Summary of requirements and proposal of run schedule

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Present baseline lumi requirements and schedule

- ALICE L_{int} requirements (Upgrade LOI):
  - Pb-Pb: 10/nb @0.5T + 3/nb @0.2T
  - pp 5.5 TeV: 6/pb (4e11 events)
  - p-Pb: 50/nb
  - pp 14 TeV: introduced in 2015 (O^2 TDR)
- ATLAS/CMS:
  - Pb-Pb: 13/nb
  - pp 5.5 TeV: 300/pb (equivalent NN lumi of 10/nb Pb-Pb)
  - p-Pb: no lumi limitations
- LHCb:
  - Committed to participate in all runs, but no specific lumi requests up to now

Year	System	$\sqrt{s_{NN}}$ (TeV)	L_{int} pp: (pb^{-1}) p–Pb: (nb^{-1}) Pb–Pb: (nb^{-1})	$N_{collisions}$
2021	pp	14	0.4	$2.7 \cdot 10^{10}$
	Pb–Pb	5.5	2.85	$2.3 \cdot 10^{10}$
2022	pp	14	0.4	$2.7 \cdot 10^{10}$
	Pb–Pb	5.5	2.85 **0.2T**	$2.3 \cdot 10^{10}$
2023	pp	14	0.4	$2.7 \cdot 10^{10}$
	pp	5.5	6	$4 \cdot 10^{11}$
2027	pp	14	0.4	$2.7 \cdot 10^{10}$
	Pb–Pb	5.5	2.85	$2.3 \cdot 10^{10}$
2028	pp	14	0.4	$2.7 \cdot 10^{10}$
	Pb–Pb	5.5	1.4	$1.1 \cdot 10^{10}$
	p–Pb	8.8	50	10^{11}
2029	pp	14	0.4	$2.7 \cdot 10^{10}$
	Pb–Pb	5.5	2.85	$2.3 \cdot 10^{10}$

Updated (years) from ALICE O^2 TDR, CERN-LHCC-2015-006

L_{int} requirements: Pb-Pb summary

- **The initial requirements are confirmed: 13/nb**
  - **Heavy flavour:** 10/nb with ALICE at full field → Λ_c and Λ_b down to p_T of about 2-5 GeV/c; B-meson (+ non-prompt D and J/ψ) R_{AA} and v_2 down to p_T~1 GeV/c with ALICE and CMS
  - **Quarkonia:** 10/nb → ψ(2S) R_{AA}, J/ψ v_2 down to p_T=0; Υ(2S) R_{AA} vs cent. <10%, first Υ(3S) R_{AA} in min. bias
  - **Jets:** 10/nb with ALICE at full field → e.g. D-jet FF, jet-h large-angle scattering; 10/nb with ATLAS/CMS → e.g. Z-jet momentum imbalance vs Z p_T, jet R_{AA} at 1 TeV with ~10% unc
  - **Light nuclei:** 10/nb with ALICE at full field → e.g. $^4_\Lambda$He (signif~5) and $^4_\Lambda$H (signif~10)
  - **Thermal radiation:** 3/nb with ALICE at low field → di-electron inverse slope with ~20% unc and v_2 with ~0.01 unc
  - **Flow:** 10/nb with ALICE at full field → D meson charge-dep v_1 with 3% unc on slope
  - …

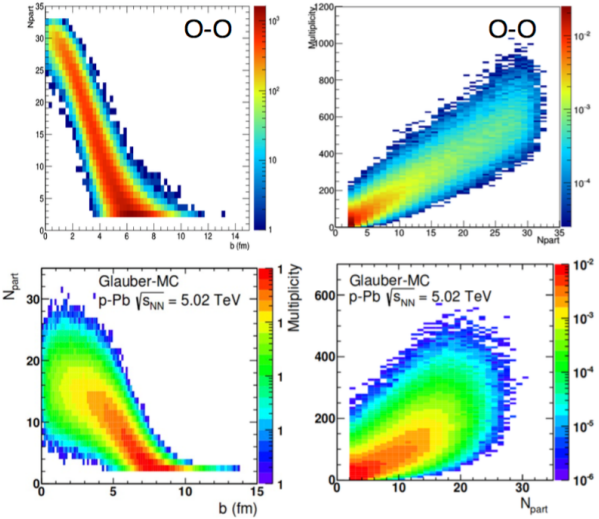
p-Pb summary: L_{int}, energy and timing

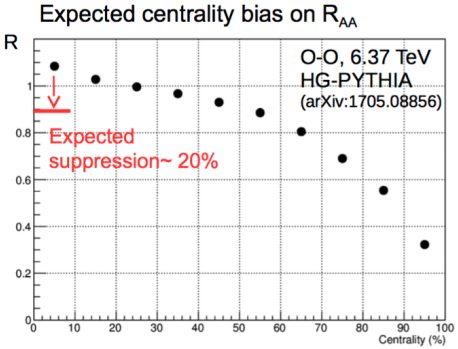
- **L_{int} requirements increased to: ~2/pb for ATLAS/CMS, ~1/pb for ALICE, 0.5/pb LHCb**
- **Energy: 8.8 TeV**
  - Optimal for most measurements: larger cross sections, N_{ch}, lumi, lower Bjorken-x
    - needs pp reference at 8.8 TeV (1-2 days enough for ATLAS/CMS/LHCb; ALICE requirements to be assessed, e.g. ~1/pb in 2 days @ 1 MHz)
- Timing:
  - Physics potential of p-Pb favours having a first p-Pb run in Run-3 (giving ~half of L_{int} goals)
    - Constraining nPDFs at large Q^2 (dijets, W, Z, ttbar) and small Q^2 (Drell-Yan)
    - Precise heavy flavour dynamics in high-mult p-Pb
    - Study J/ψ flow in high-mult p-Pb and constrain $\psi(2S)$ dynamics (needed for Pb-Pb)
    - Search for jet quenching and thermal radiation in high-mult p-Pb
  - A second p-Pb run in Run-4 to complete L_{int} goals
    - Extended tracker for ATLAS/CMS (from $|\eta|<2.5$ to $|\eta|<4$), for multi-particle correlations
    - FoCal in ALICE?

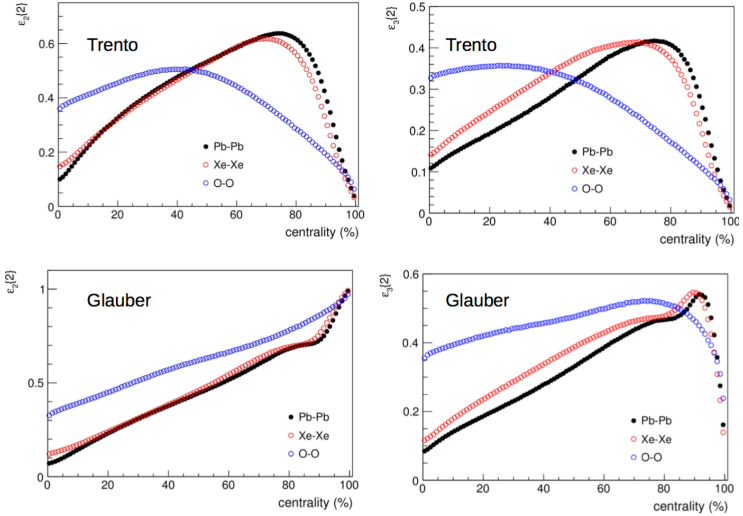
New: O-O: onset of medium effects

See also Zvi's talk tomorrow

- Physics case for O-O presented by C. Loizides at the June WG5 WS
  - Search for energy loss in small system with AA geometry but same N_{ch}, N_{part}, N_{coll} as p-Pb
  - 20% R_{AA} suppression in central O-O (N_{coll}~35) expected on the basis of Xe-Xe
  - Moreover: strangeness/pion, initial vs final state effects in flow, J/ψ (non-)regeneration
- Pilot-like run of 2-3 days (few 100/μb) would address most of these
  - Discussion with J. Jowett: could work well after a EYETS and together with p-O → Second year of Run-3?



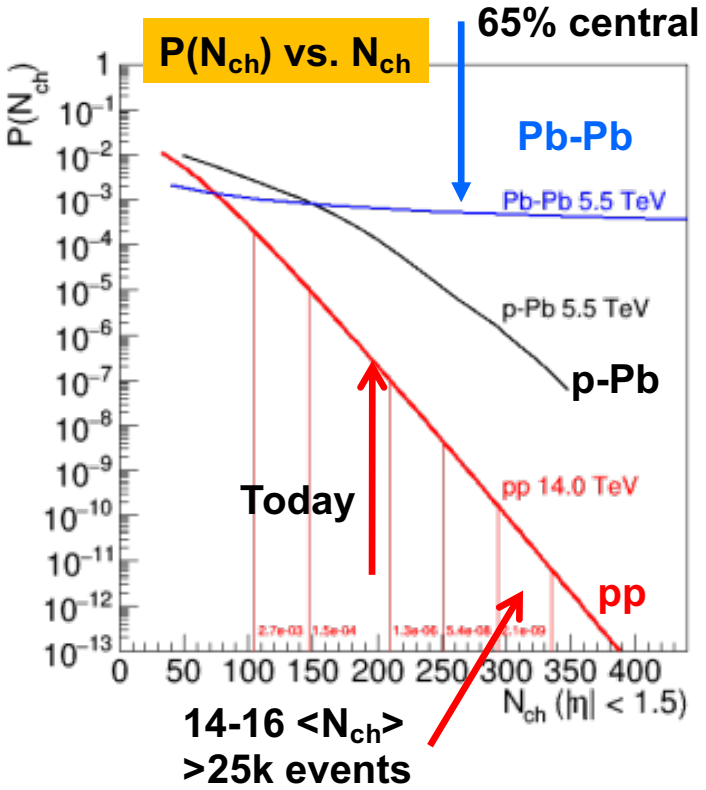




New: proton-proton programme at 14 TeV

See also Jan's talk

- HM pp 14 TeV data at low/moderate μ
  - Opens opportunity of large overlap in N_{ch} between pp, p-Pb and Pb-Pb
  - Requirement by all experiments of **200/pb** with HM (and diffr.) triggers in **Run-3** (2021-22-23)
    - ALICE μ~0.01 (ideal conditions, negligible pileup); compare to 17/pb Run-2 target
    - ATLAS/CMS μ~1-2 (pileup under control)
  - Reach 15x<N_{ch}>: ~60% Pb-Pb centrality (E-loss!), full overlap with p-Pb range



Updated programme and requirements (WG5)

- **Pb-Pb (confirmed)**: 13/nb
- **pp 5.5 TeV (confirmed)**: 6/pb ALICE, 600/pb ATLAS/CMS, LHCb tbd
- **pp 14 TeV (updated)**: 200/pb in Run-3 at low(er) μ
- **p-Pb 8.8 TeV (updated)**: 2/pb ATLAS/CMS, 1/pb ALICE, 0.5/pb LHCb
  - For ALICE 1/pb would be two months, the second with FoCal (Run-4)
- **pp 8.8 TeV (new):** 200/pb ATLAS/CMS, 100/pb LHCb, ALICE few/pb tbd
- **O-O 7 TeV (new):** few 100 /μb – pilot-like 3-4 days
- **p-O (new):** requested by cosmic-ray community via LHCb, pilot-like 1-2 days
- **"Ar-Ar" (new)**: 3 months → L_{NN} equiv 75-250/nb Pb-Pb = 6-18x"Pb-Pb 13/nb"
  - Using latest machine projections $L_{NN}^{ArAr} \sim 8\text{-}25\ L_{NN}^{PbPb}$
  - Choice of Ar is not final, driven by the maximum gain in L_{NN}. E.g. Kr-Kr (A=78) gain is x2-6.5
  - Detailed assessment of quenching effects needed
- Priorities are Pb-Pb 13/nb and p-Pb → "Ar-Ar" would extend HI programme to Run-5

Schedule considerations: Run 3 and 4

- **pp 14 TeV**: 200/pb in 12 months in Run-3
- **O-O and p-O:** 1 week in Run-3, after a EYETS
- **pp 5.5 TeV**: 1 week in Run-3 + 1 week same in Run-4
- **p-Pb 8.8 TeV**: 3 weeks in Run-3 + 3 weeks in Run-4
- **pp 8.8 TeV:** few days in Run-3 + same in Run-4, before p-Pb
- **Pb-Pb**: 6.2/nb in Run-3, 6.8/nb in Run-4

- Net changes: + 6 wks p-Pb+pp 8.8; +1 wk O-O+p-O; - 2 wks pp 5.5; -1 wk Pb-Pb*

→ + 4 weeks → Proposal to extend HI running by 2 (2) weeks in Run-3 (4)

(* increase of L_{int}/run projection by LHC)

Revised schedule proposal (2 longer runs in 2022 and 2028)

Year	Systems, time, L_{int}	Total per Run (3, 4, 5)
2021	Pb-Pb, 3 weeks, 2.3/nb pp 5.5, 1week, 3/pb @ ALICE, 350/pb ATLAS, CMS	**Pb-Pb, 6.2/nb** pp 5.5, "half L_{int} target" p-Pb, 0.6/pb ATLAS,CMS, 0.3/pb ALICE, 0.25/pb LHCb pp 8.8, "half L_{int} target" O-O p-O
2022 (extended from 4 to 6 weeks)	p-O + O-O 7 TeV, 1 week, few 100/μb (after EYETS?) Pb-Pb, 5 weeks, 3.9/nb	
2023	pp 8.8 TeV, few days p-Pb 8.8 TeV, 3.x weeks	

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2022 (extended from 4 to 6 weeks)	p-O + O-O 7 TeV, 1 week, few 100/μb (after EYETS?) Pb-Pb, 5 weeks, 3.9/nb	
2023	pp 8.8 TeV, few days p-Pb 8.8 TeV, 3.x weeks	
LS3	ATLAS/CMS upgrades, ALICE: ITS3? FoCal?	
2027	Pb-Pb, 3 weeks, 2.3/nb pp 5.5, 1week, 3/pb @ ALICE, 350/pb ATLAS, CMS	**Pb-Pb, 6.8/nb** pp 5.5, "half L_{int} target" p-Pb, 0.6/pb ATLAS,CMS, 0.3/pb ALICE, 0.25/pb LHCb pp 8.8 "half L_{int} target"
2028 (extended from 4 to 6 weeks)	Pb-Pb, 2 weeks, 1.5/nb p-Pb 8.8 TeV, 3.x weeks pp 8.8 TeV, few days	
2029	Pb-Pb, 4 weeks, 3/nb	

Pb-Pb total = 13/nb

Note: a "Ar-Ar" pilot run (~1 day) in Run 4 may be needed to prepare Run-5 campaign

Revised schedule proposal (2 longer runs in 2022 and 2028)

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2021	Pb-Pb, 3 weeks, 2.3/nb pp 5.5, 1week, 3/pb @ ALICE, 350/pb ATLAS, CMS	**Pb-Pb, 6.2/nb** pp 5.5, "half L_{int} target" p-Pb 8.8, 1/pb ATLAS,CMS, 0.5/pb ALICE, 0.25/pb LHCb pp 8.8, "half L_{int} target" O-O p-O
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2027	Pb-Pb, 3 weeks, 2.3/nb pp 5.5, 1week, 3/pb @ ALICE, 350/pb ATLAS, CMS	**Pb-Pb, 6.8/nb** pp 5.5, "half L_{int} target" p-Pb, 0.6/pb ATLAS,CMS, 0.3/pb ALICE, 0.25/pb LHCb pp 8.8 "half L_{int} target"
2028 (extended from 4 to 6 weeks)	Pb-Pb, 2 weeks, 1.5/nb p-Pb 8.8 TeV, 3.x weeks pp 8.8 TeV, few days	
2029	Pb-Pb, 4 weeks, 3/nb	
LS4	LHCb upgrade? ALICE faster?	
2031	"LightA-LightA", 3 weeks, 6.3 TeV, pp, 1 week	"LightA-LightA": e.g. Ar-Ar (A=40), L_{NN} equiv 6-18 x Pb-Pb 13/nb Kr-Kr (A=78), L_{NN} equiv 1.5-5 x Pb-Pb 13/nb
2032	"LightA-LightA", 4 weeks	
2033	"LightA-LightA", 4 weeks	

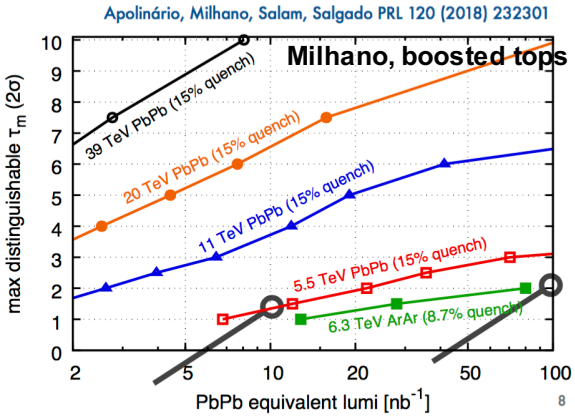
EXTRA SLIDES

Revised schedule: option 2 (a bit less Pb-Pb, or only one p-Pb)

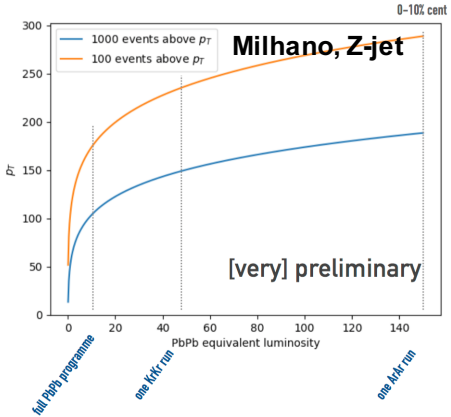
Year	Systems, time, L_{int}	Total per Run (3, 4, 5)
2021	Pb-Pb, 3 weeks, 2.5/nb pp 5.5, 1week, 3/pb @ ALICE, 350/pb ATLAS, CMS	**Pb-Pb, 5/nb** pp 5.5, "half L_{int} target" p-Pb 8.8, 1/pb ATLAS,CMS, 0.5/pb ALICE, LHCb 0.25/pb pp 8.8, "half L_{int} target" O-O p-O
2022	p-O + O-O 7 TeV, 1 week, few 100/μb (after EYETS?) Pb-Pb, 3 weeks, 2.5/nb	
2023	pp 8.8 TeV, few days p-Pb 8.8 TeV, 3 weeks	
LS3	ATLAS/CMS upgrades, ALICE ITS3? FoCal?	
2027	Pb-Pb, 3 weeks, 2.5/nb pp 5.5, 1week, 3/pb @ ALICE, 350/pb ATLAS, CMS	**Pb-Pb, 5.5/nb** pp 5.5, "half L_{int} target" p-Pb 8.8, 1/pb ATLAS,CMS, 0.5/pb ALICE, LHCb 0.25/pb pp 8.8, "half L_{int} target"
2028	p-Pb 8.8 TeV, 3 weeks pp 8.8 TeV, few days	
2029	Pb-Pb, 4 weeks, 3/nb	
LS4	LHCb upgrade? ALICE faster?	
2031	"LightA-LightA", 3 weeks, 6.3 TeV, pp, 1 week	"LightA-LightA": e.g. Ar-Ar (A=40), L_{NN} equiv 6-18 x Pb-Pb 13/nb Kr-Kr (A=78), L_{NN} equiv 1.5-5 x Pb-Pb 13/nb
2032	"LightA-LightA", 4 weeks	
2033	"LightA-LightA", 4 weeks	

Ar-Ar: high luminosity

- Higher NN L_{int}, because lumi limitations scale with large powers of Z, e.g. EMD ~Z^4 and BFPP ~Z^7
- New projection by J. Jowett: → ~8-25x gain in hard-scattering yields with Ar-Ar wrt Pb-Pb
- Access new tools to probe QGP properties, e.g. boosted tops → time-dep. of opacity
- Much higher precision for standard tools, e.g. Z-jet → access to differential measurements
- Next step: quantify precision gain, including expected reduction of quenching effects in Ar-Ar
- Also: could constrain A- and b- dependence of nPDFs and saturation effects (Q_S^2~$A^{1/3}$)



1 month Ar-Ar extends "time range" by x2 (> 2 fm/c) wrt Run3+4 Pb-Pb programme



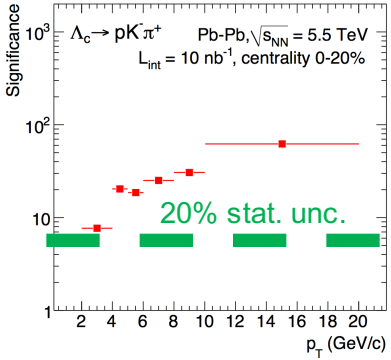
3 months Ar-Ar extends Z p_T range by x2 wrt Run3+4 Pb-Pb programme

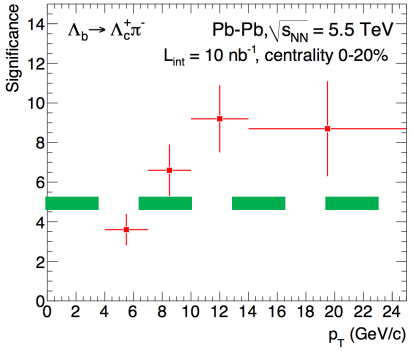
A fresh look at L_{int} requirements: p-Pb

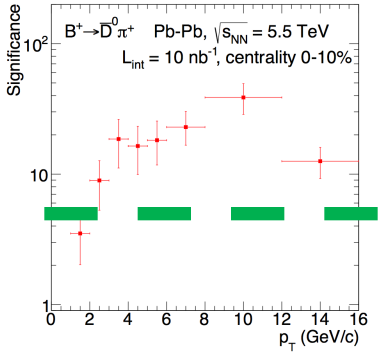
- The initial requirements are increased to ~2/pb for ATLAS/CMS, ~1/pb for ALICE, ~0.5/pb for LHCb
  - **Heavy flavour:** 50/nb (same as LOI) for ALICE D meson R_{pA}, Q_{CP}, v_2
  - **Quarkonia:** 0.5-1/pb → J/ψ v_2, v_3 down to p_T=0 in p-Pb and Pb-p
  - **UPC, nPDFs:** 2/pb for ATLAS/CMS → reduce by ~30-50% nPDF unc at high Q^2 with top, dijets, W fwd/bkwd; 0.5/pb for LHCb → Drell-Yan measurement (plots in the prep.)
  - **Jets:** 1-2/pb with ALICE/ATLAS/CMS → search for energy loss in p-Pb (support plot?)
  - **Light nuclei:** >0.1/pb → N_{ch}-dependence of ^{3}He
  - **Thermal radiation and dileptons:** 50/nb → potential observation of thermal radiation with Rapp prediction, more detailed study ongoing; ~1/pb for ALICE for low-mass dark photon search?
  - …

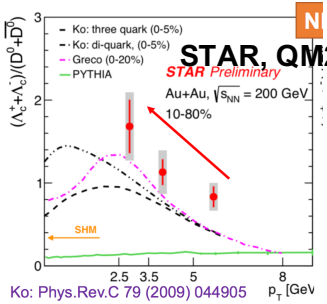
A fresh look at L_{int} requirements: Pb-Pb

- **Heavy flavour:** 10/nb with ALICE at full field → Λ_c and Λ_b down to p_T of about 2-5 GeV/c; B-meson (+ non-prompt D and J/ψ) R_{AA} and v_2 down to p_T~1 GeV/c with ALICE and CMS



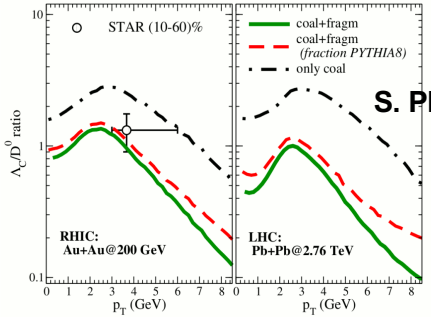






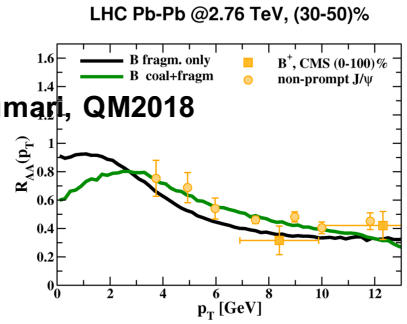
STAR, QM2018

Ko: Phys.Rev.C 79 (2009) 044905
Greco: Eur.Phys.J.C (2018) 78:348
SHM: Phys.Rev.C 79 (2009) 044905



Data taken from STAR coll. Nucl.Phys. **A967** (2017) 620

S. Plumari, QM2018



→ **<10/nb would reduce low-p_T reach by ~ 2 GeV for baryons and "full" B**

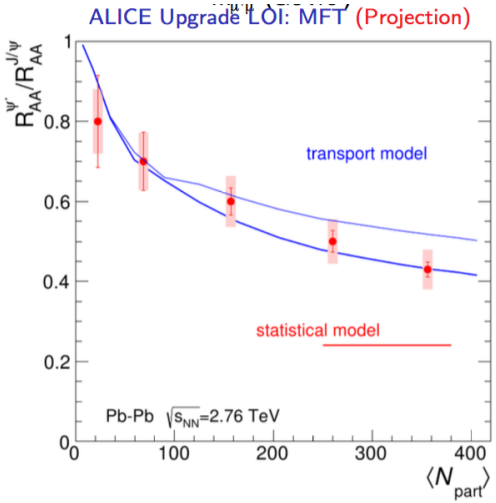
→ **Also increase extrapolation error for measurement of total Q-Qbar cross sections**

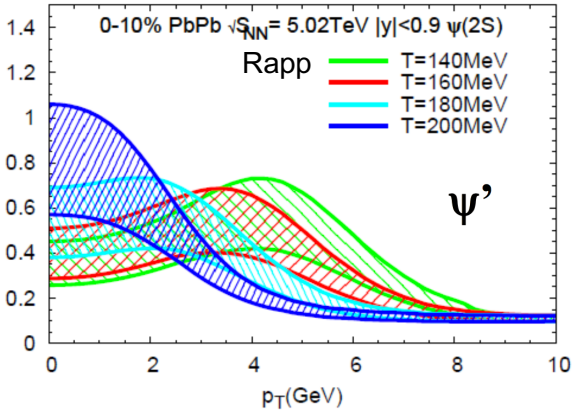
→ **Low p_T reach is crucial to characterize HQ hadronization (coalescence fraction and dynamics)**

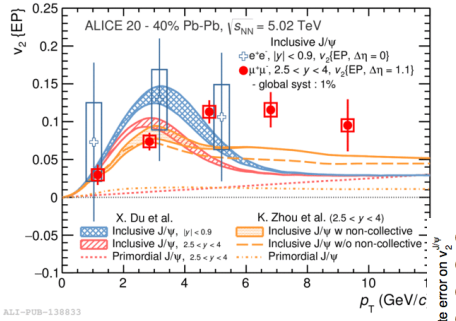
→ **Important per se and a pre-requisite to use D and B mesons to extract HQ diffusion coefficients**

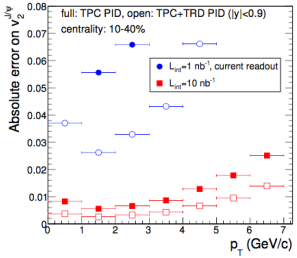
A fresh look at L_{int} requirements: Pb-Pb

- **Quarkonia:** 10/nb → ψ(2S) R_{AA}, J/ψ v_2 down to p_T=0; Υ(2S) R_{AA} vs cent. <10%, first Υ(3S) R_{AA} in min. bias









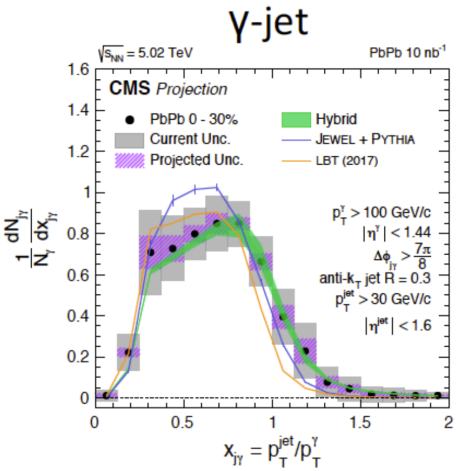
→ **<10/nb would compromise peripheral collisions, where direct comparison with p-Pb (same mult) is possible**

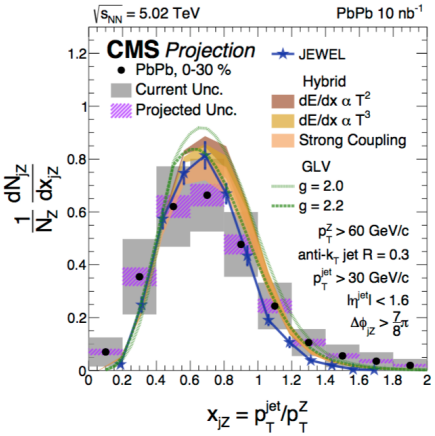
→ **Look into p_T-diff. projection?**

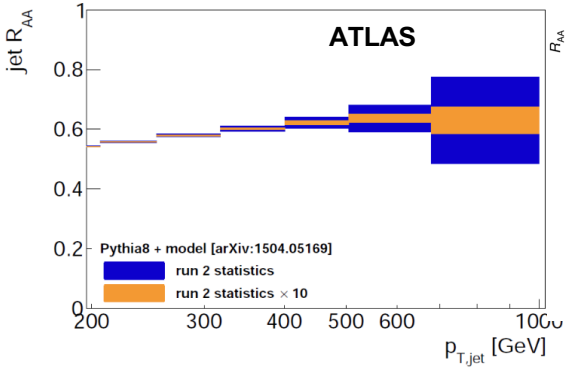
→ **<10/nb would limit precision of low-p_T mid-y J/ψ v_2, where regeneration predicts higher v_2 wrt fwd-y**

A fresh look at L_{int} requirements: Pb-Pb

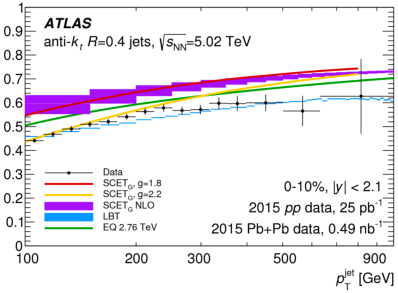
- **Jets:** 10/nb with ALICE at full field → e.g. D-jet FF; 10/nb with ATLAS/CMS → e.g. Z-jet momentum imbalance vs Z p_T (to be quantified), jet R_{AA} at 1 TeV with ~10% unc







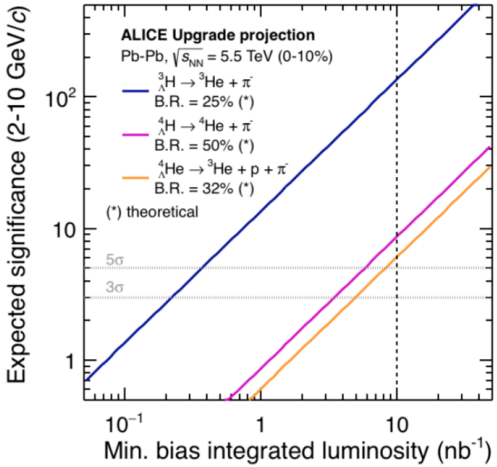
arXiv:1805.05635



→ **Z/γ-jet, high-p_T jet R_{AA} need 10/nb for x3 improvement wrt Run-2**
→ **Sensitive model comparison needs precision**
→ **Extension to higher Z p_T: increase precision at small x_{jZ}, needs statistics**
→ **Studies for jet deflection in ALICE in progress**

A fresh look at L_{int} requirements: Pb-Pb

- **Light nuclei:** 10/nb with ALICE at full field → e.g. $^{4}_{\Lambda}$He (signif~5) and $^{4}_{\Lambda}$H (signif~10)

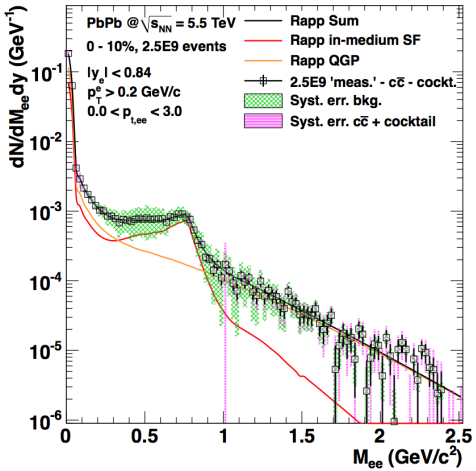


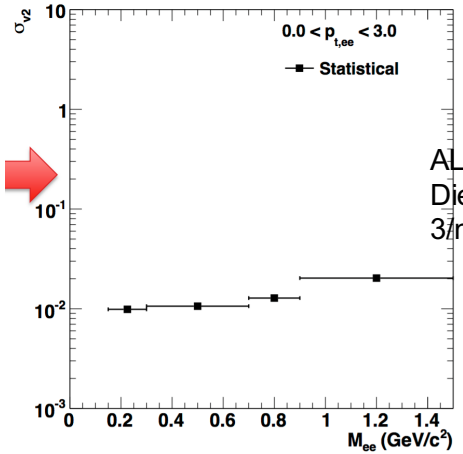
→ **<10/nb would compromise first $^{4}_{\Lambda}$He observation (drops below 5σ)**

→ **$B_{4,\Lambda}$ coalescence parameter comparison with coalescence and thermal model (ALICE plot in preparation)**

A fresh look at L_{int} requirements: Pb-Pb

- **Thermal radiation:** 3/nb with ALICE at low field → di-electron inverse slope with ~10% unc and v_2 with ~0.01 unc



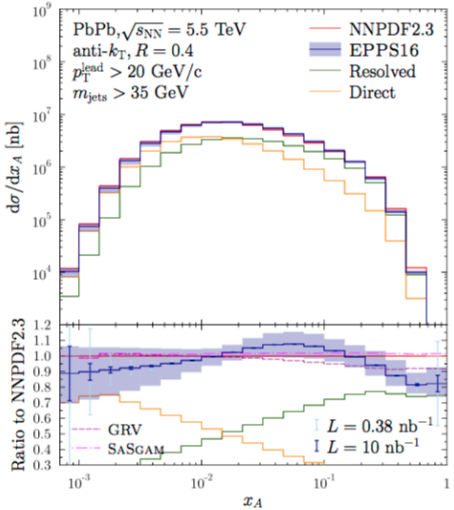


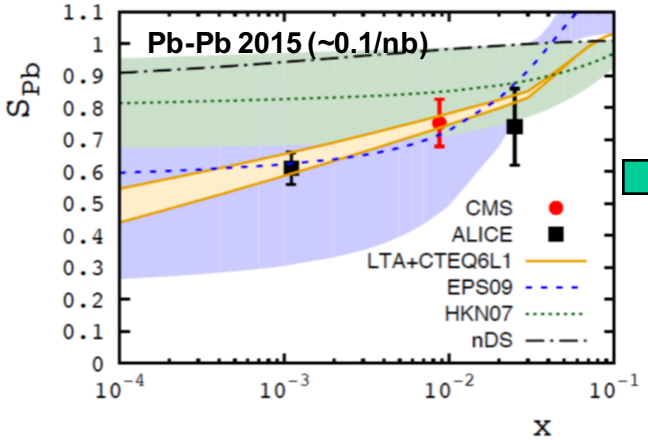
ALICE
Dielectron v_2
3/nb

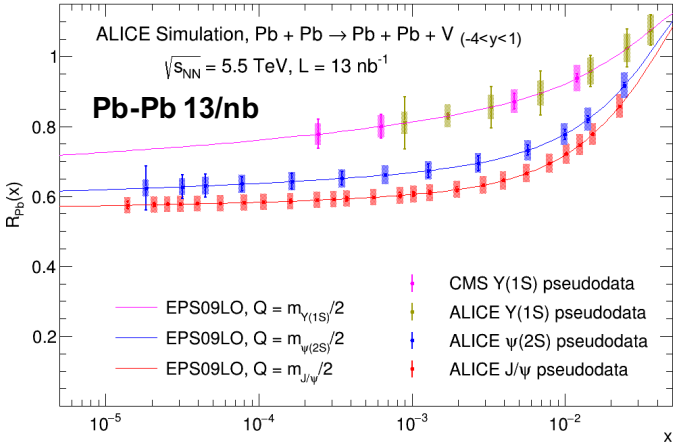
→ **Strong improvement with ITS3, see next talk by Luciano, would motivate a second Pb-Pb run at 0.2T in Run-4**

A fresh look at L_{int} requirements: Pb-Pb

- **UPCs:** 10/nb gives di-jets in UPCs with error of ~5% down to $x=10^{-3}$ and broad x coverage (10^{-5} to 10^{-2}) with quarkonia







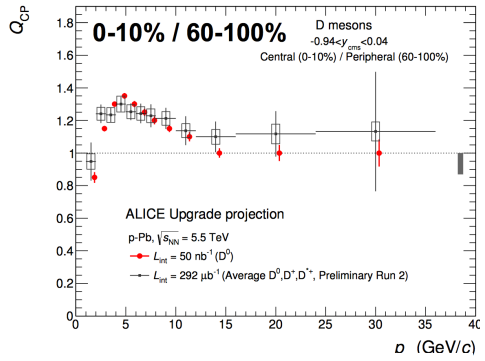
→ **UPC di-jets with error of ~5% down to $x=10^{-3}$**

→ **Map nuclear suppression as a function of Q^2 (quarkonium states) and x (fine rapidity binning). Important to constrain x-shape of nPDFs.**

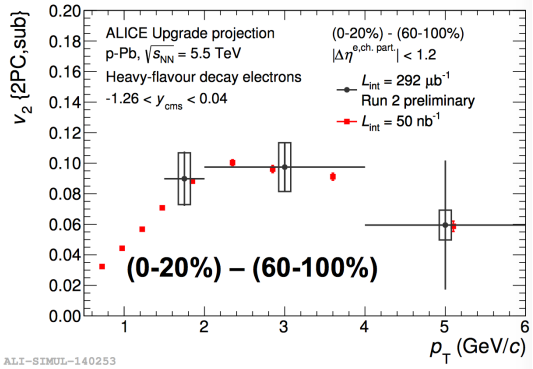
A fresh look at L_{int} requirements: p-Pb

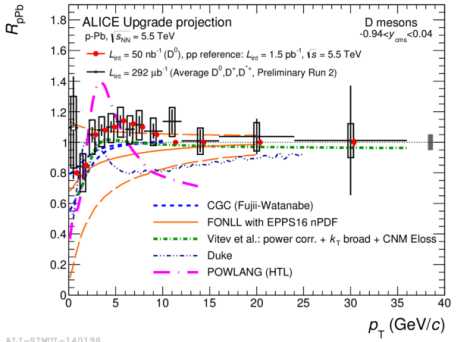
- **Heavy flavour:** 50/nb for ALICE D meson R_{pA}, Q_{CP}, HFE v_2; 1-2/pb for CMS D v_2

D mesons



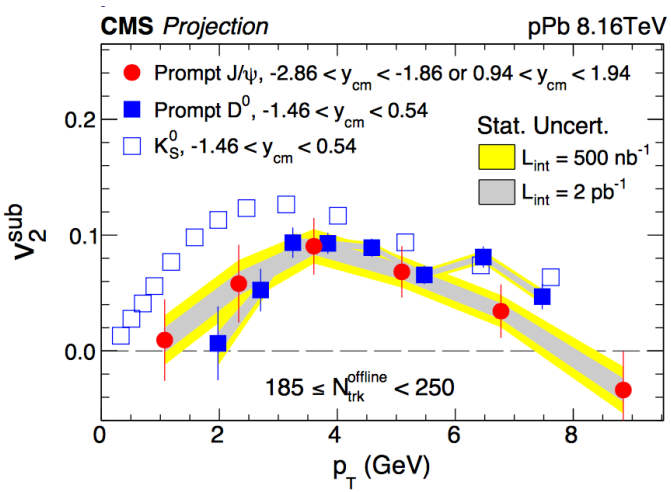
HF electron- hadron correlations





→ **Precise measurement of D meson, and HF-decay electron, radial and azimuthal dynamics down to p_T=0**

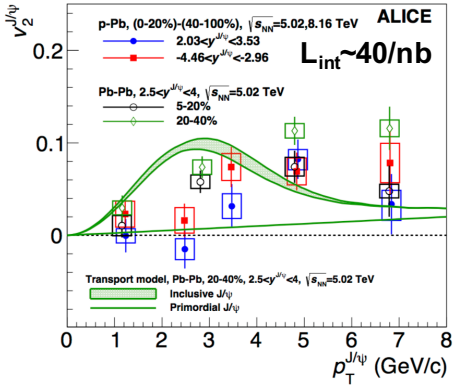
arxiv:1804.09767 **L_{int}=0.2/pb**



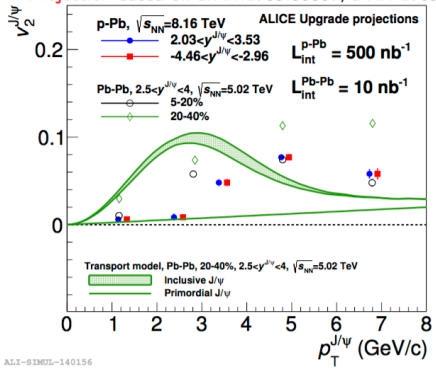
→ **Reduce x1/3 uncertainty on D, J/ψ v_2**
→ **Precise test of v_2 scaling at low p_T**

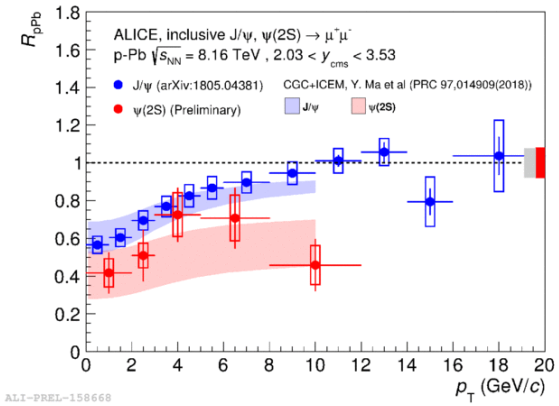
A fresh look at L_{int} requirements: p-Pb

- **Quarkonia:** 0.5/pb → J/ψ v_2, v_3 down to p_T=0 in p-Pb and Pb-p, high precision ψ(2S)



Projection based on arXiv:1709.06807, arXiv:1709.05260





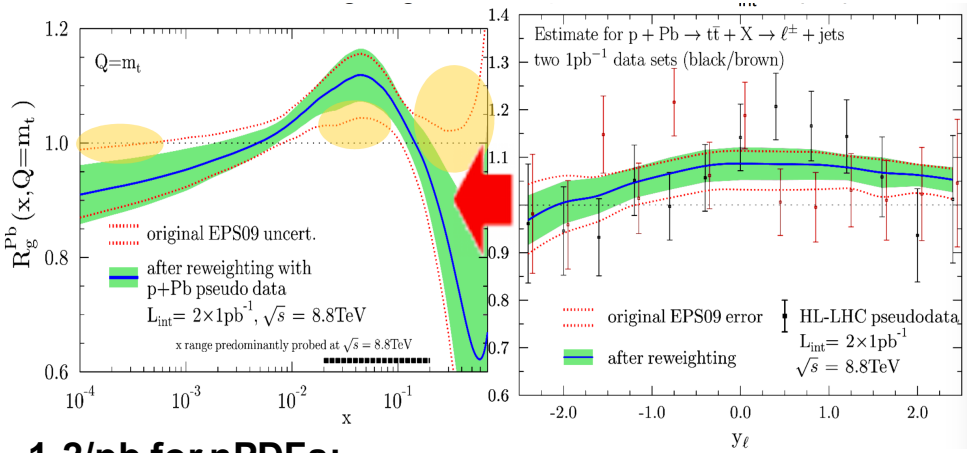
→ **x10 L_{int} increase wrt current measurements needed for precise comparison of p-Pb, Pb-p and Pb-Pb**

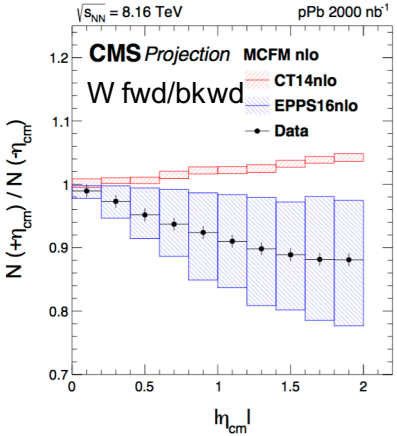
→ **ψ(2S) v_2 and J/ψ v_3 measurement may also be accessible**

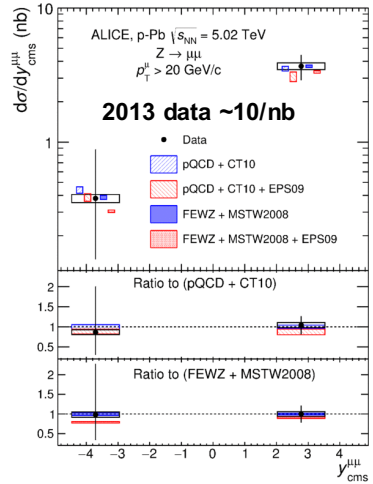
→ **x10 L_{int} increase wrt current measurements also enables precise measurement of ψ(2S) R_{pA}**

A fresh look at L_{int} requirements: p-Pb

- **UPC, nPDFs:** 1-2/pb for ATLAS/CMS → reduce by ~30-50% nPDF unc at high Q^2 with top, dijets, W fwd/bkwd; 0.5/pb for LHCb → Drell-Yan measurement







x7 smaller errors with 0.5/pb – projection in preparation

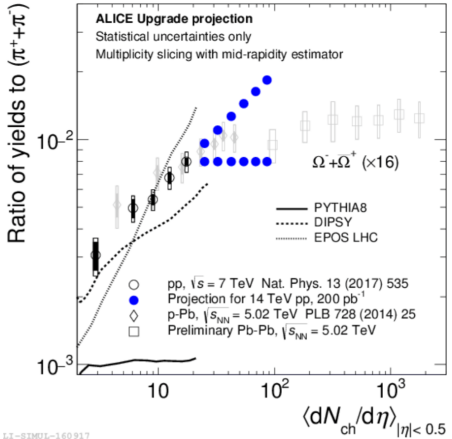
→ **1-2/pb for nPDFs:**

- **high x:**
  - **high-precision W yield asymmetry (impact on nPDFs to be estimated)**
  - **first usage of ttbar events (~30-50% reduction of EPS09 unc)**
- **small x:**
  - **LHCb D mesons and (possible) ALICE-FoCal photons not stat. limited**
  - **LHCb Drell-Yan measurement requires ~0.5/pb (plots in preparation)**

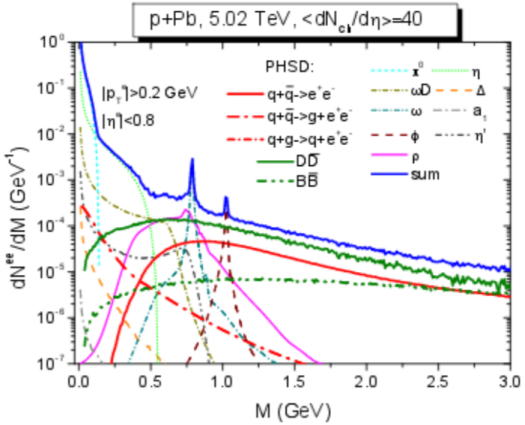
New: proton-proton programme at 14 TeV

- Some of the goals of pp programme with 200/pb (full Run-3):

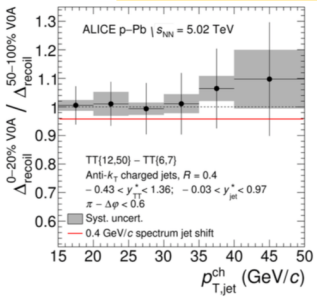
Ω/π: thermal limit in pp?



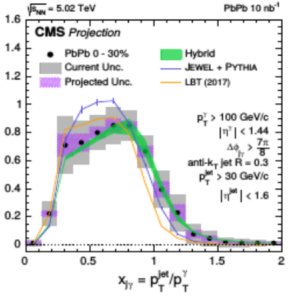
LMee & γ: radiation?



Hadron-jet, γ-jet: energy loss?



arXiV:1712.05603



CMS PAS FTR-17-002

- Flow with multi-particle cumulants
- Heavy flavour and quarkonium dynamics
- Central diffraction: x14 Run-2 L_{int}
  - precision spectroscopy, including excited quarkonium states, search for glueballs, magn. monopoles