Measured energy loss and straggling in silicon detectors for low momentum pions and kaons

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PHOBOS Collaboration Meeting

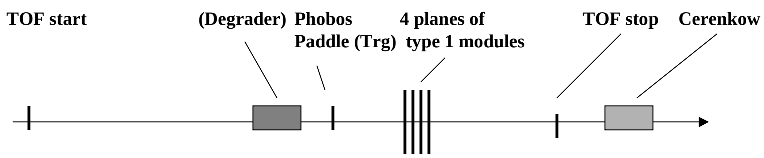
April 18, 1999

The outline

- Phobos "lives" on the Silicon analog signals
  - The multiplicity is directly calculated from the analog signal
  - The spectrometer needs it for particle identification and track reconstruction
- The aim of this measurement was
  - to measure and understand the **response of our detector** for the low momentum pions and kaons
  - measure the **dE/dx loss and straggling** for kaon and pions versus momentum
- This allows us to:
  - compare and tune our Geant simulation
  - test the particle identification

The measurement

The E913/914 beam line provided pi-/K- from 300MeV/c to 750 MeV/c

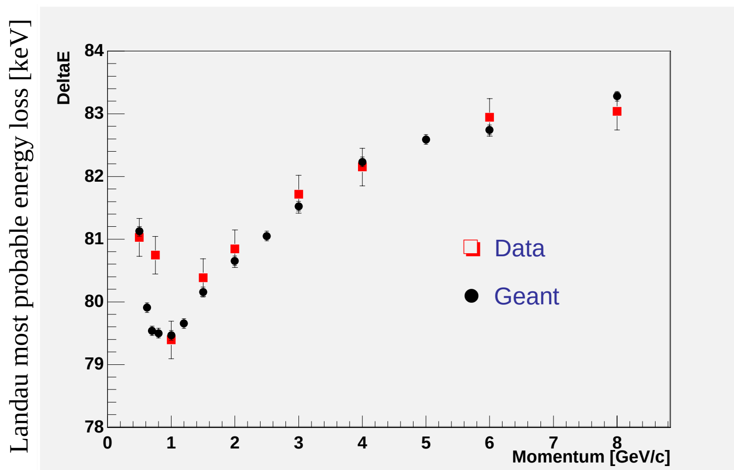


- The Silicon detector:
  - use final 4 planes of the spectrometer type 1 modules (12k channels)
  - small pads -> good and full tracking
  - high S/N -> good energy loss measurement
  - 8 sensors & 96 chips -> minimize systematic error, give redundancy and allow cross checks
- The TOF and Cerenkow:
  - provides pi/K separation and particle identification in the low p range
  - suppress e- back ground of secondary beams

How do we calibrate the signal?

- **The basic step in the signal calibration:**
- calibrate the gain and linearity of on each channel
- convert the measured output voltage to an input charge
  - used the measured test capacitor value for Q=Ct*U
- convert the measured charge to energy deposited using a constant of 3.62eV for the creation of 1 electron/hole pair
- correct for the measured detector thickness

Summary for the high momentum test:

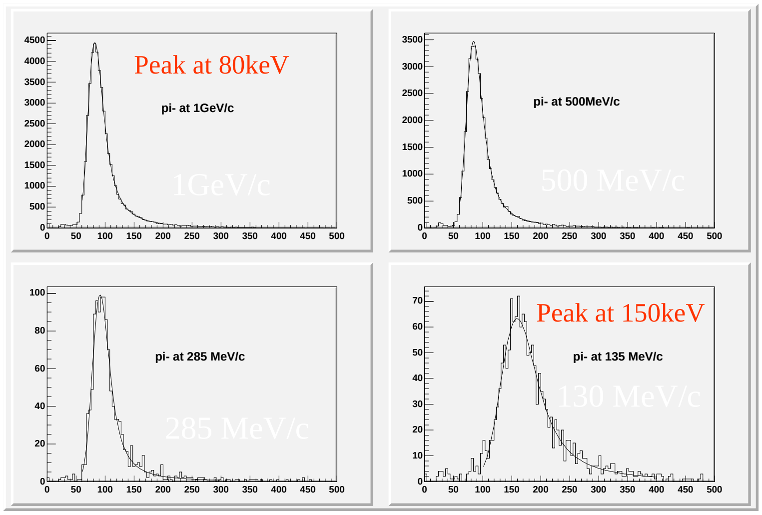


- We measure a 4 % logarithmic rise of dE/dx (0.5 - 8GeV/c) for pions
- Geant agrees very well with our measurement

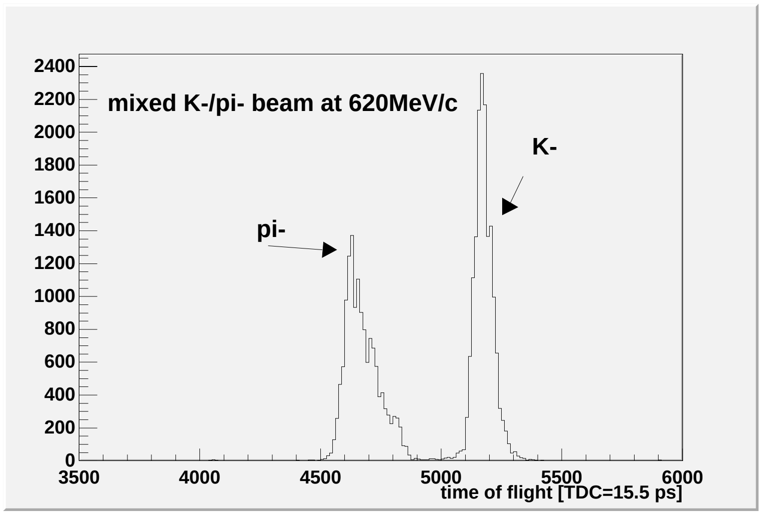
What to look for in the signal:

- The intrinsic detector signal:
  - Landau part described by restricted Bethe-Bloch
  - Intrinsic gaussian contribution to the energy loss due to variation of Ionization potential for e- in different Si- shell
  - electronic noise (5keV in our case)
- The measurements:
  - make a convolute fit to distribution
  - determine the most probable signal of the Landau part to measure dE/dx loss
  - use sigma of gaussian part and FWHM to characterize the energy straggling

Pions at low p: the measured signal

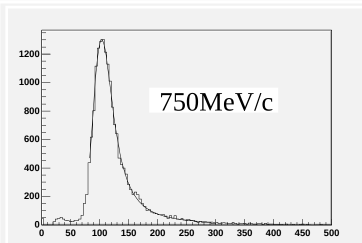


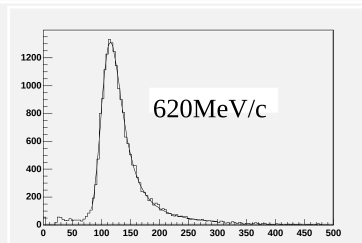
Kaons at low p: selecting K- with TOF

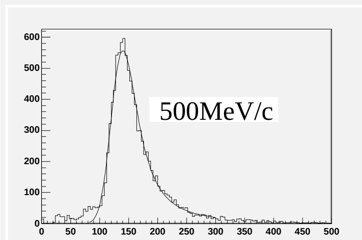


- Clear separation between pions and kaons

Kaons at low p: The measured signal vs p

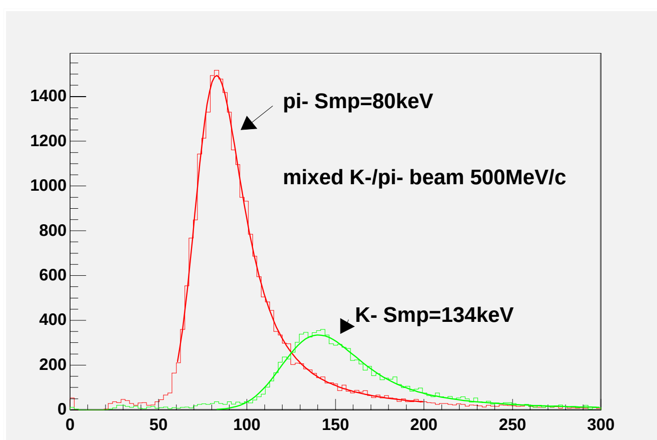






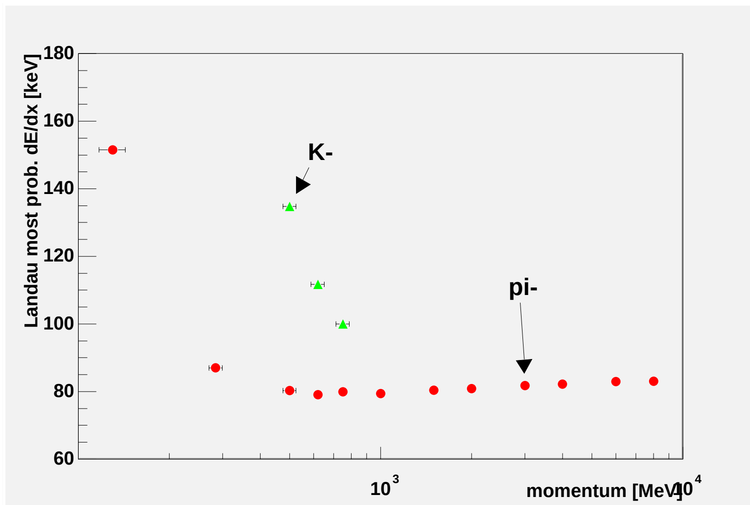
- Increase of signal and straggling at lower momentum

Kaon on Pion at the same momentum



- Use the peak (Landau mp) to determine the **dE/dx**
- use the width to measure the **straggling**

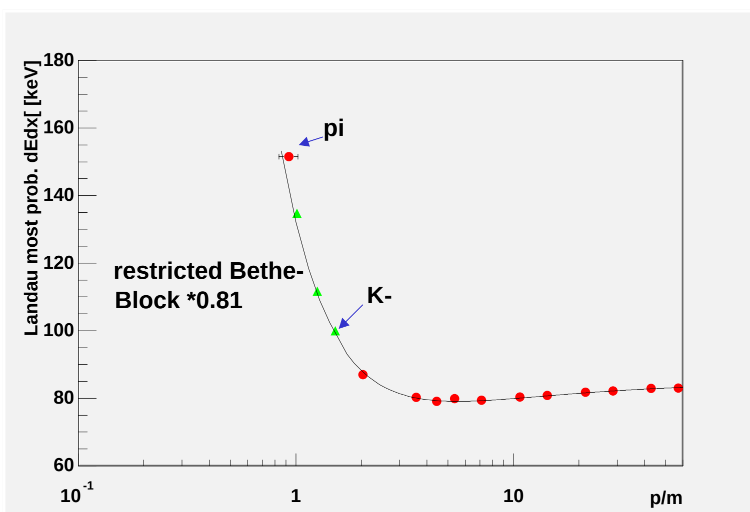
The dE/dx versus momentum for pi/K



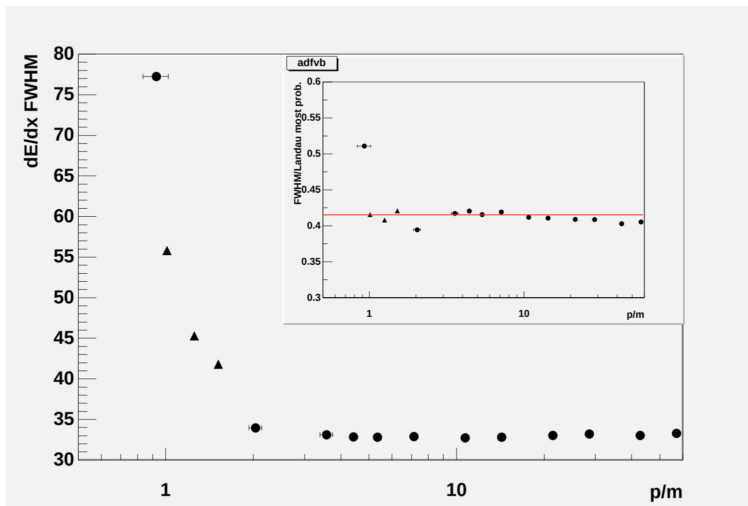
- Expect from Bethe-Bloch a scaling of dE/dx with p/m...

The measured dE/dx versus βγ compare to scaled Bethe-Bloch

- Scaling accounts for most probable to mean (as in BB) difference (determined at 1GeV)

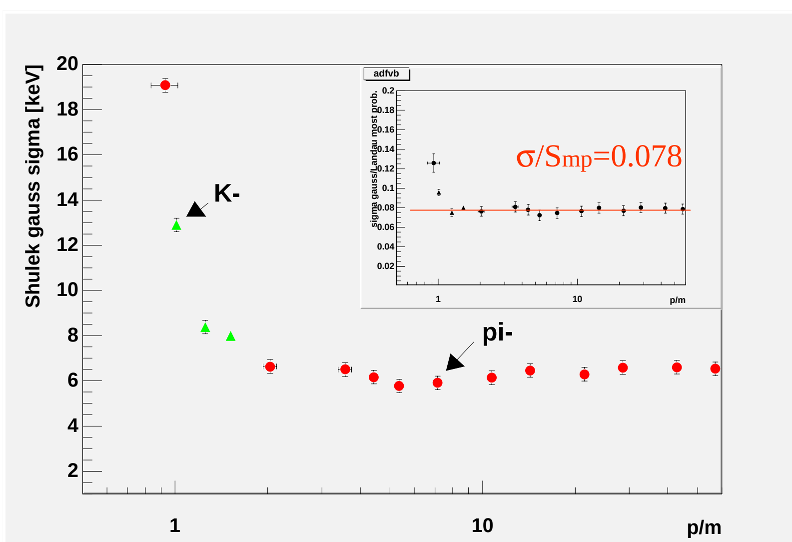


The energy straggling versus βγ



- The straggling scales with energy loss at fixed ratio (FWHM/peak=0.42)

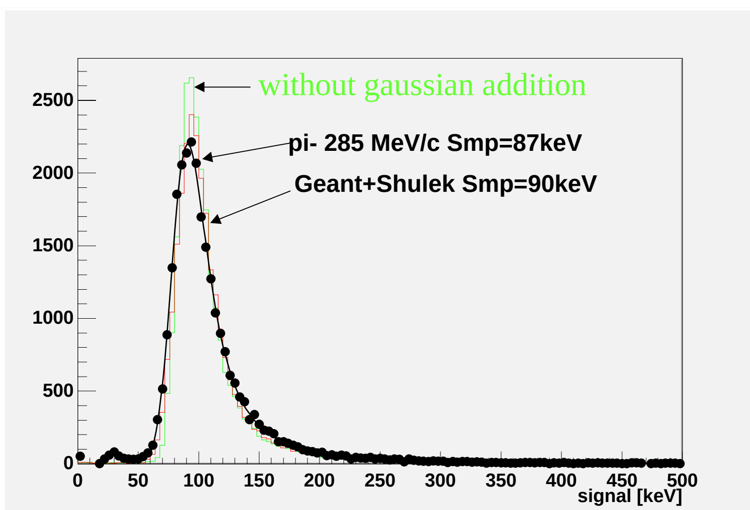
Measuring the gaussian component of energy loss (“Shulek correction”)



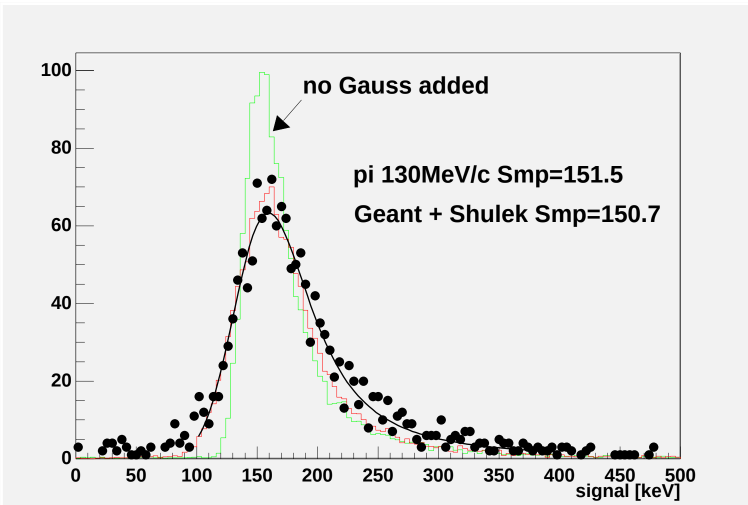
Comparison to GEANT

- use PhatPMC to simulate Geant events for our test setup
- use the standard Phobos settings in Geant (see Carla's talk) to simulate restricted Landau distribution
- BUT add Gaussian distribution for
  - electronic noise: constant 5keV
  - Shulek correction as measured for pions and kaons

Compare it for pions at 285MeV/c ("Phobos typical")



Go to even lower momentum for pions: 130 +- 10 MeV/c



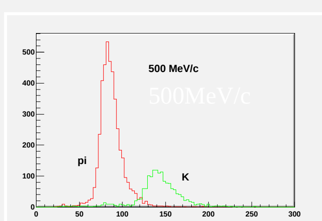
Summary: Measured Signals versus Geant and Bethe-Bloch

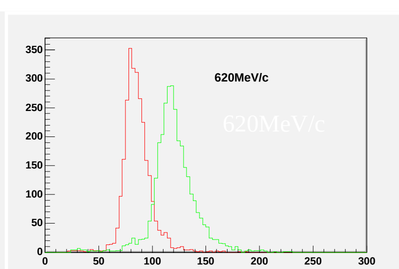
- GEANT:
  - Geant reproduces the **most probable energy loss** extremely well!!!
  - Geant has trouble with the straggling (distribution is too sharp)
  - Adding the measured values for the Shulek correction significantly improves the modelling of **energy straggling**
- Bethe-Bloch
  - need to apply an restricted energy loss calculation due to escaping δ electrons (see Carla's talk)
  - can reproduce the momentum behaviour quite well once is it normalized at one point.

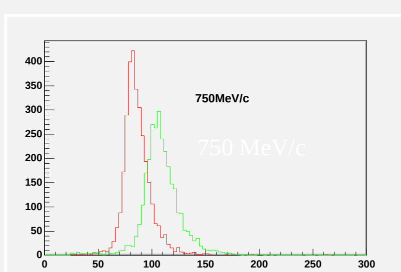
Putting it to work: Particle Identification with 4 planes only?

- Use the 4 planes and try to identify pions and kaons in our mixed data sample (in Phobos up to 14 measurements later)
- The measured momentum points are nicely at the limit of our claimed pi/K separation (750MeV/c)
- Use the TOF measurement to determine efficiency and purity

First approach: Truncated mean with 3 of 4 measurements





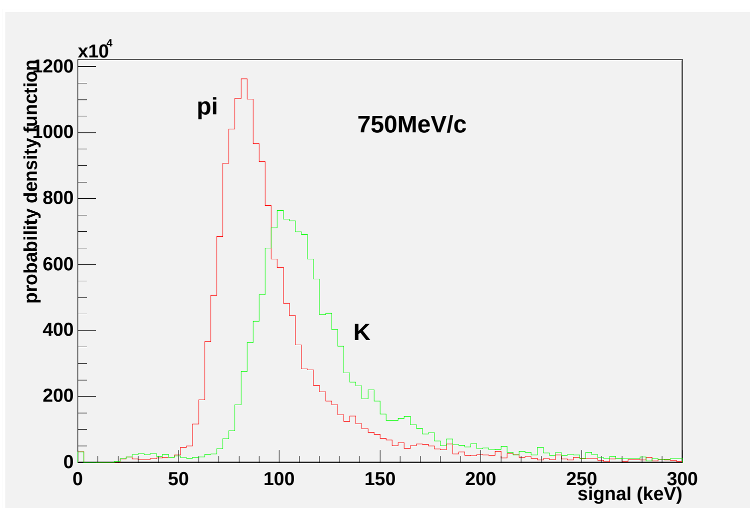


- Works up to 620 MeV/c but worsens at 750MeV/c
- requires very careful tuning of the cut
- cut strongly depends on relative fraction of pi/K

Second approach: Using a Maximum-Likelyhood estimation for pi/K

- based on calculation signal probabilities for pi and K hypothesis: $\Sigma \log(f(Si)) = \max$
  - f…probability density function for pion or kaon at fixed momentum
- requires knowledge of signal distribution at different p
- does not need a cut parameter
- does not bias the selection like in case of truncated mean when the cut parameters are obtained from simulation at fixed K/pi ratio

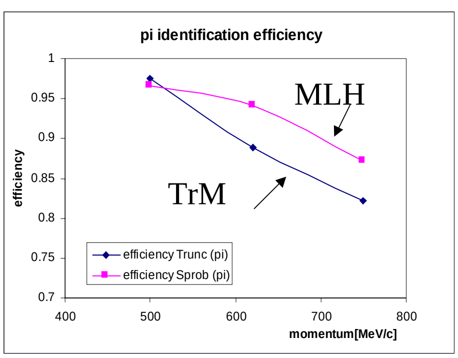
The probability density function for pi and K

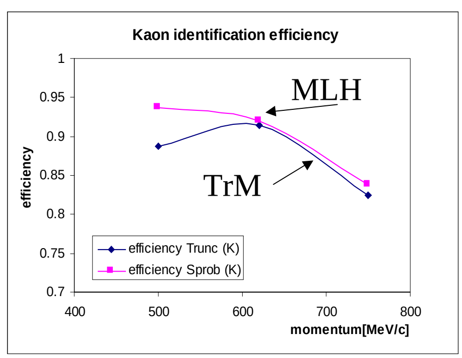


Testing the two approaches:

- identify particle with both approaches and compare the result to the TOF measurement
- define:
  - **efficiency** e(pi)= N(pi->pi)/N(pi)
  - **contamination** c(pi)= N(K->pi)/N(K)
    - and vise-versa for Kaons

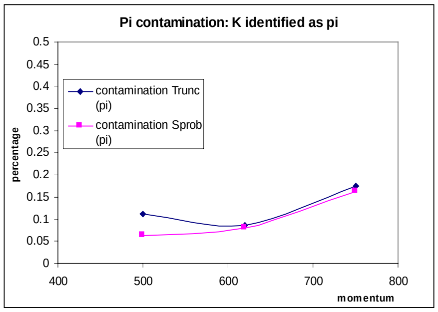
The particle ID efficiency with 4 planes

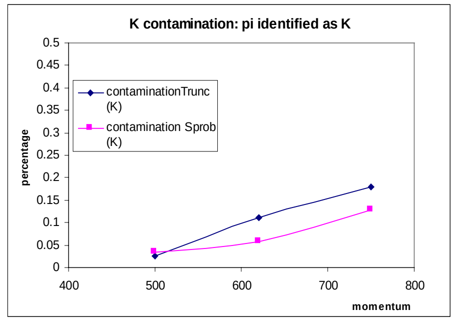




- Good efficiency already with 4 planes in both cases
  - eff (pi) > 85 to 90 % at 750MeV/c
  - eff (K) = 85% at 750MeV/c
- using Maximum Likelyhood produces slightly better efficiency (efficiency gain = 5%)

The selection contamination with 4 planes





- Very little contamination already with 4 planes in both cases
  - c (pi) <15% % at 750MeV/c and reaches levels of 5% beyond 600MeV
- using Maximum Likelyhood produces slightly better purity

The Conclusion

- Energy loss and straggling:
  - we precisely measured energy loss and straggling over 2 orders of magnitude in momentum
  - we determined the contributions to the intrinsic energy deposition
  - Geant describes the most probable energy loss very well but needs modifications to get the straggling right at low p/m
- Particle identification:
  - works amazingly well with 4 planes only!
  - Efficiency 85 to 95 % at the end of our claimed Si-PID range
  - Contamination 5 to 15 %
  - is a Maximum Likelyhood approach useful for Phobos?