THE REDTOP EXPERIMENT:

*R*are *E*ta *D*ecays with a *T*pc for *O*ptical *P*hotons

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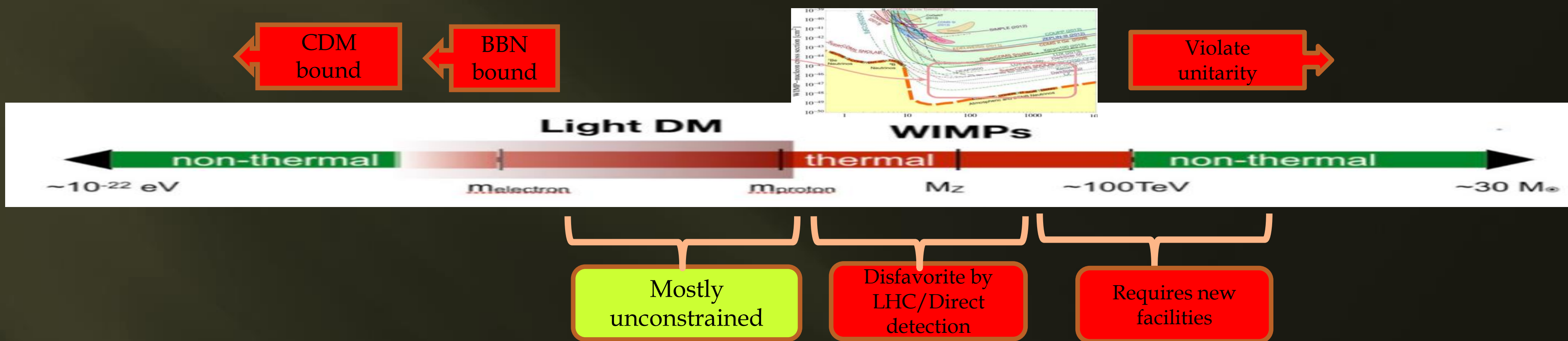
On behalf of REDTOP Collaboration

REDTOP Quest for BSM Physics

An η /η' factory with 10^4x world statistics searching for discrepancies in the Standard Model at the 1 GeV energy regime with couplings at the level of 10^{-8}



Main Physics Goals

- *CP Violation via Dalitz plot mirror asymmetry: $\eta \rightarrow \pi^o \pi^+ \pi^-$*
  Search for asymmetries in the Dalitz plot (also J. Shi & S. Gardner talk in H11)
- *CP violation via γ^* polarization studies: $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ and $\eta \rightarrow \pi^+ \pi^- \mu^+ \mu^-$*
  Measure the angular asymmetries between the $l^+ l^-$ and $\pi^+ \pi^-$ planes

Not bound by EDM

- *Dark photon searches: $\eta \rightarrow \gamma A'$ with $A' \rightarrow e^+ e^-$*
- *Dark scalar meson searches $\eta \rightarrow \pi^o H$ with $H \rightarrow e^+ e^-$ and $H \rightarrow \mu^+ \mu^-$*

Detecting BSM Physics with REDTOP (η/η' factory)

Assume a yield ~10^{13} η mesons/yr and ~10^{11} η' mesons/yr

C, T, CP-violation

- *CP Violation via Dalitz plot mirror asymmetry: $\eta \to \pi^o \pi^+ \pi^-$*
- *CP Violation (Type I – P and T odd , C even): $\eta \to 4\pi^o \to 8\gamma$*
- *CP Violation (Type II - C and T odd , P even): $\eta \to \pi^o \ell^+\ell^-$ **and** $\eta \to 3\gamma$*
- *Test of CP invariance via μ longitudinal polarization: $\eta \to \mu^+\mu^-$*
- *Test of CP invariance via γ^* polarization studies: $\eta \to \pi^+\pi^- e^+e^-$ and $\eta \to \pi^+\pi^-\mu^+\mu^-$*
- *Test of CP invariance in angular correlation studies: $\eta \to \mu^+\mu^- e^+e^-$*
- *Test of T invariance via μ transverse polarization: $\eta \to \pi^o\mu^+\mu^-$ and $\eta \to \gamma\mu^+\mu^-$*
- *CPT violation: μ polariz. in $\eta \to \pi^+\mu^-\nu$ vs $\eta \to \pi^-\mu^+\nu$ and γ polarization in $\eta \to \gamma\gamma$*

New particles and forces searches

- *Scalar meson searches (charged channel): $\eta \to \pi^o H$ with $H \to e^+e^-$ and $H \to \mu^+\mu^-$*
- *Dark photon searches: $\eta \to \gamma A'$ with $A' \to \ell^+\ell^-$*
- *Protophobic fifth force searches : $\eta \to \gamma X_{17}$ with $X_{17} \to e^+e^-$*
- *New leptophobic baryonic force searches : $\eta \to \gamma B$ with $B \to e^+e^-$ or $B \to \gamma\pi^o$*
- *Indirect searches for dark photons new gauge bosons and leptoquark: $\eta \to \mu^+\mu^-$ and $\eta \to e^+e^-$*
- *Search for true muonium: $\eta \to \gamma(\mu^+\mu^-)|_{2M_\mu} \to \gamma e^+e^-$*

Other discrete symmetry violations

- *Lepton Flavor Violation: $\eta \to \mu^+e^- + c.c.$*
- *Double lepton Flavor Violation: $\eta \to \mu^+\mu^+e^-e^- + c.c.$*

Other Precision Physics measurements

- *Proton radius anomaly: $\eta \to \gamma\mu^+\mu^-$ vs $\eta \to \gamma e^+e^-$*
- *All unseen leptonic decay mode of η / η' (SM predicts 10^{-6} -10^{-9})*

Non-η/η' based BSM Physics

- *Dark photon and ALP searches in Drell-Yan processes: qqbar $\to A'/a \to l^+l^-$*
- *ALP's searches in Primakoff processes: p Z $\to$ p Z a $\to l^+l^-$ (F. Kahlhoefer)*
- *Charged pion and kaon decays: $\pi^+ \to \mu^+\nu A' \to \mu^+\nu e^+e^-$ and $K^+ \to \mu^+\nu A' \to \mu^+\nu e^+e^-$*
- *Neutral pion decay: $\pi^o \to \gamma A' \to \gamma e^+e^-$*

High precision studies on medium energy physics

- *Nuclear models*
- *Chiral perturbation theory*
- *Non-perturbative QCD*
- *Isospin breaking due to the u-d quark mass difference*
- *Octet-singlet mixing angle*
- *Electromagnetic transition form-factors (important input for g-2)*

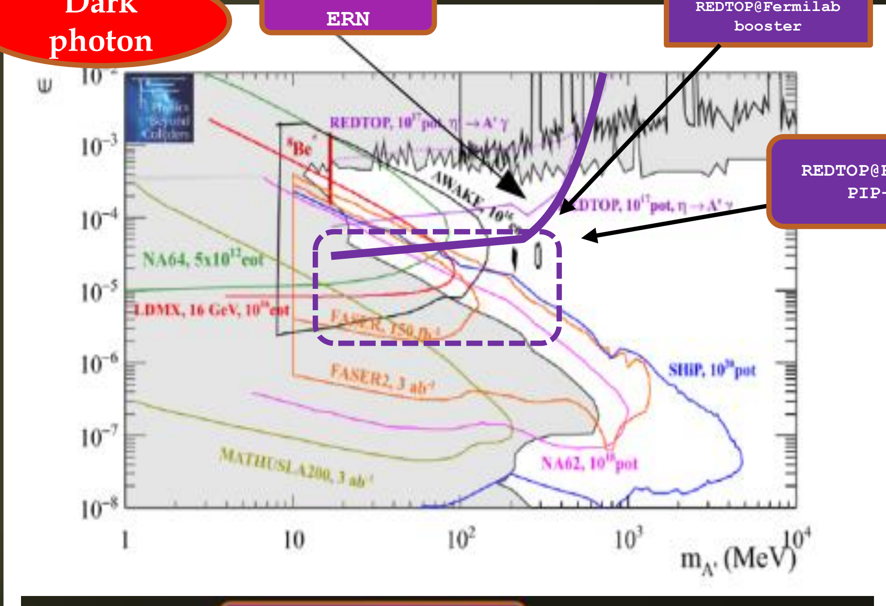
Why the η meson is special?

It is a Goldstone boson	Symmetry constrains its QCD dynamics
It is an eigenstate of the C, P, CP and G operators (very rare in nature): $I^G J^{PC} = 0^+ 0^{-+}$	It can be used to test C and CP invariance.
All its additive quantum numbers are zero $Q = I = j = S = B = L = 0$	Its decays are not influenced by a change of flavor (as in K decays) and violations are "pure"
All its possible strong decays are forbidden in lowest order by P and CP invariance, G-parity conservation and isospin and charge symmetry invariance. EM decays are forbidden in lowest order by C invariance and angular momentum conservation	It is a very narrow state (Γ_η=1.3 KeV vs Γ_ρ=149 MeV) Contributions from higher orders are enhanced by a factor of ~100,000 Excellent for testing invariances
The η decays are flavor-conserving reactions	Decays are free of SM backgrounds for new physics search
The quark content of the η / η′ is extremely simple and thus SM background is known	

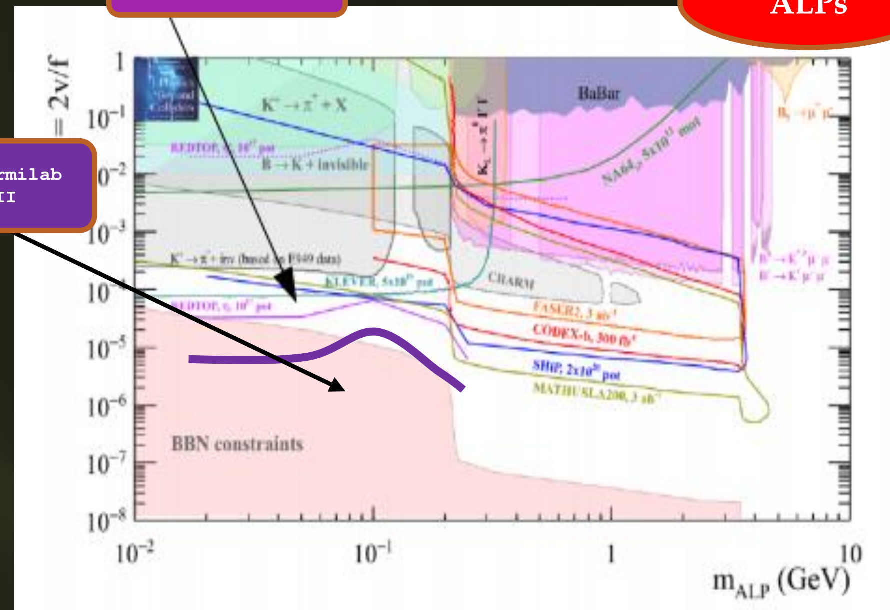
η is an excellent laboratory to search for physics Beyond Standard Model

Examples of sensitivity studies

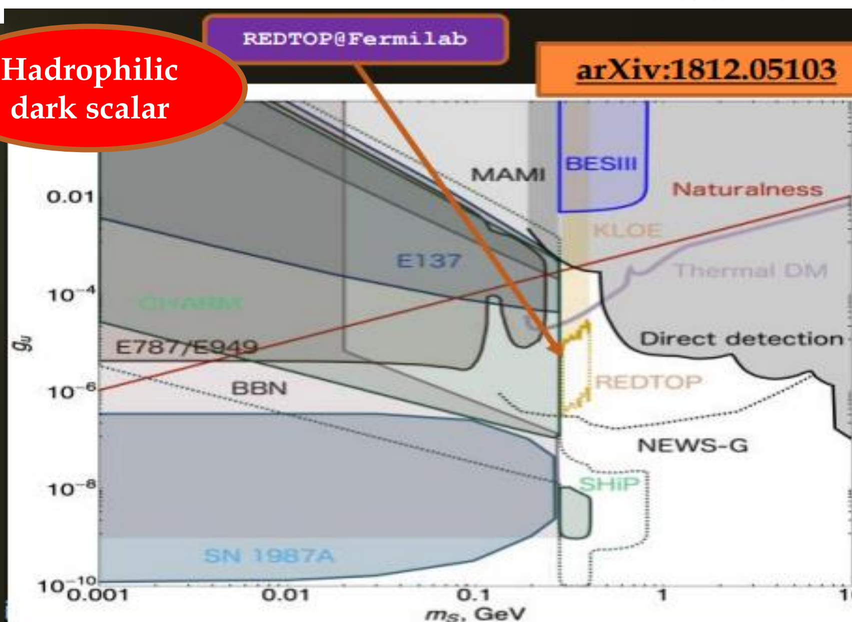
Dark photon



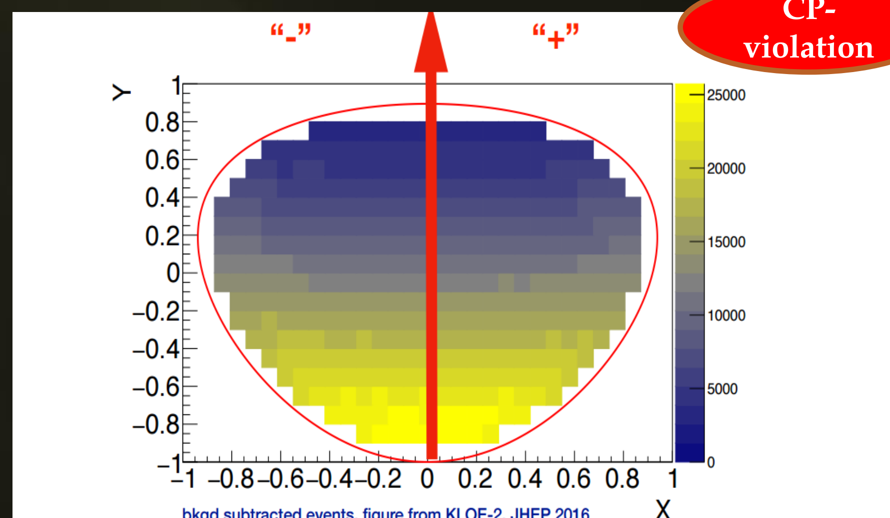
ALPs



Hadrophilic dark scalar



CP-violation



Slide Credit: Susan Gardner & Jun Shi

University of Kentucky

Phase-I run (Delivery Ring) - Experimental Techniques

- *Incident proton energy ~1.8 GeV (3.5 GeV for η')*
- *CW beam, 10^{17}-10^{18} POT/yr (depending on the host laboratory)*
- *η/η' hadro-production from inelastic scattering of protons on Li or Be targets*
- *η–production rate: 10^6 Hz (total: 10^{13}/yr) (η' : 10^{11}/yr)*

charged tracks detection

- *Use Cerenkov effect for tracking charged particles*

- *Baryons and most pions are below Č threshold*
- *Electrons and most muons are detected and reconstructed in an **Optical-TPC***

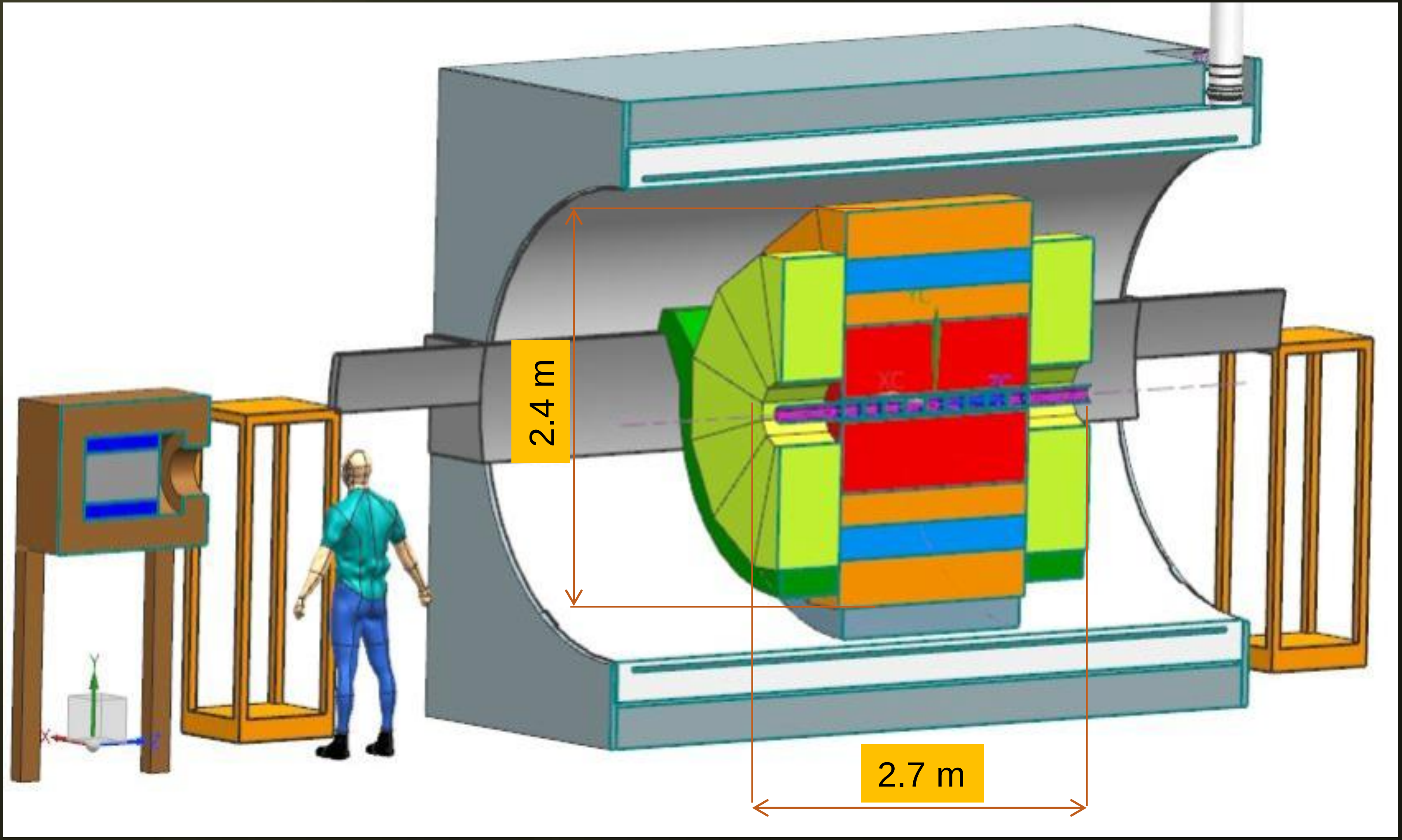
γ detection

- *Use **ADRIANO2** calorimeter (Calice+T1015) for reconstructing EM showers*

- *$\sigma_E/E < 5\%/\sqrt{E}$*
- *PID from dual-readout to disentangle showers from γ/μ/hadrons*
- *96.5% coverage*

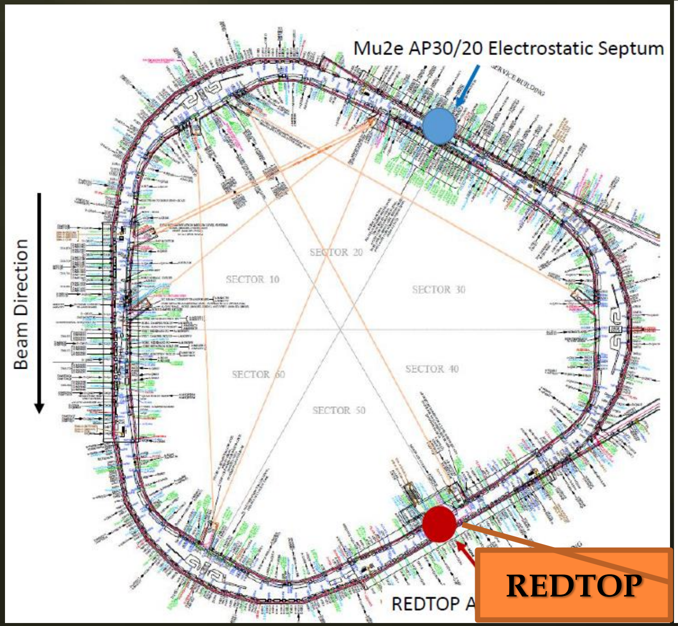
- ***Fiber tracker** (LHCB style) for rejection of background from γ-conversion and reconstruction of secondary vertices (~70μm resolution)*

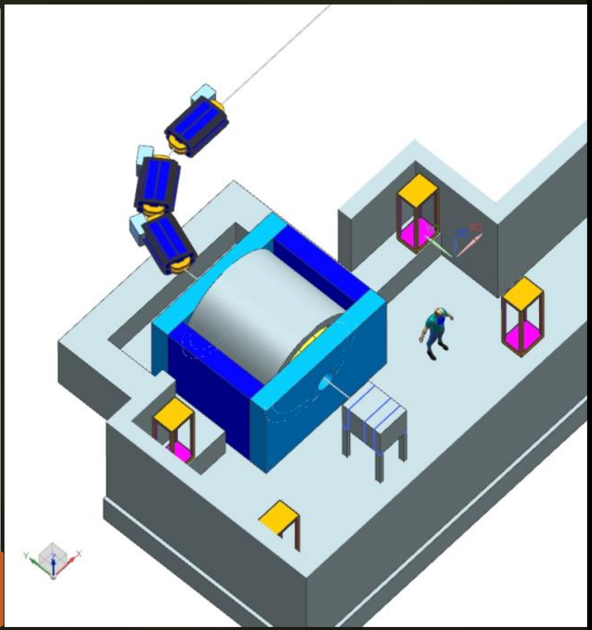
REDTOP Detector+ Magnet

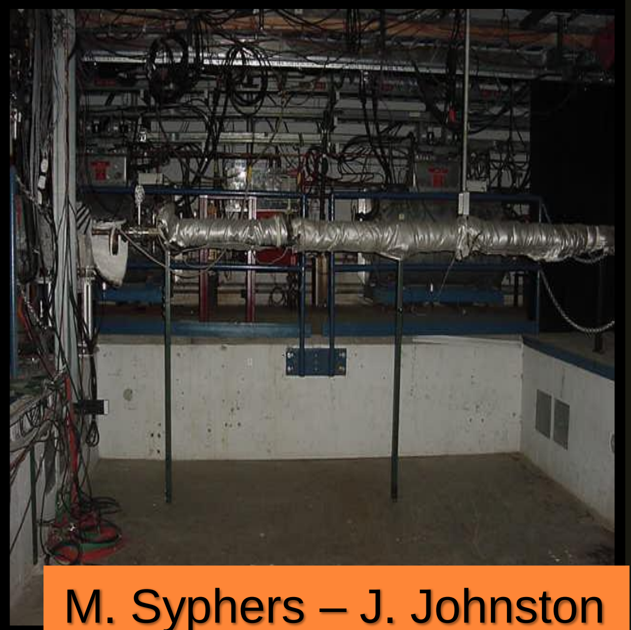


Phase-I Run: Acceleration Scheme

- *Single p pulse from booster (≤4x10^{12} p) injected in the DR (former debuncher in anti-p production at Tevatron) at fixed energy (8 GeV)*
- *Energy is removed by adding 1-2 RF cavities identical to the one already planned (~5 seconds)*
- *Slow extraction to REDTOP over ~40 seconds.*
- *The 270^{o} of betatron phase advance between the Mu2e Electrostatic Septum and REDTOP's Lambertson magnet is ideal for AP50 extraction to the inside of the ring.*
- *Total time to decelerate-debunch-extract: 51 sec: duty cycle ~80%*







M. Syphers – J. Johnston

Phase-II Run: tREDTOP at PIP-II

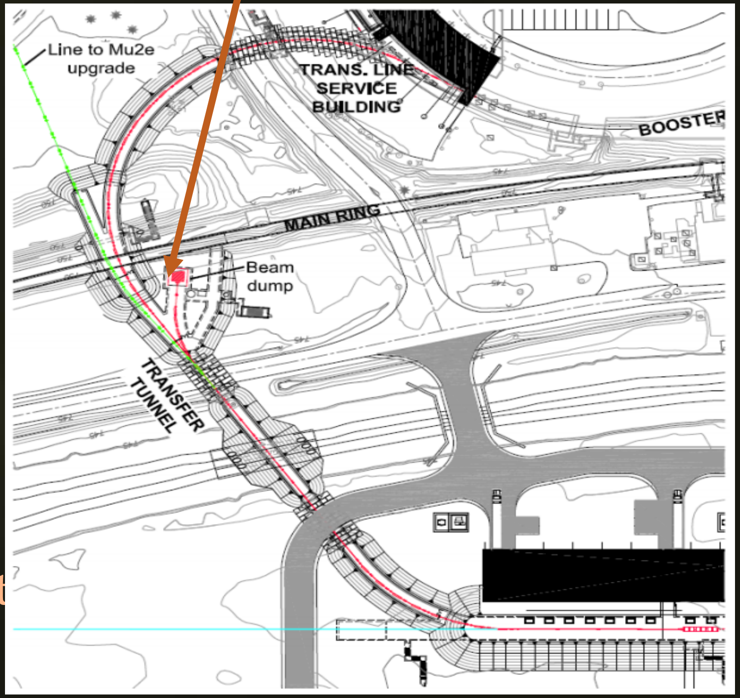
A tagged eta factory

- Full use of ~1 GeV – CW proton beam provided by PIP-II.

$$p + De \rightarrow \eta + {}^{3}He^{+}$$

- η-meson tagging by detecting the 3He+ ion (higher QCD background rejection)
- Measuring the momentum of the $^{3}He^{+}$ the kinematics is fully closed.
  - Long lived, dark particle escaping detection could be identified using the missing 4-momentum technique.
- The latter is considerably more powerful than the, missing pt or missing energy (proposed at beam-dump or e^{-}-fixed target experiments)

tREDTOP



Detector upgrades

New Target: Li foils -> gaseous De

New Central tracker: Optical-TPC -> LGAD tracker

New 3He+ ion detector

Timeline & Costing

- *Once approved and funded, REDTOP needs:*
  - *2-3 years detector R&D + detector design*
  - *2 yrs construction*
- *Accelerator mods required:*
  - *CERN: need further studies – but beam structure is sub-optimal*
  - *FNAL-DR: ~1yr (add a SC cavity to the DR and build an extraction line*
  - *FNAL-PIPII: new experimental hall required (PIP-III)*
- *R&D required*
  - *ADRIANO2: ongoing*
  - *Fiber tracker: none*
  - *LGAD tracker: piggy-back on existing R&D (ATLAS, EIC)*
  - *O-TPC: very late*

Cost (estimate for ESPP)

- *In kind contribution from INFN*
  - *Solenoid (from Finuda experiment at Frascati)*
  - *¾ of Pb-glass (from NA62)*

Solenoid	**0.2**
Refurbishing, shipping	0.2
Supporting structure	**1.0**
Target+beam pipe	**0.5**
Fiber tracker	**0.93**
Fiber mats	0.01
Tooling	0.45
SiPM array	0.1
Front-end electronics	0.12
Back-end electronics	0.05
Mechanics and cooling	0.2
Optical-TPC	**10.0**
Vessel	0.5
Aerogel	1.0
Photo-sensors (LAPPD option)	6.0
Front-end electronics	1.8
Back-end electronics	0.7

ADRIANO2	**16.0**
Pb-glass	2.7
Cast scintillator	0.75
Tile fabrication	0.6
SiPM	6.0
Front-end electronics	4.0
Back-end electronics	1.5
Mechanics and cooling	0.5
Trigger	**1.2**
L0 + L1	1.0
L2 farm + networking	0.2
DAQ	**5.0**
Digitizer	
Networking	
Contingency	**17.0**
50% Contingency	17.0
Total REDTOP	**51.3**

- *For Fermilab*
  - *Add labor and accelerator (R.F.cavities and EM septum are available at Fermilab)*
  - *Adjust contingency from 50% to 25%*

Status of the collaboration

The REDTOP collaboration

11 Countries, 33 Institutions, 86 Collaborators

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Potential hosting laboratories: BNL, CERN, FNAL (DR and PIP-II)

Future Prospects

- *The Collaboration is currently engaged in the ESPP and the Snowmass2021-P5 processes*

- *Current activities aiming at the preparation of a full proposal in a timeframe consistent with Snowmass2021-P5*
  - *Montecarlo campaign ongoing for Snowmass (Run-I and II)*
  - *~10^{10} events being generated and reconstructed (GenieHad+slic+lcsim)*
  - *(Almost) full reconstruction in place (include track and vertex fitting)*

- *Competition from several other experiments (LHCB, LDMX, etc.)*
  - *But, REDTOP experimental techniques is unique (i.e., missing 4-momentum)*

More details: https://redtop.fnal.gov

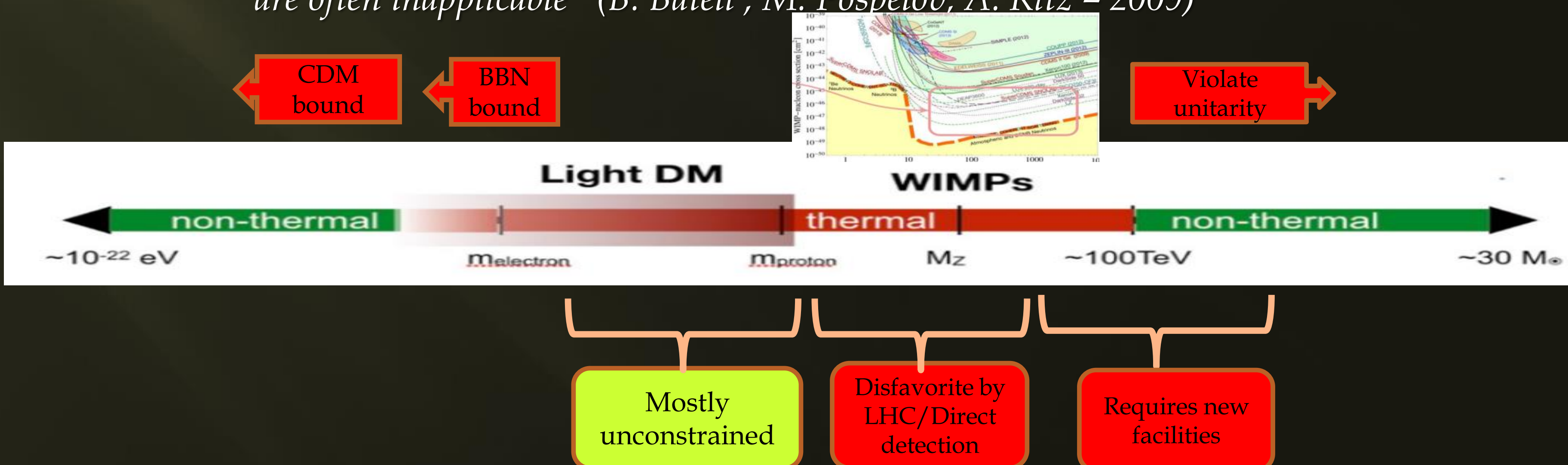
Summary

- *The η/η' meson is a excellent laboratory for studying rare processes and physics BSM*
- *Existing world sample not sufficient for breaching into decays violating conservation laws or searching for new particles*
- *REDTOP goal is to produce ~10^{13} η mesons/yr in phase I and ~ 10^{11} η' /year in phase II*
- *More running phases could use different beam species:*
  - *PIP-II for a tagged-η experiment*
- *Several labs could host the experiment (FNAL is the most optimal)*
- *New detector technique would set the stage for next generation High Intensity experiments*
- *Moderate cost (50-60 M$)*

Backup slides

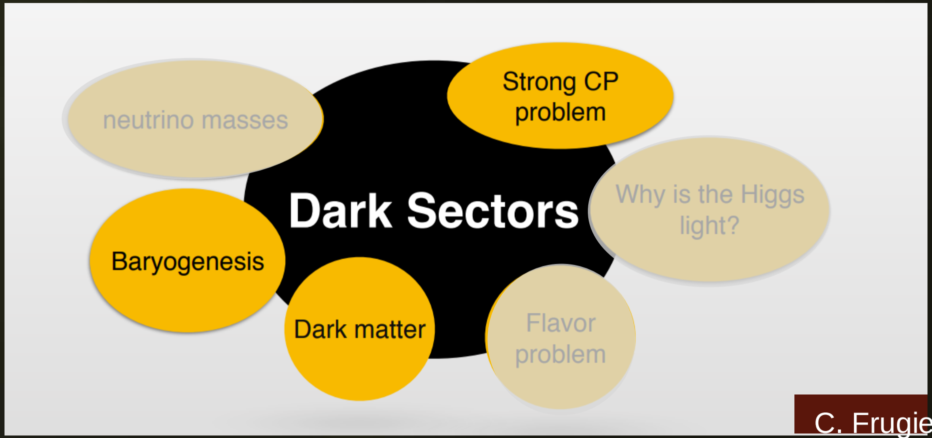
REDTOP Quest for BSM Physics

- *As LHC found no hint of new physics at high energy so far*
  - *New physics could be at much lower energy*
  - *Colliders have insufficient luminosity ($\mathcal{O}(10^{41})$ cm^{-2} vs $\mathcal{O}(10^{44})$ cm^{-2} for 1–mm fixed target)*
- *An η /η′ factory with 10^4x world statistics would search for discrepancies in the Standard Model at the 1 GeV energy regime with couplings at the level of 10^{-8}*
  - *Newest theoretical models prefer gauge bosons in MeV-GeV mass range as "…many of the more severe astrophysical and cosmological constraints that apply to lighter states are weakened or eliminated, while those from high energy colliders are often inapplicable" (B. Batell , M. Pospelov, A. Ritz – 2009)*



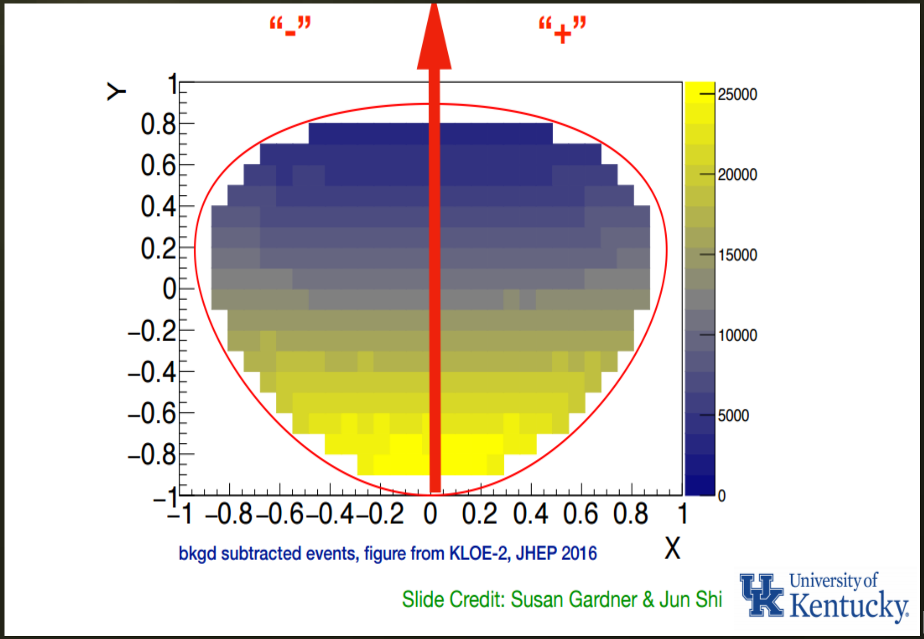
Main Physics Goals of REDTOP

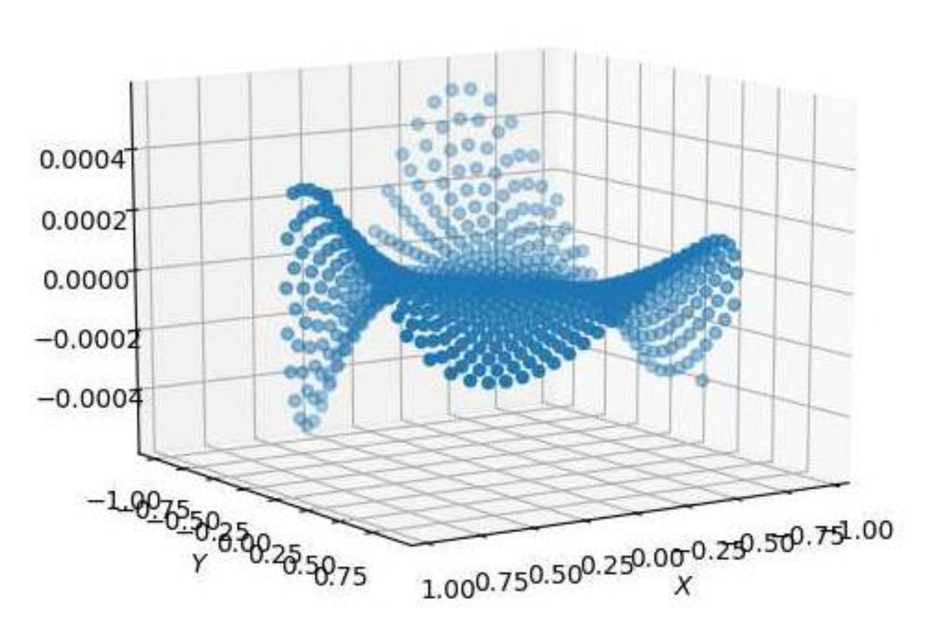
- *CP Violation via Dalitz plot mirror asymmetry:* $\eta \rightarrow \pi^o \pi^+ \pi^-$
  Search for asymmetries in the Dalitz plot.
- *Test of CP invariance via* $\gamma*$ *polarization studies:* $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ *and* $\eta \rightarrow \pi^+ \pi^- \mu^+ \mu^-$
  Measure the angular asymmetries between the $l^+ l^-$ *and* $\pi^+ \pi^-$ *planes*
- *Dark photon searches:* $\eta \rightarrow \gamma A'$ *with* $A' \rightarrow \ell^+ \ell^-$
  Need excellent vertexing and particle i.d
- *Scalar meson searches* $\eta \rightarrow \pi^o H$ *with* $H \rightarrow e^+ e^-$ *and* $H \rightarrow \mu^+ \mu^-$
  Dual (or triple!) calorimeters and fast (<100 psec) play important role



CP Violation from Dalitz plot mirror asymmetry in $\eta \rightarrow \pi^+ \pi^- \pi^0$

- *CP-violation from this process is not bounded by EDM as is the case for the $\eta \rightarrow 4\pi$ process.*
- *Complementary to EDM searches even in the case of T and P odd observables, since the flavor structure of the eta is different from the nucleus*
- *Current PDG limits consistent with no asymmetry*
- *REDTOP will collect 4×10^{11} decays (100x in stat. err.) in B-field insensitive detector*
- *New model in GenieHad (collaboration with S. Gardner & J. Shi – UK) based on* https://arxiv.org/abs/1903.11617





Searches for light scalar mesons

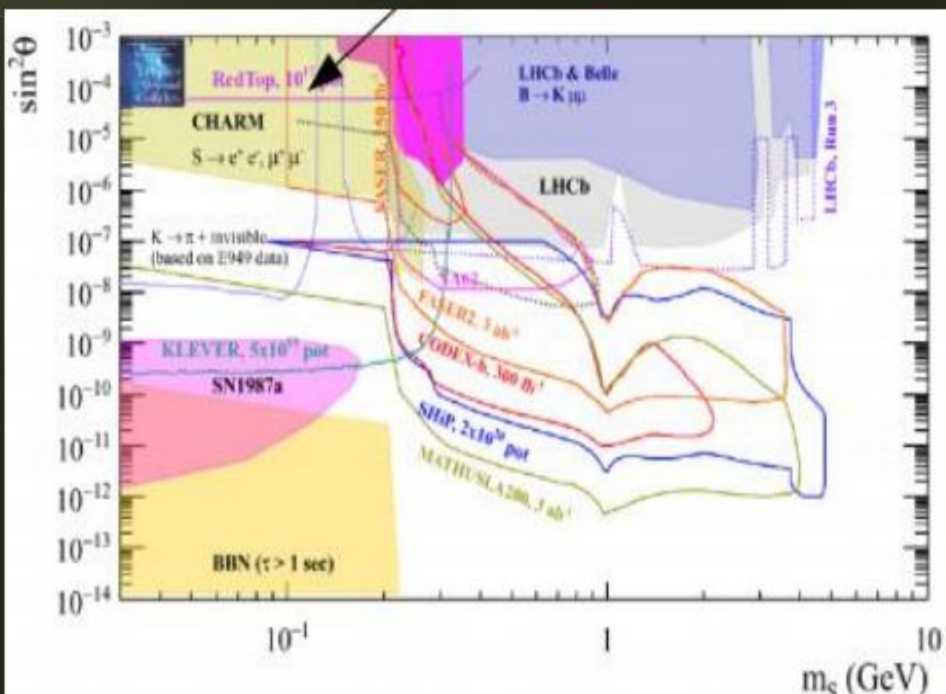
Minimal SM Higgs extension

- *Studied within the "Physics Beyond Collider" program at CERN for 10^{17} POT*
- *FNAL and BNL can provide 10x more POT*
- *Only "bump hunt analysis". Vertexing add 10x more sensitivity*

Hadrophilic Scalar Mediator

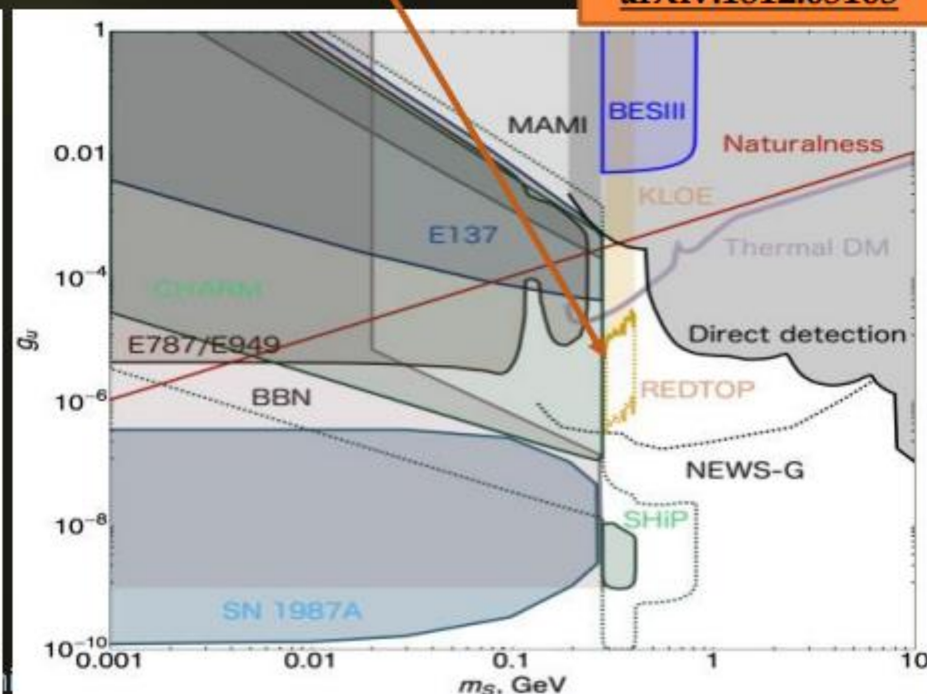
- *Studied in* **arXiv:1812.05103**
- *Only bump hunt - no vertexing*

REDTOP@CERN



REDTOP@Fermilab

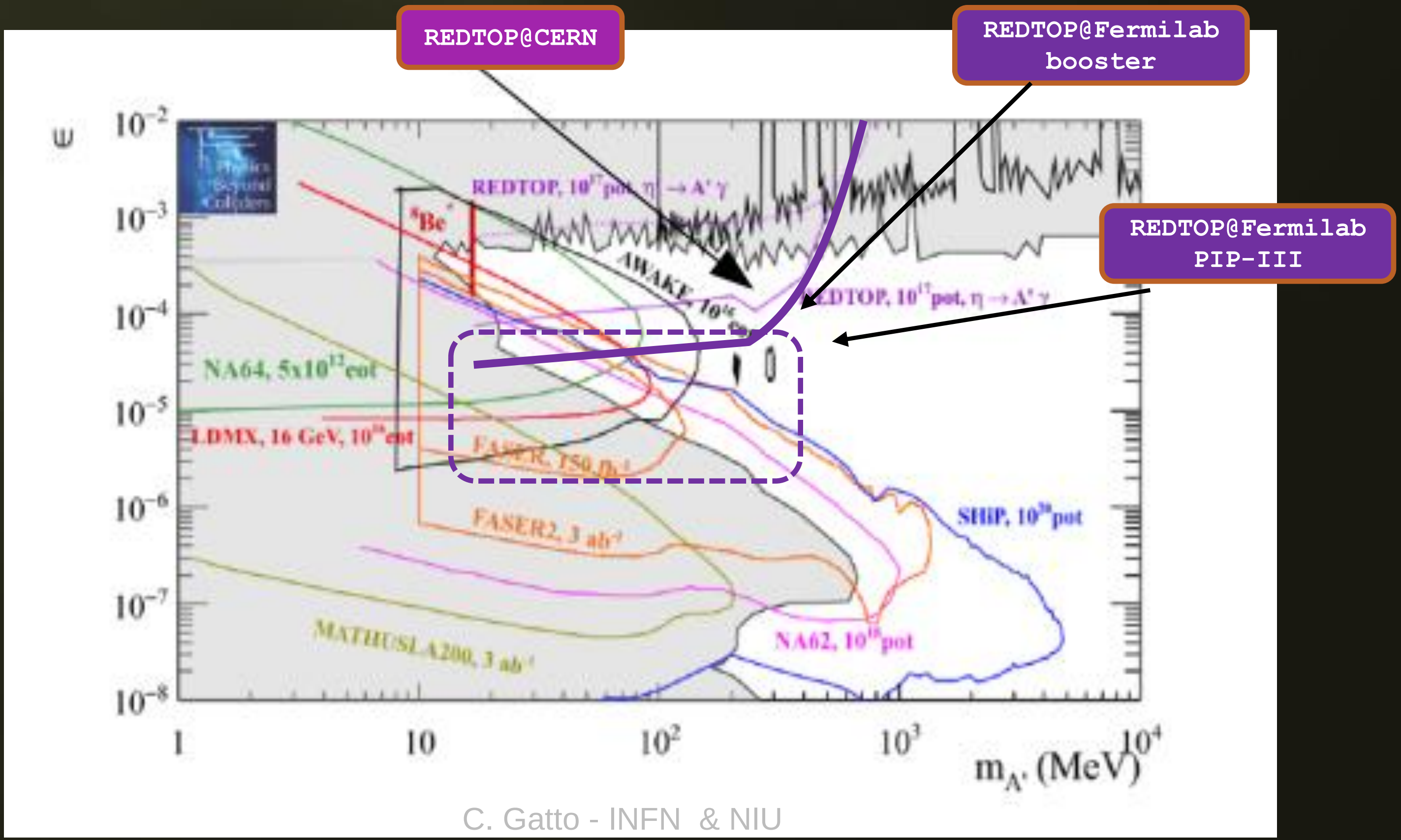
arXiv:1812.05103



Dark photon searches:

$$\eta \to \gamma A' \;\; with \;\; A' \to \mu^+ \mu^- \;\; and \;\; e^+ e^-$$

- *Studied within the "Physics Beyond Collider" program at CERN for 10^{17} POT*
- *FNAL and BNL can provide 10x more POT*
- *Studies in progress add vertexing+timing to improve the sensitivity to physics BSM.*



Searches for ALPs with fermion or gluon coupling

- *Beam emitted ALP's from the following processes:*
  - *Drell-Yan processes:* $q\bar{q} \rightarrow A'/a \rightarrow l^+l^-$
  - *Proton bremsstrahlung processes:* $pN \rightarrow pNA'/a$ *with* $A'/a \rightarrow l^+l^-$ *(J. Blümlein and J. Brunner)*
  - *Primakoff processes:* $pZ \rightarrow pZa \rightarrow l^+l^-$ *(F. Kahlhoefer, et. Al.)*
- *Only "bump hunt analysis" with* 10^{17} *POT (CERN). Will add vertexing+timing to the analysis.*
- *Redtop@PIP-II will provide x100 sensitivity (ALPACA study).*

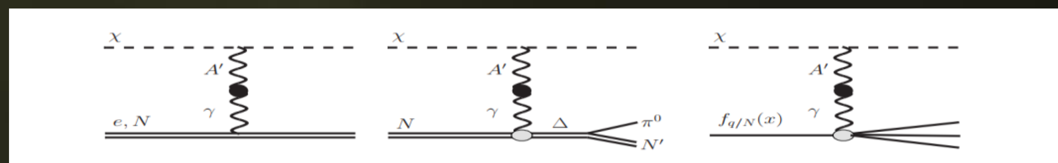
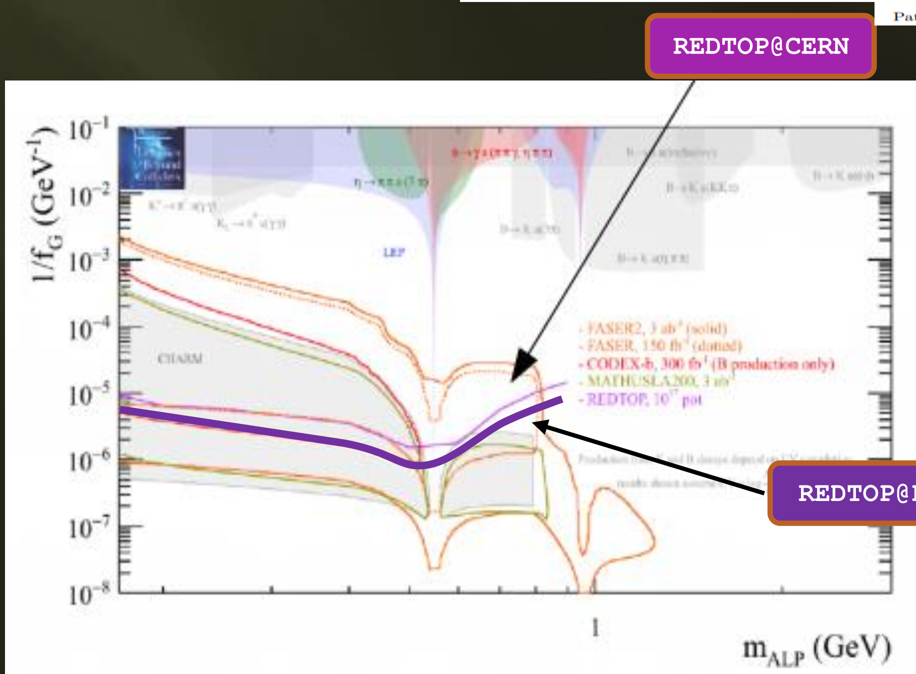
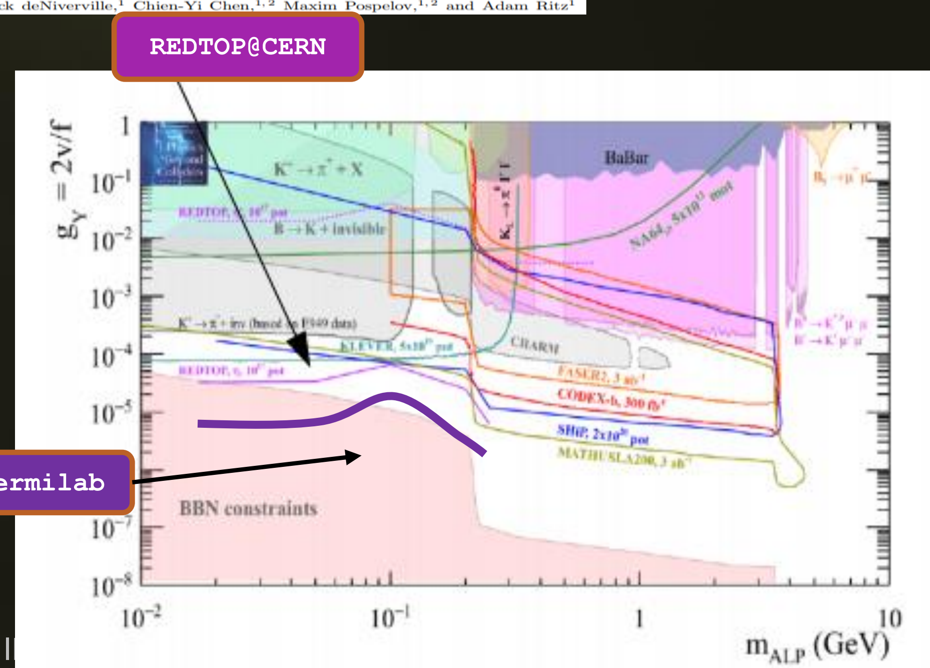


FIG. 4. Scattering channels analyzed: from left to right, elastic scattering on electrons or nucleons, quasielastic (incoherent) single pion production, and deep inelastic scattering.

Patrick deNiverville,[1] Chien-Yi Chen,[1,2] Maxim Pospelov,[1,2] and Adam Ritz[1]





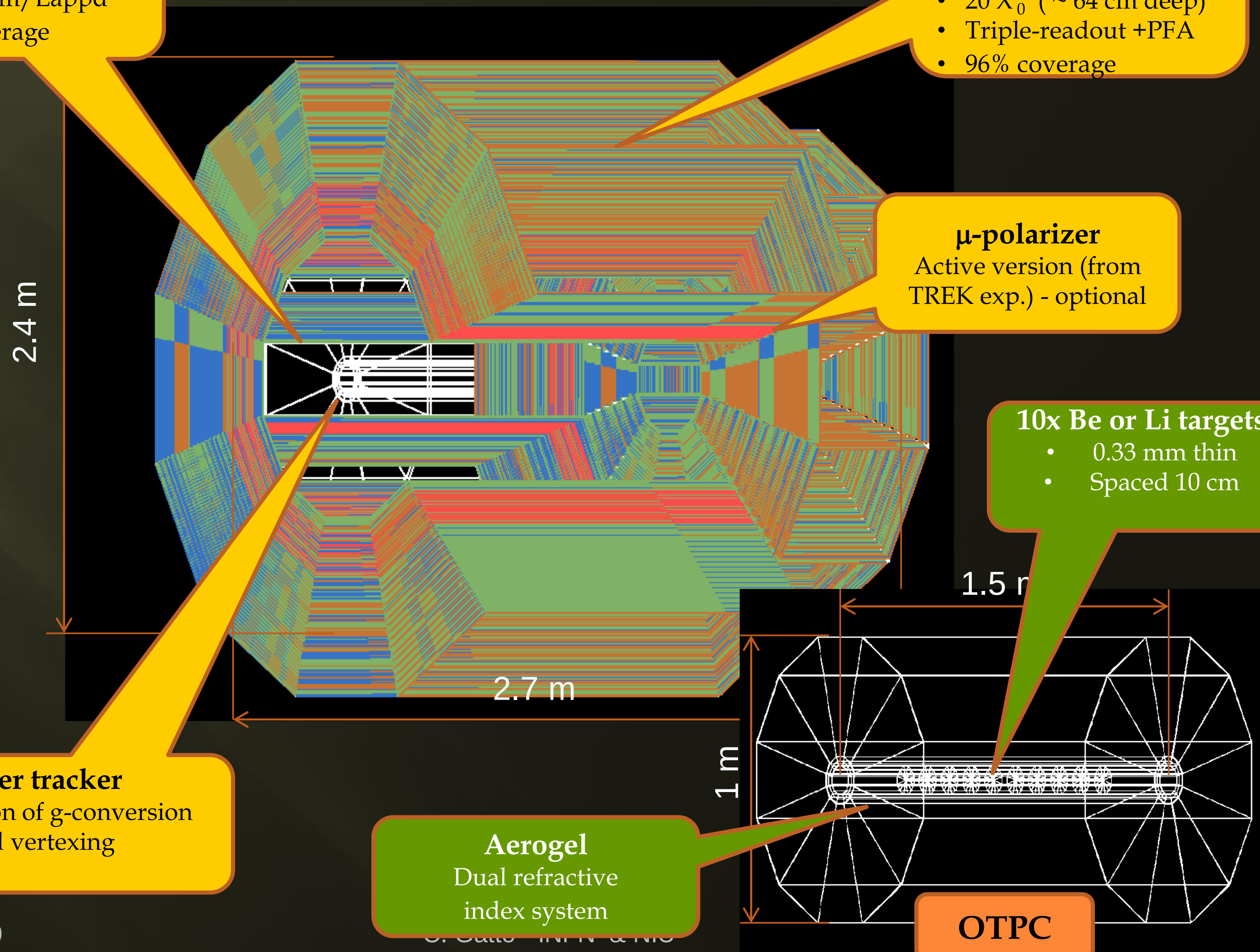
REDTOP Phase-I Requirements

- *Medium energy proton beam 1.5 – 4 GeV*
- *Proton economics:*
  - *Min: 10^{17} POT/yr - CERN*
  - *Optimal: 10^{18} POT/yr - FNAL or BNL*
  - *Produce ~10^{13} η mesons/yr – reco eff > 10%*
  - *Produce ~10^{11} η' mesons/yr– reco eff > 10%*
- *Efficient detection of the leptonic decays of the η*
- *Blind to protons and low energy charged pions.*
- *Neutron rejection (via ADRIANO2 dual-readout calorimeter)*
- *near 4π detector acceptance.*

REDTOP detector

Optical TPC
- ~ 1m x 1.5 m
- CH_4 @ 1 Atm
- $5x10^5$ Sipm/Lappd
- 98% coverage

ADRIANO2 Calorimeter (tiles)
- Scint. + heavy glass sandwich
- 20 X_0 (~ 64 cm deep)
- Triple-readout +PFA
- 96% coverage



μ-polarizer
Active version (from TREK exp.) - optional

10x Be or Li targets
- 0.33 mm thin
- Spaced 10 cm

Fiber tracker
for rejection of g-conversion and vertexing

Aerogel
Dual refractive index system

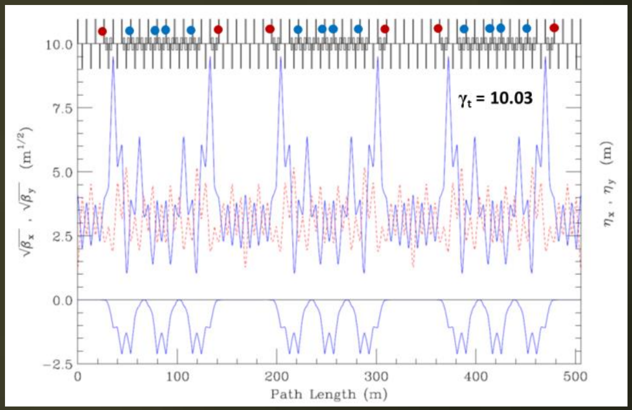
Present & Future η Samples

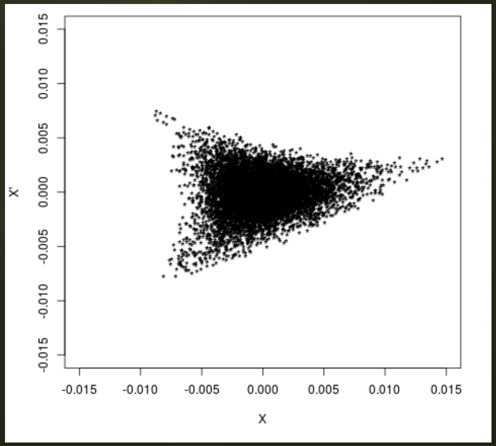
	Technique	$\eta \to 3\pi^0$	$\eta \to e^+e^-\gamma$	Total η
CB@AGS	$\pi^- p \to \eta\, n$	9×10^5		10^7
CB@MAMI-B	$\gamma p \to \eta\, p$	1.8×10^6	5000	2×10^7
CB@MAMI-C	$\gamma p \to \eta\, p$	6×10^6		6×10^7
KLOE	$e+e- \to \Phi \to \eta\gamma$	6.5×10^5		5×10^7
WASA@COSY	$pp \to \eta\, pp$ $pd \to \eta\, {}^3He$			$>10^9$ (untagged) 3×10^7 (tagged)
CB@MAMI 10 wk (proposed 2014)	$\gamma p \to \eta\, p$	3×10^7	1.5×10^5	3×10^8
Phenix	$d\, Au \to \eta\, X$			5×10^9
Hades	$pp \to \eta\, pp$ $p\, Au \to \eta\, X$			4.5×10^8
		Near future samples		
GlueX@JLAB (just started)	$\gamma_{12\,\mathrm{GeV}}\mathbf{p} \to \boldsymbol{\eta}\ \mathbf{X} \to$ **neutrals**			5.5×10^7/yr
JEF@JLAB (recently approved)	$\gamma_{12\,\mathrm{GeV}}\mathbf{p} \to \boldsymbol{\eta}\ \mathbf{X} \to$ **neutrals**			3.9×10^5/day
REDTOP@FNAL (proposing)	$p_{1.8\,\mathrm{GeV}} Be \to \eta\ X$			2.5×10^{13}/yr

Transitionless Deceleration in the Delivery Ring (J. Johnstone)

- Large beam losses will occur if beam is decelerated from injection @ 8 GeV (γ = 9.53) to 2 GeV (γ = 3.13) through the DR natural transition energy γ_t = 7.64.
- Transition is avoided by using select quad triplets to boost γt above beam γ by 0.5 units throughout deceleration until γ_t = 7.64 and beam γ = 7.14 (5.76 GeV kinetic).
- Below 5.76 GeV the DR lattice reverts to the nominal design configuration
- Optical perturbations are localized within each triplet
- Straight sections are unaffected thereby keeping the nominal M3 injection beamline tune valid.

Accelerator Physics Issues



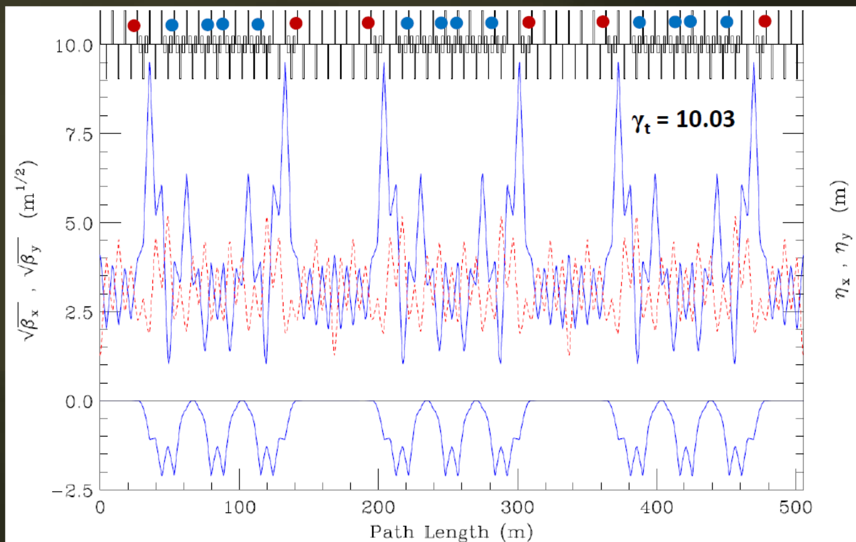


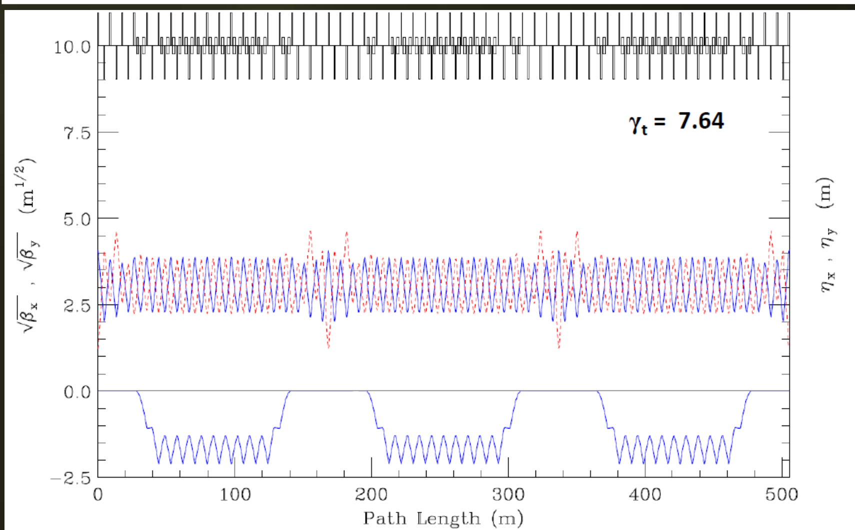
- *Transition Energy*
  - γ_t is where $\Delta f/f = 1/\gamma 2 - \langle D/\rho \rangle = 0$; synchrotron motion stops momentarily, can often lead to beam loss
  - beam decelerates from $\gamma = 9.5$ to $\gamma = 3.1$
  - original Delivery Ring $\gamma_t = 7.6$
  - a re-powering of 18 quadrupole magnets can create a $\gamma_t = 10$, thus avoiding passing through this condition
    - Johnstone and Syphers, *Proc. NA-PAC 2016*, Chicago (2016).
- *Resonant Extraction*
  - Mu2e will use 1/3-integer resonant extraction
  - REDTOP can use same system, with use of the spare Mu2e magnetic septum
  - initial calculations indicate sufficient phase space, even with the larger beam at the lower energies
- *Vacuum*
  - REDTOP spill time is much longer than for Mu2e
  - though beam-gas scattering emittance growth rate 3 times higher at lower energy, still tolerable level

Ring Optics through Deceleration (J. Johnstone)

Transition is avoided by using select quad triplets to boost γt above beam γ by 0.5 units throughout deceleration until γ_t = 7.64 and beam γ = 7.14 (5.76 GeV kinetic).

Below 5.76 GeV the DR lattice reverts to the nominal design configuration





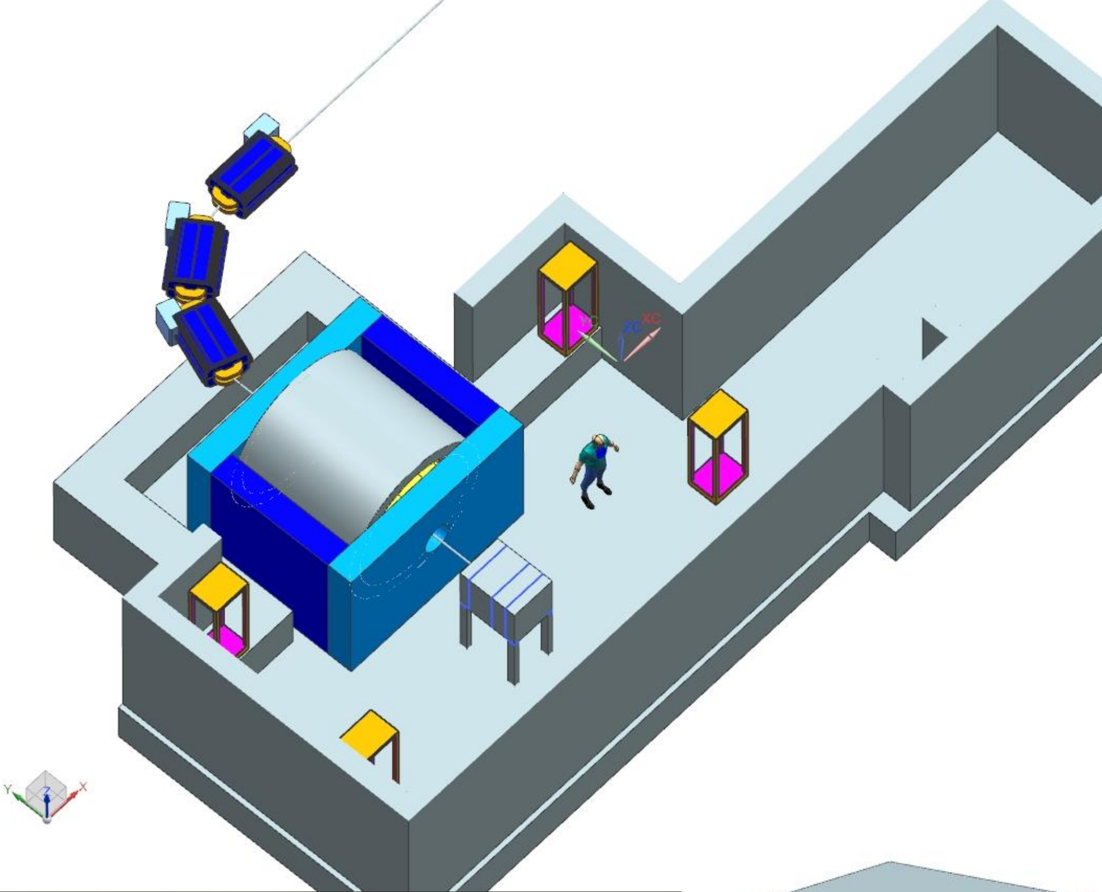
8 GeV injection energy (top) and <5.8 GeV (bottom)

- Blue & red circles indicate sites of the γ_t quad triplets.

p (GeV/c)	8.89	8.33	7.76	7.20	6.63
KE (GeV)	8.00	7.45	6.88	6.32	5.76
γ_{BEAM}	9.53	8.93	8.33	7.74	7.14
$\gamma_{transition}$	10.03	9.43	8.83	7.74	7.64
β_{max} (m)	94.9	72.5	49.5	30.1	15.1
q (m^{-1})	.0697	.0573	.0416	.0236	0.0
3σ (mm)	15.0	13.6	11.6	9.4	6.9

Variation of γ_t, β_{max}, and the 15π 99% beam envelope through deceleration

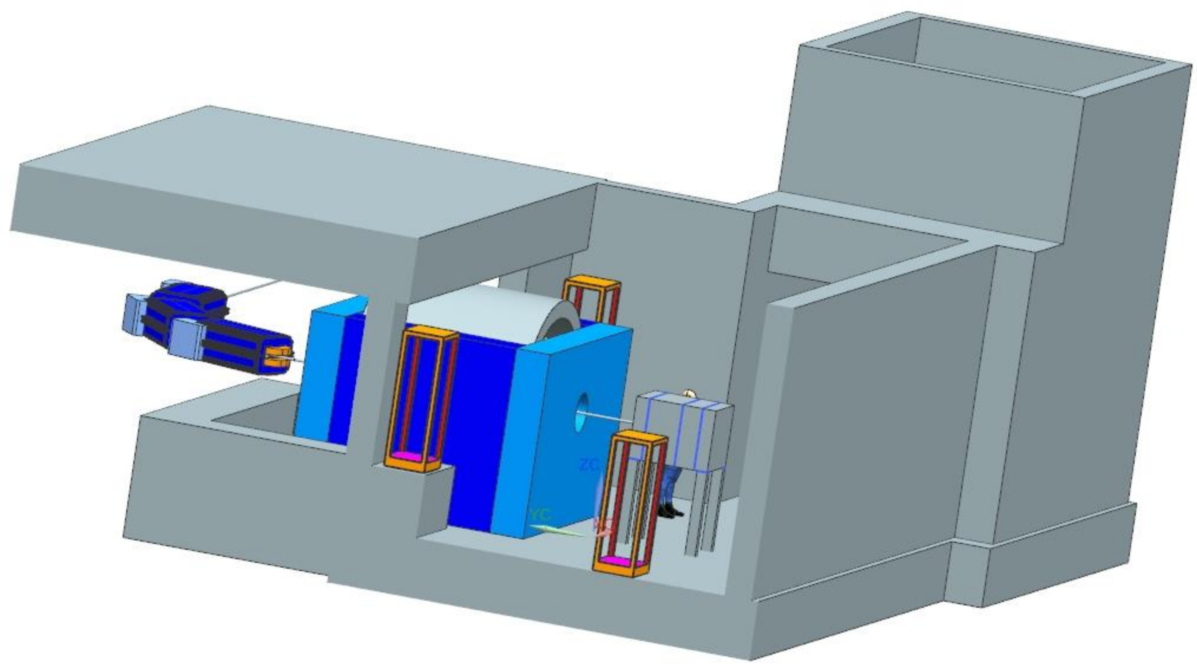
"J.Johnstone, M.Syphers, NA-PAC, Chicago (2016)"



REDTOP detector in AP50

J. Kilmer
J. Rauch

(Many thanks to K. Krempetz, as well)

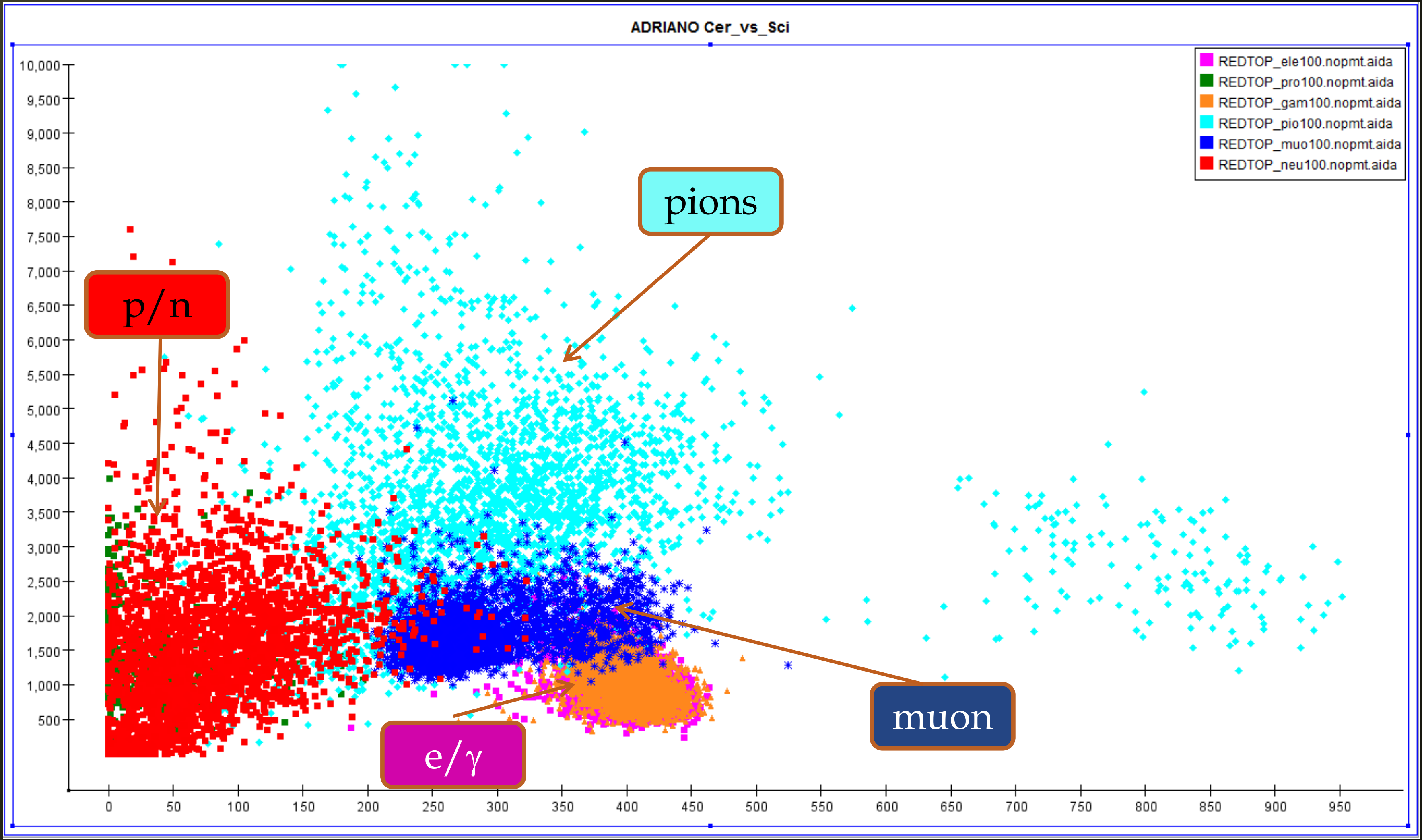


The ADRIANO2 Calorimeter

- *Sandwich of Pb-glass and scintillating plastic tiles with direct SiPM reading*
  - *Evolution of ADRIANO dual-readout calorimeter (A Dual-Readiut Integrally Active Non-segmented Option)*
- *Triple-readout obtained from waveform analysis*

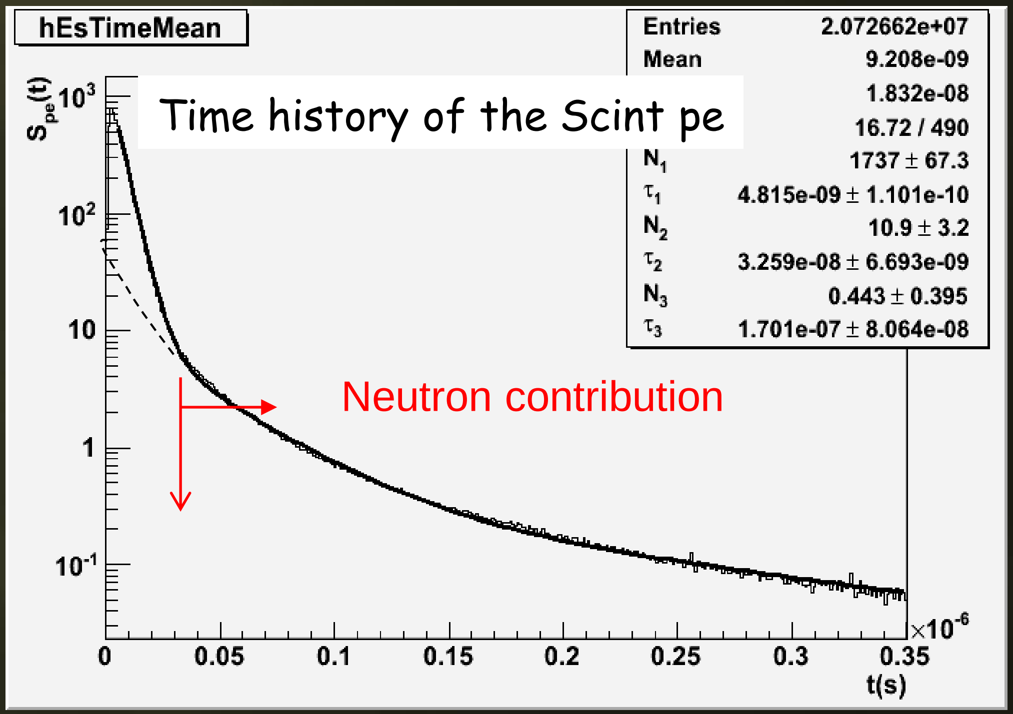
- *Rationale for multiple readout calorimetry at η -factory*
  - *Particle identification (see next)*
  - *Integrally active (no sampling)*
  - *Prompt Cerenkov light fed to L) trigger*
  - *Good granularity helps disentangling overlapping showers*

ADRIANO PID @ 100MeV



From Dual to Triple Readout

Disentangling neutron component from waveform



ILCroot simulations

40 Gev pions

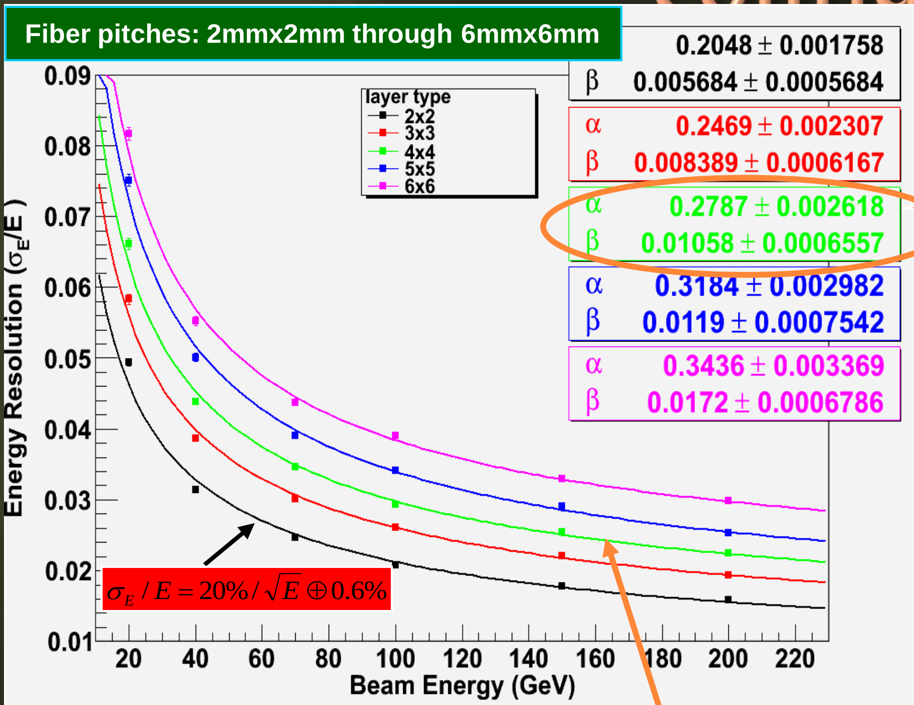
Time history of the scintillation signal in *ADRIANO* for π^-@40 GeV.

The contribution after 35 ns is from neutrons only. The distribution has been fitted with a triple exponential function .

$$E_{HCAL} = \frac{\eta_S \cdot E_S \cdot (\eta_C - 1) - \eta_C \cdot E_C \cdot (\eta_S - 1)}{\eta_C - \eta_S} + \eta_n \cdot E_{neutrons}$$

Triple Readout aka Dual Readout with time history readout

ADRIANO in Triple Readout configuration

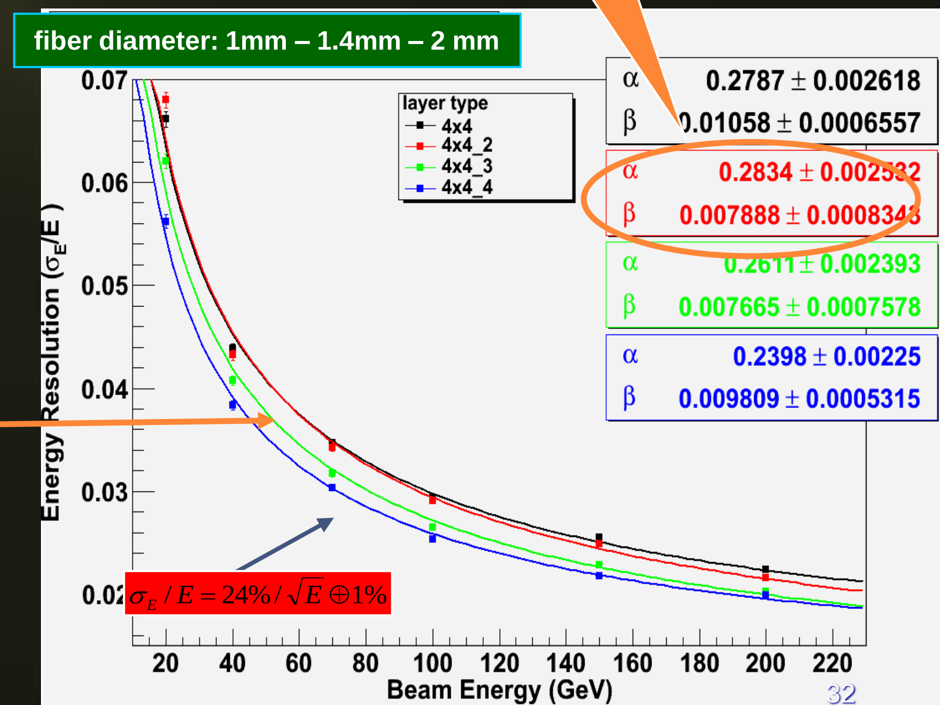


Baseline configuration

Pion beams

ILCroot simulations

$$\sigma_E / E = 28\% / \sqrt{E} \oplus 1\%$$

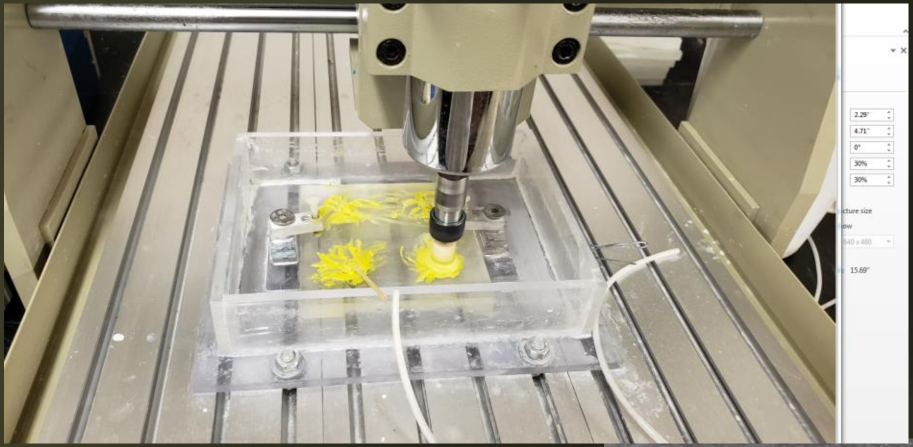


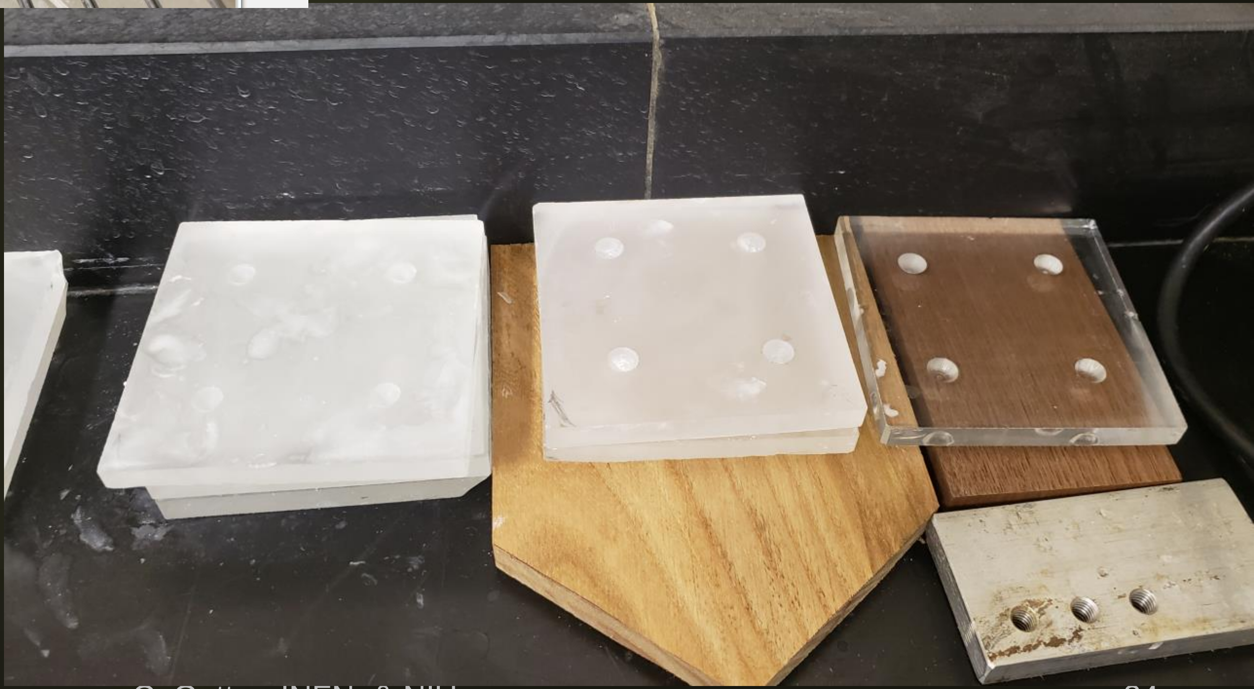
ompare to ADRIANO in Double Readout configuration

$$\sigma_E / E = 33\% / \sqrt{E} \oplus 2\%$$

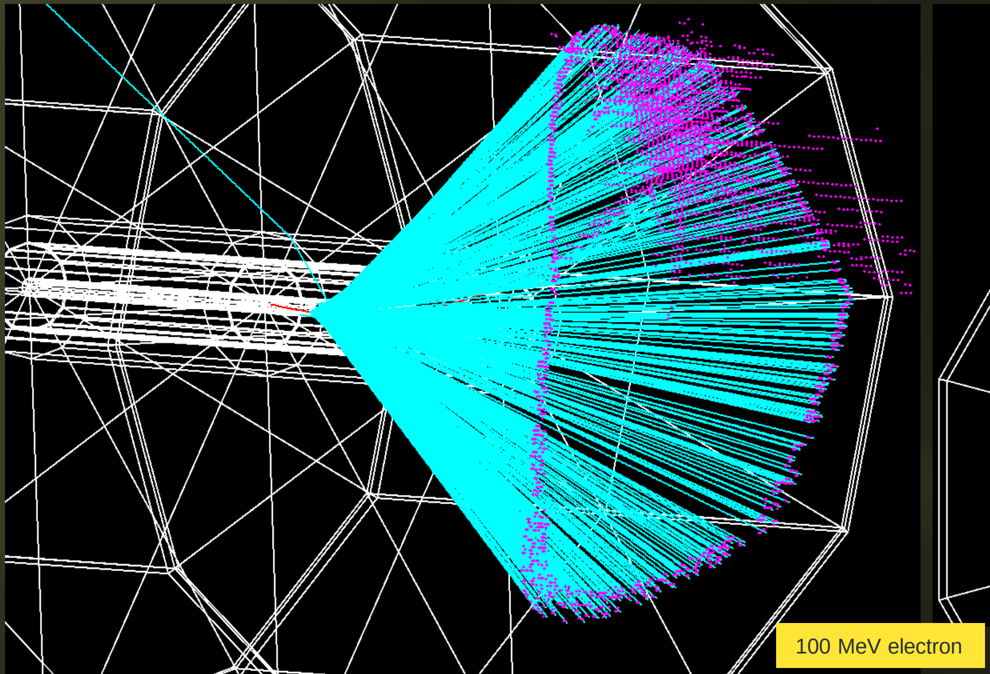
Nov. 2015 test Beam at Fermilab

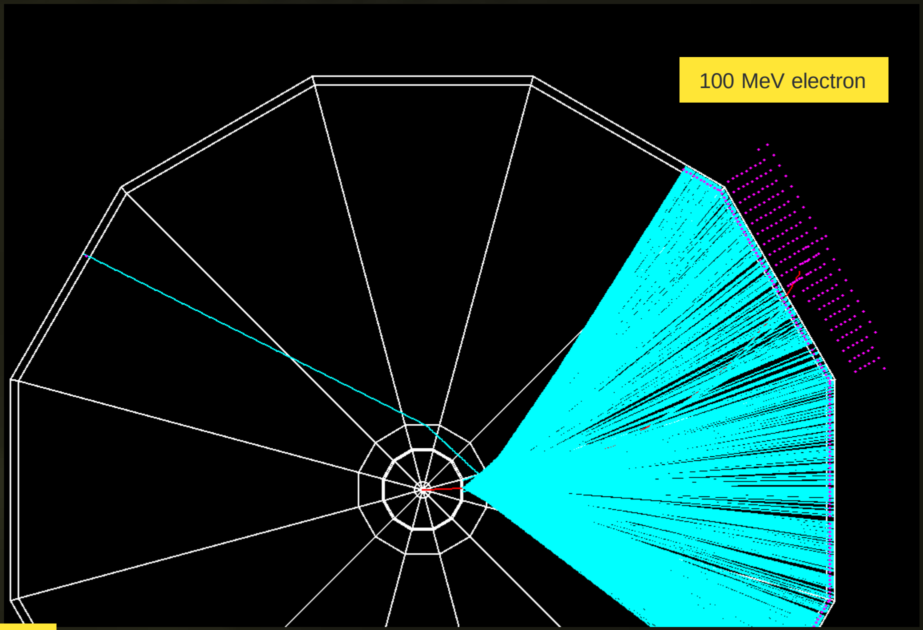
Polishing

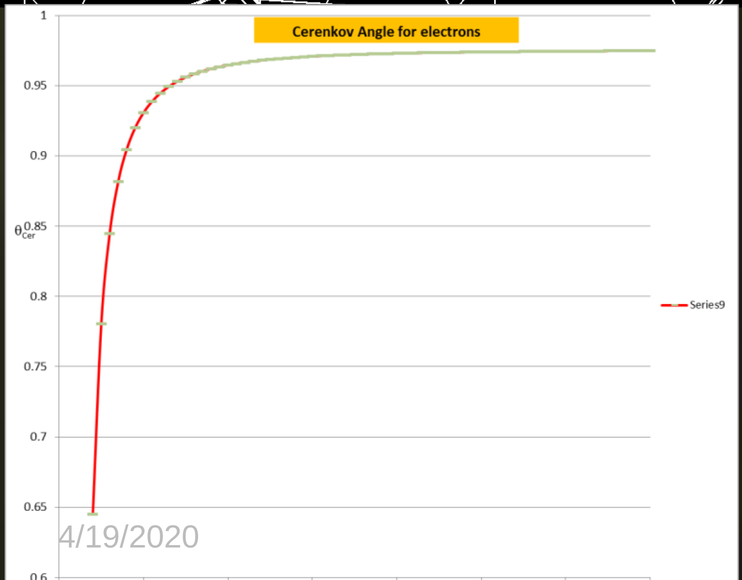




Electron Detection







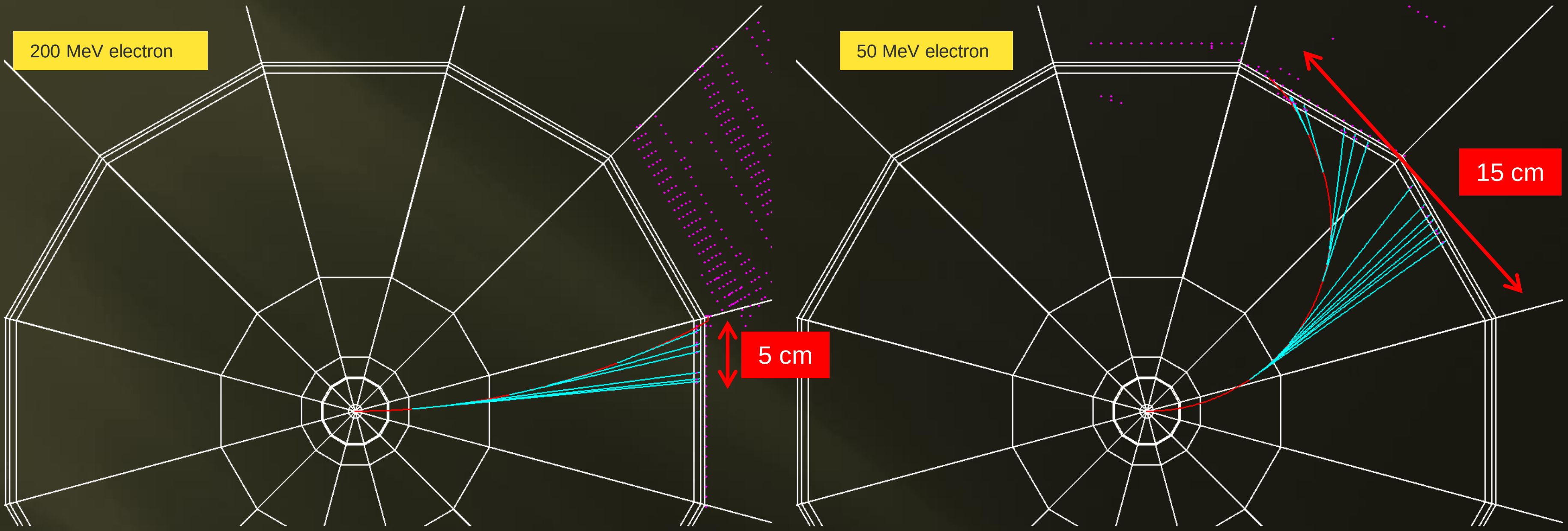
$n_D(N_2@2.7psi)=1.000145$

Č threshold for e- in N_2: P=40 mev

n_D(aerogel1)=1.12

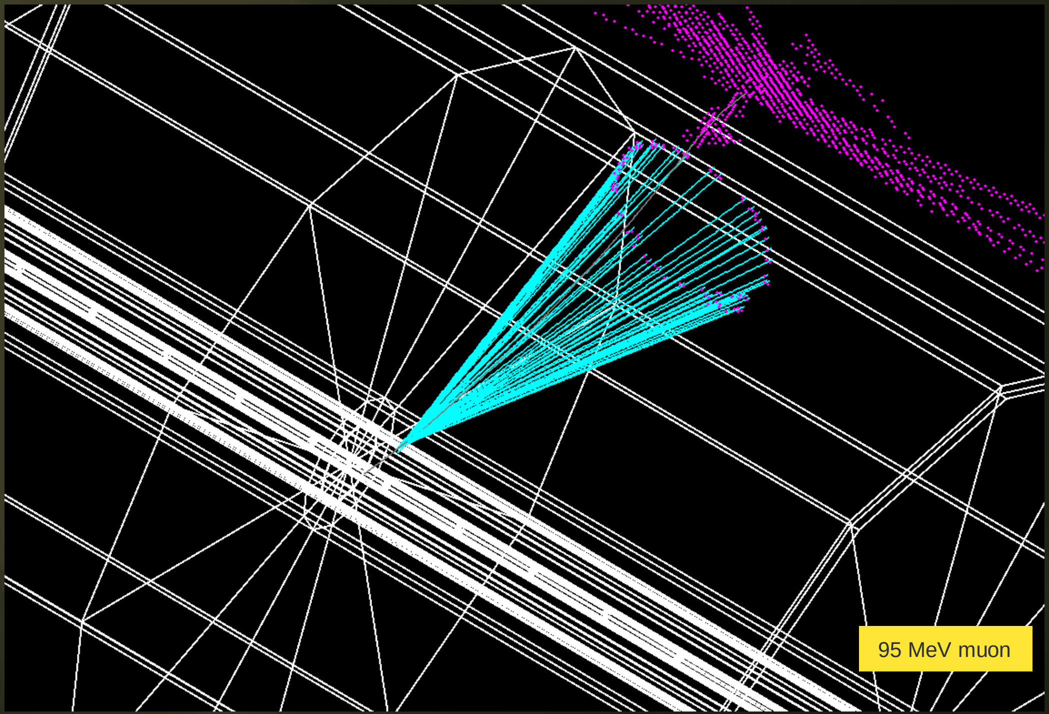
n_D(aerogel2)=1.22

Electron Momentum Reconstruction

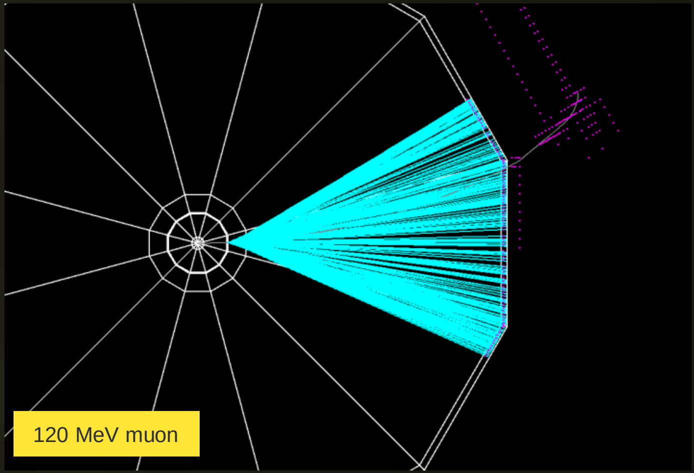


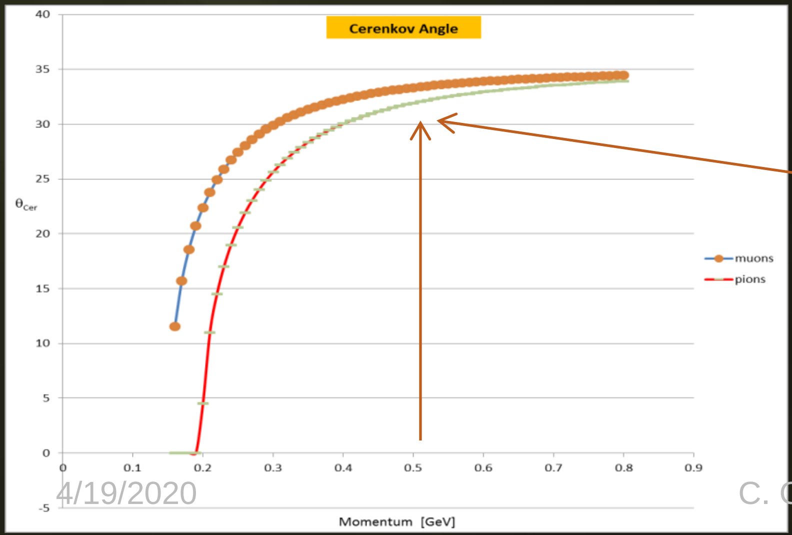
- Electrons are recognized by:
  1. a large (>30 cm dia) circle of photons generated in the aerogel
  2. A sweep of photons circles with dia < 1cm and several cm long (depends on P_t)
  3. An EM shower in ADRIANO (identified by Č vs S)

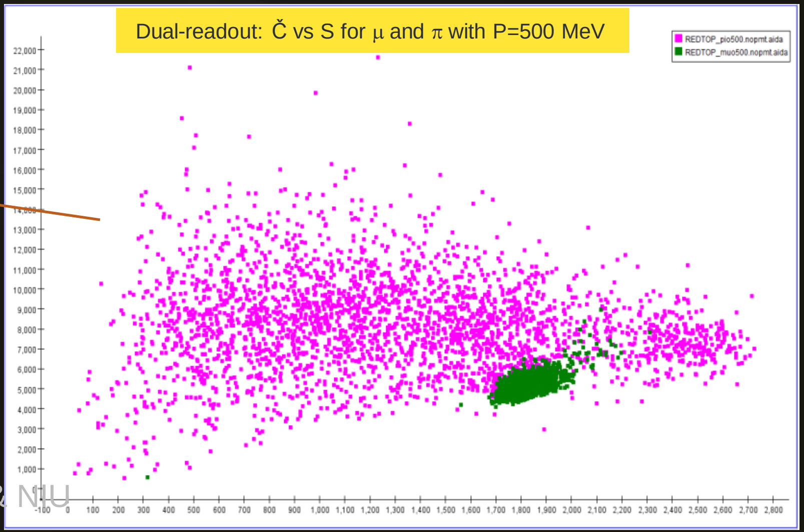
Muon/pion Detection



- n_D(aerogel)=1.22/1.12
- Č threshold for muons: P=160 mev
- Č threshold for pions: P=200 mev



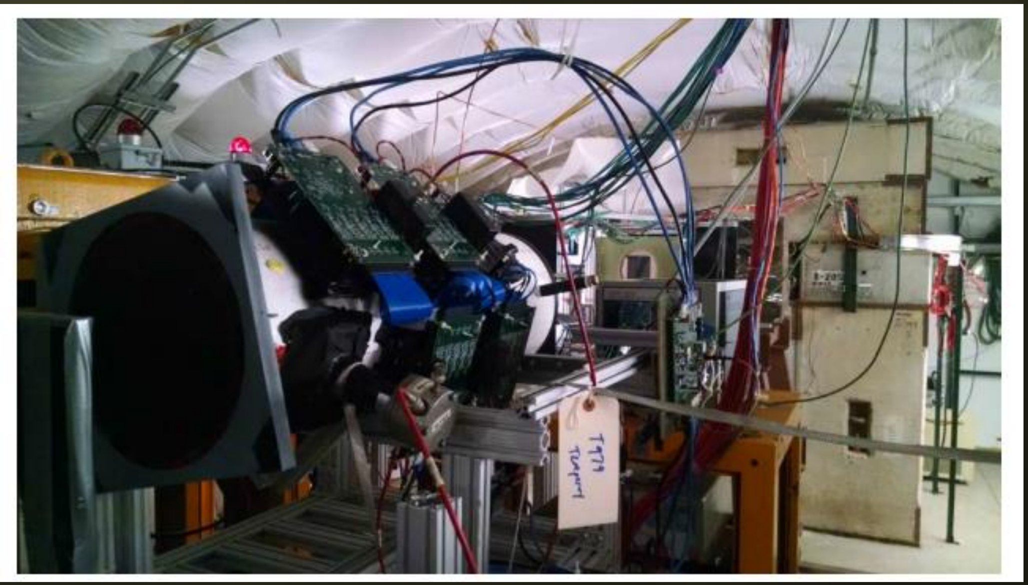


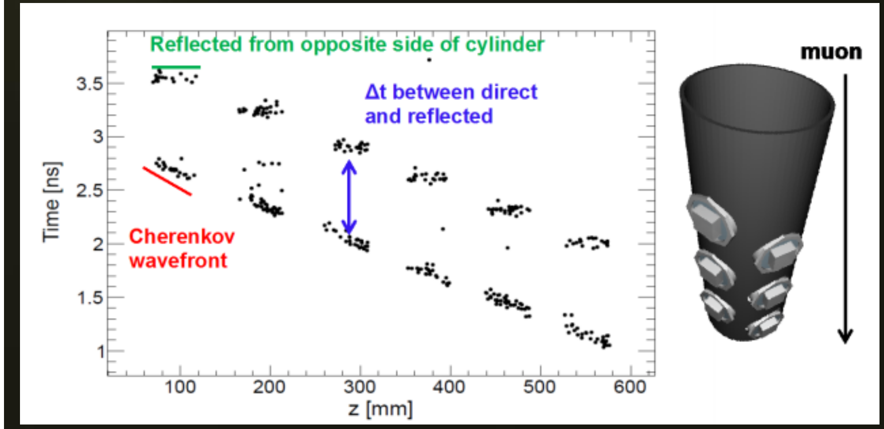


Detector R&D: OTPC

Fnal –T1059 (H. Frisch, E. Oberla)

- *Successful proof of principle in 2015 at FTBF*
- *Instrumented with an MCP photo-detector, three boards each with thirty channels of 10 GSPS waveform digitizing readout*
- *http://ppd.fnal.gov/ftbf/TSW/PDF/T1059_tsw.pdf*



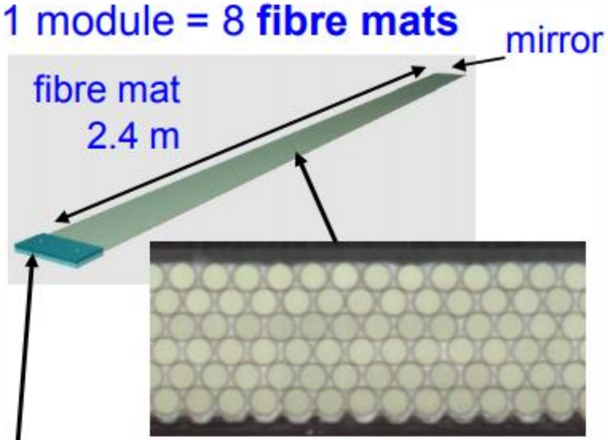


It requires a robust and dedicated R&D (LDRD)

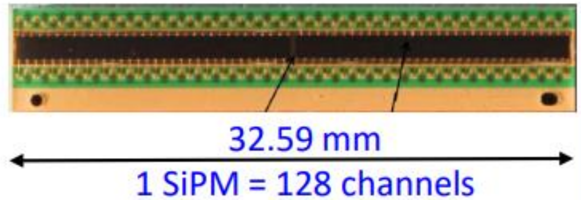
The Fiber Tracker – LHCb design

128 modules (0.5 x 5 m^2)
arranged in 3 stations × 4 layers (XUVX)

1 module = 8 **fibre mats**



4 silicon photomultipliers (SiPM)



128 modules (0.5 x 5 m^2)
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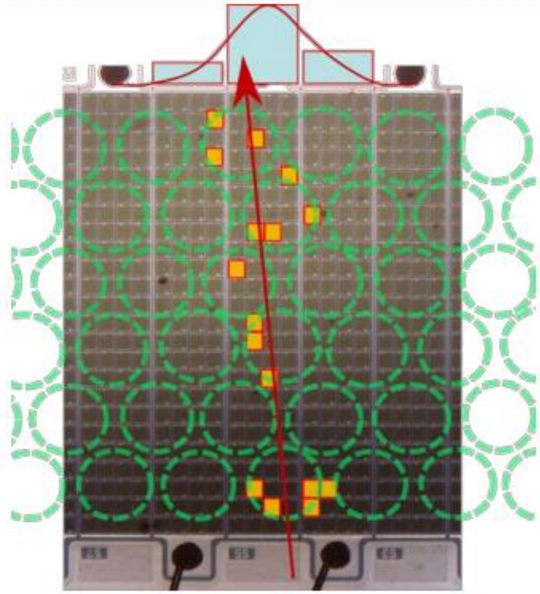


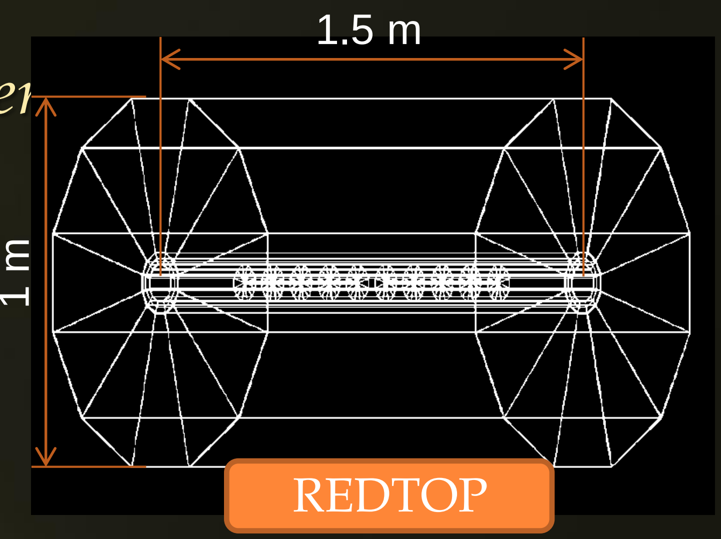
Light yield for 6-layer mat:
16–20 photo-electrons
(for particles near mat mirror)

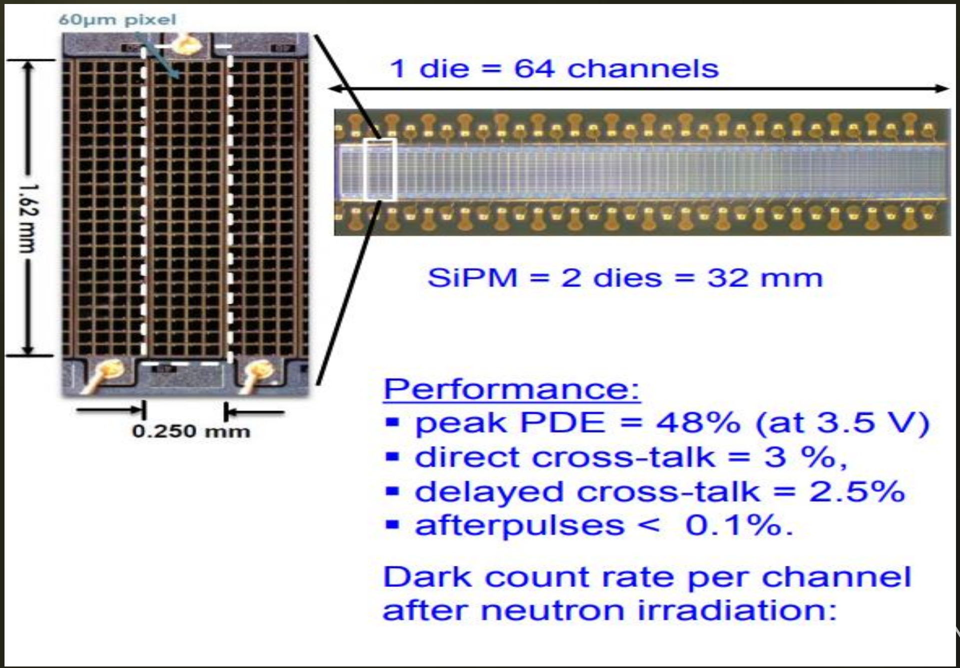
Ulrich Uwer

Layout for LHCb vs REDTOP

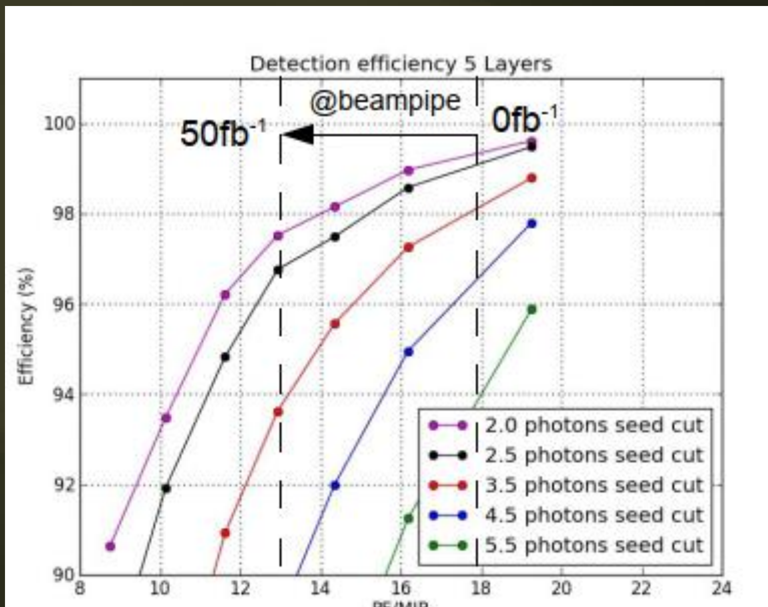
Input parameters

- ~ 360 m^2 vs 0.24m^2
- 1152 mats vs 36 mats
- 524,000 vs 18,000 channels

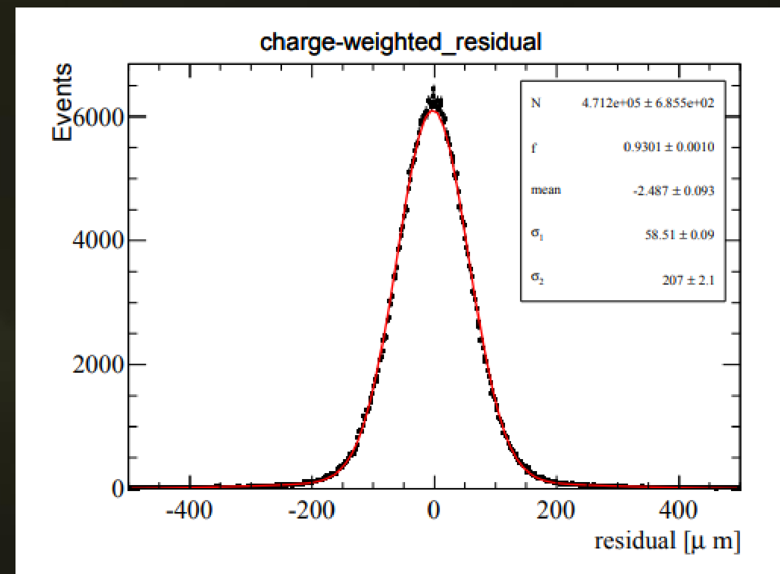




Results from LHCb Test Beam



Seed	Neighbour	Sum	Hit Eff.
1.0	1.0	1.0	0.9993 ± 0.0001
1.5	1.5	1.5	0.9990 ± 0.0001
2.0	1.5	2.0	0.9972 ± 0.0002
2.5	1.5	2.5	0.9946 ± 0.0003
3.0	1.5	3.0	0.9990 ± 0.0004
3.5	1.5	3.5	0.9817 ± 0.0005
4.0	1.5	4.0	0.9693 ± 0.0006
4.5	1.5	4.5	0.9540 ± 0.0007
2.5	**1.5**	**4.0**	0.9866 ± 0.0004

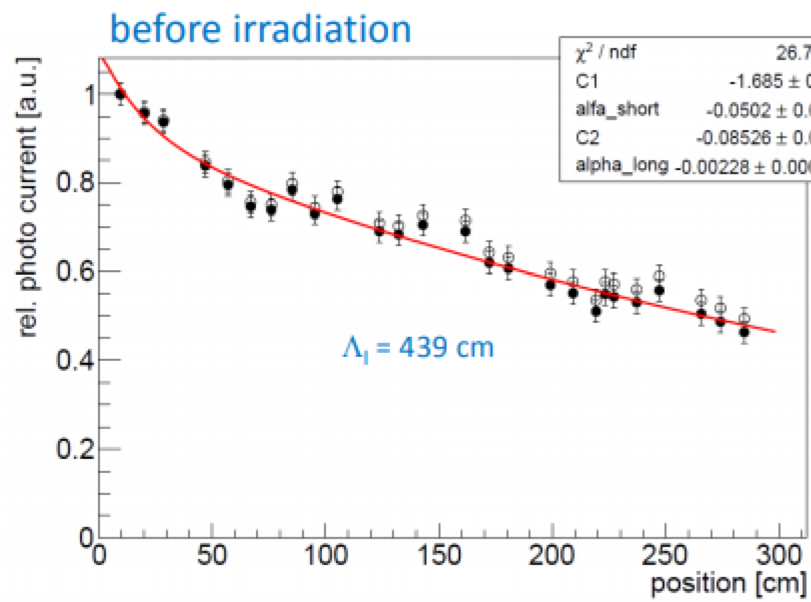


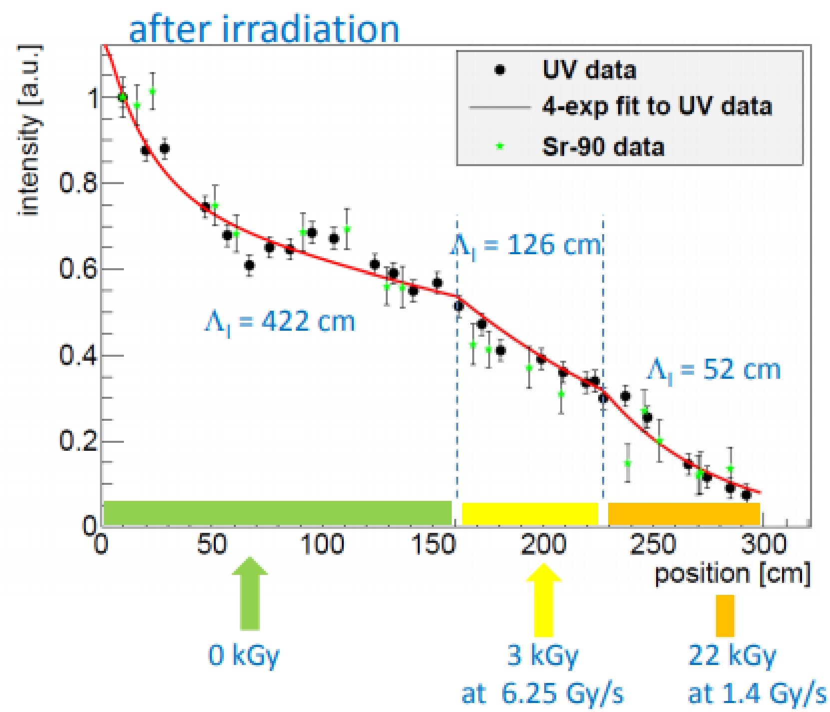
	at the mirror	centre	50 cm from SiPM
$\sigma_{eff,charge}$ [μm]	66.78 ± 0.23	65.93 ± 0.18	61.22 ± 0.21
$\sigma_{eff,Pacific}$ [μm]	73.27 ± 0.26	73.18 ± 0.20	73.64 ± 0.20

Christian Joram

Fiber Tracker Radiation Hardness

- 3 m long SCSF-78 fibres (Ø 0.25 mm), embedded in glue (EPOTEK H301-2)
- irradiated at CERN PS with 24 GeV protons (+ background of $5 \cdot 10^{12}$ n/cm2)





Christian Joram

Expected irradiation at REDTOP

- Worst case (forward detector): ~10^{13} n/cm^2
- Average: ~10^{12} n/cm^2

Theoretical Analysis: $\eta \to \pi^+\pi^-\pi^0$

C and CP violation poorly constrained in flavor diagonal processes

New way to construct CPV amplitudes in $\eta \to \pi^+\pi^-\pi^0$

- Use NLO ChPT result & project it to the isospin basis of two pions (I=0,1,2)

[Gasser & Leutwyler, 1985; note also Anisovich & Leutwyler, 1996; Bijnens & Ghorbani, 2007]

- Add CP violating terms controlled by "a" and "b"

$$A(s,t,u) = M_0(s) + (s-u)M_1(t) + (s-t)M_1(u) + M_2(t) + M_2(u) - \frac{2}{3}M_2(s)$$
$$+a[(s-u)M_1(t) - (s-t)M_1(u)] + b[M_2(t) - M_2(u)]$$

- Expand 8 CPV interferences in $|A(s,t,u)|^2$ in terms of (X, Y)=(0,0)

- Can fit the Dalitz plot to get Re(a), Im(a), Re(b), Im(b) and/or study charge asymmetries

Preliminary analysis shows the largest CPV contributions could come from the interference with $M_0(s)$

[Gardner & Shi, 2017, to appear]

Slide Credit: Susan Gardner & Jun Shi

University of Kentucky

Expected η/η' Yield

- Assume: $1x10^{11}$ POT/sec – CW
  - Beam power @ 3 GeV: 10^{11} p/sec $\times$ 1.9 GeV $\times$ 1.6 $\times$ 10^{-10} J/GeV = 30 Watts (48 W for η')
- Target system : 10 x 0.33mm Be or 0.5 mm Li foils, spaced 10 cm apart
  - Be is thinner (better vertex resolution) but makes more primary hadrons (final state hadron multiplicity ≈ $A^{1/3}$)
  - Prob(p + target $\rightarrow$ X) ~ 0.5% or 5× 10^8 p-Be inelastic collisions per second

- p-inelastic production: 5 x 10^8 evt/sec (1 interaction/2 nsec in any of the 10 targets)
-
- production: 2.5 x 10^6 η /sec (2.5 x 10^4 η'/sec) or
  ')
- Preliminary di-lepton reconstruction efficiency (no-vertexing/timing): 30-50%
- Preliminary background rejection (no-vertexing/timing): < 10^{-8} (from QCD) or ≈ 0.1% from η (need to improve 100x with vertexin+timing)