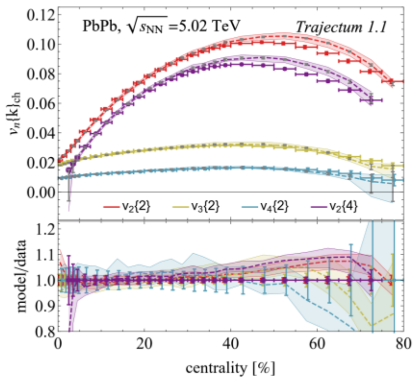
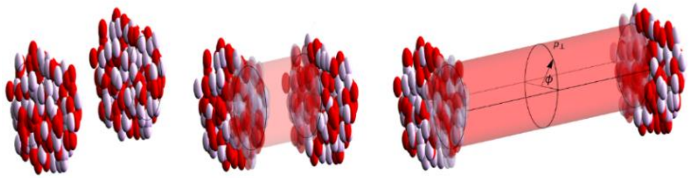
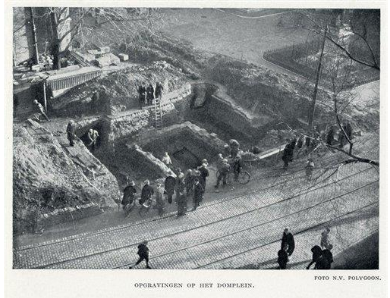




Measuring the quark-gluon plasmas viscosities by colliding heavy ions on lxplus

Based on *Trajectum* with Govert Nijs

2010.15130 (PRL), 2010.15134 (PRC) with Govert Nijs, Umut Gursoy and Raimond Snellings

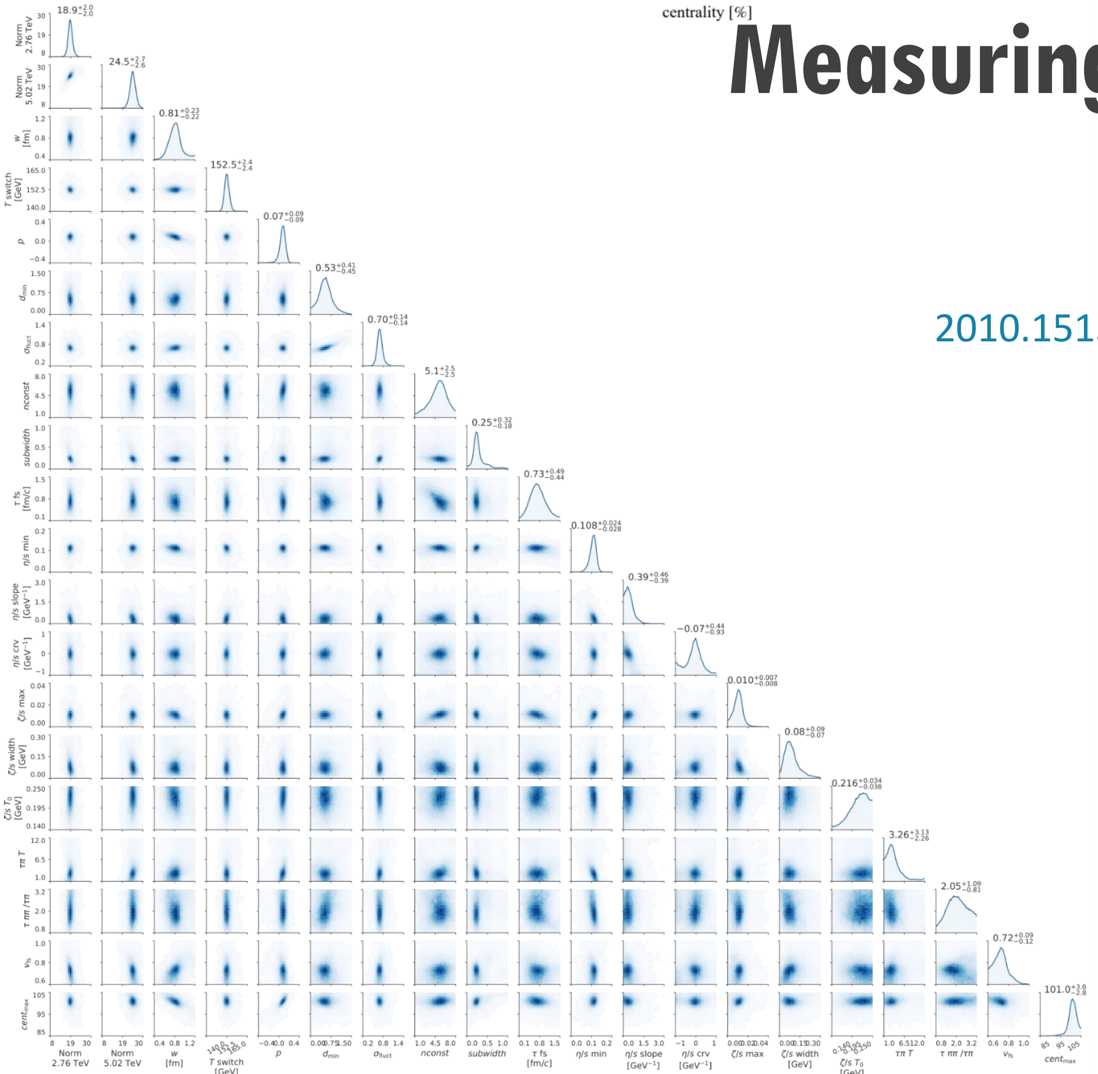


Roman excavations in Utrecht (from Trajectum, or bridge) in 1929

Wilke van der Schee

EOS forum

8 December 2021



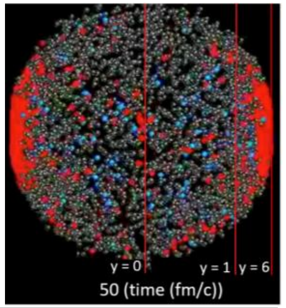
Heavy ions as a laboratory for non-Abelian quantum field theory (QCD)

1. What are the fundamental degrees of freedom of the Quark-Gluon Plasma?

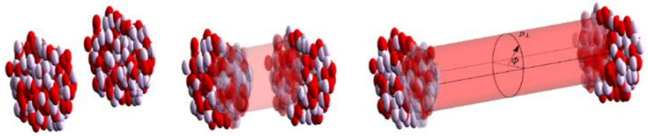
2. Is QGP strongly coupled? And at what energy or length scale?

3. At what timescale does a non-Abelian gauge theory thermalise?

Wilke van der Schee, CERN

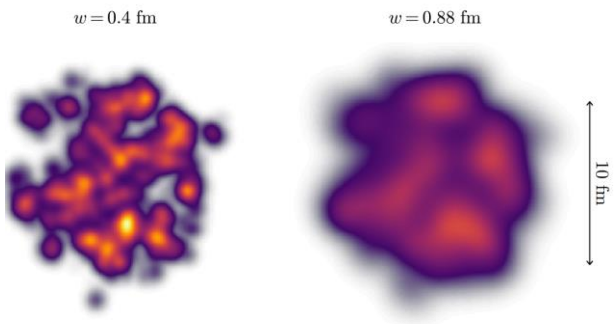


Standard model of heavy ion collisions



Initial stage (9)

Subnucleonic structure? (7)

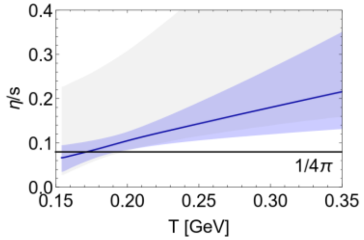


Non-thermal flow? (2)
for time τ with varying speed (***new***)

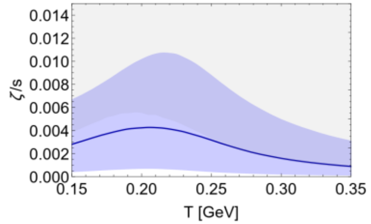
Fluctuations? (1)

Viscous hydrodynamics (9)

Shear viscosity (3)



Bulk viscosity (3)



Second order transports: 3 (***new***)

Cascade of hadrons (1)

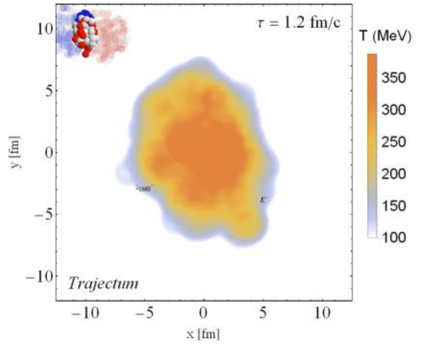
Convert quark-gluon plasma at T_{switch} to particles following Boltzmann distribution (particlization, 1)

Subtle: viscous corrections

Evolve particles with hadronic code: SMASH

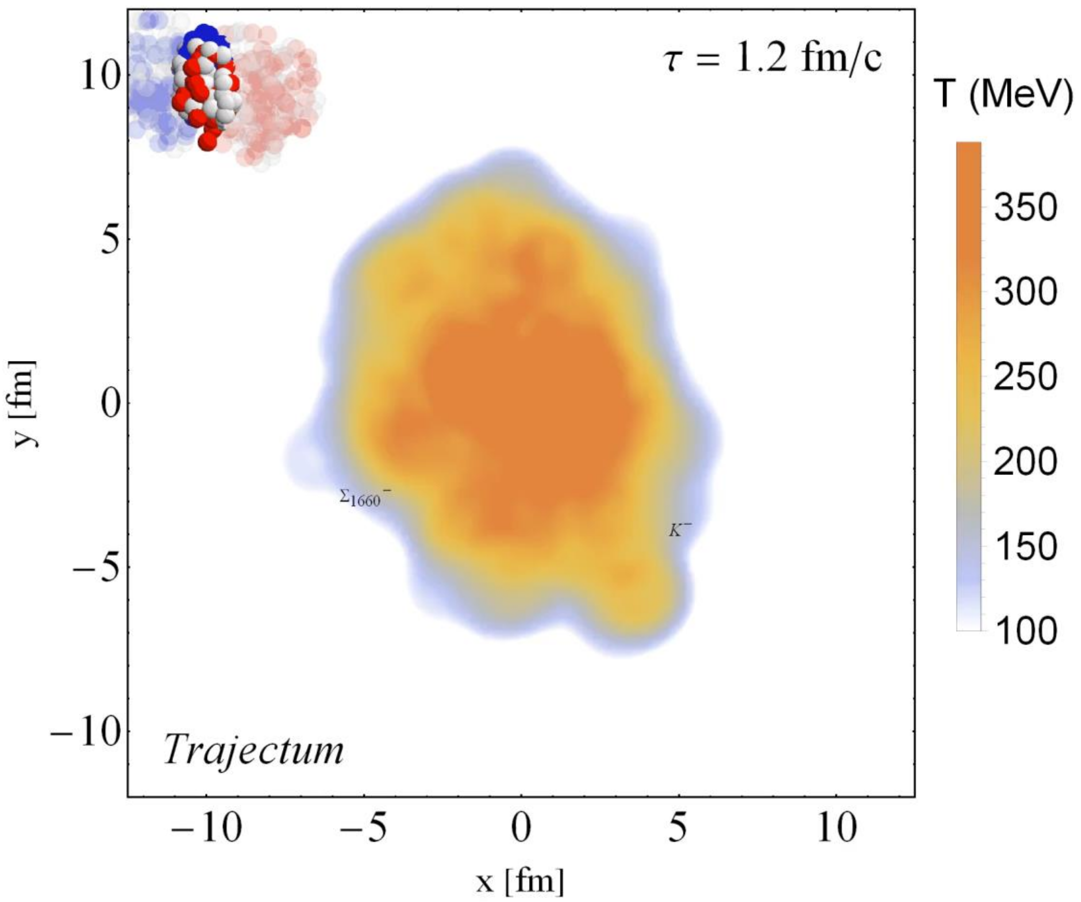
Sort events in centrality classes (1) (***new***)

Trajectum



1. Quite straightforward to use (see param file, right)
   - Second order hydro + freeze-out
   - SMASH

2. Includes analyse routine
   - Parallelised: can analyse unlimited number of events
   - Most soft observables are currently implemented



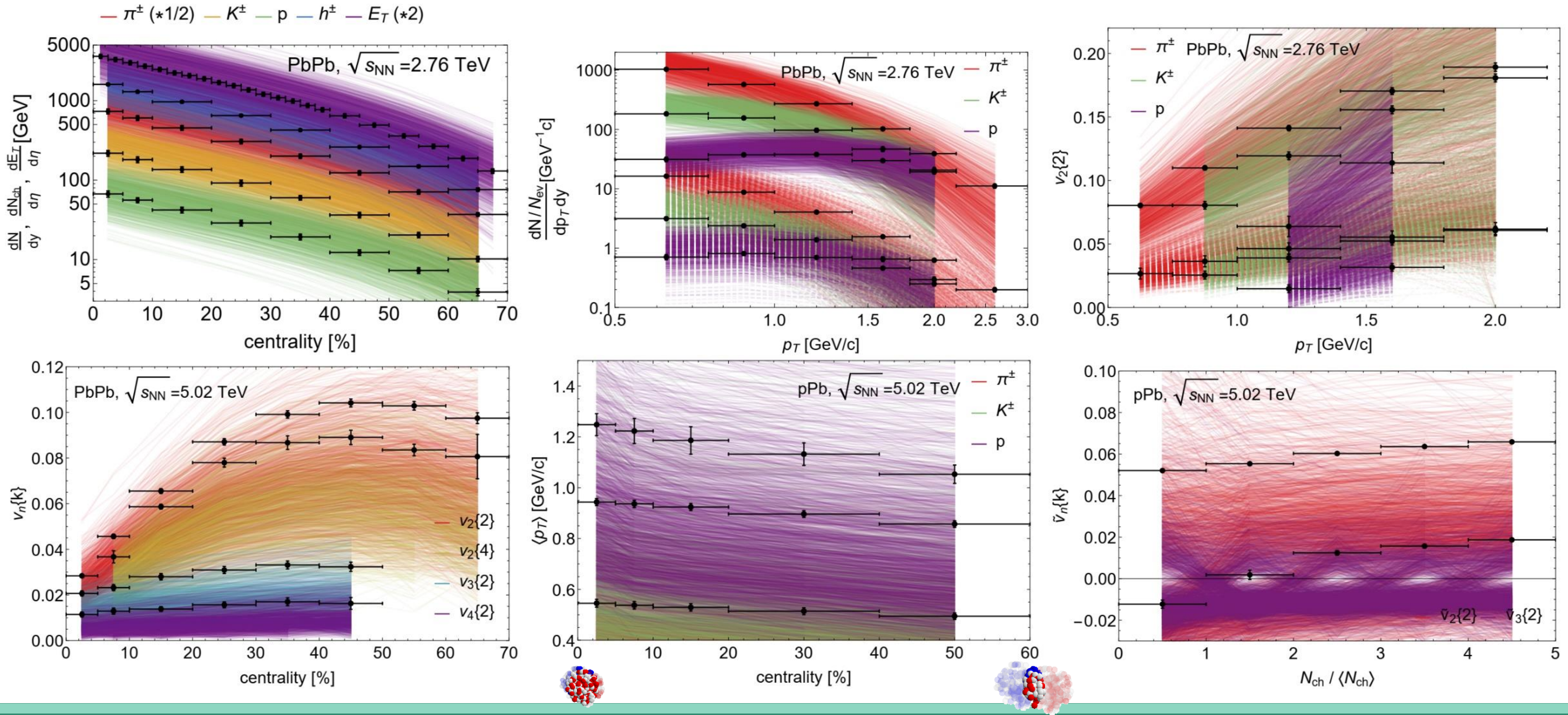

```
general{
    output=out
    format=smash
    f0500=false
    numevents=1
    seed=7398984.747399307
    debugoutput=true
    numthreads=2
}

entropyacceptanceprobability{
    0:0.0
    24:0.0
    24.5:0.05
    25.5:0.05
    26:0.0
    100:0.0
}

trentosubstructurePbPb{
    dmin=0.63933
    w=0.701919
    sigmann=70.0
    sigmafluct=0.73579
    p=0.14388
    q=1.0
    Eref=0.2
    norm=23.507
    freestreamingreferencetime=1.17085
    freestreamingvelocity=0.62672
    weaktostrong=0.0
    nref=20
    alpha=0
    nc=3.2747
    voverw=0.4892041602706295
}

secondorderhydro{
    numlatticesites=166.0
    latticesize=33.2
}

musclsolverktminmodfastmidpoint{
    cflconstant=0.08
}

LatticeEOStempdepDuke{
    shearhrg=0.0895066
    shearmin=0.0895066
    shearslope=0.43252
    shearcrv=0.231195
    shearrelaxationtime=6.318855
    bulkmax=0.0030138
    bulkT0=0.21471
    bulkwidth=0.10906
    bulkrelaxationtime=0.0687
    deltapipiovertaupi=1.3333333333333
    phi7overpressure=0.128571
    taupipiovertaupi=1.61033
    lambdapiPiovertaupi=1.2
    deltaPiPiovertauPi=0.6666666666666
    lambdaPipiovertauPi=1.6
    phi1overpressure=0
    phi3overpressure=0
    phi6overpressure=0
}

cooperfryehadronizer{
    freezeouttemp=153.456
    rapidityrange=0.1
}
```

Computing

1000 design points in parameter space * 20000 events

1 million hours later …… (6 TB)

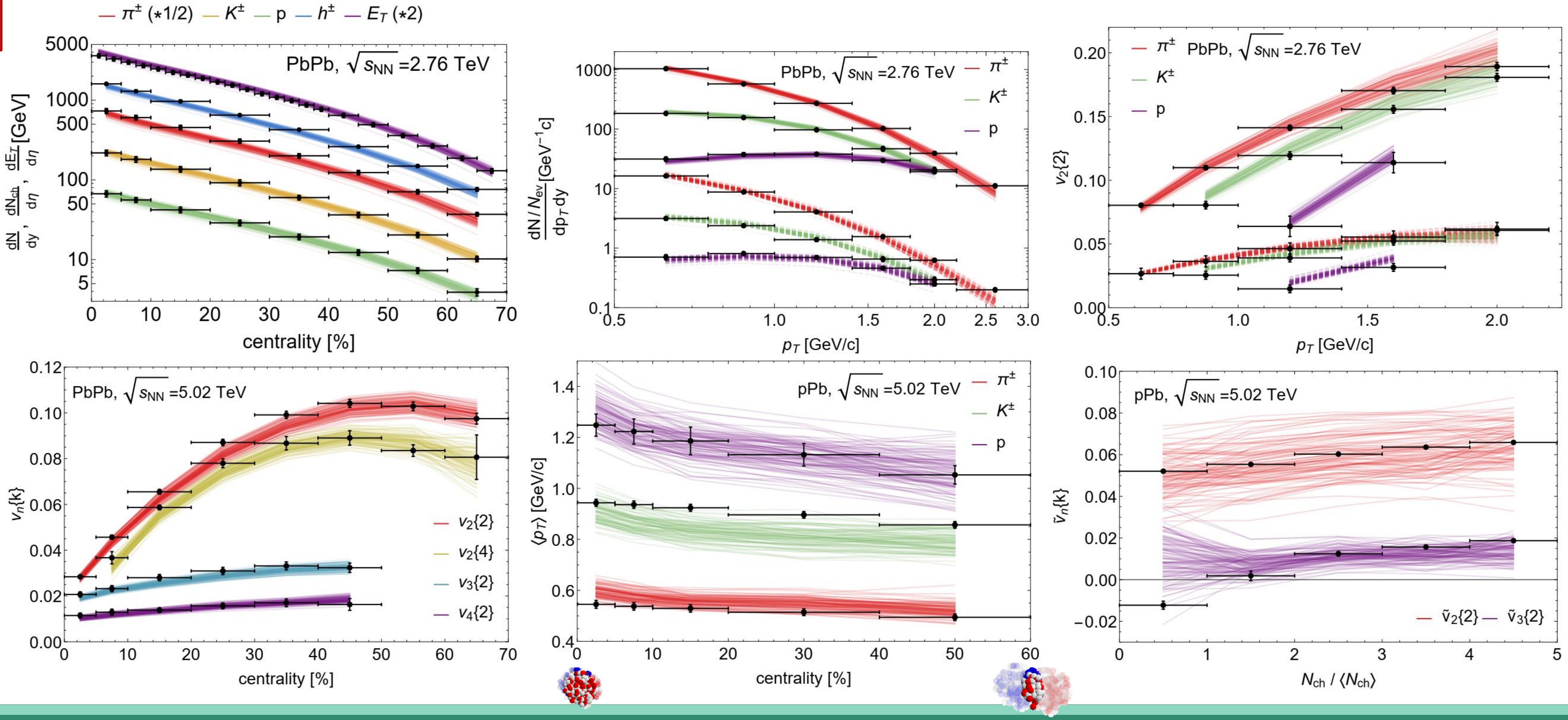
Design



Experimental observables: *a wealth of data*

1. Yields, spectra, identified $v_n\{2\}$ versus p_T, pPb and PbPb (514 datapoints)
2. First study with a comprehensive analysis including **p_T-differential observables**

Posterior



Experimental observables: *a wealth of data*

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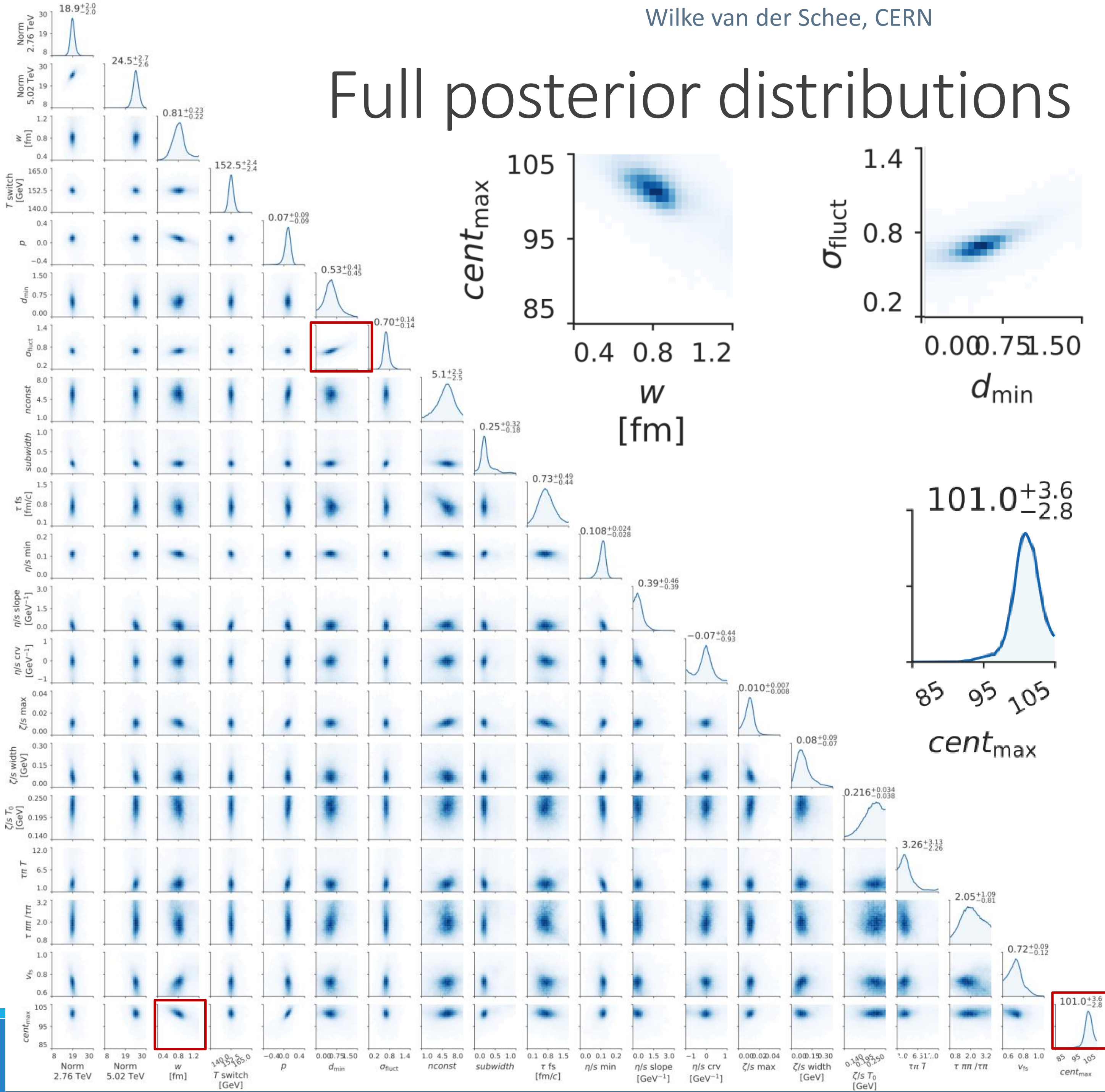
Wilke van der Schee, CERN

Full posterior distributions

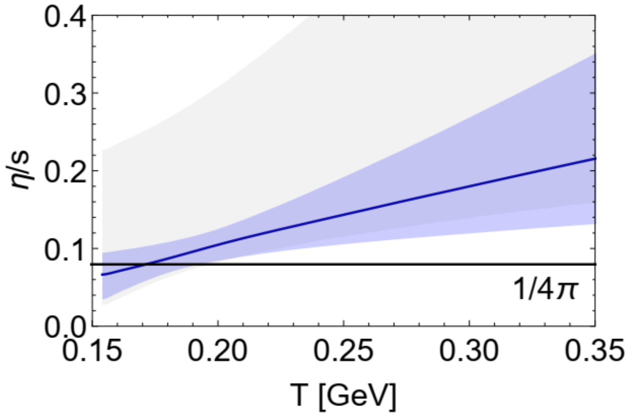
1. Some parameters better constrained than others
   - Correlations add important information, e.g. width constrained much more accurately if $cent_{norm}$ is known
   - Similar for d_{min} and σ_{fluct}



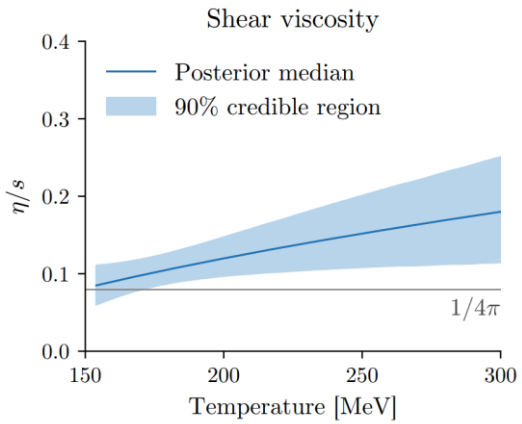
Plots made using Bayesian code by Jonah Bernhard and Scott Moreland

Posterior distributions – shear viscosity

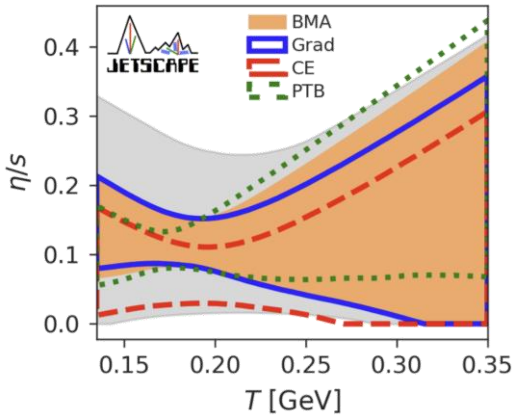
1. Shear viscosity consistent with previous work
    - More data, but also enlarged model → similar constraint on η/s
    - New JETSCAPE slightly broader band (larger priors, single PbPb energy but including RHIC)
    - Consistent with state-of-the-art pQCD computations



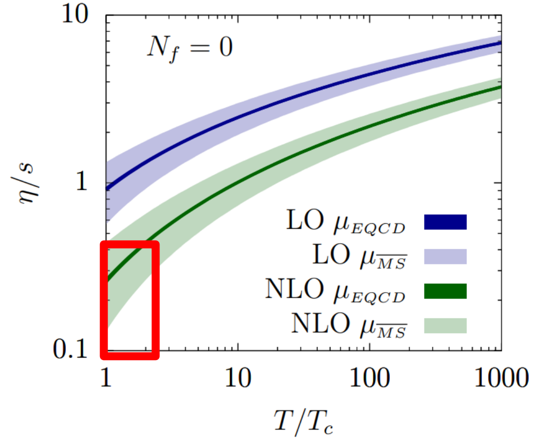
Trajectum (2020)



J. Bernhard, S. Moreland and S. Bass, Nature Physics (2019)



JETSCAPE (2020)

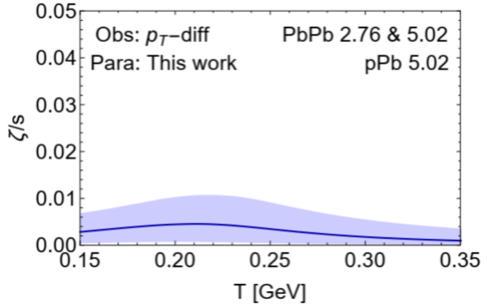


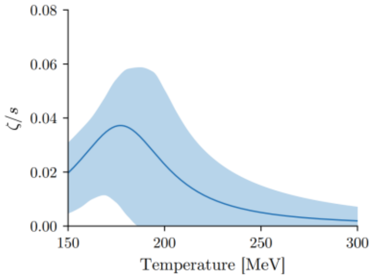
Jacopo Ghiglieri, Guy Moore and Derek Teaney
QCD Shear Viscosity at (almost) NLO (2018)

Govert Nijs, WS, Umut Gursoy and Raimond Snellings, A Bayesian analysis of Heavy Ion Collisions with Trajectum (2020)

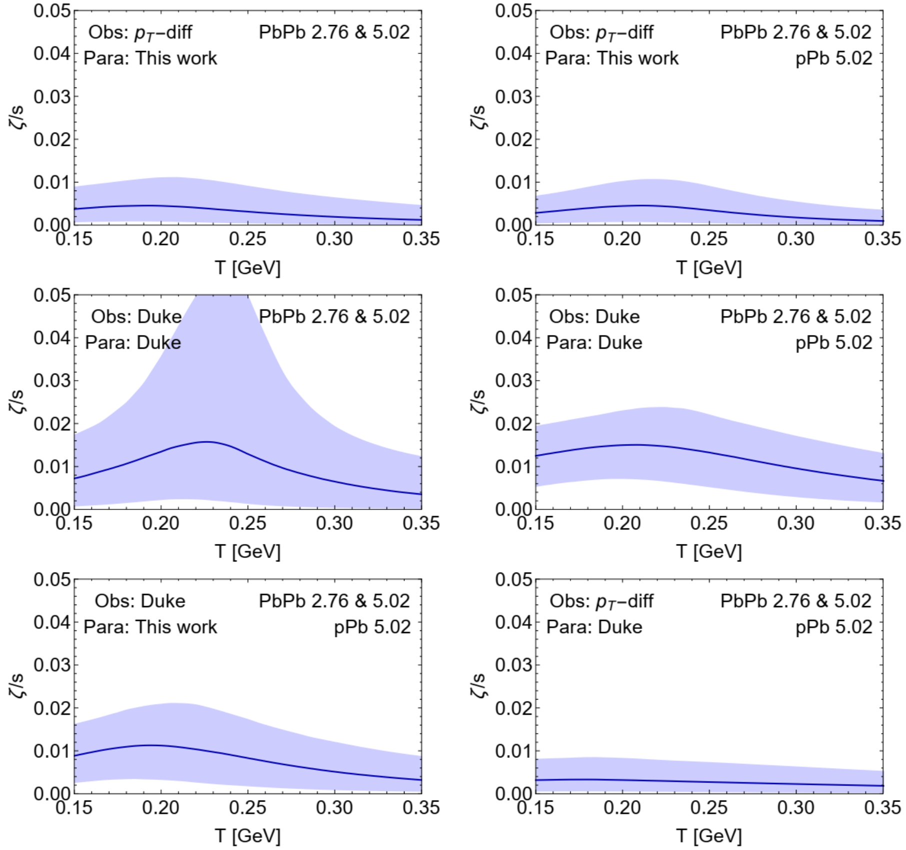
Posterior distributions – bulk viscosity:

Much smaller, even consistent with zero





J. Bernhard, S. Moreland and S. Bass, Nature Physics (2019)

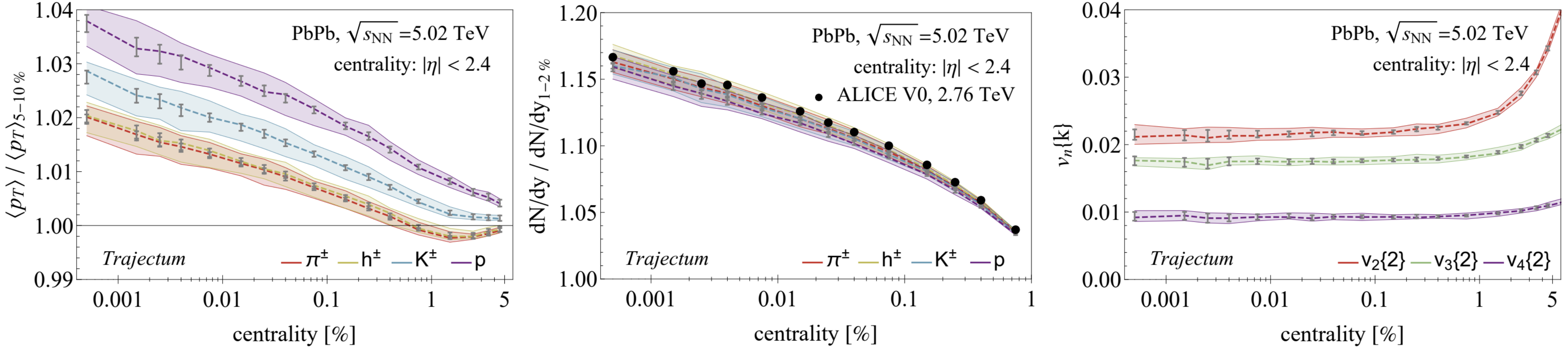


Bulk viscosity, varied several aspects:

- More limited parameter set
  - All versus only `Duke’
- Include or not include p-Pb collisions
- **Include p_T-differential observables**

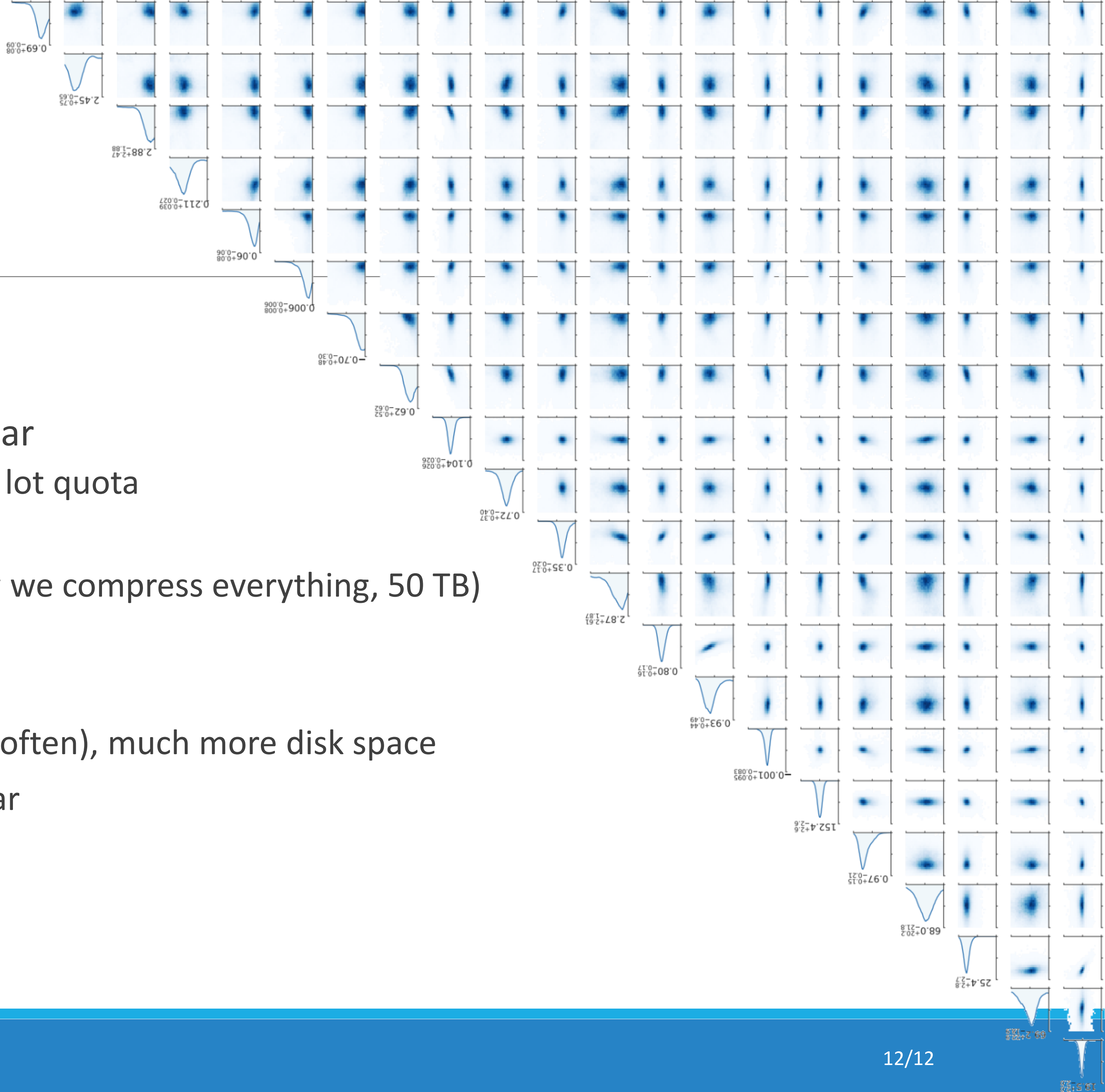
Extremely ultra-central collisions

1. Interesting to go to extremely ultra-central collisions:
   - Keep size fixed, but increase temperature by means of fluctuations → increased radial flow → mean pt
   - Trajectum has entropy acceptance feature, but still statistically non-trivial (33M Trento events and 0.5M hydro events used)
   - Multiplicity matches well with ALICE V0 (5.02 data not available due to pile-up)
   - Small but significant dip in pion mean transverse momentum at 1-2%; explanation?



Govert Nijs and WS, Predictions and postdictions for relativistic lead and oxygen collisions with Trajectum (2021)

Trajectum and EOS



1. Very happy with performance

2. In beginning some things not entirely clear
   - When overwriting files hidden files took a lot quota
   - eos cp, though cp also works
   - How limited are we with disk space? (now we compress everything, 50 TB)

3. Very convenient:
   - In principle seems to work as well as AFS (often), much more disk space
   - Sometimes difference with AFS not so clear