



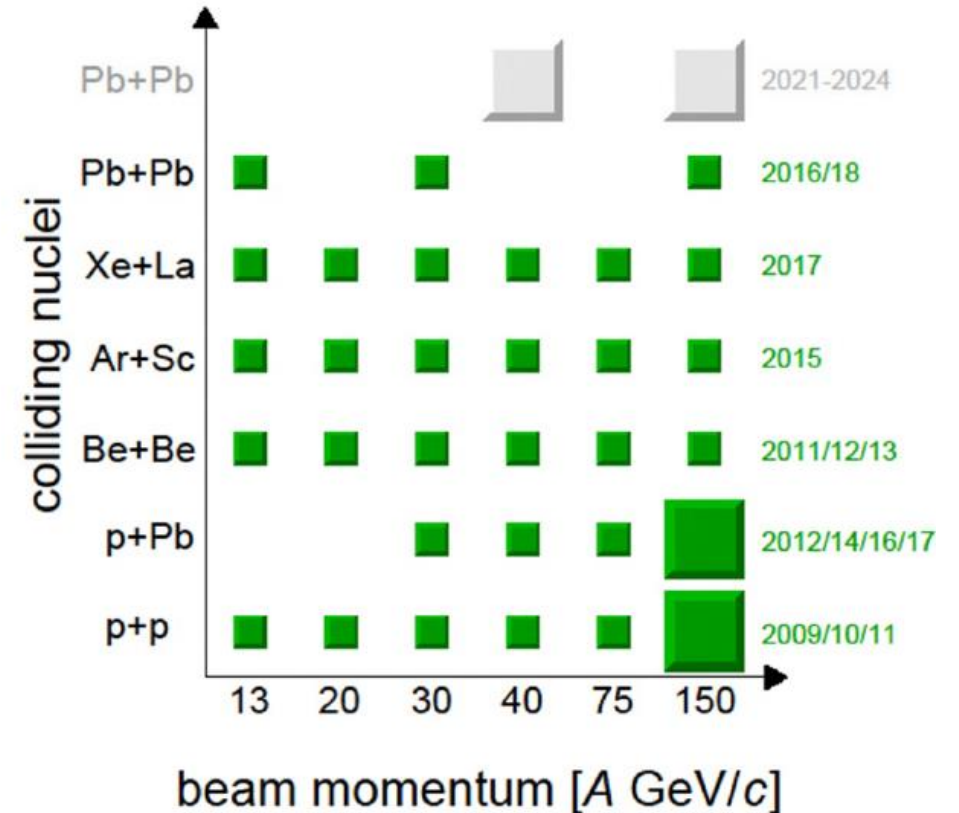
NA61/SHINE at the CERN SPS – upgrade status and future plans

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for the NA61/SHINE Collaboration

Outlook

- **2019-2024:**
 - Detector upgrade
 - Strong interaction programme Pb+Pb at 150A and 40A GeV/c
 - Open charm production
 - Measurements of nuclear fragmentation cross section for cosmic ray physics
 - Measurements of hadron production induced by proton and kaon beams for neutrino physics
 - **SPSC recommended**
- **2026-2029: 2D scan phase II**
 - Study of the onset of fireball
 - **The very first idea**





NA61/SHINE 2019-2024

- **Measurements of charm hadron production in Pb+Pb collisions for heavy ion physics**
- **Measurements of nuclear fragmentation cross section for cosmic ray physics**
- **Measurements of hadron production induced by proton and kaon beams for neutrino physics**

NA6 I/SHINE and European Strategy for Particle Physics

- Towards the European Particle Physics Strategy Update
 - Summary Report of Physics Beyond Colliders at CERN
 - Physics Beyond Colliders: QCD Working Group Report
 - Conclusions of the Neutrino Town Meeting
 - Conclusions of the Heavy Ion Town Meeting

The Briefing Book for the 2020 European Strategy Particle Physics

„... The NA6 I/SHINE experiment at SPS, currently being upgraded with vertex capability (using pixel sensors developed for ALICE), will extend in the coming years its suite of observables into the charm sector... NA6 I and its upgrade are an important component of this programme for the determination of the neutrino fluxes...”

Detector upgrade during LS2

Construction of Vertex Detector (VD)
for D^0 , \bar{D}^0 decay reconstruction

Replacement of the TPC
read-out electronics
to increase data rate to 1 kHz

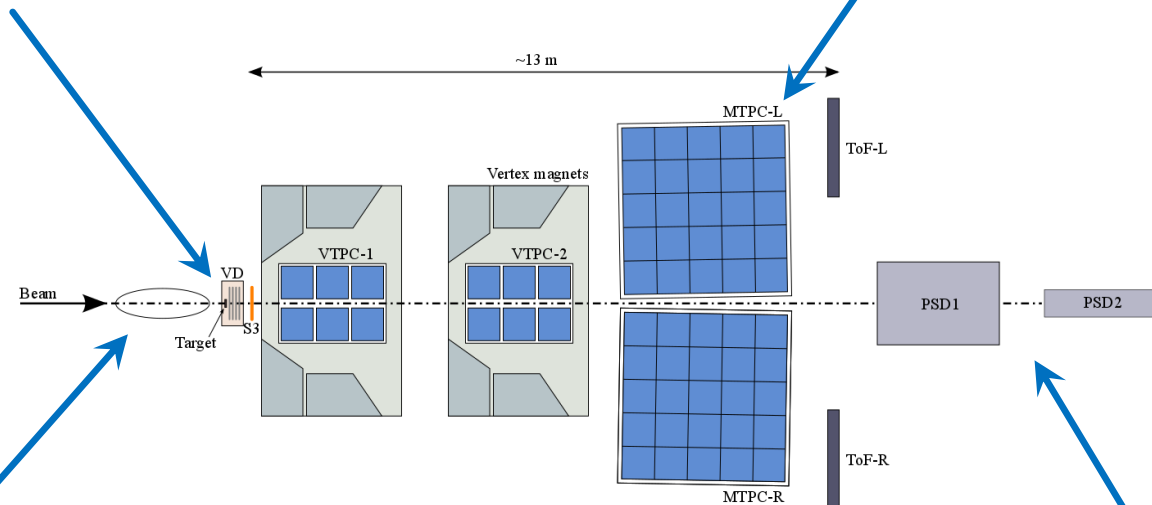
Higher ion intensities 10^6 ions/spill
for charm programme

Low energy beam (<30 GeV/c)
for neutrino physics

New trigger and data
acquisition system

New Time-of-Flight
detectors

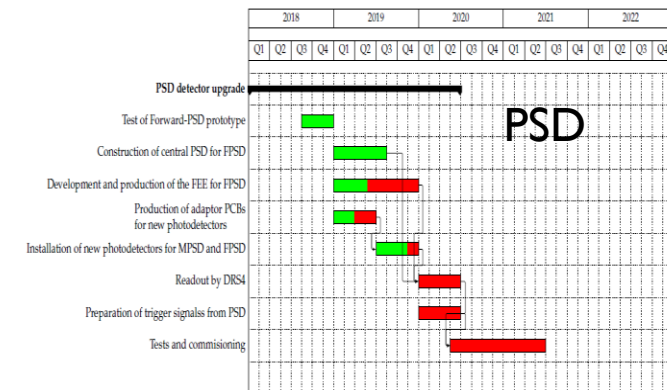
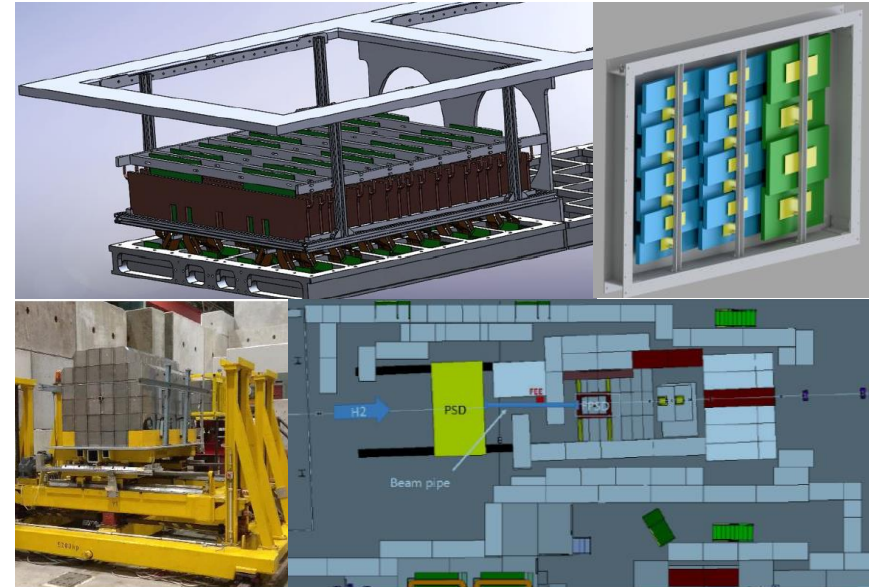
Upgrade of Projectile
Spectator Detector



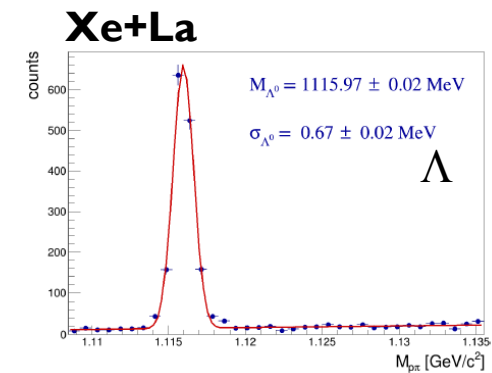
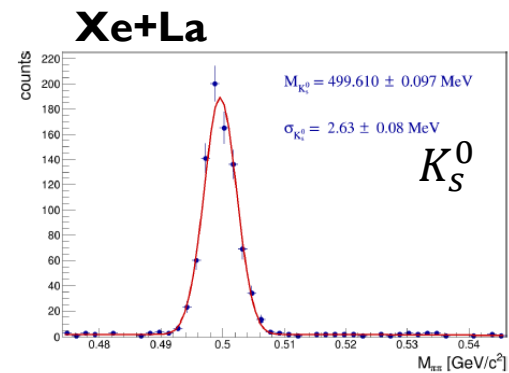
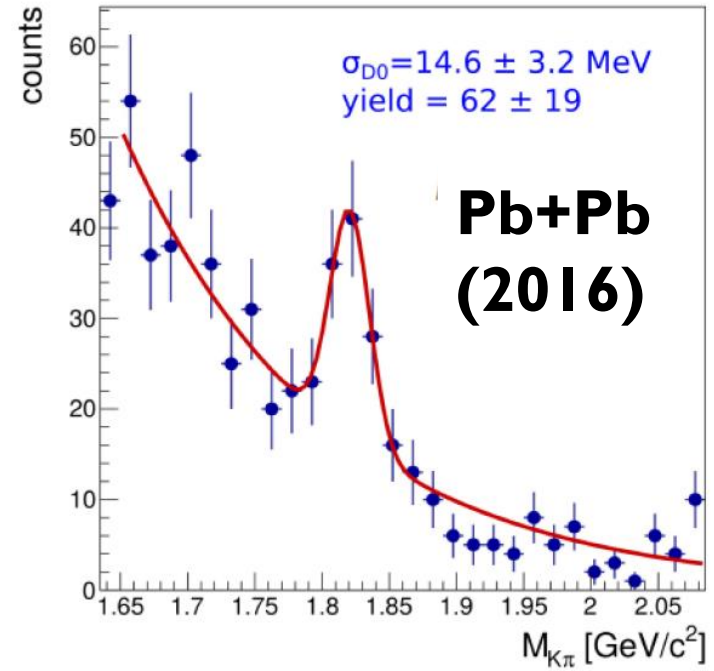
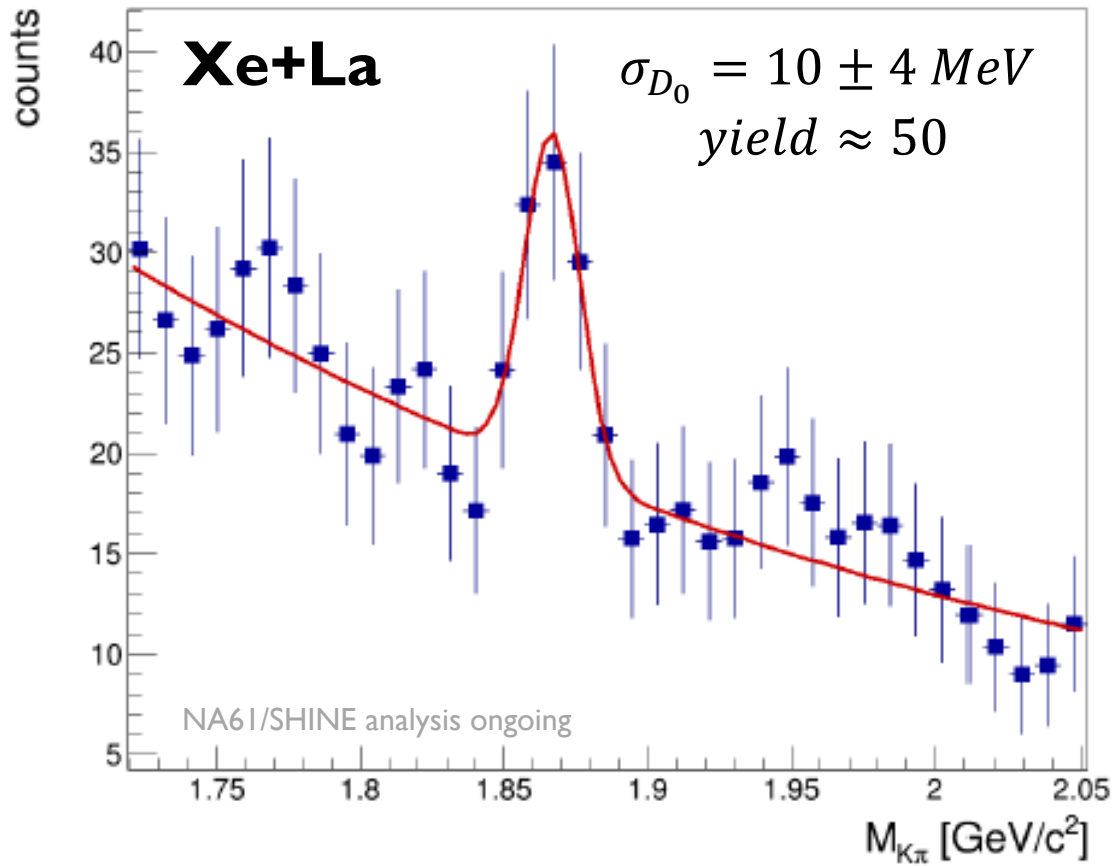
Upgrade status

- Design of TPC electronics adapters and mechanical support is ongoing.
 - The test was performed during Pb+Pb 2018 runs
- Design of Vertex Detector is completed
- Main and Forward PSD was installed.
 - Installation of the FEE is ongoing
 - Forward PSD shielding is designed
- New DAQ and trigger test bench was constructed and infrastructure for new DAQ system is almost ready
- New ToF detector based on MRPC is under construction

The first physics data taking is planned in 2021 (default financial scenario) or in 2022 (contingency financial scenario)

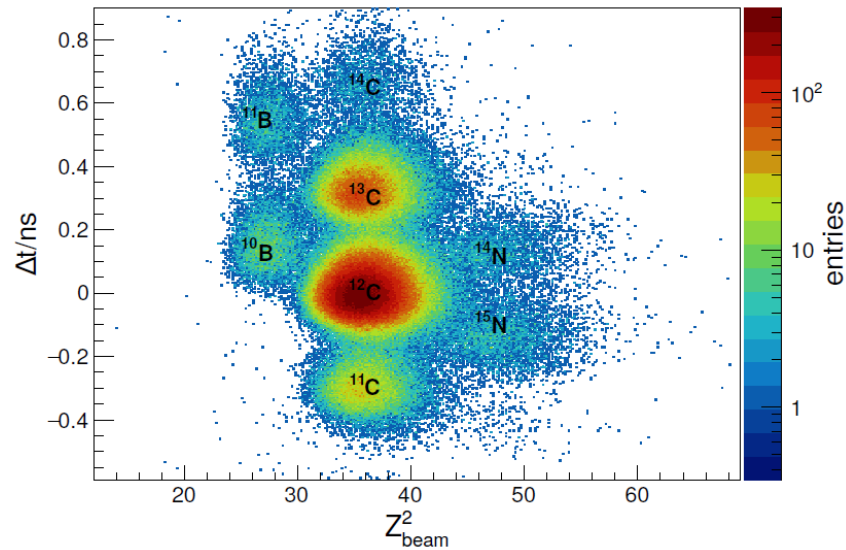


Test measurements - open charm signal in A+A at 150A GeV/c



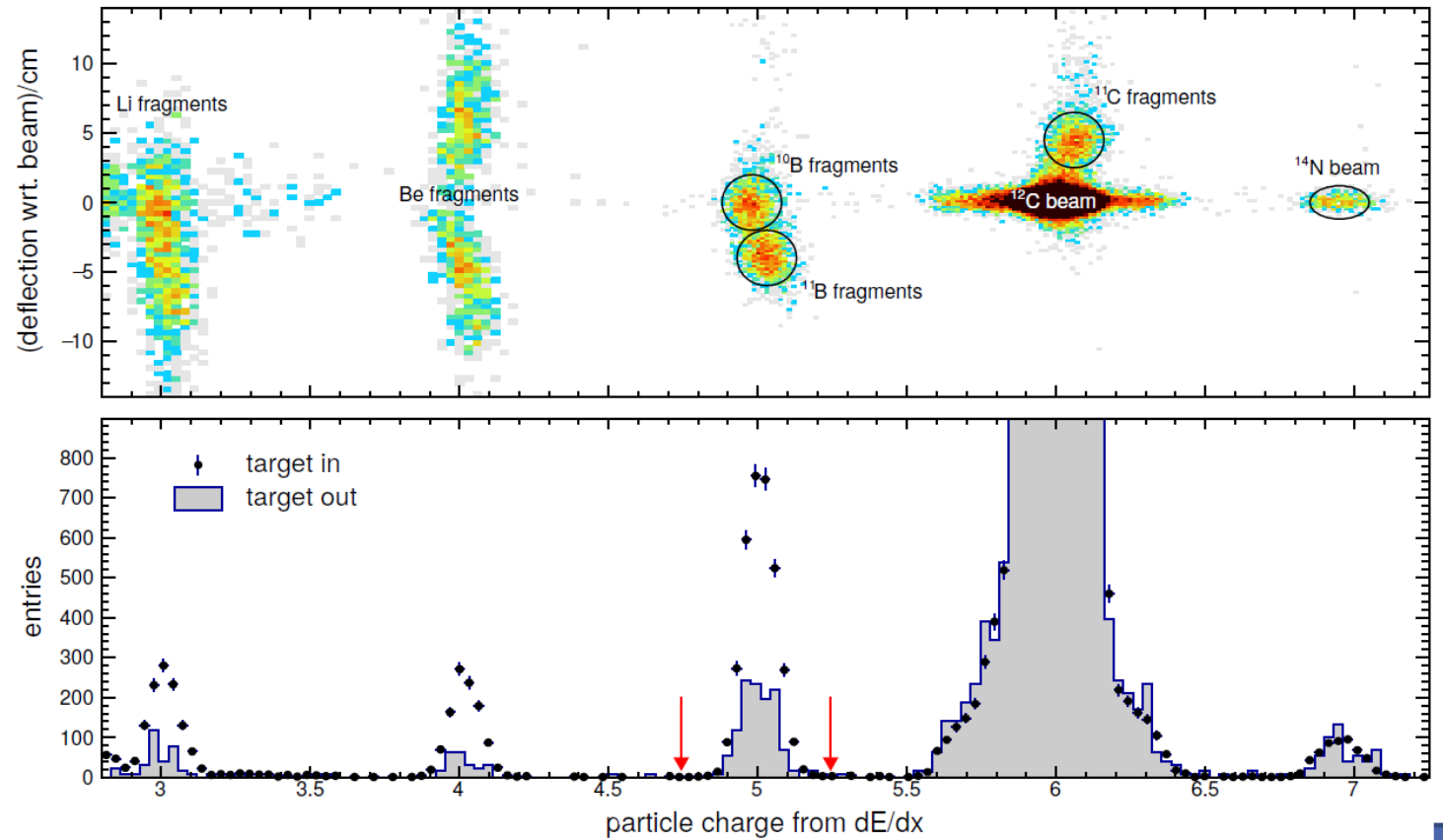
Test measurement - nuclear fragmentation cross section

^{12}C beam:



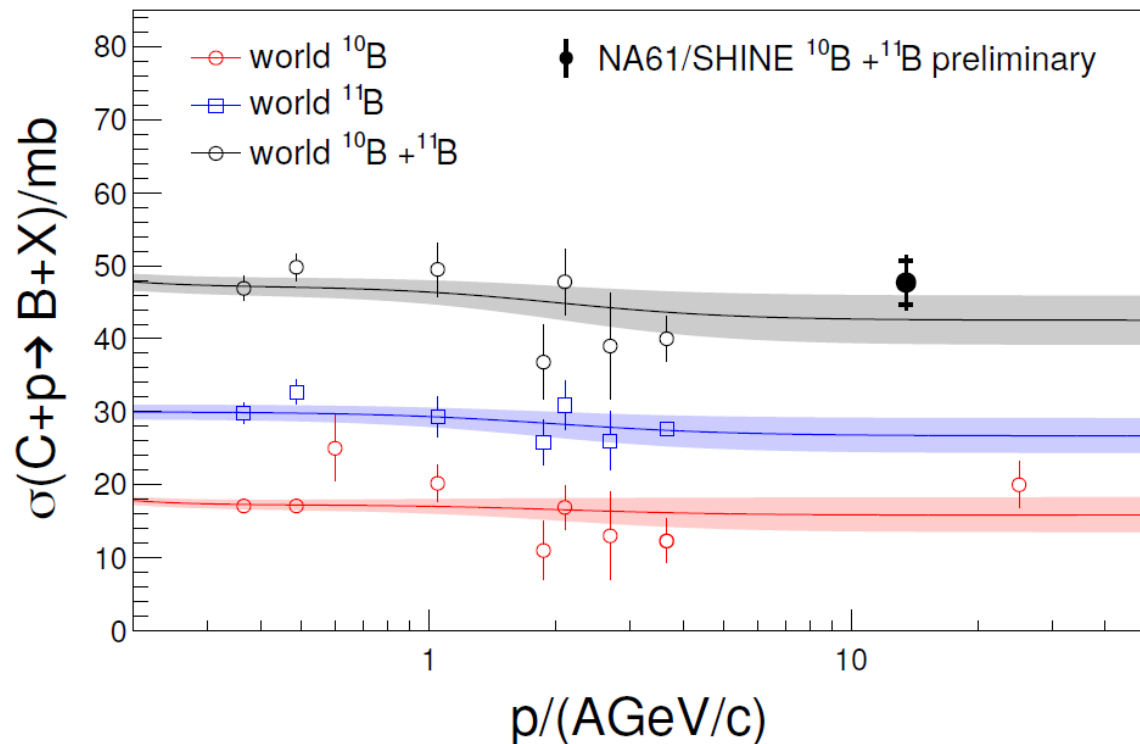
^{12}C purity: 99.2%
B contamination: < 0.1%

Identification of Isotopes Produced in Target



Test measurement: nuclear fragmentation cross section

$$\sigma(^{12}\text{C} + \text{p} \rightarrow ^{10}\text{B} + X) + \sigma(^{12}\text{C} + \text{p} \rightarrow ^{11}\text{B} + X) = \underline{47.7 \pm 3.0 \text{ (stat.)} \pm 2.3 \text{ (syst.) mb}}$$



2018 Pilot Run on Nuclear Fragmentation:

CERN-SPSC-2017-035

Addendum to the NA61/SHINE Proposal SPSC-P-330
**Feasibility Study for the Measurement of
 Nuclear Fragmentation Cross Sections with
 NA61/SHINE at the CERN SPS**

The NA61/SHINE Collaboration

- demonstrated **unique capabilities of NA61/SHINE + SPS** for nuclear fragmentation measurements
- preliminary results presented at ICRC2019
- test data already useful to constrain asymptotic $\sigma(^{12}\text{C} + \text{p} \rightarrow \text{B} + X)$

Future Plans:

CERN-SPSC-2018-008

Addendum to the NA61/SHINE Proposal SPSC-P-330
**Study of Hadron-Nucleus and Nucleus-Nucleus Collisions
 at the CERN SPS**
 Early Post-LS2 Measurements and Future Plans

The NA61/SHINE Collaboration and the CERN team

- precise reaction data base for Galactic cosmic-ray studies

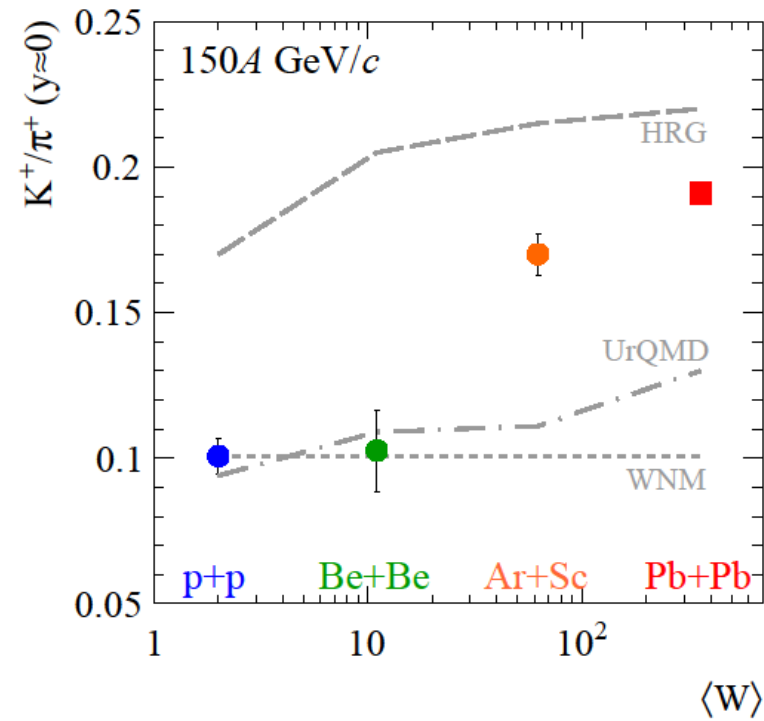
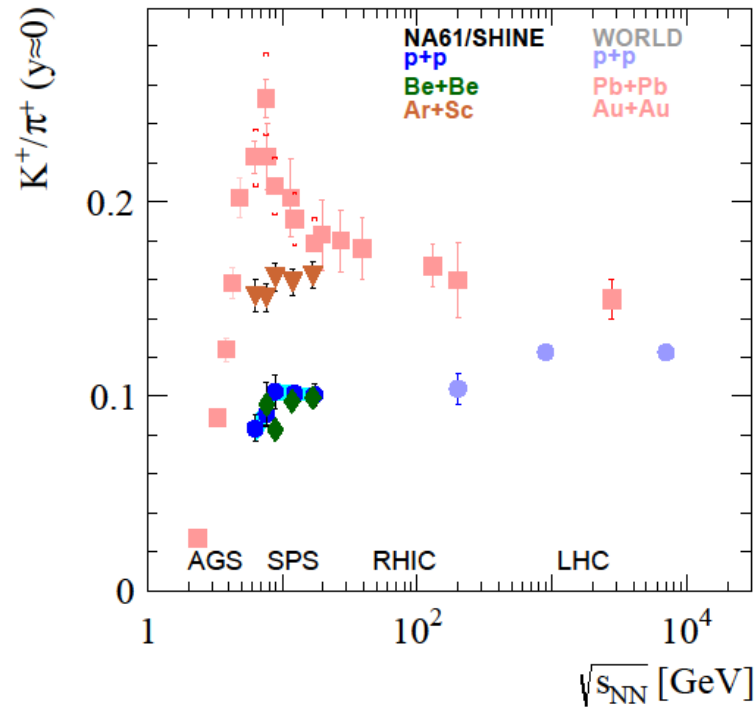


NA61/SHINE 2026-2029

- Detailed 2D scan to study onset of fireball region
- Measurements of hadron production from the HYPER-K replica target

Onset of fireball

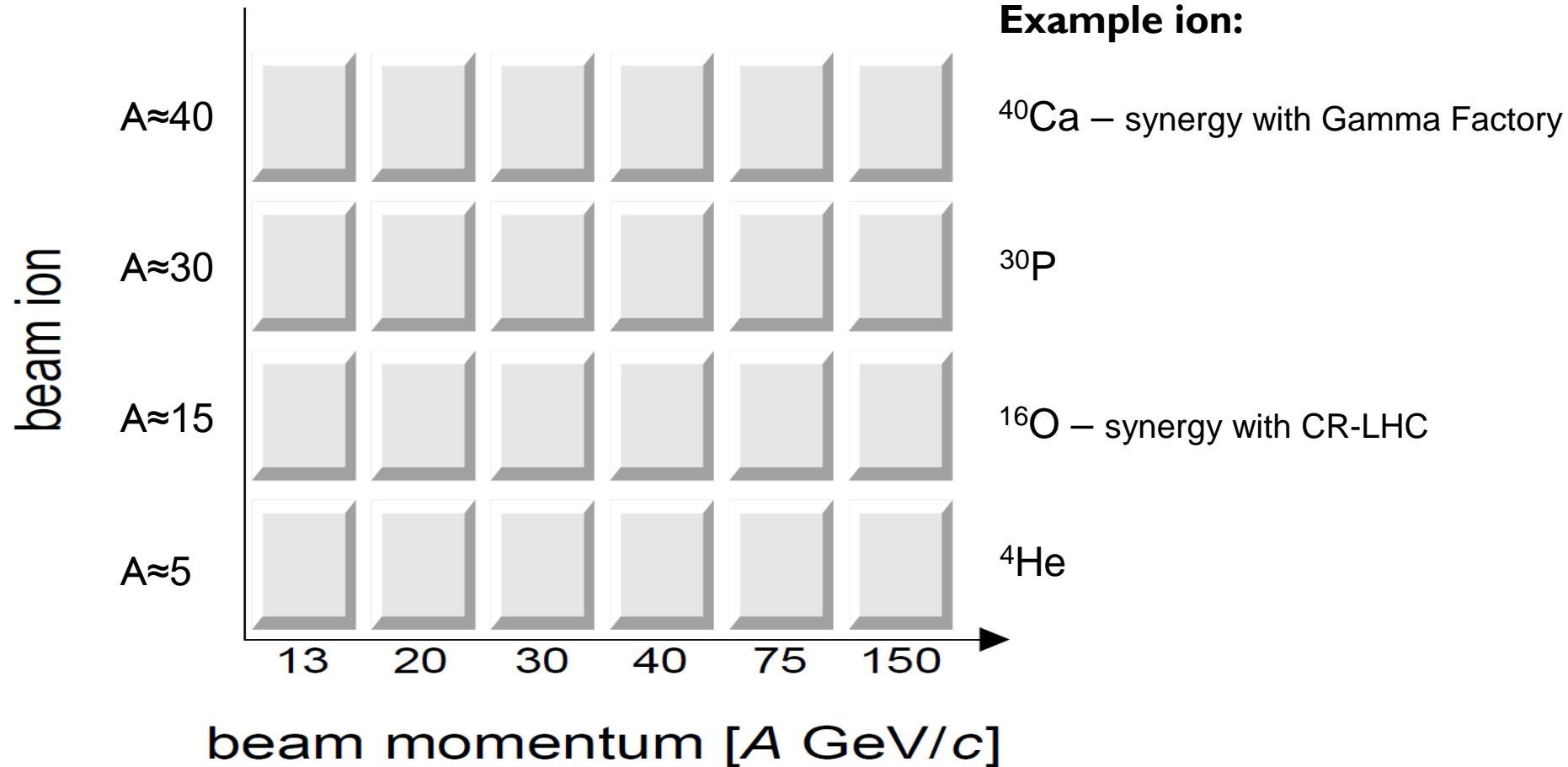
Onset of fireball – beginning of creation of strongly interacting matter with increasing nuclear mass number. Transition from **non-equilibrium** strings and resonances to **equilibrium** hadron gas or quark gluon plasma.



$$p + p \approx Be + Be \neq Ar + Sc \leq Pb + Pb$$

Onset of fireball – ion beam request for 2026-2029

The very first idea



Summary

- **2019-2026:**
 - **NA61/SHINE in The Briefing Book for the 2020 European Strategy Particle Physics**
 - **The upgrade is progressing according to schedule**
 - **Results from test measurements:**
 - D^0 meson signal for open charm programme
 - Nuclear fragmentation for space cosmic-ray programme
- **2026-2029**
 - **The very preliminary idea to extend physics programme beyond 2026**
 - Study of the onset of fireball – 2D scan with low and medium size ions
 - Hadron production from the HYPER-K replica target



THANK YOU

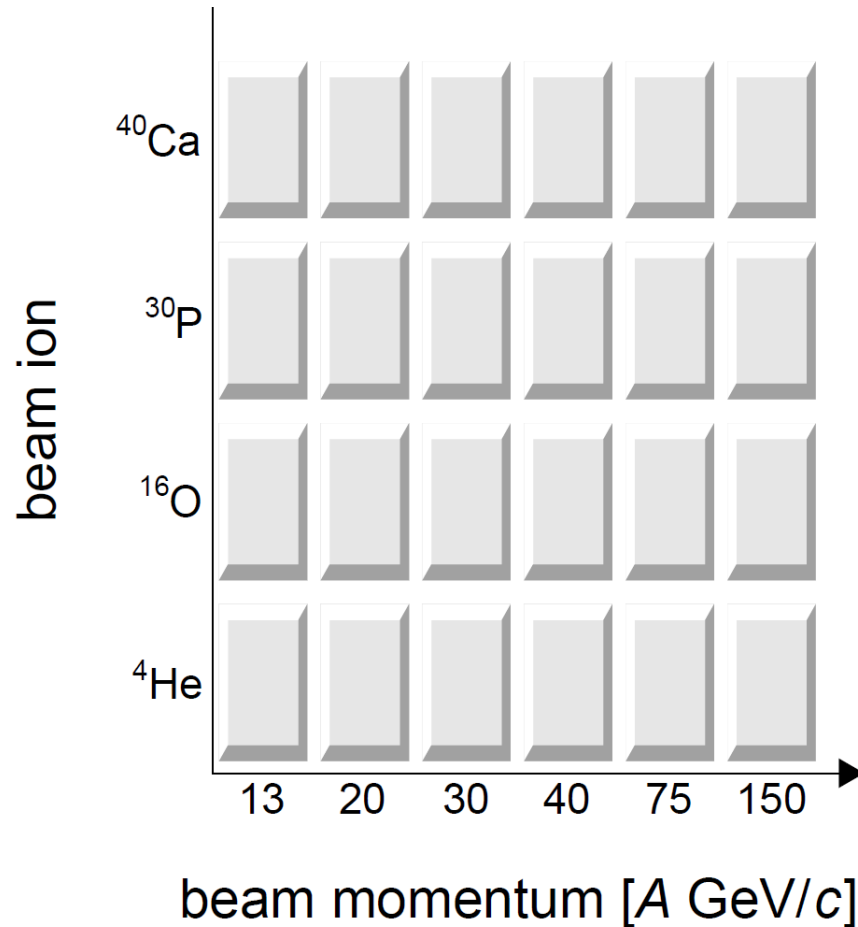


BACKUP



Onset of fireball – ion beam request for 2026-2029

The very first idea



A	synergy
≈ 40	Gamma Factory
≈ 30	
≈ 15	CR-LHC
≈ 5	

Detailed scan in nuclear mass number and collision energy should be possible at:

- NICA (<11 GeV) – 2022+
- FAIR (< 5 GeV) – 2025+
- SPS (5-17 GeV) – 2025+
- J-PARC (<6 GeV) - ?

Financial scenarios

Default spending profile

year	2018	2019	2020	2021	2022	sum	source of funding
TPC upgrade	-	115k	459k	-	-	574k	DFG grant (44%), CF (22%) or Polish/Norwegian Grant (66%), US DOE SHINE Request (17%), CF (17%)
VD	-	-	130k	-	-	130k	NCN OPUS (100%)
PSD	-	55k	-	-	-	55k	INR grant - contribution to NA61-CF (55%), NA62 payment for old PSD (45%)
MRPC ToF	50k	90k	376k	10	-	526k	JINR grant (100%)
BPD	-	-	60k	-	-	60k	NCN/DFG Beethoven (100%) or Japan grant (100%)
TDAQ	30k	93k	93k	-	-	216k	NCN Maestro (55%), NCN/DFG Beethoven (24%), CF 2018 (21%)
DRS4	-	40k	90k	-	-	130k	US DOE SHINE Request (55%), JINR grant (16%), CF (29%)

Contingency spending profile

year	2018	2019	2020	2021	2022	sum	source of funding
TPC upgrade	-	115k	165k	175k	-	455k	CF (100%)
VD	-	-	-	40k	90k	130k	CF (100%)
PSD	-	55k	-	-	-	55k	INR grant - contribution to NA61-CF (55%), NA62 payment for old PSD (45%)
MRPC ToF	50k	90k	376k	10k	-	526k	JINR grant (100%)
BPD	-	-	30k	-	30k	60k	CF (100%)
TDAQ	30k	93k	41k	-	-	164k	NCN Maestro (73%), CF 2018 (27%)
DRS4	-	40k	20k	-	30k	90k	JINR grant (23%), CF (77%)

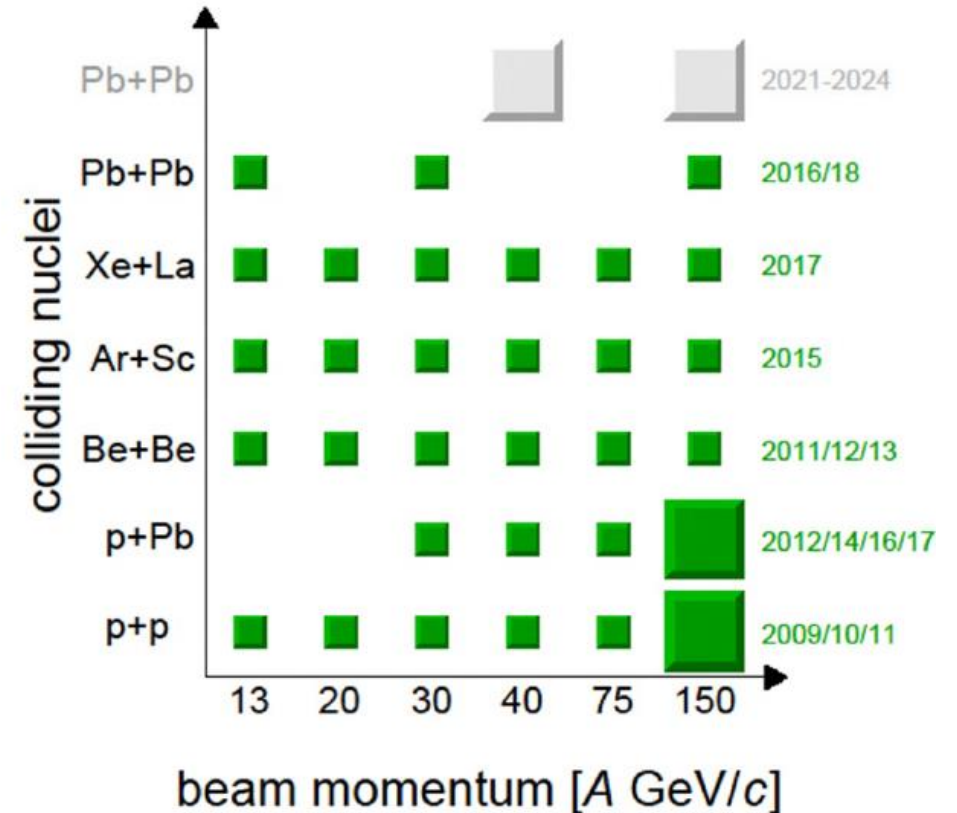
The upgrade of TPC read-out, Trigger and DAQ, PSD, DCS, MRPC is progressing according to schedule

The minutes of the June Research Board meeting

The SPSC considers that the NA6I run foreseen for 2021 could be postponed to 2022, if compatible with the NA6I funding, given the status of work in the PBC study together with the indication that there is no competition for the North Area beam line used by NA6I. **The Research Board agreed that the run of NA6I can be included in the beam-line planning for the moment;** however, full funding for the detector should be available before final approval of the run in 2021 is given, or before granting operation beyond 2021.

NA6 I/SHINE programme - outlook

- 2009-2018:
 - Strong interaction programme - 2D scan:
 - Study of the onset of deconfinement
 - Search for critical point
 - Unexpected result: onset of fireball
 - Measurements of hadron production properties for neutrino and cosmic-ray physics
 - **Data taking completed**
- **2021-2024:**
 - Strong interaction programme Pb+Pb at 150A and 40A GeV/c
 - Open charm production
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The logo for SHINE, featuring the letters 'S' and 'INE' in a bold, dark blue font. The 'S' is stylized with several parallel, slightly curved lines that create a sense of depth and movement, resembling a particle beam or a detector structure. The text is set against a white background with a subtle drop shadow.

S·INE

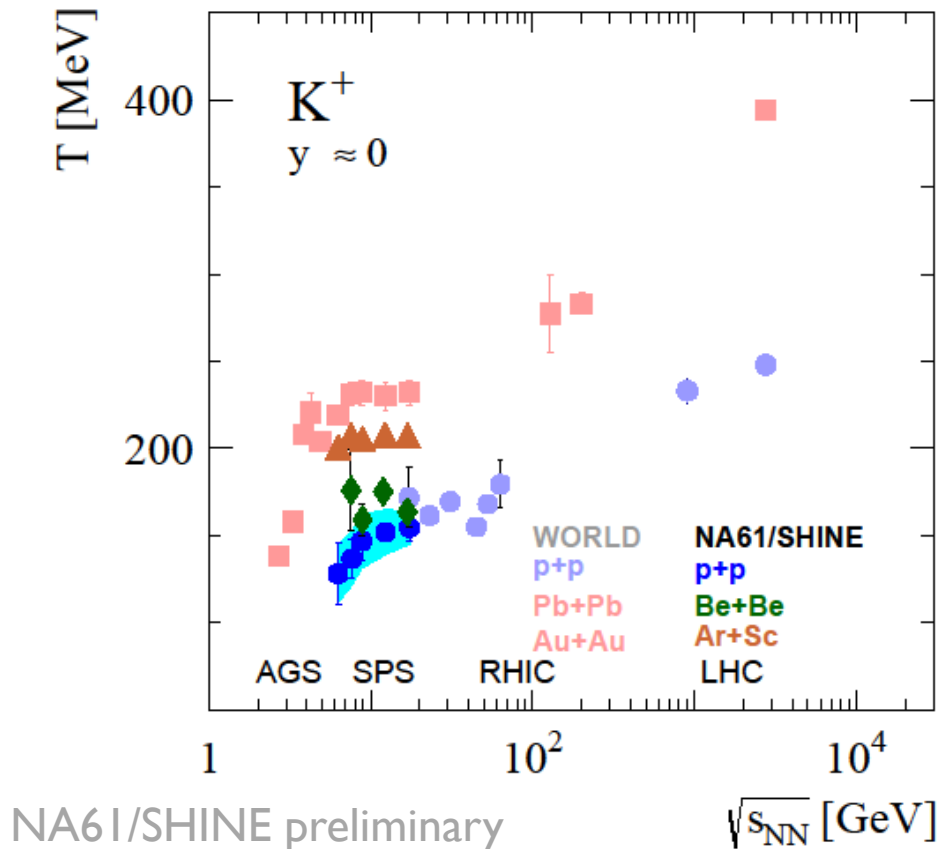
NA61/SHINE 2009-2018

and cosmic-ray physics

Study of the onset of deconfinement - Step

Plateau – STEP – in the inverse slope parameter T of kaon m_T spectra in Pb+Pb collisions observed at SPS.

Predicted signature of the onset of deconfinement.



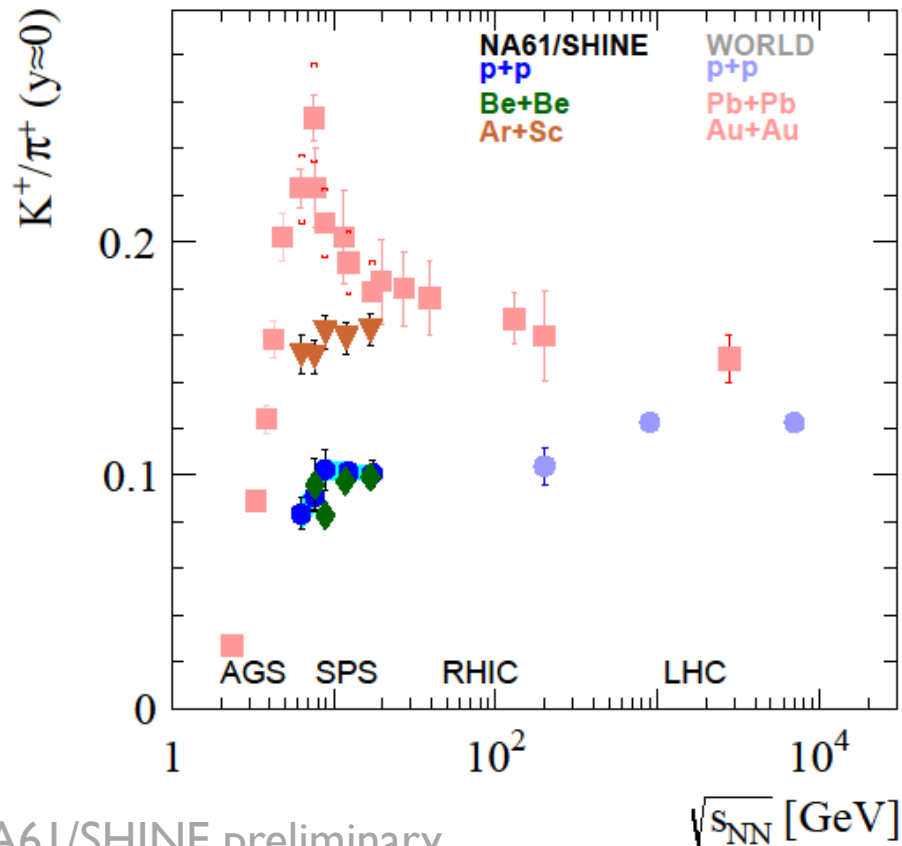
Qualitatively similar energy dependence is seen in p+p, Be+Be and Pb+Pb collisions

Magnitude of T in Be+Be slightly higher than in p+p

Ar+Sc results between p+p/Be+Be and Pb+Pb

Study of the onset of deconfinement - Horn

Rapid changes in K^+/π^+ energy dependence – **HORN** – were observed in Pb+Pb collisions at SPS (NA49).
Predicted signature of onset of deconfinement.



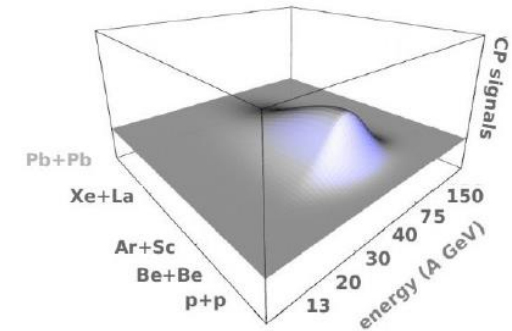
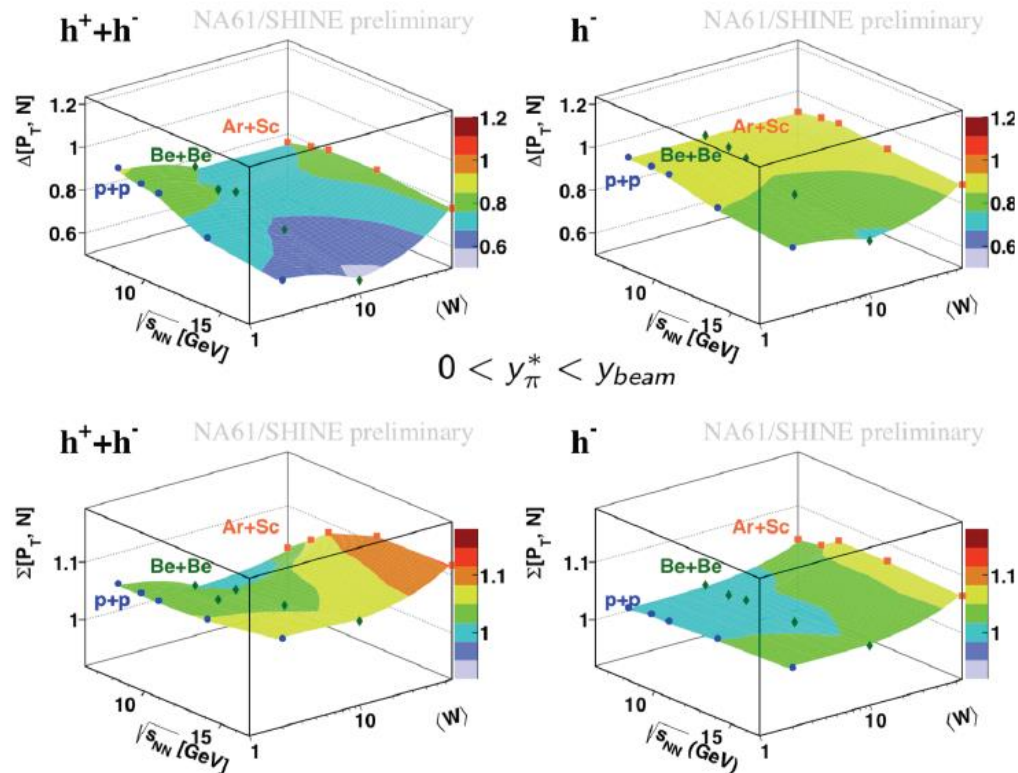
NA61/SHINE: unexpected system size dependence

- Plateau like structure visible in p+p
- Be+Be close to p+p

Ar+Sc is significantly higher than p+p \approx Be+Be (at the top SPS energy Ar+Sc \approx Pb+Pb). No horn structure in Ar+Sc.

Search for the critical point

Expected region of enhanced fluctuations



NA61/SHINE:
No prominent structures which could be related to the critical point

$$\Sigma[P_T, N] = \frac{1}{C_\Sigma} [\langle N \rangle \omega[P_T] + \langle P_T \rangle \omega[N] - 2 \cdot (\langle P_T \cdot N \rangle - \langle P_T \rangle \langle N \rangle)]$$

$$\Delta[P_T, N] = \frac{1}{C_\Delta} [\langle N \rangle \omega[P_T] - \langle P_T \rangle \omega[N]], \quad C_\Sigma = C_\Delta = \langle N \rangle \omega(P_T)$$