Track based maximum likelihood ring search algorithm

Marko Starič
Institut Jožef Stefan, Ljubljana, Slovenia

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Introduction

Motivation

- measurement of (anti-)deuteron production in proton-nucleus collisions

Standard PID method at HERA-B

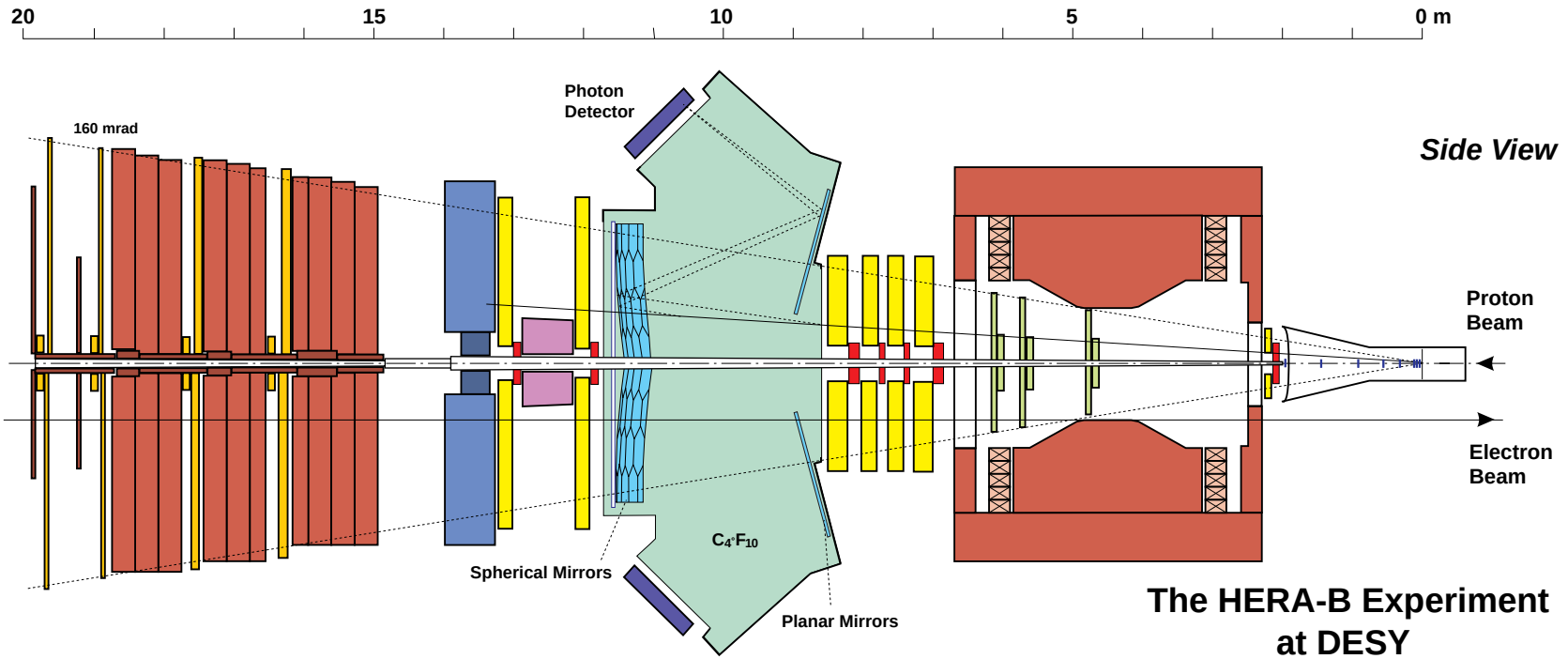
- extended likelihood method giving normalized likelihood probabilities:
  $l_e,\ l_\mu,\ l_\pi,\ l_K,\ l_p,\ l_{other} \qquad (\sum_i l_i = 1)$
- particle selection made by applying a cut on the appropriate likelihood
- after the selection:
  - ▷ selected particles relatively enhanced
  - ▷ some (small) fraction of other particles remain (mis-identification)
- we can introduce also deuteron hypothesis in the above method, but ...
- for inclusive particle production measurement mis-identification should be known very well
- possible to measure it for pions, kaons and protons, but not for deuterons

Other method needed ...

- which searches for the ring and measures the radius without using any particle hypothesis

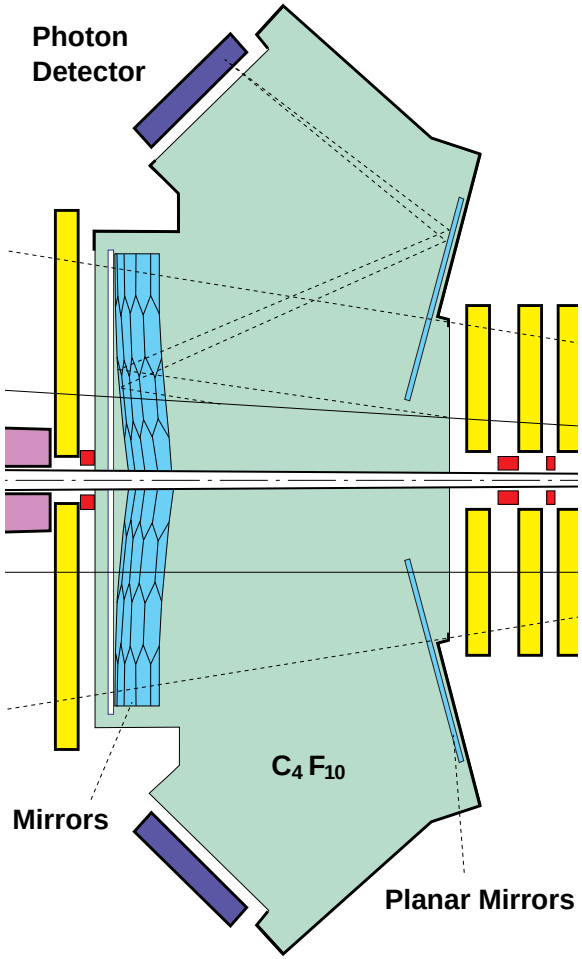
The HERA-B experiment

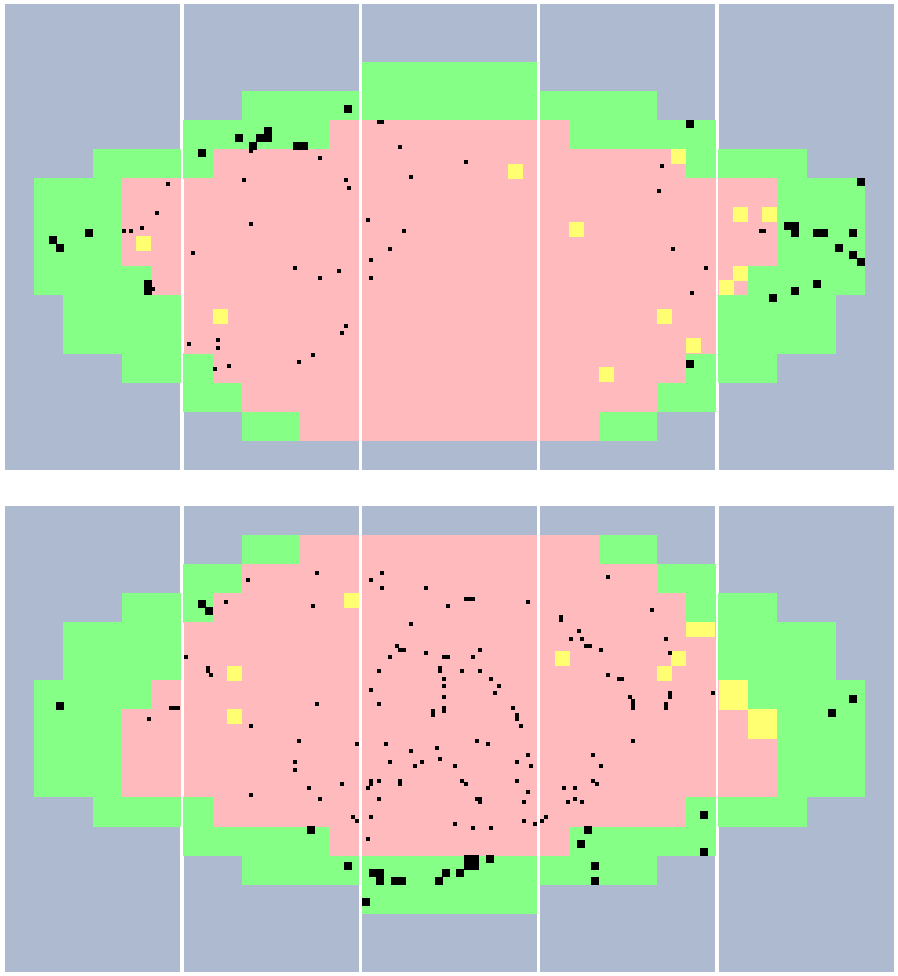
- Fixed target experiment at HERA proton beam (920 GeV/c)
  - High rate forward spectrometer (<40 MHz interaction rate)
  - Wire targets of different material in the beam halo
  - High resolution vertexing
  - Very good particle ID for e, μ, π, K and p
  - Hardware track trigger for lepton pairs ($J/\psi \rightarrow l^+l^-$)



The HERA-B RICH

- $108m^3$ of C_4F_{10} ($\gamma_t = 19.1$)
- Two spherical mirrors, tilted by 9^0, $f = 5.7m$
- Photon detector with Hamamatsu multi-anode PMT's





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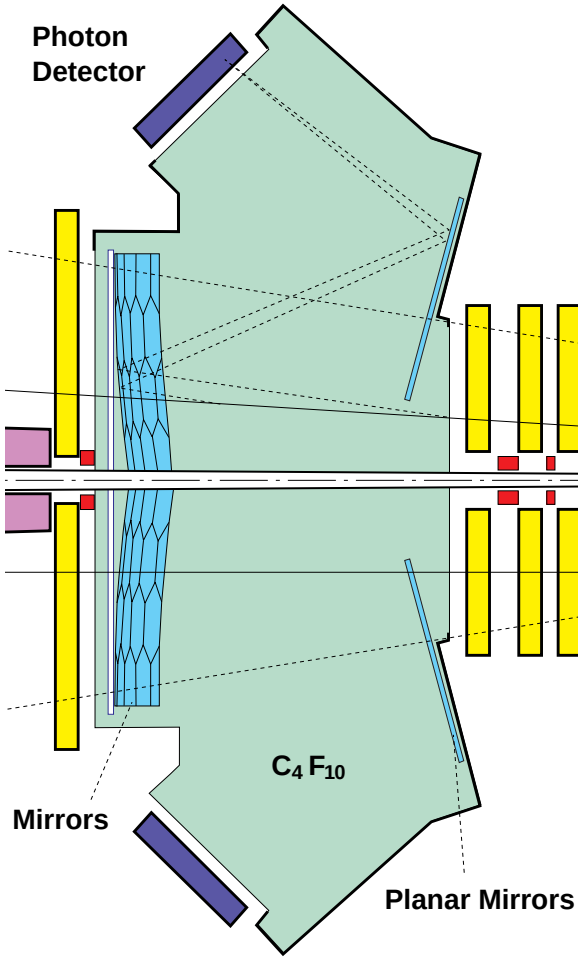
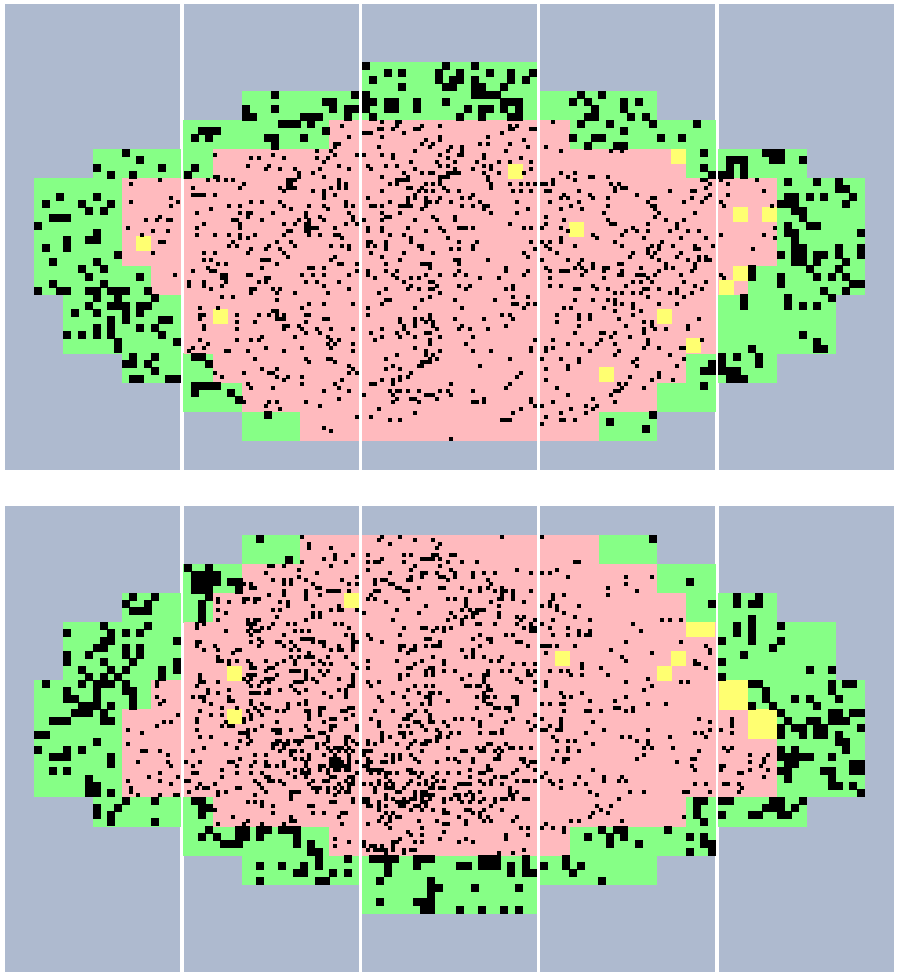
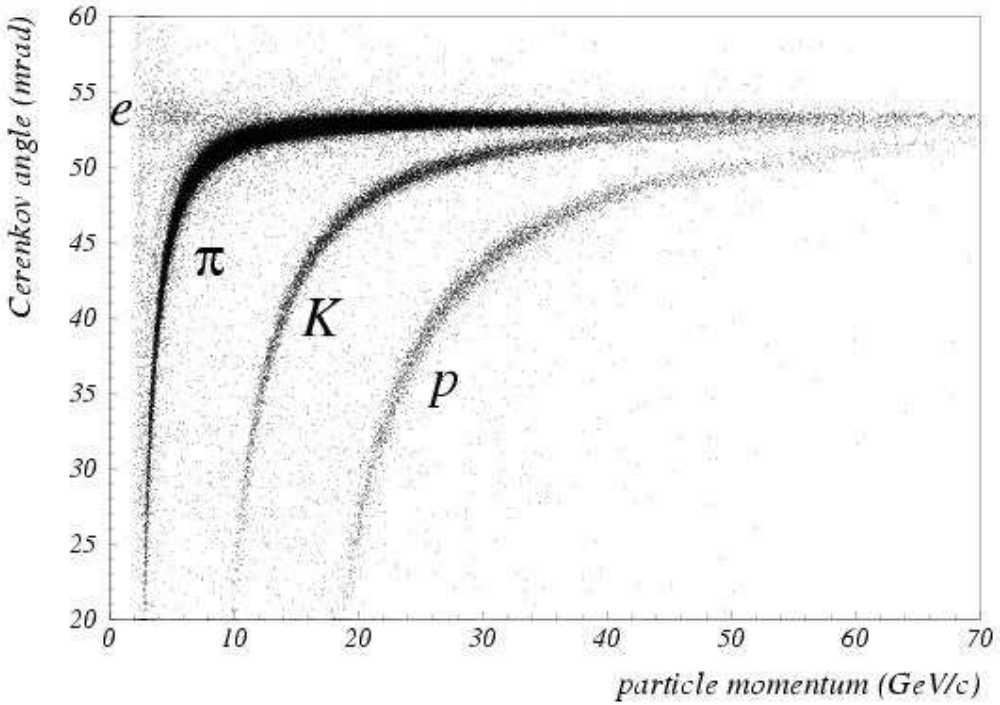




Parameters of the RICH

- Čerenkov angle for $\beta = 1$ particle: 52 mrad
- Number of photons per $\beta = 1$ particle: 32
- Figure of merit N_0: $42cm^{-1}$
- Single photon angular resolution:
  - 16 channel PMT region: $(0.7 \oplus 3.5/p)$ mrad
  - 4 channel PMT region: $(1.0 \oplus 3.5/p)$ mrad
  - including track error: 1.2 mrad (mean) , 0.8 mrad (above 40GeV/c)



$\pi - K$ separation:
5 - 50 GeV/c

$\pi - p$ separation:
5 - 100 GeV/c

$K - p$ separation:
10 - 100 GeV/c

Ring search algorithm

- Measurements: hits in the RICH, reconstructed tracks
  - Čerenkov angles θ_i of pairs (hit,track)
  - right and wrong combinations
  - distribution (1D) of θ_i for a given track:
    peak (right combinations) above background (wrong combinations).
  - search for the peak in the θ_i distribution ($\theta_i < \theta_m$)
- The peak is searched by maximizing unbinned log likelihood of the form:

$$\log L(\theta) = \sum_{i=1}^{N_{ph}} \log \left(p(\theta) \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\frac{(\theta_i-\theta)^2}{2\sigma_i}} + (1-p(\theta)) \frac{2}{\theta_m^2} \theta_i \right)$$

where

$$p(\theta) = \frac{N(\theta)}{N_{ph}} \quad , \qquad N(\theta) = A_{geo} N_0 l \theta^2$$

and σ_i is the resolution of single photon Čerenkov angle (incl. RICH and track)

- If the peak is found, its "significance" is calculated:

$$\log L_{sign} = \log P_{N_{ph}}(N(\theta) + N_{bgr}) - \log P_{N_{ph}}(N_{bgr})$$

  - the number of background photons inside the signal window N_{bgr}
    is estimated from side bands.

Particle mass measurement with RICH

- Once the ring is found and radius measured, we can calculate the velocity

$$\cos\theta = \frac{1}{\beta n} \ , \qquad \beta > \beta_{thr}$$

- For gaseous radiator ($n - 1 \ll 1$) this relation could be written as:

$$\theta^2 = \theta_0^2 - (\frac{m}{p})^2 \ , \qquad p > p_{thr} = \frac{m}{\theta_0} \ , \qquad \cos\theta_0 = \frac{1}{n}$$

- With known particle momentum, we could calculate the mass:

$$m = p\sqrt{\theta_0^2 - \theta^2}$$

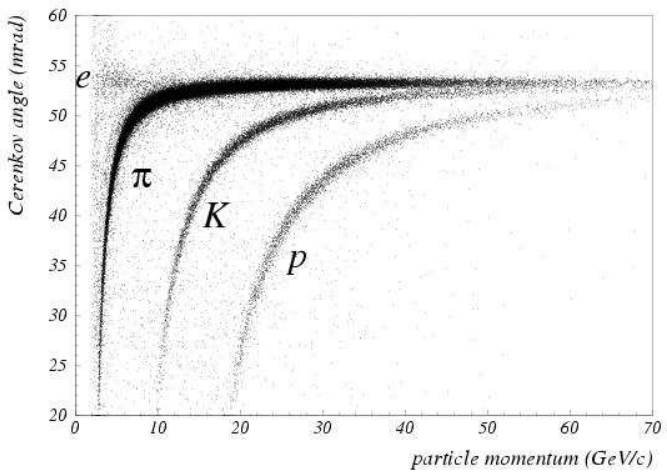
- Mass resolution is (naively; assuming $\sigma_\theta = \sigma_{single}/\sqrt{N}$)

$$\frac{\sigma_m}{m} = (\frac{p}{m})^2 \theta_0 \sigma_{\theta_0} = \left(\frac{p}{p_{thr}}\right)^2 \frac{\sigma_{\theta_0}}{\theta_0}$$

  $\rightarrow$ the best near threshold
  $\rightarrow$ lost, when θ get close to saturation (θ_0)
  $\rightarrow$ mass distribution is not Gaussian

Performance (I)

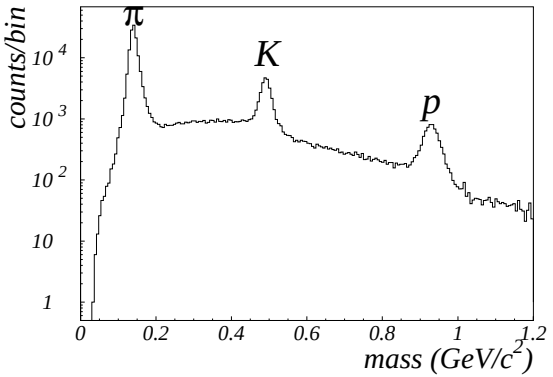
- Reconstructed Čerenkov angle vs. momentum ($\log L_{sign} > 5$)



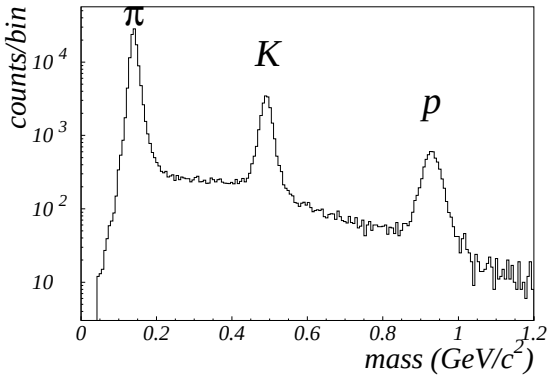
Čerenkov thresholds

particle	p_{thr} (GeV/c)
pion	2.7
kaon	9.4
proton	17.9
deuteron	35.8

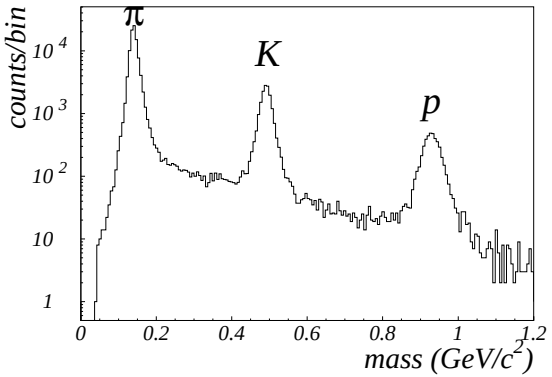
- Particle masses determined from Čerenkov angle measurement



no cut



$\log L_{sign} > 3$

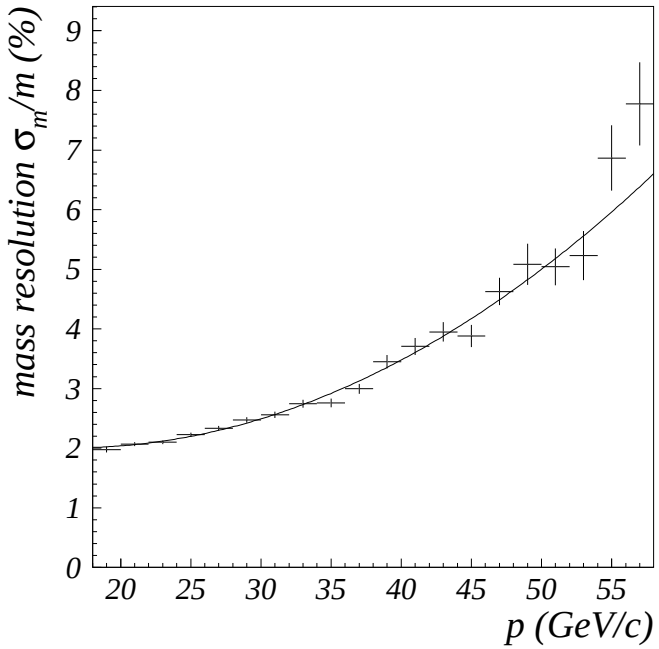


$\log L_{sign} > 5$

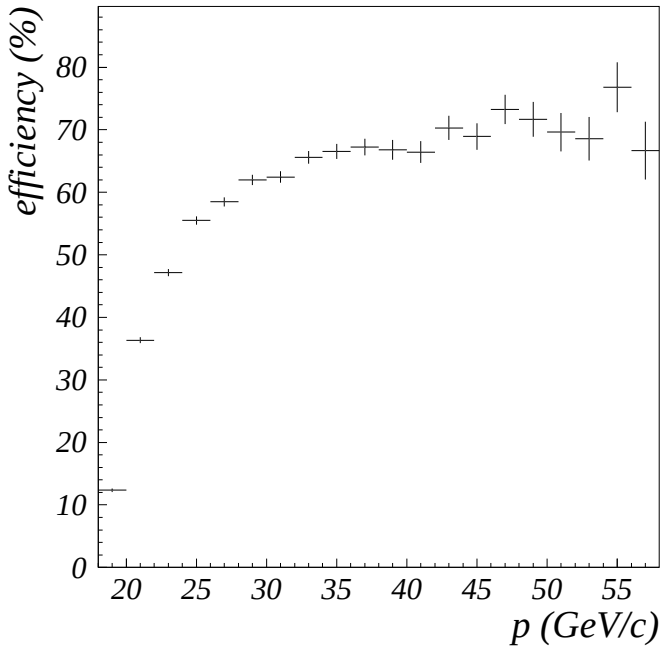
Performance (II)

- Efficiency and mass resolution for protons (real data)
- Protons from reconstructed $\Lambda \rightarrow p\pi^-$ decays used
- Significance cut: $\log L_{sign} > 4$

mass resolution (%)

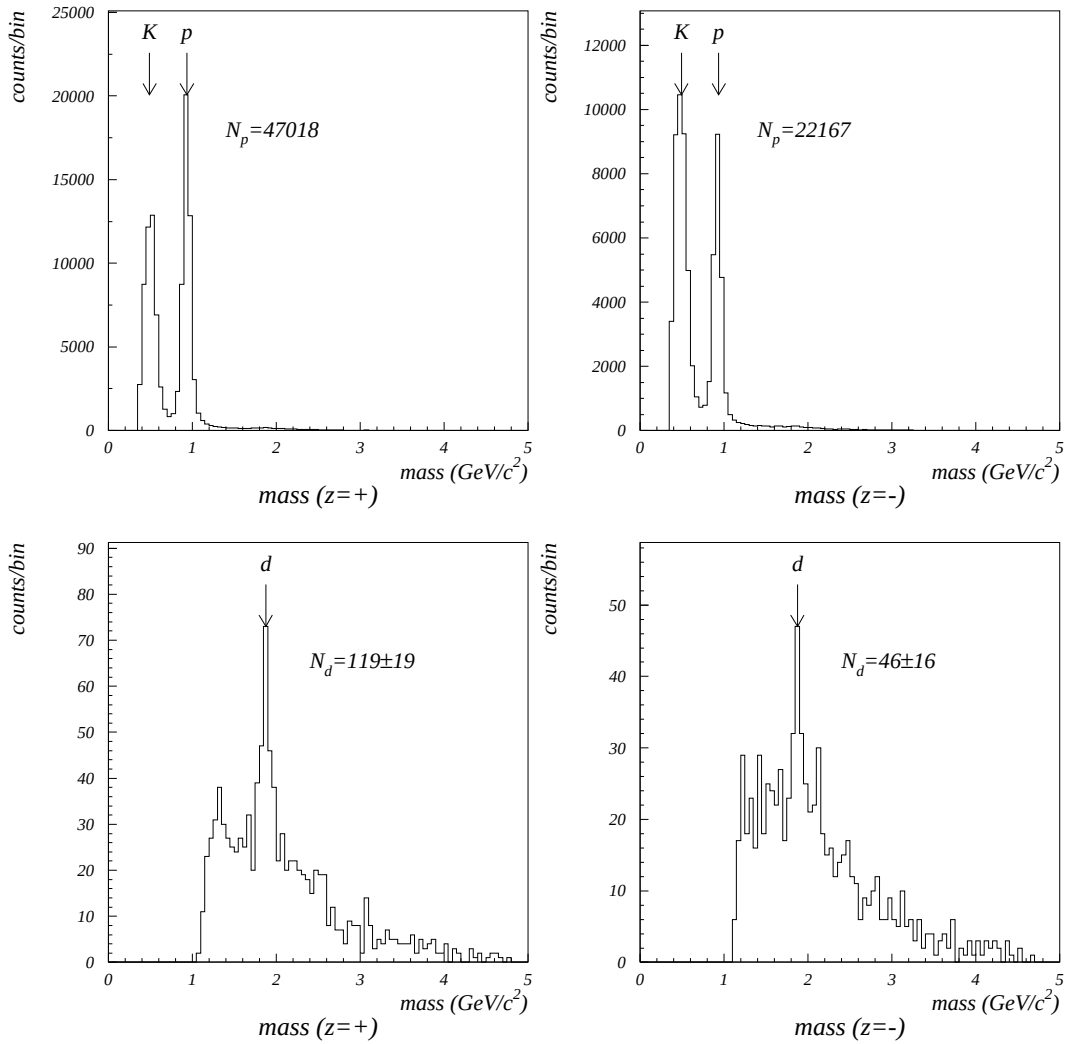


efficiency (%)



Results (I)

- Subsample of MB data (10%)



selection:
40 < p < 100 GeV/c
$\log L_{sign} > 5$

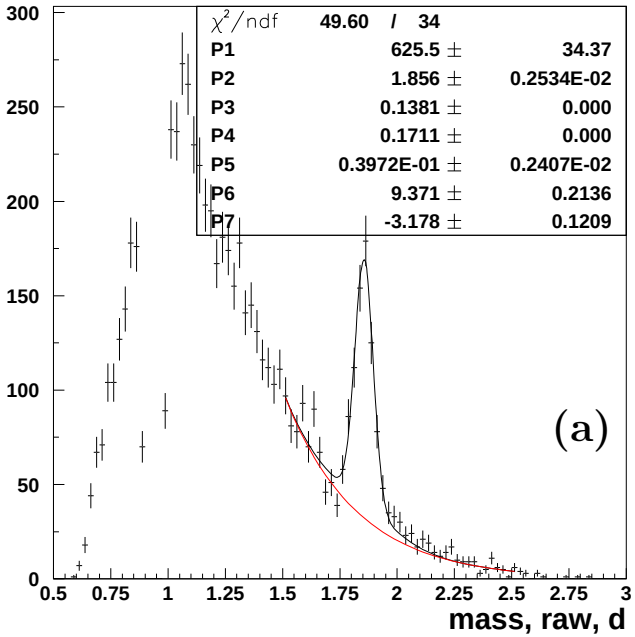
$\longleftarrow$
π removed by:
$l_e + l_\mu + l_\pi < 0.5$

$\longleftarrow$
π, K and p removed:
$l_{other} > 0.9999$

Results (II)

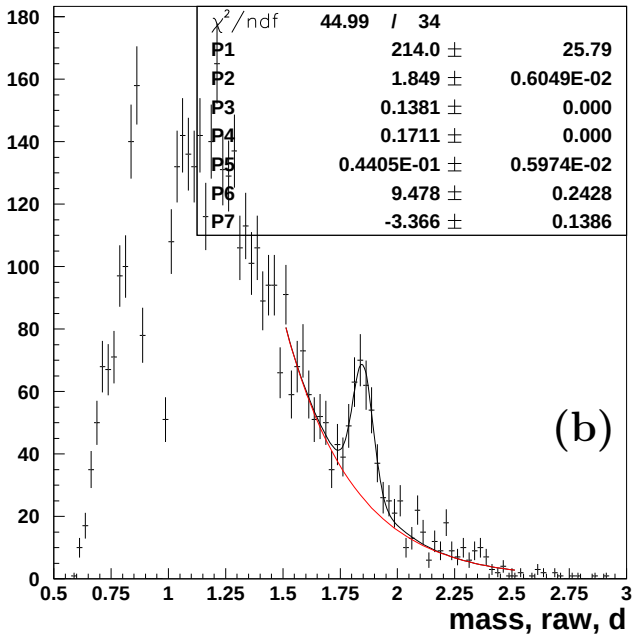
- Full MB data sample (180M events; C, Ti and W targets)

deuterons



$N_d = 626$

anti-deuterons



$N_{\overline{d}} = 214$

- Measurements to be published:
  - ▷ Coalescence parameter B_2 for d and $\overline{d}$
  - ▷ $d/\overline{d}$ cross section ratio
  - ▷ A dependence of d and $\overline{d}$ production

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Conclusions

- New RICH reconstruction algorithm has been developed
- The algorithm is suitable for inclusive particle production measurements
- Deuterons and anti-deuterons were identified in the momentum range 40<p<100 GeV/c
- A publication of deuteron and anti-deuteron production measurement in proton-nucleus interactions is under preparation

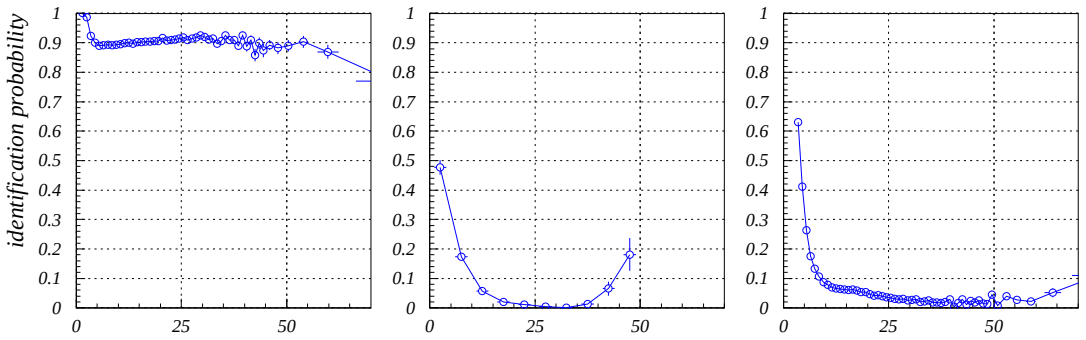
Backup slide: Identification efficiencies

- with extended maximum likelihood method (reported on RICH2002, Pylos)
- Measured on real data by using the decays:

$$K_s^0 \rightarrow \pi^+\pi^-$$
$$\phi \rightarrow K^+K^-$$
$$\Lambda(\bar{\Lambda}) \rightarrow p\pi^-(\bar{p}\pi^+)$$

Pion identification

$lre+lrmu+lrpi > 0.05$

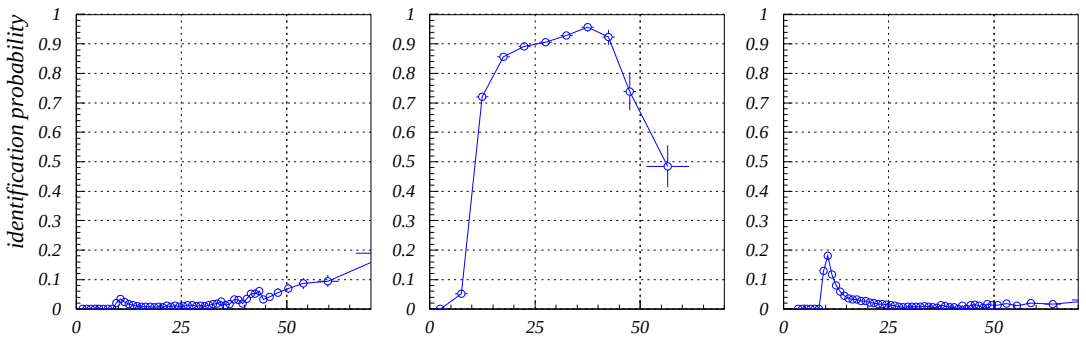


Pions *Kaons* *Protons*

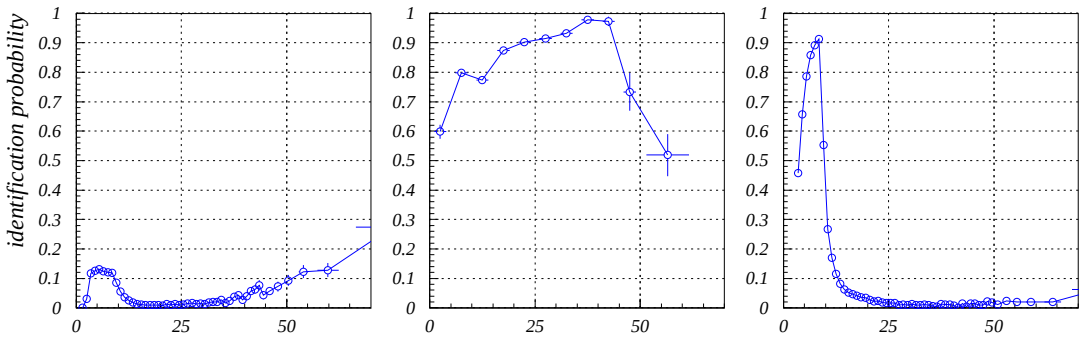
Kaon identification

- with extended maximum likelihood method

lrk > 0.50



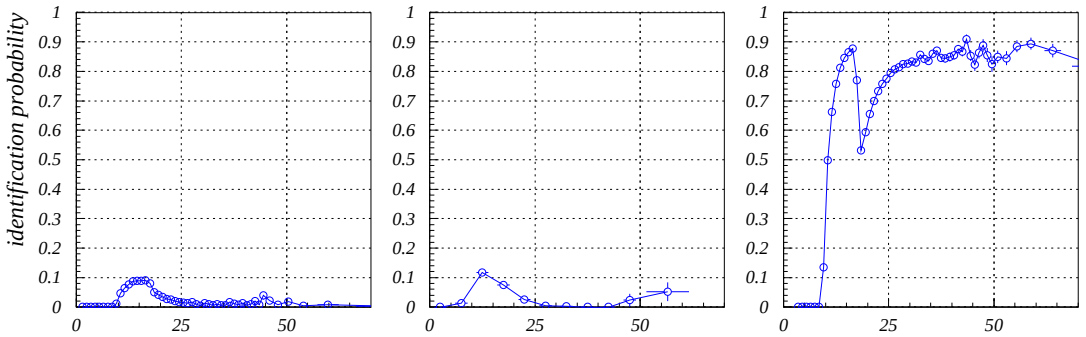
lrk > 0.30



Proton identification

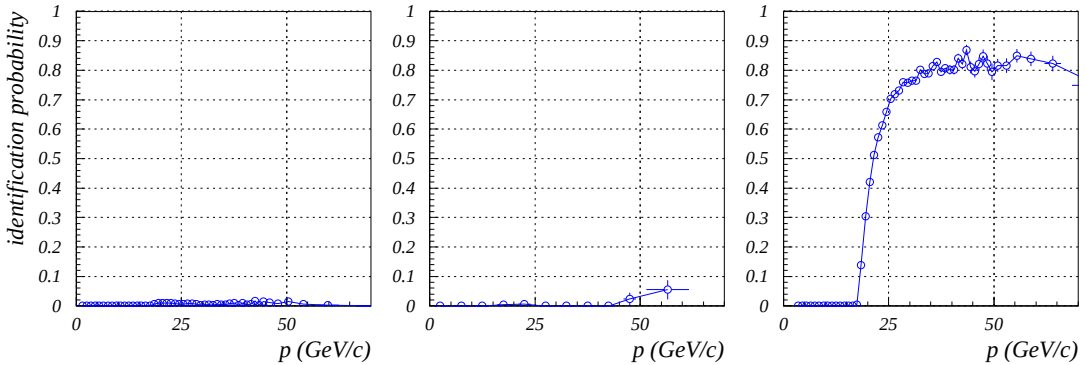
- with extended maximum likelihood method

lrp > 0.45



Pions *Kaons* *Protons*

lrp > 0.90



Pions *Kaons* *Protons*