# How to Identify the 1.O.P.T QCD Transition by using the Deep Learning Technique

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HIC for FAIR Helmholtz International Center

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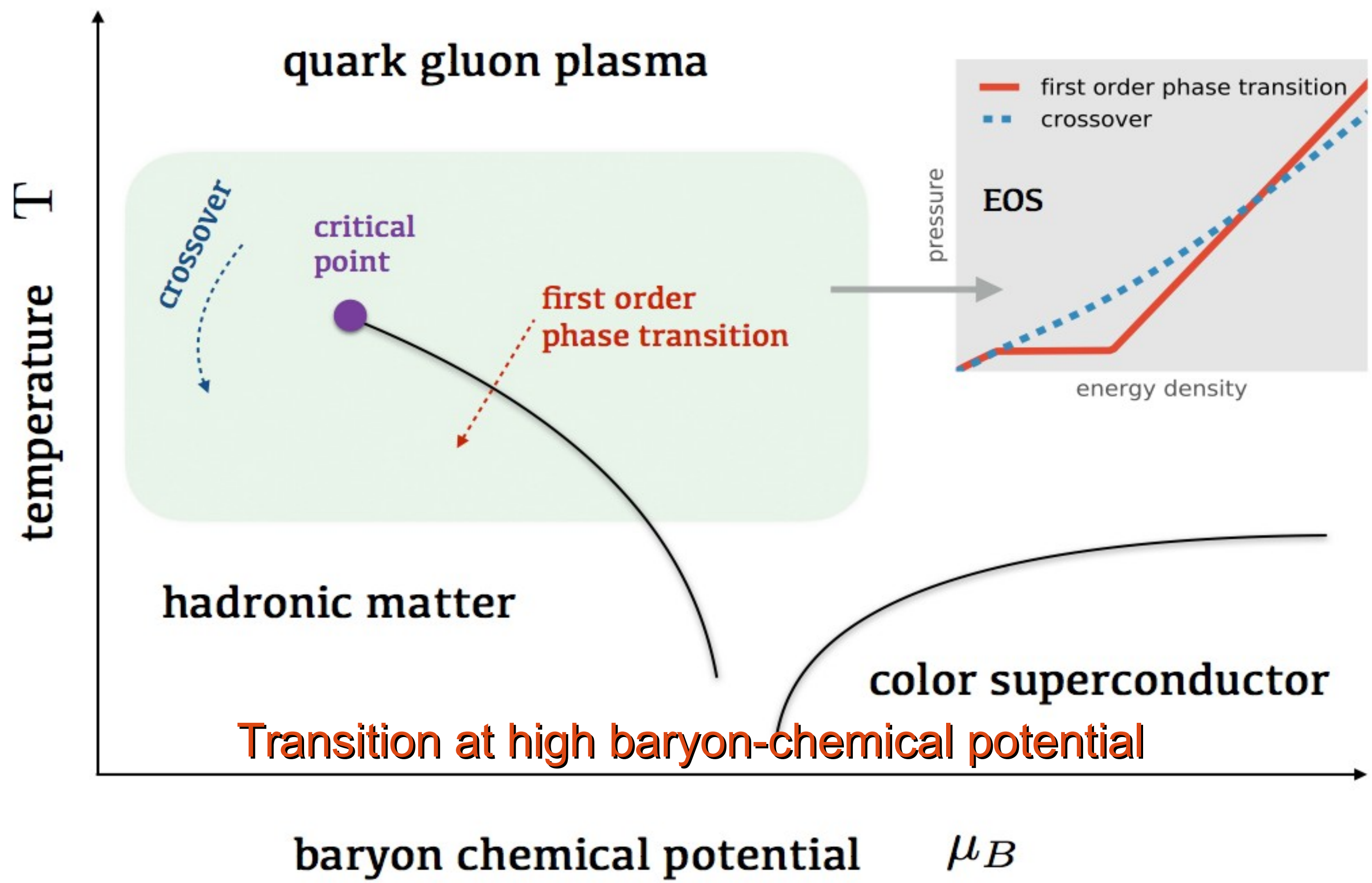
# Outline

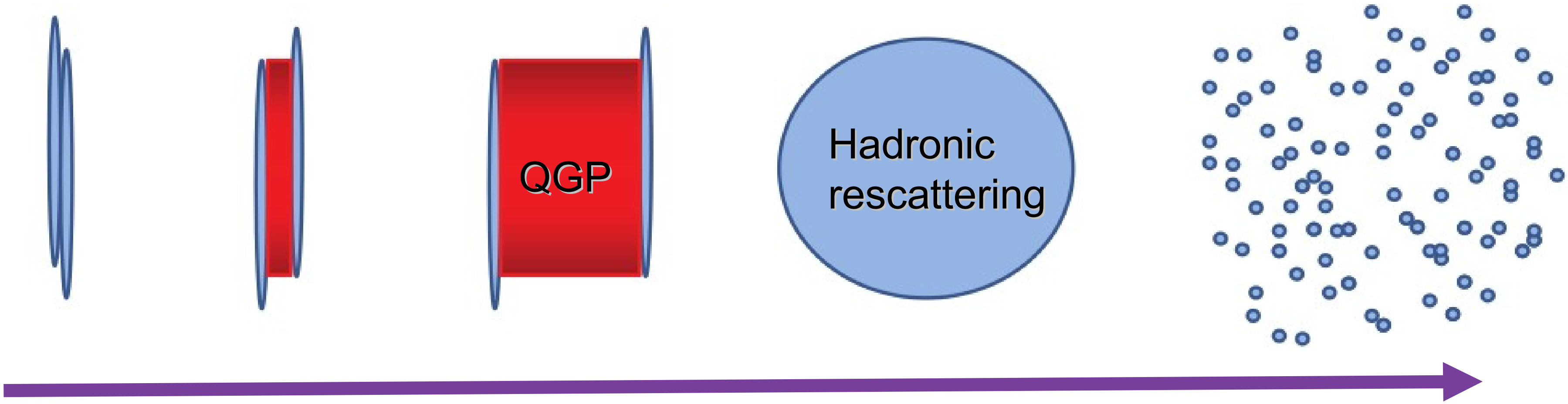
- Introduction: FAIR and RHIC & Deep Learning
- Convolutional Neural network for EoS-Meter
- Novel Perspectives & Outlook

# Compressed matter in Heavy Ion Collisions FAIR and RHIC

## QCD Transition: first order OR crossover



# Standard HIC Model facing many Uncertainties




**Initial Stage**

Fluctuation?
Pre-equilibrium?
Baryon Stopping?
Initial flow?

$$\nabla_\mu T^{\mu\nu} = 0$$
$$\nabla_\mu N^\mu = 0$$

EoS ?
Viscosity?
T_freeze-out?

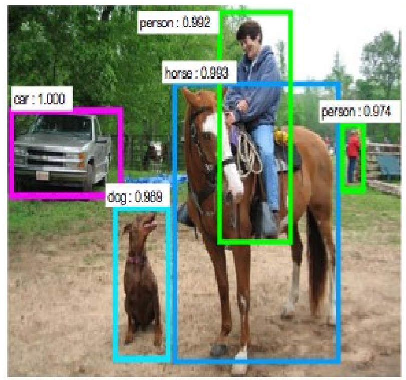
$$p^\mu \partial_\mu f + F \cdot \partial_p f = C$$

Scattering
Cross Section?
…?

**Final State**

Interference
Uncertainties
when confronting
Exp. data

# Deep Learning

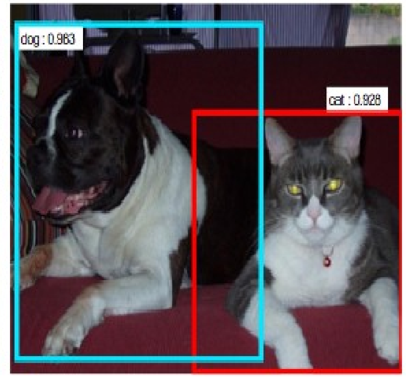
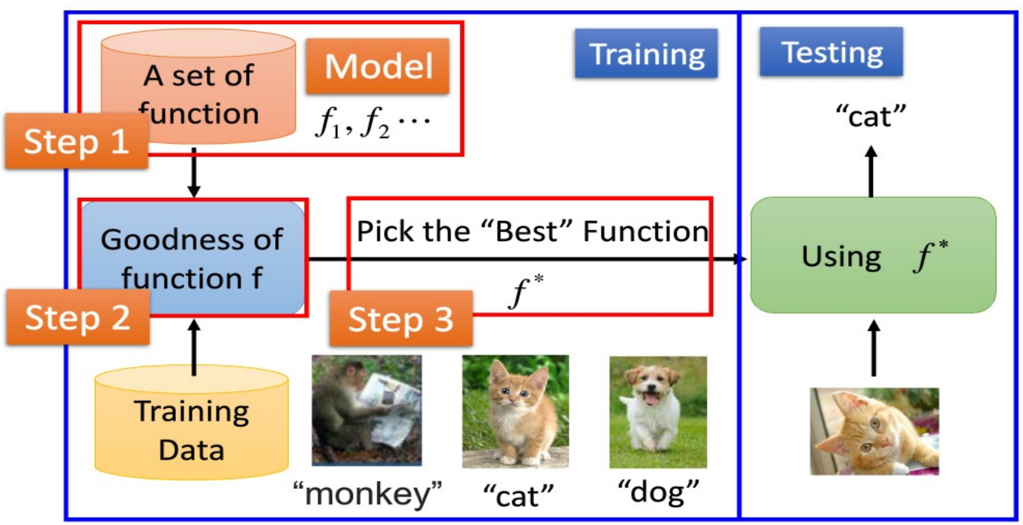





Image Recognition:

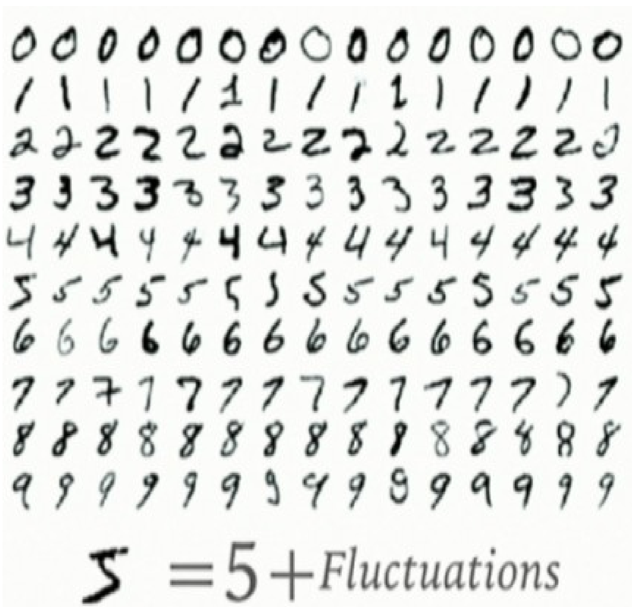
Framework

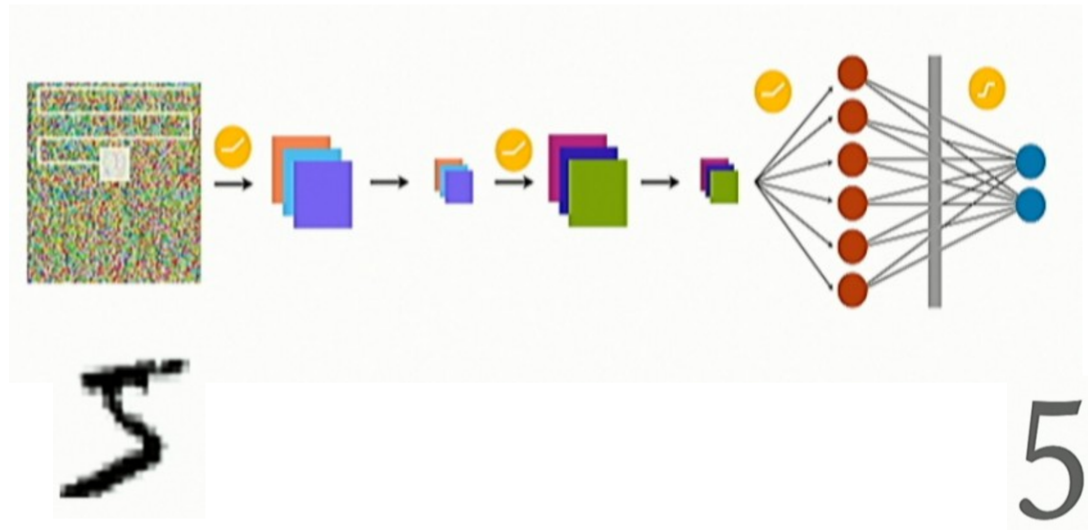
$f($  $)=$ "cat"




Find and Decode the mapping/representations into Deep Neural Network (----- function).

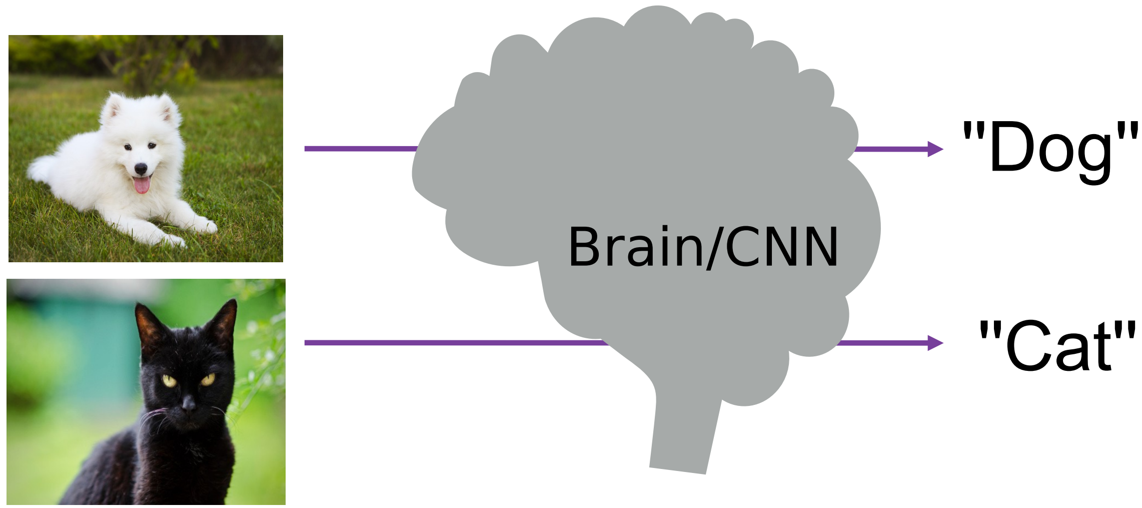
# Convolutional Neural Network

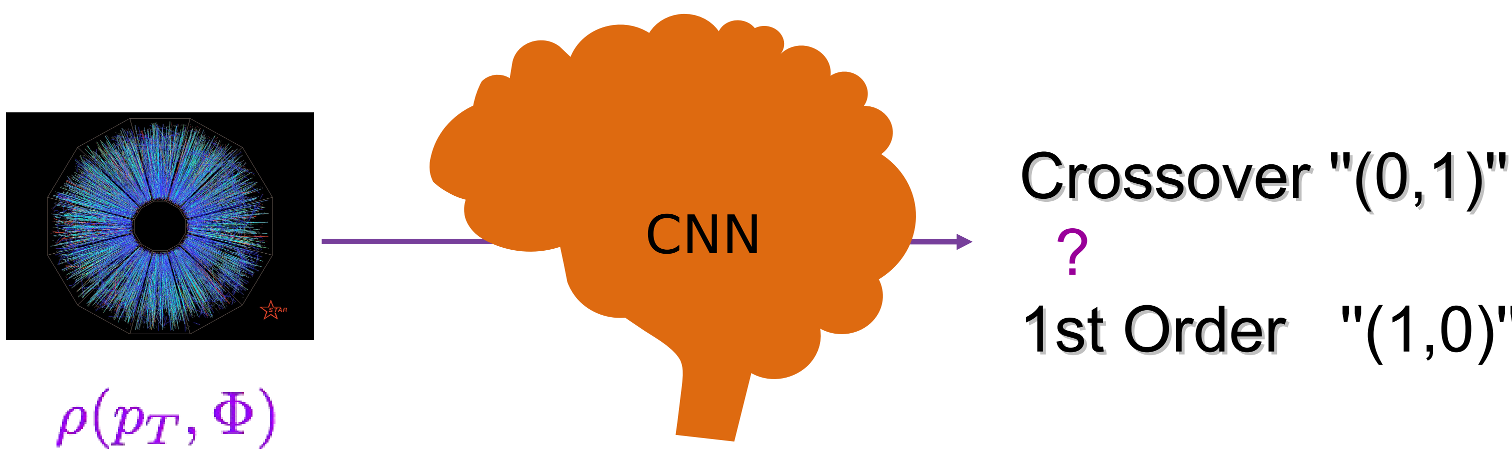


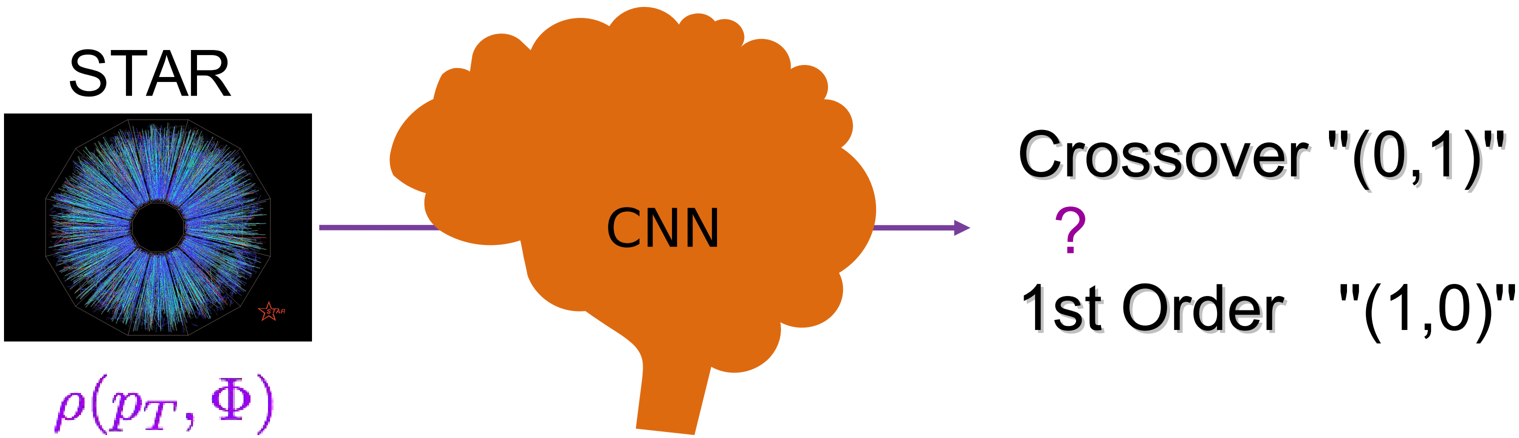

Convolutional Neural Network has proved to be extremely powerful in Pattern Recognition, Image Classification

# Inspired from Brain/CNN



# Inspired from Brain/CNN




Supervised learning using deep Convolution Neural Network

with huge amount of labelled training data *(spectra, EoS type)* from

event-by-event relativistic Hydrodynamic simulations.

# Training Dataset

Final Spectra for charged pions at mid-rapidity : $\rho(p_T, \Phi) \equiv \frac{dN_i}{dY p_T dp_T d\Phi} = g_i \int_\sigma p^\mu d\sigma_\mu f_i$

| | TRAINING DATASET | $\eta/s = 0$ | | $\eta/s = 0.08$ | |
|---|---|---|---|---|---|
| | | EOSL | EOSQ | EOSL | EOSQ |
| RHIC | Au-Au $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ | 7435 | 5328 | 500 | 500 |
| LHC | Pb-Pb $\sqrt{s_{NN}} = 2.76\,\mathrm{TeV}$ | 4967 | 2828 | 500 | 500 |

- CLVisc 3+1 D viscous hydrodynamics with AMPT initial conditions
- $\tau_0$ is 0.4 fm for Au-Au STAR and 0.2 fm for Pb-Pb
- T_freeze-out is 137 MeV

~22000 events, doubled by left-right flipping along \phi,
10% for validation during the training

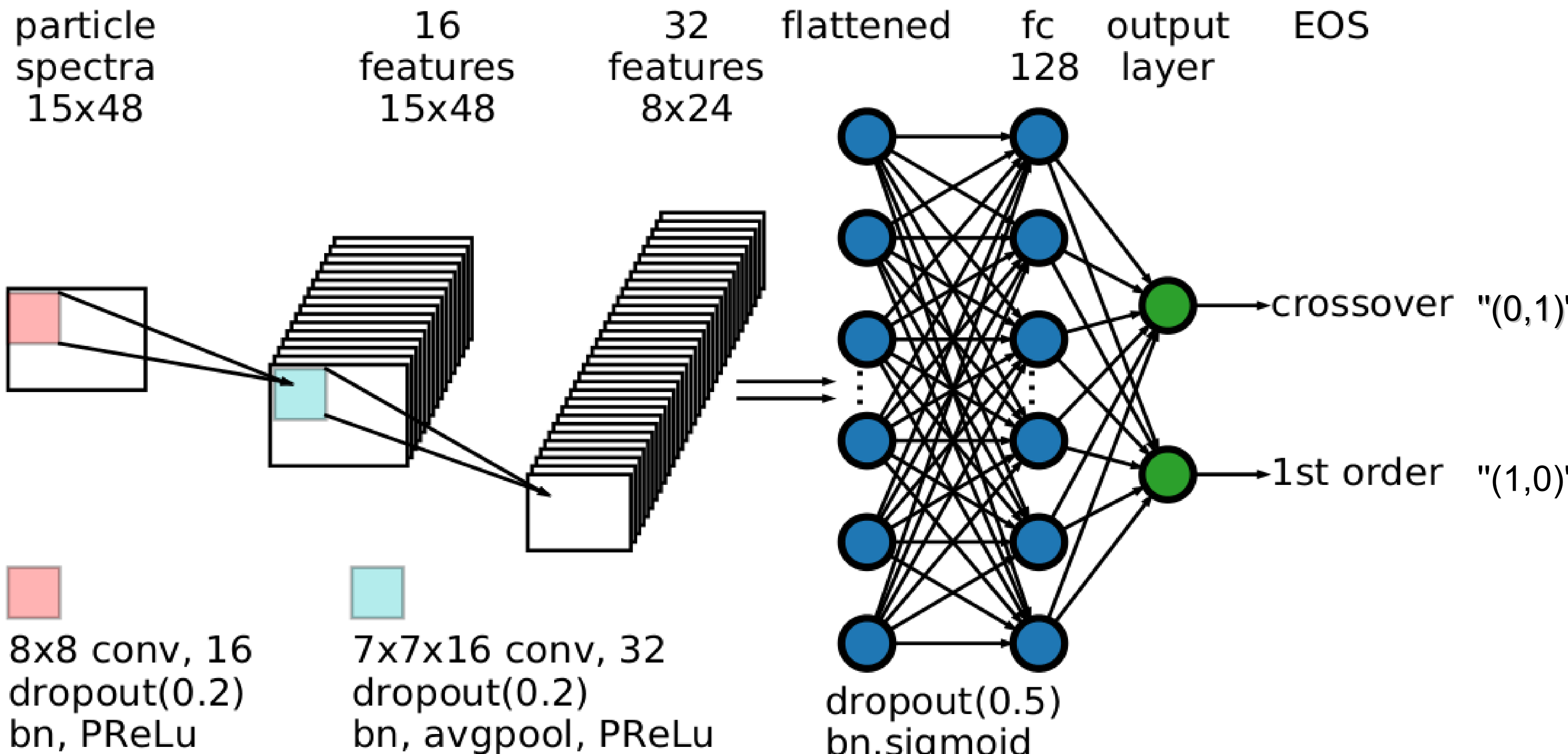
# Testing Dataset

| TESTING DATASET GROUP 1 : iEBE-VISHNU + MC-Glauber | | | | | | |
|---|---|---|---|---|---|---|
| Centrality: | $\eta/s \in [0, 0.05]$ | | $\eta/s \in (0.05, 0.10]$ | | $\eta/s = (0.10, 0.16]$ | |
| 10-60% | EOSL | EOSQ | EOSL | EOSQ | EOSL | EOSQ |
| Au-Au $\sqrt{s_{NN}} = 200$ GeV | 650 | 850 | 900 | 750 | 200 | 950 |
| Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV | 500 | 650 | 600 | 644 | 499 | 150 |
| TESTING DATASET GROUP 2 : CLVisc + IP-Glasma | | | | | | |
| Au-Au $\sqrt{s_{NN}} = 200$ GeV | EOSL | | | EOSQ | | |
| b$\lesssim$8 fm & $\eta/s = 0$ | 4165 | | | 4752 | | |

- iEBE-VISHNU a hydro packag with a <u>different numerical solver</u> and with different initial condition (MC-Glauber)
- $\tau_0$ is 0.6 fm , eta/s within [0, 0.16]
- T_freeze-out in [115, 142] MeV for iEBE-VIS, 137 MeV for CLVisc

# Convolutional Neural Network architecture

STAR,CBM...

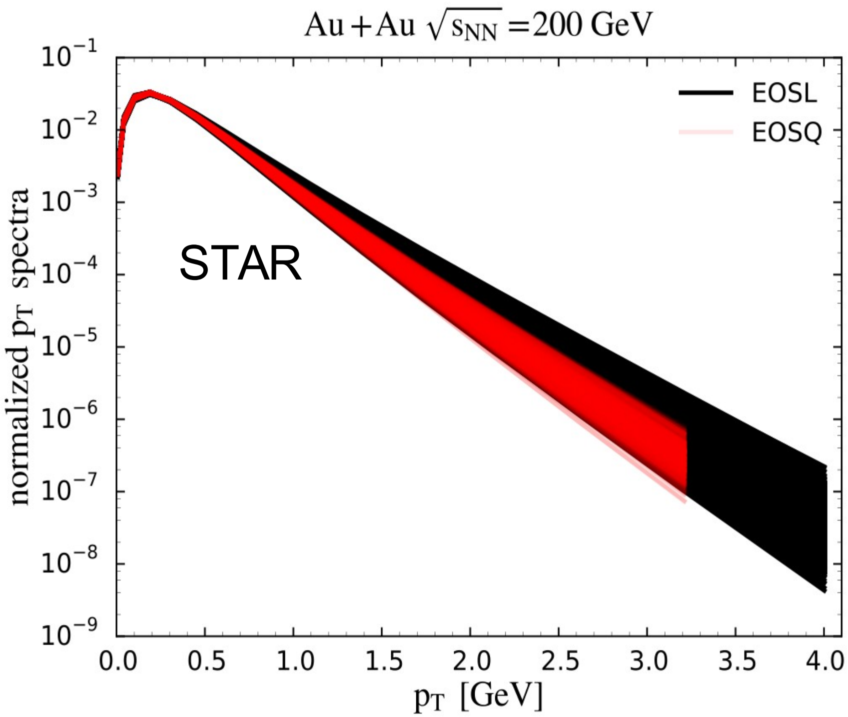


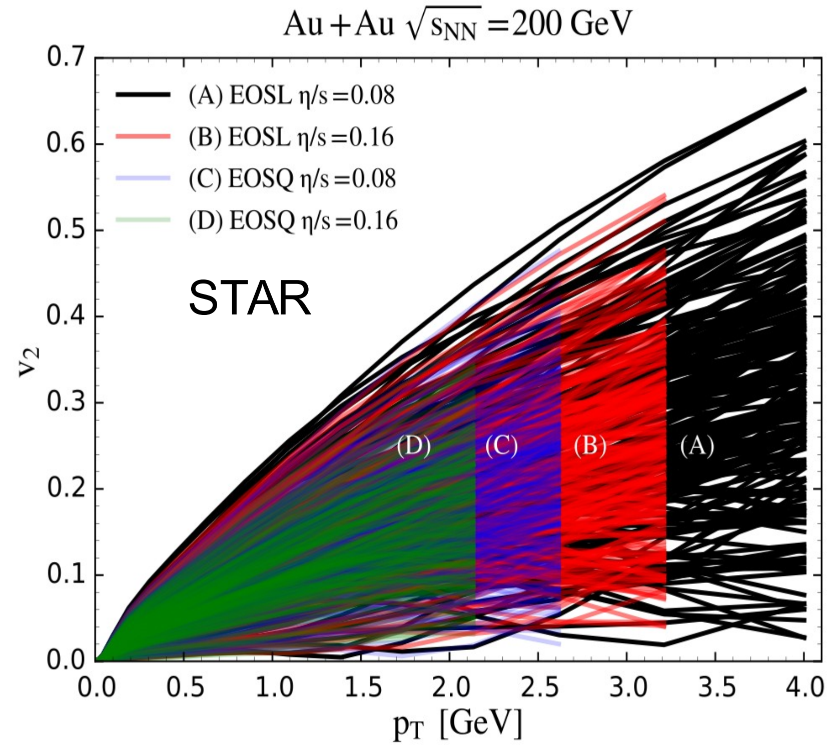
# Testing Results

| TESTING ACCURACIES | GROUP 1 (1OPT) | | GROUP 2 (1OPT) | |
|---|---|---|---|---|
| | EOSL | EOSQ | EOSL | EOSQ |
| Number of events | 3349 | 3994 | 4164 | 4752 |
| Accuracy | 98.5% | 91.6% | 99.2% | 99.2% |

- On average ~97% prediction accuracy, the trained CNN model identifies the type of QCD transition solely from the raw spectra
- The performance is robust against : initial conditions, $\eta/s, \tau_0, T_{fo}$
  model independent!

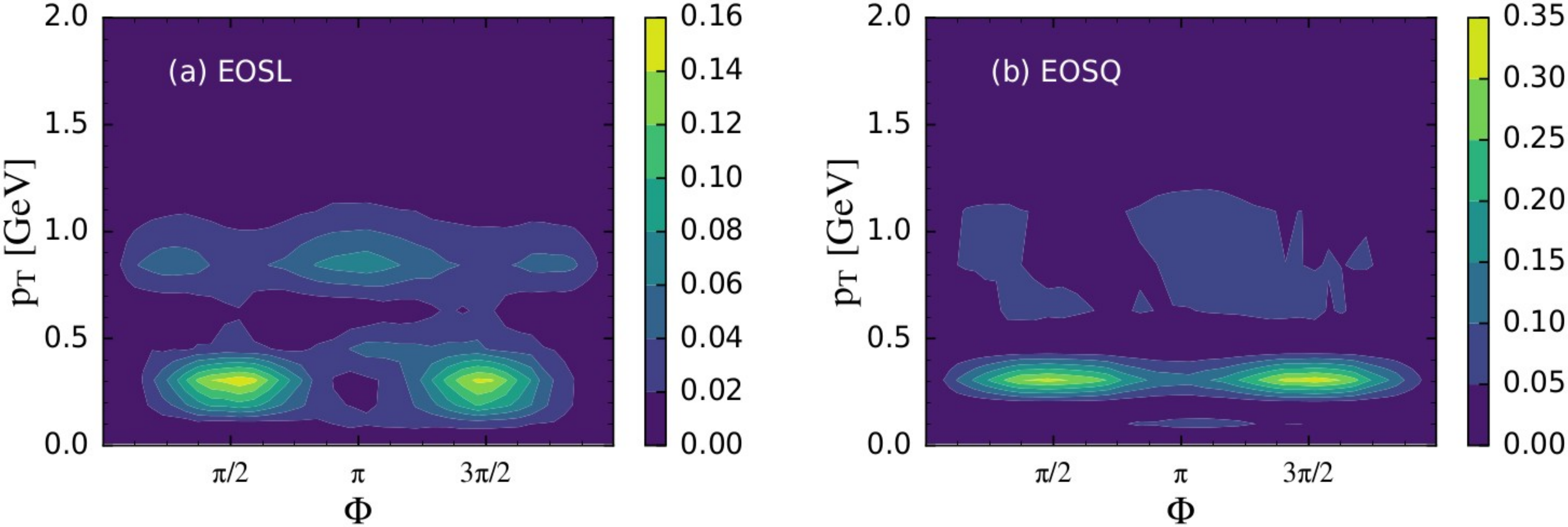
# Conventional Observables



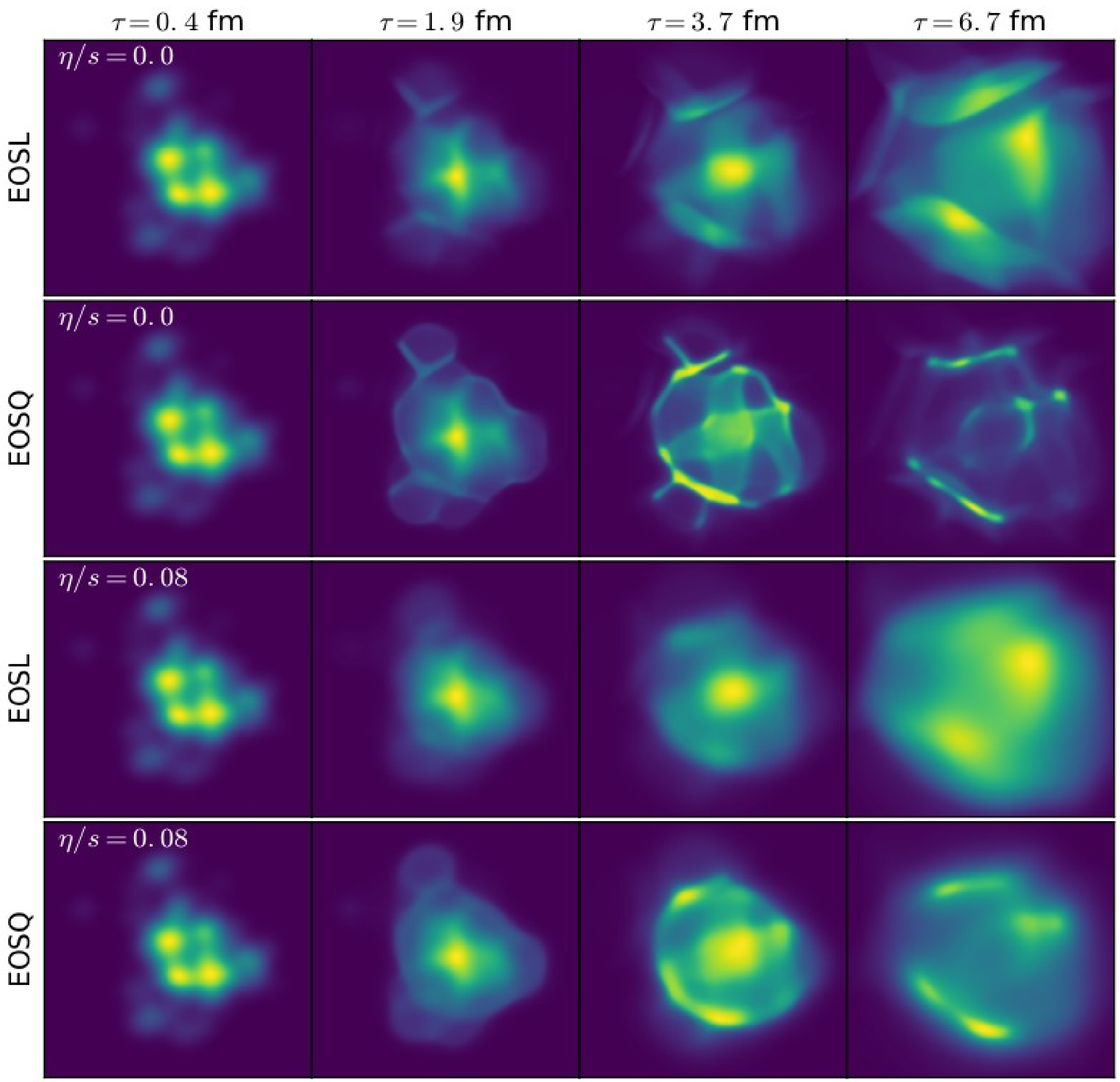

- Strongly depends on initial fluctuations and other uncertainties !

# Importance Maps




- Distinct structure of relevant feature space for each class
- Low pT relevance can be taken care of at FAIR/CBM & STAR/BES

# Evolution history of QGP energy density in x-y plane




- Hot-spots in initial stage
- Hot ridges ~1.9 fm
- Skeletons for EOSQ diffusion out for EOSL
- Cooper-Frye to spectra ?

## Novel Perspectives

- We found the "Encoder" ( mapping / projection ) of the QCD Transition onto final state Raw Spectra (pT, phi)
  Although it is NOT intuitive for traditional observables

  This Encoder is CLEAN - robust to uncertainties and other parameters

- Deep CNNs provide powerful and efficient "Decoder" for this "Encoder"

  which can act as "EoS-Meter"

- Deep CNNs help to directly connect CBM & STAR with QCD properties
  help searching for critical end point.

# Outlook

- Extend to CBM & STAR data
- Other dynamical properties : eta/s, bulk visc, freeze-out
- Use lattice configurations to correlate to CBM and STAR data

  and study phase structure of QCD

**Thank you !**