

Физика столкновений тяжелых ионов

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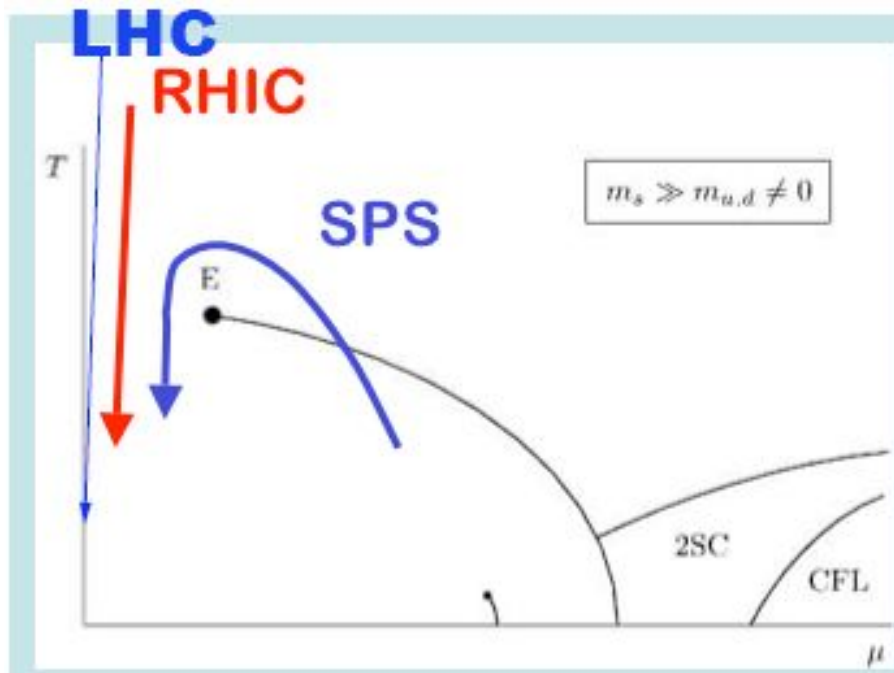
Московский инженерно-физический институт
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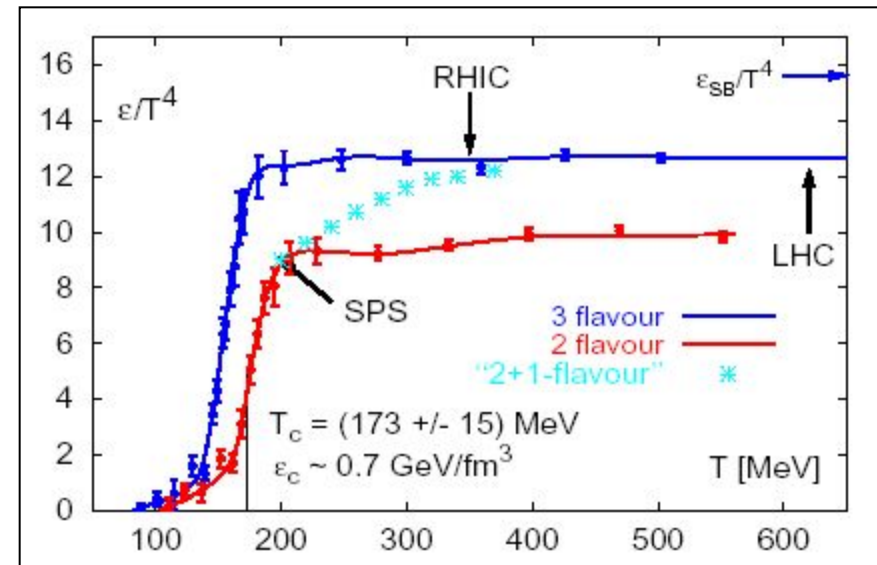
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Фазовые переходы в сжатой и нагретой ядерной материи

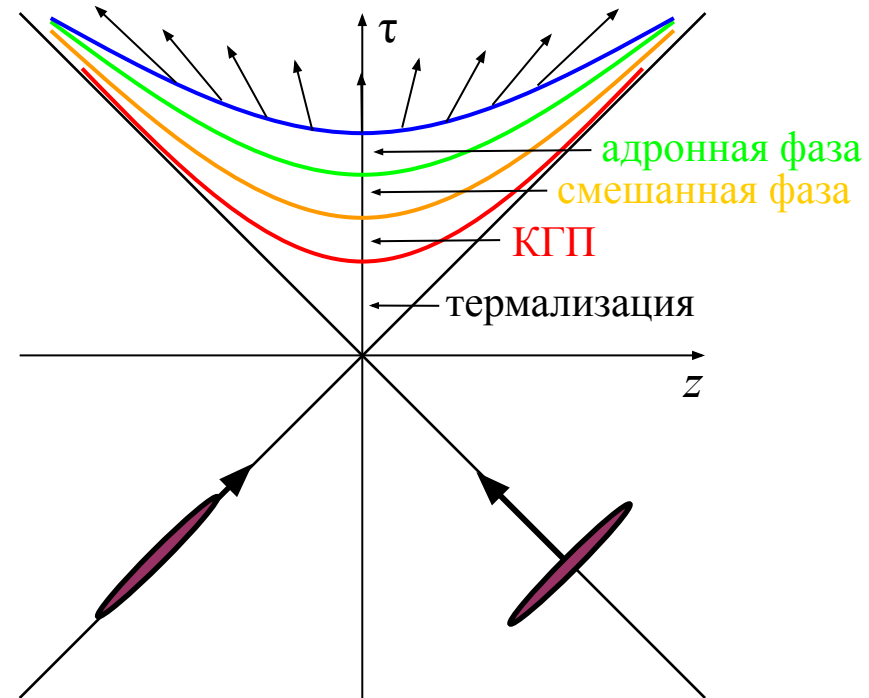
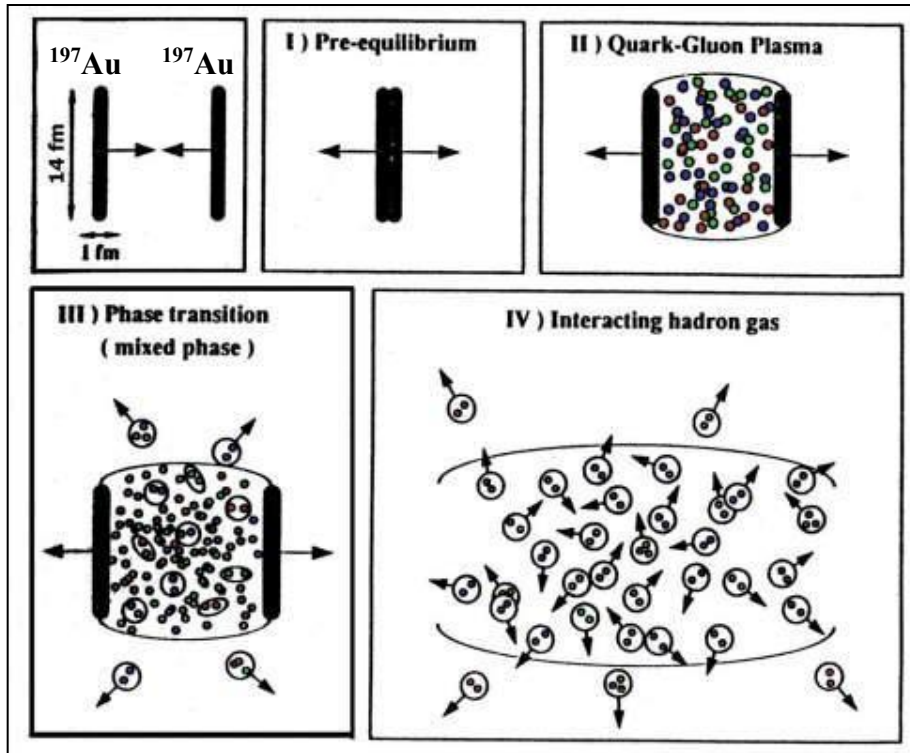
фазовая диаграмма
состояния адронной материи



плотность энергии как
функция температуры



Пространственно-временная картина ядро-ядерных взаимодействий



Сигналы нового состояния вещества

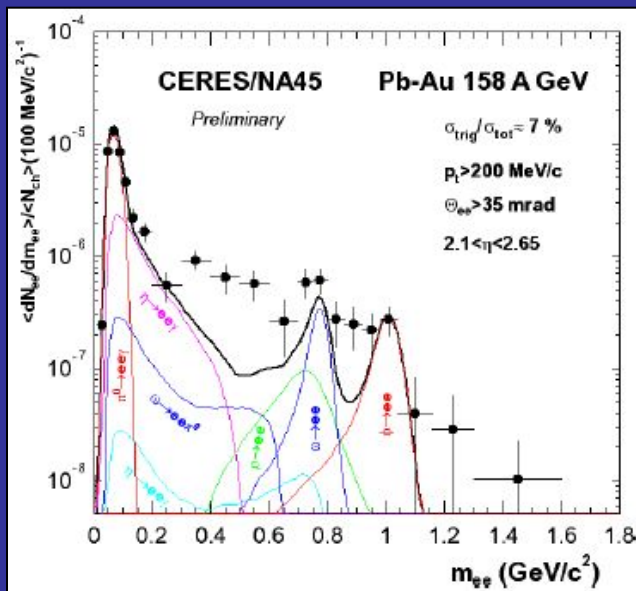


жесткие сигналы («реликтовое излучение»)
(e^+e^- , γ , $\gamma\gamma$, струи, J/ψ подавление)

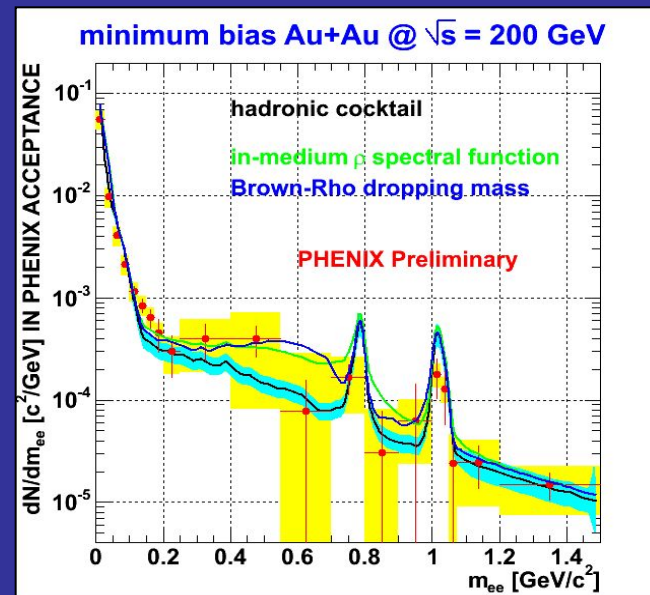
мягкие (адроны)
(коллективные течения,
корреляции, выходы
странных частиц)

Жесткие сигналы

1. Дилептоны



SPS

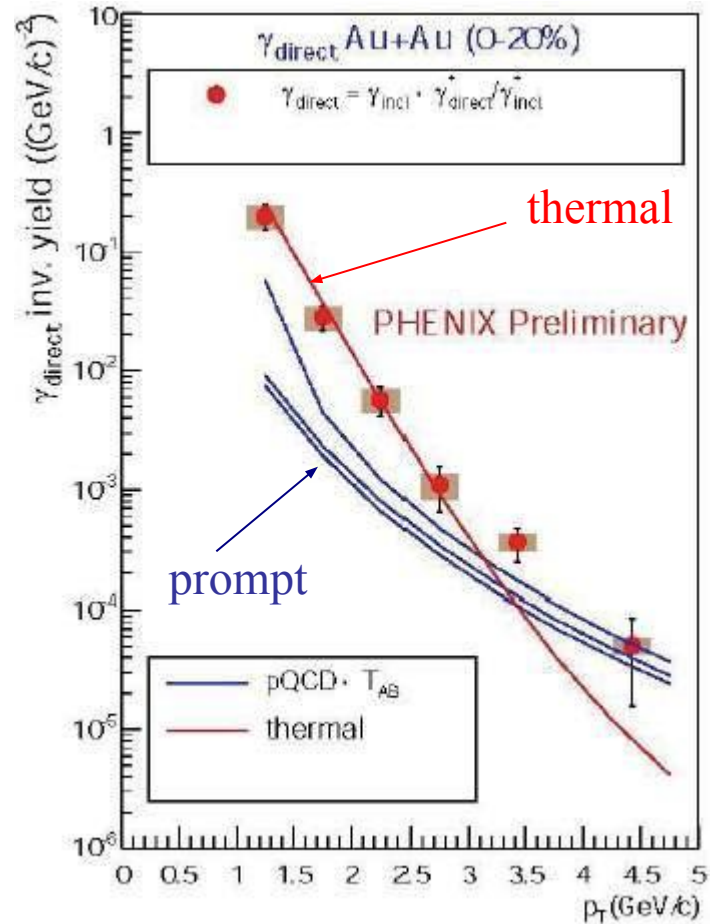


RHIC

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

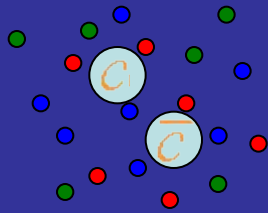
КГП на RHIC

прямые фотоны



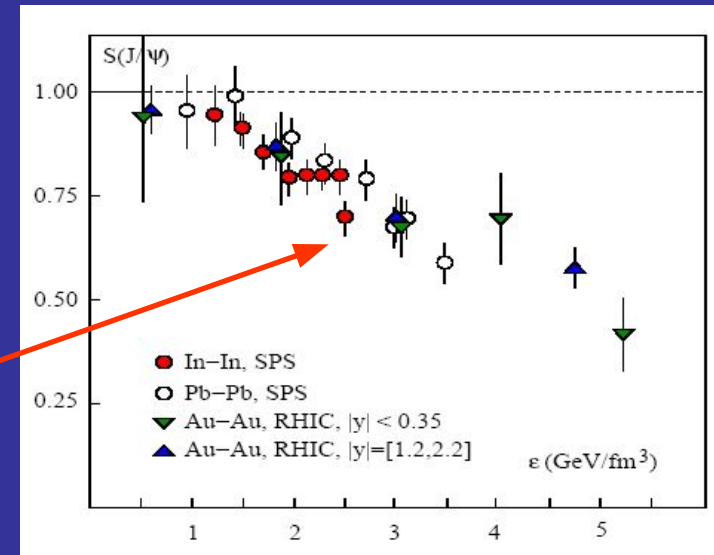
DATA = prompt + thermal

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



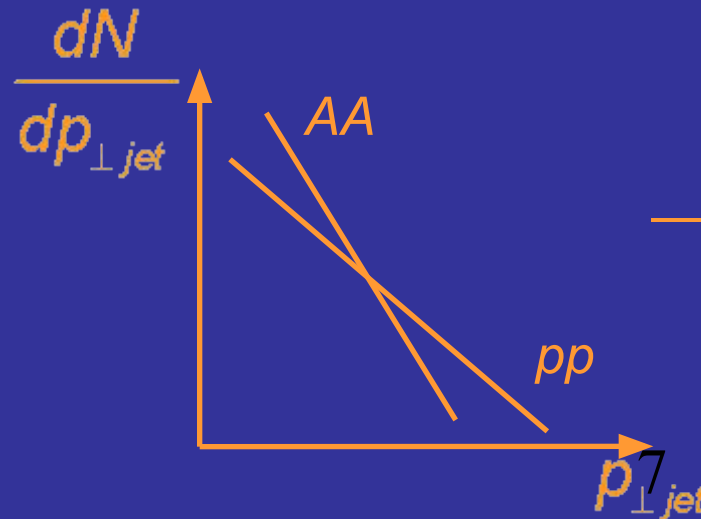
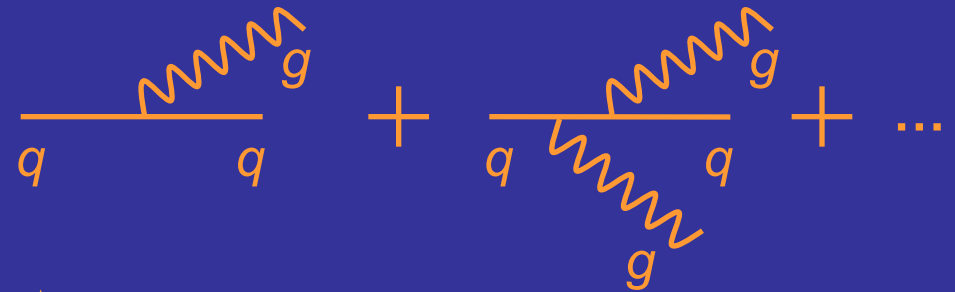
$r_D(T)$ — дебаевский радиус экранирования

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



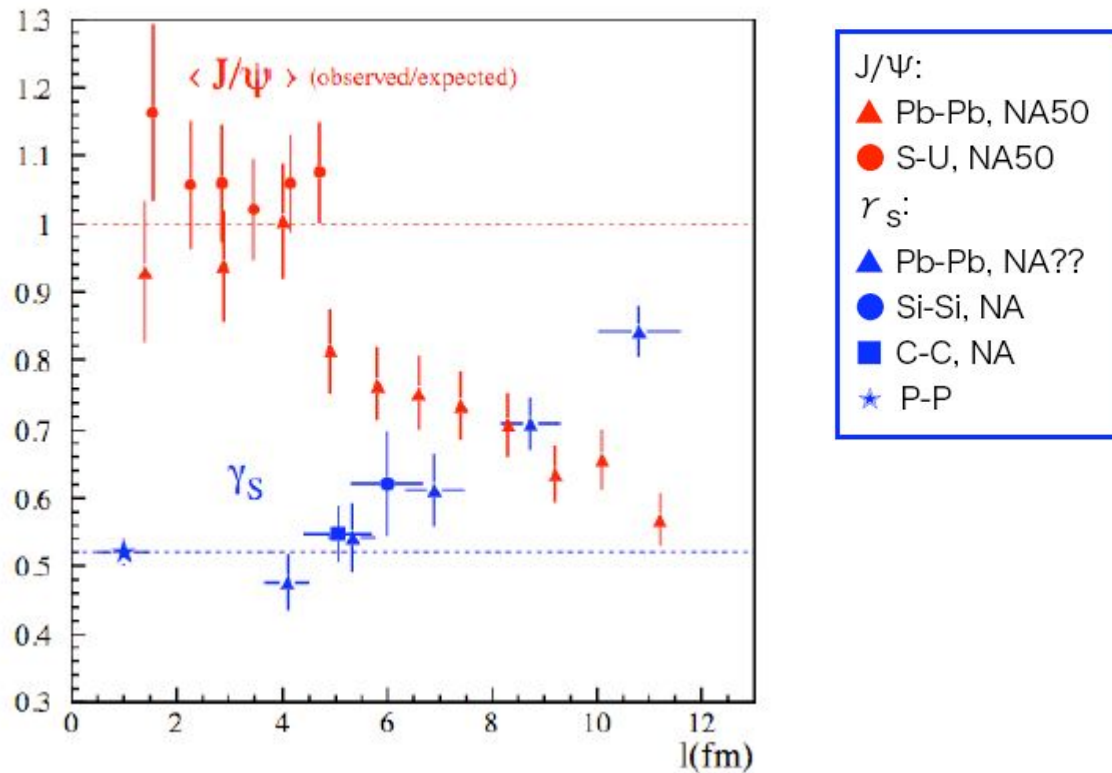
4. Струи

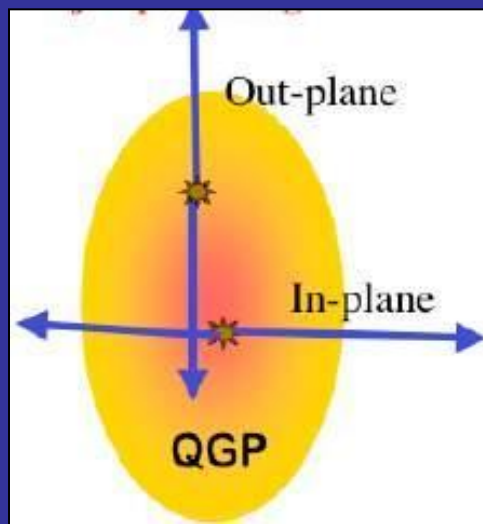
Струя в адронной среде



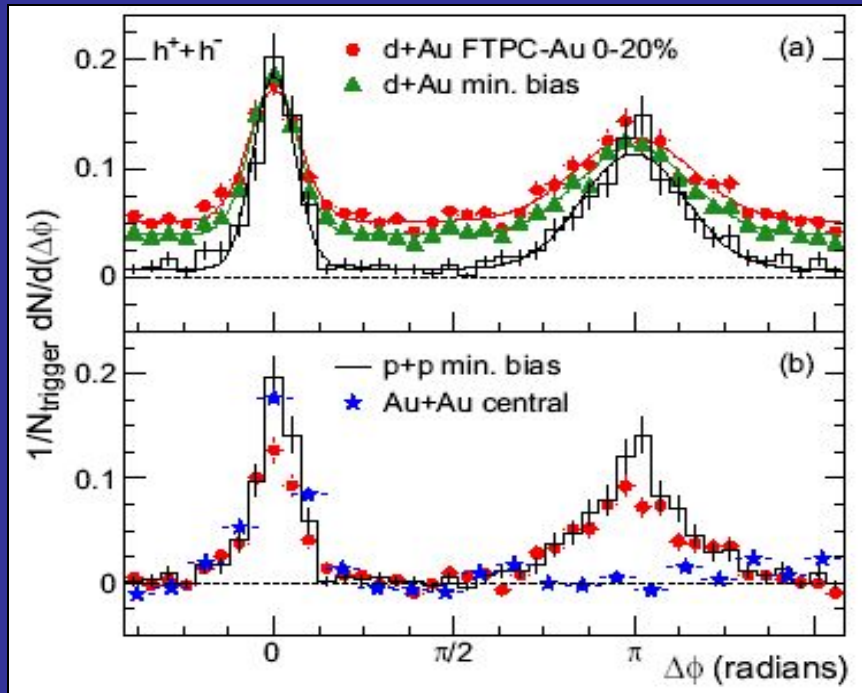
— “jet quenching”

Корреляция подавления J/ψ и увеличения выхода странных частиц

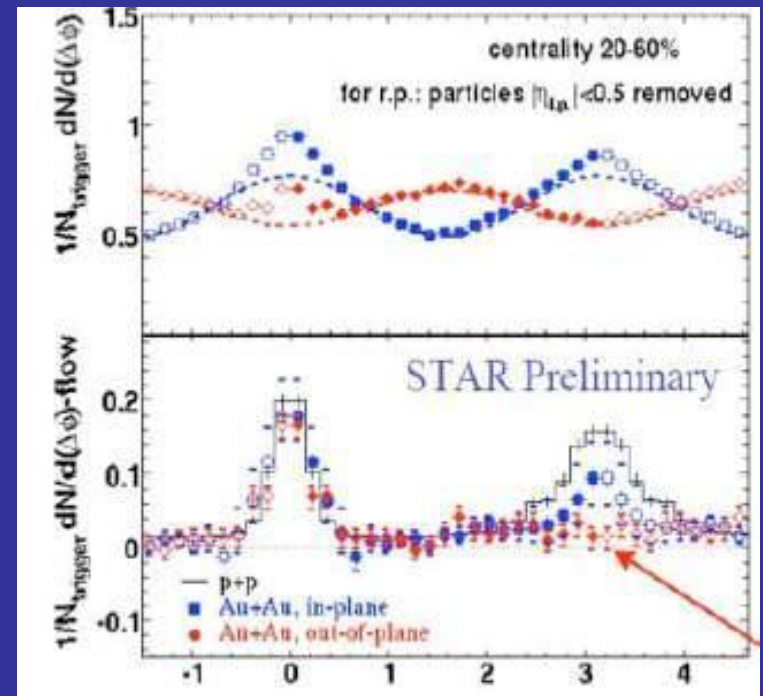




Струи в Au+Au и d+Au и p+p
нет подавления в p+p и d+Au



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



Адронные пробники нового состояния вещества

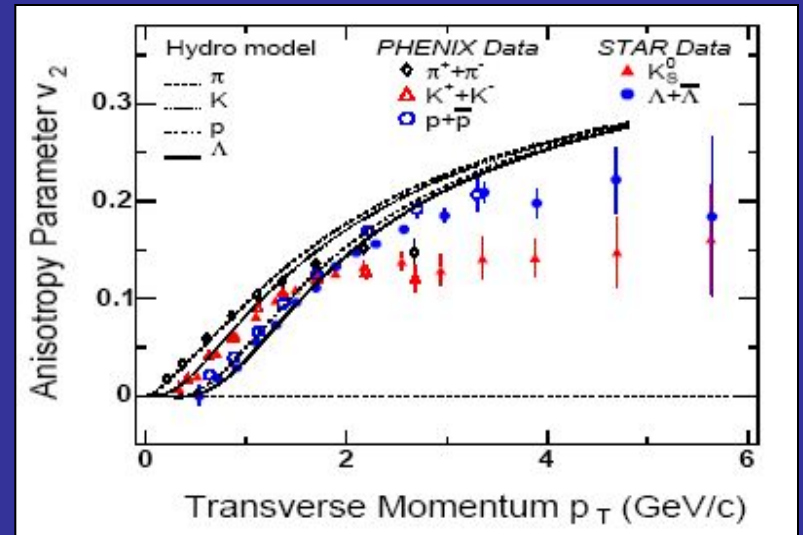
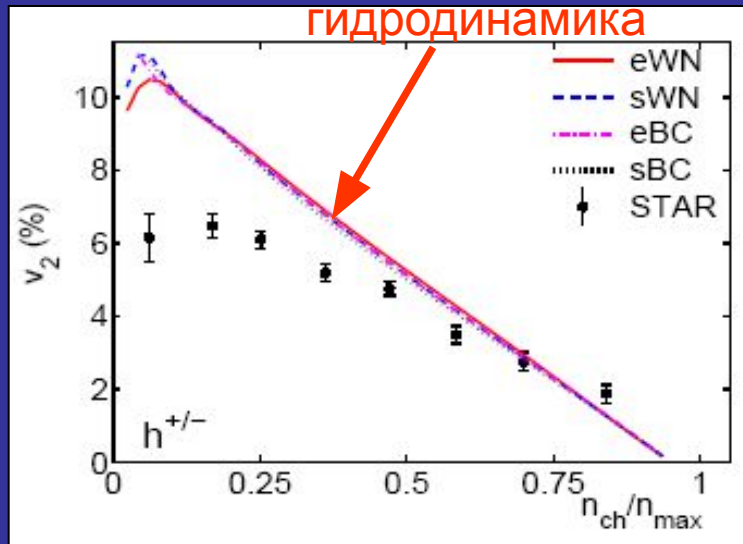
Коллективное течение

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

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

гидродинамика нарушена для

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



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

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

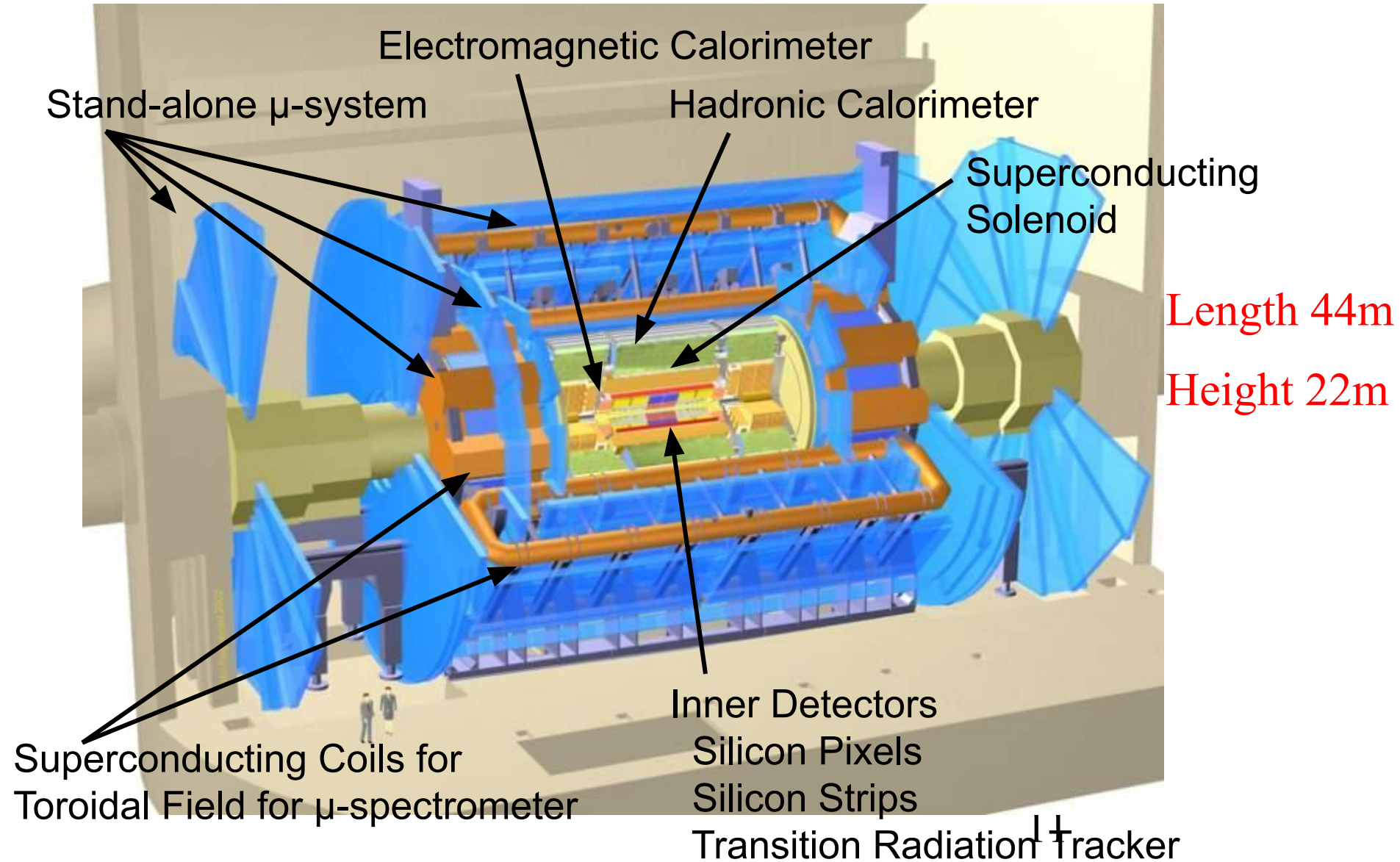
гидродинамика

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

(отношение числа валентных кварков)

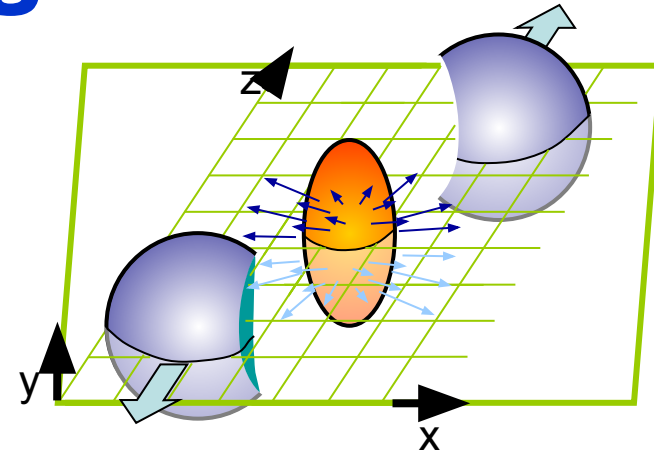
v_2 описывается течением кварков и глюонов с очень малой вязкостью

The ATLAS detector



ATLAS physics program

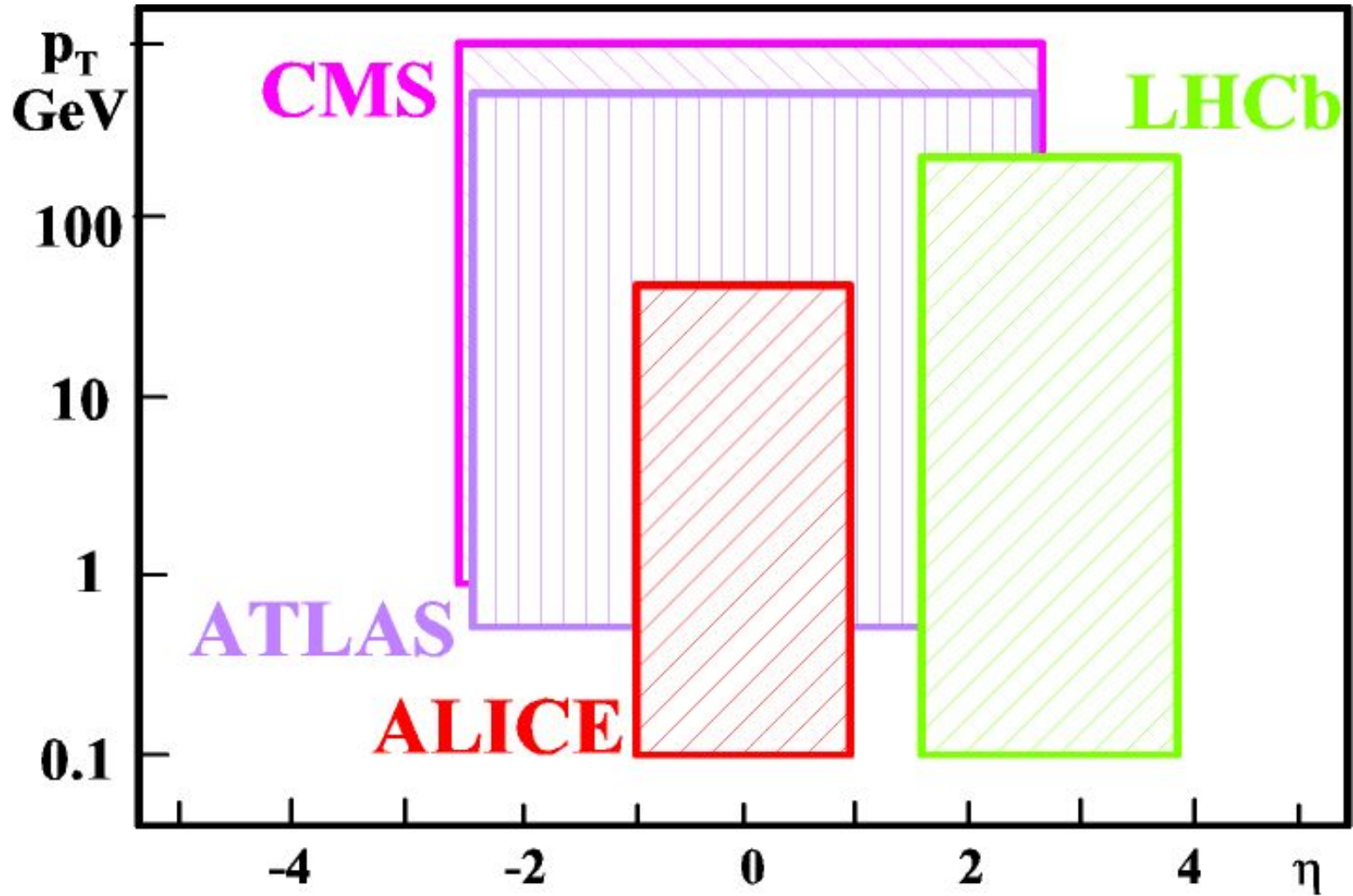
- **Global variable measurement**
 $dN/d\eta$ $dE_T/d\eta$ elliptic flow
azimuthal distributions
- **Jet measurement and jet quenching**
- **Quarkonia suppression**
 J/Ψ Υ
- **p-A physics**
- **Ultra-Peripheral Collisions (UPC)**



Direct information
from QGP

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

Acceptance



ATLAS Physics Rates

A few key numbers and maybe a plot.

~ 8,000 collisions per second
luminosity ~ 10^{27} cm⁻²s⁻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 -->

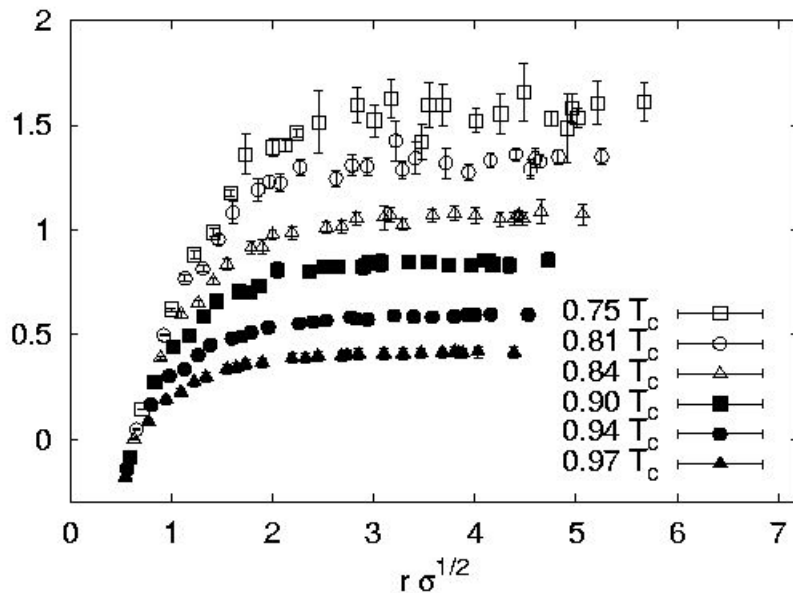
With central barrel in one month running for central events:
1e3 counts at 60 GeV in 1 GeV pt bin!

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)



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

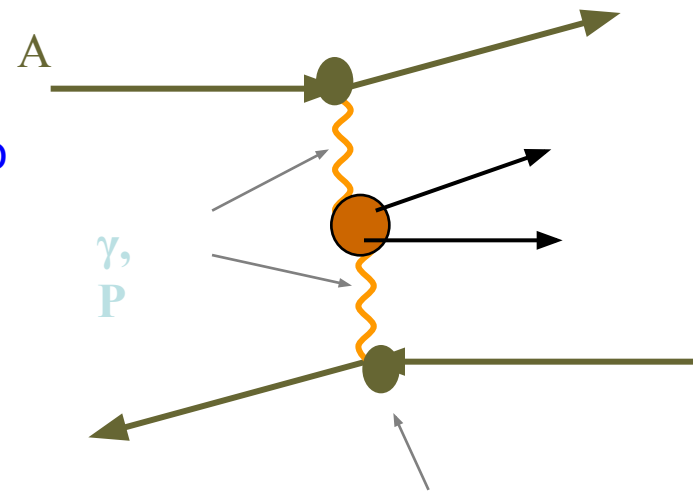
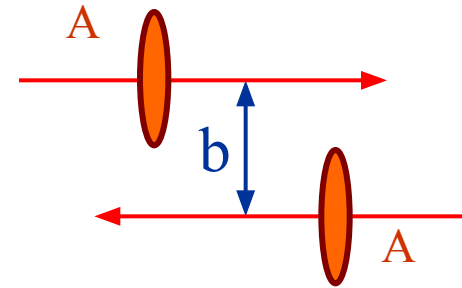
- Photon and pomeron can couple coherently to the nuclei if its have:

- ◆ Small transverse momentum:

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

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

$$p_L <$$



nuclear form factor

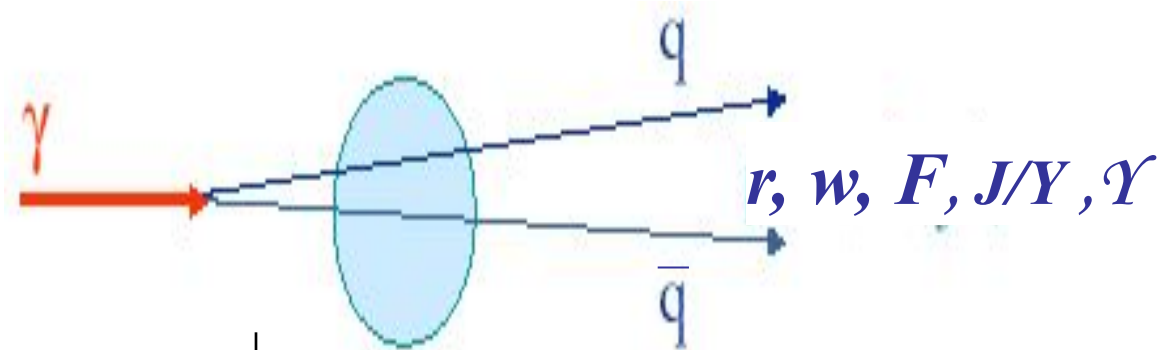
$$E_\gamma \sim 3 (80) \text{ GeV at RHIC (LHC)}$$

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

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)

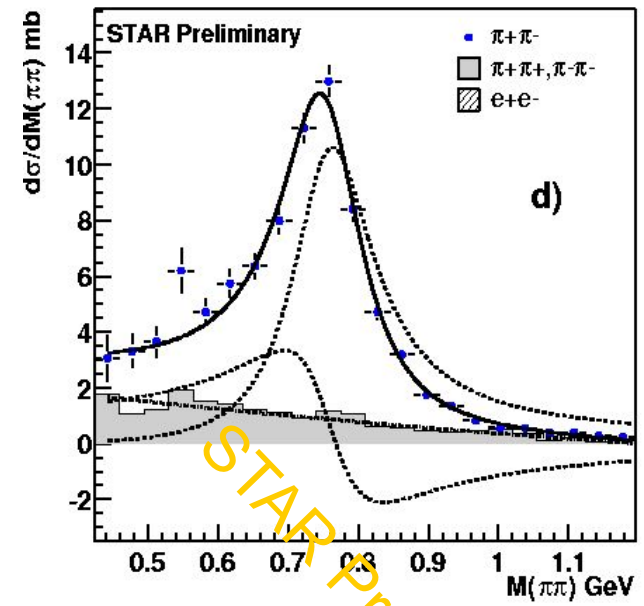
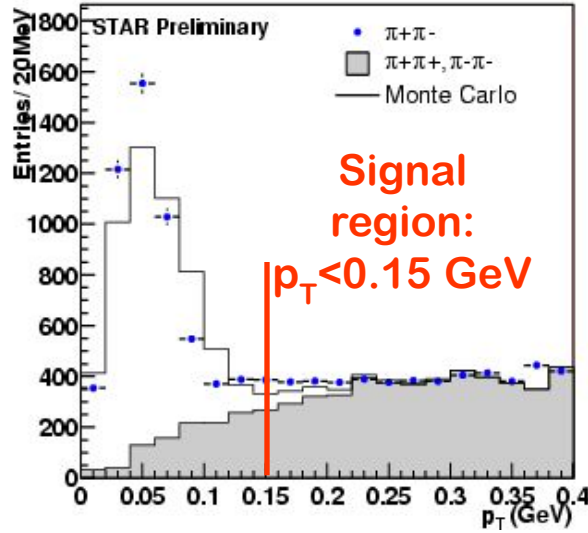


Meson	Au+Au, RHIC $\sigma(\text{mb})$	Pb+Pb, LHC $\sigma(\text{mb})$
ρ^0	590	5200
ω	59	490
ϕ	39	460
J/ψ	0.29	32

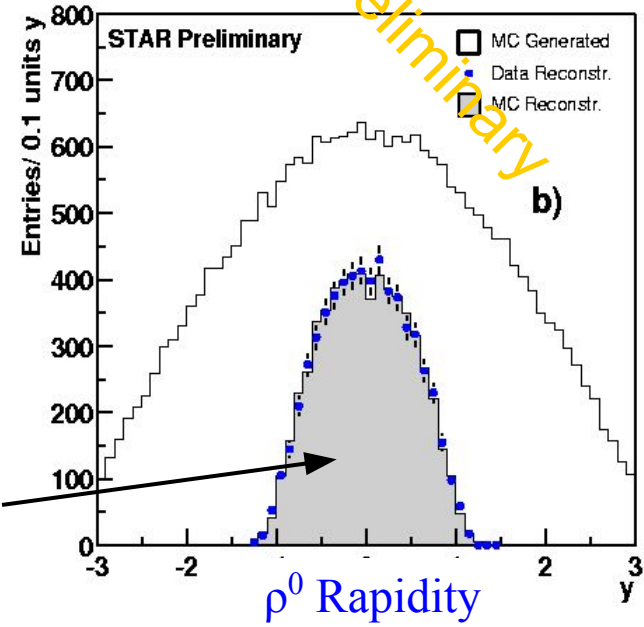
$$\sigma(\text{AA} \rightarrow \text{AA}Y) = 150 \text{ mb}$$

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

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



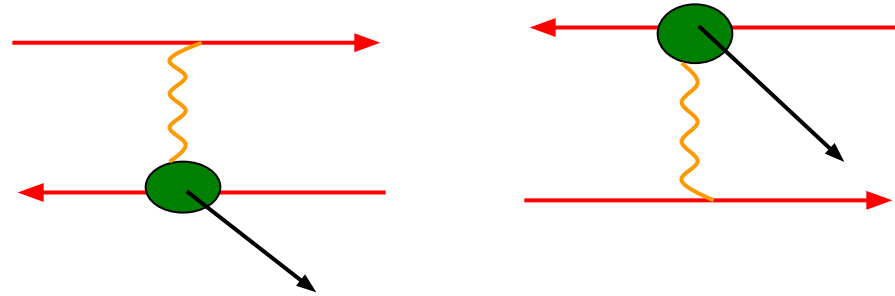
- ❑ 1.7 million ZDC coincidence triggers in 2002
- ❑ Require a 2 track vertex
- ❑ p^+p^+ and p^-p^- model background
 - scaled up to 2
- ❑ single (1n) and multiple (Xn) neutron production
 - 1n mostly from Giant Dipole Resonance
- ❑ Cross section and rapidity distribution match soft Pomeron model



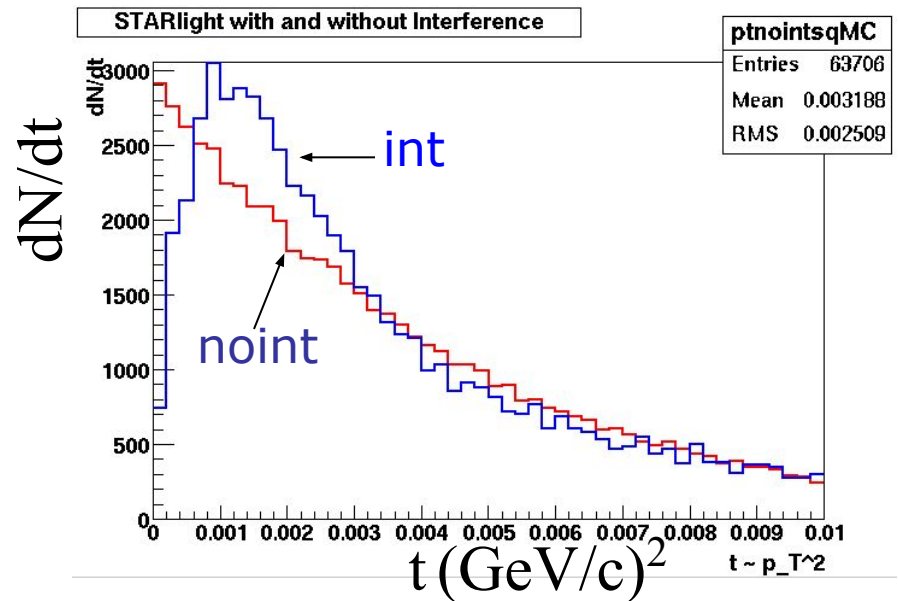
After detector simulation

Interference

- 2 indistinguishable possibilities
 - Interference!!
- 2-source interferometer with separation b
- ρ 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 $p\bar{p}$ p: CP transform \rightarrow
 - $\sigma \sim |A_1 + A_2 e^{ip \cdot b}|^2$
- b is unknown
 - Reduction for $p_T \ll 1/\langle b \rangle$



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

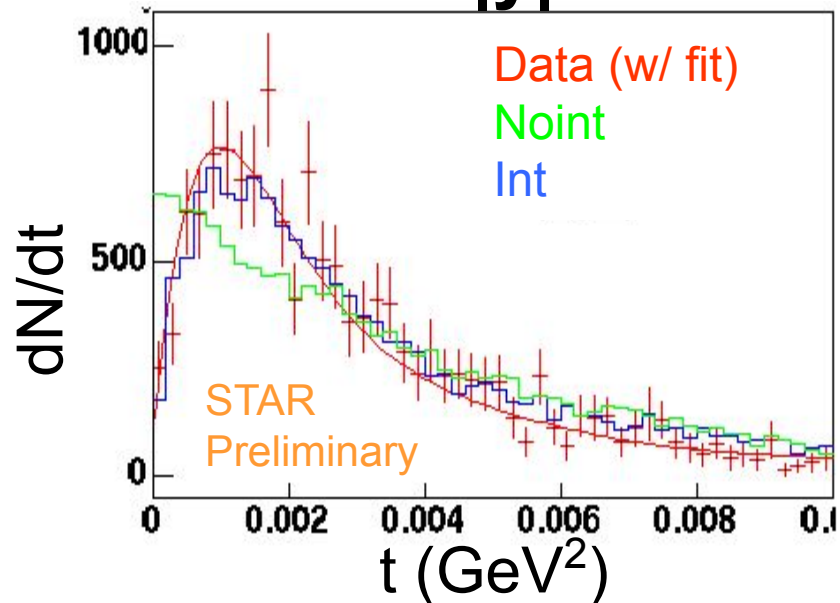


Interference

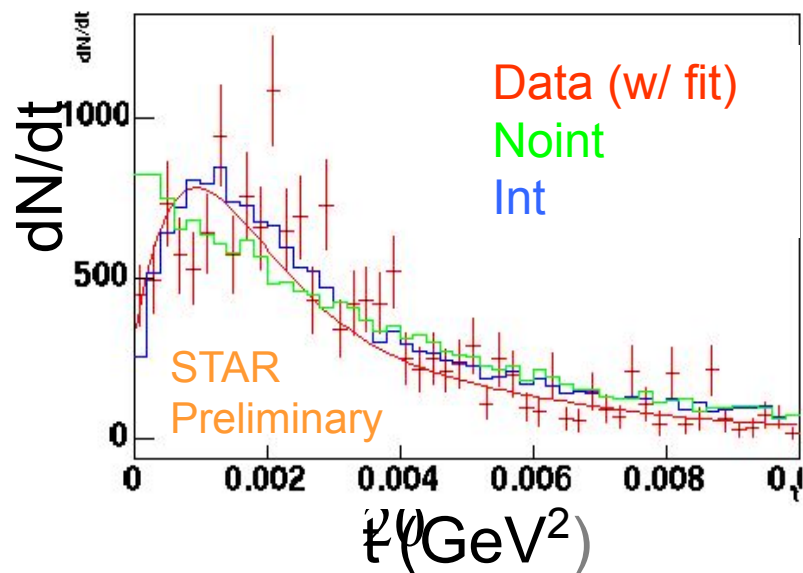
AuAu \rightarrow r^0 Au*Au* 200 GeV

- 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 ± 0.13

$0.1 < |y| < 0.5$

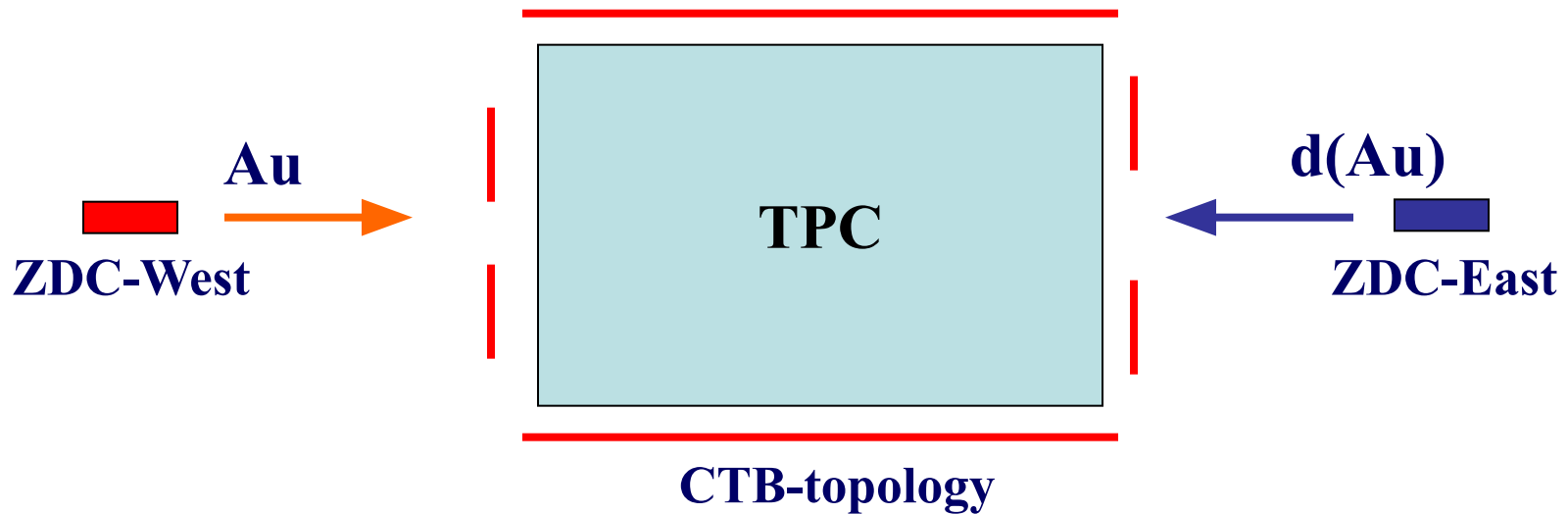


$0.5 < |y| < 1.0$



Types of trigger

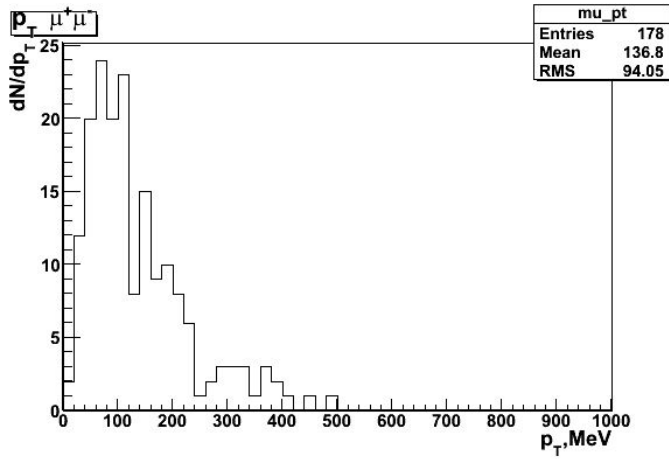
- **Topology trigger + ZDCs** (r^0 in TPC + signals in forward (zero degree calorimeters))
 - Topology trigger + West ZDC: Au+d- \rightarrow rAu+pn
 - required break up d
 - Topology trigger + both ZDC: Au+Au- \rightarrow rAuAu+Xn



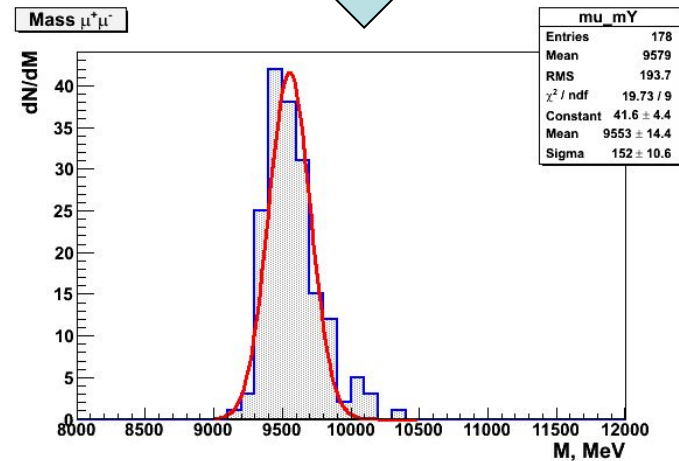
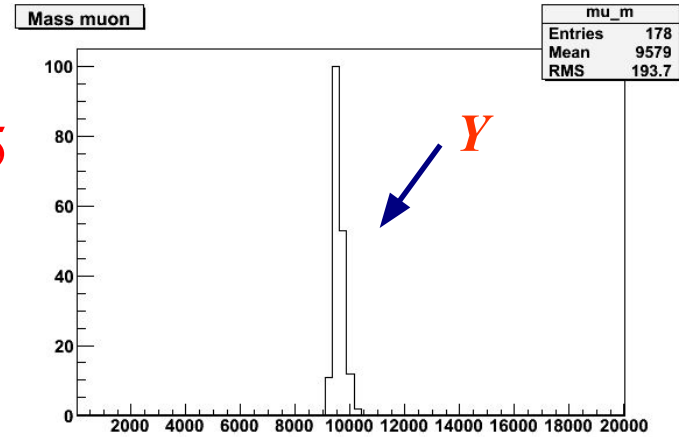
- **Backgrounds**
 - ◆ peripheral hadronic events
 - ◆ cosmic rays, beam gas interactions, pile-up

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

MUID



$|\eta| < 2.5$



530 Y/month

LL

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
Υ	150 μ b	2.38%	23.6%	400-1400	
Υ	150 μ b	2.38%	35%	400-1400	ATLAS

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

