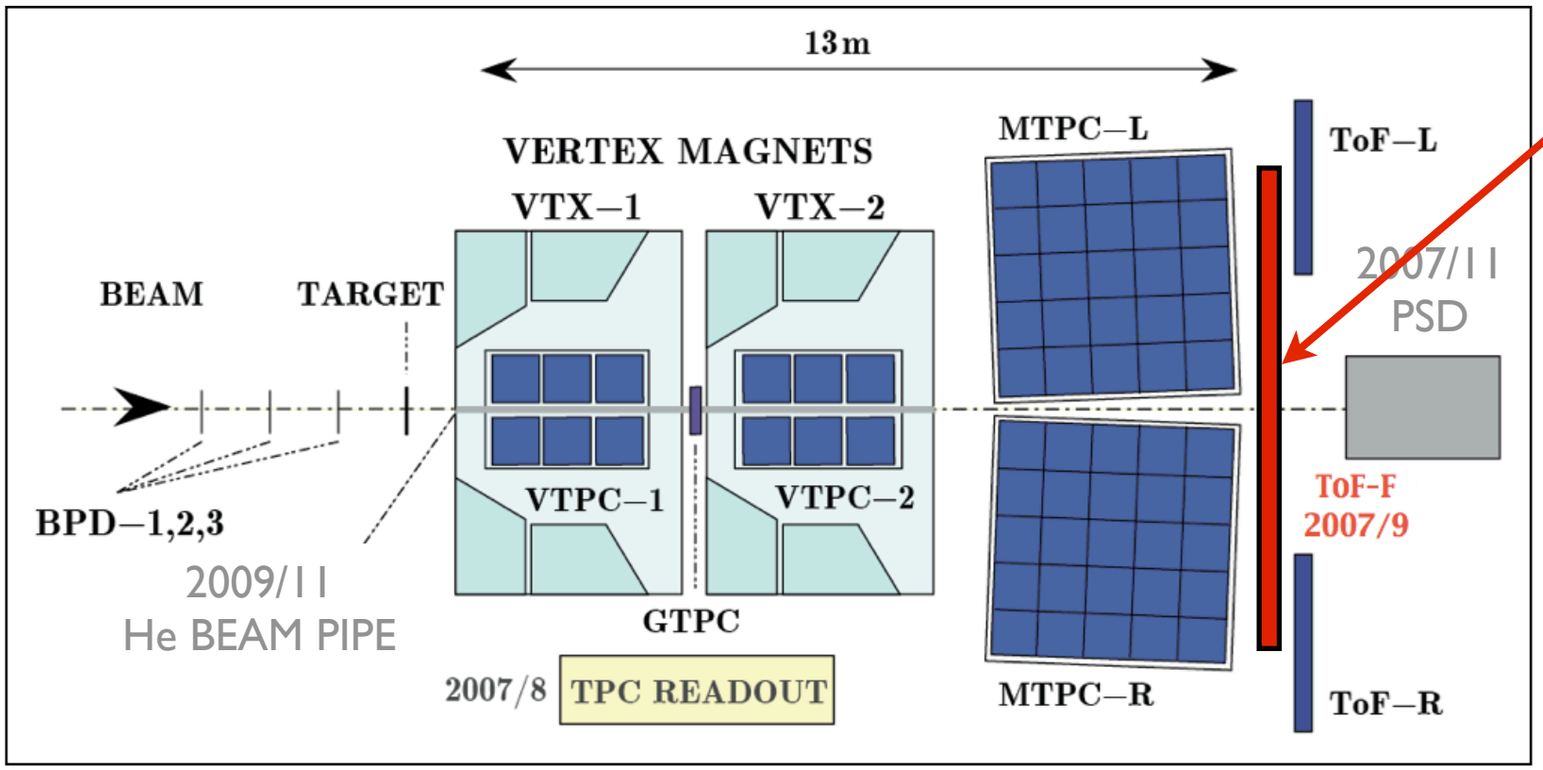
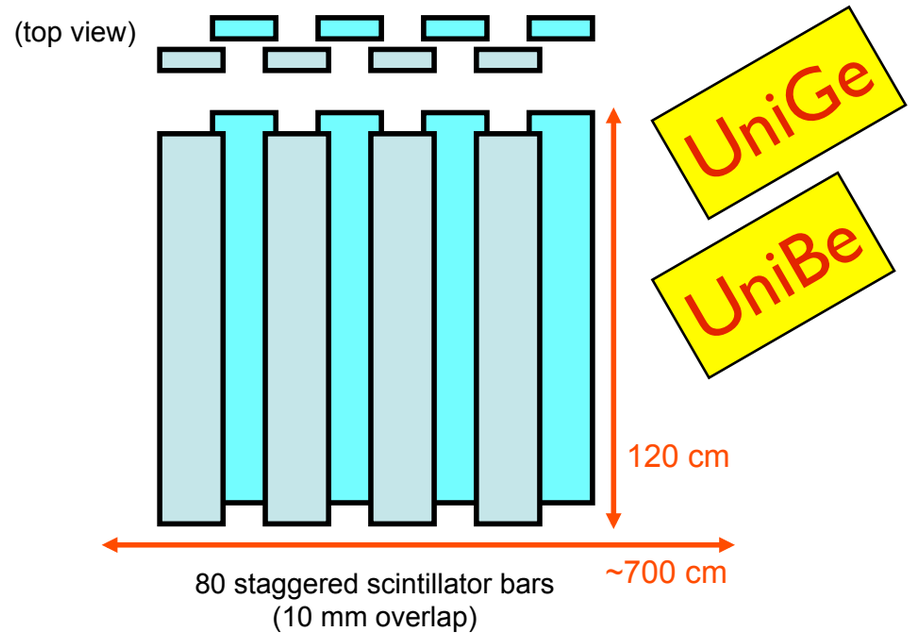
T2K-NA61 internal notes: http://www.t2k.org/beam/NuFlux/HadronInt/note-01/view
http://www.t2k.org/beam/NuFlux/HadronInt/note-03/view

The NA61 experiment: detectors and data sets



Major detector upgrade, added for T2K neutrino physics program



Measurements with thin AND long targets

- Thin Carbon target
  (2.5x2.5x2 cm^3, 1.84 g/cm^3, 4% λ_{int})
  - 670k triggers in 2007
  - Set of data used to produce preliminary pion spectra.
- T2K replica Carbon target
  (90 cm, 2.6 cm ∅, 1.83 g/cm^3,1.9 λ_{int})
  - 230k triggers in 2007
  - Data under first analysis loop.
- **2009 data under calibration**

Large acceptance spectrometer:

- 5 TPCs:
  2 dipole magnets with high momentum resolution
- 3 ToFs:
  $\sigma_{ToF\text{-}F}$ ~ 120 ps
  $\sigma_{ToF\text{-}L/R}$ ~ 70 ps

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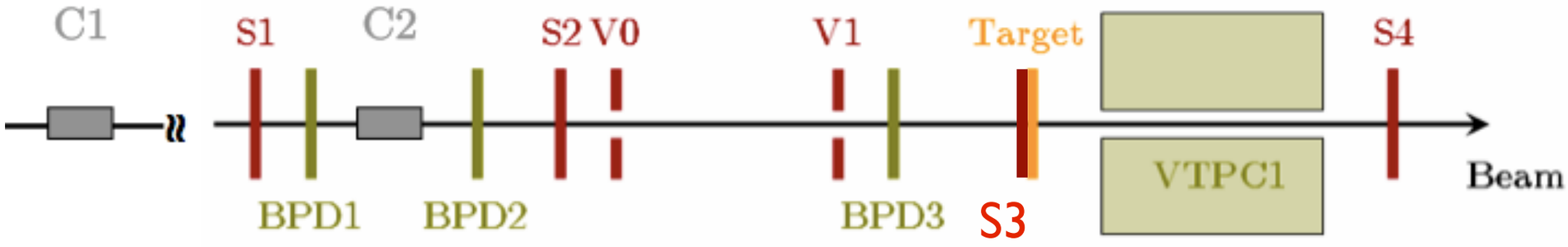
Mechanical support for replica target including trigger counter

The NA61 experiment: beam line



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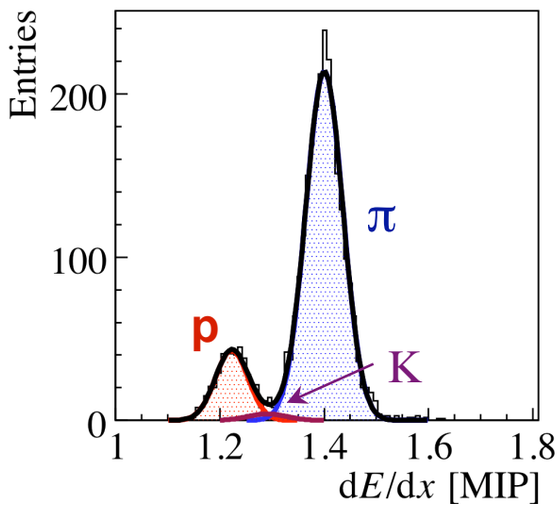
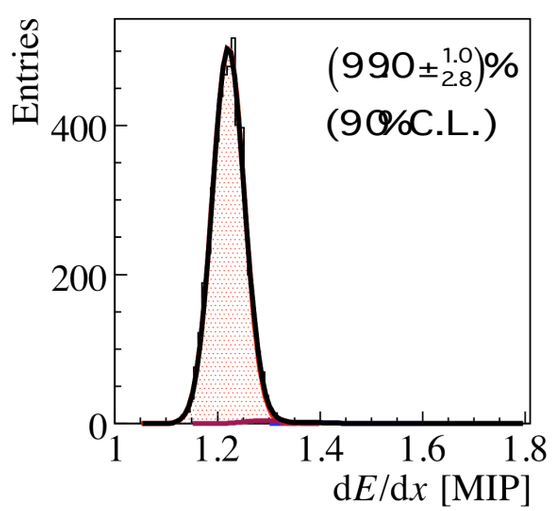
Much effort put into setting up the beam line and beam QA

- Secondary hadron beam composed of 83.7% pions, 14.7% protons and 1.6% kaons
- Beam particles identified by CEDAR (C1) and threshold Cherenkov (C2) counters
- Beam defined as: S1.S2.V.C1.C2
- Beam trajectory measured by a set of three beam position detectors (BPDs)
- Thin target: interactions selected by anti-coincidence of the beam particle with S4
- Long target: selection in coincidence with S3

All beam particles

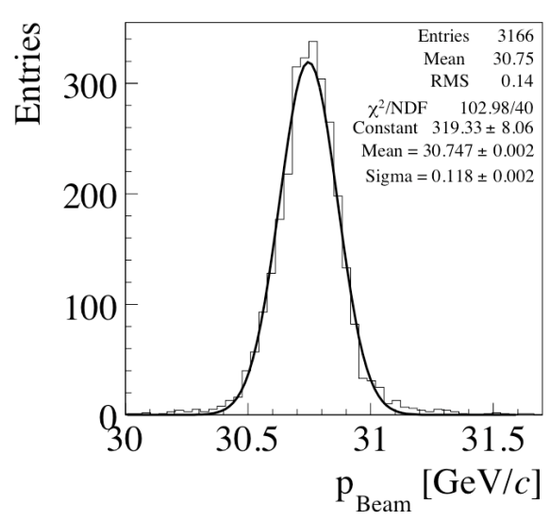


protons: C1.$\overline{C2}$

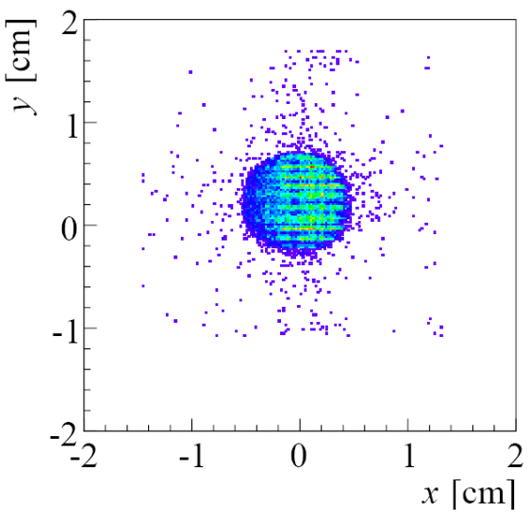


2007 data

Beam momentum



Beam spot on BPD3



C.Strabel

The NA61 experiment: trigger system

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divided in 3 sequential logic blocks

16 inputs

physics

logic (and & or)

prescaler

trigger pattern

trigger mixing

delay4

S1b synchro

T1...T4

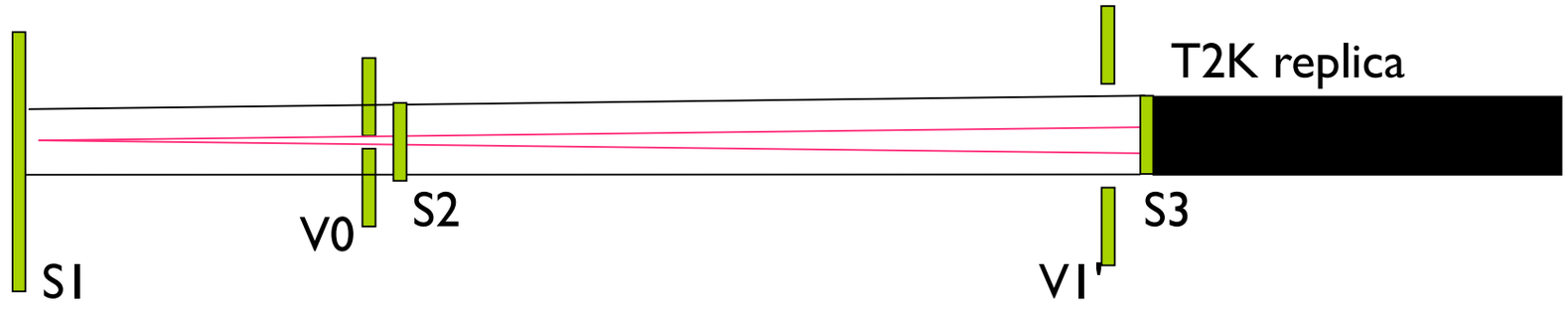
Main trigger (MT)

delay4

S1b synchro

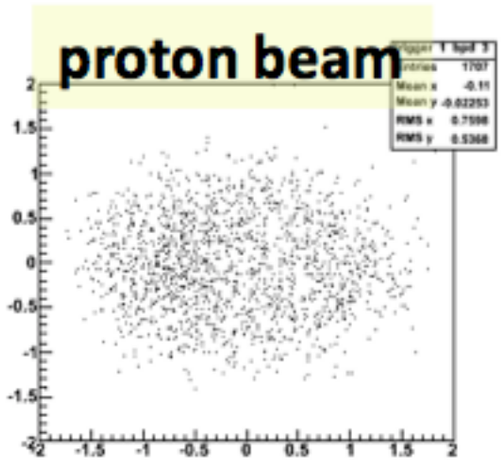
S1 synchronization

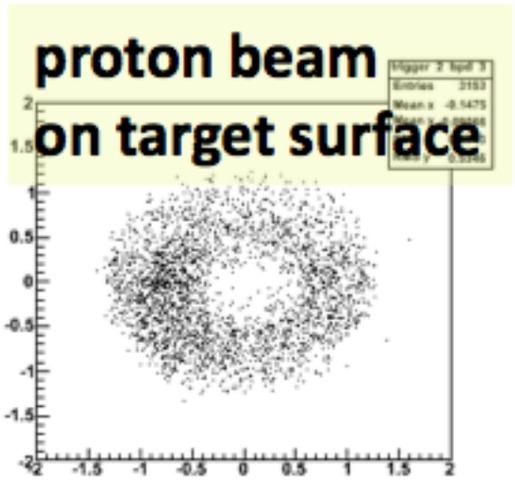
T1 = S1.S2.$\overline{V1}$'.C1.$\overline{C2}$ downscale 20
T2 = S1.S2.$\overline{V1}$'.C1.$\overline{C2}$.S3 2/4
T3 = S1.S2.$\overline{V1}$'.C1.$\overline{C2}$.S3.$\overline{V0}$ 1
T4 = S1.S2.$\overline{V1}$'.S3 200

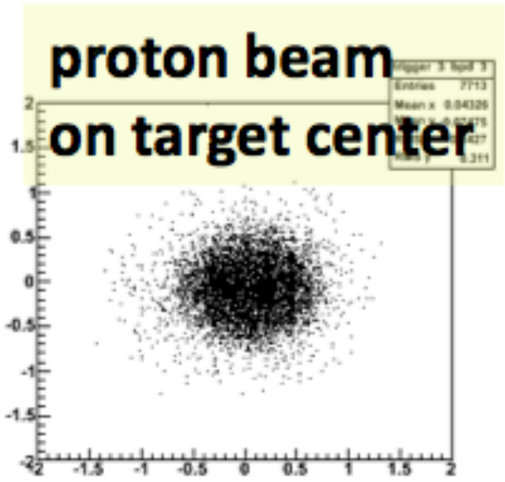


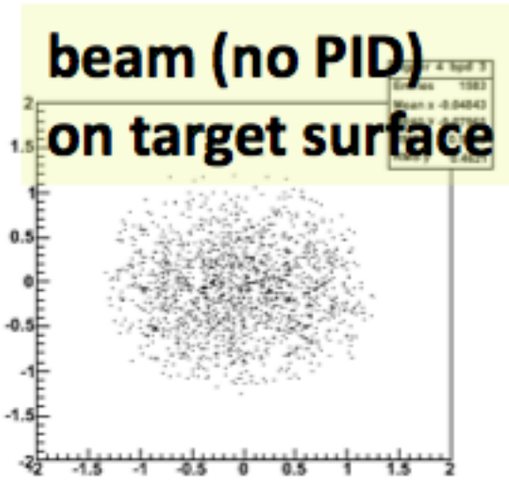
The NA61 experiment: target alignment

4 different triggers running in parallel









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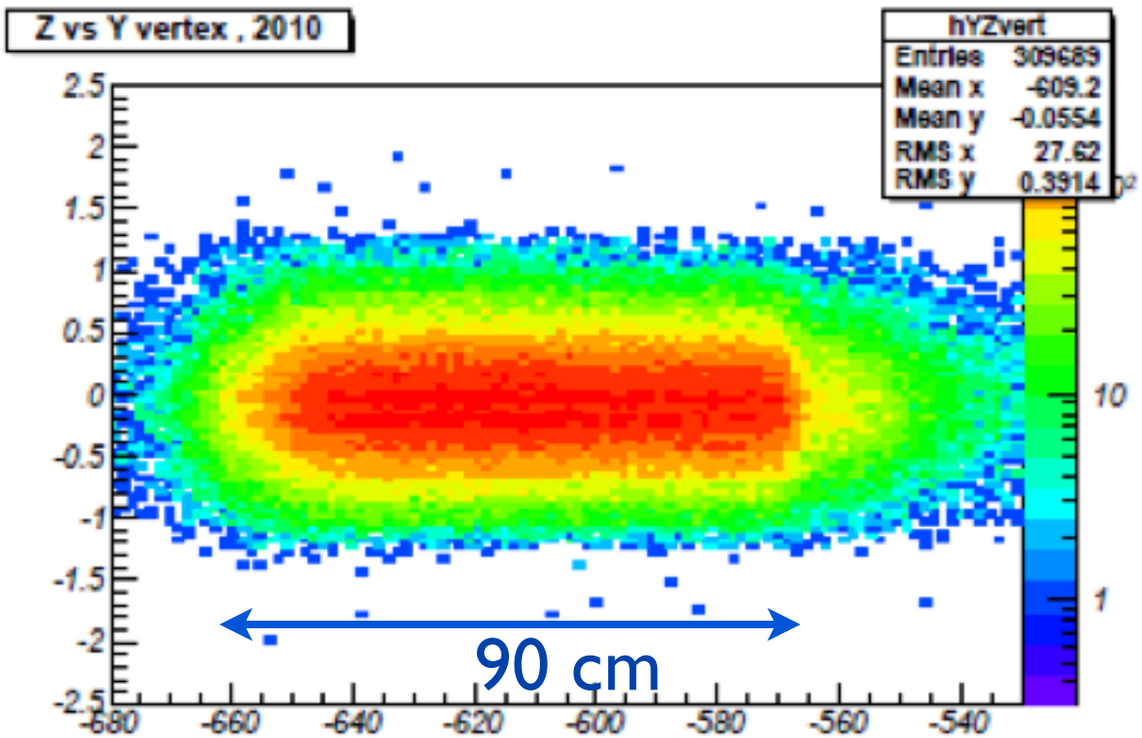
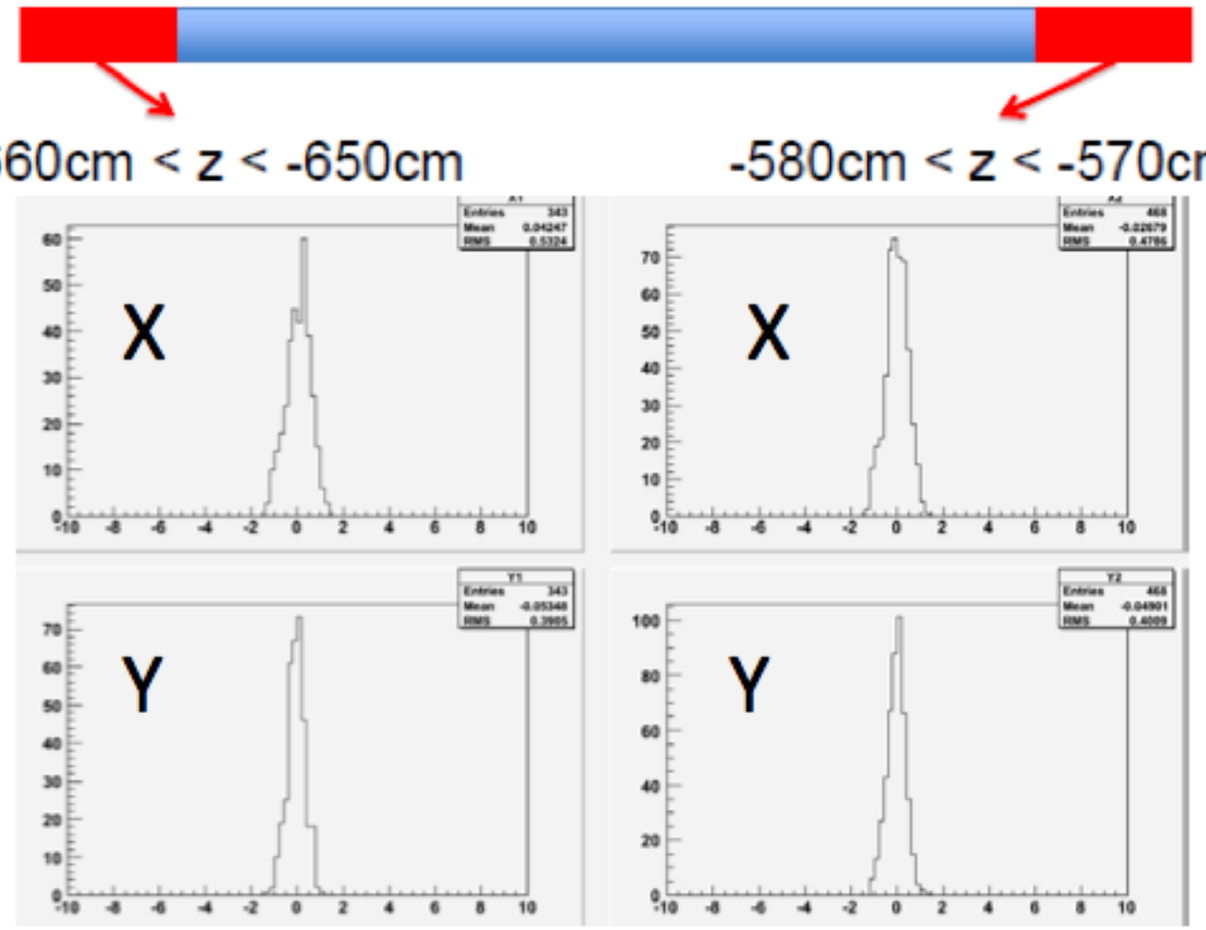
reconstructed vertex



target aligned to better than 1 mrad

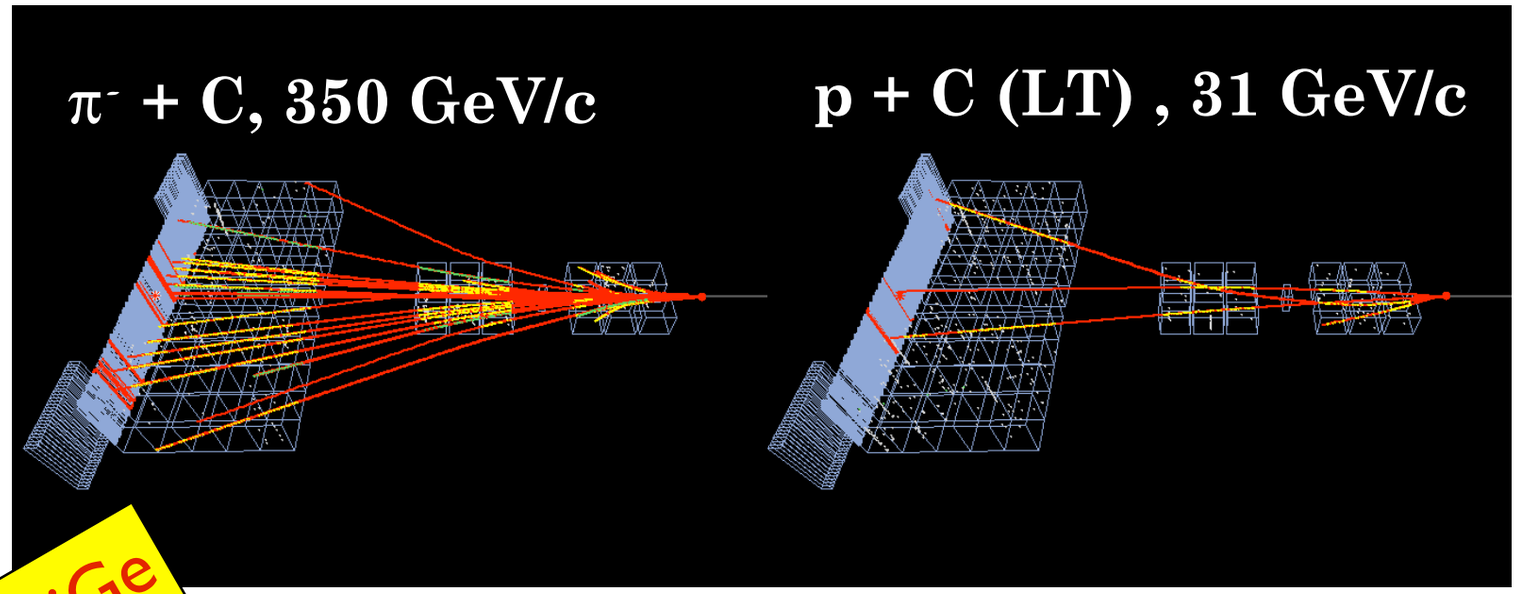


The NA61 experiment: data reconstruction

High quality of data reconstruction

Major updates to the reconstruction chain:

- Kalman filter (get track param. at z position of any cluster)
- new parametrization of spatial resolution of TPCs



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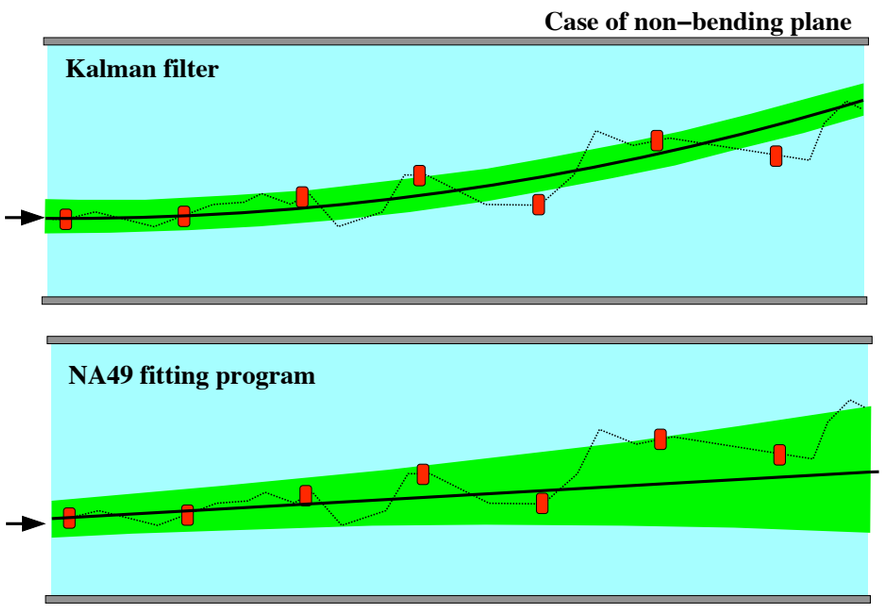
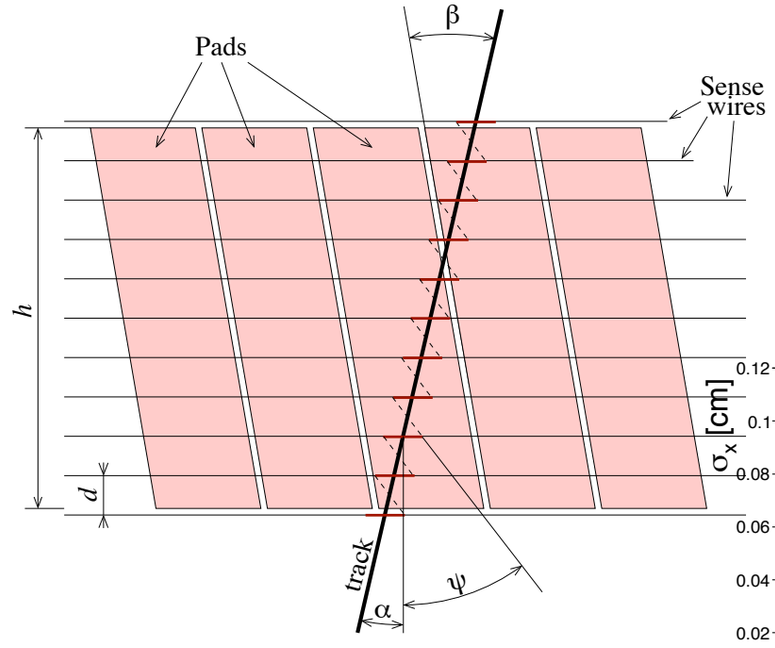


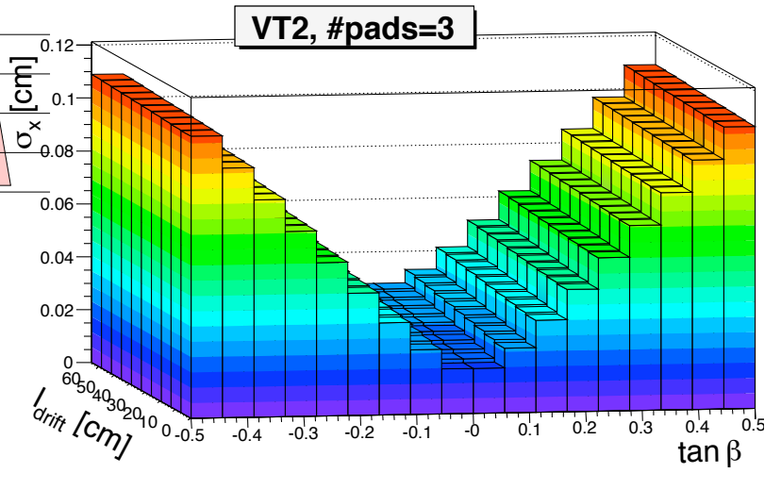
Accounts for multiple scattering, error propagation, ... Presently used in many hep experiments, e.g. CMS, COMPASS, ...

Resolution parametrized as:

$$\sigma_x^2 = A \cdot \frac{l_{drift}}{h} \cdot \cos\beta \cos^2(\alpha - \beta) + B \cdot h \cdot \cos\beta \cdot \tan^2\beta + C$$



Computed separately for clusters with n=2,3,4,... pads.



A.Korzenev

The NA61 experiment: data simulation

Development & maintenance of the NA61 Monte-Carlo chain:

- implementation of new detectors (forward TOF, GAP TPC)
- full production of mc data for thin and replica targets
- bookkeeping

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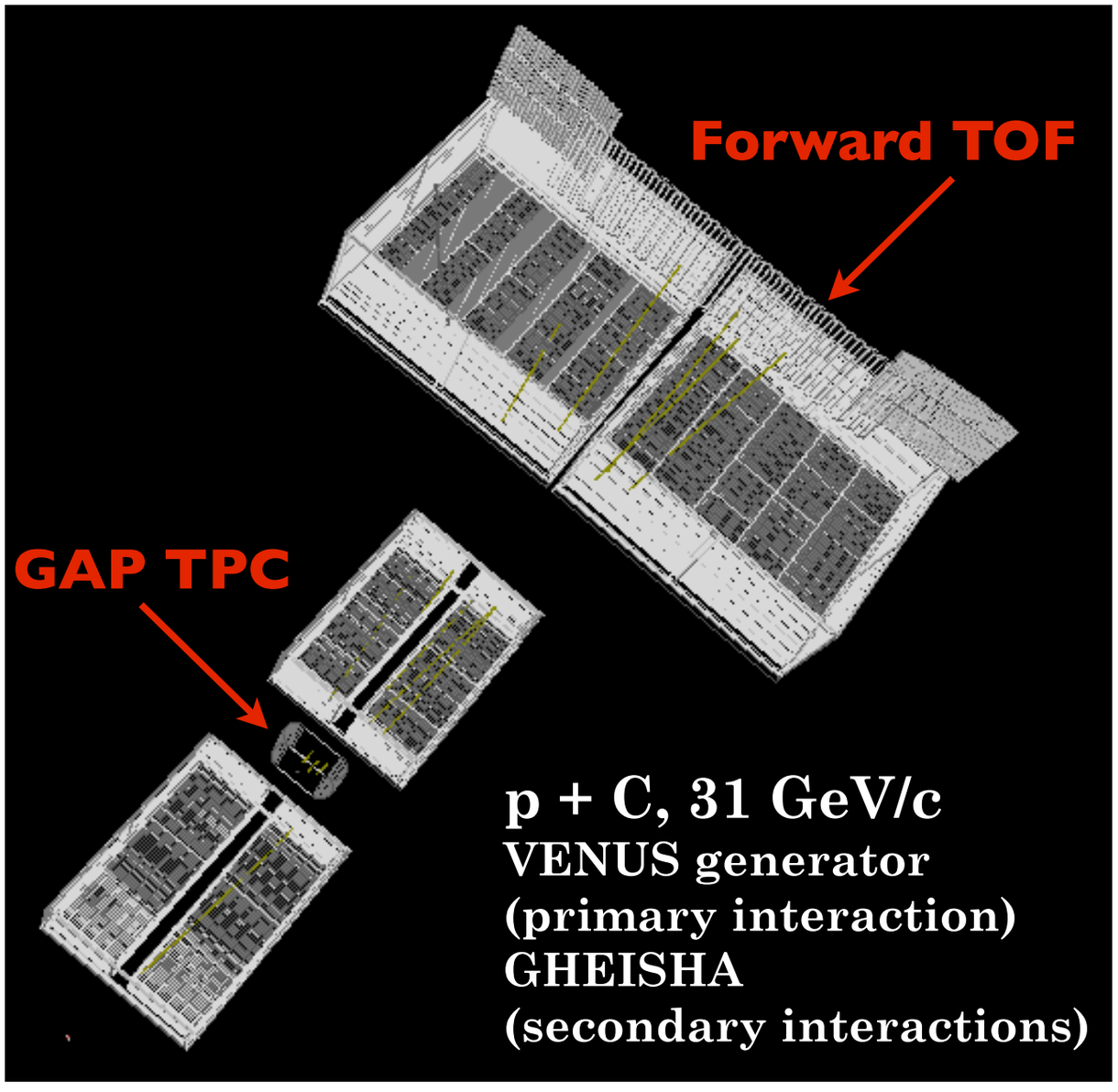

e.g. NA61 TWiki page

Full productions

E_beam [GeV]	Projectile	Target	Production	N_events	Description
30	p	2C	07H*	0.55M	details
30	p	2C	07I	1.1M	details
30	p	T2K	07I	0.2M	details

** read the details!*

Pre-productions

E_beam [GeV]	Projectile	Target	Production	N_events	Description
30	p	2C	pre-07L	100k	details
30	p	2C	pre-07H	100k	details
30	p	2C	pre-07I	10k	details; physics and ExB distortions **off**

Planned

E_beam [GeV]	Projectile	Target	Production	N_events	Description
30	p	2C	07H	1M	details; no GTPC
30	p	2C	07H	1M	no GTPC; replacing VENUS with Fluka
30	p	2C	07I	100k	details; physics and ExB distortions **off**
30	p	2C	07L	1M	details
30	p	2C	07L	1M	replacing VENUS with Fluka
30	p	T2K	07L	1M	details

The NA61 experiment: data normalization

Normalization:

- determination of trigger cross-section:

$$\frac{\Delta\sigma^{meas}_{inel,\alpha}}{\Delta p\Delta\theta} = \frac{1}{nN_{Beam}}\frac{\Delta n_\alpha}{\Delta p\Delta\theta} = \frac{\sigma_{trig}}{N_{trig}}\frac{\Delta n_\alpha}{\Delta p\Delta\theta} \qquad \sigma_{trig} = \frac{1}{n}\frac{N_{trig}}{N_{beam}} \qquad n = \rho L N_A/A$$

triggered events from the target

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	P_{int}^{Tin} (%)	P_{int}^{Tout} (%)	$P_{int}^{Tin-Tout}$ (%)	σ_{trig} (mb)
2007	7.105 ± 0.009	1.718 ± 0.008	5.378 ± 0.012	300.1 ± 0.7
2009	6.998 ± 0.007	1.590 ± 0.010	5.398 ± 0.012	300.8 ± 0.7

σ_{trig} corrected for:
- absorption in the target, λ_{abs}
- events outside of the Carbon target

$$\left(\frac{\Delta n_\alpha}{N_{trig}}\right)^C = \frac{1}{1-\varepsilon}\left(\left(\frac{\Delta n_\alpha}{N_{trig}}\right)^{T_{in}} - \varepsilon\left(\frac{\Delta n_\alpha}{N_{trig}}\right)^{T_{out}}\right) \longrightarrow \text{yields corrected for non-target events}$$

$$\varepsilon = P_{T_{out}}/P_{T_{in}}$$

- total inelastic cross-section: **obtained from σ_{trig} after some corrections are applied**

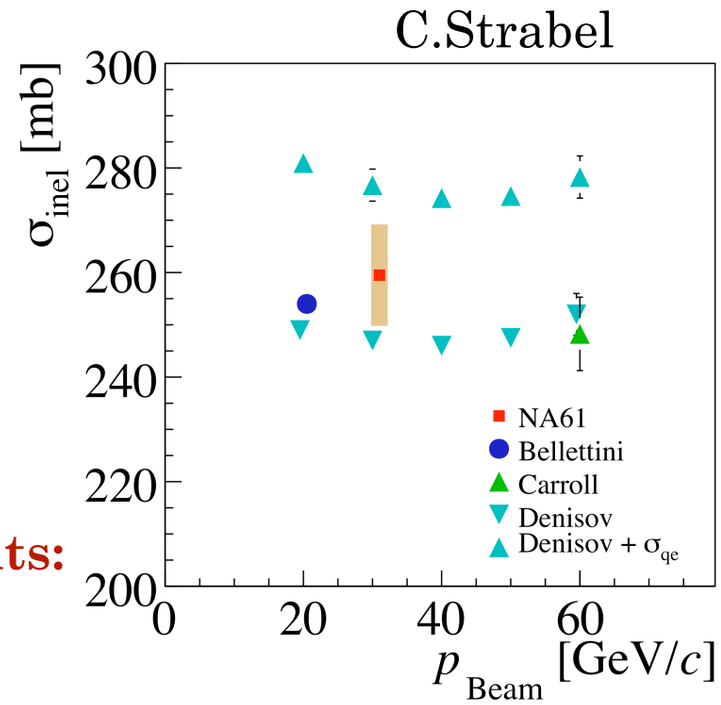
2007 data

σ contribution	value [mb]
σ_{trig}	$300.1 \pm 0.7 \pm 8.7$
σ_{loss-p}	$5.7 \pm 0.1 \pm 0.9$
$\sigma_{loss-\pi/K}$	$0.54 \pm 0.02 \pm 0.04$
$\sigma_{elastic}$	$-46.8 \pm 0.2 \pm 4.2$
σ_{inel}	$259.5 \pm 0.7 \pm 9.7$

Geant4 based corrections:

fake beam signal
positive correction

large angle
coherent scattering
fake data signal
negative correction



NA61 preliminary σ_{inel} value consistent with previous measurements:

The NA61 experiment: data analysis

Thin target results:

Analyzed p-C data @ 31 GeV/c from 2007 pilot run:

- determination of absolute inelastic cross-section — ***10% systematic error***
- π^- up to **15 GeV/c** in angular bins of 60 mrad
- π^+ up to **10 GeV/c** in angular bins of 60 mrad

} ***20% systematic errors***

(Current binning suggested by T2K : 200 MeV/c x 20 mrad (p, ϑ) bins. A coarser binning might be required for the publication of the 2007 data.)

Work ongoing to extend coverage to higher momenta !

- preliminary comparisons with different models: GiBUU, Geant4, VENUS, GFLUKA and FLUKA-standalone
- no measurements of re-interactions yet: need to analyze long target data.

Those preliminary results have already been shown at international conferences and are currently being used by the T2K beam Monte-Carlo group.

Work on paper preparation started.

The NA61 experiment: thin target analysis

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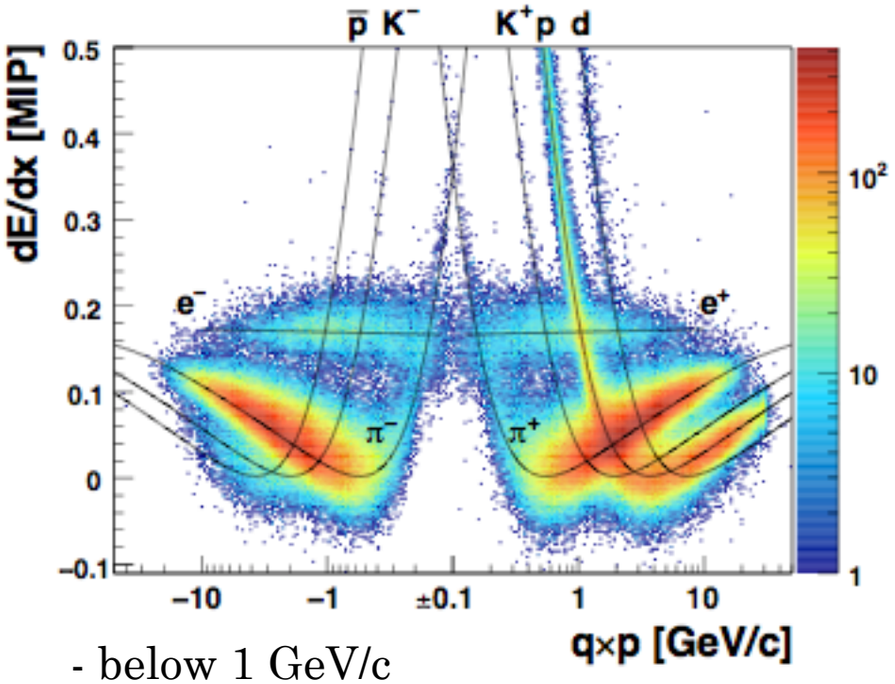
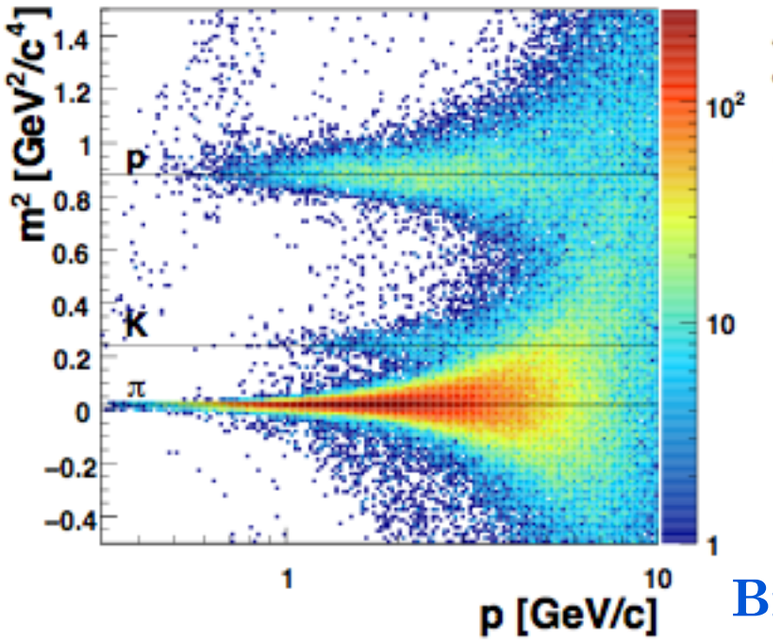
- **Combined ToF-dE/dx analysis:** S.Murphy

dEdx measurements



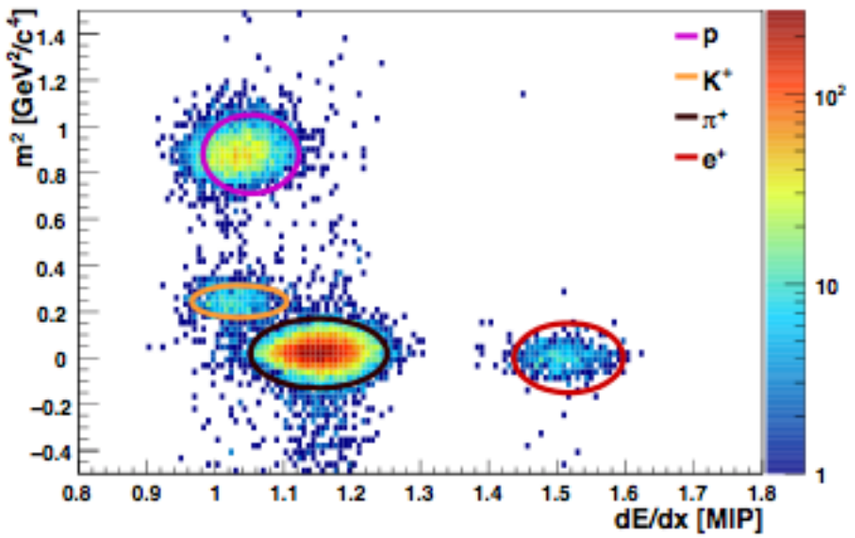
- below 1 GeV/c
- above 4 GeV/c (relativistic rise region)

ToF measurements (m2 vs p)



between 1 and 6 GeV/c

Combined ToF/dEdx measurements



Bi-dimensional max. likelihood fit to extract particle yields.

- **dE/dx analysis in the relativistic rise region:** S.di Luise

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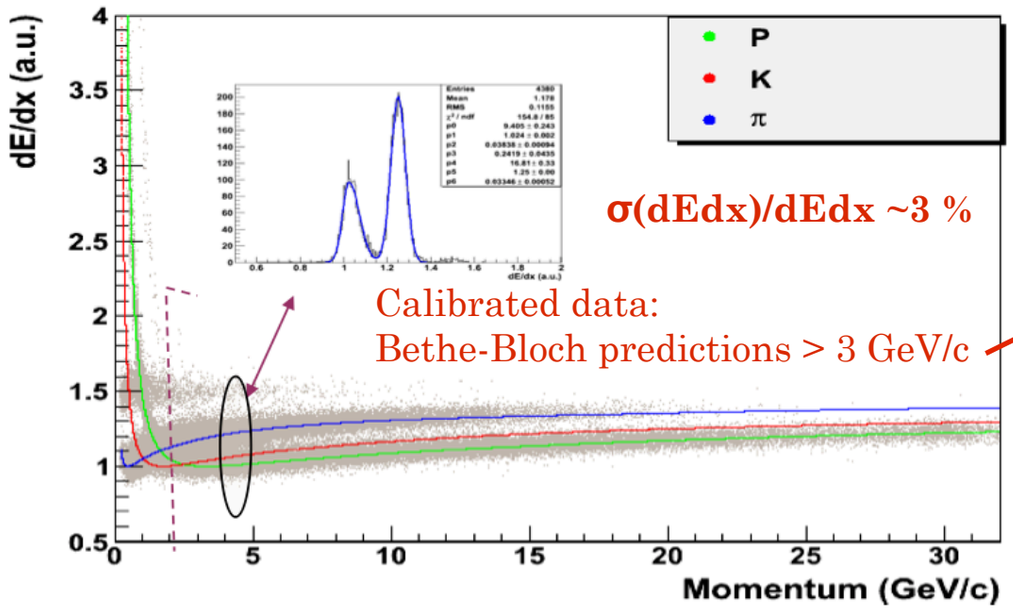
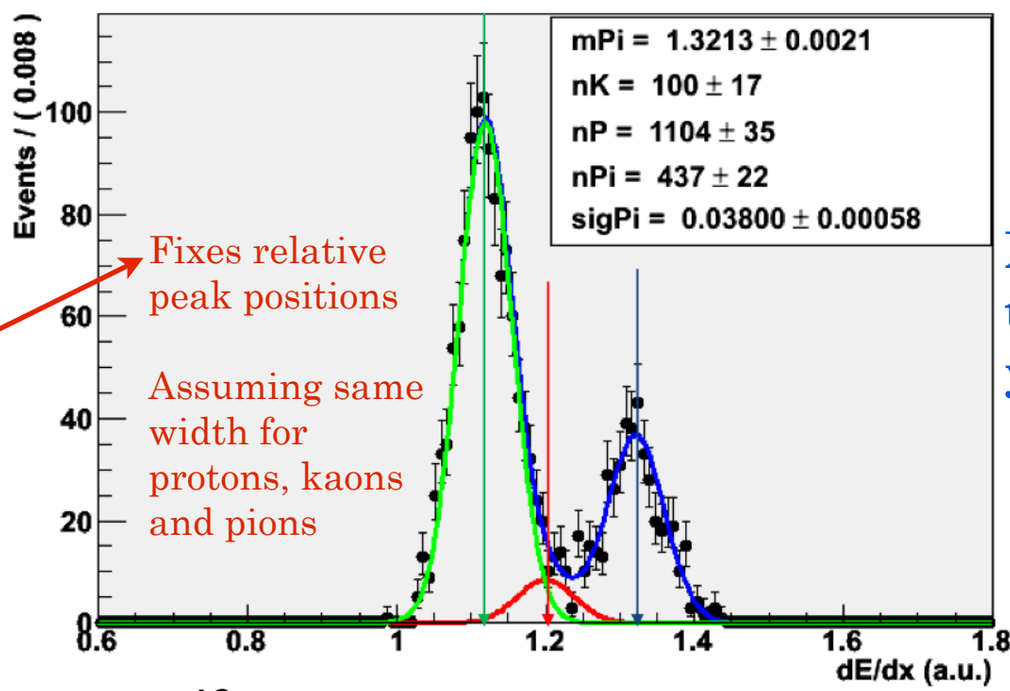


σ(dEdx)/dEdx ~3 %

Calibrated data:
Bethe-Bloch predictions > 3 GeV/c

Fixes relative peak positions

Assuming same width for protons, kaons and pions

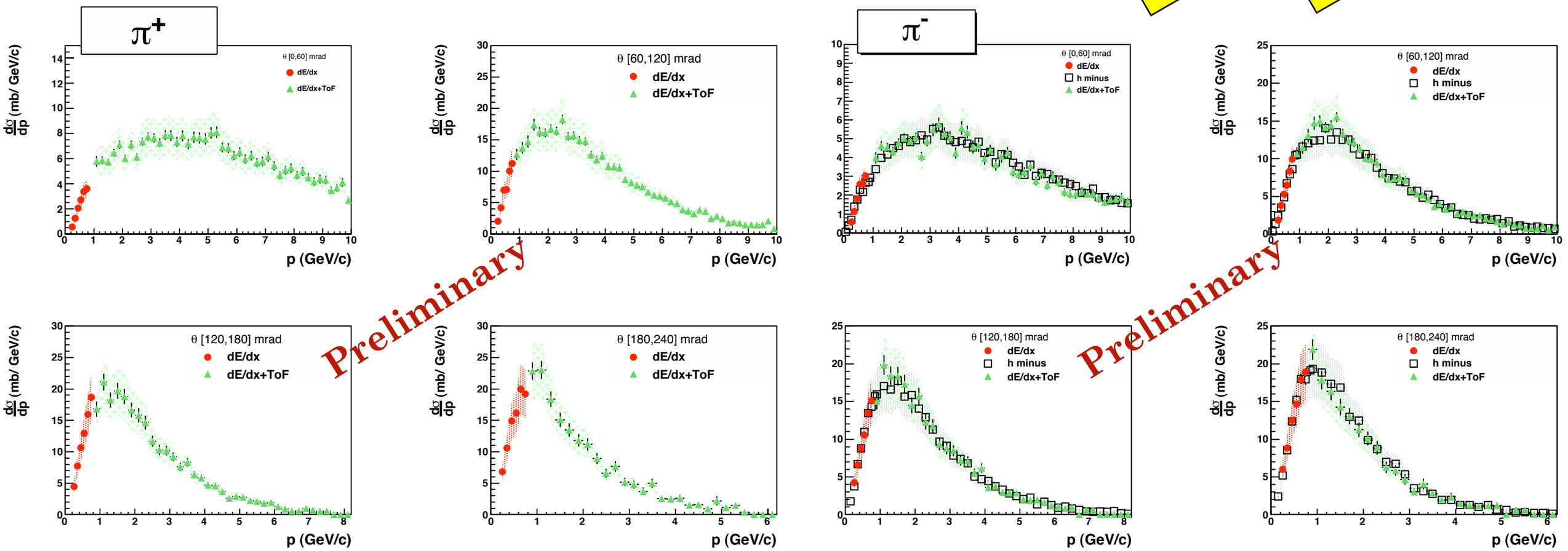


Max. likelihood fit to extract particle yields.

The NA61 experiment: thin target analysis

Differential cross-sections in different bins of ϑ (angle at production point):

UniGe ETHZ



S.Murphy

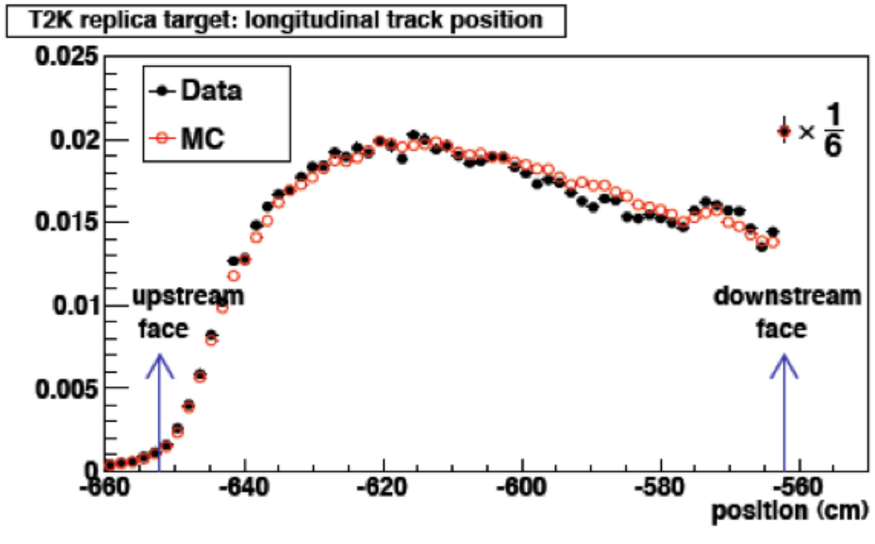
Different analysis procedures have been developed:

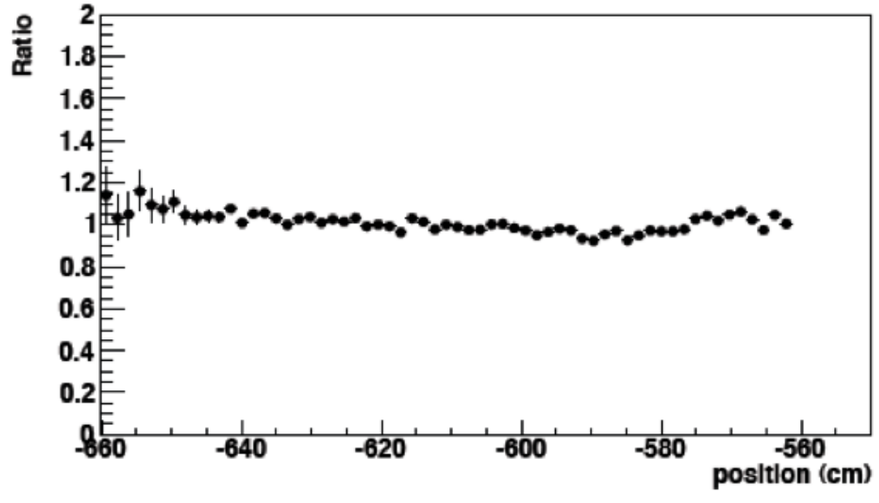
- dEdx only (< 1GeV/c)
- negative hadrons analysis
- combined ToF/dEdx

Results between those different approaches are consistent within **20% systematic errors**. Only statistical errors are shown here. Work is in progress to understand and lower the current systematics.

The NA61 experiment: replica target analysis

- **Dedicated reconstruction procedure:**
  - **no vertex constraint**
  - **tracks reconstructed in the TPCs are back-propagated to the target skin (closest approach)**





ETHZ

L.Esposito

- **first PID results:**
  - **track length computed from back-propagation to the middle of the target**
  - **first combined ToF-dEdx plots**

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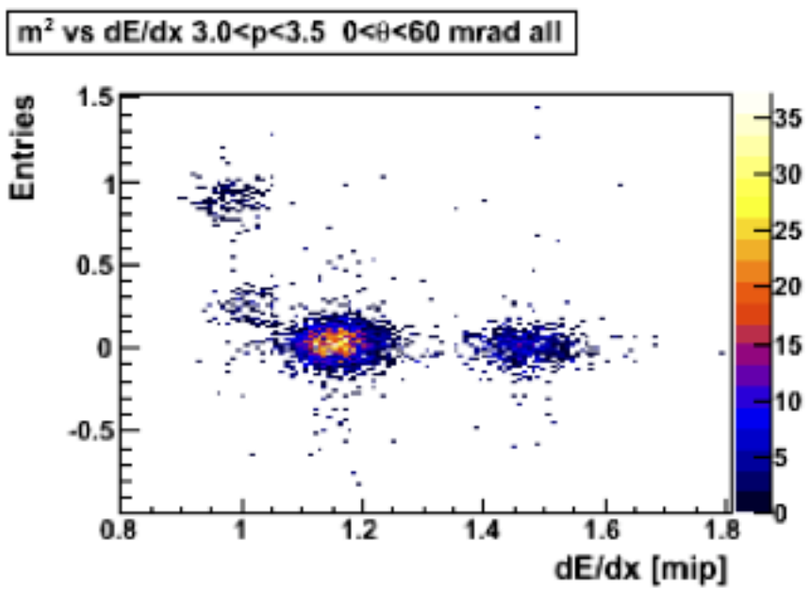
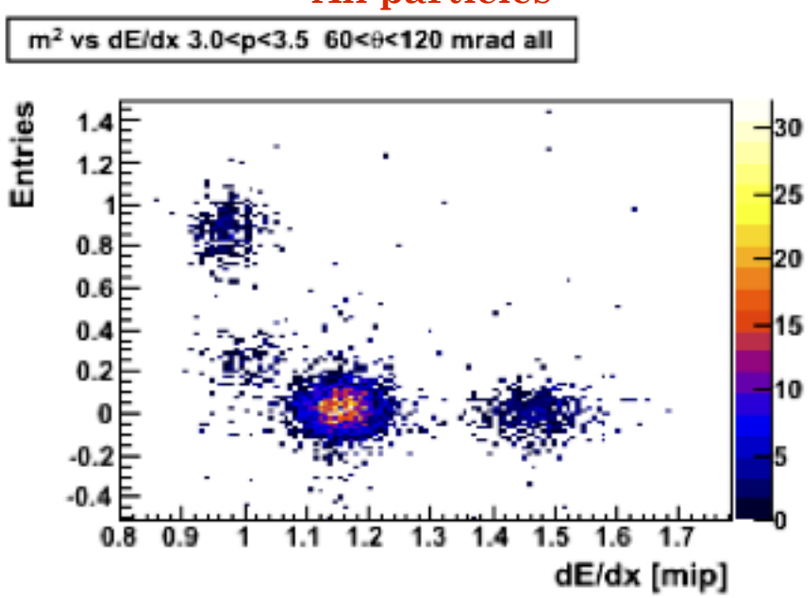
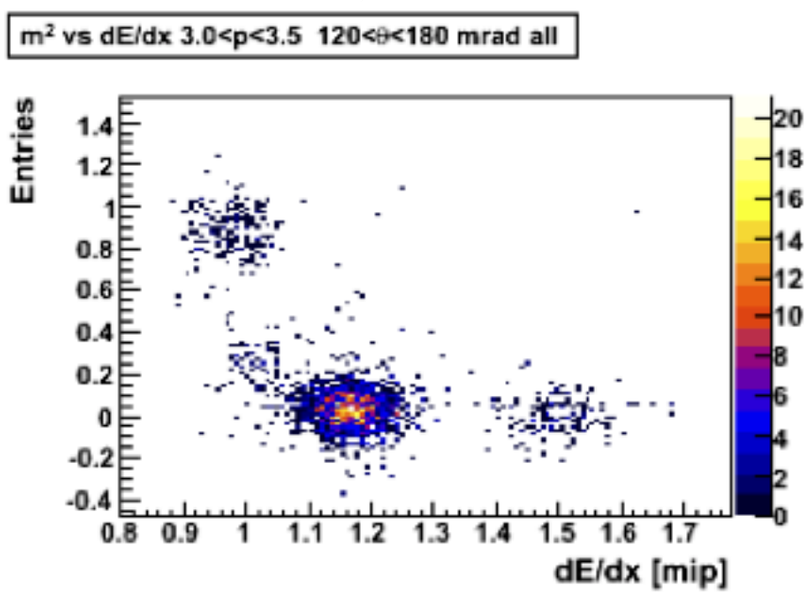
All particles



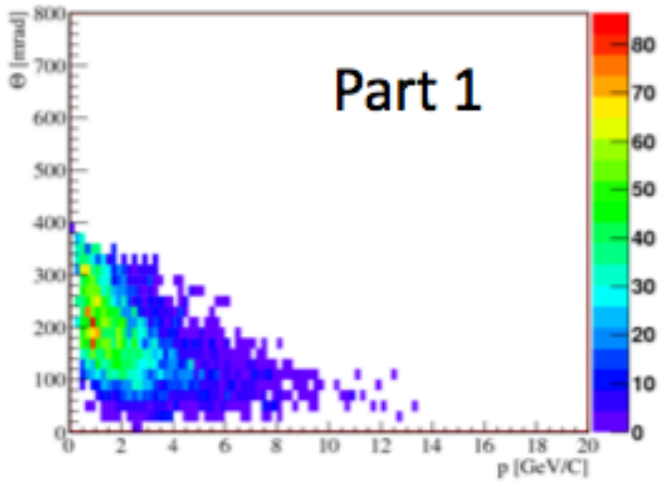


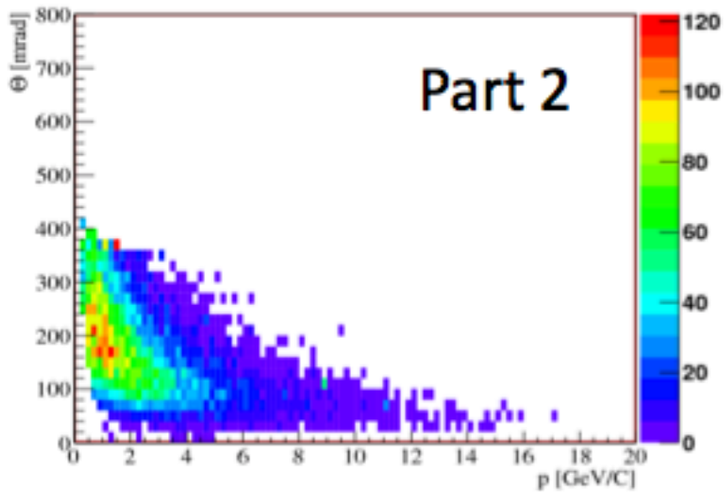


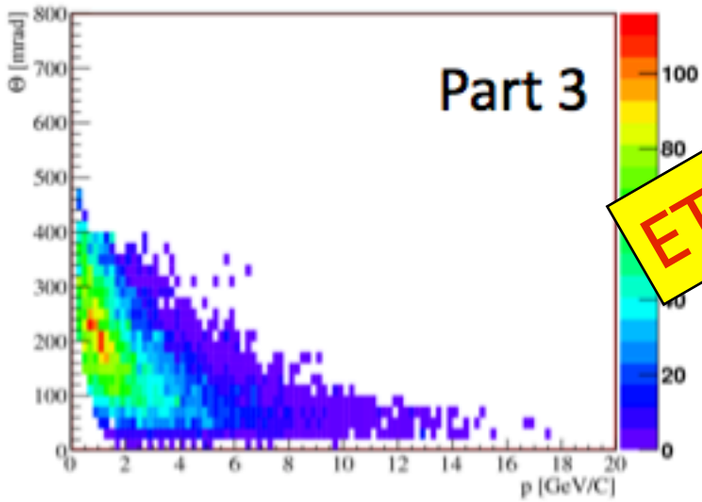
S.Murphy

The NA61 experiment: replica target analysis

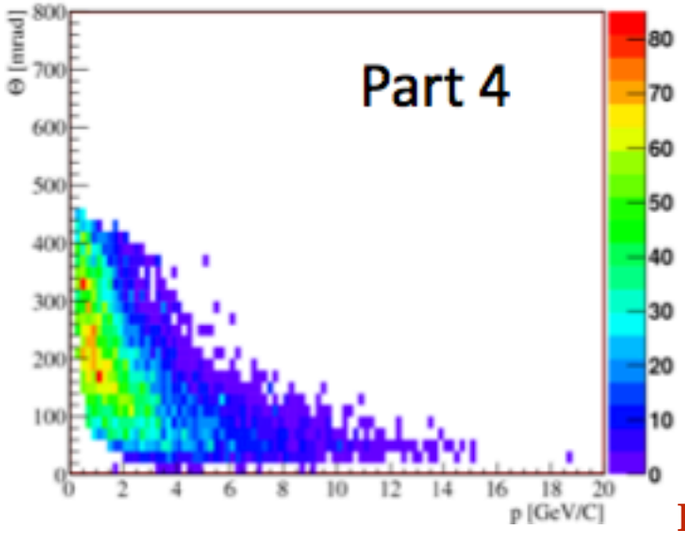
Negative hadrons analysis (h^-):

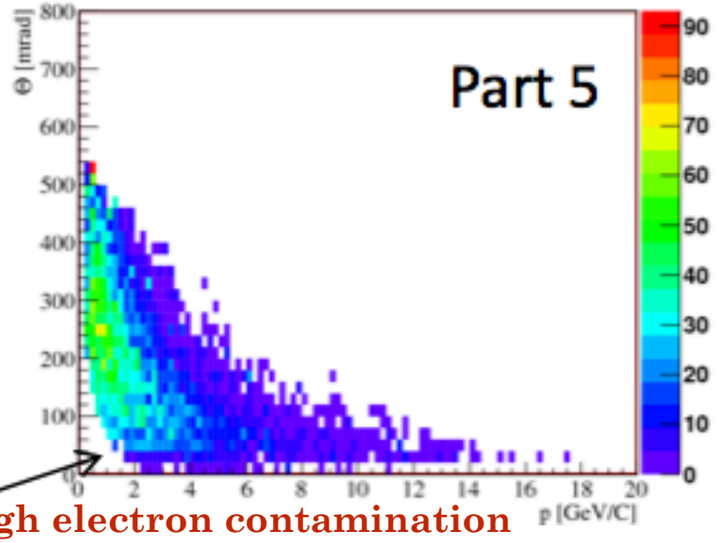


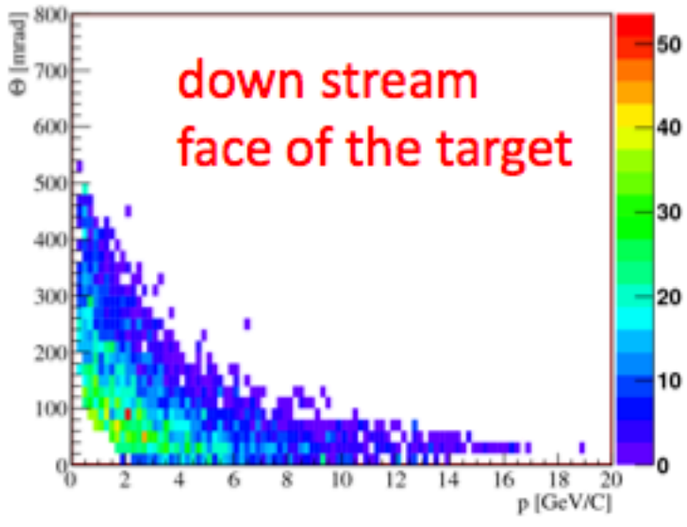




ETHZ



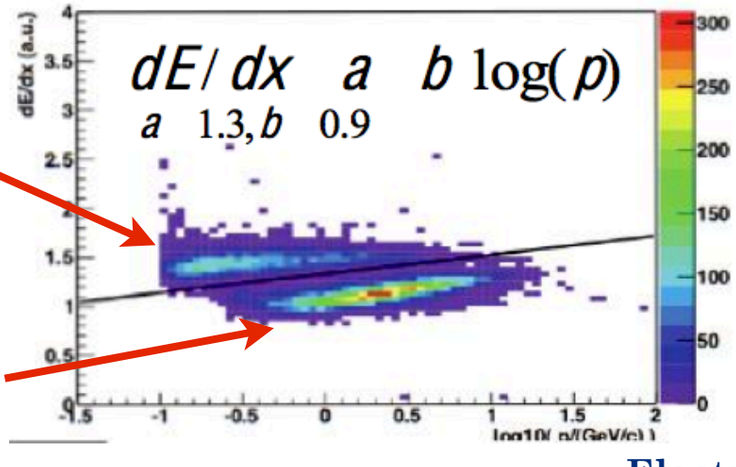


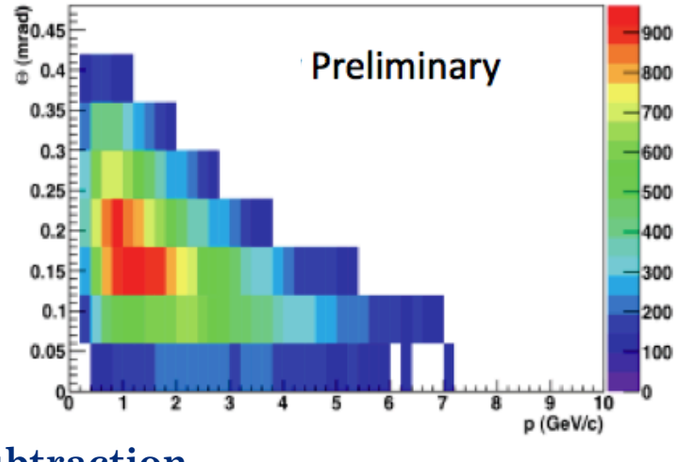


High electron contamination

Mainly electrons (additional pions, kaons and anti-protons in the rising part at low p)

Mainly pions (small admixture of kaons and anti-protons)





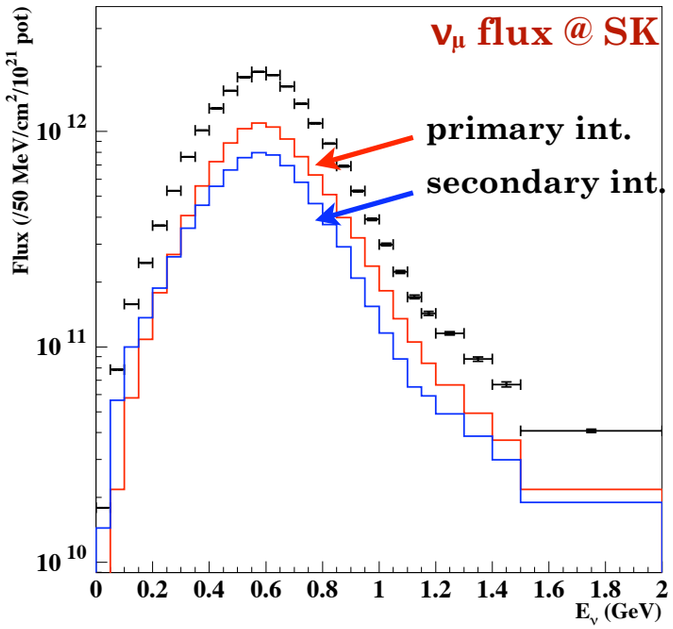
Electron subtraction

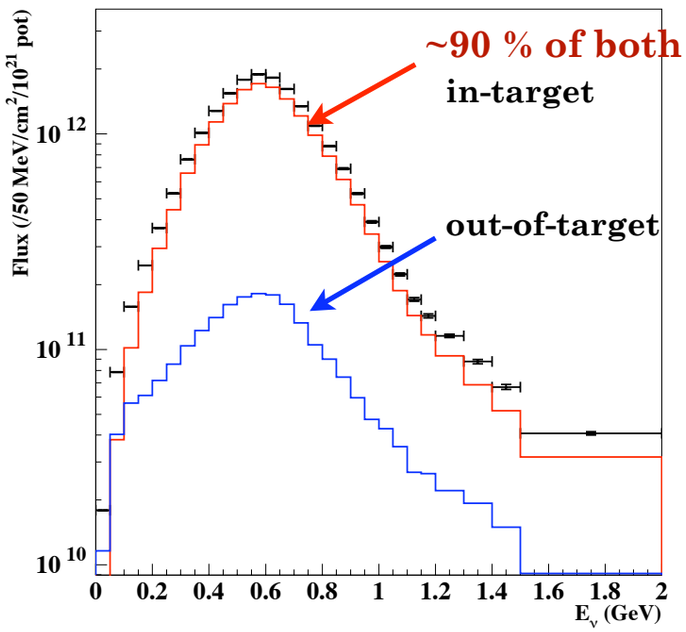
L.Esposito

The NA61 experiment: T2K beam group analysis

Performed several studies:

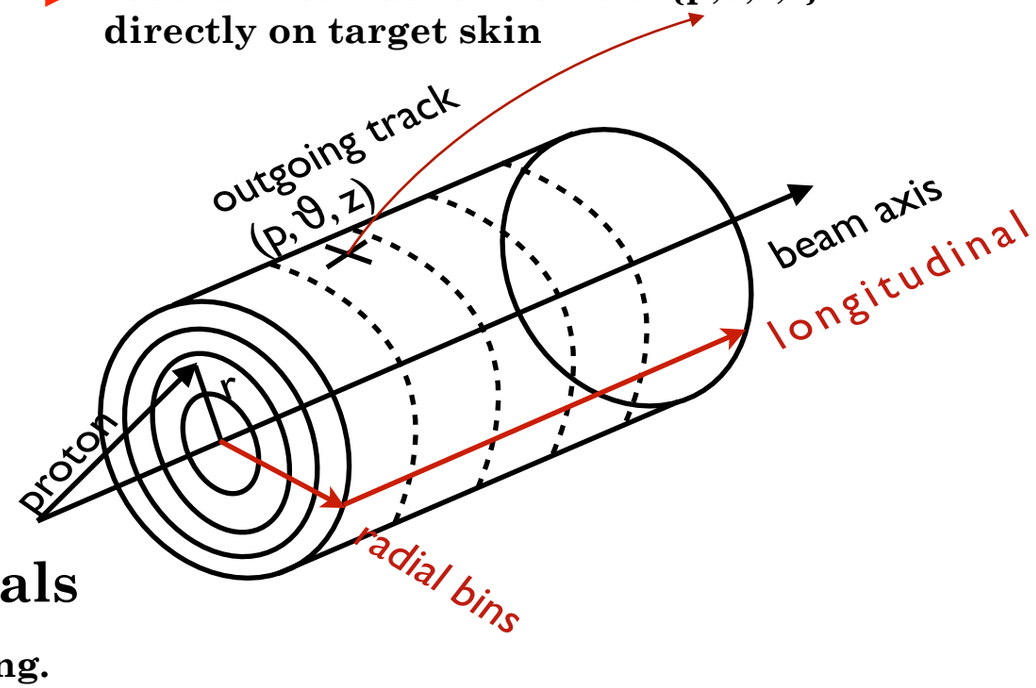
- **Define analysis strategy for the replica target**





UniGe

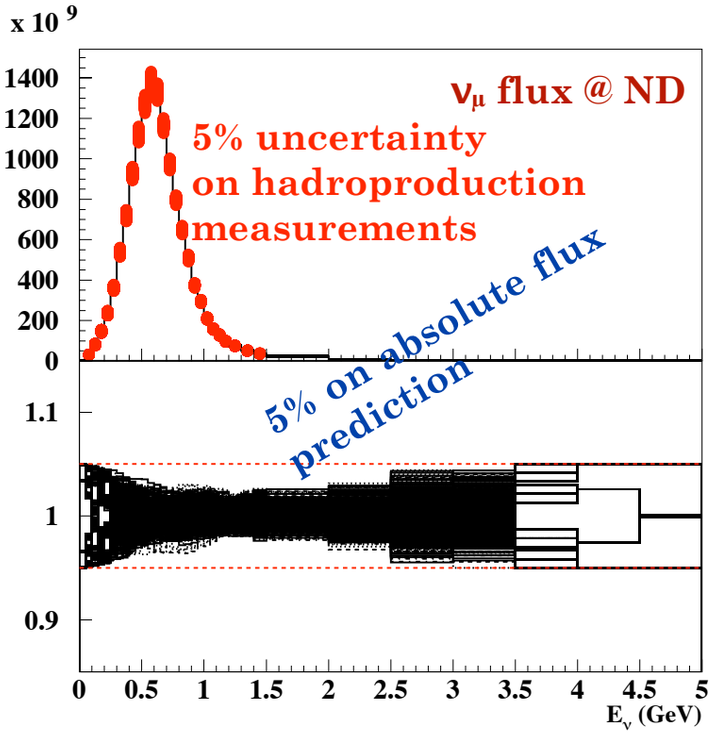
reconstruct tracks in bins of {p,ϑ,z,r} directly on target skin

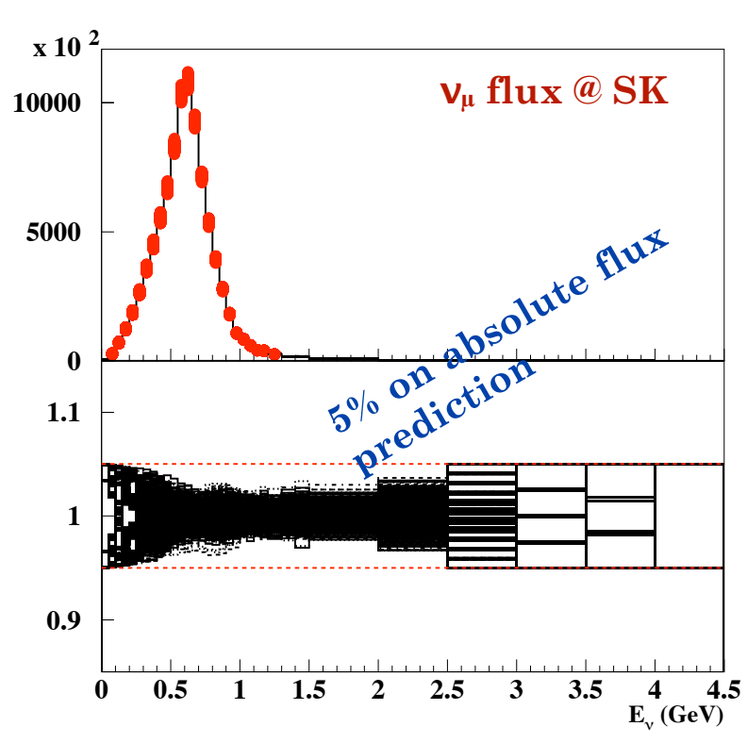


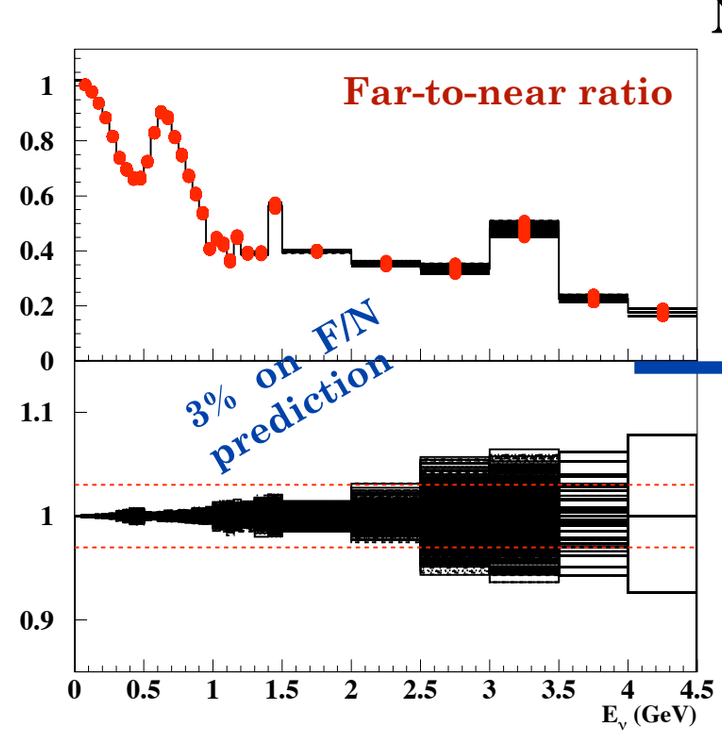
- **NA61 required statistics to fulfill T2K physics goals**

New studies taking NA61 acceptance into account for the {p,ϑ} binning.

N.Abgrall



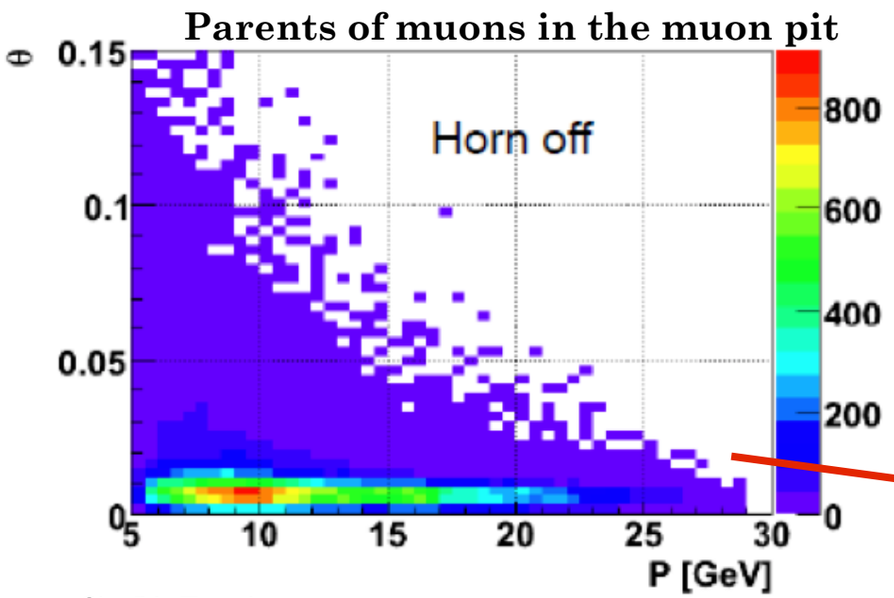




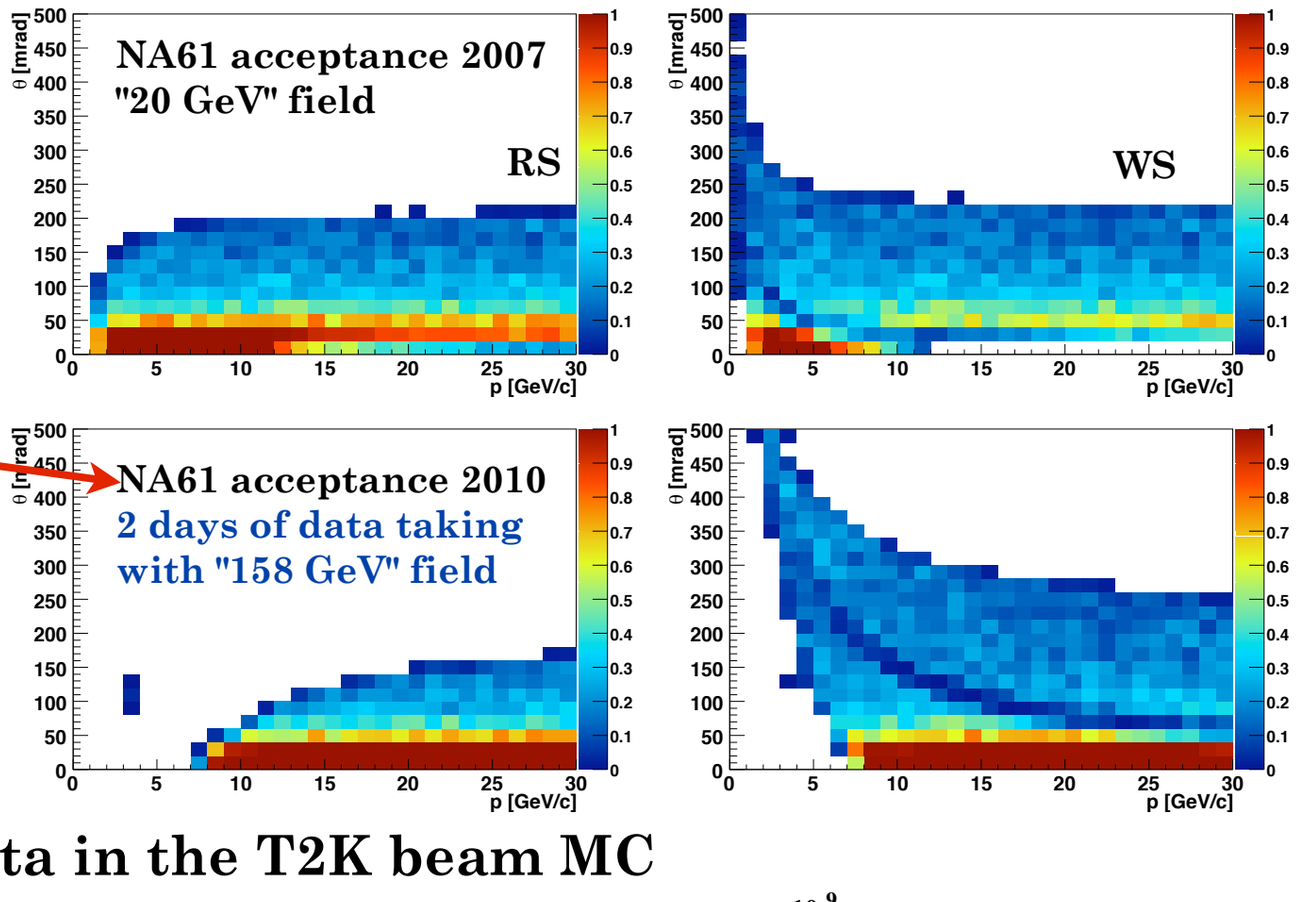
7M triggers
Got > 7M
in 2010

The NA61 experiment: T2K beam group analysis

- **Further acceptance studies for forward beam particles**



S.di Luise



UniGe

ETHZ

- **Implementation of the NA61 data in the T2K beam MC**

N.Abgrall

Developed a method to propagate NA61 hadroproduction data and corresponding uncertainties over the T2K phase space:

- track parameters propagated onto the target skin

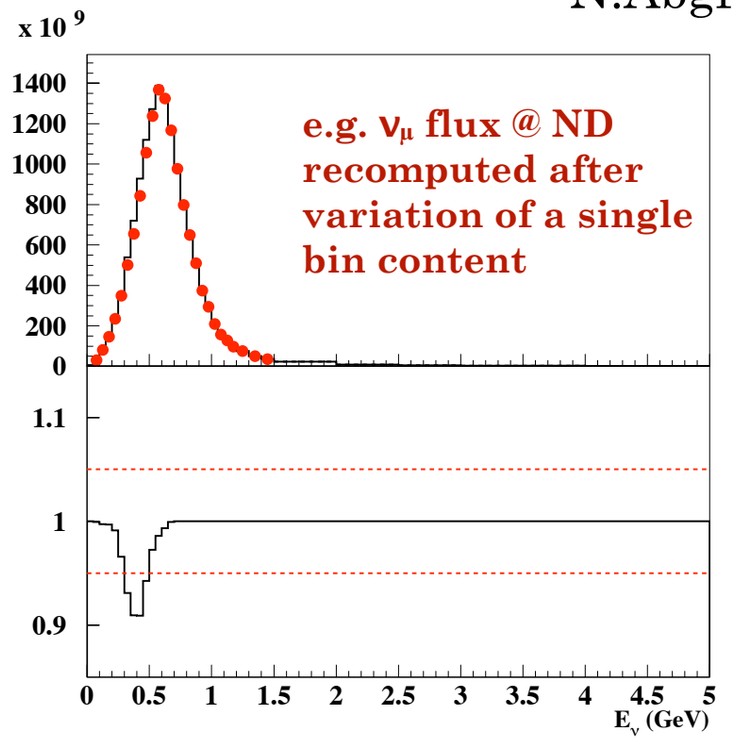
- account for the NA61 acceptance

- target radial + longitudinal binning

- global re-weighting approach (direct use of data in principle not possible due to the non-uniform azimuthal acceptance of the NA61 apparatus)

$$N'_{ij}(E_\nu) = N'_i(p,\theta) \times w^f_{ij}(E_\nu) \times w^n_{ij}(E_\nu)$$

Work ongoing !



Conclusions

- **The Swiss groups play a crucial role in the NA61 experiment both in hardware/ software and analysis efforts !**
- First NA61 preliminary results from the 2007 pilot run have been made public.
- The NA61 large acceptance is adequate for hadron production measurements needed by neutrino experiments and are important to constrain hadron production models used in the T2K beam Monte-Carlo.

- **Swiss groups led data taking for T2K over 3 years:**

❑ **Thin target**
- **2007 pilot run: 670 K proton interaction triggers**
- **2009: 4.4 M proton interaction triggers**

❑ **T2K replica target**
- **standard magnetic field configuration**
  - **2007 pilot run: 230 K proton triggers**
  - **2.4 M (2209) + 7 M (2010) 'proton on target' triggers**
- **high magnetic field configuration**
  - **1 M (2010) 'proton on target' triggers**

- **Short term goals of the Swiss groups in NA61:**

- **finalize pion distributions from 2007 thin target data for publication** (S. Murphy, T. Palczewsky, M. Posiadala, C. Strabel)
- **preliminary results on pions from 2007 thin target data in the 0-20 mrad angular bin for MUMON muon flux measurement comparison** (S. di Luise)
- **preliminary results on kaons (dE/dx&TOF PID) from 2007 thin target data above 3-4 GeV with coarse binning** (S. di Luise, S. Murphy)
- **preliminary results on pions from 2007 long target data** (L. Esposito, N. Abgrall)
- **Improve reconstruction and MC (A.Korzenev)**

- **Long term goal of the Swiss groups in NA61:**

- **precise flux predictions for precision xsection and oscillation measurements in T2K**