Heavy ion physics with PHENIX upgrades

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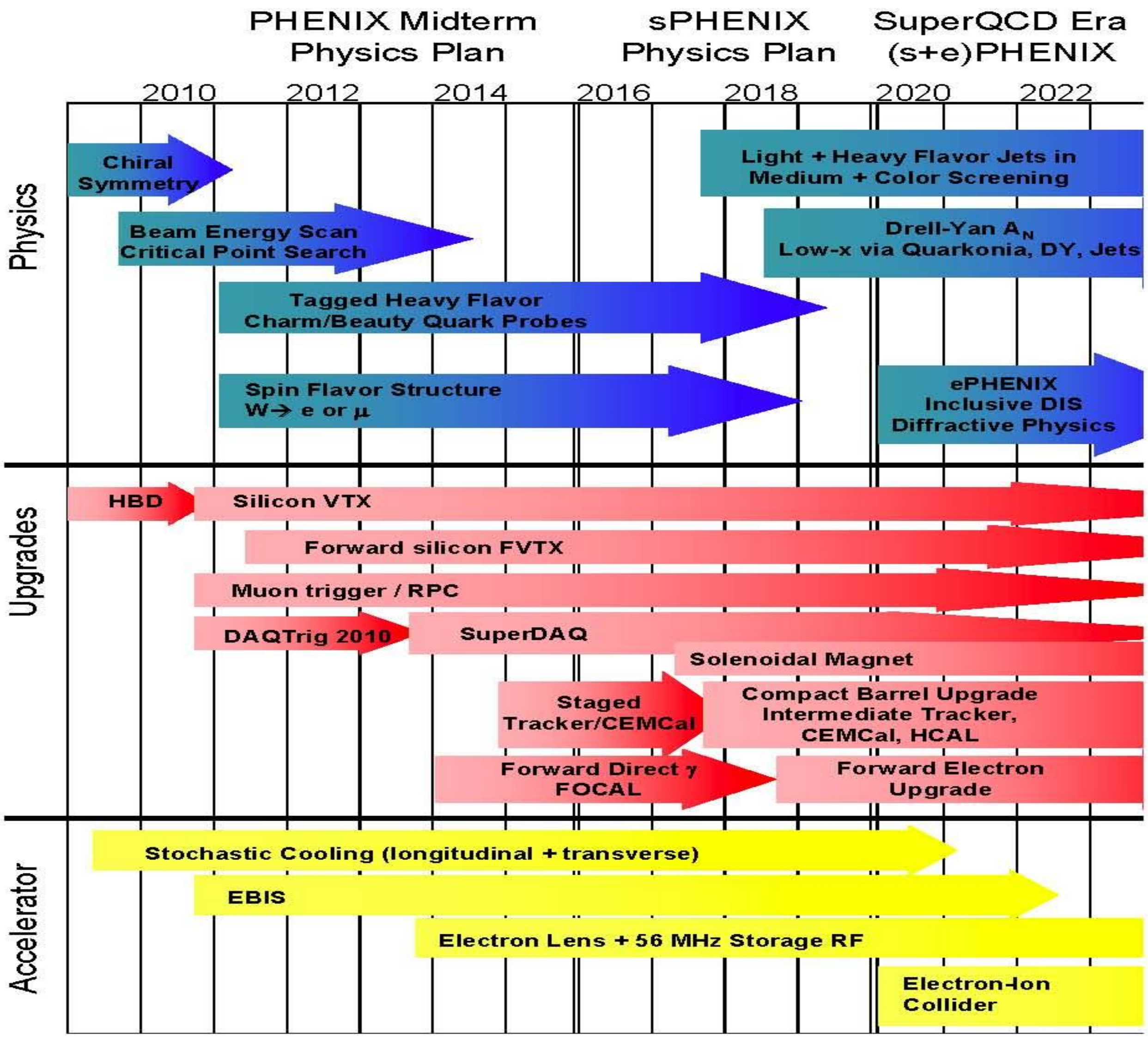
For Future direction in High Energy QCD, RIKEN, Oct 20, 2011

PHENIX upgrade plans



Major upgrades for next ~5 years

- Hadron Blind Detector (HBD)
  - Tag and reject electron-pairs that have small opening angles (likely due to conversions or Dalitz decay)
  - Installed in Run-10 and completed mission

- Resistive Plate Chamber (RPC) & Muon Trigger upgrade
  - Installed in Run-11 in Muon Arm. Measure timing of muons in order to select muons from a same bunch-crossing.

- Silicon Vertex Detector (VTX)
  - Measure DCA of tracks, and tag D, B originated electrons
  - Installed in Run-11. Now in repair for Run-12

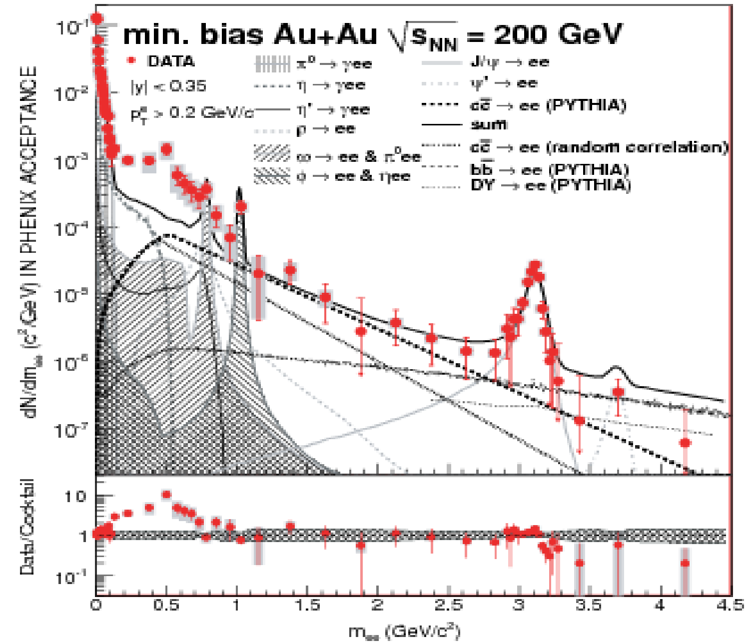
- Forward Vertex Detector (FVTX)
  - Measure DCA of tracks in forward rapidity region
  - To be installed in Run-12

- Muon Piston Calorimeter extension (MPC-EX) ($3.1<|\eta|<3.8$)
  - Shower max detector in front of existing MPC
  - Measure direct photons/π^0 in forward rapidity region

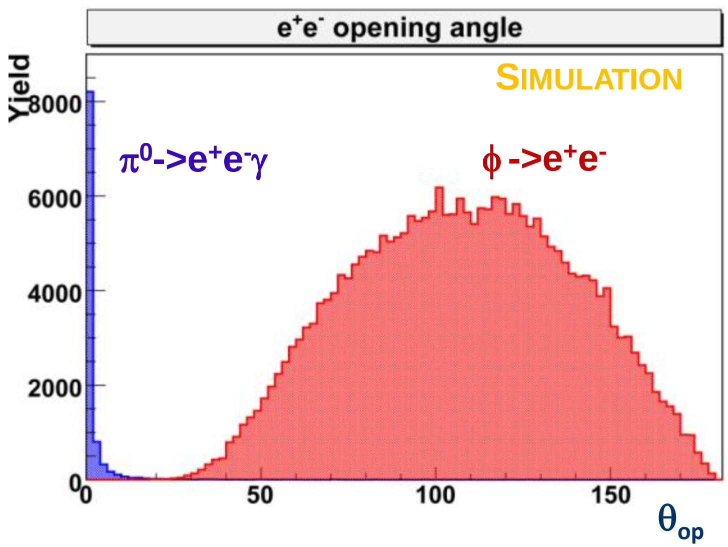
Low mass dilepton issue

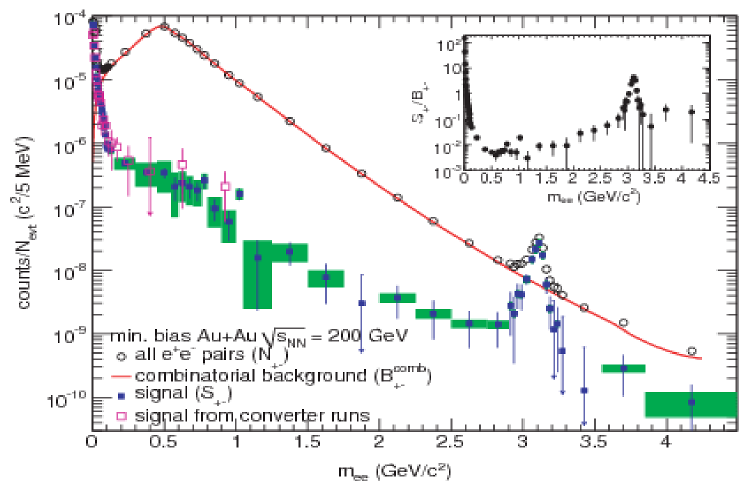
*Phys.Rev.C81, 034911 (2010)

- Results* from RHIC Run-4:
  Yield in m_{ee} = 0.15 - 0.75 GeV/c^2 larger by a factor **4.7 +/- 0.4(stat.) +/- 1.5(syst.) +/- 0.9(model)** compared to the expected hadronic contribution
- S/B in this mass region is **1/200**
- combinatorial background should be reduced!



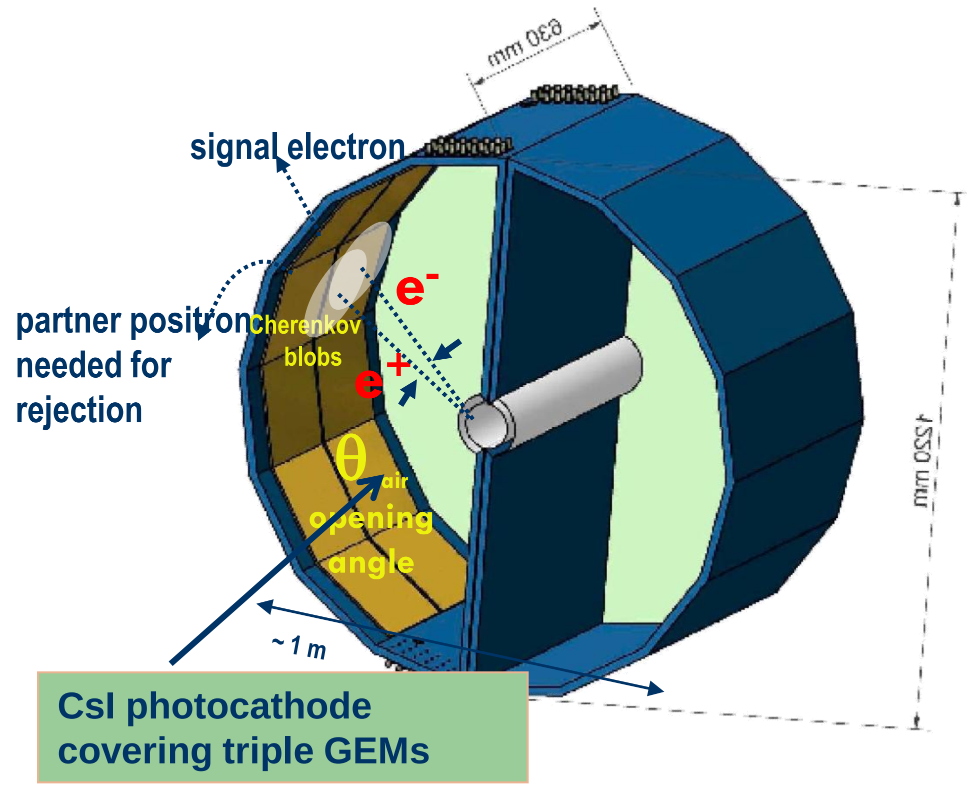
One way is to look at the opening angle of electron-pairs





Hadron Blind Detector

- Designed for low-mass dileptons in A+A
  - Operated in Run-9 and 10
- Removes Dalitz and conversion pairs
  - Reduce background γ^*



Windowless Cerenkov detector with CF4 avalanche/radiator gas (2 cm pads)

HBD performance

- The average number of photo-electrons N_{pe} in a Cherenkov counter: $N_{pe} = N_0 L / \bar{\gamma}_{th}^2$

with: $N_0 = \frac{\alpha}{hc} \int \varepsilon(E) dE = 714\,\mathrm{cm}^{-1}$

- $\bar{\gamma}_{th} = 29$
-
- bandwidth: 6.2 eV (CsI photo-cathode threshold) - 11.5 eV (CF_4 cut-off)

N_0 ideal value	$714\ cm^{-1}$
Optical transparency of mesh	88.5 %
Optical transparency of photocath.	81.0 %
Radiator gas transparency	89.0 %
Transport efficiency	80.0 %
Reverse bias and pad threshold	90.0 %
N_0 calculated	328 +/- 46 cm^{-1}
N_{pe} expected	20.4 +/- 2.9
N_{pe} measured	20
N_0 measured value	**330 cm^{-1}**

The highest ever measured N_0!

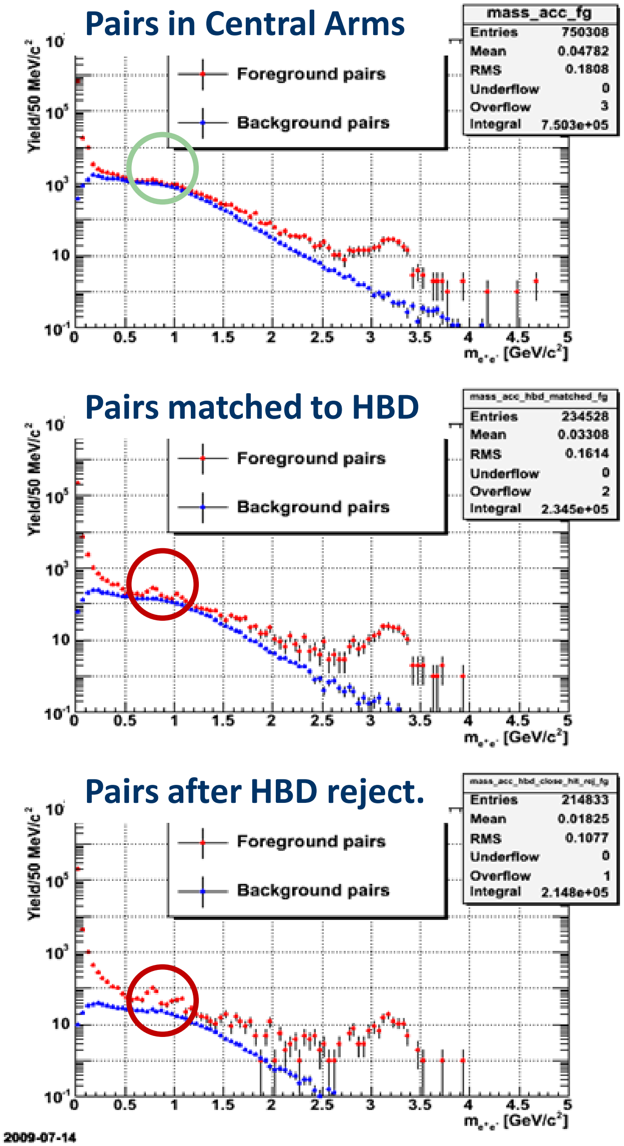
The high photoelectron yield → excellent single electron detection efficiency:
→ Single electron efficiency using a sample of open Dalitz decays: ε ~ 90 %
→ Single electron efficiency derived from the J/Ψ region: ε = 90.6 ± 9.9 %

Background rejection in p+p

Present status from Run-9 p+p:

Background reduction in m_{ee} > 0.15 GeV/c^2
(not fully optimized)

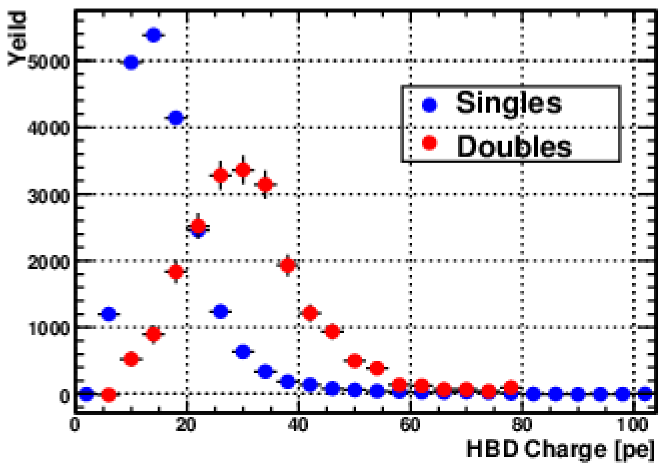
	Step	Bckg. reduction factor
1	matching to HBD	7.1
2	double hit cut close hit cut	6.5



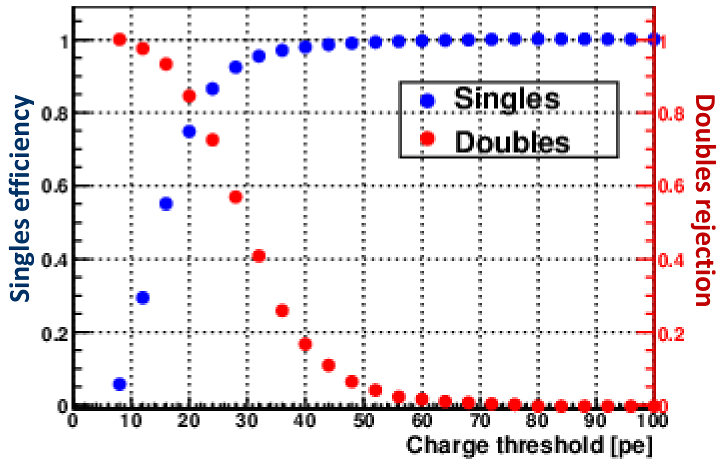
The HBD analysis in Au+Au (Run-10):

- Rejection of upstream conversions and π^0 Dalitz pairs is achieved with single/double charge cut
- This requires good gain calibration throughout the entire run
- Single electrons hits studied using MC electrons from $\phi \to e^+e^-$ embedded in Au+Au data
- Double electron hits studied using MC $\pi^0 \to \gamma\gamma$ embedded in Au+Au data

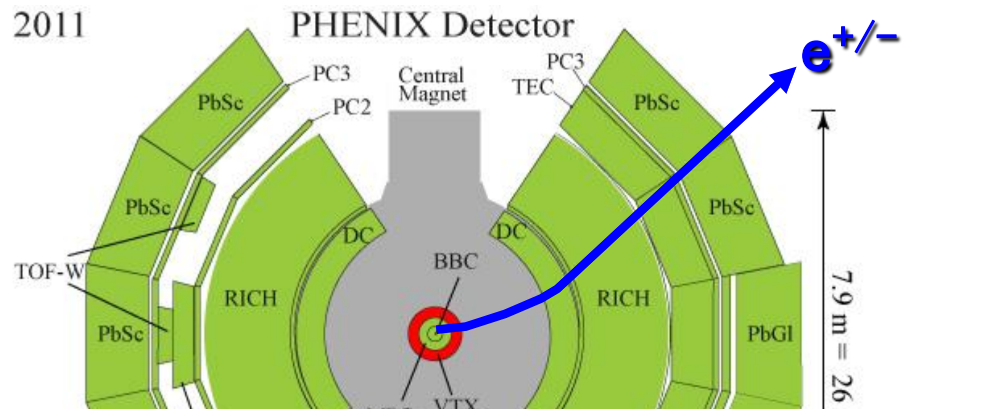
Single vs. double charge



Single efficiency vs. double rejection

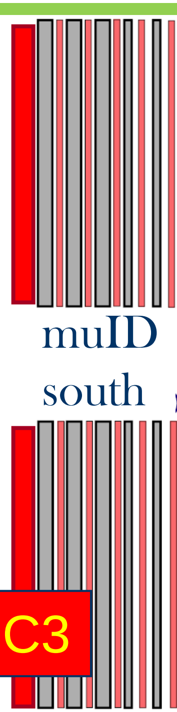


Run-11 PHENIX detector



Central Arms:
- hadrons, photons, electrons
- $|\eta| < 0.35$
- $\Delta\varphi = \pi$ (2 arms x $\pi/2$)

Global Detectors:
- Beam-Beam Counter (
- Zero Degree Calorimet

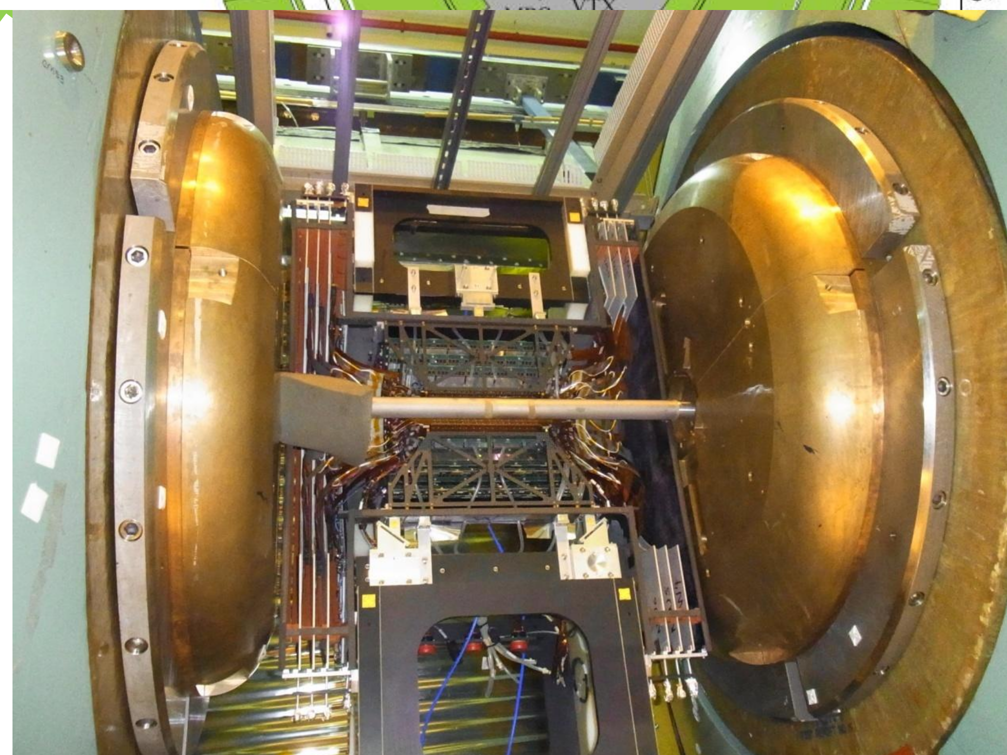


muID south

Muon Arms:
- muons
- $1.2 < |\eta| < 2.2$
- $\Delta\varphi = 2\pi$

MPC $3.1 < |\eta| < 3$

RPC3



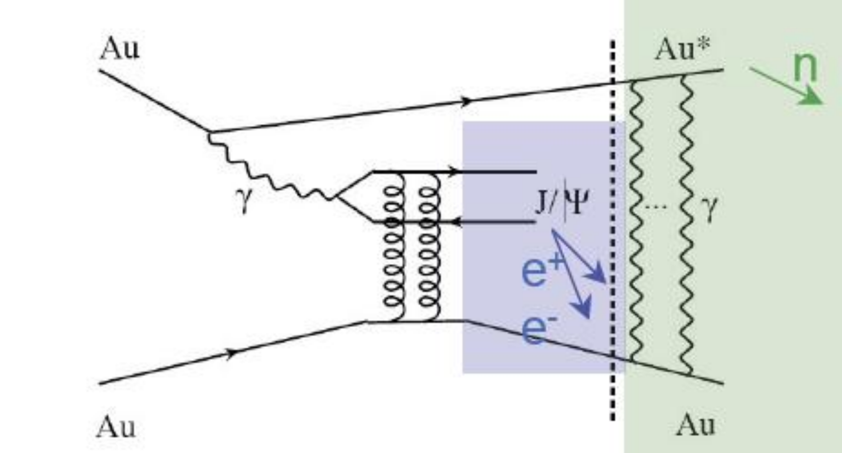
RPC3

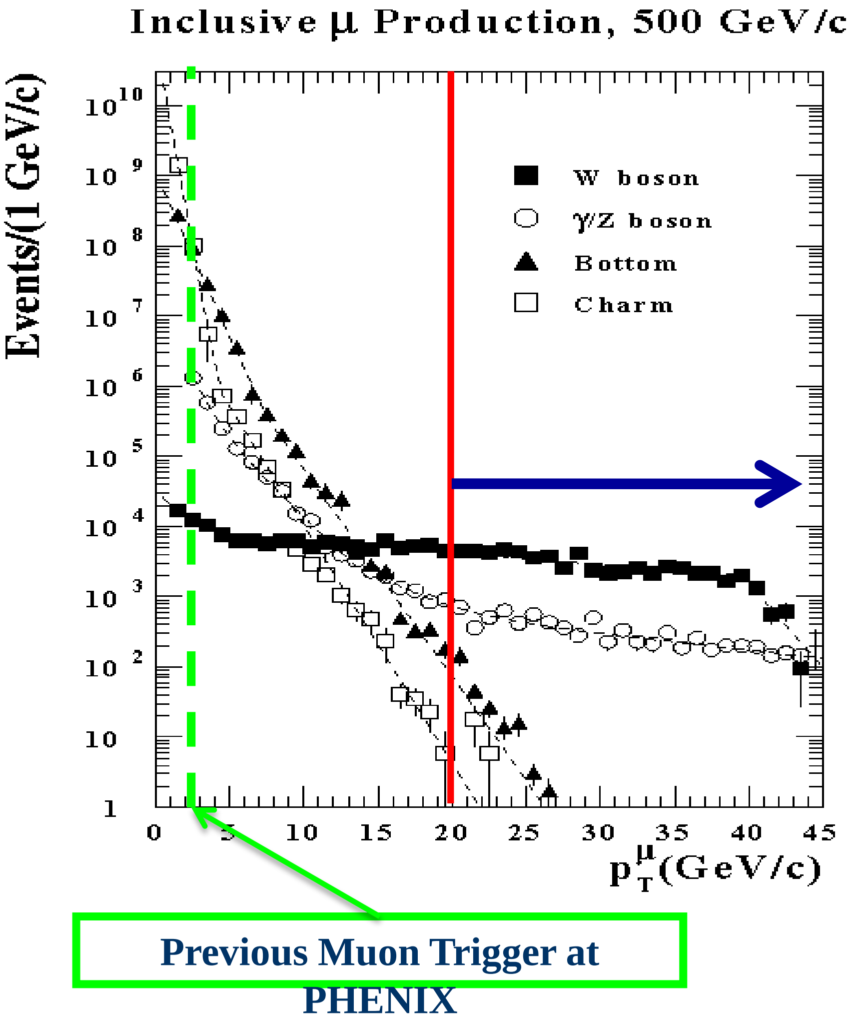
18.5 m = 60 ft

Triggering muons from *W*

- In order to measure *W* at 500 GeV, a first level trigger rejection of a factor 10000 is needed

•For heavy ion physics:
•Extend capability of accepting ultra peripheral collisions

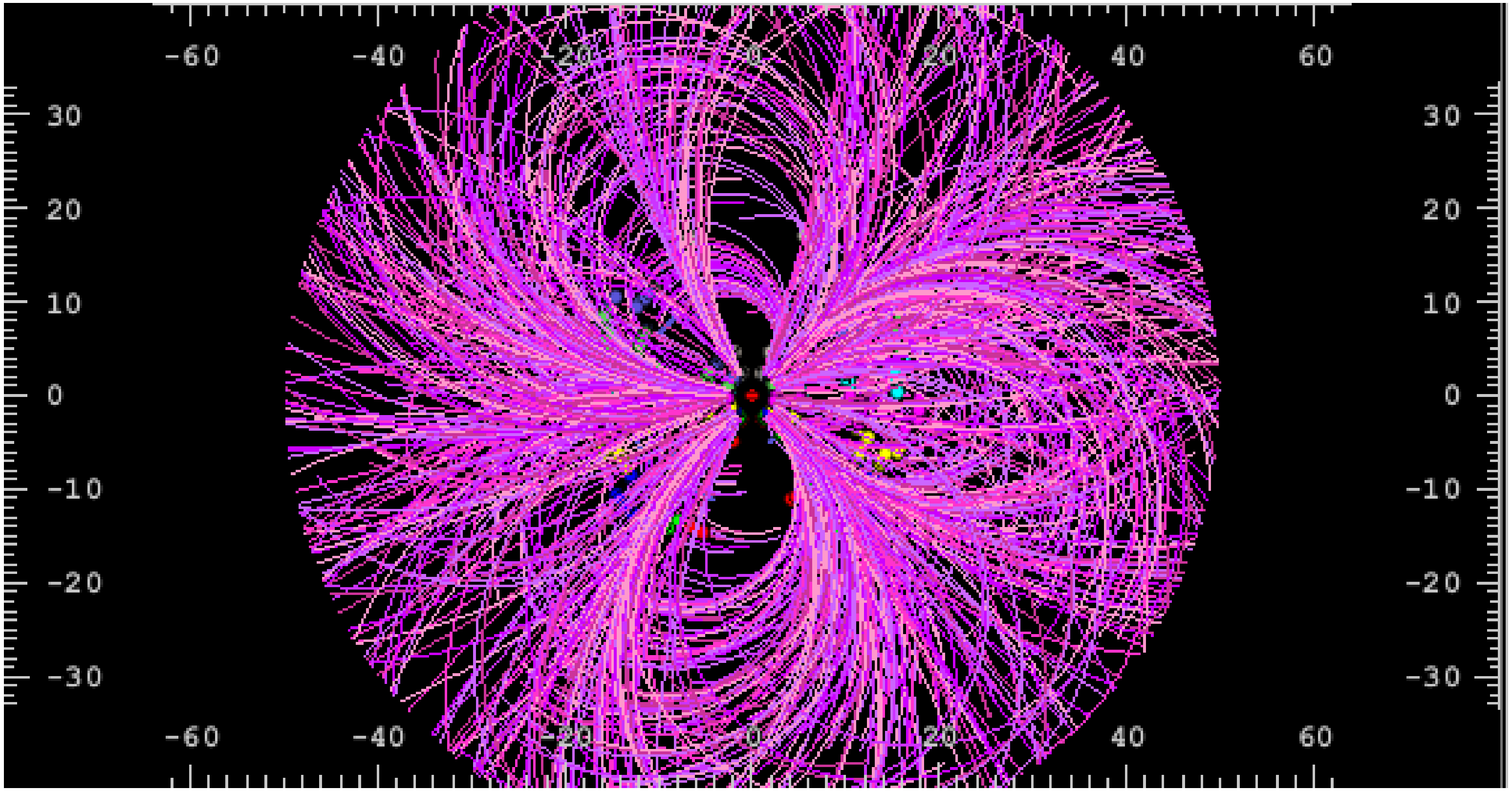




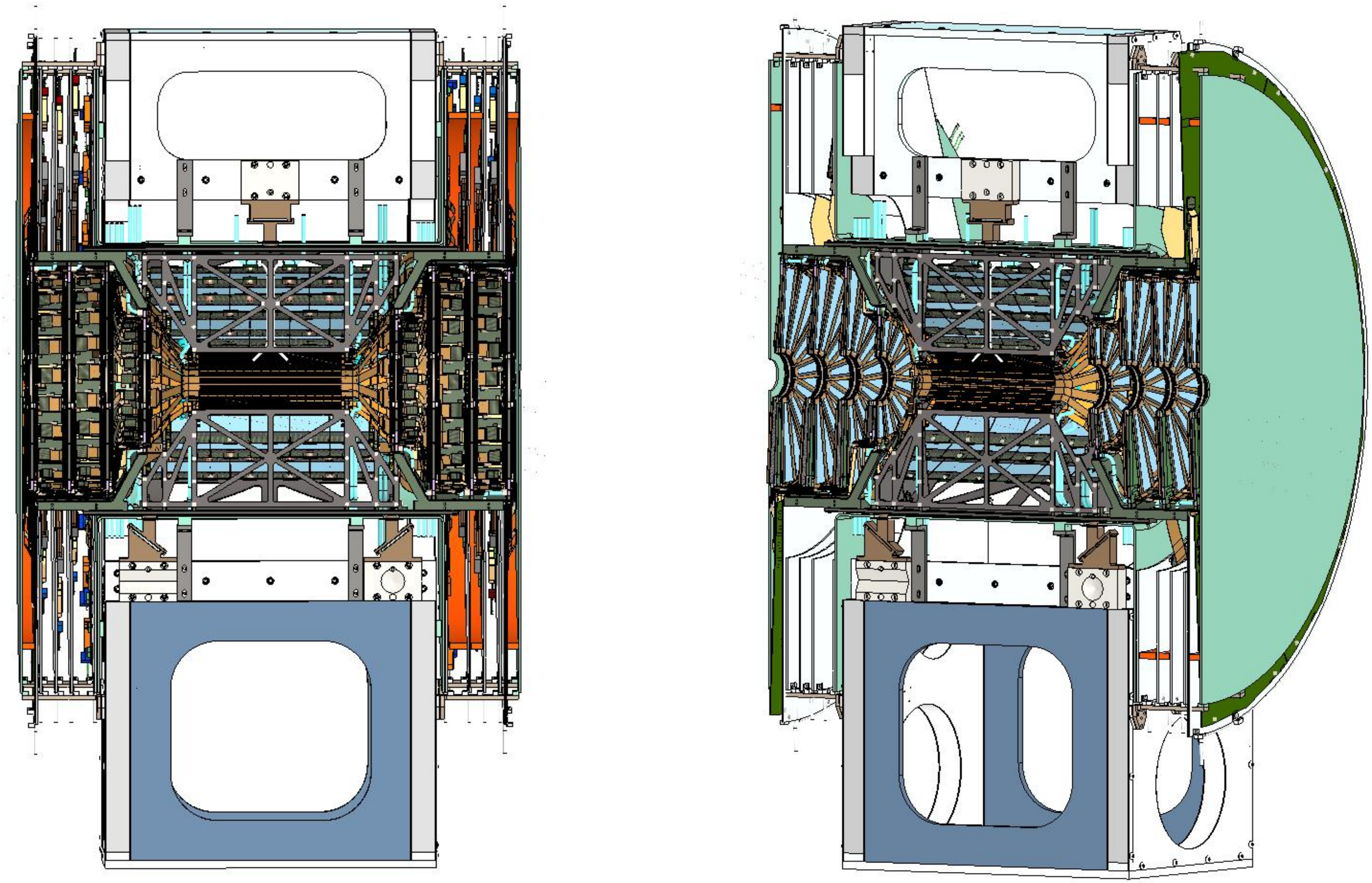
Run-11: Single event from Au+Au at 200 GeV

VTX event display

Run # 343450-0014 Event 13



VTX with FVTX (Run-12 goal)



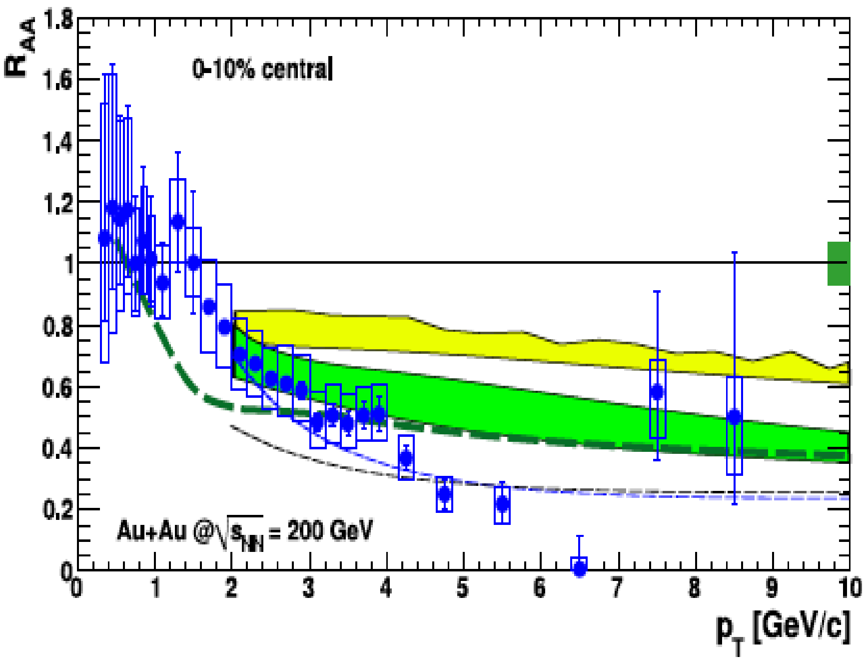
Heavy quark suppression & flow? FVTX/VTX physics

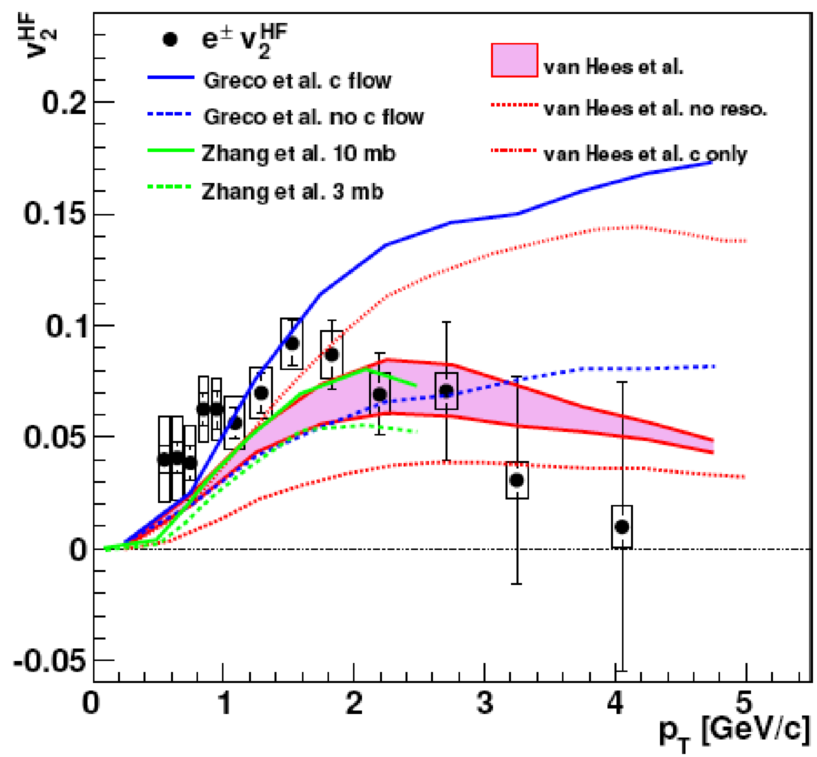
Collisional energy loss?

v_2 decrease with p_T?

role of b quarks?

PRL.98: 172301,2007
arXiV: 1005.1627

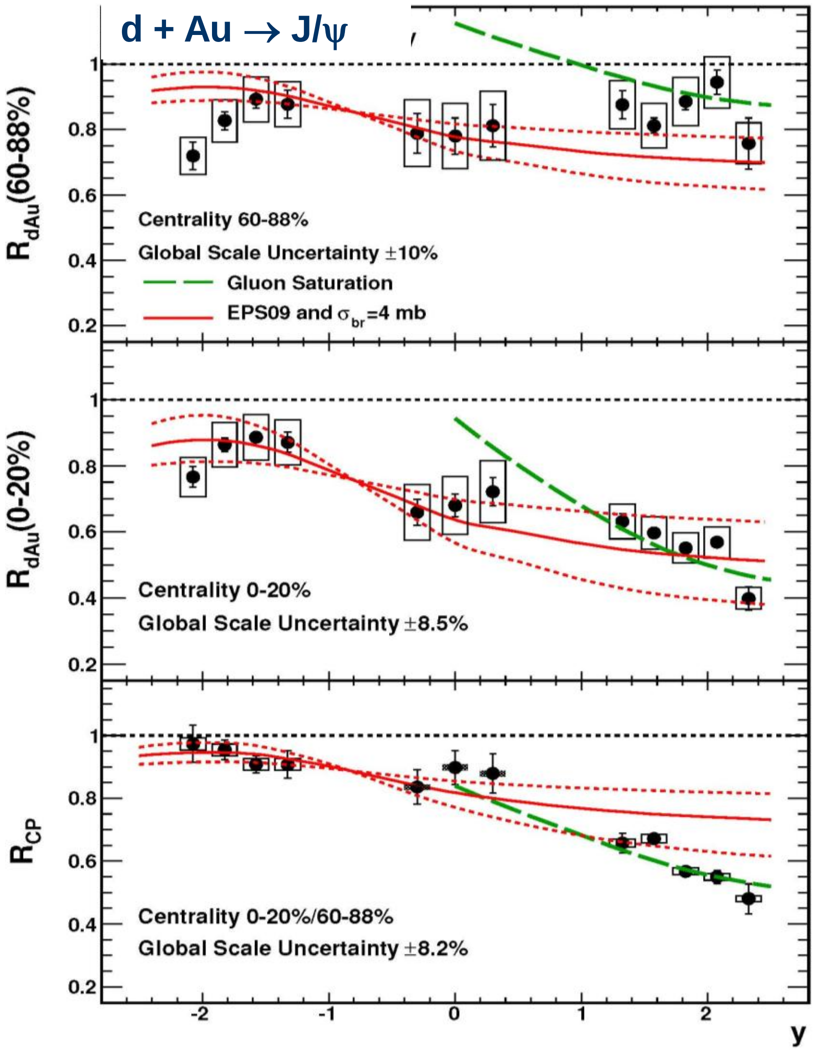




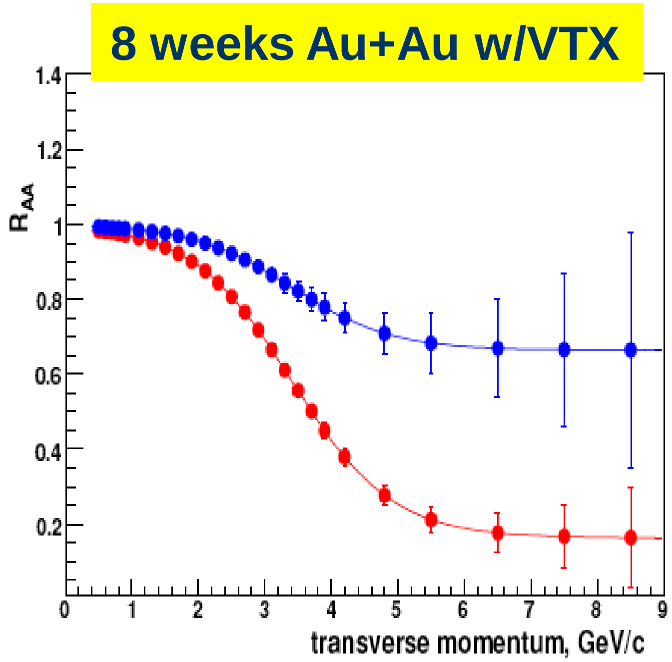
FVTX specific

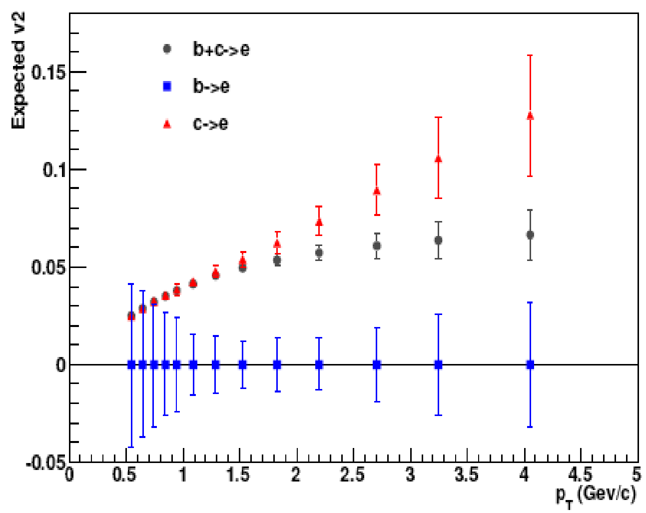
arXiv:1010.1246

- As far as heavy ion physics is concerned, we might focus on cold nuclear matter (CNM) effect
- Resolving J/ψ and ψ' in Muon arms
- Direct measure of B meson through displaced J/ψ
- Drell-Yan or J/ψ Measurements in dAu at both forward rapidity
  - Detect quark distribution in nuclei
  - Combining with mid-rapidity results



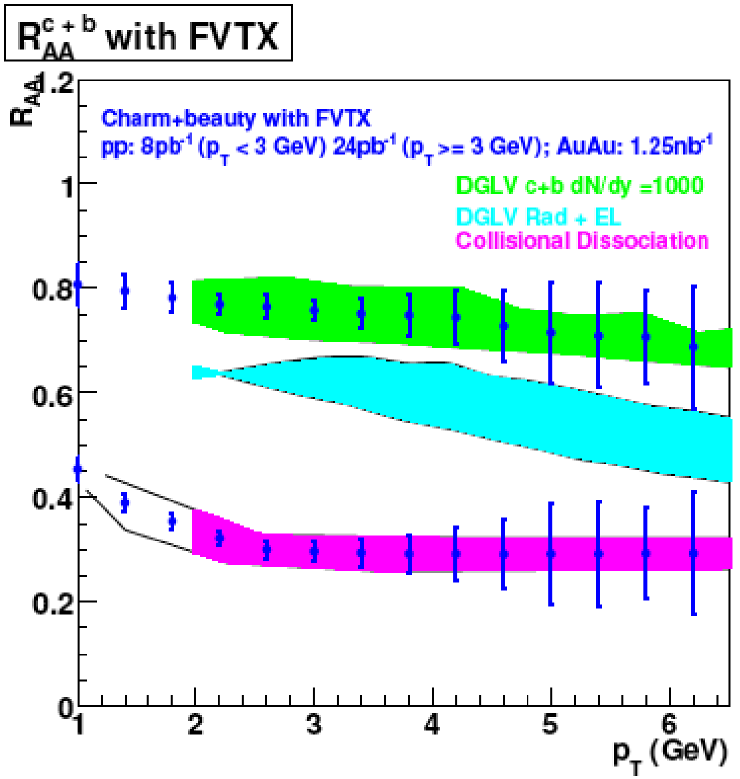
VTX/FVTX physics capabilities





In Run-11 ~ two good weeks for VTX Au+Au data taking

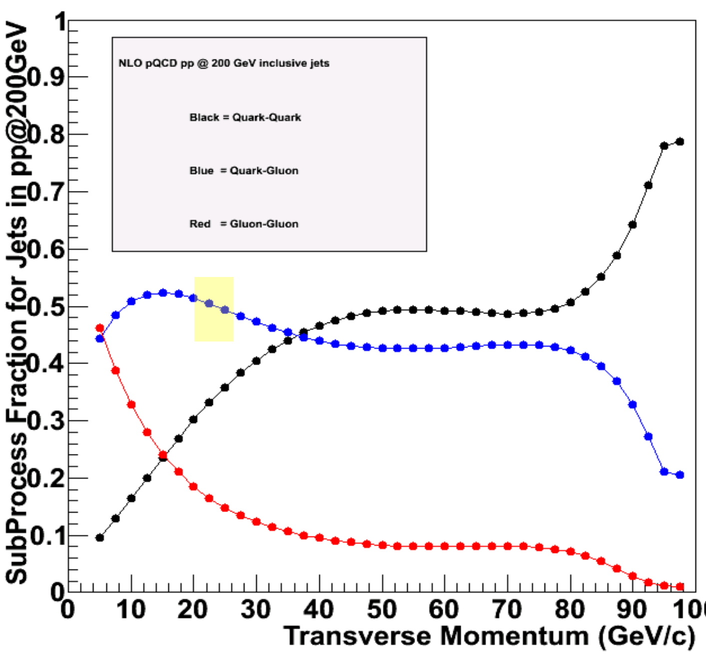
Run-12 Goal for FVTX: Commission

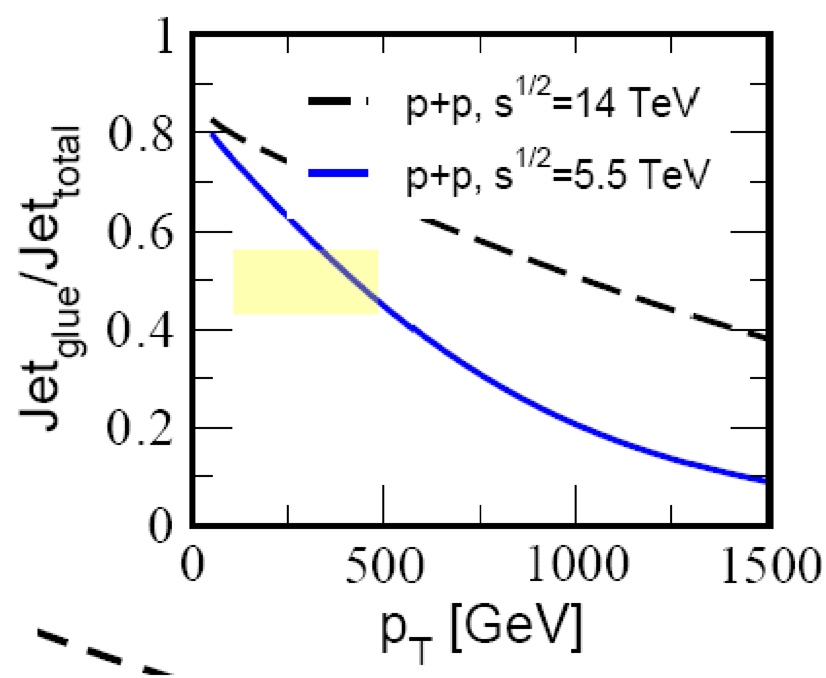


RHIC (hard) studies in LHC era

- Hard probe difference
  - More quark jets instead of gluon jets
  - PHENIX can select pure sample of quark jets via γ-jet correlation (demonstrated in our paper in p+p measurement, PRD82, 072001 (2010))
- Medium difference
- Key machine flexibillity
  - pA, light AA, asymmetric systems such as Cu+Au.

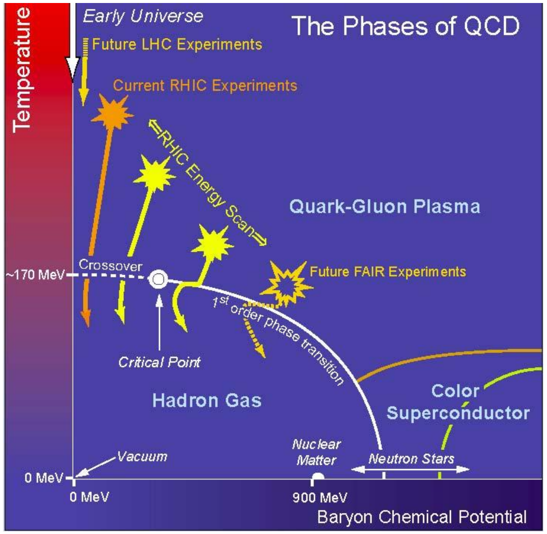
LHC ~ 50-75% gluon jets
RHIC ~ 75% quark jets





Finding the QCD Critical Point

Singular point in phase diagram that separates 1st order phase transition (at small T) from smooth cross-over (at small μ_b)



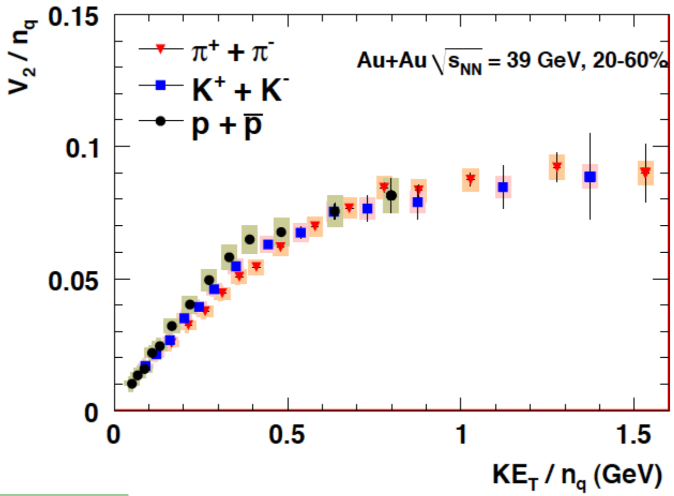
Quark-number scaling of V_2

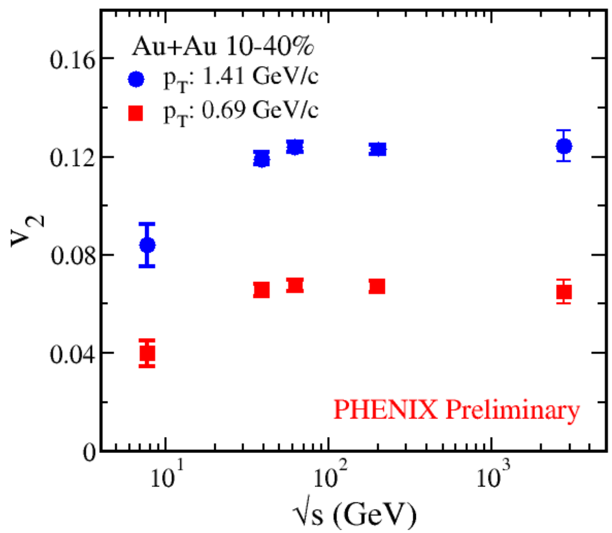
- saturation of flow vs collision energy
- η/s minimum from flow at critical point

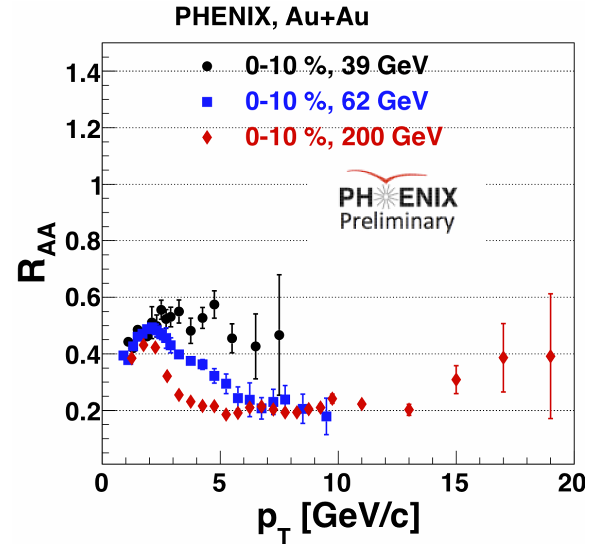
Critical point may be observed via:

- fluctuations in <p_T> & multiplicity
- K/π, π/p, pbar/p chemical equilibrium
- R_{AA} vs $\sqrt{s}$, ….

VTX provides large azimuthal acceptance & identification of beam on beam-pipe backgrounds





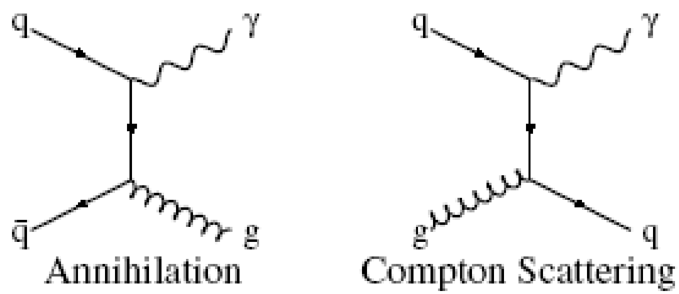


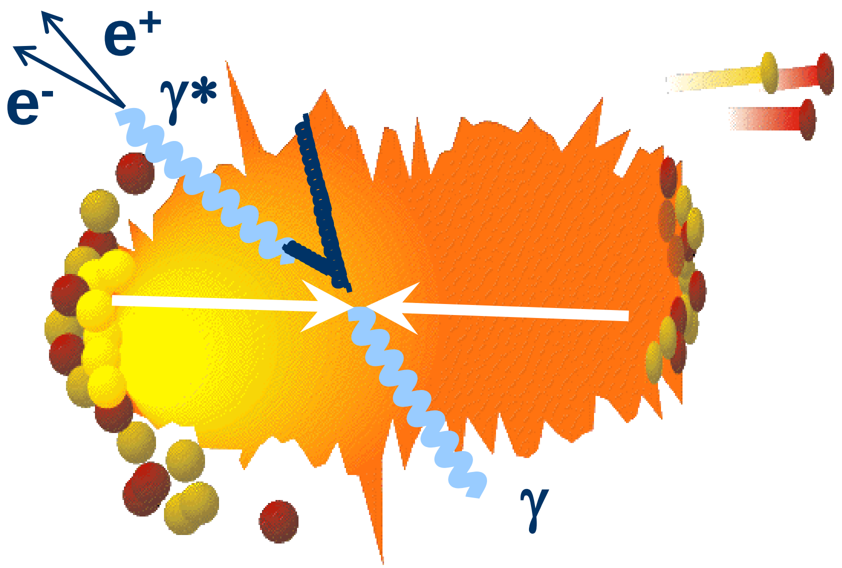
A thing we don’t want to throw out

Electromagnetic probes

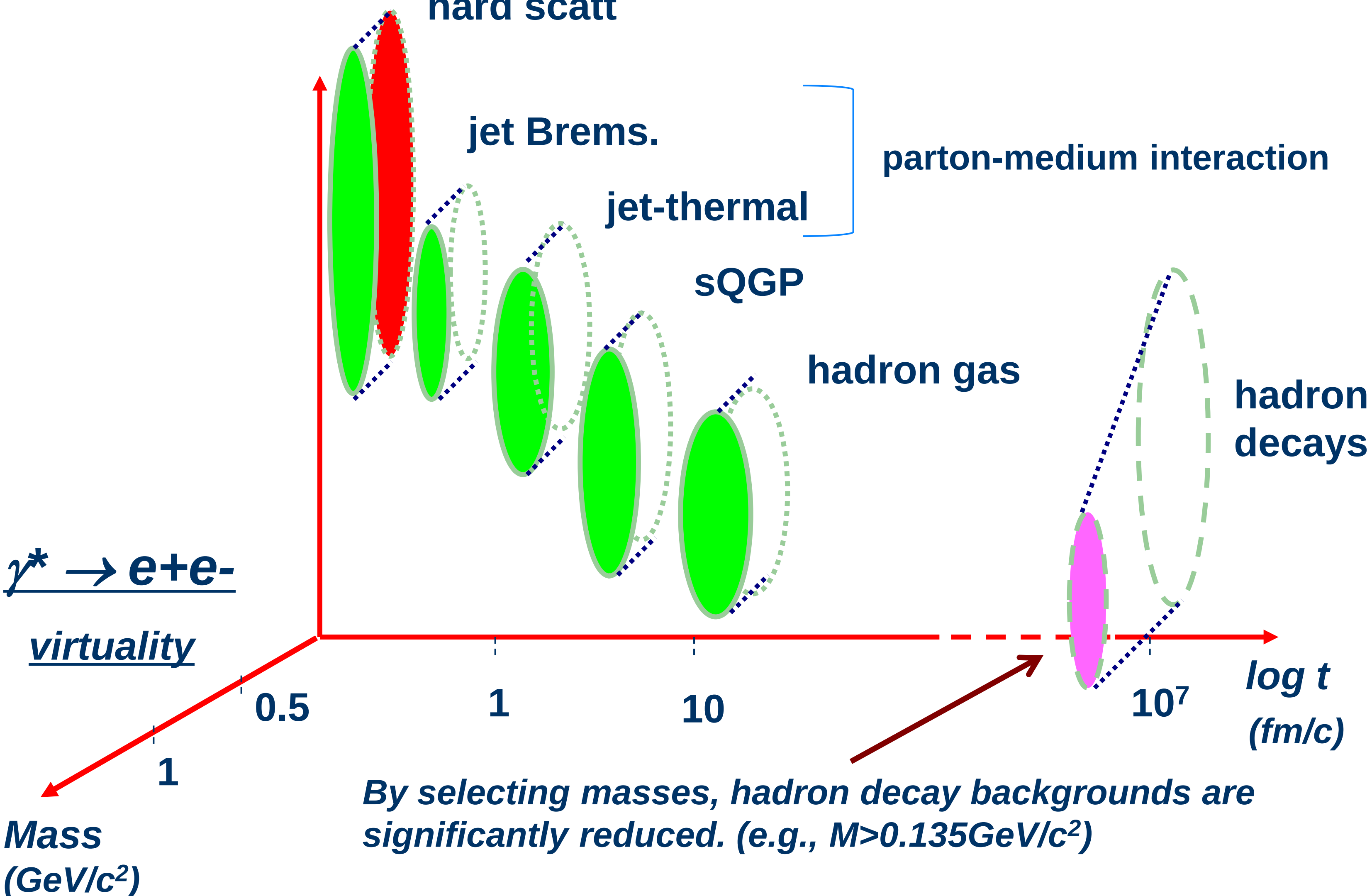
- Production Process
  - Compton and annihilation (LO, direct)
  - Fragmentation (NLO)
  - Escape the system unscathed
- Carry dynamical information of the state
- Temperature, Degrees of freedom
  - Immune from hadronization (fragmentation) process at leading order
  - Initial state nuclear effect
    - Cronin effect (k_T broardening)

Photon Production: **Yield $\propto \alpha\alpha_s$**





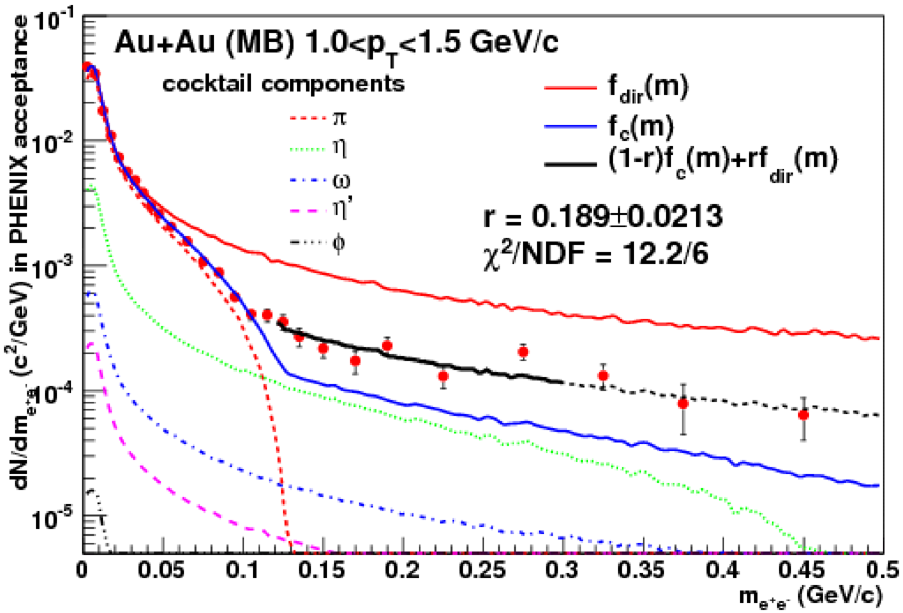
Possible sources of photons



By selecting masses, hadron decay backgrounds are significantly reduced. (e.g., M>0.135GeV/c²)

Low p_T photons with very small mass

PRL**104**,132301(2010), arXiv:0804.4168



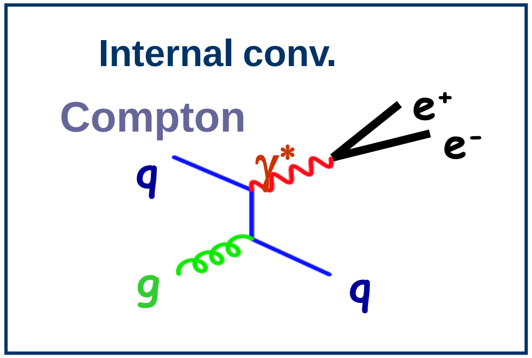
One parameter fit: $(1\text{-}r)f_c + r\ f_d$

f_c: cocktail calc., f_d: direct photon calc.

- Focus on the mass region where π^0 contribution dies out
- For $M \ll p_T$ and $M<300\text{MeV}/c^2$
  - $q\bar{q} \rightarrow \gamma^*$ contribution is small
  - Mainly from internal conversion of photons
- Can be converted to real photon yield using Kroll-Wada formula
  - Known as the formula for Dalitz decay spectra

$$\frac{1}{N_\gamma}\frac{dN_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)\frac{1}{m_{ee}}\left|F(m_{ee}^2)\right|^2\left(1-\frac{m_{ee}^2}{M^2}\right)^3$$

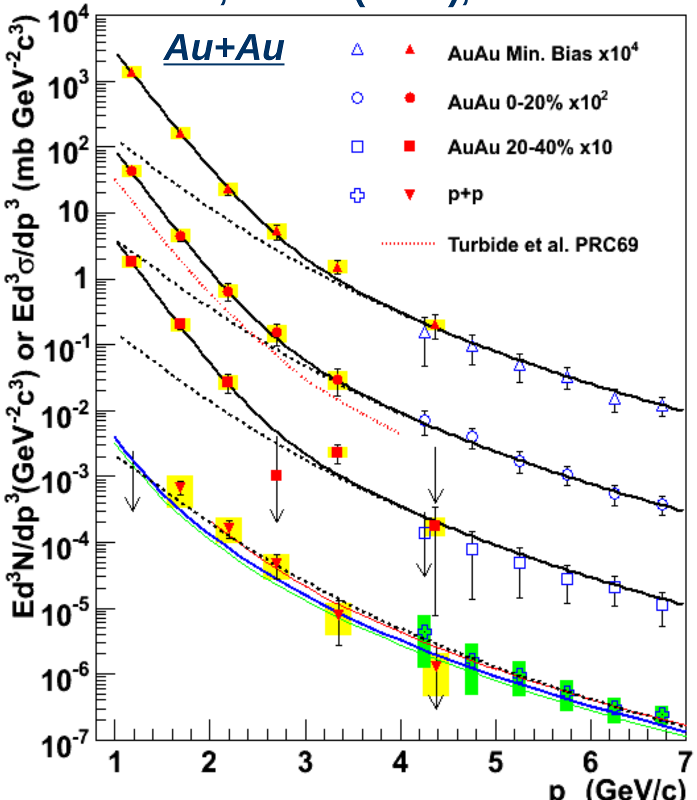
$$r = \frac{\gamma^*_{dir}(m>0.15)}{\gamma^*_{inc}(m>0.15)} \propto \frac{\gamma^*_{dir}(m\approx 0)}{\gamma^*_{inc}(m\approx 0)} = \frac{\gamma_{dir}}{\gamma_{inc}}$$

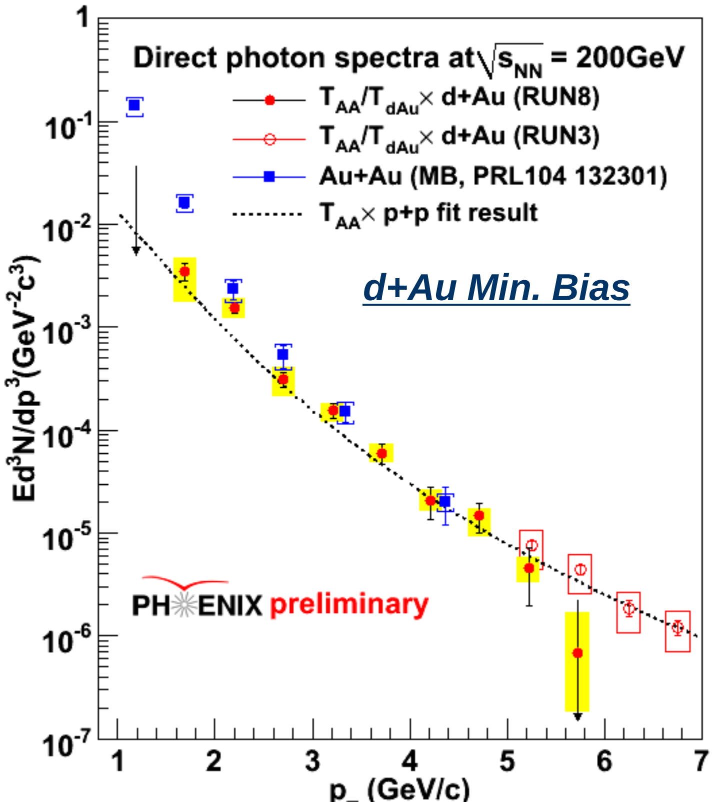


Low p_T photons in Au+Au (thermal?)

- Inclusive photon × $\gamma_{dir}/\gamma_{inc}$
- Fitted the spectra with p+p fit + exponential function
  - $T_{ave} = 221 \pm 19^{stat} \pm 19^{syst}$ MeV (Minimum Bias)
- Nuclear effect measured in d+Au does not explain the photons in Au+Au

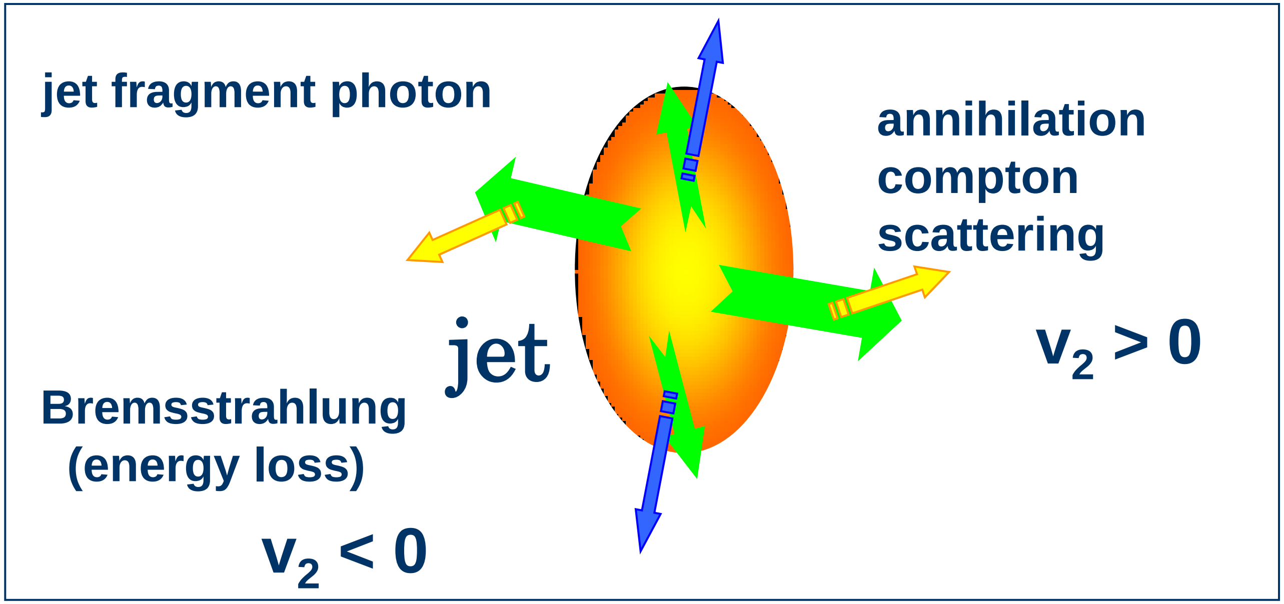
PRL104,132301(2010), arXiv:0804.4168





Photon source detector

- Depending the process of photon production, path length dependence of direct photon yield varies
  - v_2 of the direct photons will become a source detector
  - Later thermalization gives larger v_2

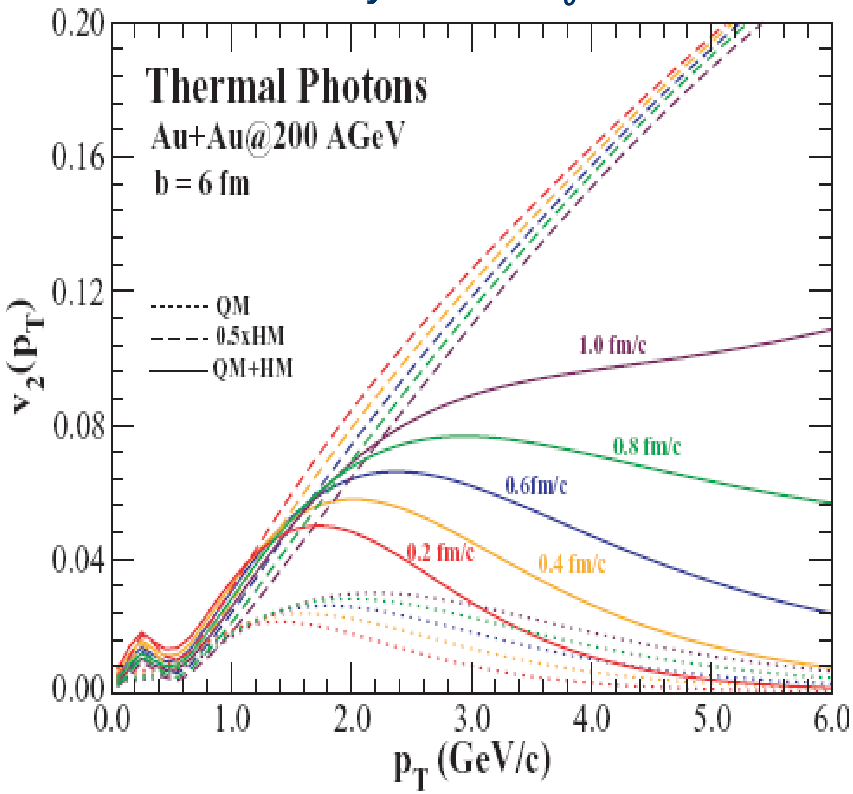


<u>**For prompt photons: v_2~0**</u>

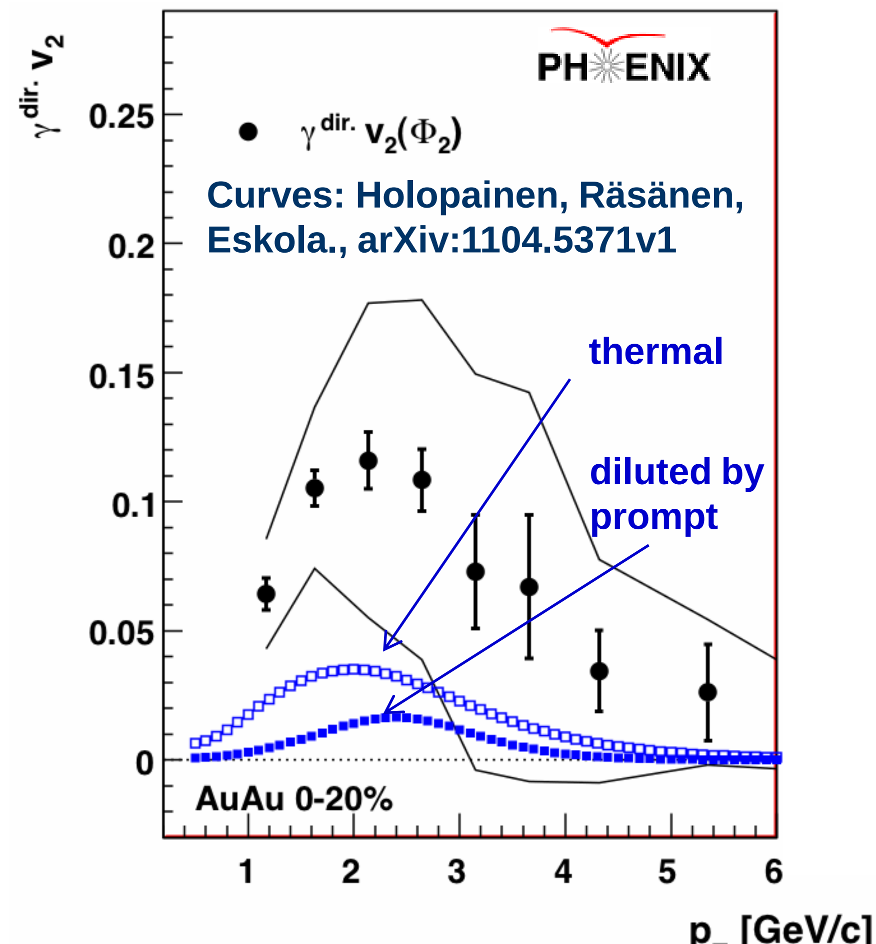
What we learn from model comparison

- Later thermalization gives larger v_2 (QGP photons)
- Large photon flow is not explained by models

Hydro after τ_0

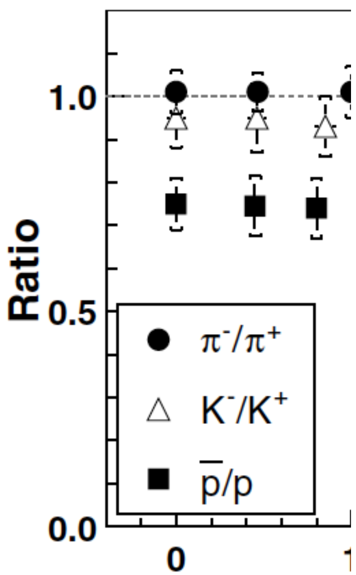


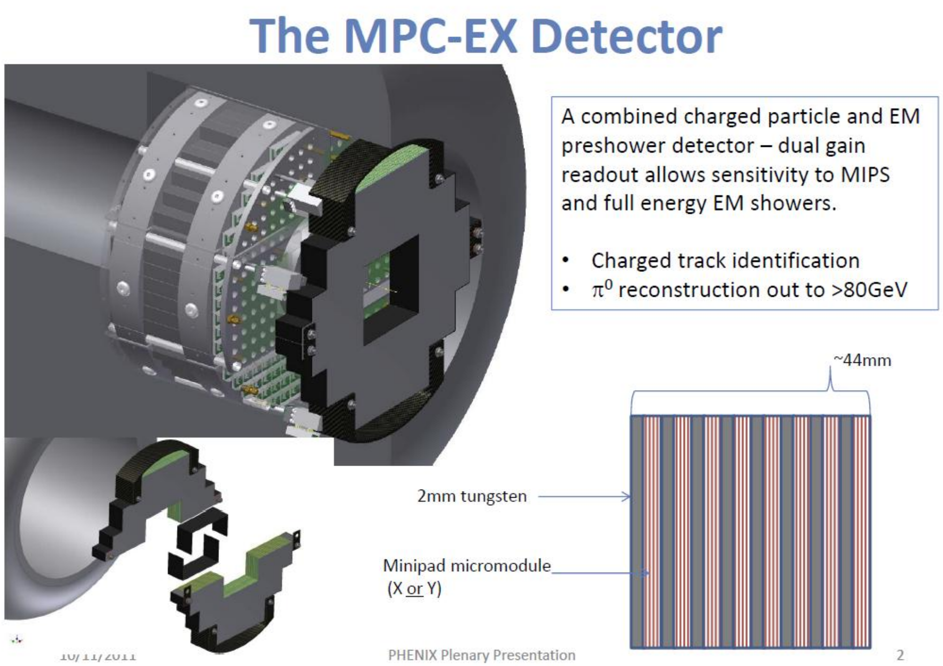
Chatterjee, Srivastava PRC79, 021901 (2009)

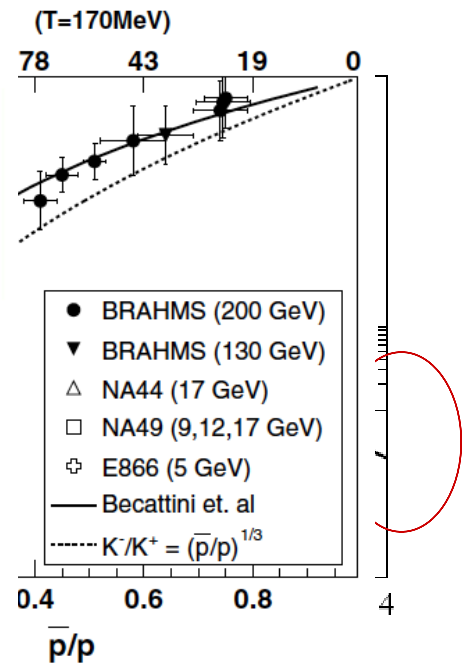


Another interest ~rapidity dependence~

- Forward direct photons may shed light on time evolution scenario
  - Real photons, γ^*->ee, γ^*->$\mu\mu$
- Higher rapidity goes, earlier the stage we may be able to explore
  - e.g., priv. comm. K. Itakura. Glasma dynamics, through photons
- Higher the rapidity goes, higher the baryon density we may be able to reach
  - BRAHMS plot. Another good way to access to the critical point?
- MPC-EX and/or Muon arm upgrades in PHENIX (Covering 1<|y|<3)
  - Needs serious studies of how high in centrality we can go

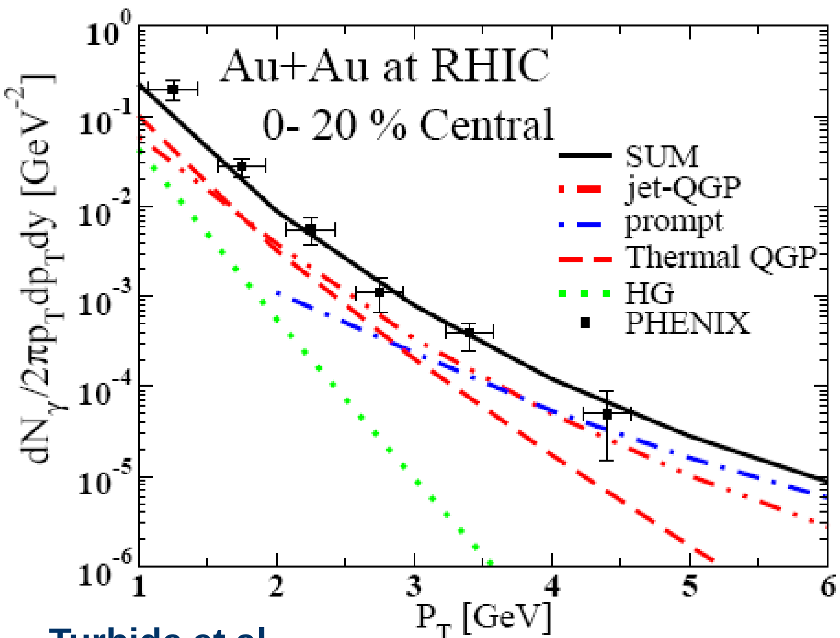




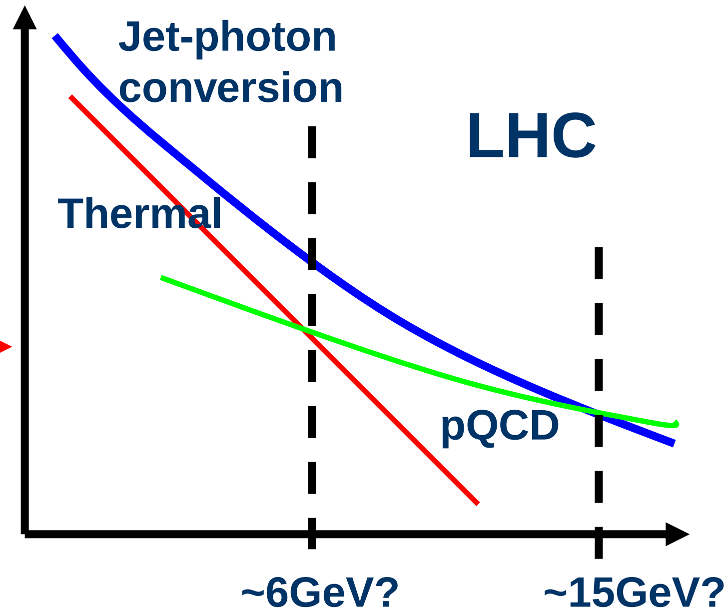


My LHC favorite

- A calculation tells that even in low pT region(pT~2GeV/c), jet-photon conversion significantly contributes to total
- What do we expect naively? (or guessively?)
  - Jet-Photon conversions $\propto$ Ncoll $\times$ Npart $\times$ $(s^{1/2})^8 \times$ f(xT), “8” is xT-scaling power
  - Thermal Photons $\propto$ Npart $\times$ (equilibrium duration) $\times$ f($(s^{1/2})^{1/4}$)
  - ***Bet: LHC sees huge Jet-photon conversion contribution over thermal?***
- Together with v_2 measurement, the “thermal region” would be a new probe of medium response to partons



Turbide et al., arXiv:0712.0732



Summary

- PHENIX has major upgrades in the near term future (~five years)
  - HBD to tag and reject electron-pairs that have small opening angles. Installed in Run-10 and completed mission. Analysis on going.
  - RPC & Muon Trigger to measure timing of muons in order to select muons from a same bunch-crossing. Installed in Run-11
  - VTX to measure DCA of tracks, and tag D, B originated electrons Installed in Run-11. Now in repair for Run-12
  - FVTX to measure DCA of tracks in forward rapidity region. To be installed in Run-12
  - MPC-EX to measure direct photons/π^0 in forward rapidity region

- Many studies to be done at RHIC in LHC era

- Direct photon measurement is very important at RHIC.
  - Should explore new degrees of freedom: Elliptic flow has been measured.
  - Rapidity dependence of direct photon production is a key to understand time evolution of collision system.
  - High rapidity to find critical points?

Backup