Towards HIC simulations at NICA energies - MexNICA Collaboration

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1st Collaboration meeting of MPD and BM@N @ NICA Facility, VBLHEP, Dubna, 11 - 13 April, 2018.

2nd Intl. Workshop on Simulations HIC @ NICA energies, Dubna, 16 - 18 April, 2018.

MexNICA at NICA-JINR

MexNICA is a Mexican collaboration
BUAP, CINVESTAV, UAS, UCOL, UNAM, USON
joint efforts for the MPD-NICA

with a proposal

Beam-Beam (Be-Be) Monitoring Detector

MexNICA team

A. Ayala (Theory/Effective Models)
I. Dominguez (Experiment/Simulations)
W. Bietenholz (Theory/Lattice)
L. Montaño (Experiment/Hardware)
E. Moreno (Experiment/Hardware)
M. Palomino (Experiment/Hardware)
M. Rodríguez (Experiment/Simulations)
G. Tejeda (Experiment/Hardware)
M. Tejeda-Yeomans (Theory/Simulations)
L. Diaz (IT-site admin), E. Murrieta (IT-tech),
M. Patiño, M. Fontaine (Electronics),
H. Zepeda (Postdoc), P. Gonzalez (CONACyT fellow)

Students:
E. Marquez, E. Quecholac, F. Morales, J. Tolentino (BUAP)
M. Alvarado (UNAM); L. Valenzuela, J. Maldonado (USON)

Applying for SSP@JINR:
M. Ayala (CINVESTAV), V. Reyna (BUAP)
P. Valenzuela, A. Guirado, R. Zamora (USON)

Focus in this talk (MexNICA research agenda)

- √ to explore the QGP through hard probe mechanisms of E and p loss/interchange
- √ to study the B-fields generated in HICs and early particle production effects
- → to identify critical behaviour in collision systems at finite T and μ
- → to investigate the pattern of χSB in the scalar/pseudo-scalar & vector/axial-vector channels
- → to identify the features of T_C using lattice techniques in order have new conjectures for QCD phase diagram

. . .

Focus in this talk: HIC simulations and flow analysis

> Key task: determine the event plane using Be-Be @ MPD

> Perform correlations/flow analysis for

(1) hadronic "jetty"events $\leftrightarrow$ compare with simulation using e.g. ADJMT toolkit

(2) primordial photons produced by strong *B*-fields $\leftrightarrow$ compare with simulation

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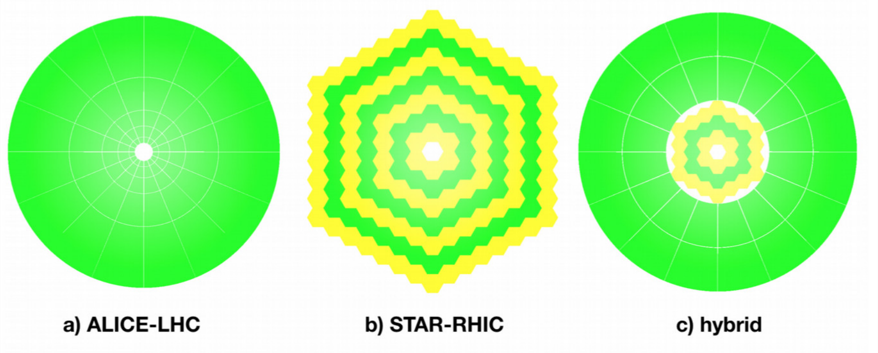
Be-Be @ MPD



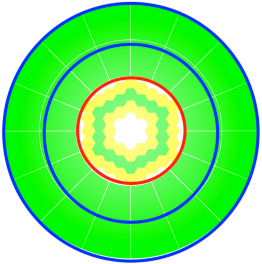
Be-Be @ MPD

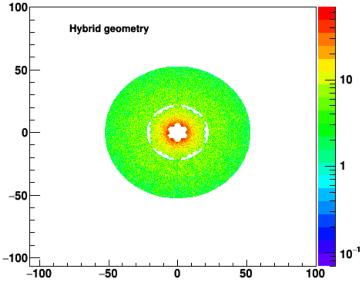
Beam-Beam monitoring detector geometry

To fulfill the trigger requirements of MPD, we propose the BE-BE geometry as follows

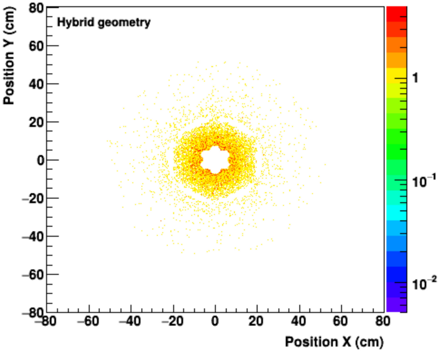
Inner part: Made of 54 hexagonal cells, 50 mm in height, arranged in three rings.

Outer part: Made of two rings segmented in 16 cells. These rings could be used to optimize the event plane resolution and centrality determination in heavy ion collisions.

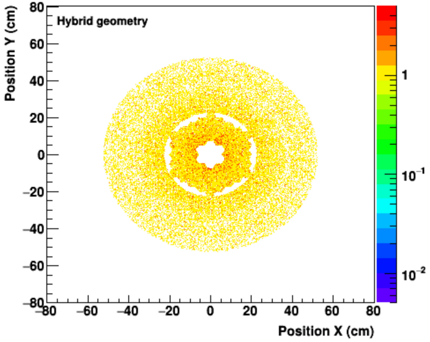




Be-Be @ MPD

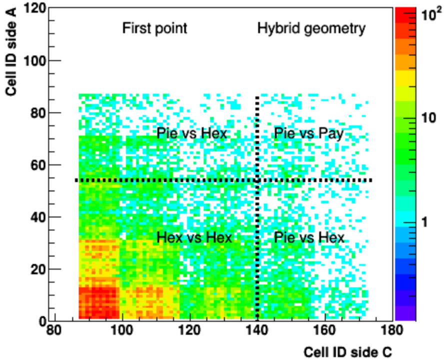


Simulation details
Number of generated events: 40 000, Minimum Bias
Enabled detectors: TPC, BE-BE
System: Au-Au
Energy in the center of mass: 11.5 GeV
Magnetic Field: 0.5 T



Simulation details
Number of generated events: 50000, Minimum Bias
Enabled detectors: TPC, BE-BE
System: p-p
Energy in the center of mass: 22 GeV
Magnetic Field: 0.5 T
Generator: pythia 8

Be-Be @ MPD



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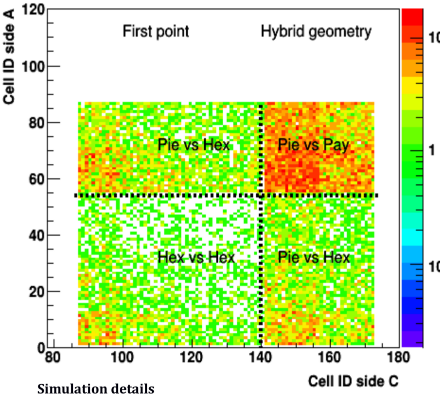

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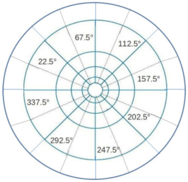
V0 @ ALICE: EP resolution

Azimuthal anisotropy

To compute the EP resolution, we assumed the angles showed in figure.

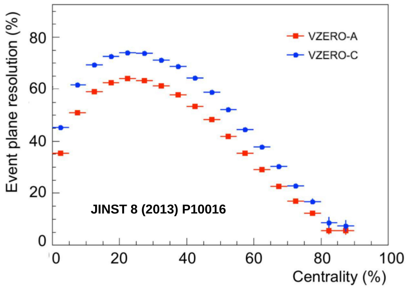
$$\Psi = \frac{1}{n} \text{ATan2}\left[\frac{\sum_{i=1}^{m} w_i \,\text{Sin}(n\varphi_i)}{\sum_{i=1}^{m} w_i \,\text{Cos}(n\varphi_i)}\right]$$



Φ_i → cell angle
w_i → multiplicity in *i-cell*
n → *order of the azimuthal anisotropy*

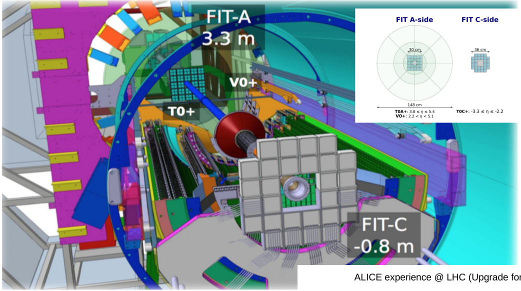
$$\text{Cos}\,(n * [\Psi_{V0+} - \Psi_{MC}])$$

ALICE experience @ LHC (Run 1)



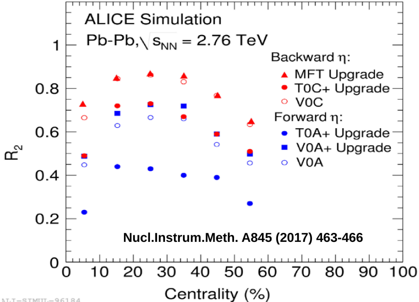
Be-Be @ MPD: potential for event plane resolution

ALICE experience @ LHC (Upgrade for Run 3)



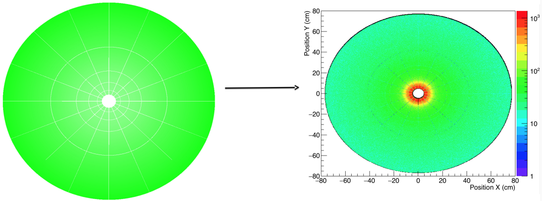
ALICE experience @ LHC (Upgrade for Run 3)

ALICE expects a resolution of EP of about 70% with the upgrade of Minimum Bias detector for 30% of centrality in PbPb collisions



Be-Be @ MPD: potential for event plane resolution

Beam-Beam monitoring detector geometry (BeBe, "pie" geometry like LHC, ALICE)



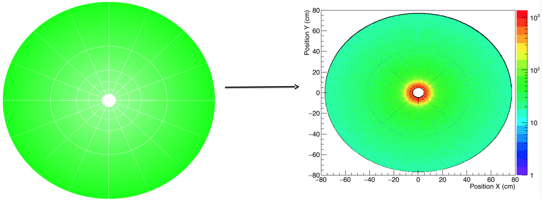
How it looks the EP resolution with BeBe?

Beam-Beam monitoring detector geometry (BeBe, "pie" geometry like LHC, ALICE)

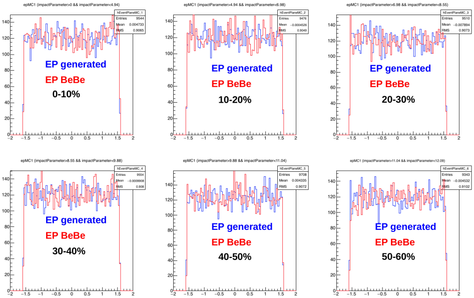
- Generator used: URQM
- Six centrality ranges: 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%
- Au-Au collisions at 9 GeV
- Software: MPD-ROOT modified with BMD geometry compiled.
- Production made in Puebla's farm

Be-Be @ MPD: potential for event plane resolution

Beam-Beam monitoring detector geometry (BeBe, “pie” geometry like LHC, ALICE)

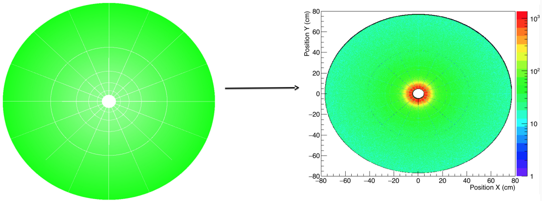


Beam-Beam monitoring detector geometry (BeBe, “pie” geometry like LHC, ALICE)



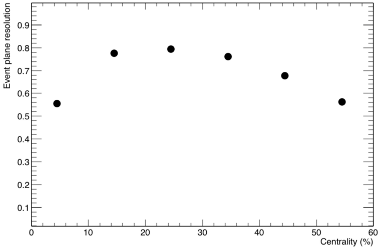
Be-Be @ MPD: potential for event plane resolution

Beam-Beam monitoring detector geometry (BeBe, “pie” geometry like LHC, ALICE)



Beam-Beam monitoring detector geometry (BeBe, “pie” geometry like LHC, ALICE)

BeBe could have a resolution of EP of about 80% with the upgrade of Minimum Bias detector from 15 % to 30% of centrality in AuAu collisions @ 9 GeV



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(2) primordial photons produced by strong *B*-fields $\leftrightarrow$ compare with simulation

ADJMT Toolkit

A. Ayala + I. Domínguez + J. Jalilian-Marian + J. Magnin + M. Tejeda-Yeomans

pQCD

MadGraph for $2 \to 2$ and $2 \to 3$ parton events in p + p collisions at RHIC and LHC energies

partons $\to$ hadrons $\to$ e-loss mechanism

hydro

linear viscous hydrodynamics

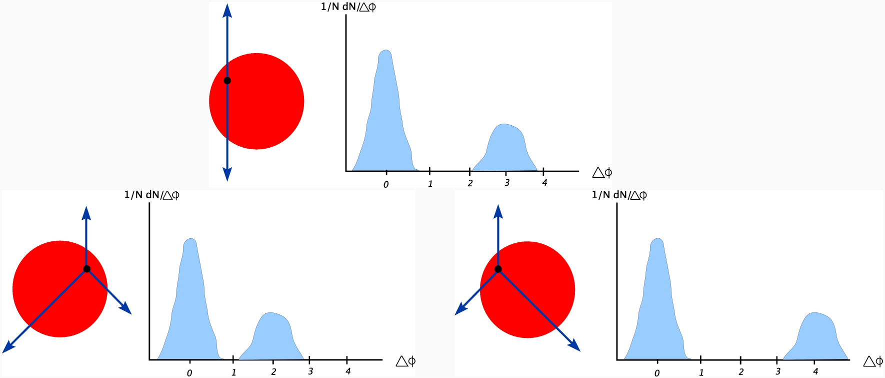
in-medium hard probe as point-like source*

hadron dist

Cooper-Frye hadronization

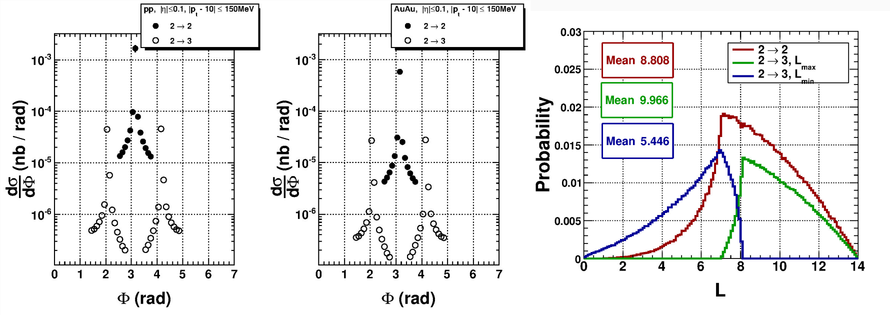
energy and momentum deposited in-medium small compared to unperturbed medium

$2 \to 2$ vs $2 \to 3$: path length

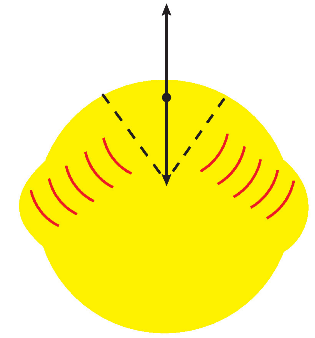


$2 \to 2$ vs $2 \to 3$: path length

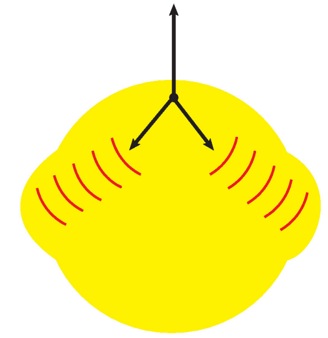
Ayala, Jalilian-Marian, Magnin, Ortiz, Paic, T-Y, PRL 104 (2010)



$2 \to 2$ vs $2 \to 3$: head shock vs Mach cones



1 parton deposits energy as shock wave (Mach cone)



2 partons deposit energy as a wake (Head shock)

ADJMT Toolkit: linearized hydro

medium energy momentum $T^{\mu\nu}$: medium in equilibrium with small perturbation

$$T^{\mu\nu} = T^{\mu\nu}_{eq} + \delta T^{\mu\nu},$$

hydro eqns with J^{ν} source of disturbance (fast moving parton)

$$\partial_\mu \delta T^{\mu\nu} = J^\nu \quad \Rightarrow \begin{cases} \delta T^{00} = \delta\epsilon \\ \delta T^{0i} = \mathbf{g} \\ \delta T^{ij} = \delta^{ij} c_s^2 \delta\epsilon - \frac{3}{4}\Gamma_s(\partial^i \mathbf{g}^j + \partial^j \mathbf{g}^i - \frac{2}{3}\delta^{ij}\nabla\cdot\mathbf{g}) \end{cases}$$

$\Gamma_s \equiv \frac{4\eta}{3\epsilon_0(1+c_s^2)}$ sound attenuation length
$c_s = \sqrt{1/3}$ speed of sound

ADJMT Toolkit: linearized hydro

If source is modelled as

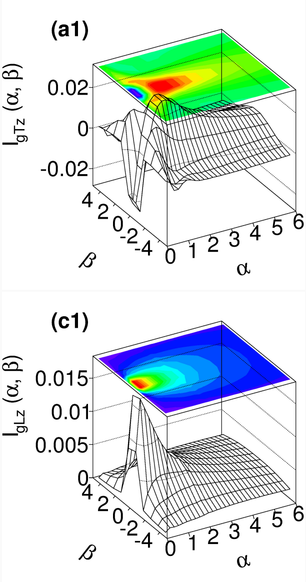
$$J^\nu(\mathbf{r},t) = \left(\frac{dE}{dx}\right) v^\nu \delta^3(\mathbf{x} - \mathbf{v}t)$$

then

$$\delta\epsilon \sim \left(\frac{dE}{dx}\right)\left(\frac{2v}{3\Gamma_s}\right)^2\left(\frac{9}{8v}\right) I_{\delta\epsilon}(\alpha,\beta)$$

$$\mathbf{g}_i \sim \left(\frac{dE}{dx}\right)\left(\frac{2v}{3\Gamma_s}\right)^2 I_{\mathbf{g}_i}(\alpha,\beta)$$

where (dE/dx) is the energy loss per unit length



ADJMT: partons $\rightarrow$ hydro+e-loss ($\delta\epsilon$, $\mathbf{g}_i$) $\rightarrow$ hadrons

Particle yield at midrapidity (Cooper-Frye):

$$\frac{dN}{d\phi}(y=0) = \int_{p_T^{\text{min}}}^{p_T^{\text{max}}} \frac{dp_T\, p_T}{(2\pi)^3} \int d\Sigma_\mu p^\mu [f(p \cdot u) - f(p_0)]$$

constant freeze-out hyper surface $d\Sigma_\mu p^\mu = d^3 r\, p_T$

equilibrium dist. (Boltzmann): $f(p_0) = e^{-p_T/T_0}$

medium's energy density and temp: ϵ_0, T_0

ADJMT: can also distinguish e-loss mode

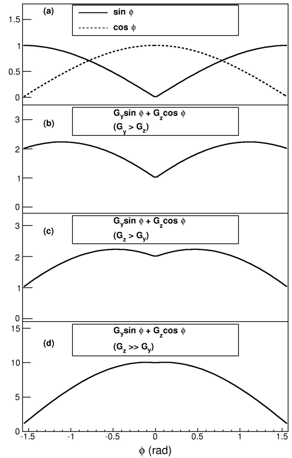
$$f(p \cdot u) - f(p_0) \simeq \left(\frac{p_T}{T_0}\right)\left(\frac{\delta\epsilon}{4\epsilon_0} + \frac{\mathbf{g}_y \sin\phi + \mathbf{g}_z \cos\phi}{\epsilon_0(1+c_s^2)}\right) e^{-p_T/T_0}$$

Shape of distribution depends on $G_i \equiv \int d^2r\, \mathbf{g}_i$

$G_y > G_z$: $\sin\phi$ two peaks away from $\phi = 0$

$G_z > G_y$: $\cos\phi$ two peaks close to $\phi = 0$

$G_z \gg G_y$: peaks become one



ADJMT: partons → hydro+e-loss → hadrons → v_n

Cooper-Frye formula ⇝ azimuthal angle distributions at midrapidity ⇝ flow coefficients:

event plane angle of the *n*-th order for the *i*-th event

$$\tan n\Psi_n^i = \frac{\langle \sin n\phi \rangle_i}{\langle \cos n\phi \rangle_i},$$

average over the particle ensemble at midrapidity in a single event

$$\langle \mathcal{O} \rangle_i = \frac{\int dp_T d\phi \, \mathcal{O} \, \frac{dN^i}{dp_T d\phi}}{\int dp_T d\phi \frac{dN^i}{dp_T d\phi}}$$

ADJMT: partons → hydro+e-loss → hadrons → v_n

Cooper-Frye formula ⇝ azimuthal angle distributions at midrapidity ⇝ flow coefficients:

event plane angle of the n-th order for the i-th event

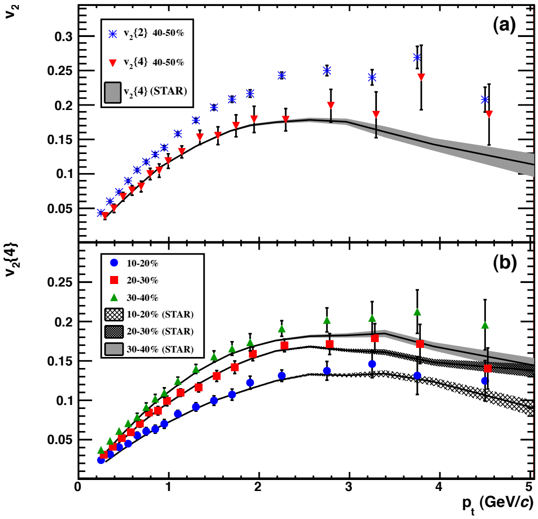
$$\tan n\Psi_n^i = \frac{\langle \sin n\phi \rangle_i}{\langle \cos n\phi \rangle_i},$$

average over all events

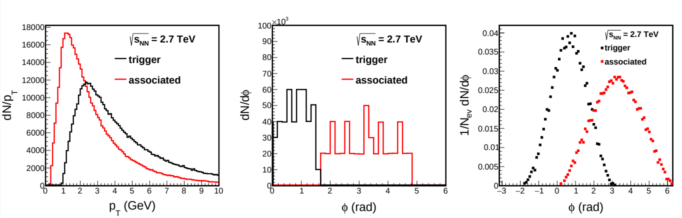
$$v_n(p_T) = \frac{1}{N_{\text{ev}}} \sum_j^{N_{\text{ev}}} \frac{\int d\phi \cos n(\phi - \Psi_n^i) \frac{dN^i}{dp_T d\phi}}{\int d\phi \frac{dN^i}{dp_T d\phi}}$$

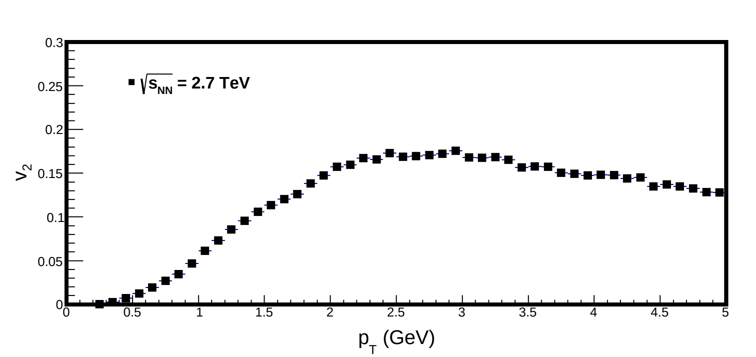
v_2: Pb-Pb @ 2.76 TeV ALICE-LHC

ALICE Collaboration, Phys.Rev.Lett. 105 (2010).



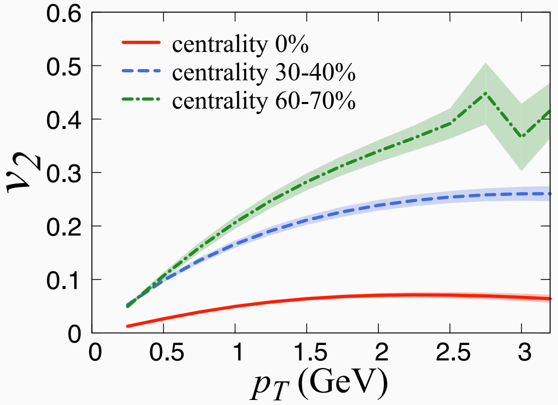
ADJMT: partons → hydro+e-loss → hadrons → v_n





v_2 from simmilar approaches

M. Okai, K. Kawaguchi, Y. Tachibana and T. Hirano, PRC 95, 054914 (2017)



ADJMT: $\hat{q} \leftrightarrow \Delta E \leftrightarrow \eta/s$

Ayala, Dominguez, Jalilian-Marian and T-Y (2016)
Phys.Rev. C94 (2016) no.2, 024913

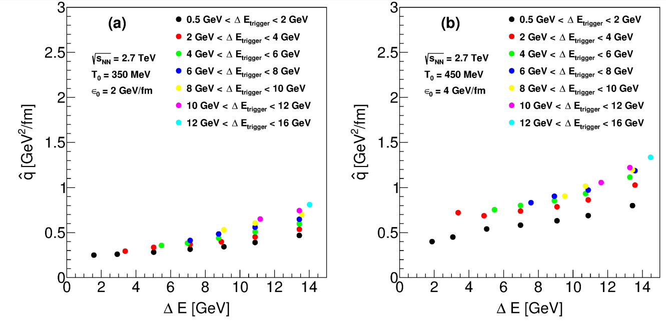
part. mom. dist. around the direction of motion of a fast moving parton in hydro approx.

$$\mathcal{P}(p_T, r, \phi) \equiv \frac{1}{N}\frac{dN}{p_T dp_T d\phi d^2 r} = \frac{1}{N}\frac{\Delta\tau(\Delta y)^2}{(2\pi)^3}\frac{p_T^2}{T_0}e^{-p_T/T_0}\left(\frac{\delta\epsilon}{4\epsilon_0} + \frac{\mathbf{g}_y \sin\phi + \mathbf{g}_z \cos\phi}{\epsilon_0(1+c_s^2)}\right)$$

avg mom squared carried by the disturbance (transverse to v)

$$\langle q^2 \rangle \equiv 2\int d^2 r \int dp_T p_T \int_0^{\pi/2} d\phi\, \mathcal{P}(p_T, r, \phi) p_T^2 \sin^2\phi,$$

$\hat{q}$ and ΔE in an expanding medium



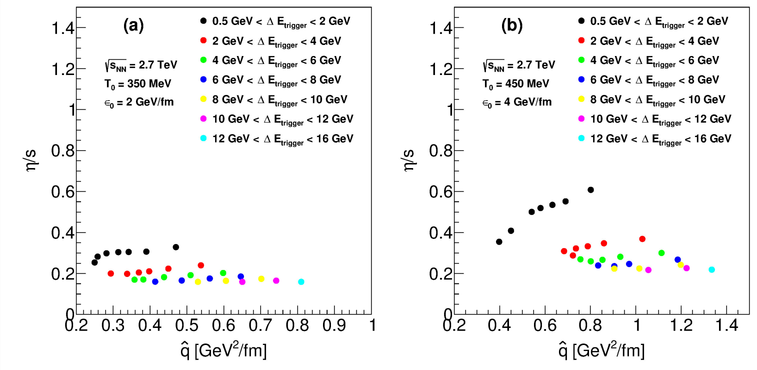
$$\hat{q}(\Delta E) \sim \begin{cases} 0.2 - 1\ \mathrm{GeV}^2/\mathrm{fm}\ \ (T_0 = 350\ \mathrm{MeV}) \\ 0.4 - 1.5\ \mathrm{GeV}^2/\mathrm{fm}\ \ (T_0 = 450\ \mathrm{MeV}) \end{cases}$$

$$\frac{\hat{q}(\Delta E)}{T^3} \sim \begin{cases} 0.9 - 4.6\ \ (T_0 = 350\ \mathrm{MeV}) \\ 0.8 - 3.3\ \ (T_0 = 450\ \mathrm{MeV}) \end{cases}$$

$$\frac{\hat{q}}{T^3} \sim 3.7 \pm 1.4\ \text{ at LHC}$$

JET Collaboration PRC 90 (2014)

η/s and $\hat{q}$ in an expanding medium



$$\frac{T^3}{\hat{q}} \begin{cases} \approx \frac{\eta}{s} , & \text{weakly-coupled} \\ \ll \frac{\eta}{s} , & \text{strongly-coupled} \end{cases}$$

Majumder, Muller, Wang, PRL 99 (2007); Casalderrey-Solana, Wang, PRC (2008); Qin, Wang, IntJMP E 24 (2015).

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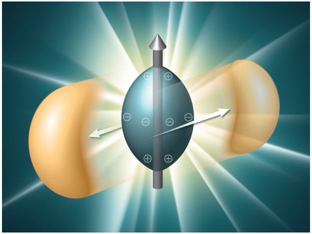
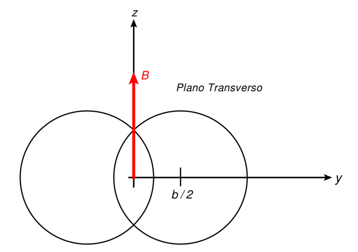
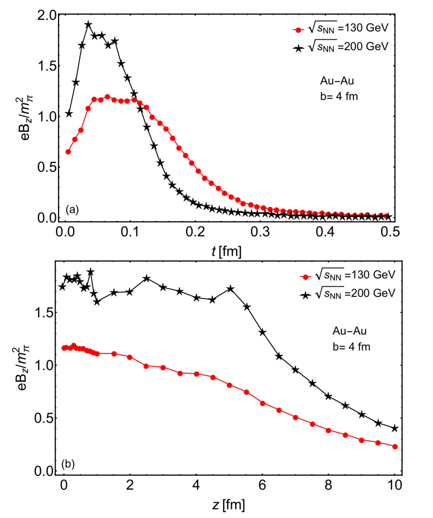
Magnetic fields in HICs

V. Skokov, A.Yu. Illarionov (Trento U.), V. Toneev, Int.J.Mod.Phys. A24 (2009).





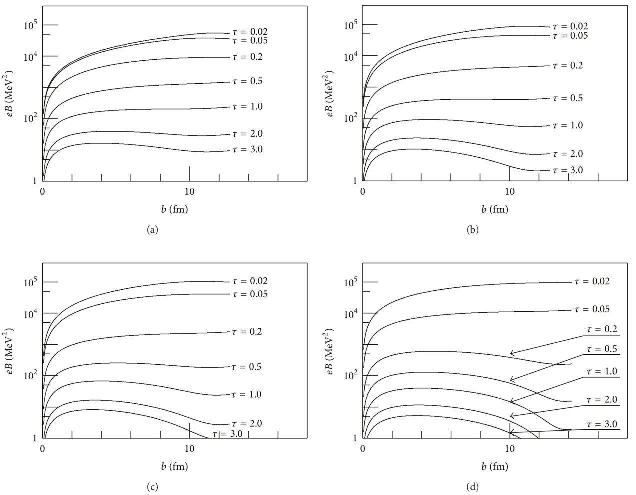


J. Castaño-Yepes, Ph. D. Thesis, UNAM, 2018

Magnetic fields in HICs

Y. Zhong, C.-B. Yang, X. Cai, S.-Q. Feng, Adv. High Energy Phys. 2014, 193039 (2014)
$\sqrt{s_{NN}}$ = 62.4 GeV (a), 130 GeV (b), 200 GeV (c), 900 GeV (d)

RHIC: $(0.1-1)m_\pi^2$, LHC: $(10-15)m_\pi^2$, $m_\pi^2 \approx 10^{19}$G



Prompt photon yield induced by B-fields in HIC

Ayala, Castano-Yepes, Dominguez, Hernandez, Hernandez-Ortiz and T-Y
Phys.Rev. D96 (2017) no.1, 014023; Phys.Rev. D96 (2017) no.11, 119901

2. Photon Production by gluon fusion

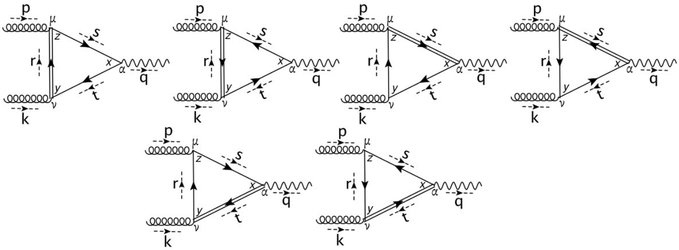


Figure 1: Dominant contribution for photon production by gluon fusion in presence of a magnetic field. The double lines represent that the corresponding propagator is in the first Landau Level $S^{(1)}$. The single lines represents the propagator in the lowest Landau Level $S^{(0)}$. The arrows in the propagators represent the direction of the flow of charge. The arrows at the sides of the propagator lines represent the momentum direction.

Prompt photon yield induced by B-fields in HIC

Ayala, Castano-Yepes, Dominguez, Hernandez, Hernandez-Ortiz and T-Y
Phys.Rev. D96 (2017) no.1, 014023; Phys.Rev. D96 (2017) no.11, 119901

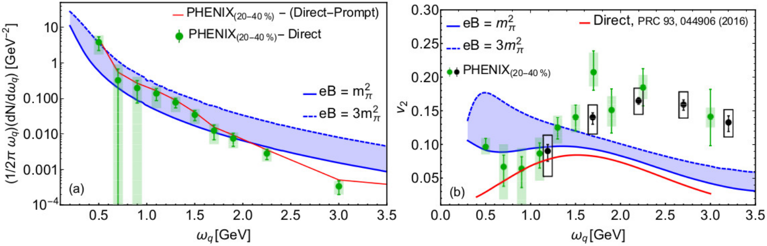
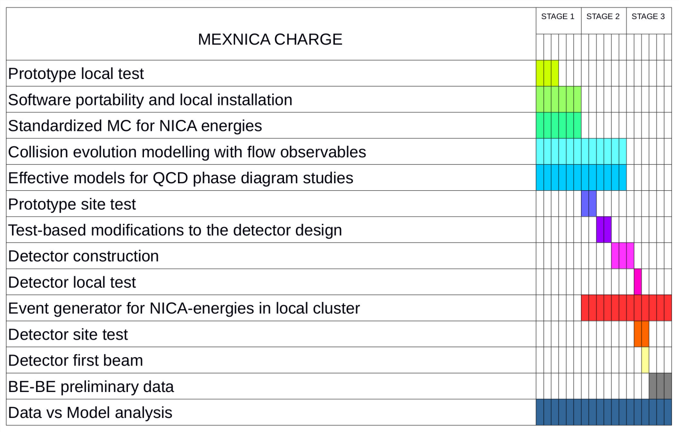


Figure 2: (Left) Difference between PHENIX photon invariant momentum distribution [11] and direct (points) or direct minus prompt (zigzag) photons from Ref. [8] compared to the yield from the present calculation. (Right) Harmonic coefficient v_2 combining the calculation of Ref. [8] and the present calculation compared to PHENIX data [12]. Curves are shown as functions of the photon energy for central rapidity and the centrality range 20-40%. Only the experimental error bars are shown. The bands show variations of the parameter eB within the indicated ranges and computed with $\alpha_s = 0.3$, $\Lambda_s = 2$ GeV, $\eta = 3$, $\Delta\tau_s = 1.5$ fm, $R = 7$ fm, $\beta = 0.25$ and $\chi = 0.8$.

MexNICA commitment to the future at NICA

- √ signed collaboration agreements between JINR and mexican institutions
- √ regional, national (CONACyT) and international grants
- √ vested interests through national labs (UNAM, CINVESTAV, BUAP, UAS): instrumentation/electronics, computing/IT services
- √ shifts, software R&D, event farm @ local cluster, cluster admin

MexNICA commitment to the future at NICA



Final remarks

Collaboration agreements between JINR and mexican institutions, signed!

Finalize geometry simulation and electronics design/test

Prepare beam test for prototype

NICA/MPD software and data admin at ICN-UNAM

MANY THANKS