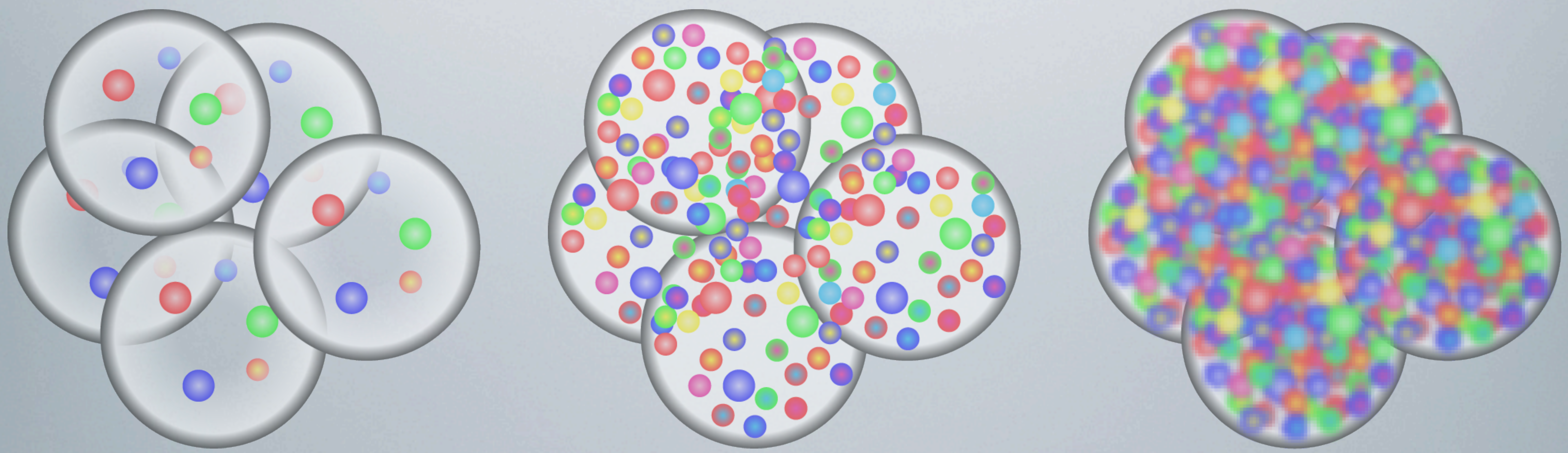


The Forward Calorimeter (FoCal) project

An ALICE upgrade for forward physics

T. Peitzmann (Utrecht University/Nikhef)
for the ALICE collaboration

Forward Physics at the LHC, CERN Feb. 11/12 2013

ALICE

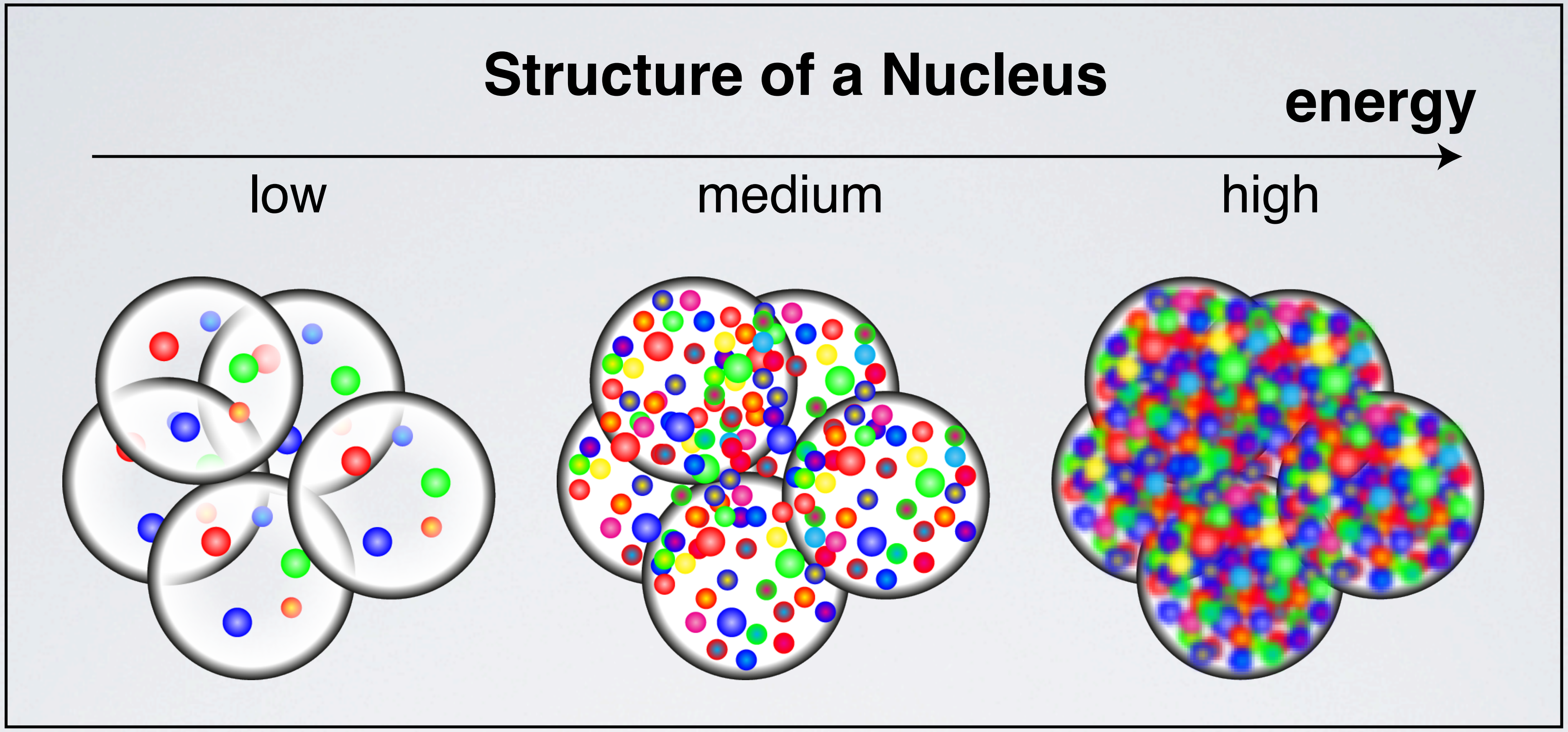
Outline

- Introduction: physics motivation
- Detector design
- Performance simulations
  - Direct photons in pp and pPb
  - First look at Pb-Pb
- Conclusions

Forward Physics in ALICE

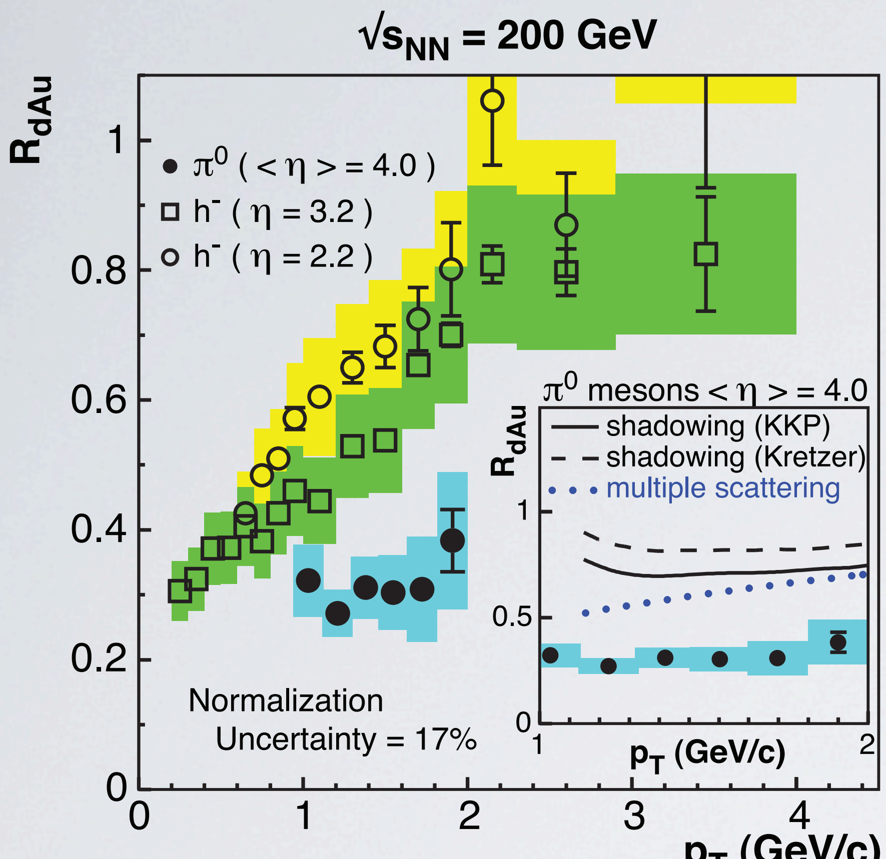
- ALICE physics program until ≈ 2025 (endorsed by LHCC)
  - study of strongly interacting matter at very high temperature: the quark-gluon plasma
- forward/low-x physics within ALICE
  - fundamental interest in gluon saturation/color glass condensate
  - information on initial state yields important constraints for interpretation of QGP studies
    - e.g. knowledge of eccentricity for elliptic flow
  - forward detector enhances general physics scope
    - em calorimeter (FoCal): significant increase of coverage for photons, jets compared to existing calorimeters (PHOS, EMCal)
- FoCal: new upgrade project for installation in LS2
- ALICE decision in March 2013

Color Glass Condensate

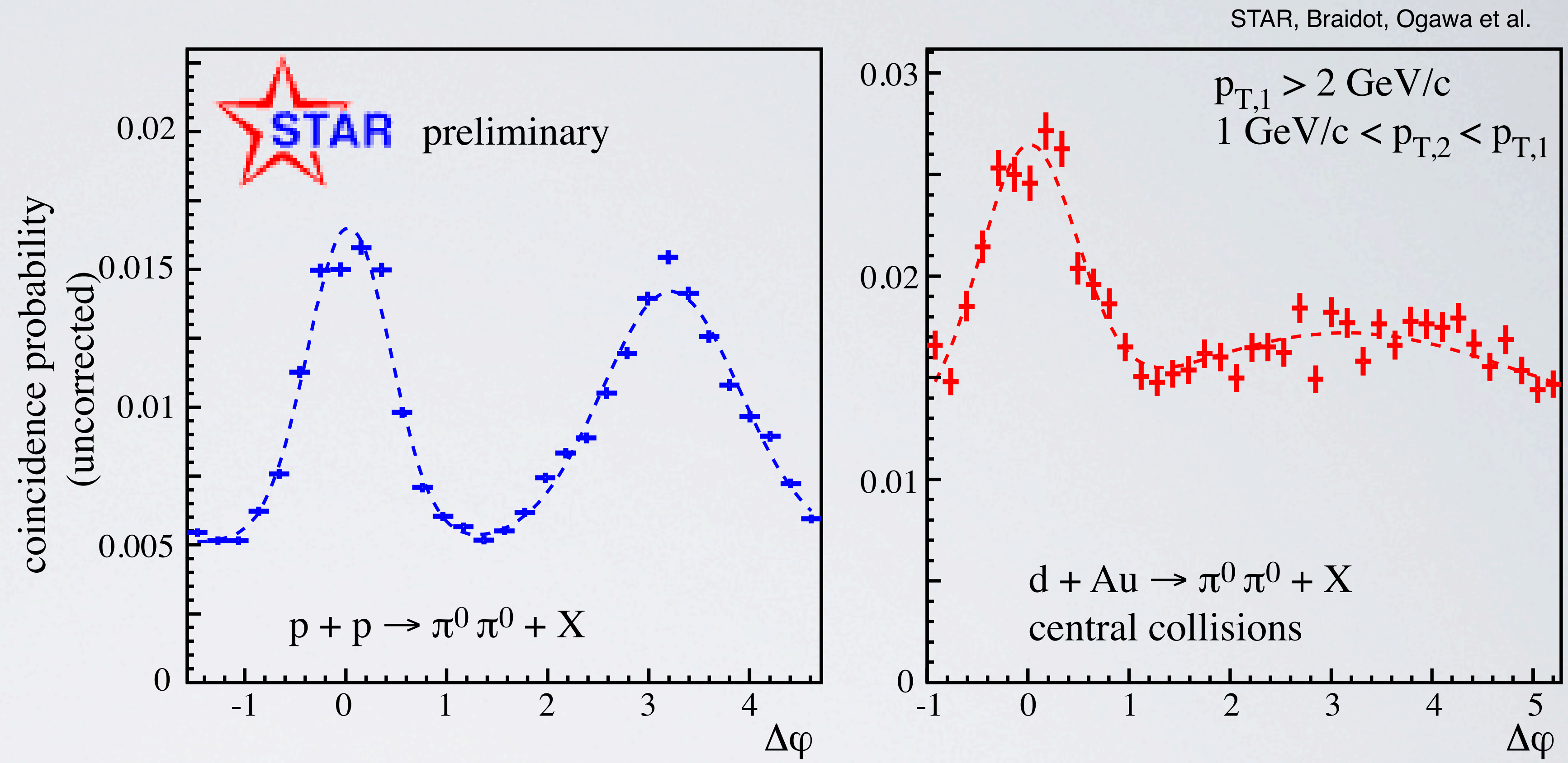


- low-x, low Q^2: high gluon occupation number, strong fields
  - classical color fields, theoretically calculable (JIMWLK)
- new phenomena: yield suppression, monojets
  - enhanced in nuclei (stronger color field compared to proton)

Indications from RHIC



STAR, PRL97, 152302

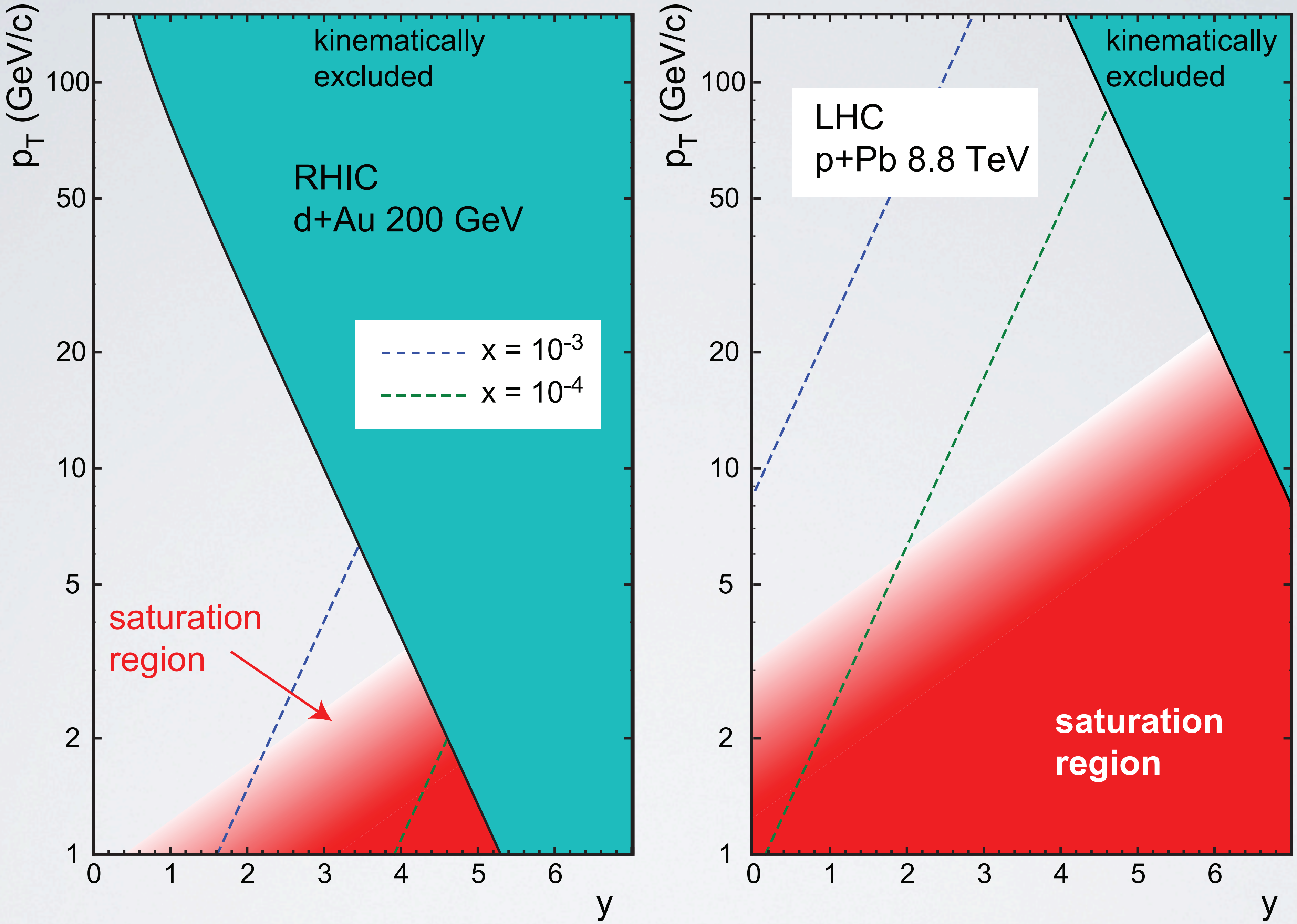


R_{dA}: strong suppression of hadron yield at forward rapidity

di-hadron correlations: broadening/suppression of away-side peak in dAu

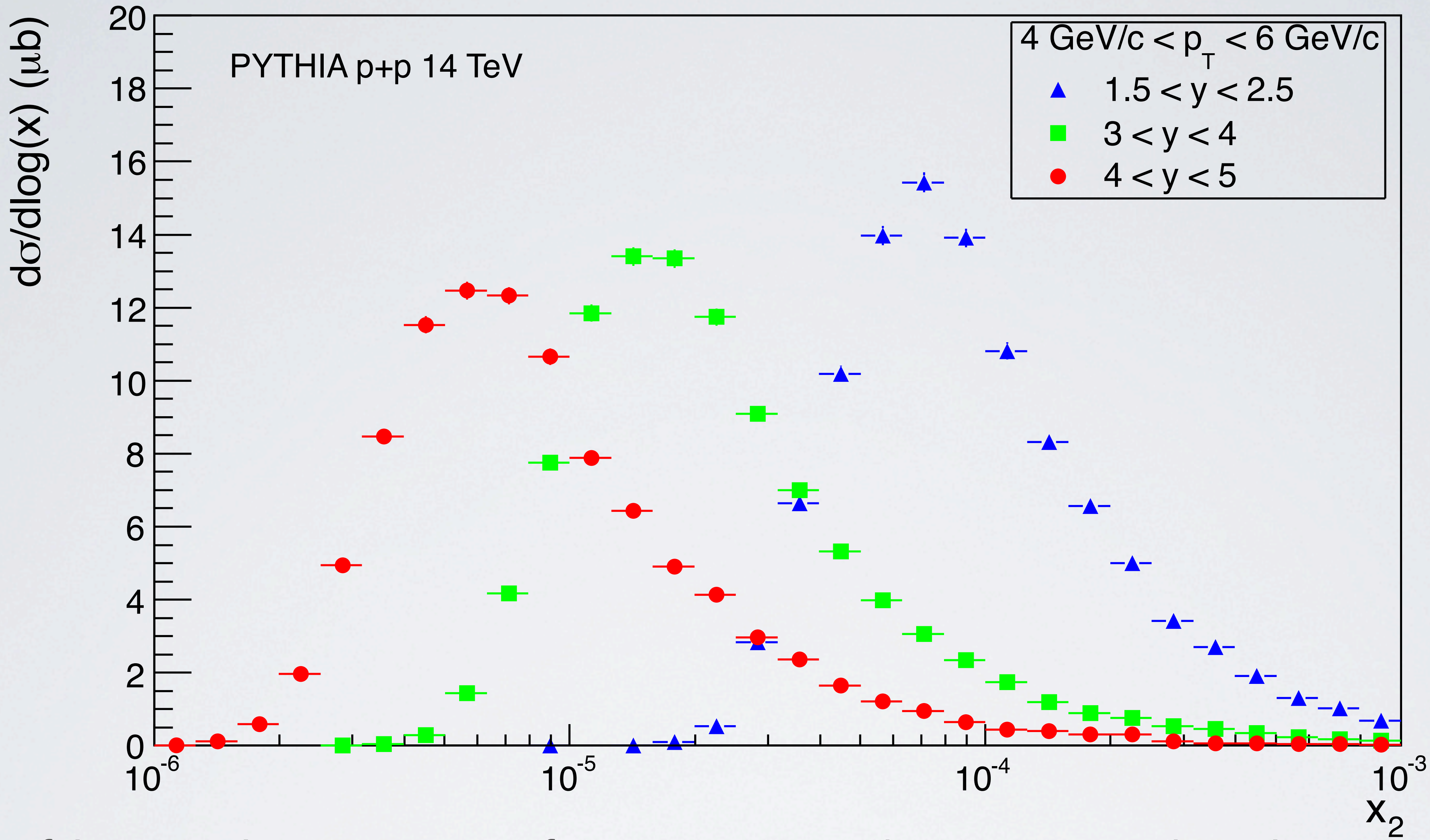
- qualitatively consistent with CGC, but ...
  - very low p_T, hadron observable (final state interactions)!
- extend p_T and y range (not possible at RHIC)
- measure prompt photons

LHC vs RHIC



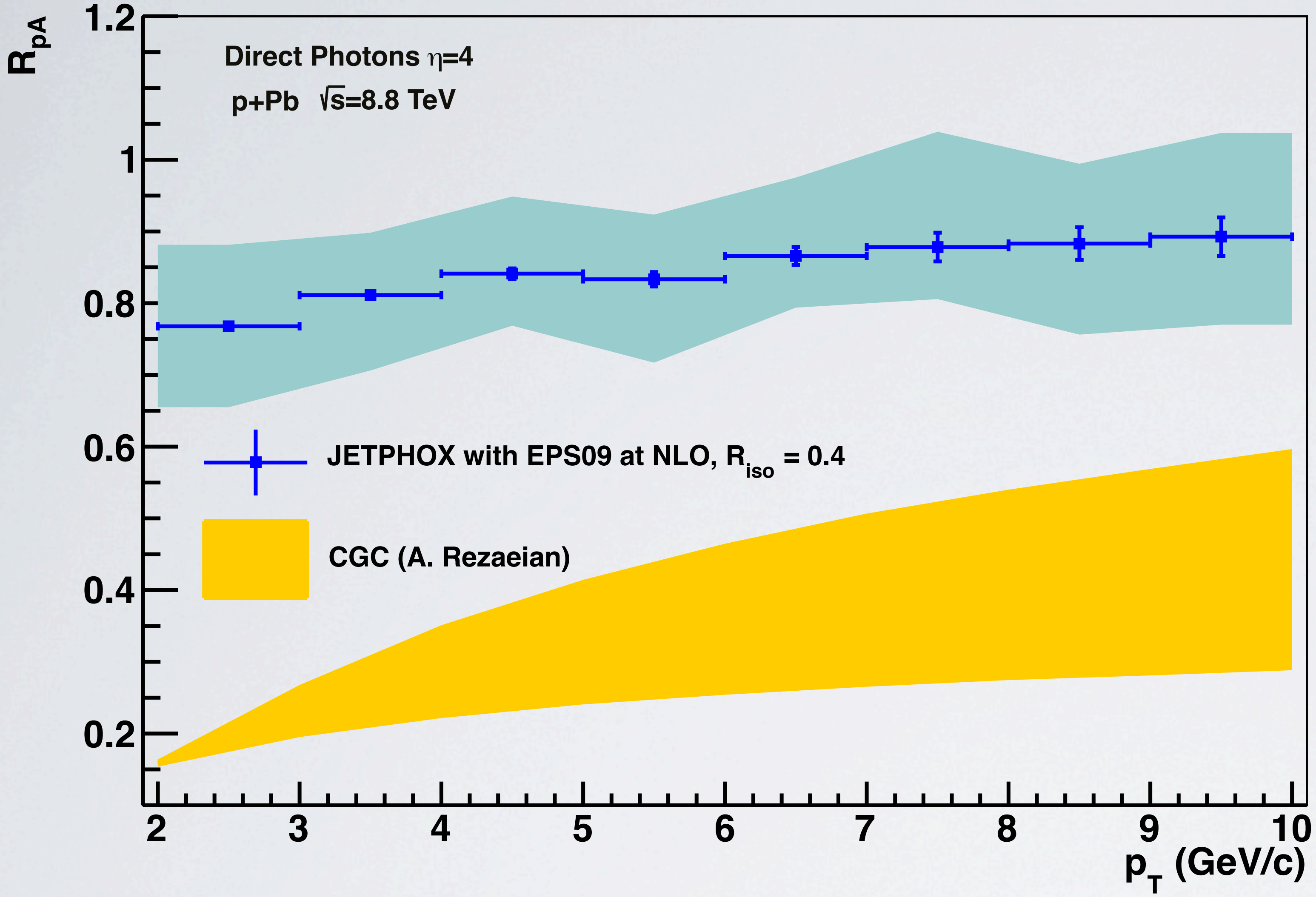
- Q_{sat} larger: saturation in perturbative regime?
- larger energy: lower x at same rapidity, not constrained by kinematic limit

x-Reach with Direct Photons



- x of incoming parton for prompt photon production with p_T > 4 GeV/c
- changes with NLO effects to be checked
  - should be small for isolated photons

nPDF/DGLAP vs CGC

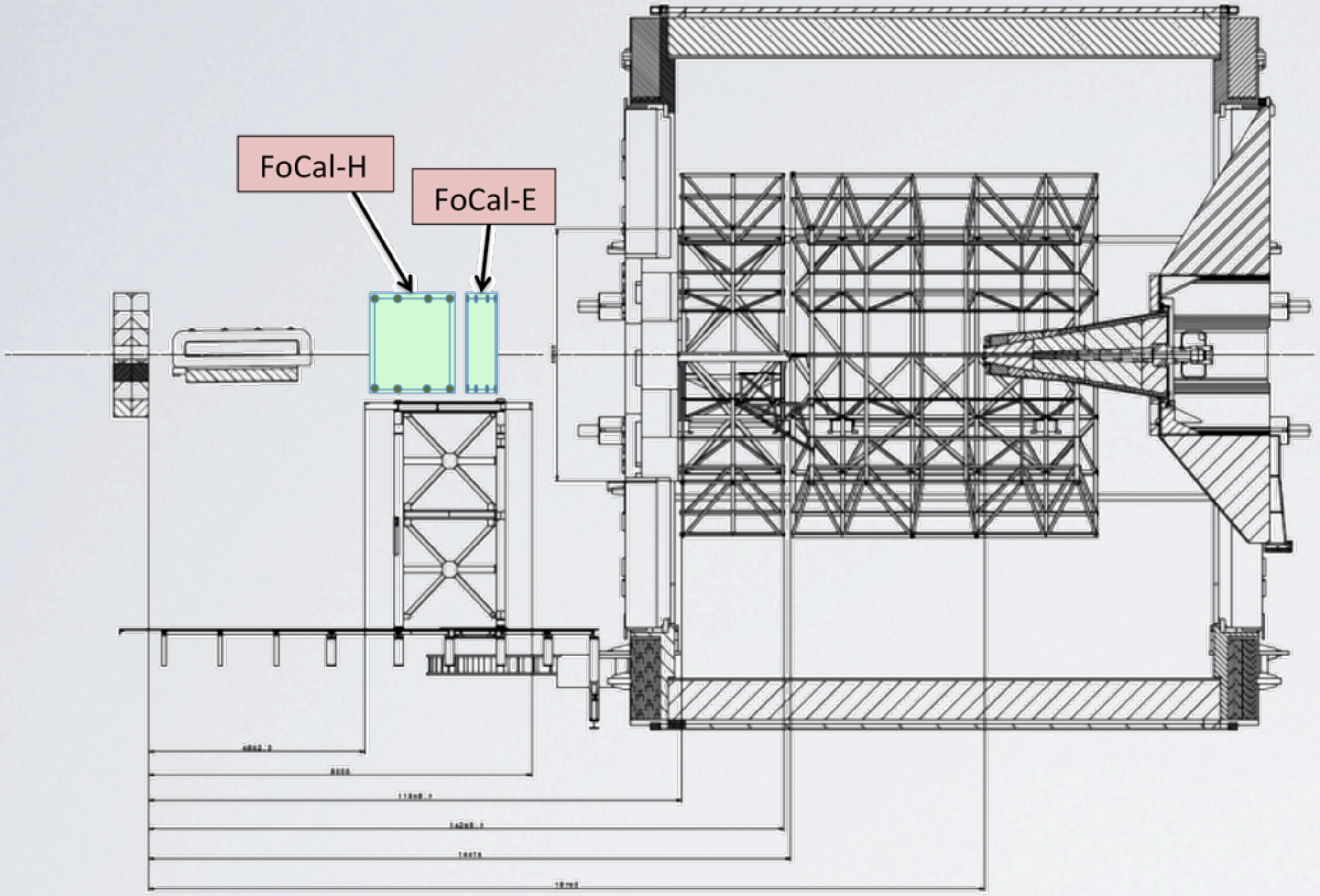


two scenarios for forward γ production in p+A at LHC:

- normal nuclear effects
  linear evolution, shadowing
- saturation/CGC
  running coupling BK evolution

- strong suppression in direct γ RpA
- signals expected at forward η, low-intermediate p_T
  - transition expected - where?

FoCal in ALICE



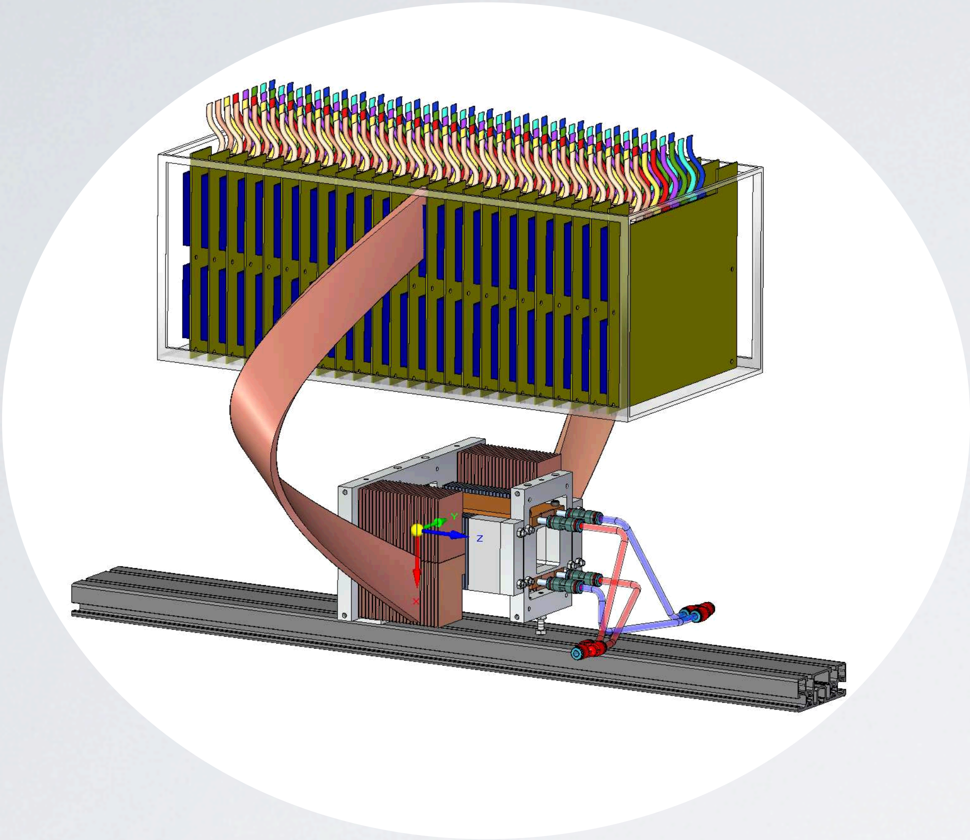
electromagnetic calorimeter for γ and π^0 measurement

two scenarios:

- at $z \approx$ 8m (outside magnet)
  $3.3 < \eta < 5.3$
  (space to add hadr. calorimeter)
- at $z \approx$ 3.6m (current PMD)
  $2.5 < \eta < 4.5$

- main challenge: separate γ/π^0 at high energy
- need small Molière radius, high-granularity read-out
  - Si-W calorimeter, granularity $\approx$ 1mm^2

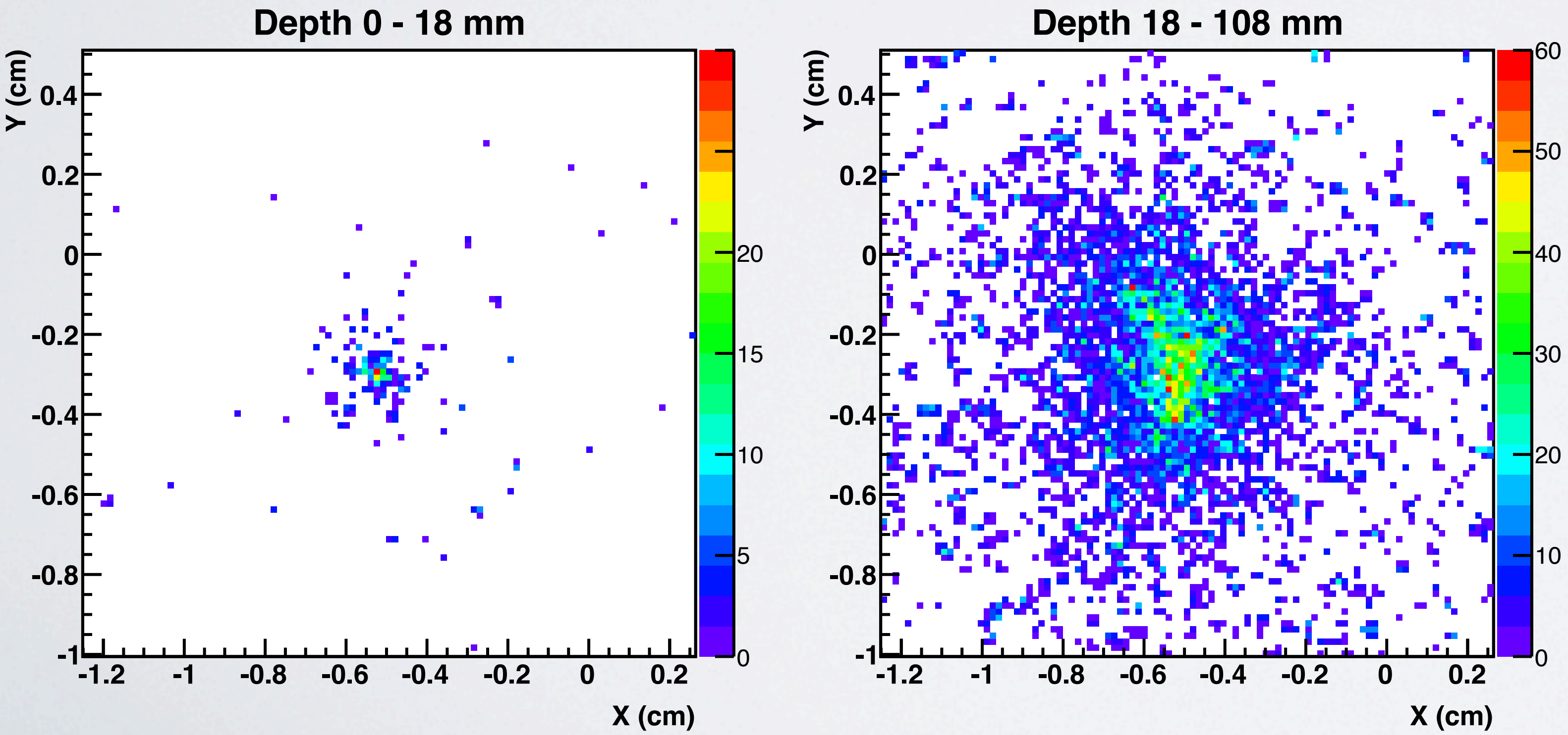
Prototypes and Test Beams



R&D ongoing
(Utrecht/Nikhef, Bergen, Tokyo, ORNL, Kolkata, Prague, ...)

e.g. full MAPS prototype

- 39 M pixels in 4x4x10 cm^3 !



single electron (200 GeV)

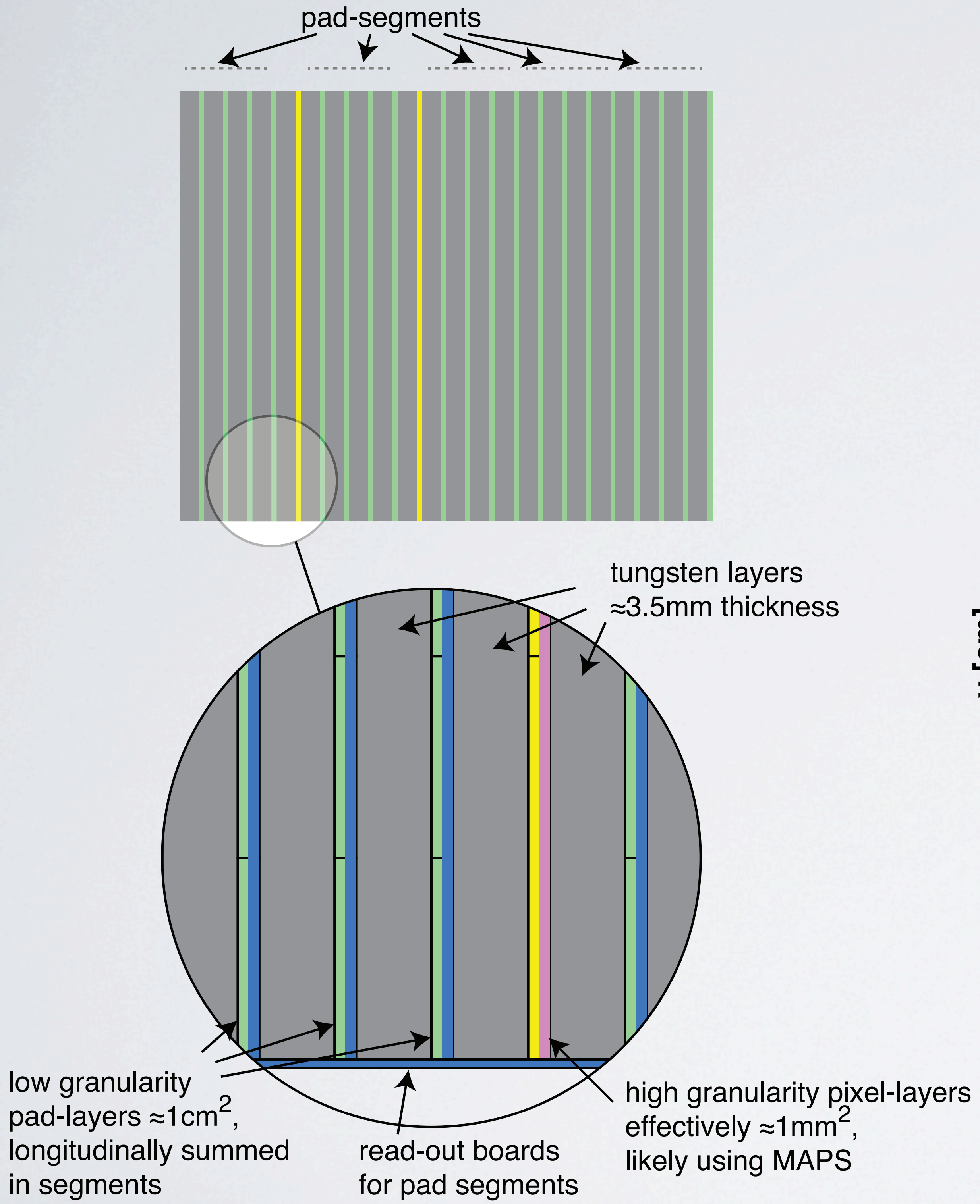
first results from test beams encouraging

high granularity should be feasible, depends on pixel development

FoCal Physics Program

- p+Pb: saturation/CGC effects
  - forward direct γ spectra, γ-hadron/jet correlations (unique!)
  - π^0 spectra, π^0-π^0 correlations, possibly jets (had. calorimeter!)
- p+p: reference measurements
  - constraints on PDFs?
- Pb+Pb: QGP studies
  - extend acceptance for γ-hadron/jet, π^0-π^0 correlations
  - π^0 R_{AA} forward
    - longitudinal density profile, compare to forward J/ψ
  - event plane determination, ...

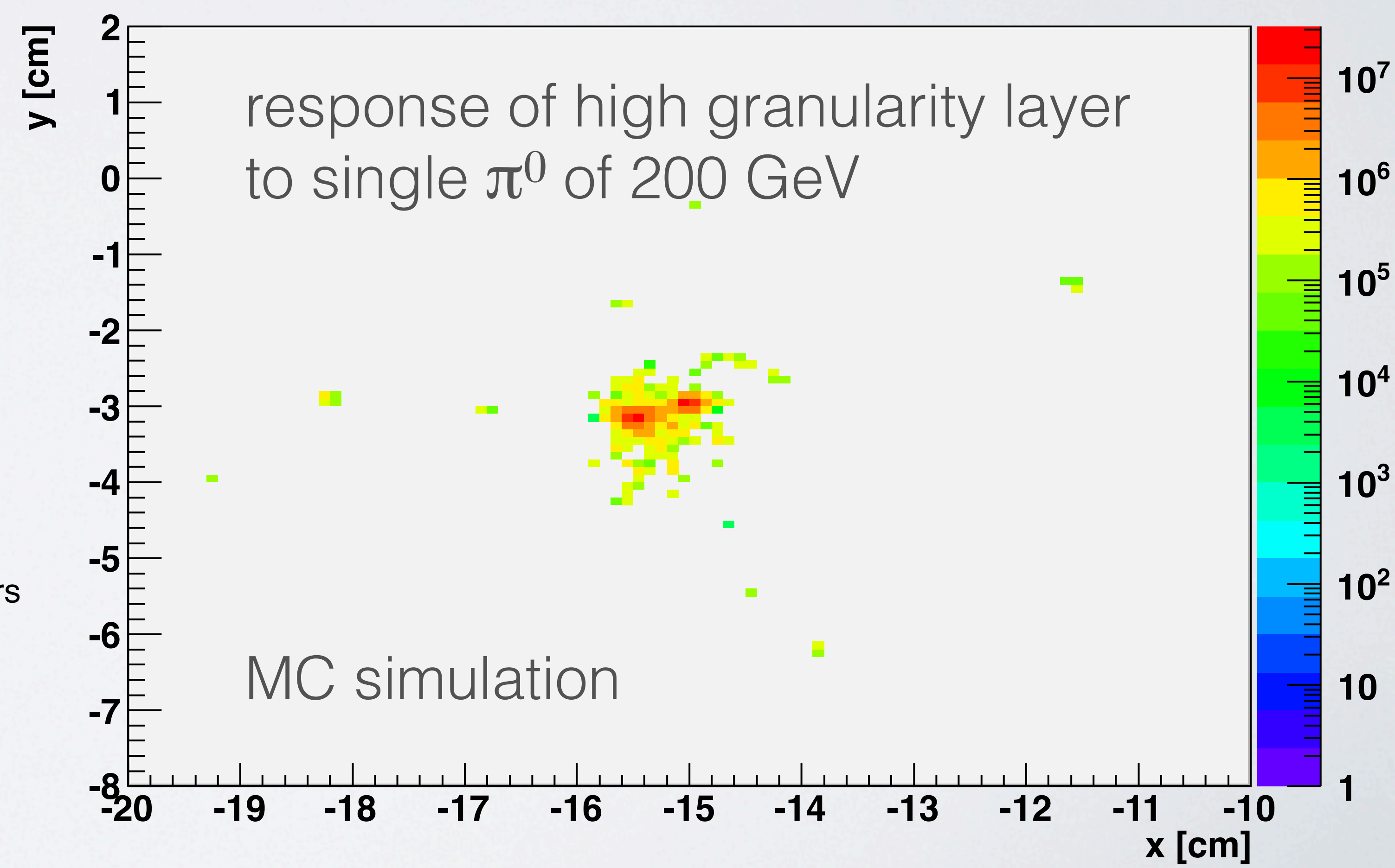
Strawman Design



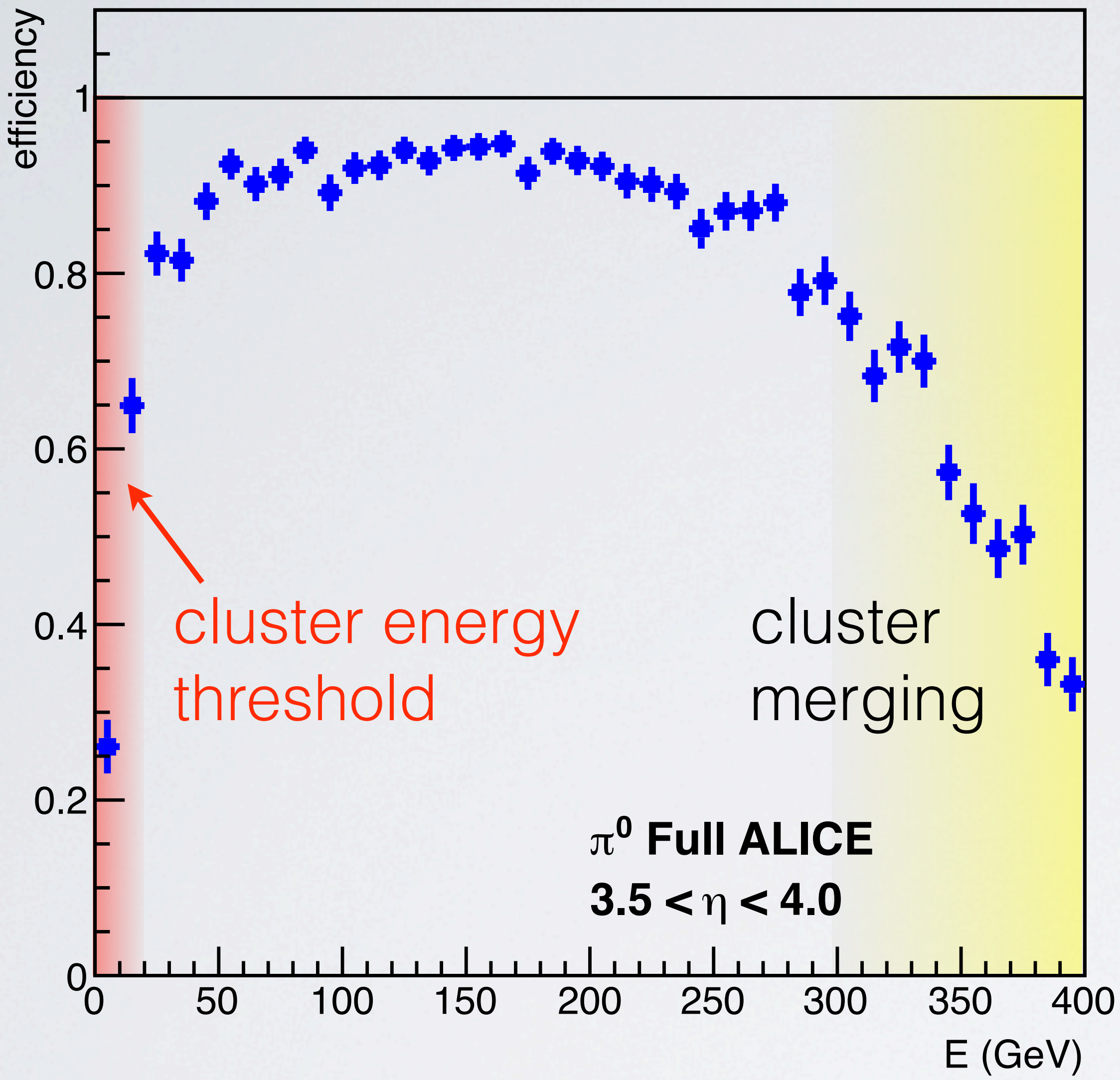
studied in performance simulations:

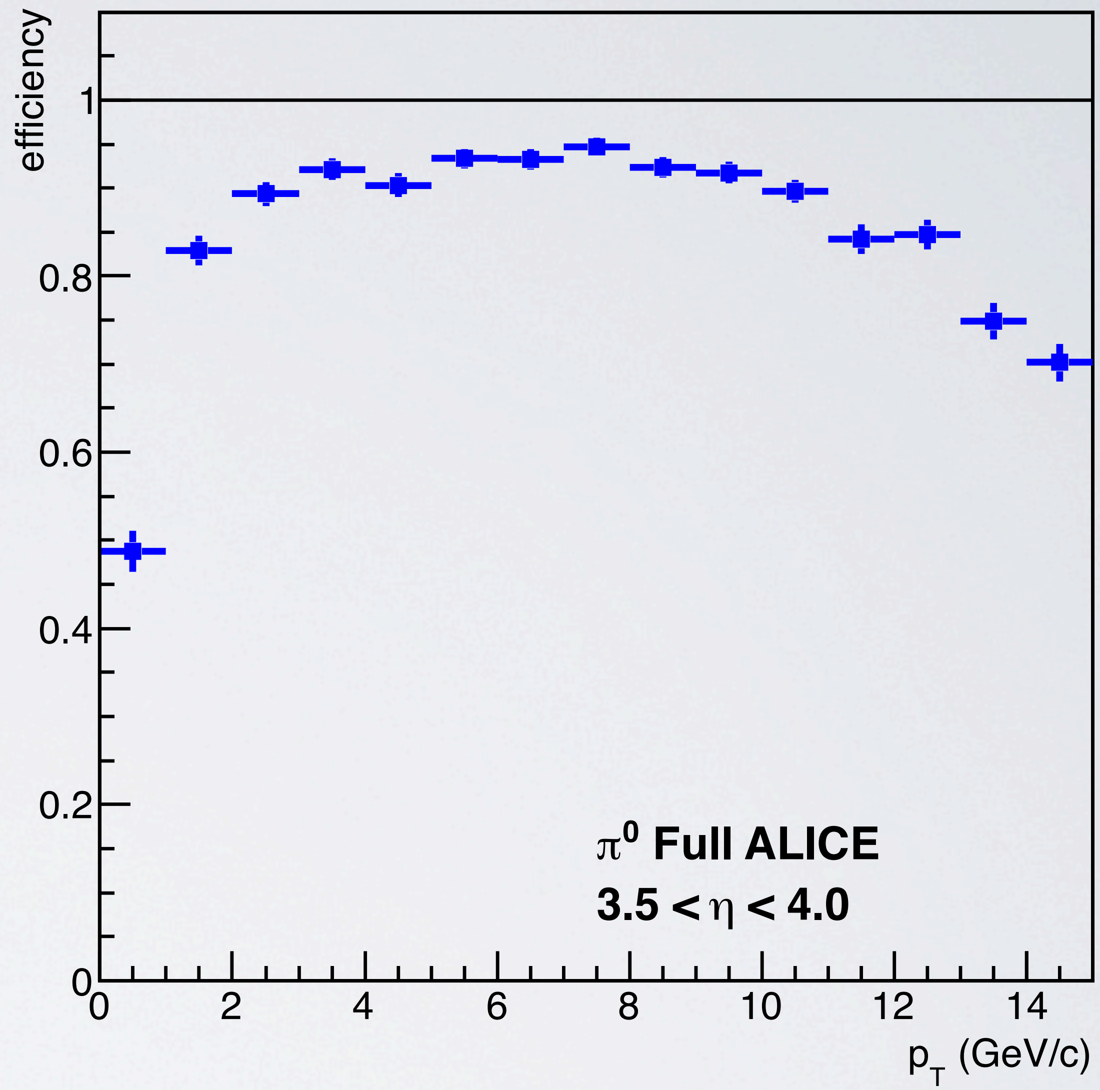
24 layers:
W (3.5mm ≈ 1 X_0) + Si-sensors (2 types)

- low granularity (≈ 1 cm^2), Si-pads
- high granularity (≈ 1 mm^2), obtained with pixels (e.g. CMOS-MAPS)



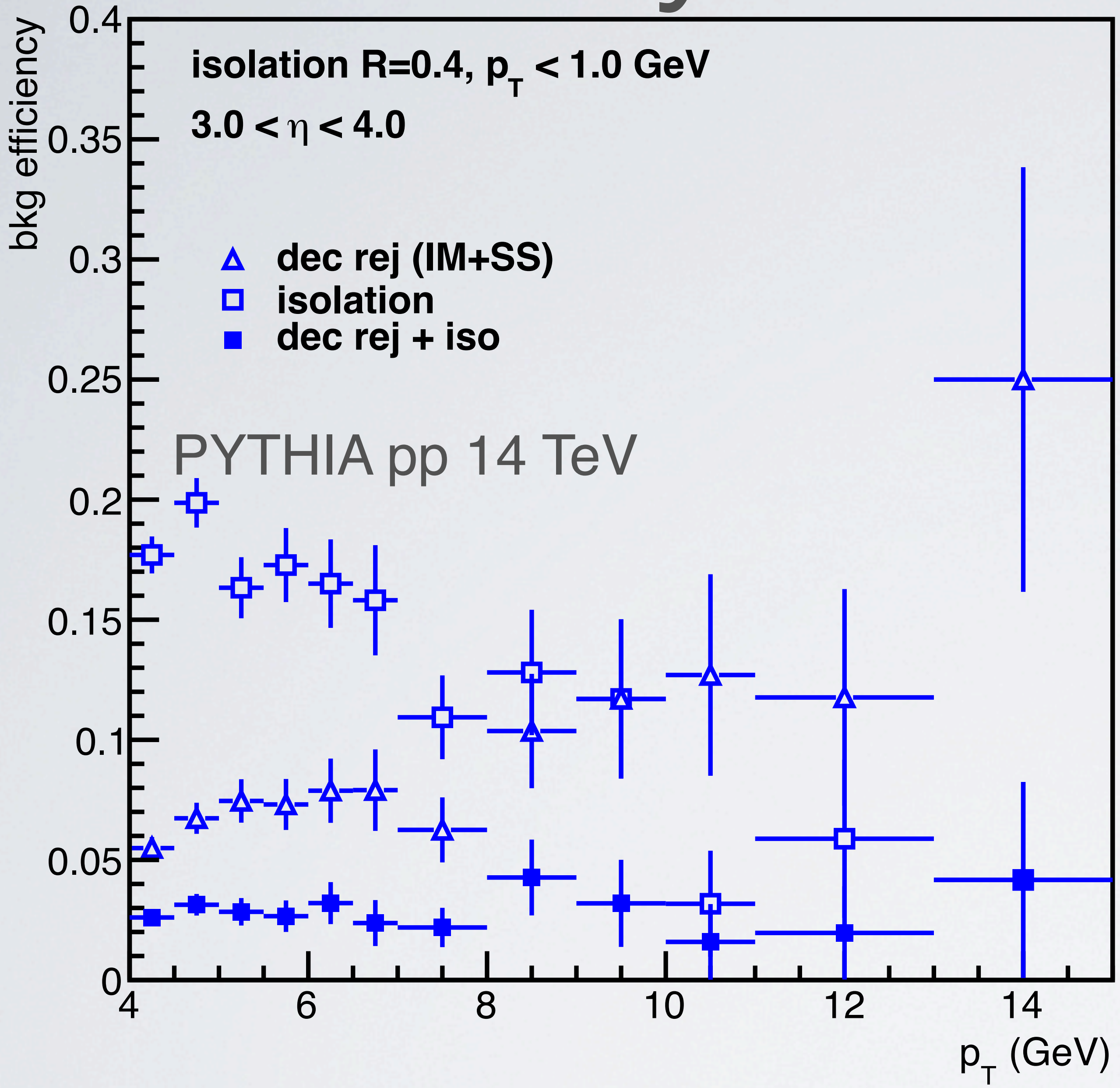
π^0 Efficiency

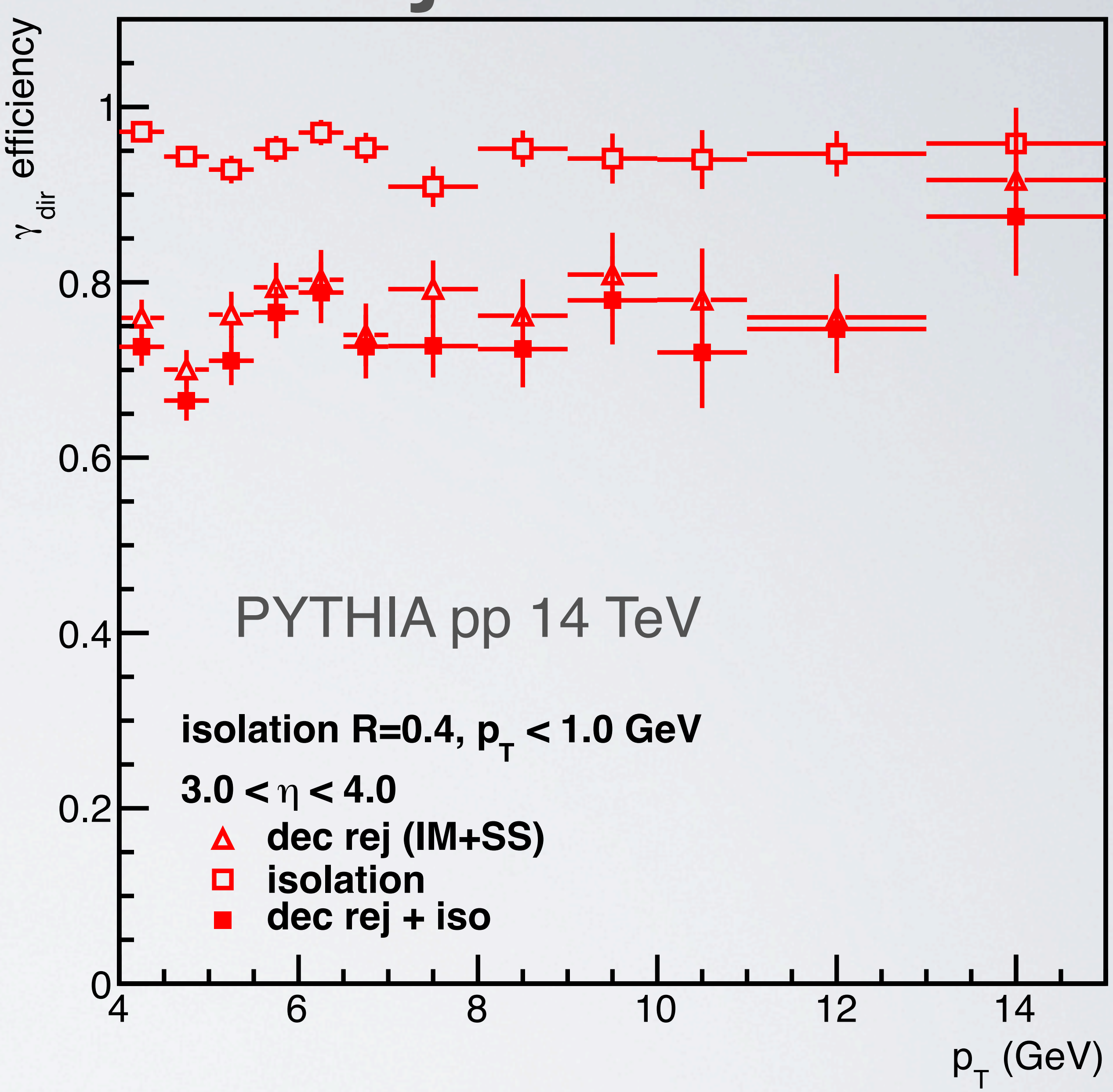




- results of single particle simulations using full ALICE setup
- excellent π^0 efficiency for $20 < E < 300$ GeV, $2 < p_T < 10$ GeV/c

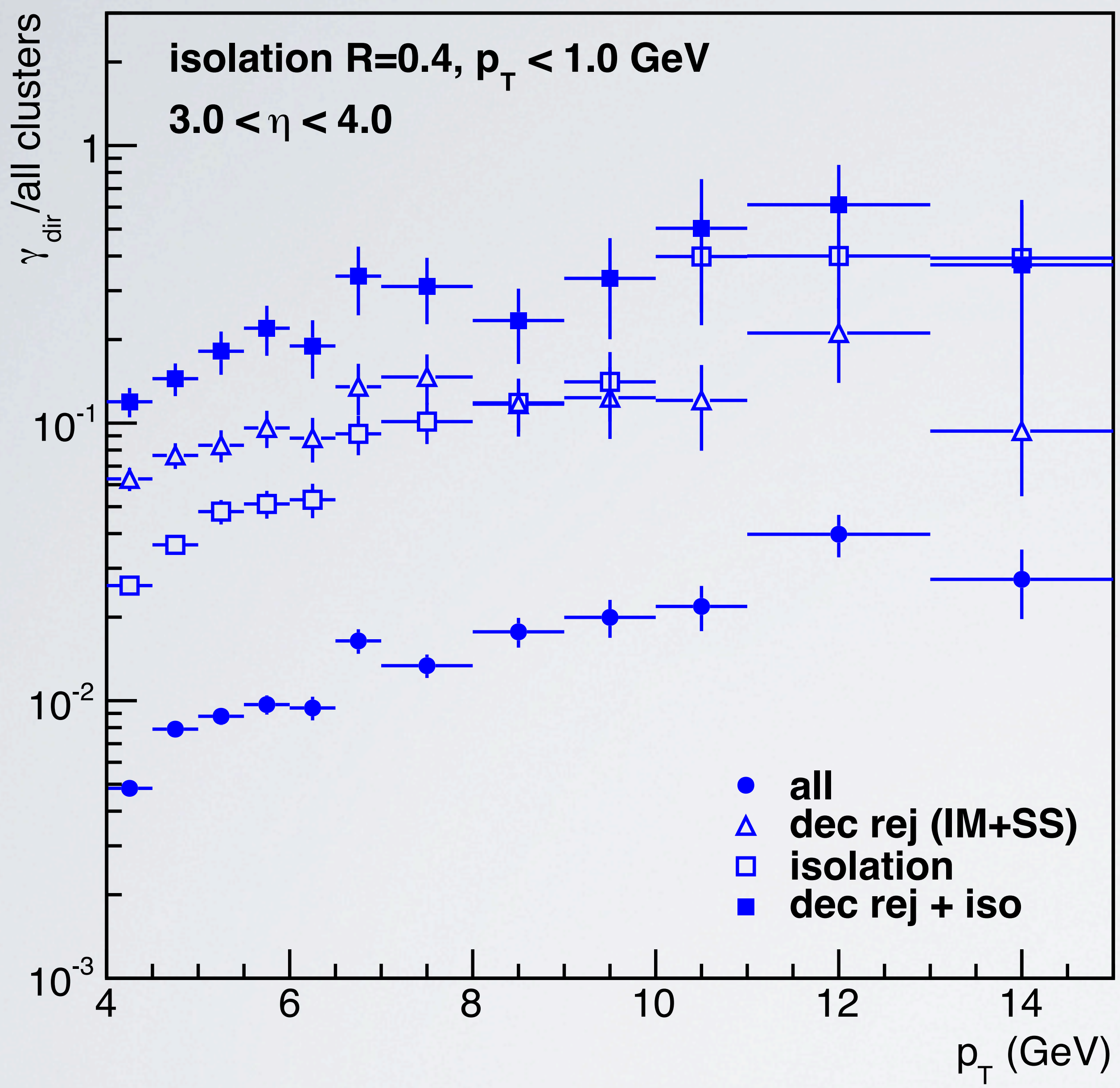
Decay Photon Rejection

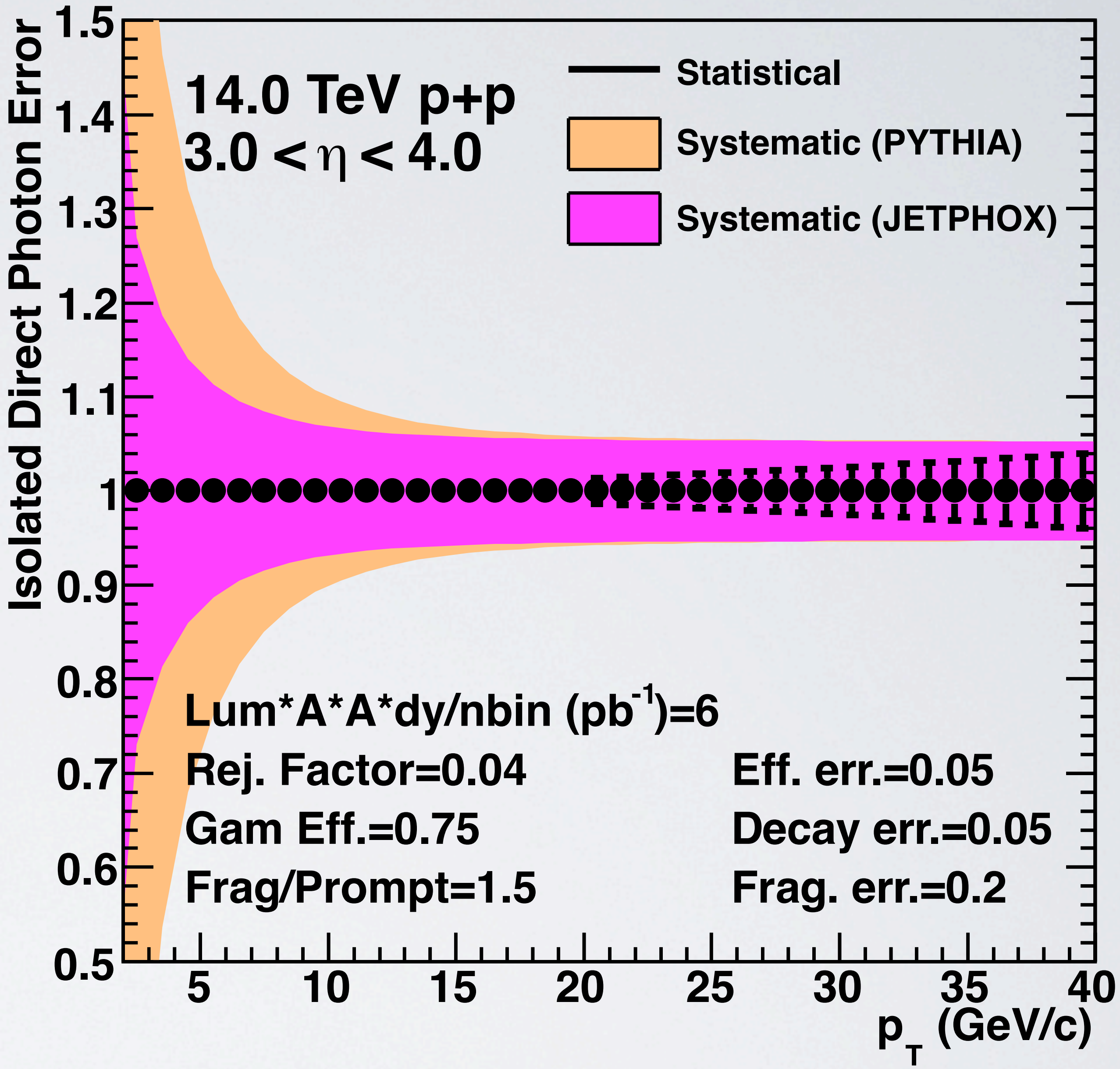




- combined rejection (invariant mass + shower shape, isolation)
- rejection factor ≈30, direct photon efficiency ≈75%
  - largely p_T-independent

Direct γ Performance in pp

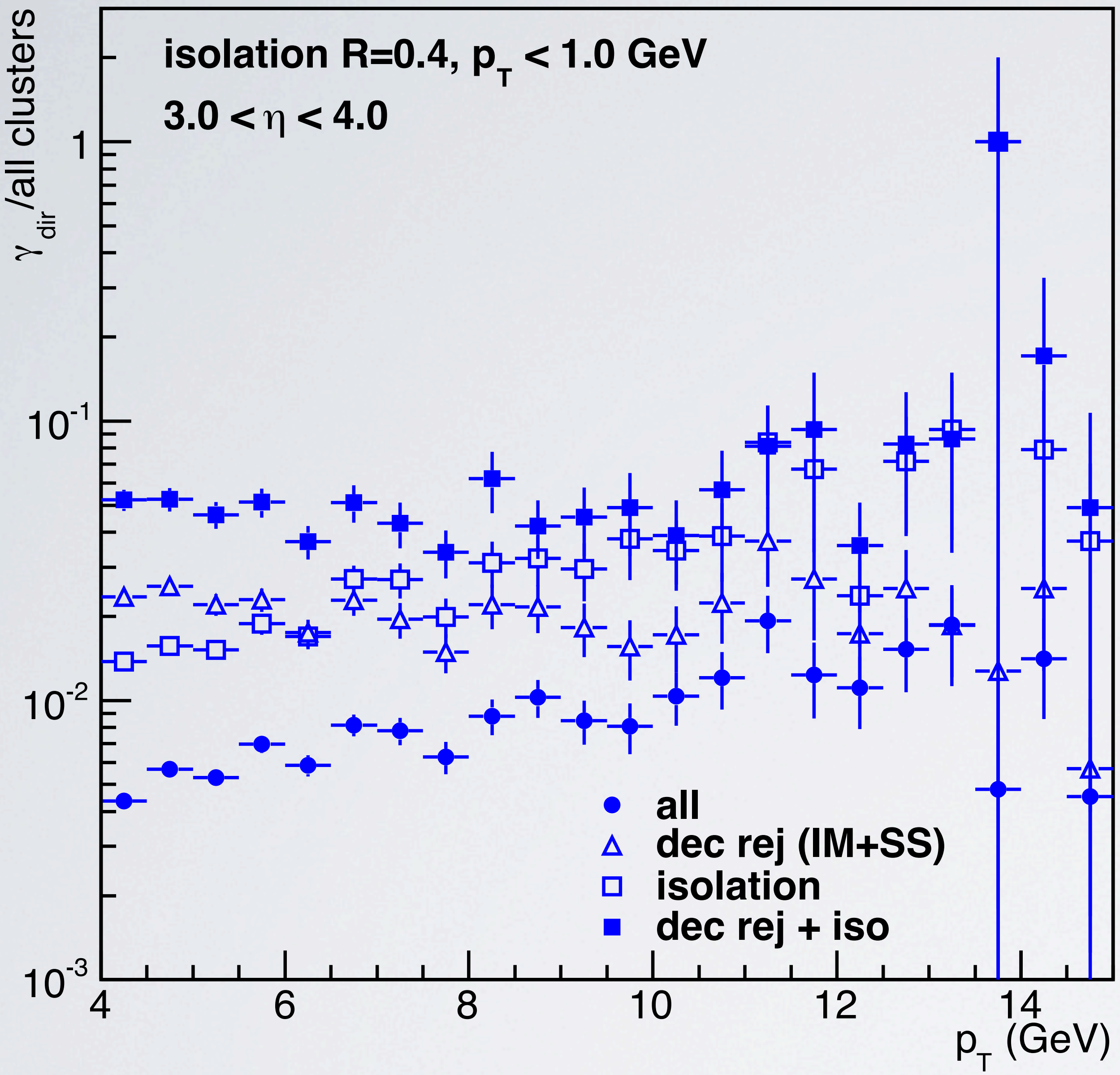


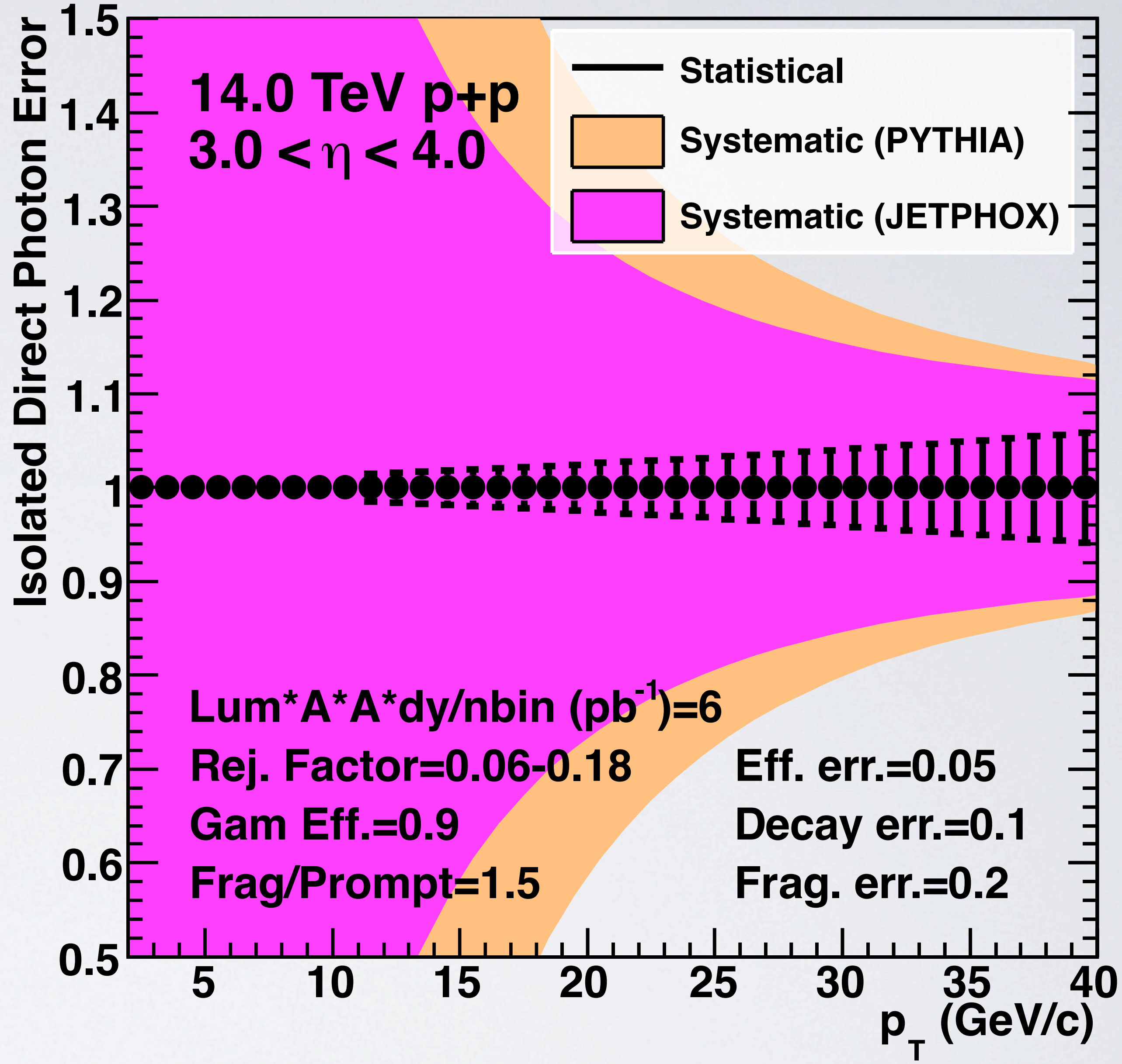


direct photon/all > 0.1
for p_T > 4 GeV/c

20-40% uncertainty
at p_T = 4 GeV/c
decreases with increasing p_T

Low Granularity Measurement



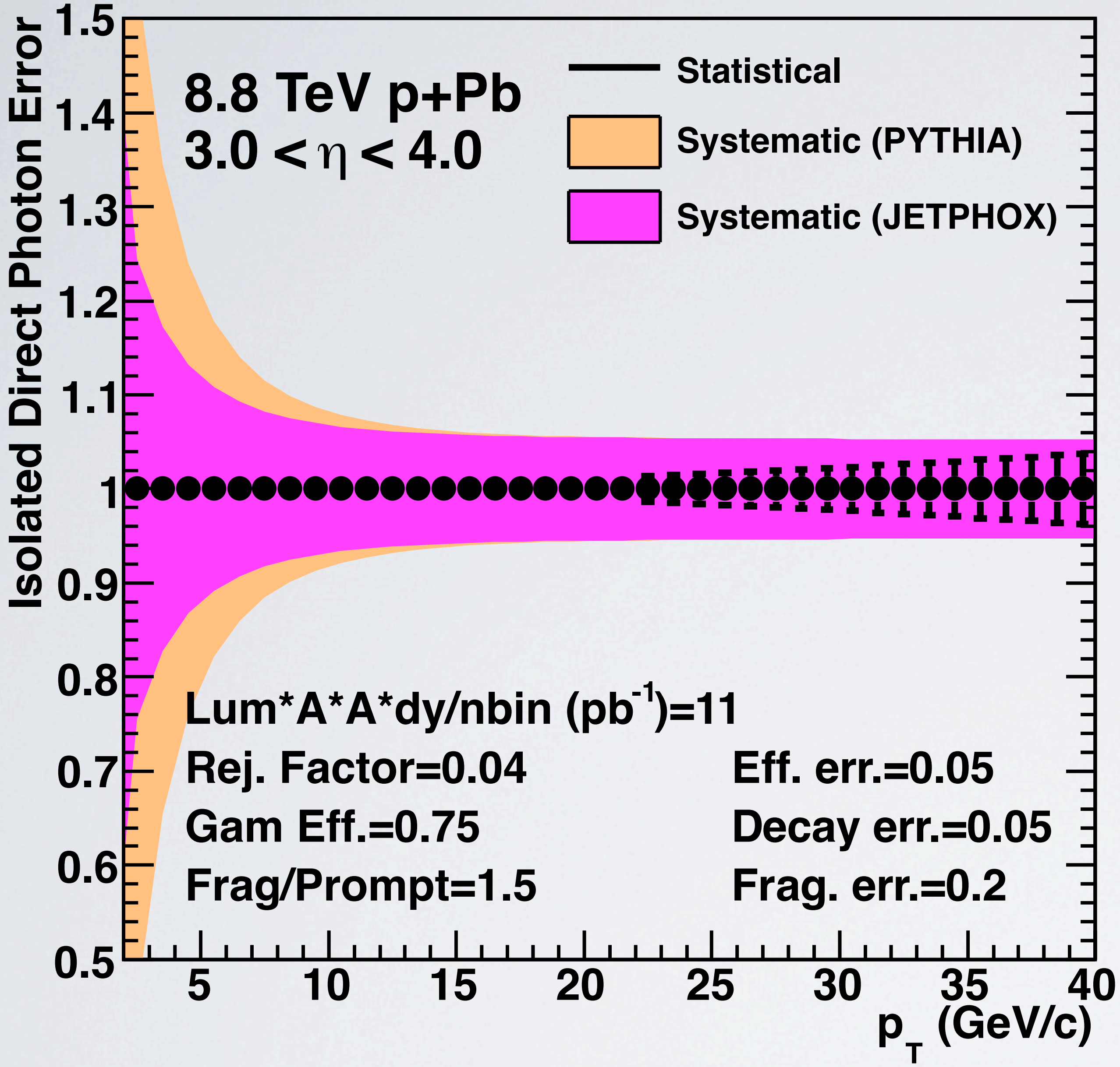


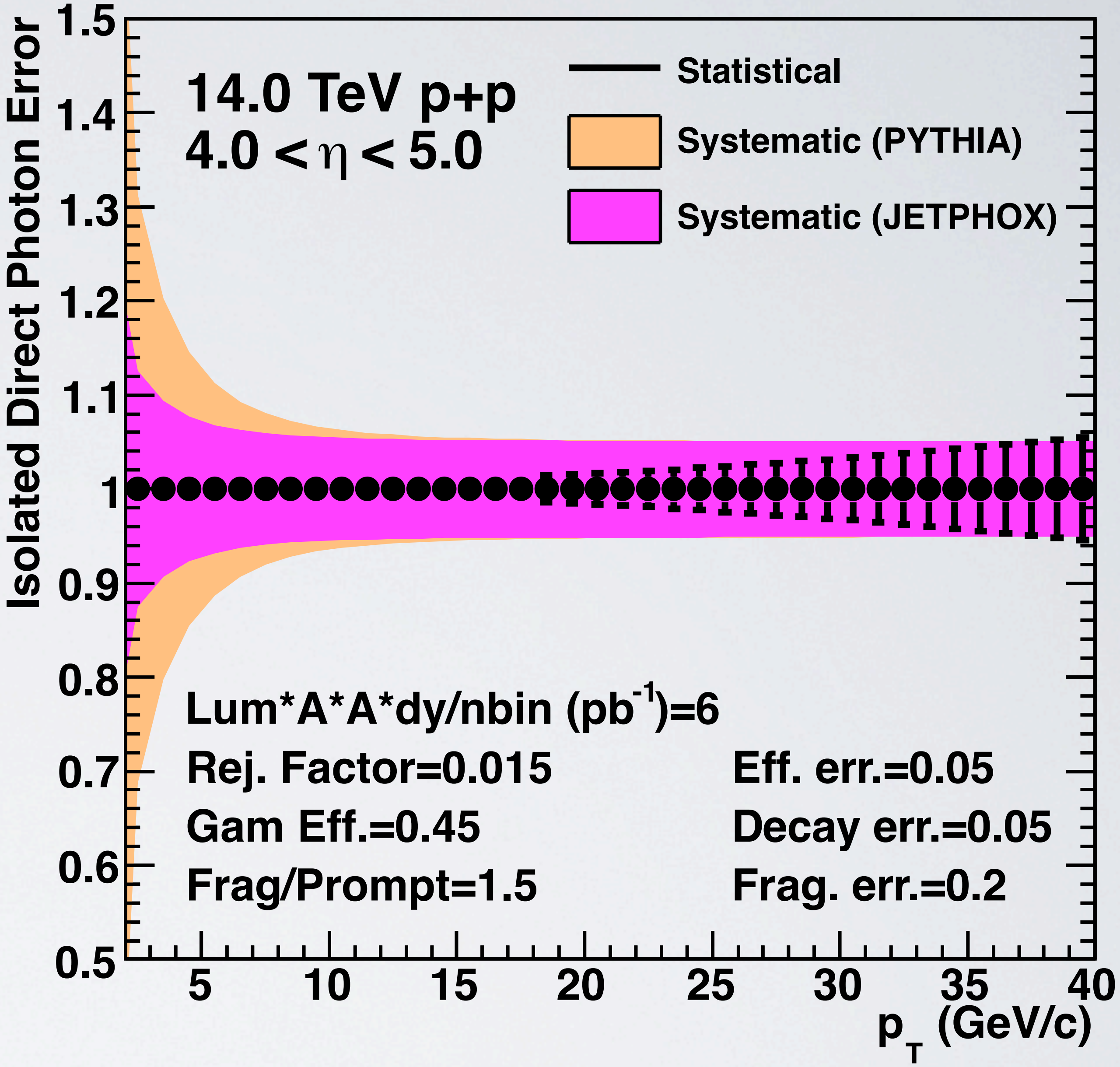
- low granularity (1cm²) does not allow efficient decay rejection
- direct photon/all ≈ 0.05 for all p_T

significant measurement not possible at low p_T

NB: conditions similar to LHCb

More Performance ...

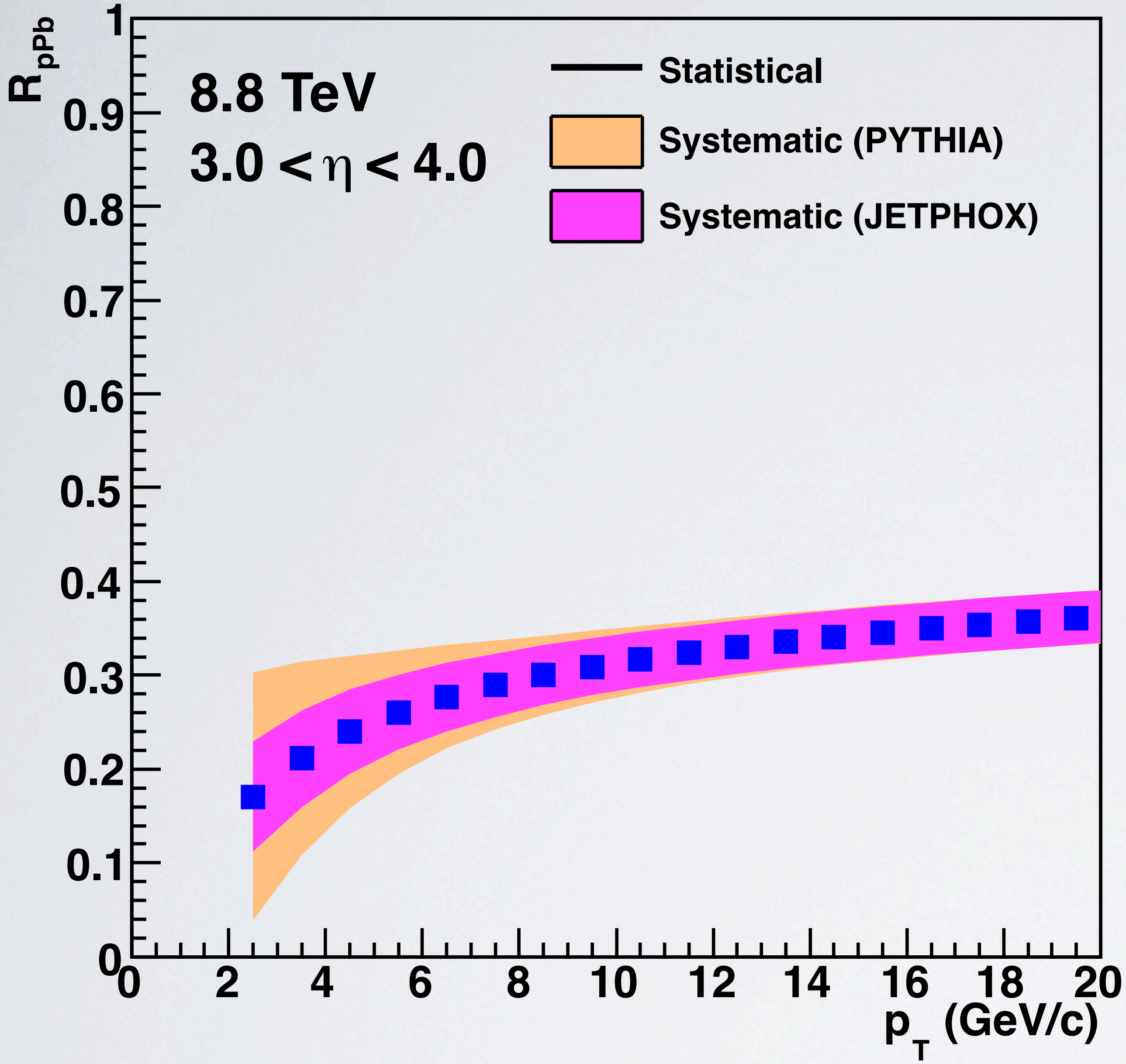


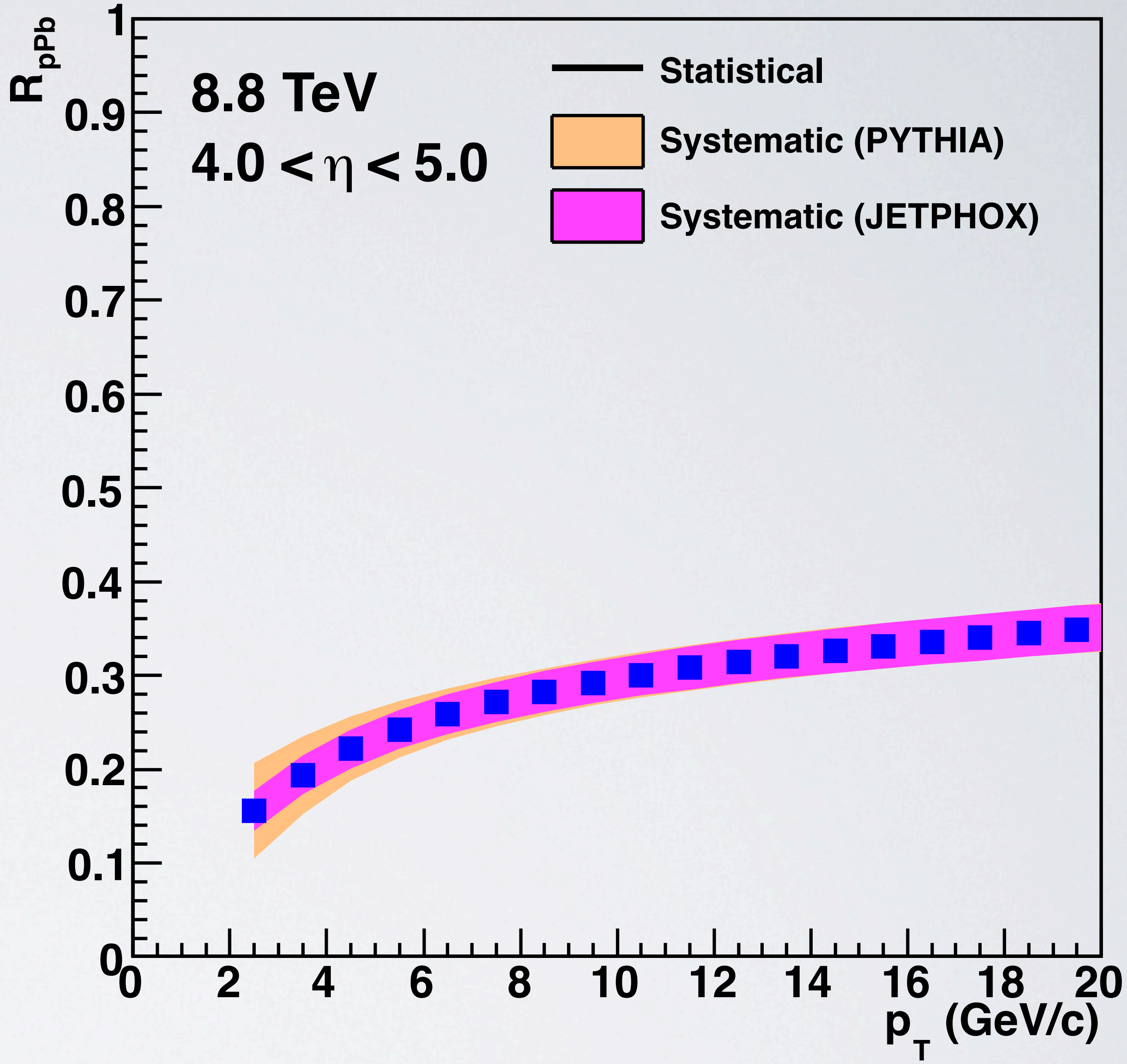


better performance for 8.8 TeV (pA equivalent to pp)

better performance for larger η (only possible for z=8m, requires more integration work)

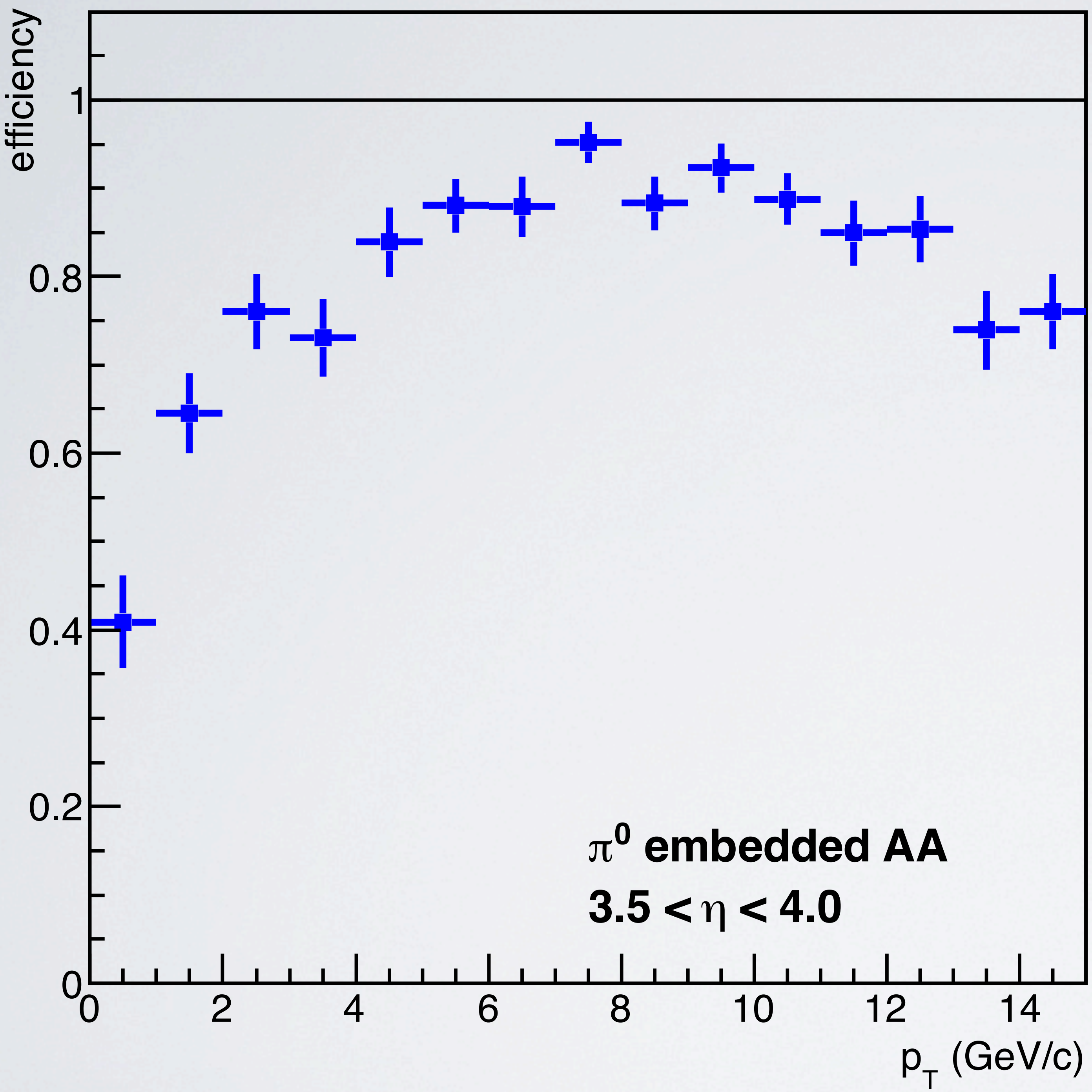
Performance on R_{pPb}





- expect significant constraint on direct photon R_{pPb}
  - confirm or refute CGC effects, constrain nPDF

Performance in Pb+Pb



first studies of π^0 efficiency only:

- good efficiency, slight deterioration at low p_T (overlap with underlying event)
- expect larger uncertainty from larger background in invariant mass

direct photon measurement difficult

- should be possible in limited p_T range

work in progress!

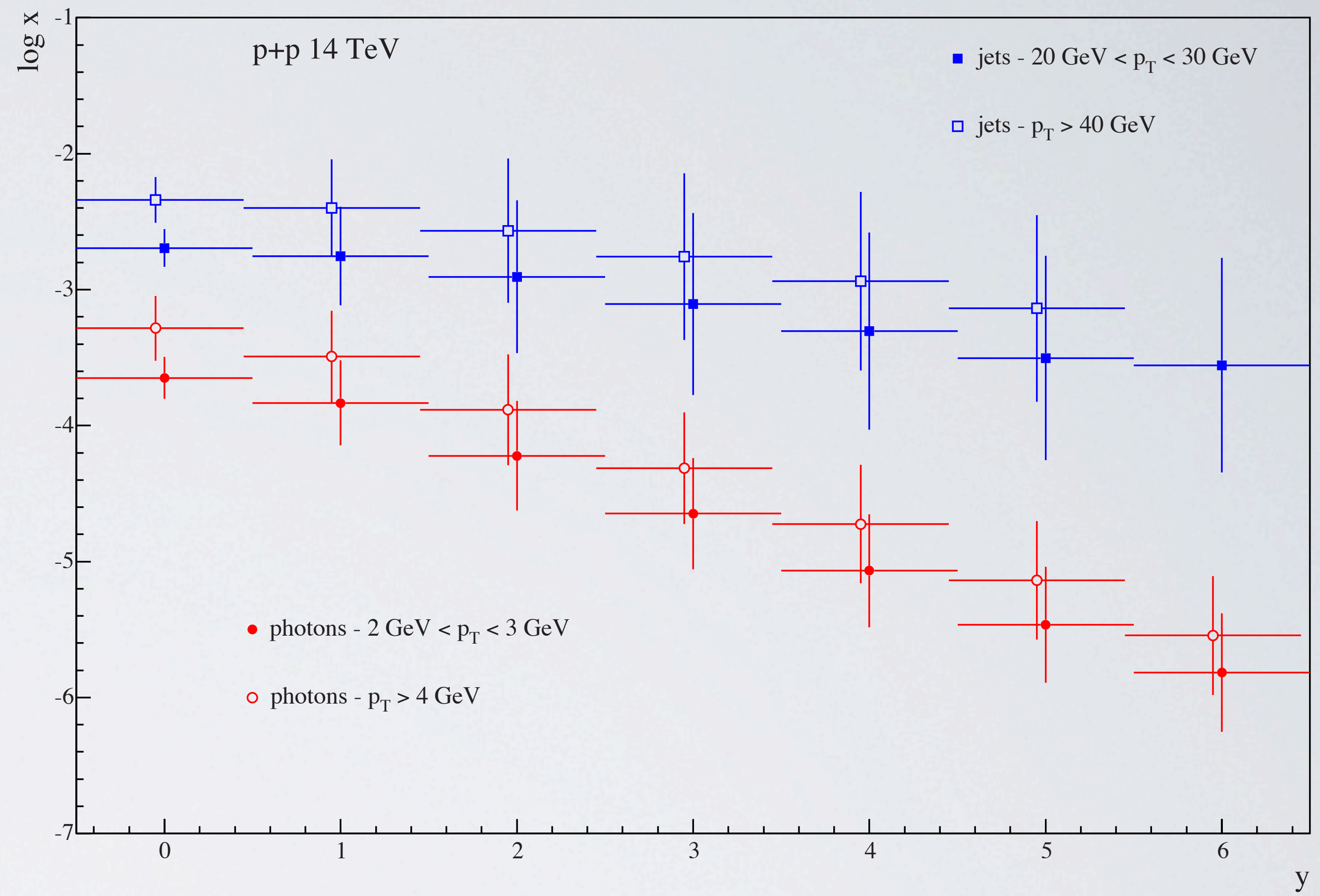
Conclusions

- FoCal should allow direct photon measurements in pp and pA at forward rapidity
  - Uncertainty ≈30% at low p_T
  - Large z distance preferable (larger rapidity, favorable measurement conditions)
  - High granularity is crucial
- Measurements in Pb+Pb
  - Reasonable performance for π^0
  - Direct photon measurement under study
  - Performance improvements possible!

Backup Slides

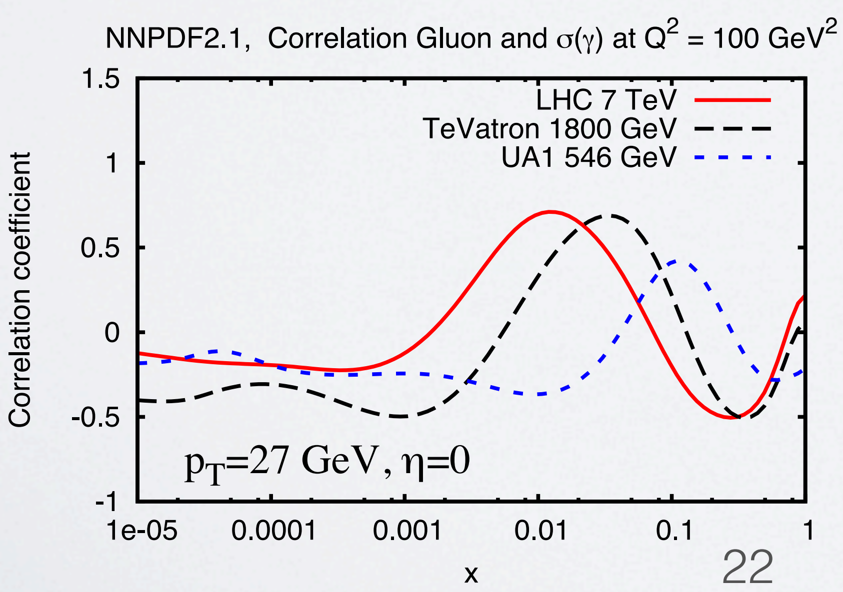
Kinematic Constraints

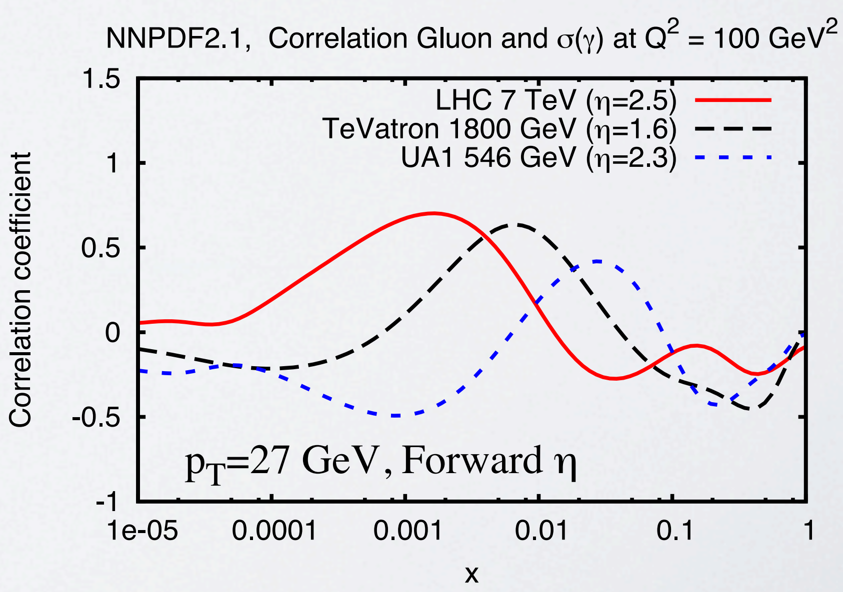
- large y prompt photons effective to constrain kinematics to low x
  - obvious in LO (PYTHIA)



- NLO studies in JETPHOX:
  - indicate clear sensitivity of isolated photons, dedicated calculations under way

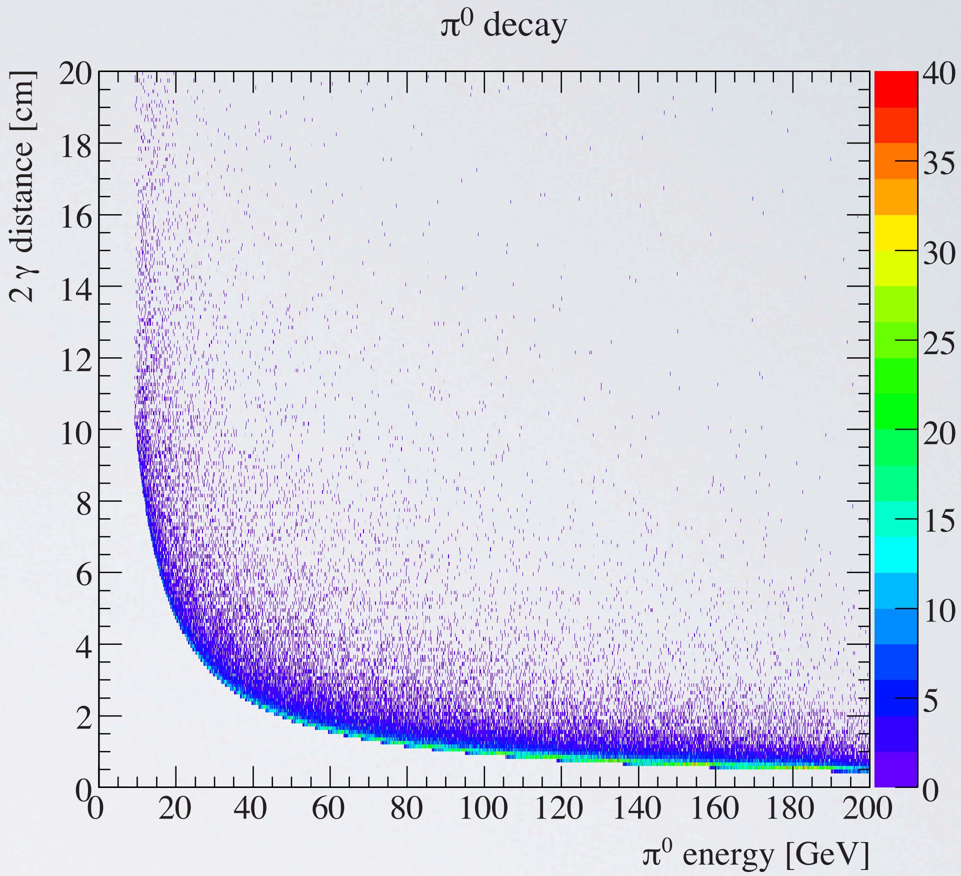
from D. d'Enterria and J. Rojo, arXiv:1202.1762

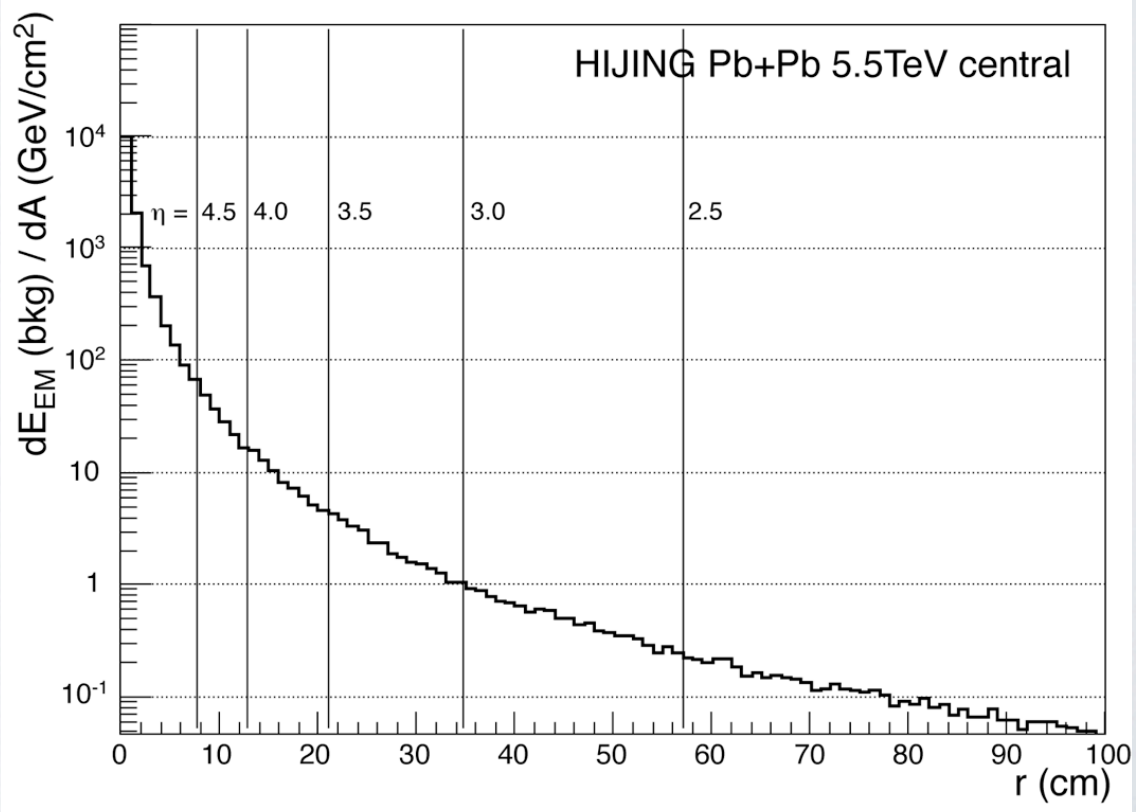




Main Design Issue: Granularity

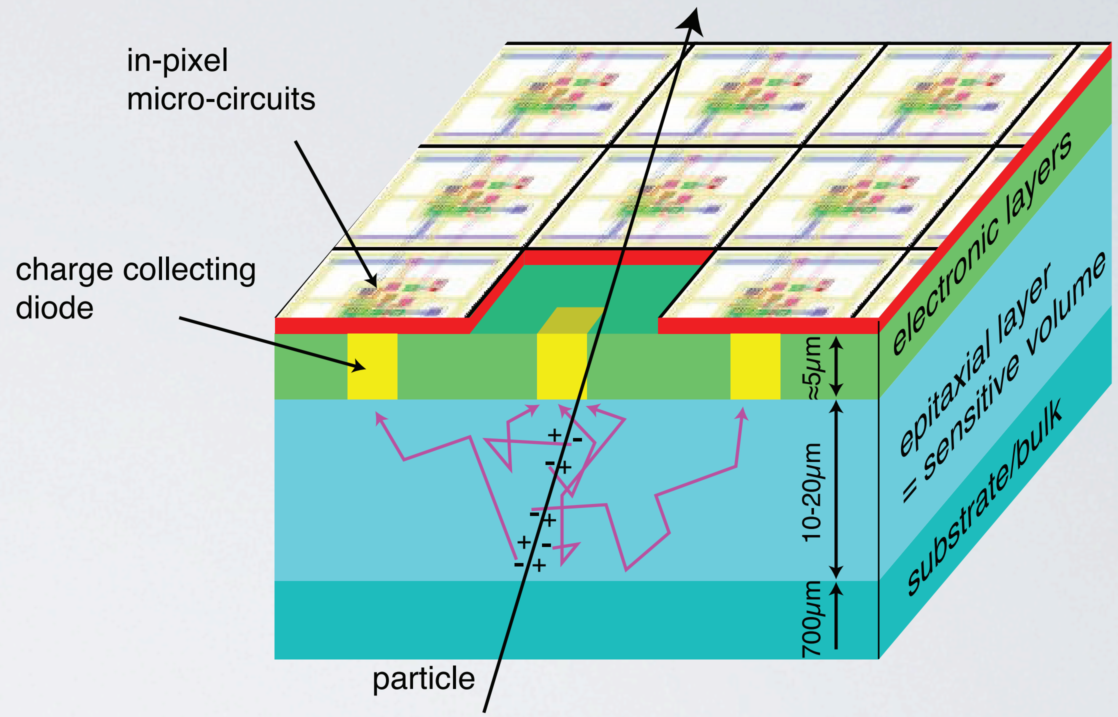
- π^0/γ discrimination
  - separation of decay gammas < 1 cm at high energy
  - requires adequate granularity of *some* layers
- particle density in Pb+Pb
  - even stronger requirements on granularity
  - optimum: high granularity (≈1mm²) for all layers
- realistic compromise?

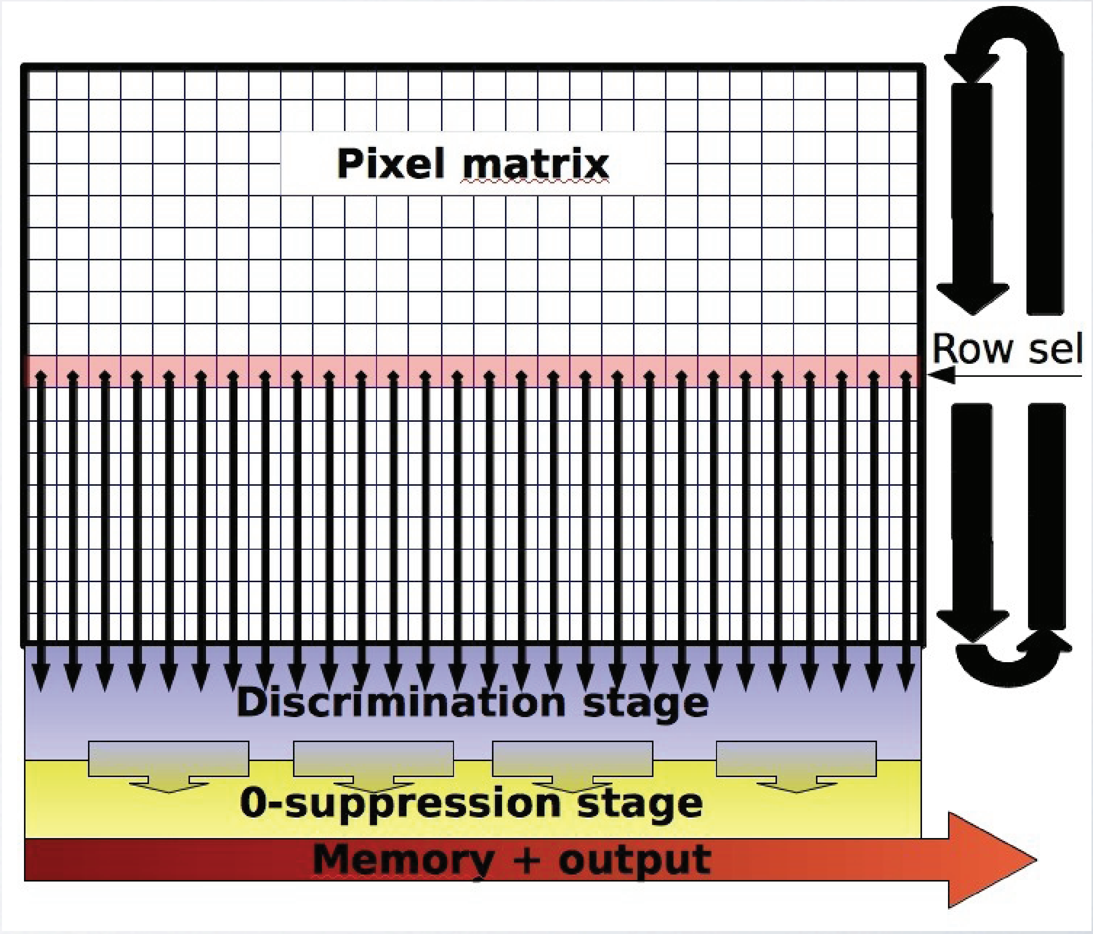




MIMOSA Sensors

- Monolithic Active Pixel Sensors (MAPS)
  - Si-sensors + electronics in CMOS on single substrate
  - thin sensitive layer (≈20μm)
  - charge collection by diffusion
- existing chips
  - readout of analog signals by rolling shutter
    - slow: 640μs readout time
  - 0.35μm technology



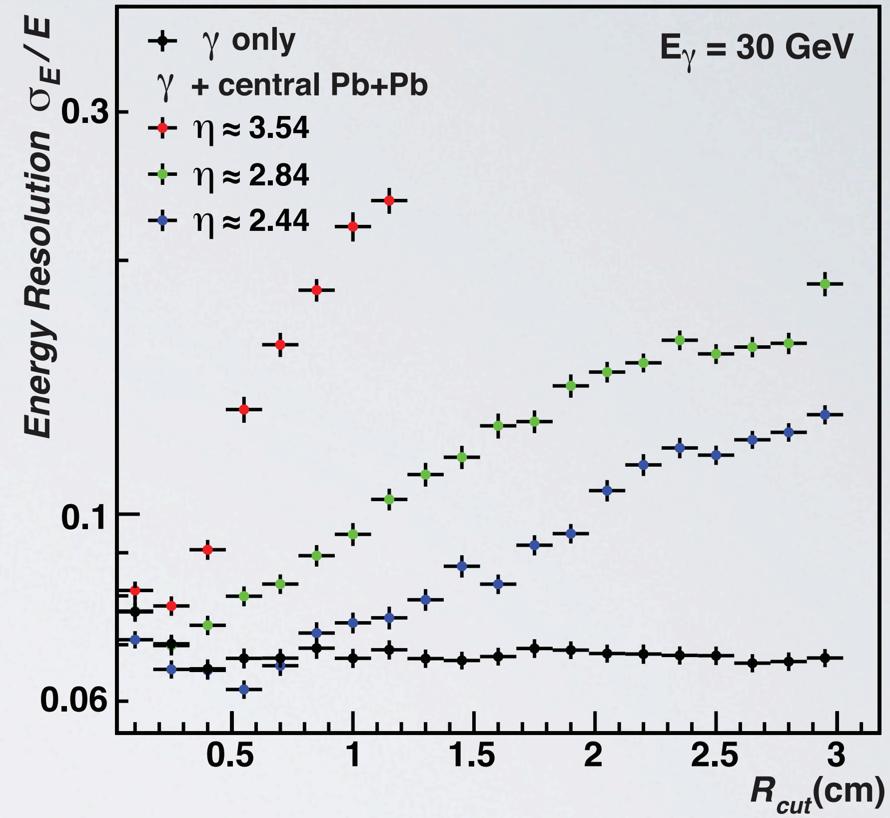


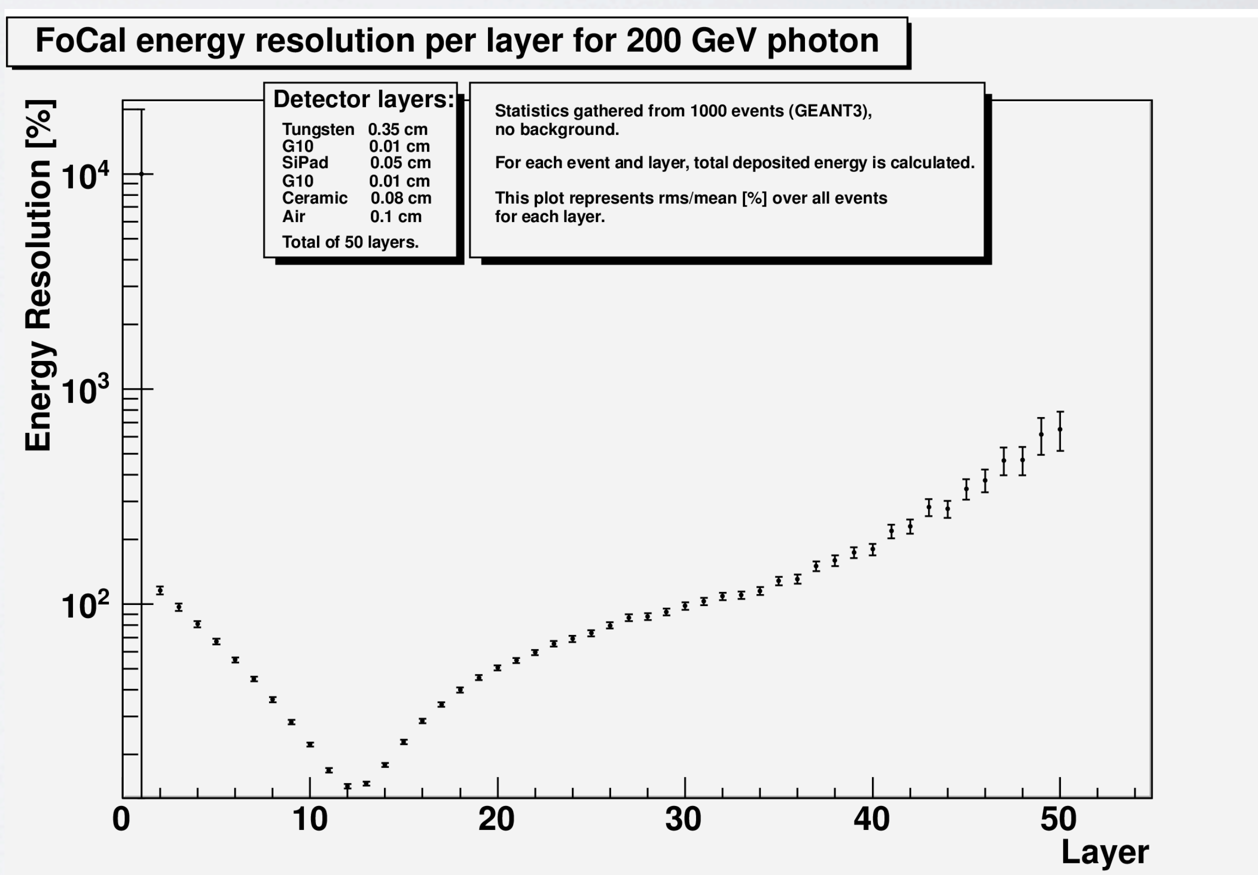
MIMOSA: Next Steps

- modifications under way (current production):
  - move from 0.35μm technology to 0.18μm (TOWER)
    - lower power consumption, better radiation hardness
  - in-pixel discriminator
    - rolling shutter for digital signals: higher frequency
    - readout time possible: ≈10μs
  - other pixel sizes (currently 30x30μm^2) for performance checks
- digital part needs very different algorithms for calorimetry
  - need data reduction for ≈50%(?) occupancy (much higher than for tracking)
  - current idea: digital sum of # of pixels in “macro-pixel”

Detector Design Issues

- energy measurement from small transverse area possible
- longitudinal segmentation?
  - obtain good energy estimate from few layers?
  - resolution from **single layer** < 20% for high energy
- optimize granularity per layer
  - studies ongoing
- need to check GEANT!





Digital Calorimetry

- FoCal with 50x50 μm² pixels
- compare
  - sum of analog signals from energy deposit in active layer
  - number of pixels above threshold
- better resolution for digital pixel readout
  - already seen in earlier studies
  - can work when multi-hit probability of pixels low
  - can we trust GEANT here?