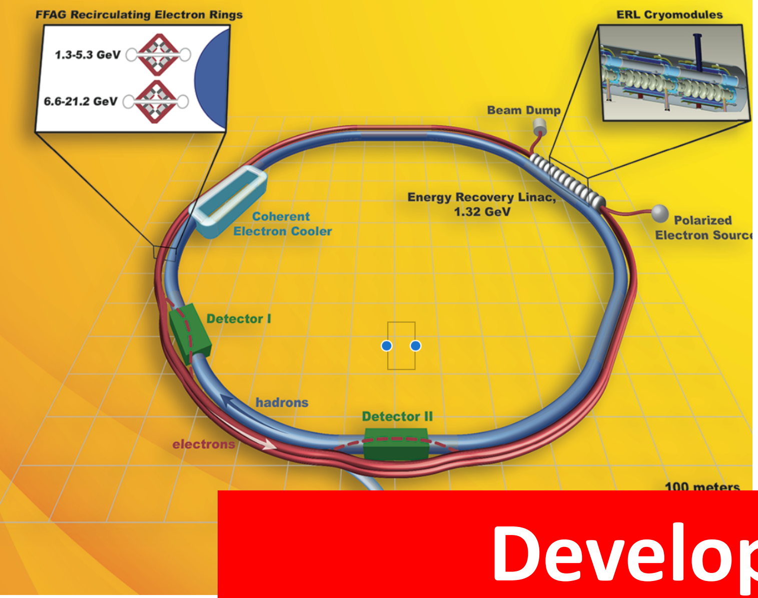
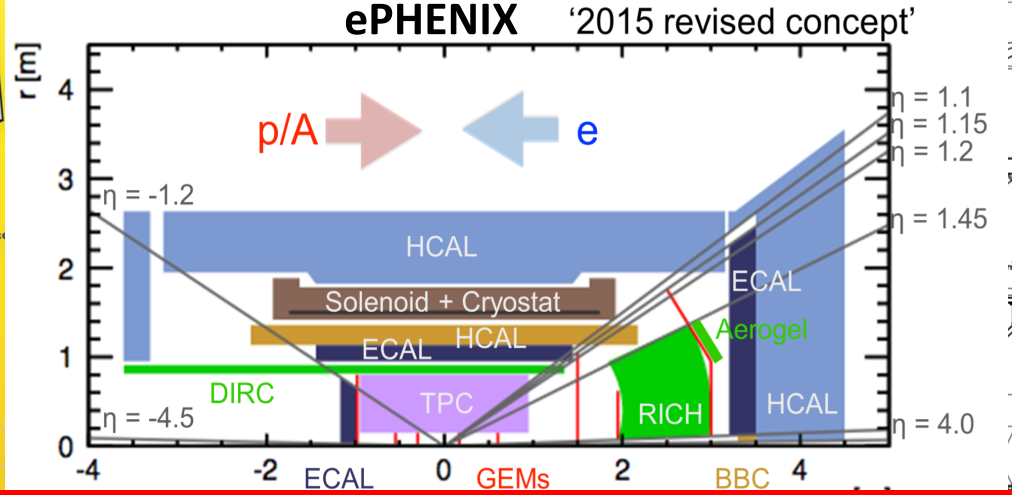
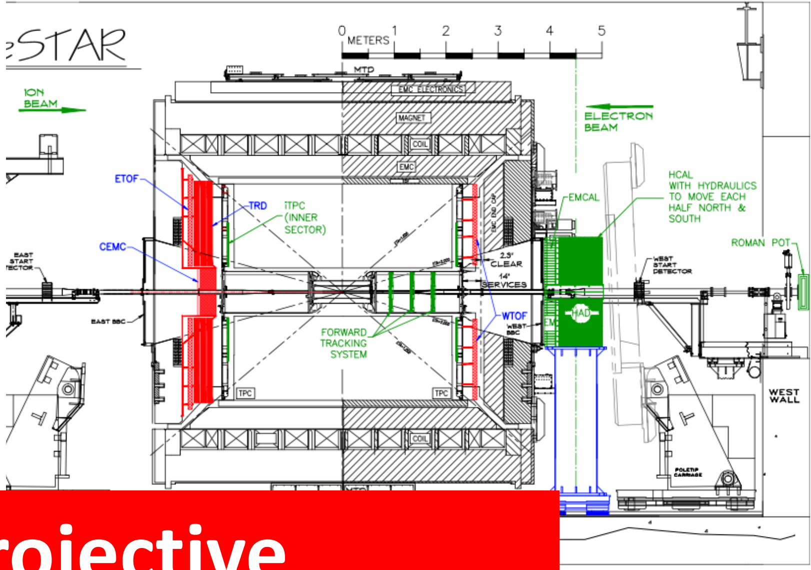
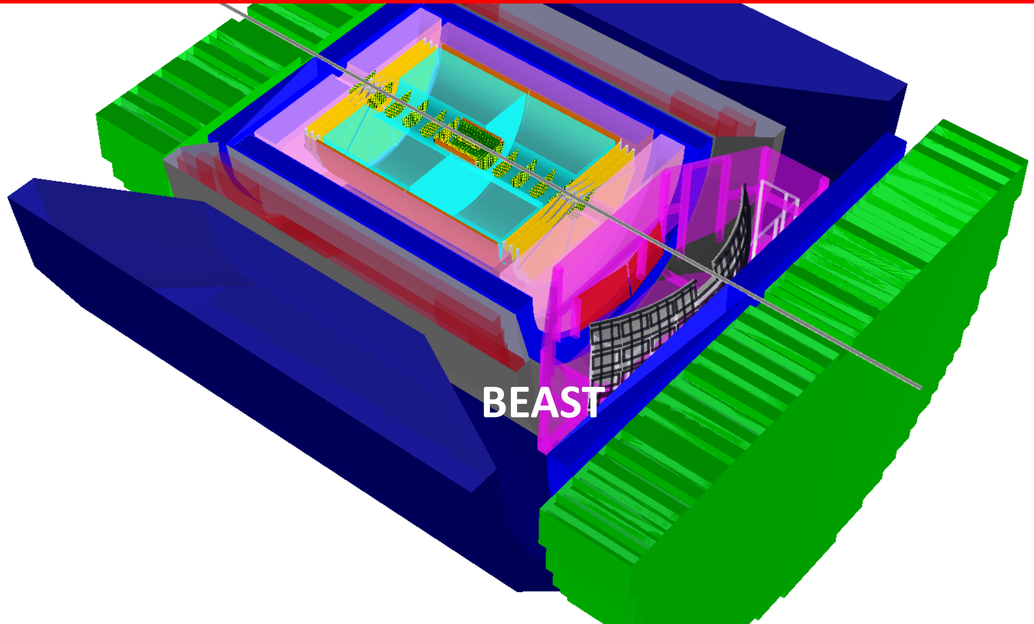






Development of the High Density Projective Shashlik EMCal for eIC Detector

BNL-UTFSM-IHEP-MEPHI-ISU



Principal Investigator
S.Kuleshov, UTFSM

Contact:
E.Kistenev, BNL

Background to proposal

The specifications for EM Calorimetry in central region of a barrel eIC detector are well established in Proposal for a dedicated eIC detector and were mostly driven by particle identification needs in SIDIS and DVCS events where all or nearly all particles in the final state shall be detected and identified.

The eIC program also includes the studies of hard processes with emphasis on identification of scattered participants resulting in jets in the central rapidity region.

The Central Electromagnetic calorimeters contribute to PId of hadrons (seeding, nature (hadronic), low momenta identification by ToF). They drive eId at the high end of momenta range (~10^{-2} purity) via E(calorimeter) vs P(tracking), photon pID (shower shape and isolation) and π^0 identification (shower shape and energy, impact mass estimate). Calorimeters are crucial to this physics, they are expensive and very difficult to upgrade – improving their economy and performance now will certainly pay off with high quality physics data later.

It is simply too premature to finish the efforts to improve the economics or performance of major component of the future experiment that "many" years before the experiment will hopefully be running. In few years since eIC got high on list of NP priorities the technology and component base have changed dramatically and we need to take advantage of these developments. This is what is our proposal about.

Optimization: boundary conditions

- **Full depth not to exceed 20cm;**
- **Full absorption for electromagnetic showers with energies up to 20 GeV ($20X_0$);**
- **Electromagnetic energy resolution better then 12% at 1 GeV;**
- **Two gamma separation matching π^0's with momenta up to 20 GeV/c at 1m radius (R_m ~1.5cm, optional);**
- **Compact calorimeter shall be a great timing detector (ToF resolution better then 0.5ns);**
- **Tunable and upgradable granularity (rapidity and/or funding dependent);**
- **Ease of industrialization (no waste, no environmental problems);**
- **No external storage/support structures;**
- **Fits all budgets ….**

The only known and tested solution able to match this list is Shashlik invented in 1980's. It is certainly not fancy – everyone knows how to make one even in his back yard. But there are now many shashlik detectors which are quietly taking data in Lab's over the world and there are close to dozen of similar Projects in construction or approval stages. There should be the reason to such popularity and they are in the list above.

Bits of history

Labarga L. and Ros E., **MonteCarlo Study** of the Light Yield, Uniformity and Energy Resolution of Electromagnetic Calorimeters with a Fiber Readout System. **Nucl. Instr. andMeth. A249 (1986)228 – amazing uniformity**

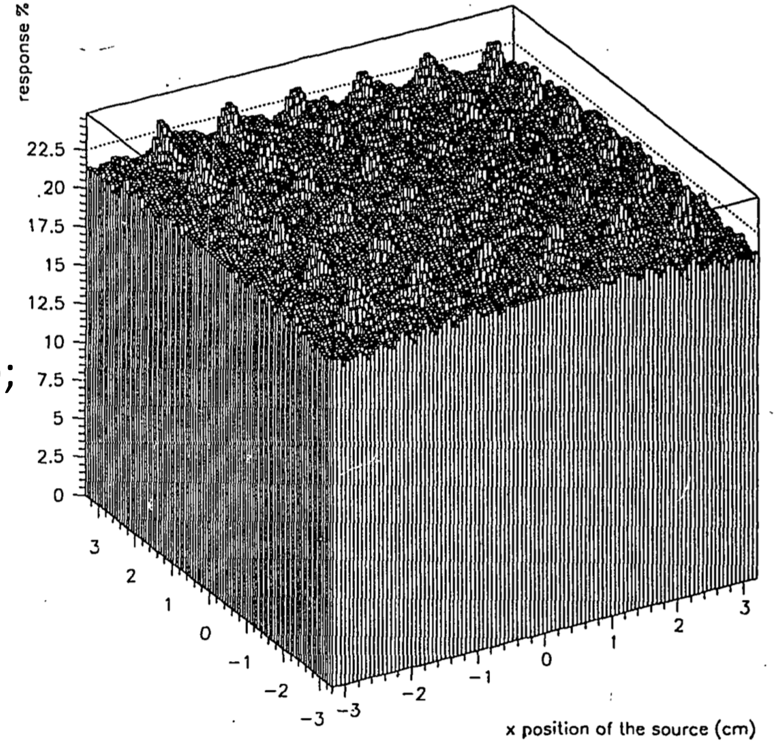


Fig. 2. Light response.

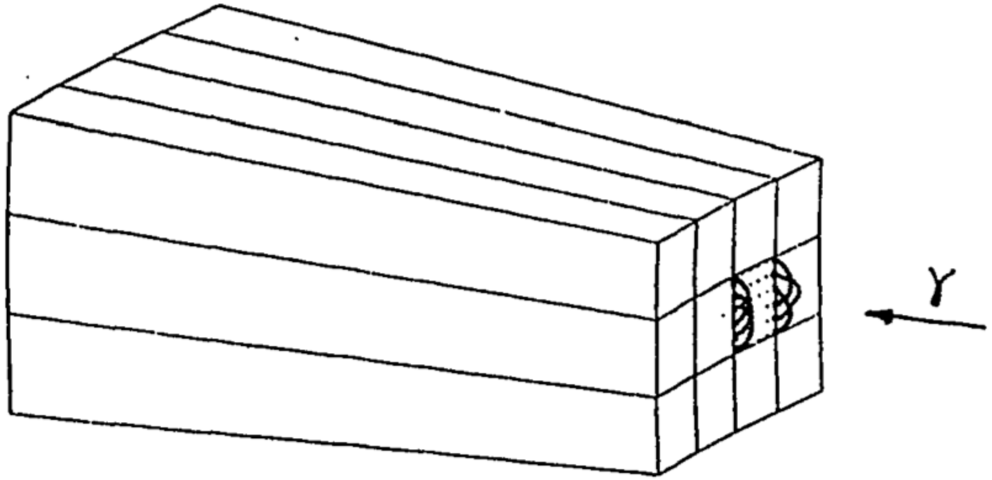
1991 – first INR made Shashlik prototype is tested for MMS experiment at AGS (BNL);

1992 – first IHEP made Shashlik prototype is tested for PHENIX at AGS (BNL);

1993 – Shashlik is approved for PHENIX (~**50 m² of coverage**)

1994 – Shashlik with projective geometry is proposed for CMS

Fig. 1. The prototype of the calori- meter SHASHLIK.



Optimization: absorber, technology and complexity

Material Id	Mix	Composition	Density [g/cm3]	Lrad [cm]	Rm[cm]	Lint[cm]	Lint/Lrad	20 X0 [cm]	Comment
W			19.3	0.35	0.93	9.54	27.3	7.0	
Pb			11.34	0.56	1.62	16.8	30.0	11.2	
Cu			8.93	1.44	1.64	15.16	10.5	28.8	
Sc			1.03	45.4	9.73	74.83	1.6	908.0	Physical propeties of epoxy assumed similar
W80Cu20	weight	80/20	15.66	0.48	1.06	10.97	22.9	9.6	Nearly x3 reduction in price compared to W
W-Sc-Ep (BEAST/sPHENIX)	**volume**	**50/25/25**	**10.15**	**0.69**	**1.61**	**16.92**	**24.5**	**13.8**	**Powder EMC has only 25% of Sc, the rest is epoxy**
W80Cu20-Sc (this prop.)	**volume**	**50/50**	**8.33**	**0.94**	**1.86**	**19.13**	**20.4**	**18.8**	
Pb-Sc	volume	50/50	6.17	1.11	2.55	27.44	24.7	22.2	
Pb-Sc (PHENIX)	volume	33.3/66.7	4.45	1.64	3.27	34.79	21.2	32.8	

- BEAST and ePHENIX do show ~20cm radial space reserved for EM Calorimeters;
- With very similar designs both BEAST and ePHENIX will have only ~60% efficiency of space use (active media depth is 12 cm);
- Epoxy in the detector keeps it solid but it uses the space and degrades energy resolution by reducing SF (~sqrt(2));
- Both BEAST and ePHENIX detectors plan to use novel silicon photomultipliers and old fashioned light collection scheme (plastic light guides, very ineffective).

<u>This Proposal:</u>

- **Cheap and easy to machine absorber of W80Cu20 alloy used in electrochemistry (any shape and form on Internet);**
- **Injection molded scintillating tiles. Single clad WLS fibers ~1mm diameter;**
- **One per fiber cheap ~1.5mm^2 SiPM's (compare to $8.5 per 9mm^2 SiPM quoted by Hamamatsu to sPHENIX)**
- **Fiber (SiPM) density ~1/cm^2;**
- **Readout density (and light collection!!!) 1 channel/cm^2 or lower (by passive gangling of SiPM's)**

Confirmation: parallel approach

arXiv:1605.09630v1 [physics.ins-det] 31 May 2016

A compact light readout system for longitudinally segmented shashlik calorimeters

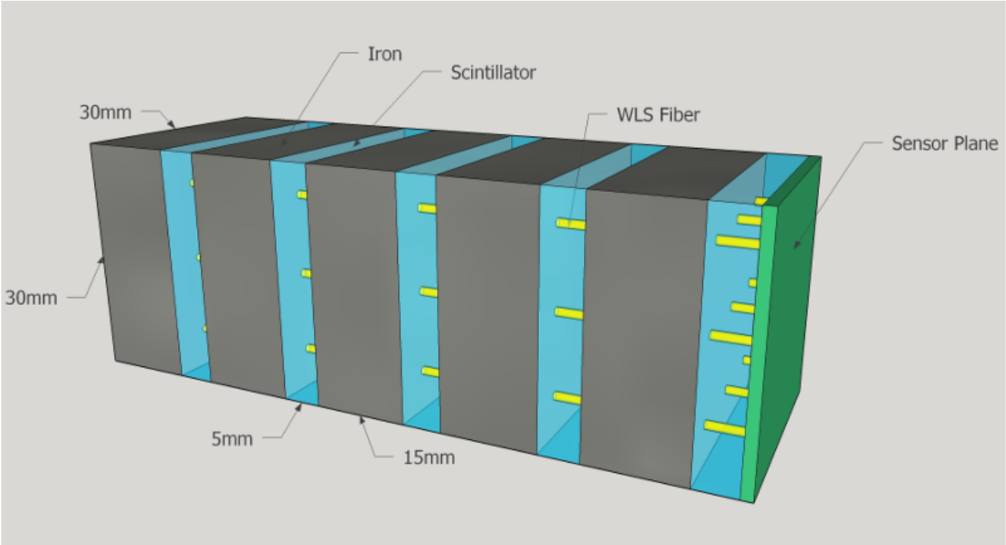
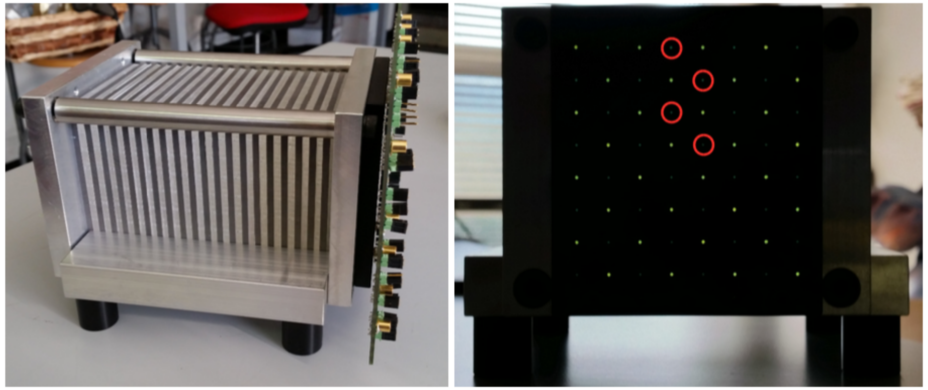


Figure 1: Schematics of the ultra-compact module that is being developed by SCENTT. The module corresponds to a 4 X_0 sampling and a transverse granularity of 3×3 cm^2 (9 fibers per module).

each module consists of 8×8 cm$_2$ tiles of lead interleaved with plastic scintillator. The thickness of both the lead and scintillator tiles is 3.3 mm and each module groups 20 (lead) + 20 (scint.) tiles. The depth of the module corresponds to ~ 12 X_0

of different lengths to sample different parts of the shower and improve the e/π discrimination capability. The energy resolution obtained with this readout scheme ($13\%/\sqrt{E(GeV)} \oplus 3\%$) is comparable to the standard fiber bundling readout and, therefore, the new compact scheme with the photosensors embedded in the bulk of the calorimeter fully retains the performance of the device. Deviations from linearity were observed at beam momenta > 4 GeV/c and are attributed to the limited dynamic range of the SiPMs used in the test. At 98% electron efficiency, the sample purity increases from 91% to 95% when employing both long and short fibers for electron identification.



(a) (b)

Figure 2: Picture of the first module of the calorimeter prototype (a); close-up on the WLS fibers (b) and the long/short alternated pattern: short fibers (some of them highlighted with red circles) are less bright than long ones due to the different ambient light collection efficiency.

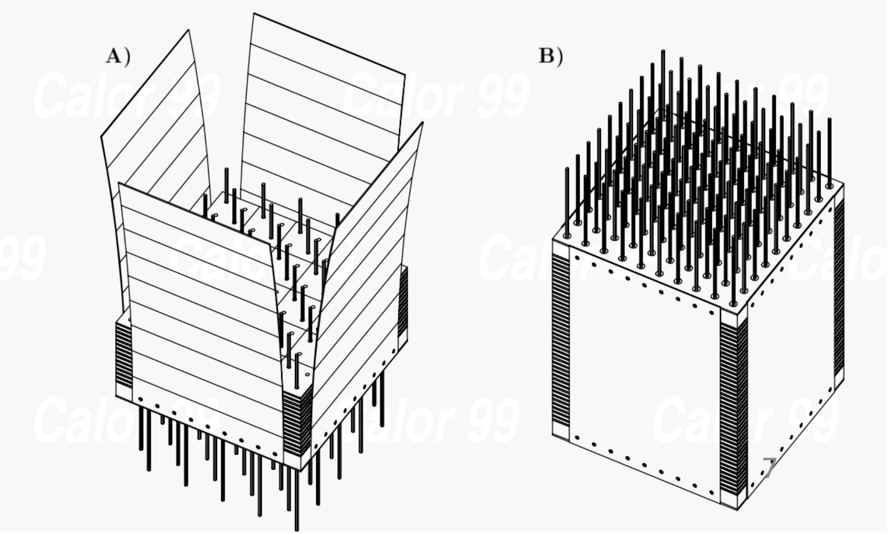
$X_0 \sim 1.1$cm, SF ~ 6%

Proposal goals: design, prototype and research

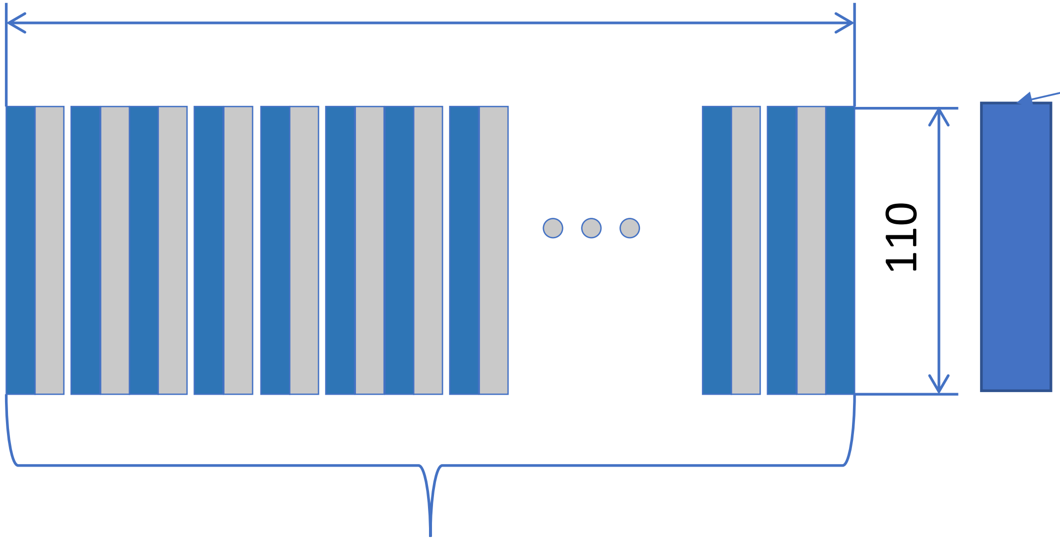
Milestones:

- **Technological prototype (2018)**
  - On-shelf availability of components;
  - Market analysis;
  - Mechanical design;
  - Assembly technology & experience;
  - Readout;
  - Cosmics test bench measurements.
- **Projective prototype and G4 model (2019)**
  - Construction experience;
  - Industrialization;
  - Response uniformity around fibers, in the corners and on boundaries;
  - Test beam measurements;
  - G4 & Beam data projections for improved tile geometry.
- **Projective prototype with improved response uniformity (2020)**
  - Injection mold modifications;
  - Prototype rebuild with new tiles;
  - Test beam and conclusion

Depending on funding and on-shelf component availability at participating institutions the design will be based upon modules of ~180mm depth with lateral sizes in the range of ~38x38mm^2 (3 x L_m) and 110x110mm^2 each with fiber density ~1/cm^2 .



2018: Technological prototype eIC Shashlik module (KOPIO brand tiles)



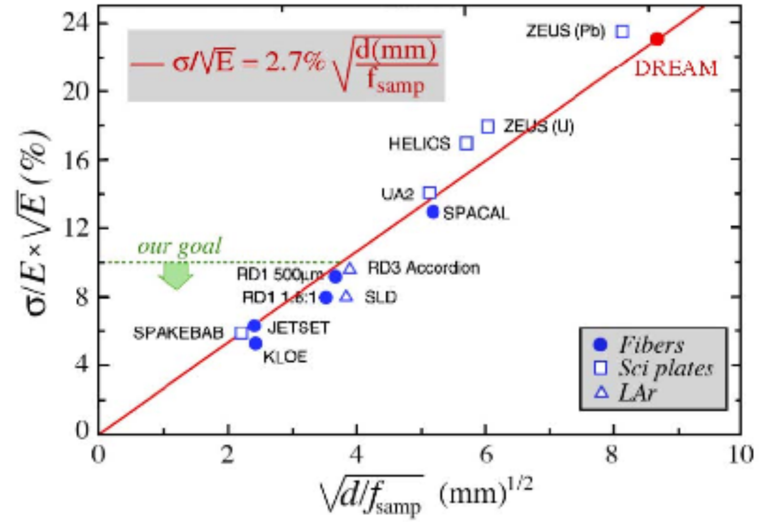


Fig. 3. Electromagnetic energy resolution as a function of sampling fraction, for various non-gaseous calorimeters. This figure is taken from R. Wigmans presentation at CALOR2010, see also ref. [1].

20 X0 prototype calorimeter

60 W80Cu20 1.5 mm plates and 60 1.5 mm scintillator plastics

Active depth	180mm
Surface area	110x110 mm^2 (preferred option)
WLS fibers:	up to 144
Average density	8.33 g/cm^3
Sampling fraction	~6-8% (depending on dE/dx)

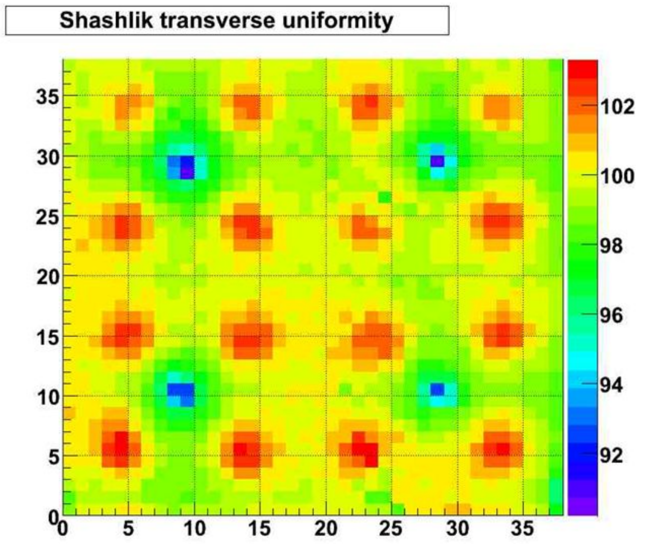
Expected energy resolution

Wigmans: **σ/√E ~ 12% +3%(constant term)**

G4 simulation: **σ/√E ~ 10%**

2019-2012: Projective prototypes with improved response uniformity.

- **We expect that measurements with technological prototype will indicate ~10% nonuniformities in light collection efficiency with maxima and minima at fiber locations and corners;**
- **This simple picture may change along two affected edges when module is "shaved" on two sides for assembled detector to match barrel shape.**
- **The G4 detector model incorporating all currently known and assumed aspects of module mechanical construction and optical coupling to photon detectors (WLS fibers) will be created (IHEP, Protvino and INR, Moscow both have related experience);**
- **Two new "shaved" 180mm blocks built following the technology developed and tested while working with technological prototype will be built using constant thickness scintillating tiles and exposed to the beam of electrons (2019);**
- **G4 simulation and response profile measurements will be used to design and implement "profiled" tiles (thickness varied with local response) to design out the residual nonuniformities while tuning the Monte-Karlo.**



Detector physics with prototype calorimeters

We propose to read every fiber in prototypes through separate readout channel (2x2mm^2 SiPM's with ~20k pixels per device).

Single fiber readout as Pid tool:

- As such the detector becomes an effective shower shape measuring tool (~9cm^2 of calorimeter area occupied by tipical shower are viewed by 9 fibers) with data sufficient to resolve narrow shower core.
- The confluence of a short Rm and high density readout shall deliver unparalleled shower-to-shower separation power and lateral shower width measurements and remove the need in expensive and complicated preshower and shower maximum devices.

High resolution impact position measurements with Single Fiber Readout

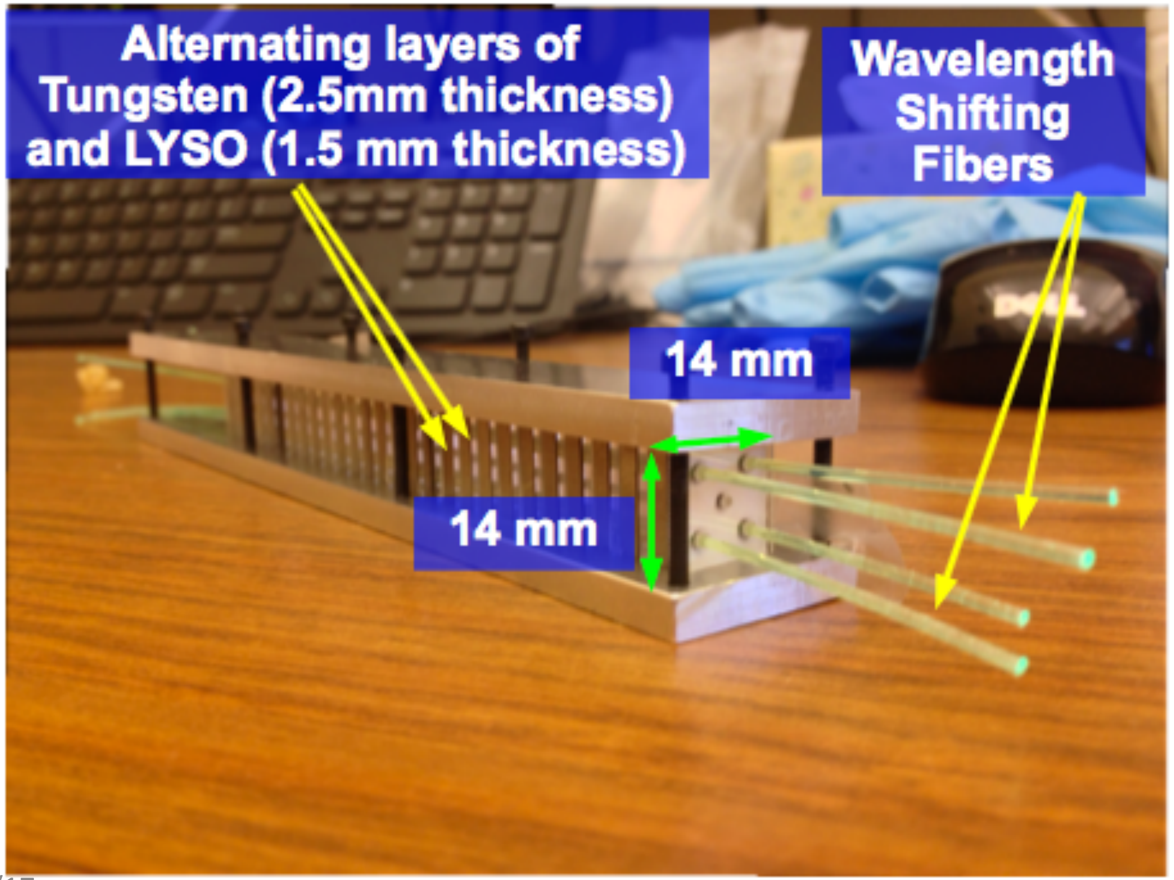
Single fiber readout as timing tool

- As a rule timing resolution of even the smallest electromagnetic calorimeter with scintillators is very difficult to make better then 0.5ns. The limit is set by spatial fluctuations in shower development resulting (fluctuations in signal arrival time on photon detector) and decay properties of scintillators.
- The single fiber signal in proposed calorimeter is saturated by light produced in a circle with area ~1cm2 which contains the shower core and only minimally affected by geometrical fluctuations (fiber-to-hit distance < 0.5cm). We believe that we may see the signs of such behavior in recently published data from W-LYSO Shashlik calorimeter.

Timing with Shashlik

FERMILAB-PUB-16-176-PPD
ACCEPTED

Precision Timing Calorimeter for High Energy Physics



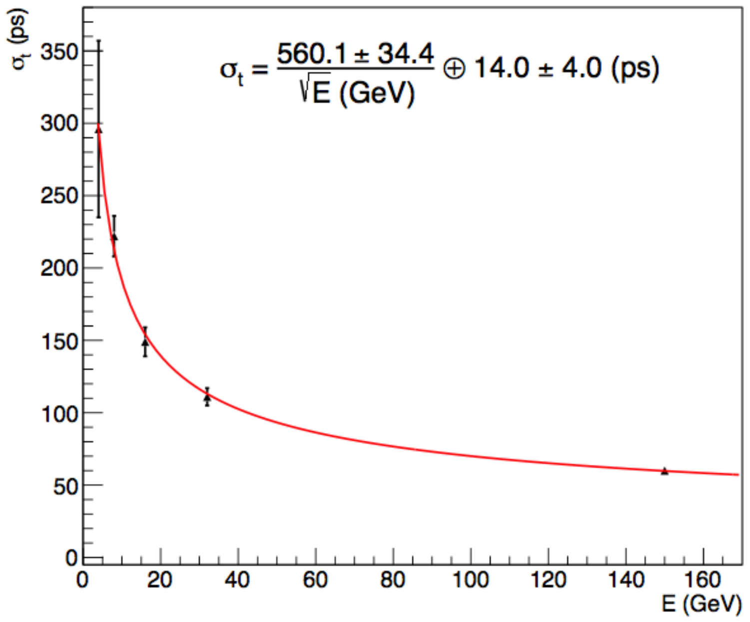


Fig. 7. The time resolution measured using the LYSO-tungsten shashlik calorimeter with light extracted using DSB1 wave length shifting fibers is plotted as a function of the electron beam energy, and fitted to a $1/\sqrt{E}$ functional form, with E in GeV.

Summary: why eIC shall fund the development of Shashlik

- **It conforms and exceed eIC performance specifications in what concerns energy resolution;**
- **It allows for a deeper (in terms of X0) calorimeter in available space;**
- **It offers tunable granularity (vs rapidity) if so desired;**
- **It offers improved position resolution for anything showering in calorimeter;**
- **It offers improved timing resolution based on shower core measurements;**
- **Its readout can be located downstream. An experience with SBND Veto system indicates that with proper selection of biasing/cabling the preamplifiers could be located more then 1m away from SiPM's removing needs for in-situ cooling at SiPM locations;**
- **It can easily be matched to any predesigned support structure;**
- **We have at least 100 years of combined experience in building Shashlik calorimeters in our Collaboration;**
- **It can be built on the budget. We have a team.**

Funding request (2018-2020)

Year	Request to eIC	Potential Team Funding	Total
2018	81	67	148
2019	34	63	96
2020	30	17	47
Total	**145**	**145**	**290**

Machining K$	Equipment K$	M&S K$	Manpower K$	Travel	Source Team / eIC
44	40	63	66	77	290(145/145)

eIC Funds Allocation (money matrix) 2017-2020 (k$US)

	Technological prototype and Assembly Laboratory (at UTFSM)	Geant4 simulation	Prototypes	Cosmic ray facility (in UTFSM)	Test beam experiment and related analysis	Total for each institution
UTFSM	31	4	9	20	5	69
IHEP	0	2	1	0	0	3
MEPHI	0	2	0	0	2.5	4.5
ISU	0	2	0	0	2.5	4.5
BNL	20	4	7	7	26	64
Total for subproject	51	14	17	27	36	145

Members of our team are currently applying to funding agencies in their respective countries for grants which will include funds to cover their contributions to this Proposal.

In general funding agencies in different countries follow the reciprocity principle in fund allocation. Grant requestors in international Projects are expected to show a certain (equal or larger) support level on part of host Country/Institution (major contributor to Project is FONDECYT grant to Detector Laboratory at UTFSM in Valparaiso, Chile).

20% underfunding on part of eIC will direct us towards building smaller, less efficient modules and at worst cause ~6 month delays in prototype's readiness for beam testing in 2019.

40% reduction may trigger disproportional reductions to Institutional contributions and have a major adverse effect on the Project.

The End