Particle identification with Cherenkov counters in 2011 W-AHCAL SPS runs

CALICE collaboration meeting
Annecy-le-Vieux

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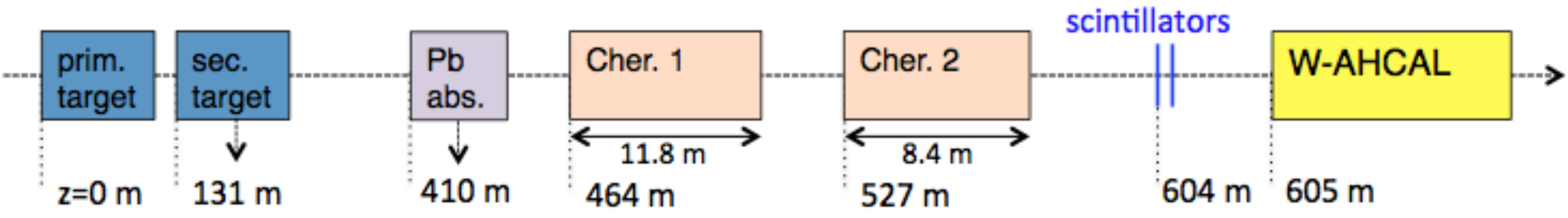
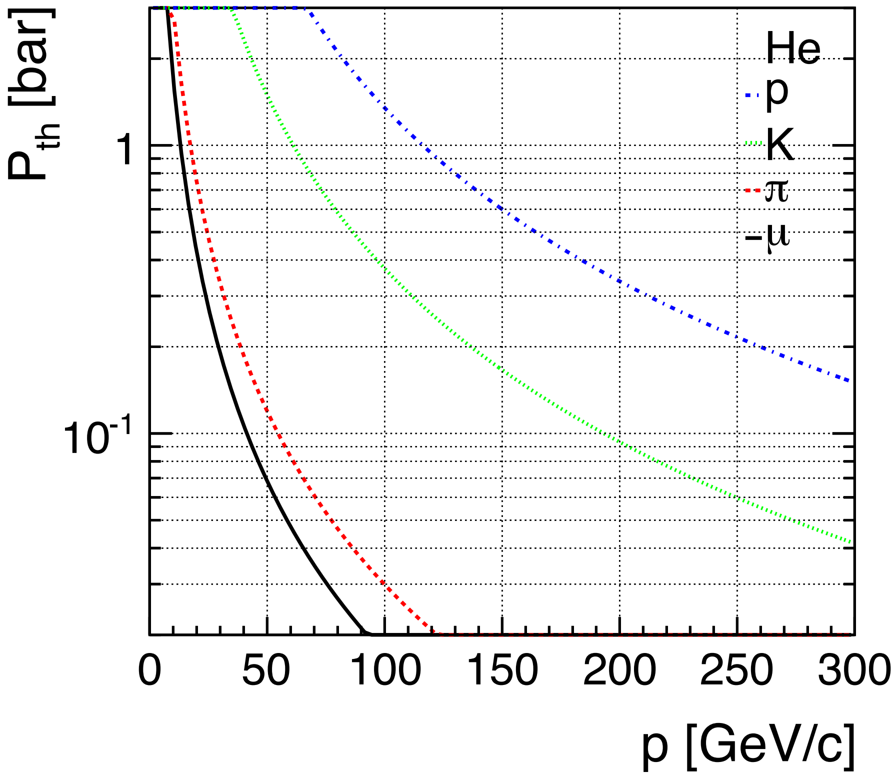
Particle Identification in SPS-H8

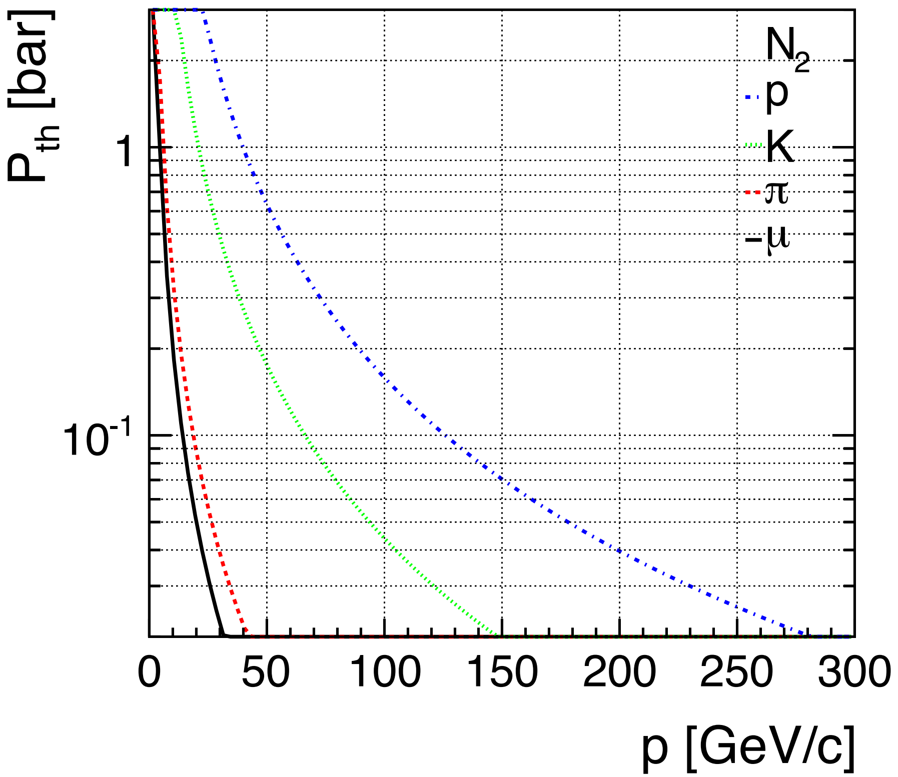
- Two Cherenkov threshold counters upstream W-AHCAL
- Helium (Cherenkov 1 / 2) or Nitrogen (Cherenkov 2 for some runs), adjustable pressure: 0.02 < P < 3 bar
- PMT + Discriminator system (beyond our control)
  - → get only ON/OFF signal in DAQ
  - → only used offline (hundreds of ns delay, too slow for trigger)
- Threshold pressure for Cherenkov light emission depends on gas type (refractive index), mass and momentum of particles
  - → used to discriminate between pions, kaons, protons
- Turn-on behavior for detection efficiency after threshold is passed

SPS H8 beam line in 2011, not to scale



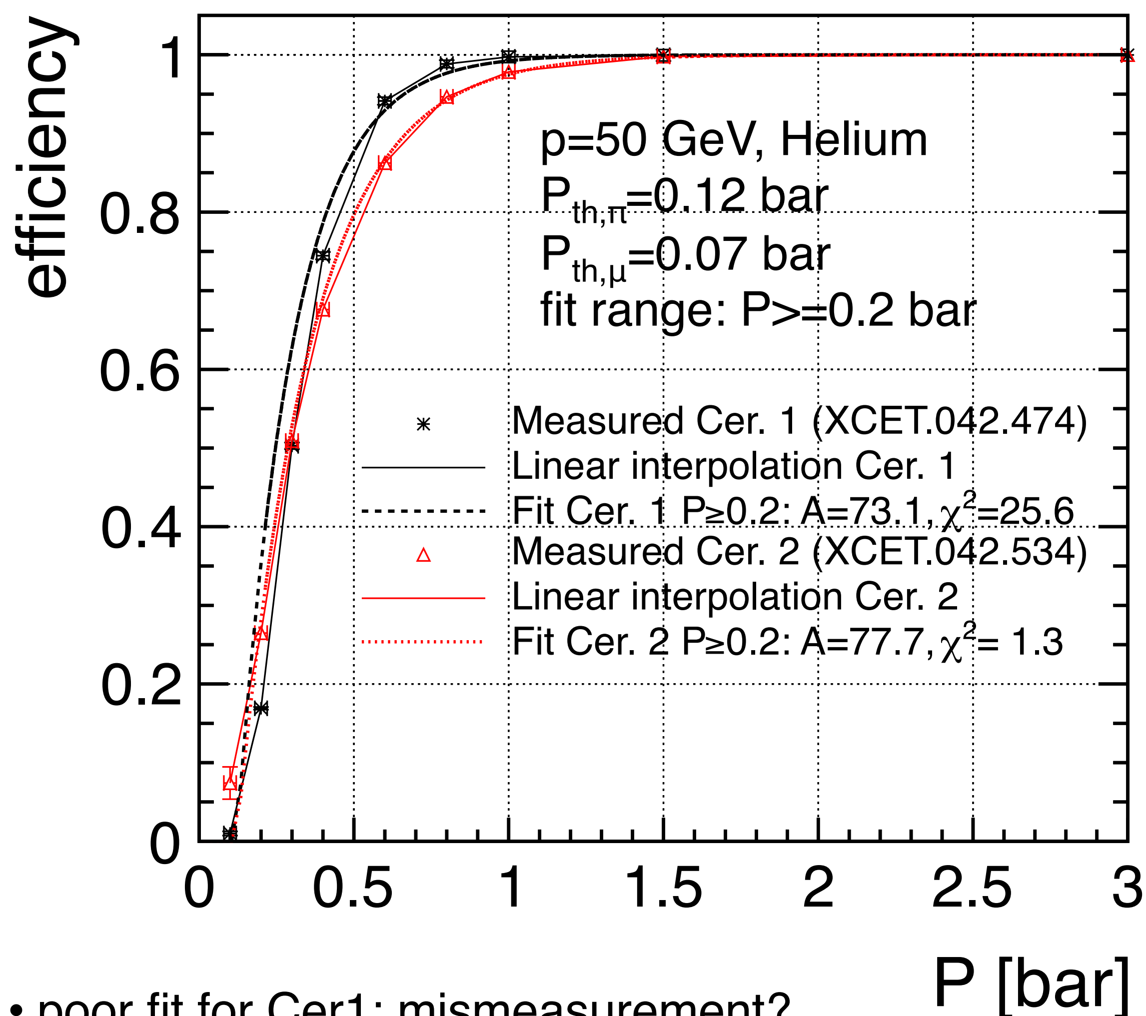
Threshold pressures





- Helium for higher energies
- Nitrogen gives better K/pi/p separation for lower energies

Cherenkov efficiency turn-on (I)



- poor fit for Cer1: mismeasurement?
- reasonable fit for Cer2, except first point
- consider also simple linear interpolation

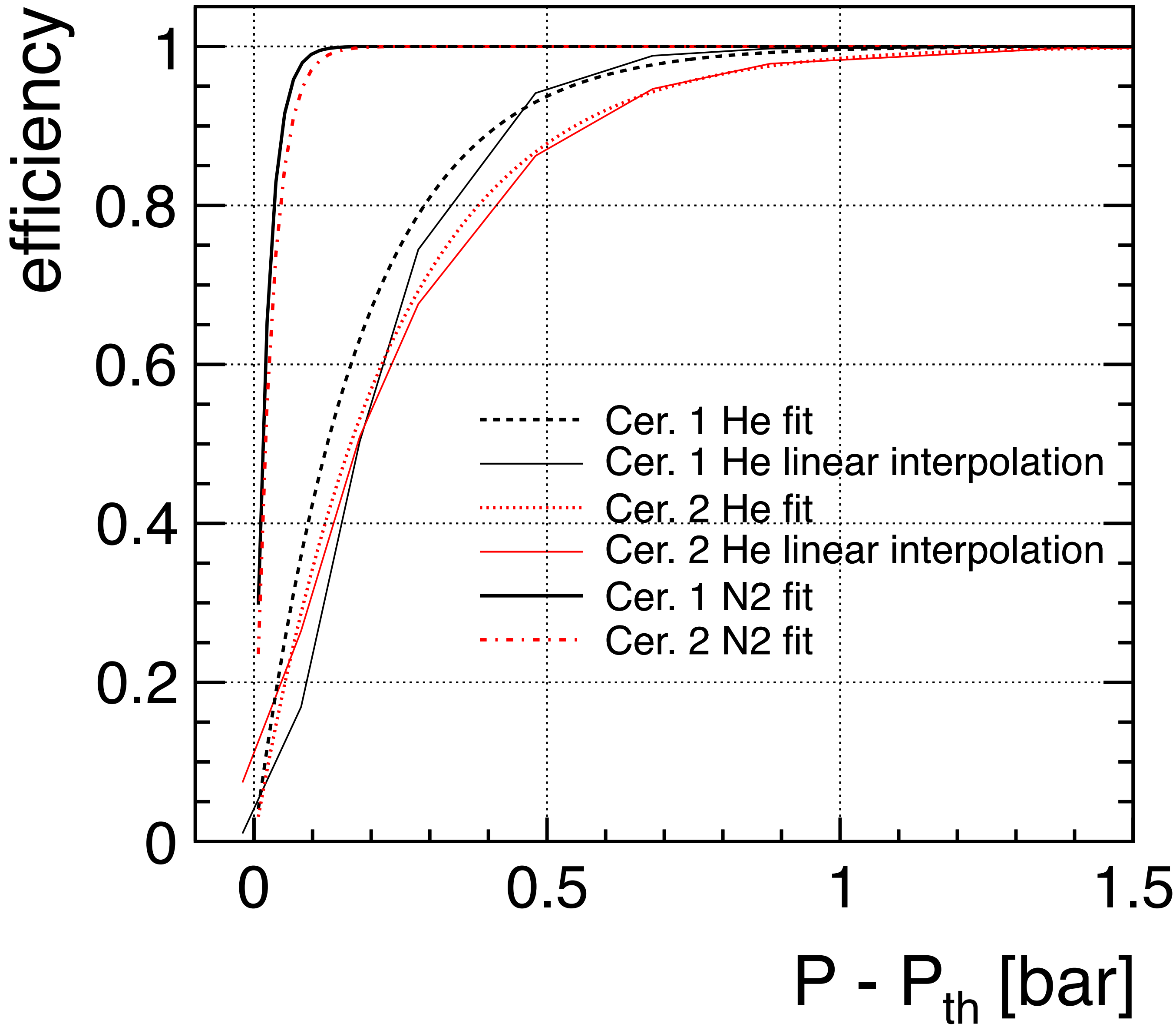
- Tag-and-probe method:
  - Cer1 and Cer2 at same P
    eff1=N(1&2)/N(2)
    eff2=N(1&2)/N(1)

- Poisson distribution for probability to detect one or more photo-electrons

eff=1-exp($-N_{p.e.}$)
$N_{p.e.}$ = A L 2 (n-1) (P – P_{th})

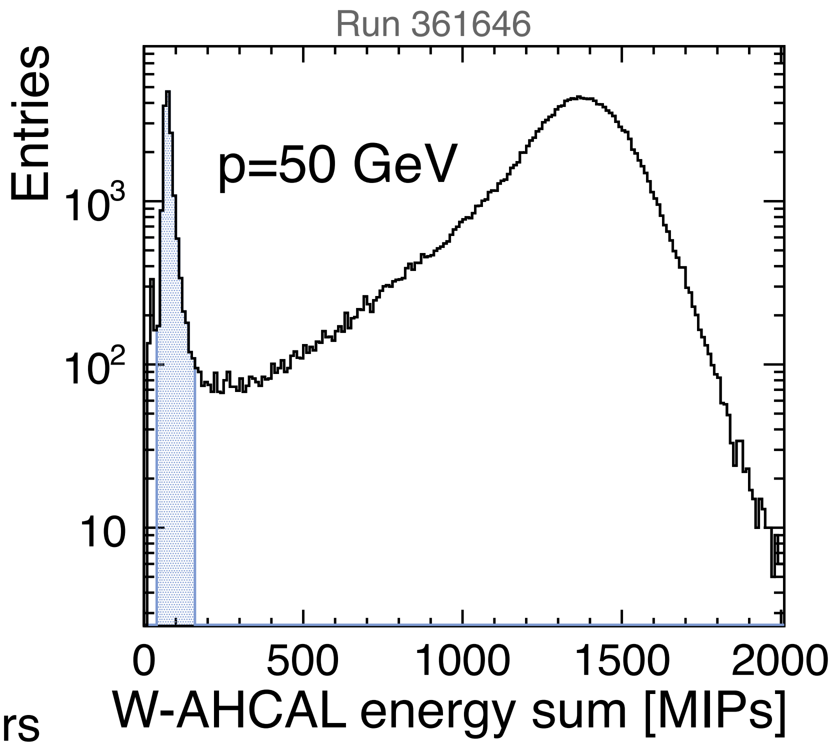
A: quality factor (efficiency of optical system, photon collection efficiency, quantum eff. of photocathode, discr. threshold, ...) → fit parameter
L: length of counter
n: refractive index

Cherenkov efficiency turn-on (II)



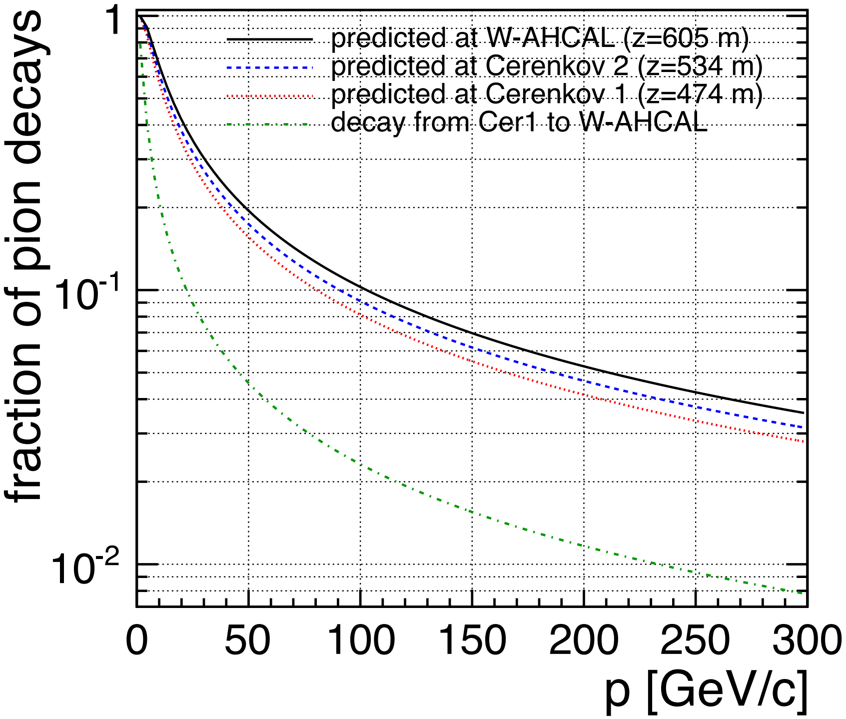
Particle content in H8 beamline

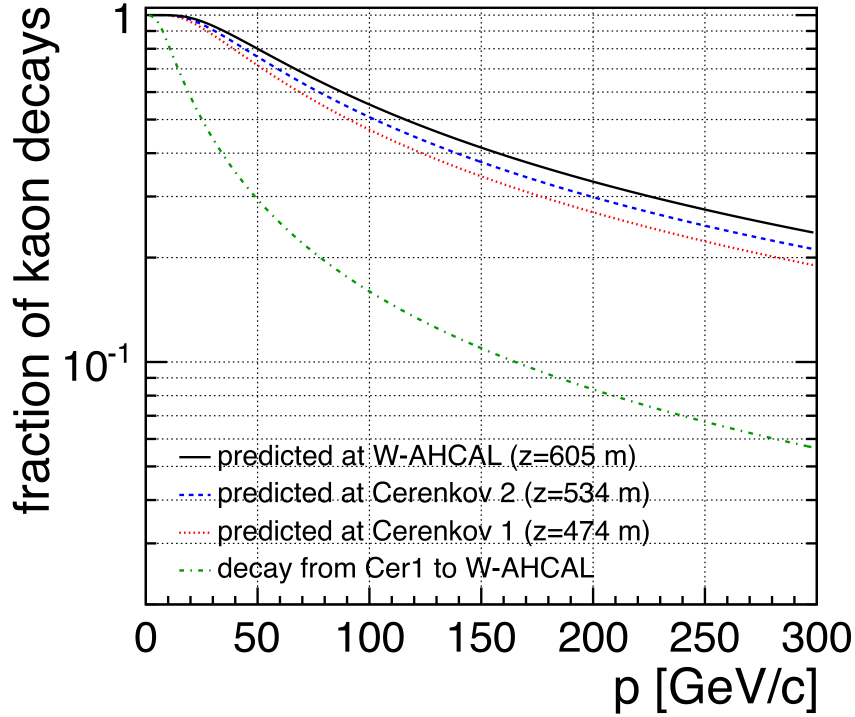
- Mixture of electrons, muon, pions, kaons, protons
- electrons:
  - in e-runs: no absorber in beam line, assume ~100% pure electron beam
    → not considered here
  - in hadron runs: e efficiently removed by 18 mm lead absorber, some remaining e contamination in early runs with 8 mm lead absorber, suppressed based on shower-shapes
    → not considered here



- muons:
  - from in-flight pion + kaon decay, collimators, ...
  - present in all runs → see following slides
  - efficiently identified by cut on energy sum in calorimeter: 45 MIPs $< \Sigma E_\mu <$ 150 MIPs
- pions, kaons, protons:
  - similar response in calorimeter, consider all events with $\Sigma E >$ 150 MIPs
    → discrimination based on Cherenkov counters

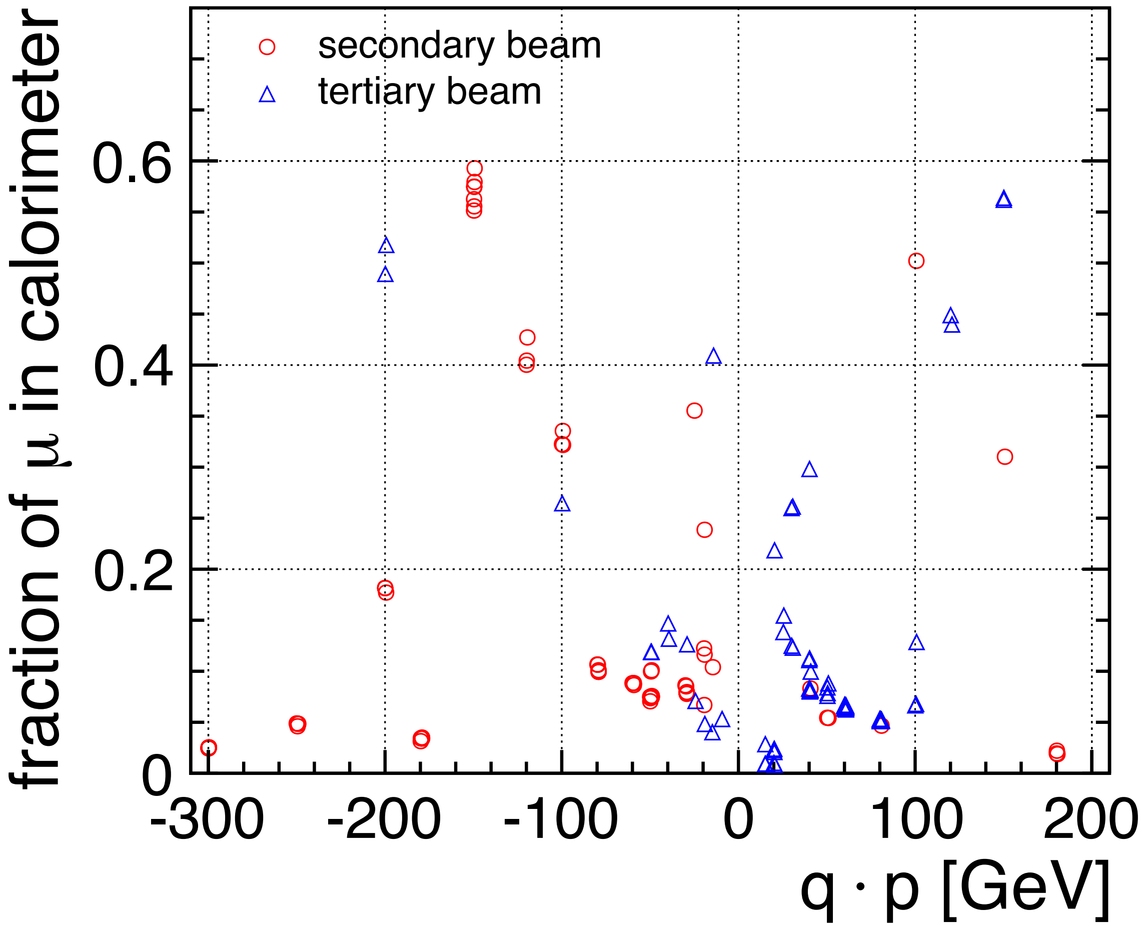
Predicted pion + kaon decays





- for lower energies: large fraction of pions and kaons decay before reaching calorimeter
- complication for particle ID if decay happens between Cherenkov counters and calorimeter
  → expected to affect only small fraction of events

Observed muon content in data

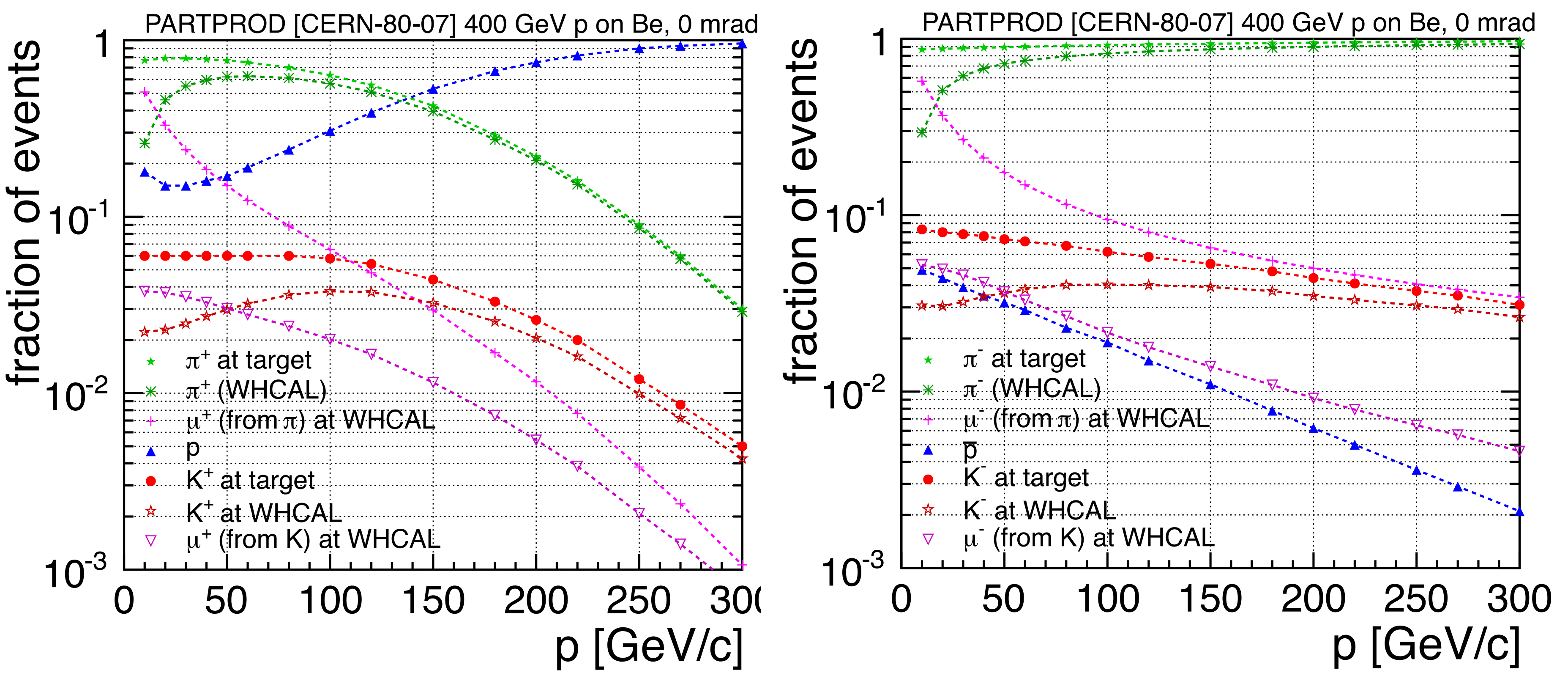


fraction of events in muon peak, no Cherenkov selection

- we observe large fluctuations in muon content for all energies
- no clear correlation with beam conditions (secondary/tertiary beam)
- muons can easily be removed based on energy sum in calorimeter

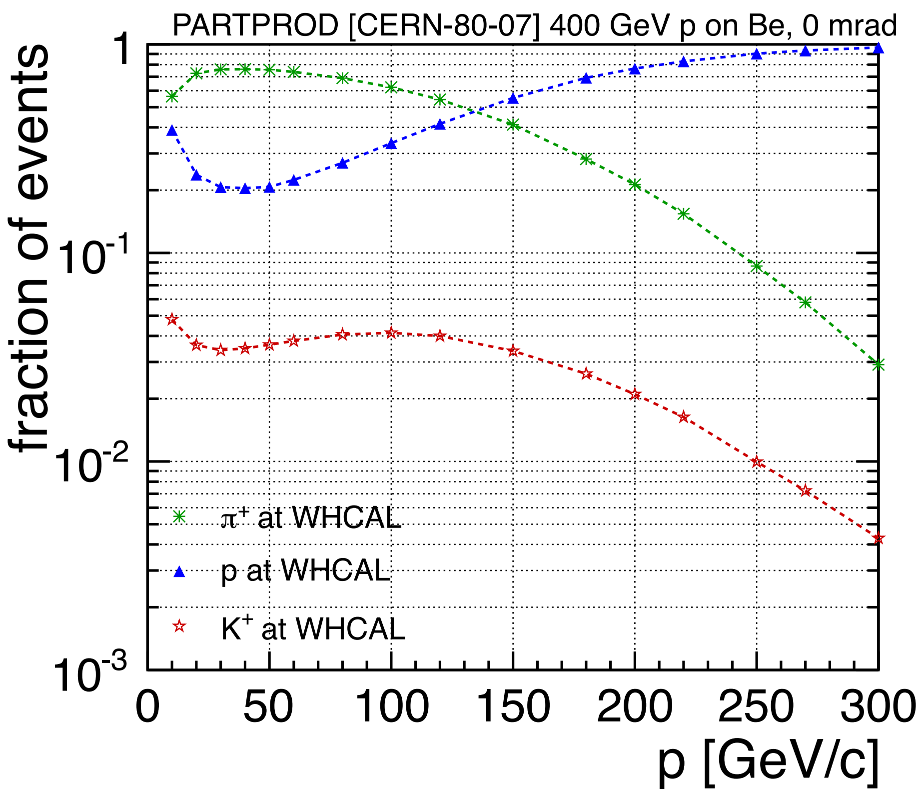
Predicted particle content

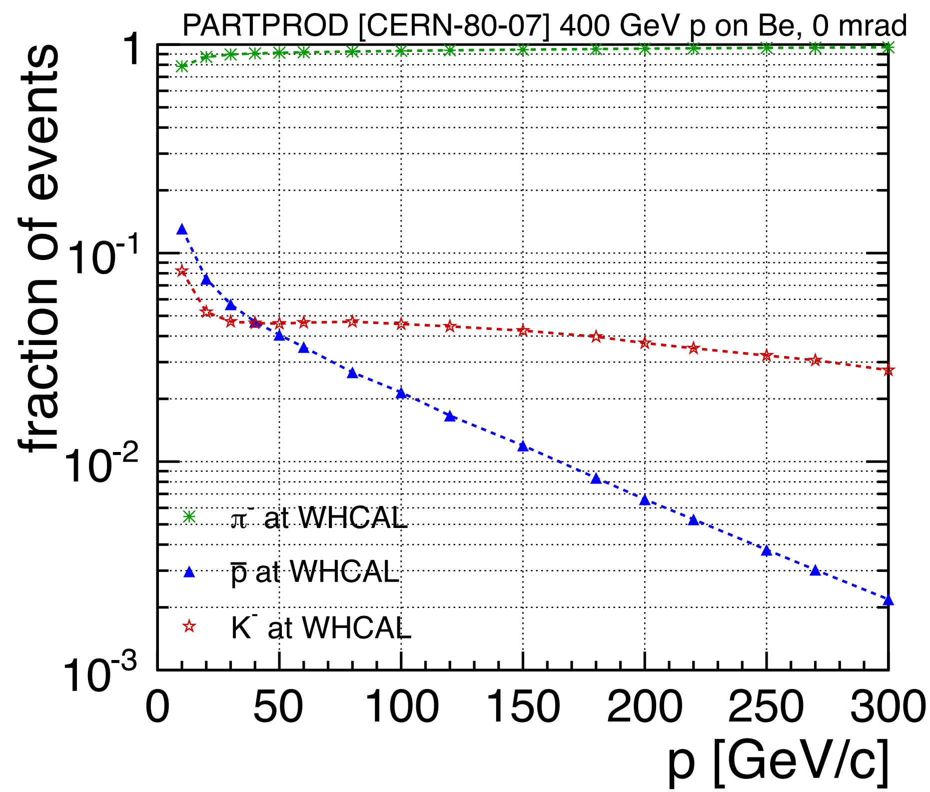
- expected particle content of secondary beam obtained from PARTPROD particle production calculator (L. Gatignon), based on CERN-80-07 (calculation, not simulation!): 400 GeV protons on beryllium target, particles at 0 mrad
- should be in rough agreement for secondary beam runs
- tertiary beam runs may have very different particle composition



Predicted particle content excl. muons

- to be able to compare with data samples:
  - remove expected muons from in-flight pion/kaon decays
  - → expected fractional particle content at calorimeter surface
  (Kaon decays to pions not considered here)





Particle identification in 2011 W-AHCAL runs

- 159 hadron runs with mixed beams, -300 GeV < p < 200 GeV

- aim during data taking was: select Cherenkov-counter gas and operation pressures such that clean samples (purity >~ 80%) of pions, protons and kaons can be obtained

- however: Cherenkov pressures not always the same for runs with same momenta; some runs have non-optimal settings; limited separation due to available gas types
  → for many runs not possible to obtain pure samples of all particle types

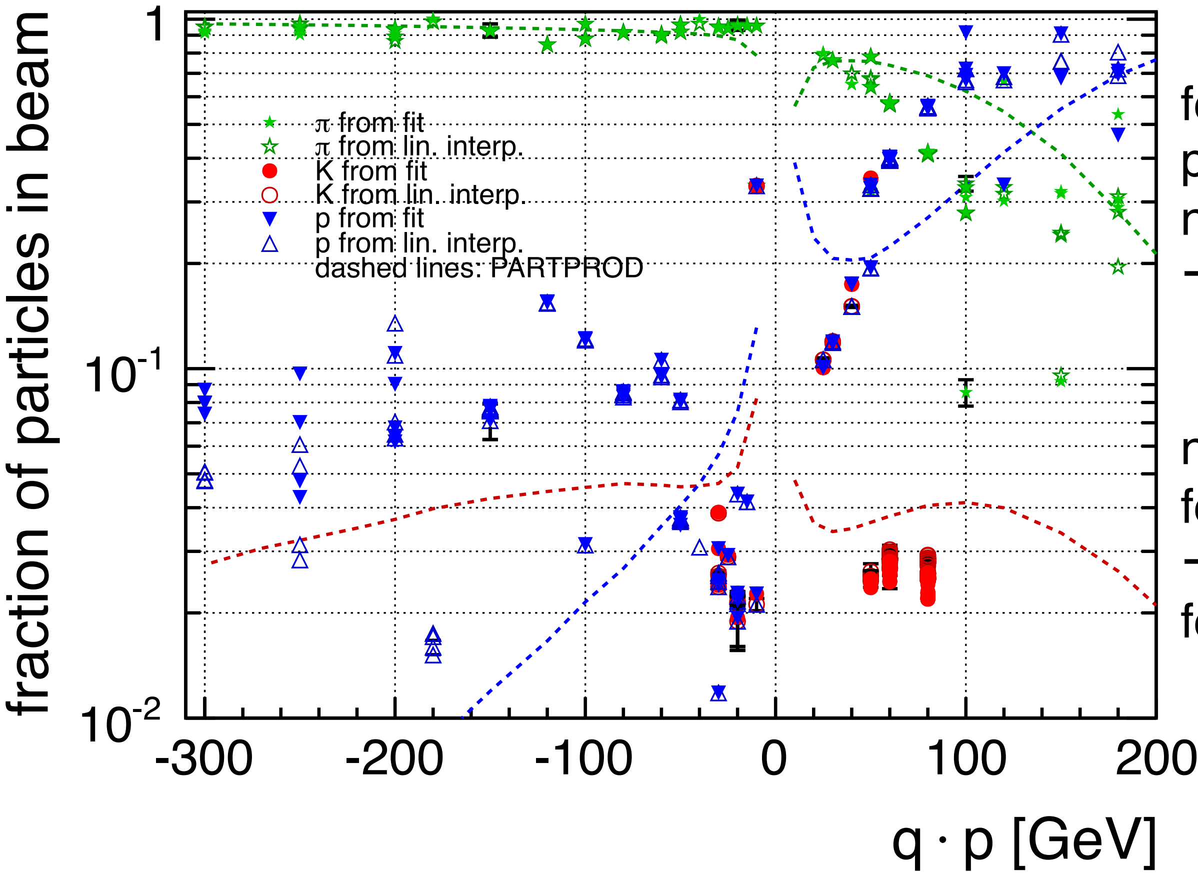
- efficiencies are obtained from calibration measurements (limited precision)

- purities depend on efficiencies (limited precision) and on beam content (limited knowledge)

Estimation of particle content

- attempt to obtain beam content from observed event numbers:
  - $n_{observed} = eff_{\pi} * n_{\pi} + eff_{K} * n_{K} + eff_{p} * n_{p}$
  - → solve system of linear equations
  - → 4 disjunct event samples for 2 Cherenkov counters:
    Cer1on&Cer2off, Cer1off&Cer2on, Cer1off&Cer2off, Cer1on&Cer2on
    - → over-constrained system (4 equations, 3 unknowns)
    - → use singular-value decomposition (SVD) method
      to estimate n_{π}, n_K ,n_p (~ matrix inversion)
    - → takes into account statistical uncertainties on $n_{observed}$,
      but not uncertainties on efficiencies and constraint that $n_{\pi,K,p} \geq 0$
    - → good results only for good Cherenkov separation and sizeable samples
- compare with expected beam content from PARTPROD

Particle content in data

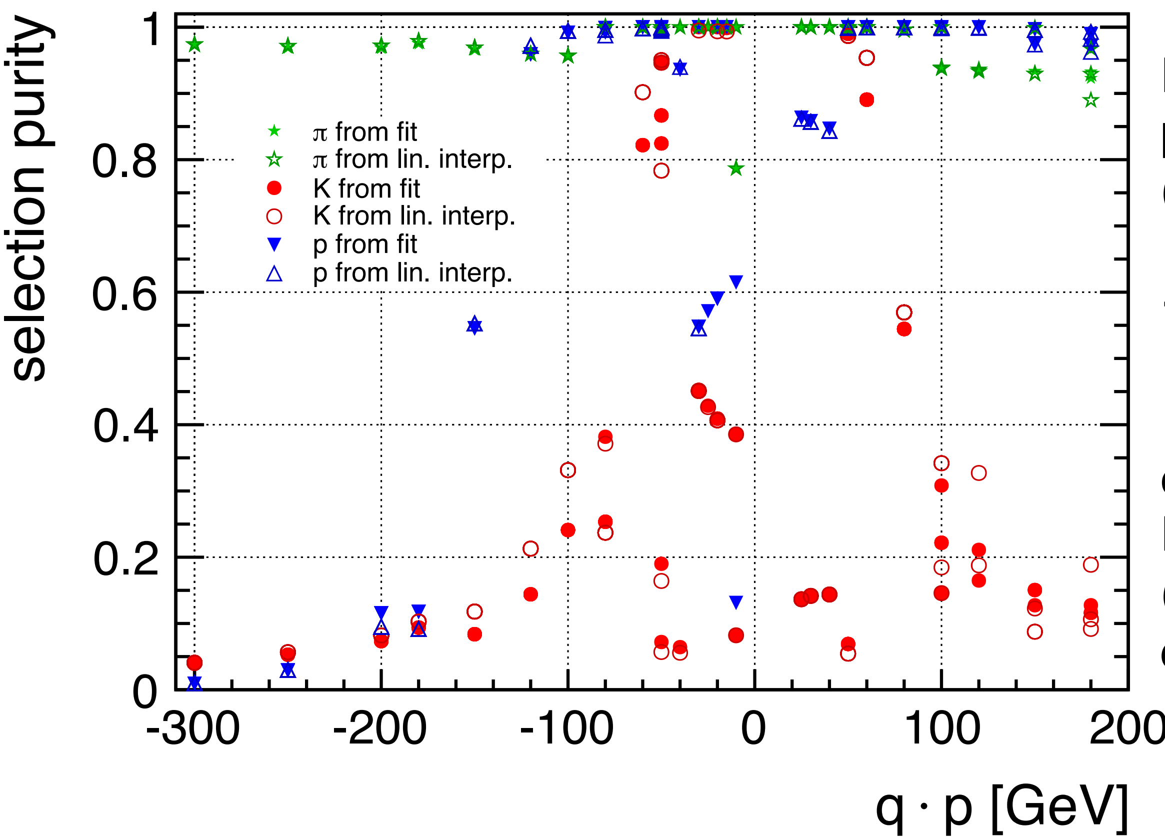


for runs with
p<-30 GeV and p>80 GeV:
no separation pions/kaons
→ include kaons in pion data points

note: no kaon/proton separation for p<50 GeV
→ fits result in ~equal numbers for kaons and protons

- qualitative agreement with expectation from PARTPROD, except:
  - data favors larger anti-proton content in runs with negative polarity
  - expected drop in pion content for low momenta due to in-flight decays is not observed in data

Estimated purities



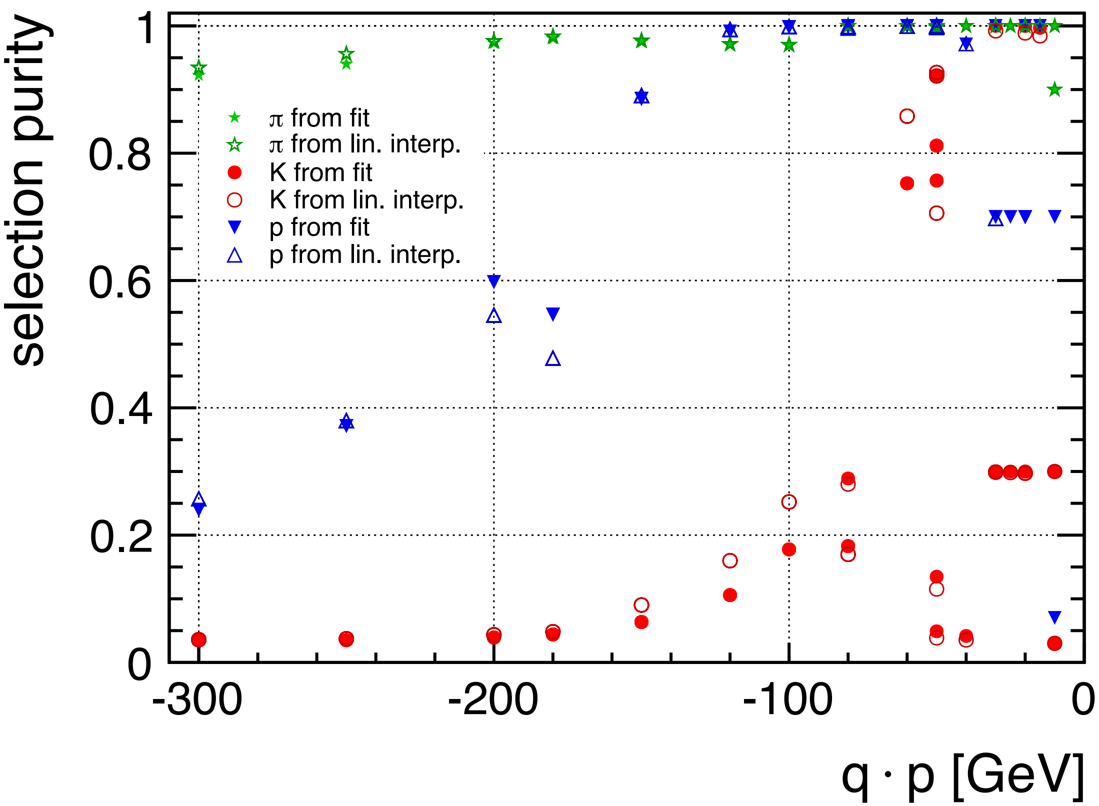
For given Cherenkov selection:
purity(π) = $eff_\pi * n_\pi$ / ($eff_\pi * n_\pi + eff_K * n_K + eff_p * n_p$)

→ for each run chose Cherenkov selection with highest purity

estimates of n_π, n_K, n_p from PARTPROD
(estimating particle content from data not always possible / reliable)

- almost all pion samples pure (>90%)
- high-energy proton samples pure (>~90%), for <50 GeV only ~85%
- anti protons pure only up to 100 GeV
- few runs with pure (>80%) kaon selection: 15-60 GeV

Estimated purities (fixed anti-particle content)



same as before,
but use fixed particle content
for the negative polarity runs:
90% π^-, 7% p^-, 3% K^-

motivated by measurement,
see slide 13

With this assumption:

- slightly reduced π^- purities, but still above 90%

Conclusions

- Cherenkov counters used to obtain pure samples of kaons, protons, kaons for 2011 W-AHCAL analysis (CAN-044, see following talk by Angela)
- observed limitations:
    - accuracy and understanding of calibration
    - non-optimal operation conditions for some runs
    - fluctuations in muon content
    - a-priory unknown particle composition of beams

- Possible improvements for current W-AHCAL (and W-DHCAL) analysis:
    - consistency checks for Cherenkov efficiencies: look at runs with P1=P2
    - improve parameterization of Cherenkov turn-on curve
    - obtain better estimates for particle content of beams (Simulation? Try fit instead of SVD for observed beam content?)

- Possible improvements for future data taking:
    - improve precision of Cherenkov efficiency calibration: more/longer calibration runs, record them also with calorimeter
    - optimize Cherenkov operation settings (aim for higher purity)
    - combine with other detectors for particle ID?

References

LCD-Note-2012-002

Beam tests with the CALICE tungsten analog hadronic calorimeter prototype

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April 25, 2012

Abstract

The CALICE Analog Hadronic Calorimeter prototype has been equipped with layers of tungsten absorber. Together with the MICROMEGAS and T3B experiments the calorimeter was operated in test beams at the CERN PS and SPS with mixed beams of muons, electrons, pions, kaons and protons in an energy range from 1 to 300 GeV. This note describes the experimental configurations and data taking conditions.

LCD-Note-2013-006

Particle Identification with Cherenkov detectors in the 2011 CALICE Tungsten Analog Hadronic Calorimeter Test Beam at the CERN SPS

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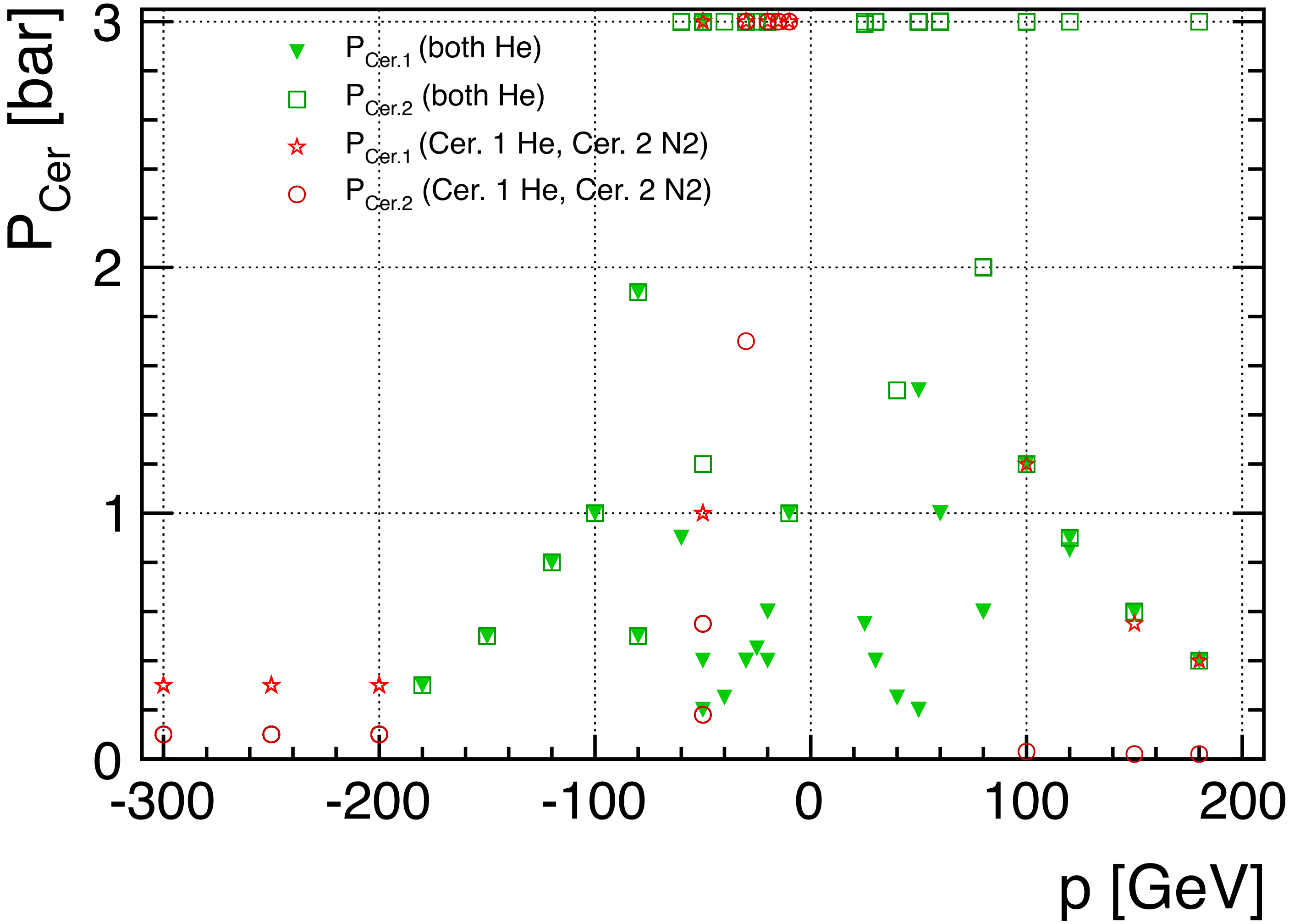
June 19, 2013

Abstract

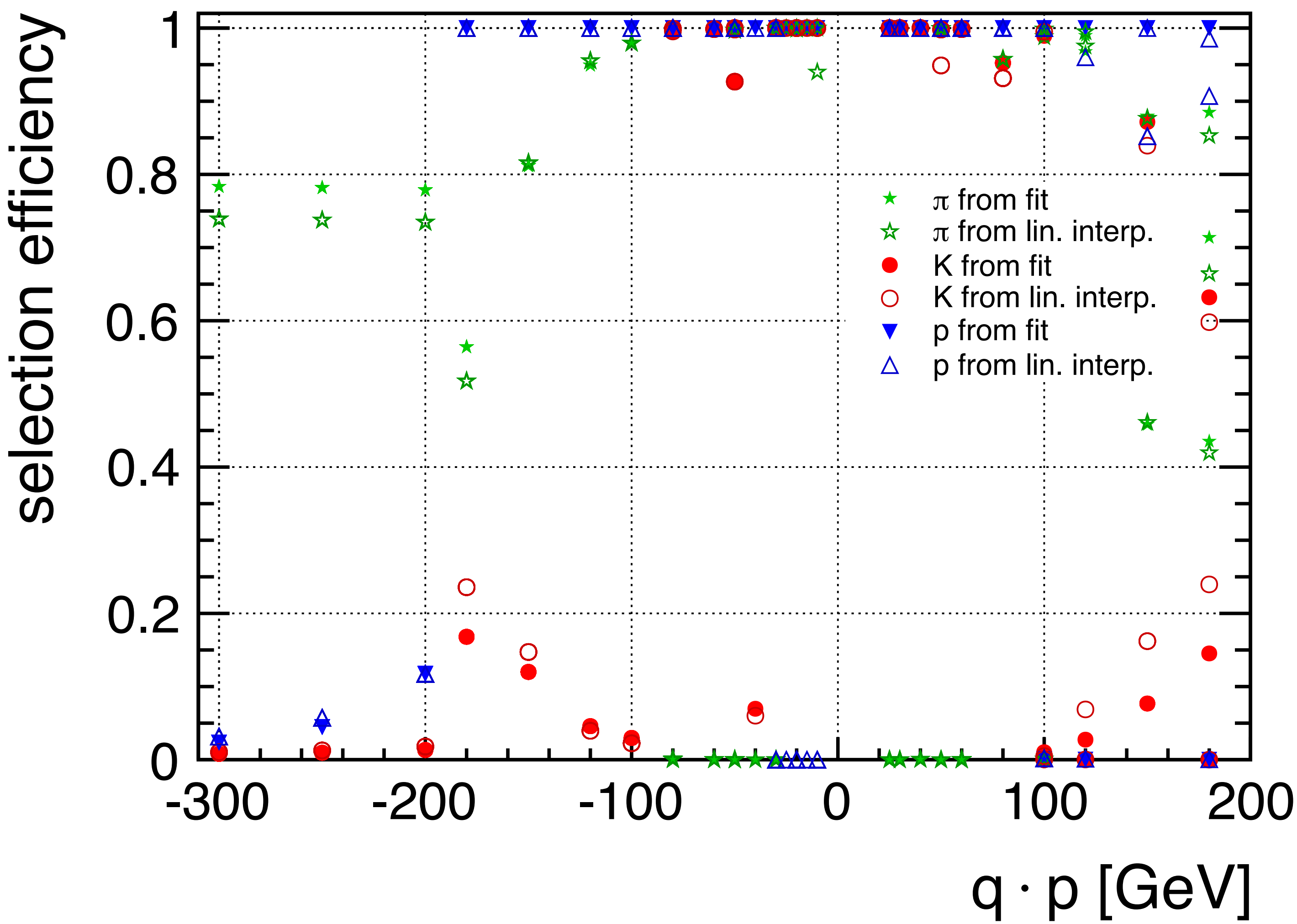
In 2011 the CALICE Tungsten Analog Hadronic Calorimeter prototype (W-AHCAL) was exposed to mixed beams of electrons, pions, kaons and protons with momenta from 10 to 300 GeV in the CERN SPS H8 beam line. The selection of pion, kaon and proton samples is based on the information obtained from two Cherenkov threshold counters. This note presents the strategy for the particle identification, as well as the calibration, operation and analysis of the Cherenkov counters. Efficiency and sample-purity estimates are given for the data selected for the W-AHCAL data analysis.

Additional material

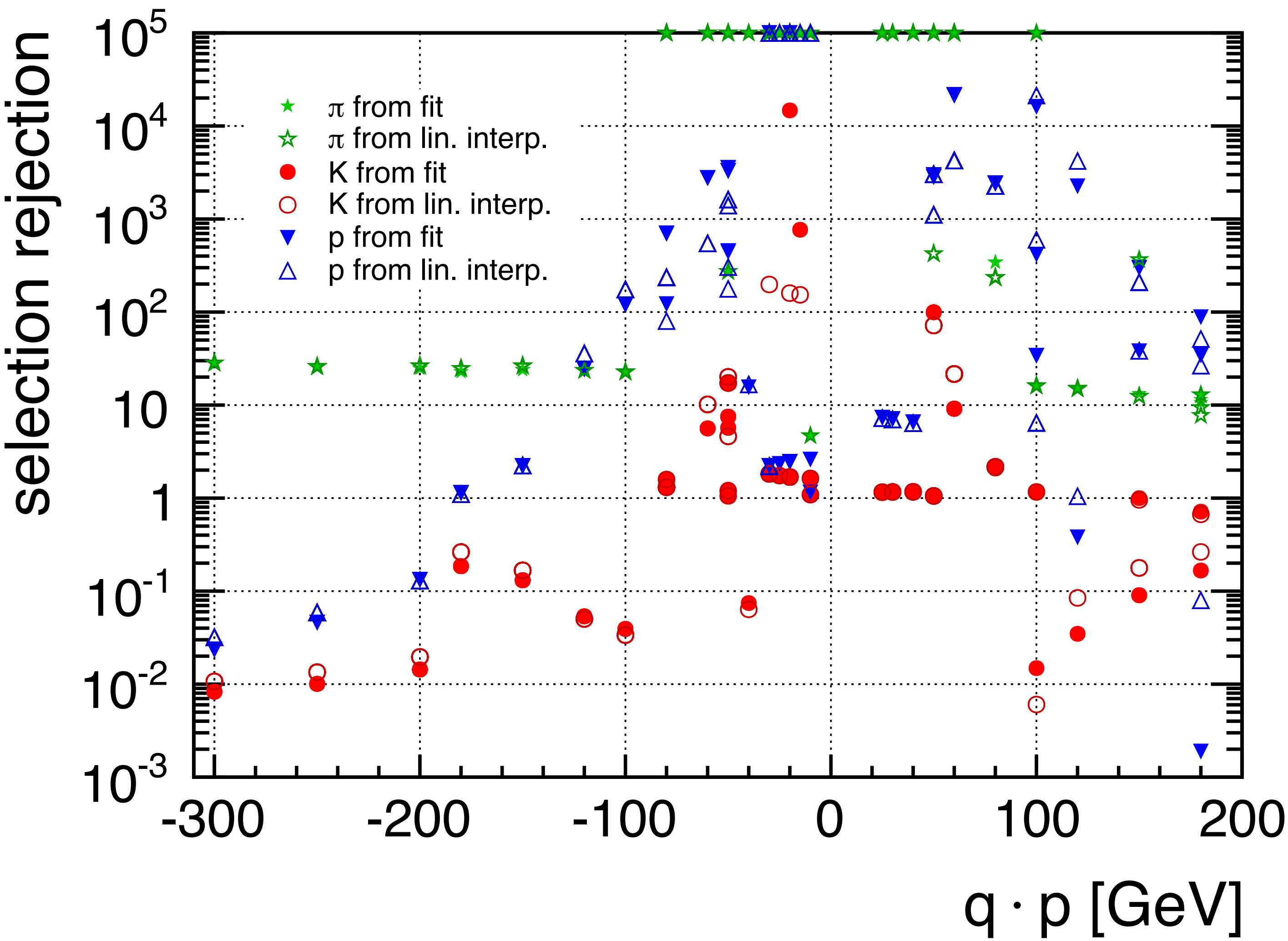
Cherenkov pressure settings



Efficiencies for selections with highest purity



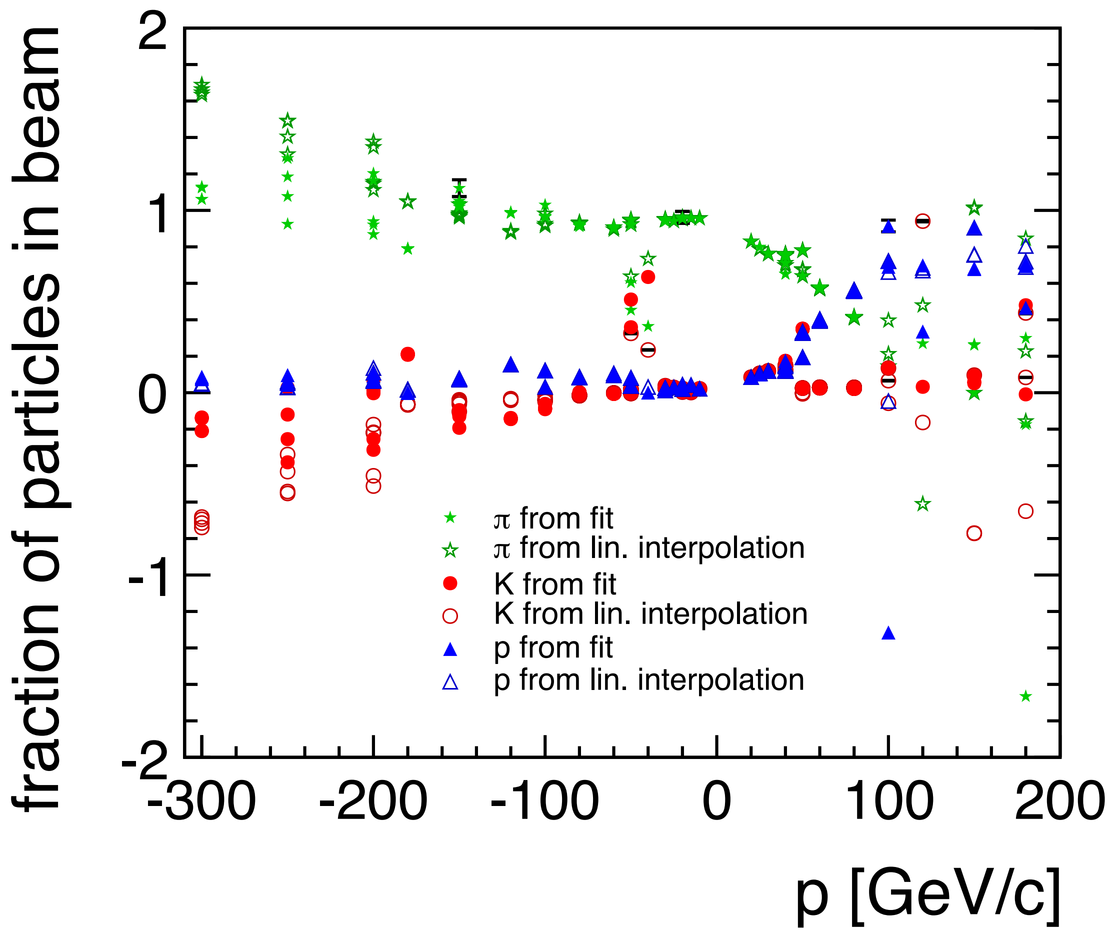
Rejection for selections with highest purity



Rejection power of the event selections corresponding to the highest purity for each run and particle type.

The rejection power is defined as
rej = eff / (1 – purity)
and is set to 10^5 for cases where the purity reaches 100%.

Particle content in data (raw results from SVD)



no constraint on $n_{\pi,K,p} \geq 0$
→ unphysical results for small samples

in general: poor accuracy for cases with bad discrimination / small samples

Pure pion runs

Table 2: Runs with pure (> 80%) pion selection. The quoted purity and efficiency refer to the Cerenkov selections used in the W-AHCAL analysis and correspond to the average of all considered runs, weighted by the number of selected events in each run. Run numbers in bold correspond to runs with tertiary beam setttings.

q ·p [GeV]	# ev. sel.	purity	efficiency	run number - 361000
25	96514	100%	70%	**225 233**
30	151332	100%	70%	**216 217**
40	213184	100%	71%	**214 215**
50	383288	98%	88%	**235 249 250 646** 703 704
60	2014543	100%	99%	**645 659 660 661 664 665 666 667 668 669 670 671 672 673 681 683 719 720 721 722 724 726**
80	1501068	100%	95%	**728 729 730 731 732 733 735 737 738 739 740 741 756 757 758 759 760 761 762 763 765**
100	73466	95%	95%	621 **636 637 747**
120	64902	93%	98%	**643 745**
150	41529	93%	88%	619 **743 744**
180	56579	92%	87%	618 663 742
-10	26830	100%	100%	**471**
-15	105575	100%	100%	**470**
-20	526999	100%	100%	255 256 257 264 469
-25	140139	100%	100%	269
-30	748435	100%	84%	267 270 271 472 473
-40	133575	94%	71%	**253**
-50	1371469	99%	95%	273 274 375 415 479 480 481 482 483
-60	314198	100%	99%	354 356 357
-80	475632	100%	86%	351 376 377 400 416
-100	340177	96%	98%	**341** 352 353 404
-120	280329	96%	95%	358 359 405
-150	391386	97%	81%	360 361 406 407 408 409 410
-180	211185	98%	56%	369 371 372 412
-200	236246	97%	80%	427 428 431 **452 464**
-250	307326	96%	100%	426 434 436 448
-300	550201	97%	100%	424 425 450 451

Pure proton / kaon runs

Table 3: Runs with pure (> 80%) proton selection. The quoted purity and efficiency refer to the Cerenkov selections used in the W-AHCAL analysis and correspond to the average of all considered runs, weighted by the number of selected events in each run. Run numbers in bold correspond to runs with tertiary beam setttings.

q ×p [GeV]	# ev. sel.	purity	efficiency	run number - 361000
25	33559	86%	100%	**225 233**
30	59383	86%	100%	**216 217**
40	106175	85%	100%	**214 215**
50	169775	100%	100%	**235 249 250 646** 703 704
60	1396605	100%	100%	**645 659 660 661 664 665 666 667 668 669 670 671 672 673 681 683 719 720 721 722 724 726**
80	2115700	100%	100%	**728 729 730 731 732 733 735 737 738 739 740 741 756 757 758 759 760 761 762 763 765**
100	205694	100%	100%	621 **636 637 747**
120	152651	99%	100%	**643 745**
150	233756	98%	100%	619 **743 744**
180	180429	96%	100%	618 663 742
-40	7085	94%	100%	**253**
-50	71759	100%	100%	273 274 375 415 479 480 481 482 483
-60	33985	100%	100%	354 356 357
-80	50770	100%	100%	351 376 377 400 416
-100	41815	99%	100%	**341** 352 353 404
-120	53288	96%	100%	358 359 405

Table 4: Runs with pure (> 80%) kaon selection. The quoted purity and efficiency refer to the Cerenkov selections used in the W-AHCAL analysis and correspond to the average of all considered runs, weighted by the number of selected events in each run. Run numbers in bold correspond to runs with tertiary beam setttings.

q ×p [GeV]	# ev. sel.	purity	efficiency	run number - 361000
50	8765	99%	100%	358 359 405 **646** 703 704
60	105331	89%	100%	**645 659 660 661 664 665 666 667 668 669 670 671 672 673 681 683 719 720 721 722 724 726**
-15	141	100%	100%	**470**
-20	576	100%	100%	469
-30	6812	100%	100%	473
-50	18255	89%	98%	479 480 481 482 483
-60	1205	82%	100%	354 356 357