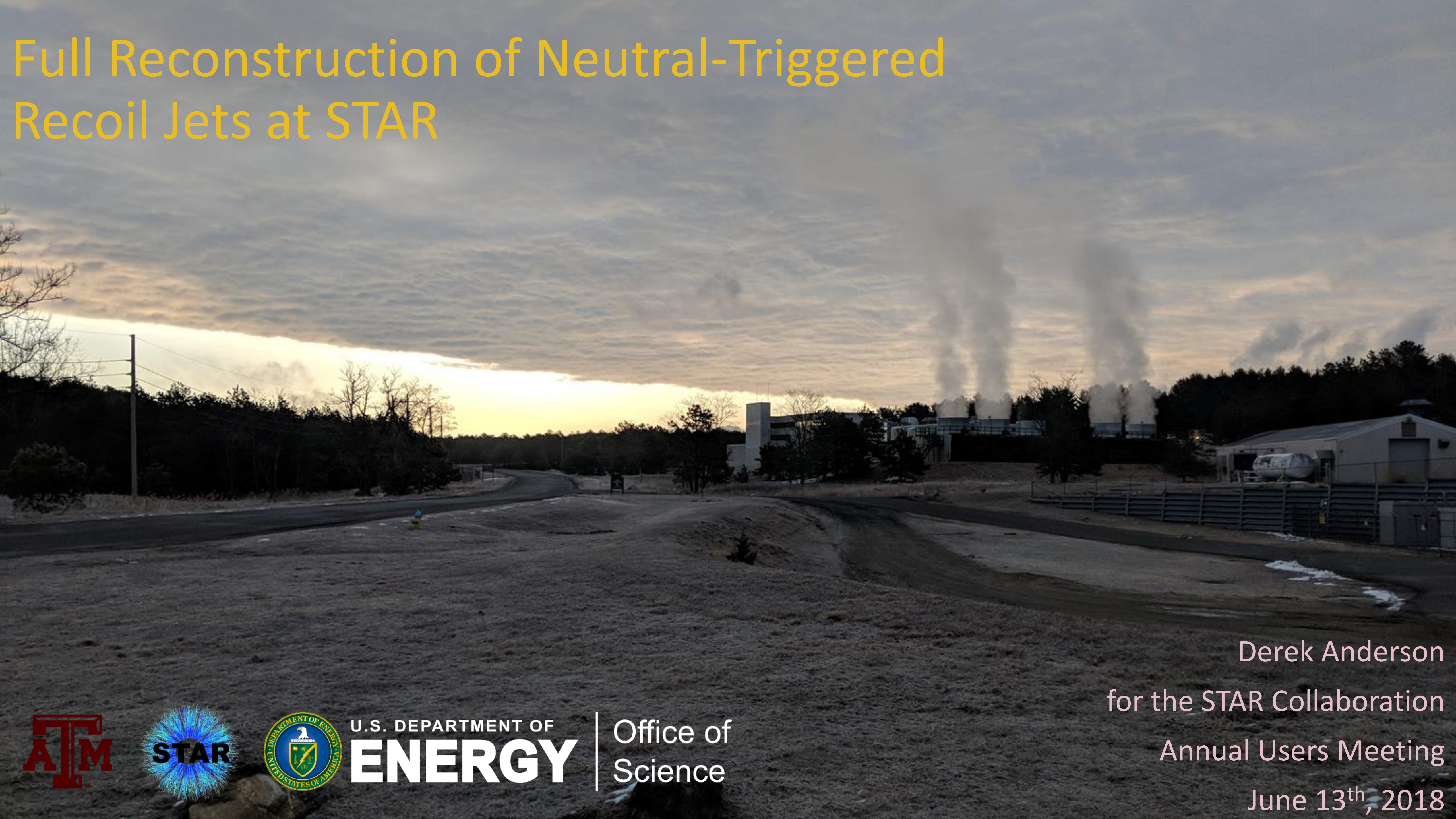
Full Reconstruction of Neutral-Triggered Recoil Jets at STAR



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for the STAR Collaboration

Annual Users Meeting

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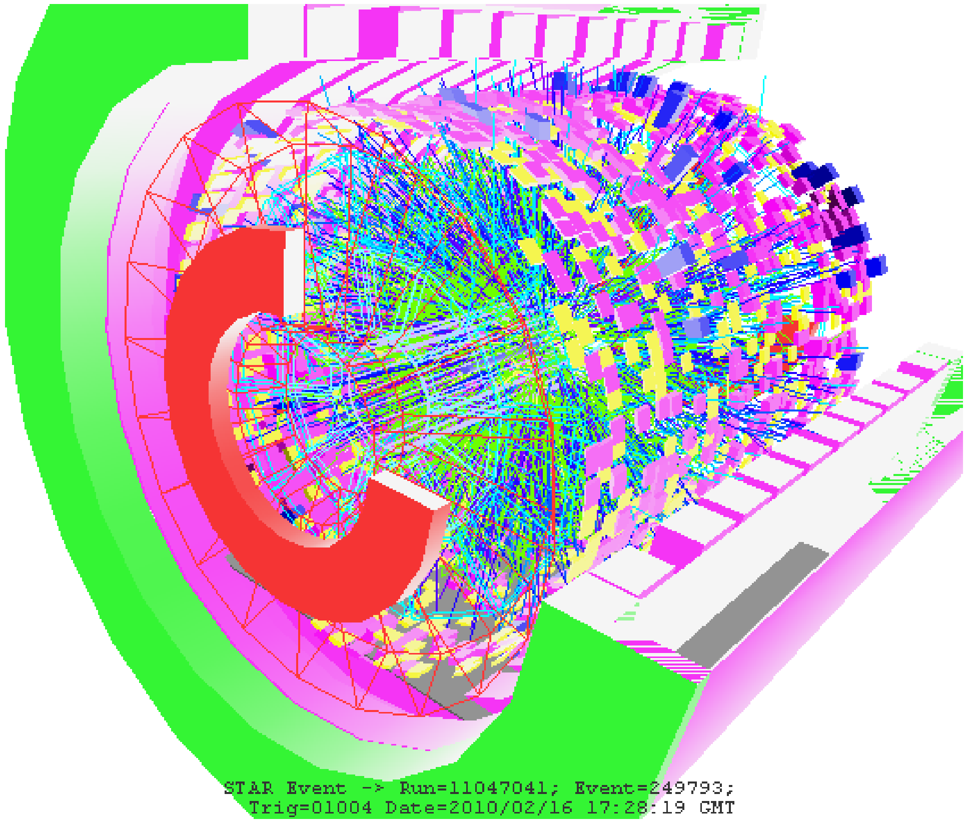
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

1. Introduction and Background
2. STAR and Neutral Triggers
3. Previous Measurements
4. Jet Reconstruction
5. Summary and Outlook

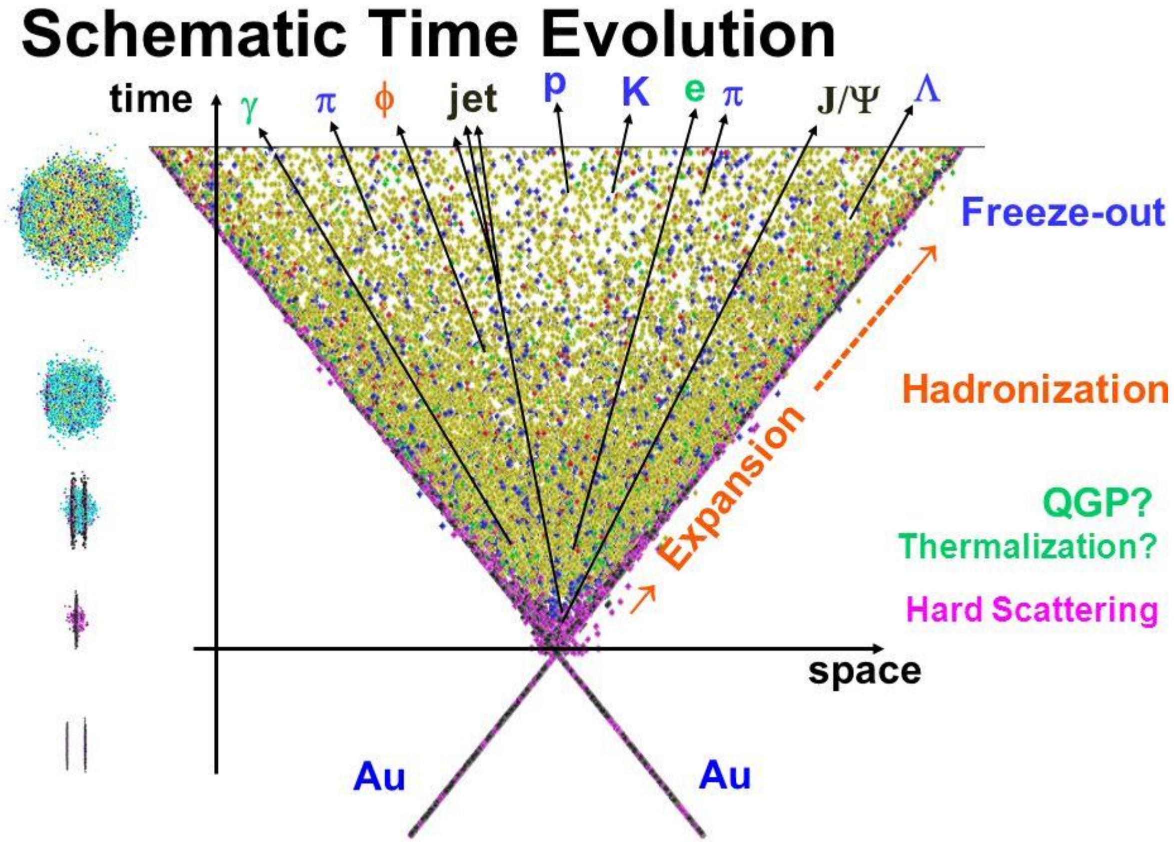


www.flickr.com/photos/brookhavenlab/

Introduction and Background

Why Jets?

- **Jets** are excellent probes of medium properties
  - » Produced early in collision by hard-scattered partons
  - » Described perturbatively
- **Jet-Quenching:** suppression of high energy particles due to partonic energy loss
  - » Partons lose energy via radiative and collisional interactions with QGP
  - » Depends on E_0, L, C_A/C_F, $\hat{q}$, α_s, etc…
  - » **Can measure by comparing Au+Au-collisions to p+p-collisions**



Adapted from Tatsuya Chujo, JPS RHIC Symposium 2001

Direct Photons

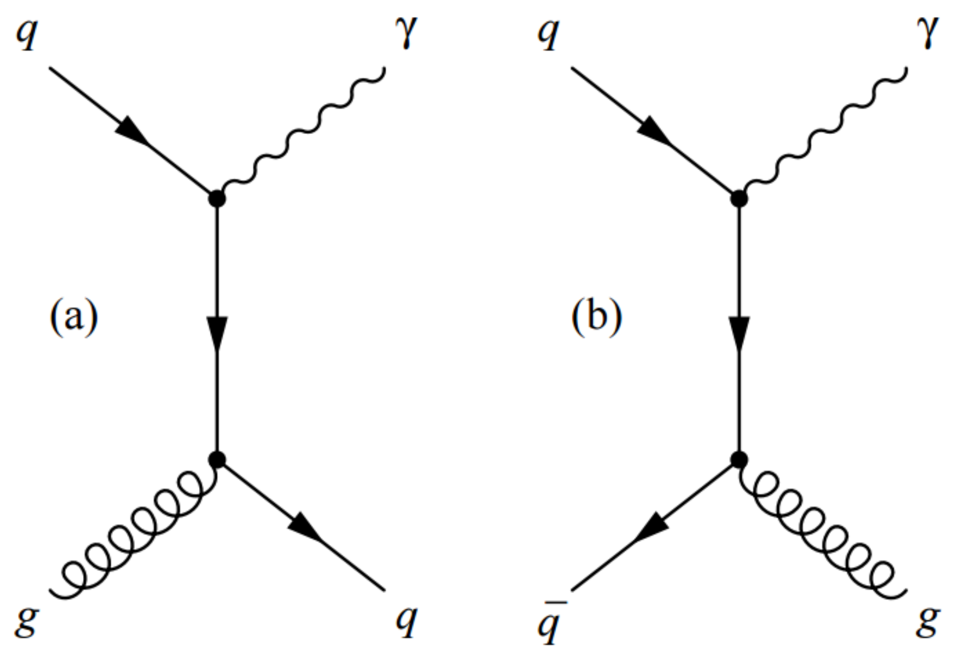
- **Prompt photon (γ^{prompt}):** photon scattered from energetic partons
  - » Doesn't strongly interact with medium so (to leading order)

$$E_T^{\gamma} \approx E_T^{parton}(t_0)$$

  - ∴ Provides a well-calibrated probe of partonic energy loss…
    - Wang et al.; PRL 77, 231 (1996)

- An admixture of prompt, thermal, and fragmentation photons is measured
  - » Collectively referred to as **direct photons (γ^{dir})**
  - » Thermal contribution is negligible (at sufficient energies)

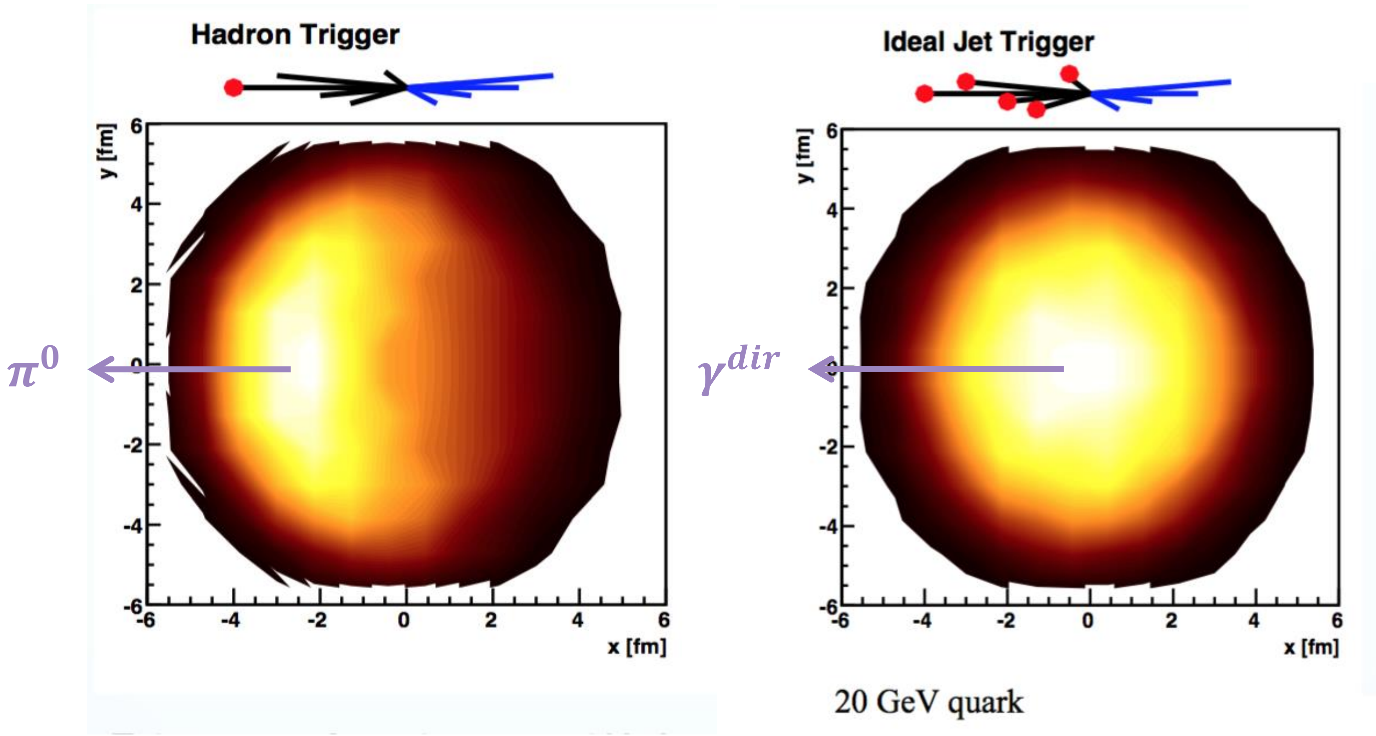
Campbell; PRC 92, 014907 (2015)



Neutral Triggered Jets

- **Energetic π^0:** produced as part of a jet
  - Biased towards surface emission
  - Mostly opposite gluon jets ($C_A = 3$)
    - De Florian et al.; PRD 75, 114010 (2007)
    - Albino et al.; Nucl. Phys. B 725, 93206 (2005)
- **Energetic γ^{dir}:** on the other hand…
  - No surface bias
  - Mostly opposite quark jets ($C_F = 4/3$)

- Comparison of jets opposite γ^{dir} to those opposite energetic π^0
  - might illuminate path length and color factor dependence…
  - ∵ On average, jets opposite γ^{dir} expected to **lose less energy** than those opposite π^0

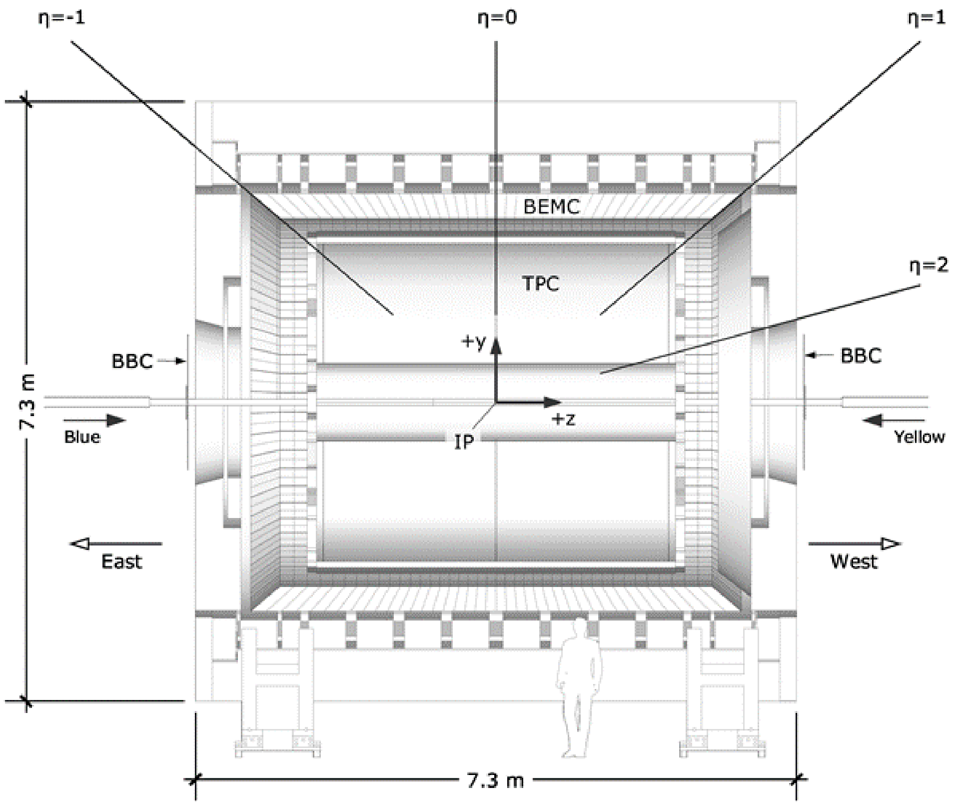


T. Renk; arXiv:1212.0646

STAR and Neutral Triggers

STAR As a Jet Detector

- STAR is well-equipped for jet measurements:
  a) **Time Projection Chamber (TPC)**
     – Charged particles
     – $p \in (0.1, 30)\ \text{Gev}/c$
  b) **Barrel Electro-Magnetic Calorimeter (BEMC)**
     – Neutral particles
     – π^0, γ discrimination
     – $\Delta\varphi \times \Delta\eta = 0.05 \times 0.05\ \text{sr}$
  » Both cover $\varphi = 2\pi, \eta = \pm 1$ in acceptance



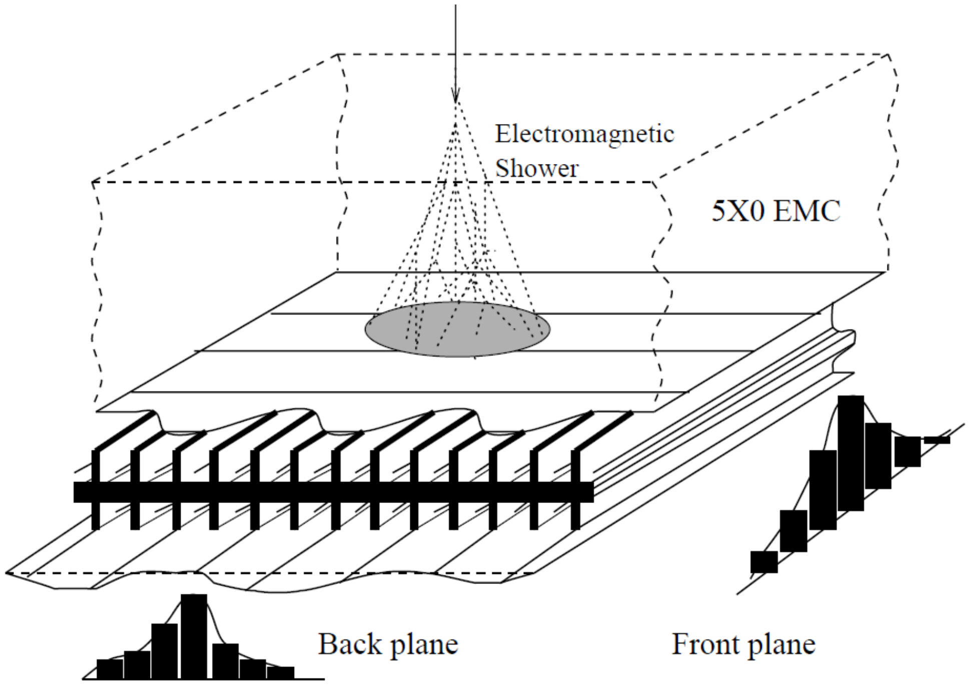
STAR; PRD 86, 032006 (2012)

The BSMD

- A grid of readout wires situated at $\sim 5.6X_0$ in each BEMC tower
  - » Used to create spatial profile of EM shower in BEMC
  - » Very fine granularity: 0.007×0.007 in $\Delta\eta \times \Delta\varphi$

- Permits discrimination of π^0 from isolated γ
  1) Clusters of 1 – 2 towers are created from BEMC response
  2) Centroid of cluster determined by BSMD
  3) Then π^0 and γ discriminated via shape analysis of EM shower.

Beddo et al.; NIM A499, 725 (2003)



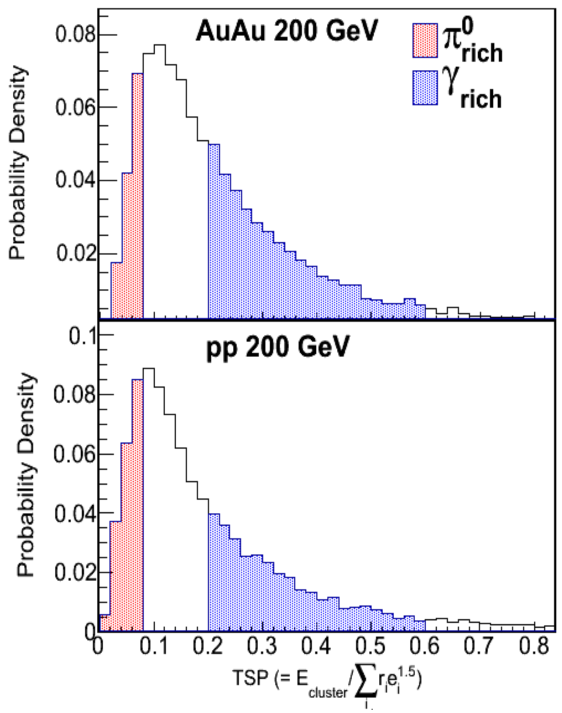
TSP

- **Transverse Shower Profile (TSP):** tuned to give biggest discrimination between π^0 and isolated γ showers:

$$TSP \equiv \frac{E_{cluster}}{\sum_i E_i^{strip} r_i^{1.5}}$$

  - » $E_{cluster}$ is total energy of cluster
  - » E_i^{strip} is energy of i^th strip
  - » r_i is distance from strip to center of cluster

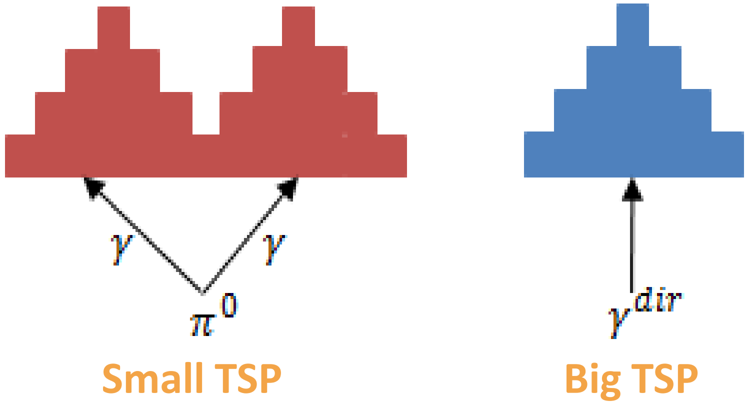
Sahoo; arXiv:1512.08782



- Split triggers into a sample of nearly pure π^0 (~99%) and a sample with enhanced fraction of γ^{dir} (γ^{rich})

$$N^{\gamma^{dir}} / N^{\gamma^{rich}} \sim 40\% \text{ (p+p)}$$

  - » Purity is $\sim 70\%$ for Au+Au (due to jet quenching)
  - » Viable for $p_T^{trg} \in (8,20)\ \mathrm{GeV}/c$



Previous Measurements

γ, π^0-$h^\pm$ Measurement at STAR

- γ^{dir}, π^0-hadron correlation measured by STAR:
  - Measure per-trigger yield of away-side charged hadrons opposite γ^{dir}, π^0
  - **Away-Side:** $|\Delta\varphi - \pi| < 1.4$

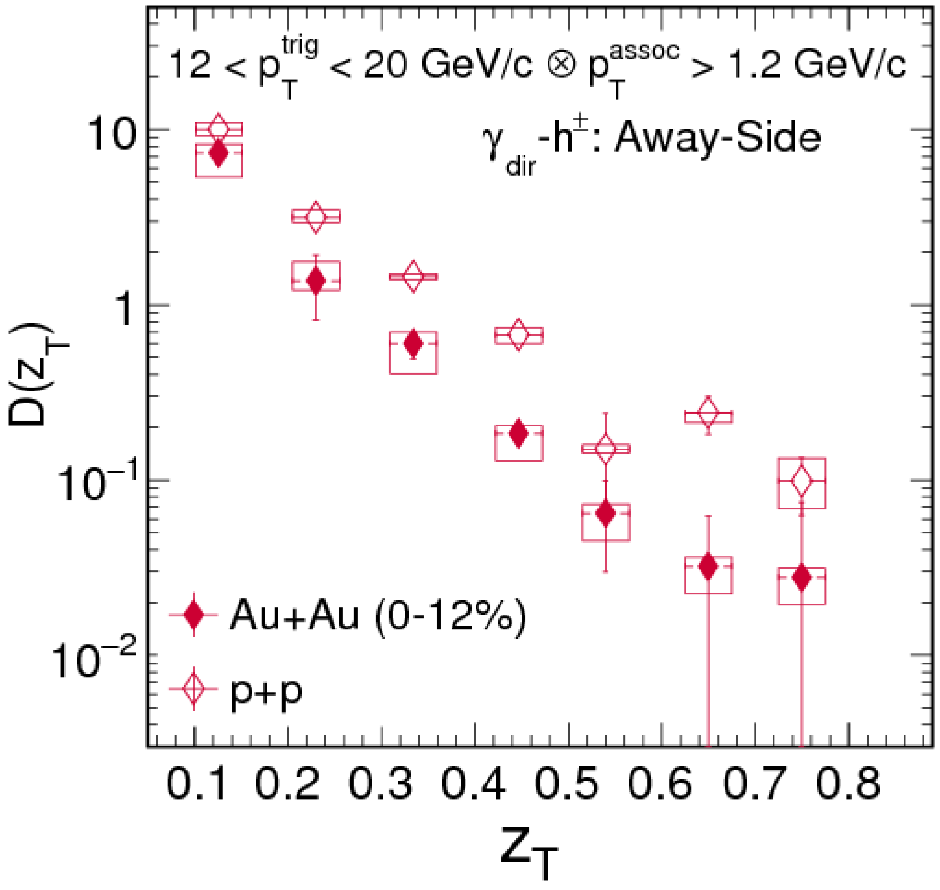
- **Nuclear Modification Factor:** quantifies medium modification

$$I_{AA}(x) \equiv \frac{D^{AuAu}(x)}{D^{pp}(x)}$$

  - $D^{\cdot\cdot}(x)$ is the (conditional) per-trigger yield
  - x can be p_T^{assoc}, z_T, etc.

$$z_T \equiv p_T^{assoc} \Big/ p_T^{trig}$$

STAR; PLB 760, 689 (2016)

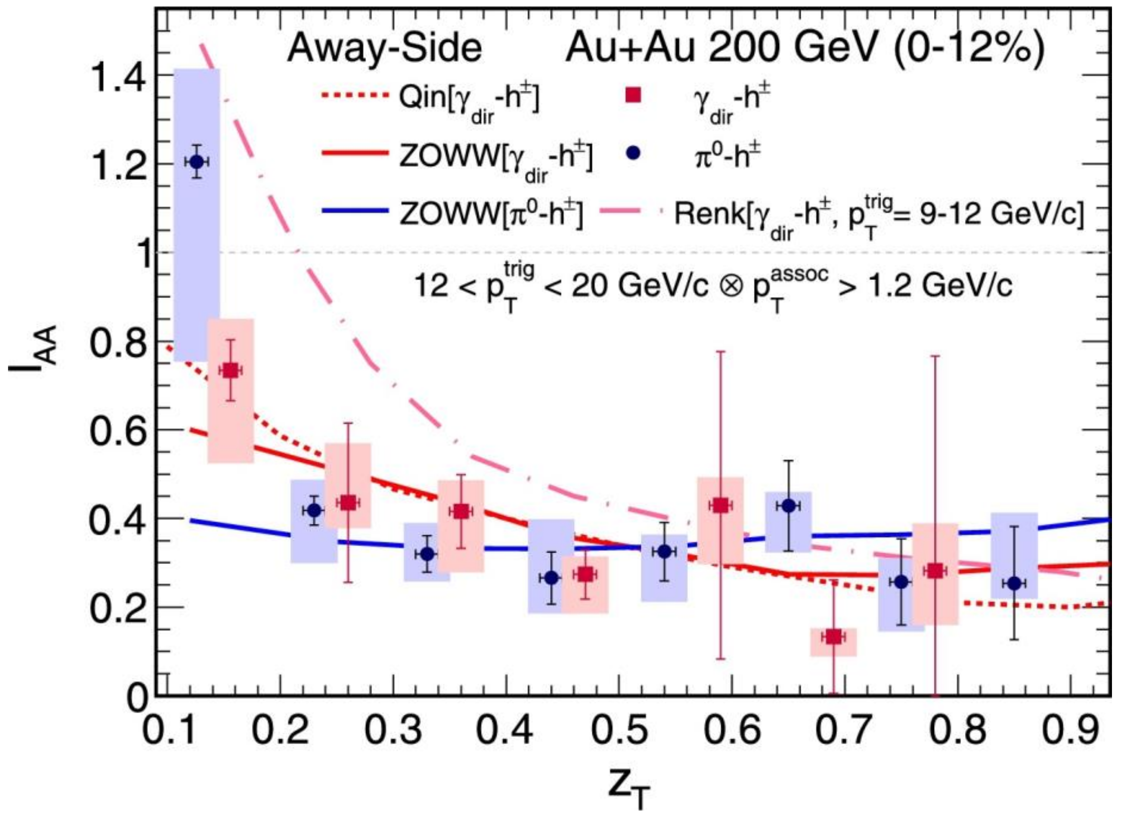


γ, π^0-$h^{\pm}$ Measurement at STAR

- Suppression expected to differ between γ^{dir}-hadrons and π^0-hadrons
  - » **NOT** seen within uncertainties

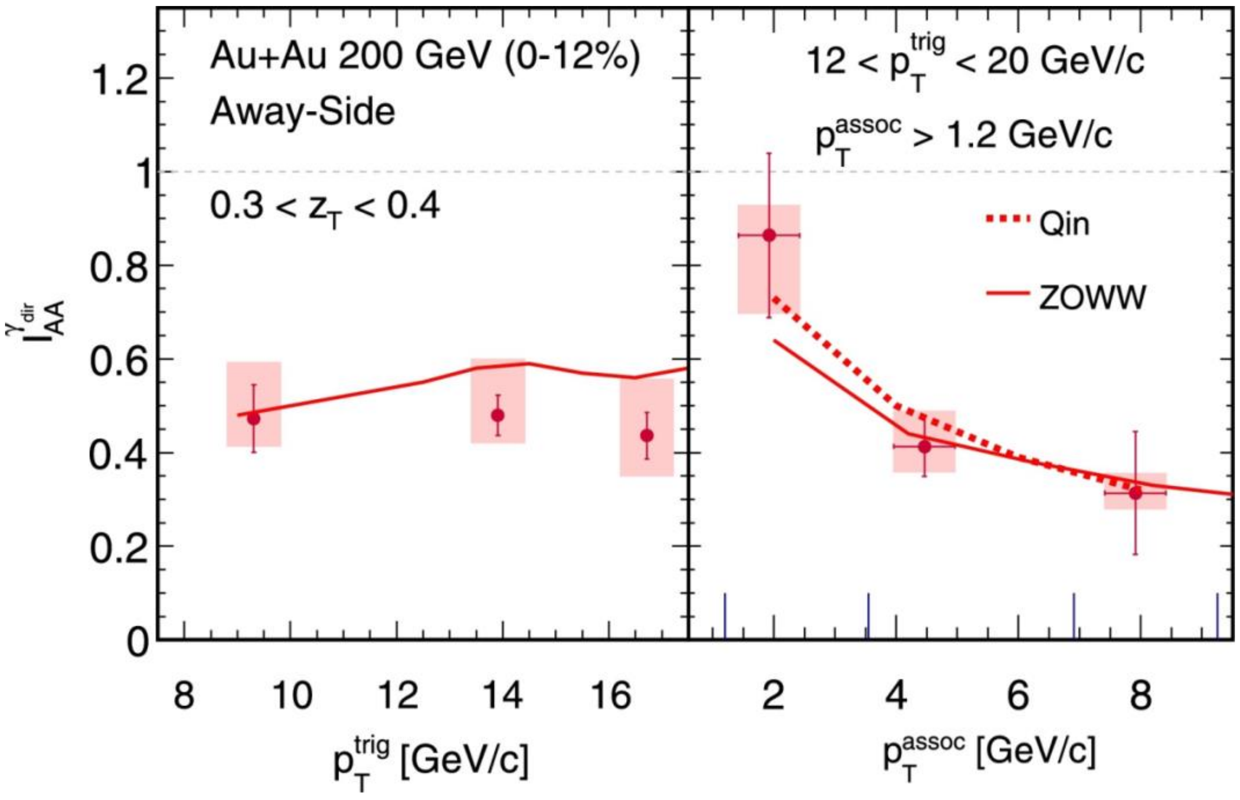
- **Qin:** PRC 80, 054909 (2009)
- **ZOWW:** PRL 103, 032302 (2009)

STAR; PLB 760, 689 (2016)



γ, π^0-$h^\pm$ Measurement at STAR

- However, γ^{dir}-hadrons suggest that…
  - **Lower p_T^{assoc} less suppressed than higher p_T^{assoc}**
  - Consistent with previous STAR jet-hadron correlation
    - STAR; PRL 112, 122301 (2014)
    - Cf. N. Elsey's talk



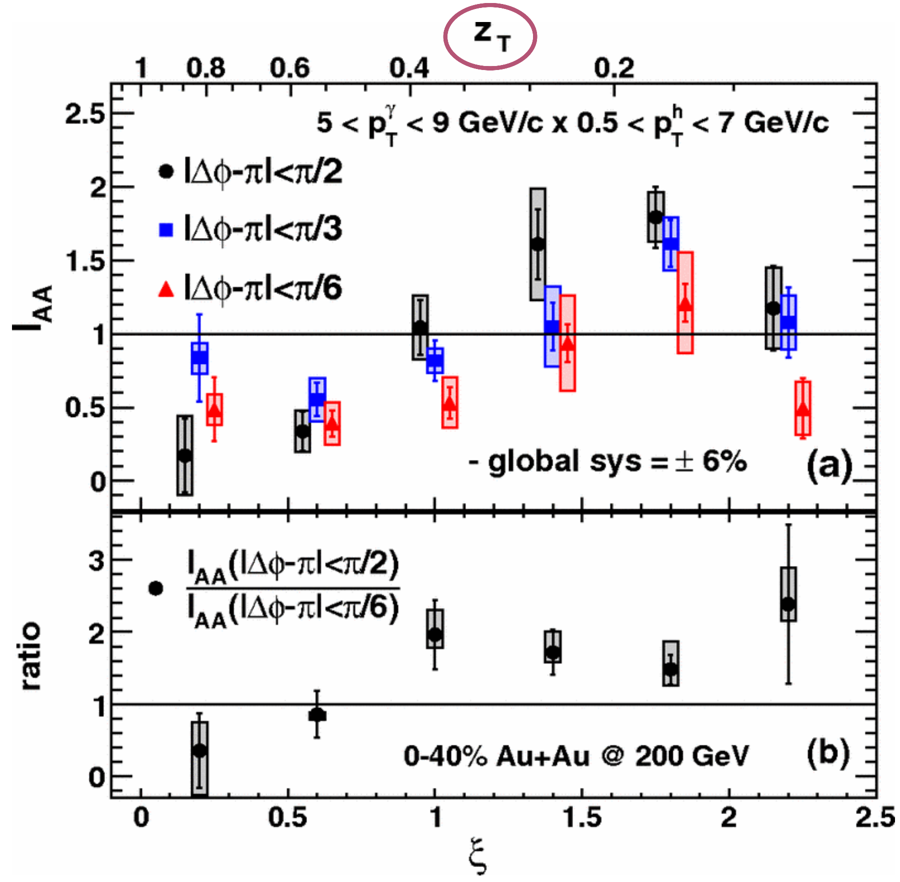
STAR; PLB 760, 689 (2016)

- **Qin:** PRC 80, 054909 (2009)
- **ZOWW:** PRL 103, 032302 (2009)

γ-$h^{\pm}$ Measurement at PHENIX

- Lost energy reappearing at **low p_T** rather than **low z_T** corroborated by PHENIX measurements:
  - » Reported $I_{AA}^{\gamma^{dir}} > 1$ for low z_T
    - – PHENIX; PRL 111, 032301 (2013)
  - » For fixed $z_T \in (0.1, 0.4)$
    - – **STAR:** $p_T^{trig} \in (12, 20) \Rightarrow p_T^{assoc} \in (1.2, 8)$
    - – **PHENIX:** $p_T^{trig} \in (5, 9) \Rightarrow p_T^{assoc} \in (0.5, 3.6)$
  - » See also M. Connors' talk

- Now pursuing more precise techniques to better
  - » Probe suppression at lower p_T^{assoc}
  - » Investigate non-observation of differences between γ^{dir} and π^0 suppression



PHENIX; PRL 111, 032301 (2013)

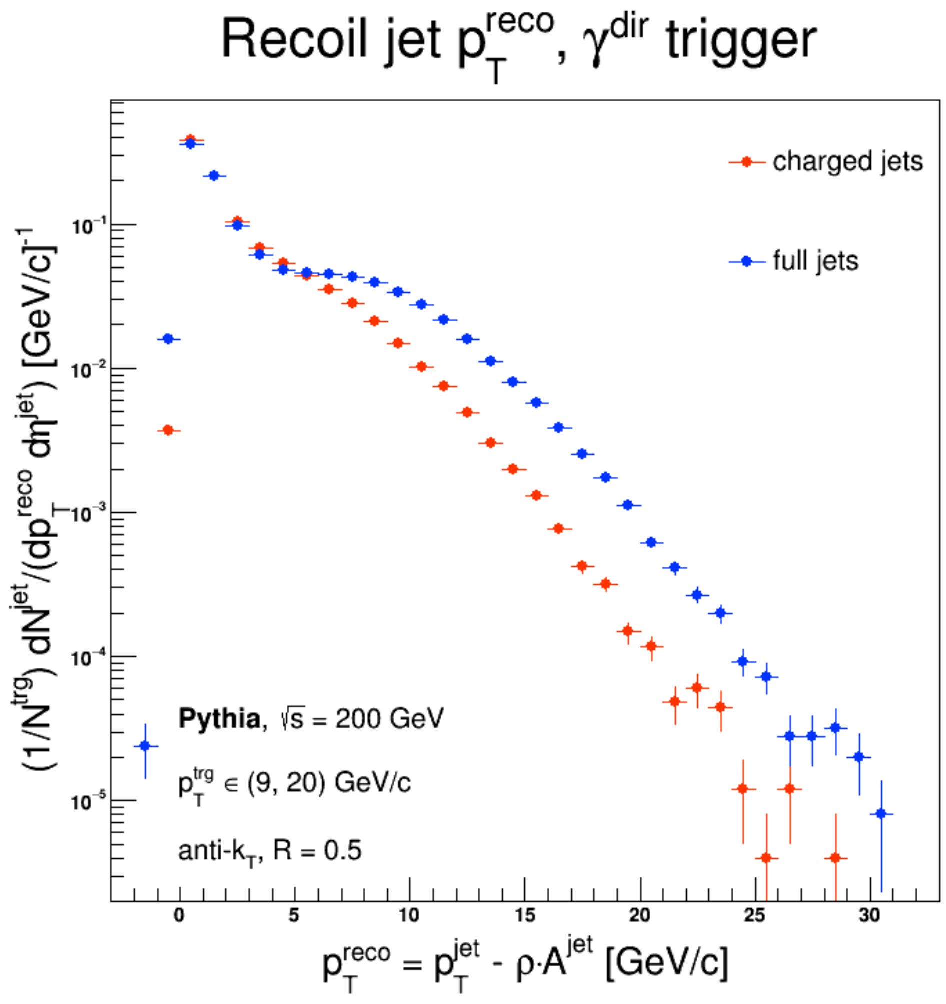
$\xi \equiv \ln\frac{1}{z_T}$

Jet Reconstruction

Semi-Inclusive Jets

- Jets are attractive observables…
  - » Sensitive to soft sector:
    - – $p_T^{cst} > 0.2 \text{ GeV}/c$
  - » Integrates over details of hadronization
  - » Allows for inter-jet correlations

- Jets are built from TPC tracks (charged constituents) and BEMC towers (neutral constituents)
  - » **Charged Jets:** built from only charged constituents
    - – Easy to calibrate
    - – But still sensitive to medium modifications
  - » **Full jets:** built from charged **and** neutral constituents
    - – Not as easy to calibrate
    - – But offer much more precise measurement of jet energy

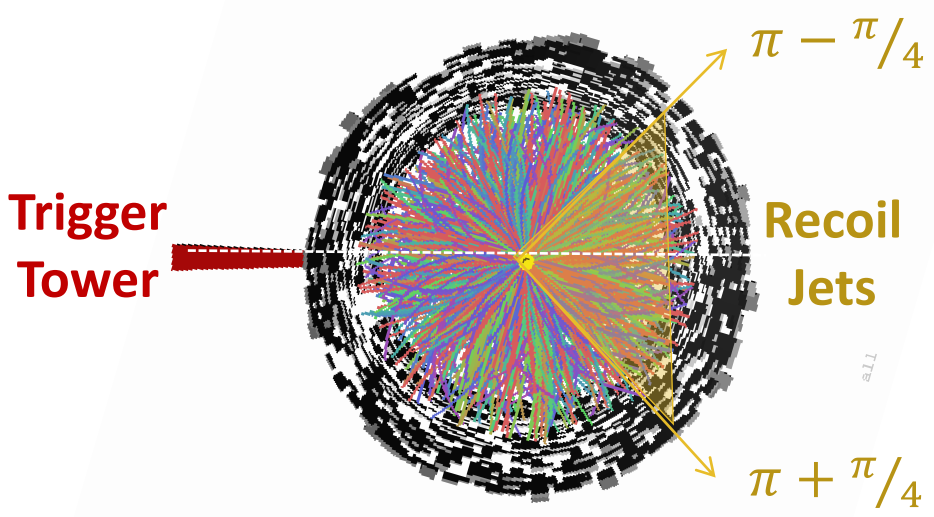


Semi-Inclusive Jets

- **Recoil Jets:** any jet satisfying $|\Delta\varphi^{jet} - \pi| < \pi/4$
  - » $p_T^{jet} \in (0.2, 30)\ \mathrm{GeV}/c$
  - » Event-wise energy pedestal via:

$$p_T^{reco} = p_T^{jet} - \rho \cdot A^{jet}$$

- **Semi-Inclusive Jet Measurement:**
  1) Select collisions with high energy γ^{dir} or π^0
  2) Cluster **charged (and neutral)** constituents into full jets using anti-k_T
  3) Count all recoil jets
  4) Compare yields in Au+Au to those in p+p



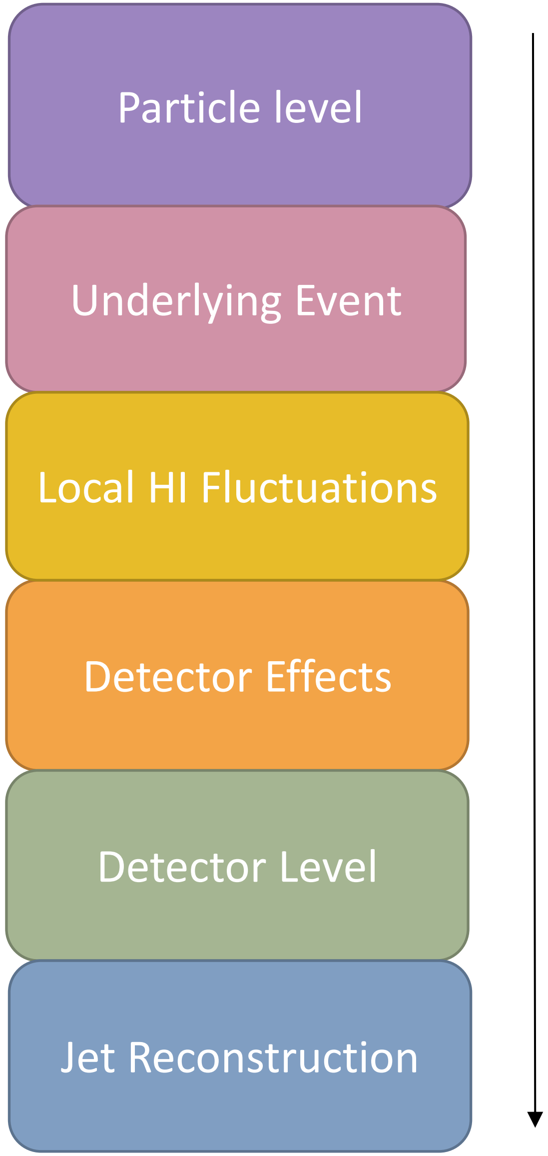
Jet Corrections

- Numerous sources of background and distortion:
    a) Jet reconstruction
    b) Underlying event
    c) Local fluctuations in the HI bkgd. (Au+Au)
    d) Detector effects

- Similar measurement of semi-inclusive hadron-jet correlations by STAR utilizes these correction schemes:
    a) Mixed event: correct background on statistical basis (Au+Au only)…
    - Underlying event

    b) Regularized unfolding: correct for fluctuations in bkgd. and bin migration…
    - Detector effects
    - Local fluctuations in HI bkgd.

    » STAR; PRC 96, 024905 (2017)



Detector Effects

- **Unfolding:** detector effects, pileup, etc. encoded in a Response Matrix R_{ij} i.e.

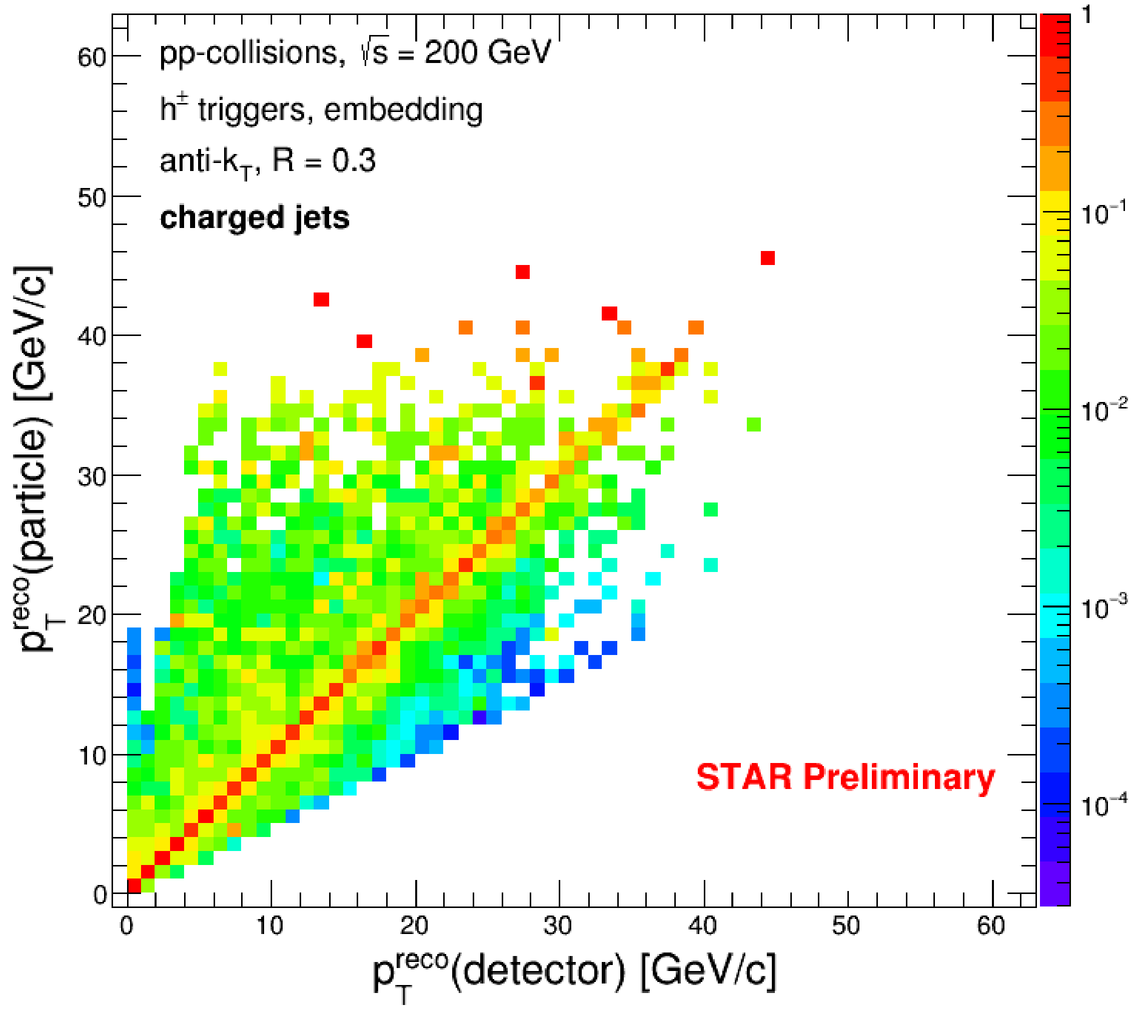
$$M_j = R_{ij} T_i$$

  - » True spectrum can be obtained from measured spectrum via unfolding:

$$R_{ij}^{-1} M_j = T_i$$

    - – Unfolding **approximates** R_{ij}^{-1}
    - – And mitigates influence of fluctuations

- Response matrix obtained via embedding procedure:
  1) Dijet (2-to-2 scattering) events are simulated using PYTHIA6 (Perugia 0)
  2) Dijet events are passed through Geant simulation of STAR
  3) Simulated detector response is mixed in with real zero-bias pp-data
  - » Matching **particle jets** to **detector jets** gives response matrix



Summary and Outlook

- Jets opposite neutral triggers may provide a powerful probe of in-medium energy loss
  - Comparison of jets opposite γ^{dir} to those opposite energetic π^0 may shed light on path-length and color factor dependence
- **Gamma-Hadron Measurement:** **No** difference in suppression observed **within kinematic range** between charged hadrons opposite γ^{dir} to those opposite energetic π^0
  - Now investigating with more precise techniques
  - i.e. full jet reconstruction
- Gamma-Jet Analysis in p+p and Au+Au is well underway!

Thank You!

Backup

Analysis Details

- **Data used:**
  - » Run 9, 200 GeV pp-collisions
  - » L2-Gamma Stream
  - » 42,508 triggered events
    - – 18,426 π^0-triggers
    - – 24,082 γ^{rich}-triggers
  - » π^0 and γ^{rich} identified using Transverse Shower Profile (TSP) cuts

- **Trigger definition**:
  - » $E_T^{trg} \in (9{,}20)\ GeV$, $|\eta_{det}^{trg}| < 0.9$
  - » TSP cuts:
    - – $TSP < 0.08$ for π^0
    - – $TSP \in (0.2{,}0.6)$ for γ^{rich}
  - » Additional QA cuts:
    - – $\sum p^{match} < 3\ GeV/c$
    - – $e_\eta^{strip}, e_\varphi^{strip} \geq 0.5\ GeV$

- **Tower requirements**:
  - » $E_{raw}^{twr} > 0.2\ GeV$
  - » $E_{corr}^{twr} \in (0.2{,}20)\ GeV$
    - – 'corr' indicates 100% hadronic correction
  - » $|\eta_{det}^{trg}| < 0.9$

- **Track requirements**:
  - » $p_T^{trk} \in (0.2{,}20)\ GeV/c$
  - » $|\eta^{trk}| < 1$
  - » Additional QA cuts:
    - – $N_{fit} \geq 15$, $N_{fit}/N_{poss} \geq 0.52$
    - – $dca < 1$ cm (global)

- **Jet details**:
  - » Clustered with FastJet 3.0.6
  - » Anti-k_T algorithm
  - » $R = 0.3$ (and more)
  - » $|\eta^{jet}| < 1 - R$
  - » $p_T^{jet} \in (0.2, 30)\ GeV/c$
  - » $A^{jet} > 0.2$ (for $R = 0.3$)
  - » Recoil jets is any jet with $|\Delta\varphi^{jet} - \pi| < \pi/4$

Data Analyzed

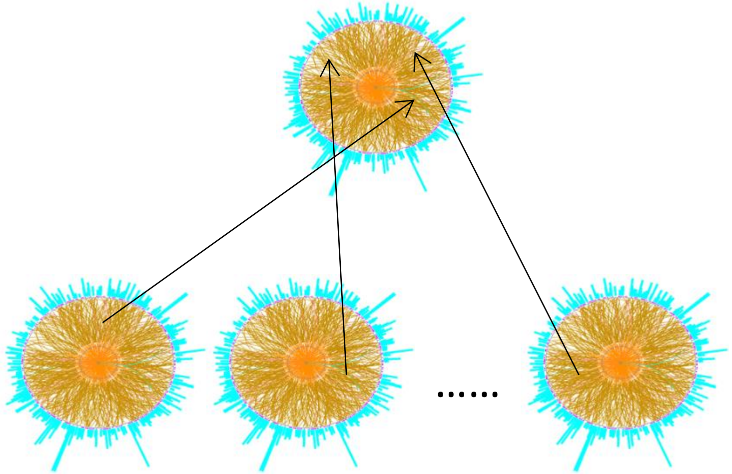
- **pp-data:**
  - Recorded in 2009 (**Run 9**)
  - $\sqrt{s} = 200$ GeV

- **AuAu-data:**
  - Recorded in 2014 (**Run 14**)
  - $\sqrt{s_{NN}} = 200$ GeV

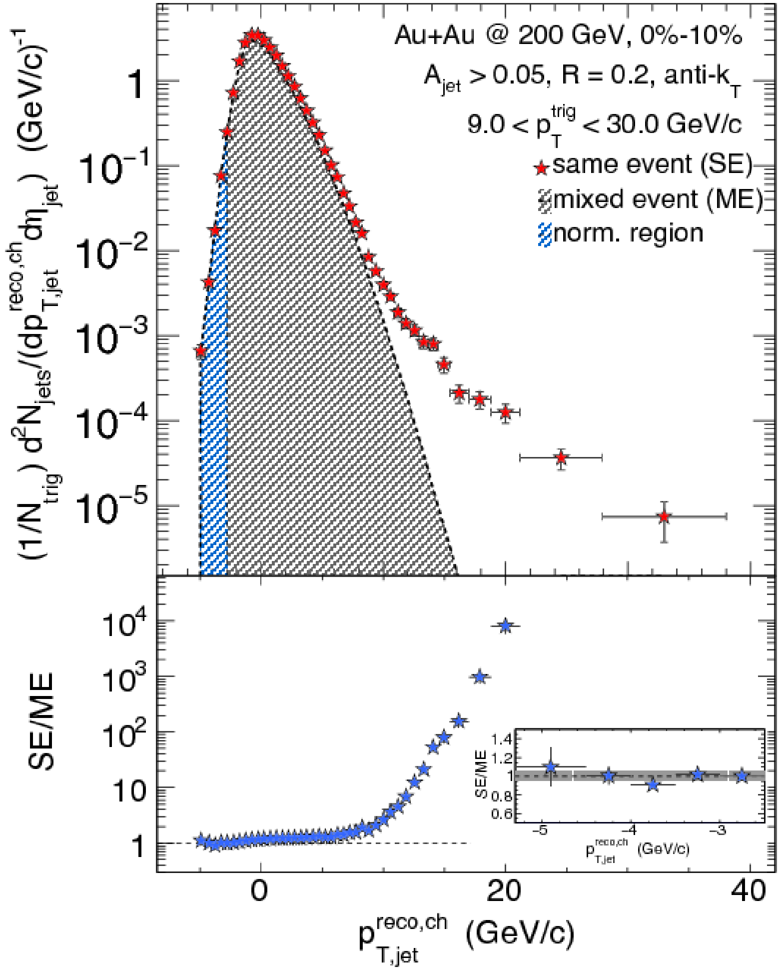
- **Embedding Sample**
  - Used to assess efficiencies, etc.
  - Simulated pp-collisions embedded into 2009 zero-bias pp-data (**Run 9**), $\sqrt{s} = 200$ GeV

Underlying Event

- **Mixed Event:**
  - » Create pseudo-event from randomly selected tracks
    - – Randomly select 1 track per real event
    - – Add it to the Mixed Event
    - – Use only events with same centrality, evt. plane, vtx. z-position
  - » Very good description of combinatorial background (in AuAu)



Au+Au charged hadron-triggered jet spectrum compared to mixed-event spectrum



STAR; PRC 96, 024905 (2017)

- **Off-axis cone:** one possible alternative to Mixed Events in pp…
  - » Select jets falling in these regions:

$$\Delta\varphi^{jet} \in (\pi/4\,,\pi/2)$$
$$\Delta\varphi^{jet} \in (3\pi/2\,,7\pi/4)$$

  - » Possible way to extract large-angle correlations in AuAu…
    - – By comparison to Mixed Events

- Off-axis yield normalized to:

$$\frac{\left\langle N_{OA}^{jet}\right\rangle - \left\langle N_{RE}^{jet}\right\rangle}{\left\langle N_{OA}^{jet}\right\rangle}$$

  - » N_{OA}^{jet} is the no. of jets in off-axis region
  - » N_{RE}^{jet} is the no. of recoil jets in acceptance