Constraining models of initial conditions with elliptic and triangular flow data

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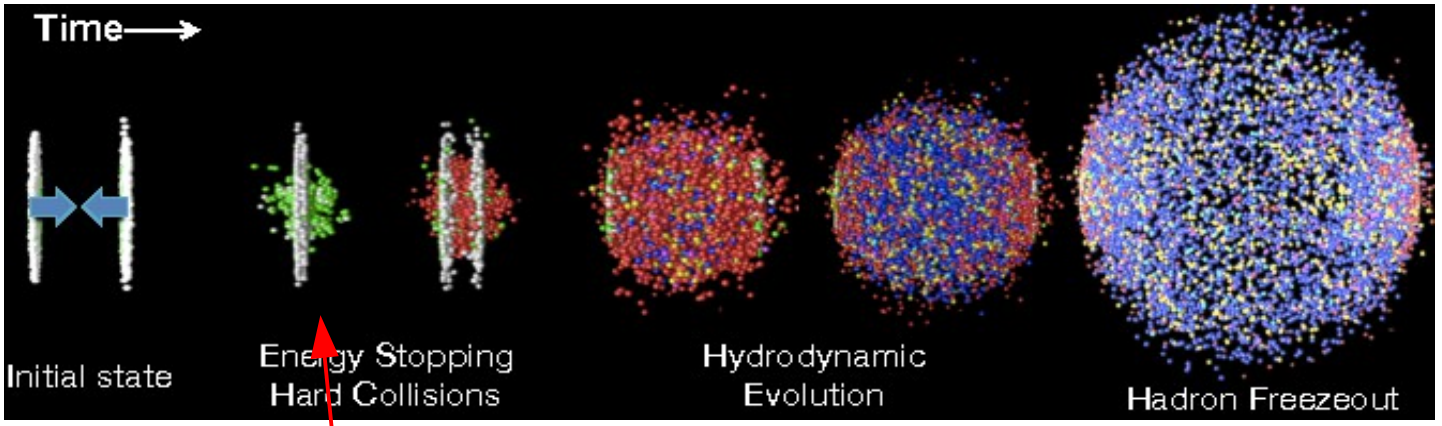
IS2013
Illa da Toxa, Spain
8-14 September 2013

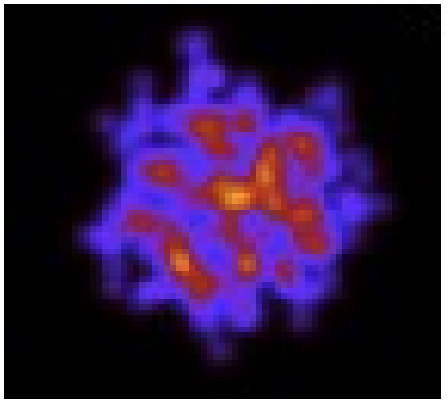
Heavy-ion collision



We are interested in initial energy-density profile at t_0.

Initial conditions

B.Schenke



initial energy-density

- **Fluctuations:**

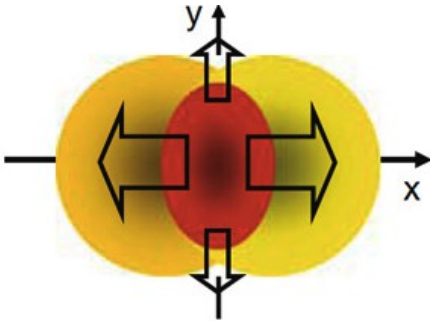
-From wave-functions of incoming nuclei

-How large are these fluctuations?

- **Non-central collisions:**

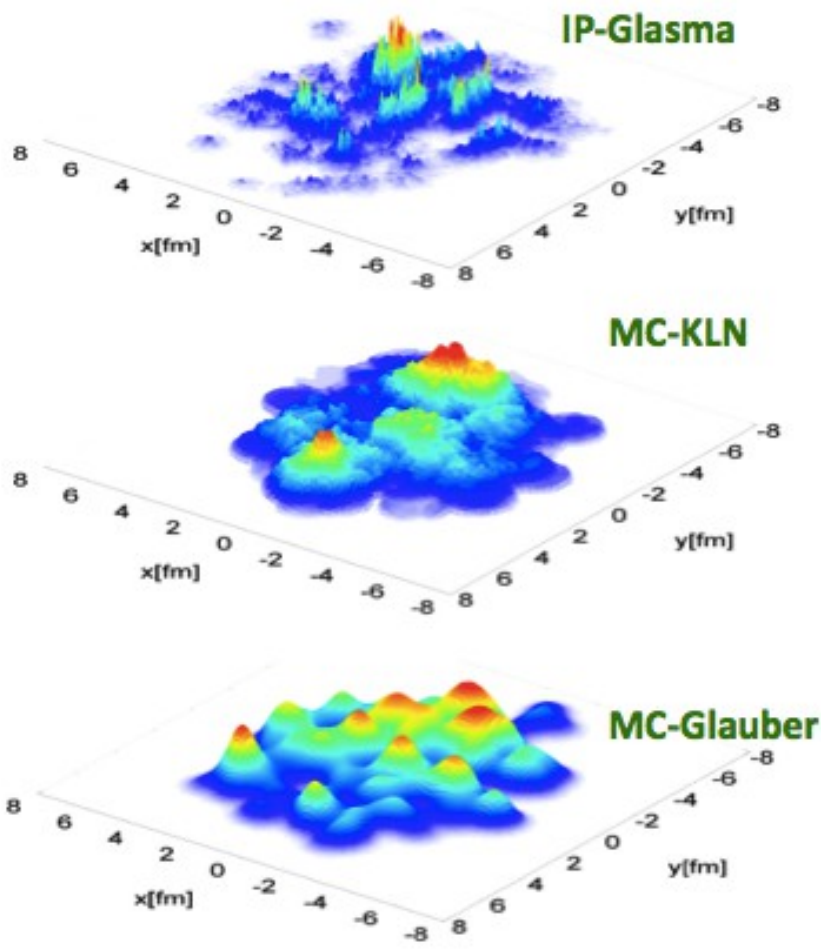
-Almond shape of overlap area

-How elongated is the almond?



- **Can we constrain models using experimental data?**

Monte-Carlo models of Initial state



Schenke, Venugopalan

- **Glauber models:**

  MC-Glauber

- **QCD-inspired models:**

  MC-KLN

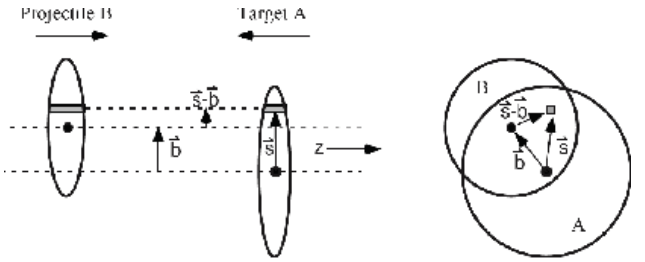
  MCrcBK

  IP Glasma

  DIPSY

MC Glauber

- Positions of nucleons within nuclei sampled through Monte-Carlo
- Nucleons move on straight lines
- Interaction if distance is $< \sqrt{\sigma_{NN}/\pi}$



- Wounded nucleon: nucleon, interacting a least once
- Model of energy-density: typically, each wounded nucleon is represented as gaussian source, so energy-density=sum of gaussians
- Weight of each wounded nucleon varies with # of binary collisions

B. Alver, M. Baker, C. Loizides and P. Steinberg,, arXiv:0805.4411

QCD-inspired models

- **MC-KLN**: k_T factorization, positions of the nucleons fluctuate

  Drescher and Nara, Phys. Rev. C 76, 041903 (2007), Albacete and Dumitru, arXiv:1011.5161

- **MCrcBK**: + fluctuations added to match multiplicity distribution in pp collisions

  Dumitru and Nara, Phys. Rev. C 85, 034907 (2012)

- **DIPSY**: +multiple gluon cascade

  Flensburg, arXiv:1108.4862

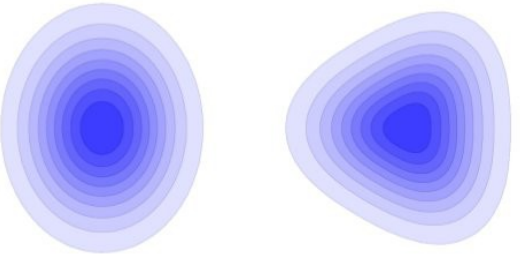
- **IP Glasma**: no k_T factorization, non-linearities, fluctuations of color charges within a nucleon

  Schenke, Tribedy, Venugopolan: PRL108 (2012), 252301

Hydro evolution

- The initial profile expands hydrodynamically
- Breaks down into particles: we can describe with Fourier series:

$$\frac{dN}{d\varphi} = \frac{N}{2\pi}\left(1 + \sum 2v_n \cos\left(n\left(\varphi - \Psi_n\right)\right)\right)$$



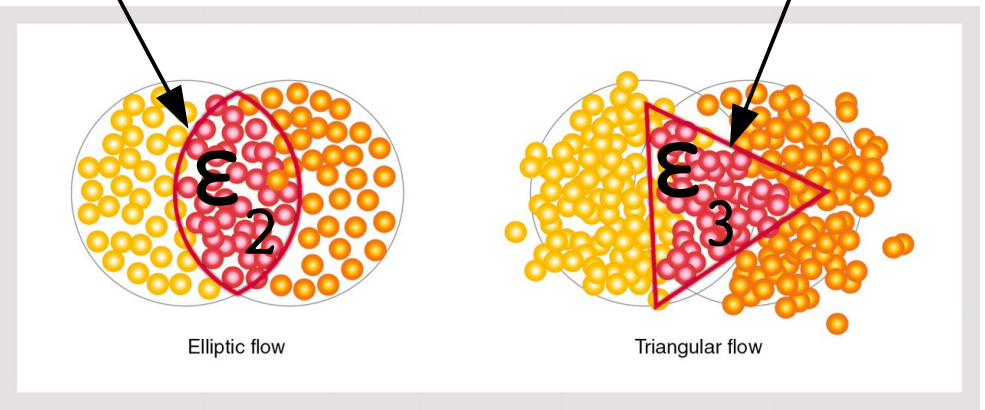
$n = 2$ elliptic flow

$n = 3$ triangular flow

Ellipticity and triangularity

B. Alver et al.

PRL. 98, 242302 (2007)



H. Petersen, G. -Y. Qin, S. A. Bass and B. Muller,

PRC 82, 041901 (2010)

Hydro response to the initial state is linear:

- Originates from the elliptic shape of the overlap area

$$v_2 \propto \varepsilon_2 \text{ and } v_3 \propto \varepsilon_3$$

- Generated by fluctuations

Participant eccentricity is:

$$\varepsilon_n = \frac{\left| \int e(r,\varphi) r^n e^{in\varphi} r\, dr\, d\varphi \right|}{\left| \int e(r,\varphi) r^n r\, dr\, d\varphi \right|}$$

Methodology

The linear-response approximation:

$$v_n = \left(\frac{v_n}{\varepsilon_n}\right)_{hydro} \varepsilon_n$$

Experimental data

Average over event, r.m.s.

hydro

const

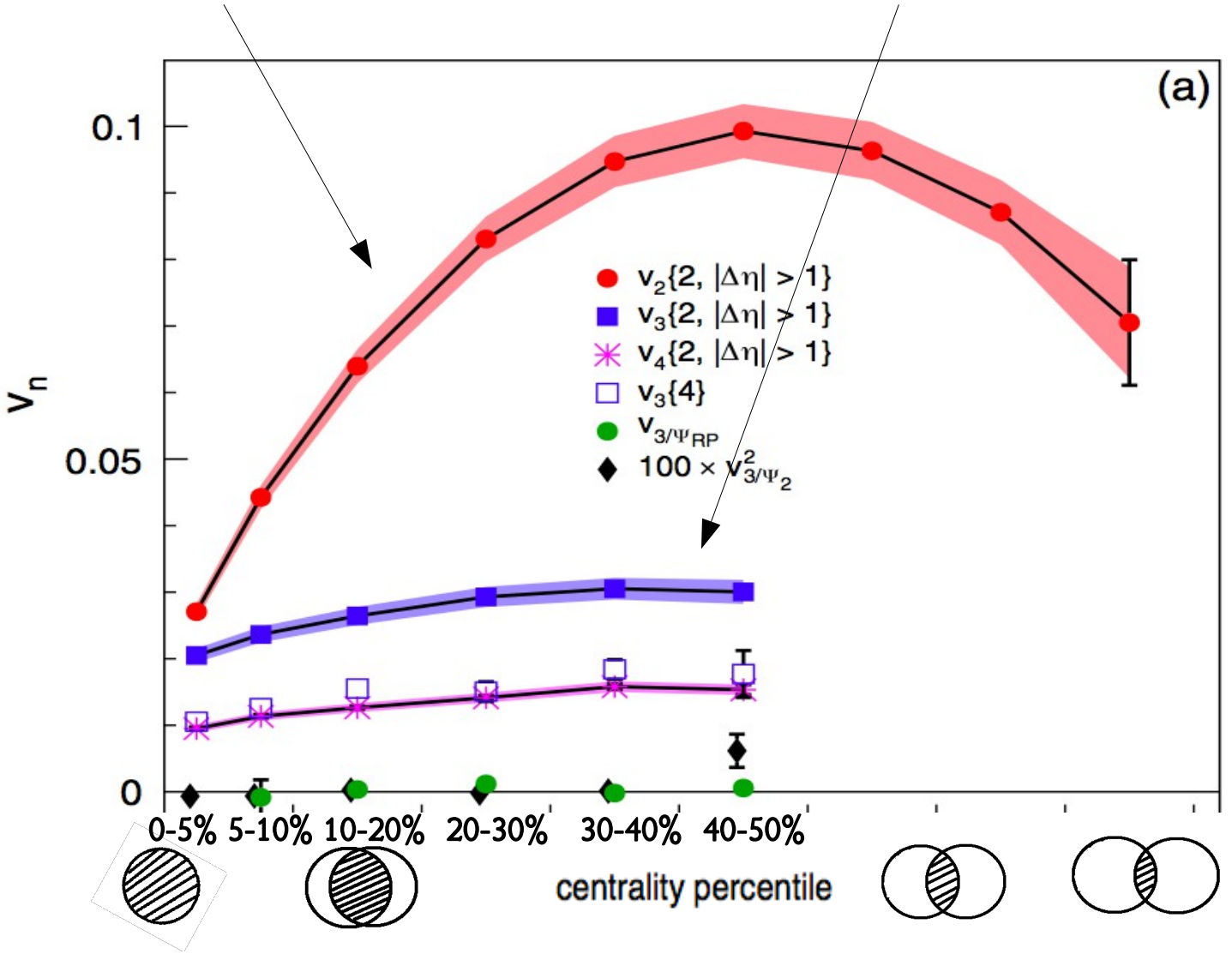
We can extract ε_2 and ε_3 !

-> r.m.s.

ER, J.-Y.Ollitrault, M.Luzum:

In preparation...

Experimental data: elliptic and triangular flow



ALICE Collaboration, Phys. Rev. Lett. 107, 032301 (2011)

Calculating the hydro response

- Initial conditions
- Relativistic hydro evolution
- Hadronization

Each step gives uncertainties!

Main uncertainty in the hydro evolution

The value of the **shear viscosity** of the strongly-interacting quark-gluon plasma.

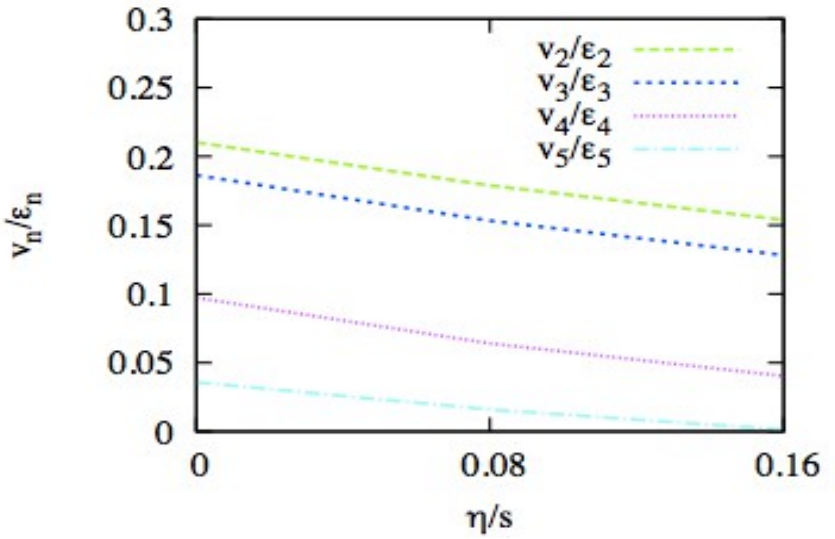
We vary:

Viscosity/entropy

η/s: from 0 to 0.24

in steps of 0.04

Viscosity influence:

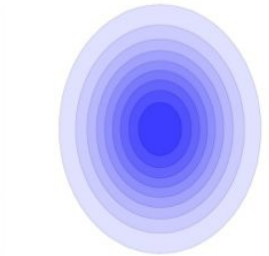


Alver, Gombeaud, Luzum, Ollitrault, Phys.Rev.C82:034913,2010

Initial conditions

Our calculation is a 2+1D viscous hydrodynamic uses as initial condition the transverse energy density ($\epsilon(r, \phi)$) profile from an optical Glauber model.

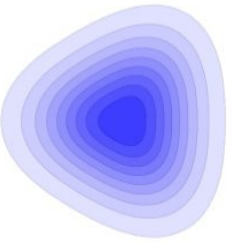
For $(v_2/\varepsilon_2)_{\text{hydro}}$



$n = 2$

For $(v_3/\varepsilon_3)_{\text{hydro}}$ the profile is deformed:

$$\epsilon(r,\phi) \rightarrow \epsilon\left(r\sqrt{1+\varepsilon'_3 \cos 3(\phi-\Psi_3)},\phi\right)$$



$n = 3$

Free parameters in initial conditions

1)Definition of the eccentricity: energy-density weighting or entropy density weighting

2)Thermalization time $\mathbf{t_0}$: from 0.5fm/c to 1fm/c

↓ **tune**

2a)Starting temperature $\mathbf{T_{start}}$ and

2b)Freezeout temperature $\mathbf{T_{fr}}$ in order to fit Multiplicity and $\langle p_t \rangle$ from experimental data

Free parameters in hadronic part

Freezeout

Viscous correction:

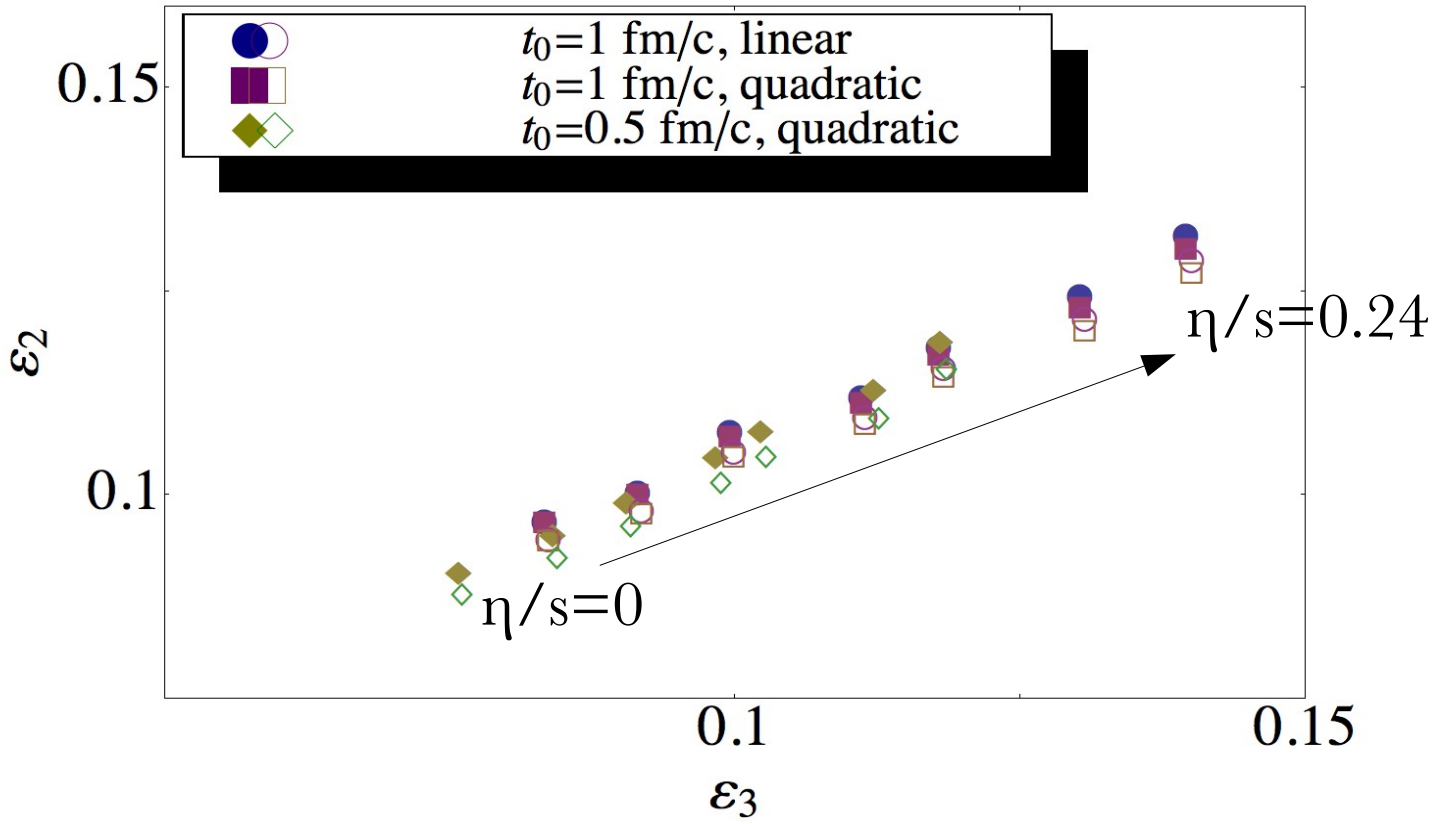
dependence on momentum p is unknown.

We test two possible ansatzs:

linear $\propto p$, quadratic $\propto p^2$

$(\varepsilon_3 , \varepsilon_2)$

$$\varepsilon_n = \frac{V_n}{\left(\frac{V_n}{\varepsilon_n}\right)_h}$$



Values of $(\varepsilon_2 , \varepsilon_3)$ spanned by hydrodynamic calculations, in combination with ALICE data for the 5% most central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.

ER, J.-Y.Ollitrault, M.Luzum:

In preparation...

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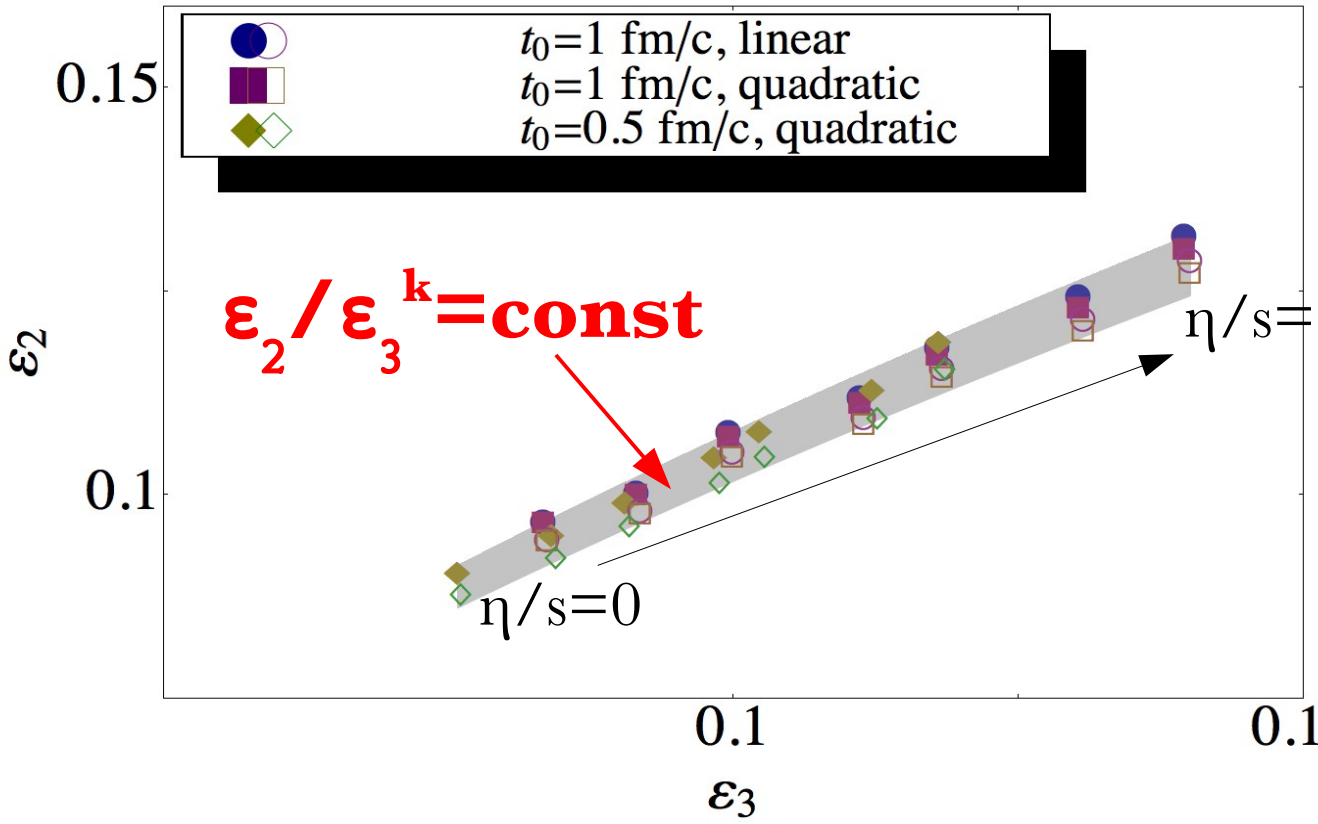

k=0.6 (LHC)
k=0.5 (RHIC)

Values of $(\varepsilon_2 , \varepsilon_3)$ spanned by hydrodynamic calculations, in combination with ALICE data for the 5% most central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.

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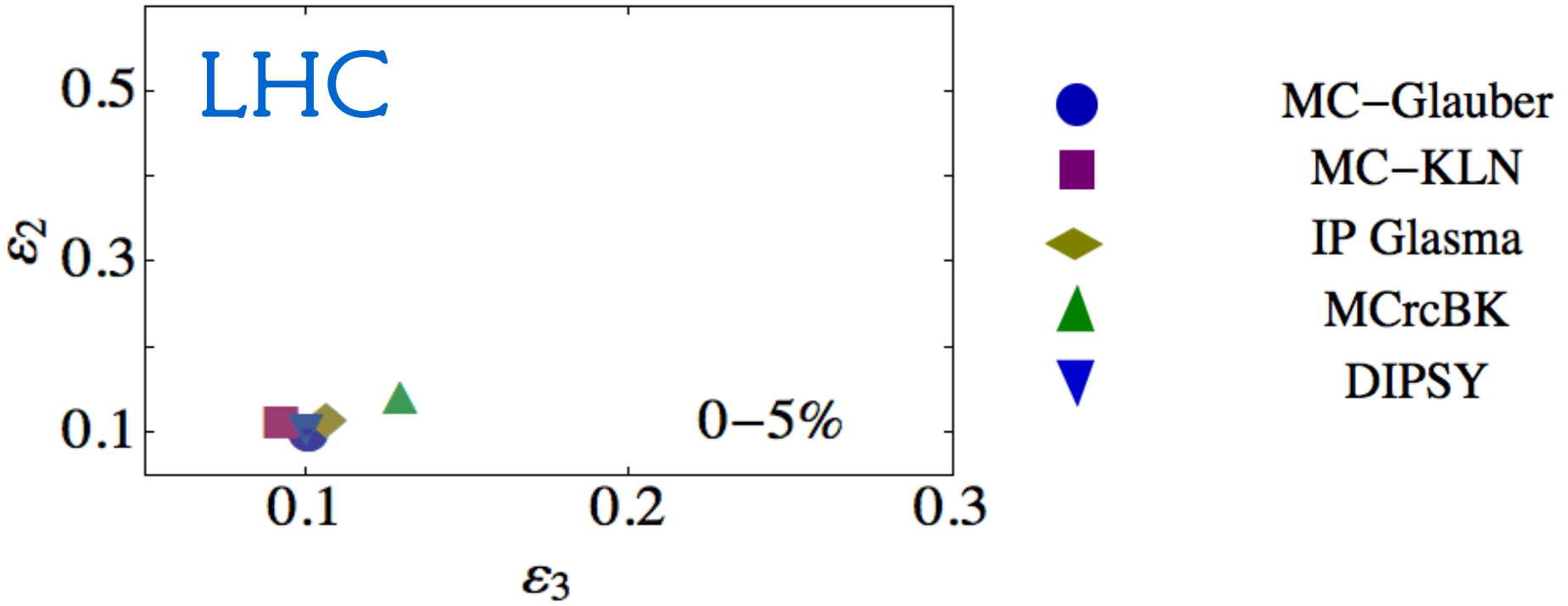
In preparation...

Models of initial state



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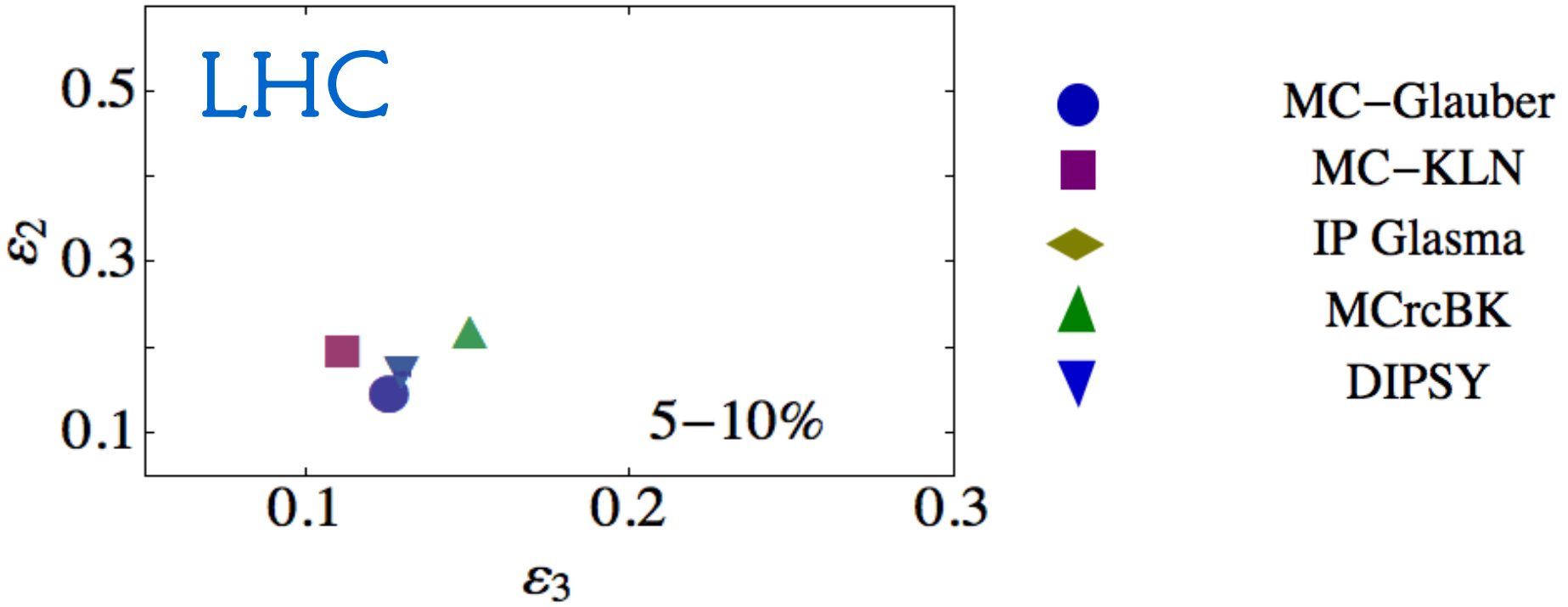

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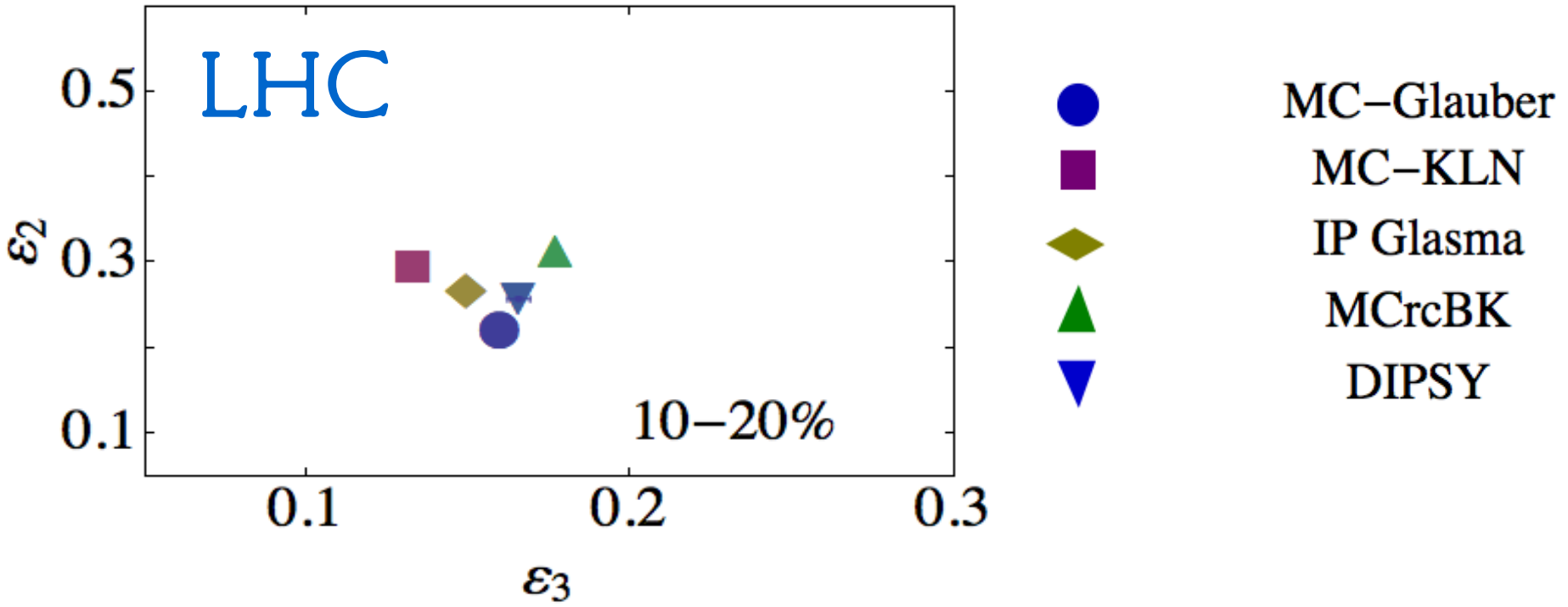

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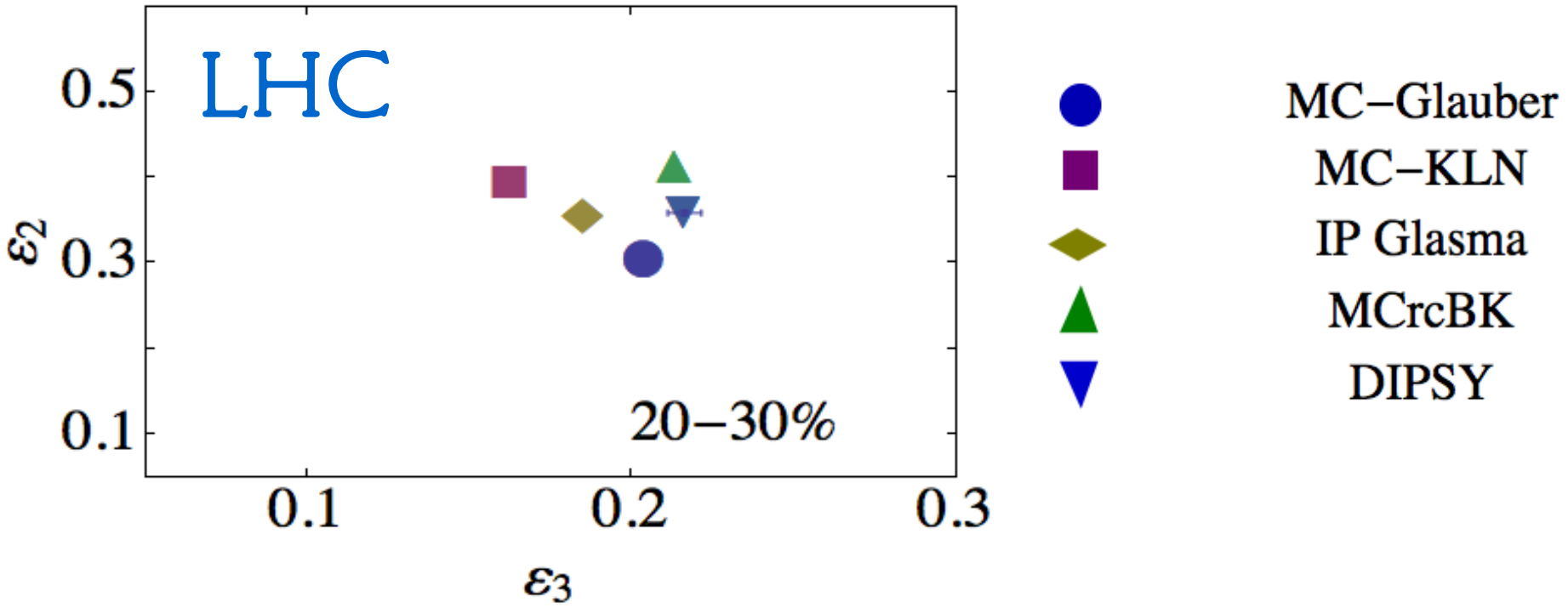

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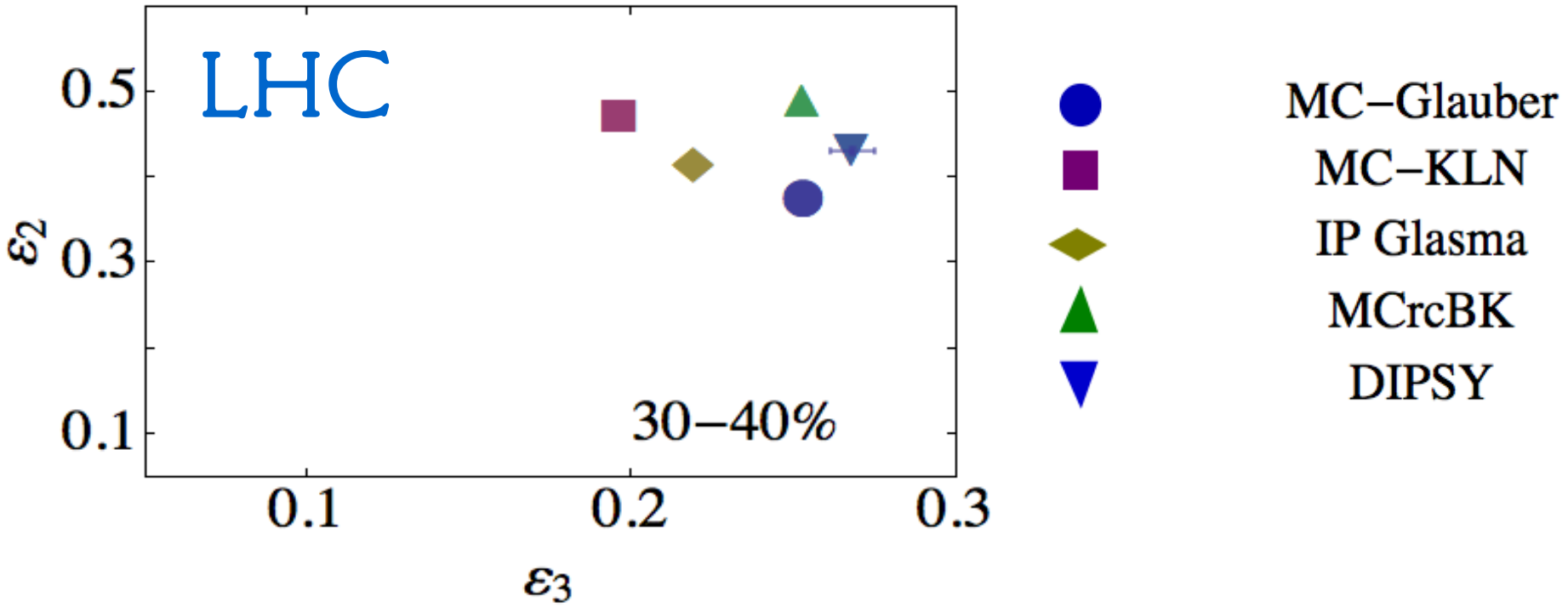
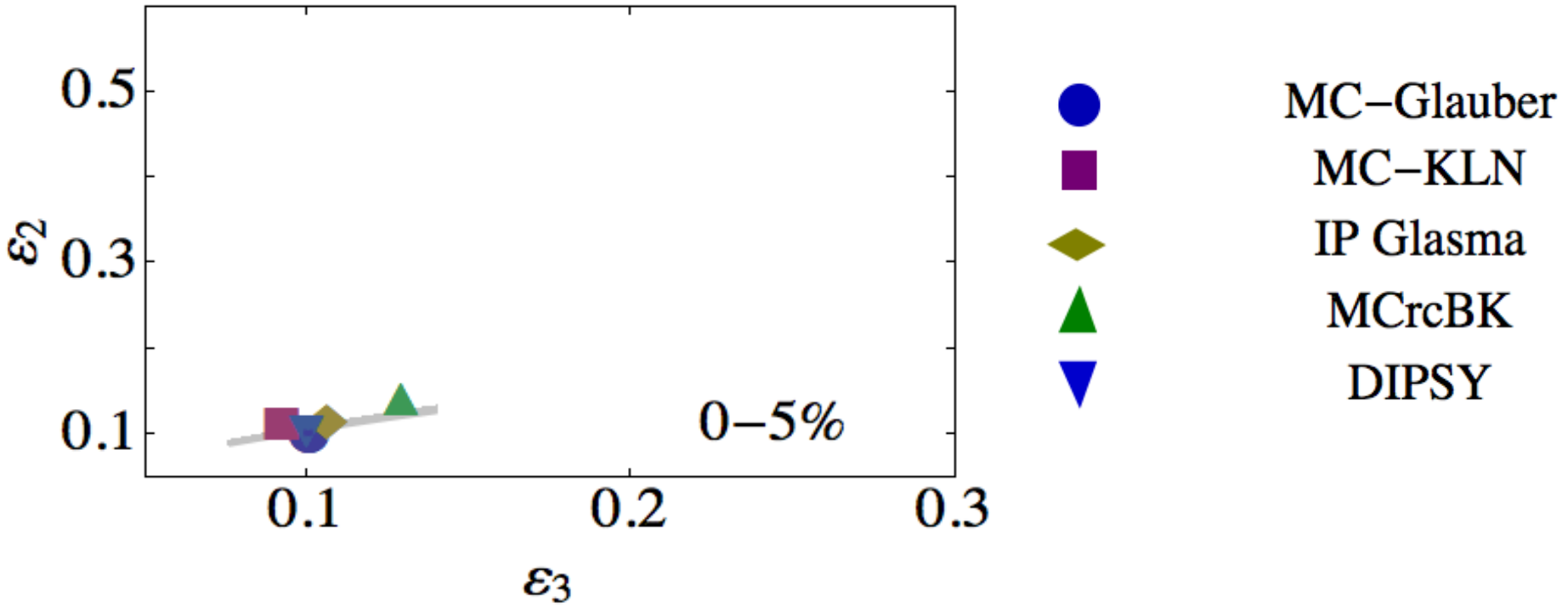


Constraint of models of IS

LHC



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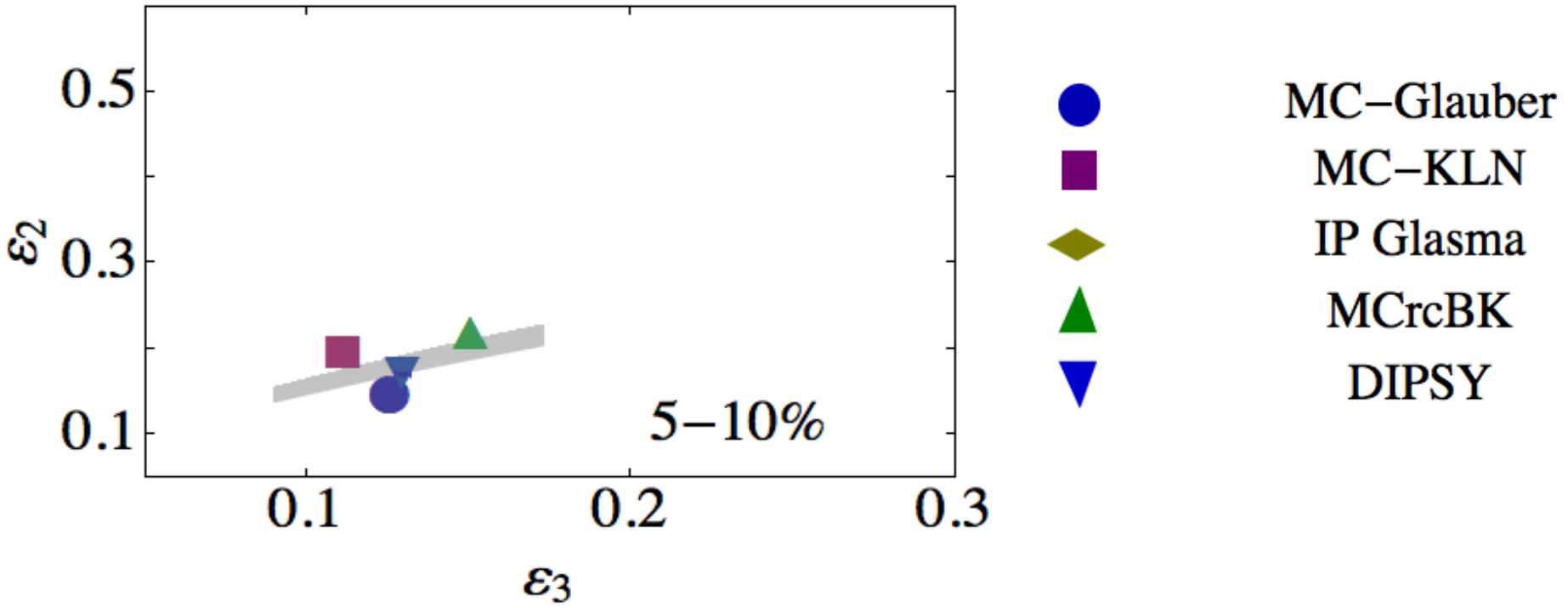

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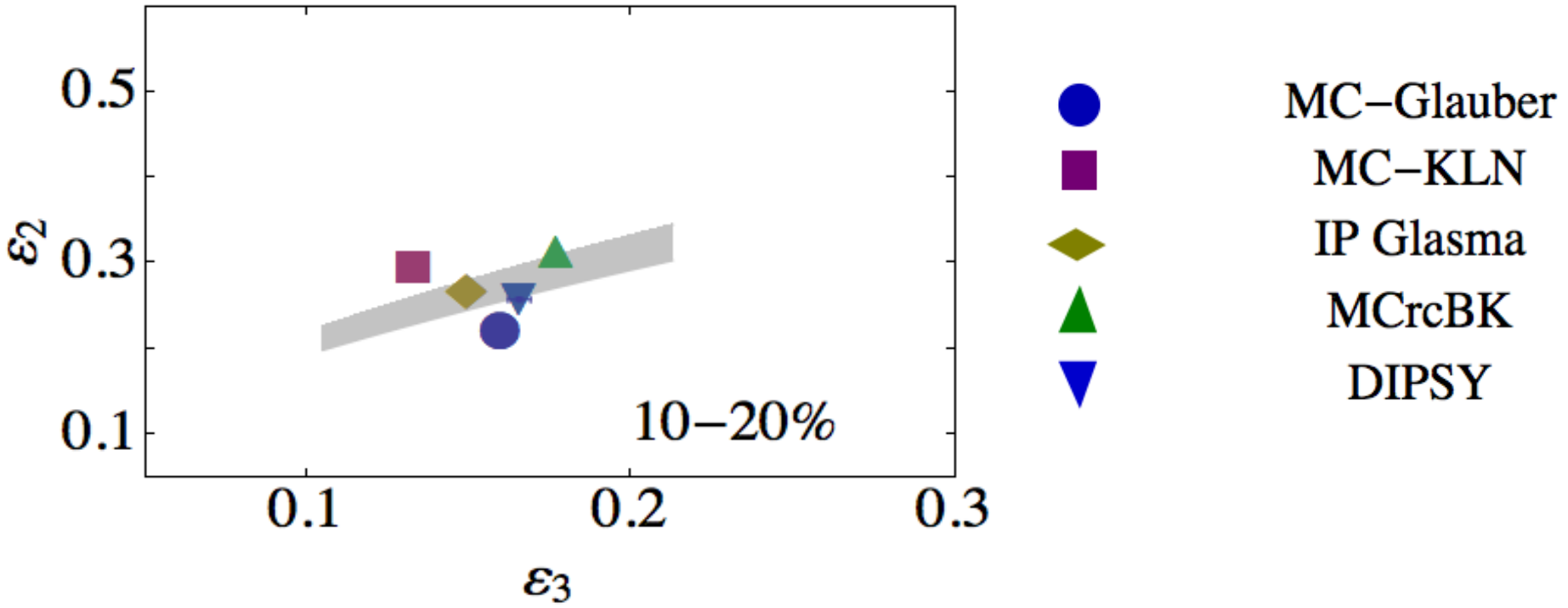

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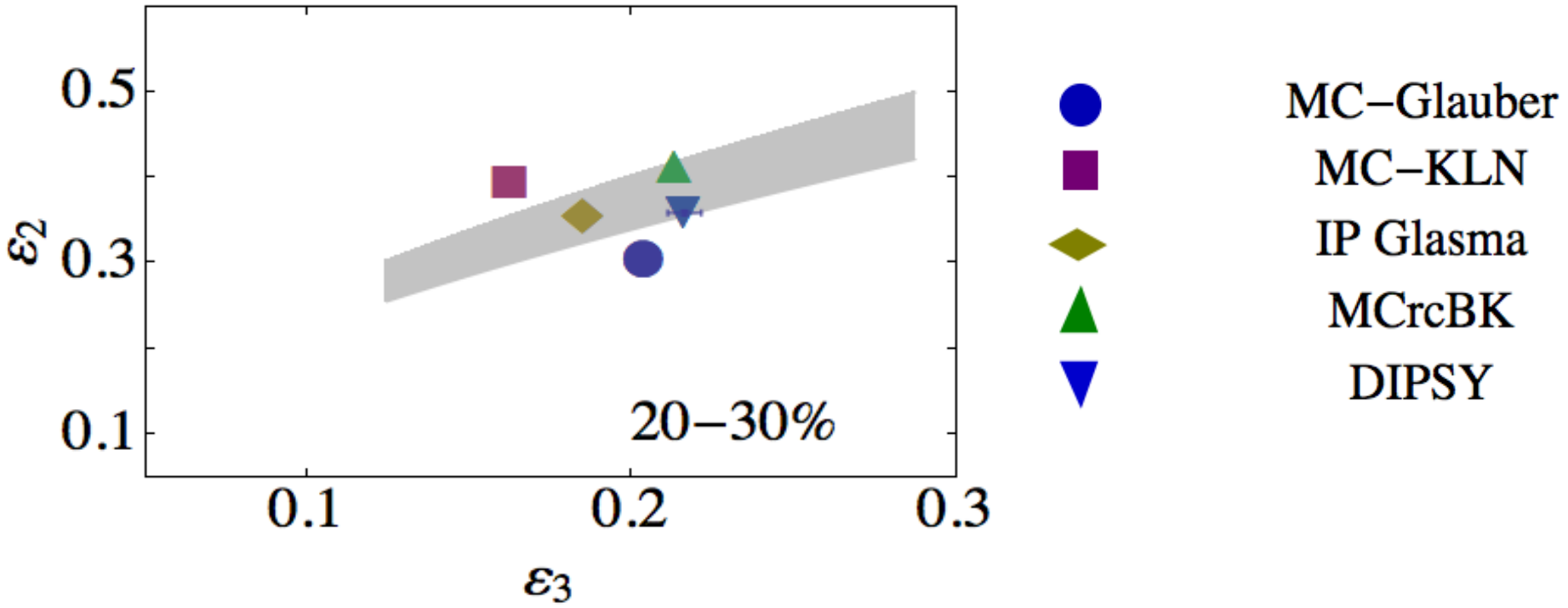

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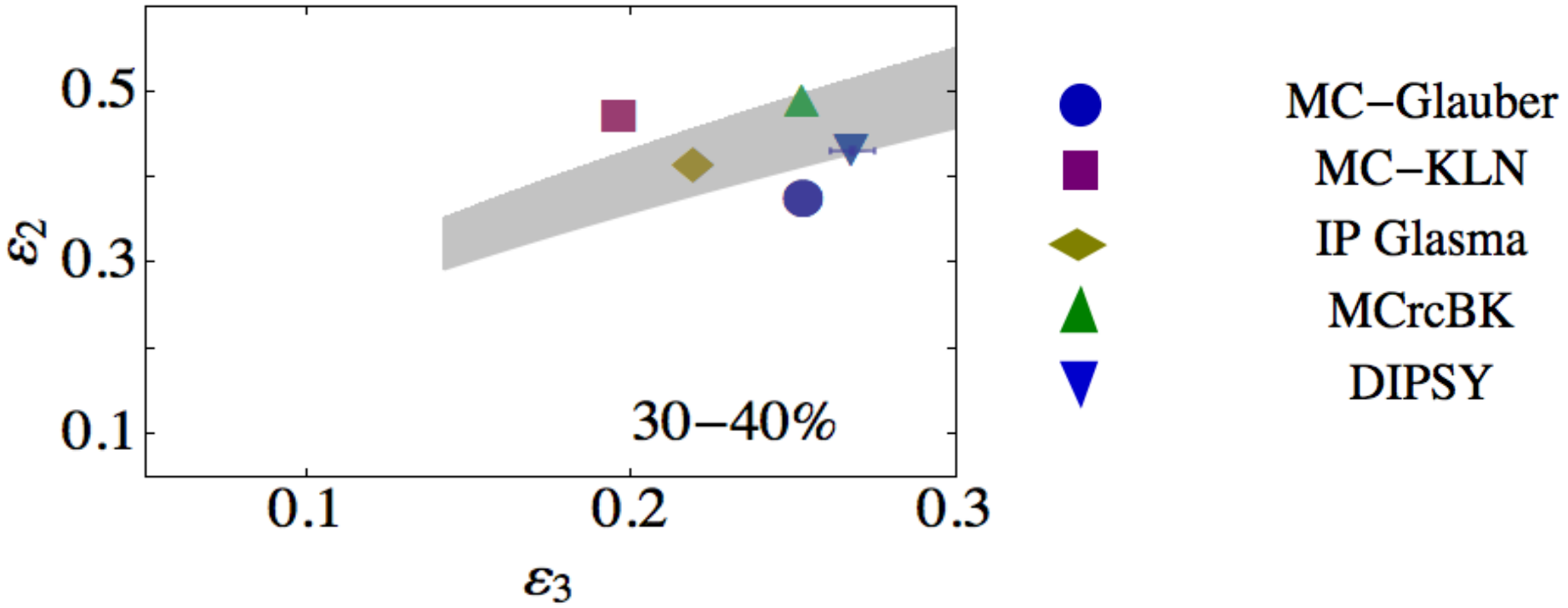

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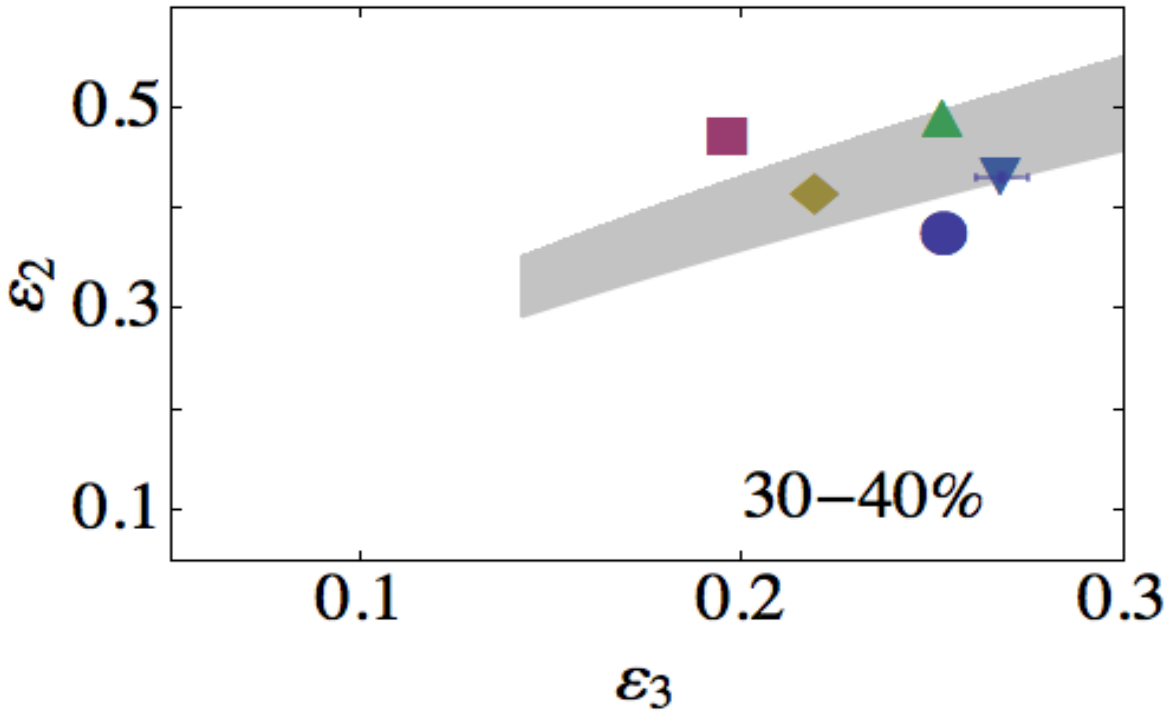


~~MC–Glauber~~

~~MC–KLN~~

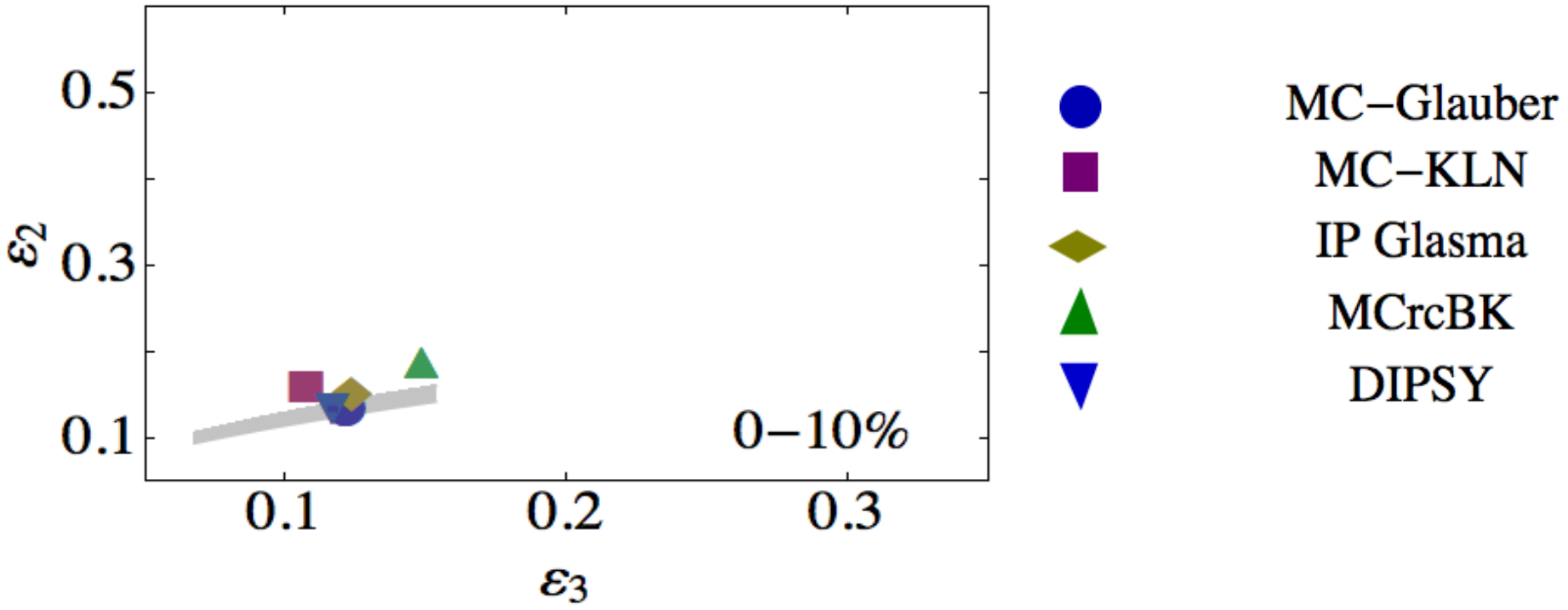
IP Glasma

MCrcBK

DIPSY

Constraint of models of IS

RHIC



Constraint of models of IS

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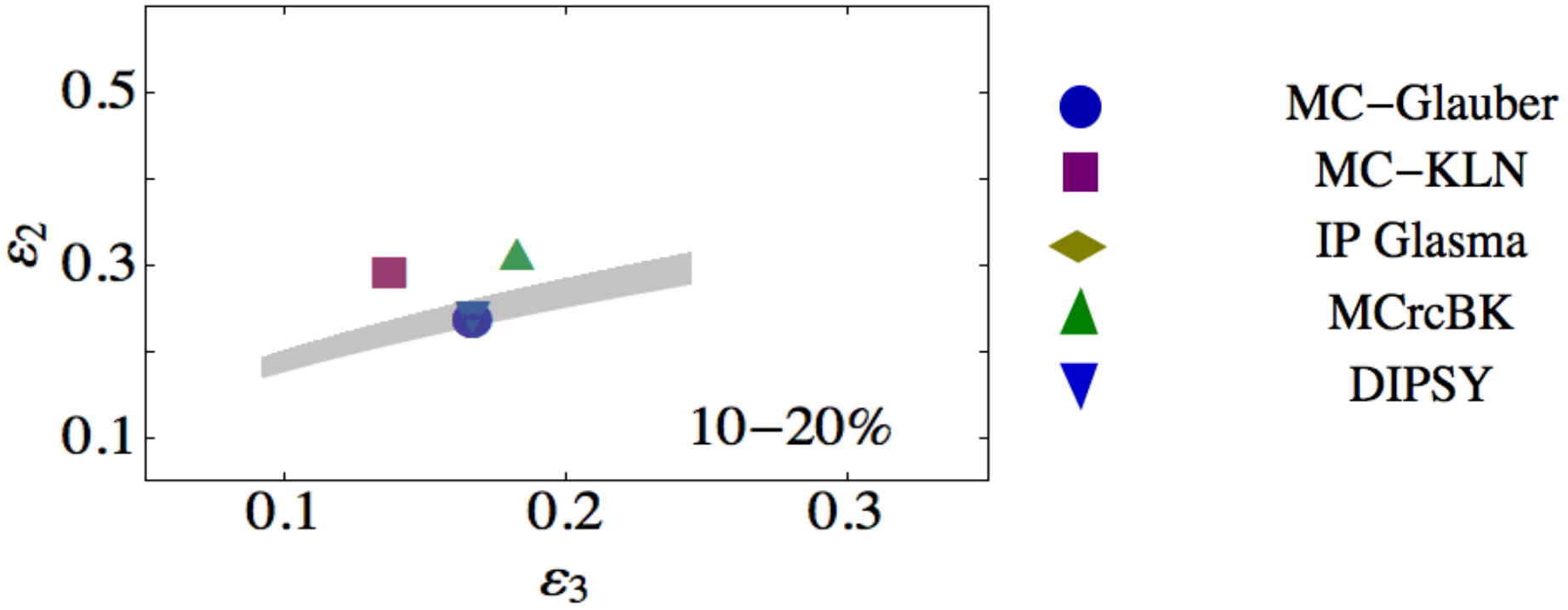

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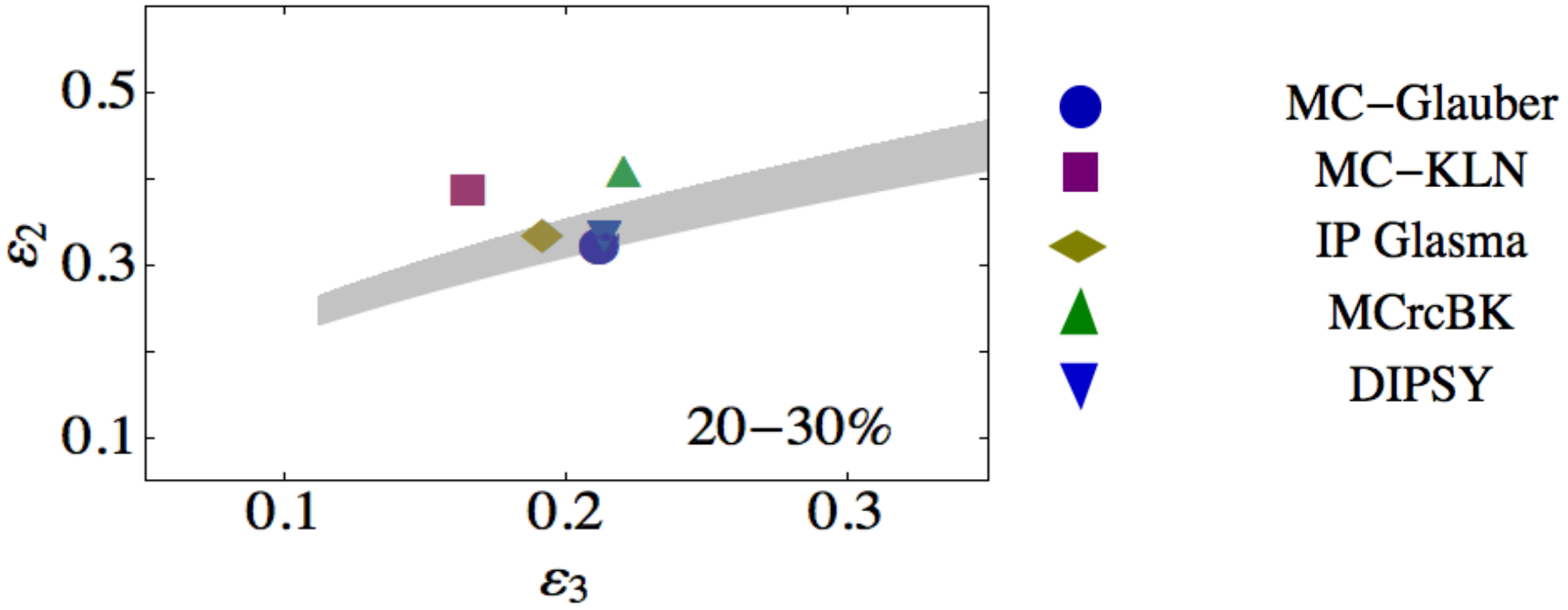

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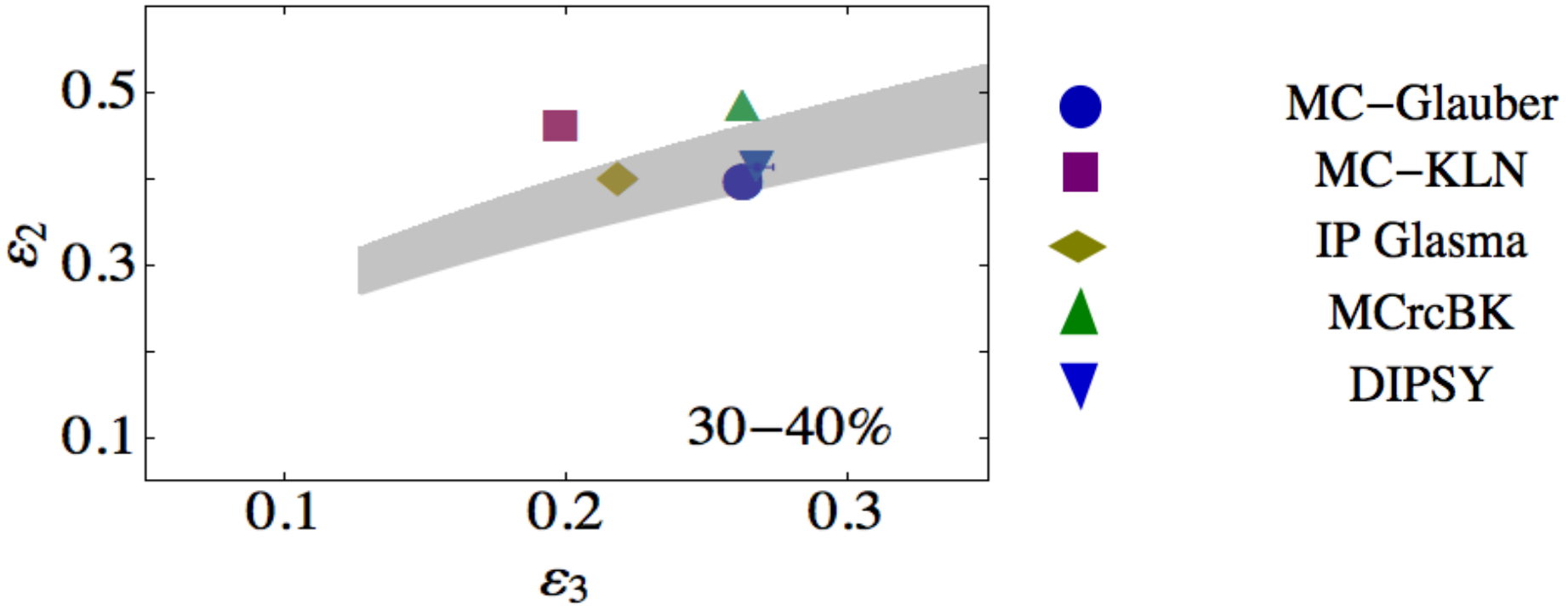

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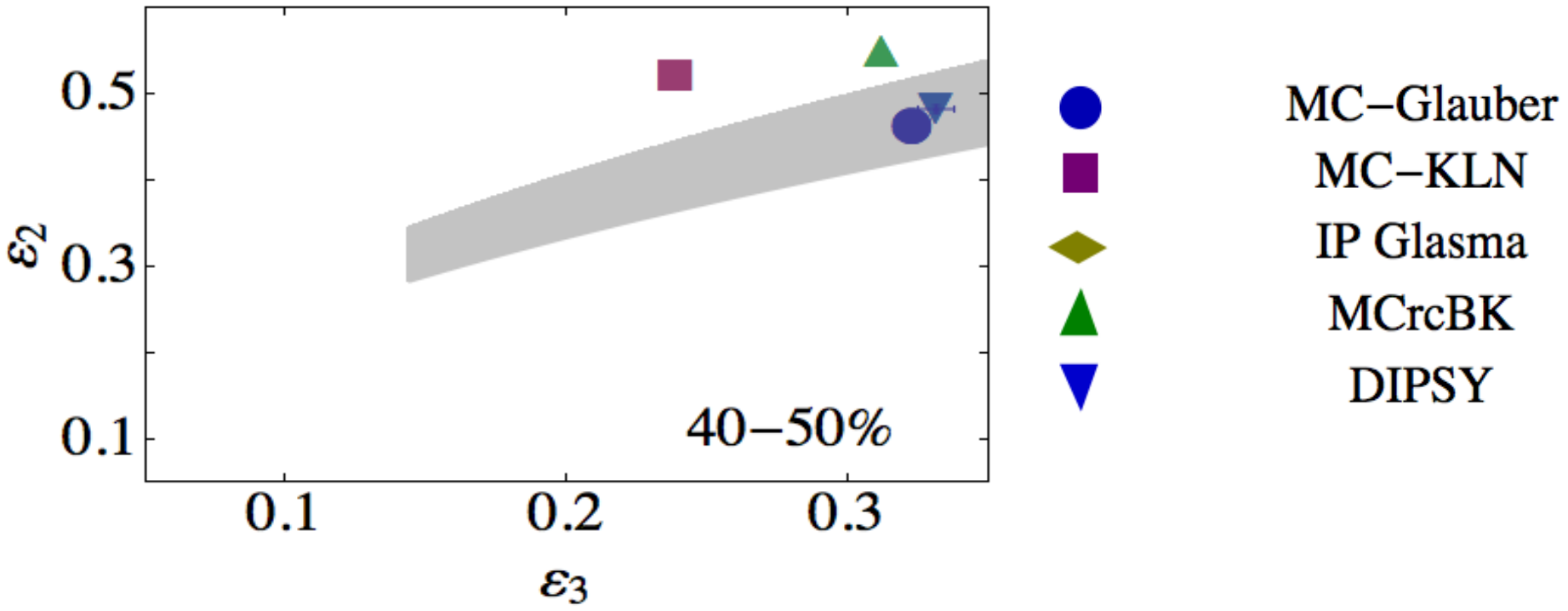

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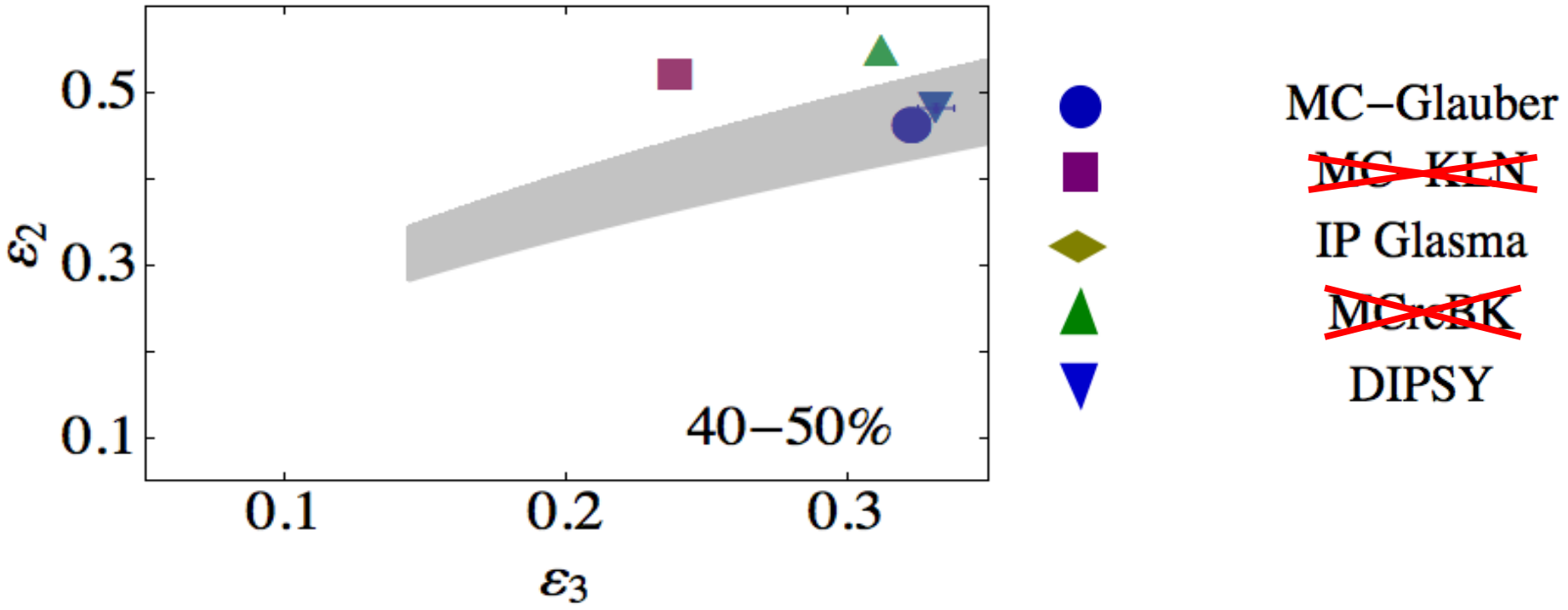


Conclusions:

- We have extracted ellipticity ε_2 and triangularity ε_3, using experimental data and hydro calculations with different sources of uncertainties and created a narrow allowed region on the $(\varepsilon_3,\varepsilon_2)$ plane
- We have shown that we are able to constrain some of the models of initial state.
- It was shown that we can exclude MC-Glauber and MC-KLN models for LHC and MC-KLN and MCrcBK models for RHIC

Backup slides

Central line values with errorbars

LHC

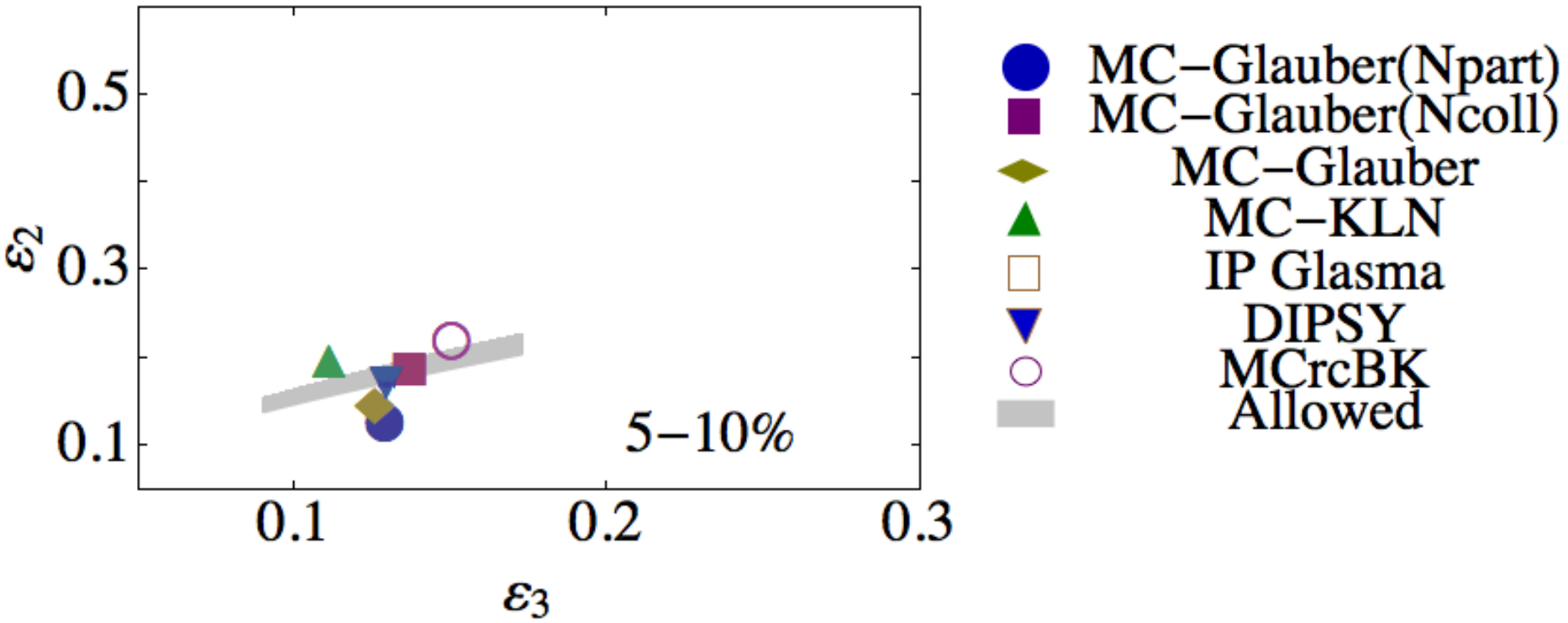
centrality	$C = \varepsilon_2/\varepsilon_3^{0.6}$	$\pm\delta C$
0-5%	0.416798	0.0120745
5-10%	0.616212	0.0326033
10-20%	0.818089	0.0521990
20-30%	0.97171	0.0825677
30-40%	1.03739	0.0956076

RHIC

centrality	$C = \varepsilon_2/\varepsilon_3^{0.5}$	$\pm\delta C$
0-10%	0.387388	0.023447
10-20%	0.600063	0.0346716
20-30%	0.741210	0.0476817
30-40%	0.824749	0.0740677
40-50%	0.826721	0.0827121

Constraint of models of IS

LHC



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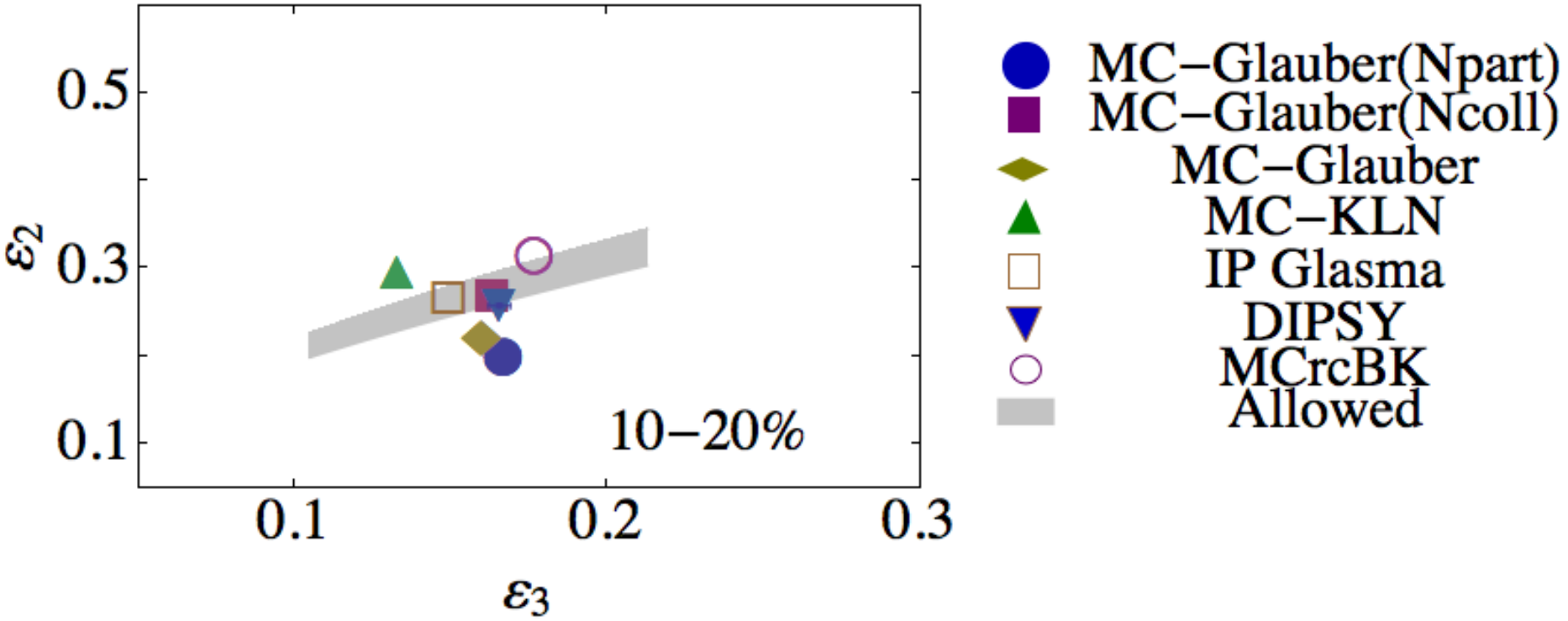

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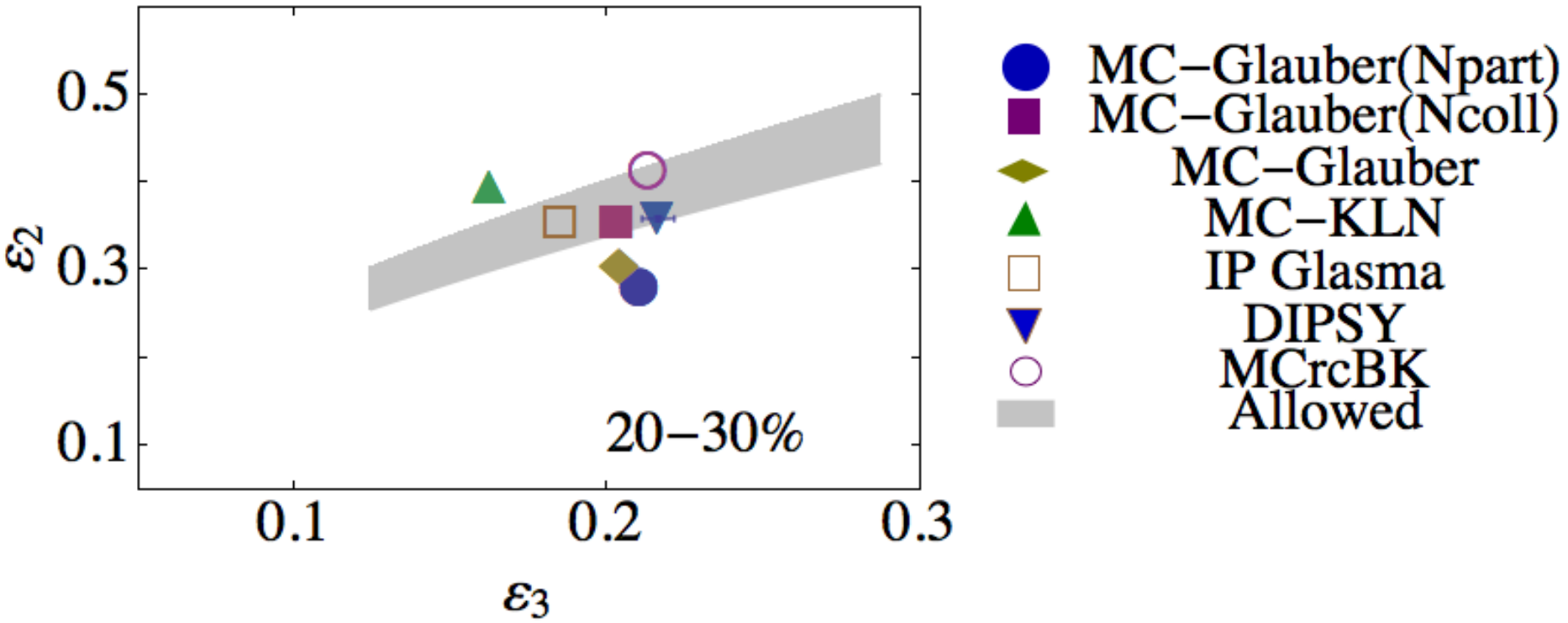

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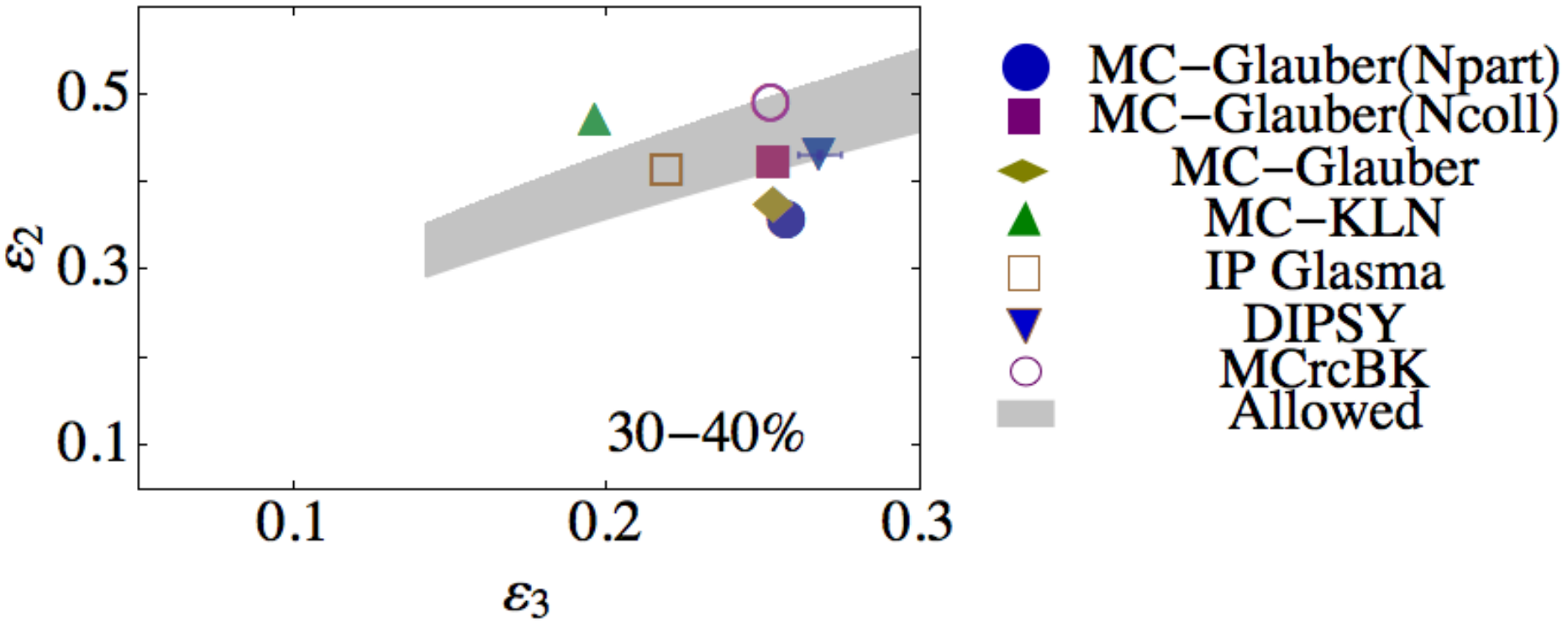

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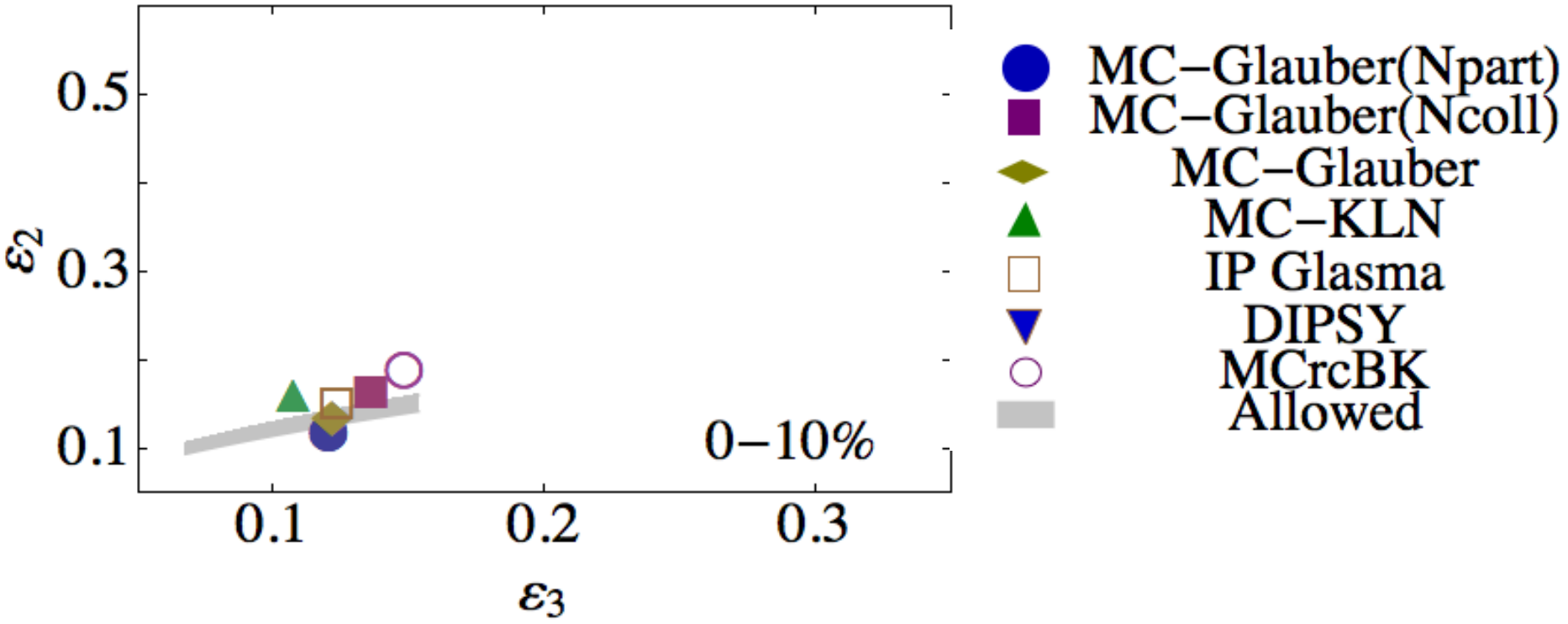

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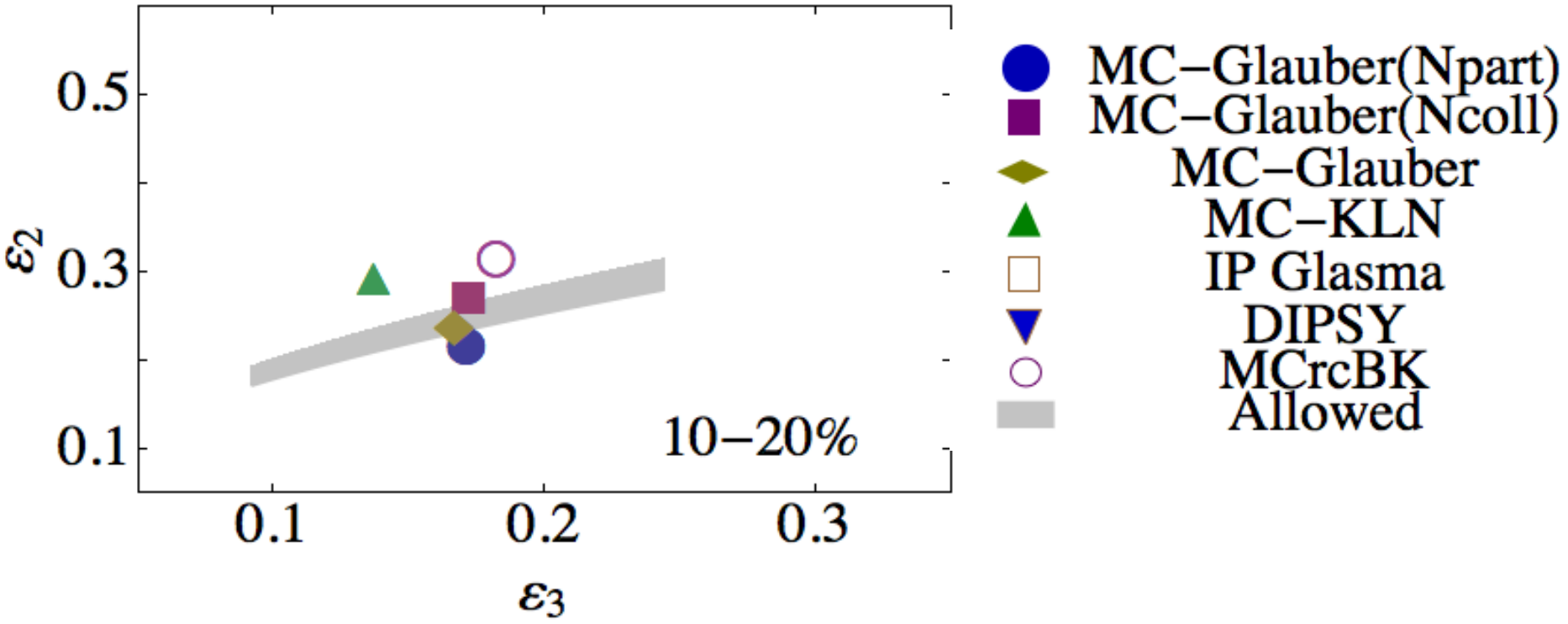

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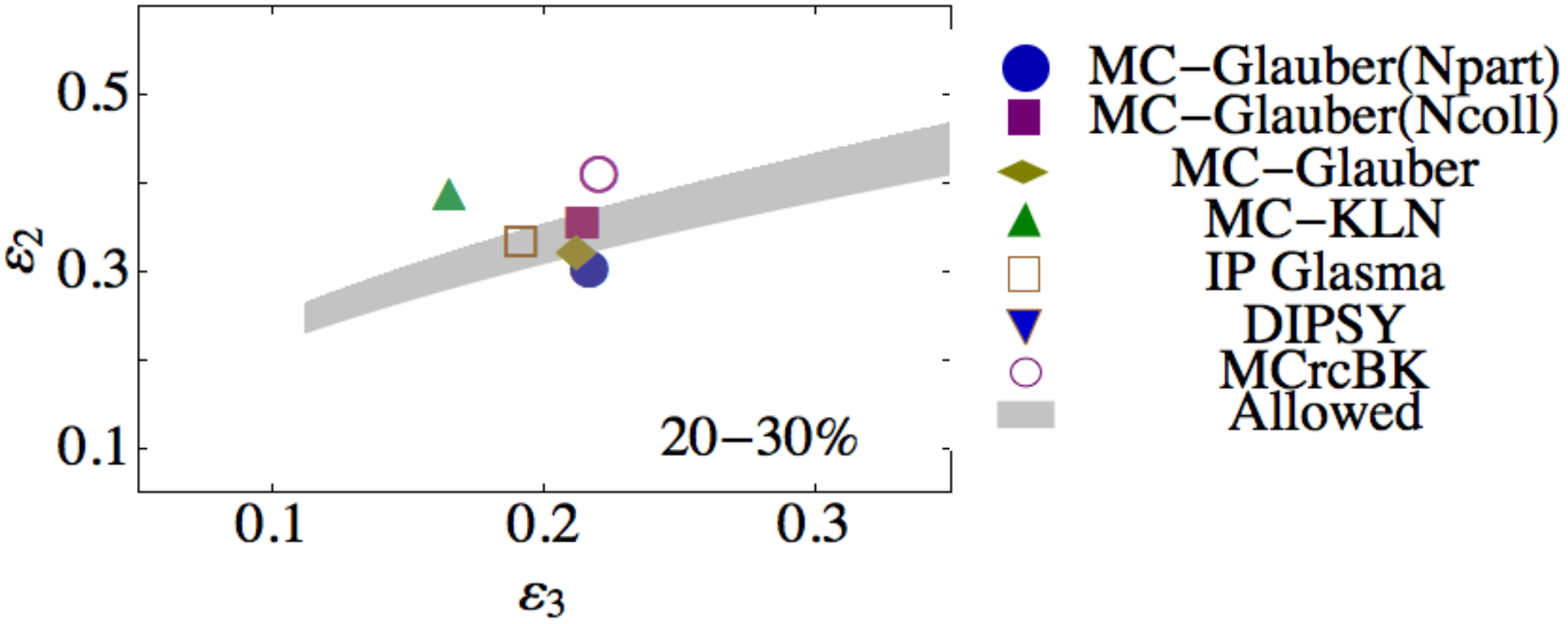

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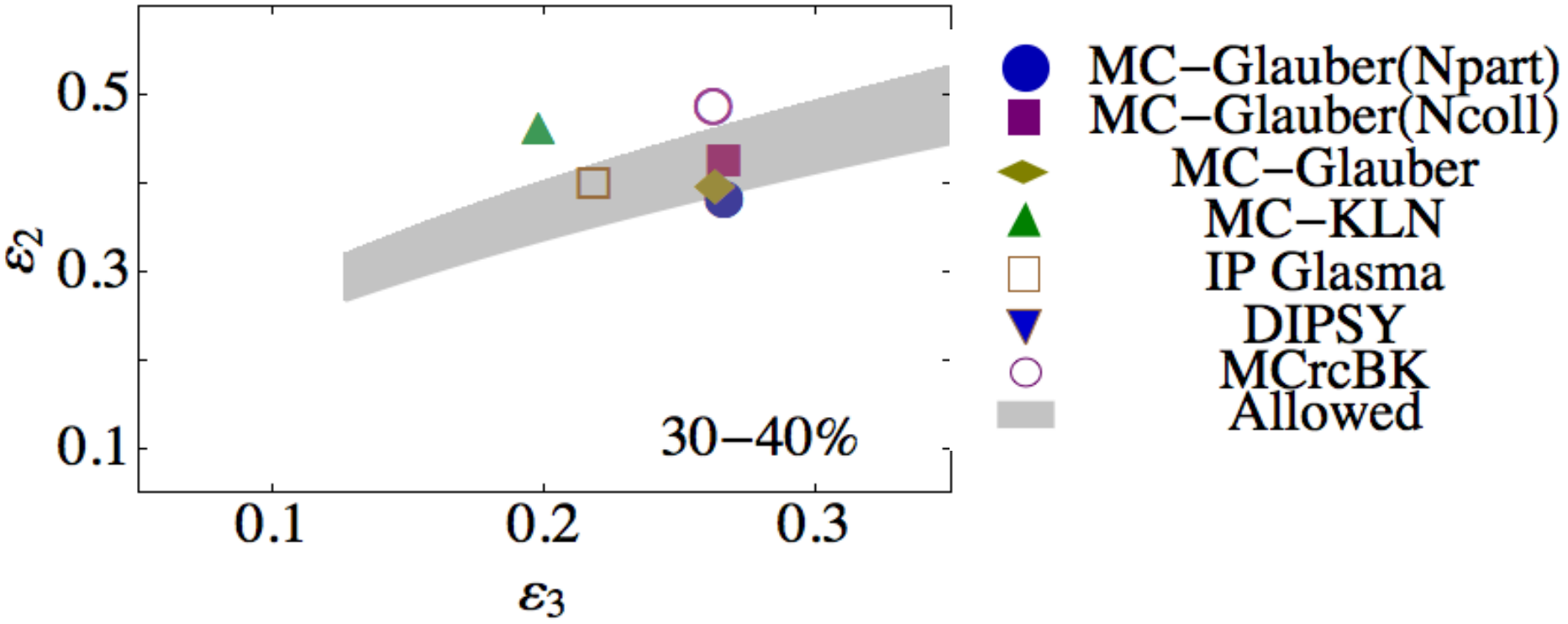

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