Design of a toy MonteCarlo model to predict experimental precision on flow measurement

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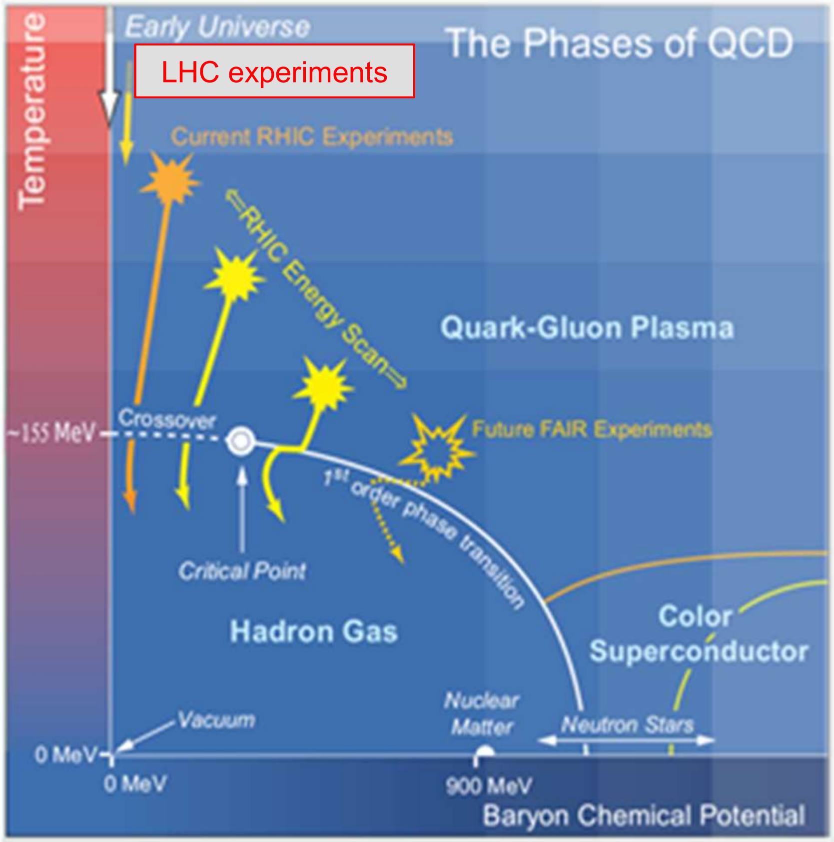
Outline

- The heavy ion collisions and QGP
- QGP anisotropic flow (v_n)
- The goals of the project
- Results

QGP and heavy ion collisions

Quark-Gluon Plasma (QGP)

- Free quark and gluon soup
- Produced few μs after the Big Bang
- Predicted by Quantum ChromoDynamics (QCD)

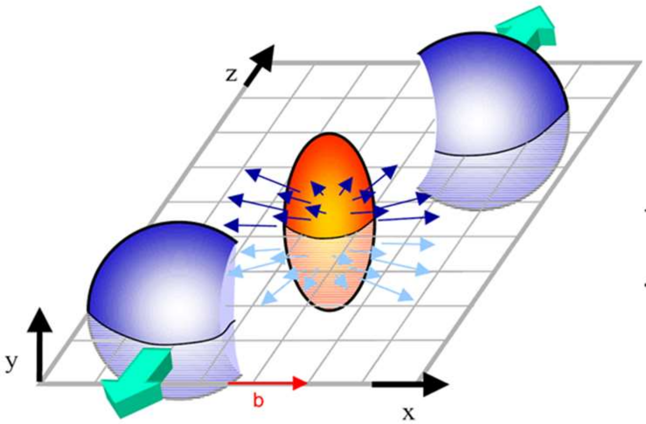


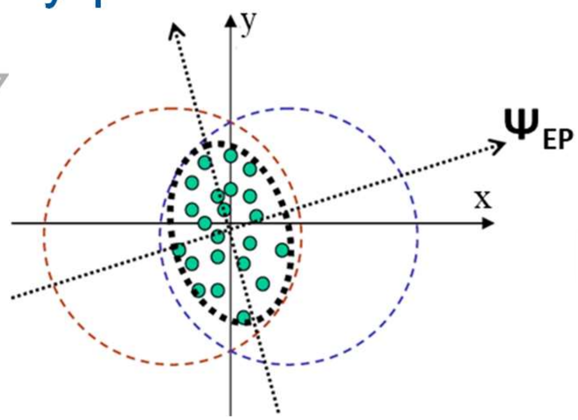
How to study QGP at the LHC?

- Heavy ion (Pb-Pb) collisions: little bang
- High temperature and zero density

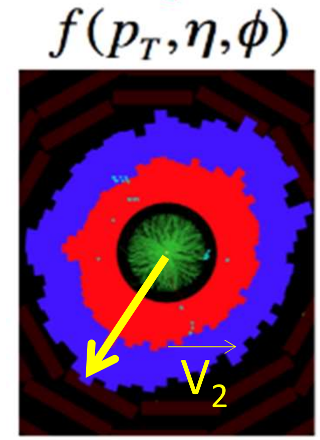
QGP – a nearly perfect fluid

It behave a nearly perfect fluid → very small viscosity





Flow



Initial state

Final state

Characteristic patterns of the anisotropic:

Initial spatial/momentum anisotropy → **final state particle** distribution Φ anisotropy

$$\frac{dN}{d\Phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\Phi - \Psi_{EP}))$$

Where Φ is azimuthal angle , v_n are Fourier coefficients and Ψ_{EP} is the reaction plane angle

The goals of the project

- Make a prediction on v_n measurement precision (using cumulant)
- Check that cumulant calculations and error calculations are valid at all M and v_n values
    - σ_{v_n} should scale as $M \times v_n^2$ if $M \times v_n^2 \gg 1$

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Why?

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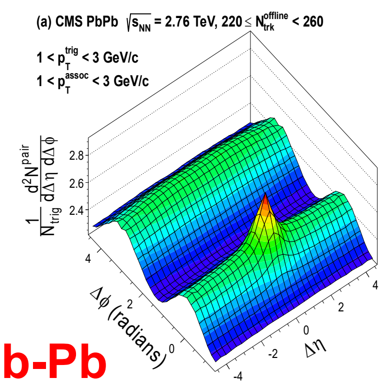
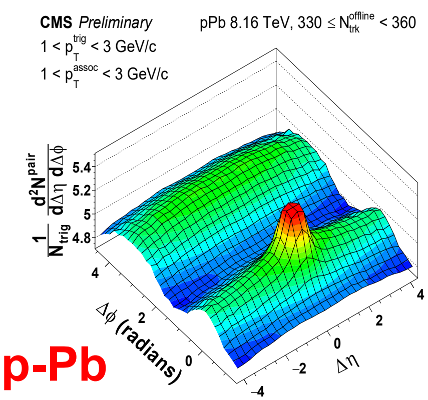
Why?

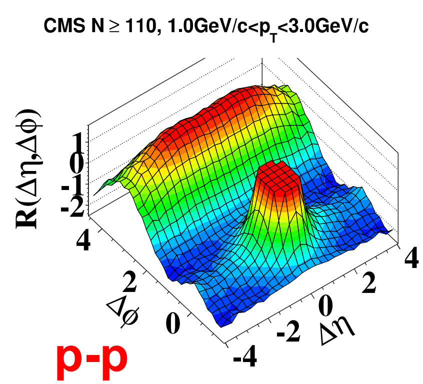
Flow (Ridge) can be observed in all collisions



Pb-Pb

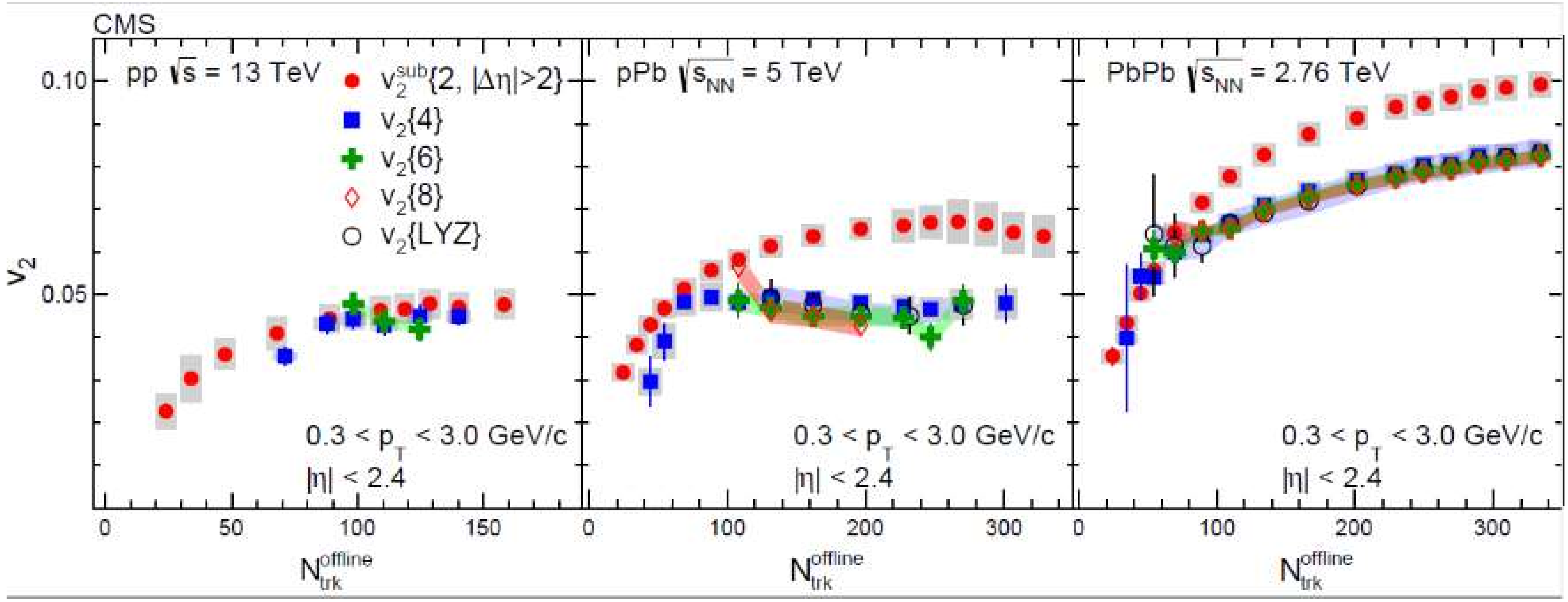


p-Pb



p-p

The goals of the project (II)



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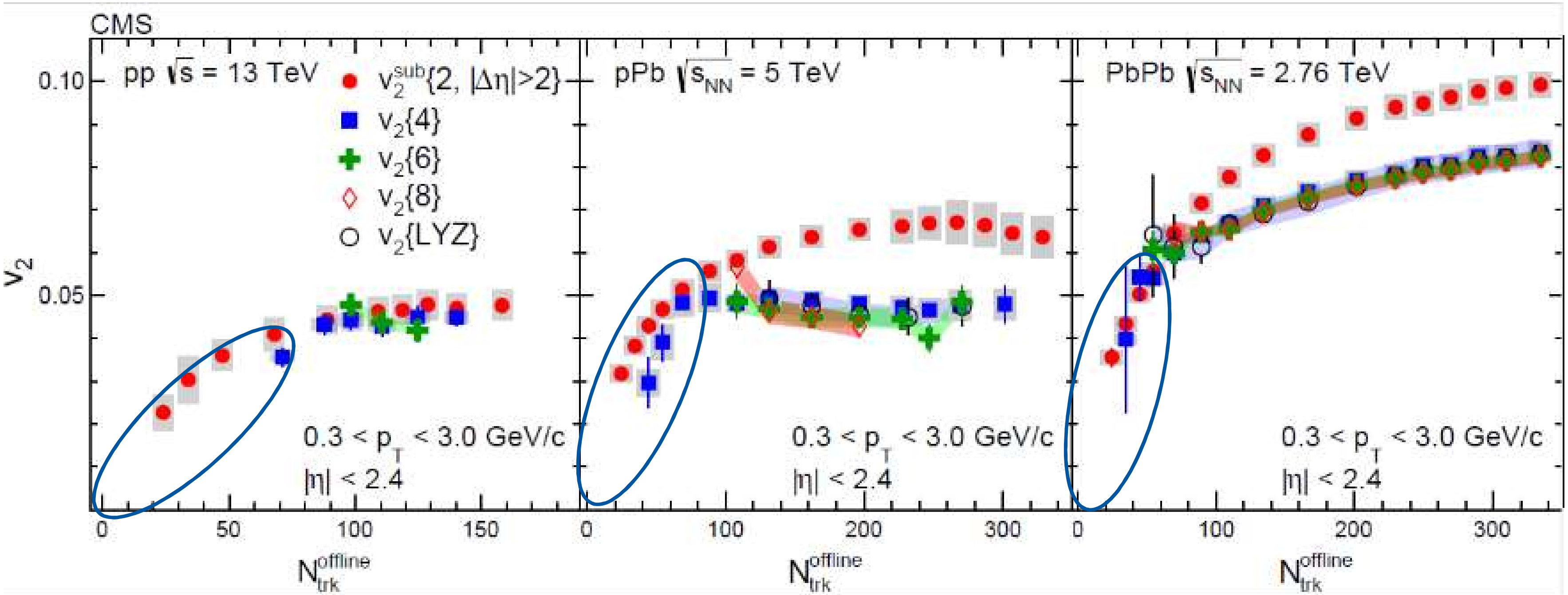
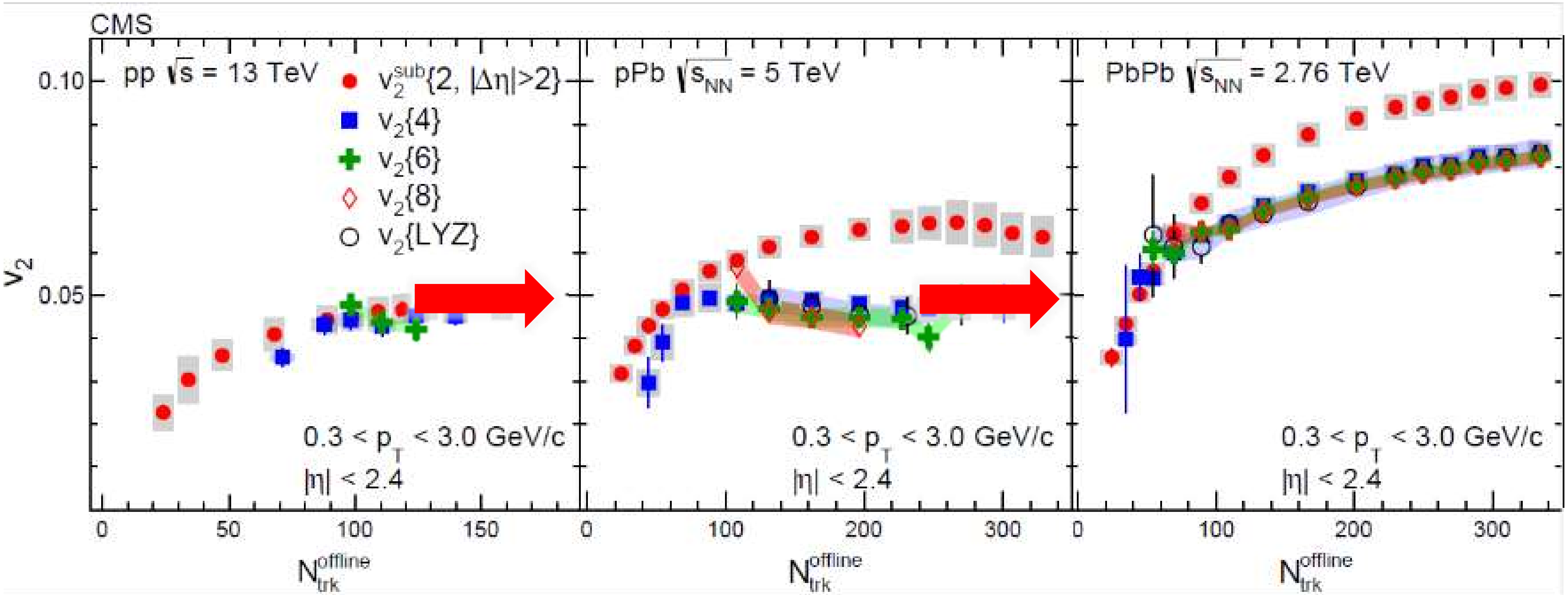


→ **Are cumulant still valid to extract v_n at low multiplicity?**

The goals of the project (II)



→ **Are cumulant still valid to extract v_n at low multiplicity?**

→ **How much more events do we need to extend our multiplicity reach in small systems?**

Extracting v_n coefficient : Cumulants

2-particle cumulant correlation:

$$Q_n = \sum_{i=1}^{M} e^{in\phi_i} \qquad <2>_{n,n} = \frac{|Q_n|^2 - M}{M(M-1)} \qquad v_n\{2\} = \sqrt{\ll 2 \gg_{n,n}}$$

Fluctuation (width) of v_n distribution

$$v_n\{2\}^2 = < v_n^2 > = < v_n >^2 + \sigma_{v_n}^2$$

mean of v_n distribution

Where

M	is a number of particles
$<2>_{n,n}$	is an average over all particles of 1 event
$\ll 2 \gg_{n,n}$	is an average over all particles and events
$v_n\{2\}$	is a Fourier coefficient of 2-particle correlation
v_n	is a true value of v_n

Can be extended to more particle correlation: 4, 6, 8, …

Toy Monte Carlo Model: Methodology

Input v_2, v_3 , v_4 distribution

Build the TRUE ϕ particle distribution

Generate events with particle randomly In the ϕ distribution

Compute 2-particle correlation

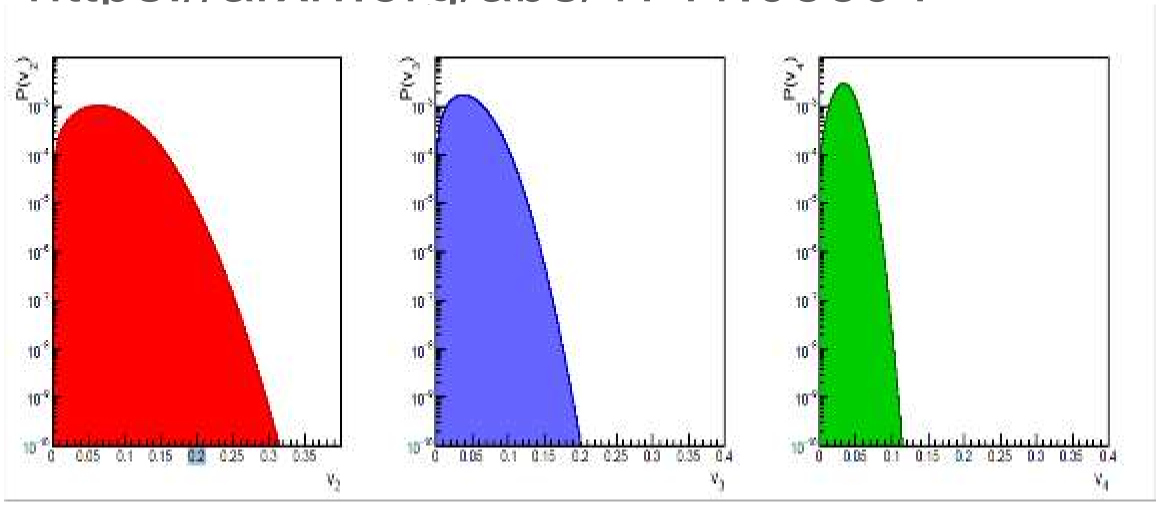
$$\ll 2 \gg = \frac{\sum_{i=1}^{Nevt} < 2 >_i}{Nevt}$$

Get the measured v_n coefficient

$$v_n\{2\} = \sqrt{\ll 2 \gg_{n,n}}$$

Input distribution and random generator

Realistic v_n distribution **based on CMS data**
https://arxiv.org/abs/1711.05594



Use this distribution to generate the **TRUE ϕ particle distribution**

With v_2=0.1,
v_3=0.05,
v_4=0.03

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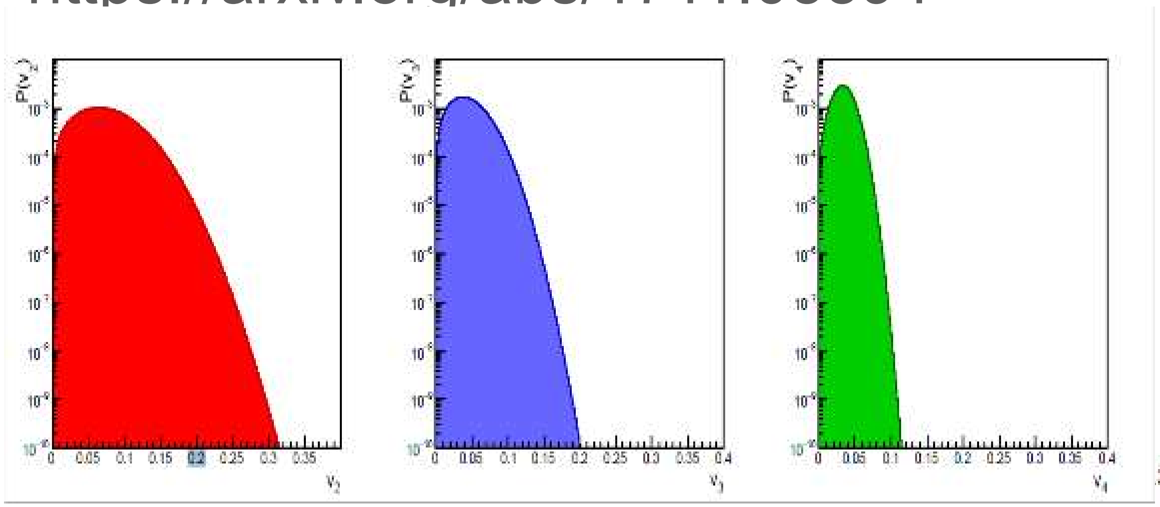
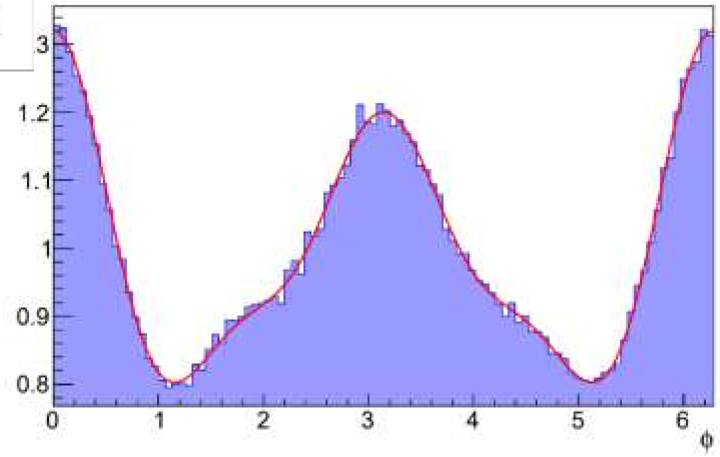


Generate **MEASURED ϕ particle distribution** using a random generator



Use this distribution to generate the **TRUE ϕ particle distribution**

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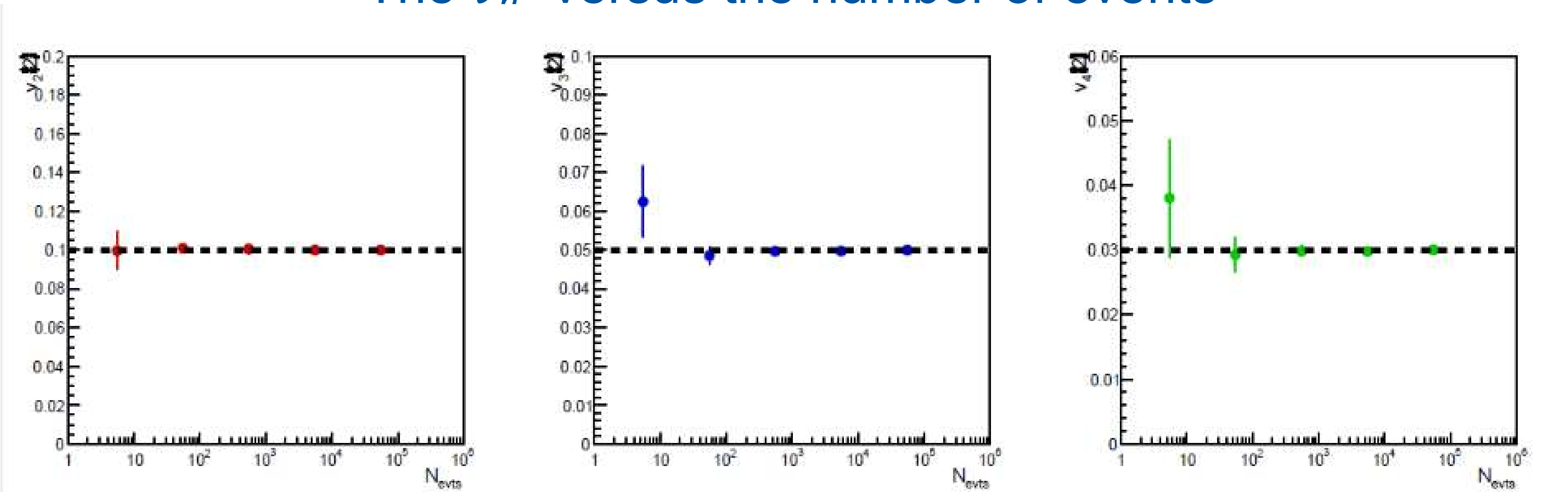
Precision predictions as a function of number of events

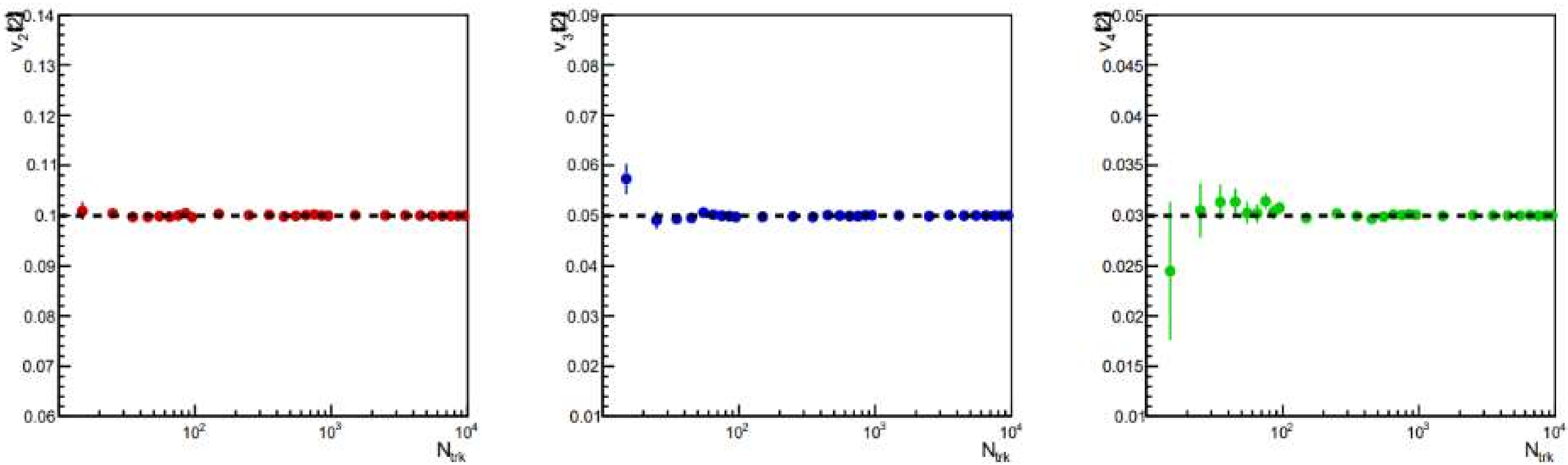
The v_n versus the number of events



**$v_n\{2\}$ depend on the $< v_n >$ and the width but in our work we fix width to be zero (no fluctuation)

Cumulant measurement as a function of multiplicity

The v_n versus multiplicity



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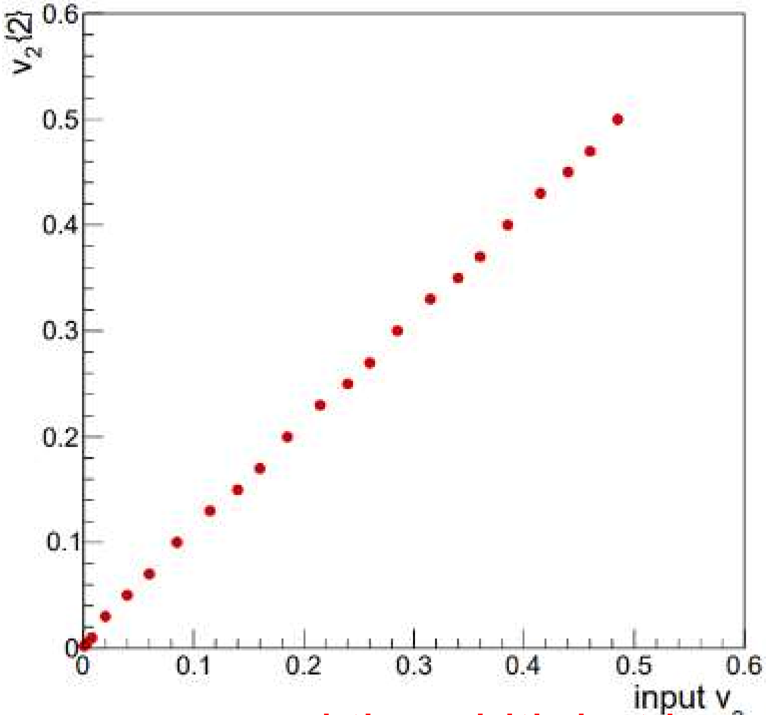
Cumulant measurement as a function of v_n strength

The measured v_n versus input v_n



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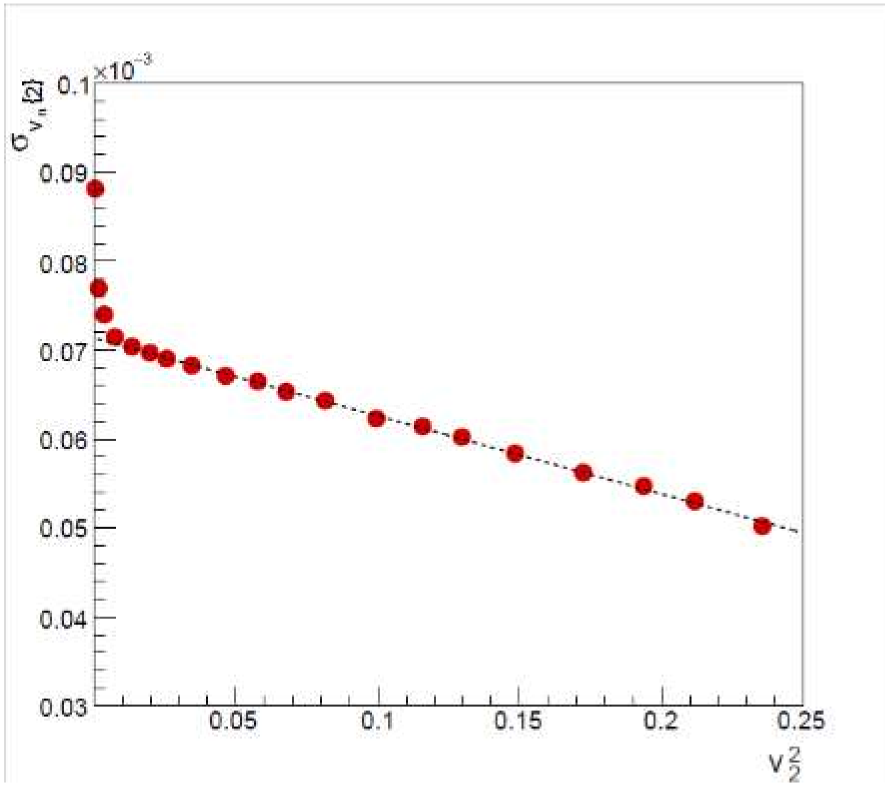
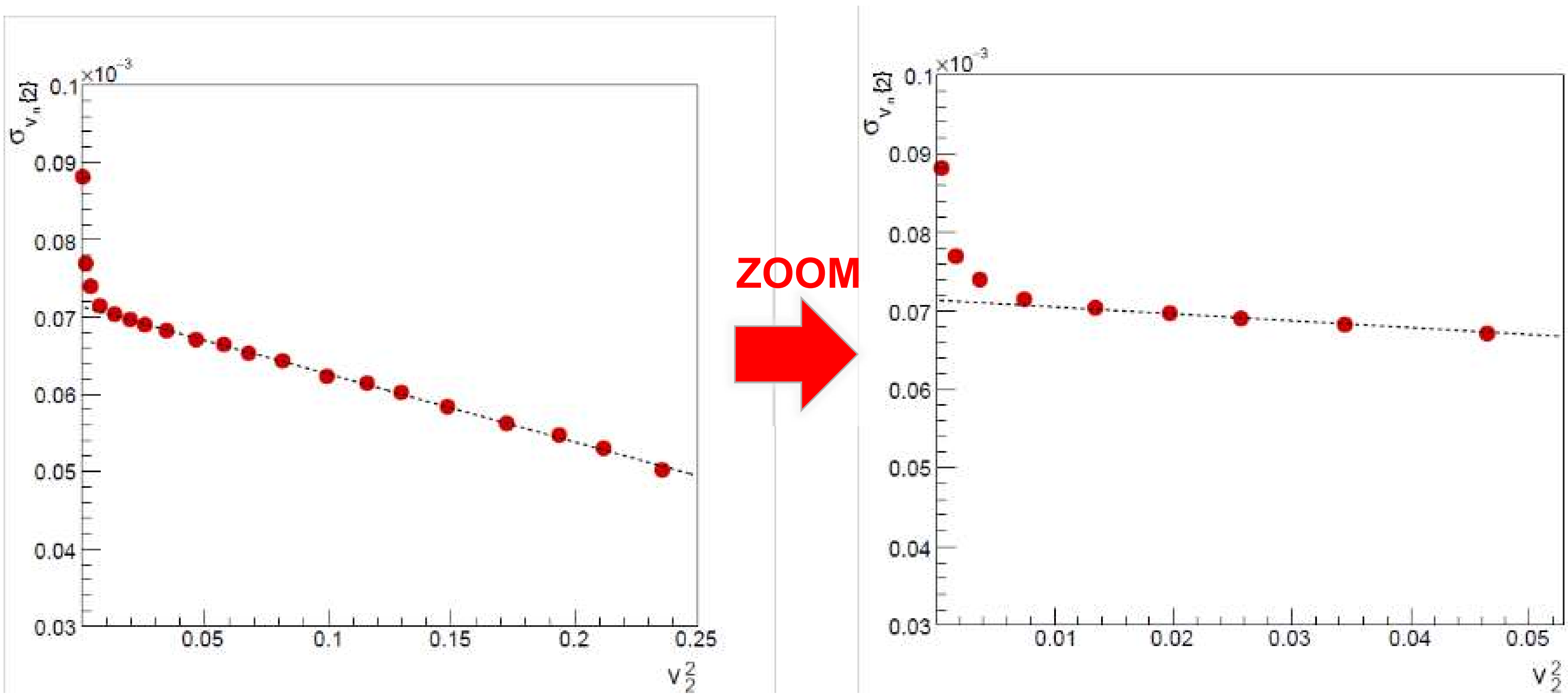
v_n statistical uncertainties calculation

- Analytical formula are useable if σ_{v_n} scales with $M \times v_n^2$



v_n statistical uncertainties calculation

- Analytical formula are useable if σ_{v_n} scales with $M \times v_n^2$
  - **When v_n is small, $M \times v_n^2 \gg 1$ is not valid anymore**



Conclusion

- A Toy Monte Carlo model created to reproduce flow like effect
- Got back correctly the input value for **multiple flow coefficients** with **different magnitudes, multiplicities, …**
- The statistical precision evolution as a function of events was extracted

The current model will allow more precise predictions on the number of events needed for all cumulant analysis in AA, pA and pp collisions

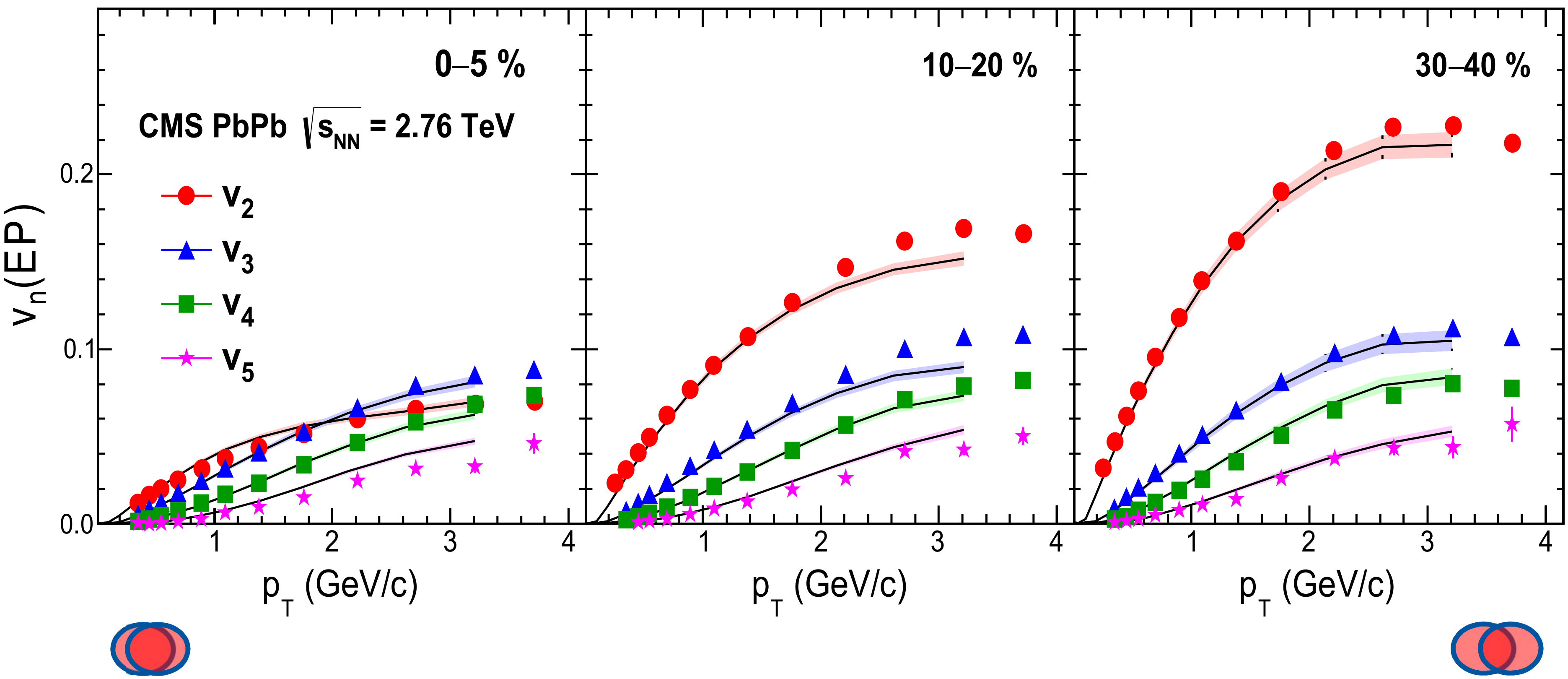
Perspectives

- Increase higher order cumulant $v_n\{4\}$, $v_n\{6\}$, $v_n\{8\}$,…
- Use realistic eta , p_T particles distribution

Thank you

Question ?

v_n and viscosity



Phys. Rev. C 89, 0449076 **CMS results**

Phys. Rev. Lett. 110, 012302 **IP glasma + MUSIC**