Why Ions @ Future Hadron Collider?

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The following aims at formulating the most basic tentative answers to this question. It remains to be seen whether key elements of these answers stand the test of a detailed investigation.

Answer 0: It's a discovery regime, stupid!

Historically, any significant increase in center of mass energy has lead to significant discoveries, surprises and insights. This is true not only for high energy physics, but also for ultra-relativistic heavy ion physics.

(This alone will never be sufficient to initiate a program, but it may be a good argument for participating 'at some scale' in a program that is motivated and spearheaded by HEP.)

To go beyond, we need to ask:
Which elements in the existing data and our theoretical understanding make an increase in energy / luminosity interesting?

This is relevant not only for FHC. Our field needs to address the same question on the much shorter time scales relevant for LHC after LS1 and the high-luminosity upgrade of LHC.

What are the direction in which we can seek answers?

Answer 1: Large quantitative gains

Increasing the center of mass energy implies

⇒ Denser initial system

⇒ Longer lifetime

⇒ Bigger spatial extension

⇒ Stronger collective phenomena

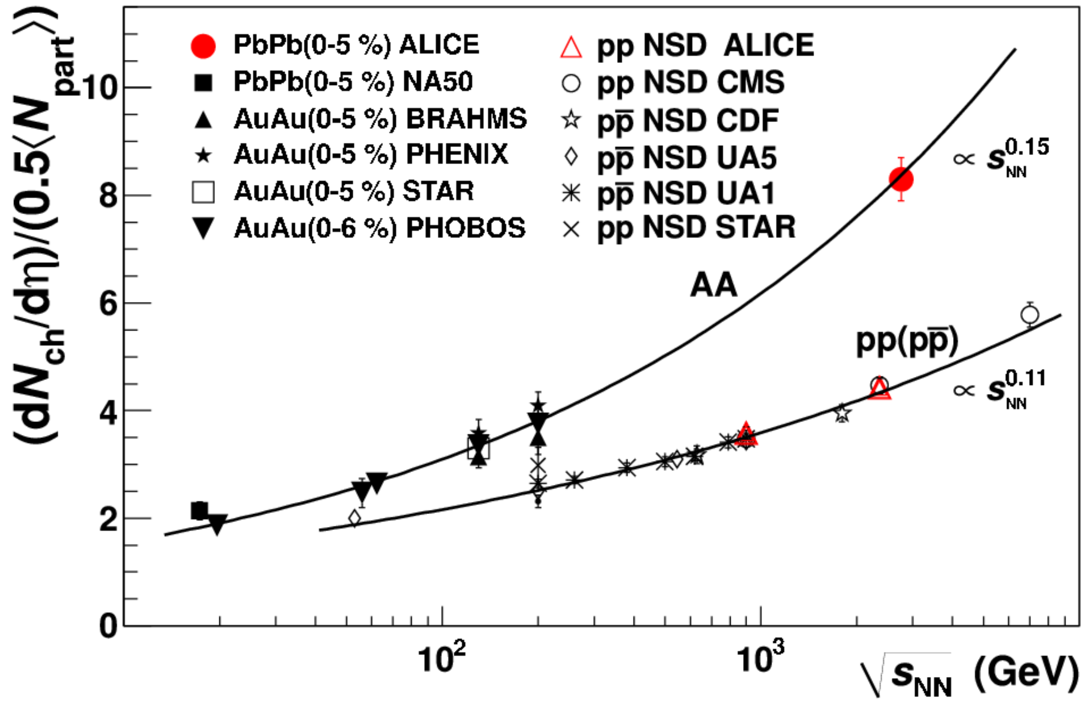
A large body of experimental data from the CERN SPS, RHIC and LHC supports this argument.

Event multiplicity is central for soft physics

$$\frac{dN_{ch}}{dh}\left(\sqrt{s_{NN}} = 2.76\ TeV\right) = 1600$$

$$\frac{dN_{ch}}{dh}\left(\sqrt{s_{NN}} = 40\ TeV\right)$$

$$= 1600 * (40/2.76)^{0.3} = 3570$$



Factor f= 2 – 2.5 increase is comparable to the step from RHIC to LHC.

Initial temperature: $T(t_0, FHC) = T(t_0, LHC) f^{1/3}, \quad 1.25 < f^{1/3} < 1.36$

(Moderate increase, but possibly of qualitative interest if sufficient to induce thermal production of c-cbar pairs)

HBT radius parameters: $R_{HBT}\ \mu\ f^{1/3}$ Moderate increase

But this is not the main advantage of LHC over RHIC, either!

Advantage of increased event multiplicity for soft physics: example flow

- Have to measure particle correlations:

$$\left\langle e^{in(\phi_1-\phi_2)}\right\rangle_{D_1\cup D_2} = v_n(D_1)\,v_n(D_2) + \left\langle e^{in(\phi_1-\phi_2)}\right\rangle^{corr}_{D_1\cup D_2}$$

"Non-flow effects"

$\sim O(1/N)$

But this requires signals $v_n > \frac{1}{\sqrt{N}}$

Uncertainties decrease for higher multiplicity!!

- Improve measurement with higher cumulants: Borghini, Dinh, Ollitrault, PRC (2001)

$$\left\langle e^{in(\phi_1+\phi_2-\phi_3-\phi_4)}\right\rangle - \left\langle e^{in(\phi_1-\phi_3)}\right\rangle\left\langle e^{in(\phi_2-\phi_4)}\right\rangle - \left\langle e^{in(\phi_1-\phi_4)}\right\rangle\left\langle e^{in(\phi_2-\phi_3)}\right\rangle = -v_n^4 + O\left(1/N^3\right)$$

Higher multiplicity of LHC events enhances potential of flow measurements compared to RHIC. What is the impact of factor 2-2.5 increase in multiplicity on

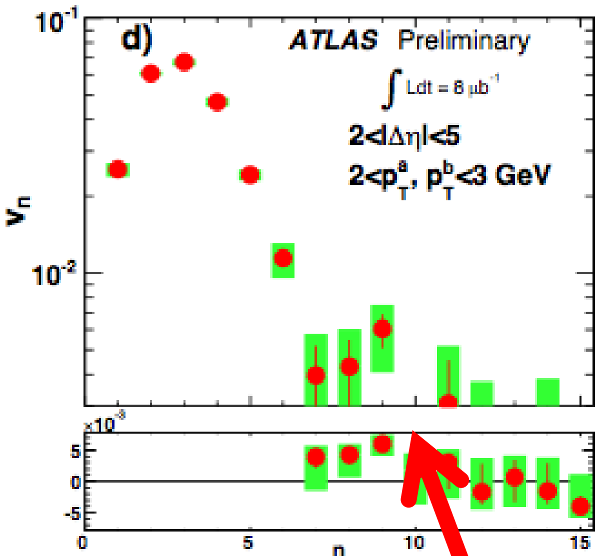
- *Flow harmonics v_n*
- *Reconstruction of reaction planes and their correlations*

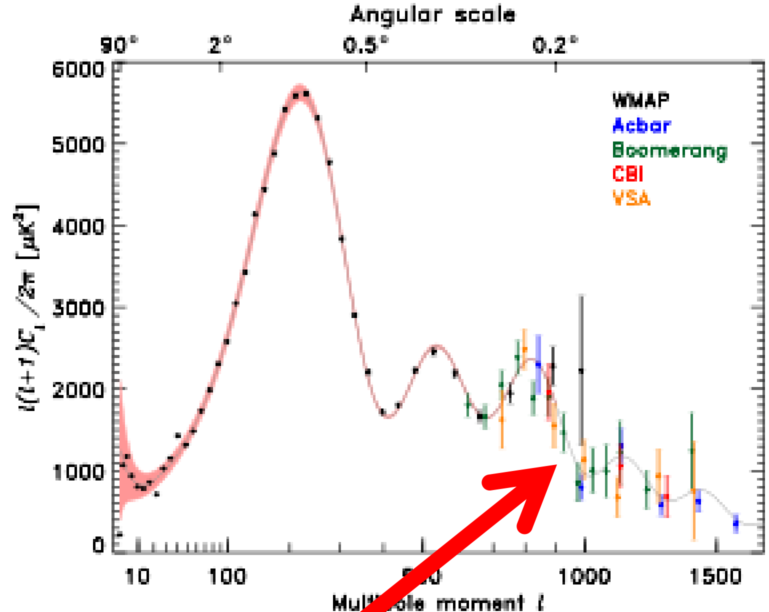
Little Bangs – Large Bangs – Big Bang

Hydro evolution of fluctuating initial condition reveals matter properties.
How can FHC help?

$h/s = 0.08^{+\dots}_{-\dots}$

$W_b = 0.044^{+0.04}_{-0.04}$ $W_L = 0.73^{+0.04}_{-0.04}$





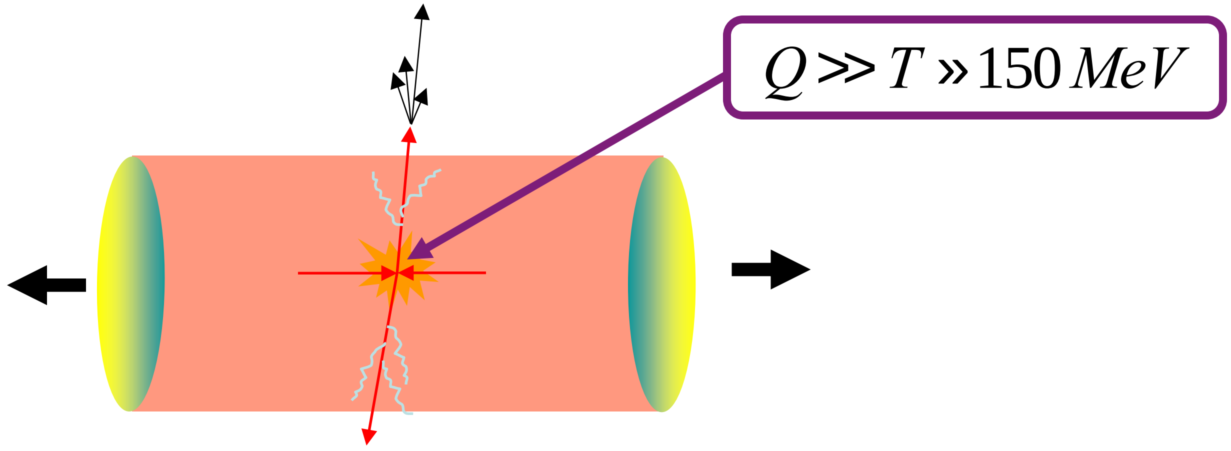
Improvable by FHC? Sensitive to matter properties?

Improved by many experiments, Decisive for quantiative understanding.

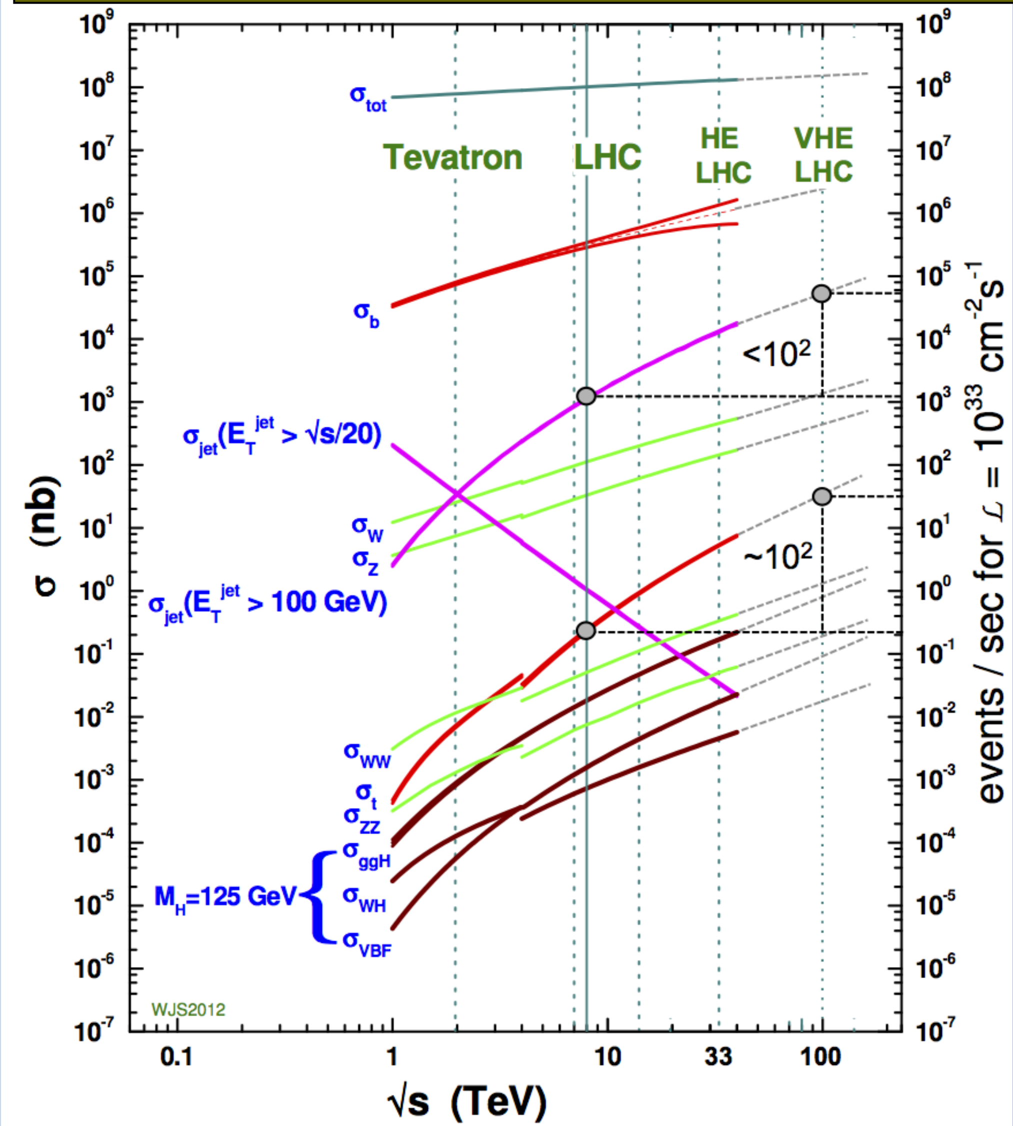
Answer 2: Qualitatively novel access to properties of dense matter via hard probes

To test properties of QCD matter, large- Q^2 processes provide well-controlled tools (example: DIS).

Heavy Ion Collisions produce auto-generated probes at high $\sqrt{s_{NN}}$



Projections to 100 TeV made by hand by Anna Sfyrla starting from original Stirling's plot



Projections to 100TeV done 'by hand'

Process	R(100 TeV/14 TeV)
W	6.7
Z	7.2
WW	9.6
ZZ	10.3
tt	32.5
bb	~ 3

M. Mangano

Hard Probes: what could be new at FHC?

- Top-physics

  Testing jet quenching without the complications of hadronization is of conceptual interest. Top quark decays electro-weak prior to hadronization. Can one outline a strategy of how to utilize that?

- Higgs, boosted Higgs, Z, W, …

  are (via their QCD branchings) also a source of color-singlet dipoles that are embedded into the medium at later times. Could they help in a time-differential mapping of medium properties?

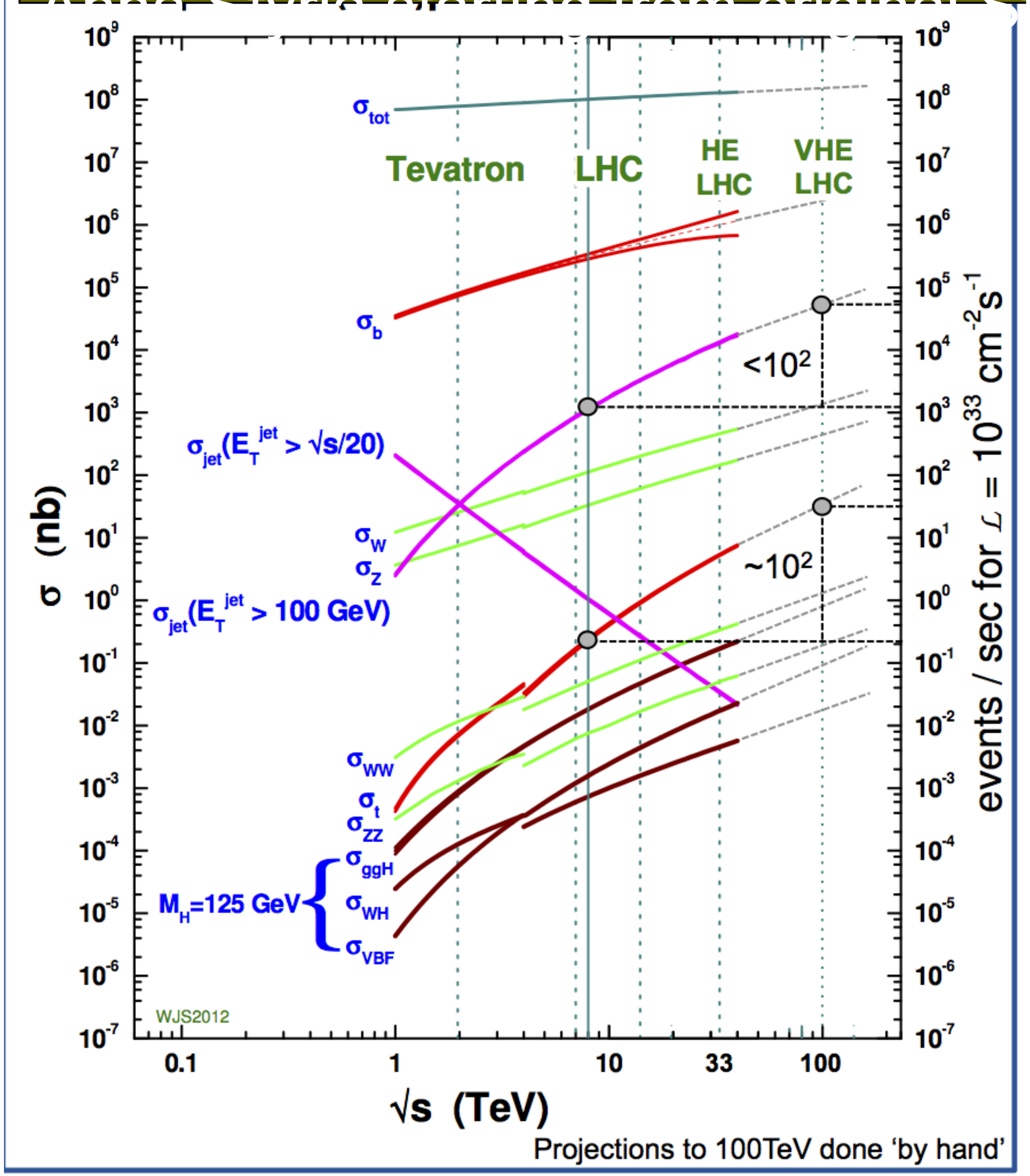
- Z-tagged jets, etc.

  clearly interesting as soon as abundantly available. Competition/ improvement over LHC-potential needs to be studied.

- Abundance of hard probes

  Clearly an asset. But how does it compare to high-luminosity LHC? And what are the quantitative improvements that

Projections to 100 TeV made by han



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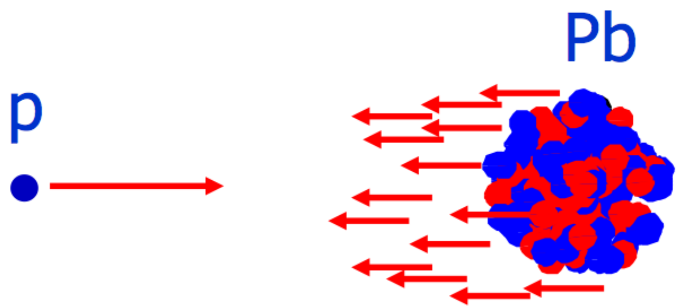
Longer-term: studies vs √s r

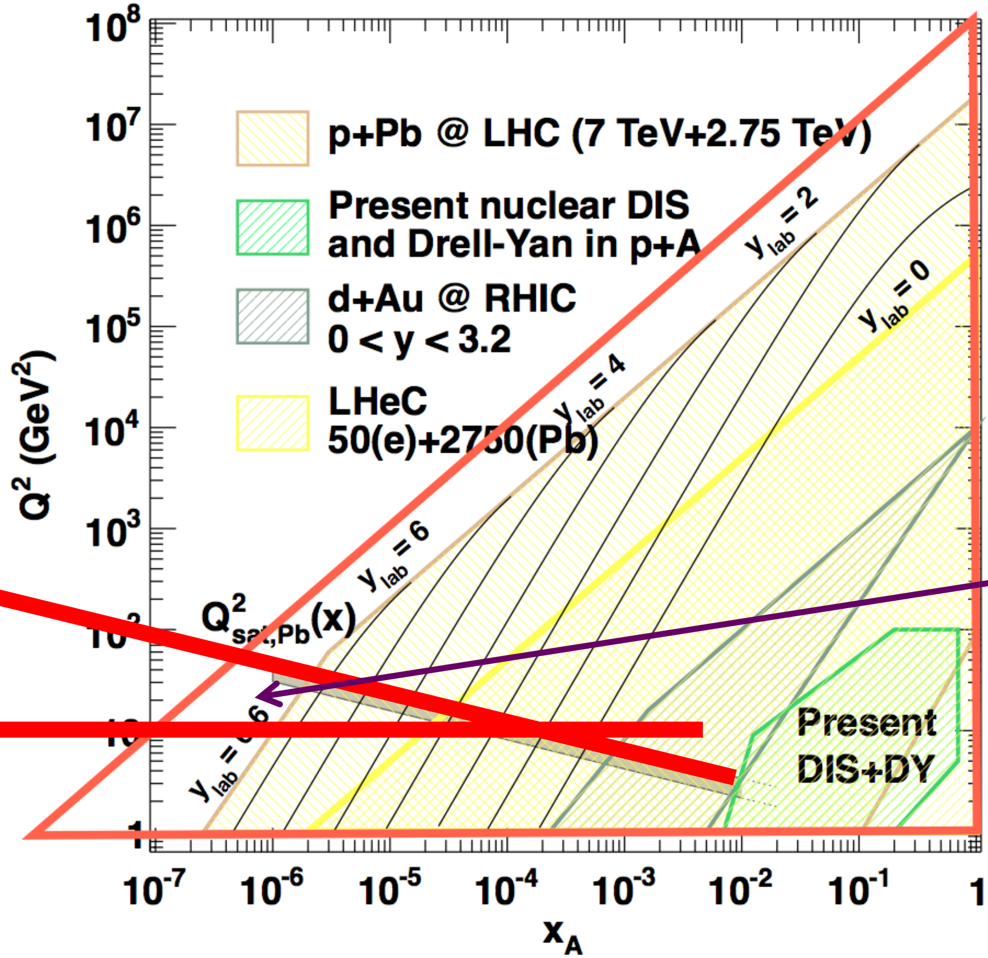
- ❑comparison with HE-LHC
- ❑if cost forces machine stag

Could p-Pb @ FHC be the main driver for a programme with nuclear beams?



Interests include:
- n-pdfs (linear evolution)
- Tests of saturation physics (i.e. sensitivity to non-linear evolution)
- Hard probes in simpler environments
- Collective phenomena in small systems (constraints from small multiplicity less severe)

Saturation physics …



Assuming 50+20 FHC

$x_{\rm FCC} \sim x_{\rm LHC}\, e^{-2}$

Apparently moderate increase, but …

This is the triangle relevant for testing non-linear evolution. And this triangle opens up substantially!

Conclusion slide:

No Conclusions yet!