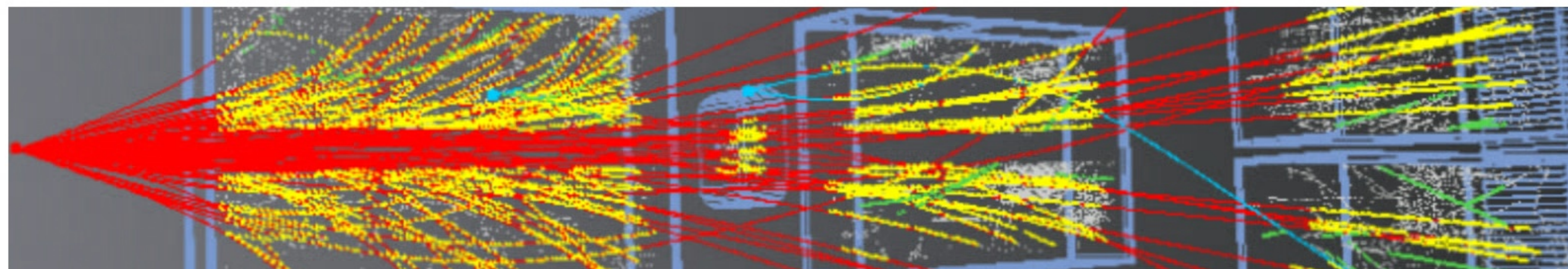


# NABI/SHINE PHYSICS

MG FRANKFURT, KIELCE

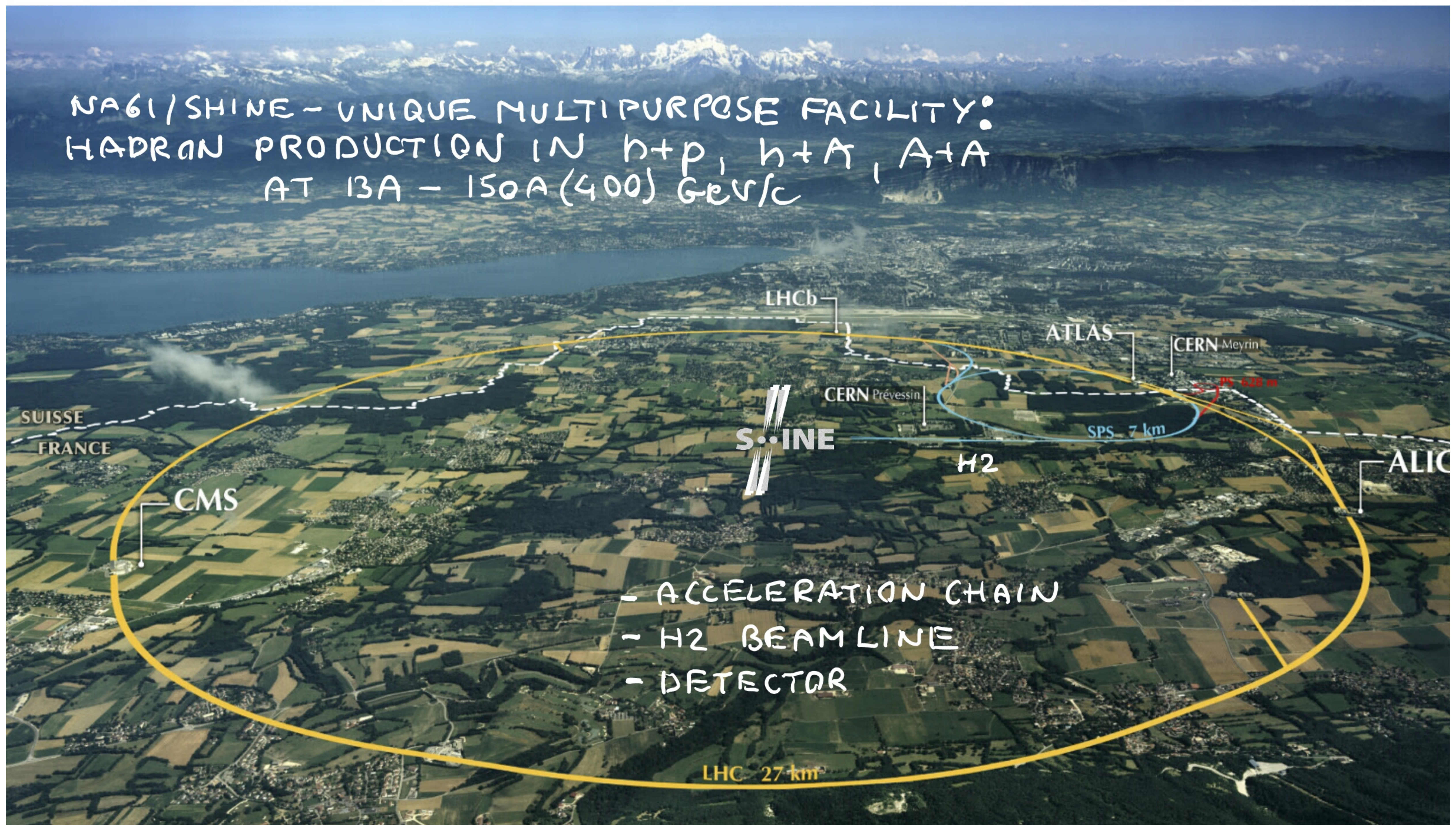
- FACILITY POTENTIAL
- ■ PHYSICS PROGRAMMES
- ■ ■ LESSONS FOR FUTURE





# FACILITY POTENTIAL

NA61/SHINE - UNIQUE MULTIPURPOSE FACILITY:  
HADRON PRODUCTION IN  $h+p$ ,  $h+A$ ,  $A+A$   
AT 13A - 150A (400) GeV/c

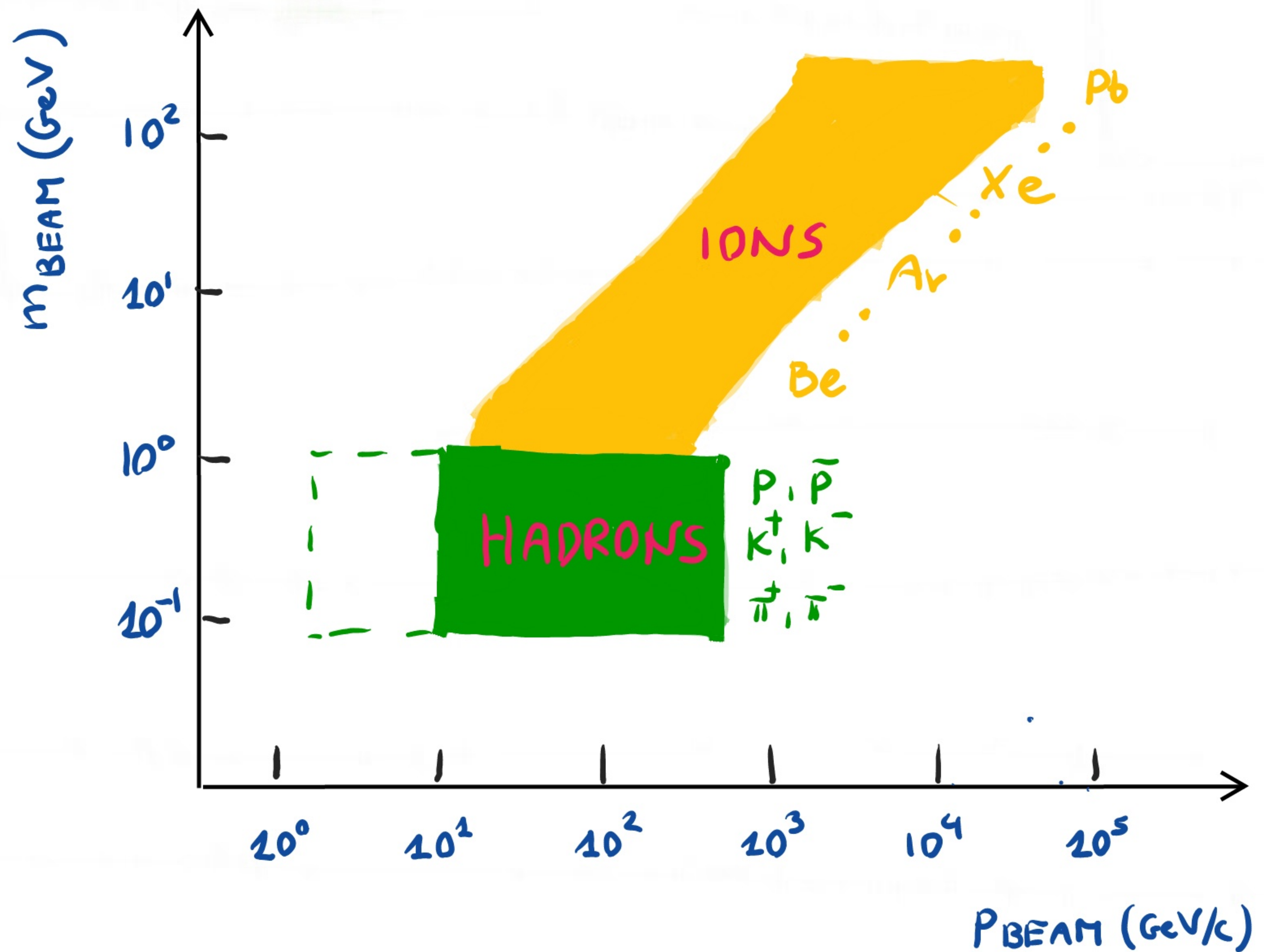


- ACCELERATION CHAIN
- H2 BEAMLINE
- DETECTOR

LHC 27 km



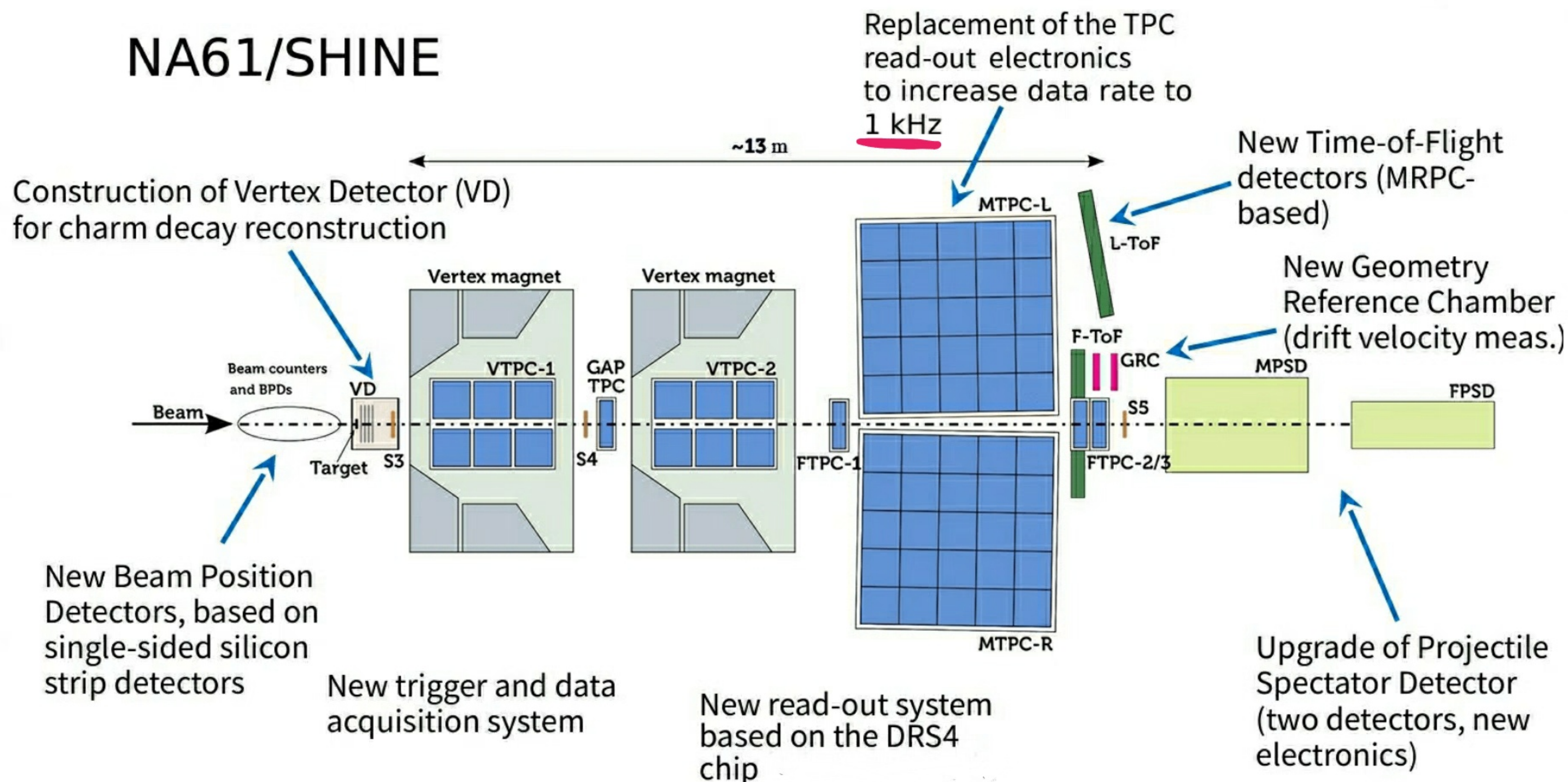
# BEAMS: UNPRECEDENTED VARIETY OF MASSES AND MOMENTA





# DETECTOR IN 2022

## NA61/SHINE



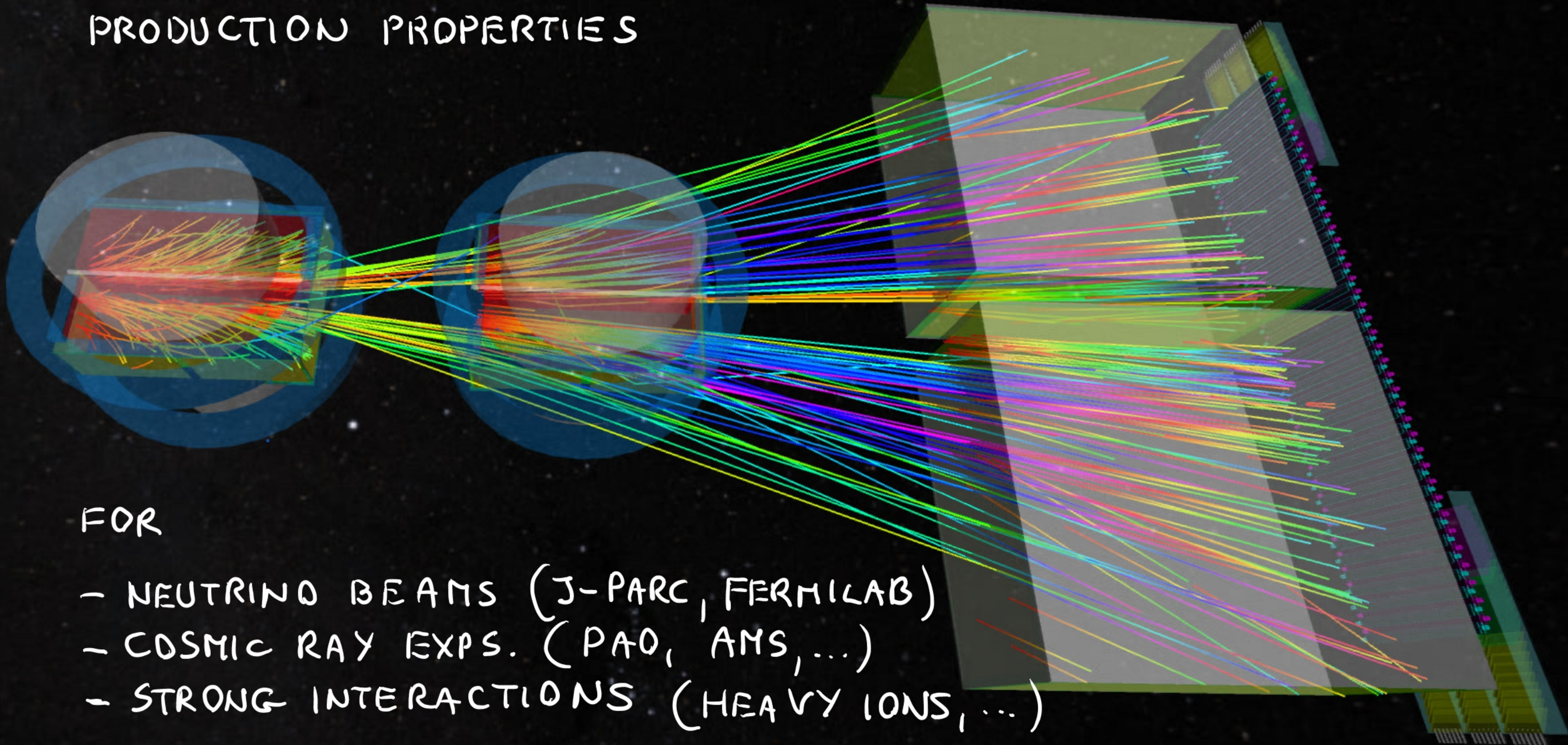
- $B \cdot L \lesssim 9 \text{ T} \cdot \text{m}$
- LARGE ( $\approx 50\%$ ) ACCEPTANCE
- $\sigma(x), \sigma(y) \approx 5 \text{ mm VD}$   
 $200 \text{ mm TPC}$
- $\sigma(p)/p^2 \approx 10^{-4} (\text{GeV}/c)^{-1}$
- $\sigma(dE/dx)/dE/dx \approx 4\%$
- $\sigma(\text{tof}) \lesssim 100 \text{ ps}$
- EVENT RATE  $\approx 1 \text{ kHz}$





## PHYSICS PROGRAMMES

### MEASUREMENTS OF HADRON PRODUCTION PROPERTIES



FOR

- NEUTRINO BEAMS (J-PARC, FERMI LAB)
- COSMIC RAY EXPS. (PAG, AMS, ...)
- STRONG INTERACTIONS (HEAVY IONS, ...)



# NAGI/SHINE DATA-TAKING PERIODS

RUN 1 (2008 - 2012)

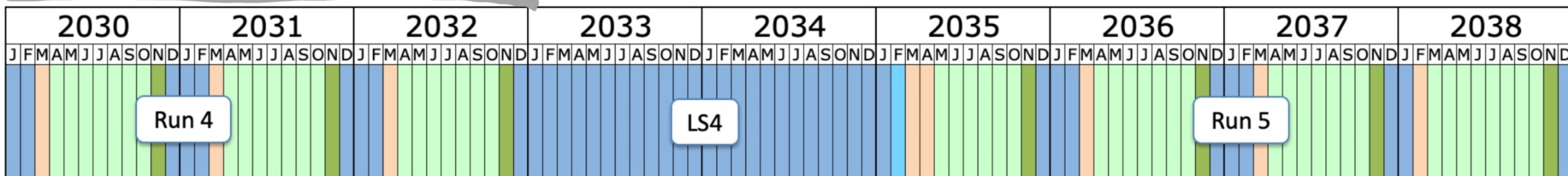
RUN 2 (2015 - 2018)

In January 2022, the schedule was updated with long shutdown 3 (LS3) to start in 2026 and to last for 3 years.

NOW (RUN 3)



THIS WORKSHOP (RUN 4)



Last updated: January 2022

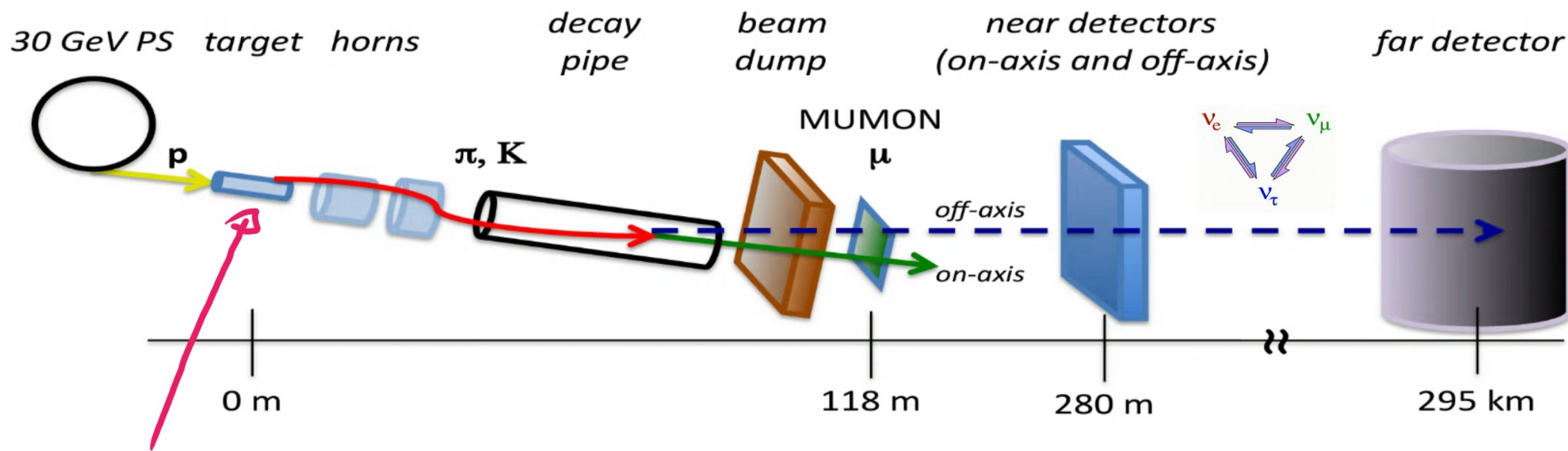
- Shutdown/Technical stop
- Protons physics
- Ions
- Commissioning with beam
- Hardware commissioning/magnet training



# NEUTRINOS

WHAT HAPPENS WITH NEUTRINOS FLYING ACROSS JAPAN AND UNITED STATES?

## THE T2K LONG-BASELINE NEUTRINO OSCILLATION EXPERIMENT



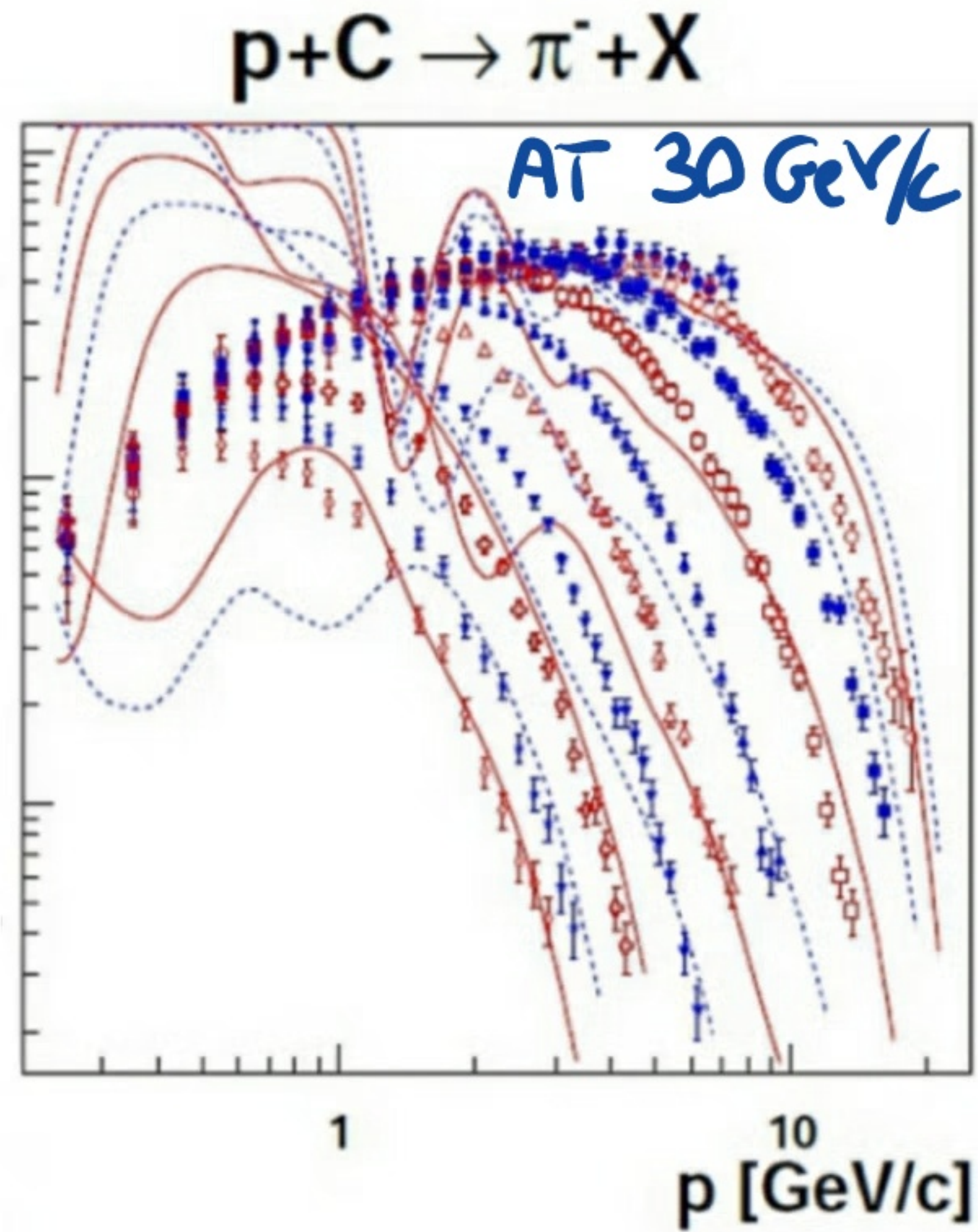
NAGI/SHINE:

WHAT HAPPENS IN TARGETS OF NEUTRINO EXPERIMENTS?



# NEUTRINOS: KEY RESULTS

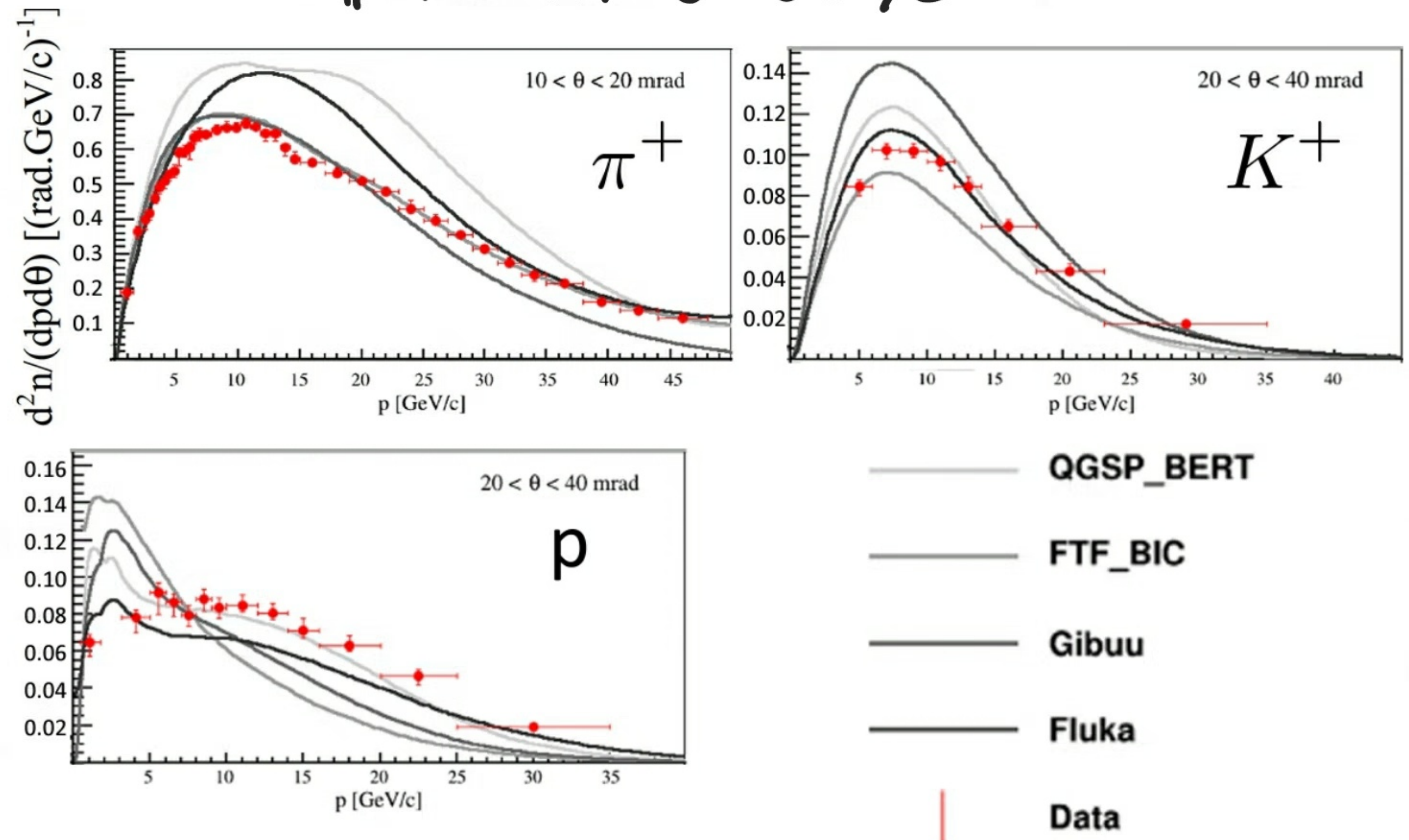
FOR J-PARC:



comparison to Gheisha2002

FOR FNAL:

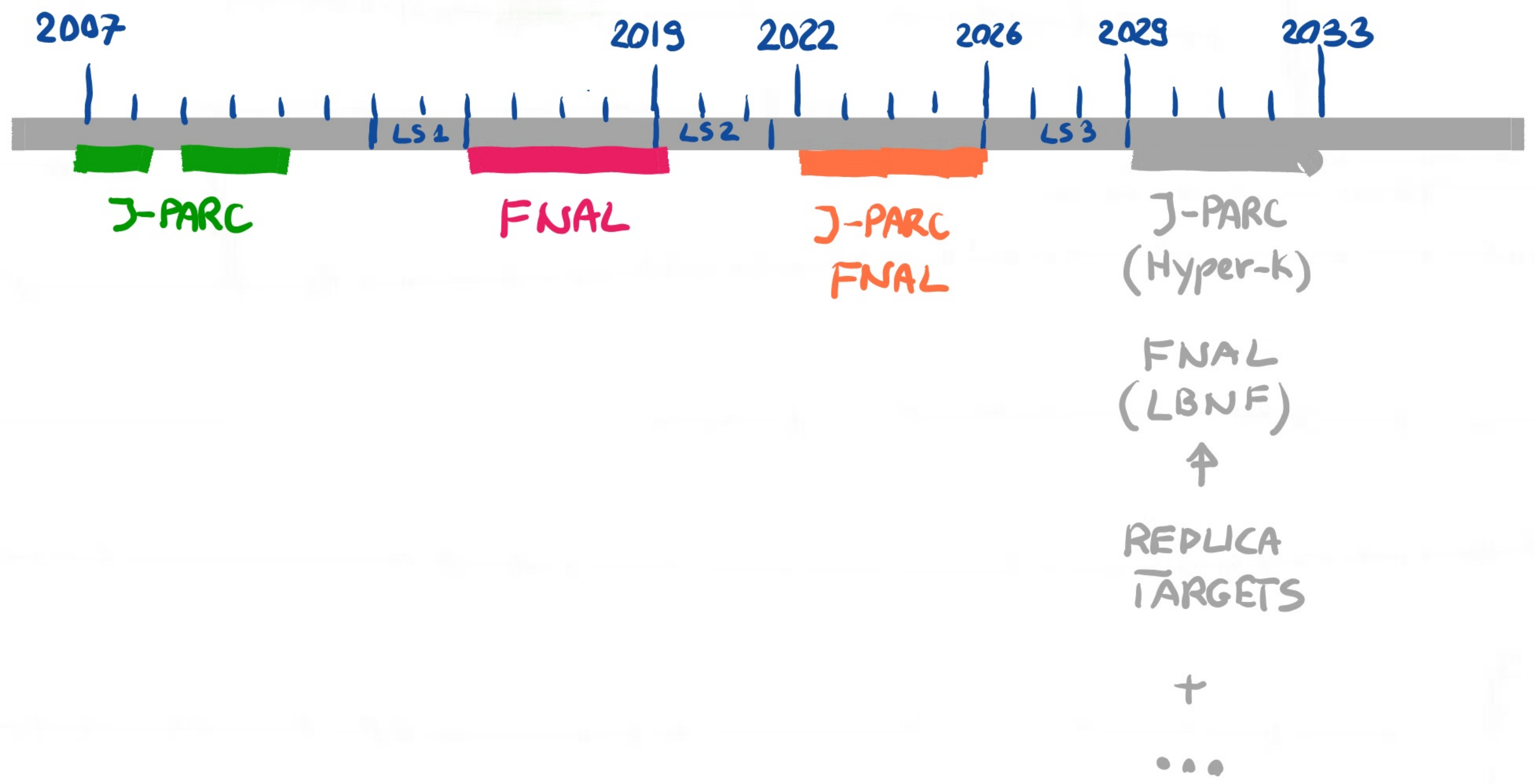
$\pi^+ + C$  AT 60 GeV/c



NAGI/SHINE DATA REDUCE DECISIVELY  
UNCERTENTIES OF FINAL RESULTS OF NEUTRINO EXPERIMENTS

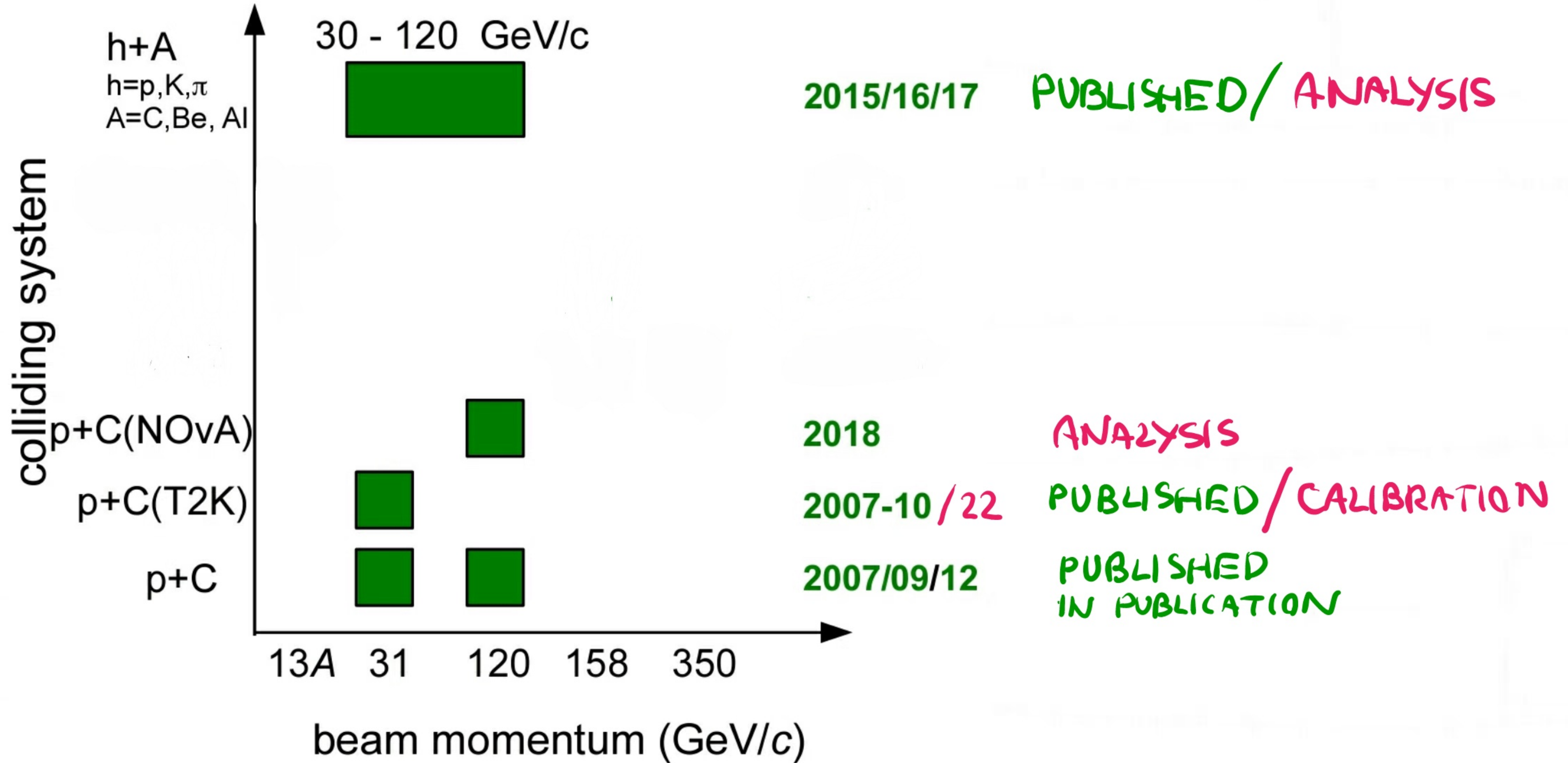


# NEUTRINOS: DATA TAKING





# COLLECTED DATA AND ITS STATUS





# NEUTRINO-ORIENTED INSTITUTIONS/PUBLICATIONS

## Bulgaria

- **University of Sofia**  
Faculty of Physics, University of Sofia, Sofia, Bulgaria  
M. Bogomilov, S. Ilieva, D. Kolev, R. Tsenov

## France

- **LPNHE**  
LPNHE, University of Paris VI and VII, Paris, France  
A. Blondel, C. Dalmazzone, J. Dumarchez

## Hungary

- **ELTE**  
Eötvös Loránd University, Budapest, Hungary  
Y. Nagai

## Japan

- **KEK Tsukuba**  
Institute for Particle and Nuclear Studies, Tsukuba, Japan  
M. Friend, T. Nakadaira, S. Nishimori, K. Sakashita
- **Okayama University**  
Okayama University, Japan  
H. Kitagawa, Y. Koshio, Y. Shiraishi

## USA

- **Fermilab**  
Fermilab, Batavia, USA  
A. Wickremasinghe, R. Zwaska
- **University of Notre Dame**  
University of Notre Dame, Notre Dame, USA  
D. Battaglia, N. Bostan, L. Fields
- **University of Colorado**  
University of Colorado, Boulder, USA  
K.K. Allison, S.R. Johnson, A.D. Marino, L. Ren, B.T. Rumberger, E.D. Zimmerman
- **University of Pittsburgh**  
University of Pittsburgh, Pittsburgh, USA  
A.F. Messerly, V. Paolone

3 INSTITUTIONS

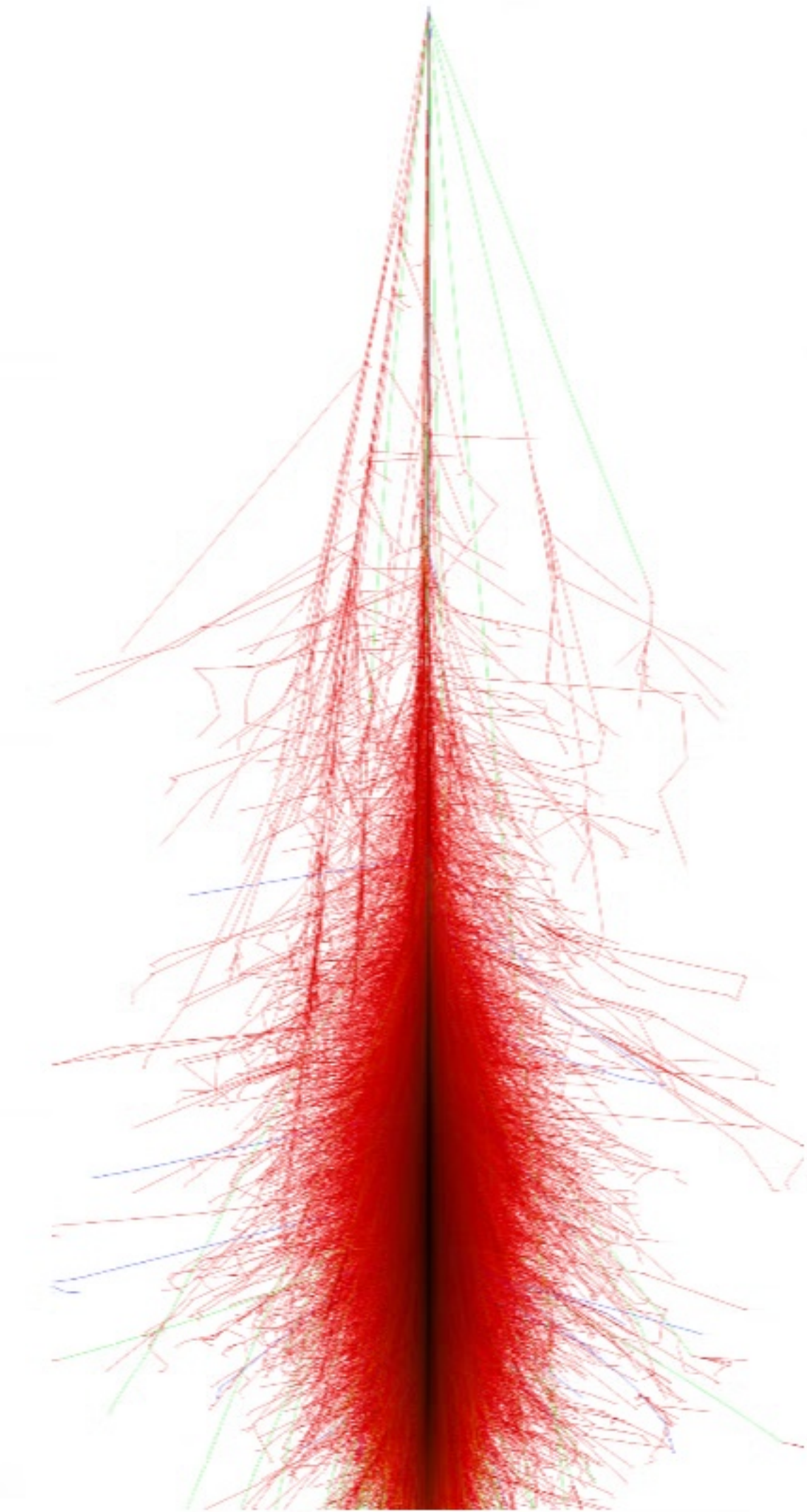
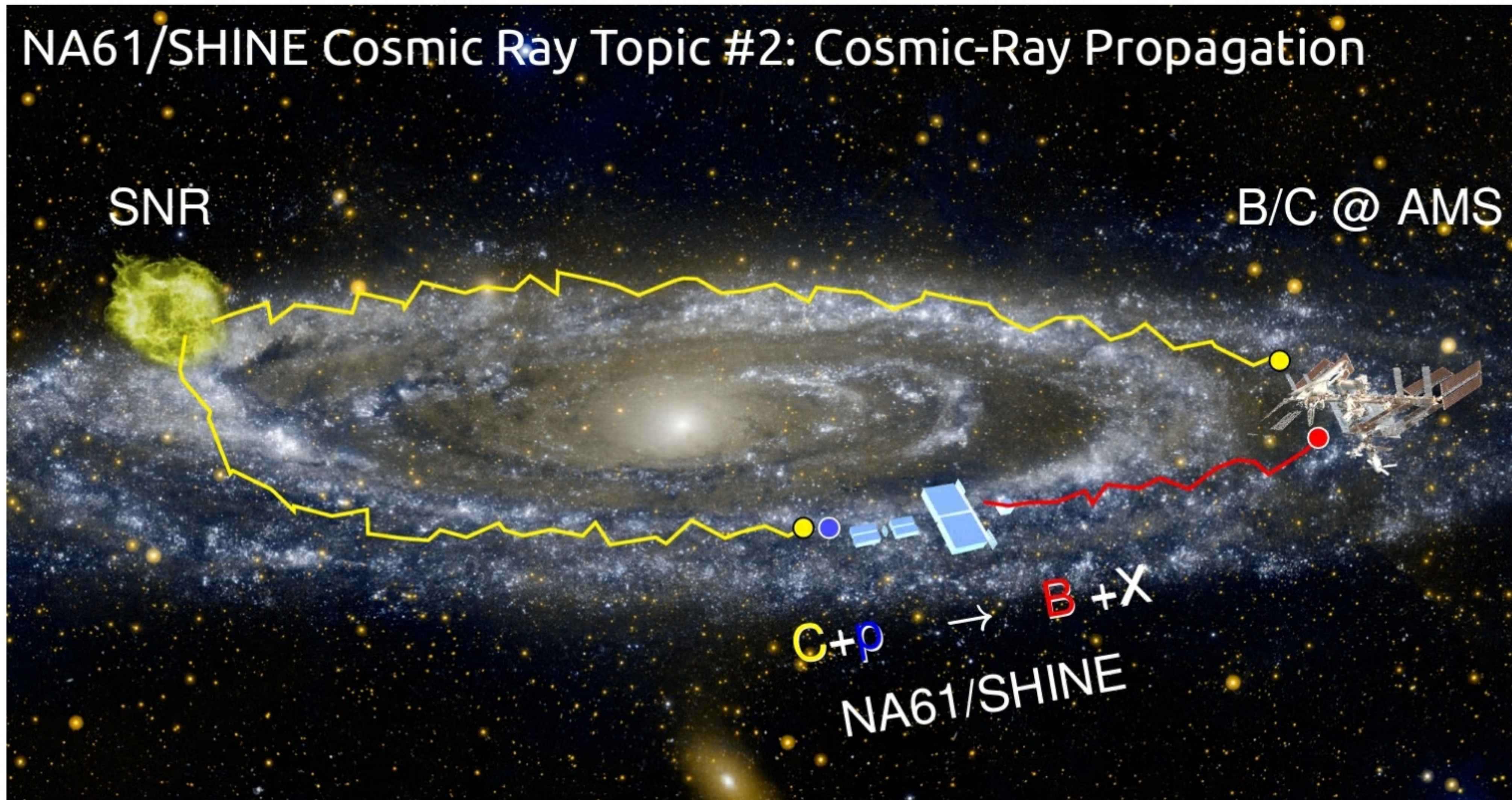
28 COLLABORATORS

11 PAPERS



# COSMIC - RAYS

WHAT IS THE ORIGIN OF VERY HIGH ENERGY COSMIC - RAYS ?



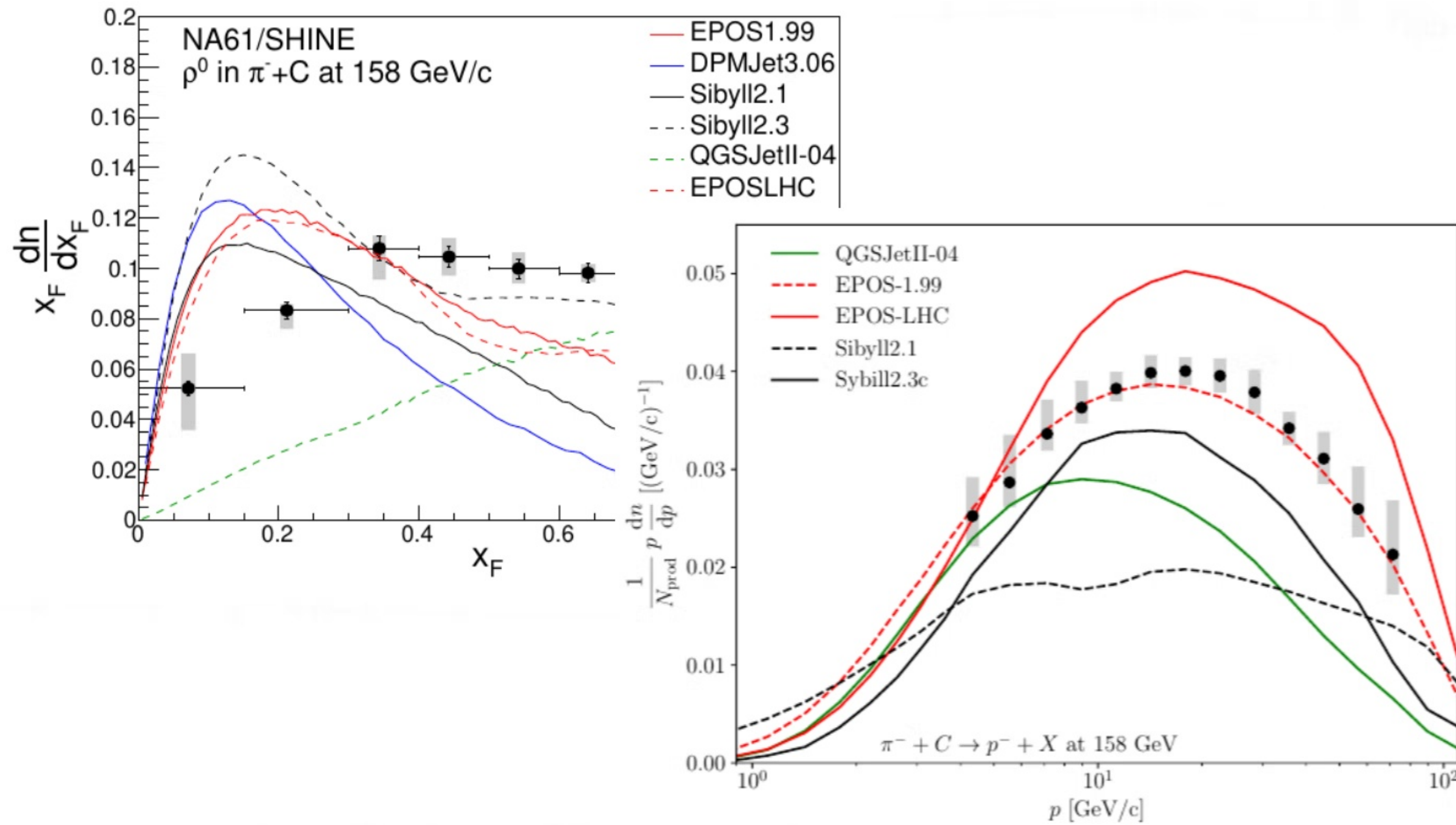
NA61/SHINE: WHAT HAPPENS WITH COSMIC RAYS  
IN INTERSTELLAR MEDIUM?

IN EARTH'S' ATMOSPHERE ?

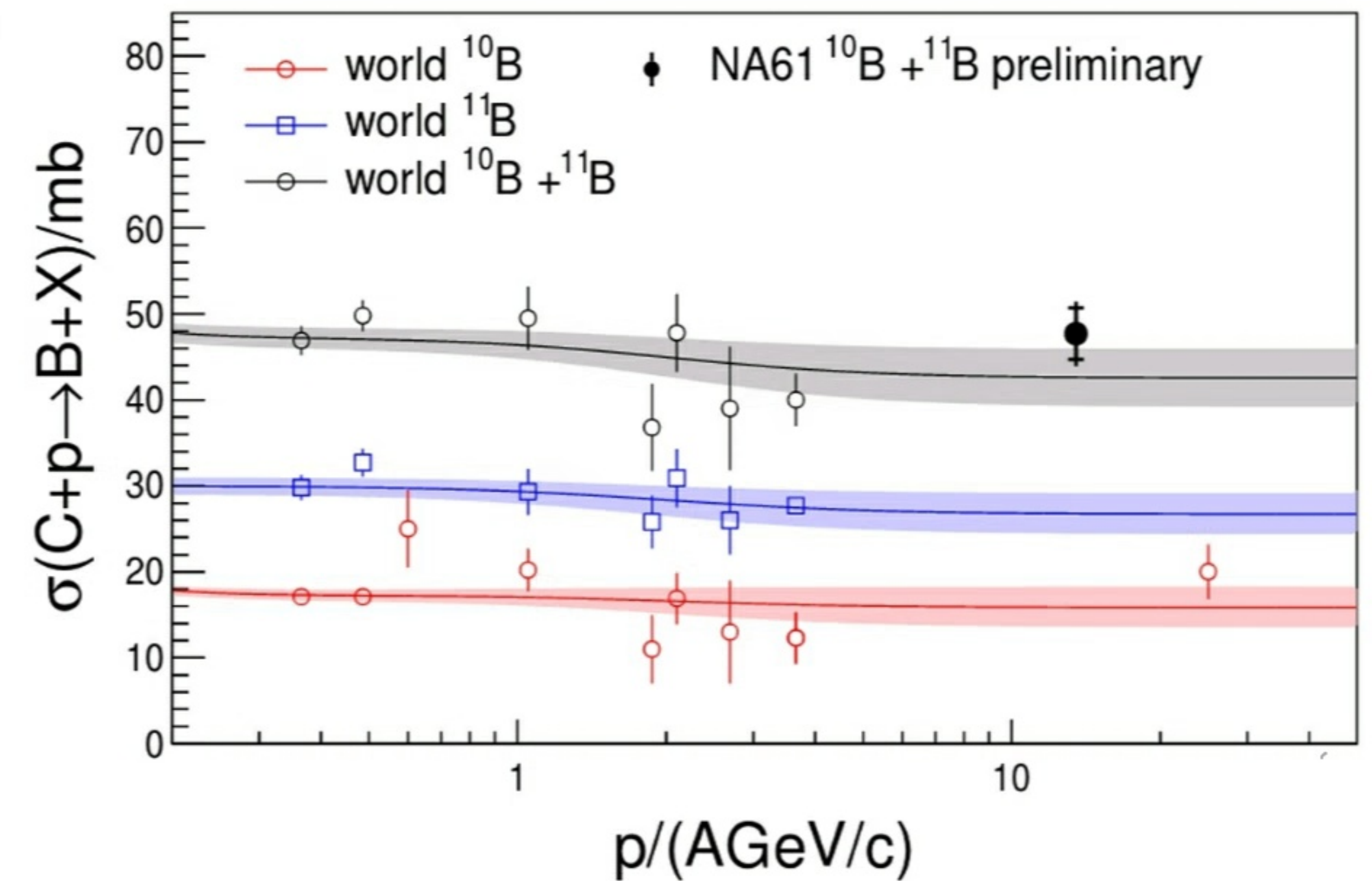


# COSMIC-RAYS: KEY RESULTS

## EXTENSIVE AIR SHOWERS:



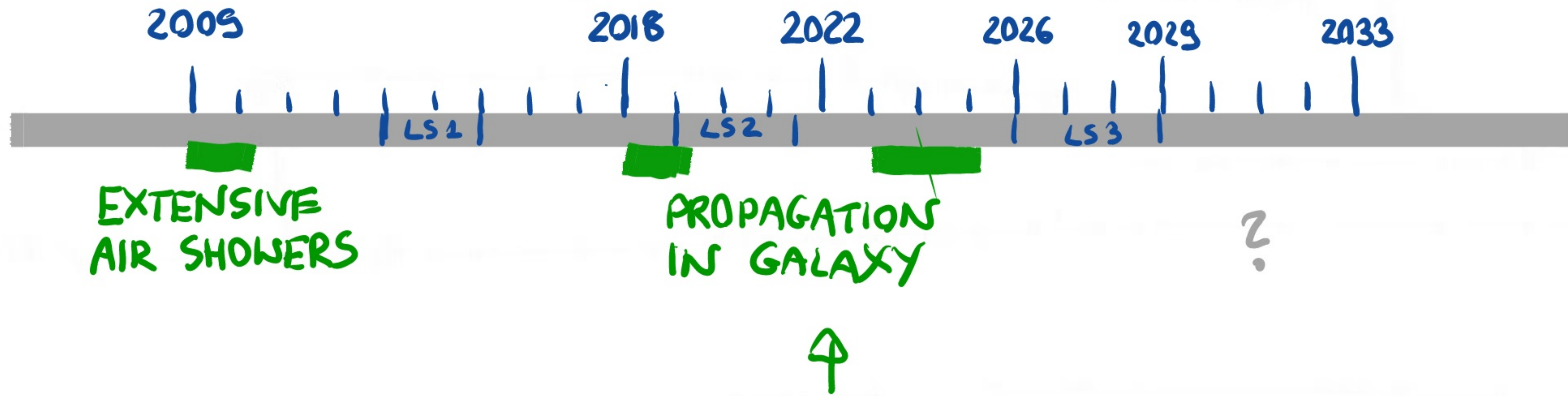
## PROPAGATION IN GALAXY:



UNIQUE RESULTS WHICH CONSTRAIN MODELS NEEDED TO INTERPRET  
HIGH PRECISION DATA ON COSMIC RAYS



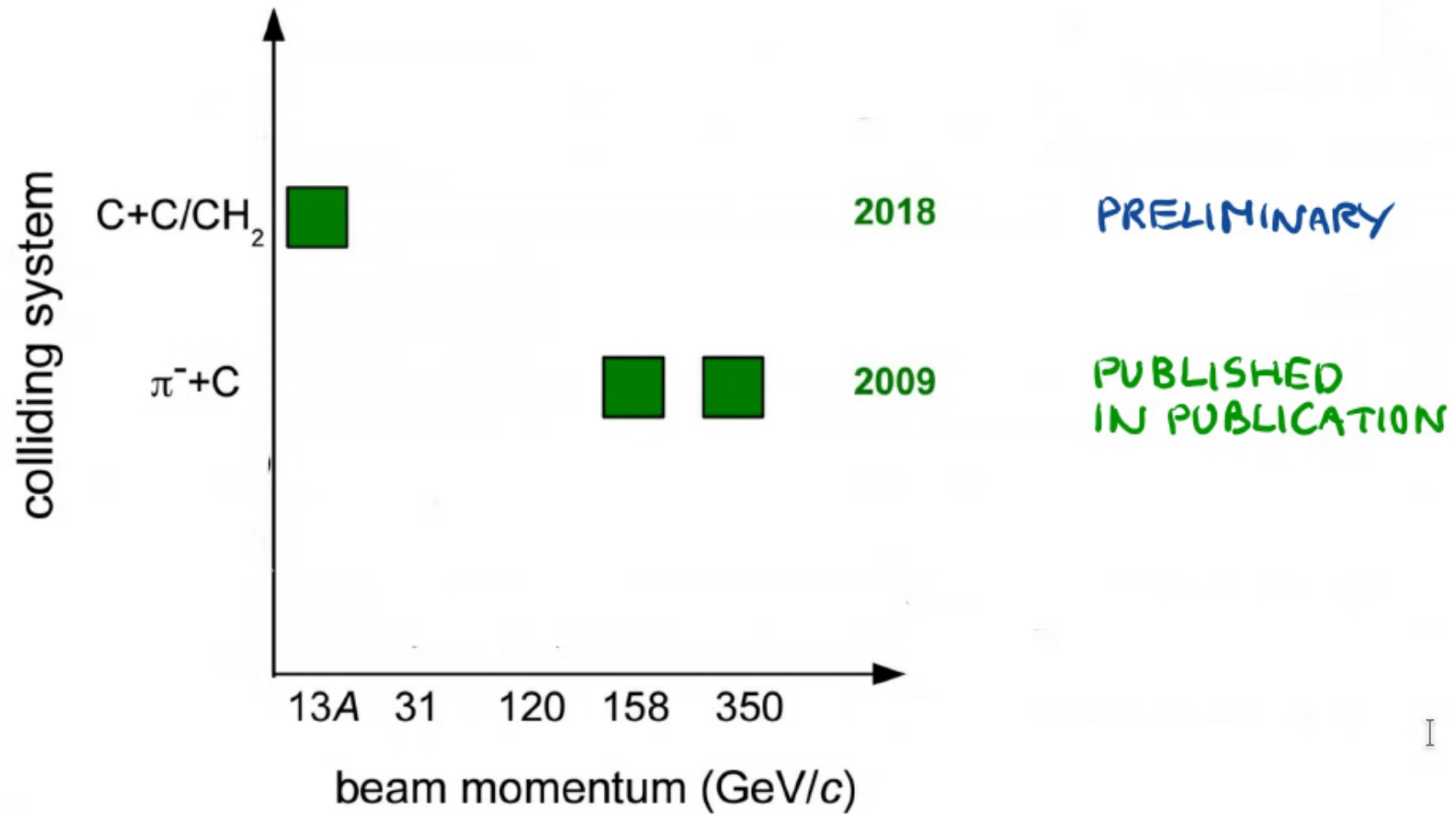
# COSMIC-RAYS: DATA TAKING



reaction	$N_{\text{inter}}$	A/Z
$^{16}\text{O} + \text{H}$	250k	2
$^{12}\text{C} + \text{H}$	150k	2
$^{16}\text{O} + \text{He}$	100k	2
$^{14}\text{N} + \text{H}$	40k	2
$^{10}\text{B} + \text{H}$	5k	2
$^{11}\text{B} + \text{H}$	5k	2
$^{12}\text{C} + \text{He}$	5k	2
$^{13}\text{C} + \text{H}$	5k	11/5
$^{15}\text{N} + \text{H}$	5k	13/6
$^{20}\text{Ne} + \text{H}$	5k	15/7
$^{24}\text{Mg} + \text{H}$	5k	2
$^{28}\text{Si} + \text{H}$	5k	2
$^7\text{Li} + \text{H}$	5k	7/3
$\Sigma = 0.6\text{M}$		



# COLLECTED DATA AND ITS STATUS





# COSMIC-RAY-ORIENTED INSTITUTIONS/PUBLICATIONS

## Germany

- **KIT**  
Karlsruhe Institute of Technology, Karlsruhe, Germany  
N. Amin, R. Engel, H.-J. Mathes, M. Roth, M. Unger, D. Veberič

## USA

- **University of Hawaii**  
University of Hawaii at Manoa, USA  
P. von Doetinchem, A. Shukla

## Poland

- **University of Silesia**  
University of Silesia, Katowice, Poland (1/2 ALSO SI)  
Y. Balkova, S. Kowalski, S. Puławski, R. Renfordt, K. Schmidt, M. Urbaniak, K. Wójcik

2.5 INSTITUTIONS

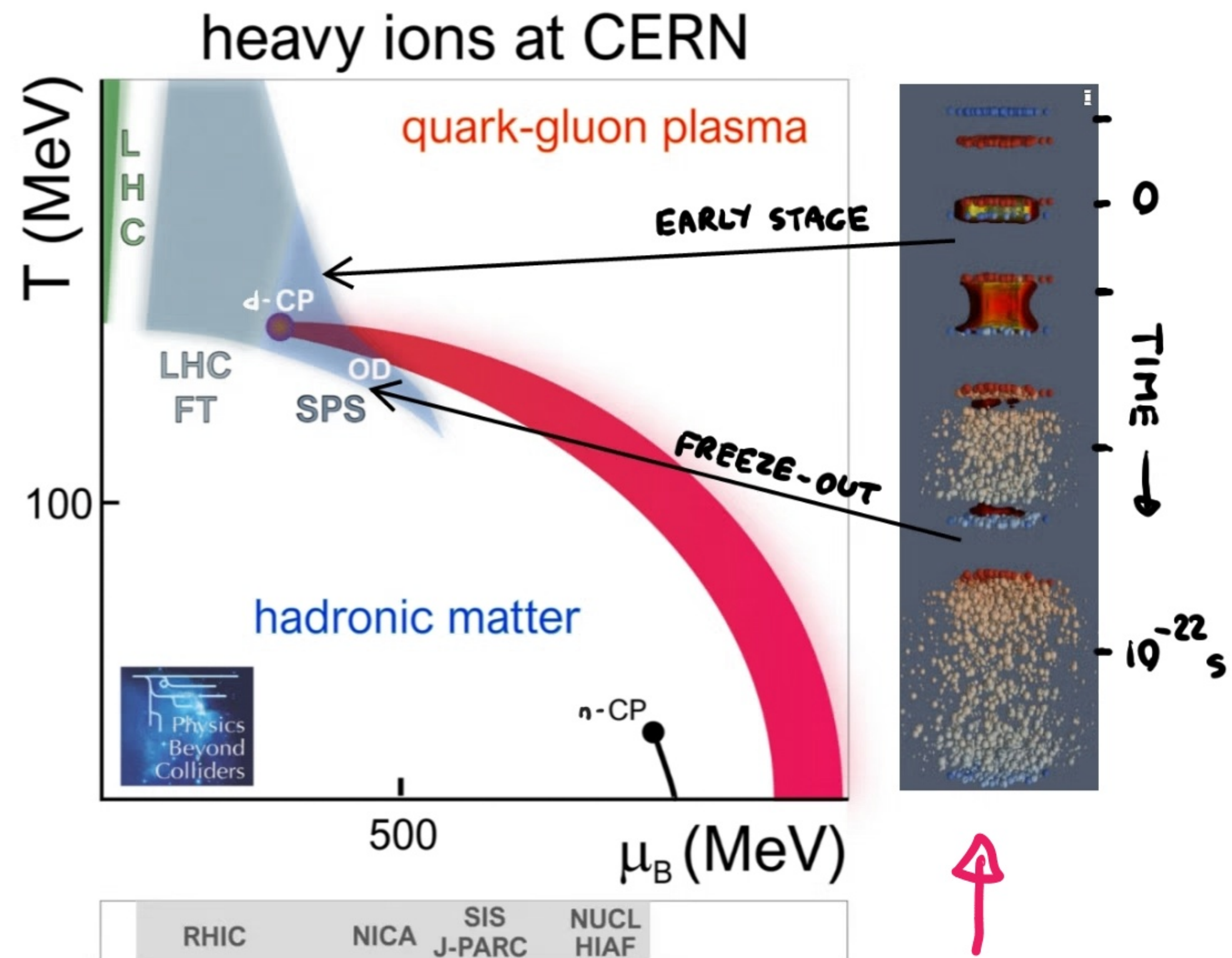
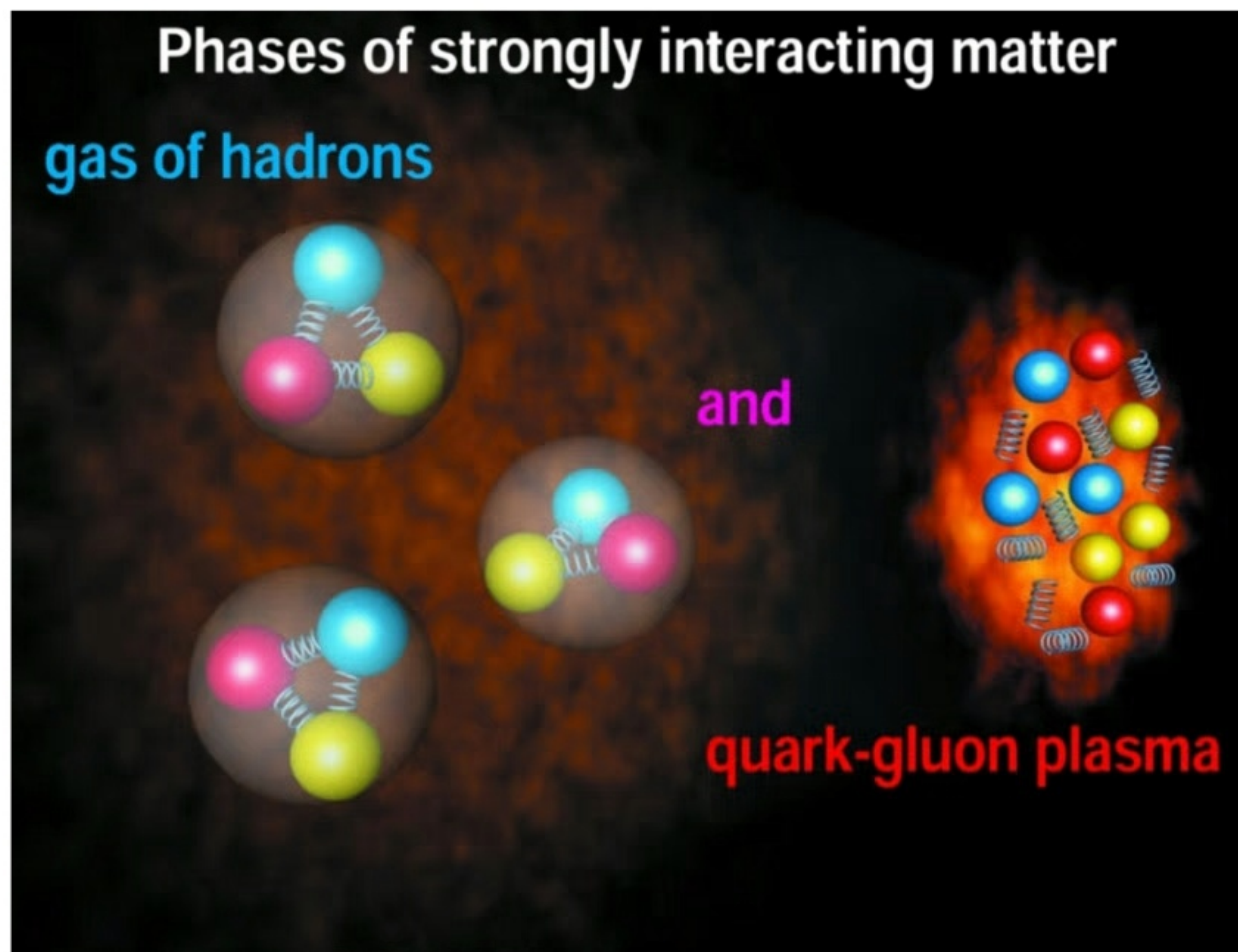
11 COLLABORATORS

1 PAPER (+ 1 SUBMITTED)



# STRONG INTERACTIONS

WHAT HAPPENS WHEN STRONGLY INTERACTING MATTER GETS HOTTER/DENSER AND ITS VOLUME CHANGES?



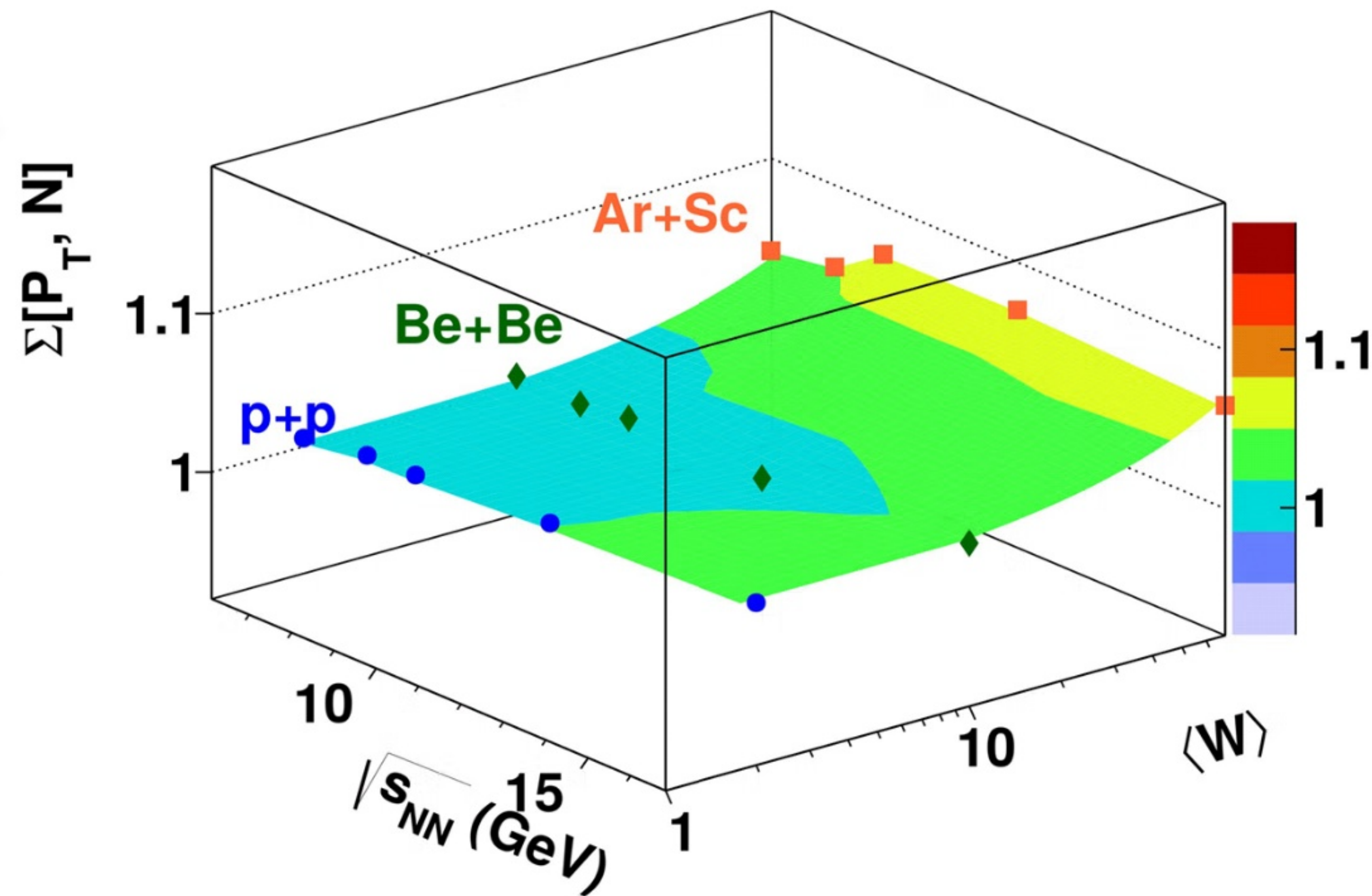
NAGI/SHINE: WHAT HAPPENS IN HEAVY ION COLLISIONS?



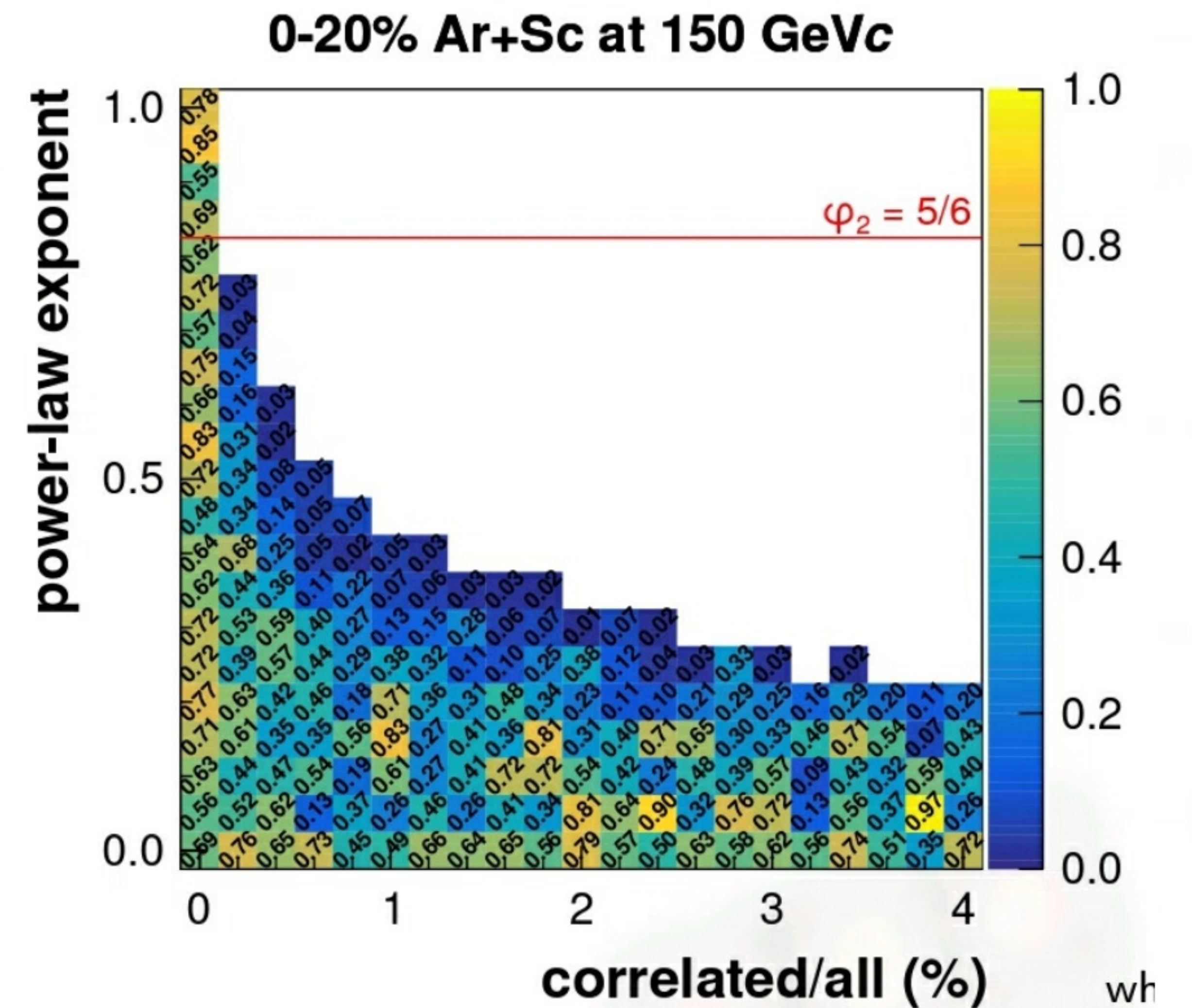
# STRONG INTERACTIONS: KEY RESULTS

## CRITICAL POINT

TRANSVERSE MOMENTUM -  
MULTIPLICITY FLUCTUATIONS



EXCLUSION PLOT DERIVED FROM  
NAGI/SHINE PROTON-INTERMITTENCY



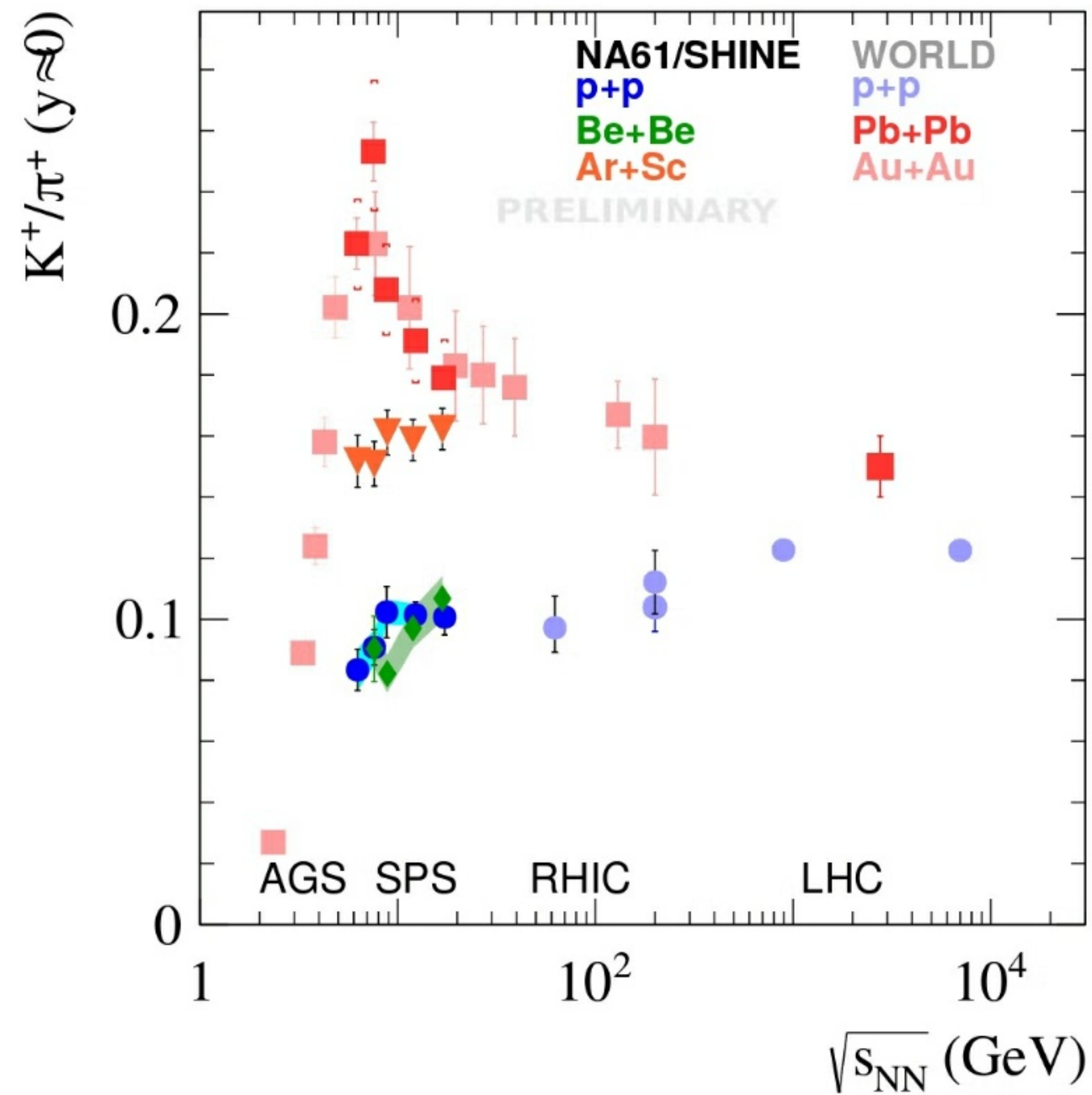
NO EVIDENCE FOR CRITICAL POINT SO FAR



# STRONG INTERACTIONS: KEY RESULTS

## DIAGRAM OF HIGH ENERGY NUCLEAR COLLISIONS

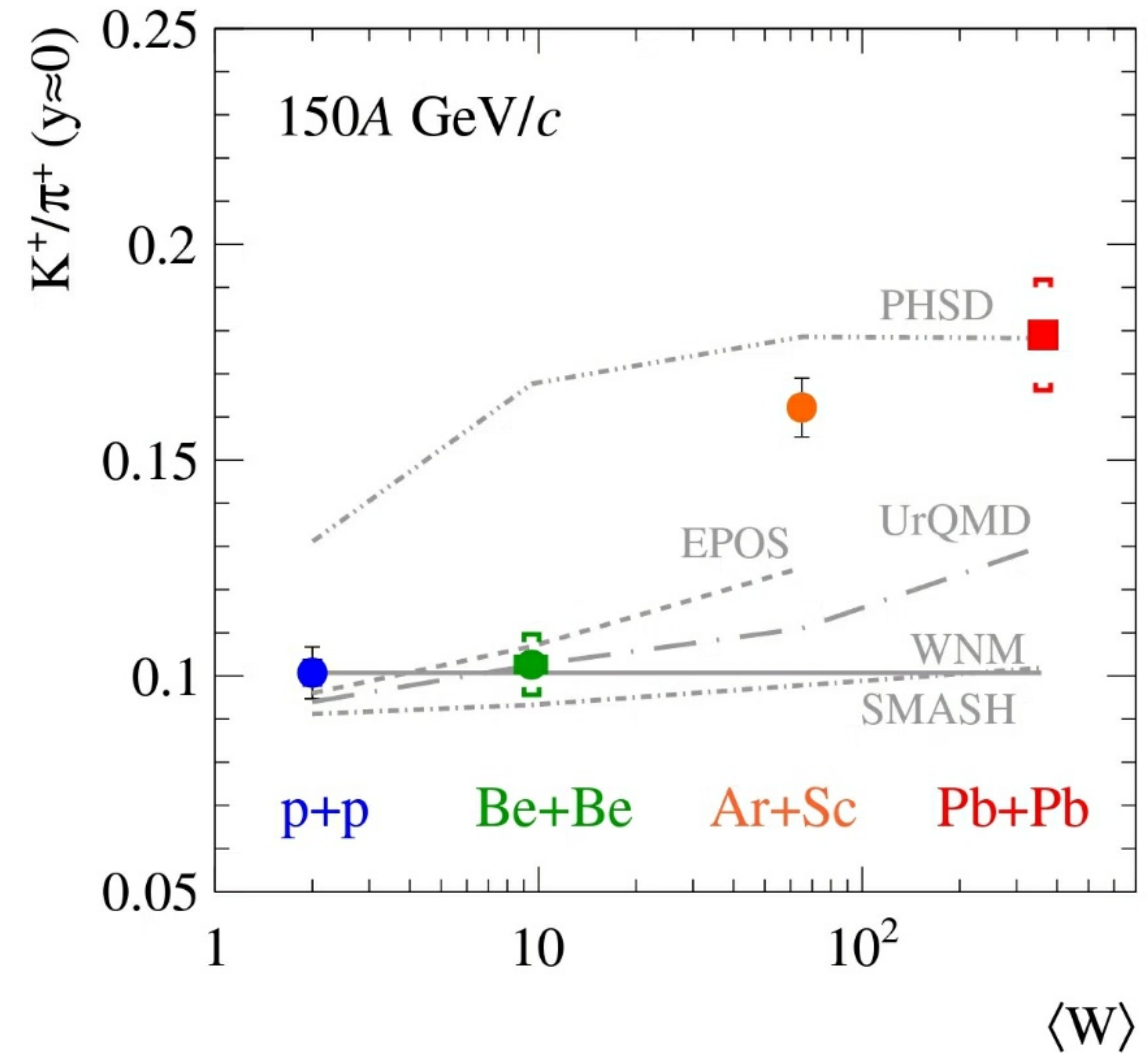
### ONSET OF DECONFINEMENT



UNEXPECTED COLLISION ENERGY DEPENDENCE FOR SMALL/MEDIUM SIZE IONS

HORN  $\rightarrow$  BREAK

### ONSET OF FIRE BALL

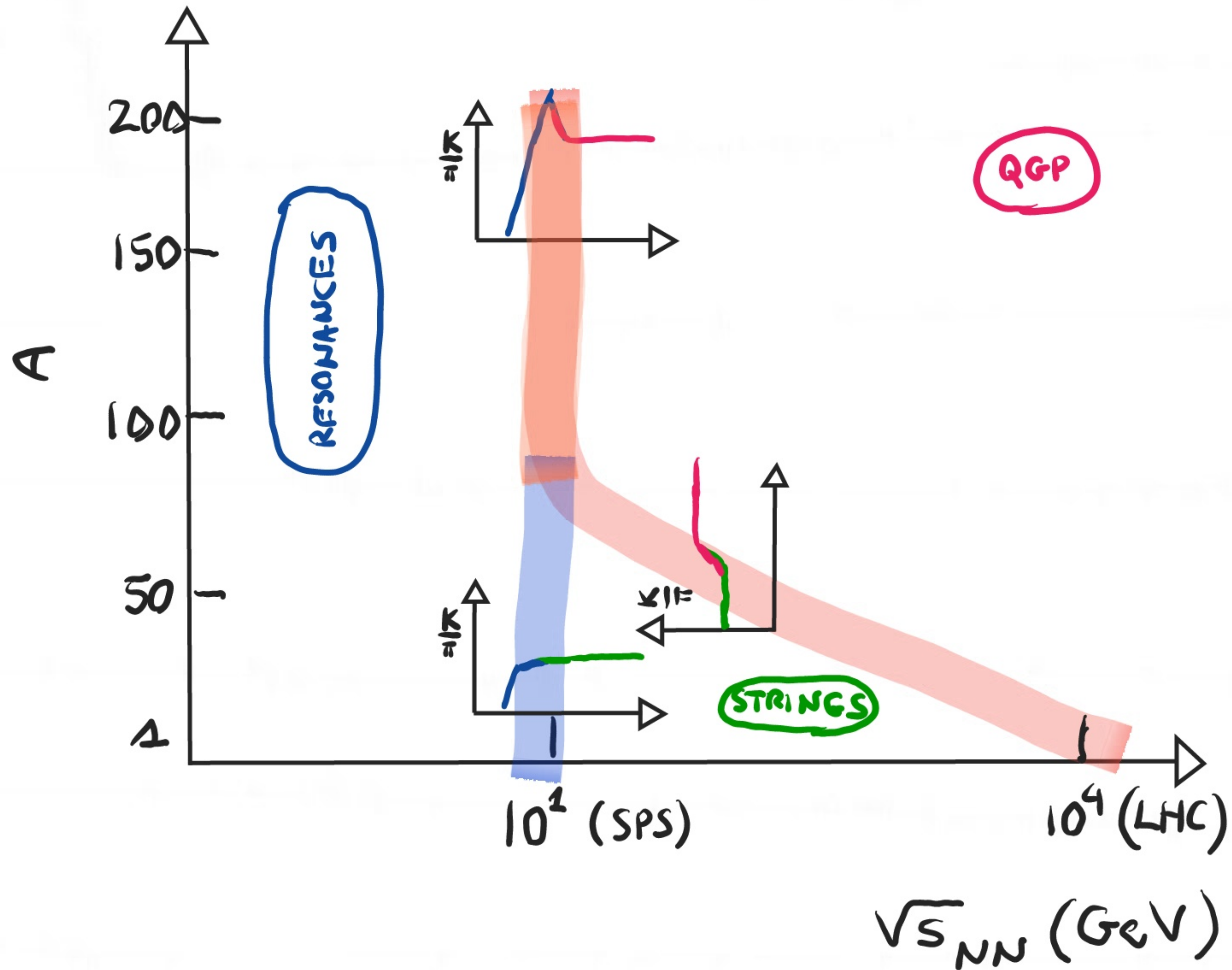


UNEXPECTED SYSTEM SIZE DEPENDENCE FOR SMALL/MEDIUM SIZE IONS



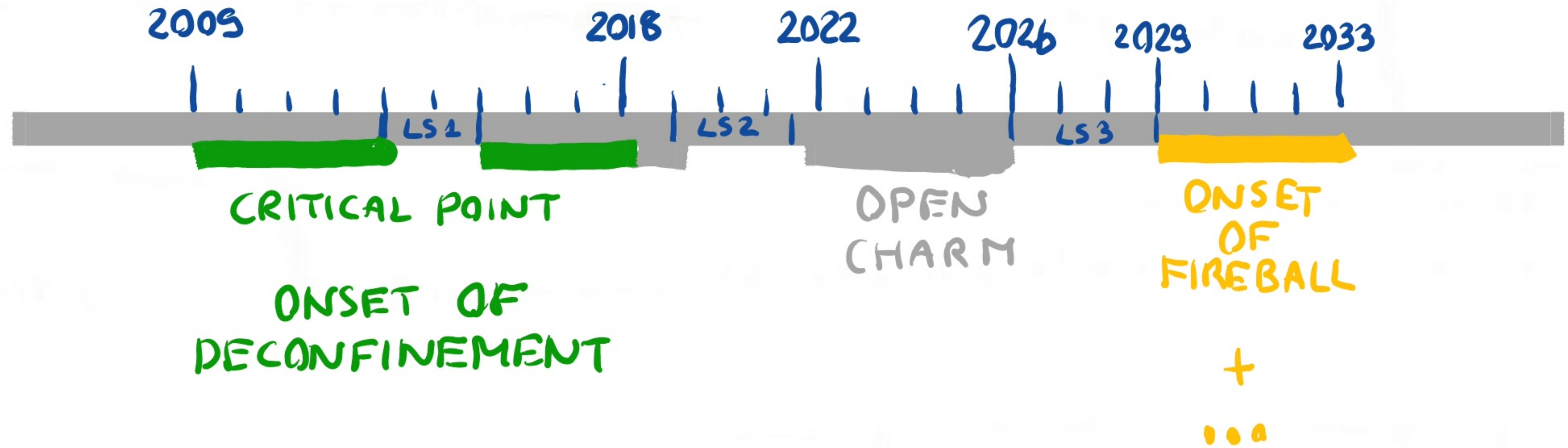
# STRONG INTERACTIONS: KEY RESULTS

## DIAGRAM OF HIGH-ENERGY NUCLEAR COLLISIONS CENTRAL A+A



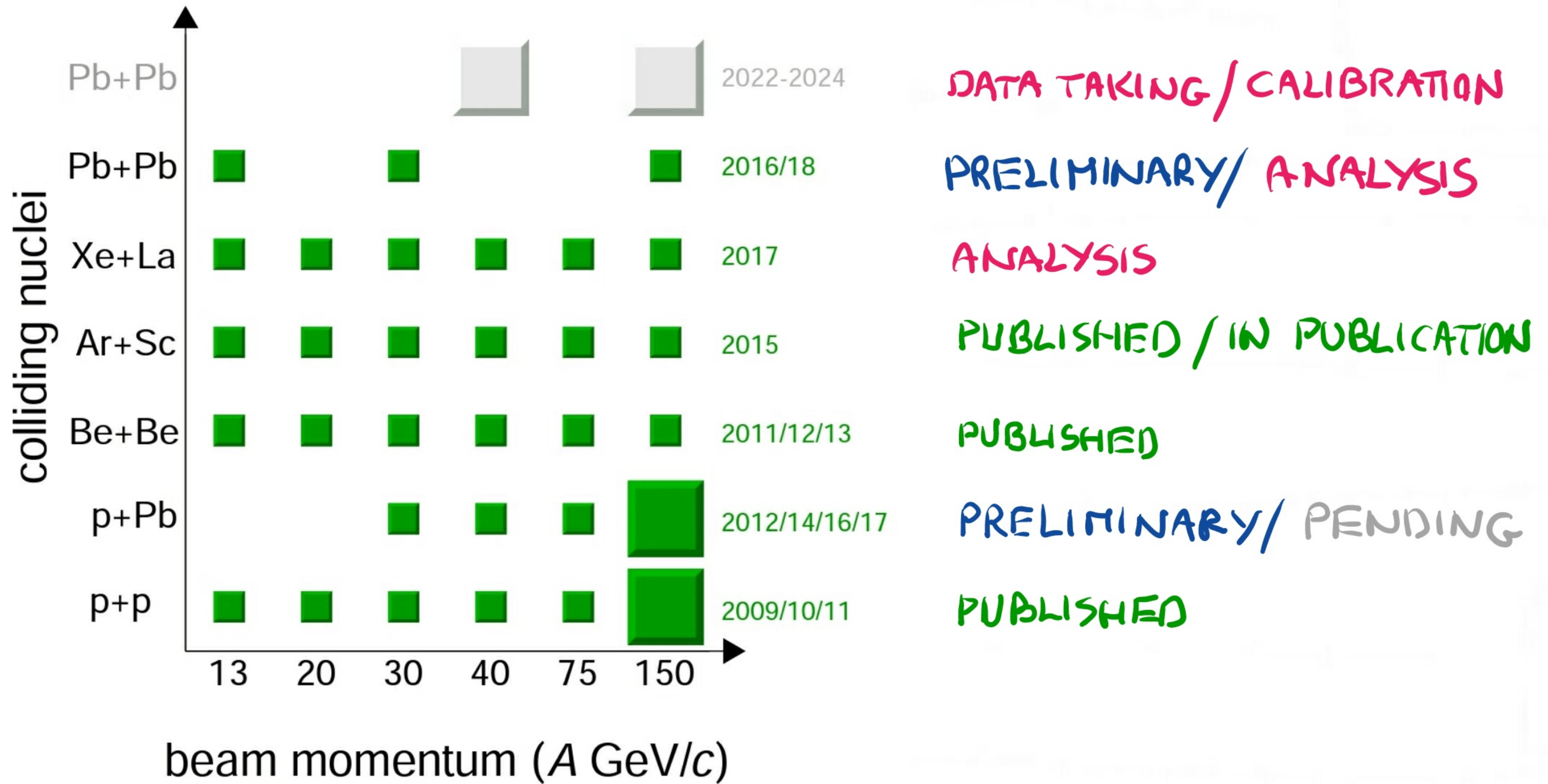


# STRONG INTERACTIONS: DATA TAKING





# COLLECTED DATA AND ITS STATUS





# STRONG-INTERACTION ORIENTED INSTITUTIONS/PUBLICATIONS

## Azerbaijan

- **NNRC**  
National Nuclear Research Center, Baku, Azerbaijan  
A. Garibov, A. Rustamov

## Germany

- **University of Frankfurt**  
University of Frankfurt, Frankfurt, Germany  
I. Pidhurskyi, H. Ströbele, A. Toia

## Hungary

- **Wigner RCP**  
Wigner Research Centre for Physics, Budapest, Hungary  
M. Csanad, Z. Fodor, A. László, K. Marton, B. Porfy

## Norway

- **University of Bergen**  
University of Bergen, Bergen, Norway  
D. Röhrich
- **University of Oslo**  
University of Oslo, Oslo, Norway  
I.-C. Arsene, A. Merzlaya, T.S. Tveter

## Serbia

- **University of Belgrade**  
University of Belgrade, Belgrade, Serbia  
M. Čirković, J. Puzović

## Poland

- **UJK**  
Jan Kochanowski University in Kielce, Poland  
H. Adhikary, A. Bazgir, Y. Bondar, T. Czopowicz, M. Gaździcki, O. Panova, V. Reyna, M. Rybczynski, P. Seyboth, U. Shah, G. Stefanek, O. Wyszynski
- **IFJ PAN**  
Institute of Nuclear Physics, Polish Academy of Sciences, Cracow, Poland  
S. Bhosale, N. Davis, M. Kielbowicz, A. Marcinek, V. Ozvenchuk, Ł. Rozpłochowski, A. Rybicki
- **NCBJ**  
National Centre for Nuclear Research, Warsaw, Poland  
P. Adrich, M. Bielewicz, B. Maksiak, D. Pszczel, E. Rondio, J. Stepaniak, Ł. Świdorski, J. Szewiński
- **Jagiellonian University**  
Jagiellonian University, Cracow, Poland  
M. Bajda, J. Brzychczyk, Z. Majka, A. Morawiec, R. Planeta, P. Staszal
- **AGH**  
AGH - University of Science and Technology, Cracow, Poland  
M. Baszczyk, P. Dorosz, W. Kucewicz, Ł. Mik
- **University of Silesia** (1/2 ALSO CR)  
University of Silesia, Katowice, Poland  
Y. Balkova, S. Kowalski, S. Puławski, R. Renfordt, K. Schmidt, M. Urbaniak, K. Wójcik
- **University of Warsaw**  
University of Warsaw, Warsaw, Poland  
W. Dominik, M. Kuich, T. Matulewicz, P. Podlaski, M. Posiadała-Zezula
- **University of Wrocław**  
University of Wrocław, Wrocław, Poland  
M. Kuchowicz, M. Lewicki, M. Naskręt, R. Szukiewicz, L. Turko
- **WUT**  
Warsaw University of Technology, Warsaw, Poland  
W. Bryliński, J. Cybowska, K. Grebieszkow, B. Kozłowski, M. Maćkowiak-Pawłowska, M. Słodkowski, A. Tefelska, D. Tefelski

## Russia

- **INR Moscow**  
Institute for Nuclear Research, Moscow, Russia  
M. Golubeva, F. Guber, A. Ivashkin, A. Izvestnyy, N. Karpushkin, A. Kurepin, A. Makhnev, S. Morozov, O. Petukhov, V. Volkov
- **JINR Dubna**  
Joint Institute for Nuclear Research, Dubna, Russia  
M. Buryakov, A. Dmitriev, V. Golovatyuk, V.A. Kireyeu, R. Kolesnikov, A. Krasnoperov, G. Lykasov, V.V. Lyubushkin, A.I. Malakhov, V. Matveev, G.L. Melkumov, B.A. Popov, M. Romyantsev, V. Tereshchenko, A. Zaitsev
- **MEPhI Moscow**  
National Research Nuclear University (Moscow Engineering Physics Institute), Moscow, Russia  
A. Brandin, O. Golosov, N. Kargin, E. Kashirin, M. Strikhanov, A. Taranenko
- **SPBU**  
St. Petersburg State University, St. Petersburg, Russia  
E.V. Andronov, G.A. Feofilov, S.N. Igolkin, V.N. Kovalenko, D.S. Prokhorova, A.Yu. Seryakov, F.F. Valiev, V.V. Vechernin, A. Zviagina

18.5 INSTITUTIONS

113 COLLABORATORS (2/3)

18 PAPERS



## LESSONS FOR FUTURE

UNIQUE FACILITY → MANY DIFFERENT DATA SETS ( $\approx 50$ )

MULTI-COMPONENT  
ADVANCED DETECTOR → COMPLICATED CALIBRATION, ANALYSIS  
AND PUBLICATION PROCESS

V + CR  
REFERENCE  
MEASUREMENTS

✗ DIFFICULT TO ATTRACT COLLABORATORS

HEAVY-IONS  
STRONG COMPETITION  
WITH OTHER PROJECTS

→ ( $\approx 2-3$  PARTICIPANTS/DATA SET)

---

50K CHF/RUN-WEEK,

50 AUTHOR-YEARS/PAPER



## LESSONS FOR FUTURE

- MINIMUM "PHYSICS-UNIT"  $\approx$  2-3 GROUPS  
 $\approx$  10 PARTICIPANTS  
 $\approx$  5 YEARS
- STRONG PHYSICS CASE TO GET FUNDING
- STRONG PHYSICS CASE TO WIN COMPETITION FOR HADRON BEAMS
- VERY STRONG PHYSICS CASE TO WIN COMPETITION FOR ION BEAMS





## MORE ON NAGI/SHINE

### WEBSITE:

<https://shine.web.cern.ch>

### PUBLICATIONS:

[https://inspirehep.net/literature?sort=mostrecent&size=25  
&page=1&q=find%20cn%3Ana61/shine%20and%20tc%20p](https://inspirehep.net/literature?sort=mostrecent&size=25&page=1&q=find%20cn%3Ana61/shine%20and%20tc%20p)

### PROPOSAL, ADDENDA, REPORTS:

[https://inspirehep.net/literature?sort=mostrecent&size=25  
&page=1&q=find%20cn%3Ana61/shine%20and%20tc%20p](https://inspirehep.net/literature?sort=mostrecent&size=25&page=1&q=find%20cn%3Ana61/shine%20and%20tc%20p)

### HOW TO JOIN US:

<https://indico.cern.ch/event/350633/>





**Measurements of Cross Sections and Charged Pion Spectra in Proton-Carbon Interactions at 31 GeV/c** #1  
 NA61/SHINE Collaboration · N. Abgrall (Geneva U.) et al. (Feb 6, 2011)  
 Published in: *Phys.Rev.C* 84 (2011) 034604 · e-Print: 1102.0983 [hep-ex]  
[pdf](#) [DOI](#) [cite](#) 269 citations

**Measurement of Production Properties of Positively Charged Kaons in Proton-Carbon Interactions at 31 GeV/c** #2  
 NA61/SHINE Collaboration · N. Abgrall (Geneva U.) et al. (Dec 1, 2011)  
 Published in: *Phys.Rev.C* 85 (2012) 035210 · e-Print: 1112.0150 [hep-ex]  
[pdf](#) [DOI](#) [cite](#) 158 citations

**Measurement of negatively charged pion spectra in inelastic p+p interactions at  $p_{lab} = 20, 31, 40, 80$  and 158 GeV/c** #3  
 NA61/SHINE Collaboration · N. Abgrall (Geneva U.) et al. (Oct 9, 2013)  
 Published in: *Eur.Phys.J.C* 74 (2014) 3, 2794 · e-Print: 1310.2417 [hep-ex]  
[pdf](#) [DOI](#) [cite](#) 93 citations

**Measurements of  $\pi^\pm$ ,  $K^\pm$ ,  $K_S^0$ ,  $\Lambda$  and proton production in proton-carbon interactions at 31 GeV/c with the NA61/SHINE spectrometer at the CERN SPS** #4  
 NA61/SHINE Collaboration · N. Abgrall (Geneva U.) et al. (Oct 9, 2015)  
 Published in: *Eur.Phys.J.C* 76 (2016) 2, 84 · e-Print: 1510.02703 [hep-ex]  
[pdf](#) [DOI](#) [cite](#) 92 citations

## SELECTED PUBLICATIONS



**Pion emission from the T2K replica target: method, results and application** #5  
 NA61/SHINE Collaboration · N. Abgrall (Geneva U.) et al. (Jul 9, 2012)  
 Published in: *Nucl.Instrum.Meth.A* 701 (2013) 99-114 · e-Print: 1207.2114 [hep-ex]  
[pdf](#) [DOI](#) [cite](#) 70 citations

**Measurements of  $\pi^\pm$ ,  $K^\pm$ , p and  $\bar{p}$  spectra in proton-proton interactions at 20, 31, 40, 80 and 158 GeV/c with the NA61/SHINE spectrometer at the CERN SPS** #6  
 NA61/SHINE Collaboration · A. Aduszkiewicz (Warsaw U.) et al. (May 6, 2017)  
 Published in: *Eur.Phys.J.C* 77 (2017) 10, 671 · e-Print: 1705.02467 [nucl-ex]  
[pdf](#) [DOI](#) [cite](#) 66 citations

**Multiplicity and transverse momentum fluctuations in inelastic proton-proton interactions at the CERN Super Proton Synchrotron** #7  
 NA61/SHINE Collaboration · A. Aduszkiewicz (Warsaw U.) et al. (Oct 1, 2015)  
 Published in: *Eur.Phys.J.C* 76 (2016) 11, 635 · e-Print: 1510.00163 [hep-ex]  
[pdf](#) [DOI](#) [cite](#) 57 citations

**Measurements of production properties of  $K_S^0$  mesons and  $\Lambda$  hyperons in proton-carbon interactions at 31 GeV/c** #8  
 NA61/SHINE Collaboration · N. Abgrall (U. Geneva (main)) et al. (Sep 8, 2013)  
 Published in: *Phys.Rev.C* 89 (2014) 2, 025205 · e-Print: 1309.1997 [physics.acc-ph]  
[pdf](#) [DOI](#) [cite](#) 34 citations

**Measurements of  $\pi^\pm$  differential yields from the surface of the T2K replica target for incoming 31 GeV/c protons with the NA61/SHINE spectrometer at the CERN SPS** #9  
 NA61/SHINE Collaboration · N. Abgrall (Geneva U.) et al. (Mar 22, 2016)  
 Published in: *Eur.Phys.J.C* 76 (2016) 11, 617 · e-Print: 1603.06774 [hep-ex]  
[pdf](#) [DOI](#) [cite](#) 34 citations

**Ion Program of Na61/Shine at the CERN SPS** #10  
 NA61/SHINE Collaboration · Marek Gazdzicki (Frankfurt U., Inst. Kernphys. and Jan Kochanowski U.) for the collaboration. (Dec 23, 2008)  
 Published in: *J.Phys.G* 36 (2009) 064039 · Contribution to: SQM 2008 · e-Print: 0812.4415 [nucl-ex]  
[pdf](#) [DOI](#) [cite](#) 28 citations

**Production of  $\Lambda$ -hyperons in inelastic p+p interactions at 158 GeV/c** #11  
 NA61/SHINE Collaboration · A. Aduszkiewicz (Warsaw U.) et al. (Oct 13, 2015)  
 Published in: *Eur.Phys.J.C* 76 (2016) 4, 198 · e-Print: 1510.03720 [hep-ex]  
[pdf](#) [DOI](#) [cite](#) 21 citations

**Measurements of  $\pi^\pm$ ,  $K^\pm$  and proton double differential yields from the surface of the T2K replica target for incoming 31 GeV/c protons with the NA61/SHINE spectrometer at the CERN SPS** #12  
 NA61/SHINE Collaboration · N. Abgrall (Geneva U.) et al. (Aug 14, 2018)

**Measurement of meson resonance production in  $\pi^- + C$  interactions at SPS energies** #13  
 NA61/SHINE Collaboration · A. Aduszkiewicz (Warsaw U.) et al. (May 23, 2017)  
 Published in: *Eur.Phys.J.C* 77 (2017) 9, 626 · e-Print: 1705.08206 [nucl-ex]  
[pdf](#) [DOI](#) [cite](#) 18 citations

**Measurements of total production cross sections for  $\pi^+ + C$ ,  $\pi^+ + Al$ ,  $K^+ + C$ , and  $K^+ + Al$  at 60 GeV/c and  $\pi^+ + C$  and  $\pi^+ + Al$  at 31 GeV/c** #14  
 NA61/SHINE Collaboration · A. Aduszkiewicz (Warsaw U.) et al. (May 11, 2018)  
 Published in: *Phys.Rev.D* 98 (2018) 5, 052001 · e-Print: 1805.04546 [hep-ex]  
[pdf](#) [DOI](#) [cite](#) 10 citations

**Two-particle correlations in azimuthal angle and pseudorapidity in inelastic p + p interactions at the CERN Super Proton Synchrotron** #15  
 NA61/SHINE Collaboration · A. Aduszkiewicz (Warsaw U. (main)) et al. (Oct 3, 2016)  
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