Analysis of dE/dx in p+p collisisons at 158 GeV/c

Maciej Lewicki

University of Wrocław
Faculty of Physics and Astronomy
Institute of Theoretical Physics

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Section 1

NA61/SHINE experiment

Strong interaction programme

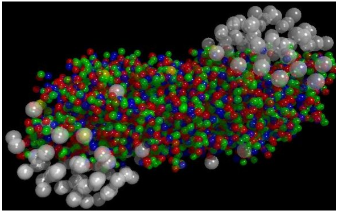


Image source: UrQMD group

Strong interactions investigation

- **The Onset of Deconfinement**
  Phase transition where the matter gets hot and/or dense enough for releasing confined quarks, creating *Quark-Gluon Plasma*.
- **The Critical Point**
  The three-critical point is expected in a low baryon density region.

QCD phase-diagram

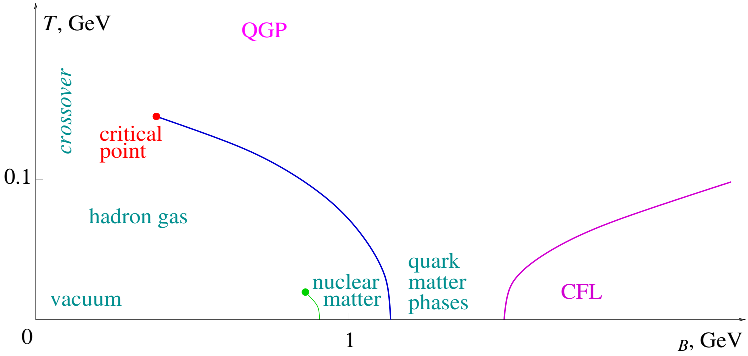
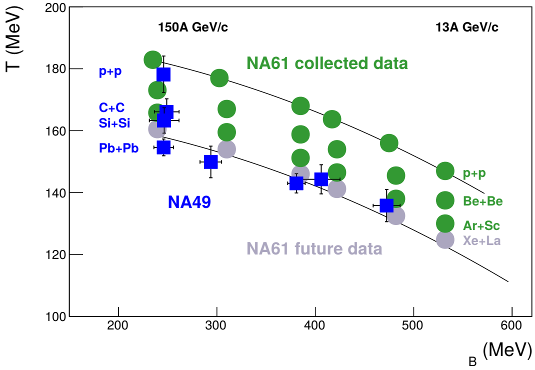


Image source: M. Stephanov

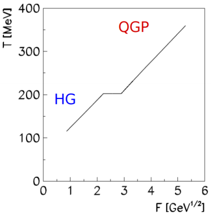
NA61/SHINE energy – system size scan

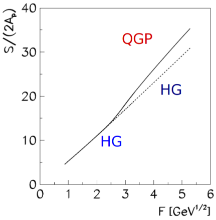


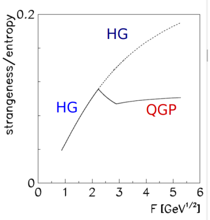
- Measured freeze-out points of NA49 data.
- Estimated freeze-out points for NA61/SHINE.

Statistical Model of the Early Stage

- Statistical Model – beautiful simplicity.
- Assumes formation of the QGP.
- Makes qualitative predictions (only).

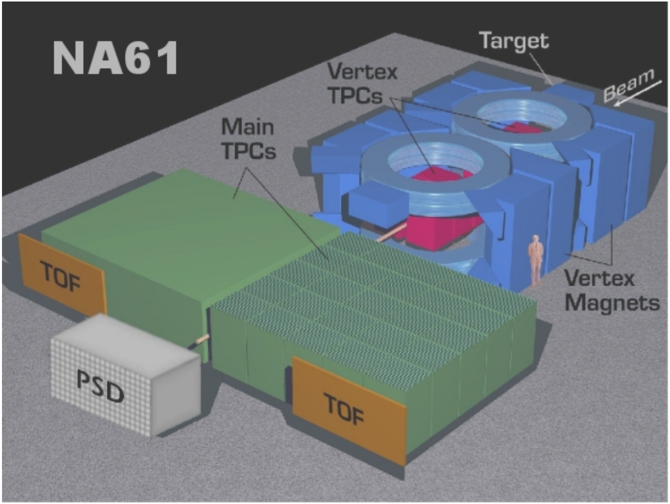






SMES Predictions

- **Step**
  Constant temperature in phase transition.
- **Kink**
  Pion (entropy) enhancement in QGP.
- **Horn**
  Strangeness suppression in QGP.


NA61
Target
Vertex TPCs
Beam
Main TPCs
TOF
PSD
TOF
Vertex Magnets

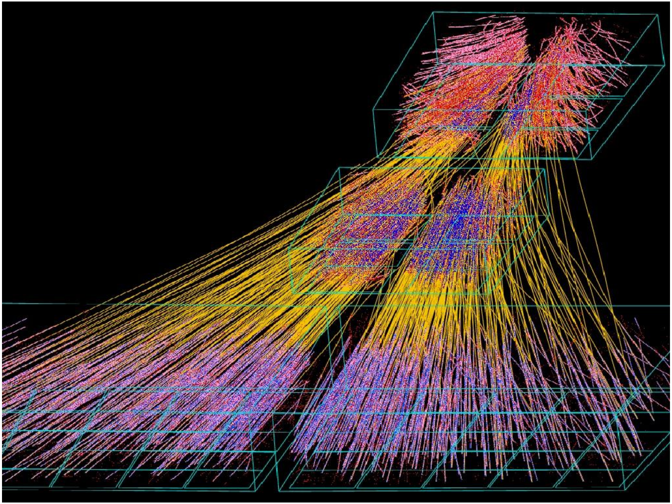


Image source: NA61/SHINE Geant3 generated image

Particle identification

Using the tracks curvature we obtain the momentum.
To identify a particle – another variable is needed.

$$p = \gamma m_0 \beta c$$

Second variable (β or γ):

- Time of flight (scintillators): $\tau \propto 1/\beta$
- **Energy loss** (Bethe-Bloch): $\frac{dE}{dx} \propto \frac{1}{\beta^2} \ln(\beta^2 \gamma^2)$
- Total energy (calorimeter): $E = \gamma m_0 c^2$

Section 2

dE/dx analysis basics

Bethe-Bloch functions

The mean loss of the energy dE per unit path dx is described by the **Bethe-Bloch** formula:

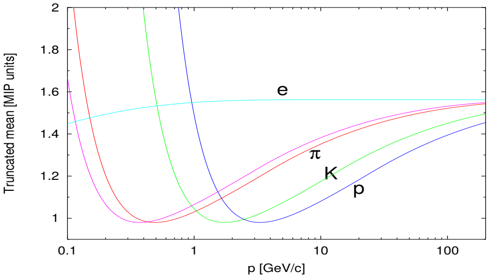
$$\left\langle -\frac{dE}{dx} \right\rangle = \frac{4\pi N e^4}{m_e c^2 \beta^2} Z^2 \left(\ln\left(\frac{2 m_e c^2 \beta^2}{I(1-\beta^2)} \right) - \beta^2 - \delta(\beta) \right)$$

Where I is excitation potential and N number density of electrons in the material traversed.
The δ function is a Fermi's correction, limitting the energy loss to finite values:

$$\delta(\beta) = \begin{cases} 0 & \beta\gamma < a_1 \\ 2(\ln\beta\gamma - b) + c(\ln a_2 - \ln\beta\gamma)^d & a_1 < \beta\gamma < a_2 \\ 2(\ln\beta\gamma - b) & \beta\gamma > a_2 \end{cases}$$

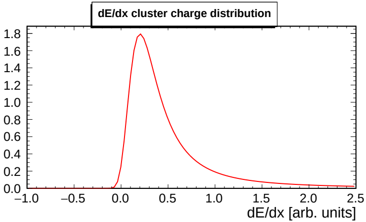
The values of a_1 and a_2 are calculated by requiring continuity of the term δ. The constanst b, c and d are specific to the medium.

Bethe-Bloch functions



- In low energies the factor $1/\beta^2$ dominates.
- About $v \approx 0.96c$ minimum is reached (*minimum ionizing particles*).
- In high energies the logarithmic term becomes dominant.

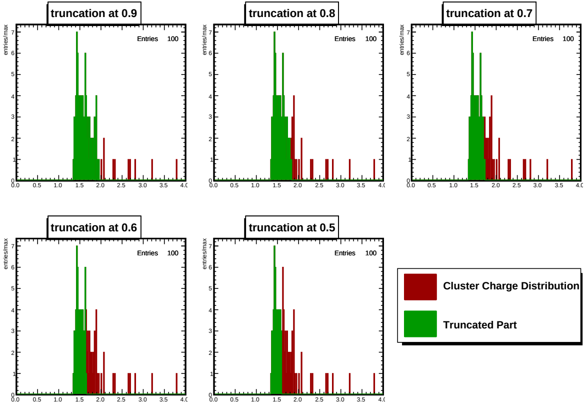
Charge deposition follows the Landau distribution:



- The **long tale –** large energy transfers (δ-electrons).
- $\approx$ tens of *clusters* along the particle trajectory.
- The ionization estimated by an **averaging procedure** (statistically independent samples – clusters).
- Averaging procedure is not straight forward due to the tail in high energy – **large fluctuations**.
- To increase accuracy we use **truncated mean** method.

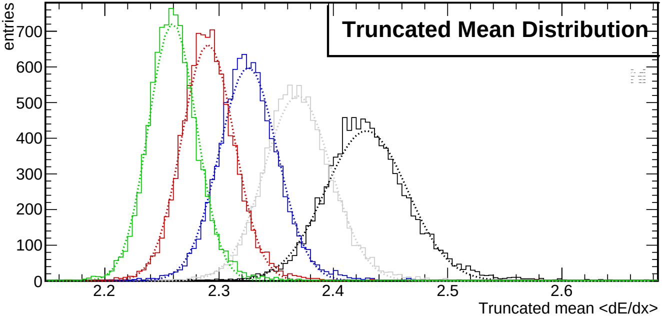
Charge Truncation

The truncated mean method rejects a fraction of highest charge clusters for each track.
Plots in following slides show data on simulated proton hits.



Truncated Mean – truncation dependence

Averaged over track's clusters (10k events)

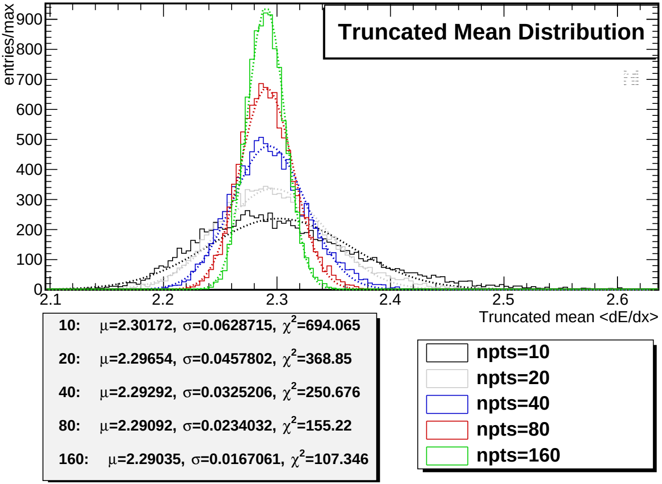


0.9:	μ=2.42893, σ=0.0358479, χ^2=330.696
0.8:	μ=2.36886, σ=0.0292379, χ^2=265.173
0.7:	μ=2.32555, σ=0.0254694, χ^2=229.787
0.6:	μ=2.29034, σ=0.0229791, χ^2=238.114
0.5:	μ=2.25934, σ=0.0210637, χ^2=253.255

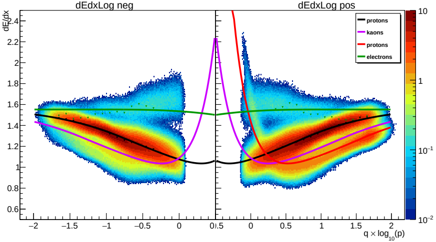
Simulation for 10k events.

Truncated Mean – track length dependence

Averaged over track's clusters (10k events, truncation at 0.65)



Real Data



- Binning in p_{tot}, $p_T = \sqrt{p_x^2 + p_y^2}$ and charge.
- In each bin 100 to 30k tracks.
- Multiple particle species: $\pi^{+,-}$, $K^{+,-}$, p, $\bar{p}$, d, e
- Each with a different n_{pts}

In order to extract particle yields we need a very good fitting function.

Fitting dE/dx histograms

The basic peak shape is assumed to be a sum of asymmetric Gaussian with widths $\sigma_{i,l}$:

$$\sigma_{i,l} = \frac{\sigma_0}{\sqrt{l}} \left(\frac{x_i}{x_1} \right)^{\alpha}$$

- The σ_0 is fitted for all bins.
- Dependence on the path length assumed to be: $1/\sqrt{l}$. l - number of clusters.
- $\alpha = 0.625$.
- Asymmetry in gaussian accounts for the reminder of the tail of Landau distribution.

Total formula for fitting real dE/dx distribution is given as:

$$\left\langle \frac{dE}{dx} \right\rangle_{total} = \sum_{i=d,p,K,\pi,e} N_i \frac{1}{\sum_l n_l} \sum_l \frac{n_l}{\sqrt{2\pi}\sigma_{i,l}} \exp -\frac{1}{2} \left(\frac{x - x_i}{(1 \pm \delta)\sigma_{i,l}} \right)$$

- N_i are yields of each particle species.
- n_l is the number of tracks with a l clusters.
- Total 12 parameters: 5 amplitudes, 5 peak positions, width and asymmetry.
- Some of the parameters are p_T-idependent, e. g. relative peak positions: x_i/x_1.
- Simultaneous fit at all p_T bins is performed at each p for such parameters.

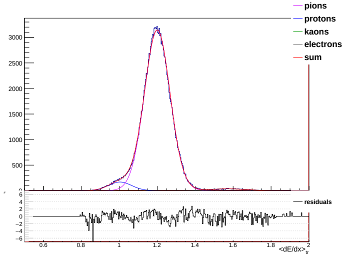
Section 3

Analysis results

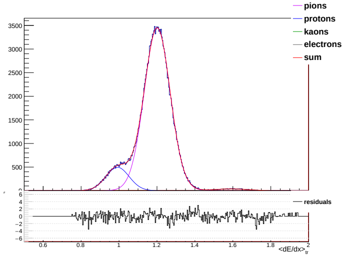
Low Momentum

Bin: $p_{tot} \in [3.16; 3.98)$ GeV/c $p_T \in [0.2; 0.3)$ GeV/c

negative



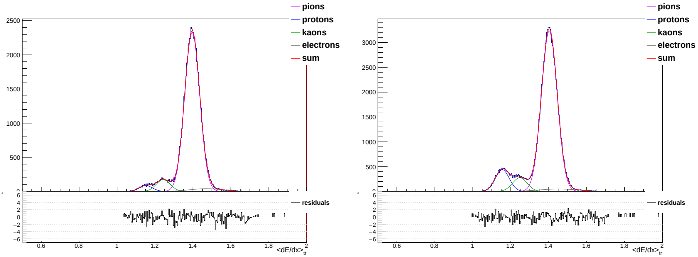
positive



Medium Momentum

Bin: $p_{tot} \in [15.85; 19.95)$ GeV/c $\quad p_T \in [0.3; 0.4)$ GeV/c

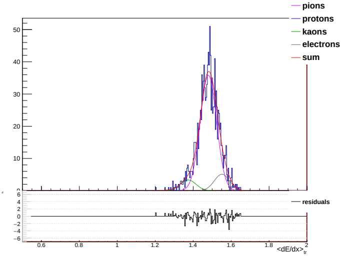
negative | positive



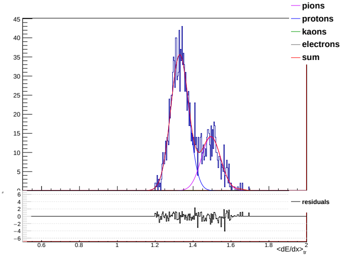
High Momentum

Bin: $p_{tot} \in [63.1; 79.4)$ GeV/c $p_T \in [0.3; 0.4)$ GeV/c

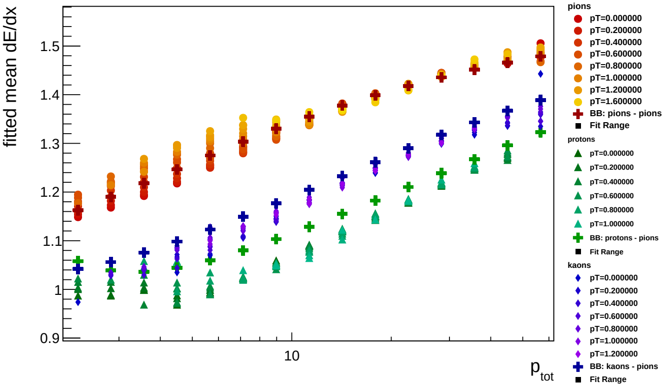
negative



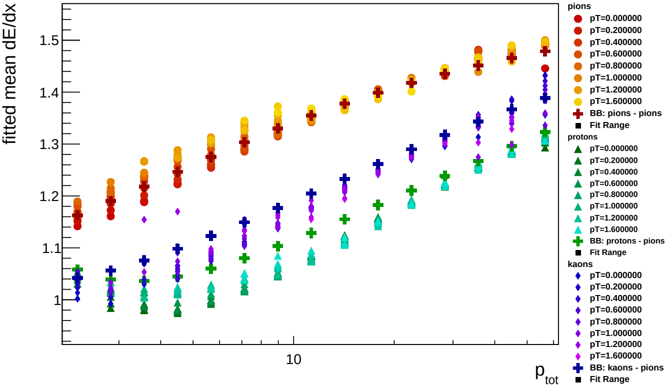
positive



Negative Mean Positions



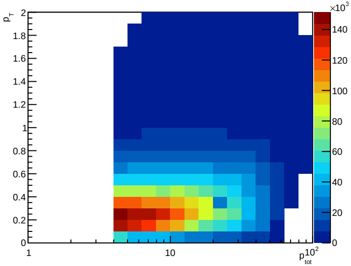
Positive Mean Positions



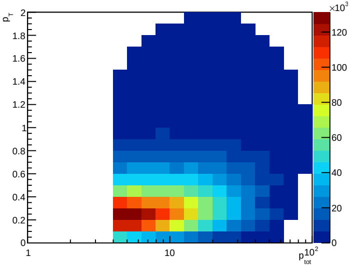
Pions' yields

p_T vs p_{tot}

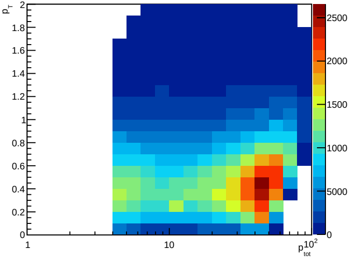
positive



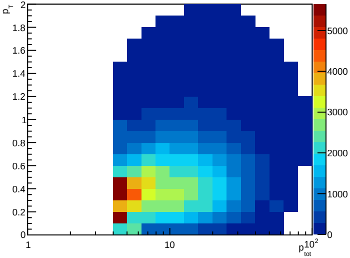
negative



positive



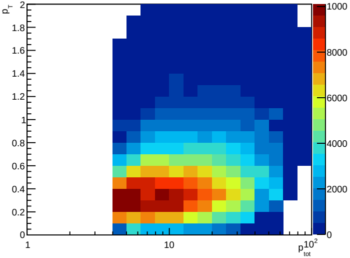
negative



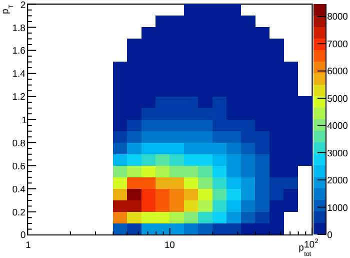
Kaons' yields

p_T vs p_{tot}

positive

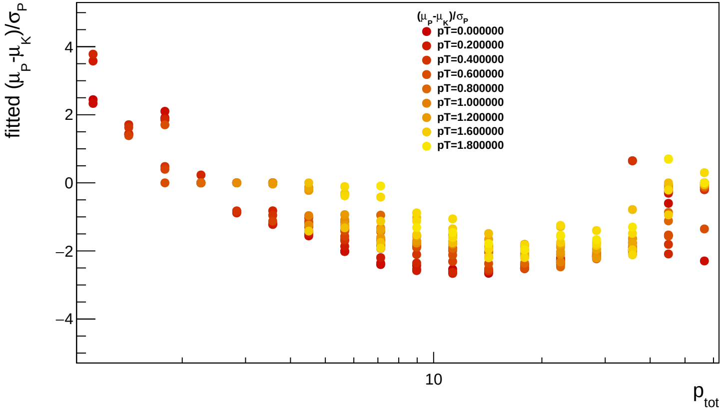


negative

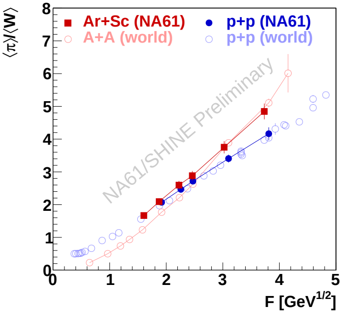


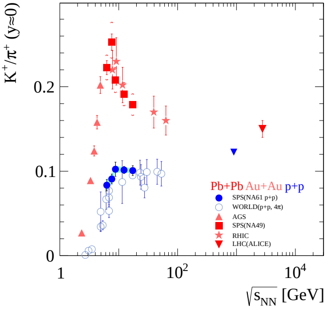
Peak distance

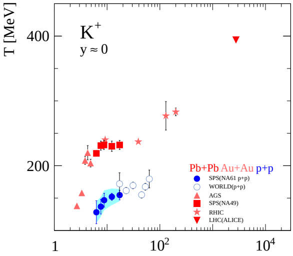
in sigmas



Final results







Thank you for your attention!