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Yale University, Sep 1998

Can STAR Measure Quarkonium Production in AuAu Collisions?

– status of current studies –

- **Introduction**
- **The STAR Experiment**
  - **components relevant for J/Ψ measurement**
  - **trigger**
- **Particle Identification**
- **Estimates for J/Ψ production at RHIC**
  - **cross-section**
  - **kinematics**
- **Simulations**
  - **acceptance**
  - **signal**
  - **background**
  - **results**
- **Comments on charm**
- **Summary**

Lot of work done by: T. LeCompte (Argonne) and Manual Calderon (Yale)

Introduction

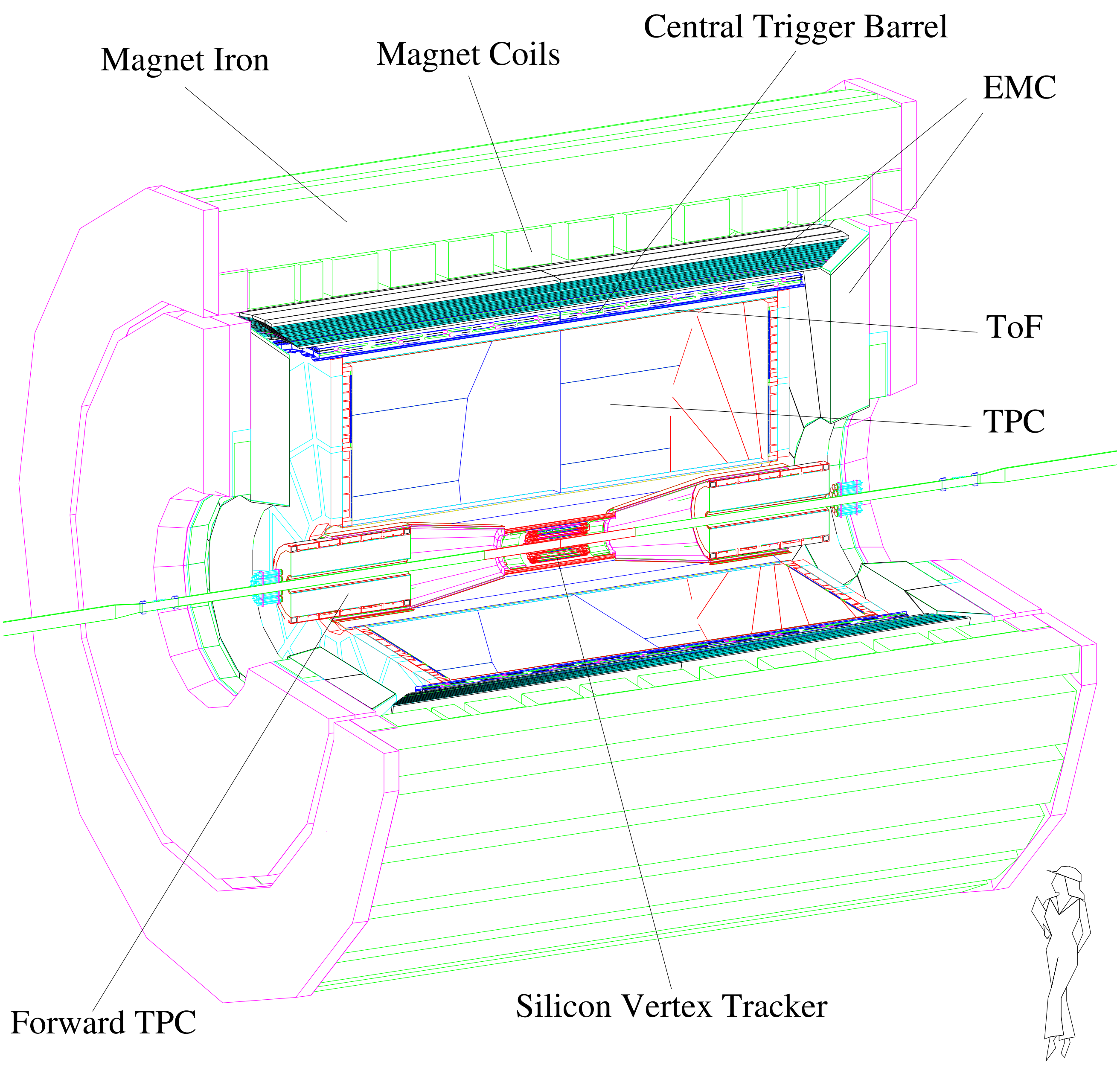
- STAR is designed for:
  - study of charged particles spectra, emphasis on hadrons
  - measurement and correlation of global observables event-by-event
  - study of hard scattering processes
- it is not designed for:
  - measurement of lepton pairs
  - measurement of rare particles/decays
- therefore STAR:
  - is not hadron blind
  - has to deal with thousands of charged tracks
  - runs with a moderate data taking rate ~ 1 Hz

$\Rightarrow$ STAR was not designed with Quarkonia in mind!

- BUT:
  - STAR has a large acceptance $\rightarrow N \propto$ acceptance^2
  - and good particle ID (PID) capabilities $\rightarrow$ electrons
  - and an EMC $\rightarrow$ e/h
  - and (hopefully soon) an excellent level-3 trigger $\rightarrow$ dielectron trigger

$\boxed{\text{Golden decay mode for STAR is: } \mathrm{J}/\Psi \rightarrow \mathrm{e}^+\mathrm{e}^-}$

The STAR Detector



Important for $J/\Psi \rightarrow e^+e^-$ measurement:

- Silicon Vertex Tracker SVT $\rightarrow$ tracking, PID
- Time Projection Chamber TPC $\rightarrow$ tracking, PID
- Electromagnetic Calorimeter EMC + EEMC $\rightarrow$ PID
- solenoidal magnet $\rightarrow$ momentum

Silicon Vertex Tracker

- 3 layers of SDD detectors
- $-1 < \eta < 1$, $\Delta\phi = 2\pi$
- impact parameter resolution $\sigma_b \approx 70\mu\mathrm{m}$ at 1 GeV/c
- PID via dE/dx, rejection of conversions ($b \neq 0$)

Time Projection Chamber

- 45 padrows
- high tracking efficiency ($\geq 90\%$)
- $-2 < \eta < 2$, $\Delta\phi = 2\pi$
- momentum resolution: $\sigma_p/p \leq 1\%$ for $p < 5$ GeV/c
- PID via dE/dx, particle momentum, tracking

Electromagnetic Calorimeter

- Pb-scintillator sampling em calorimeter
- stack and shower maximum detector
- barrel: $|\eta| < 1.0$, $\Delta\phi = 2\pi$
- endcap: $1.05 < |\eta| < 2.0$, $\Delta\phi = 2\pi$
- 120 modules, each: $|\eta| = 1$, $\Delta\phi = 6^\circ$
- resolution $\sim 16\%/\sqrt{E}$
- E measurement, e/h

The STAR Trigger

RHIC parameters for Au+Au, $\sqrt{s} = 200$ GeV:

- design: $\mathcal{L} = 2 \cdot 10^{26}$ cm^{-2} s^{-1} $\rightarrow$ $\sim$100 Hz central collisions
- 1999: $\sim 10\%$ of design value

STAR:

- max. TPC rate ≈ 100 Hz
- DAQ limit (tape): 1–2 Hz

Basic Trigger – L0:

- interaction/multiplicity trigger
- combined information CTB+MWC $\otimes$ ZDC $\otimes$ VPD $\otimes$ EMC
- more complex as it sounds ...

Other Trigger – L1, L2: future

High level trigger – L3:

- software trigger
- proposed by Frankfurt University
- currently reviewed
- can be ready for 1999

L3 is one of the key elements for a J/Ψ measurement

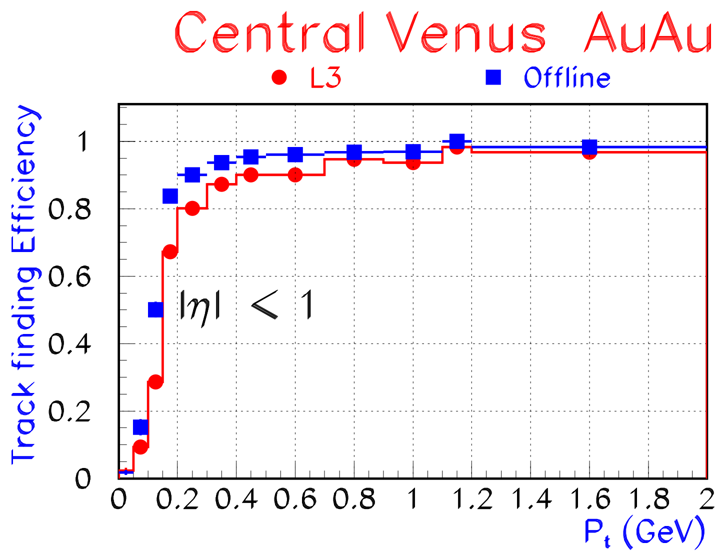
The Level-3 Trigger

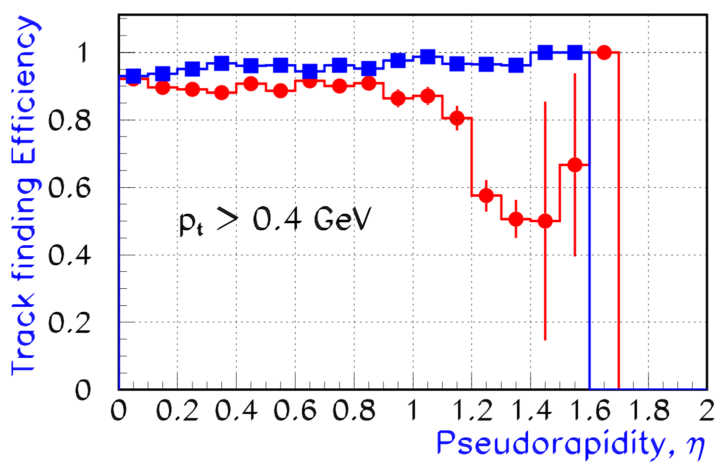
Basic Idea:

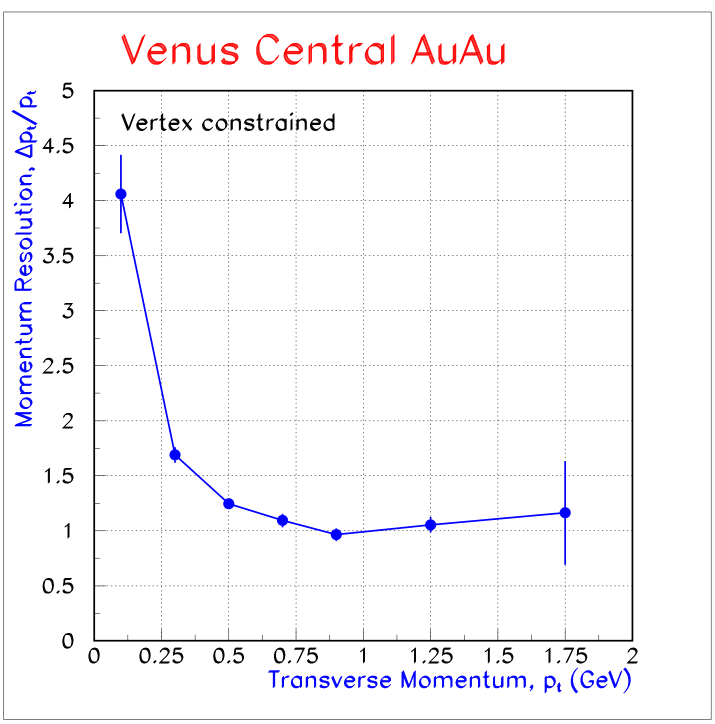
- pattern recognition in real time
- TPC tracking + PID (+ EMC)
- select events according to
  - event topology
  - specific signature

Implementation:

- one CPU for each TPC sectors
- reconstruction of full event/sector
- track merging
- hierarchical structure of processors
- $\Rightarrow$ scalable to 100 Hz !!!







J/Ψ trigger:

- find electron candidates
- loop over candidates
  - calculate mass with vertex constraint
  - select event if $|m - m_{J/\Psi}| < x \cdot \sigma_{res}$

plots: C. Struck, ICHEP '98

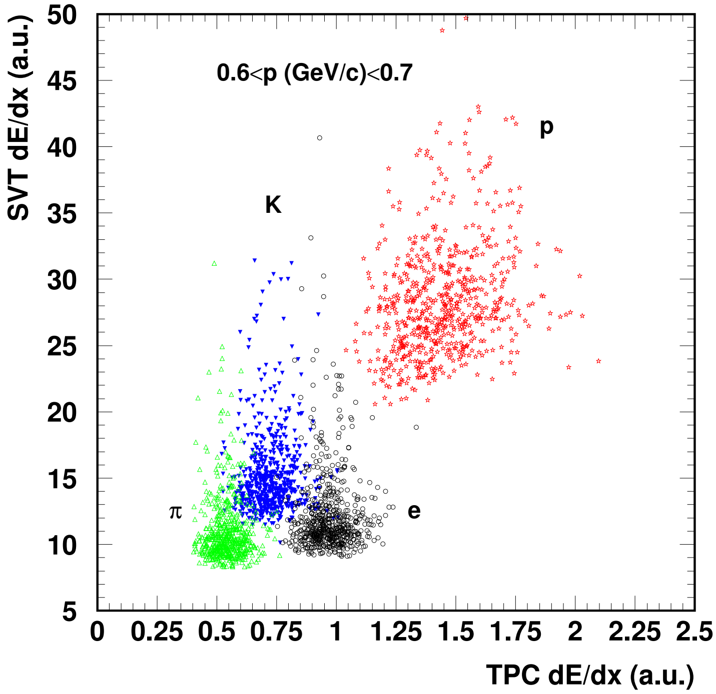
Particle Identification

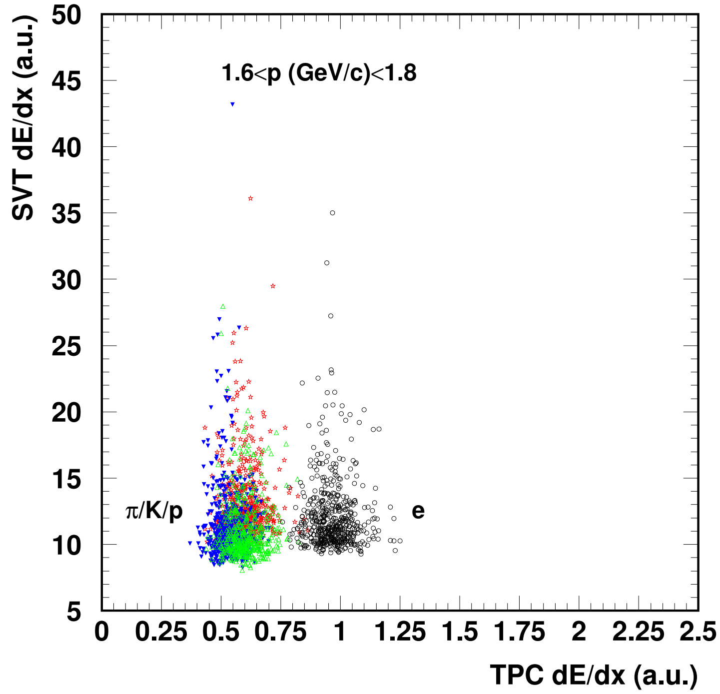
Tools for PID (in chronological order):

- dE/dx in TPC (45 measurements)
- dE/dx in SVT (3 measurements)
- E/p and shower profile in EMC

PID via dE/dx:

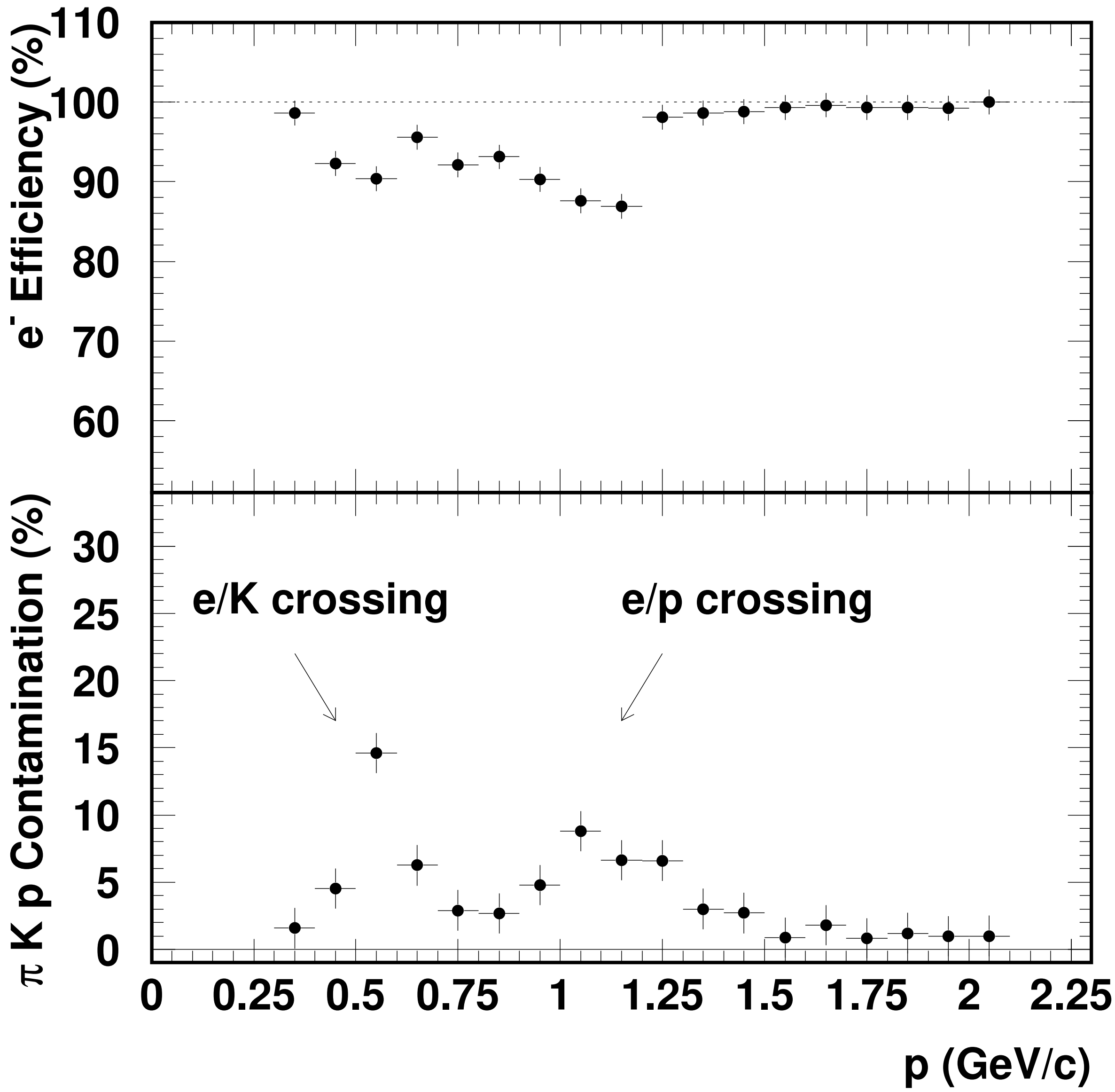
- combine dE/dx from SVT and TPC ($\sim 8\%$ dE/dx resolution each)
- exploit different profiles of Bethe-Bloch curves
- electrons always saturated (rel. plateau)





plots: B. Lasiuk, SN0312

$\Rightarrow$ surprising power of the SVT $\otimes$ TPC in e/h separation



plot: B. Lasiuk, SN0312

– PID via dE/dx usable up to 2.5 GeV/c

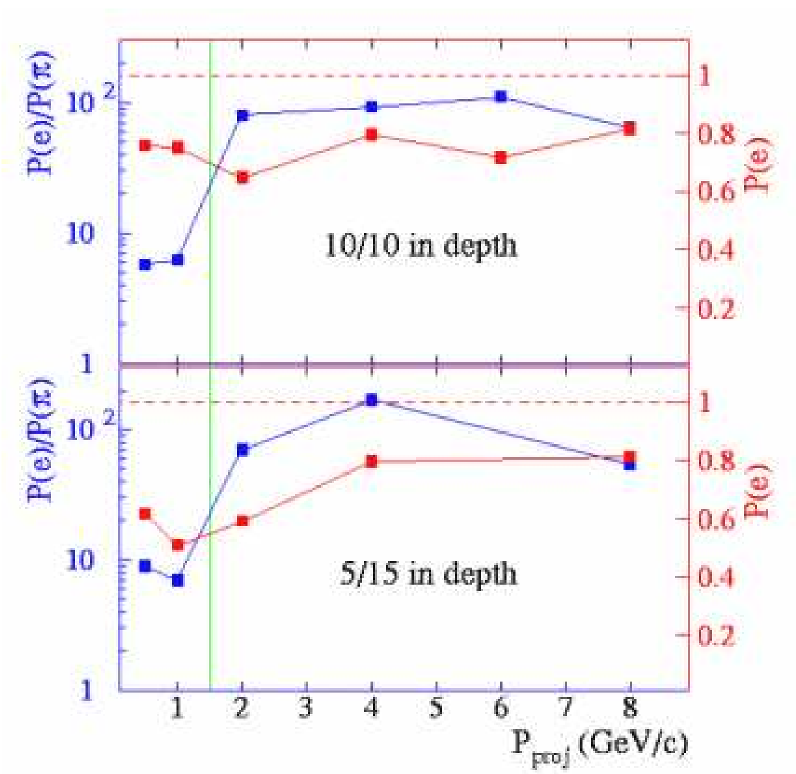
– hadron rejection factor $\gtrsim 10$

PID with the EMC:

1. E/p ≈ 1 for electrons, for hadrons well below
2. transverse shower energy profile (shower maximum detector)
3. longitudinal shower energy deposition
4. background: e.g. $\pi^- + p \rightarrow \pi^0 + n, \quad \pi^0 \rightarrow \gamma\gamma \Rightarrow$ E/p ≈ 1

EMC simulations and prototype tests:

- SMD improves rejection power of the non-segmented EMC by factor 3
- Small Prototype EMC: hadron suppression (80-120 for $\mathrm{p}_\perp > 2\ \mathrm{GeV}/c$)
- Below $1\ \mathrm{GeV}/c$ supression ~ 10
- Problematic: extrapolation between 1 and $2\ \mathrm{GeV}/c$



plot: B. Llope, http://www.rhic.bnl.gov/STAR/html/spec_l/STARSpec_pid.html

Estimates for J/Ψ production at RHIC

STAR Charm Fest '97:

- what ever we use might be wrong
- use *one* common (STAR-wide) estimate
- at least we will *all* be wrong by the *same* factor

J/Ψ cross-section

$\Rightarrow$ use numbers from *Hard Probe Collaboration* (LBL-36948, CERN-95-05)

$$\sigma_{pp} = 0.62 \mu b \ \text{ at } \ \sqrt{s} = 200 \text{GeV} \ \text{ and } \ y = 0$$

$$\sigma_{AA} = 3881 \ \times \ \sigma_{pp} = 2.4 mb \ \text{ for } \ \sigma / \sigma_{tot} = 10\%$$

$$f = 2 \cdot 10^{26} \times 2.4 mb = 0.48 Hz$$

$$\text{BR}(\text{J}/\Psi \rightarrow \text{e}^+\text{e}^-) \times f = 0.06 \times 0.48 Hz = 0.03 Hz$$

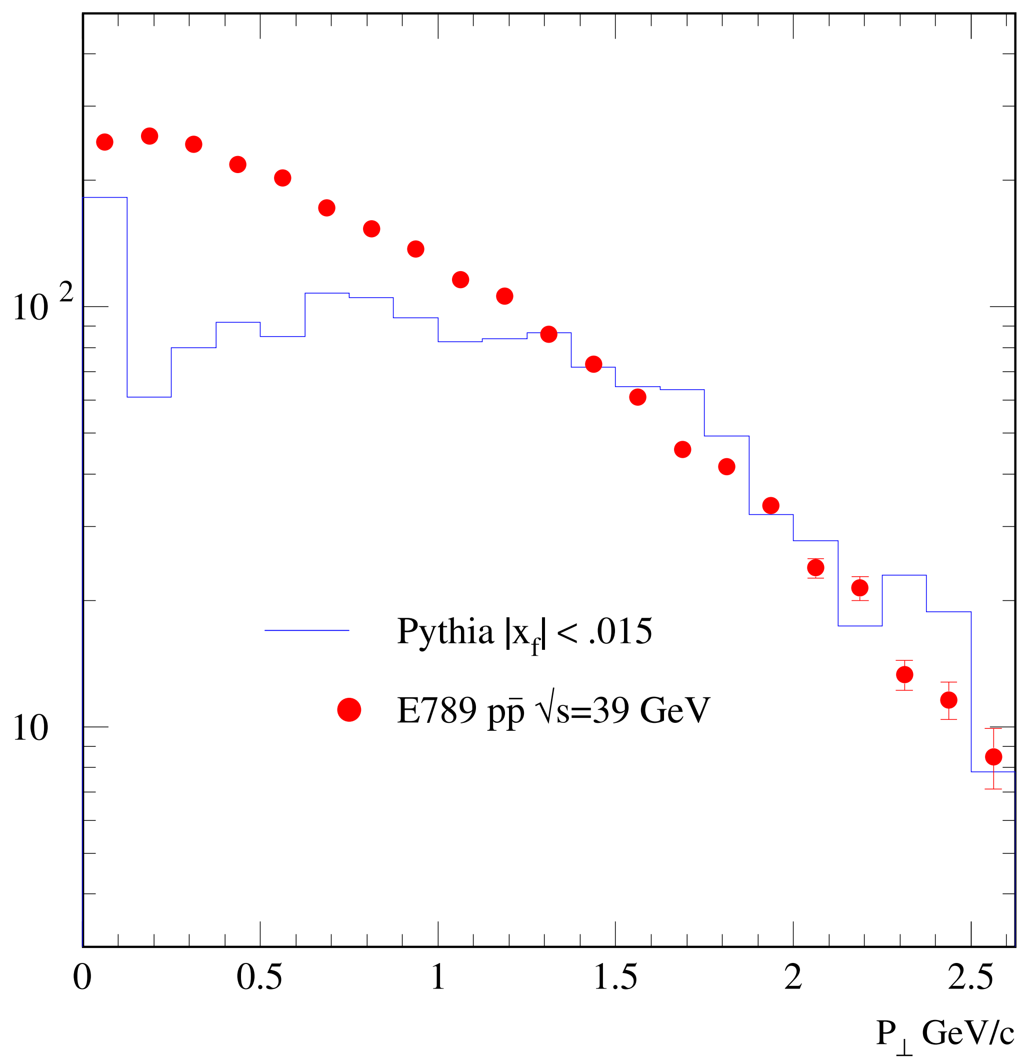
$$\boxed{\text{STAR: } 0.03 \text{ Hz} \times \Delta y \times \varepsilon_{eff} \times \varepsilon_{trigger} \times S = ?}$$

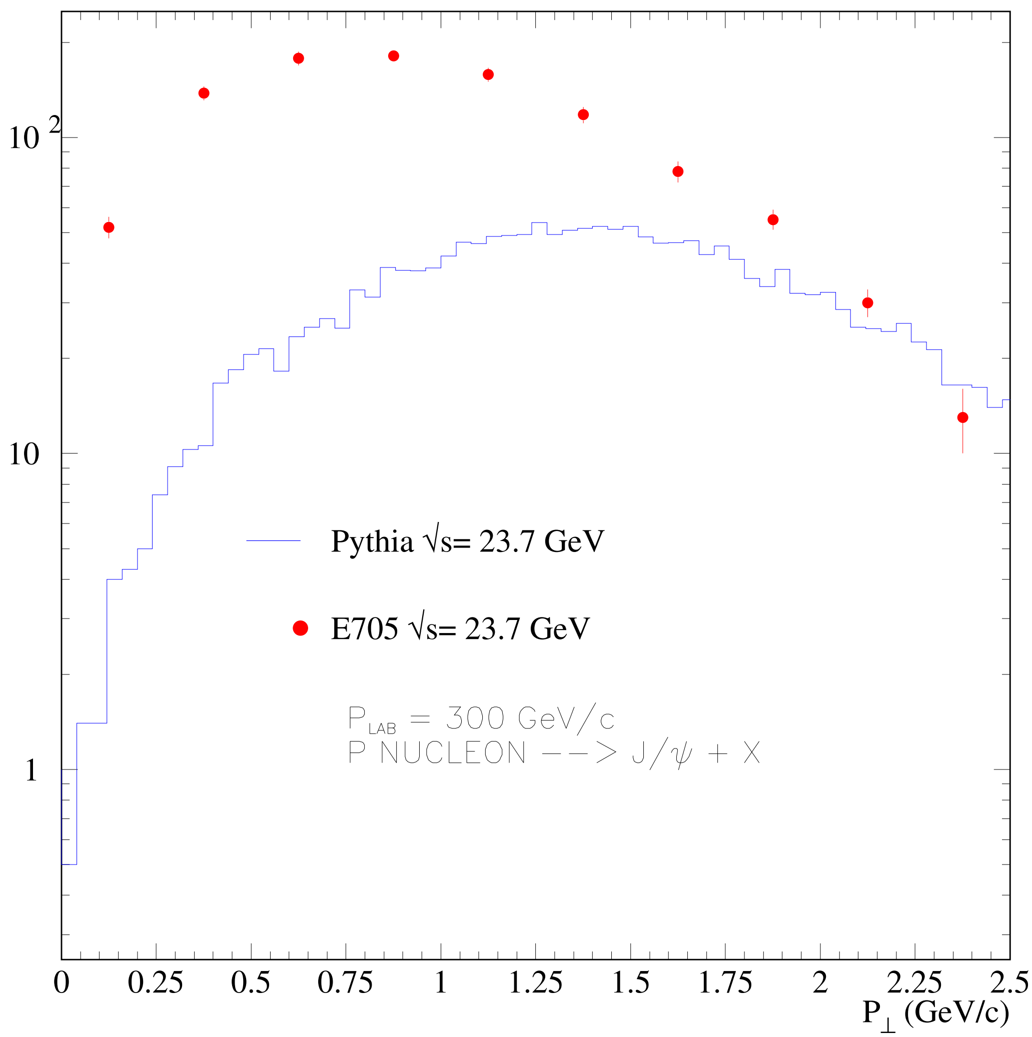
$\Delta y, \varepsilon_{eff}, \varepsilon_{trigger}$ can be estimated (simulations)
suppression/absorption S = 1 (for now)

J/Ψ kinematics

$$\textbf{Which} \quad \frac{dN}{dp_\perp dy} \quad \textbf{to use?}$$

- PYTHIA
  - based on LUND string fragmentation model
  - Lund does not produce J/Ψ in any quantity
  - PYTHIA is *tuned* to produce any J/Ψ
  - and is not doing a good job in the low $p_\perp$ region





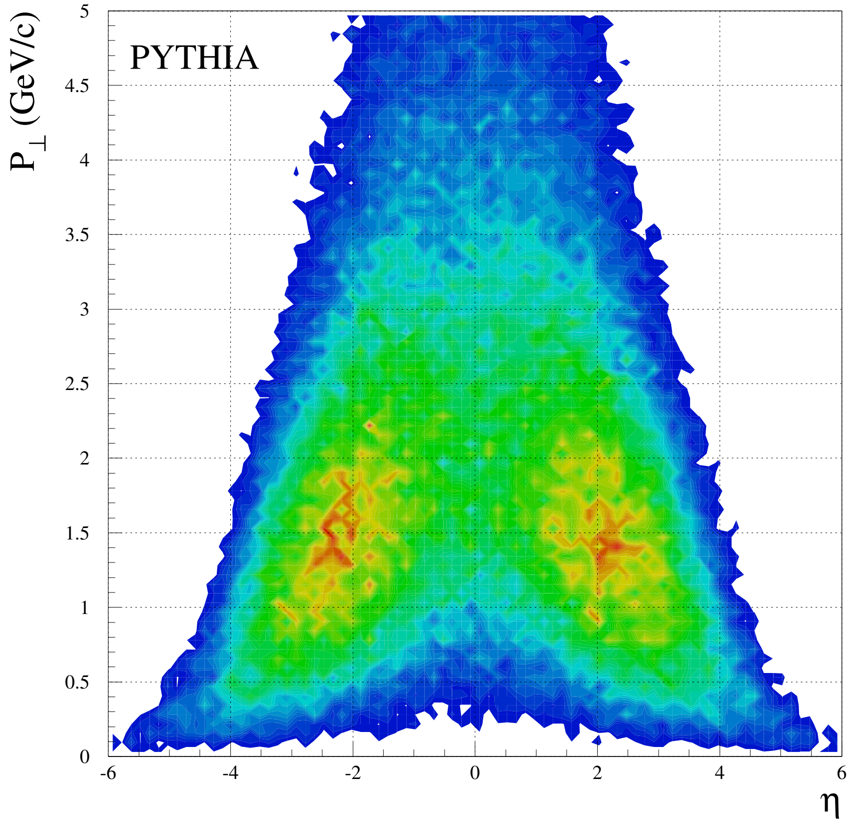
- PYTHIA predicts 70% of J/Ψ from χ (should be $\sim$30%)
  $\rightarrow$ influence on $\mathrm{p}_\perp$ spectra
- PYTHIA underestimates J/Ψ production (at CDF $\sim$ 3.5)
- PYTHIA has severe problems at low $\mathrm{p}_\perp$

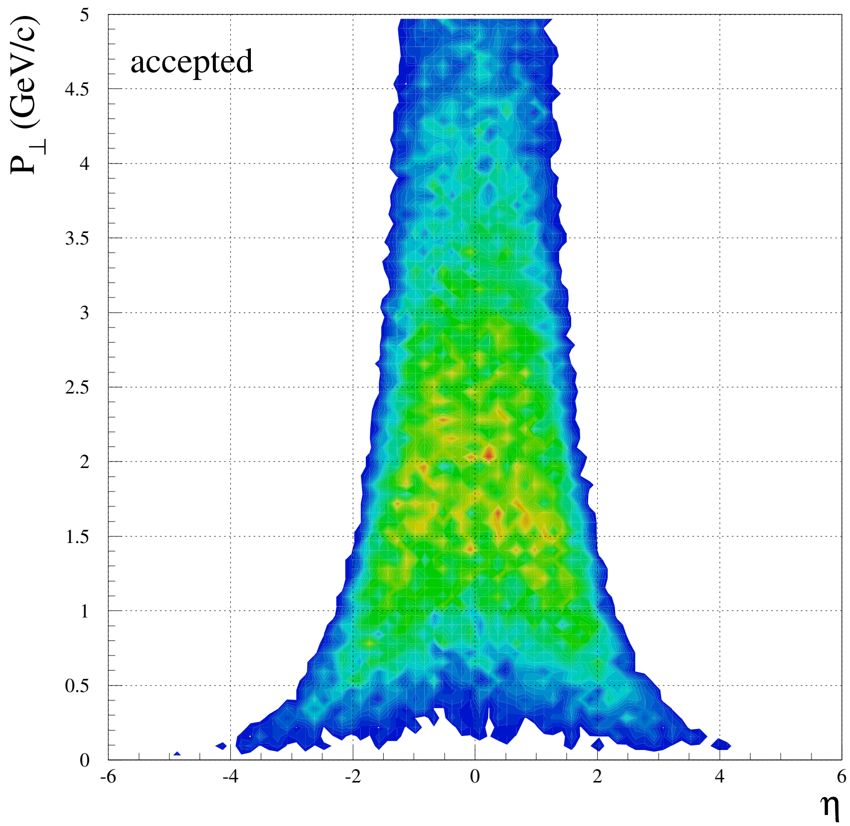
but its simple to use and more or less transparent $\Rightarrow$ current choice

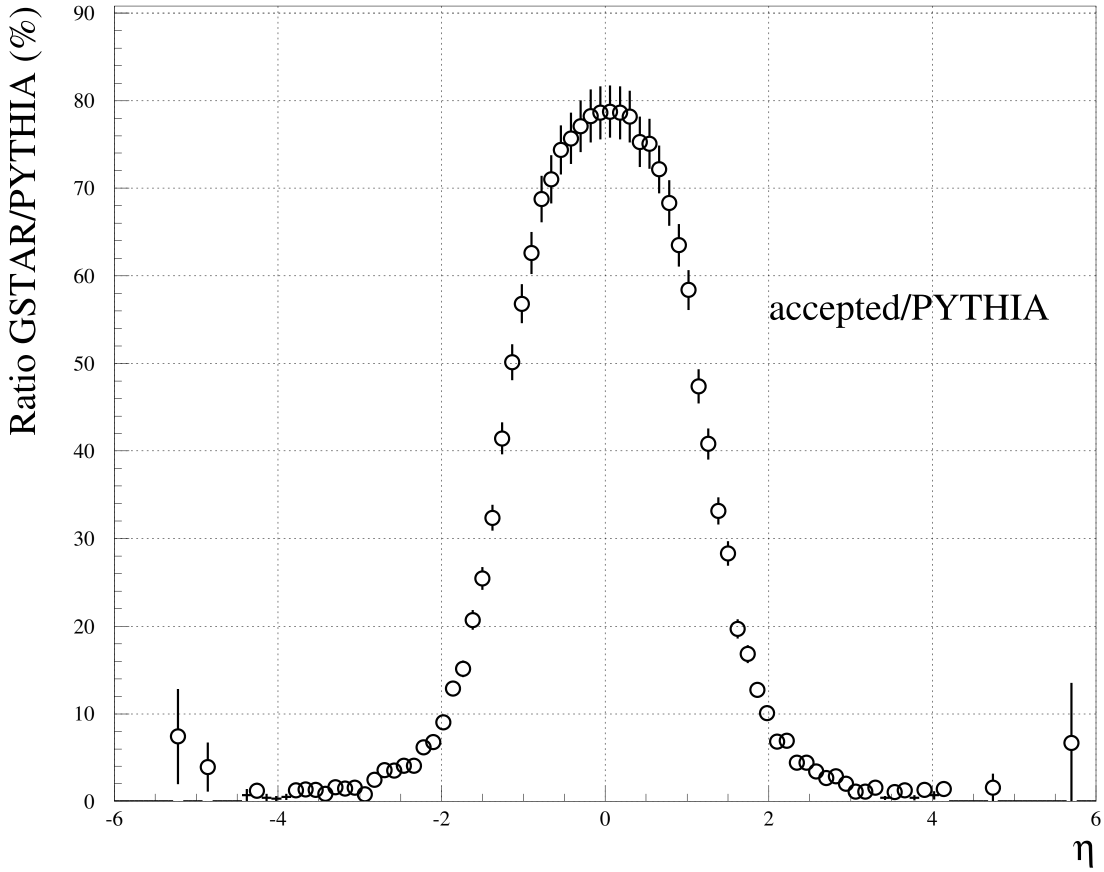
- Model calculations by D. Kharzeev
  - $\mathrm{d}N/\mathrm{dp}_\perp\mathrm{d}y$ as table ✔
  - but unfortunately coarse binning (exactly where it hurts STAR)
  - will replace PYTHIA as soon as available

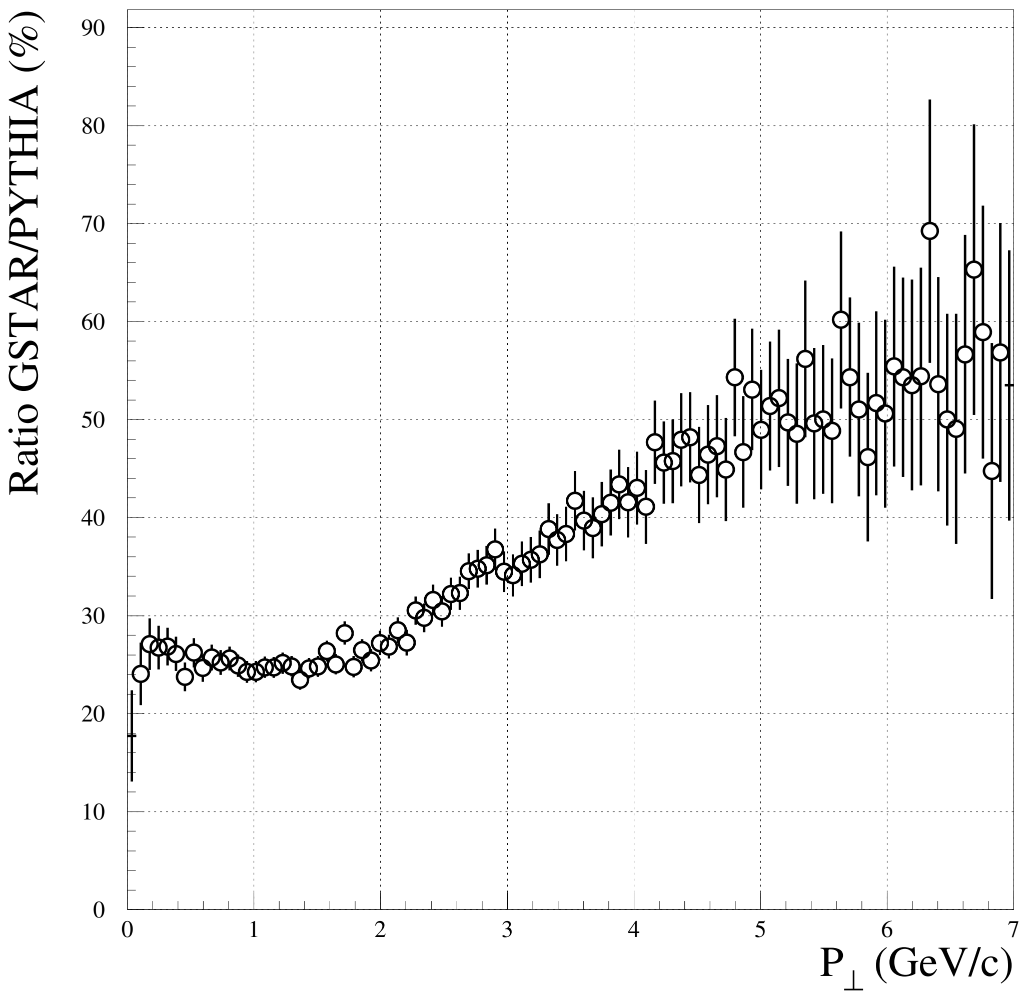
J/Ψ acceptance in STAR

geometrical acceptance: both electrons in TPC acceptance, each > 20 hits





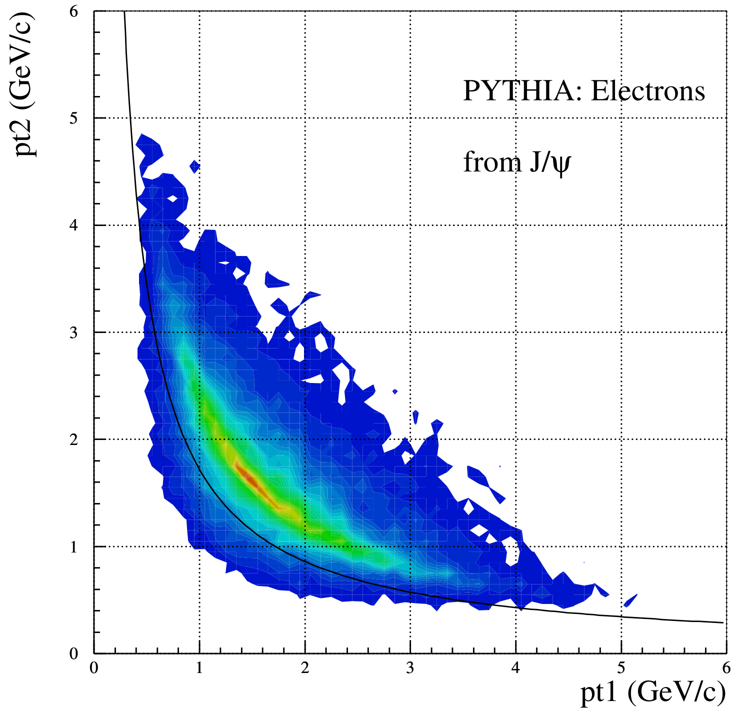

Ratio GSTAR/PYTHIA (%)
accepted/PYTHIA
η

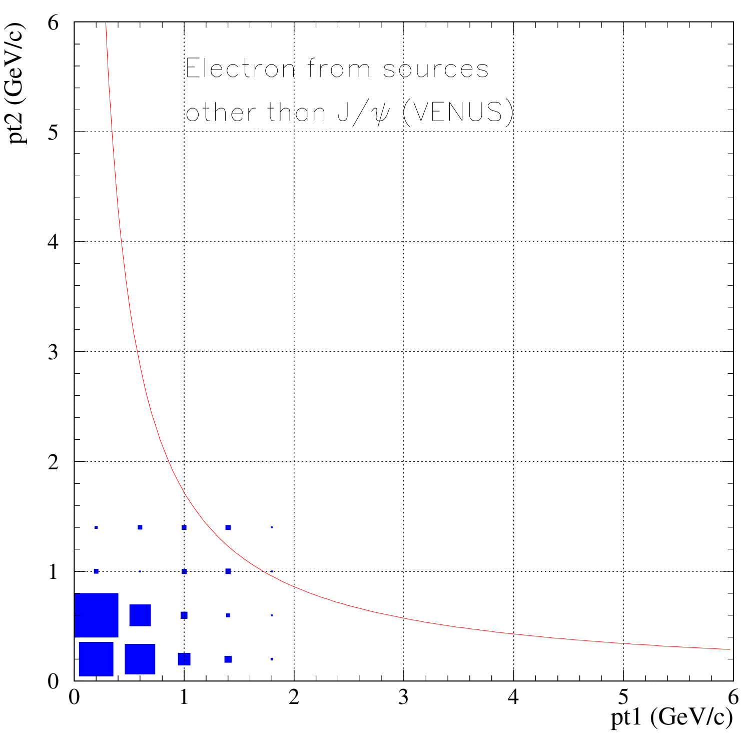

Ratio GSTAR/PYTHIA (%)
P⊥ (GeV/c)

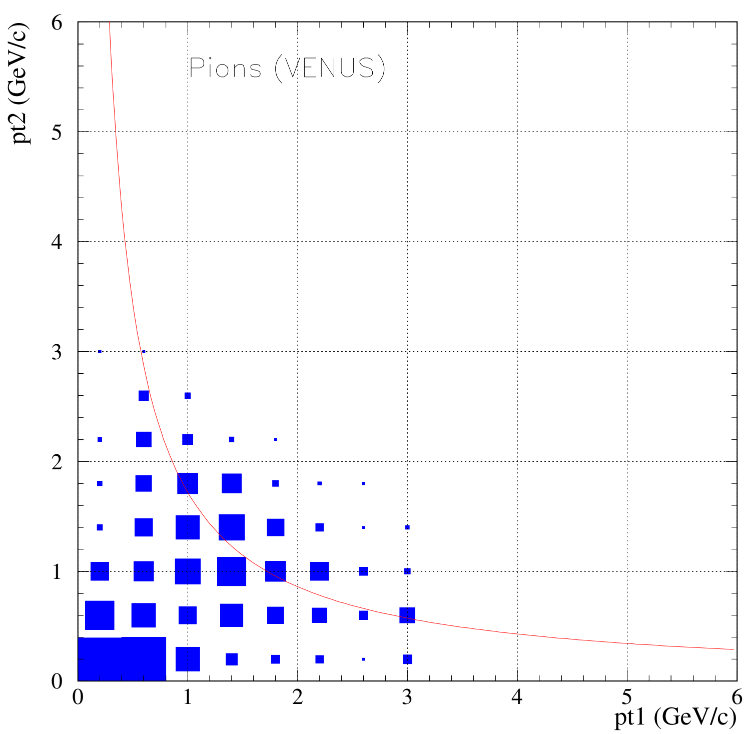
Acceptance for Signal and Background Electrons

background:

- electrons (soft)
  - π^0, η, η' Dalitz decays ($e^+e^-\gamma$)
  - photo conversions in material
  - $\Rightarrow$ combinatorial background
- electrons (hard)
  - open charm
  - Drell-Yan
  - $\Rightarrow$ correlated background
- misidentified pions
  - $\Rightarrow$ combinatorial background







$\Rightarrow$ misidentified pions main background source

Simulations

STAR: TPC 'sees' ~ 5000 tracks in a central collisions
(Generation + Geant + Analysis takes a loooong time)

J/Ψ MC studies:

- full MC chain for rare particles not convenient
- determine parameters separately (fast simulator)
  - 'J/Ψ only' study (many events), no tracking
  - background study (few events), no tracking
  - compile numbers using results (tracking efficiency, PID, ...) from other studies
  - many parameters (PID) only 'best guess'

Caution:

- can we understand the expected yield within a factor of 2 ?
- are assumptions about efficiencies and hadron rejection realistic enough ?
- generator dependencies ?

The simulations can only give an idea of what sort of hadron rejection we need to do physics.

Signal

- $\mathrm{J}/\Psi \rightarrow \mathrm{e}^{+}\mathrm{e}^{-}$ in acceptance : 0.025 Hz
  (each track > 40 hits + 3 SVT hits + EMC)
- both electrons tracked and identified: $(0.9 \times 0.7)^2 = 0.4$
- $\mathrm{p}_{\perp}$-cut:

cut	efficiency
$\mathrm{p}_{\perp}(e) > 1.0$ GeV$/c$	0.72
$\mathrm{p}_{\perp}(e) > 1.5$ GeV$/c$	0.23
$\mathrm{p}_{\perp}(e) > 2.0$ GeV$/c$	0.06
$\mathrm{p}_{\perp}(e) > 2.5$ GeV$/c$	0.025

big error bars here !

Assume:

- one year RHIC running $\rightarrow 10^7$s
- nominal luminosity $\mathcal{L} = 2 \cdot 10^{26}$ cm^{-2} s^{-1}
- 100% trigger efficiency

$\Rightarrow$ annual STAR yield:

cut	approx. annual yield ($\mathrm{J}/\Psi \rightarrow \mathrm{e}^{+}\mathrm{e}^{-}$)
$\mathrm{p}_{\perp}(e) > 1.0$ GeV$/c$	$72 \cdot 10^4$
$\mathrm{p}_{\perp}(e) > 1.5$ GeV$/c$	$2.5 \cdot 10^4$
$\mathrm{p}_{\perp}(e) > 2.0$ GeV$/c$	$0.6 \cdot 10^4$

Background

$\Rightarrow$ HIJING b=0 Au+Au

Fake Electrons:

- use HIJING b=0 Au+Au
- form hadron pairs in: $3.0 < m < 3.2$ GeV$/c^2$

cut	approx. annual yield (h^+ h^-)
$p_\perp(e) > 1.5$ GeV$/c$	$2360 \cdot 10^6$
$p_\perp(e) > 2.0$ GeV$/c$	$80 \cdot 10^6$

- hadron suppression: (varies strongly with $p_\perp$)
  - TPC + EMC: $1.5 < p_\perp < 2.5$ GeV$/c$
  - EMC: $p_\perp > 2.5$ GeV$/c$

Real Electrons:

- Dalitz and Conversions
- form h-e and e-e pairs

cut	fake $e^\pm$ $h^\mp$ (conversions)	fake $e^\pm$ $h^\mp$ (Dalitz)	$e^\pm$ $e^\mp$ (Conv./Dalitz)
$p_\perp(e) > 1.5$ GeV$/c$	$0.16 \cdot 10^6$	$0.015 \cdot 10^6$	–
$p_\perp(e) > 2.0$ GeV$/c$	$0.03 \cdot 10^6$	–	–

- Conversion suppression:
  - impact parameter cut (not from primary vertex)

Results

cut	S	S/B	S_{eff}	Significance (σ)
$p_\perp(e) > 1.5$ GeV$/c$	$2.5 \cdot 10^4$	1:5	2300	48
$p_\perp(e) > 2.0$ GeV$/c$	$0.6 \cdot 10^4$	2:1	3000	55

A lot of "best guesses" can be made better

Trigger:

- rate of detectable $J/\Psi \rightarrow e^+e^-$ in detector: 0.025 Hz
- STAR: 1Hz
- assume L3 copes with L0 rate (~ 100 Hz)

To keep loss of signal (dead-time) small:

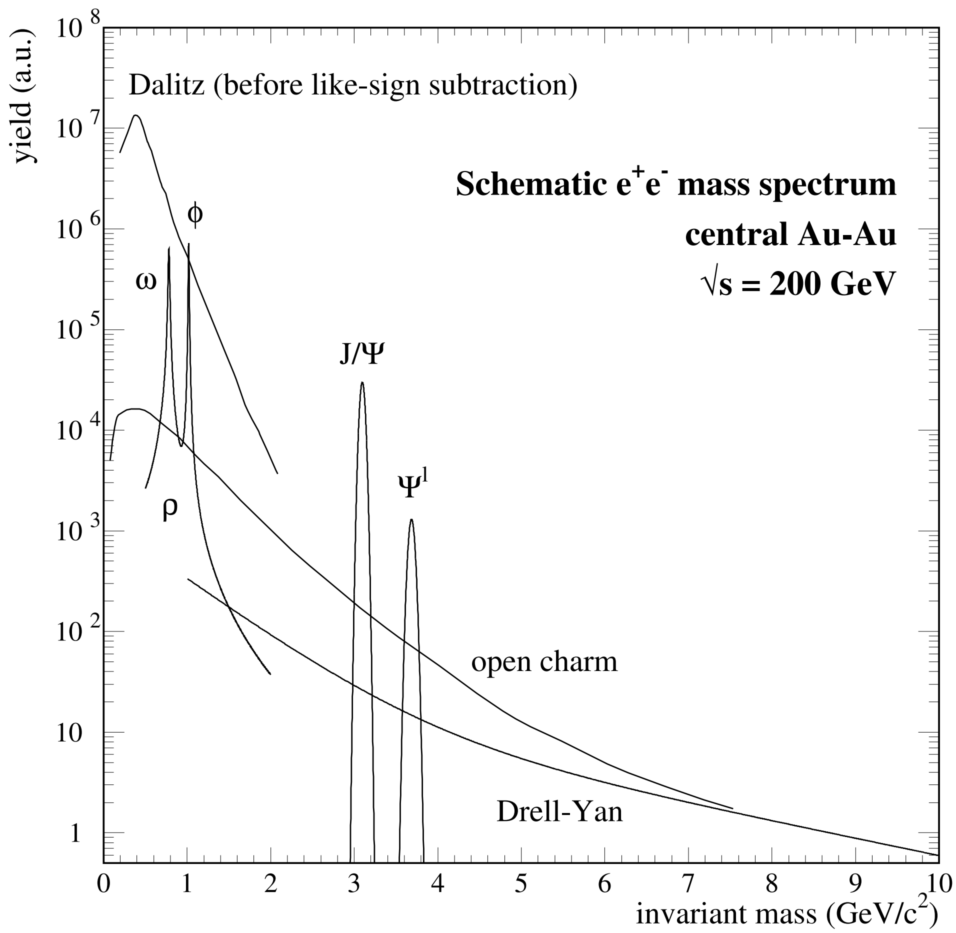
$$\frac{S}{B} > \frac{0.025 \text{ Hz}}{1 \text{ Hz}} = \frac{1}{40}$$

$\Rightarrow$ need L3 trigger studies

- Ups:
  - jet quenching (signal requires 2 high-$p_\perp$ tracks)
  - recent improvements in EMC design
  - use cuts on the pair instead at the single electron level
- Downs:
  - trigger losses
  - $\bar{p}$ in EMC (fake electrons)
  - Hijing underestimates background

Comments on charm

- SPS: suppression $S \equiv \frac{\mathrm{J}/\Psi}{D{-}Y}$ $\rightarrow$ study $S(\mathrm{E}_\perp)$
  - many systematic errors cancel out
  - absolute normalizations always difficult (sometimes impossible)
- RHIC:
  - D-Y continuum dominates only $m > 7\ \mathrm{GeV}/c^2$
  - D-Y quark induced process
  - charm is gluon induced process
  - change in structure functions may alter charm/D-Y
  - J/Ψ sits on open charm continuum (J/Ψ/charm ?)
  - QGP: higher gluon flux $\rightarrow$ increased charm production



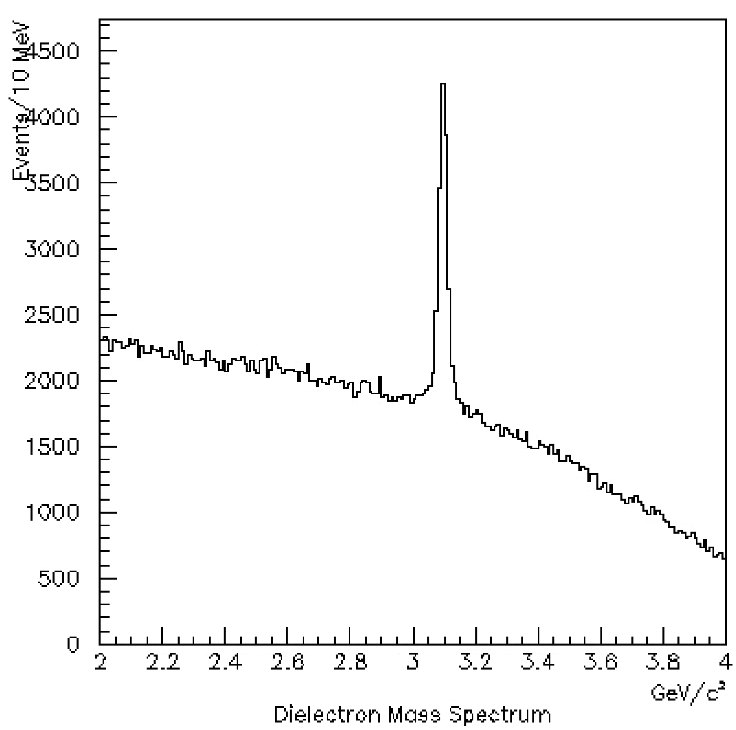
To fully understand J/Ψ production (suppression)

$\Rightarrow$ we have to measure charm production

- PHENIX:
  - e-μ coincidence, open charm $\rightarrow$ Y. Akiba
- STAR:
  - $D^0 \rightarrow K + \pi,\ D^{\pm} \rightarrow K + \pi + \pi$
    * S/B too low
    * requires upgrade of SVT (future)
  - $c \rightarrow K + X$
    * lack of PID for K with $\mathrm{p}_{\perp} > 1\ \mathrm{GeV}/c$
  - open charm: $c \rightarrow \mathrm{e}^{+} + X,\ \bar{c} \rightarrow \mathrm{e}^{-} + X$
    * very similar to J/Ψ study
    * add impact parameter cut (distinguish DY/charm)

Summary

- Charmonium physics in STAR looks possible
- There are good reasons to believe that STAR can
  - find J/Ψ's via $J/\Psi \rightarrow e^+e^-$
  - and even find open charm via semileptonic decays
- the requirements are:
  - L3 trigger
  - EMC
  - both are on their way ...
- we are extremely sensitive to the level of background
- predictions not yet entirely stable
- small inprovements in hadron rejection correspond to large improvement in S/B
- current results at this point just a snapshot of work in progess



plot:T. LeCompte