FoCal – An ALICE USA project for Run-4?

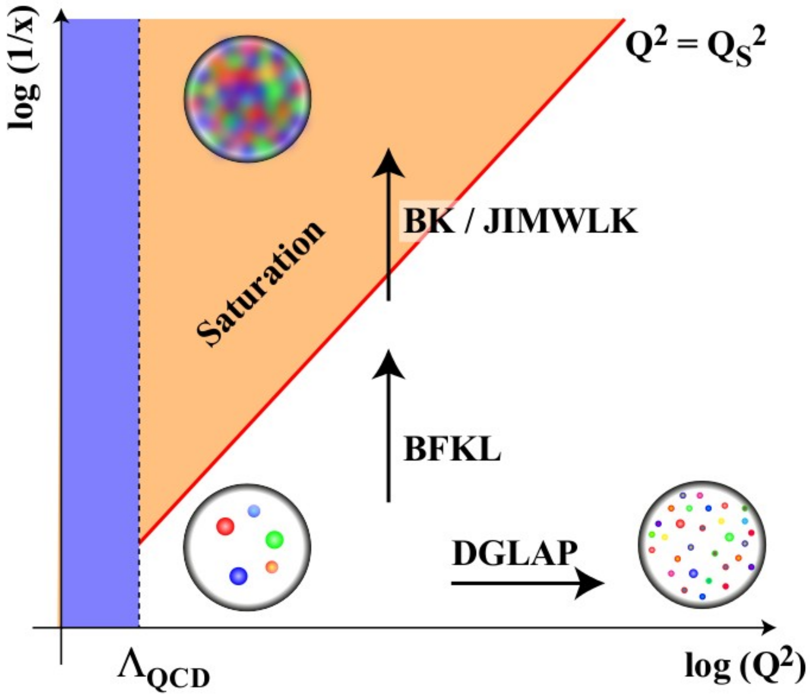
(C.L., 28.Nov.2018)

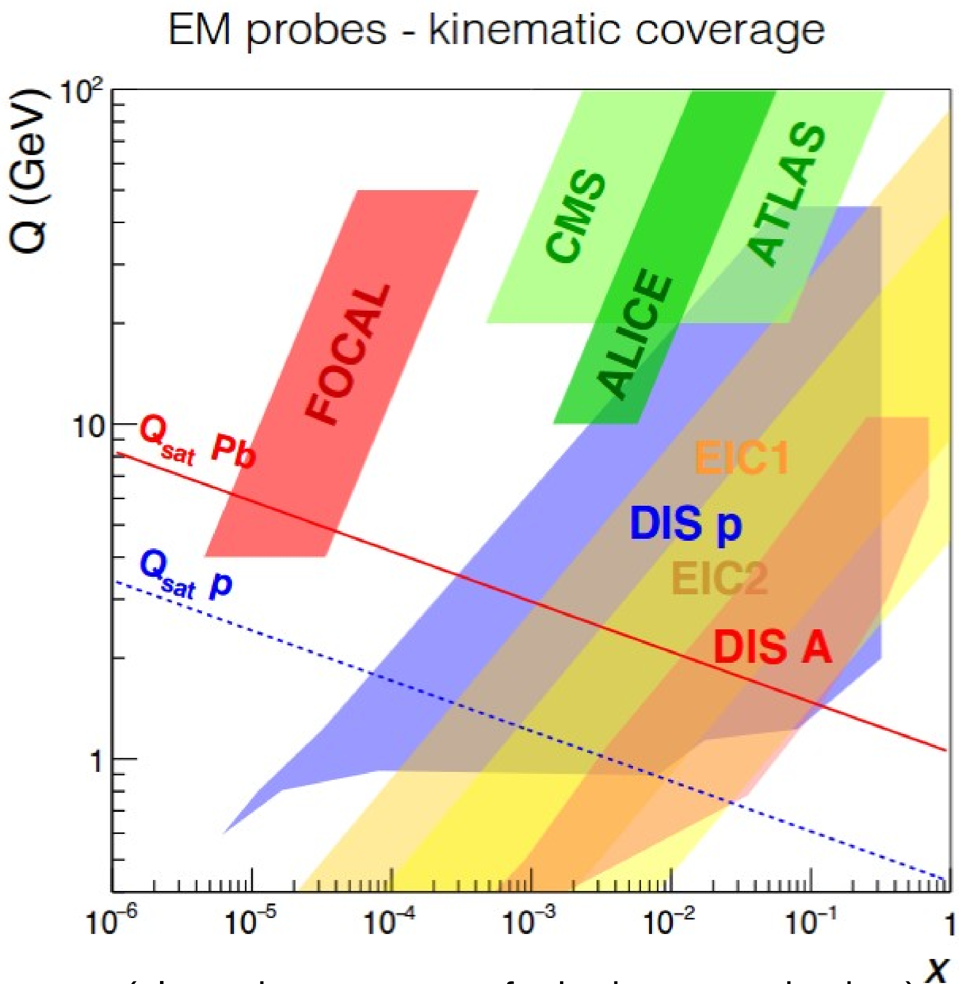
See slides from T.Peitzmann at ALICE Inda meeting Sep, 2018

FoCal as a bridge to the EiC

- By ~2020, Run-3 ALICE upgrades are completed; time to think about a new project targeting at the mid-20 range
  - For some, this is sPhenix, but not many of ALICE-USA groups have large hardware obligations
  - For some, this may already be the EiC, but given its overall timescale this is may be too early
- FoCal provides an excellent opportunity
  - Addresses (part of the) EIC physics case well before an EIC
  - Comes with the right time scale and scope; and new techology
  - DOE has questioned the benefit of gaining a factor 2 in Run-4 at the last meeting in August. FoCal could secure strong ALICE-USA support by DOE even in Run-4.

Main physics motivation for FoCal

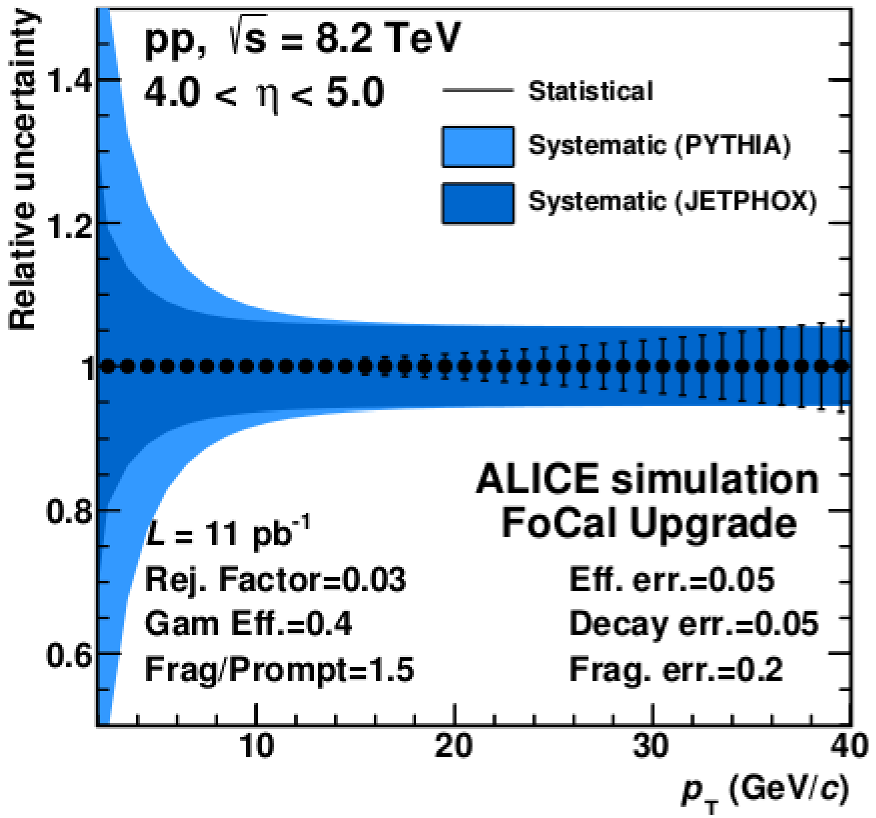


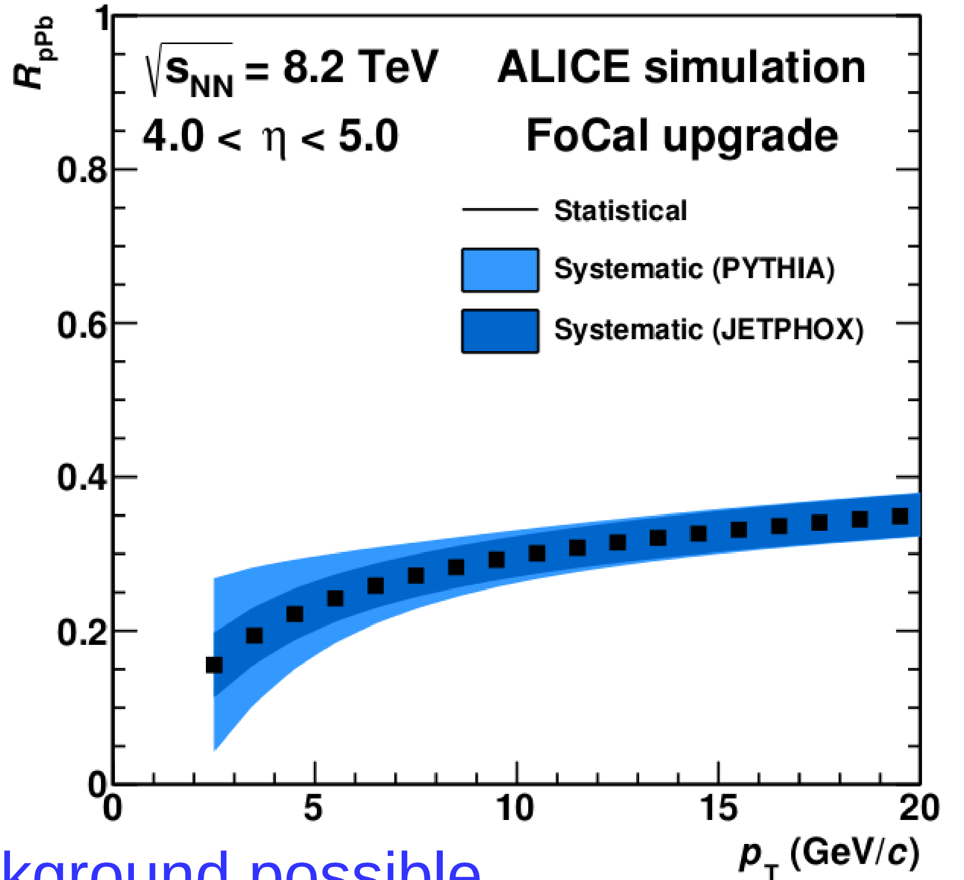


(also unique coverage for hadrons, see backup)

- Access gluon saturation region
  - Compare gluon saturation models with linear QCD
  - Show invalidity of linear QCD at low x
  - Constrain PDFs at low x
- Unique coverage for clean (direct photon) channels
  - At LO direct sensitivity to gluons (no fragmentation/final state bias)

Direct-photon performance



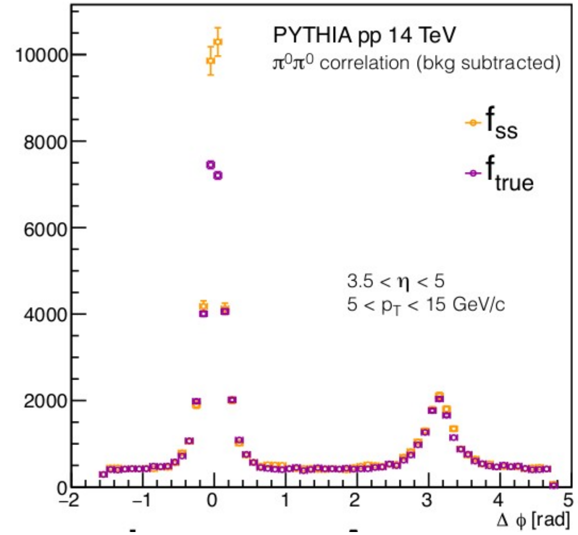


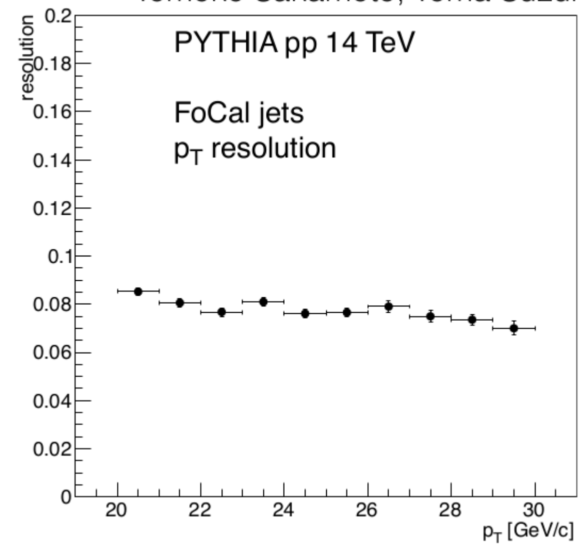
- About factor 10 reduction of background possible
  - Needs combined rejection (inv. mass, shower shape, isolation)
  - Requires high granularity
- Expected uncertainty <20% at p_T ~ 4 GeV, decreasing with increasing p_T
- → Improvement in PDF uncertainties by ~factor 2

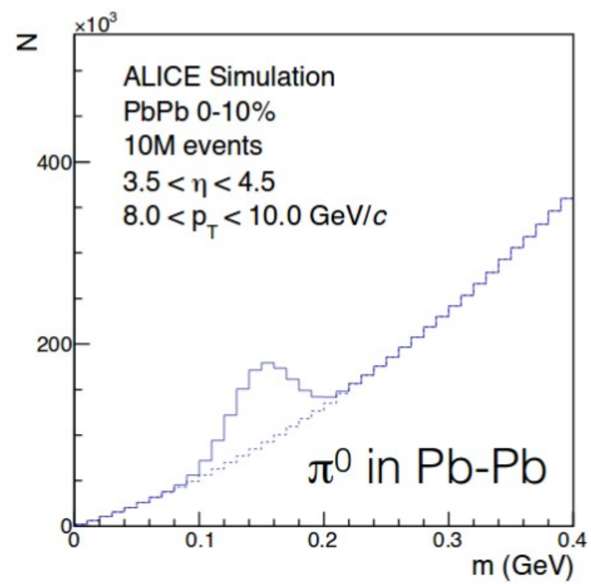
List of physics topics

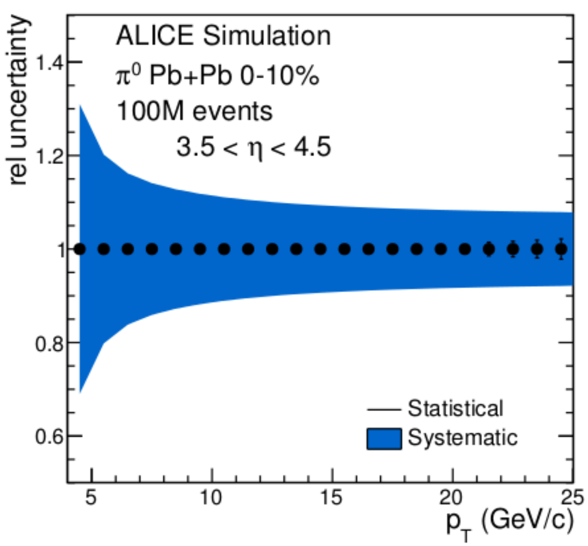
- Low-x physics
  - Direct photons
  - π^0-π^0 correlations
  - Di-jet correlations
- Ridge/flow phenomena in pp/pA
  - Fwd/mid correlations
- Jet quenching at large y
  - Neutral pion R_{AA}
- Reaction plane determination

Tomoko Sakamoto, Toma Suzuki

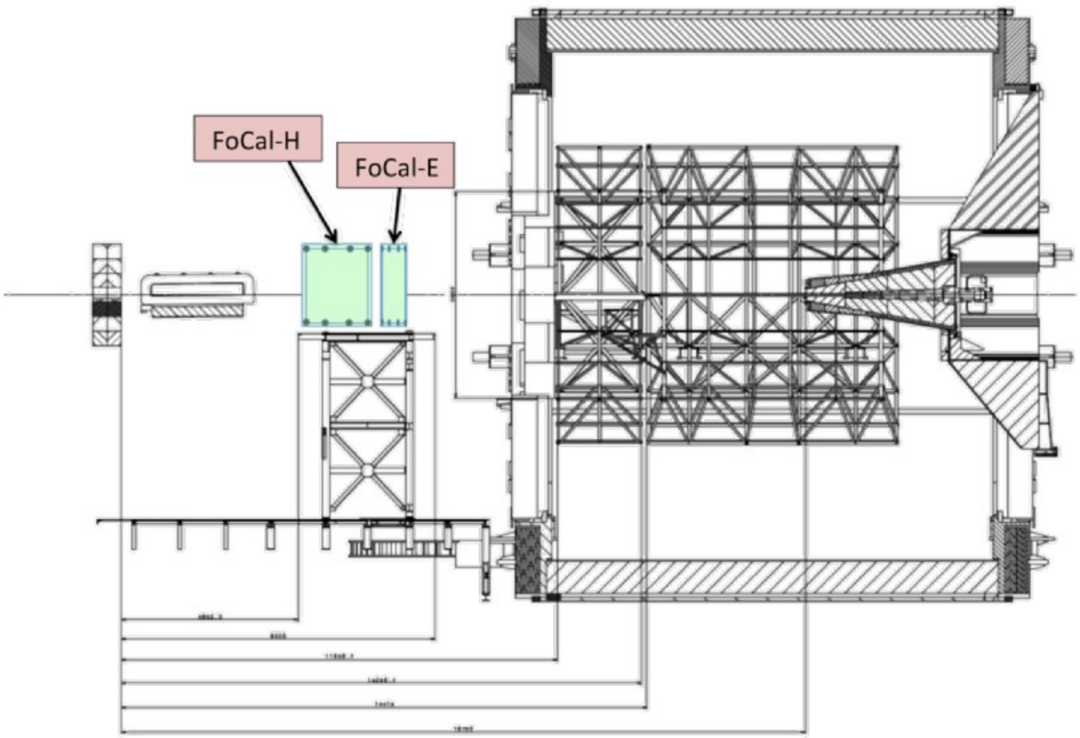








FoCal in ALICE



electromagnetic calorimeter for γ and π^0 measurement

preferred scenario:

- at $z \approx 7$m (outside solenoid magnet) $3.3 < \eta < 5.3$
- add hadronic calorimeter

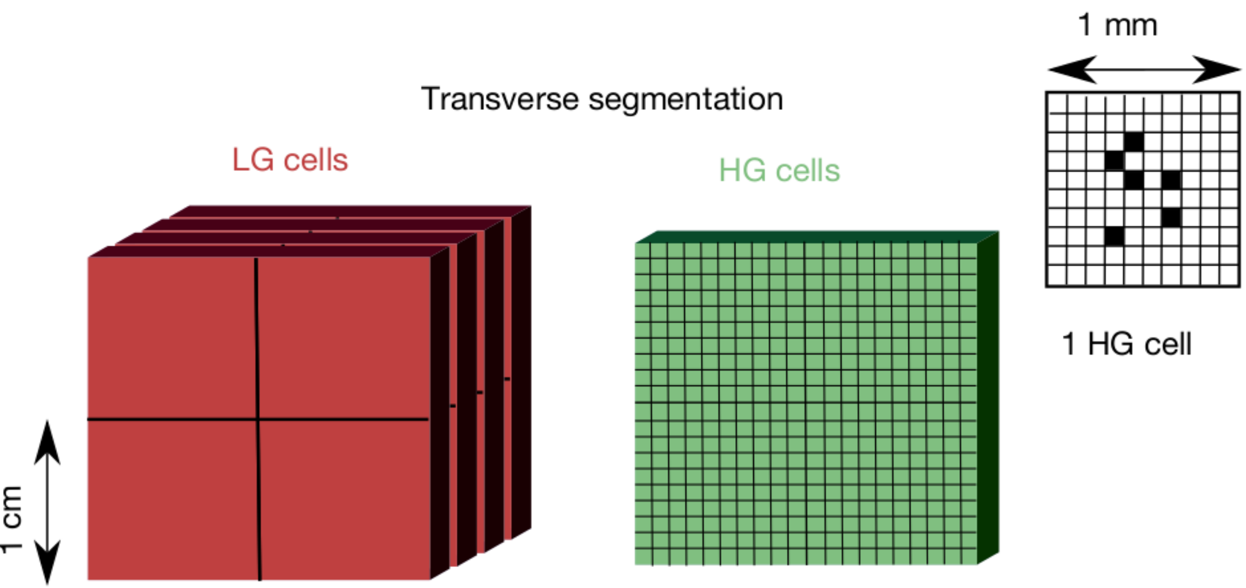
under internal discussion
possible installation in LS3

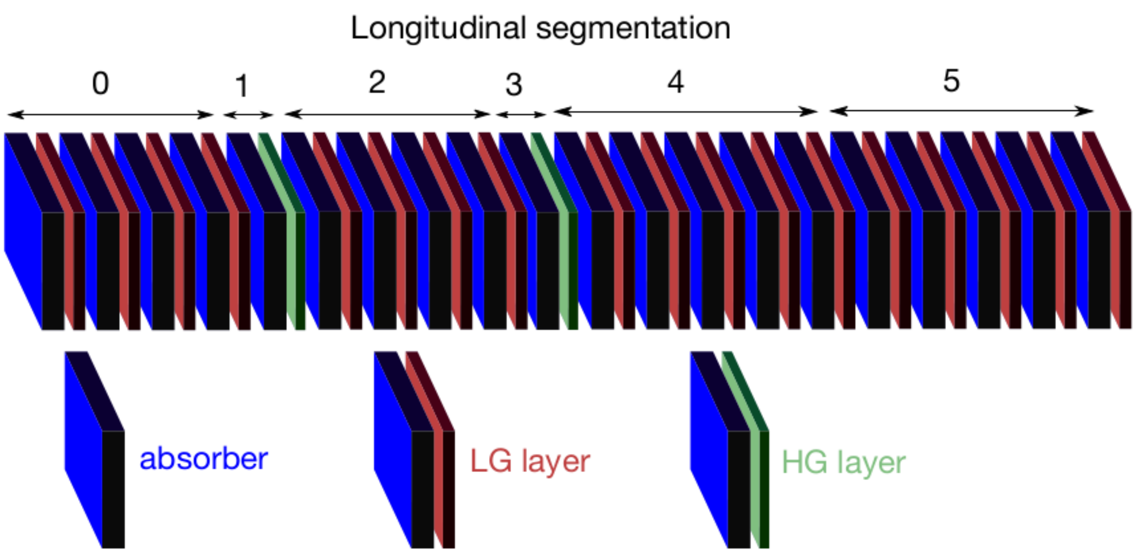
advantage in ALICE: forward region not instrumented, “unobstructed view”

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

note: two-photon separation from π^0 decay (p_T = 10 GeV/c, y = 4.5, α = 0.5) is d = 2 mm!

FoCal-E strawman design





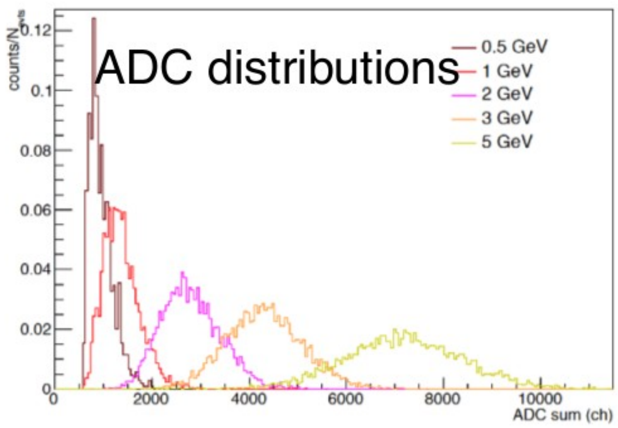
studied in performance simulations:

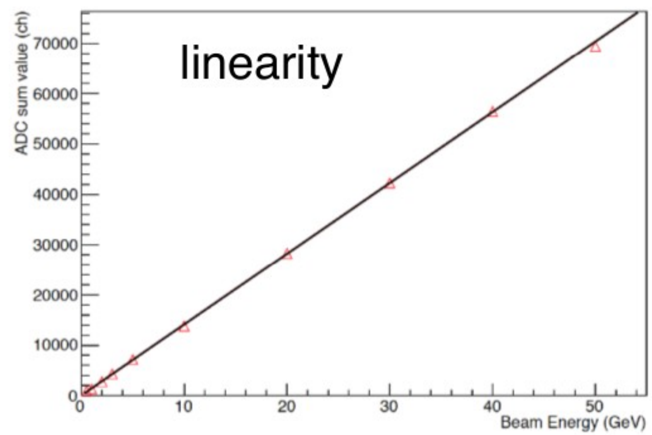
20 layers: W (3.5mm ≈ 1 X_0) +
Si-sensors (2 types)
low granularity (LG), Si-pads
high granularity (HG), pixels
(e.g. CMOS-MAPS)

	LG	HG
pixel/pad size	≈ 1 cm^2	≈ 30x30 μm^2
total # pixels/pads	≈ 2.5 x 10^5	≈ 2.5 x 10^9
readout channels	≈ 5 x 10^4	≈ 2 x 10^6

assuming ≈ 1m^2 detector surface

W/Si-Pad Test Beam Performance (LGL)





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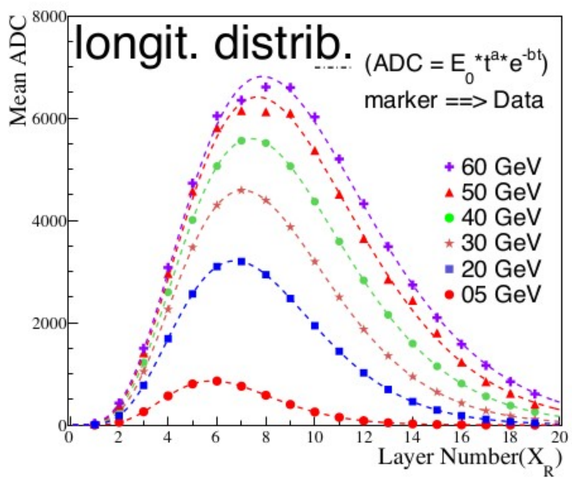
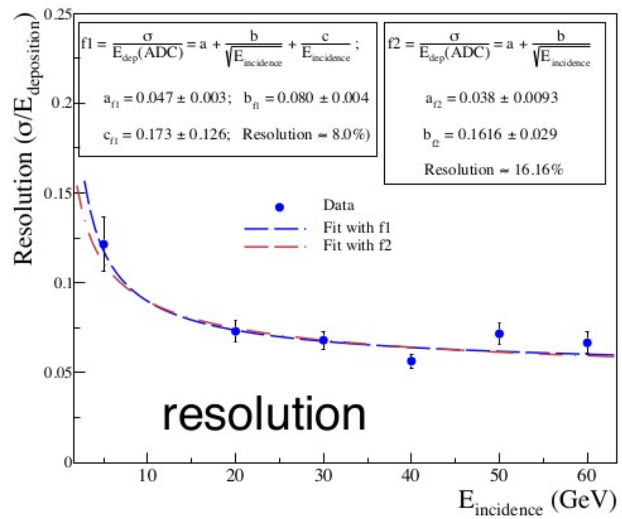
ORNL/Japan Pad prototype with APV/SRS readout





S. Muhuri

India Pad prototype with custom chip (MANAS/ANUSANSKAR)

test beam performance agrees with simulations
instrumental papers in preparation

(More info in attached EOI)

Current estimate of costs

	Cost (kCHF)
tungsten	700
unit mechanics	500
silicon sensors (pads)	2500
pad electronics	800
MAPS + electronics	2000
cables and connections	200
support + integration	1200
cooling	600
total detector cost	8500

Table 1: Project cost estimate for FoCal-E

	Cost (kCHF)
Pb plates	700
scint. Fibers + Diffuser	300
tools	150
APD + accessories	150
LED system + CR calibration	130
misc. electronics	100
packing/shipping	120
integration	350
total detector cost	2000

Table 2: Project cost estimate for FoCal-H.

Σ~10.5MChf (European accounting)

Main interested institutes/countries:
Netherlands, Japan, Danemark, Norway, India, Brazil
(possible commitment about 2-4MChf) → US contr. 10-15M$?

- Main open points:
  - Dynamic range for analog pad sensor front end (mod SAMPA or x2, time-over-threshold from CMS HGCAL, or ATLAS VMM)
  - ALPIDE for pixels need adaption for high occupancy
  - FoCal-H not really specified (iron/copper-scintillator sandwich with 2x2cm segmentation?)

Tentative timeline

2018?	Internal ALICE Approval
2018/19	Mini-FoCal Construction/Installation
2018/2019	LoI to LHCC
2020	TDR
2020/21	Chip design (MAPS, Pad Readout)
2021/22	FoCal Production
2023	FoCal Test Beam
2024	FoCal Installation

Current list of tasks (mostly design)

- PAD layers
  - Interested groups: Brazil, India, Japan
  - Select/develop analog readout technology. Four most likely directions:
    - SAMPA - would need dual gain setup
    - adopt HG-ROC from CMS HG-CAL
    - use VMM - x
    - design own or adapt existing design (e.g. from SAMPA, HG-ROC, ANUSANSKAR)
  - Decision about dynamic range/resolution
  - Evaluate cost for different options
  - Test 1 or more technologies?
  - Sensor design: have existing solution (Tsukuba/Hamamatsu)
  - Explore 8 inch wafers?
  - Readout design
  - Evaluate bandwidth/data rates/storage requirements
  - Thin PCB/flex substrate design + integration (minimise layer thickness; preliminary design exists: Tsukuba)
    - Option 1: readout ASIC in layer: tests for cooling/shielding
    - Option 2: readout ASIC at end of layer/slat; test for long signal paths
  - Cooling/thermal design
  - Power design
  - Mechanical design

- Pixel layers
  - Interested groups: Bergen, Netherlands
  - Evaluate bandwidth requirements; do we need a modified/high rate ALPIDE?
  - Readout design: need a form of on-board clustering/summing for data size? Evaluate bandwidth. (Bergen?)
  - Choice of substrate/cooling: flex cables or (thin) PCB? Preliminary design exists: (Nikhef/UU)
  - Mechanical design, cooling: preliminary design exists (Nikhef/UU)
  - Power circuit design (ITS solution expensive; too many independent channels?)

Current list of tasks (mostly design)

- HCAL
  - Full design needed:
  - Mechanics/construction of sensitive layers (metal/scintillator? Spaghetti/shaslick?)
  - Readout technology choice? Multi-anode PMTs? APV? SiPM?
  - Readout electronics and power

- Integration
  - Beam pipe design/discussion
  - (Re)placement of FIT
  - Support structure design
  - Integration of PAD and PIXEL layers and HCAL

- Trigger
  - Can we use the PAD layers? Do any of the technologies have trigger capabilities?
  - Can we run with a high-level trigger only; i.e. read out the detector with the heartbeat signal or with an interaction trigger and ship all data to HLT where we can do a cluster energy trigger in software?
  - Data rate for the pads would be something like 2 bytes with 200k channels and 1 MHz: 40 Gb/s to the HLT which I think it managable (total in ALICE will be ~1 Tb/s)
  - Other options? Separate summing/digitization for trigger?
  - Scintillator layers: poor energy resolution if have only one or two

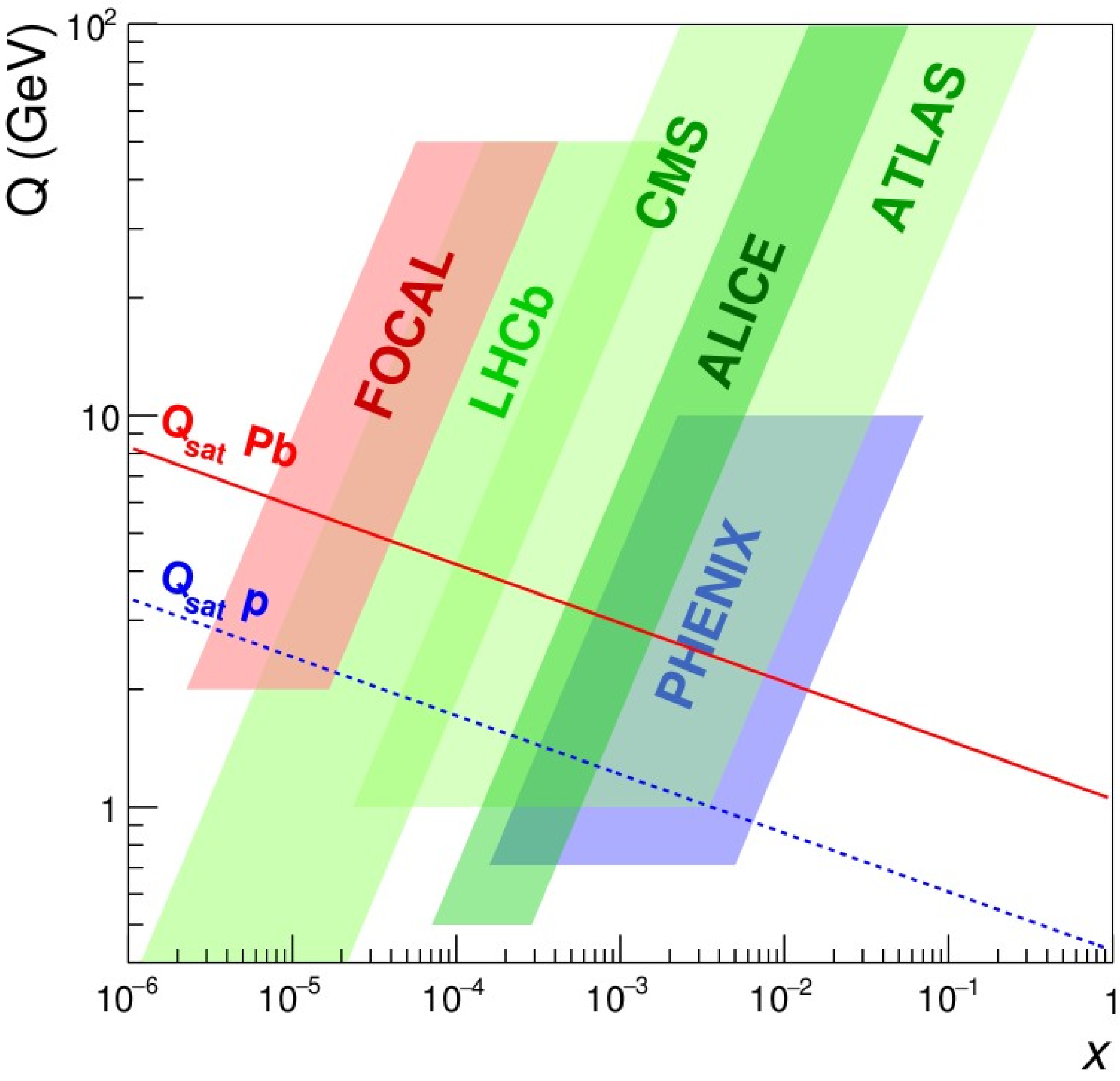
Tasks not yet well (precisely) defined and many/most open. Opportunity for us?

Summary and points for discussion

- FoCal has interesting physics potential and technology
  - Well aligned with NP-DOE programme, and path to EiC (both in physics as in instrumentation)
- After commissioning of BTU, ALICE-USA has no essential hardware commitments at LHC, and involvement in ALICE could in principle end after run-3. FoCal would secure our LHC efforts up to end of run-4.
- FoCal originated from ALICE-US and still today we would be taking a (the?) leading role
- Some points for discussion
  - Is there support from the council to explore FoCal as the future project with DOE?
  - If so communicate to DOE our desire to put together a technical proposal of 10-12M$

Extras

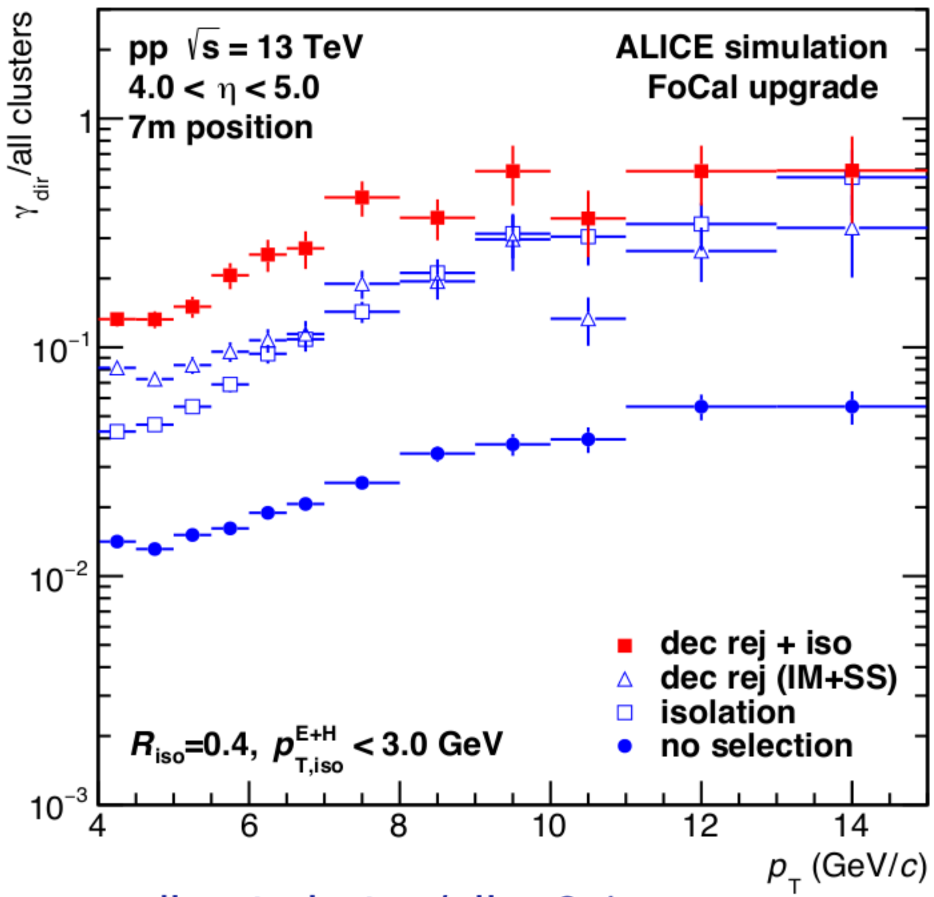
Hadron coverage



Direct photon performancw

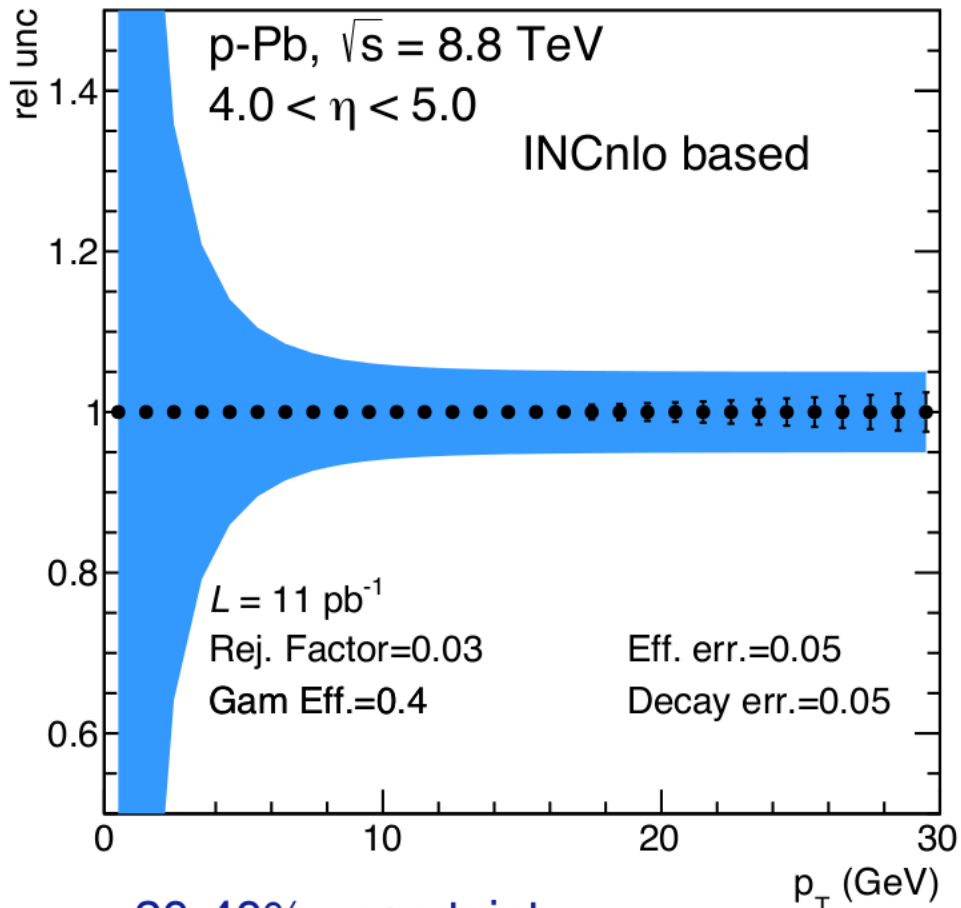
- combined rejection (invariant mass + shower shape, isolation)
- combined suppression of background relative to signal: factor ≈ 10
  - largely p_T-independent

Direct γ/all cluster ratio



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

Direct γ uncertainty



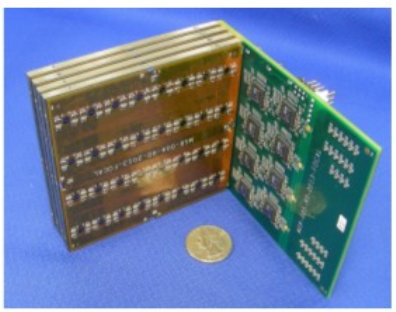
20-40% uncertainty
at p_T = 4 GeV/c
decreases with increasing p_T

LDRD SEED Fund R&D Project: Compact Calorimeter Module for Beam Test

Kenneth Read (PI), David Silvermyr, Terry Awes, Paul Stankus – ORNL Physics Division
Charles Britton, Bruce Warmack, Dianne Bull – Measurement Science & Systems Engineering Division

Project Objectives

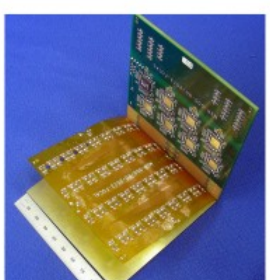
- To prepare prototype calorimeter module and novel associated readout ready for testing at accelerator test beam.
- First real-world use of new ORNL Application-Specific Integrated Circuit (ASIC) designed for next generation compact calorimetry in nuclear physics and Homeland Security.
- To test technologies proposed for a forward calorimeter subsystem upgrade for the ALICE Experiment at the CERN Large Hadron Collider in Geneva and the proposed sPHENIX Upgrade at the Brookhaven National Laboratory Relativistic Heavy Ion Collider.

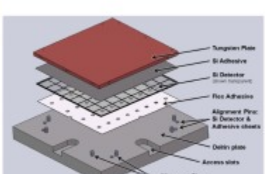


First of four segments of prototype module. Four tungsten plates are interleaved with silicon pad sensor layers. ORNL ASICs are located on (green) summing board on side of module (right). Beam direction is from upper left towards lower right.

Technical Challenges

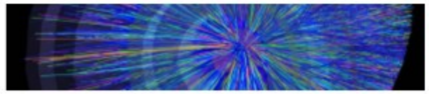
- Must measure and buffer energy deposition for each hit.
- Silicon sensors are fragile and must be handled and mounted without damage.
- The longitudinal periodicity is 6 mm with only 2.5 mm available per sensor layer.
- Signals must be summed and driven over a meter with low noise.





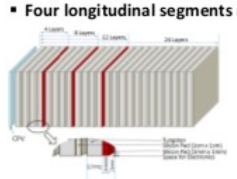
Left: Sensor layer flex board (yellow) and summing board (green) before assembly. Right: Construction design details.

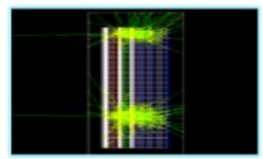
Approach



Collision of two lead ions at 2.76 TeV per nucleon pair measured by the ALICE Experiment.

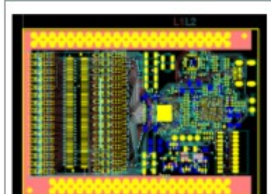
- Stack 2-D planar arrays of silicon sensor pads interleaved with tungsten absorber.
- Fine granularity: 8 x 8 sensor pads per layer, each 11 mm x 11 mm
- 8 custom 8-channel ASIC buffer chips per segment
- Signals from each of the 64 pixels from 4 successive layers in a segment are summed, buffered, and interfaced to new CERN Scalable Readout System.
- Four longitudinal segments result in 256 channels

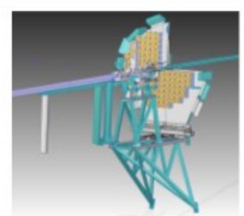




Left: Schematic drawing of complete prototype module. Right: simulated particle shower generated by incident beam from left.

Novelty

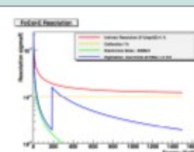




Left: Beetle hybrid chip. Right: Forward calorimeter system proposed for upgrade of ALICE Experiment at CERN.

- First use of new custom ORNL ASIC for use in readout of compact calorimeters for nuclear physics and Homeland Security
- Low-cost, fine granularity calorimetry
- Early adoption of new turn-key SRS readout framework.

Results



Simulated performance of a proposed forward calorimeter system.

- ALICE Experiment Forward Calorimeter Upgrade Letter of Intent
- sPHENIX Experiment Letter of Intent
- ORNL ASIC test data report in preparation
- Prototype calorimeter module testbeam results forthcoming

Table 2: Institutional responsibilities and contributions (preliminary).

Project Component	Participating Institution(s)
FoCal-E	
HGL sensors	Amsterdam, Bergen, Prague, Utrecht
HGL module	Amsterdam, Utrecht
cooling	Amsterdam, Prague, Utrecht
HGL readout	Amsterdam, Bergen, Utrecht
LGL sensors	Detroit, Knoxville, Kolkata, Mumbai, Oak Ridge, Prague, Tokyo
LGL FEE/TRG	Detroit, Knoxville, Kolkata, Mumbai, Oak Ridge, São Paolo, Tokyo
LGL modules	Detroit, Knoxville, Kolkata, Mumbai, Oak Ridge, Prague, Tokyo
slow control	Detroit, Kolkata, Mumbai, Prague, Tokyo
integration	Amsterdam, Detroit, Knoxville, Livermore, Oak Ridge, Prague, Tokyo, Utrecht
FoCal-H	
mechanics	Detroit, Knoxville, Livermore, Oak Ridge
photosensors	Detroit, Knoxville, Oak Ridge
FEE/TRG	Detroit, Knoxville, Oak Ridge
slow control	Detroit, Prague
integration	Detroit, Knoxville, Livermore, Oak Ridge, Prague

Back a few years ago, when running as a potential run-2 upgrade was very much ALICE-US project