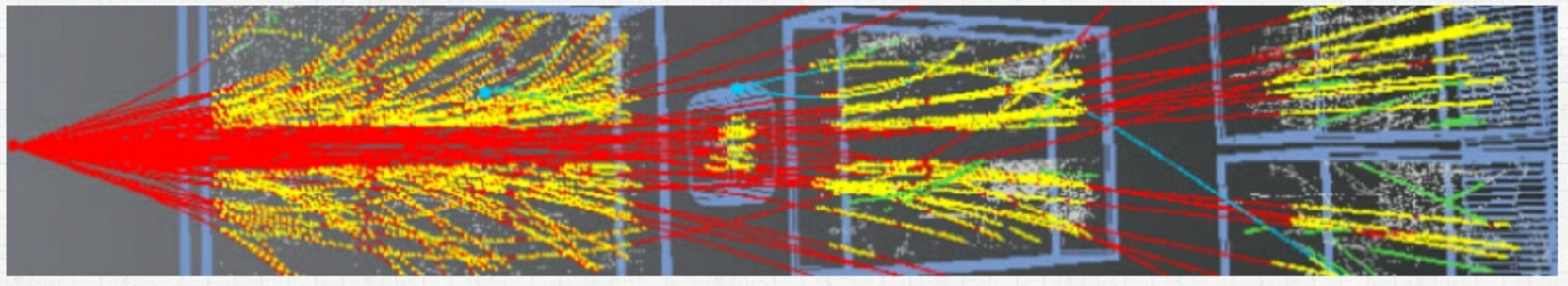
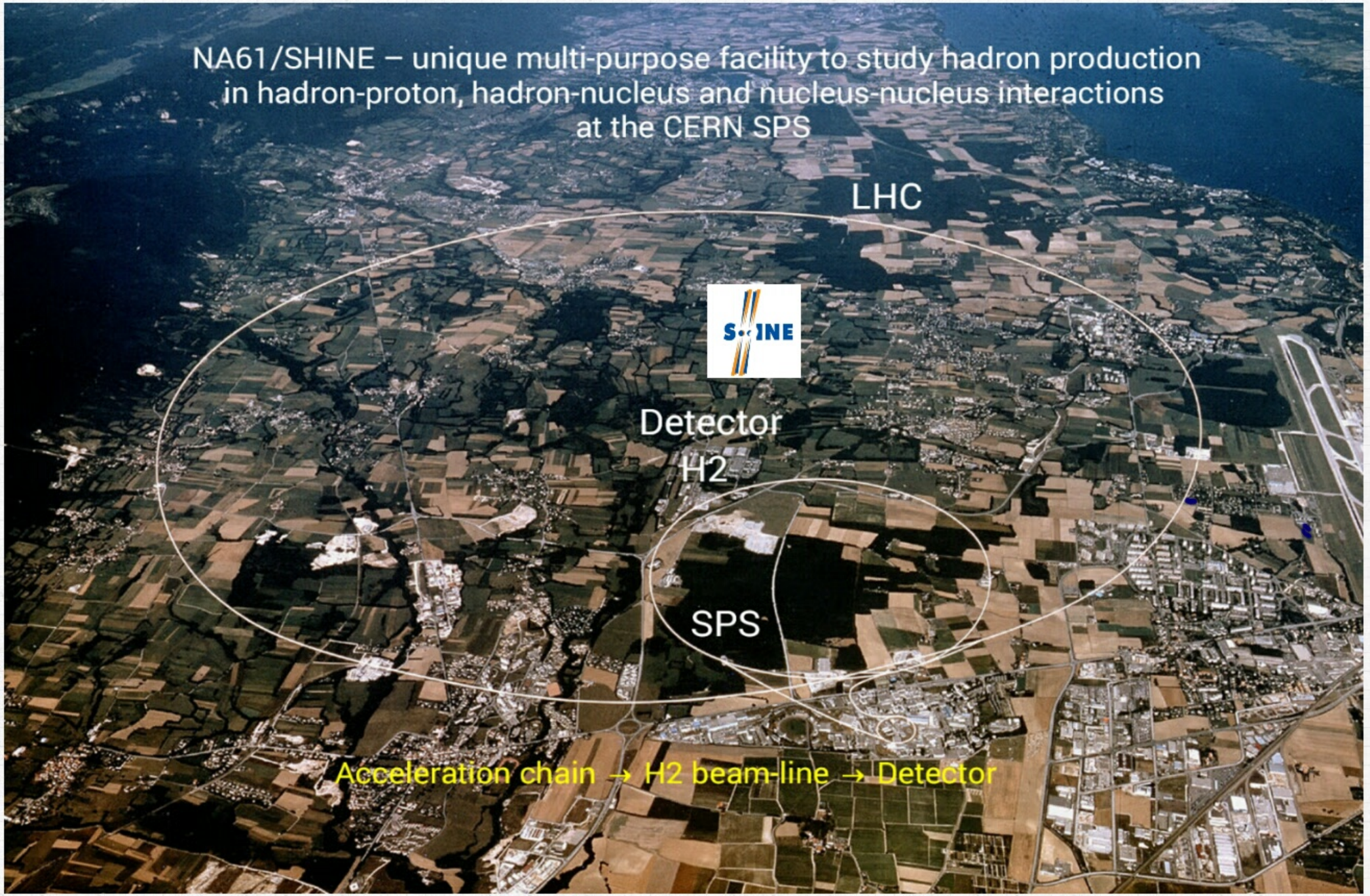
RECENT RESULTS FROM NA61/SHINE

MG for the NA61/SHINE Collaboration

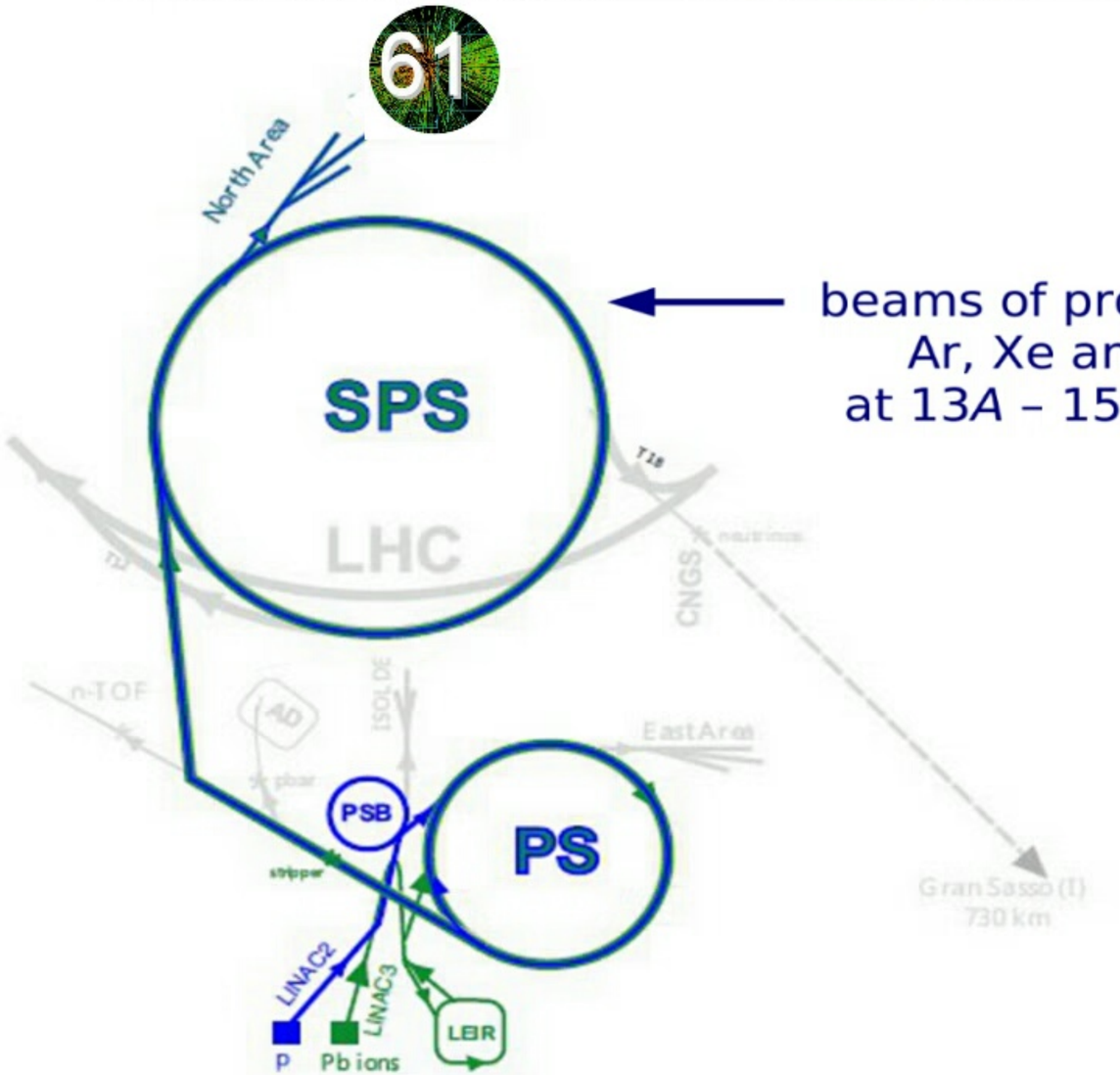
- FACILITY
- STRONG INTERACTIONS
- NEUTRINOS
- COSMIC RAYS



FACILITY


NA61/SHINE – unique multi-purpose facility to study hadron production
in hadron-proton, hadron-nucleus and nucleus-nucleus interactions
at the CERN SPS
LHC
SHINE
Detector
H2
SPS
Acceleration chain → H2 beam-line → Detector

Acceleration chain → H2 beam-line → Detector

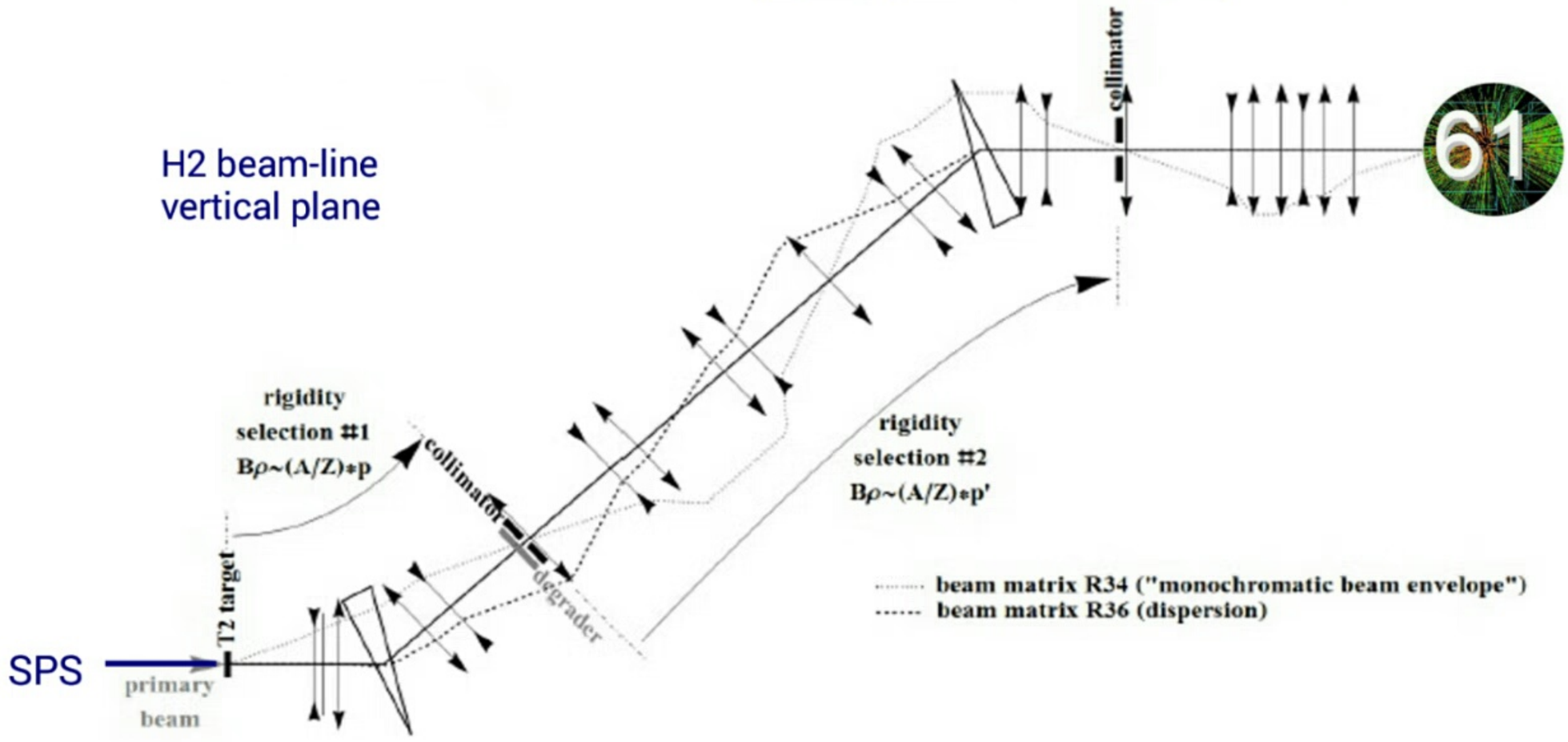


beams of protons as well as
Ar, Xe and Pb nuclei
at 13*A* – 150*A*(400) GeV/c

JINST 9 P06005

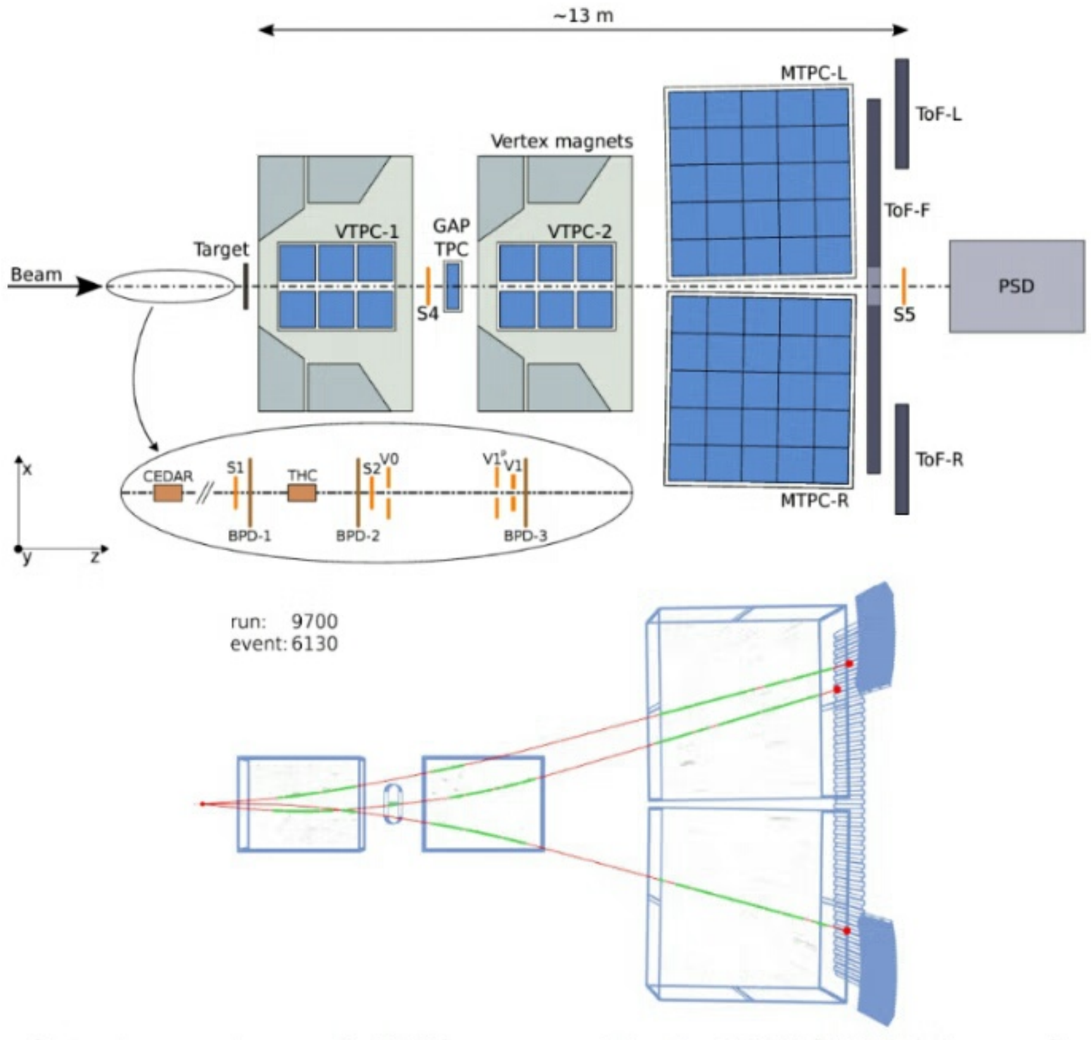
beams of secondary protons, kaons and pions
as well as Ar, Xe and Pb nuclei and their fragments
(e.g. ^{7}Be) at 13A – 150A(400) GeV/c

H2 beam-line
vertical plane



JINST 9 P06005

NA61/SHINE detector



(p+p interaction at 40 GeV/c measured in the NA61/SHINE detector)

JINST **9** P06005

- A large acceptance hadron spectrometer
- Beam particles measured in set of counters and MWPC detectors
- Charged tracks measured in set of 5 **TPC**s → measurement of ***q***, ***p*** and identification via $\mathrm{d}E/\mathrm{d}x$
- 3 ToF walls: identification via time of flight measurement
- **Projectile Spectator Detector** counts the non-interacting nucleons of the beam particle

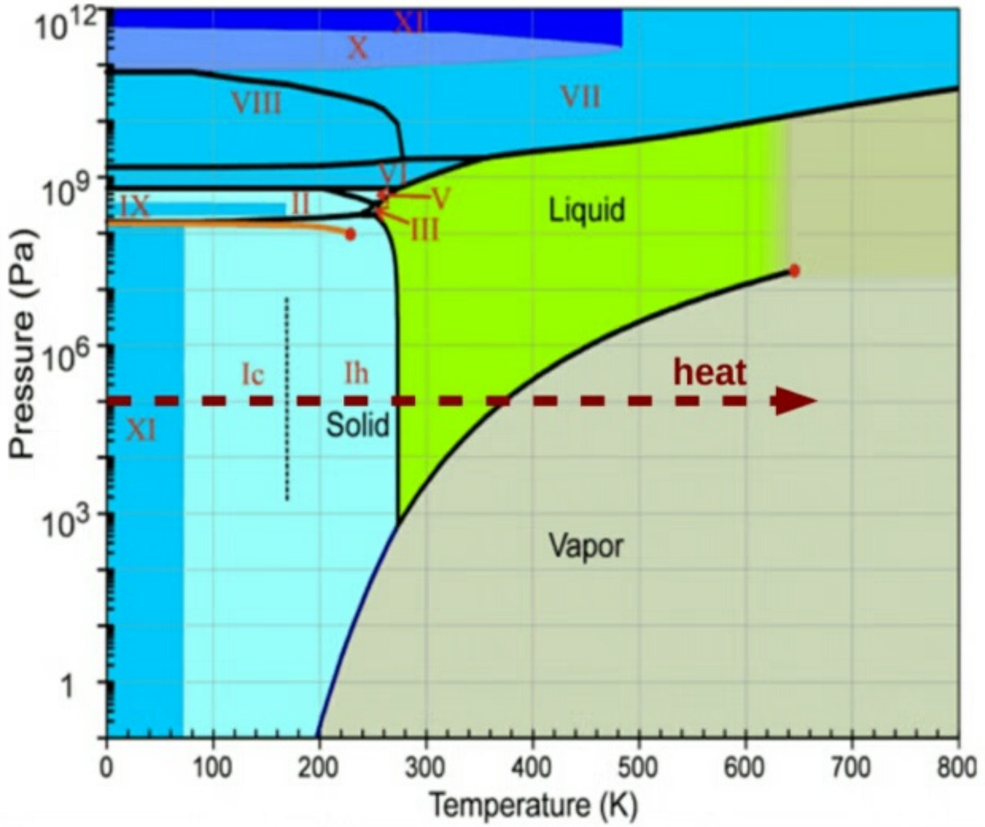
NA61 → CBM

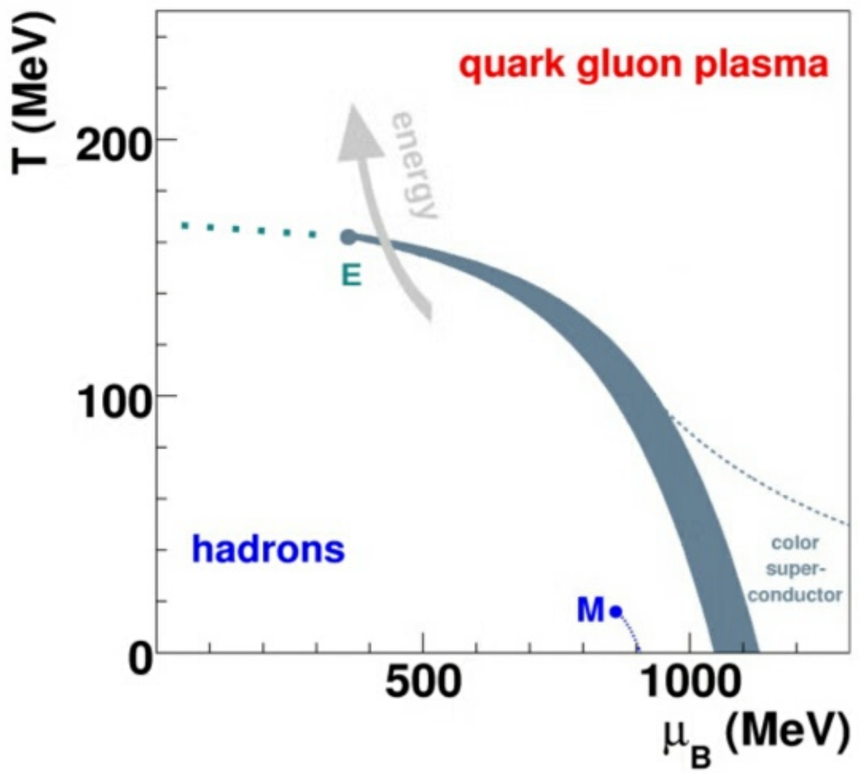
- VERTEX DETECTOR

CBM → NA61

STRONG INTERACTIONS

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



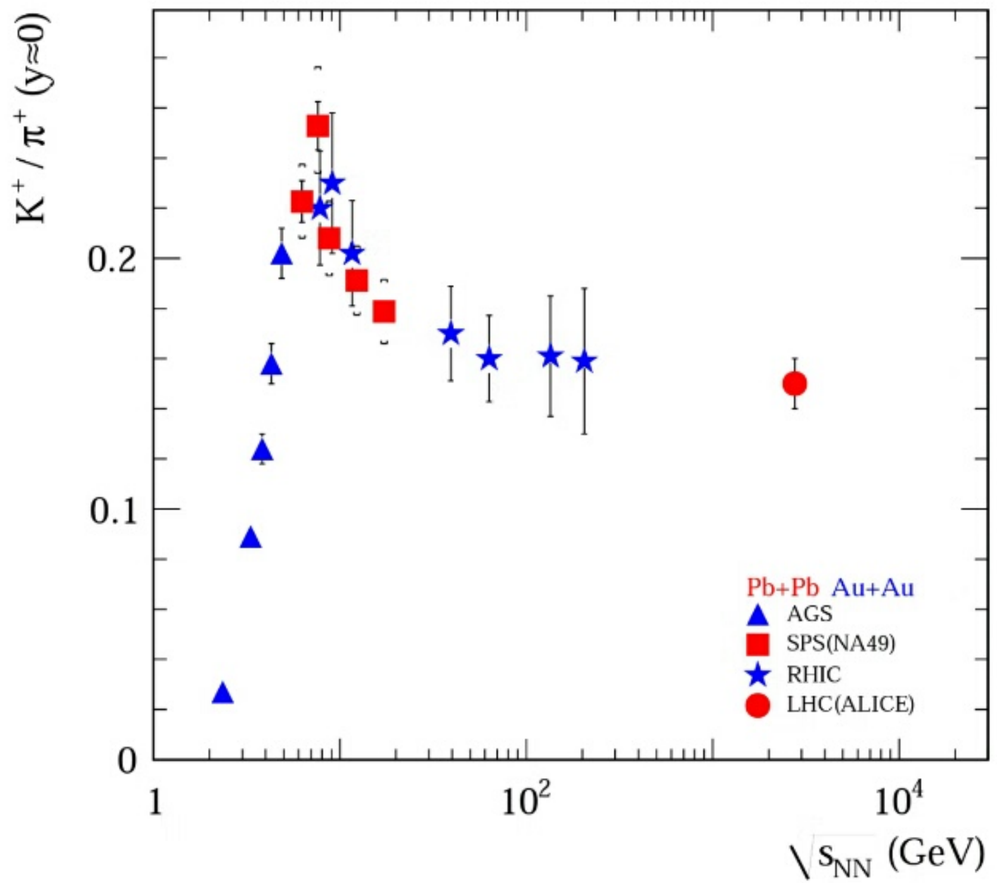


NA61/SHINE → PROPERTIES OF THE ONSET OF DECONFINEMENT
→ SEARCH FOR THE CRITICAL POINT

ONSET OF DECONFINEMENT: EXPERIMENTAL EVIDENCE

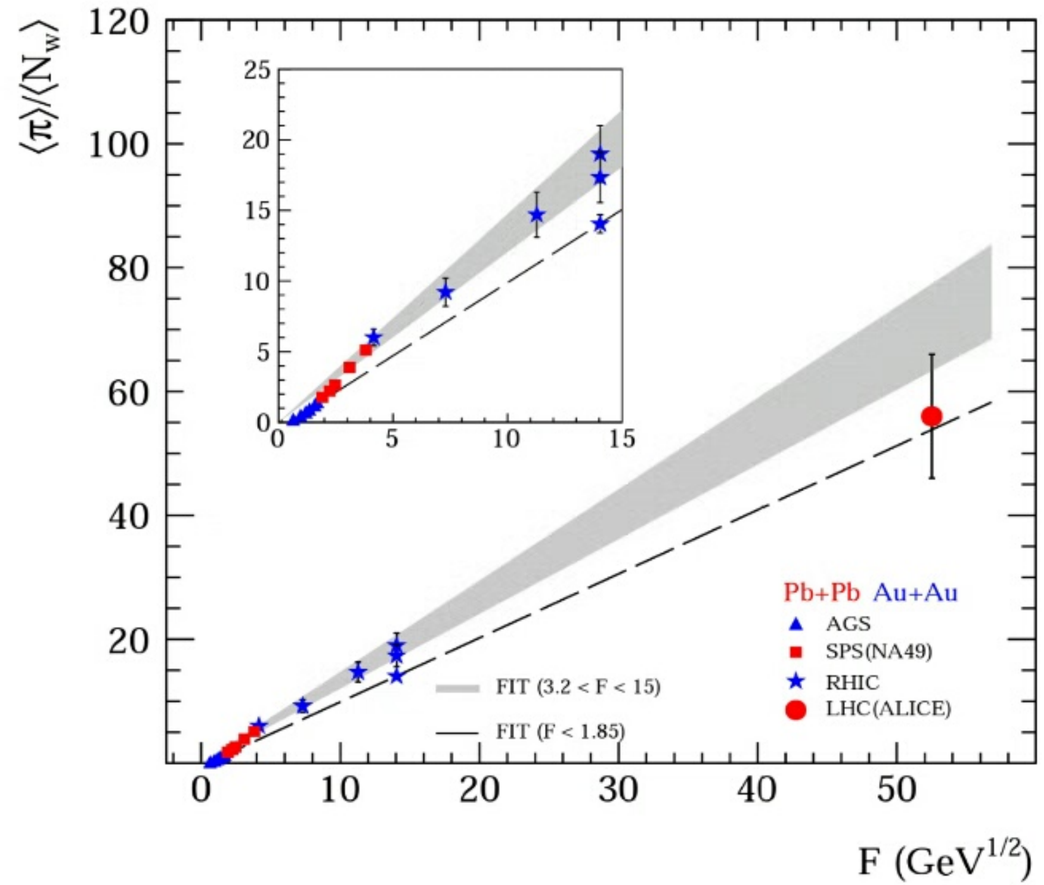
MEAN HADRON MULTIPLICITIES

THE HORN ($\langle K^+ \rangle / \langle \pi^+ \rangle$)



DATA-BASED SIGNAL

THE KINK ($\langle \pi \rangle$)



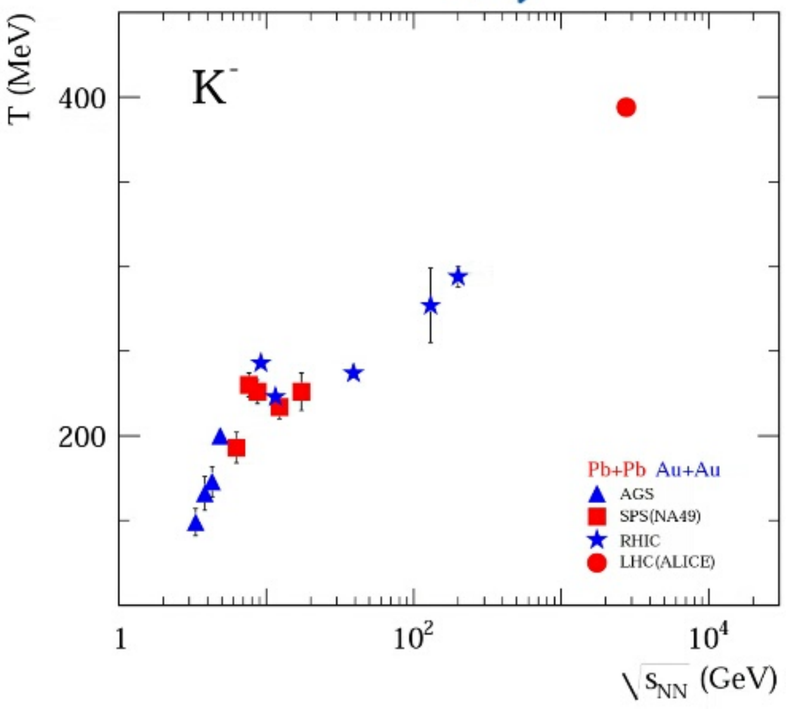
DATA/MODEL-BASED SIGNAL

IJMP E 23 1430008

ONSET OF DECONFINEMENT: EXPERIMENTAL EVIDENCE

SINGLE PARTICLE SPECTRA

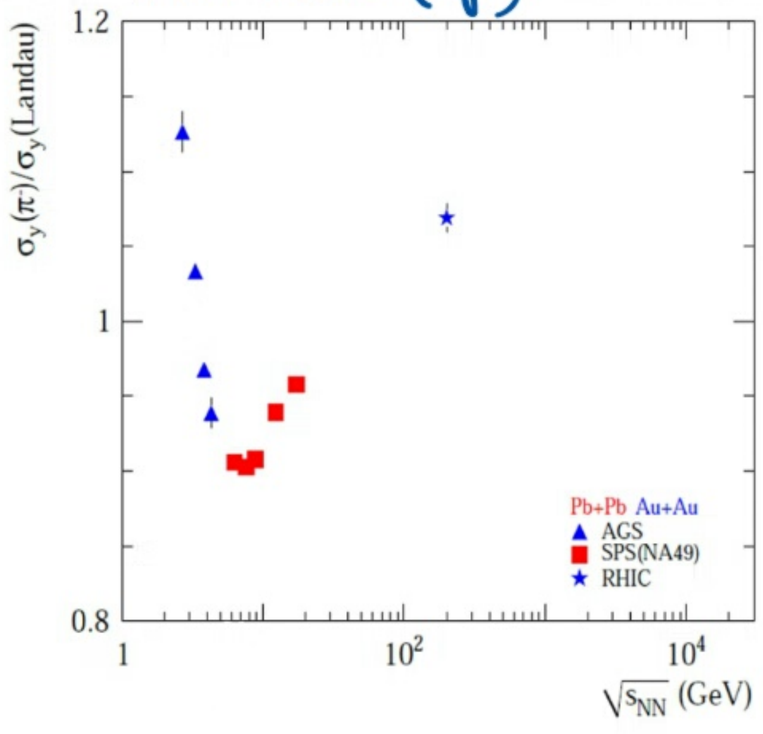
THE STEP (p_T)



DATA-BASED

IJMP E 23 1430008

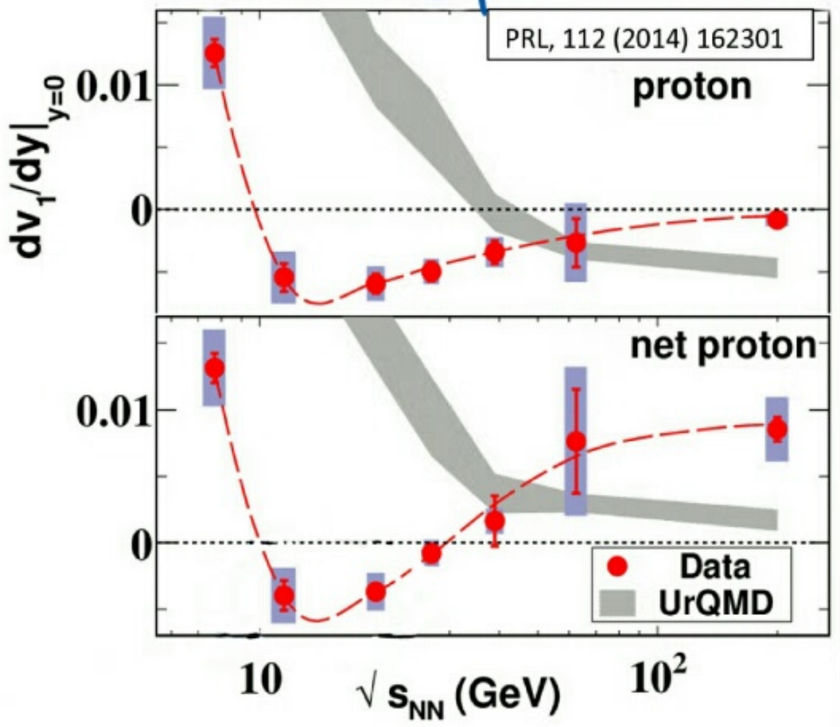
THE DALE (y)



DATA/MODEL-BASED

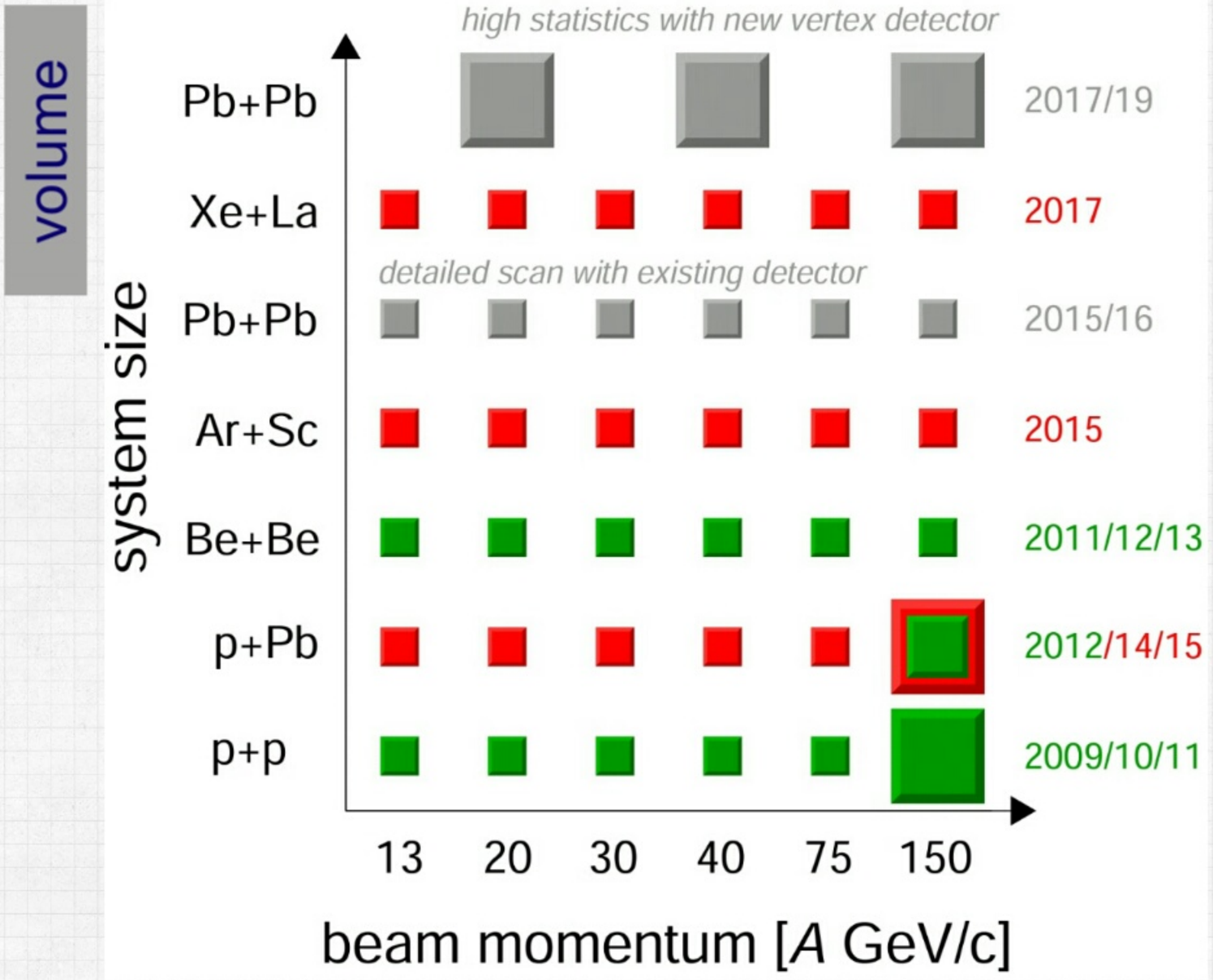
hep-ph/0509314

THE DIP (φ)



DATA-BASED

NA61/SHINE DATA TAKING SCHEDULE

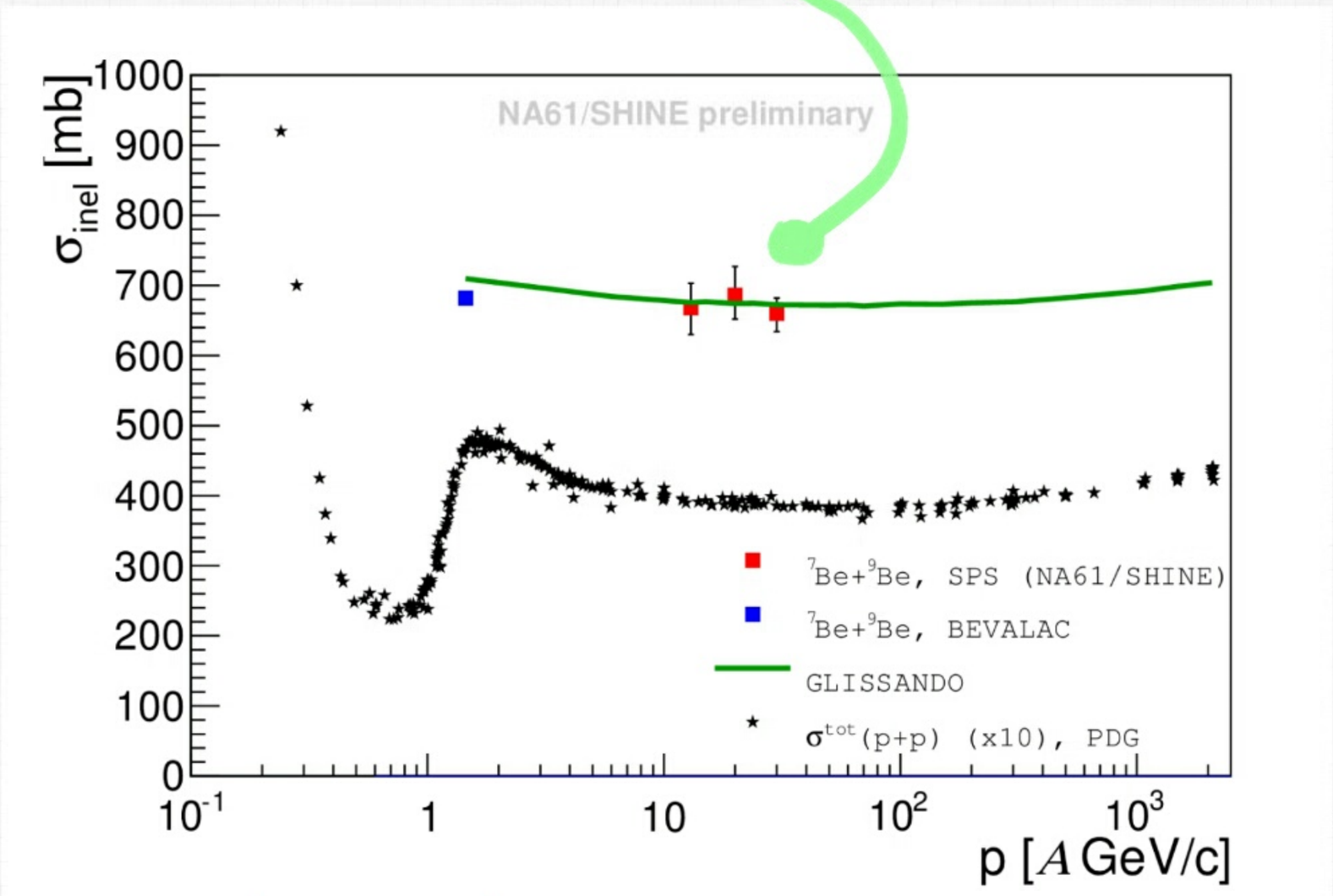


RECORDED

APPROVED

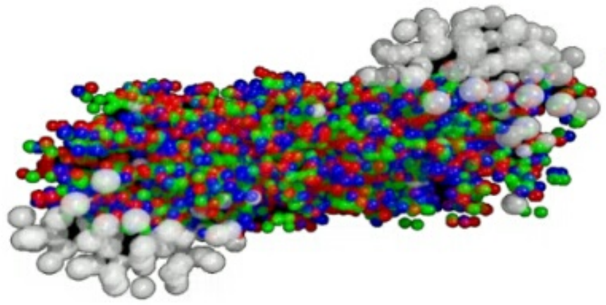
CONSIDERED

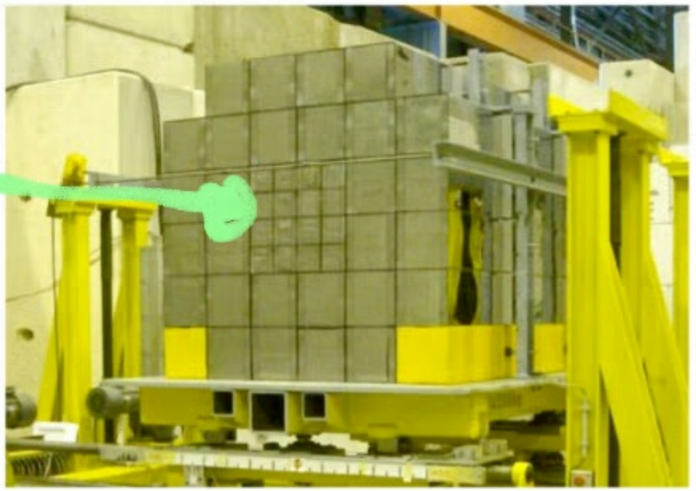
INELASTIC CROSS SECTION FOR $^7Be + ^9Be$



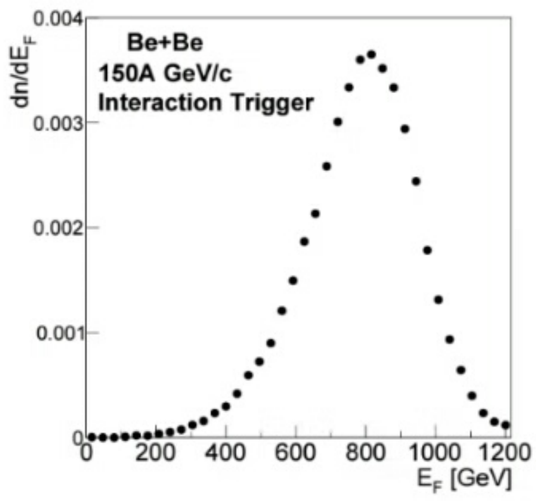
σ_{INEL} (Be+Be) – WEAKLY DEPENDENT ON p
– REPRODUCED BY GLAUBER MODEL

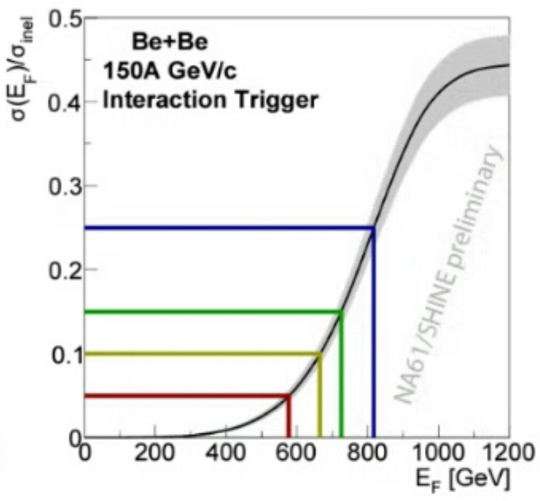
Centrality selection in Be+Be collisions with Projectile Spectator Detector





- PSD is located on the beam axis and measures the forward energy E_F related to the non-interacting nucleons of the beam nucleus
- Cuts on E_F allows to select different centrality classes

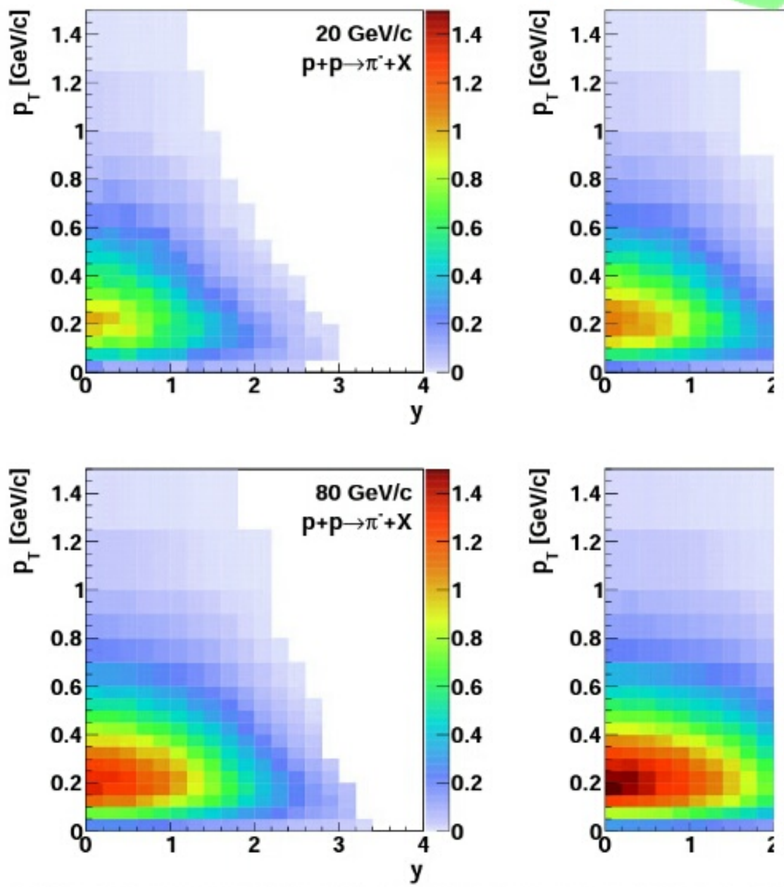


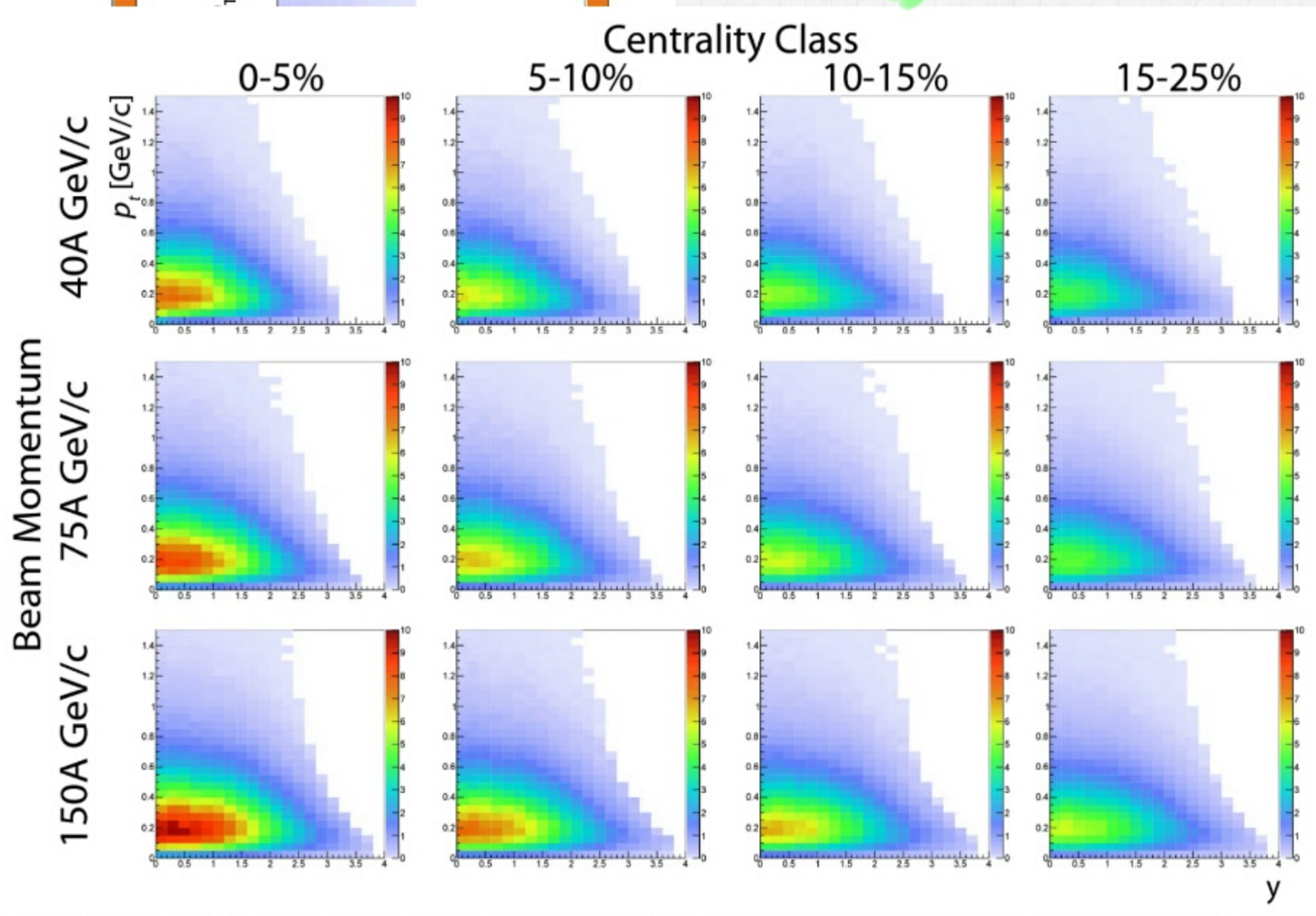


π^- SPECTRA IN p+p AND Be+Be COLLISIONS

p+p

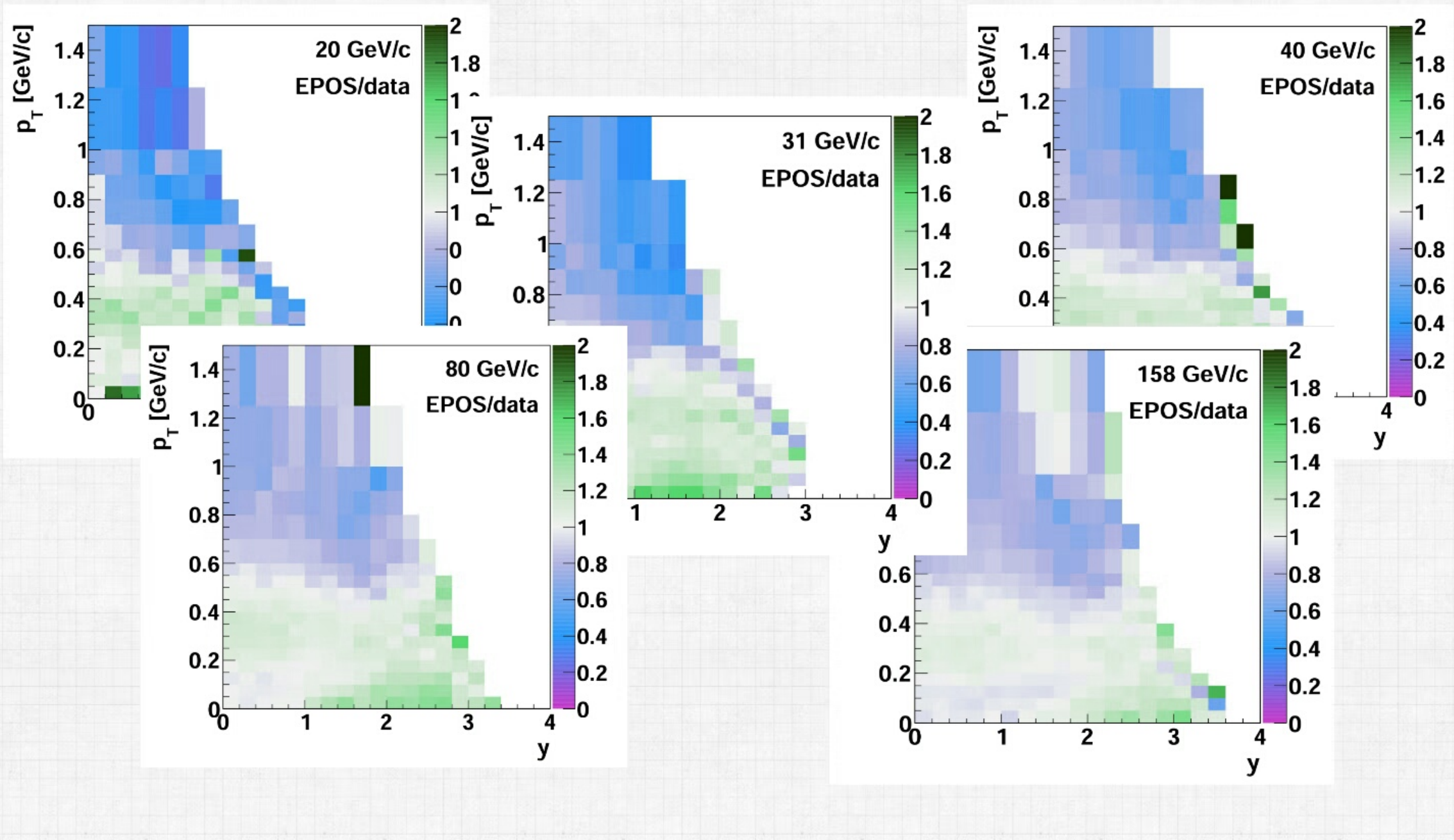
Be+Be



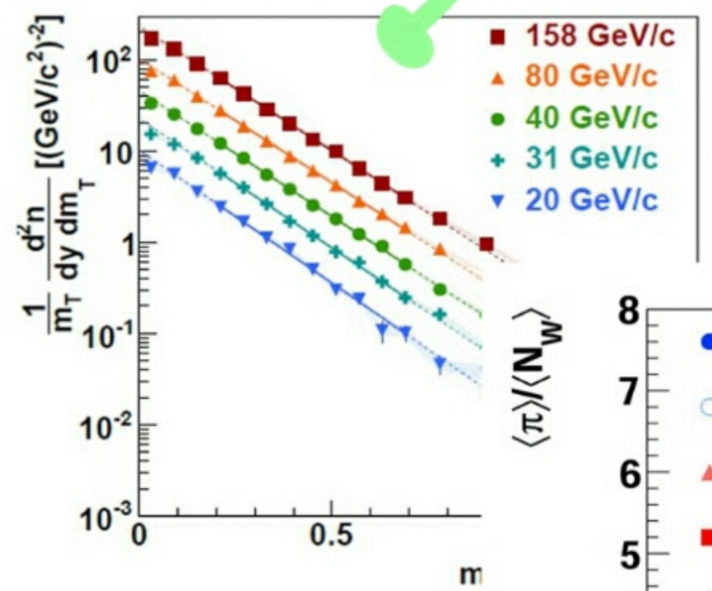


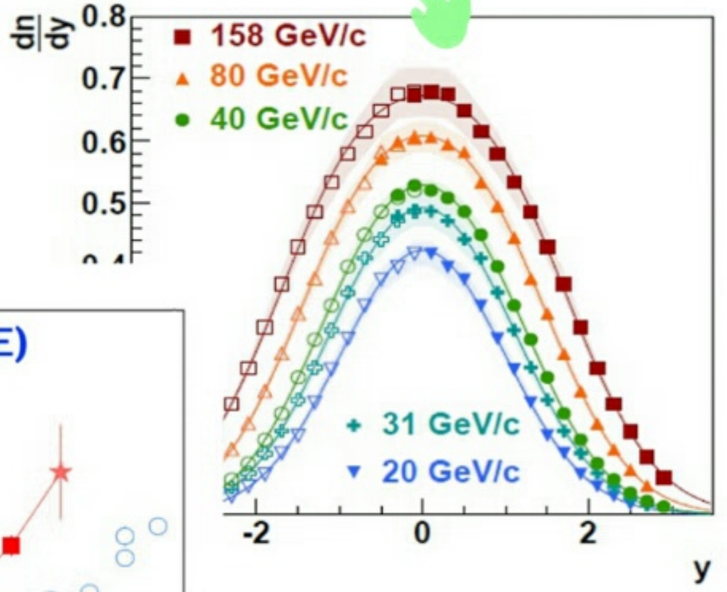
UNIQUE PRECISE MEASUREMENTS OF 2-DIMENSIONAL SPECTRA

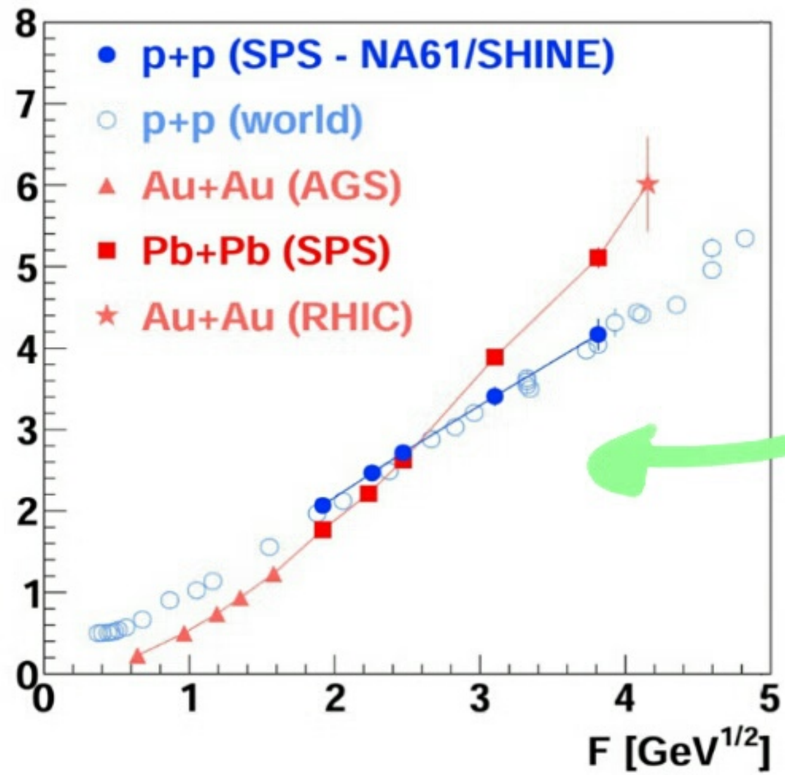
π^- SPECTRA IN p+p: EPOS/(NA61 DATA)



π^- SPECTRA IN p+p: COLLISION ENERGY DEPENDENCE



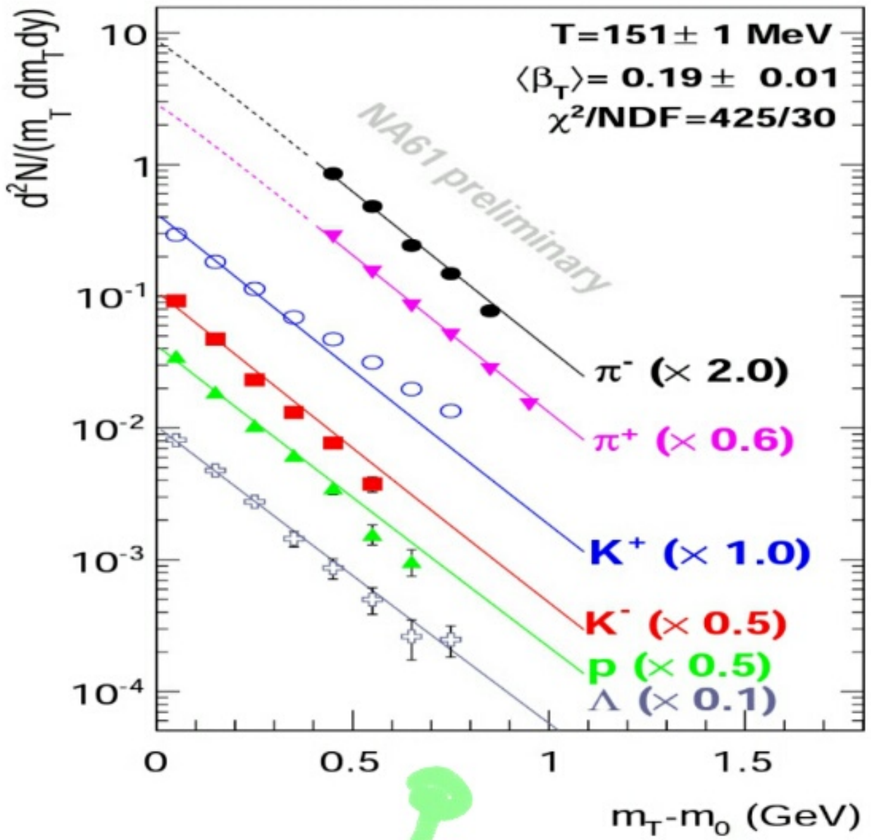


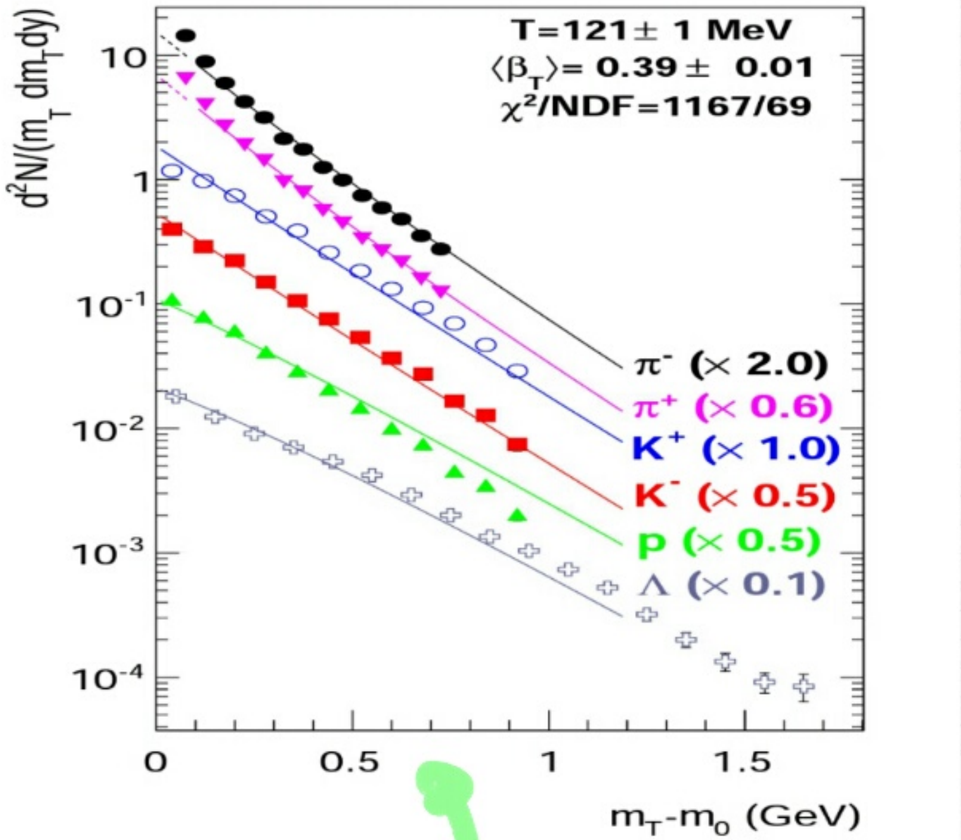


COMPARISON
p+p vs Pb+Pb

NA61/SHINE, Eur. Phys. J. C (2014) 74:2794

COMPARISON p+p vs Pb+Pb: m_T SPECTRA

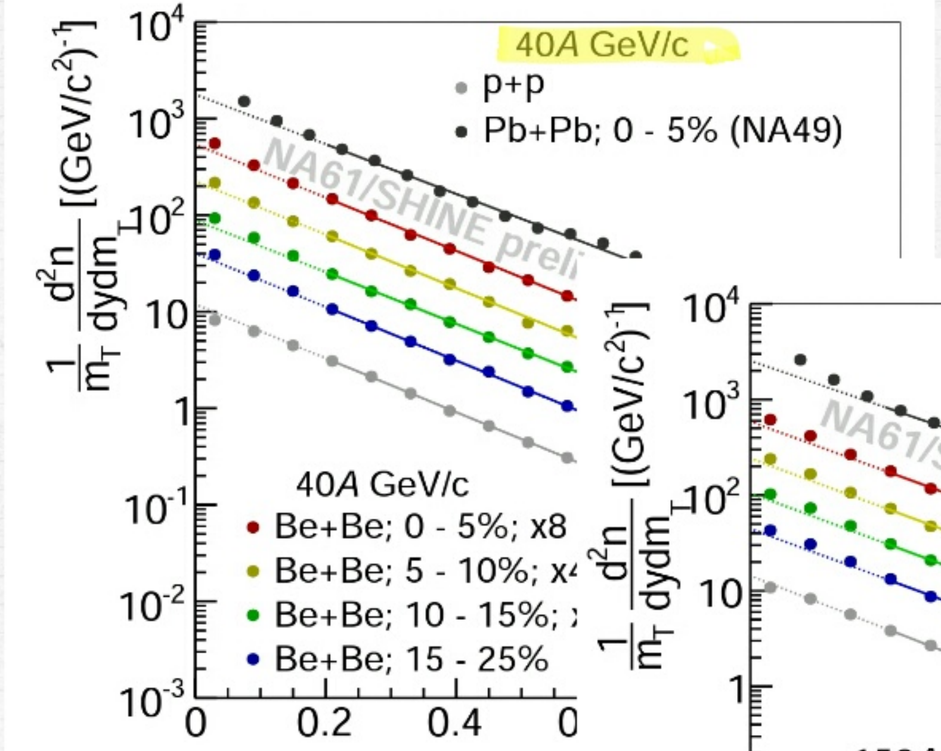


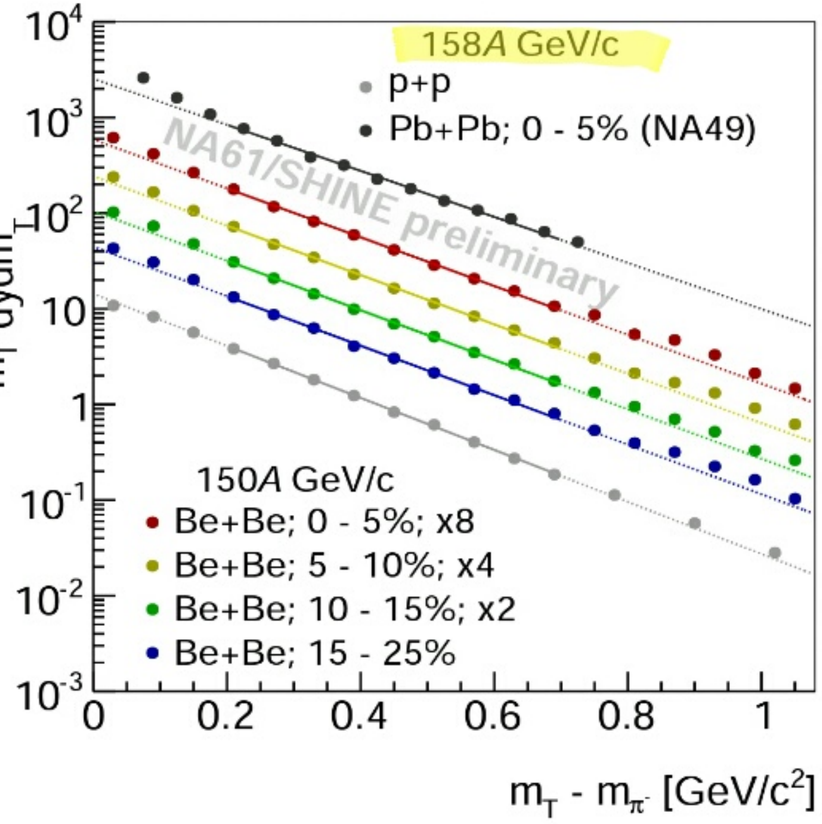


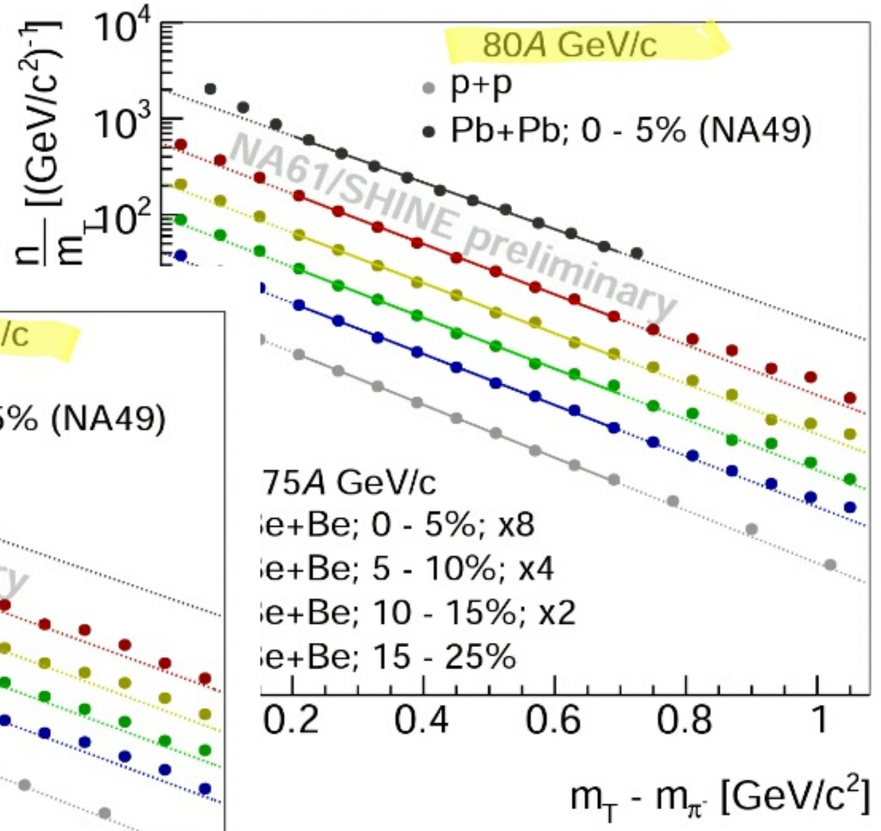
p+p: EXPONENTIAL
→ STATISTICAL

Pb+Pb: NON-EXPONENTIAL
→ TRANSVERSE FLOW

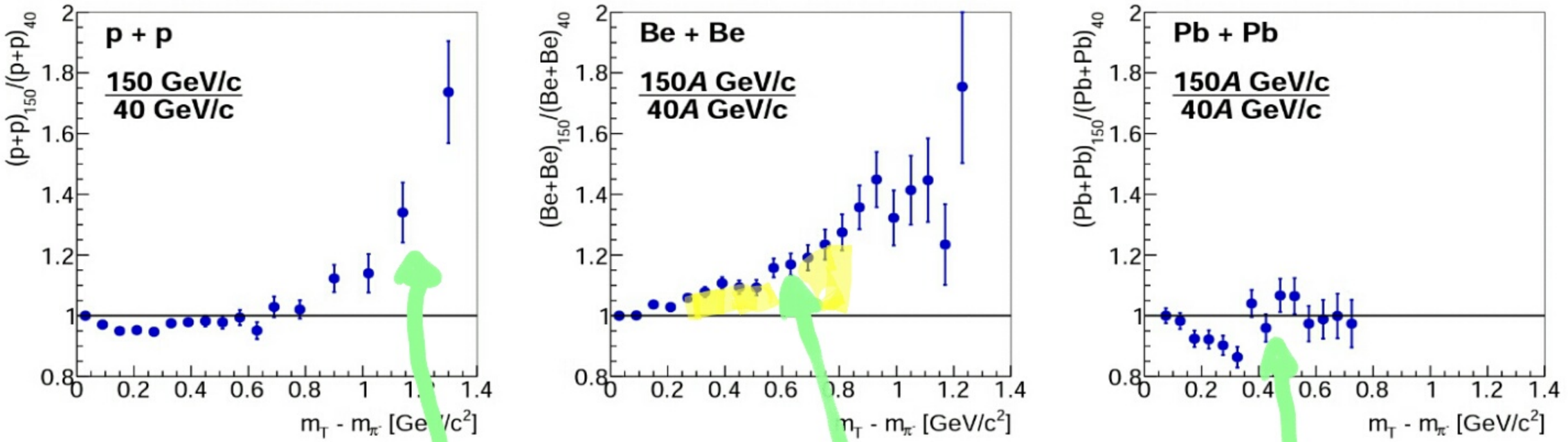
π^- m_T SPECTRA: (p+p vs Be+Be vs Pb+Pb) vs $\sqrt{s_{NN}}$







π^- m_T SPECTRA: (p+p vs Be+Be vs Pb+Pb) vs $\sqrt{s_{NN}}$

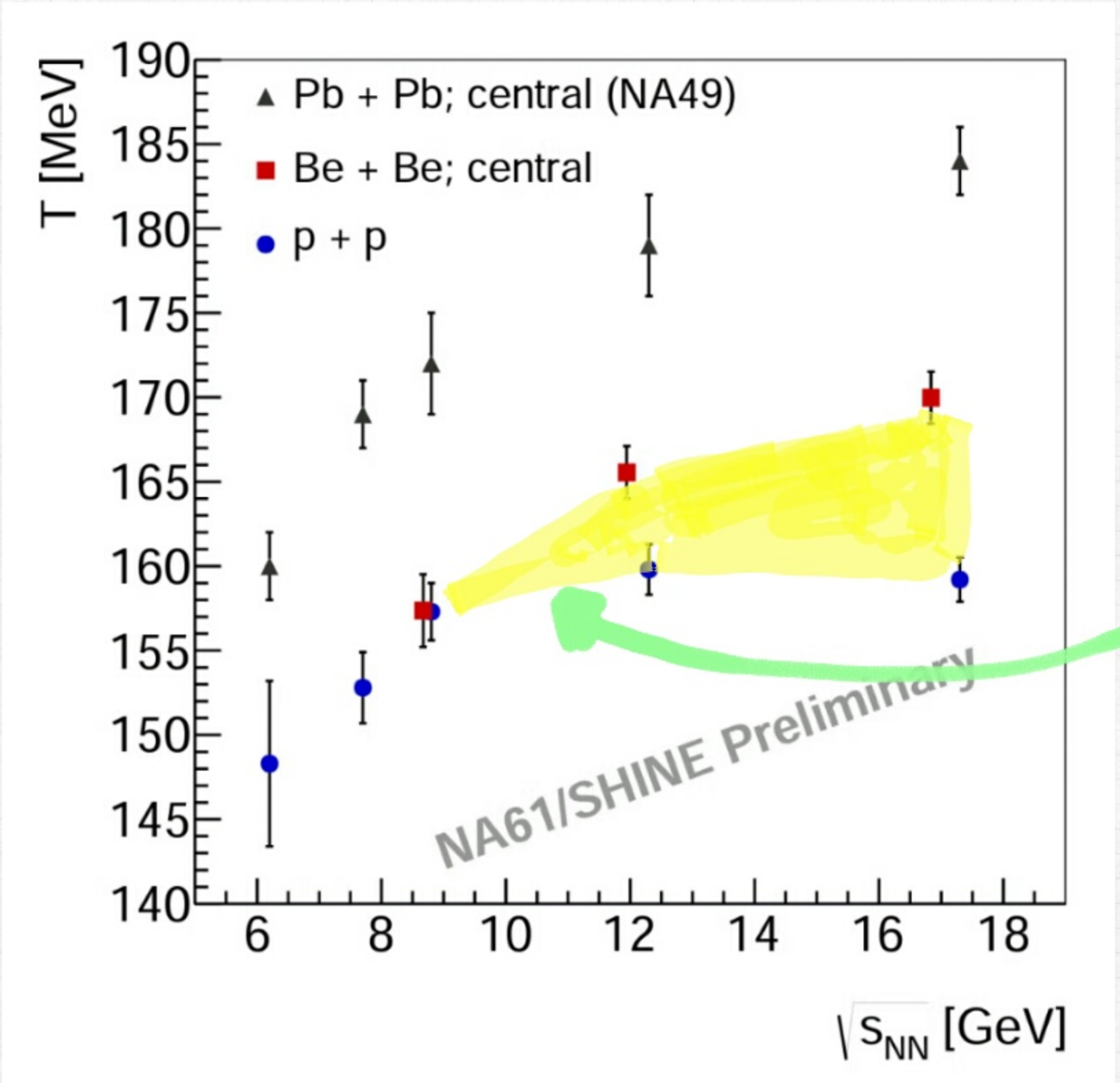


ENERGY-MOMENTUM CONSERVATION?

ONSET OF COLLECTIVITY?

SIMILAR TRANSVERSE FLOW AT 40A AND 158A GeV/c?

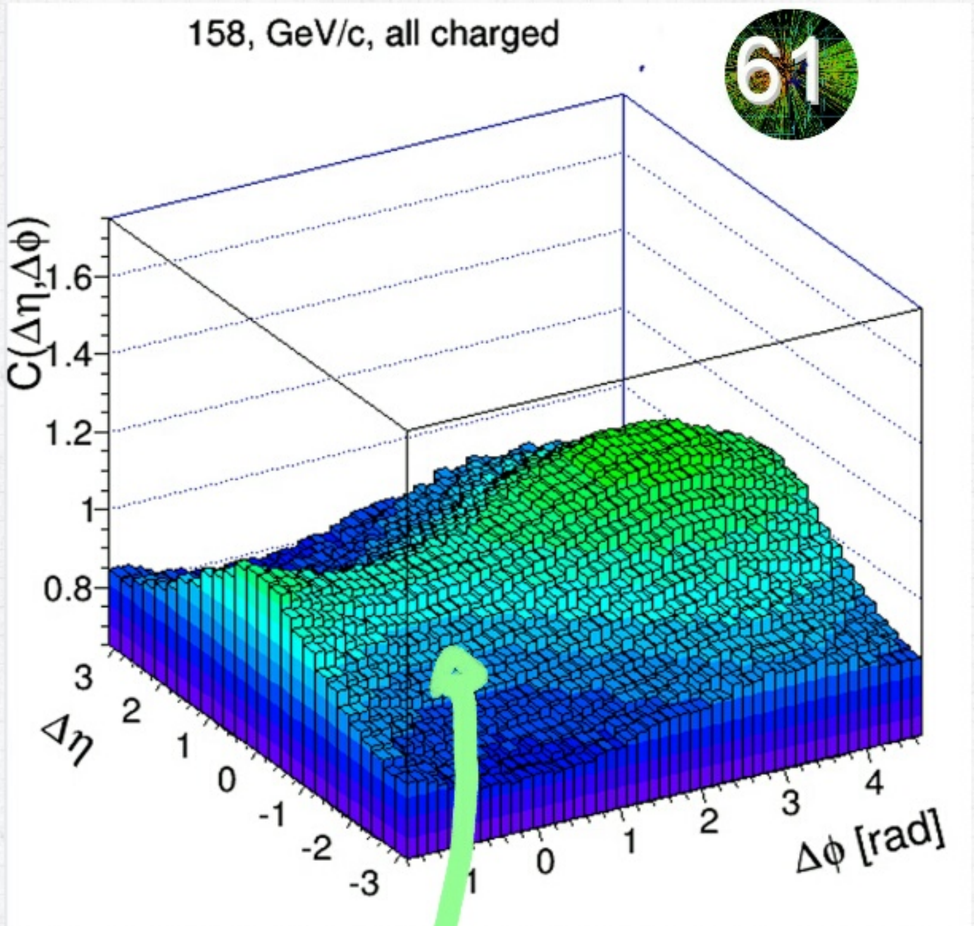
π^- m_T SPECTRA: (p+p vs Be+Be vs Pb+Pb) vs $\sqrt{s_{NN}}$

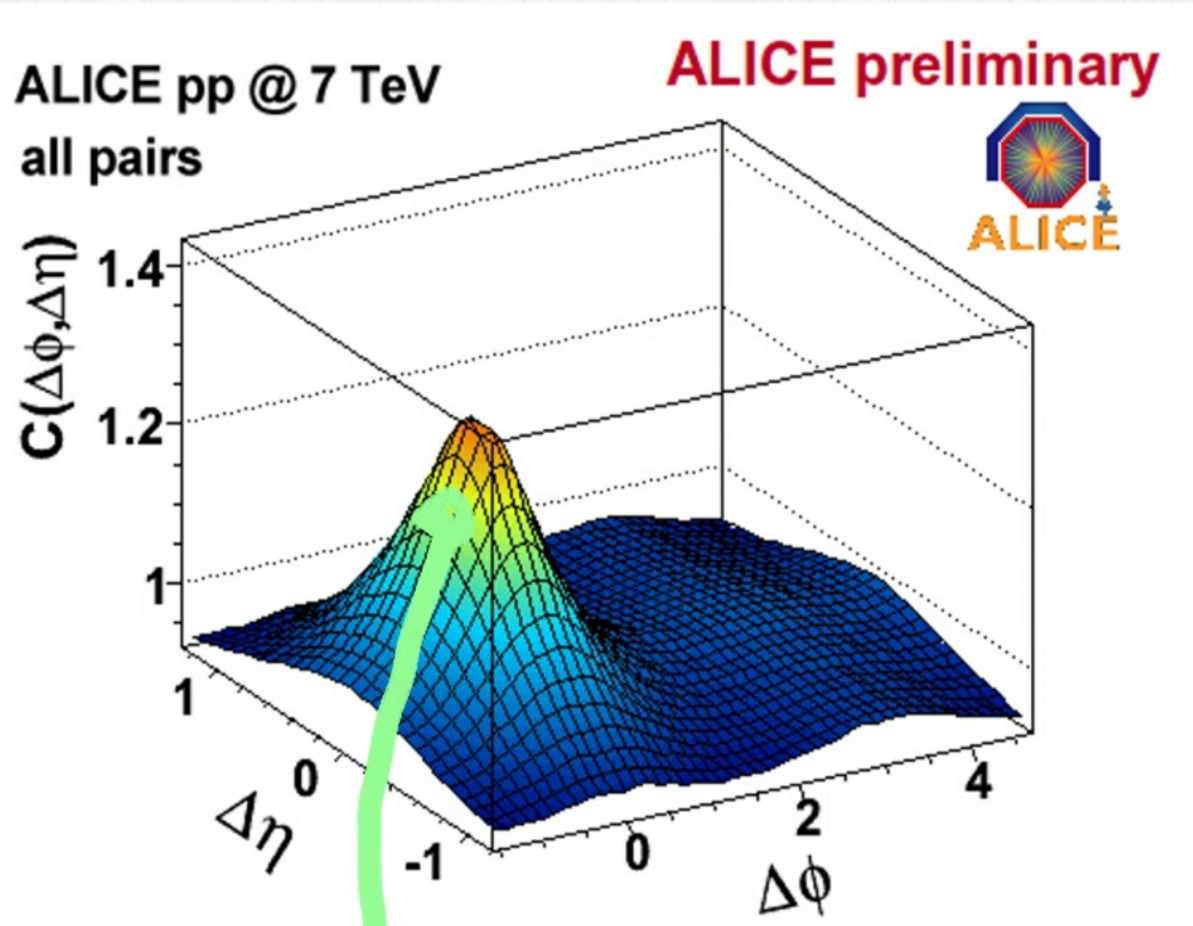


ONSET OF COLLECTIVITY IN Be+Be AT ≈ 75A GeV/c

p+p INTERACTIONS: SPS → LHC

TWO PARTICLE CORRELATION FUNCTION: NA61 vs ALICE





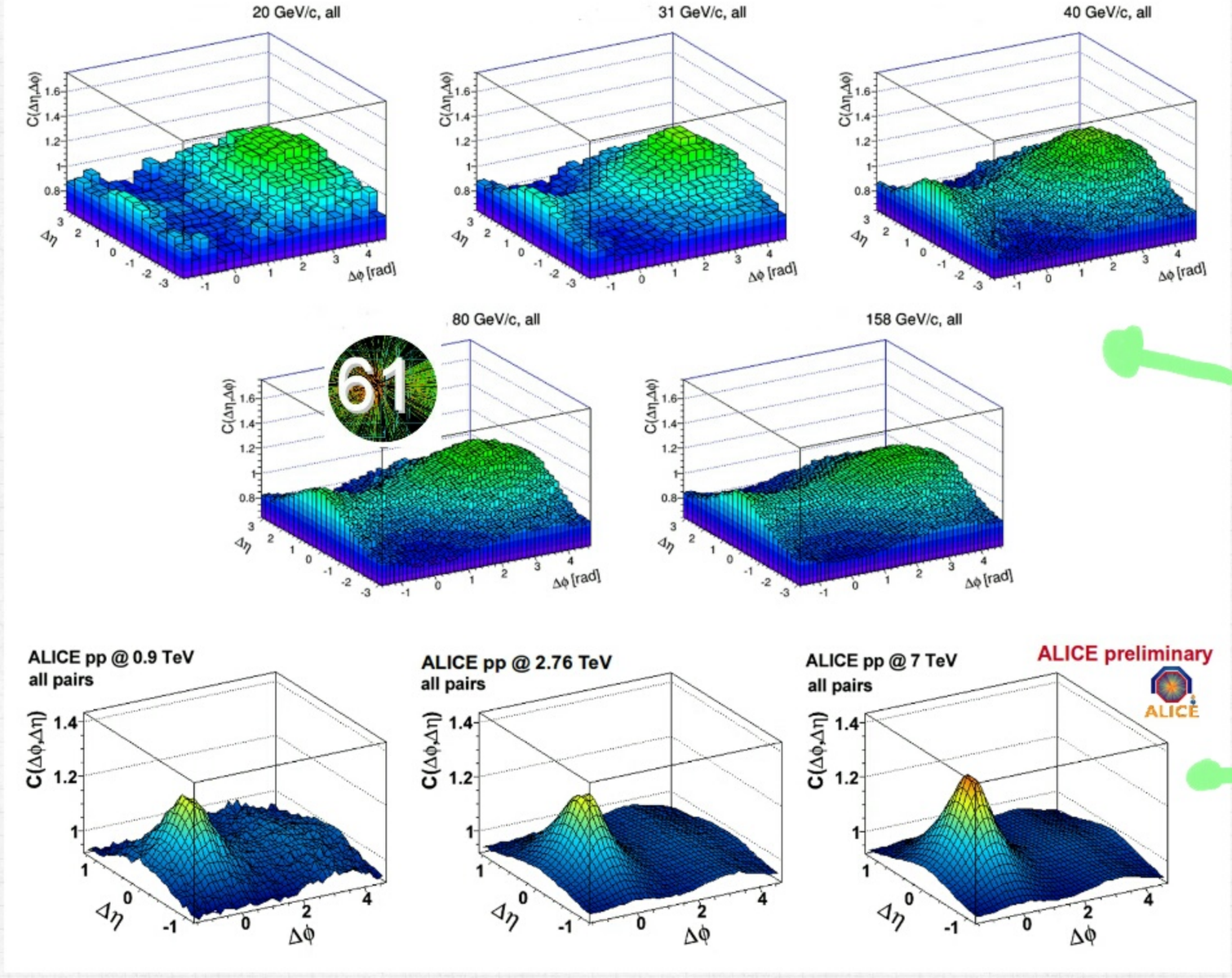
AT (0,0):

THE SADDLE AT SPS

THE PEAK AT LHC

p+p INTERACTIONS: SPS → LHC

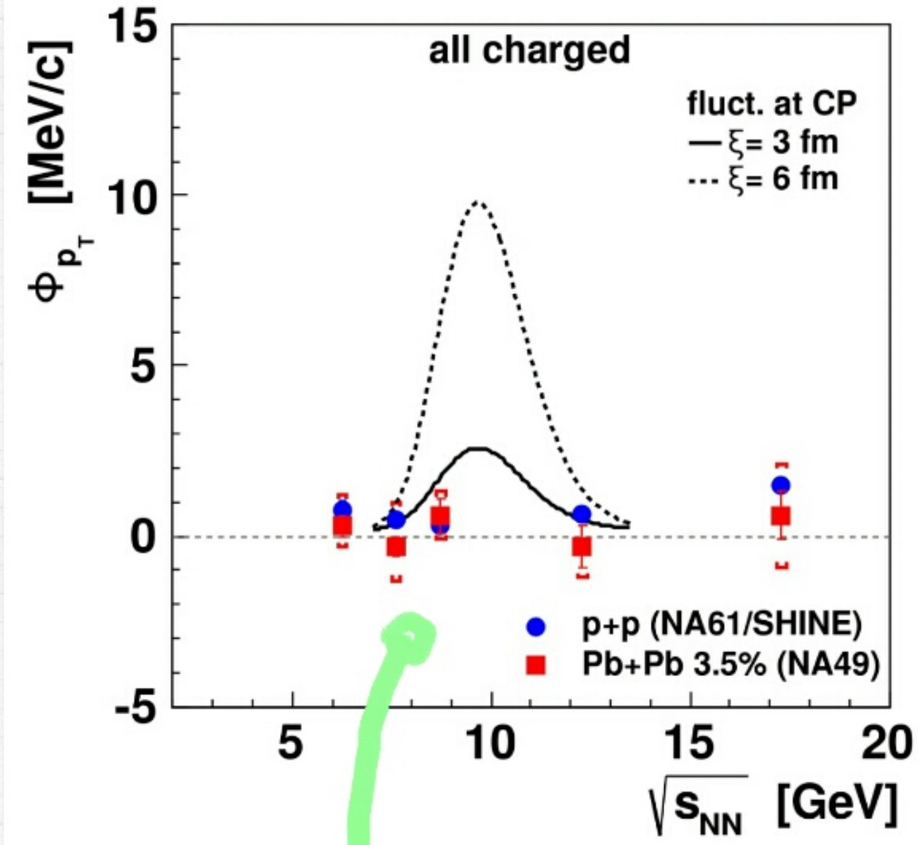
TWO PARTICLE CORRELATION FUNCTION VS $\sqrt{s_{NN}}$



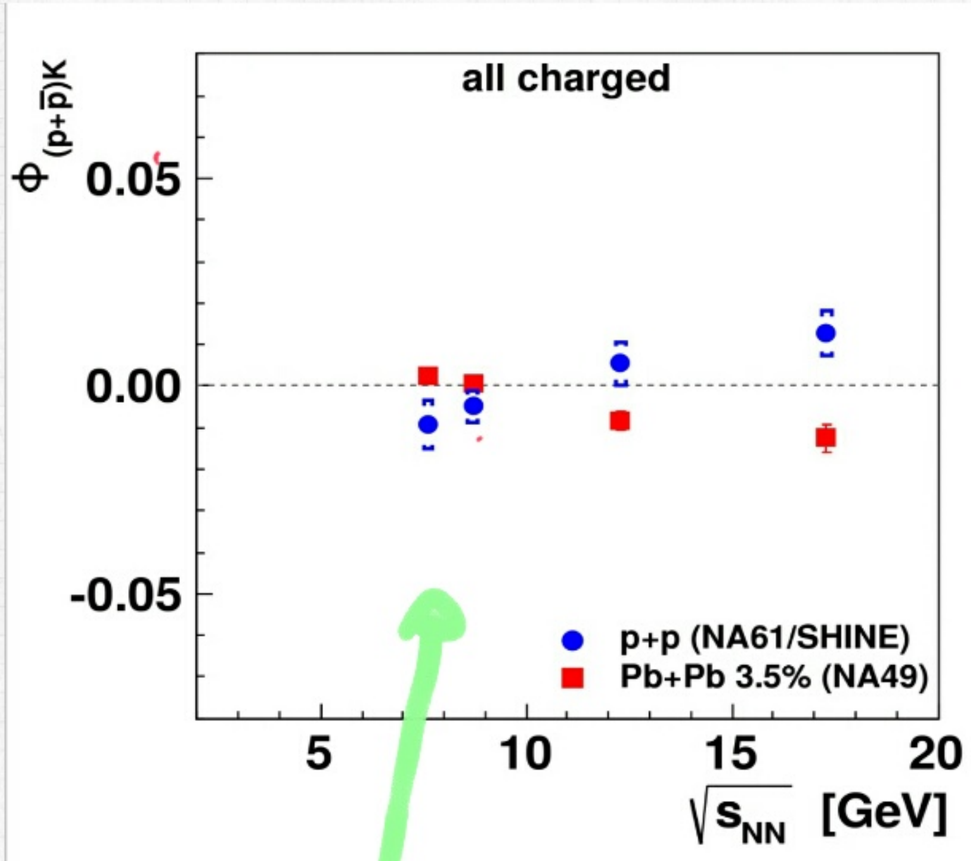
AT SPS
THE HEIGHT OF THE SADDLE
AT (0,0) ↗ $\sqrt{s_{NN}}$ ↗

AT LHC
THE SADDLE CHANGES
INTO SHARP (JET) PEAK

EVENT-BY-EVENT FLUCTUATIONS: (p+p vs Pb+Pb) vs $\sqrt{s_{NN}}$



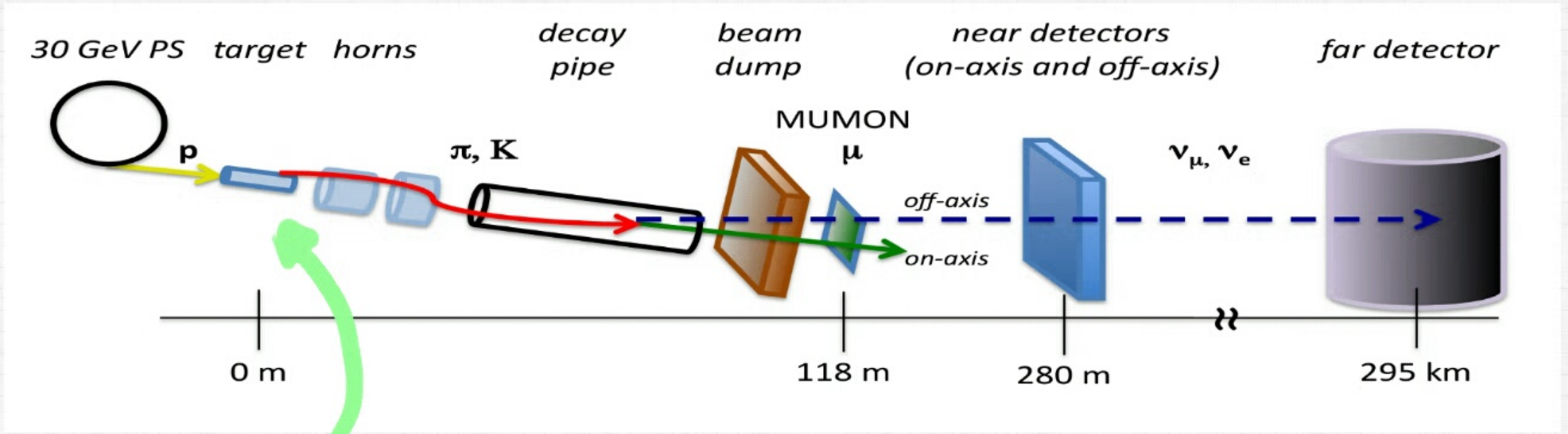
PROPERLY NORMALIZED $[p_T, N]$ FLUCTUATIONS ARE SIMILAR IN p+p AND Pb+Pb



DIFFERENCES ARE OBSERVED FOR CHEMICAL FLUCTUATIONS, THE LARGEST FOR $[p, K]$

NEUTRINOS

WHAT HAPPENS WITH NEUTRINOS FLYING ACROSS JAPAN?
→ THE T2K LONG-BASELINE NEUTRINO OSCILLATION EXPERIMENT



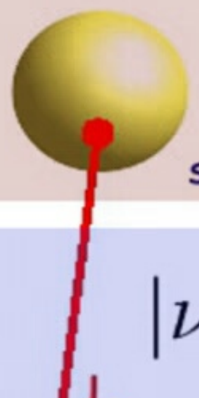
NA61 RESULT ARE USED
FOR DETERMINATION OF
THE INITIAL NEUTRINO FLUX

NEUTRINO OSCILLATIONS: A TOY MODEL

- Oscillations: rotation of states during propagation

$$|\nu(x_0)\rangle = |\nu_e\rangle = c|\nu_1\rangle + s|\nu_2\rangle$$

One given flavour produced by weak interaction



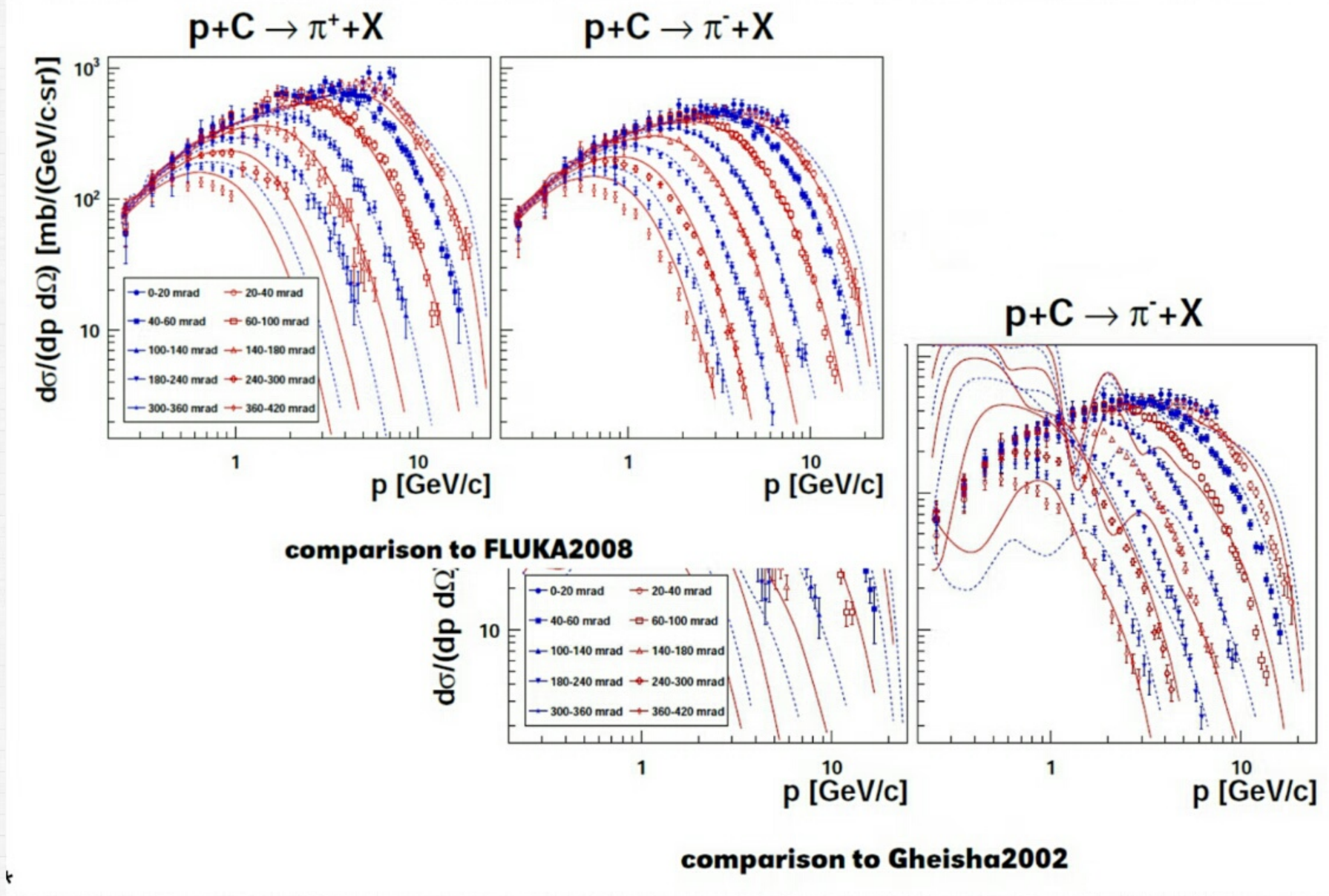
$$|\nu(x)\rangle = c|\nu_1\rangle e^{i(Et-\vec{k_1}\vec{x})} + s|\nu_2\rangle e^{i(Et-\vec{k_2}\vec{x})}$$

Mass eigenstates propagate at different velocity

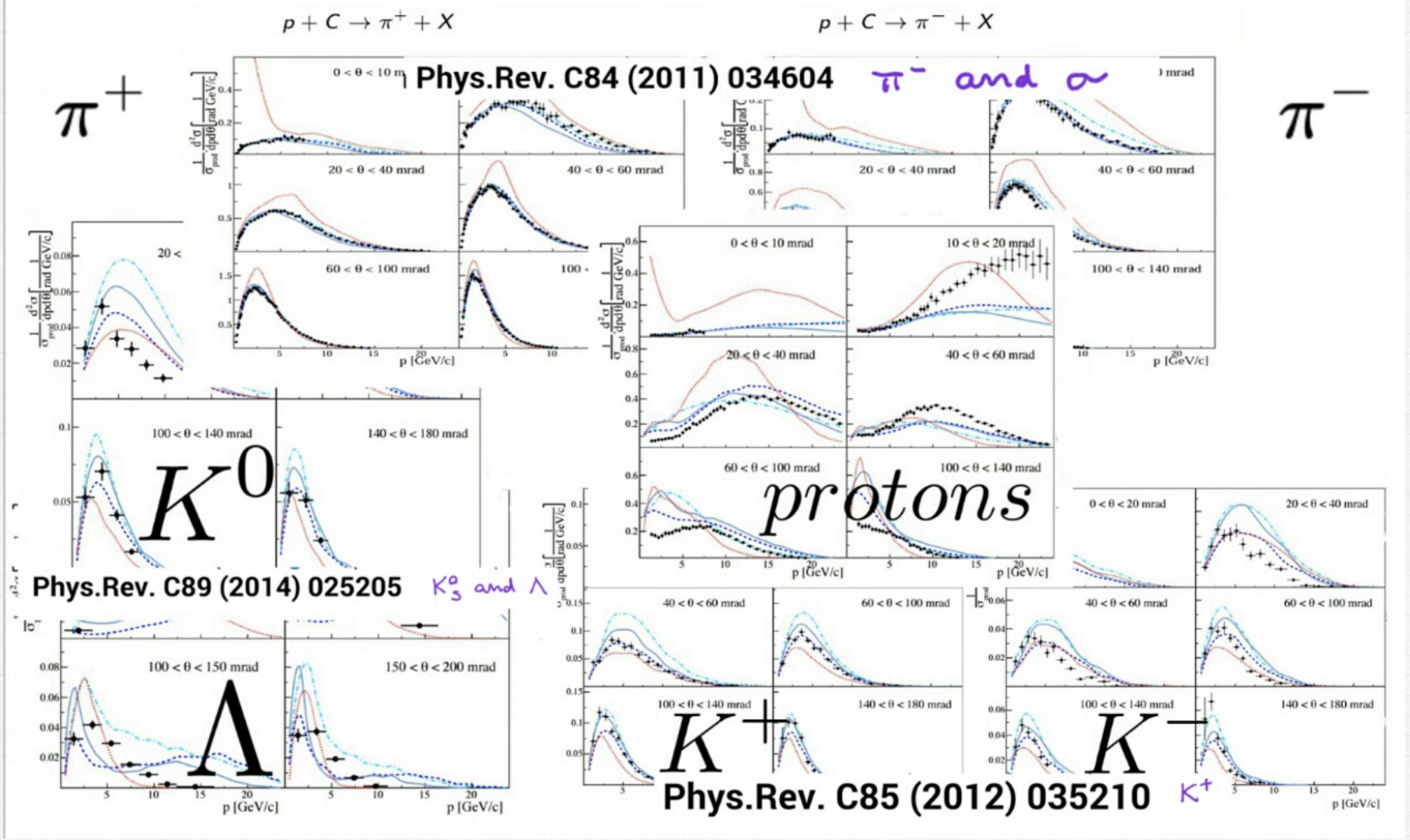
$$P(\nu \to \nu_\mu) = |\langle \nu_\mu | \nu(t) \rangle|^2$$

Weak interaction selects component of one flavour

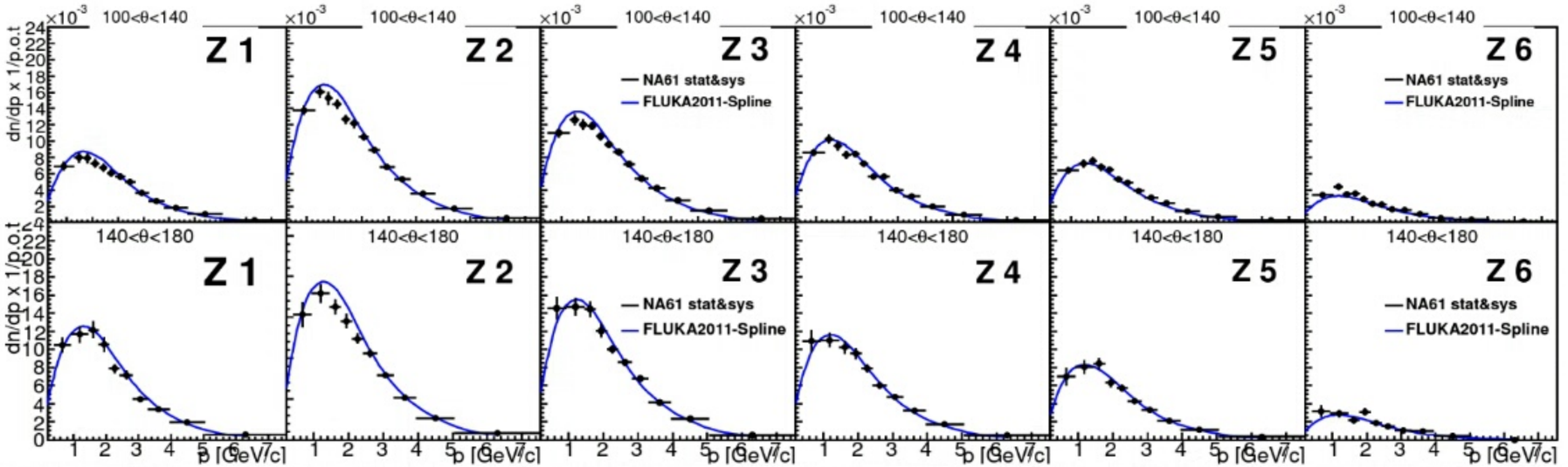
PRECISE DATA FOR T2K

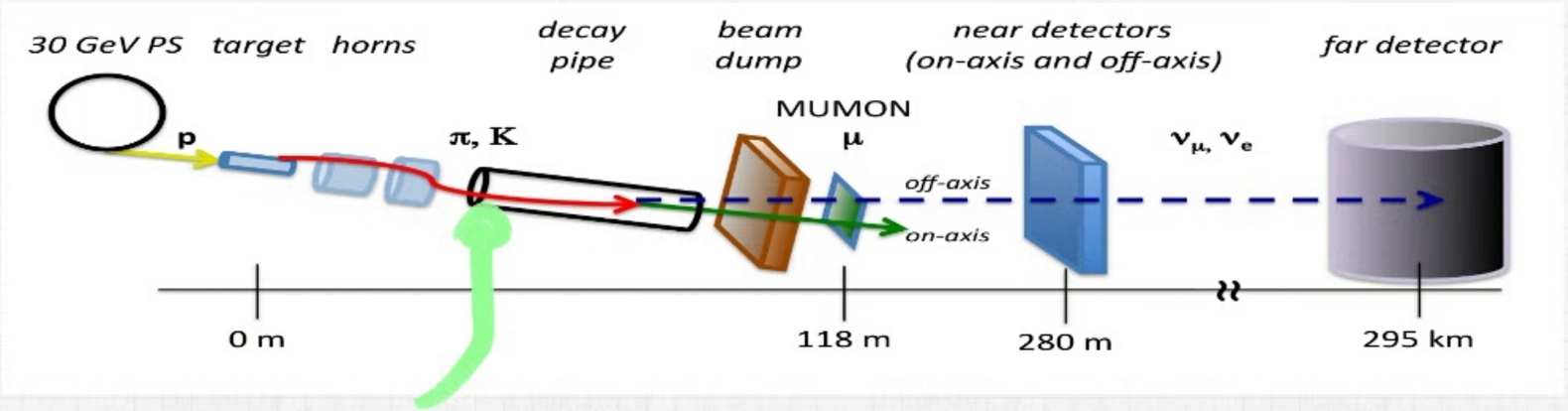


PRECISE DATA FOR T2K: SEVEN PARTICE SPECIES IN p+C AT 31 GeV/c



PRECISE DATA FOR T2K: π FLUX FROM T2K REPLICA TARGET





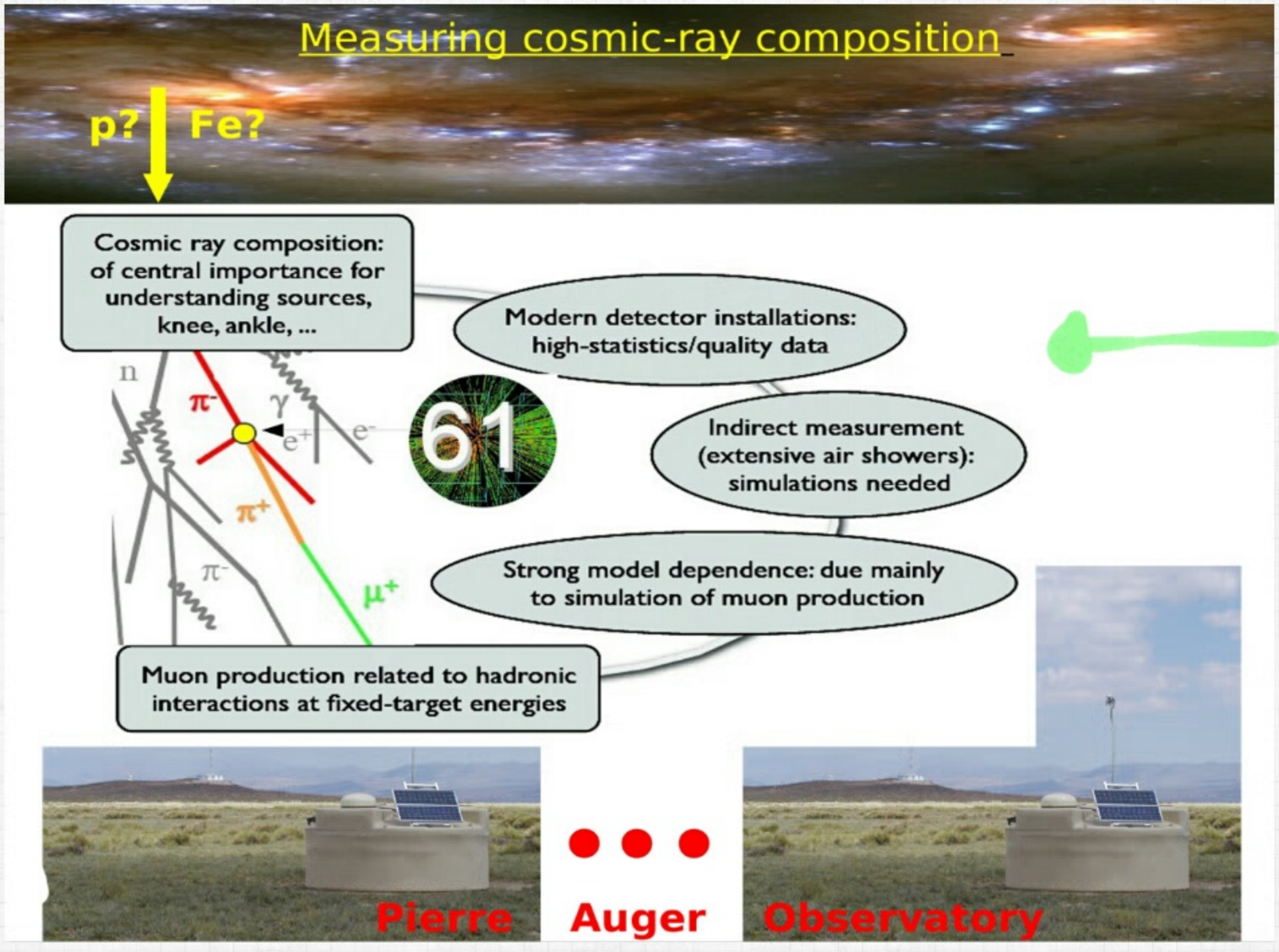
THE NA61 RESULTS ARE USED FOR DETERMINATION OF THE INITIAL NEUTRINO FLUX

MEASUREMENTS FOR THE FERMILAB NEUTRINO BEAMS ARE CONSIDERED

Nucl.Instrum.Meth. A701 (2013) 99

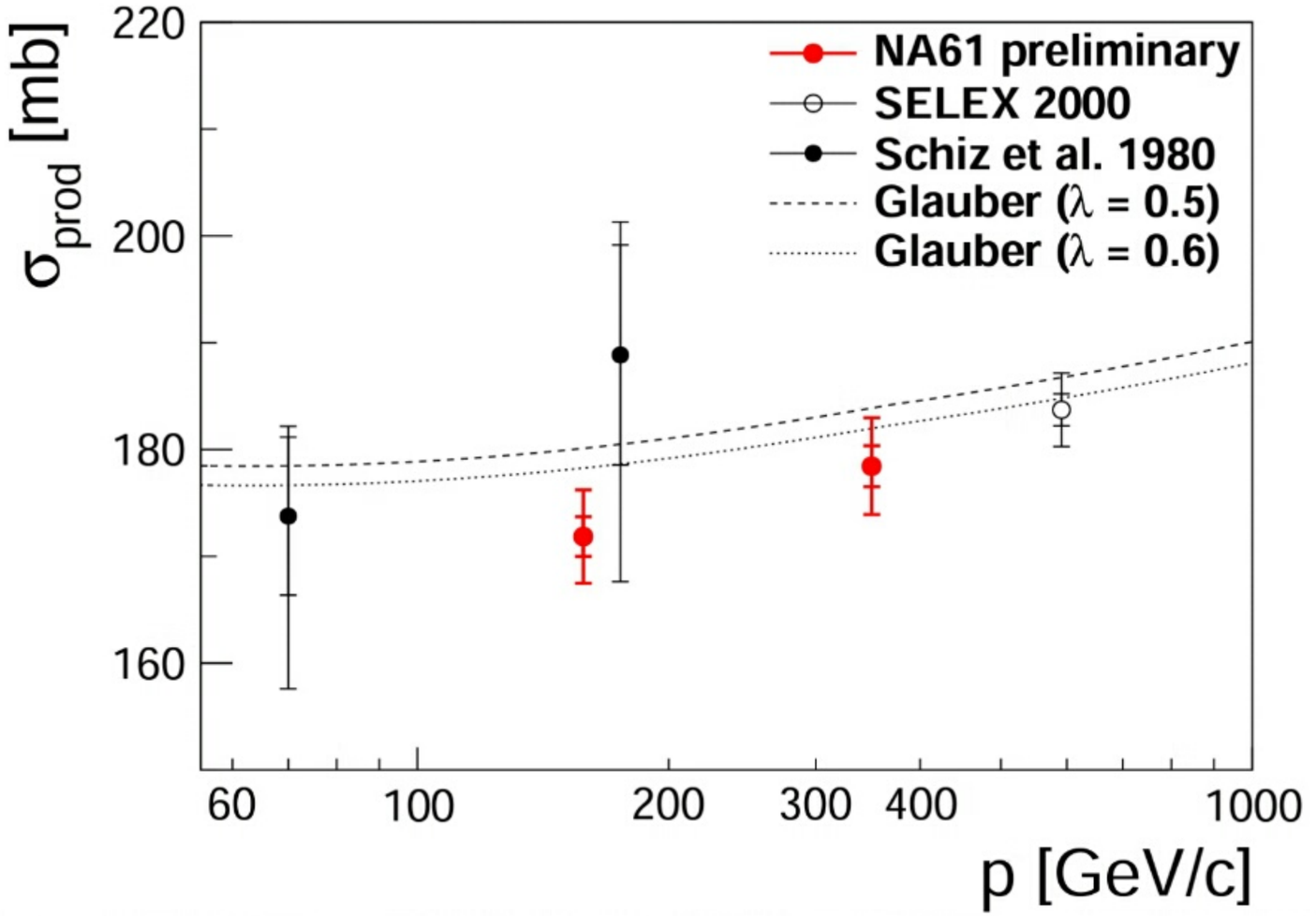
COSMIC RAYS

WHAT IS ORIGIN OF VERY HIGH ENERGY COSMIC RAYS



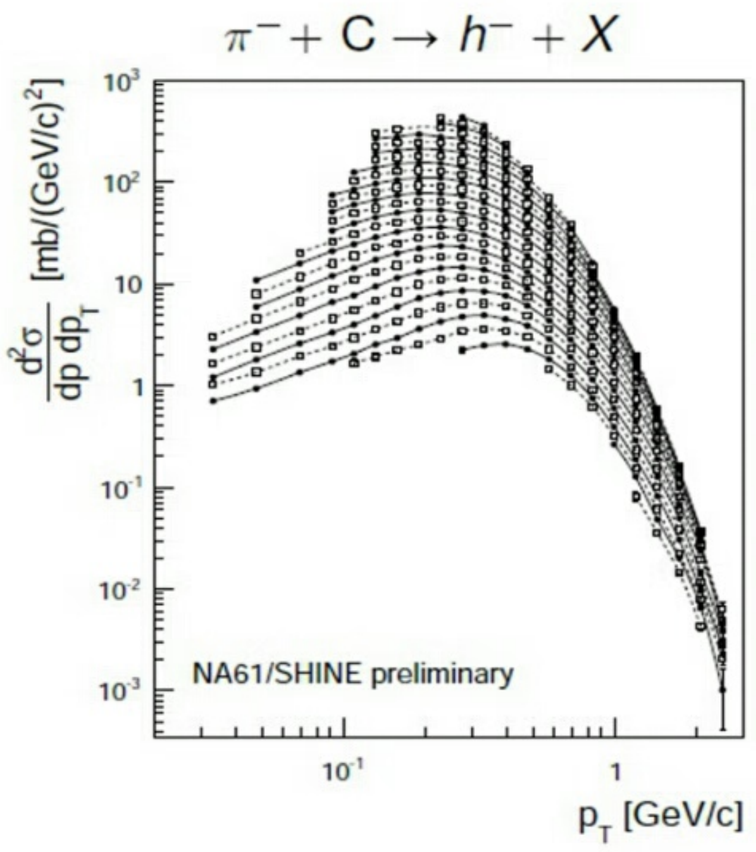
THE NA61 DATA ARE USED TO FIT MODELS RELEVANT FOR SIMULATIONS OF EXTENSIVE AIR SHOWERS

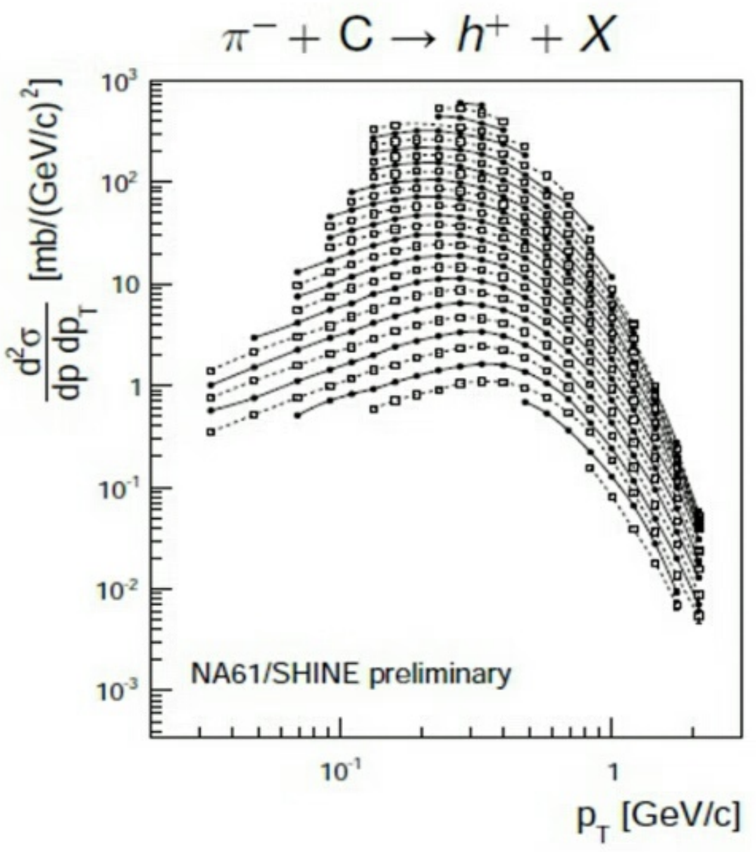
PRODUCTION CROSS SECTION FOR π^- + C INTERACTIONS



NA61 SIGNIFICANTLY IMPROVES PRECISION OF THE WORLD DATA

CHARGED HADRON SPECTRA IN π^-+C AT 350 GeV/c

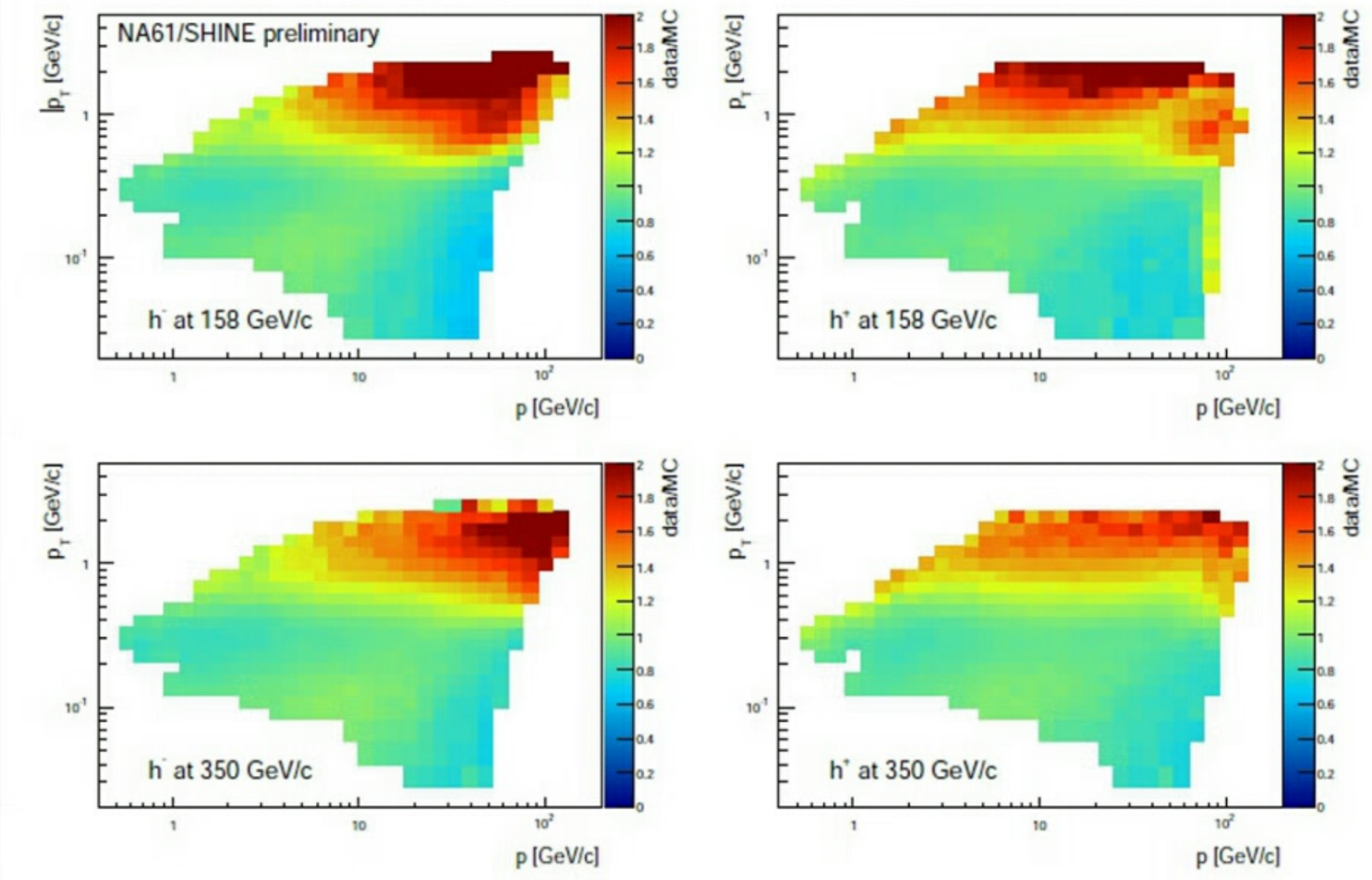




$p = 0.6 \ldots 121$ GeV/c in steps of $\lg p/(\mathrm{GeV}/c) = 0.08$

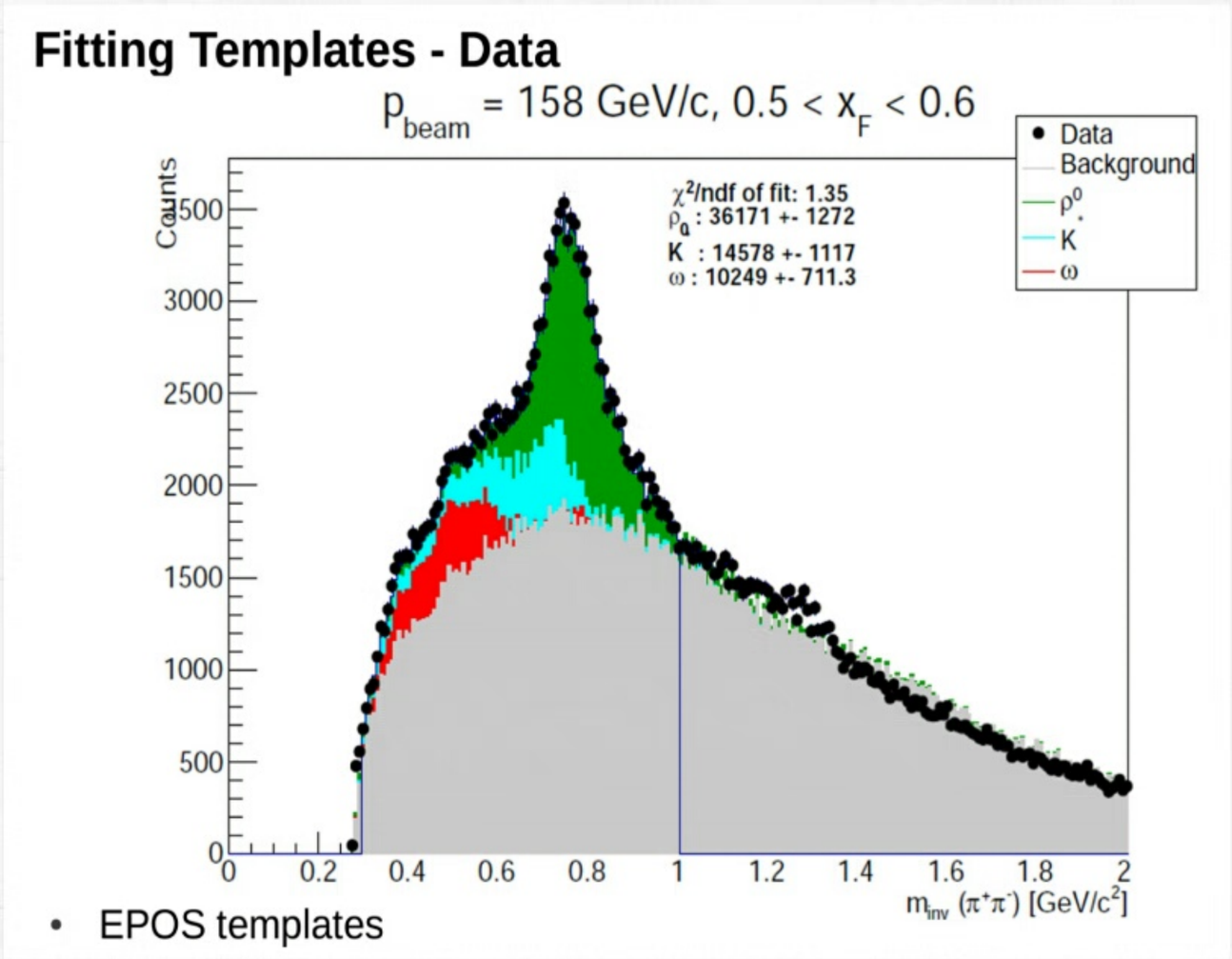
CHARGED HADRONS IN π^- + C at 158 AND 350 GeV/c

(NA61 DATA)/EPOS



NA61 DATA ARE USED FOR FITTING MODELS RELEVANT FOR SIMULATIONS OF EXTENSIVE AIR SHOWERS

$\pi^- + C$ at 158 AND 350 GeV/c: ANALYSIS OF RESONANCES



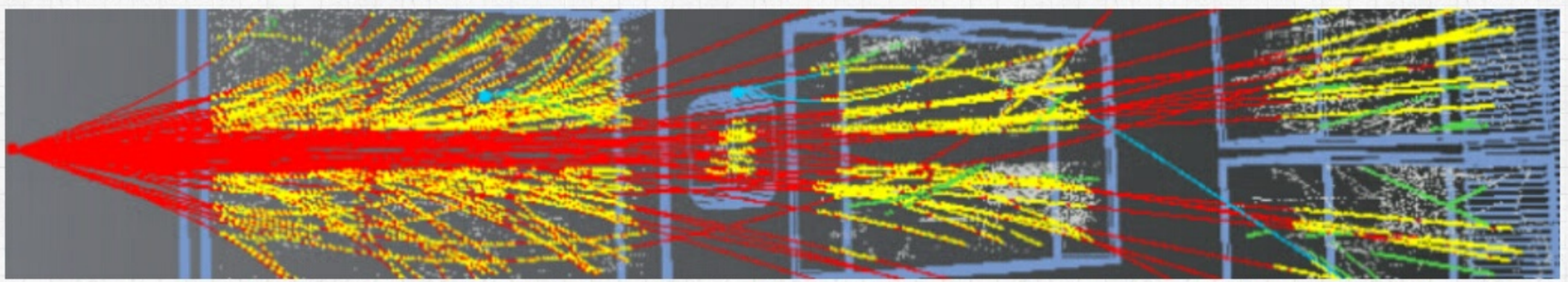
PRODUCTION OF LEADING ρ^0 MESONS IS IMPORTANT FOR EAS SIMULATIONS

SUMMARY OF RECENT NA61/SHINE RESULTS

STRONG INTERACTIONS:
- SPECTRA OF IDENTIFIED HADRONS IN p+p AND Be+Be
- FLUCTUATIONS AND CORRELATIONS IN p+p

NEUTRINOS:
- SPECTRA OF IDENTIFIED HADRONS IN p+C AT 31 GeV/c
- SPECTRA OF IDENTIFIED PIONS IN p+(T2K RT) at 31 GeV/c

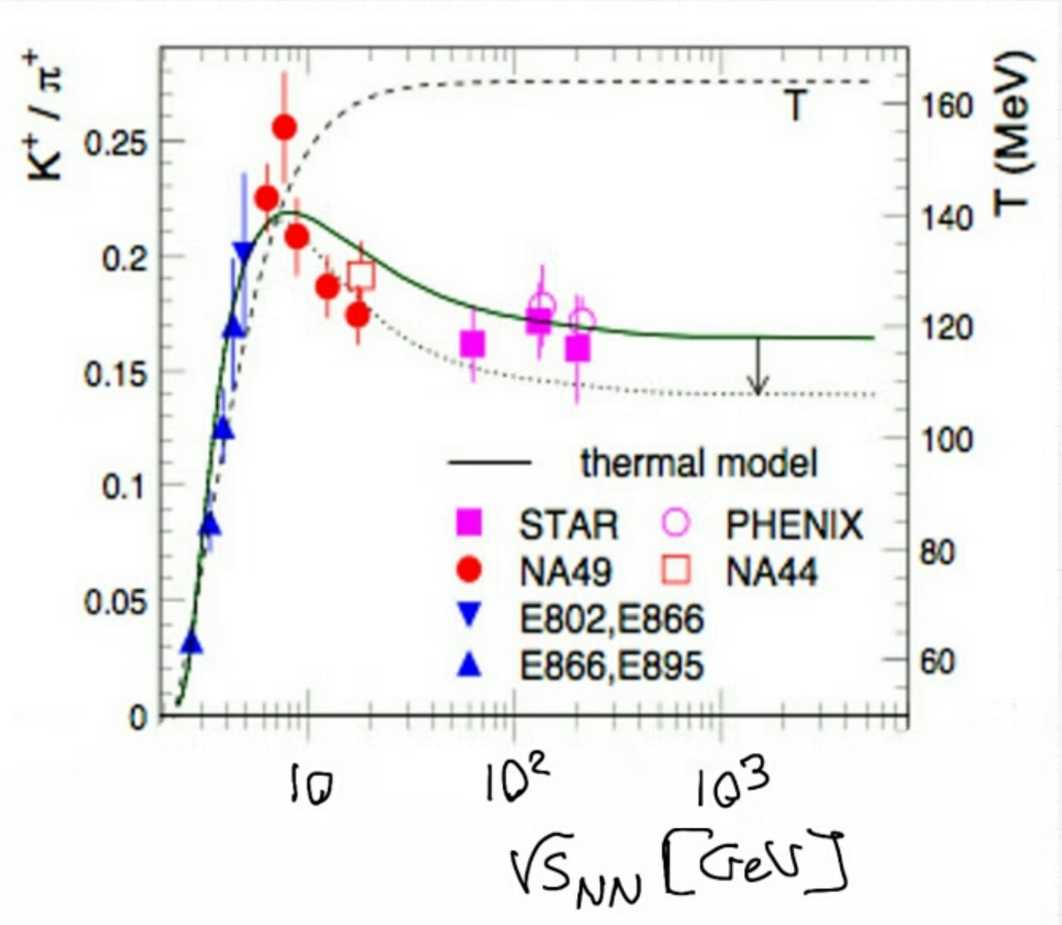
COSMIC RAYS:
- SPECTRA OF CHARGED HADRONS IN π^-+C at 158 AND 350 GeV/c



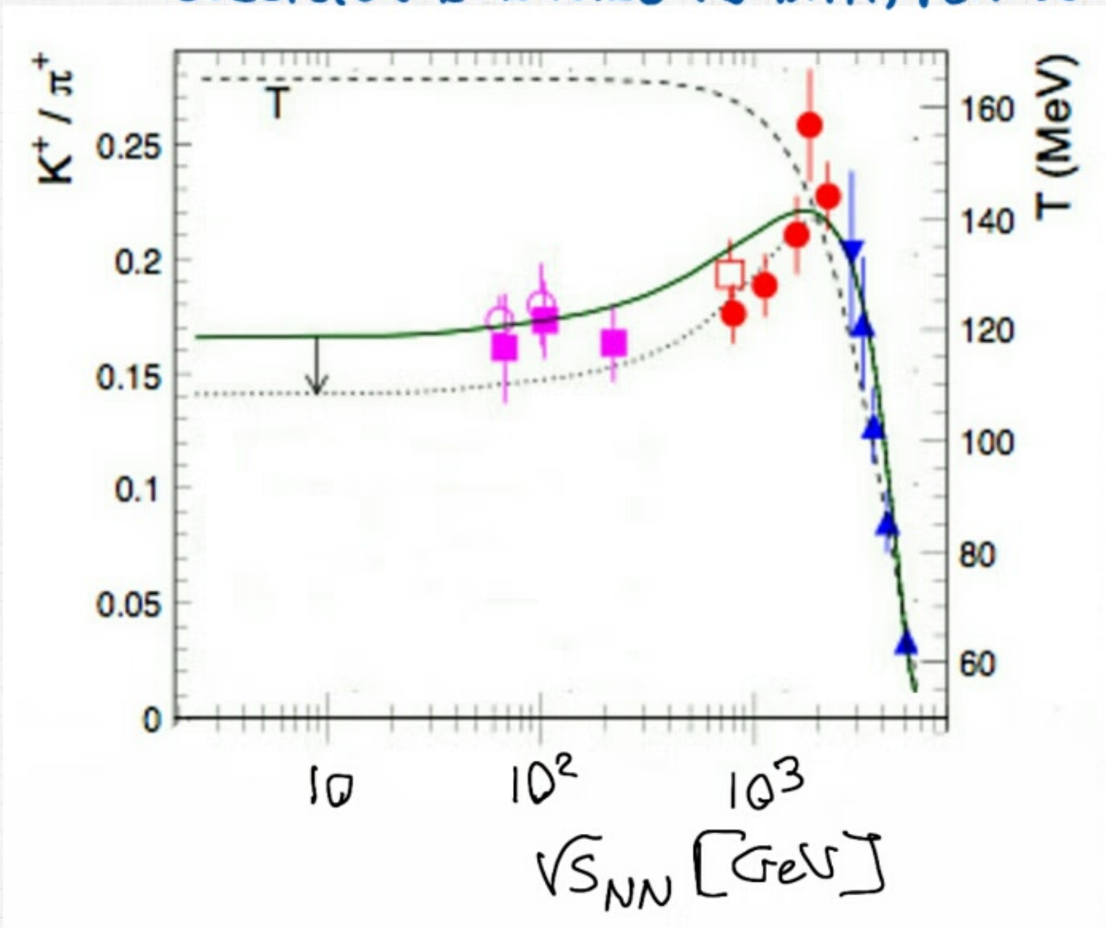
ADDITIONAL SLIDES

ONSET OF DECONFINEMENT: HADRON GAS MODEL: FIT VS EXPLANATION

STUDENT CORRECTLY ATTRIBUTED COLLISION ENERGIES TO DATA POINTS



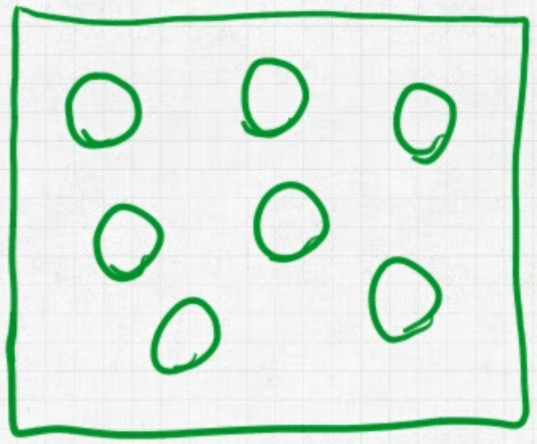
STUDENT INCORRECTLY ATTRIBUTED COLLISION ENERGIES TO DATA POINTS



IN BOTH CASES HADRON GAS MODEL EQUALLY WELL FITS THE DATA

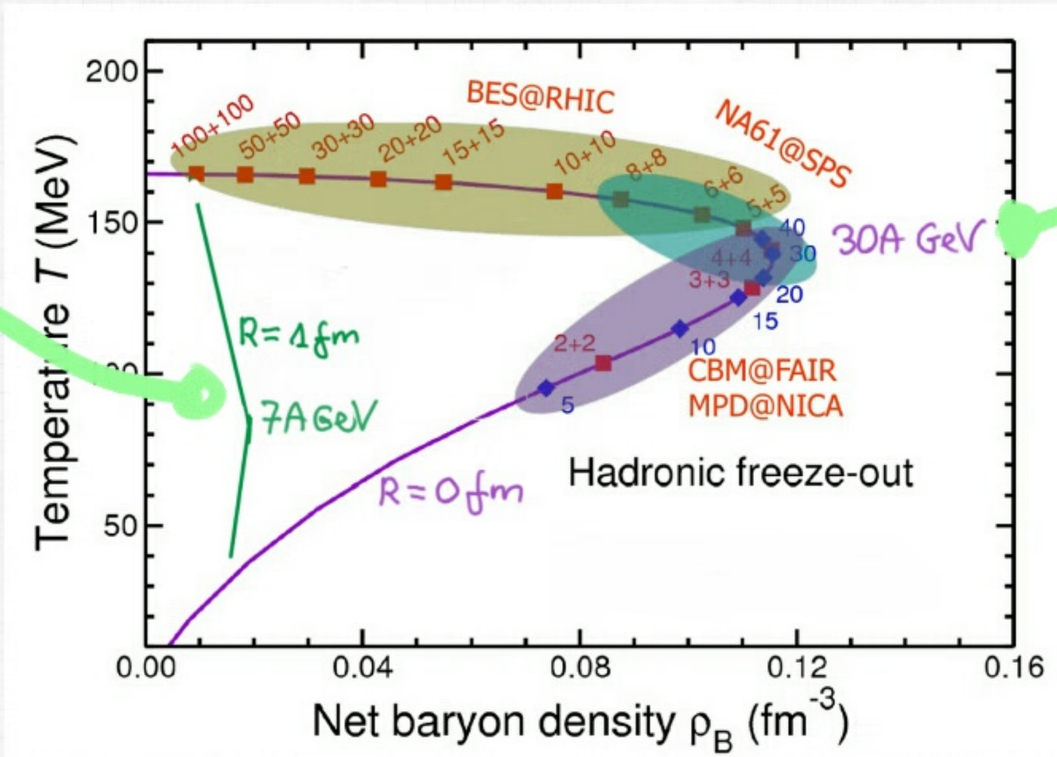
⇒ HADRON GAS MODEL (APPROXIMATELY) FITS MEASURED ENERGY DEPENDENCE, IT DOES NOT EXPLAIN IT !

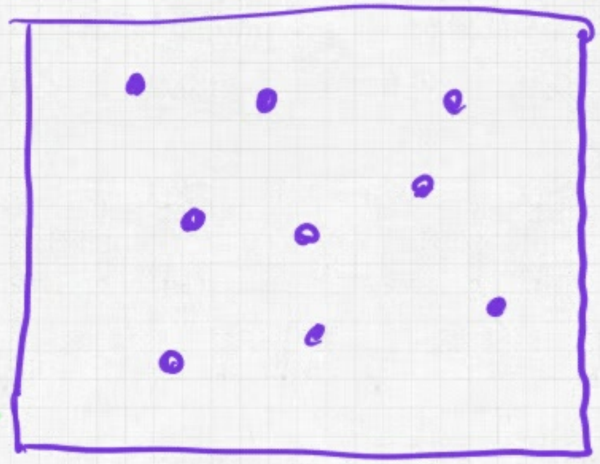
ONSET OF DECONFINEMENT: "MAXIMUM" BARYON DENSITY



REPULSIVE ON
(R=1 fm)

PRC 88, 024902

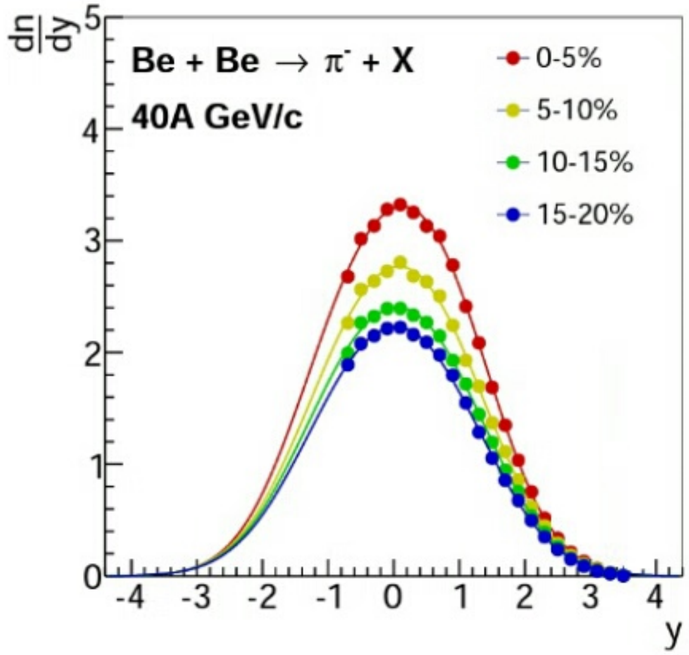


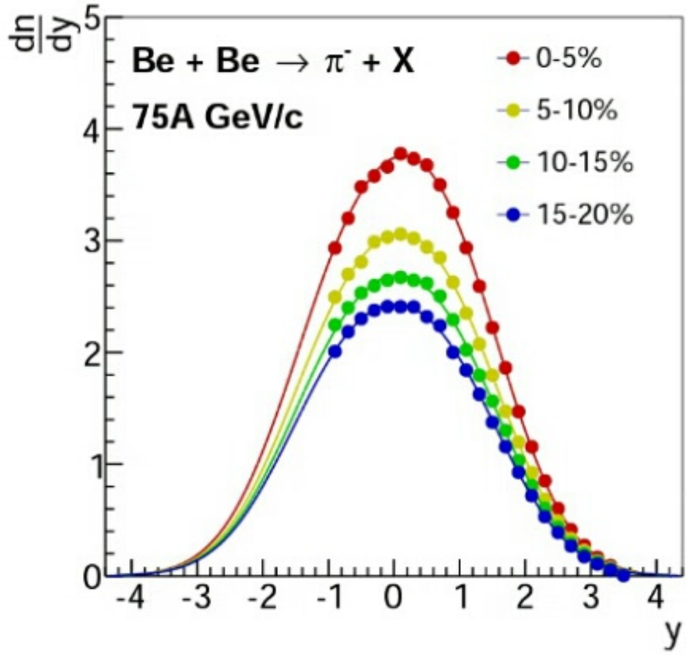


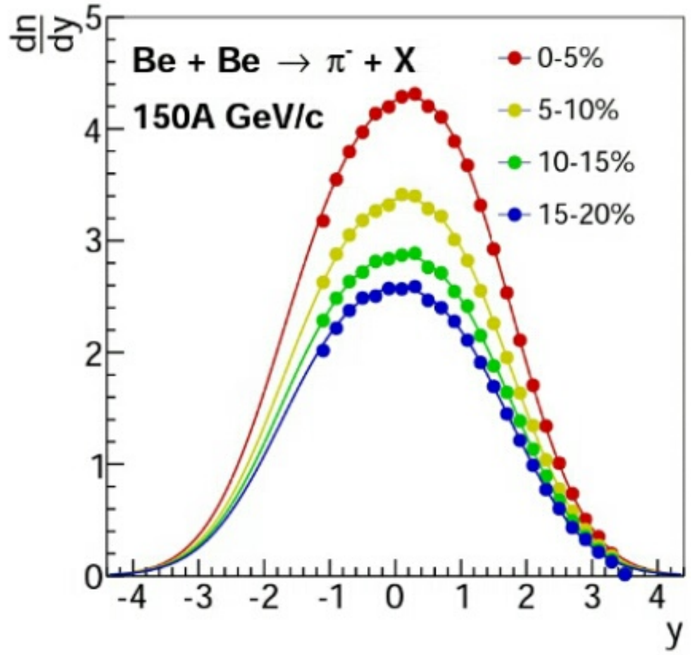
REPULSIVE OFF
(R=0 fm)
POINT-LIKE
HADRONS/NUCLEONS!

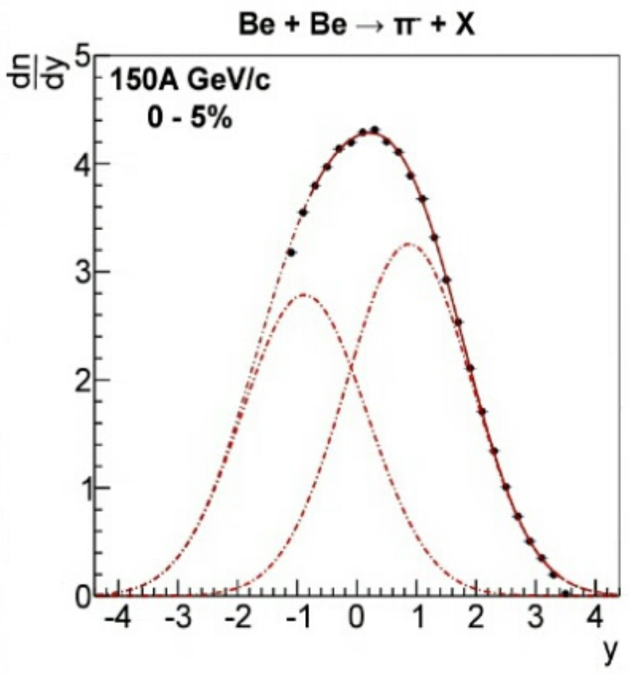
PRC C74 047901

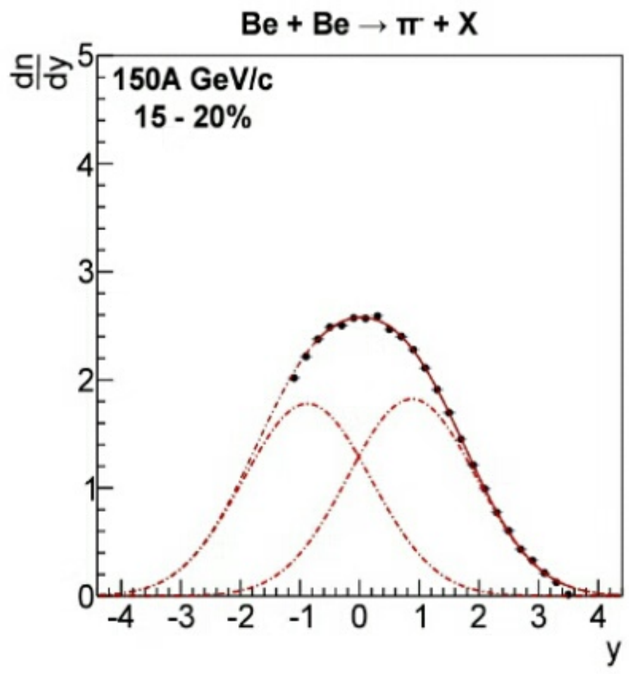
RESULTS DEPEND STRONGLY ON MODELLING OF REPULSIVE INTERACTIONS
MAXIMUM OF χ_B at 30A GeV FOR UNREALISTIC MODEL WITH
NO REPULSIVE INTERACTIONS

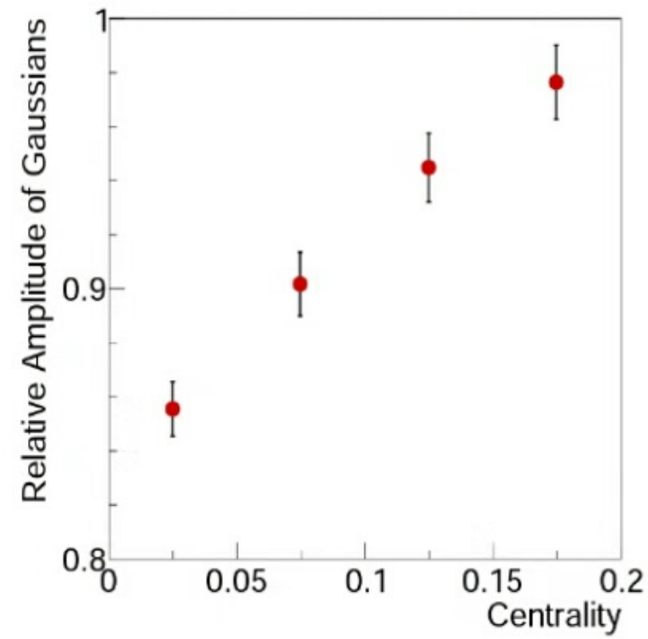

dn/dy
Be + Be → π⁻ + X
40A GeV/c
0-5%
5-10%
10-15%
15-20%
y


dn/dy
Be + Be → π⁻ + X
75A GeV/c
0-5%
5-10%
10-15%
15-20%
y


dn/dy
Be + Be → π⁻ + X
150A GeV/c
0-5%
5-10%
10-15%
15-20%
y


Be + Be → π⁻ + X
dn/dy
150A GeV/c
0 - 5%
5
4
3
2
1
0
-4 -3 -2 -1 0 1 2 3 4
y


Be + Be → π⁻ + X
dn/dy
150A GeV/c
15 - 20%
5
4
3
2
1
0
-4 -3 -2 -1 0 1 2 3 4
y


Relative Amplitude of Gaussians
1
0.9
0.8
0
0.05
0.1
0.15
0.2
Centrality