Electron identification from dE/dx measurements in the MPD TPC

I. Rufanov, A. Zinchenko

RFBR conference, JINR, Dubna, Russia
21-23 October 2020

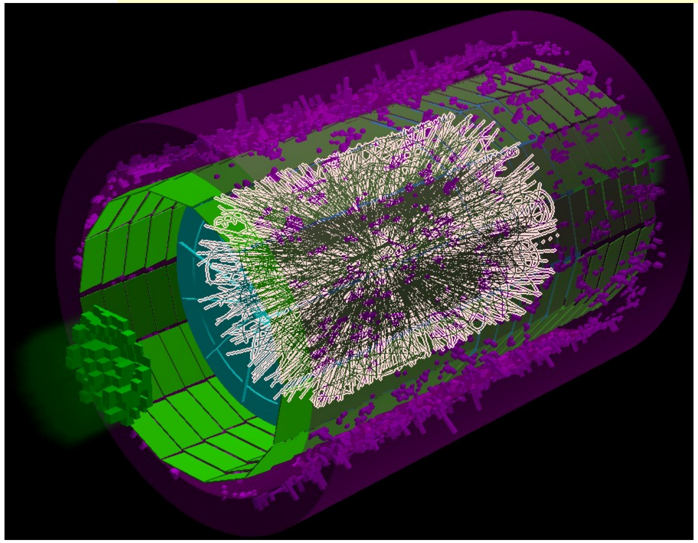
This work was supported by the Russian Foundation for Basic Research (RFBR):

grant No. 18-02-40060

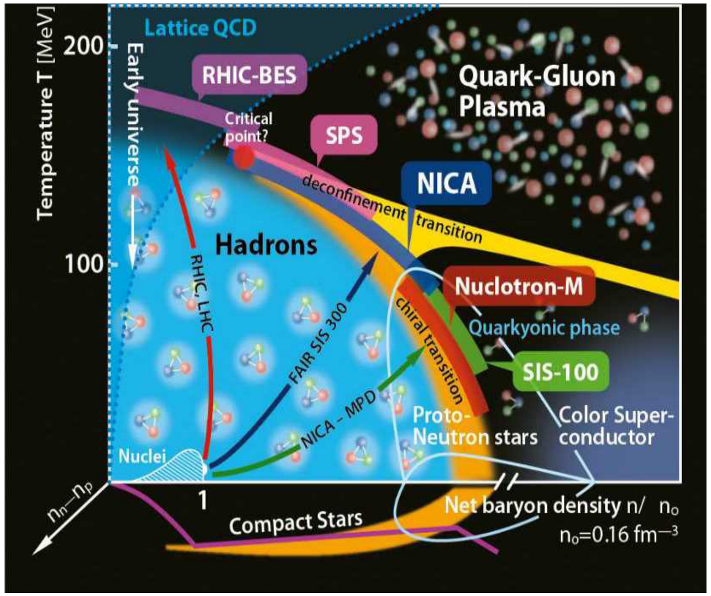
Outline

- MPD/NICA project
- Need of realistic electron simulation and identification
- TPC detectors in MPD and STAR
- Current version of TPC simulation
- Bichsel’s and HEED models of energy loss calculation
- Realistic TPC tracking and new *dEdx*
- dE/dx resolution and electron identification results
- Summary

NICA MPD physical motivation.



Au+Au collision in MPD



highest net baryon density

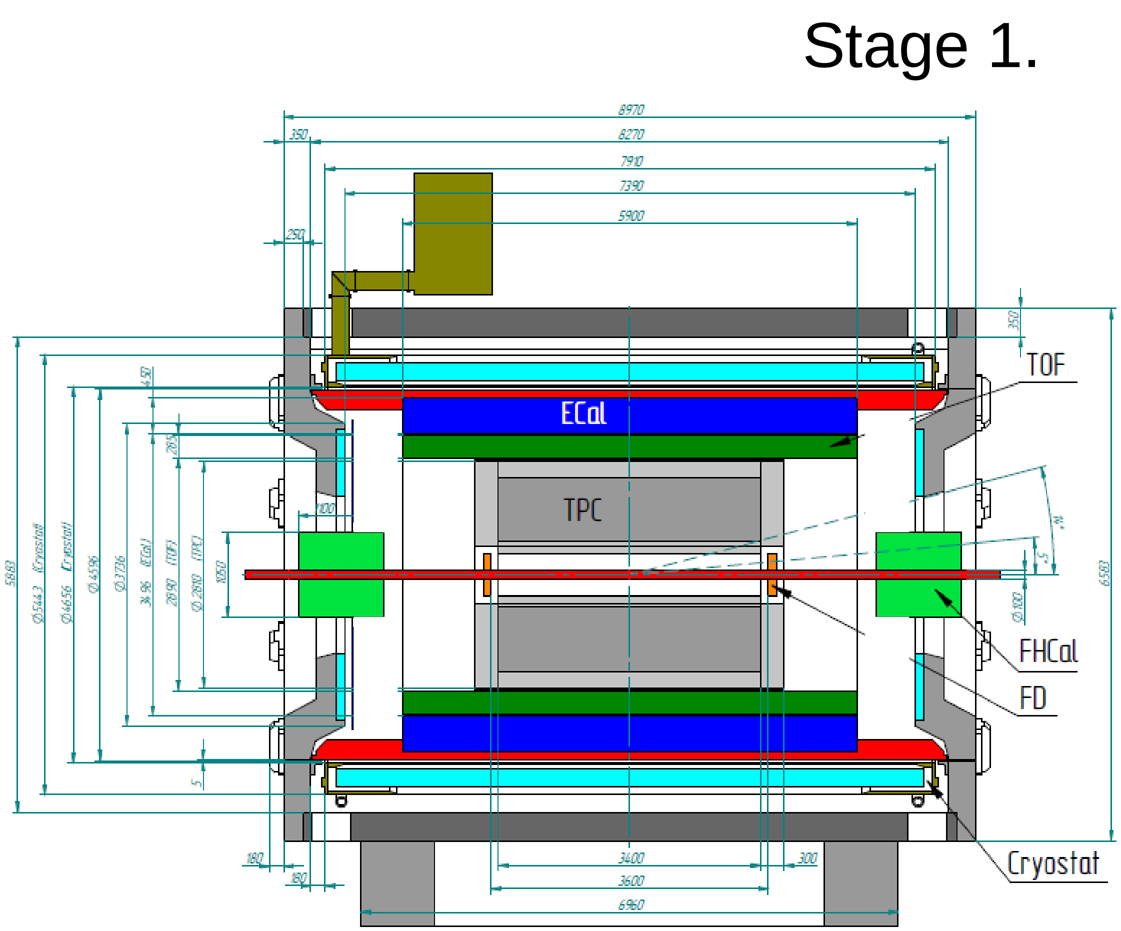
Multi **P**urpose **D**etector at **N**uclotron-based **I**on **C**ollider f**A**cility

is now is preparation stage at the JINR

- study of hot and dense baryonic matter in collisions of heavy ions (up to Bi) at a centre-of-mass energy up to 11 GeV per nucleon
- search for possible signs of phase transitions and critical phenomena
- energy and system size scan to measure a variety of signals systematically changing collision parameters

Bulk properties, EOS
particle yields & spectra, ratios, femtoscopy, flow
In-Medium modification of hadron properties
dileptons and resonances
Deconfinement (chiral) phase transition at high ρ_B
strangeness, Chiral Magnetic (Vortical) effect
QCD Critical Point
event-by-event fluctuations and correlations
YN, YY interactions in nuclear matter
hypernuclei

Multi-Purpose Detector at NICA.

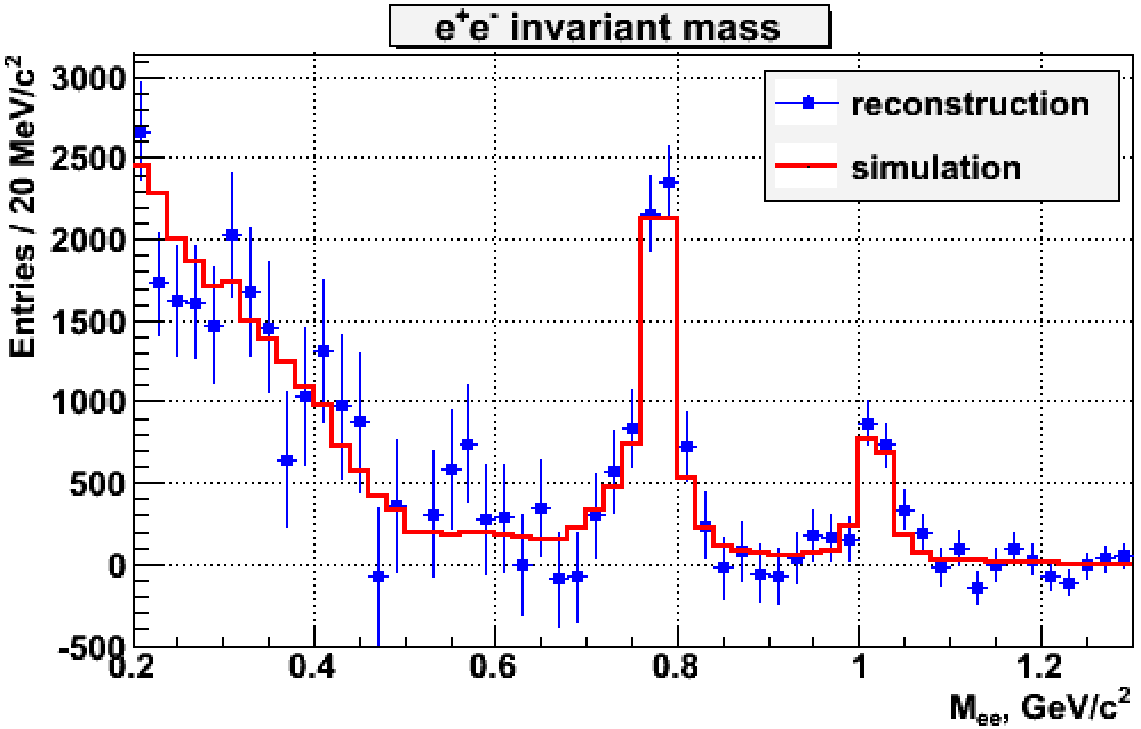


Magnet: 0.5 T superconductor
Tracking: TPC
ParticleID: TOF, ECAL, TPC
T0, Triggering: FFD
Centrality, Event plane: FHCAL

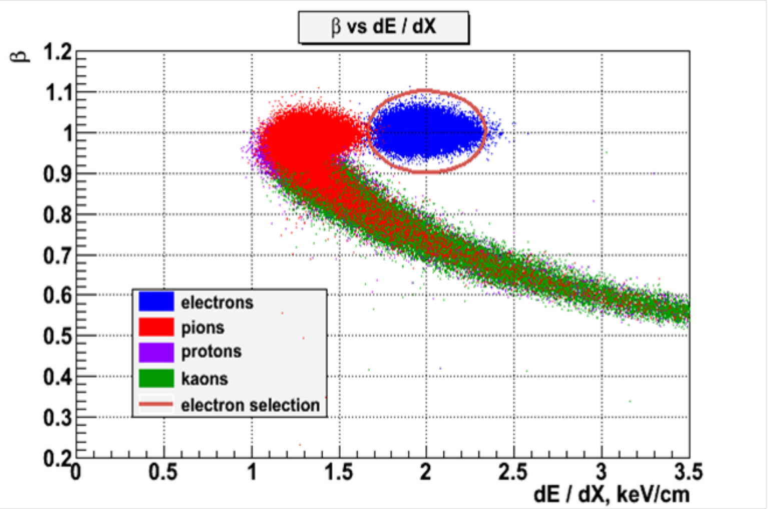
MPD detector comprises
- large acceptance (|η|<1.8) efficient track reconstruction;
- precise and wide angle mesurements of electromagnetic probes;
- powerful particle identification;
- careful event characterization: impact parameter & event plane reconstruction
- event rate capability up to ~ 6 kHz

Need of realistic $e^{-/+}$ simulation and PID

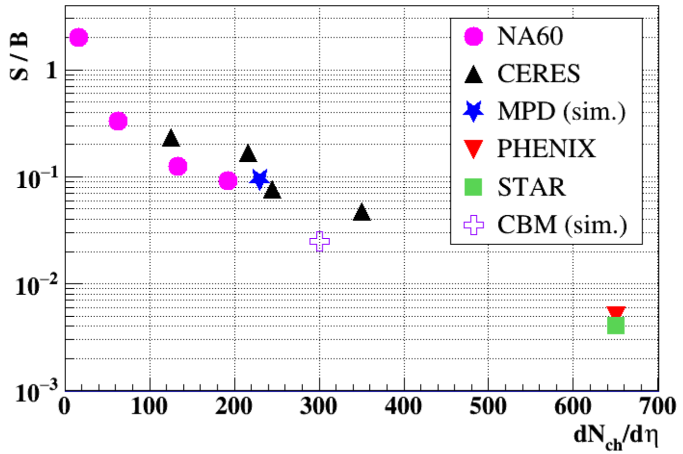
Early results on MPD performance for e+e- pair reconstruction.



background-subtracted e+e- invariant mass distribution



β vs dE/dx electron PID

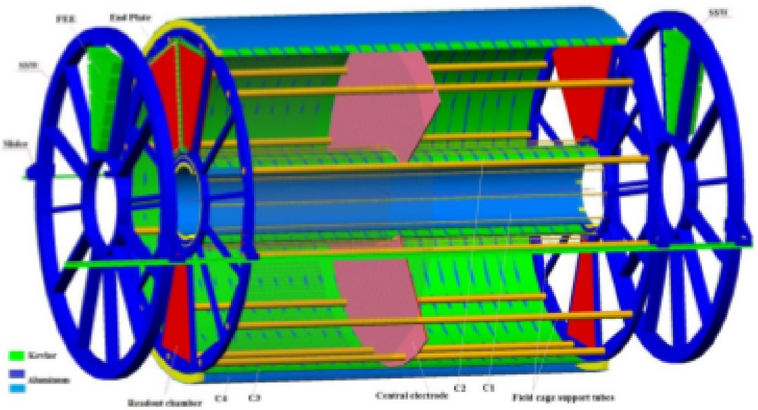


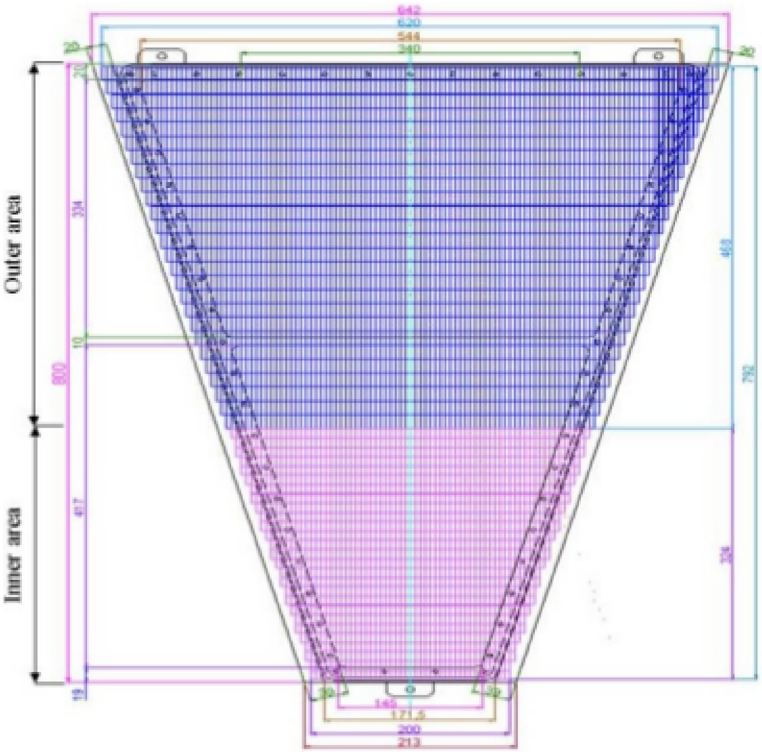
signal-to-background ratios for different experiments

Current task is to perform a similar analysis with up-to-date detector response simulation and event reconstruction (including electron identification).

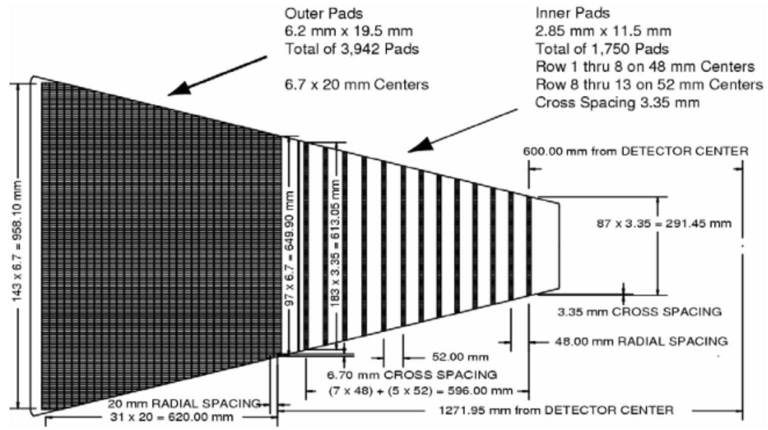
MPD and STAR TPCs

MPD





STAR

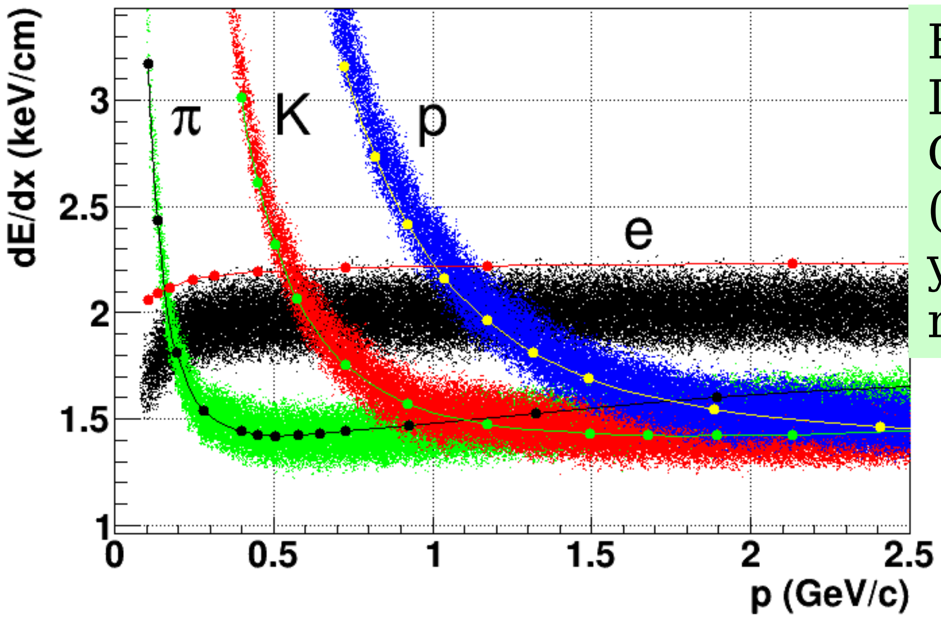


	ALICE	STAR	MPD
Gas	85% *Ne* mixtures	P10	P10
Inner pads	64 x 7.5 mm	13 x 12 mm	26 x 12 mm
Outer pads	64 x 10 mm	32 x 20 mm	27 x 18 mm
Outer-2 pads	32 x 32 mm	–	–

P10 mixture – 90% *Ar*, 10% methane

MPD and STAR TPC have the same magnetic field 0.5 T and track length of 79 cm along pads area. At STAR 13 inner rows have ~4 cm separation gaps, this reduces signal correlations.

STAR dE/dx vs current version of MPD MC



Energy loss distributions for e, π, K and p.
Dots – MPD with GEANT-3 energy loss (current),
Circles and lines – STAR Bichsel's predictions (*M.Shao et al / NIM A 558 (2006) 419-429*) y-scaled by 1.18 to get agreement for minimum ionizing particles.

Bichsel's predictions – reference functions of STAR for ionization energy loss analysis before iTPC upgrade in 2019.

"dE/dx" denotes C_{70} parameter of track which is a mean value of hit amplitude Δ over 70% of selected hits with the smallest amplitude.

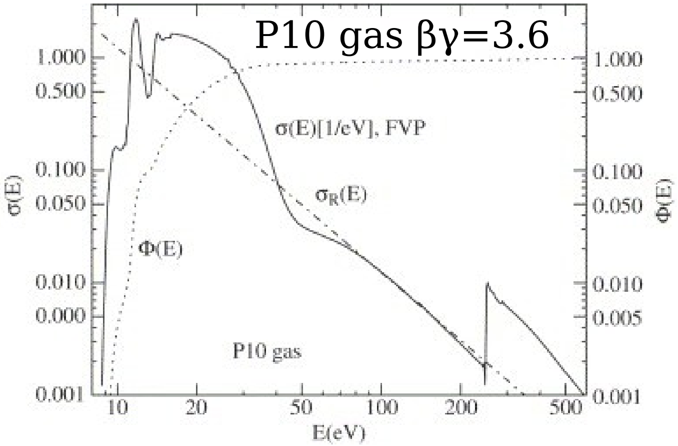
Conclusion on current GEANT-3 simulation.

- essentially (~20%) underpredicts relativistic rise of the ionization energy loss as seen from comparison of pion and electron bands;
- overpredicts energy loss at low momentum (protons at p<1 GeV/c);
- gives shifted momentum of intersections of electron and other particles bands;
- gives distorted input for realistic PID.

Bichsel's model of energy loss

Developed by Hans Bichsel for straggling function $f(\Delta)$ calculation in gas and silicon detectors (NIM A 562 (2006) 154-197).

Fermi virtual photon method also known as PAI model. Interaction with bounded electron is considered as emission of virtual photons by the fast particle, which then are absorbed by the material. The differential Collison Cross-Section σ(E;βγ) then is closely related to the photo absorption cross-section of the molecules. Data input is from variety of optical measurements.



Number of collisions n of ionizing particle with charge z in track segment of length D is a Poisson distributed value with mean of $z^2 D M_0(\beta\gamma)$, where $M_0(\beta\gamma)$ is a collision density.

- analytically: $$f(\Delta;x,\beta\gamma)=\sum_{n=0}^{\infty} P(n)\cdot\sigma(\Delta,\beta\gamma)^{*n}, \quad \sigma(\Delta)^{*n}=\int_0^{\Delta}\sigma(E)\cdot\sigma^{*(n-1)}(\Delta-E)\,dE$$
- MC: sum random energy loss from n (Poisson distributed) collisions (in further named Poisson Segment Model PSM) $$\Delta=\sum_{i=1}^{n} E_i$$

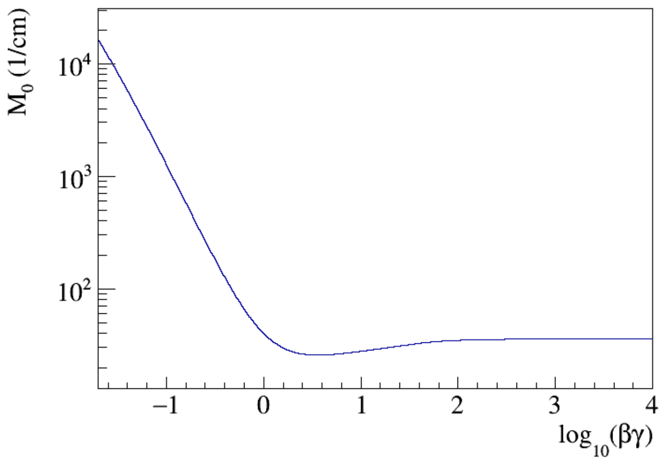
Energy loss consideration only gives a rather precise approach for description of TPC parameters.

$M_0(\beta\gamma)$ and $\sigma(E;\beta\gamma)$ parametrizations from HEED

High Energy Electro-Dynamics (HEED) - modern C++ program written by Igor Smirnov implementing of PAI model. (NIM A 554 (2005) 474-493)
Integrated in Garfield++ as a model of energy loss and ionization calculation.
https://garfieldpp.web.cern.ch/garfieldpp/examples/heed/ → edep.C macro simulates energy loss and ionization spectra in 1 cm^3 gas cell.

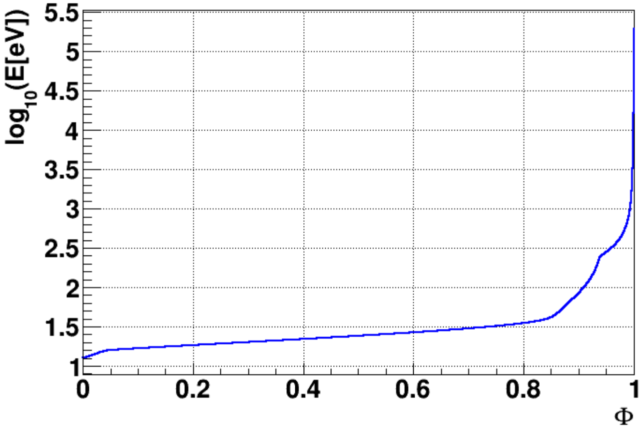
Parametrization of collision density $M_0(Z)$ $Z=log_{10}(\beta\gamma)$ and energy loss in one collision $dN/dE(E,Z)$:

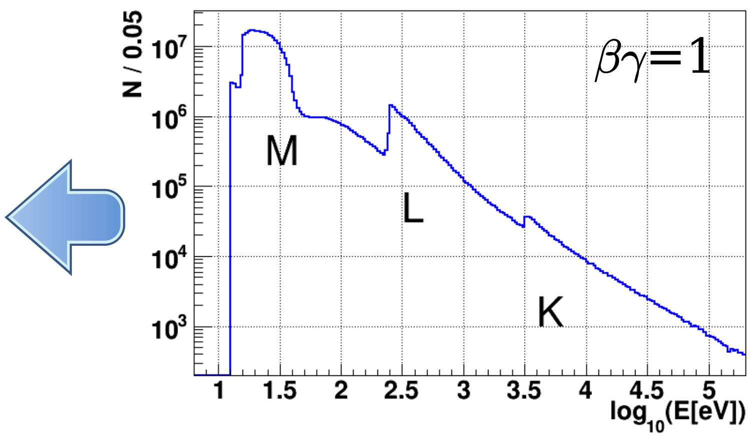
- Z range from -1.7 to 4.0;
- M_0 10k equidistant values of Z;
- dN/dE distributions for 115 equidistant values of Z_i ; with 3.2x10^8 generated collisions in each one
- $\Phi_i(E)$ - cumulative distribution function of dN/dE at Z_i;
- use of inverted functions $E_i(\Phi)$ for MC calculations.



MpdTpcEDepParams
class of MPDROOT

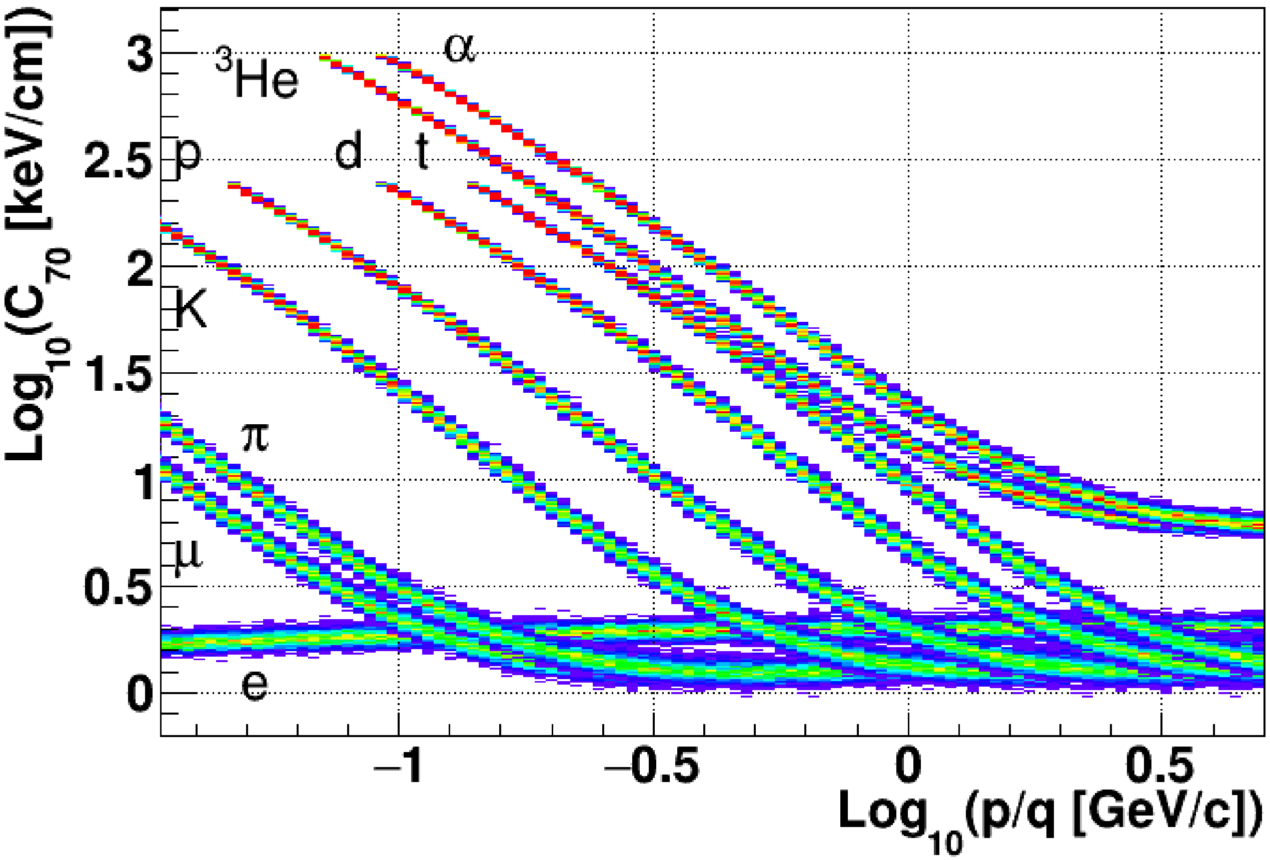
1000 times faster calculates struggling function then original example





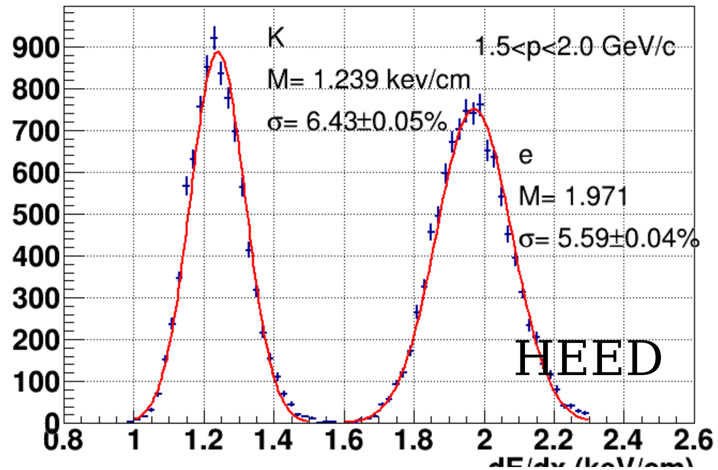
Poisson Segment Model Test

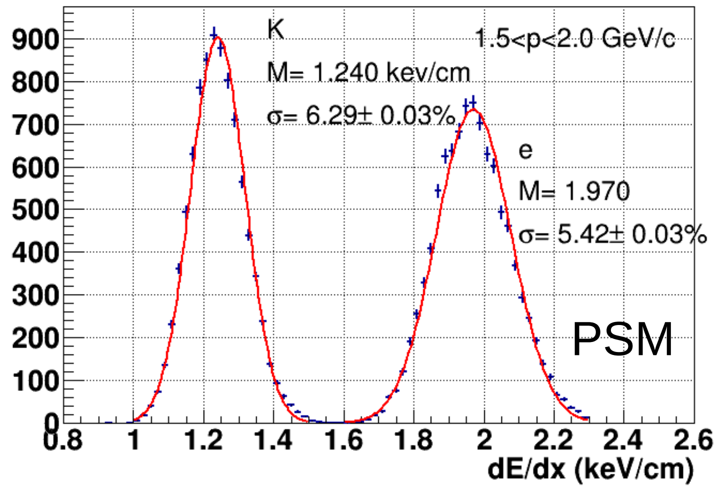
C70 calculations with HEED based parametrization in PSM framework.
53x1.8 cm "track", no field, no stopping.



- wide momentum and energy loss ranges
- no spreading at large dE/dx

K and e at 1.5<p<2.0 GeV/c



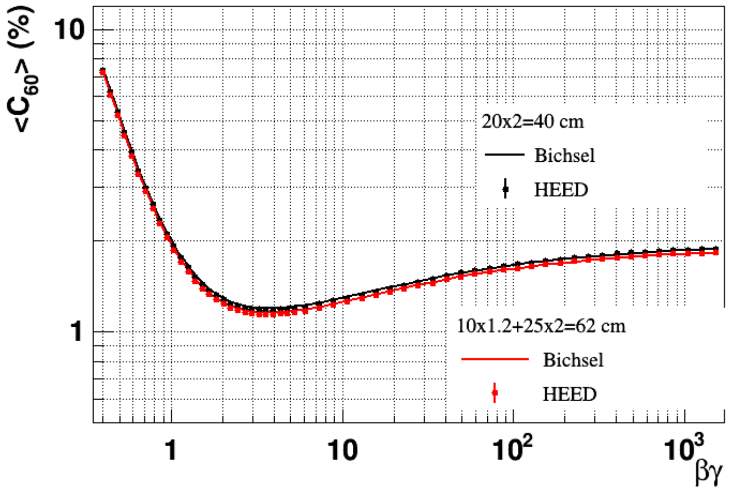


- same for HEED and PSM

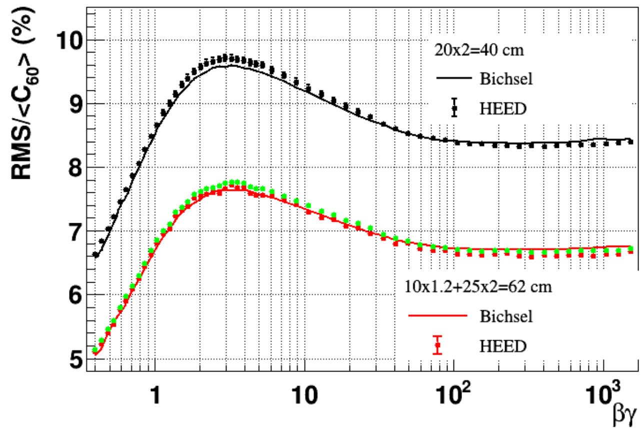
Bichsel's reference data vs PSM

C_{60} for **20*2.0** cm and **10*1.2+25*2.0** cm tracks as a function of $\beta\gamma$ (table).
(NIM A 562 (2006) 154-197)

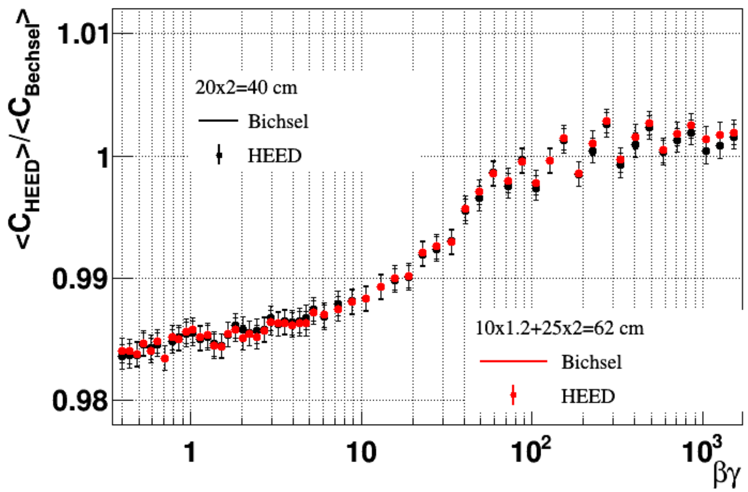
Mean values.



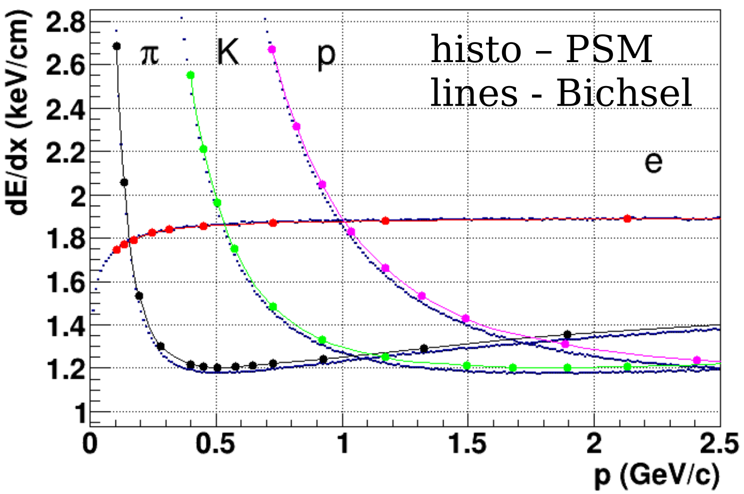
Resolution



PSM to Bichsel ratio



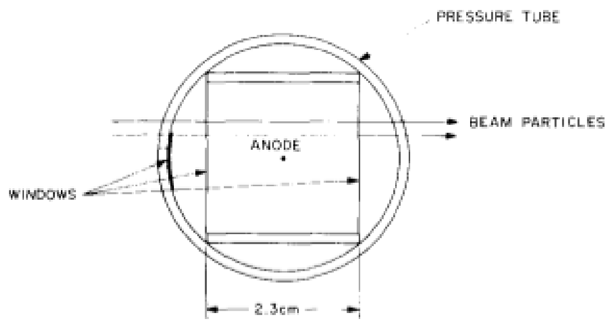
C_{70} for STAR reference track



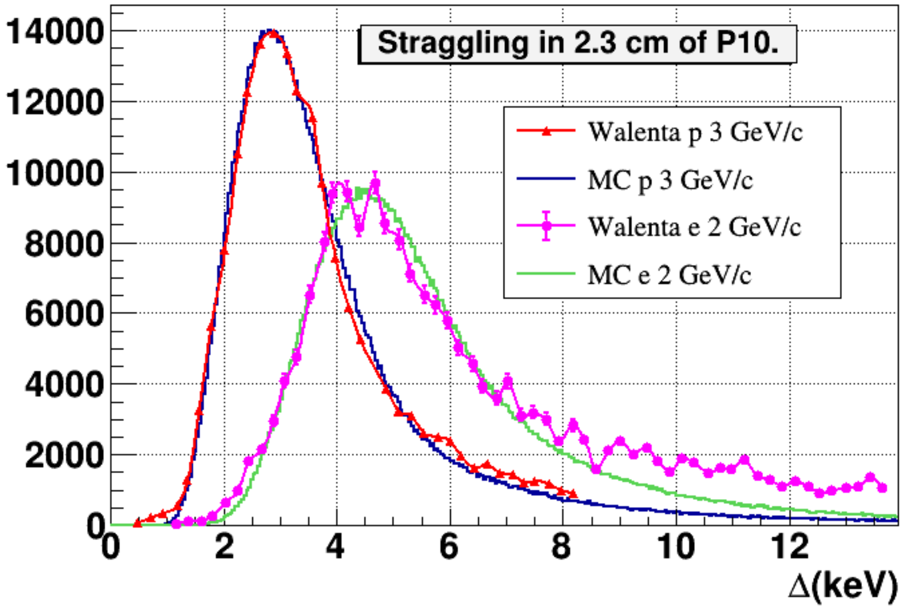
e/π at 0.5 GeV/c: **1.563** – Bichsel; **1.585** – PSM.

Comparisions with other data

A.H.Walenta et al., NIM 161 (1979) 45-58.
Struggling distributions in 2.3 cm gas cell of minimum ionizing proton and 2 GeV/c electron.

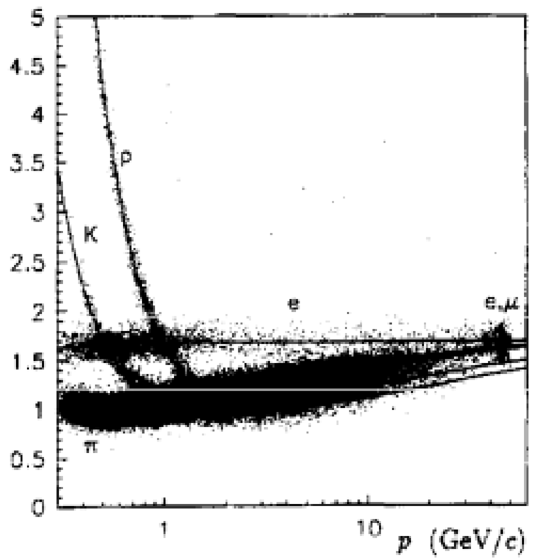


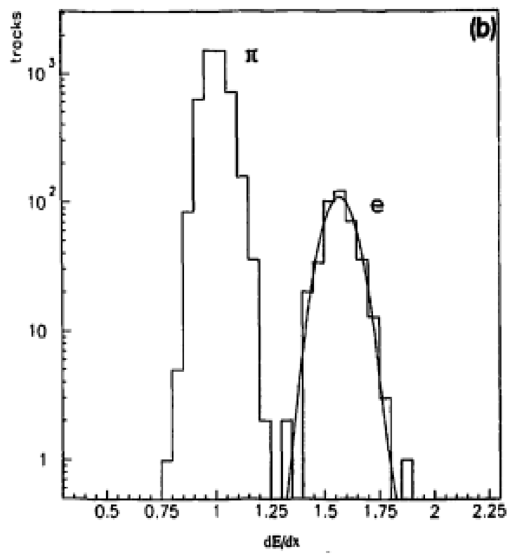
Fit with PSM.



ALEPH TPC

NIM A 360 (1995) 481-506
The “relativistic rise”, the height of the plateau relative to minimum ionization, is found to be **1.66**.





NIM A 294 (1990) 121-178
$0.3 < p < 0.6$ GeV/c
$e/\pi \approx \mathbf{1.57}$

Realistic MPD tracking

Simulation and digitization:

- Primary ionization (ionization clusters)
- Drift and diffusion of ionization electrons
- Gas gain fluctuations (Polya distribution)
- Pad response (charge distribution on pad plane)
- Electronics shaping
- Signal digitization (ADC overflow)

TPC parameters.

Parameter	Value
Magnetic field	0.5 T
Drift gas	P10 (90% Ar + 10% CH_4)
Drift velocity	5.45 cm/µs
Transverse diffusion at 0.5 T	185 µm/√cm
Longitudinal diffusion	320 µm/√cm
Pad size	5x12 mm^2 (27 rows) + 5x18 mm^2 (26 rows)
Charge spread σ	0.196 mm
Electronics shaping time	180 ns (FWHM)
ADC dynamic range	10 bits
ADC sampling frequency	10 MHz

Cluster / hit reconstruction

- Precluster finder (group of adjacent pixels in time bin – pad space)
- Hit finder ("peak-and-valley" algorithm either in time bin – pad space (for simple topologies) or in time-transverse coordinate pixel space after Bayesian unfolding (for more complicated topologies)) → COG around local maxima

More details in A. Zinchenko's talk

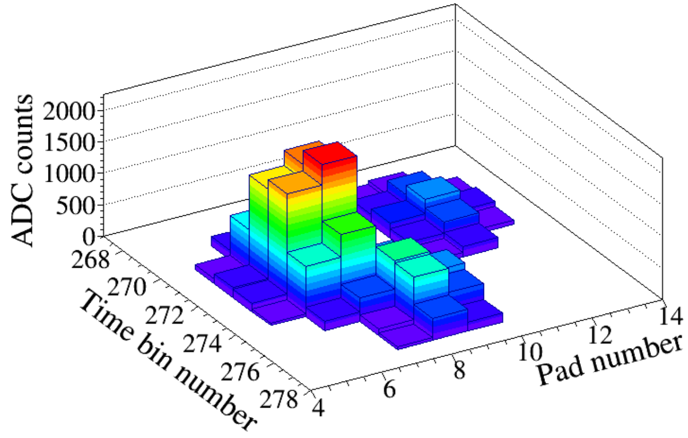
Cluster topologies and MLEM procedure

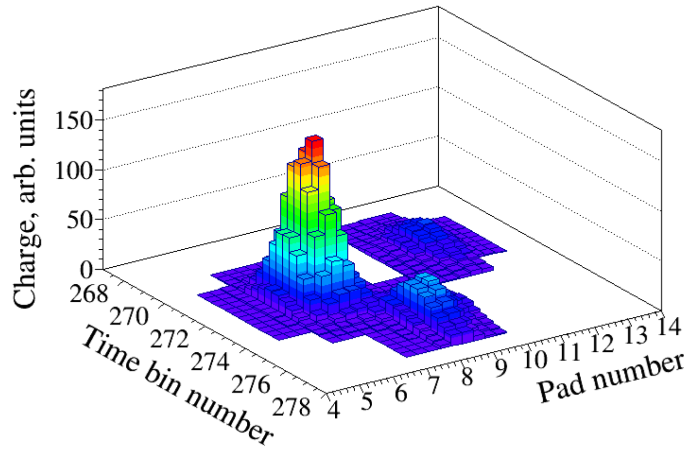
Likelihood—Expectation Maximization

More details in A. Zinchenko's talk

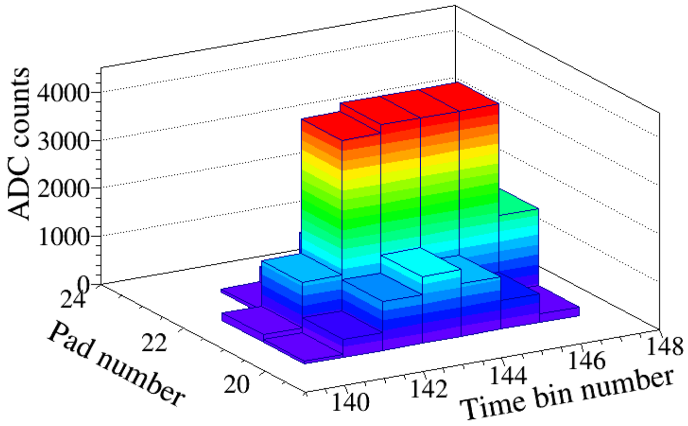
MLEM procedure

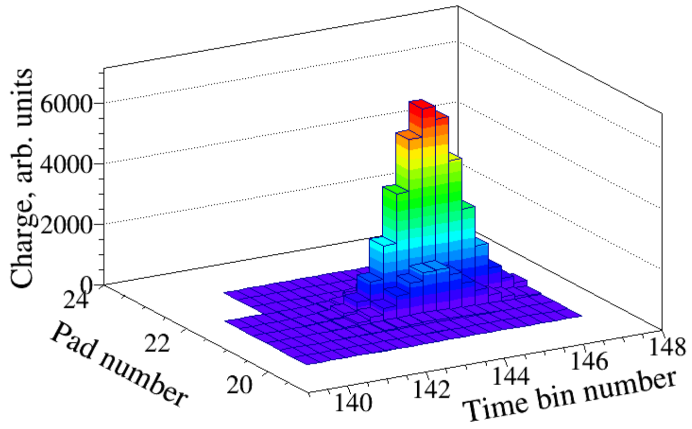
Precluster of three tracks.





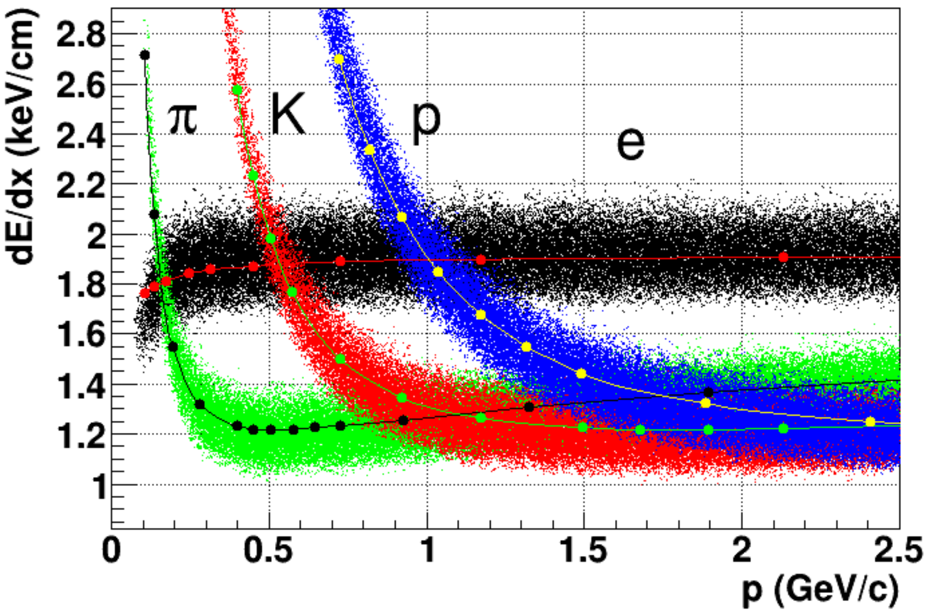
Cluster with ADC overflows.





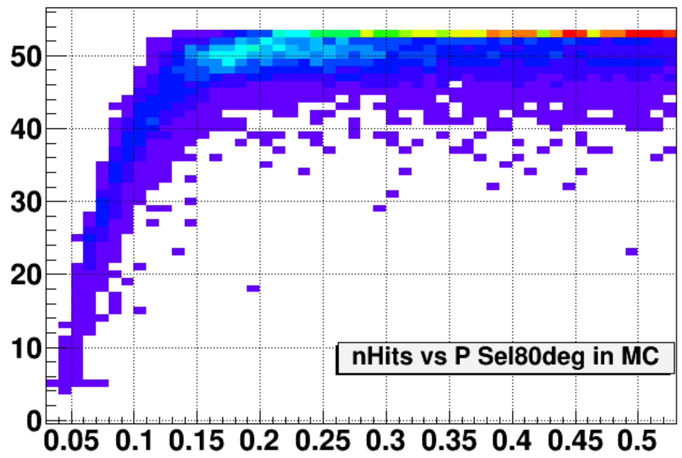
MPDROOT

Full chain of MC and reconstruction.



Keeps the same e/pi as in PSM

Nhits vs momentum
|η|<1, primary vertex



Transitional region is up to 0.25 GeV/c

$\mathrm{Log}_{10}(dE/dx)$ for $n\sigma$ analysis

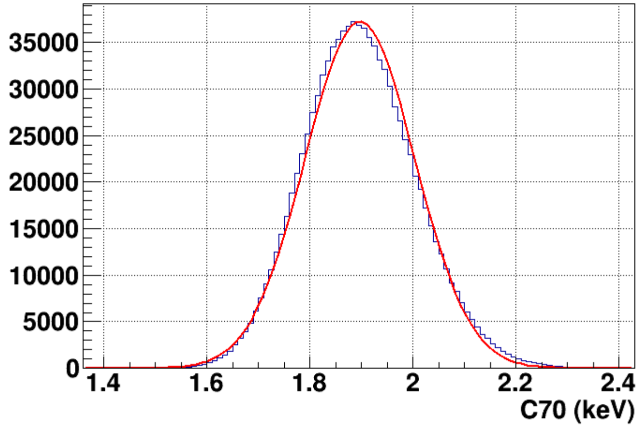
The method is used in STAR.

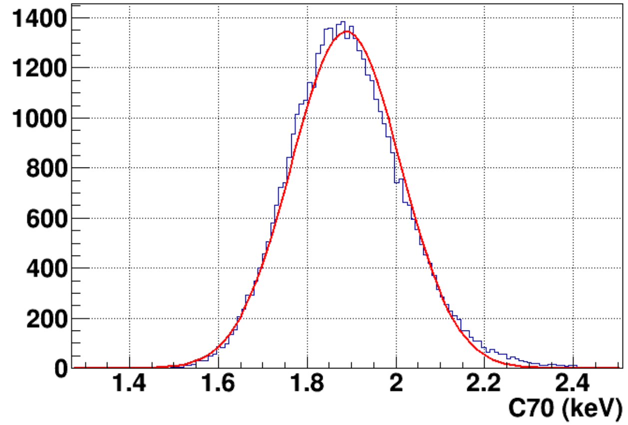
"Log(dE/dx) follows a Gaussian distribution"
Z. Phys. C - Particles and Fields 50, 405~426 (1991)

C_{70} of electron at p=0.5 GeV/c

PSM

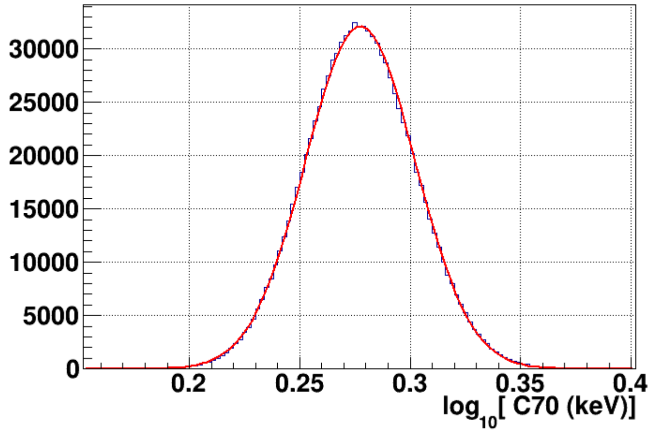
MPDROOT reco

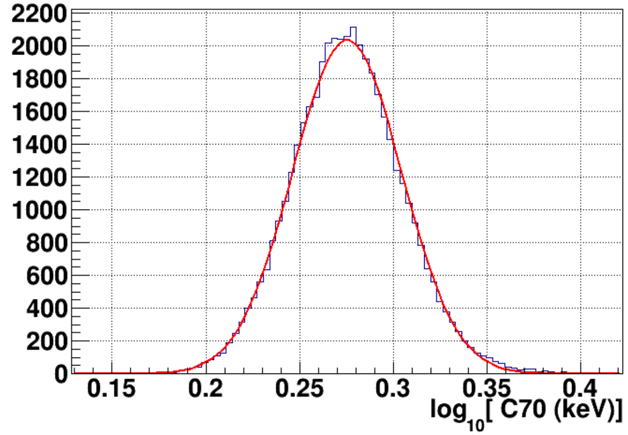




C_{70}

$\log_{10}(C_{70})$





Assymetry comes from energy loss.

Resolution and $n\sigma$

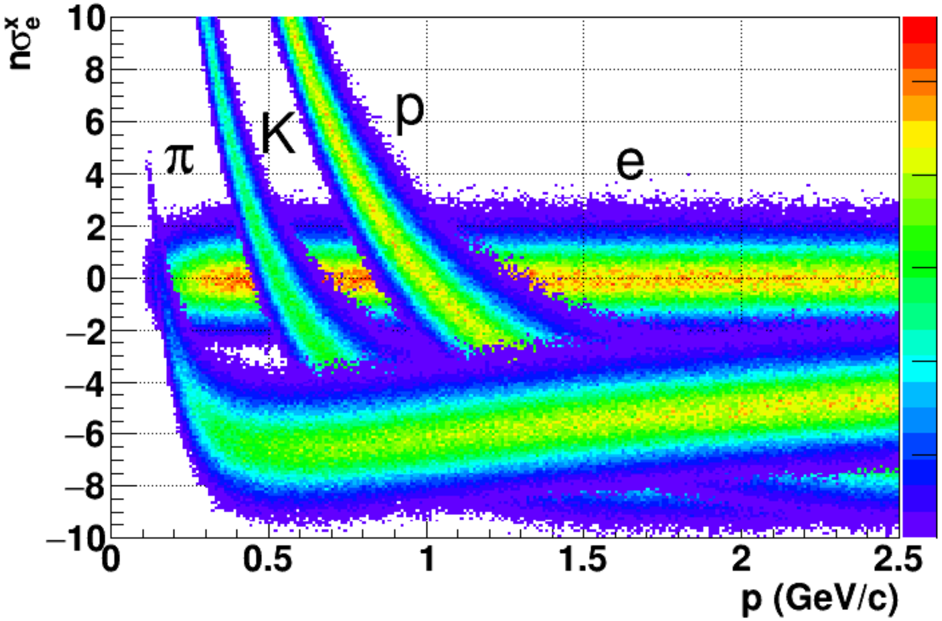
dE/dx resolution (|η|<1.0, Nhits>44, Chi2/N<2.5)

	p (GeV/c)	dE/dx (keV/cm)	σ (%)
π	0.5	1.211	8.12 (MIP)
e	0.5	1.910	6.89
p	0.8	2.449	7.30*
p	0.6	3.605	7.21*

* - including momentum resolution

STAR for 76 cm track σ= 7.31%

$n\sigma$ for electron



Summary.

- The previous version of dE/dx simulation in TPC gas volume essentially underpredicted effect of relativistic rise of energy loss, leading to distorted picture of particle identification particularly affecting electron and positron as the fastest ionizing particles.
- New energy loss model for TPC gas volume was developed. The model bases on HEED program calculations of each collision of the particle with atoms of the media. Parametrizations of collision density and energy loss in one collision significantly accelerate calculations of track dE/dx keeping the same mean value and resolution parameters.
- The similarity of configuration and operation conditions of MPD and STAR TPC detectors gives a way to verify our simulation parameters. The major material on STAR TPC is obtained from Bichsel theoretical predictions, which were used as reference functions in STAR analysis.
- Poisson Segment Model (analog of Bichsel method) with HEED parametrization is used to compare our and Bichsel predictions for track. It is found that models give very close results in absolute value and resolution, however our model predicts 4% larger relativistic rise effect (0.58 instead of 0.56 at momentum of pion minimum ionization).
- The dE/dx model was implemented in new version of MPDROOT, which also includes several important improvements of signal digitization and hit reconstruction algorithms.
- Following the STAR experience we showed that a value of log(dE/dx) instead of dE/dx is a better input for nSigma PID analysis.
- Results on dE/dx track reconstruction and nSigma analysis for electron were presented.