# Selection of proposed forward photon related measurements

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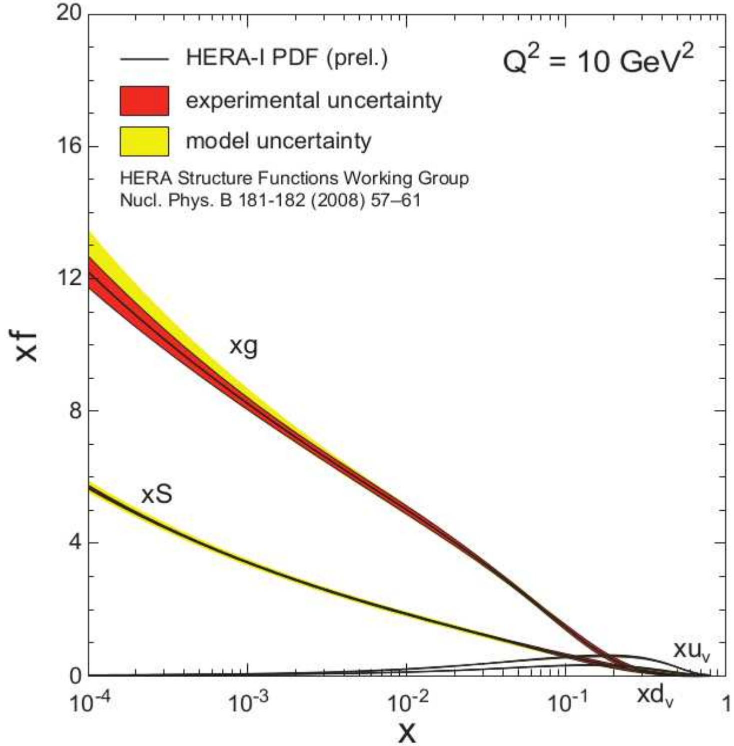
(ORNL)

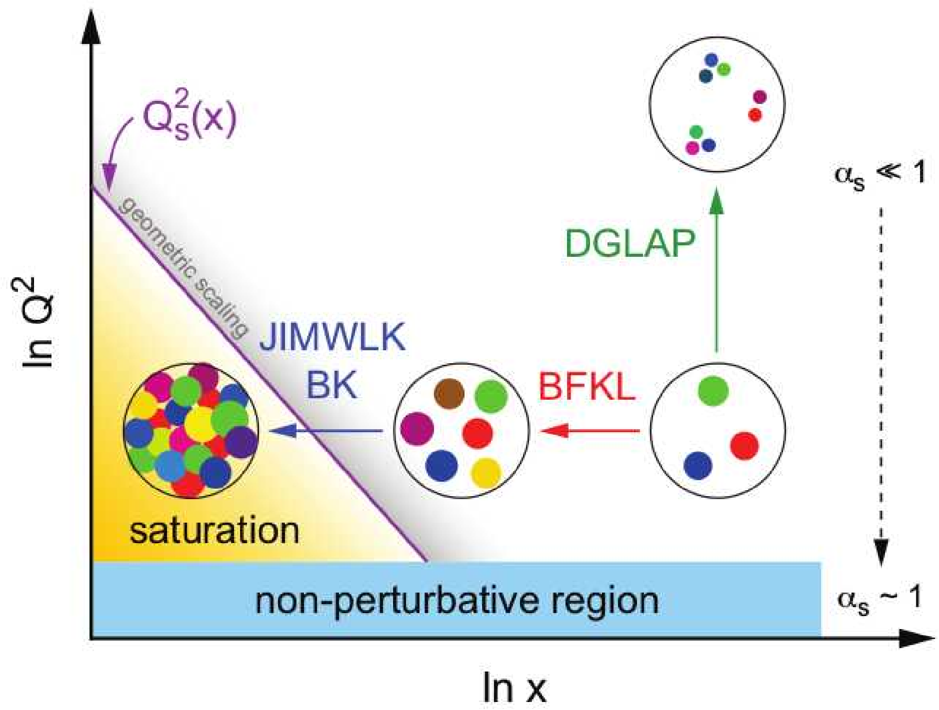
8 March 2019

Focal workshop, Tsukuba, https://indico.cern.ch/event/783989/

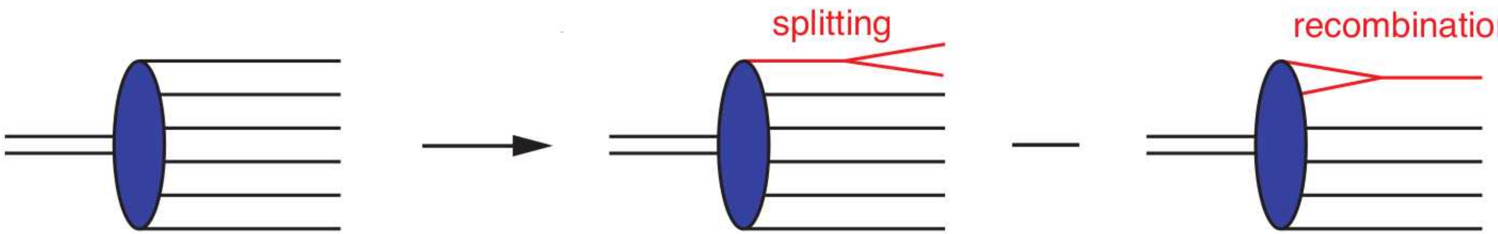
# The structure of matter at small-x





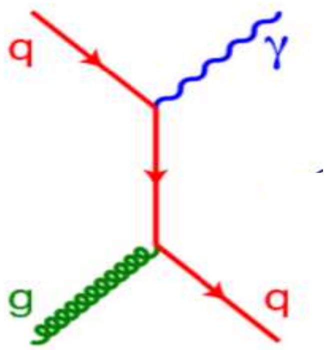




- Gluons dominate PDFs at small-x (<0.1)
  - Rapid rise in gluons naturally described by linear pQCD evolution
  - The rise can not be forever due to limits on cross section (unitarity)
  - Non-linear pQCD evolution equations tame this growth, leading to saturation of gluons, characterized by the saturation scale, $Q^2_s(x)$

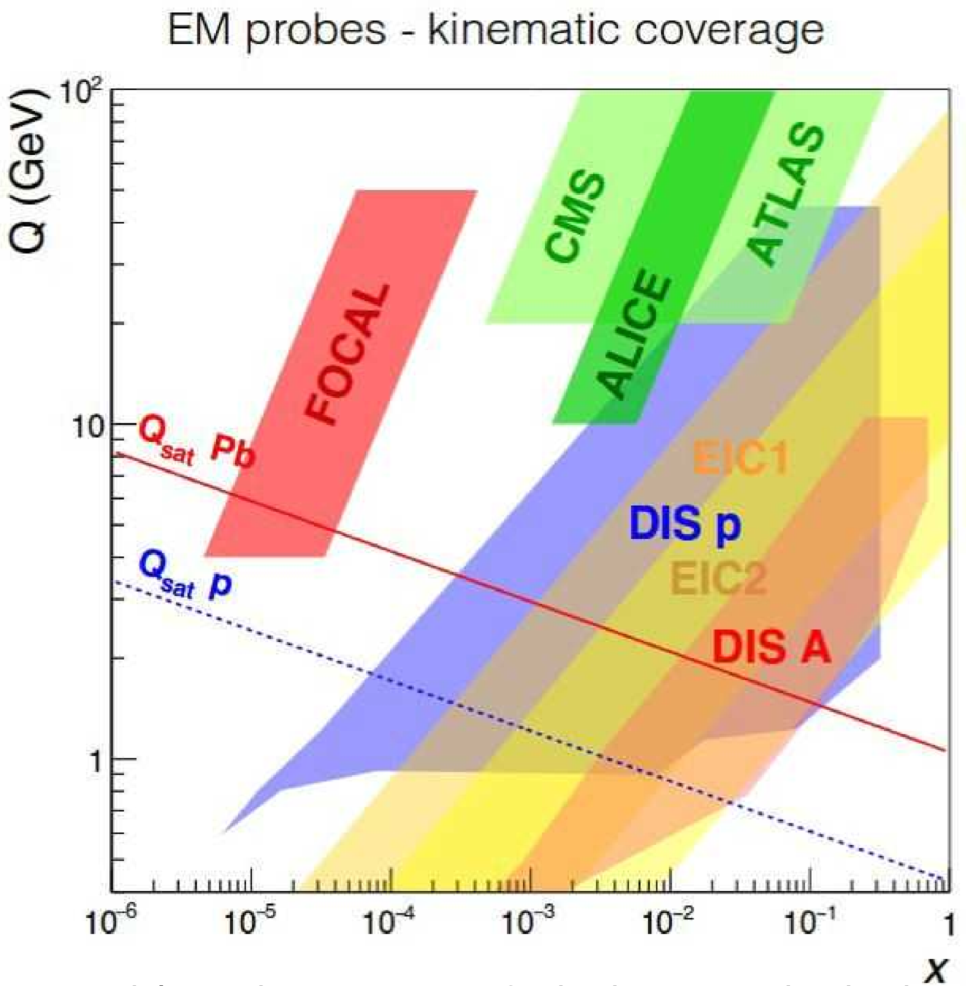


# Main physics motivation for FoCal





Direct-γ (LO)

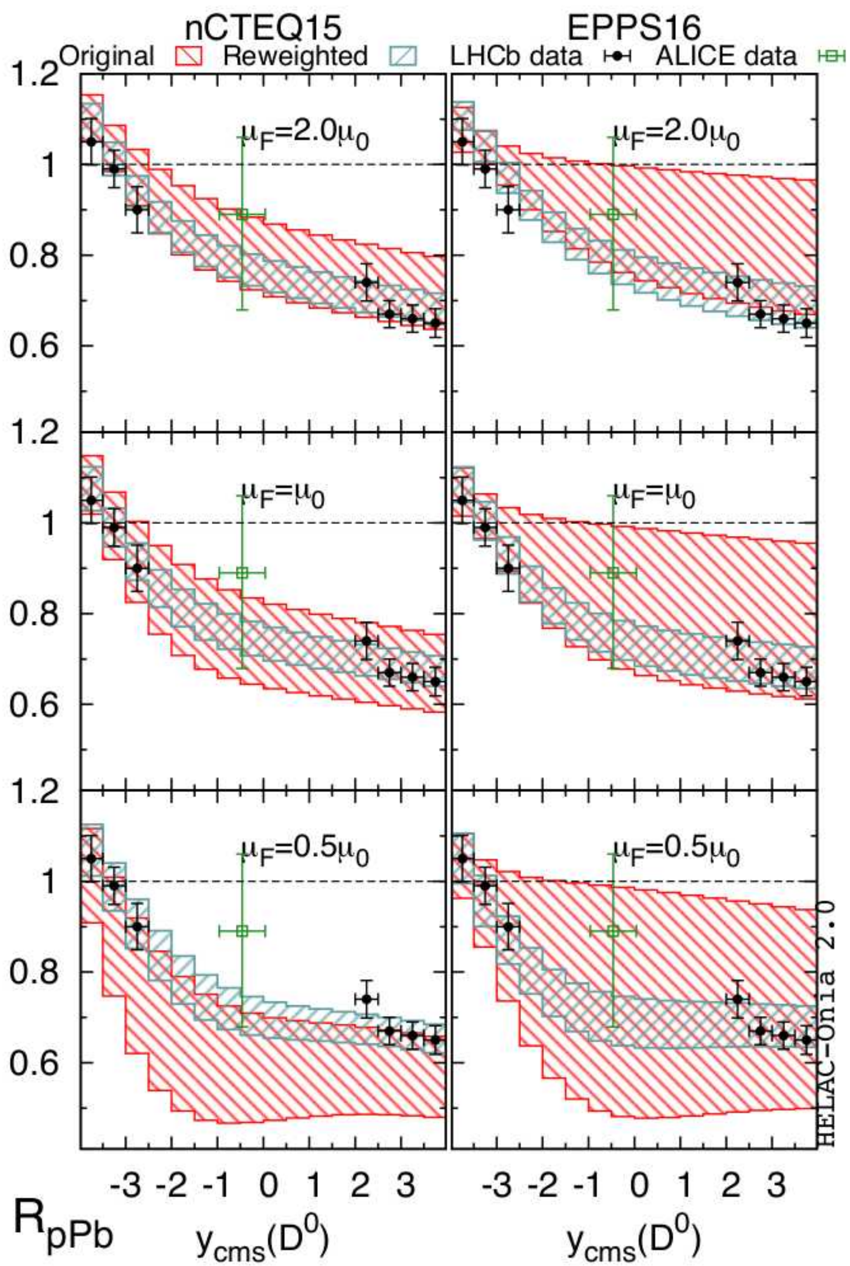


(also unique coverage for hadrons, see backup)

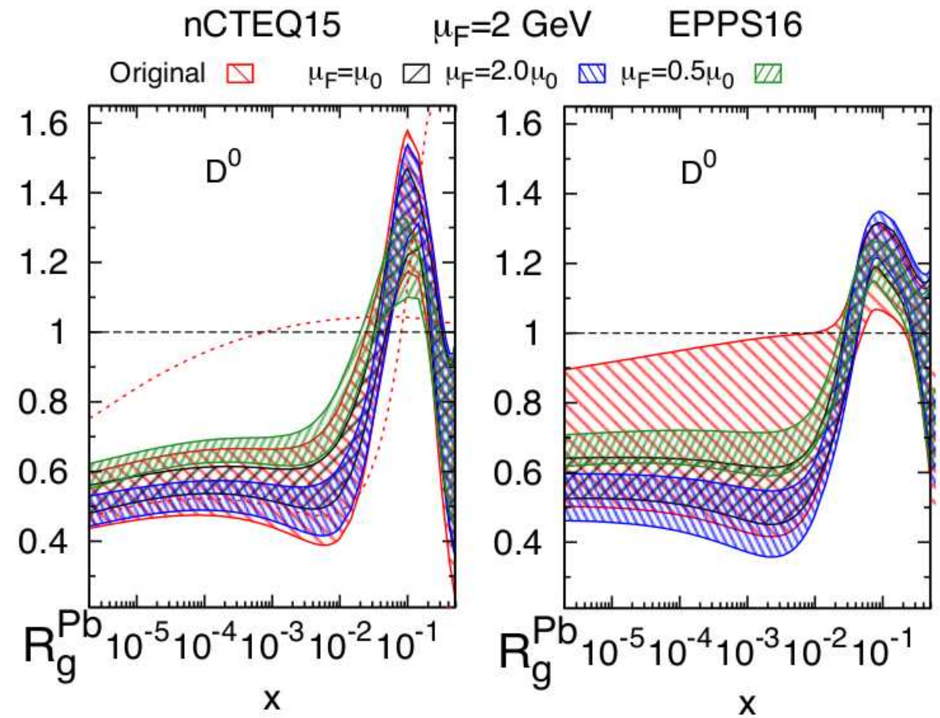
- Measure direct photons forward
  - At LO direct sensitivity to gluons
  - No final state effects or hadronization
  - Uniquely low coverage
- Access gluon saturation region to
  1) Prove or refute gluon saturation
  2) Explore non-linear QCD evolution at small-x
  3) Constrain nuclear PDFs at very small x

# Competition from LHCb run-1 open charm






- open charm used in re-weighting
  - significant reduction of uncertainties
  - significant suppression – on the low side of current PDFs
  - significant pQCD uncertainties (scale, fragmentation)
  - relies on shape of parameterisation: very little *x*-dependence at low *x*!



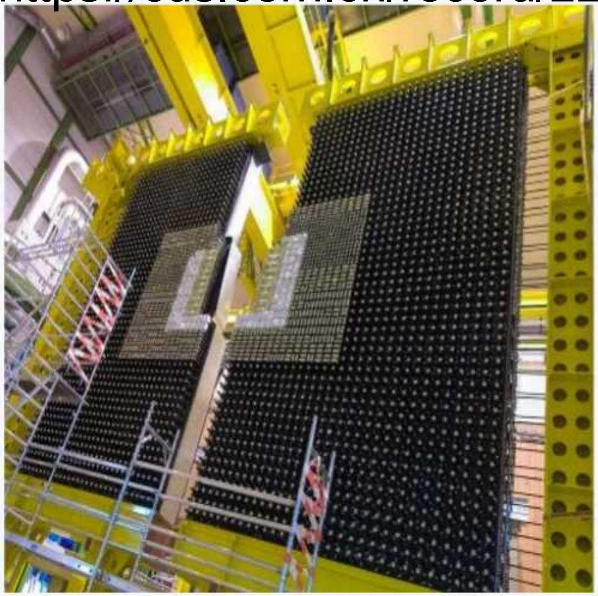
# LHCb EMCAL

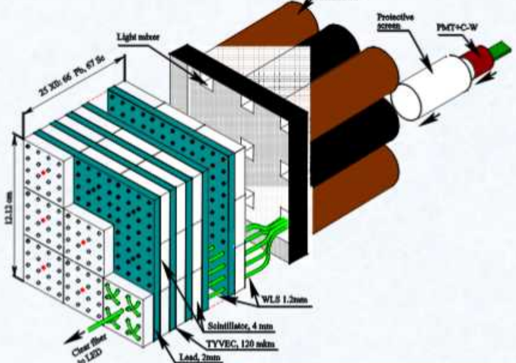
$1.9 < \eta < 4.9$

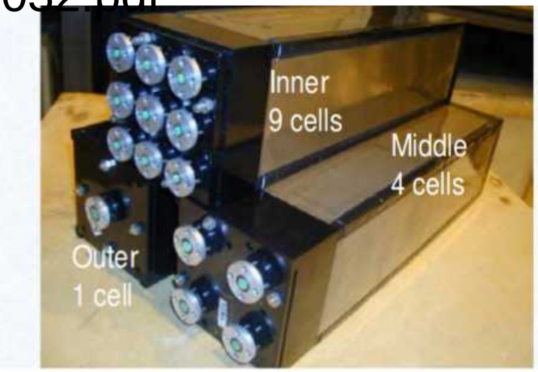
z~12.5m

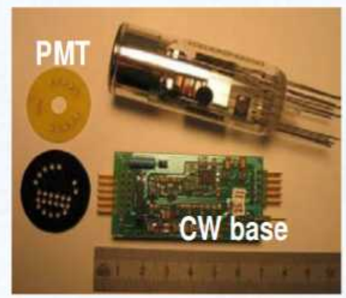


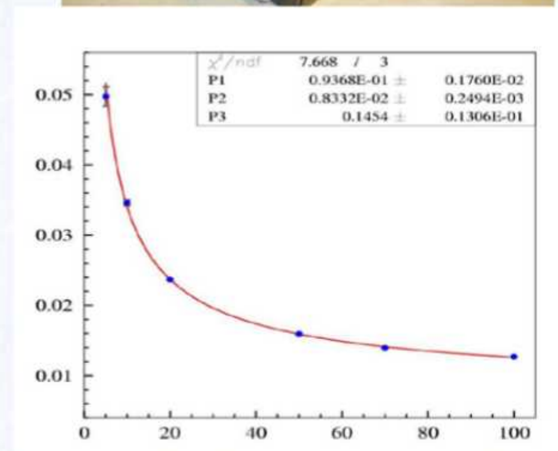
https://cds.cern.ch/record/2255089/files/LHCb-TALK-2017-032.pdf






Shashlik technology

- 4 mm thick scintillator tiles and 2 mm thick lead plates, ~25 $X_0$ (1.1 $\lambda_I$); Moliere radius ~ 36 mm;
- modules 121.2 x 121.2 mm², 66 Pb +67 scintillator tiles;
- Segmentation: 3 zones → 3 module types, Inner (9 cells per module), Middle (4), Outer (1). Total of 3312 modules, 6016 cells, (7.7 x 6.3) m², ~100 tons.
- Light readout: PMT R-7899-20, HAMAMATSU. HV supply: individual Cockcroft-Walton circuit at each PMT.

Average performance figures from beam test (there is slight difference between zones):

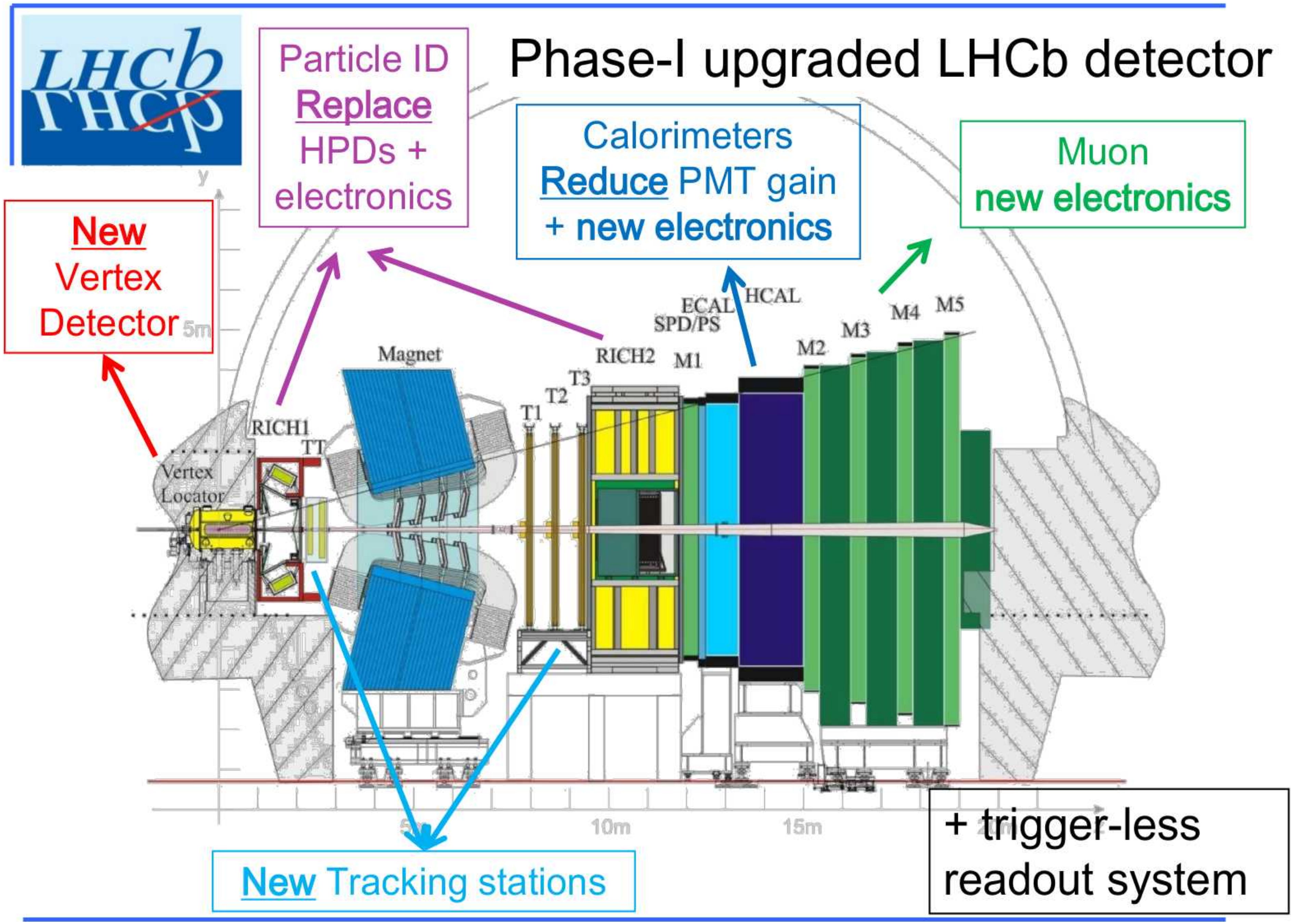
Light yield: ~ 3000 ph.el. / GeV

Energy resolution: $\frac{\sigma_E}{E} = \frac{(8 \div 10)\%}{\sqrt{E(\text{GeV})}} \oplus 0.9\%$

→ Powerful detector, but not good for forward pi0/photon discrimination:
At η≈4, pi0 shower merge at pT = 3.5 GeV.

# PHASE-I upgrade LHCb

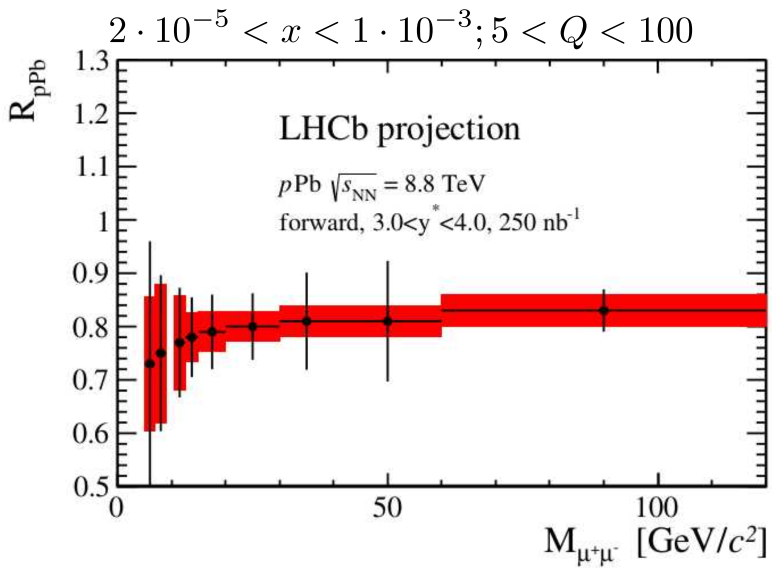


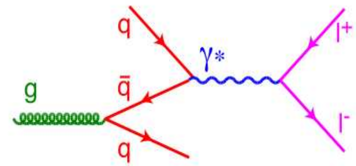


# LHCb run-3/4 projections

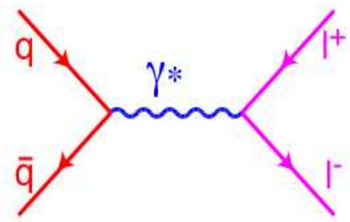


LHCb-CONF-2018-005

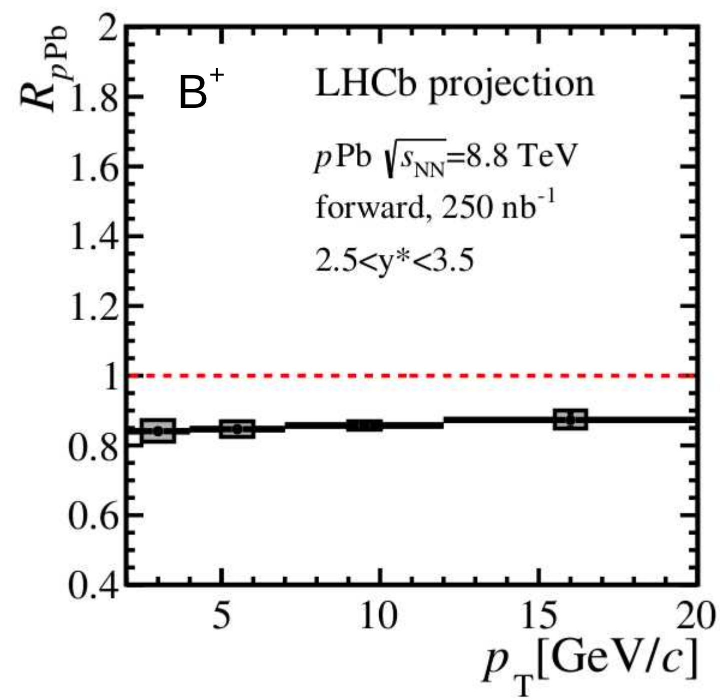


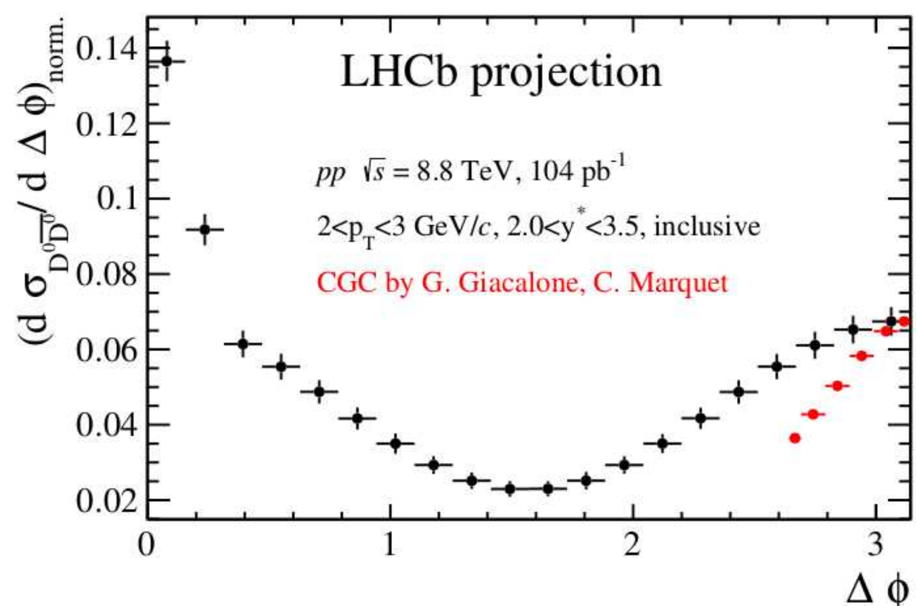

DY, virtual Compton (NLO)




DY (LO)




- DY forward (and backward)
  - Sensitive to gluons only at NLO
- In addition to $D^0$ production, measure $D^0D^0$ correlations
- Precision measurements of $B^+$
  - Advantage higher scale for calculation (but also higher x)

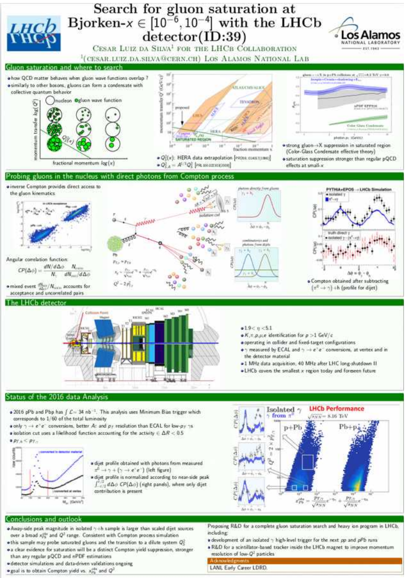


# Gamma-hadron correlations



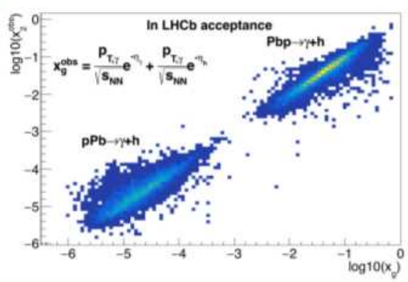
https://cds.cern.ch/record/2319876?ln=en

Early Career Award (DOE)
→ Analysis (isolated conversions)
→ Develop dedicated high level trigger
→ R&D for small tracking stations inside the LHCb magnet to improve low-momentum tracking




## Probing gluons in the nucleus with direct photons from Compton process

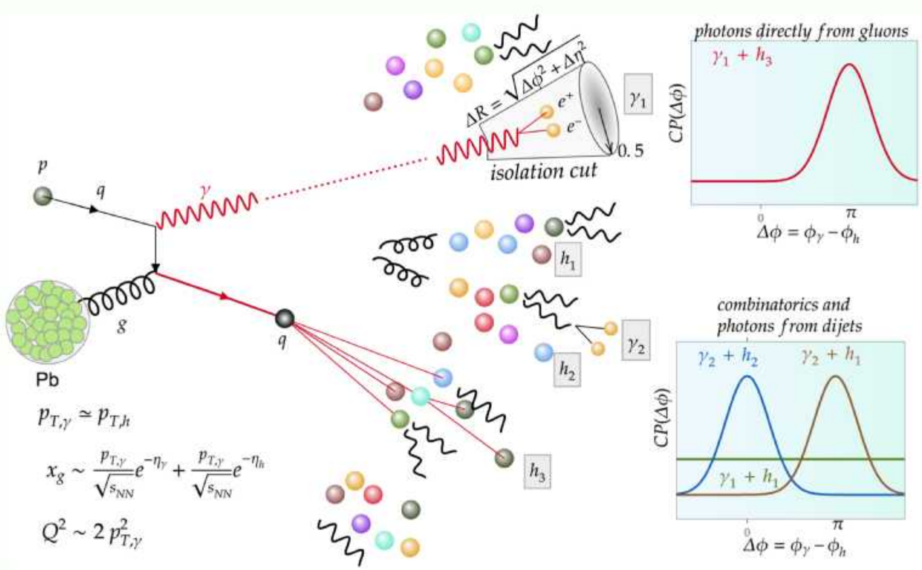
- inverse Compton provides direct access to the gluon kinematics




Angular correlation function:

$$CP(\Delta\phi) = \frac{dN/d\Delta\phi}{N_\gamma}\frac{N_{\rm norm}}{dN_{\rm mix}/d\Delta\phi}$$

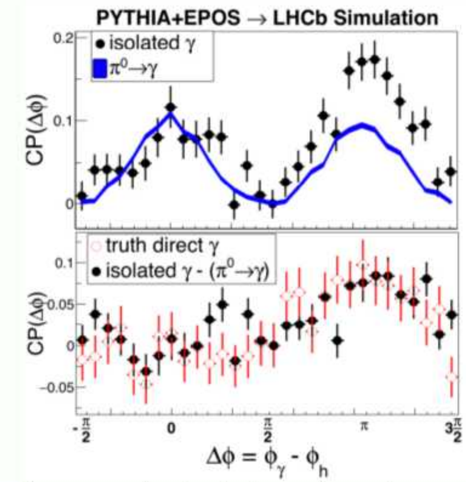
- mixed event $\frac{dN_{\rm mix}}{d\Delta\phi}/N_{\rm norm}$ accounts for acceptance and uncorrelated pairs




$p_{T,\gamma} \simeq p_{T,h}$

$x_g \sim \frac{p_{T,\gamma}}{\sqrt{s_{NN}}}e^{-\eta_\gamma} + \frac{p_{T,\gamma}}{\sqrt{s_{NN}}}e^{-\eta_h}$

$Q^2 \sim 2p^2_{T,\gamma}$

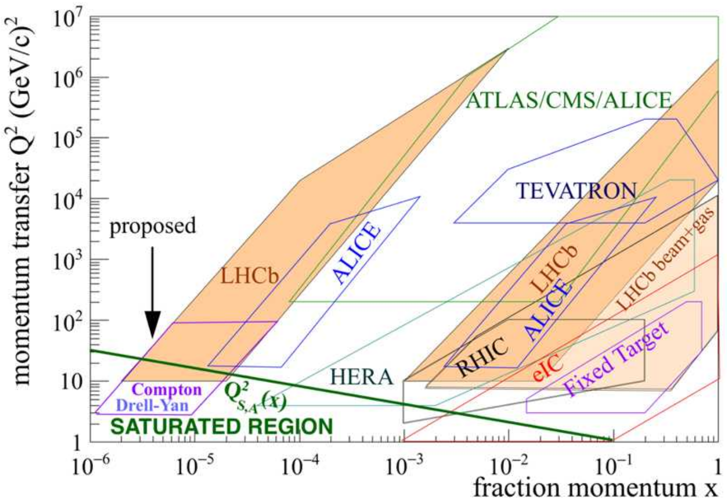



- Compton obtained after subtracting $(\pi^0 \to \gamma)$+h (profile for dijet)

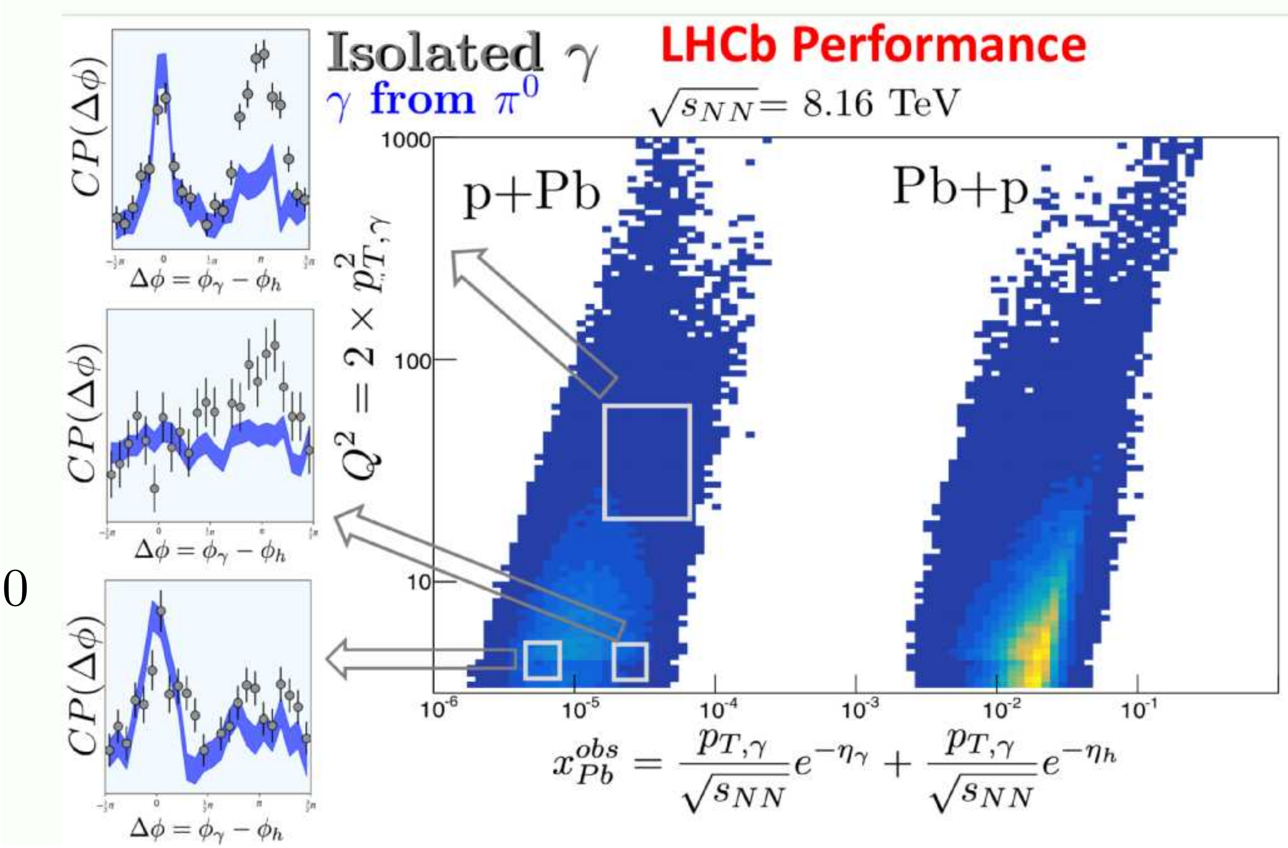
# Gamma-hadron correlations



https://cds.cern.ch/record/2319876?ln=en



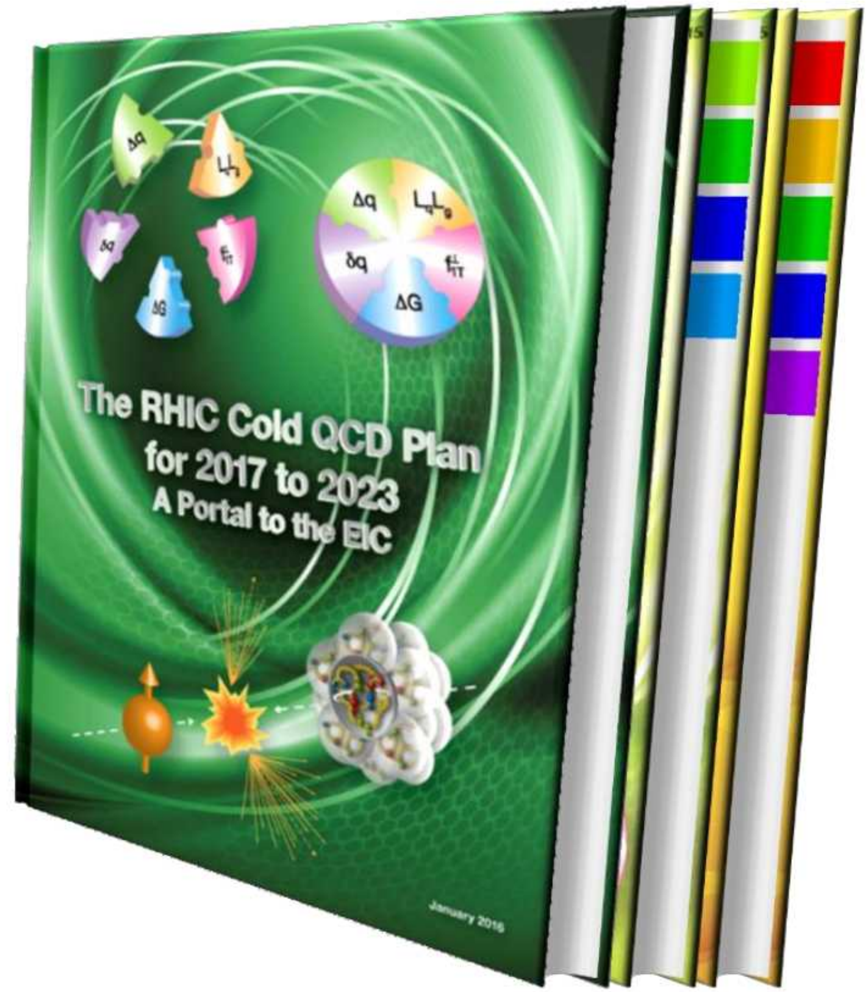

$$3 \cdot 10^{-6} < x < 6 \cdot 10^{-4}; 2 < Q < 20$$




- The measurement can (probably?) be done with the existing LHCb measurement (modulo statistics)
  - Tracking stations would only be needed to improve tracking at low pT to access particles produced by soft gluons
- One should also be able to provide the absolute efficiency corrected compton yield, which would make this measurement a direct competitor to Focal.
- We could try the LHCb exercise ourselves to see if one can actually really subtract the pion contribution in the isolation cone

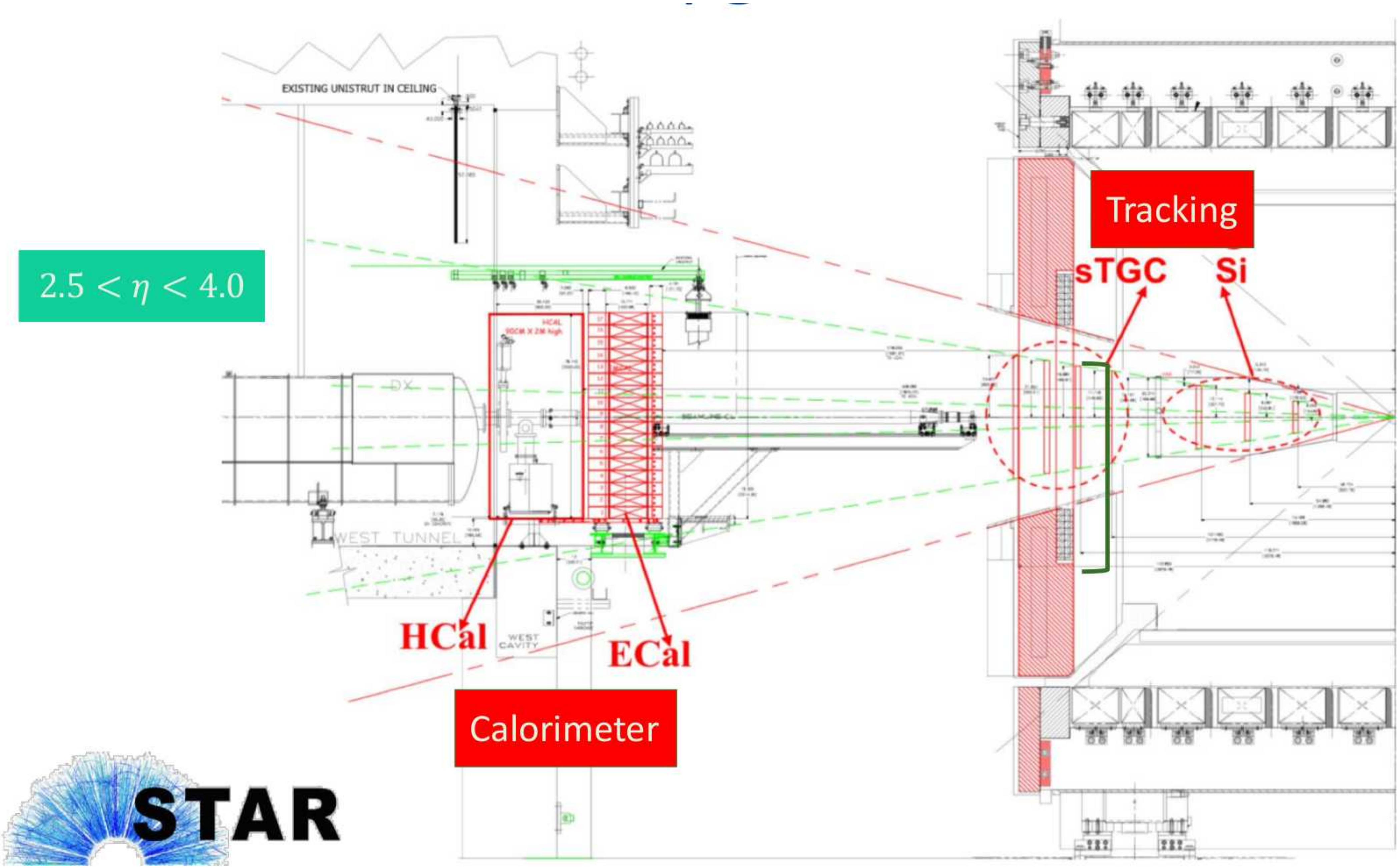
# RHIC Cold QCD plan




- Utilize existing RHIC infrastructure
- Complete measurements that are unique in $p + p$ and $p + A$
- Pursue measurements that will optimize the program at a future electron-ion collider

arxiv:1602.03922

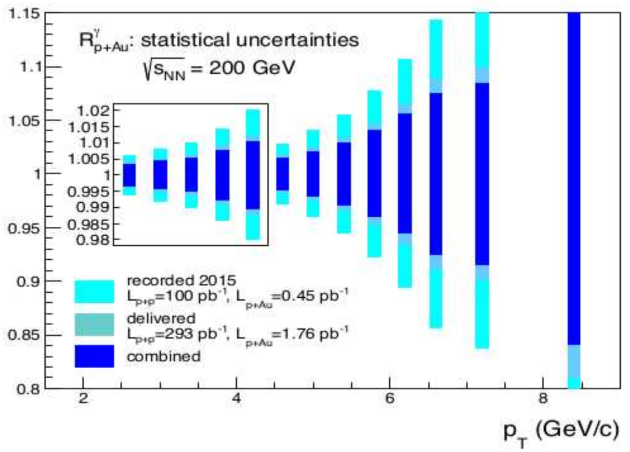


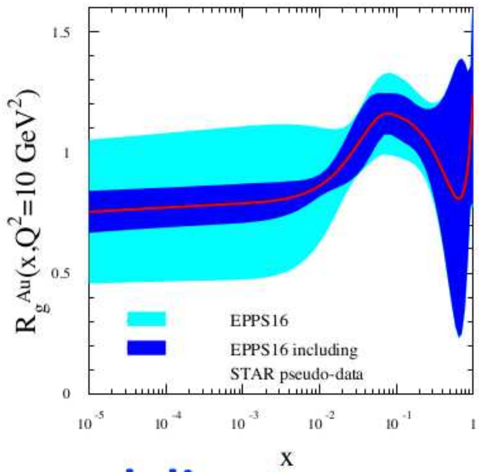

https://drupal.star.bnl.gov/STAR/files/ForwardUpgrade.v20.pdf

# Direct photons and DY projections

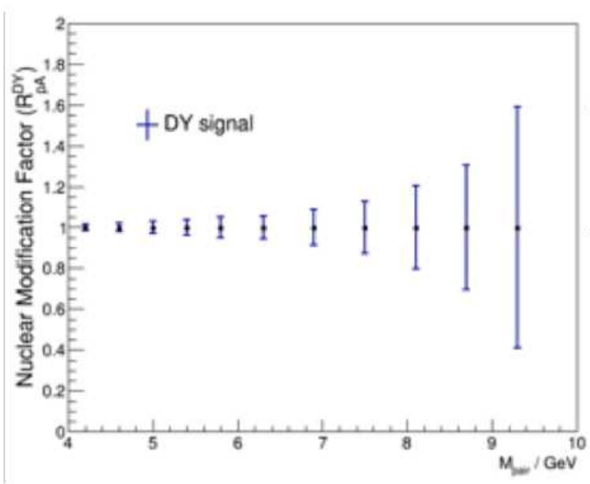


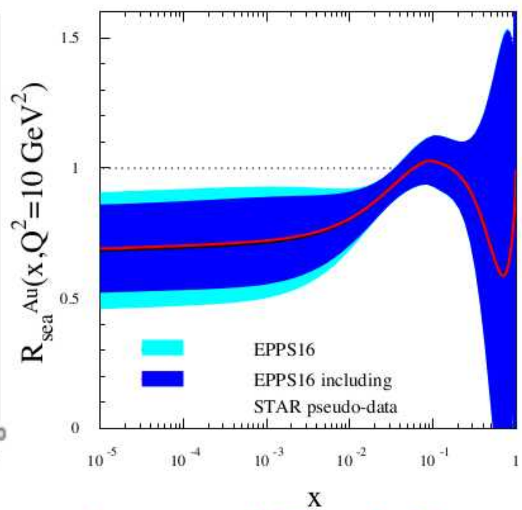
$$5 \cdot 10^{-4} < x < 2 \cdot 10^{-2}; 2.5 < Q < 10$$




Probe **gluon** nPDF via **forward direct-$\gamma$**

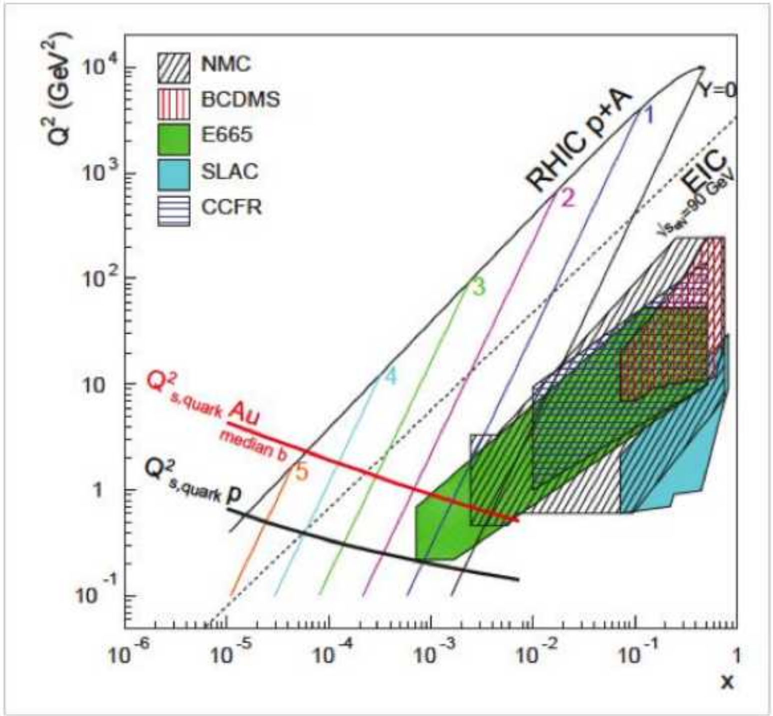



Probe **sea-quark** nPDF via **forward Drell-Yan**

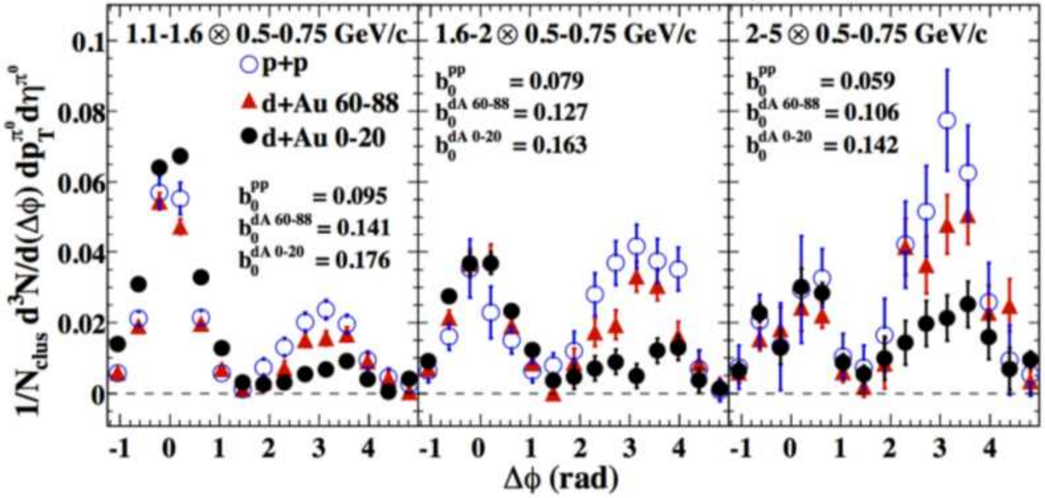
- Pilot measurements from 0.45 $\mathrm{pb}^{-1}$ $pAu$ and 1 $\mathrm{pb}^{-1}$ $pAl$ taken in 2015
- Planned 2023 runs → significant impact on global analyses
- Sensitive to $10^{-3} \lesssim x \lesssim 10^{-2}$ and $6 \lesssim Q^2 \lesssim 40\ \mathrm{GeV}^2$, where nuclear modifications should be significant
- Precision of $pA$ data → enable stringent test of nPDF universality when combined with data from EIC

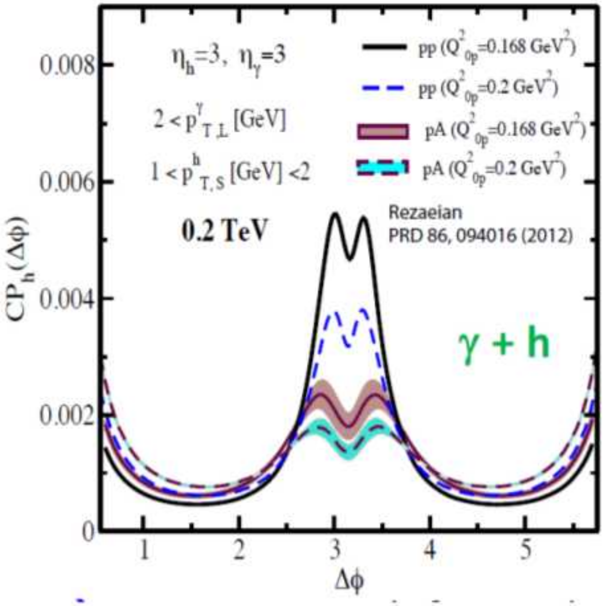
# Correlations

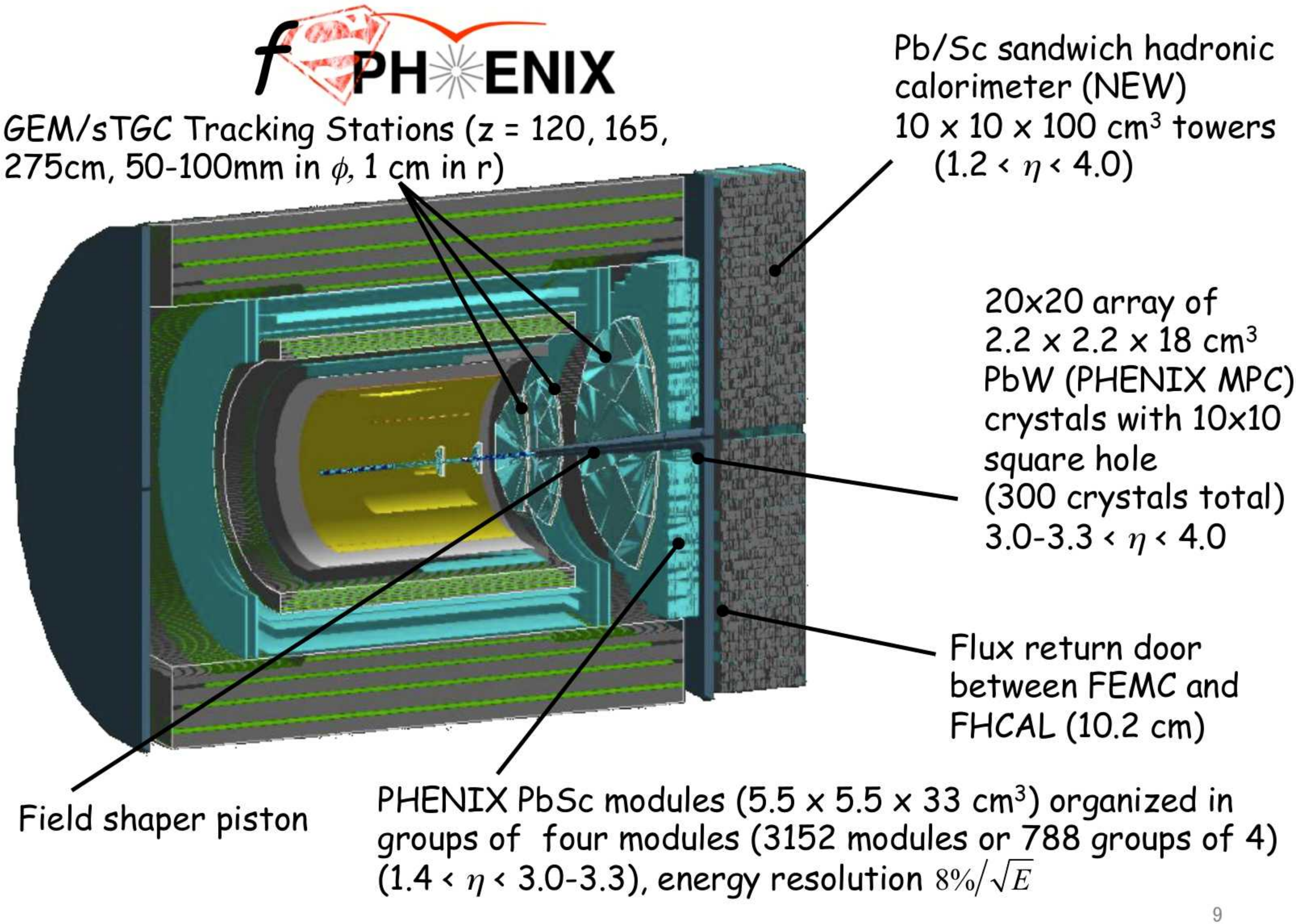



- Saturation scale $Q_s^2(x)$
- Scan kinematic range: $x$ & $Q^2$
  - Trigger $p_T$
  - Associated $p_T$
- Test $A$-dependence
- Other probes (forward)
  - $\gamma$-hadron correlation
  - $\gamma$ –jet correlation

Phys. Rev. Lett. 107, 172301 (2011)



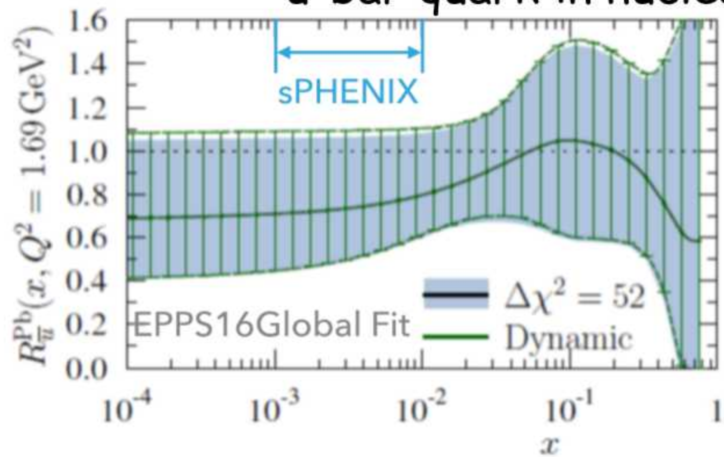


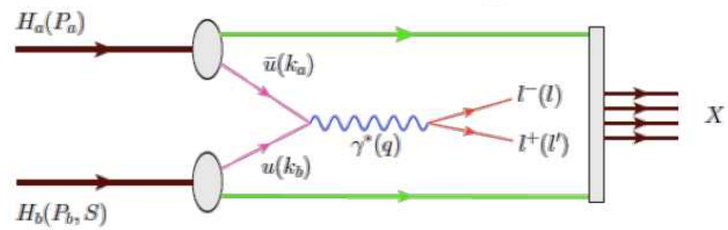

https://www.sphenix.bnl.gov/web/system/files/sPH-cQCD-2017-001_draft_2017_06_02.pdf

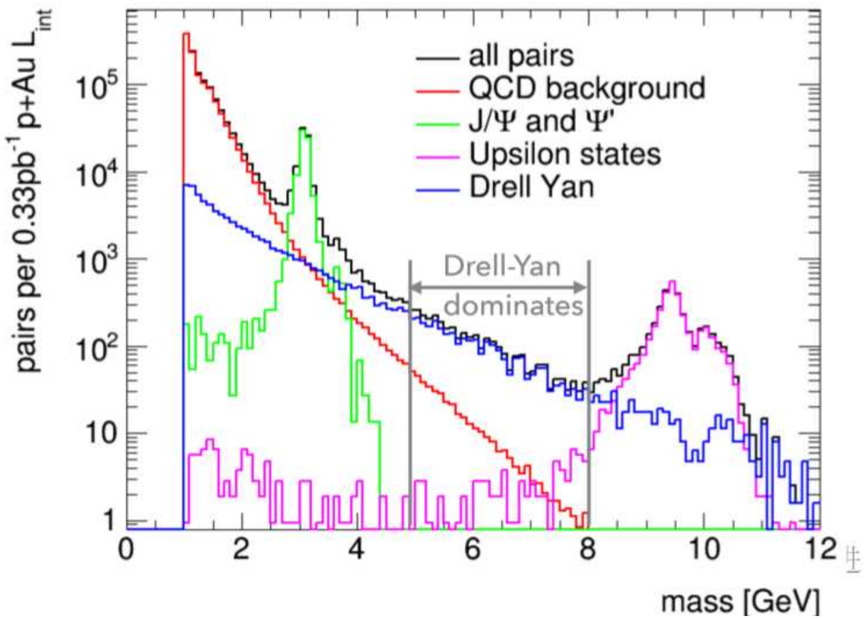
# Forward DY

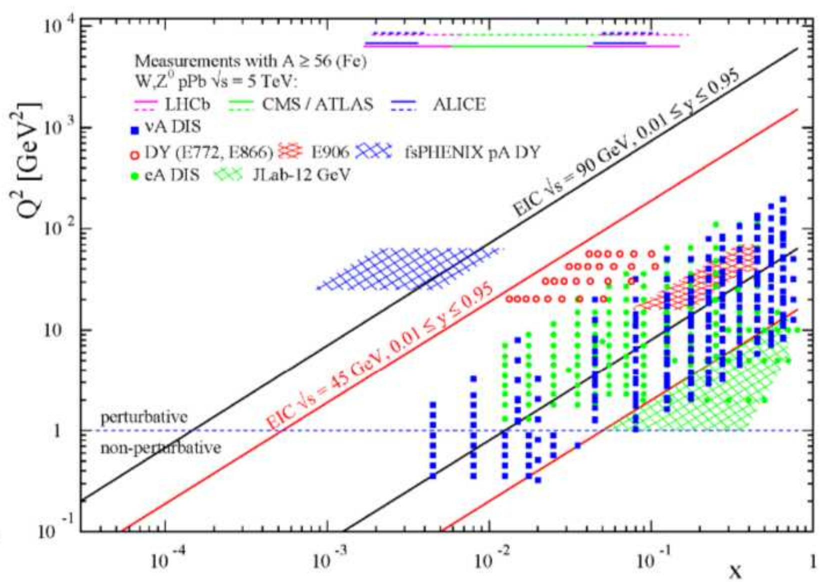
- DY in p+A provides clean access to sea quark distribution → gluon in nuclei
- fsPHENIX measure DY via di-electron final states
- Benefit from continuous and large calorimetry + tracking coverages

u-bar quark in nuclear



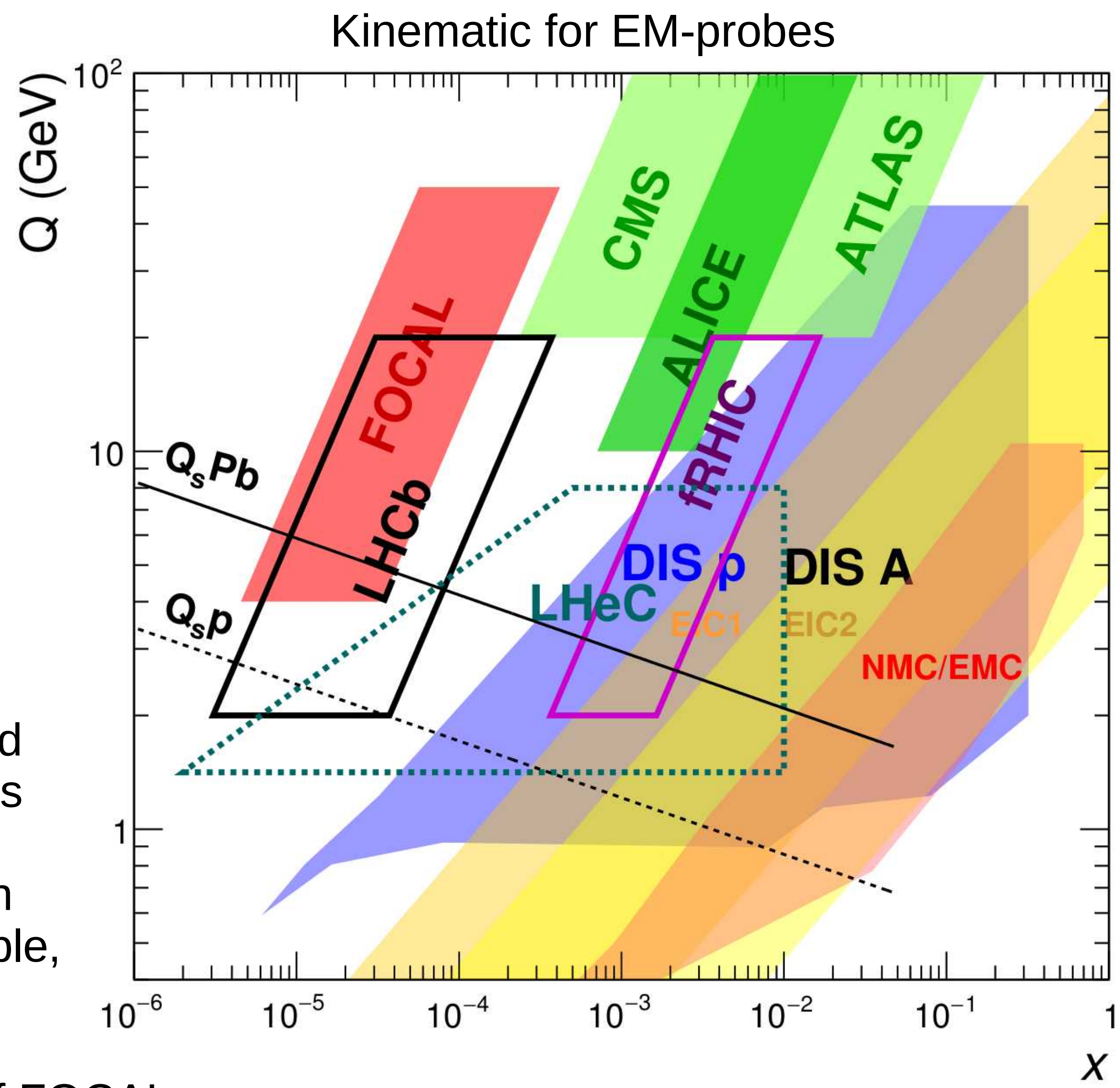




Of course also direct photons (with MPC-EX) ongoing, allowing to access up to $x{\sim}5\cdot10^{-4}$

# Conclusion: Expected landscape






We should try to understand betterthe photon capabilities of LHCb, and to access whether the gamma-hadron measurement is really doable, and will be actually done.

Pushing further the limits of FOCAL to lower Q and smaller-x feasible?

# Whitepaper



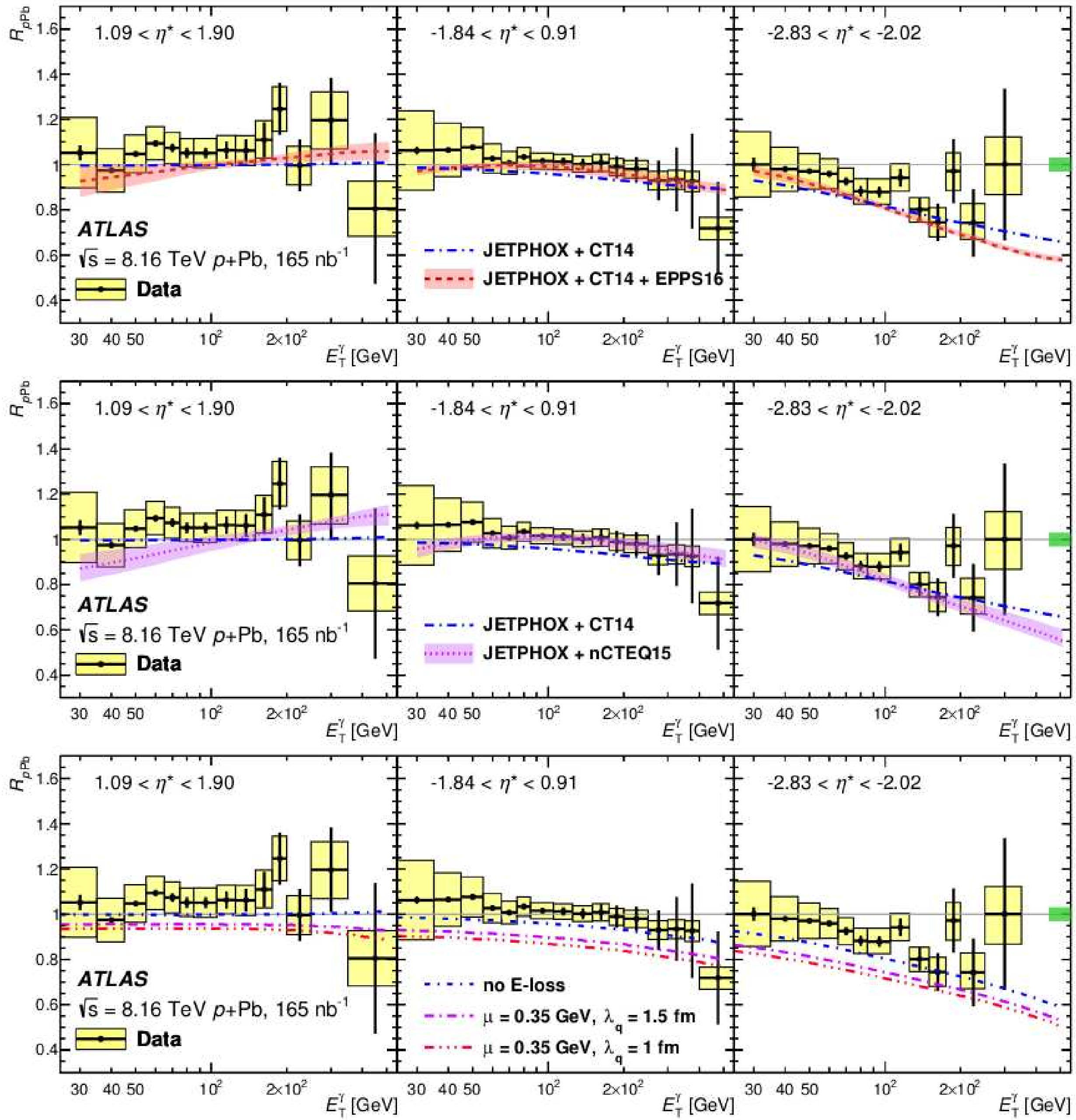
- DOE has suggested the ALICE-US collaboration to provide a short “white paper” assessing the physics potential of Focal, and comparing it with that of similar experiments
- The paper could also be very useful for the whole Focal community, in view of the LOI/TDR and discussion with FAs
- In order to be useful for the reviewing process, the time line is very tight
  - The paper would have to be written essentially in the coming weeks
  - However, it could be written independent of the ALICE collaboration

# Backup

# Prompt photons in pPb at 8.8 TeV



https://arxiv.org/abs/1903.02209

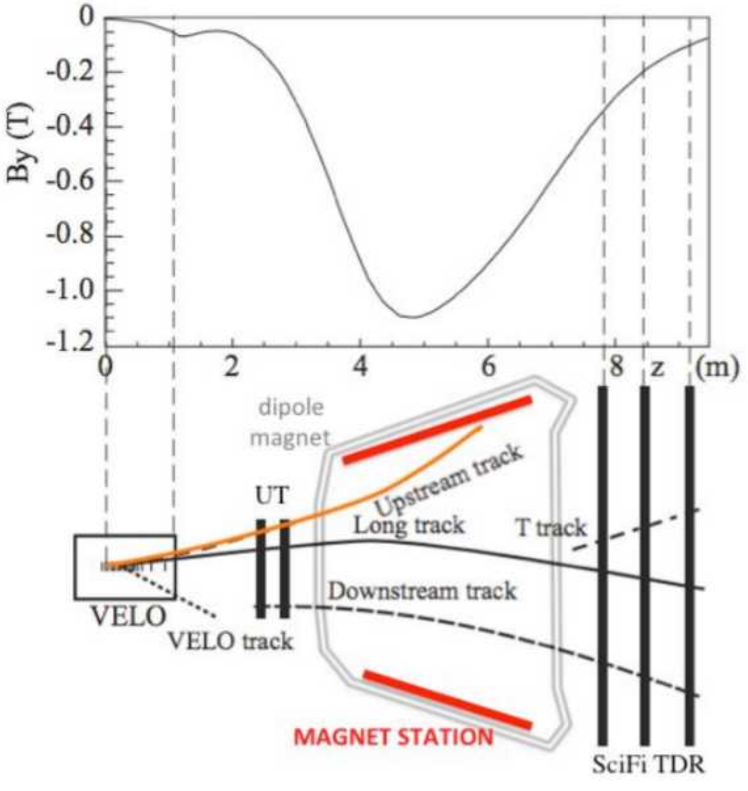


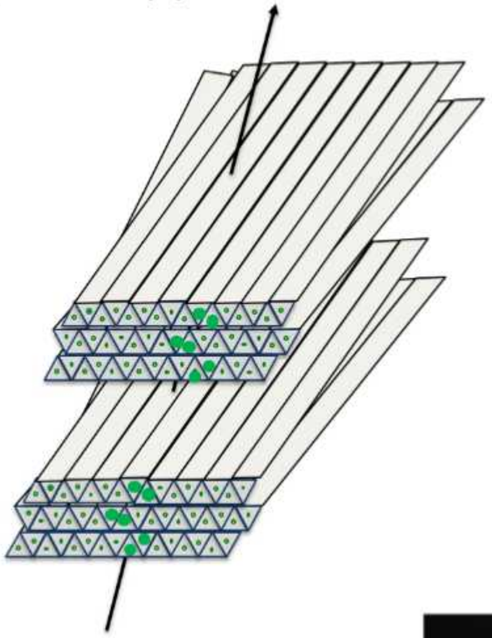

No to very little nuclear modification as expected.

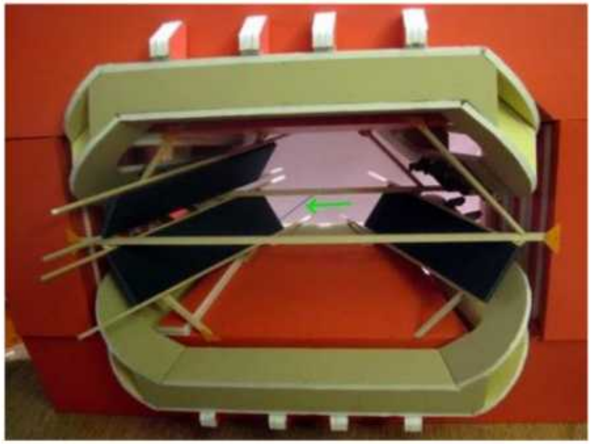
# Magnet stations for low momentum tracking 

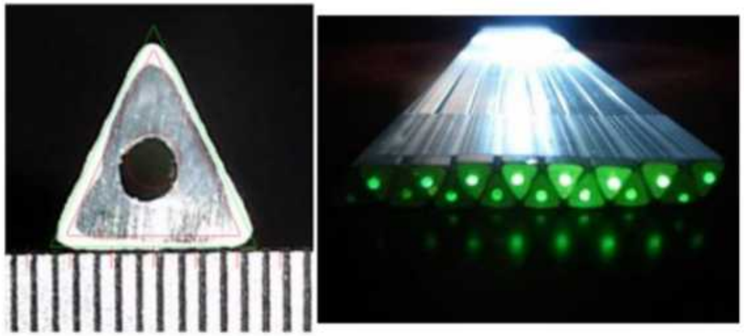
http://cds.cern.ch/record/2645499/files/Cesar%20DNP2018-gamma_hadron-LHCb.pdf

- Based on 5cm-side triangular extruded scintillators made at Fermilab
- Light guided outside the magnet to avoid the radiation on the siPM readouts
- Plans for installation in 2025, if project is approved



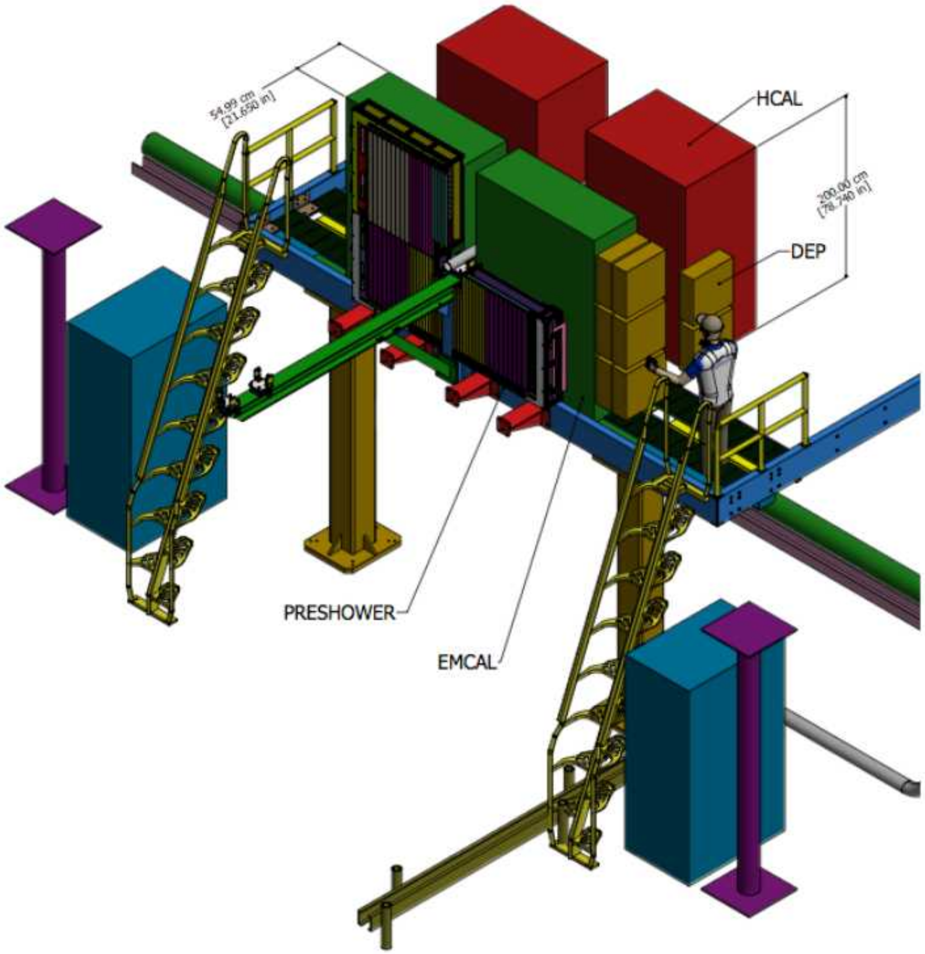







# STAR Forward Calorimeter System






**Performance Needs**

**ECal:** $\sim 10\%/\sqrt{E}$ (pp/pA) and $\sim 20\%/\sqrt{E}$ (AA)

reuse PHENIX PbSC calorimeter with new readout

- **Benefit:** significant cost reduction!
- **Tradeoff:** uncompensated calorimeter system

**HCal:** $\sim 60\%/\sqrt{E}$ (pp/pA)

- Sandwich iron-scintillator plate sampling cal.
- Same readout for both calorimeters

**Cost:**

**ECal:** \$0.57M

**HCal:** \$1.53M

**Preshower:** \$0.06M

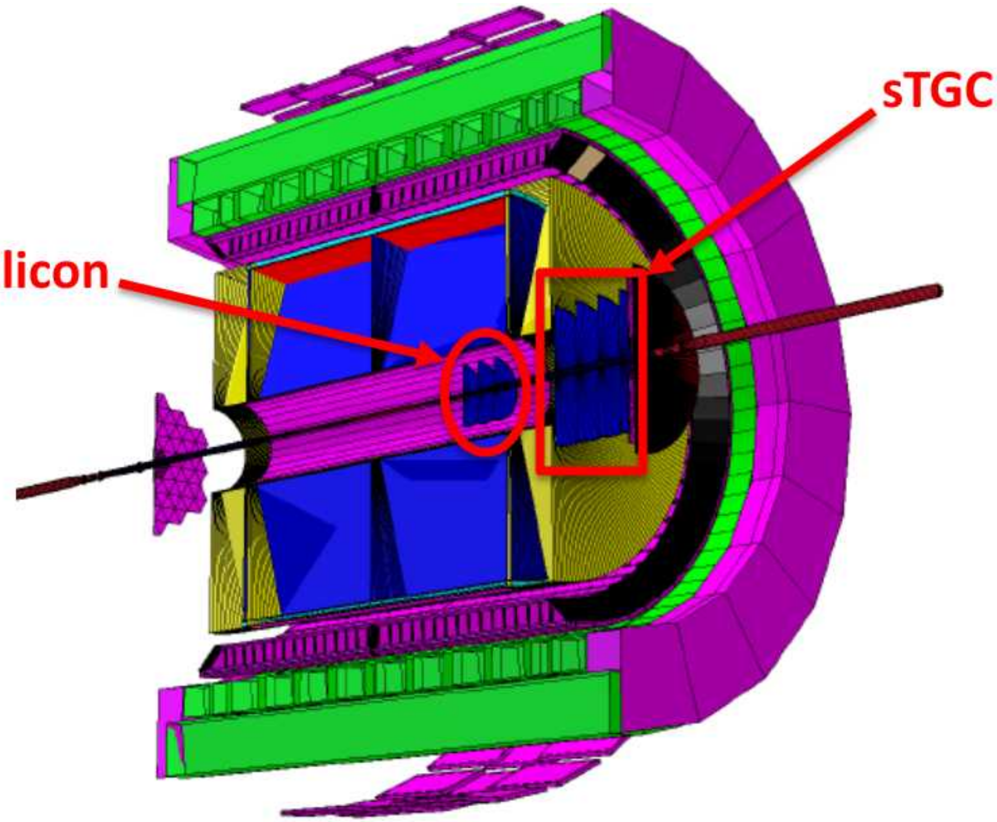
**Total: \$2.2M***

**includes contingency and manpower*

*Intensive R&D on both calorimeters as part of STAR and EIC Detector R&D, including FNAL test beam and STAR in situ tests*

# STAR Forward Tracking System





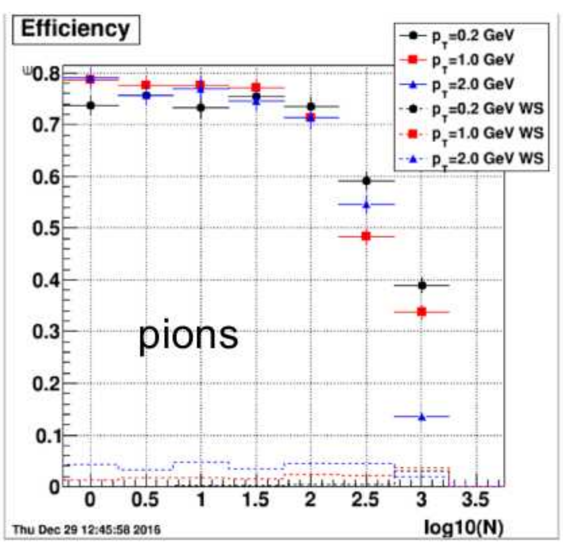

**3 Si discs + 4 Small-strip Thin Gap Chambers**

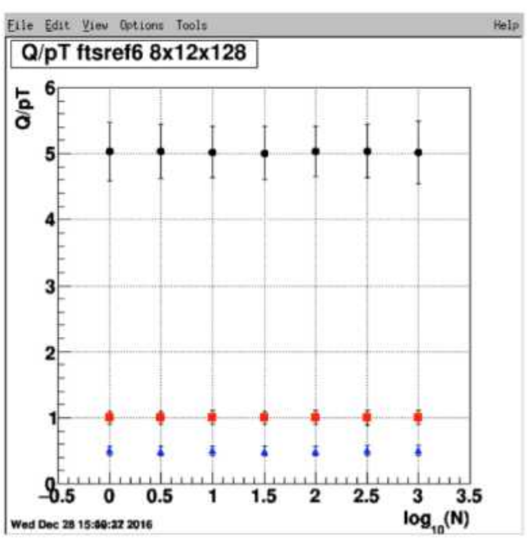
**Location from interaction point:**

**Si:** 90, 140, 187 cm

**sTGC:** 270, 300, 330, 360 cm

(*outside Magnet*)




**Performance Needs:**

**Momentum resolution:**

20-30% for $0.2 < p_T < 2$ GeV/c

**Tracking efficiency:**

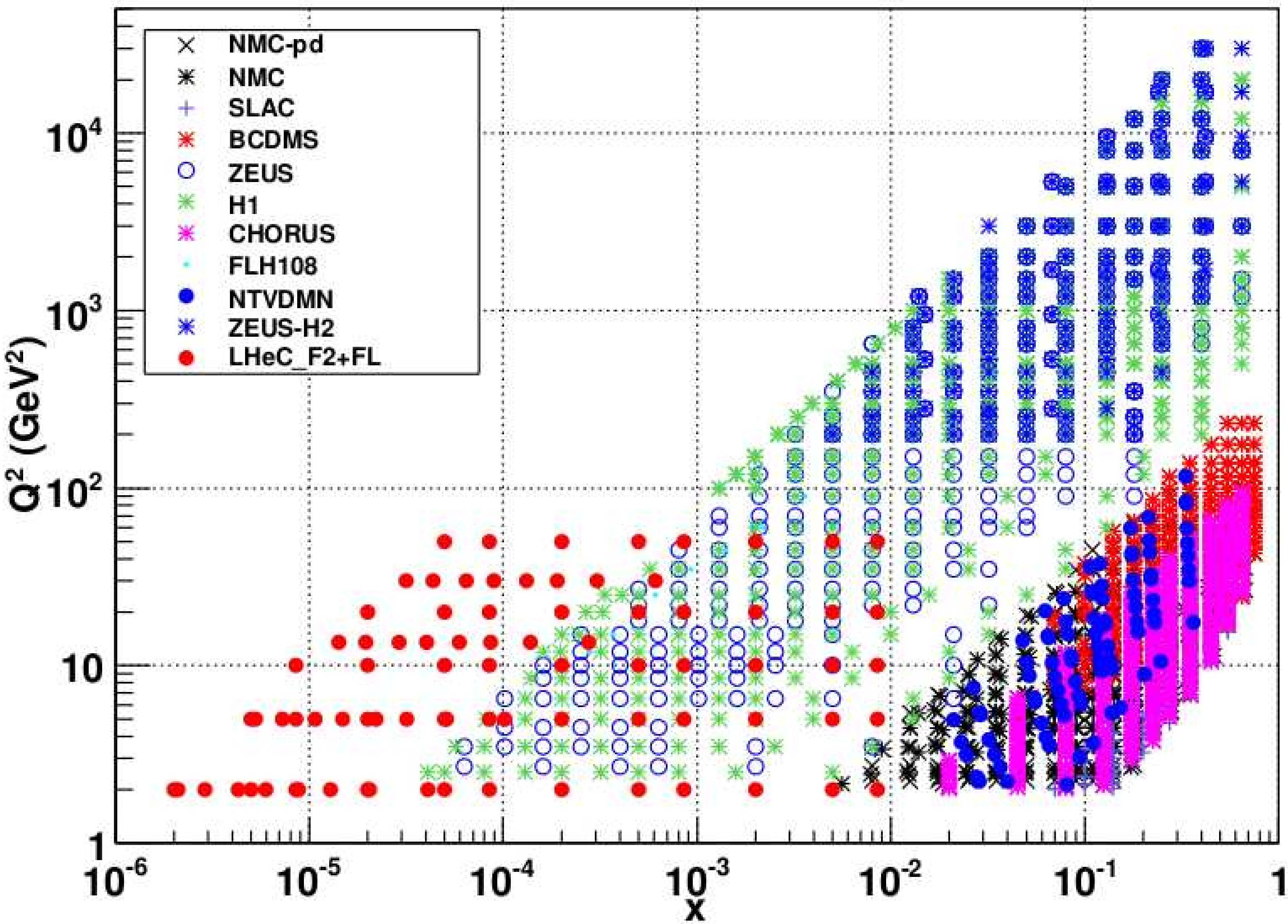
80% at 100 tracks/event

**Cost:** $3.3 M

# LHC potential for low-x



https://arxiv.org/abs/1206.2913



# LHeC potential for large x



https://arxiv.org/abs/1206.2913

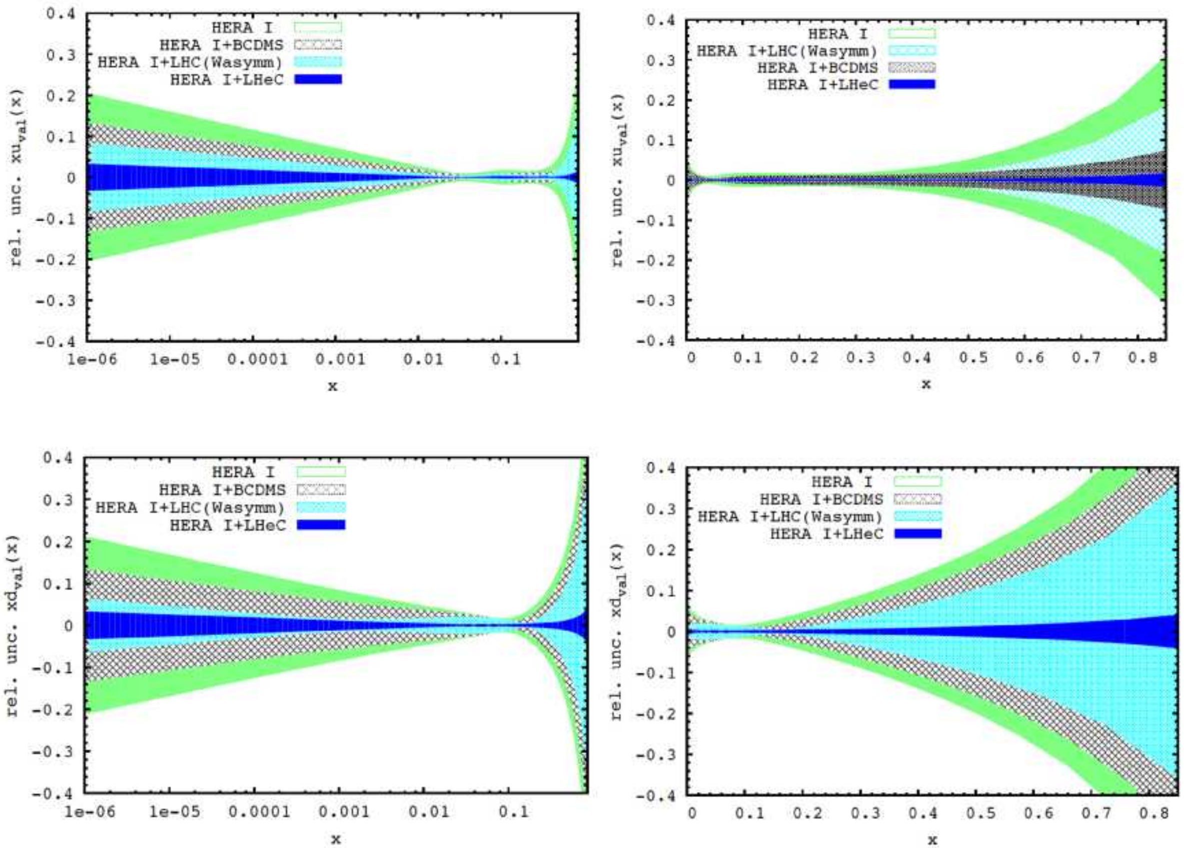



Figure 3.9: Uncertainty of valence quark distributions, at $Q^2 = 1.9\,\mathrm{GeV}^2$, as resulting from an NLO QCD fit to HERA (I) alone (green, outer), HERA and BCDMS (crossed), HERA and LHC (light blue, crossed) and the LHeC added (blue, dark). Top: up valence quark; down: down valence quark; left: logarithmic $x$, right: linear $x$.

Factor ~10 improvement at x=0.7