



May 25-30, 2020

Online



The Eighth
Annual Conference
on Large Hadron
Collider Physics

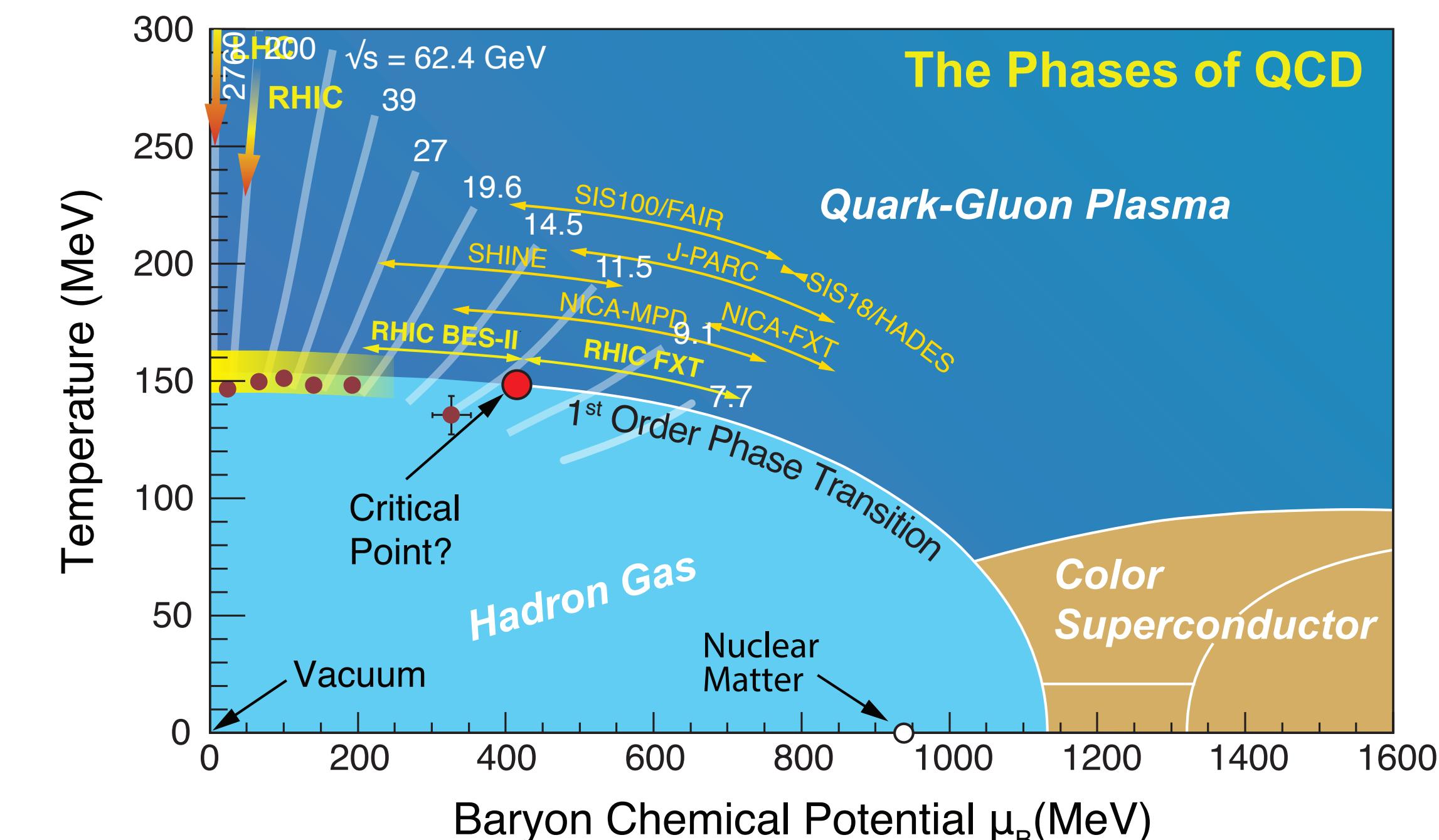
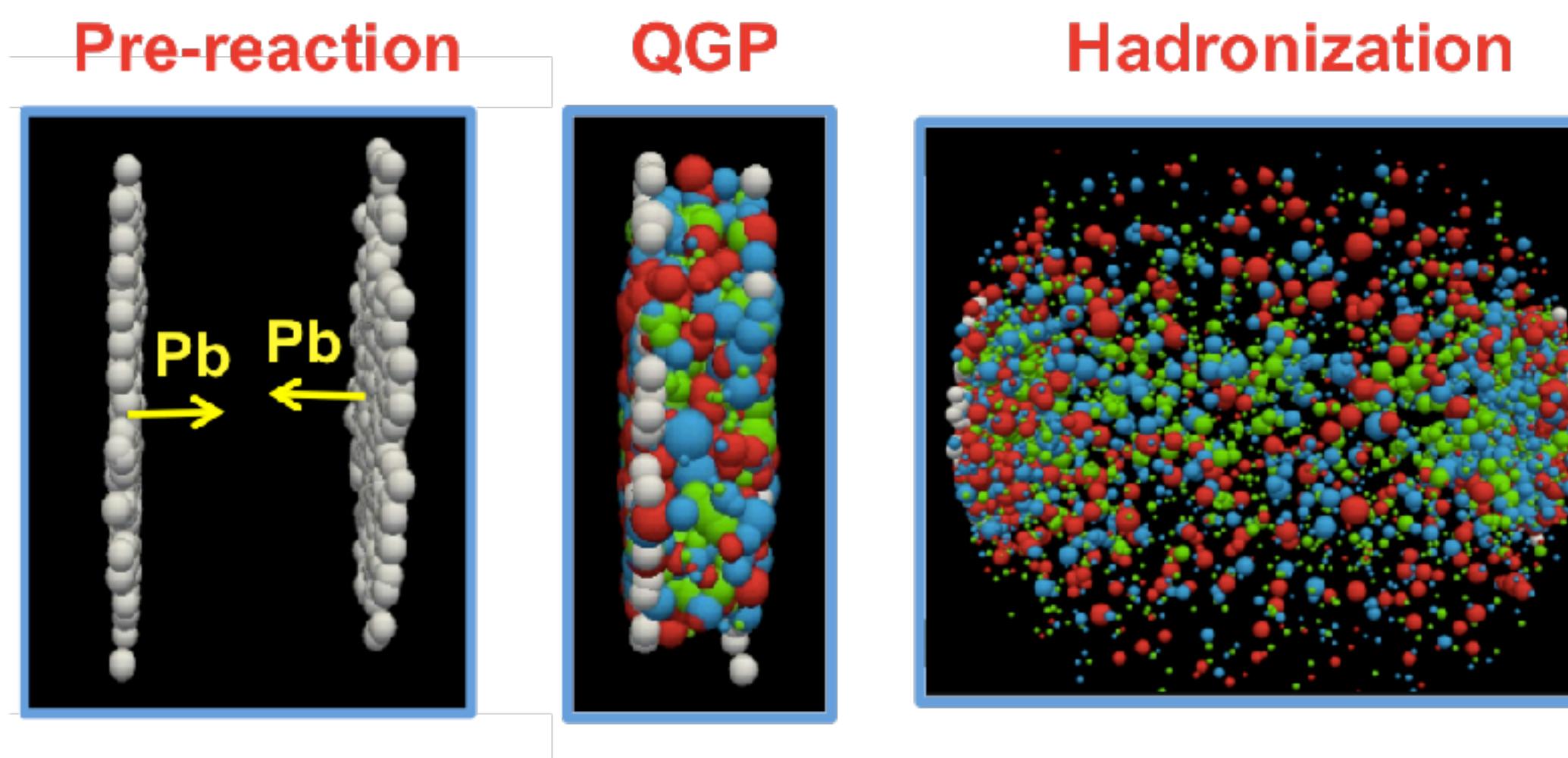
FABRIZIO GROSA
ON BEHALF OF THE ALICE COLLABORATION
INFN TORINO



PHYSICS PERSPECTIVES FOR ALICE IN RUN 4

HEAVY-ION PHYSICS AND QUARK-GLUON PLASMA

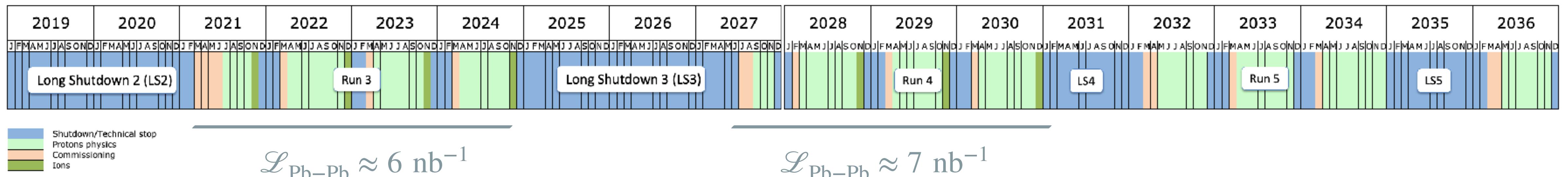
- Primary goal of heavy-ion program at the LHC: study of the properties of colour-deconfined strongly interacting matter, *quark-gluon plasma (QGP)*



- The QGP is created in **ultra-relativistic heavy-ion collisions at the LHC**
 - initial energy density $\sim 15 \text{ GeV/fm}^3$
 - after a pre-equilibrium phase **expands hydrodynamically like a nearly perfect fluid**
 - hadronises in thermal equilibrium**

- Ideal probes: **heavy-flavour (HF) quarks**
 - created at **short time scales**
 - experience the **full system evolution**
 - Brownian motion **markers of the QGP**

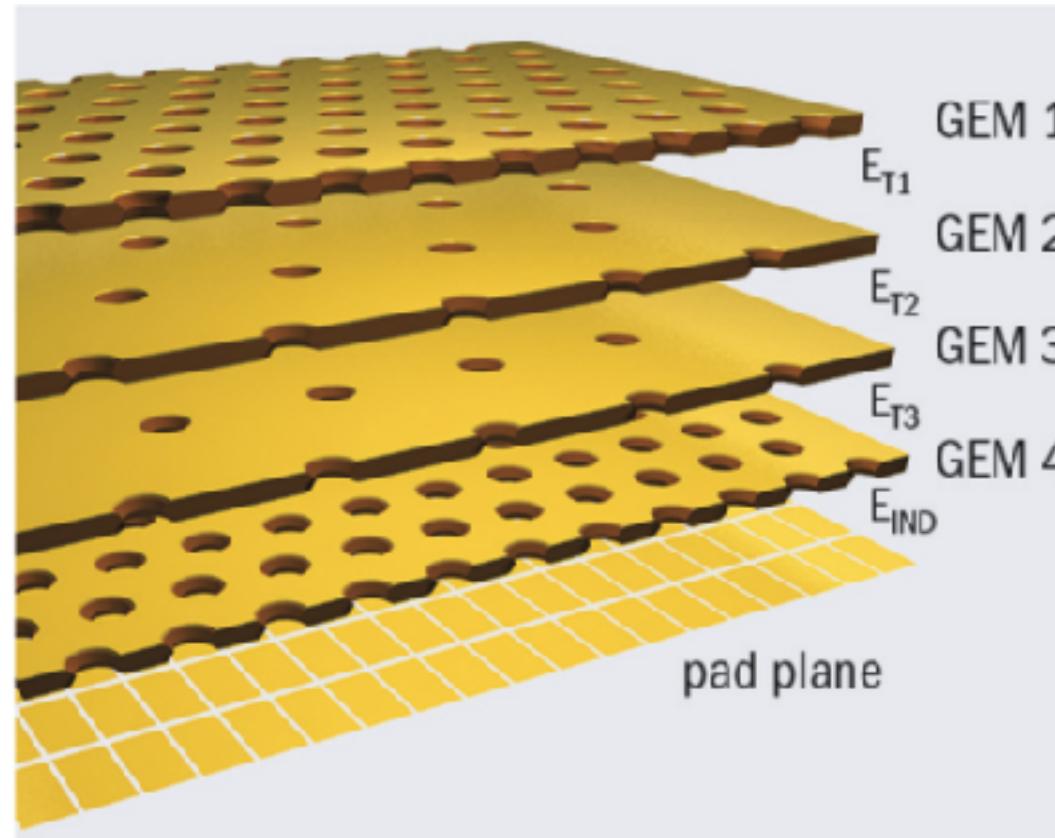
TOWARDS LHC RUN 3 AND 4



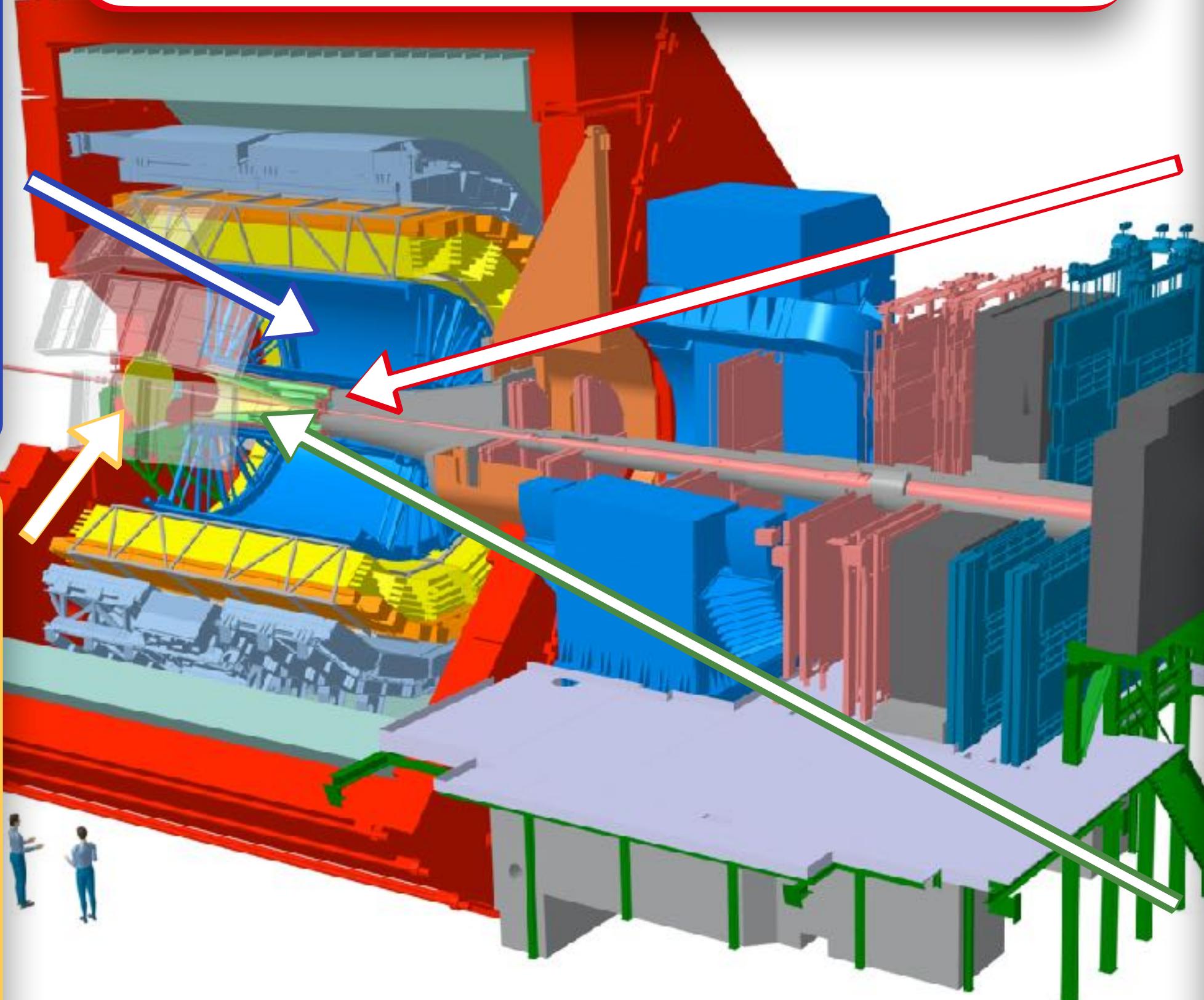
- Run 3 and 4: **increase collected Pb-Pb luminosity** by more than one order of magnitude
 - ▶ upgrades to LHC needed for Pb-Pb luminosity will be **completed in LS2**
- Main **Physics motivations**:
 - ▶ HF hadrons at low p_T (**charm and beauty interaction and hadronisation in the QGP**)
 - ▶ Quarkonia down to $p_T = 0$ (**melting and regeneration in the QGP**)
 - ▶ Thermal dileptons, photons, vector mesons (**thermal radiation, chiral symmetry restoration**)
 - ▶ Precision measurements of light (**hyper)nuclei and searches for charmed hypernuclei**)
- Main **requirements**:
 - ▶ Increase **readout rate**, reduce data size for storage (online data reduction)
 - ▶ Improve tracking and vertexing at **low p_T**
 - ▶ preserve **particle-identification (PID) capabilities**

CURRENT: ALICE UPGRADES FOR LHC RUN 3

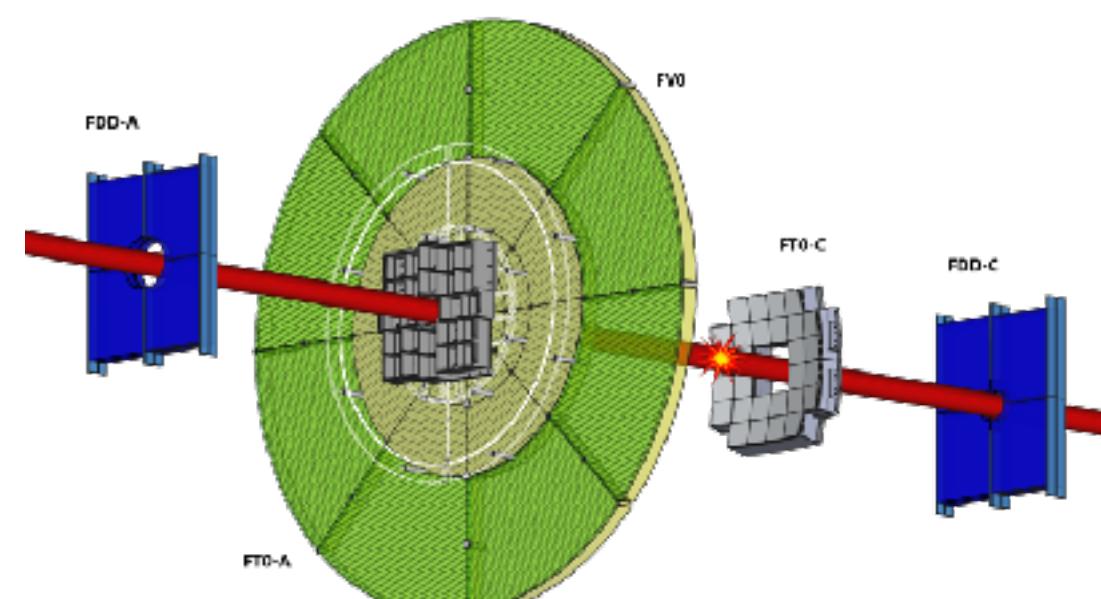
Time Projection Chamber



Upgrade readout electronics for
TOF, TRD, MUON spectrometer,
ZDC, V0, EMCAL



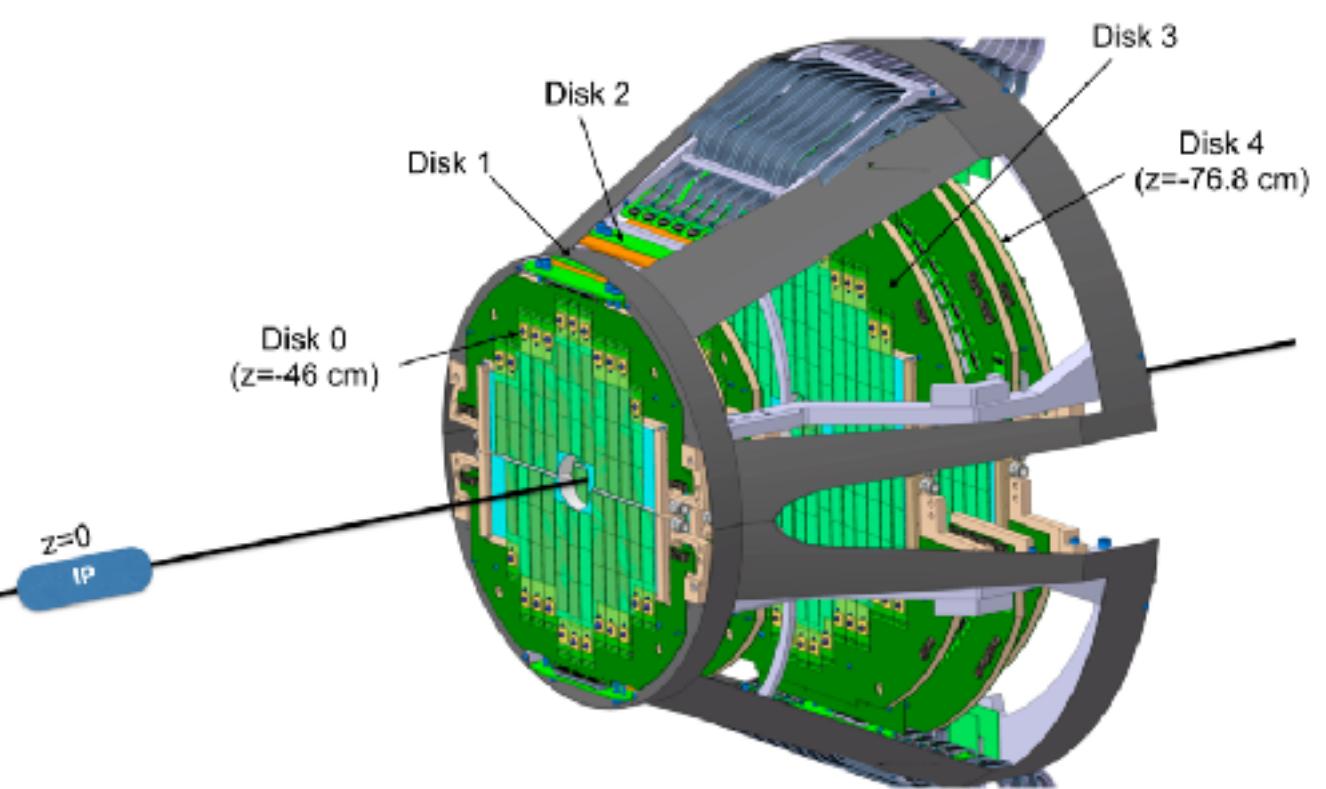
Fast Interaction Trigger



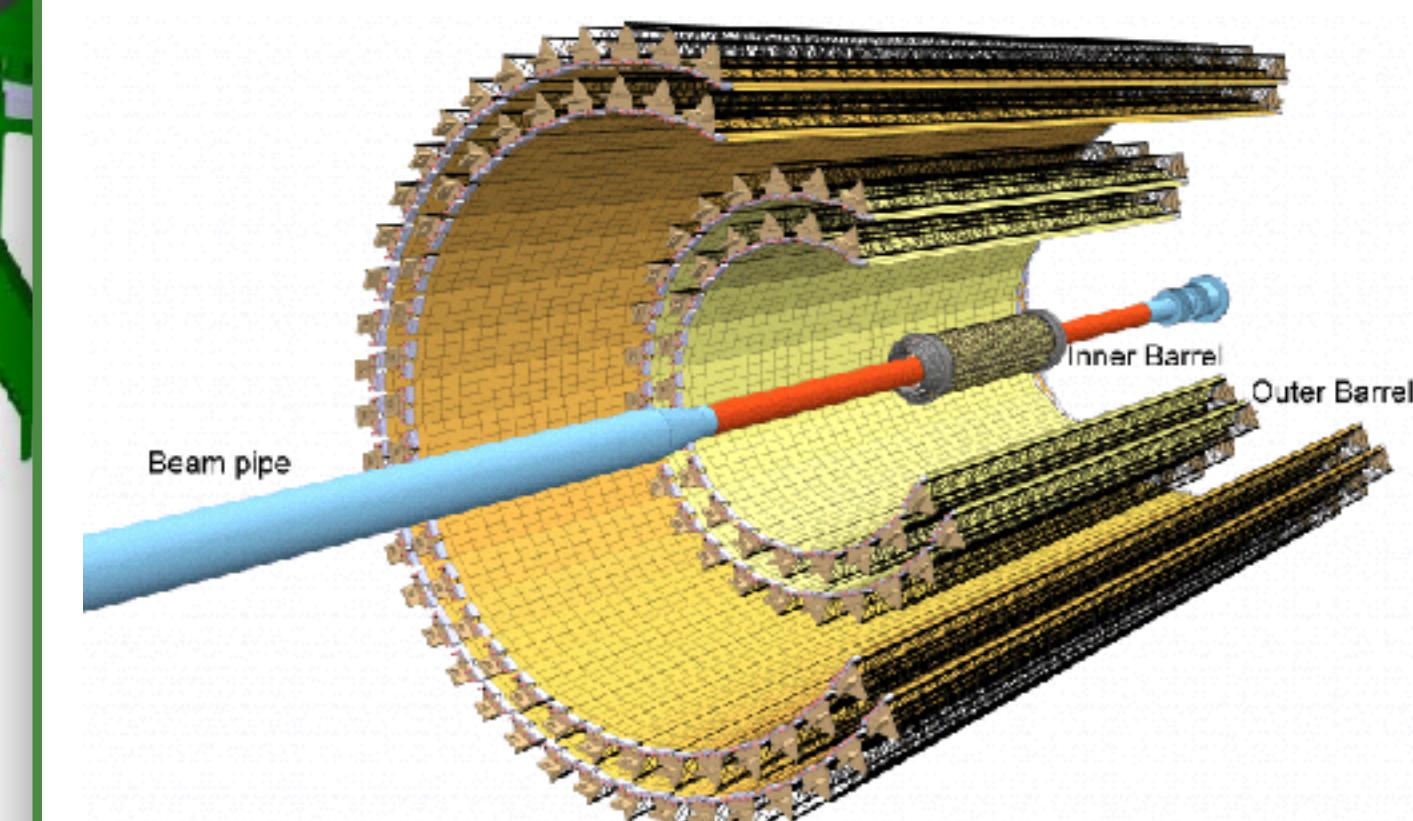
Poster by S. A. Bysiak
Poster by S. R. Torres

P. Gasik 25 May, 16h45

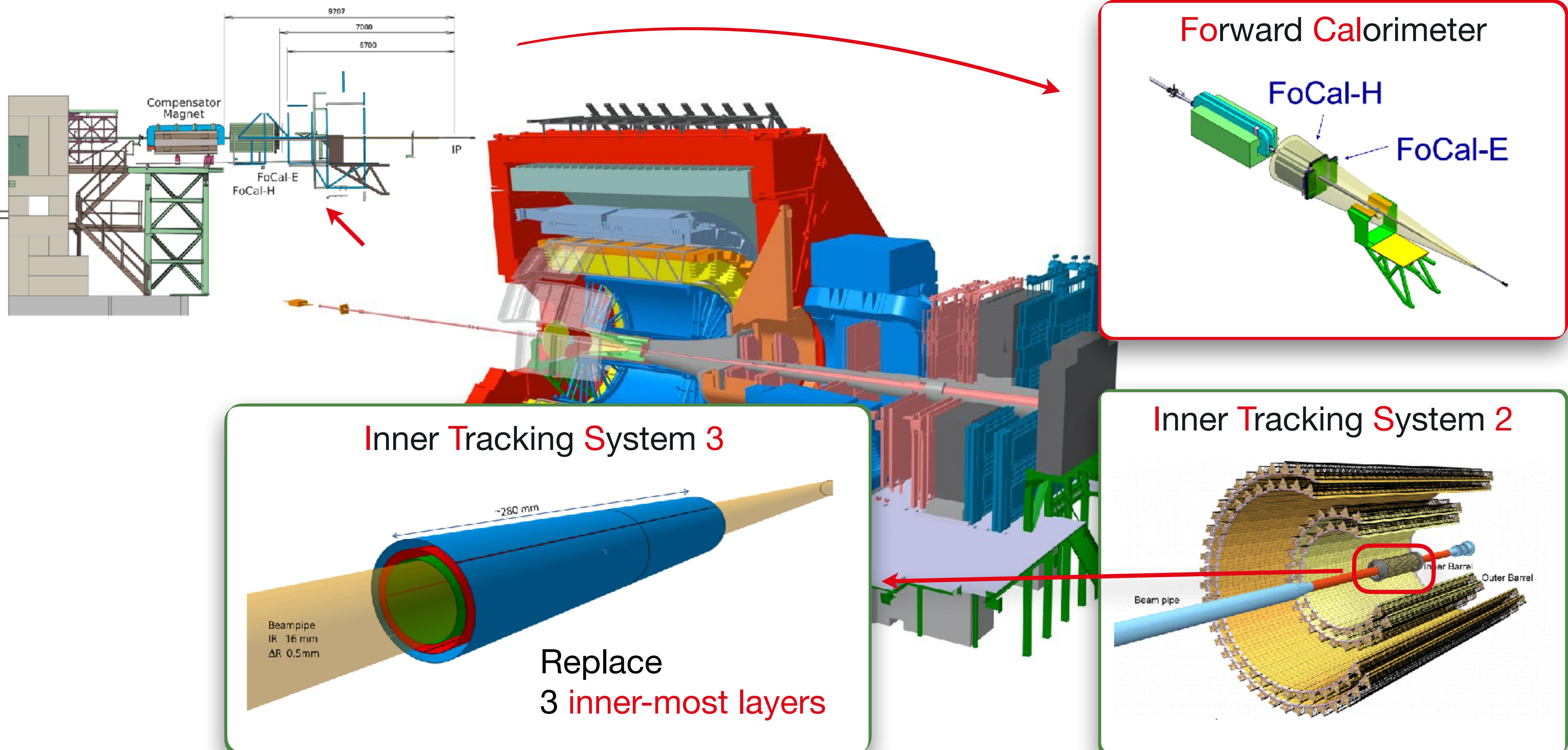
Muon Forward Tracker



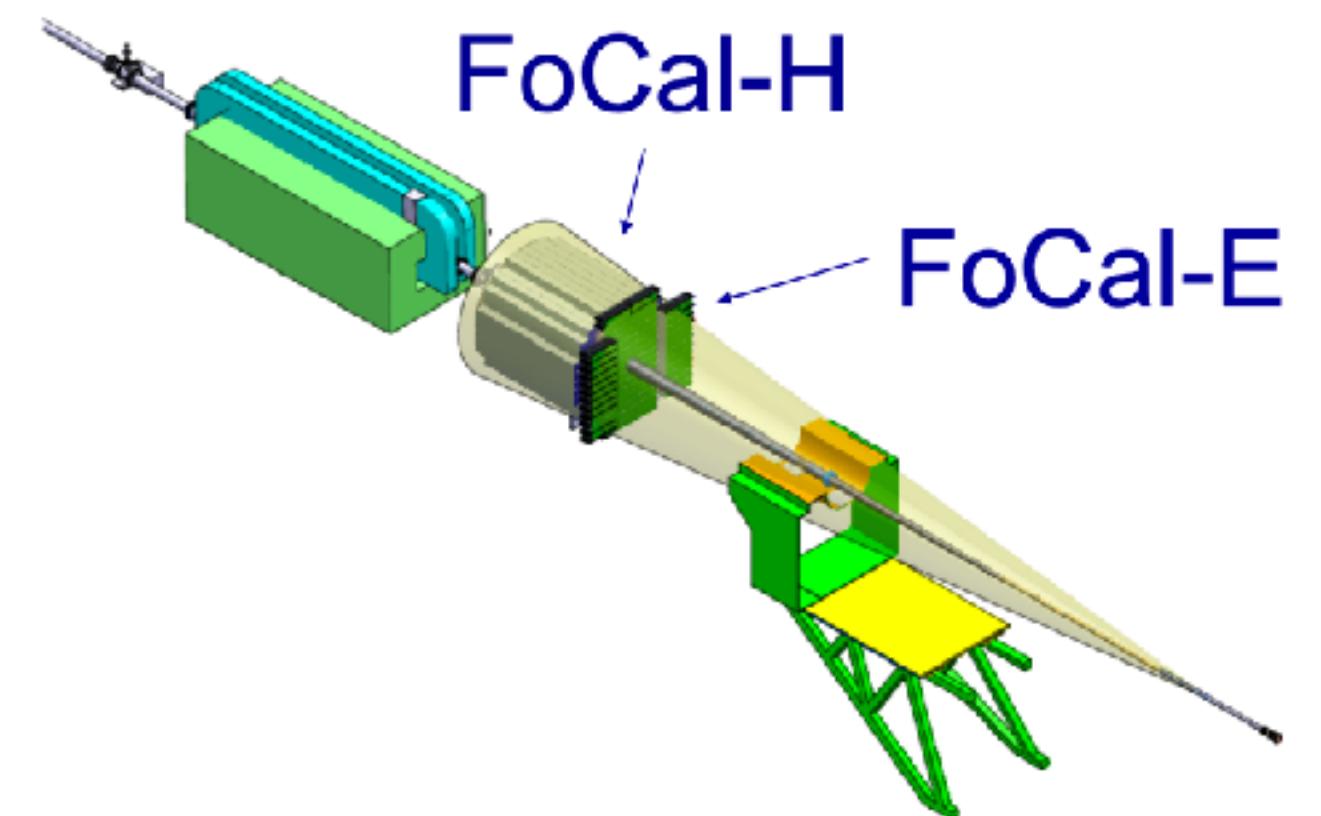
Inner Tracking System 2



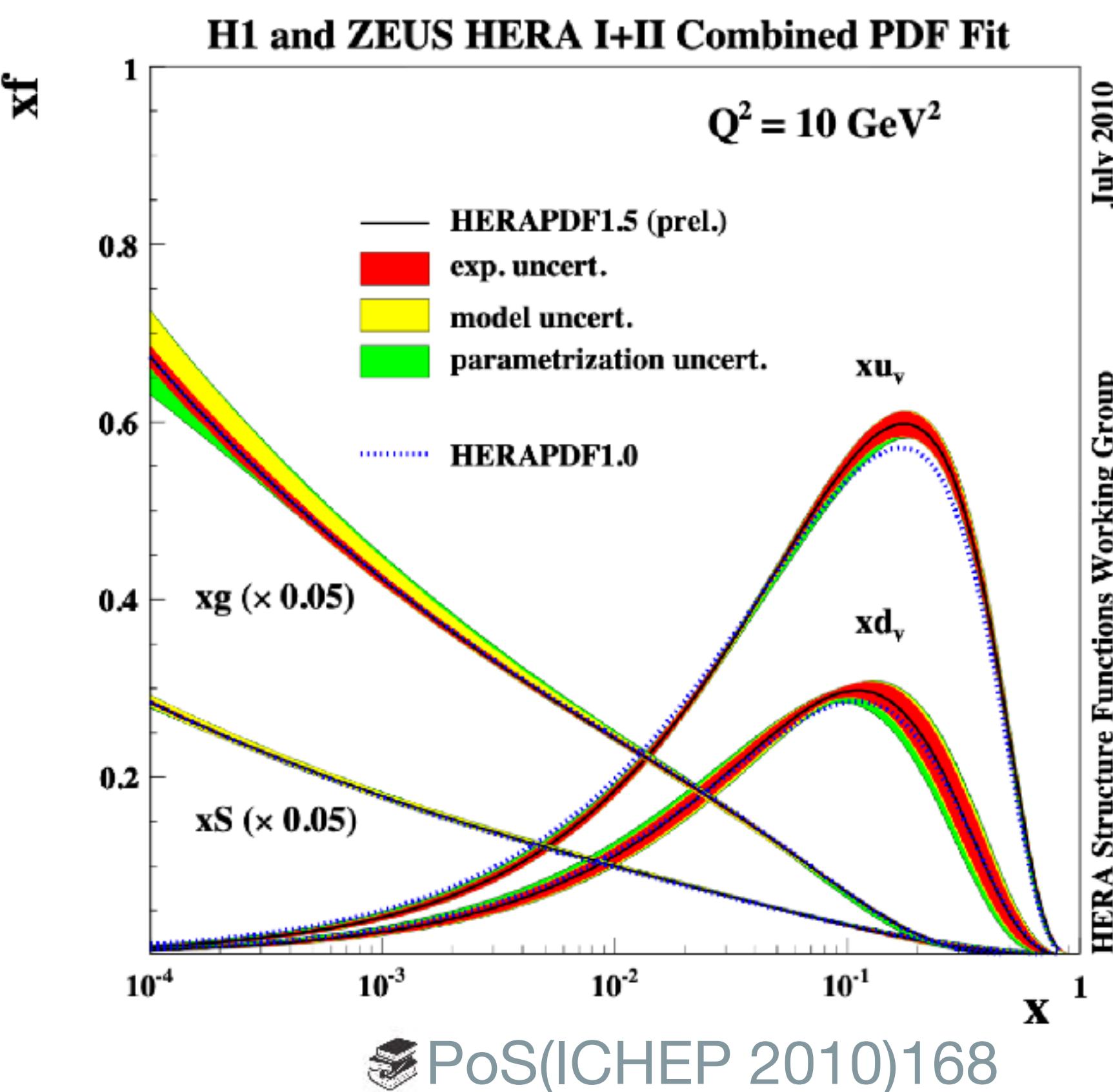
NEXT: ALICE UPGRADES FOR LHC RUN 4



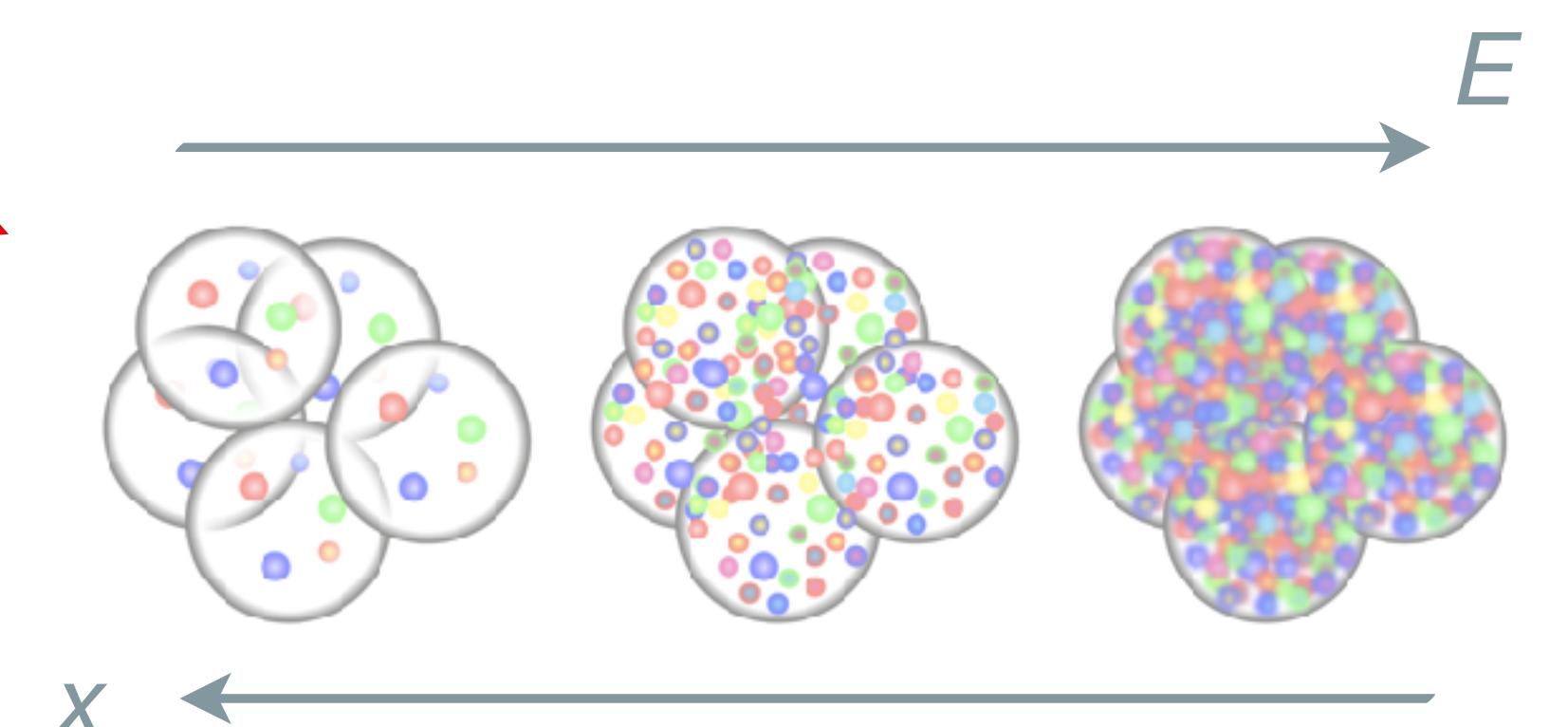
FOCAL: A FORWARD CALORIMETER

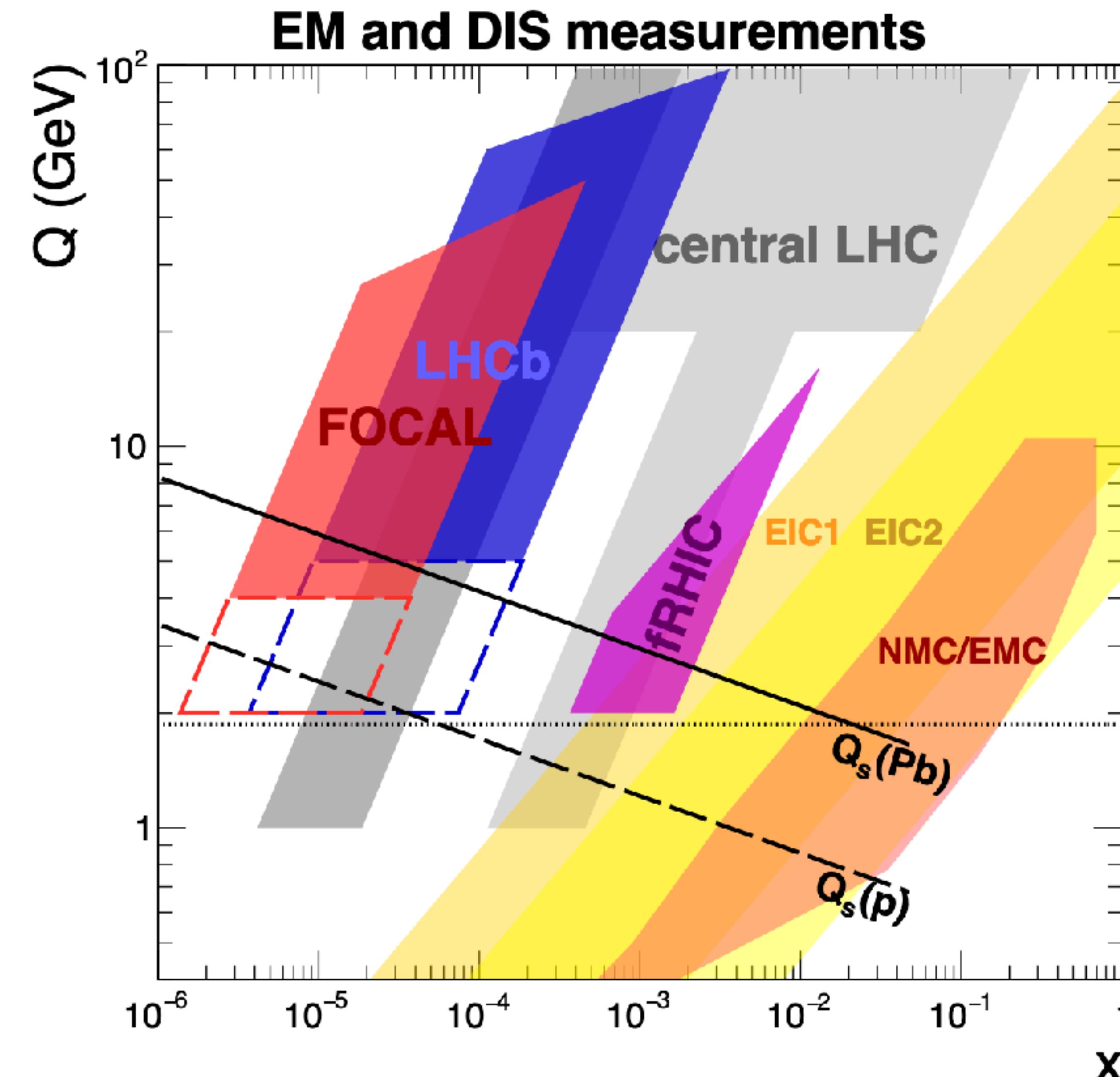


- **FoCal**: forward electromagnetic and hadronic calorimeters
 - ▶ **FoCal-E**: high-granularity Si-W sampling calorimeter for the measurement of **direct γ** and π^0
 - ▶ **FoCal-H**: Pb-Sc sampling calorimeter for **photon isolation** and jets

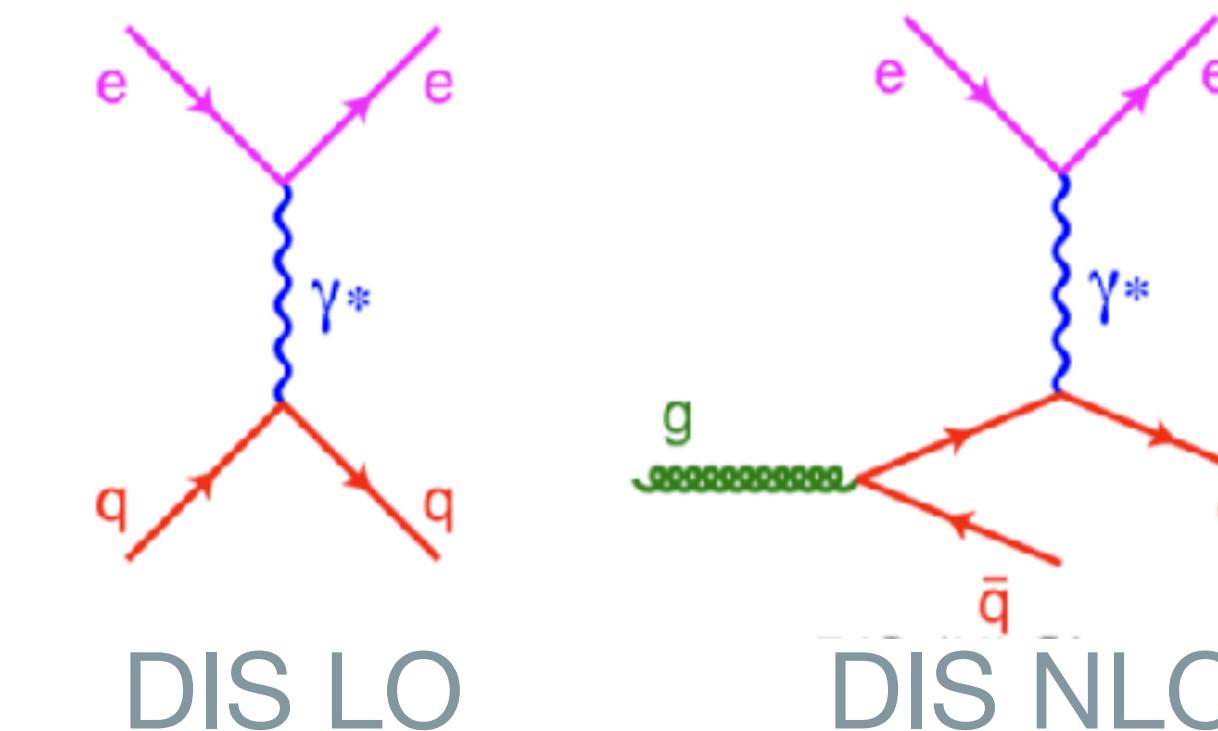


- **Main goal:**
 - constrain nuclear PDFs at small x , in particular **gluon PDFs**
 - Even for proton **limited information about gluons for $x < 10^{-4}$**
 - from DIS, HERA: **gluon density increases rapidly at low x**
 - further growth** predicted by DGLAP, BFKL
- Infinite growth or mechanism that “tame” the gluons at low x
- ▶ **gluon fusion / gluon saturation?**

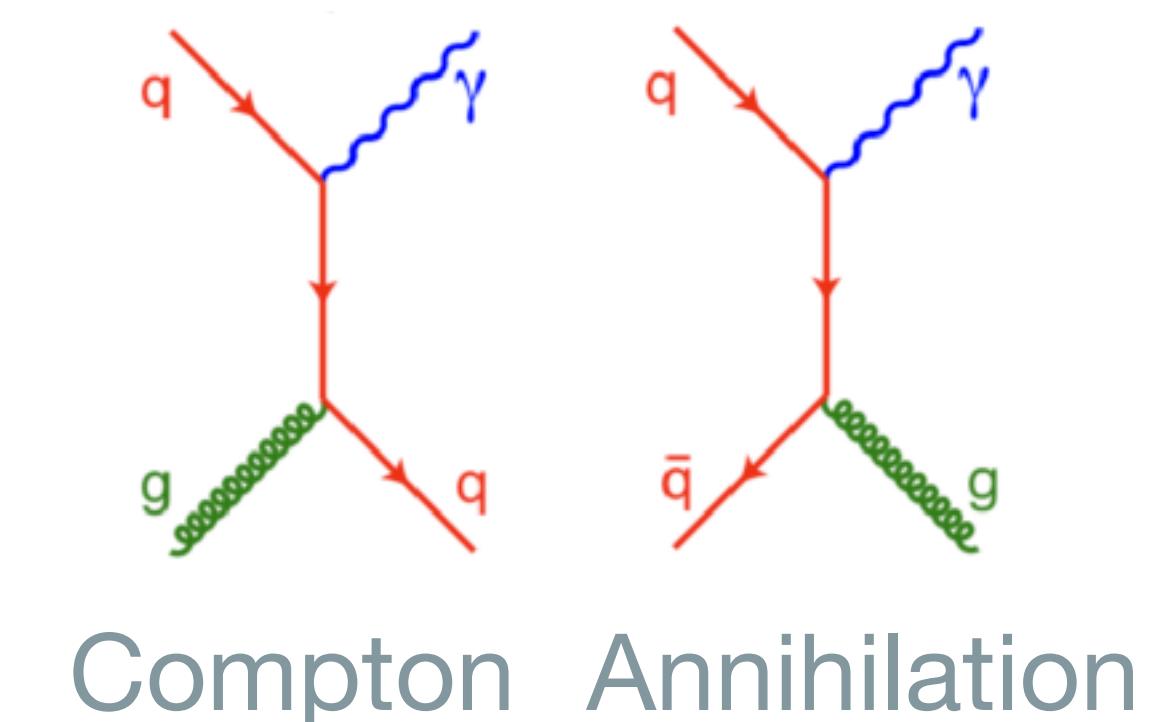




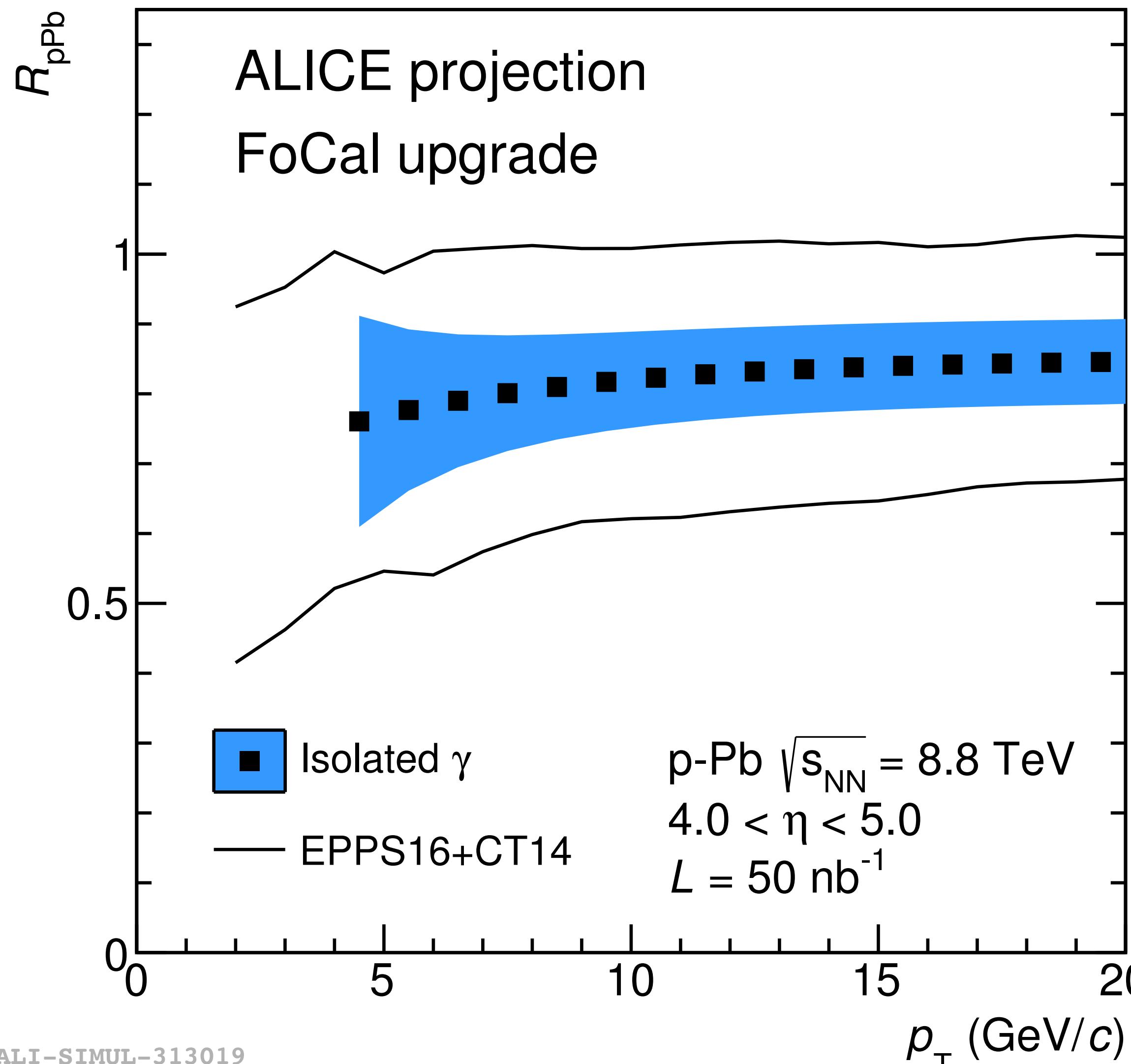
LOI: ALICE-PUBLIC-2019-005



- **DIS experiments**
 - ▶ Classical method to measure PDFs
 - ▶ **not sensitive to the gluon PDFs at the leading order (LO)**
- Measure **isolated γ forward**
 - ▶ at LO more than 70% from Compton
 - ▶ direct sensitivity to gluon density
- Lower x reached compared to LHCb thanks to pseudorapidity coverage



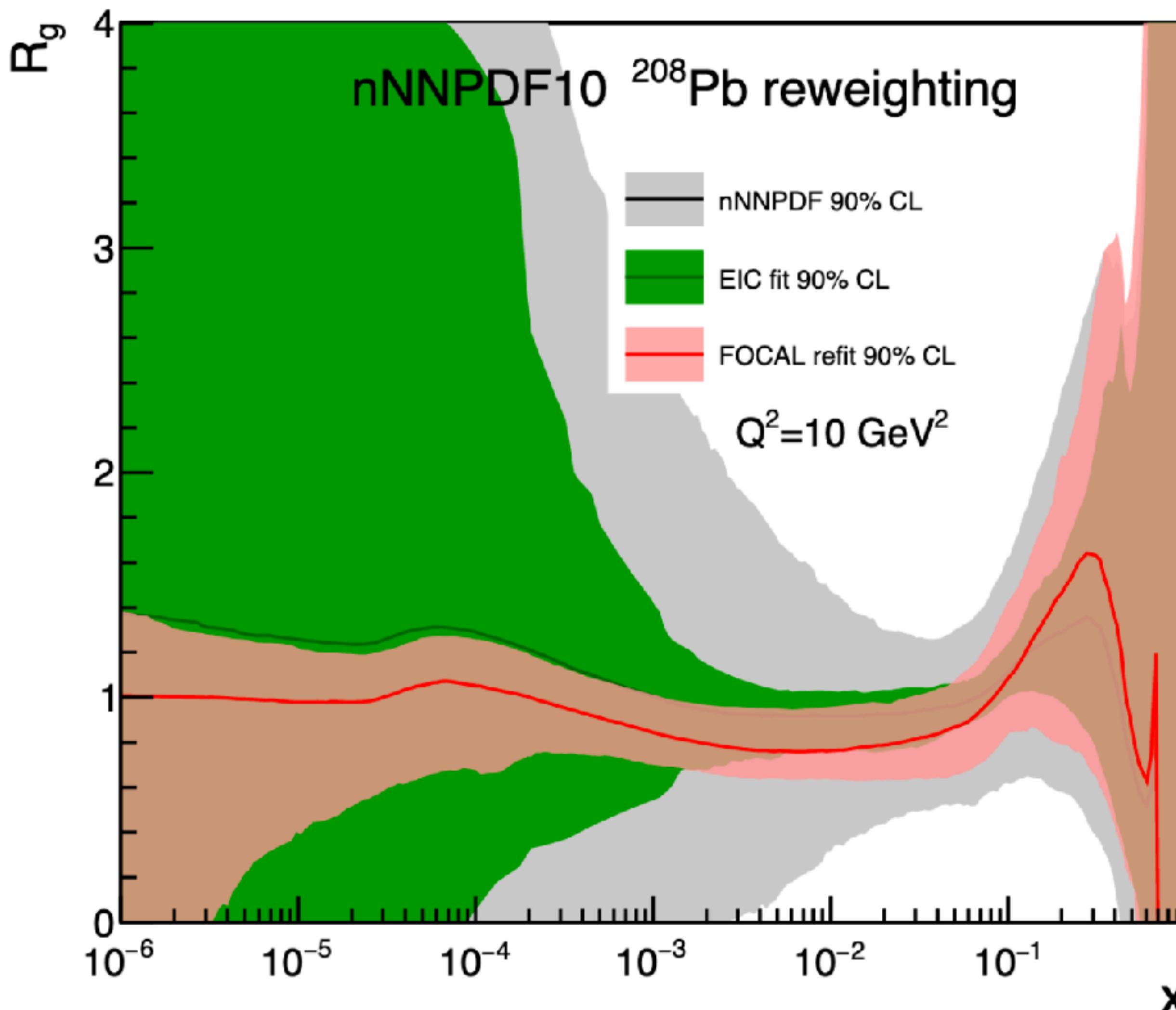
EXPECTED PERFORMANCE: ISOLATED PHOTON MEASUREMENT



$$R_{\text{pPb}} = \frac{1}{\langle N_{\text{coll}} \rangle} \cdot \frac{dN_{\text{pPb}}/dp_T}{dN_{\text{pp}}/dp_T}$$

- Expected 20% of relative uncertainties above 6 GeV/c
- Significant improvement up to factor 2 on EPPS16 gluon nuclear PDF

EXPECTED PERFORMANCE: CONSTRAINING NUCLEAR PDFs



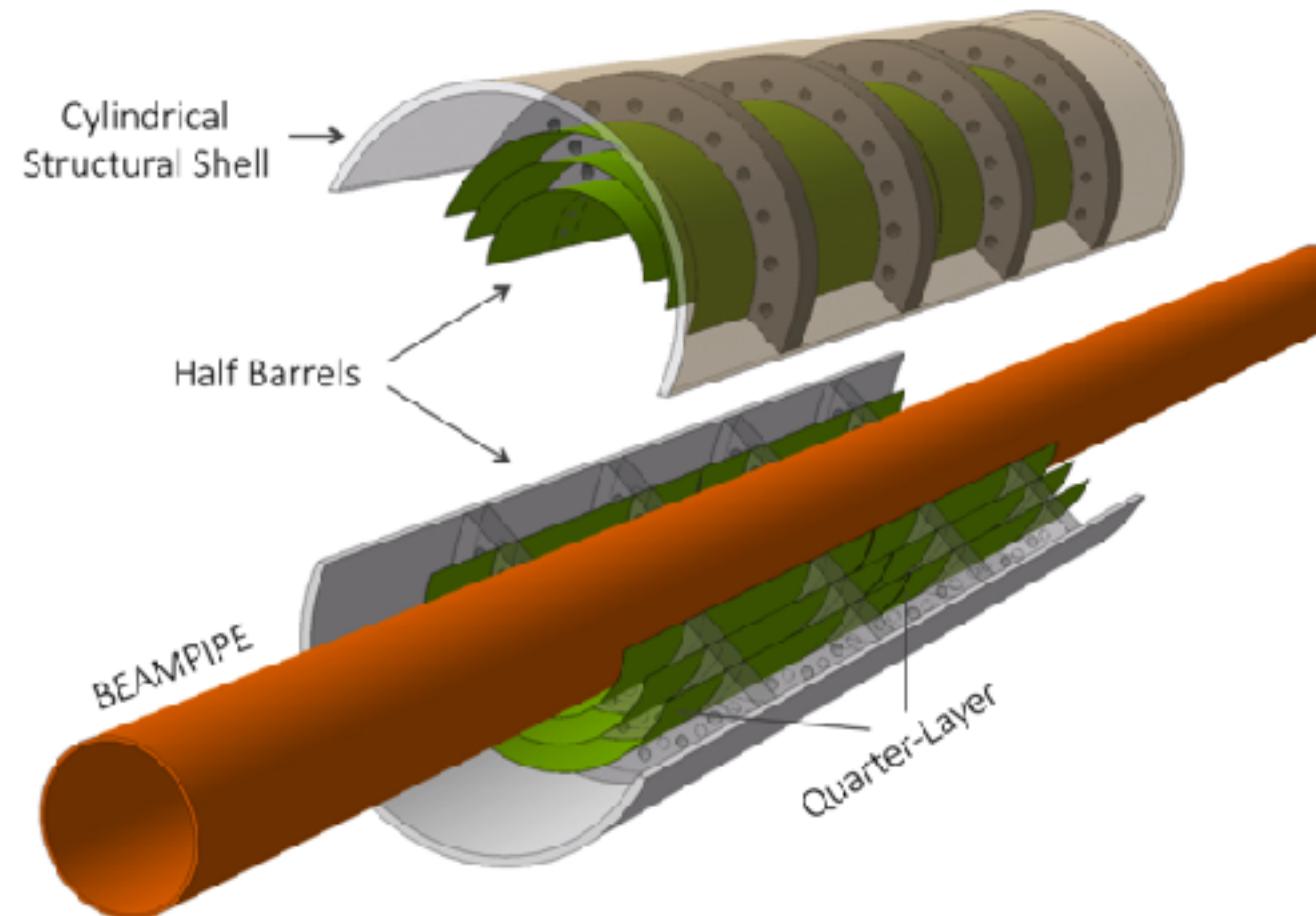
- Recent nNNPDF from DIS measurements unconstrained for $x < 10^{-2}$
- Current constraints provided by HF measurements at forward rapidity by ALICE and LHCb
 - Acta Phys. Polon. B 49 (2018), 1185-1198
 - arXiv:1912.09128
- FOCAL is expected to provide significant constraints at $\sim 10^{-5} < x < 10^{-2}$
- Expected to be more precise than electron-ion collider (EIC) experiments for $x < 10^{-3}$

LOI: ALICE-PUBLIC-2019-005

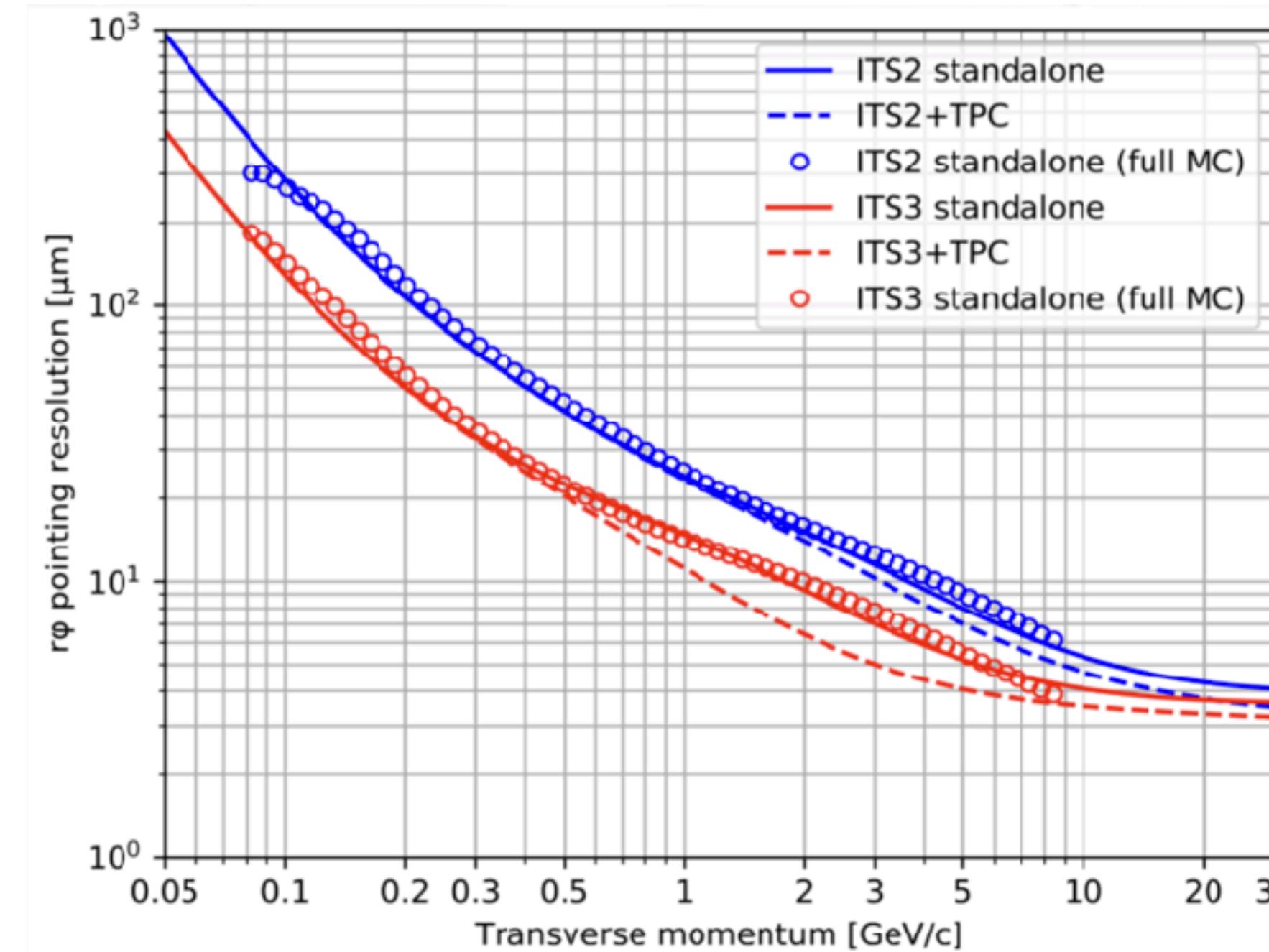
arXiv:1904.00018

ITS3: A TRULY CYLINDRICAL INNER TRACKING SYSTEM

LOI: CERN-LHCC-2019-018



- New detector technology:
 - ▶ three truly cylindrical Si pixel layers based on ultra-thin wafer-sized curved sensors
 - ▶ no external connections nor cooling
 - ▶ new beam pipe
 - ▶ new concept for future detectors



inner layers	ITS1	ITS2	ITS3
X/X_0	1.14%	0.38%	0.05%
innermost radius	39 mm	22 mm	18 mm
pixel size	$50 \times 425 \mu\text{m}^2$	$30 \times 30 \mu\text{m}^2$	$O(15 \times 15 \mu\text{m}^2)$

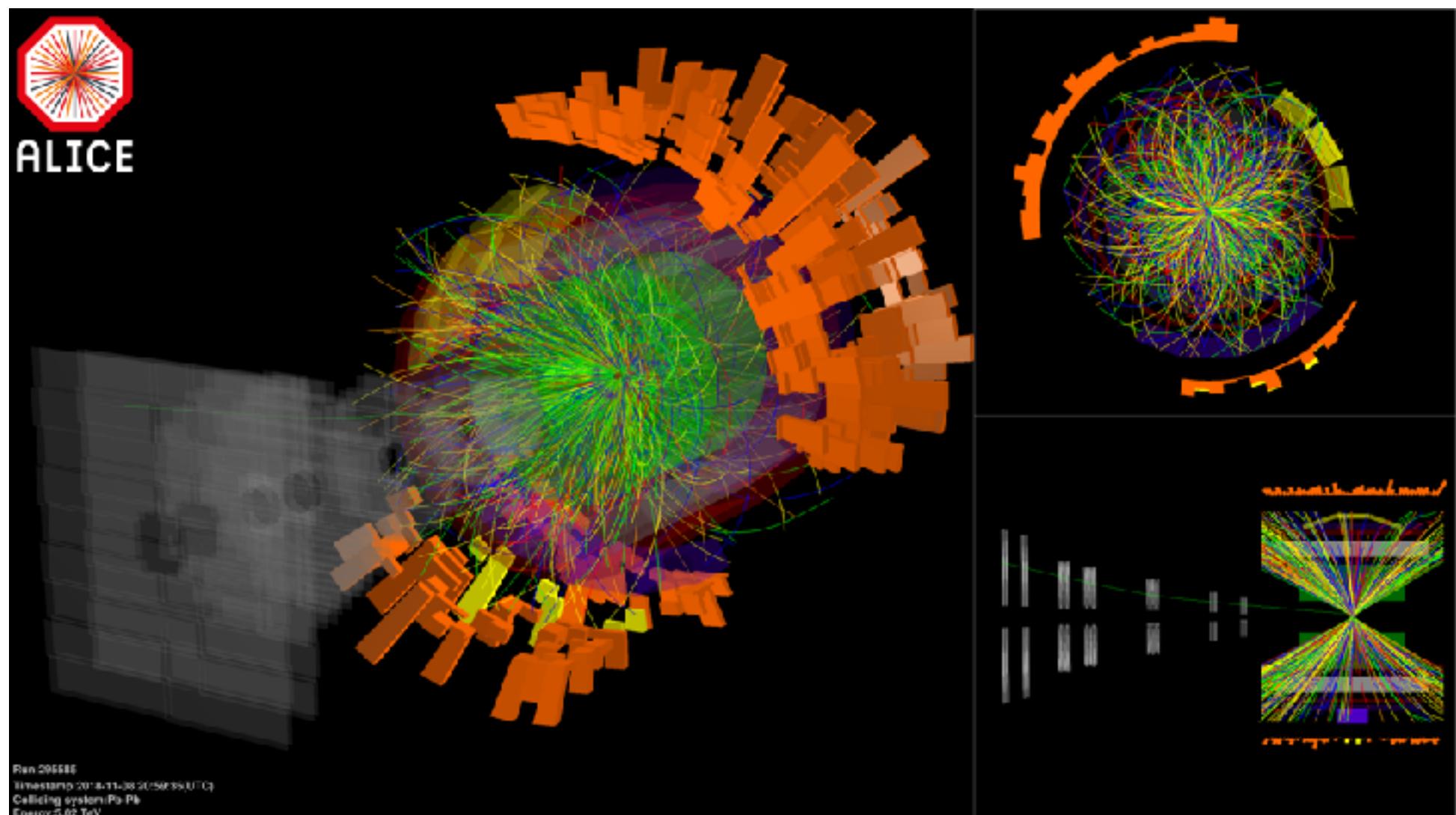
- Pointing resolution improves by a factor 2 compared to ITS2 in the full p_T range
- Tracking efficiency increases by a factor 1.2-2 compared to ITS2 in $p_T < 100 \text{ MeV}/c$

MEASUREMENTS THAT WILL BENEFIT FROM THE ITS3 UPGRADE

- Low-mass dileptons
- Beauty-strange mesons
 - exclusive reconstruction of B_s^0
 - non-prompt D_s^+ ($\sim 50\%$ from $B^{0,+}$ and $\sim 50\%$ from B_s^0)
- Beauty baryons
 - non-prompt Λ_c^+
 - exclusive reconstruction of Λ_b^0
- Charm strange and multi-strange baryons
 - Ξ_c^0 (cds), Ξ_c^+ (cus), Ω_c^0 (css)
- Searches for light charm hypernuclei
 - bound state of a Λ_c^+ and a neutron (c-deuteron)
 - bound state of a Λ_c^+ and a deuteron (c-triton)

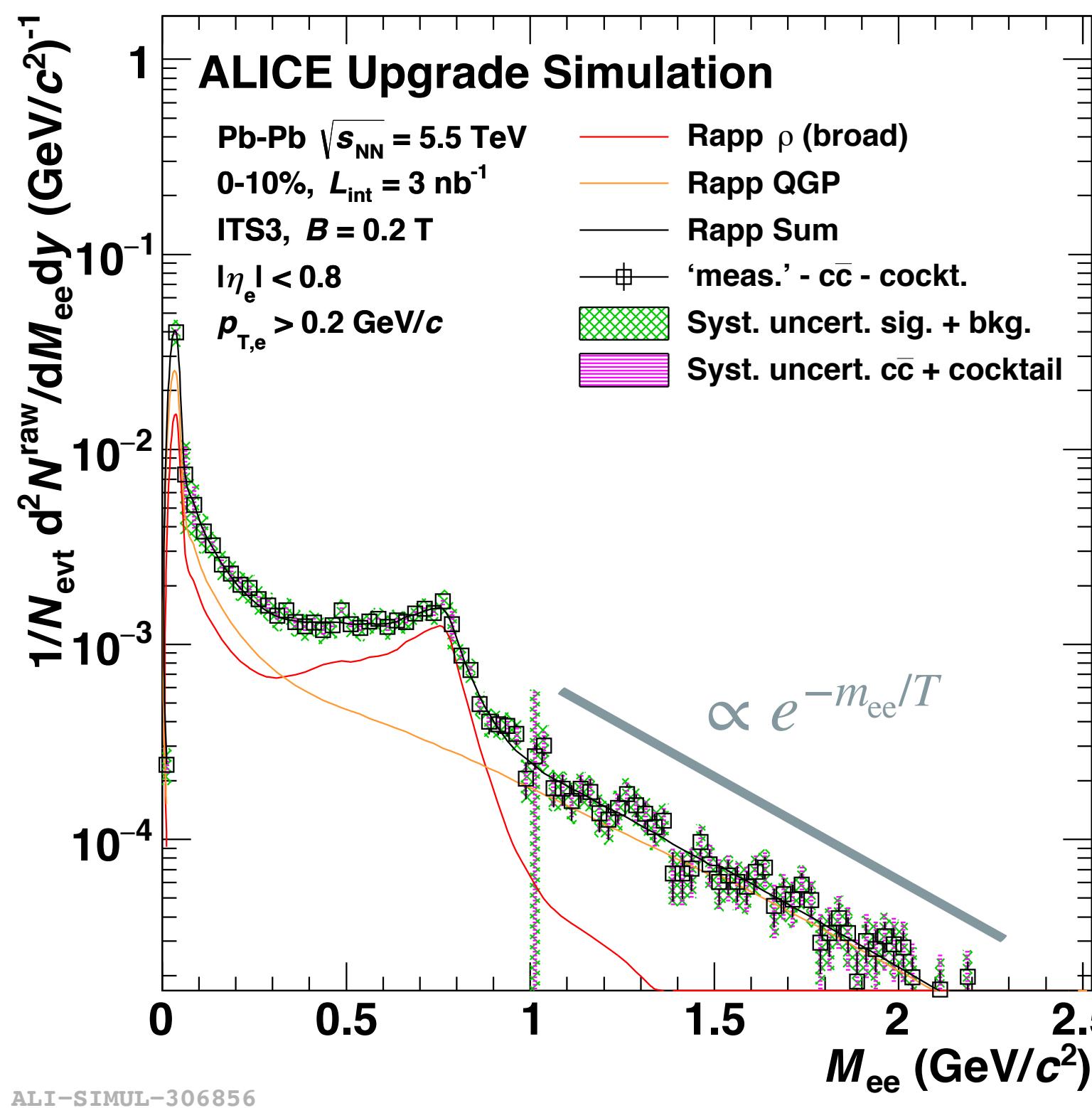
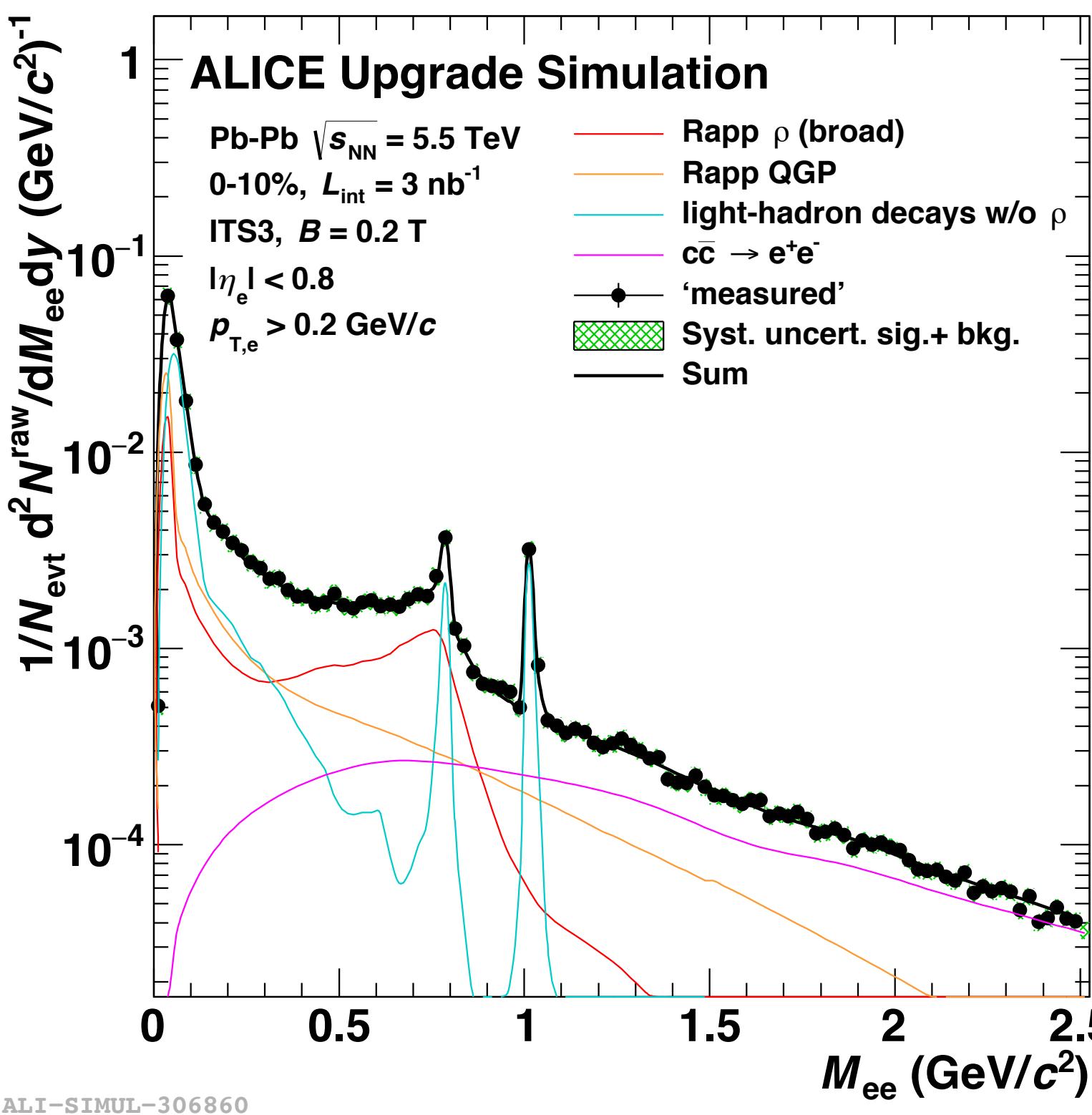


PRD 98, 030001 (2018)



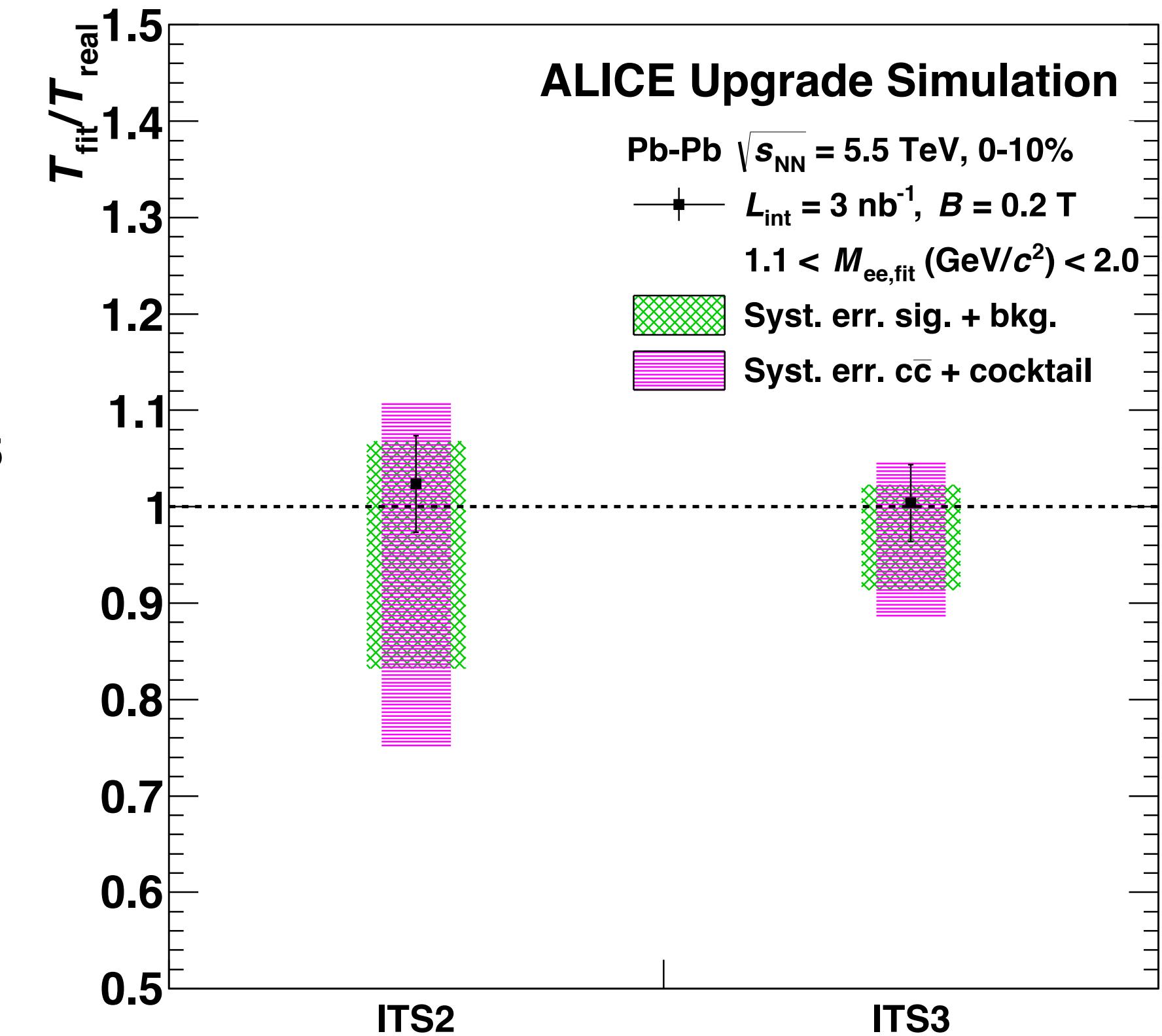
Extremely challenging measurements
in a high multiplicity environment
(up to $\sim 10^4$ charged tracks per event)

EXPECTED PERFORMANCE: LOW-MASS DILEPTONS AND THERMAL RADIATION



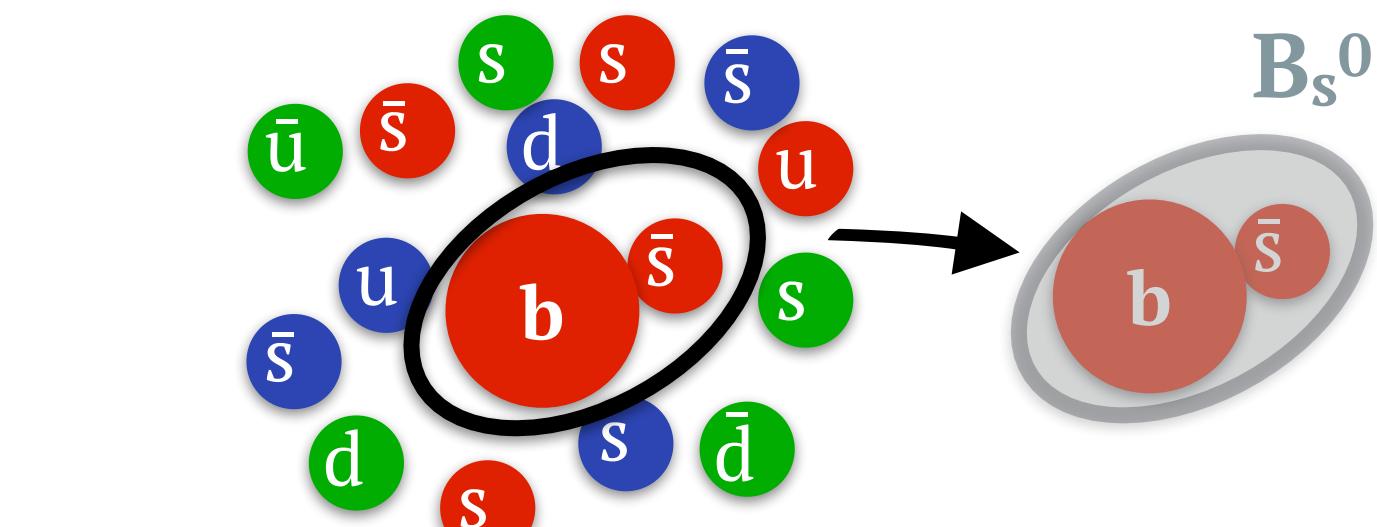
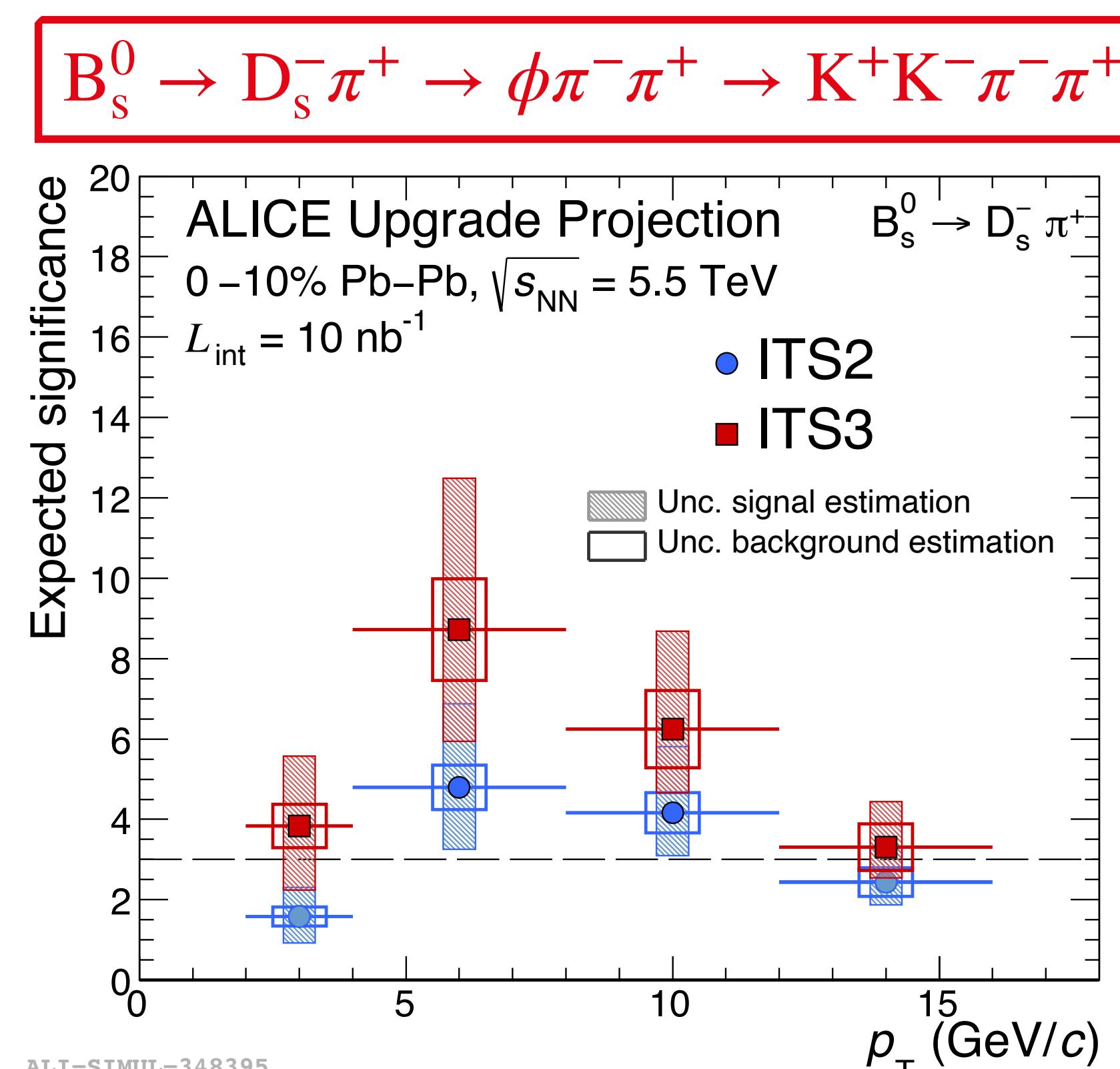
- **ITS3:**
 - ▶ better charm rejection (vertexing)
 - ▶ reduced contribution from conversion (low material budget)
- Reduction of **systematic uncertainties** by a factor 2
- Reduction of **statistical uncertainties** of a factor 1.3

- The **thermal radiation** contributes to the low-mass dilepton M_{ee} distribution
- M_{ee} slope \rightarrow **QGP temperature**

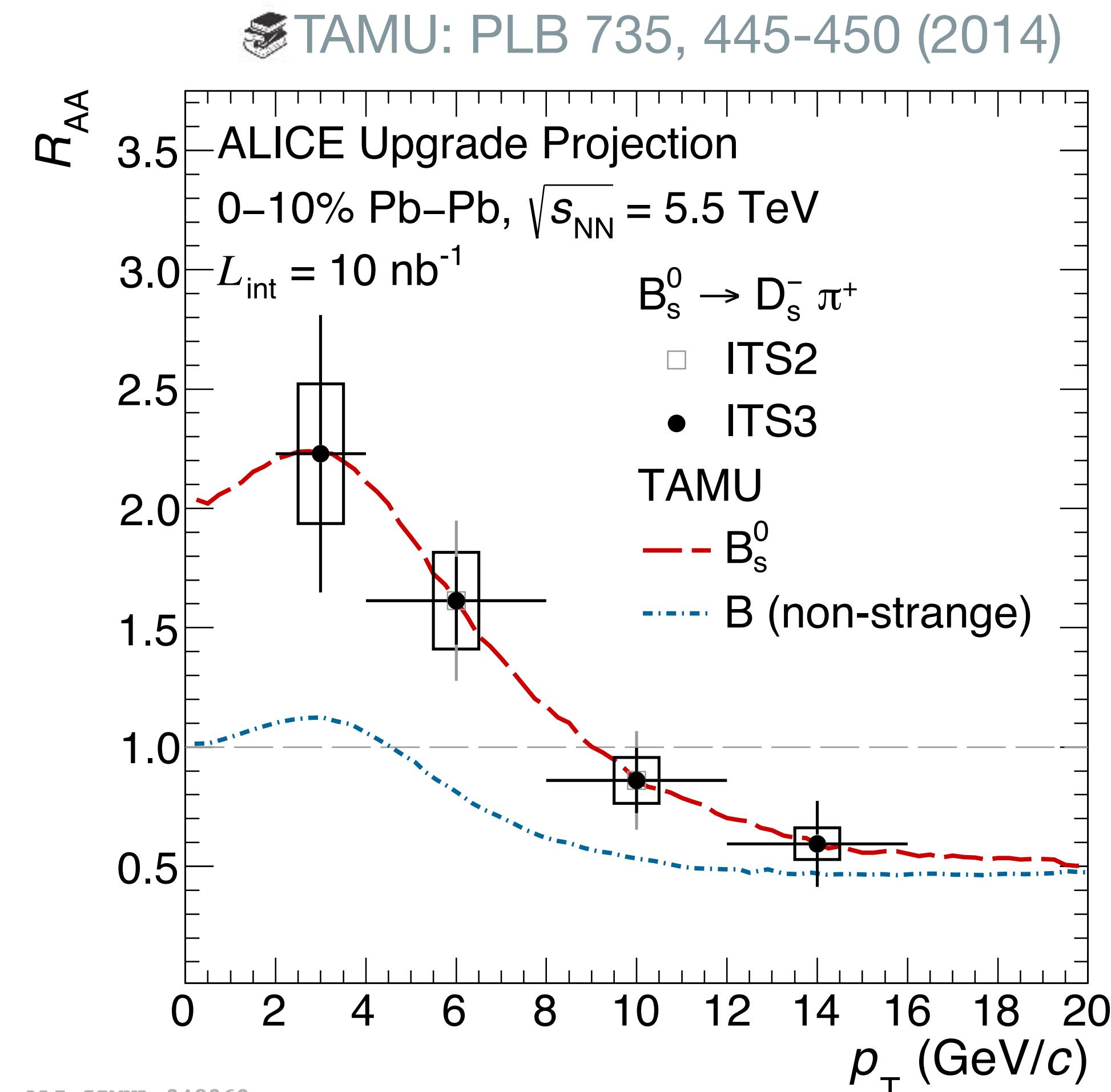


EXPECTED PERFORMANCE: B_s^0 MESONS

- Study **beauty-quark hadronisation mechanism**
 - ▶ B_s^0 production **expected to be enhanced**
 - ▶ hadronisation of beauty quarks via **recombination**
 - + **enhanced strange-quark production in the QGP**



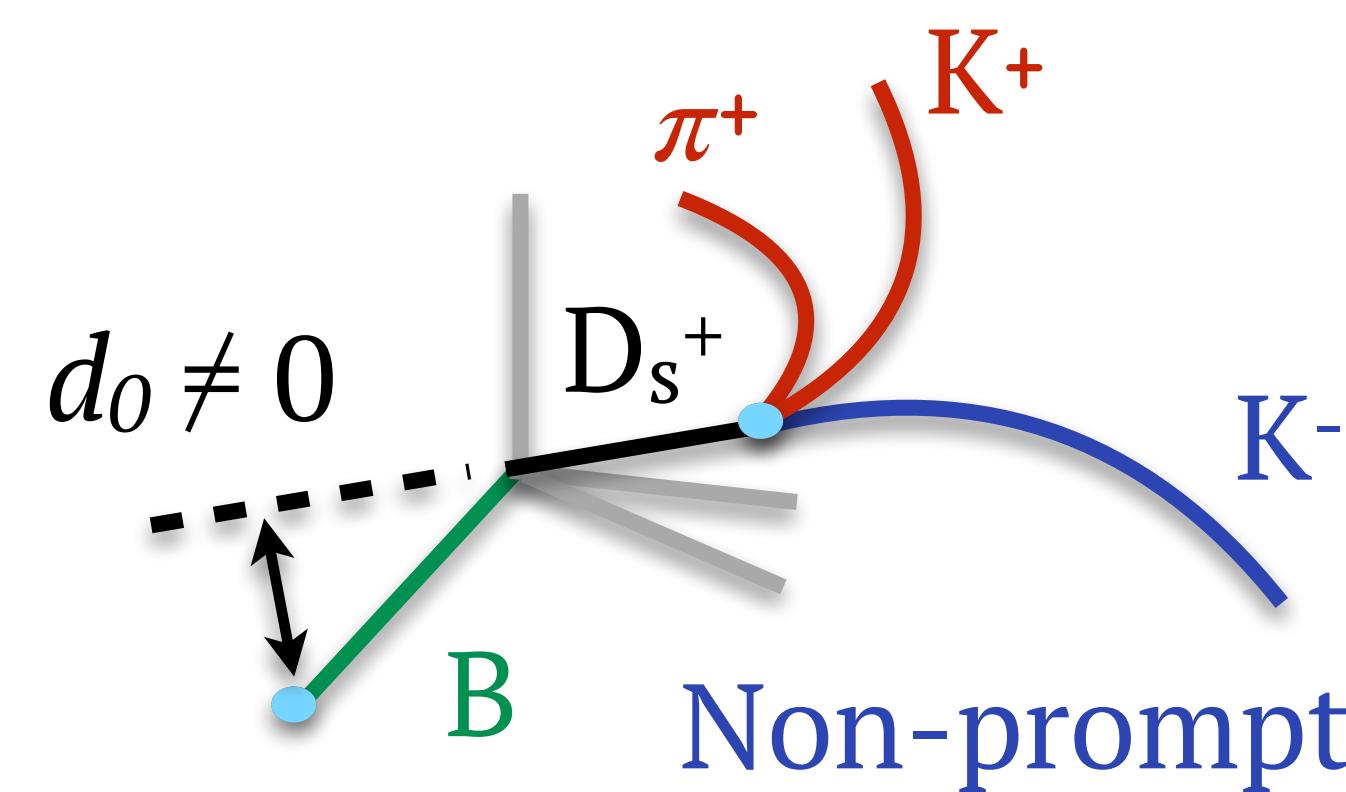
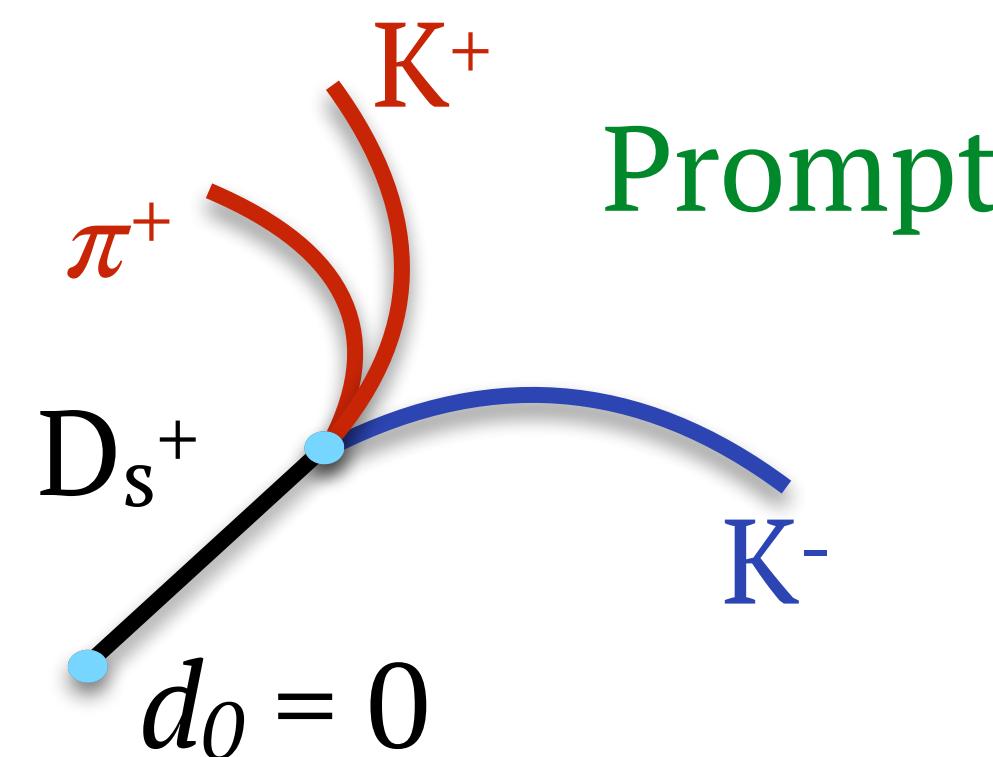
- Improvement by a factor 2 in significance with ITS3
 - ▶ provide access to B_s^0 measurement at very low p_T



$$R_{\text{AA}} = \frac{1}{\langle N_{\text{coll}} \rangle} \cdot \frac{dN_{\text{AA}}/dp_T}{dN_{\text{pp}}/dp_T}$$

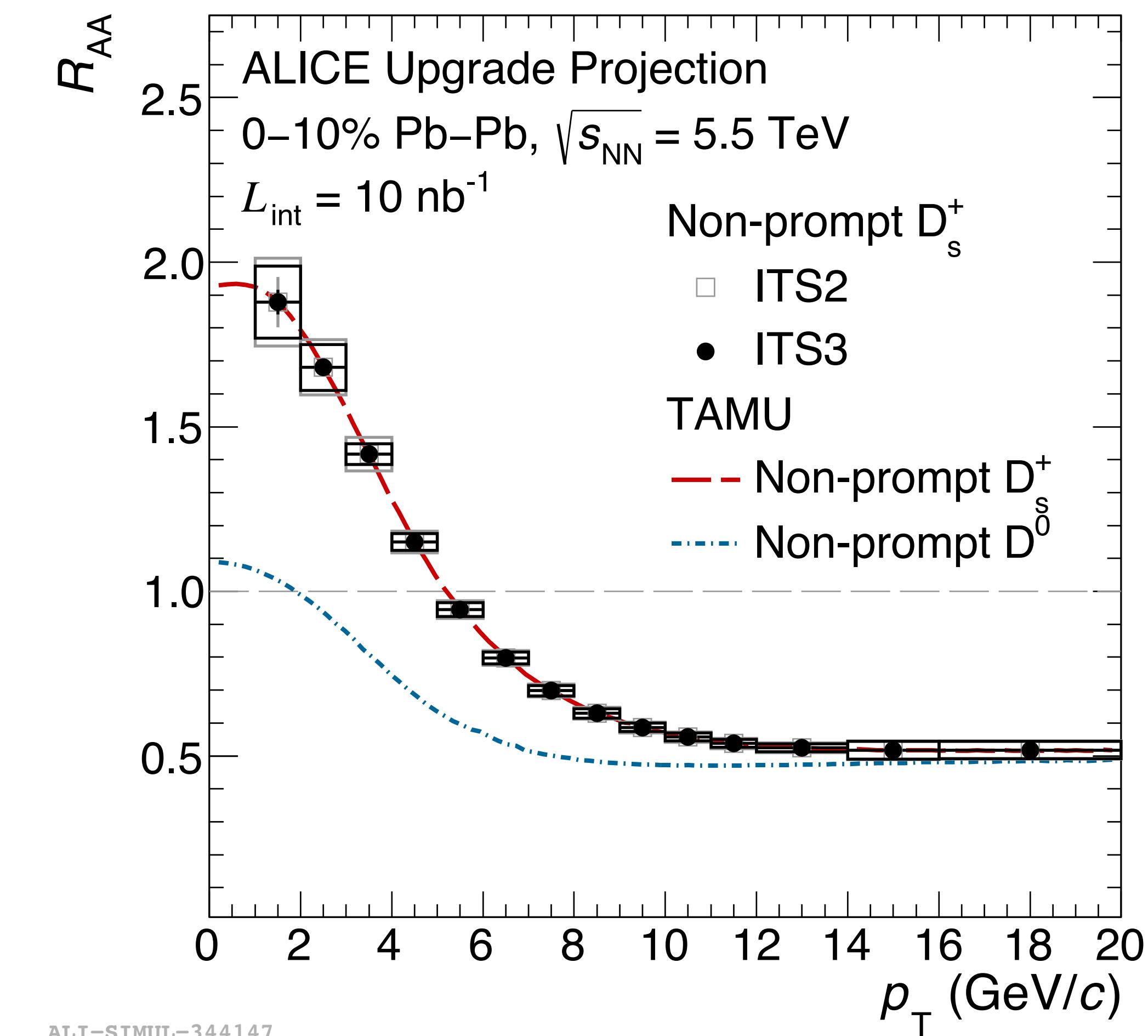
EXPECTED PERFORMANCE: NON-PROMPT D_s^+ NUCLEAR MODIFICATION FACTOR

$$D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+$$



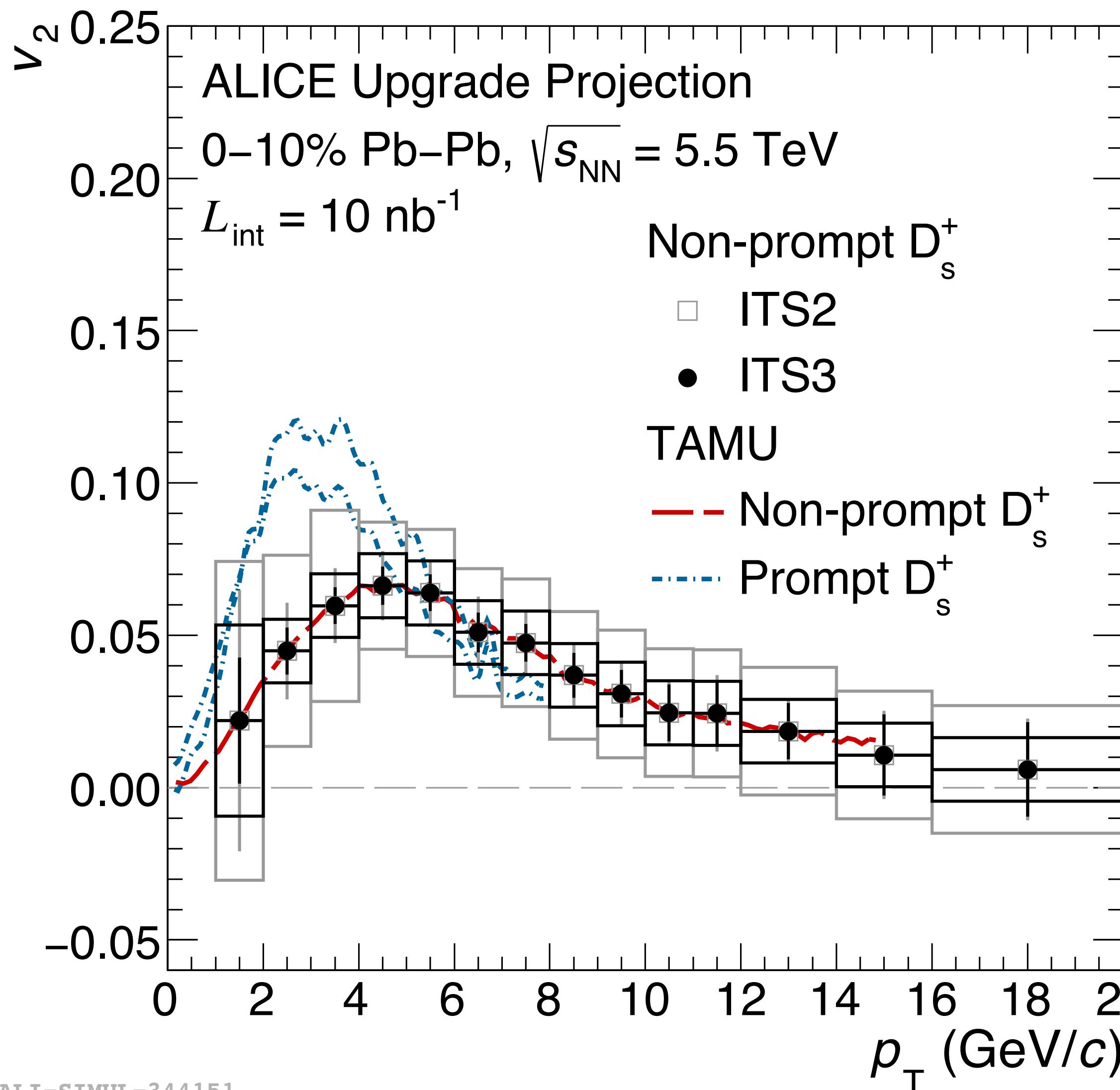
- non-prompt D_s^+ from B decays:
 - ▶ even if not direct measurement, **sensitive to B_s^0**
 - ▶ **larger statistical precision** than exclusive B_s^0 reconstruction
- Comparison between **non-prompt D_s^+** and **non-strange D mesons** sensitive to **beauty-quark hadronisation** and **strangeness enhancement**

$$R_{AA} = \frac{1}{\langle N_{\text{coll}} \rangle} \cdot \frac{dN_{\text{AA}}/dp_T}{dN_{\text{pp}}/dp_T}$$



ALI-SIMUL-344147

EXPECTED PERFORMANCE: NON-PROMPT D_s^+ AZIMUTHAL ANISOTROPY



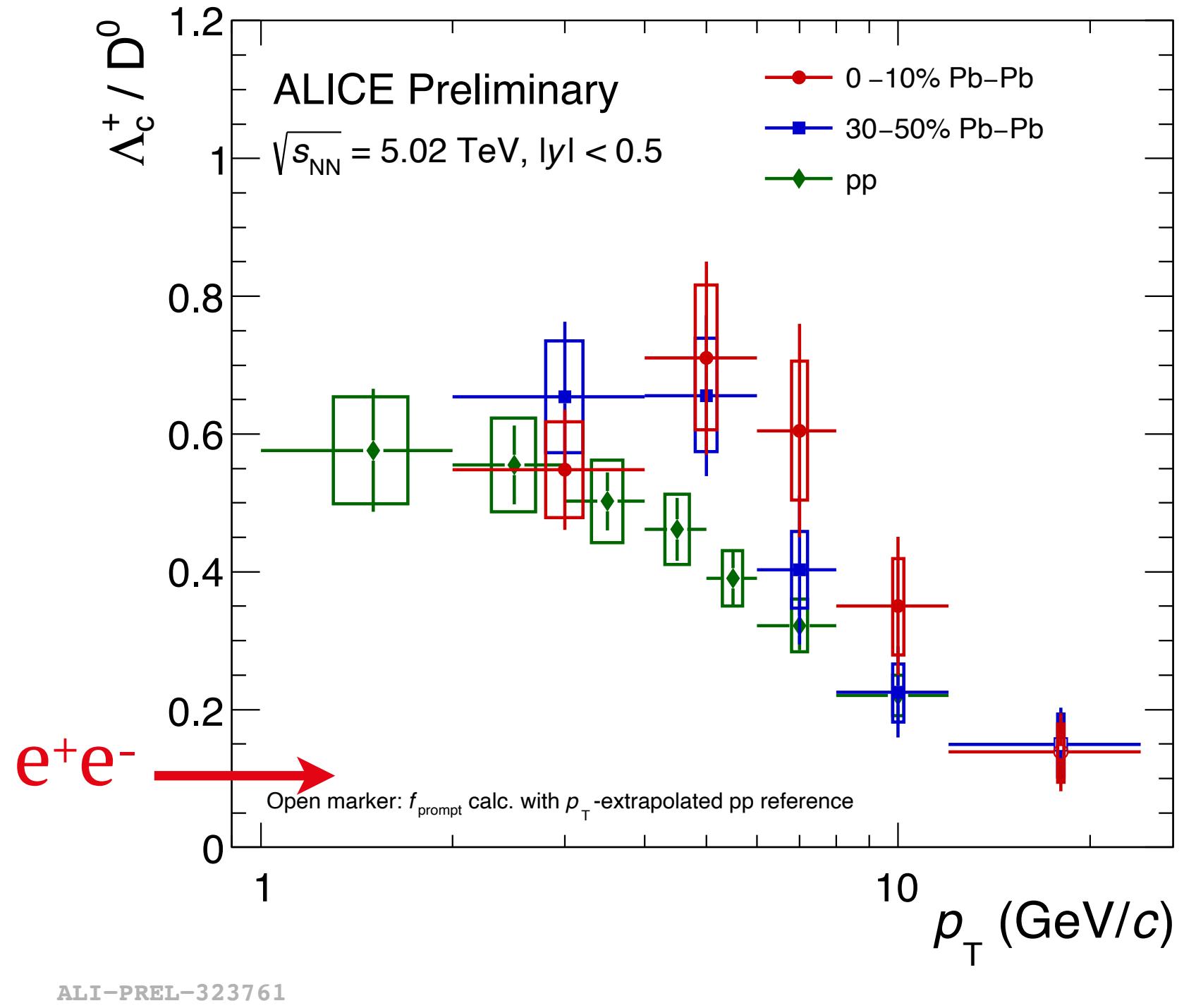
ALI-SIMUL-344151

TAMU: PLB 735, 445-450 (2014)

- Non-prompt D_s^+ azimuthal anisotropy
 - ▶ Participation of beauty quarks in the collective motion and possible thermalisation in the QGP
 - ▶ Information about beauty-quark diffusion coefficient in the QGP
- ITS3:
 - ▶ sensitivity to discriminate azimuthal anisotropy for prompt and non-prompt D_s^+ (charm vs. beauty)

EXPECTED PERFORMANCE: Λ_b^0 BARYONS

charm baryon-over-meson ratios in Run 2

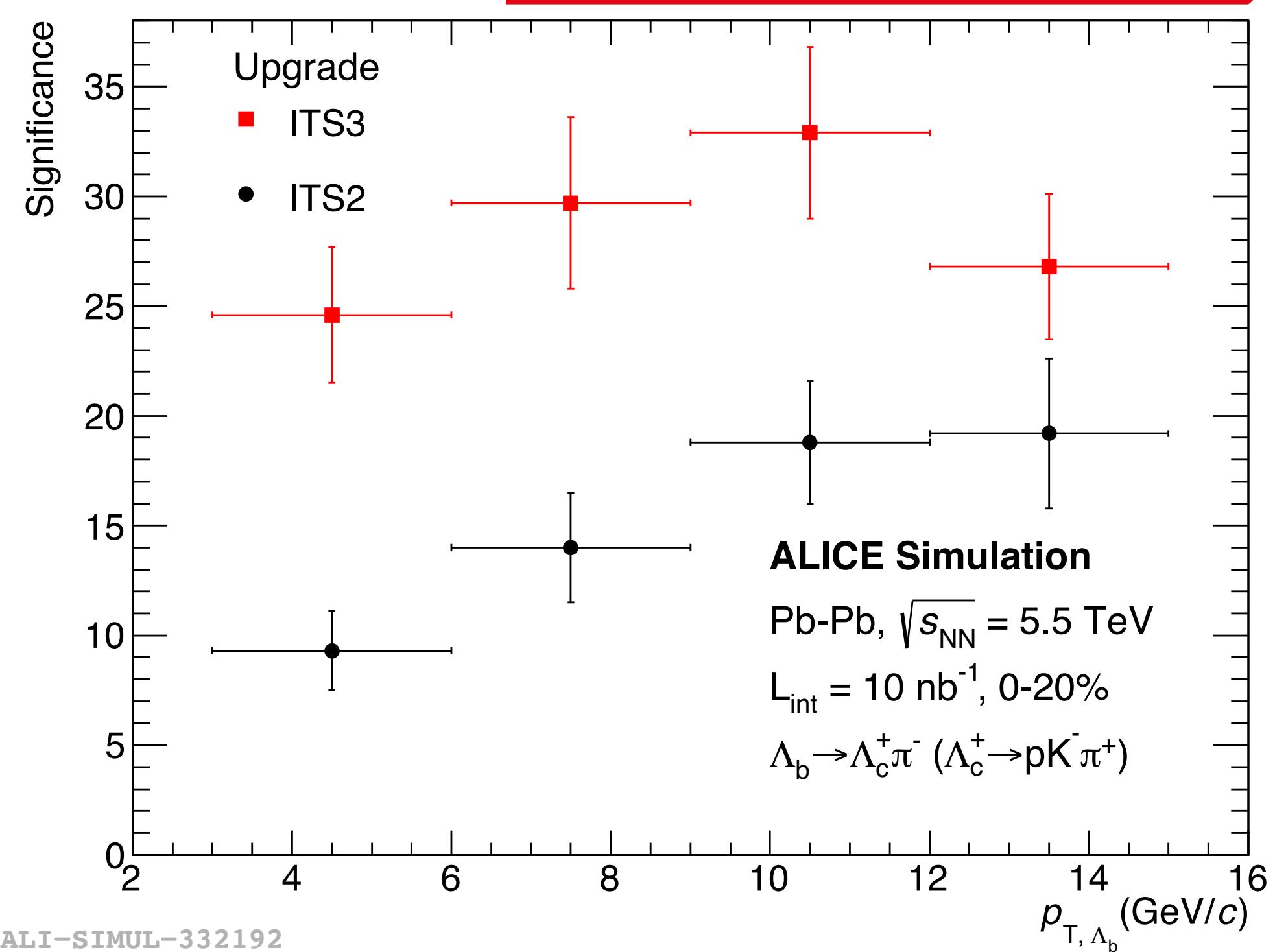
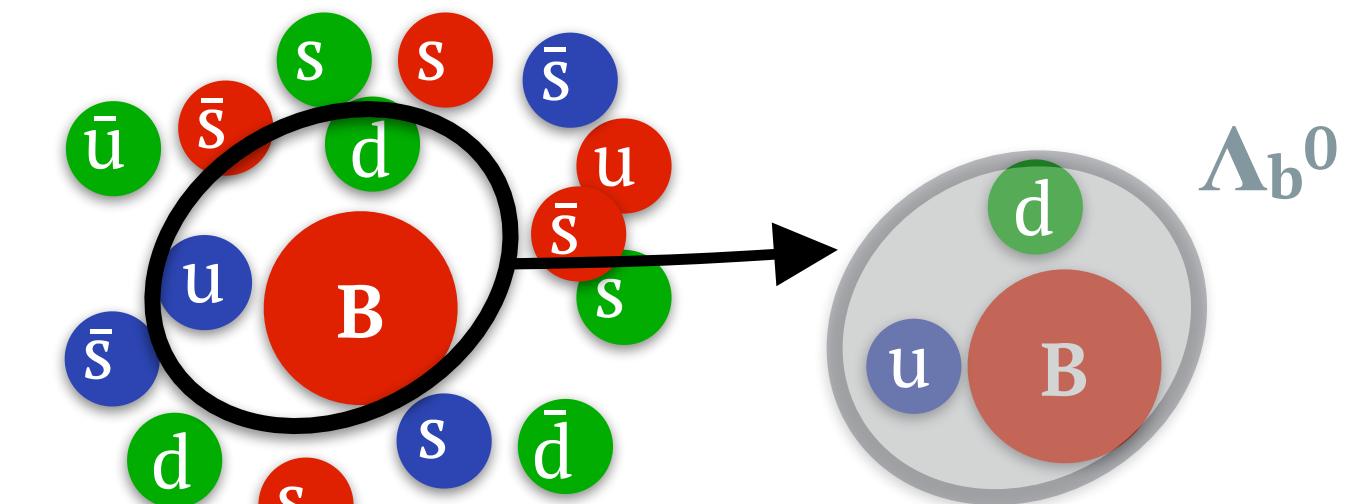


- Enhanced production of HF baryons in pp even more in Pb-Pb collisions

► probes of heavy-quark hadronisation and baryon formation

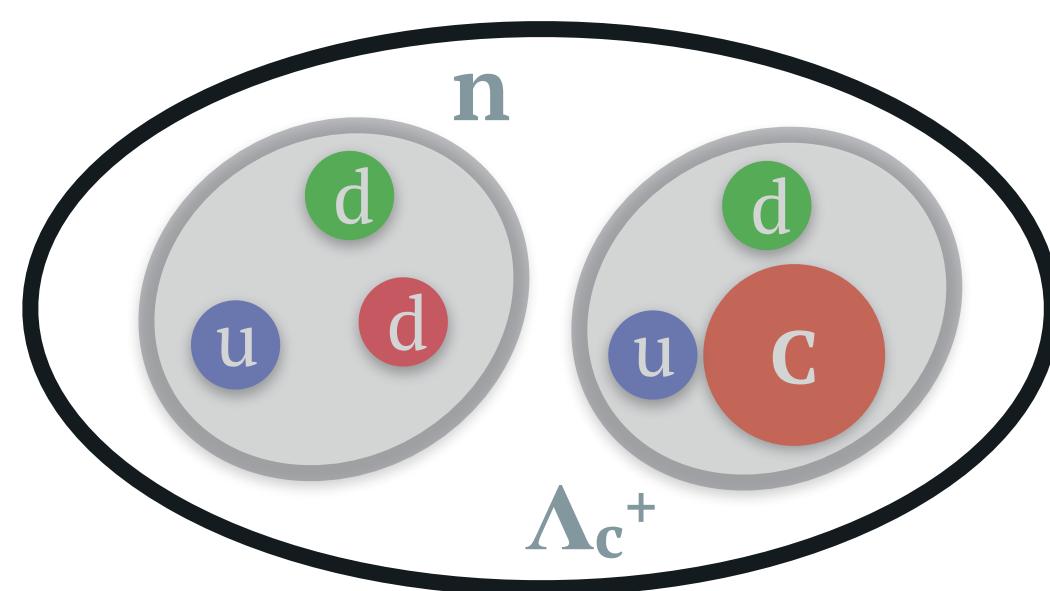
beauty baryons in Run 3 and 4

- Measurement of Λ_b^0 in Pb-Pb collisions already accessible with ITS2
- Expected improvement of statistical significance up to a factor 2.5 with ITS3

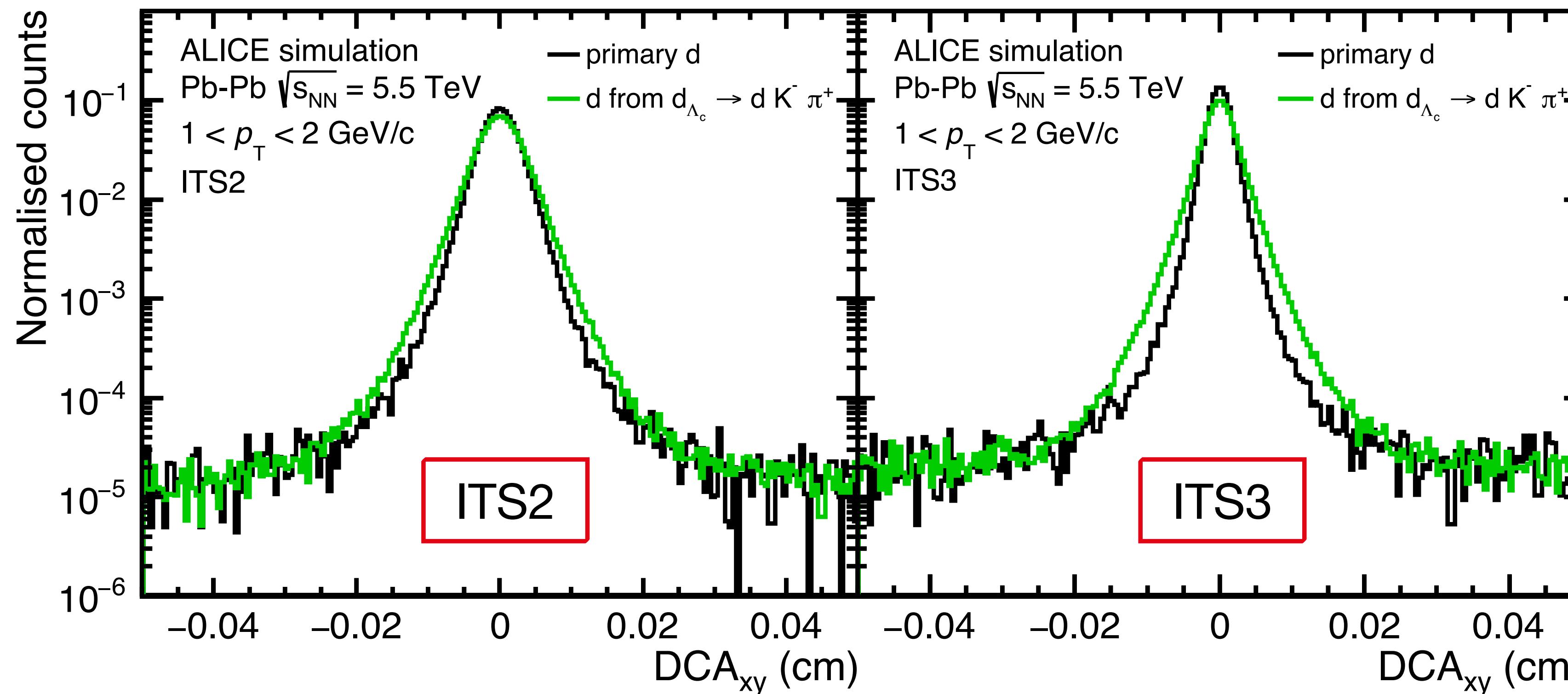


EXPECTED PERFORMANCE: C-DEUTERON

c-deuteron



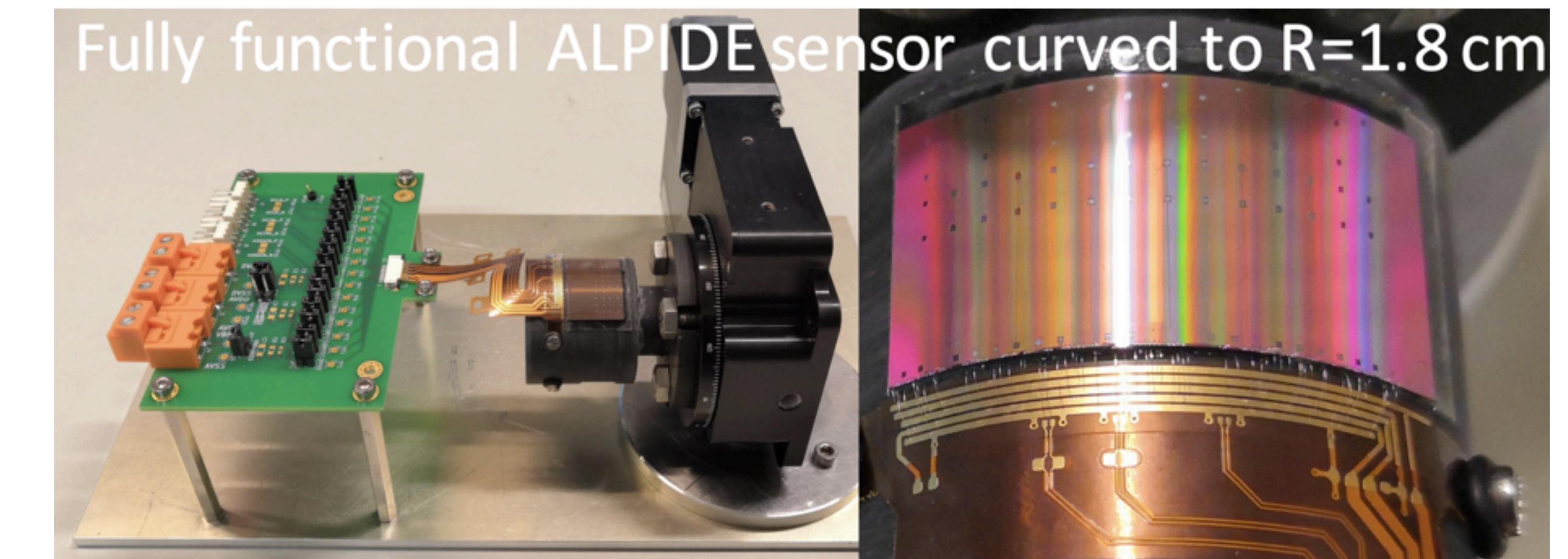
- Predicted already in the 70s  PRL 39, 1506 (1977)
- Never observed
- Lighter possible state: **c-deuteron (bound state of Λ_c^+ and neutron)**
- Considered decay $(\Lambda_c^+ n) \rightarrow d K^- \pi^+$



ALI-SIMUL-350149

- $c\tau(\Lambda_c^+) \approx 59.9$ μm  PRD 98, 030001 (2018)
- Impact-parameter distribution of **decay deuteron** crucial to discriminate signal from background

- The ALICE experiment is undergoing a **major upgrade** in LS2 in view of LHC Run 3
- New **upgrades** for LHC Run 4:
 - ▶ **FoCal**
 - ▶ high **granularity Forward Calorimeter** to instrument the forward region
 - ▶ measure photons, π^0 , and **jets** and **constrain the nuclear PDFs** in the low x region
 - ▶ **ITS3**
 - ▶ **truly cylindrical** silicon detector
 - ▶ novel detector technology based on **ultra-thin wafer-sized curved sensors**
 - ▶ improve measurements of **low-mass dileptons** and **HF particles**
 - ▶ searches for **exotic nuclei**





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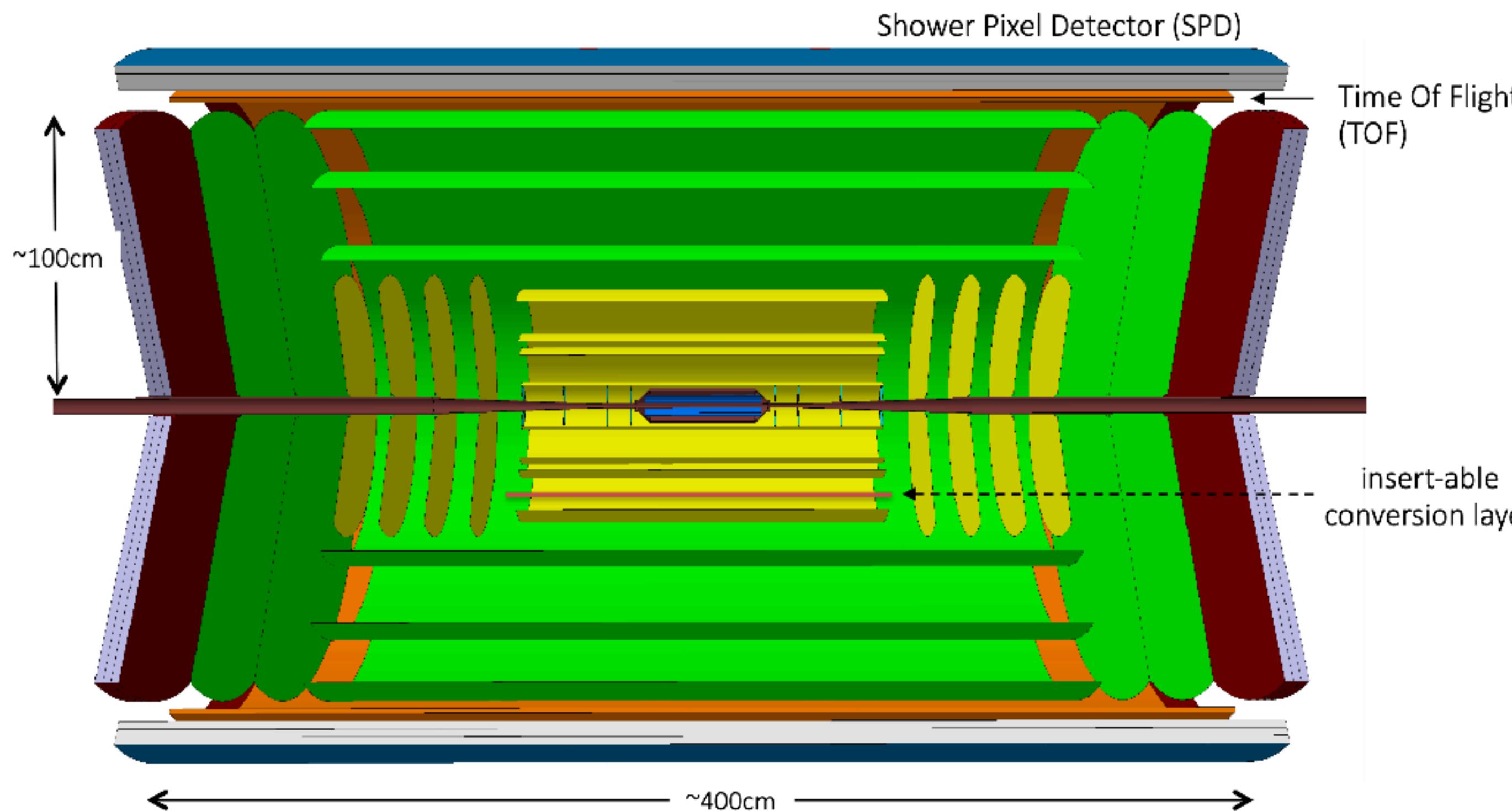
Bruno Mazoyer - LAL Orsay 2020



BACKUP SLIDES

WHAT'S NEXT?

arXiv:1902.01211



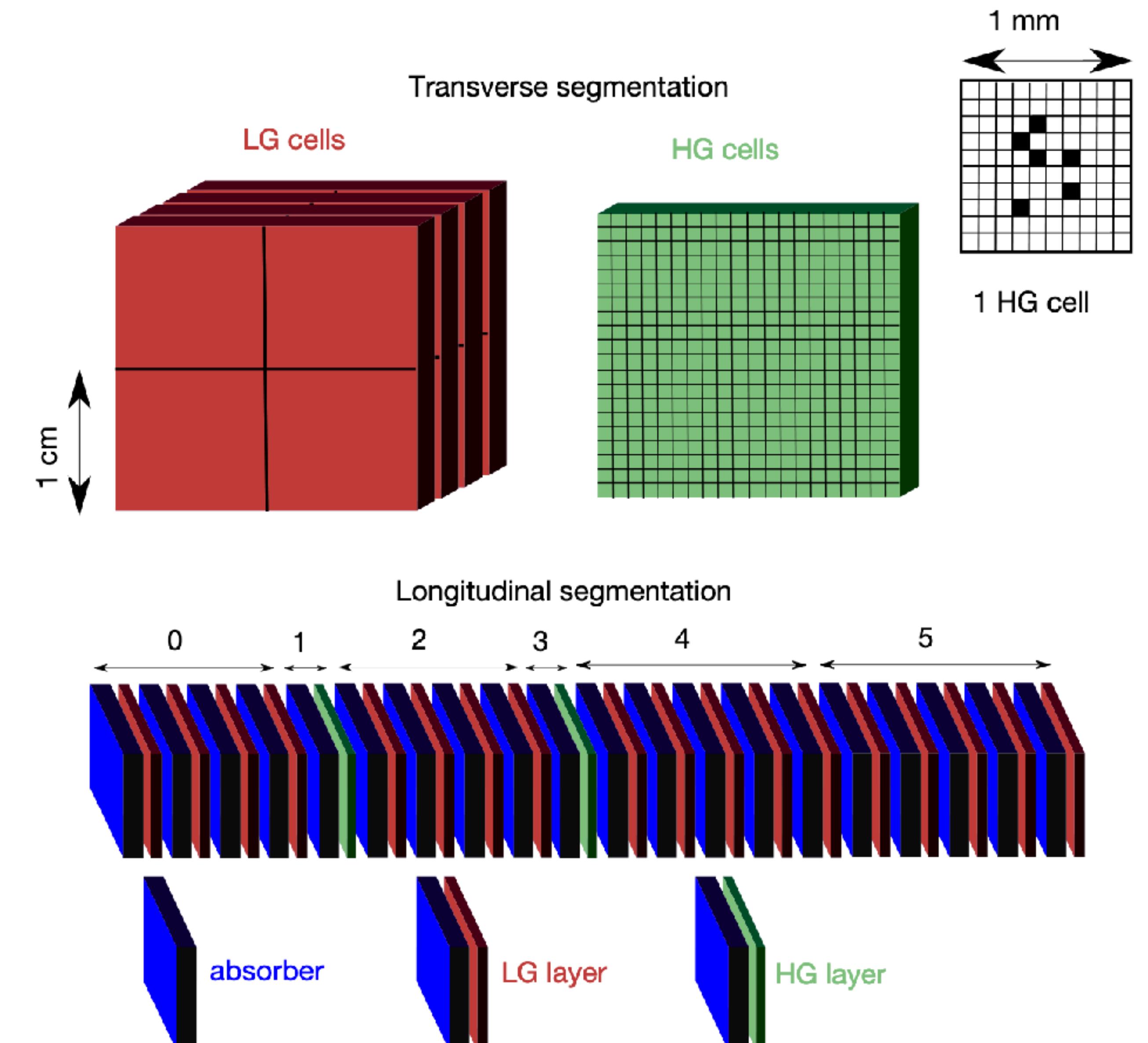
- Access to new measurements in heavy-ion collisions
 - ▶ multi-charm baryons
 - ▶ precision measurements of di-lepton spectra
 - ▶ soft and ultra-soft photons

- Expression of interest for a “all silicon” detector to be installed during LS4
 - ▶ increase rate capabilities
 - ▶ high spatial resolution ($\sim 3\text{-}5 \mu\text{m}$)
 - ▶ wide momentum and pseudorapidity acceptance
 - ▶ particle identification via time-of-flight layers
- Submitted as input to the European Strategy Update

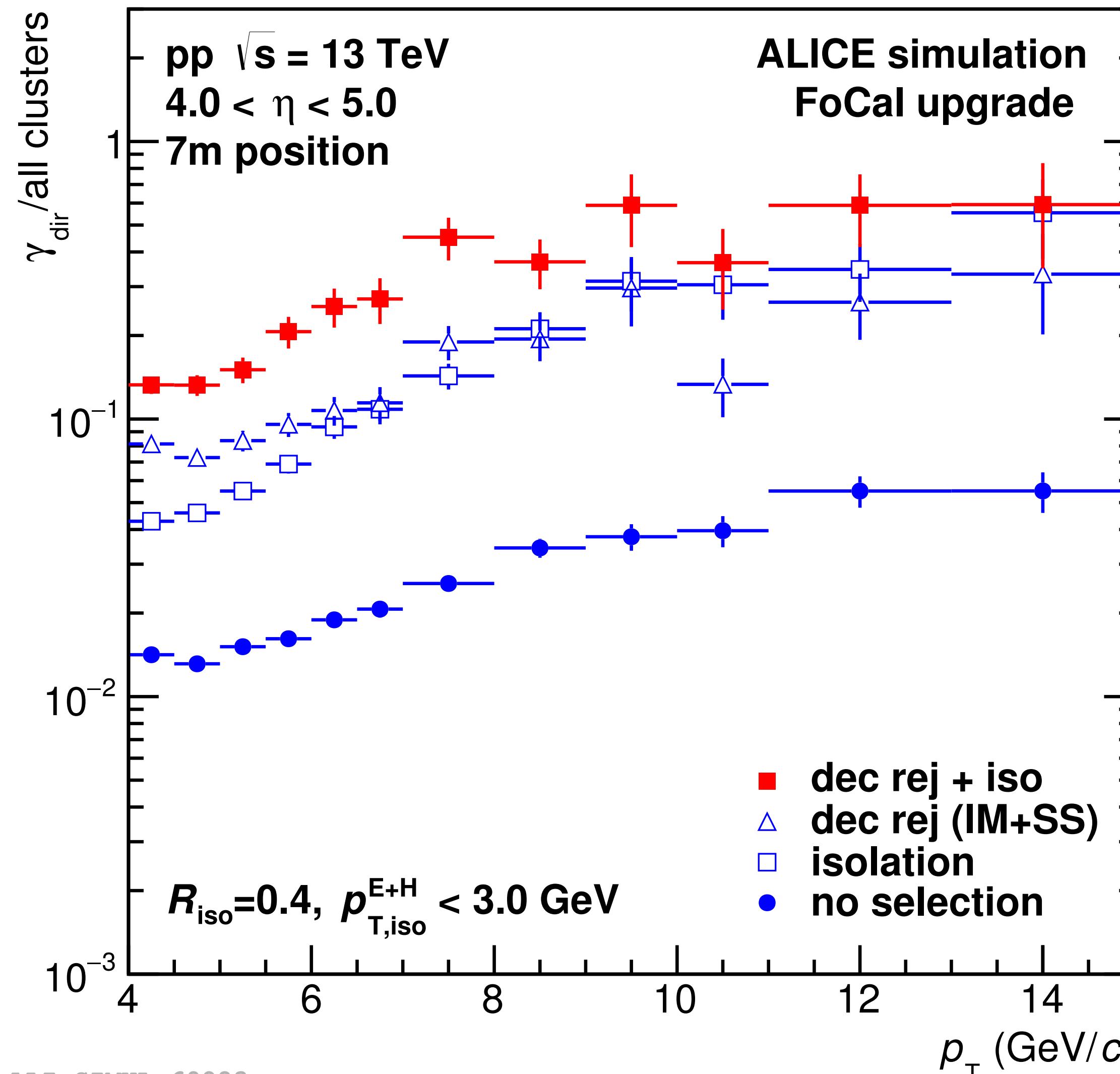
R. Preghenella 25 May, 15h00

THE FOCAL DESIGN

- The design of the detector:
 - 20 layers: W ($3.5 \text{ mm} \sim 1X_0$)
 - Si sensors of 2 types:
 - low granularity (LG) Si pads**
 - high granularity (HG), pixels** (e.g. CMOS MAPS)
- Moliere radius $\sim 1\text{-}2 \text{ cm}$



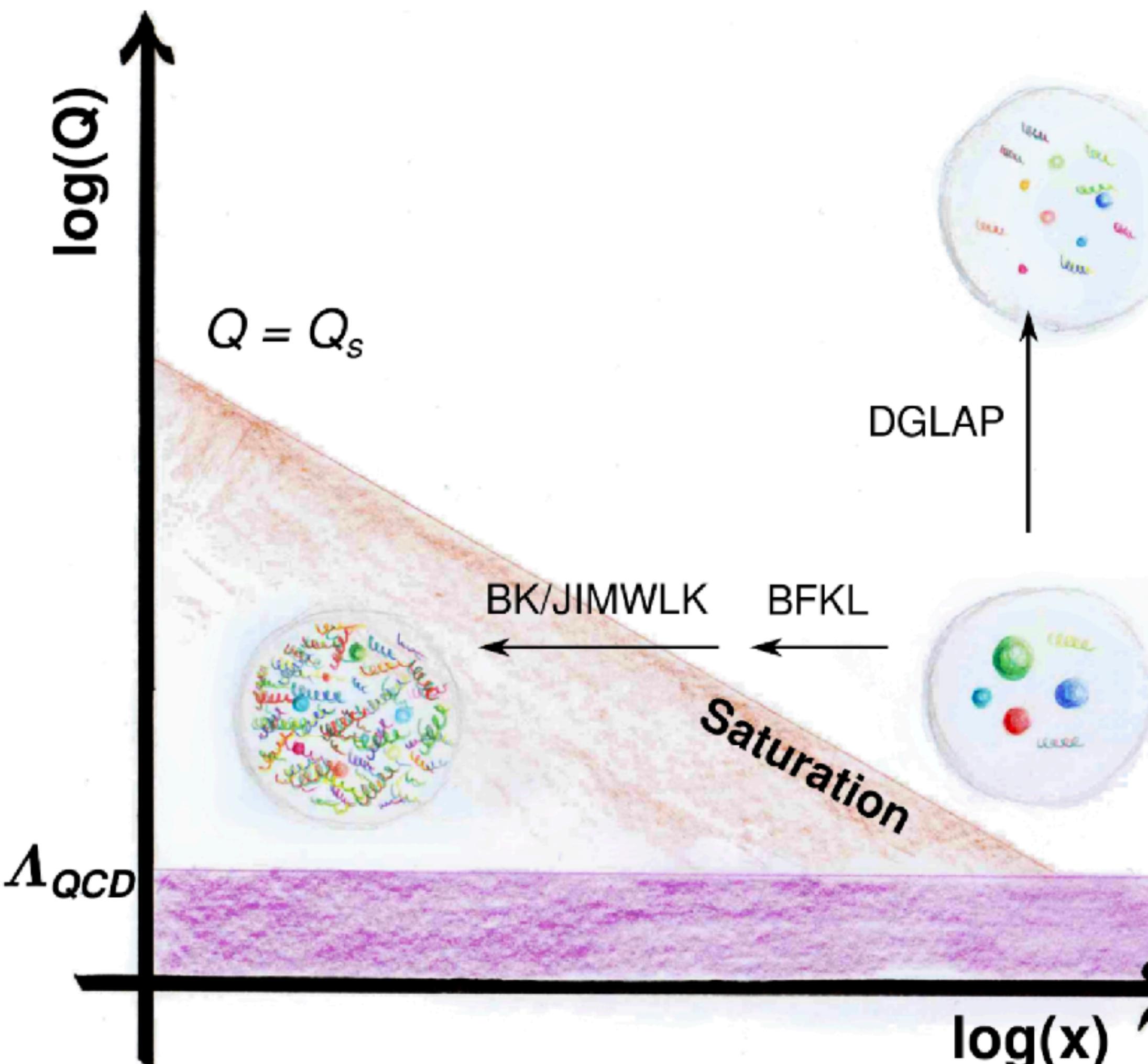
EXPECTED PERFORMANCE: ISOLATED PHOTON MEASUREMENT



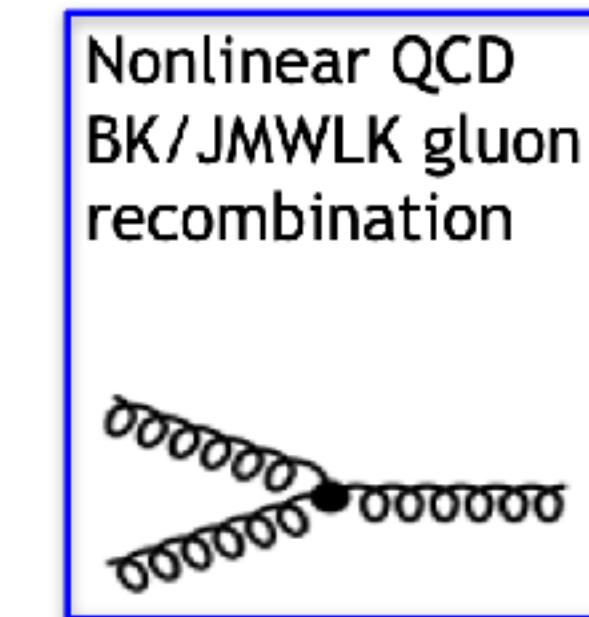
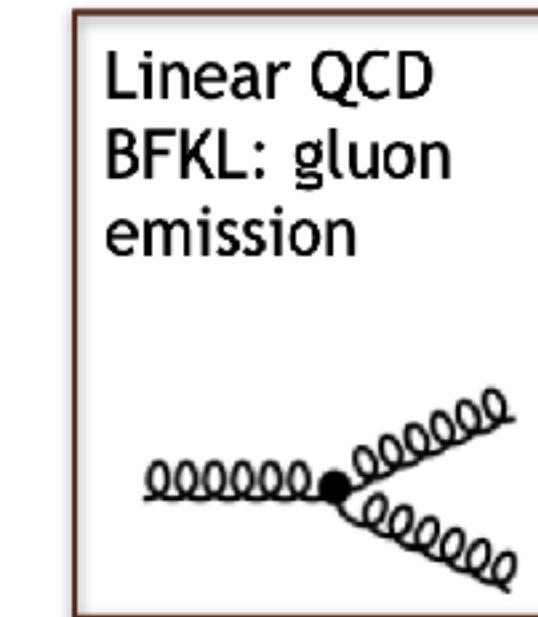
ALI-SIMUL-69823

- Small direct γ over π^0 ratio requires rejection of decay photons
- Direct rejection: pair mass selection + shower shape selection enabled by high granularity
- Isolation cut: reject decay (+fragmentation) photons based on energy in cone
- Combined background rejection factor around 10

GLUON SATURATION



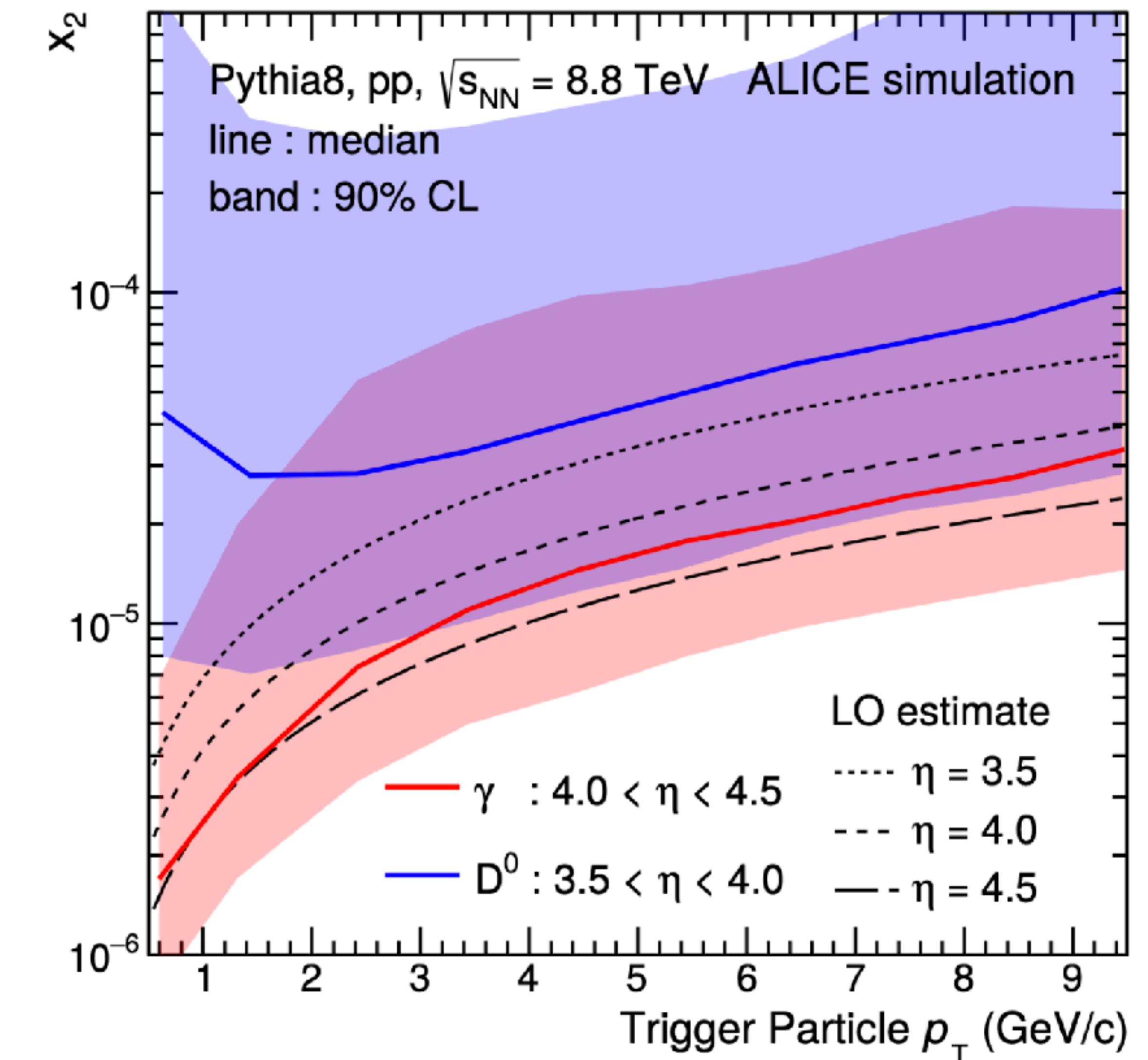
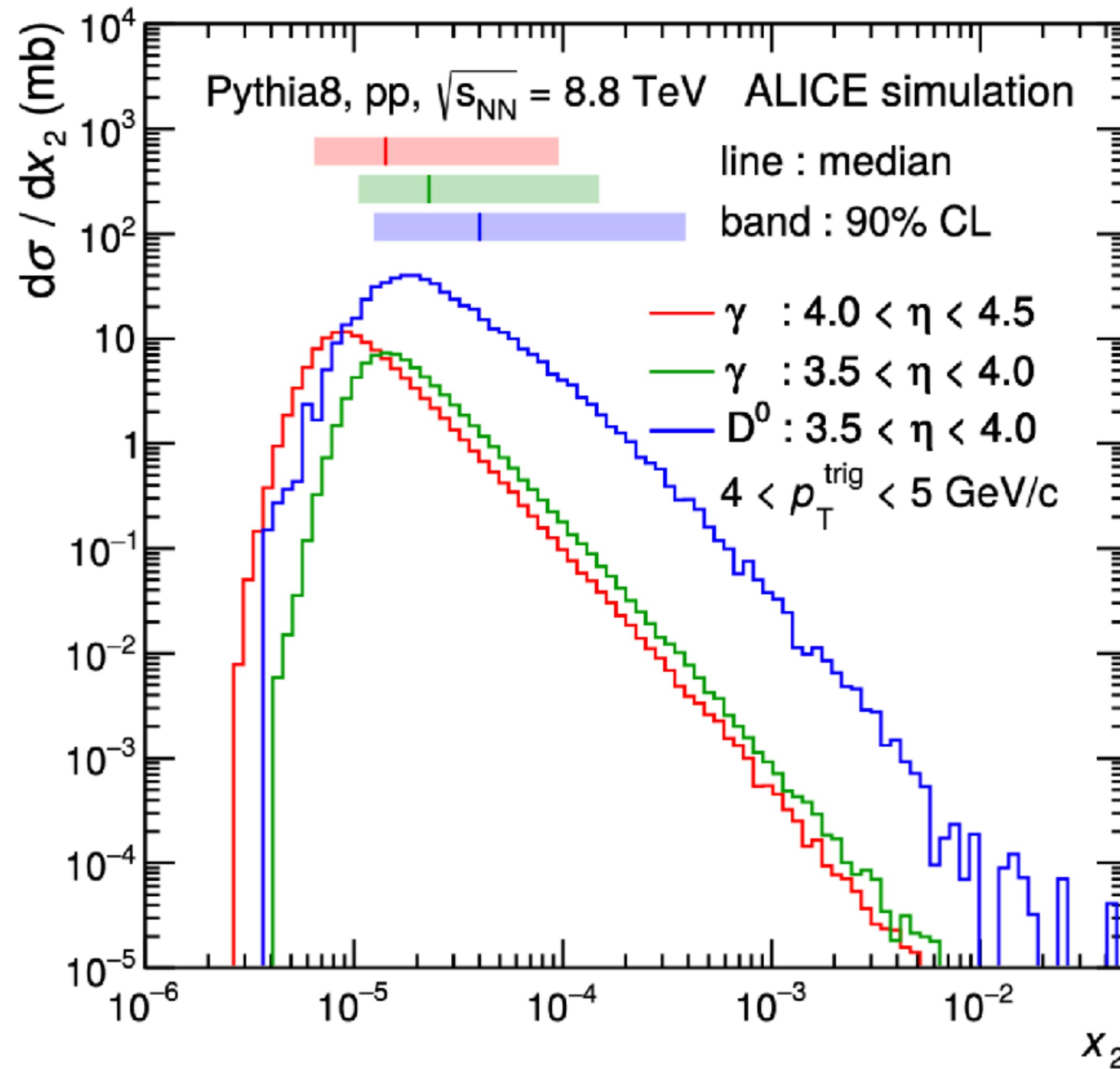
- BFKL as well as DGLAP are linear equations and only include parton splitting
- At sufficiently high gluon densities, gluon would also recombined as described by BK/JMWLK equations



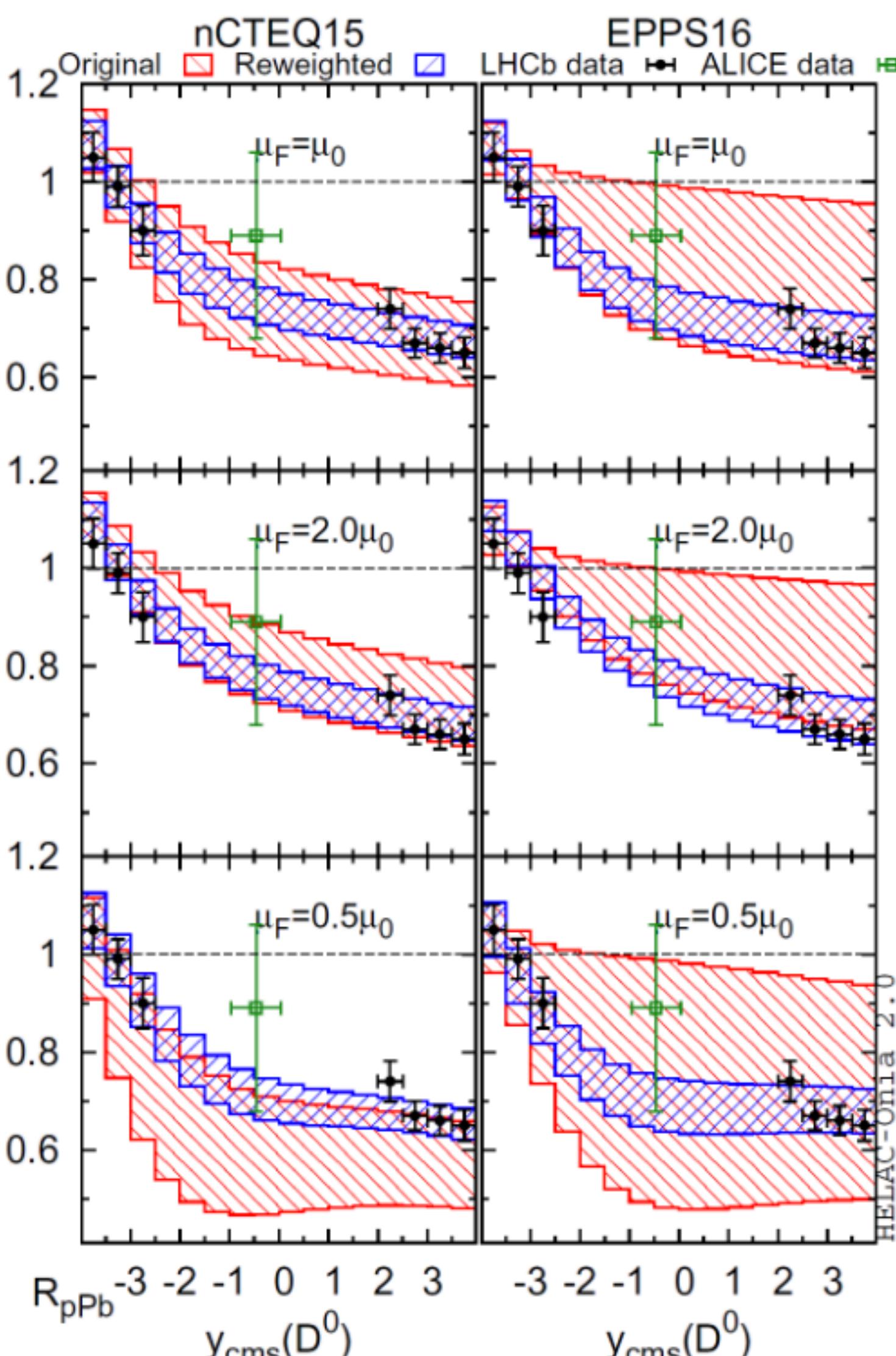
- When these two processes are in equilibrium, the number of gluons are constant

$$Q_s^2 \approx \frac{x G_A(x, Q^2)}{\pi R_A^2} A^{1/3} x^{-\lambda}$$

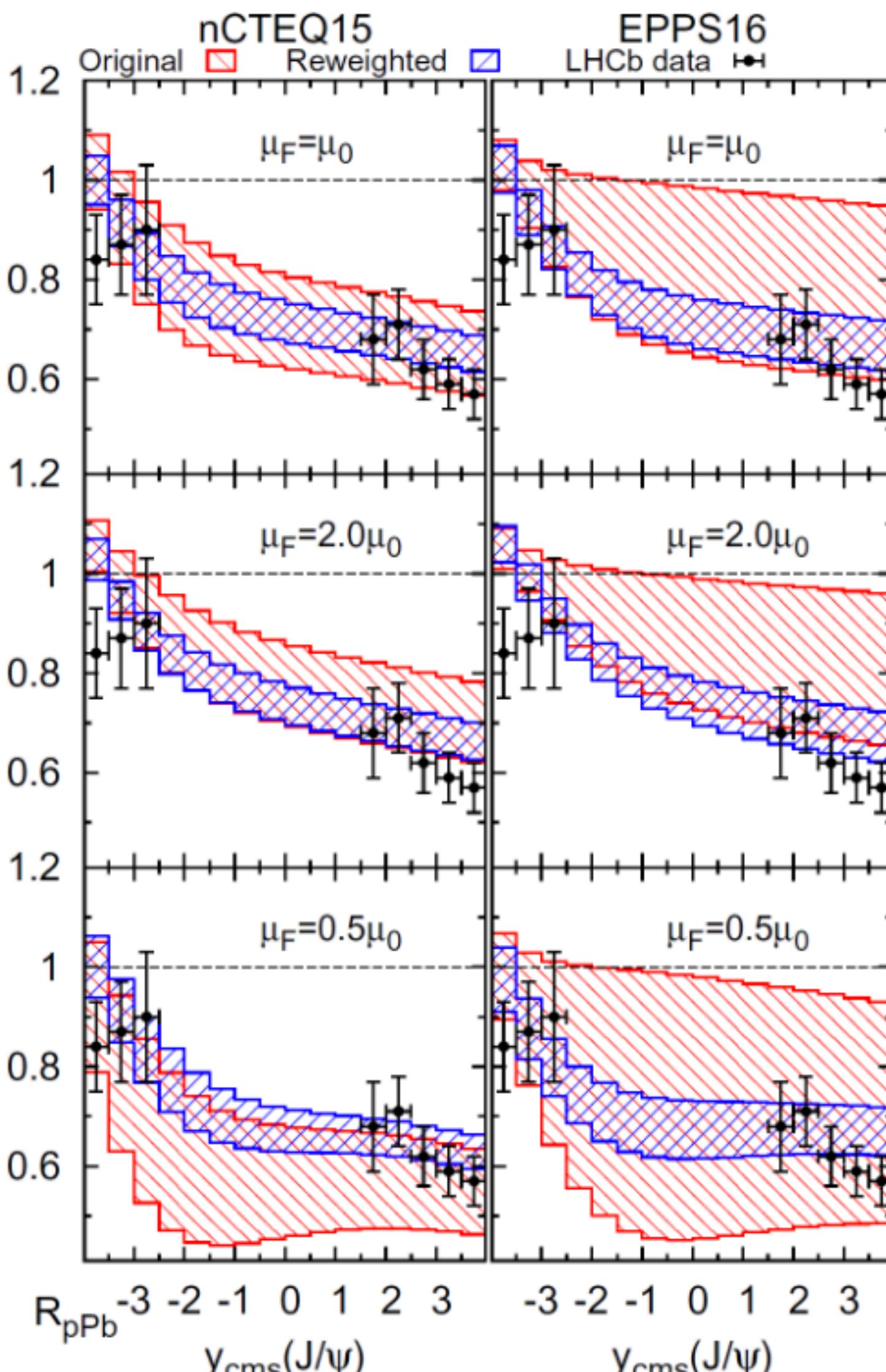
SENSITIVITY TO LOW-X NPDF_S: OPEN CHARM VS. PHOTONS



CONSTRAIN TO NPDF_S FROM FORWARD HF MEASUREMENTS



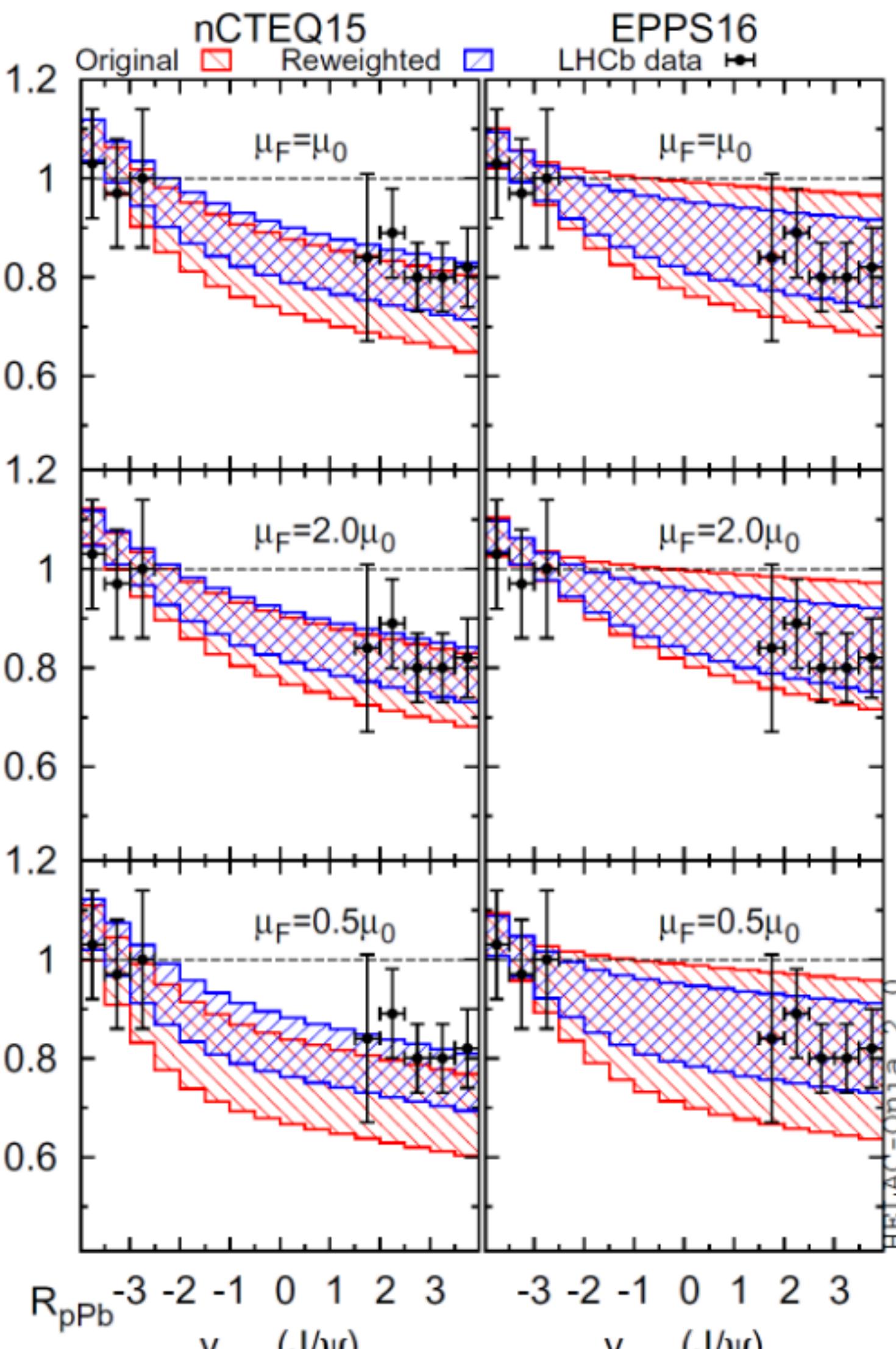
(a) Prompt D^0



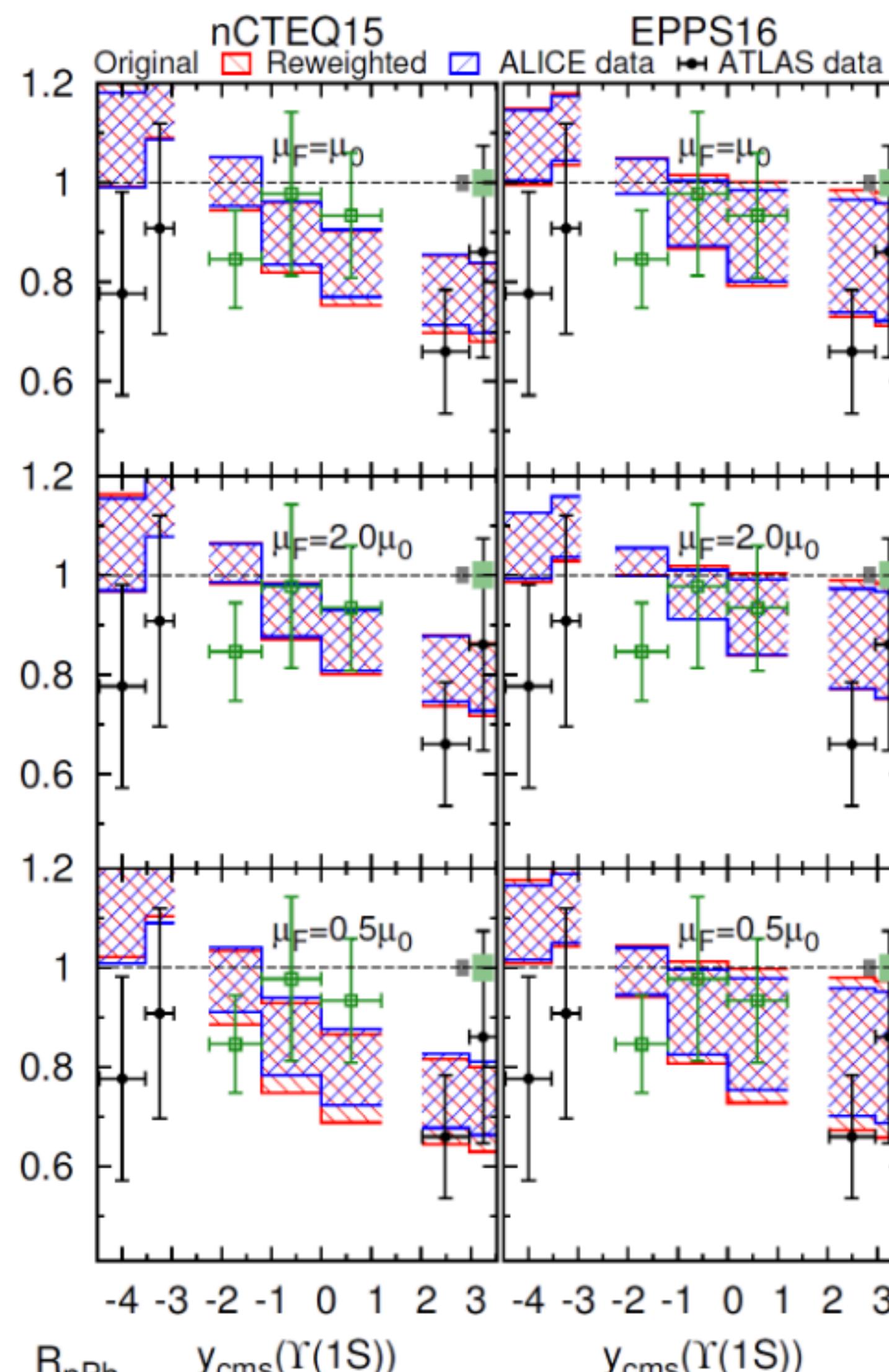
(b) Prompt J/ψ

- Acta Phys. Polon. B 49 (2018), 1185-1198
- arXiv:1707.02750
- PLB 774, 159 (2017)
- PLB 740, 105 (2015)
- PRC 94, 054908 (2016)
- EPJC 78, 171 (2018)

CONSTRAIN TO NPDF_S FROM FORWARD HF MEASUREMENTS



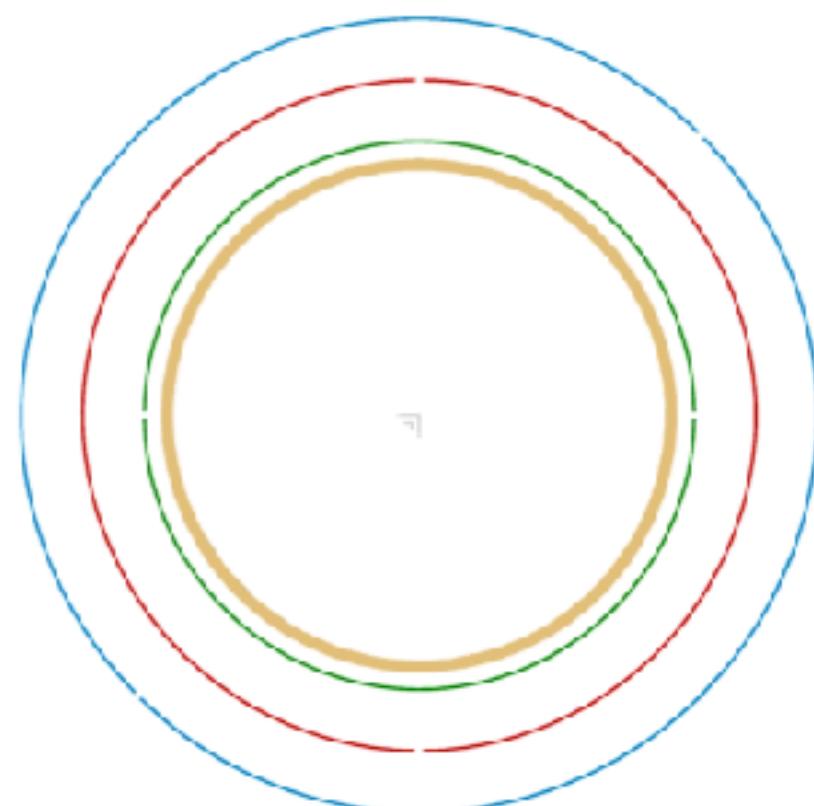
(c) $B \rightarrow J/\psi$



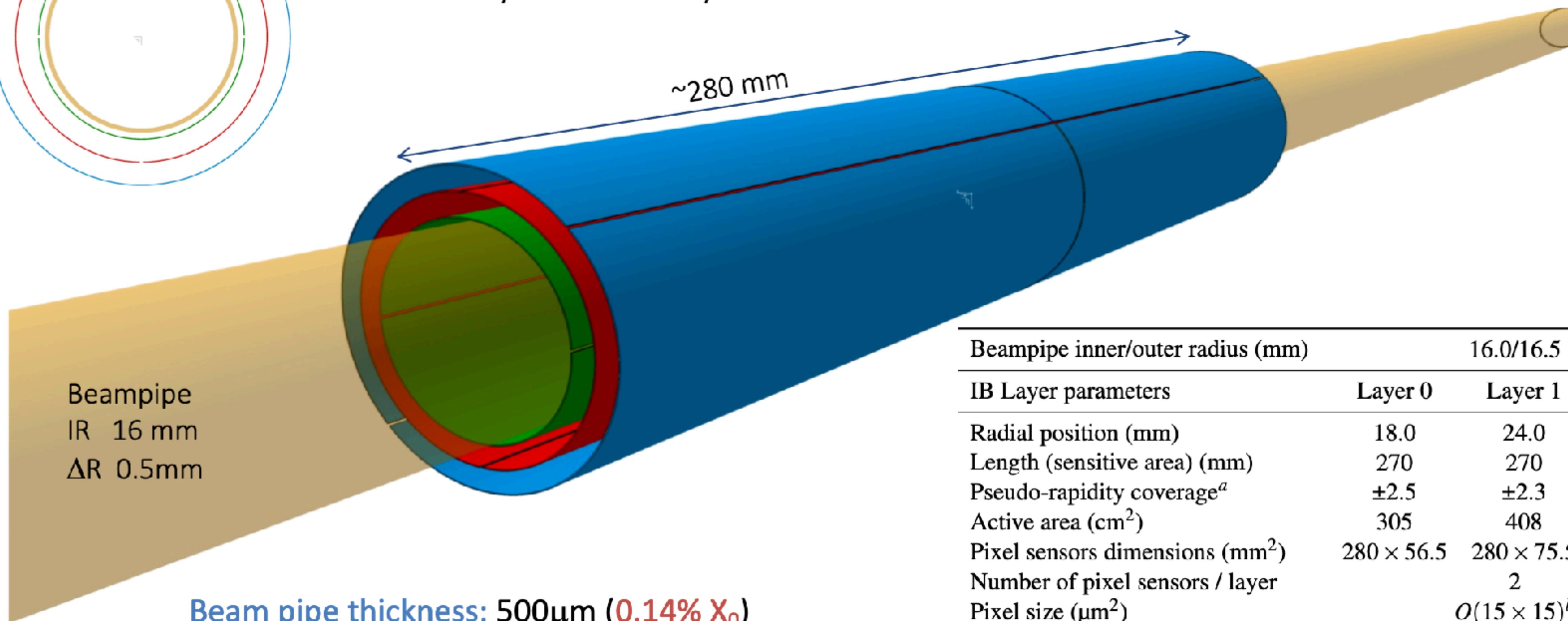
(d) $\Upsilon(1S)$

- Acta Phys. Polon. B 49 (2018), 1185-1198
- arXiv:1707.02750
- PLB 774, 159 (2017)
- PLB 740, 105 (2015)
- PRC 94, 054908 (2016)
- EPJC 78, 171 (2018)

GEOMETRICAL PARAMETERS OF ITS3



New Beampipe: $r \approx 16\text{mm}$, $\Delta R = 0.5\text{mm}$
L0: $r \approx 18\text{mm}$, **L1:** $r \approx 24\text{mm}$, **L2:** $r \approx 30\text{ mm}$

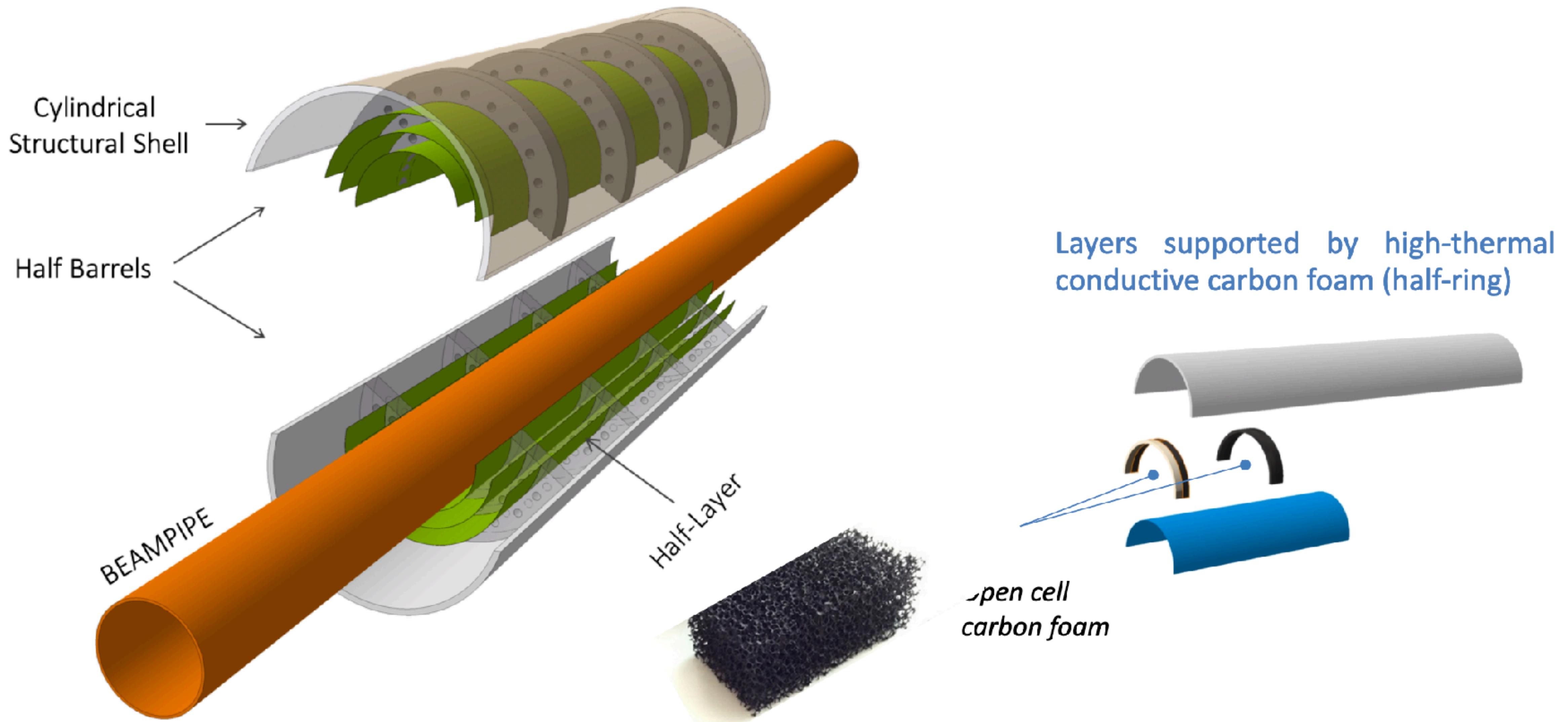


Beampipe inner/outer radius (mm)	16.0/16.5		
IB Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	270	270	270
Pseudo-rapidity coverage ^a	± 2.5	± 2.3	± 2.0
Active area (cm^2)	305	408	508
Pixel sensors dimensions (mm 2)	280×56.5	280×75.5	280×94
Number of pixel sensors / layer	2		
Pixel size (μm^2)	$O(15 \times 15)^b$		

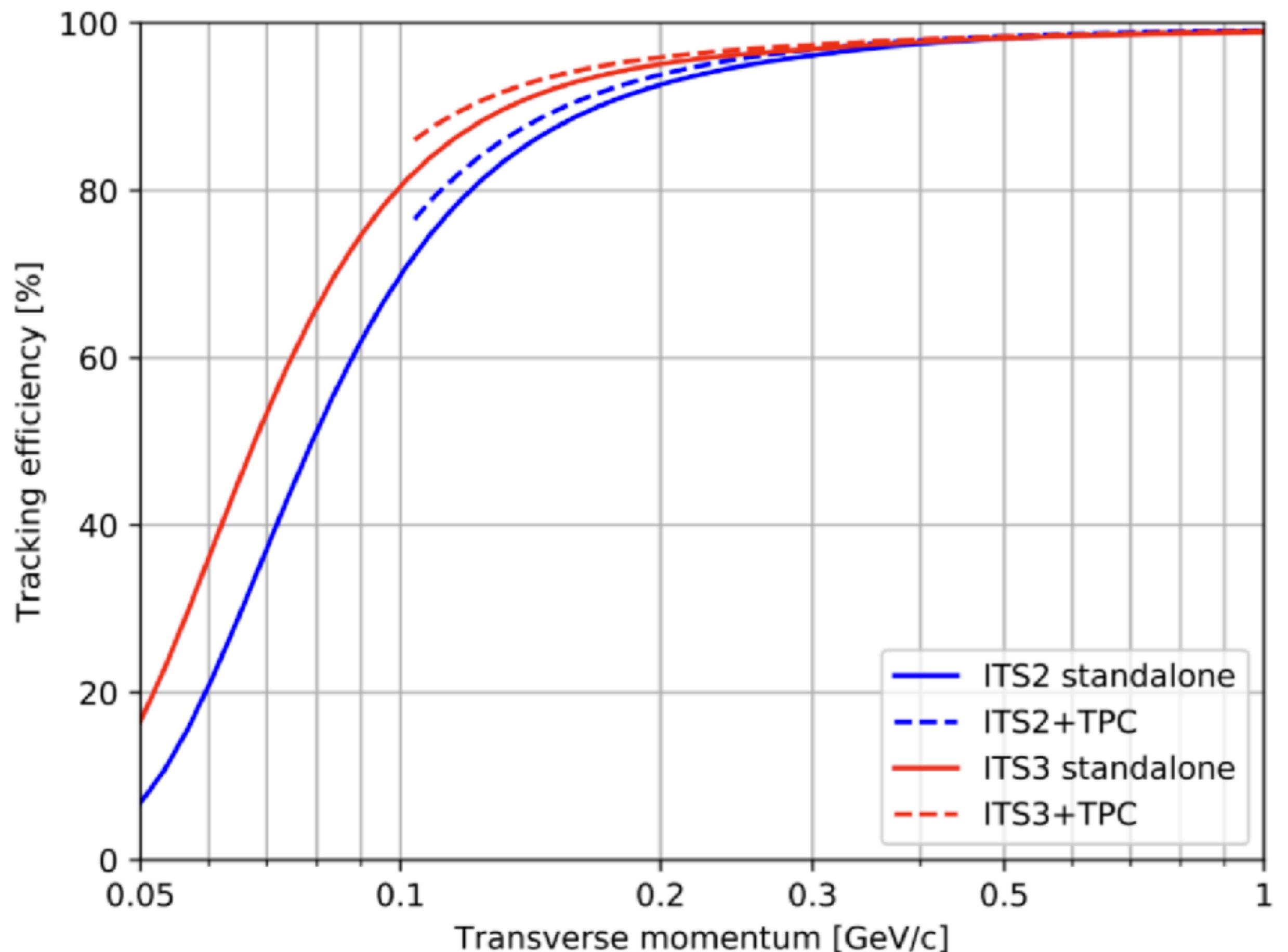
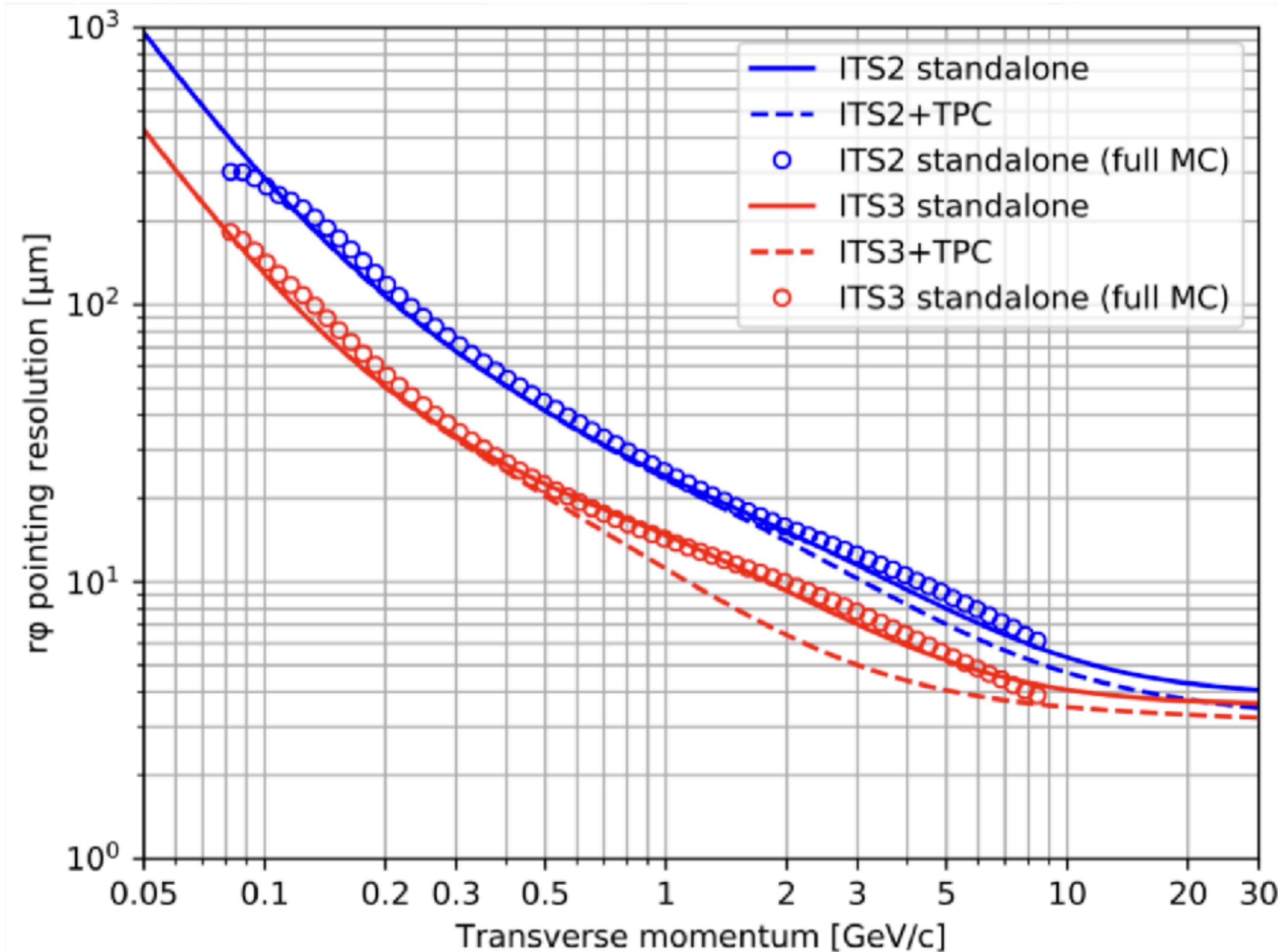
^a The pseudorapidity coverage of the detector layers refers to tracks originating from a collision at the nominal interaction point ($z = 0$).

^b For the fallback solution the pixel size is about a factor two larger ($O(30 \times 30) \mu\text{m}^2$).

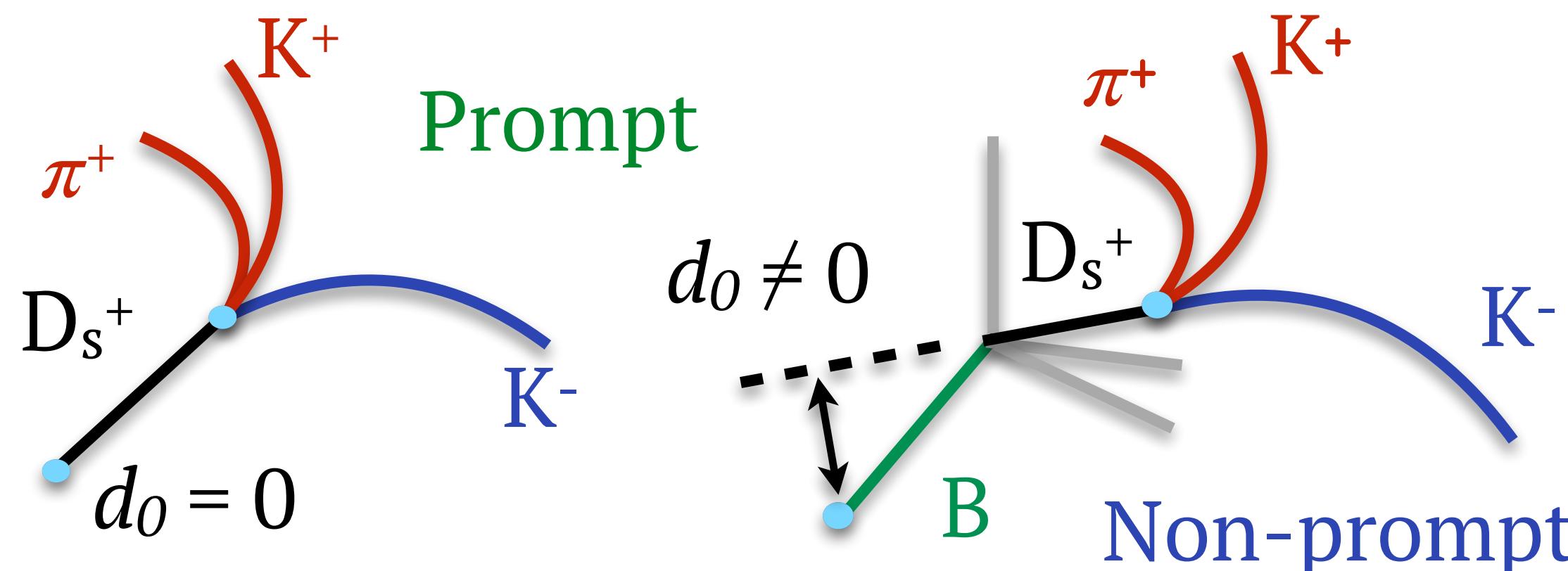
MECHANICAL LAYOUT OF ITS3



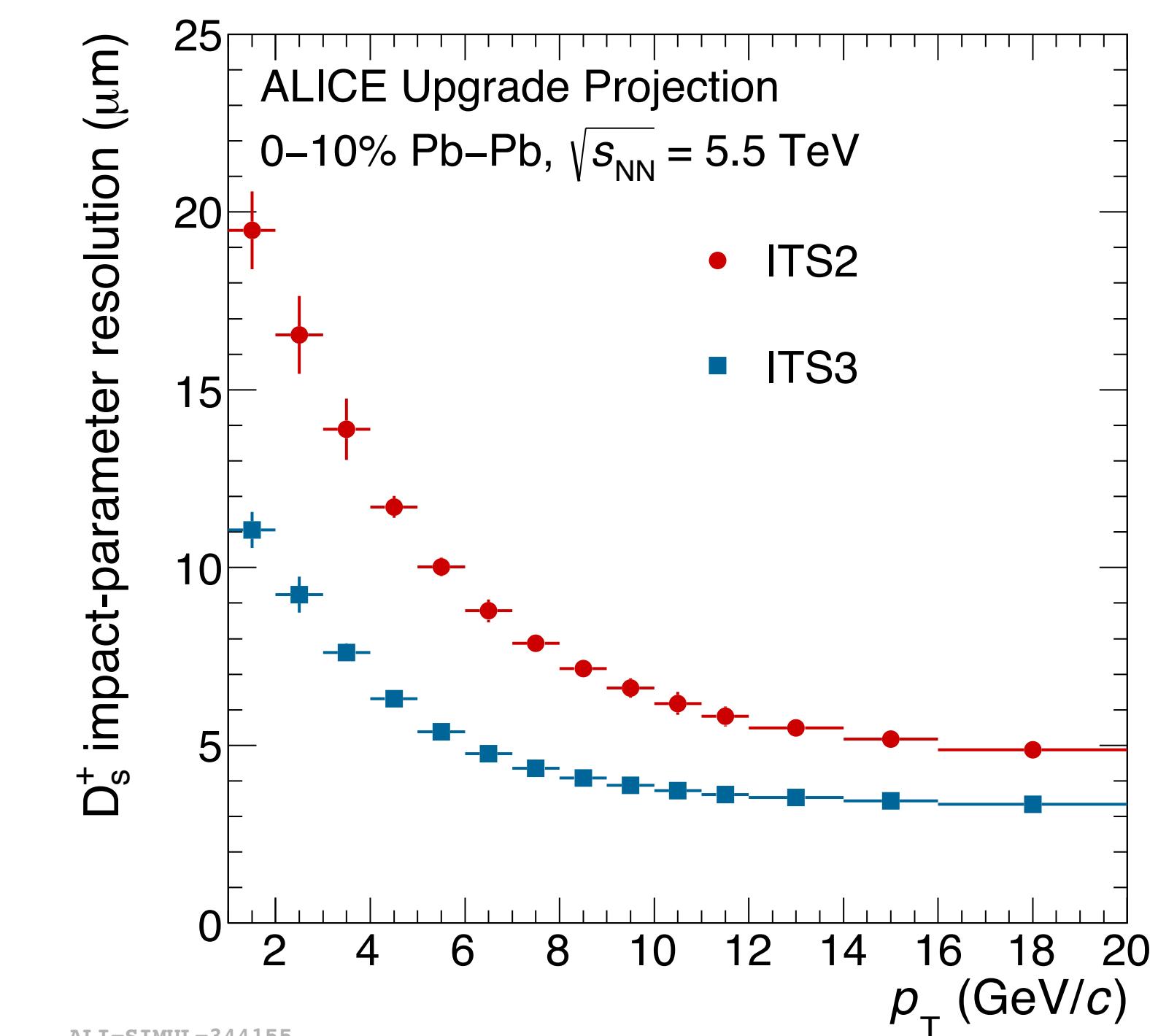
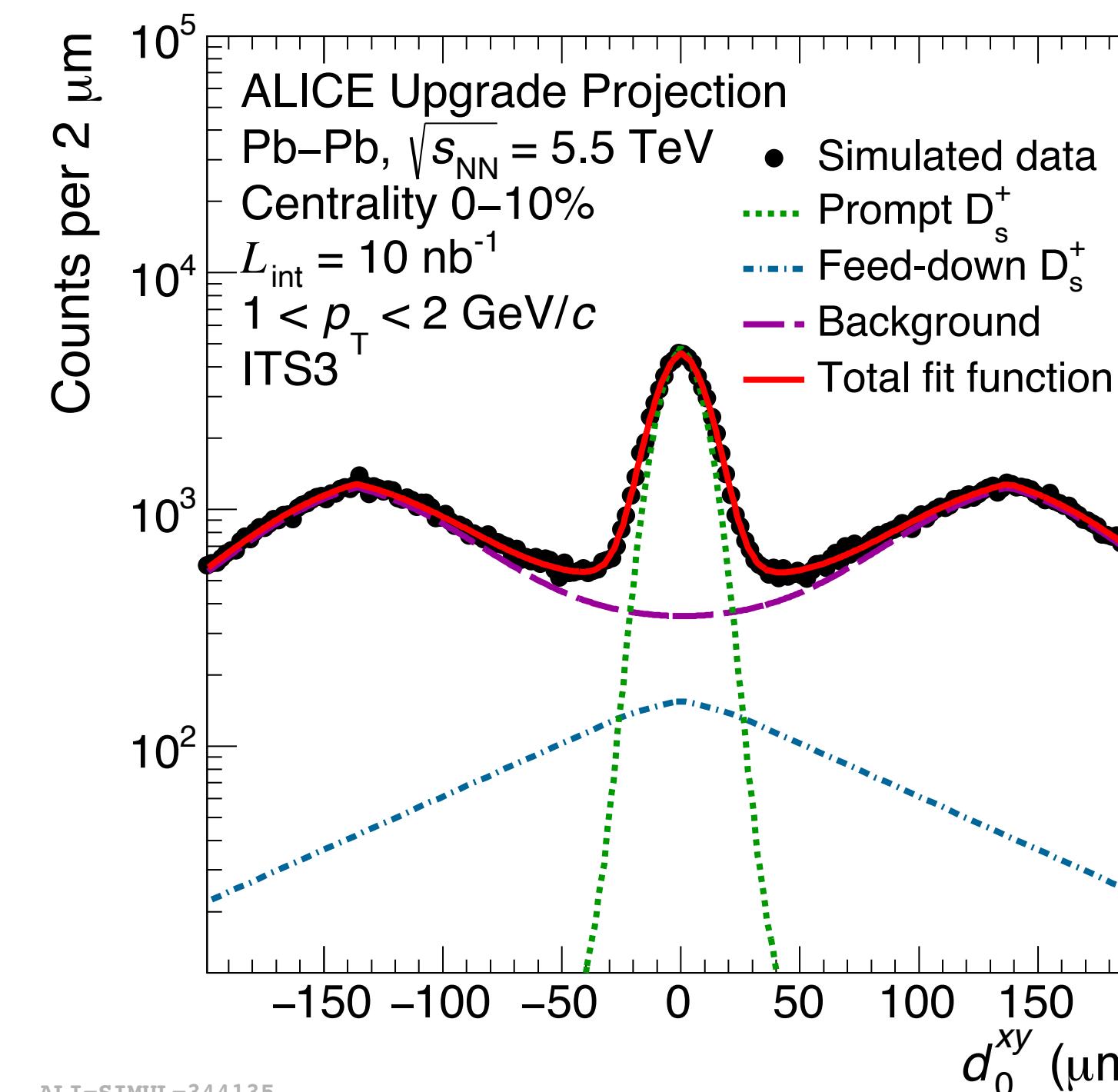
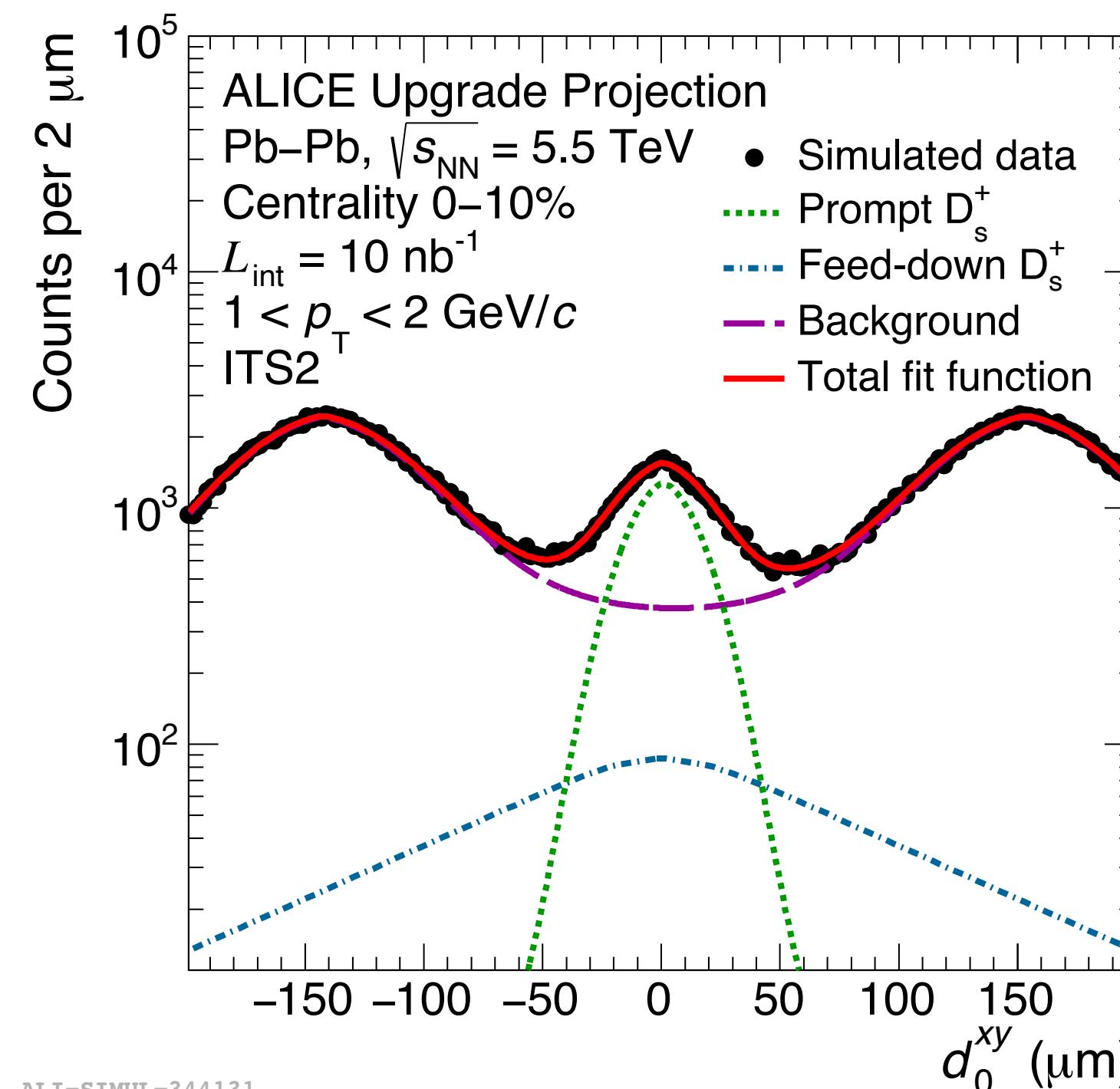
ITS3 TRACKING AND VERTEXING PERFORMANCE



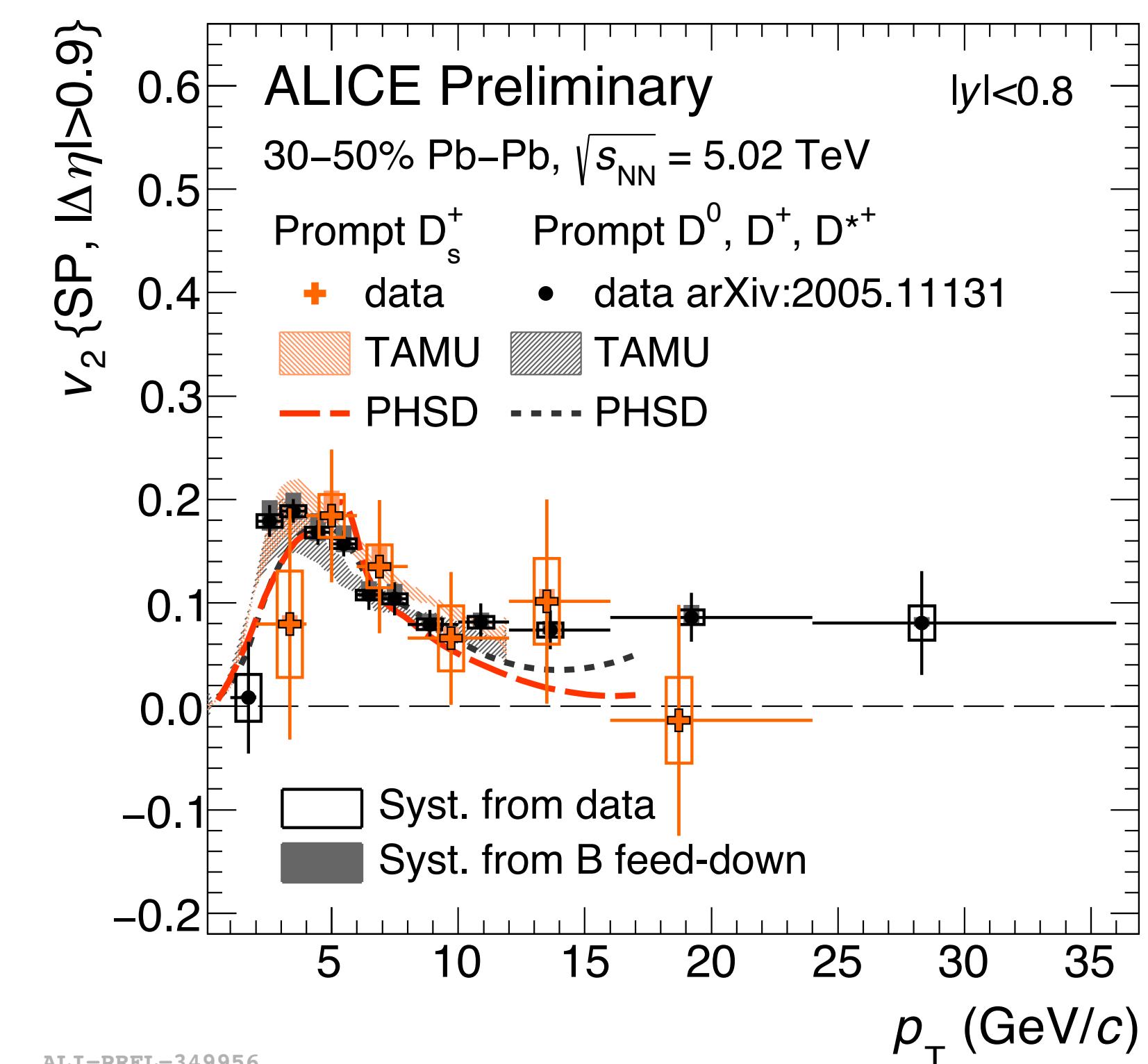
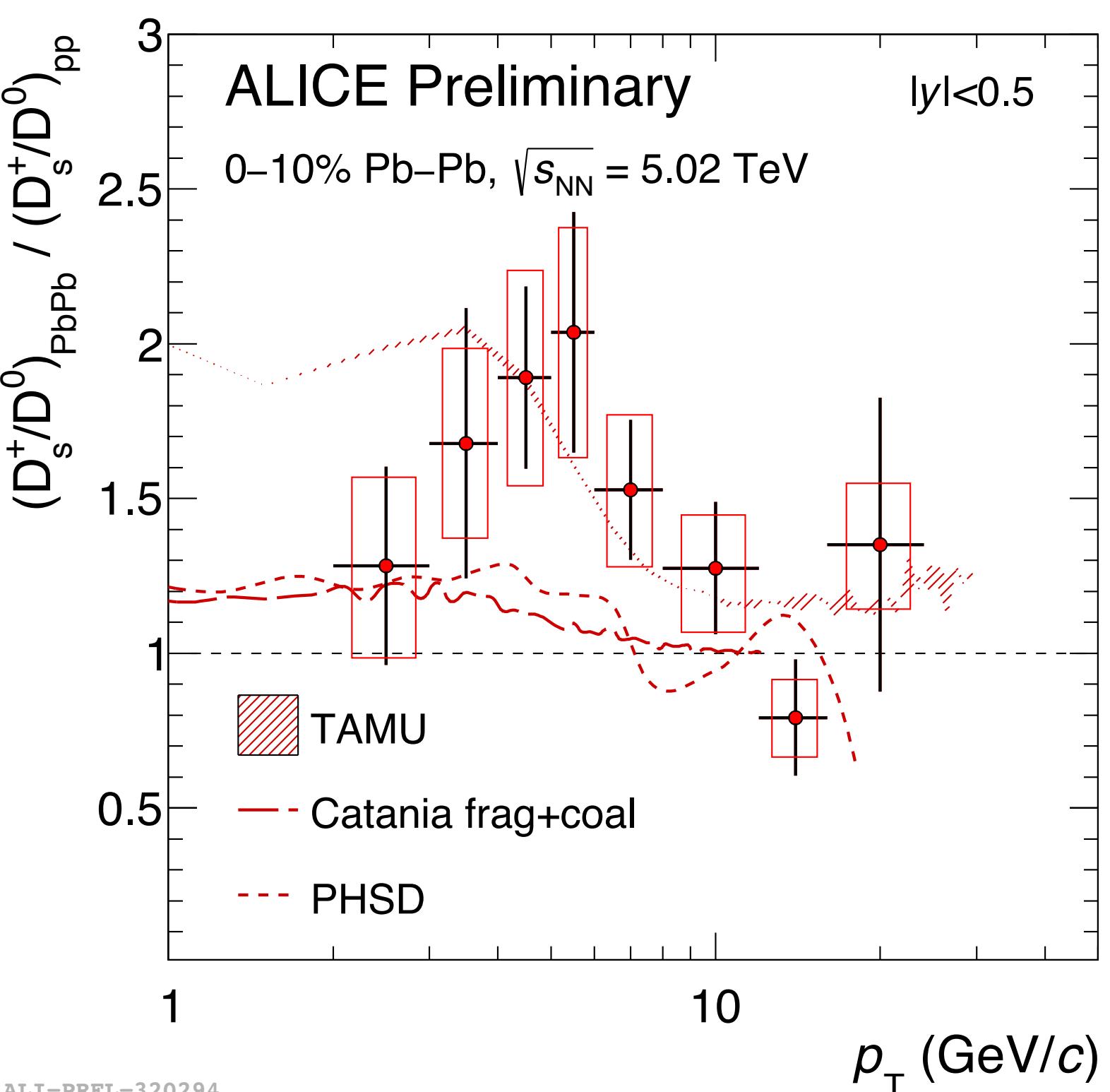
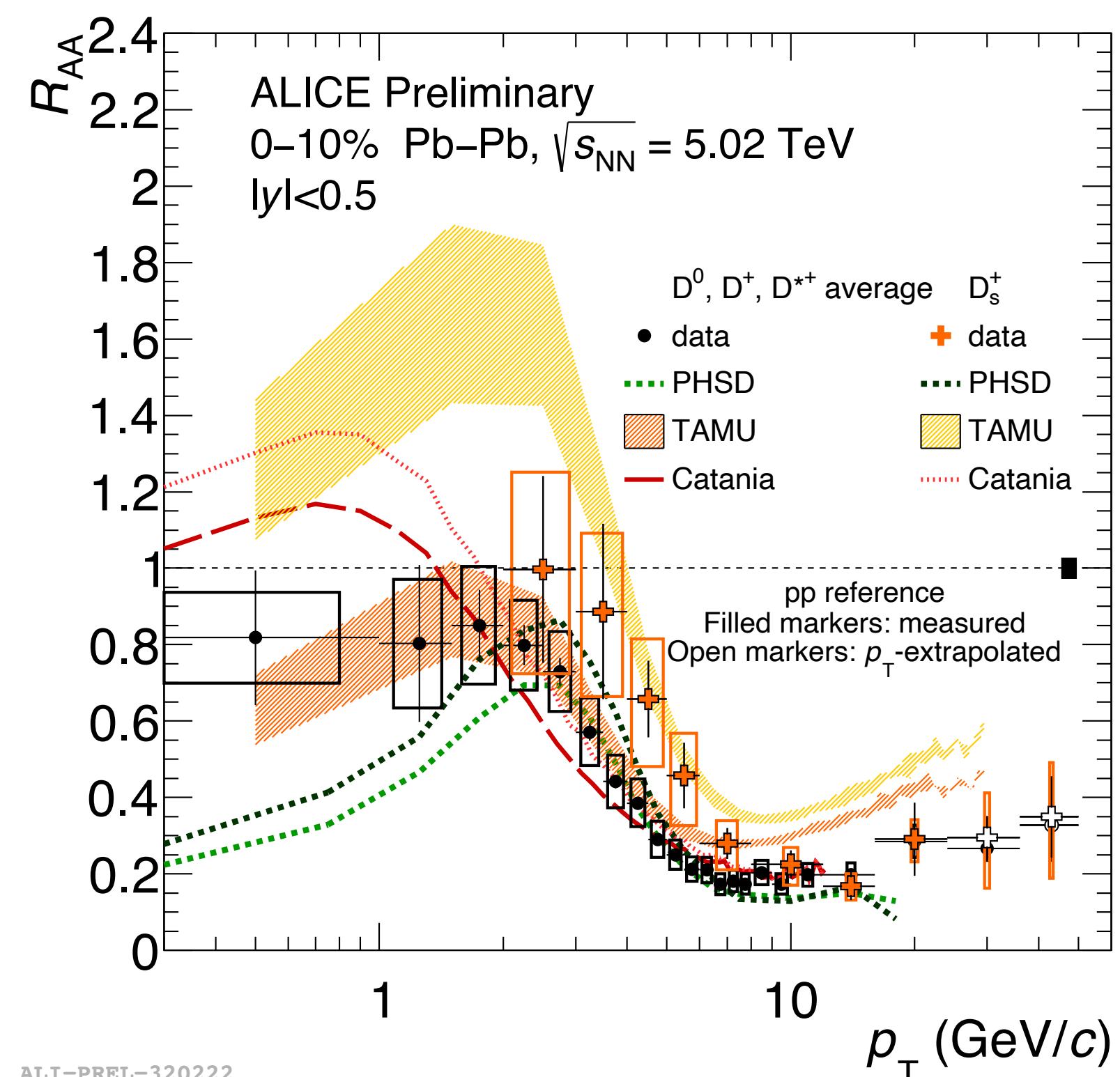
EXPECTED PERFORMANCE: NON-PROMPT D_s^+ MESONS



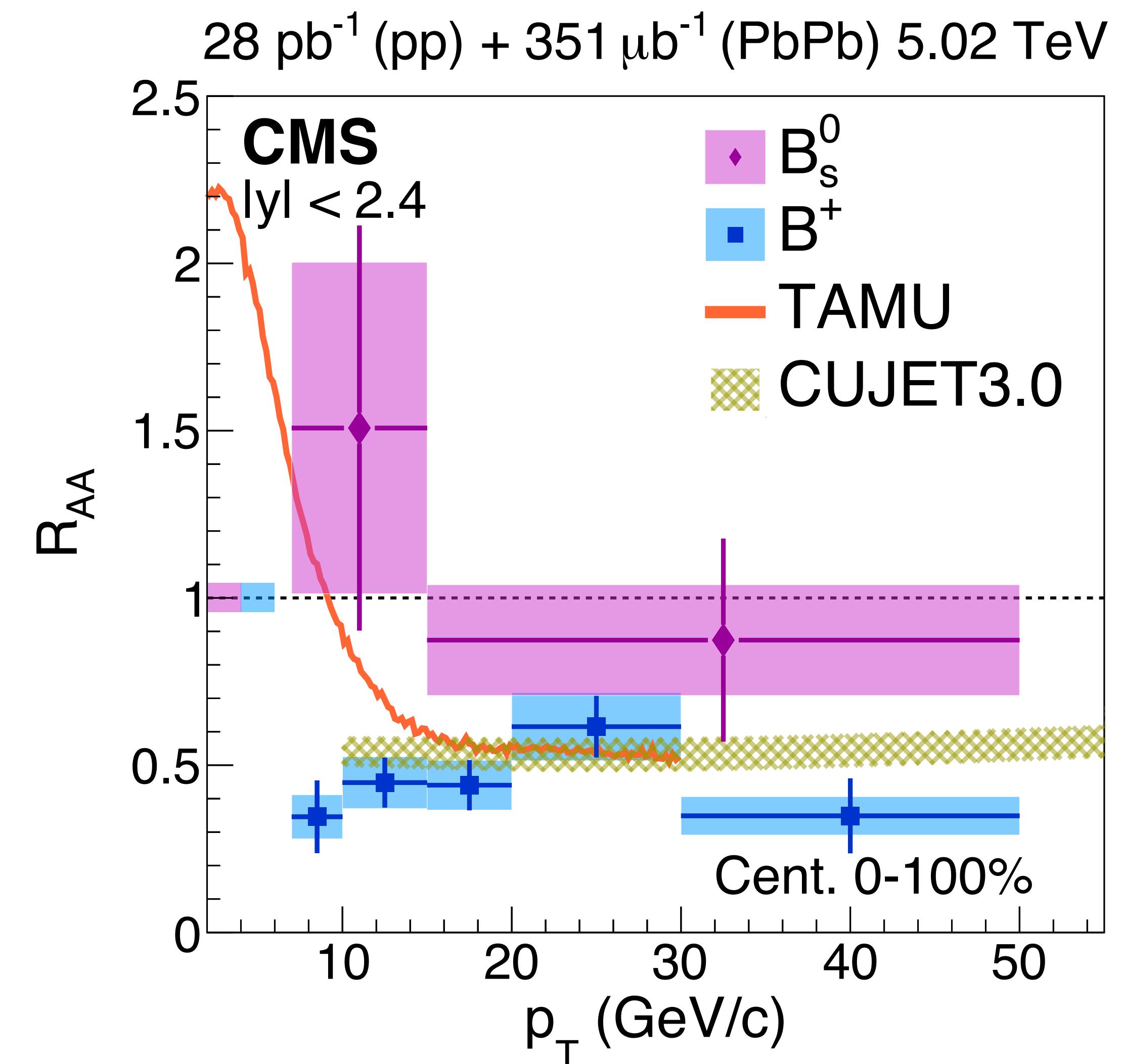
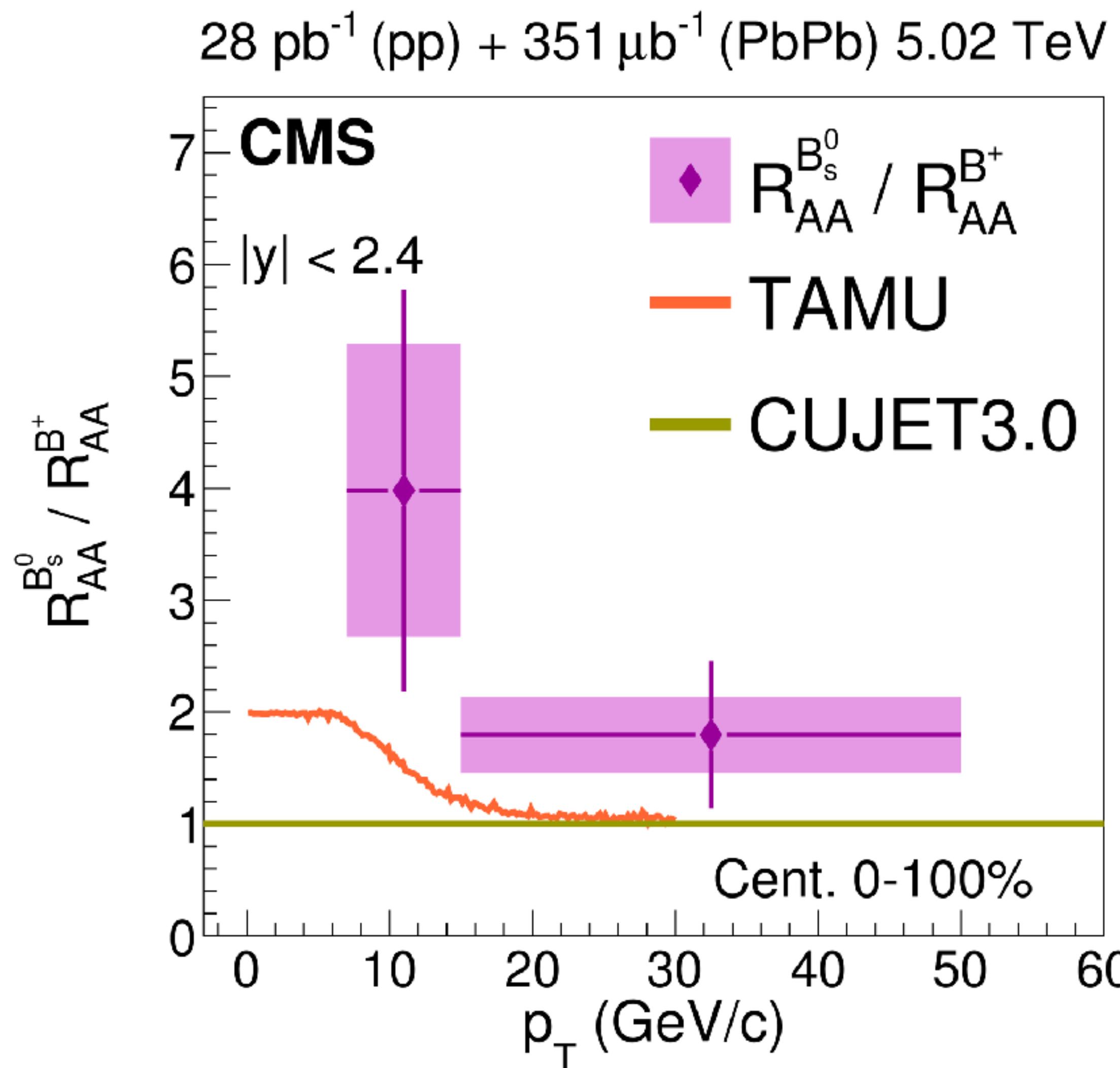
- Impact-parameter (d_0) distribution of prompt D_s^+ mesons only driven by resolution
- Improvement in D_s^+ impact-parameter resolution up to a factor 2 with ITS3
- better separation of prompt and non-prompt D_s^+



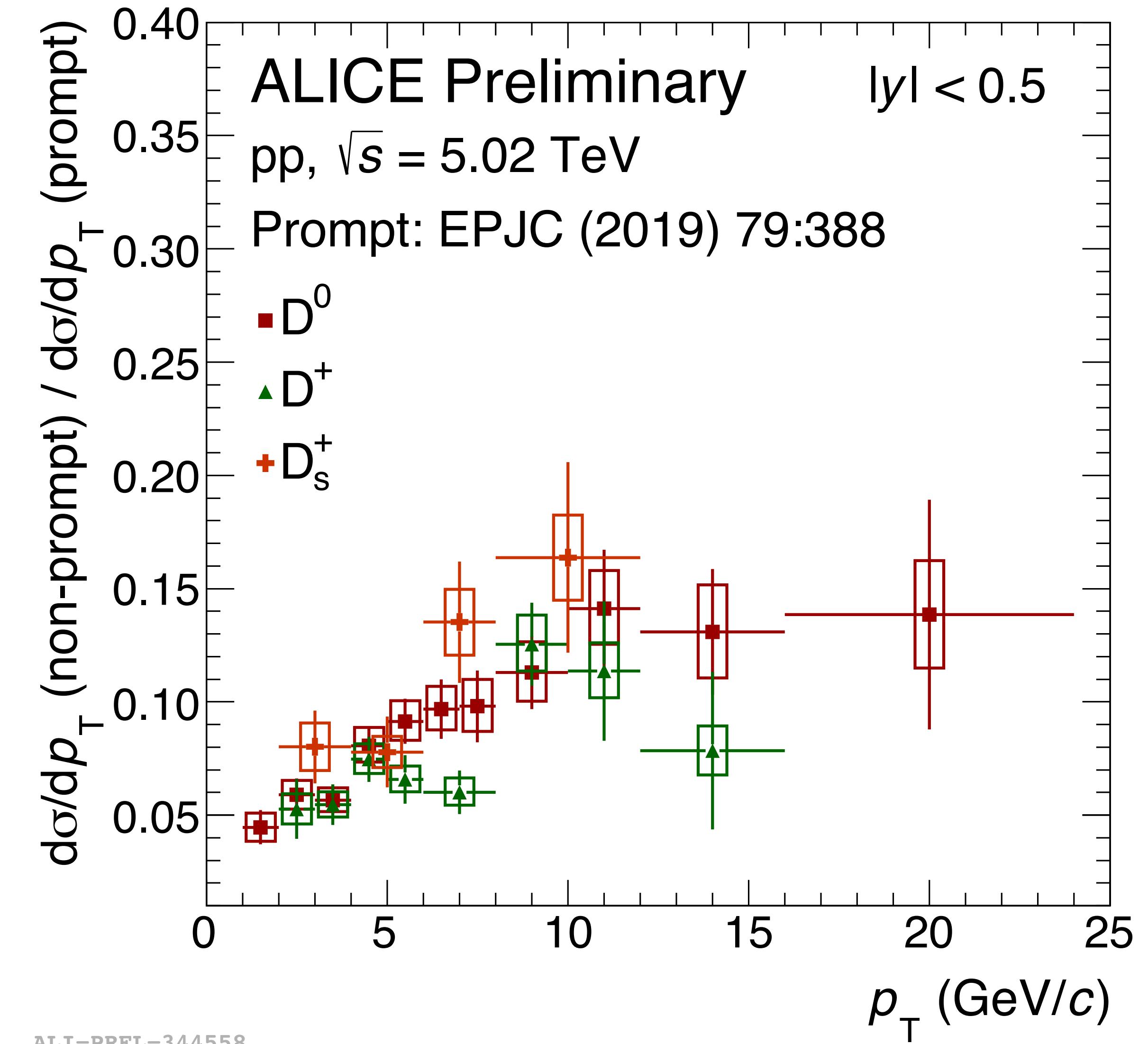
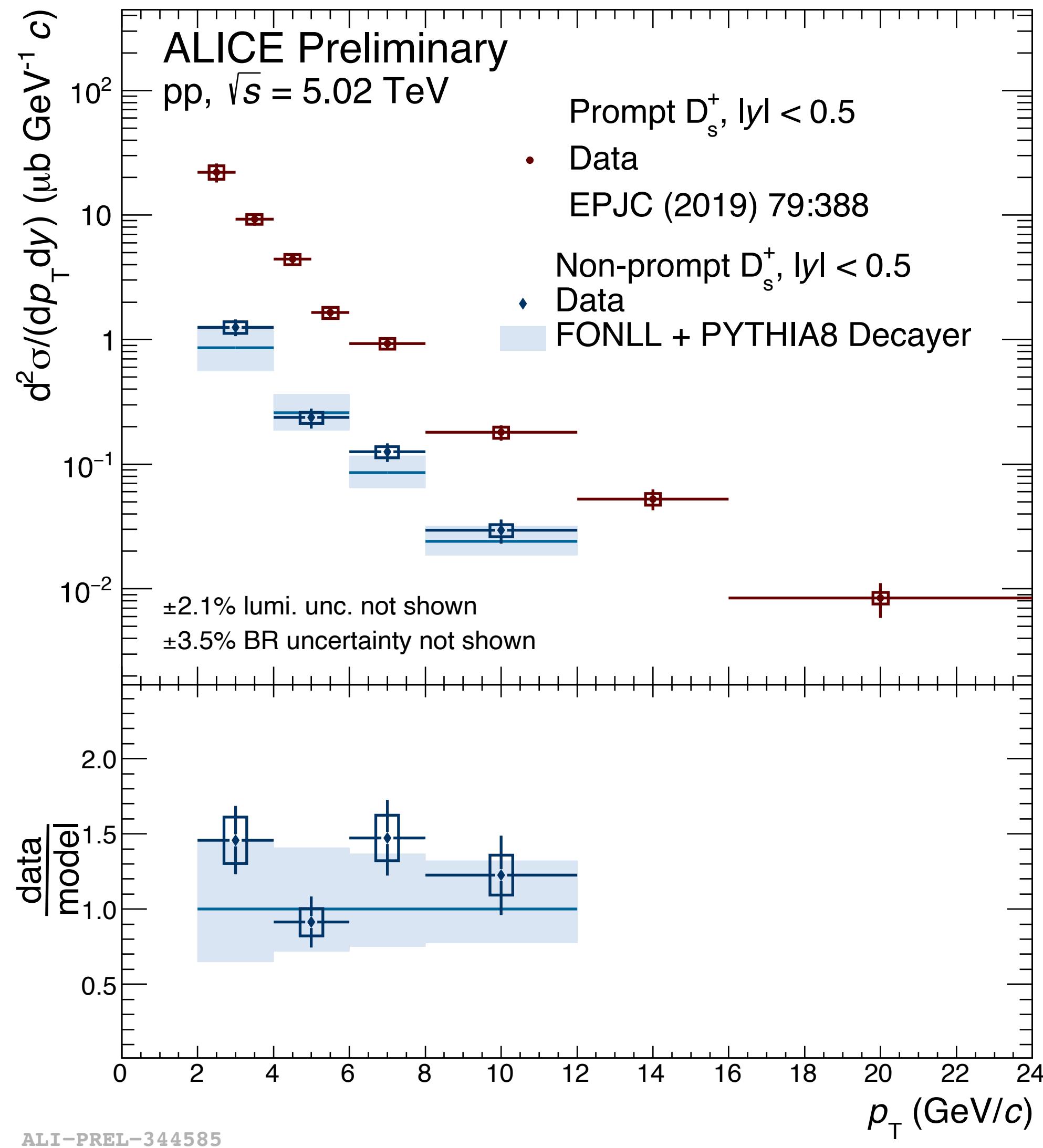
PROMPT D_s^+ MESONS IN RUN 2



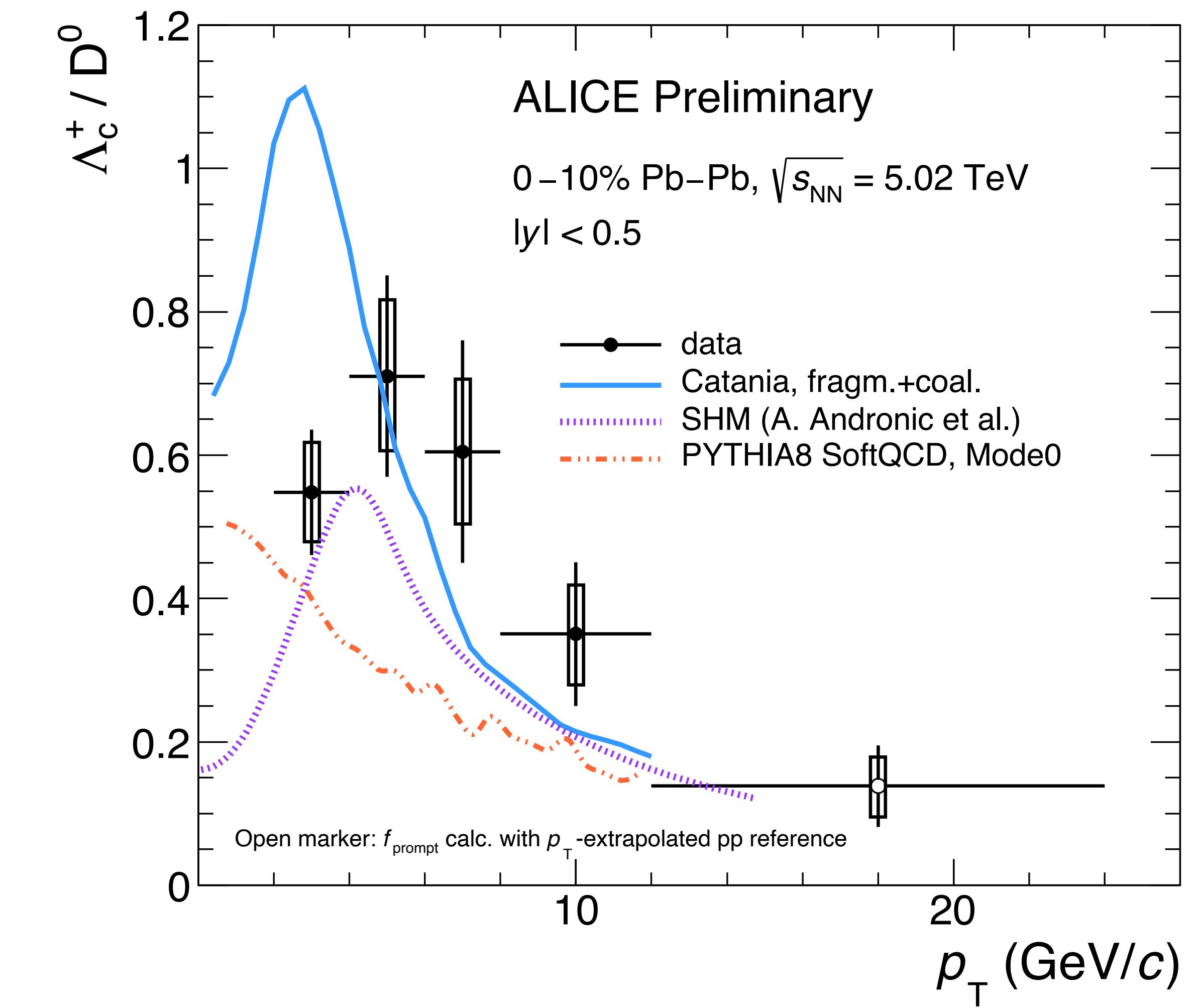
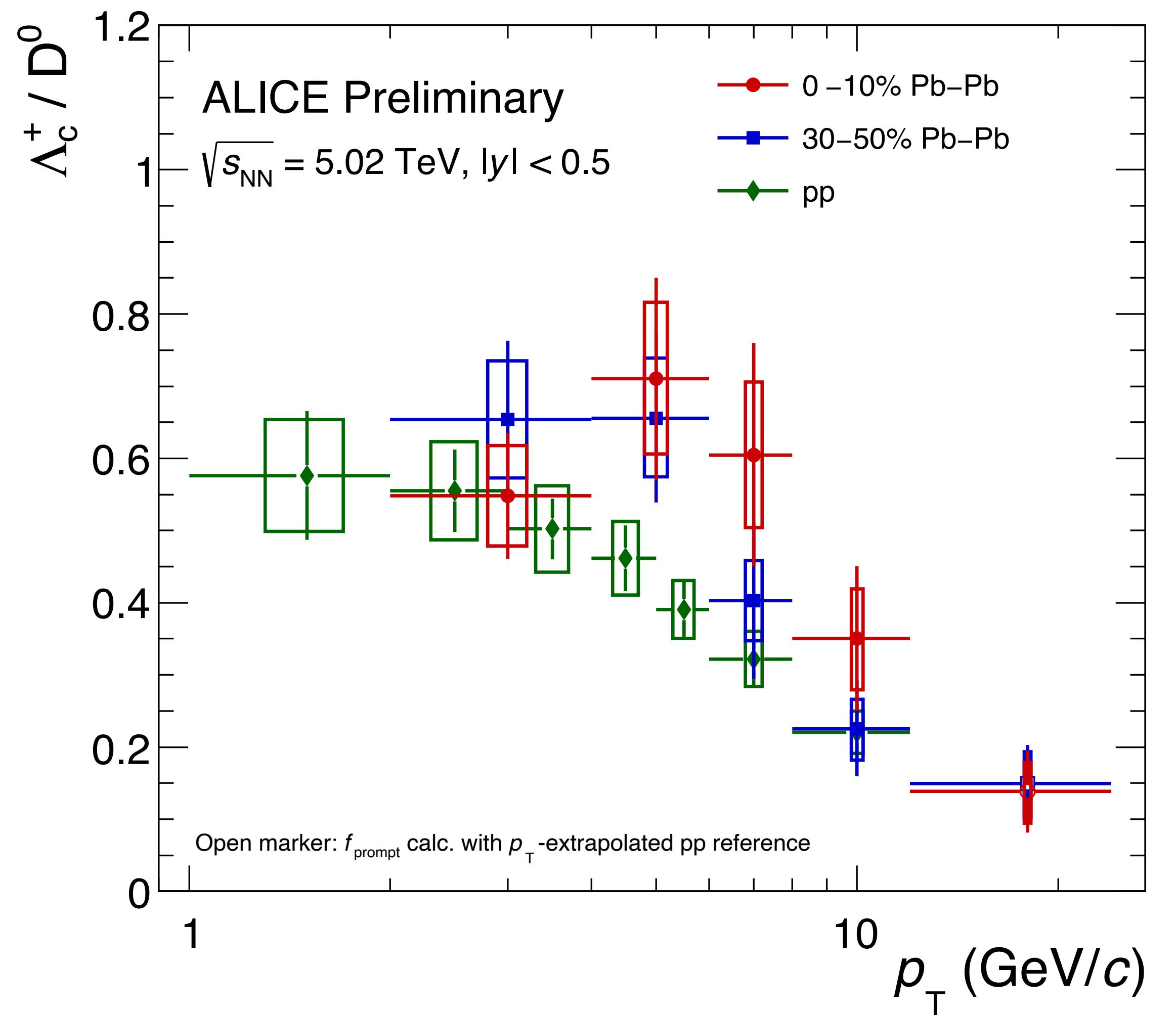
CMS B_s^0 MESONS



NON-PROMPT D_s^+ MESONS IN RUN 2 (PP COLLISIONS)



CHARM BARYONS IN RUN 2



ALI-PREL-323761

ALI-PREL-325749

HYPERNUCLEI IN RUN 2

