ATLAS jet quenching plan, needs & other issues

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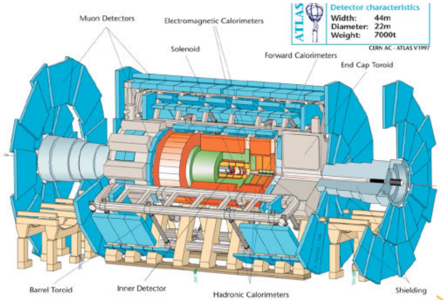
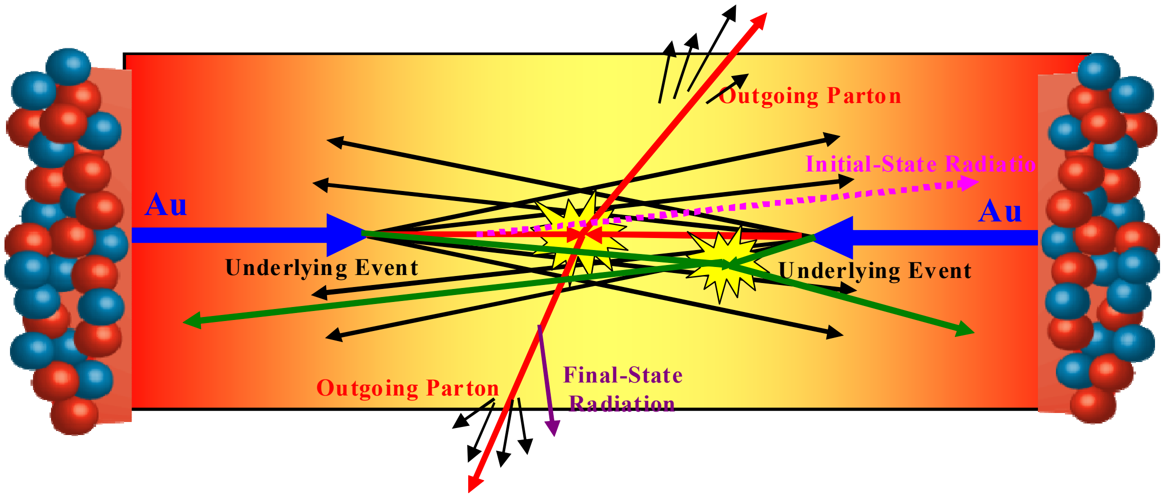
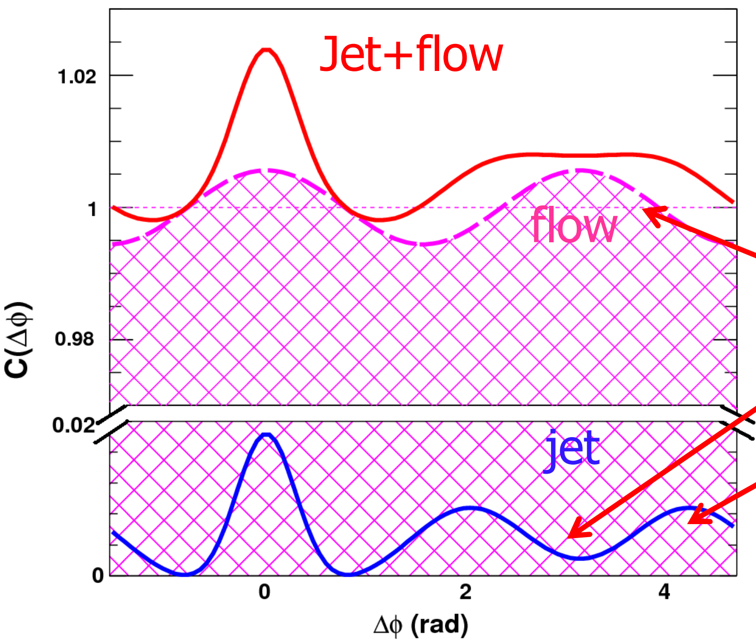
- Current issues with pQCD models
- What ATLAS can do to help the situation
- Issues with $R_{AA} = \dfrac{\text{Yield}_{AA}}{\langle N_{binary}\rangle \text{Yield}_{pp}}$



Interaction Between Jet and the Medium





Modified jet + flowing medium

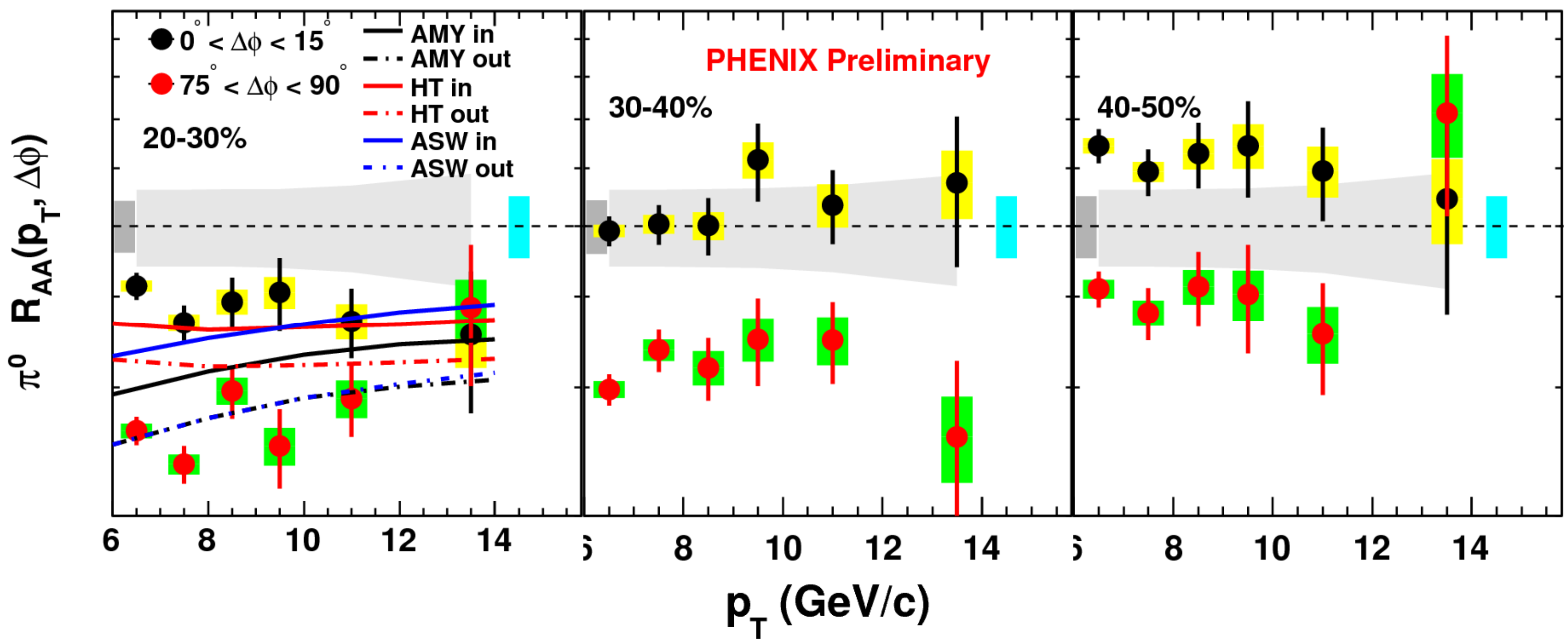
- Three inseparable aspects:
  - Jet quenching
  - medium response
  - Medium collectivity

pQCD relies on separation of scales

Status of Jet Tomography

- Our understand of the energy loss not complete
  - Current pQCD models describe centrality dependence of suppression but not the RP dependence. *S.Bass et.al arXiv:0808.0908*
  - Sensitivity to initial geometry and hydro-evolution.
  - Difference among the models→ x4 difference in qhat

R. Wei arXiv:0907.0024



Beyond pQCD Mechanism?

- Is pQCD treatment of eloss applicable for sQGP?

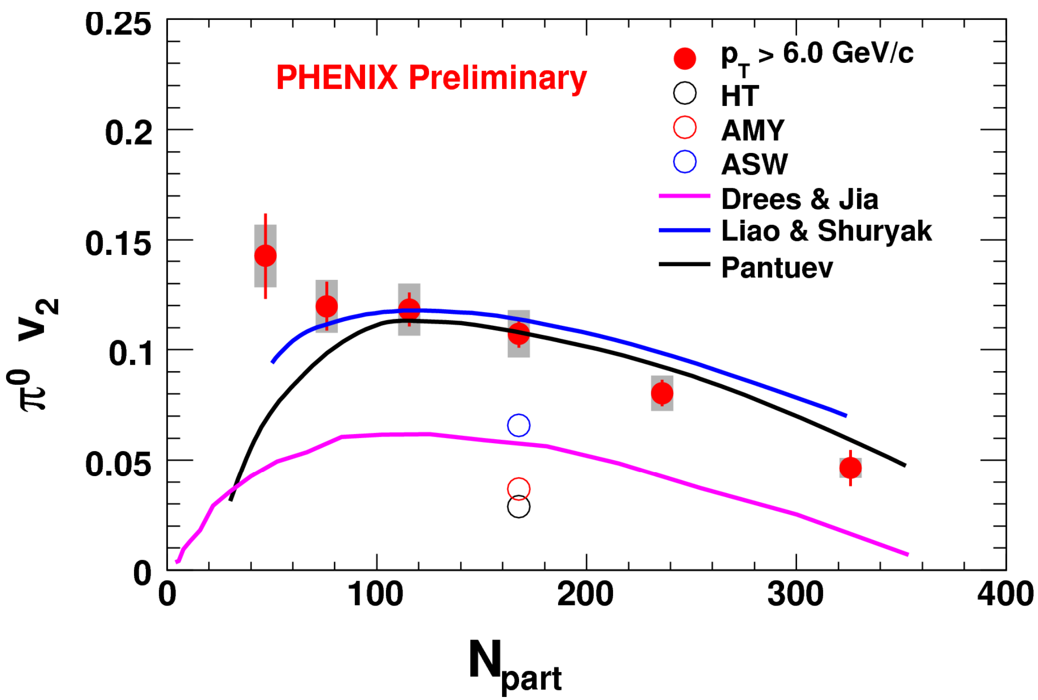
$$\hat{q} \propto \alpha_s N_c^2, \Delta E \propto L^2, \frac{dE}{dx} \propto \log E$$

- Non-perturbative approaches give very different density, path length dependence.

$$\hat{q} \propto \sqrt{\alpha_{SYM} N_c} \text{ (liu,urs 2007)}, \Delta E \propto L^3 \text{ (Gubsor 2008)}, \frac{dE}{dx} \propto E^2 \text{ (Khazeev 2008)}$$

Liao, Shuryak: energy loss is strongest around T_C.

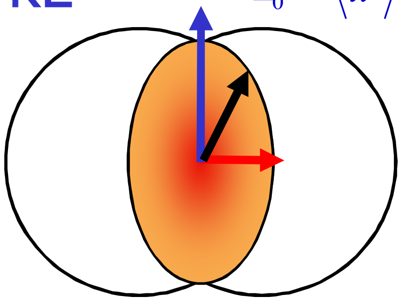
R. Wei arXiv:0907.0024



The Scaling Pattern of the RHIC Data

- In absorption picture: $R_{AA}=\exp(-kL)$, $\log R_{AA}=-kL$
  - 6 centrality and 6 angular bin

$$\frac{1}{L_0^2}=\frac{1}{\langle x^2\rangle}+\frac{1}{\langle y^2\rangle}$$



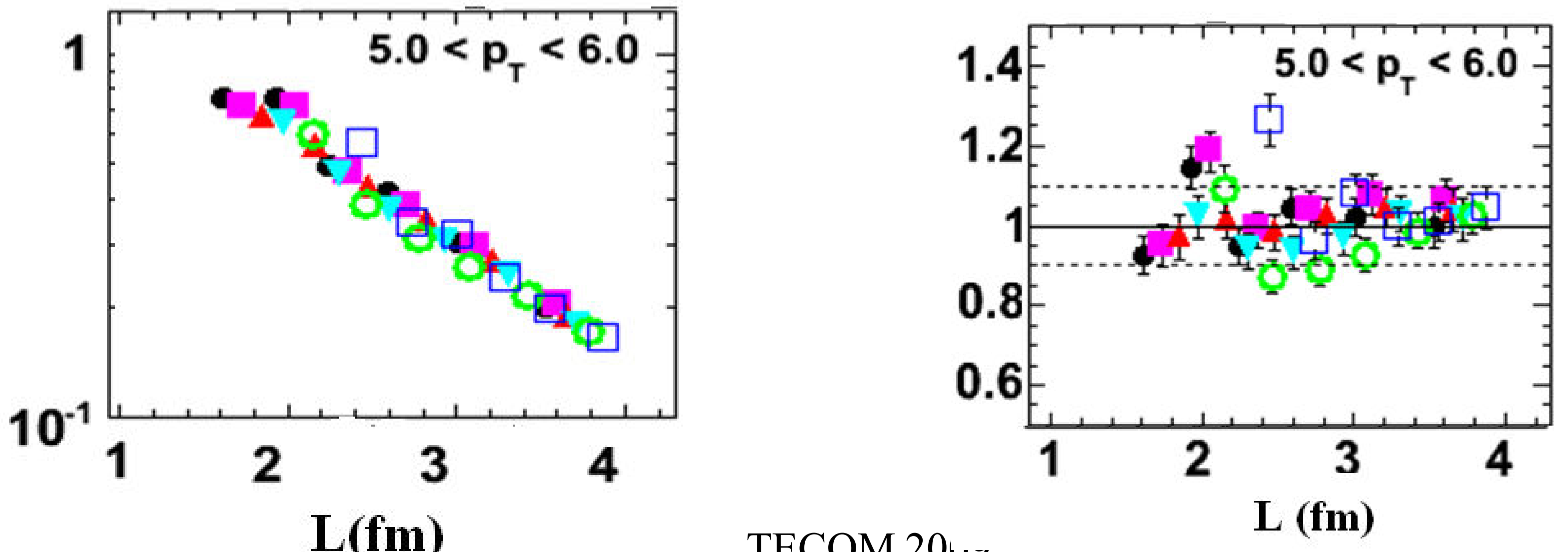
$$L_0^2=\langle x^2\rangle \qquad L_\varepsilon(\Delta\phi)=\frac{L_0\sqrt{1+\varepsilon}}{\sqrt{1+\varepsilon\cos 2\Delta\phi}}$$

0903.4886

- Very good scaling, but this L is different from the length implied by energy loss models

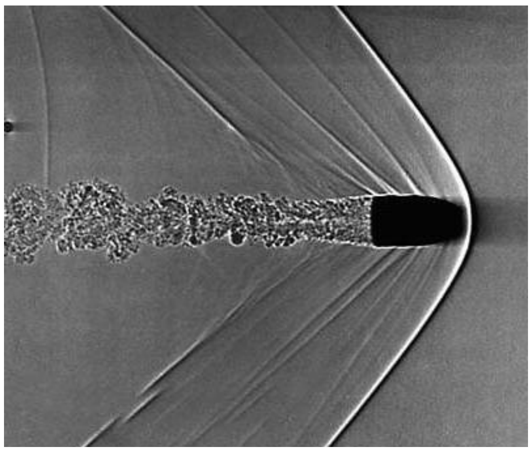
$$L=\int \rho_{bin}(\vec{r})\rho(\vec{r}+\vec{l})d\vec{r}d\vec{l}$$

R. Lacey et. al. 0907.0168, figure made by R. Wei

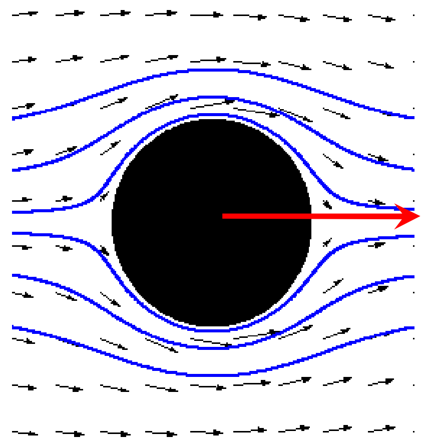


How to Study Jet-medium Interaction at LHC?

- Would like to use probes with different coupling (quarks, gluons, photons, Z, heavy quarks) to understand jet quenching, medium response, medium collectivity

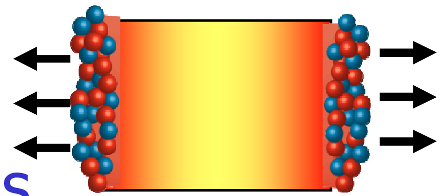


Supersonic: probe
Energy loss/medium response



Stationary: probe
Collective flow

ATLAS HI Physics Program Overview



- "Day-1" measurements to probe bulk properties
  - Multiplicity, anisotropy, spectra.

- Jet and photon measurement to probe the jet quenching & medium response.
  - Jet reco., jet multiplicity and shape, dijet, γ, γ-jet, μ-tagged jet.

- Upsilon and J/Ψ to probe Debye screening.

- Low x physics at forward η to probe the initial condition.
  - Jet, spectra, correlation at forward η

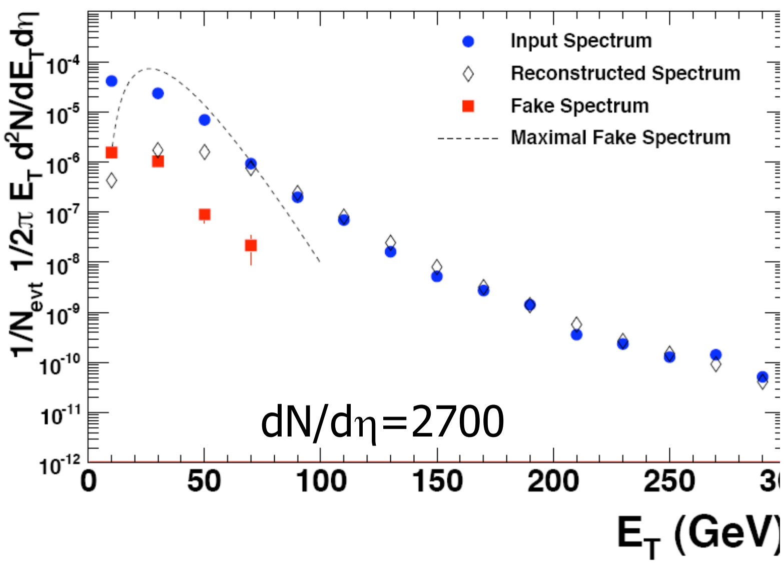
Strategy for Jet Tomography

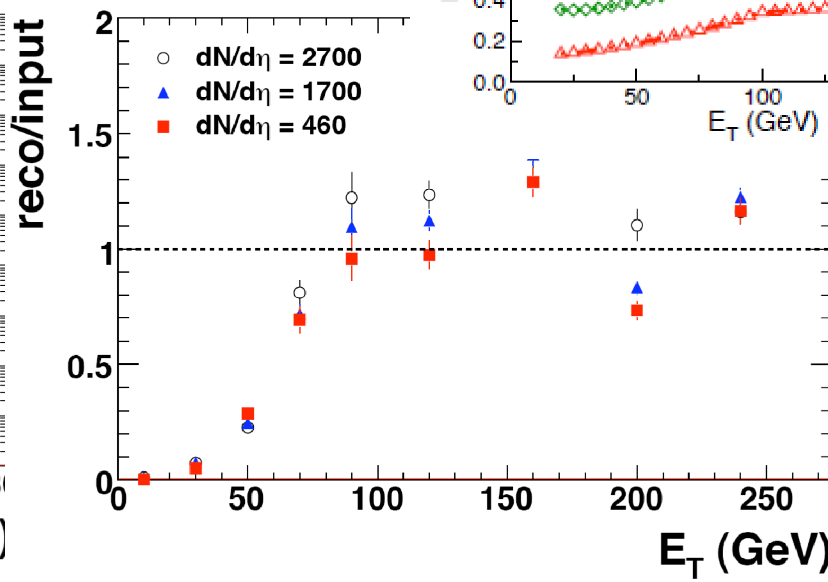
- Suppression and Anisotropy (R_{AA} and v2) for single particles
  - Charged hadrons, photons, heavy quarks
  - Heavy quark eloss puzzle? Surface bias? Anisotropy at high pT?

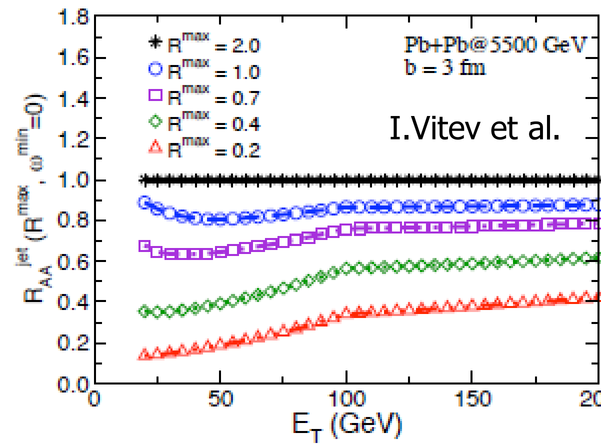
- Suppression, Shape modification and Anisotropy for jets
  - Single jets, di-jets, γ-jet, b-jet
- Jet reconstruction will be an iterative process.
  - Jet shape, jet multiplicity unknown: Likely different from p+p
  - Understand background subtraction: Should medium response be included in jet definition? How to separate it from jet shower?
  - Require comparison of different jet algorithms to reach sensible jet definition: R_{AA} will depends on the jet algorithm (cone size, etc)

Inclusive Jet Spectra

- Reconstruction is fully efficient above 100 GeV in most central Pb+Pb event
  - Expect $>10^6$ jets with 100 GeV in 0.5 nb^{-1} Pb+Pb events
  - Sensitive to >20% level suppression.

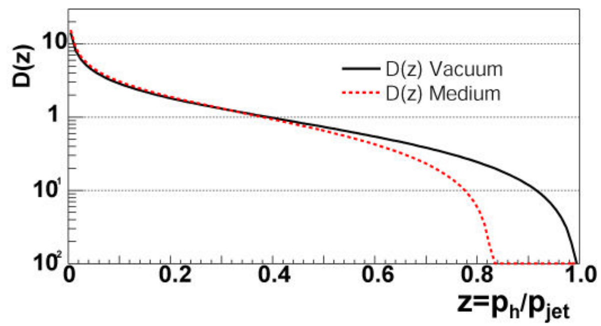


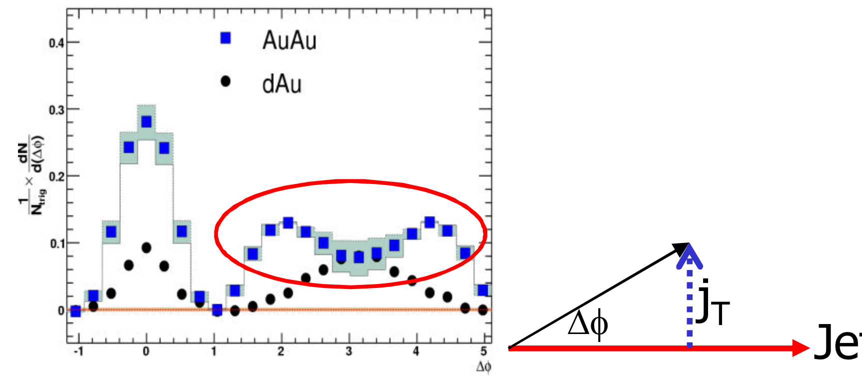


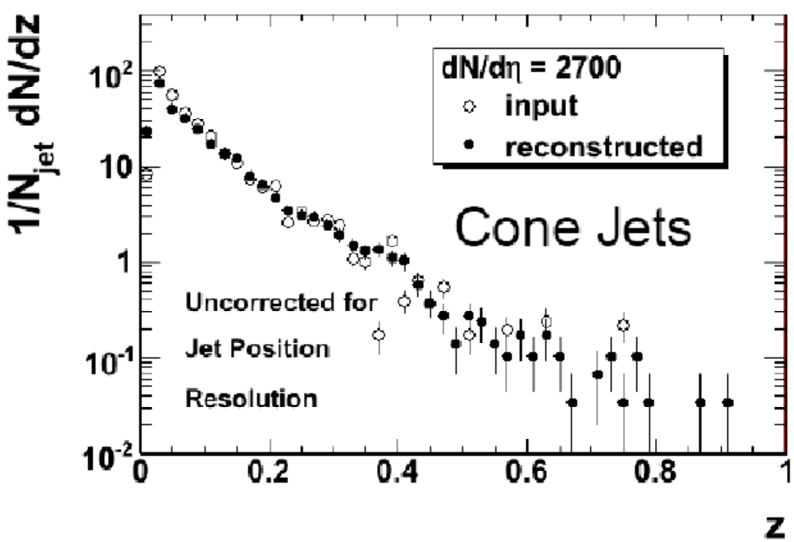


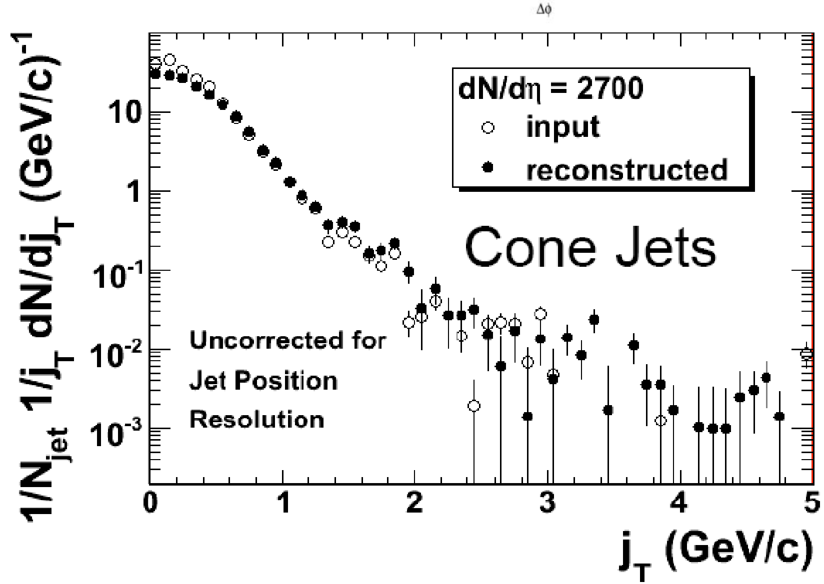
Study Jet Modification

- Jet multiplicity and Jet shape
  - Reflect energy loss and medium response (eg. the ridge)
  - Sensitive to 20% level modification.



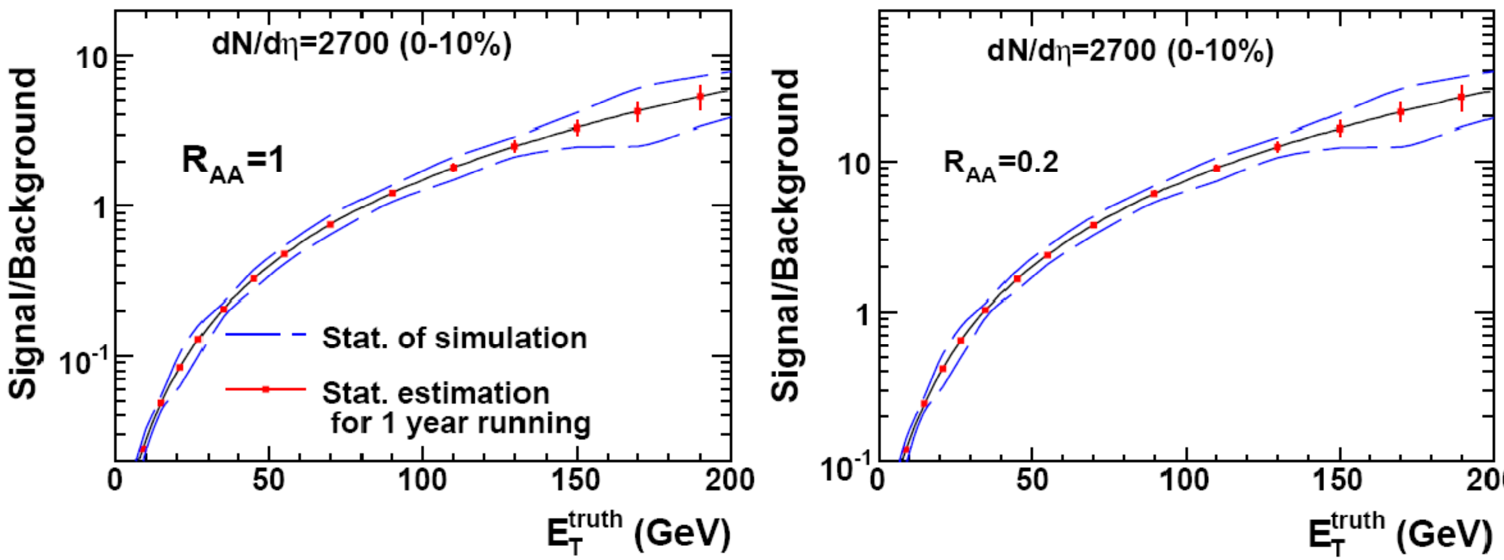




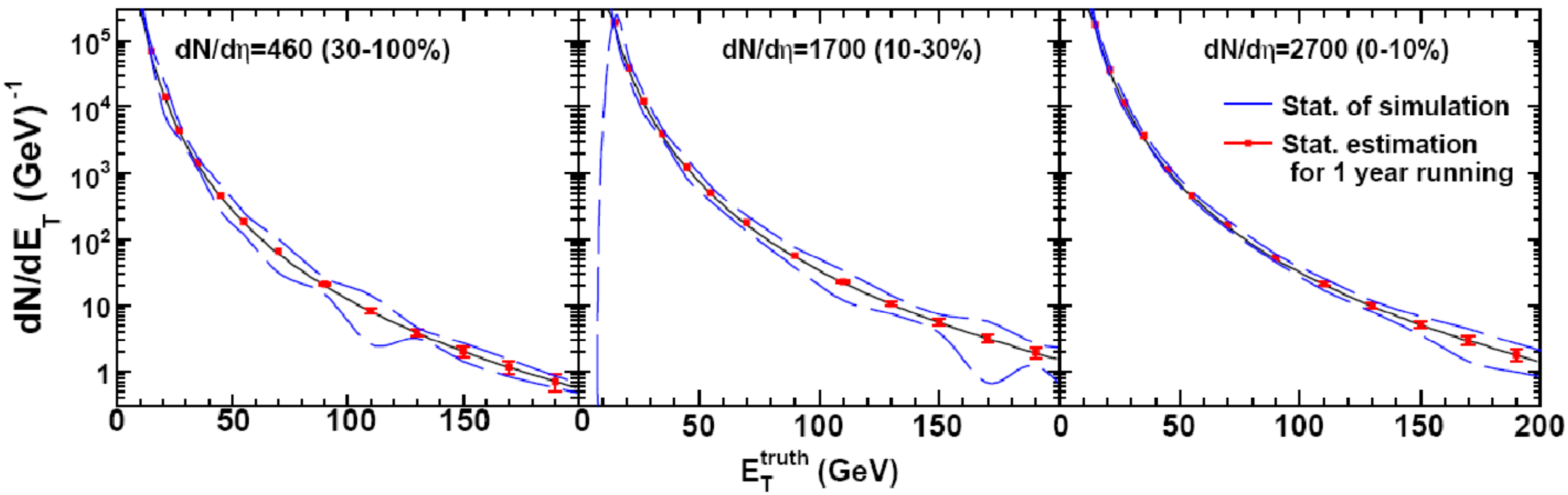


Identifying Direct γ

- Combine γ-ID and isolation cuts with relative rejection:20-50
  - S/N ~ 1 at 100 GeV assuming hadrons not suppressed
  - S/N ~ 1 at 30 GeV assuming factor of 5 suppression on hadrons.



Direct Photon Spectra

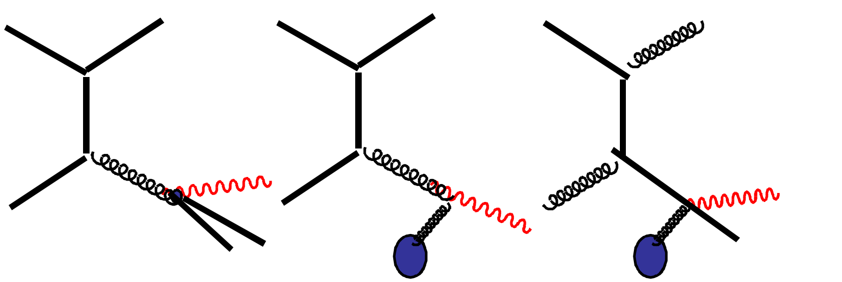


- Expected direct photon spectra for 0.5 nb^{-1} in $|\eta|<2.4$
  - Assuming neutral hadron $R_{AA}=1$ (worst case).
- γ rate for 1 year LHC run of 0.5 nb^{-1}.
  - 200k at E>30 GeV, 10 k at E>70 GeV
- Measurement γ-jet correlation and fragmentation function

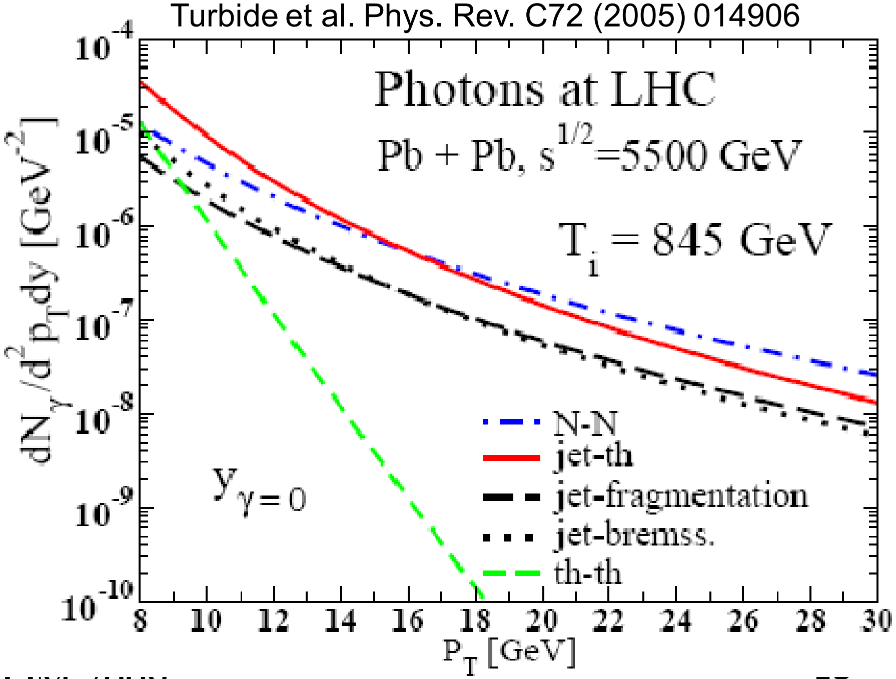
Final-State Direct γ

- Fragmentation, conversion, bremsstrahlung photons
  - Carry detailed information about the jet-medium interaction
  - Dominate/important at pT<30-50 GeV, not isolated.
  - Can be enriched via γ-ID cuts

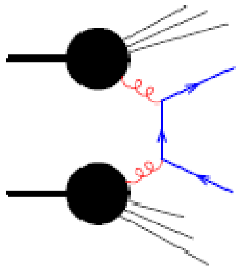
Strip layer provide unbiased/centrality-independent factor of 3-6 background rejection



Turbide et al. Phys. Rev. C72 (2005) 014906

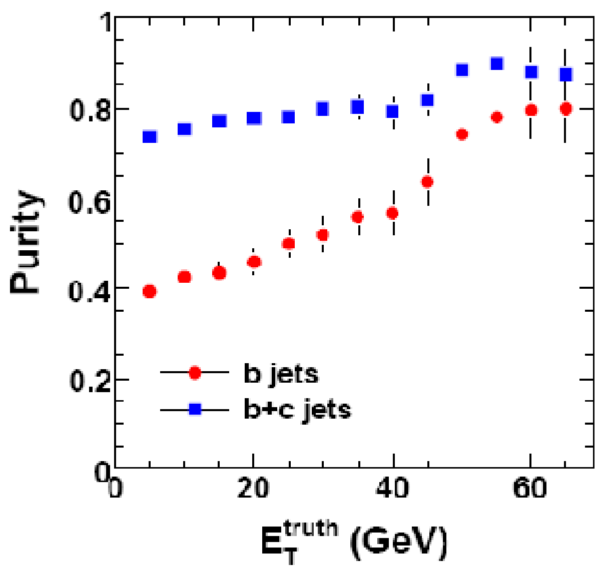


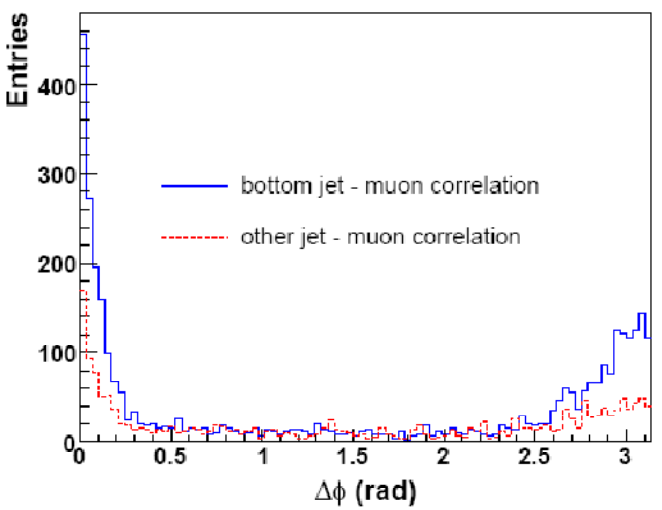
Heavy Quark-jet Correlation



- Tag heavy quark jet (c,b) by high p_T muons
  - Require muon p_T>5 GeV and jet E_T>35 GeV
- Low p_T: 1/3 of away-side jet each from b,c, light quarks+gluons.
- High p_T: dominated by bottom quark.

Heavy quark energy loss





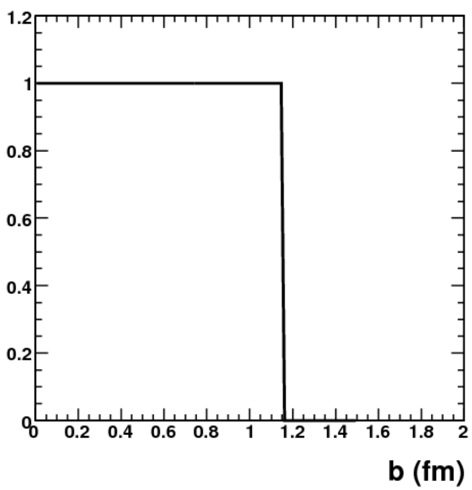
Different Collision Geometry: pp(in Au+Au) ≠ pp

- NN collision geometry not the same in A+A/p+A/p+p collisions
- Minimum bias condition: a p+p collision happens when the distance is less than

$$R_{AA} = \frac{\mathrm{Yield}_{AA}}{\langle N_{binary} \rangle \mathrm{Yield}_{pp}}$$

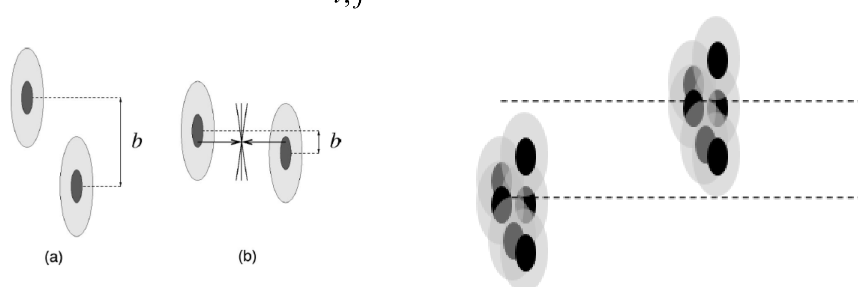
$$d_{\max} = \sqrt{\sigma_{pp}^{inel} / \pi} = 1.1562\, fm,$$

$$\sigma_{pp}^{inel} = 42mb = 4.2\, fm^2$$



- Condition used to evaluate the Npart and Ncoll in Au+Au collisions via Glauber framework

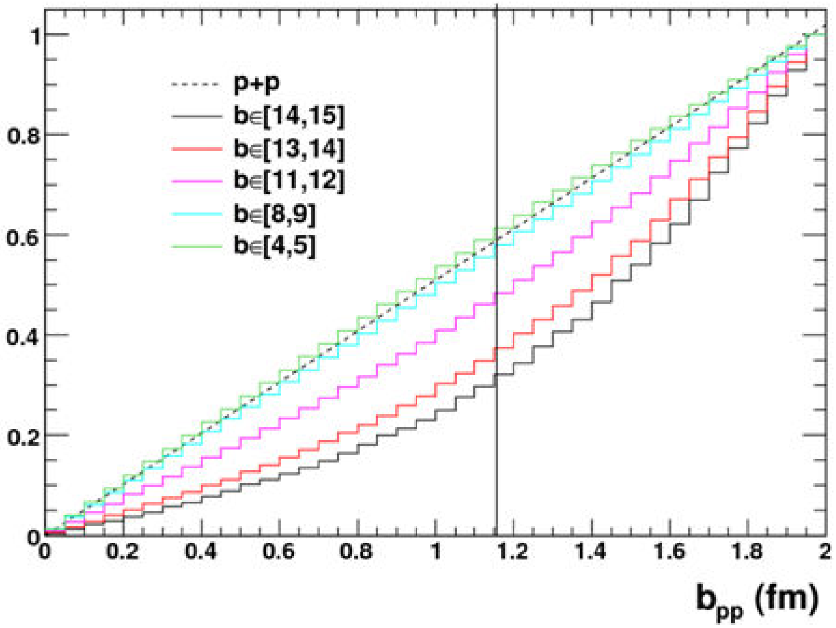
$$N_{coll} = \sum_{i,j} \left(\left| \vec{r}_i - \vec{r}_j \right|_{xy} < d_{\max} \right)$$

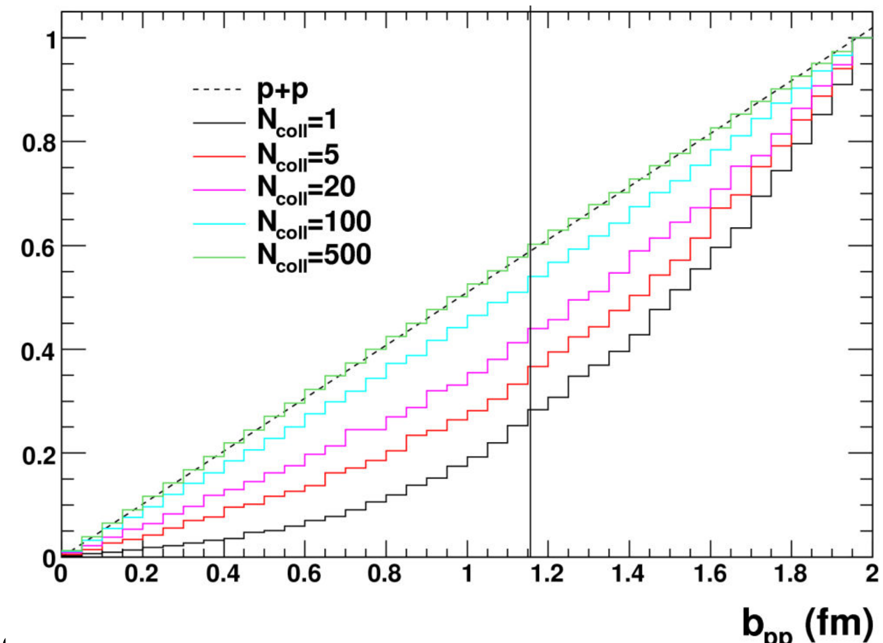


Distinguish between two impact parameters: b_{AuAu} and b_{pp}

p+p Impact Parameter Distribution

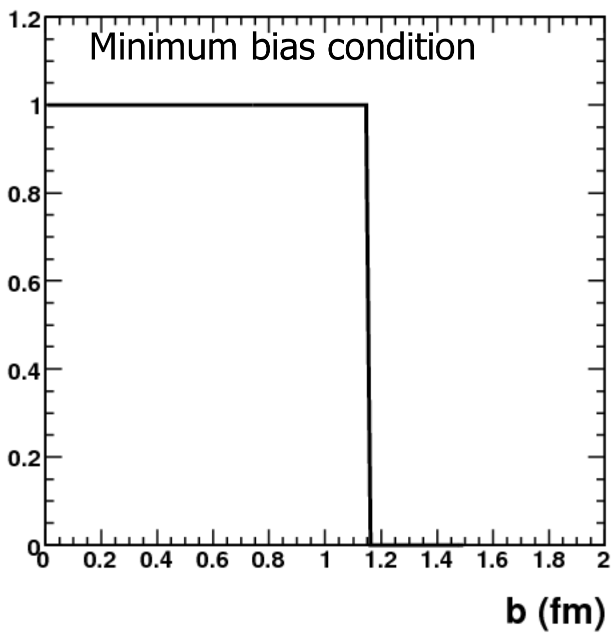
- The impact parameter distribution for p+p $\rho \propto 2\pi b$
- Non-linear dependence is seen for very peripheral collisions with small b or small ncoll. $N_{coll} \neq T_{AB}\sigma_{pp}^{inel}$!!
  - Peripheral Au+Au events are bias to peripheral p+p collisions
    - Not a problem with minimum bias A+A collision.
  - Bias increases with p+p cross section (such as LHC)

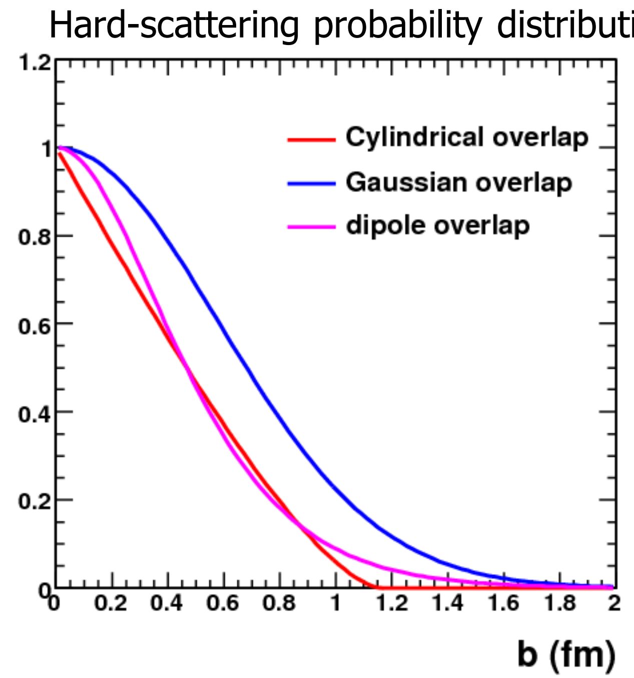




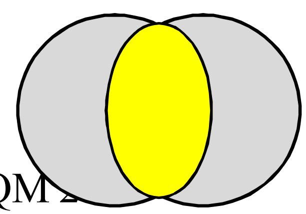
Hard-scattering Transverse Distribution

- Hard-scattering probability depends on the impact parameter
  - Distribution different from minimum bias condition
  - Impact parameter bias leads to less hard scattering cross section.





$$d\sigma_{hs} \propto \text{ over lap}$$



Calculating Ncoll

$$N_{coll}^{w} = \frac{\sum_{i^{th}\text{ pair in event}} f_{mb}(b_i)\frac{d\sigma_{hs}}{db}(b_i)}{\dfrac{\int db2\pi b\, f_{mb}(b)\frac{d\sigma_{hs}}{db}(b_i)}{\int db2\pi b\, f_{mb}(b)}} = \frac{\sum_{i^{th}\text{ pair in event}} f_{mb}(b_i)\frac{d\sigma_{hs}}{db}(b_i)}{\int db2\pi b\, f_{mb}(b)\frac{d\sigma_{hs}}{db}(b_i)}\sigma_{pp}^{inel}$$

$\propto\sigma_{hs}$

T_{AB}

- However, MC glauber calculate Ncoll by setting dσ/db=const (i.e the hard-scattering has same profile as mb)

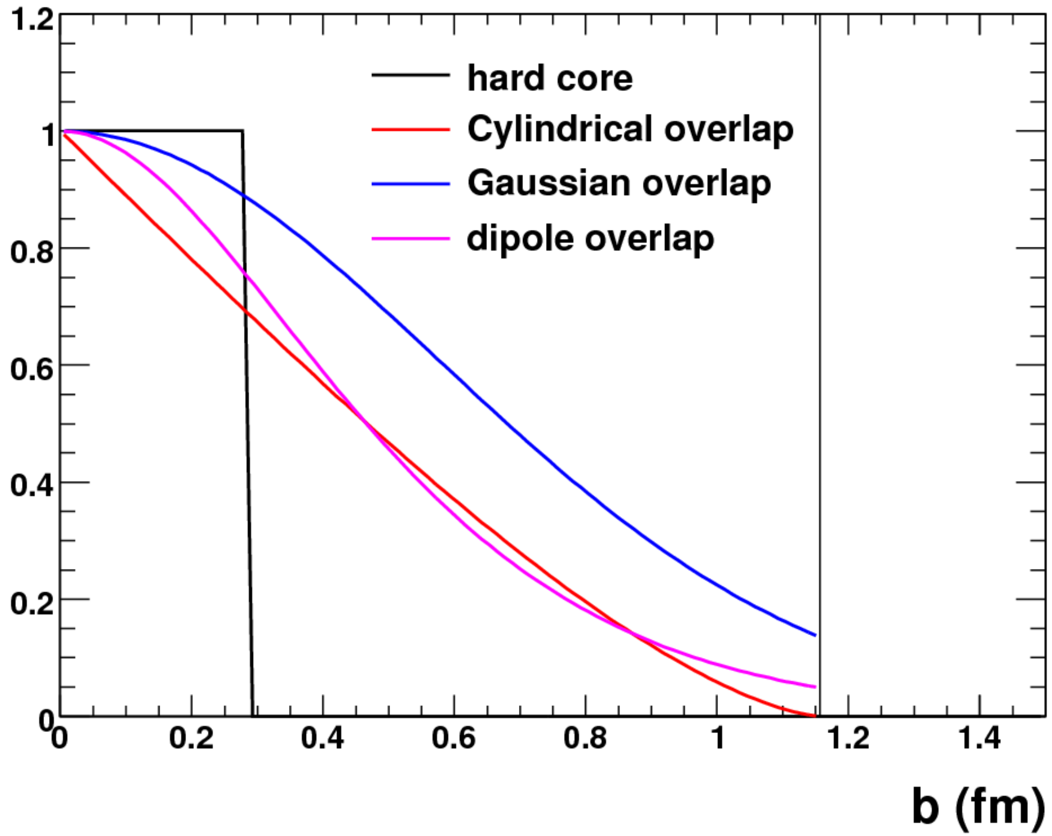
$$\frac{\int db2\pi b\, f_{mb}(b)\frac{d\sigma_{hs}}{db}(b_i)}{\int db2\pi b\, f_{mb}(b)} = 1 \quad \text{i.e. } N_{coll} \text{ for pp equal 1.}$$

$$N_{coll} = \sum_{i^{th}\text{ pair in event}} f_{mb}(b_i) = \sum_{i,j\text{ in event}} \left(\left|\vec{r}_i - \vec{r}_j\right|_{xy} < d_{\max}\right)$$

- In general for centrality selected bins $N_{coll}^{w} \neq N_{coll}$
- But one can show that for minimum bias $N_{coll}^{w} \equiv N_{coll}$

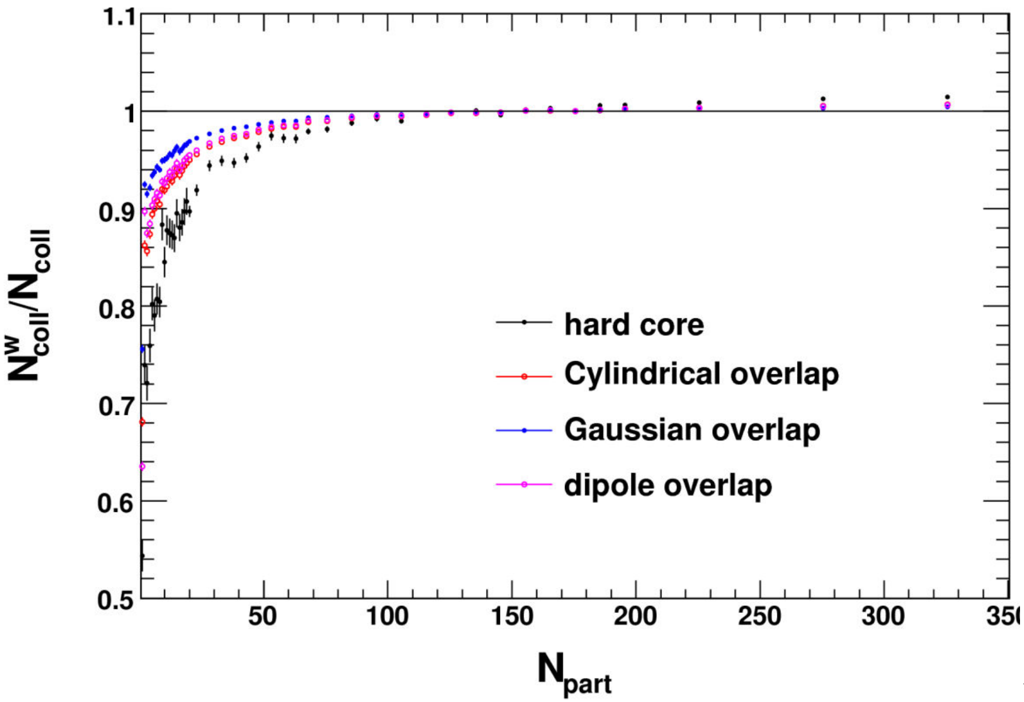
Checking the Size of the Effect

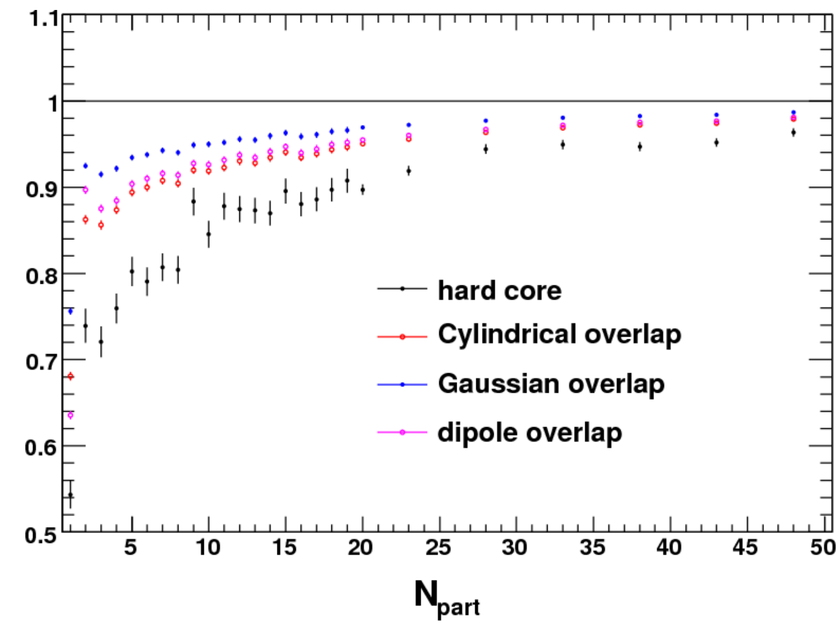
- We check the following four different hard-scattering profile.



Checking the Size of the Effect : AuAu

- The effects are significant in peripheral collisions.
  - hard-core: >20% correction for Ncoll <5, 15% for Ncoll upto 15.
  - Positive correction in central, but <2% for all cases.

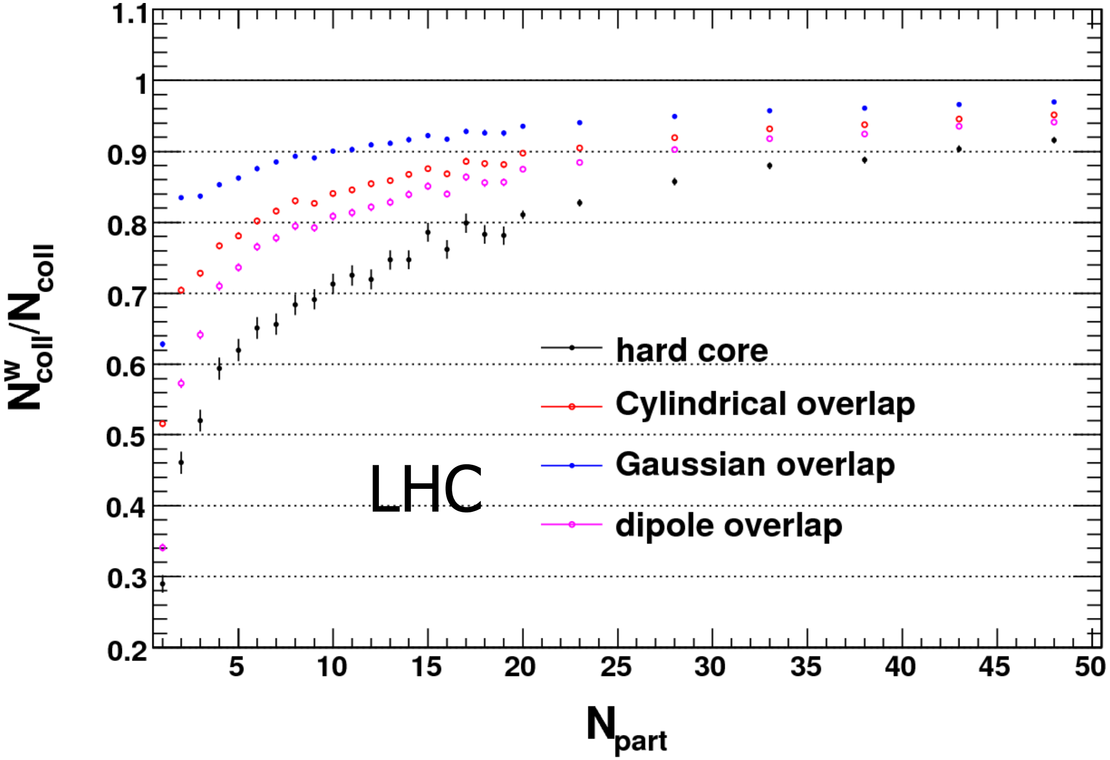


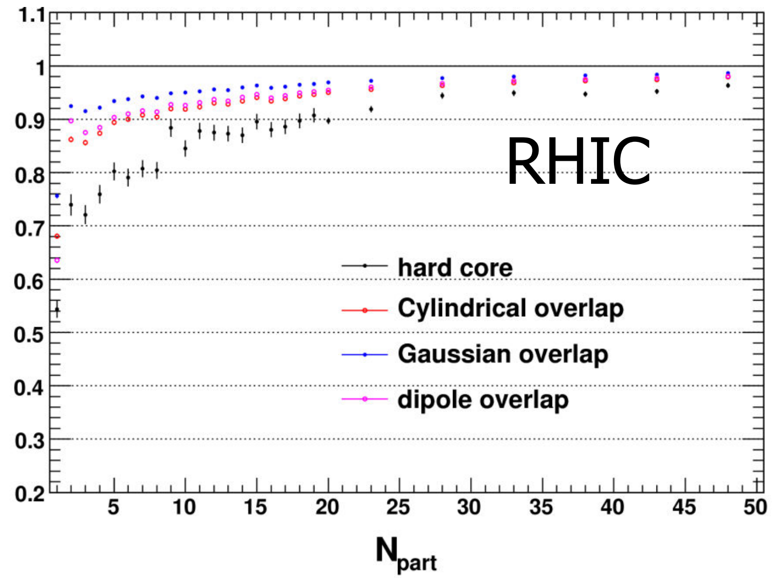


LHC Prediction

- pp cross section is bigger, bias is bigger.

$$\sigma_{pp}^{inel} = 7.2\,fm^2 \text{ at } \sqrt{s}=5.5 \text{ TeV}$$





Summary

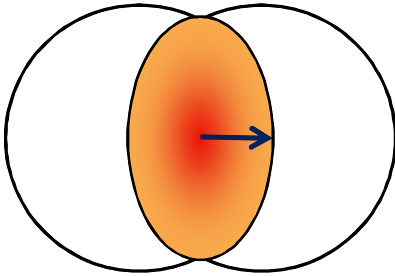
- Uncertainties of pQCD models need to be quantified.
  - Powerful constraints can be provided by ATLAS@LHC.
    - Single particle, correlation and jet observables

- ATLAS Heavy-ion program plan to probe the QCD matter via jets, photons, and heavy quark.
  - Large rate, large acceptance and triggering capability.
  - Jet tomography with reduced bias.

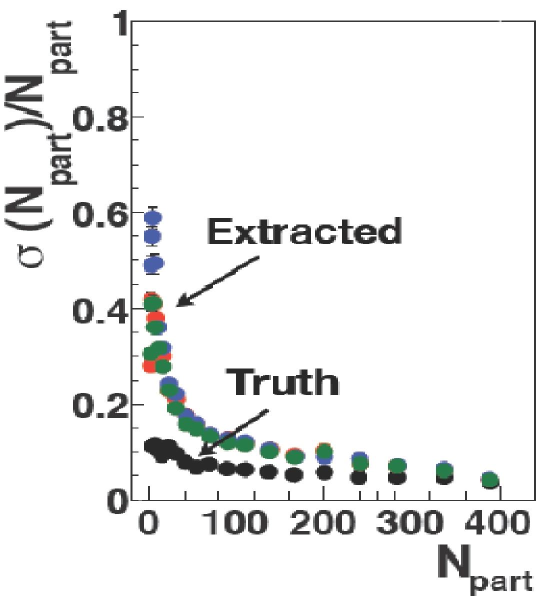
- Understanding the collision geometry is crucial for R_{AA}.
  - For both p+Pb and Pb+Pb

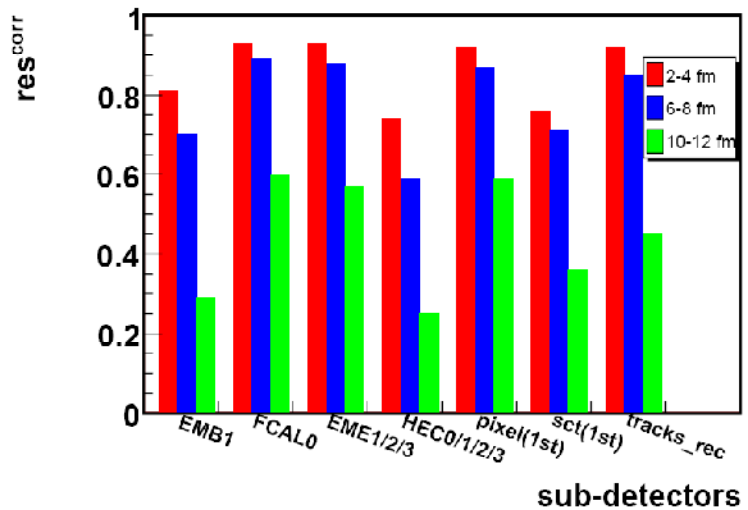
Detailed Control on Collision Geometry

- High precision measurement on event centrality.
  - High multiplicity give resolution better than 10% in most bins.
  - Redundant measurement in many detectors.
- Excellent reaction plane resolution
  - Redundancy help to suppress the non-flow effect

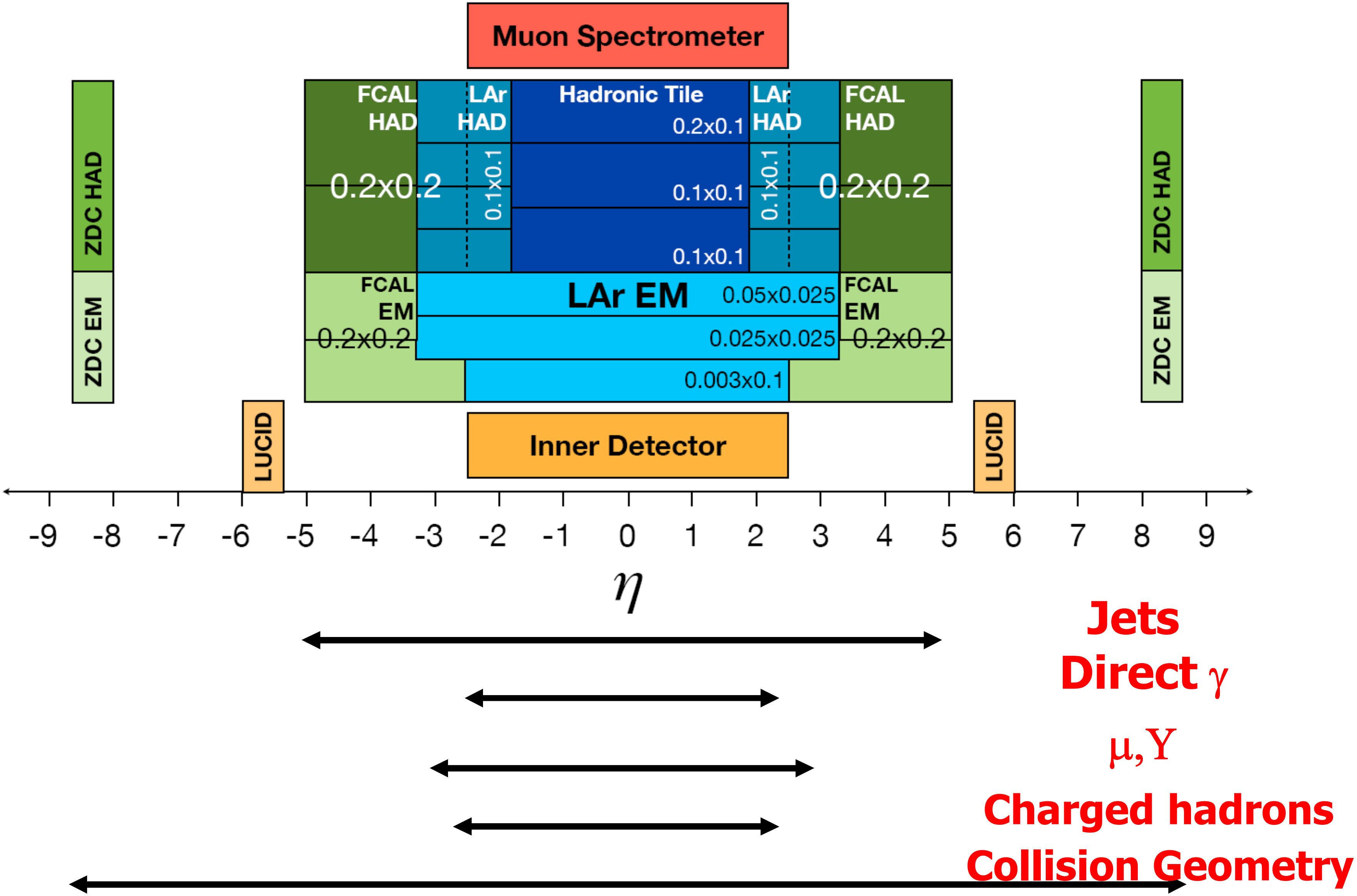


Detailed jet-tomography studies!

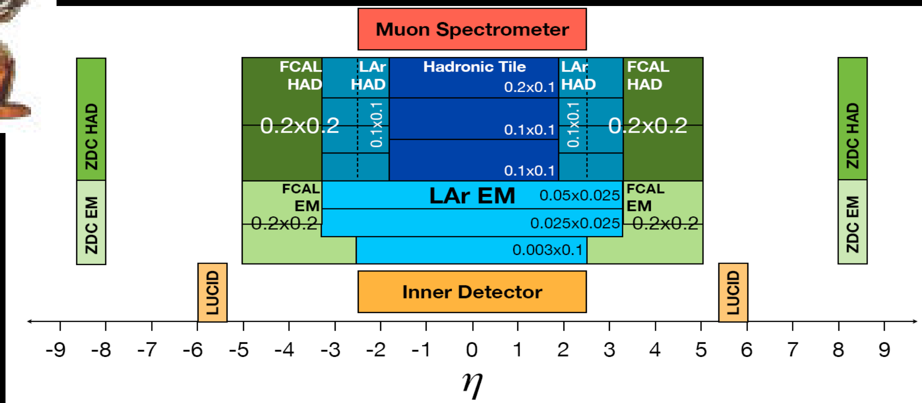




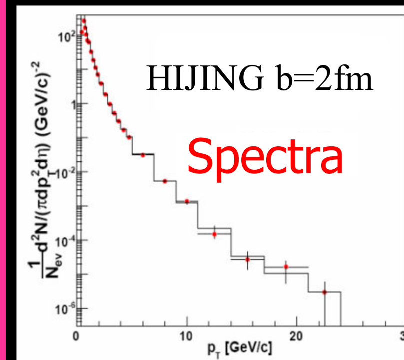
ATLAS HI Physics Potentials

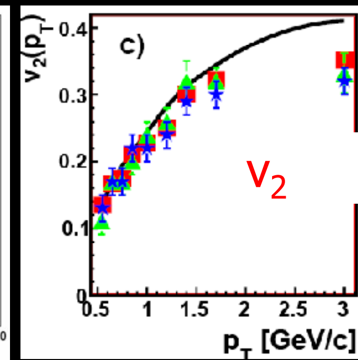


ATLAS Heavy Ion Physics Program

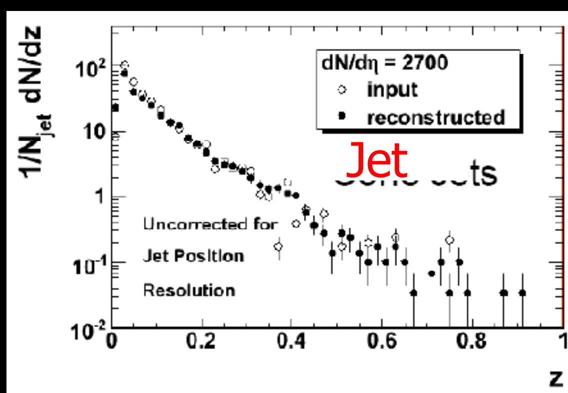


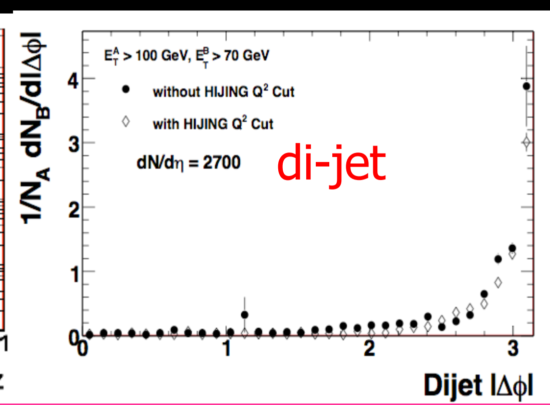
"Day-1" measurements: Bulk properties

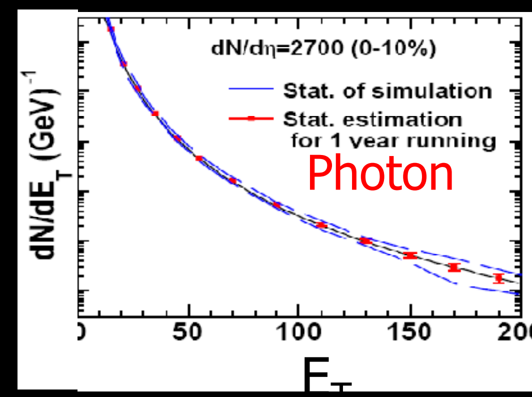




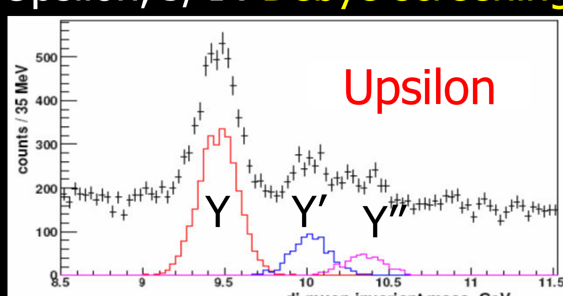
Jet and photon measurement: Jet quenching & medium response.





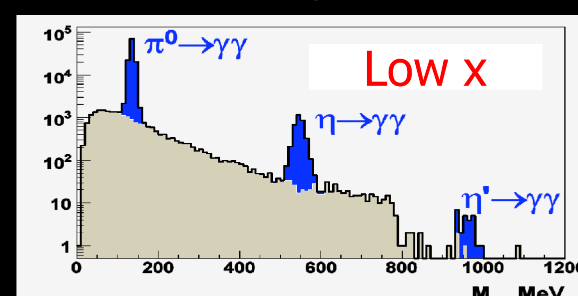


Upsilon, J/Ψ: Debye screening

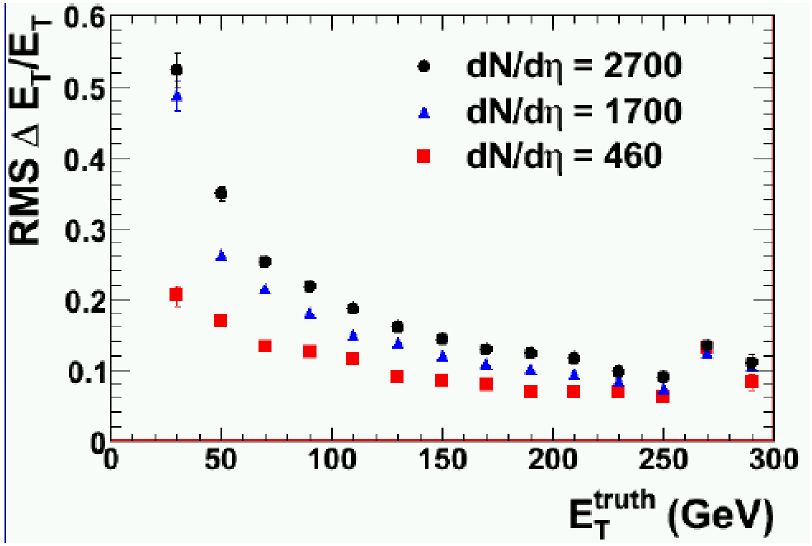


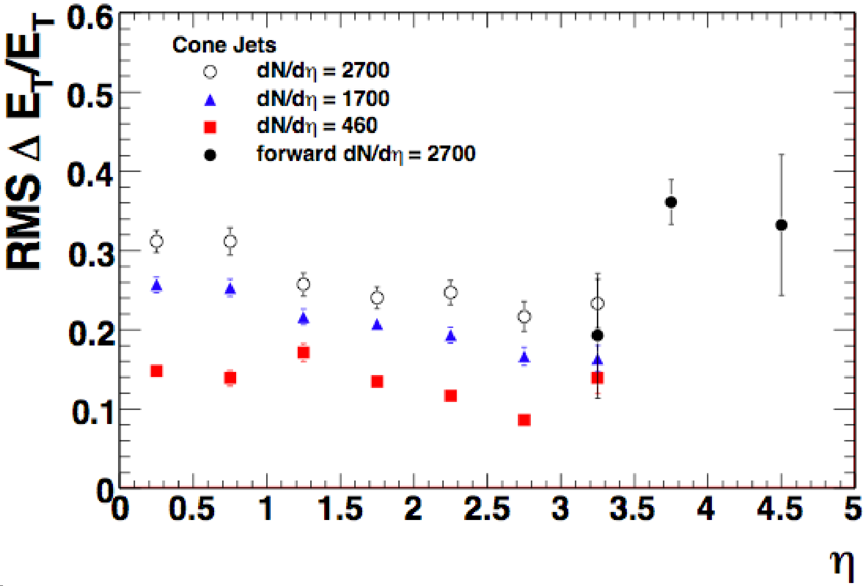
Low x physics at forward η: Initial condition

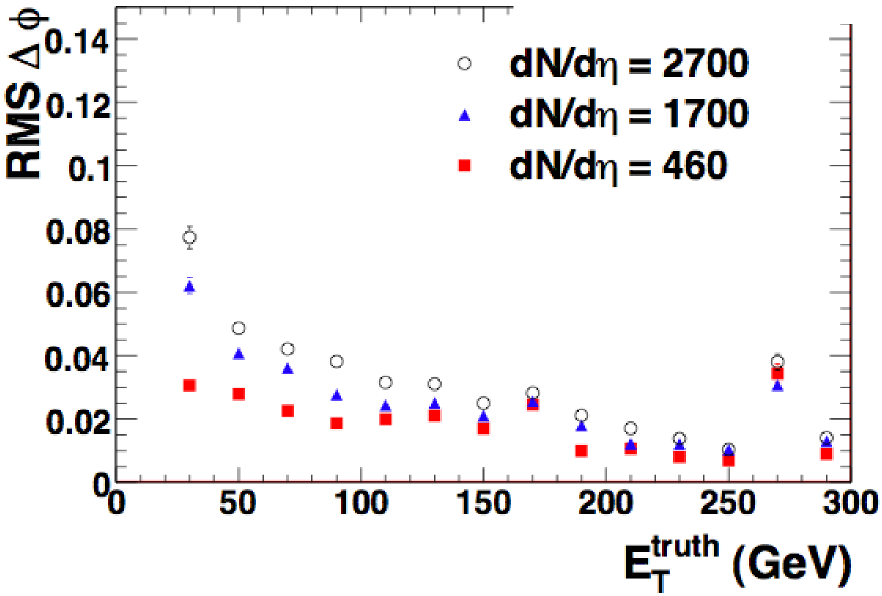
ZDC



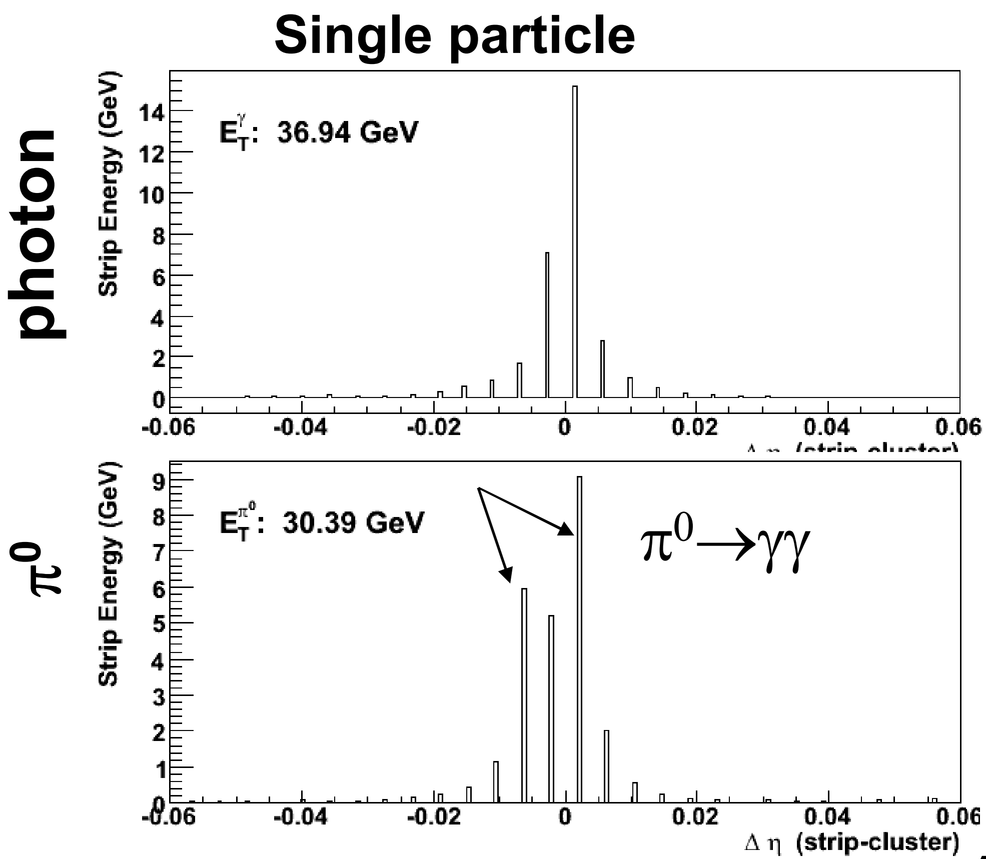
Energy and position resolution for Cone jet





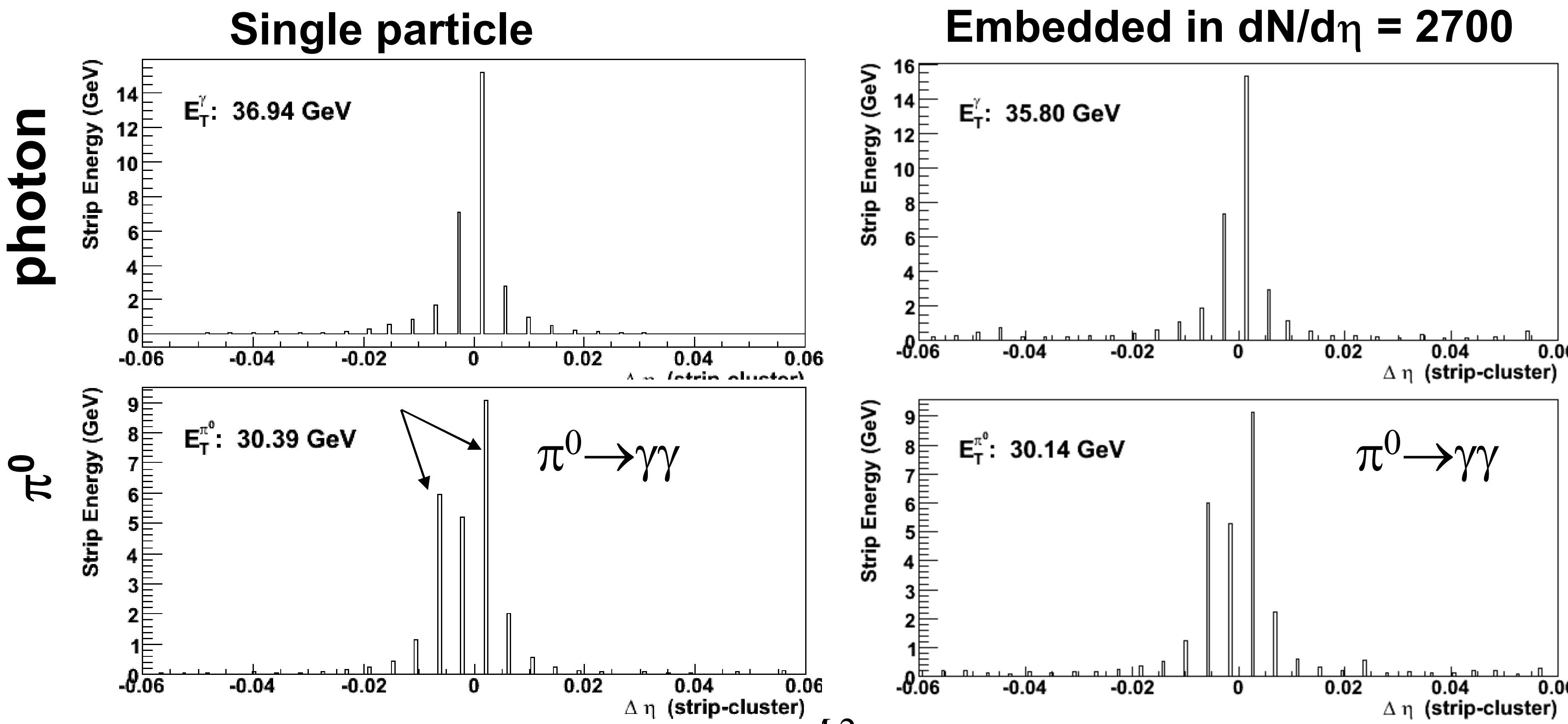


γ-ID in central Pb+Pb

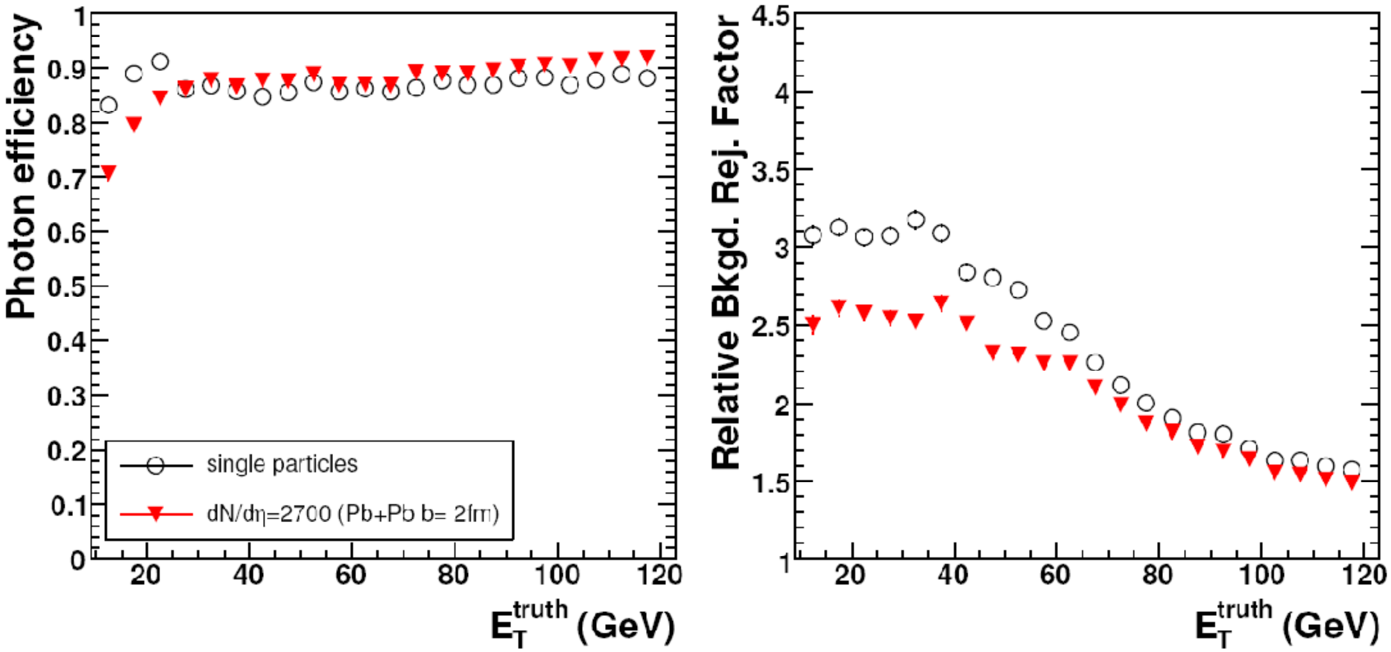


γ-ID in central Pb+Pb

- Very little background (<50MeV/strip in b=2fm Pb+Pb)
- Can separate single γ from π^0,η in central event
  - Photon identification without isolation in $|\eta|<2.4$



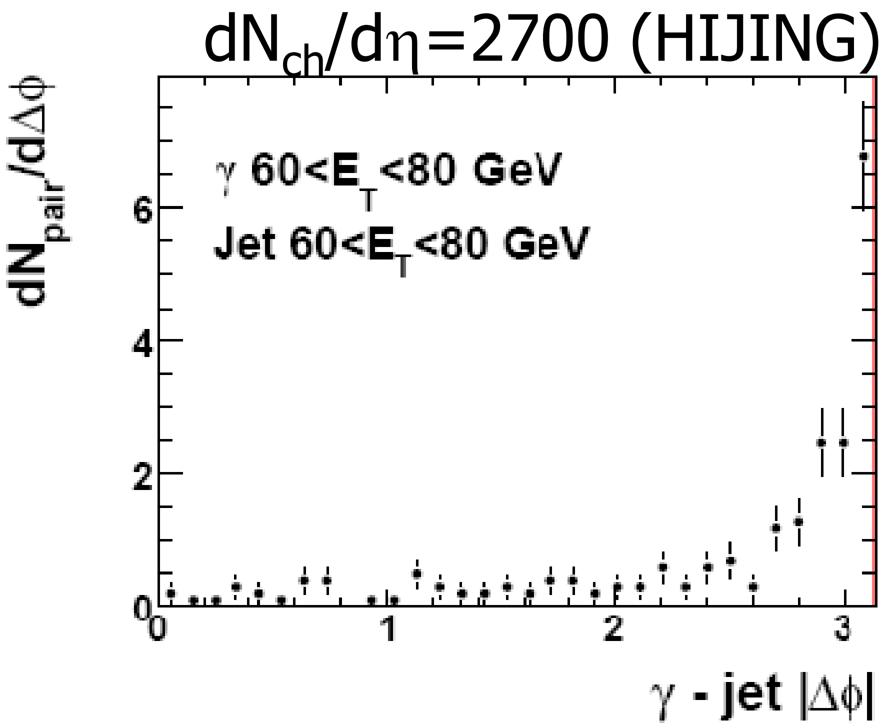
Performance of γ-ID Cuts



- Using the standard egamma variables, but selected for HI environment
- Rejection up to factor of 3 with efficiency of 90% (medium cut)
  - Rejection up to factor of 5-6 with efficiency of 50%
- Study final state γ: Fragmentation, conversion, bremsstrahlung
  - Carry detailed information about the jet-medium interaction
  - Dominate/important at p_T<30-50 GeV, not isolated

Turbide et al. Phys. Rev. C72 (2005) 014906

γ-jet Correlation



- Clean γ-jet $\Delta\phi$ distribution in central Pb+Pb
  - Tail comes from pQCD radiation
- Measure in-medium jet fragmentation function
- Can help jet analysis at low E_T.
  - Tune jet reco. algorithms.
  - Reject fake jets.

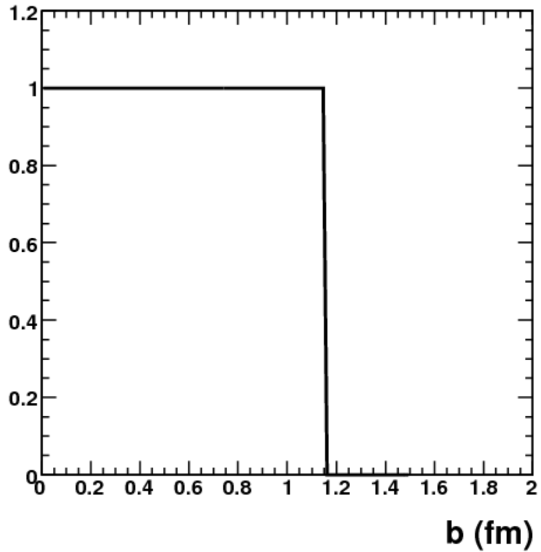
Glauber model

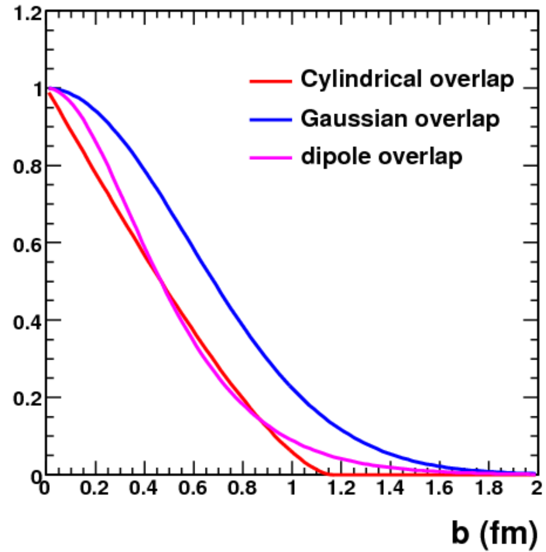
- The hard-scattering cross-section is the convolution of the minimum bias p+p cross section with the hard-scattering probability for each minimum bias collision.
  - In p+p collision the event distribution is flat in b.
  - In peripheral Au+Au collisions, the distribution biased towards larger b.

$$\sigma_{hs}^{pp} = \frac{\int db 2\pi b\ f_{mb}(b) \frac{d\sigma_{hs}}{db}}{\int db 2\pi b\ f_{mb}(b)}$$

$$f_{mb}(b) = \begin{cases} 1 & \text{in p+p} \\ \text{bias to large b} & \text{in Au+Au} \end{cases}$$

$$\int db 2\pi b\ f_{mb}(b) = \sigma_{pp}^{inel} = 4.2\, fm^2 \ \text{ in p+p}$$

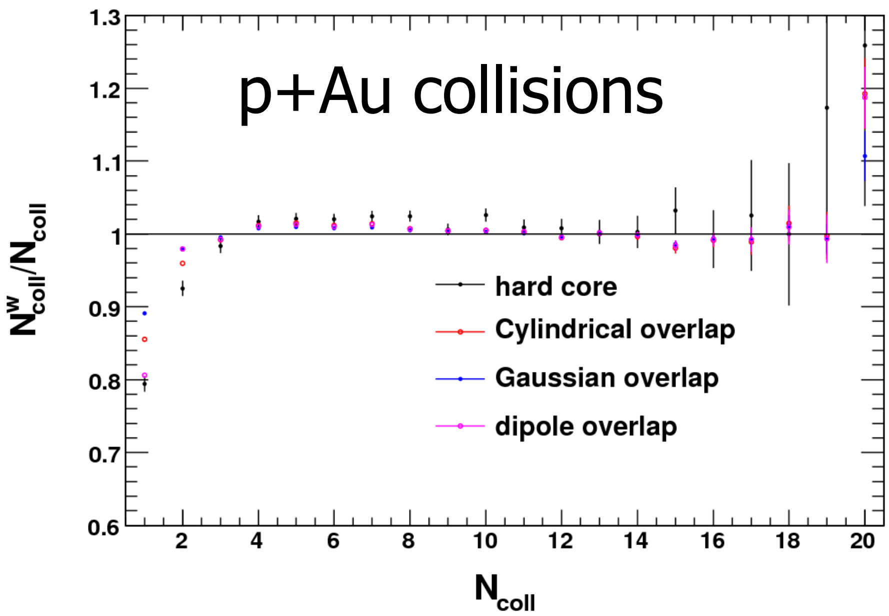




Size of the bias in pAu/dAu collisions

- Effects is smaller since the edge effects is small

RHIC



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