Study of heavy-ion and proton interactions with nuclei on the LHC beams with fixed target.

N.S.Topilskaya and A.B. Kurepin
INR RAS, Moscow

1. Fixed target proposal.
2. Physical motivation.
3. Experimental situation.
4. Summary.

Proposal of fixed target experiments at the LHC

1. **Fixed-target experiment with wire target at the LHC— energy between SPS and RHIC was proposed in 2005 and then in 2009 at CERN Workshop "New opportunities at CERN" by INR RAS.**

   A.B.Kurepin, N.S.Topilskaya, M.B.Golubeva

   Charmonium production in fixed-target experiments with SPS and LHC beams at CERN.
   Phys.Atom.Nucl.74:446-452, 2011, Yad.Fiz.74:467-473, 2011.

2. **Then proposal of experiment AFTER@LHC**
   (A Fixed Target ExpeRiment at the LHC).

   S.J.Brodsky, F.Fleuret, C.Hadjidakis and J.P.Lansberg

   Physics Opportunities of a Fixed-Target Experiment using the LHC Beams
   Phys. Rept. 522 (2013) 239

3. **Started at LHCb with low density gas target (SMOG)**

Current study group of AFTER@LHC experiment

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Special issue " Advances in High Energy Physics 2015 (2015)"

Physics at a Fixed-Target Experiment Using the LHC Beams

Study and physical ideas

The Gluon Sivers Distribution: Status and Future Prospects,
D.Boer et al., ID 371396

Transverse Single-Spin Asymmetries in Proton-Proton Collisions at the AFTER@LHC Experiment in a TMD Factorization Scheme,
M.Anscelmino et al., ID 475040

A Gas Target Internal to the LHC for the Study of *pp* Single-Spin Asymmetries and Heavy Ion Collisions,
C.Barschel et al., ID 463141

Quarkonium Production and Proposal of the New Experiments on Fixed target at the LHC,
A.B.Kurepin and N.S.Topilskaya, ID 760840

Feasibility Studies for Quarkonium Production at a Fixed-Target Experiment Using the LHC Proton and Lead Beams (AFTER@LHC),
I.Massacrier et al., ID 986348

Advantages of the fixed target experiments

Four features:

- **accessing the high x,** $[x_F = |p_z|/ p_{zmax} \rightarrow 1]$
- **achieving high luminosities**
- **varying the beams and atomic mass of the target**
- **polarizing the target**

Three physics reasons:

- **Heavy-ion physics between SPS&RHIC energies towards large rapidities**

  (Test of factorization of the cold nuclear matter effects from p+A to A+B collisions,

  study of quarkonia production and suppression depending on the phase transition of matter to quark-gluon phase)

- **High –x gluon, antiquark and heavy quark content in the nucleon&nucleus**

  (Very large PDF uncertainties for x>0.5,could be crucial to characterize possible BSM discoveries)

- **Transverse dynamics and spin of quarks/gluons inside (un)polarized nucleon**

  (Possible missing contribution to the proton spin from quark/gluon orbital angular momentum)

All this can be realized at CERN without disturbing other experiments at the LHC with the beams of highest energy and luminosities

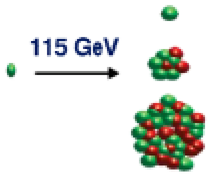
Note, that all accelerators with energy E_p > 100 GeV now have fixed target program: (Tevatron, HERA, SPS, RHIC)

Fixed target experiment at the LHC: main kinematical features

Energy range

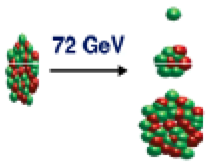
7 TeV proton beam on a fixed target

c.m.s. energy:	$\sqrt{s}=\sqrt{2m_N E_p}\approx 115\,\mathrm{GeV}$	**Rapidity shift:** $y_{c.m.s.}=0\rightarrow y_{lab}=4.8$
Boost:	$\gamma=\sqrt{s}/(2m_N)\approx 60$	



2.76 TeV Pb beam on a fixed target

c.m.s. energy:	$\sqrt{s_{NN}}=\sqrt{2m_N E_{Pb}}\approx 72\,\mathrm{GeV}$	**Rapidity shift:** $y_{c.m.s.}=0\rightarrow y_{lab}=4.3$
Boost:	$\gamma\approx 40$	



Such energy allow systematic studies of quarkonia, p_T spectra, associated production and W -boson production in a fixed target mode

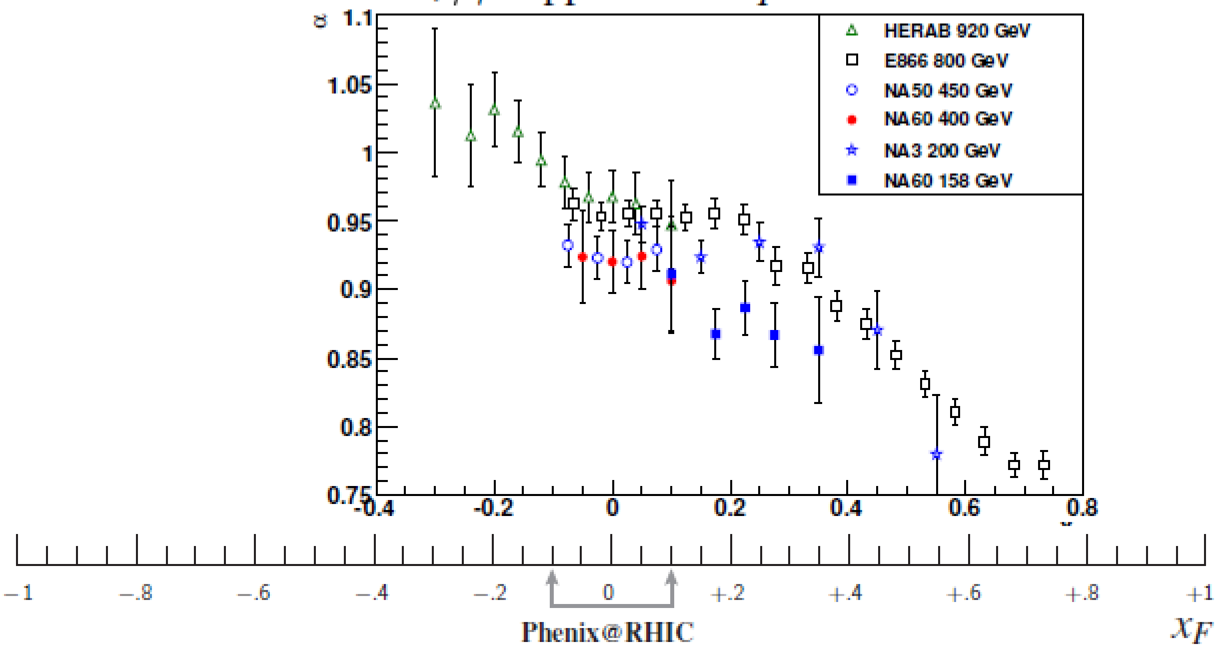
- LHCb and the ALICE muon arm become backward detectors [$y_{c.m.s.}<0$]
- With the reduced $\sqrt{s}$, their acceptance for physics grows and nearly covers half of the backward region for most probes [$-1<x_F<0$]
- Allows for backward physics up to high x_{target} ($\equiv x_2$) [uncharted for proton-nucleus; most relevant for p-p$^\uparrow$ with large $x^\uparrow$]

The new target rapidity region

First systematic access to the target-rapidity region

($x_F \to -1$)

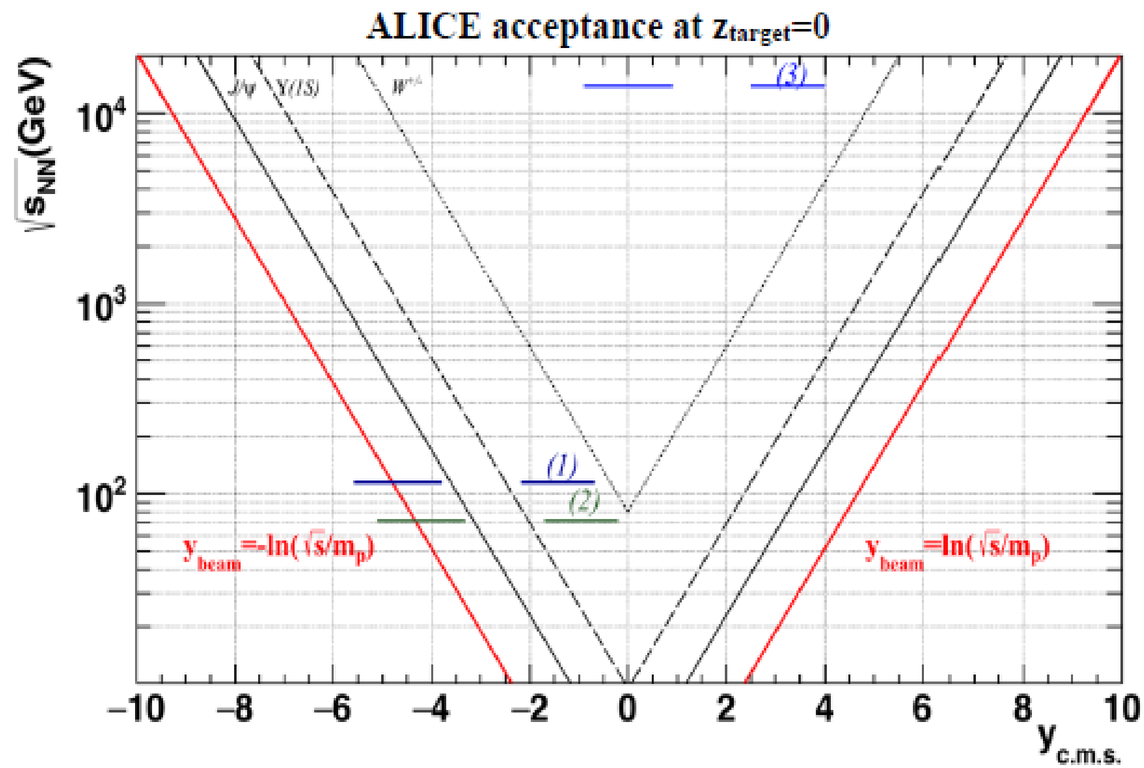
J/ψ suppression in pA collisions



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb-collider: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$
- If we measure $\Upsilon(b\bar{b})$ at $y_{\rm cms} \simeq -2.5 \Rightarrow x_F \simeq \frac{2m_\Upsilon}{\sqrt{s}} \sinh(y_{\rm cms}) \simeq -1$

Rapidity shift and kinematical coverage in experiment AFTER

(1) fixed-target mode with 7 TeV p beam
(2) fixed-target mode with 2.76 TeV Pb beam
(3) collider mode with 7 TeV p beams



- With a forward detector, access mid- to backward-rapidity region ($y_{CM} < 0$)
- With mid-rapidity detector, probe very backward-rapidity region (end of phase space)

Three possibilities for fixed target experiment:

1. **To use extracted with bent crystal part of the beam and then put fixed target**

   – Beam "split" with a bent crystal
   - beam halo is deflected by a bent crystal on a solid target internal to the LHC beam pipe
   - expected proton flux ~5 x 10^8 p/s (LHC beam loss: ~10^9 p/s), Pb flux ~2 x 10^5 Pb/s

   → beam halo on dense target

2. **To put the internal gas target like SMOG at LHCb**

   – Internal gas target similar to SMOG at LHCb / inspired by HERMES at HERA
   - full LHC proton flux: 3.4 x 10^{18} p/s and Pb flux: 3.6 x 10^{14} Pb/s on internal gas target
   - currently used by the LHCb collaboration via the luminosity monitor (SMOG) at low gas density

   → high intensity beam on gas target

3. **To use wire target in the beam halo**

   – Internal wire/foil target
   - beam halo is recycled directly on internal solid targets (HERA-B, STAR)

At the LHC the possible technical implementation are discussed within the Physics Beyond Collider Fixed-Target working group.

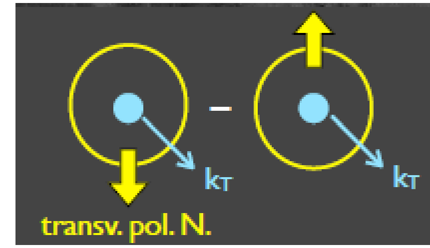
Conveners: S.Redealli and M.Ferro-Luzzi

http://pbc.web.cern.ch

p-p$^{\uparrow}$

Spin physics in AFTER@LHC

The orbital angular momentum (OAM) of the quarks and gluons

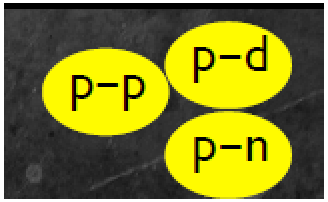


- Missing knowledge on the contribution of the orbital angular momentum (OAM) L_g and L_q to the proton spin

- In fixed-target experiment is possible to use polarized target.
- The polarization can be longitudinal and transverse.
- Single Transverse Spin Asymmetries connected with the correlations between parton k_T and the proton spin
  $\longrightarrow$ information about orbital motion of partons in the proton

- Quark/Gluon Sivers function : distortion in the distribution of an unpolarized partons with momentum fraction x and transverse momentum $k_{\perp}$ due to the proton transverse polarization: $f^{\perp}_{1T}(x, k_{\perp}^{2})$
- First sugested by D.Sivers to explain the large observed left-right single transverse spin asymmetries A_N in $p^{\uparrow}p \longrightarrow \pi X$
- Non-zero quark/gluon Sivers function $\rightarrow$ non-zero quark/gluon OAM

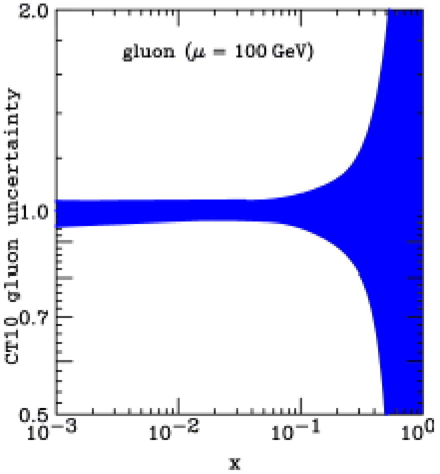
The gluon PDF



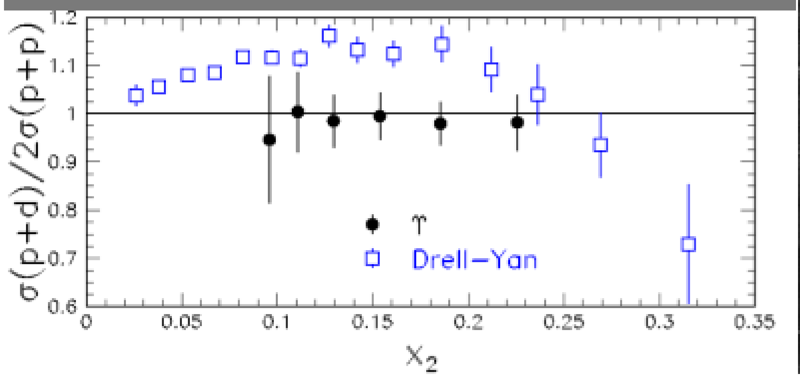
- Gluon distribution at high and ultra-high x_B in the
  - proton
  - neutron (via deuteron target)

gluon PDF experimentally unknown for neutron

gluon PDF at high x :
with large uncertainties for proton
need high luminosity to reach large x
exp. probes :
- heavy quarkonia (gg fusion at high energy)
- isolated photons (gq fusion)
- high p_T jets (p_T >20 GeV, accessible up to 40 GeV)



[E866, PRL 100 (2008) 062301]



Pioneering measurement by E866 @ Fermilab :
- using Υ
- at Q^2 ~ 100 GeV^2 similar gluon distribution in proton and neutron

could be extended using J/Ψ :
- to (~10x) lower x
- to lower Q^2

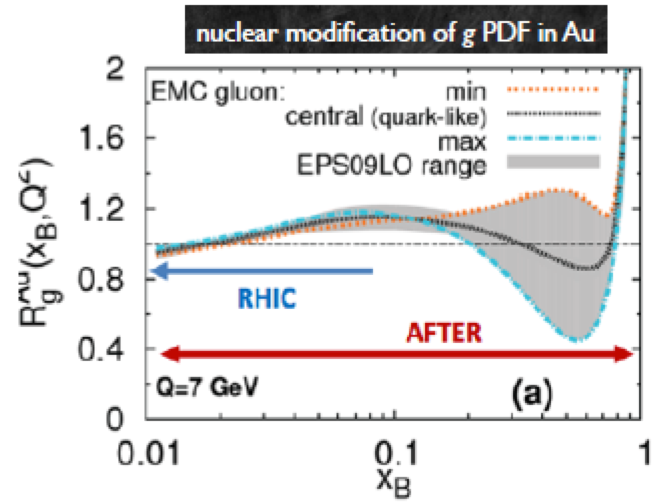
Need high luminosity.

The gluon nPDF

p-A

Pb-p

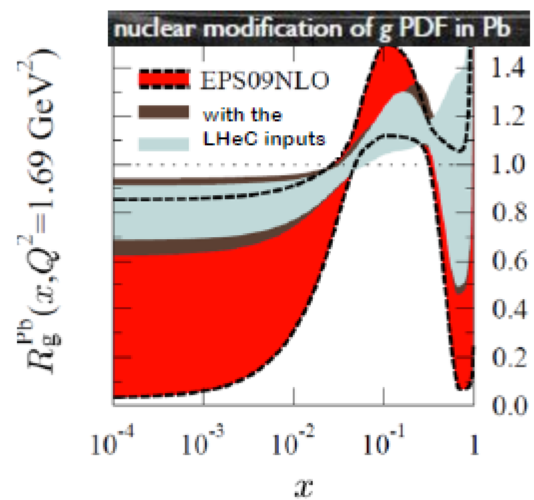
- A dependence thanks to target versatility
- nuclear PDF from intermediate to high x : antishadowing , EMC region , Fermi motion
- extraction using quarkonia, isolated photons, photon-jet correlation



- **Experimental probes @ AFTER**
  - Quarkonia
  - Isolated photons
  - High p_T jets (p_T > 20 GeV/c)

  → to access target x_g = 0.3 - 1 (>1 Fermi motion in nucleus)

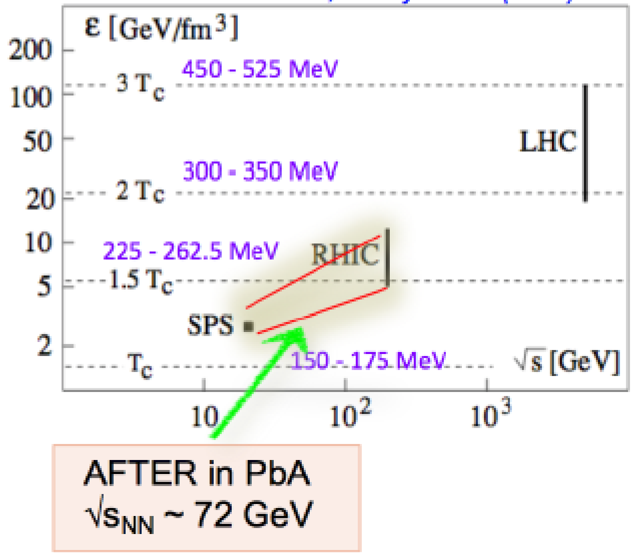
- **Target versatility**
  - Probing the A-dependence of shadowing and nuclear matter effects



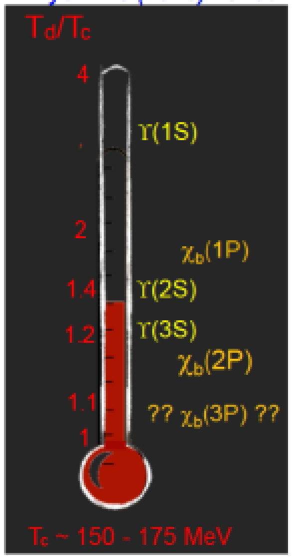
Heavy-ion physics

- QGP studies between SPS and RHIC energies (e.g. with quarkonia)

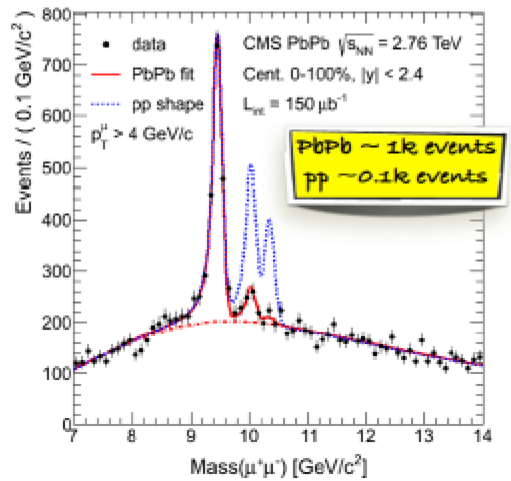
Satz, J. Phys. G32 (2006) R25



Mocsy et al, Int. J. Mod. Phys. A28 (2013) 1340012



Dissociation temperature from lattice QCD (+hydro)



Phys. Rev. Lett. 109 (2012) 222301

- At 72 GeV, Y(3S) and Y(2S) are expected to melt: perform the same study as CMS at low energy

Heavy-ion collisions towards large rapidities

A complete sets of quarkonium studies between SPS and RHIC energies (calibration of quarkonium thermometer (J/ψ, ψ', χ_c, Υ, D, J/$\psi \leftarrow b$ +pairs)

Test on the formation of azimuthal asymmetries: hydrodynamics vs initial-state radiation

Investigation of the longitudinal expansion of QGP formation

Factorization of cold nuclear matter effects from p+A to A+B collisions in new energy and kinematical ranges

Fixed-target charmonium data (SPS, FNAL, HERA)

AA collisions
SU, PbPb, InIn

NA38
S-U 200 GeV/nucleon, $0<y_{cm}<1$, $\sqrt{s}=19.4$ GeV
NA50
Pb-Pb 158 GeV/nucleon, $0<y_{cm}<1$, $\sqrt{s}=17.3$ GeV
NA60
In-In 158 GeV/nucleon, $0<y_{cm}<1$, $\sqrt{s}=17.3$ GeV

pA collisions

HERA-B
p-Cu,(Ti),W 920 GeV, $-0.34<x_F<0.14$, $\sqrt{s}=41.6$ GeV
E866
p-Be, Fe, W 800 GeV, $-0.10<x_F<0.93$, $\sqrt{s}=38.8$ GeV
NA50
p-Be,Al,Cu,Ag,W,Pb 400/450 GeV, $-0.1<x_F<0.1$, $\sqrt{s}=27.4/29.1$ GeV
NA51
p-p, d 450 GeV, $-0.1<x_F<0.1$, $\sqrt{s}=29.1$ GeV
NA3, NA38
p-p,Pt, Cu,U 200 GeV, $0<x_F<0.6$, $\sqrt{s}=19.4$ GeV
NA60
p-Be,Al,Cu,In,W,Pb,U 158/400 GeV, $-0.1<x_F<0.35$, $\sqrt{s}=17.3/27.4$ GeV

Colliders (RHIC, LHC)

AA collisions

RHIC CuCu, AuAu $\sqrt{s}$ =39, 62, 130 GeV, 200 GeV
UU $\sqrt{s}$ =193 GeV
LHC PbPb $\sqrt{s}$ = 2.76, 5.02 TeV (max 5.5 TeV)

pA collisions

RHIC pp, dAu $\sqrt{s}$ = 130, 200 GeV
LHC pp $\sqrt{s}$ = 2.76, 7, 8, 13 TeV (max 14TeV)
pPb $\sqrt{s}$ = 5.02 , 8.16 TeV

Fixed target experiment at LHC

AA collisions

Pb-Pb 2.75 TeV/nucleon, $\sqrt{s}$ = 72 GeV

pA collisions

p-A 7.0 TeV , $\sqrt{s}$ = 115 GeV
(5.0 TeV, $\sqrt{s}$ = 97 GeV)

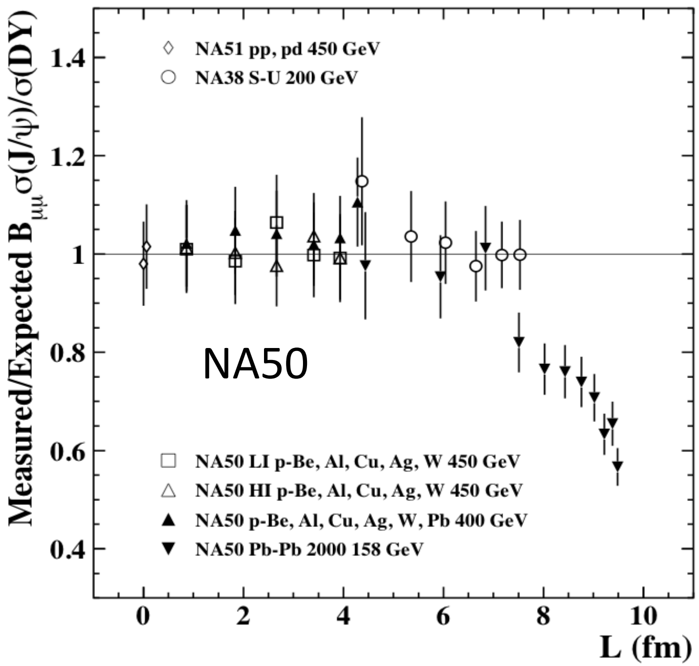
The quarkonium study in experiment AFTER

Target	A	$\int\mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	1.1 10^8	2.2 10^5
1cm Cu	64	0.42	5.3 10^8	1.1 10^6
1cm W	185	0.31	1.1 10^9	2.3 10^6
1cm Pb	207	0.16	6.7 10^8	1.3 10^6
LHC pPb 8.8 TeV	207	10^{-4}	1.0 10^7	7.5 10^4
RHIC dAu 200GeV	198	1.5 10^{-4}	2.4 10^6	5.9 10^3
RHIC dAu 62GeV	198	3.8 10^{-6}	1.2 10^4	18

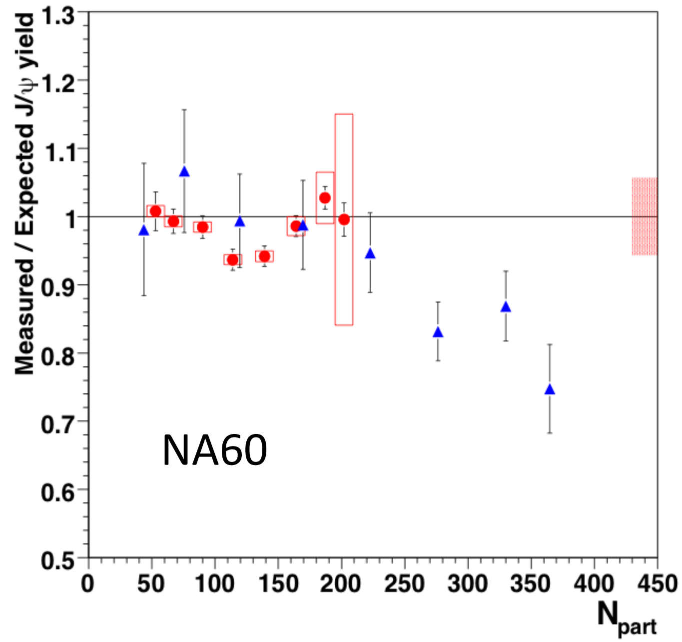
- In principle, one can get 300 times more J/ψ –not counting the likely wider y coverage– than at RHIC, allowing for
  - χ_c measurement in pA via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, y or P_T
  - Ratio ψ' over direct J/ψ measurement in pA
  - not to mention ratio with **open charm, Drell-Yan,** etc ...

J/ψ suppression at SPS

NA50



NA60



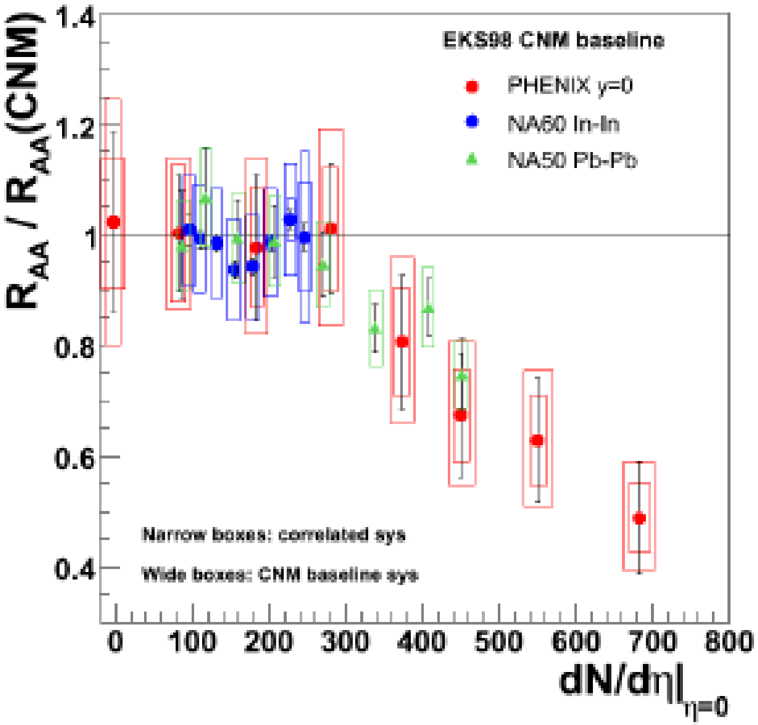
Suppression (~40%);
ψ' suppression is measured

σ_{abs} **depends on energy ;**
Suppression (~20-30%);

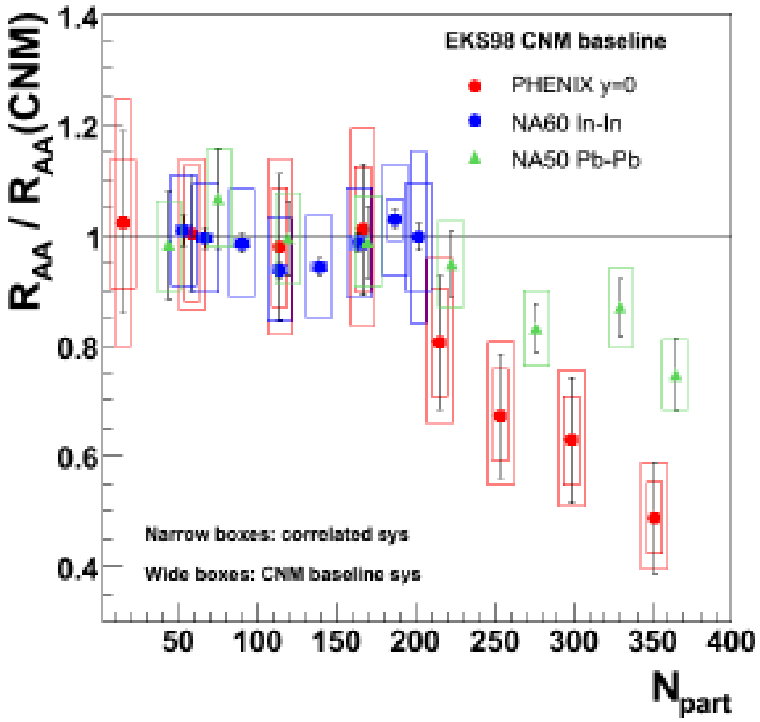
$\sigma_{abs}^{J/\psi}$ (158 GeV) = 7.6 ± 0.7 ± 0.6 mb
$\sigma_{abs}^{J/\psi}$ (400 GeV) = 4.3 ± 0.8 ± 0.6 m

Comparison of SPS and RHIC J/ψ data at mid rapidity

R_{AA} as a function of multiplicity (~ε)



R_{AA} as a function of N_{part}



Which dependence to choose?

With NA60 data (σ_{abs} depends on energy) suppression of charmonium production at PHENIX larger that at NA50

N.Brambilla et al. , EPJ C71 (2011) 1534

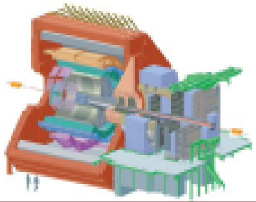
Quarkonium production at LHC: ALICE, ATLAS, CMS and LHCb .

ALICE

$J/\psi \rightarrow \mu^+\mu^-$ $2.5<y<4$ p_T coverage down to

$J/\psi \rightarrow e^+e^-$ $|y|<0.9$ $p_T \sim 0$

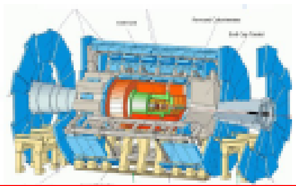
(up tp now only inclusive J/ψ results)



ATLAS

$J/\psi \rightarrow \mu^+\mu^-$ $|y|<2.4$ $p_{T\mu}>3$GeV, $|\eta_\mu|<2.5$ → p_T $J/\psi>6.5$GeV/c

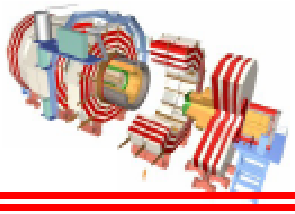
(separation between B and prompt J/ψ)



CMS

$J/\psi \rightarrow \mu^+\mu^-$ $|y|<2.4$ p_T coverage depending on the y region

(separation between B and prompt J/ψ)



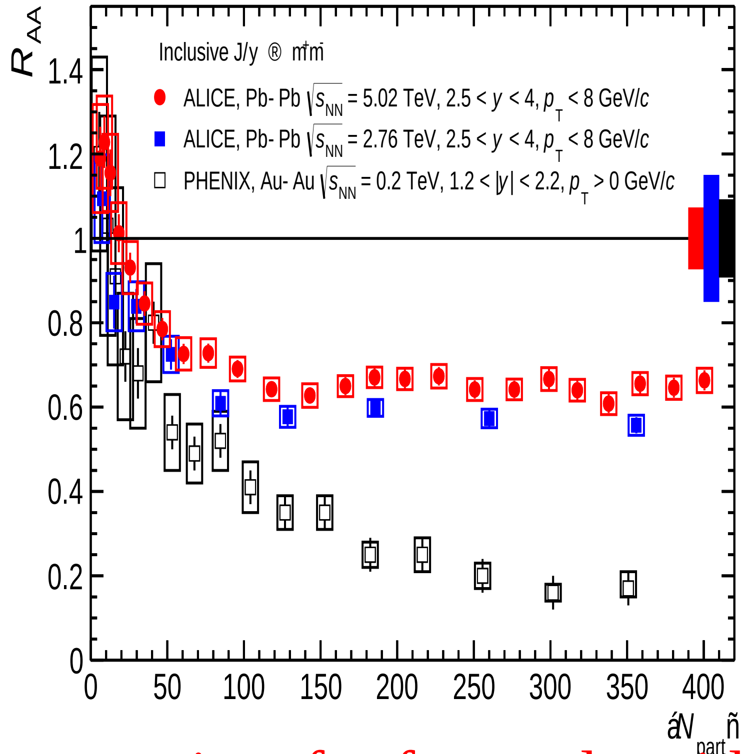
LHCb

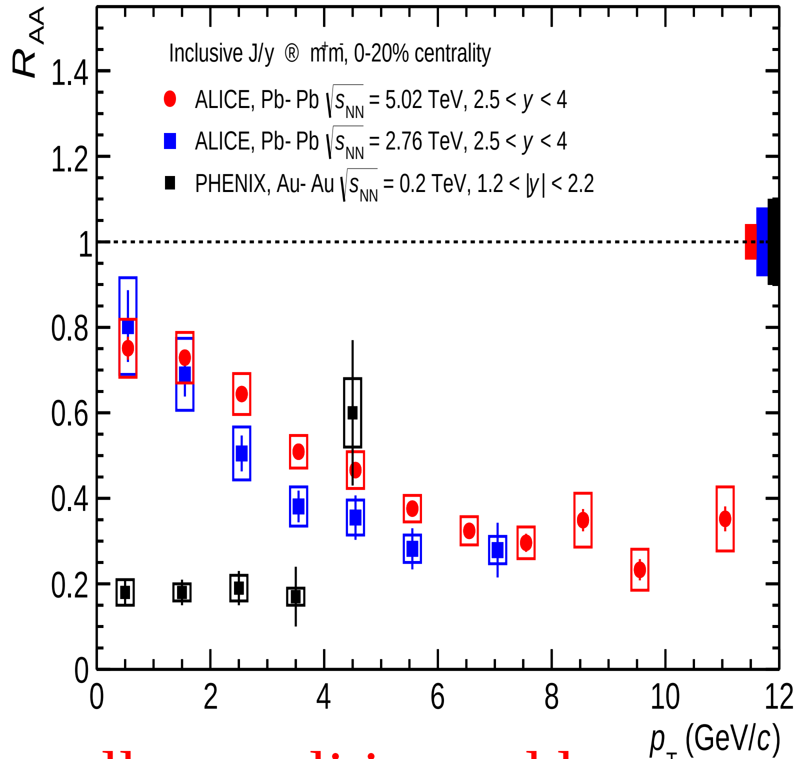
$J/\psi \rightarrow \mu^+\mu^-$ $2.5<y<4$ p_T coverage down to $p_T \sim 0$

(separation between B and prompt J/ψ)

(no heavy ion physics program) Now they have HI program

R_{AA} vs number of participant and pt. Comparison of ALICE and PHENIX data.





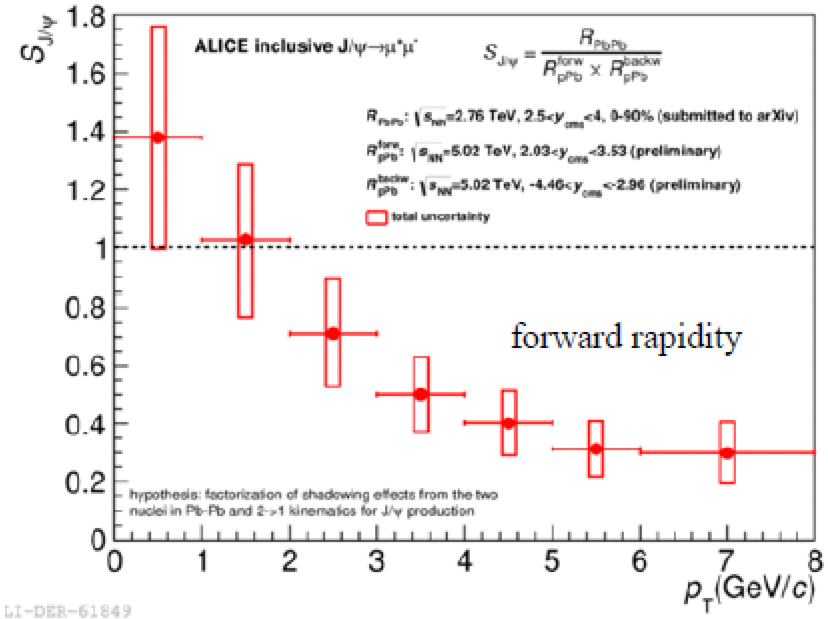
Suppression for forward rapidity at all centralities and low pt at ALICE lower than at PHENIX.

Different behavior between RHIC and LHC data .

Models with all J/ψ produced at hadronization or models including large fraction (>50% in central collisions) of J/ψ produced from recombinations can describe ALICE results.

R_{AA} (PbPb) for forward rapidity vs transverse momentum without shadowing and CNM effects

$$R^{\text{Shad}}_{\text{PbPb}} = R_{\text{pPb}}(y \geq 0) \times R_{\text{pPb}}(y \leq 0) \Rightarrow S_{J/\Psi} = R_{\text{PbPb}} \,/\, R^{\text{Shad}}_{\text{PbPb}}$$



At low transverse momentum J/ψ are produced with indication on enhancement in agreement with regeneration model. At high transverse momentum strong suppression is seen – QGP formation?

Final state effects

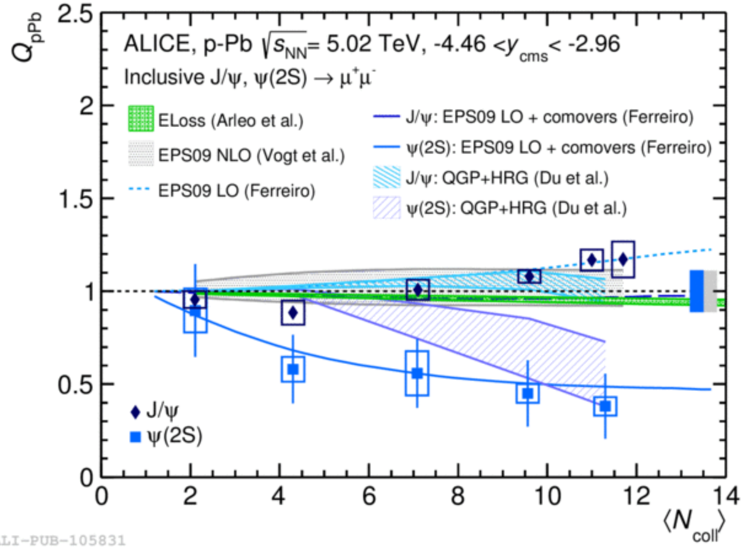
J/ψ and ψ(2S) production in *p*Pb-collisions at 5.02 TeV

- **Different behavior for J/ψ and ψ(2S) production.**

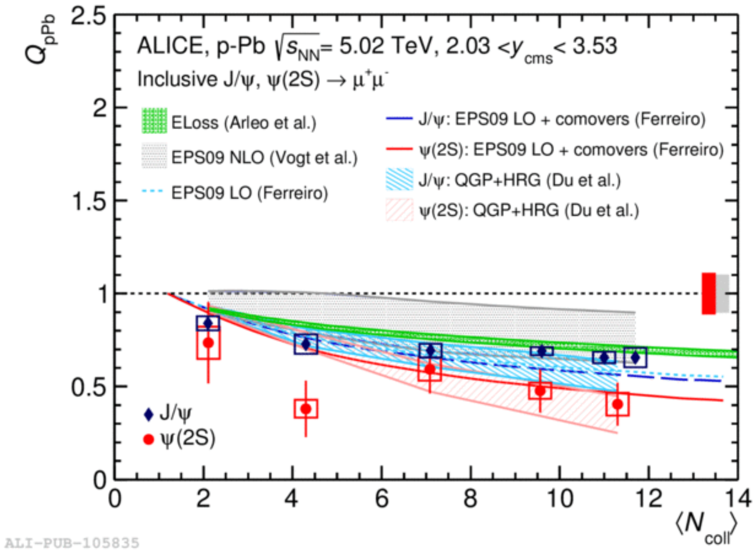
- **ψ(2S) is more suppressed than J/ψ.**

  more pronounced in Pb-going direction than in p-going

Pb-going



p-going



JHEP 1606 (2016) 050

Final state effects ?

At LHC -some evidence for collective behavior in high-multiplicity p-Pb and pp collisions

No theoretical model that could reproduce all data.

Fixed target experiment at LHC for quarkonium production at the energy range between SPS and RHIC in p-A and A-A collisions with planning proton beam at T=7 TeV ($\sqrt{s}$ = 114.6 GeV) and Pb beam at 2.75 TeV ($\sqrt{s}$ = 71.8 GeV) with high statistics is possibility to clarify the mechanism of quarkonium (J/ψ, ψ(2S), ϒ(1S,2S,3S) and χ_c) production, to investigate the contribution of recombination .

proton and lead beams, different targets, possible scan of the energy

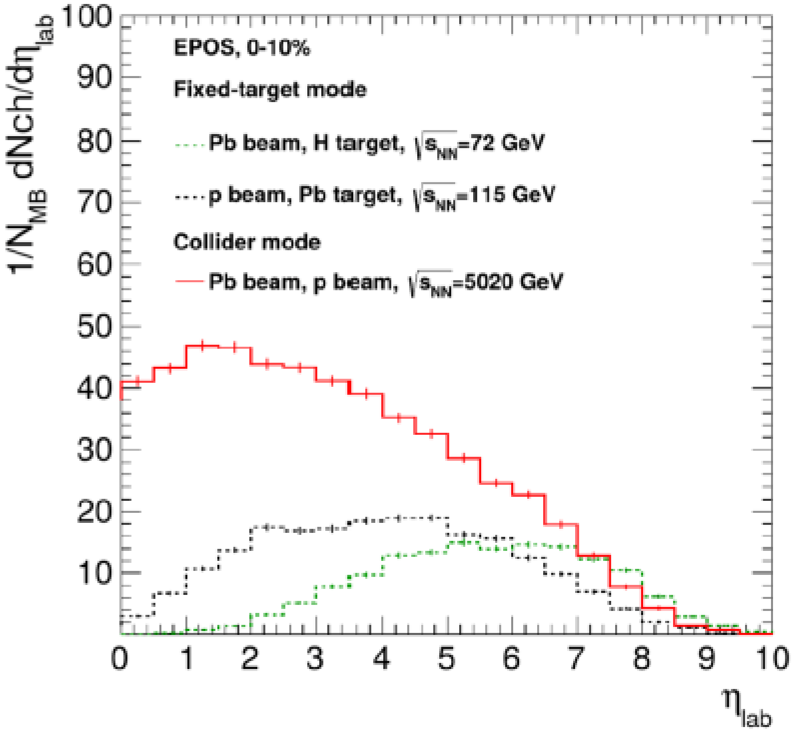
Luminosities for 500 µm target length

LHC beam	Target species	Density ρ [g cm^{-3}]	M [g mol^{-1}]	Thickness ℓ [μm]	θ_{target} [cm^{-2}]	beam flux [s^{-1}]	$\mathcal{L}$ [cm^{-2}s^{-1}]
p	C	2.25	12	500	$5.6 \cdot 10^{21}$	5×10^{8}	$2.8 \cdot 10^{30}$
p	Ti	4.43	48	500	$2.8 \cdot 10^{21}$	5×10^{8}	$1.4 \cdot 10^{30}$
p	W	19.25	184	500	$3.1 \cdot 10^{21}$	5×10^{8}	$1.6 \cdot 10^{30}$
Pb	C	2.25	12	500	$5.6 \cdot 10^{21}$	10^{5}	$5.6 \cdot 10^{26}$
Pb	Ti	4.43	48	500	$2.8 \cdot 10^{21}$	10^{5}	$2.8 \cdot 10^{26}$
Pb	W	19.25	184	500	$3.1 \cdot 10^{21}$	10^{5}	$3.2 \cdot 10^{26}$

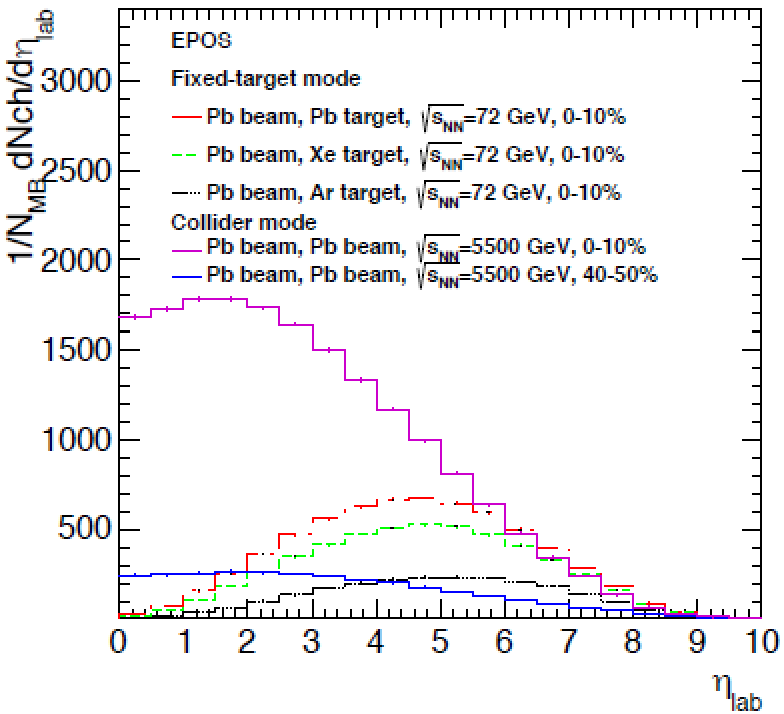
Typical luminosities integrated over a month (10^6 s): L_{PbW} (72 GeV) = 0.3/nb

Charge particle multiplicities

p+A



Pb+A



- Charge particle multiplicities for all fixed target modes: p+Pb at 115 GeV and Pb +H at 72 GeV (left) and Pb+Pb, Pb+Xe, Pb+Ar at 72 Gev (right)
- Multiplicities smaller than reached in collider mode for η_{lab} <6
- ALICE would be possible to use such multiplicities

Large yields expected for charmonia

Experiment AFTER

AFTER :

- Offers a wide physical program.
- Possibility to use different targets with high thickness – higher luminosity (20 times more for 1 cm target vs 500 μm)
- Possibility to use 1 meter-long liquid H_2 and D_2 targets: extremely high luminosity ~20 fb^{-1} yr^{-1} -compatible to LHC. But – high cost.

Fixed target experiment with the target in the form of thin ribbon:

- Only after beam tuning with the aid of rotation system-put in the working position
- Used only halo of the beam (and may be used as extra collimator)
- May be placed at existing experimental installation (for example, ALICE and/or LHCb)
- Possibility to measure charmonium production with rather high statistics on different targets in pA and PbA. First step ?

Conclusions

- Three main themes push for a fixed-target program at the LHC

  [without interfering with the other experiments]

  - The large x frontier: new probes of the confinement

    and connections with astroparticles
  - The nucleon spin and the transverse dynamics of the partons
  - The approach to the deconfinement phase transition:

    new energy, new rapidity domain and new probes

The measurement in energy range for fixed target experiment between SPS and RHIC with high statistics gives important additional information for quarkonium (J/ψ, $\psi(2S)$, $\Upsilon(1S,2S,3S)$ and χ_c) production.

proton and lead beams, different targets, possible scan of energy

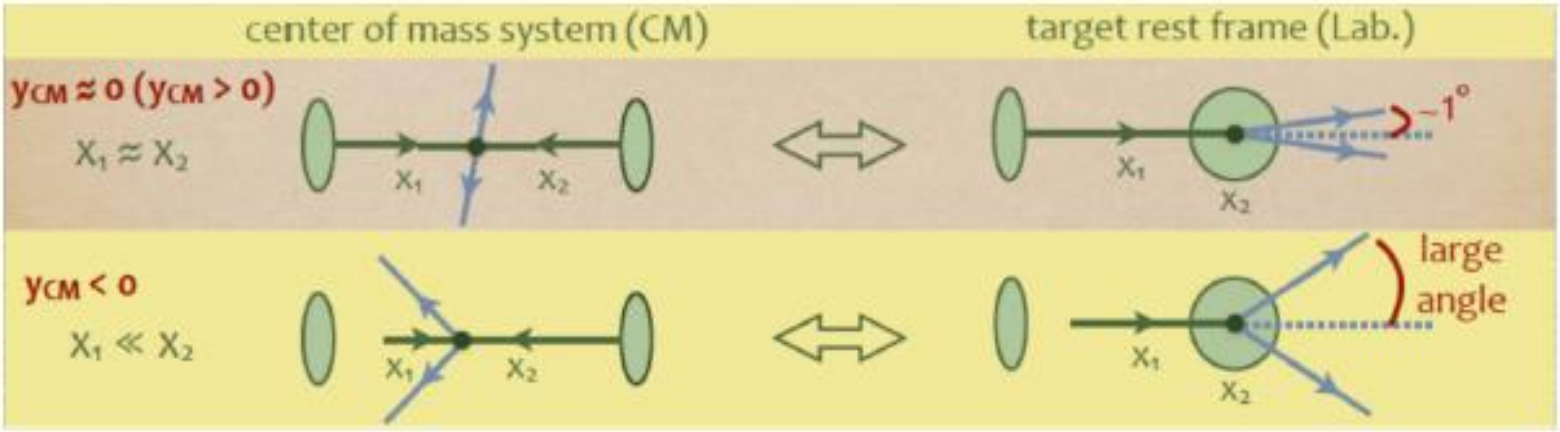
- **The possible technical implementation are discussed at the LHC:**

  internal gas target, beam extraction with bent crystal or internal wire target

- **The Expression of Interest is preparing to be sent to the CERN LHCC**

Backup

Fixed target experiment at the LHC: main kinematical features

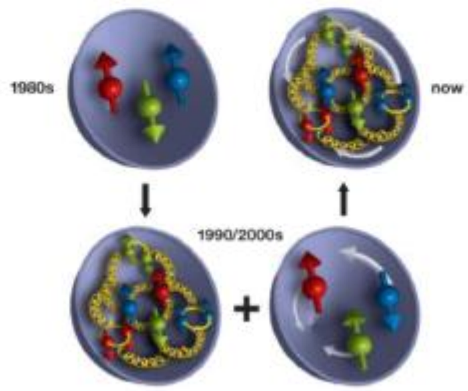


- Entire center-of-mass forward hemisphere ($y_{CM} > 0$) within 1 degree
- Large angle gives access to large parton momentum fraction (x_2) of the target

- LHCb and the ALICE muon arm become backward detectors [$y_{c.m.s.} < 0$]
- With the reduced $\sqrt{s}$, their acceptance for physics grows and nearly covers half of the backward region for most probes [$-1 < x_F < 0$]
- Allows for backward physics up to high x_{target} ($\equiv x_2$) [uncharted for proton-nucleus; most relevant for p-p$^\uparrow$ with large $x^\uparrow$]

Spin physics in AFTER@LHC

- Unraveling the spin of the nucleon



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \mathcal{L}_g + \mathcal{L}_q$$

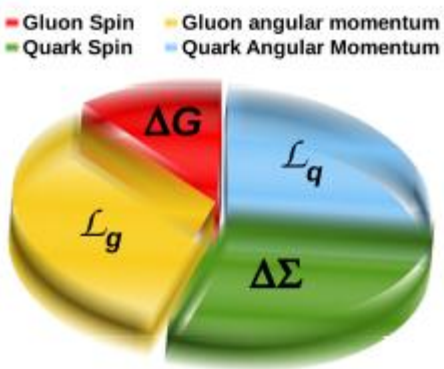
- Possible missing contribution to the proton spin: Orbital Angular Momentum $\mathcal{L}_{g;q}$:

$$\boxed{\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \mathcal{L}_g + \mathcal{L}_q}$$

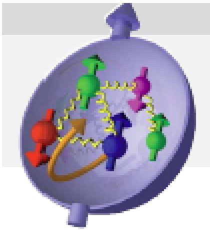
[First hint by COMPASS that $\mathcal{L}_g \neq 0$]

- Test of the QCD factorisation framework

[beyond the DY A_N sign change]



The quarks orbital angular momentum (OAM) .

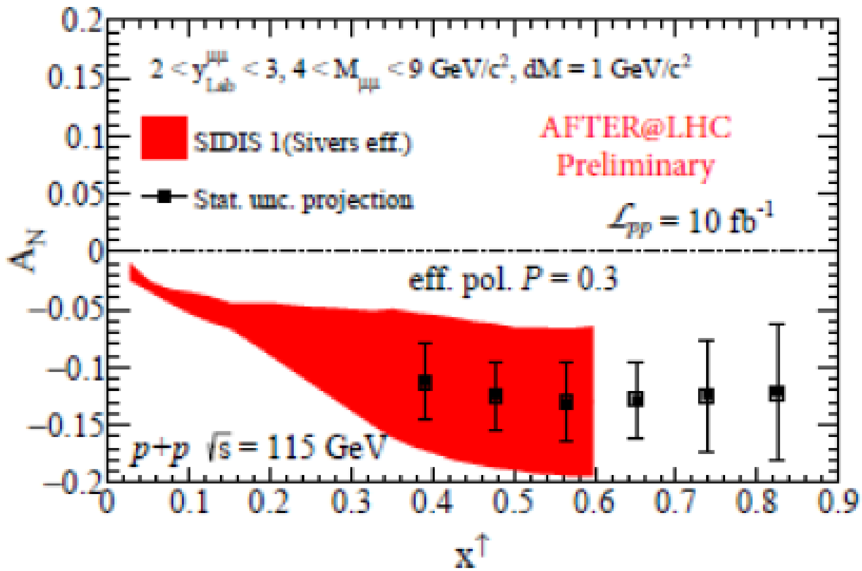


Single spin asymmetry (STSA) in Drell-Yan studies with AFTER@LHC. **Expected asymmetries.**

The target-rapidity region (negative x_F) corresponds to high $x^{\uparrow}$

where the k_T-spin correlation is the largest

Experimental goal: to measure asymmetries on the order of 5-10 % at $x_F < 0$

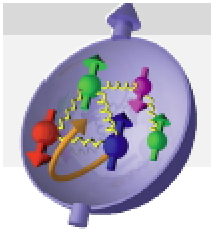


Transverse Single-Spin Asymmetries in Proton-Proton Collisions…
M.Anscelmino et al., Adv. High Energy Physics **2015** (2015) ID 475040

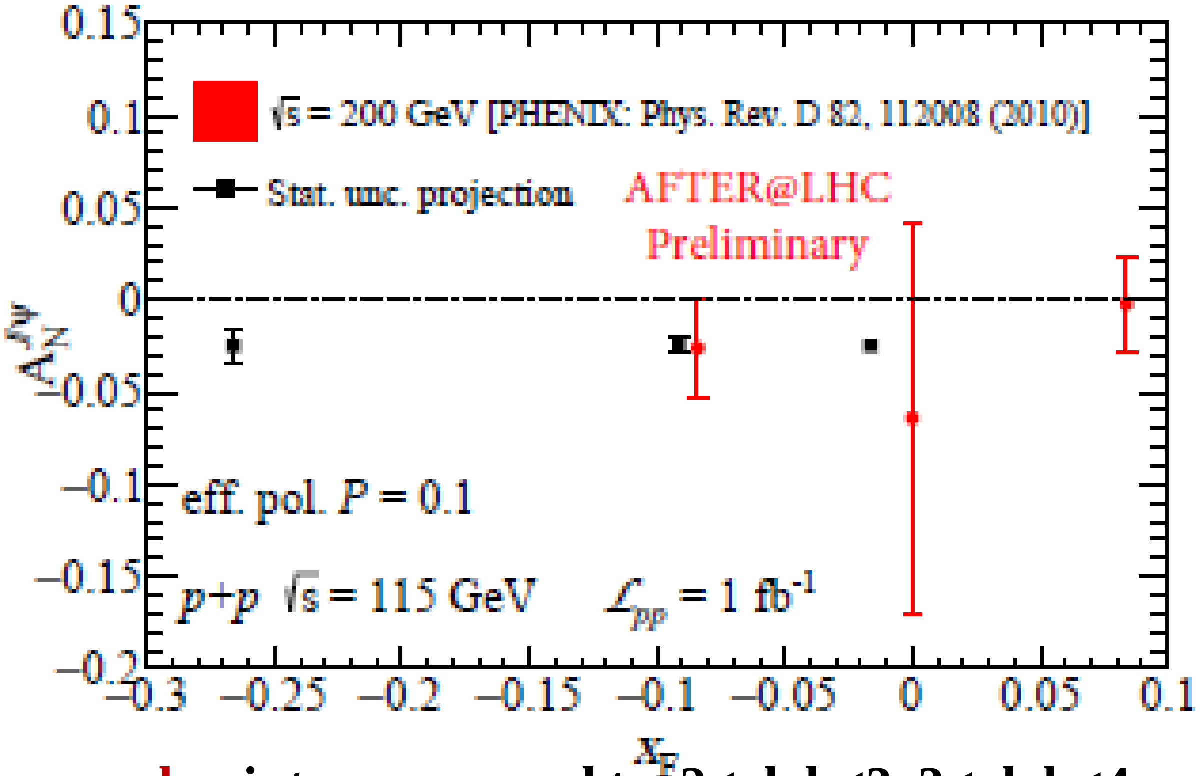
Black points – calculated AFTER@LHC values.

The gluon orbital angular momentum (OAM) contribution to the proton spin in J/ψ production

Single transverse spin asymmetry (STSA) for J/ψ production



- It can be measured via A_N of gluon sensitive probes [as opposed to DY for quarks]



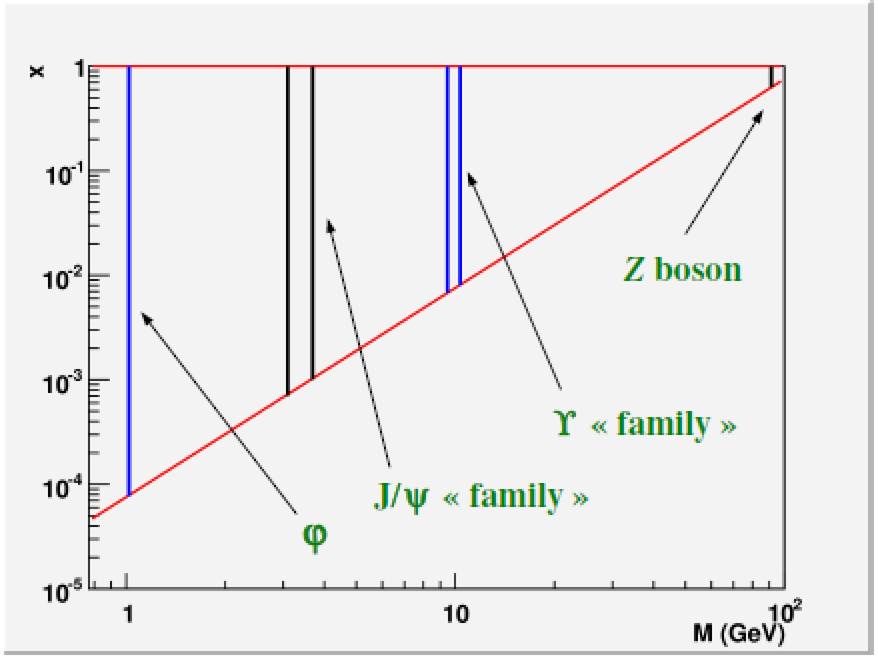
The three red points correspond to 2<ylab<3, 3<ylab<4 and 4<ylab<5 PHENIX data, with average central value $A_N(J/\psi)$ =-0.025.
Black points – calculated AFTER@LHC values.

The dilepton study

➟ Region in x probed by dilepton production as function of $M_{\ell\ell}$

→ Above $c\bar{c}$: $x \in [10^{-3}, 1]$

→ Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$



Note: $x_{target} (\equiv x_2) > x_{projectile} (\equiv x_1)$
"backward" region

→ sea-quark asymetries
via p and d studies

- at large(est) x: backward ("easy")

- at small(est) x: forward (need to stop the (extracted) beam)

➟ To do: to look at the rates to see how competitive this will be

Charmonium production in fixed target mode with the wire target

In the frame of AliRoot fast simulation we calculated the geometrical acceptances for fixed target experiment at LHC with the target in the form of thin ribbon placed around the main orbit for charmonium production at the energy range between SPS and RHIC in p-A and A-A collisions with planning proton beam at T=7 TeV ($\sqrt{s}$ = 114.6 GeV) and Pb beam at 2.75 TeV ($\sqrt{s}$ = 71.8 GeV) at IP z=0 and at z= - 50cm.

Then - luminosity and counting rate estimation for J/ψ production .

Luminocity, cross sections($x_F>0$) , counting rates

System	$\sqrt{s}$ (TeV)	σ_{nn} (μb)	$\sigma_{pA}=\sigma_{nn}\cdot A^{0.92}$ (μb)	I (%)	$I\cdot B\cdot\sigma_{pA}$ (μb)	L ($cm^{-2}s^{-1}$)	Rate ($hour^{-1}$)
pp	14	32.9	32.9	4.7	0.091	$5\cdot10^{30}$	1635
pp_{RHIC}	0.200	2.7	2.7	3.59	0.0057	$2\cdot10^{31}$	410
pPb_{fixed}	0.1146	0.65	88.2	5.98	0.310	$1\cdot10^{29}$(*)	112
pPb_{fixed}	0.0718	0.55	74.6	7.97	0.349	$1\cdot10^{29}$	126
pPb_{NA50}	0.0274	0.19	25.8	14.0	0.212	$7\cdot10^{29}$	535
$PbPb_{fixed}$	0.0718	0.55	11970	7.97	47.9	$2.2\cdot10^{27}$(**)	378

(*) pPb_{fixed}, 500 μ wire, $3.2\cdot10^{11}$ protons/60 min

(**) $PbPb_{fixed}$, 500 μ wire, $6.8\cdot10^{8}$ ions/60 min

The luminosity for extracted proton beam in experiment AFTER

★ The LHC beam may be extracted using "Strong crystalline field"

without any decrease in performance of the LHC !

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$
- Instantaneous Luminosity:

$$\mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$$

[ℓ: target thickness (for instance 1cm)]

- Integrated luminosity: $\int dt \mathcal{L}$ over 10^7 s for p^+ and 10^6 for Pb

[the so-called LHC years]

Target	ρ (g.cm⁻³)	A	$\mathcal{L}$ (μb⁻¹.s⁻¹)	$\int\mathcal{L}$ (fb⁻¹.yr⁻¹)
1m Liq. H_2	0.07	1	2000	20
1m Liq. D_2	0.16	2	2400	24
1cm Be	1.85	9	62	.62
1cm Cu	8.96	64	42	.42
1cm W	19.1	185	31	.31
1cm Pb	11.35	207	16	.16

- For *pp* and *pd* collisions : $\mathcal{L}_{H_2/D_2} \simeq 20\ \text{fb}^{-1} y^{-1}$

3 orders of magnitude larger than RHIC (200 GeV)

The luminosity for extracted lead beam in experiment AFTER

- *Pbp* or *PbA* with a 2.75 TeV Pb beam : $\sqrt{s_{NN}} \simeq 72$ GeV
- Crystal channeling is also possible (to extract a fraction of the beam)
- May require crystals highly resistant to radiations: bent diamonds ?

P. Ballin *et al.*, NIMB 267 (2009) 2952

- Expected luminosities with 2×10^5 Pb/s extracted (1cm-long target)

Target	ρ (g.cm⁻³)	A	$\mathcal{L}$ (mb⁻¹.s⁻¹)=∫$\mathcal{L}$ (nb⁻¹.yr⁻¹)
Sol. H_2	0.09	1	11
Liq. H_2	0.07	1	8
Liq. D_2	0.16	2	10
Be	1.85	9	25
Cu	8.96	64	17
W	19.1	185	13
Pb	11.35	207	7

- Planned lumi for PHENIX Run15AuAu 2.8 nb^{-1} (0.13 nb^{-1} at 62 GeV)
- Nominal LHC lumi for PbPb 0.5 nb^{-1}

The quarkonium study in experiment AFTER

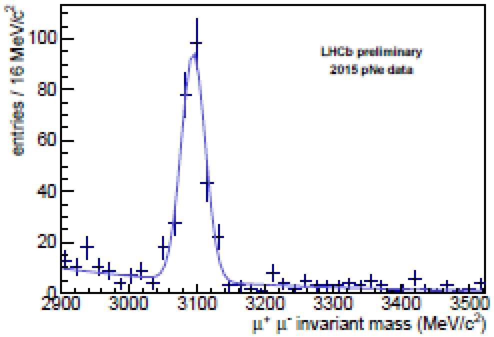
Target	A	$\int \mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} =$A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	1.1 10^8	2.2 10^5
1cm Cu	64	0.42	5.3 10^8	1.1 10^6
1cm W	185	0.31	1.1 10^9	2.3 10^6
1cm Pb	207	0.16	6.7 10^8	1.3 10^6
LHC pPb 8.8 TeV	207	10^{-4}	1.0 10^7	7.5 10^4
RHIC dAu 200GeV	198	1.5 10^{-4}	2.4 10^6	5.9 10^3
RHIC dAu 62GeV	198	3.8 10^{-6}	1.2 10^4	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider y coverage– than at RHIC, allowing for
  - χ_c measurement in pA via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, y or P_T
  - Ratio ψ' over direct J/ψ measurement in pA
  - not to mention ratio with **open charm, Drell-Yan,** etc ...

Internal gas targets

SMOG(-like) system

- SMOG: System for Measuring Overlap with Gas
- Designed for precise luminosity determination
- Noble gas directly injected in the VELO
- ✓ p(He,Ne,Ar), Pb(Ne,Ar) tested : completely parasitic [up to one week, so far]
- ✓ New pressure monitoring to be installed
- ✓ Could be coupled to ALICE: ideal demonstrator
- ✗ No specific pumping system: limit in the gas inject [pressure and duration]
- ✗ No possibility to use polarised gases
- ✗ Gas flows in the beampipe; pressure profile not optimised
- ✗ Kr and Xe maybe only at end of a run



HERMES(-like) system

- Injection of gas in an open-end storage cell
- Used e.g. at DESY for 10 years
- ✓ Dedicated pumping system [turbo-molecular pumps]
- ✓ Pressure in the cell significantly higher [diameter $\leq$ 2cm in the closed position]
- ✓ Polarised H and D can be injected ballistically with high polarisation
- ✓ Polarised ^{3}He or unpolarised heavy gas (Kr, Xe) can also be injected
- ✗ Not compatible with an injection inside ALICE; only upstream
- ✗ May need complementary vertexing capabilities