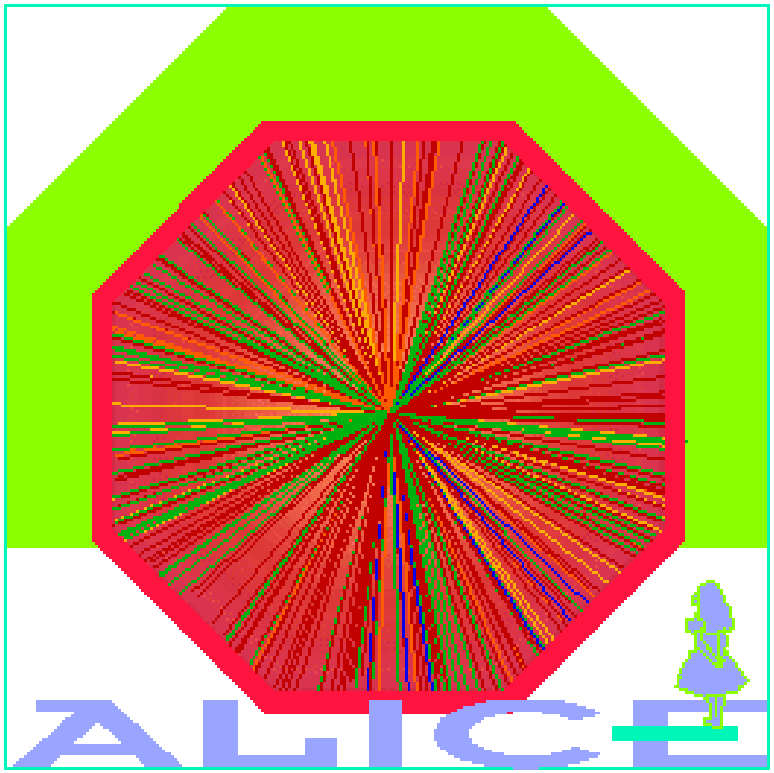
Heavy Ion Program@LHC
ALICE View

- Summary
- ALICE constraints
- Heavy Ions (Pb-Pb)
- pp and pA
- Light Ions
- Options



See internal note ALICE-INT-2001-10 V2.0

Summary

- **initial 4-5 years** (1HI 'year' = 10^6 effective s)
  - ⇨ regular pp running at $\sqrt{s}$ = 14 TeV — **L ~ 10^{29} and < $3x10^{30}$ $cm^{-2}s^{-1}$**
  - ⇨ **2 - 3 years Pb-Pb** — **L ~ 10^{27} $cm^{-2}s^{-1}$**
  - ⇨ **1 year p - Pb 'like'** (p, **d** or α beams) — **L ~ 10^{29} $cm^{-2}s^{-1}$**
  - ⇨ **1 year light ions** (eg Ar-Ar) — **L ~ few 10^{27} to 10^{29} $cm^{-2}s^{-1}$**

- other **options**, depending on physics priorities & results
  - ⇨ pp collisions at $\sqrt{s}$ = 5.5 TeV/n
    - ✪ short energy scan of interest also to pp expts ? (connect to Tevatron ?)
  - ⇨ lower energy Pb-Pb
  - ⇨ **possibly further** high energy Pb-Pb
  - ⇨ **possibly** another light system **(**out of **O-O, Kr-Kr, Ar-Ar, Sn-Sn)**
  - ⇨ **possibly** another pA system

ALICE constraints

- **Luminosity with Ions (light or heavy)**
  - ⇨ pile-up in **TPC** => **MinBias rate < 8 kHz**
    - ✪ Pb-Pb: L < 10^{27} Ar-Ar: L < $3x10^{27}$ p-p: L < 10^{29}
  - ⇨ **muon spectrometer** 'stand-alone': **RPC limit ~ 50-100 Hz/cm²**
    - considered for high statistics runs with light ions (Y suppression)
    - 'soft' limit, depends on RPC properties (trying to improve)
    - machine background (in particular pp) a major concern !
    - ✪ Pb-Pb: L < few 10^{28} Ar-Ar: L ~ 10^{29} p-p: L < $5x10^{31}$
- **Luminosity pp, p-A 'like'**
  - ⇨ **no pile-up** (clean events, low data volume) => **MinBias rate < 8 kHz**
    - ✪ untriggerd **MB events**, large rate (kHz)
  - ⇨ **pile-up** TPC < 20 events, no pile-up in SDD => **MinBias rate < 200 kHz**
    - ✪ triggered **rare events**, small rate (Hz)
    - ✪ pp: L < $3x10^{30}$ d-Ar: L < $2x10^{29}$ d-Pb: L < $8x10^{28}$
- **DAQ limits: BW = 1.25 Gbyte/s to storage**
  - ⇨ **Pb: 20 Hz MB, 20 Hz central+rare triggers, ~ 1 kHZ muon arm**
  - ⇨ **pp, d-A: ~ 1 kHz (limited by R/O time, TPC gating)**

H.I. Event samples

- **global event properties (large x-sections, soft processes)**
  - trigger on MB and central (~ 5% of total x-section)
  - data sample **limited by DAQ** capability for MB rate > 400 Hz
    - Pb-Pb: L > 5 x 10^{25} (5% of design L)
    - one reason for large DAQ bandwidth of ALICE
    - 1 'effective day' (10^5 s) = 2x10^6 evts @ 20 Hz

- **semi-rare, but untriggerable events**
  - eg Ω, heavy quark mesons (D, B) hadr. & semi-leptonic decays,
  - trigger would need full, good online reconstruction to be selective
    - rate for inclusive hadrons/leptons of relevant p_t >> 1/event !
  - needs **large statistics** of MB/central events (few 10^7 evts)

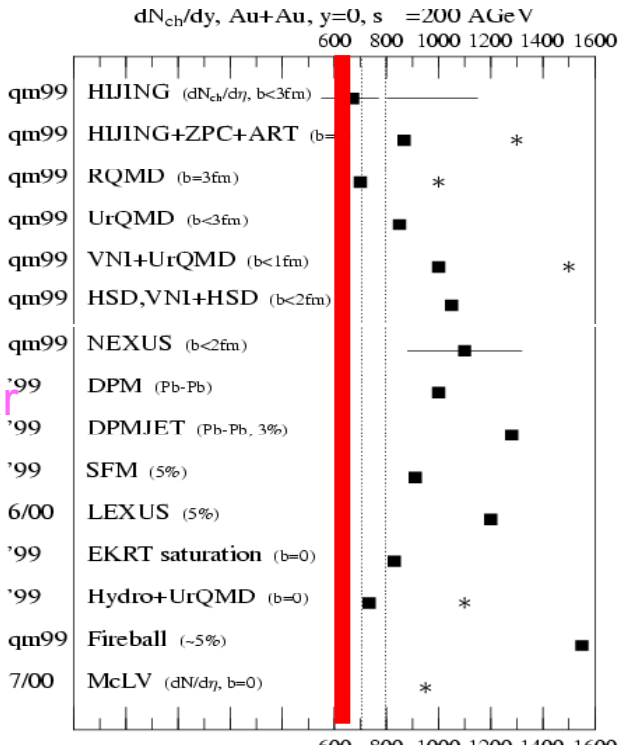
- **rare triggered events**
  - lepton pairs (e, μ), high p_t particles, jets > 100 GeV
  - need **max Luminosity**, not limited by DAQ ('high priority' scheme)

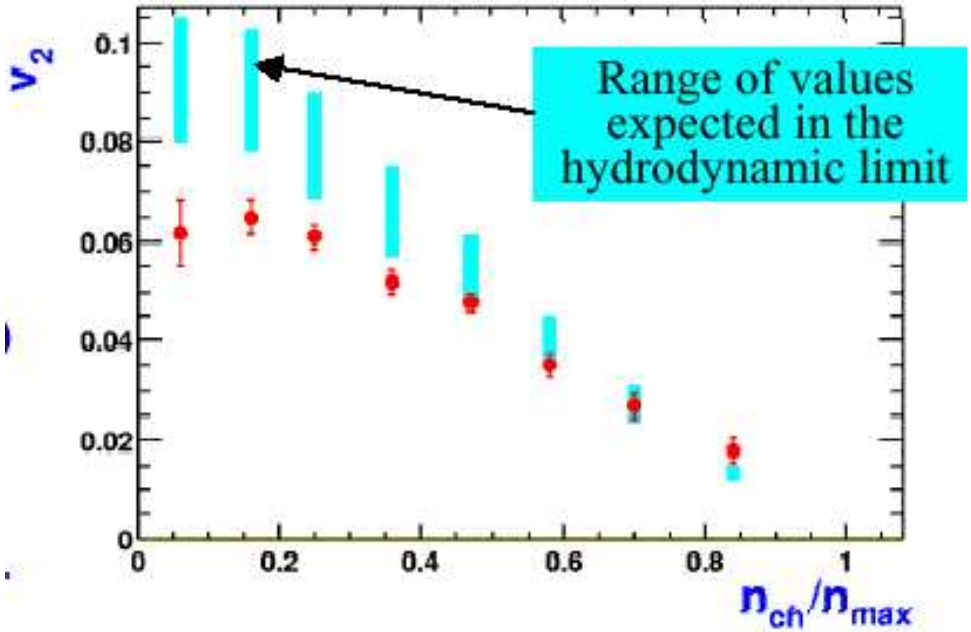
Base Program I

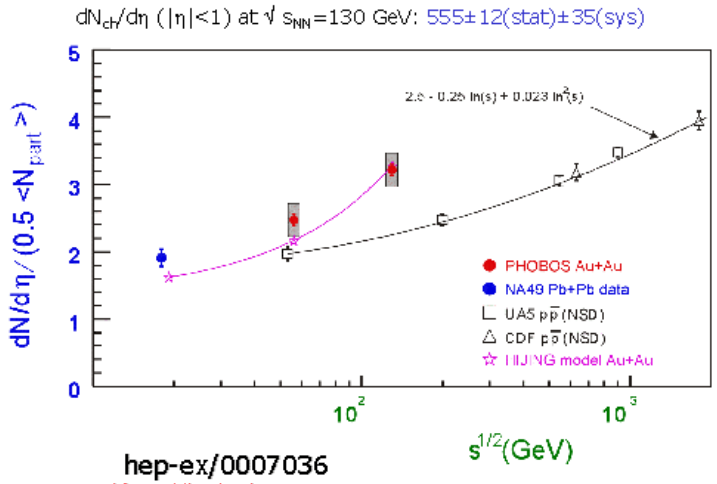
- **start with heaviest ion, max. Energy**
  - ⇨ **Pb-Pb at 5.5 TeV/A**
  - ⇨ **Step 1:** ~ **day** even at very low initial Luminosity
    - ✪ few 10^3 - 10^5 events => global event properties
  - ⇨ **Step 2:** ~ **week**, still below design Lum.
    - ✪ some 10^6 events => most of hadronic signals
  - ⇨ **Step 3:** ~ **month** (> 10^6 effective s), max Lum.
    - ✪ Integrated luminosity => rare hard signals

Statistics needed in Ion Program

- Minimum: 6366 MB (382 central) events
  - ⇨ **few seconds at 1% design L**
- RHIC in 2000
  - ⇨ first collisions June 12, first PRL subm. July 19 (2nd: Aug 24, 22k MB events)
  - ⇨ ~ 3 weeks run, very low L, > 10 PRL's within < 1 year
    - ✪ RHIC was commissioned with HI !
- SPS in 1986
  - ⇨ first spectrum 1 week **before** start of HI run !







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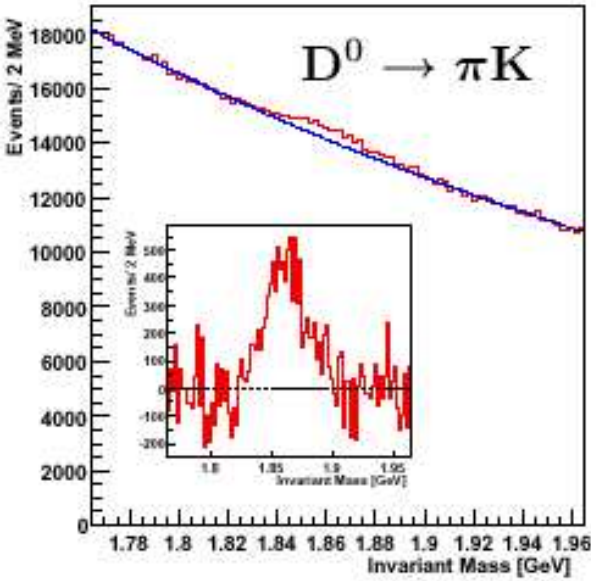
Hadronic observables

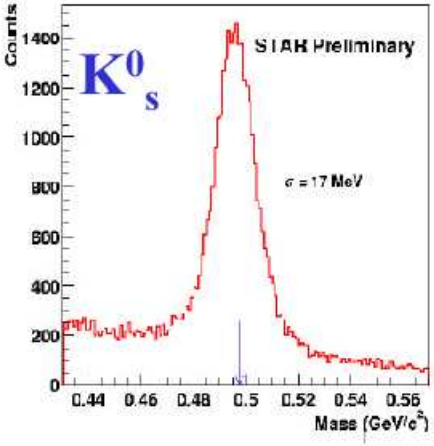
- **STAR, ~ 10^6 central events (Oct. 2000 conf)**
  - ⇨ most global properties & hadronic observables
    - ✪ (particle ratios & spectra, HBT, flow, ….): Thermodynamics & Hydrodynamics
- **some 10^7 evts needed for full hadronic physics**
  - ⇨ p_t spectra > 5-10 GeV
  - ⇨ Ω, charm, beauty, ..

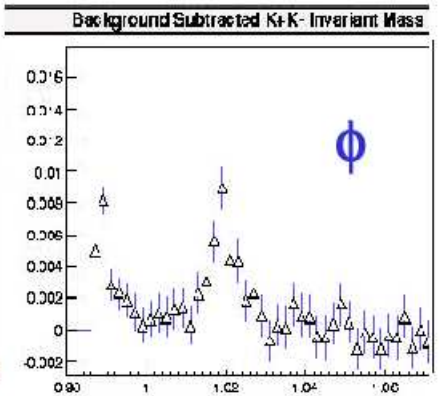


~ 8100 $D^0/10^7$ central PbPb evts

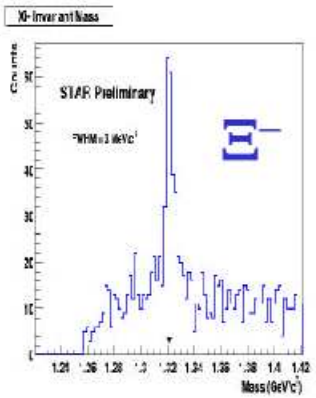
case A (the K is identified)

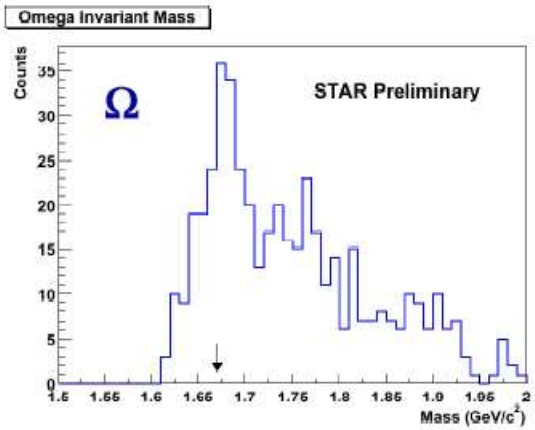
$(dN_{ch}/dy)_{y=0}$	8000	4000	2000
S/B	5.3 %	> 21 %	> 85 %
S/√B	10.9	> 22	> 44

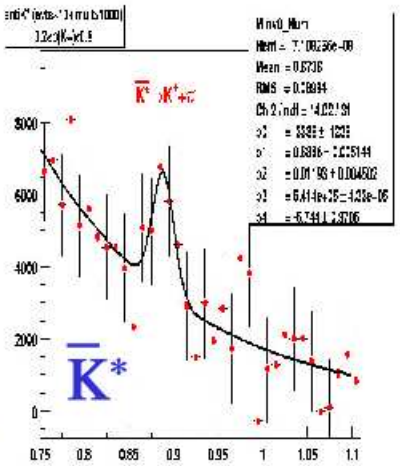




Long way from "peaks" to final spectra and ratios but the signal strength is sufficient in all cases.



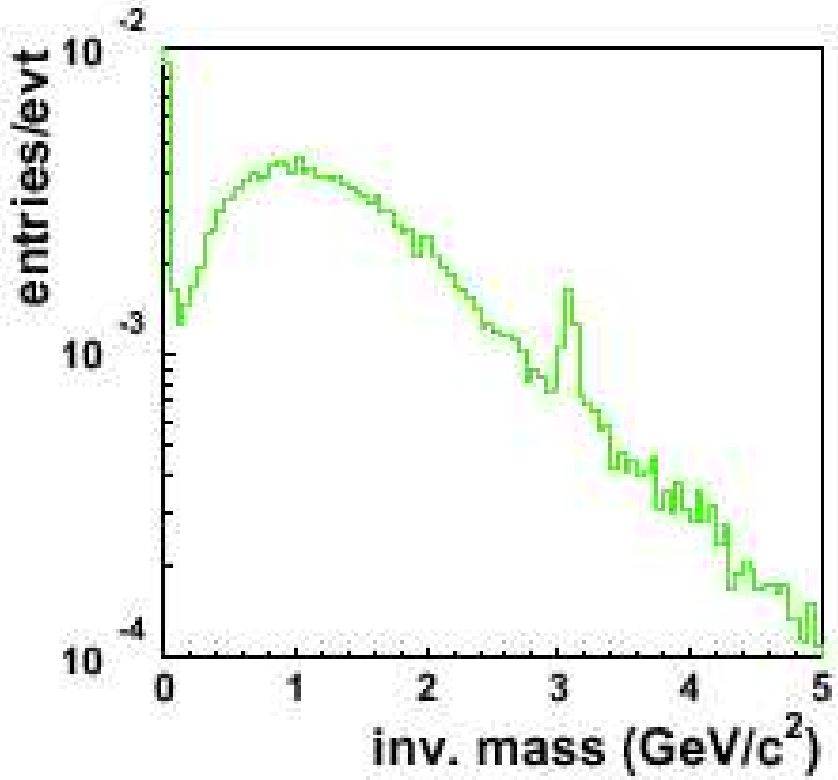




Rare Hard signals

- **need max Lum, max time**

B -> J/Psi -> e+e-
(sec. vertex)
- b x-section,
- b energy loss
- J/Psi suppression



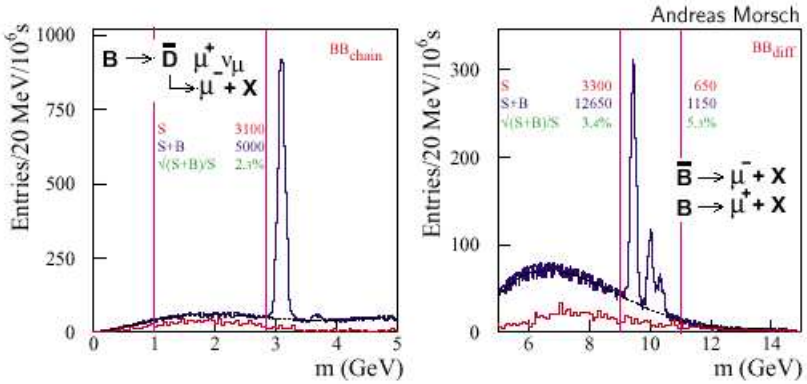
- expected statistics

  - input x-sections from R. Gavai et al., Int.J.Mod.Phys.A10(1995)3043
  - extrapolation to central (10%) PbPb with $A^2/4$
  - no suppression/enhancement
  - includes all efficiencies and analysis cuts
  - $L = 5 \cdot 10^{26} cm^{-2} s^{-1}$, 10^6 s running time, 1 σ mass cut

	S	S/B	S/√S+B
J/ψ	230000	0.72	310
ψ'	4600	0.03	12
Υ	1800	7.10	39
Υ'	540	2.50	19
Υ''	260	1.50	12

- correlated bottom measurements

Andreas Morsch



with $p_t^\mu > 3$ GeV/c, large relative yield of dimuons from bottom decay all over invariant mass

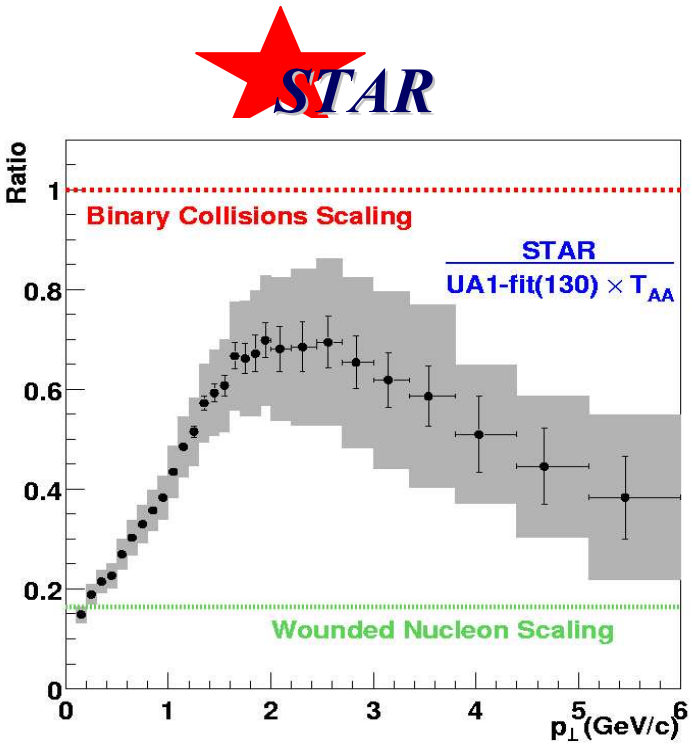
Need for pp & pA collisions at LHC

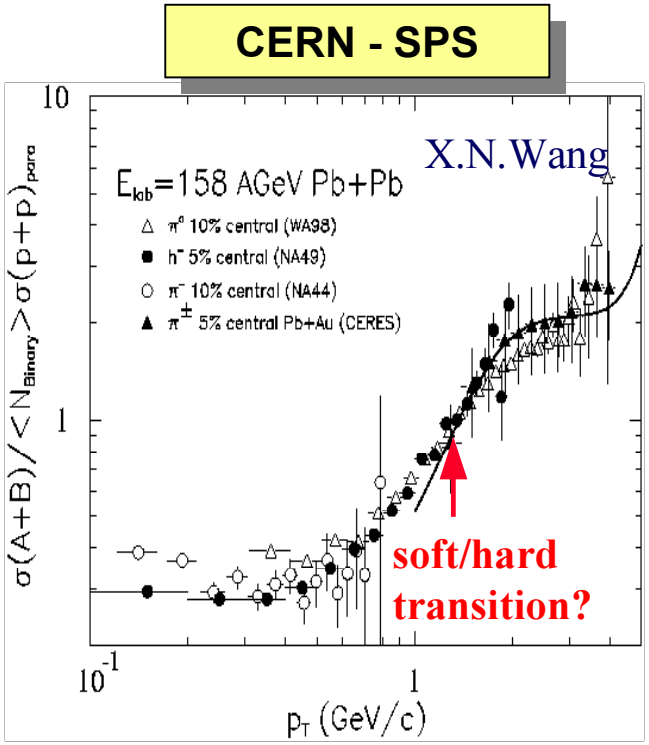
- **QGP analysis: study changes to signals**
  - measure same signal pp -> pA -> AA
  - same program at AGS, SPS, RHIC
- **baseline: pp reactions**
  - comparison running with pp to measure basic x-sections
  - very few results make **NO** reference to pp
  - **pp essential part of base program. Needed to analyse AA data !**
- **'trivial' nuclear modifications: pA**
  - initial state **structure functions** (shadowing)
    - large but unknown gluon shadowing at LHC
    - factor two or more uncertainty in pQCD x-sections
  - **final state interaction** in cold nuclear matter (quarkonia, jets, p_t distributions,..)
    - big effects, directly relevant for extracting QGP related modifications
  - **pA essential part of base program. Needed to analyse AA data !**
    - even more than at SPS (more shadowing, more emphasis on hard probes !)
- **number of genuine physics topics in pp, pA**
  - parton saturation, double parton scattering, diffraction, …(not further discussed)

Example: pt Spectra

- **measure $p_t(AA)/p_t(pp)$**
  - ⇨ low/med p_t: thermo- & hydrodynamics
  - ⇨ at high p_t sensitive to 'jet-quenching'
  - ⇨ **needs pp data to compare**

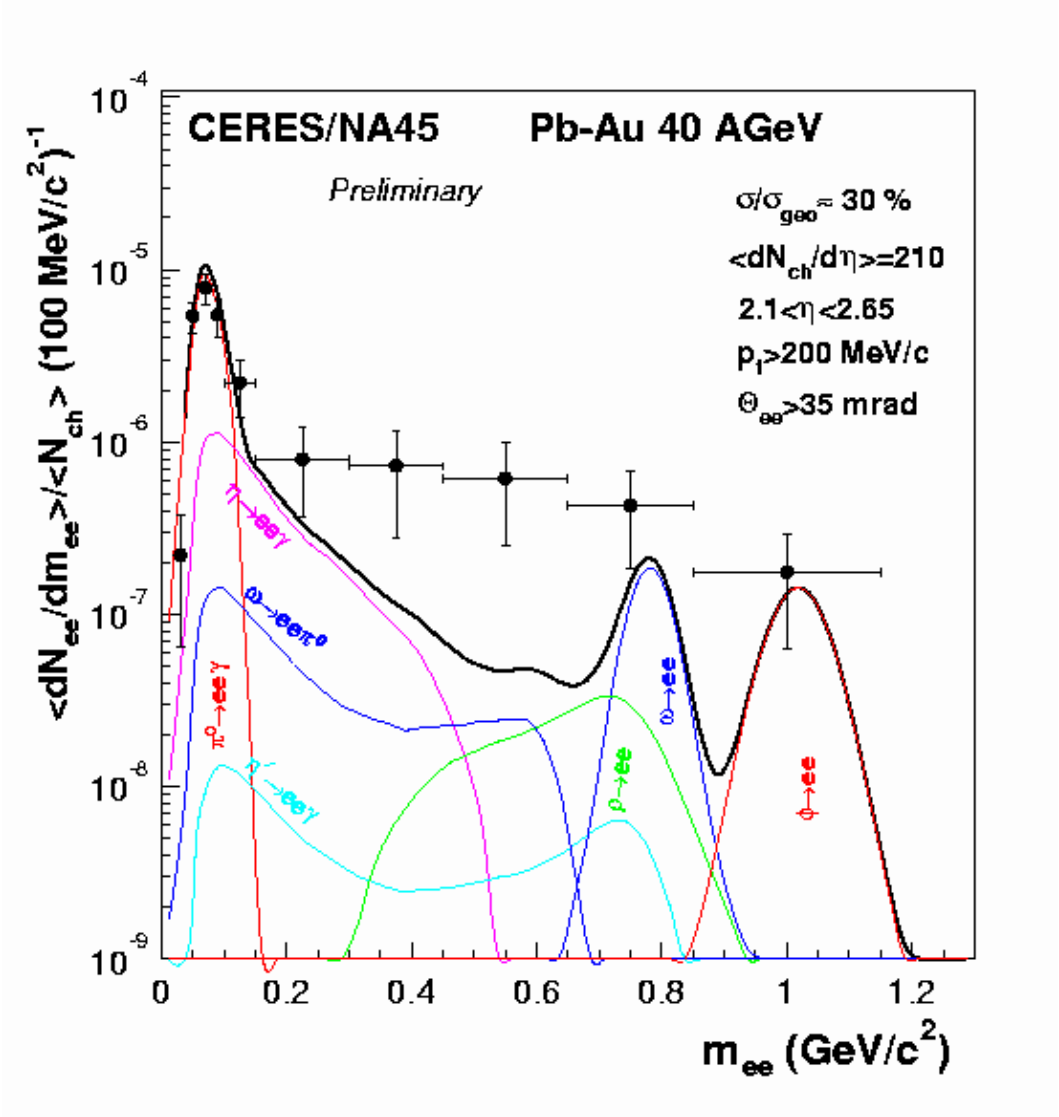
- **complication: Cronin effect**
  - ⇨ final state parton scattering
  - ⇨ depends on A, sqrt(s)
  - ⇨ **needs pA data at LHC**



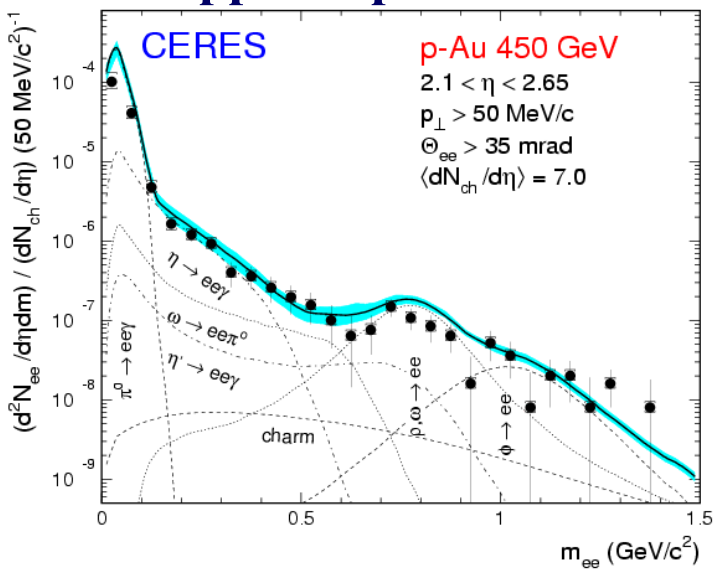


Example: Lepton Pairs

- **get confidence in simulation of 'normal' behavior**
  - ⇨ need pp and/or pA data in same detector, same analysis

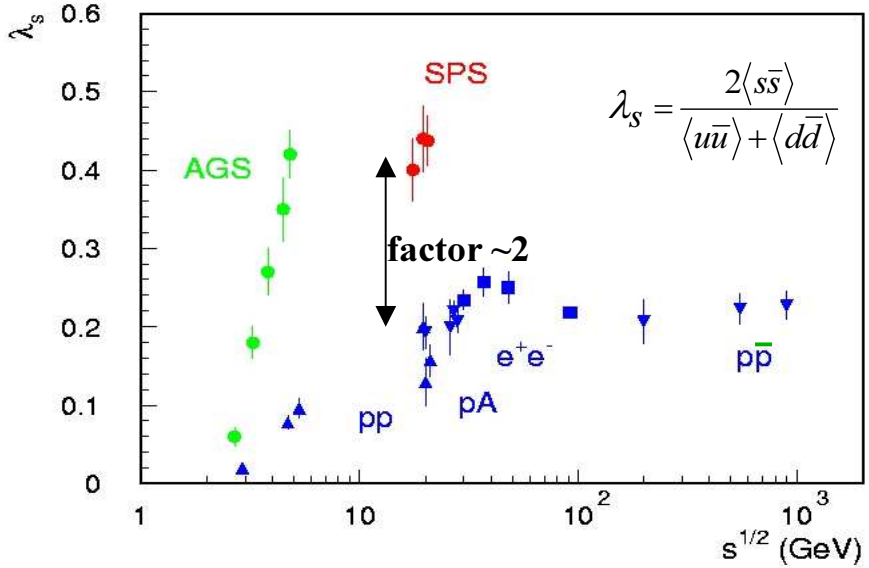


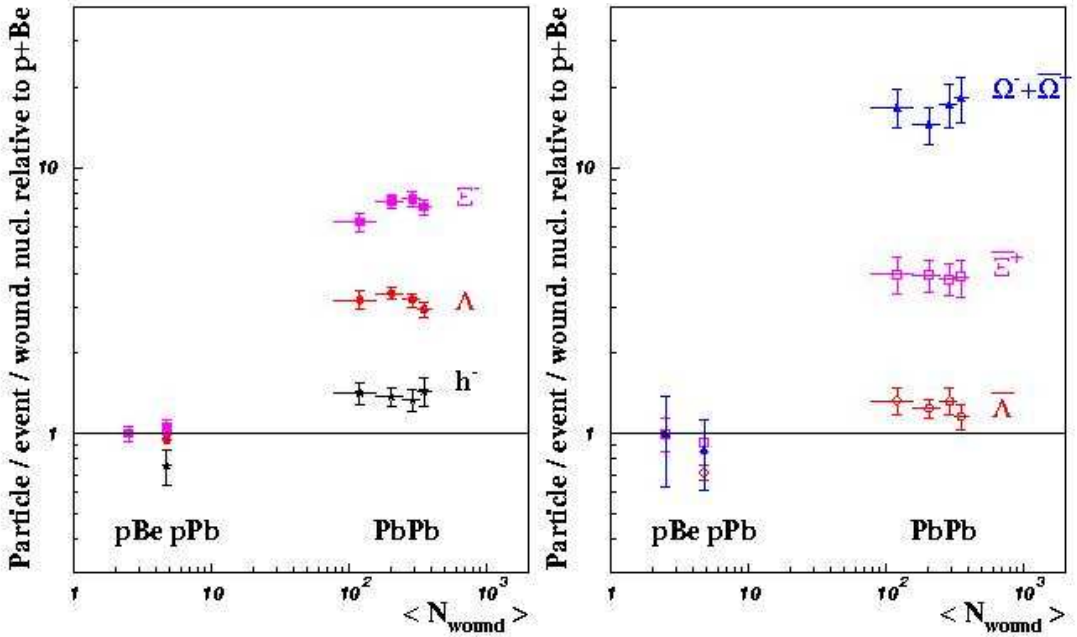
No enhancement in pp and pA collisions



Example: Strangeness

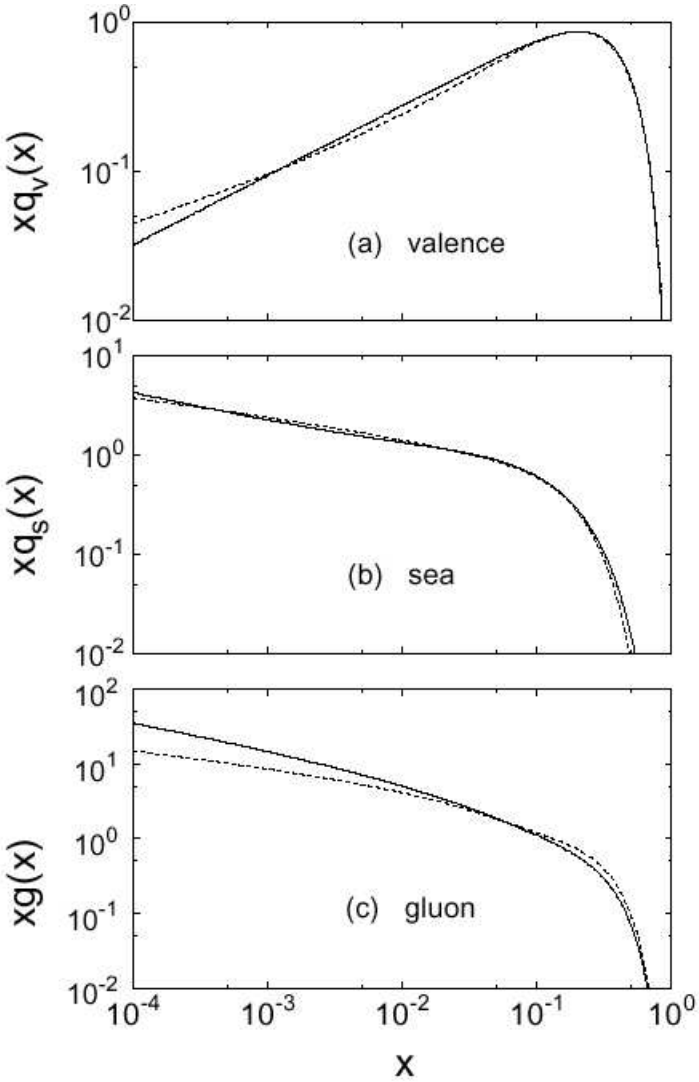
- **Enhancement compared to pp and pA**





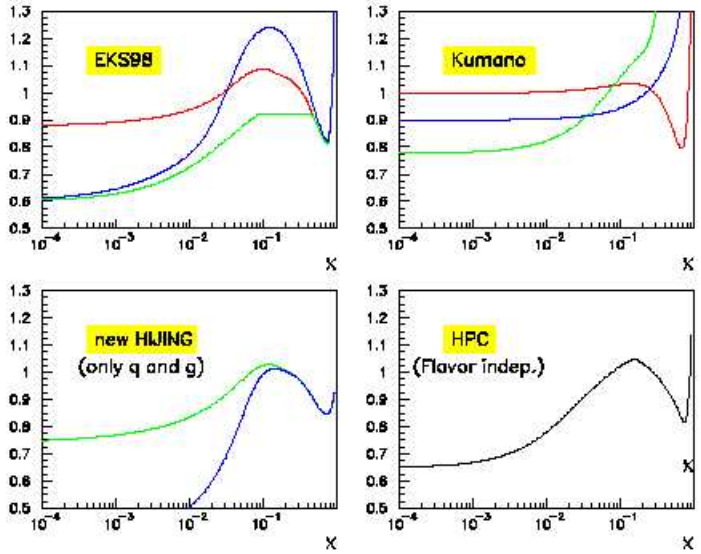
Gluon Structure Functions

Hard processes ~ (#partons)2
unknown structure functions major reason for e.g. uncertainty in dN/dy



GRV94, MRST p structure functions

Initial ratios $R_i^A(x)$ for evolution.



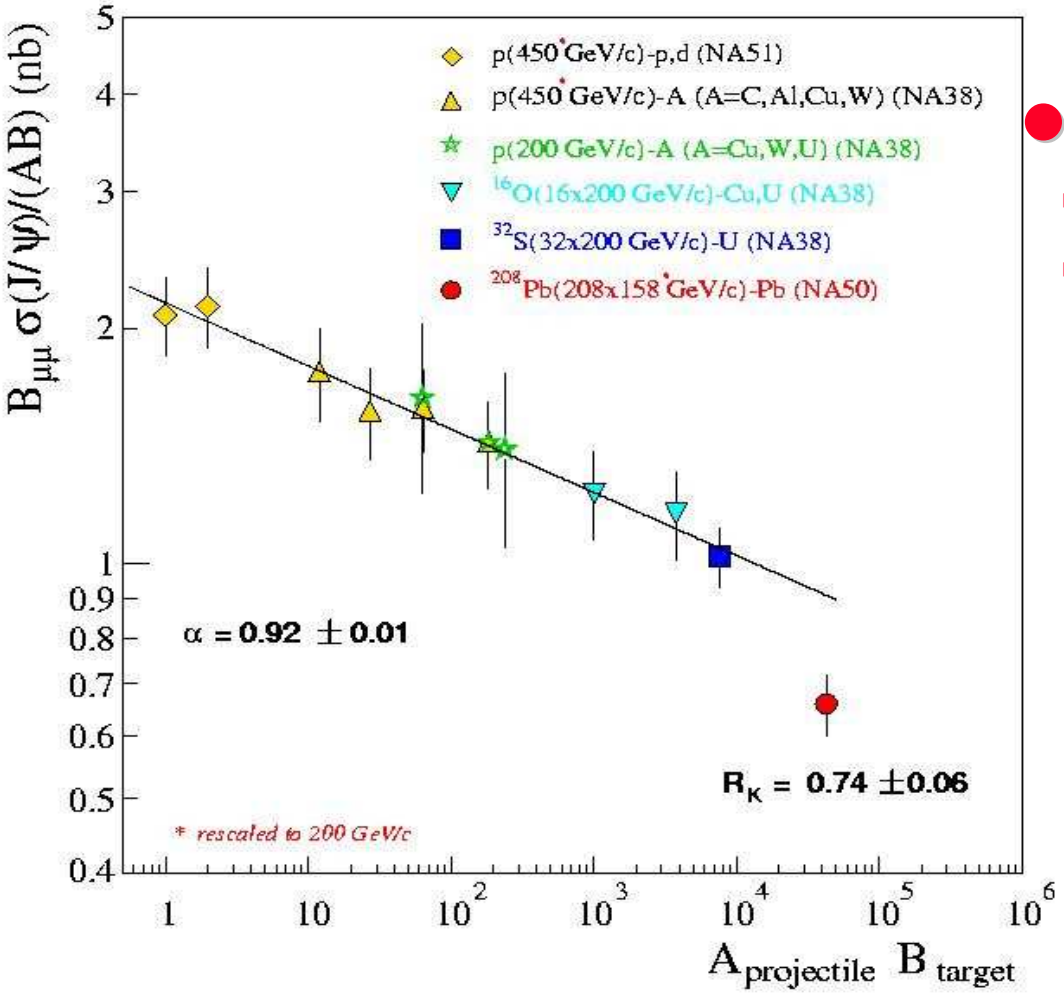
EKS98 is the one with more constraints from data.
(new HIJING gluons ruled out by data in the LT, LO DGLAP).

Green: Sea quarks
Blue: gluons
Red: Valence quarks

Shadowing parameterizations

Final State Interactions in Nuclei

- **needs to be (re) measured at LHC for J/Psi, Y, jets,..**

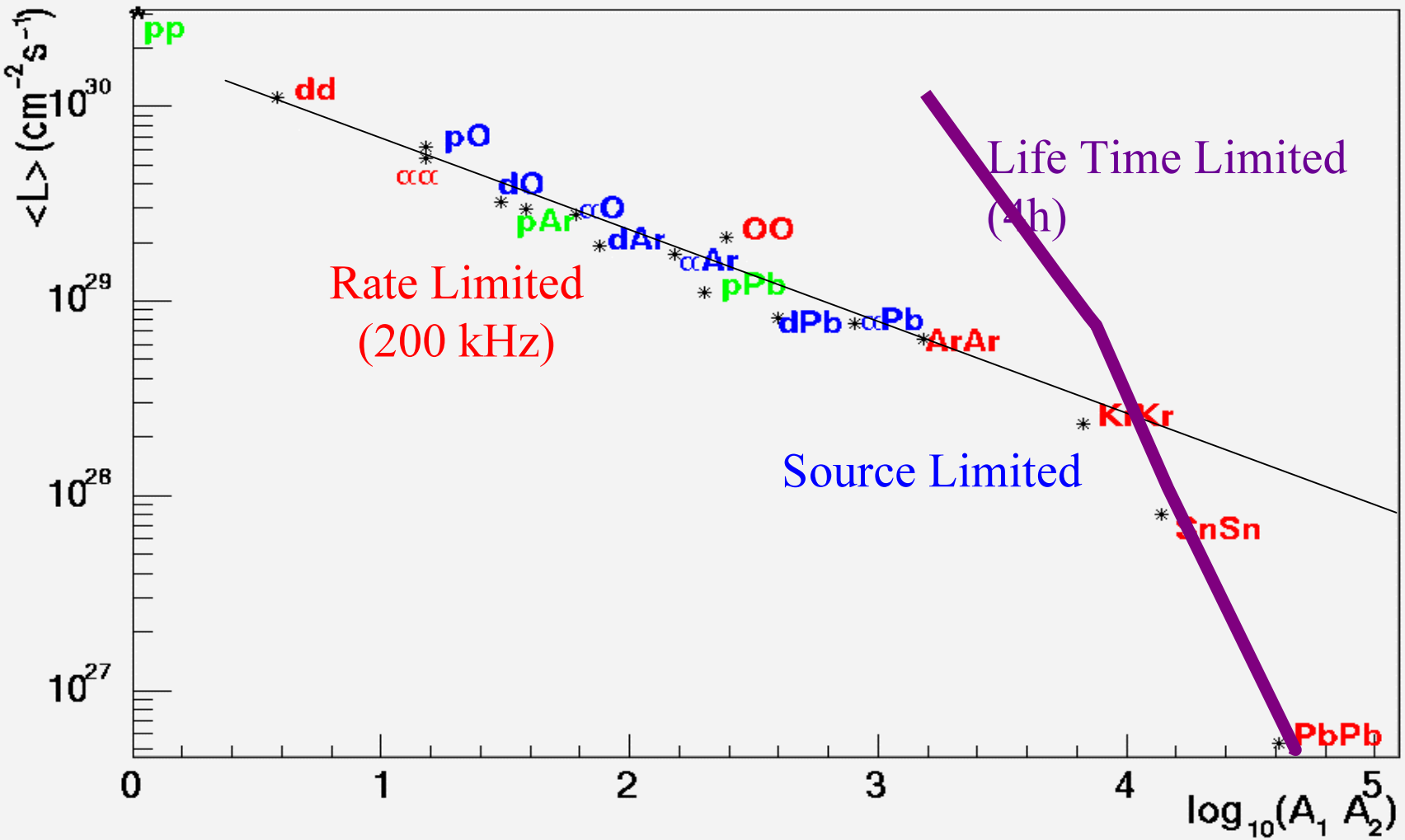


- **pA was essential to establish:**
  - ⇨ **'normal'** suppression up to S-U
  - ⇨ **'abnormal'** suppression in Pb-Pb

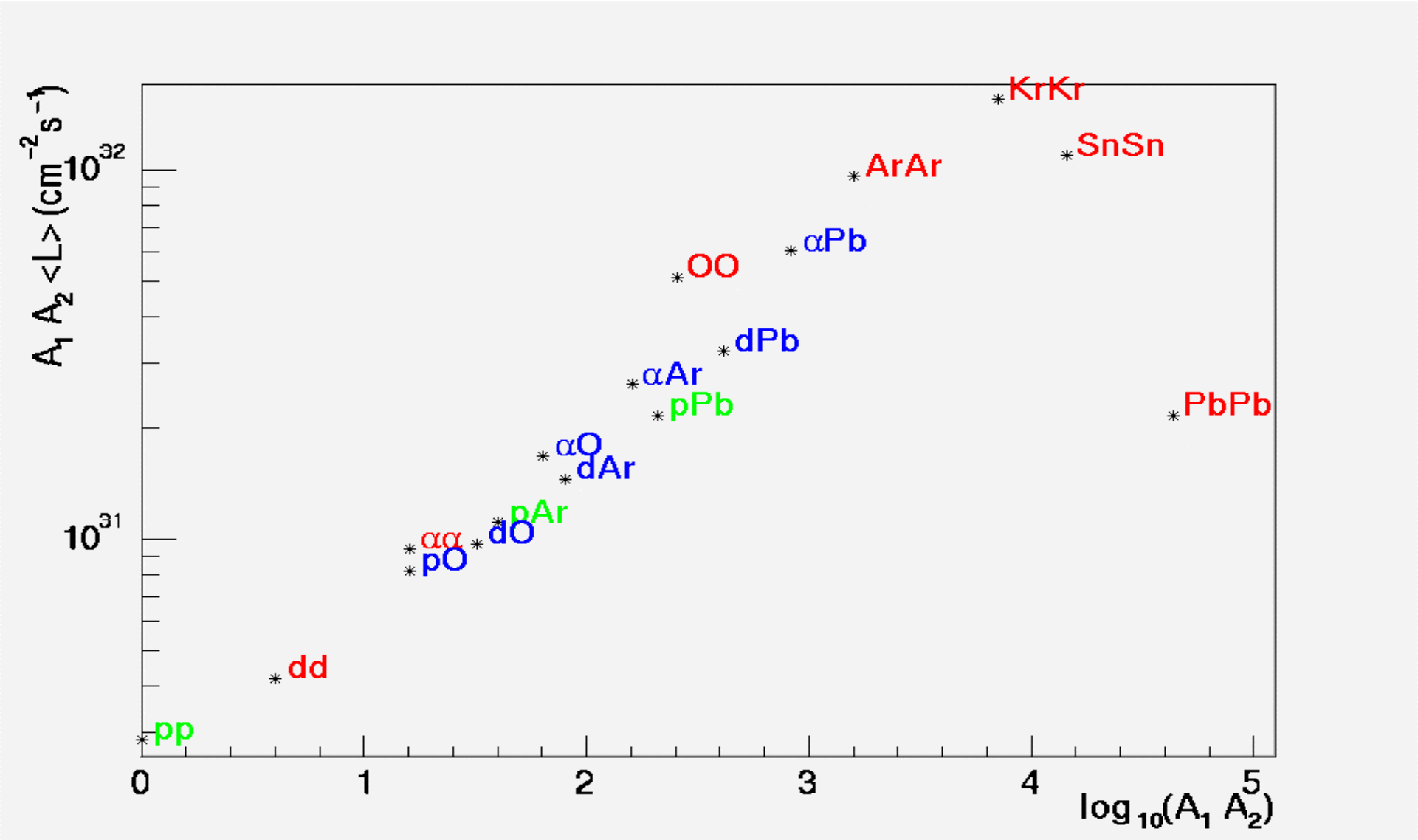
Base Program II

- **detector commissioning and start-up with pp**
  - ⇨ **few months at LHC start-up**, to get detector in shape & understood
  - ⇨ **few weeks before each ion run**, even if no pp data is needed (after few years)
    - ✪ SPS praxis, to not waste the short HI run after longer shut-down
- **comparison running pp, 'p'A**
  - ⇨ σ**(AA) ~ A** σ**(pp) - A**$^{4/3}$ σ**(pp)** (1 central AA event ~ 200 - 1000 pp events)
  - ⇨ statistics **untriggered**: few 10^9 events (error comparable to few 10^6 AA events)
    - ✪ needs few 10^6 s @ up to 1 kHz to tape
    - ✪ preferably 'clean' events ($L < 10^{29}$), only 0.3 Pbyte (versus 1.2 Pbyte with pile-up) at few 10^{30} > 90% of hits are from pile-up !
  - ⇨ statistics **triggered** events (eg Y, jets..)
    - ✪ few months as well, see below
- **'default' scenario: ~ 5 years pp, 1 month 'p'A**
  - ⇨ pp running probably more defined by practical considerations
    - ✪ **change of detector** over time, **new physics questions** to be answered, ..
    - ✪ **in practice:** full running in early years, shorter runs later

Luminosity Requirements

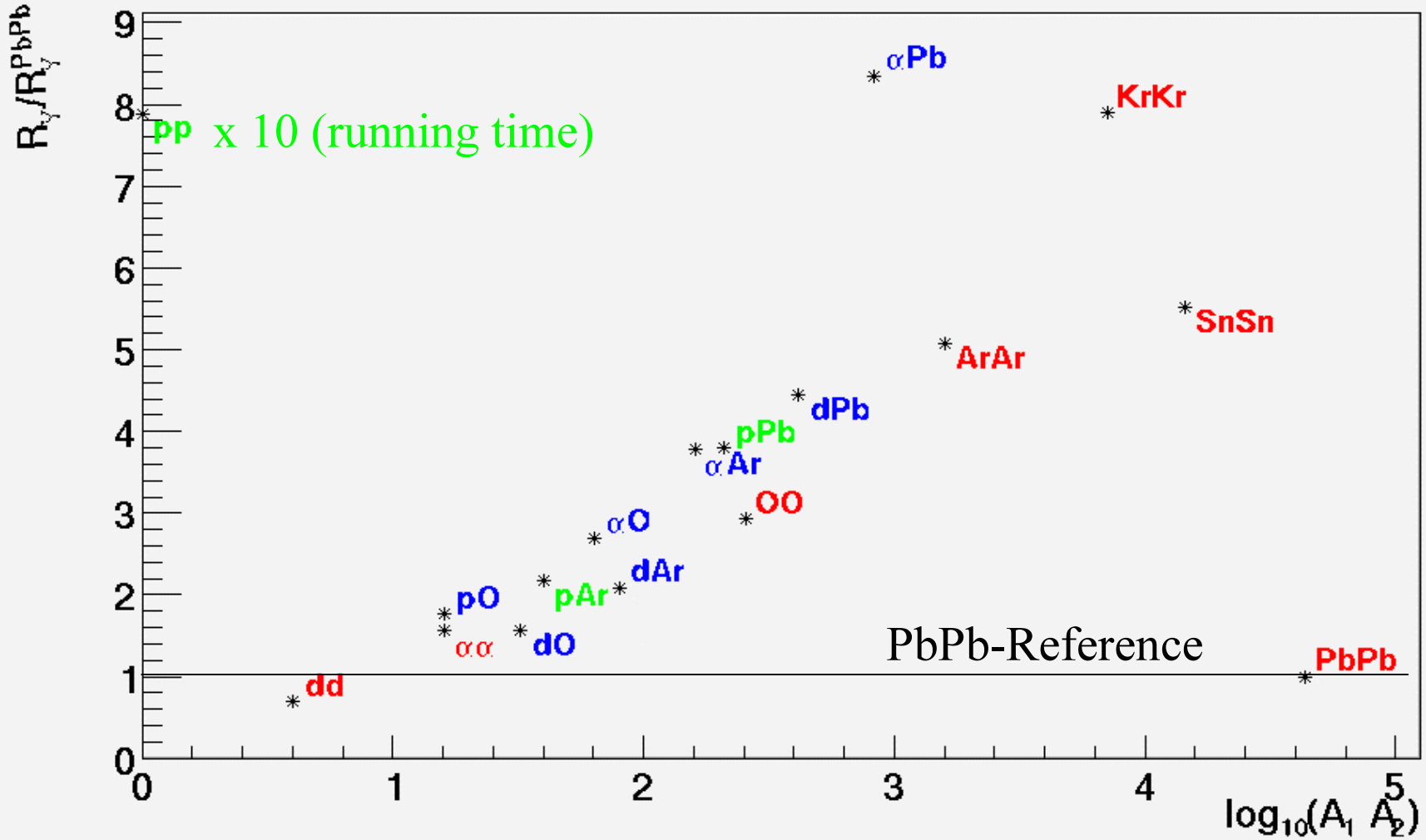


Nucleon Luminosity



Y-Rate *vs* Collision-System

- **pp comparison data: ~ 1 year needed for statistics**
  - ⇨ split between **high and low** Luminosity
  - ⇨ pp error < Pb-Pb, ~ comparable to high Lumi Ar-Ar

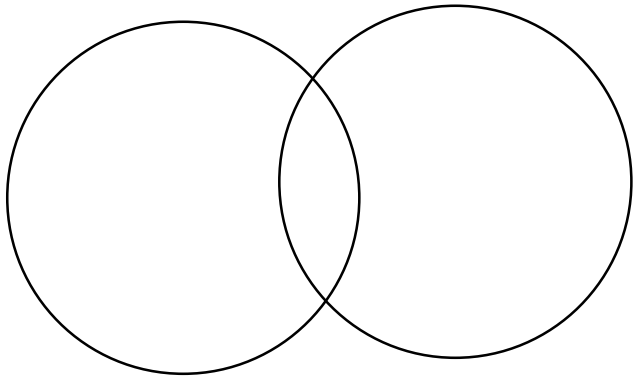


pA versus dA

- **advantage of deuteron beams**
  - ⇨ center of mass energy closer to AA cms
    - d-Pb: 6.4 TeV p-Pb: 8.8 TeV
    - d-Ar: 7 TeV p-Ar: 9.9 TeV
  - ⇨ shift of midrapidity smaller
    - d-Pb: 0.12 p-Pb: 0.46
    - d-Ar: 0 p-Ar: 0.35
  - ⇨ factor 2 larger cross section for hard processes !
  - ⇨ isospin similar to nuclei (less important at LHC, only for large x_F)
- **pA versus dA still being discussed**
  - ⇨ larger x_F-range for PDF's (pA, Ap) ?
  - ⇨ problems with multiple parton scatterings ?
- **Luminosity for 200 kHz interaction rate**
  - d-Pb: 7×10^{28} cm^{-2} s^{-1}
  - d-Ar: 2×10^{29} cm^{-2} s^{-1}

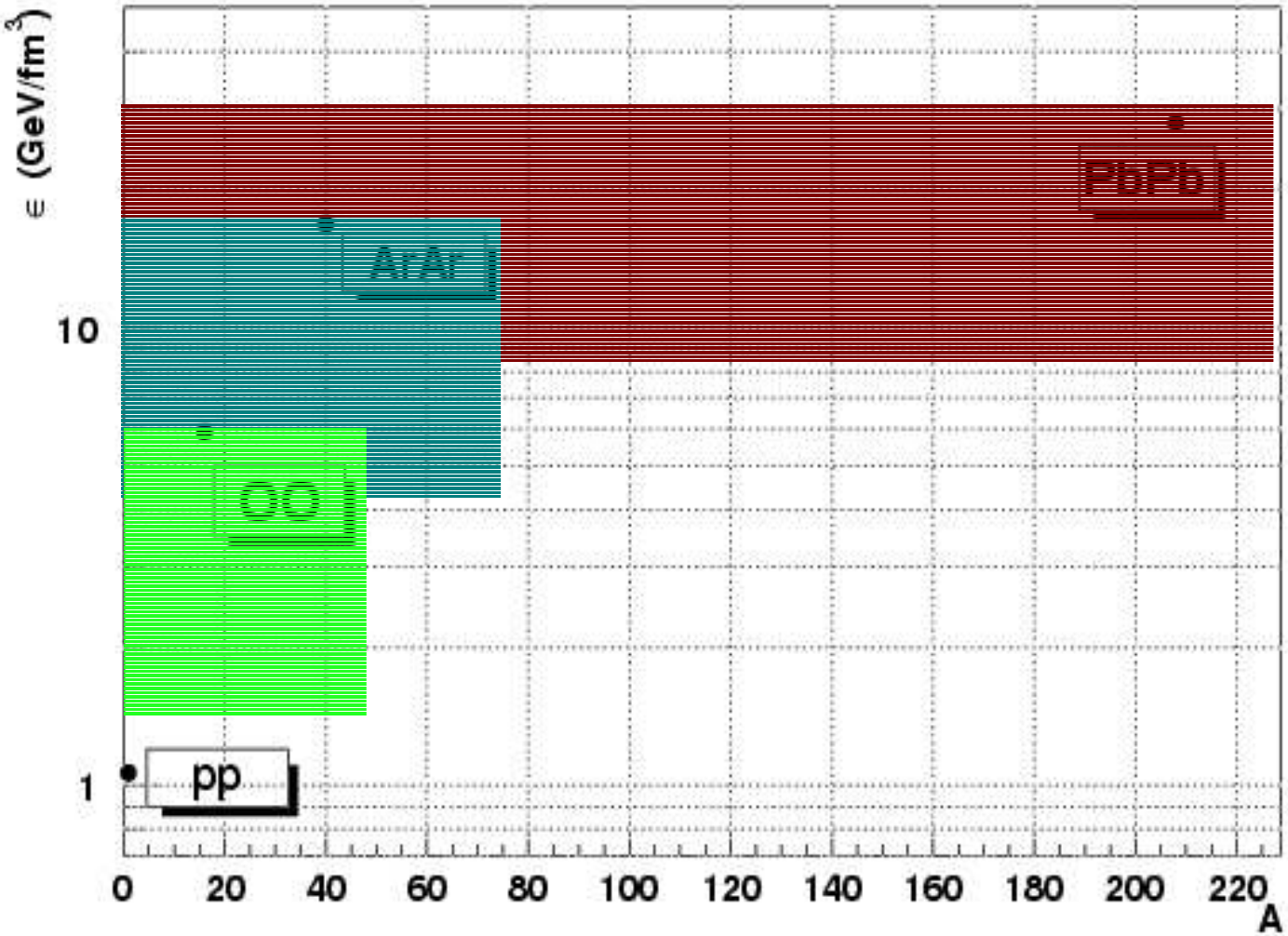
Base Program III

- **energy density dependence**
  - ⇨ scale parameter(s) of QGP physics
    - ✪ ε, T_c, parton density, volume, impact parameter, # of participants..
    - ✪ all related via nuclear geometry ('Glauber' calculation)
  - ⇨ investigate quantitative (smooth) and qualitative (thresholds) variations
- **mostly done via impact parameter variation**
- **special cases need light ions instead**
  - ⇨ very peripheral :
    - ✪ difficult experimentally (background)
    - ✪ low statistics for hard processes
    - ✪ 'diffuse' geometry (colliding nuclear tails)
  - ⇨ scale parameter for specific structures (if present)
    - ✪ eg NA60 experiment (J/Psi threshold behaviour)



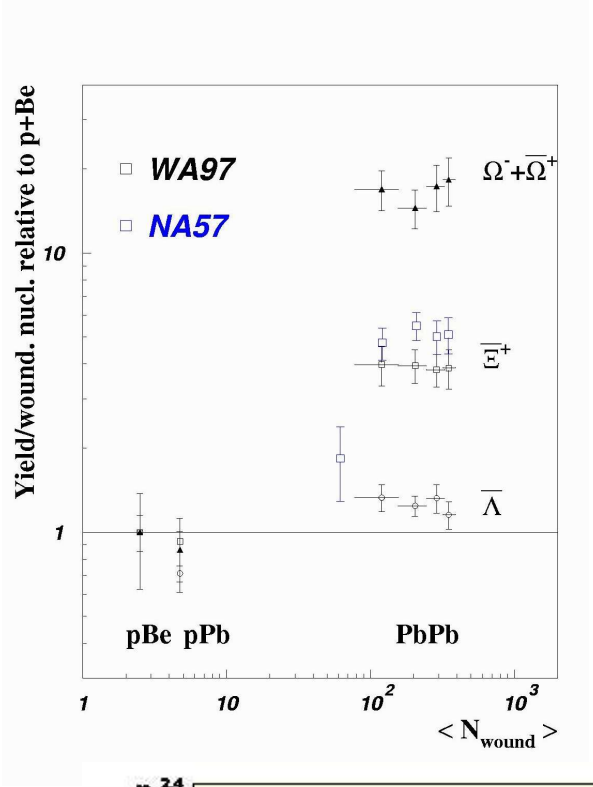
- **Luminosity (light) versus energy density (heavy) ???**
  - ⇨ good statistics Y', Y'' only possible with light ions !!
- **choice of light ions:**
  - ⇨ 'light' (eg Ar) for lowest energy density, but choice might change after first runs !
  - ⇨ split into **low** (8 kHz, TPC) and **high** (200 kHz, muons) Lumi run

Energy Density

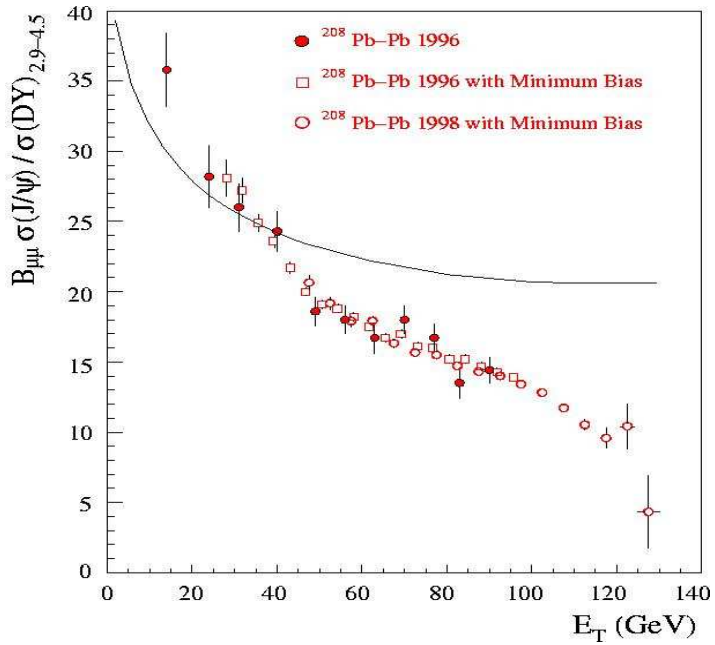


Examples

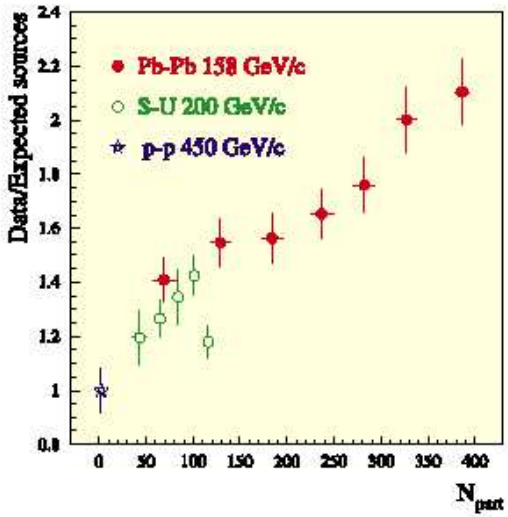
- **Strangenes**
  - ⇨ low statistics at large b



- **J/Psi suppression**
  - ⇨ low statistics, large systematics at large b
  - ⇨ crucial region to establish 'threshold'

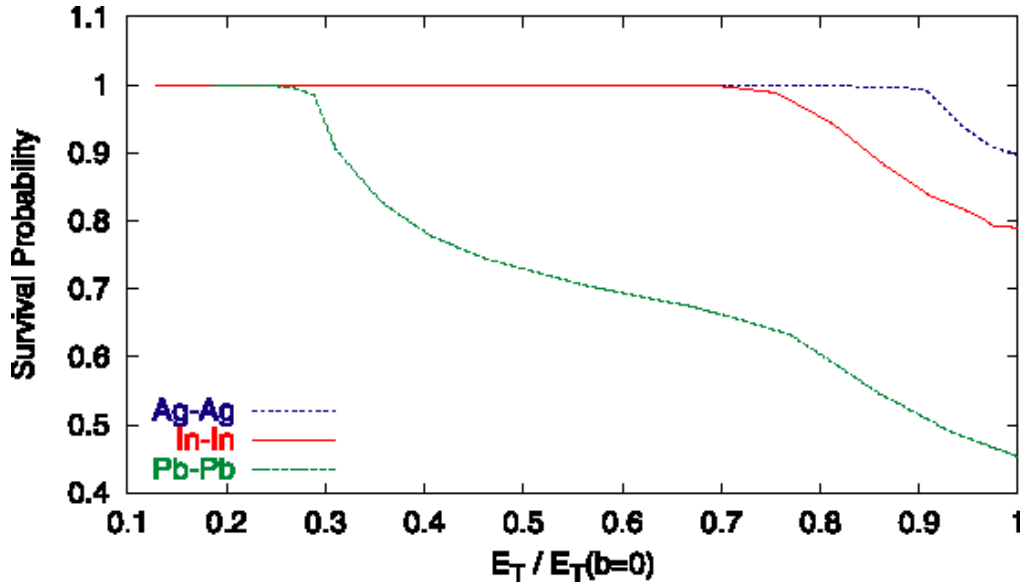


- **lepton pair continuum**
  - ⇨ connect to pp via S-U

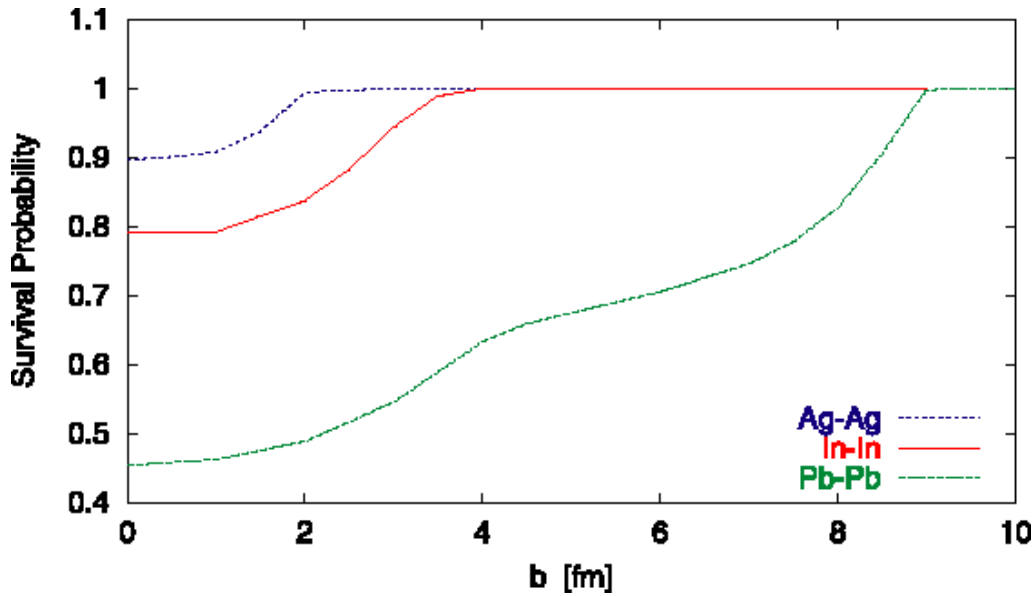


Origin of Charmonium Suppression

• A measurement of charmonia melting in a lighter collision system will confirm or rule out **specific** deconfinement models

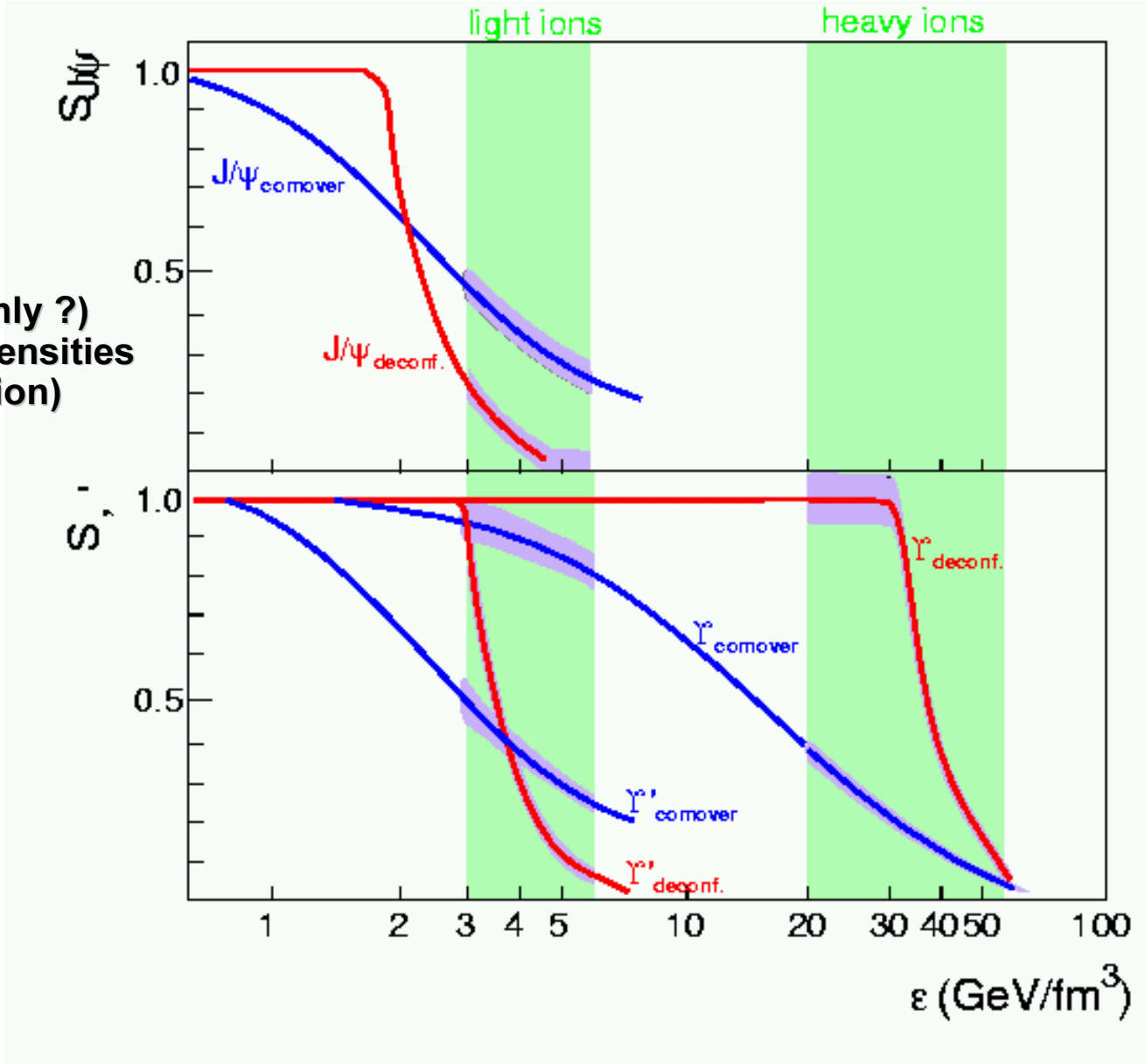


• A specific **prediction** :
the J/ψ suppression pattern in In-In collisions exhibits a break at an impact parameter ~ 3.5 fm (M. Nardi & H. Satz)



Quarkonium predictions for LHC

Light ions are the best (only ?) way to scan low energy densities (around the phase transition)



Options: Energy scan

- **pp at 5.5 TeV**
  - interpolation Tevatron - top LHC should be **rather reliable**
    - done at RHIC, adds some (but not major) systematic error
  - currently looks not very urgent, but I might be wrong...
  - eventually, **some energy scan will be done** in any case at LHC
    - was done at SppS, Tevatron
- **Ions at lower energy**
  - connect to RHIC results ?
  - strong case only if some drastic changes between RHIC and peripheral LHC

Beam Conditions

- **pp**
  - ⇨ really low Lumi for MB events (few months), because of:
    - ✪ **data quality** (no pile-up)
    - ✪ **data volume**, offline CPU, already 'promised' to LCG project !
  - ⇨ ~ stable conditions at both 10^{29} and few 10^{30}
    - ✪ displaced beams, highest possible β^*
  - ⇨ acceptable background (beam gas)
    - ✪ data quality, data volume, RPC limit !
    - ✪ currently under investigation...

- **Pb-Pb**
  - ⇨ max integrated luminosity
  - ⇨ stable rate during spill as far as possible
    - ✪ space charge effects in TPC
  - ⇨ both is very much helped by β^* tuning
    - ✪ better also for >1 experiment (quench limit in machine)