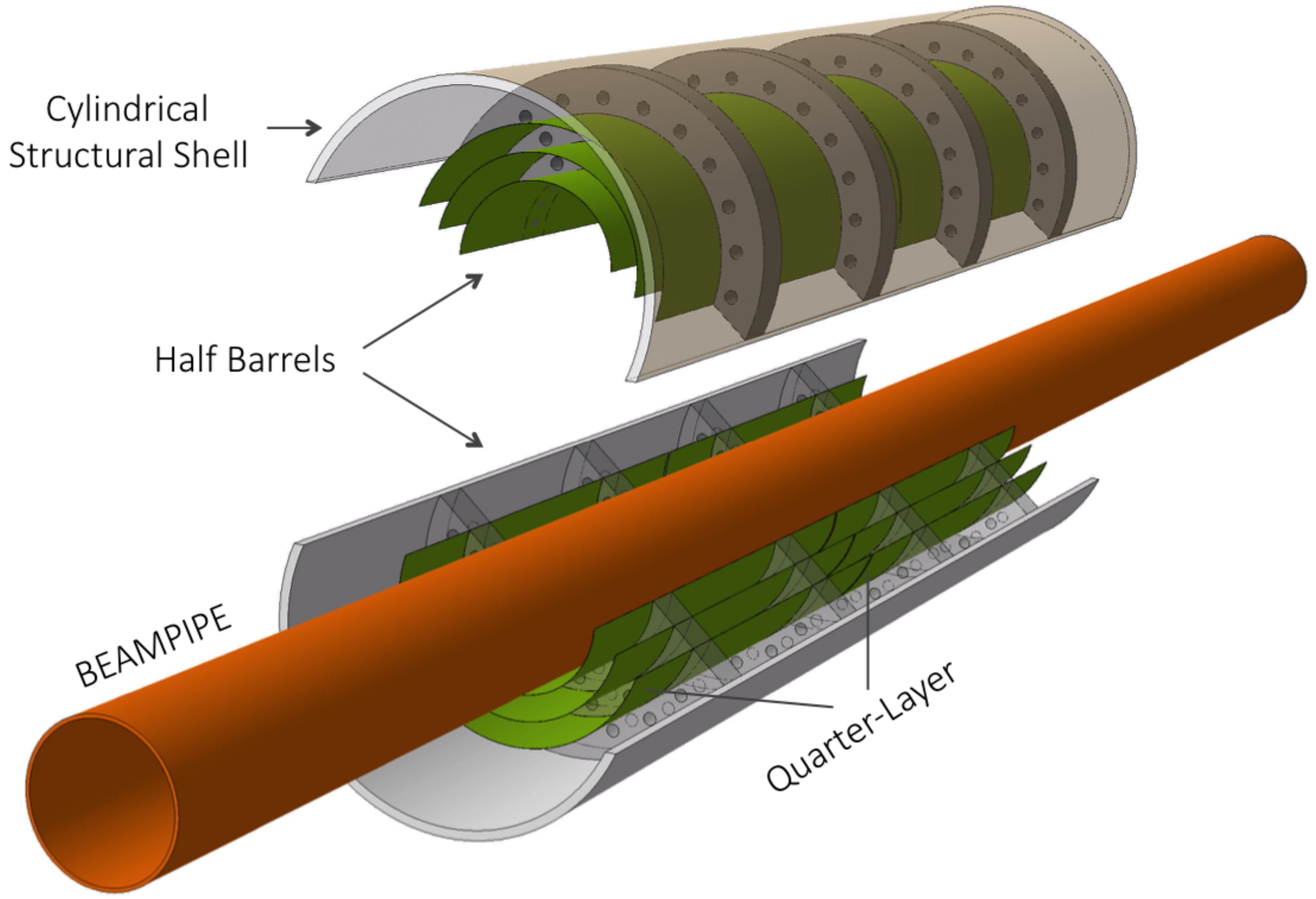
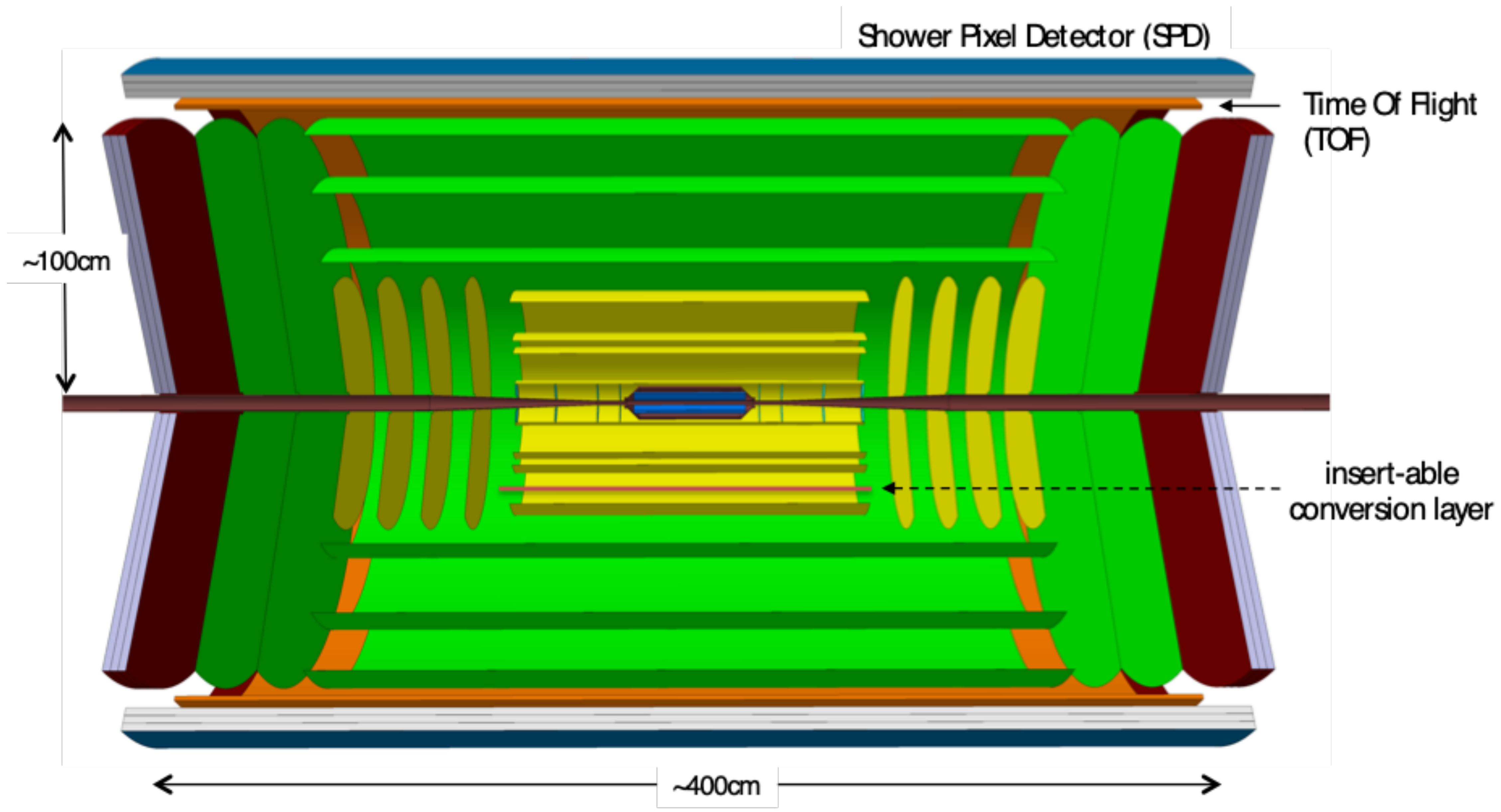
Prospects with advanced Silicon Technologies in ALICE

Marco van Leeuwen, Nikhef
On behalf of the ALICE Collaboration



ITS3 for run 4



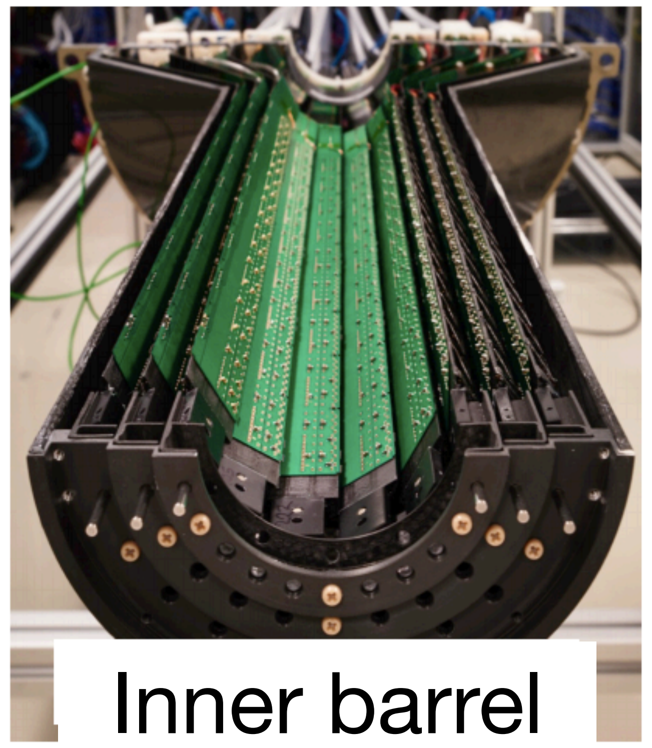
New experiment: run 5

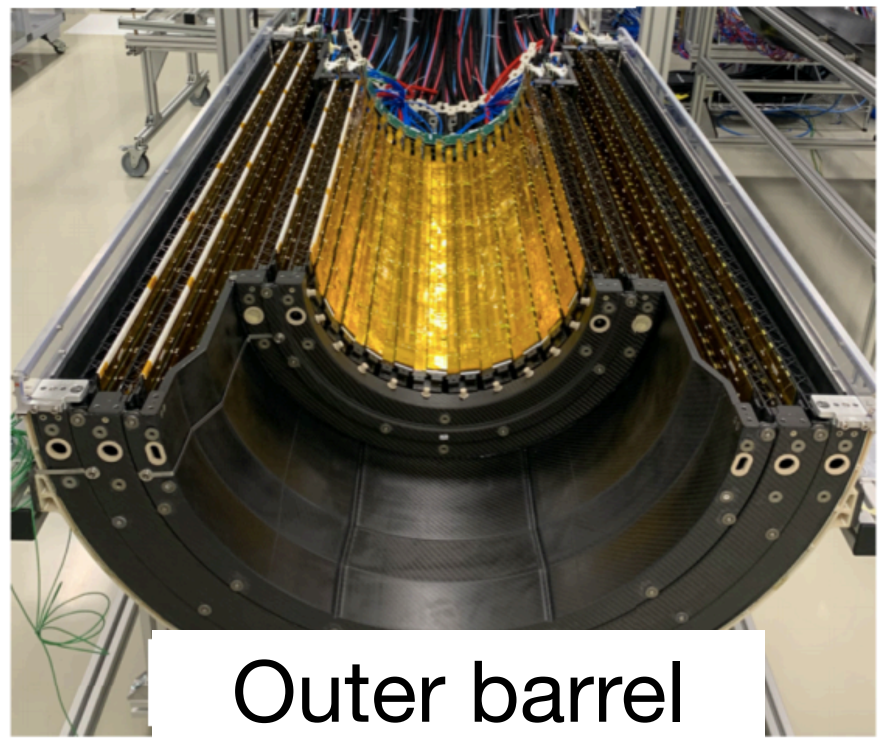
ALICE

Nikhef

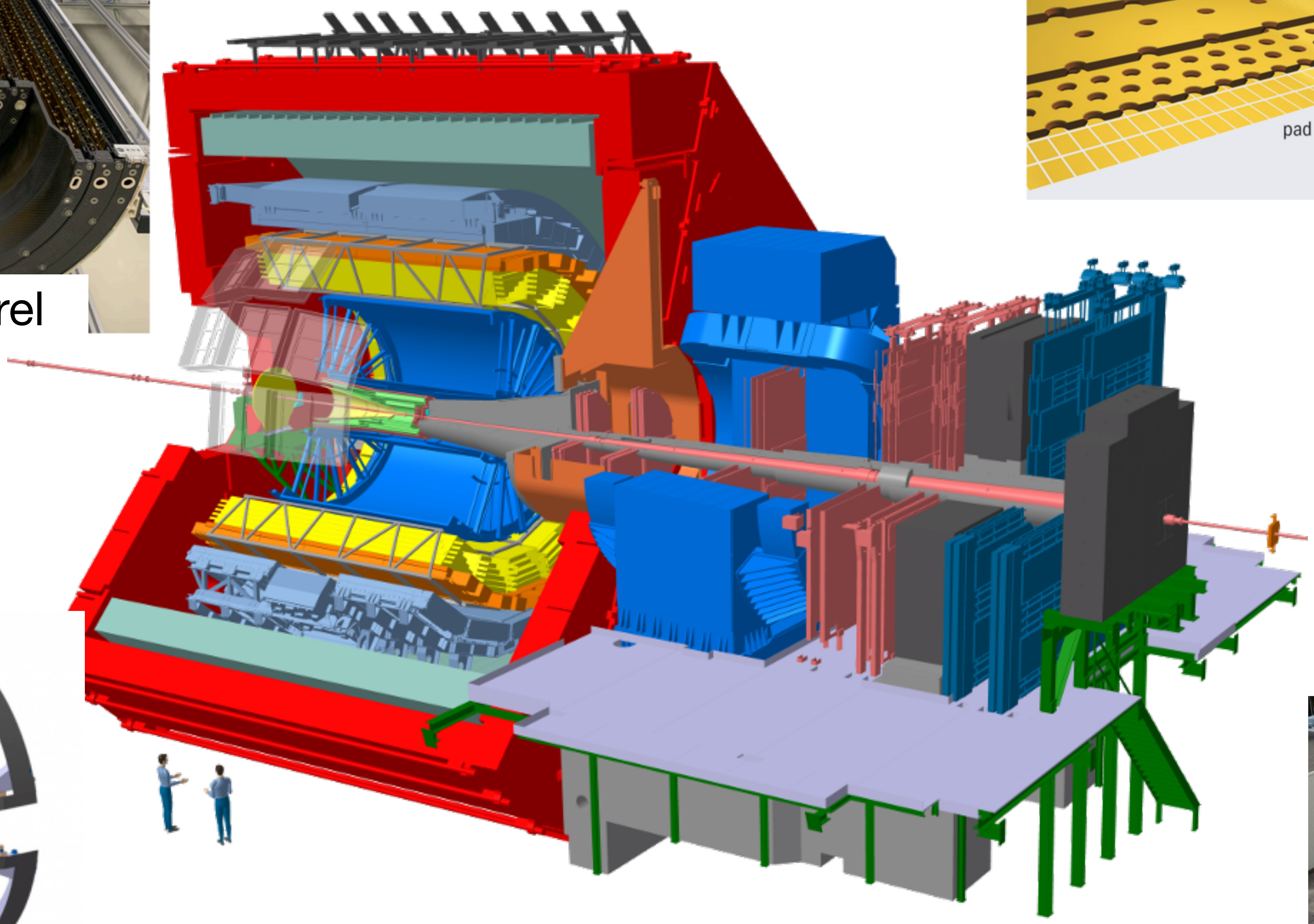
ALICE upgrades in LS2

New ITS

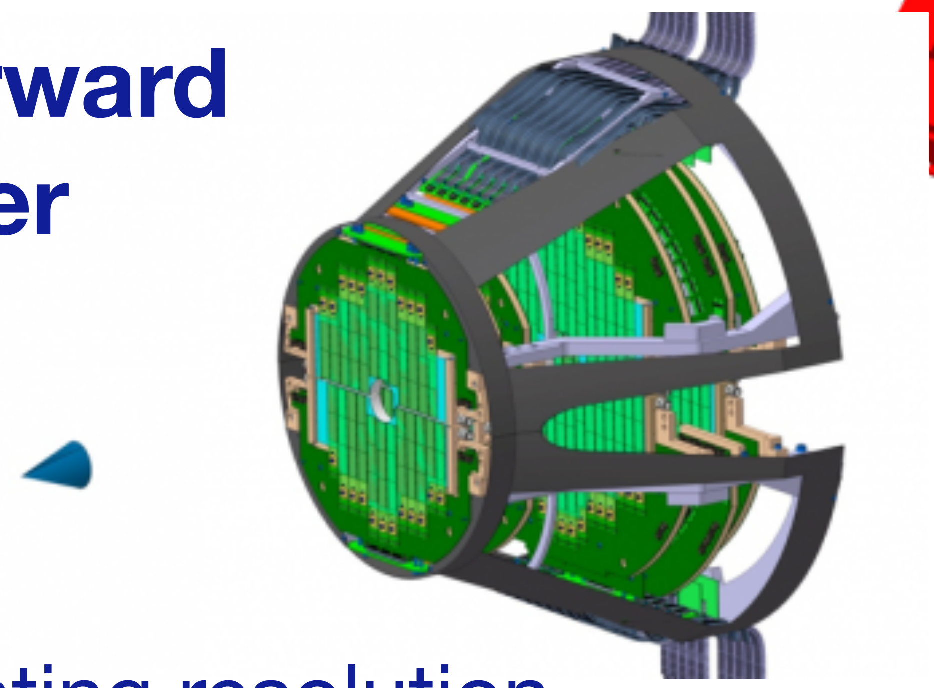

Inner barrel


Outer barrel

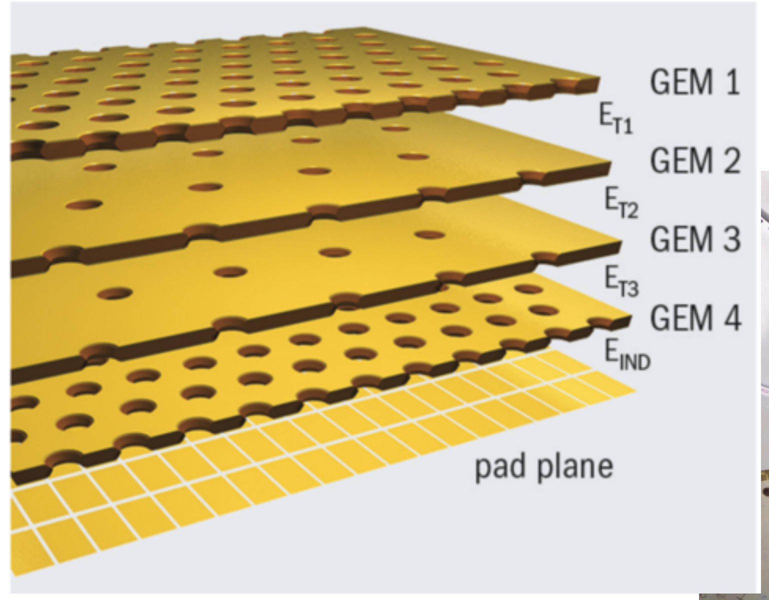
Full pixel detector
Improved read-out rate,
spatial resolution



Muon Forward Tracker



Improved pointing resolution
for muons



TPC: GEM readout

Continuous readout
Higher rates

Upgraded readout and online processing

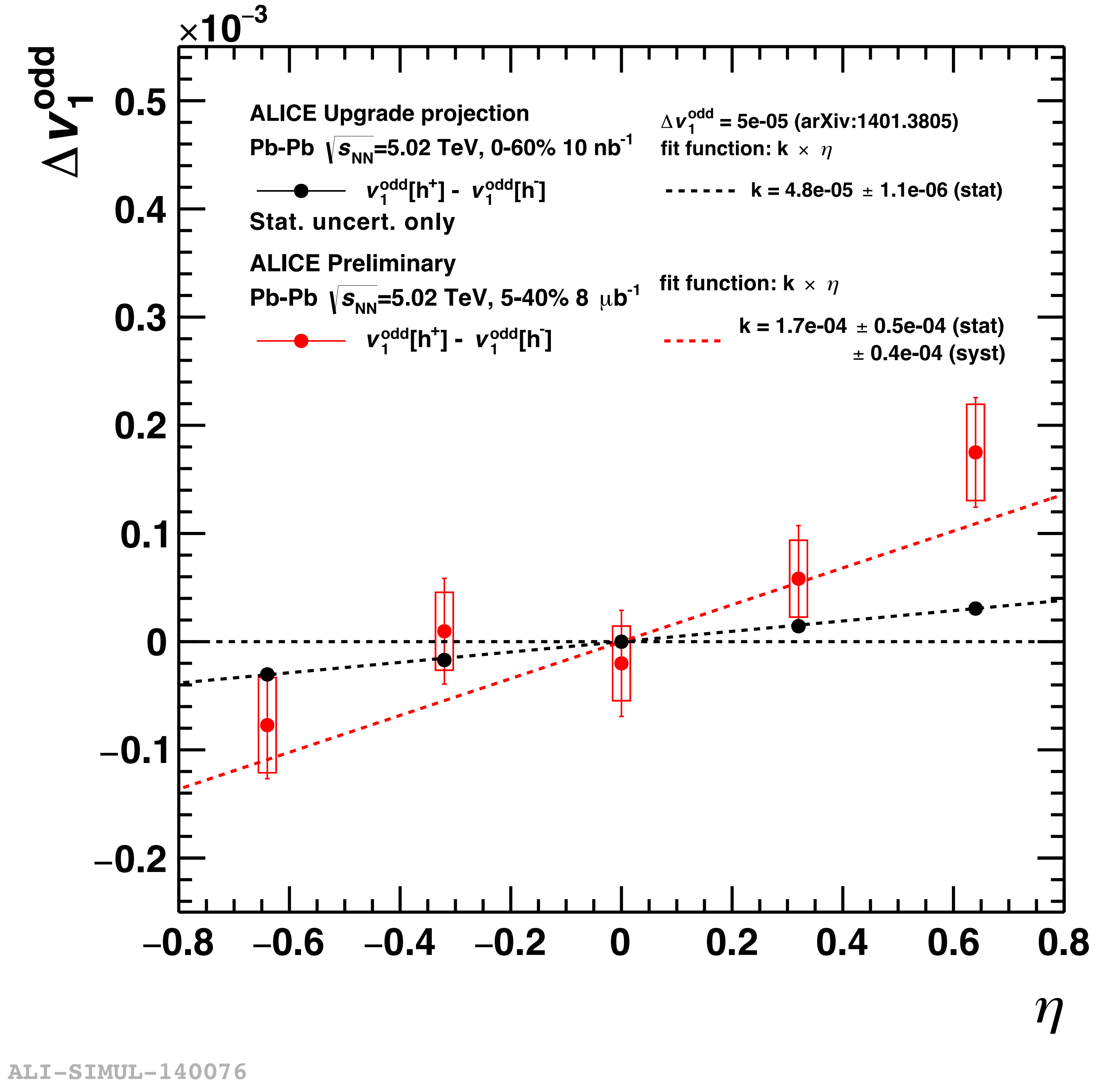
Run 3 and 4: collect 13 nb^{-1} Pb—Pb: 50-100x more minimum bias data; 10x more triggered data

ALICE upgrade goals and performance

ALICE-PUBLIC-2019-001

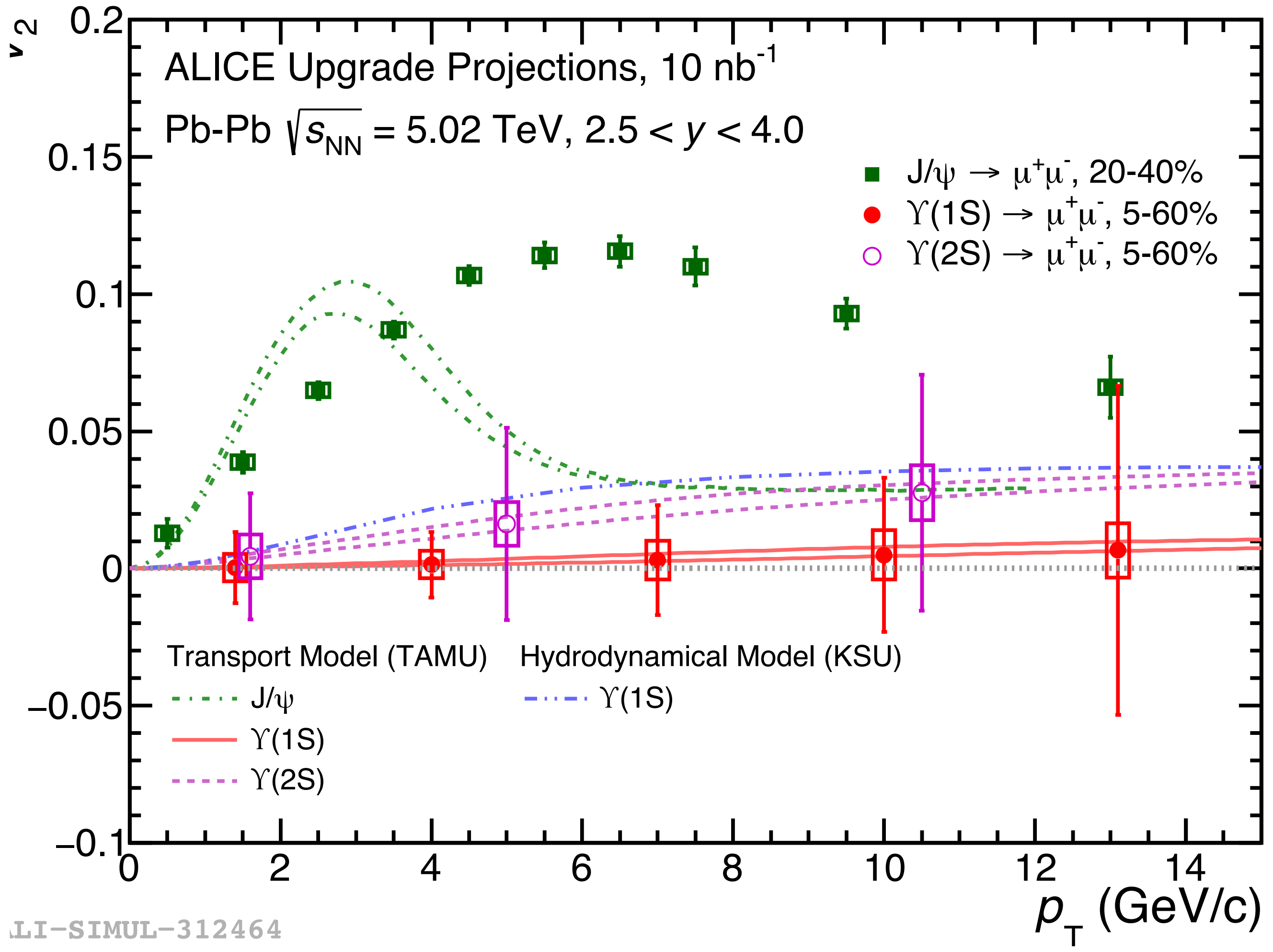
HL-LHC WG5 report

Charge dependent v_1

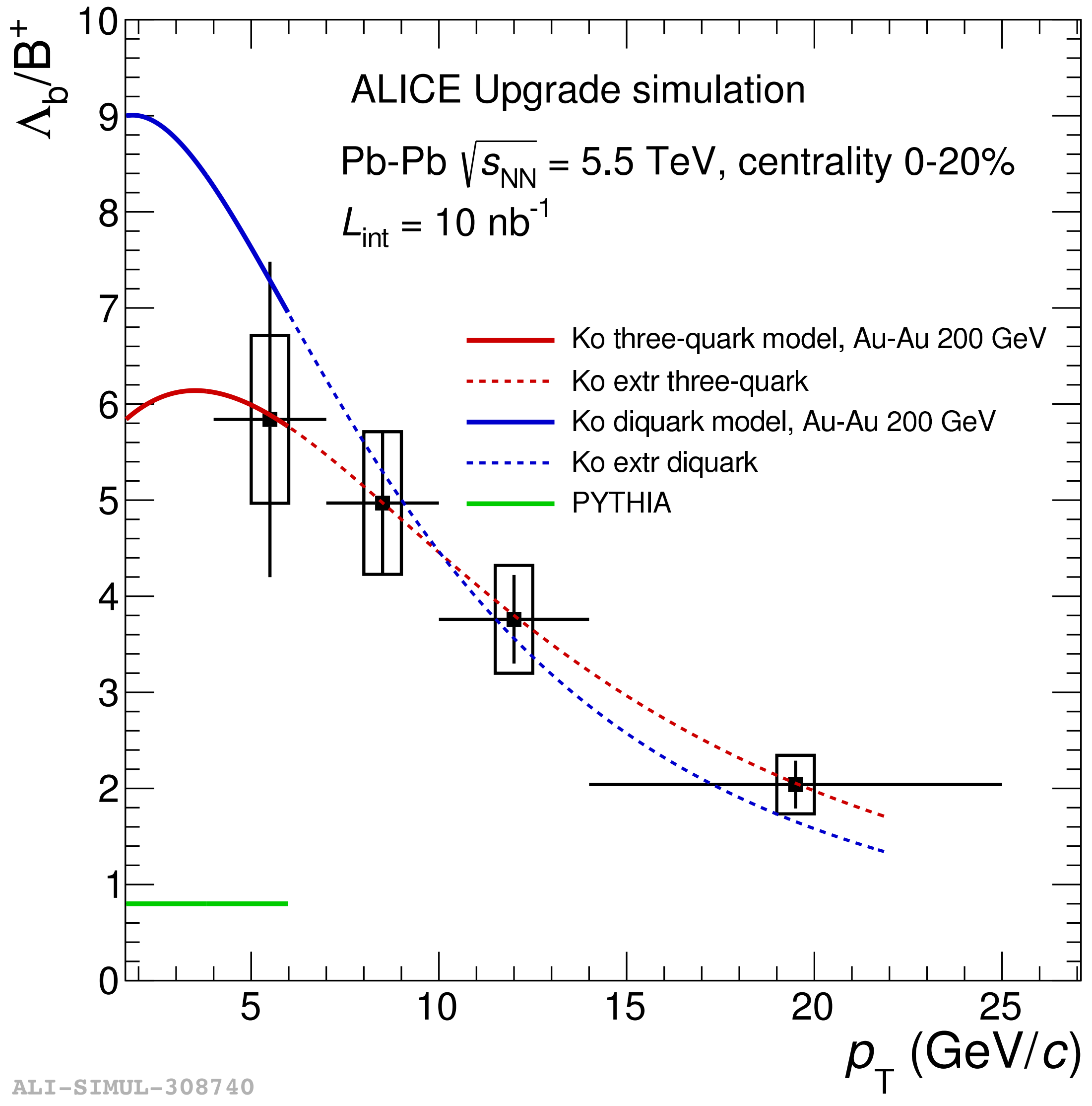


Initial state magnetic fields

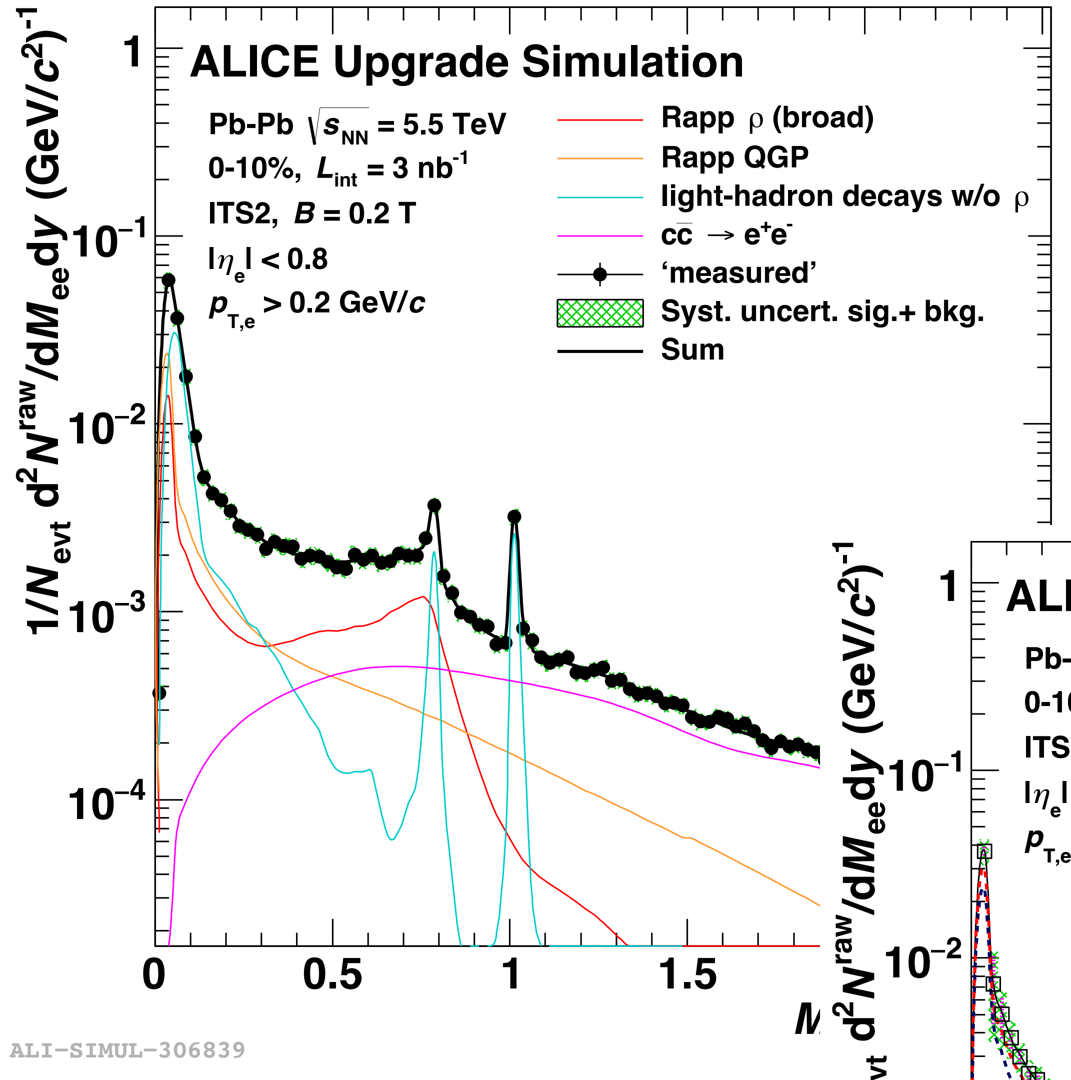
J/ψ and ϒ v_2

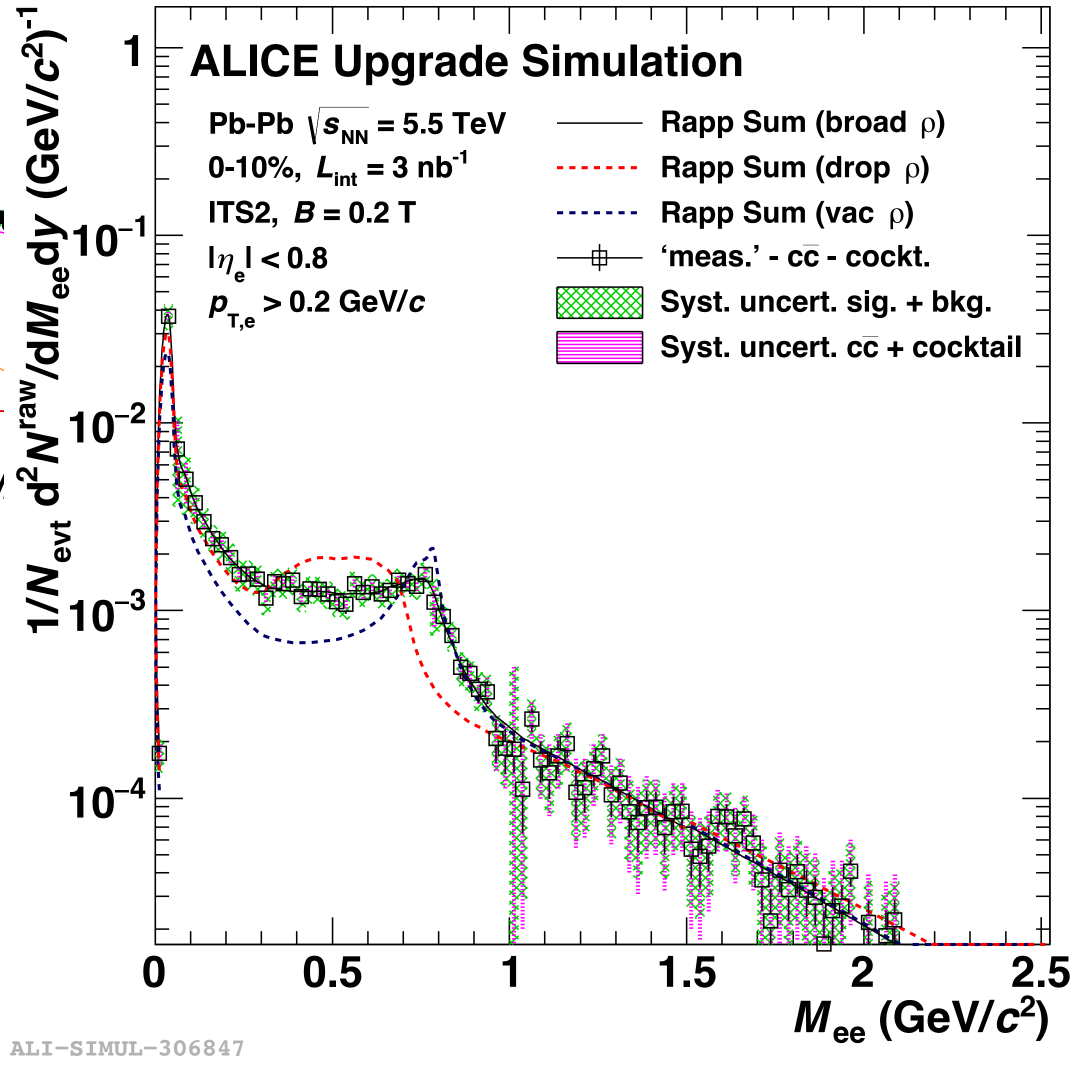


Λ_b and B mesons



Dileptons



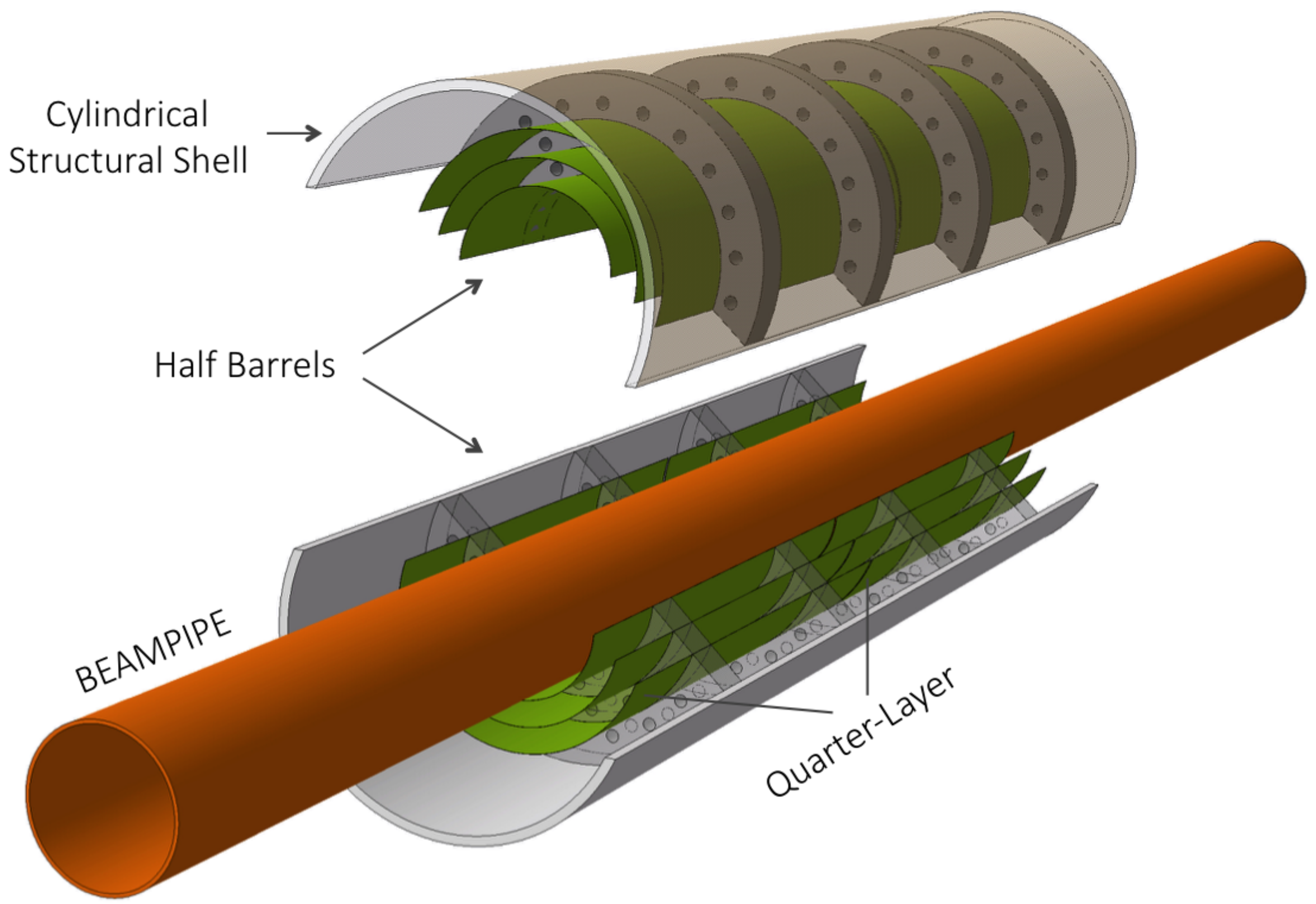


Thermal radiation

…and much more…

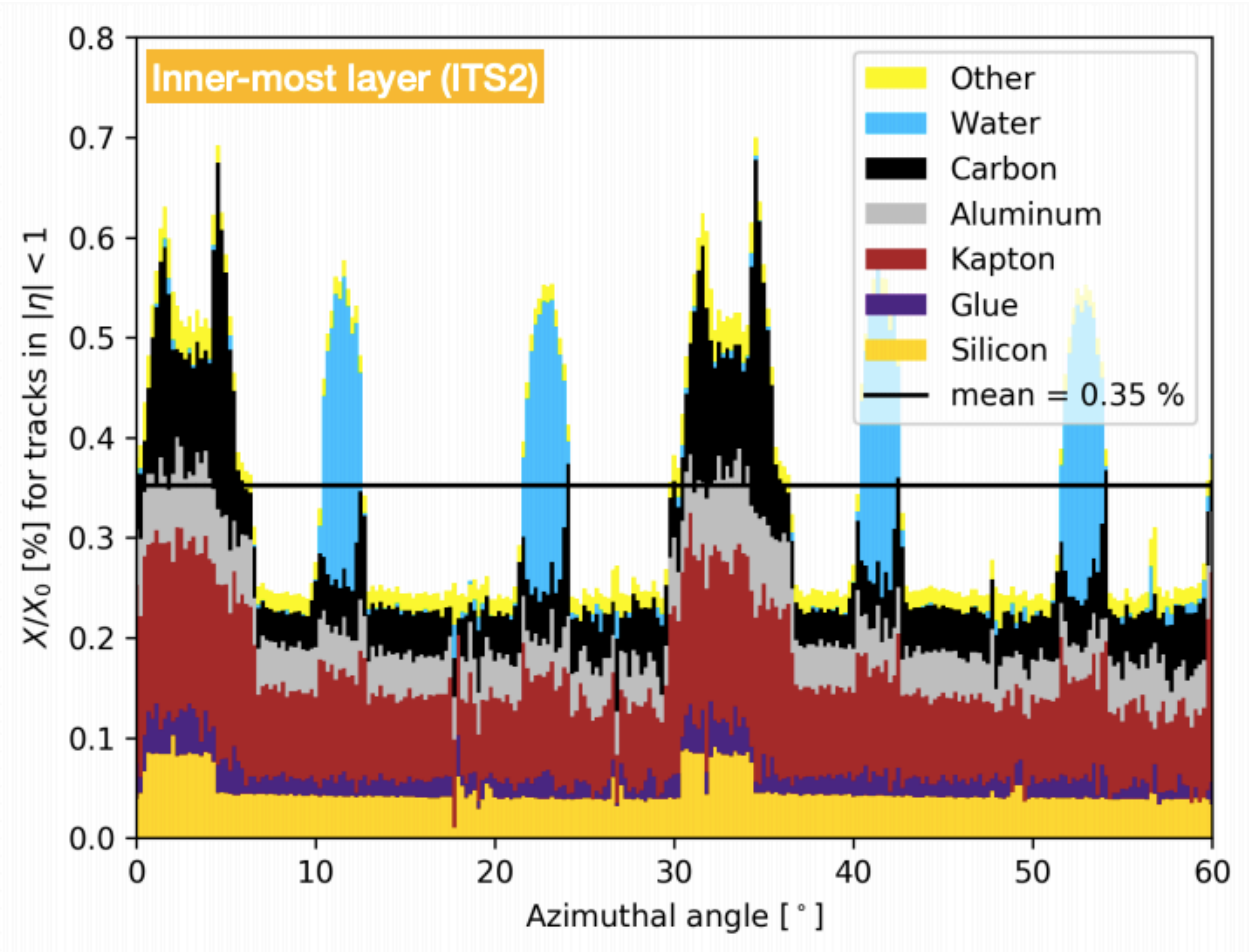
ITS3 upgrade: ultra-low material tracking

LoI: LHCC-2019-018



- Low power < 20 mW/cm²
  - Allows air cooling
  - Minimize power distribution infrastructure
- Thinned Si: bendable
- Large area, wafer-scale, sensors (stitching)
  - Use shape for rigidity —> light support (C foam)

Material budget ITS2



Si (50 µm) is only ~15% of the total material

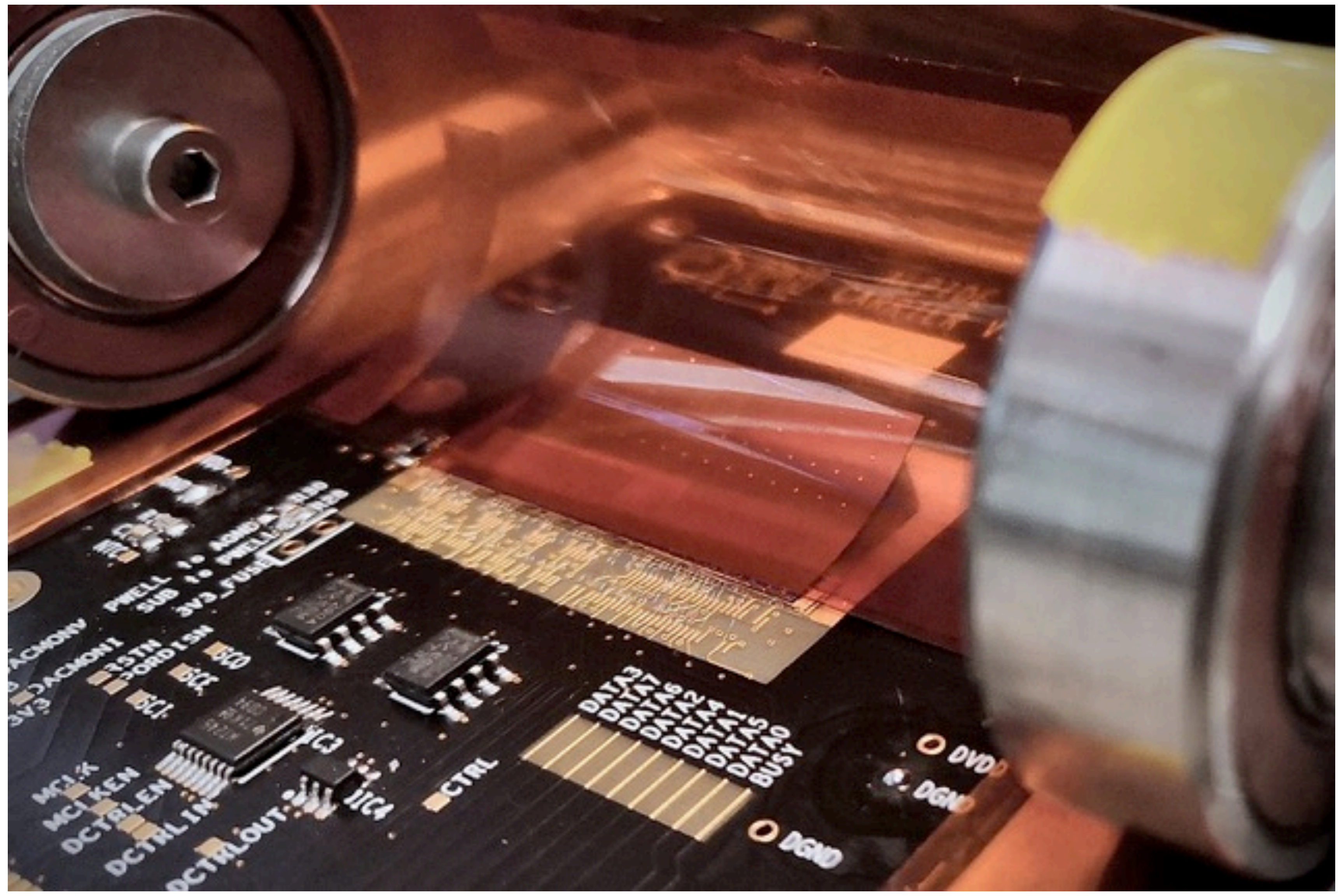
< 0.05% X_0 per layer

Goal: 20-40 µm

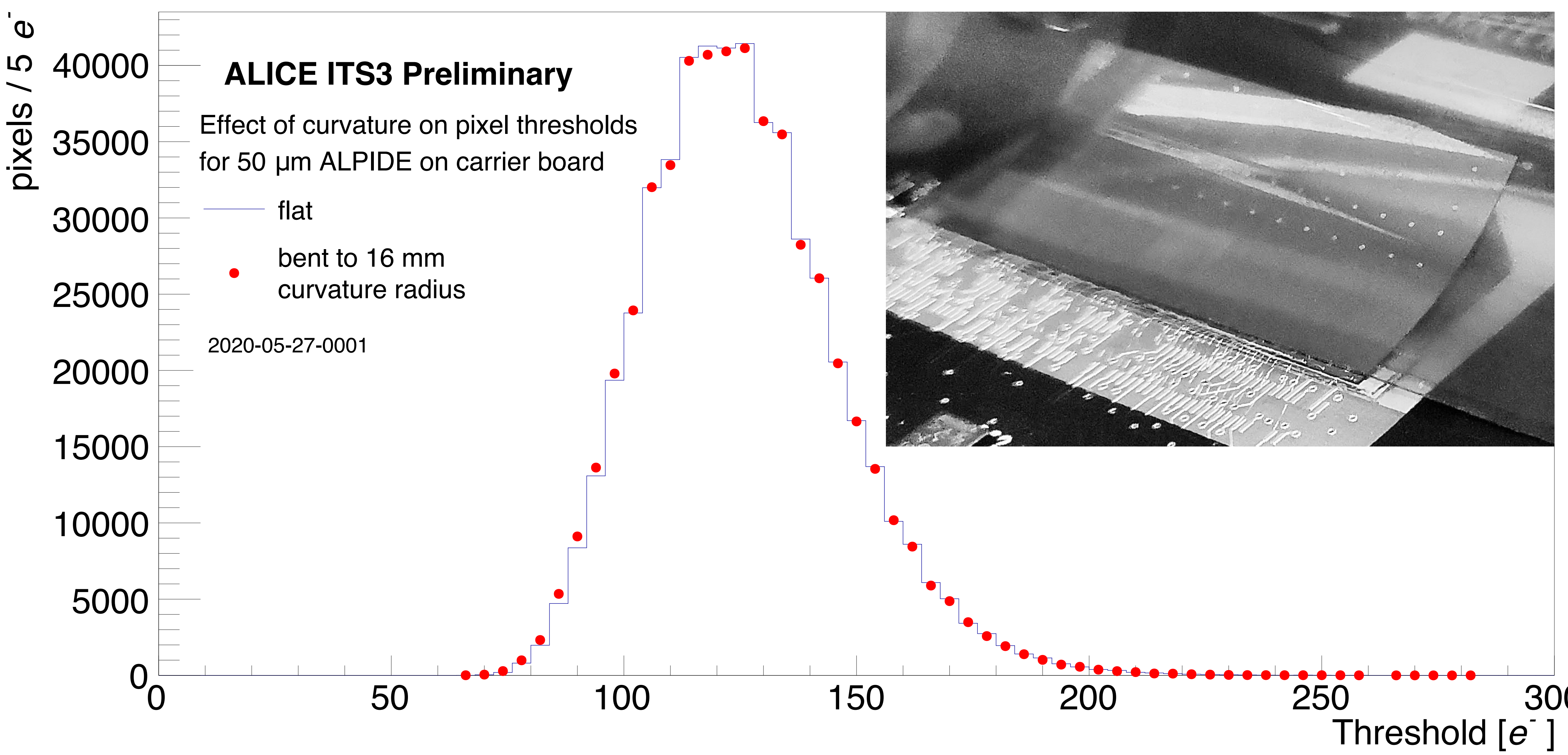
R&D ongoing; installation in LS3 (2025/2026)

R&D results: curved senors

Bending setup



Thresholds before/after

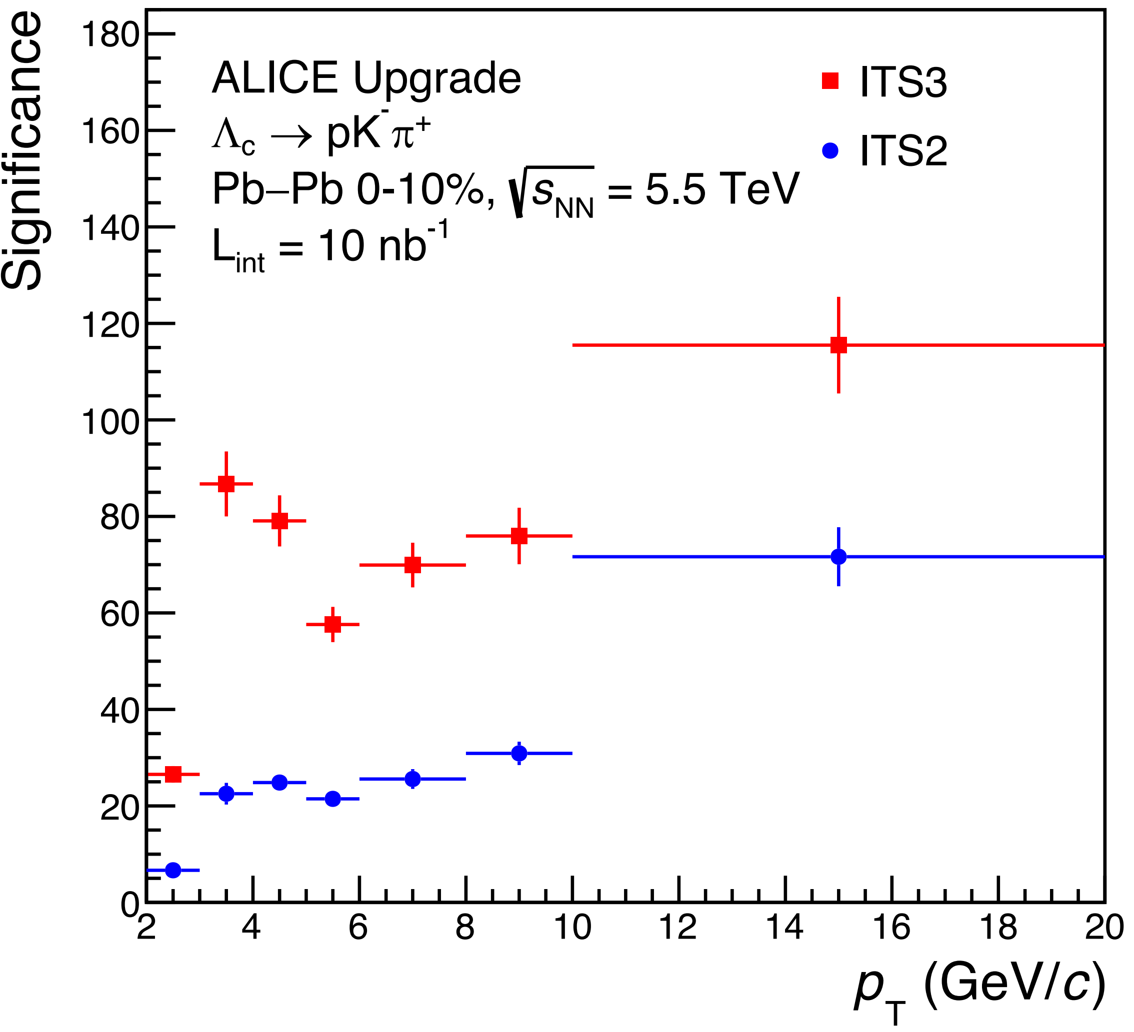


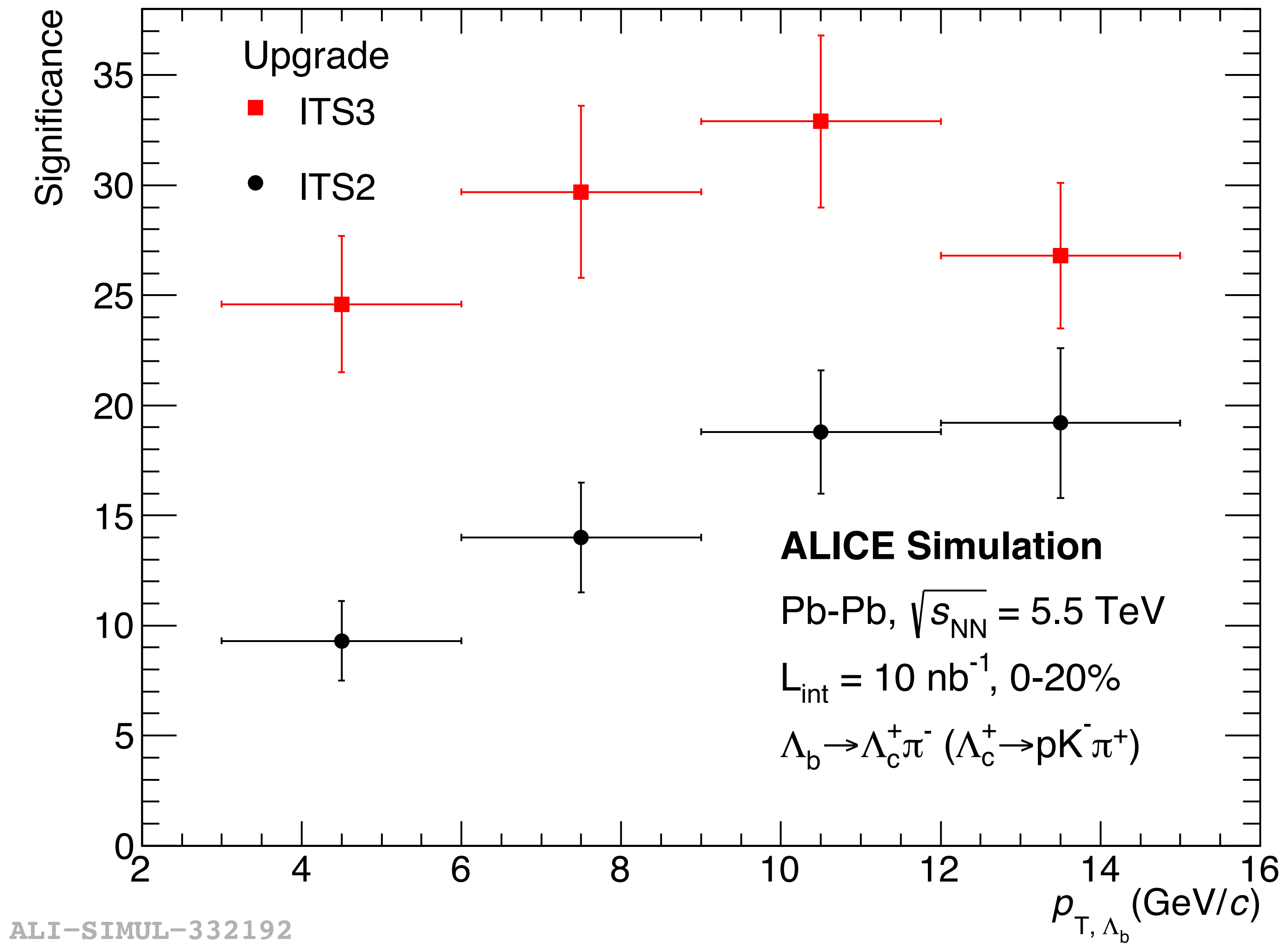
First test results with bent 50 µm sensor

Sensor works well; no change of thresholds/gains

ITS3 physics goals: heavy flavour

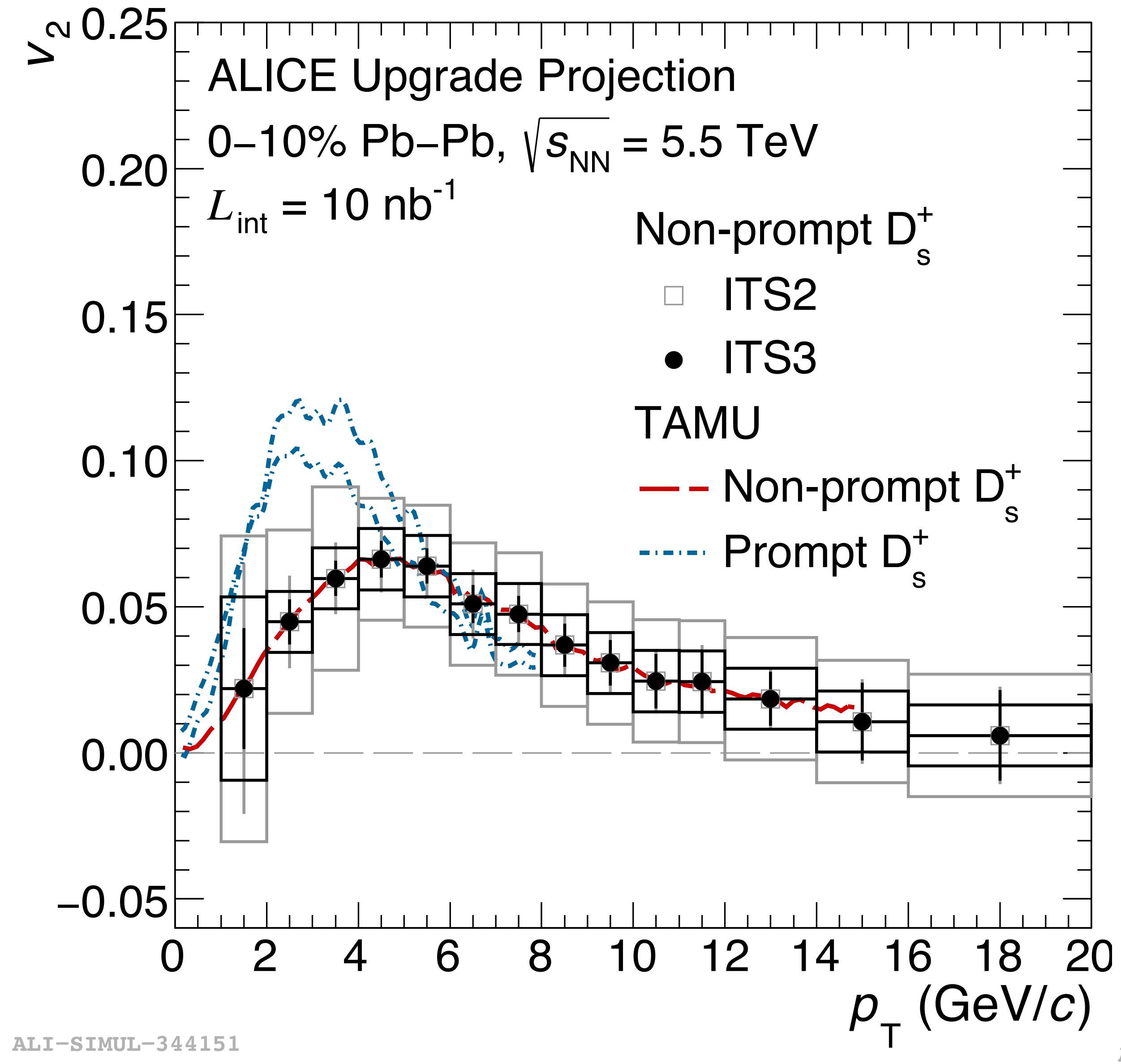
Charm and beauty baryons

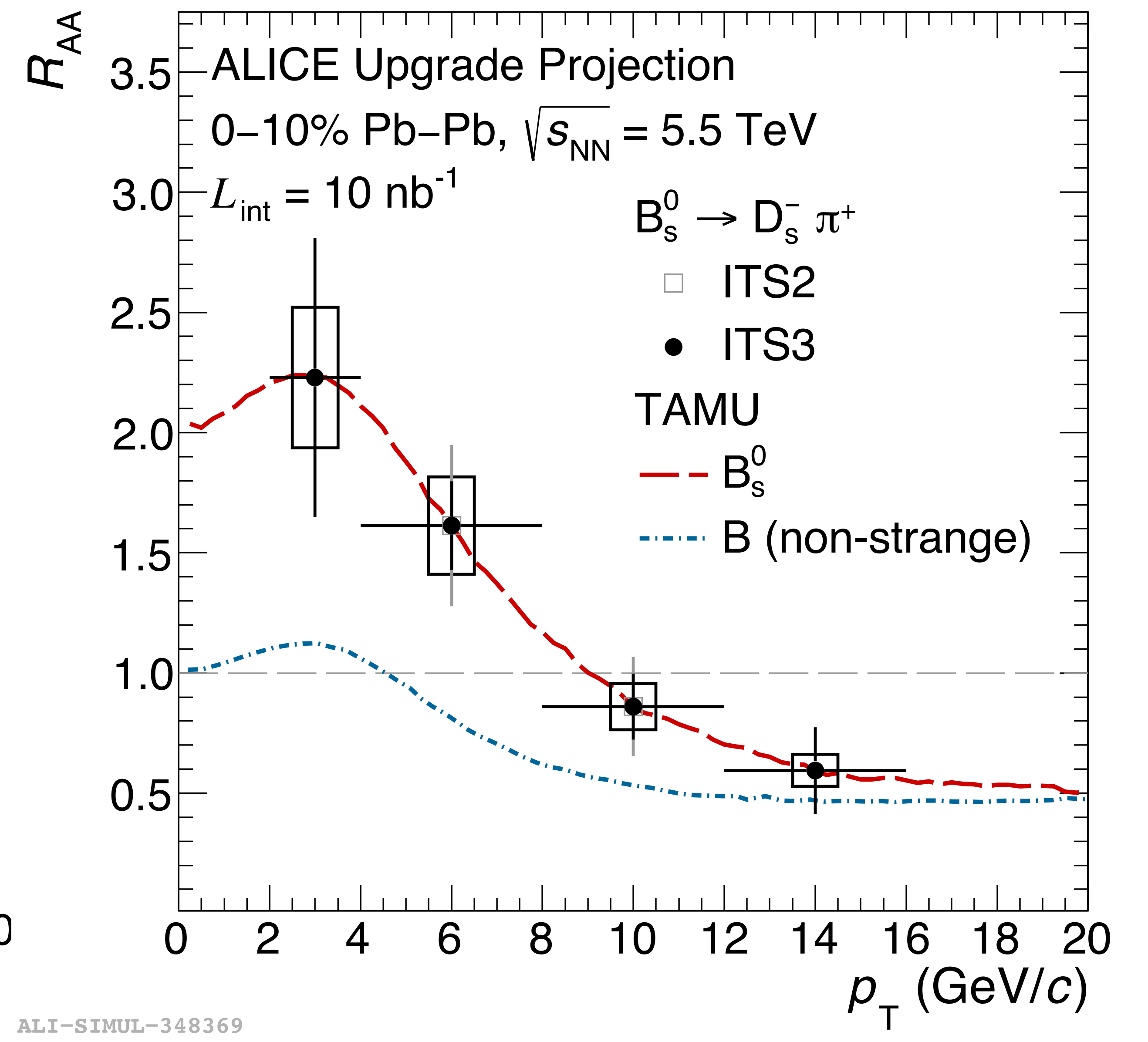




Physics of baryon formation, baryon enhancement

D_s/B_s production and flow





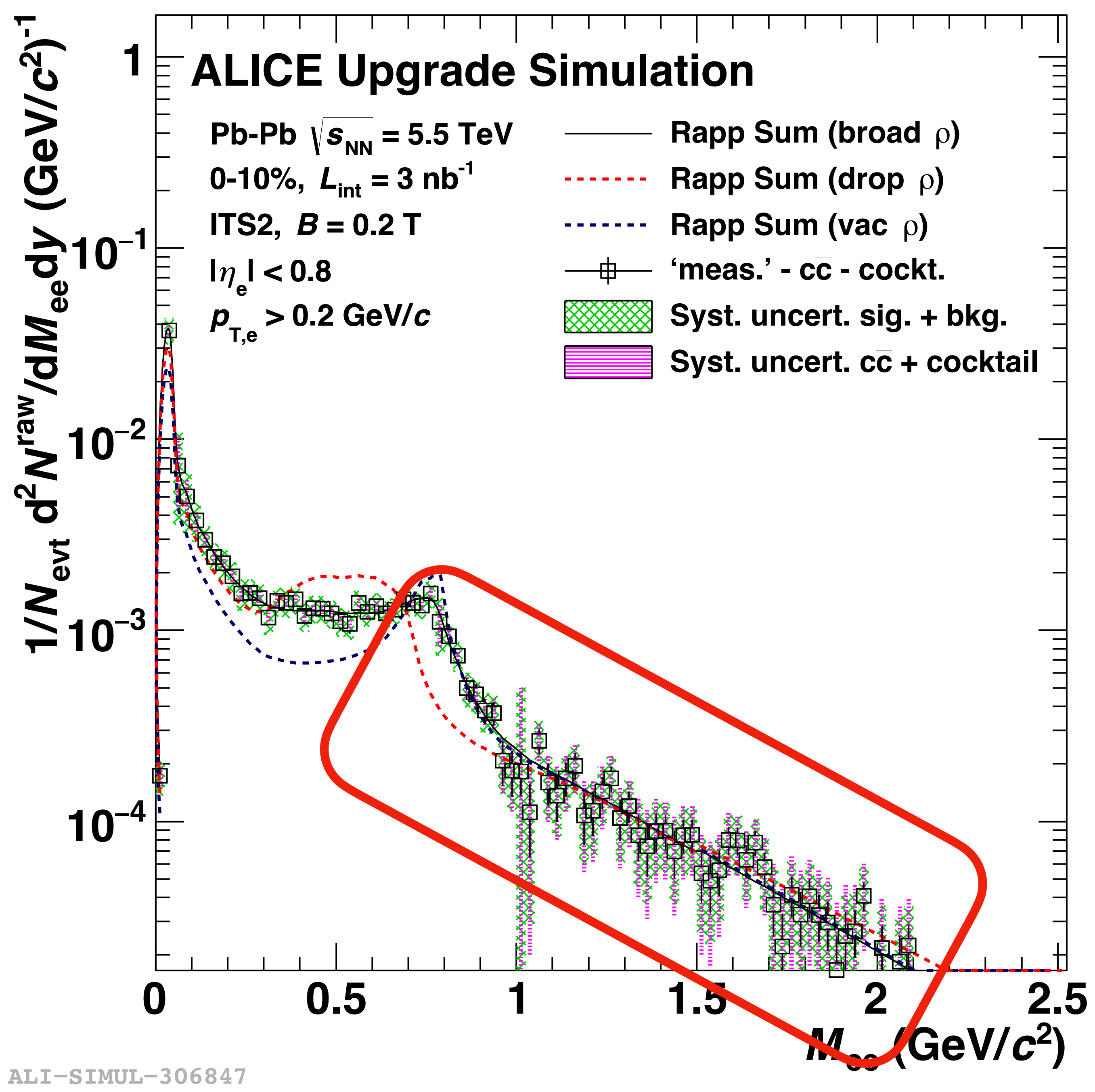
Strangeness enhancement and coalescence

Thinner/lighter structure, closer to IP: improve significance by factor 3-5
Enables more differential measurements, e.g. flow

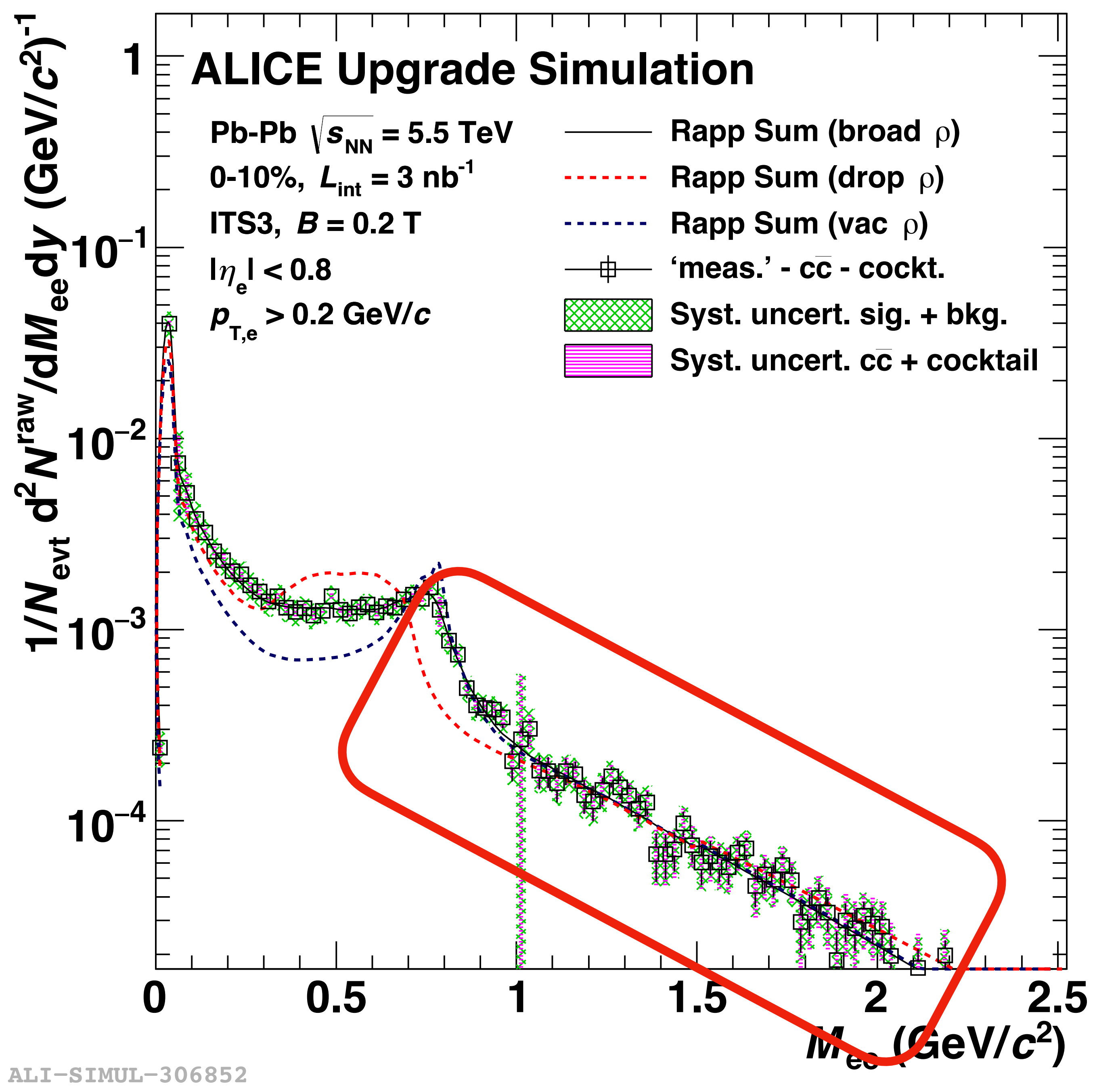
ITS3 physics: dileptons

Di-electron spectra

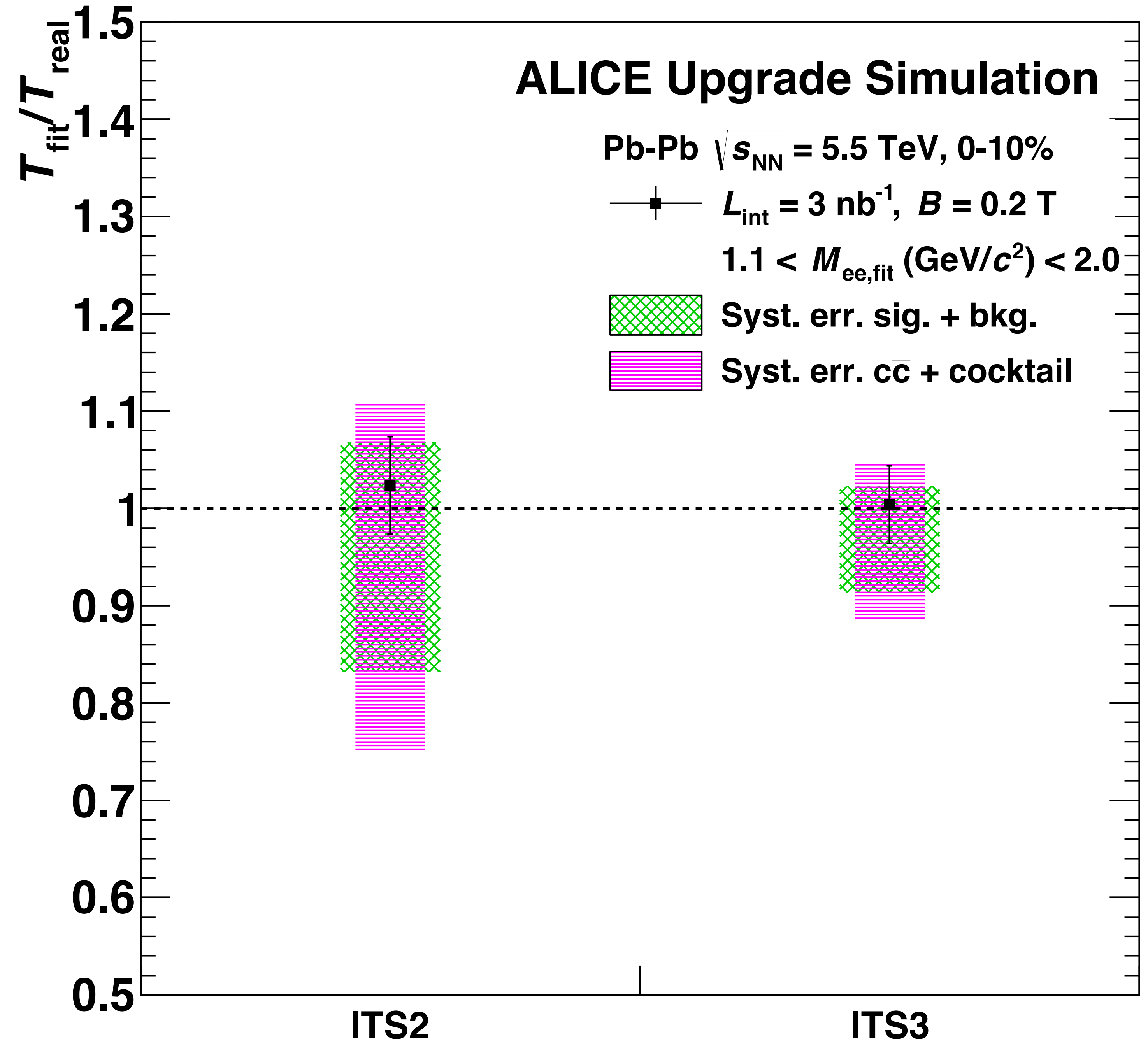
Upgraded ITS



ITS3



Dilepton temperature fit



- less material: fewer photon conversions
- better pointing resolution: charm rejection
- better tracking at low p_T: conversion rejection

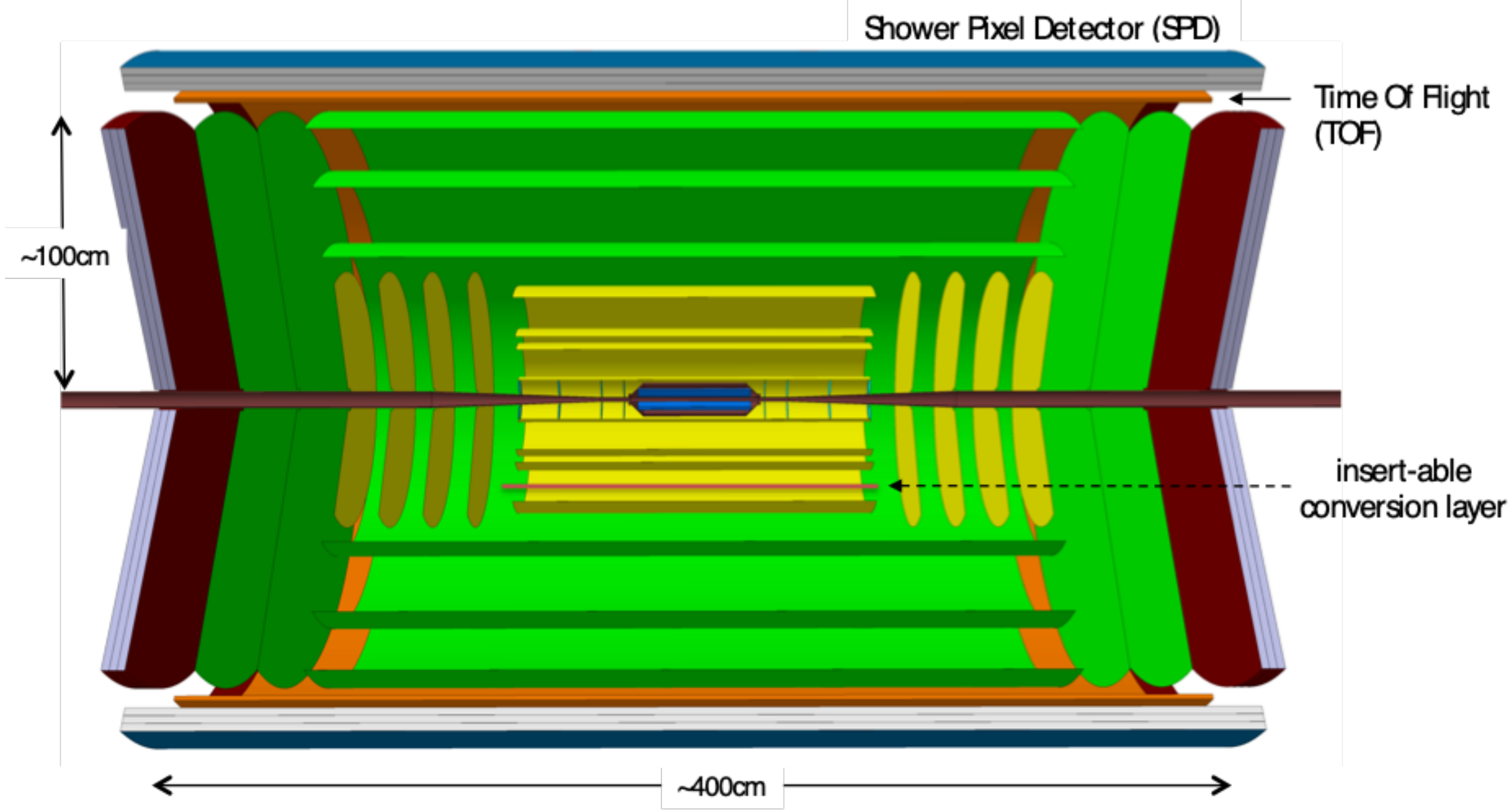
ITS3 improves systematic uncertainty on *T* by a factor 2

A next-generation heavy-ion experiment

A completely new detector at point 2: low-material, high-rate, all-Si

Could be installed in LS4 (2031)

High-resolution tracking à la ITS3
Extremely good pointing resolution
10 layers for tracking
Forward coverage up to $\eta \approx 4$



Time-of-flight layer(s) for
particle identification:
electrons, hadrons

Shower Pixel Detector:
electron ID at higher momentum

Additional capabilities for photons
via conversions

European Particle Physics Strategy Process input: arXiv:1902.01211

High rate: light ions at LHC

HL-LHC WG5 report arXiv 1812.06772

Luminosity limited by losses due to bound-free pair production
Lighter nuclei improve rate

moderately optimistic

	$^{16}O^{8+}$	$^{40}Ar^{18+}$	$^{40}Ca^{20+}$	$^{78}Kr^{36+}$	$^{129}Xe^{54+}$	$^{208}Pb^{82+}$
γ	3760.	3390.	3760.	3470.	3150.	2960.
$\sqrt{s_{NN}}$/TeV	7.	6.3	7.	6.46	5.86	5.52
σ_{had}/b	1.41	2.6	2.6	4.06	5.67	7.8
$\langle L_{AA} \rangle$ cm^{-2}s^{-1}	8.99×10^{30}	8.34×10^{29}	6.17×10^{29}	9.46×10^{28}	2.23×10^{28}	3.8×10^{27}
$\langle L_{NN} \rangle$ cm^{-2}s^{-1}	2.3×10^{33}	1.33×10^{33}	9.87×10^{32}	5.76×10^{32}	3.71×10^{32}	1.64×10^{32}
$\int_{month} L_{AA}$ dt/nb^{-1}	1.17×10^4	1080.	799.	123.	28.9	4.92
$\int_{month} L_{NN}$ dt/pb^{-1}	2980.	1730.	1280.	746.	481.	213.
R_{had}/kHz	2.07×10^4	3340.	2440.	653.	270.	106.
μ	1.64	0.266	0.194	0.0518	0.0215	0.00842

optimistic

	$^{16}O^{8+}$	$^{40}Ar^{18+}$	$^{40}Ca^{20+}$	$^{78}Kr^{36+}$	$^{129}Xe^{54+}$	$^{208}Pb^{82+}$
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σ_{had}/b	1.41	2.6	2.6	4.06	5.67	7.8
$\langle L_{AA} \rangle$ cm^{-2}s^{-1}	4.54×10^{31}	2.45×10^{30}	1.69×10^{30}	1.68×10^{29}	2.95×10^{28}	3.8×10^{27}
$\langle L_{NN} \rangle$ cm^{-2}s^{-1}	1.16×10^{34}	3.93×10^{33}	2.71×10^{33}	1.02×10^{33}	4.91×10^{32}	1.64×10^{32}
$\int_{month} L_{AA}$ dt/nb^{-1}	5.89×10^4	3180.	2190.	218.	38.2	4.92
$\int_{month} L_{NN}$ dt/pb^{-1}	1.51×10^4	5090.	3510.	1330.	636.	213.
R_{had}/kHz	1.33×10^5	1.12×10^4	7540.	1260.	378.	106.
μ	10.6	0.893	0.598	0.1	0.03	0.00842

Ar-Ar: 3-10 MHz interaction rate

Kr-Kr: 0.6-1.3 MHz interaction rate

Reach fb^{-1} of *NN*-equiv luminosity per month

Strength of QGP effects →

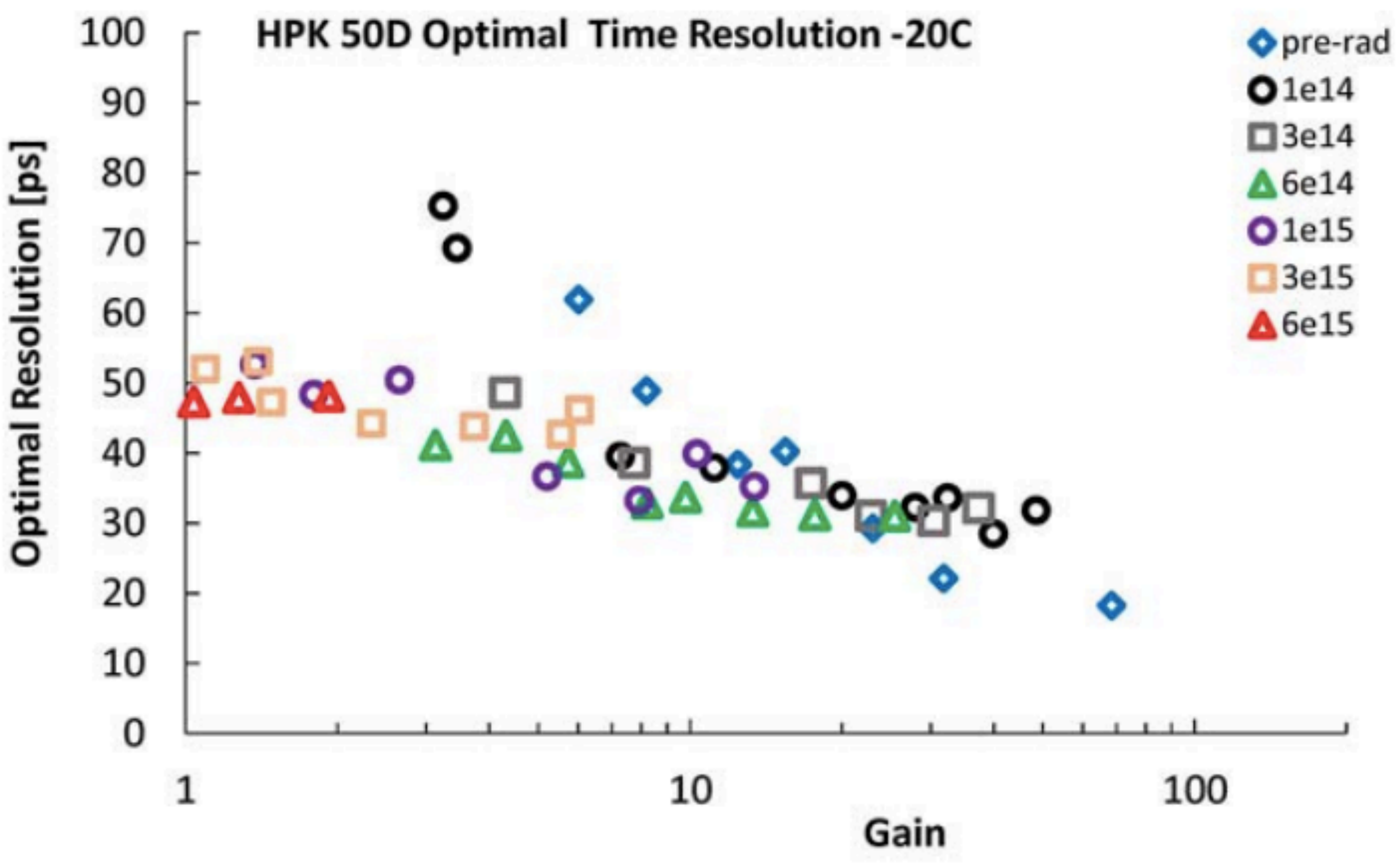
← luminosity

Trade-off: higher signal (probe) rates
vs reduced impact of QGP-effects

Particle identification with Silicon timing technologies

- Low-Gain Avalanche Photo Diodes (LGAD)
  - HEP-specific (ATLAS/CMS phase 2)
  - 20-30 ps time resolution
  - Rad hard to 10^{14} 1 MeV n_{eq} cm^{-2}
  - Concept demonstrated; scaling up to full size
- Single-Photon Avalanche Diodes (SPAD)
  - Commercial process, applications (LIDAR)
  - High sensitivity - high noise: reduce gain?
  - Fill factor limited at present
- Monolithic active pixels
  - Concept: extend MAPS technology with timing
  - Optimise sensor cell geometry/properties for timing
  - No gain/modest gain

LGAD time resolution



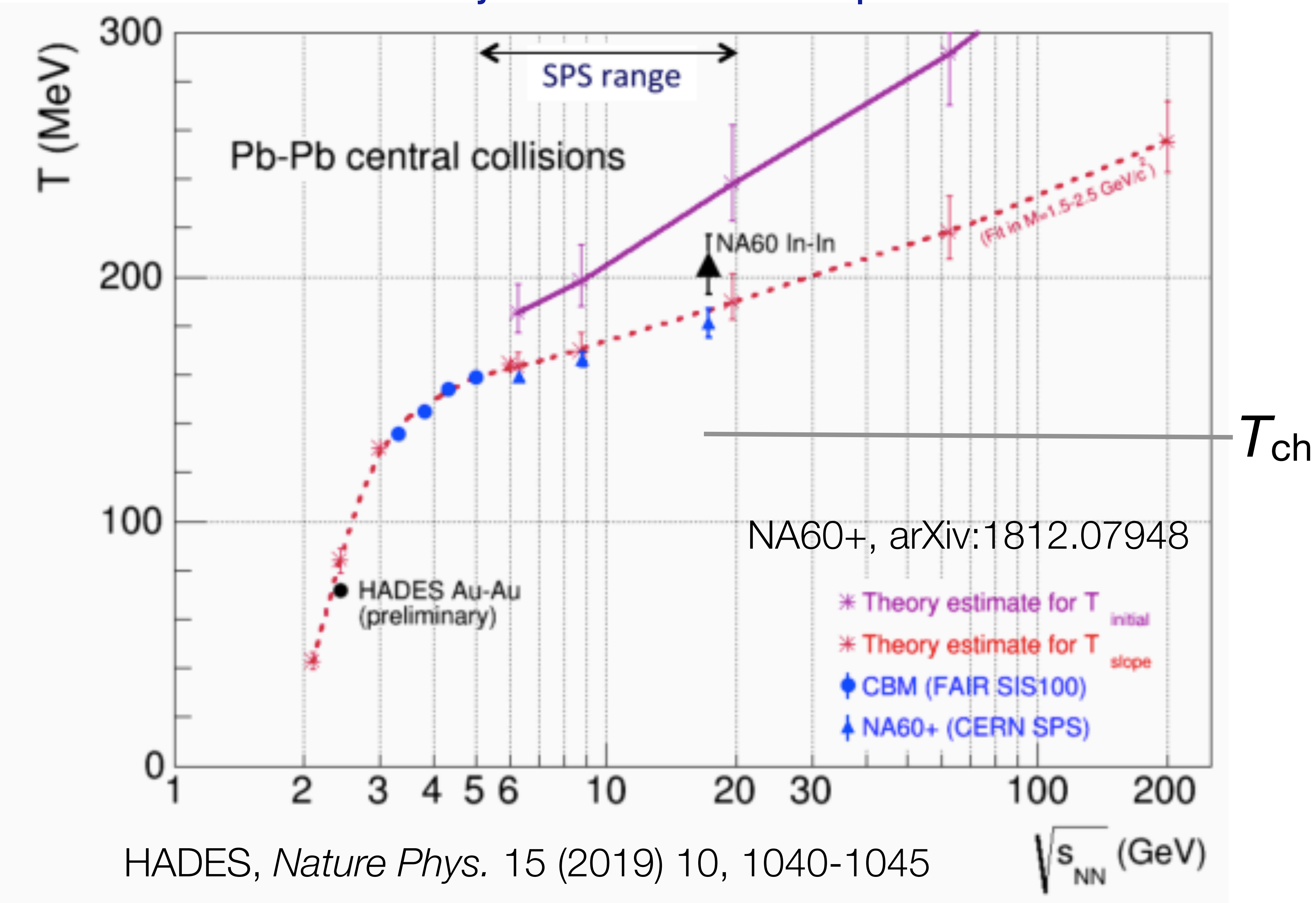
Galloway et al, NIM A 940, 19

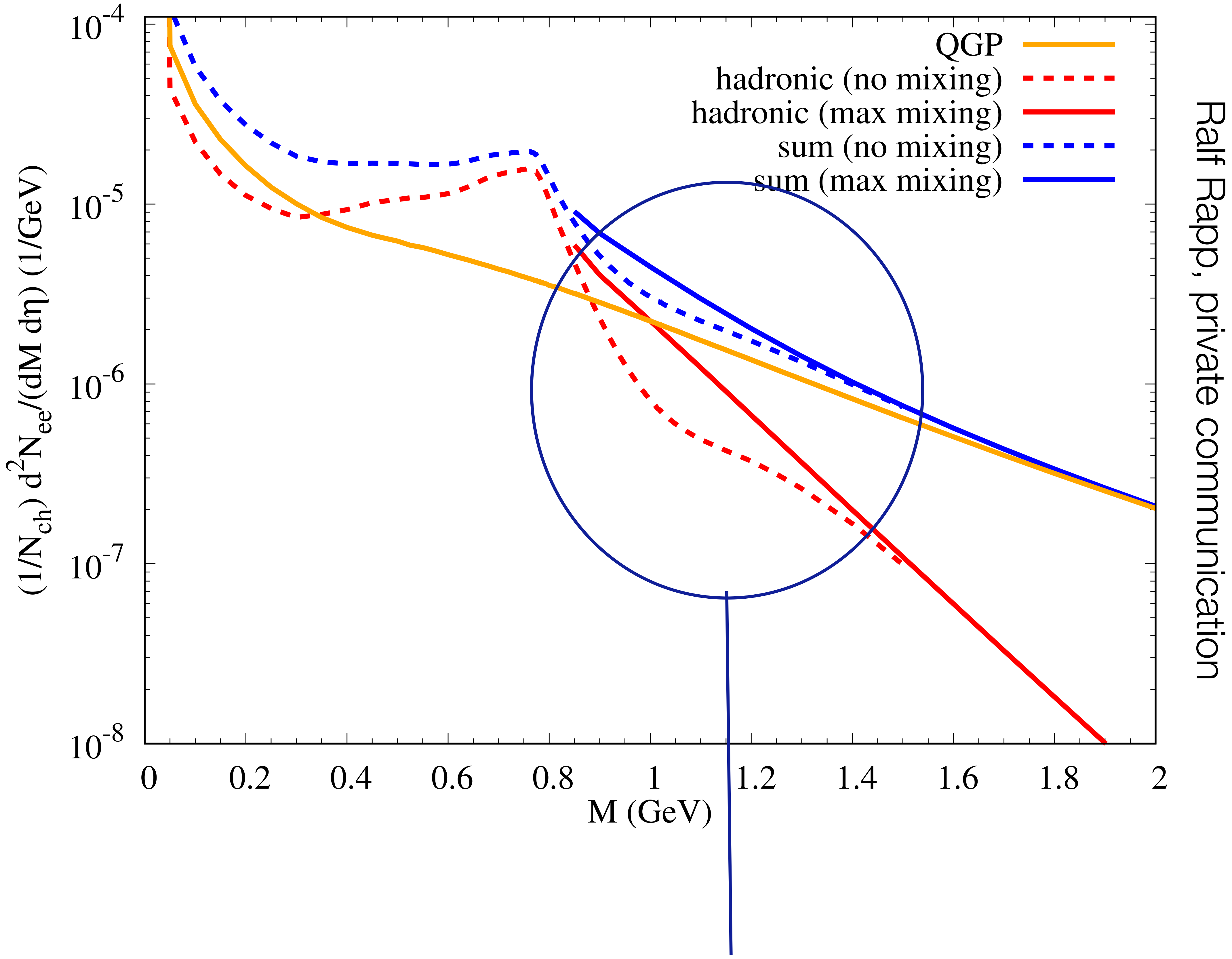
Main physics goals:
- Identification electrons for dilepton measurements
- Identification of heavy flavor decay products

Need ≲ 20 ps resolution for PID

Dileptons: early stage temperature - ρ-a_1 modification

Projected T from dileptons





Dileptons sensitive to early stage temperature

$T_{slope} \approx 300$ MeV expected at LHC

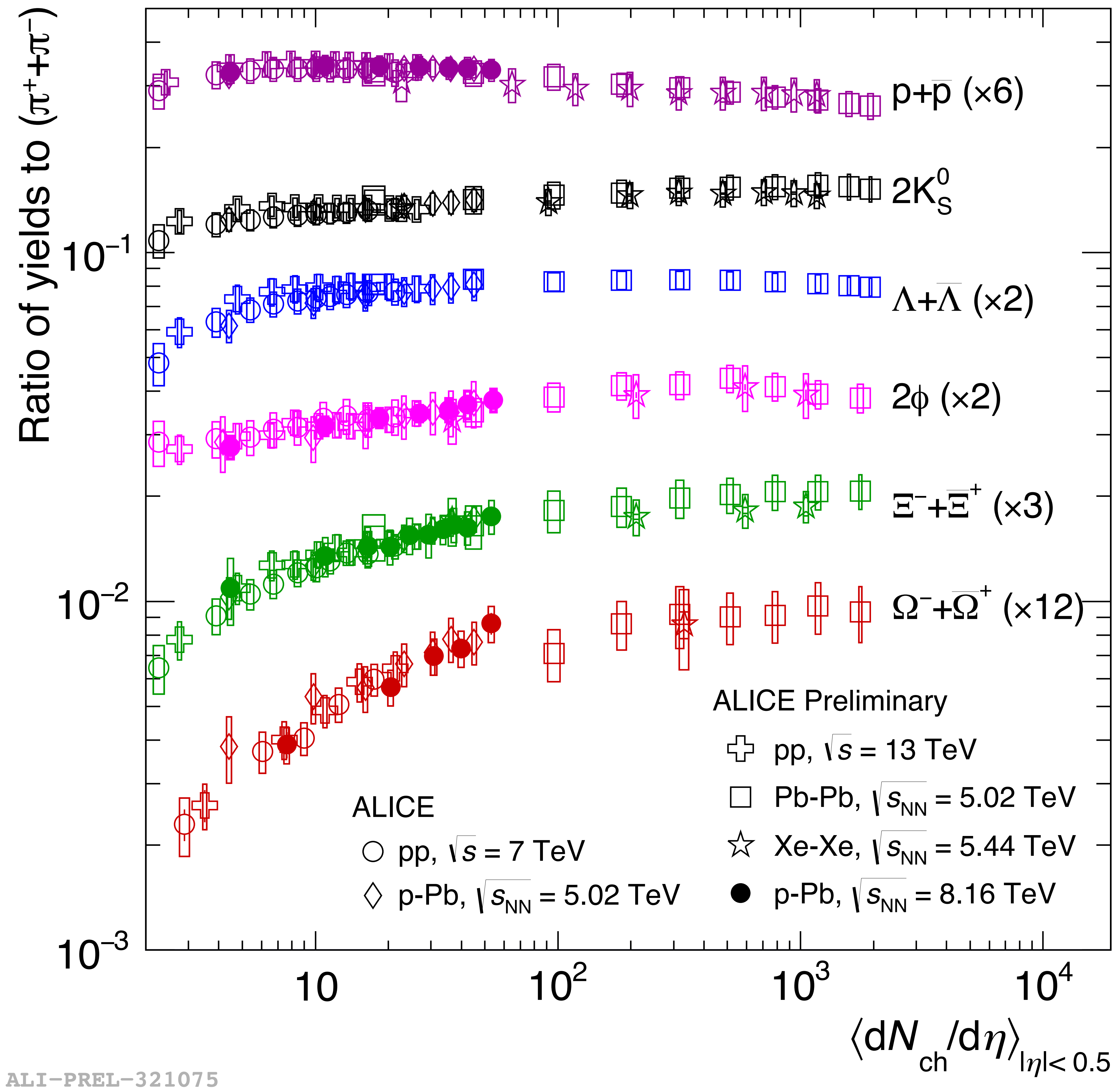
$T_{initial} \approx 600$ MeV expected at LHC

Will measure this in run 3 and 4

Next steps: v_2, momentum/time dependence

Access this region with precision

From strange to charmed baryons



Strangeness enhancement at LHC

- Effect largest for Ξ, Ω
- Small effect for Λ, K

Large enhancements expected for multi-charm baryons formed by coalescence in Pb-Pb

Beccattini, PRL 95 022301 (2005)

hadron	**per-event yield** central Pb-Pb full phase space	**enhancement w.r.t. pp**
Ξ_{cc}, Ω_{cc}	0.02 - 0.38	1-10
Ξ_{bc}, Ω_{bc}, B_c	$3{\cdot}10^{-4}$ - $2{\cdot}10^{-2}$	> 10 for Ξ_{bc}
Ξ_{bb}, Ω_{bb}	$2.6{\cdot}10^{-6}$ - $7{\cdot}10^{-5}$	-
Ω_{ccc}	10^{-3} - $3{\cdot}10^{-2}$	100 - 1000

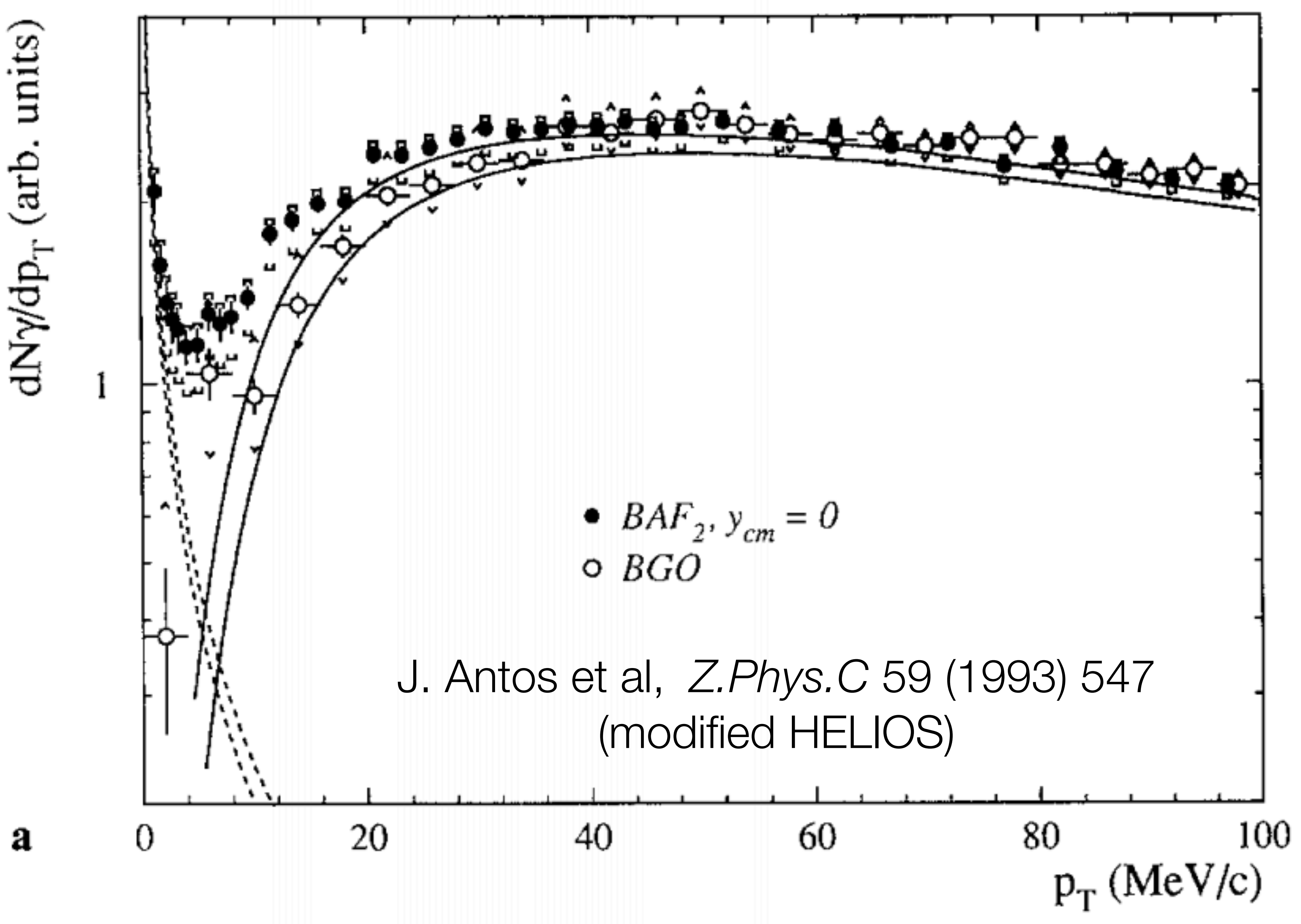
Multi-charmed baryons:
clean probe of baryon formation and coalescence

Ultra-soft physics

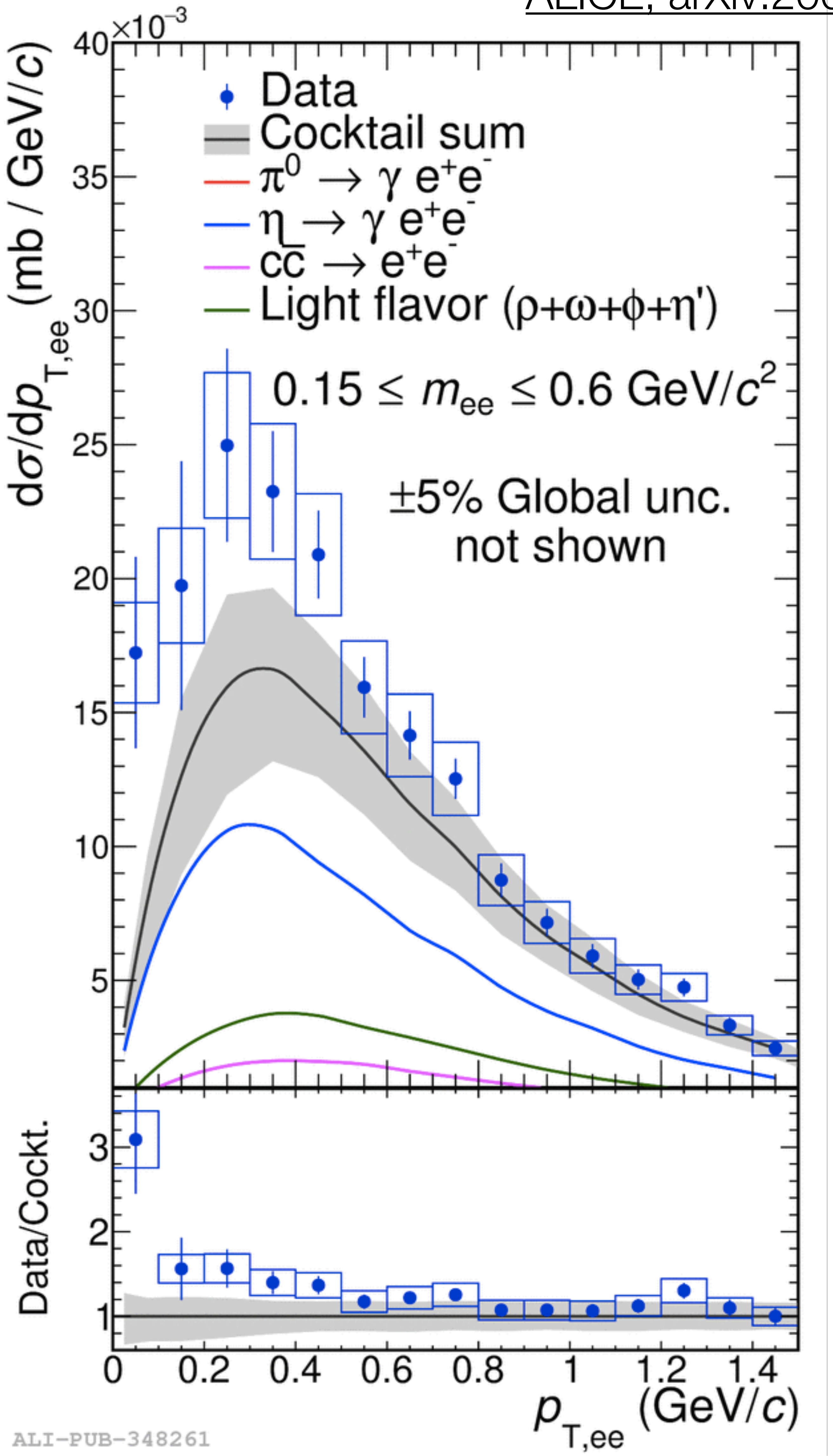
Low material budget: access to lowest p_T, potential for fundamental studies

ALICE, arXiv:2005.14522

Low-momentum photon spectrum



J. Antos et al, *Z.Phys.C* 59 (1993) 547
(modified HELIOS)



Low momentum enhancement of photons seen in several experiments

Possible links to fundamental field theory

'Low's theorem'

Francis E. Low, Phys.Rev.Lett. 110 (1958) 468

Lepton/photon structure of the proton

L Buonocore et al, arXiv:2005.06477

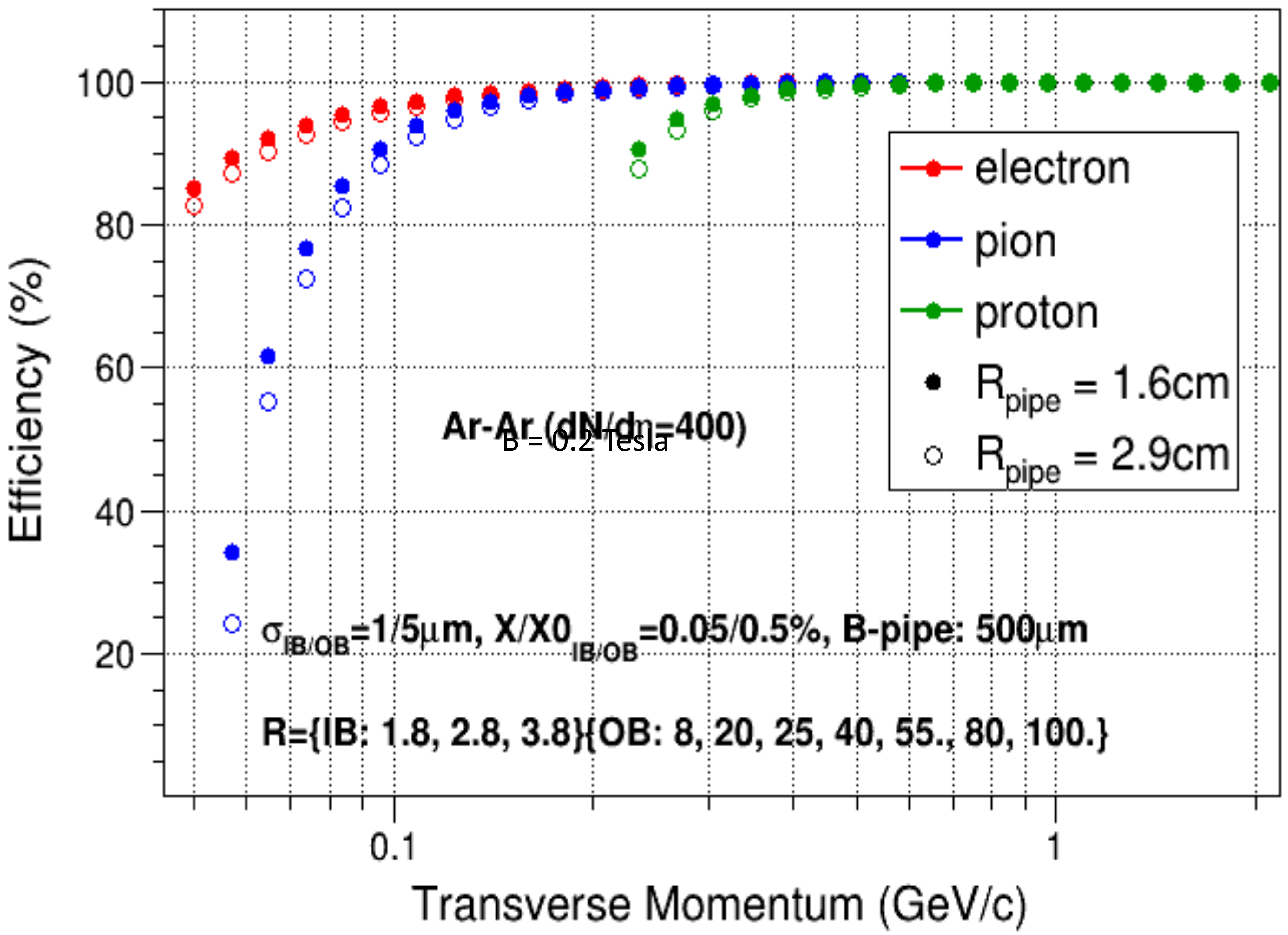
Conclusion

- New Si detector technologies provide new opportunities for heavy-ion physics
- Large-scale sensors: extremely low-mass detectors — ITS3 and after LS4
- Time-of-flight with Si for PID — after LS4
  - Several technologies under consideration
- Physics goals
  - Large vertex precision for heavy flavour production
    - Post-LS4: multi-charm baryons
  - Clean dilepton measurements
  - Ultra-low p_T: soft theorems, condensates — after LS4

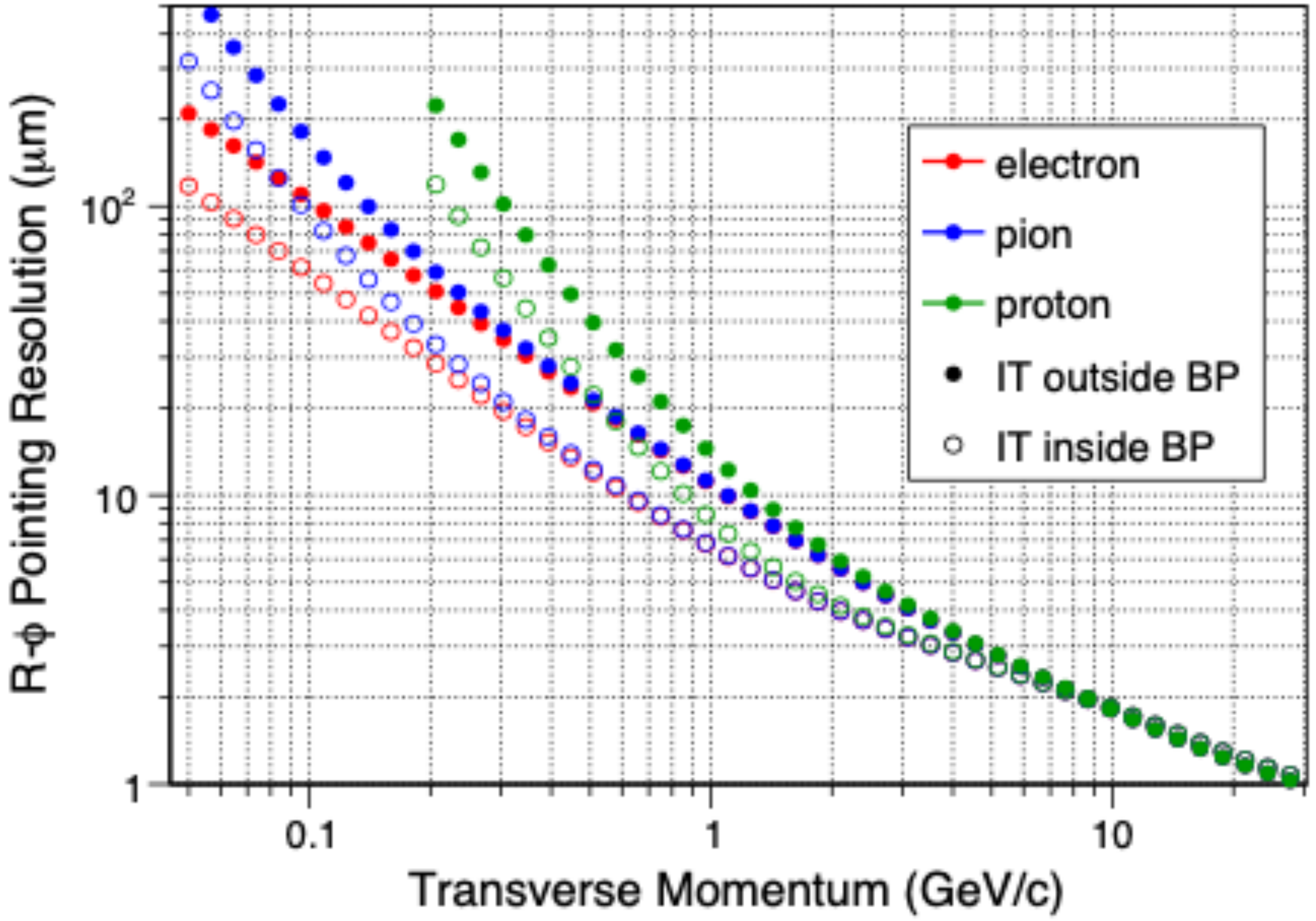
Extra slides

Tracking performance of next-generation experiment

Tracking efficiency



Impact parameter resolution



Indicative performance only - design parameters still evolving

European Particle Physics Strategy Process input: arXiv:1902.01211