

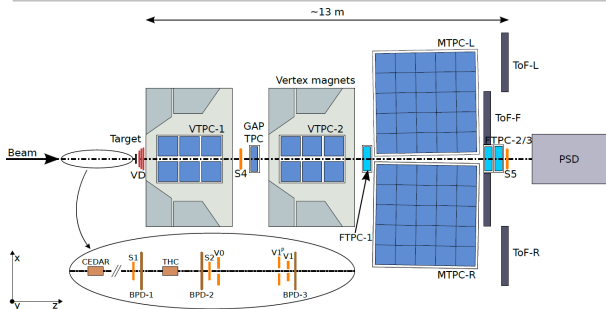


## Latest results from the NA61/SHINE experiment

Dag Toppe Larsen  
for the NA61/SHINE Collaboration

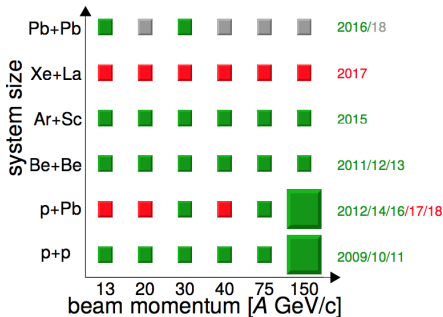
ICCPA at MEPHI/Moscow  
2017-10-03

# Multi-purpose fixed-target experiment at CERN SPS



- ▶ 2D scan of energy and system size to study phase diagram of strongly interacting matter

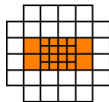
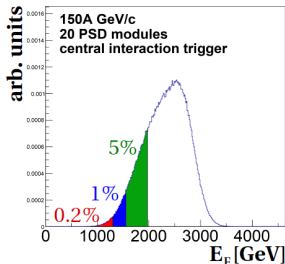
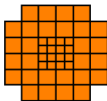
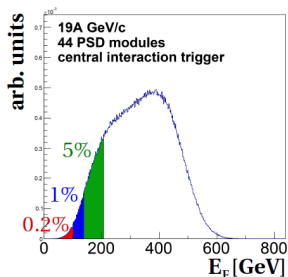
- ▶ Ion beams: Be, Ar, Xe, Pb  
13A – 150A GeV/c
- ▶ Hadron beams:  $\pi$ , K, p  
13 – 400 GeV/c
- ▶ Large acceptance hadron spectrometer: covering full hemisphere down to  $p_T=0$



# Event selection by forward energy measurements

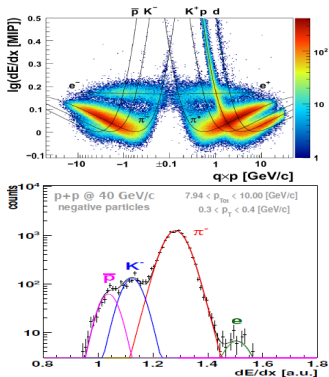


- ▶ Forward energy measured by PSD (Projectile-Spectator Detector) (mostly spectator energy) is used to group events in Forward Energy event classes
- ▶ PSD talk by S. Morozov, Thursday 11:45



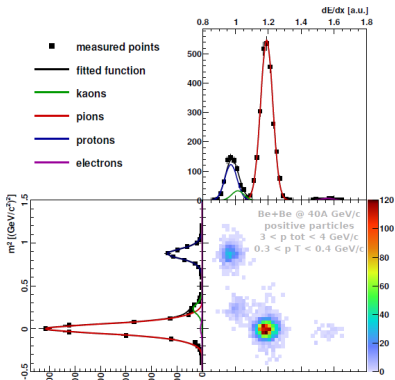
# Charged particle identification

- ▶ dE/dx method – TPC energy loss used for particle identification

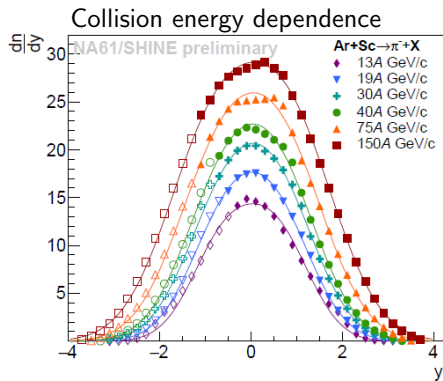


- ▶  $h^-$  method – based on most negatively charged particles being  $\pi^-$ ; contribution of other particles subtracted using EPOS monte-carlo

- ▶ TOF-dE/dx method – estimates number of  $\pi$ , K, p from particle energy loss and time-of-flight measurements

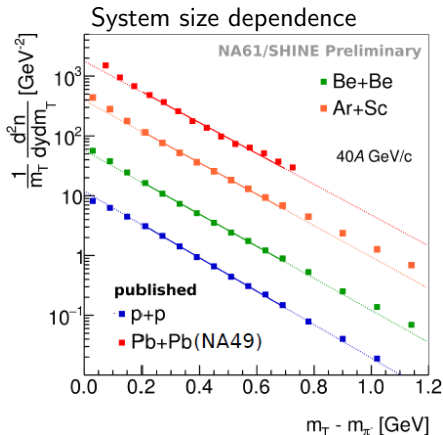


# $\pi^-$ spectra from 2D-scan

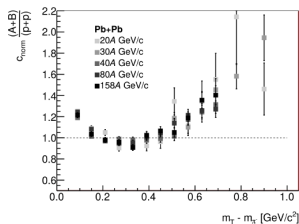
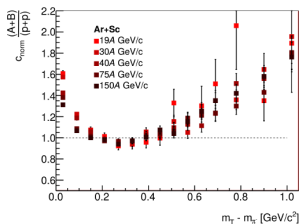
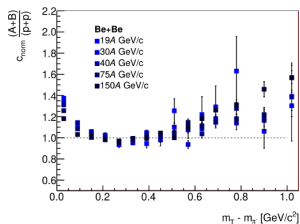


- ▶ Measured in large acceptance:  $p_T$  down to 0 in full forward hemisphere
- ▶  $4\pi$  multiplicity obtainable

- ▶ Rapidity spectra approximately Gaussian, independent of system size or energy



# $\pi^-$ spectra: $m_T$



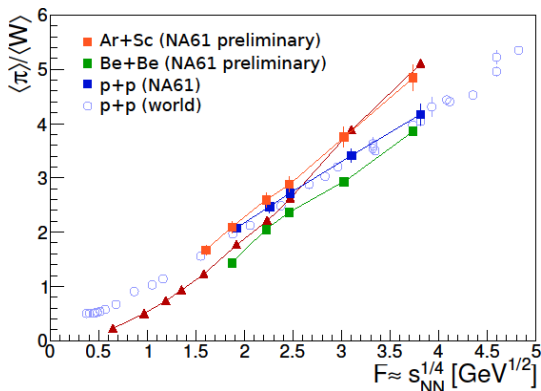
- ▶ Shape differs significantly between p+p and A+A

- ▶ Clear system size dependence, small energy dependence

- ▶ Effect may be attributable to transverse collective flow

# Onset of deconfinement: kink

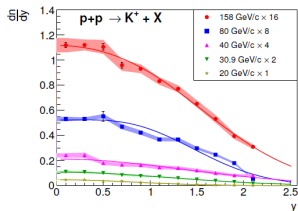
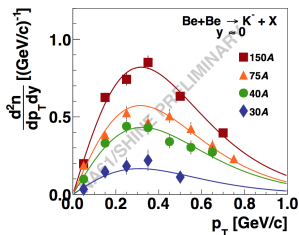
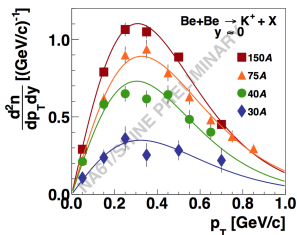
- ▶  $\langle \pi \rangle$  - mean multiplicity in full acceptance
- ▶  $\langle W \rangle$  - mean number of wounded nucleons



- ▶ Slope of energy dependence for heavier systems larger than for lighter systems at high SPS energies

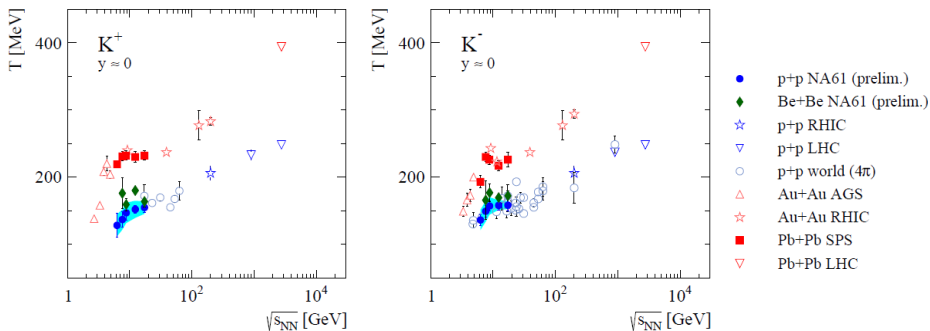
# Onset of deconfinement: step and horn

- ▶ 20% most central events (Be+Be) (according to PSD forward energy)
- ▶ PID by TOF-dE/dx (Be+Be); TOF-dE/dx & dE/dx (p+p)
- ▶ Measurement in wider rapidity range by dE/dx method in progress for Be+Be (already done for p+p)
- ▶  $m_T$  exponential fit used to extrapolate to unmeasured region





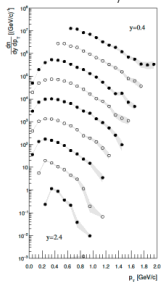
# Onset of deconfinement: step



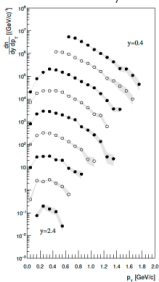
- ▶ Plateau/step in the inverse slope parameter of  $m_T$  spectra in Pb+Pb collisions observed. It is expected for the onset of deconfinement due to mixed phase of HRG and QGP
- ▶ Qualitatively similar structure is visible in p+p and it seems to emerge in Be+Be
- ▶ Be+Be slightly above p+p

# $K^+$ and $K^-$ from $Ar+Sc$

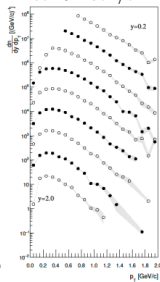
$Ar+Sc \rightarrow K^+ + X$   
at 30A GeV/c



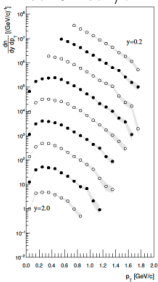
$Ar+Sc \rightarrow K^- + X$   
at 30A GeV/c



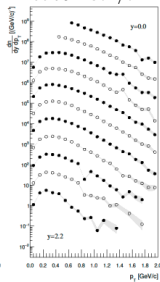
$Ar+Sc \rightarrow K^+ + X$   
at 40A GeV/c



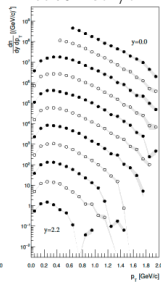
$Ar+Sc \rightarrow K^- + X$   
at 40A GeV/c



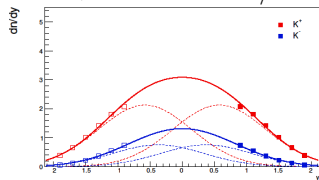
$Ar+Sc \rightarrow K^+ + X$   
at 75A GeV/c



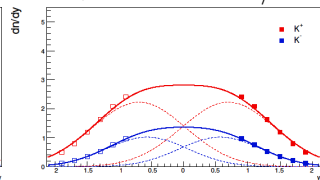
$Ar+Sc \rightarrow K^- + X$   
at 75A GeV/c



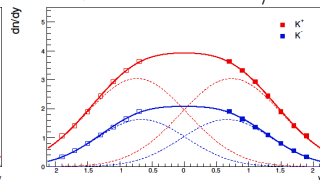
$Ar+Sc$  at 30A GeV/c



$Ar+Sc$  at 40A GeV/c

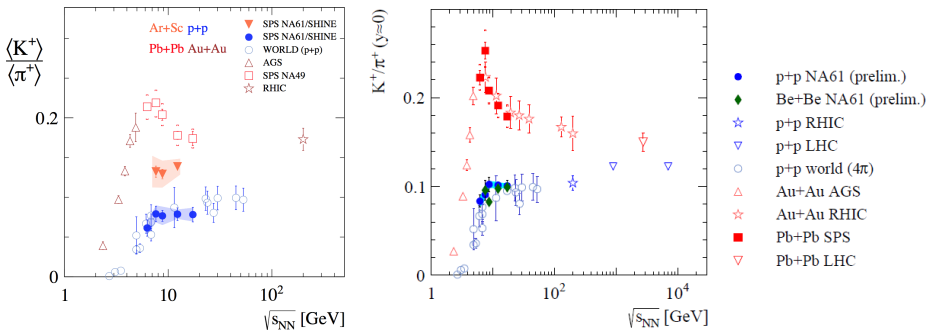


$Ar+Sc$  at 75A GeV/c



► Results fitted by double Gaussian with Pb+Pb parameters

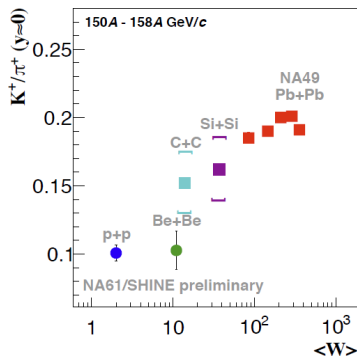
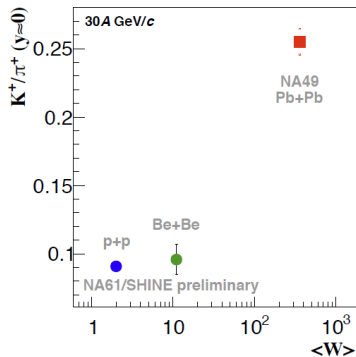
# Onset of deconfinement: horn



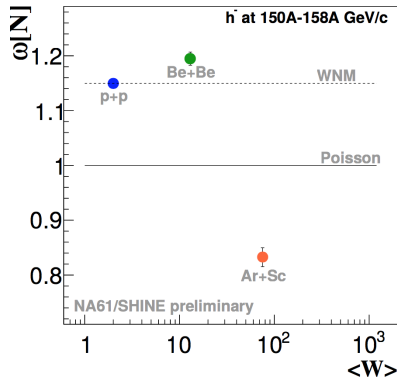
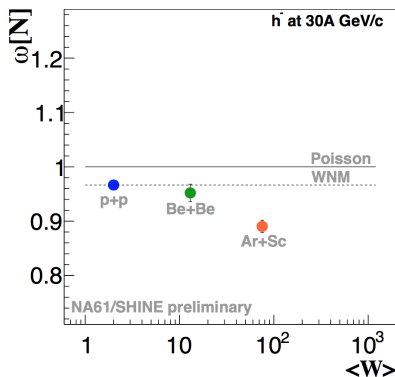
- ▶ Rapid changes in  $K^+/\pi^+$  (horn) observed in Pb+Pb collisions. Predicted as a signature of onset of deconfinement
- ▶ Plateau-like structure visible in p+p
- ▶ Be+Be close to p+p
- ▶  $\langle K^+ \rangle / \langle \pi^+ \rangle$  in Ar+Sc between p+p and Pb+Pb dependence of collision energy

# System size dependence of $K^+/\pi^+$

- ▶ Surprisingly Be+Be results are very close to p+p independent of collision energy
- ▶ As in the case of multiplicity fluctuations data suggest a jump between light and heavy systems



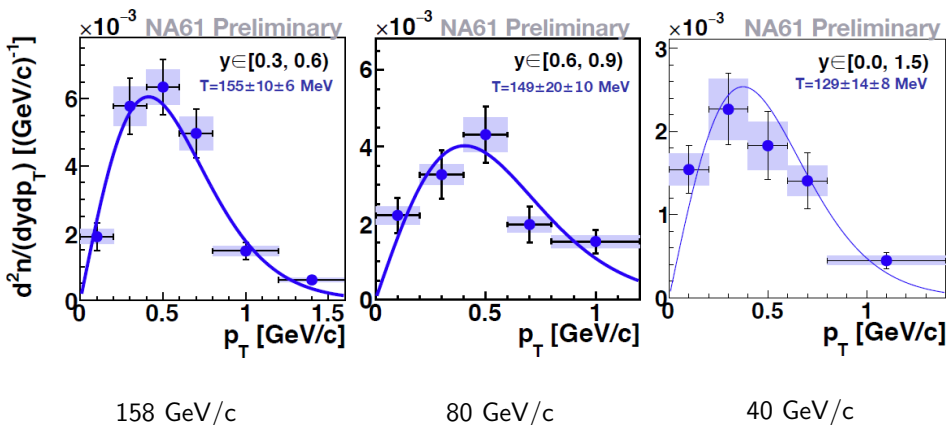
# System size dependence: multiplicity fluctuations



- ▶ Be+Be results close to p+p and significantly higher than Ar+Sc
- ▶  $\omega[N]$  decreases with the system size  $\rightarrow$  not expected in ideal Boltzmann gas, grand canonical ensemble (Poisson) or the wounded nucleon model (p+p)
- ▶ Fluctuation talk by A. Seryakov, Thursday 18:50

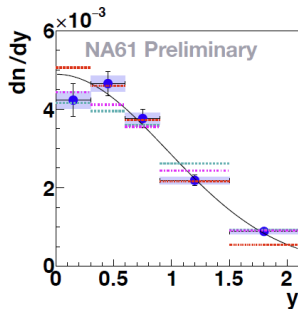
# $\Phi(1020)$ in p+p

- ▶ First measurement of production in p+p interactions at 40 and 80 GeV/c, more detailed and precise measurement at 158 GeV/c

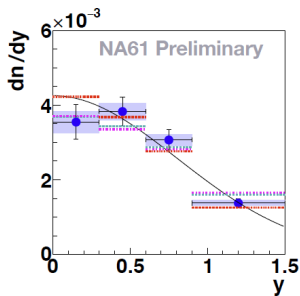


# $\Phi(1020)$ in p+p: rapidity spectra

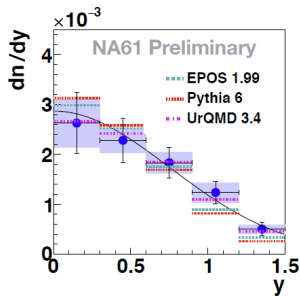
- ▶ Large coverage in rapidity, shape approximately described by Gaussian (black curve)
- ▶ Models approximately describe spectra shape (models normalised to the integral of data)



158 GeV/c

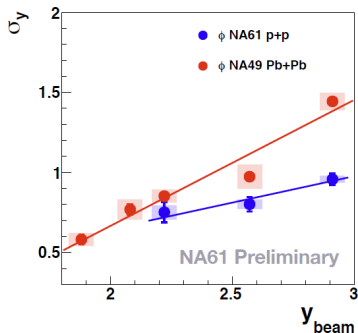
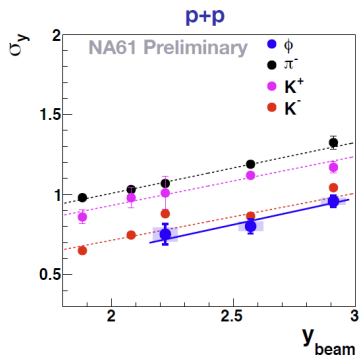


80 GeV/c



40 GeV/c

# $\phi(1020)$ in p+p: width of rapidity

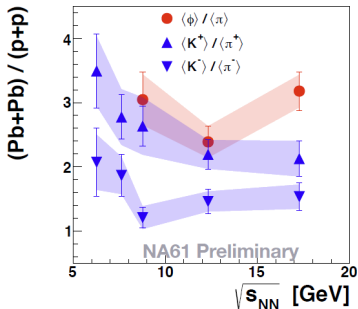
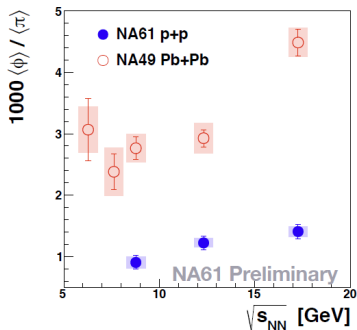


- ▶  $\sigma_y$  in p+p follows the trend of other hadrons
- ▶  $\sigma_y$  in p+p and Pb+Pb exhibit different  $y_{beam}$  dependence



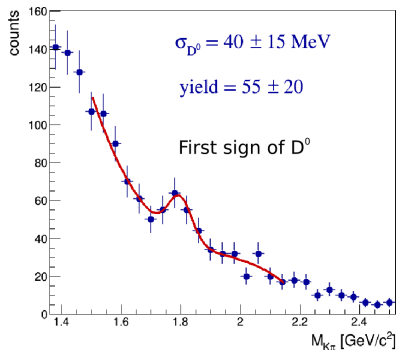
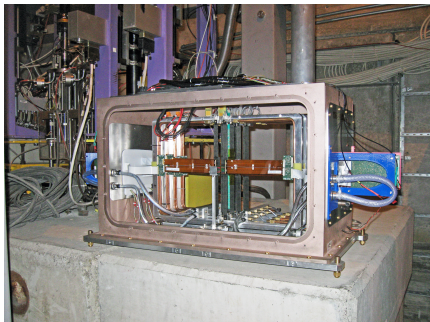
## $\Phi(1020)$ in p+p: $\sqrt{s_{NN}}$ dependence

- ▶  $\langle\Phi\rangle/\langle\pi\rangle$  in p+p increases with  $\sqrt{s_{NN}}$
- ▶  $\langle\Phi\rangle/\langle\pi\rangle$  ratio about 3x larger in Pb+Pb collisions independently of interaction energy
- ▶ Enhancement of  $\langle\Phi\rangle/\langle\pi\rangle$  ratio is close to  $\langle K^+\rangle/\langle\pi^+\rangle$ , larger than for  $\langle K^-\rangle/\langle\pi^-\rangle$



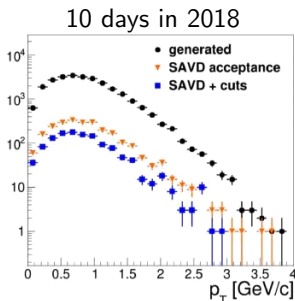
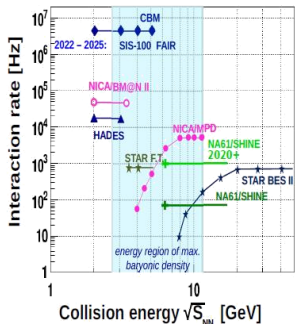
# New Vertex Detector

- ▶ Small Acceptance Vertex Detector introduced to NA61/SHINE in 2016 for Open Charm measurements
- ▶ Pb+Pb 158 GeV/c (pilot) (2016), Xe+La (2017), Pb+Pb (2018)
- ▶ Upgraded Large Acceptance Vertex Detector expected to be introduced in 2021

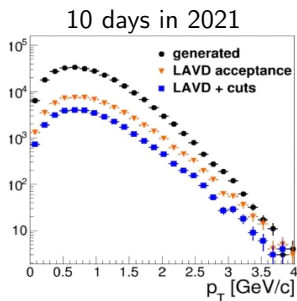


- ▶ Vertex Detector talk by A. Merzlaya, today 18:45, Petrovsky hall

# NA61/SHINE in 2021–2024



3000  $D^0$  in 4M events



40000  $D^0$  in 40M events

- ▶ Several detector upgrades during long shutdown 2019-2020
- ▶ TPC read-out electronics upgraded from 100Hz  $\rightarrow$  1kHz
- ▶ Upgraded Large Acceptance Vertex Detector
- ▶ Improved Time-Of-Flight and Projectile-Spectator Detector
- ▶ Improved beam intensity

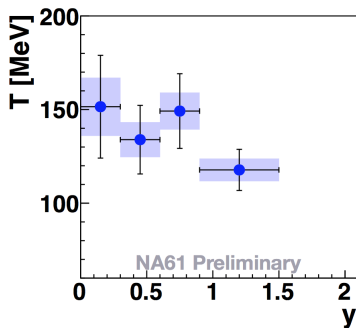
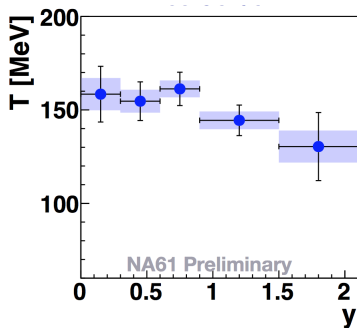
# Summary and outlook

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- ▶ NA61/SHINE performs the unique system size vs energy scan for systematic study of the phase diagram of strongly interacting matter
- ▶ p+p, Be+Be and Ar+Sc data collected and being analysed
- ▶ Unexpected system size dependence of  $K^+/\pi^+$  ratio observed in p+p and Be+Be
  
- ▶ Measurement of Xe+La collisions in 2017 and Pb+Pb collisions in 2018 with new Vertex Detector for Open Charm measurement
  
- ▶ Plans to extend NA61/SHINE program with measurements of Open Charm and multi-strange hyperon production in 2021-2024

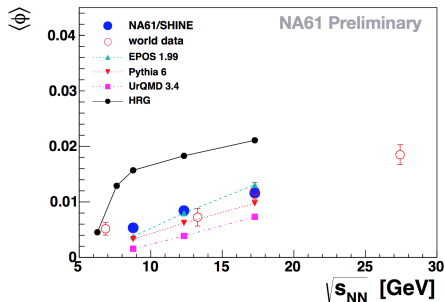
Backup

## $\Phi(1020)$ in p+p: inverse slope parameter



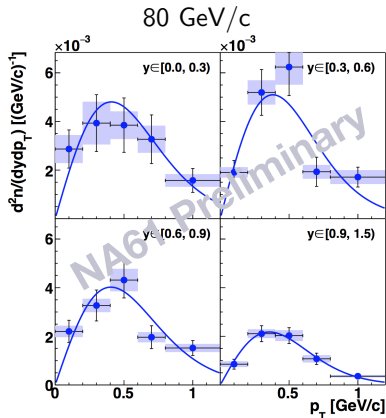
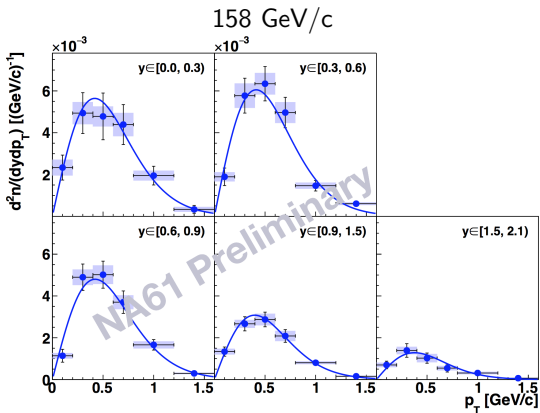
- ▶ Inverse slope parameters of  $m_T$  spectra are in the range 120 - 160 MeV, decreasing with rapidity
- ▶ The systematic uncertainty is shown by a blue shaded box, horizontal error bars indicate width of the rapidity bins

# $\Phi(1020)$ in p+p: world data and models



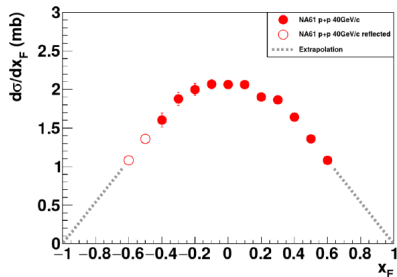
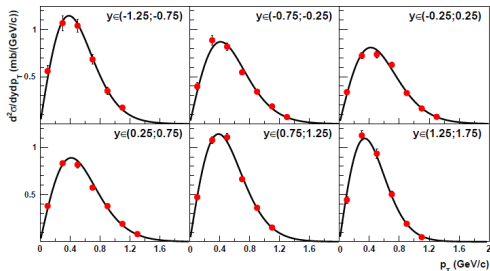
- ▶ Results consistent with world data
- ▶ EPOS close to data, Pythia underestimates experimental data, UrQMD underestimates 2x
- ▶ HRG (V. Vovchenko, V. V. Begun, M. I. Gorenstein, Phys.Rev. C93 (2016) 064906)
  - ▶ Canonical ensemble,  $\pi^\pm$ ,  $K^\pm$ , anti-protons used in the fit,  $\gamma_S$  included; overestimates yield 2x

# $\Phi(1020)$ in p+p: $p_T$ spectra





# $\Lambda$ in p+p at 40 GeV/c

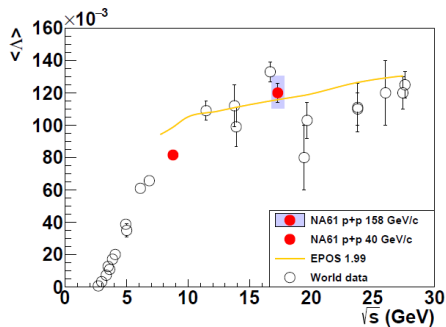


- ▶ Solid lines:  
exponential fit

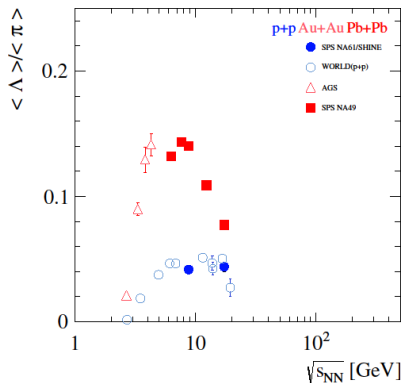
- ▶ Dotted lines:  
extrapolation to  $4\pi$

# $\Lambda$ in p+p

- ▶ NA61 data agrees with, and improves, world data



- ▶ EPOS overestimates  $\Lambda$  at 40 GeV/c



- ▶ A+A collisions at AGS and NA49 show different behaviour than p+p due to baryon density