# Report from NA61/SHINE experiment - physics of strong interactions and detector upgrade

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for the NA61/SHINE Collaboration

SPSC Open Session
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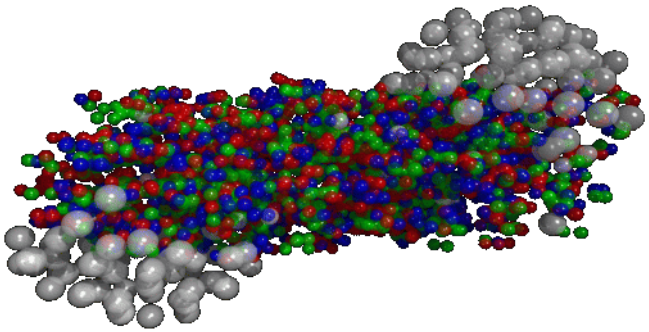
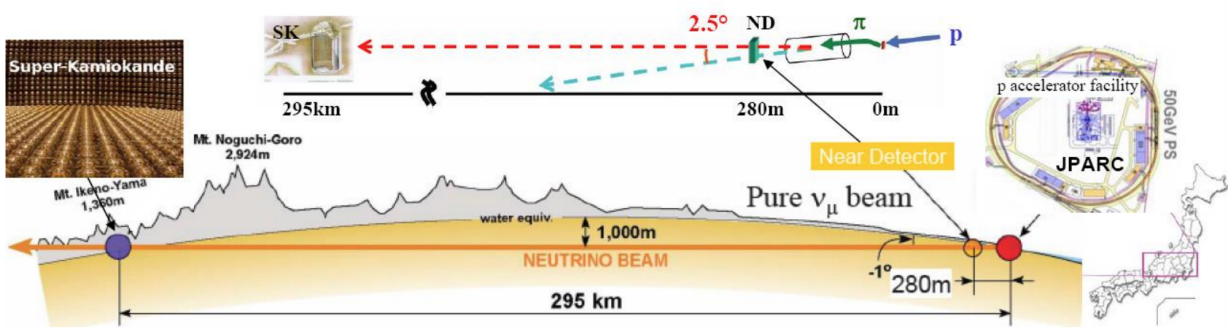
# NA61/SHINE experiment

NA61/SHINE is a fixed target experiment located in the North Area of the SPS accelerator. NA61/SHINE uses primary and secondary ion and hadron beams.

NA61/SHINE programme:

- Strong Interaction physics
  - search for the critical point of strongly interacting matter
  - study of the properties of the onsets of deconfinement and fireball
  - heavy flavours: direct measurement of open charm at CERN SPS energies
- Neutrino and cosmic ray physics
  - hadron production measurements for the J-PARC and Fermilab neutrino programmes
  - hadron production measurements for cosmic-ray physics (Pierre-Auger and KASCADE experiments) for improving air shower simulations
  - measurements of nuclear fragmentation cross sections of intermediate mass nuclei
  - for more news on neutrino and cosmic ray programmes see the following talk by **Laura Fields**





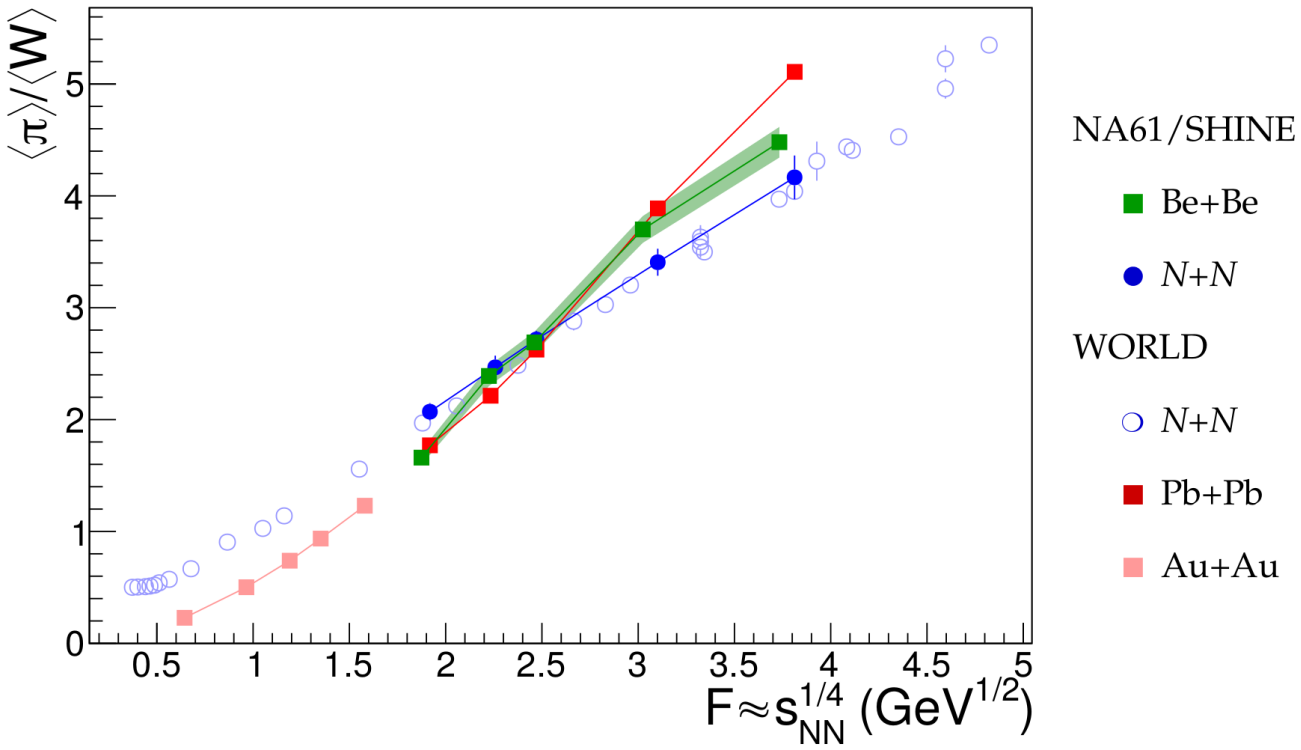
# Selected new results:

# Strong Interaction Physics

- Final results concerning $p + p$ interactions and onset of deconfinement, Phys. Rev. C 102 no. 1, (2020) 011901
- **Final results on $\pi^-$ production in Be+Be,** arXiv:2008.06277
- **Final results on fluctuations of identified particles in inelastic $p$+$p$ interactions,** arXiv:2009.01943
- Preliminary results on higher order moments of multiplicity and net-charge in central Be+Be collisions at 150$A$ GeV/$c$ arXiv:2002.04847
- Higher-statistics preliminary results on intermittency analysis in central Ar+Sc collisions at 150$A$ GeV/$c$, arXiv:2002.06636
- **Preliminary results on intermittency analysis using cumulative variables in central Ar+Sc collisions at 150$A$ GeV/$c$**
- **Final results on $\Xi^-$ and $\overline{\Xi}^+$ production in inelastic $p$+$p$ interactions at 158 GeV/$c$,** EPJC 80 no.9,(2020) 833
- Final results on search for pentaquarks in inelastic $p + p$ interactions at 158 GeV/$c$, Phys. Rev. D 101 no. 5, (2020) 051101
- Final results on $\phi$ meson production in inelastic $p + p$ interactions at 40–158 GeV/$c$, EPJC 80 no.3,(2020) 199
- Final results on $K^*(892)^0$ production in inelastic $p + p$ interactions at 158 GeV/$c$, EPJC 80 no.5,(2020) 460
- **Final results on two-particle correlations in azimuthal angle and pseudorapidity in Be+Be collisions at 19$A$-150 GeV/$c$,** arXiv:2006.02153
- **Preliminary results on electromagnetic effects in Ar+Sc collisions at 40$A$ GeV/$c$**

# $\pi^-$ production in Be+Be interactions

- Final results on $\pi^-$ multiplicity in Be+Be interactions were accepted for publication in Eur. Phys. J. C [1]

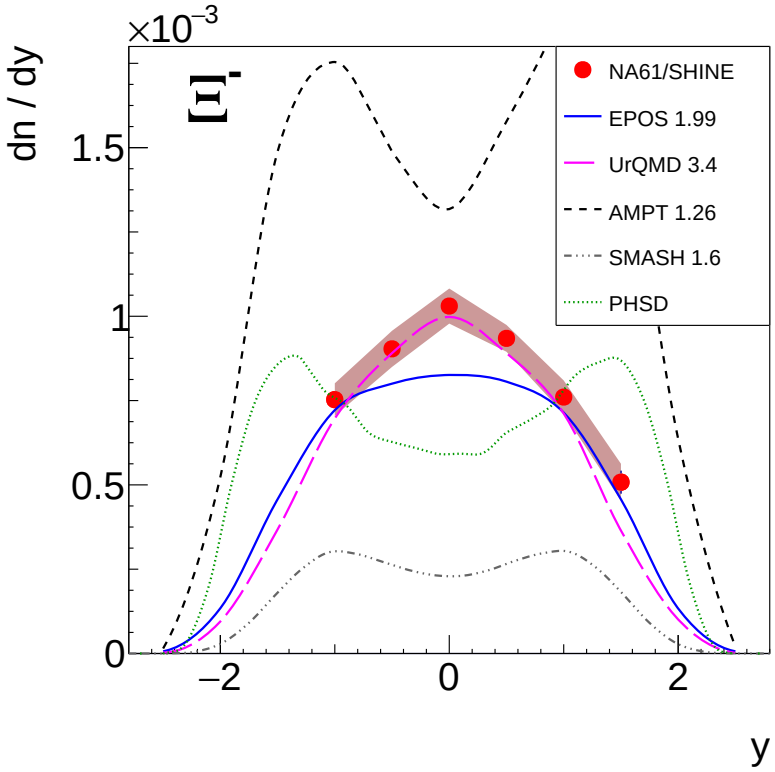


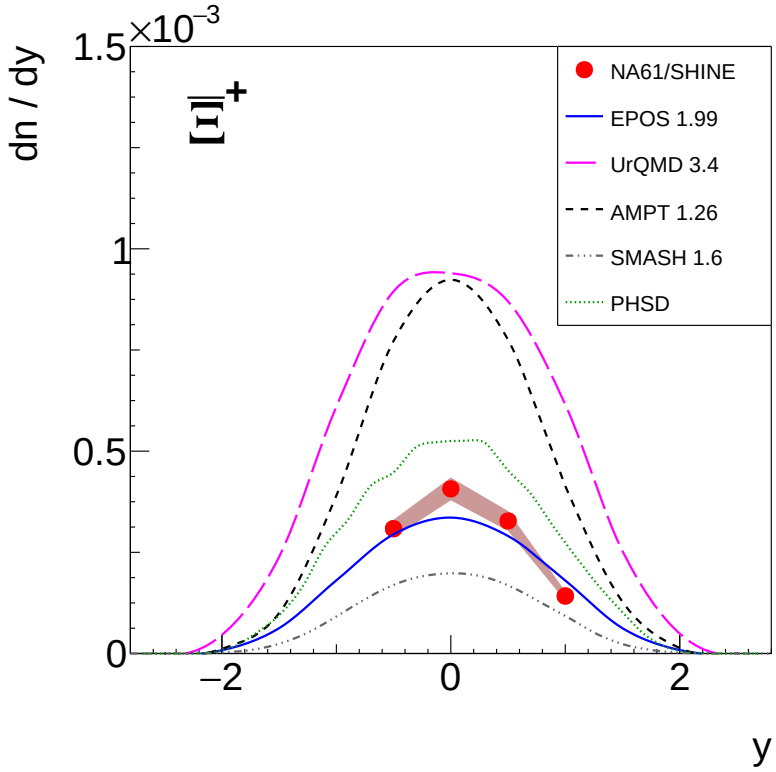

- $\langle\pi\rangle/\langle W\rangle$ in Be+Be interactions for low $F$ follows Pb+Pb (Au+Au), while for top recorded collision energy it is close to $N$+$N$

[1] arXiv:2008.06277

# $\Xi^-$ and $\overline{\Xi}^+$ production in $p$+$p$ at 158 GeV/$c$

- Final results on production of $\Xi(1321)^-$ and $\overline{\Xi}(1321)^+$ hyperons in inelastic $p+p$ interactions at 158 GeV/$c$ were recently published in Eur. Phys. J. C [2]



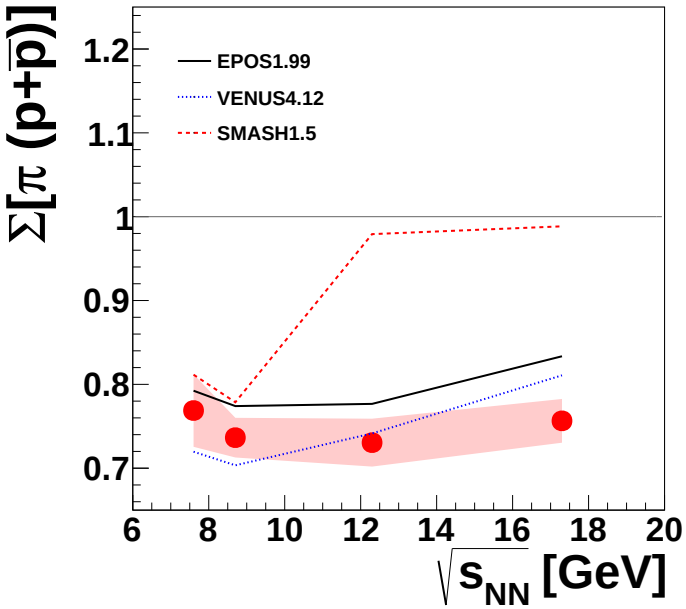



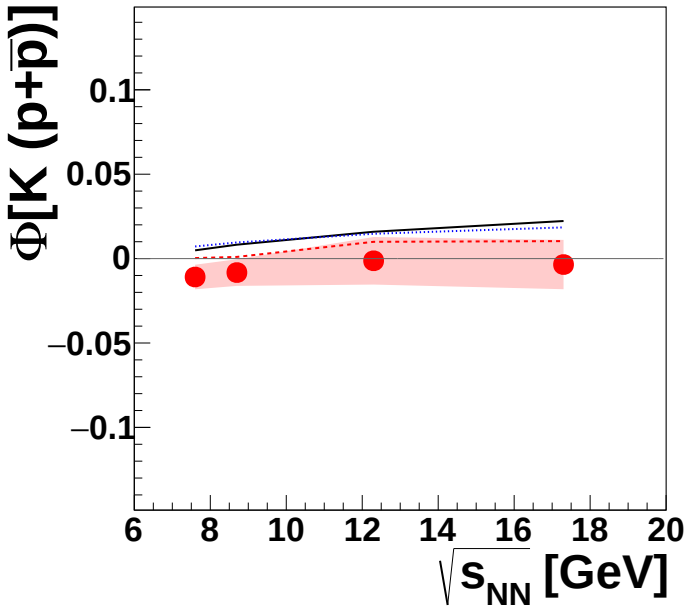

- Results on $\Xi$ production obtained by the NA61/SHINE set a new baseline for calculation of strangeness enhancement factors in A+A collisions

[2] Eur. Phys. J. C 80 no. 9, (2020) 833

# Fluctuations of identified particles in $p$+$p$

- Final results on multiplicity fluctuations of identified hadrons in $p + p$ interactions were submitted to Eur. Phys. J. C [3]



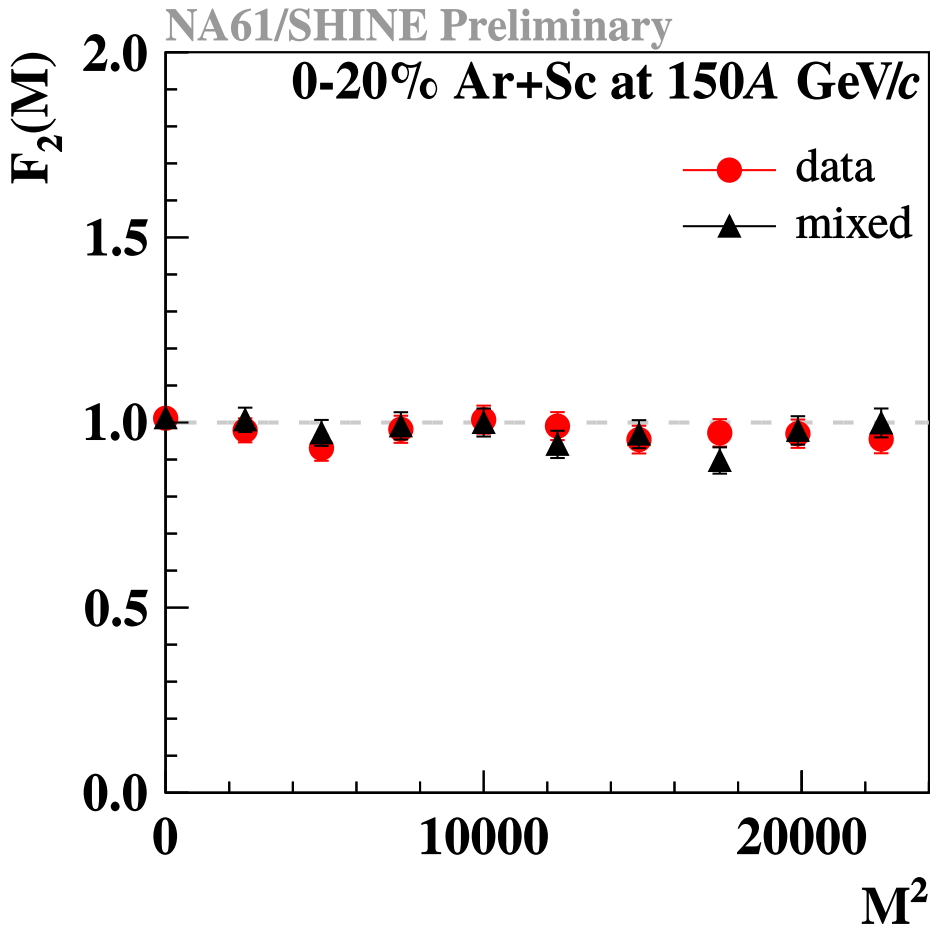




- Strongly intensive quantities are used in order to allow for a direct comparison with corresponding results on nucleus-nucleus collisions
- Results were compared with models, none of the models fully agree with obtained results

[3] arXiv:2009.01943

# Proton intermittency in Ar+Sc

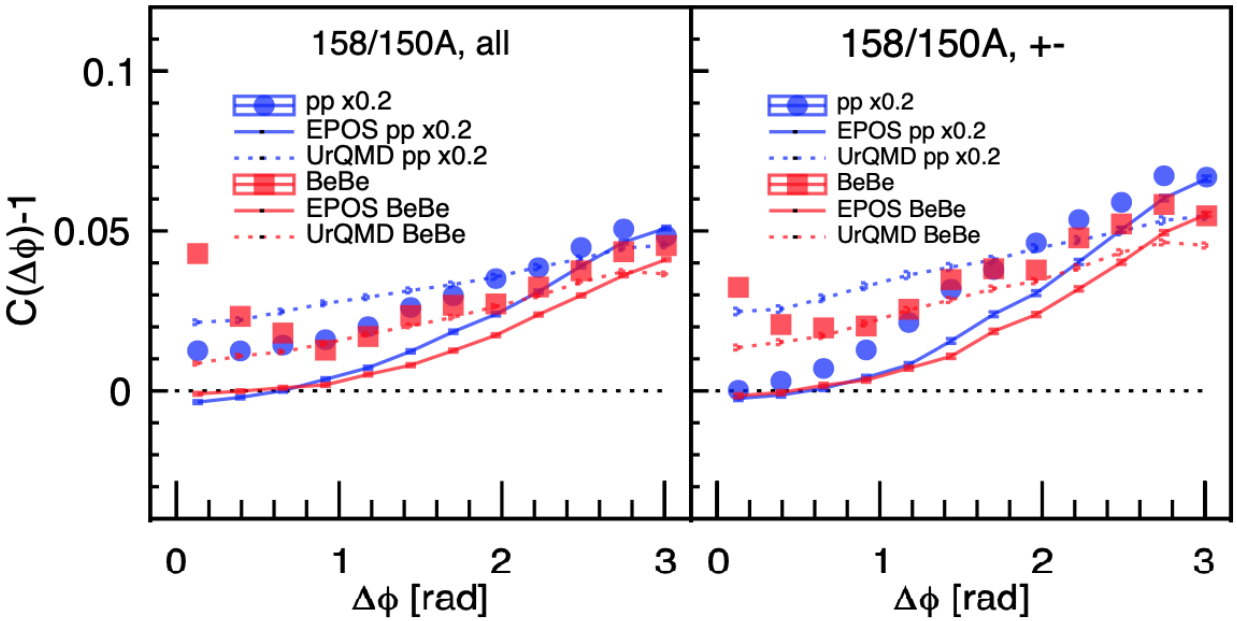
- New preliminary results on proton intermittency in Ar+Sc obtained using cumulative transverse momentum variables and uncorrelated points were released




- No critical point signal is visible in this approach to proton intermittency analysis

# Two particle correlations in Be+Be

- Final results on $\Delta\eta\Delta\phi$ correlations in central Be+Be collisions were submitted to Eur. Phys. J. C [4]

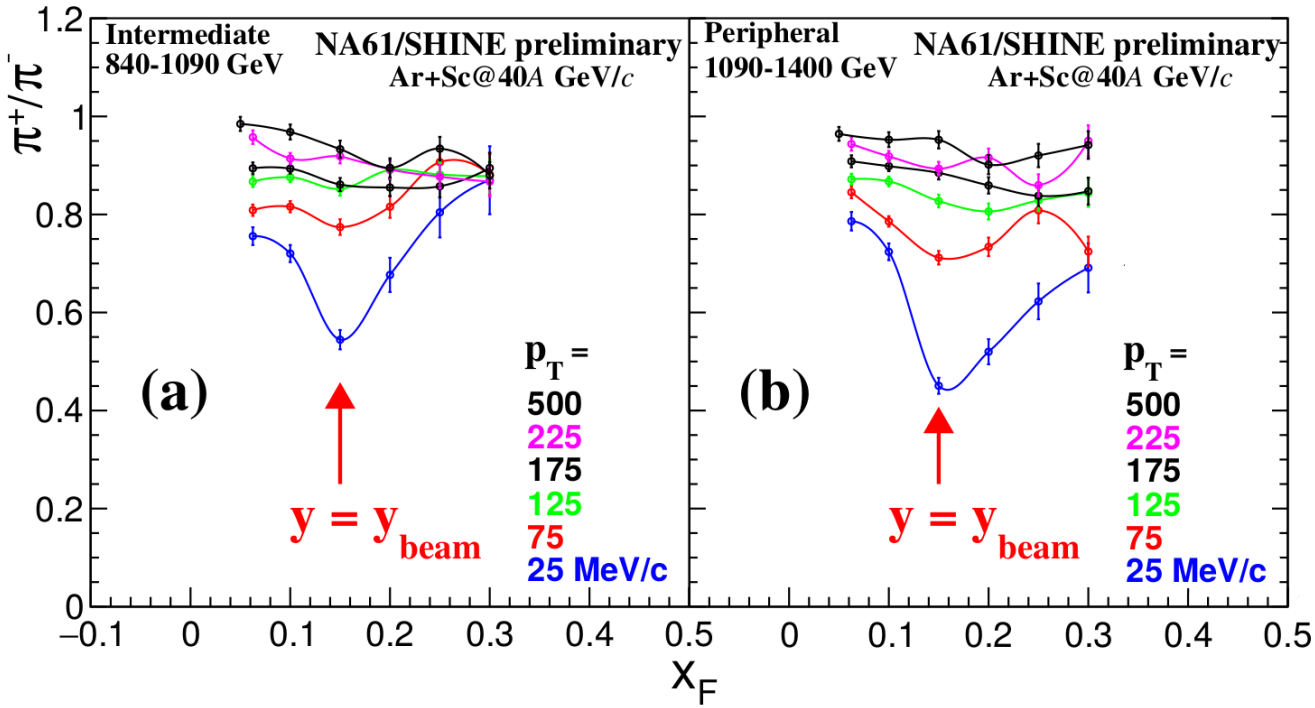



- Correlation patterns are qualitatively similar to ones seen in $p+p$, but strongly suppressed by combinatorial background
- Be+Be data show enhancement in correlation function around $(\Delta\eta, \Delta\phi) = (0, 0)$ not visible in $p+p$ and not predicted by the models used for comparison

[4] arXiv:2006.02153

# Electromagnetic effects in Ar+Sc at 40$A$ GeV/$c$

- New preliminary results on electromagnetic effects in Ar+Sc at 40$A$ GeV/$c$ were released

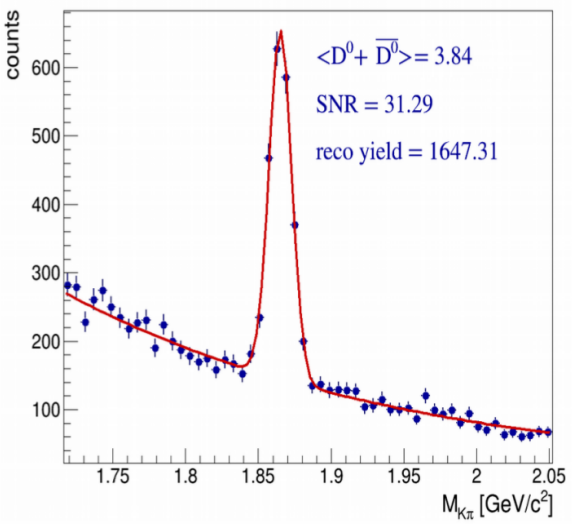



- It is the first observation of this effect in peripheral small system at the CERN SPS

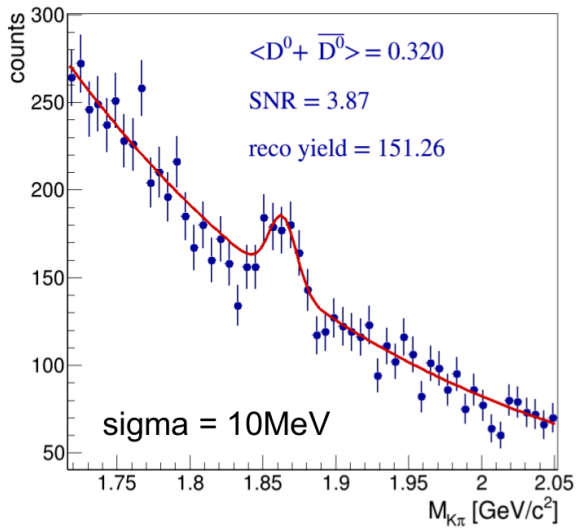
# Open charm in Xe+La

- Full simulation chain including the Vertex Detector was developed
- Simulation was done assuming $D^0 + \overline{D}^0$ phase space as predicted by the PHSD for three different assumed $\langle D^0 + \overline{D}^0 \rangle$ for 1.8 M 0-20% central Xe+La at 150$A$ GeV/$c$ collisions

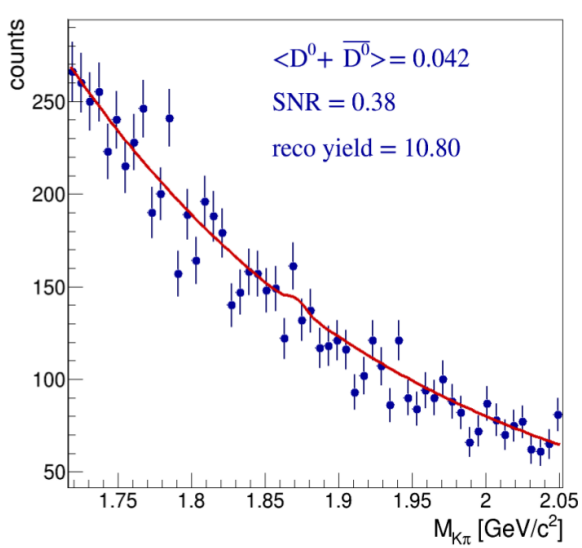
SMES




NA50 (≈ pQCD×3)




PHSD




- Results reported last year [5] favor $\langle D^0 + \overline{D}^0 \rangle$ about 0.2 however with large statistical uncertainty. It agrees with the estimates provided by NA50 from di-muon measurements.
- Analysis of Pb+Pb at 150$A$ GeV/$c$ data taken in 2018 is in progress

[5] CERN-SPSC-2019-041

# New measurements:

# Strong Interaction Physics

Measurements after LS2:

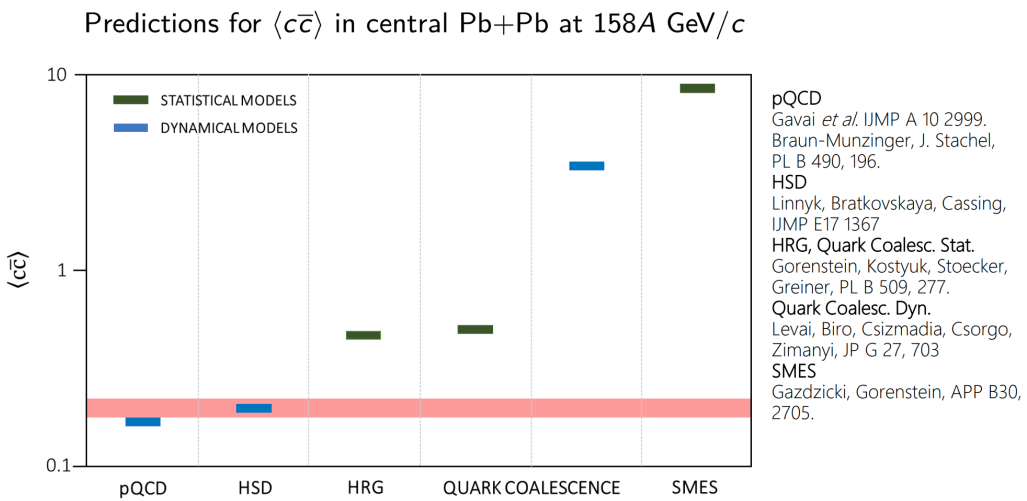
- Open charm measurements in Pb+Pb interactions

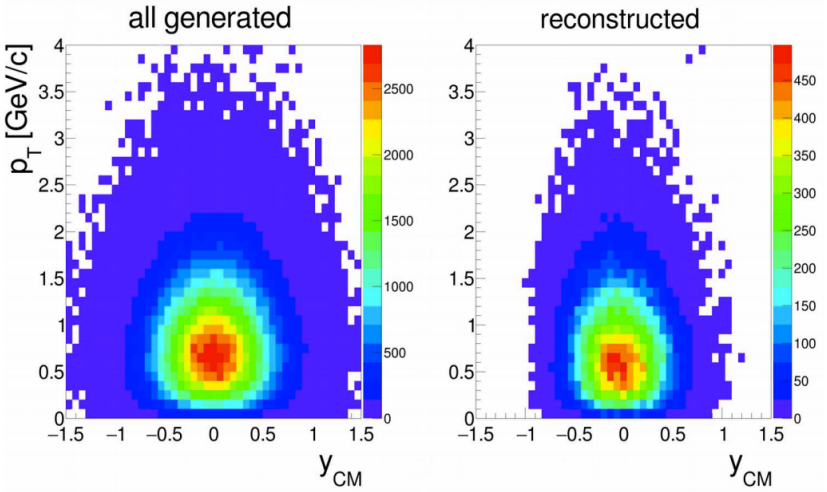
Ideas for measurements after LS3:

- Extension of 2D scan in system size and energy of the collision with intermediate and light systems
- Physics with anti-proton beams on hadron and nuclear targets

# Open charm measurements after LS2

- Precise measurements of charm hadron production by NA61/SHINE are expected to be performed after LS2



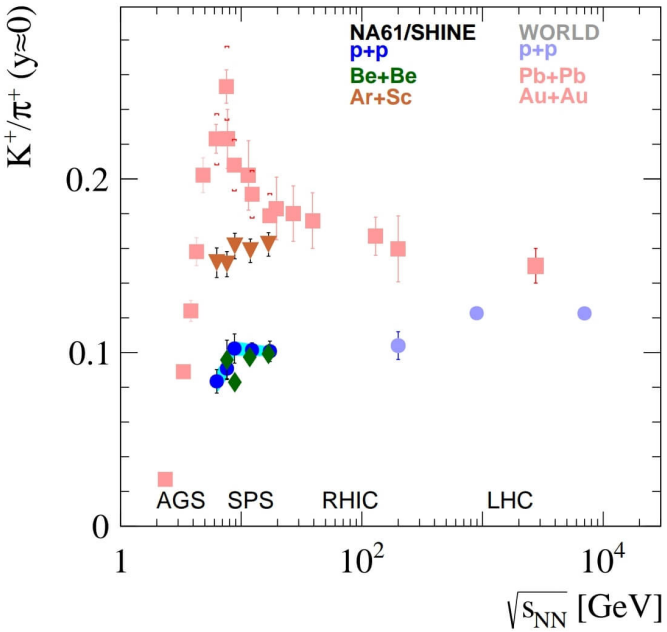



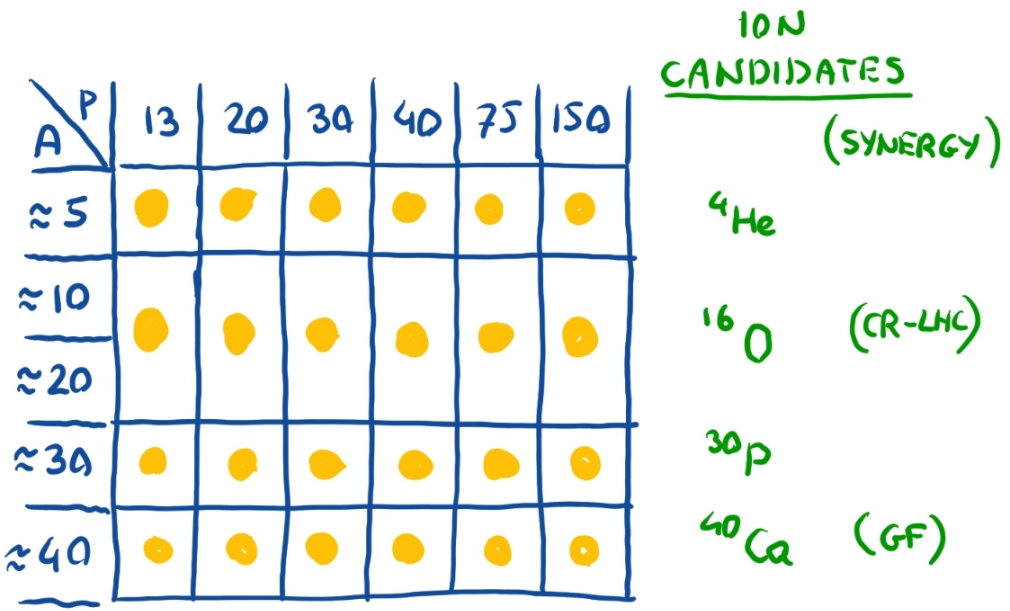

- The Lorentz boost makes the measurements significantly easier than in case of collider experiments.
- Acceptance extends up to $p_T = 0$, which allows for measurement of total charm yield
- NA61/SHINE will measure charm production as a function of centrality for 40$A$ and 150$A$ GeV/$c$ beam momenta

Details can be found in SPSC-P-330-ADD-10

# Ideas for measurements after LS3 - 2D scan

- NA61/SHINE observed rapid change of hadron production properties when moving from Be+Be to Ar+Sc (onset of fireball)



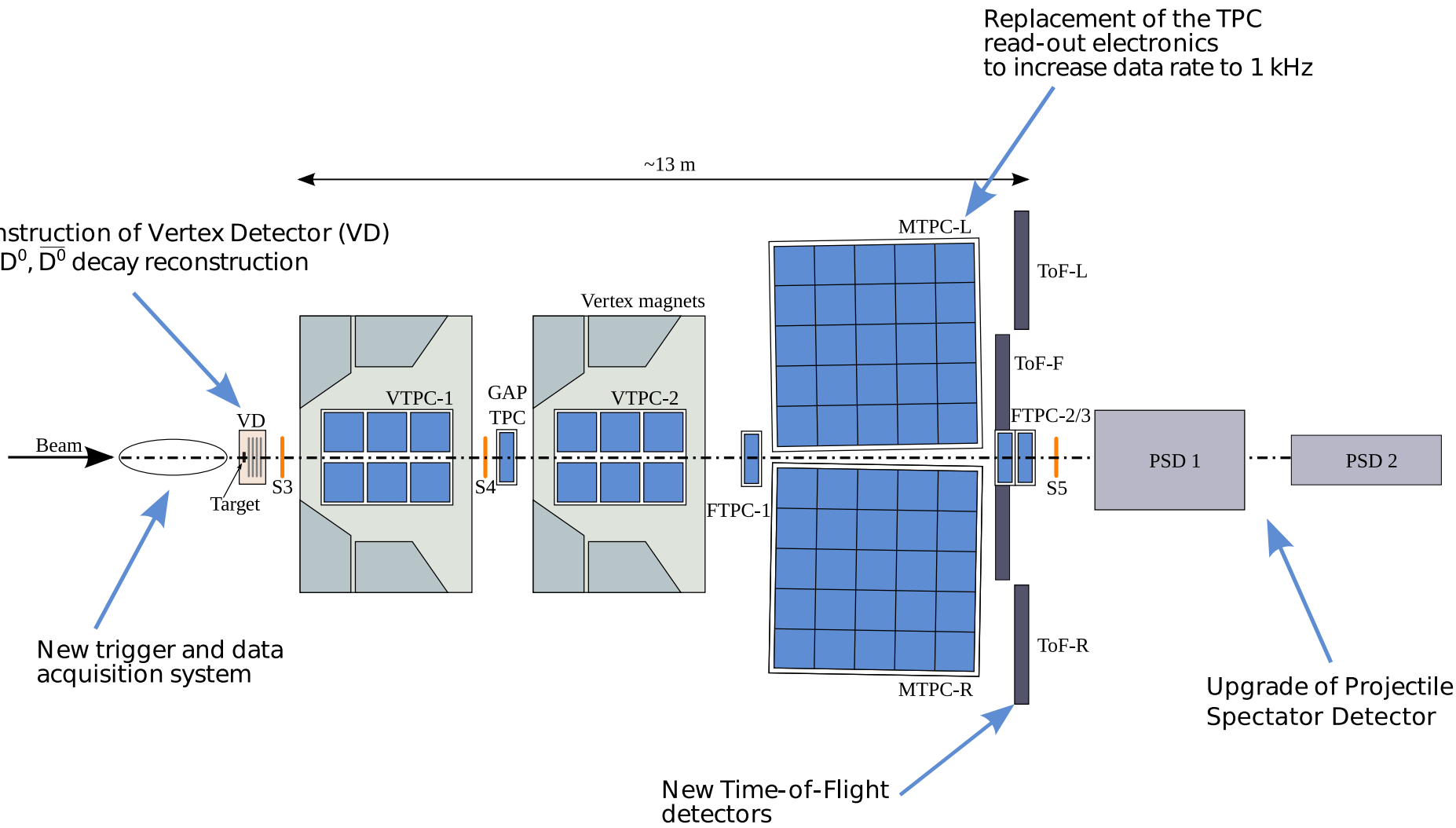




- NA61/SHINE proposes to explore hadron production in low and intermediate mass systems
- Draft beam request for a new 2D scan programme after LS3 has been established
- Discussion with CERN BE and EN departments on feasibility of having such beams has been started

# NA61/SHINE detector upgrade:

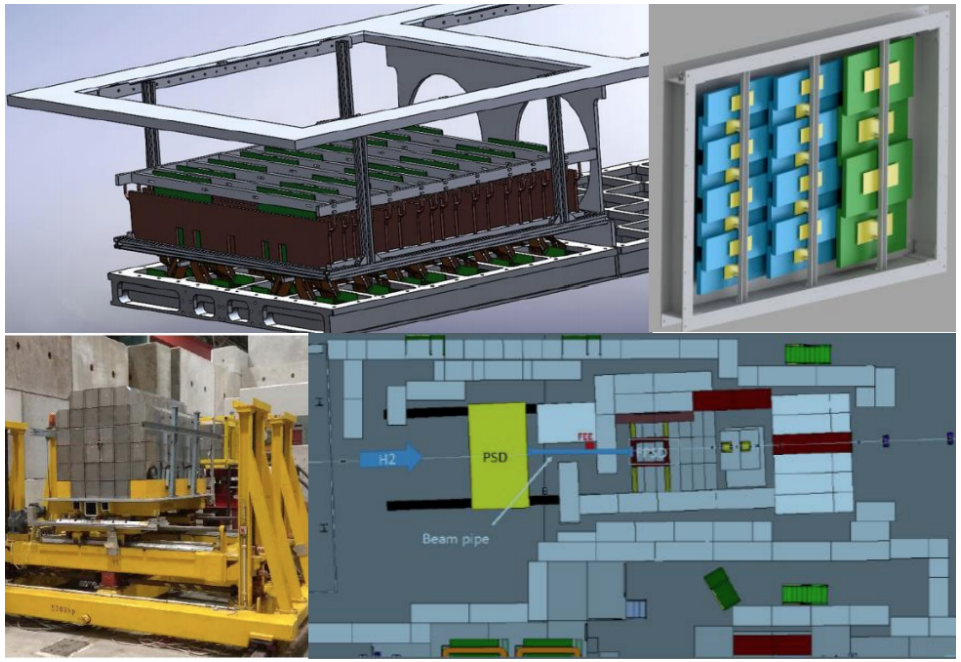
# Current status

# NA61/SHINE detector upgrade during LS2



# Upgrade status

- Work schedule was adjusted due to COVID-19 pandemic
- Full technical documentation is available [6]
- **Funding for the whole detector upgrade is secured**
- Work on the upgrade is on schedule




**No obstacles are seen to complete the upgrade by summer 2021 and have full readiness of the NA61/SHINE detector for the first beam delivered to North Area in July 2021.**

NA61/SHINE detector upgrade benefits from synergies with ALICE, MPD/BM@N and CBM experiments

[6] https://edms.cern.ch/document/2422986/1

# Summary

- Many new final and preliminary results from the NA61/SHINE strong interaction programme
- Measurements after LS2:
  - High statistics open charm production measurement in Pb+Pb
- Ideas for measurements after LS3:
  - Continuation of 2D scan in system size and collision energy for light and intermediate systems
  - Physics with anti-proton beams on hadron and nuclear targets
- Detector upgrade:
  - Upgrade is progressing according to schedule
  - **Upgraded NA61/SHINE detector will be ready in Summer 2021**

**We would like to thank the CERN EP, BE, EN and HSE departments for the strong support of NA61/SHINE.**

*Thank You*

# *Backup*

# Upgrade status - details

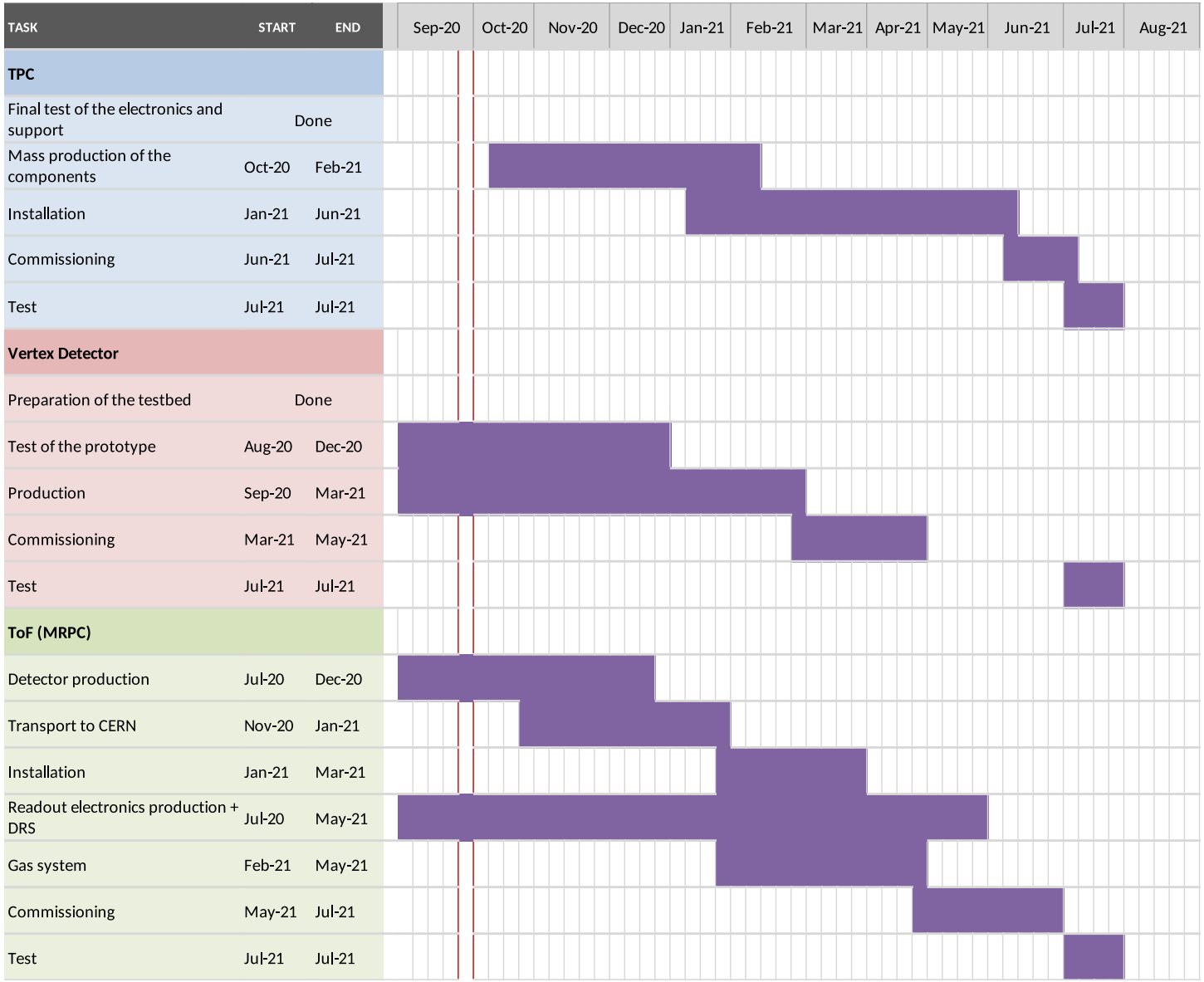
- TPC upgrade
  - Design of electronic adapters and mechanics for TPC readout electronics is finalized
  - Mass production ordering in progress
- Vertex Detector
  - Detector design is ready
  - Firmware and software development in progress
- Projectile Spectator Detector
  - Construction of radiation shielding to be started soon
  - Detector ready, waiting for production of readout electronics
- mRPC TOF
  - Detector construction in progress
- Trigger and DAQ
  - Procurement of network equipment in progress
  - Small scale DAQ test-bed is operational, software development in progress
  - Manufacturing of custom trigger modules is ongoing

# Detector upgrade - funding

| year | 2018 | 2019 | 2020 | 2021 | 2022 | sum | source of funding |
|---|---|---|---|---|---|---|---|
| TPC upgrade | - | 50k | 450k | - | - | 500k | US DOE (USA) grant (32%)<br>Greig (Poland/Norway) grant (48%)<br>CF (20%) |
| VD | - | - | 130k | - | - | 130k | CF (100%) |
| PSD | - | 55k | - | - | - | 55k | INR (Russia) NA61/SHINE contribution |
| MRPC ToF | 50k | 90k | 376k | 10 | - | 526k | JINR grant (100%) |
| BPD | - | - | 30k | - | - | 30k | Beethoven (Poland/Germany) grant (100%) |
| TDAQ | - | 130k | 120k | - | - | 250k | Maestro (Poland) grant (52%),<br>Beethoven (Poland/Germany) grant (48%) |
| DRS4 | - | 40k | 90k | - | - | 130k | JINR grant (30%),<br>US DOE (USA) grant (70%) |

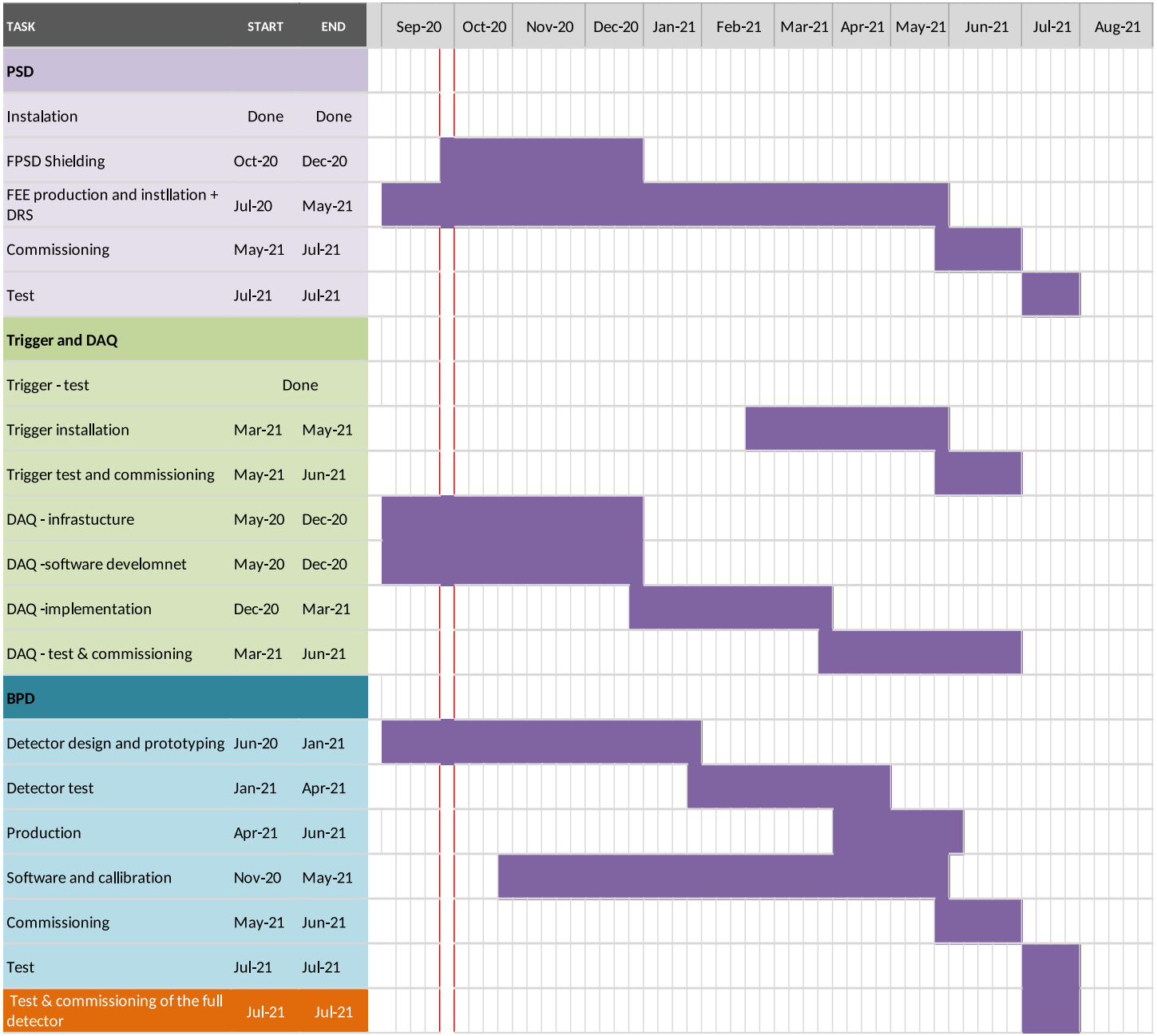
**All funds for NA61/SHINE detector upgrade are granted**

# Detector upgrade - schedule 1/2

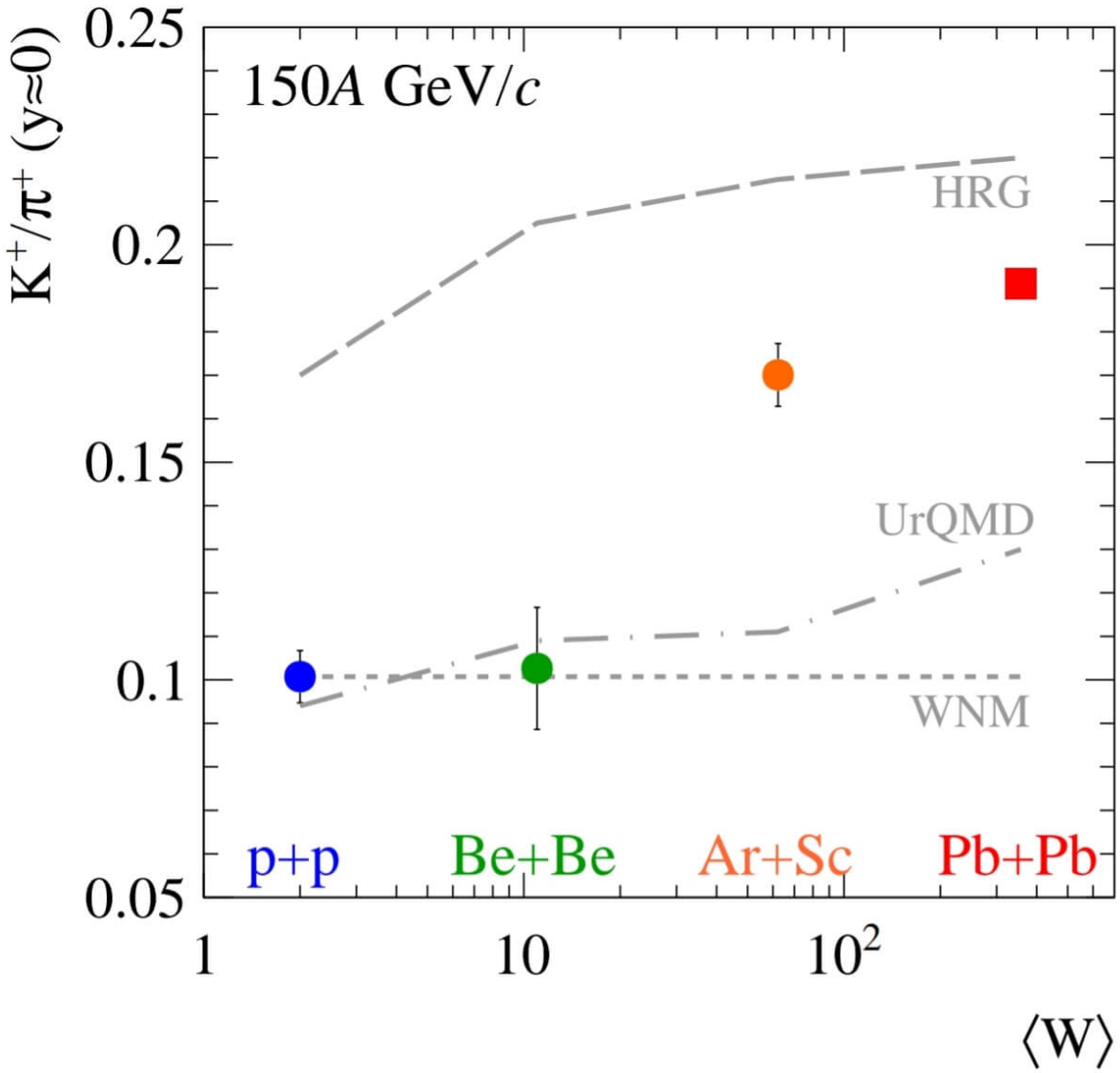


| TASK | START | END |
|---|---|---|
| **TPC** | | |
| Final test of the electronics and support | Done | |
| Mass production of the components | Oct-20 | Feb-21 |
| Installation | Jan-21 | Jun-21 |
| Commissioning | Jun-21 | Jul-21 |
| Test | Jul-21 | Jul-21 |
| **Vertex Detector** | | |
| Preparation of the testbed | Done | |
| Test of the prototype | Aug-20 | Dec-20 |
| Production | Sep-20 | Mar-21 |
| Commissioning | Mar-21 | May-21 |
| Test | Jul-21 | Jul-21 |
| **ToF (MRPC)** | | |
| Detector production | Jul-20 | Dec-20 |
| Transport to CERN | Nov-20 | Jan-21 |
| Installation | Jan-21 | Mar-21 |
| Readout electronics production + DRS | Jul-20 | May-21 |
| Gas system | Feb-21 | May-21 |
| Commissioning | May-21 | Jul-21 |
| Test | Jul-21 | Jul-21 |

# Detector upgrade - schedule 2/2

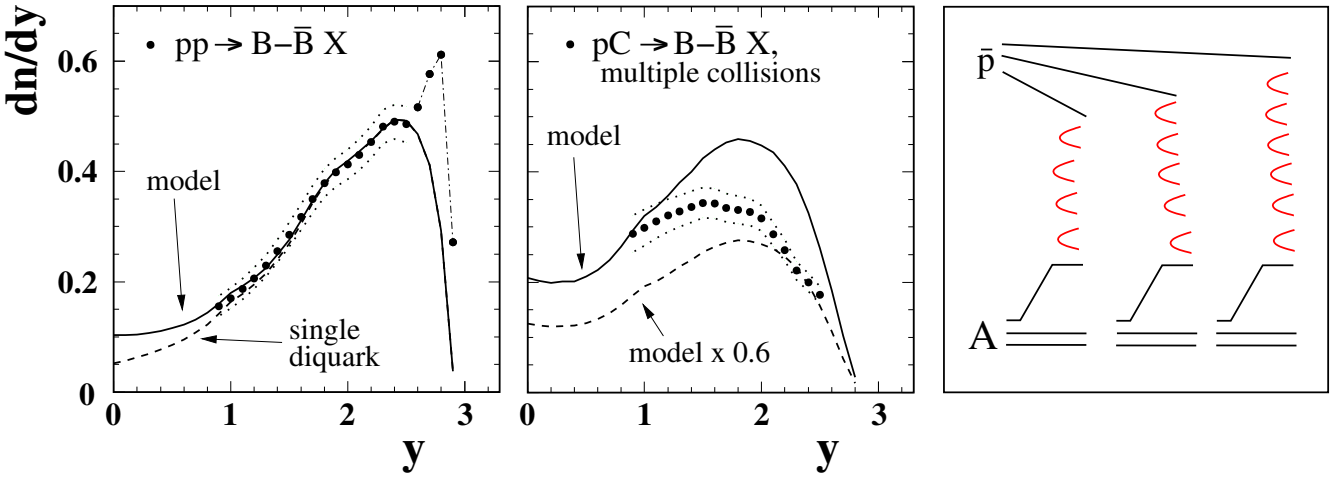


# Ideas for measurements after LS3 - 2D scan




System size dependence of $K^+/\pi^+(y \approx 0)$

# Ideas for measurements after LS3 - physics with anti-proton beams




- baryon transport studies with NA49/NA61/SHINE data are not subject to limitations of the earlier data sets
- isospin-dependence of baryon number transfer over the full projectile hemisphere becomes a measured quantity ($\rightarrow$ neutrons)
- the standard mechanism by Capella & Tran Thanh Van cannot account for more than 60% of multiple collision p+C processes $\rightarrow$ in the remaining 40% the diquark must be disintegrated [7]
- antiprotonic beams open extra diagrams with BN annihilation from disintegrated anti-diquark $\rightarrow$ this will be the *final word* on baryon stopping

[7] M.Jeżabek, A.Rybicki, APPB 51 (2020) 1207

## (O) Open charm signal in Xe+La at 150A GeV/c