

Физика столкновений тяжелых ионов

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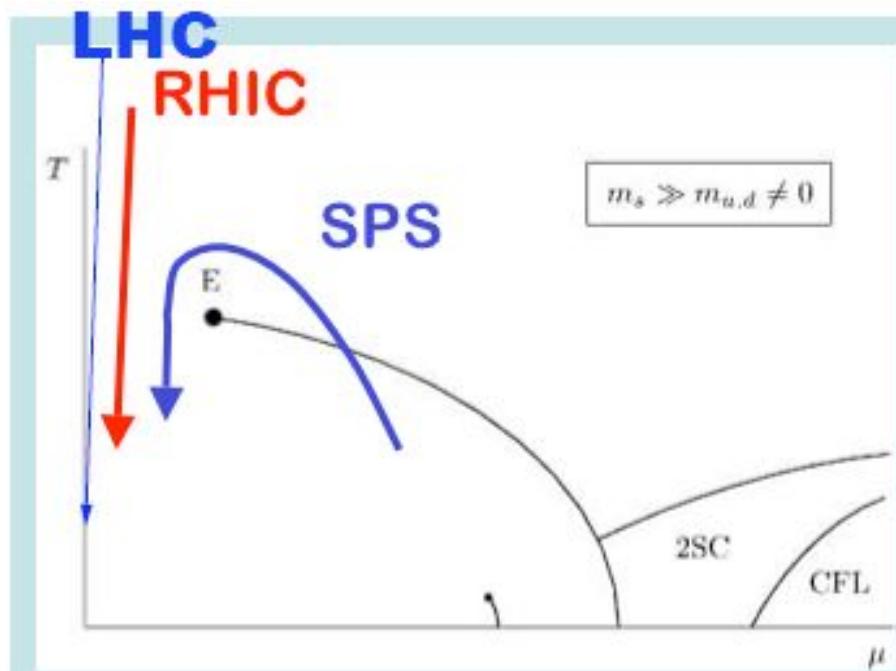
**Московский инженерно-физический институт
(государственный университет)**

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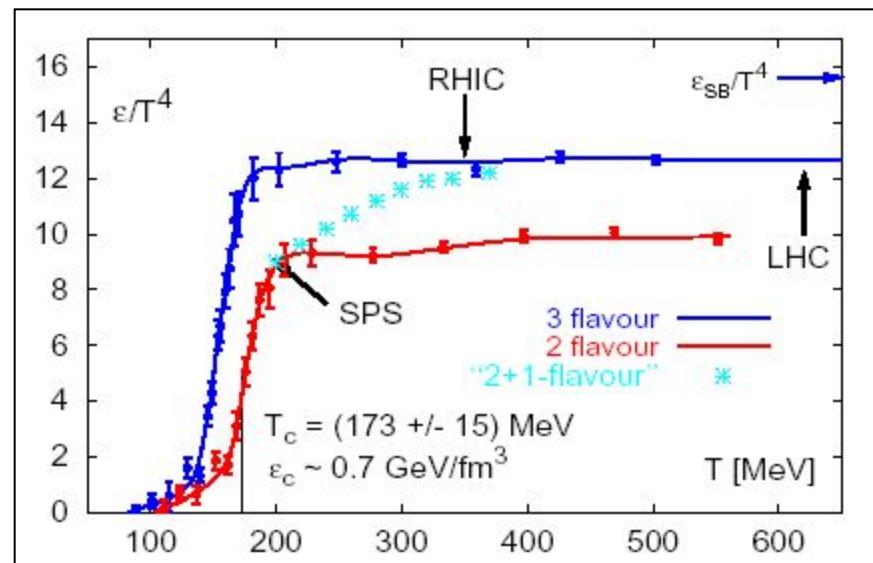
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Фазовые переходы в сжатой и нагретой ядерной материи

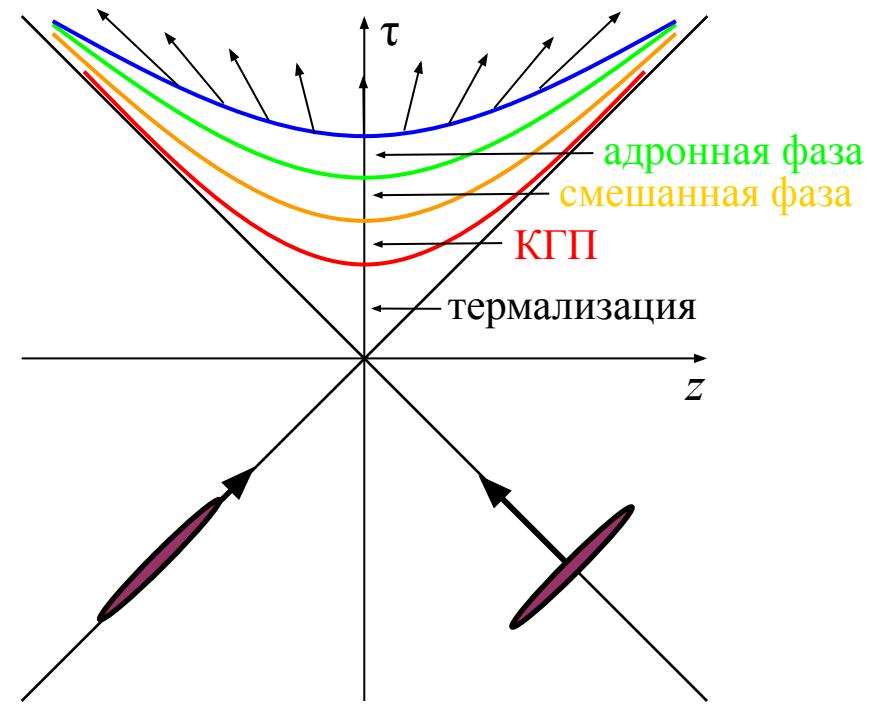
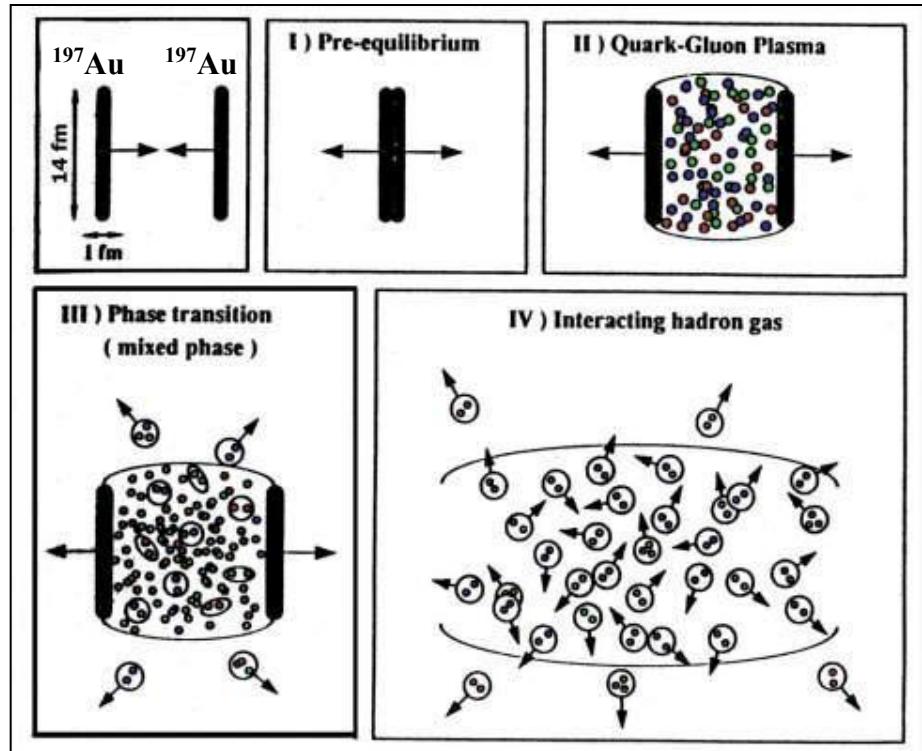
фазовая диаграмма
состояния адронной материи



плотность энергии как
функция температуры



Пространственно-временная картина ядро-ядерных взаимодействий



Сигналы нового состояния вещества

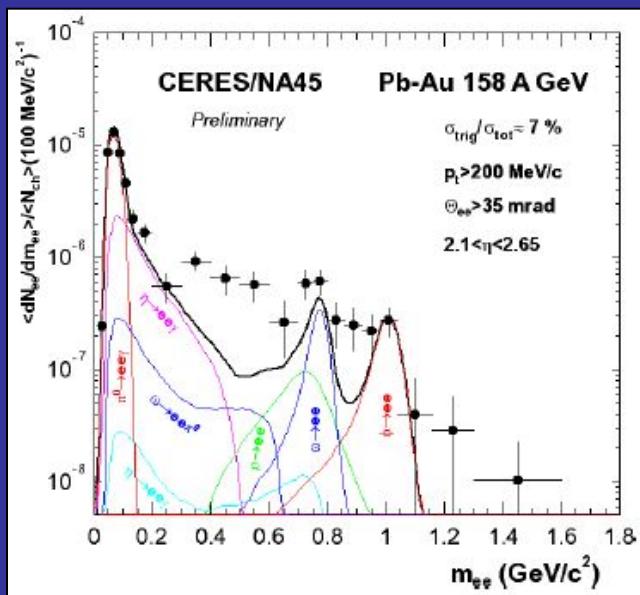


жесткие сигналы («реликтовое излучение»)
(e^+e^- , γ , $\gamma\gamma$, струи, J/ψ подавление)

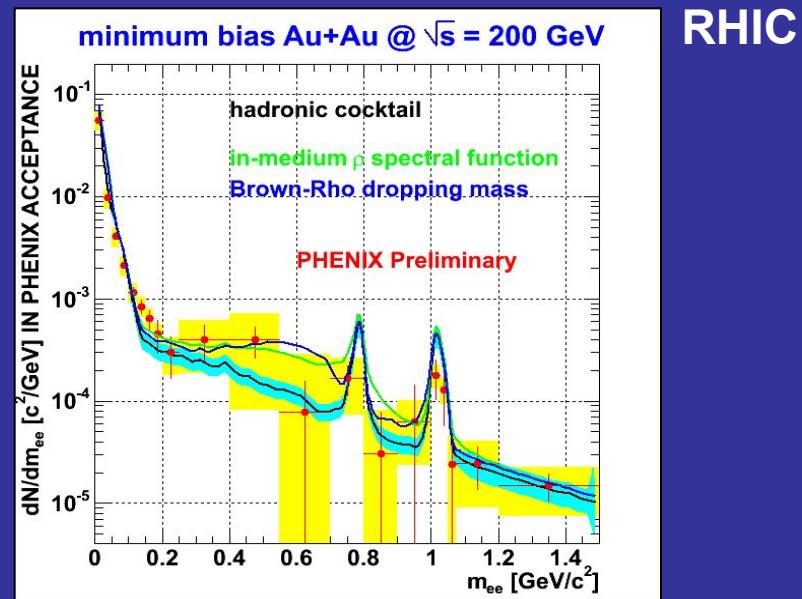
мягкие (адроны)
(коллективные течения,
корреляции, выходы
странных частиц)

Жесткие сигналы

1. Дилептоны



SPS

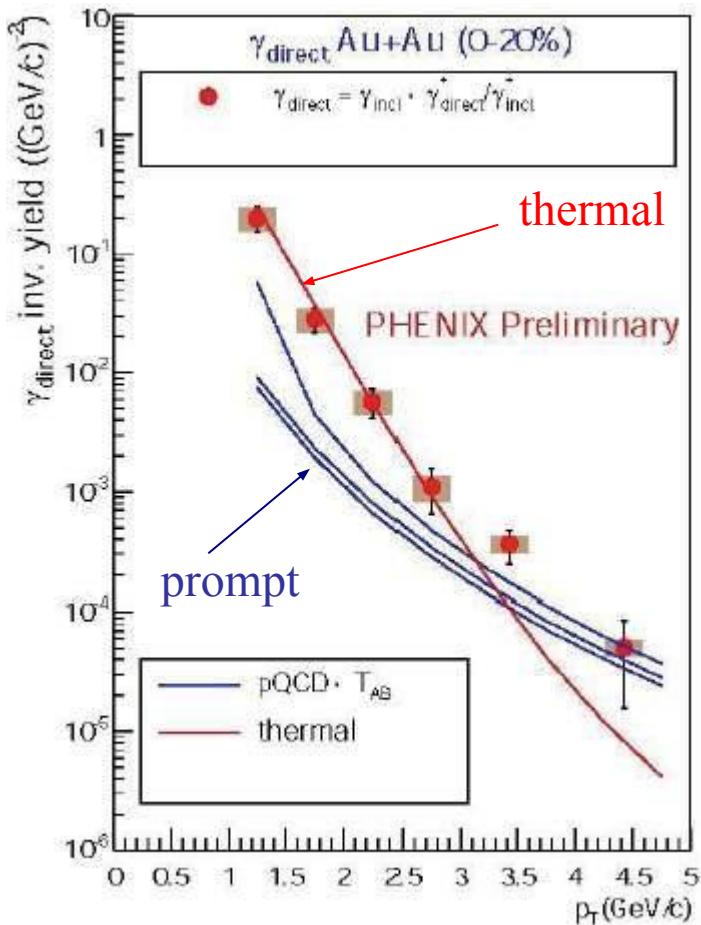


RHIC

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

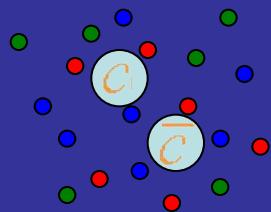
КГП на RHIC

прямые фотоны



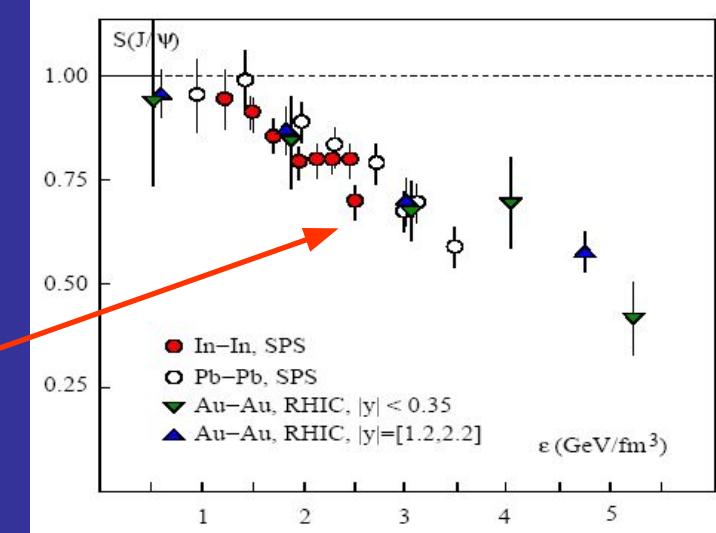
DATA = prompt + thermal

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

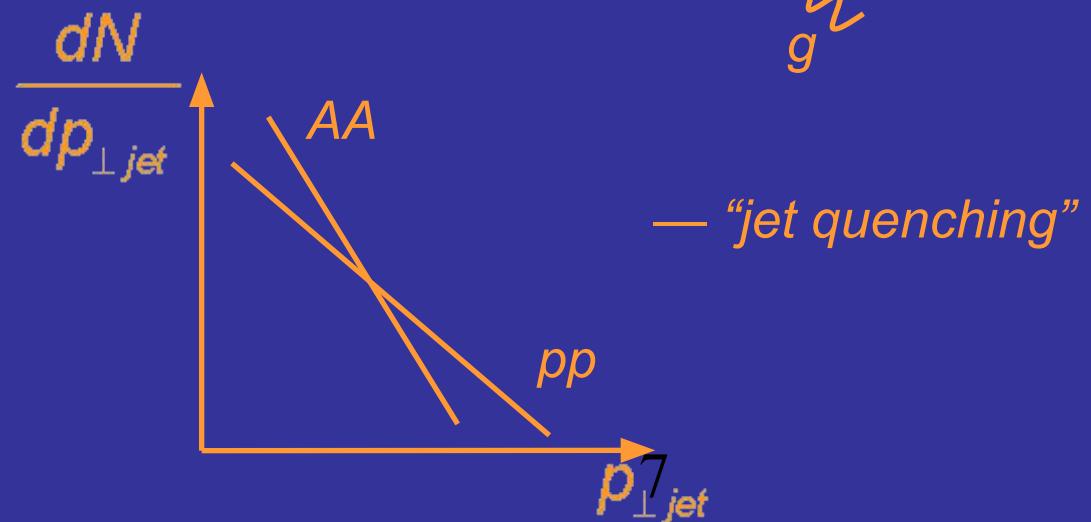
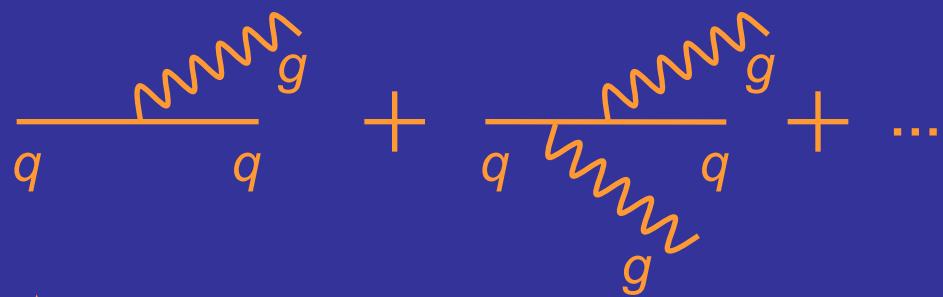


$r_D(T)$ — дебаевский радиус экранирования

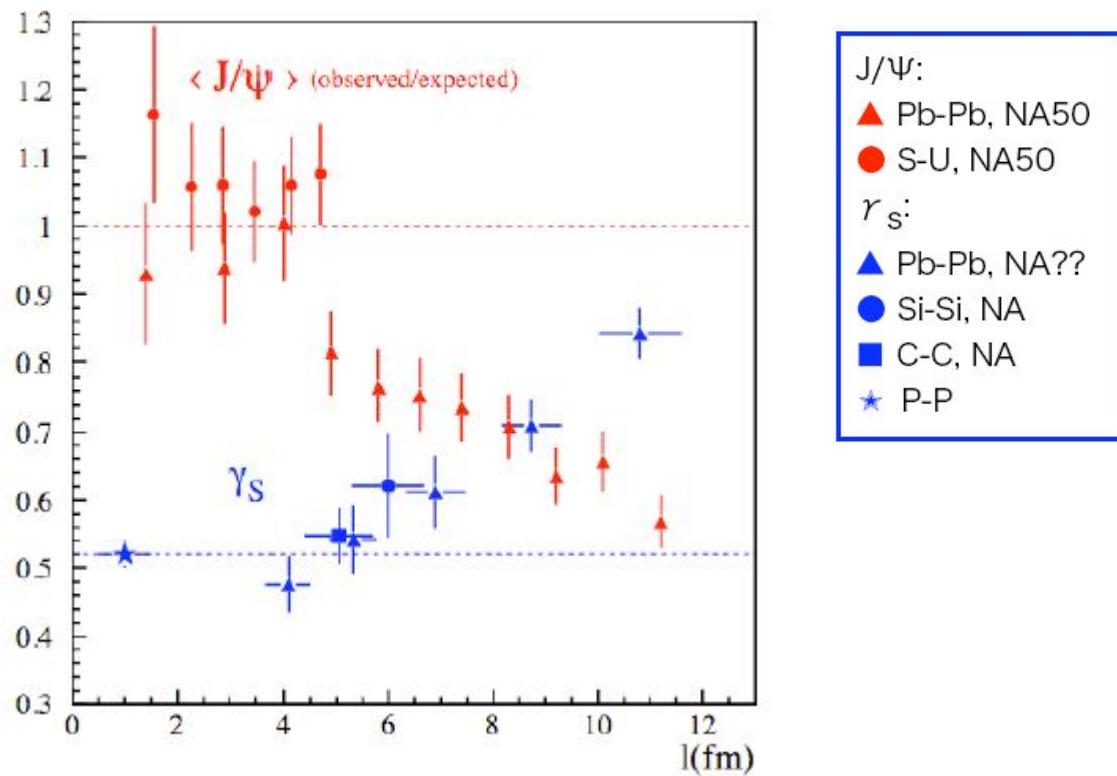
$r_\Psi > r_D(T)$ — выход J/Ψ подавлен

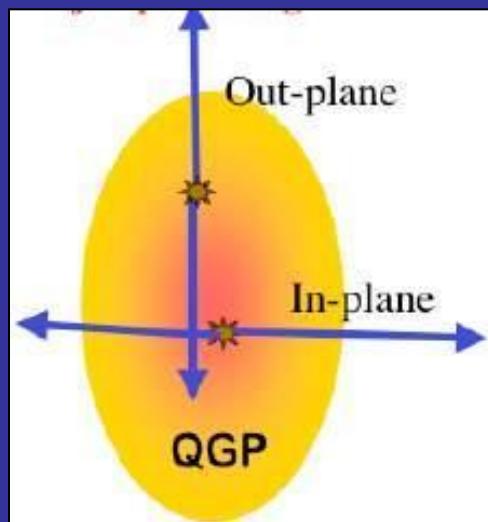


Струи



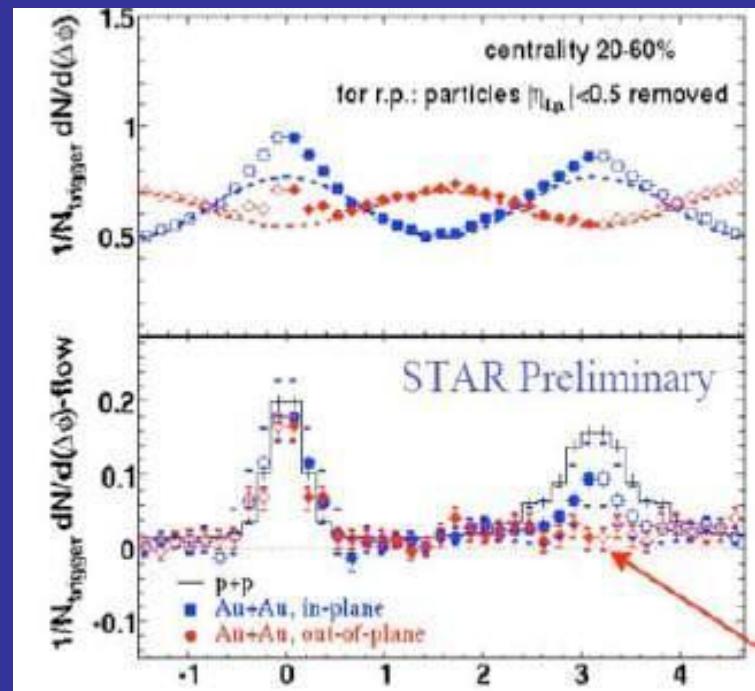
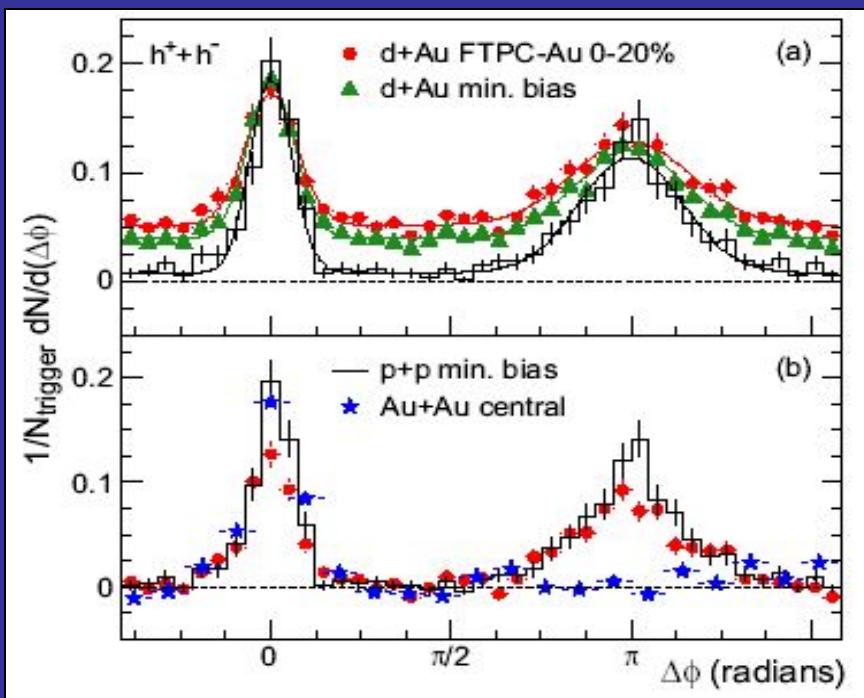
Корреляция подавления J/ψ и увеличения выхода странных частиц





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!*

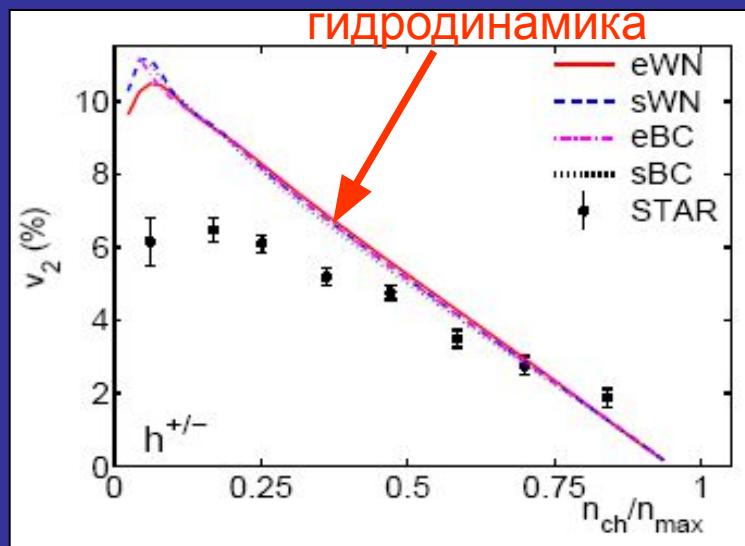


Адронные пробники нового состояния вещества

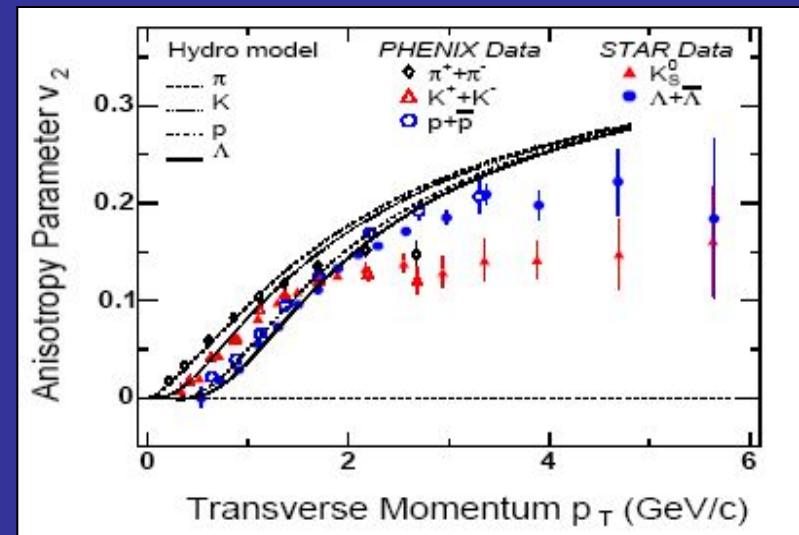
Коллективное течение

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

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



гидродинамика нарушена для
 $p_{\perp}^{\text{мез.}} > 1.5 \text{ ГэВ}$ $p_{\perp}^{\text{бар.}} > 2.2 \text{ ГэВ}$



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

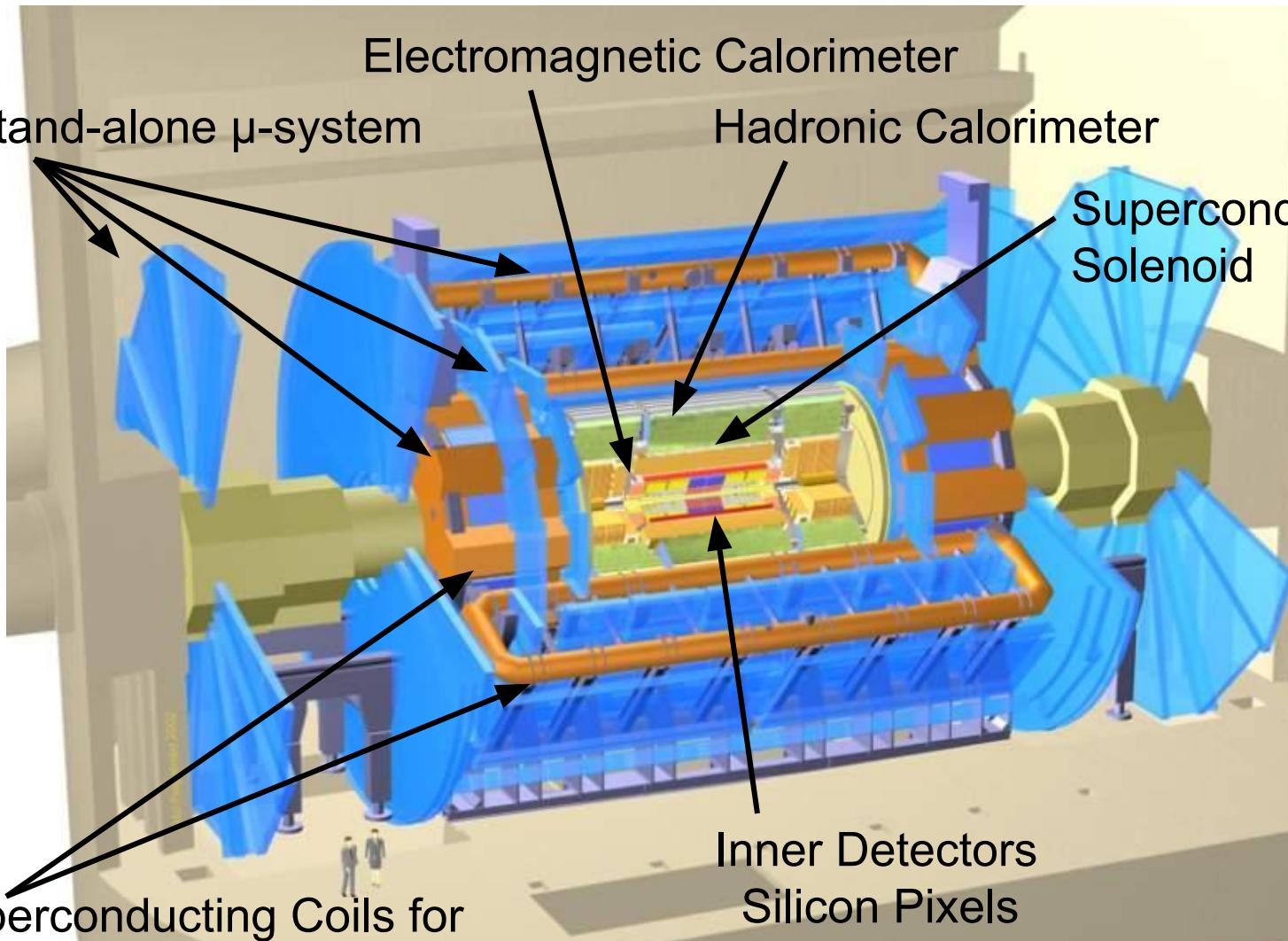
$p_{\perp} < 1.5 \text{ ГэВ}$ —
гидродинамика

v_2 описывается течением夸克ов и глюонов с очень малой вязкостью

$$\frac{p_{\perp}^{\text{мез.}}}{p_{\perp}^{\text{бар.}}} \approx \frac{2}{3} \quad \text{(отношение числа валентных夸克ов)}$$

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The ATLAS detector



Length 44m
Height 22m

ATLAS physics program

- **Global variable measurement**

- $dN/d\eta$ $dE_T/d\eta$ elliptic flow

- azimuthal distributions

- **Jet measurement and jet quenching**

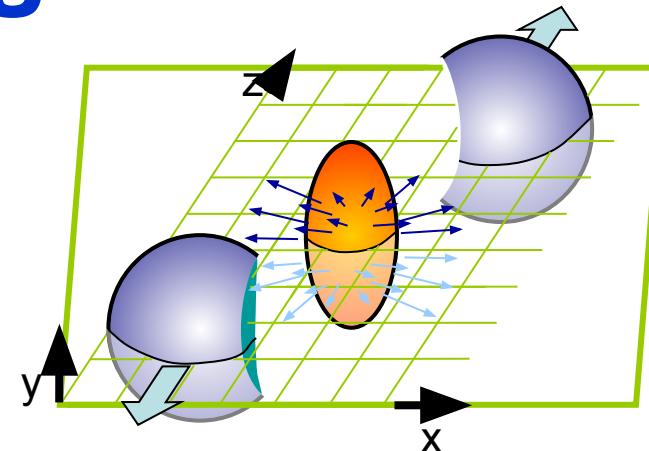
- **Quarkonia suppression**

- J/Ψ Υ

- **p-A physics**

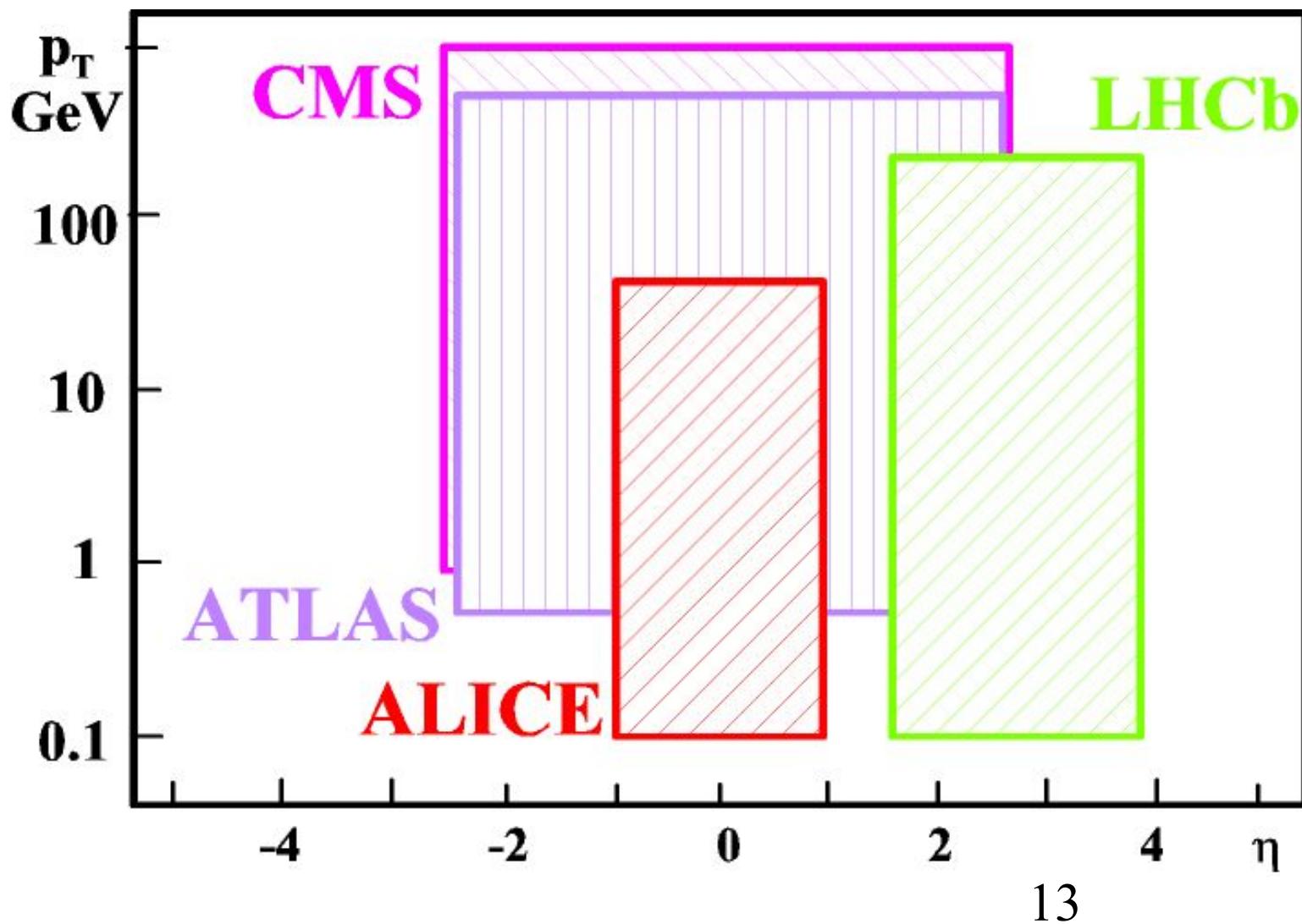
- **Ultra-Peripheral Collisions (UPC)**

Idea: take full advantage of the large calorimeter and μ -spectrometer



Direct information
from QGP

Acceptance



ATLAS Physics Rates

A few key numbers and maybe a plot.

~ 8,000 collisions per second

luminosity ~ 10^{27} cm $^{-2}$ s $^{-1}$

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:

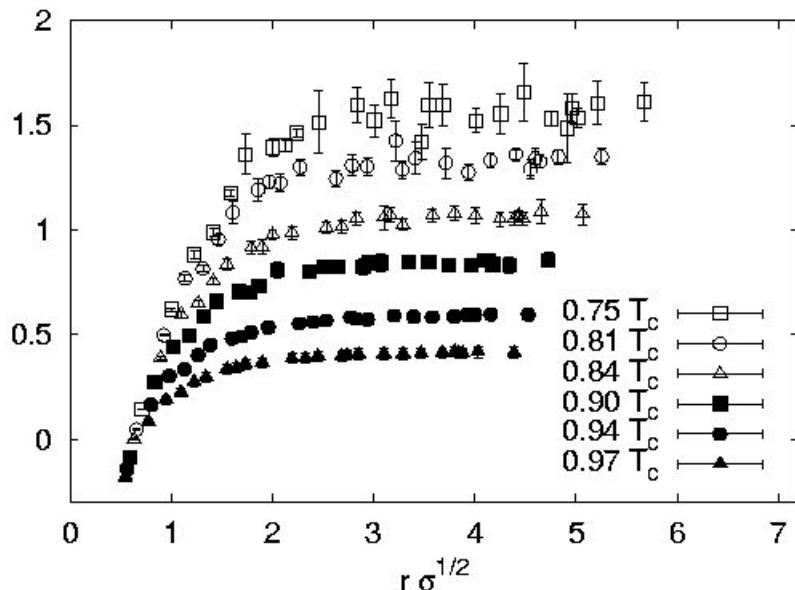
1e3 counts at 60 GeV in 1 GeV pt bin!

Jets -->

B Jets-->

Quarkonia suppression

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



Upsilon family

- Binding energies (GeV)
- Dissociation at the temperature

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

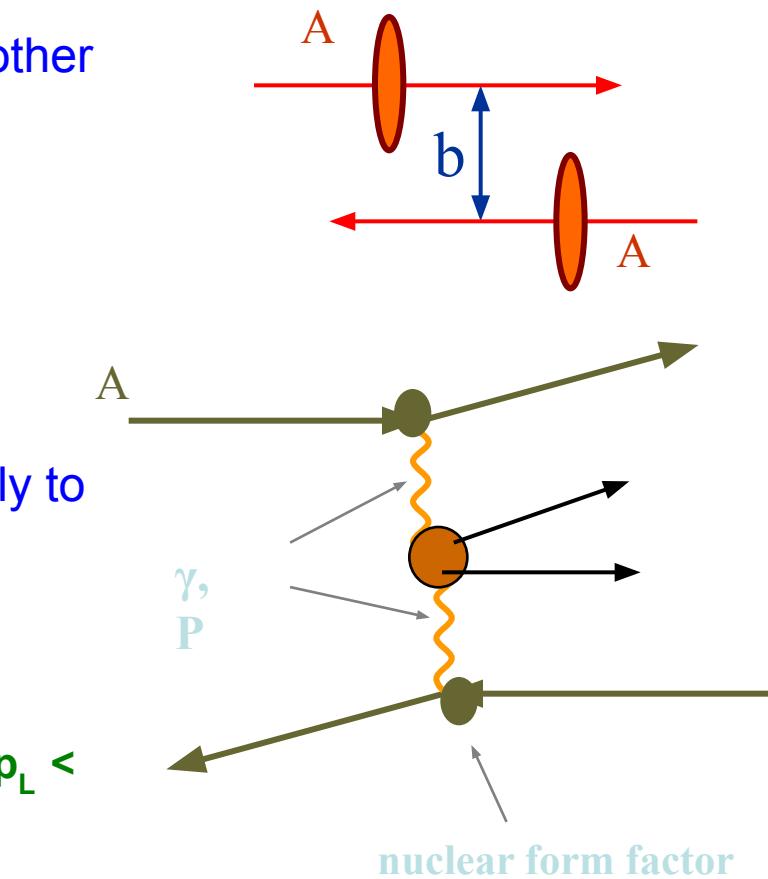
Modification of the potential can be studied by a systematic measurement of heavy quarkonia states characterized by different binding energies and dissociation temperatures

~thermometer for the plasma

$\Upsilon(1s)$	$\Upsilon(2s)$	$\Upsilon(3s)$
1.1	0.54	0.2
$\sim 2.5 T_{\text{trans}}$	$\sim 0.9 T_{\text{trans}}$	$\sim 0.7 T_{\text{trans}}$

Ultraperipheral 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:
 $p_T < h/R_A \sim 90$ MeV
 - ◆ Maximum longitudinal component
 $gh/R_A \sim 100$ GeV



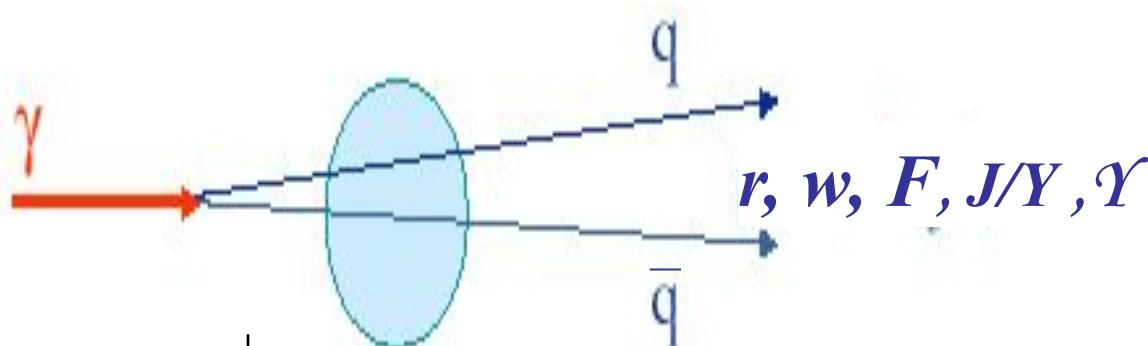
$$E\gamma \sim 3 \text{ (80)} \text{ GeV at RHIC (LHC)}$$

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

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)

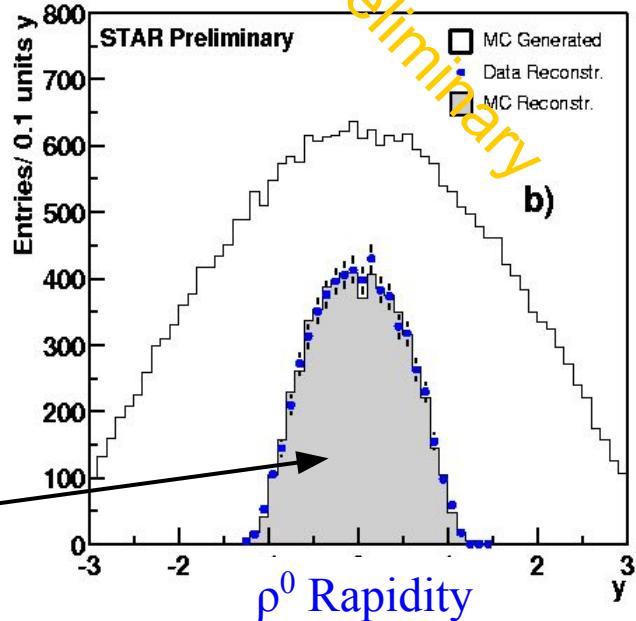
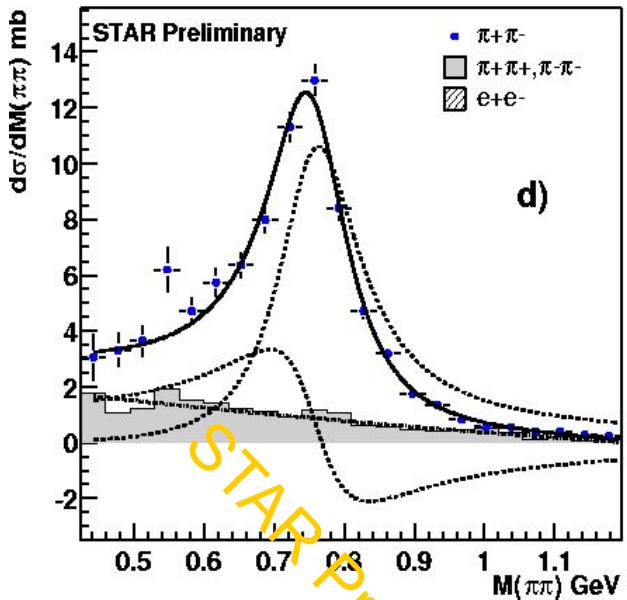
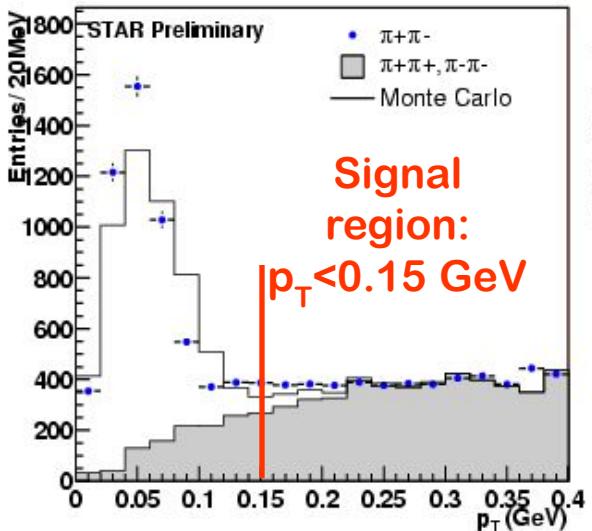


Meson	Au+Au, RHIC $\sigma(\text{mb})$	Pb+Pb, LHC $\sigma(\text{mb})$
ρ^0	590	5200
ω	59	490
φ	39	460
J/ψ	0.29	32

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

$$L = 4 * 10^{26} \text{ cm}^{-2}\text{s}^{-1}, H = 0.06 \text{ Hz}, \text{ Br}(Y \rightarrow \text{mm}) = 2.48\% \Rightarrow \sim 1500 \text{ Y/month} \quad ^{17}_{\text{month}} \sim 10^6 \text{ sec}$$

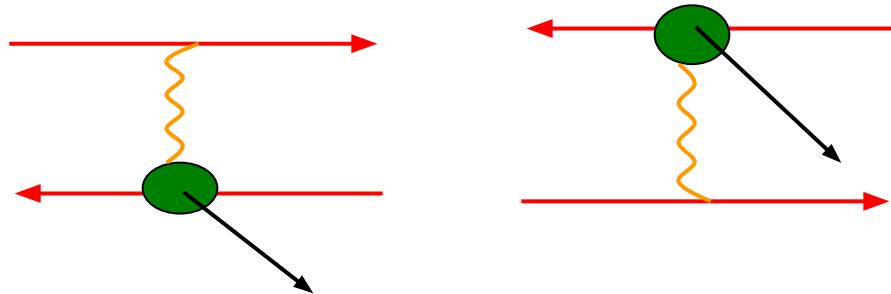
$AuAu \rightarrow \rho^0 Au^* Au^* 200 \text{ GeV}$



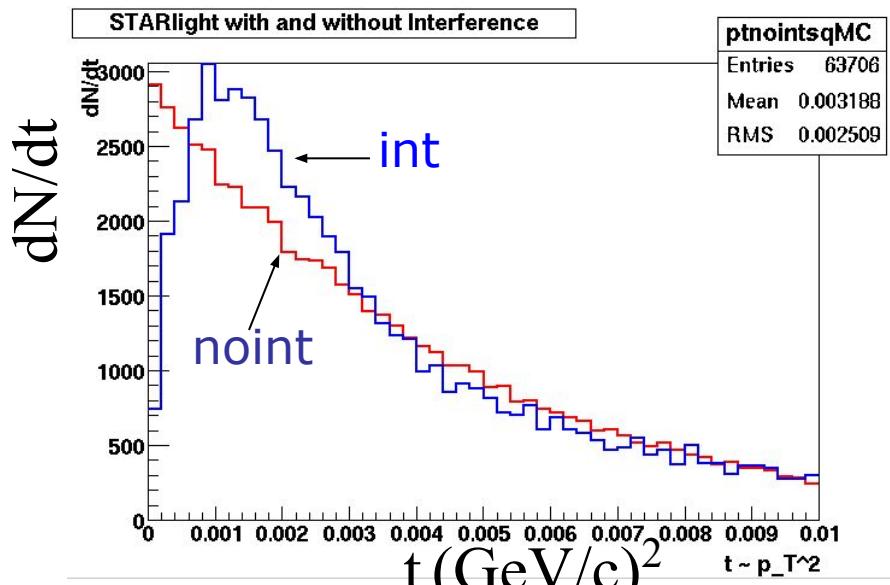
- 1.7 million ZDC coincidence triggers in 2002
- Require a 2 track vertex
- p^+p^+ and p^-p^- model background
 - scaled up to 2
- single (1n) and multiple (Xn) neutron production
 - 1n mostly from Giant Dipole Resonance
- Cross section and rapidity distribution match soft Pomeron model

Interference

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



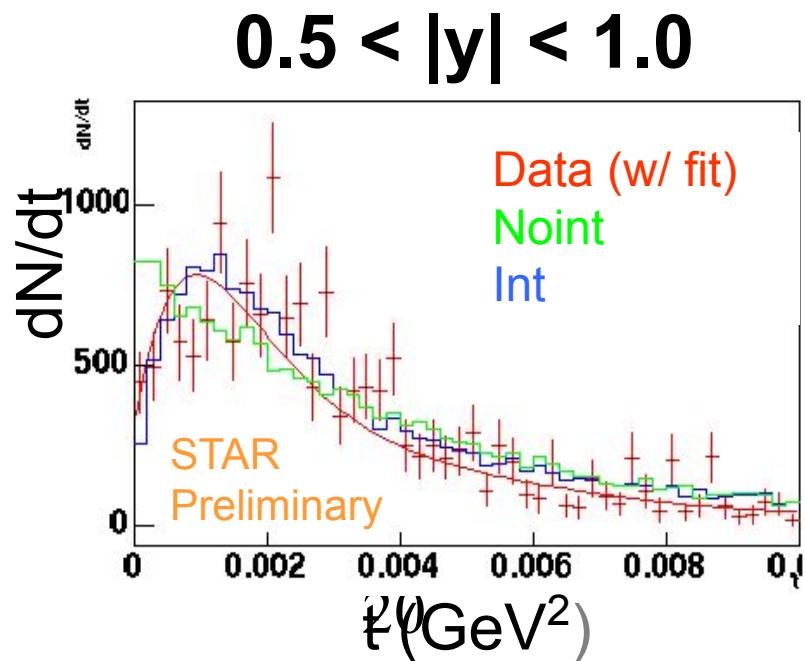
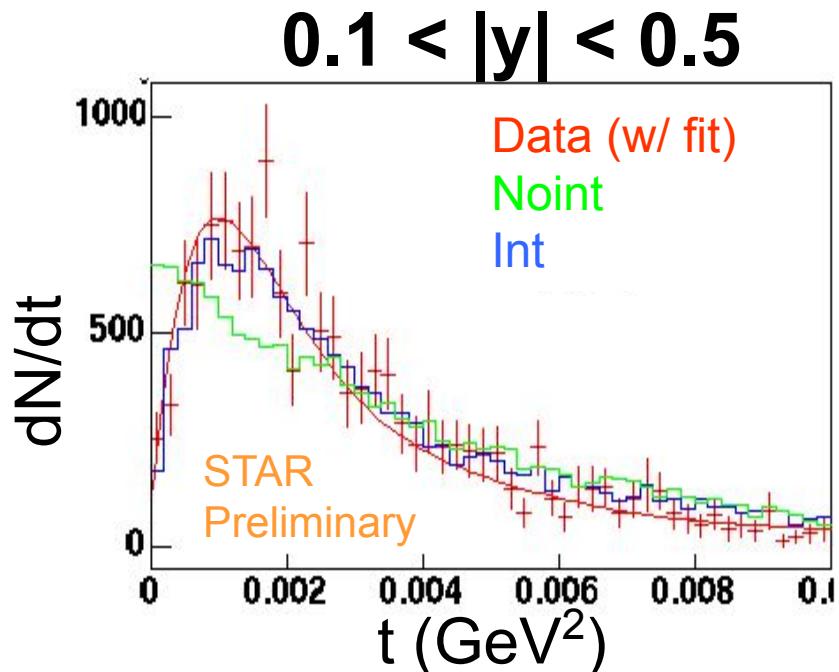
- ρ^0 w/ mutual Coulomb dissociation
- $0.1 < |y| < 0.6$



Interference

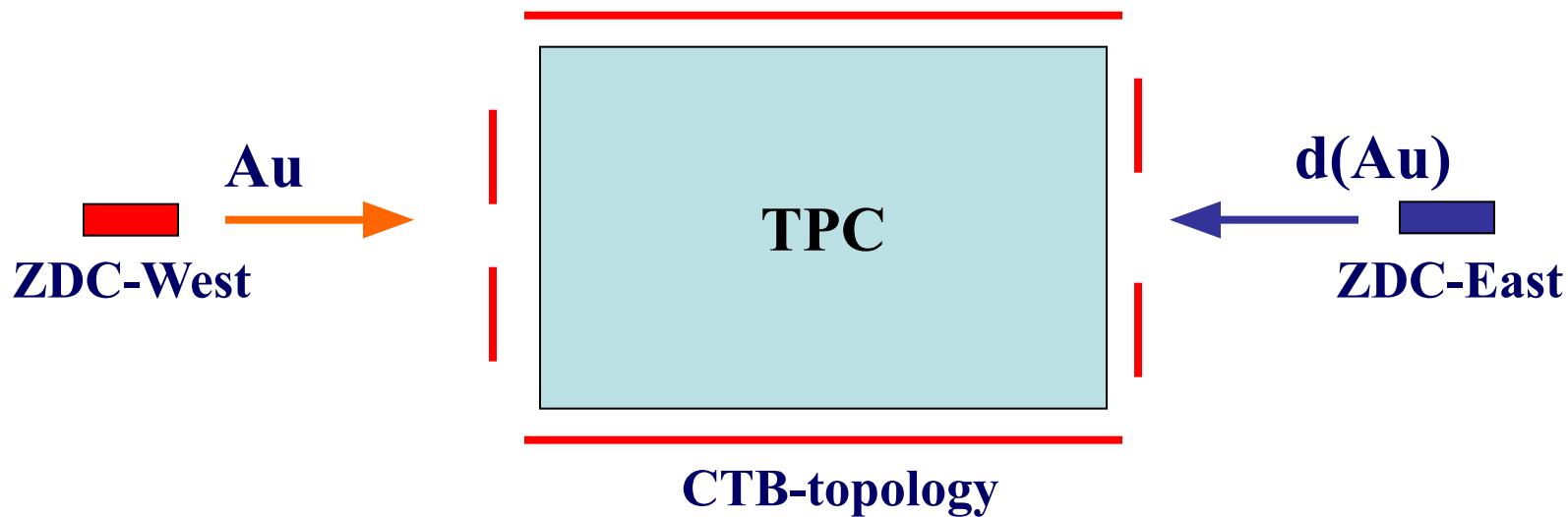
$AuAu \rightarrow r^0 Au^* Au^* 200 \text{ GeV}$

- Efficiency corrected t
- 1764 events total
- $R(t) = \text{Int}(t)/\text{Noint}(t)$
 - Fit with polynomial
- $dN/dt = A * \exp(-bt)[1 + c(R(t)-1)]$
 - A is overall normalization
 - b is slope of nuclear form factor
 - $b = 301 \pm 14 \text{ GeV}^{-2}$
 - $304 \pm 15 \text{ GeV}^{-2}$
- syst. 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 ± 0.13



Types of trigger

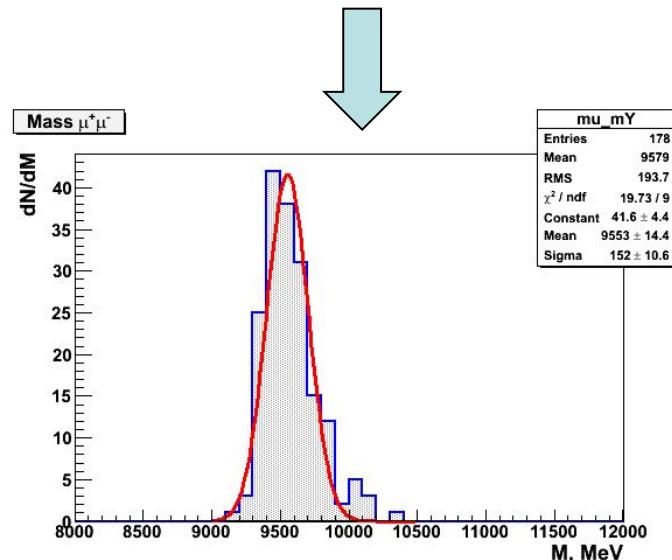
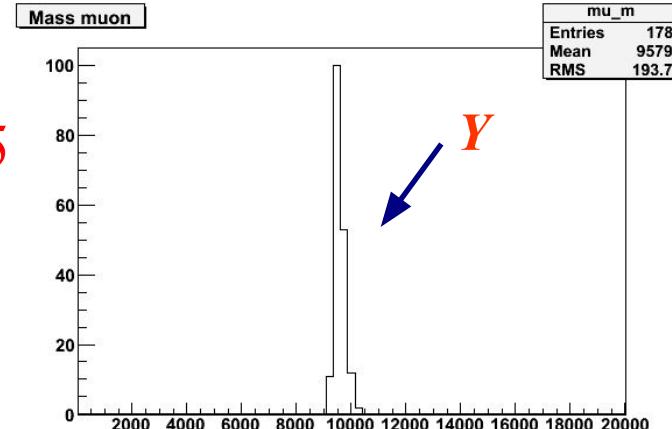
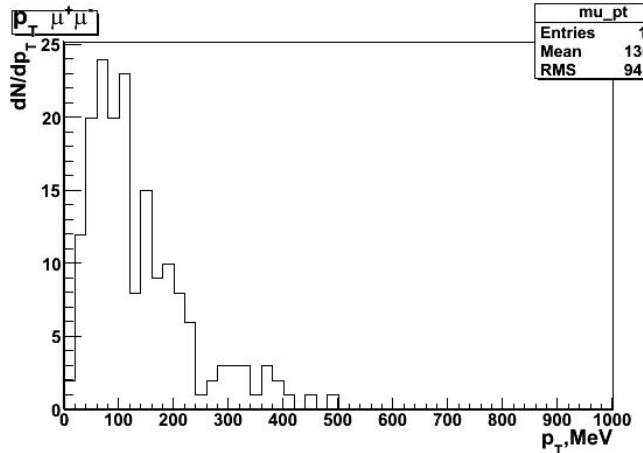
- **Topology trigger + ZDCs** (r^0 in TPC + signals in forward (zero degree calorimeters)
 - Topology trigger + West ZDC: $\text{Au} + d \rightarrow r\text{Au} + pn$
 - required break up d
 - Topology trigger + both ZDC: $\text{Au} + \text{Au} \rightarrow r\text{AuAu} + Xn$



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

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

MUID



530 Y/month

$\angle \angle$

Plans on LHC: ALICE, ATLAS

- Cross-section,rate:

Meson	σ	BR	Acc	rate (10^6 sec)	
J/ ψ	32 mb	5.93%	16.4%	150000	ALICE
Y	150 μ b	2.38%	23.6%	400-1400	
Y	150 μ b	2.38%	35%	400-1400	ATLAS

$g+A \rightarrow J/\psi, Y+A$ in UPC A+A

