

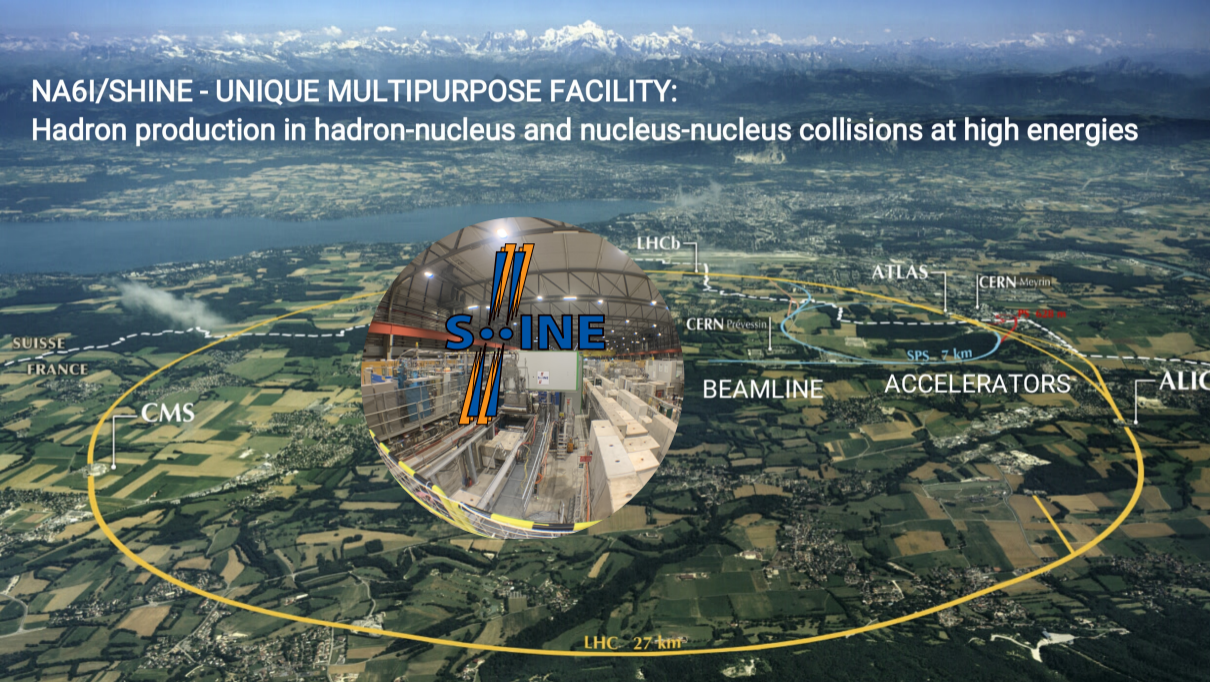
Results on system size dependence of strangeness production in the CERN SPS energy range from NA61/SHINE

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Strangeness in Quark Matter Conference
13-17.06.2022

NA6I/SHINE - UNIQUE MULTIPURPOSE FACILITY: Hadron production in hadron-nucleus and nucleus-nucleus collisions at high energies



SUISSE
FRANCE

CMS

SHINE

LHCb

CERN Prévessin

ATLAS

CERN Meyrin

SPS 7 km

BEAMLINE

ACCELERATORS

ALICE

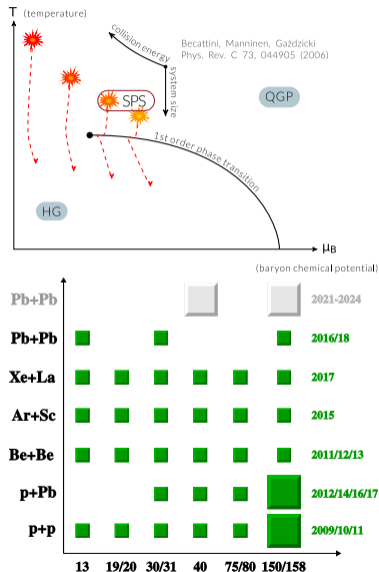
LHC 27 km

Strong interaction physics:

- study properties of the **onsets of deconfinement and fireball**
- search for the **critical point** of strongly interacting matter
- direct measurements of **open charm**

Neutrino and cosmic ray physics:

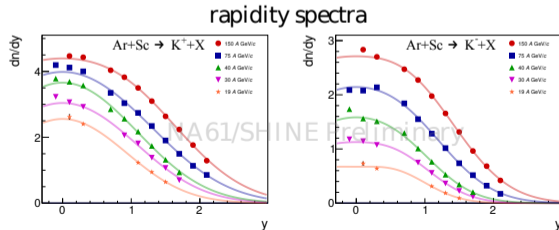
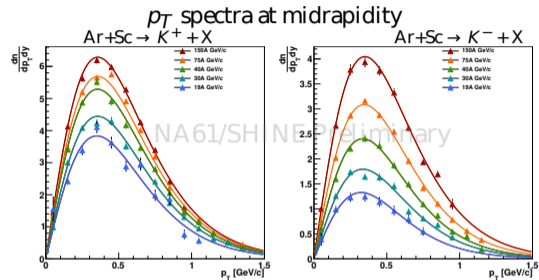
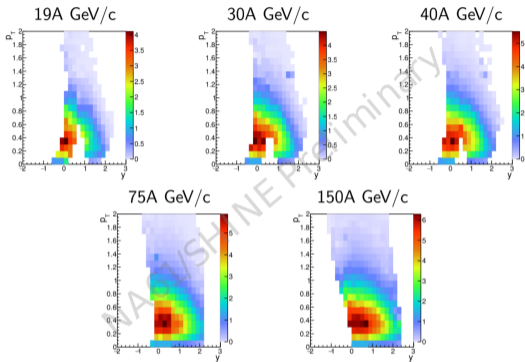
- measurements for neutrino programs at J-PARC and Fermilab
- measurements of nuclear fragmentation cross section for cosmic ray physics



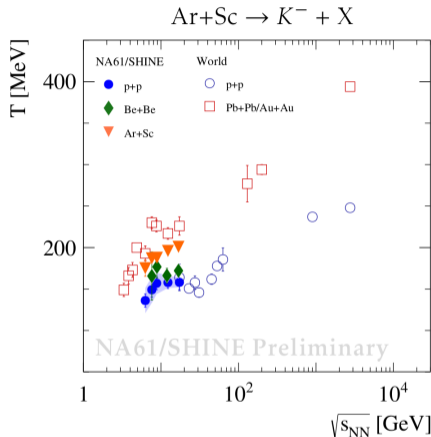
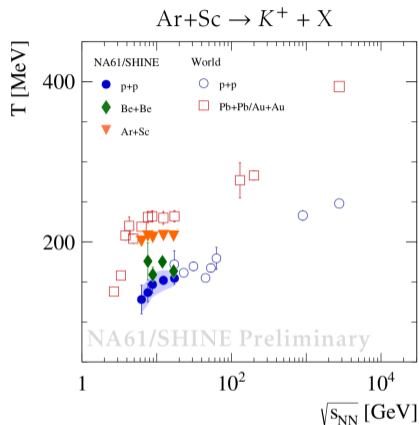


Study of the onset of
deconfinement

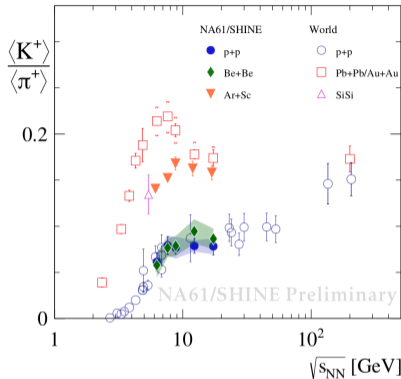
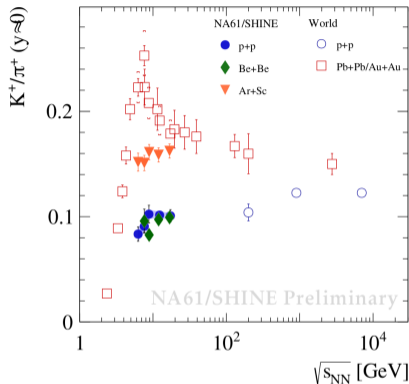
K^\pm spectra in Ar+Sc collisions



- 10% most central $^{40}\text{Ar}+^{45}\text{Sc}$ collisions
- p_T spectra fitted with exponential dependence
- rapidity spectra fitted with sum of two Gaussians to obtain mean multiplicities $\langle K^+ \rangle$, $\langle K^- \rangle$

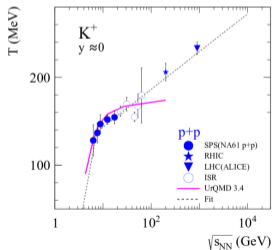
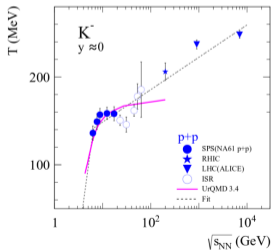
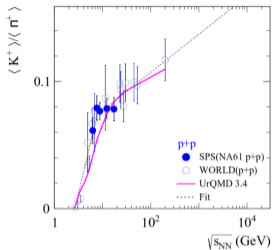
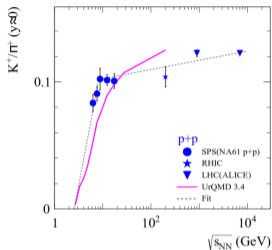


- Plateau in the inverse slope parameter T of m_T spectra of K^\pm spectra in Pb+Pb was predicted within SMES due to mixed phase of hadron gas and QGP *Acta Phys. Polon. B30, 2705 (1999)*
- Similar structures are visible in recently measured reactions *Eur.Phys.J.C 81 (2021) 1, 73 (Be+Be)*
- Magnitude of the T parameter increases with the colliding system size *Eur.Phys.J.C 77 (2017) 10, 671 (p+p)*



- Rapid change in the energy dependence of K^+/π^+ ratio in Pb+Pb collisions indicated the onset of deconfinement in the SPS energy range, as predicted within SMES
- Plateau like structure visible in light systems ($p+p$ and Be+Be)
- Ar+Sc systematically higher, shows dependence on collision energy qualitatively similar to $p+p$ and Be+Be (no horn structure)

Onset of deconfinement: $p+p$ data

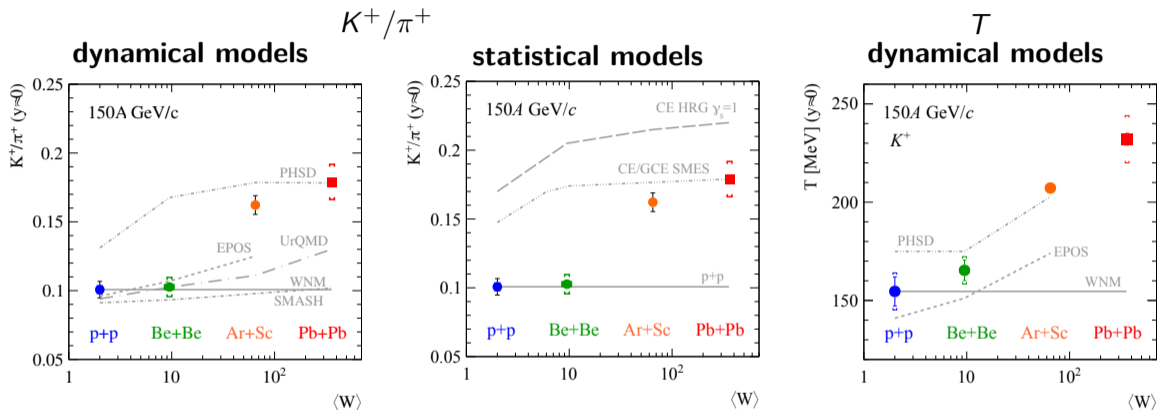


- Rates of increase of K^+/π^+ and T change sharply in $p+p$ collisions at SPS energies
- The fitted change energy is ≈ 7 GeV - close to the energy of the onset of deconfinement ≈ 8 GeV
- Models assuming change from resonances to string production mechanism show similar trend

Phys.Rev.C 102 (2020) 1, 011901



Study of the onset of fireball



- None of the models reproduce K^+/π^+ ratio or T in the whole $\langle W \rangle$ range

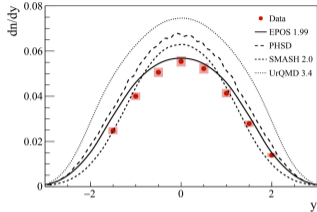
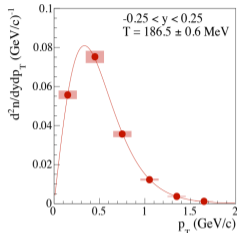
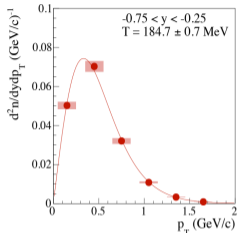
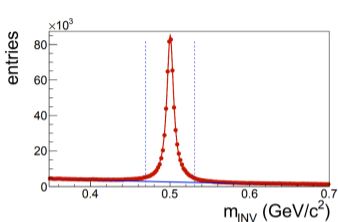
PHSD: Eur.Phys.J.A 56 (2020) 9, 223, arXiv:1908.00451 and private communication;
 SMASH: J.Phys.G 47 (2020) 6, 065101 and private communication;
 UrQMD and HRG: Phys. Rev. C99 (2019) 3, 034909;
 SMES: Acta Phys. Polon. B46 (2015) 10, 1991 - recalculated

p+p: Eur. Phys. J. C77 (2017) 10, 671
 Be+Be: Eur. Phys. J. C81 (2021) 1, 73
 Ar+Sc: NA61/SHINE preliminary
 Pb+Pb: Phys. Rev. C66, 054902 (2002)

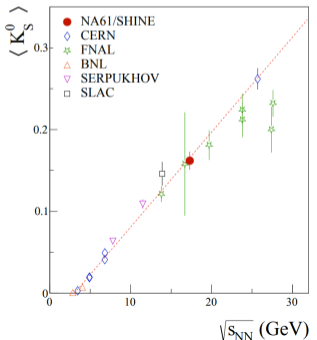


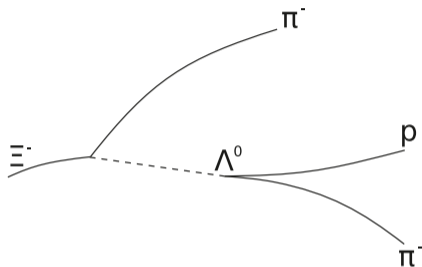
(Multi-)strange hadron
production in $p+p$ interactions
at $\sqrt{s} = 17.3$ GeV

K_S^0 meson production in $p+p$ interactions at 158 GeV/c

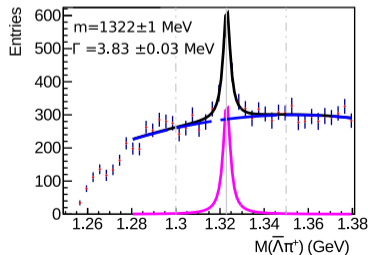
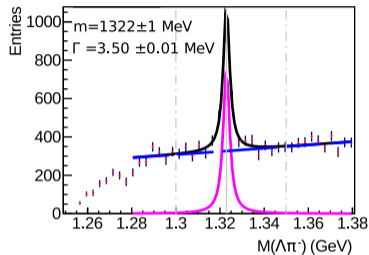


- Results on K_S^0 production were recently published in Eur.Phys.J.C 82 (2022), 96
- Mean multiplicity: $\langle K_S^0 \rangle = 0.162 \pm 0.001 \pm 0.011$
- Model predictions deviate by up to 20% from the measurements

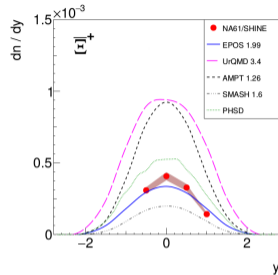
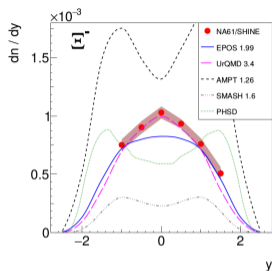
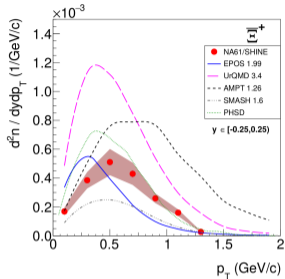
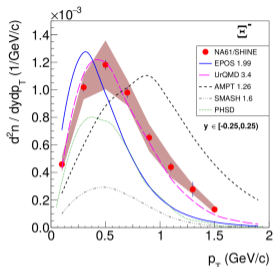




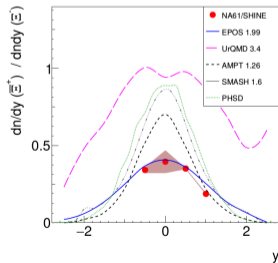
- Reconstruction based on decay topology
- Ξ^\pm decays into π^\pm and $\Lambda(\bar{\Lambda})$ with $BR \approx 99.9\%$
- A set of quality cuts is imposed onto Ξ candidates to improve SNR
- Breit–Wigner function is used to describe signal



Ξ^- and Ξ^+ production in $p+p$ interactions at 158 GeV/c



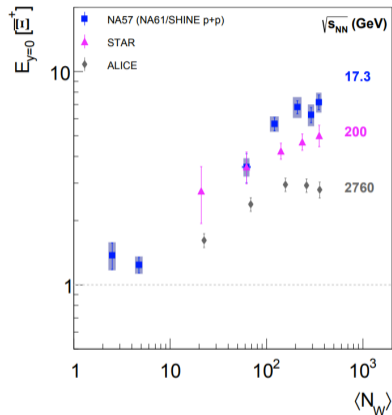
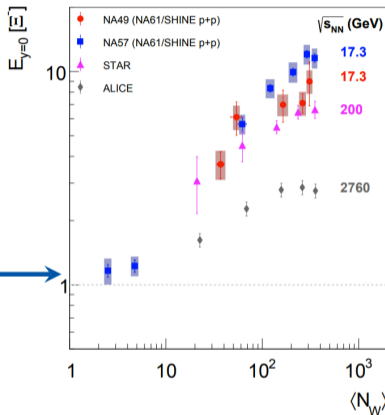
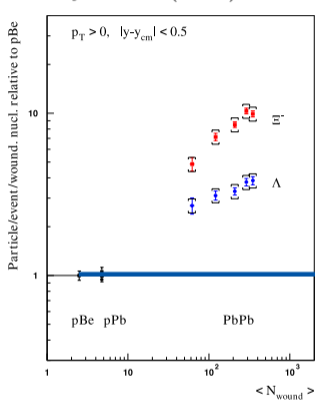
- The only existing results on Ξ^- and Ξ^+ production in SPS energy range in $p+p$ interactions
- Strong suppression of Ξ^+ : $\langle \Xi^+ \rangle / \langle \Xi^- \rangle = 0.24 \pm 0.01 \pm 0.05$
- Transport models fail to describe the results on Ξ production in $p+p$ collisions



Eur.Phys.J.C 80 (2020) 9, 833, Erratum: Eur.Phys.J.C 82 (2022) 2, 174

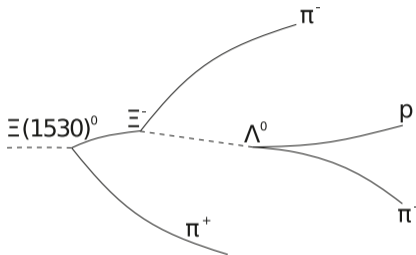
J. Phys. G 32 (2006) 427–442

Eur.Phys.J.C 80 (2020) 9, 833, Erratum: Eur.Phys.J.C 82 (2022) 2, 174

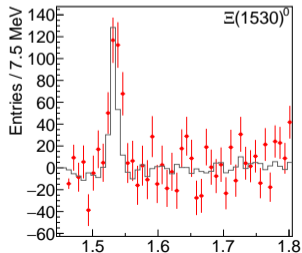
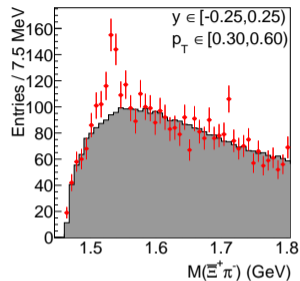


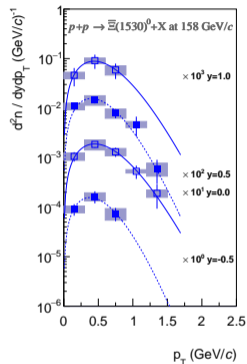
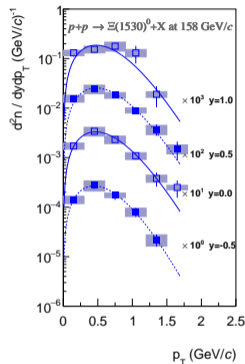
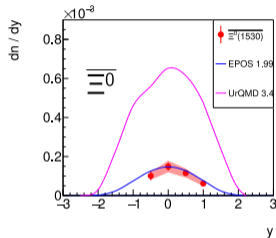
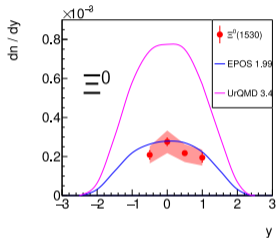
$$E_{\Xi_s} = \frac{2}{\langle W \rangle} \frac{dn/dy(A+A)}{dn/dy(p+p)}$$

NA61/SHINE results give new base-line for strangeness enhancement study in SPS energy range

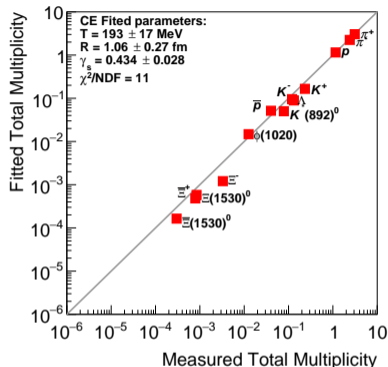
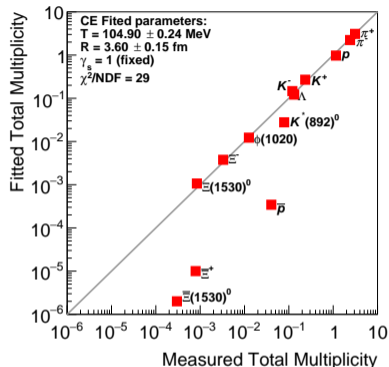


- Reconstruction based on decay topology
- $\Xi^0(1530)$ decays into Ξ and π exclusively
- A set of quality cuts is imposed onto Ξ candidates to improve SNR
- Breit–Wigner function is used to describe signal





- The first results on $\Xi^0(1530)$ production in $p+p$ in SPS energy range
- The second result results on $\Xi^0(1530)$ production in $p+p$ (other measurement was provided by ALICE at 7 TeV Eur.Phys.J.C 75 (2015) 1)
- Suppression of $\Xi^0(1530)$: $\langle \Xi^0(1530) \rangle / \langle \Xi^0(1530) \rangle \approx 0.40 \pm 0.03 \pm 0.05$



Fit done with different variants of HRG (THERMAL_FIST1.3):

- Canonical Ensemble with fixed $\gamma_s = 1$
- Canonical Ensemble with fitted γ_s

- Statistical model fails when strangeness saturation parameter γ_s is fixed
- The fit with free γ_s finds $\gamma_s = 0.434 \pm 0.028$
- Disagreement between model predictions and data is slightly reduced by allowing for out-of-equilibrium strangeness production

- Many new measurements for the study of the onset of deconfinement
- No horn structure observed in Ar+Sc data
- Unexpected system-size dependence: $(p+p \approx \text{Be+Be}) \neq (\text{Ar+Sc} \leq \text{Pb+Pb})$
- Unique results on multi-strange baryons production in $p+p$ interactions in SPS energy range
- Present transport models do not describe well the NA61/SHINE results on strange particles production (K^\pm , K^0 , Ξ and $\Xi(1530)$)



Thank you



Backup

- In order to obtain the dn/dy yields, the data is extrapolated beyond the detector acceptance
- Exponential dependence in p_T is assumed:

$$f(p_T) = S \cdot p_T \cdot \exp\left(-\frac{\sqrt{p_T^2 + m_K^2} - m_K}{T}\right)$$

- To obtain mean multiplicity of produced particles rapidity distribution is fitted with following function:

$$f_{fit}(y) = \frac{A}{\sigma_0 \sqrt{2\pi}} \exp\left(-\frac{(y - y_0)^2}{2\sigma_0^2}\right) + \frac{A}{\sigma_0 \sqrt{2\pi}} \exp\left(-\frac{(y + y_0)^2}{2\sigma_0^2}\right)$$

- A , y_0 and σ_0 parameters are fitted