Jets: Hands-On Sesssion [Day2]

[#jul23-jul26-jets]

Yasuki Tachibana for the JETSCAPE Collaboration

JETSCAPE

Online, July 26th, 2021

Jet Analysis with JETSCAPE events

Goals

- **Run JETSCAPE and simulate hard scattering events**
  - Generate hard parton shower in pp and PbPb collisions
  - Evolution without interaction with medium in pp
  - Evolution with interaction with medium in PbPb

- **Analyze JETSCAPE data and study medium effects on jets**
  - Reconstruct jet (collimated cluster of particles) from particles in the final states
  - Calculate jet spectrum and jet substructure observables
  - Compare between pp and PbPb results

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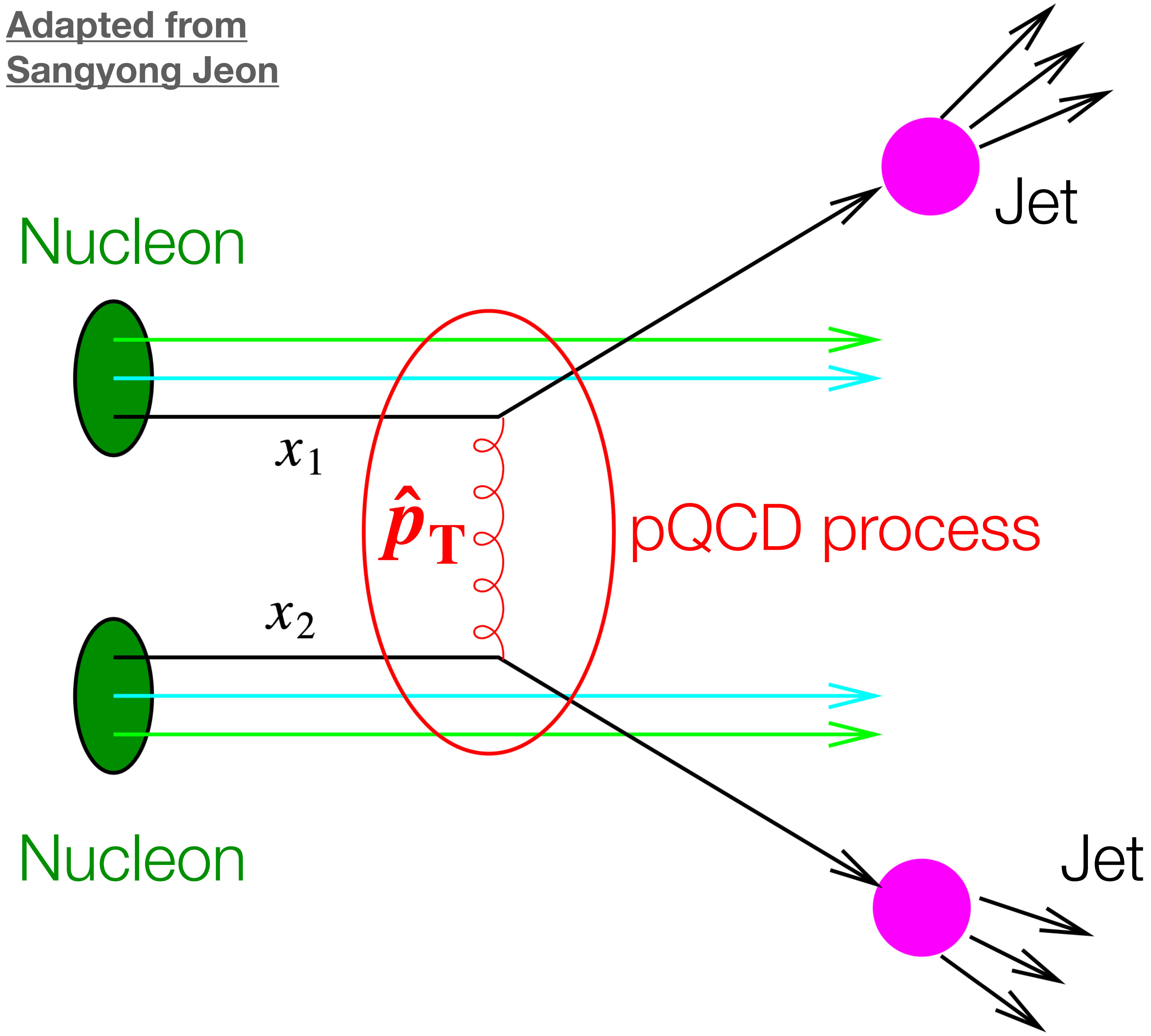
Day 2

Event Generation (Done on the first day)

Simulation Setup in the Session

- **Hard scatterings at $5.02\ \mathrm{TeV}$ by PythiaGun**

Adapted from Sangyong Jeon



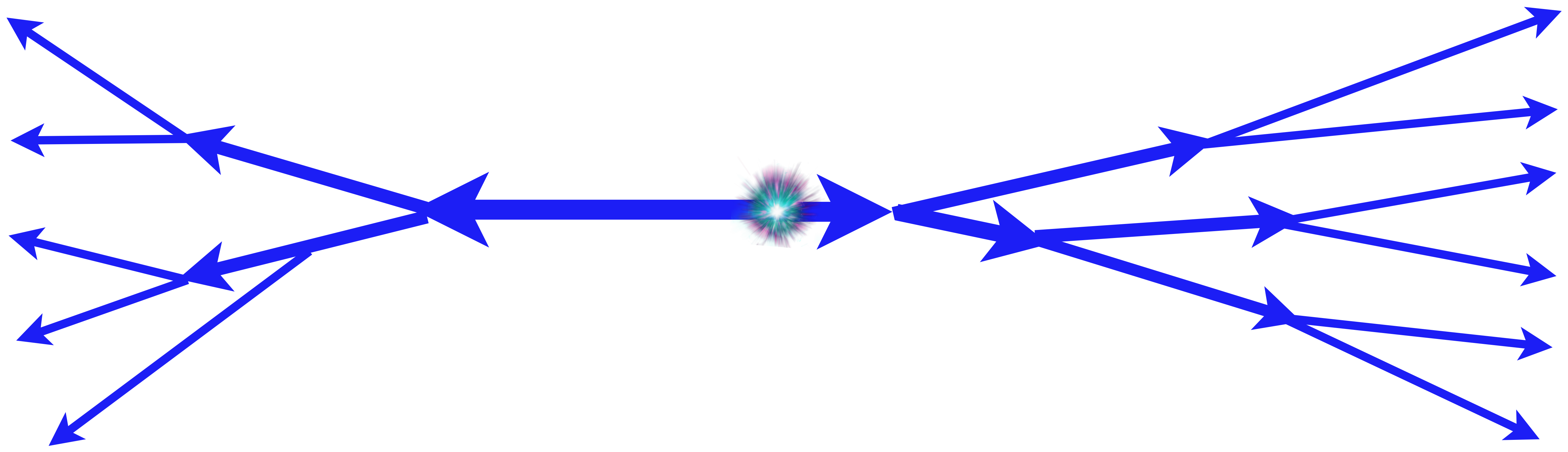
- Generate only scatterings with $100 < \hat{p}_\mathrm{T} < 160\ \mathrm{GeV}$.
- Same number of hard scatterings for pp and PbPb (not the number of collision events)

XML File

```
<!-- Hard Process -->
<Hard>
  <PythiaGun>
    <pTHatMin>100</pTHatMin>
    <pTHatMax>160</pTHatMax>
    <eCM>5020</eCM>
  </PythiaGun>
</Hard>
```

Simulation Setup

Parton shower evolution in pp



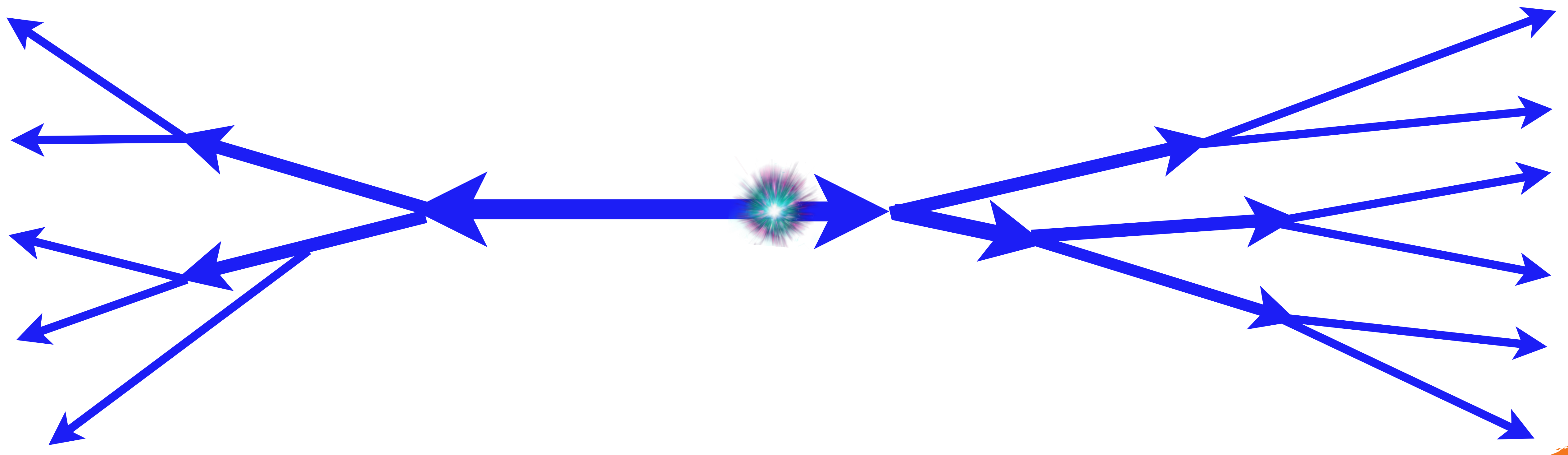
XML File [jetscape_user_PP_PHYS.xml]

```xml
<!--Eloss Modules -->
<Eloss>
  <Matter>
    <Q0> 1.0 </Q0>
    <in_vac> 1 </in_vac>
    <vir_factor> 0.25 </vir_factor>
    <recoil_on> 0 </recoil_on>
    <broadening_on> 0 </broadening_on>
    <brick_med> 0 </brick_med>
  </Matter>
</Eloss>
```

- Vacuum shower by MATTER without medium effect
- Hadronization via Lund String Model

Simulation Setup

- **Parton shower evolution in pp**



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</Eloss>
```

- Vacuum shower by MATTER without medium effect
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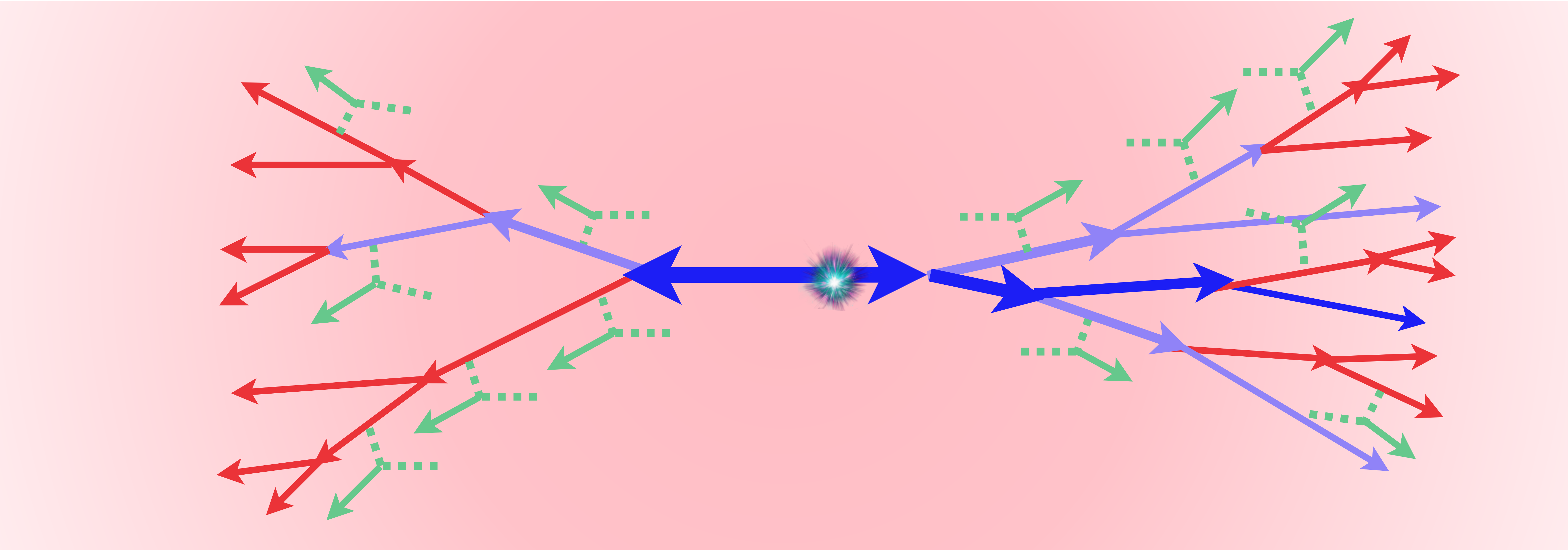
Simulation Setup

- **Parton shower evolution in PbPb**



- MATTER for Partons with $Q > 2\ \mathrm{GeV}$
- LBT for Partons with $Q < 2\ \mathrm{GeV}$
- Coupling with medium $\alpha_s = 0.25$
- Medium: QGP fluid in PbPb 30-40%
- Hadronization via Lund String Model

XML File [jetscape_user_PbPb_PHYS.xml]

```
    <Matter>
      <name>Matter</name>
      <useHybridHad>0</useHybridHad>
      <matter_on>1</matter_on>
      <Q0>2.0</Q0>
      <vir_factor>0.25</vir_factor>
      <in_vac>0</in_vac>
      <recoil_on>1</recoil_on>
      <broadening_on>0</broadening_on>
      <brick_med>0</brick_med>    <!-- Set b
      <T0>0.16</T0>
      <hydro_Tc>0.16</hydro_Tc>
      <qhat0>-2.0</qhat0>    <!-- If Type=0,
      <alphas>0.25</alphas>
    </Matter>

    <Lbt>
      <name>Lbt</name>
      <Q0>2.0</Q0>
      <in_vac>0</in_vac>
      <only_leading>0</only_leading>
      <hydro_Tc>0.16</hydro_Tc>
      <alphas>0.25</alphas>
    </Lbt>
  </Eloss>
```

Simulation Setup

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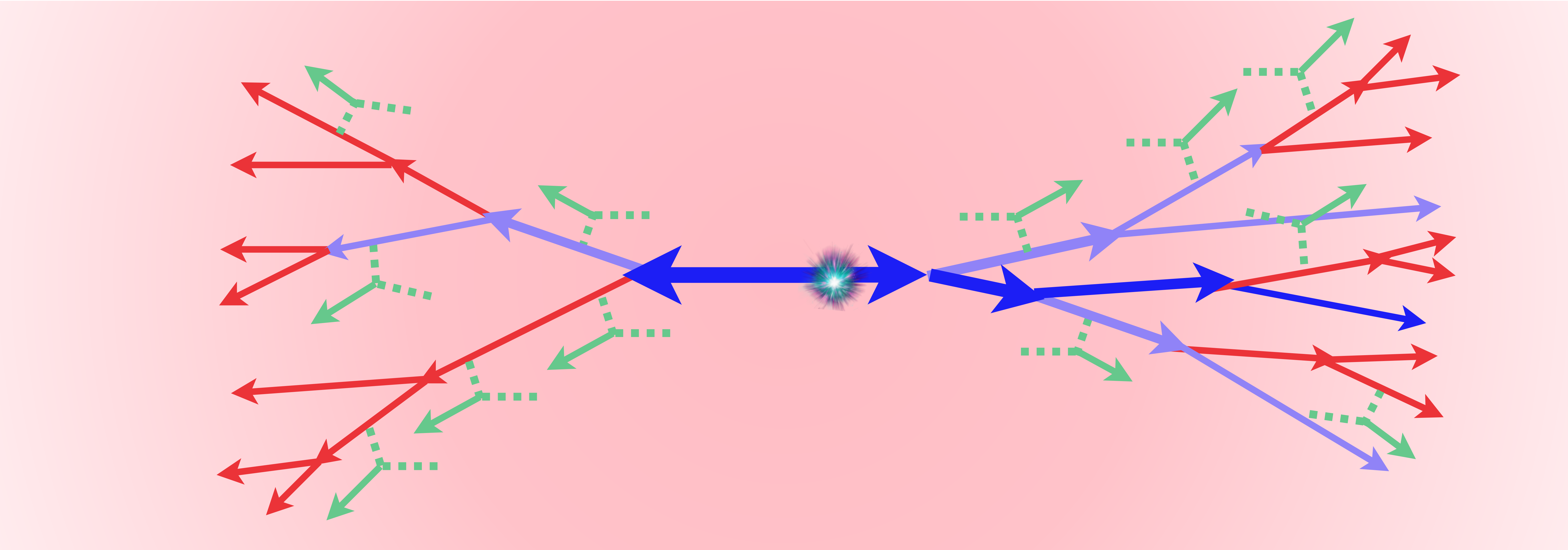

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Simulation Setup

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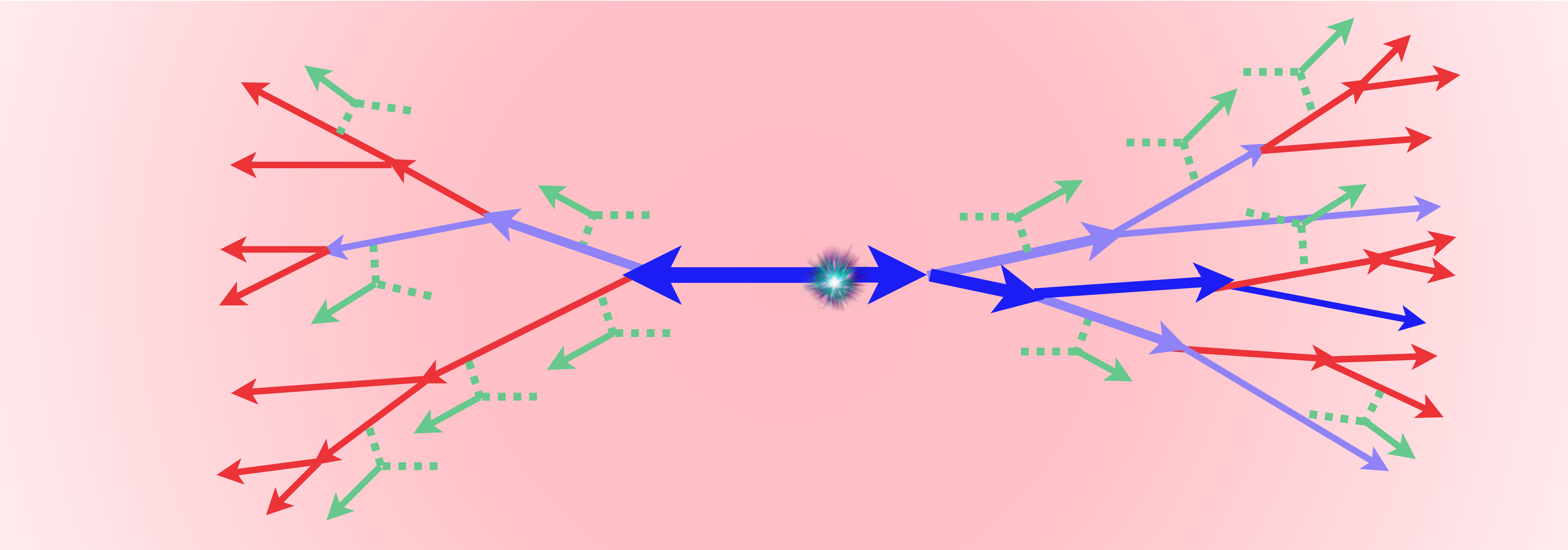

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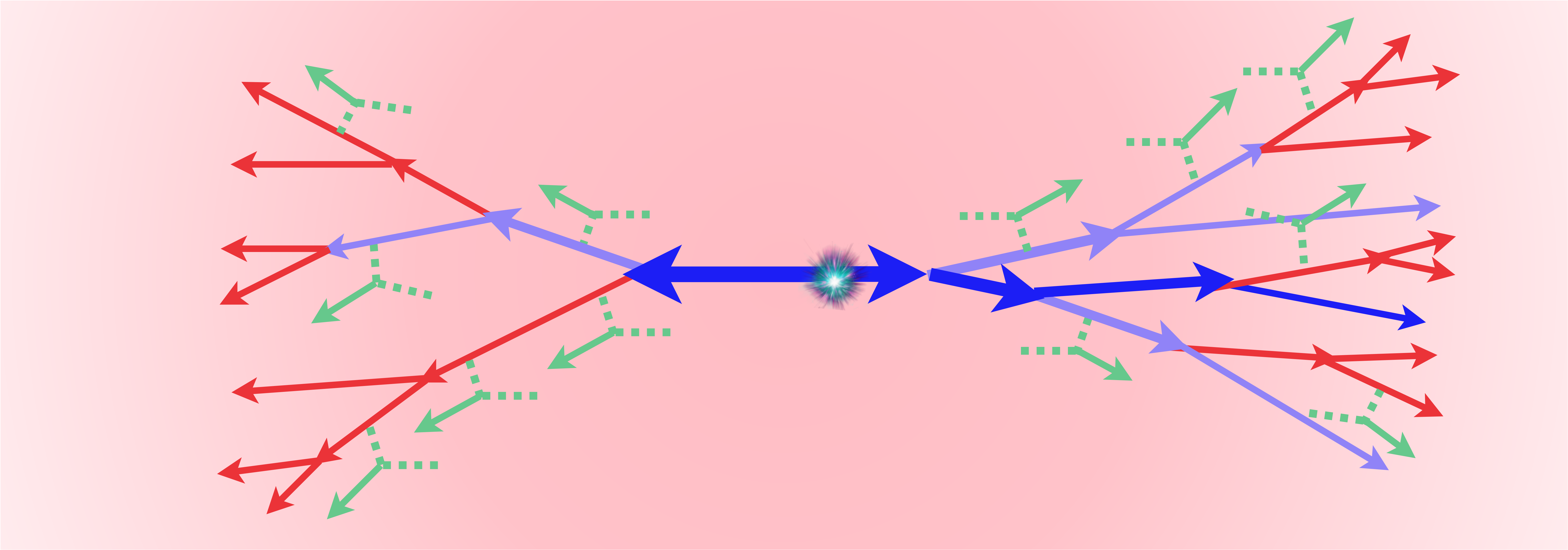
Jet Analysis with JETSCAPE events

Jet Reconstruction

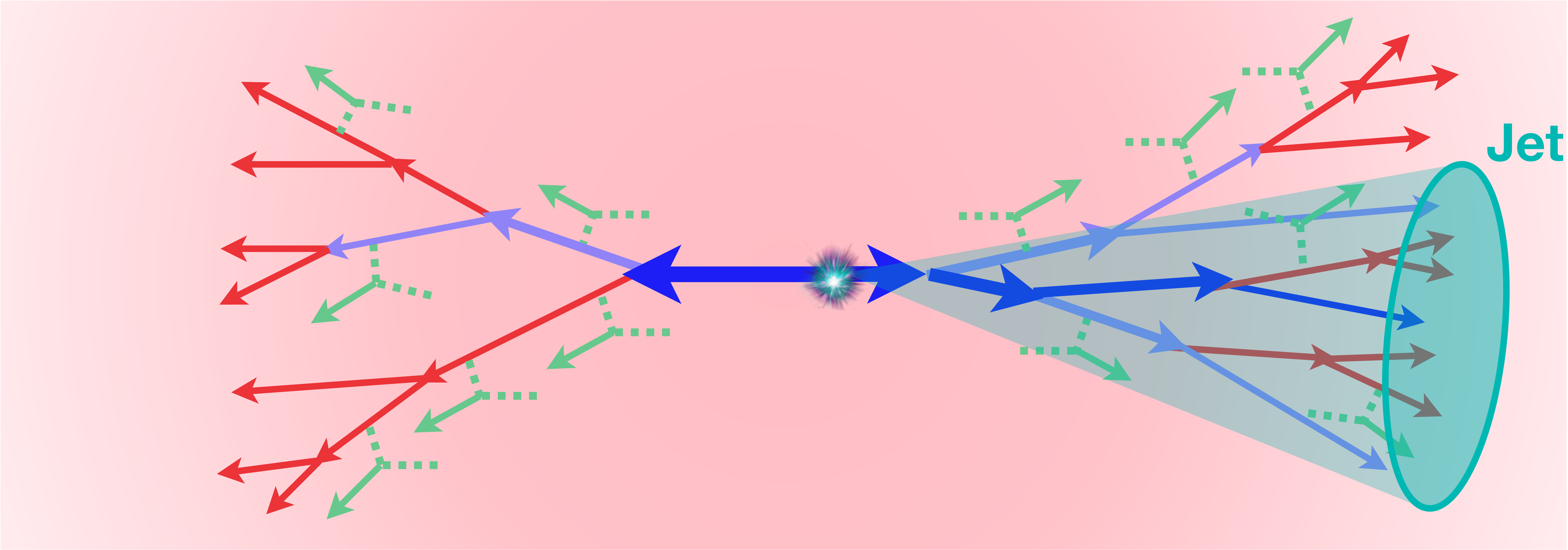
- **Clustering by jet reconstruction algorithm**



  - Employ anti-k_t algorithm with $R = 0.4$
  - Find Jets with $p_{\mathrm{T}}^{\mathrm{jet}} > 100\ \ \mathrm{GeV}$

Jet Reconstruction

- **Clustering by jet reconstruction algorithm**



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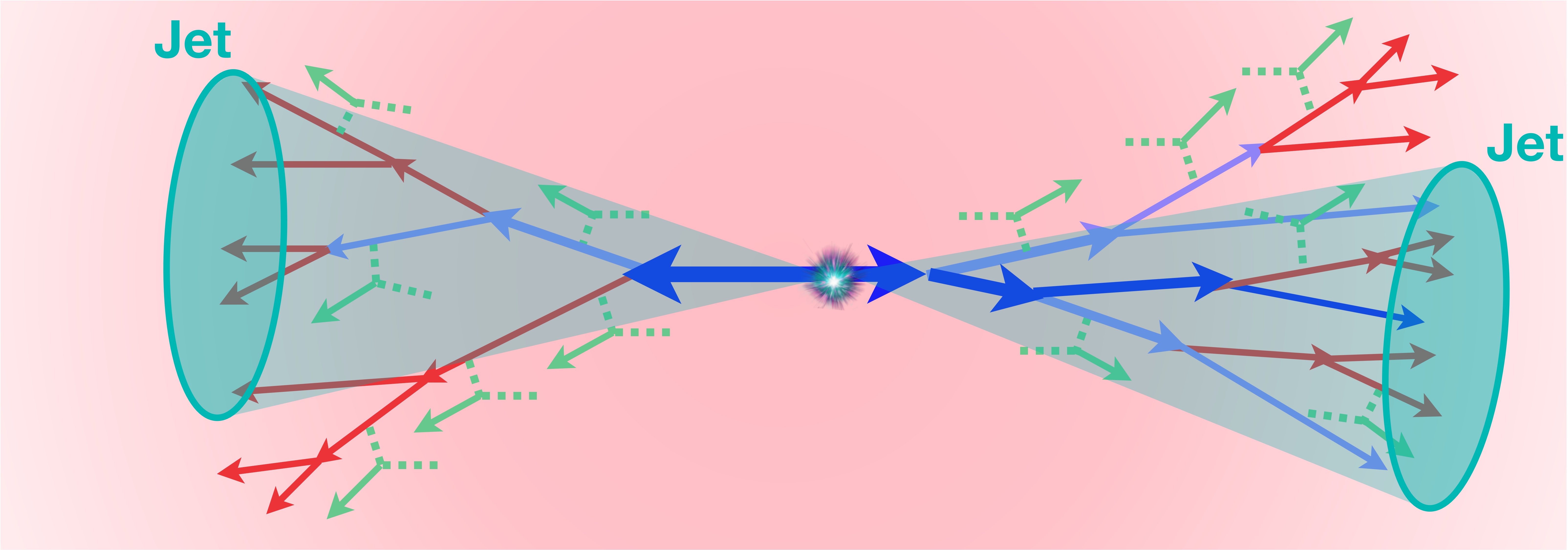
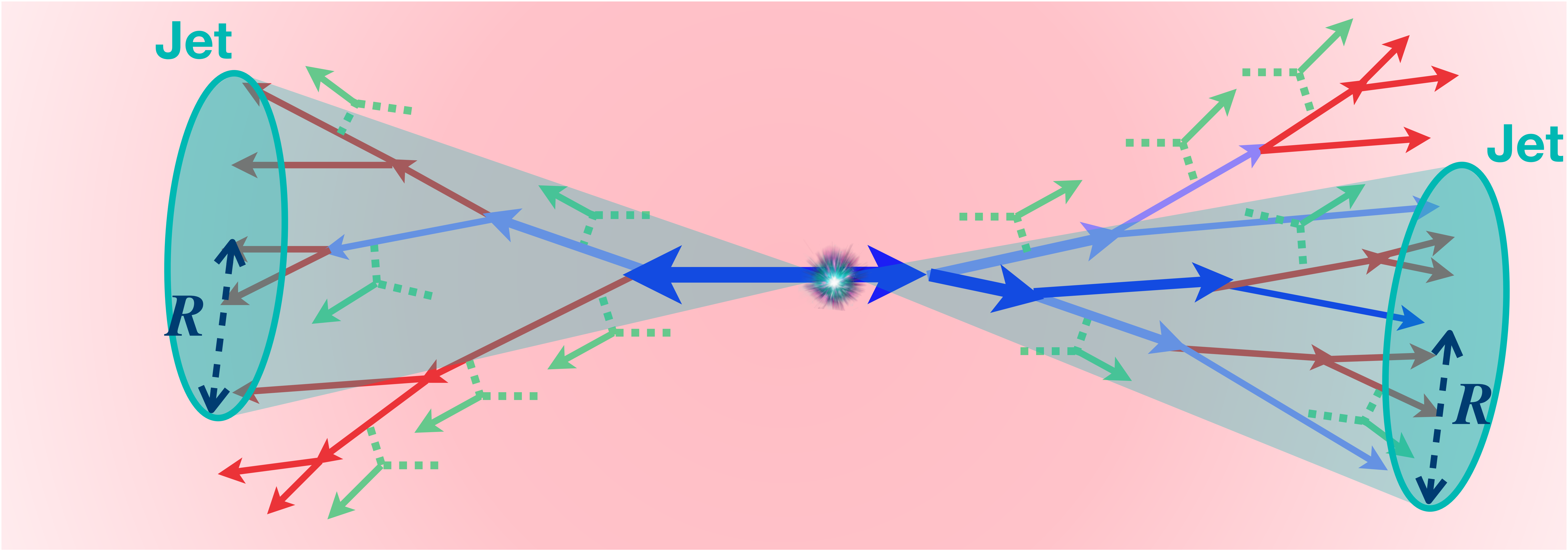


- Employ anti-k_t algorithm with $R = 0.4$
- Find Jets with $p_{\mathrm{T}}^{\mathrm{jet}} > 100\ \ \mathrm{GeV}$

Jet Reconstruction

- **Clustering by jet reconstruction algorithm**

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

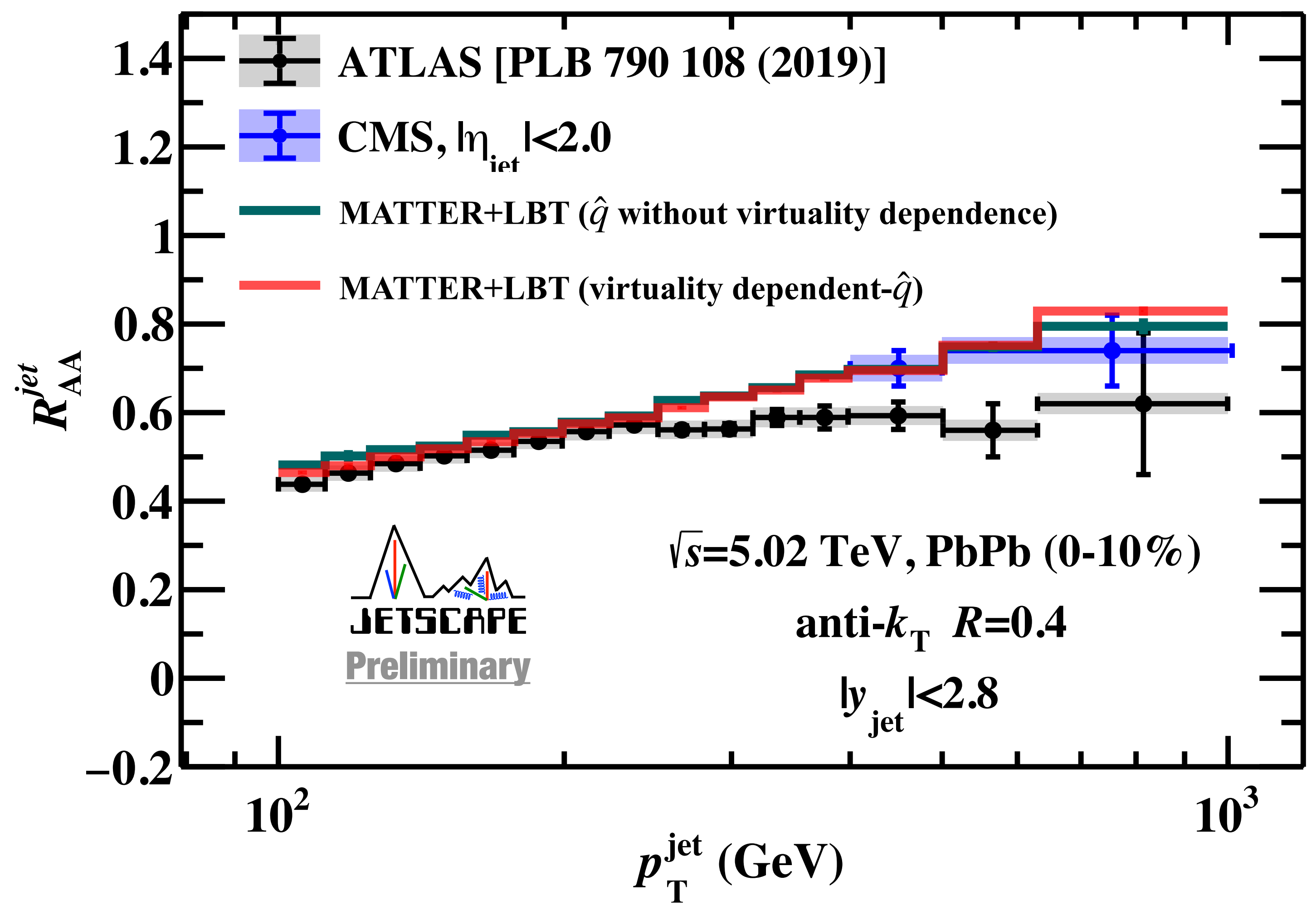


- Employ anti-k_t algorithm with $R = 0.4$
- Find Jets with $p_{\mathrm{T}}^{\mathrm{jet}} > 100\ \ \mathrm{GeV}$

Analysis for Jet Observables

- Jet-R_{AA}

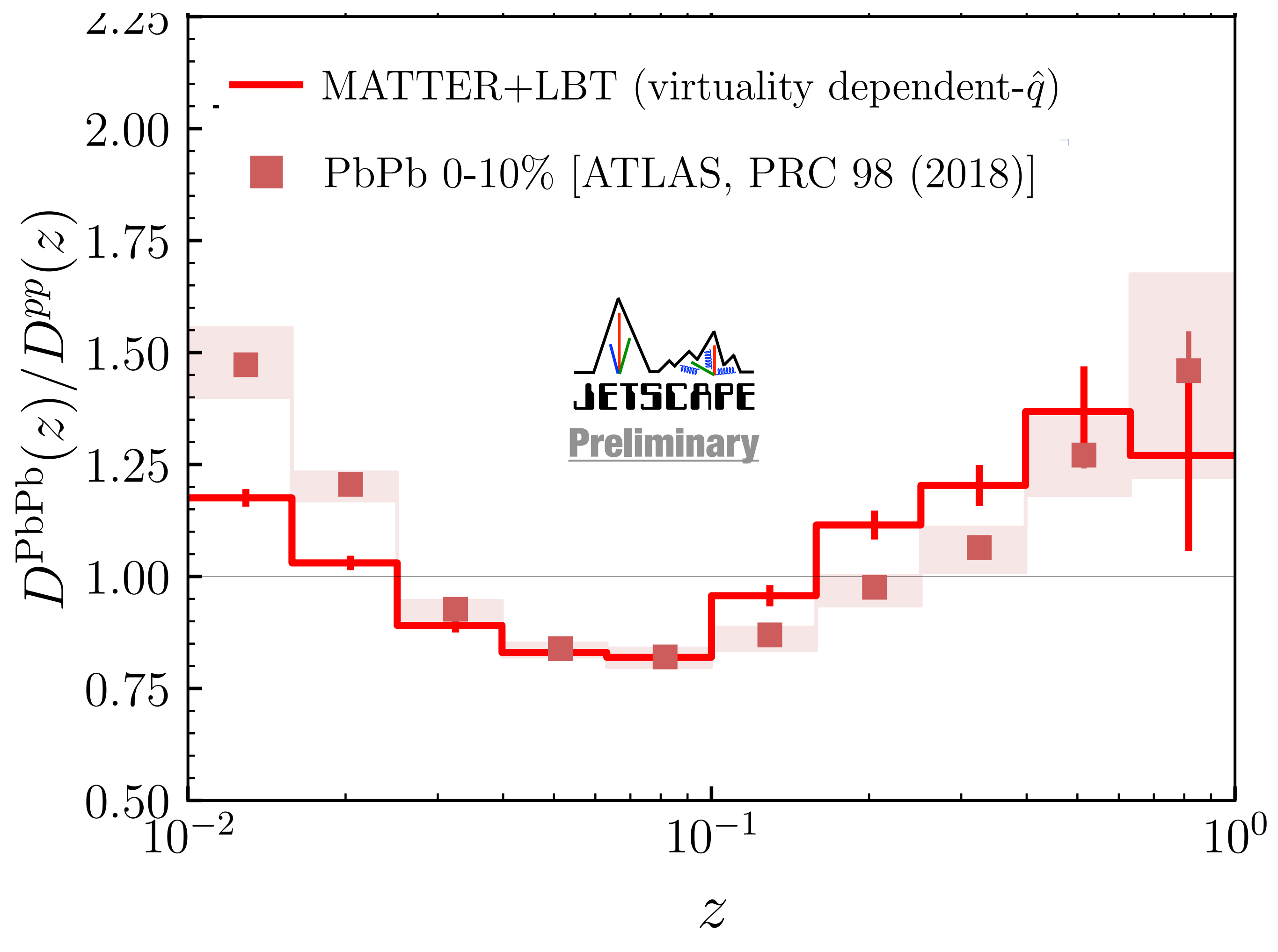
$$R_{AA}^{\text{jet}} = \frac{\left.\frac{1}{N_{\text{ev}}}\frac{dN_{\text{jet}}}{dp_T^{\text{jet}}}\right|_{\text{PbPb}}}{\left.\frac{1}{N_{\text{ev}}}\frac{dN_{\text{jet}}}{dp_T^{\text{jet}}}\right|_{pp}}$$



- Jet Fragmentation Function

$$D(z) = \frac{1}{N_{\text{jet}}}\frac{dN_{\text{ch}}}{dz}$$

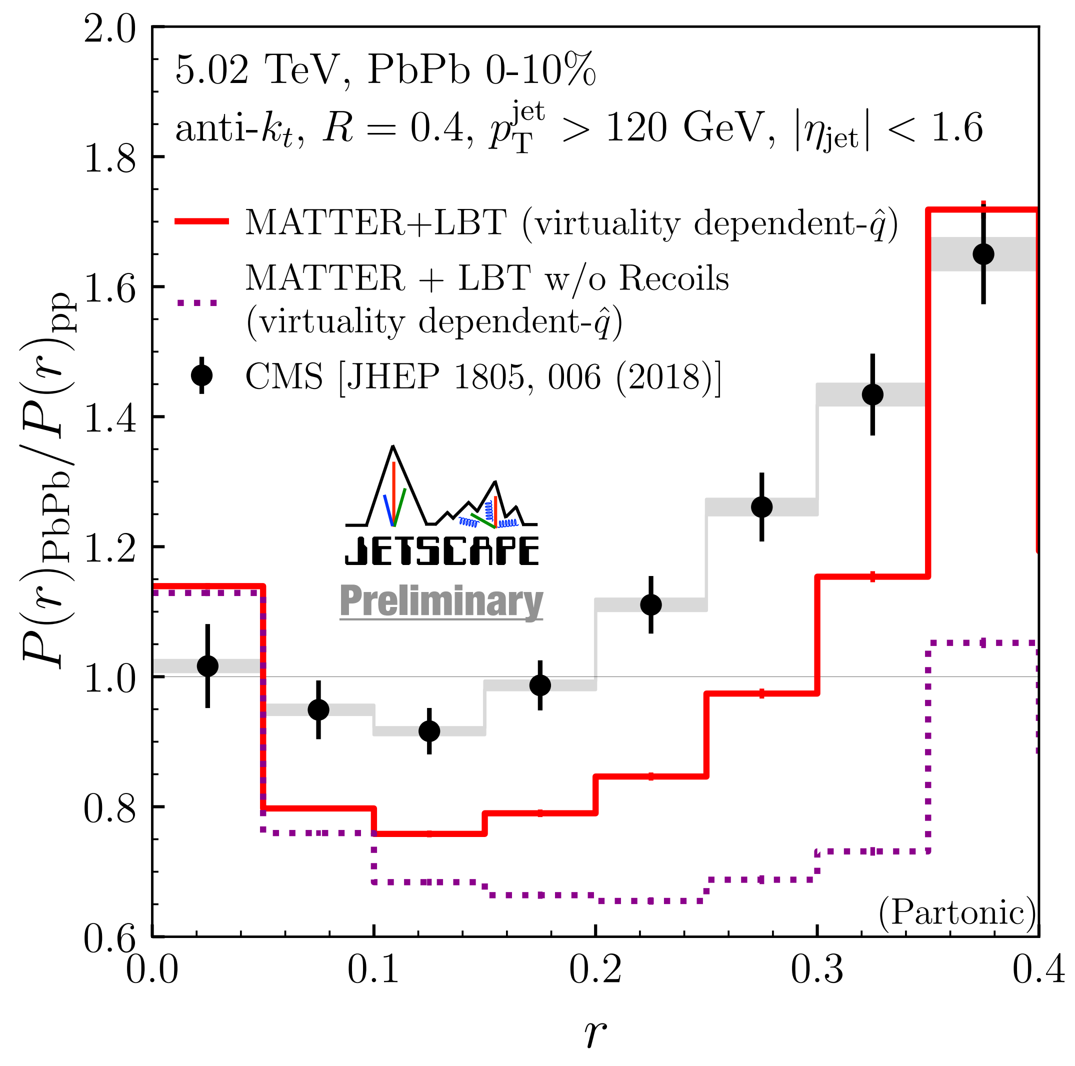
$$z = \frac{p_T^{\text{ch}}}{p_T^{\text{jet}}}$$



- Jet Shape Function

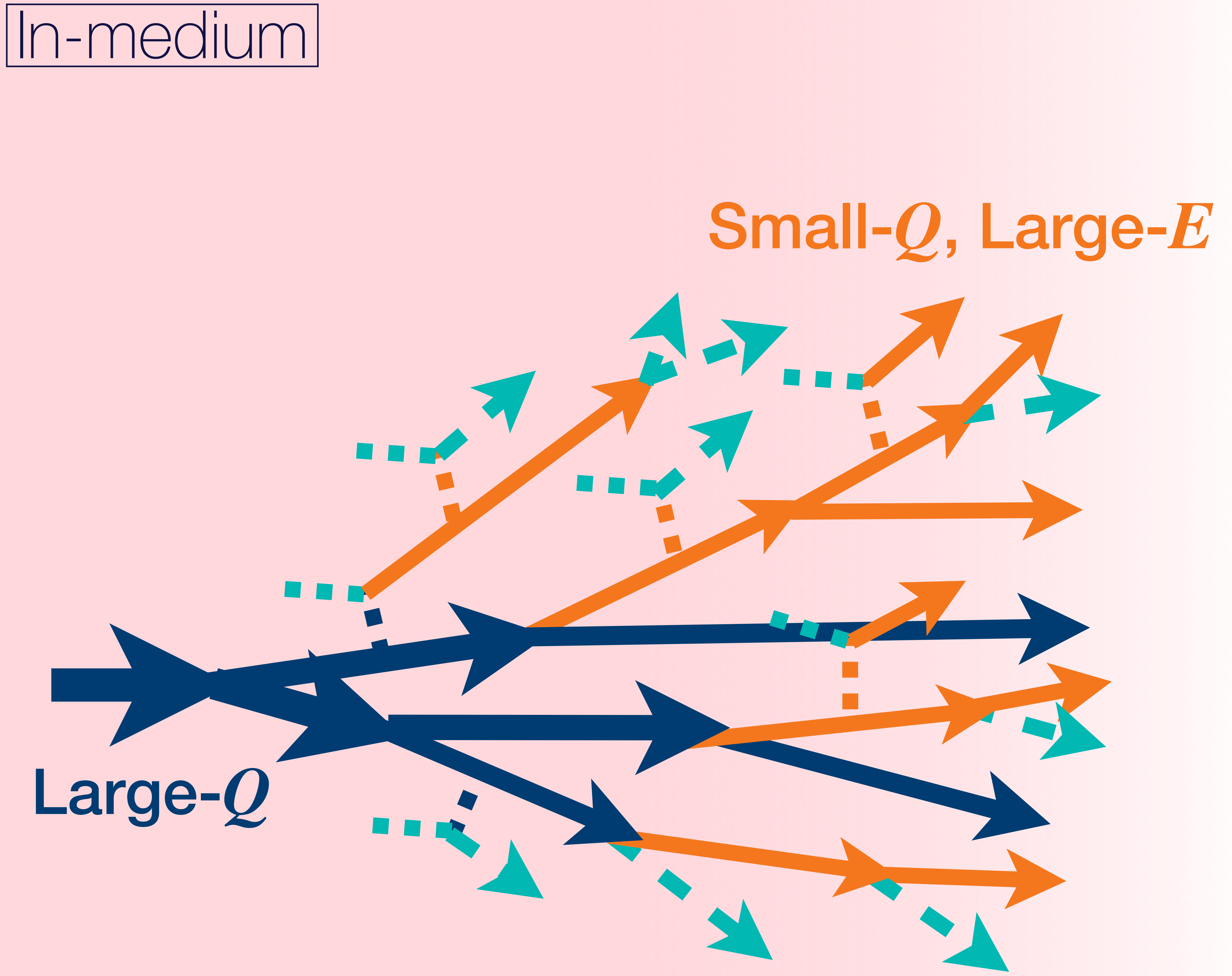
$$P(r) = \frac{1}{N_{\text{jet}}}\frac{d\sum_i p_T^i}{dr}$$

$$r = \sqrt{(\eta - \eta_{\text{jet}})^2 + (\phi - \phi_{\text{jet}})^2}$$



Two-stage Hydro

Simulation with JETSCAPE (Im-medium Jet Evolution)



Q^2: virtuality (off-shellness)

Large-Q

Virtuality ordered splittings with small medium effect

Model: Medium-modified Sudakov (**MATTER**)

Small-Q, Large-$E(>E_{\mathrm{th}})$

Splittings driven by in-medium scatterings

Models: Kinetic Theory (**LBT, MARTINI**)

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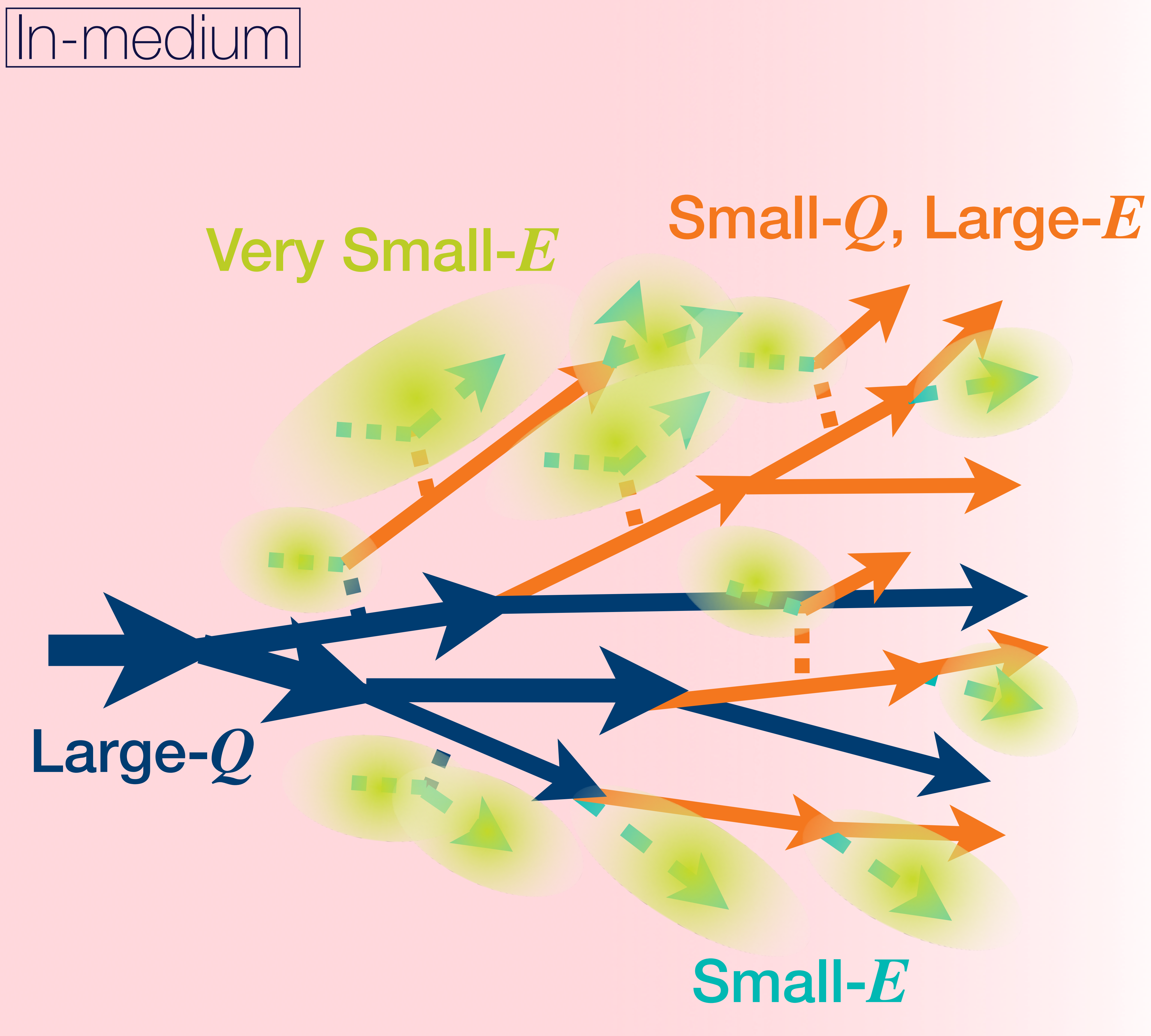

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Splittings driven by in-medium scatterings

Models: Kinetic Theory (**LBT, MARTINI**)

Small-$E(\leq E_{\text{th}})$

Energy-momentum diffusion into medium

Model: Causal Diffusion (**Causal Liquefier**)

Very Small-$E(\sim E_{\text{med}})$

Hydrodynamical evolution with bulk medium

Model: Hydrodynamics (**MUSIC**)

Summary of the Simulation in this session

- **Settings in TwostageHydro for PbPb collisions at 5.02 TeV**

Jet Shower

- In-medium shower with ***MATTER***+***LBT*** (Recoil ON, Virtuality separation $Q_{\rm sw} = 2\,{\rm GeV}$)
  Majumder, Cao, Vujanovic,… Luo, Wang, Cao, He,…
- Initial condition from ***PGun*** (single parent jet parton with a fixed-initial $p_{\rm T} = 200\,{\rm GeV}$ and a fixed creation point $(x\!=\!0, y\!=\!0, z\!=\!0)$).
- Hadronization with ***Colorless Hadronization*** (Lund string model of Pythia)
  Pablos, Majumder

Source Term

- Source generated by ***Causal Liquefier*** based on relativistic diffusion equation
  YT, Shen, Majumder
- Absorption of partons with energy at LRF of medium $p \cdot u_{\rm fluid} < E_{\rm th} = 2\,{\rm GeV}$

Medium Fluid

- Initial medium profile generated by ***TREONTo*** (PbPb 5020 GeV, 0-10%)
  Moreland, Bernhard, Bass
- (2+1)-D viscous hydro calculation with source term by ***MUSIC***
  Denicol, Gale, Jeon, Luzum, Paquet, Schenke, Shen
- Particle emission at freezeout via Cooper-Frye sampling by ***iSS***
  Shen

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- **Settings in TwostageHydro for PbPb collisions at 5.02 TeV**

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- In-medium shower with ***MATTER+LBT*** (Recoil ON, Virtuality separation $Q_{\rm sw} = 2\,{\rm GeV}$)
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- Hadronization with ***Colorless Hadronization*** (Lund string model of Pythia)

Pablos, Majumder

⚠️ This setup is NOT realistic at all

Medium fluid must be simulated in (3+1)-D, since jets and their sources are 3-D objects.

Just to save time, we use (2+1)-D in this session.

Source Term

- Source generated by ***Causal Liquefier*** based on relativistic diffusion equation

YT, Shen, Majumder

- Absorption of partons with energy at LRF of medium $p \cdot u_{\rm fluid} < E_{\rm th} = 2\,{\rm GeV}$

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Shen

Dialog between Jet Shower and Medium Fluid

- **TwostageHydro in JETSCAPE**

1) MUSIC1

Hydro calculation w/o source

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

Medium Infos

$T(x), u^\mu(x), \ldots$

2) MATTER+LBT with E_{th}-cut

In-medium Jet Evolution

Deposited Parton Infos

3) MUSIC2 + Causal Liquefier

Hydro calculation w/o source

$$\nabla_\mu T^{\mu\nu} = J^\nu$$

Source Term $J^\nu(x)$

Source Term Generation

Dialog between Jet Shower and Medium Fluid

- **TwostageHydro in JETSCAPE**

1) MUSIC1

Hydro calculation w/o source

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

Medium Infos

$T(x), u^\mu(x), \ldots$

2) MATTER+LBT with $E_{\rm th}$-cut

In-medium Jet Evolution

Deposited Parton Infos

The same initial condition

3) MUSIC2 + Causal Liquefier

Hydro calculation w/o source

$$\nabla_\mu T^{\mu\nu} = J^\nu$$

Source Term $J^\nu(x)$

Source Term Generation

XML for TwostageHydro

XML for TwostageHydro

Hydro 1st Run

```
<!--Preequilibrium Dynamics Module -->
<Preequilibrium>
  <NullPreDynamics> </NullPreDynamics>
</Preequilibrium>

<!-- Hydro  Module 1 -->
<Hydro>
  <MUSIC>
    <name>MUSIC_1</name>
    <freezeout_temperature>0.150</freezeout_temperature>
  </MUSIC>
</Hydro>

<!-- Create liquifier -->
```

Hydro 2nd Run

- Add Liquefier

```
      <in_vac> 0 </in_vac>
      <only_leading> 0 </only_leading>
      <hydro_Tc> 0.16 </hydro_Tc>
      <alphas> 0.25 </alphas>
    </Lbt>
  <AddLiquefier> true </AddLiquefier>
</Eloss>

<!-- Hydro  Module 2 -->
<Hydro>
  <MUSIC>
    <name>MUSIC_2</name>
    <freezeout_temperature>0.150</freezeout_temperature>
  </MUSIC>
  <AddLiquefier> true </AddLiquefier>
</Hydro>
```

XML for TwostageHydro

Liquefier

```xml
    <freezeout_temperature>0.150</freezeout_temperature>
  </MUSIC>
</Hydro>

<!-- Create liquifier -->
<Liquefier>
    <!-- CausalLiquefier -->
    <CausalLiquefier>
        <name>CausalLiquefier</name>
        <dtau>0.02</dtau><!-- fluid time step in [fm] -->
        <dx>0.3</dx><!-- fluid cell size in [fm] -->
        <dy>0.3</dy><!-- fluid cell size in [fm] -->
        <deta>5</deta><!-- fluid cell size -->
        <tau_delay>2.0</tau_delay><!-- in [fm] -->
        <time_relax>0.1</time_relax><!-- in [fm] -->
        <d_diff>0.08</d_diff><!-- in [fm] -->
        <width_delta>0.1</width_delta><!-- in [fm] -->
    </CausalLiquefier>
</Liquefier>

<!--Eloss Modules -->
```

XML for TwostageHydro

Energy Loss Modules

- Add Liquefier

```xml
  </Liquefier>

  <!--Eloss Modules -->
  <Eloss>
      <deltaT>0.1</deltaT>
      <formTime> -0.1</formTime>
      <maxT>250</maxT>
      <mutex>ON</mutex>

      <Matter>
        <name>Matter</name>
        <matter_on> 1 </matter_on>
        <Q0> 2.0 </Q0>
        <T0> 0.16 </T0>
        <vir_factor> 0.25 </vir_factor>
        <in_vac> 0 </in_vac>
        <recoil_on> 1 </recoil_on>
        <broadening_on> 0 </broadening_on>
        <brick_med> 0 </brick_med>
        <hydro_Tc> 0.15 </hydro_Tc>
        <qhat0> -2.0 </qhat0>
        <alphas> 0.25 </alphas>
      </Matter>

      <Lbt>
        <name>Lbt</name>
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  <!-- Hydro  Module 2 -->
```