Energy dependence of transverse momentum fluctuations in p+p interactions

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Statistical Particle Production:
Particle Production in Proton-Proton and Beyond
Bad Liebenzell
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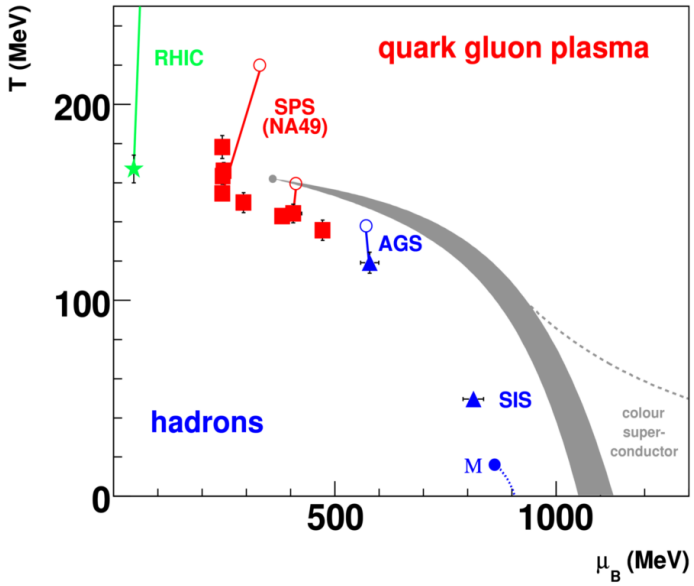
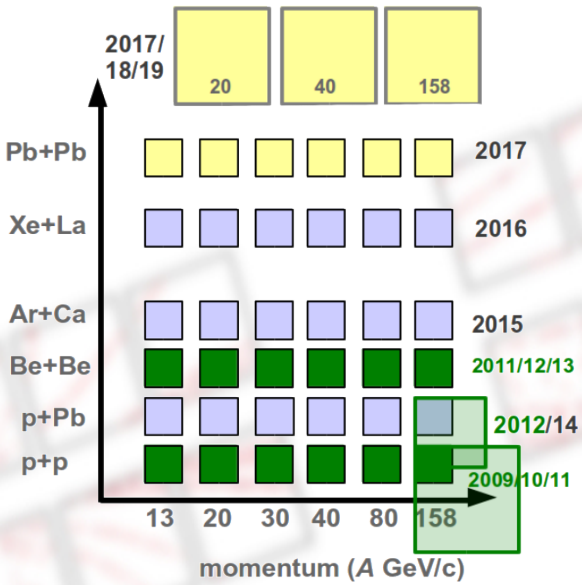
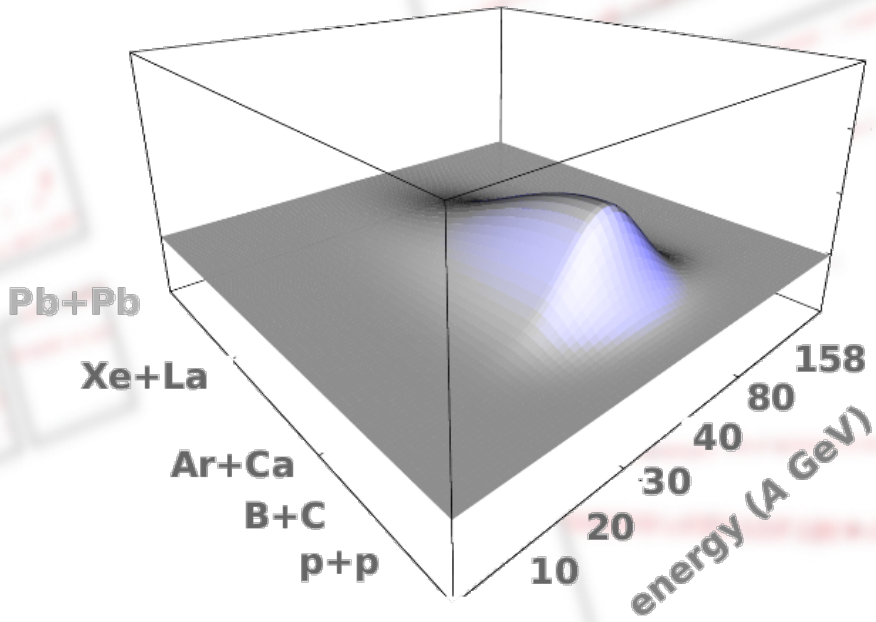
Fluctuations in NA61/SHINE



The NA61/SHINE experiment aims to discover the critical point of strongly interacting matter and study the properties of the onset of deconfinement by performing a two dimensional phase diagram scan. Close to the critical point increase of fluctuations is predicted. Also, at the Onset of Deconfinement fluctuations are expected to change.





Fluctuation measures

Two families of strongly intensive quantities

$$\Delta[A,B] = \frac{1}{C_\Delta}\Big[\langle B\rangle\omega[A] - \langle A\rangle\omega[B]\Big]$$

$$\Sigma[A,B] = \frac{1}{C_\Sigma}\Big[\langle B\rangle\omega[A] + \langle A\rangle\omega[B] - 2\big(\langle AB\rangle - \langle A\rangle\langle B\rangle\big)\Big]$$

where $\omega[A] = \frac{\langle A^2\rangle - \langle A\rangle^2}{\langle A\rangle}$ $\omega[B] = \frac{\langle B^2\rangle - \langle B\rangle^2}{\langle B\rangle}$

- independent of system size fluctuations
- independent of the average number of sources and source number fluctuations in the model of independent particle sources
- $\Delta[A,B] = \Sigma[A,B] = 0$ in the absence of fluctuations
- normalization factors chosen, that
  - both quantities dimensionless
  - $\Delta[A,B] = \Sigma[A,B] = 1$ for independent particle sources

[Phys. Rev. C 84, 014904 (2011), arXiv:1303.0871]

The Φ measure

Φ_x is defined as:

$$\Phi_x \stackrel{\text{def}}{=} \sqrt{\frac{\langle Z^2 \rangle}{\langle N \rangle}} - \sqrt{\overline{z^2}} \ ,$$

where:

$$z \stackrel{\text{def}}{=} x - \overline{x}$$

and Z being a multiplicative analog of z

$$Z \stackrel{\text{def}}{=} \sum_{i=0}^{N} (x_i - \overline{x})$$

with $\overline{x}$ denoting averaging over a single-particle inclusive distribution and $\langle ... \rangle$ representing averaging over events.

Φ_x has some interesting properties:

- it is independent of the source number distribution.
  If A+A is a superposition of independent N+N collisions, then
  $\Phi_x(A + A) = \Phi_x(N + N)$
- it vanishes for a system of independently emitted particles (no inter-particle correlations)
  $\Phi_x = 0$.

[Z. Phys. C54, 127 (1992)]

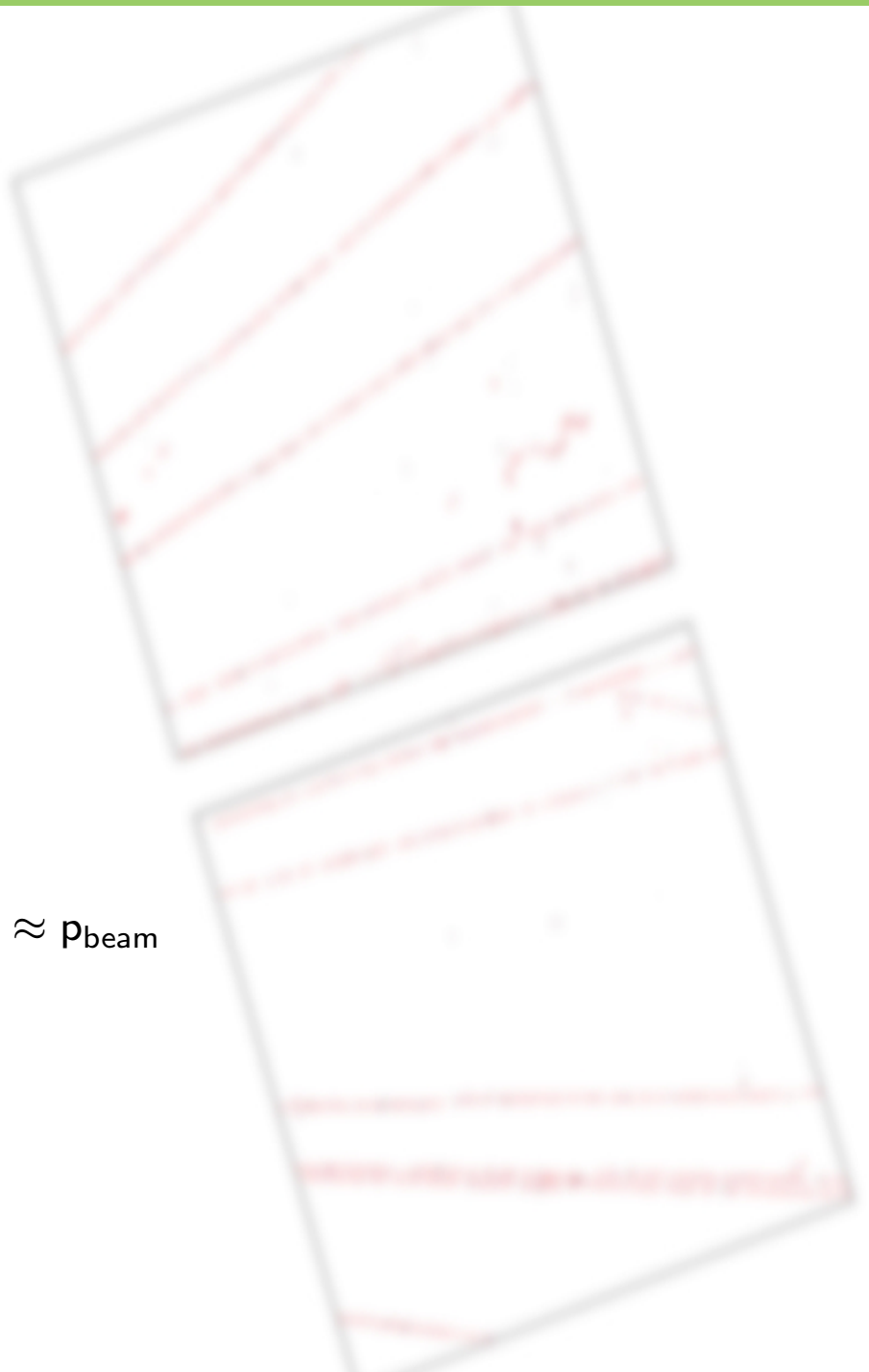
Data set

p+p interactions recorded in 2009:

Momentum [GeV/c]	Production	$N_{events}^{target\ in}$	$N_{events}^{target\ out}$	$\sqrt{s_{NN}}$ [GeV]	y^*_{beam}
20	12E002	1.32M	123k	6.27	1.90
31	12E002	3.20M	332k	7.62	2.10
40	12D002	5.23M	528k	8.73	2.23
80	12E002	4.44M	458k	12.32	2.57
158	12E002	3.54M	427k	17.27	2.91

Event selection

1. **T2 trigger**
   ensure there was an interaction
2. **BPD**
   good quality signal in Beam Position Detectors
3. **WFA**
   no off-time particles within $\pm 1\mu$s
4. **fitted vertex**
   good quality fitted vertex
5. **elastically scattered beam protons**
   no events with only one positive particle with $p \approx p_{beam}$



Event selection

	Target inserted				
	20 GeV/c	31 GeV/c	40 GeV/c	80 GeV/c	158 GeV/c
Before cuts	1324198 (100%)	3140477 (100%)	5226264 (100%)	4444027 (100%)	3538884 (100%)
T2 trigger	1093748 (82%)	2834337 (90%)	4672772 (89%)	3727116 (83%)	2857871 (80%)
BPD	626625 (47%)	2079904 (66%)	3691589 (70%)	2498753 (56%)	2148386 (60%)
WFA	532253 (40%)	1782544 (56%)	3140087 (60%)	2357109 (53%)	2082838 (58%)
Fitted Vertex	274872 (20%)	1095388 (34%)	2045427 (39%)	1792674 (40%)	1818955 (51%)
$p \approx p_{beam}$	254504 (19%)	1057802 (33%)	2007731 (38%)	1790653 (40%)	1818954 (51%)
After cuts	254504 (19%)	1057802 (33%)	2007731 (38%)	1790653 (40%)	1818954 (51%)

	Target removed				
	20 GeV/c	31 GeV/c	40 GeV/c	80 GeV/c	158 GeV/c
Before cuts	122885 (100%)	331933 (100%)	528195 (100%)	458390 (100%)	426187 (100%)
T2 trigger	109179 (88%)	248343 (74%)	364490 (69%)	249203 (54%)	159618 (37%)
BPD	37741 (30%)	124838 (37%)	225421 (42%)	151352 (33%)	110826 (26%)
WFA	31765 (25%)	104680 (31%)	188118 (35%)	141901 (30%)	107409 (25%)
Fitted Vertex	8005 (6%)	36130 (10%)	88783 (16%)	88109 (19%)	74088 (17%)
$p \approx p_{beam}$	7661 (6%)	35426 (10%)	87794 (16%)	88027 (19%)	74088 (17%)
After cuts	7661 (6%)	35426 (10%)	87794 (16%)	88027 (19%)	74088 (17%)

Track selection

1. **points**
   - maximum points (at least 30)
   - VTPC/GTPC points (at least 15 in VTPCs or 5 in GTPC)
   - points/max points ratio (at least 0.5)
2. **impact parameters**
   - $-4 < B_x < 4$ cm
   - $-2 < B_y < 2$ cm
3. p_T
   must be smaller than 1.5 GeV/c
4. **electron/positron**
   cut based on dE/dx
5. **acceptance**
   3D histograms in y^*_π-p_T-ϕ are created for generated and reconstructed MC data. A bin is within acceptance if $\frac{N^{\text{reconstructed}}}{N^{\text{generated}}} > 90\%$

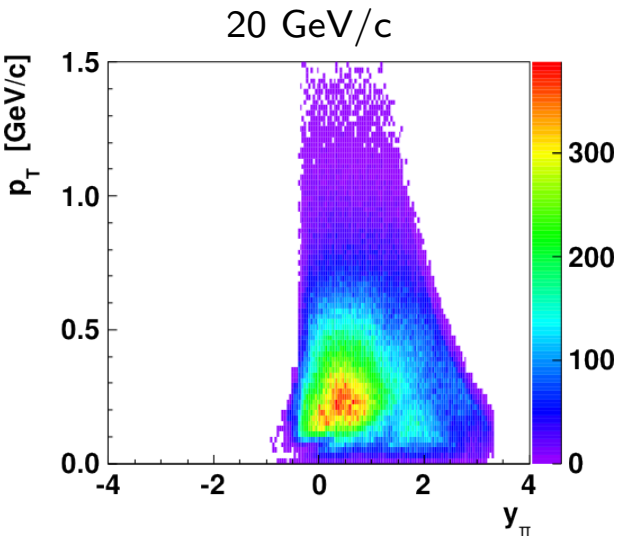
Track selection

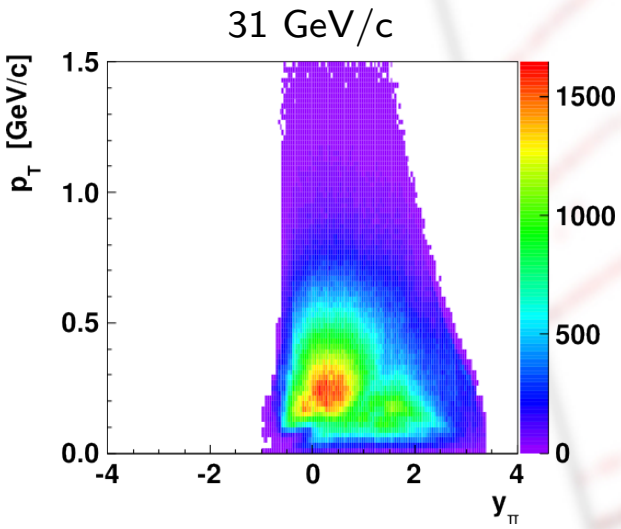
	Target inserted				
	20 GeV/c	31 GeV/c	40 GeV/c	80 GeV/c	158 GeV/c
Before cuts	798079 (100%)	3697024 (100%)	7706191 (100%)	9008974 (100%)	12297034 (100%)
Maximum points	562430 (70%)	2718126 (73%)	5713643 (74%)	6882809 (76%)	9429892 (76%)
VTPC points	534933 (67%)	2590144 (70%)	5451052 (70%)	6585736 (73%)	9021205 (73%)
Points/max. points	529969 (66%)	2567473 (69%)	5410607 (70%)	6551988 (72%)	8986324 (73%)
B_x	513004 (64%)	2498978 (67%)	5280964 (68%)	6456596 (71%)	8876147 (72%)
B_y	499657 (62%)	2469380 (66%)	5244175 (68%)	6447724 (71%)	8867516 (72%)
p_T	498464 (62%)	2464636 (66%)	5235000 (67%)	6435494 (71%)	8847636 (71%)
electron/positron	453584 (56%)	2316212 (62%)	5001613 (64%)	6259963 (69%)	8682535 (70%)
After cuts	358257 (44%)	1805921 (48%)	3920306 (50%)	5176466 (57%)	7588463 (61%)

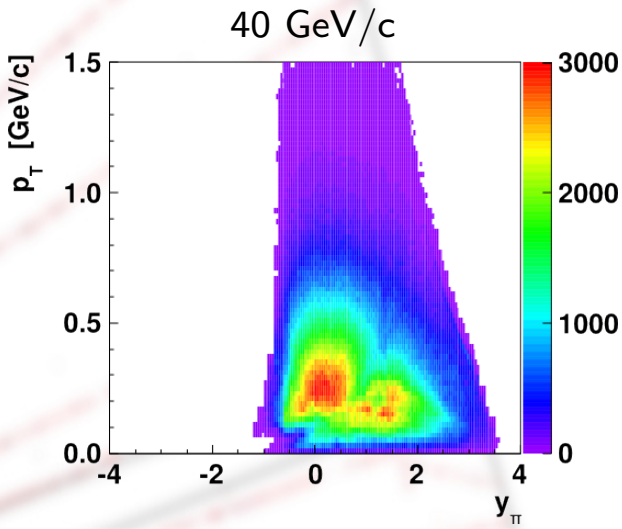
	Target removed				
	20 GeV/c	31 GeV/c	40 GeV/c	80 GeV/c	158 GeV/c
Before cuts	28095 (100%)	149548 (100%)	400386 (100%)	518691 (100%)	581057 (100%)
Maximum points	17701 (63%)	99521 (66%)	275590 (68%)	377412 (72%)	427306 (73%)
VTPC points	16490 (58%)	92555 (61%)	257847 (64%)	354377 (68%)	402153 (69%)
Points/max. points	15974 (56%)	89578 (59%)	251714 (62%)	348886 (67%)	396832 (68%)
B_x	15312 (54%)	86464 (57%)	244159 (60%)	342758 (66%)	390395 (67%)
B_y	14912 (53%)	85168 (56%)	241876 (60%)	341766 (65%)	389277 (66%)
p_T	14835 (52%)	84840 (56%)	241159 (60%)	340800 (65%)	388076 (66%)
electron/positron	13116 (46%)	79064 (52%)	230766 (57%)	332680 (64%)	382303 (65%)
After cuts	10078 (35%)	60118 (40%)	177241 (44%)	269985 (52%)	329651 (56%)

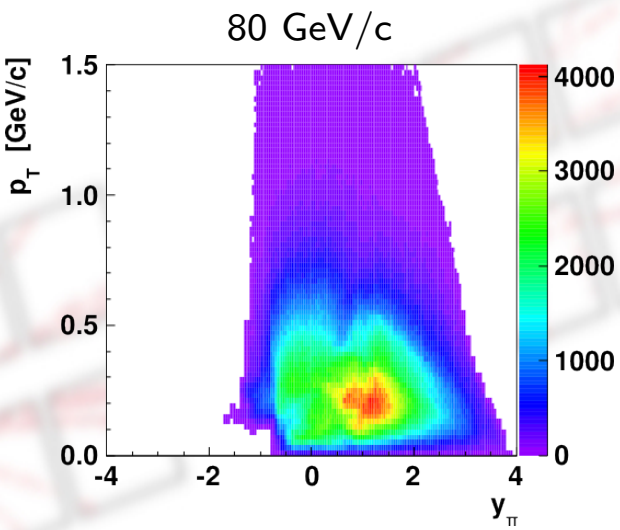
y^*_π-pT

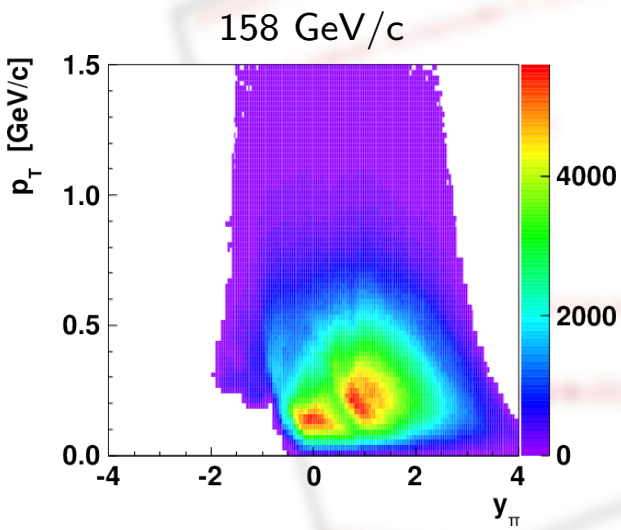
target inserted





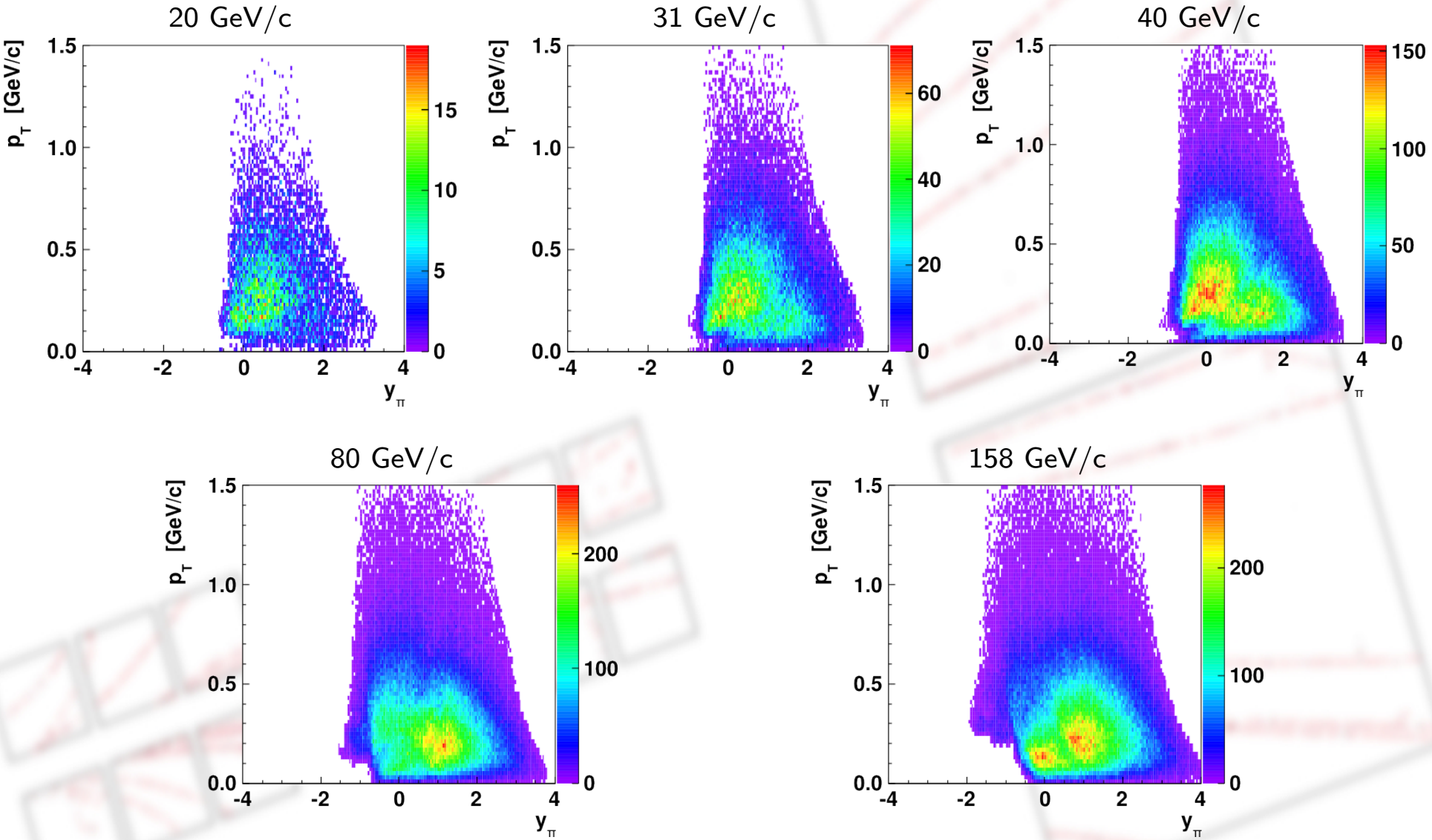






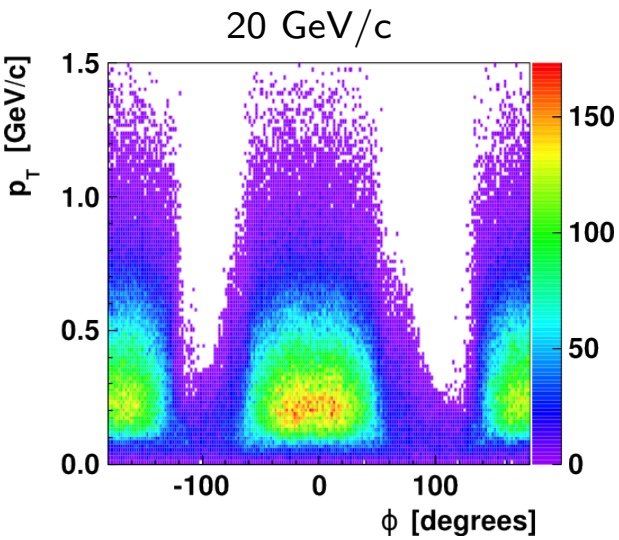
y^*_π-pT

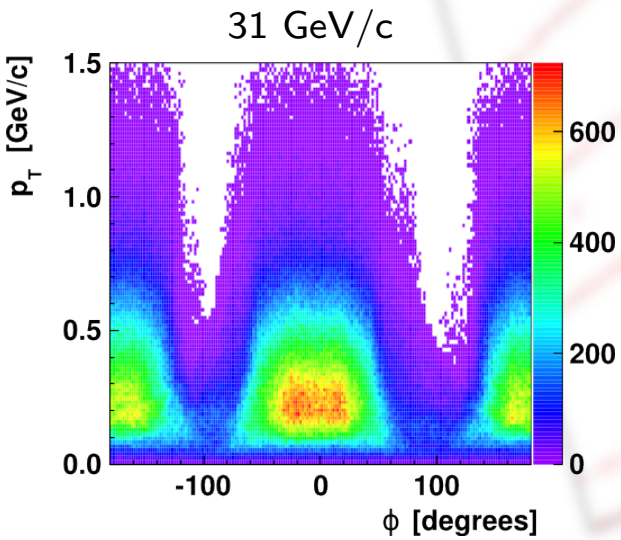
target removed

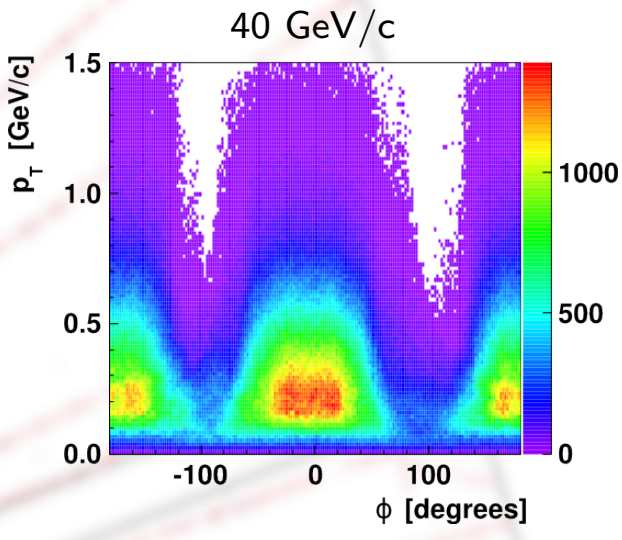


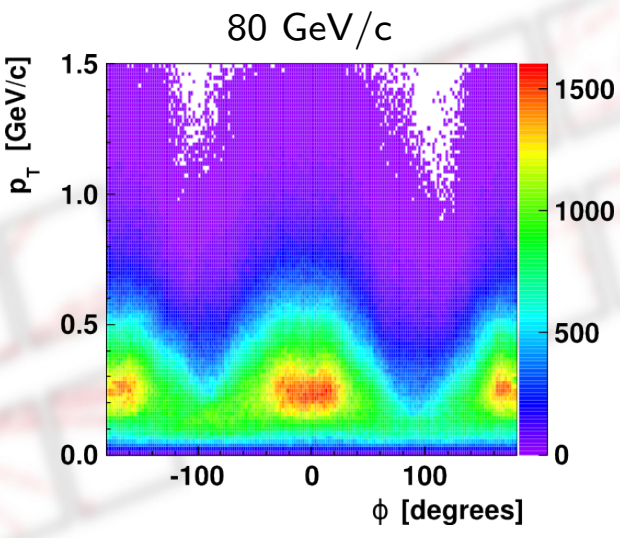
ϕ-pT

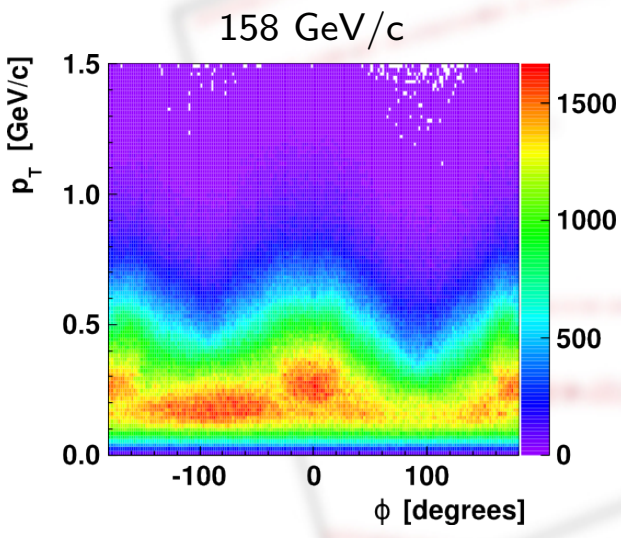
target inserted





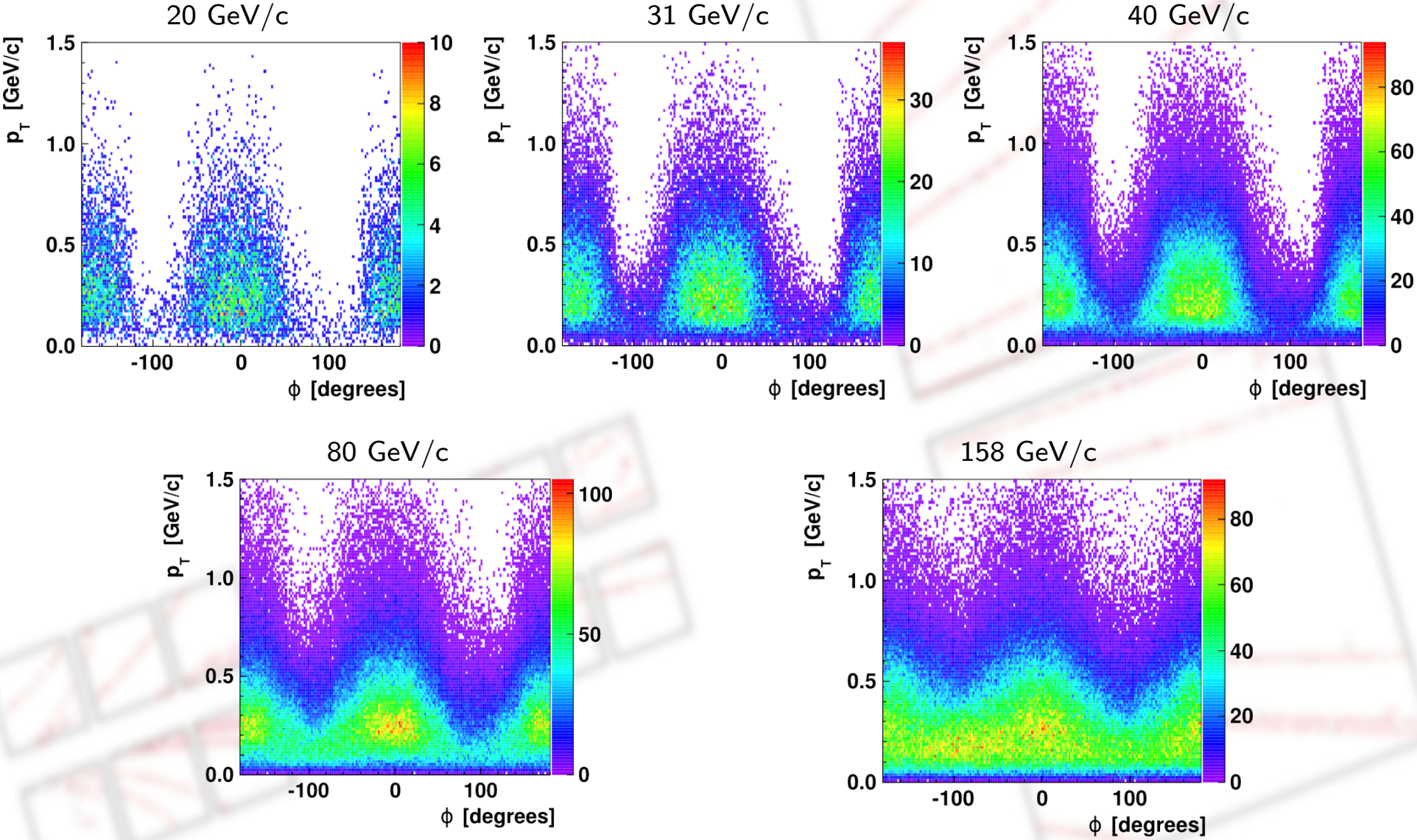






ϕ-p_T

target removed



Analysis procedure

Φ_{p_T} formula

$$\Phi_{p_T} \equiv \sqrt{\frac{\langle X^2 \rangle}{\langle N \rangle} - \frac{2\langle X \rangle \langle NX \rangle}{\langle N \rangle^2} + \frac{\langle X \rangle^2 \langle N^2 \rangle}{\langle N \rangle^3}} - \sqrt{\frac{\langle X_2 \rangle}{\langle N \rangle} - \frac{\langle X \rangle^2}{\langle N \rangle^2}}$$

$$X \stackrel{\text{def}}{=} \sum_{i=0}^{N} p_{Ti}$$

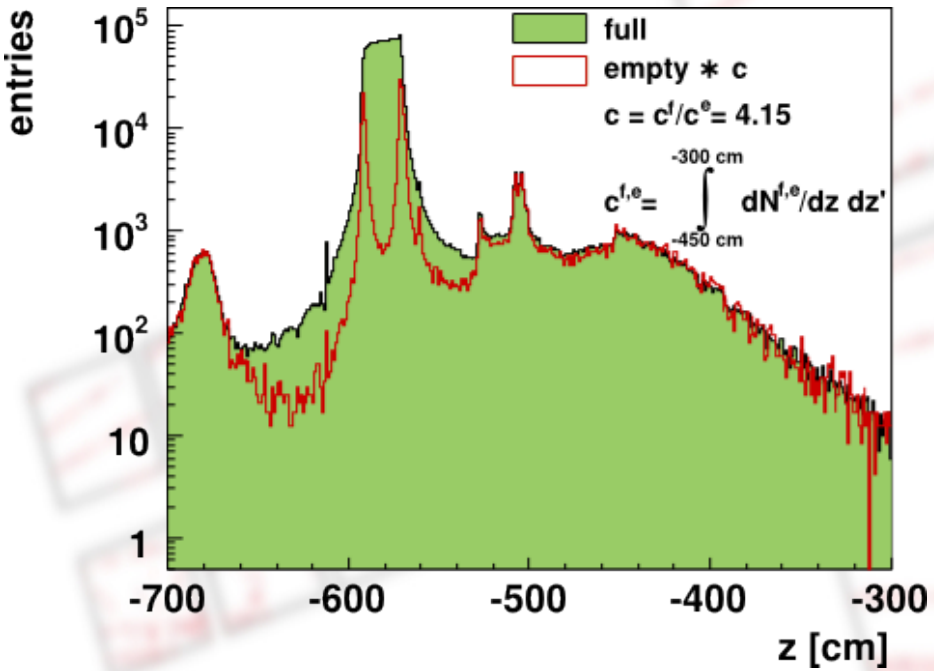
$$X_2 \stackrel{\text{def}}{=} \sum_{i=0}^{N} \left(p_{Ti}^2 \right)$$

1. prepare text files with multiplicity, sum of p_T and sum of squared p_T for each event
2. prepare correction factor table
3. correct for non-target interactions and detector effects
4. calculate Φ_{p_T}

Non-target interactions correction

In order to correct the data for non-target interactions, NA61/SHINE acquires data of both target-inserted (with the LH cylinder filled) and target-removed (with the LH cylinder empty) collisions. Then, in the analysis procedure, non-target interactions are subtracted.

Example of z position of the fitted vertex for p+p at 158 GeV/c:



Correction for detector effects

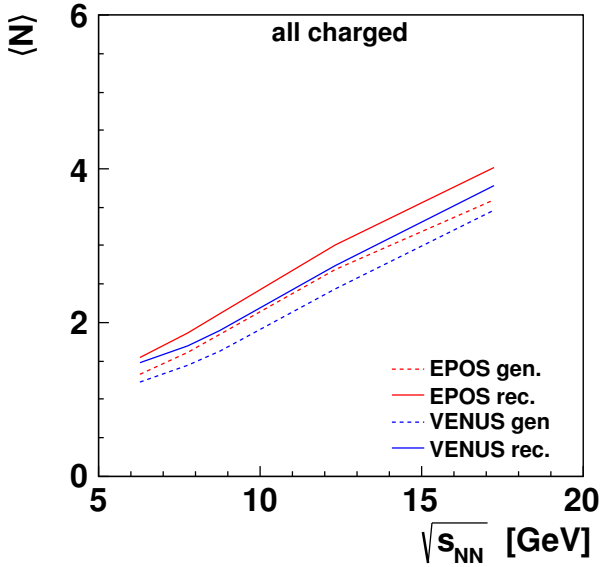
NA61/SHINE introduces method to correct the results for the detector effects: correct event mean quantities that enter the Φ_{p_T} formula (i.e. $\langle N \rangle$, $\langle N^2 \rangle$, $\langle X \rangle$, $\langle X^2 \rangle$, $\langle NX \rangle$, $\langle X_2 \rangle$).

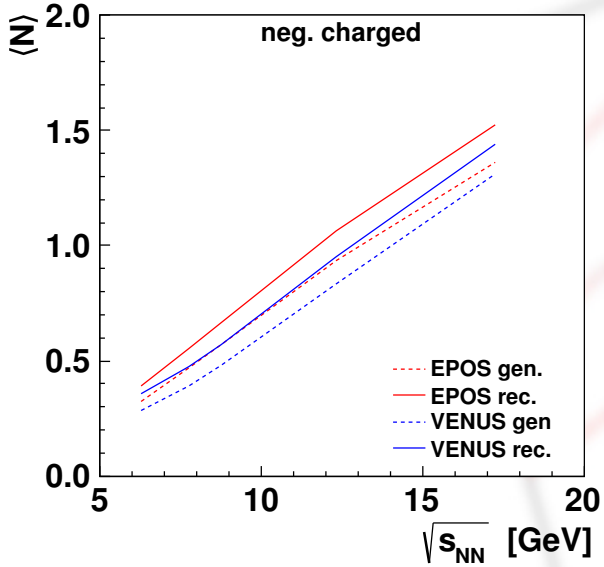
6D correction table is produced by comparing generated and reconstructed model data (EPOS and VENUS). Each event quantity is corrected with the table according to the formula:

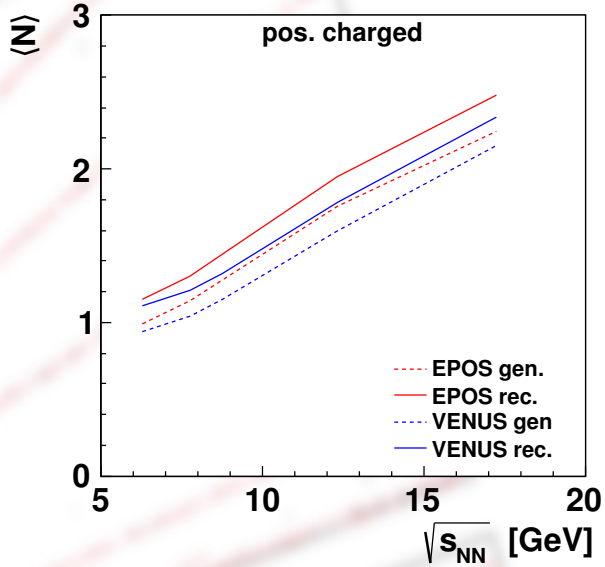
$$\langle Q \rangle = \frac{1}{\sum_{i=1}^{n^{full}} c_i - B \cdot \sum_{j=1}^{n^{empty}} c_j} \times \left(\sum_{i=1}^{n^{full}} c_i Q_i - B \cdot \sum_{j=1}^{n^{empty}} c_j Q_j \right)$$

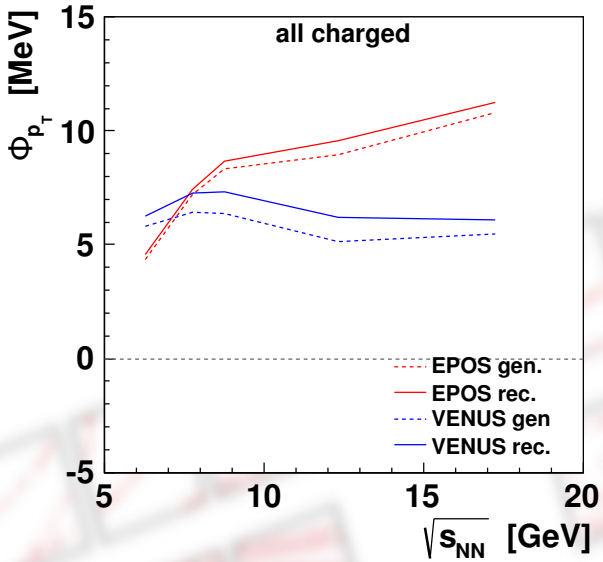
Q - any of event quantities needed to calculate the Φ_{p_T}
c_i - correction factors from MC
B - normalization factor of empty-target data
n - number of events

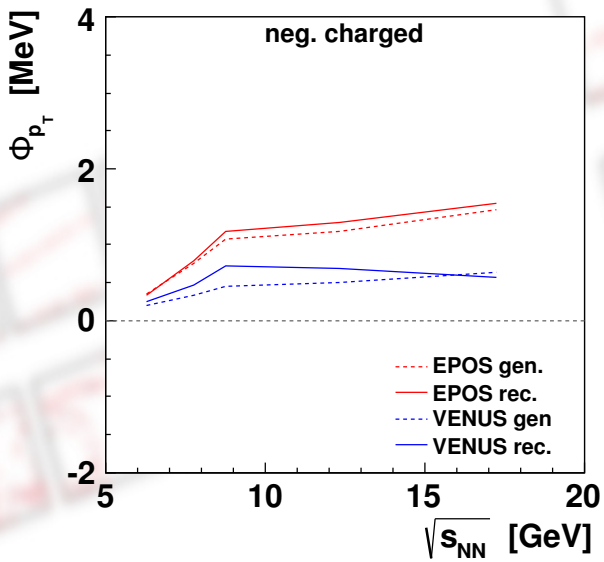
Results: models

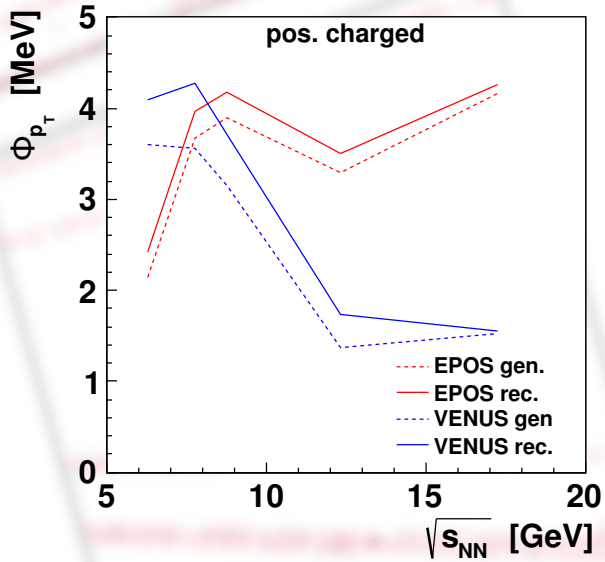






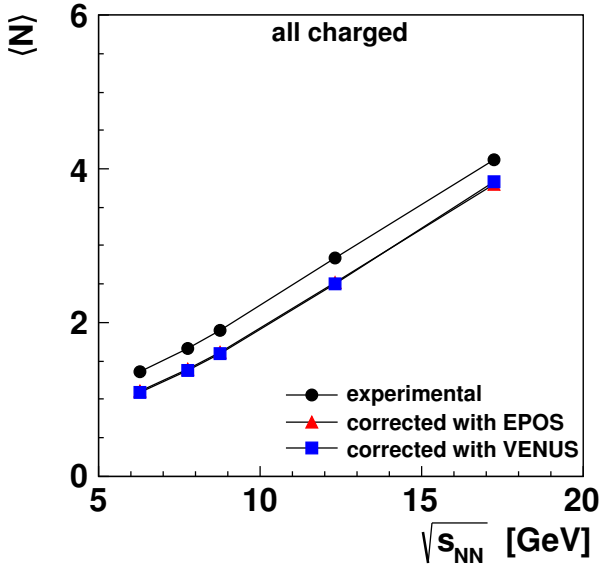


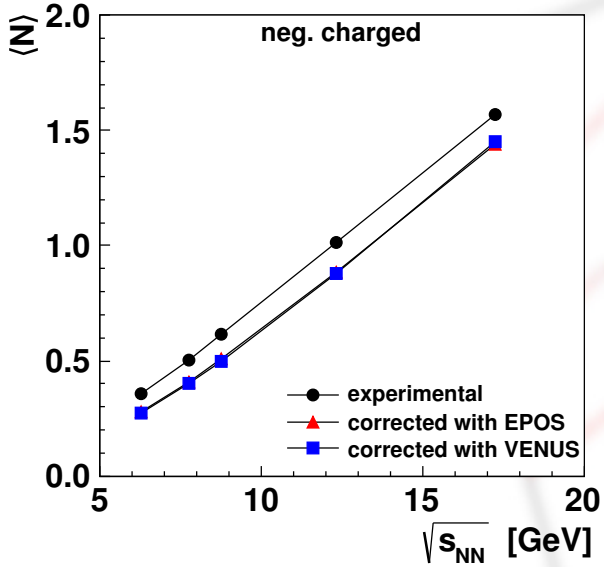


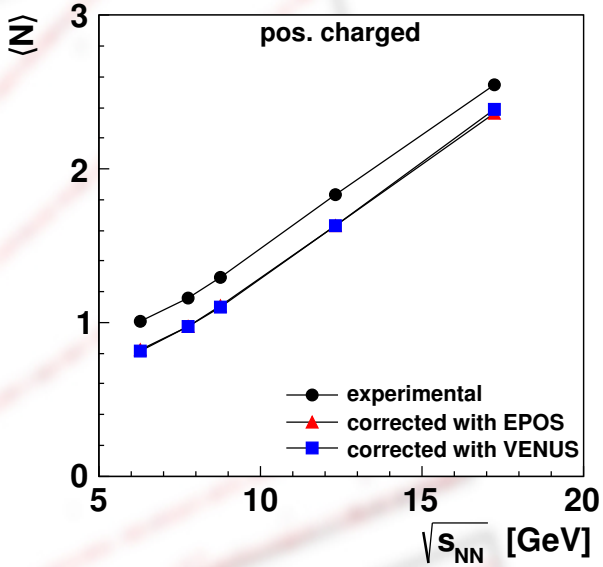


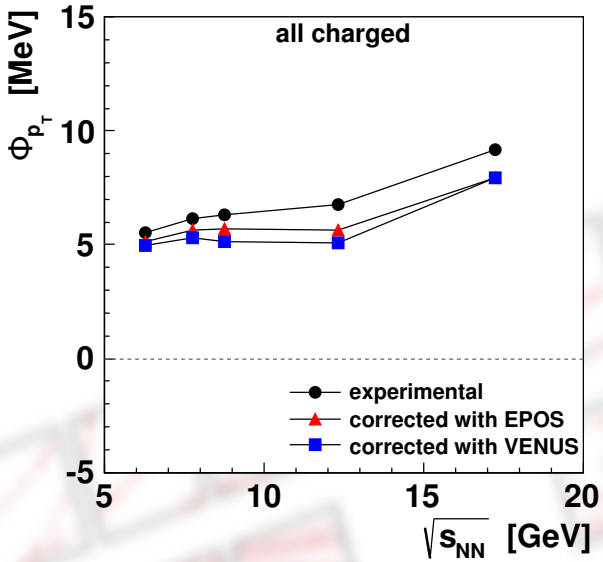
(uncertainties under study)

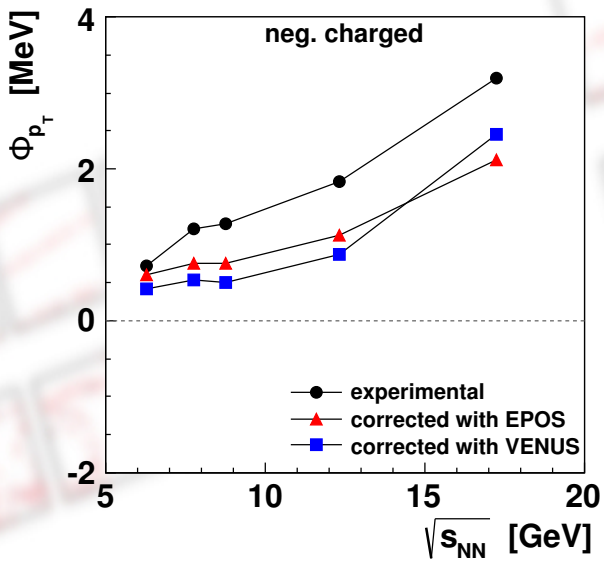
Results: experimental data

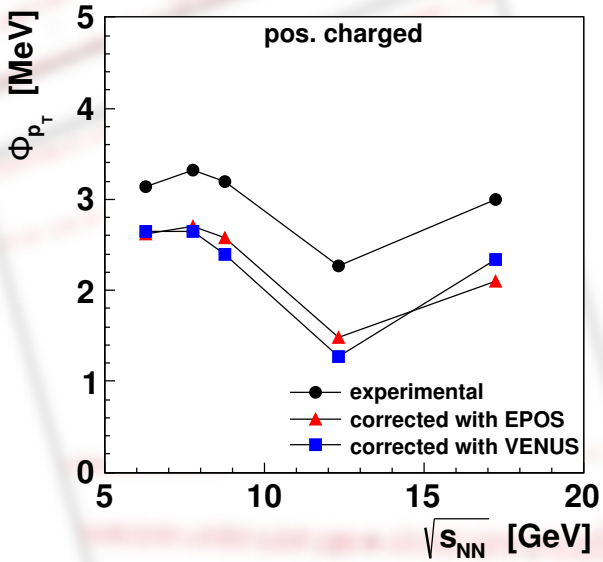










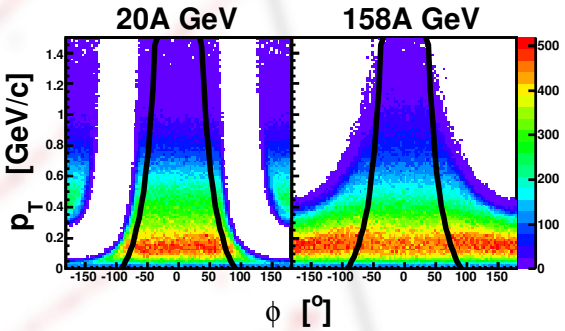


(uncertainties under study)

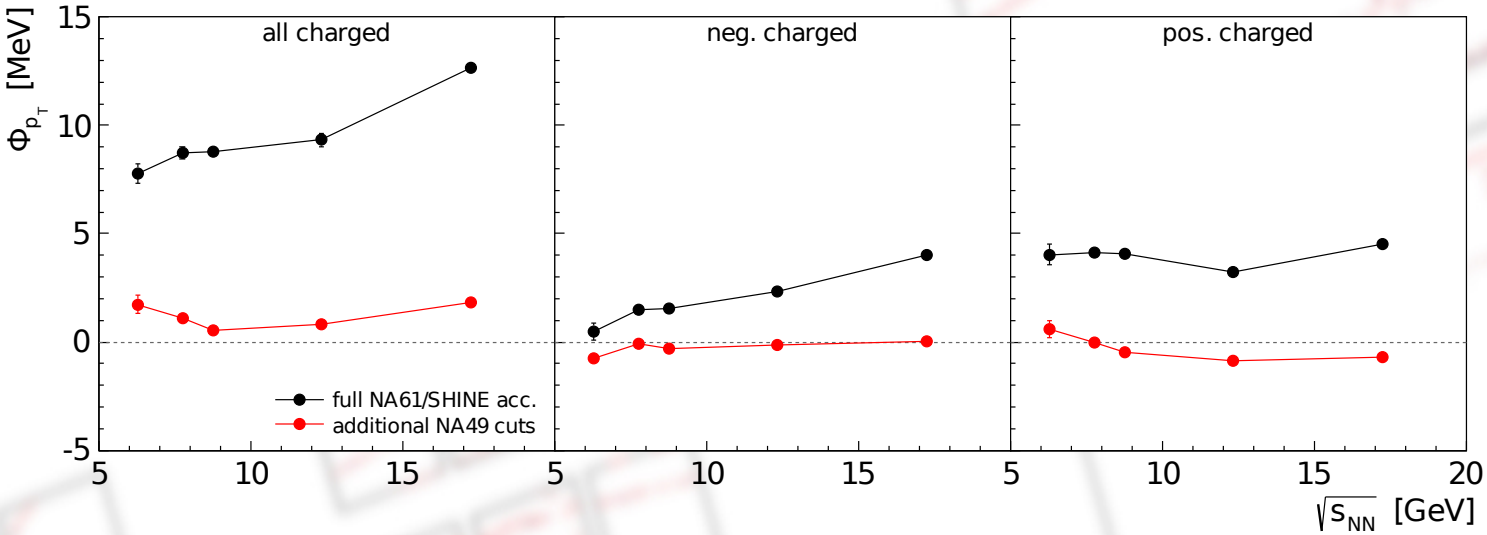
p+p vs. Pb+Pb

To compare the Φ_{p_T} results, NA49 cuts have been applied to the NA61/SHINE data. In NA49:

- because of high density of tracks, analysis was limited to forward rapidity region ($1.1 < y^*_\pi < 2.6$)
- common ϕ acceptance for all energies was used



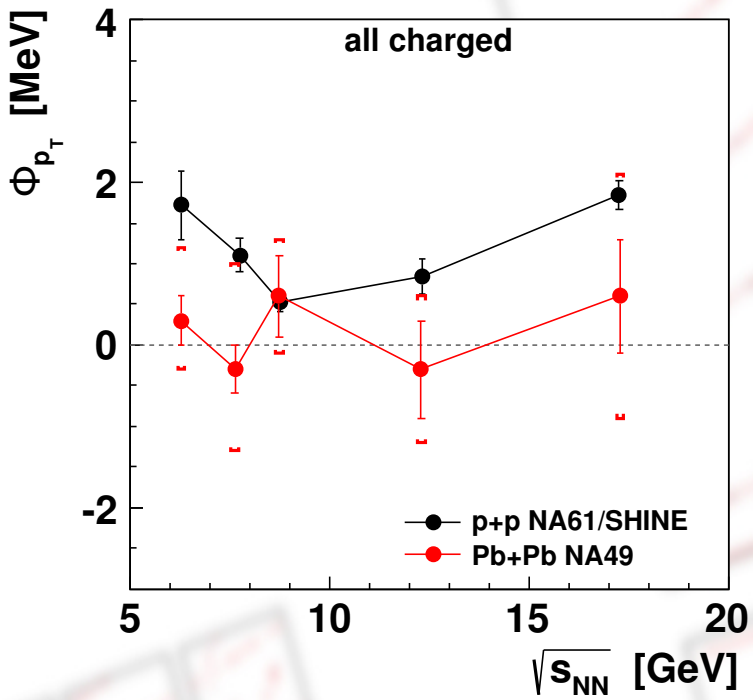
NA61/SHINE p+p data before and after applying additional NA49 cuts:



By applying NA49 cuts Φ_{p_T} decreases. Mainly because of narrower rapidity range.

NA61/SHINE is planning to extend the physics program to repeat and complement NA49 Pb+Pb measurements. The new helium beam pipe reduces the number of delta electrons in VTPCs by a factor of 10 and allows to extend the acceptance towards the mid-rapidity.

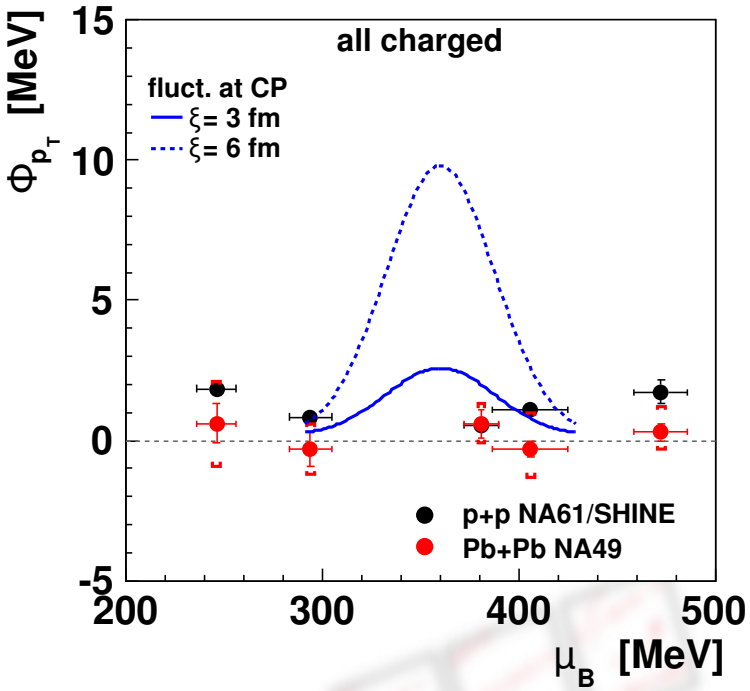
p+p vs. Pb+Pb

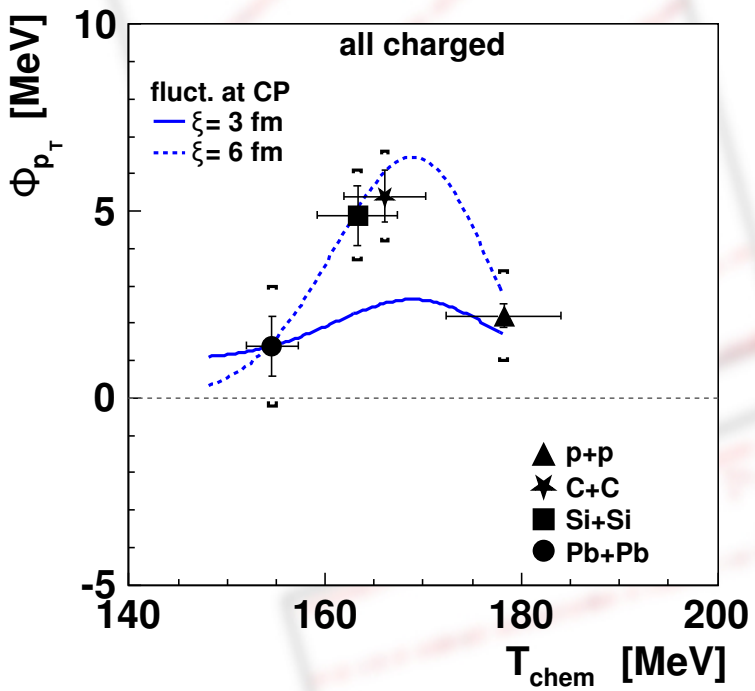


Comparison of Φ_{p_T} between NA61/SHINE p+p and NA49 Pb+Pb* in the NA49 acceptance. No significant difference is observed.

*) NA49 Collaboration, Phys.Rev.C **79** (2009)

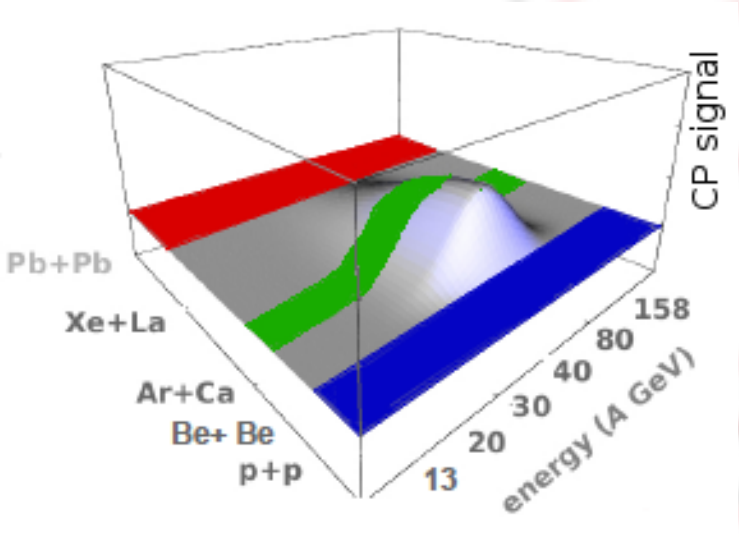
p+p vs. Pb+Pb





Critical Point predictions from Stephanov, Rajagopal, Shuryak (PR D60, 114028 (1999)).
No indication of Critical Point in p+p and Pb+Pb.
Critical Point indication predicted for medium-size systems.

p+p vs. Pb+Pb



The energy scan with Ar and Xe beam may lead to the discovery of the Critical Point.

Summary

- Φ_{p_T} results for p+p collisions at beam momenta: 20, 31, 40, 80, 158 GeV/c were presented
- new method of event-by-event corrections was introduced (and is still under study...)
- comparison of p+p and Pb+Pb data shows no significant difference
- no structure indicating the Critical Point is observed

NA61/SHINE resolution is sufficient to search for the Critical Point

Thank You!