A brief introduction

Jasmine Brewer

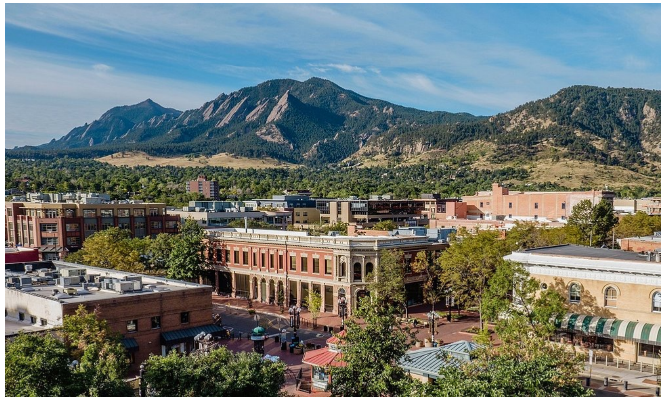
CERN-TH Retreat

Bozeman, MT

Boulder, CO

University of Colorado Boulder

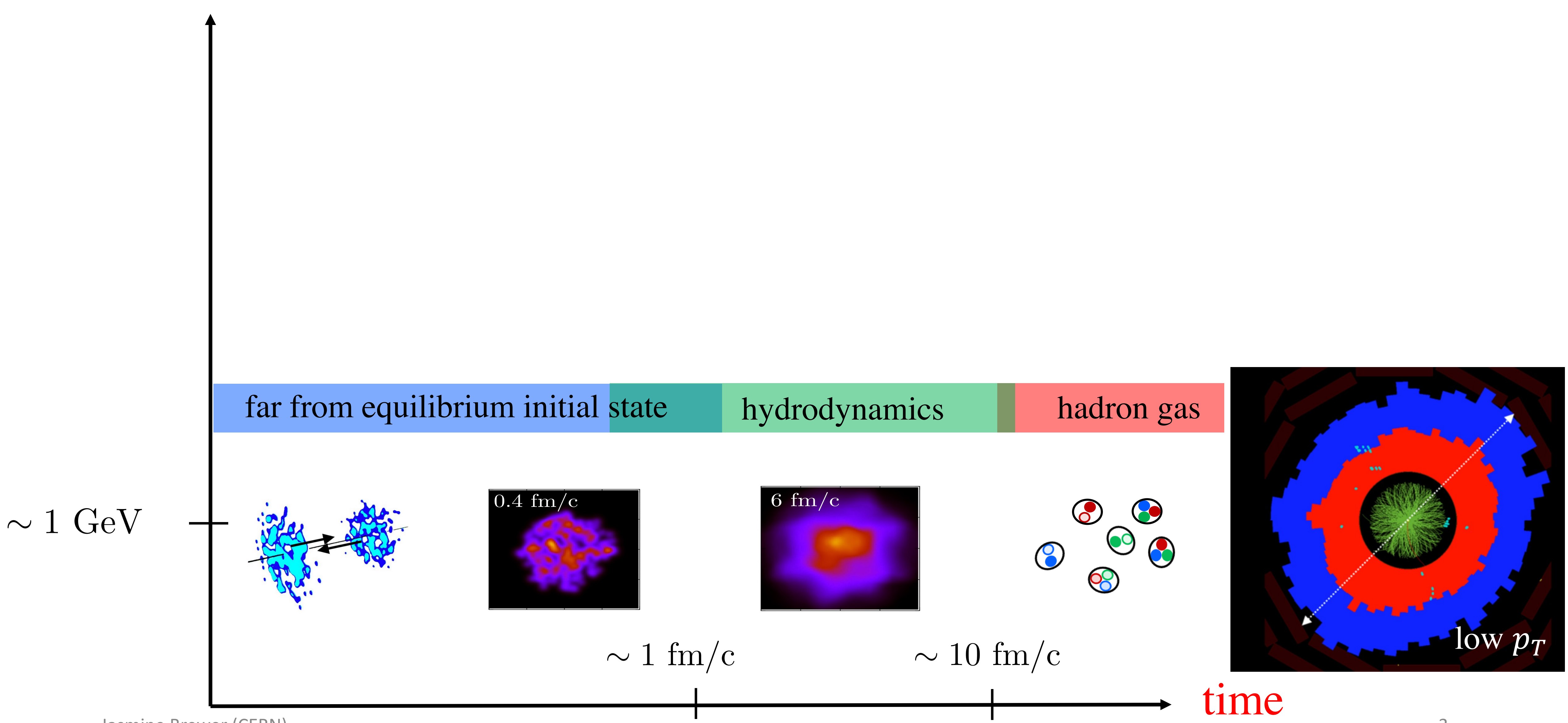
Undergrad
2011-2015



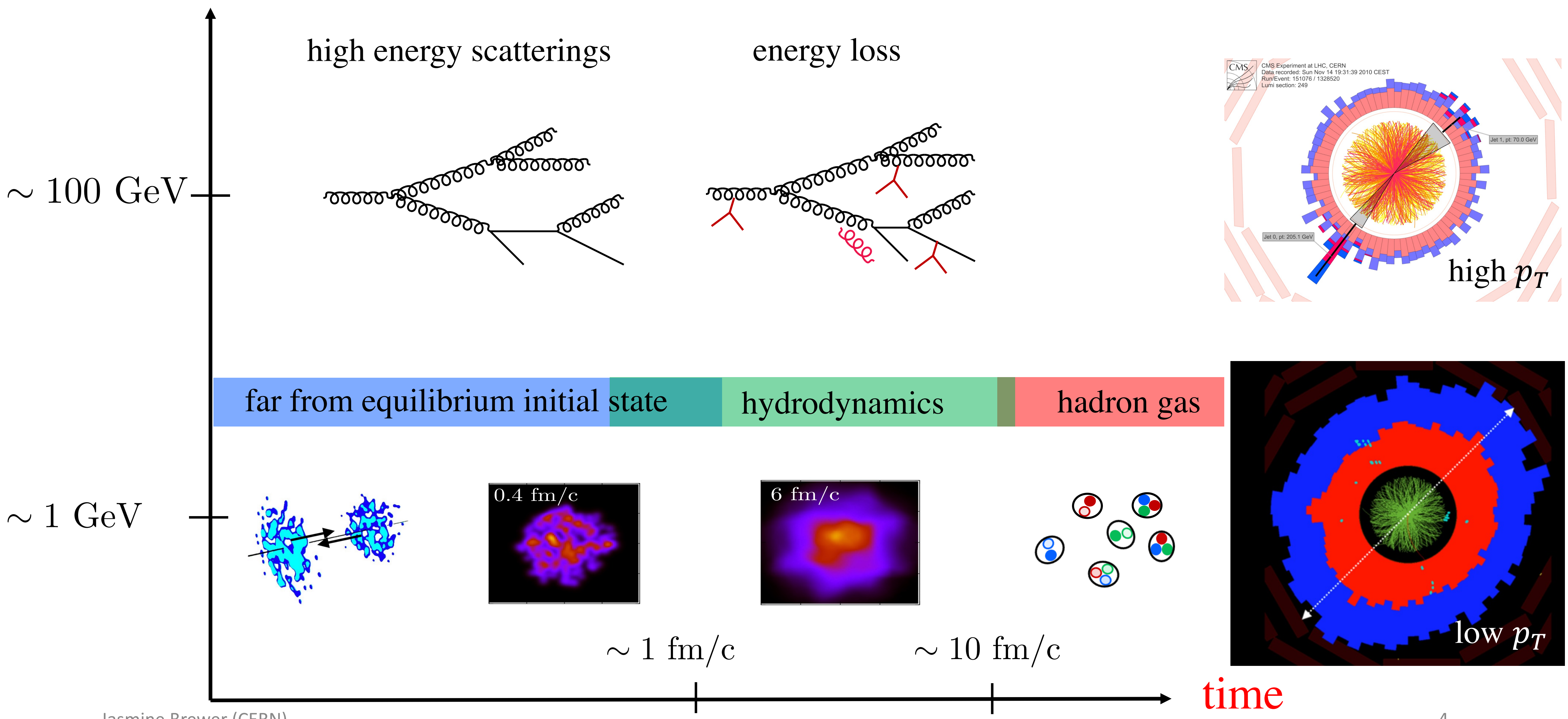
Boston, MA

PhD
2015-2020

Heavy-ion collisions

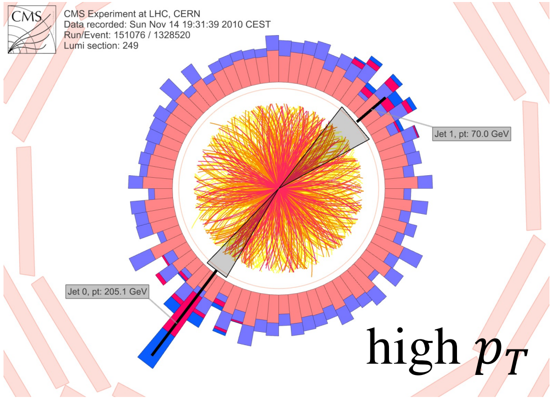


Heavy-ion collisions

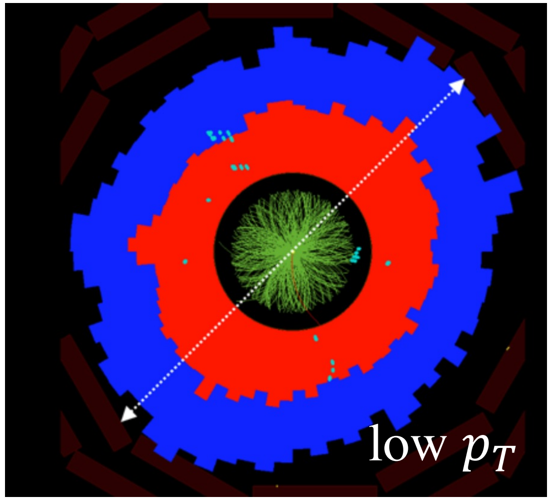


Research directions

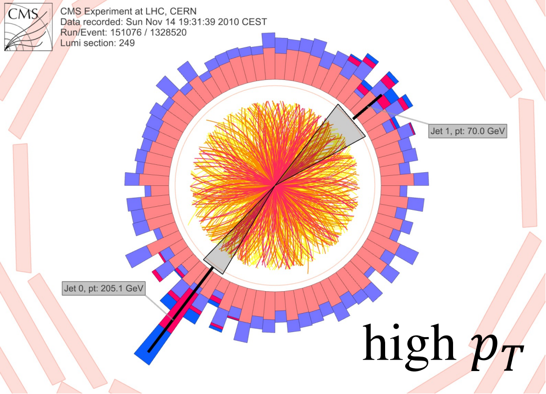
Interpreting jet modification in heavy-ion collisions



Far-from-equilibrium dynamics and thermalization in kinetic theory



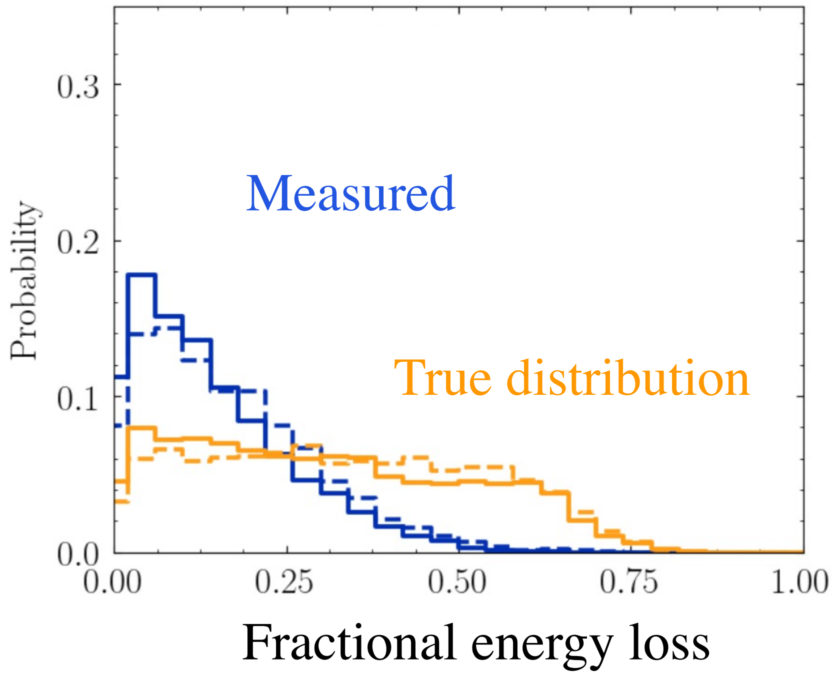
Small collision systems: intersection of quenching and equilibration

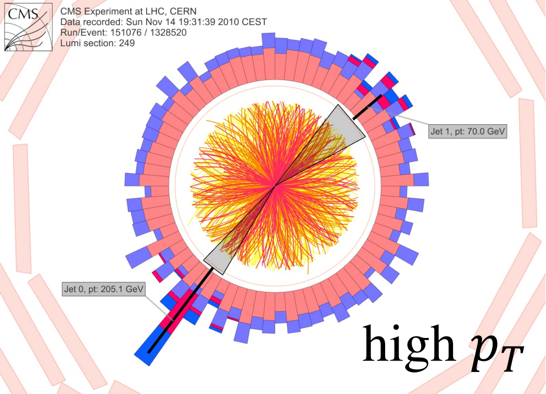


Jet modification in QCD medium

Interpretation of jet substructure modification

JB, Brodsky, Rajagopal [2110.13159]
Ongoing work with Quinn Brodsky





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Interpretation of jet substructure modification

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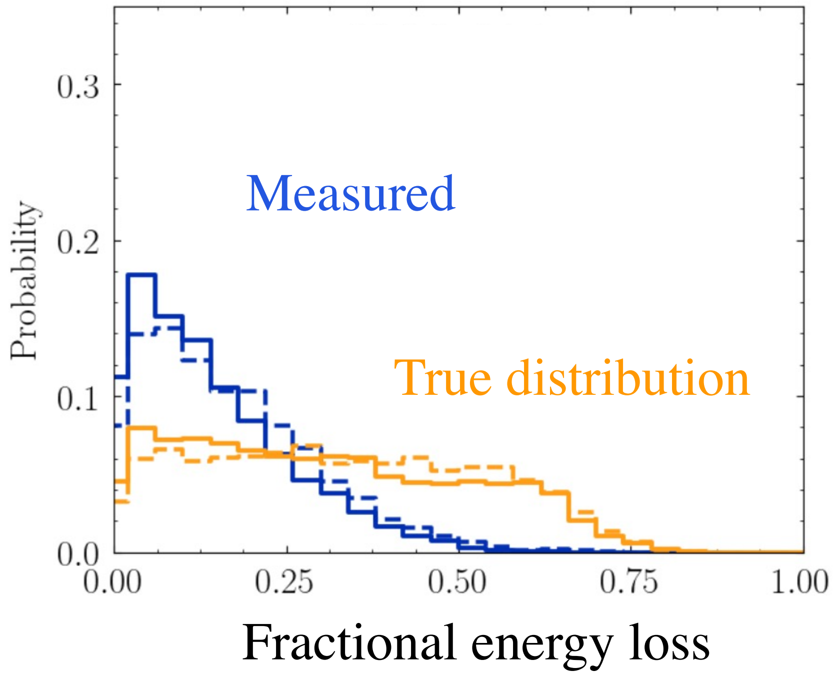
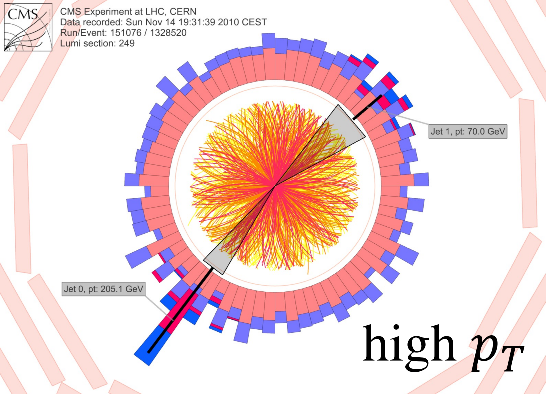


Separating quark and gluon jet modification

JB, Turner, Thaler [2008.08596]
With Kylie Ying, Yen-Jie Lee, Yi Chen *(forthcoming)*



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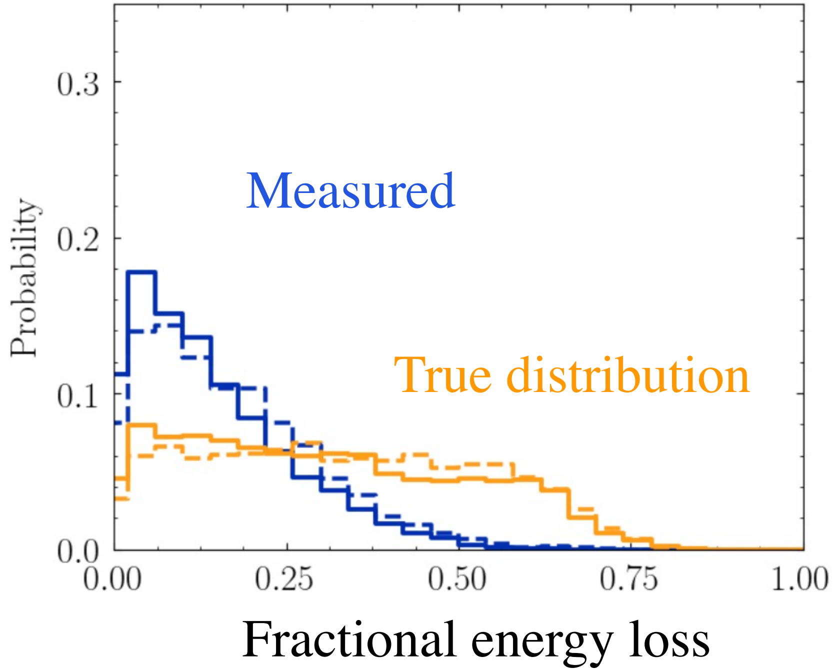
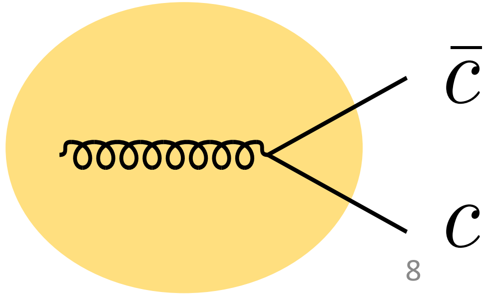


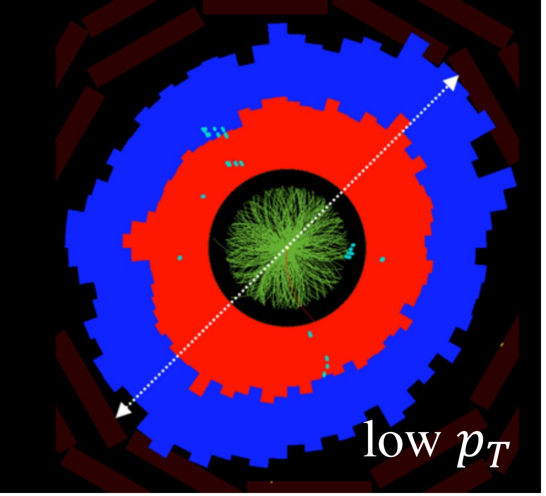
Separating quark and gluon jet modification

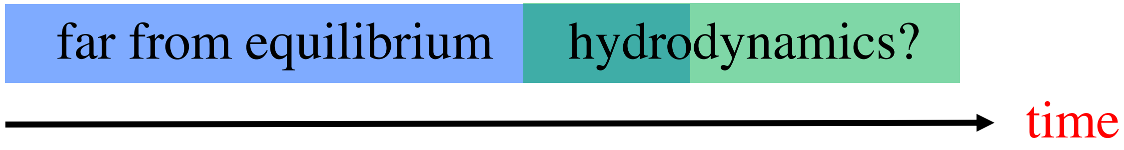
JB, Turner, Thaler [2008.08596]
With Kylie Ying, Yen-Jie Lee, Yi Chen *(forthcoming)*

Delayed probe of QGP with $g \to c\bar{c}$

CERN HI group project



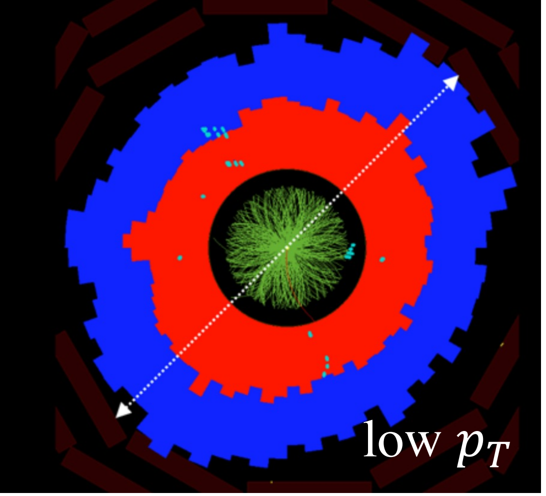




kinetic theory

expansion collisions

$$\partial_\tau f - \frac{p_z}{\tau}\partial_{p_z} f = -C[f]$$



far from equilibrium | hydrodynamics?

time

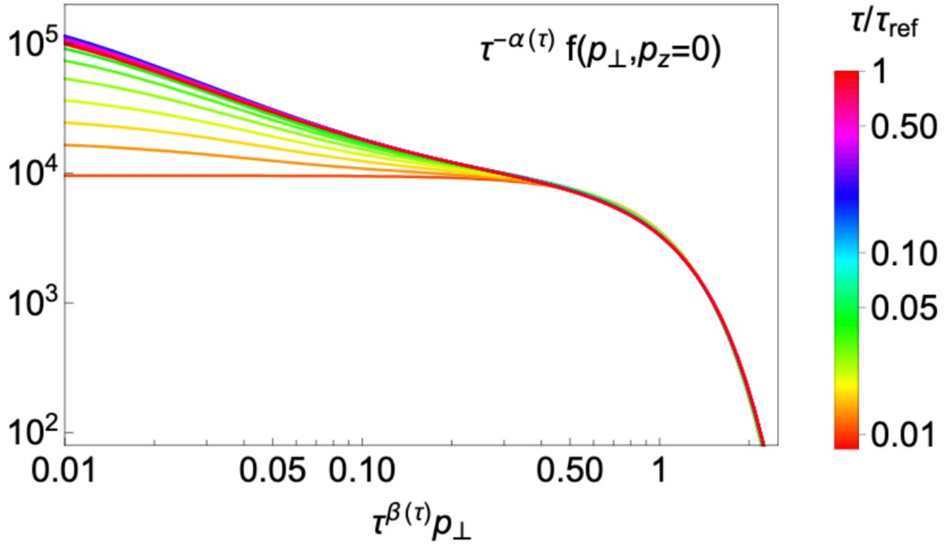
kinetic theory

expansion collisions

$$\partial_\tau f - \frac{p_z}{\tau}\partial_{p_z} f = -C[f]$$

Far-from-equilibrium scaling of distribution function

Scaled gluon distribution

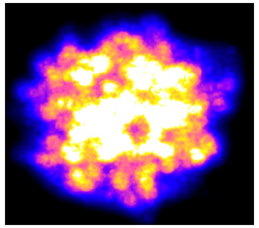


With Bruno Scheihing-Hitschfeld and Yi Yin *(forthcoming)*

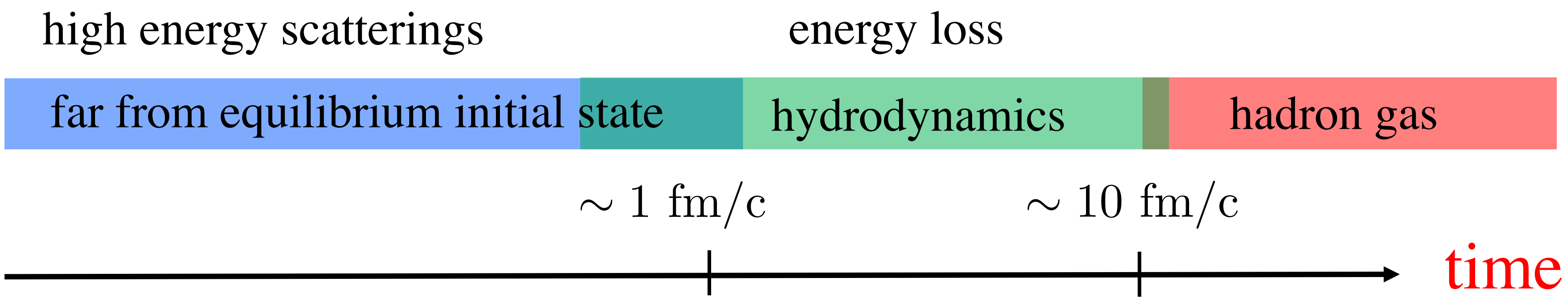
Equilibration of momentum-space anisotropy

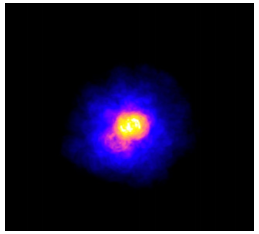
With Weiyao Ke, Li Yan, and Yi Yin *(forthcoming)*

Pushing our knowledge of heavy-ion physics in smaller systems

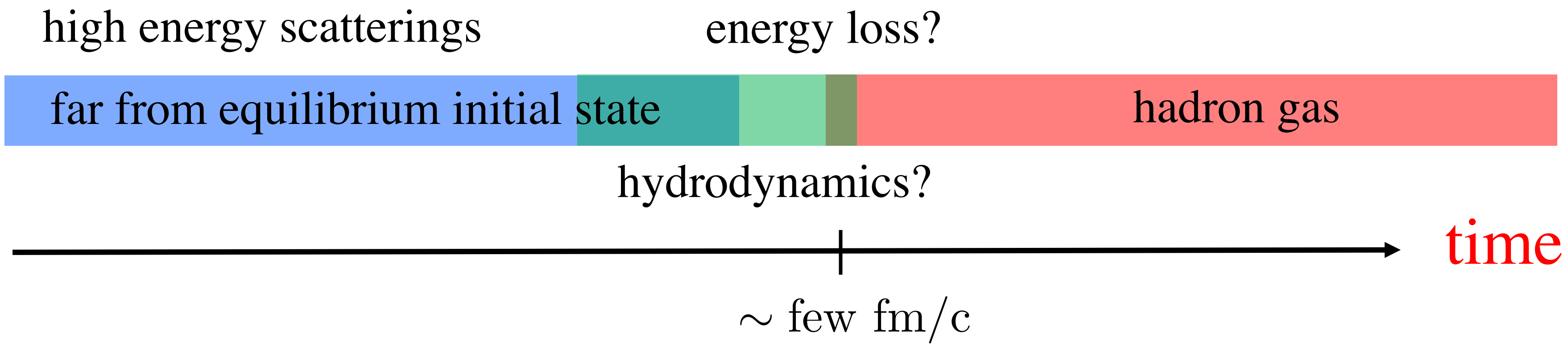


Heavy-ion collisions





Smaller systems (e.g. p-Pb, O-O)



Intersection of hard and soft sector very important in small systems

With Aleksas Mazeliauskas and Wilke van der Schee
workshop summary: [2103.01939]

Short run of oxygen planned in LHC Run 3

Constructing a pp reference for OO run JB, Huss, Mazeliauskas, van der Schee [2108.13434]

Speculative future directions: interplay of jet quenching and equilibration in kinetic theory




https://aleksas.eu/

Aleksas Mazeliauskas About me Research projects Code Publications Talks Blog Contact CV

Aleksas Mazeliauskas

Theoretical Physicist

Theoretical Physics Department, CERN

About me

['aːlɛksɐs mɐzɛˈlʲæuˑskɐs]

[AH-lexas ma-zeh-LYOW-skas]

I am a theoretical physicist working on **many-body phenomena** emerging from fundamental interactions of elementary particles.

In my research I connect models of **nuclear**, **hadronic** and **particle physics** with methods of relativistic hydrodynamics, statistical physics and out-of-equilibrium dynamics to study the **hot and dense nuclear matter** created in high-energy hadron collisions. My work has contributed to a better understanding of fundamental states of matter, thermalisation of isolated quantum systems, and how a fluid-like behaviour emerges from a relatively small number of constituents interacting via the strong force.

I work at Theoretical Physics department at **CERN**, Switzerland. Previously I was a postdoctoral researcher at **Heidelberg University**, Germany. I had a joint postdoctoral research position in the groups of Prof. Dr. Jürgen Berges and Priv.-Doz. Dr. Stefan Flörchinger at the Institute for Theoretical Physics under the

My route from Lithuania to CERN (via UK, USA and Germany)

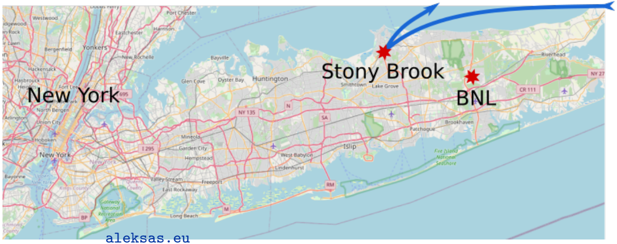
2007–2008 — Vilniaus universitetas

2008–2012 BA+MMath — UNIVERSITY OF CAMBRIDGE

2012–2017 PhD — Stony Brook University

2017–2019 postdoc — UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

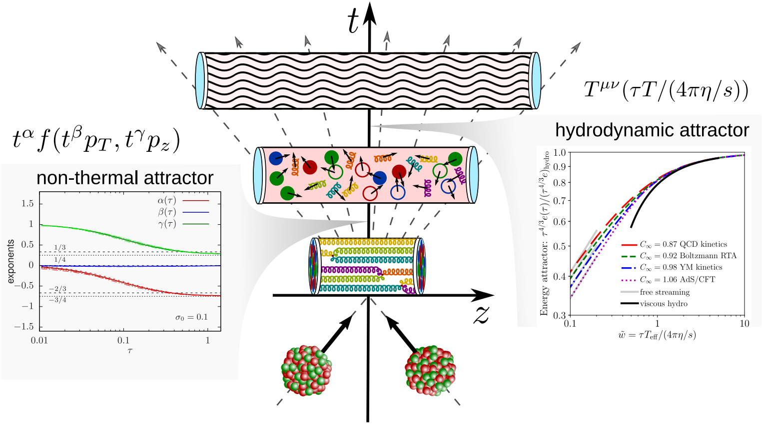
2019– fellow — CERN



QCD thermalization: ab-initio approaches and interdiciplinary connections

Berges, Heller, AM, Venugopalan Rev.Mod.Phys (2021), arXiv:2005.12299

- Effective descriptions of QCD: Classical Yang-Mills, QCD kinetic theory, hydrodynamics
- Simplification of non-equilibrium evolution $\Longrightarrow$ attractors
  pre-scaling AM, Berges, *PRL* (2019), *entropy production*, Giacalone, AM, Schlichting, *PRL* (2019)

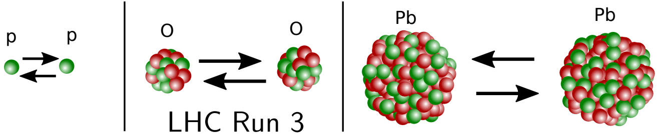


Significant loss of detail occurs well before thermalization.

Light-ion collisions at LHC

Puzzle: many heavy-ion phenomena observed in pp and pPb collisions.

New collision system – upcoming special run of oxygen



- Opportunities of OO and pO collisions at LHC
- 5-day virtual workshop Feb 4-10, 2021.
- Summary document: arXiv:2103:01939
- Successful oxygen test at LINAC 3 in May 2021

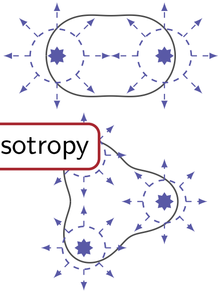
The workshop demonstrated the community interest and crystallized open questions and challenges.

Collective flow in small collision systems

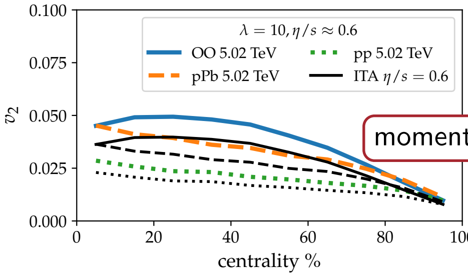
Describe small droplets of QGP with kinetic theory of quarks and gluons

$$\text{Boltzmann eq.:}\quad \underbrace{\partial_t f + \frac{\mathbf{p}}{|p|}\cdot\nabla f}_{\text{expansion}} = -\underbrace{\mathcal{C}_{2\leftrightarrow 2}[f] - \mathcal{C}_{1\leftrightarrow 2}[f]}_{\text{in-medium QCD collisions}}$$

In small collision systems expect only few interactions.



spatial anisotropy



momentum anisotropy

We estimated elliptic flow generation after single elastic rescattering.

Kurkela, AM, Törnkvist, arXiv:2104.08179

Discovering high-p_T parton rescattering in oxygen-oxygen collisions

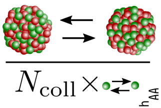
Perturbative QCD spectra modified by secondary scatterings.

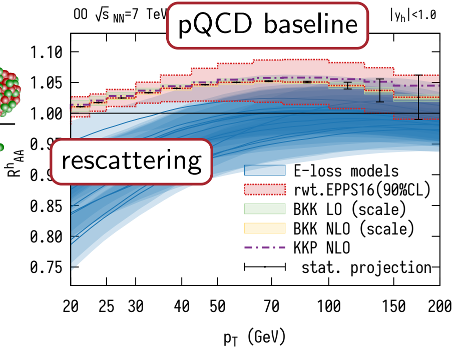
- Compare spectra in pp and OO at the same collision energy.

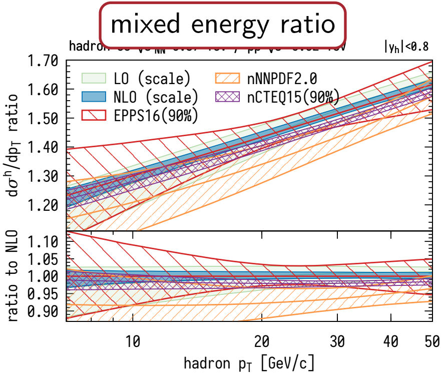
  Huss, Kurkela, AM, Paatelainen, van der Schee, Wiedemann, (PRL, PRC) 2007.13754, 2007.13758

- Short run $\Rightarrow$ no pp reference. Construct pp spectra or use mixed energy ratio.

  Brewer, Huss, AM, van der Schee, 2108.13434







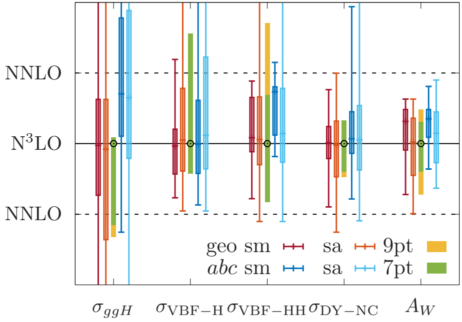
Discovery of physics beyond pQCD at 100 GeV scale in OO collisions.

Estimating uncertainty of the missing high order terms

Given cross-sections Σ_n at LO, NLO, N2LO,... what is $\Delta\Sigma_n$?

$$abc\text{-model}: \quad -ca^n < \frac{\Sigma_n - \Sigma_{n-1}}{\Sigma_0} - ba^n < ca^n.$$

Perform Bayesian inference of the hidden parameters and estimate $\Delta\Sigma_n$.



Duhr, Huss, AM, Szafron JHEP (2021), 2106.04585

pQCD theory uncertainties with clear statistical interpretation.

Summar: LHC phenomenology with pp, heavy and light ions

- Collective flows via single elastic scattering Kurkela, AM, Törnkvist, 2104.08179
- Signals of high-p_T suppression in OO collisions
  TH team: Huss, Kurkela, AM, Paatelainen, van der Schee, Wiedemann, PRL, PRC, 2007.13754, 2007.13758
  TH team: Brewer, Huss, AM, van der Schee, 2108.13434
- Charmed hadron spectra in heavy ion and light ion collisions
  Andronic, Braun-Munzinger, Köhler, Mazeliauskas, Redlich, Stachel, Vislavicius, JHEP (2021), 2104.12754
- Bayesian estimates of missing higher order terms.
  TH team: Duhr, Huss, AM, Szafron JHEP (2021), 2106.04585
- Space-time structure of parton showers (ongoing work with heavy-ion group)
- Other interests: soft pion production, Λ polarization.

Sohyun Park

CERN TH Retreat 3 Nov 2021

My path to CERN

2007 - 2012
University of Florida, USA
PhD

2011 - 2012
Fermilab, USA
Student Fellow

2012 - 2015
Penn State University, USA
Postdoc

2015 - 2016
KASI, Daejeon, Korea
Postdoc

2017 - 2019
CEICO, Prague, Czech Republic
Postdoc

2019 -
CERN-Korea
Postdoc Fellow

My past research before joining HI at CERN

Park, Sohyun

Fields of interest

Cosmology and Astroparticle Physics
Gravity
Heavy Ion Physics
Quantum Field Theory

Quantum loop effects during inflation

- How scalars and gravitons interact in de Sitter background?

  1101.5804 &1109.4187 SP, Woodard

  1403.0896 Leonard, SP, Prokopec, Woodard

  1510.03352 SP, Prokopec, Woodard

  1409.7753, 1704.05880, 1708.01831 Boran, Kahya, SP

Phenomenology of nonlocal gravity

- How structure grows in nonlocal gravity?

  1209.0836 &1310.4329 S. Dodelson, SP

  1608.02541 SP, Shafieloo

  1711.08759 SP

  1901.07832 Amendola, Dirian, Nersisyan, SP

- How GWs propagate in nonlocal gravity?

  1811.04647 Chu, SP

- Is the nonlocal model stable (no ghost excitation)?

  1809.06841 SP, Woodard

- Is there a bouncing solution in nonlocal gravity?

  1905.04557 C. Chen, P. Chen, SP

- How QNMs behave in nonlocal gravity?

  2101.06600 C. Chen, SP

My current research at CERN

Phenomenology of heavy ion collisions

- Dynamics of light (anti)-nuclei in QCD matter

  Jasmine, Aleksas, SP, Urs

- Spatio-temporal ordering of partonic fragmentation in QCD medium

  Maximilian, Jasmine, G.M. Innocenti, Aleksas, SP, Wilke, Urs

- Electromagnetic radiation in ALICE-3

  "Bremsstrahlung photons from stopping in heavy-ion collisions"

  PRC 104, 044903, arXiv:2107.05129 SP and Urs A. Wiedemann

Bremsstrahlung from stopping

- Pb-ions are 82+ → each PbPb collision decelerates a net-charge 164+
- Classical Electrodynamics: charge deceleration → photon bremsstrahlung
- Why is this interesting?
  - Robust prediction but never measured → experimental challenge
    (could serve to illustrate novel opportunities of a novel detector)
  - Bremsstrahlung sensitive to the degree of longitudinal stopping
  - Longitudinal stopping determines rapidity distribution of net electric charge
    (complementary access to longitudinal initial conditions)

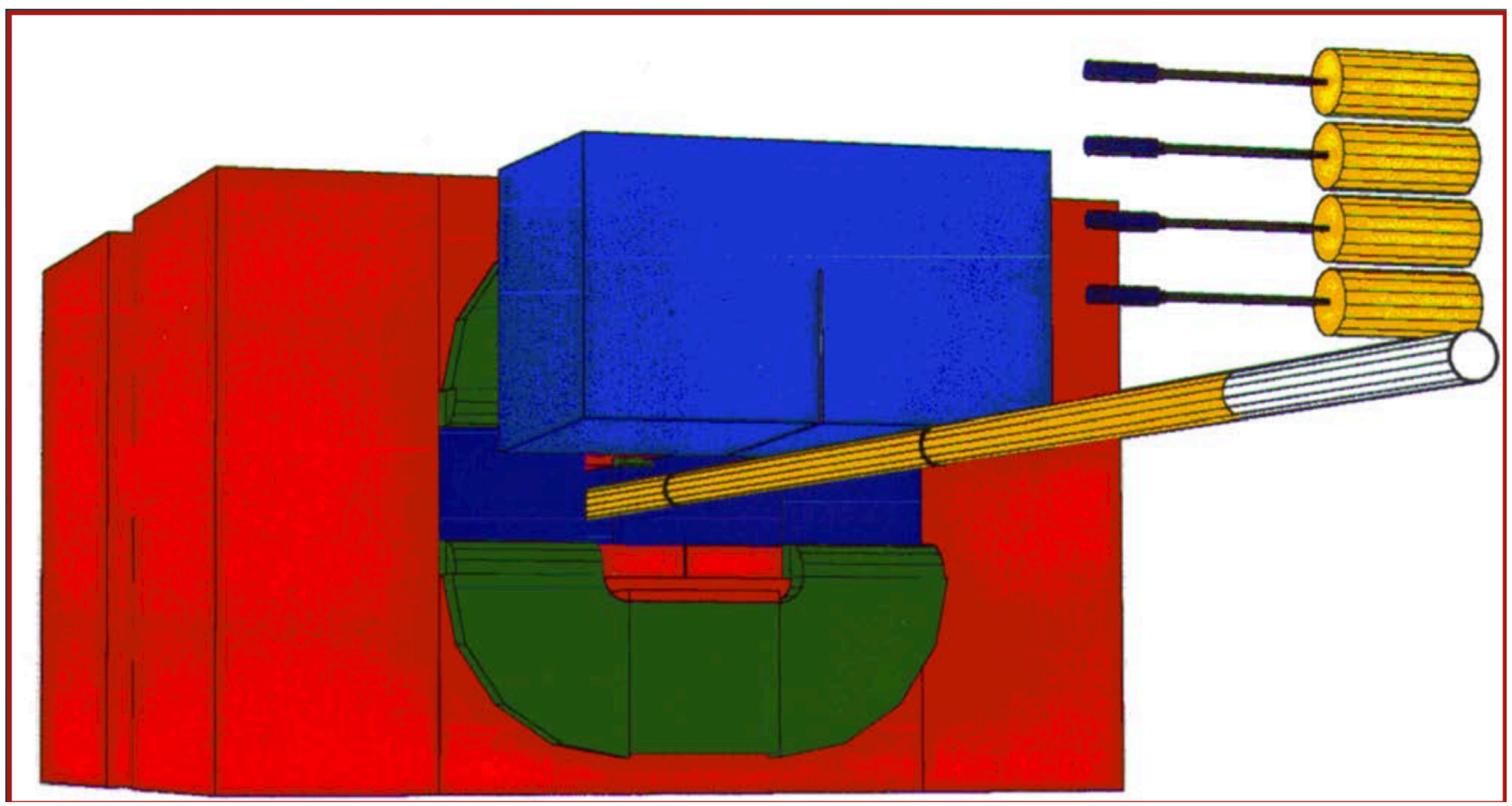
A detector at RHIC proposed but never realized

- This idea is not new but actually is as old as the field of heavy-ion physics:

  Kapusta 1977; Bjorken and McLerran 1985

- Calculations of classical electromagnetic bremsstrahlung in the late 1990s;
  The effect is measurable; Proposed a detector at RHIC but it was never realized

  Jeon, Kapusta, Chikanian and Sandweiss, 1998



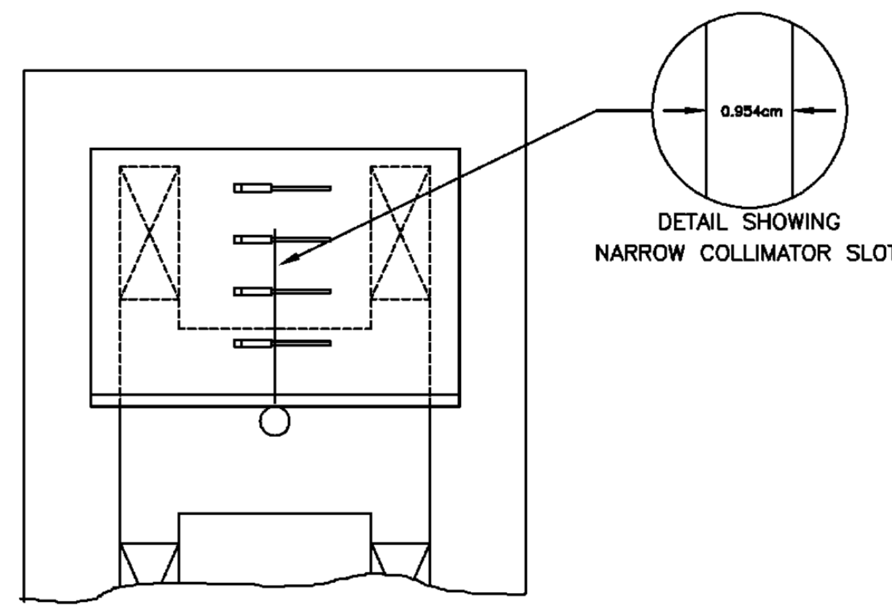


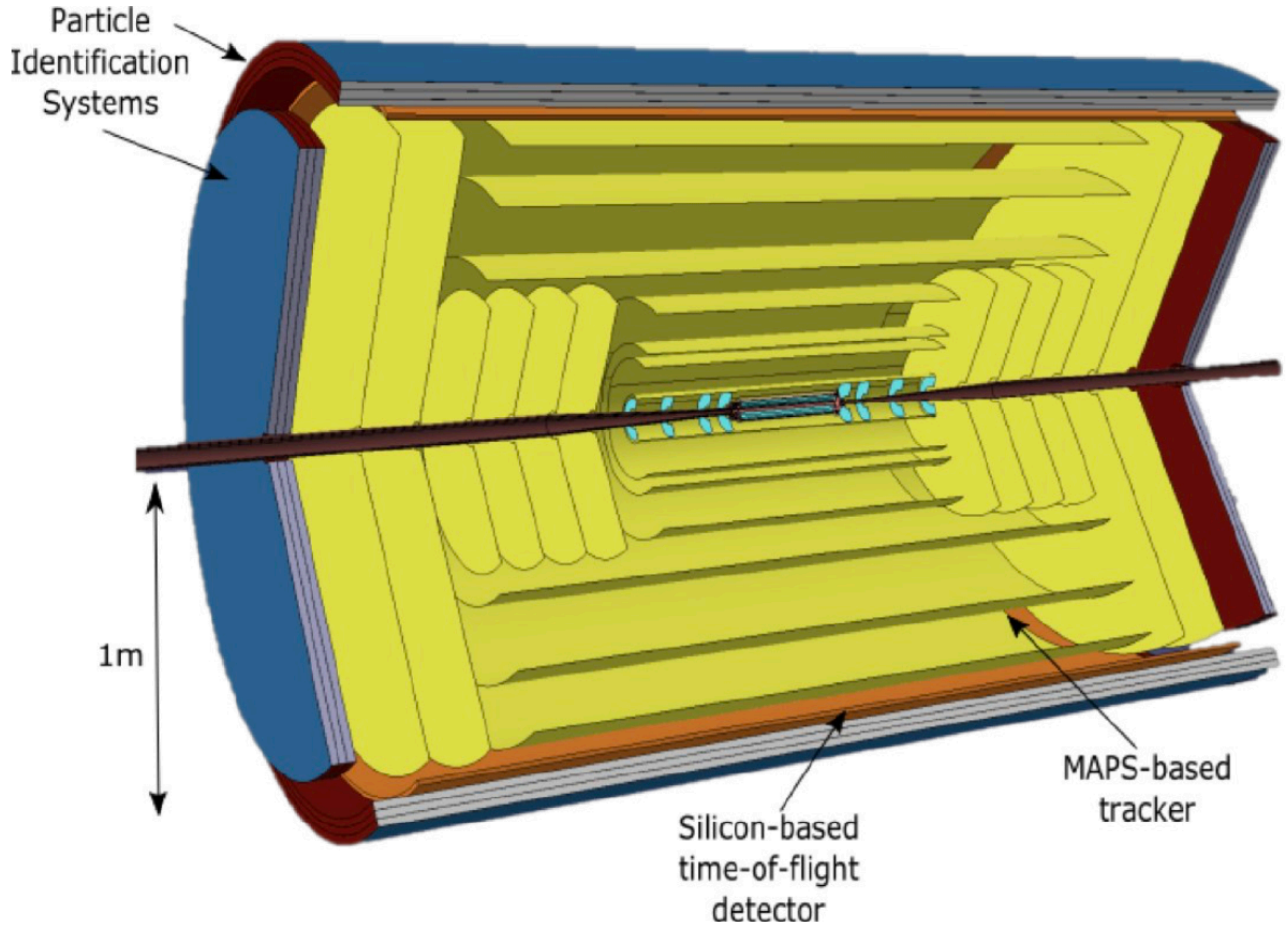
FIG. 7. View of the experiment along the beam, looking back from the detector side.

PRC 58 (1998), 1666
Jeon, Kapusta, Chikanian and Sandweiss

Image Credit: Jack Sandweiss Memorial by Evan Finch at SQM 2021

A next-generation LHC heavy-ion experiment 1902.01211

- A next-generation ALICE detector based on ultra-thin silicon technology: ALICE-3
- We adapted RHIC studies of late 90's to the kinematics of LHC.
- We asked: what acceptance ALICE-3 should have
  in order to measure bremsstrahlung photons in PbPb @ LHC?



Classical bremsstrahlung

- The intensity of photons of energy ω in direction $\mathbf{n}$ from charge current $\mathbf{J} = \mathbf{J}_+^{(in)} + \mathbf{J}_-^{(in)} + \mathbf{J}^{(out)}$

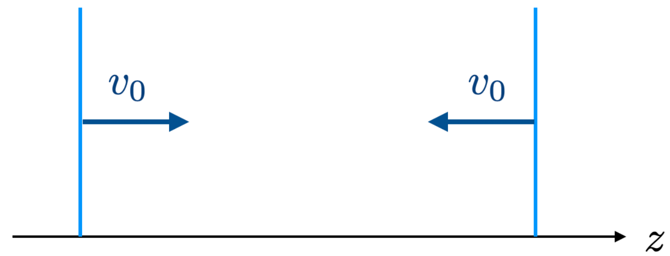
$$\frac{d^2 I}{d\omega d\Omega} = |\mathbf{A}|^2\,,\;\; \mathbf{A}(\mathbf{n},\omega) = \int dt \int d^3x\mathbf{n} \times (\mathbf{n} \times \mathbf{J}(\mathbf{x},t))e^{i\omega(t-\mathbf{n}\cdot\mathbf{x})}$$

Eq. (14.67) in Jackson, *Classical Electrodynamics* (1998) 3rd ed.

- Incoming current: incoming charges with projectile rapidity y_0 along the beam direction z

$$J_\pm^{(in)}(\mathbf{x},t) = \pm Z\, e\, v_0\, \rho_{\rm in}(r)\, \delta(z \mp v_0 t)\, \Theta(-t)$$

$\rho_{\rm in}(r)$: incoming charge density in the transverse plane



$$v_0 = \tanh y_0$$

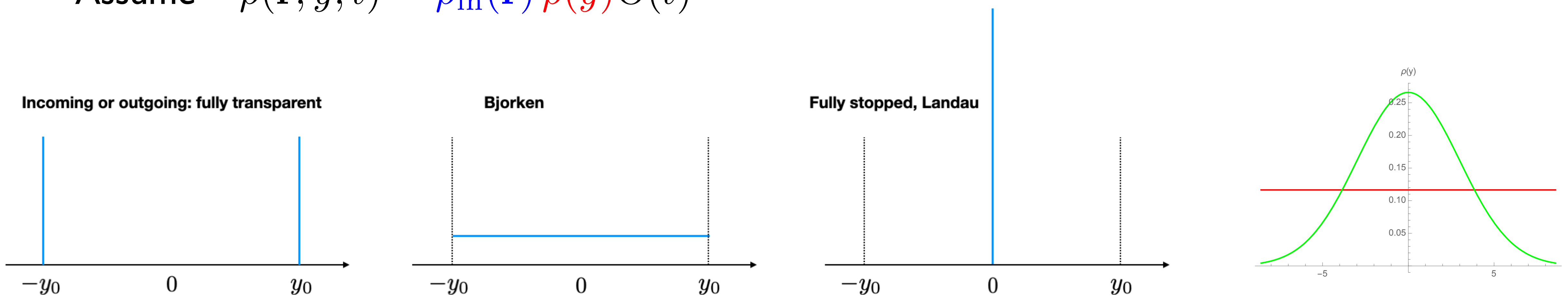
$$y_0 \simeq \ln\left(\frac{\sqrt{s_{\rm NN}}}{m_N}\right)$$

- Outgoing current at shifted velocity $v(y)$ after collision at time $t=0$

$$J^{(out)}(\mathbf{x},t) = \Theta(t) \int_{-y_0}^{y_0} \rho(\mathbf{r},y,t)\, v(y)\, \delta\left(z - v(y)t\right)\, dy \qquad -v_0 < v(y) = \tanh y < v_0$$

Modelling the charge-rapidity distribution

- Assume $\rho(\mathbf{r}, y, t) = \rho_{\text{in}}(\mathbf{r})\, \rho(y) \Theta(t)$



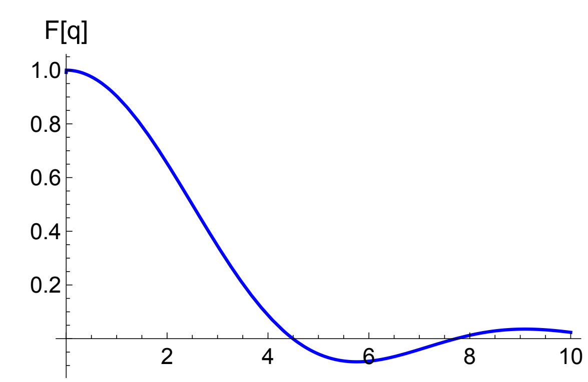
- The intensity of photons

$$\frac{d^2 I}{d\omega d\Omega} = \frac{\alpha Z^2}{4\pi^2} \sin^2\theta \, |F(\omega R \sin\theta)|^2 \left| \left[\int dy \frac{v(y)\rho(y)}{1 - v(y)\cos\theta} - \frac{2 v_0^2 \cos\theta}{1 - v_0^2 \cos^2\theta} \right] \right|^2$$

Transverse form factor: $F(\omega R \sin\theta) = \int d^2 r_\perp \, \rho_{\text{in}}(r_\perp) e^{-i\omega \mathbf{n}\cdot\mathbf{r}_\perp} = \frac{3}{q^2}\left(\frac{\sin q}{q} - \cos q\right) \;, \; q = \omega R \sin\theta$

solid sphere

- Applicability of classical formula
  - For soft and collinear photons, i.e., $q = \omega R \sin\theta \lesssim 1$
    the transverse profile of the charge distribution is not resolved
  - For Lorentz contraction $\gamma_{\text{LHC}} \approx 2700$
    longitudinal structure is resolved only for photon energies $1/\omega \gg 0.005 \text{ fm/c}$

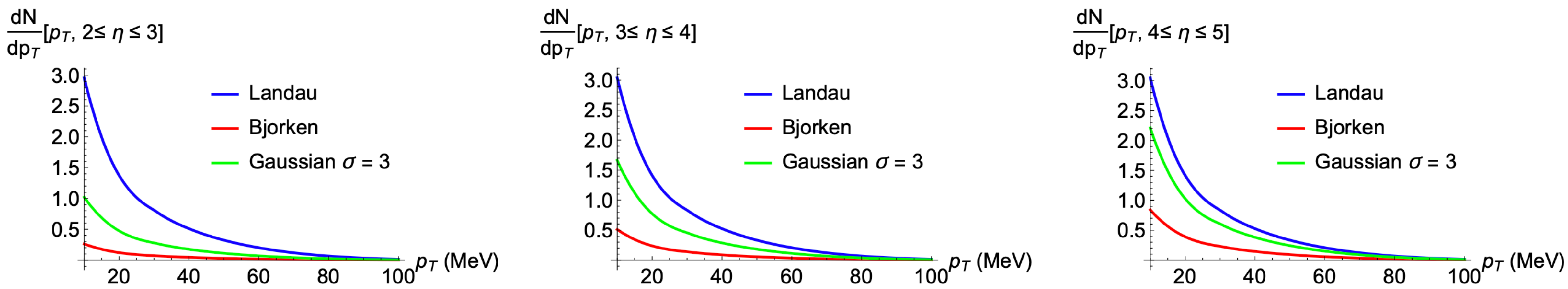


  - Classical formula is sufficient for soft/collinear photons that do not resolve internal structure.

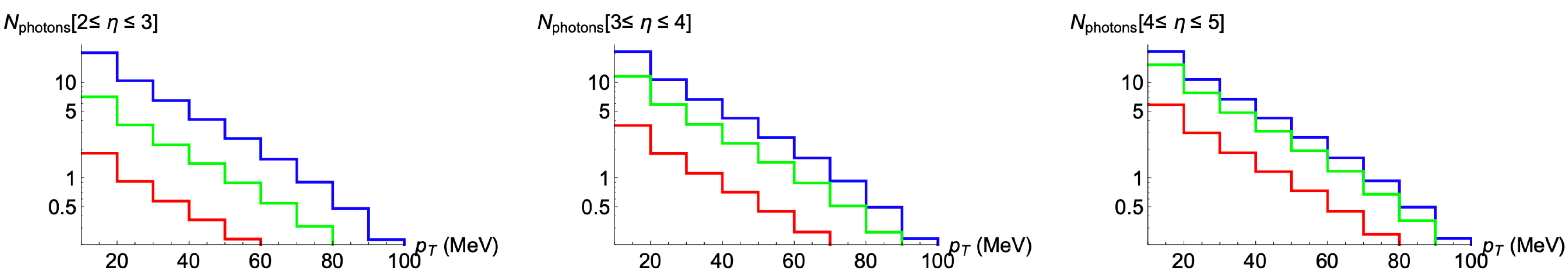
Numerical results: Photon number distribution

- Number of photons radiated per unit phase space $$\frac{d^2N}{dp_T d\eta} = \frac{1}{p_T \cosh\eta} \frac{d^2I}{dp_T d\eta}$$

- Number spectrum as a function of pT in pseudo-rapidity bins



- Number of photons in pT bins

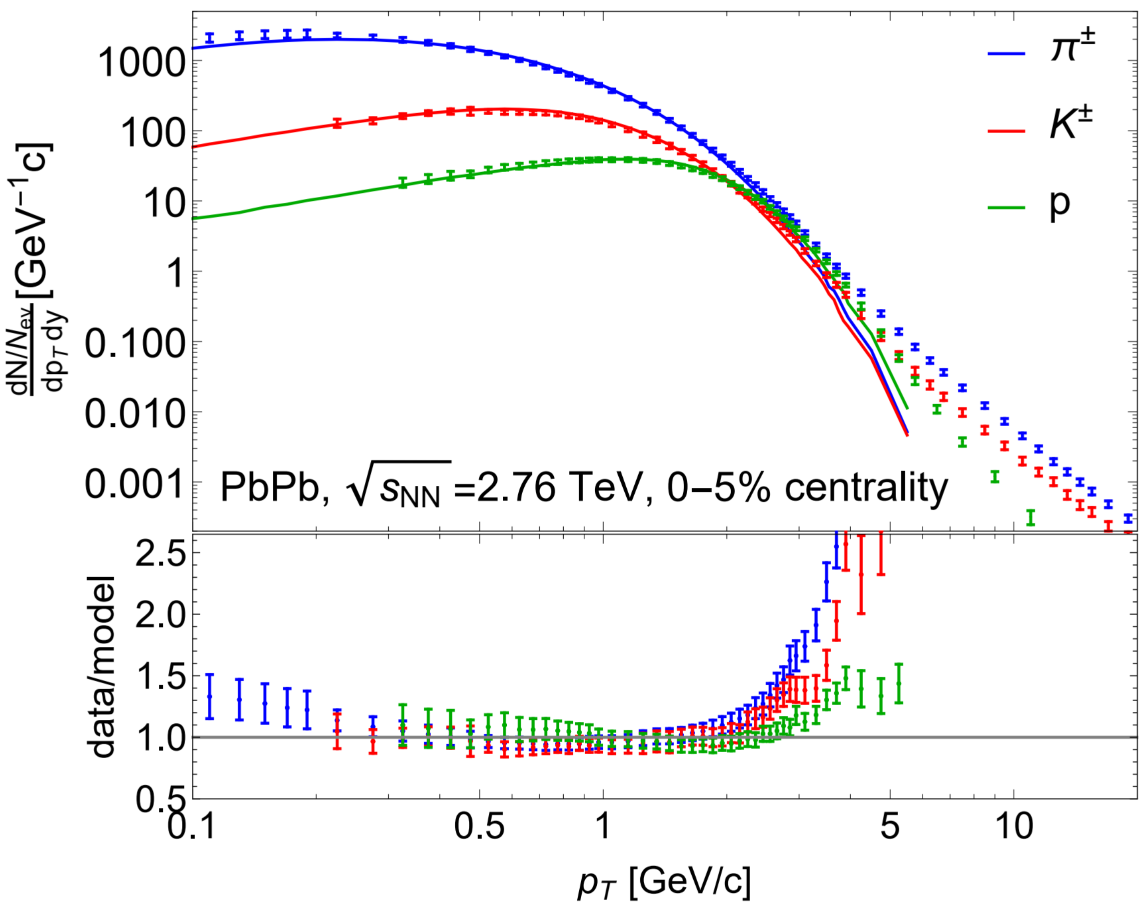


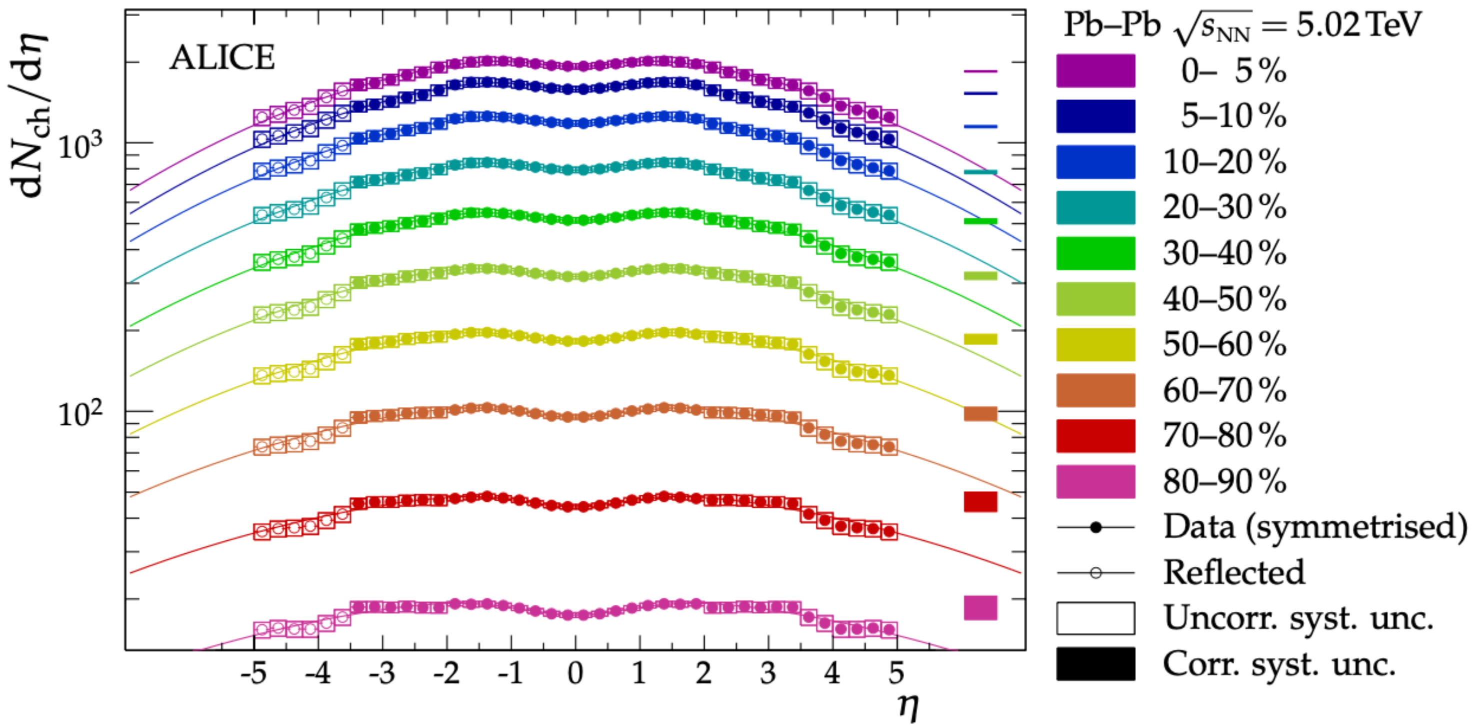
Background photons

- Photons do not come only from electromagnetic bremsstrahlung
- π^0 decay photons are expected to be the dominant background
- How many? How are they distributed?

PLB 772 (2017) 567
ALICE Collaboration

Soft $\frac{dN^{\pi^0}}{dp_T}$ is flat.





PRC 103 (2021) 054909
Nijs, van der Schee, Gursoy and Snellings

$$\left.\frac{dN^{\pi^0}}{dp_T d\eta}\right|_{\eta=4} \simeq \frac{500}{\mathrm{GeV}} \qquad \left.\frac{dN^{\gamma}}{dp_T d\eta}\right|_{\eta=4} \simeq \frac{1}{\mathrm{MeV}}$$

Can bremsstrahlung photons be separated from background?

- Signal-to-background

$$0.1 \lesssim \frac{S}{B} \lesssim 1 \quad \text{for} \quad p_T \lesssim 50\,\text{MeV} \quad \text{and} \quad \eta \gtrsim 3$$

- characteristically different pT dependence

$$\frac{dN^{\text{bgd}}}{dp_T} \simeq \text{const.} \quad \text{vs} \quad \frac{dN^{\text{brems}}}{dp_T} \propto \frac{1}{p_T}$$

- characteristically different centrality dependence

$$\frac{d^2N^{\text{bgd}}}{dp_T d\eta} \propto N_{\text{part}} \quad \text{vs} \quad \frac{d^2N^{\text{brems}}}{dp_T d\eta} \propto Z^2 \propto N_{\text{part}}^2$$

Conclusion

- ALICE 3 is a new detector to have acceptance at very low-pT and rather forward rapidity.

- We asked: what acceptance ALICE-3 should have
  in order to measure bremsstrahlung photons in PbPb @ LHC?

- Our answer is: $\eta \gtrsim 3$
  $p_T \gtrsim 10\ \mathrm{MeV}$

- Characteristically different pT & centrality dependence may help to separate bremsstrahlung photons from background photons.

Thank you for listening!