System size and energy dependence of proton rapidity spectra from NA61/SHINE at the CERN SPS

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for the NA61/SHINE collaboration

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1. Introduction
2. NA61/SHINE experiment
3. Experimental methods and techniques for particle identification
4. NA61/SHINE experimental results and comparison with world data and models
5. Conclusions

Protons and the onset of deconfinement

Protons at SPS energies:

- relatively abundant among products of nuclear collisions,
- relatively easy to identify (mass is significantly larger than π and K masses),
- rapidity distributions are weakly affected by processes at the final stages of collisions,
- **rapidity distributions were suggested to be sensitive to the onset of deconfinement**.

Ivanov, PLB 690 (2010) 358

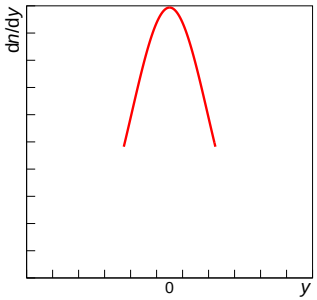
“Peak-dip-peak-dip” irregularity in p rapidity spectra

Reason of irregularity – onset of deconfinement!

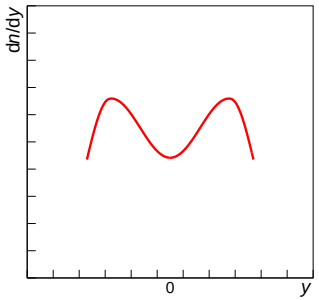
For the EoS with a phase transition:

$\sqrt{s_{NN}}_1$ < $\sqrt{s_{NN}}_2$ < $\sqrt{s_{NN}}_3$ < $\sqrt{s_{NN}}_4$

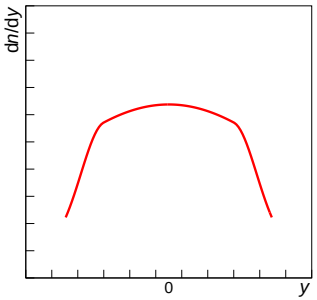
peak dip peak dip



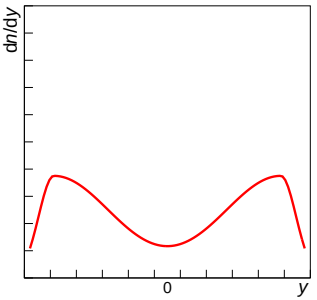
stiff EoS – spherical fireball



softest point region of the EoS – deformed fireball



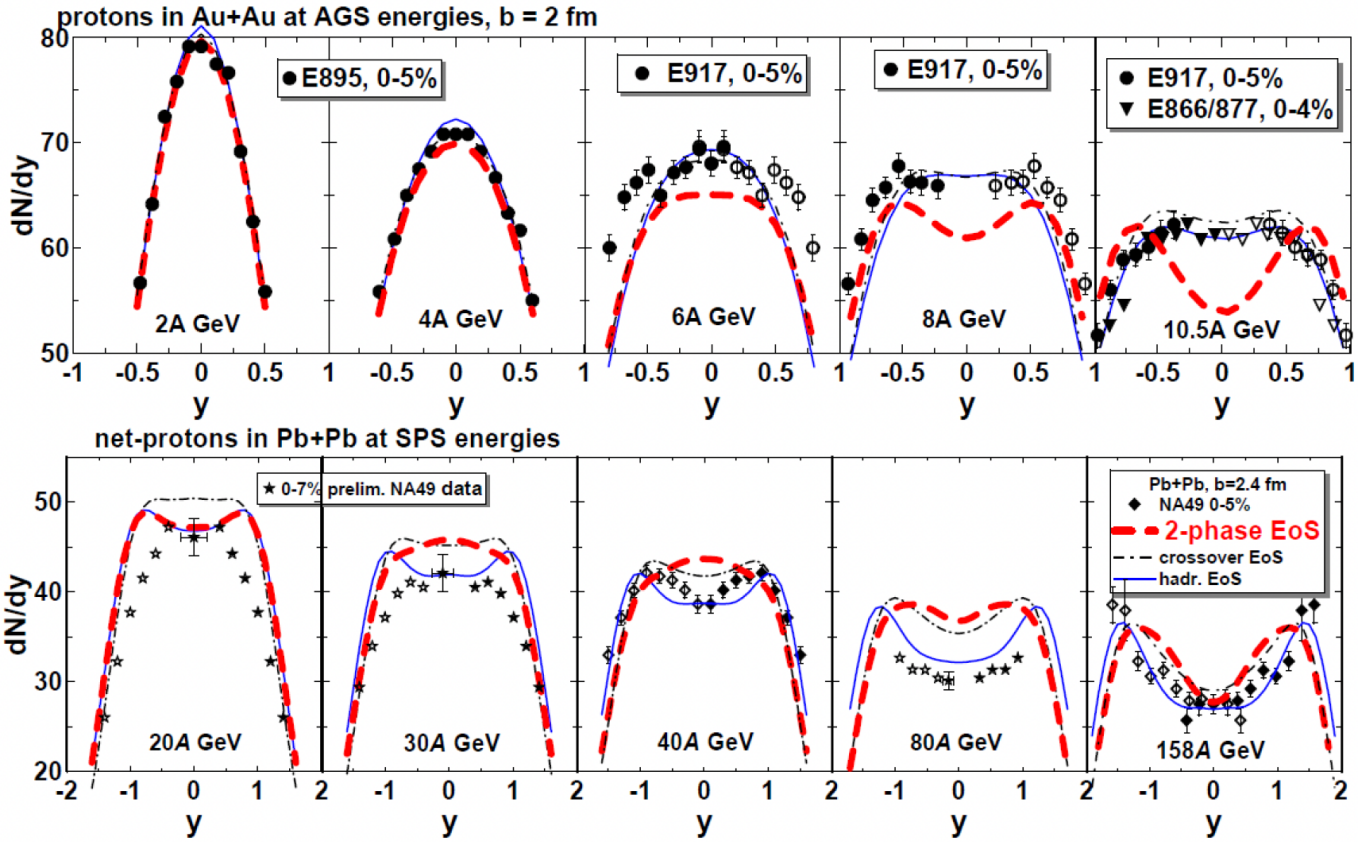
stiffness of the EoS grows – less deformed fireball



kinetic pressure overcomes stiffness of the EoS – deformed fireball

Ivanov, Blaschke, EPJ A (2016) 52: 237

“Peak-dip-peak-dip” irregularity in p rapidity spectra

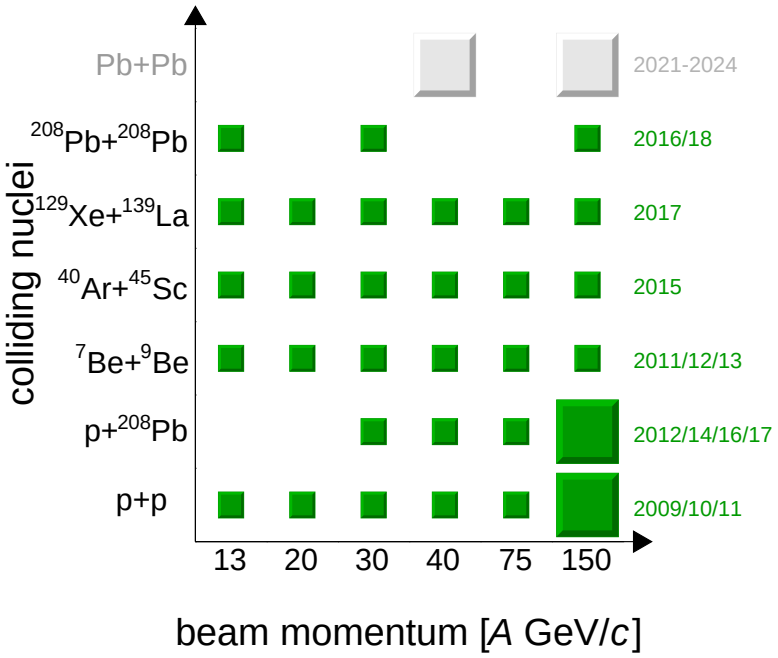


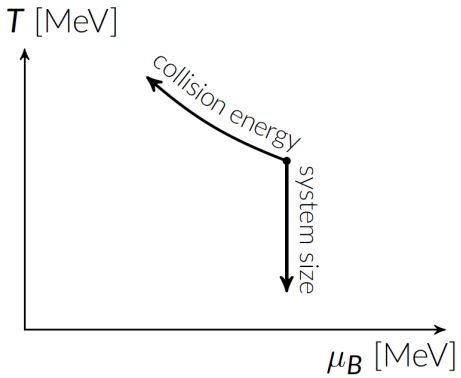
“Peak-dip-peak-dip” irregularity exists for experimental proton spectra.

Ivanov, Blaschke, EPJ A (2016) 52: 237

NA61/SHINE – fixed target experiment at CERN SPS

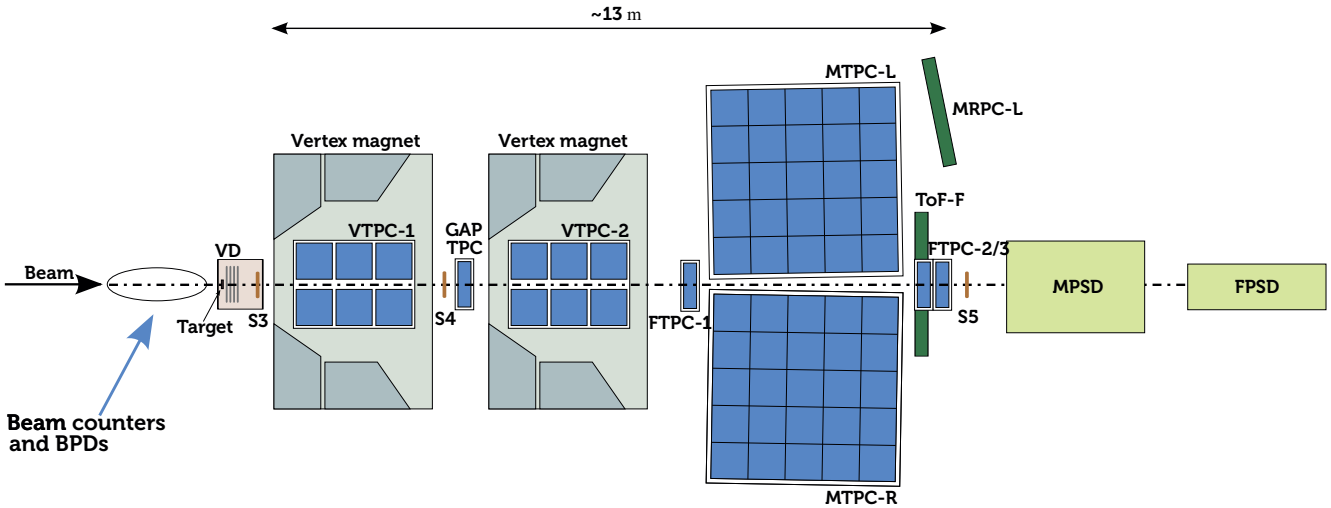
NA61/SHINE's strong interaction programme – 2D scan in collision energy and mass of the colliding nuclei.





PRC 73, 044905 (2006)

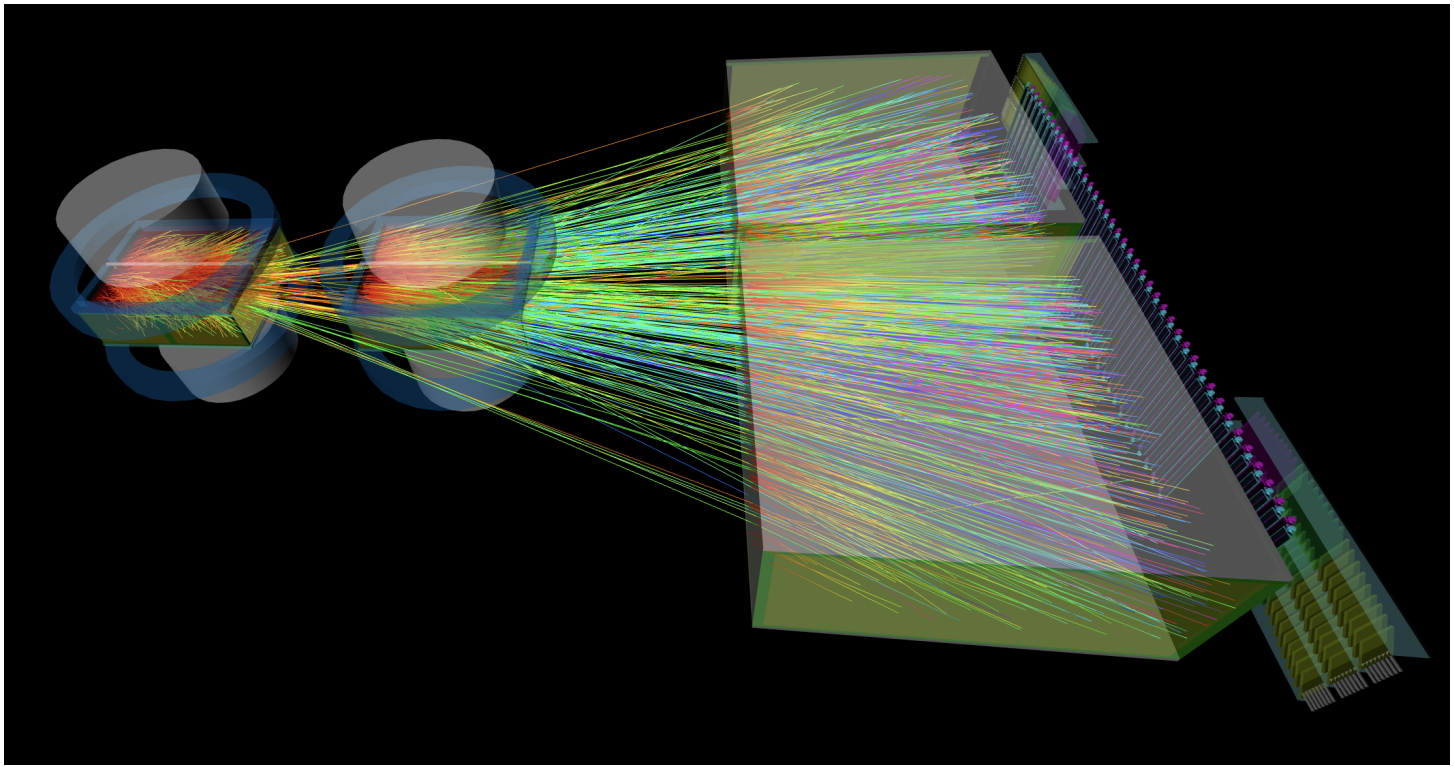
Layout of the NA61/SHINE experimental setup



Large acceptance hadron spectrometer

– coverage of the full forward hemisphere, down to $p_T = 0.0$

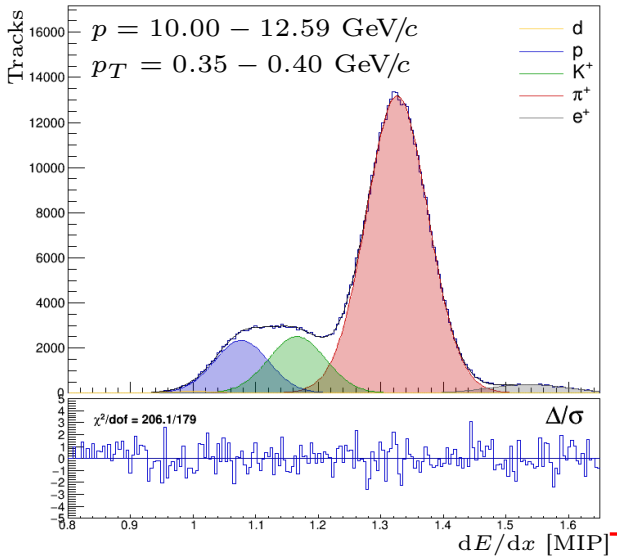
3D visualization of the collision

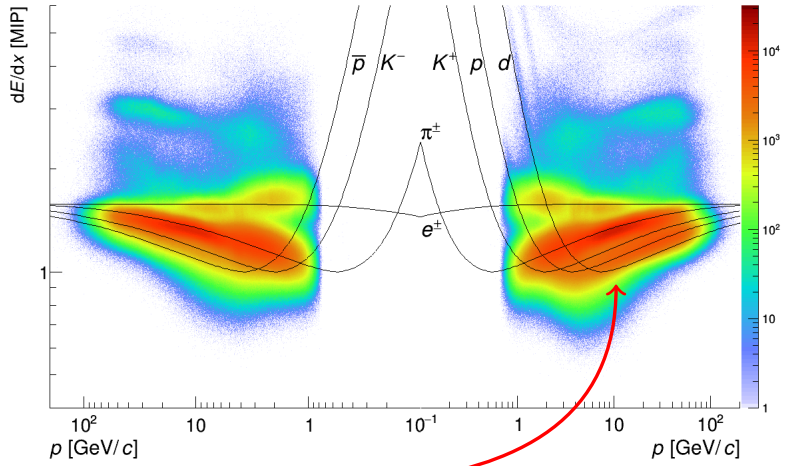


3D visualization of ^{129}Xe + ^{139}La collision at 150A GeV/c: shine3d.web.cern.ch

Particle identification — $\mathrm{d}E\,/\,\mathrm{d}x$

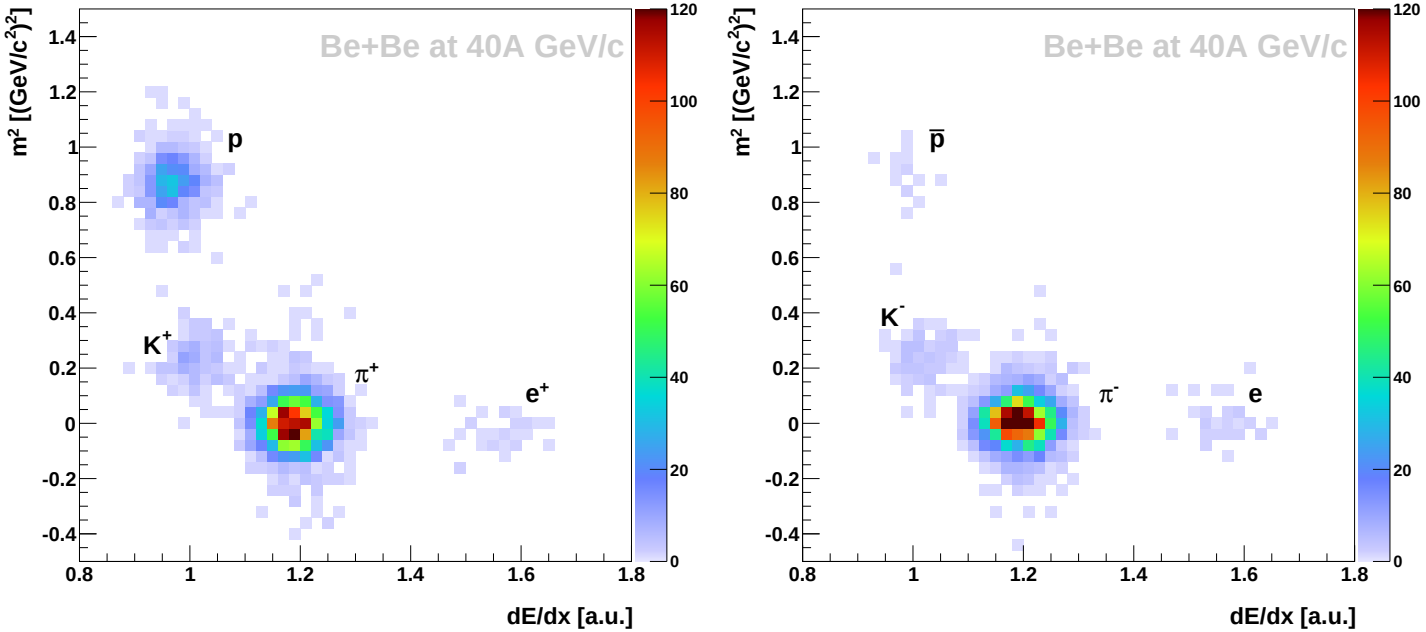
Xe+La at 150A GeV/c





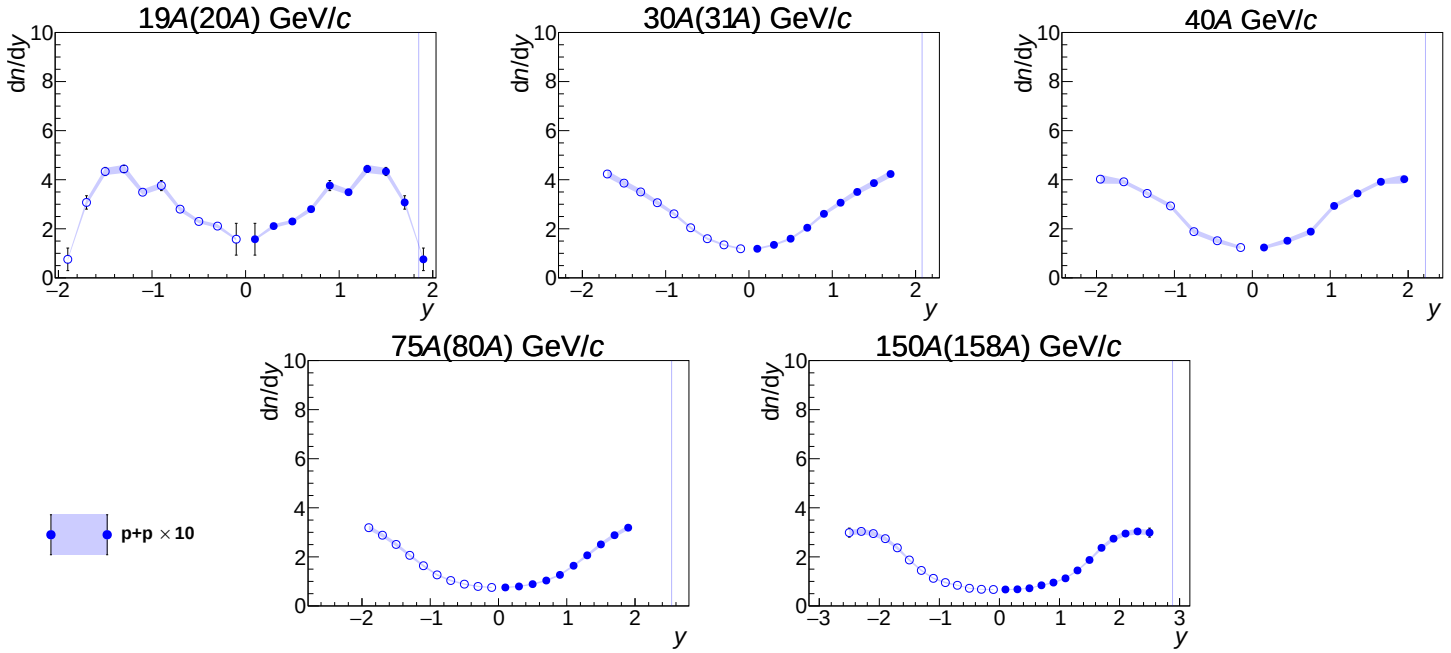
Only for momenta $\gtrsim 5$ GeV/c

Particle identification – $\mathrm{d}E\,/\,\mathrm{d}x$ + *tof*



For momenta $\lesssim 5$ GeV/c

dn/dy spectra of protons

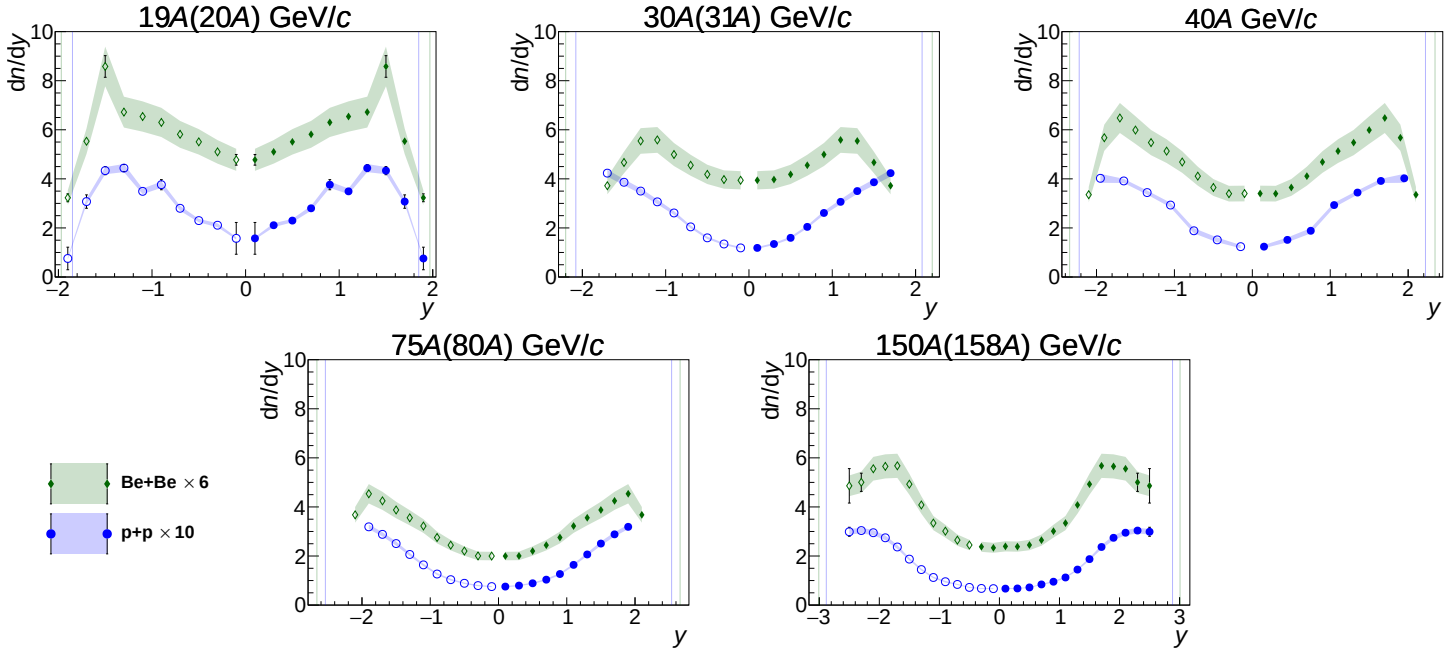


"Dip" for p+p at all energies.

p+p: NA61/SHINE, EPJ C 77 (2017) 671

Vertical lines – beam rapidity.

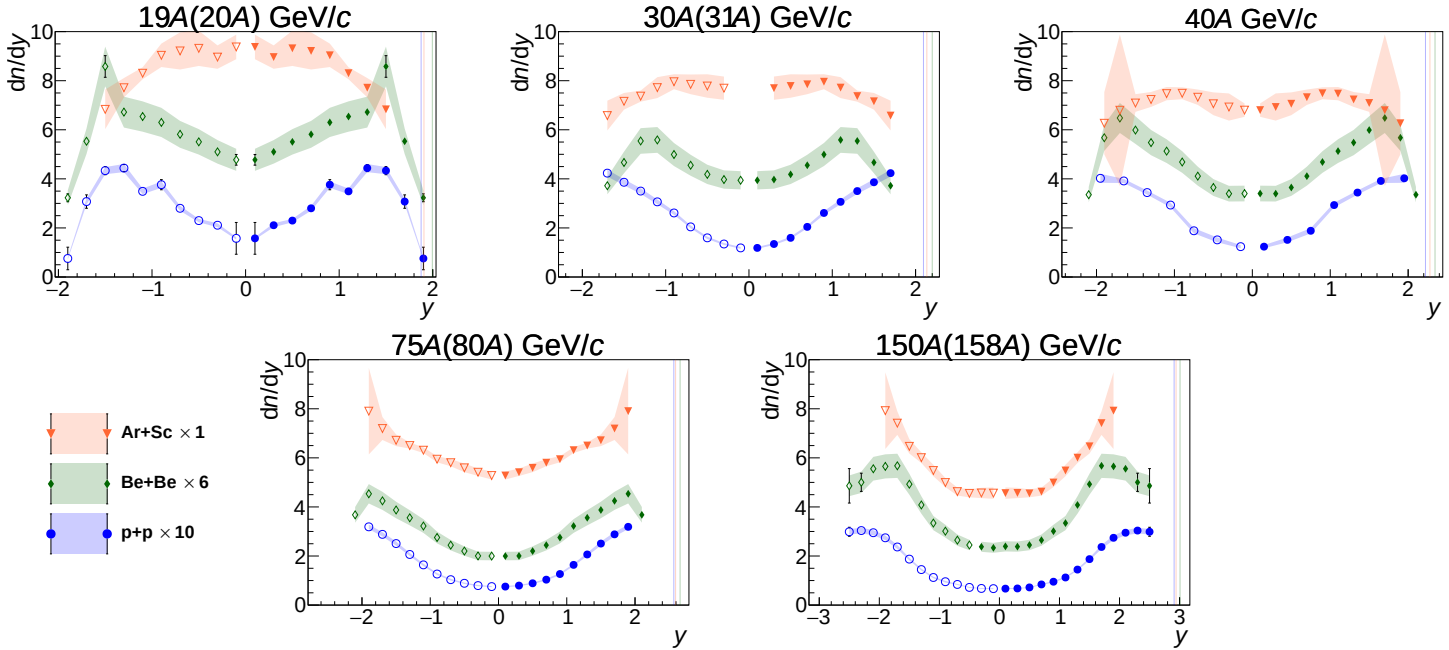
dn/dy spectra of protons



"Dip" for p+p and Be+Be at all energies.

p+p: NA61/SHINE, EPJ C 77 (2017) 671
Be+Be: NA61/SHINE, EPJ C 80 (2020) 961

dn/dy spectra of protons

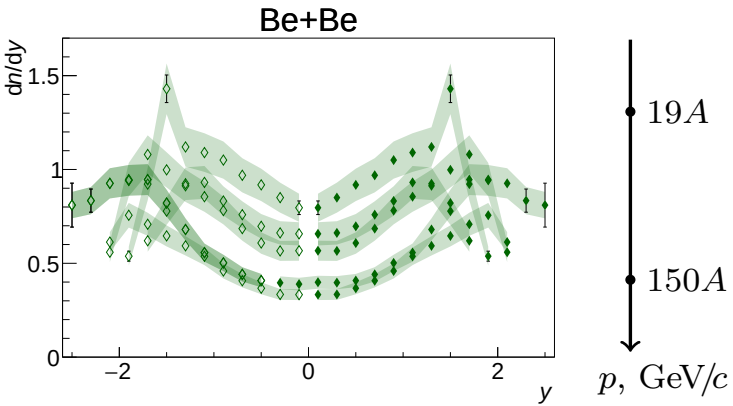


"Dip" for p+p and Be+Be. "Peak-dip" transition for Ar+Sc.

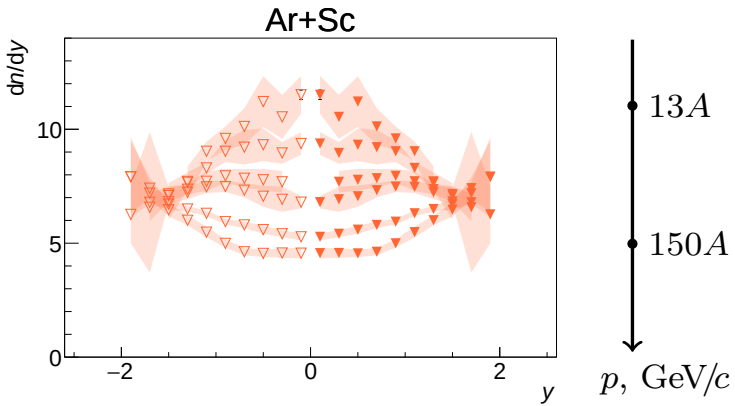
p+p: NA61/SHINE, EPJ C 77 (2017) 671
Be+Be: NA61/SHINE, EPJ C 80 (2020) 961
Ar+Sc: NA61/SHINE preliminary

dn/dy spectra of protons

Two classes of collisions:

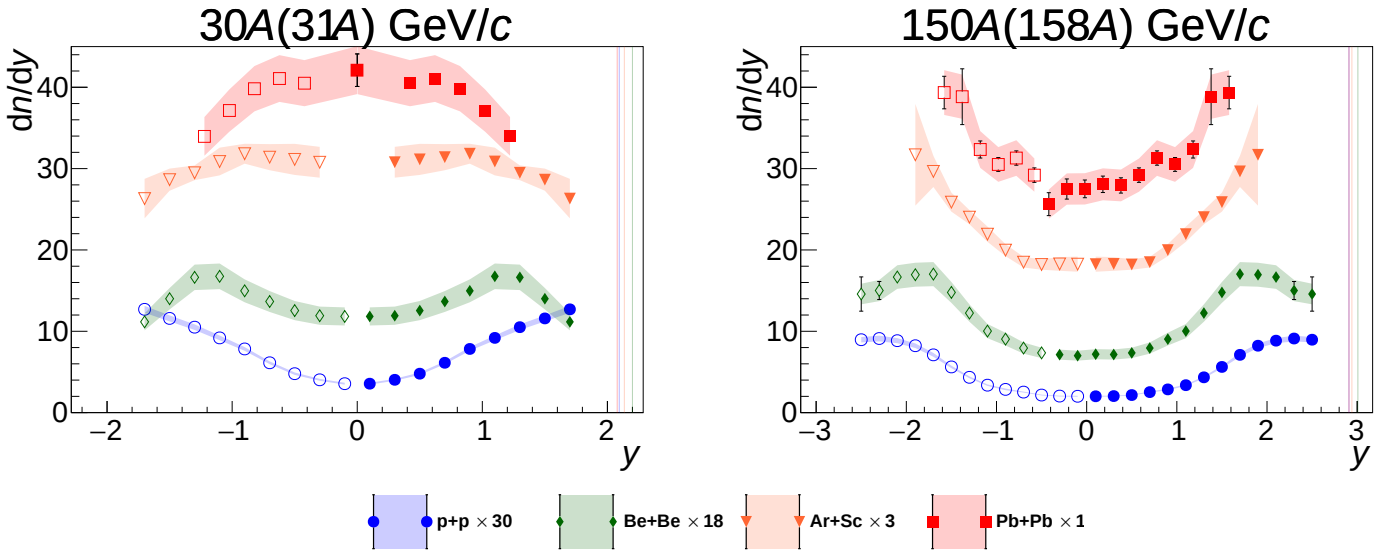


"Dip" for small systems:
p+p and Be+Be



"Peak-dip" transition for medium size system: Ar+Sc

Comparison of NA61/SHINE data with Pb+Pb world data



- "Peak-dip" transition is observed medium and heavy systems: Ar+Sc and Pb+Pb within SPS energy range.
- No such transition for small systems: p+p and Be+Be.

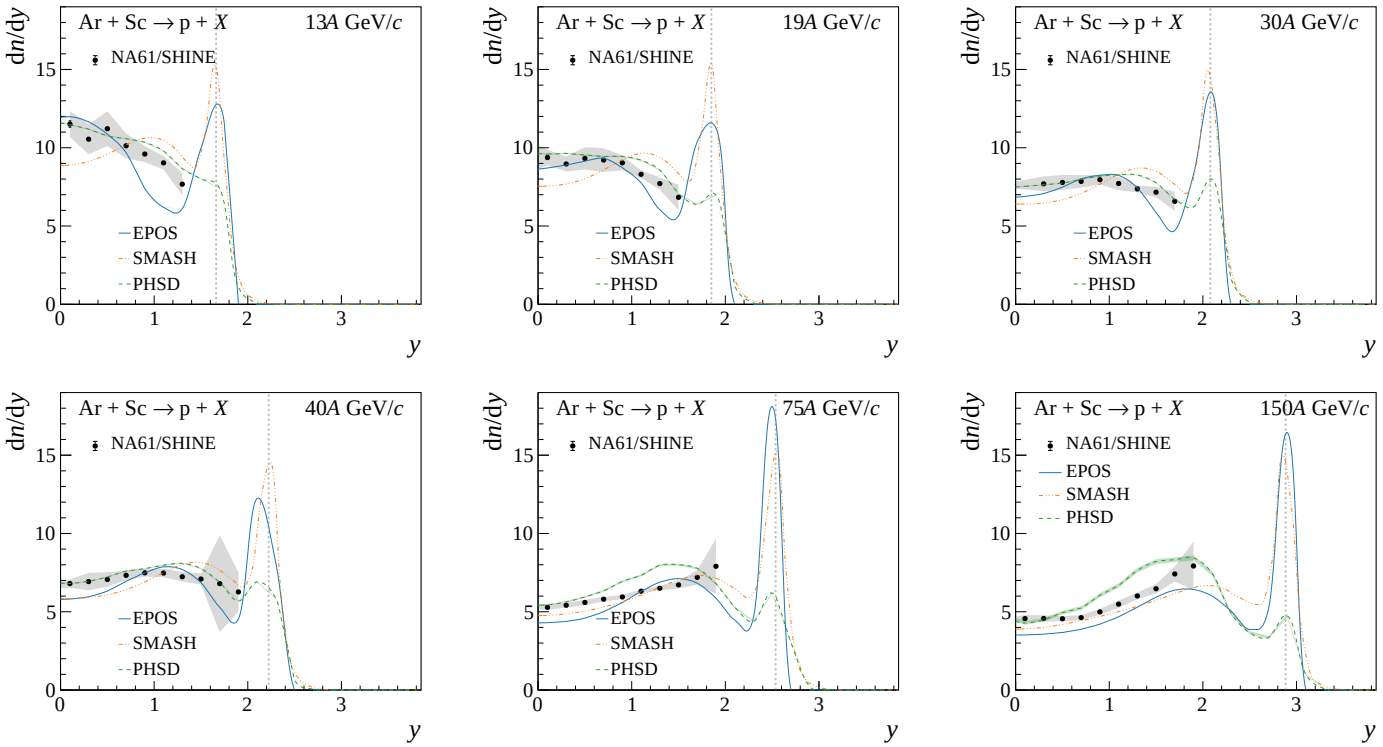
Pb+Pb at 30A GeV/c: NA49 preliminary
Pb+Pb at 150A GeV/c: NA49, PRC 83 (2011) 014901

System size and energy dependance of the shape of proton dn/dy spectra

p, GeV/c	$\sqrt{s_{NN}}$, GeV	p+p	Be+Be	Ar+Sc	Pb+Pb
13A (10.5A)	5.1	–	–	peak	flat?
20A (19A)	6.3	dip	dip	flat?	flat?
31A (30A)	7.7	dip	dip	flat?	peak
40A	8.8	dip	dip	flat?	dip
80A (75A)	12.3	dip	dip	dip	dip
158A (150A)	17.3	dip	dip	dip	dip

- "Peak-dip" transition is observed medium and heavy systems: Ar+Sc and Pb+Pb within SPS energy range.
- No such transition for small systems: p+p and Be+Be.

Comparison of dn/dy spectra with models for Ar+Sc



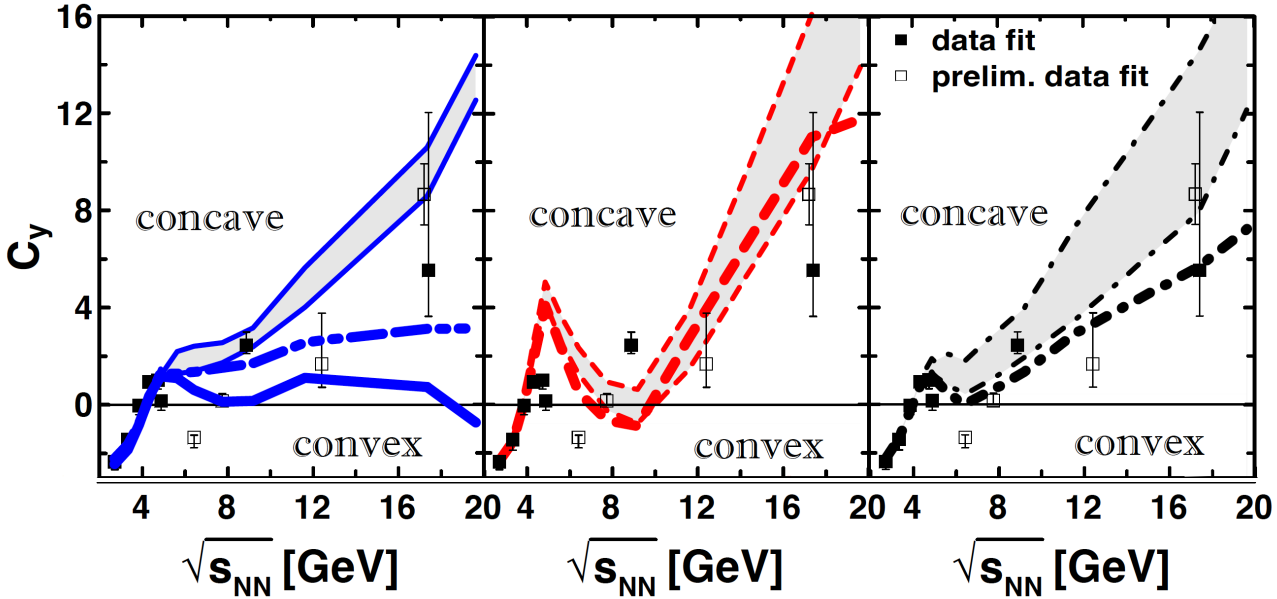
PHSD reproduces behaviour of dn/dy spectra for Ar+Sc.

Conclusions

- Data for p+p, ^{7}Be+^{9}Be and ^{40}Ar+^{45}Sc collisions from NA61/SHINE at $\sqrt{s_{NN}} = 5.1 - 17.3$ GeV were presented.
- Evolution of the shape of the rapidity distribution of protons as a function of system size and collision energy was studied.
- **"Peak-dip" transition is observed for Ar+Sc and Pb+Pb within SPS energy range.**
- No irregularity is observed for small systems: p+p and Be+Be.
- "Peak-dip-peak-dip" irregularity is observed for world Pb+Pb data.
- Current studies of ^{129}Xe+^{139}La by NA61/SHINE will allow to investigate region between ^{40}Ar+^{45}Sc and ^{208}Pb+^{208}Pb.
- High demand for new data!

Backup Slides

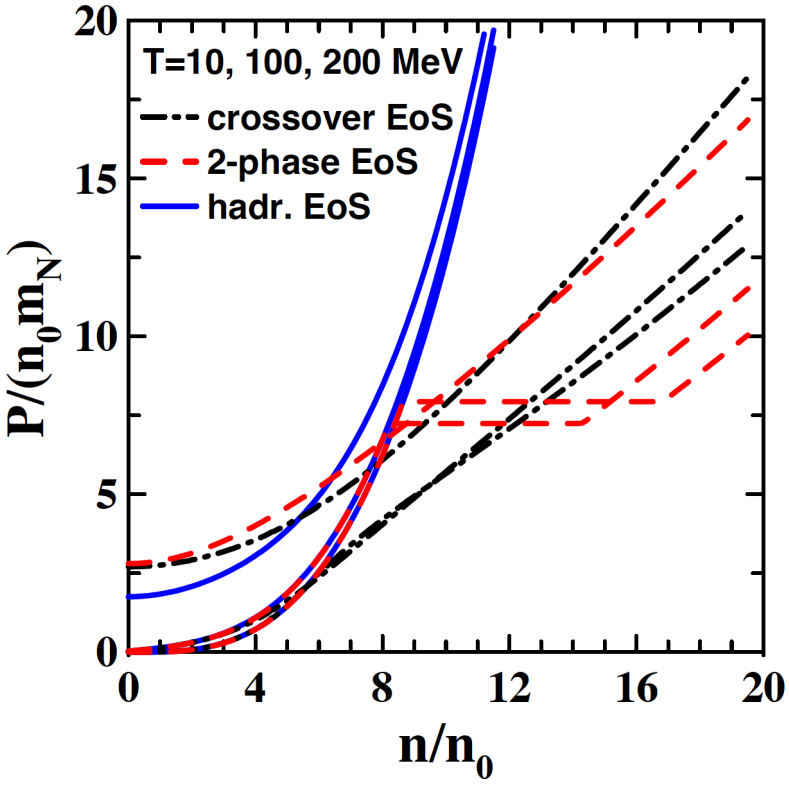
Curvature of spectra



Midrapidity reduced curvature of the (net)proton dn/dy as a function of $\sqrt{s_{NN}}$ as deduced from experimental data and predicted by 3FD calculations with different EoS's.

Ivanov, Blaschke, PRC 92, 024916 (2015)

Equations of state



Pressure as a function of baryon density for considered EoS's.

Ivanov, Blaschke, PRC 92, 024916 (2015)