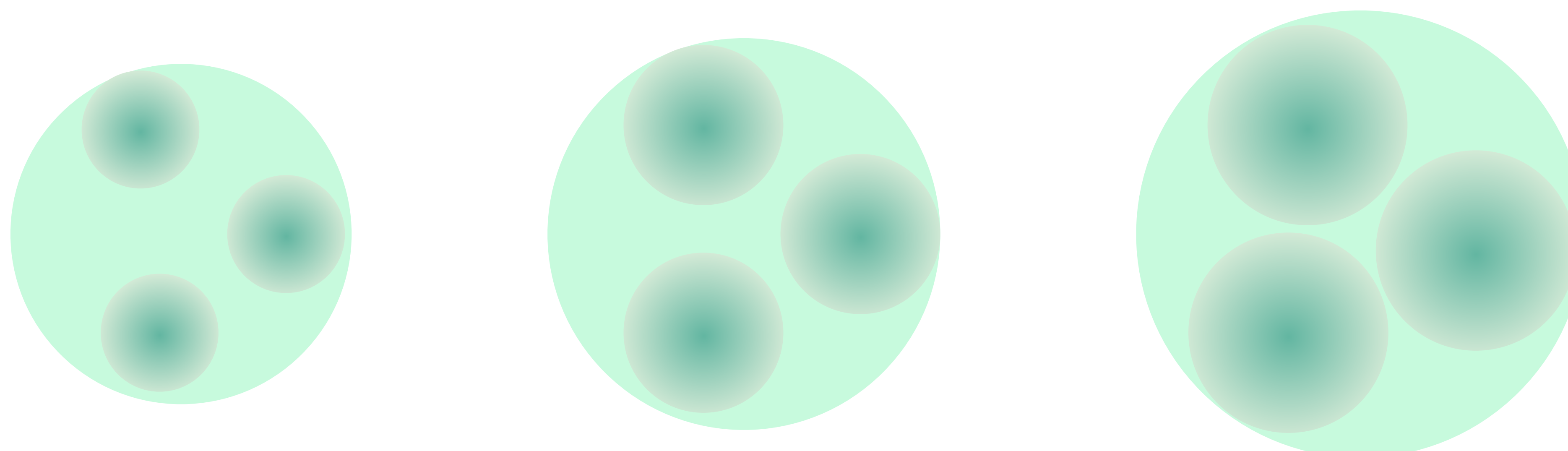
# GLUONIC HOT SPOTS AND SPATIAL CORRELATIONS INSIDE THE PROTON



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+ Hannah Petersen[1], Javier L. Albacete[2]

based on arXiv: 1605.09176, 1612.06274(v2) [hep-ph]

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# Motivation

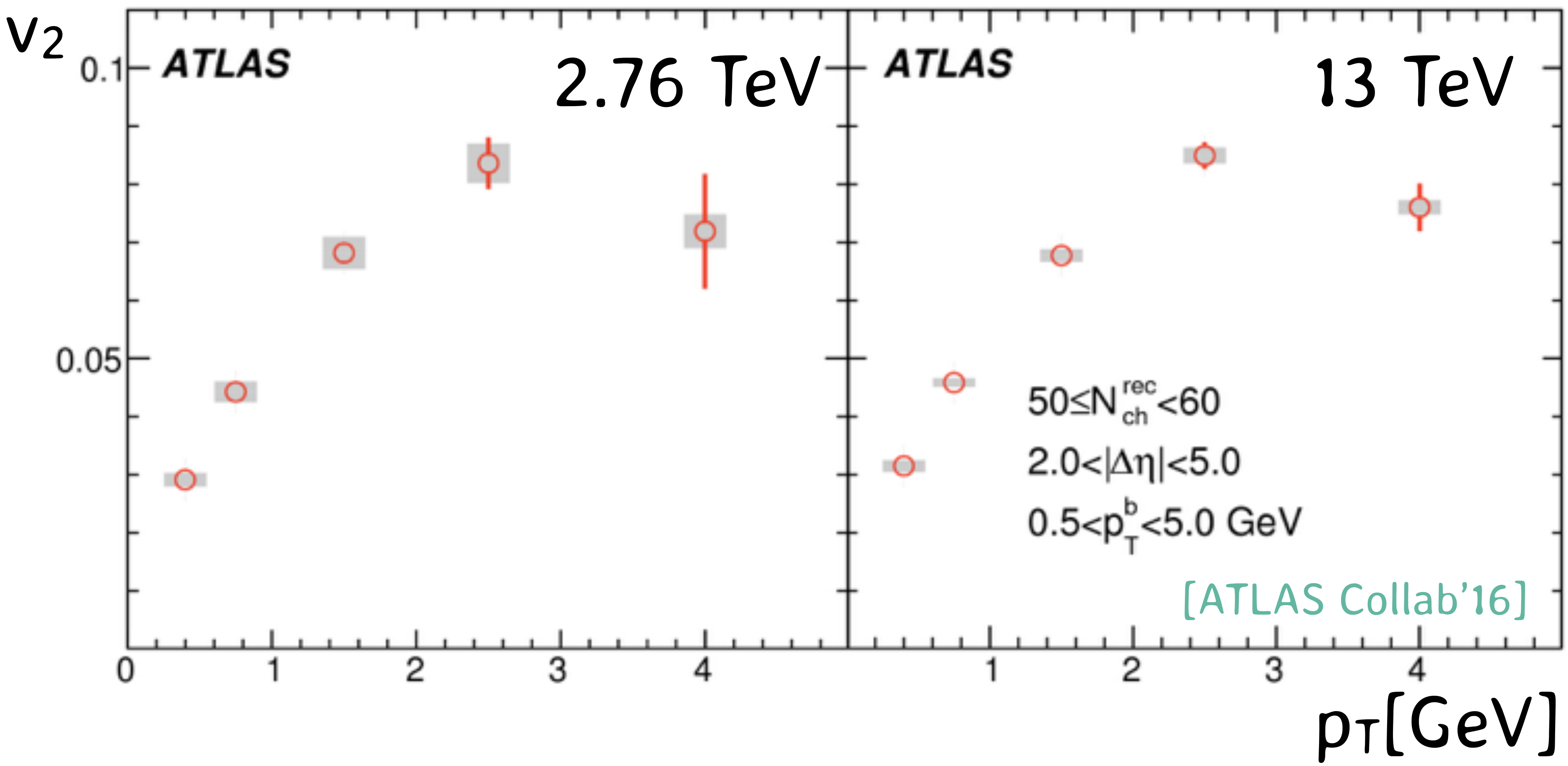
# Quark-gluon-plasma in p+p?

See talks by Christiansen, Jenkovszky & Beck

➡ In principle, p+p too dilute to produce a fluid-like state.

**HOWEVER**

➡ Suggestive signals of collective behavior in high multiplicity events




➡ Non-vanishing triangular flow, the ridge…

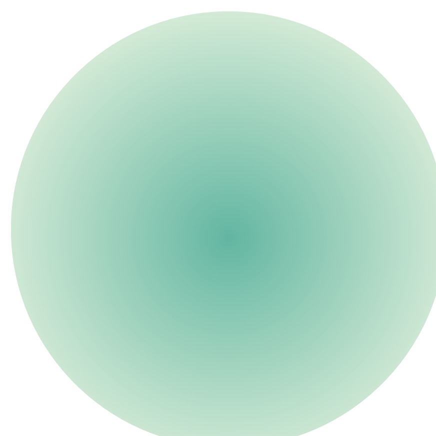
# Quark-gluon-plasma in p+p?

➡Intense theoretical interest on the initial geometry in p+p interactions

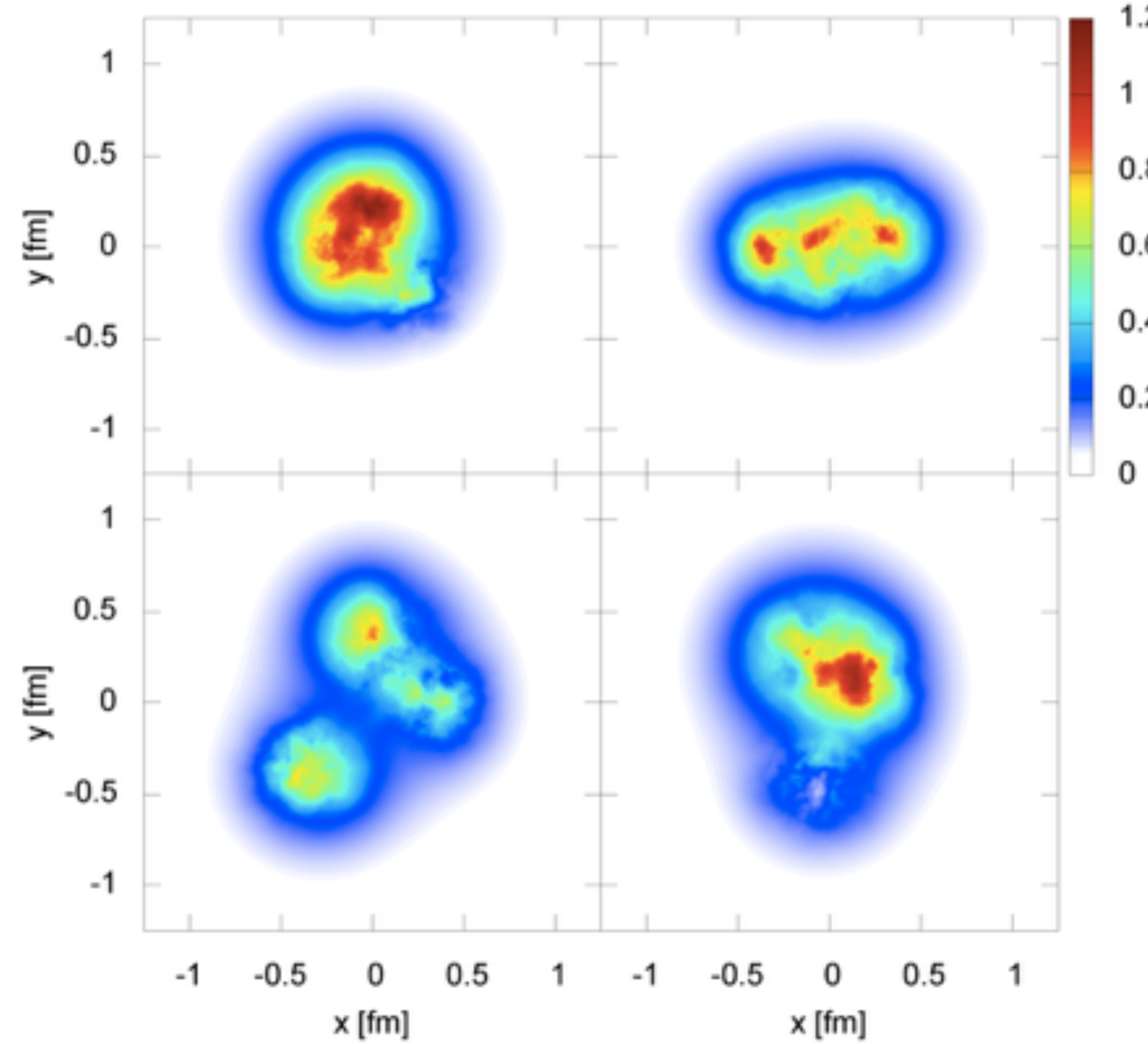
[Mäntysaari et Al.'16]



Black-disk



Gaussian



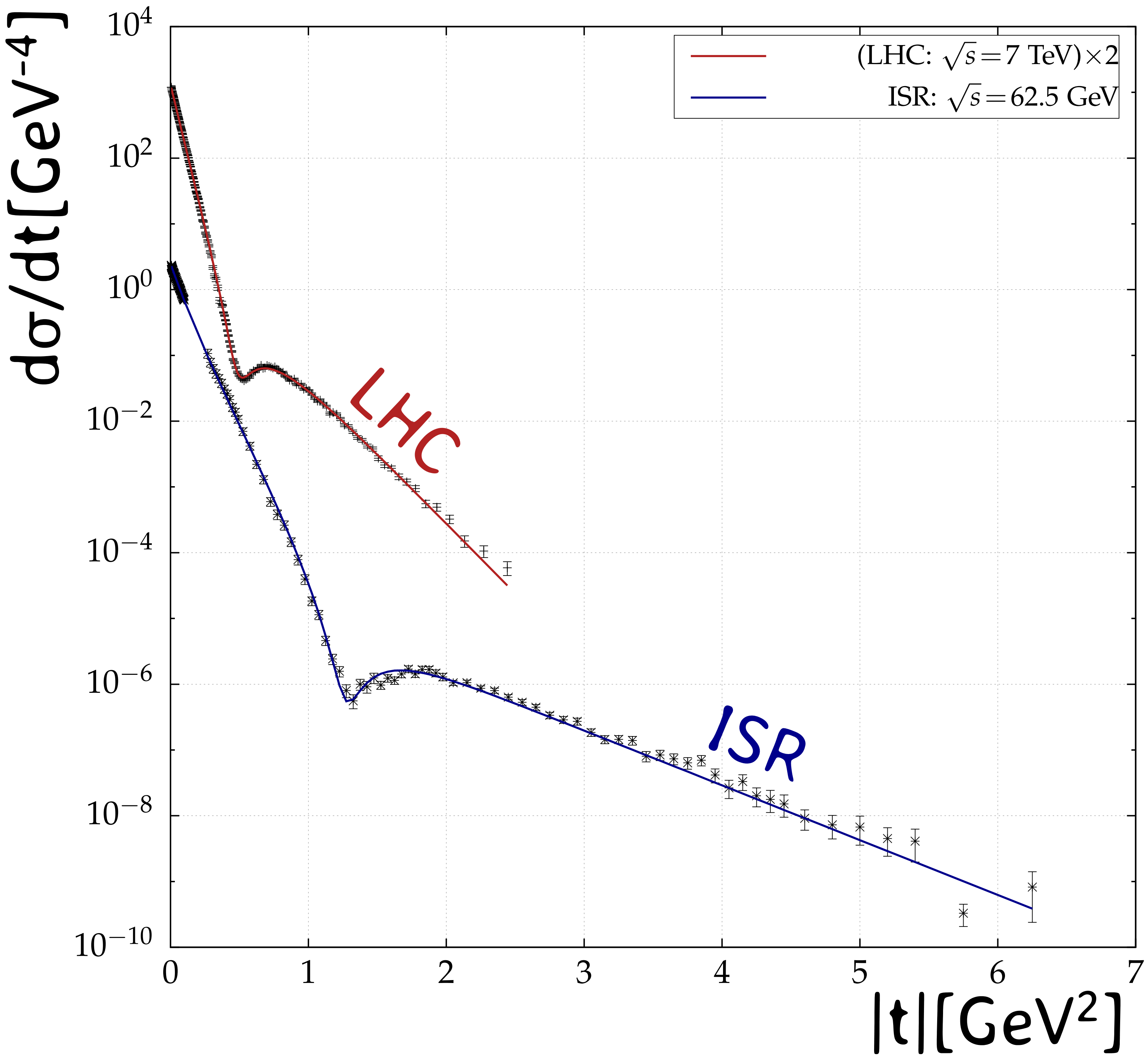

TIME

➡Models @market assume UNCORRELATED subnucleonic components

# p+p elastic scattering

[TOTEM Collab '11]
[Amaldi et Al. '80]

➡Observable: elastic differential cross section in p+p collisions




$$\frac{d\sigma_{\rm el}}{dt} = \frac{1}{4\pi}|T_{\rm el}(s,t)|^2$$

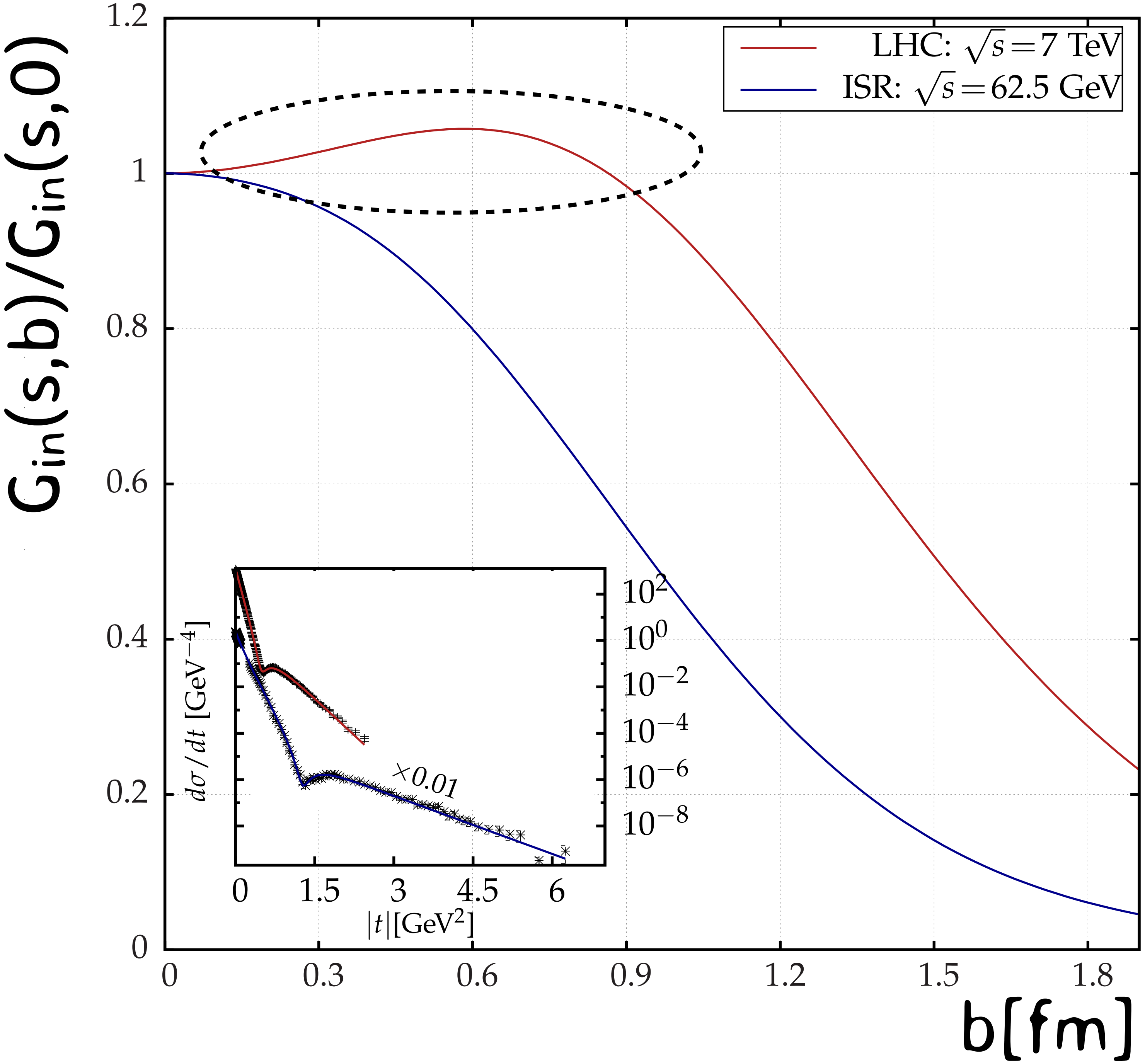
# p+p elastic scattering

[Alkin et Al.'14, Arriola&Broniowski'16, Dremin'16, Troshin et Al.' 16...]

➡Unexpected properties can be extracted from the data

$$G_{\text{in}}(s,\vec{b}) = 2\text{Im}\widetilde{T}_{\text{el}}(s,\vec{b}) - |\widetilde{T}_{\text{el}}(s,\vec{b})|^2$$

$$G_{\text{in}} = d^2\sigma_{\text{inel}}/d^2b$$



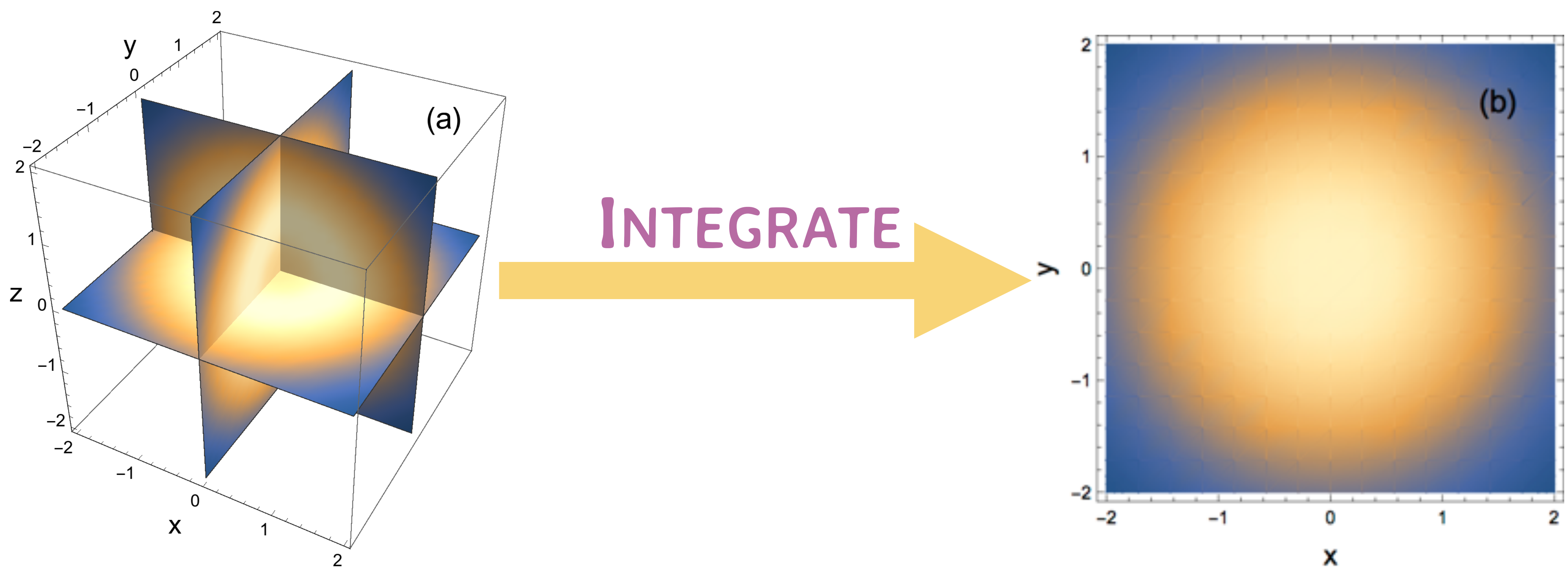




contributes more to $\sigma_{\text{inel}}$ than

# The hollowness effect

- ➡Toroid like interaction region at high energies?
- ➡Critical regime at the LHC?
- ➡Disclaimer: Present data compatible with NO hollowness effect within error bars. [Dremin '16,'17]
- ➡Flattening of $G_{in}$ (2D) indicates a hollow in 3D [Arriola&Broniowski '16,'17]




- ➡It precludes UNCORRELATED proton structures.

# The hollowness effect

QCD CHALLENGE

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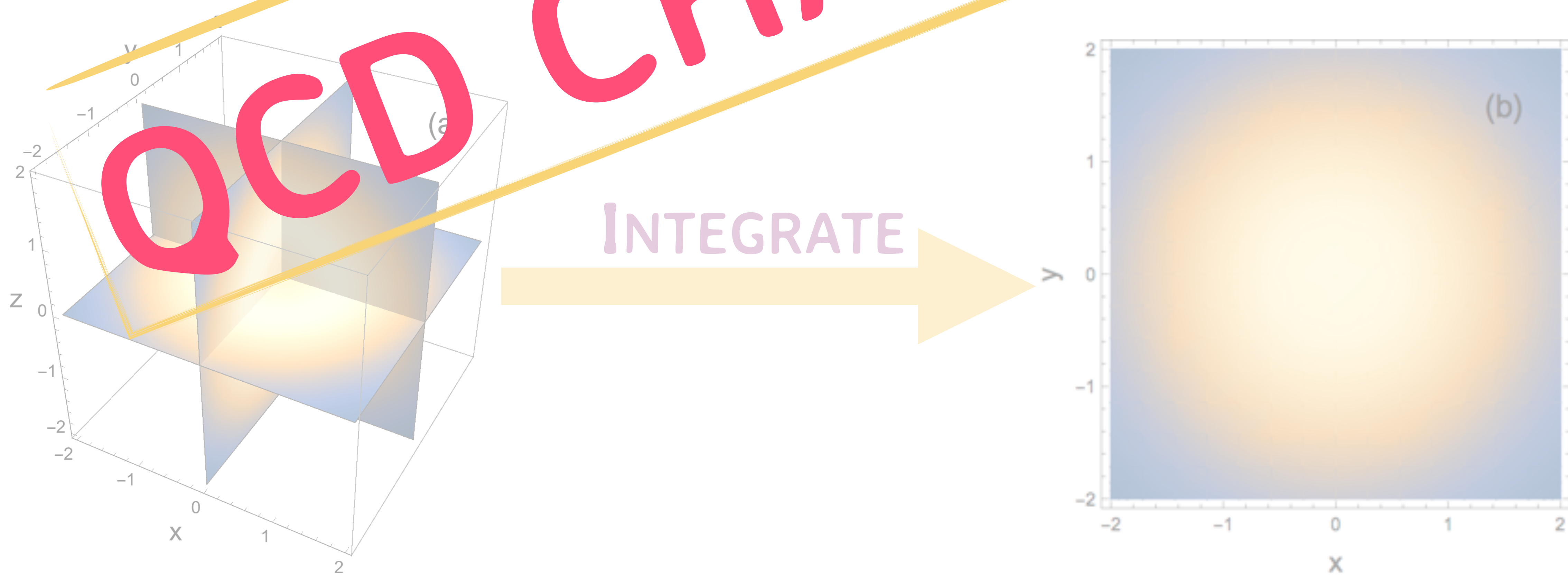



- ➡It precludes UNCORRELATED proton structures.

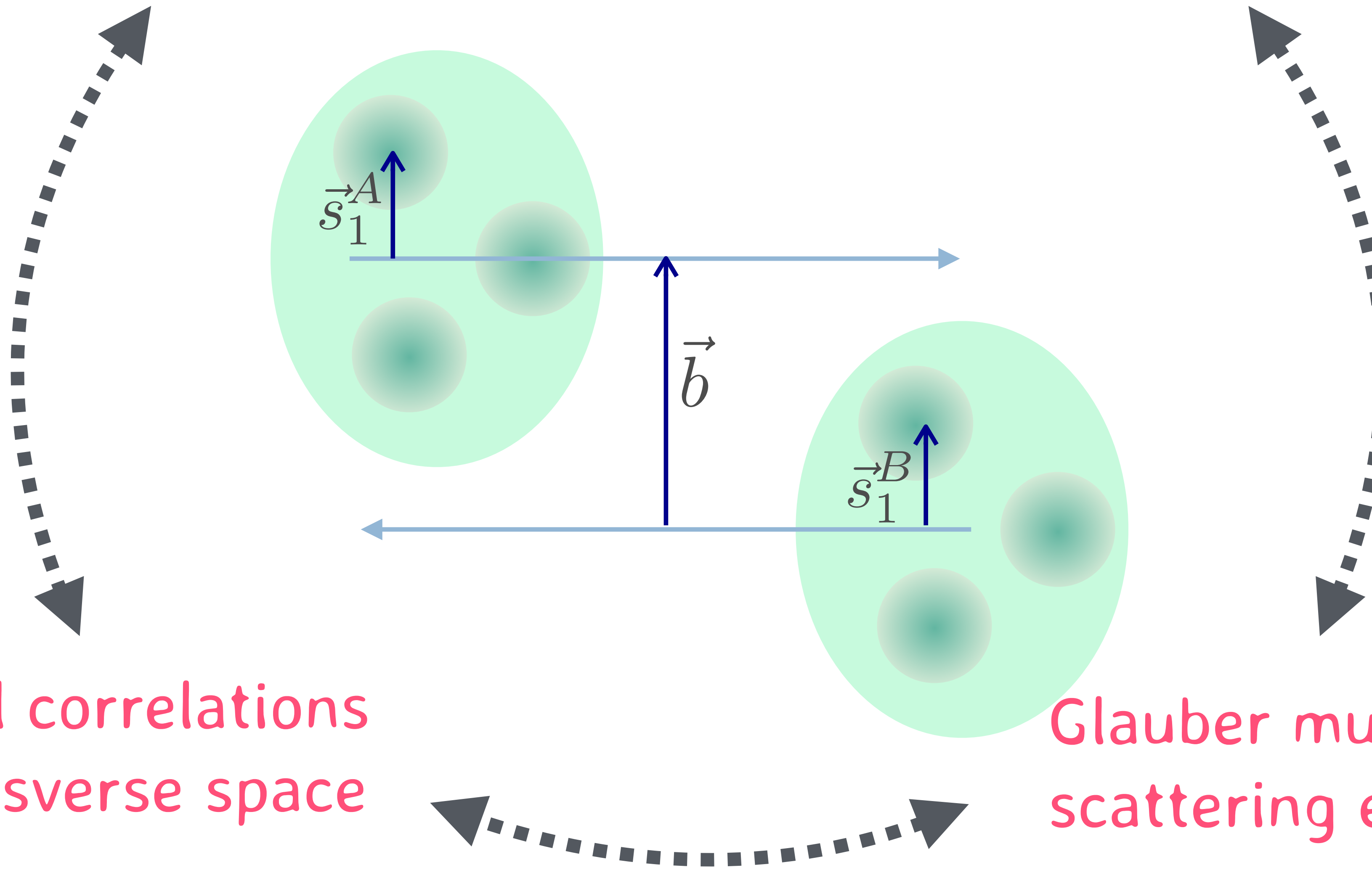
# Ingredients

# The model

[Similar to A. Bialas et Al. '70s]

➡A novel initial state geometry for p+p interactions based on:

Gluonic hot-spots as effective d.o.f




Spatial correlations in transverse space

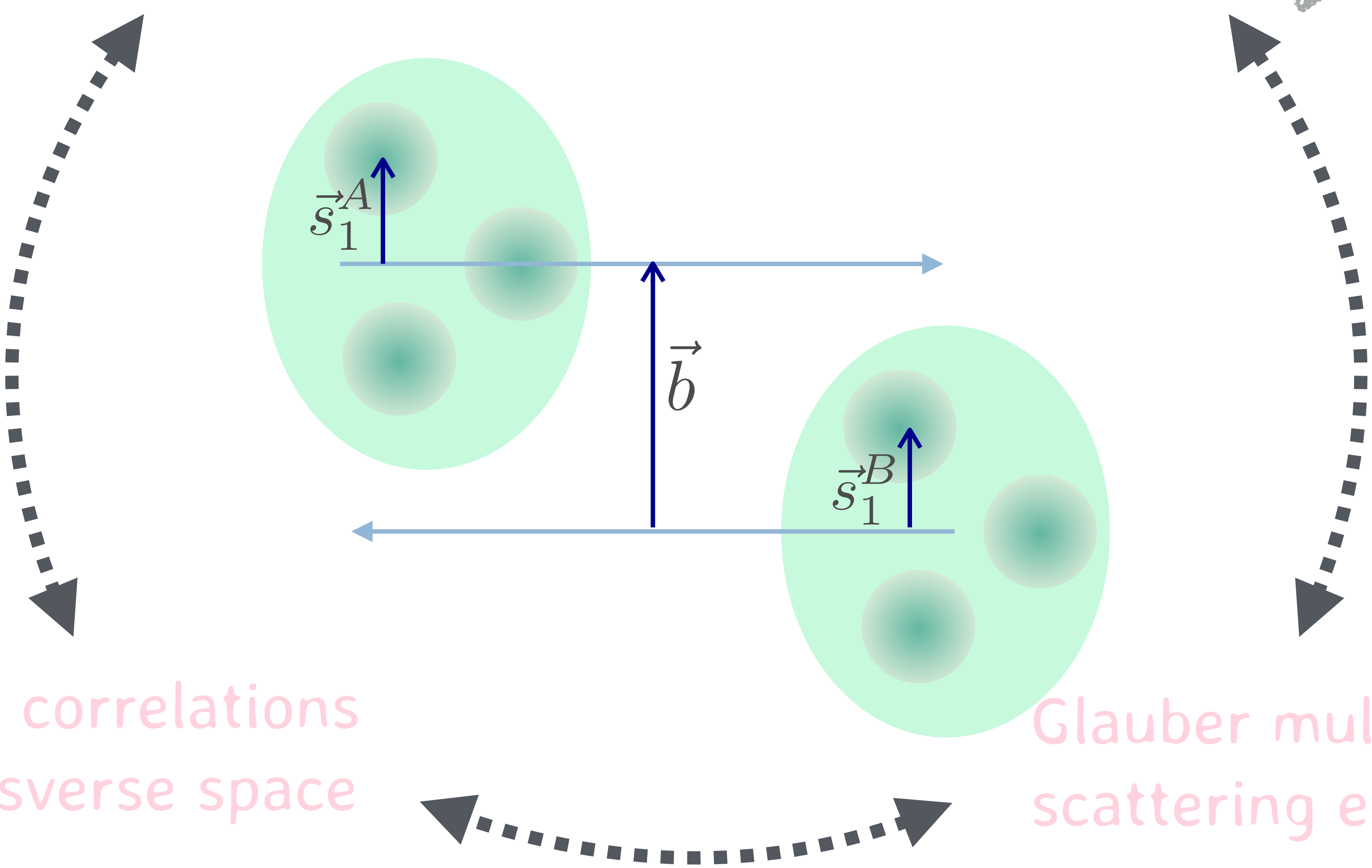
Glauber multiple scattering expansion

# The model

[Similar to A. Bialas et Al. '70s]

➡A novel initial state geometry for p+p interactions based on:

Gluonic hot-spots as effective d.o.f → Fock space of valence partons

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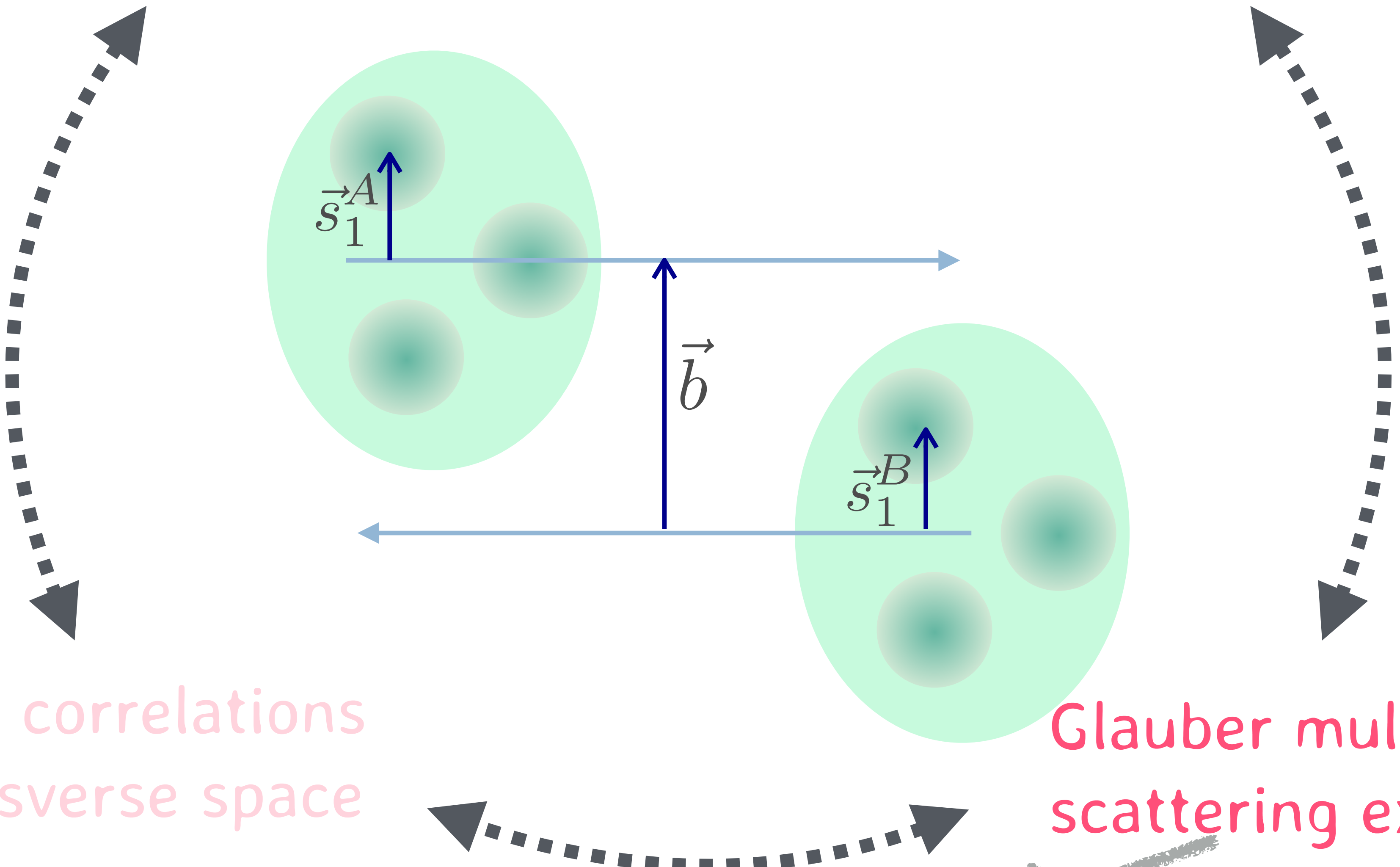

Spatial correlations in transverse space

Glauber multiple scattering expansion

$$\widetilde{T}_{\rm el}(\vec{b}) = \int \prod_{k,l} d^2 s_k^A d^2 s_l^B D_A(\{\vec{s}_k^A\}) D_B(\{s_l^B\}) \left(1 - \prod_i \prod_j \left[1 - \Theta_{ij}(\vec{b} + \vec{s}_i^A - \vec{s}_j^B)\right]\right)$$

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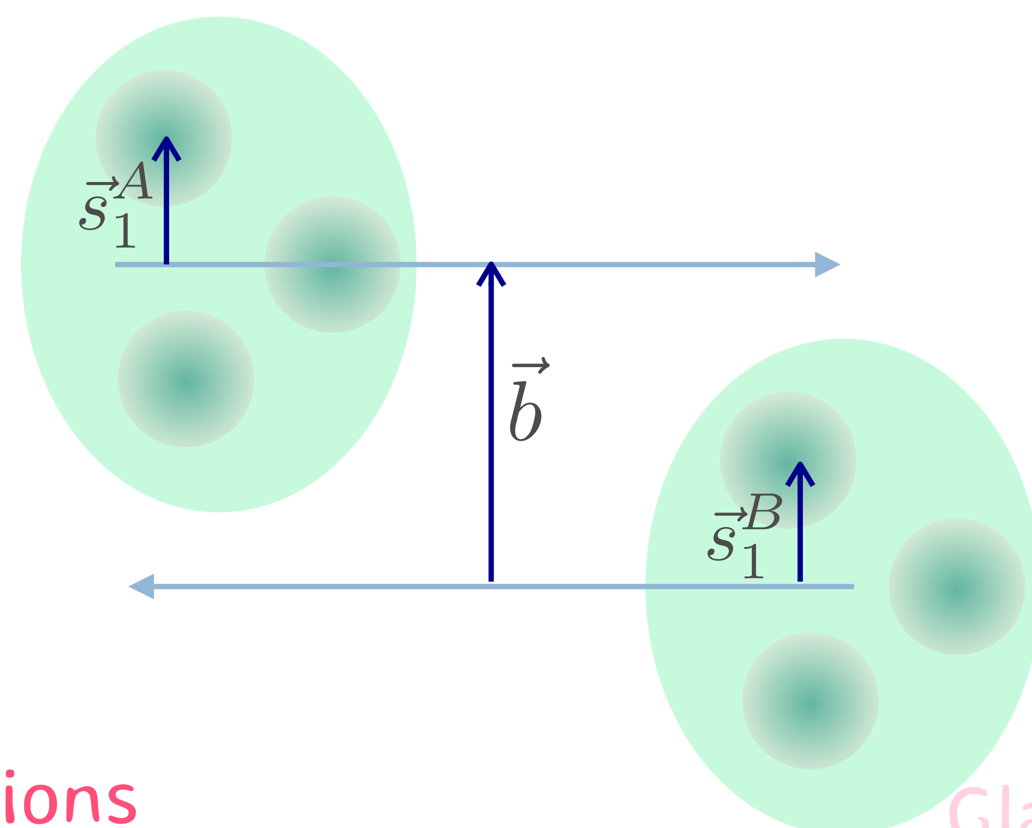



Spatial correlations in transverse space

Glauber multiple scattering expansion

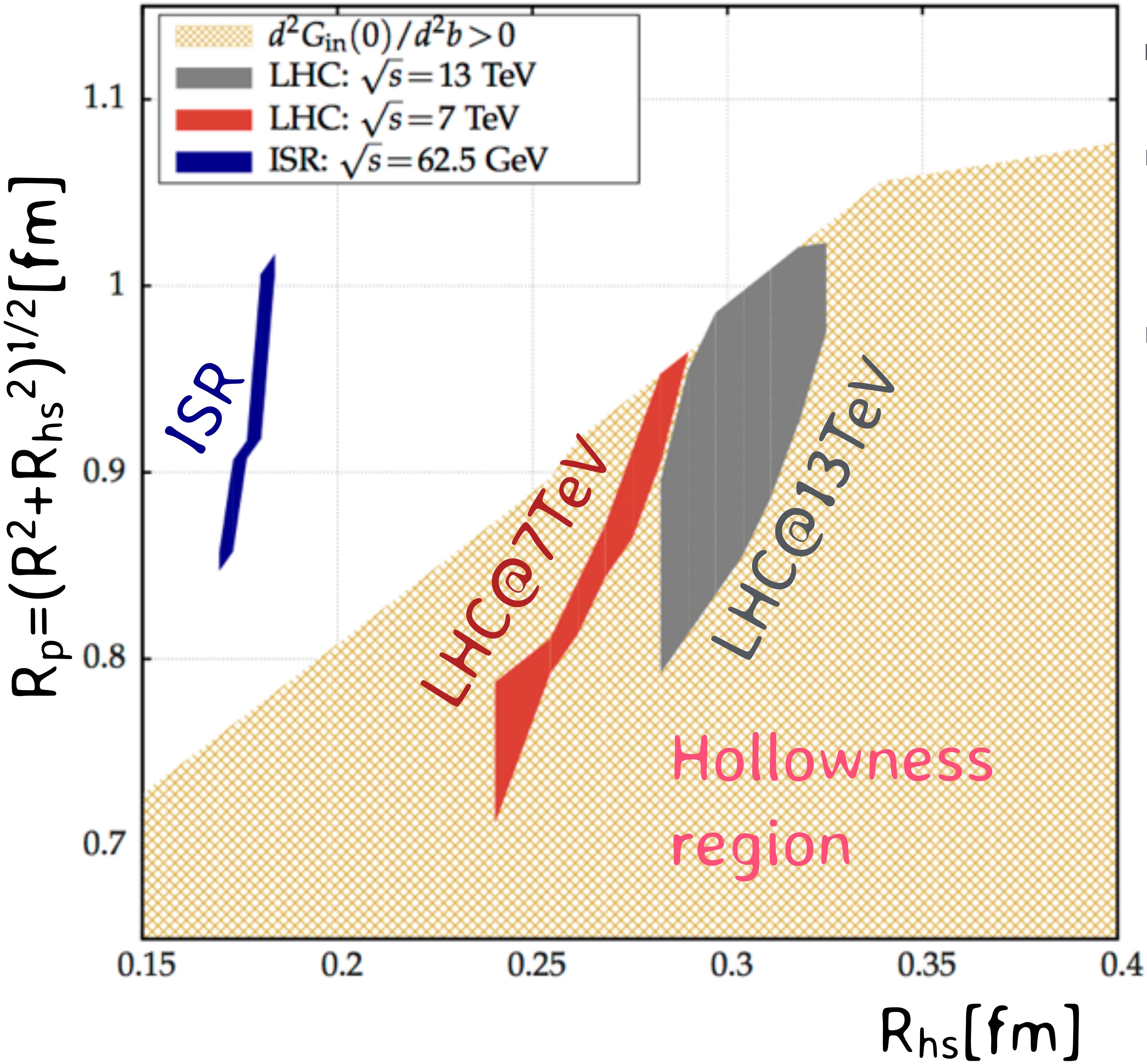
$$D(\vec{s}_1,\vec{s}_2,\vec{s}_3) \propto \prod_{i=1}^{3} e^{-s_i^2/R^2}\, \delta^{(2)}(\vec{s}_1+\vec{s}_2+\vec{s}_3) \times \prod_{\substack{i<j \\ i,j=1}}^{3} \left(1-e^{-\mu|\vec{s}_i-\vec{s}_j|^2/R^2}\right)$$

uncorrelated | fixes C.o.M | Repulsive correlations

# Results

# Hollowness effect

[Albacete & ASO'16]



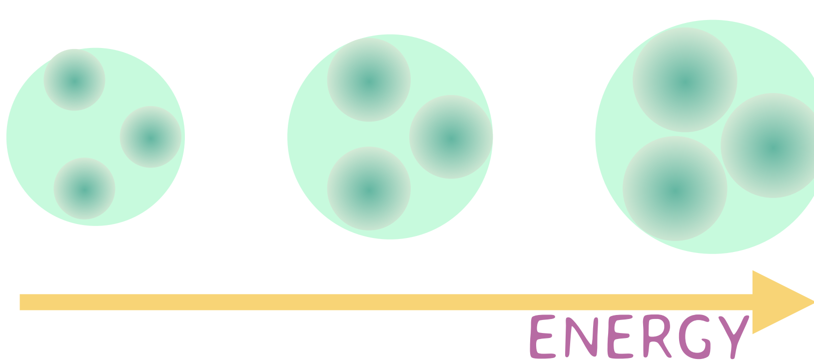

➡It works for $N_{hs} \geq 3$

➡In the absence of non-trivial correlations, no hollowness effect.

➡Transverse diffusion of $R_{hs}$ as the main dynamical mechanism for:

★Onset hollowness effect

★Growth of $\sigma_{tot}$ with $\sqrt{s}$



## Natural question

**Influence of spatial correlations between proton constituents on the initial conditions of p+p collisions???**

# MC Implementation

# MC Glauber

[Albacete,Petersen & ASO'16]

➡ Monte-Carlo implementation (ROOT/C++) needed for event-by-event fluctuations.

➡ For each pp event we follow several steps

★ Impact parameter of the collision $dN_{\rm ev}/db \propto b$

★ Transverse positions of the hot spots inside the proton $D(\vec{s}_1, \vec{s}_2, \vec{s}_3)$

★ Probability of two hot spots to collide

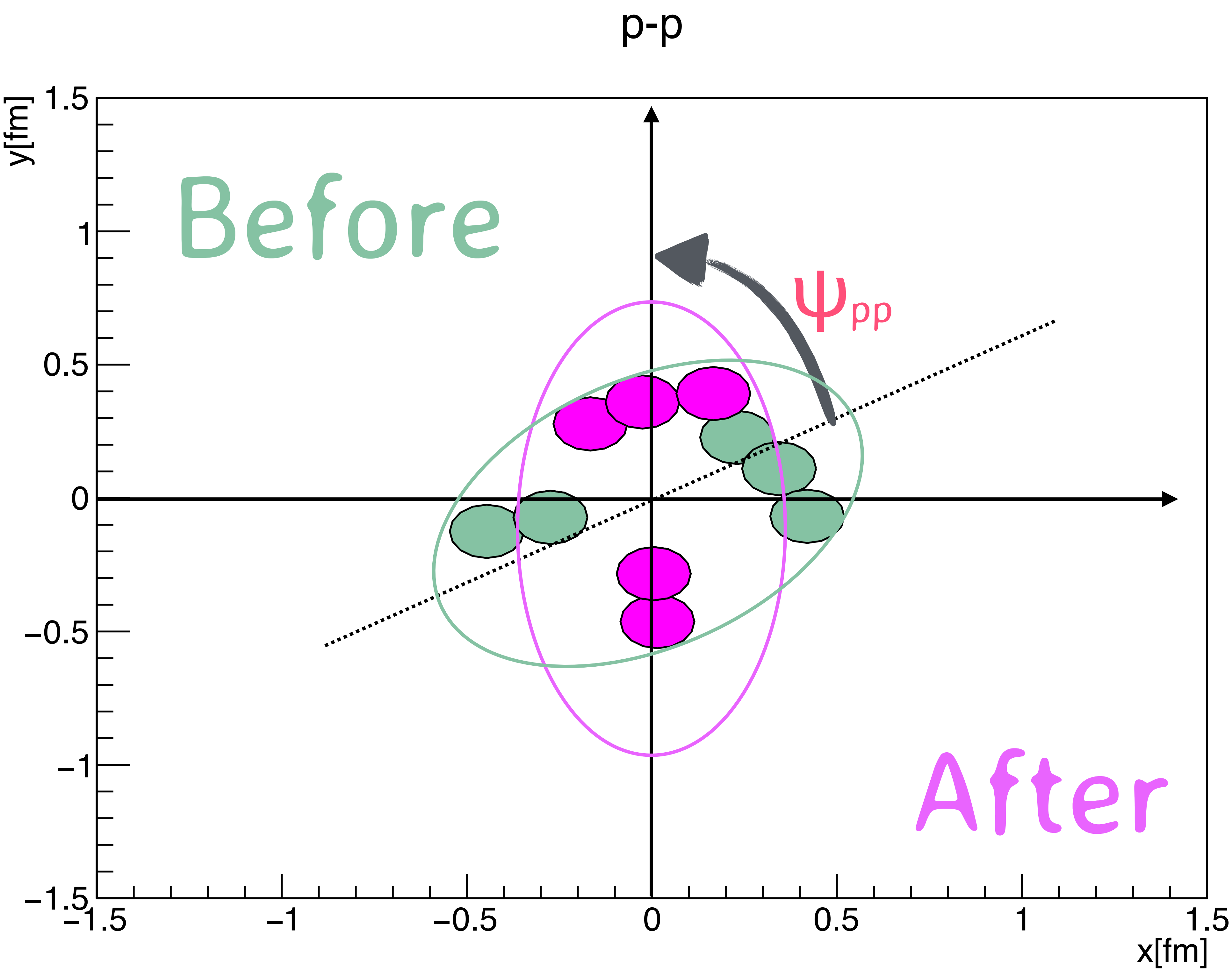
$$G_{\rm in}(d) = 2e^{-d^2/R_{hs}^2} - (1+\rho_{hs}^2)e^{-d^2/R_{hs}^2}$$

Wounded hot spot == suffered at least one collision

★ Rotate to the participant plane [to appear in 1612.06274(v2)]

# MC Glauber

[Albacete,Petersen & ASO'17]

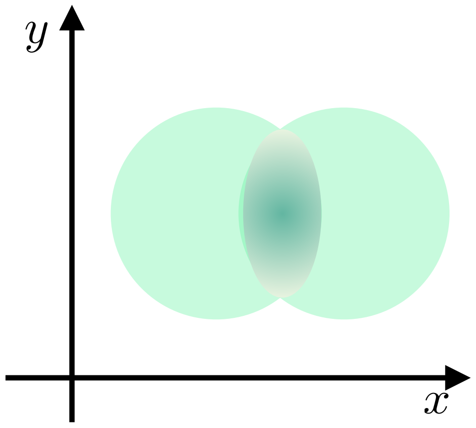


# Spatial eccentricities

[Albacete,Petersen & ASO'17]

➡Quantitative measurement of the initial anisotropy of the geometry

$$\epsilon_n = \frac{\sqrt{\langle \sum_{i=1}^{N_w} r_i^n \cos(n\phi_i) \rangle^2 + \langle \sum_{i=1}^{N_w} r_i^n \sin(n\phi_i) \rangle^2}}{\langle \sum_{i=1}^{N_w} r_i^n \rangle}$$




★ $(r_i, \phi_i)$ :wounded hot spots positions after rotation $\Psi_{pp}$.

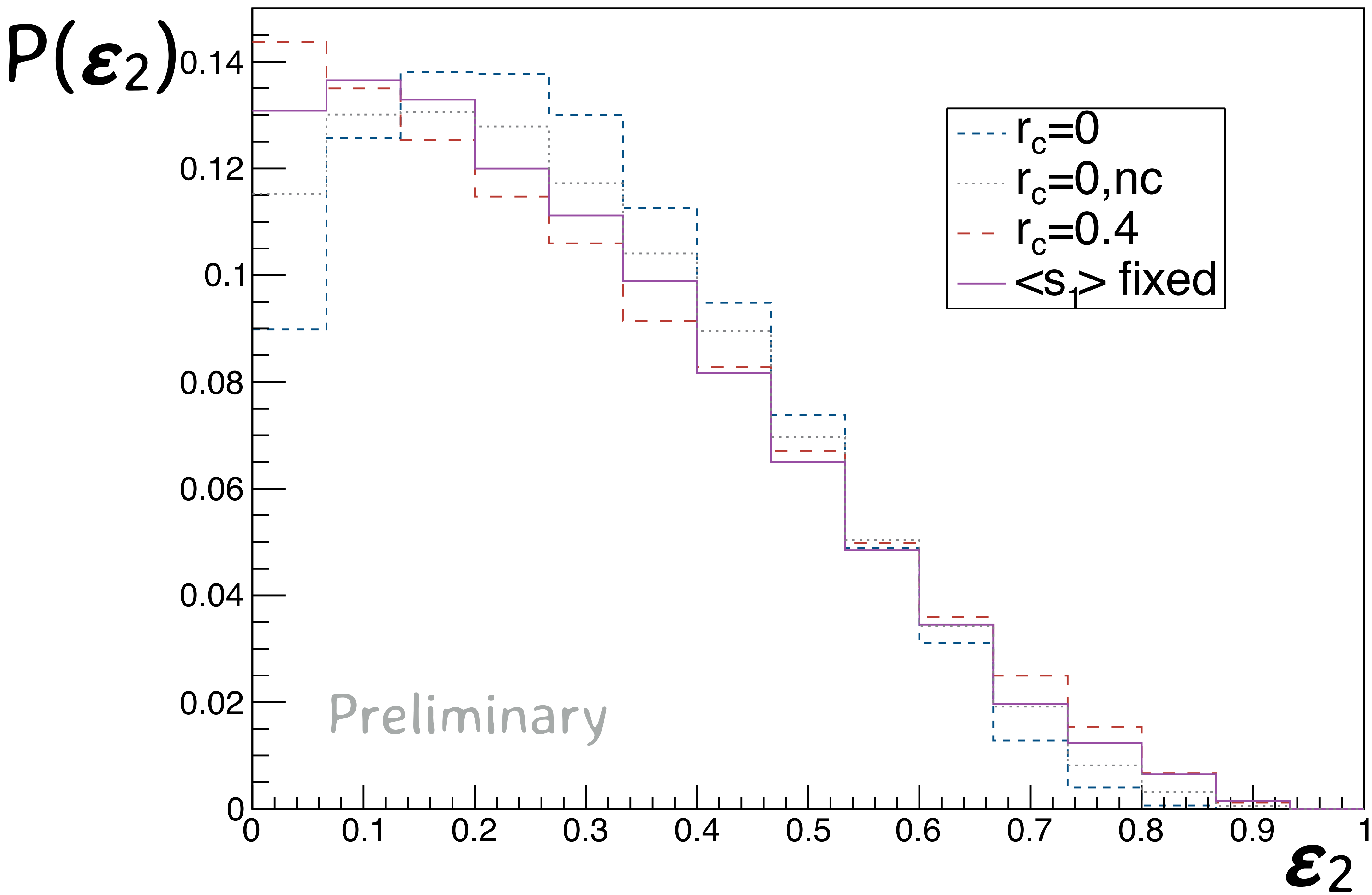
★ <...> :average over events weighted by $\int dx \int dy s(x,y)$

$$s(x,y) = \frac{1}{\pi R_{hs}^2} \sum_i^{N_p} s_0^i e^{-((x-x_i)^2+(y-y_i)^2)/R_{hs}^2}$$

where $s_0$ fluctuates independently for each participant assuming $\mathcal{P}(s_0) \propto \mathcal{P}(N_{\rm ch})$

# Spatial eccentricities

[Albacete,Petersen & ASO'17]




➡Reduction of initial eccentricities after inclusion of correlations between subnucleonic d.o.f

## Take home message

[Albacete,Petersen & ASO'16]

➡New and intriguing feature of hadronic interactions: hollowness effect.

➡Correlations between hot spots & transverse growth of $R_{hs}$ essential.

➡Monte-Carlo implementation to obtain event-by-event eccentricities.

★Eccentricities reduced after inclusion of correlations.

## Outlook

[Albacete,Petersen & ASO'17]

➡Improvements of the model:

★Fluctuating number of hot spots.

★Extension to p+A and AA collisions.

★Coherent description of particle production (à la CGC).

➡Our to do list:

★Symmetric cumulants.

★Hydrodynamic evolution.

★Implications in Multi Parton Interactions $\sigma_{\rm eff}$

★Hard-soft correlations.

See talks by Maciula, Staszevski