

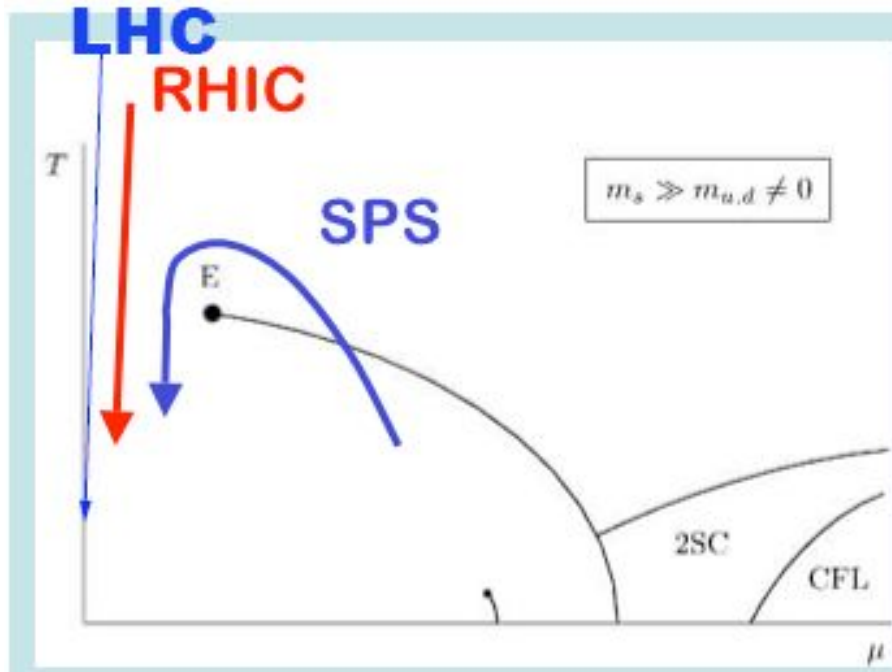
# **Физика столкновений тяжелых ионов**

# Содержание

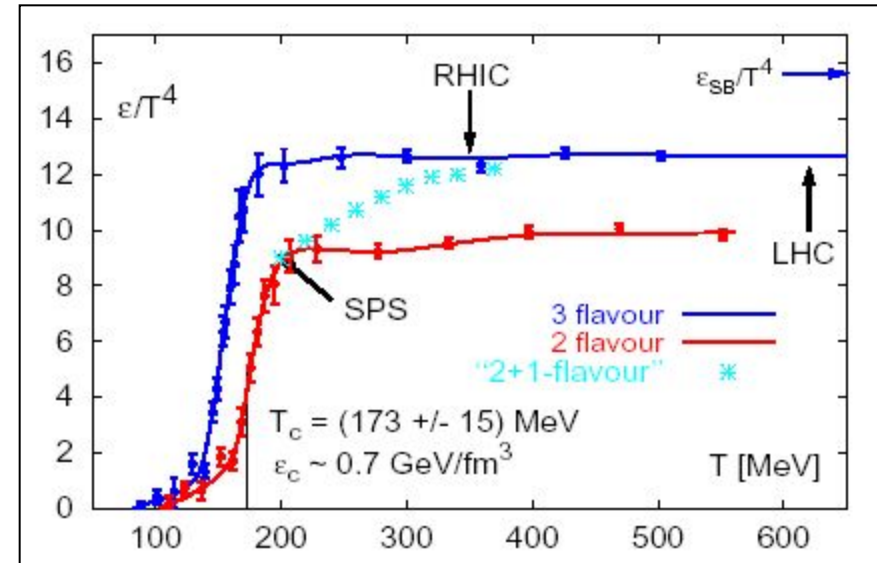
- Введение
- Фазовые переходы в сжатой и нагретой ядерной материи
- Пространственно-временная картина  $AA$  взаимодействий
- Уроки RHIC
- Столкновения тяжелых ионов на LHC
- Ультрапериферические столкновения на LHC
- Заключение

# Фазовые переходы в сжатой и нагретой ядерной материи

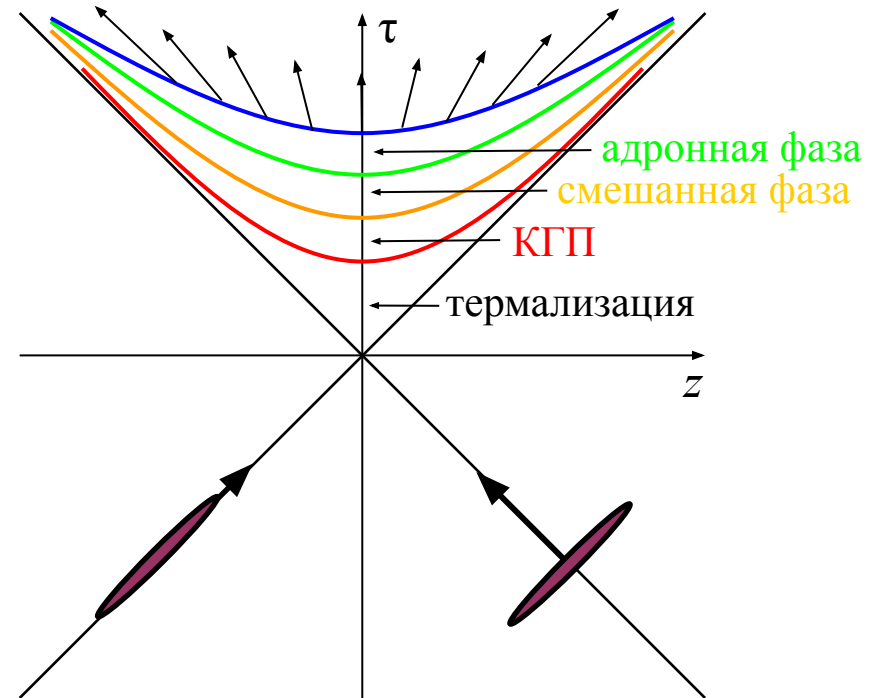
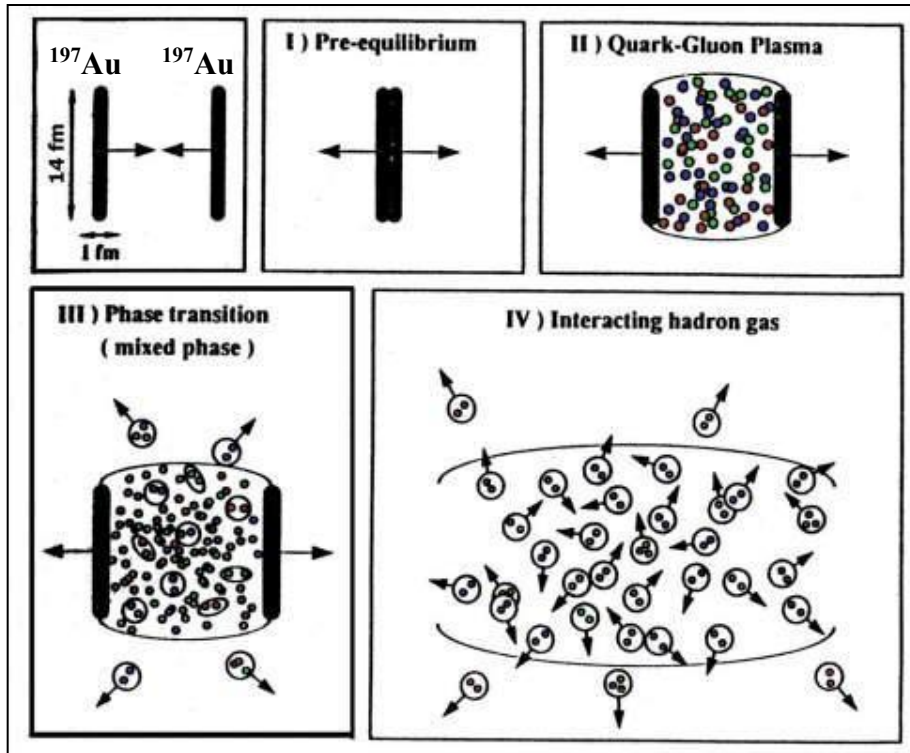
фазовая диаграмма  
состояния адронной материи



плотность энергии как  
функция температуры



# Пространственно-временная картина ядро-ядерных взаимодействий



# Сигналы нового состояния вещества

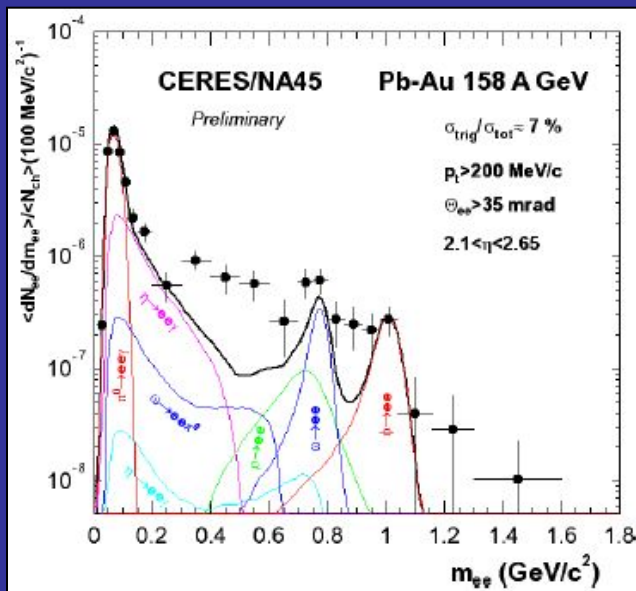


жесткие сигналы («реликтовое излучение»)  
( $e^+e^-$ ,  $\gamma$ ,  $\gamma\gamma$ , струи,  $J/\psi$  подавление)

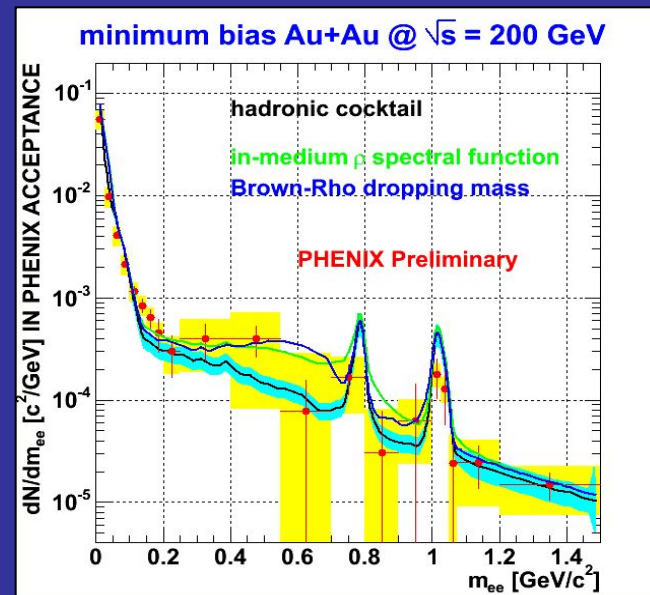
мягкие (адроны)  
(коллективные течения,  
корреляции, выходы  
странных частиц)

## Жесткие сигналы

### 1. Дилептоны



SPS

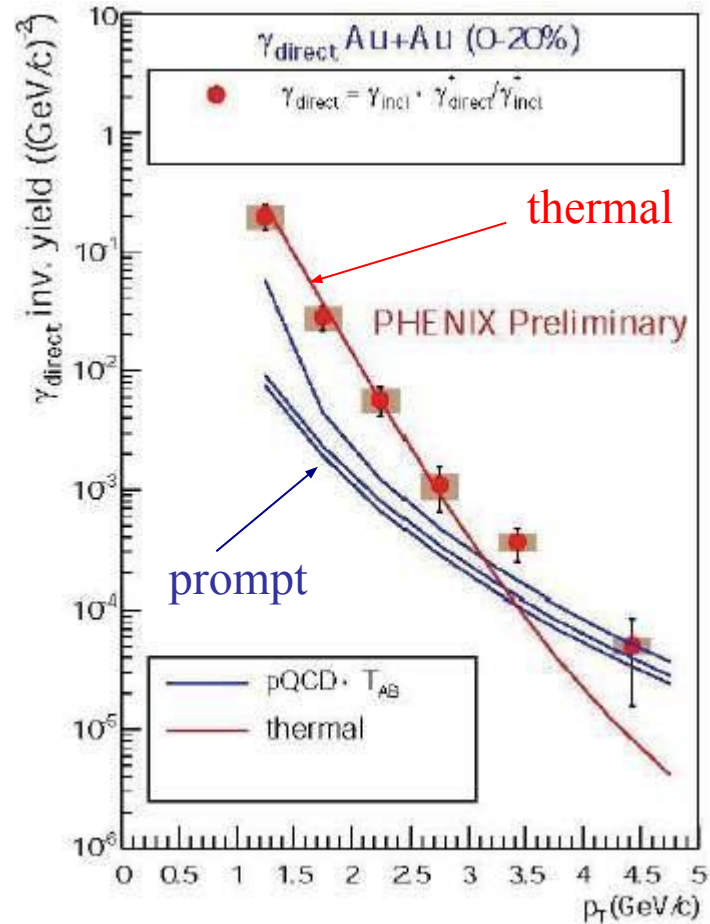


RHIC

Вывод: новый механизм генерации дилептонов на ранней стадии (кварк-антикварковая аннигиляция, восстановление киральной симметрии)

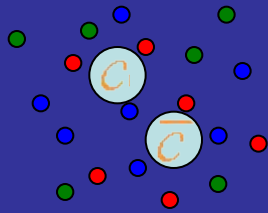
# КГП на RHIC

## прямые фотоны



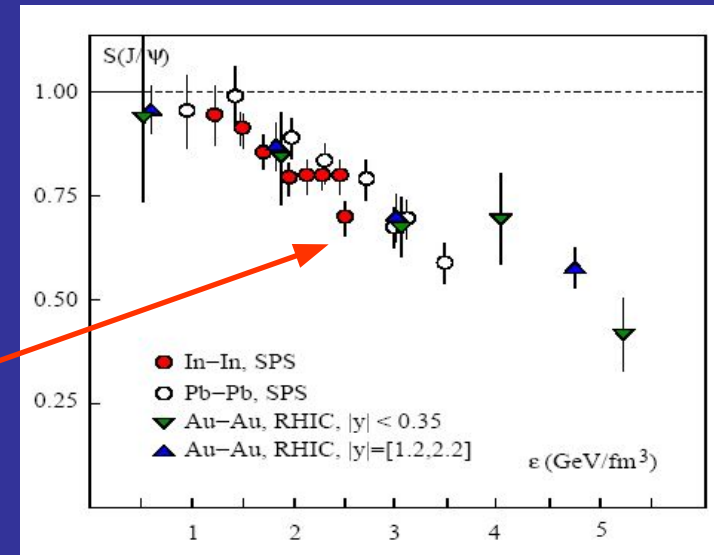
**DATA = prompt + thermal**

D. d'Enterria, D. Perresounko  
nucl-th/0503054



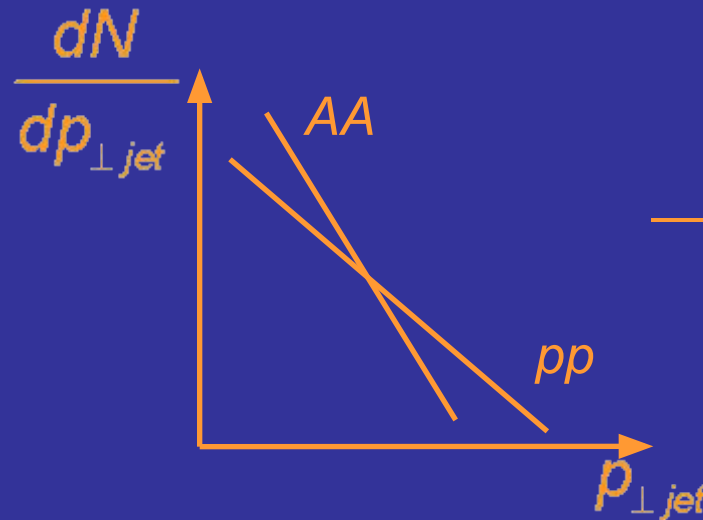
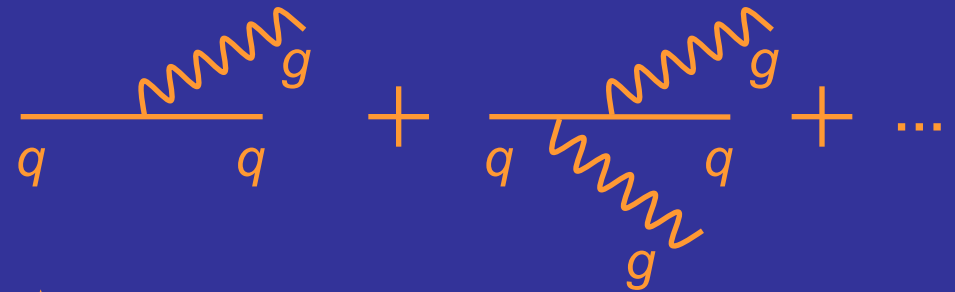
$r_D(T)$  — дебаевский радиус экранирования

$r_\psi > r_D(T)$  — выход  $J/\psi$  подавлен



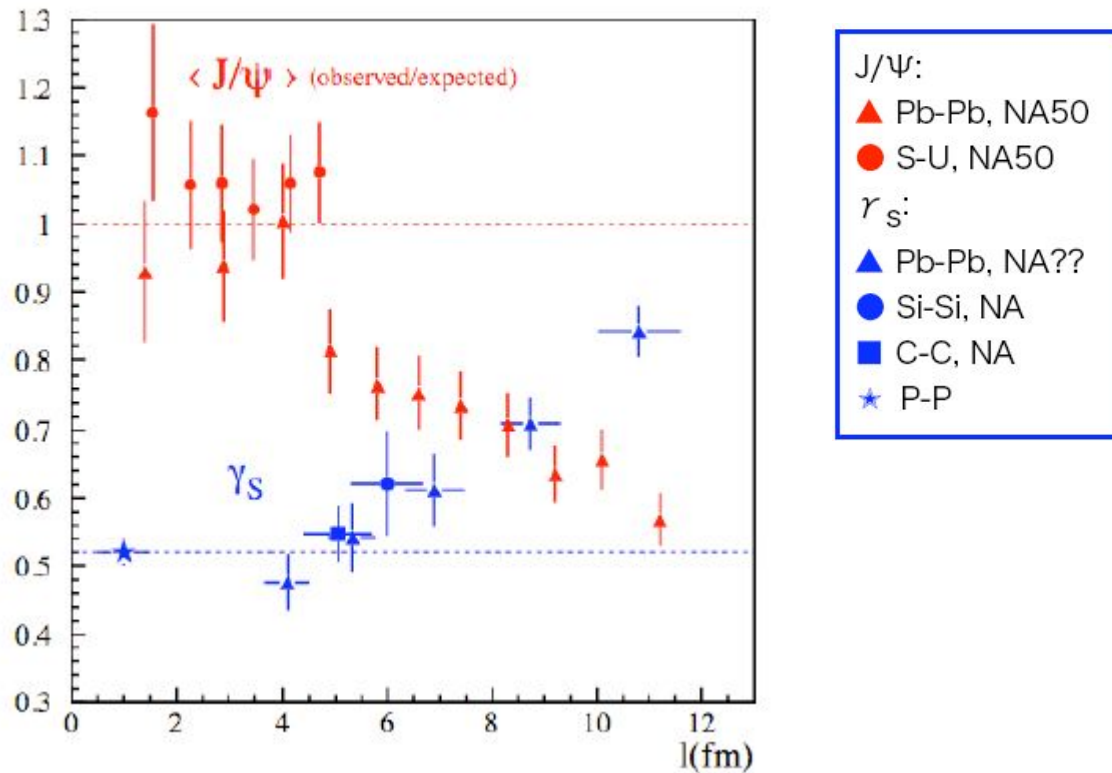
## 4. Струи

### Струя в адронной среде

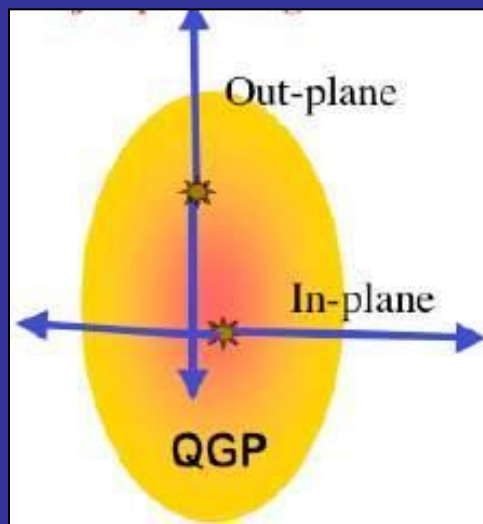


— “jet quenching”

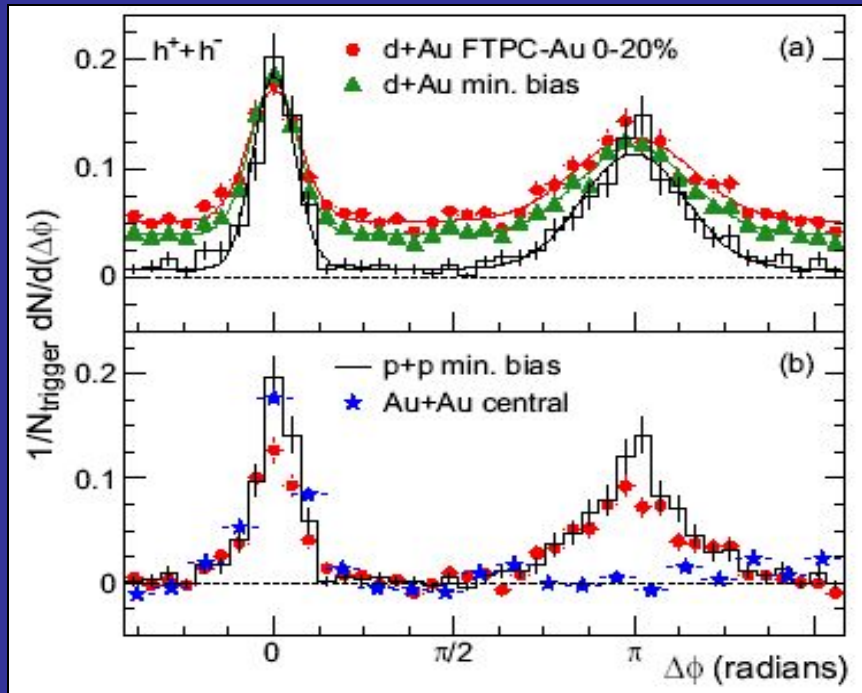
# Корреляция подавления $J/\psi$ и увеличения выхода странных частиц



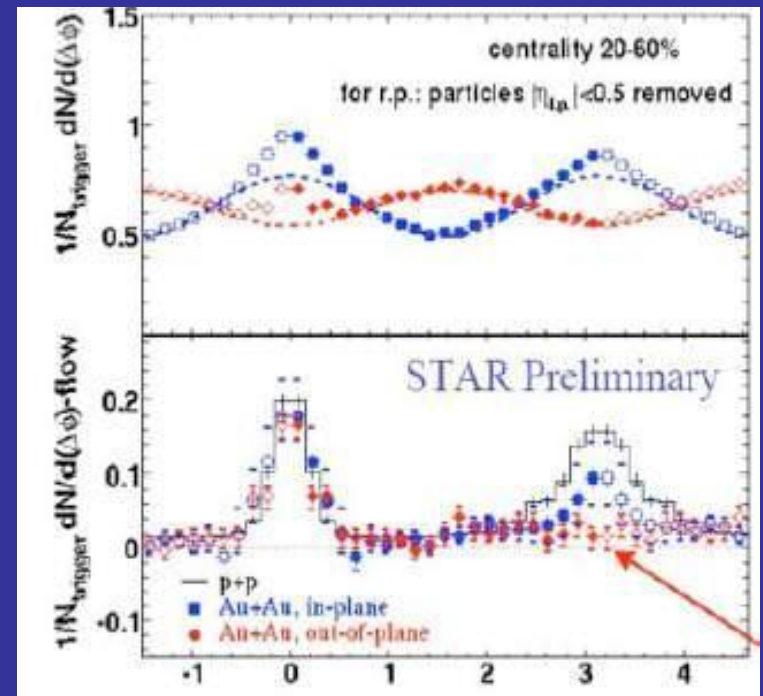




Струи в Au+Au и d+Au и p+p  
нет подавления в p+p и d+Au



“in” и “out” струи  
подавляются по разному!



# Адронные пробники нового состояния вещества

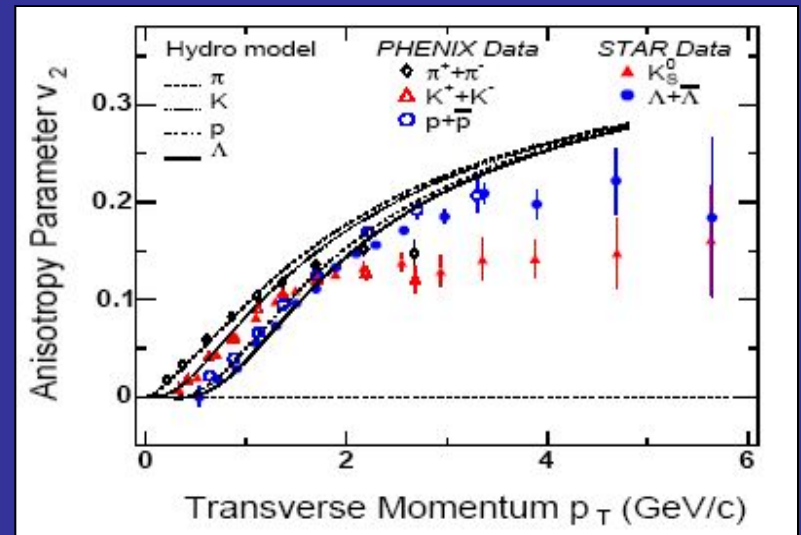
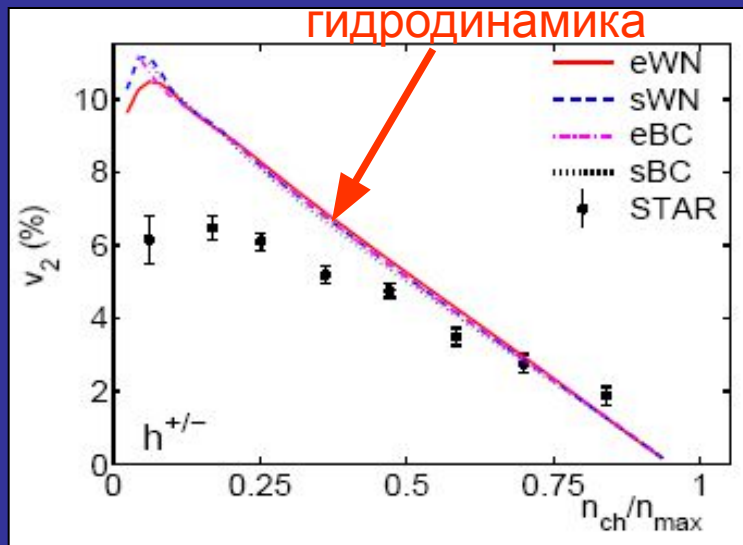
## Коллективное течение

$$\frac{dN}{dy p_{\perp} dp_{\perp} d\phi_p} \quad \phi_p \text{ — азимутальный угол}$$

$$v_2(p_{\perp}, b) \text{ — коэффициент Фурье}$$

гидродинамика нарушена для

$$p_{\perp}^{\text{мез.}} > 1.5 \text{ ГэВ} \quad p_{\perp}^{\text{бар.}} > 2.2 \text{ ГэВ}$$



$$b < 7 \text{ fm} \quad (n_{ch}/n_{max} > 0.5)$$

$$p_{\perp} < 1.5 \text{ ГэВ} \text{ —}$$

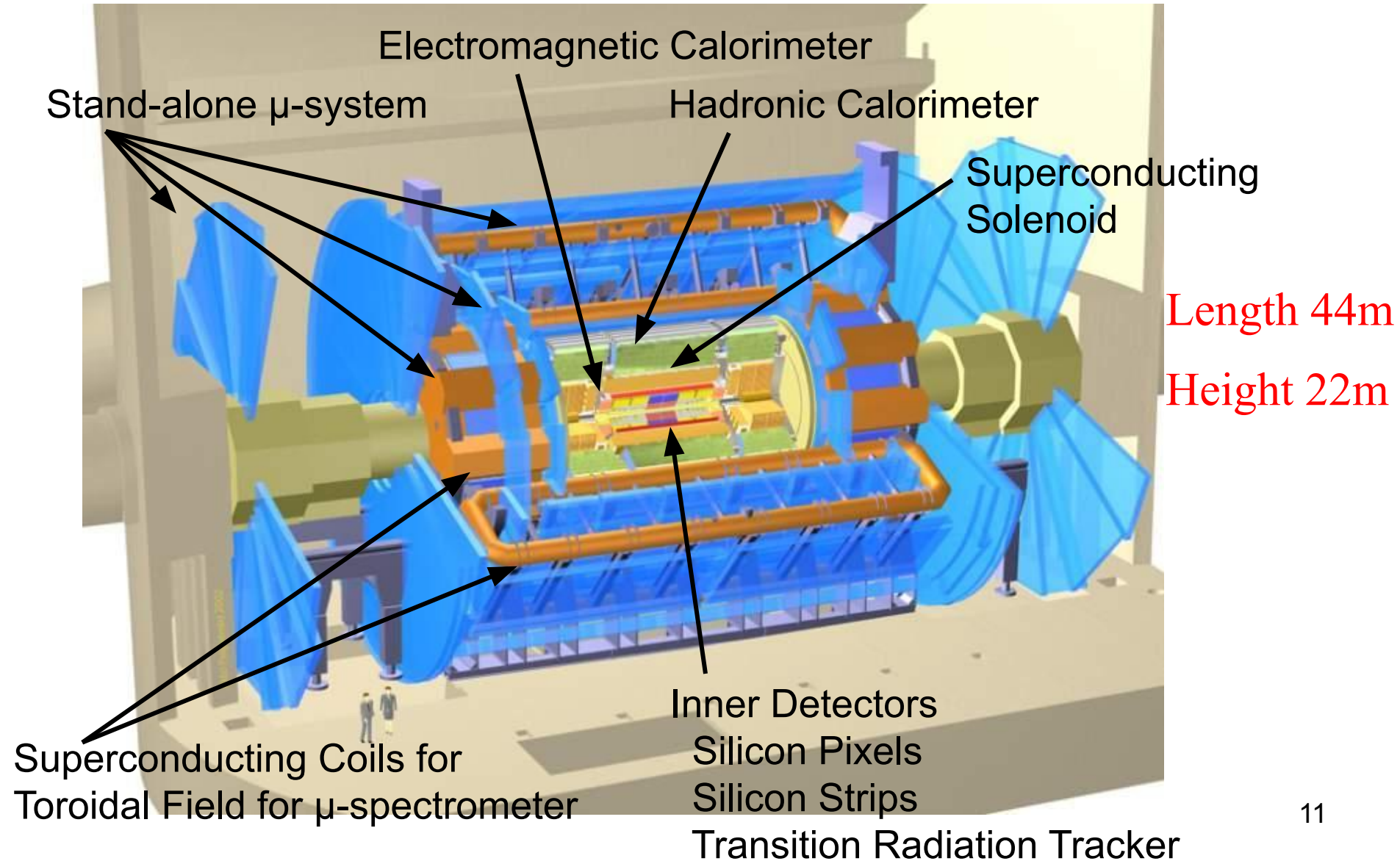
гидродинамика

$$\frac{p_{\perp}^{\text{мез.}}}{p_{\perp}^{\text{бар.}}} \approx \frac{2}{3}$$

(отношение числа валентных кварков)

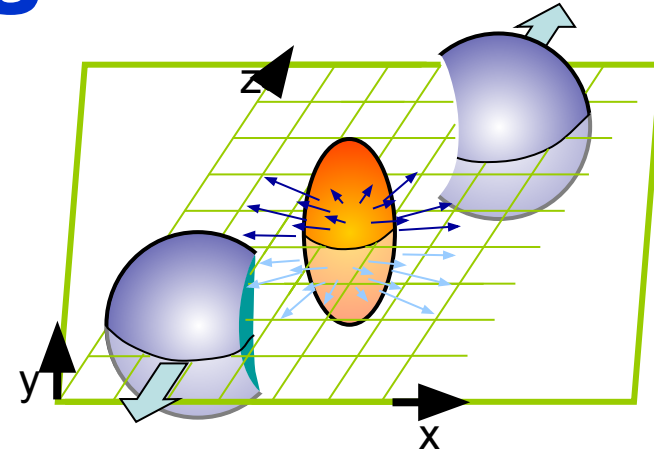
$v_2$  описывается течением кварков и глюонов с очень малой вязкостью

# The ATLAS detector



# ATLAS physics program

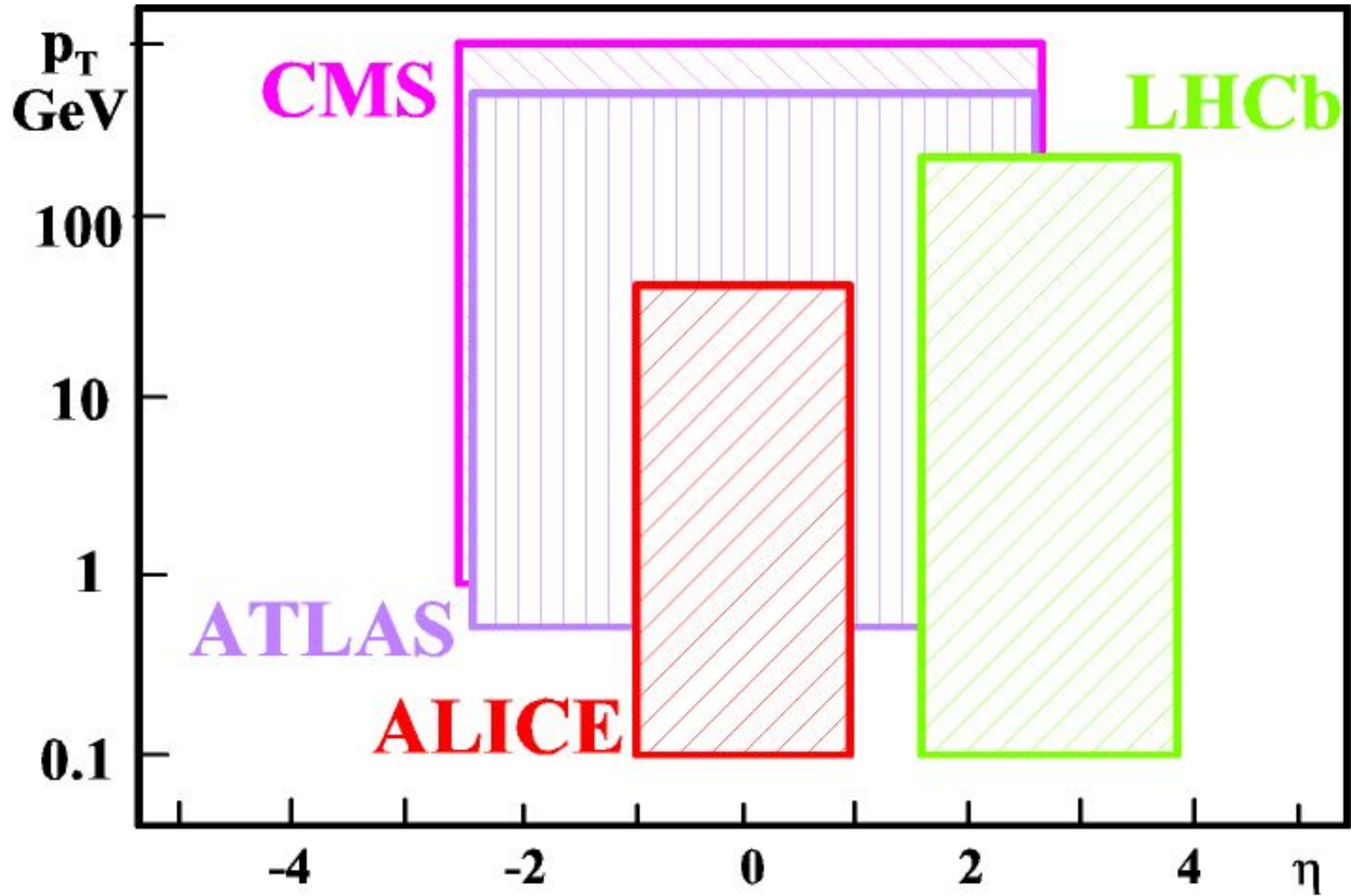
- **Global variable measurement**  
 $dN/d\eta$   $dE_T/d\eta$  elliptic flow  
azimuthal distributions
- **Jet measurement and jet quenching**
- **Quarkonia suppression**  
 $J/\Psi$   $\Upsilon$
- **p-A physics**
- **Ultra-Peripheral Collisions (UPC)**



Direct information  
from QGP

Idea: take full advantage of the large calorimeter and  $\mu$ -spectrometer

# Acceptance



# ATLAS Physics Rates

A few key numbers and maybe a plot.

~ 8,000 collisions per second  
luminosity ~  $10^{27}$  cm<sup>-2</sup>s<sup>-1</sup>

1 month is  $10^6$  seconds  
implies possible sampling of  $10^{10}$  min bias and  $10^9$  central Pb-Pb events.

5 bbar per central event.

Direct photons -->

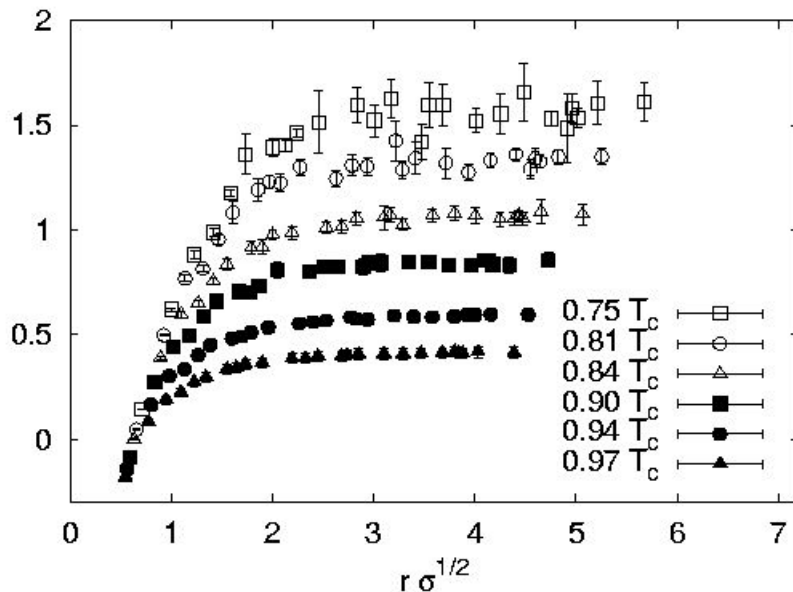
With central barrel in one month running for central events:  
1e3 counts at 60 GeV in 1 GeV pt bin!

Jets -->

B Jets-->

# Quarkonia suppression

Color screening prevents various  $\psi$ ,  $\Upsilon$ ,  $\chi$  states to be formed when  $T \rightarrow T_{\text{trans}}$  to QGP (color screening length  $<$  size of resonance)



Modification of the potential can be studied by a **systematic measurement of heavy quarkonia states** characterized by different binding energies and dissociation temperatures

$\sim$ thermometer for the plasma

**Upsilon family**

$\rightarrow$  **Binding energies (GeV)**

$\rightarrow$  **Dissociation at the temperature**

**$\Upsilon(1s)$**

**1.1**

**$\sim 2.5 T_{\text{trans}}$**

**$\Upsilon(2s)$**

**0.54**

**$\sim 0.9 T_{\text{trans}}$**

**$\Upsilon(3s)$**

**0.2**

**$\sim 0.7 T_{\text{trans}}$**

$\Rightarrow$  Important to separate  $\Upsilon(1s)$  and  $\Upsilon(2s)$

# Ultrapерipheral collisions

- The two nuclei geometrically “miss” each other

- $b > 2R_A$

- Ions are source of fields

- photons  $s_{gg} \sim Z^4$
  - pomerons  $s_{gp} \sim Z^2 A^2$  – for ‘heavy’ states  
 $s_{gp} \sim Z^2 A^{5/3}$  - for lighter mesons

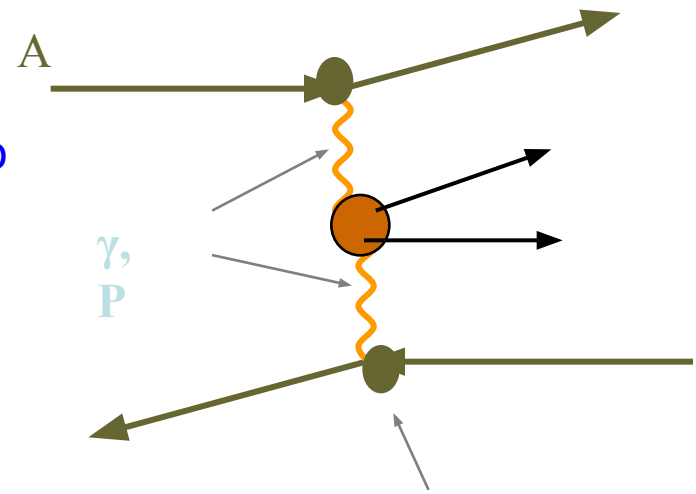
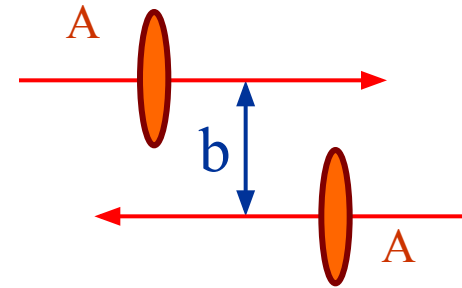
- Photon and pomeron can couple coherently to the nuclei if its have:

- ◆ Small transverse momentum:

- $p_T < h/R_A \sim 90 \text{ MeV}$

- ◆ Maximum longitudinal component  
 $gh/R_A \sim 100 \text{ GeV}$

$p_L <$



$E_\gamma \sim 3 (80) \text{ GeV}$  at RHIC (LHC)

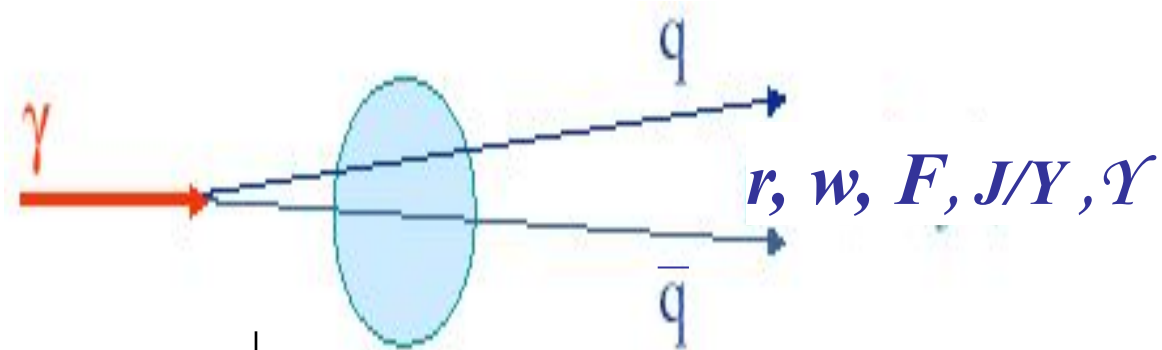
$W_{\gamma\gamma} \sim 6 (160) \text{ GeV}$  at RHIC (LHC)

Pomeron carry the strong interaction but is colorless and it has the quantum number of the vacuum  $J^P = 0^{++}$



# Vector meson production

- Vector mesons production (photon-pomeron interaction)

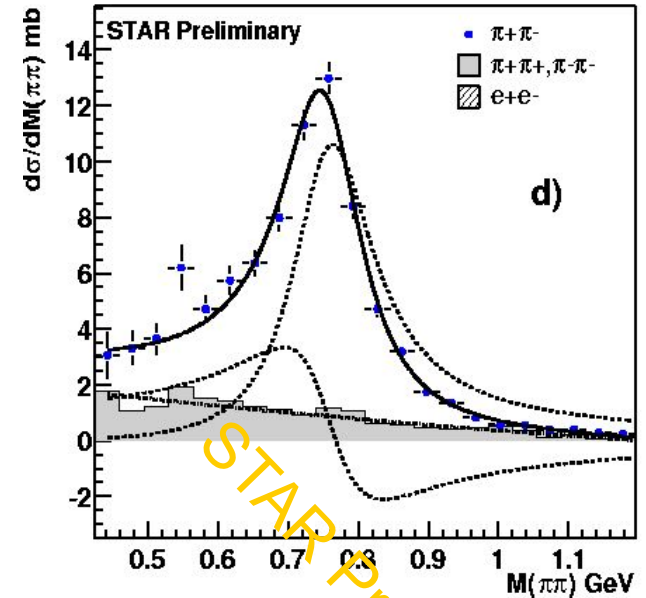
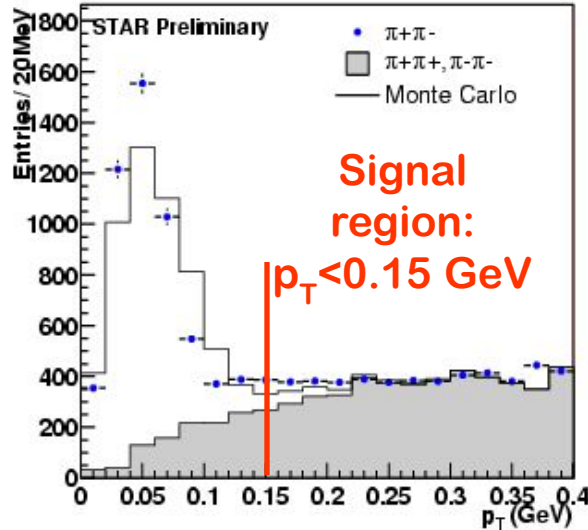


Meson	Au+Au, RHIC $\sigma(\text{mb})$	Pb+Pb, LHC $\sigma(\text{mb})$
$\rho^0$	590	5200
$\omega$	59	490
$\phi$	39	460
$J/\psi$	0.29	32

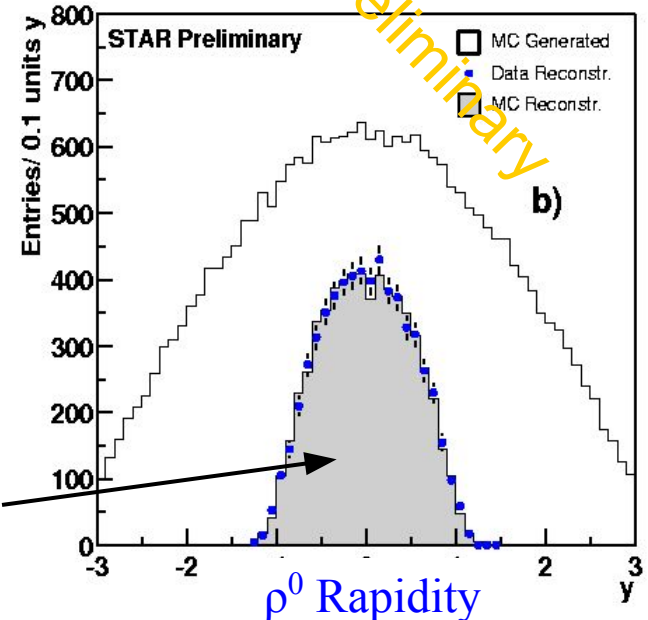
$$\sigma(\text{AA} \rightarrow \text{AA}\gamma) = 150 \text{ mb}$$

$$L = 4 \cdot 10^{26} \text{ cm}^{-2} \text{ s}^{-1}, H = 0.06 \text{ Hz}, \text{ Br}(\Upsilon \rightarrow \text{mm}) = 2.48\% \Rightarrow \sim 1500 \text{ Y/month (month} \sim 10^6 \text{ sec)}$$

# AuAu $\rightarrow \rho^0$ Au\* Au\* 200 GeV



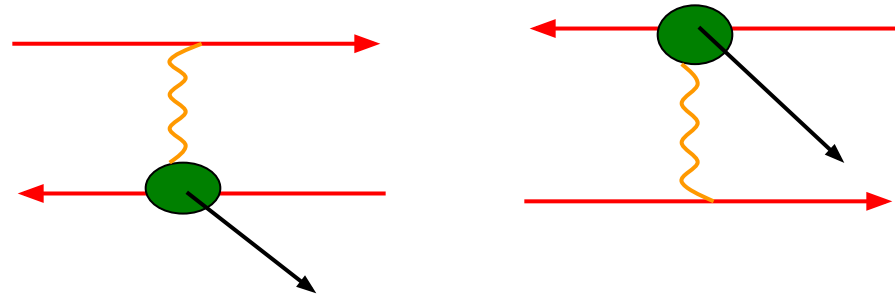
- ❑ 1.7 million ZDC coincidence triggers in 2002
- ❑ Require a 2 track vertex
- ❑  $p^+p^+$  and  $p^-p^-$  model background
  - scaled up to 2
- ❑ single (1n) and multiple (Xn) neutron production
  - 1n mostly from Giant Dipole Resonance
- ❑ Cross section and rapidity distribution match soft Pomeron model



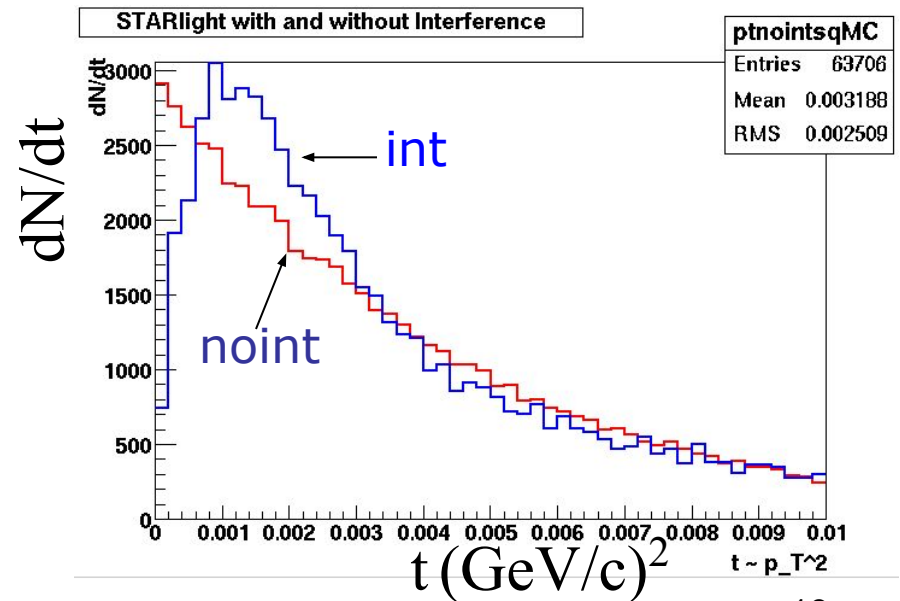
After detector simulation

# Interference

- 2 indistinguishable possibilities
  - Interference!!
- 2-source interferometer with separation  $b$
- $\rho$  is negative parity
- For  $pp$ , AA parity transform  $\rightarrow$ 
  - $\sigma \sim |A_1 - A_2 e^{ip \cdot b}|^2$
  - At  $y=0$   $\sigma = \sigma_0 [1 - \cos(p \cdot b)]$
- For  $p\bar{p}$  CP transform  $\rightarrow$ 
  - $\sigma \sim |A_1 + A_2 e^{ip \cdot b}|^2$
- $b$  is unknown
  - Reduction for  $p_T \ll 1/\langle b \rangle$



- $\rho^0$  w/ mutual Coulomb dissociation.
- $0.1 < |y| < 0.6$

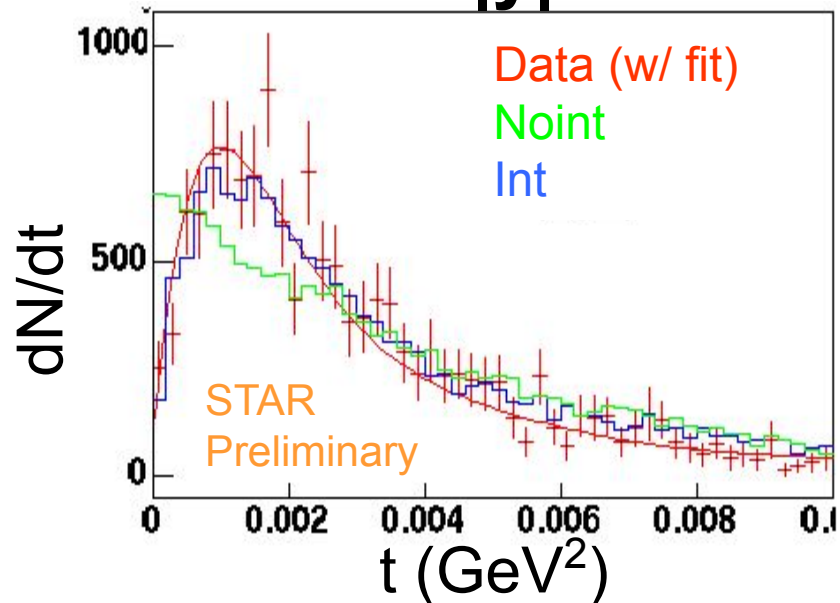


# Interference

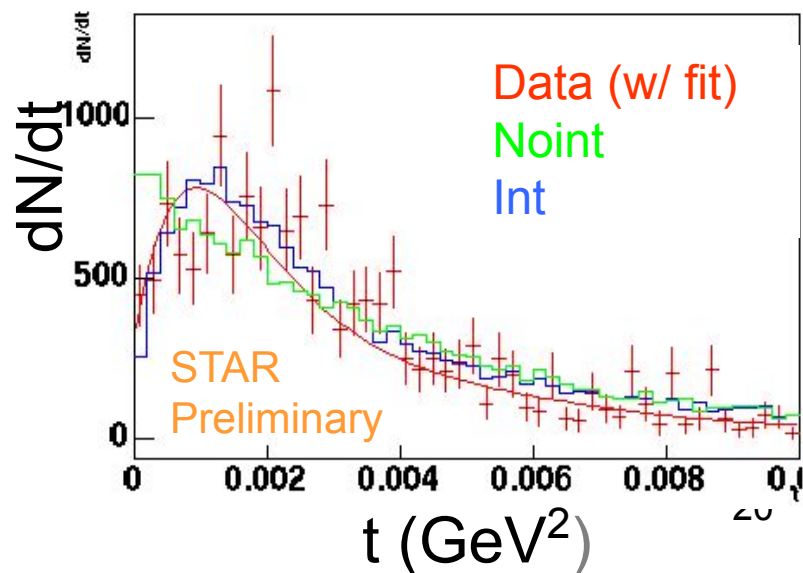
**AuAu  $\rightarrow$   $r^0$ Au\*Au\* 200 GeV**

- Efficiency corrected t
  - 1764 events total
  - $R(t) = \text{Int}(t)/\text{Noint}(t)$ 
    - Fit with polynomial
  - $dN/dt = A \cdot \exp(-bt) [1 + c(R(t) - 1)]$ 
    - A is overall normalization
    - b is slope of nuclear form factor
      - $b = 301 \pm 14 \text{ GeV}^{-2}$
      - $304 \pm 15 \text{ GeV}^{-2}$
- sys. uncertainties:  $\pm 8(\text{syst}) \pm 15\%(\text{theory})$
- $c=0$  -- > no interference
  - $c=1$  -- > “full” interference
- Data and interference model match
    - $c = 1.01 \pm 0.08$
    - $0.78 \pm 0.13$

**$0.1 < |y| < 0.5$**

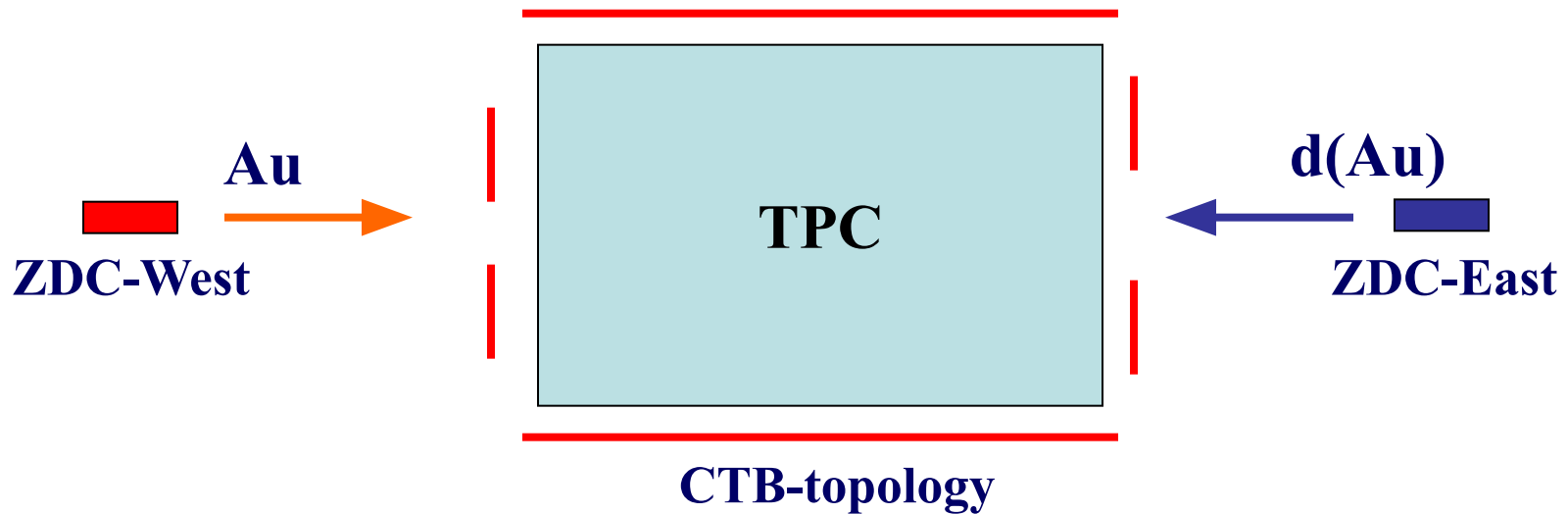


**$0.5 < |y| < 1.0$**



# Types of trigger

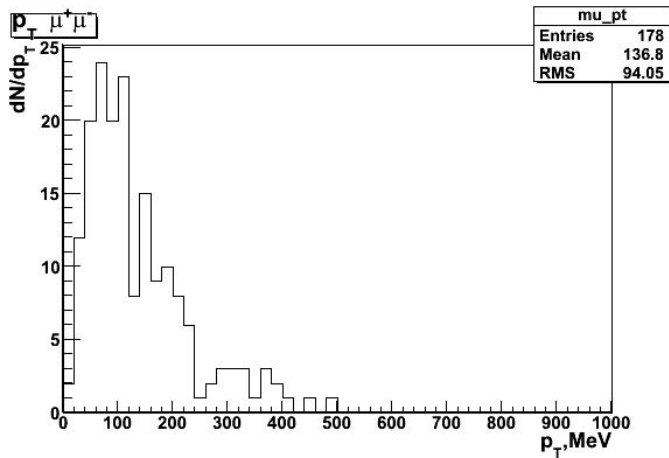
- **Topology trigger + ZDCs** ( $r^0$  in TPC + signals in forward (zero degree calorimeters))
  - Topology trigger + West ZDC: Au+d- $\rightarrow$ rAu+pn
    - required break up d
  - Topology trigger + both ZDC: Au+Au- $\rightarrow$ rAuAu+Xn



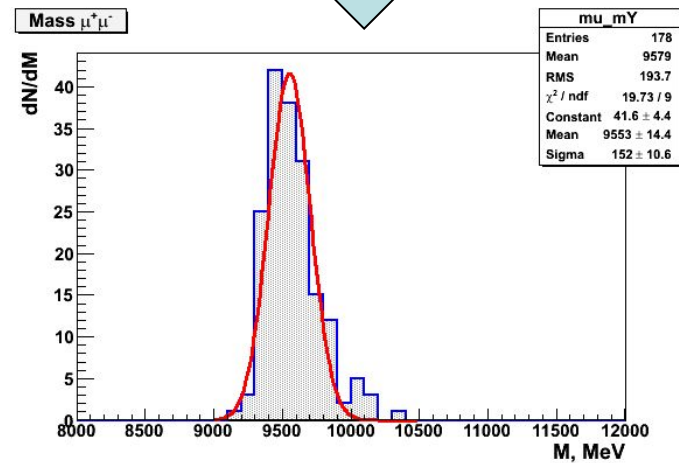
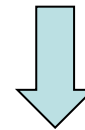
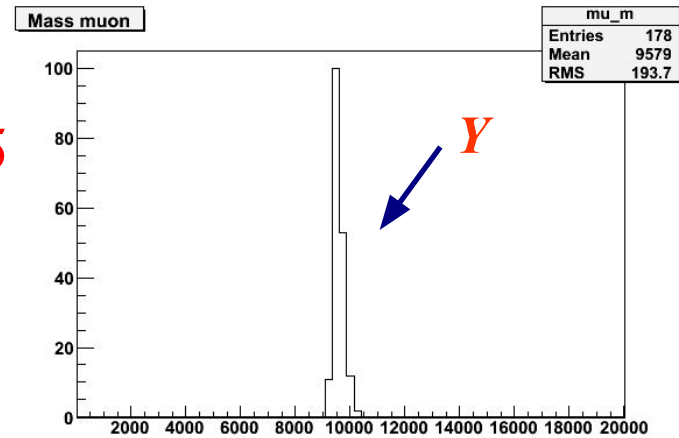
- Backgrounds
  - ◆ peripheral hadronic events
  - ◆ cosmic rays, beam gas interactions, pile-up

# $\gamma \rightarrow \mu^+ \mu^-$ (Combined Muon)

MUID



$|\eta| < 2.5$



530 Y/month

# Plans on LHC: ALICE, ATLAS

- Cross-section, rate:

Meson	$\sigma$	BR	Acc	rate ( $10^6$ sec)	
J/ $\psi$	32 mb	5.93%	16.4%	150000	ALICE
$\Upsilon$	150 $\mu$ b	2.38%	23.6%	400-1400	
$\Upsilon$	150 $\mu$ b	2.38%	35%	400-1400	ATLAS

g+A  $\rightarrow$  J/ $\Upsilon$ ,  $\Upsilon$ +A in UPC A+A

