Phenomenological Implications of the p_T spectra of ϕ and Ω produced at LHC and RHIC

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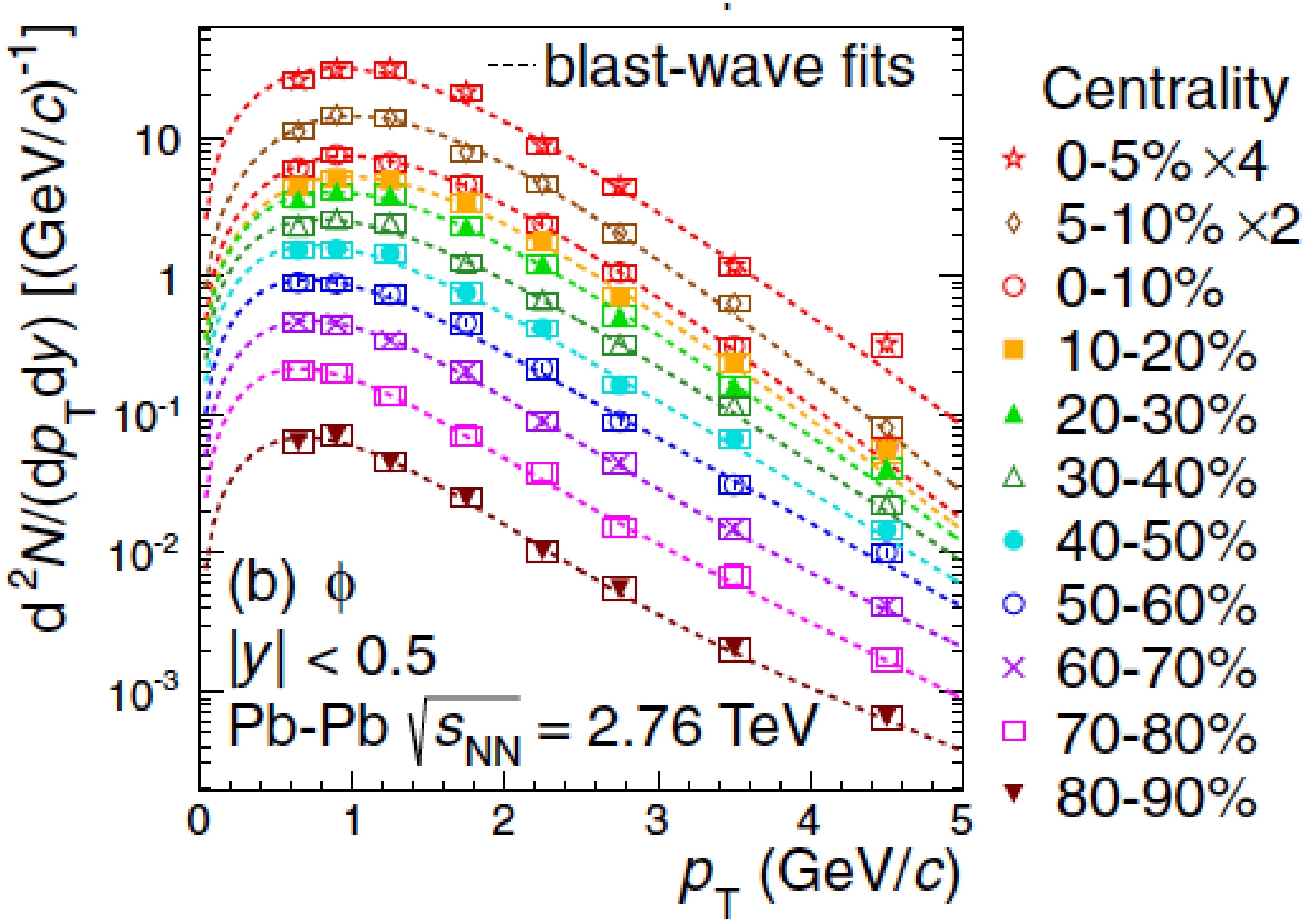
~~Outline~~ Nature of this talk

- Mostly data
- Search for simplicity and regularity
- Not much theory
- Implications

more far-reaching than ϕ and Ω themselves

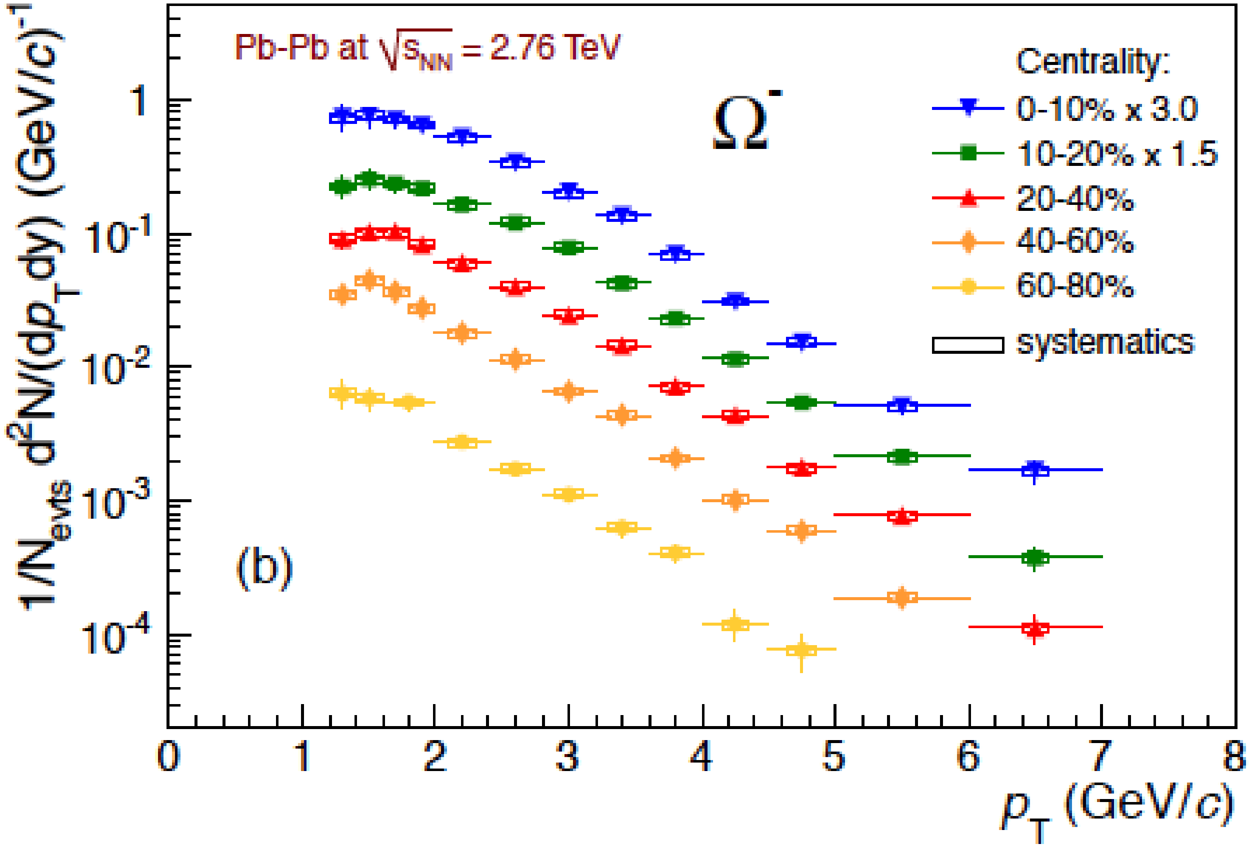
Work done in collaboration with
Lilin Zhu (Sichuan University)

ϕ production at LHC --- ALICE Phys. Rev. C 91, 024609 (2015)



$$\frac{1}{p_{\mathrm{T}}}\frac{dN}{dp_{\mathrm{T}}} \propto \int_0^R r\,dr\,m_{\mathrm{T}}\,I_0\left(\frac{p_{\mathrm{T}}\sinh\rho}{T_{\mathrm{kin}}}\right)K_1\left(\frac{m_{\mathrm{T}}\cosh\rho}{T_{\mathrm{kin}}}\right), \quad \rho = \tanh^{-1}\beta_{\mathrm{T}} = \tanh^{-1}\left[\left(\frac{r}{R}\right)^n\beta_s\right]$$

Ω production at LHC



ALICE PLB **728**, 216 (2014)

A different presentation of data

Mesons

$$\frac{dN_h}{p_T dp_T} \quad ´ \quad \frac{m_T^h}{p_T} \quad \cup \quad M_h\left(p_T\right) \qquad (\mathrm{GeV/c})^{-2}$$

usual presentation of data

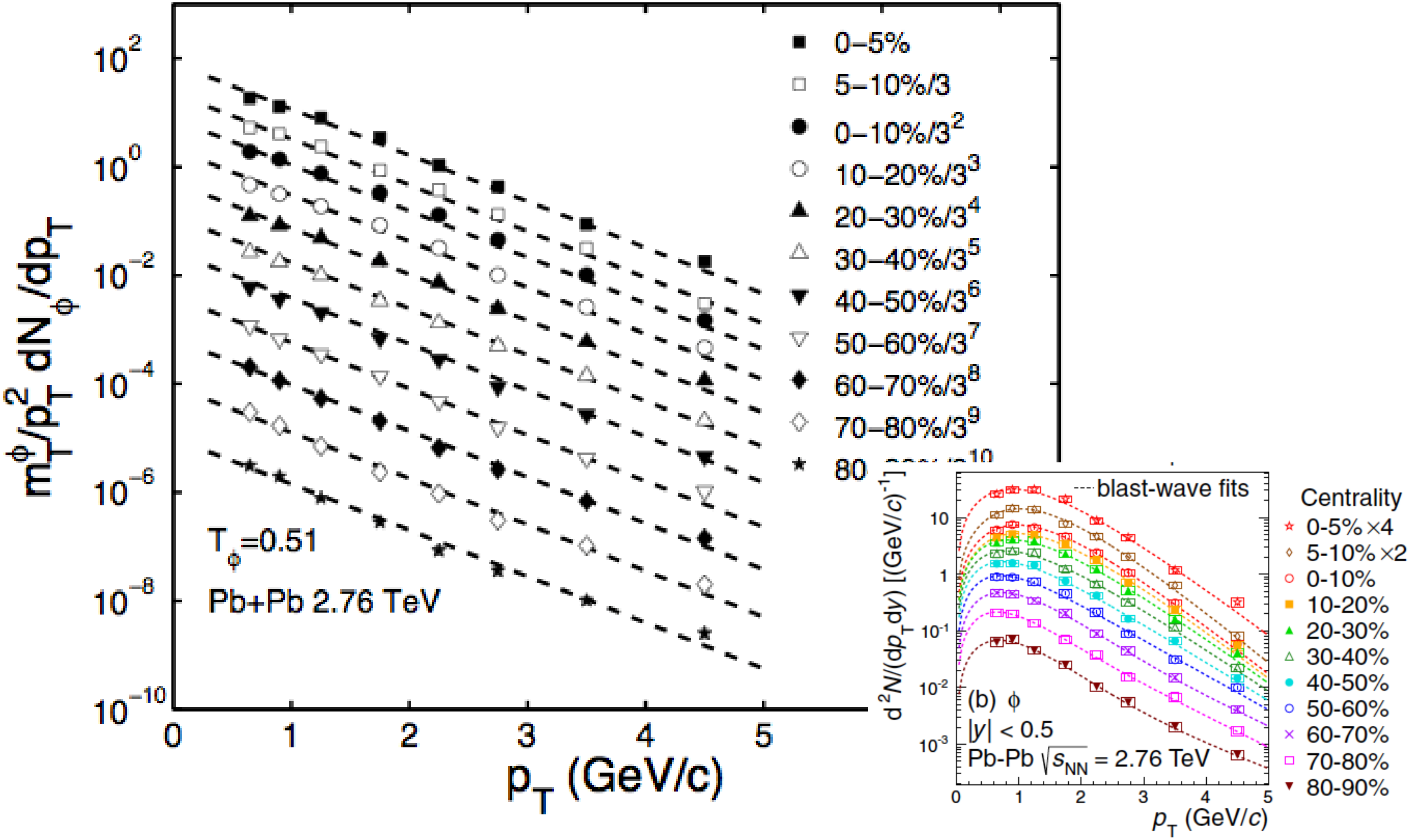
modified presentation of data

different dimensions

Baryons

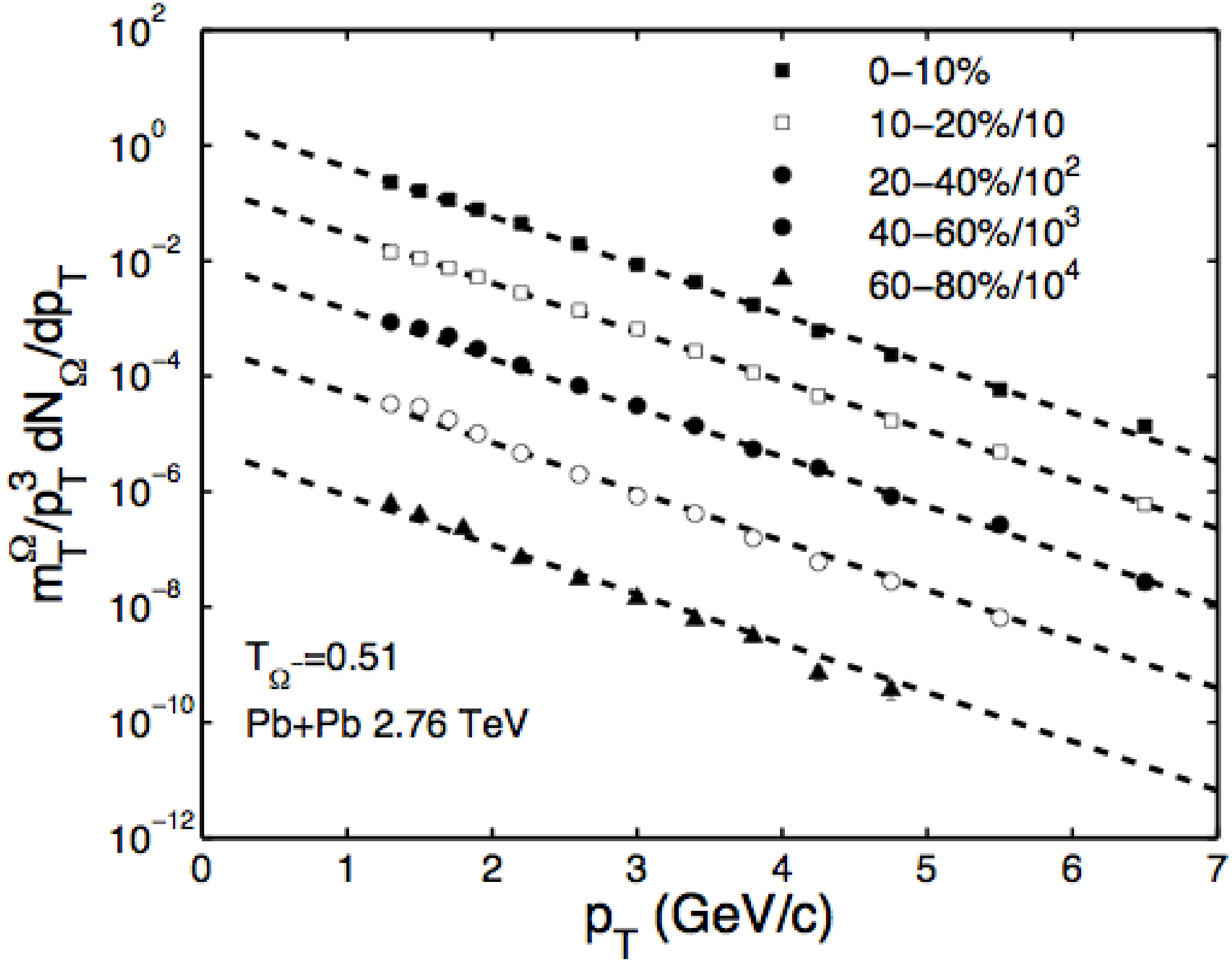
$$\frac{dN_h}{p_T dp_T} \quad ´ \quad \frac{m_T^h}{p_T^{\text{\textcircled{2}}}} \quad \cup \quad B_h\left(p_T\right) \qquad (\mathrm{GeV/c})^{-3}$$

$M_f(p_T, N_{part})$



One parameter: Inverse slope T_ϕ for all centralities

$B_W(p_T, N_{part})$



One parameter: Inverse slope T_Ω for all centralities

- No theory
- $T_\phi = T_\Omega$ same inverse slope for M_ϕ and B_Ω of different dimensions
- Exponential in p_T Þ thermal, out to p_T=6 GeV/c!

$$M_f(p_T, N_{part}) = A_f(N_{part})\exp(-\frac{p_T}{T_f})$$

$$B_W(p_T, N_{part}) = A_W(N_{part})\exp(-\frac{p_T}{T_{W'}})$$

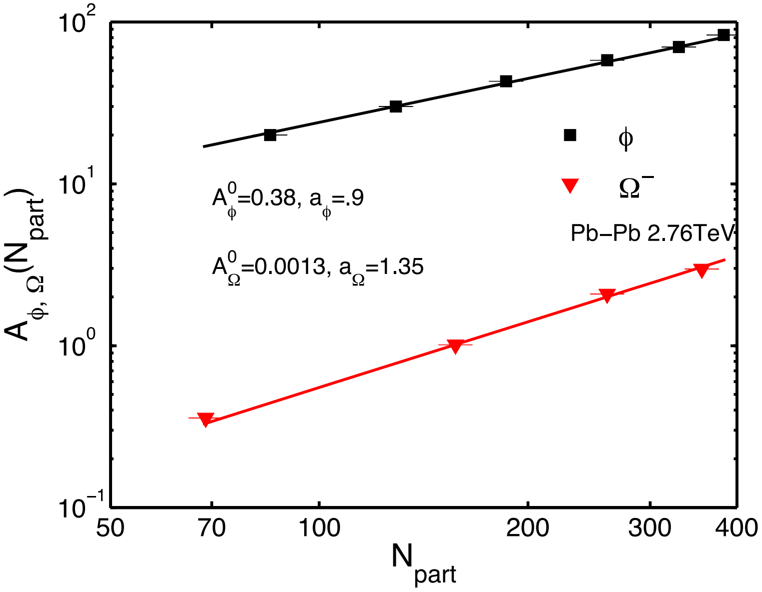
p_T and N_{part} dependencies are factorizable

Centrality dependence

$$A_f(N_{part}) = A_f^0 N_{part}^{a_f}$$

$$A_W(N_{part}) = A_W^0 N_{part}^{a_W}$$

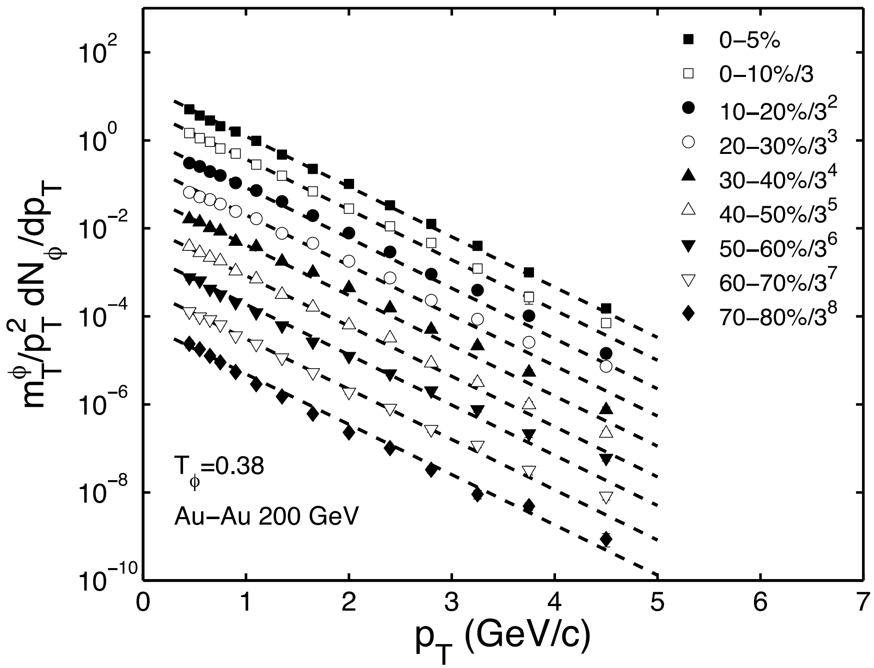
a_ϕ=0.9 , a_Ω=1.35



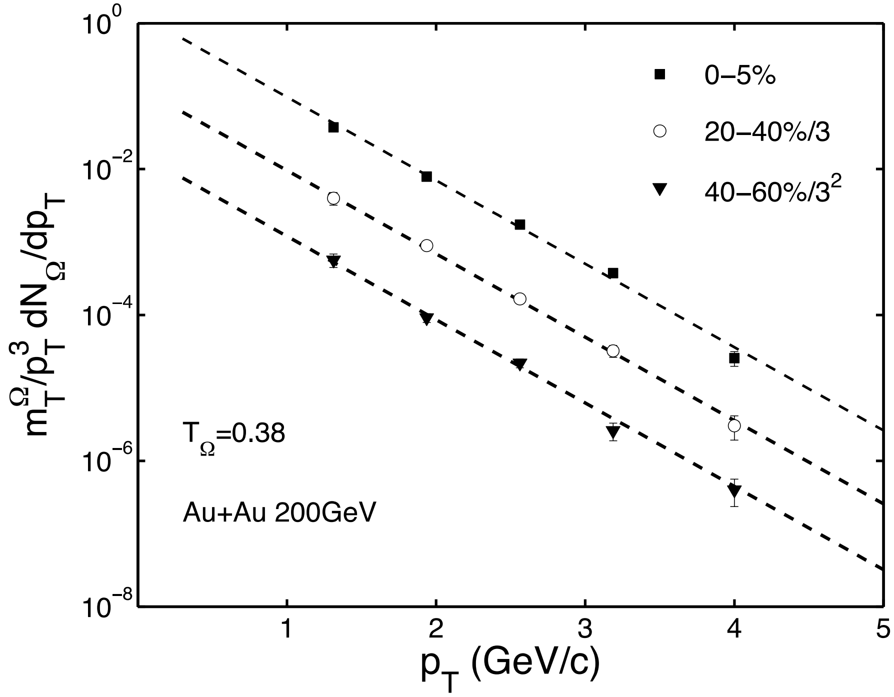
That is for LHC energy at 2.76 TeV, but true also for nearly all lower energies.

At RHIC 200 GeV

ϕ



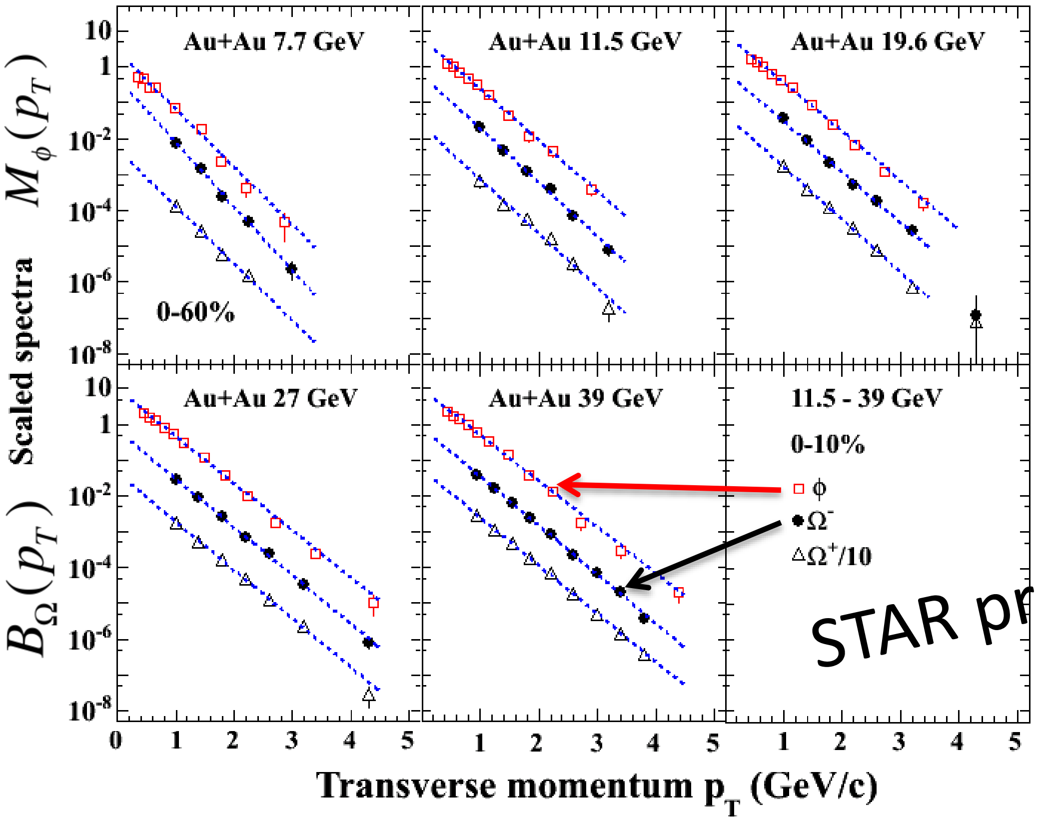
Ω

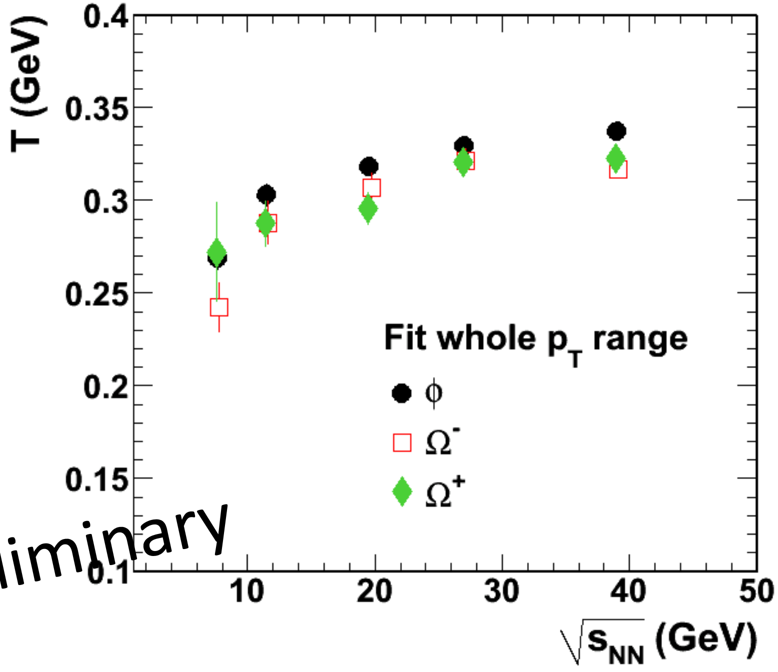


and at 130 GeV

STAR BES PRC 93, 021903 R (2016)

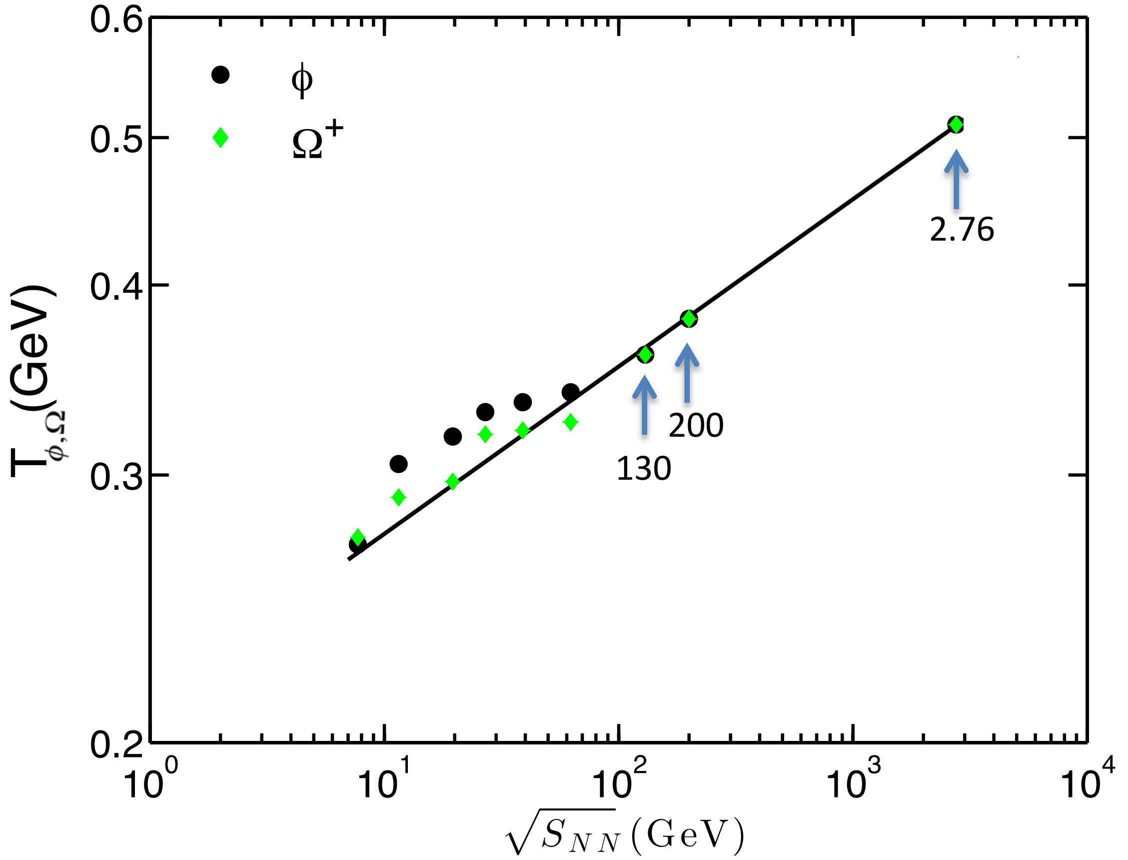
$$7.7 \leq \sqrt{s_{NN}} \leq 39 GeV$$





STAR preliminary

Courtesy of Xiaoping Zhang (STAR)



Prediction without theory

At √s=5.02 TeV, $T_{\phi\Omega}$=0.54 GeV for 0<p_T<7 GeV/c, N_{part}>100

The simple description works very well for ϕ and Ω because s quarks are suppressed in jet fragmentation.

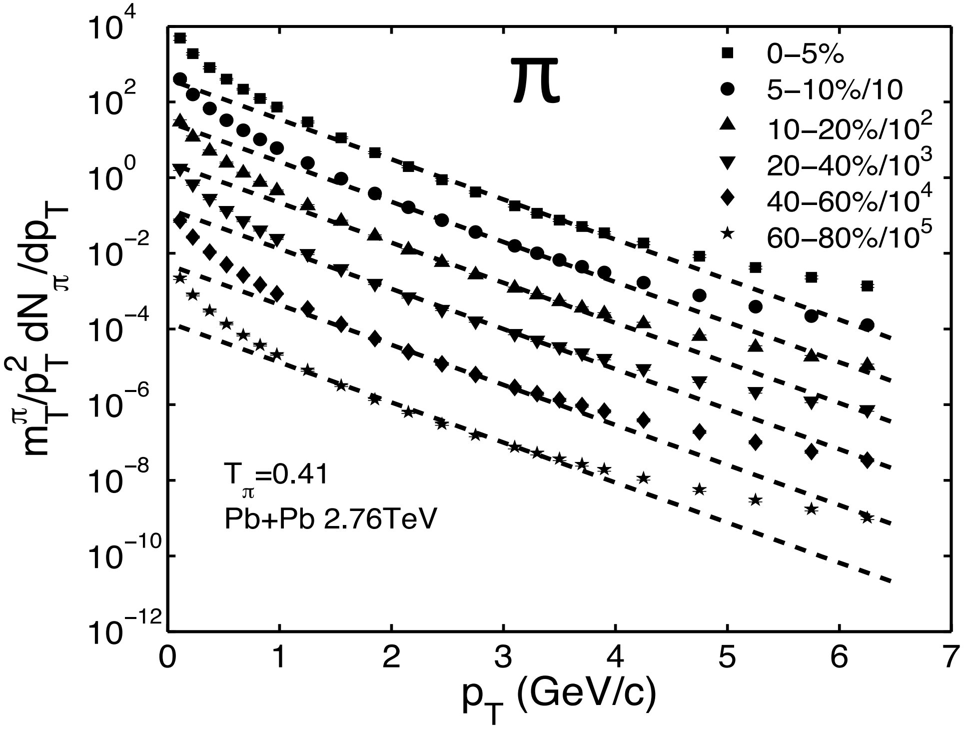
There are few s quarks in parton showers.

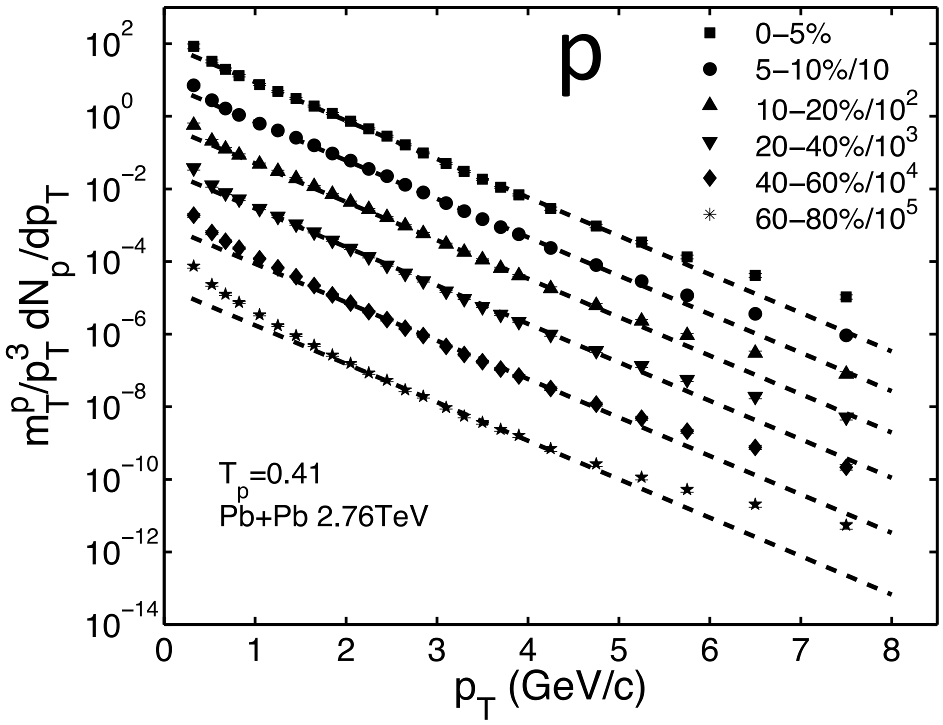
$$TT + \cancel{TS} + \cancel{SS} \qquad TTT + \cancel{TTS} + \cancel{TSS} + \cancel{SSS}$$

The situation is different for <u>light</u> quarks.

- u, d quarks dominate parton showers
- hard partons generate soft pions
- semihard partons (minijets) give rise to soft partons in medium
- resonance decays
- + …

ALICE 2.76 TeV



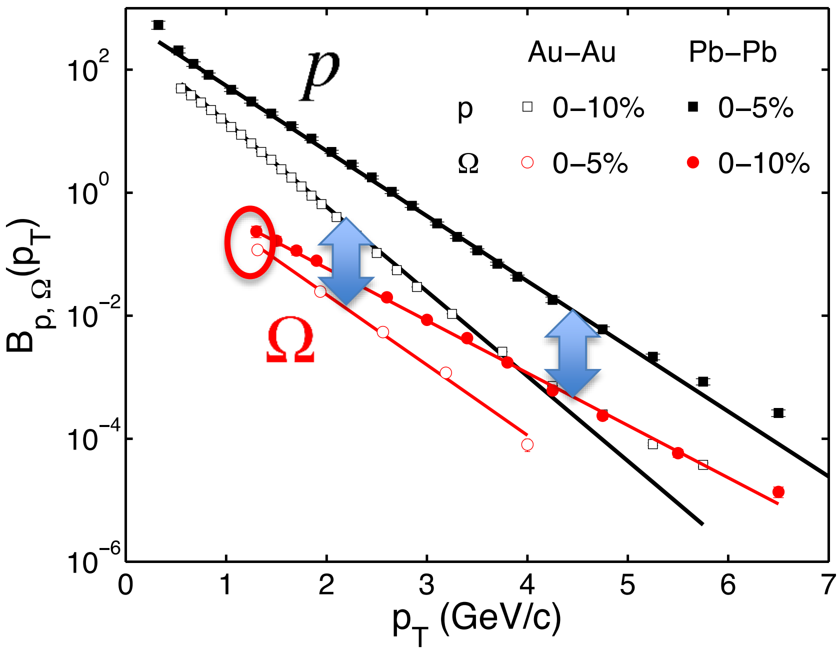


The origin of $M_f(p_T, N_{part})$ and $B_W(p_T, N_{part})$ can be found in the Recombination Model.

It can be shown that $T_\phi = T_\Omega$.

(2 slides at the end)

Continue with phenomenological observations.



ALICE PRC **93**, 034913 (2016)
PLB **728**, 216 (2014)

STAR PRC **88**, 024906 (2013)
PRL **98**, 062301 (2007)

Not much change at low p_T.

Not what hydro can explain.

No mention of flow .

No need for radial velocity, T_{kin}, blast wave, etc.

We are concerned about the physics that make sense for p_T up to 7 GeV/c.

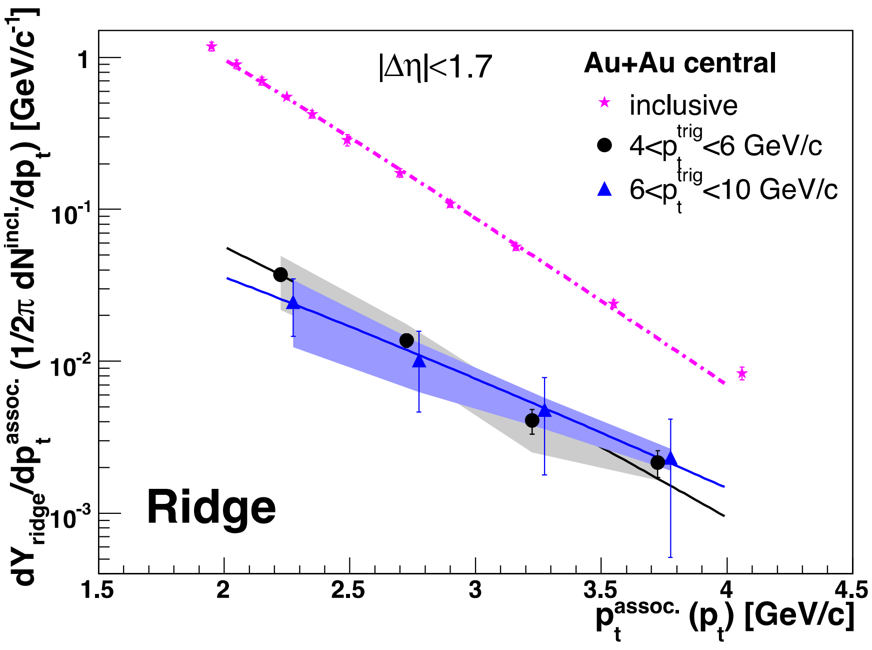
Compare the data of W to p.

$\Delta T = T_\Omega - T_p$ = 65 MeV (Au-Au 200 GeV)
=100 MeV (Pb-Pb 2.76 TeV)

Ridge

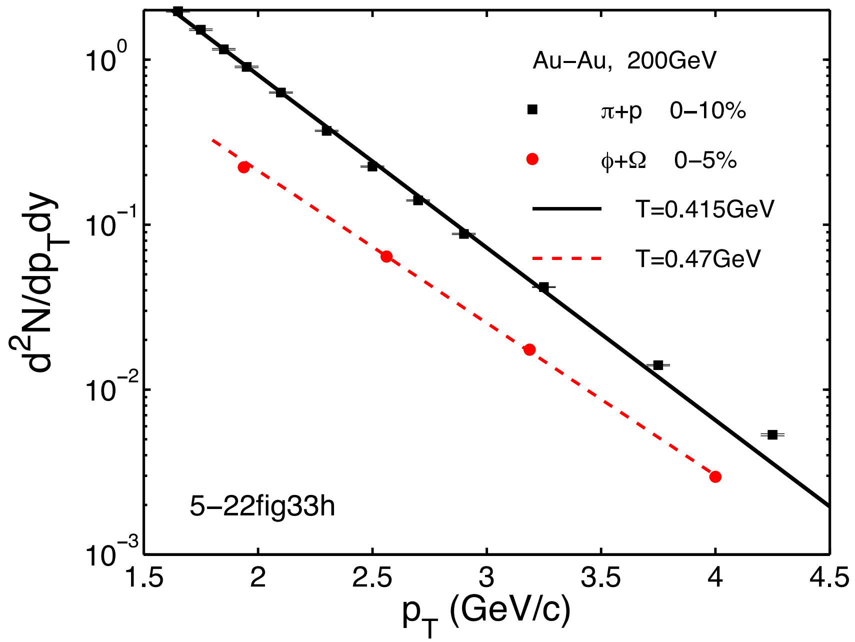
Recall the original discovery of Ridge by STAR ---
J. Putschke at QM06

STAR PRC **80**, 064912 (2009)



$$\Delta T = 40 - 50\mathrm{MeV}$$

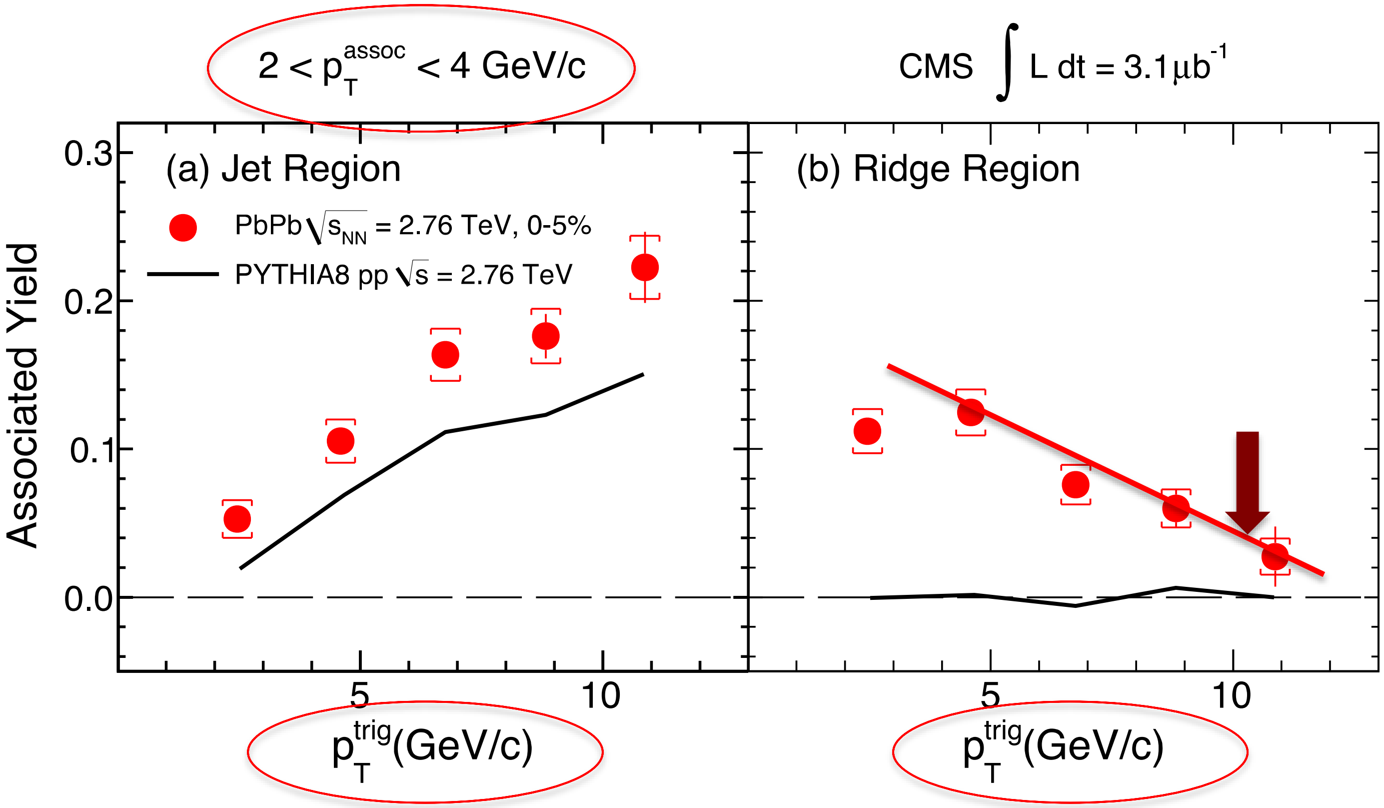
Identified, un-triggered



$$\Delta T = 55\mathrm{MeV}$$

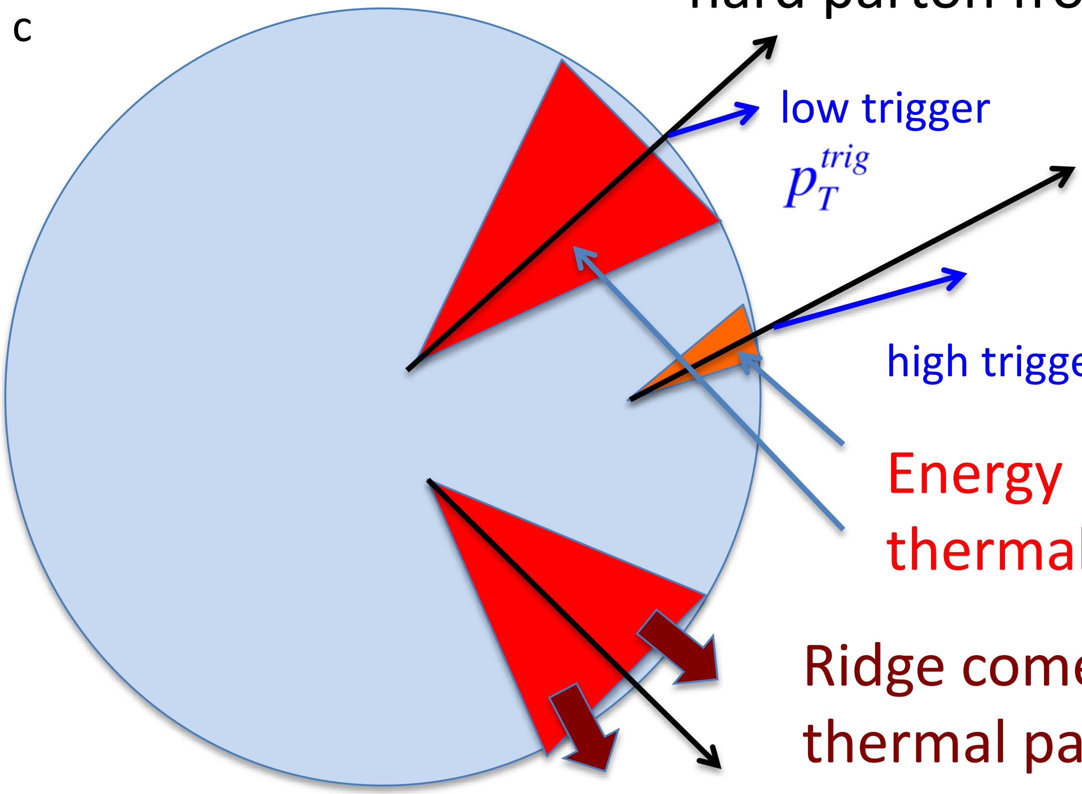
So far no LHC data on p_T^{assoc} dependence of Ridge.

CMS JHEP07(2011)076 on p_T^{trig} dependence



Ridge is suppressed at high trigger p_T.

Transverse plane



0-5% c

hard parton from interior

low trigger p_T^{trig}

hard parton from near the surface

high trigger p_T^{trig}

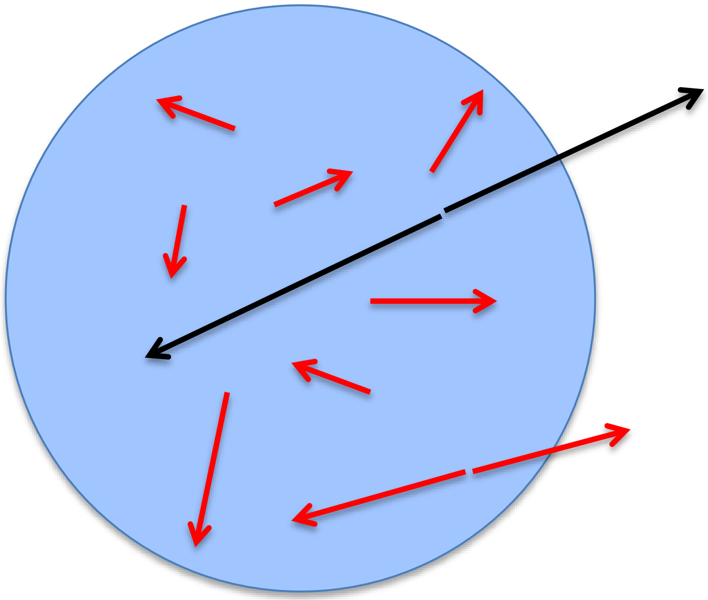
Energy loss enhances thermal partons

Ridge comes from the enhanced thermal partons

Thus ridge yield is suppressed at high p_T^{trig}

ϕ and Ω are in the Ridge with higher T

Jets and Ridges are in all events, whether triggered or not.



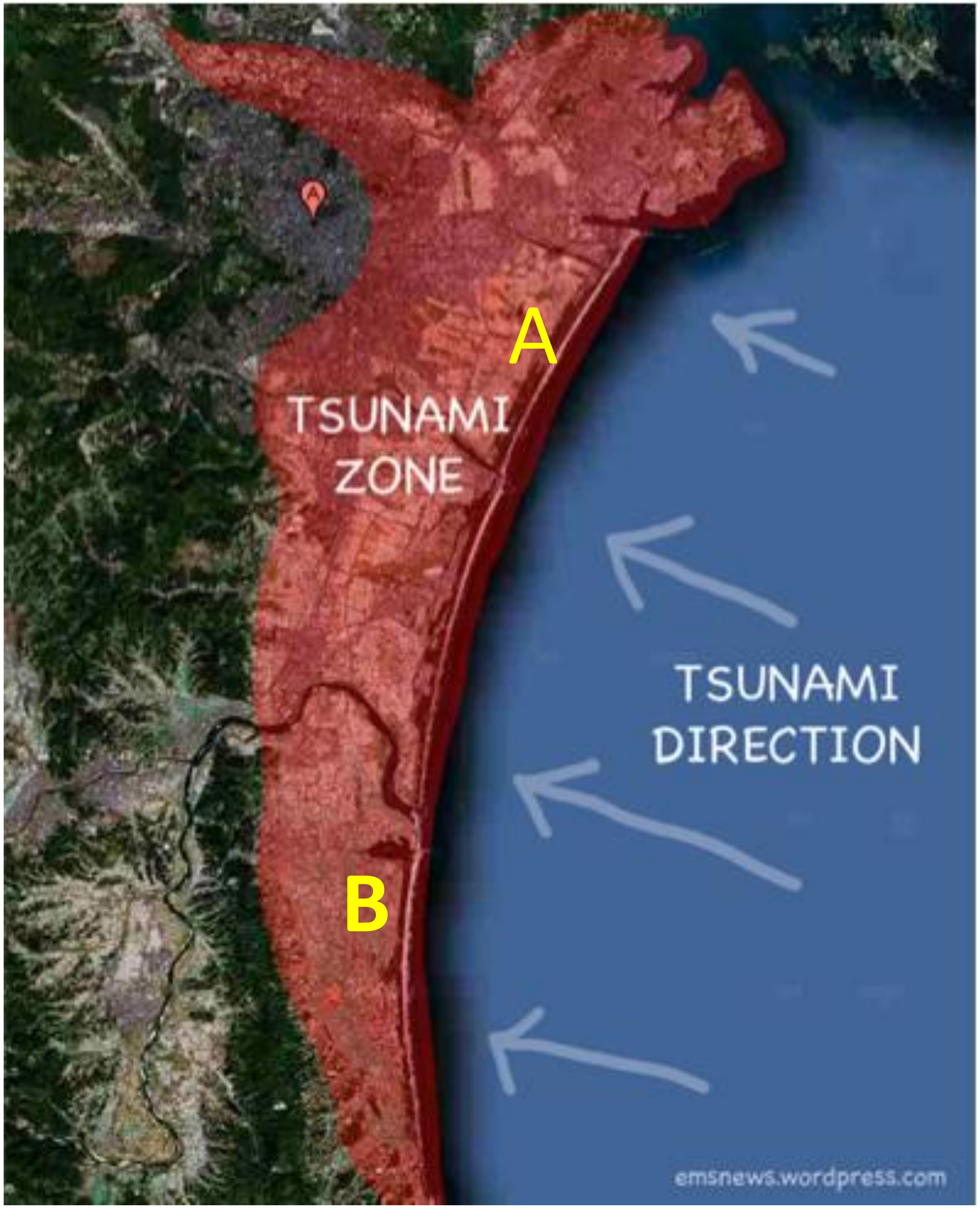
For every hard parton that emerges, there may be a partner that traverses the whole medium without emerging.

The energy-losing processes take time, since partons can take 10 fm/c to traverse …

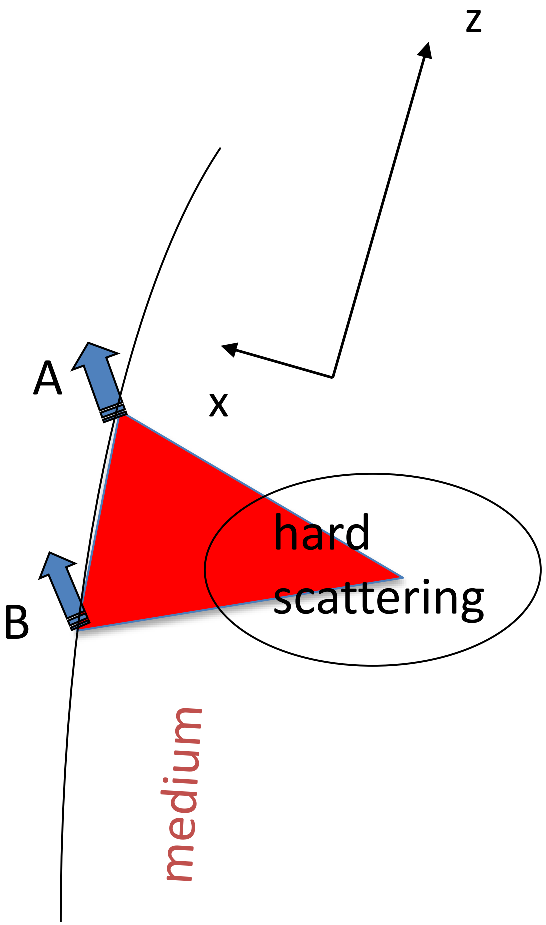
There can be many semihard partons, copiously produced at LHC, that can alter the thermal description throughout the evolution.

Hard and soft processes are intricately mixed.

Ridge-tsunami analogy



A & B are not longitudinally correlated, but are "vertically" correlated, when a tsunami strikes.



Ridge is analogous to tsunami.

Rising tide raises all boats

SUMMARY

- Mainly empirical observations
- Not much theory
- ϕ and Ω are special, since they receive no contribution from jet fragmentation
- No need for flow, radial velocity, or blast wave
- Usual hydrodynamics cannot generate thermal s quark distribution out to 4 GeV/c
- It is suggested that ϕ and Ω are to be found in the Ridge.

We need more experimental and theoretical verification of that idea.

Derivation of $M_f(p_T, N_{part})$ and $B_{\mathrm{W}}(p_T, N_{part})$ in the Recombination Model.

In the Recombination Model

Invariant distribution at hadronization at y≈0

$$E\frac{dN_f}{dp_T} = \int \frac{dp_1}{p_1}\frac{dp_2}{p_2}\mathcal{T}_s(p_1)\mathcal{T}_{\bar{s}}(p_2)R_f(p_1,p_2,p_T)$$

$$\mathcal{T}_s(p_1) = p_1^0\frac{dN_s}{dp_1} = C_s p_1 e^{-p_1/T_s} \qquad C_{\bar{s}} p_2 e^{-p_2/T_s} \qquad R_\phi^0\left(\frac{p_1}{p_T},\frac{p_2}{p_T}\right)\delta\left(\frac{p_1+p_2}{p_T}-1\right)$$

$$= C_s C_{\bar{s}} e^{-p_T/T_s} p_T^2 \underbrace{\int dz_1 dz_2 R_\phi^0(z_1,z_2)\delta(z_1+z_2-1)}_{Z_\phi}$$

$z_i = p_i / p_T$

$$\underbrace{\frac{m_T}{p_T}\frac{dN_\phi}{p_T dp_T}}_{} = \underbrace{C_s C_{\bar{s}} Z_\phi}_{} e^{-p_T/T_s}$$

$$\boxed{T_s = T_\phi}$$

$$M_\phi(p_T, N_{part}) = A_\phi(N_{part}) e^{-p_T/T_\phi}$$

Similarly, Baryons

$$E\frac{dN_\Omega}{dp_T dy}\bigg|_{y=0} = \int \frac{dp_1}{p_1}\frac{dp_2}{p_2}\frac{dp_3}{p_3}\mathcal{T}_s(p_1)\mathcal{T}_s(p_2)\mathcal{T}_s(p_3)R_\Omega(p_1,p_2,p_3,p_T)$$

$$= p_T^3 \underbrace{C_s^3 Z_\Omega}_{} e^{-p_T/T_s}$$

exponential in p_T

$$\boxed{T_{\mathrm{W}} = T_s = T_f}$$

$$\frac{m_T^\Omega}{p_T^2}\frac{dN_\Omega}{p_T dp_T} = A_\Omega(N_{part})e^{-p_T/T_\Omega}$$

$$B_\Omega(p_T, N_{part})$$

$$A_{\mathrm{W}} \propto C_s^3$$

$$A_f \ \mu \ C_s C_{\bar{s}} = C_s^2$$

$$\boxed{3:2}$$

Expected in Recombination model

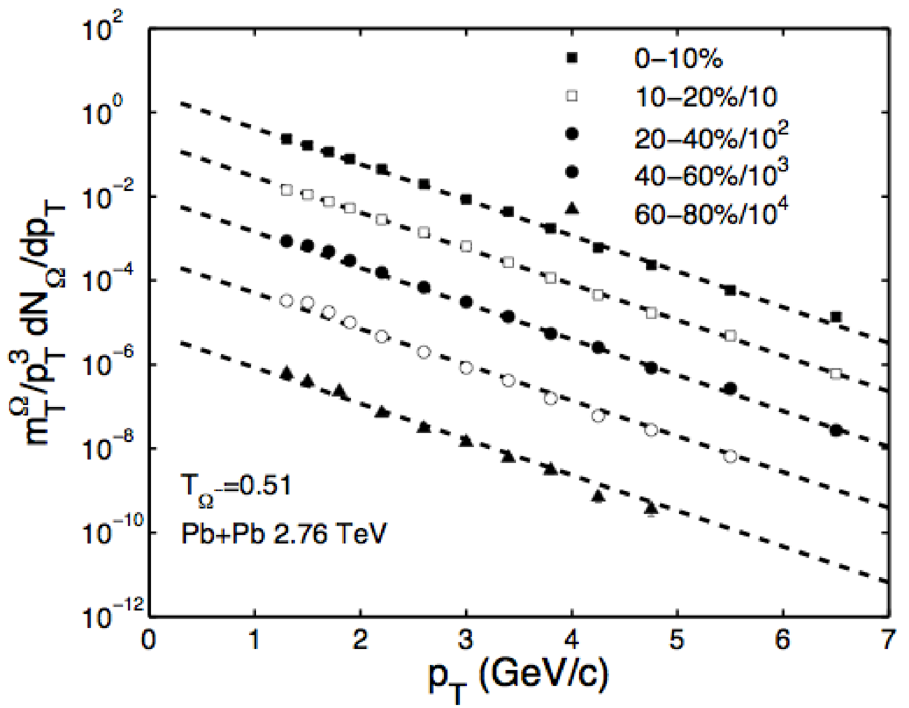
Empirical

$$A_{\mathrm{W}} \propto N_{part}^{a_{\mathrm{W}}}, \quad a_{\mathrm{W}} = 1.35$$

$$A_f \ \mu \ N_{part}^{a_f}, \quad a_f = 0.9$$

$$\boxed{3:2}$$

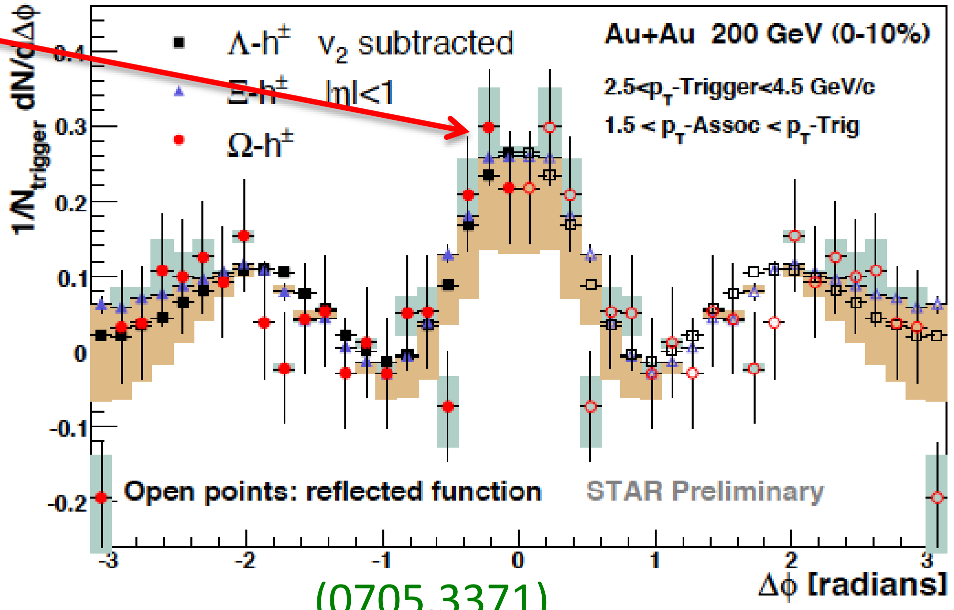
Ω spectra are exponential out to p_T=6.5 GeV/c



If it is thermal, randomness would imply that particles are uncorrelated.

But STAR has found hadrons correlated to Ω triggers.

That can be explained by Ω being in the Ridge: all particles in the Ridge are correlated to the trigger and to each other.



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