Understanding Energy Loss in the QGP

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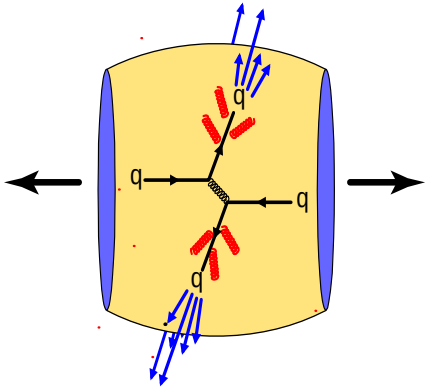
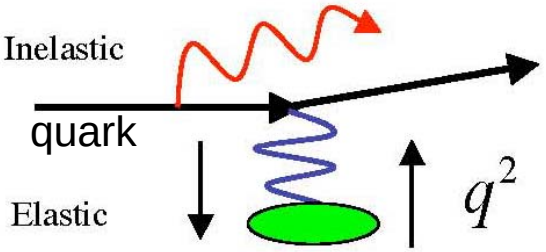
To quantitatively extract QGP parameters, such as temperature and energy density, partonic energy loss of light quarks, gluons and heavy quarks needs to be completely understood.

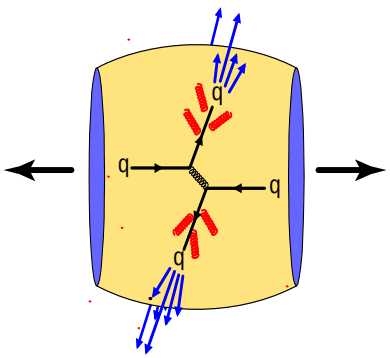
Outline:

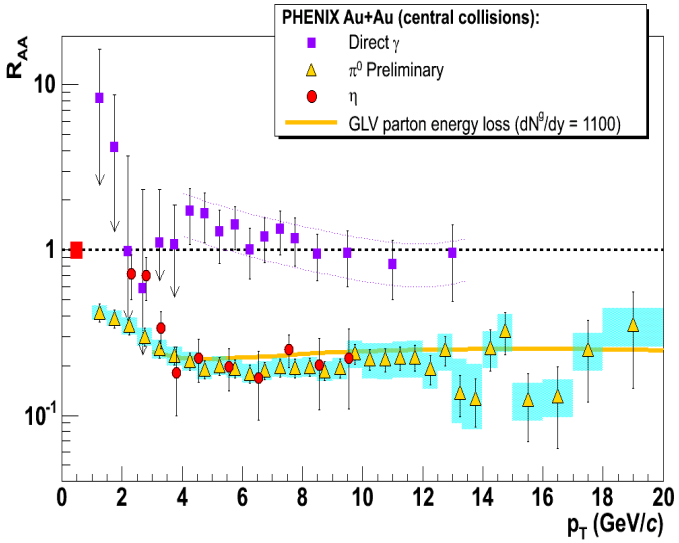
- Experimental Status
- Theoretical Status
- FVTX Measurements
- LHC Measurements

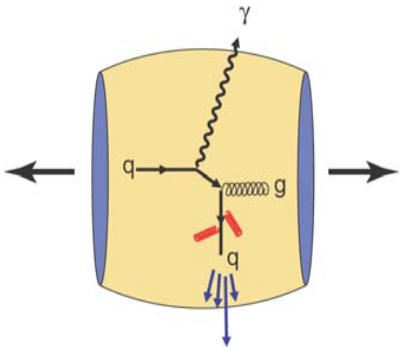




Experimental Status: Light Quarks Suppression



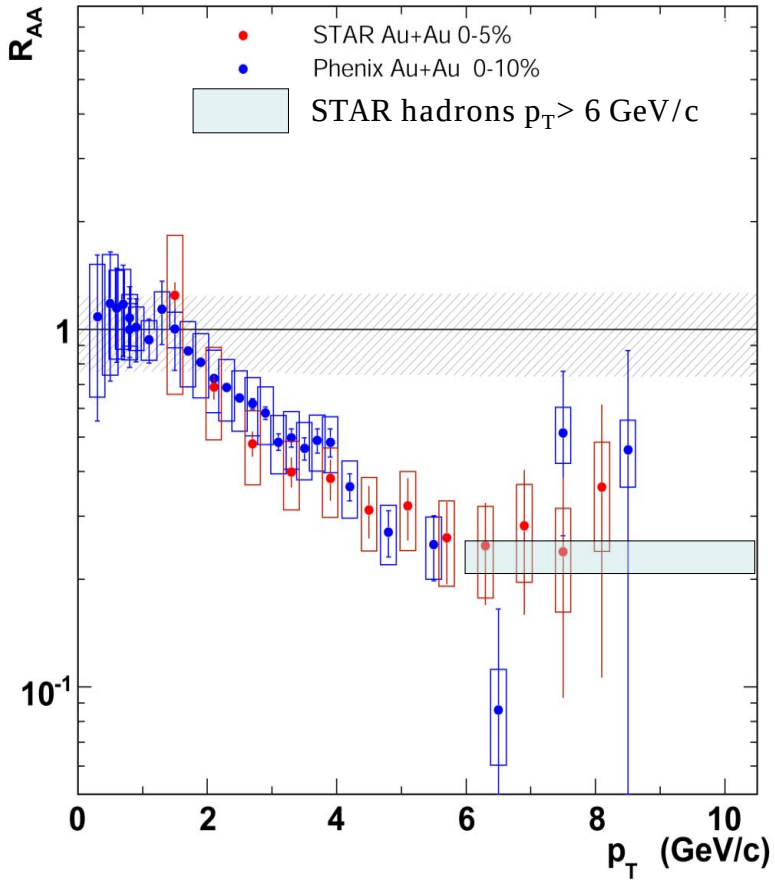


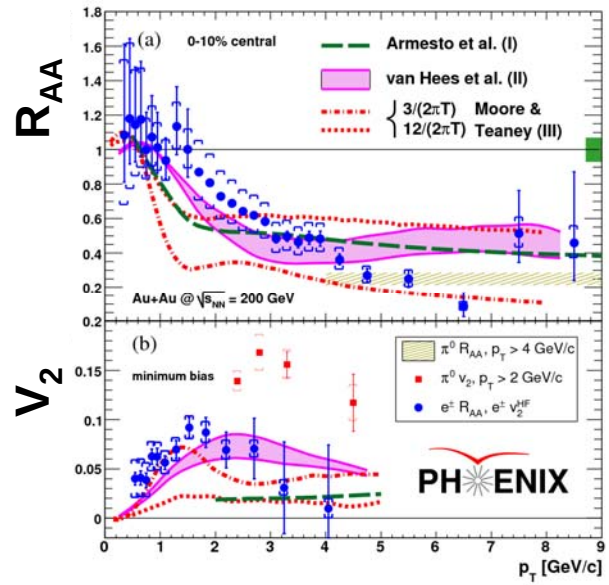


- R_{AA}: Light quarks are suppressed, photons 'shine', interplay of soft physics, recombination (parton coalescence into hadrons) and jet remnants
- **Quest**: What is the rapidity-density of gluons. What are, quantitatively, the plasma properties ?
  - **Currently extracted parameters differ up to a factor of ~10**
- Need to go beyond R_{AA} which integrates over many initial states and mechanisms …

Experimental Status: Heavy Quark Suppression

STAR : PRL98, 192301 (2007)
PHENIX : PRL98, 172301 (2007)

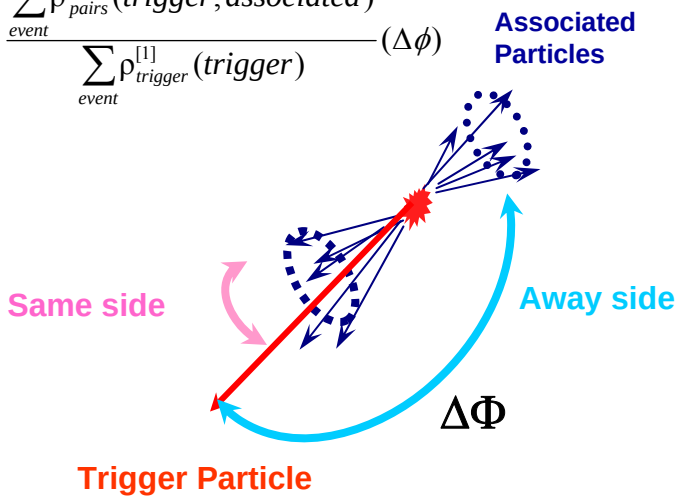


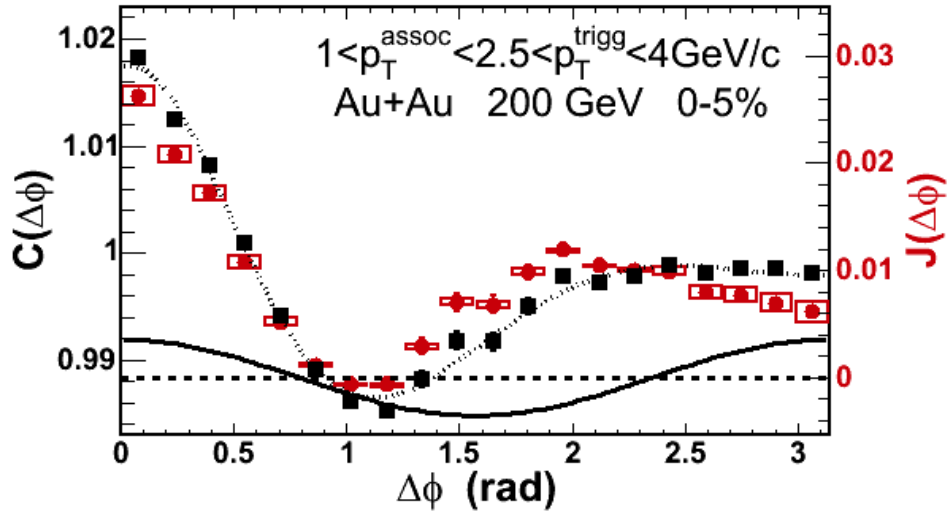


- Heavy quarks show same behaviors as light quarks
- Task: Determine relative role of collisional versus radiative energy loss
- Task : Identify heavy quarks directly
  - **Currently a cocktail subtraction from all measured leptons (non-photonic)**

Experimental Status: Light Quark Correlations

$$C(\Delta\phi) \equiv \frac{\sum_{event} \rho^{[2]}_{pairs}(trigger, associated)}{\sum_{event} \rho^{[1]}_{trigger}(trigger)}(\Delta\phi)$$





PHENIX publications on:

Dense Medium Effects Phys. Rev. Lett. 97, 052301 (2006) (165 citations)

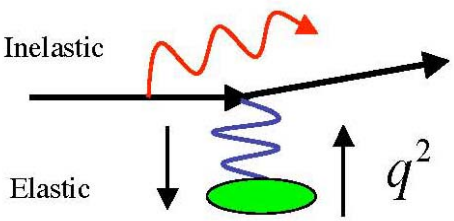
System Size and Energy Dependence Phys.Rev.Lett. 98, 232302 (2007) (24 citations)

- Jet Yield J(ΔΦ) has far side structure ! Tremendous attention of the community ….
  - **Mach cones, Cherenkov etc …**
- Task: Remove collective effects properly (v_2) …

Theoretical Status (QM2008)

I.Vitev, LANL

Toward Proper Comparison of ΔE^{rad} / ΔE^{coll}



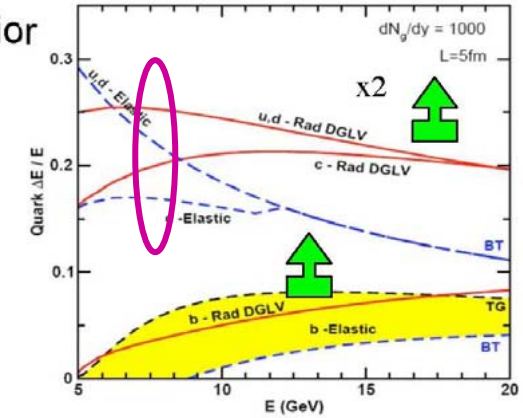
- LPM - new path length and energy behavior

Majumder, A. (2007)

Radiative E-loss: $$\frac{d\Delta E^{rad}}{dL} = \frac{2\alpha_s}{3}\frac{\mu^2 L}{\lambda_g}\log\left(\frac{2E}{\mu^2 L}\right)$$

Collisional E-loss: $$\frac{d\Delta E^{coll}}{dL} = \frac{2\alpha_s}{3}\mu^2\frac{1}{2}\log\left(\kappa\frac{TE}{\mu^2}\right)$$

Mustafa, M et al. (2005) Wicks et al. (2006)



radiative

collisional

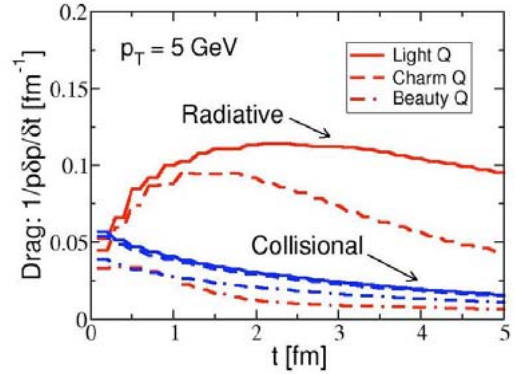
- Comparison in the the same model of the medium / momentum exchanges

V., I. (2006) Wang (2006)

$$\frac{1}{\sigma}\frac{d\sigma}{d^2q} = \frac{\mu^2}{\pi\left(q^2+\mu^2\right)^2}$$

$$\frac{\mu^2}{\pi\left(q^2+\mu^2\right)^2} \rightarrow \frac{\mu^2}{\pi q^2\left(q^2+\mu^2\right)}$$

Djordjevic, M et al. (2007) Wang, X.-N. (2000)



radiative

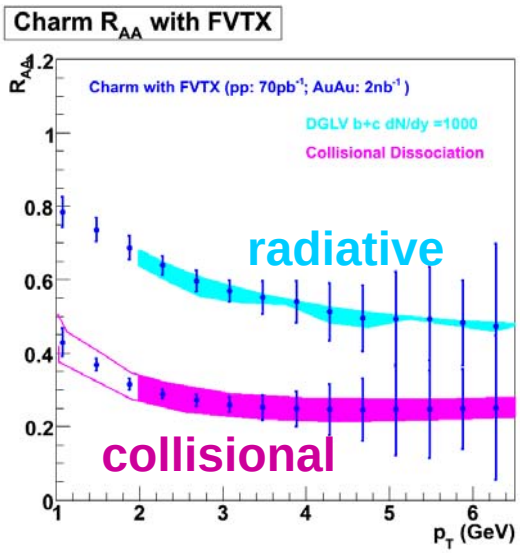
collisional

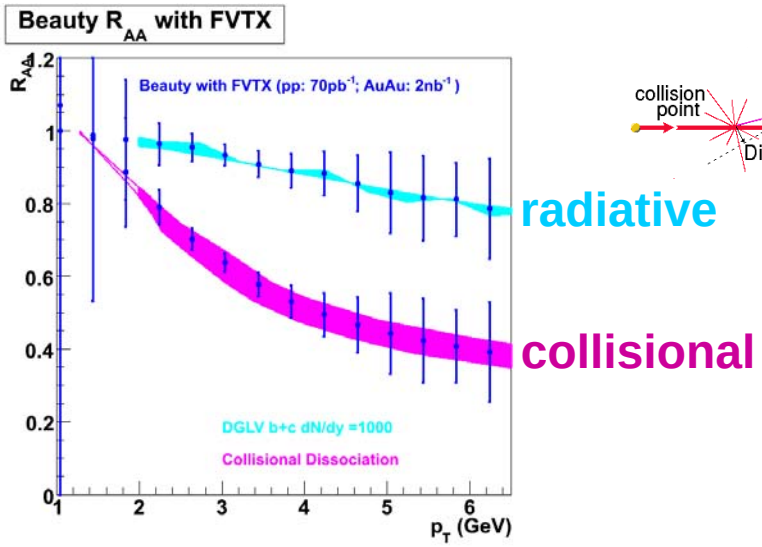
- Inelastic E-loss dominates $\gamma = \frac{E}{m} \geq few$

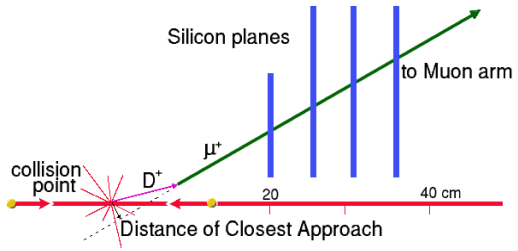
Los Alamos NATIONAL LABORATORY

- Tasks
  - Experimentally differentiate between radiative and collisional dE/dx
  - What is the exact path length dependence ?
  - Differentiate between light quarks/gluons and heavy quarks

Future RHIC with the FVTX





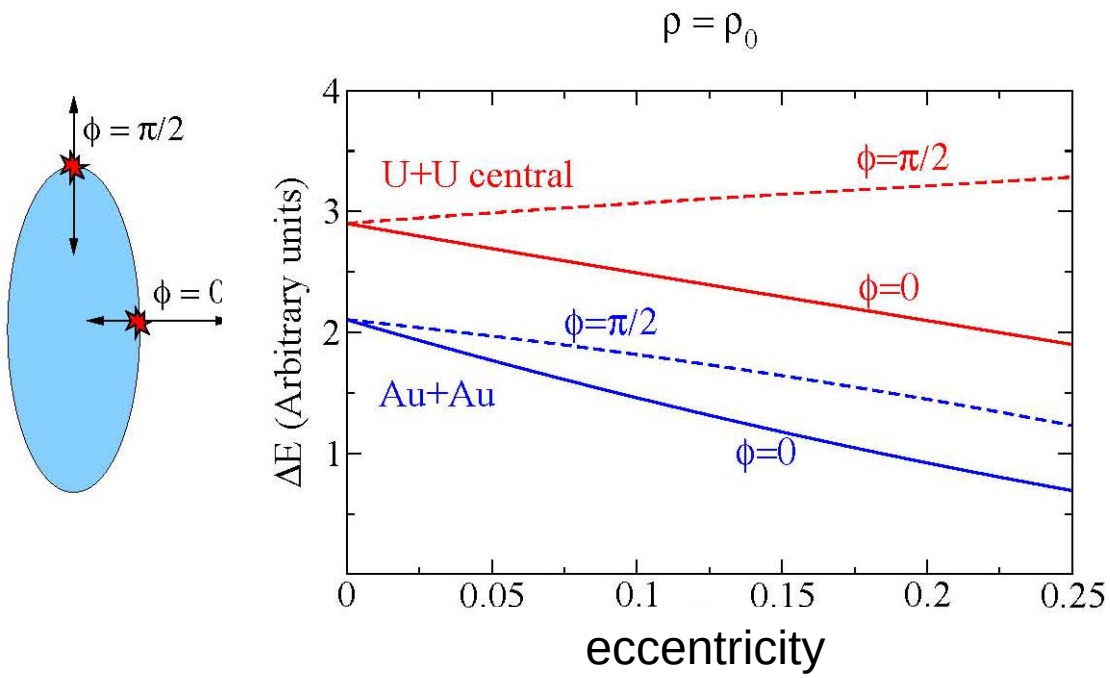


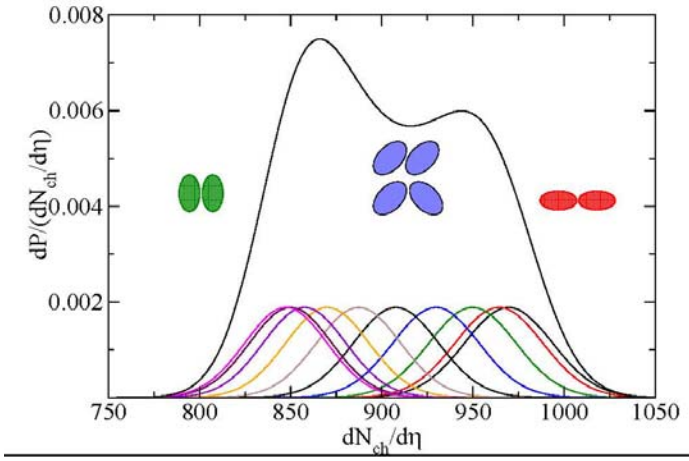
Only the key plots are shown, this constitutes a whole program

- Task: Identify Heavy Quarks rather than cocktail extraction
- FVTX allows displaced vertex/track analysis
  - Directly identifies muons from semi-leptonic decay of heavy quarks
- Measurable differences between collisional and radiative models !

Future RHIC Uranium + Uranium

Or 'Exploiting big, non-spherical nuclei'

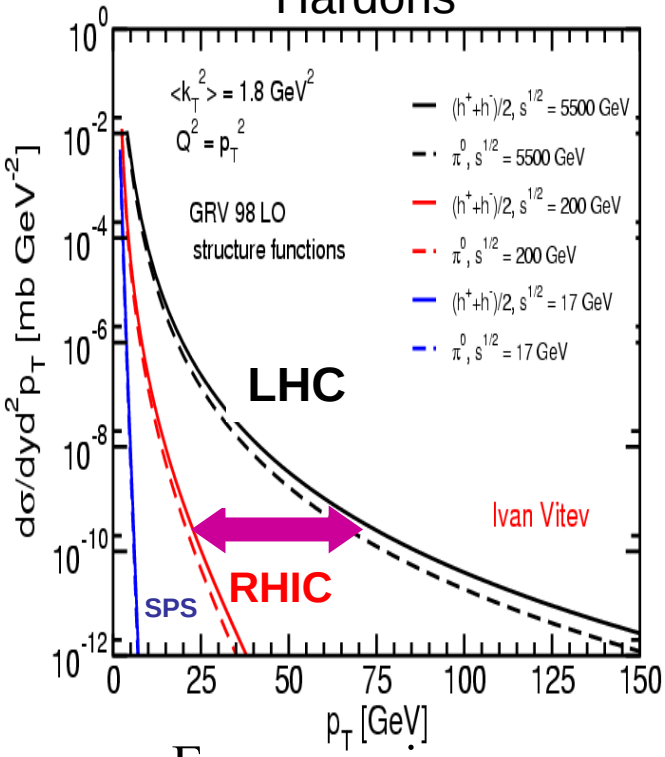




- Task: What is the exact path length dependence ?
- Most exciting development at RHIC to address energy loss and path length dependence
- Quantitative differently from Au+Au, plus eccentricity in most central collisions
- Study with 2 particle correlations !

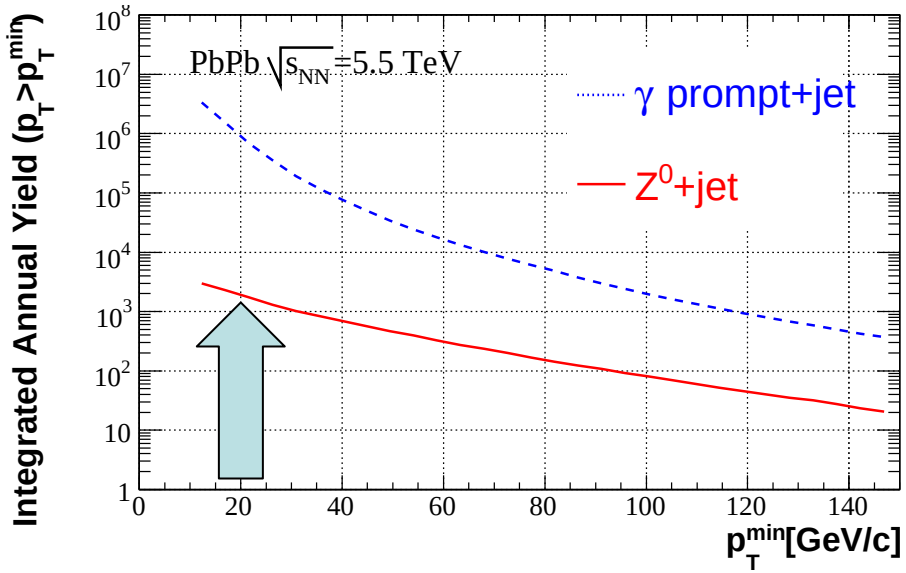
Future LHC with CMS

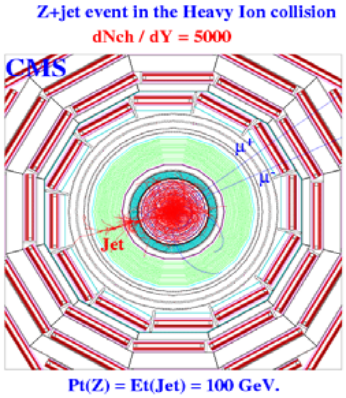
Hardons



Enormous increase

Tagged Jets

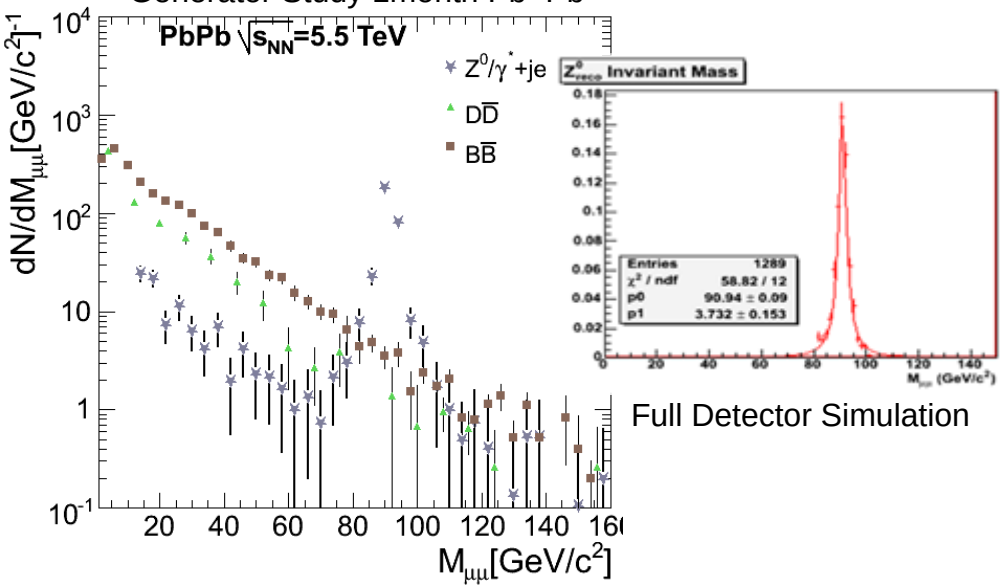




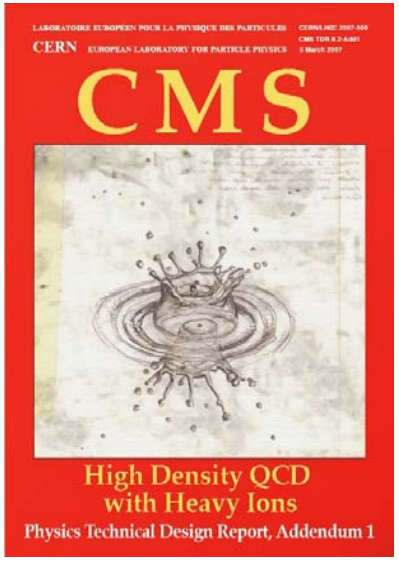
- Task: Go beyond R_{AA} which integrates over many initial states …
- High cross sections for hard probes at LHC
- CMS at LHC ideally suited for electromagnetic tagging of whole jets (not just leading particles)
- LDRD-ER since 2006

CMS Physics Technical Design Report

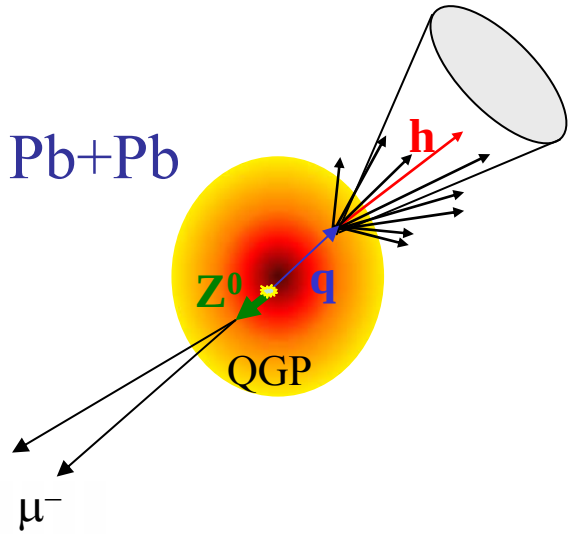
Generator Study 1month Pb+Pb



Full Detector Simulation

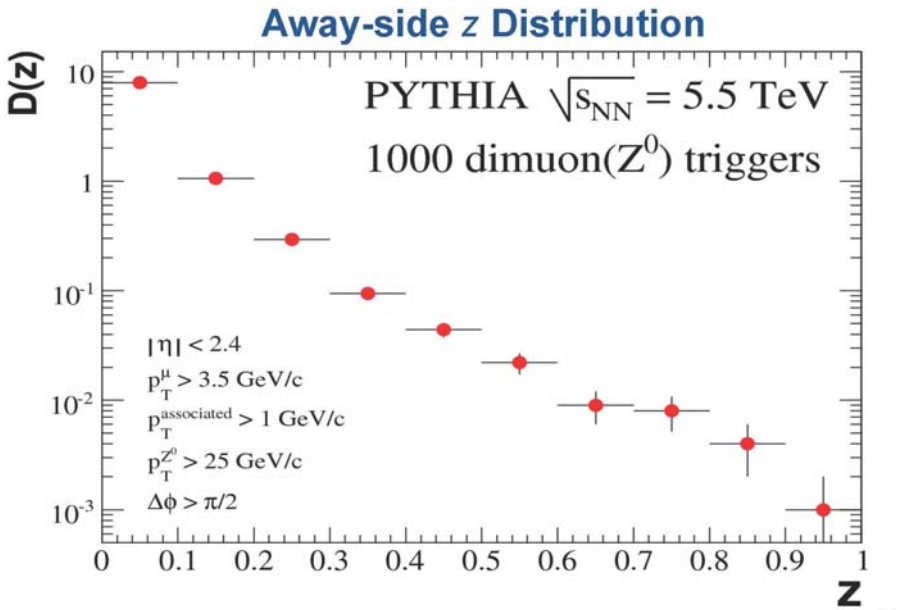


J. Phys. G: Nucl. Part. Phys. 34 (2007) 2307-2455

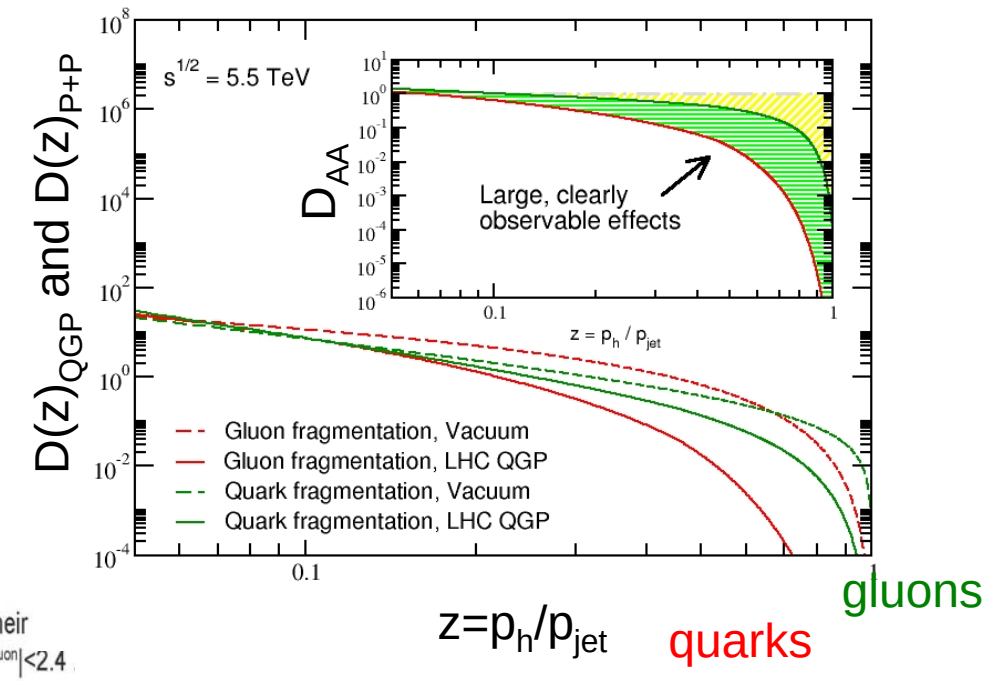


- Task: Go beyond RAA which integrates over many initial states …
- LANL LDRD-ER 06 established tagging with Z^0
  - Measures initial jet energy directly
  - Tag has no collective motion !!!

CMS Program: Fragmentation Functions



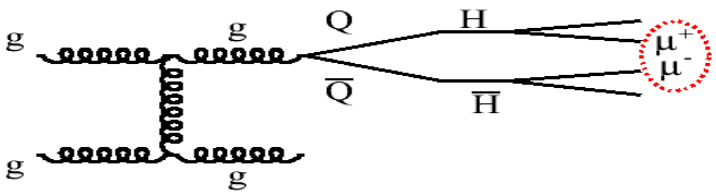
The number of associated charged hadrons ($\Delta\Phi>\pi/2$) per trigger dimuon as a function of their momentum fraction z for p_T^{dimuon}>25GeV/c and $p_T^{associated}$>1 GeV/c, p_T^{muon}>3.5 GeV/c and $|\eta^{muon}|$<2.4
The statistical error bars reflect a sample of 1000 Z^0 dimuon triggers.

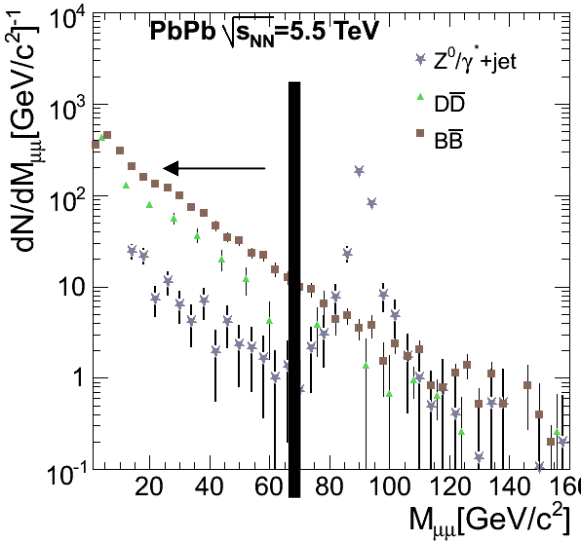


- Task: Need to go beyond R_{AA} which integrates over many initial states …

- Measurement of initial energy via Z^0-tag allows for a new measurement: the fragmentation function D(z)
- 'z' is the fractional momentum of particle
- Replace R_{AA} with Ratio $D_{AA}= D(z)_{QGP}/D(z)_{P+P}$

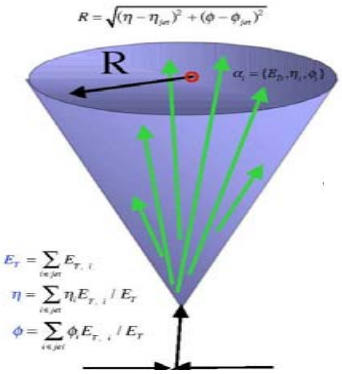
CMS Program: Heavy Flavor Tagged Jets



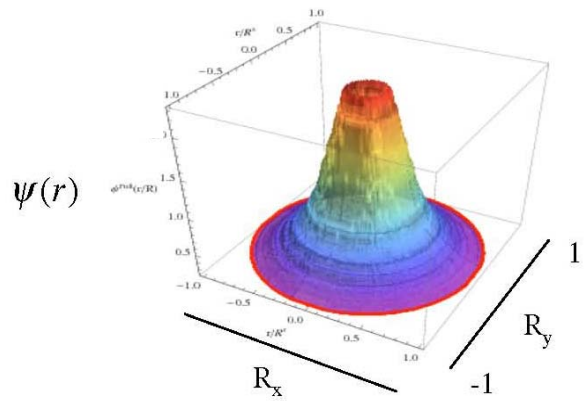


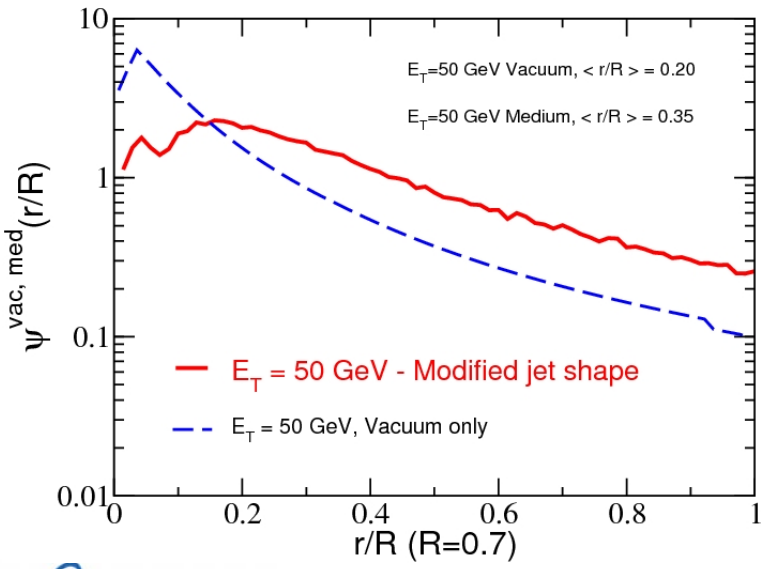
- Task: Differentiate between light quarks/gluons and heavy quarks
- Tagging of heavy quark pairs via the dimuon channel
- Test production mechanisms and measure fragmentation functions
  - p+p baseline is very important
- Compare dimuon spectra between vacuum (p+p) and QGP and future p+A
- Potentially go beyond R_{AA} via jet cone algorithm to measure the jet energy

CMS Program: Jet Shapes



Medium-induced Shape

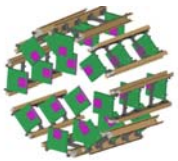




- Task: Experimentally differentiate between radiative (gluon bremsstrahlung) and collisional (particle-particle scattering) dE/dx
- Jet Shapes are a differential measure and can distinguish between:
- **Collisional energy loss**
  - **Excited particles in the medium scatter transversely to the jet axis and will not be detected as part of the modified jet.**
- **Radiative energy loss**
  - **Enhancement of the low momentum particles in a jet, since bremsstrahlung is predominantly collinear with the direction of the jet.**

LANL LDRD-DR, starting 2009, submitted

- Discover nature of partonic energy loss at the LHC
- Proposal for joint experiment and theory effort for LHC/CMS
  - Members from 2 exp. Groups, plus lattice QCD (Gupta) and pQCD (Vitev)



- **Collaboration 'buy-in'** via hardware effort on diamond pixel telescopes for luminosity measurements (experts in other LANL exp. group)
- Would cover 1.1 FTE for PHENIX team and 1.5 Postdocs

- **Why LANL ?**
  - **Invited to join the CMS collaboration because of our unique skill set and the resources of this national laboratory.**
    - **Experts in muon measurements in the high multiplicity environment of heavy ion collisions (analysis of PHENIX muon arm data at RHIC),**
    - **Displaced vertex tracking (LDRD-DR and FVTX projects and FNAL)**
    - **Pixel detector construction, leading expertise in bump bonding (P-23).**
  - **Analysis track record and publication of physics of p+p and A+A collisions.**
  - **Contributed important section to the CMS pTDR on High Density QCD.**
  - **Both, the US-CMS Heavy-Ion Project Manager Bolek Wyslouch and the US-CMS Manager of the Operations Program Joel Butler, would support our application to join CMS.**

Draft 4 Year Program

Year	RHIC Run *	Upgrade	Phenix-Analysis	LHC Run *	CMS-Analysis
2009	p+p, AuAu		Leading particle Jet Shapes	p+p	Tagged fragmentation functions, Jet Shapes
2010	p+p, low Energy Au+Au	FVTX proto-type	Open Charm	pp, first Pb+Pb	Heavy flavor tagging in PbPb, Jet Shapes
2011	Au+Au, U+U	FVTX	2 particle Corr. For UU, Open Beauty, Leading particle Jet Shapes	pp, PbPb	Z tagged fragmentation functions in PbPb, Precision cross sections in pp (PLT)
2012	low E Au+Au	FVTX	Start of full suite of FVTX analysis	pp, PbPb	Tagged Jet Shapes

* Run plans are subject to change (funding, commisioning etc.)

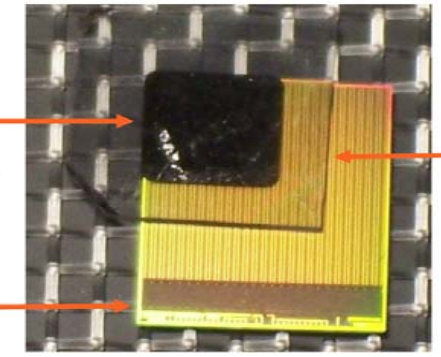
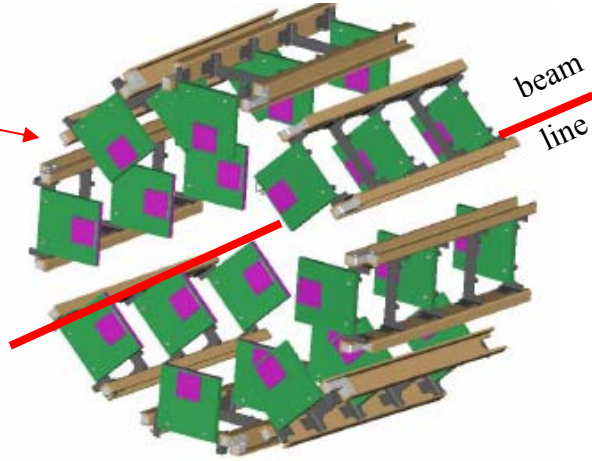
Summary

Light quarks, heavy quarks and gluons undergo energy loss while propagating though a dense medium consisting of quarks and gluons (the QGP). The proposed tasks and new tools will lead to a detailed understanding of partonic energy loss mechanisms and thus will allow for the determination of the density of the medium.

Assuming local thermal equilibrium, the QGP density behaves as the third power of the plasma temperature (T), which allows for the ***direct*** determination of **T** and the energy density of the plasma (ε) from the measurement of energy loss.

LANL's contribution to CMS Experiment Pixel Luminosity Telescope

To be build by other LANL group
on LDRD funds



- Physics Justification
  - 1% precision luminosity measurement needed for precision QCD studies and determination of Beyond the Standard Model parameters, dedicated radiation hard detector (>10 % precision without)
- Technology
  - Diamond pixel is only detector choice: radiation hardness and pixel size
  - Collaboration with Rutgers and Princeton for **Pixel Luminosity Telescope** (PLT)
- LANL's Expertise
  - Pixel Detectors, Bump Bonding Assembly, Particle Tracking, Frontend Electronics