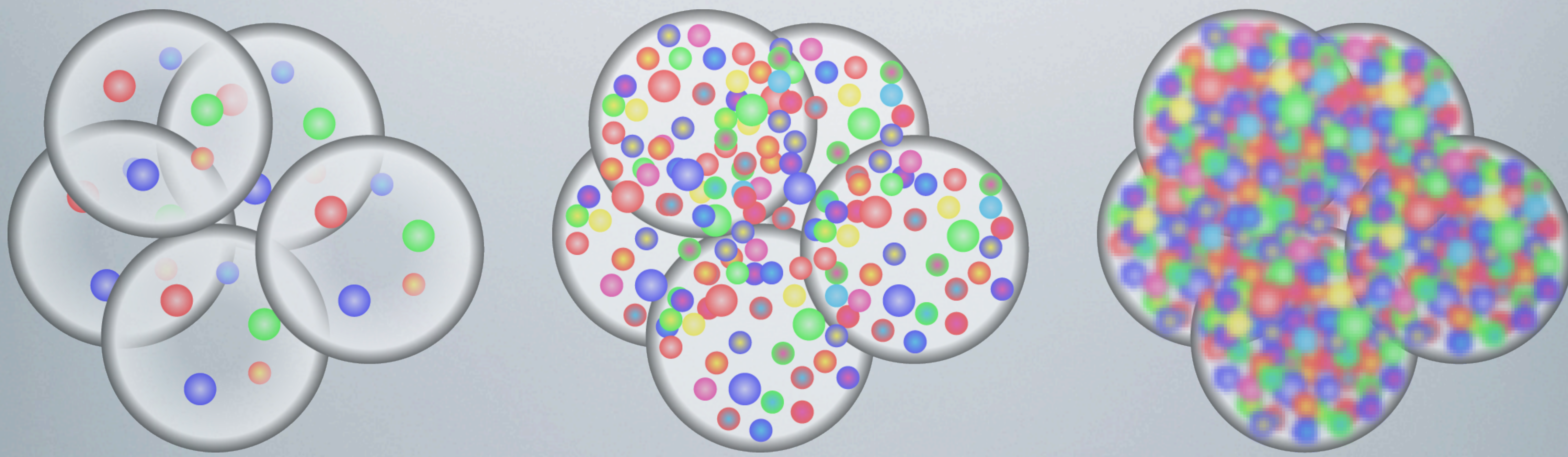


The Forward Calorimeter Proposal in ALICE

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

III. Workshop on QCD and Diffraction at the LHC joint with
LHC Forward Physics and Diffraction WG Meeting, Cracow, Nov. 18-20, 2013

Outline

- Introduction
  - ALICE upgrades
  - Small-x physics
- Sensitivity of probes
- Detector design
- Performance simulations
- Conclusions

ALICE Upgrade Physics

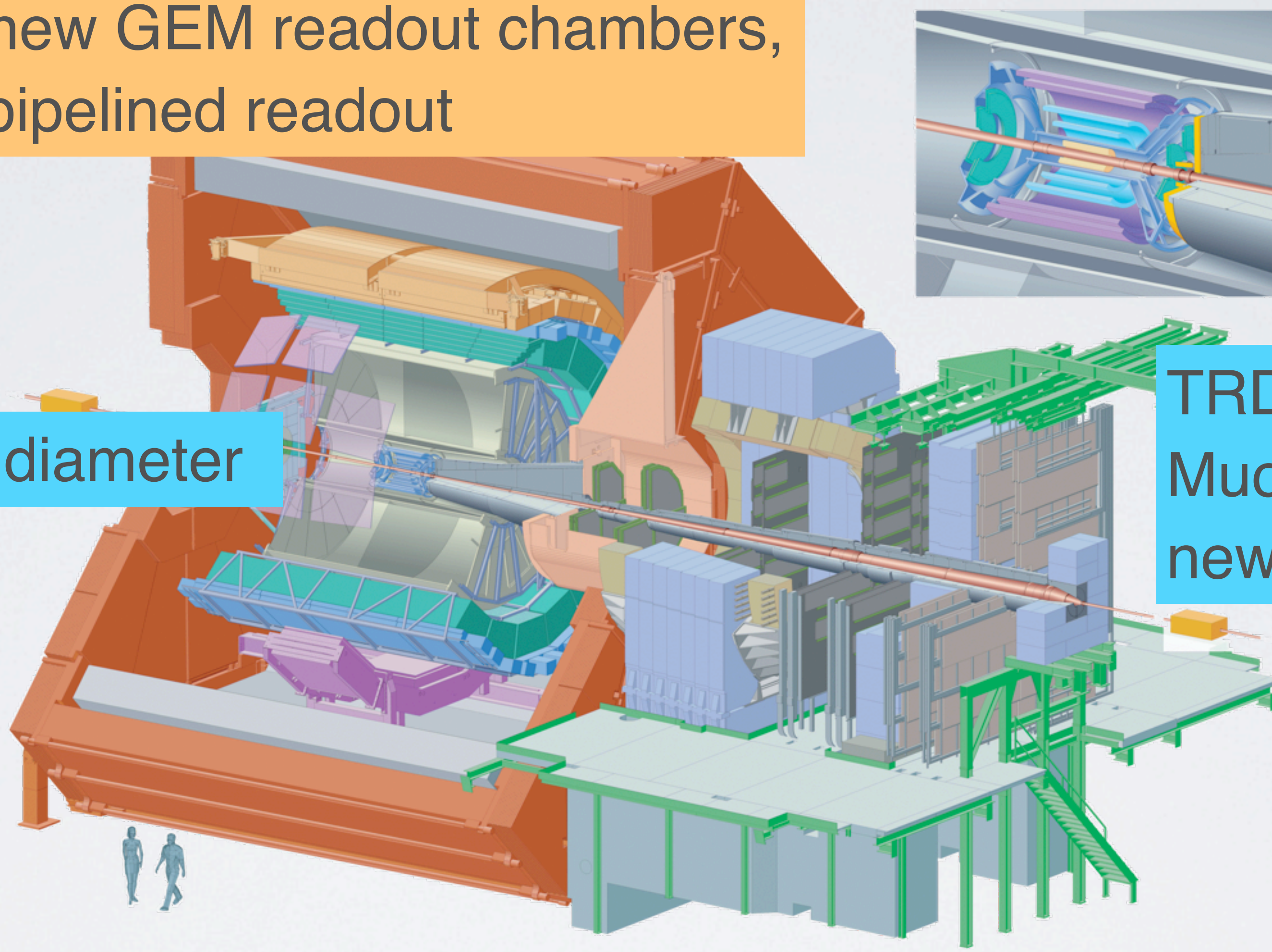
- ALICE physics program until ≈ 2025 (endorsed by LHCC)
  - study of strongly interacting matter at very high temperature: the quark-gluon plasma
- measurement of heavy-flavour transport parameters
  - study of QGP properties via transport coefficients
- charmonium states down to $p_T = 0$
  - statistical hadronization vs. dissociation/recombination
  - enhancement of forward measurement (to be endorsed)
- measurement of low-mass and low-p_T dileptons
  - chiral symmetry restoration, thermal radiation
- jet quenching and fragmentation (with PID)
- light anti- and hyper-nuclei

Main Upgrade Strategy

- focus on low p_T, untriggerable probes requiring high statistics
  - increase rate capabilities for minimum bias heavy-ion collision
    - upgrade of TPC and ITS, all readout electronics, etc.
  - target: inspection of 50 kHz of minimum bias Pb+Pb
    - factor 100 increase in statistics (for untriggered probes)
  - collect $> 10\ \mathrm{nb}^{-1}$ of integrated luminosity
    - upgrade in LS2, implies running up to ≈2026
- ALICE is unique in low-p_T/low-mass measurements and particle identification
  - further enhance capabilities, in particular with upgraded ITS
    - closer to beam, less material, better resolution

for details see: ALICE Upgrade LoI, CERN-LHCC-2012-012

ALICE Detector Upgrades



- LoI endorsed by LHCC, TDRs in preparation/submitted
- LoI (addendum) submitted to LHCC

– planned for installation in LS2

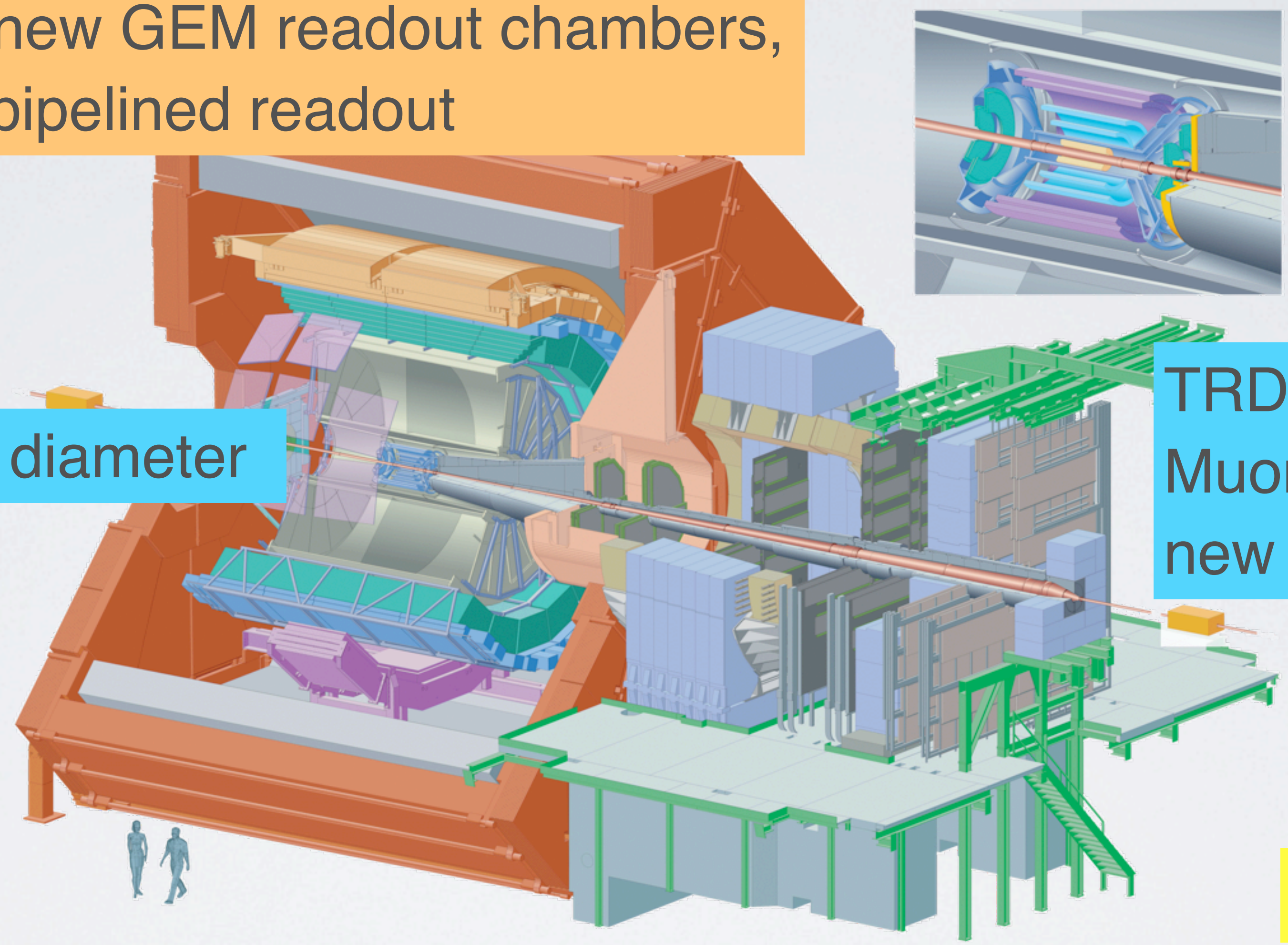
ALICE Detector Upgrades

new ITS: high resolution,
low material budget

TPC: new GEM readout chambers,
pipelined readout

FoCal project

new beam pipe: smaller diameter



TRD, TOF, PHOS, EMCal,
Muon spectrometer:
new readout electronics

Upgrade of forward/
trigger detectors
(ZDC, VZERO, T0)

MFT project

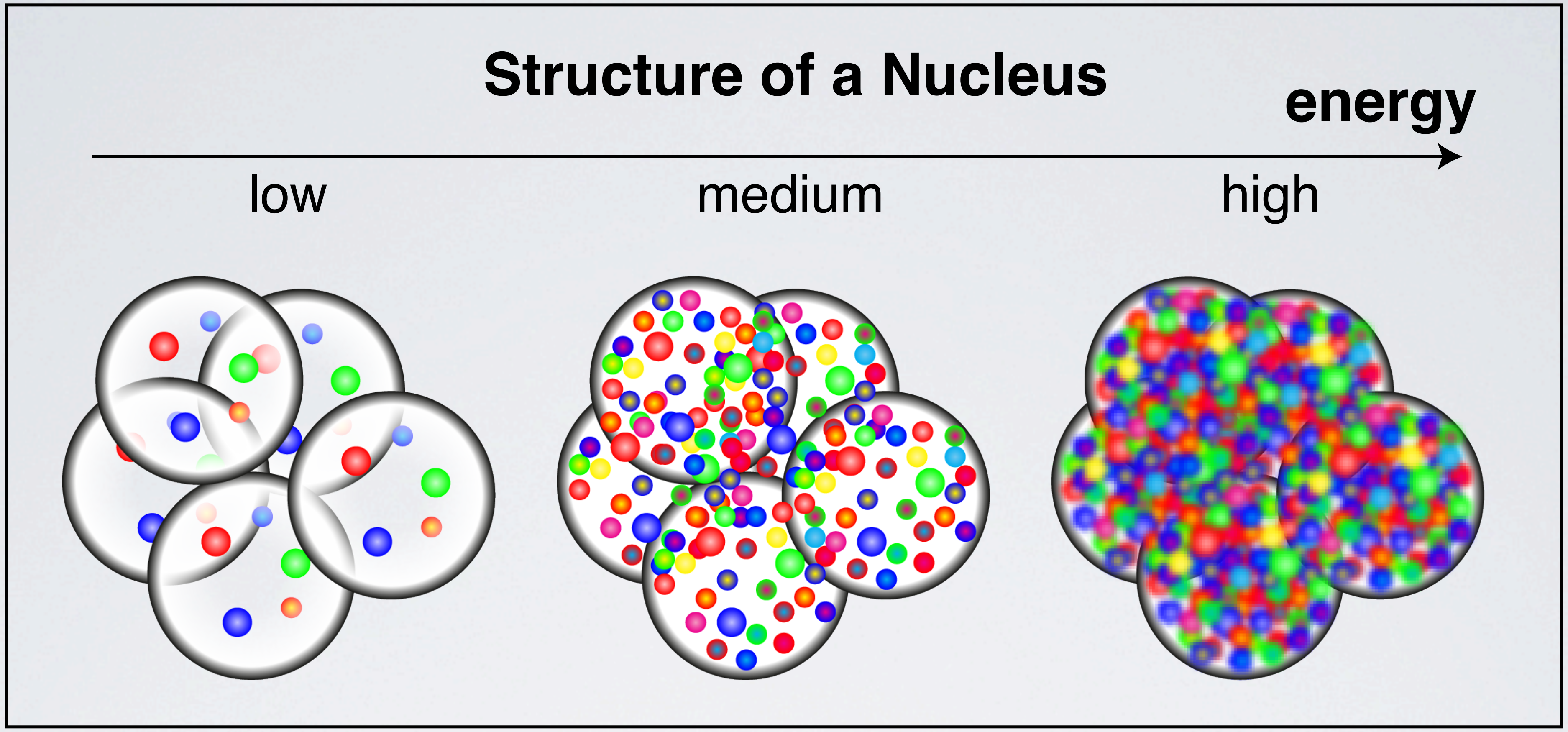
- (orange/blue) LoI endorsed by LHCC, TDRs in preparation/submitted
- (yellow) LoI (addendum) submitted to LHCC
- (green) under internal review

] – planned for installation in LS2

Forward Physics in ALICE

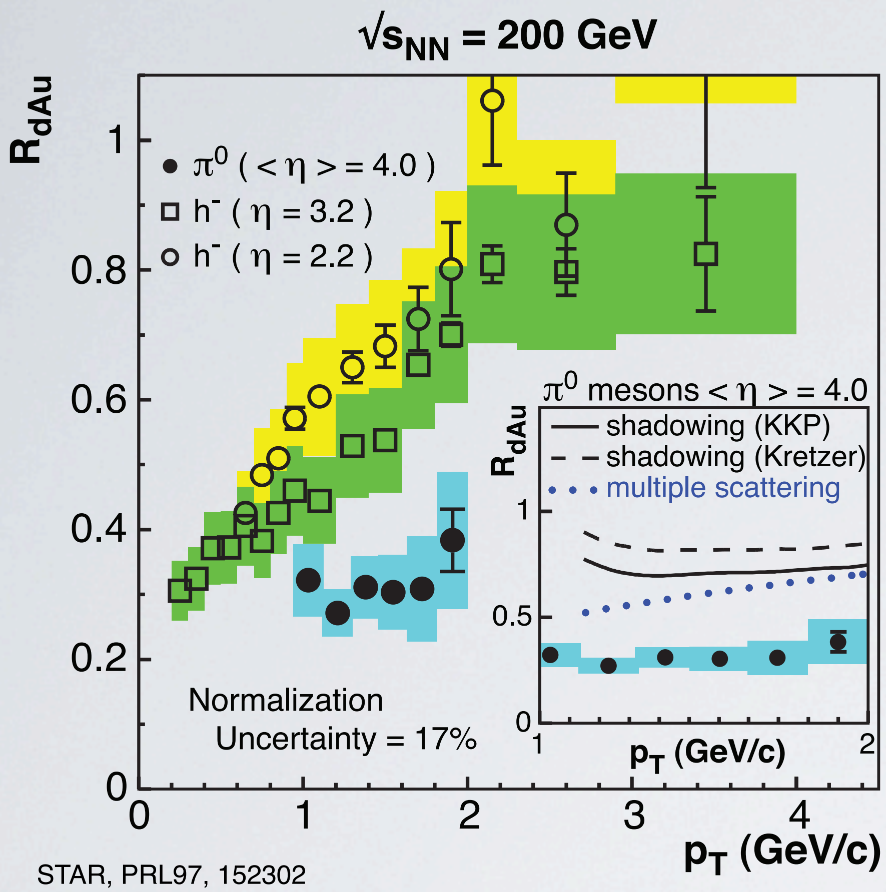
- additional physics potential in ALICE: forward/low-x physics
  - fundamental interest in low-x PDFs/gluon saturation
  - information on initial state yields important constraints for interpretation of QGP studies
    - e.g. knowledge of eccentricity for elliptic flow
  - forward detector enhances general physics scope
    - em calorimeter (FoCal): significant increase of coverage for photons, jets compared to existing calorimeters (PHOS, EMCal)
- FoCal: new upgrade project under discussion
  - main objective: measurement of large rapidity direct photons
  - possible installation in LS3

Gluon Saturation

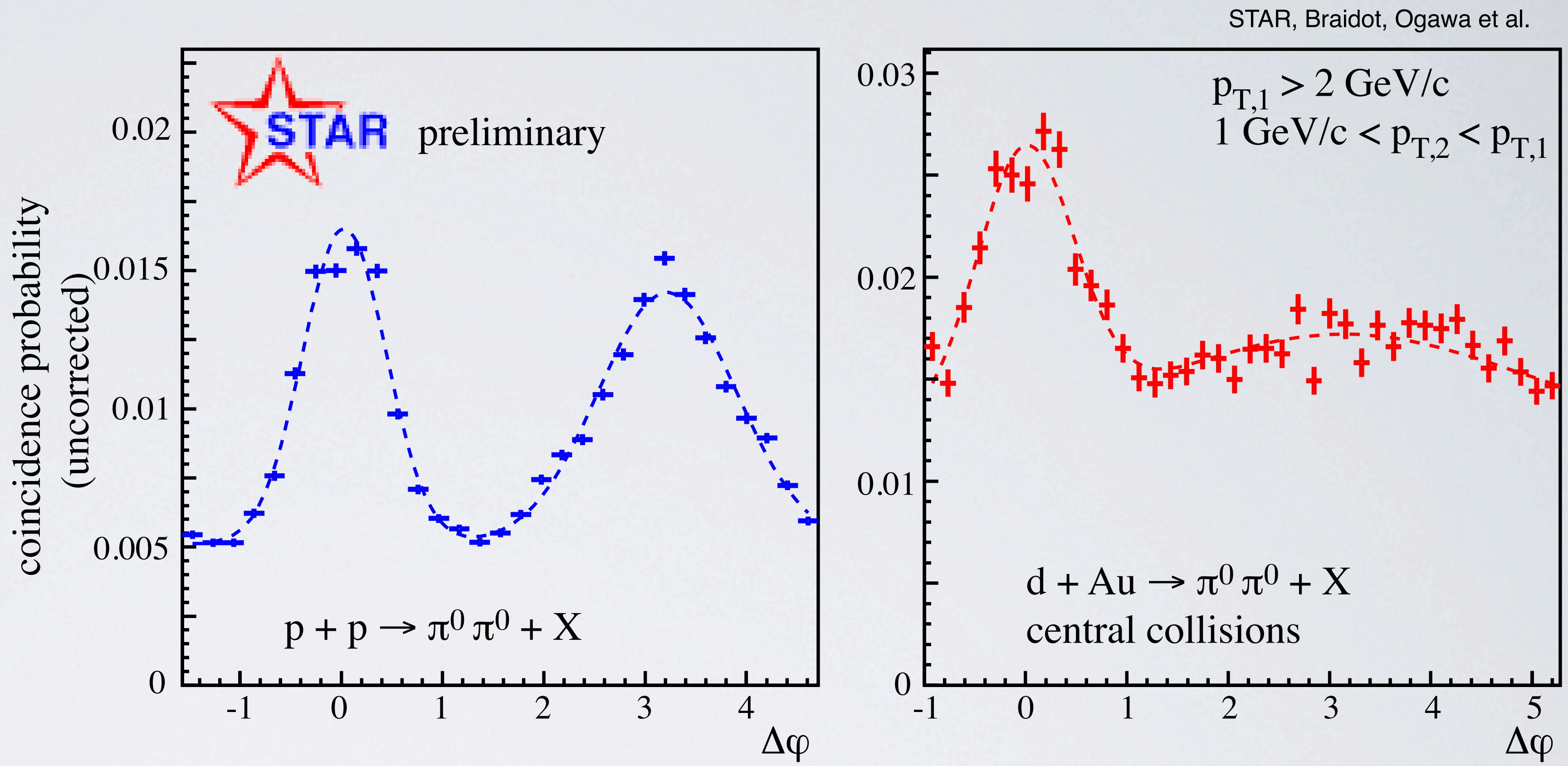


- low-x, low Q^2: high gluon occupation number, strong fields
  - classical color fields, theoretically calculable (JIMWLK)
- new phenomena: yield suppression, monojets
  - enhanced in nuclei (stronger color field compared to proton)

Indications from RHIC



STAR, PRL97, 152302

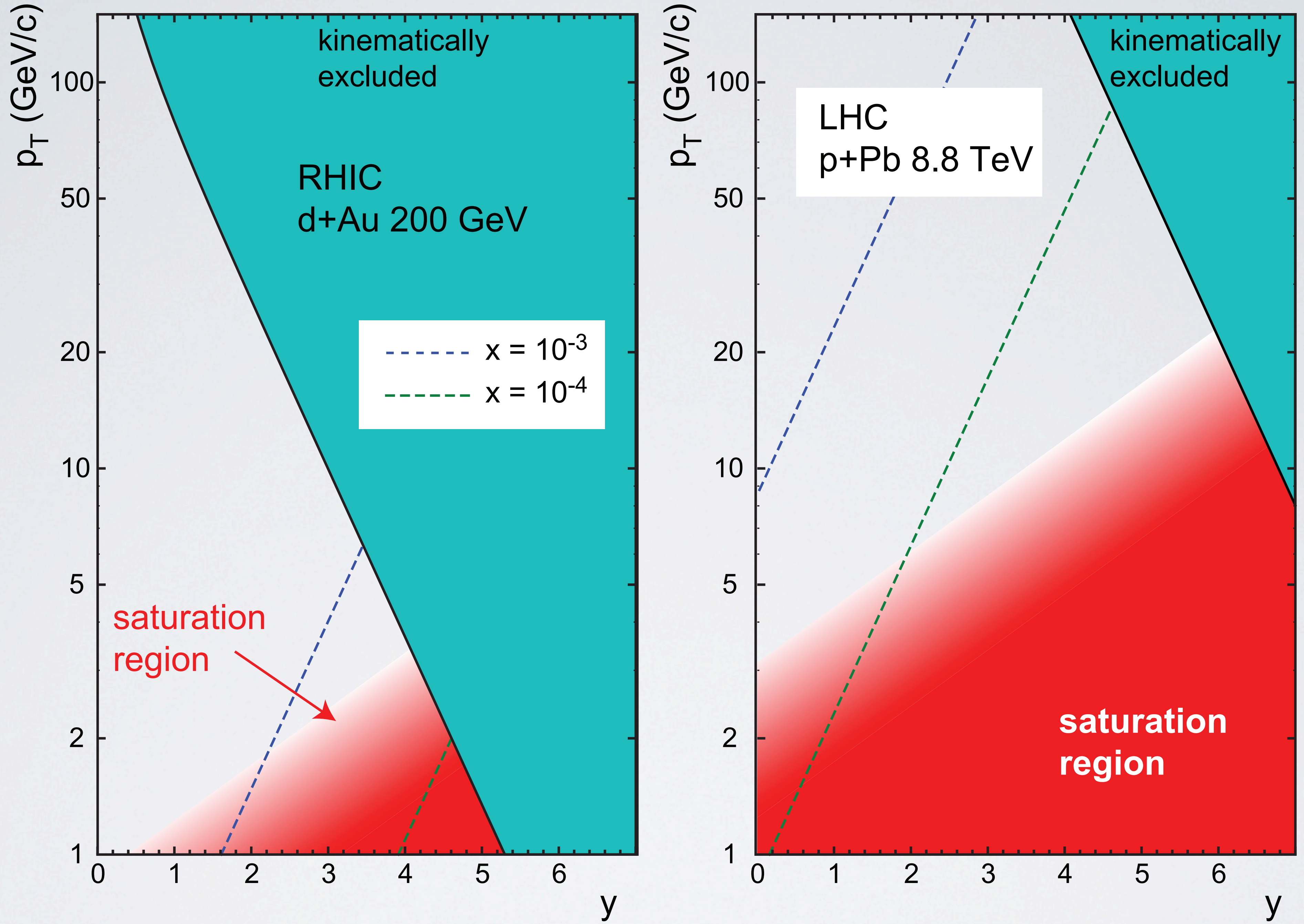


R_{dA}: strong suppression of hadron yield at forward rapidity

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

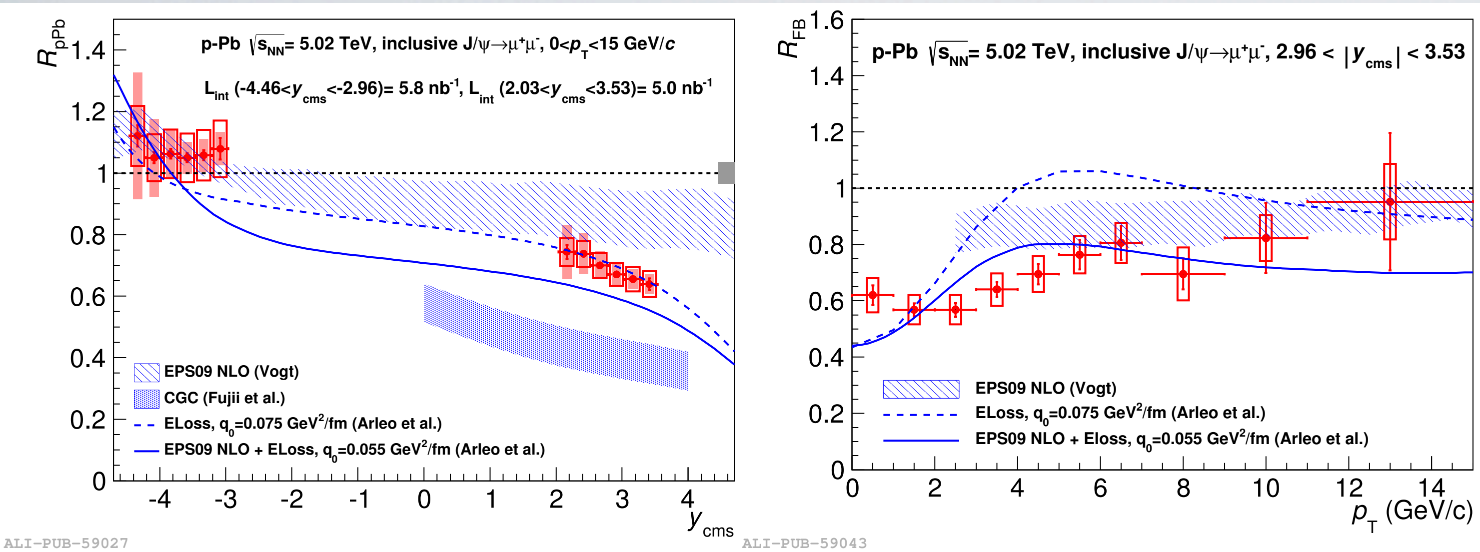
- qualitatively consistent with gluon saturation, but ...
  - very low p_T, hadron observable (final state interactions)!
- extend p_T and y range (not possible at RHIC)
- measure prompt photons

LHC vs RHIC



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

First Results from p-A at LHC



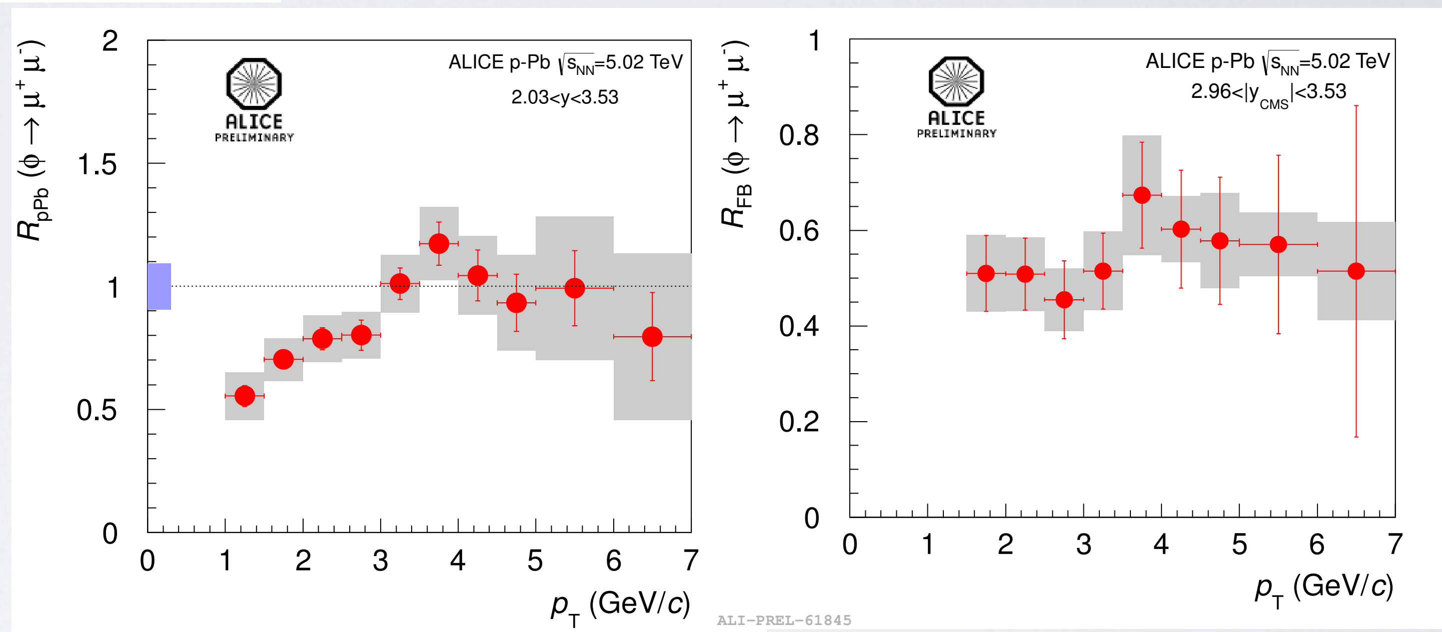
$J/\psi \rightarrow \mu^+ + \mu^-$

- R_{pPb} compared to models
- forward/backward ratio

ALICE, arXiv:1308.6726

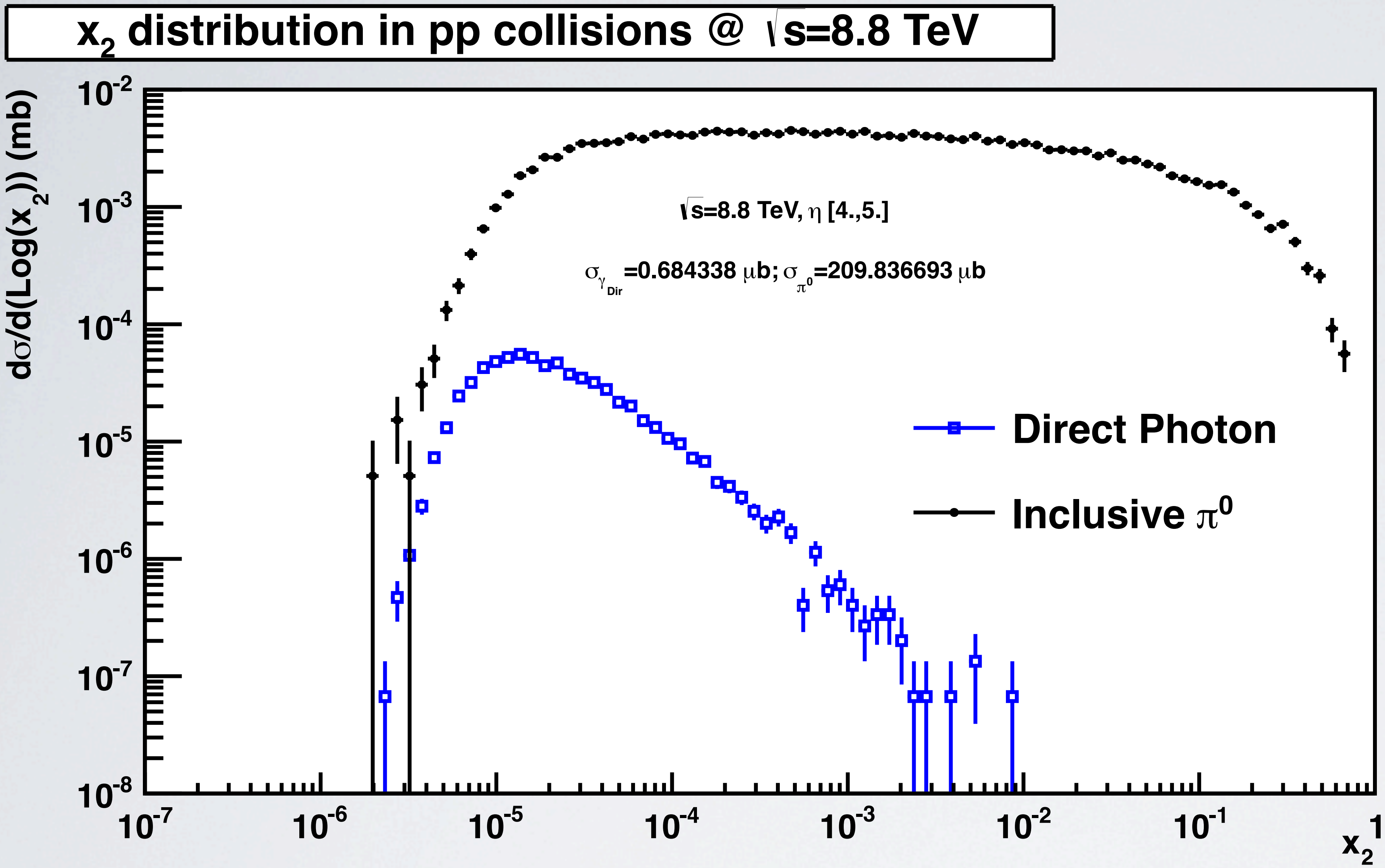
$\phi \rightarrow \mu^+ + \mu^-$

- R_{pPb} at forward rapidity
- forward/backward ratio



- hadron suppression on forward (proton-going) side at low p_T
  - J/ψ not described by nPDFs nor by a CGC calculation
- uncertainties on
  - production mechanism (x,Q^2 -sensitivity)
  - other nuclear modifications (e.g. energy loss, thermalization in pA?)

x-Reach with Hadrons



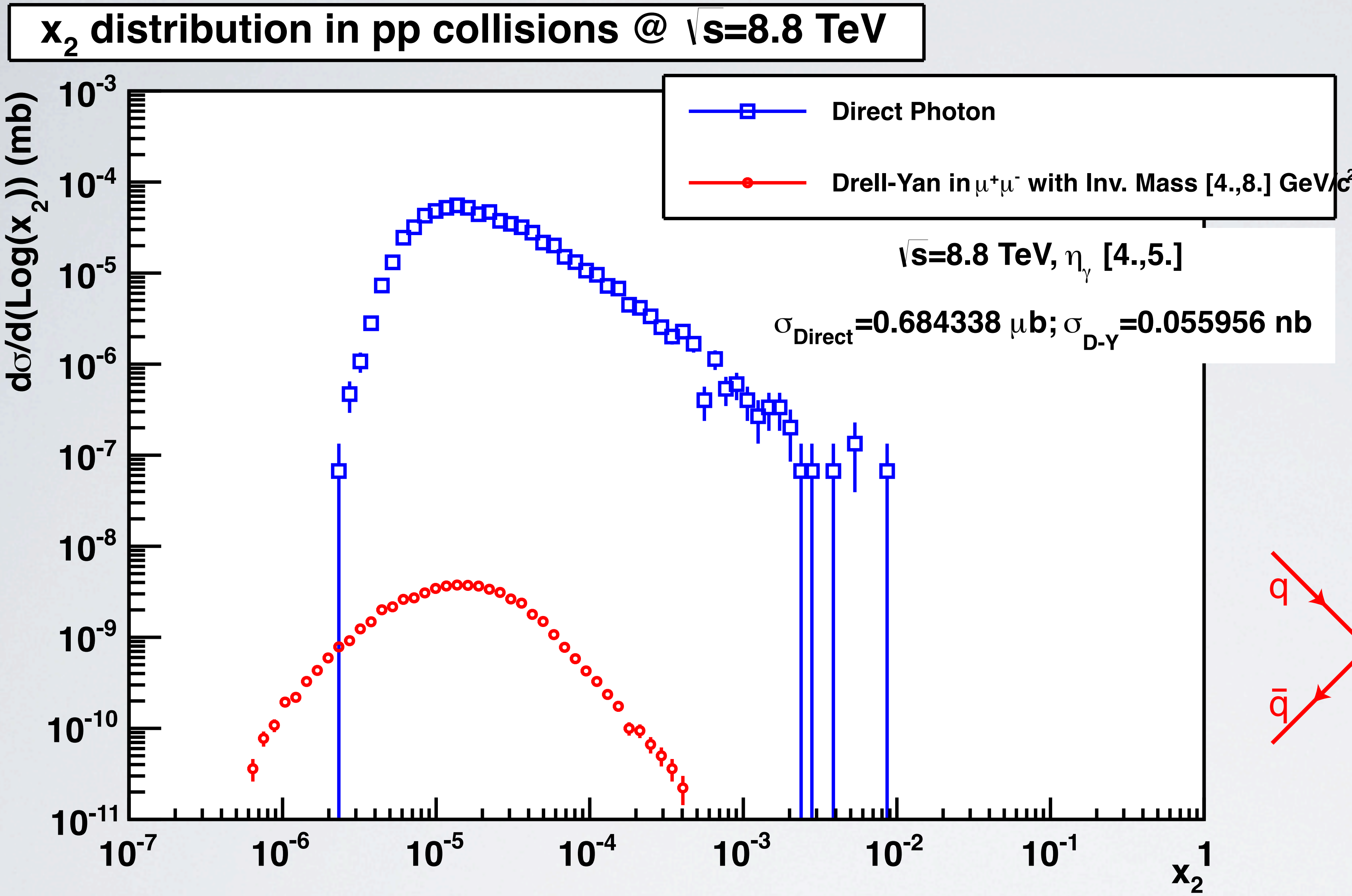
PYTHIA simulations (D. Lodato)

neutral pions:
  $p_T > 2.5$ GeV/c

direct photons:
  $p_T > 4$ GeV/c

- very limited x-sensitivity with light hadrons
- advantage for direct photons (to be checked with NLO)

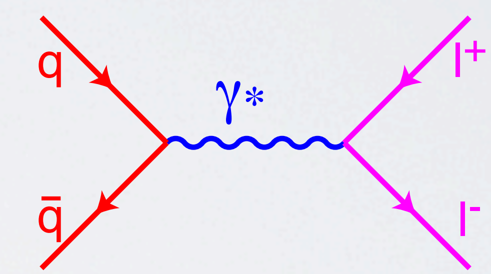
Drell-Yan Production



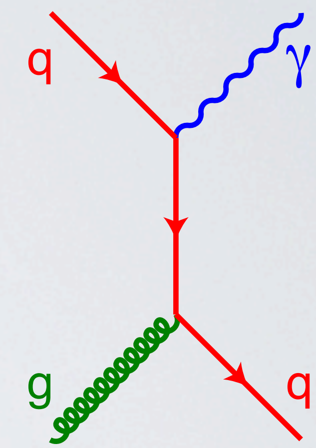
PYTHIA simulations (D. Lodato)

direct photons:
$p_T > 4$ GeV/c

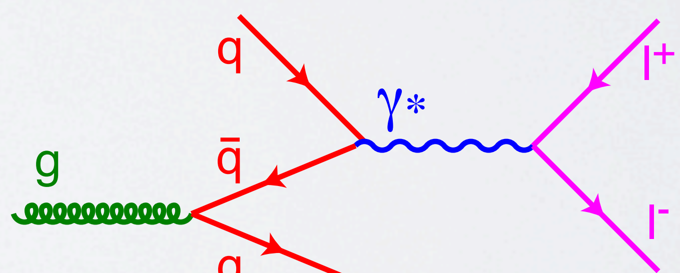
Drell-Yan:
4 GeV/c^2 < M < 9 GeV/c^2



DY (LO)



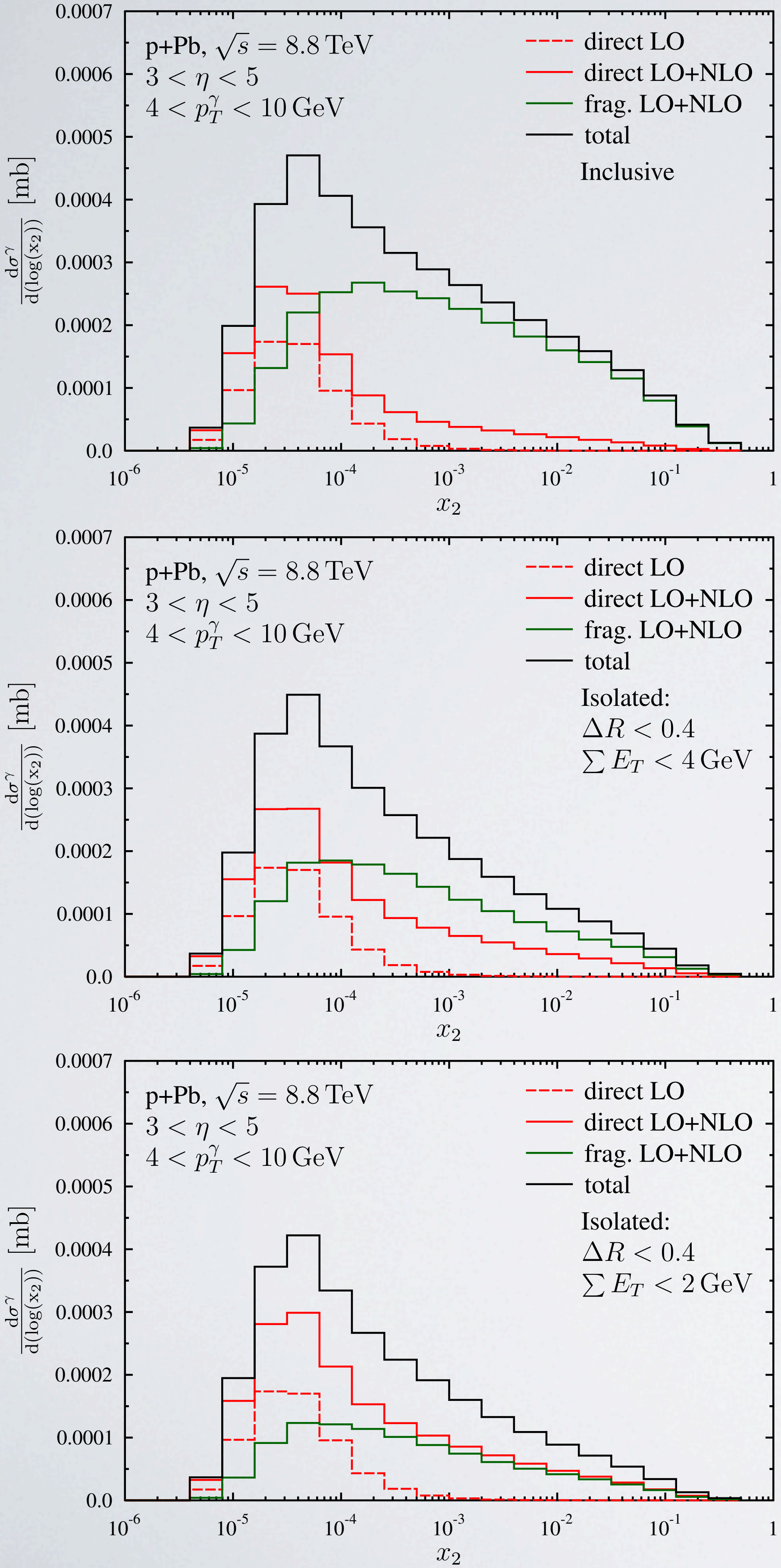
direct-γ, Compton (LO)



DY, virtual Compton (NLO)

- similar x-sensitivity with Drell-Yan vs. photons
  - gluon sensitivity via NLO/DGLAP?
- very (too?) small cross section

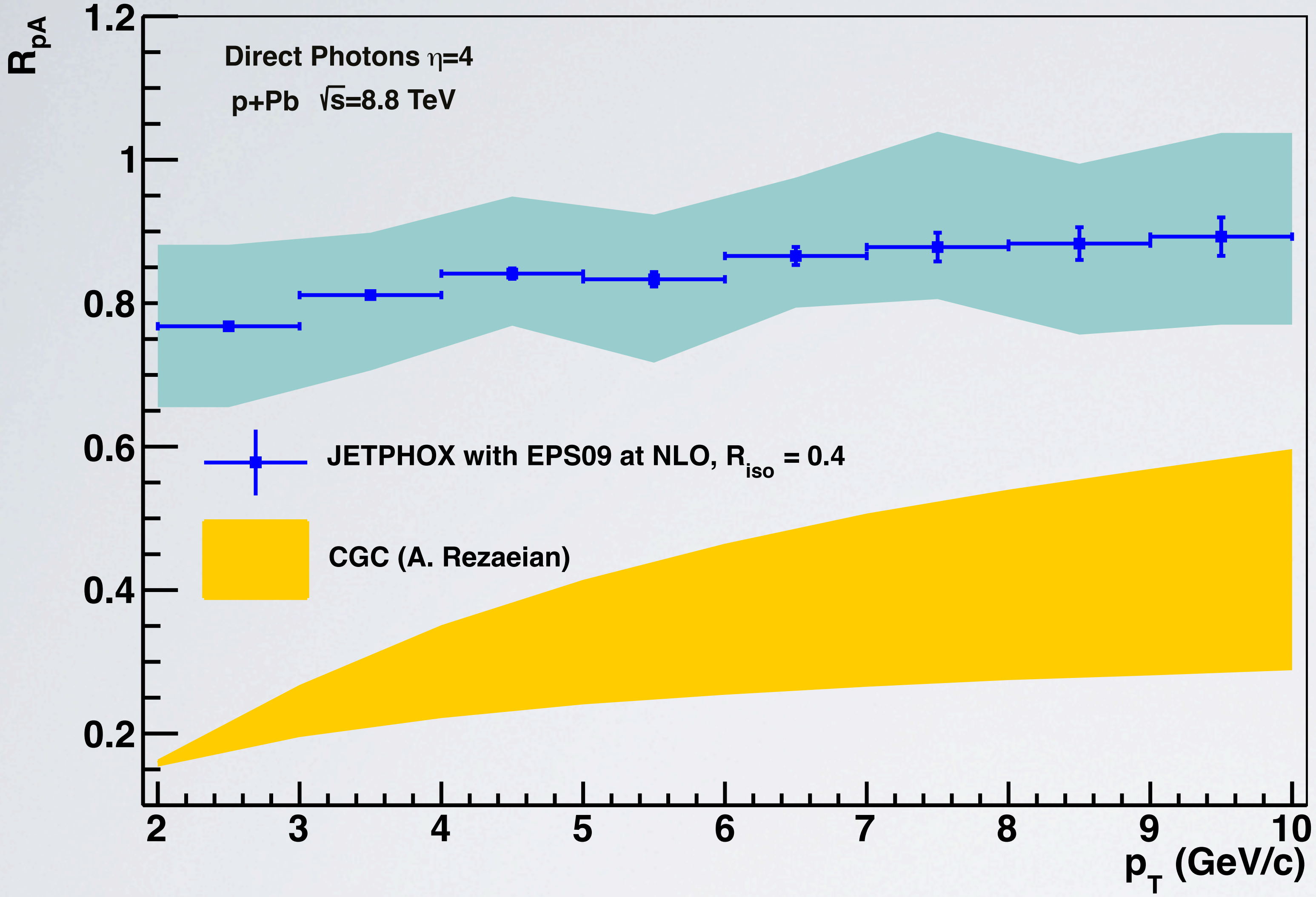
x-Reach with Direct Photons



- still reasonable x-sensitivity at NLO
  - significant contribution from fragmentation
- isolation cuts effective to suppress fragmentation
- can obtain very good x-sensitivity
- continue to optimize isolation cuts

Helenius, Paukkunen, Eskola
work in progress

nPDF/DGLAP vs CGC

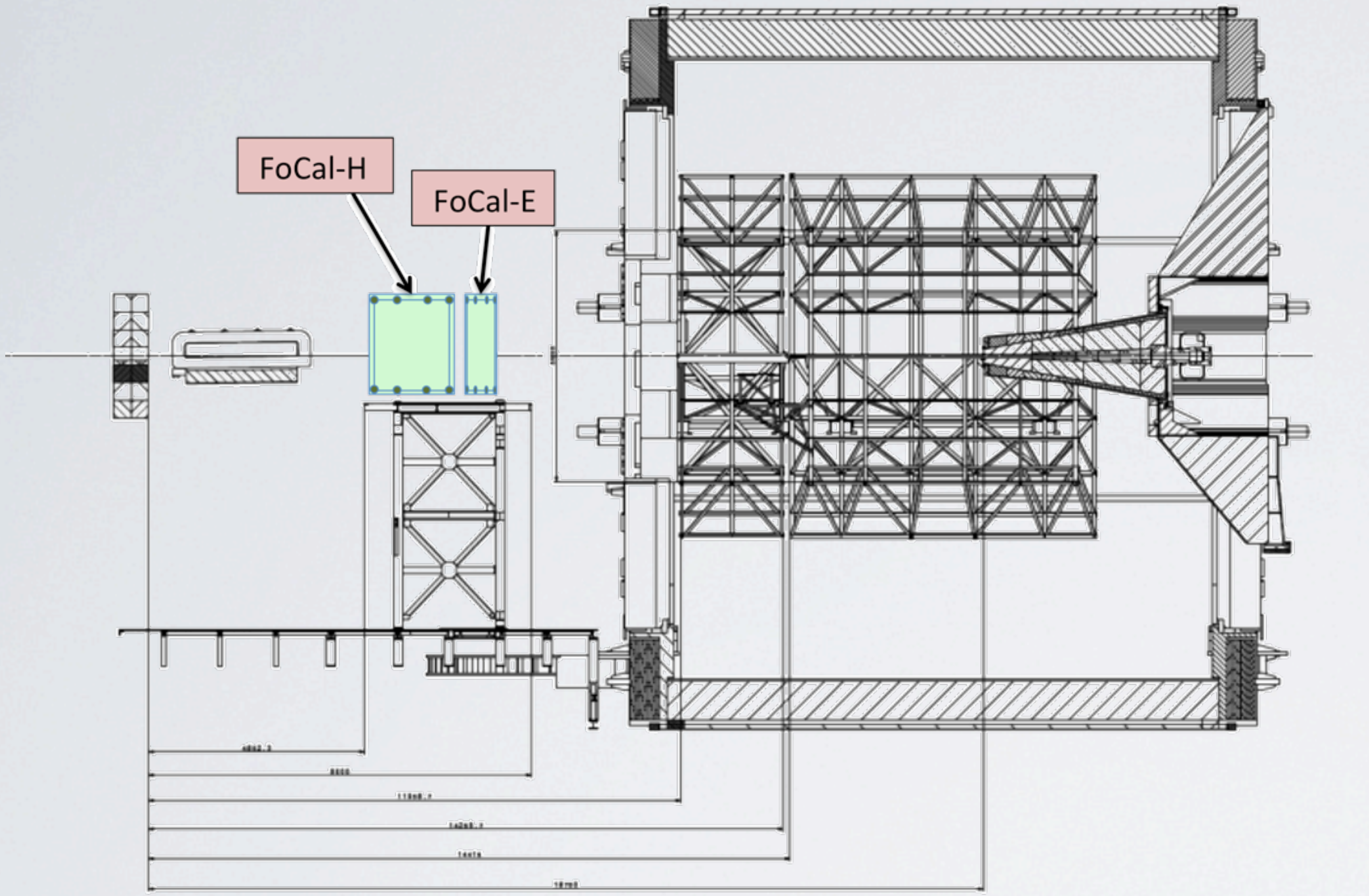


two scenarios for forward γ production in p-A at LHC:

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

- strong suppression in direct γ R_{pA}
- signals expected at forward η, low-intermediate p_T
  - transition expected - where?

FoCal in ALICE

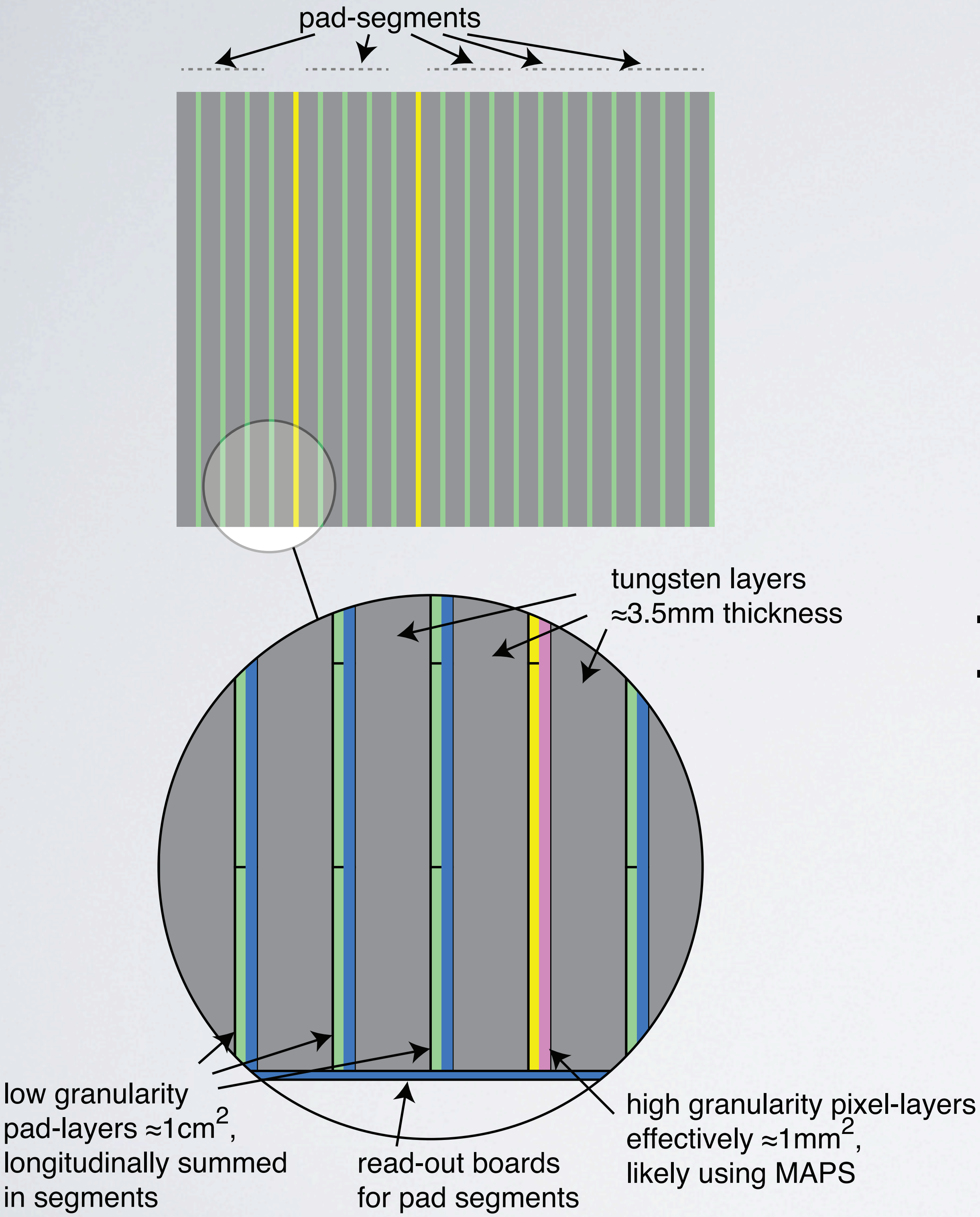


electromagnetic calorimeter for γ and π^0 measurement
+ **hadronic calorimeter** for isolation and jet measurement

baseline scenario:
at $z \approx 7$m (outside magnet)
$3.3 < \eta < 5.3$

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

Strawman Design

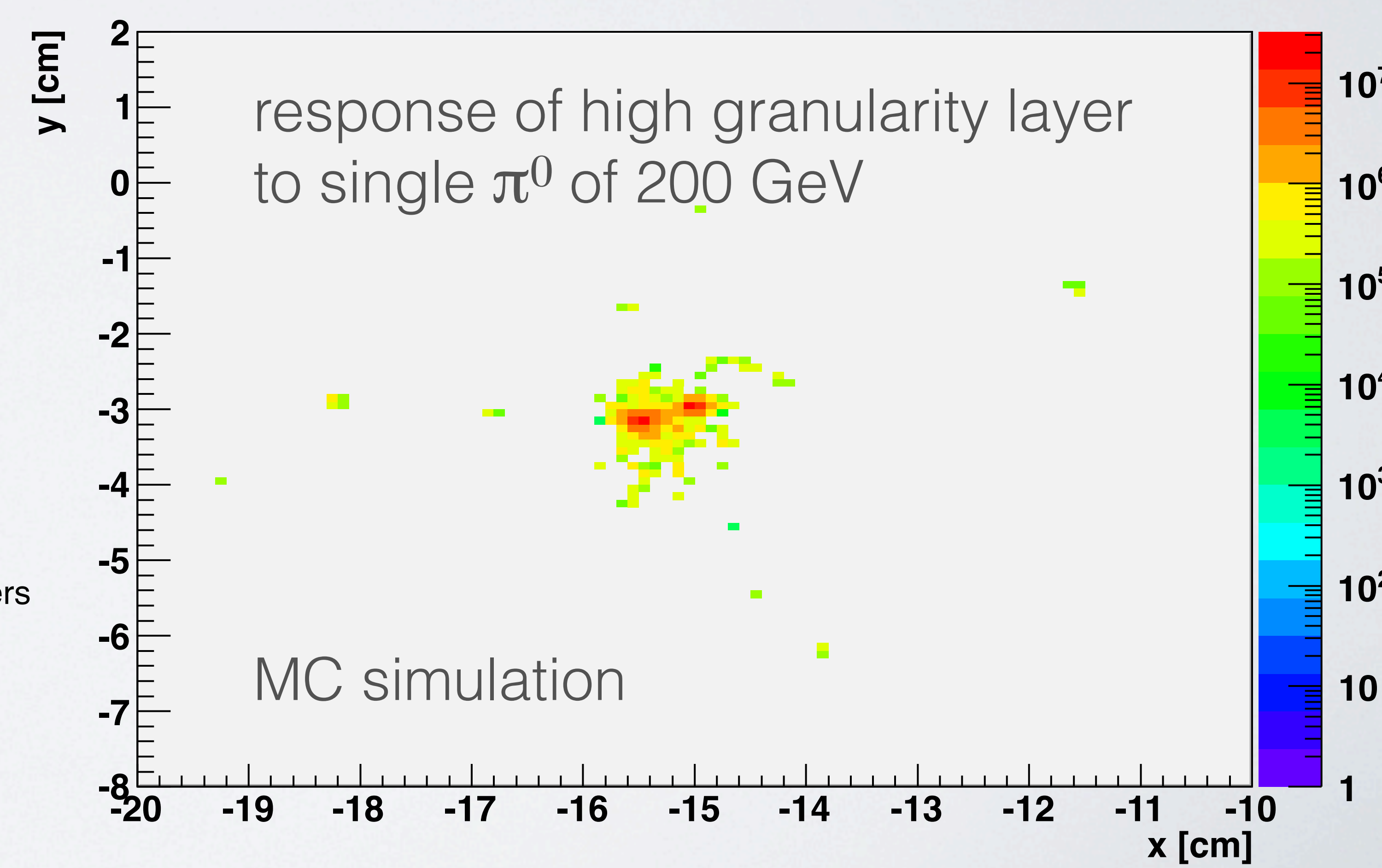


studied in performance simulations:

24 layers:

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

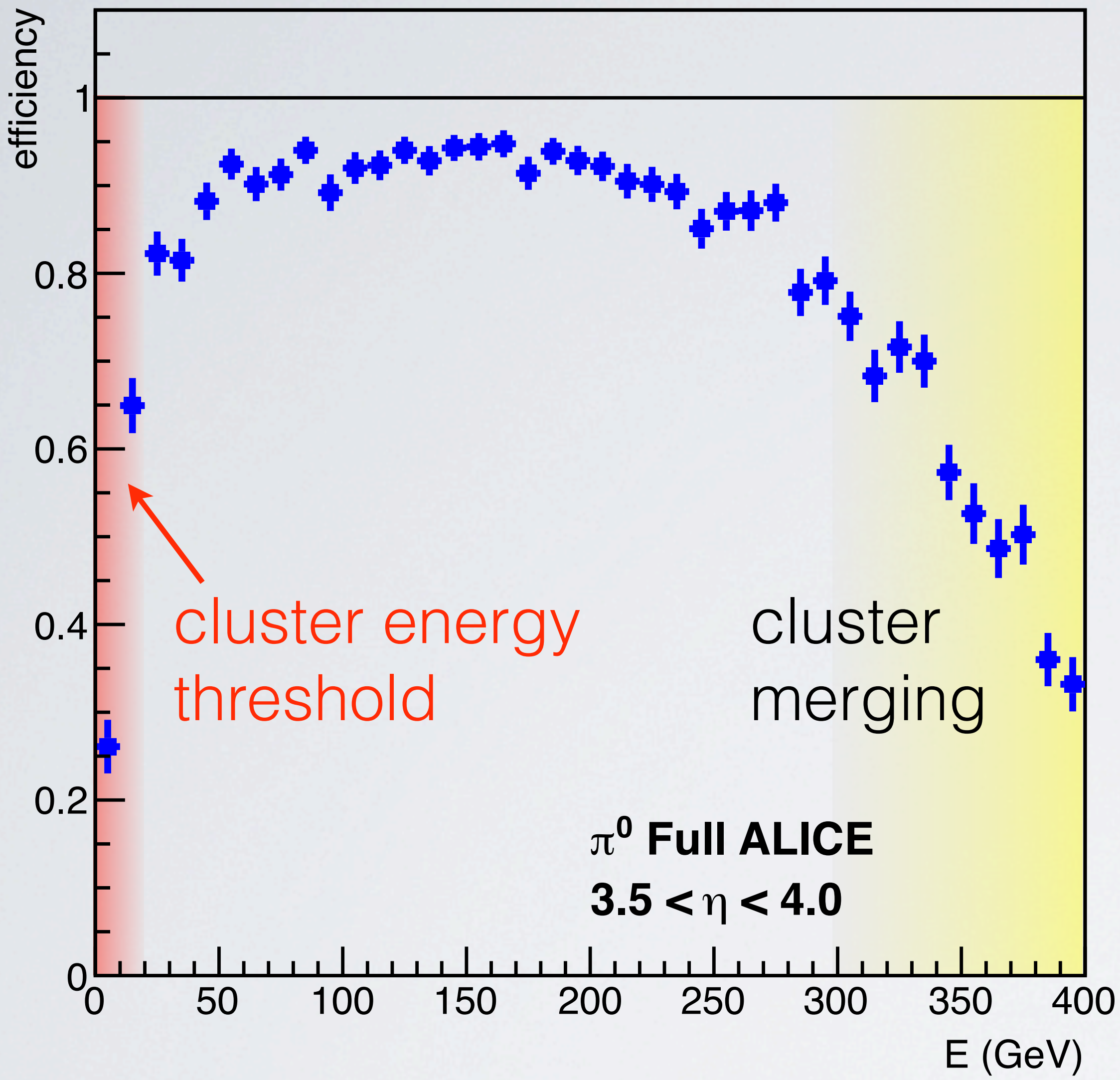
- low granularity (≈ 1 cm^2), Si-pads
- high granularity (≈ 1 mm^2), obtained with pixels (e.g. CMOS-MAPS)



FoCal Physics Program

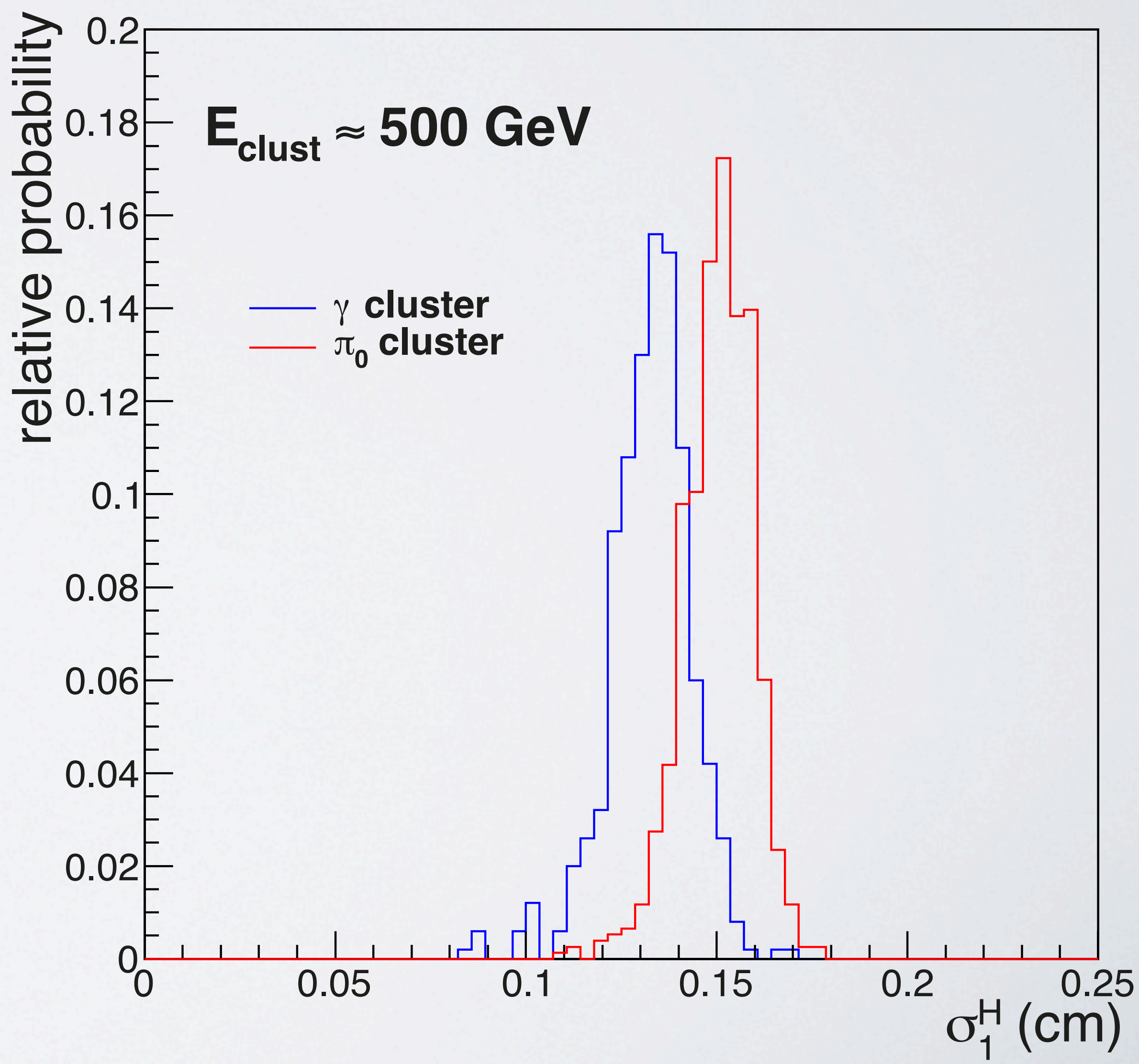
- p-Pb: saturation/CGC effects
  - forward direct γ spectra, γ-hadron/jet correlations (unique!)
  - π^0 spectra, π^0-π^0 correlations, possibly jets (had. calorimeter!)
- p+p: reference measurements
  - constraints on PDFs?
- Pb-Pb: QGP studies
  - extend acceptance for γ-hadron/jet, π^0-π^0 correlations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

π^0 Efficiency



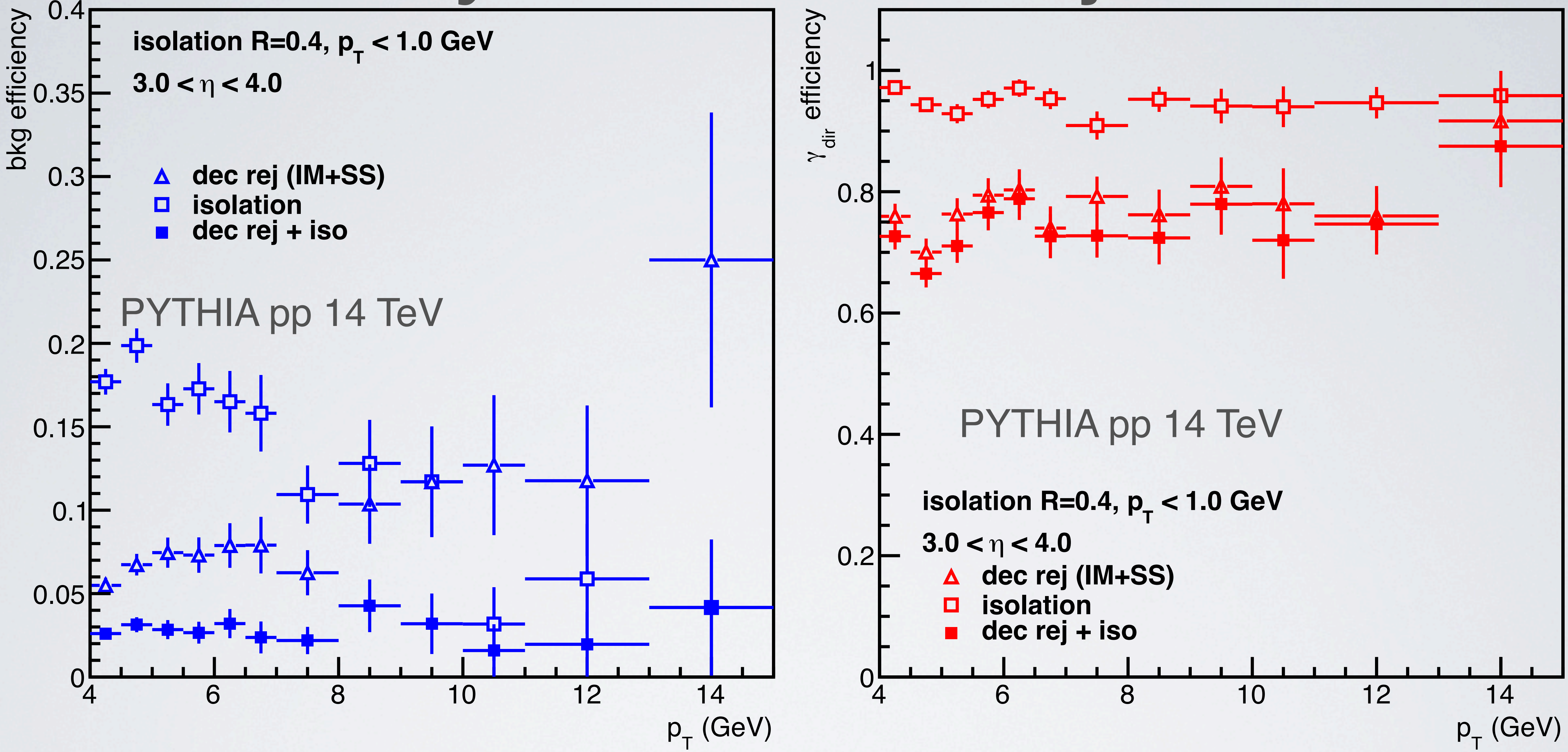
single particle simulation in full ALICE setup, good efficiency up to E ≈ 300 GeV (p_T ≈ 10 GeV/c)

can still be improved by shower shape analysis in HGL



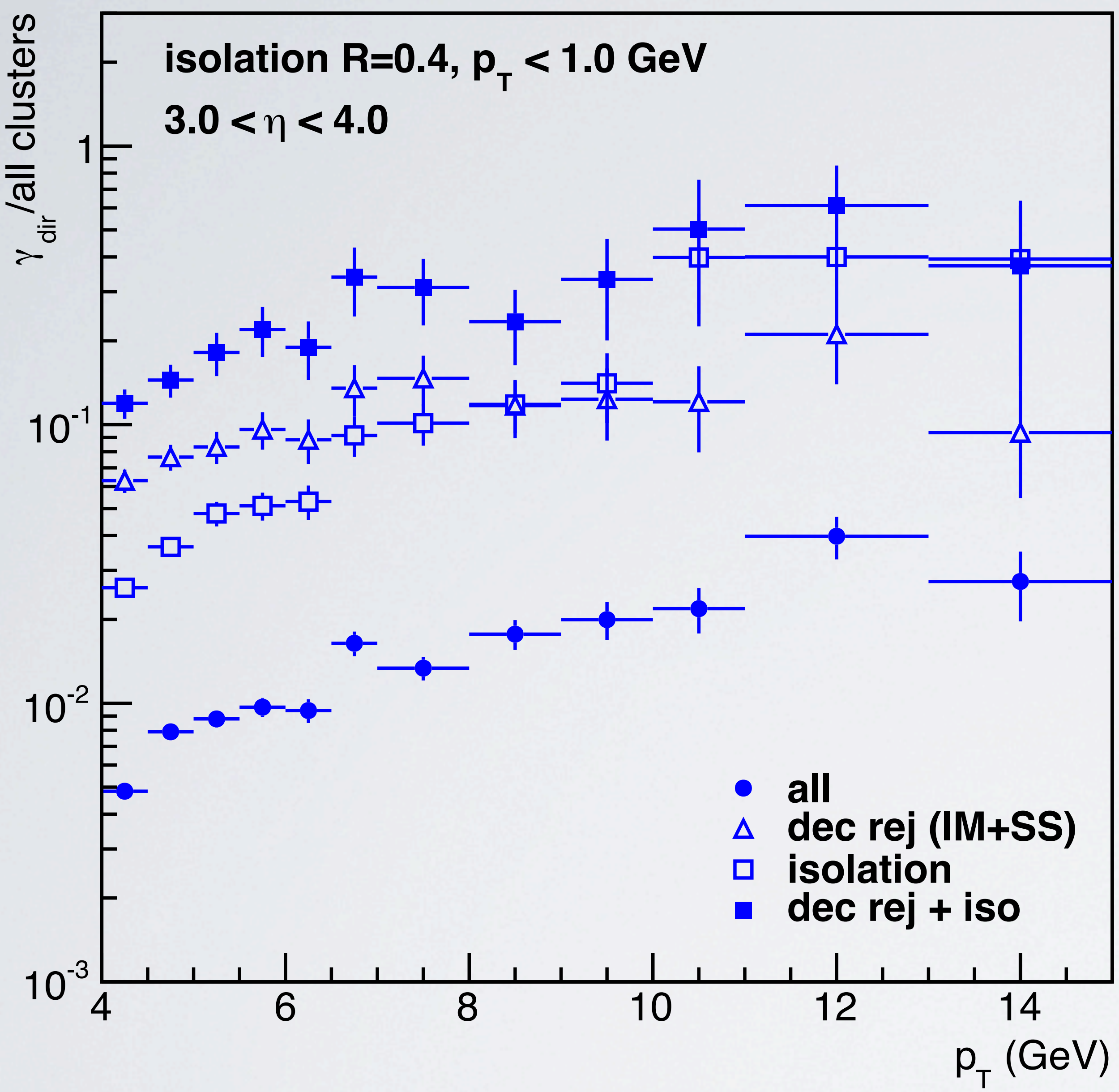
expect good discrimination from HGL info up to E ≈ 500 GeV

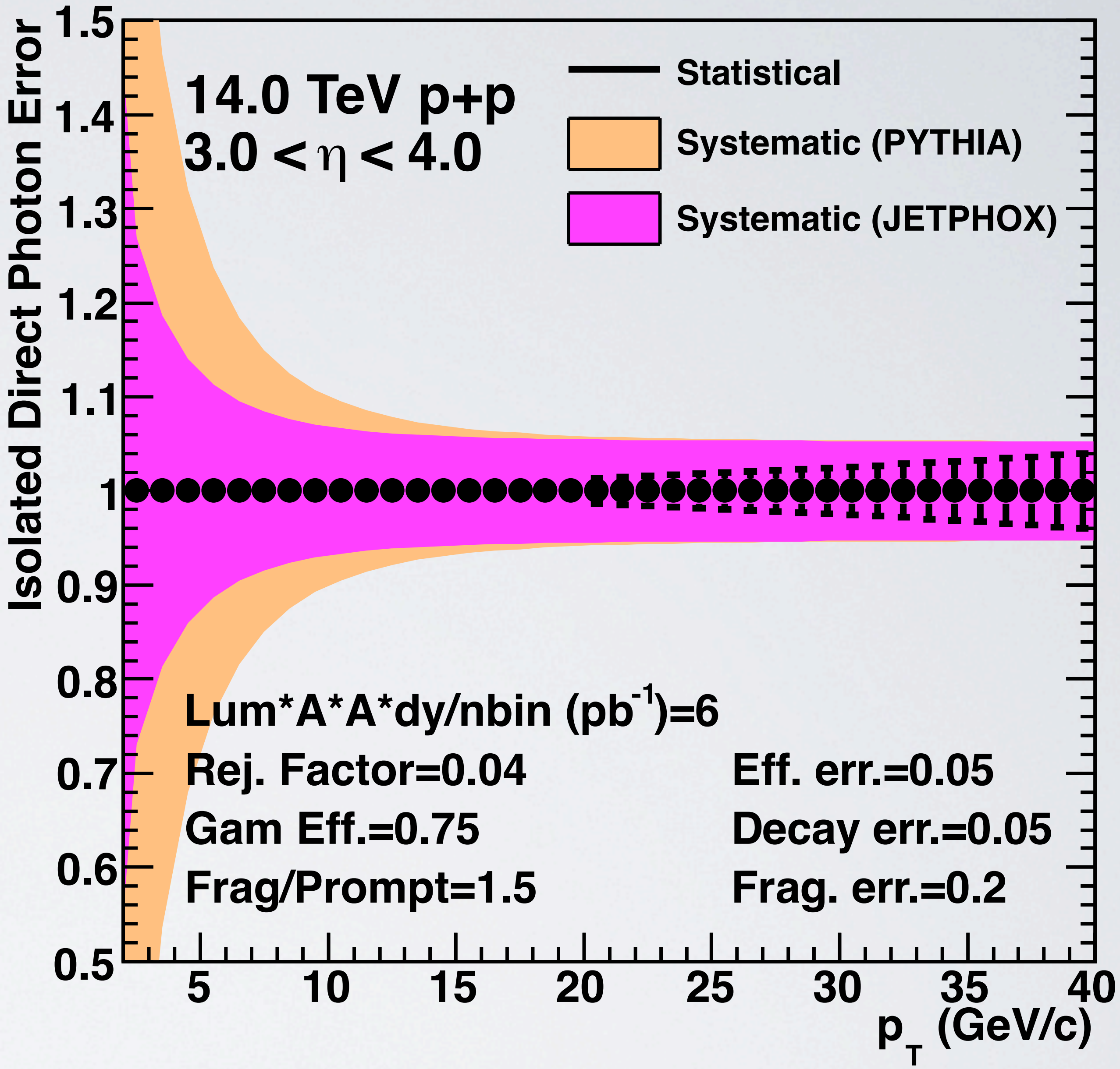
Decay Photon Rejection



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

Direct γ Performance in pp

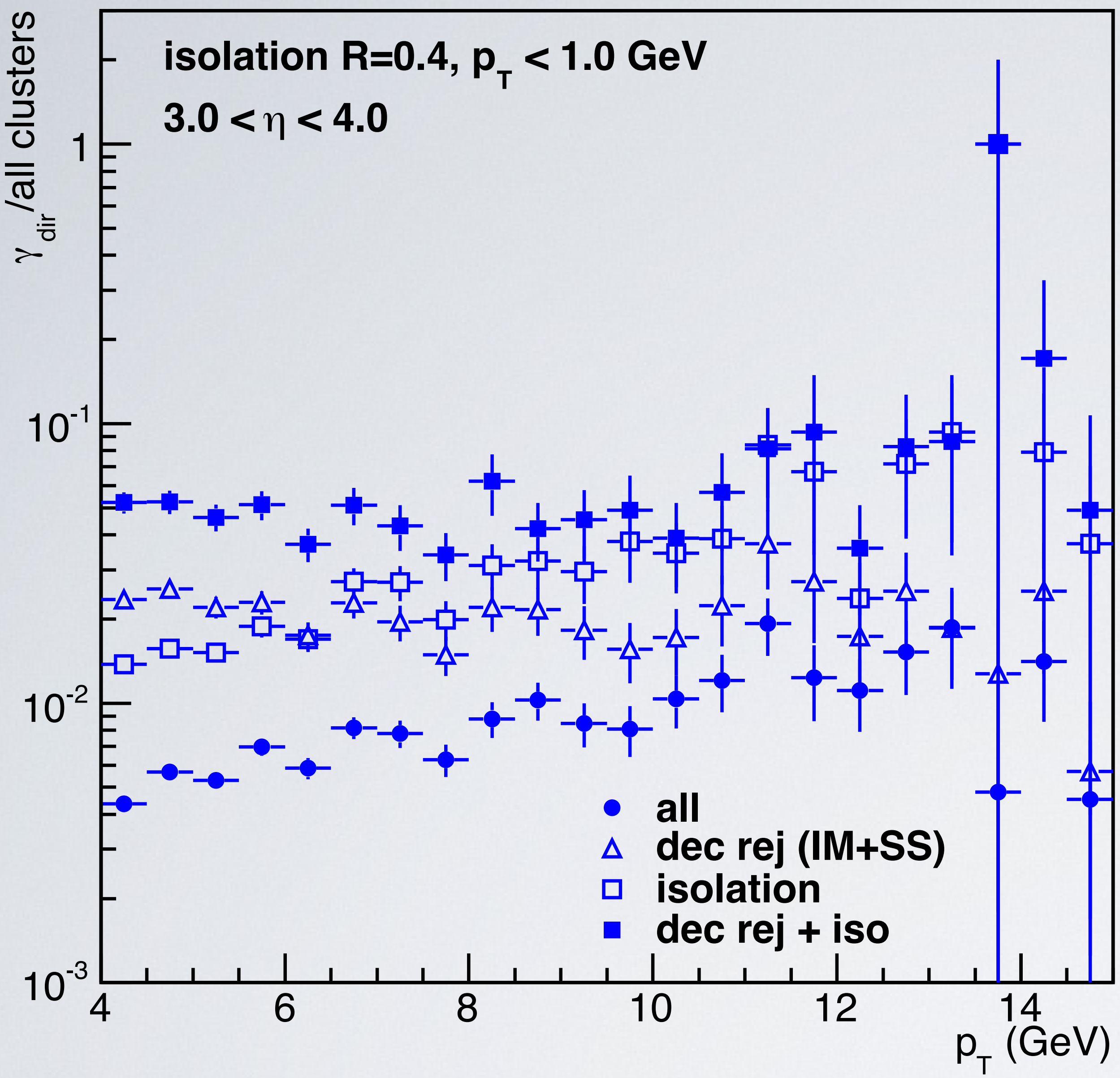


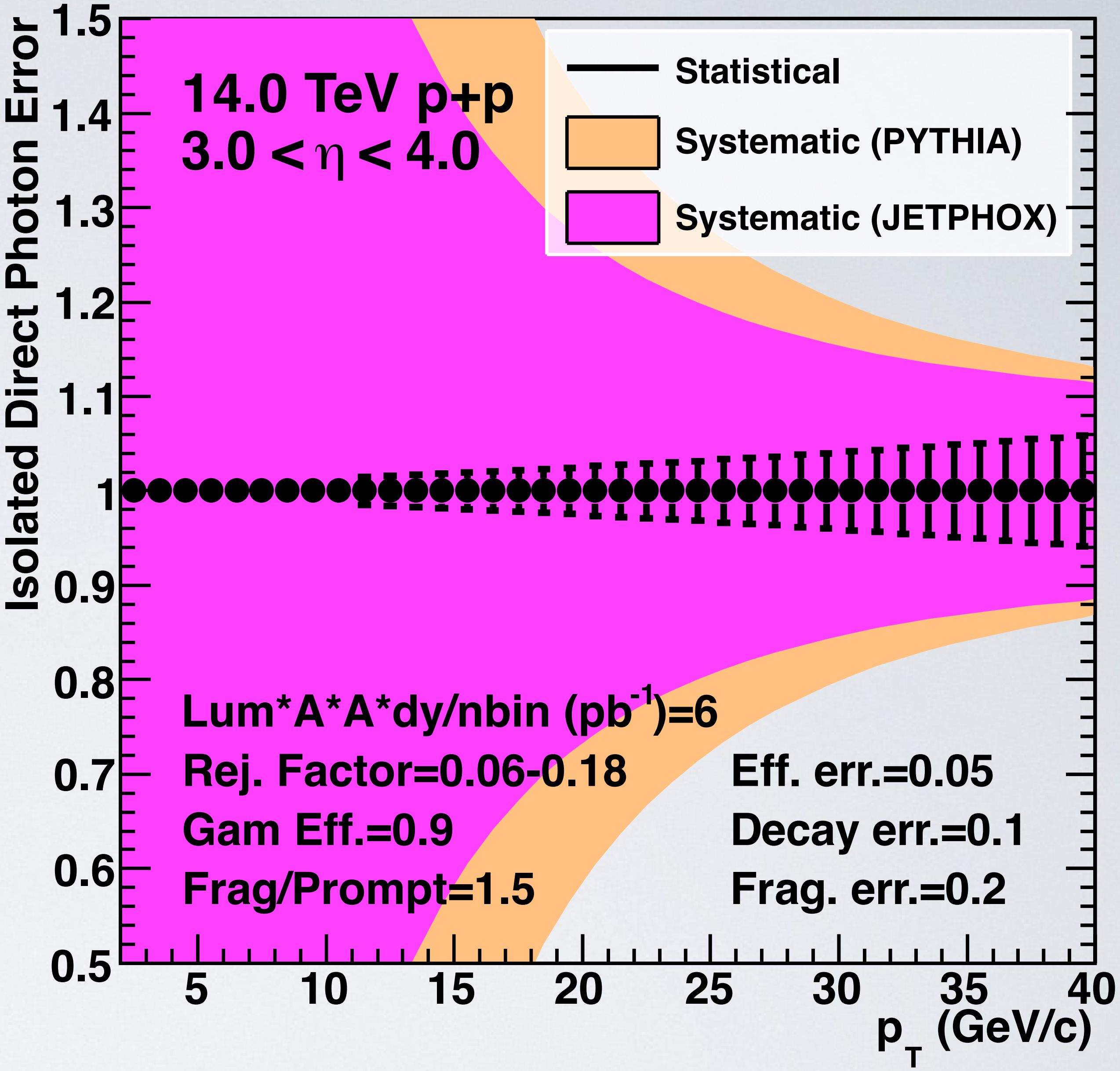


direct photon/all > 0.1
for p_T > 4 GeV/c

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

Low Granularity Measurement



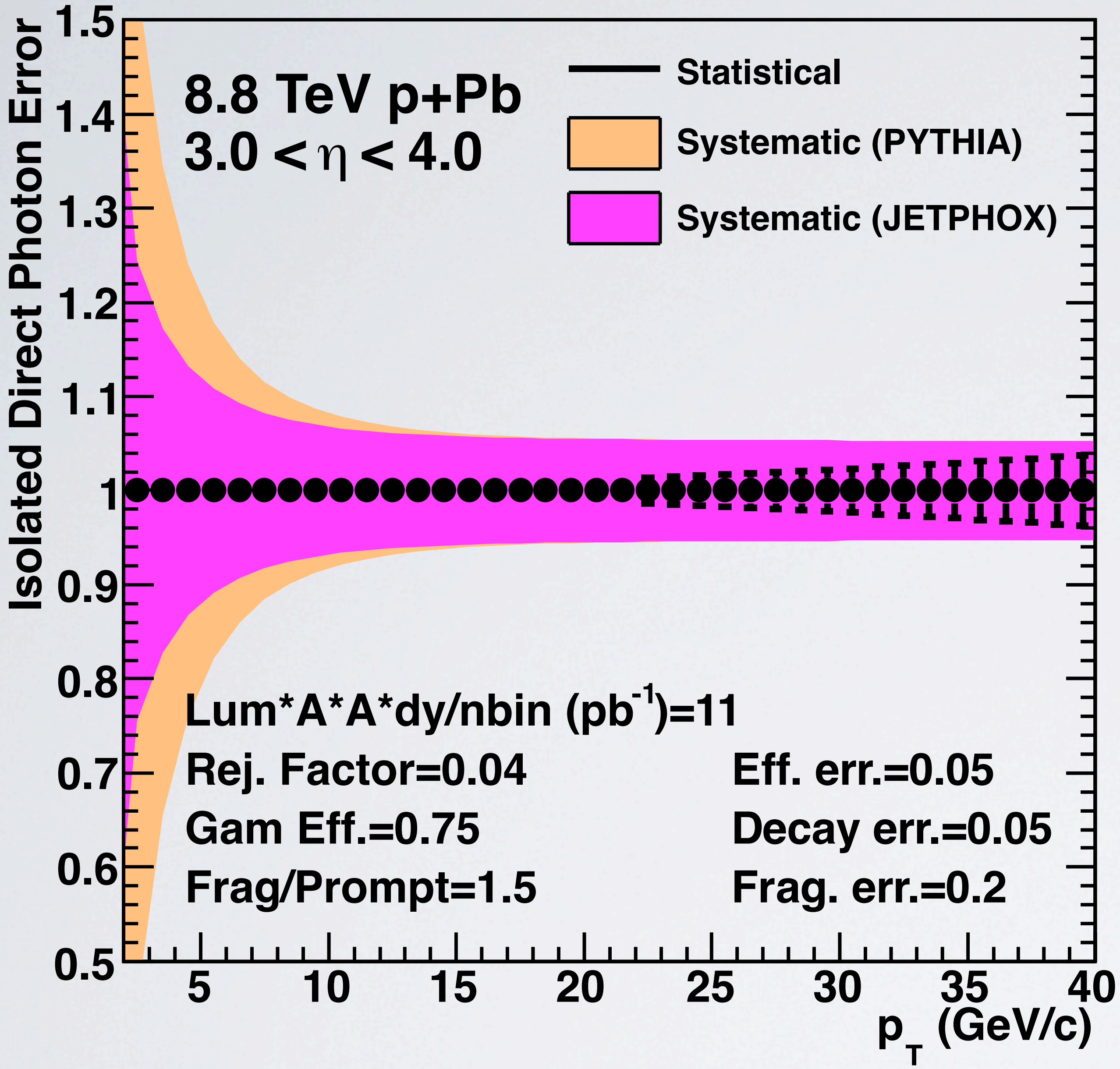


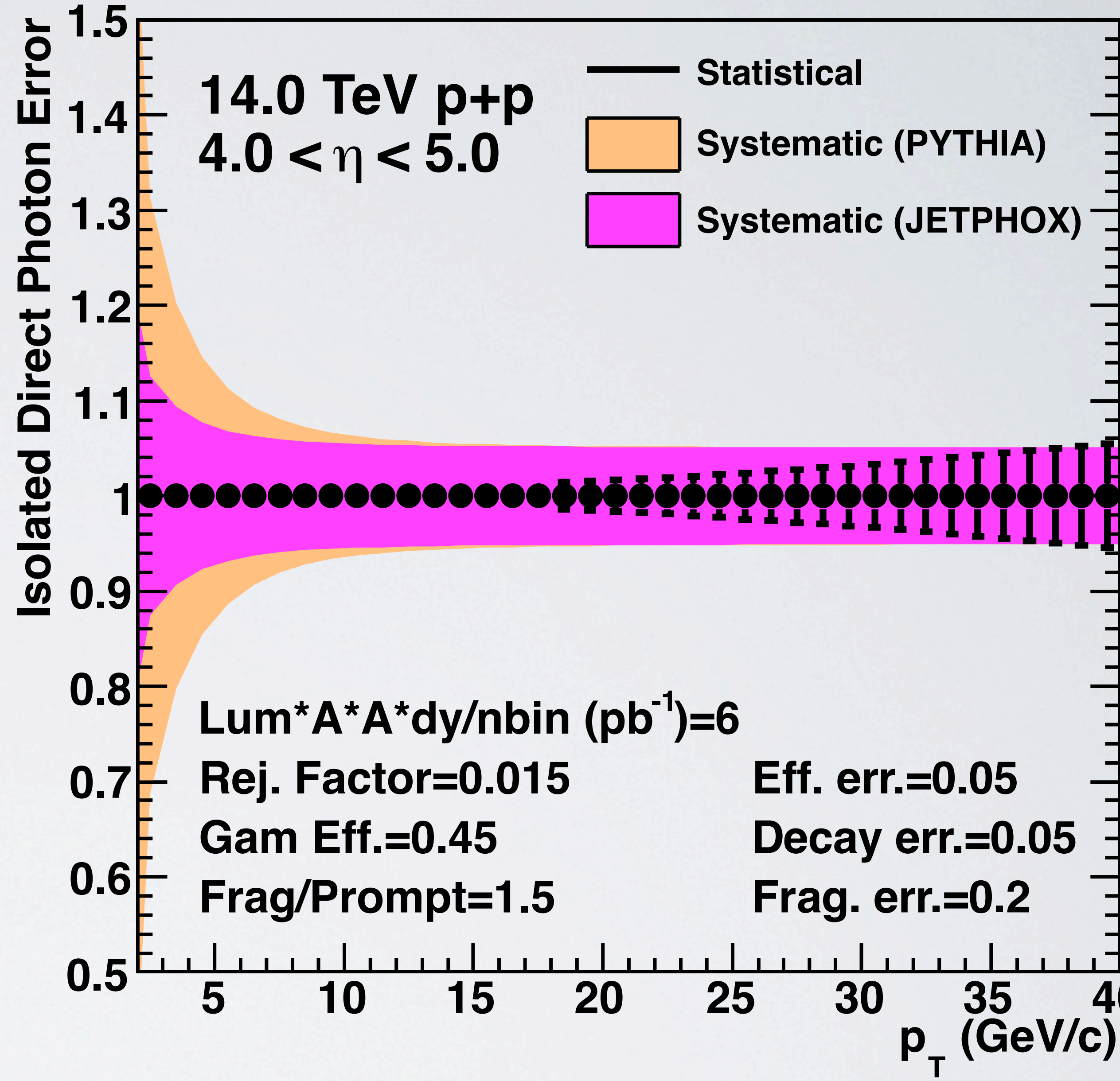
- low granularity (1cm²) does not allow efficient decay rejection
- direct photon/all ≈ 0.05 for all p_T

significant measurement not possible at low p_T

NB: conditions similar to LHCb

More Performance ...

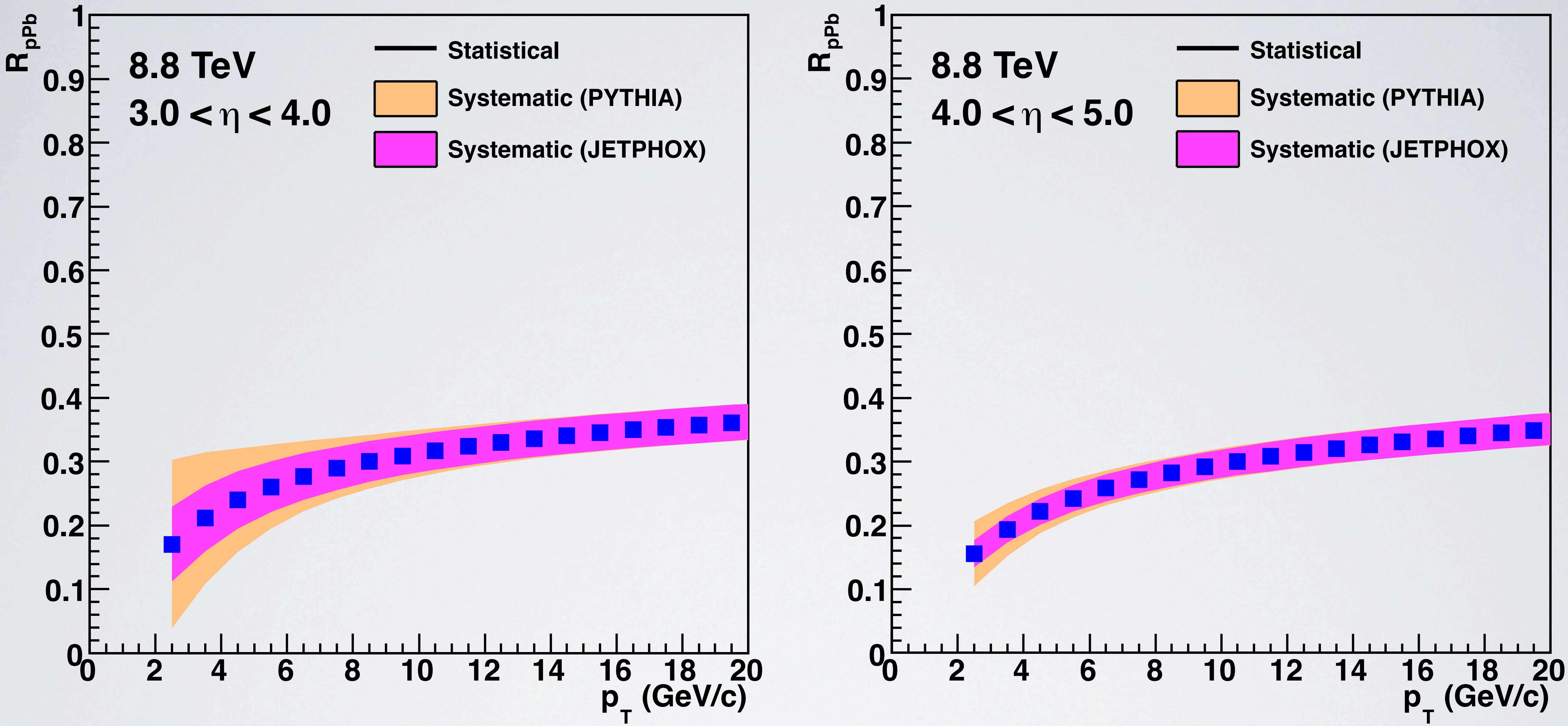




better performance for 8.8 TeV (p-A equivalent to pp)

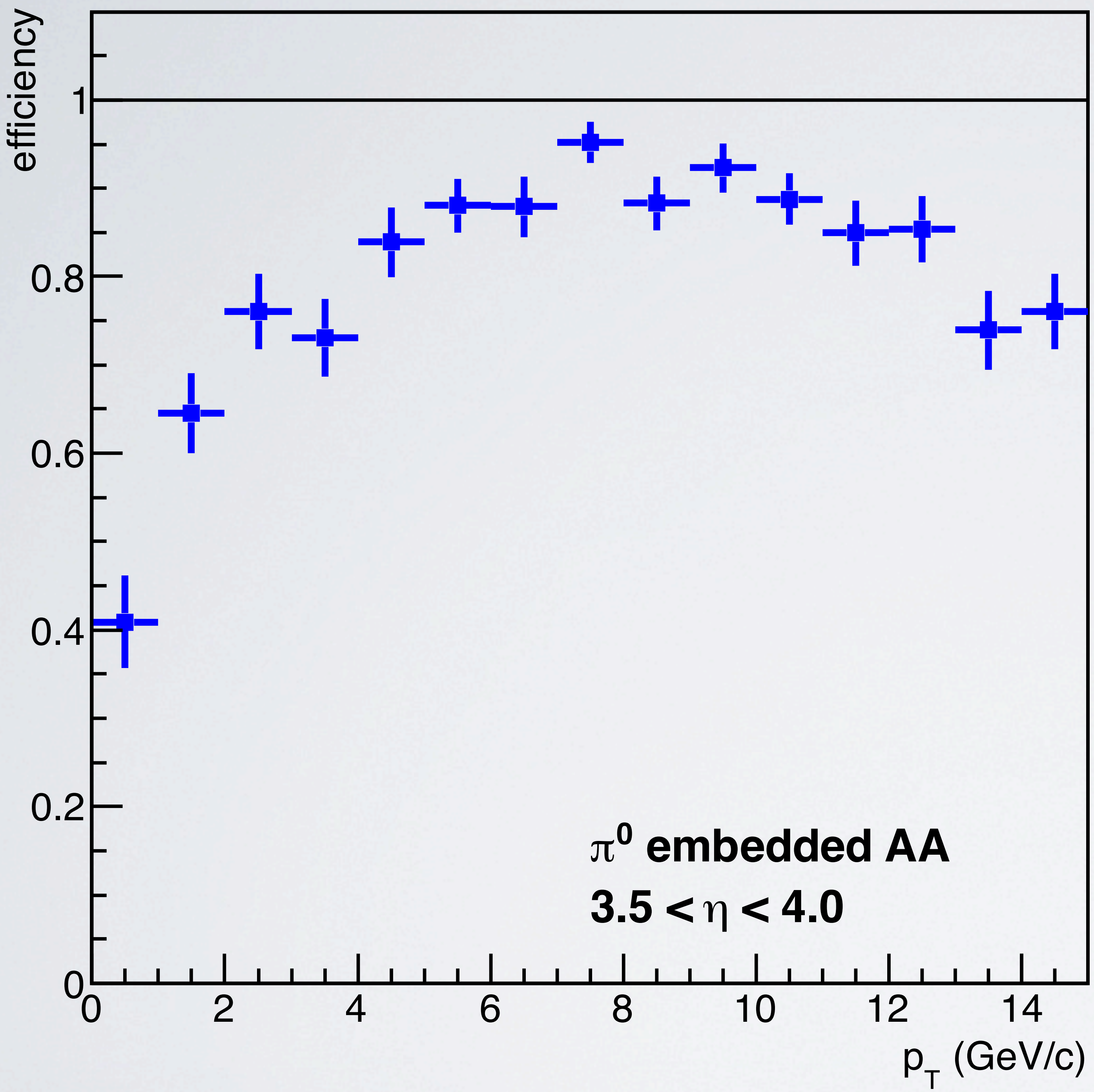
better performance for larger η (only possible for z=8m, requires more integration work)

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:

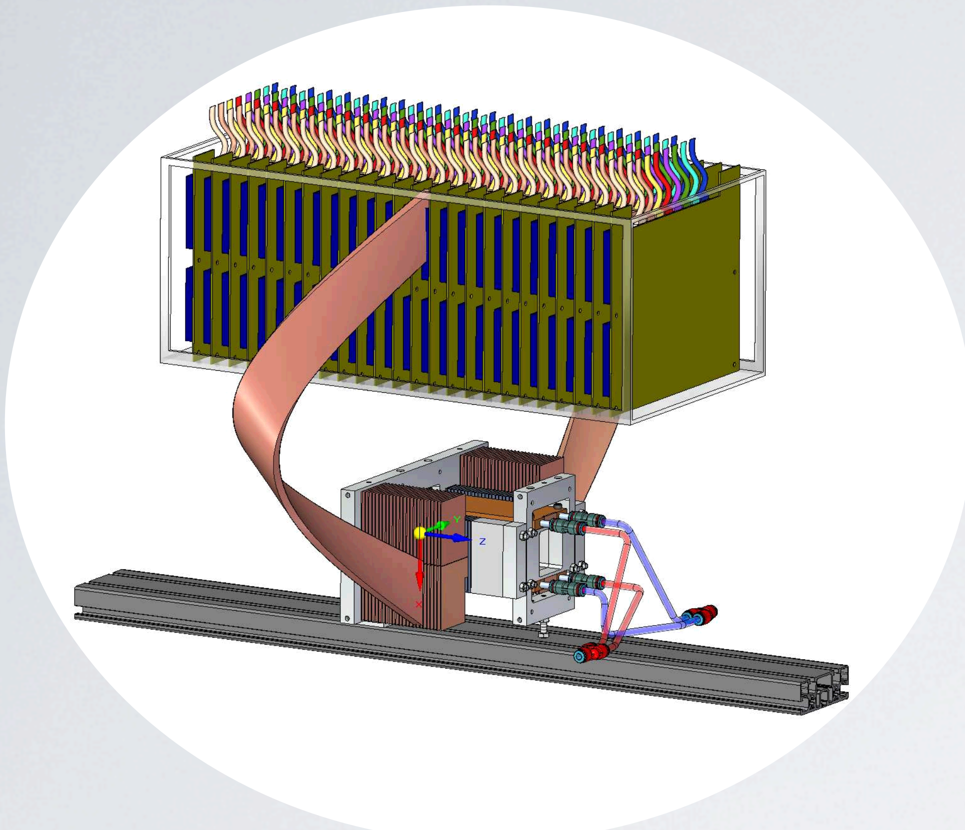
- good efficiency, slight deterioration at low p_T (overlap with underlying event)
- expect larger uncertainty from larger background in invariant mass

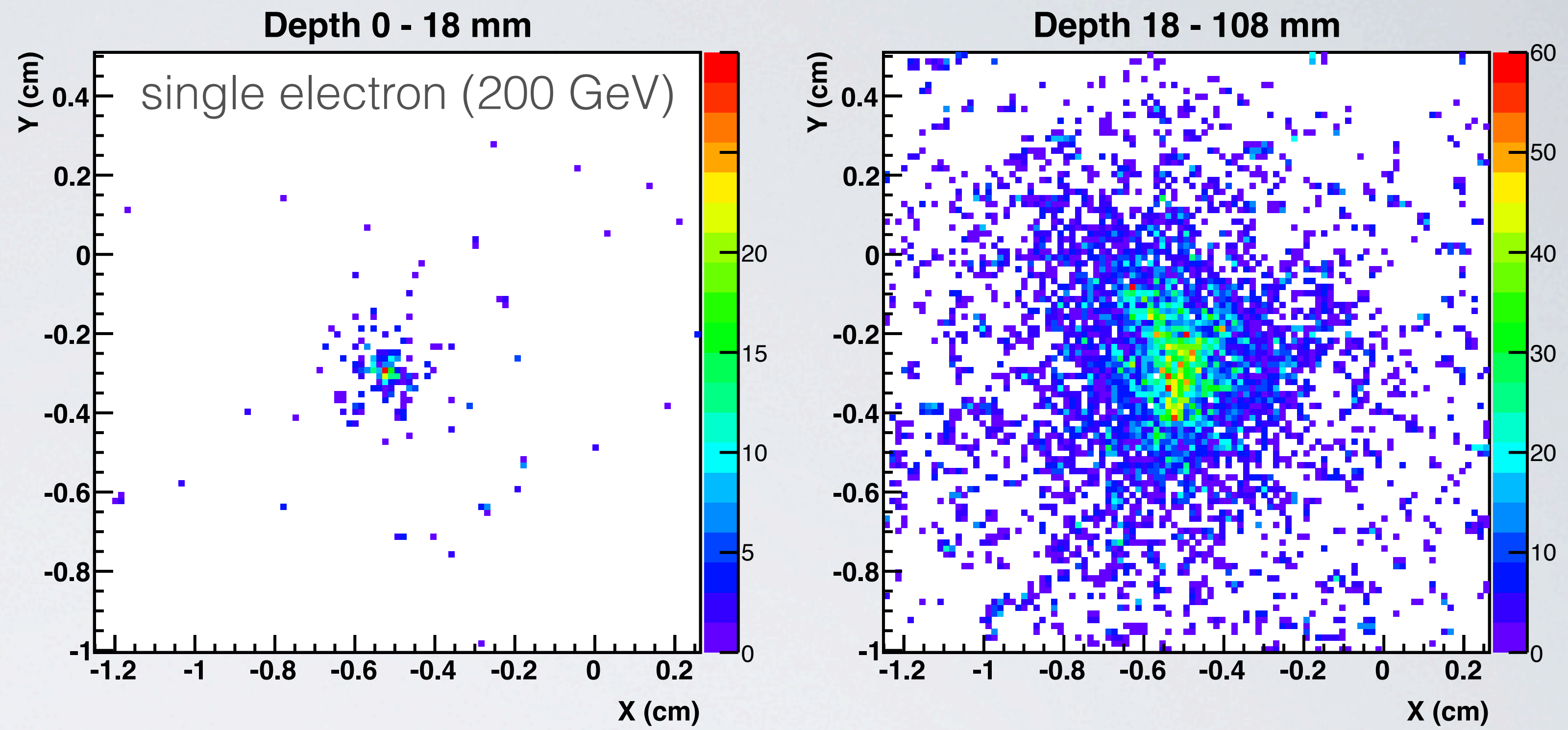
direct photon measurement difficult

- should be possible in limited p_T range

work in progress!

Prototypes and Test Beams



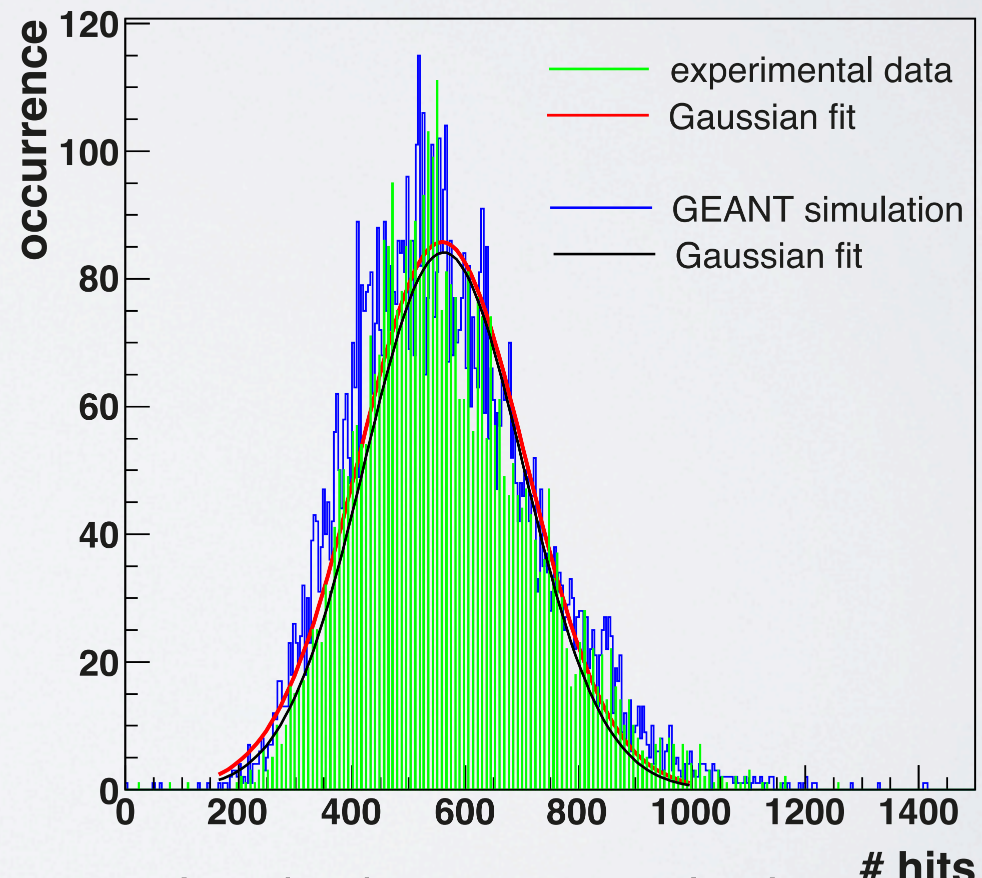


R&D ongoing (Utrecht/Nikhef, Bergen, Tokyo, ORNL, Kolkata, Prague, ...)

e.g. full MAPS prototype

- 39 M pixels in 4x4x10 cm^3 !

first results from test beams encouraging



single layer resolution agrees with simulation

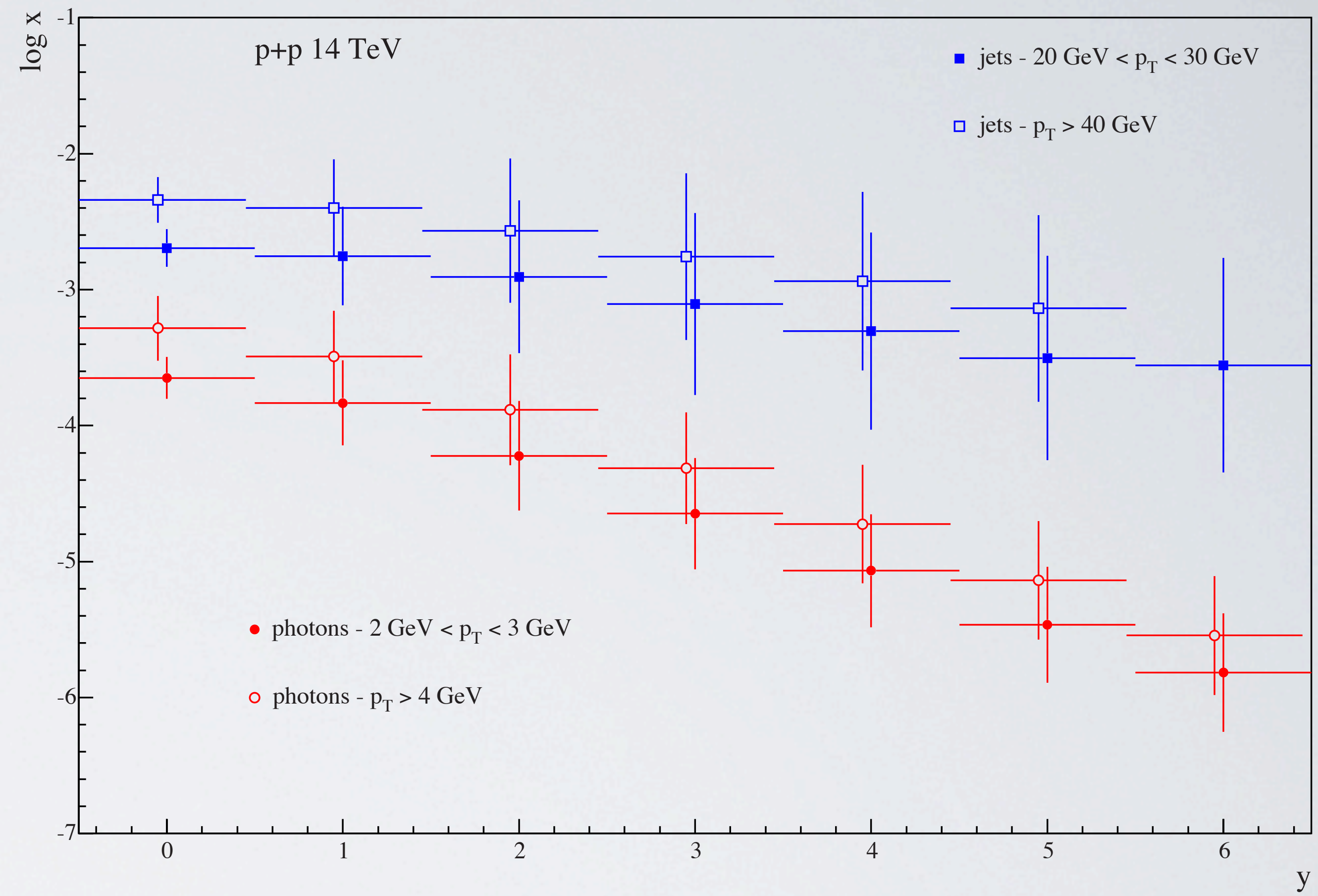
Conclusions

- Isolated photons at forward rapidity are the best probe for low-x gluons
  - too many uncertainties in hadrons
  - too low cross section in Drell-Yan
- FoCal should allow unique direct photon measurements in pp and p-Pb at forward rapidity
  - Uncertainty ≈30% at low p_T
  - High granularity is crucial (competitiveness)
  - Technology should be feasible
- Rich additional physics program (also in Pb-Pb)

Backup Slides

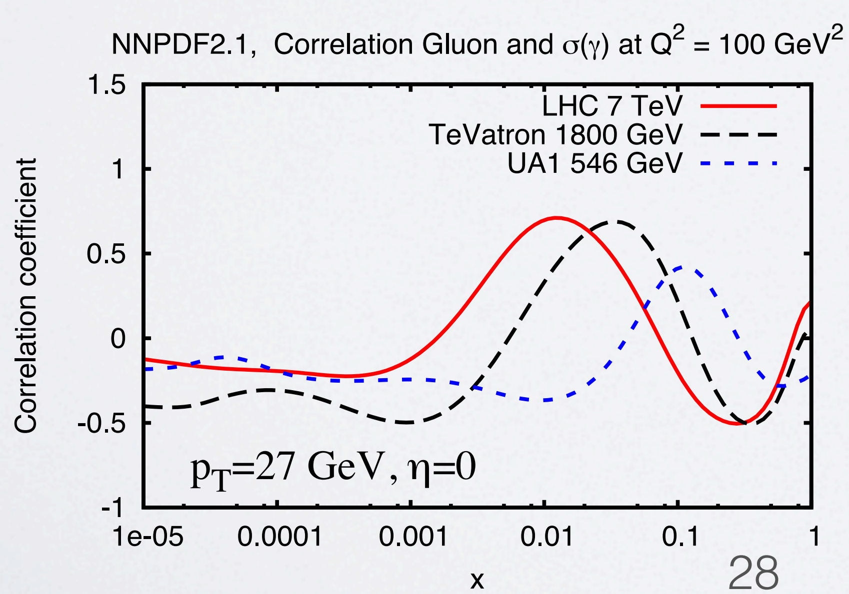
Kinematic Constraints

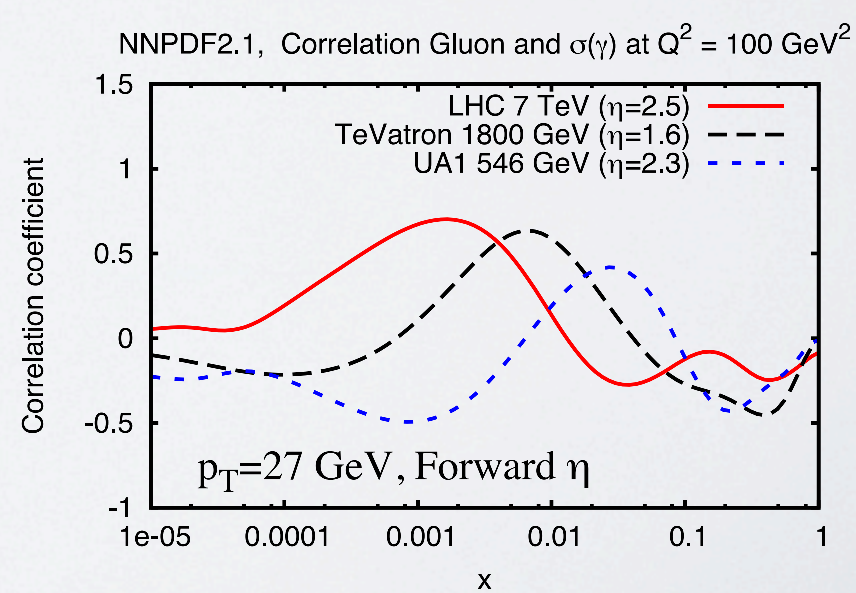
- large y prompt photons effective to constrain kinematics to low x
    - obvious in LO (PYTHIA)



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

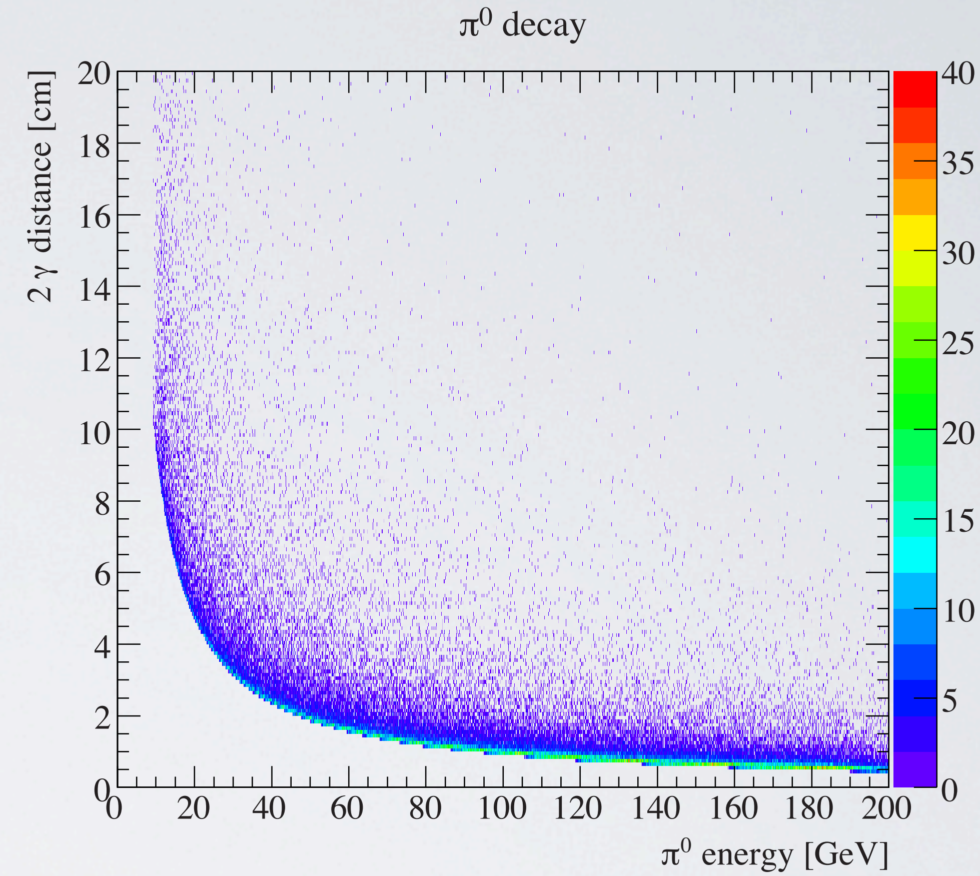
from D. d'Enterria and J. Rojo, arXiv:1202.1762

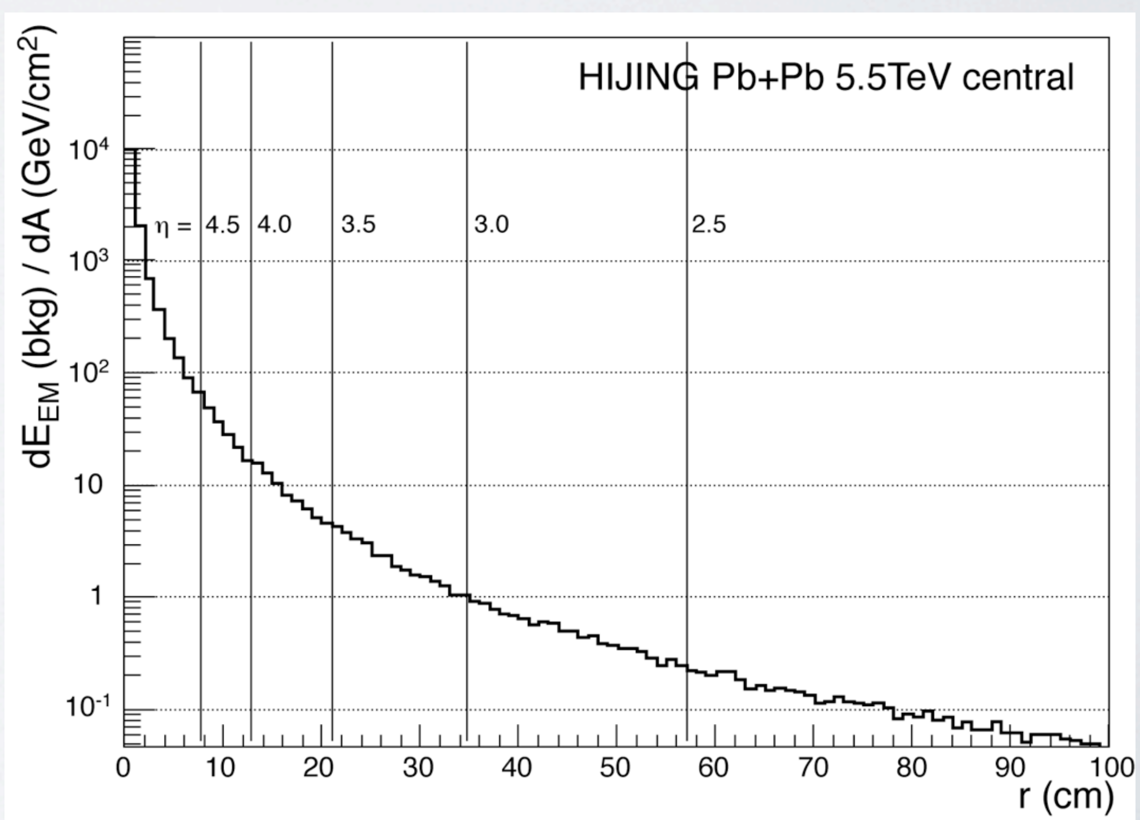




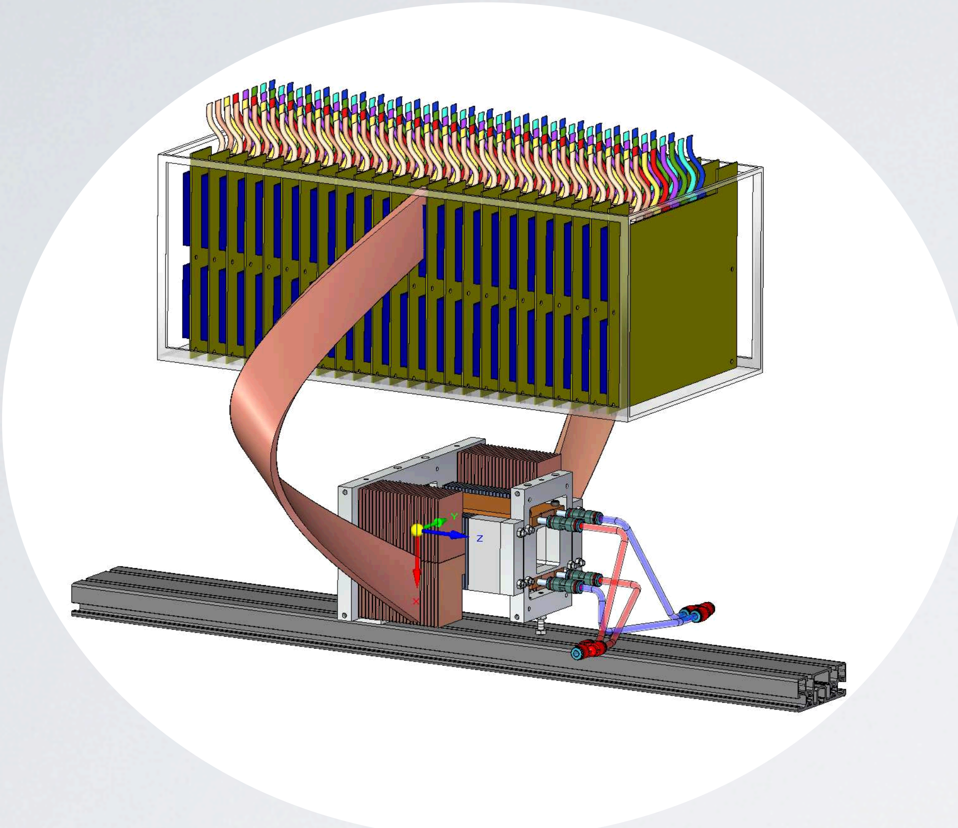
Main Design Issue: Granularity

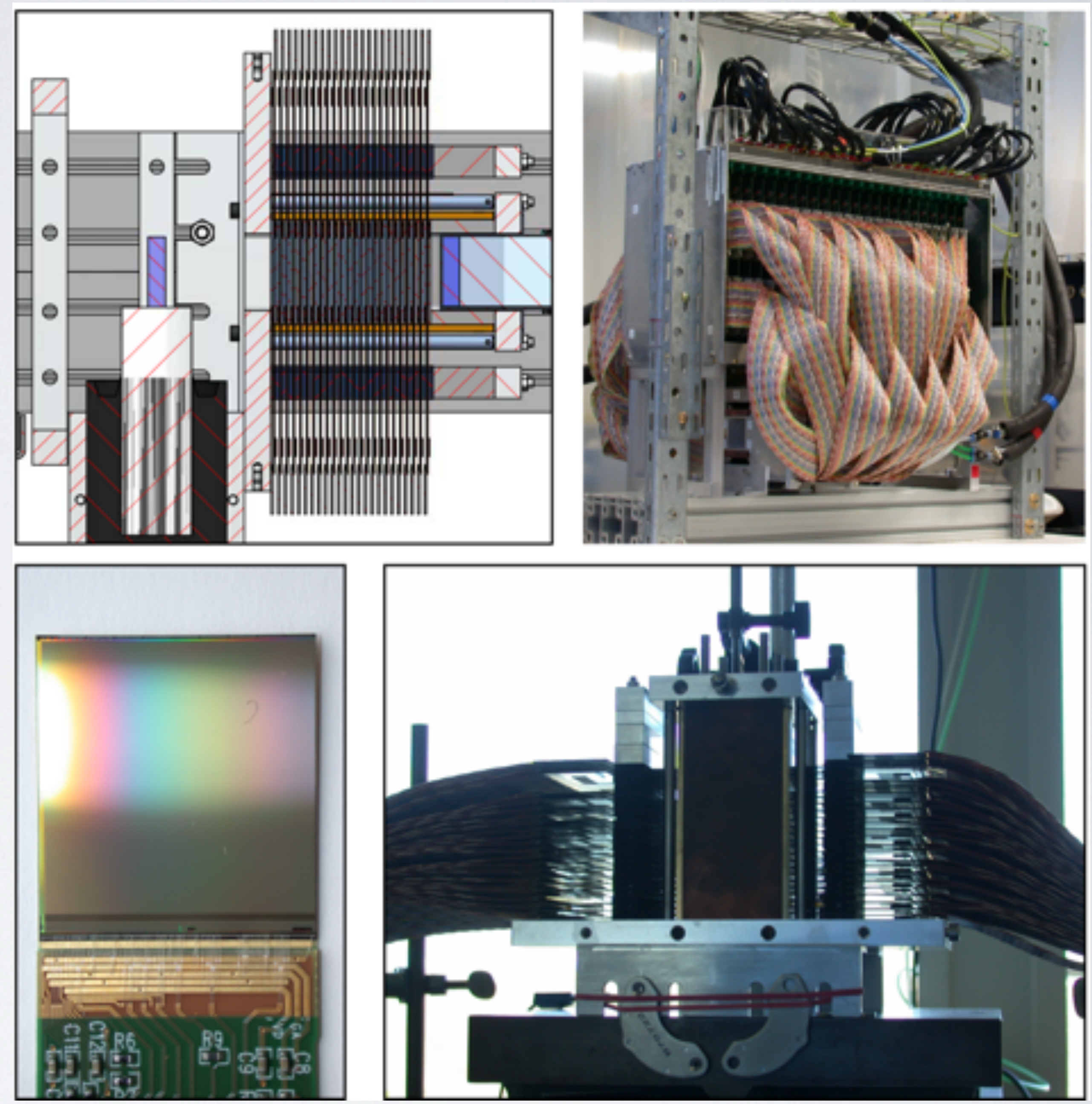
- π^0/γ discrimination
  - separation of decay gammas < 1 cm at high energy
  - requires adequate granularity of *some* layers
- particle density in Pb+Pb
  - even stronger requirements on granularity
  - optimum: high granularity ($\approx$1mm²) for all layers
- realistic compromise?





Pixel Calorimeter Prototype



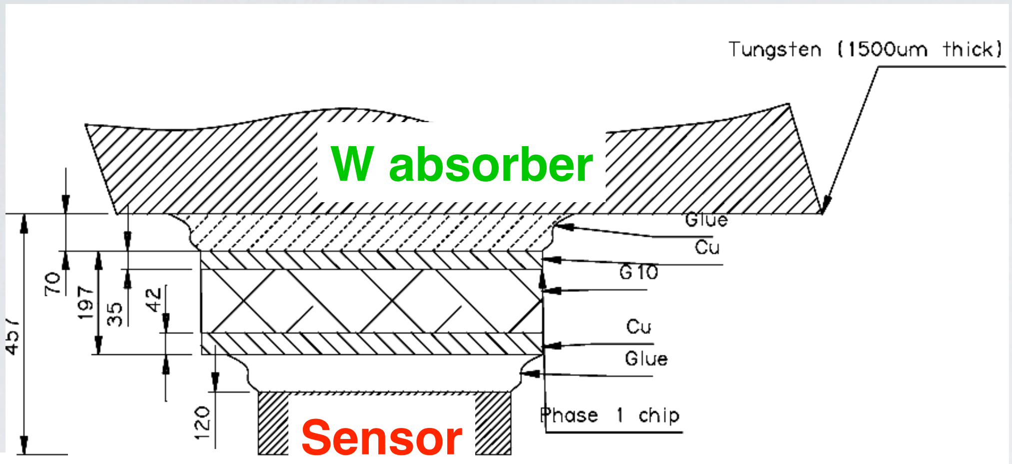


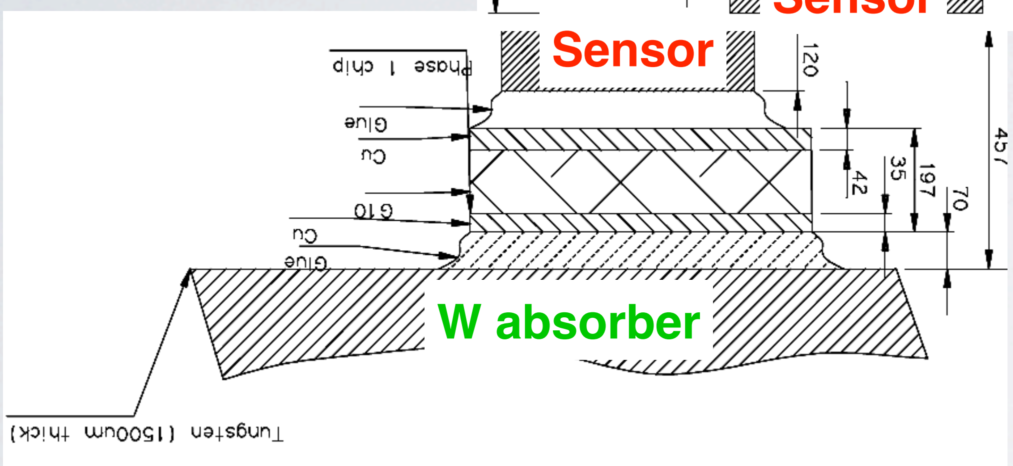
R&D (Utrecht/Nikhef, Bergen):
full MAPS prototype
24 layers

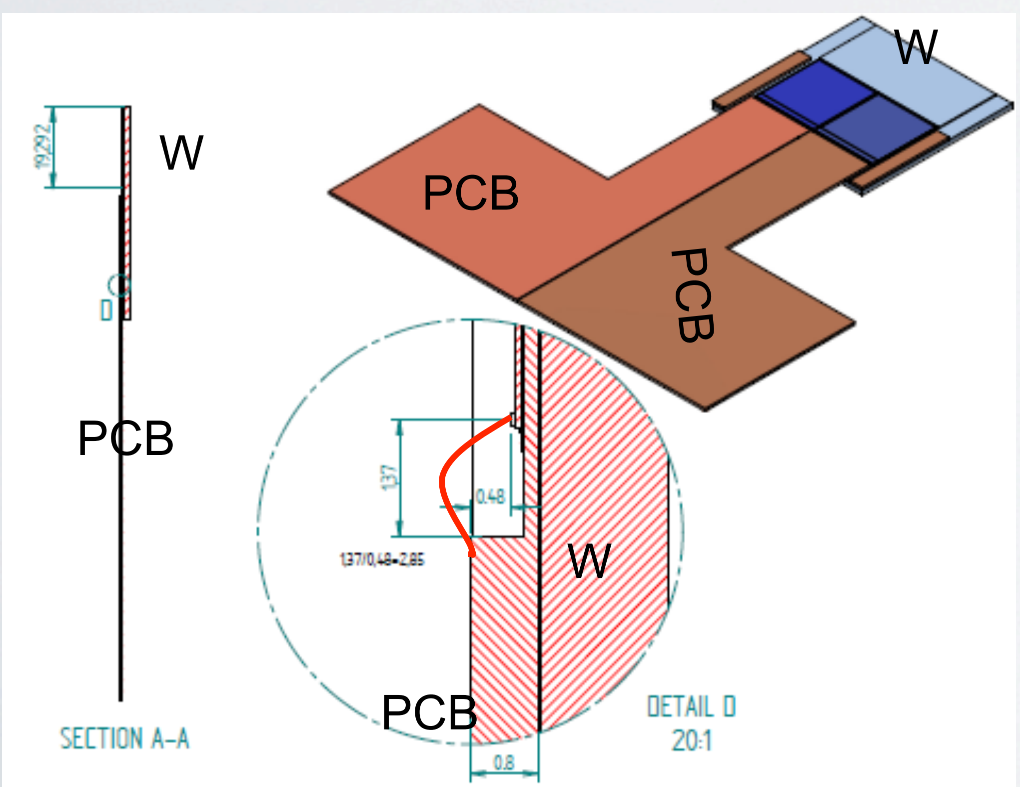
- 3mm W
- 1mm sensor layer
  - 120μm sensor (2x2 chips) + PCB, glue, air, ...
- 39 M pixels in 4x4x10 cm^3 !

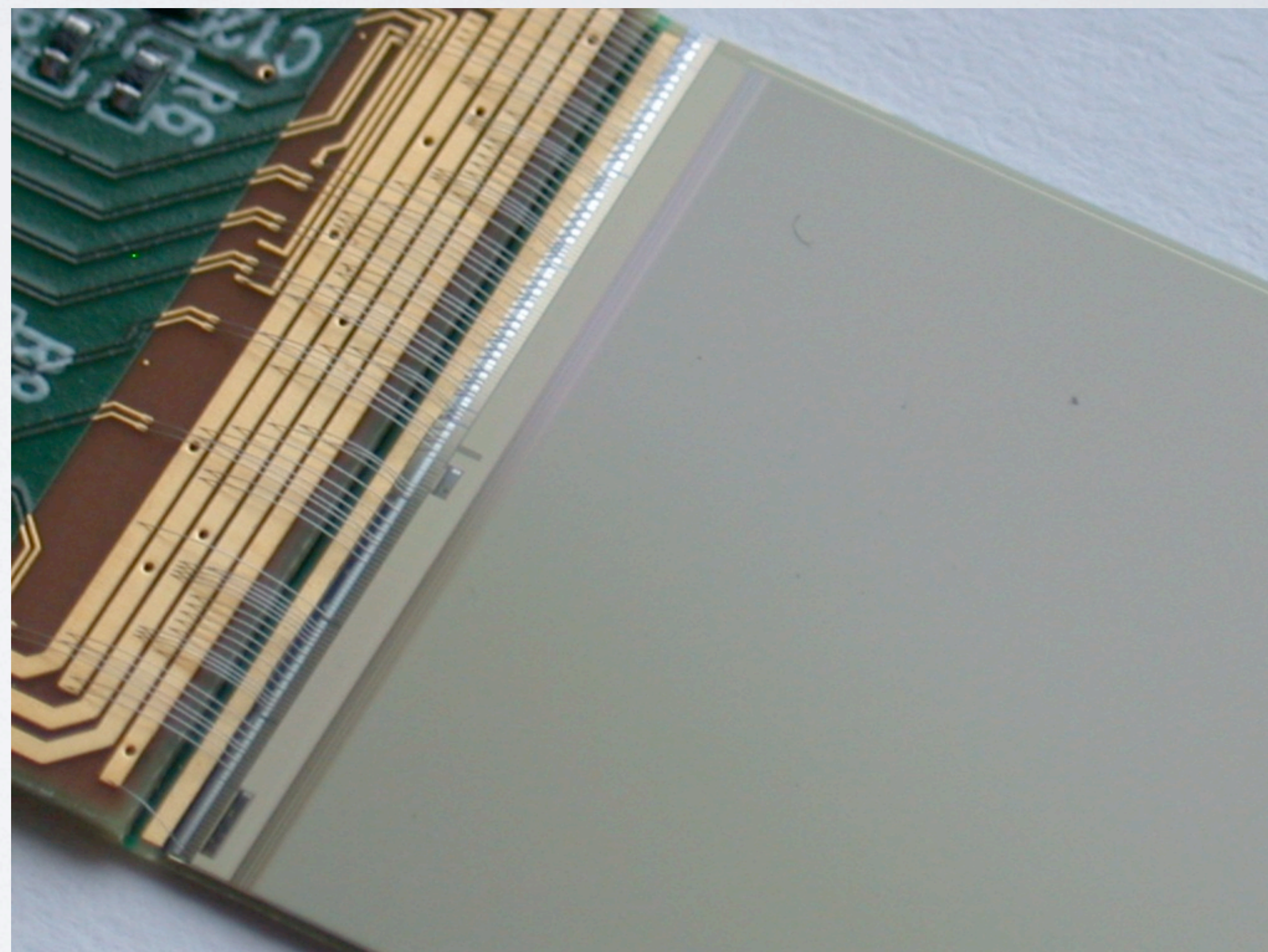
other R&D with prototypes ongoing at Tokyo, ORNL, Kolkata, Prague, ...

Prototype Details

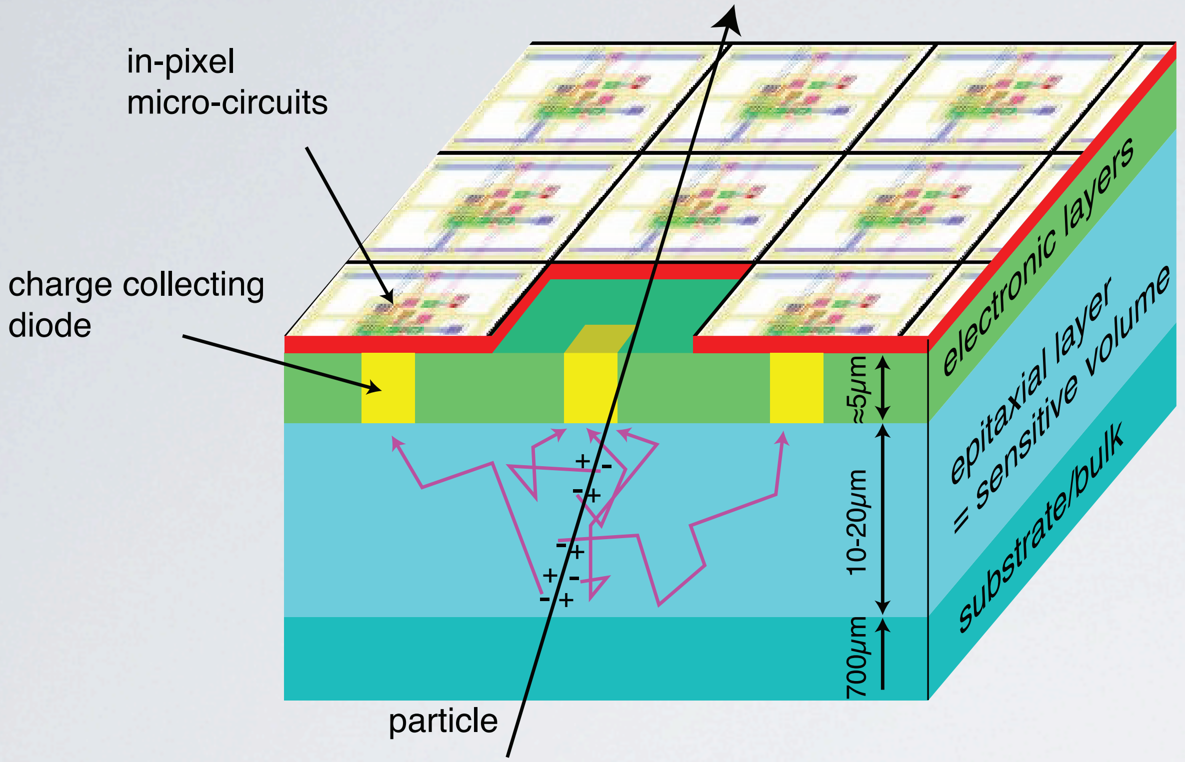


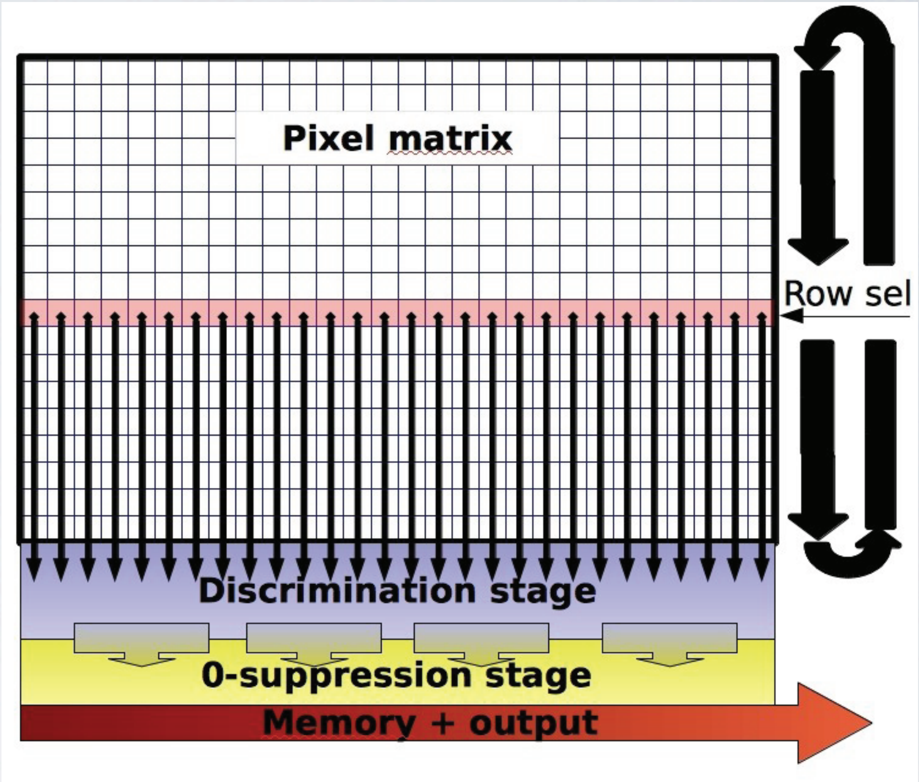






CMOS Sensor

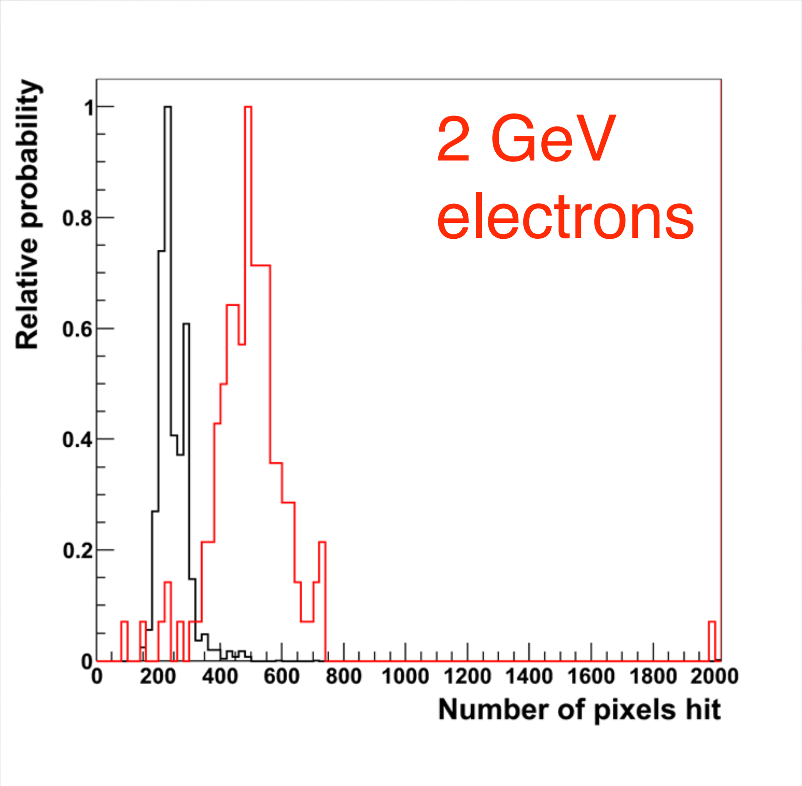


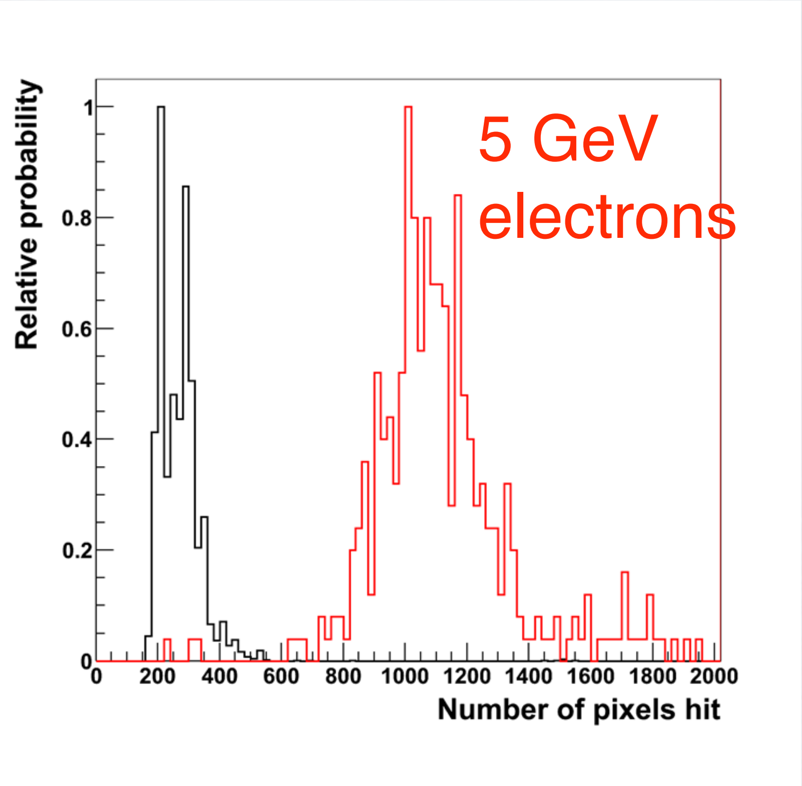


- Monolithic Active Pixel Sensors: Mimosa (IPHC Strasbourg)
  - here: MIMOSA23 (PHASE 2)
- rolling shutter: 640 µs total RO time
- digital readout
  - likely algorithm for real detector:
    on-chip hit count in macro pixel of 1 mm^2,
    for 30 µm pixels equivalent to 10bit analog value

chip size	19.5 x 21 mm^2
active area	19.2 x 19.2 mm^2
pixels	640 x 640
pitch	30 x 30 μm

Preliminary Results

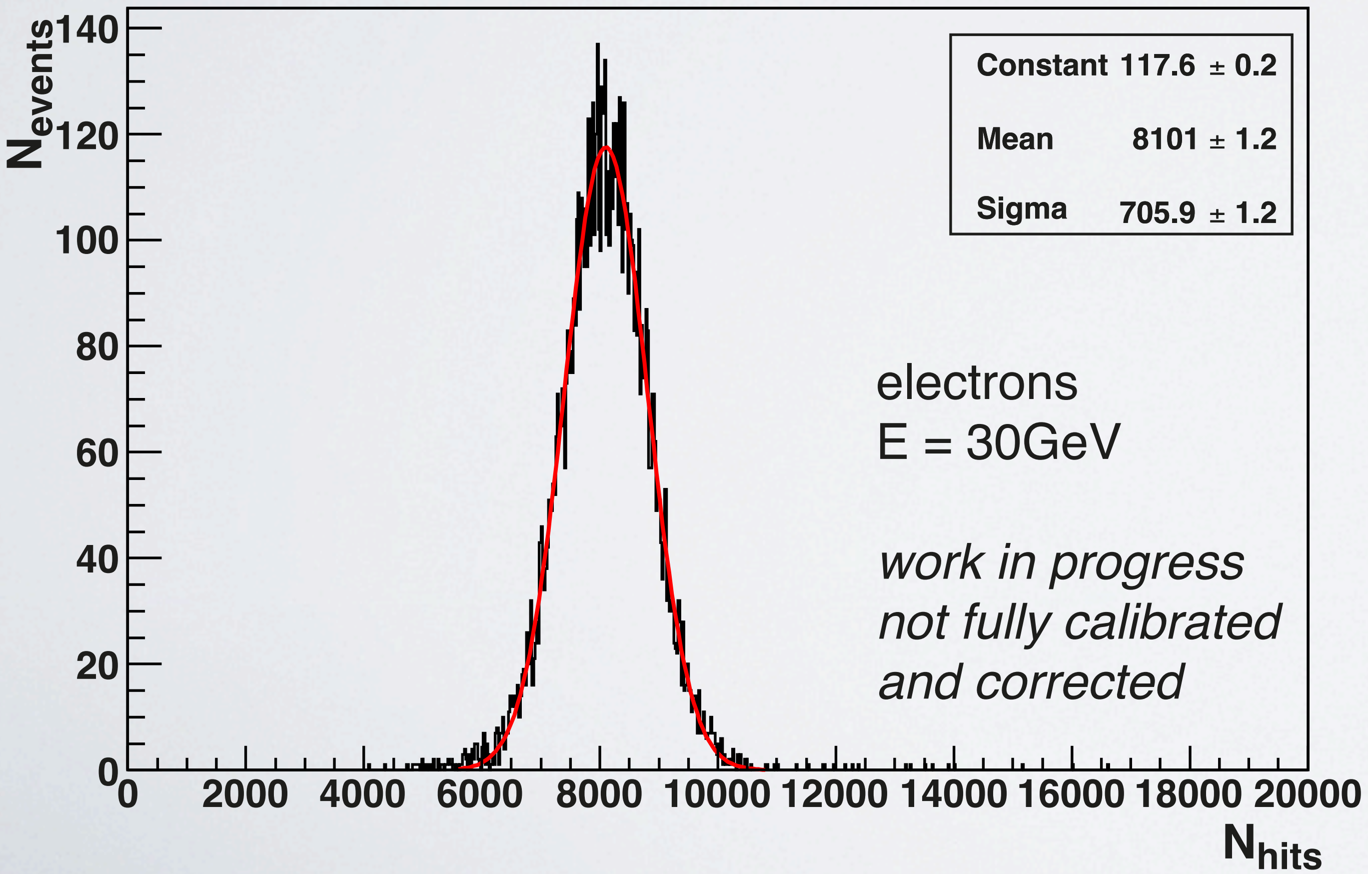




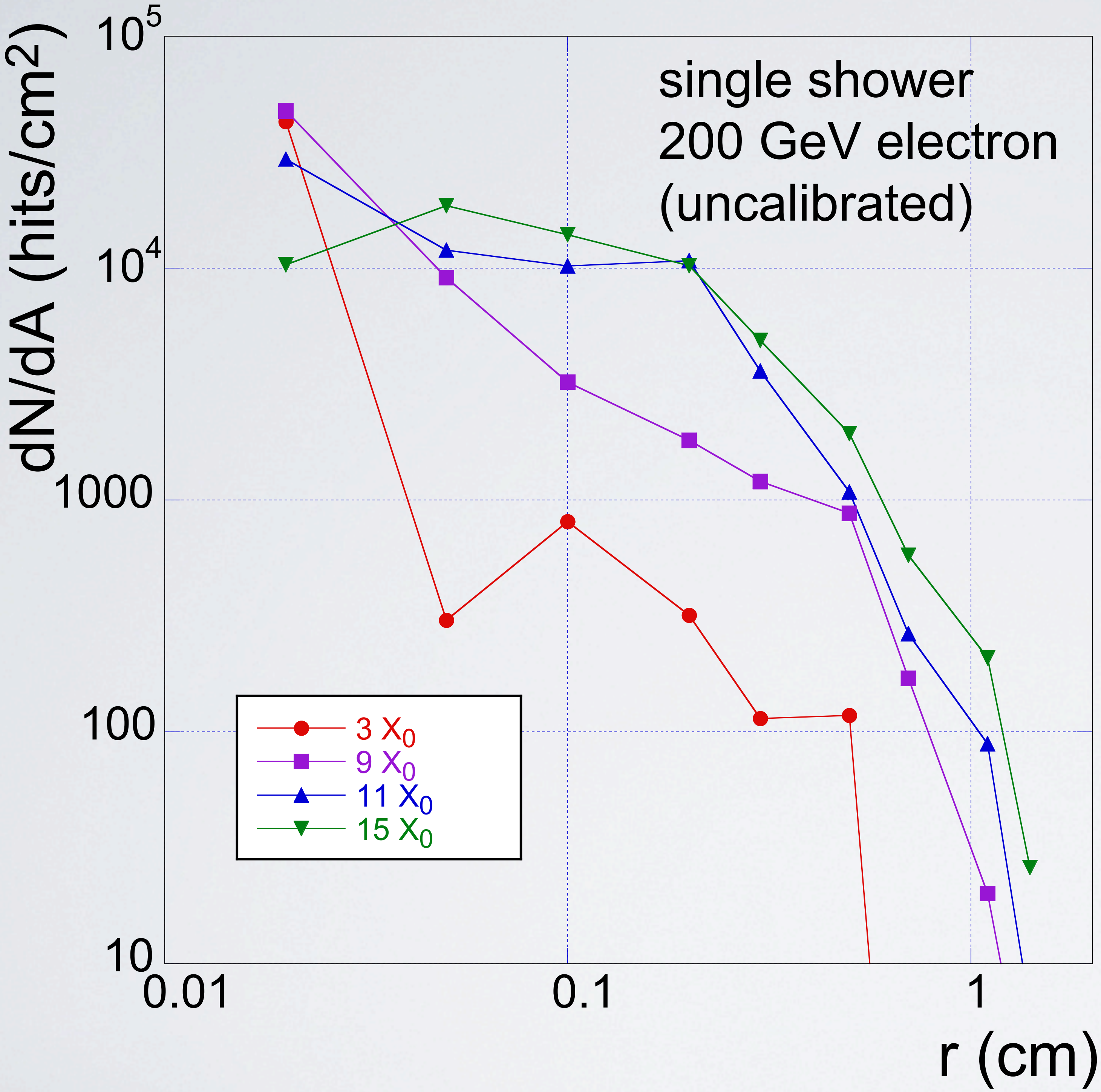
raw hit counts:
reasonable linearity and energy resolution

current resolution ≈2x ideal value from simulation

- more corrections under way
  - calibration (what level?)
  - alignment
  - dead chips/channels
  - particle ID
- energy resolution of fine layers does not limit full resolution of calorimeter



Shower Profiles



high granularity allows detailed measurements of shower distribution below the mm scale

narrow shower in front layers, significantly broadening during shower development

systematic studies require precise alignment

work in progress

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"