Progress on hadron production in NA61/SHINE

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Outline:
• The NA61/SHINE experiment
• Calibration status
• Φ(1020) meson production
Detector

**BPDs:** for each beam particle: *straight line trajectory*

**TPCs:** for each charged particle: *charge, momentum, mass (dE/dx)*

**TOFs:** for each charged particle: *mass (tof)*

**PSD:** for all particles: *total energy*
p+p data collected in 2009

<table>
<thead>
<tr>
<th>beam energy [GeV]</th>
<th>number of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>2M</td>
</tr>
<tr>
<td>31</td>
<td>3M</td>
</tr>
<tr>
<td>40</td>
<td>6M</td>
</tr>
<tr>
<td>80</td>
<td>4M</td>
</tr>
<tr>
<td>158</td>
<td>4M</td>
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</tbody>
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Liquid Hydrogen Target

selection → 1.7M
BPD calibration Status

- BPD alignment was performed for the whole data set up to 2013. Identified 42 settings of the BPD geometry.
- BPD-TPC alignment was done for 2010 pC and pp, 2011 BeBe.
- A general-purpose production management system was developed, which allowed for significant automation of above steps.
dE/dx calibration status

- Calibration consists of several steps, some of them iterative; has 2 modes – including fit of Bethe-Bloch and using known parametrisation.
  - Initially done largely manually, took several weeks per data set; procedure very error prone.
  - Automated one of legacy substeps, making Bethe-Bloch fitting step 7 times faster.
  - Parallelized and automated whole dE/dx calibration procedure – after fixing Bethe-Bloch, whole chain takes ~2 days of CPU and ~1h of human attention per data set. About 10 times faster than legacy.
  - Done calibration of Bethe-Bloch for 2009 data (9 periods) and full dE/dx calibration for 2011 data (5 periods).
Φ(1020) meson analysis

- The goal is to measure Φ(1020) multiplicities in pp collisions for 5 energies available in NA61 by means of invariant mass spectra fits in the Φ→K⁺K⁻ decay channel.

- Kaons identified with dE/dx → need to correct for PID efficiency → introduced Tag and Probe method.

- NA49 – fully corrected (PID, acceptance, reconstruction, off-target, trigger bias)

- uncorrected – from fit to probe sample

- corrected for PID – from Tag and Probe method
Conclusions

- Calibration almost finished
- Did a lot of automation
- Making steady progress in the $\Phi(1020)$ production analysis
BACKUP
SHINE – SPS Heavy Ion and Neutrino Experiment

- Fixed target experiment in the north area of the CERN SPS
- Beams:
  - Ions (secondary: Be, primary: Ar and Xe) at 13A - 158A GeV/c
  - Hadrons (secondary): p at 13 - 158 GeV/c, \( \pi^- \) at 158 and 350 GeV/c, \( K^- \) at 158 GeV/c
- Based on the upgraded NA49 detector
- Proposal November 2006, pilot run 2007, first physics run 2009, further runs in 2010-2013
- Collaboration of ~150 physicists, 28 institutes, 16 countries
NA61/SHINE physics program

Hadron production in p+p, p+A, h+A, A+A at various energies

- **Heavy ion program - spectra, fluctuations, correlations**
  - search for the critical point of strongly interacting matter
  - study of the properties of the onset of deconfinement
  - study high $p_T$ particles (energy dependence of nuclear modif. factor)

- **Neutrino and cosmic-ray physics programs - precision data on hadron production (spectra)**
  - reference measurements of p+C interactions for the T2K experiment for computing initial neutrino fluxes at J-PARC
  - reference measurements of p+C, p+p, p+C, and K+C interactions for cosmic-ray physics (Pierre-Auger and KASCADE experiments) for improving air shower simulations

- **Considered extensions beyond the approved program**
  - measurements of Pb+Pb collisions for the ion program
    (+ open charm and multi-strange particles, high $p_T$ spectra)
  - measurements for the Fermilab neutrino program
  - measurements for the CERN (LBNO) neutrino program
Status of the NA61 data taking within the heavy ion program

- 2017/18/19:
  - Pb+Pb
  - Xe+La
  - Ar+Ca
  - Be+Be
  - p+Pb
  - p+p

Status of the NA61 data taking within the neutrino and CR programs

- Considered extension of n-program for CERN (LAGUNA-LBNO) and US experiments (MINERnA, MINOS, NOnA and future LBNE)

- p+A
  - A=C, Be, Al, etc.
- K⁺+C
- π⁻+C
- p+C(LT)
- p+C

Legend:
- Green: recorded data
- Light green: pilot (test) data
- Purple: planned data (approved)
- Yellow: beyond the approved program
Kaon candidate selection

- Tracks in detector acceptance passing quality selection
- Accept tracks in +/- 5% band around Kaon Bethe-Bloch curve; area between black curves (PID cut) is accepted as Kaons

$p + p \at 158 \text{ GeV}$
Kaon selection efficiency correction

- Not all K accepted by the cut → loss in φ yield
- Correction method used by NA49
  - $\sigma \rightarrow$ Gaus fits
  - cut: Bethe-Bloch +/- nσ
  - e.g. for n=1.5, efficiency $\epsilon = 87\%$
  - correction = $1/\epsilon^2$
- The other method is the tag and probe method (next slide)

Depends strongly on quality of dE/dx calibration → big systematic errors:

1% bias in Bethe-Bloch → 4% bias in correction, 5% bias in $\sigma$ → 5% in correction
The tag and probe method

- Assuming:
  \[ N_\phi \] — true number of resonances, \( \epsilon \) — PID cut efficiency

- Yields in both samples:
  \[ N_t (N_\phi, \epsilon) = 2N_\phi \epsilon (1 - \epsilon) + N_\phi \epsilon^2 \]
  \[ N_p (N_\phi, \epsilon) = N_\phi \epsilon^2 \]

- Fit is done simultaneously to both distributions with:
  \[
  f(m_{inv}) = \begin{cases}
    N_t (N_\phi, \epsilon) V(m_{inv} - m_\phi; \sigma, \Gamma) + N_{bkg,t} B_t(m_{inv}) & \text{tag sample} \\
    N_p (N_\phi, \epsilon) V(m_{inv} - m_\phi; \sigma, \Gamma) + N_{bkg,p} B_p(m_{inv}) & \text{probe sample}
  \end{cases}
  \]