Outline

- **Performance considerations**
- **Comparison of crystal properties**
- **Properties of lead tungstate**
- **Lead tungstate applications**
- **Caesium iodide applications**
- **Summary**

Performance Considerations

- **Light yield**
- **Resistance to radiation-induced darkening**
- **Radiation length / Molière radius**
- **Speed (scintillation decay time)**
- **Emission spectrum**
- **Cost (including implications for associated detectors)**

The relative weight given to these considerations depends on the application.

The choice of crystal usually involves a compromise

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Crystal Properties

	NaI (Tl)	CsI (Tl)	CsI	BGO	BaF_2	CeF_3	PWO	LSO (Ce)	LYSO (Ce)	GSO (Ce)	NE 110
Light Yield (ph/MeV)	4.10^4	5.10^4	200	9000	1.10^4 1400	1600	100	3.10^4	4.10^4	10^4	1.10^4
λ_{max} (nm) (slow/fast)	410	565 /420	450 /320	480	310 /220	310 /340	530 /440	440	420	430	434
Decay (ns) (slow/fast)	230	600 /3.5	1000 6-28	300	600 /0.8	30 /9	40 /10	40	40	60	3.3
Radiation length (cm)	2.59	1.86	1.86	1.12	2.06	1.68	0.89	1.14	1.2	1.38	43
Moliere radius (cm)	4.8	3.8	3.8	2.3	3.4	2.6	2.2	2.3	2.4	2.37	
Density (g/cm^3)	3.7	4.5	4.5	7.1	4.9	6.2	8.3	7.4	7.1	6.71	1.0
Refractive Index	1.85	1.80	1.95	2.15	1.50	1.68	2.16	1.81	1.81	1.85	1.58
Rad Hard (Gy)	1	10	100	10	10	10^4	10^4	10^6		10^6	
Hygro-scopic?	Yes	Slight	Slight	No	No	No	No	No	No	No	No

Cautionary note: This table is indicative only. Properties such as light yield, fast/slow components, radiation hardness, may depend sensitively on purity, growth conditions, etc

Lead tungstate properties

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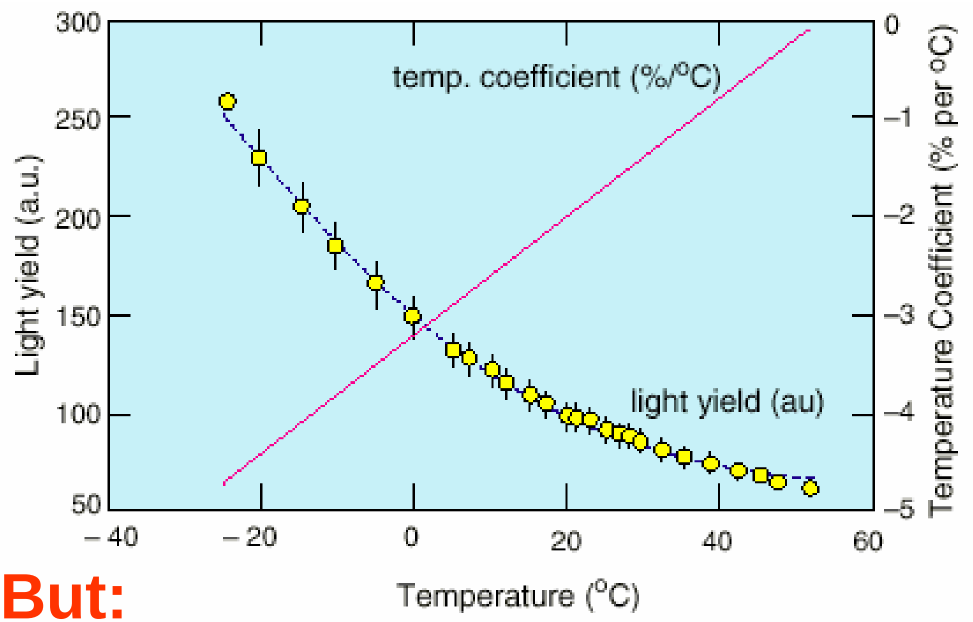
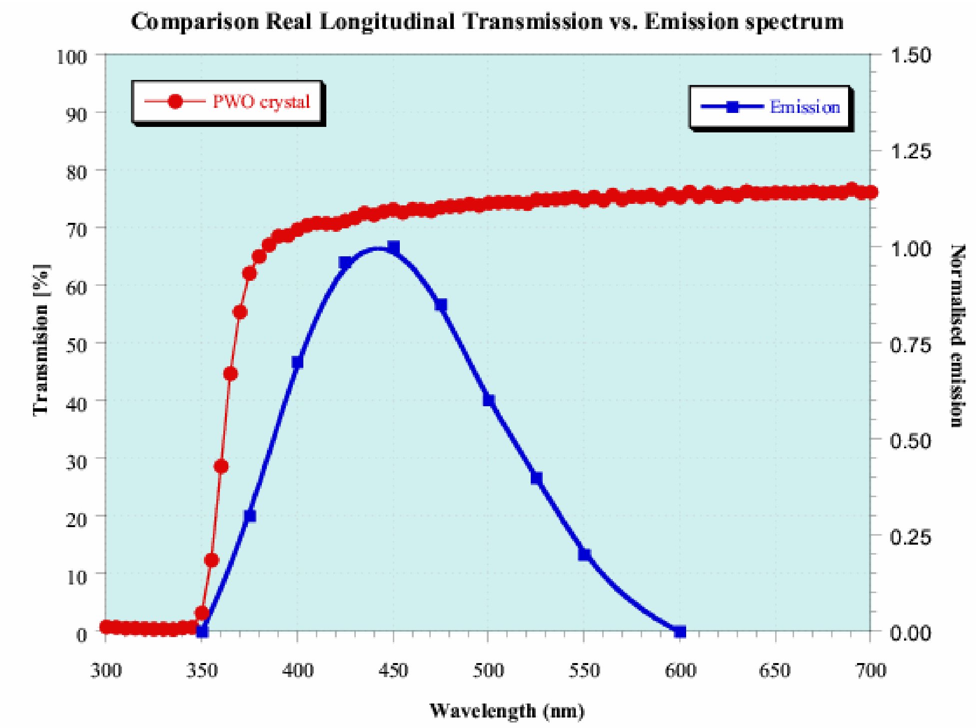
Fast light emission: ~80% in 25 ns
Peak emission ~425 nm (visible region)
Short radiation length: X_0 = 0.89 cm
Small Molière radius: R_M = 2.10 cm
Radiation resistant to very high doses





But:

Temperature dependence ~2.2%/°C
→ Stabilise to ≤ 0.1°C

Formation and decay of colour centres in dynamic equilibrium under irradiation
→ Precise light monitoring system

Low light yield (1.3% NaI)
→ Photodetectors with gain

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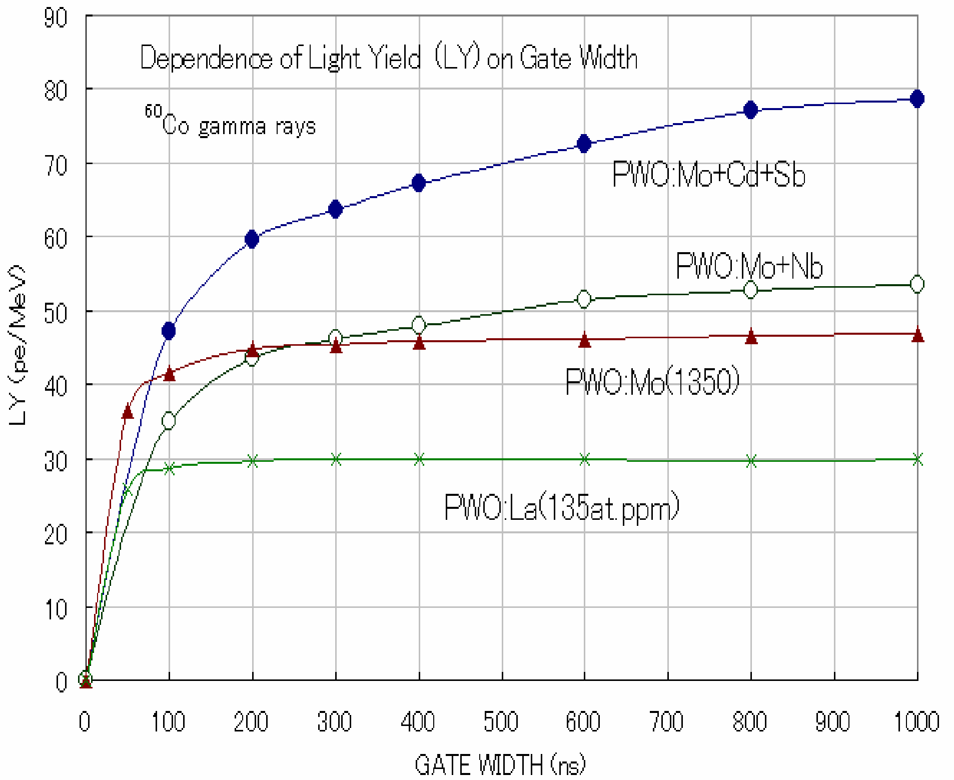
Increasing PWO light yield

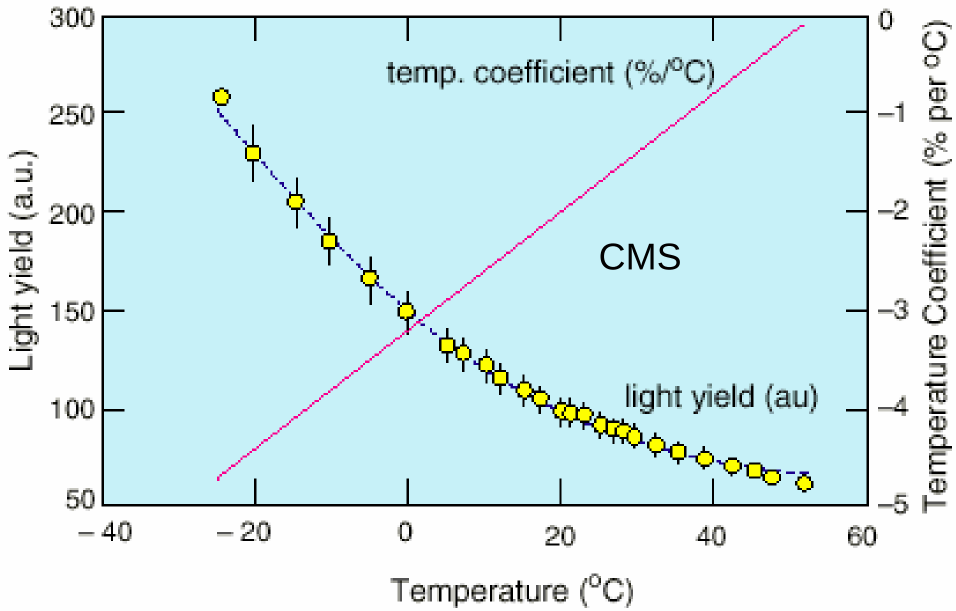
Doping: Mo, Tb, Cd, Sb...(Yield vs speed)

M.Kobayashi et al, Proc. SCINT2001, Chamonix, France, sept 2001
M.Kobayashi et al, NIMA 434 (1999) 412-423

(Similar results: R. Zhu, Proceedings IEEE2000, Lyon)



Cooling: dY/dT = -2.2%/°C(20°C), -4.5%/°C(-20°C)



LY_{-20}/LY_{+20} ~ 2.5 - 5.0

τ_D(-20) < 20 ns (Shigaki, APS, Denver 2004)

Pro: Reduced APD dark current
Con: Reduced radiation resistance
Increased temperature sensitivity

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Lead tungstate applications

PWO - currently the most popular material for particle physics applications

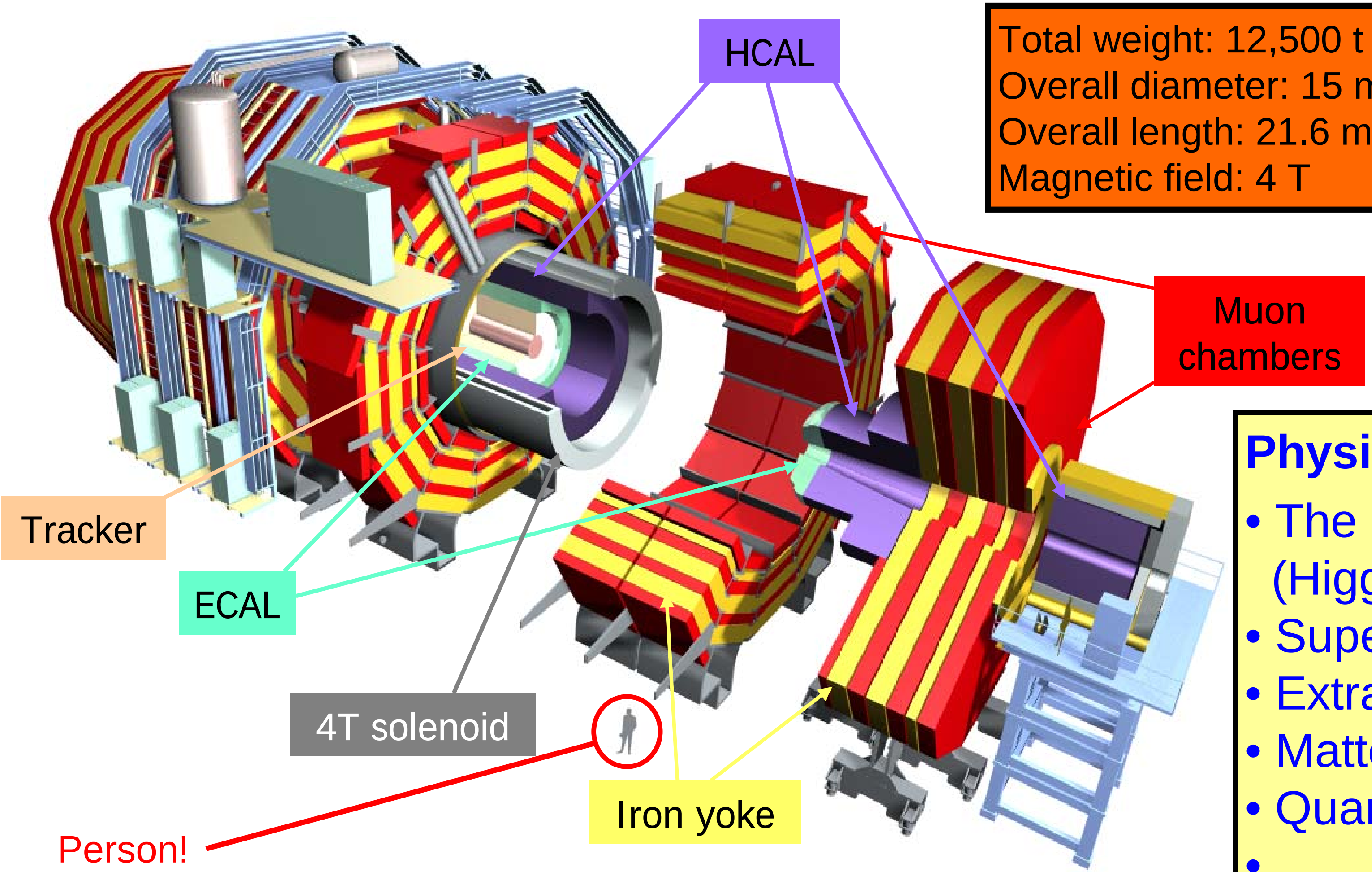
Current / planned

CMS (CERN - LHC):	~78000 Crystals (~ 130/190 cm^3)	~ 92 t
ALICE (CERN - LHC):	~17920 Crystals (~ 87 cm^3)	~ 13 t
B-TeV (FNAL - Tevatron):	~10000 Crystals (~ 170 cm^3)	~ 14 t
PRIMEX (Jefferson Lab):	~ 1200 Crystals (~ 76 cm^3)	~ 0.7 t

Future

PANDA (GSI - $p\bar{p}$):	~7150 Crystals (~ 185 cm^3)	~ 11 t
MECO (BNL – AGS):	~1150 Crystals (~ 190 cm^3)	~ 1.8 t
CLAS (Jefferson Lab)	~ 424 Crystals (~ 40 cm^3)	~0.14 t
CLAS upgrade….	~1080 Crystals (~ 70 cm^3)	~0.64 t

Compact Muon Solenoid



Total weight: 12,500 t
Overall diameter: 15 m
Overall length: 21.6 m
Magnetic field: 4 T

Physics objectives:

- The origin of mass (Higgs boson search)
- Supersymmetry
- Extra Dimensions
- Matter/antimatter asym.
- Quark gluon plasma
- ………………….

CMS Electromagnetic Calorimeter

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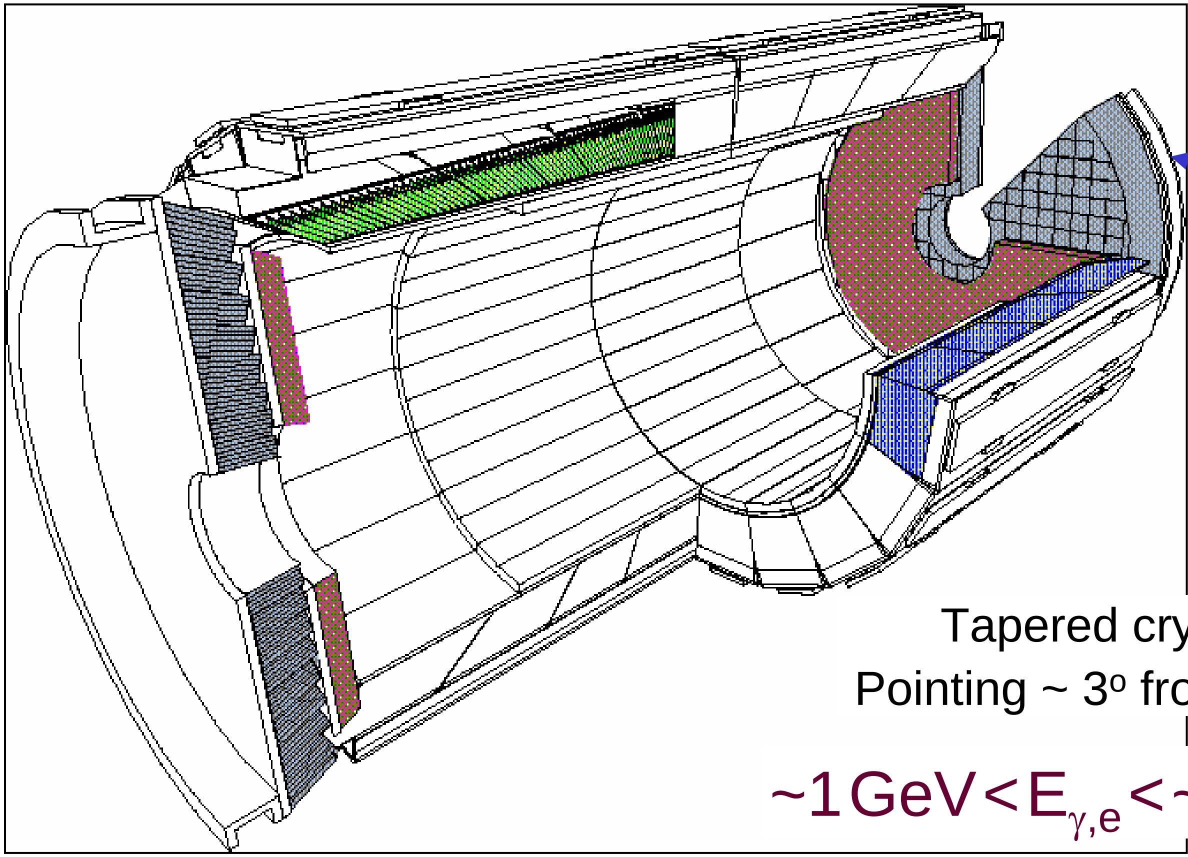

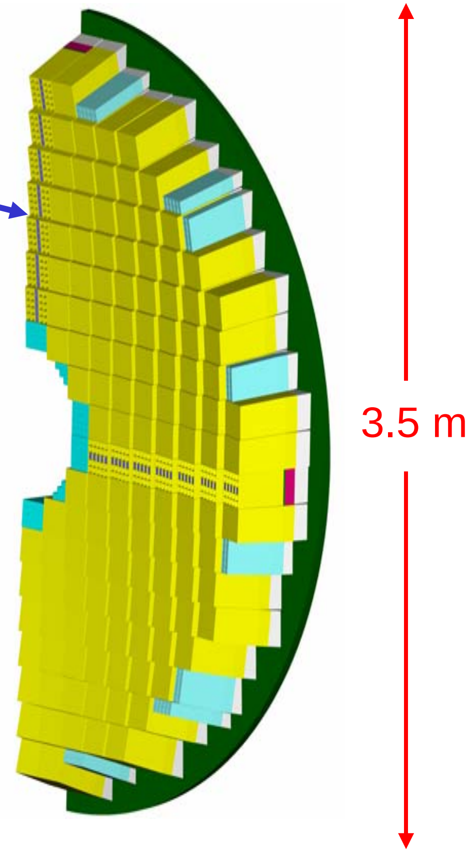

Tapered crystals

Pointing ~ 3º from vertex

$\sim 1\,GeV < E_{\gamma,e} < \sim 1\,TeV$

Barrel:
36 Supermodules (18 per half-barrel)
61200 Crystals
Total mass 67.4 t

Endcaps:
4 Dees (2 per endcap)
14648 Crystals
Total mass 22.9 t

CMS ECAL status

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~ 30000 Barrel crystals delivered

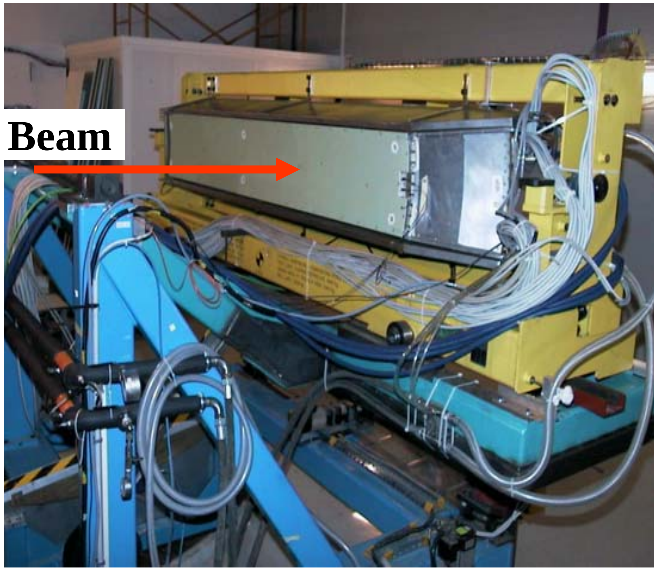
~ 11000 Barrel Crystals under contract

Tender exercise launched in July 04 for procurement of remaining crystals

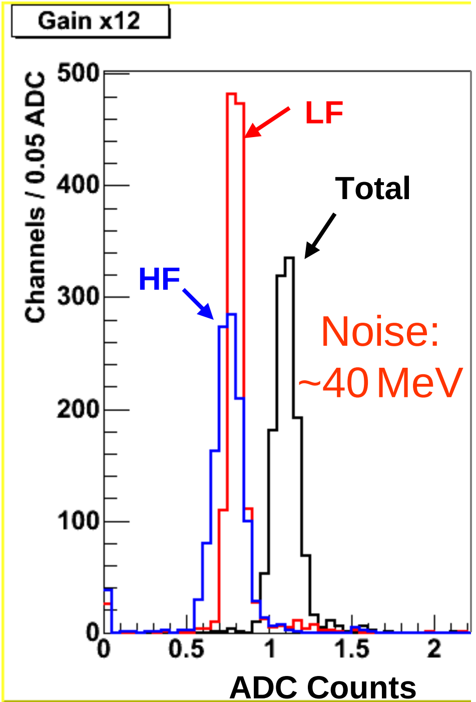
~ 21000 Barrel crystals and

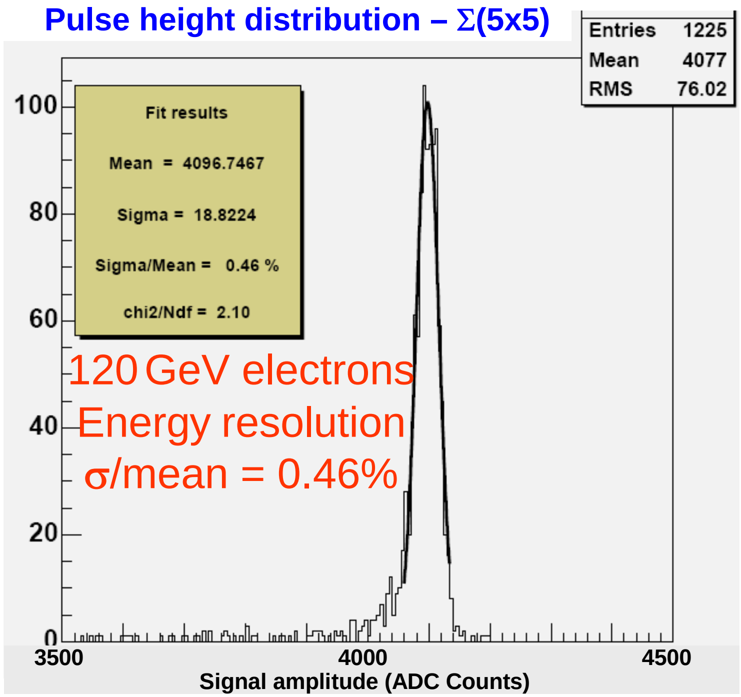
~ 15000 Endcap crystals

(Total mass ~ 46 t)



First 'Supermodule' (1700 channels) in test beam at CERN





PWO Production at BTCP - Russia

ALICE (A Large Ion Collider Expt for LHC)

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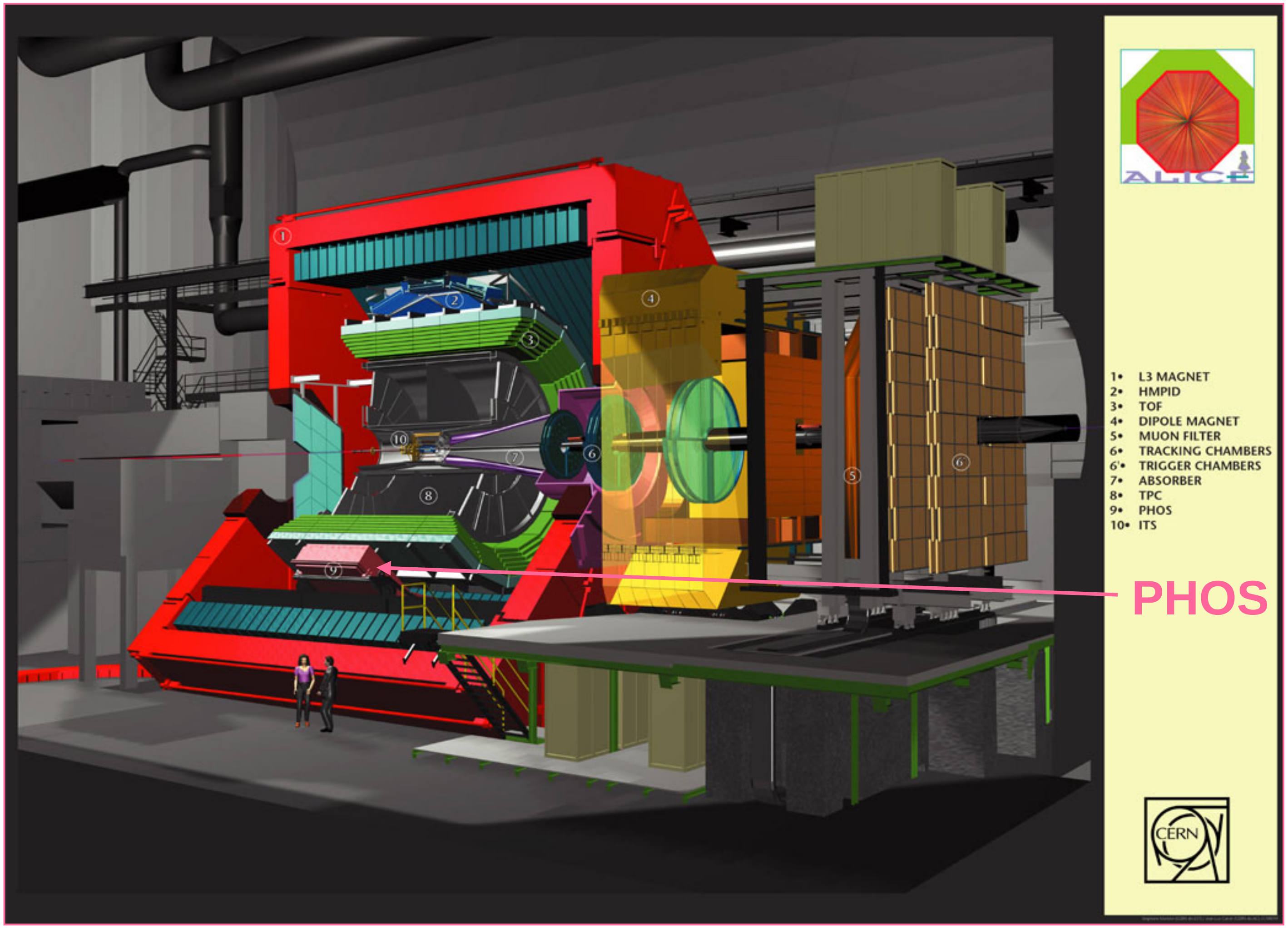

Physics objectives

Heavy ion collisions:
the physics of matter at extreme energy densities

Search for a new state of matter:
the 'quark-gluon plasma'

Courtesy: J.Schukraft

PHOS (Photon Spectrometer)

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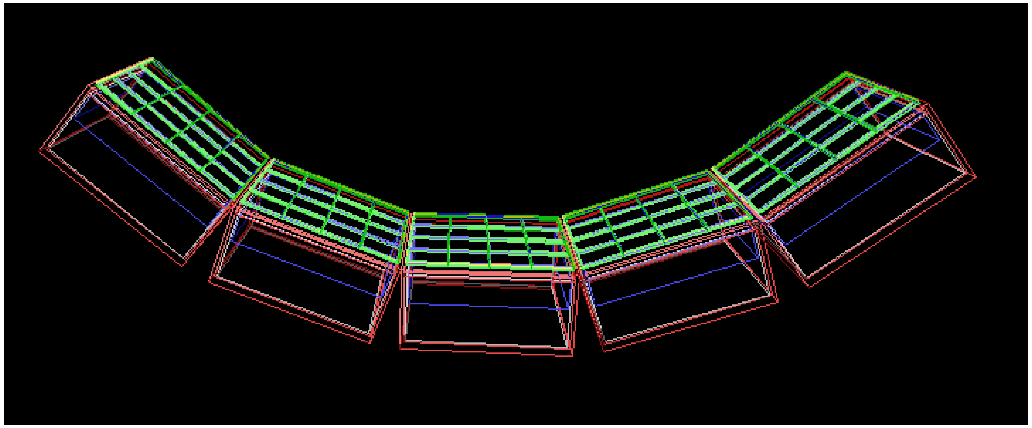
PbWO$_4$ with avalanche photodiode readout



~0.5 GeV < E_γ < ~100 GeV

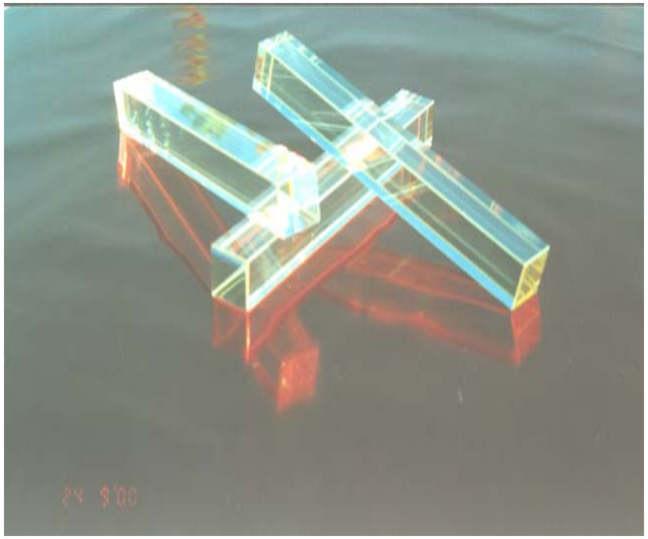
(Operate at -25^{O}C → Noise ~13 MeV)

17 920 Crystals

(5 Modules x 3 484)

(180 x 22 x 22 mm^3)

1.5 m^3, ~12.5 t



Current Status:

Funding available for 3 modules (~10 500 Xtals)

~7 000 crystals delivered

Install 1 module/year in 2006/2007/2008

Crystals from North Crystals - Apatity

Courtesy: J.Schukraft

BTeV at Fermilab

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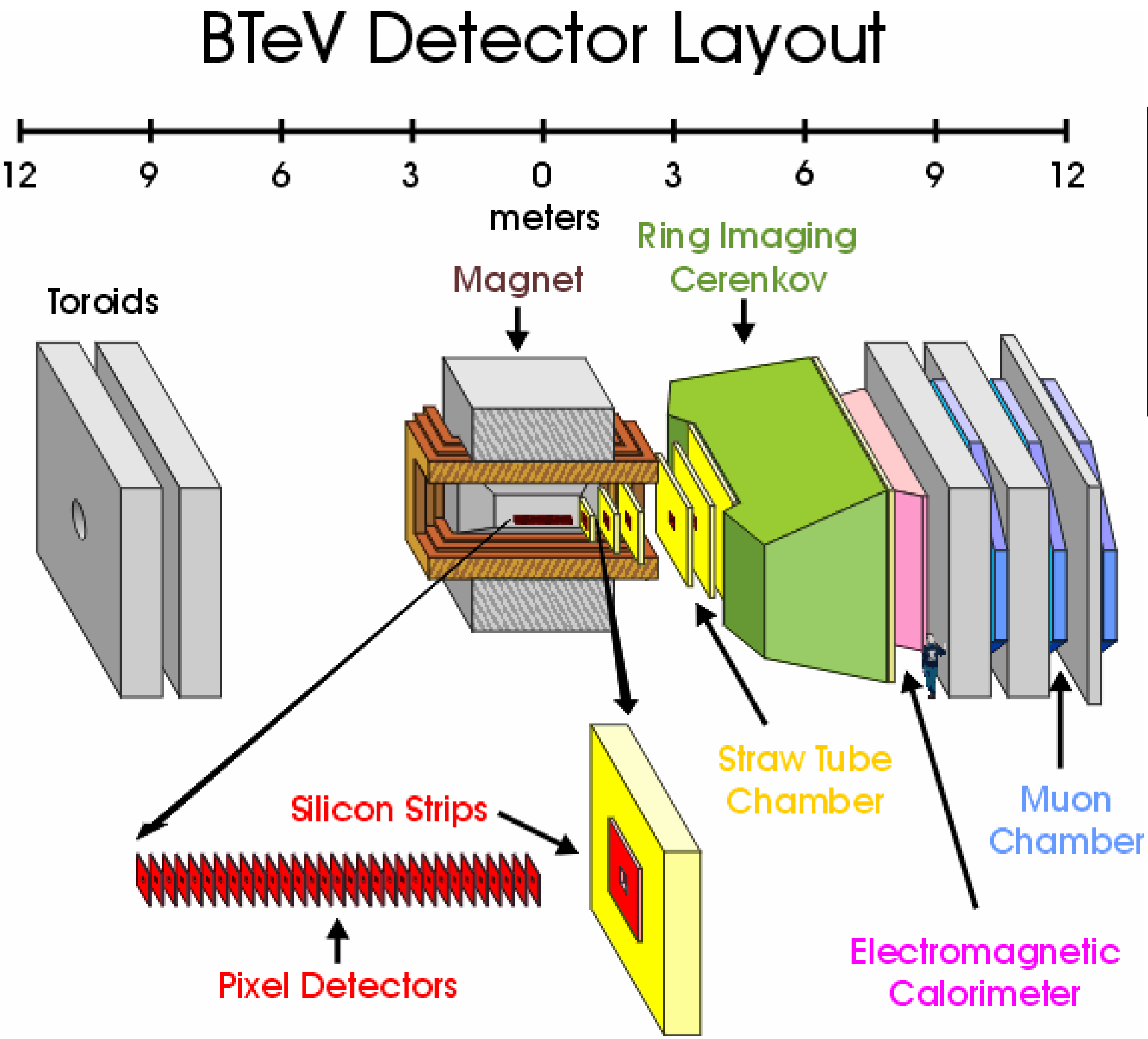

Physics objectives:

Investigate matter-antimatter asymmetry through the study of mixing and rare decays of beauty and charm quark states.

Courtesy: J.Butler

BTeV Electromagnetic Calorimeter

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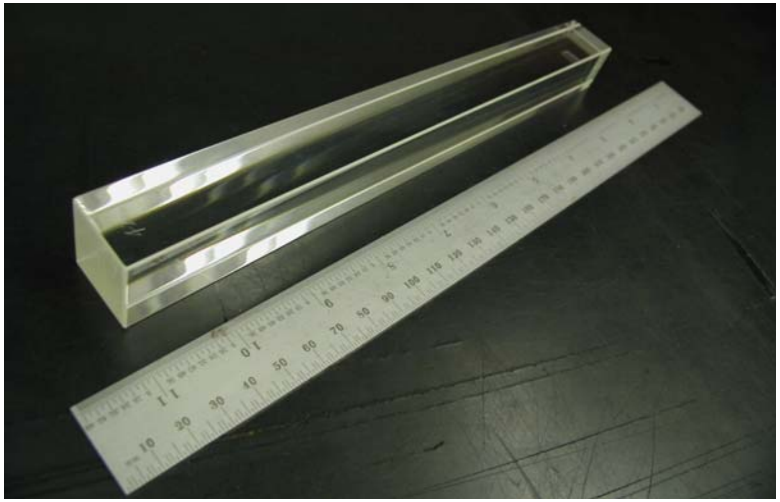
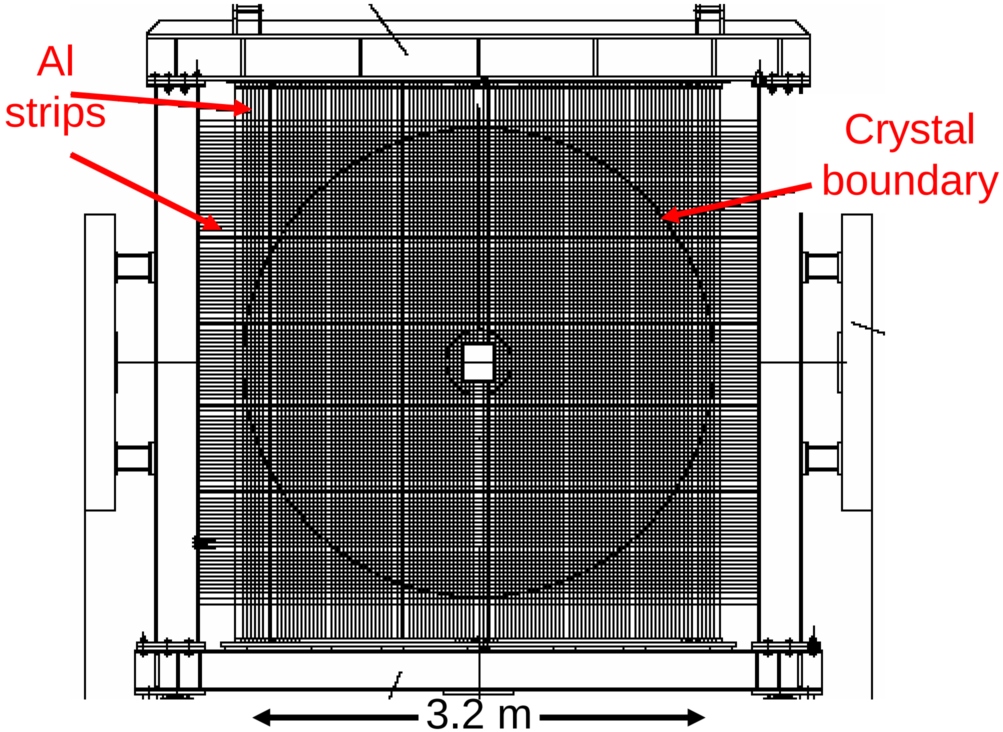
$PbWO_4$ with pmt readout



Prototype crystals:
- Shanghai Institute of Ceramics
- BTCP (Bogoroditsk)
- North Crystals (Apatity)

Schedule:
BTeV construction starts in 2005
Crystal production: 2006 - 2009
First phase operation starts in 2009



10 100 Crystals
(220 x 28 x 28 mm^3)
1.7 m^3, ~14.3 t

$\sim 1.0\ GeV < E_\gamma < \sim 70\ GeV$

Courtesy: J.Butler

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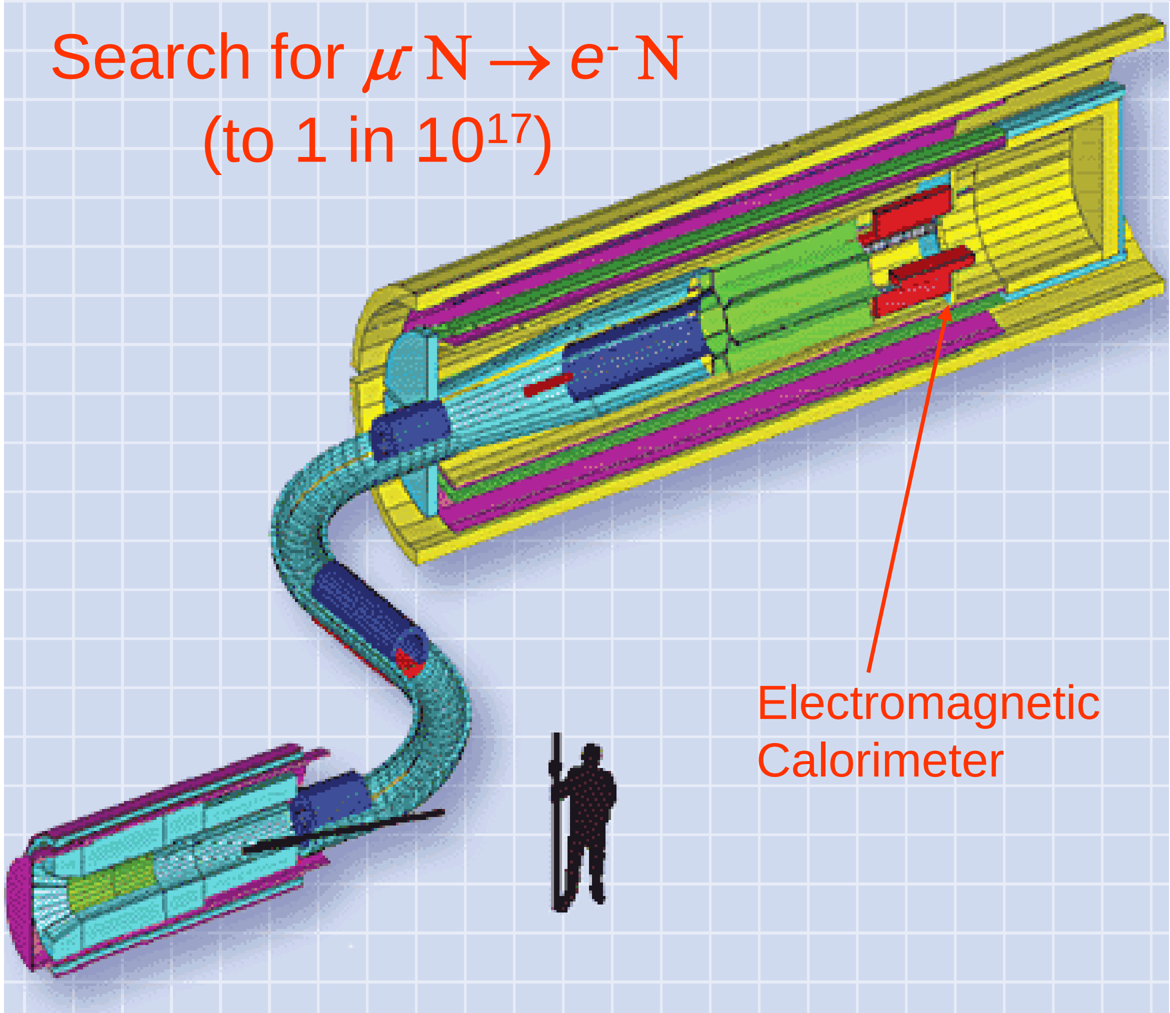
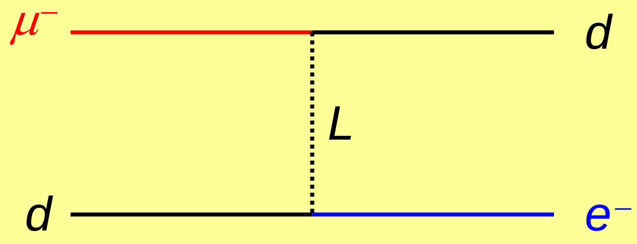
MECO (Muon-electron conversion) BNL



Physics objectives:

Search for ‘lepton flavour’ violation as a signature for physics beyond the Standard Model

Eg existence of ‘Leptoquarks’



Courtesy: W.Molzon

MECO Crystal absorption calorimeter

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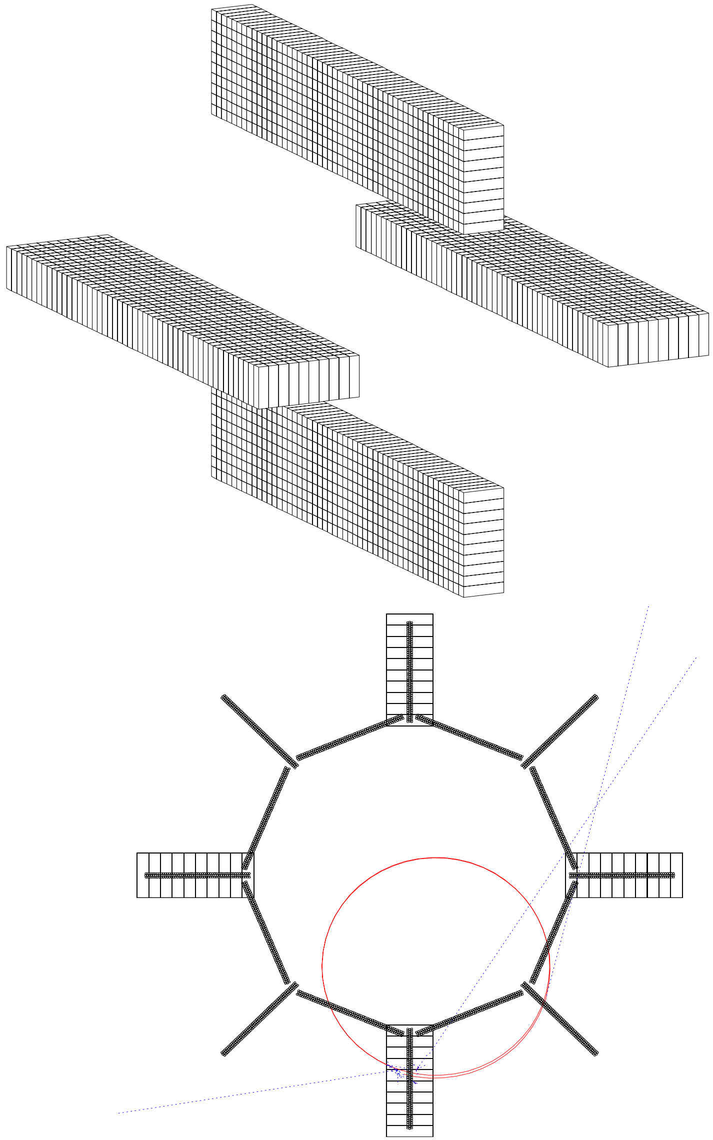


GSO, BGO, PWO, CsI(pure) considered
Prototype tests on GSO, BGO, PWO with APDs
GSO considered too expensive → BGO or PWO
PWO cooled to $-25^{O}C$ would meet requirements
(→ 20-30 photoelectrons/MeV)

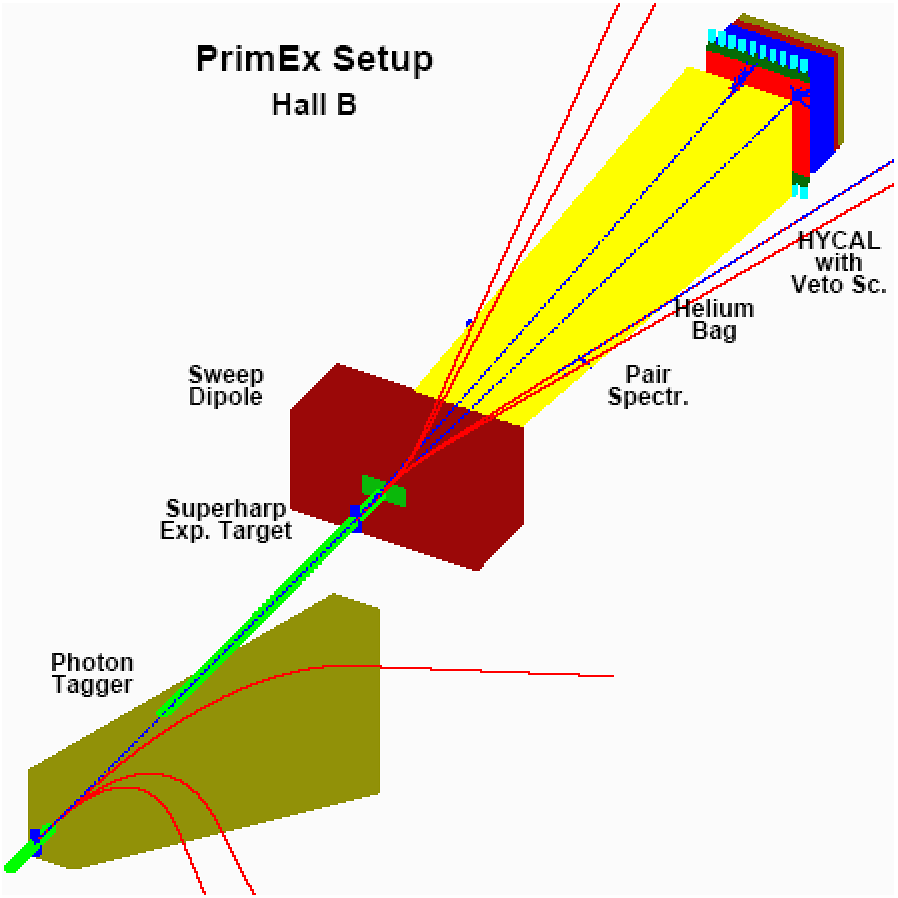
$E_e \sim 100\,MeV$

Possible PWO design:
1152 Crystals
(120 x 40 x 40 mm^3)
0.22 m^3, ~1.8 t

Schedule:
MECO Project plan in Sept 03:
Construction 2006-2009

Courtesy: W.Molzon

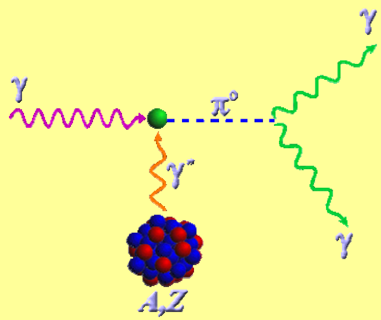
Primex at Jefferson Lab



Physics objectives:

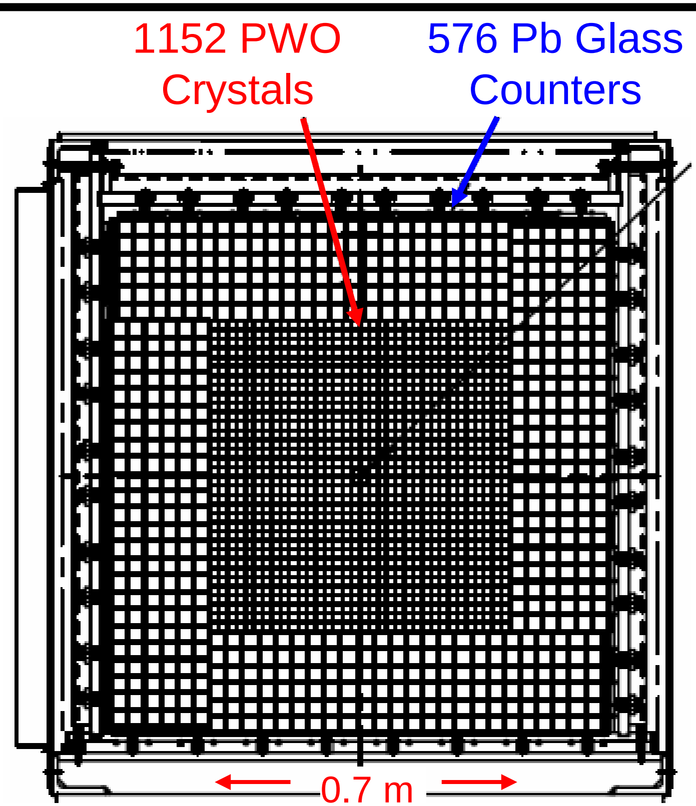
High precision measurement of the π^0 lifetime via the Primakoff effect

(Measure symmetry breaking in QCD due to quantum fluctuations of quark field → the ‘axial anomaly’)

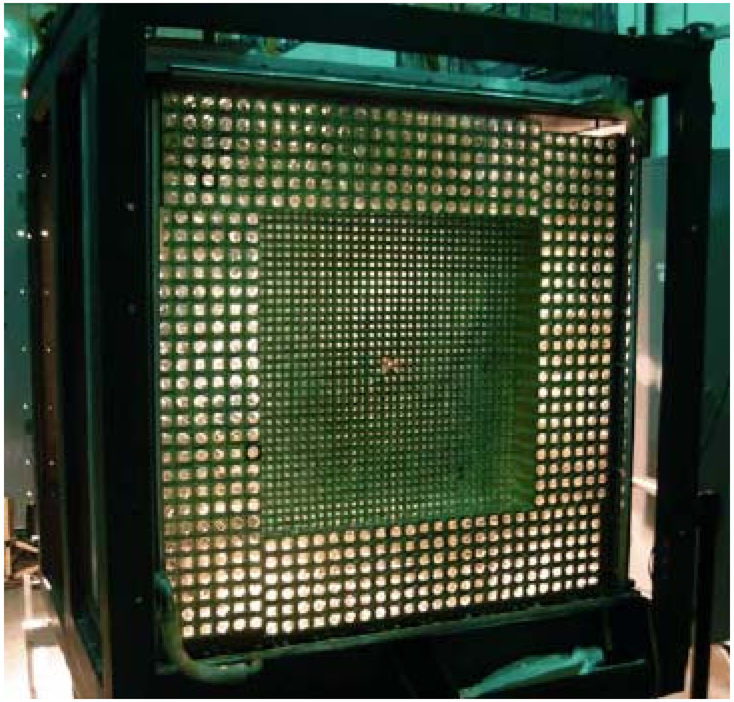


Courtesy: A.Gasparian

PRIMEX HYCAL
(HYbrid CALorimeter)



Operate at ~5ºC
pmt readout



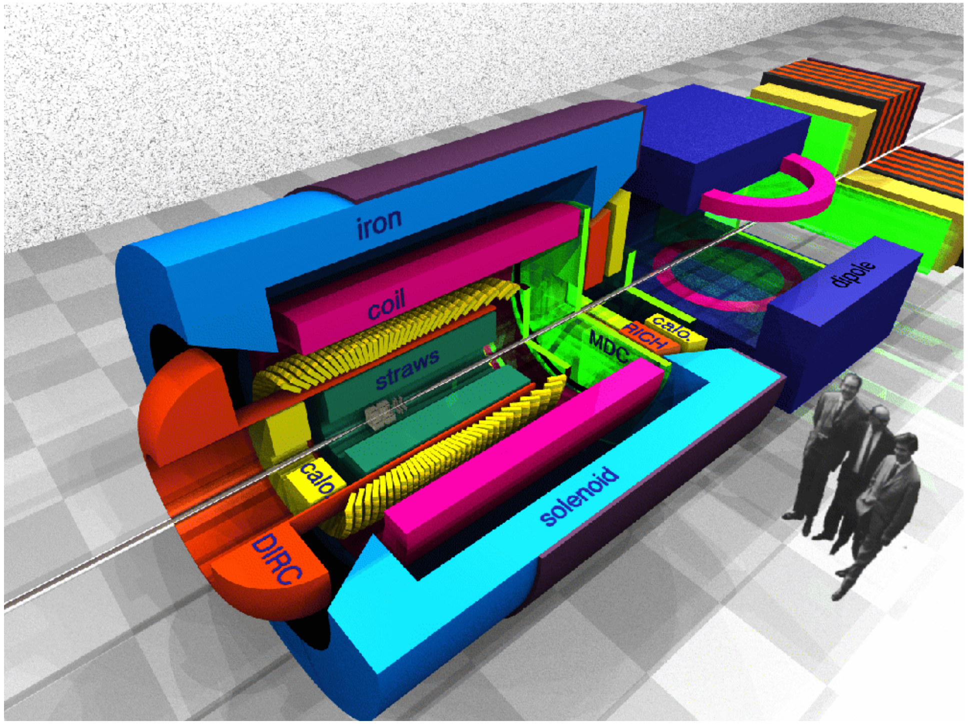
$\sim 0.1\,\text{GeV} < E_\gamma < \sim 5\,\text{GeV}$

1152 Crystals
(180 x 20.5 x 20.5 mm^3)
0.09 m^3, ~0.7 t

Status:
Construction complete
(PWO procured from SIC)
Now taking data

Courtesy: A.Gasparian

PANDA
(Anti-Proton ANnihilations at DArmstadt)



Detector for the
High Energy Storage Ring
(1.5 -15 GeV/c antiprotons)
proposed at GSI Darmstadt

Physics objectives:

- Search for ‘glueballs’

  In Quantum ChromoDynamics (theory of strong nuclear force) the force carriers (gluons) are self-interacting

  QCD therefore predicts the existence of particles consisting only of gluons: ‘glueballs’
- ‘Charmonium’ ($c\bar{c}$) spectroscopy (a sensitive probe of QCD)

Courtesy: A.Wilms

PANDA Electromagnetic calorimeter

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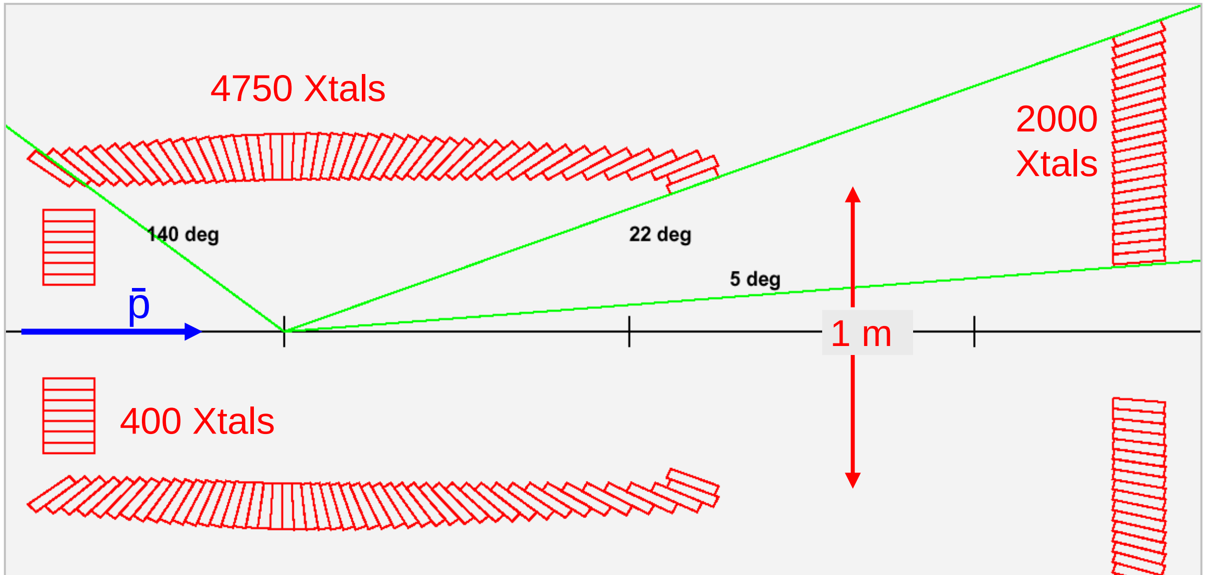

Schematic arrangement: PWO option

$\sim 10\ MeV < E_\gamma < \sim 5\ GeV$

BGO and PWO under consideration

PWO option: 7150 crystals
3.5 x 3.5 x 15 cm^3 (~185 cm^3)
~11 t

Proposed schedule:

2005 (Jan)	Proposal
2005 (May)	Start construction (CE)
2005-2008	Detailed design reports
2012	Complete detector
2013	Start operation

Courtesy: A.Wilms

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Caesium Iodide (CsI)

CsI – Still the material of choice in applications where high light yield crucial and radiation levels tolerable (eg e^+e^- colliders)

Current / planned

BaBar (SLAC – PEPII)	~6580 Crystals (~ 800 cm^3)	CsI(Tl)	~ 23.5 t
Belle (KEK - KEKB):	~8736 Crystals (~1000 cm^3)	CsI(Tl)	~ 43 t
BESIII (Beijing - BEPCII)	~6240 Crystals (~ 950 cm^3)	CsI(Tl)	~ 27 t
WASA (CELSIUS→COSY):	~1012 Crystals	CsI(Na)	

etc….

Future:

KEK and SLAC have agreed to cooperate on a single super-B experiment to be built either at SLAC or KEK.

Timescales are different for the 2 designs: SLAC sees ending BaBar around 2009/10 and bringing super-B online in 2012, though the dates are tentative

Super B experiments

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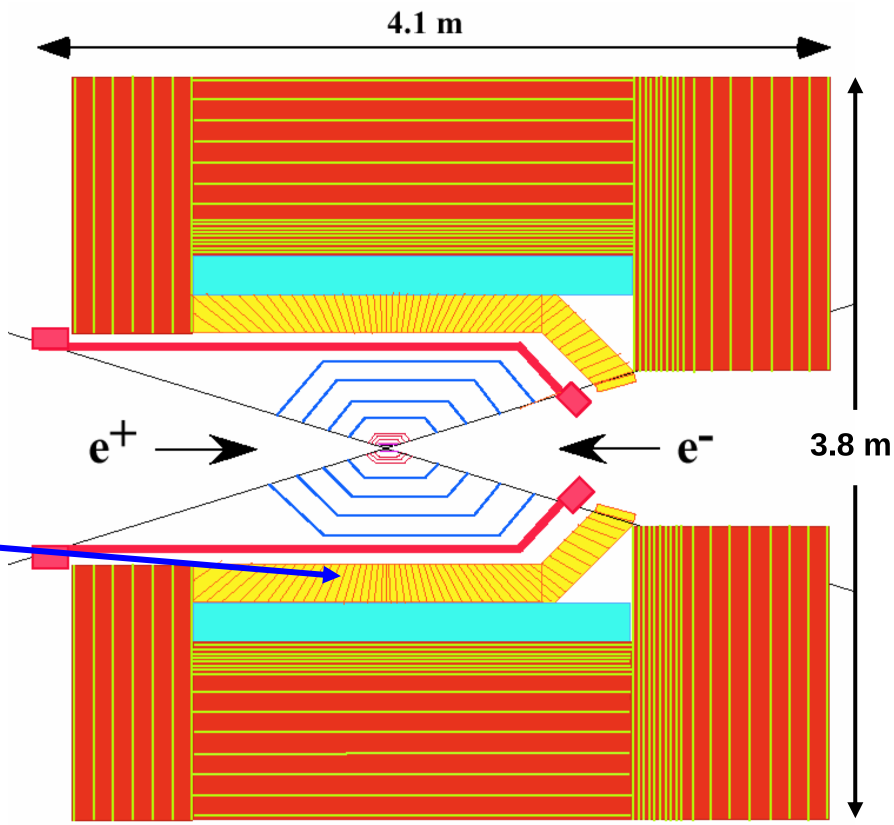
Belle: Barrel: CsI(Tl) + photodiodes
Endcaps: CsI(pure) + phototetrodes
LoI to KEK Directorate in spring 2004

BaBar: Various options considered
CsI(pure), LSO/LYSO, PWO, Liq Xe
Document in preparation



'Strawman' Super BaBar detector
(B.Wisniewski, Calor02, Pasadena)

Summary

- Continuing demand from particle physics/nuclear physics for large volumes of affordable scintillating crystals
- Current material of choice is $PbWO_4$ (Density, speed, radiation resistance, cost)
- Despite low light yield, $PbWO_4$ is also proposed for medium energy applications
- Improvements in light yield through doping could extend the range of applications of $PbWO_4$
- A Super B-Factory experiment would require a fast, high light-yield, Radiation-resistant scintillator: LSO/LYSO under consideration