Catalytic phi meson production …

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OZI suppression rule for quarkonia ($Q\bar{Q}$, Q=s,c,b) production

Catalytic reactions

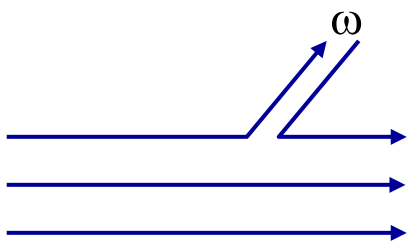
Comparison of phi sources
in a simpe model for strangeness production

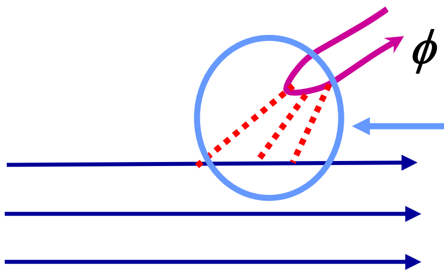
Influence of catlytic reactions
on centrality dependence and rapidity distribution

Okubo-Zweig-Iizuka suppression rule

the interactions of a pure (ss) vector state with non-strange hadrons are suppressed

- $N \to N\omega$
- $N \to N\phi$ **suppressed**





1/N$_c$ counting

need 3 gluons to form a white hadron state

Experiment: $\frac{\sigma(\pi N \to \omega N)}{\sigma(\pi N \to \phi N)} \sim 75$

3 times smaller than expected from pure octet-singlet mixing:
$\phi\rho\pi$ coupling due to the anomaly

*for **charm** the OZI suppression factor is ~10^6*

1985 Asher Shor [PRL 54, 1122] proposed enhancement of phi meson yield as a signal of a „colour liberation“

AGS [E917, PRC 69, 054901 (2004)]
SPS [NA49, PRC 78, 044907 (2008)]

found enhancement factor 3-4

This factor can be explained by *strangenss coalecence* [Ko, Sa,PLB 258]

$$K\bar{K} \longrightarrow \phi\rho \qquad K\Lambda \longrightarrow \phi N$$

+ phi mass drop

Surprises at low energy

FOPI: Ni +Ni @ 1.97 GeV/A [NPA 714 (2003) 89]

Large yield of phi meson wich cannot be explained in theoretically

[Kämpfer, Kotte, Hartnack, Aichelin, J. Phys. G 28 (2002) 2035]

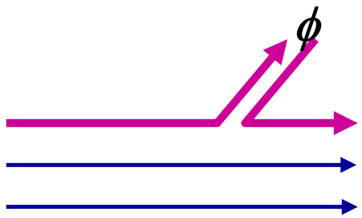
HADES: Ar+KCl @ 1.76 GeV/A [Arxive: 0902.3487] phi meson enhancement

18±7 % K^- mesons stem from phi decays! **strangeness ballance??**

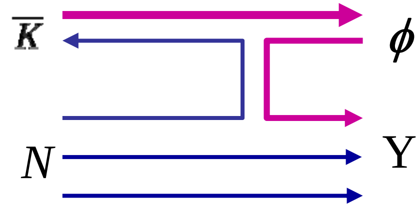
Phi production in reactions involving strange particles is not OZI suppressed!

- **strangeness "annihilation"** $\bar{K}Y \to \phi N$ strangeness hides into ϕ

- $Y \to \phi Y$



- $\bar{K}N \to \phi Y$



a new type of the ϕ production mechanism

catalytic phi meson production

$$\pi Y \to \phi Y' \qquad \bar{K}N \to \phi Y$$

strangeness content does not change

Can these reaction be more efficient then $\pi\, N \to \phi\, N$ and $N\, N \to N\, N\, \phi$?

$$V \frac{dN_\phi}{dt} = R_{\pi N} + R_{\pi\Lambda} + R_{\overline{K}N} + \ldots$$

$R_{\pi N} = \langle v\,\sigma(\pi\, N \to \phi N)\rangle\, N_\pi\, N_N$ — traditional

catalytic — $R_{\pi\Lambda} = \langle v\,\sigma(\pi\,\Lambda \to \phi Y)\rangle\, N_\pi\, N_\Lambda$

$R_{\overline{K}N} = \langle v\,\sigma(\overline{K}\, N \to \phi Y)\rangle\, N_{\overline{K}}\, N_N$

dominant source of phi considered so far

$$R_{\pi\Lambda} > R_{\pi N} \;\Rightarrow\; \sigma(\pi\Lambda \to \phi Y) \gtrsim \frac{N_{\rm part}}{\langle\Lambda\rangle}\, \sigma(\pi N \to \phi N)$$

$$R_{\overline{K}N} > R_{\pi N} \;\Rightarrow\; \sigma(\bar{K} N \to \phi Y) \gtrsim \frac{\langle\pi^+ + \pi^-\rangle}{2\,\langle K^-\rangle}\, \sigma(\pi N \to \phi N)$$

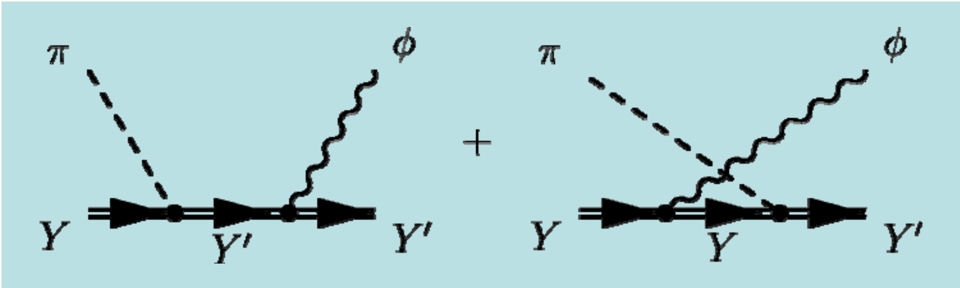
$E_{\rm lab}$	2 GeV/A	4 GeV/A	6 GeV/A	8 GeV/A	10 GeV/A
$\frac{\langle K^+\rangle}{N_{\rm part}}$	1.1×10^{-3}	7.0×10^{-3}	14×10^{-3}	23×10^{-3}	32×10^{-3}
$\frac{\langle\Lambda\rangle}{N_{\rm part}}$	1.3×10^{-3}	8.4×10^{-3}	15×10^{-3}	20×10^{-3}	30×10^{-3}
$\frac{2\,\langle K^-\rangle}{\langle\pi^+ + \pi^-\rangle}$	—	5.8×10^{-3}	14×10^{-3}	22×10^{-3}	34×10^{-3}
$\sigma(\pi\Lambda \to \phi Y) \gtrsim$	23 mb	3.5 mb	2 mb	1.5 mb	1 mb
$\sigma(\bar{K} N \to \phi Y) \gtrsim$	—	5.2 mb	2 mb	1.3 mb	0.9 mb

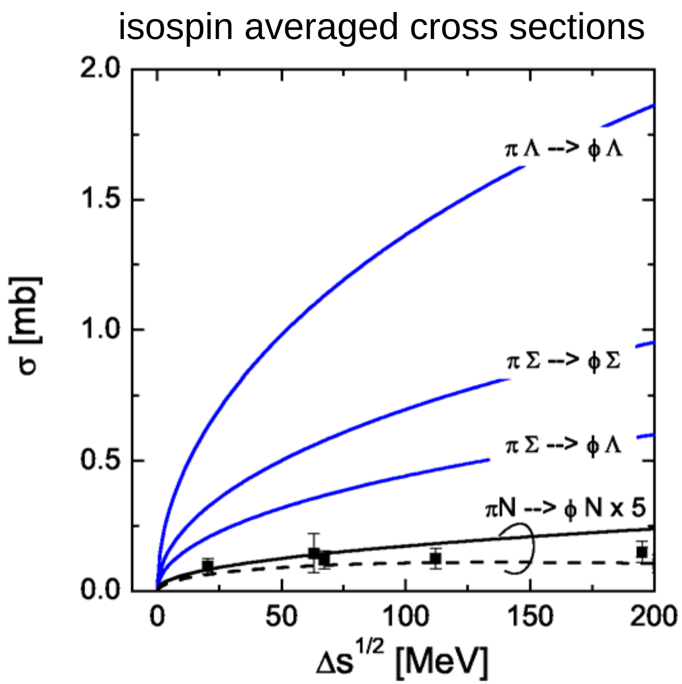
[Andronic, PBM, Stachel, NPA 772, 167]

typical hadronic cross sections

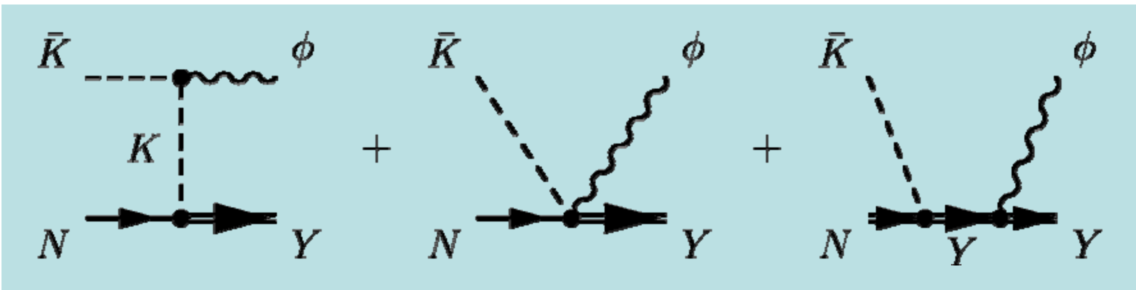
Cross section of catalytic reactions

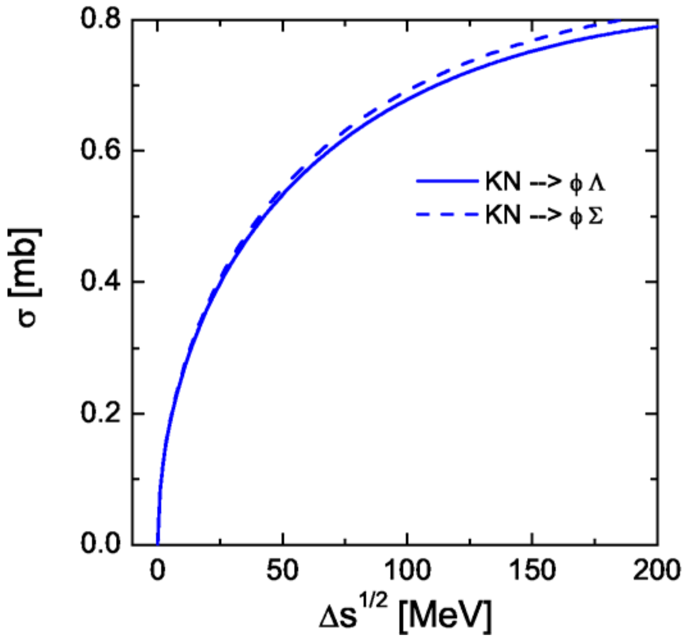
- $\pi Y \to \phi Y'$





- $\overline{K}N \to \phi Y$





Cross sections ~ 1 mb

much larger than π N->φ N

Simple model for strangeness production

$$T(t) = \frac{T_m}{(t^2/t_0^2+1)^{\alpha}} \qquad \rho_B(t) = \frac{\rho_m}{(t^2/t_0^2+1)^{3\alpha/2}}$$

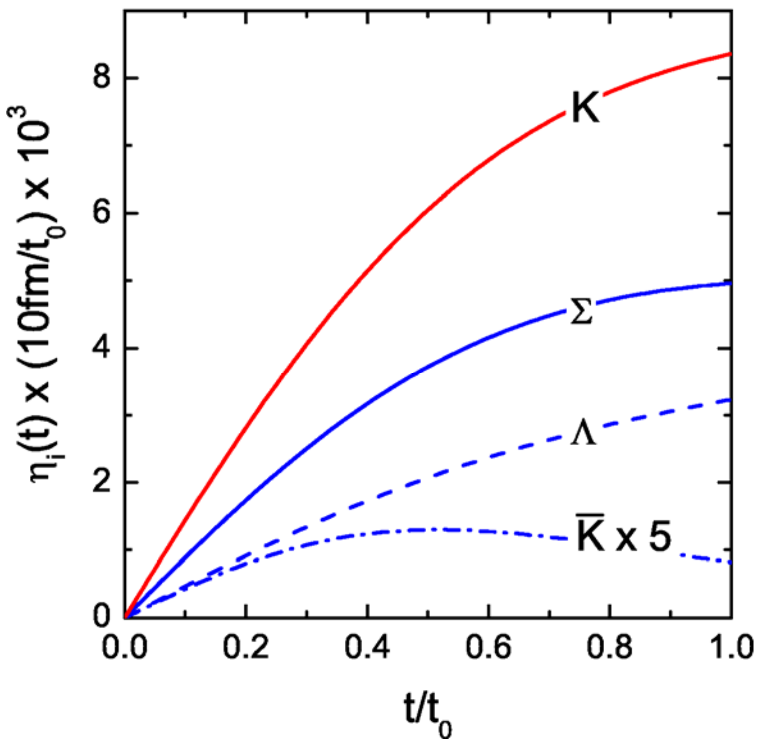
$\rho_\pi(t)\,,\ \rho_N(t)\,,\ \rho_\Delta(t)$ follow

Diff.eq. for K^+ production

annihilation neglected, $\rho_K \ll \rho_B$

$$\frac{d\rho_K}{dt} - \rho_K(t)\,\frac{\dot\rho_B(t)}{\rho_B(t)} = \mathcal{R}(t,\rho_B(t))\,, \qquad \rho_K(0)=0\,.$$

$$\rho_K(t) = \rho_B(t)\,t_0 \int_0^{t/t_0} dx\,\frac{\mathcal{R}(T(t_0\,x),\rho_B(t_0\,x))}{\rho_B(t_0\,x)} = \rho_B(t)\,t_0\,F(t/t_0)$$



$\rho_{\overline{K}}(t)\,,\ \rho_\Lambda(t)\,,\ \rho_\Sigma(t)$ follow

$$\rho_i(t) = \rho_K(t)\,\frac{n_i(t)}{n_{\overline{K}}(t)+n_\Lambda(t)+n_\Sigma(t)}$$

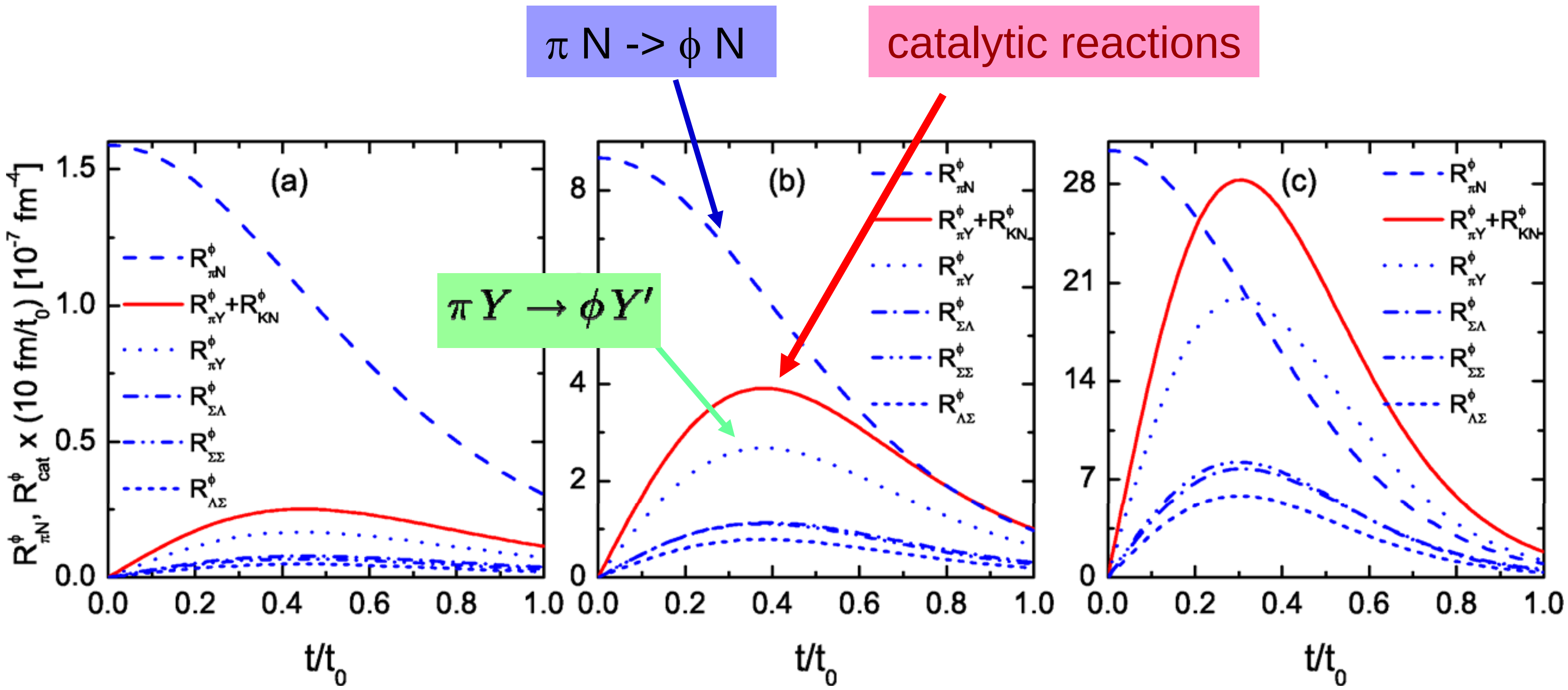
thermal weights

$$\eta_i(t) = \frac{\rho_i(t)}{\rho_B(t)}$$

scales with t_0 !

Phi production

$$\frac{\mathrm{d}\rho_\phi}{\mathrm{d}t} - \rho_\phi(t)\,\frac{\dot\rho_B(t)}{\rho_B(t)} = R^{\phi}_{\pi N}(t) + \sum_{\bar Y, Y=\Lambda,\Sigma} R^{\phi}_{Y\bar Y}(t) + R^{\phi}_{\bar K N}(t) + \ldots$$



$T_m = 110$ MeV, $\rho_m = 4\,\rho_0$ $T_m = 130$ MeV, $\rho_m = 5\,\rho_0$ $T_m = 150$ MeV, $\rho_m = 6\,\rho_0$

$\alpha = 0.2$ $\alpha = 0.3$ $\alpha = 0.5$

Red lines scale with t_0 !!!

Catalytic reactions can be competitive if T>110 MeV and t_0>10 fm

Centrality dependence

Consider a collision at some fixed energy

the mean number of projectile participants N_{pp} fireball volume $V \propto N_{pp}$

units of length and time $l \sim V^{1/3} \propto N_{pp}^{1/3}$ $t_0 \sim l/c \propto N_{pp}^{1/3}$ [Russkikh, Ivanov, NPA 543 (1992)]

# of non-strange particles

$$N_\pi \propto V \propto N_{pp}$$
$$N_\Delta \sim N_{pp}$$

# of kaons

$$N_{K^+} \propto V\, t_0 \propto N_{pp}^{4/3}$$

# of strange particle

$$N_{\Lambda,\Sigma,\bar{K}} \sim N_{pp}^{4/3}$$

# of phis

$$N_\phi \sim \kappa_{\pi N} \frac{N_\pi N_{pp}}{V} t_0 + \kappa_{\pi Y} \frac{N_\pi N_Y}{V} t_0 + \kappa_{\bar{K} N} \frac{N_{\bar{K}} N_{pp}}{V} t_0 \sim a_{conv} N_{pp}^{4/3} + a_{cat} N_{pp}^{5/3}$$

(κ – reaction rate)

$$\frac{N_\phi}{N_\pi} \sim a \left(\frac{N_{pp}}{A}\right)^{1/3} + b \left(\frac{N_{pp}}{A}\right)^{2/3} \qquad \frac{N_\phi}{N_{K^+}} \sim a' + b' \left(\frac{N_{pp}}{A}\right)^{1/3}$$

catalytic reactions

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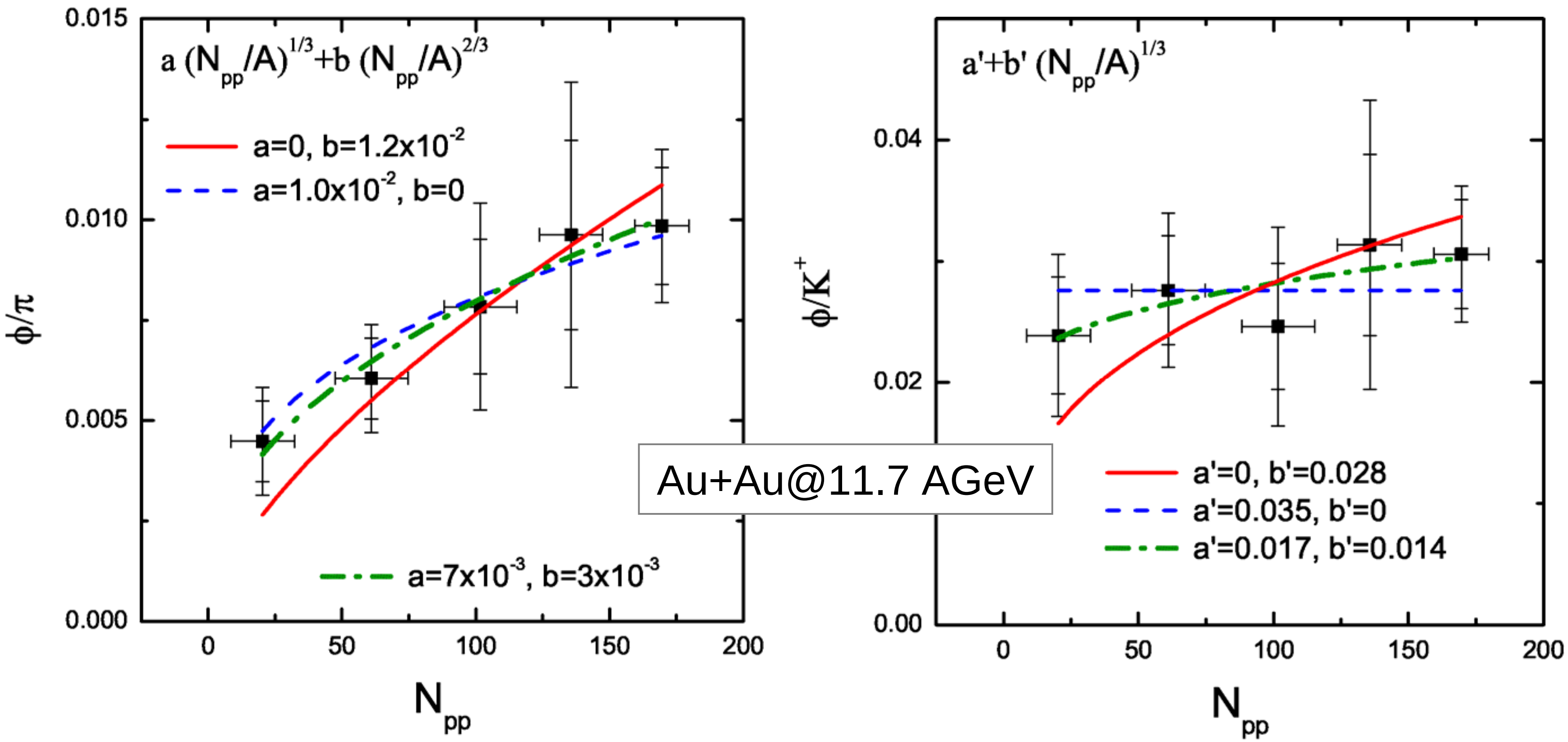
fit coefficients to data point

[E917 Collaboration, PRC 69 (2004) 054901]



The catalytic reaction contribution can be about 30%-40% for N_{pp}=A.

Phi rapidity distribution

The distributions can be fitted with a sum of two Gaussian functions placed symmetrically around mid-rapidity

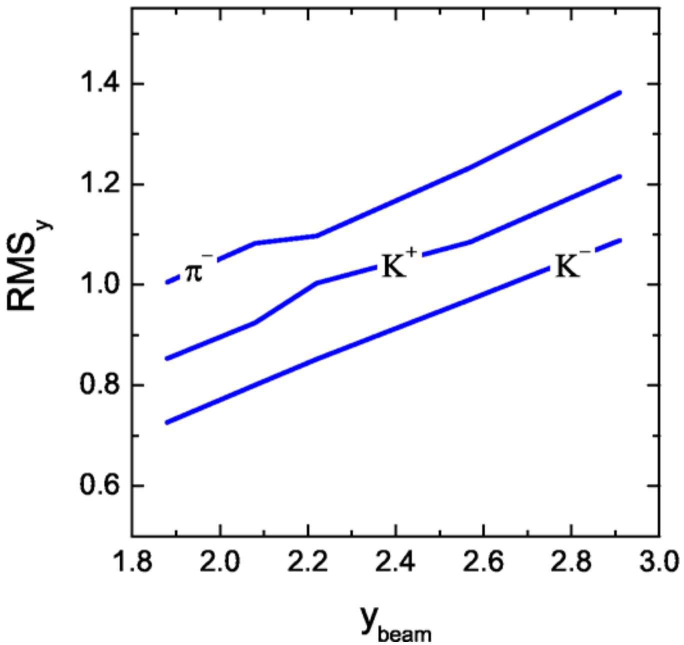
$$\frac{1}{\langle N \rangle} \frac{\mathrm{d}N}{\mathrm{d}y} = \frac{1}{\sqrt{8\,\pi\,\sigma^2}} \left[e^{-\frac{(y-a)^2}{2\,\sigma^2}} + e^{-\frac{(y+a)^2}{2\,\sigma^2}} \right]$$

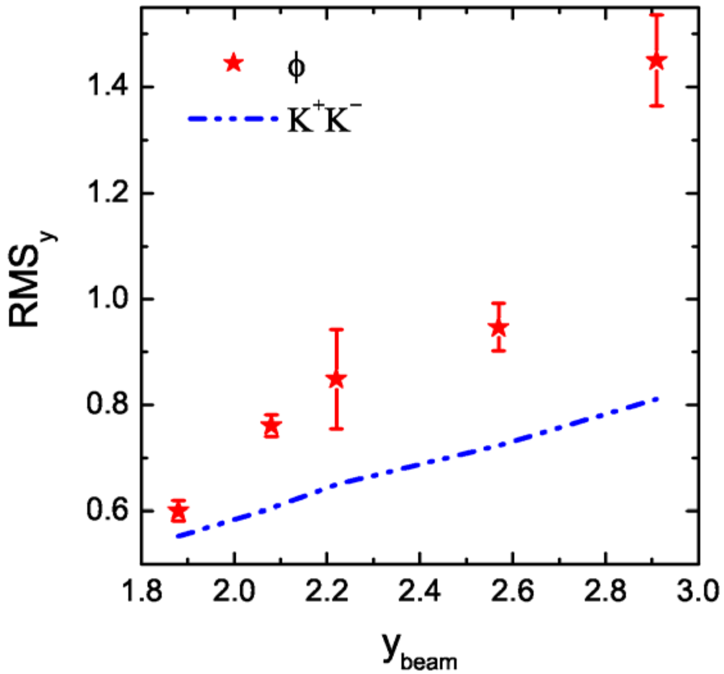
the root mean square of the distribution $\mathrm{RMS}^2 = \sigma^2 + a^2$

If ϕ are produced in $K^+ K^- \rightarrow \phi$

$$\mathrm{RMS}_{\phi} = \mathrm{RMS}_{K^+K^-} = \frac{\mathrm{RMS}_{K^+}\,\mathrm{RMS}_{K^-}}{\sqrt{\mathrm{RMS}_{K^+}^2 + \mathrm{RMS}_{K^-}^2}}$$

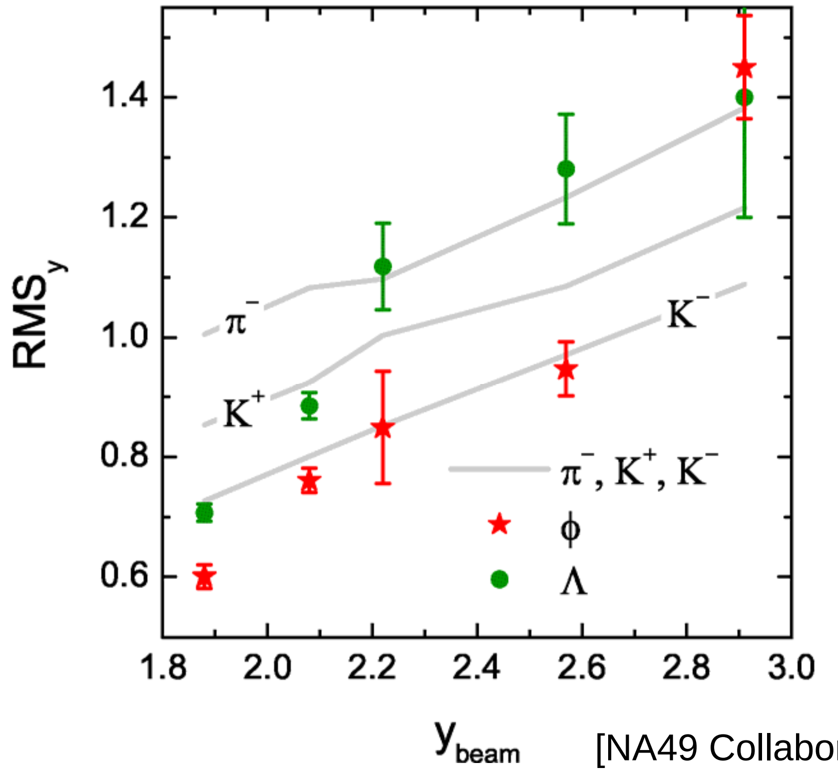
[NA49 Collaboration, PRC 78 (2008) 044907]



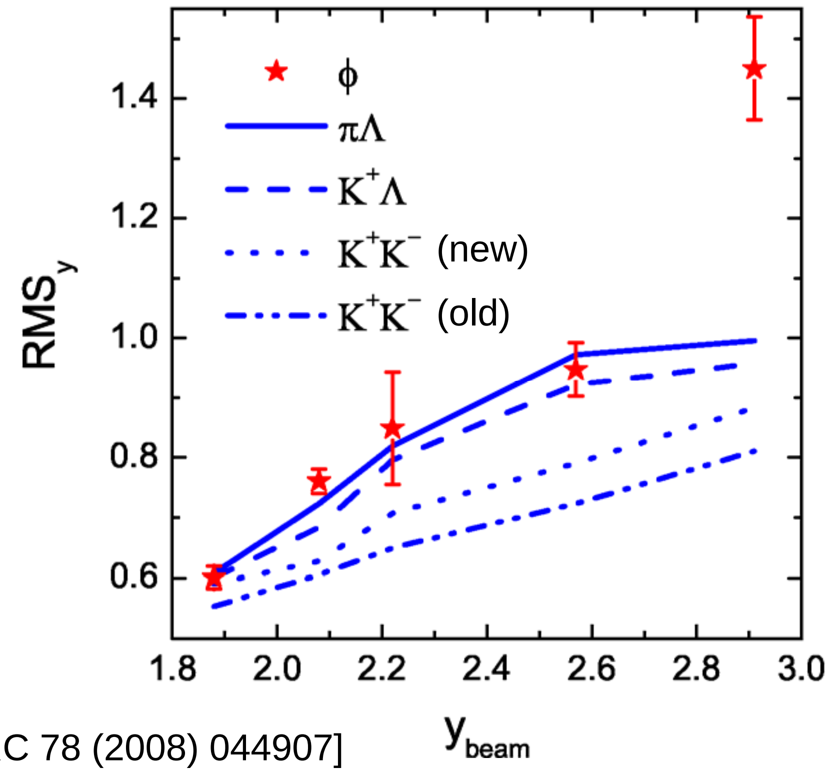


Assume: **the rapidity distributions of particles do not change after some initial stage**.
The absence or weakness of acceleration and diffusion processes.
The collision **kinematics** is restricted mainly to the **exchange of transverse momenta** .
The rapidity distribution of ϕs produced in the reaction 1+2 -> ϕ +X is roughly proportional to the **product of rapidity distributions** of colliding particle species 1 and 2.

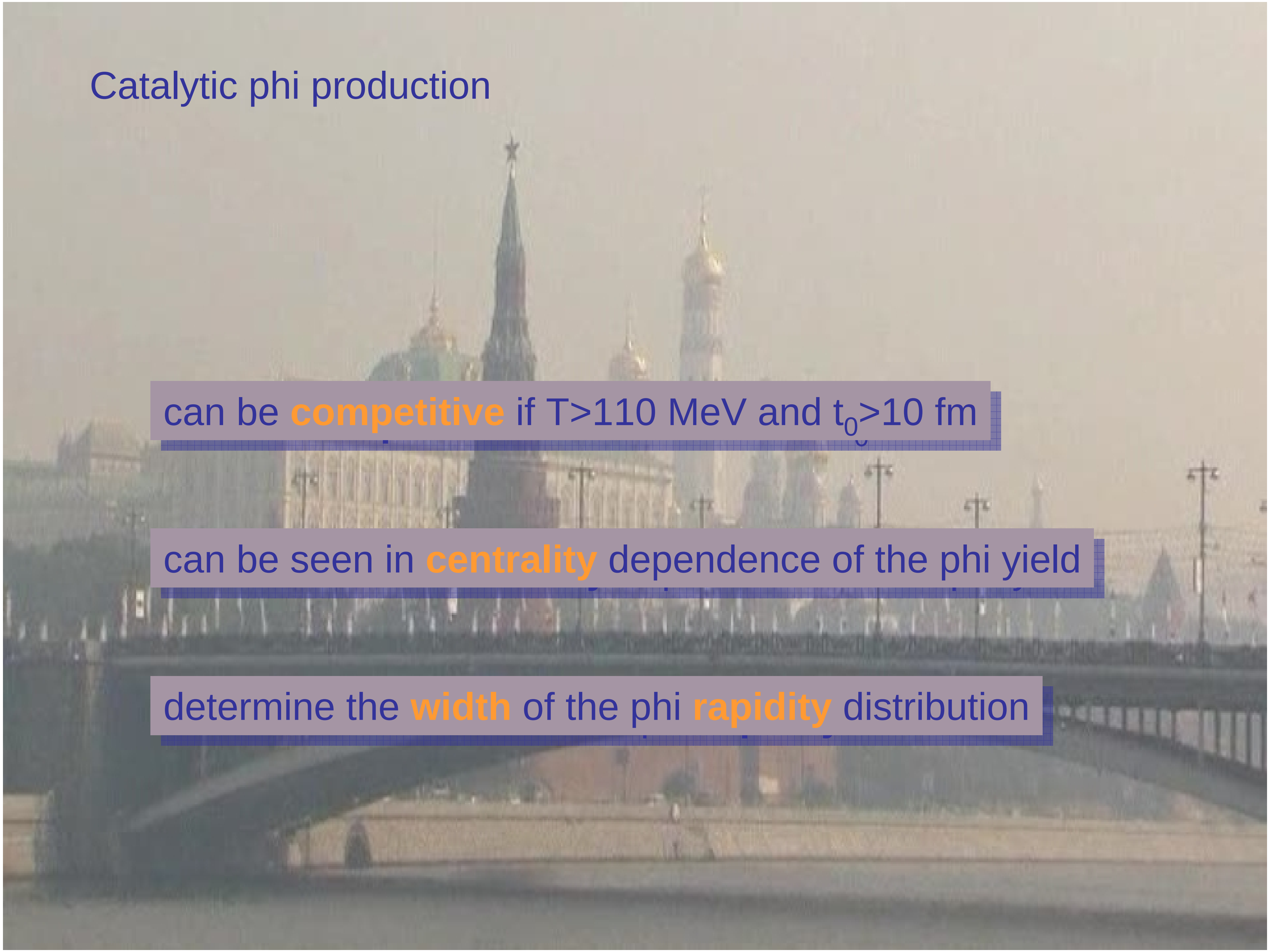
$$\mathrm{RMS}_{12}^2 = = \frac{\sigma_1^2\,\sigma_2^2}{\sigma_1^2+\sigma_2^2} + \frac{a_1^2\sigma_2^4 + a_2^2\,\sigma_1^4}{(\sigma_1^2+\sigma_2^2)^2} + \frac{2\,a_1\,a_2\,\sigma_2^2\,\sigma_1^2}{(\sigma_1^2+\sigma_2^2)^2}\tanh\frac{a_1\,a_2}{\sigma_1^2+\sigma_2^2}$$



[NA49 Collaboration, PRC 78 (2008) 044907]



Catalytic phi production



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determine the **width** of the phi **rapidity** distribution

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